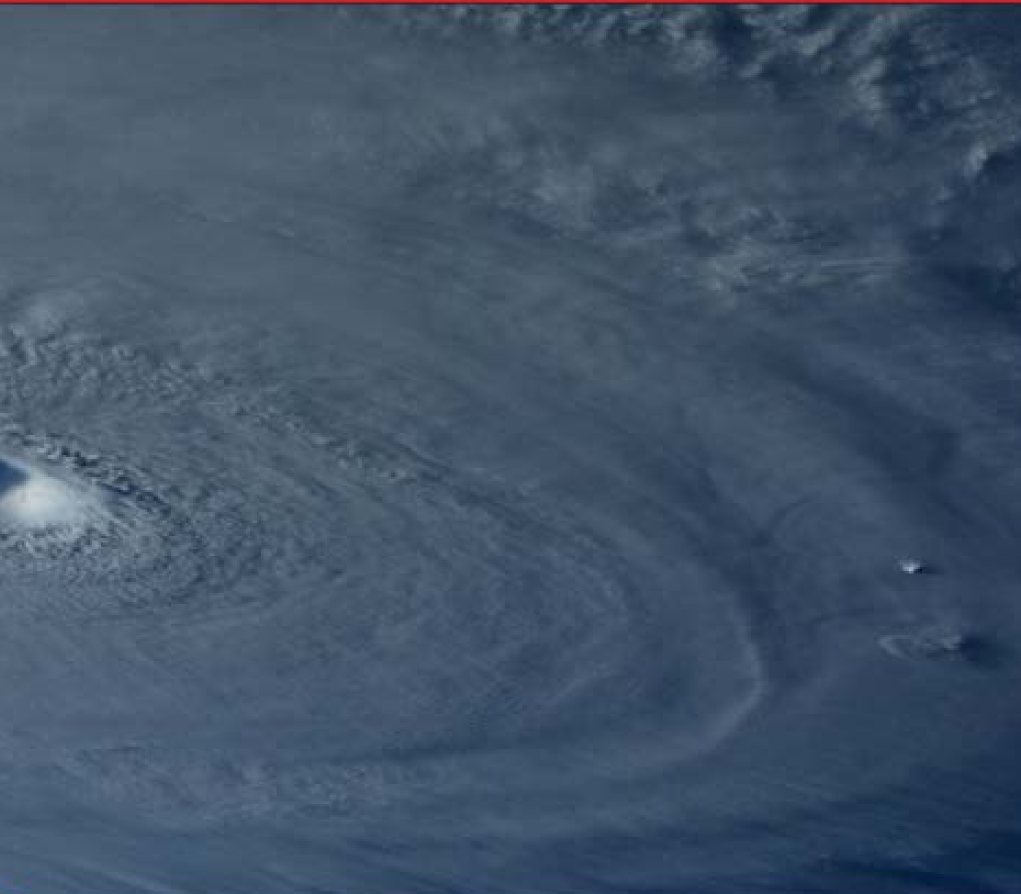
METEOROLOGY: THE SCIENCE OF THE ATMOSPHERE



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A tornado near Elmwood, Nebraska. A painting made from what is probably one of the most remarkable photographs ever taken of a tornado. The original photograph was made in two parts, as the photographer was too close to get the whole funnel cloud into the field of his camera.

(Photograph by G. B. Pickwell)

PREFACE

Meteorology is the science of the atmosphere and its phenomena, including weather.

Nowadays, when we speak of a "meteor," we generally mean a shooting star; but formerly this term was applied (and it still often is in technical literature) to a great variety of phenomena and appearances in the atmosphere, including clouds, rain, snow, rainbows, and so forth. That is how the science of the atmosphere came to have its present name.

Meteorology is not a branch of astronomy. These two sciences are as different from each other as zoölogy is from botany. They are both founded on physics, and they "overlap" each other to some extent, just as every science does certain others; but if you want information about the atmosphere, weather and climate, an astronomical observatory is not the place to seek it; while if you wish to make inquiries about comets, sun spots, eclipses, standard time, or the date on which Easter fell in the year 1666, do not apply to the Weather Bureau.

In the city of Washington the Government maintains an astronomical and timekeeping institution known as the Naval Observatory, and it maintains in the same city the central office of the United States Weather Bureau. The two establishments are a mile apart in space and nearly a whole library apart in the subjects with which they are concerned. The fact that their functions are persistently confounded by the public indicates the necessity of writing this preface to a popular book on meteorology.

CHAPTER I

THE ANATOMY OF THE ATMOSPHERE

Two quite different conceptions of the substance called "air" are current in the world. One has prevailed from time immemorial. The other is wholly modern. One is the popular view, the other the scientific.

Ancient philosophers regarded air as one of the four "elements" of which all things were supposed to be made. Average humanity, though it did not concern itself with philosophy, must have begun, almost as soon as it realized the existence of air at all, to think of it as something that, however it changed its state from hot to cold, dry to moist, pure to impure, was fundamentally uniform—a single entity. Certainly this idea is in full vigor today. The air that we breathe, supply to our fires, stir with fans, pump into bicycle tires, fly in—the air that asserts its independence of our will in the wind and the weather—gives us the impression of individuality. We instinctively rank it with water among the simple, definite things in the repertory of nature.

Even the man of science often finds it convenient to discuss and deal with air as if it were a single substance, but he is well aware that it is nothing of the kind. He knows that it is, in fact, a jumble of gases having very different properties. Some are heavy, others light. Some are chemically very active, others extremely inactive. Some are abundant, others very rare. These gases constitute the earth's atmosphere. Other planets have atmospheres that are quite different in composition from ours. The sun itself has a very complex atmosphere.

The earth's atmosphere is, then, a collection of gases, which are mixed but not chemically combined. Some of them are themselves chemical compounds. Each of these gases behaves very much the same as if the others were not present, and each of them has its separate business to perform in the economy of nature. For example, a tree draws upon the store of carbon dioxide gas in the atmosphere to build up its tissues. Presently the tree is cut down and its wood is burned for fuel. In this process a different atmospheric gas is brought into play. We often say that the "air" supports combustion—that we supply "air" with a bellows to make a fire burn more brightly—but it is not the air as a whole that enables things to burn. Four-fifths of the atmospheric substance takes no part in the process. We burn with oxygen alone. So it is with breathing. Oxygen and not air constitutes the breath of life.

Near the surface of the earth the proportions of the more abundant gases mixed together in the air are remarkably constant. Ignoring a variable admixture of water vapor, oxygen is always about 21 per cent, by volume, and nitrogen about 78 per cent. The remaining 1 per cent is mainly argon. At great altitudes, however, these percentages no longer obtain. The atmospheric gases differ greatly among themselves in weight, and in the high atmosphere, where they are not mixed by the winds, as they are below, the heavier tend to settle to the bottom and the lighter to float on top, as oil floats on water. It is calculated that at a height of thirty miles above sea level the percentage of nitrogen is about 86½ and of oxygen only 10, while at the same altitude the gas hydrogen, which at low levels constitutes less than one-hundredth of 1 per cent of the atmosphere amounts to more than 2½ per cent. Going higher, the percentage of hydrogen is supposed to increase rapidly, until, at an altitude of forty-eight miles, the atmosphere is more than half hydrogen, and at eighty miles above the earth this gas forms 99 per cent of the whole. These figures are not necessarily final; for some authorities believe that the atmosphere contains an unknown gas lighter than hydrogen, while others think that the hydrogen found in the lower air enters into chemical combinations before it can reach the higher levels; but it is beyond doubt that the composition of the upper atmosphere is quite different from that of the lower.

Of course almost any gas may be found locally and occasionally in the atmosphere, but there are several that are always found wherever a refined analysis of the air is made, and others that are generally present. The following is a fairly complete list: Nitrogen, oxygen, water vapor, argon, carbon dioxide, hydrogen, helium, neon, krypton, xenon, niton (radium emanation), ozone, hydrogen dioxide, ammonia and other compounds of nitrogen.

A number of these substances have only become known to science within the last quarter of a century. Argon, though it constitutes nearly 1 per cent of the atmosphere, escaped detection until the year 1894. The investigation of argon led to the discovery of some of the others. In 1895 it was found that the air, as well as certain minerals, contains helium. This substance was not new to science, but it had never before been found on earth. It was discovered in the atmosphere of the sun, by means of the spectroscope, as early as 1868. Terrestrial helium, neon, krypton, and xenon were all discovered by Sir William Ramsay, who also shared with Lord Rayleigh the distinction of discovering argon.

Ramsay has published the following figures for the proportions in which some of the rare gases exist in the atmosphere:

Helium	1	part in	245,320	by volume
Neon	1	“	80,800	““
Krypton	1	“	2,000,000	““
Xenon	1	“	17,000,000	““

Niton, or radium emanation, is one of the products of the disintegration of radium. Niton itself disintegrates very rapidly, one-half of any given quantity disappearing in about four days, and one of its products is helium. The amount of niton in the atmosphere is never more than an infinitesimal trace. Thus we are told that the total quantity of this substance present in the atmosphere of the whole earth up to an altitude of one kilometer (0.6 mile) weighs less than nine ounces, and that each cubic centimeter of air contains among its thirty million million million molecules only between one and two molecules of niton, on an average.

Turning, now, to the more abundant constituents of the atmosphere, we find that oxygen and nitrogen differ strikingly from each other in the fact that, while the former has a strong chemical affinity for nearly all other elements, the latter is chemically inert, having little tendency to unite directly with other elements, though by indirect processes, and chiefly through the agency of plants and animals, a large number of nitrogen compounds are produced. Oxides of nitrogen are formed directly from the atmospheric gases by lightning discharges, and these unite with the moisture of the air to form nitric and nitrous acids. A certain amount of ammonia (a compound of nitrogen and hydrogen) may also be formed by lightning from nitrogen and atmospheric water, but most of the ammonia in the air is derived from the decomposition of plant and animal matters. The compounds of nitrogen that occur in the air are washed down by rain in considerable quantities. Analyses of rain water made in different parts of the world show from one to nine pounds of such substances per acre per annum.

Carbon dioxide (more familiarly known as carbonic acid gas) occurs in the atmosphere in the almost constant proportion of three parts in 10,000 by volume. It is a little more abundant in the air of towns than in the open country or over the ocean, and it undergoes slight periodic variations, but the fact that it is not much more variable is rather surprising, considering that it is continually being added to and abstracted from the air by numerous agencies that have no dependence upon one another. It is supplied to the air by volcanoes, mineral springs, the combustion of fuel, the respiration of animals and plants, and the decay of organic matter. The amount supplied annually by the burning of coal alone is estimated to be equivalent to more than one-thousandth of the total volume of the gas present in the atmosphere at any one time. On the other hand, all green plants, in the presence of sunlight, withdraw carbon dioxide from the air, abstract the carbon from it for the use of the plant, and return the oxygen to the atmosphere. Thus it is estimated that an acre of beech forest takes a ton of carbon out of the air annually. A vast amount of atmospheric carbon dioxide enters into chemical combination with certain rocks at the earth's surface. Lastly, a large quota of this atmospheric gas is absorbed by sea water, and certain authorities have seen in this process a regulator of the total amount in the atmosphere, the hypothesis being that the ocean gives back some of the carbon dioxide whenever this substance becomes deficient in the air.

Water vapor—i. e., water in an invisible gaseous form—is always present in the atmosphere, but its amount is subject to wide fluctuations. An important fact in this connection is that, at any given temperature, the air can hold only a definite amount of this vapor. This maximum amount increases rapidly with temperature. When the air is fully charged with water vapor it is said to be "saturated." Properly speaking, the temperature limits the amount of the vapor that can occur in a given space, regardless of the presence of the other constituents of air, and in scientific language it is the vapor itself that is said to be saturated, and not the air; but in a popular book about the atmosphere, where much has to be said about atmospheric water vapor, adherence to scientific usage in this matter invariably leads to awkward complications. Speaking, then, in familiar terms—when the air is saturated with water vapor, a fall in temperature causes some of the vapor to condense in visible form, as cloud, fog, rain, dew, snow, hail, etc. As the sole source of these various forms of moisture, and on account of the important part it plays in many atmospheric processes, water vapor is, from a meteorological point of view, the most interesting constituent of the atmosphere.

One more atmospheric gas requires notice here, both on account of the great popular interest attaching to it, and because of recent scientific discoveries concerning it—viz., ozone. This substance may be described, in nontechnical language, as a concentrated form of oxygen. It is one of the most powerful oxidizing agencies known, and has found useful applications in medicine and various industries. Its popular renown, however, is due to the fact that for many years it was regarded as a great natural purifier of the atmosphere. "Life-giving ozone" was reputed to be abundant in the air of forests, mountains, and the seashore. Systematic observations were made of the prevalence of ozone at different places throughout the world, generally by noting the change of color of test-papers exposed to the air. These "ozonometric" observations are now a closed chapter in the history of meteorology, for it has been found that the reactions of so-called ozone papers are due chiefly or entirely to atmospheric substances other than ozone. Moreover, direct examination of the air by more accurate methods—including samples collected with the aid of kites and balloons up to a height of several thousand feet above the earth—shows that the amount of ozone in the whole of the lower atmosphere is exceedingly small—much too small to be of hygienic significance. Whatever ozone is produced from oxygen at such levels by lightning discharges or other possible agencies probably enters promptly into chemical union with oxidizable substances and therefore has only a brief existence.

On the other hand, the spectroscope has brought us evidence that far aloft in the atmosphere, many miles above the earth, ozone is quite abundant. Here it is supposed to be generated by two agencies—the electrical discharges of the aurora and ultra-violet radiations from the sun. The ultra-violet rays that help to produce it are prevented from reaching the earth, and astronomers are thus deprived of much interesting information they might otherwise obtain concerning the spectra of the sun and stars. However, as the present Lord Rayleigh has pointed out, we can console ourselves for this fact by reflecting that if the ozone did not shut off much of the ultra-violet light from the sun, this light would probably ruin our eyesight; or, rather, we should be put to the inconvenience of constantly wearing some sort of protective spectacles in the daytime.

The high-level ozone is further interesting because of exercising a certain control over the temperature of the lower air. It is more transparent for incoming solar radiation than for outgoing earth radiation. Hence, when it is unusually abundant, it should raise the general temperature of the earth. This presumably happens when the condition of the sun is such that an unusual amount of ultra-violet radiation reaches the upper atmosphere, a fact that must be taken into consideration in any attempt to establish a relation between climatic fluctuations and the sun-spot period.

The lowest part of our atmosphere is the densest because it is compressed by the weight of the air above it. Thus it happens that, although the atmosphere is at least several hundred miles in height, one-half of its mass—i. e., one-half of the quantity of matter in it, as expressed in terms of weight—lies below an altitude of about 3½ miles above sea level, while about seven-eighths lies below the ten-mile level. Above about five miles the atmosphere is too rare to support life. The highest clouds seldom occur higher than ten miles. Storms hardly ever reach that height. In short, the phenomena of life and the phenomena of weather are confined to a layer of air so shallow, in proportion to the dimensions of our globe, that on the surface of an orange it would be represented by a sheet of thin paper.

The actual height of the atmosphere is not even approximately known. There are theoretical reasons for believing that even at a height of thousands of miles above the earth there are molecules of atmospheric gases still under the control of the earth's gravity, while at such levels yet other atmospheric molecules are constantly escaping into outer space. At an altitude of fifty miles the atmosphere is less than 1/75,000 as dense as at sea level—i. e., more than seventy-five times as attenuated as the best "vacuum" obtainable with an ordinary mechanical air pump. At 300 miles it is computed to be about one two-millionth as dense as at sea level.

The loftiest atmospheric phenomenon that we can observe directly is the aurora, which has been photographed up to heights of more than 300 miles. The altitude of the aurora is determined by simultaneous observations made at two or more points, and the same is true of shooting stars and their trails, which seem to be especially numerous between the levels of sixty and ninety miles. The so-called "noctilucent clouds," which shone by reflected sunlight throughout the night for some years after the great eruption of Krakatoa and were supposed to consist of fine dust from that volcano, were probably about fifty miles above the earth. From the duration of twilight we infer that above about forty-five miles the air is so tenuous that it cannot reflect sunlight to the earth. Clouds furnish information concerning the movements of the air at various levels up to ten miles or more. Observations on mountains contribute further to our knowledge of the atmosphere above the ordinary levels of habitation.

Of all methods of exploring the atmosphere in a vertical direction, the most fruitful is the use of kites and balloons. In recent years investigations of this character have become so extensive and so highly specialized that they are regarded as forming a separate department of meteorology, known as Aerology. It is by virtue of developments in this field that meteorology has become "a science of three dimensions." Formerly meteorologists could do but little more than study the *bottom* of the weather, so to speak; but now they observe it and chart it at all levels. The weather forecaster has daily reports of conditions aloft to aid his predictions both for dwellers on *terra firma*and for the aeronaut; while the accumulated data of upper-air observations are throwing new light on many difficult atmospheric problems.

Scientific balloon ascents are no novelty. Some were made in the eighteenth century, and many famous ones in the nineteenth, including those of Biot, Gay-Lussac, Glaisher, Tissandier, and other daring *savants*. The "record" height for such personal ascents was attained in 1901, when Berson and Süring rose to 35,400 feet above Berlin. Kites were sent up for meteorological purposes even before Benjamin Franklin's immortal experiment in 1752. Modern aerological methods have, however, little in common with these pioneer undertakings. Existing types of box kites, pilot balloons, sounding balloons, and self-registering meteorological apparatus for upper-air research were developed in the latter part of the nineteenth century, but their use did not begin to bulk large in meteorology until about the beginning of the present century. The epoch-making event in these undertakings was the discovery of the *isothermal layer*.

It is a matter of common knowledge that the air is found to be colder the higher one ascends in the atmosphere. Thus, even in equatorial regions, the tops of high mountains are mantled in perpetual snow. The rate of this temperature decrease averages about 1 degree Fahrenheit per 300 feet.

Previous to the year 1902 meteorologists supposed that the atmosphere continued to grow steadily colder in an upward direction indefinitely; but in that year a Frenchman, M. Teisserenc de Bort, who had sent aloft hundreds of small unmanned balloons carrying self-recording thermometers, announced that above a height of about six and one-half miles the temperature ceased to fall. In fact, he found that at about that level there was often a slight *increase* of temperature with increasing altitude for a certain distance upward, and then a nearly uniform temperature as high as the balloons ascended. This announcement was at first received with considerable skepticism, but very soon similar observations were reported from other parts of the world. A new "shell" of the atmosphere had been revealed—which, as subsequent investigations proved, differs from the lower air in other respects besides temperature—and it was at first named by its discoverer the isothermal layer. He afterward substituted the name *stratosphere*, now generally employed. In distinction from the stratosphere, the part of the atmosphere lying below it is called the *troposphere*.

The stratosphere has been explored in widely scattered parts of the earth, and information concerning it is daily accumulating. Although it extends over the whole world, the altitude at which it begins is by no means uniform. The altitude is greater in summer than in winter; it varies with the barometric pressure at the earth's surface; and it is decidedly greater over the equator than over the poles. The last fact leads to an interesting paradox. Since over the equatorial regions the temperature keeps on falling with ascent to a greater height than in other latitudes, it is here that the lowest temperatures in the atmosphere are found. A sounding balloon sent up from Batavia, Java, in November, 1913, recorded 113° below zero Fahr., the lowest air temperature ever observed. In middle latitudes the temperature of the stratosphere averages something like 68° below zero Fahr.

The temperature of this interesting upper atmosphere varies a good deal, both vertically and horizontally, but never shows the steady vertical variation that characterizes the lower air. The stratosphere contains no clouds (except occasional dust clouds), and has a circulation quite distinct from that of the troposphere, the exact nature of which, however, has not yet been determined.

The sounding balloon, already mentioned, is one of the four principal types of aerial vehicle used in the study of the atmosphere, the others being the pilot balloon, the captive balloon, and the kite. The sounding balloon, or *ballon-sonde*, is a small free balloon that carries no human aeronaut, but instead a set of superhuman meteorological instruments, which register the temperature, the barometric pressure, and sometimes the humidity continuously and automatically through the whole course of their journey. The record is traced on a revolving drum or disk, usually coated with lampblack. In its commonest form the balloon is made of india-rubber, and when launched is inflated to less than its full capacity with hydrogen. As it rises to regions of diminished air pressure it gradually expands, and it finally bursts at an elevation determined approximately in advance. A sort of parachute, or sometimes an auxiliary balloon, insures a gentle fall to the ground. Attached to the apparatus there is generally a ticket offering the finder a reward for its return, and giving instructions as to packing and shipping. Sooner or later it generally comes back. In fact, the large percentage of records recovered, even in sparsely settled countries, is not the least remarkable feature of this novel method of research. Thus, of seventy-two balloons sent up by a Franco-Swedish expedition in Lapland, forty-one were eventually recovered with their instruments. One of these fell into a lake and was found after three years.

No instruments are carried by the pilot balloon, which merely serves to show, by its observed drift, the speed and direction of the air currents at different levels. The pilot balloon is sighted, while in flight, through a special form of theodolite, or, preferably, two theodolites some distance apart. Several ingenious methods have been devised for computing and plotting its actual course through the air. Such balloons, apart from their use in scientific research, have become one of the principal adjuncts of aeronautical undertakings all over the world, and are also used by artillerists to enable them to make proper allowance for the deflective effect of the wind on the flight of projectiles. Hundreds of thousands of pilot balloons were sent aloft for military purposes during the world war.

Meteorological instruments are sent up attached to kites or captive balloons whenever—as in connection with weather forecasting—the observations must be obtained more promptly than would be possible with the aid of sounding balloons, but such devices can attain only moderate altitudes. Kites have been raised to about four and one-half miles above sea level, as compared with nearly twenty-two miles reached by a sounding balloon and twenty-four miles by a pilot balloon. The average height of sounding-balloon ascents is about ten miles. As already stated, balloonists have risen to 6.7 miles. This is a little higher than the best aeroplane record.

The use of the aeroplane for making meteorological observations is still quite limited, but will inevitably increase. One other device gives promise of yielding valuable aerological information, on account of its ability to rise to extraordinary altitudes. This is a special form of rocket, recently invented by Prof. R. H. Goddard, which is propelled by several successive discharges of an explosive in the course of its upward flight, and with which the inventor thinks it will be possible to explore the whole vertical extent of the atmosphere. Meteorological apparatus for use with the Goddard rocket has been planned by Mr. S. P. Fergusson of the Weather Bureau.

The atmosphere presses down upon the earth with a weight that, at sea level, amounts to about 14.7 pounds to the square inch, on an average. This pressure is, at any point, exerted equally in all directions; it acts, for example, on the whole surface of the human body, and this means that a man of average size lives under a burden of some seventeen tons of air. He is not incommoded because the pressure from without is balanced by that of the air that permeates his body.

The pressure of the atmosphere decreases upward at nearly the same rate as its density. Thus on mountains and plateaus it is considerably less than in lowlands. At no place is the pressure invariable, nor is there a constant relation between pressure and altitude, but, knowing approximately the average atmospheric pressure over the earth's surface, and knowing also the area of the latter, we can compute in round numbers the total weight of the atmosphere—about 5,000,000,000,000,000 tons. This is about 1/1,200,000 of the entire weight of the earth.

CHAPTER II

THE RESOURCES OF THE ATMOSPHERE

In the economic stress of our times much is heard about "natural resources." This phrase suggests to most people's minds the store of minerals, fuels, and oil locked up in the ground; the waters available for drinking, washing, irrigation, power production, and navigation; the forests and other natural growths of useful vegetation; and the soil in which we raise our crops. A moment's reflection, however, will show that this is a one-sided enumeration. The resources of the *atmosphere* are as essential to humanity as those of the land and the waters, if not more so.

The coal that is dug out of the earth consists mainly of carbon, which, in bygone ages, was extracted by plants from the air. Moreover, it would be of no use to us if we did not have the oxygen of the air in which to burn it. Neither could we smelt metallic ores without oxygen. All our forests and all our crops draw far more of their solid substance from the air than from the soil. Fuel and water are valuable sources of power, but so is the moving air that drives sailing ships and windmills, and the atmospheric pressure that helps to operate suction pumps. It is the moisture of the air that feeds our streams and, directly or indirectly, waters all plants that grow upon the land. Lastly, it is the atmospheric oxygen that we breathe that keeps us from very speedily becoming incapable of using any of the other resources of Nature.

Air and water together contain, in their oxygen, nitrogen, hydrogen, and carbon, all the major constituents of our foods in unlimited abundance. It is tantalizing to think of the slow and roundabout way in which these things are wrought into edible shape—and the prices we have to pay for them. No less tantalizing, when coal is scarce and costly, is the thought that every vagrant breeze is laden with the carbon dioxide from which the chemistry of living plants so readily extracts the chief element of fuels. The total carbon dioxide of the atmosphere amounts to something like 2,200,000,000,000 tons, equivalent to 600,000,000,000 tons of carbon.

We have spoken of the utility of the air as a source of power. It is, perhaps, even more useful as providing an easy means of storing and transmitting power. The engineer stores up energy in a mass of air by compressing it. When the air subsequently expands it gives up its energy, and, in so doing, may be made to perform a variety of useful tasks. By a somewhat analogous process energy is applied to creating a vacuum, in order that the ordinary pressure of the atmosphere may be made available for doing a particular piece of work. The suction pump, the siphon, and the vacuum cleaner furnish examples of this process; and so do such familiar operations as sucking beverages through a straw and filling a medicine dropper.

From crude types of bellows, with which, from remote antiquity, air was compressed for the purpose of blowing fires, have been developed a host of wonder-working appliances of the present day, such as the air brake, the pneumatic tube, the compressed-air locomotive, diving apparatus, the caisson, certain kinds of refrigerating machinery, and a long list of pneumatic tools. To cap the climax of ingenuity in this field, methods involving both the compression and the expansion of air have been discovered whereby this invisible, elusive substance may be changed to a visible liquid and a visible solid; a process having extremely valuable applications, as we shall presently see.

Compressed air, as a means of transmitting power, rivals such mechanical devices as gearing, belting, and rope drives, when it is applied near the compressor; or it may be conducted for many miles in pipes, thus competing with the electric current; or, finally, it may be transported in tanks to the place where it is to be used, a process analogous to the use of the electric storage battery. Compressed air has, moreover, certain advantages over other methods of transmitting power for a number of special purposes. Thus for use in coal mines it is safer than electricity because it is free from the danger of sparks. There are a great many cases in which the air itself is used in the process to which the power is applied, as in different kinds of air blast, from the simple bellows to the blowers of blast furnaces; also in aerating apparatus, oil and fuel burners, spraying, cleansing, etc.

A familiar form of air compressor is the hand pump used for inflating bicycle tires. This simple device illustrates two important facts; first, that a considerable amount of energy must be used to overcome the expansive force of the air, and, second, that part of the energy applied to the pump produces heat. That the heat thus produced and dissipated in the surrounding air represents a loss of energy is apparent; but energy is wasted in another way that is, perhaps, not so evident. When a gas is heated its expansive force is increased. Hence, on account of the heating of the air in the tire, the pump has to do more work to accomplish a given amount of compression than it would need to do if the air remained cool.

In order to avoid this loss, the air compressors used for industrial purposes are provided with some sort of device for keeping the air cool during compression. This is accomplished by a spray of water inside the compressor cylinder, or, more commonly, by inclosing the cylinder in a water jacket. In producing high pressures, the air is compressed by degrees in two or more cylinders, and cooled between the successive stages. Lastly, before compressed air is applied to driving tools or machinery, it is often reheated to increase its pressure. For most industrial purposes the pressure of compressed air does not exceed 75 pounds to the square inch (5 "atmospheres"). For charging the tanks of compressed-air locomotives, for liquefying gases, and a few other purposes, much higher pressures are used. In laboratory experiments air has been compressed to the enormous pressure of 60,000 pounds to the square inch, or 4,000 atmospheres. At a pressure of 14,000 pounds to the square inch compressed air has been successfully used for blasting in mines in place of ordinary explosives.

The use of pneumatic tools began in the sixties of the last century, when pneumatic drills were employed with conspicuous success in the construction of the Mont Cenis and Hoosac tunnels. Such tools are now indispensable adjuncts not only of tunneling and mining, but also of nearly every department of metal-working and wood-working, and have contributed incalculably to the welfare of mankind.

Imagine a workman with an ordinary hammer driving such a tool as a chisel, punch, or calking iron, and estimate the amount of work accomplished in the course of a day spent in this wearisome labor. Then consider how such operations are performed with the help of that versatile substance, air. The pneumatic hammer consists of a piston working in a cylinder, to which compressed air is conveyed from a compressor by means of a flexible hose. The hammer is so designed that the air causes the piston to work back and forth with great rapidity. A chisel, rammer, or other percussion tool is loosely fitted in the nose of the hammer, so that the piston will strike it a blow at each forward motion. The workman has nothing to do but hold the tools in place. With a common hammer or mallet a workman will strike from twenty to a hundred blows a minute, according to the nature of the work. The speed of the pneumatic hammer ranges from 1,000 to 20,000 blows per minute, so that its sound is a continuous buzz. Such hammers are used for calking, chipping, riveting, and a great number of other purposes.

In another large class of pneumatic tools work is done by rotation instead of percussion. The piston is replaced by a motor, which turns an auger, drill, or other tool for such operations as boring, screwing, reaming, etc.

The use of pneumatic tubes for transporting letters, parcels, and the like, although suggested as early as 1667, has been in practical operation only since 1854, when a tube 220 yards long was built in London to convey telegraphic dispatches. The articles to be transported are placed in a carrier fitting closely inside the tube and propelled either by introducing air under pressure behind it or by exhausting the air in front of it. Scores of miles of such tubes laid underground are now in operation in London, Paris, Berlin, New York, and other large cities for carrying mail matter. In the United States the pneumatic cash carrier, used in stores, is the commonest application of "pneumatic dispatch," as this system of transportation is called.

The use of compressed air instead of a brush for applying paint, varnish, and whitewash is a further illustration of the versatile possibilities of air as a means of transmitting power.

When an inclosed body of air or other gas is subjected to pressure, its volume is diminished and its density is increased. It is natural to inquire what will happen if the external pressure be increased indefinitely. Will the inclosed substance eventually cease to be gaseous and become a solid or a liquid? The answer to this question, furnished about half a century ago through the researches of Thomas Andrews, is that no amount of pressure will liquefy a gas unless its temperature is below a certain point. This point, known as the *critical temperature*, is widely different for different substances. For most of the atmospheric gases it is exceedingly low. Thus oxygen must be cooled to 118° below zero Centigrade (180° below zero Fahrenheit) before it will liquefy under any pressure, and the critical temperature of nitrogen is still lower. Efforts to liquefy the gases of the atmosphere were unsuccessful for a long time on account of the difficulty of attaining such low temperatures.

Nowadays the problem is so completely solved that the manufacture of liquid air is a commonplace commercial enterprise, and millions of gallons are produced every year. Liquid air is the principal commercial source of pure oxygen, nitrogen, and other gases found in the atmosphere. It is also used as a refrigerating substance in various industrial and scientific processes, and new uses are being found for it from year to year.

Like many other latter-day miracles, compared with which the alleged feats of necromancy seem tame and puerile, the liquefaction of air is founded on quite simple principles. The earliest commercial process was invented, in its main features, by Linde in 1895, and the newer processes are merely modifications of this one.

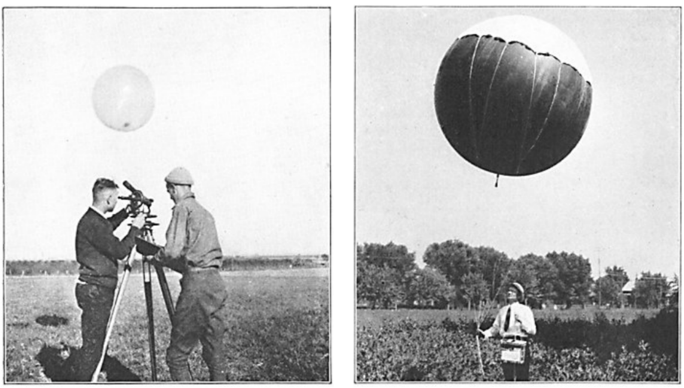
Experiments of the English physicists Joule and Thomson showed that when a gas under pressure is forced through a small orifice, beyond which it expands, it undergoes a certain amount of cooling. This fall in temperature, known as the "Joule-Thomson effect," is generally quite small, but Linde devised a means of multiplying it in his "regenerative cooling process." The air to be liquefied is first compressed to, say, 100 atmospheres, cooled as much as possible by water, and passed through a long spiral tube. At the end of the spiral it escapes through a small nozzle, and is thus somewhat further cooled by the effect above mentioned. This cooled air then passes back around the spiral tube, and causes still more cooling of the air in the latter. The escaping air is again compressed and goes through the same process as before. Thus its temperature grows constantly lower, until finally the stream issuing from the nozzle is a liquid instead of a gas. The liquid collects in a reservoir, from which it can be drawn off when desired.

The liquid air thus obtained has a temperature of about 315° below zero Fahrenheit. It is generally drawn into a vessel called, from the name of the inventor, the Dewar flask, which is open at the top, but otherwise insulated from the temperature of the surrounding air by having a double wall, with a vacuum between the walls. The familiar thermos bottle is constructed on the same principle. In such a vessel liquid air can be kept for hours and even days, and it is thus available for use in many interesting laboratory experiments.

Liquid air looks much like water, except for its slight bluish color. It boils—i. e., changes back to ordinary air—at a temperature only slightly above that at which it is produced, and this boiling, of course, goes on rapidly at the surface of the liquid, owing to absorption of heat from the air above. Liquid air is lighter than water, upon which it consequently will float. A cubic foot of liquid air is the equivalent of about 800 cubic feet of ordinary air at 60° Fahrenheit and atmospheric pressure.

The curious effects of liquid air, only a few of which can be mentioned here, are not irrelevant to the subject of atmospheric resources, since they aid in various ways in carrying out important scientific researches. Almost all liquids are solidified and almost all solids are hardened and stiffened by immersion in liquid air. Alcohol is promptly frozen in it, and at the same time gives out so much heat that the liquid air boils violently and the congealing alcohol overflows the vessel in a little avalanche of snow. India rubber becomes as brittle as glass. Meats become so hard that when struck by a hammer they ring like steel. Chemical action is enormously reduced by exposure to the low temperature of liquid air, and so is the electric resistance of metals. One might suppose that such a temperature would be fatal to all forms of life, but this is not the case. A goldfish, frozen solid in liquid air, revives and swims vigorously a few seconds after being replaced in water. Bacteria survive hours of exposure to the temperature of liquid air, while the seeds of higher plants, even after several days of similar treatment, sprout the same as other seeds.

Most of the atmospheric gases have not only been liquefied, but also frozen solid. An important exception is helium, which has been liquefied only at a temperature of 452° below zero Fahrenheit. The remarkable feat of liquefying helium was accomplished in 1908 by the Dutch physicist Kamerlingh Onnes, who subsequently, in his attempts to solidify this substance, attained the unprecedented temperature of less than 2 (Centigrade) degrees above "absolute zero," or 456° below zero Fahrenheit, by the rapid evaporation of the liquid under greatly reduced pressure.

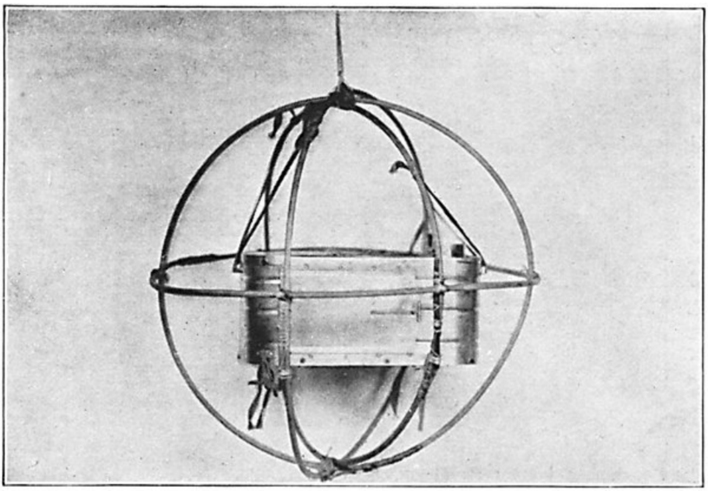


Exploring the Upper Air. Left: Beginning of a pilot-balloon flight. Right: Sending up a sounding-balloon. Note the parachute, which wafts the basket of instruments gently to the ground after the balloon bursts. (*Photographs from U. S. Weather Bureau.*)

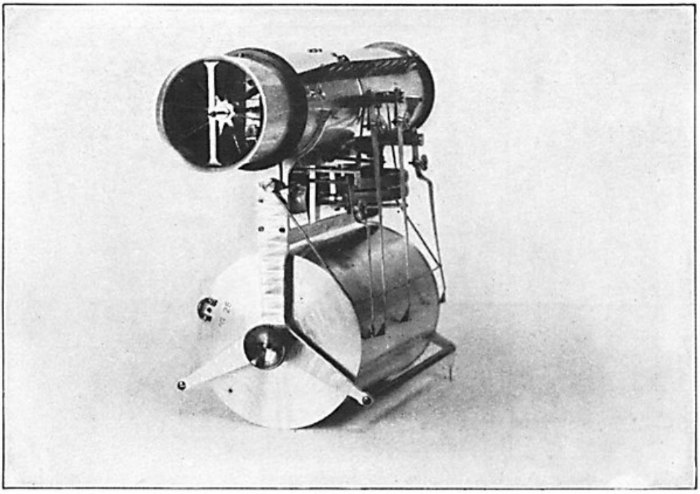
Although, when air is liquefied, the oxygen and nitrogen are condensed simultaneously, the latter has a lower boiling point than the former and therefore passes off more rapidly when the liquid is allowed to evaporate. This fact makes it possible to separate the two substances, by the process known as "fractional distillation," and hence liquid air plants have been established for the special purpose of manufacturing oxygen and nitrogen, for both of which there is a large and growing commercial demand. Scores of millions of cubic feet of oxygen are used every year in the wonderfully efficient process of welding metals with the oxyacetylene blowpipe, the flame of which has a temperature of about 6,000° Fahrenheit. Most of the supply now comes from liquid air. An equally large amount is used in a recently introduced method of cutting metal. The object to be cut is first heated to incandescence, after which a jet of oxygen is played upon it. The metal actually burns away in the stream, and a clean cut is made like that of a saw. It is interesting to reflect, when we fill our lungs with oxygen in order to keep our bodily machinery in operation, that the same atmospheric gas is applied to the building of motor cars, bicycles, safes, boilers, and battleships. Cartridges made of lampblack, dipped for a few moments in liquid oxygen and then primed with a fulminate cap, constitute an explosive as powerful as dynamite and much cheaper to produce. A small percentage of oxygen added to the air supplied to blast furnaces has been found to effect a great saving of fuel used in the furnace.

The most important industrial demand for nitrogen is for use in "fixation" processes—i. e., for making nitrogen compounds to be used as fertilizers, explosives, etc. Before describing these processes, it may be of interest to mention that some of the "rare" gases of the atmosphere are now obtained on a commercial scale as by-products of the manufacture of oxygen and nitrogen from liquid air. Thus neon, on account of its exceedingly small resistance to the passage of electric discharges, is a promising substance for filling glow lamps; especially as means have been found of correcting the glaring red color of the light which characterized the original neon lamps. Argon is likewise used for filling electric lamps.

The idea of using the unlimited store of atmospheric nitrogen for the benefit of agriculture and the manufacturing industries has been very prominently before the public in recent years, and gained special notoriety during the late war, when great efforts were being made to increase the supply of nitrogenous materials suitable



Meteorograph for use with Sounding Balloon. (Fergusson pattern. U. S. Weather Bureau, 1919.) The aluminum case, surrounded by hoops of rattan to protect the apparatus when it falls to the ground at the end of the flight, contains a set of very light self-registering meteorological instruments. (*Photograph from U. S. Weather Bureau.*)



Kite Meteorograph. (U. S. Weather Bureau Pattern.) The four pens record the barometric pressure, temperature, humidity, and wind-force on a sheet of paper wound around the large cylinder, which is turned by clockwork. Note the fan wheel inside the tube, for measuring the force of the wind. The apparatus is made chiefly of aluminum and is inclosed in an outer case of aluminum when sent aloft attached to the kite. (*Photograph from U. S. Weather Bureau.*)

for use in explosives. Nitrogenous matters in the soil are indispensable to the growth of plants, and as long ago as 1898 Sir William Crookes, in an address before the British Association for the Advancement of Science, alarmed the world by pointing out the possibility of a general famine owing to the prospective exhaustion of Chilean nitrates and other sources of nitrogenous fertilizers. Nitrogen also enters on an immense scale into the composition of many industrial products besides explosives. No wonder popular writers have dwelt upon the fact that the atmosphere contains far more nitrogen than mankind needs for every possible purpose—actually something like 20,000,000 tons over every square mile of the earth's surface.

A widespread misunderstanding, however, prevails as to the problem involved in utilizing this supply of nitrogen. Free (i. e., uncombined) nitrogen is of no use as a fertilizer, and it cannot be readily used in the arts. The process of extracting it from the atmosphere is an easy one, thanks to the liquid air industry. The real difficulty is to make this inert gas enter into chemical combination with other substances, forming useful compounds such as ammonia and nitrates; in other words, to "fix" it.

As we have stated on another page, lightning discharges cause nitrogen and oxygen to combine in the atmosphere, and perhaps also combine nitrogen and hydrogen to form ammonia. There is one other natural process by which atmospheric nitrogen is fixed. Certain species of bacteria are able to extract this gas from the atmosphere and combine it with other materials. Some of these bacteria are independent organisms, while others form colonies of parasites growing on the roots of higher plants, chiefly members of the pea family. In the latter case the bacteria use the nitrogen of the air and carbohydrates drawn from the roots on which they grow to form nitrogenous compounds, which are, in part, transmitted to the host plant.

Unfortunately these natural processes do not suffice to maintain agricultural soils in a high state of fertility. Mineral deposits of combined nitrogen are practically limited to the nitrate fields of Chile, from which more than two million tons of nitrate of soda are exported annually; but this supply cannot last more than a few decades. Combined nitrogen in the form of ammonia is supplied on a large and rapidly growing scale from by-product coke ovens, and another perennial source of nitrogenous matter is found in animal and vegetable refuse of all kinds, including fish scrap and slaughter-house refuse, garbage, sewage, manure, etc. Since, however, the demands of agriculture and the manufacturing industries greatly exceed the total amount of combined nitrogen obtainable from all these sources, the ingenuity of inventors has been spurred to the task of fixing atmospheric nitrogen by artificial methods, and several such methods have now been put in operation commercially. Their combined product at present constitutes nearly one-third of the total nitrogen supply of the world.

It is not proposed here to describe these methods in detail, but it may be mentioned that one of them, known as the "arc process," imitates the action of lightning in combining the nitrogen and oxygen that occur naturally in the air, while the others utilize nitrogen that has been previously separated from the air by the liquid air process. The arc process requires, for commercial success, a large supply of cheap electrical power, and it is at present almost confined to Norway and Sweden, where electricity is obtained from waterfalls. In this process air is blown through a huge electric flame, spread out by a powerful electromagnet. The air yields nitric oxide, which is combined with water to form nitric and nitrous acids, and these substances are combined with others to form marketable products. The most widely used fixation process, and the one which the United States Government proposed to employ in the large plants that were in course of construction in this country at the close of the war, is known as the "cyanamide process." This process requires, as a part of its raw materials, large supplies of limestone and coke, from which calcium carbide is made in an electrical furnace. The calcium carbide, at red heat, absorbs nitrogen, forming an intermediate product from which, by further processes, are made ammonia and nitric acid. A third method of fixing atmospheric nitrogen, which has been applied on a vast scale in Germany and is now coming into use in other countries, is commonly called the “Haber process.” In this process nitrogen is combined with hydrogen, obtained from water, to form ammonia, the combination being facilitated by the presence of what chemists call a “catalyzer,” i. e., a substance that enables other substances to combine without itself undergoing any change. Several different catalyzers have been used in the Haber process.

Two or three other methods of nitrogen fixation are beginning to assume commercial importance.

While the power of the wind holds an important place among the resources of the atmosphere, it cannot be said that the utilization of this resource has undergone developments in modern times at all comparable with the striking inventions and discoveries we have just been recording, if we except the use of the wind in aeronautics. Atmospheric resources used by aeronauts will be discussed in subsequent chapters.

The chief use made of the wind to-day, as in ages past, is to propel sailing ships, and its use for this purpose is, of course, of less importance, in a relative sense, than it was before the introduction of steam. The importance of windmills has also greatly declined. This fact was strikingly brought out some years ago when the United States Bureau of Statistics collected, through American consuls abroad, detailed information concerning the use of the windmills in foreign countries. In most parts of Europe windmills are rapidly disappearing. In Holland, for example, the traditional home of the windmill, the perpetual task of draining the polders is now performed by steam pumps, and the total number of windmills is estimated to be only about one-tenth what it was centuries ago. Our own country is probably the only one in which the use of windmills is increasing. The modern American windmill, with its disklike assemblage of numerous light sails, and ingenious contrivances for veering, reefing, etc., is a much more efficient contrivance than the old-fashioned windmill; but its utility, like that of other windmills, is limited by the irregular force of the winds.

For years the hope has been entertained that the windmill would eventually become a common means of generating electricity, but this hope has not yet been realized, though isolated installations of this character are in successful use.

CHAPTER III

THE ATMOSPHERE AS A HIGHWAY

Within the last few years the atmosphere has assumed a new and tremendous importance in human affairs as a medium that affords facilities for travel and transportation far superior, in many respects, to those offered by the land or the water. The aerial highways are now open for business and pleasure. This is a fact that the majority of people find it difficult to realize. The navigation of the air on a general scale has so long been looked upon as a dream of the future that we cannot readily adjust our minds to the reality.

The story of the slow steps by which this momentous fact has been brought to pass is far too long to be told here. What we purpose to do in the present chapter is to sketch the multifarious uses to which man is now applying the aeronautical knowledge and skill that he has acquired. At the same time we shall anticipate, to some extent, the developments of the near future; for the lines of progress are so clearly marked out that it is possible to do this without giving too much rein to the imagination.

In a subsequent chapter, dealing with Aeronautical Meteorology, we shall touch briefly upon the mechanical principles that underlie aerial navigation, by way of preface to a more detailed description of the conditions of wind and weather encountered by aircraft, and of the services that the meteorologist is rendering to the aeronaut.

The history of aeronautics may be divided into two periods, with the year 1914 as the dividing line between them. Before the great war the many brilliant minds that were trying to solve the problems of aerial navigation received comparatively little help or encouragement from humanity at large. The airship and the aeroplane were both accomplished facts, but most people looked upon them as ticklish contrivances of very little practical value. From the year 1909 onward aviation occupied an immense share of public attention; liberal prizes for aerial feats were offered; new records for speed, altitude, and endurance were made from day to day; but to the public, and perhaps to most of the aviators themselves, all this meant merely that a new and thrilling sport had been created, rather than a new art of boundless utility. Very few business men felt inclined to invest money in the development of aircraft, and the governments of the leading nations, with a single exception, were incredibly blind to the importance of building air fleets for use in war. The exception was Germany, which not only gave strong support to Count Zeppelin in the building of his dirigibles, but developed military aviation to such an extent that she entered the war with about 800 aeroplanes and a thousand trained pilots.

With the outbreak of the war the budding art burst into vigorous bloom. Unlimited funds were now available for experimenting and building. Thousands of flyers invaded the air, and the battle zone was a testing ground on a vast scale, where one improvement was hardly introduced before it was replaced by another. Some of the best engineering talent of the world was diverted from many and various fields to the one task of supplying the demands of the military aeronauts for more speed, more power, more reliable motors, better materials and appliances. Thus the war not only perfected aeronautics—especially aviation—as an art, but practically created it as an industry. At the close of hostilities the world found itself in possession of a vast fleet of aircraft, a multitude of aircraft factories, and a great army of trained aeronauts. For a time people asked—and perhaps some still ask—"What shall we do with them?"

There are many answers to this question, and new ones are coming to light every day. In the aggregate they mean that a new era has dawned in human affairs—the era in which the sky has been annexed to the world in which man lives. Henceforth we shall have more elbow room. We shall no longer be imprisoned in Flatland, but set free in Spaceland. It is impossible to foresee all the implications of this fact, but those that are already apparent suffice to fill us with enthusiasm.

Some of the most vexed problems of the present day will soon be solved by aerial navigation. Take that of our overcrowded cities. Everybody knows how first the trolley car and then the automobile helped to relieve the congestion of towns by making it feasible for people to live many miles from the scenes of their daily work, but at the same time seriously swelled the traffic of the streets in business quarters. Aircraft will bring far greater improvements in this respect, without corresponding disadvantages. In a few years it will probably be no inconvenience to live fifty or a hundred miles from one's place of business. Aeroplanes, built for carrying several passengers in perfect comfort, *already* fly at speeds of from 120 to 150 miles an hour, and are almost independent of weather. Much greater speeds will doubtless be common in the future. Automobiles, all running on the same level, have almost reached the limit of space available in our busiest streets, and, under such conditions, they have nearly lost the advantage of speed they once possessed over the obsolete horse-drawn vehicle. There can never be such crowding in the air. When a great volume of aerial traffic is concentrated toward the centers of towns, people will fly their vehicles at various prescribed levels, and probably "park" them on many-storied landing stages. New methods of landing will undoubtedly be invented. The device known as the "helicopter," which has made progress toward the practical stage during the past year, points out the possibilities in this direction. In the helicopter the propeller blades revolve around a vertical shaft, thus permitting the vehicle to rise or descend vertically. A prize of $100,000 has recently been offered by M. Michelin, the well-known French patron of aviation, for the perfection of this device, which may soon revolutionize the design of flying machines.

Mr. Holt Thomas, the Englishman whose foresight and enthusiasm have done so much to hasten the arrival of practical commercial aeronautics, believes that in the near future the main airways of the world will be served by airships rather than by aeroplanes. For long journeys the airship has the advantage that it can carry an ample supply of fuel without encroaching too much upon the space available for passengers and cargo. It is, therefore, especially suitable for transoceanic journeys. Hitherto airships, when not in flight, have been housed in enormous hangars, involving heavy cost of installation and their landing has required the services of hundreds of men—an operation that will probably seem laughable in its crudity to the next generation. The airship of the future will probably never go into a hangar at all except for occasional overhauling, as an ordinary ship goes into drydock. Hence only a few of these costly structures will be needed. While in service the airship will, on reaching an air port, moor herself at the bow to a great steel tower, and swing with the wind as a marine vessel swings at her anchor. At the top of the tower there will be a landing stage for passengers and freight, connected by lifts with the ground below. From the main air ports, thus equipped, will radiate minor air routes, served by aeroplanes, and, in some cases, by flying boats.

Such landing places for airships were predicted by Kipling in his "With the Night Mail"—but the author's vista was of the year 2000! We are not traveling so slowly as that. Consider what it means that the world heard with bated breath of Blériot's flight over the English Channel in 1909; and just ten years later men had flown over the Atlantic Ocean.

We have been writing of the future; but we need not look ahead for illustrations of the practical value of aerial navigation. Useful feats already accomplished are so astonishing in their variety that they make one cautious about assigning a limit to the possible applications of the new art. It has happened, for example, that a man who had booked passage on a trans-Pacific steamer missed his boat at Seattle; whereupon he hired an aeroplane, at a cost of $75, and overtook the steamer on her way down Puget Sound, thus saving some weeks of delay in waiting for the next one. Another man, who produces honey on a large scale, found that spray-poisoned orchards were playing havoc with his bees. He traveled in an aeroplane over the surrounding country, selecting stands for his hives at safe distances from such orchards, and he estimates that this precaution saved him $10,000 in a single year. In August, 1919, a flying boat deposited a bag of mail on the White Star liner *Adriatic* two hours after the ship had left New York.

Several aerial mail routes are now in operation on both sides of the Atlantic. The first regular service of this character in America was begun May 15, 1918, between New York and Washington, and during the first year carried 7,720,840 letters, with few accidents and no fatalities. The first year of service cost the Government $137,900, and the sale of aeroplane mail stamps during the same period yielded a revenue of $159,700. Out of 1,261 possible trips on this route, 1,206 were undertaken, and only fifty-five were abandoned on account of unfavorable weather. During 1919 the Post Office Department not only established other aerial routes, but relegated the aerial mail service to the ranks of the commonplace by reducing the postage on letters carried by aeroplane to the ordinary first-class rate of two cents an ounce.

In Europe lines of fast aeroplanes carrying mails, passengers, and freight daily over regular routes are becoming part of the established order of things. The operators of a line between London and Paris, which was inaugurated in November, 1919, are now planning to establish an hourly service. Some of these lines have been equipped with wireless telephony, so that the pilots can keep in constant communication with numerous stations of the company along the route, and also with one another. They are thus able to obtain, among other things, current information about the prevalence of fog or other atmospheric conditions at points ahead of them. Presumably the passengers who patronize the aeroplane express will also, eventually, enjoy the use of the wireless telephone *en route*. In connection with the new air routes suitable landing grounds, for regular or emergency use, are being laid out at short intervals; the ideal aimed at, for the present, being the so-called "ten-mile chain"; i. e., a series of emergency landing grounds about ten miles apart. From ordinary flying levels a pilot on such a route can always glide to one of these grounds in case his motor fails. The landing grounds will be utilized, under certain restrictions, for grazing cattle and for agricultural purposes, to help cover the cost of rental and maintenance. During 1919 the British Government established a chain of landing grounds in Africa, all the way from Cairo to the Cape.

One of the developments of the war was the use of aeroplanes for photographic mapping. The aeroplane flies over a long tract of ground, and the camera, exposed vertically, takes pictures automatically at fixed intervals. The pictures thus taken are carefully joined together in a single strip. A second tract, parallel with the first, is photographed in the same manner, and so on, until the whole area has been covered. Eventually all the pictures are assembled to form a so-called "mosaic." This process is highly successful for mapping a flat country, but presents difficulties when there are hills and mountains. Some sort of stereoscopic process will probably be perfected for depicting accurately differences in level and producing a "contoured" map.

Although aeronautical mapping does not yet replace old-fashioned methods, it already has several obvious uses. It is especially suitable for the revision of existing maps. Thus the plan of a city can be quickly brought up to date by this process. In the United States the Geological Survey has been engaged for many years in producing large-scale topographic maps of all parts of the country. This work proceeds slowly, and some of the maps are ten or fifteen years old. The contours and other natural features on such a map are still correct, but changes in the region due to the work of man are often extensive. Revision of these features can easily be made by the method above described.

For the preliminary mapping of a new country, by photography or by hand, the aeroplane offers the means of saving an immense amount of time and effort. The surveyor no longer needs to cut tracks through the jungle or scale mountains. No region is very difficult of access to the aviator. The summit of Mount Everest, the highest mountain in the world, is actually a mile lower than the greatest altitude attained by an aeroplane. Aviation has become an important feature of exploring expeditions. Captain Amundsen, the polar explorer, qualified as an air pilot before he embarked on his drift across the North Polar basin, and took aeroplanes with him on that journey. In India the Survey Department has organized a regular aerial photographic and reconnoissance service, and has lately photographed the high waters of the River Sutlej in order to obtain data for a big electrification project. Photographs of the Nile country have also been made for hydrological purposes. British aviators in Mesopotamia have mapped the flood boundaries of the Tigris and provided data for estimating crop areas. In the Philippines an engineer recently made a long aeroplane flight to determine which of three general routes was most suitable for a new railway. Many months of time and thousands of dollars were thus saved, as it was only necessary to send out one party of locating engineers instead of three after the selection had been made.

Recently the aerial surveyor has become the rival of the hydrographer in mapping shoals, channels, submerged rocks, and other features beneath the water. If the water is clear and suitable atmospheric conditions prevail, objects submerged to a considerable depth may be distinctly seen from an aeroplane flying far above the surface. It was on account of this fact that Allied aviators were able to spot submerged German submarines during the World War. The camera, equipped with proper plates and ray filters, can pierce the water even better than the eye. Thus objects have been photographed at a depth of more than 50 feet. British aviators charted the harbor of Rahbeg, on the coast of Arabia, by the process in 1917. In this country the leading exponent of underwater photography is Dr. Willis T. Lee, of the United States Geological Survey, who has taken scores of photographs showing submerged features of the waters adjacent to Chesapeake Bay. It is likely that rivers like the Mississippi, with ever shifting sand bars, will soon be made safe by monthly or weekly mapping from the air. In earthquake regions, such as southern Italy and Japan, the changing coast lines, shallows and harbors can easily be photographed after each new quake, thus keeping navigation open and protecting the lives of mariners.

Another application of this process of sighting submerged objects from the air is the aerial fish patrol. The plan of using aircraft to locate schools of fish appears to have been first suggested by Professor Joubin, of the Oceanographic Institute of Monaco, and it has been carried out with much success in both Europe and America. Its promoters hope that it will eventually revolutionize the fishing industry and add greatly to the world's food supply. In the year 1919 seaplanes from the North Island Air Station at San Diego, California, made regular flights at an altitude of about 500 feet over the adjacent waters as an adjunct to the important fisheries in that vicinity. When a school of fish was detected, the aviator dropped low enough to ascertain the species, and if it proved to be of a commercial kind, such as the sardine, the news was flashed by wireless to the fishing fleet. The ocean in the neighborhood of San Diego was divided into numbered squares, shown on charts, and locations were reported by number. In 1920 a daily patrol was maintained by Navy seaplanes over the waters of Chesapeake Bay in behalf of the menhaden fishery. According to an official report, "the experiments fully demonstrated the commercial value of planes in this fishery." It is believed that aircraft might be used with equal success in connection with the whaling industry.

The United States Forest Service has made considerable use of Army aeroplanes and aviators in patrolling the great forests of the West, where a constant lookout for fires must be kept throughout the summer. There are about 28,000 forest fires in this country every year, and the average area burned over amounts to more than 8,000,000 acres, entailing an average annual loss of $10,000,000 worth of timber. Observations are maintained on mountain peaks and towers, but the aerial watchman commands a much greater range of vision and can readily detect fires in places such as deep canyons where they are, in many cases, hidden from the existing lookout points. When a big fire is in progress, the aviator can quickly ascertain its extent and report the information by wireless to the fire-fighting forces. In case the fire is difficult of access on account of the absence of roads, the fire fighters can be transported to the spot in aeroplanes. It has even been proposed to fight forest fires by dropping bombs filled with fire-extinguishing chemicals. At one time it was thought that aeroplanes might largely replace fixed lookout stations, but experience shows that both systems of observation are desirable. Many foresters favor the use of small dirigible airships in place of aeroplanes, owing to their ability to fly very low, when desired, land in any small clearing, discharge passengers by rope-ladder while hovering over a selected spot, and transport relatively large loads of men and supplies.

Such are a few of the valuable peace-time uses that have already been found for the aerial vehicles that owed their production chiefly to the late war and for the host of pilots trained during the same conflict. Undoubtedly the immediate future holds far more interesting developments in store.

One important practical aspect of aeronautics remains to be mentioned, and that is the question of safety. In their early days the steamboat and the steam railway were both risky contrivances. It is recorded that at one time steamboats were barred from the Thames on account of their dangers. Undoubtedly the tradition of frequent boiler explosions lingered in people's minds long after it had ceased to be a substantial fact. Aerial navigation—and particularly aviation—has now passed beyond the pioneer stage, but it still bears the dubious reputation that it acquired when it was in its infancy. Aerial travel, under standardized conditions, is no longer unsafe. There are good reasons for regarding it already as safer than automobiling. According to a report of the British Department of Civil Aviation, there were 21,000 commercial flights in Great Britain during the six months from May 1 to October 31, 1919, and 52,000 passengers were carried. The total mileage covered was 303,000. Not a single passenger was killed during this period, and only ten were injured. There were two fatalities among pilots and six pilots were injured.

Commander Read, who made the first transatlantic flight, writes on this subject:

"There are some pilots with whom I would refuse to risk my life. But, given a modern machine with the proper attention paid it, and a skillful but conservative flyer, it is as safe a means of rapid transit as an automobile traveling at less than half the speed. Nowadays there is scarcely ever an accident in an aeroplane of standard type due to the fault of material; they are all due to the inexperience or to the dare-devil stunting proclivities of the pilot—the pilot who 'takes chances.'"

Aeronautics is now more than an art. It is a rapidly expanding branch of applied science. Aeronautical engineering has become one of the recognized professions. Some of the leading government laboratories of the world, including the National Physical Laboratory in Great Britain and the United States Bureau of Standards, are devoting their attention to aeronautical research. There are also many unofficial "aerodynamical" laboratories for studying, with the aid of wind tunnels and other apparatus, the many problems pertaining to the physics of flight and the principles of aeroplane designing.

Aeronautical questions have begun to figure conspicuously in jurisprudence. Legislators, as somebody has said, are busy making vertical laws to supplement the old-fashioned horizontal ones. In international law, especially, aerial navigation has given rise to thorny problems and it is already the subject of elaborate international agreements.

The physiological effects of flight and altitude have added a new chapter to the science of medicine. Seasickness has been the crux of the ship's doctor; will "air sickness" prove equally baffling? What are the therapeutic possibilities of flying? Will physicians advise their patients to seek a "change of air" vertically instead of horizontally?

The atmosphere, once monopolized by the birds, has become the abode of man. That is one excellent reason why everybody should acquire a knowledge of meteorology—the science of the air.

CHAPTER IV

DUST AND SMOKE IN THE ATMOSPHERE

When the moralist reminds us that we are children of the dust and predestined to a dusty end, there is a grain of comfort in the discovery that modern science regards dust as one of the most important things in the whole economy of nature. No longer does dust seem an appropriate symbol of insignificance and humility when one surveys the bulk of serious literature that has been written about it, considers the caliber of the men who have devoted the better part of their lives to the study of it, or inspects the great array of ingenious apparatus that has been devised for its investigation.

The dust of which we have to speak in the present chapter embraces all small particles of solid matter found anywhere, or at any time, in the earth's atmosphere. Particular kinds of dust have, of course, their special names. Soot, the visible part of smoke, is a form of dust that has played a very conspicuous part in human affairs; hence the separate mention of smoke in the heading of this chapter.

While there are many agencies that help to charge the atmosphere with dust, the most important of them all is the wind. Let us see what happens when the wind blows over the surface of a dusty road, for example. If the air flowed in a smooth horizontal stream over such a surface, its friction would drag the dust along on the ground, but would not lift it. Such surface drifting, due to the horizontal component of the wind's motion, does, of course, occur, and its effects are strikingly visible in the shifting dunes that often form over a broad surface of sand or snow. All winds near the earth's surface are, however, full of waves and eddies, and in many cases, as over a stretch of strongly heated soil, there are strong updrafts, sometimes extending to a great height in the atmosphere. All kinds of dust are heavier than air, and, contrary to popular belief, never truly “float” in the atmosphere. Dust may enter the atmosphere at high levels, through the disintegration of meteors, or it may be spouted up by volcanoes, but dust blown up from the earth’s surface rises only because the air is rising with it; and, in still air, all dust sinks more or less rapidly toward the ground. The rate of its fall depends upon its specific gravity, and upon the size and shape of the dust particles. Other things being equal, the finest particles fall most slowly. Exceedingly fine dust, even without upward air movements to support it, requires months or even years to fall to the ground from the higher levels of the atmosphere.

Upward movements in the air suffice to carry millions of tons of dust aloft every year, and horizontal air currents carry the same dust far and wide over the earth. The transportation of soil by the wind leads to some results of remarkable interest, practical as well as scientific. In the first place, far-reaching changes in topography are brought about by this process. Thus in China vast areas are covered to a depth of hundreds or even thousands of feet with a fine yellowish earth, called “loess,” which is believed to have been blown thither by the winds from the deserts of Central Asia. Less extensive deposits of this wind-borne material are found in many other parts of the world, including the Mississippi Valley. Another effect of wind transportation is the mixing of soils. There is a constant interchange of soil material between different regions, so that the composition of the soil on a particular farm, for instance, is not the same now that it was a few years ago or that it will be a few years hence. Lastly, the presence of dust in the atmosphere, whether derived from the soil or otherwise, has various interesting and important effects upon the heat and light we receive from the sun and modifies, in numerous ways, the conditions of human life upon our planet.

Several cases in which enormous quantities of solid matter have been carried to great distances by the wind have formed the subject of elaborate investigations on the part of meteorologists. Thus, during the three days, March 8–10, 1901, heavy dust storms occurred in the deserts of southern Algeria, and the sequel of these storms was carefully studied by Hellmann and Meinardus. A widespread cyclonic storm, central over Tunis at the time, sucked up the dust, which was carried northward by the winds at high altitudes. Deposits from this dust cloud occurred over an area extending as far as 2,500 miles from the place of origin. Reports collected from hundreds of observers indicated that 1,800,000 tons of dust fell over the continent of Europe, and one-third of this fell north of the Alps. As much more is believed to have fallen over the Mediterranean, while on the African coast itself the deposit is supposed to have amounted to 150,000,000 tons. In March, 1918, a shower of dust discolored falling snow at various places in the United States over an area of at least 100,000 square miles, extending in an east-west direction from Dubuque, Iowa, to Chelsea, Vt. Reports of this shower were collected by Messrs. E. R. Miller and A. N. Winchell, who estimate that the amount of dust could not have been less than a million tons, and may have been several hundred million. The dust is believed to have been blown up from the arid regions of the far southwestern United States and to have been transported a thousand miles or more.

Off the west coast of Africa, between the Canaries and the Cape Verde Islands, haze due to dust blown up from the Sahara Desert is frequently encountered by vessels, especially during the first four months of the year. This haze probably gave rise to the ancient legend of a Sea of Darkness—the *Mare Tenebrosum*—one of the mysterious terrors of the ocean reported by the navigators who first sailed toward the New World.

Extensive deposits of atmospheric dust have attracted attention from the earliest times. Ehrenberg, in 1849, collected records of 349 such cases, and published a map showing their distribution, which embraces the greater part of the world. Atmospheric dust is always brought down in greater or less quantities by rain. When it consists of fine powdery sand, the rain sometimes acquires a brownish or reddish tinge, staining objects on which it falls and constituting the "showers of blood" that have been regarded as prodigies from remote antiquity. Homer describes such a shower, and many similar occurrences are recorded by the Roman historians. Italy, owing to its proximity to the African coast, is often visited by these showers, which still strike superstitious terror into the hearts of the peasantry.

The millions of meteors that enter the earth's atmosphere every day contribute their quota of dust, though the total amount is small compared with that of the material lifted from the earth. Fine ferruginous particles are often seen on the snowy summits of high mountains and the polar ice fields, and both their appearance and their composition indicate that they are derived from meteors.

Forest fires, burning peat beds, and other conflagrations on a large scale discharge quantities of dust into the atmosphere. Cinders from the great Chicago fire spread over a large part of the globe. They are said to have reached the Azores some forty days after the beginning of the catastrophe. In Europe, the once common practice of burning the moors to prepare them for cultivation gave rise to huge volumes of smoke, which was carried by the wind hundreds and even thousands of miles. The stronghold of this old custom—which still survives to some extent—was East Friesland, in northwestern Germany, and the characteristic haze to which it gave rise, known as "moor smoke" (German, *Moorrauch*), was sometimes observed as far away as Spain, Italy, and Greece.

The famous "dark days" that figure in both ancient and modern history, though in a few cases probably due to eclipses of the sun, have generally been the result of an abnormal accumulation of smoke or dust in the air; sometimes arising from volcanic eruptions, but more often from burning forests, moors, or prairies. Forest fires are the principal cause of dark days in the United States. Probably the most celebrated of such days was May 19, 1780, when, in consequence of great forest fires along Lake Champlain and down to the vicinity of Ticonderoga, darkness like that of night prevailed in New England. All but the most necessary business was suspended, the schools were dismissed, and the greater part of the population flocked to church to prepare for the end of the world, which was believed to be at hand. The great Idaho fire of August, 1910, was responsible for dark days over a larger area than in any other case on record in this country. Artificial light was required in the daytime over a broad belt, extending from Idaho to northern Vermont, but smoke was observed far beyond this area. The British ship *Dunfermline* reported that on the Pacific Ocean, 500 miles west of San Francisco, the smell of smoke was noticed and haze prevailed for ten days. When smoke in the air forms a rather thin layer, through which the sunlight penetrates feebly, we sometimes get an effect similar to the golden glow of sunset, a yellow or coppery tinge being cast over the landscape. Such was the cause of the "yellow day" still remembered in New England—September 6, 1881—attributed to the burning of the immense peat bogs of the Labrador barrens.

Another occasional cause of atmospheric dustiness is the eruption of volcanoes, especially those of an explosive character, which carry fine dust to heights at which it cannot be washed out of the atmosphere by rain. The remarkable dry fog of 1783—the most famous in history—which covered the greater part of Europe and North America for three or four months—was undoubtedly due to the violent eruptions of that year in Iceland and Japan. Its connection with the Iceland eruption was suggested even by contemporary writers. The outbreak of Krakatoa, in the East Indies, in 1883, spread a veil of dust over the greater part of the globe. For two or three years its presence in the air was the cause of striking optical phenomena, including gorgeous sunset glows. The story is told of an American fire brigade which, deceived by one of these brilliant sunsets, set out to extinguish what was mistaken for a great fire in a neighboring village. A large species of corona around the sun, known as "Bishop's ring," because it was first observed by the Rev. Sereno Bishop of Honolulu, appeared shortly after the eruption and reached its maximum intensity the following year. This was due to the diffraction of light by the exceedingly fine dust from the volcano, and the same phenomenon has been seen after other great explosive eruptions; e. g., that of Mont Pelée, in 1902. Some authorities believe that the finest particles of dust from the Krakatoa eruption were carried to an altitude of over fifty miles above the earth, and remained suspended at very high levels for several years, constituting the strange "noctilucent clouds," seen on summer nights from 1885 onward. These clouds glowed with a silvery luster, attributed to reflected sunlight.

A persistent veil of volcanic dust in the upper air is thought to exercise marked effects upon terrestrial temperatures, and prolonged periods of intense vulcanism have been regarded as the cause, or one of the causes, of the recurrent ice ages of which geology furnishes the record. This explanation of ice ages was advanced by P. and F. Sarasin, in 1901, and was first put upon a scientific basis by Dr. W. J. Humphreys in 1913; but the idea that volcanic dust might be the cause of cold seasons was suggested by Benjamin Franklin as early as 1784. Franklin's speculations on this subject were prompted by the cold winter of 1783–1784, which followed the extraordinary fog of 1783, already mentioned. Humphreys has published a list of all the great volcanic outbreaks recorded since 1750, and has shown that each of them registered itself in the temperatures of the earth and also, since accurate measurements began to be made of solar radiation, in these instrumental records. Thus, the intensely cold winters of 1783–1785 followed the tremendous eruptions of Asama, Japan, and Skaptar Jökull, Iceland, in 1783; the famous "year without a summer" (1816) was the sequel of the gigantic outbreak of Tomboro, in the Sunda Islands, in 1815, which is said to have hurled thirty-six cubic miles of solid matter into the atmosphere; and definite periods of low temperatures and reduced sunshine were observed after the eruptions of Mont Pelée, in 1902, and Mount Katmai, Alaska, in 1912.

The effect of a volcanic dust veil in lowering temperatures on earth is attributed chiefly to the fact that, while the fine grains of dust are able to reflect back into space the short waves of radiation coming from the sun, they do not bar the passage of the long heat waves radiated outward from the earth. According to Humphreys's calculations, such a veil is about thirtyfold more effective in shutting solar radiation out than in keeping terrestrial radiation in. This process is just the reverse of the familiar effect of the greenhouse; where the glass lets in the short waves of solar radiation but does not readily let out the long waves of earth radiation.

A small contingent of atmospheric dust consists of common salt (sodium chloride) due to the evaporation of spray from the ocean. This substance is frequently found in rain, as well as in samples of air, not only near the seashore, but even in the interior of continents and on high mountains. According to Du Bois the amount of sodium chloride annually deposited on the dunes of Holland is at least 6,000,000 kilograms (more than 6,600 tons).

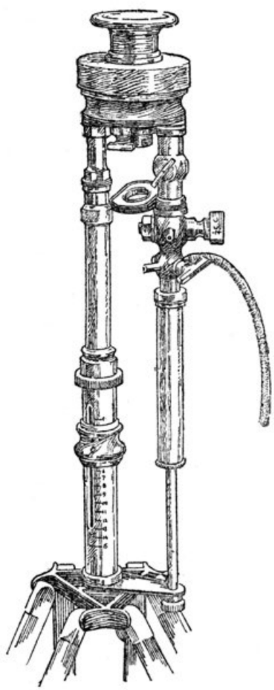
One of the striking phenomena of arid regions is the dust whirlwind; exemplified in the "devils" of India and

South Africa, the "twisters" of Texas, etc. E. E. Free, in his treatise on "The Movement of Soil Material by the Wind" (U. S. Bureau of Soils, Bulletin 68), says of these whirls:

"They may be seen nearly every hot day, sometimes running rapidly over the surface; sometimes remaining nearly, if not quite, stationary, but never losing their rapid rotation. They usually last only a few minutes, but occasionally persist much longer. One observed by Pictet lasted for over five hours. They are largest and last longest on the flat, bare plains of the desert, and are usually seen in a calm or when only a light breeze is blowing, although their occurrence in windy weather is not unknown. These whirls have been noticed by many travelers in desert and steppe regions and have been carefully observed by Baddeley in India, and by Pictet in Egypt. They are frequent in China and on the pampas of South America, and occasionally occur during the dry season even in the humid regions. One of the most interesting phenomena in connection with the dust whirls is the occurrence of systems of several whirls, each revolving rapidly about its own center and also moving about a common center in a more or less perfect circle a few rods in diameter."

The little whirls often seen on dusty roads are a miniature variety of the same phenomenon.

One very important class of dust particles in the atmosphere consists of organic matter, living or dead, including the pollen of plants and the countless myriads of microorganisms, as well as a variety of other products of the animal and vegetable kingdoms. An abundance of pollen in the air accounts for the occasional fall of yellow rain, described as "sulphur rain," "golden showers," etc. The promptness with which a piece of stale bread becomes moldy in a damp atmosphere is one of many proofs of the omnipresence in the atmosphere of the microscopic spores of fungi, ready to propagate their species with amazing rapidity as soon as they light upon a suitable nutrient medium. Last, but not least, bacteria, the most minute of all known organisms—so small that thousands or millions of them clustered together would make a mass not larger than the head of a pin—swarm in the air, as they do in water, the soil, and the bodies of animals. Fortunately, while certain species of bacteria carry disease and death with them, the great majority are harmless to mankind.



AITKEN'S DUST COUNTER

A great many different methods are in use for determining the total amount of solid matter present in a given volume of air, counting the number of particles, or gathering samples for microscopic examination. Thus a known volume of air may be drawn through a filter of cotton wool or bubbled through distilled water, and the dust detained by the cotton or deposited in the water may be weighed. In certain types of apparatus the air is drawn or forced against a plate or tube coated with glycerin, oil, varnish, gelatin, or other adhesive surface, to which the dust remains attached. Several devices depend for their operation upon the fact that when a volume of confined air is cooled by expansion a point is eventually reached at which the water vapor present condenses to form a fog, each droplet of which is supposed to have a single particle of dust as its "nucleus." This is the principle involved in the well-known Aitken dust counter, which has been so extensively used in different parts of the world, and has furnished most of the impressive statistics of air dustiness found in textbooks and reference books. Thus, from indications supplied by this instrument, it is stated that a cubic inch of town air contains 50,000,000 particles of dust; that a room, near the ceiling, was found to contain 88,000,000 particles per cubic inch; and that a cigarette smoker sends 4,000,000,000 particles into the air at every puff. Recent authorities are inclined to look upon these figures as misleading, for the reason that the nuclei counted with Aitken's instrument are probably so infinitesimal in size that they hardly deserve to be called dust; indeed there is good reason to believe that an indefinitely large proportion of them may actually be molecules of gases.

The effects of dust, both inorganic and organic, upon the health of humanity will be considered in another chapter. Certain kinds of dust are of economic importance on account of their inflammable and explosive character when mixed with the right proportions of air. Thus the cereal dusts made in the handling and working up of grain into food products occasionally give rise to serious accidents. These occur in cereal, flour, and feed mills, grain elevators, starch and glucose factories, and on farms in connection with the use of threshing machines. During a period of ten years, 1906–1916, cereal dust explosions resulted in the loss of eighty lives and the destruction of property to a value of $2,000,000 in the United States. A study of this subject has been made by the United States Department of Agriculture, and various recommendations have been published with a view to preventing the occurrence of sparks in the neighborhood of these dangerous dusts. Coal dust in mines likewise causes numerous explosions. Preventive measures include wetting the dust, moistening the air, and powdering the walls, roof and floor of the mine with a nonexplosive rock dust, which has the effect of stifling an incipient fire or explosion.

The last species of dust that we have to consider in this chapter is one that constitutes a literal blot on civilization, since the noblest cities and monuments of mankind are defaced with it. Neither are the evils of this kind of dust wholly æsthetic, for it is extremely injurious to health and enormously expensive. After enduring coal smoke as a necessary evil for generations, civilised humanity has now embarked upon a vigorous campaign for its elimination, and very encouraging results have already been achieved in many parts of the world. The war against smoke is carried on by numerous societies in Europe and America; a multitude of laws and ordinances (not all of them effective) have been enacted on the subject; it has been the occasion of international conferences and expositions; and its literature has grown so copious that a partial bibliography of the subject, published a few years ago by the Mellon Institute, of Pittsburgh, fills 164 pages.

The smoking of chimneys is costly, in the first place, because it is due to imperfect combustion and the waste of part of the heating value of the fuel, and, in the second place, on account of the damage wrought by the deposit of the soot. Thus a smoky atmosphere entails big laundry and dry-cleaning bills, frequent repainting of houses, injury to metal work, damage to goods in shops, and excessive artificial lighting in the daytime. Throughout the United

States it is said that smoke causes an annual waste and damage amounting to five hundred million dollars. In Pittsburgh alone—before the reform produced by vigorous legislative and scientific measures, following an exhaustive investigation by the Mellon Institute of Industrial Research—the cost of the smoke nuisance was estimated at nearly ten million dollars a year. Means of mitigating this evil include the introduction of improved appliances for burning soft coal, and the use of other kinds of fuel. The electrification of the railway lines entering cities is an important measure of relief. It is estimated that more than one-third of the smoke found in certain American cities comes from locomotives.

Systematic measurements of the amount of solid matter contributed to the atmosphere by smoke have been made at various places in this country and abroad, and yield startling figures. Measures of the "sootfall" in Pittsburgh, before the evil there was mitigated, showed an annual average deposit amounting to 1,031 tons per square mile. London's average is 248 tons per square mile for the whole city and 426 tons in the central districts. In the heart of Glasgow the annual sootfall is 820 tons per square mile.

In Great Britain measurements and analyses of soot and the study of its effects have been carried out on a large scale for a number of years by the Advisory Committee on Atmospheric Pollution, attached to the Meteorological Office. The Committee has installed "pollution gauges," of uniform type, at about twenty-five places in England and Scotland. The soot that falls into these gauges is collected once a month, weighed and analyzed. This organization also makes direct measurements of the purity of the air, and has acquired a unique body of observations that can be used to test the success of efforts made to abate the smoke nuisance, besides providing interesting comparisons between the incidence of respiratory diseases and the amount of solid matter in the air.

CHAPTER V

WEATHER AND WEATHER INSTRUMENTS

The fact that a vast proportion of the conversations in which human beings engage begin with remarks about the weather has often been noted, but perhaps never fully explained. Meteorologists sometimes adduce this fact as evidence that weather is a subject of overshadowing importance. This bit of reasoning will not, however, bear critical analysis. It carries with it the implication that people talk about weather because weather is uppermost in their thoughts. How often is such the case? Brown, meeting Jones, remarks that it is a fine day. Are we to infer that Brown was meditating upon the agreeable state of the atmosphere before he vouchsafed this not altogether novel observation? Hardly. There is about one chance in a thousand that weather was in his mind at all.

It is a plausible thesis that people talk so much about weather because, at an earlier period in the history of mankind, this subject *was* of supreme importance. Perhaps it is a custom handed down from our remote ancestors, whose occupations were nearly all carried on out-of-doors and who enjoyed but a precarious shelter from the elements in their rude habitations. In India, as the period of the monsoon rains approaches, anxiety about the timely arrival and the abundance of these showers eclipses all other thoughts in the mind of the peasant, because a severe drought at this season means a famine. When our forefathers lived by hunting, fishing, and crude systems of grazing and agriculture, they were, no doubt, equally solicitous about atmospheric conditions that directly affected their food supply. In those days comments on the weather were by no means empty formulas. Men rejoiced together that the day was fine, because it was a circumstance upon which their dinner depended; and the prehistoric equivalent of "What beastly weather!" was probably accompanied by a significant tightening of the belt.

Certain it is that in very early times people gave a great deal of attention to the weather and acquired a fund of wisdom on the subject which, along with a certain amount of superstitious unwisdom, has come down to us in the shape of weather proverbs. Many of these proverbs undoubtedly originated before the dawn of history, for they are found in substantially the same form among widely scattered races of mankind. Various popular weather prognostics familiar at the present day are mentioned in such ancient documents as the Vedas, the Bible, and the cuneiform tablets from the library of Assurbanipal.

Speculations about the weather occupy much space in the writings of the Greek philosophers, and a formal treatise on meteorology, written by Aristotle (fourth century B. C.), remained the standard work on this subject for two thousand years. More or less systematic weather records were kept by the Greeks long before the Christian era, and they produced a number of almanacs, in the shape of marble tablets, showing the average winds and weather for particular dates throughout the year. A copious collection of the weather indications found in both Greek and Roman almanacs, dating back to the fifth century B. C., has been made by Dr. Gustav Hellmann.

Some of the meteorological instruments used today have a very respectable antiquity. Ancient statistics of the rainfall of India, recently brought to light, show that some sort of rain gauge must have been in use in that country in the fourth century before our era. Measurements of rainfall were made in Palestine in the first century A. D. The only other meteorological instrument dating back to classical antiquity, so far as known, is the weather vane. The Tower of the Winds, at Athens, built about a century before the Christian era, originally bore at its summit a vane in the shape of a bronze Triton, holding in his hand a wand, which was designed to point at one or another of the eight symbolical figures of the principal winds surrounding the octagonal tower, thus showing which way the wind was blowing at the time. The Roman writer Varro has left us a description of a vane that could be read indoors by means of a dial on the ceiling.

Instrumental weather observations did not become the rule, however, until the end of the seventeenth century, when the use of thermometers, hygrometers, barometers, and rain gauges began in Italy and spread rapidly to other countries. The origin of each of these instruments is commonly ascribed to a particular inventor—the thermometer to Galileo, the barometer to Torricelli, etc.—but the truth is that the idea of the instrument was, in each case, a slow growth, to which many minds contributed. Thus a form of thermoscope—a device for showing but not for measuring the expansion and contraction of air with changes of temperature—was described by Philo of Byzantium in the third century B. C. Galileo supplied such an instrument with a scale, but without fixed points, thus converting it into a crude thermometer, but it was not until half a century later that the Grand Duke Ferdinand II of Tuscany introduced the idea of filling the thermometer with alcohol, in place of air, and sealing it so that it was not affected by changes in barometric pressure. The thermometric scale now used in English-speaking countries, which bears the name of Fahrenheit, appears to have been devised by the Danish astronomer Ole Römer, from whom Fahrenheit borrowed it. In short, any *brief* account of the invention of the principal meteorological instruments necessarily ignores the just claims of many inventors; to say nothing of the fact that what is written on the subject to-day is likely to be refuted to-morrow by the discovery of some forgotten book or manuscript.

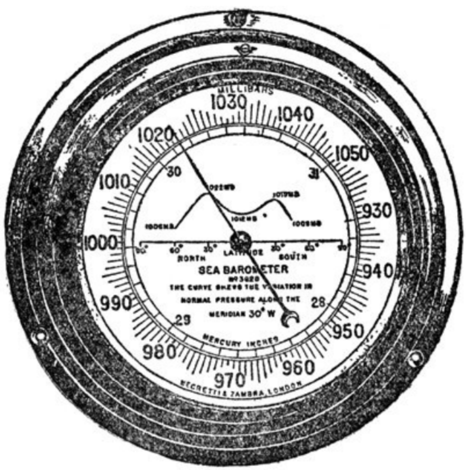
We are on safer ground in saying that the plan of *measuring* the weather, instead of merely observing it, became general early in the eighteenth century; and that about the middle of the nineteenth century the further improvement was introduced of making meteorological instruments trace their own records, so that the human observer was, to a great extent, dispensed with. Self-registering instruments are now the rule at important meteorological observatories and stations, though they do not, even yet, record all the elements of weather, and at a host of minor stations none of them have yet replaced the eye of the observer.

Now let us see what things go to make up the weather, and how these things are observed by the modern meteorologist.

The pressure of the atmosphere, if not exactly a part of the weather, is so intimately associated with it that we cannot exclude it from our list of weather phenomena. Atmospheric pressure is measured with the *barometer*, and the importance of this instrument as a key to weather changes is fully recognized—and indeed overrated—by the layman, who sometimes calls it the "weather glass."

MERCURIAL BAROMETER (Fortin type)

Until recently all British and American barometers were read in inches and all others in millimeters. Since atmospheric pressure is a force, the practice of measuring it in units of length is rather like measuring time in bushels or potatoes in hours. The inconsistency is serious from a scientific point of view, because it divorces barometric measurements from other physical measurements, in which pressures are measured in units that have nothing to do with length; viz., dynes per square centimeter. Accordingly, some of the leading meteorological services of the world have lately adopted a new unit of barometric pressure, known as the *bar*, which is equivalent to 1,000,000 dynes per square centimeter. It is subdivided according to the ordinary metric notation, and its most commonly used subdivision is the *millibar*, equivalent to 0.03 inch on the old-fashioned barometer scale, under standard conditions.



ANEROID BAROMETER, GRADUATED IN MILLIBARS AND INCHES

For the benefit of sailors a curve is shown indicating the *mean annual pressure* in different latitudes along the meridian of 30° W. (Courtesy of the British Meteorological Office.)

The mercurial barometer is so delicate and cumbersome that for many practical purposes it is replaced by the more convenient though less accurate *aneroid barometer*. A self-recording barometer (usually an aneroid) is called a *barograph*. In its ordinary form, this instrument carries a pen, which traces a continuous record of the barometric pressure on a strip of paper wound around a cylinder turned by clockwork. Generally the instrument runs for a week before the paper has to be changed. The barograph is a very instructive instrument, because it shows, not only the pressure, but also the *changes* of pressure—i. e., just how fast the barometer is rising or falling, or, as meteorologists say, the "barometric tendency." The way in which barometric changes are related to weather will appear in a later part of this book.

The mercurial barometer consists of a glass tube, sealed at its upper end and having at its lower end a "cistern," which is open to the air. The tube is filled with mercury at its open end, and then inverted over the cistern, and the mercury descends until the weight of the portion standing above the level of the mercury in the cistern just balances the pressure of the air on an area equal to the cross section of the tube. The height of the mercurial column is read from a graduated scale attached to the tube. Certain corrections are applied to the reading, in order to eliminate variations due to temperature, etc., and, if to be entered on a weather map, the reading is reduced to sea-level value. In the aneroid barometer, a thin-walled metal box, exhausted of air, undergoes changes of shape in response to changes in atmospheric pressure. The movements of the box are communicated by levers to a pointer moving around a dial (or to the recording pen, in the barograph).

Since the pressure of the atmosphere diminishes with increasing altitude at a fairly definite rate, the barometer is used for measuring heights. Sometimes it is graduated directly, for this purpose, in feet or meters, and it is then called an *altimeter*.

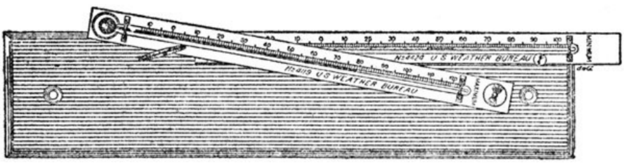
Among the meteorological elements that unmistakably pertain to weather the most important is the*temperature* of the air. The thermometer, with which temperature is measured, is, in its common form and in its essential features, too familiar to require description here; but we may remark that, as in the case of the barometer, several methods of graduating this instrument have been used. Besides numerous obsolete systems, there are three different thermometric scales—the Fahrenheit, the Centigrade, and the Absolute. The first is still the prevailing one in English-speaking countries, and the second prevails in all other countries. The Absolute scale, long familiar to physicists, has recently come into somewhat limited use in meteorology. It starts at the "absolute zero"—the temperature of a body totally devoid of heat. This temperature has been nearly attained in laboratory experiments with liquid helium. One advantage that the Absolute scale possesses over the others is that it has no below-zero readings. Such readings are a source of occasional errors when temperature is recorded on the Fahrenheit or the Centigrade scale.

The freezing point of water is 32° Fahrenheit = 0° Centigrade = 273° Absolute. The boiling point of water, at sea level, is 212° Fahrenheit = 100° Centigrade = 373° Absolute.

While the layman is well acquainted with the thermometer, he sometimes fails to understand certain differences between the scientific and unscientific methods of using this instrument for weather-measuring purposes. On a hot summer day he is, perhaps, inclined to feel aggrieved because the official record of temperature does not adequately express the state of his feelings, to say nothing of being at odds with the impressive instrument displayed at the corner drug store. Hence the following explanation is in order:

It is the function of the official thermometer to indicate the true temperature of the *air*. A thermometer exposed to direct sunshine records its own temperature—i. e., the temperature of the glass and mercury—and nothing else. A thermometer "in the shade"—under a tree, for example—comes nearer to showing the true air temperature; but it is exposed to radiation from surrounding objects and its readings will vary with the nature and location of these objects. The meteorological thermometer is nearly always installed in a kind of latticed screen, or shelter. It is thus largely protected from radiation, while the air circulates freely around it. Only when thermometers are exposed under such standard conditions is it possible to obtain comparable readings of the temperature at different places, so that, for instance, maps may be drawn showing the distribution of this element over a country. The best location for the thermometer screen is a few feet above sod. Many thermometers of the United States Weather Bureau are installed on the roofs of tall buildings; not because this is an ideal location, but because no better is available in the heart of a large city, where, for practical reasons, the office has to be placed. In many small towns the site of the station is such that the thermometer screen (or "instrument shelter," as it is called in the Weather Bureau) can be placed close to the ground, and at the same time get ample ventilation and be free from the radiation of buildings. In certain large cities the Bureau maintains a branch station in a park or in the suburbs, where a satisfactory exposure for all instruments can be secured.

The artificial temperature of a city street is too local and indefinite a thing to be inscribed on weather maps, utilized by the forecaster, or embodied in climatic statistics. As a concession, however, to the demand of the "man in the street" for a record of conditions prevailing in his own sphere, the Weather Bureau has installed in several cities little pavilions in which working meteorological instruments are displayed for the benefit of the public. The thermometers in these so-called “kiosks”—which are modeled, with improvements, after the weather pavilions found at European health resorts—always read several degrees higher in hot weather than the thermometer at the regular Weather Bureau station in the same vicinity. Such records are erratic, at best, and present indications are that the kiosks will eventually be abolished.



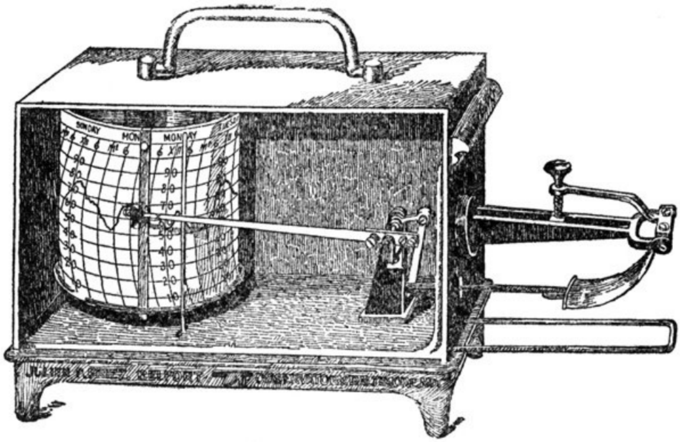
MAXIMUM AND MINIMUM THERMOMETERS

Besides the ordinary thermometer, there are instruments that answer the questions “How hot was it to-day?” and “How cold was it last night?” These are known, respectively, as the *maximum* and the *minimum thermometer*. They hang almost horizontally in the screen. The former has a constriction just above the bulb, which prevents the mercury from retreating after it has reached the highest reading for the day. It can be reset by whirling it on a pivot. The minimum thermometer is filled with spirit instead of mercury. A little index inside the column is carried toward the bulb by the surface of the alcohol as the temperature falls. When the temperature rises the index remains behind, marking the lowest point reached. The highest and lowest temperature of the day, as well as the temperature at any moment of the day, can be read from the *thermograph*, or self-registering thermometer. In the commonest type of thermograph changes of temperature alter the curvature of a flexible metal tube filled with spirit, and the movements of the free end of the tube are communicated by levers to a recording pen.

On an average day, in our climates, the air is coldest about sunrise. The appearance of the sun checks the atmospheric cooling due to the loss of heat from the earth that has been going on through the night, and the air begins to warm up. As long as the amount of incoming heat from the sun is greater than the amount of outgoing heat from the earth, the temperature will continue to rise. After noon, when the sun is highest, the supply of solar heat diminishes, but it is still greater, for a time, than the heat loss from the earth, and for this reason the temperature, as a rule, keeps on rising until some time toward the middle of the afternoon, when the maximum temperature of the day occurs.

Humidity is an element of weather that is more often talked about than understood. Atmospheric humidity is the state of the atmosphere with respect to the amount of moisture it contains in a gaseous form, not in the form of a liquid. This gaseous moisture is called *water vapor*, and it is not directly perceptible to the senses, as liquid water is. As we have explained elsewhere, the capacity of the air for water vapor increases with the temperature. The actual amount present at any time, per unit volume, is called the *absolute humidity*, and the ratio of this amount to the maximum amount the air can hold at the same temperature is called the *relative humidity*. The latter is generally expressed in percentage. When the air is charged to its full capacity with aqueous vapor its relative humidity is 100 per cent.

The relative humidity usually varies greatly through the day, being generally lowest when the temperature is highest, and *vice versa*. It is an element of much practical interest, because it is one of the main factors in determining the drying power of the air, the other important one being wind. The air feels dry when evaporation proceeds rapidly from our skin, either on account of low relative humidity, brisk air movement, or both. People are hardly conscious of high relative humidity except when, in hot weather, it retards the evaporation of perspiration, and the latter collects in liquid form on the skin.



THERMOGRAPH

Relative humidity does not owe its importance in human affairs solely to its physiological effects, for it plays a prominent part in numerous industries—textile, metallurgical, chemical, leather, food, and all those employing drying processes. In the spinning of cotton and wool, for example, the humidity of the workroom greatly affects the weight of the material, the size of the yarn, and the length and flexibility of the fibers. Humidity must likewise be taken into account in such diverse industries as manufacturing candy, bread, high explosives and photographic films, drying macaroni and tobacco, and operating blast furnaces. There are engineers who specialize in the business of installing "humidifying" and "dehumidifying" systems in workshops, and also, for hygienic purposes, in schoolhouses and other public buildings.

The absolute humidity, the relative humidity and the *dew point* (the temperature to which the air must be brought to start condensation of its moisture) are all determined by means of instruments called *hygrometers*. The hair hygrometer depends for its action upon the fact that a hair, freed from oil, not only absorbs moisture from the atmosphere, but elongates when damp and contracts when dry. The instrument, which includes a single human hair or a bundle of such hairs, is so designed that these changes move an index over a graduated scale. This and other types of hygrometer can be arranged to record their own readings continuously, constituting a *hygrograph*.

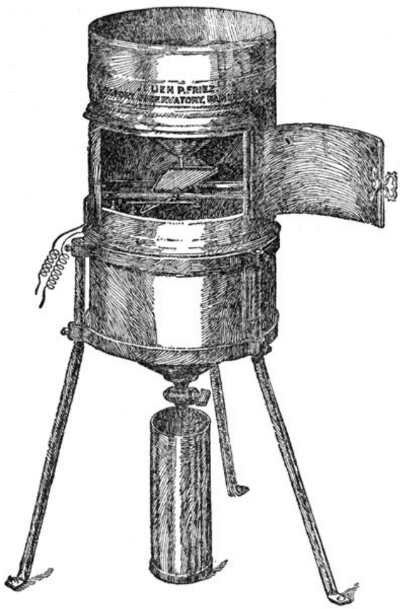
The form of hygrometer most commonly met with at meteorological stations is called a *psychrometer*. This usually consists of a pair of mercurial thermometers, one of which, known as the "wet-bulb thermometer," has its bulb wrapped in thin muslin. The other, called the "dry-bulb," is an ordinary thermometer. The muslin is moistened, either just before making a reading, or continuously with a wick. In the former case the thermometer is generally whirled several times before the reading is taken. Unless the air is saturated, the wet bulb is cooled by evaporation, and the difference between the readings of the two instruments enables the observer, with the aid of suitable tables, to obtain the absolute and relative humidity and the dew point. The most accurate results are obtained from the *aspiration psychrometer*, of Assmann, in which air is drawn past the bulb of the thermometer by a small fan, driven by clockwork.

Deposits of liquid and frozen water from the atmosphere, in their various forms, are known collectively as "precipitation," and in the aggregate they constitute a feature of the weather hardly less important than temperature. Indeed an average rainstorm or snowstorm is a more obtrusive event than any other equally common manifestation of the weather; while an excess of precipitation or a prolonged lack of it, constituting a *drought*, may be as serious in its consequences as a "hot wave" or a "freeze."

Precipitation—familiarly called "rainfall"—is much more extensively measured than any other meteorological element, for there are, throughout the world, a vast number of places at which this is the only feature of the weather that is regularly observed. In Europe alone there are about 19,000 "rainfall stations." Rainfall is measured in depth; viz., in inches or millimeters. A moderate shower of several hours' duration will yield an inch or two of rain, while in extreme cases several inches may fall in an hour. Snow is sometimes measured as such—i. e., the actual depth that falls, or, more commonly, the amount lying on the ground from day to day—but in order that records of snowfall may be combined with those of rainfall for the purpose of determining the total precipitation, the snowfall must be reduced to its "water equivalent," either by melting the snow before measurement or by estimating this equivalent or by weighing the snow caught in a receiver of known area and computing the corresponding depth of water.

There are many kinds of *rain gauge*. As a rule the gauge has a funnel-shaped receiver with a small opening through which the water flows into the lower part of the gauge; loss of the accumulated water by evaporation is thus checked. There is usually some device for magnifying the depth of rainfall in order to facilitate measurement. In American gauges the rain flows into an inner tube having one-tenth the horizontal area of the receiver, and its depth is thus magnified ten times. A measurement is made by thrusting a graduated wooden stick to the bottom of the tube and noting the height to which the stick is wetted.

Of devices for obtaining an automatic record of rainfall, the *tipping bucket* (or, as the British call it, the "tilting bucket") is probably the most serviceable, and it is the one most widely used in this country. This instrument is as simple as it is ingenious. The "bucket" is a little metal trough, pivoted in the middle, so that it can tilt back and forth, seesaw-fashion. It is divided into two compartments by a central partition. Rain falling into the funnel-shaped receiver at the top of the gauge flows into whichever compartment of the bucket is uppermost, until the weight of the water causes the bucket to tip, thus emptying one compartment and presenting the other to the incoming stream. When the second compartment is filled, the bucket tips in the opposite direction. The parts of the gauge are of such dimensions that each tip of the bucket corresponds to 0.01 inch of rainfall. The gauge is connected electrically with registering apparatus indoors, so that every tip of the bucket is recorded. The registration sheet shows the time of occurrence as well as the amount of rainfall.



TIPPING-BUCKET RAIN GAUGE

The two most important things about the wind that are observed and recorded by meteorologists are its direction and its force. It is the universal custom to regard as "the direction of the wind" the direction *from* which, rather than toward which, it blows. Moreover, it is only the horizontal direction of the wind that is ordinarily observed, though many winds have a considerable upward or downward slant, and, locally, a wind may even blow straight up or straight down. The direction of the wind may be observed in several makeshift ways, such as by watching the drift of smoke from chimneys, or, as sailors do, holding up a wet finger to the breeze. Instrumentally and scientifically it is observed with a special type of *vane*, much more accurate in its indications than the weather vanes and weather cocks of ornamental and symbolical architecture. The nonscientific vane, once set in motion, is likely to be carried too far by its own momentum, and may even spin completely around under a sudden impulse. In the scientific vane this tendency is restrained by means of a spread tail; the pressure of the wind on the diverging blades serving to hold the vane in the correct position. The vane, like most other meteorological instruments, is self-recording at all important meteorological stations. The type used by the Weather Bureau registers the direction of the wind every minute.

The force of the wind is obtained from an *anemometer*. Most anemometers do not, however, show this directly, but are designed to measure the speed or so-called "velocity" of the wind, from which its force may be computed. The speed is observed in miles per hour or meters per second. In considering some of the possible effects of wind it is well to bear in mind that its force increases as the square of the velocity. This means, for example, that a wind of 20 miles an hour is four times as strong, and one of 30 miles an hour nine times as strong as a wind of 10 miles an hour.

One of the external features of a weather station that invariably attracts the attention of the passer-by is an instrument consisting of four hemispherical cups revolving horizontally in the wind. This scientific whirligig is the *Robinson cup anemometer*, which, in spite of its shortcomings, is the most widely used instrument of its class throughout the world. As generally constructed, the cups are supposed to turn 500 times for a mile of wind movement. Actually the relation between the speed of the cups and the speed of the wind is somewhat variable, and at high velocities the indications of the instrument are seriously erroneous. The Robinson anemometer has a dial from which direct readings can be made, but at large stations it is connected electrically with a registering device in the observer's office, which makes a mark for each mile of wind and shows how the speed of the wind varies through the day.

There are many other types of anemometer, and some of them tell a much more detailed story of the wind's variations than does the Robinson instrument. On the other hand, thousands of weather observers dispense with anemometers altogether and merely estimate the strength of the wind from its effects. This applies to nearly all observers at sea, and, in Europe, to the vast majority of observers on land. Such estimates are recorded on a scale ranging from zero, for a calm, generally up to ten or twelve for the strongest winds ever experienced. Several different scales are in use. The best known is the Beaufort Scale, devised by Admiral Sir F. Beaufort, in 1805. The following table of the Beaufort Scale, as adapted for use on land, is from the "Observer's Handbook" of the British Meteorological Office:

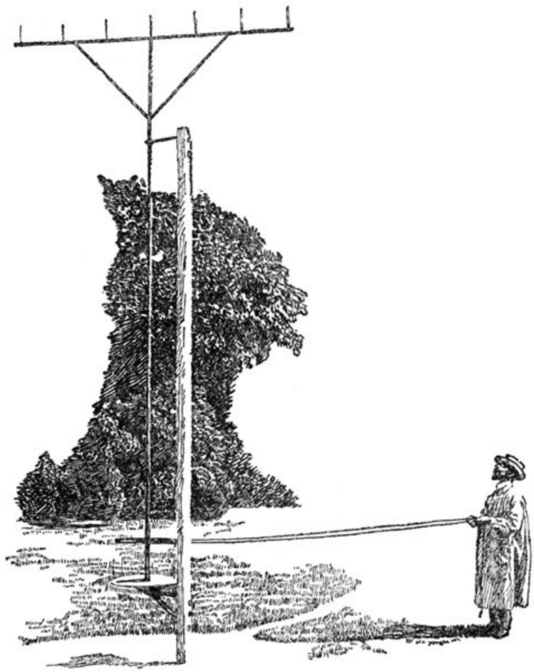
Beaufort number	**Explanatory titles**	**Specification of Beaufort Scale for use on land based on observations made at land stations**	**Equivalent speed in miles per hour at 33 feet**
0	Calm	Calm; smoke rises vertically	0
1	Light air	Direction of wind shown by smoke drift, but not by wind vanes	2

2	Slight breeze	Wind felt on face; leaves rustle; ordinary vane moved by wind	5
3	Gentle breeze	Leaves and small twigs in constant motion wind extends light flag	10
4	Moderate breeze	Raises dust and loose paper; small branches are moved	15
5	Fresh breeze	Small trees in leaf begin to sway; crested wavelets form on inland waters	21
6	Strong breeze	Large branches in motion; whistling heard in telegraph wires; umbrellas used with difficulty	27
7	High wind	Whole trees in motion; inconvenience felt when walking against wind	35
8	Gale	Breaks twigs off trees; generally impedes progress	42
9	Strong gale	Slight structural damage occurs (chimney pots and slates removed)	50
10	Whole gale	Seldom experienced inland; trees uprooted; considerable structural damage occurs	59

11	Storm	Very rarely experienced; accompanied by widespread damage	68
12	Hurricane		Above 75

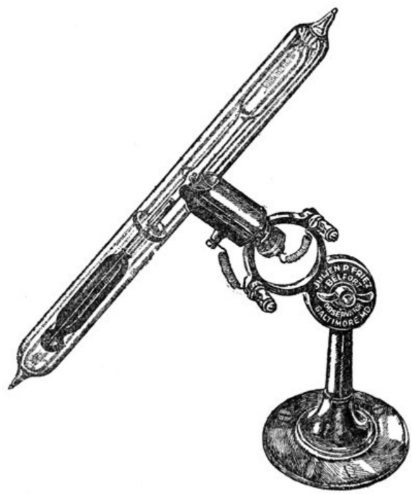
The clouds receive more attention at some weather stations than at others. A routine observation consists of noting the kinds of clouds visible, the direction or directions from which they are moving, and the degree of cloudiness—i. e., the extent to which the sky is clouded, stated in tenths, from O = cloudless, to 10 = completely overcast. At many of the more important stations the movements of clouds are observed with a *nephoscope*. The reflecting nephoscope, used in this country, consists of a black mirror in which the image of the moving cloud is watched, the direction of its motion being read off from the graduated circular frame of the mirror. There is also a device for measuring the apparent speed of the cloud. From this the actual speed can be calculated if the height of the cloud is known. There are other nephoscopes, such as Besson's in which the cloud's movements are watched directly, and not by reflection.

The importance of sunshine among the elements of weather and climate is evidenced by the fact that at least two States of the Union, South Dakota and California, contend for the title of "the Sunshine State"—which does not properly belong to either of them. Arizona is the sunniest State of all, and the whole Southwest is sunnier than South Dakota.



BESSON'S COMB NEPHOSCOPE

Devices for registering the duration of sunshine are called *sunshine recorders*. One type (the Campbell-Stokes) works on the burning-glass principle; in others the sun's rays trace a record on photographic paper. The instrument used by the Weather Bureau consists of an air thermometer having a bulb at each end, one bulb being coated with lampblack. There is a small column of mercury between the two inclosed masses of air. The thermometer is inclosed in a sheath of glass, from which the air is exhausted. When the sun shines on this instrument, the air in the black bulb warms and expands, and the mercury is forced toward the other bulb until it comes in contact with a pair of electrodes, thus closing an electrical circuit. While the circuit is closed, the registering apparatus connected with the instrument makes a step-shaped mark once every minute. When the sun stops shining, the mercury drops back, the circuit is broken, and the recording pen merely traces a straight line.



ELECTRICAL SUNSHINE RECORDER

At the larger stations of the United States Weather Bureau the direction and speed of the wind, the rainfall and the duration of sunshine are all recorded on a single sheet of paper, wound around a large cylinder, which is turned by clockwork. The paper is ruled with lines to denote the hours and minutes of the day, and a fresh sheet is put on the cylinder every day at noon. This complex registering device, sometimes called in book language a *meteorograph*, but colloquially referred to by weather men as the "triple register," is entitled to high rank among labor-saving machines; for, with hardly any attention, except for a few minutes at noon, it does the work of a staff of trained meteorologists on duty day and night.

BRITISH TYPE OF SUNSHINE RECORDER

(*Campbell-Stokes Pattern*)

We have now enumerated the elements of weather most commonly observed at meteorological stations, and the principal types of meteorological instruments, with special reference to those used in the United States. In nearly every civilized country there are certain stations at which regular observations are maintained of a number of phenomena not mentioned in the foregoing paragraphs, such as the intensity of solar radiation (measured with the *pyrheliometer*), evaporation (measured with *atmometers*or *evaporimeters*), and the temperature of the soil; and the number of stations is rapidly growing at which the winds and weather far aloft in the atmosphere are observed by means of kites and balloons. Meteorologists of the Old World use a great many types of apparatus that are rarely seen in this country, and some of our instruments are but little known abroad.

CHAPTER VI

CLOUDLAND

One of the things a tea kettle is good for is to provide, by means of the little cloud seen at its nozzle and erroneously called "steam," an example of what happens when the invisible gas that is truly steam, or water vapor, is cooled below its dew point in the free air. This cloud has, however, been the starting point of a vast number of halfway explanations. A generation or so ago physicists were content to say that aqueous vapor turns to drops of water in the air merely on account of being cooled. The question of how the drops get their start, or why the moisture forms drops at all, does not seem to have troubled them.

One way in which air or any other gas is cooled is by expanding against pressure. Some of the energy in the gas, originally manifesting itself as heat, is applied to the work of expansion, and thus ceases to be heat. Hence the temperature of the gas falls. Conversely, if a mass of gas is compressed, the mere process of compression raises its temperature. The heat produced in pumping up a bicycle tire is the classic example of the latter fact. Heating by compression and cooling by expansion are called, respectively, "dynamic heating" and "dynamic cooling." The processes thus described are of the utmost importance in meteorology.

If air of average humidity is admitted to the receiver of an air pump in the usual way and suddenly expanded by partial exhaustion, a cloud of moisture is seen to form in the receiver. This moisture is condensed and made visible by the dynamic cooling of the air. If, however, after the receiver is exhausted air of the same humidity as before is admitted through a filter of cotton wool, and is then similarly cooled by expansion, no cloud will form. Evidently the filter has removed from the air something that is essential to the process of condensation.

Perhaps it will occur to the reader that, in some obscure way, the filter has prevented water vapor itself from entering the receiver. There are several methods by which we can ascertain whether such is the case. One of the simplest is to admit a little smoke to the receiver before expanding the filtered air. In this case the cloud *does* form, showing that moisture is present, and also showing that smoke, though a perfectly dry substance, aids the formation of the water drops.

Such experiments have led to the conclusion, now universally admitted, that when water drops form in the atmosphere they always form around "nuclei" of something that is not water. These nuclei are often referred to as "dust particles," but it is recognized that a vast proportion of them are very much more minute than the dust that worries housewives. They are largely beyond the power of the microscope, and some of them, indeed, appear to be of molecular size, consisting of molecules of hygroscopic gases, such as the oxides of sulphur and of nitrogen.

Another important fact about water drops in the atmosphere has come to light within the last half century. Since water is much heavier than air, meteorologists of an earlier generation were puzzled by the fact that the drops in clouds apparently float, instead of falling to the ground. In the attempt to account for this supposed floating, bygone authorities assumed that the drops were hollow "vesicles," like little bubbles. This assumption was eventually disproved by the optical phenomena exhibited by the drops, as well as on other physical grounds. Moreover, it is now known that a cloud never really floats, though the rate at which its constituent particles fall with respect to the air is generally very small, on account of the resistance they encounter.

Thus a very slight upward current usually suffices to maintain the altitude of a cloud, or even to increase it. The speed with which a drop falls increases with its size. Hence large drops may fall rapidly from great heights all the way to the ground, constituting rain; but in a great many cases such drops evaporate on falling into warmer air below the cloud level, and thus the lower surface of the visible cloud remains at about a constant height.

The drops in clouds and fog have often been measured, either by noting their optical effects or by microscopic examination. Many are found to be from 0.0006 to 0.0008 inch in diameter. The speed with which such drops fall through still air can be calculated. A drop 0.0008 inch in diameter falls at the rate of about half an inch a second, or 150 feet an hour. Even if a cloud consisting of such drops preserved its integrity for an hour or more while sinking, its descent at this slow rate would hardly be perceptible from the ground.

Some clouds consist of ice needles or tiny snowflakes. Apparently these icy particles are produced directly in solid form, without passing through the liquid stage. It is supposed that, like drops, they require nuclei on which to condense, but this matter has not been fully investigated. Another point that awaits elucidation is the fact that the clouds that form in air much below the freezing point sometimes consist of water and sometimes of ice. The common fleecy clouds of our winter skies are composed of water drops, and such clouds also occur in the polar regions. Dr. G. C. Simpson, when serving as meteorologist of Scott's antarctic expedition, observed fog consisting of liquid water at a temperature of 29° below zero, Fahrenheit. Why such greatly "undercooled" drops should sometimes occur in the atmosphere when at other times, with higher temperatures, atmospheric moisture takes the form of ice is not at all clear.

There are several ways in which the free air may be cooled to the point at which condensation occurs. The commonest is dynamic cooling, due to the rise of a mass of moist air and its expansion under the reduced pressure that prevails at the higher levels. This process is beautifully illustrated in the formation of the roundish masses of fleecy cloud known as *cumulus*, on a warm summer day. Each of these clouds marks the summit of a column of air that is rising after having been heated at the surface of the earth. When the process goes on very actively, the cloud may tower up to enormous heights, forming a thundercloud. Some clouds are formed by the mixing of air of different temperatures. Fog, which is merely cloud at the surface of the earth, is often formed by the cooling of the air in contact with cold land or water. The persistent fogs of the Newfoundland Banks are due to the passage of warm moist air from the Gulf Stream region over the cold Labrador Current. On the other hand, a cold wind blowing over warm water will also often produce a fog by lowering the temperature of the moist air overlying the water. A common cause of land fog is the cooling of the air adjacent to the ground in consequence of nocturnal radiation. The moister the air, the more readily fog forms, and hence the frequent formation of fog by night along rivers and over marshes and damp valleys.

Town fogs, such as the famous "London particular" and the fogs of Lyons, usually consist partly of smoke. Dense fogs of this sort occur when the conditions of the atmosphere are such as to cause the smoke to hang low over the city, instead of being dispersed. These fogs constitute a serious economic problem. Thus it is estimated that they cost the people of London upwards of half a million dollars a year, due to extra lighting, damage to vehicles, loss of business, etc. Since marine fog is also a source of enormous loss, through causing delays and accidents, and since fog along air routes is the greatest of all obstacles to successful aerial navigation, it is no wonder that much ingenuity has been devoted to the attempt to disperse fog artificially. Electric discharges have been successfully used for this purpose on a small scale.

The depth of a fog may be anything from inches to miles. Measurements made by the United States Coast Guard during the international ice patrol of the North Atlantic show that the fogs on the Newfoundland Banks are very commonly so shallow that the mastheads of vessels rise above them, though in some cases they were found, from observations with kites, to be from 2,500 to 3,000 feet thick. Observations on the mountains of the California coast show that the upper level of fog in that region rarely exceeds 4,000 feet. On the other hand, aviators flying between London and Paris have encountered fog more than 10,000 feet deep.

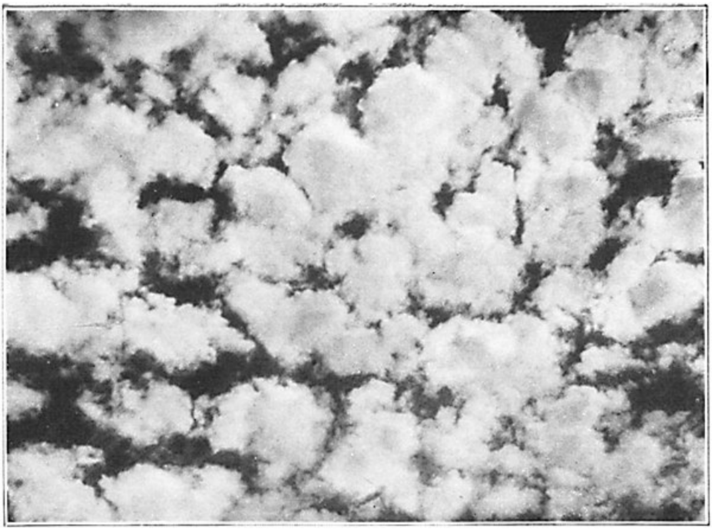
The United States Weather Bureau classifies a fog as "dense" if it hides objects at a distance of 1,000 feet; otherwise it is described as "light." British meteorologists record fogs on a scale of five degrees.

During the ice patrol of the *Seneca* in 1915 samples of foggy air were examined for the purpose of calculating the amount of water and the number of drops they contained per unit volume, as well as the size of the drops. A block of dense fog 3 feet wide, 6 feet high, and 100 feet long was found to contain less than one-seventh of a glassful of water, distributed in 60,000,000,000 drops. During the densest fog of the voyage the diameter of the fog particles averaged 0.0004 inch; just about the limit of visibility with the naked eye.

In spite of the extremely attenuated state of the water in fogs, as indicated by these figures, the moisture they deposit on terrestrial objects is great enough to be of considerable agricultural importance in some parts of the world. Thus along the coast of Peru, where the rainfall is negligible (though not, as often stated, nonexistent), a wet fog known as the "garúa" suffices to maintain a luxuriant vegetation during several months of each year.

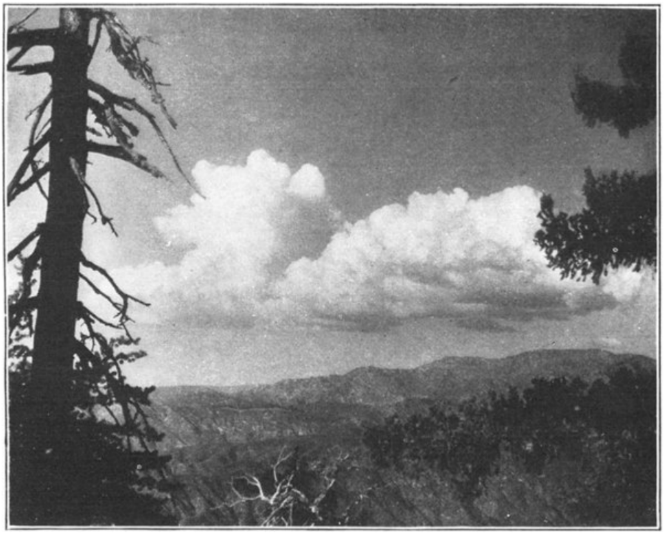
There are frozen fogs as well as frozen clouds. The "frost smoke" that rises over the Norwegian fjords and over ice-free spots in the polar seas is generally composed of icy particles or snowflakes. An ice fog that sometimes forms in mountain valleys in the western United States is known as the "pogonip"—a name derived from the Shoshonean language. This fog often appears very suddenly, even in the brightest weather. The minute needles of ice of which it consists are said to be extremely injurious to the lungs. There are tales of a whole tribe of Indians perishing from its effects. Whatever truth there may be in such stories, it is greatly dreaded by both the Indians and the whites. The mountains of Nevada appear to be the favorite home of the pogonip.

What meteorologists call "dry fog" is a haze of dust or smoke, sometimes very dense. We have already described the prevalence of this turbid state of the atmosphere following volcanic eruptions, the burning of forests and moors, and desert dust storms. Under the head of dry fog many writers include a sort of heat haze, which does not necessarily involve the suspension of either solid or liquid matter in the air, but is due to the mixing of local air currents of different densities, especially when evaporation is proceeding rapidly from moist ground under strong sunshine. The *callina* of Spain and the *qobar* of the upper Nile region are probably due partly to this cause, and partly to dust.



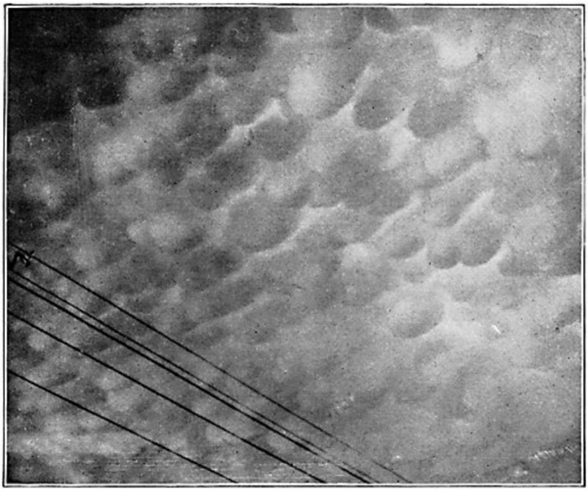
Alto-Cumulus Clouds. These clouds always occur in roundish fleecy masses or in elongated fleecy rolls, with blue sky between. A score of different types have been distinguished and named by certain cloud specialists. (*Photographed by A. J. Weed.*)

One more species of fog requires mention here, viz., the dirty, foul-smelling "painter" of the Peruvian coast, which deposits on vessels lying in the harbor of Callao and elsewhere a slimy brown substance known as "Peruvian paint." This substance comes from the ocean and is probably due to the decomposition of marine organisms. The "painter" prevails during the months December to April. According to a plausible hypothesis a change in the temperature of the water at that season, resulting from a periodical shift of ocean currents, kills vast quantities of plankton, the decay of which would give rise to the phenomena observed.



CUMULUS. Cloud photography has become a special branch of photographic art, entailing not only the use of appropriate lenses and plates, but also of ray filters, or other special devices for sharpening the contrast between the cloud and the blue sky. Mr. Ellerman's pictures, made on Mt. Wilson and elsewhere in California, stand in the front rank. (*Photographed by F. Ellerman.*)

Clouds, though they are nothing more than masses of fog situated at some distance from the earth, are susceptible of a classification, according to shape and texture, that is not applicable to fog. Among the billions of human beings who, in all ages, have amused themselves by discovering pictures in the clouds it would be remarkable if a good many had not, from time to time, conceived the idea of reducing these pictures to a few general types. According to a note published a few years ago in the "Quarterly Journal" of the Royal Meteorological Society, there is some reason to believe that an elaborate classification of the clouds was in use amongthe ancient Hindus.



MAMMATO-CUMULUS. A rather rare cloud form, associated with thunderstorms and tornadoes. It is known in Scotland as the "pocky" (i. e. baggy) cloud and in parts of England as "rain balls." (*Photographed by L. C. Twyford.*)

CUMULO-NIMBUS. This is the thundercloud. (*Courtesy of the Naval Air Service.*)

A passage quoted from an Indian work of the fourth century B. C. says:

"Three are the clouds that continuously rain for seven days; eighty are they that pour minute drops; and sixty are they that appear with the sunshine."

In the occidental world, however, we have no record of any attempt to classify the clouds prior to the year 1801, when the following classification was proposed by the French naturalist Lamarck:

Nuages en balayures (cloud sweepings),

Nuages en barres (clouds in bars),

Nuages pommelés (dappled clouds),

Nuages groupés (grouped or piled clouds),

Nuages en voile (veil clouds),

Nuages attroupés ou moutonnés (clouds in flocks).

In 1803 the English meteorologist Luke Howard published the system of classification that, with some additions and modifications, is now in general use. This system is based upon three fundamental forms; viz., fibrous or feathery clouds (*cirrus*), clouds with rounded tops (*cumulus*), and clouds arranged in horizontal sheets or layers (*stratus*). Intermediate forms are described by compounding the names of the primary types; e. g., *cirro-cumulus*, *cirro-stratus*, etc. The rain cloud is called *nimbus*. Howard's classification was quickly adopted in all countries. His definitions were translated into German by no less a personage than Goethe, who, in his enthusiasm over Howard's achievement, wrote a poem about it, and also a separate poem about each of the principal types of cloud!

The Latin names that Howard gave to the clouds made his system immediately available for international use; and in nearly all of the many systems of cloud nomenclature that have since been proposed the excellent plan of using Latin names has been preserved. Very soon, however, after Howard's classification appeared, a list of proposed English equivalents of his names was published in the "Encyclopædia Britannica"—which, nevertheless, did not change its name to "British Encyclopædia"—for the benefit of the unlettered majority, supposed to be incapable of using a few Latin terms that were, in fact, shorter and no more difficult to pronounce than their suggested English substitutes! A piquant sequel to this episode is that these superfluous English cloud names, "curl cloud," "stackencloud," "fall cloud," "sondercloud," "wane cloud," and "twain cloud," still survive in the dictionaries—and nowhere else. They are practically unknown to meteorologists, and were never adopted generally by the laity.

Of course some English names, which have been evolved and not deliberately invented, are applied to certain types of cloud in English-speaking countries; but the Latin names, comprised in the International Cloud Classification, should be learned by everybody. This classification, which has been adopted by the International Meteorological Committee and is used by all official weather services, is a little more detailed than Howard's, upon which it is based; and there is a tendency to add new terms to it from time to time.

There are ten principal types of cloud in the International Classification, and the name of each type has an official abbreviation (a great convenience for those who record the clouds from day to day). The following definitions, translated from the French text of the "International Cloud Atlas," have been published by the British Meteorological Office:

1. Cirrus (Ci.)—*Detached clouds of delicate appearance, fibrous (threadlike) structure and featherlike form, generally white in color.*

Cirrus clouds take the most varied shapes, such as isolated tufts of hair—i. e., thin filaments on a blue sky—branched filaments in feathery form, straight or curved filaments ending in tufts (called *cirrus uncinus*), and others. Occasionally cirrus clouds are arranged in bands, which traverse part of the sky as arcs of great circles, and as an effect of perspective appear to converge at a point on the horizon, and at the opposite point also, if they are sufficiently extended. Cirro-stratus and cirro-cumulus also are sometimes similarly arranged in long bands. [Certain forms of cirrus are called "mares' tails." The long bands crossing the sky, as just described, are known as "polar bands" or "Noah's ark."]

2. Cirro-stratus (Ci.-St.)—*A thin sheet of whitish cloud; sometimes covering the sky completely and merely giving it a milky appearance; it is then called cirro-nebula, or cirrus haze; at other times presenting more or less distinctly a fibrous structure, like a tangled web.*

This sheet often produces halos around the sun or moon.

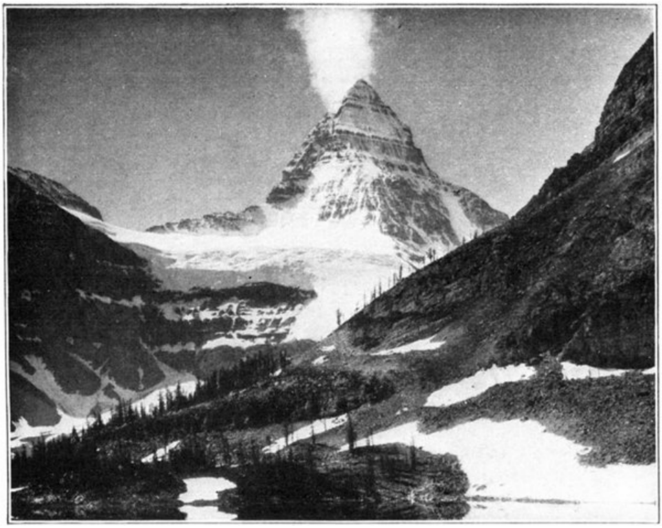
3. Cirro-cumulus (Ci-Cu.) (*Mackerel sky*)—*Small rounded masses or white flakes without shadows, or showing very slight shadow; arranged in groups and often in lines.*

4. Alto-stratus (A.-St.)—*A dense sheet of a gray or bluish color, sometimes forming a compact mass of dull gray color and fibrous structure.*

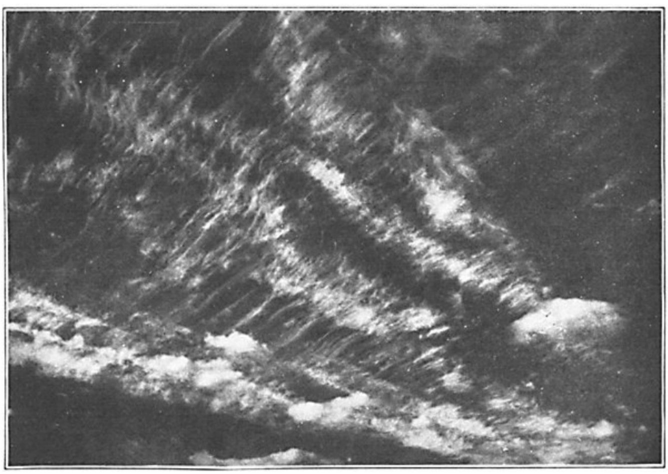
At other times the sheet is thin, like the denser forms of cirro-stratus, and through it the sun and moon may be seen dimly gleaming as through ground glass. This form exhibits all stages of transition between alto-stratus and cirro-stratus, but, according to measurements, its normal altitude is about one-half that of cirro-stratus.

5. Alto-cumulus (A.-Cu.)—*Larger rounded masses, white or grayish, partially shaded, arranged in groups or*

lines, and often so crowded together in the middle region that the cloudlets join.



A Cloud Banner Over Mt. Assiniboine, Canadian Rockies. (*Photographed by Dr. C. D. Walcott.*)



Cirrus (with a few patches of lower clouds in the foreground). This is cirrus, but not of the "mare's tail" variety. There are many distinct types of cirrus, which have sometimes been given separate names. (*Photographed at the Observatory of Trappes, France.*)

The separate masses are generally larger and more compact (resembling strato-cumulus) in the middle region of the group, but the denseness of the layer varies and sometimes is so attenuated that the individual masses assume the appearance of sheets or thin flakes of considerable extent with hardly any shading. At the margin of the group they form smaller cloudlets resembling those of cirro-cumulus. The cloudlets often group themselves in parallel lines, arranged in one or more directions.

6. Strato-cumulus (St.-Cu.)—*Large lumpy masses or rolls of dull gray cloud, frequently covering the whole sky, especially in winter.*

Generally strato-cumulus presents the appearance of a gray layer broken up into irregular masses and having on the margin smaller masses grouped in flocks, like alto-cumulus. Sometimes this cloud form has the characteristic appearance of great rolls of cloud arranged in parallel lines close together ("roll cumulus"). The rolls themselves are dense and dark, but in the intervening spaces the cloud is much lighter and blue sky may sometimes be seen through them. Strato-cumulus may be distinguished from nimbus by its lumpy or rolling appearance, and by the fact that it does not tend to bring rain.

7. Nimbus (Nb.)—*A dense layer of dark, shapeless cloud with ragged edges from which steady rain or snow usually falls. If there are openings in the cloud an upper layer of cirro-stratus may almost invariably be seen through them.*

If a layer of nimbus separates in strong wind into ragged cloud, or if small detached clouds are seen drifting underneath a large nimbus (the "scud" of sailors), either may be specified as *fracto-nimbus* (FR.-NB.).

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A Lenticular Cloud Over Mt. Rainier

8. Cumulus (Cu.) (*Wool-pack cloud*)—*Thick cloud of which the upper surface is dome-shaped and exhibits protuberances, while the base is generally horizontal.*

These clouds appear to be formed by ascensional movement of air in the daytime, which is almost always observable. When the cloud and the sun are on opposite sides of the observer, the surfaces facing the observer are more brilliant than the margins of the protuberances. When, on the contrary, it is on the same side of the observer as the sun, it appears dark with bright edges. When the light falls sideways, as is usually the case, cumulus clouds show deep shadows. True cumulus has well-defined upper and lower margins; but one may sometimes see ragged clouds, like cumulus torn by strong wind, of which the detached portions are continually changing; to this form of cloud the name fracto-cumulus may be given.

9. Cumulo-nimbus (Cu.-Nb.)(*The thundercloud*)—*Great masses of cloud rising in the form of mountains or towers or anvils, generally having a veil or screen of fibrous texture ("false cirrus") at the top, and at its base a cloud mass similar to nimbus.*

From the base local showers of rain or snow, occasionally of hail or graupel, usually fall. Sometimes the upper margins have the compact shape of cumulus, or form massive heaps round which floats delicate "false cirrus." At other times the margins themselves are fringed with filaments similar to cirrus clouds. This last form is particularly common with spring showers. The front of a thunderstorm of wide extent is frequently in the form of a large low arch above a region of uniformly lighter sky.

10. Stratus (St.)—*A uniform layer of cloud, like fog, but not lying on the ground.*

The cloud layer of stratus is always very low. If it is divided into ragged masses in a wind or by mountain tops, it may be called *fracto-stratus*. The complete absence of detail of structure differentiates stratus from other aggregated forms of cloud.

We have given the foregoing official definitions and descriptions in full in order to aid the reader as much as possible, so far as verbal information goes, in learning to call the common clouds by their names. Good pictures are, of course, an essential part of this process, and apart from those that illustrate the present text, many collections of such pictures are easy of access. Some may be obtained free or at nominal cost from the Weather Bureau in Washington and from the Meteorological Office in London. The "International Cloud Atlas" (second edition, Paris, 1910) is now out of print, but may be consulted in libraries.

Of the clouds above enumerated, cirrus, cirro-cumulus, and cirro-stratus are the highest, and are always ice clouds. They consist in some cases of separate, minute crystals—a fine dust of ice—producing, according to the forms of the crystals, one or another of the various forms of halo around the sun and moon; while in other cases the crystals are aggregated in small snowflakes, so that the cloud is a real snowstorm in midair. The altitude of these clouds generally ranges from 4 to 8 miles. In the equatorial region their height is often 10 miles or more. The other main types of cloud are composed wholly or chiefly of water. Alto-cumulus and alto-stratus are clouds of medium altitude; strato-cumulus and nimbus are low clouds (generally not more than a mile high); while stratus, the lowest cloud of all, grades into fog, which commonly rests on the earth. Since cumulus and cumulo-nimbus are produced by the condensation of moisture from rising air currents, the height of their bases varies widely with the temperature and humidity of the lower air; the average height is rather less than a mile. Their vertical extent, however, is much greater than that of the other cloud types. Cumulo-nimbus sometimes towers to a height of 4 or 5 miles above its base, and it is then commonly crowned with ice clouds, including a filmy "scarf cloud" draping the summit, and spreading wisps of so-called "false cirrus," drawn out horizontally by the upper winds.

Besides the ten main classes of clouds, a few distinct minor varieties are recognized by all meteorologists. Among these is the "lenticular cloud"; an isolated small cloud, which frequently shows iridescence, and the shape of which has been compared to that of a lens or an almond. This cloud may remain stationary, or nearly so, but it really marks the position of a billow in a stream of air, the moisture condensing at one edge of the cloud and dissolving at the other. Another distinctive and rather rare form of cloud, seen chiefly in connection with thunderstorms, is *mammato-cumulus*, likewise known as "pocky cloud," "festoon cloud," "rain balls," etc. It consists of numerous sacklike or udderlike protuberances, convex downward.

When a stream of moist air is forced to ascend in passing over a mountain its moisture is often condensed by the process of dynamic cooling, already explained, and a "cloud cap" is seen over the summit. In local weather lore such caps are generally regarded as a sign of rain. These clouds attached to mountains were called "parasitic clouds," by writers of a century ago, who proposed some naïve explanations of them. Occasionally a "cloud banner" streams far to the leeward of the mountain. One of the most famous and striking of cloud caps is the "tablecloth" that spreads over Table Mountain, near Cape Town, when a moist wind blows in from the sea. Sometimes the local topography causes the wind that has swept up over a mountain to form a second "standing" wave to the leeward of the summit, and this may also be marked by a cloud, which, like the cloud cap, presents a delusive appearance of permanence, while it is, in reality, in constant process of formation on the windward side and dissipation on the leeward. The two clouds thus formed, one over the summit and the other to the leeward, are often seen at Table Mountain, and are further exemplified in the celebrated "helm and bar" of Crossfell, in the English Lake District.

In the case of a wind blowing athwart a ridge or mountain range, a bank of cloud may extend along the whole crest, as in the "foehn wall" that appears along Alpine heights when the foehn wind is blowing.

Some day meteorology will be taught in art schools, for the same reason that anatomy now is. When that blissful day arrives painters will probably show us skies less at odds with nature than those that deface the work of artists of all degrees of celebrity, including the "old masters."

CHAPTER VII

PRECIPITATION

Meteorologists have been in much perplexity over the naming and classification of the various deposits of atmospheric moisture known collectively as "precipitation." The subject is one to which a good deal of attention has been paid in recent years, but it must be admitted that, even at the present time, the terminology of this group of atmospheric phenomena is not yet satisfactorily settled, either in English or in any other language.

When, for example, a record of weather occurrences states that hail has fallen, this statement, unequivocal as it may seem to the layman, often raises a question in the mind of the meteorologist. For centuries people talked and wrote about hail before it occurred to men of science to inquire whether one and the same thing was always described under this name. The pursuit of this inquiry led to disconcerting results, one of them being the discovery that we do not now know, in many cases, what bygone weather observers meant when they made the entry "hail" in their records.

There are at least three different kinds of icy lumps and pellets that fall from the sky, and they have all been called hail. What science now regards as true hail occurs only in connection with thunderstorms, and therefore chiefly in warm weather. It consists of balls or irregular lumps, each of which, on examination, is found to have an opaque snowlike center, surrounded by ice, which is often in alternately clear and opaque layers. The second class of icy particles takes the form of miniature snowballs, about the size of large shot or small peas. It falls in cold weather, often in conjunction with ordinary snow. Because it readily crumbles, English-speaking meteorologists have called it "soft hail"; but this name is inappropriate for the two cogent reasons that, though friable, it is not soft, and that it is not hail; hence this term is now giving way to the German name "graupel" (in which *au* = *ow* in "growl"). Lastly, little pellets or angular particles of clear ice sometimes fall in cold weather. These frozen drops, though fairly common, have, until recently, enjoyed the distinction of being anonymous, so far as the scientific world was concerned, while the general public called them various things, including "hail." A few British authorities have tentatively styled this form of precipitation "ice rain," a name which has, however, been otherwise applied. Finally, in the year 1916, the United States Weather Bureau took the bull by the horns and decreed that such ice particles should be called "sleet."

Although this decision of the Weather Bureau was arrived at only after an exhaustive overhauling of literature and much correspondence with philologists, scientific men, engineers, and others, it remains to be seen whether it will eventually prevail throughout the English-speaking world. In England "sleet" nearly always means a mixture of snow and rain. On the other hand, a great many Americans have been in the habit of applying this term to the coating of smooth ice, due to rain in cold weather, which often breaks down the branches of trees, lays low miles of wires, and incidentally produces one of the most beautiful spectacles of American winters.

This leads us to another difficulty. The icy coating just mentioned has, for some years, been called "glazed frost" by the British Meteorological Office, and the United States Weather Bureau now calls it "glaze." It has likewise been called, even in scientific books, "silver thaw"; and an instance of its occurrence on a large scale is termed, both popularly and scientifically, an "ice storm."

To pursue this lamentable record of cross-purposes just a little further, it may be added that the expression "silver thaw," besides being one of the aliases of glaze, or glazed frost, has been applied in various official British publications, until recently, to a very different rough or feathery deposit of ice from fog, now called by both the Meteorological Office and the Weather Bureau "rime."

Needless to say, when the scientific authorities are unable to agree about these terms, our dictionaries are sadly at sea in regard to them; so, altogether, the task of writing a chapter on precipitation is beset with verbal difficulties that would not be encountered in writing on many far more recondite subjects.

Fortunately the name of the most important kind of precipitation—rain—is reasonably free from ambiguity. To be sure, opinions may differ as to whether a "Scotch mist" is a rain or a wet fog—and if one happened to have insured a lawn fête against rain at Lloyds' the uncertainty on this point might lead to litigation—but, generally speaking, "it rains or it does not rain," as we are told in the books on logic.

"Rain," says Dr. Hellmann, "is the most widespread, most frequent, and most copious form in which the aqueous vapor of the atmosphere condenses. The area of its distribution embraces the whole surface of the earth, with the exception of the interior of Antarctica and probably of northern Greenland. The English and the Norwegian expeditions found no rain even at the edge of Antarctica. As the land rises inland to an altitude of about 2,800 meters about the South Pole, it may safely be assumed that only snow and no rain falls in the heart of Antarctica. At the North Pole, which lies in the midst of the sea, it probably rains at times; while on the high plateau of northern Greenland probably snow alone falls. As to its frequency, there are arid regions in which the average annual number of days with rain is less than one, while this number probably rises to 280 in some tropical districts. With the exceptions of the polar regions already mentioned, there are probably no regions where it never rains."

In its intensity rain varies all the way from the finest drizzle or the sprinkle of occasional drops up to the torrential downpours often known as "cloud-bursts." Before citing instances of heavy rains, it may be well to remind the reader that an inch of rainfall is equivalent to 101 tons of water per acre, or 64,640 tons per square mile. In the county of Norfolk, England, in August, 1912, a single day's rainfall brought down 670,720,000 tons of water—more than twice the volume of water contained in England's largest lake, Windermere. Doubtless this record, for showers of similar extent and duration, has often been surpassed in other countries, including our own, and *a fortiori* within the tropics.

The most remarkable example of a heavy brief shower was recorded at Porto Bello, on the Isthmus of Panama, May 1, 1908, when a fall of 2.47 inches *in three minutes*was registered by a self-recording rain gauge. An average heavy rainstorm in the eastern United States yields about this amount in twenty-four hours. At Baguio, in the Philippines, forty-six inches of rain fell from noon of July 14, 1911, to noon of the following day—probably a "world record" for twenty-four-hour rainfall. The corresponding record for the United States is 22.22 inches at Altapass, N. C., July 15–16, 1916.

Statistics of what the meteorologist calls "excessive rainfall"—i. e., abnormally heavy rain during brief periods—have been collected over the greater part of the world for much more weighty reasons than to satisfy curiosity as to which showers were "record breakers." Such data are indispensable to engineers in connection with the building of sewers, reservoirs, and dams, and in flood-protection work. Sewers must be made large enough to carry off the "storm water" from the heaviest showers that ever occur in the locality; while, on the other hand, in the absence of rainfall statistics, much money might be wasted in making them larger than necessary. A great flood raises questions as to the intensity of the rainfall that caused it, and the frequency with which similar rains may be expected to occur in the drainage area concerned. The unprecedented floods in the Ohio Valley and adjacent regions in March, 1913, which caused losses amounting to $200,000,000, led to an exhaustive study of the records of storm rainfall in the eastern United States, carried out by the engineers of the Miami Conservancy District. Their report on this subject (published at Dayton, Ohio, in 1917) is probably the most elaborate discussion of the kind hitherto prepared for any part of the world. Of the 2,641 storms investigated, seventy-eight, which covered areas of 500 square miles or more, were found to have had a rainfall amounting to at least 20 per cent of the normal rainfall for a year.

The distribution of rainfall over the earth (using the word "rainfall" in the broad sense to include snow reduced to its water equivalent) is most conveniently described in terms of mean annual values. This element is very unevenly divided between different parts of the globe and between the different regions of every large country. The raininess or dryness of a climate is determined especially by the prevailing movement of moisture-bearing winds and the relief of the land, while a second important control is the location of a region with respect to storm tracks. The rainiest regions are found on the windward slopes of mountain ranges not far from the ocean, where the moist winds, forced by the mountains to ascend rapidly, cool dynamically and shed their moisture. Thus the southern slopes of the eastern Himalaya receive an enormous rainfall from the southwest monsoon, blowing from the

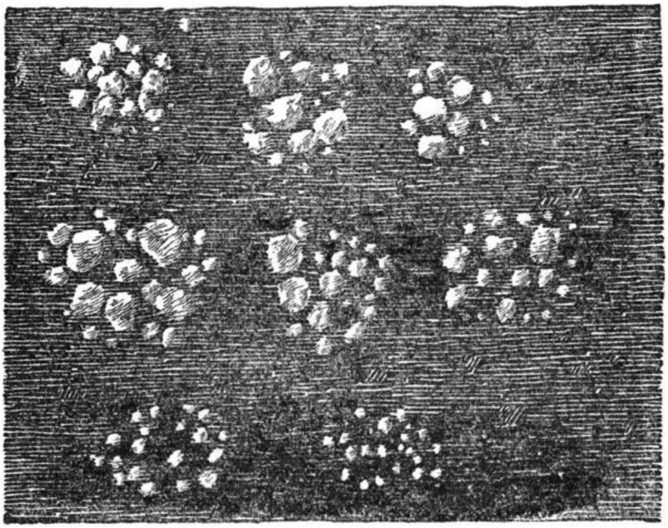
Indian Ocean, and an abundant rainfall also prevails on the south slopes of the high mountains of eastern Tibet, while northern Tibet, in the lee of the mountains, is a desert.

For more than half a century the little hill station of Cherrapunji, in Assam, at an altitude of 4,100 feet, has been credited with having the heaviest rainfall in the world. According to the latest official record, its average annual precipitation is 426 inches. Recently it has come to light that Cherrapunji has a serious rival in the Hawaiian Islands. A fragmentary record totaling 90 months, between 1911 and 1921, kept on Mount Waialeale (altitude 5,075 feet), in the island of Kauai, showed an average of 455 inches per annum, and there is reason to believe that a longer record will give an even higher average for this place. The spot in question, which has been described as "Uncle Sam's dampest corner," is so difficult of access that it can be reached only after a three-day trip on foot over mountain trails. Hence the United States Geological Survey has installed here a huge rain gauge—said to be the largest in the world—capable of holding an entire year's rainfall, so that measurements need be made only once a year.

The heaviest average annual rainfall in the United States (not including Alaska) is about 130 inches in Tillamook County, Ore. Over most of our Atlantic seaboard States the rainfall ranges from forty to fifty inches. Extensive tracts in southern California and western Nevada have a rainfall of five inches or less. Any region with an annual rainfall of less than ten inches is normally a desert, though irrigation or "dry farming" methods may enable its inhabitants to practice agriculture.

The process of rain formation is not well understood. As we have seen, the existence of nuclei in the air serves to explain why, when the conditions of temperature and humidity are right, moisture condenses in the tiny droplets that constitute clouds. The difficulty is to explain how, at certain times, quantities of drops are formed of a size large enough to carry them rapidly to the earth. The number of nuclei is so great that, as Humphreys has pointed out, even if all the water vapor in a volume of humid air was condensed upon them, the size of each drop would remain very small. He has suggested that, in a column of rising air, the small drops formed at the base of a cloud filter out most of the nuclei, so that at greater heights there are relatively few of the latter, which can, therefore, gather sufficient water about them to form drops of "falling" size.

The speed with which drops fall through the air, which is only a fraction of an inch per second for the average cloud droplet, increases rapidly with the size of the drop up to a certain point, but for the drops that reach the earth as rain the speed of fall tends to become approximately uniform. Several investigators have measured the size of raindrops. One method of doing this is to allow the drops to fall into a shallow layer of fine, uncompacted flour. Each drop forms a little pellet of dough, which is found, by experiments with previously measured drops (produced for the purpose and dropped from various heights), to correspond very closely with the size of the drop. These pellets dry and harden, and can then be carefully measured, photographed, etc. Hundreds of samples of raindrops were thus measured by Mr. W. A. Bentley of Jericho, Vt., and the measurements were tabulated with reference to the kinds of clouds from which they fell, the distribution of large and small drops in the different parts of a storm, and other circumstances attending their fall. Drops of very different dimensions are found to fall at one time. The commonest sizes recorded by Bentley were from one-thirtieth to one-eighth of an inch in diameter; but many drops too minute to form casts were estimated to be less than a hundredth of an inch in diameter, while the largest drops observed had a diameter of a quarter and even a third of an inch. This range of size corresponds to a range in the rate of fall from about five feet a second for the smallest drops up to about twenty-five feet a second for the largest. The maximum size of raindrops is limited by the fact that very large drops are broken up in their fall through the air. Theoretically, the limiting size is somewhat less than the largest sizes found by Bentley.



CASTS OF RAINDROPS FROM A THUNDERSHOWER
Collected and Photographed by W. A. Bentley

While rain is often the final product of snow that melts before it reaches the ground, snow is probably never formed from raindrops, but always condensed directly from water vapor. The finest snow consists of separate ice crystals, while snowflakes of larger sizes are always made up of several crystals partly melted together. The flakes on rare occasions attain a diameter of three or four inches, and larger sizes have been reported.

For ages mankind has admired the diversity of beautiful forms exhibited by snow crystals. Drawings of such crystals, and also of the frost tracery on window-panes, were made as early as the sixteenth century, by the learned Swedish historian Olaus Magnus, and many collections of similar drawings have been published since his time; but nowadays the combination of the camera and the microscope gives us a far greater wealth of information concerning these interesting objects. Bentley, whose study of raindrops we have just mentioned, has made and published photomicrographs of hundreds of different forms of snow and ice crystals, and several collections have been published in Europe.

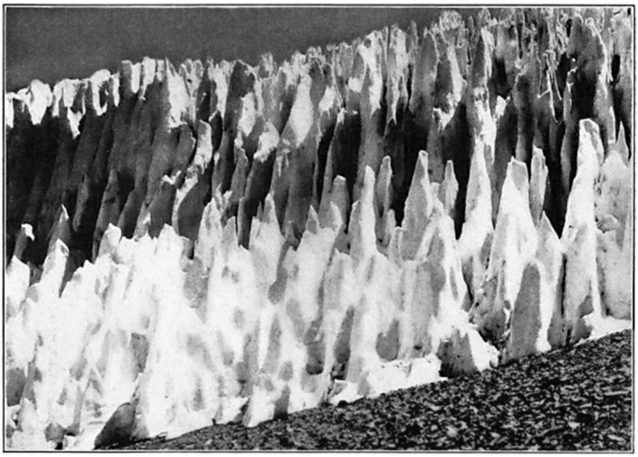
One of the facts revealed by the camera is that the perfectly regular forms of these crystals seen in drawings are comparatively uncommon in snow as it reaches the ground. A snow crystal is so fragile that it is easily mutilated by the wind and by contact with other crystals. In very calm weather and at the beginning of a snowstorm many single and perfect crystals are wafted gently to the ground, and their beauty is revealed when they fall on dark objects, especially if they are examined with a magnifying glass. In spite of their immense variety in detail, all perfect snow crystals and other ice crystals have six sides or principal rays. When secondary rays form they are parallel with the adjacent primary rays. There are two principal forms of ice crystal—the tabular and the columnar. Sometimes the two forms are combined; a column or rod of hexagonal section will have at one or both ends a hexagonal plate. Both the size and the shape of snow crystals depend to some extent upon the temperature of the air. The smallest crystals form in the coldest weather. Star-shaped crystals are most abundant when the temperature is not far below freezing, while at lower temperatures there is a preponderance of hexagonal plates.

The cohesive character of moist snow, which is utilized by the younger generation in the making of snowballs and snow men, enables this substance to assume naturally a variety of striking forms. Thus a strip of snow lying along a window ledge or the branch of a tree, will sometimes slip down in the middle and hang in festoon-shape, supported only at the ends, constituting a "snow garland." Over a level or gently sloping surface of snow the wind occasionally rolls muff-shaped snowballs, which are known as "snow rollers." Thousands of them are sometimes formed at once, and the largest may grow to the size of barrels. Huge overhanging caps of snow formed on tree stumps, posts, and the like have been aptly named "snow mushrooms" by Mr. Vaughan Cornish, who has described those that occur in great numbers in the Selkirk Mountains of western Canada.

An Ice Storm at Philadelphia, December, 1914. The branches are broken by heavy deposits of glaze. The photograph in the upper left corner, by Dr. David Fairchild, shows a glaze-incased twig. (*Photographs from U. S. Weather Bureau.*)

Perhaps the strangest of all the shapes assumed by snow is seen in the greatest perfection in the high Andes of tropical Argentina and Chile. Here are found innumerable pinnacles of snow or glacier ice, averaging from four to seven feet in height, though sometimes much higher. Viewed from a distance, they bear an uncanny resemblance to throngs of white-robed human beings, and they have thus acquired the Spanish name of *nieve de los penitentes* ("snow of the penitents"). In the abridged form *nieve penitente* this name is now applied to more or less similar formations in other mountainous regions.

Fine examples are found in the Himalaya, and one of the Himalayan peaks has been named Mount Nieves Penitentes. The origin of these pinnacles has been the subject of much discussion. Sunshine and wind both appear to take part in their formation. Some remarkable "snow honeycombs," approaching the form of *nieve penitente*, are produced in hot, dry summer weather among the glacier fields of Mount Rainier.



THE NIEVE PENITENTE IN THE ARGENTINE ANDES

(*Photograph by Dr. Juan Keidel.*)

Snow has its economic aspects, comparable in importance to those of rain. The problem of snow-removal crops up every winter in our American cities, and is not always solved with brilliant success. In the larger cities of Europe snow is removed by spreading salt on the streets to reduce the snow to slush, which is then washed into the sewers with water, but this method does not seem to be generally applicable to the heavier snowfall of this country. The snow-removal conference held by a number of municipal engineers in Philadelphia in 1914 brought this difficult phase of street cleaning prominently before the engineering world, and it has been actively discussed in recent years in the technical journals. Snow presents a formidable problem in the operation of many railway lines, the solution of which takes the form of snow sleds, fences, plows of various types, flangers, gasoline torches for melting snow in switches, etc.

Economically, snow is perhaps most important in its effects on water supply, and this is true especially of mountain snowfields, the melting of which feeds adjacent streams. There are great areas in our Western States where the water required for irrigation is obtained almost entirely from melting snow. The mountain slopes constitute natural reservoirs, from which the moisture that falls in the winter as snow is gradually fed through the spring and summer to the surrounding country. In these regions extensive "snow surveys" are sometimes made in the early spring, in order to ascertain the total amount of water available. Professor J. E. Church, of the University of Nevada, was one of the pioneers of this idea, and both he and the experts of the Weather Bureau have developed ingenious apparatus and methods for making rapid estimates of the snowfall and its equivalent volume of water lying over a given area. The snow surveyor travels over the watershed, often on skis or snowshoes, cutting sections of snow with a cylindrical "snow sampler" and weighing them with a small spring balance. The Weather Bureau also maintains in the Western mountains a number of special stations at which daily measurements of snowfall are made for the benefit of irrigation projects. The use of "snow bins" and other forms of gauge for holding an entire winter's snowfall—thus obviating the necessity of frequent measurement—has not proved very satisfactory in this country. An analogous device, known in French as a *totalisateur*, is, however, very extensively used in the Swiss and Italian Alps.

The heaviest snowfall in the United States occurs in the high Sierra Nevada of California and in the Cascade

Range of Washington and Oregon. At places in both of these regions more than sixty-five feet of snow has fallen in a single winter. The snow sometimes lies twenty-five feet deep on the ground, burying one-story houses to the eaves.

A fall of snow under a cloudless sky is fairly common in the polar regions and is sometimes observed in calm and very cold weather in the temperate zones. Rain from a cloudless sky is a more doubtful phenomenon, of which only a few observations are recorded, most of them of early date. If such rain occurs, it may come from clouds that have passed beyond the horizon before the raindrops reach the earth. Probably the older reports of this phenomenon really relate to dew, which was once believed to fall from the sky.

Of the three haillike forms of precipitation that we have mentioned above, true hail is much the most important, on account of the large size sometimes attained by hailstones and the damage that they are consequently able to cause. The maximum possible size of a hailstone cannot be positively stated, but stones larger than a man's fist and weighing over a pound have several times been reported on good authority. During a hailstorm in Natal, on April 17, 1874, stones fell that weighed a pound and a half and passed through a corrugated iron roof as if it had been made of paper. Hailstones fourteen inches in circumference fell in New South Wales in February, 1847. At Cazorla, Spain, on June 15, 1829, houses were crushed under blocks of ice, some of which are said to have weighed four and one-half pounds. In October, 1844, a hailstorm at Cette, France, wrecked houses and sank vessels. In the state of Bihar, India, October 5, 1893, hail covered the ground to a depth of four to six feet; six persons were buried beneath it and perished, and hundreds of cattle were killed. In the Moradabad district of India, May 1, 1888, about 250 people were killed by hail. The velocity attainable by falling hailstones is perhaps most strikingly shown by the fact that, even when falling obliquely, they have been known to pierce a pane of glass with a clear round hole, like a bullet hole, leaving the rest of the pane intact.

Hail appears to be formed in the violent updraft of air at the front of a thunderstorm. In this turbulent region the hailstone, first frozen at a high level, probably makes several journeys alternately up and down, as it encounters stronger or weaker rising currents; at one time gathering a coating of snow aloft, and at another a coat of ice from the rain below, until finally, on account of its large size or on account of a weakening of the upward blast, it falls to the ground. A record of these ups and downs in the life of a hailstone is seen in the concentric layers of clear and snowlike ice of which it is composed.

Although, from immemorial usage, we still speak conventionally of the "falling of the dew," it has now been known for more than a century—especially since the publication of Wells's "Essay of Dew" in 1814—that dew does not fall. The cooling of air below the dew point of its water vapor by contact with any cold object results in a deposit of visible moisture, which is liquid or frozen, according to whether the temperature is above or below the freezing point, respectively. This process is not exclusively nocturnal. It is observed by day in the familiar "sweating" of ice pitchers and also in the appearance of moisture on pavements, stone walls, and the like, in places shaded from the sun. At night the rapid cooling of the earth by radiation, especially (but not, as often stated, exclusively) under a clear sky and in still weather, favors this condensation of moisture, in the liquid form, as dew, or in the frozen form, as hoarfrost. The deposit occurs most copiously on objects that lose heat rapidly by radiation and gain it but slowly by conduction. Water vapor exhaled from the tissues of plants and from the soil undoubtedly contributes its quota to the moisture available for condensation, but this hardly seems to be a reason for asserting, as some writers have done, that dew comes mainly from the earth rather than the air.

Hoarfrost is often described as "frozen dew." This expression is misleading, for, although dew-drops are sometimes frozen into little globules of ice, hoarfrost is more often condensed directly from atmospheric water vapor in the shape of ice crystals.

"Glaze" and "rime"—to use the latest official designations of the two kinds of ice coating formed from water in the atmosphere—differ greatly in appearance, as a rule, though transition forms are sometimes found. Glaze is produced by the falling of rain on surfaces whose temperature is below freezing, and is typically smooth and transparent. Rime is a rough deposit formed from fog, the drops of which are "undercooled"—i. e., are below the freezing point—and turn to ice on coming in contact with solid objects. The most remarkable examples of rime are seen on mountains and in the polar regions. It occurs on the branches and leaves of trees, and on the corners and edges of upright objects, rather than on horizontal surfaces. In drifting fog it grows most rapidly if not entirely on the windward side of objects—i. e., it builds up against the wind. On Ben Nevis it has been observed to grow at a rate of more than an inch an hour. Trees, posts, telegraph poles, and the like are thus eventually changed to shapeless masses of rough or feathery ice.

CHAPTER VIII

WINDS AND STORMS

The study of the movements of the atmosphere constitutes a rather formidable branch of science known as *dynamic meteorology*. This subject has engaged the attention of a number of able physicists—though far too few—and has begun to assume the character of an exact science, but is still fruitful of unverified hypotheses.

We shall have only a little to say here about the theories and hypotheses relating to atmospheric circulation. They are at present, to a notable degree, in process of revision. Important modifications in them have resulted from the revelations of upper-air research, as well as from progress in other fields of inquiry. There are, however, a few fundamental matters that we must not ignore. We shall start with the solar heat that keeps the atmospheric machinery in motion.

Of the heat that comes to us from the sun, it is estimated that more than one-third is reflected by clouds and the earth, or scattered by dust and air molecules, and thus passes back into space without having had any effect in heating the atmosphere. Part of the remainder heats the atmosphere directly, and the rest indirectly, after first heating the underlying land and water. In both cases, certain atmospheric gases—notably water vapor—absorb a great deal more heat than others.

The first step in the production of a wind is a difference in temperature between two parts of the earth's surface, and hence of the overlying air. Such contrasts of temperature always exist, both locally and on a large scale. The high sun of the equatorial regions heats the earth much more strongly than the low sun of high latitudes; a water surface has a more equable temperature than an adjacent land surface; a stretch of bare earth is warmer by day and colder by night than a neighboring tract covered with vegetation; and so on. Differences in atmospheric temperature produce differences in pressure, which gravity tends to adjust by setting up a circulation.

The exact manner in which this circulation is begun and maintained is not yet perfectly clear, and current ideas on the subject are difficult to put into brief language. Meteorological writers now lay less stress than formerly upon the lateral spreading, at high levels, of air that has been heated and expanded at the earth's surface, and the inward flowing of the lower air toward the heated area. There is, we know, an initial impulse that tends to drive air from a region of high pressure toward a region of low pressure; but the actual movement of the air is another matter. The "life history" of an air current is found to be a very devious affair.

The important fact, for practical purposes, is that air does not flow in a straight line from the place where the pressure is high to that where it is low. As soon as it begins to flow it curves from the straight path, in accordance with Ferrel's Law, which is thus stated:

"In whatever direction a body moves on the surface of the earth, there is a force arising from the earth's rotation that deflects it to the right in the northern hemisphere, and to the left in the southern hemisphere."

This law applies to all bodies moving freely over the earth, and not merely to the winds.

At the earth's surface, if the atmospheric pressure is measured simultaneously at various places by means of barometers, we can get a clear picture of the horizontal distribution of pressure by drawing on a map lines, called *isobars*, through places at which the pressure is identical. The isobars reveal the presence of extensive areas over which the pressure is above the average and of others over which it is below the average. If, at the same time, we chart the flow of air by indicating the direction of the winds at various points, we shall notice that the air shows a strong tendency to travel *around* these areas; and if we could observe its course a thousand feet or so above the earth we should find the tendency even more pronounced at that level.

Another important law, springing in part from Ferrel's Law and describing the movements of the air around areas of high and low pressure, is called Buys Ballot's Law. One way of stating this law is as follows:

"If you stand with your back to the wind, in the northern hemisphere, the barometer will be lower on your left than on your right. The reverse is true in the southern hemisphere."

The reader, whether he lives in the United States or any other civilized country, will have no difficulty in securing documentary evidence of the correctness of Buys Ballot's Law in the shape of the daily weather maps issued by the various meteorological services. On a weather map showing conditions anywhere in the northern hemisphere it will be found that the winds (which are indicated by little arrows), though subject to a good many local variations, have a general tendency to blow in the direction followed by the hands of a clock ("clockwise") around an area of high pressure, and in the opposite direction ("counterclockwise") around an area of low pressure. It will likewise be noticed that, in general, the winds, instead of blowing along the isobars, are strongly inclined inward in the case of a low-pressure area and outward in the case of a high-pressure area. Lastly, if the map indicates the force of the winds at different places, it will be seen that winds are strongest where the isobars are close together and weakest where they are far apart.

It is a matter of much interest to aeronauts that the force of the wind generally increases with altitude, and that, in the lower flying levels, the winds are little, if any, inclined to the isobars.

The spacing of the isobars is called the *barometric gradient*. One of the conventional ways of expressing a gradient numerically is to state the horizontal difference of pressure, in hundredths of an inch, for an interval of fifteen nautical miles; but meteorologists as a rule merely describe gradients as "steep," "gentle," "moderate," etc., without indicating their numerical values.

If the great difference in temperature between the equatorial and polar regions were the only factor in the control of atmospheric circulation, there would be a strong barometric gradient between these regions and there would result a simple circulation of winds, blowing poleward from the equator aloft and equatorward from the poles at the earth's surface. The former tendency of writers on meteorology and physical geography was to regard such a circulation as a substantial fact, though modified by the effects of the earth's rotation and various local causes. Thus the idea has prevailed of a wholesale, direct exchange of air between the poles and the equator. Nowadays we can hardly maintain this idea, because we see that, on account of the great deflections they undergo, the main drifts of air are approximately along parallels of latitude and not along meridians of longitude. Within the tropics the general drift of the lower air is from the east (and near the equator this drift prevails up to a great height); in middle latitudes it is from the west; and in the circumpolar regions it is again from the east. Air from the equator presumably does find its way to high latitudes, and *vice versa*, but neither rapidly nor directly.

Perhaps the dominant feature of the whole circulation is the banking up of the air in so-called high-pressure belts at about latitude 30° North and South. From these "belts"—which are really broken up into separate areas of high pressure, and which shift north and south to a certain extent with the seasons—blow the northeast and southeast *trade winds*, in the full development of which, found only over the Atlantic and the eastern Pacific, we have the most remarkable "permanent winds" of the globe.

Between the trade wind belts lies the equatorial region of low pressure, known as the "doldrums." This is, in general, a region of light and variable winds, heavy rains, and thunderstorms.

In the temperate zones of both hemispheres, on the poleward side of the high-pressure belts above mentioned, the general drift of the atmosphere near the earth's surface is from west to east. In the south temperate zone there is a very strong preponderance of west winds, especially over the vast oceanic tract of the "roaring forties," where blow the boisterous "brave west winds," well known to sailors. The corresponding belt of the northern hemisphere, which includes all but the southernmost part of the United States, is described as a region of "prevailing westerly winds," but it is also a region of storm tracks, and hence, as local episodes in the general movement of the atmosphere from west to east, there are constant shifts of the wind to all points of the compass, for reasons that will presently be explained.

On the poleward borders of the two belts of "prevailing westerlies," a little outside the Arctic and Antarctic Circles, there are zones of low pressure. That of the southern hemisphere is a continuous girdle around the earth, and has the lowest pressures found anywhere in the world. The corresponding subarctic zone, while fairly continuous in summer, is broken up in winter by the formation of high-pressure areas over Siberia and northern Canada.

The permanent ice sheets of Greenland and Antarctica are regions of high pressure, with calm air in the interior and strong outblowing winds at the borders. Furious blizzards prevail at the margin of Antarctica.

The table on the opposite page will serve as a recapitulation of the facts above stated.

NORTH POLE

Calms and high pressure over the interior of Greenland. Out-blowing winds at the border.

More or less broken subarctic belt of low pressure.

Prevailing westerlies (much interrupted by moving cyclones and anticyclones).

Belt of high pressure at about lat. 30° N. "Horse latitudes," or "calms of Cancer."

Northeast trade winds.

Equatorial belt of low pressure, calms, and variable winds. The "doldrums."

Southeast trade winds.

Belt of high pressure at about lat. 30° S. "Calms of Capricorn."

Prevailing westerlies, more constant than in the northern hemisphere. "Brave west winds."

Subantarctic belt of very low pressure.

Calms and high pressure over the interior of Antarctica. Violent outblowing winds at its border.

SOUTH POLE

WIND AND PRESSURE BELTS OF THE GLOBE.

The great wind and pressure belts of the globe are much more constant and sharply defined over the oceans than over the land, and it was upon the high seas that mankind first distinguished them and gave them their names. The northeast trade winds of the Atlantic wafted Columbus to the New World and aroused the misgivings of his sailors, who wondered how they should ever sail homeward against them. The high-pressure belt north of these trade winds is a region of calms, which Maury called the "calms of Cancer." This region, or a part of it, is likewise known as the "horse latitudes," the story being that, in the old sailing days, vessels laden with horses were often becalmed here so long that the cargoes had to be thrown overboard. As a matter of course, the prosaic modern etymologist declines to accept this origin of the name and has proposed others less picturesque. The so-called equatorial calms, which lie mostly a little north of the equator, are often nicknamed the "doldrums," or sometimes the "equatorial doldrums," to distinguish them from other regions of dolorous, baffling calms. The doldrums vary a great deal in width and the masters of sailing ships try to cross them where they are narrowest.

The name of the trade winds implies that, according to the old nautical phrase, they "blow trade," or constantly in one direction. Strictly speaking, they vary considerably in direction, at any one spot, though they are nearly always from an easterly quadrant, and they are even more variable in force. The average speed of the Atlantic trades is about eleven miles an hour. In view of the prospective requirements of aeronauts, it is a fact of much interest that the trades are rather shallow winds. Their vertical thickness has been found, by observations with pilot balloons and otherwise, to range from less than a mile to two or three miles. Some distance above the trades there are winds blowing more or less in the opposite direction, known as the *counter-trades*. Aircraft will probably use the trade winds in flying from southern Europe to the Caribbean, and the countertrades on the return voyage to Europe.

In contrast to the permanent or quasi-permanent winds just described, there are certain important winds of the "periodic" type, which reverse their directions in the course of the year or from day to night. Some of these, also, first became generally known through the reports of mariners. The ancient Greek navigators utilized the monsoons in trading with India; while we owe to the voyages of William Dampier, in the seventeenth century, one of the earliest and best descriptions of land and sea breezes.

A monsoon is a wind that blows from a continent toward the sea in winter, when the land is colder than the water, and in the opposite direction in summer, when the reverse conditions of temperature prevail. The pressure gradient is reversed with the seasons, and the wind varies accordingly. The most striking example of monsoon winds is found in southern Asia—where these winds are of special economic importance because they control the rainfall of India—but well-developed monsoons also occur in Australia and West Africa, over the Caspian Sea, on the coast of Texas, and elsewhere.

An analogous reversal of gradients, due to the change of temperature over the land from day to night, is of common occurrence on the shores of large bodies of water, resulting in land and sea breezes (or land and lake breezes). The breeze blows from the land to the water by night and in the opposite direction by day. These breezes are generally best developed and most regular within the tropics, and particularly on shores adjacent to mountains. East Indian fishermen put out to sea with the land breeze in the early morning and come home with the sea breeze in the afternoon. The refreshing and health-giving character of the sea breeze of tropical climates has earned it the sobriquet of "the doctor."

Mountain and valley breezes furnish another example of diurnally reversed winds. Relatively cold and heavy air drains down from the upper slopes by night, constituting the mountain breeze. By day the air in the valley is warmed and expanded, and as it is confined laterally by the sides of the valley it flows up the slopes, constituting the valley breeze. Long before meteorologists undertook to classify the winds of the globe, these mountain air currents attracted attention and acquired local names. Among the Alps, alone, we find scores of such names. In many cases, too, the breezes have acquired a legendry of their own. Thus the *pontias*, a cold, nocturnal wind that blows out of a narrow valley opening upon the plains of the Rhône near the town of Nyons, is said to have been brought thither in a glove by St. Cæsarius, Archbishop of Aries, for the purpose of improving the fertility of the valley! There is a quaint little book about the pontias, published by Gabriel Boule in 1647, in which the author sets forth at length the arguments for and against the miraculous origin of this wind. The Italian lakes are especially rich in locally named mountain and valley breezes.

Parenthetically it may be remarked that wind nomenclature in general is a vast subject, owing to the habit that prevailed in prescientific times, and still prevails to some extent among nonscientific people, of giving individual names to the winds characteristic of different localities. As a matter of curious interest, we set down here some of these names (a small fraction of the total number):

Khamsin, *leveche*, *leste*, *levanter*, *pampero*, *zonda*, *papagayo*, *buran*, *purga*, *brickfielder*, *southerly burster*, *williwaw*, *willy-willy*, *pontias*, *vésine*, *solore*, *joran*, *morget*, *rebat*, *vaudaire*, *breva*, *tivano*, *ora*, *Wisperwind*, *Erlerwind*, *Rotenturmwind*, *vent du Mont Blanc*, *vent d'aloup*, *autan*, *tramontana*, *gregale*, *imbat*, *kite and junk winds*, *bad-i-sad-o-bist roz* (the furious "wind of 120 days" of Persia and Afghanistan).

The present writer has collected several hundred local wind names—and is constantly adding to the list.

There are several other types of wind peculiar to mountains besides the alternating mountain and valley breezes. Most of these are descending winds, or "fall winds," which may blow by day as well as by night. Thus a strong daytime wind sometimes blows down from lofty snowfields and glaciers. A *foehn* (pronounced like "fern," but without the *r*) is a wind that has been robbed of most of its moisture through precipitation on the windward slope of mountains and which is further dried, and also strongly heated by compression, in descending the leeward slope. Winds of this type are common in the Alps, where they were first described and named, and their heat and aridity led to the belief that they came by way of the upper atmosphere from the distant deserts of Africa. Now that their origin is better understood, we find that foehns prevail in many other mountainous countries throughout the world, including the western United States, where they are called *chinooks*. When the foehn blows in winter, it causes snow to disappear with amazing rapidity—not only melting it, but speedily drying the ground—whence it has earned the name of "snow eater" in America, and "*Schneefresser*," which means the same thing and a little more, in Switzerland.

The *bora* of the Adriatic and the *mistral* of southern France are winds that blow from a cold, mountainous interior down to a warm coastal region, where they arrive as relatively cold winds, in spite of the dynamic heating they have undergone in their descent. The bora is sometimes moderate (*borina*) and at other times a tremendous gale (*boraccia*), while the mistral has been known to blow a railway train from the track in the valley of the Rhône.

The *blizzard* is a wind of which Americans once thought they had almost a monopoly until Sir Douglas Mawson located the "home of the blizzard" on the shores of the Antarctic continent. The true blizzard, whether American or Antarctic, is a violent, intensely cold wind, heavily charged with snow. Such winds are a characteristic feature of the winter climate of our Middle Western States. Although the name of this wind first became current as recently as the seventies of the last century, nobody knows its origin. Nowadays the name is often loosely applied to big snowstorms that are not really blizzardlike.

The dry "hot winds" that sometimes wither the crops of our western plains are the American antithesis of the blizzard. These winds belong to the great sirocco family—the name "sirocco" having become, in recent scientific usage, a generic designation for extensive hot winds, whether dry or moist, as distinguished from local hot winds, such as the foehn.

The *harmattan* of West Africa is a dry, dusty wind from the Sahara, and one that feels relatively cool; perhaps on account of causing rapid evaporation from the skin. The *simoom* (with a final *m*), especially the variety blowing in southern Asia, is perhaps the hottest and most parching of all winds—judging from its effects on animal life.

The great majority of the winds above enumerated are merely minor features of what are called *cyclonic* and *anticyclonic* wind systems. Reverting to what has been said about weather maps and Buys Ballot's Law—if the reader will examine a series of maps for successive days, he will notice that the areas of high pressure and low pressure are not stationary, but show a more or less rapid displacement, the general direction of which, in our latitudes, is from west to east. The fact that there are great traveling vortices or swirls in the atmosphere, which, in whatever regions they occur, partake of the general drift of the air around the globe, has been known for about a century, and constitutes the corner stone of practical meteorology. In the temperate zone, where these swirls are sometimes of moderate force and sometimes very stormy, they are the chief factor in controlling changes of weather from day to day, and their observation is the basis of weather forecasting. Within the tropics, where they are much less frequent and are confined to a few restricted regions, they are always violent storms.

An area of high pressure, with its attendant system of winds, is called an *anticyclone* or *high*. An area of low pressure, with its winds, is called a *cyclone*—sometimes. The word "cyclone" was invented by Henry Piddington in the year 1848. Nearly all the early studies of cyclones were made chiefly for the benefit of mariners, and related to the severe revolving storms encountered at sea. Hence the word "cyclone" passed into the general vocabulary with a connotation of violence, which, in everyday speech, it still retains. Perhaps the early "cyclonologists" themselves hardly realized that a "gentle cyclone" was not a contradiction in terms.

Meteorologists are still so much under the influence of the popular idea of a "cyclone" that they hesitate to apply this term to a disturbance of moderate force, except in a few special phrases (such as "extra-tropical cyclone"), though the adjective "cyclonic" is used freely without reference to the force of the wind. British meteorologists speak mostly of "depressions," while American meteorologists speak of "lows." The status of the latter term, as well as that of the term "high," is, however, paradoxical.Though both words have been used for years, they are nearly always printed with quotation marks around them, as if they had not yet been assimilated in the vocabulary. The Weather Bureau has lately taken to printing these words in capital letters. Neither of these practices will be followed in the present book.

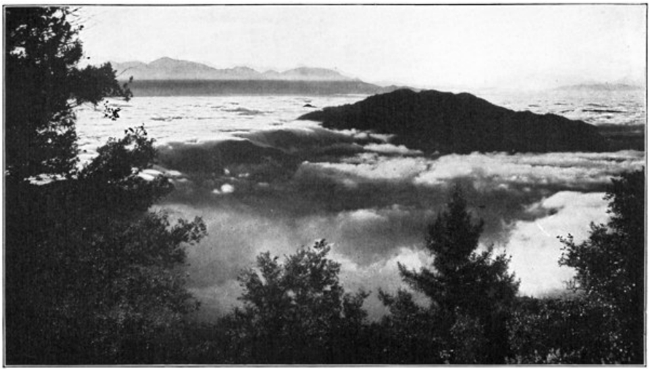


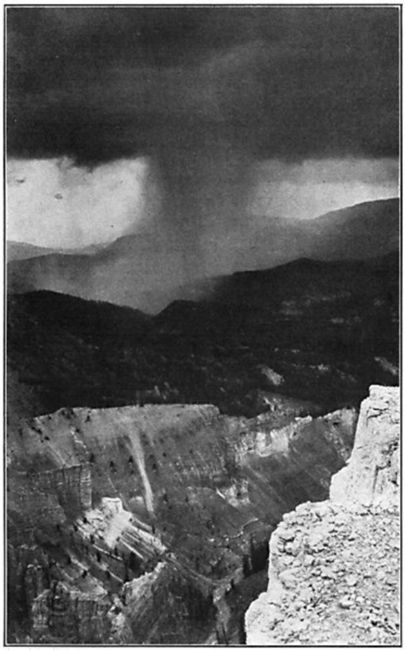
Photo by Prof. Ellerman Showing Clouds or Fog Cascading Through Last Fork Cañon and into the Santa Anita Cañon. (*Letter from F. A. Carpenter, May 29, 1919.*)

Tropical cyclones are called "hurricanes" in the West Indies and the South Pacific, "typhoons" off the east coast of Asia, "baguios" in the Philippines, and "cyclones" in the Indian seas. They form in the doldrums, and generally take a long, sweeping course, curving westward and poleward, and sometimes passing into the temperate zones, where they either die out or increase in size, diminish in violence, and become similar to the storms originating in the higher latitudes. One of the curious features they often exhibit within the tropics is the calm center at the "eye of the storm," to which Tennyson alludes when he writes of the blast (unknown to meteorologists) that drove a ship

> Across the whirlwind's heart of peace,
> And to and thro' the counter-gale.

These cyclones are the worst of all storms found at sea, and also exercise their destructive effects over islands and along continental coasts. The greatest disasters attending them have been due to the inundation of low-lying shores by the huge waves they generate, as in the

Galveston hurricanes of 1900 and 1915 and in the far worse catastrophes that have occasionally visited the coast of India. Hurricanes of the West Indies occur chiefly from August to October, inclusive. The number varies from none to a dozen a year (with four as an average).



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A CLOUDBURST NEAR CEDAR BRAKES, UTAH

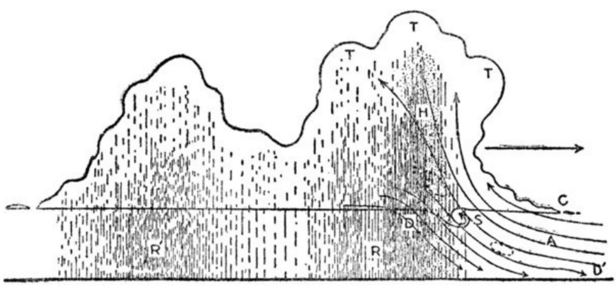
A snapshot taken from the edge of the cañon.

Over the large land areas of the north temperate zone highs and lows show a tendency to travel over typical tracks, the locations of which vary a good deal with the season. One of the most remarkable facts about the lows of North America is that, wherever they come from, whether from the Canadian northwest, the western United States, or the West Indies, they nearly always leave the continent by way of the Gulf of St. Lawrence or the northeastern corner of this country. Our North American lows travel at an average speed of 600 miles a day. Highs travel somewhat more slowly; about 540 miles a day is the average in this country.

A *tornado* is a small vortex in the atmosphere, occurring generally in the southeastern part of a cyclonic area, where, in some cases, several separate tornadoes develop at the same time. The tornado, for some reason that is not altogether clear, is far more common in the interior of North America, east of the Rocky Mountains, than anywhere else in the world, though true tornadoes do occur in other countries. The West African storms bearing this name are merely thundersqualls, quite different from the American tornado. The chief visible feature of a tornado is the so-called funnel-shaped cloud (sometimes balloon-shaped or, again, like a great coiling serpent), which is always in contact with the ground when destruction is in progress. The passage of the storm is attended by a loud roaring or rumbling. The path of a tornado varies in width from a few rods to half a mile or (rarely) more. Within its borders buildings are blown to pieces, trees are uprooted and human beings only find safety underground; while even at a distance of a few yards outside the path no damage is done. The tornado travels at an average speed of about twenty-five miles an hour. Its speed of rotation has been estimated, from the effects produced, to amount to 500 miles an hour in some cases; a wind force far exceeding that of any other type of storm.

Waterspouts, which occur on the ocean and other large bodies of water, are similar in character to tornadoes, though much less violent. They range in height from 100 to 1,000 yards, or more. One measured recently from the British steamer *War Hermit*, near Cape Comorin, was 4,600 feet high to the base of the overlying cloud. The column tapered from 500 feet wide at the junction with the cloud to 150 feet wide at the sea. Spray was thrown up to a height of more than 800 feet over a region 250 feet in diameter.

Thunderstorms occur chiefly in warm climates and during the warm season in temperate climates, but they are by no means unknown in the polar regions. They are characterized by rapidly rising air currents, which may be either incidental to the circulation of a low, or due to local overheating of the lower atmosphere. In the former case they are called "cyclonic thunderstorms," and in the latter "heat thunderstorms." This is only a rough classification, however. Some thunderstorms partake of the features of both these types, and, on the other hand, additional classes are distinguished by many authorities. It is a common occurrence for thunderstorm conditions, starting in some small area, to travel across country at a speed of perhaps thirty or forty miles an hour, at the same time spreading out fanwise until the front of the storm is hundreds of miles in length. This front constitutes a "line squall" (so called from the long line or apparent arch of dark cloud that marks its location), and is attended by more or less thunder and lightning, but is not necessarily a continuous thunderstorm. The characteristic wind of a thunderstorm is the squall that rushes out in front of the storm when close at hand. This blast of wind, lightning, hail and torrential rain are all agencies of destruction in severe thunderstorms.



IDEAL CROSS SECTION OF A TYPICAL THUNDERSTORM

A, ascending air; *D*, descending air; *C*, storm collar; *D'*, wind gust; *H*, hail; *T*, thunderheads; *R*, primary rain; *R'*, secondary rain. (W. J. Humphreys.)

Concerning the winds of the globe in general and the remarkable atmospheric interchanges that they involve, Sir Napier Shaw writes:

"Of the millions of tons of air which form the atmosphere nearly the whole is moving. The regions of calm at the surface at any one time, taken all together, do not form a large part of the earth's surface, and above the surface calm regions are still rarer. Let us remember that the motion of the air is always 'circulation'; air cannot move forward or backward or upward or downward without displacing other air in front of it and being replaced by other air behind it, though the circulation may be quite local and limited in extent, as is frequently the case when warm air rises or cold air sinks. In the course of investigations into the life history of surface air currents in the Meteorological Office we have traced air over long stretches of the surface of the Atlantic. We have found, on one occasion, the shores of Greenland to be fed with air that left the middle of the Atlantic four days previously, while in the course of six days air traveled from Spitsbergen to join the northeast trade wind off the west coast of Africa. On another occasion the air that formed the wind off the south of Ireland was traced back to the north of Africa, but that which blew at the opening of the Channel two days later came from Hudson Bay, via the Azores."

Such are the ever-shifting currents of the ocean of air.

CHAPTER IX

ATMOSPHERIC ELECTRICITY

Every schoolboy has read how Benjamin Franklin, by means of his famous kite experiment, demonstrated the electrical nature of lightning, and how the same versatile genius invented the lightning rod. It is not proposed to repeat familiar history here. Neither shall we discuss the dubious statements frequently put forth that lightning rods were known before Franklin's time, nor consider how much credit is due the many philosophers who, at earlier periods, suspected lightning to be a manifestation of electricity. The facts and ideas concerning atmospheric electricity that we have to present in this chapter were, for the most part, quite unknown to Franklin and to many generations of *savants* after him, and some of them are just now finding their way into the textbooks.

Science still recognizes the existence of two kinds of electricity—positive and negative—which, by combining, neutralize each other's effects. According to current ideas, however, the more active agent in electrical phenomena is negative electricity, which is believed to consist of (or to provide electrical charges for) exceedingly minute particles called *electrons*.

Only a few years ago the smallest thing that science had to deal with was the atom, and the lightest of atoms is that of hydrogen. The discovery of electrons marks a new step toward the infinitely little. The mass of the electron—or, in more popular and less exact terms, its weight—is about 1/1800 that of a hydrogen atom. As to its size: Imagine a billiard ball magnified to the size of the earth. Its constituent atoms would be the actual size of billiard balls, but the electrons of which each atom is composed would still be too small to be seen with the naked eye. Now imagine each of these billiard-ball atoms further magnified to the size of a large church. The electrons would then be about as big as one of the periods on this page.

When we say that a body has an electrical charge we mean that it has an *excess* of positive or negative electricity. An ordinary molecule of an atmospheric gas contains (or perhaps actually consists of) equal amounts of the two kinds of electricity, and is therefore not charged. There are, however, various ways in which an electron may be detached from such a molecule, leaving it positively charged; and again it may receive an extra electron, and thus acquire a negative charge. Under the former circumstances it becomes a *positive ion*, and under the latter a *negative ion*. Ions play a very important role as carriers of electricity, because they are impelled to move toward oppositely charged bodies or particles and combine with them. A gas containing ions is said to be *ionized*; and it is the ionization of the atmosphere that makes it a conductor of electricity.

The number of ions in a given volume of air has been the subject of a great many measurements, both at observatories on land and in the course of scientific expeditions at sea. There are ingenious instruments called "ion counters," in which air is drawn at a measured rate through the apparatus and its electrical effects are noted. The number of positive ions found in a cubic centimeter of the lower atmosphere varies from a few hundred to a thousand or more, while the number of negative ions in the same space is generally one or two hundred smaller. The ionization is about the same over the ocean as over the land.

There are several ways in which the air may become ionized. The different rays given off by radioactive substances (Alpha, Beta, and Gamma rays) all have the power of driving off electrons from the molecules of gases; i. e., ionizing them. Air is undoubtedly ionized by radioactive matters in the soil (radium and thorium) and especially by the gaseous "emanations" of these substances in the atmosphere, which are also radioactive. It has, however, been a problem to account for ionization over the ocean; because the amount of radioactive matter in sea water is immeasurably small, while the amount of radioactive emanation in sea air is, according to the latest observations, only about 2.5 per cent of that occurring over the land.

The clue to this mystery seems to be found in a special kind of Gamma rays coming from some region far above the surface of the earth. These rays are called the "penetrating radiation," because they not only are able, like the Gamma rays due to radioactive substances on earth, to pass through the walls of hermetically sealed metal vessels and ionize the air inside, but they also have the power of passing through a great extent of atmosphere without being absorbed. They are estimated to be about ten times as "penetrating" as the Gamma rays coming from known terrestrial substances. The best proof that a radiation of this sort comes from above is that when closed metal vessels are carried up in balloons, there is, above an altitude of about half a mile, a rapid increase in the rate at which ions are produced within them. As to the source of this radiation, one suggestion has been that it comes from strongly radioactive cosmic dust in the upper atmosphere. A hypothesis that seems more plausible at present attributes it to the bombardment of the atmosphere by electrons shot off from the sun.

The knowledge of ions in the atmosphere is one of the recent acquisitions of science. On the other hand, it has been known for some generations that the earth has normally a negative charge as compared with the air, or the air a positive charge as compared with the earth. Thus between the earth and any point in the air (except, as we now know, at great altitudes) there is a difference of what is called "potential," of such a character that negative electricity will follow any conductor provided for it away from the earth. Variations of potential with altitude have long been measured by means of instruments called "collectors," which gather, so to speak, a sample of the electrical charge of the air at any point and enable it to be compared with that of the earth. The difference of potential is measured in volts per meter of vertical distance. Thus we get the "potential gradient," which averages about 150 volts per meter in the lowest part of the atmosphere. It is subject to great irregular variations—especially during thunderstorms—and also to somewhat regular rises and falls during each day, and to an annual fluctuation, being much greater in winter than in summer.

It has also been known for a good many years that the air is a conductor of electricity—though a poor one—and, therefore, does not insulate the earth. Dr. W. F. G. Swann has expressed the extremely small conductive capacity of the air for electricity in the statement that a column of it one inch long offers as much resistance to the passage of an electrical current as a copper cable, of the same cross section, thirty thousand million million miles long!

A fact more recently learned, from observations in balloons, is that the potential gradient falls off rapidly at high levels, and becomes practically zero at an altitude of about six miles. From this fact it is concluded that the lower six miles of the atmosphere contains a charge of positive electricity just equal to the negative charge at the earth's surface. In other words, the lower atmosphere is not only positive with respect to the earth, but in an absolute sense it contains an excess of positive electricity.

Thus we have a negatively charged earth surrounded by a layer of positively charged air. Since air is a conductor, it is not easy to see why the opposite charges of the earth and the atmosphere do not combine and neutralize each other. An interchange is, in fact, always going on between them; negative ions flow upward from the earth and positive ions flow in the opposite direction. This "earth-air current" is, however, exceedingly small. Moreover, the opposite charges of the earth and air remain from year to year in spite of it.

How does the earth retain its negative charge and the air its positive charge? No other question relating to atmospheric electricity has, in recent years, been so much debated as this. Discussion centers, as a rule, upon the negative charge of the earth; for there are certain reasons for assuming that, when once this is explained, the positive charge of the atmosphere will require no special explanation.

One hypothesis is that the earth is bombarded by positive and negative corpuscles from the sun, and that the negative corpuscles have such penetrating power that they are able to reach the earth, while the positive corpuscles are caught by the atmosphere. Another hypothesis (Swann's) is that the same "penetrating radiation" that, as we have seen, helps to ionize the lower atmosphere has the effect of driving downward a stream of electrons detached from the air molecules, thus maintaining a constant supply of negative electricity to the earth. The question is not yet settled.

It is now time to turn from these somewhat abstruse matters to a subject of universal interest; viz., lightning. As recently as a few decades ago, though there was already a copious literature on the subject of lightning, very little was really known about it. Even its superficial features were strikingly misunderstood until the advent of photographic methods of investigation. Thus until the middle of the nineteenth century sharply zigzag lightning flashes were represented in scientific books as they still are in conventional art. That so-called zigzag lightning is really sinuous was first asserted by James Nasmyth, in 1856, and his contention was soon afterward confirmed by photography. The camera has revealed a large number of other interesting things about lightning.

Everybody has noticed an appearance of flickering in lightning flashes that are of sensible duration. Several early investigators, such as Arago, Dove, and O. N. Rood, had reached the conclusion that such flashes are multiple, consisting of several successive discharges along an identical path. Rough measurements of the intervals of time between these discharges were made with various forms of rotating disk. Far more accurate information is now obtained on this subject by the use of a camera mounted on a vertical axis and swung in a wide arc, at a fixed rate, by clockwork. The perfection of this device is due, in part, to A. Larsen, in America, but especially to Dr. B. Walter, of Hamburg, whose achievements in the photography of lightning far surpass those of any other investigator.

It is obvious that if a discharge of lightning is not instantaneous, but has a sensible duration, the rotary movement of the camera, arranged as just mentioned, will spread out the image of the flash, on the photographic plate, into a more or less broad band or ribbon. Most photographs of ribbonlike streaks of lightning made with ordinary cameras are, in fact, due to accidental movements of the apparatus during exposure—such as an involuntary start of the operator, in case the camera is held in the hands—though a certain amount of spreading of the image is sometimes caused by what photographers call "halation." Pictures taken with the revolving camera show that some flashes are practically instantaneous while others may last as long as half a second or more. Those of the latter class nearly always show several parallel streams of light, more or less distinctly separated by darker spaces. Each of these bright streams represents a separate discharge along the common path. As the speed with which the camera turns is known, it is possible to determine the intervals of time between the discharges of a multiple flash. These intervals may vary from a few thousandths to one or two-tenths of a second, while the duration of each of the consecutive discharges is probably not more than two or three hundred-thousandths of a second in most cases. Sometimes the path of the lightning flash is shifted by the wind while the picture is being taken. In one case this shift was estimated at 36 feet.

Photography is also applied to determining the distance of a lightning flash and hence the dimensions of any of its features. For this purpose a stereoscopic method is used, two cameras being mounted side by side and exposed at the same time. Sometimes one of the cameras is made to revolve, while the other remains stationary. The stationary camera will then show the relative positions of the flashes occurring during exposure, while the moving camera will indicate the times at which they occurred.

Streaks of "black lightning" and black borders of the white flashes, both often seen in photographs, are a trick of the camera and are due to what is called the "Clayden effect." Some kinds of plates are much more susceptible to this effect than others. When a flash of lightning has registered its impression on such a plate, and, before the shutter is closed, another flash occurs, the general illumination of the field by light reflected from clouds, etc., often "reverses" the original image, and consequently it prints black.

"Sheet lightning" presents the appearance of a diffuse glow over the sky. When lightning of this character is seen playing about the horizon on summer evenings, in the absence of an audible thunderstorm, it is often called "heat lightning." Most sheet lightning is probably a mere reflection of ordinary streak lightning below the horizon or hidden by clouds. Some authorities believe, however, that diffuse, silent discharges actually occur in the clouds. Balloonists claim to have encountered such discharges near at hand. An analogous phenomenon is the glowing of so-called "incandescent" or self-luminous clouds, to which several observers have called attention. A remarkable phenomenon of somewhat similar character has been reported by Dr. Knoche, late director of the Chilean meteorological service, who states that it occurs on a vast scale along the crest of the Andes during the warm season. The mountains seem to act as gigantic lightning rods, giving rise to more or less continuous diffuse discharges between themselves and the clouds, with occasional outbursts simulating the beams of a great searchlight. These displays are visible hundreds of miles out at sea. Something akin to this so-called "Andes lightning" has occasionally been reported from other mountainous regions, including the mountains of Virginia and North Carolina.

"Beaded" lightning and "rocket" lightning are as rare as they are interesting. The former resembles a string of glowing beads, while the latter is a form of streak lightning that shoots up into the air at about the apparent speed of a skyrocket.

"Ball lightning" takes the form of a fiery mass (not always globular), which generally moves quite deliberately through the air or along the ground, and in many cases disappears with a violent detonation. It occurs inside of buildings, as well as out of doors.

In order that a discharge of electricity may break through the resistance of the air along paths as long as those commonly observed, enormous differences of potential must exist in the atmosphere during thunderstorms. How such conditions arise has been the subject of an immense amount of speculation. The explanation now generally accepted was proposed in the year 1909 by the English physicist and meteorologist, Dr. George Simpson. This hypothesis is based upon the fact, well attested by laboratory experiments, that the breaking up of drops of water involves a separation of positive from negative electricity; in other words, the production of both positive and negative ions. In this process the drops become positively charged; i. e., they retain a greater number of positive than of negative ions, the latter being set free in the air. About three times as many negative as positive ions are thus released.

Now a thunderstorm is accompanied by strong upward movements of the air; so strong that small drops cannot fall to the ground, while large drops, which would be heavy enough to fall through such rising currents if they could retain their integrity, are broken up by the blast of air and carried aloft, where they tend to accumulate, recombine, and fall again. This process may be repeated many times, so that the positive charge of the drops is continually increasing, and at the same time negative ions are being set free and carried by the ascending air to the upper part of the clouds. Here they unite with the cloud particles and give them a strong negative charge. Thus eventually there is formed a heavily charged positive layer of cloud between a heavily charged negative layer above and the negatively charged earth beneath. When the differences of potential thus brought about become great enough, disruptive discharges of electricity will occur, and these may be either between the upper and lower layers of cloud or between the clouds and the earth, or, sometimes, between two different clouds.

Probably much the most frequent lightning flashes are those that occur within a single thundercloud and do not reach the earth. However, it will often happen that the negatively charged upper layer of cloud is either carried very high or drifted away by the wind, and then the discharges that occur will be chiefly between cloud and earth. Such conditions are likely to prevail in the case of cyclonic thunderstorms, in which there is often great difference in the direction and force of the winds at different levels. On the other hand, heat thunderstorms usually occur when the general winds are light at all levels, and it is probable that such storms are relatively free from cloud-to-earth discharges. We seem to have here an explanation of the paradox that tropical thunderstorms, which are nearly always of the noncyclonic type, though notoriously violent, are generally harmless.

It must not be inferred from what has been said above that the mystery of the lightning flash is now fully resolved. This is far from being the case. It is not at all clear how an electrical discharge can break down the resistance of the air along a path a mile or more in length, as commonly happens in the thunderstorm. It was formerly stated, on good authority, that the difference of potential required to produce such a flash would amount to upward of 5,000,000,000 volts. Certain facts have lately been adduced to show that such great differences of potential need not be assumed. Moving-camera photographs of the sparks produced by electric machines show that such sparks begin with small brush discharges which gradually ionize the air and thus build up a conductive path for the complete discharge. Something of this kind may occur in the atmosphere. Streaks of air already strongly ionized and more or less continuous sheets of rain would also help to provide conductors for a discharge. If lightning does build up its path somewhat gradually, the process might, in certain cases, be so slow as to account for the deliberate movement of rocket lightning, and also, perhaps, furnish a clue to the hitherto unsolved mystery of ball lightning. Humphreys has tentatively suggested that all genuine cases of ball lightning are "stalled thunderbolts"; i. e., lightning discharges that have come to a halt, or nearly so, in their progress through the air.

As to the visibility of lightning Humphreys says, in his "Physics of the Air":

"Just how a lightning discharge renders the atmosphere through which it passes luminous is not definitely known. It must and does make the air path very hot, but no one has yet succeeded, by any amount of ordinary heating, in rendering either oxygen or nitrogen luminous. Hence it seems well-nigh certain that the light of lightning flashes owes its origin to something other than high temperature, probably to internal atomic disturbances induced by the swiftly moving electrons of the discharge, and to ionic recombination."

A few attempts have been made to measure the strength of current in a lightning discharge. Many substances become magnetized when an electric discharge occurs in their vicinity, and it has been pointed out by F. Pockels that when basalt rock is magnetized in this way the amount of magnetism is an indication of the greatest strength of current to which it has been exposed. Pockels examined specimens of basalt from the top of Mount Cimone, in the Apennines, where lightning strokes are common, and found many of them more or less magnetized. He also exposed blocks of basalt close to a branch of a lightning rod in the same region. He thus obtained values for the strength of current in lightning discharges ranging from 11,000 to 20,000 amperes. Humphreys, from the crushing effect of a lightning stroke upon a hollow lightning rod, has computed the strength of current in the case examined to be about 90,000 amperes.

The effects of lightning are so various that it would take a book to describe them all. Its audible effects are discussed in our chapter on atmospheric acoustics. Its chemical effects consist chiefly in the production of oxides of nitrogen, ozone, and probably ammonia from the constituents of the atmosphere along the path of the discharge, and these substances, either directly or after further combinations in the atmosphere, contribute to the fertility of the soil. Lightning sometimes bores holes several feet deep in sandy ground and fuses the material along its path, forming the glassy tubes known as *fulgurites*. Similar holes are bored in solid rock.

The destructive effects of lightning are due chiefly to the heat generated by the passage of an electric current through a poor conductor. When moisture is present in the object struck, its sudden conversion into steam produces the explosive effects seen in the shattering of trees, the ripping of clothes from the human body, etc. There is almost no end to the curious pranks played by lightning—some disastrous, some comical, and some benevolent, as when persons crippled with rheumatism, after having been knocked down and temporarily stunned by a stroke of lightning, have found themselves completely cured of their malady! A well-known book by Camille Flammarion, translated into English under the title "Thunder and Lightning," is almost wholly devoted to these eccentricities of the lightning stroke.

A LIGHTNING PRINT ON THE ARM OF A BOY STRUCK BY LIGHTNING NEAR DUNS, SCOTLAND, IN 1883

Drawn from a photograph taken a few hours after the accident. From the Lancet.

There is a very common belief that lightning sometimes impresses a photographic image of trees or other objects of the landscape upon the human body. The ramifying pink marks, known as "lightning prints," often found on the skin of persons who have been struck by lightning, are, however, in no sense photographic, but are merely the lesions due to the passage through the tissues of a branching electric discharge.

A few practical suggestions in regard to danger from lightning are offered by Humphreys, as follows:

"Generally it is safer to be indoors than out during a thunderstorm, and greatly so if the house has a well-grounded metallic roof or properly installed system of lightning rods. If outdoors it is far better to be in a valley than on the ridge of a hill, and it is always dangerous to take shelter under an isolated tree—the taller the tree, other things being equal, the greater the danger. An exceptionally tall tree is dangerous even in a forest. Some varieties of trees appear to be more frequently struck, in proportion to their numbers and exposure, than others, but no tree is immune. In general, however, the trees most likely to be struck are those that have either an extensive root system, like the locust, or deep tap roots, like the pine, for the very obvious reason that they are the best grounded and therefore offer, on the whole, the least electrical resistance.

"If one has to be outdoors and exposed to a violent thunderstorm, it is advisable, so far as danger from lightning is concerned, to get soaking wet, because wet clothes are much better conductors, and dry ones poorer, than the human body. In extreme cases it might even be advisable to lie flat on the wet ground. In case of severe shock, resuscitation should be attempted through persistent artificial respiration and prevention from chill.

"The contour of the land is an important factor in determining the relative danger from lightning because the chance of a discharge between cloud and earth, the only kind that is dangerous, varies somewhat inversely as the distance between them. Hence thunderstorms are more dangerous in mountainous regions, at least in the higher portions, than over a level country. Clearly, too, for any given region the lower the cloud the greater the danger. Hence a high degree of humidity is favorable to a dangerous storm, partly because the clouds will form at a lower level and partly because the precipitation, and probably therefore the electricity generated, will be abundant. Hence, too, a winter thunderstorm, because of its generally lower clouds, is likely to be more dangerous than an equally heavy summer one."

It is estimated that the total property loss due to lightning in the United States is about $8,000,000 a year, and the number of persons struck about 1,500, of whom one-third are killed. Nine-tenths of these accidents occur in rural localities.

Lightning rods neither prevent lightning stroke nor do they, as is sometimes alleged, attract lightning to buildings. They merely provide good conductors along which a stroke of lightning may reach the earth without doing damage, and, within very moderate limits, determine the path of discharge. While there are many unsettled points regarding the theory of lightning rods and details of construction, their general utility is strikingly indicated by statistics showing the comparative amount of damage done by lightning to rodded and unrodded buildings. According to the United States Bureau of Standards, information gathered in this country shows that "taking rods as they come in the general run of installations, they reduce the fire hazard from lightning by 80 to 90 per cent in the case of houses, and by as much as 99 per cent in the case of barns." The same bureau, in its valuable publication, "Protection of Life and Property Against Lightning" (Washington, 1915), supplies the answers to a multitude of questions that are constantly asked about lightning rods.

Buildings with metal roofs and frames connected with the ground are generally well protected from lightning (except as to nonmetallic chimneys) without rods.

During actual thunderstorms, and also at other times when there are high potential gradients in the atmosphere, luminous electric discharges of a more or less continuous character are sometimes observed to occur in the shape of small jets and flames, chiefly from pointed objects, including lightning rods, the masts and spars of vessels, the angles of roofs, etc. These are identical in character with the "brush" discharges, or incomplete sparks, produced by electric machines. They are accompanied by a hissing or crackling sound. Their luminosity is comparatively feeble, and for this reason they are much more often observed by night than by day. They are especially common during snowstorms.

This phenomenon is known as *St. Elmo's fire* or *corposants* (not to mention a score of other names, ancient and modern). As seen at sea, corposants sometimes take the form of one or two starlike objects at the trucks of the masts or the ends of yard arms, but occasionally the spars, rigging and other parts of the ship are lighted up with a great number of stationary or moving flames, producing a weird spectacle. The finest examples of corposants are, however, observed on high mountains, and the phenomenon has been carefully studied at certain mountain observatories, such as those on Ben Nevis and the Sonnblick.

Of its occurrence on Ben Nevis, Angus Rankin writes: "The most frequent manner in which it makes its appearance is as caps of light on the tips of the lightning rod, but occasionally it appears as jets of flame projecting from all objects on the top of the tower and from the cowl of the kitchen chimney, which rises from the roof at some distance from the tower. These jets are at times from 4 to 6 inches in length, and make a peculiar hissing sound.

During a very brilliant display, the observer's hair, hat, pencil, etc., are aglow with the 'fire,' but, except for a slight tingling sensation in the head and hands, he suffers no inconvenience from it. On such occasions, if a stick be raised above the head, jets of electric light will be seen at its upper end. The only drawback to observing it with advantage is the unpleasant character of the weather in which it appears, namely blinding showers of snow and hail, and squally winds, causing a good deal of snowdrift." Rankin records that it was sometimes *heard* in the daytime, when its light was invisible. On the Sonnblick a display of St. Elmo's fire has been observed to last as long as eight hours.

No luminous electrical phenomenon is more beautiful or, at first sight, more mysterious than the *aurora*, popularly known, in the northern hemisphere, as the "northern lights." This phenomenon is due to the passage of electrical discharges through the rarefied gases of the upper atmosphere, and it now appears to be settled beyond controversy that the discharges are caused by corpuscles or radiations of some kind emitted from the sun.

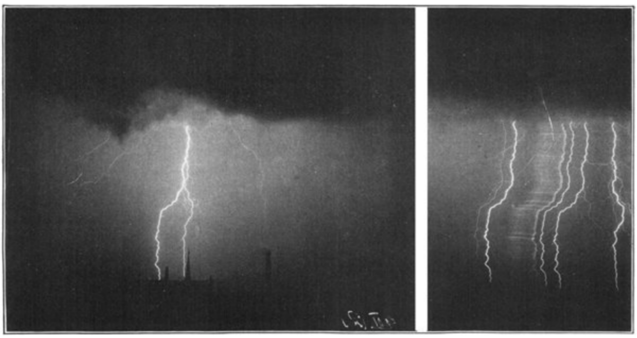
Most accounts of the aurora describe the typical appearances that it assumes as seen from a single place on the surface of the earth, but say little, if anything, about the form of the phenomenon as a whole or about its position in space. We shall follow a different plan here, and ask the reader, first of all, to imagine himself viewing the aurora from a point some thousands of miles away from our planet.

The solar emission above mentioned, when sufficiently intense, produces in the upper atmosphere a glow like that seen in a vacuum tube when an electrical discharge passes through it. From our vantage point in outer space we shall notice that this glow is not spread over the whole globe, but forms two rings, which encircle the polar regions of both hemispheres, though neither the geographic nor the magnetic poles lie at their centers. The rings do not extend down into the lower atmosphere, but hang about 60 miles above the earth's surface.

The reason for this segregation of the aurora in high latitudes is that the earth is a great magnet, and magnets have the power of deflecting an electrical discharge in their vicinity. An appearance much resembling the two auroral zones of the earth was produced, on a small scale, by the late Professor Kr. Birkeland of Christiania, who magnetized a metal globe and allowed an electrical discharge to play upon it in a vacuum. The surface of the globe was coated with a phosphorescent substance, which glowed under the discharge in two rings, corresponding roughly to those of the aurora. In both cases the discharge follows what are called the magnetic "lines of force." Our earth, like other magnets, is enveloped and penetrated by such lines. At any point on the earth the direction of the neighboring lines of force is shown by the dipping needle, which assumes a position parallel to them. At a magnetic pole the needle points straight up and down, and everywhere in high latitudes it has a position not very much inclined to the vertical, while in low latitudes it is more or less horizontal.

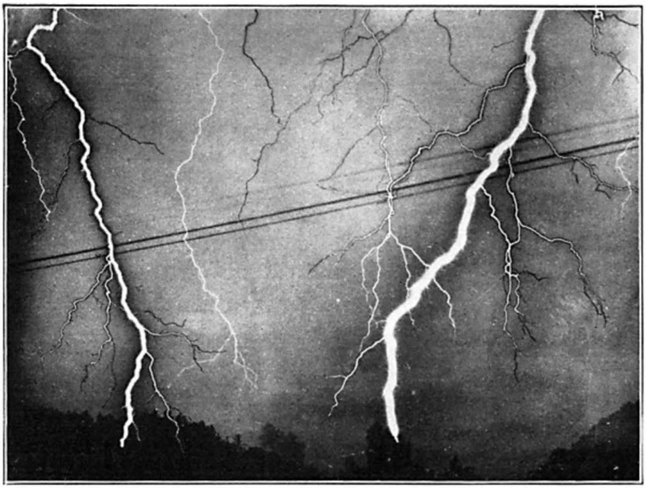
If, now, for the sake of simplicity we confine our attention to the northern hemisphere, and imagine ourselves maintaining our watch for months and years together, we shall discover that much of the time there is no ring to be seen; at other times there may be a small or partial ring; and occasionally there is a very broad, conspicuous ring, spreading so far south that it overlies the northern part of the United States and most of Europe. Evidently the emission from the sun that causes the auroral discharge varies greatly in strength, and this is in accordance with what we know about solar activities in general.

Next let us take a closer look at the ring, whether from outer space or from the earth's surface. We shall find that it is made up, at least in part, of a multitude of luminous beams directed out into space and undergoing rapid changes in position and form. These beams, which really mark out the streams of the discharge in the upper air, follow the lines of force. In high latitudes they are nearly vertical with respect to the underlying surface of the earth. Even in the United States (when the aurora extends so far south) they are much more nearly vertical than horizontal. A dipping needle will show, at any place, just how they should stand.

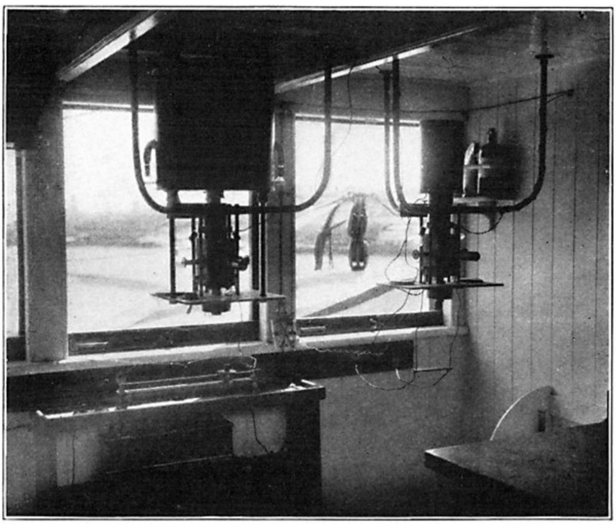


PHOTOGRAPHIC ANALYSIS OF LIGHTNING. This double photograph was made by Dr. B. Walter of Hamburg, the leading expert in the field of lightning photography. The picture at the left was taken with a stationary camera. The photograph at the right, taken at the same time with a revolving camera, shows that one of the main flashes (the one to the right) was a single discharge, and the other a multiple discharge.

From any distant point on the earth's surface either north or south of it, the visible portion of the auroral ring presents the appearance of an arch across the horizon. Arctic explorers, far within the Arctic Circle, see this arch to the south of them. In our latitudes it spans the northern horizon. Separate beams or streamers may be distinguishable or not, according to the brightness of the discharge or its distance from the point of observation. Combinations of beams constitute so-called "draperies."



PHOTOGRAPH OF LIGHTNING, SHOWING "BLACK" FLASHES. (*graph by F. Ellerman.*)



ATMOSPHERIC ELECTRICITY INSTRUMENTS ON BOARD THE "CARNEGIE." Left: Penetrating radiation apparatus. Right: active-content apparatus. Below: Arrangement for supplying potentials to electroscopes and ionization chambers, (*Carnegie Institution.*)

Occasionally, at times of great solar activity, part of the ring actually overlies our Northern States, and the aurora then becomes a magnificent spectacle in this part of the world. The whole sky may be filled with the shifting streamers, along which travel rapid pulsations of light, so that the phenomenon then suggests strongly what it really is—a vast electrical discharge passing down through the atmosphere from outer space. When the observer is thus surrounded by the beams, they seem, on account of perspective, to converge toward a point south of the zenith, where they form a beautiful *corona* or crown. The position of this crown depends upon the slant of the beams, which, as already explained, follow the lines of force.

A brilliant aurora is always accompanied by disturbances of the magnetic needle, which moves about erratically, so that compasses can no longer be depended upon. At the same time there are strong "earth currents," which interfere with the operation of telegraph lines.

Observations with the spectroscope seem to show that the light of the aurora is chiefly due to glowing nitrogen, though the most prominent line in the auroral spectrum has sometimes been referred to an unknown atmospheric gas. The various colors seen in bright auroras, including reds, greens, and yellows, are believed by some authorities to depend upon the varying speed of the electrical discharge. Experiments with vacuum tubes show that nitrogen, especially, gives great changes of color with changes in the velocity of the discharge. Another interesting revelation of the spectroscope is that there is apparently, a faint auroral illumination in the sky at all times and in all parts of the world, the so-called "permanent aurora."

Photography has been used with great success in studying the aurora, especially by the Norwegian physicists Störmer, Vegard, and Krogness. Simultaneous photographs of a single detail are taken from two points several miles apart against a background of stars. The apparent position of the auroral detail among the stars will differ in the two pictures, and a comparison of them makes it possible to determine the actual position of the aurora in space. A slow-moving cinematograph has also been used to obtain series of pictures. The measurements of these observers show that the base of the aurora is, generally between 60 and 70 miles above the earth with a strong tendency to assume a definite location at an altitude of about 61 or 67 miles. Its upper limits are not well defined, but it has been photographed up to an altitude of more than 300 miles. Earlier observers reported seeing the aurora at altitudes of only a few miles, and even down to the earth's surface, but recent authorities are inclined to discredit these observations.

One more phenomenon of atmospheric electricity requires brief mention, viz., the electric waves that produce the erratic disturbances known to wireless telegraph operators as "strays" or "static." As heard in the receiver of a wireless outfit the noise of strays has been described as "like hailstones beating against a sheet of tin," or "short hisses from a steam pipe," or "periodic discharges of coal down a chute." Another characteristic sound is a sharp "click." The study of strays has been carried out on a world-wide scale by a committee of the British Association for the Advancement of Science, but their nature is not yet fully understood. Some strays are undoubtedly due to near or distant discharges of lightning, and special forms of wireless apparatus, known as "thunderstorm recorders" or "ceraunographs," have been used to give notice of the approach of thunderstorms. On the other hand, strays seem frequently to have no connection with thunderstorms, and their principal origin is now sought in electrical disturbances in the upper atmosphere, perhaps similar to those which cause the aurora, and, as in the case of the aurora, having their ultimate source in the sun.

CHAPTER X

ATMOSPHERIC OPTICS

When we look up into the sky on a cloudless day we behold a continuous canopy, the prevailing color of which is blue. This canopy is a veil that hides the starry hosts beyond, and its presence seems, at first sight, incompatible with the fact that the air is a transparent medium. We see the stars by night through the same intervening atmosphere. Why are they cut off from our sight by day? The answer to this question can, perhaps, best be made plain by a simple experiment. Place a lighted candle behind a sheet hung across a room not otherwise illuminated. The flame of the candle will be distinctly visible through the sheet. Next, let the room be brightly lighted, say with electric light or daylight. The candle can now no longer be seen through the sheet, owing to the bright illumination of the latter as compared with the feeble light of the candle.

In the atmosphere the counterpart of our sheet is a layer, several miles in depth, of minute particles, which by day are lighted up by the sun. Some of the particles are tiny dust motes, others are fine droplets of water or bits of ice, and the rest are the molecules of the atmospheric gases themselves. It is the light that comes to us from these particles that makes our eyes insensitive to the fainter light of the stars, and makes the sky itself a visible luminous vault.

Next, why is the clear sky generally blue, rather than some other color? To answer this question, we must recall the fact that sunlight is made up of ether waves of many different sizes. In combination, these waves produce upon our eyes the sensation of white light. When they are separated, as by passing through a prism, the smallest waves—or, in more technical language, the vibrations of shortest wave length—register the sensation of violet, and the largest or longest waves that of red. The whole sequence of colors runs in the order violet, indigo, blue, green, yellow, orange and red (easily fixed in the memory by means of the word VIBGYOR, formed from the initial letters of these words).

Now the passage of sunlight through the atmosphere is obstructed to a certain extent, not only by suspended dust particles, but also by the molecules of the air. Let us consider, first, the effect of air molecules and of the finest dust particles, not much above molecular size. These tiny objects have different effects on light waves of different lengths. The longest waves are little disturbed by them, just as ordinary waves in water are little affected by a floating cork, for instance. The shortest waves are so small in proportion to the size of the obstacles that they are diffused or scattered by them, as a tiny ripple in water might be broken up by a floating cork. It is this diffuse light, of short wave length, that gives the sky its color. A large part of the violet and indigo light is lost by further scattering before it reaches the earth, leaving a preponderance of blue in the sky as we see it. When the air contains a considerable amount of suspended particles larger than those above considered—whether in the form of solid dust or crystals of ice or tiny droplets of water—light of all wave lengths is reflected by them, and the sky looks white or grayish.

On account of the action of atmospheric particles in filtering out the shorter light waves, as just described, sunlight becomes relatively rich in red and orange in passing through the air. When the sun is high, the path of the sunbeams to the earth is short, and the color of their light is but little affected. Near the time of sunrise and sunset, however, sunlight comes to us through a much greater extent of air, and the filtering process is much more effective. Hence the sunshine is both enfeebled and reddened when the sun is near the horizon. The diffuse light of the sky around the sun is filtered in the same manner, and therefore is commonly red when the sun is low.

A gray sunset sky after a clear day is due to the presence of water drops in the air, and indicates conditions favorable for rain, since, unless the air were saturated to a considerable altitude, the comparatively warm sunshine of the afternoon would favor evaporation rather than condensation of moisture. A gray sunrise sky has, as a general rule, just the opposite meaning. It often indicates the presence in the air of water drops formed on dust particles during the night, after the manner of dew, because the upper air has been *dry* enough to permit rapid radiation from the dust. These drops will be speedily evaporated by the rising sun, and the general dryness of the atmosphere will not favor further condensation. Several familiar weather proverbs are thus justified, e. g.:

Evening red and morning gray
Help the traveler on his way;
Evening gray and morning red
Bring down rain upon his head.

There are many other interesting optical phenomena connected with sunrise and sunset, including, first of all, the morning and evening twilight. When the sun, or any other heavenly body, is only a little below a clear horizon, it is still visible, on account of the bending of its rays by the atmosphere. This lifting effect, known as *astronomical refraction*, amounts to about half a degree (at the horizon), which is about equivalent to the apparent diameter of the sun or moon. As the sun sinks farther below the horizon, in the evening, the only daylight that comes to us is that reflected from the upper levels of the atmosphere, which are still illuminated. This is called twilight, and it lasts until the sun is about 18 degrees below the horizon, when total darkness sets in. The period as a whole is sometimes called *astronomical twilight*, in distinction from the briefer period known as *civil twilight*, during which there is light enough for outdoor occupations; the latter lasts from sunset until the sun is about 6 degrees below the horizon. Morning twilight is more commonly called "dawn."

An interesting succession of light and color effects is observed before and after sunset and, in inverse position and order, about sunrise. Considering sunset only: After the sun has sunk out of sight, a broad band of golden light, called the *bright segment*, is seen along the western horizon. Above this, in the western sky, appears a more or less circular expanse of rosy glow, known as the *purple light*. In the eastern heavens, after sunset, there rises steadily from the horizon the so-called *dark segment*, which is the blue or ashy shadow of the earth on the sky. This is bordered above by the pink or purplish *antitwilight arch*. As time goes on, the purple light in the west, after increasing in brightness for a while, finally sinks behind the bright segment; while in the east the rising dark segment encroaches upon and finally obliterates the antitwilight arch. Sometimes, in clear weather, there is a fainter repetition of these lights and colors (*second purple light*, etc.).

Among the Alps and other snow-capped mountains, these sunset and sunrise phenomena assume a particularly beautiful form, known as the *Alpenglow*. In fine weather, just before sunset, the peaks to the eastward begin to show a reddish or golden hue. This fades gradually, but in a few minutes, when the sun is a little below the horizon of the observer, but the peaks themselves are still bathed in direct sunlight, an intense red glow, beginning down the slopes, moves upward to the summits. This is identical with the antitwilight arch described above. Presently this glow is succeeded by an ashy tint, as the peaks are immersed in the rising shadow of the earth (the dark segment). Their rocks and snows assume a livid appearance, aptly described by the inhabitants of Chamonix, whence the phenomena in question are well seen on the summit of Mont Blanc, as the *teinte cadavéreuse*. In ordinary weather darkness succeeds without any further notable phenomena, but occasionally there occurs a remarkable renewal of rosy light upon the peaks, known as the *recoloration* or *afterglow*. At Chamonix this is termed the "resurrection of Mont Blanc." The afterglow has been variously explained, but it is probably due, mainly at least, to the reflection of the purple light in the western sky. Sometimes it lasts until an hour after sunset, and it passes away from below upward. On very rare occasions there is a second afterglow, presumably the reflection of the second purple light mentioned above. Similar phenomena are often seen in reverse order at sunrise.

A pretty phenomenon observed chiefly in the late afternoon and early morning consists of beams of light radiating from the sun, known technically as *crepuscular rays*. The beams are made visible by the presence of abundant dust or water droplets in the atmosphere, and the intervening dark spaces are the shadows of clouds. When the sun is above the horizon and the beams are directed downward, the phenomenon is popularly described as "the sun drawing water" and is regarded as a sign of rain. Sailors call these beams the "backstays of the sun," and they have several other names based upon the legendry associated with them in different parts of the world. After sunset or before sunrise a fanlike sheaf of the beams often extends upward from the western or eastern horizon, respectively. The Homeric expression "rosy-fingered dawn" probably refers to this phenomenon. In all cases the apparent divergence of these beams is an effect of perspective, as they are really parallel. A rarer phenomenon is that of *anticrepuscular rays*, which appear to converge to a point opposite the sun. In this case the beams and shadows are projected entirely across the sky, but their paths can very seldom be traced in the upper part of the heavens because in this direction the observer's line of sight passes through a comparatively shallow extent of dusty atmosphere.

An analogous phenomenon is seen in the shadows which near-by isolated mountain peaks frequently cast upon the sky opposite the sun at sunrise and sunset. Travelers have described such shadows cast by Adam's Peak in Ceylon, Pike's Peak in the Rocky Mountains, and Fujiyama in Japan. The phenomenon is said to be especially striking in the polar regions, where the air is often heavily charged with particles of ice.

One more optical phenomenon of sunrise and sunset that requires mention here seems to be comparatively little known to the nonscientific public, notwithstanding the fact that it has supplied the subject and title of a diverting novel by Jules Verne. The conditions required for its appearance are a clear and steady atmosphere and a sharply defined horizon, such as that of the ocean. At the instant the sun is appearing or disappearing, and when only a very small segment of its disk is visible above the horizon, this portion appears to be colored a bright emerald green, sometimes blending into blue. This transient phenomenon is known as the *green flash*. It is best explained as due to the different degrees of refraction undergone by rays of different wave lengths coming to us from the sun. The effect of refraction in elevating the solar image as a whole when near the horizon has already been mentioned. This effect is a little greater for the green and blue rays than for the orange and red. It is still more pronounced for the violet and indigo rays, but these are mostly sifted out of the solar beams in their long passage through the atmosphere when the sun is low. Hence at the upper edge of the solar image there is a narrow green or blue fringe, which is not, however, perceptible except when a screen is interposed between the eye and the bright image of the sun. A sharp horizon furnishes such a screen. Through a telescope it is possible, in suitable weather, to see the green flash—and also a corresponding "red flash" at the lower edge of the sun—by placing an opaque diaphragm in the focal plane of the object glass. Another explanation of the green flash—which could, however, account only for its appearance at sunset and not at sunrise—is that it is a physiological effect; the eye, fatigued by the reds and yellows that predominate in the light of the setting sun, sees an "after image" of complementary hue the instant after the real image has disappeared.

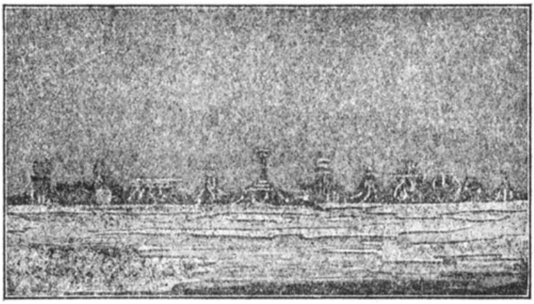
We now turn to a group of phenomena, also due to atmospheric refraction, which includes some of the most bizarre of optical illusions. The simplest of these phenomena consists of a slight apparent elevation of all objects in the surrounding landscape through *terrestrial refraction*, which is identical in principle with astronomical refraction and depends upon the difference in density, and hence of refractive power, of the air at different levels above the earth.

Normally the air decreases in density at a nearly regular rate with increasing altitude. Sometimes, however, this change in density is greatly modified by local effects of temperature. Over a cold surface of land or water the adjacent air may be abnormally dense, resulting in an unusually rapid decrease of density with altitude. Over a hot surface, as in the case of a desert under strong sunshine, the adjacent air may become so much rarefied that, for a certain distance upward, there is actually an increase of density with ascent, instead of the reverse. The rays of light coming to us from distant objects are bent in different directions and to various degrees by virtue of these abnormalities in the density of the atmosphere. The apparent positions of such objects depend upon the angle at which the light rays, coming from them, strike the eye of the observer. Sometimes the objects appear to be lifted far above their true positions (a phenomenon known as *looming*) and sometimes depressed far below them;

and occasionally local irregularities in air density produce curiously distorted images of these objects.

Most of these strange effects are known collectively as *mirage*. There are many varieties. There is the "desert mirage," first made famous through the experience of Napoleon's soldiers in Egypt. There are mirages that suspend the images of remote objects in the sky; sometimes inverted, sometimes right side up. There is the lateral mirage, occasionally seen when one looks along the face of a heated wall or cliff. Lastly, there are the complex displacements and distortions of objects known as the *Fata Morgana*—a name originally applied to a phenomenon of this kind visible, on rare occasions, at the Straits of Messina, but now used generically for similar appearances in other parts of the world. Some of the finest examples of Fata Morgana are witnessed in the polar regions.

In the desert mirage an image of the lower part of the sky is brought down to earth and simulates the appearance of water, while the images of terrestrial objects, also depressed and inverted by the mirage, look like the reflections of the same objects upon the liquid surface. Humphreys says: "This type of mirage is very common on the west coast of Great Salt Lake. Indeed, on approaching this lake from the west one can often see the railway over which he has just passed apparently disappearing beneath a shimmering surface. It is also common over smooth-paved streets, provided one's eyes are just above the street level." The confusing and obscuring effects of the desert mirage were illustrated during the fighting between the British and Turks in Mesopotamia, in April, 1917, when, according to the report of General Maude, a battle had to be suspended on account of one of these optical disturbances.

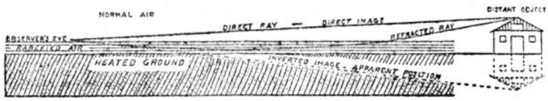


FATA MORGANA ON THE COAST OF GREENLAND
(*From drawing by Scoresby*)

The strong vertical contrasts in air temperature that occur in the polar regions produce many remarkable examples of mirage. The pictures and descriptions of those observed a century ago along the coast of Greenland by Captain William Scoresby, Jr., have become classical. A recent episode connected with mirage was the expedition sent north in 1913 to explore "Crocker Land," which Peary believed he had sighted from an elevated point in Grant Land in 1906, and which for a time figured on all maps of the Arctic. The later explorers found no land at the place indicated, but they observed the same mirage that Peary had mistaken for distant hills and mountains.

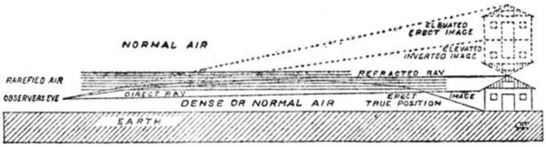
Currents of air of different densities produce, through their varying effects on atmospheric refraction, the twinkling or scintillation of the stars, as well as of distant terrestrial lights. Twinkling is much more violent near the horizon than near the zenith, and more pronounced on some nights than others. The shimmering of the air over heated surfaces faces and the "boiling" of celestial objects as seen in the telescope are analogous phenomena.

Out-of-doors when a layer of warm rarefied air arises from contact with heated ground or warm water, occupying a position below the colder, more dense normal air, two images of a distant object may be seen—one inverted beneath the other. This is "*inferior mirage*" and is explanatory of the appearance of trees and their reflections, which haunts the desert traveler with the hope of water.



INFERIOR MIRAGE

(*From American Museum Journal. Drawing by Chester A. Reeds.*)



SUPERIOR MIRAGE

(*From American Museum Journal. Drawing by Chester A. Reeds.*)

When a zone of warm rarefied air is sandwiched between normal air above and colder air below, a "*superior mirage*" of distant objects may be seen. Three images are produced, one above the other, the middle one inverted.

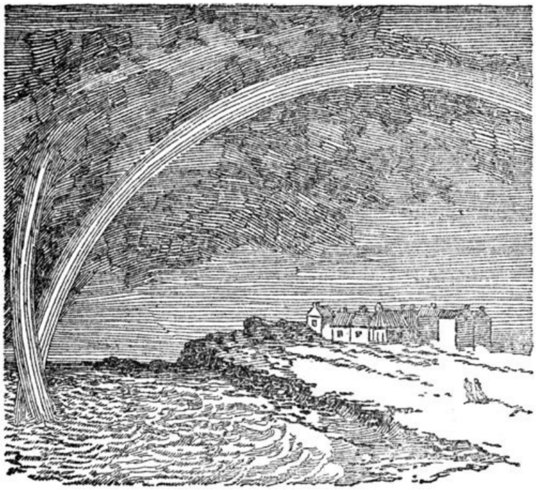
In the refraction phenomena that we have thus far considered the air is the medium in which the light rays are bent and distorted. In the production of the *rainbow*, light undergoes refraction, dispersion (separation of the spectral colors) and reflection by passing through drops of water in the atmosphere; especially falling raindrops.

The rainbow, perhaps because it is such a common sight, is seldom observed with careful attention. Hence few people realize that there are many varieties of this beautiful meteor, and various erroneous ideas about it are prevalent.

The rainbow is always seen in the part of the sky opposite the sun—or the moon, in the case of the lunar rainbow—and is high in the heavens when the luminary is low, and low when the luminary is high. Generally less than a semicircle of the bow is visible, and never more, except from an eminence. (Aeronauts occasionally see a complete circle.) The outer border of the bow is red and the inner blue or violet. Contrary to popular belief and to statements sometimes found in reference books, it is almost never possible to distinguish all seven of the spectral colors in a rainbow; four or five is the usual limit.

The ordinary or *primary rainbow* has a radius of about 42 degrees at its outer edge. Very commonly a *secondary* rainbow is seen, concentric with the primary bow, and having a radius of about 50 degrees. The secondary is fainter than the primary, and its colors are in opposite order—red inside and violet outside. Additional bands of color, chiefly red and green, may often be detected adjacent to the inner edge of the primary bow and, less frequently, along the outer edge of the secondary bow. These are known as *supernumerary bows*. The space between the primary and secondary bows is somewhat darker than the rest of the sky.

The common rainbows differ much among themselves in the number and purity of their colors, the width of the bows, etc., these differences depending especially on the size of the raindrops. The minute drops of a fog sometimes give rise to a bow that is almost devoid of color—the "white rainbow," or "fog bow." The rainbows produced by the moon commonly show little color, on account of the relative faintness of the light, but the brighter lunar rainbows are often very distinctly colored.



INTERSECTING RAINBOWS

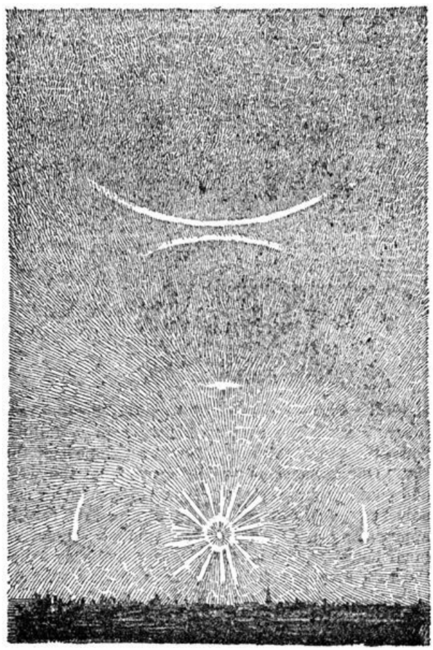
(*After a sketch by T. Hodge. Courtesy of Scientific American.*)

Reflected rainbows are sometimes seen upon a sheet of water; and again the image of the sun, as reflected by such a surface, may give rise to both primary and secondary rainbows in the sky, which appear to intersect those produced by the sun directly. A horizontal layer of water drops below the level of the observer's eye occasionally produces the so-called *horizontal rainbow*. This may be formed over a bedewed field or other surface (the "dew bow"); or the drops may be those of a low-lying sheet of fog, or of water deposited on a floating film of oil, or, finally, actual raindrops, seen from an elevation, such as the summit of a mountain. Horizontal rainbows formed by rain have been seen from the Eiffel Tower.

The common saying,

A rainbow in the morning
Is the shepherd's warning;
A rainbow at night
Is the shepherd's delight,

is, on the whole, well justified for the following reasons: We see the rainbow where rain is falling, while the sun is shining in the opposite part of the sky. Our rainstorms usually come from the west and pass away to the east. A morning rainbow can only be seen in the west, and indicates that rain is approaching us. An evening rainbow (ignoring lunar bows) is seen only in the east, and shows that the rain area is receding from us, giving place to clear skies.



THE CIRCUMZENITHAL ARC

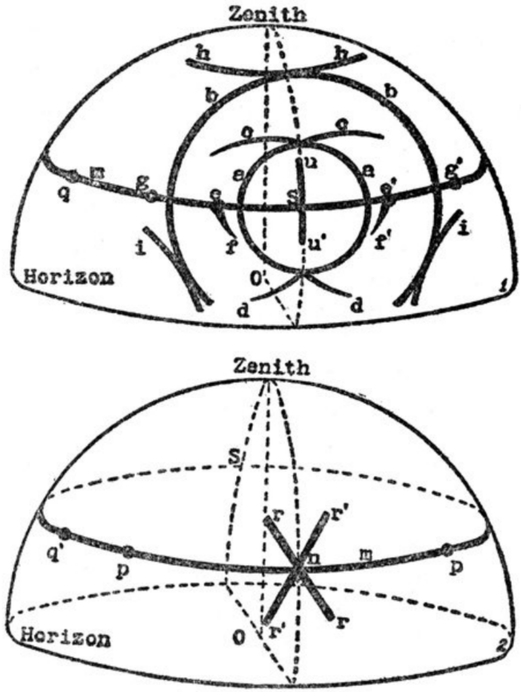
(*From a drawing by L. Besson in La Nature.*)

Parts of the halos of 22° and 46°, upper tangent arc of the 22° halo, and two parhelia are also shown. The circumzenithal arc is always brightly colored.

Ice crystals in the atmosphere, such as those composing the higher clouds, produce a great variety of optical phenomena, known as *halos*. Some phenomena of this class are common, others exceedingly rare. Moreover, there are several theoretically possible forms of halo of which observations have never yet been reported, so that halo observing can be recommended to the amateur meteorologist as offering opportunities for making interesting discoveries.

Halos take the form of narrow rings of definite angular size around the sun or moon (not to be confused with the coronas, of variable dimensions, described below), rings passing through the luminary, arcs in various other positions, and roundish spots of colored or white light. They may be seen separately or in combination. In rare cases, a dozen or more different forms of halo are visible at the same time, producing a most spectacular display. One of the most remarkable displays of this kind in the history of science was seen, in different degrees of development, over the eastern United States on November 1 and 2, 1913; an event which greatly stimulated interest in the study of halos in this country. Complex halos are quite common in the polar regions; where they are seen not only in the sky, but also in the air, charged with ice particles, close to the earth.

Whenever a thin veil of cirrus or cirro-stratus clouds overspreads the sky there is a likelihood that halos will be visible. Those formed near the sun, however, frequently pass unnoticed, on account of the dazzling brightness of that luminary. Smoked or tinted glasses greatly facilitate their observation.



DIAGRAMS OF THE PRINCIPAL FORMS OF HALO

(*After Besson, Monthly Weather Review, July, 1914.*)

1. (Upper). Perspective view of the sky, showing the sun (*S*); ordinary halo of 22° (*a*); great halo of 46° (*b*); upper tangent arc of the halo of 22° (*c*); lower tangent arc of the halo of 22° (*d*); ordinary parhelia of 22° (*e*, *e’*); Lowitz arcs (*f, f’*); parhelia of 46° (*g, g′*); circumzenithal arc (*h*); infralateral tangent arcs of the halo of 46° (*i*); the parhelic circle (*m*); a paranthelion of 90° (*q*); light pillar, (*u, u′*); the observer (*O*). 2. (Lower). Perspective view of the sky, showing the observer (*O*); the parhelic circle (*m*): ordinary paranthelia of 120° (*p*); the paranthelion of

90° (*q'*); the oblique arcs of the anthelion (*r, r'*); and the anthelion (*n*).

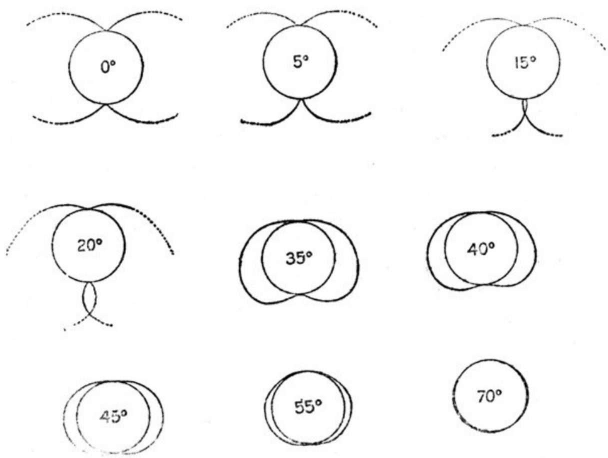
The commonest halo is a circle of 22 degrees radius (the *22-degree halo*) about the sun or moon. When formed by the sun it generally shows a distinct reddish inner border and traces of other spectral colors. The lunar 22-degree halo usually appears colorless. This halo is visible, in whole or in part, to the attentive observer about once in three days, on an average. Less common, but by no means rare, are the *parhelia* or "sun dogs" of 22 degrees (called *paraselenæ* or "moon dogs" when formed by the moon), the beautiful *circumzenithal arc*, and a few other members of the halo family. Most forms of halo are so uncommon that their appearance is an event of some scientific importance.

The accompanying diagrams, by Dr. Louis Besson of the Observatoire de Montsouris, show the positions, with respect to the sun (or moon), of the majority of known halo phenomena. The upper diagram shows the halos that occur on the same side of the sky as the sun (or moon), and the lower those that appear on the opposite side. Most of these halos, when bright, show the spectral colors. The circumzenithal arc, *h* (commonly described, by the uninitiated, as a "rainbow"), and the parhelia of 22 degrees, *e, e'*, are especially brilliant in their coloration. The *parhelic circle, m*, which sometimes extends entirely around the sky, is white, and so are a few of the rarer forms of halo.

The *upper* and *lower tangent arcs of the halo of 22 degrees*, *c* and *d*, undergo striking alterations, with changes in the altitude of the sun. When the luminary is more than about 40 degrees above the horizon, these two arcs become joined at their tips to form the *circumscribed halo*, and at still greater solar altitudes this halo contracts from an elliptical to a circular form, thus blending into the

22-degree halo as shown on the next page, where the solar altitudes corresponding to the different forms of the halo are indicated. The positions of the parhelia of 22 degrees, *e*, *e′*, also depend upon solar altitude. When the sun is on the horizon these "sun dogs" are 22 degrees from the luminary, and therefore lie in the 22-degree halo; at greater solar altitudes they lie outside this halo.

The reader who wishes to acquaint himself further with the different forms of halo and the methods of observing them will find a comprehensive article on the subject (devoid of mathematical discussions) in the "Monthly Weather Review" (Washington, D. C.) for July, 1914.



SUCCESSIVE STAGES OF THE UPPER AND LOWER TANGENT ARCS OF THE 22° HALO

When the sun is high they unite to form the "circumscribed halo." (Altitude of sun shown in the center of each figure.)

The ice crystals that produce halos consist of hexagonal plates or columns, occasionally including complications of structure, such as pyramidal bases, combinations of plates and columns, etc. These have the well-known effect of prisms in refracting and dispersing light that passes through them. It is evident that there are many possible paths for the light rays through the sides and bases of such crystals, resulting in different deflections and corresponding differences in the forms and positions of the halos produced. The attitudes assumed by the crystals as they slowly sink through the air, and the oscillations they undergo, are further points to be considered in working out the theory of each form of halo by the application of the laws of optics. Nearly all the known forms have been fully explained. A few species of halo—notably the parhelic circle (called *paraselenic circle* when formed by the moon)—are due to simple reflection from the faces of the ice crystals, and not to refraction.

The last group of optical phenomena that we shall consider consists of those due to the process called *diffraction*, which occurs when light is bent around objects in its path, instead of passing through them, as in refraction. The process involves separation of the prismatic colors. The diffraction phenomena of the atmosphere are produced by the water drops of clouds and fog, or sometimes by fine dust.

Everybody is familiar with the nocturnal spectacle which Tennyson describes as

> ... the tender amber round
> Which the moon about her spreadeth,
> Moving thro' a fleecy night.

This diffuse reddish or rainbow-tinted circle is called a *corona*. It occurs about the sun as well as the moon (though not easy to see on account of the glaring brightness of the luminary), and also about street lamps and other terrestrial lights when viewed through a misty atmosphere. Unlike the halos, it has no definite angular size. It is usually only a few degrees in radius. Small coronas are produced by large water drops and large coronas by small drops, while the largest of all coronas, known as *Bishop's ring*, is due to exceedingly fine dust in the atmosphere, and has been seen after great volcanic eruptions.

In its commonest form the corona consists of a brownish-red ring, which, together with the bluish-white inner field between the ring and the luminary, forms the so-called *aureole*. If other colors are distinguishable, they follow the brownish red of the aureole (in the direction away from the luminary) in the order from violet to red; the reverse of the order seen in halos. Sometimes the sequence of colors is repeated three or four times.

Patches and fringes of iridescence are sometimes seen in the clouds at a greater distance from the luminary than that of the ordinary corona. Probably they are fragments of coronas of unusual size produced by exceedingly fine cloud particles.

Similar in appearance to the corona is the *glory*; a series of concentric colored rings seen around the shadow of the observer, or of his head only, cast upon a cloud or fog bank. Such a shadow, with or without the glory, constitutes the *specter of the Brocken*, often seen from mountain tops and from aircraft. The colored circles are sometimes called *Ulloa's rings*, from the name of a Spanish *savant* who observed the phenomenon among the mountains of South America in the eighteenth century and has left us a vivid description of it.

The Brocken specter, though it owes its name to legends associated with the famous German mountain where witches were once believed to assemble on Walpurgis Night, is actually less frequently witnessed there than in many other parts of the world. Whenever the sun is low on one side of a mountain and a wall of mist arises from a near-by valley on the other, the mountaineer is likely to see his shadow upon the mist. If the latter consists of fine droplets of approximately uniform size, the colored rings will probably appear, and occasionally there is also a white fogbow outside of the glory. As all shadows cast by the sun taper rapidly (on account of the angular breadth of the solar disk), a well-defined Brocken specter can never be more than a few yards away from the observer. Its distance is, however, commonly overestimated—some observers have supposed it to be miles away!—and hence the erroneous idea prevails that the specters are of enormous size.

Rarely from a favorable point of vantage on a mountain, and very frequently from aircraft, the specter, instead of being seen on a vertical wall of mist when the sun is low, appears on a horizontal sheet of cloud below the observer when the sun is high. The aeronaut may thus observe the complete outline of his balloon or aeroplane, encircled with the rainbow tints of the glory. During the World War the appearance of the luminous rings was likened to the emblem painted on the wings of the Allied aeroplanes and was regarded by superstitious aviators as an omen favorable to their cause.

The glory is due to the light that is reflected back to the observer after penetrating the cloud or fog a little way and is diffracted by the superficial layer of drops in emerging.

The Brocken specter and the glory have occasionally been photographed.

CHAPTER XI

ATMOSPHERIC ACOUSTICS

Though air is but one of an unlimited number of elastic substances that transmit sound, it is the one through which sounds ordinarily reach our ears. Hence the acoustic properties of the atmosphere are of great interest to mankind.

Science deals with several kinds of "waves," and those of the atmosphere that produce the sensation of sound are quite different from the waves of the sea. In quiet unconfined air sound travels in concentric spherical waves, consisting of successive condensations and rarefactions of the medium. Sound is not transmitted through a vacuum. A familiar laboratory experiment is to install an electric bell inside the receiver of an air pump and notice the dying away of the sound as the air is exhausted. The colossal eruptions that astronomers witness on the surface of the sun would probably be audible on earth if interplanetary space were filled with air. In the rarefied air of high mountains the intensity of sounds is much reduced. Thus we are told that on the top of Mont Blanc the report of a pistol sounds no louder than that of a firecracker at sea level.

The speed with which sound travels through air depends upon the temperature. At 32° F. (the freezing point) it is 1,087 feet per second, and at 68° F. it is 1,126 feet per second. The increase of speed with increase of air temperature is very close to 2 feet per degree Centigrade, or a little more than 1 foot per degree Fahrenheit. The sounds of violent explosions travel considerably faster than ordinary sounds near the place of explosion, but slow down to the normal speed at greater distances. This is true of heavy claps of thunder. The effect is not important enough, however, to invalidate the well-known rule that, if you count seconds between the flash and the detonation and divide the result by 5, you get approximately the distance of the source of sound in miles.

Since the speed of sound varies with the temperature of the air, differences in the latter cause deviations of the paths of sound waves similar to the deviations which rays of light undergo on account of differences in the density of the air. Sound is also reflected by obstacles, in the same manner as light. Moreover, whereas light travels too swiftly to be affected by the wind, this is not true of sound. The latter travels faster with the wind than against it, and sound waves are more or less broken up by the gusts and irregularities that are a feature of most winds near the earth's surface. For all these reasons the acoustic qualities of the air are subject to marked variations, as everybody has observed.

Unusual audibility of distant sounds is a popular prognostic of rain. The fact underlying this belief is that when the air is full of moisture it is likely to be of uniform temperature, and therefore favorable for transmitting sound.

It is impossible to assign any limit to the distance at which loud sounds may occasionally be heard. No fact of nature has yet, so far as we know, matched Emerson's metaphor of the "shot heard round the world," but it is literally true that the sounds of eruption of Krakatoa, in August, 1883, were heard, like the roar of distant heavy guns, in the island of Rodriguez, in the Indian Ocean, 3,000 miles from the volcano. Moreover, the atmospheric waves set up by this outburst actually made the circuit of the globe, not only once, but at least three times, and the successive journeys were registered by barometers, if not detected by human ears. During the World War gun firing in Flanders was very commonly heard at places in England

140 to 150 miles distant. Several observers also reported that pheasants appeared, from their disturbed behavior, to hear cannonading over the North Sea that was beyond the range of the human ear.

Writers have often commented on the fact that thunder cannot be heard so far as the sounds of artillery. It has been affirmed that 10 miles or thereabouts is its maximum range of audibility. As a matter of fact, however, thunder has occasionally been heard at much greater distances, up to 20 or 30 miles; but it remains true that the distance is always much less than that at which loud terrestrial sounds are audible. The reasons why this should be so are not far to seek. In the first place, the intensity of a sound depends upon the density of the air in which it is generated, and not upon that of the air in which it is heard. The air, as we know, diminishes in density upward. Balloonists thousands of feet above the earth hear with remarkable clearness sounds from the ground below, but people on the ground cannot hear similar sounds from the balloon. As thunder is mainly produced at the level of the clouds, it is subject to this peculiarity. Again, cannonading is heard at great distances only when the air is comparatively calm, and perhaps only when it is arranged in well-defined horizontal layers of such a character as to keep the sound from spreading far aloft. Very different conditions prevail during a thunderstorm; in fact the conditions are then just such as would scatter and dissipate the sound waves. Lastly, the noise of a cannon or the like comes from a single place and the energy of the disturbance is concentrated to produce a single system of sound waves; while the disturbance due to lightning is spread over the long path of the discharge.

The audibility of sounds at abnormally great distances is not usually a matter of practical importance, but the converse phenomenon—the failure of sounds to carry to normal distances—has been responsible for a great number of marine disasters on such fog-ridden coasts as those of the British Isles, eastern Canada and California. Hence some of the ablest physicists of both the Old World and the New have tried to ascertain the conditions under which this phenomenon occurs.

The scientific study of fog signals, dating especially from Tyndall's well-known investigations at the South Foreland, in England, in 1873, and those of General Duane and Professor Joseph Henry in America, begun somewhat earlier but continued contemporaneously with Tyndall's, has probably raised more questions than it has answered. The caprices of these signals take the shape of variations in the range of audibility—a signal may at one time carry 10 miles and at another only 2—and the formation of "zones of silence," comparatively near the signal, within which the sound is not heard though audible at much greater distances. The silent zones are sometimes more or less permanent and are then generally due to peculiarities of topography; but in many cases they are transient and opinions differ as to their cause or causes. Since it is only when fog prevails that fog signals are sounded (except for experimental purposes), and that vessels meet with accidents on account of the failure to hear such signals, the idea has become rooted in the public mind that these acoustic eccentricities are entirely due to fog. When, however, experiments are made in clear weather, similar phenomena are observed.

In foggy weather audibility is often better than the average, because fog prevails chiefly when the air is still and of uniform temperature, and such conditions favor the transmission of sound. Tyndall strongly denied that either fog or falling rain, snow, and hail have, as has been commonly believed, a muffling effect on sound, and he attributed the peculiar behavior of fog signals to the presence in the atmosphere of invisible "acoustic clouds," consisting of patches of air containing irregularities of temperature and humidity. To the same cause he ascribed the occurrence of mysterious "aerial echoes," not due to any visible object. Several recent investigators have disputed these conclusions. Thus it is asserted that when the fog signal is in fog and the observer in a clear atmosphere, or *vice versa*, or when the signal and the observer are in different fog banks, the fog reflects the sound very strongly. Apart from the possible effects of fog itself, the very extensive investigations made by Prof. L. V. King, of McGill University, at Father Point, Quebec, led him to conclude that the effects are chiefly due to eddies in the atmosphere. Prof. King used in his observations the latest devices for obtaining exact measurements of sound and such up-to-date meteorological apparatus as pilot balloons for measuring the wind at various levels. He discovered, among other things, that existing types of fog-signal machinery are very wasteful of energy, and he has pointed out how their "acoustic efficiency" may be much improved. Before we dismiss this subject it should be noted that submarine bells and the radio compass have made mariners much less dependent than they formerly were upon the types of signals that are affected by meteorological conditions.

"Zones of silence" on a much more extensive scale than those that disturb the operation of fog signals have been frequently observed, in recent years, in connection with great explosions, cannonading, and volcanic eruptions. The first case of this kind to attract scientific notice was that of a dynamite explosion at Förde, Westphalia, on December 14, 1903, the acoustic phenomena of which were investigated by Dr. G. von dem Borne; and among the many cases that have since been studied was that of the bombardment of Antwerp in October, 1914. Without describing these various cases separately, we may state that when reports were collected from the surrounding country to determine the places at which the sounds were audible and these reports were entered on a map, it was found that there was a large and usually very irregular area of audibility surrounding the source of sound, beyond which lay a broad, more or less circular zone of inaudibility, and finally, beginning about 100 miles from the source, there was a second large region of audibility, extending perhaps 150 miles from the source. In some cases a single sound at the source gave multiple reports (double, triple, or quadruple), chiefly in the outer zone of audibility.

In his attempt to explain these curious silent zones, Von dem Borne pointed out that the atmosphere at very high levels is supposed to consist mainly of hydrogen, in which sound travels nearly four times as fast as in the common gases of the lower air, and that sound waves ascending to such heights along a slanting course would be bent strongly toward the earth. Another student of this phenomenon, Dr. A. Wegener, who is the champion of the idea that the atmosphere contains an unknown gas lighter than hydrogen (called "geocoronium" or "zodiacon"), sees in the prevalence of this gas at high levels the cause of a similar quasi-reflection of sound waves. Probably the majority of investigators, however, believe that the effect is due chiefly or entirely to the refraction of sound by wind.

Of acoustic phenomena that belong especially to the domain of meteorology, probably thunder is the one that excites most general interest. The sudden expansion of the air along the path of a lightning discharge, due partly but probably not entirely to the heat generated, appears to be an adequate explanation of the explosive sound of thunder, though somewhat different explanations have been suggested. If the discharge is near at hand, we generally hear a single loud crash. More distant lightning is usually attended by rumbling. The common and obvious explanation of rumbling is that it is due to the arrival of the sound progressively from different points along the path of discharge, which may be a mile or more in length. A crooked path would account for reenforcements and diminutions of the sound. Another cause of irregularities in the sound is probably "interference" (combinations of waves that tend either to strengthen or to neutralize each other), especially in the case of multiple lightning discharges, such as we have described elsewhere. Lastly, thunder is further complicated by echoes from the ground and probably also from the air (not exclusively from clouds), though much uncertainty prevails concerning these aerial echoes. The sounds of thunder have been the subject of some interesting investigations on the part of an Austrian meteorologist, Dr. Wilhelm Schmidt, who has devised apparatus for making an automatic registration of the sound waves that constitute a thunderclap. He finds that there is a great preponderance of waves of very long period, including many of too low a pitch to be audible, though perceptible through the rattling of windowpanes, etc. In fact, the greater part of the energy involved is represented by these long, inaudible waves, so that one really *hears* only a small part of a clap of thunder.

The statement has often been made, on the authority of Humboldt, that thunder is never heard at sea, at any point far from land. This matter was investigated by the magnetic survey yacht *Carnegie* during a long cruise in the Pacific in 1915. Of twenty-two displays of lightning, six were accompanied by thunder.

The late war gave prominence to certain acoustic phenomena which, though hardly mysterious, were novel to the world at large. One of those was the double report (triple in the case of an exploding shell) heard near the line of fire of large guns. This effect is due to the fact that modern projectiles travel much faster than sound. The moving projectile sets up its own waves in the air, like those at the bow of a steamer, which may reach the ear of the observer and produce the sensation of a sharp sound before he hears the sound coming from the mouth of the gun. Another phenomenon frequently observed when heavy firing was in progress was the appearance in the sky of rapidly moving parallel arcs of light and shade. These were generally seen against clouds, but sometimes they swept across blue sky. They probably occurred only in calm weather. These arcs were the result of the successive condensations and rarefactions of the air constituting waves of sound—visible sound waves. Their visibility was due to contrasts in the refraction of light passing through air of different densities; the same sort of refraction contrasts that cause the tremulous appearance of the air over a hot stove, for example. The same "flashing arcs" of light have been described by Prof. F. A. Perret as attending explosive volcanic outbursts at the craters of Vesuvius and Ætna.

The humming of telegraph wires has been the subject of a certain amount of discussion in meteorological circles, but without altogether satisfactory results. This sound is not, of course, caused or affected by the electric currents passing along the wire, and it is almost certainly due solely to the wind, though the suggestion has been made that it might be caused by the microseisms, or small and rapid earthquake tremors, that are so commonly registered by seismographs while imperceptible to the human senses. The humming is best heard when one's ear is placed against a telegraph pole. Several persons have made systematic observations of these sounds from day to day, and it has often been alleged that they vary with the temperature, the movements of storms, etc., and even constitute a safe basis for weather predictions. They are sometimes heard when the air appears to be perfectly calm, but in such cases there might be some movement of the air at the level of the wires, though there was none at the lower level of the observer. From what is known about "æolian tones" (such as those of the æolian harp), it would seem that the humming requires a wind more or less at right angles to the wire, and that the pitch of the sound depends upon the force of the wind and the diameter (but not the length or tension) of the wire. For a given wire, the stronger the wind the higher the pitch of its sound.

Of all the sounds that haunt the air, probably the most mysterious are those which are best called by the generic name "brontides" (coined, in the Italian form *brontidi*, by Prof. Tito Alippi from two Greek words meaning "like thunder"), though they rejoice in scores of other names in various parts of the world. Brontides take the form of muffled detonations, resembling the sound of distant cannon or peals of thunder, and are heard chiefly in warm, clear weather. The first systematic investigations of these phenomena were made in India. The fact that they were frequently reported from the neighborhood of Barisal, a town in the Ganges delta, led to their being called "Barisal guns," under which name they were first made known to European science in 1890. A few years later they were discussed in an extensive memoir by E. van den Broeck, who had collected numerous reports of their occurrence in Belgium, especially on the seacoast, where they are known as "mistpoeffers" (i. e., "fog belchings" or "fog hiccups"). The majority of descriptions, however, have come from Italy, where the sounds appear to be extremely common, though peculiar to certain localities, and where they bear a great variety of names. In Australia the noises are called "desert sounds," in Haiti, "gouffre," etc. They have been reported from parts of the United States, including California and, above all, from the vicinity of Moodus, Conn., which owes its original Indian name, Morehemoodus ("place of noises"), to the brontides which appear to have formerly been much more common there than they are to-day. There is a reference in one of Lord Bacon's works to "an extraordinary noise in the sky when there is no thunder"; apparently a description of brontides.

The source of these sounds is undoubtedly subterranean in a great many cases, though perhaps not in all. Prof. W. H. Hobbs, who has made a painstaking study of the seismic geology of Italy, concludes that the brontides of that country are due to the slow settling of the blocks of the earth's crust; a process which, in its more abrupt and violent phases, causes definite earthquakes. Alippi believes that in order that the sounds may be heard they must be reenforced by a peculiar configuration of the ground, above or below the surface, and he attaches special importance to the effects of caverns, which he suggests act as resonance boxes in the production of audible brontides. Occasionally an apparent brontide may be due to the explosion of an unseen meteor. Lastly, a certain proportion of these thunderlike sounds, if not merely distant thunder, may be such noises as cannonading, blasting, or the like, made audible at unusual distances by the refraction of sound waves.

CHAPTER XII

CLIMATE AND CLIMATES

SOME day the meteorologists of the world will join forces to produce a great encyclopædia of climate. No work of science is more sorely needed, but the magnitude that it would, ideally, assume is simply staggering.

Few people realize the multiplicity and complexity of climates. It is a common occurrence for a prospective traveler or a business man to write to a meteorological establishment requesting, for example, a description of the climate of South America. Of course, no such thing exists. A continent does not have a climate, but a multitude of climates. Even to set forth, in general terms, the more important types of climate that prevail between Cape Horn and Panama is no small undertaking. Moreover, general descriptions often fail to supply the needs of those who make inquiries about climate.

Suppose, instead of the wholesale order above mentioned, the meteorologist receives the relatively modest request to describe the climate of Buenos Aires or Rio de Janeiro. Is it easy to comply with such a request? That depends. If the information is sought by a tourist who wishes chiefly to know whether he will need light or heavy clothing at a specified season, or whether his excursions are likely to be hampered by frequent rains, we can enlighten him in a few brief paragraphs. If the inquiry comes from a manufacturer who aspires to invade the South American markets, we must know, before replying, what kind of goods he purposes to export, and just how they are affected by climatic conditions. Are they liable to injury by high or low temperatures, dryness or humidity? Does the demand for them depend, as in the case of rubber coats, upon the prevalence of rain, or, as in the case of electric fans, upon the occurrence of hot weather during at least a part of the year? For each branch of the export trade certain elements of climate are important, and the more detailed and explicit the information that can be obtained about them the better. Suppose, again, climatic data are desired by a horticulturist who has to solve the problem of introducing a South American plant into the United States. In order to find the best environment for it in this country, he should know something about the climate of its original home. The data he requires are, however, different from those sought by the tourist or the manufacturer. Is the plant's habitat a region where frosts occur? How long is the growing season? Is the rainfall rather evenly distributed over the year, or are there definite dry and rainy seasons? Such are some of the questions he will ask. For the purposes of medical climatology a different set of data will be sought. The astronomer, selecting a site for a new observatory, will ask about freedom from clouds, and also about the pureness and steadiness of the air that insure good "seeing." The aviator will want information about winds and fog. And so on.

Thus it appears that climate means very different things to different people.

Climate has been variously defined as the sum total of weather, average weather, typical weather, etc., but the conception is still somewhat indefinite. We know that, while the weather of any place is subject to incessant changes, its climate persists; but we need not assume that it persists indefinitely. The geological record proves, on the contrary, that vast changes of climate have occurred in the course of long ages. In Antarctica and in Spitzbergen are found deposits of coal, constituting the débris of ancient forests such as could not exist in the climates now prevailing in those regions. There are plenty of other proofs that great climatic changes have taken place from one geological period to another; but what of changes in shorter intervals of time?

An immense amount of zeal and energy has been devoted to the study of supposed changes of climate. Evidence of such changes is sought, on the one hand, in a painstaking examination of weather records (a process often involving the tabulation of hundreds of thousands of figures), and, on the other, in the collection of geographical and historical data bearing on the question. There have been numerous reports of the gradual drying up of African and Asiatic lakes, of the discovery of ancient ruins indicating that prosperous agricultural communities once flourished in regions that are now deserts, and of various other tokens that marked vicissitudes of climate have occurred within historic times. A recent ingenious method of studying climatic variations is to measure the successive annual rings seen in cross sections of old trees. Thick rings are supposed to have been formed during periods of abundant rainfall, and thin rings when the rainfall was deficient. This method has been applied to the giant *Sequoias* of California, some of which are more than 3,000 years old.

The net result of a wide range of investigations appears to be that, on the whole, climate has everywhere been remarkably constant since the dawn of human history. There is much evidence that, in certain regions, there have been alternate increases and decreases—recurrent oscillations—of temperature, rainfall, etc., but there is little evidence of progressive changes in one direction.

In contrast to the uncertainty that still prevails in the scientific world on the subject of climatic changes is the confidence with which the average layman may be heard to assert that such changes have taken place within his own recollection. The popular idea that climate has changed perceptibly within a single human lifetime is a world-wide delusion, and one that has, apparently, always flourished.

In the United States we hear of the "old-fashioned winter," with its unlimited sleighing, and also of a marked increase or falling off in the rainfall in certain districts. It is an interesting fact that a century and more ago Americans were indulging in the same sort of retrospections.

In the year 1770, when Benjamin Franklin was president of the American Philosophical Society of Philadelphia, a paper was read before that society entitled: "An Attempt to account for the Change of Climate which has been Observed in the Middle Colonies of North America." It is published in the first volume of the society's Transactions. Barring the long *s*'s and the use of the word "colonies," the greater part of it might have been addressed to the owners of automobiles and Liberty bonds. We are told of a "very observable change of climate," remarked by everybody who has resided long in Pennsylvania and the neighboring colonies. "Our winters," says the author, "are not so intensely cold, nor are our summers so disagreeably warm as they have been." These changes he ascribes to the clearing and cultivation of the country.

Another firm believer in old-fashioned winters and old-fashioned summers was Thomas Jefferson. In his "Notes on Virginia," written in 1781, he says:

"A change in our climate is taking place very sensibly. Both heats and colds are become much more moderate, within the memory even of the middle-aged. Snows are less frequent and less deep. They do not often lie, below the mountains, more than one, two or three days, and very rarely a week. They are remembered to have been formerly frequent, deep, and of long continuance. The elderly inform me, the earth used to be covered with snow about three months in every winter."

Samuel Williams, who published a "History of Vermont" in 1794, uses almost identical language in reference to the climate of that State. "Snows," he says, "are neither so frequent, deep, or of so long continuance as they were formerly; and they are yet declining very fast in their number, quantity, and duration." That these changes, he adds, "are much connected with and greatly accelerated by the cultivation of the country cannot be doubted."

What are the facts? When the statements above quoted were written few regular records of the weather had been maintained for any length of time in this country. The earliest instrumental record was begun at Charleston, S. C., in 1730. Much information was, however, available concerning the dates of harvest, of the formation and breaking up of ice in rivers and harbors, and other events dependent upon the weather, which, if anybody had taken the trouble to collect and analyze it, would have dispelled the universal belief that marked changes of climate had recently taken place. Nowadays it is much easier to refute the common assertion that the climate has changed within the memory of living men. The meteorological history of our country for more than three-quarters of a century has been recorded from day to day by a host of careful observers in every State of the Union. The records show that, while the weather of one year has often differed strikingly from that of the next, there has been no real change in climate. "Old-fashioned" winters, for example, were neither more nor less common half a century ago than they are to-day.

Our memories of past weather mislead us, chiefly because we remember the exceptional weather and forget that which commonly prevailed. Other circumstances may contribute to the illusion. Thus many people who now live in cities, where modern appliances make them more or less independent of the weather, passed their childhood under the more primitive conditions of the country.

If climates were not fairly constant for long periods of years, it would be a waste of time to compile the climatic statistics that, as we have seen, are wanted by so many different kinds of people for so many different purposes. Such statistics are based upon past events, but their practical value depends upon the fact that, within certain limits, they are a safe guide to the future.

The climatic data for any place are a sort of digest of the meteorological observations that have been made there, special emphasis being given to those features of the meteorological record that bear important relations to the life and activities of mankind. Temperature and rainfall are the leading elements of climate; others are wind, humidity, evaporation, cloudiness, etc. We have not space to enumerate here all the kinds of data found in elaborate climatic tables; but in order to illustrate how the records of a meteorological station are utilized in compiling climatic statistics and to show what complications may arise in this process, we shall consider the question of temperature alone.

The instruments used in measuring temperature have been described in another chapter. From these instruments are obtained the current temperature of the air, the wet bulb temperature (used to compute the humidity), and the maximum and minimum temperatures of the day. Readings are made at fixed hours, known as "term hours." At regular stations of the United States Weather Bureau the term hours for the observation of all the meteorological elements are 8 a. m. and 8 p. m., Eastern Time, and an observation of temperature, humidity, and clouds is made at noon. In most other countries tri-daily readings have been the rule, though in Europe four or more observations a day are now taken at many stations in order to supply the frequent weather bulletins required by aeronauts. Important stations are generally equipped with thermographs, which make a continuous record of temperature.

Theoretically, the mean temperature of any day is the average of 24 hourly observations, from midnight to midnight. In practice, the mean is generally computed from the observations at the term hours, or from the maximum and minimum. Having obtained the mean daily temperature for each day of a month, the average of these values gives us the mean monthly temperature. The average of the mean temperatures for the twelve months of the year is the mean annual temperature.

These data for each day and month, and for the year—sometimes also for other intervals, such as five-day periods, or "pentads,"—are computed year after year, and eventually the values for all the years of the record are averaged to form what are called "normals." We thus obtain, for example, for a given station, the normal temperature for January 21, the normal temperature for the month of March, the normal annual temperature, etc.

All this is a mere beginning toward the complete discussion of a body of temperature observations for the purposes of climatology. We have still to obtain from the readings of the maximum and minimum thermometers the normal maximum and minimum temperatures and range of temperature for each day, each month, and the year; also the "absolute" maxima, minima, and ranges (i. e., the extreme values that have occurred during the entire record) for corresponding intervals of time. These data furnish answers to such questions as: What was the lowest temperature ever recorded on January 21? What is the lowest on an *average* January 21? What is the average range of temperature in March? What was the highest temperature ever recorded, on any day, at the station?

Having thus disposed of the extremes and ranges, we may compute what is called the "variability" of temperature, i. e., the average difference between the means of two successive days in a given month, and the corresponding average for the entire year. These data are of considerable importance in medical climatology. We may also compute the frequency of occurrence of various values among the temperature data above enumerated. The most frequent value is often quite different from the average value. Many climatologists compute the number of days, in an average year, on which the temperature rises to 77 degrees (Fahr.) or above ("summer-days"), and the number of days on which the temperature does not rise above the freezing point ("winter-days"). Especially valuable in agricultural regions are data of the average and extreme dates of the last frost in spring and of the first frost in autumn. These define the length of the "growing season." Statistics of the temperature of the ground at the surface and at various depths below the surface are also of agricultural interest.

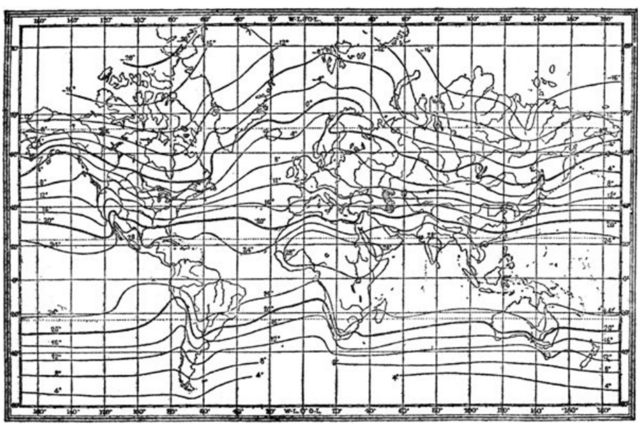
From the foregoing outline it will be seen that a bewildering variety of climatic statistics may be computed merely from observations of temperature, and the same is true of the other elements. Moreover, the list set forth above is by no means exhaustive even for temperature. In fact, there is almost no limit to the number of ways in which the raw material of climatic data—i. e., the original records of observation—may be grouped, averaged, or otherwise treated in order to bring out certain features of the climate that may conceivably serve some useful purpose. The reader will now be able to understand why a treatise on the climate of a single locality often fills a substantial volume.

The numerical data contained in such a work are generally supplemented by text descriptions and by various graphic devices, such as curves showing the normal fluctuation or "march" of a weather element during a day, year, or other interval. Works which deal with the climates of larger areas, such as whole countries, are usually accompanied by climatic charts. These charts furnish a quick and easy way of getting a general idea of the climate of a region. Among the more important climatic charts are the following:

1. *Temperature (isothermal) charts.* These include charts showing the distribution of normal temperatures for months, seasons, and the year; normal range of temperature for similar periods; highest and lowest temperatures ever recorded at the different stations; etc. Lines known as *isotherms* are so drawn as to pass through places having identical values of the element in question (mean temperature, highest temperature, etc.).

2. *Rainfall (isohyetal) charts.* These show the distribution of rainfall (including snowfall, expressed in equivalent depth of water); especially for each month and for the year. Other charts may show the average number of rainy days; average snowfall (actual depth, not water equivalent); seasonal distribution of rainfall; etc.

3. *Wind charts.* These are drawn in various forms, to show the prevailing wind directions, the frequency of winds from different directions, the average force of the winds, etc. Charts of the winds at different levels above the earth's surface will eventually be drawn for the use of aeronauts, but such charts are still in a tentative stage.



A MODERN ISOTHERMAL CHART OF THE GLOBE.
(*Hann, 1901*)
The isotherms show the mean annual temperature in centigrade degrees.

As in the case of tabulated climatic data, the number of charts that might be drawn to bring out different features of climate is practically unlimited. Sunshine, cloudiness, humidity, barometric pressure, and the frequency of various special phenomena, such as thunderstorms, hail, tornadoes, droughts, etc., are all charted in some of the more extensive works on climate. Large atlases have been published to portray the climates of certain countries. The study of the actual distribution of climates over the earth, as distinguished from that of climate in general, is sometimes called *climatography*.

Climates are variously classified, usually on the basis of one or more of the climatic elements, but sometimes with reference to their effects. The most familiar classifications refer to temperature. We speak of tropical, temperate, and polar climates; but in using these terms it should not be forgotten that other things besides latitude control the distribution of temperature. Location with respect to the ocean or other large bodies of water is almost equally important. A land surface grows warm by day and in summer, and grows cold by night and in winter, much more rapidly than a water surface, and the adjacent air varies in temperature accordingly. Hence we have a classification of climates as *marine* and *continental*. The former, under the influence of oceanic winds, have a moderate range of temperature, while the latter are subject to extremes of heat and cold. With increase of altitude temperature is diminished, but rainfall is generally increased. The distribution of rainfall is also determined to a great extent by the paths of cyclonic storms. Such are a few of the many things that control the complex distribution of climates.

People who never travel far from their own homes usually cherish quite erroneous ideas regarding the climates of distant lands. It is hard for most Americans to realize, for example, that the Isthmus of Panama, in the heart of the tropics, never experiences temperatures nearly so high as those which occur every summer in the United States. A citizen of South Dakota, where the mercury, in the shade, frequently rises above 100° Fahr., and has been known to reach 115°, will be inclined to revise his definition of the term "tropical" when he learns that at Colon, the Atlantic terminus of the Canal, a temperature as high as 90° is decidedly exceptional, and that the maximum reading during a period of six years was only 92°. In thirteen years Canal Zone vital statistics showed only two deaths from sunstroke and twenty-one non-fatal cases of heat prostration among a population of 120,000. It will also surprise most Americans to learn that the highest natural air temperatures that have been recorded anywhere on earth were not observed near the equator, but in a California desert. At a place on the edge of Death Valley, rejoicing in the ironical name of Greenland Ranch, a temperature of 134° Fahr. was registered in July, 1913. The thermometer which furnished this remarkable reading was a tested instrument, installed in a standard screen over an alfalfa sod, and not exposed to the reflected heat of the desert. At the same place the temperature reached 100° or more on 548 days in four years. Outside of the United States the highest temperature ever recorded at a meteorological station was 127° Fahr. at Wargla (Ouargla), Algeria.

The lowest temperatures encountered by polar explorers are considerably higher than those experienced each winter by the inhabitants of northern Siberia. The "record," so far as instrumental observations go, is held by the town of Verkhoyansk, at which the temperature fell to 90° below zero (Fahrenheit) in February, 1892. Strange to say, this "winter cold pole" of the earth has warm summers. At Verkhoyansk the temperature sometimes rises to 80° above zero, or higher. At Yakutsk, Siberia, the thermometer has been known to fall to 84° below zero in winter and to rise 102° above zero in summer; a range of temperature exceeding the interval between the freezing point and the boiling point of water!

Another climatic paradox is that experienced by mountaineers who, in scaling peaks mantled in eternal snow, often suffer with the heat, on account of the intensity of solar radiation in the pure, dry air of high altitudes. At the health resort of Davos, in the high Alps (altitude 5,250 feet), invalids sit out-of-doors without wraps in midwinter, and, indeed, are sometimes driven into the shade to escape the too ardent rays of the sun. At the same time the temperature of the air itself may be far below freezing, and the ground covered with snow.

Certain parts of the world are often loosely described as "rainless," but, as we have stated elsewhere, there is actually no spot on earth at which rain (or snow, in the polar regions) has never been known to fall. In the driest part of the Sahara—the Libyan Desert, between Dakhel and Kufra—the explorer Rohlfs experienced a drenching rainstorm of three days' duration in 1874. Neither is the Sahara, in spite of its proverbial heat, exempt from touches of real winter. Snow is a common occurrence in many parts of this desert, even at moderate altitudes. On the higher Saharan peaks snow lies on the ground all winter, and is sometimes found, in sheltered spots, in summer. Occasional falls of snow occur in all parts of Algeria, and several falls have been recorded in Lower Egypt.

When all is said and done, the whole fabric of what now constitutes the science of climatology leaves much to be desired. Climate is of practical interest, first of all, on account of its effects on human life and health, and secondly because of its influence upon the crops that are the mainstay of man's material prosperity. Under both these heads climatic data, as now commonly presented, ignore certain atmospheric activities of the utmost importance. For biological purposes no description of a climate can be regarded as even approximately complete that does not furnish, for the region under discussion, a detailed account of the different kinds of radiation received from the sun, their intensities and fluctuations; and there are few places in the world at which even a beginning has been made in the collection of such data. Again, the phenomena of atmospheric electricity, including radioactivity, are probably of real climatic significance, but we are still in the stage of speculation with regard to this subject. Possibly there are still other elements of climate, now wholly neglected, that will figure prominently in the climatology of the future.

CHAPTER XIII

ORGANIZED METEOROLOGY

NO other branch of science is so dependent upon the constant systematic cooperation of a multitude of workers as meteorology. There are, to be sure, some kinds of atmospheric phenomena that can be studied advantageously by the individual meteorologist, with no further aid from his scientific confrères than the same sort of interchange of ideas that prevails in all departments of knowledge; but the widespread processes that constitute weather and climate require for their observation—whether the purpose in view be weather forecasting, or the collection of climatic statistics, or the assembling of data from which to deduce the laws of atmospheric movements—a veritable army of colaborers, equipped with standardized instruments and keeping their records according to a uniform plan.

Probably few people, in looking at the charts portraying the climates of the world that are found in reference books, realize how many observers have contributed to the preparation of such charts or the number of separate instrumental observations upon which they are based. In the United States alone there are something like 6,000 meteorological stations, at which upward of two and a quarter million observations are made every year—and a climatic chart is, of course, the fruit of *many* years of observations. At the beginning of the present century it was estimated that there were 31,000 meteorological stations in operation throughout the world. The present number is doubtless much greater. At some of these stations observations have been made regularly, once, twice or three times a day, for 100 or 150 years. In round numbers one may say that, during the last few decades, meteorological observations have been made, the world over, at the rate of ten million a year, and the total number, since the keeping of regular weather records began, runs far up in the hundred millions.

Organized meteorological observations were not unknown to antiquity—we have mentioned elsewhere the early rainfall measurements in India and Palestine—but the present era of such undertakings dates back only to the middle of the seventeenth century. In the year 1654 the Grand Duke Ferdinand II of Tuscany, through his chaplain and secretary, Luigi Antinori, secured the cooperation of several observers in Italy and the adjacent countries, to whom were distributed instruments and forms for maintaining daily records of the principal meteorological elements. Antinori and most of the observers belonged to the Jesuits, an order which has displayed extraordinary zeal in the furtherance of meteorology down to the present day. The observations thus inaugurated appear to have been kept up until about 1667, but unfortunately few of the records have been preserved. Several undertakings of similar character were launched during the next hundred years in France, England, and Germany. The most notable of such enterprises, however, antedating the foundation of the present official weather services, was the international system of observations maintained by the Meteorological Society of the Palatinate, founded at Mannheim in 1780 under the auspices of the Elector Karl Theodor. The chief credit for the epoch-making work of this society is due to its secretary, J. J. Hemmer. The society distributed standard instruments to its observers, who were widely scattered over the world; viz., fourteen in Germany, two in Austria-Hungary, two in Switzerland, four in Italy, three in France, four in Belgium and Holland, three in Russia, four in Scandinavia, one in Greenland, and two in North America (at Bradford and Cambridge, Mass.). The very detailed observations of this network of stations down to the year 1792 were published in twelve large volumes.

Although the activities of the Mannheim society came to an end in the troublous days of the French Revolution, the records that it had collected served as the groundwork for fruitful studies during the next generation. There are two distinct uses that can be made of statistics of this sort. First, they can be digested in such a way as to bring out the characteristic features of the climate at each of the localities included in the collection, and likewise to illustrate the distribution of climates over the globe. Second, the data for individual days from the various stations can be charted separately, so as to illustrate the *instantaneous* distribution of barometric pressure, wind and weather, and, by a comparison of the charts for successive days, to provide a sort of moving picture of the atmospheric machinery in operation.

Charts based on approximately simultaneous observations showing the state of the atmosphere at a particular moment of time over an extensive area of the earth are called *synchronous charts*, or sometimes *synoptic charts*, though the latter term is also applicable to charts showing average values for a particular month, year, etc. Synchronous charts, as used nowadays for the purpose of making forecasts, are prepared from data collected by telegraph; but the same kind of charts can be prepared in a more leisurely manner from the statistics gathered at any previous time, and such charts were frequently made for the purpose of study before the days of telegraphy. The pioneer in such undertakings was the German physicist, H. W. Brandes, who, about 1820, utilized the observations collected by the Meteorological Society of the Palatinate, together with some others, in compiling a series of daily synchronous charts of Europe for the year 1783.

Very similar studies were carried out in America, a few years later, by J. P. Espy, W. C. Redfield and Elias Loomis. Early in the nineteenth century a copious fund of meteorological observations had already accumulated in this country. The first undertaking in the nature of a meteorological organization, foreshadowing the present Weather Bureau, was due to Josiah Meigs, Commissioner of the General Land Office, who in 1817 established a system of tri-daily observations at the various land offices. At an almost equally early period the Surgeon General of the Army inaugurated regular weather observations at the military posts throughout the country. Local systems of observations were established by the authorities of New York State in 1825 and Pennsylvania in 1837, and systems of broader scope by the Patent Office in 1841 and the Smithsonian Institution in 1847. Experiments in collecting weather reports by telegraph for the purpose of forecasting storms were undertaken by the SmithsonianInstitution as early as 1849. At about the same period Lieut. M. F. Maury, of the navy, was gathering meteorological reports from mariners and laying the foundations of marine meteorology. Finally, in 1870, Congress was induced to establish a full-fledged telegraphic weather service, similar to those that were already in successful operation in Europe. One of the great promoters of this enterprise was Dr. I. A. Lapham of Wisconsin; it had been repeatedly advocated by Maury; and a convincing object lesson in its behalf was furnished by the local service of reports and forecasts conducted by Prof. Cleveland Abbe, at the Cincinnati Observatory, with the aid of the Western Union Telegraph Company, in 1869 and 1870. During the first twenty years of its existence, from 1870 to 1890, the Federal weather service was under the Signal Corps of the army. Since 1890 it has been a branch of the Department of Agriculture, as the United States Weather Bureau, though the name "Signal Service" stuck to it, in popular speech, long after it ceased to belong to the army.

In this country weather forecasts are—or once were—said to emanate from "Old Probabilities," or "Old Probs." Our first "Old Probs" appears to have been Professor Abbe, who has explained the origin of this name in an account of his pioneer forecasting experiments at Cincinnati. He says of the initial Cincinnati Weather Bulletin, issued September 1, 1869:

"It contained only a few observations telegraphed from distant observers and announced 'probabilities' for the next day. This bulletin, in my own hand-writing, was posted prominently in the hall of the Chamber of Commerce, but unfortunately I had misspelled 'Tuesday,' and I soon found below my Probabilities the following humorous line by Mr. Davis, the well-known packer: 'A bad spell of weather for "Old Probs."' This established my future very popular name of 'Old Probs.'" The name has, however, been more particularly associated with Gen. Albert J. Myer, who, as Chief Signal Officer, was the first head of the Federal meteorological service.

Desultory experiments in the collection of current weather reports and their use in constructing weather maps were first carried out in Europe at about the same time as the early undertakings of this character in America. Such reports were gathered and published by James Glaisher, with the cooperation of the British railways, in 1849. The existing national weather services of the Old World owe their origin to an episode of the Crimean War. In November, 1854, a violent storm wrought havoc among the French and British warships in the Black Sea and sank many vessels containing invaluable stores intended for the Allied armies in the Crimea. The French astronomer Le Verrier, director of the Observatory of Paris, collected information showing the progress of this storm across Europe, and the results of this inquiry were so significant that he submitted to the Emperor Napoleon III the plan of organizing an international system of telegraphic reports, by means of which timely warning could be obtained of similar atmospheric disturbances. The French Government, with the aid of other European countries, established such a system in 1855. Within the next two decades most of these countries organized their own services, and at the same time maintained an international exchange of observations by telegraph. Before the close of the nineteenth century nearly all the civilized countries of the world, including many colonial possessions, such as Canada, Australia, Algeria and the Philippines, had established meteorological services, entailing more or less extensive arrangements for collecting daily reports by telegraph and issuing storm warnings and weather forecasts. The chief exceptions were several of the Latin-American republics and the Ottoman Empire, in which such organizations are still lacking.

Meteorology is essentially an *international* science. The atmosphere knows no political boundaries, and the more it is studied the more strongly meteorologists are impressed with the fact that intimate relations exist between the atmospheric events of widely separated regions of the world. Thus, the great anticyclone that is built up every year over the cold interior of Siberia exercises an influence upon the weather of the United States; the behavior of the Indian monsoons has been found to have some connection with barometric conditions in South America; and fluctuations in the force of the trade winds are apparently of world-wide significance—whence these winds have been described as the "pulse" of the general atmospheric circulation. The French meteorologist L. Teisserenc de Bort called attention many years ago to the existence of what he called "centers of action"; viz., large permanent or semi-permanent areas of high and low barometric pressure, the variations of which correspond strikingly with the vicissitudes of wind and weather in countries thousands of miles distant. Last but not least, persistent attempts have been made to interpret all the weather happenings on our globe in terms of a fluctuating supply of radiant energy received from the sun.

Fortunately meteorology has possessed an international organization for a great many years. The International Meteorological Organization was founded at a conference held at Leipzig in 1872, and was perfected at a formal congress of meteorologists convoked at Vienna in the following year. The International Meteorological Committee, which is the permanent working body of the organization, was established at the Vienna Congress. Finally, the organization was reconstituted at a conference held at Paris, by invitation of the French Government, in 1919.

The International Committee consists of not more than twenty members, all of whom are directors of official meteorological services. It is supposed to meet at least once in three years. At less frequent intervals are held "conferences," to which are invited representatives of all the meteorological services and the principal independent meteorological observatories of the world. Attached to the organization are several international "commissions," which supervise and coordinate the work of meteorologists in various special fields. At the close of the year 1921 there were commissions on the following subjects:

Agricultural Meteorology, Weather Telegraphy, Marine Meteorology, Solar Radiation, Application of Meteorology to Aerial Navigation, Réseau Mondial, and Polar Meteorology, Investigation of the Upper Air, Terrestrial Magnetism and Atmospheric Electricity, Study of Clouds.

Each commission includes in its membership at least one member of the International Committee, besides a number of experts, from different countries, in the particular subject with which the commission is concerned.

The resolutions adopted at the various international meetings of meteorologists have been collected in the "International Meteorological Codex," the chief object of which is to secure uniformity in methods of observation, forms of publication, etc.

One of the most notable international undertakings in the history of meteorology was the plan of simultaneous observations, at Greenwich noon, both at land stations and on board ships, adopted by the Vienna Congress at the suggestion of General Myer, and carried out under the auspices and mainly at the expense of the United States Signal Service. The results of these daily observations, from 1875 to 1887, were published in detail, with charts, by the Signal Service. The many bulky volumes of this series, illustrating the meteorology of the globe (or mainly the northern hemisphere) day by day for a period of more than a decade, are the modern analogue of the "Ephemerides" issued a century earlier by the Meteorological Society of the Palatinate—which cover very nearly the same length of time. In recent years the efforts of meteorologists have been bent toward establishing a so-called "réseau mondial," or world-wide network of stations, which will not only provide telegraphic reports for the use of forecasters, but will also send their detailed records to an international commission to be compiled and published. The telegraphic feature of this project now bids fair to be realized in a manner that was not contemplated when the plan was originally proposed; viz., by the broadcasting of weather reports from high-powered radio stations all over the world.

An effective "world weather bureau," with permanent headquarters and staff, is at present the most urgent desideratum of practical meteorology. Such a bureau would not only tie together the national weather services of the world and greatly facilitate their operations, but would also digest the great mass of existing climatic statistics and provide for extending the climatological survey of the globe to regions where meteorological stations are scarce or lacking.

A typical national meteorological service comprises a central station or institute, usually, but not always, situated at the national capital, and a network or "réseau" of subordinate stations, which are sometimes classified, according to the extent of their observations, as stations of the first, second, and third order. They may also be classified, from another point of view, as telegraphic and nontelegraphic stations. The former provide telegraphic reports of their observations, which serve as the foundation for forecasts, while the latter are maintained chiefly for the purposes of climatology. In some countries—notably in the United States—there are additional classes of stations engaged in particular lines of work; these include storm-warning stations, river stations (which report river stages and rainfall in the river basins), stations for agricultural meteorology, etc. Several of the great maritime nations collect reports from vessels on the high seas, including a small percentage of wireless reports. A number of the national meteorological services carry on work in other branches of geophysics, such as seismology and terrestrial magnetism.

The United States Weather Bureau is an exception to the rule that, apart from the central offices and a few special stations and large observatories, meteorological stations are not generally manned by professional meteorologists, nor are the observers paid specifically for their meteorological work, though in a great many cases they are public functionaries who are expected to take meteorological observations in addition to their other duties. In this country there are about 200 stations at which the observers, of whom there are from one to a dozen or more at each station, devote all their time to the work of the stations and are salaried employees of the Weather Bureau, and there are several hundred minor stations manned by part-time paid employees. But even in the United States the great majority of the meteorological stations are operated by unpaid observers. There are about 4,500 of these so-called "cooperative stations," which provide the bulk of the climatic statistics of the country.

Some of the leading meteorological services of the world, and the places at which their central offices are located, are as follows:

United States Weather Bureau (Washington), Meteorological Service of Canada (Toronto), Meteorological Office (London), Office National Météorologique (Paris), Reale Ufficio Centrale di Meteorologia e Geodinamica (Rome), Zentralanstalt für Meteorologie und Geodynamik (Vienna), Indian Meteorological Department (Simla), Central Meteorological Observatory (Tokyo), Commonwealth Bureau of Meteorology (Melbourne), Oficina Meteorológica Argentina (Buenos Aires).

In Germany there are several mutually independent meteorological establishments, of which the Prussian Meteorological Institute, with headquarters in Berlin, is the most important with respect to climatology and research, while the Deutsche Seewarte, at Hamburg, is the chief center for telegraphic weather reports and issues the principal weather map. Russia, before her debacle, had one of the most splendidly organized meteorological services in the world, with headquarters at the Central Physical Observatory in Petrograd, and a separate service for agricultural meteorology, which was the model institution of its kind. The Philippine Islands have a Weather Bureau which is entirely distinct from that of the United States. This Bureau, with headquarters at the Manila Observatory, was founded by the Jesuits, who also maintain a quasi-official meteorological service in China, with headquarters at the Zikawei Observatory, near Shanghai.

Many meteorological societies have done much for the progress of the science, and in some cases have shared the duties of the official meteorological services, especially in maintaining stations for climatology. These include the Royal Meteorological Society and the former Scottish

Meteorological Society, in Great Britain, the French, Italian, German, Austrian, and Japanese meteorological societies, and the American Meteorological Society, which was founded in December, 1919.

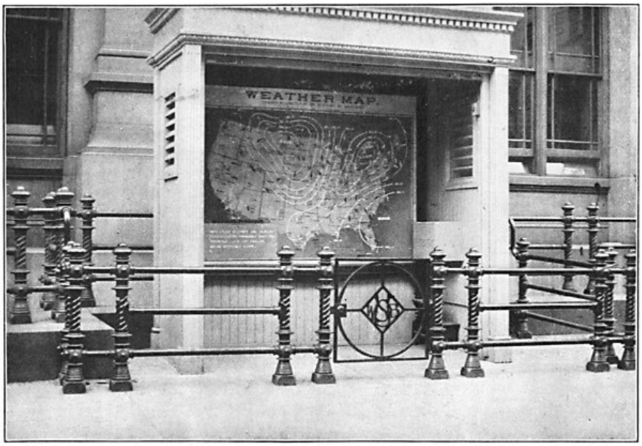
CHAPTER XIV

WEATHER MAPS AND FORECASTS

"Forecast"—with the stress on the first syllable when it is a noun, but often on the second when it is a verb—is a word that meteorology has made peculiarly its own. This fact is not the result of accident, but of design.

The founder of scientific weather prediction in Great Britain was Admiral Robert FitzRoy—the same talented officer who explored the coasts of South America in the *Beagle* and had Darwin for a fellow-voyager—and his first predictions were issued in 1861 from the Meteorological Department of the Board of Trade, which was under his charge. The boldness of this pioneer undertaking is not easily realized by the present generation, which is accustomed to see the official weather forecast at the head of every daily newspaper. Weather prognostication had previously been the undisputed province of charlatans and quacks. For a civilized government to embark upon such an enterprise must have seemed, to the educated public, very much like charging the Astronomer Royal with the duty of casting horoscopes.

There is much virtue in a name. A few years ago the United States Bureau of Fisheries persuaded the American public to eat dogfish by changing its name to "grayfish." Similarly, FitzRoy induced the British public to take his weather predictions seriously by calling them "forecasts." The name has stuck; and nowadays, throughout the English-speaking world, the expression "weather forecast"—except as applied comprehensively to predictions of the "long-range" variety—means something decidedly less chimerical than the average weather prophecy.



A GLASS WEATHER MAP OF THE UNITED STATES WEATHER BUREAU

(*Courtesy of U. S. Weather Bureau.*)

THE SUN DRAWING WATER

(*Photograph by P. K. Budlong.*)

It is still necessary, however, to emphasize the distinction. There are probably many people among us, well above the illiterate level, who have no clear idea as to what constitutes a scientific weather forecast. The distinguishing feature of such a prediction, apart from the fact that it is made by a trained meteorologist, is that it is, in all cases, based upon a weather map.

The forecasting machine is a big one, with its human gear spread over a wide territory. Eventually it will be spread over the entire globe, and then we shall have better forecasts. A little manual entitled "The Weather Map," published by the British Meteorological Office, says:

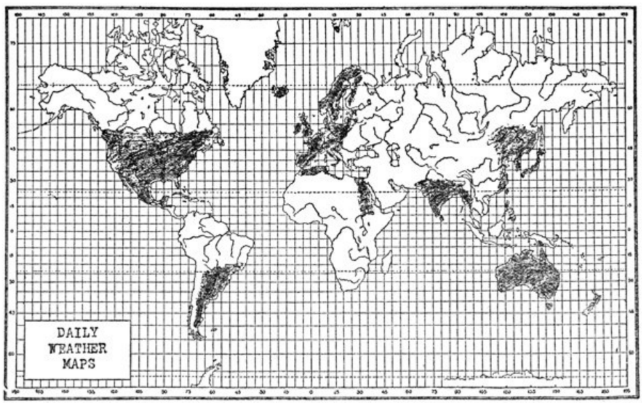
"The making of a single forecast in any one of the meteorological offices of Europe, America, Australia, or the Far East requires the organized cooperation of some hundreds of persons; about a hundred observers who note the necessary observations simultaneously at as many separate places and hand in their reports to the telegraphists who transmit them to one center, where the meteorological expert charts them on a map and draws therefrom the conclusions on which the forecasts are based. The preparation of the map is an essential part of the process. No meteorologist in the modern sense attempts to forecast the weather without reference to a map prepared either by himself or by some one with whom he is in direct communication, from observations transmitted by telegraph for the purpose. No amount of weather wisdom or weather lore or experience is a substitute for the map. The more expert and accomplished the meteorologist, the more certain he is that all he can do without the materials for constructing a map, though he may have a barometer and other instruments at hand, is to make a guess at what the map is like and think out from that what the weather changes are likely to be. It is a common experience of professional meteorologists away from their base to find themselves appealed to for an opinion about the weather, judging from the signs of the sky alone, because they are learned in such things. That is exactly what they are not. Accustomed to refer everything to a map, without one they feel themselves to be rather worse off than those who are unaccustomed to its use. A modern meteorologist thinks in maps; his language and modes of expression are formed thereby."

While the weather map is prepared, first of all, for the use of the forecaster, who makes his predictions from the map before it has passed beyond the manuscript stage, it has other important uses, which justify its publication and widespread distribution. The weather map is a weather newspaper. Like other newspapers, it is founded on a system of telegraphic dispatches and is designed to keep us in touch with what is going on in the world. Weather news is of general interest because weather plays a part in most of the doings of humanity. Sometimes the news we read on the face of the map merely satisfies our curiosity; at other times it renders us more substantial service.

By way of illustrating the manifold purposes served by weather maps, let us set down two cases that are, perhaps, at opposite ends of the scale of utility. Our first case is that of the traveler who scans the map to see whether the atmospheric conditions at his distant home are propitious, that day, for some outdoor pleasure event on the family program. This we may describe as a sentimental use of the map. The second case is that of an aviator embarking on a flight some time in the fore part of the day, soon after the morning map has made its appearance. Here is a case in which the map is of vital utility, purely as a record of current conditions. The aviator is not concerned with the forecast of the morrow's weather, unless he is making an unusually long flight, but he is immensely concerned with the winds and weather prevailing along his route at the time he flies, and these will not, as a rule, differ radically from the conditions shown on the map of the same morning.

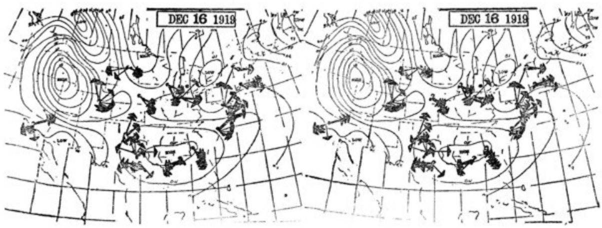
Since weather affects business in a variety of ways, people who have business interests away from their places of residence frequently have occasion to consult the weather map. The influence of the weather on crops explains why the map is watched with keen interest by dealers in agricultural products. Owners of vessels navigating the ocean or the Great Lakes take a practical interest in the present as well as the future location of storms. And so on. It is not necessary to prolong this list of those who use the weather map, because the popular demand for it speaks for itself. It is worth while to record the fact that the demand far exceeds the supply. In this country the Weather Bureau has been constantly harassed with urgent requests for the publication of maps at places where, in consequence of limited appropriations, it has not been possible to issue them.

The weather maps published in various parts of the world exhibit much diversity in detail, though they have, of course, many features in common. As a rule a weather map covers a wider area than that of the country in which it is published. The aim has always been to make these publications international, as far as practicable. The longest continuous file of printed daily weather maps in existence, viz., that established in France by Le Verrier in 1863 and still published, has been called from its beginning the "Bulletin International." It embraces nearly the whole of Europe, a little of Africa, Iceland, and the Azores. The other European maps now cover the same area or a considerable part of it. Before the war the Russian meteorological service was issuing a map that included, in addition to Europe, a wide zone of Asia extending all the way to the Pacific Ocean. The United States map, as published in its most extensive form at Washington, comprises the whole of this country and southern Canada, besides presenting tabulated statistics for more distant parts of the world. Manuscript maps prepared daily at Washington have a still broader outlook; they are drawn on a base map that covers the northern hemisphere, and the printing of a map of this sort, including a chain of stations extending around the globe, was undertaken in 1914, but was interrupted by the war. The map published by the Argentine Meteorological Office, at Buenos Aires, covers more than half of South America. Most national meteorological services issue weather maps, but there are a few that do not. No such maps are published in South Africa or any of the South American countries except Argentina.



LAND AREAS EMBRACED IN DAILY WEATHER MAPS AS PUBLISHED IN 1921

Thus there is still much room for the horizontal extension of the weather map, and there is even more room for its vertical extension. Daily weather maps for aeronauts (chiefly wind maps) are now more or less on the programme of all the leading meteorological services, and in a few cases their publication has already begun. Probably the first maps of this character, showing the winds at various levels over a whole country, were those that began to appear in Italy in 1913. The British Meteorological Office now publishes such maps, showing winds and clouds at different levels over the British Isles at three hours of the day. In the United States maps of the "wind aloft" are prepared daily, at Washington, from the reports of kite and balloon stations, but they are not yet published. The Weather Bureau has, moreover, invented an ingenious method of depicting the winds at several levels on a single map; in other words, constructing a map in three dimensions. This consists of attaching arrows to little metal posts erected on an ordinary weather map at points corresponding to the location of the upper-air stations. Each post bears a series of arrows—one arrow for each level charted—and the arrows are set in positions showing the direction of the wind at each level. Numbers on the arrowheads indicate the force of the wind. When the map is finished it is photographed from two different angles so as to make a pair of pictures suitable for viewing through a stereoscope. These stereoscopic pictures were formerly made every day and a file of them is available for reference and study.

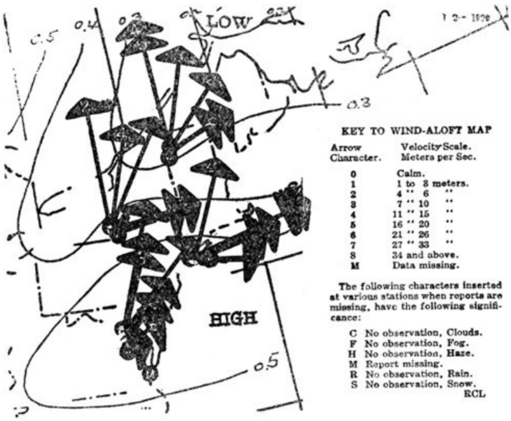


STEREOSCOPIC MAP OF THE "WINDS ALOFT"

There are a few conspicuous points of difference between the weather maps issued in foreign countries and those issued in this country. Thus a majority of the foreign weather services publish two or more charts on the same sheet; either for the sake of showing different meteorological elements separately or, in most cases, to represent the conditions prevailing not only at the hour of the current morning observation, but also at certain hours of the previous day. One of the three editions of the British map includes four charts, corresponding to observations at four different hours. By means of such series of charts one can observe the recent changes of weather as well as the current conditions. Weather maps published in the United States show primarily the conditions at 8 a. m., Eastern

Standard Time, of the morning of issue; though certain features of past weather are also indicated, including changes of temperatures, movements of storm centers, etc. Evening maps are drawn at Washington and at many other places, but are not published.

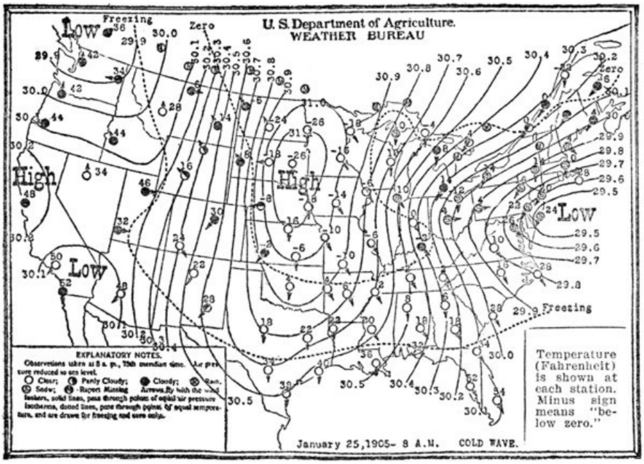
In this country the publication of weather maps has been carried out on a much more liberal scale than elsewhere. Instead of issuing maps at only one or a few places, as is the custom in other parts of the world, it has been the policy of the American service to publish them at populous centers all over the country. In some cases they are printed or manifolded at the local Weather Bureau station, and distributed by mail and messenger; in other cases they are published in the newspapers. The daily circulation of the maps has thus, at times, run up into the millions. This comprehensive duplication of the chart is made possible by special arrangements with the telegraph companies. The reports of observations are, to a large extent, sent over circuits, along which the telegraph offices, besides forwarding the local report, copy the reports from other stations as they pass over the wires. Certain stations, forming connecting links between the circuits, effect the transfer of collected reports from one circuit to another; so that, in a very short time, upward of 150 stations receive the reports from a large number of other stations. The maps issued at stations or published in newspapers are generally rather crude, though they answer their purpose; but the large lithographed map issued every day at the Central Office, in Washington, is much the most artistic production of its kind published anywhere in the world.



ENLARGED SECTION OF THE STEREOSCOPIC WIND MAP

Large weather maps, drawn with colored chalk on a ground-glass base, may be seen at certain produce exchanges and railway stations, on the "boardwalk" at Atlantic City, and in the Capitol at Washington. Motion-picture weather maps, made from series of maps showing conditions at successive intervals of time, have been prepared experimentally in this country and abroad.

The reports used in the construction of weather maps are telegraphed from the stations in cipher, in order to save expense. In Europe groups of figures are used for this purpose, but the United States Weather Bureau makes use of a word code, which offers the advantage over a figure code that, as a rule, mistakes in the telegrams can easily be detected by anybody familiar with the code. The American weather code is something of a literary curiosity. In each of the many thousand words it contains there are certain significant letters, and these must fall in certain sequences in order to convey the information required. The English language has been ransacked—and somewhat stretched—to secure the necessary words. Observers consult the code book in enciphering their reports, but translating is easily done without the book by those who have mastered the relatively simple principles on which the code is constructed.



SIMPLIFIED WEATHER MAP FOR JAN. 25, 1905, 8 A. M., EASTERN STANDARD TIME

The language of lines, shadings and symbols used in weather maps can be learned in a few minutes, and it is, as a rule, fully explained on the face of the map. This is true of foreign maps as well as American. A full-fledged weather map is hardly susceptible of reproduction in a book of ordinary dimensions. The simplified map that we show here, taken from a Weather Bureau bulletin, will, however, serve to illustrate some of the features of such publications. The reader should first fix in his mind the explanations printed at the lower left-hand corner of the map and then study the map in the light of what has been said in Chapter VIII about the circulation and movements of highs and lows. On this map we have an exceptionally well-developed high over the middle of the country and a pronounced low on the Atlantic coast. The former, with clear skies and very cold weather, constitutes a cold wave. The latter is attended by a widespread snow storm and, as may be inferred from the crowded isobars, by stormy winds.

Now bear in mind the fact that charts identical with this one, except that they contained much more detailed information, were issued in all the more important cities and towns of the United States on the morning of January 25, 1905, about a couple hours after the taking of the morning observations, at 8 a. m., Eastern time. The same morning, weather forecasts, cold-wave warnings and storm warnings, deduced from this map, were issued to some hundreds of thousands of addresses by telegraph, telephone, mail, and messenger. The map itself conveys information comparable in interest to the news of public events published on the first page of the newspapers the same day. The forecasts and especially the warnings are, in such a case, worth millions of dollars to the people of the United States. The following account of the cold wave appears in the Annual Report of the Chief of the Weather Bureau for 1905:

"A severe cold wave appeared over the Dakotas, Minnesota, Nebraska, and Iowa on January 24, 1905, and on the 25th covered the central and upper Mississippi valleys and extended over the northern portions of the east Gulf States, the line of zero temperature reaching into northern Tennessee. On the 26th the cold wave covered Florida, and temperatures below freezing were reported as far south as Tampa and Jupiter. At the latter place, the minimum temperature, 24 degrees, equaled the lowest ever recorded since the establishment of the Weather Bureau station at that point. Considerable damage was done to orange trees where groves could not be fired or protected. Ample warnings had been given of the expected low temperatures."

The subject of making forecasts from a weather map is one concerning which some big books have been written, and it cannot be dealt with very satisfactorily in the brief space at our disposal. There are two cardinal rules—viz., (1) the weather has a characteristic distribution in relation to the distribution of barometric pressure, and (2) pressure systems, with their attendant winds and weather, move, in a general way, from west to east—but these rules require various qualifications and are subject to various exceptions. Thus highs and lows generally take rather circuitous routes in getting, eventually, to the eastward, and sometimes they break up or fade out. The high shown on the annexed map actually moved much more south than east during the following twenty-four hours, while the low moved up the coast; i. e., more north than east. These were, however, the movements expected by the experienced forecaster.

Well-developed highs are nearly always regions of clear weather and, in winter, of cold weather. Lows are attended by clouds and precipitation; rising temperature usually precedes them and falling temperature follows them. The professional forecaster recognizes several types of pressure distribution other than ordinary highs and lows, and they, also, have their characteristic winds and weather. The seven typical forms of isobars, as classified many years ago by R. Abercromby, are: Cyclone; anticyclone; secondary; V-shaped depression, or trough; wedge of high pressure; col, or saddle, between two anticyclones; and straight isobars. These may be combined in a variety of ways on the weather map. The forecaster learns to classify these combinations consciously or subconsciously, and grows familiar with their habits and mannerisms. Forecasters spend a good deal of time in studying the files of weather maps for past years; but the results of such studies are not easy to reduce to definite statements. Scientific forecasting is, in its present stage, almost wholly empirical. The dependence of weather changes upon the phenomena of atmospheric circulation is generally easy to make out, but the vagaries of winds and pressure are still in the main mysterious; notwithstanding such interesting developments as (1) the much-discussed rules of M. Gabriel Guilbert for predicting the movements of barometric depressions from abnormalities in the force and direction of the winds; (2) the systematic charting of "isallobars," or lines of equal pressure change, associated especially with the name of Dr. Nils Ekholm; and finally (3) the hypothesis of a sharp line of demarcation between masses of equatorial and polar air along the so-called "polar front," forming the basis of a system of forecasting that originated at the Geophysical Institute of Bergen, Norway, and has had a marked influence upon the methods of forecasters in other parts of the world.

As to the practical results of this empirical art, one point of the utmost importance is commonly overlooked by the public when it complains about the mistakes of the forecaster. He is required to make forecasts of weather day after day, regardless of the kind of map that is laid before him. Sometimes the map is so featureless (or, as the forecasters say, "flat") that there is little in it on which to build a forecast. At other times there is an abundance of features, but they are in process of rapid and disconcerting change. In either case the ordinary day-to-day weather forecast is likely to go astray. The brighter side of this picture is that the atmospheric phenomena that count heavily in terms of dollars and imperiled human lives are not found on "flat" maps, and, when they appear on the map, generally behave in a simple, straightforward way. In other words, such events as great storms and cold waves are far easier to forecast than everyday weather, and it is the successful prediction of these events that furnishes the principal *raison d'être* of an expensive telegraphic forecasting service.

Since weather predictions serve a variety of purposes, many different kinds of forecasts and warnings have been developed by meteorological services. In this country there are, first of all, district forecasts and local forecasts;

the former, covering whole States and groups of States, being issued at a few main forecasting centers, while the latter, applying to a single town and its vicinity, are issued at a large number of the ordinary Weather Bureau stations. There is a long list of forecasts and warnings intended for special classes of the community; indeed the specialization of forecasts is carried so far that an individual citizen or a single business firm can generally obtain, by asking for it, a forecast of any specified predictable feature of the weather for a particular place. The established types of special prediction issued regularly, or when conditions warrant, include wind and weather forecasts and storm warnings for mariners; shippers' forecasts, relating to temperatures injurious to perishable goods; aviation forecasts; "fire-weather" warnings, issued when the weather is conducive to fires in the western forests; avalanche warnings; and several different kinds of advices for the benefit of agriculture and horticulture. The United States Weather Bureau, although it is not the only branch of the Government that carries on work in hydrology, is the one charged with the duty of issuing river-stage predictions and flood warnings. An elaborate organization is maintained for this purpose, and the results are extremely successful.

The period of time covered by an official weather forecast is generally from one to two days. In this country the morning forecast is ordinarily for 36 hours from 8 a. m., and the evening forecast for 48 hours from 8 p. m., but occasionally the period is extended for an additional day. For some years the Weather Bureau has issued every Saturday a forecast in quite general terms relating to the whole of the following week. These long-range forecasts are made for extensive areas of the country, such as the North and Middle Atlantic States, the Ohio Valley and Tennessee, and the Great Lakes region. "From the weekly forecast," says an official publication, "a farmer may know whether it is safe to cut his hay at the beginning of the week or whether it would be better to wait till the last of the week; and a produce dealer may know whether it is safe, at a particular time in the early spring, to start a carload of strawberries to a northern market." The British Meteorological Office follows a more cautious plan. Its regular forecasts are for twenty-four hours, but occasionally, when conditions are fairly settled, announcements are made of what is termed the "further outlook." The same office sends notices to the agricultural districts when a spell of fine weather, favorable for haying or the like, appears to be on the programme.

There are a few official meteorological establishments that have embarked on much more ambitious undertakings in long-range forecasting. The classic example is furnished by the Indian Meteorological Department, which has issued seasonal forecasts of rainfall ever since 1882. These were originally based upon reports of the snowfall in the Himalaya, abnormalities of which, as noted in the spring, appear to be related to the intensity of the subsequent monsoon rainfall. Eventually the Indian meteorologists began to seek in more remote regions for clues to the character of the Indian seasons, and they believe they have found them; the barometric pressure in South America and at Mauritius, the rainfall at Zanzibar and Seychelles, the Nile flood, and summer rains in Australia all seems to bear some relation to meteorological conditions in India.

The study of world-wide interrelations of weather, although it has not generally, as in the case just mentioned, furnished the basis of official forecasts, has engaged the attention of a great many able meteorologists. We have spoken on another page of the "centers of action" that seem to be such important indexes to changes in the circulation of the atmosphere, with concomitant fluctuations in weather. Telegraphic reports from some of these centers, including the Iceland and Aleutian lows and the Siberian and Azores highs, have helped to guide the Weather Bureau in making its weekly forecasts. Many attempts have been made to predict the weather months in advance from variations in the temperatures of the water in different parts of the ocean or from the distribution of sea ice in high latitudes. Another line of attack upon the problem of long-range forecasting is through observations of solar activities, as indicated by fluctuations in solar radiation, the prevalence of sun spots, etc. Lastly, an immense amount of energy has been expended in efforts to detect definite cycles or periodicities in the weather itself, without regard to their causes. The thirty-five year period of rainfall and temperature variations, announced in 1890 by Prof. E. Brückner, has found a place in all the current textbooks on meteorology, and several other alleged weather periods have been the subject of serious discussion.

From all of which it appears that the professional meteorologist is not at all inclined to discountenance attempts at long-range weather prediction, provided they are made both honestly and intelligently. Unfortunately the vast majority of people who, in all ages, have indulged in this sort of vaticination—and their name is legion—have been either dishonest or ignorant, or both. The world is still well supplied with them, and they are, undeniably, a thorn in the flesh of the scientific forecaster, who sometimes sees his predictions confounded with theirs by the public, and who commonly incurs the charge of jealousy and narrow-mindedness because he declines to acknowledge brotherhood with the cranks and impostors who hang about the outskirts of his profession.

Quack weather predictions are nearly always made for long periods in advance, and their popularity depends upon the fact that they give the public something—however fallacious it may be—that science does not attempt to give. The making of such predictions appears to be a particularly easy way of acquiring both fame and fortune. In this country there has hardly ever been a time when some exponent of this industry did not enjoy a nation-wide reputation. It is a satisfaction to record, however, that foreign countries produce the same sort of celebrities. Dr. Gustav Hellmann, writing in Germany, has recently published an extremely interesting account of the famous "weather prophets" of the 19th and 20th centuries. Their geographical distribution is given as follows: Belgium, 2; Germany, 36; England, 25; France, 14; Italy, 2; Austria-Hungary, 8; Russia, 1; Sweden, 1; Switzerland, 5; Spain, 2; North America, 9. The list for the United States is, to be sure, conspicuously incomplete, but we need not grieve over the fact that the fame of the American prophets omitted from the list has not spread to the Old World.

The almanac is, as it has always been, the chief stronghold of long-range weather predicting. Nobody knows to what extent the almanac prognostications are taken seriously by the public, or are meant to be by the publishers. It is to be feared that the percentage of the population that "swears by them" is not inconsiderable. Almanac publishers would undoubtedly perform a public service, and perhaps save themselves some pangs of conscience, if they would append to their weather predictions the statement that, like the portrait of the gentleman who displays his anatomy to the signs of the zodiac at the front of the book, they are published merely for the sake of keeping up an old custom, and if they would conclude every almanac with the following candid avowal, which we find in Gabriel Frende's "Almanack and Prognostication" for 1589:

> Thou hast my guess at daily weather
> Here present in thy view.
> My credit shall not lie thereon
> That every word is true:
> Yet some to please I thought it best
> To shew my mynde among the reste.

CHAPTER XV

AGRICULTURAL METEOROLOGY

Two farmers are grumbling about the weather. The scene is Ohio, the time July, and the prevalent crop corn (i. e., maize).

Farmers have grumbled about the weather from time immemorial. The point of interest in this particular case is that the two grumblers do not agree about what is wrong. Farmer A thinks the corn needs rain. Farmer B declares that at this stage rain would do more harm than good. Plenty of warm sunshine is, he thinks, the right prescription to insure a "bumper" crop. Of course Providence will do as it pleases, and whatever weather comes, since it cannot be cured, must be endured; but it is a matter of practical as well as academic interest to get some inkling betimes as to how your crop is going to turn out, and the weather is likely to be the decisive factor. Moreover, it is a very significant fact that our two farmers are not of the same mind about which atmospheric blessing is in default. It is painful to reflect that an enormous amount of grumbling about the weather on the part of the rustic community must, at one time or another, have been misapplied. It is a plausible assumption that farmers have sometimes worried themselves to death over meteorological events that were either harmless or actually beneficial to their crops.

How can we arrive at the facts? Admitting, as everybody does, that the weather has a preeminent influence upon plant life, is this influence susceptible of analysis? Is there anything definite about it? Are not the effects of various atmospheric conditions so entangled with one another, and with the effects of soil and methods of cultivation—to say nothing of insects and plant diseases—as to baffle all attempts to gauge them separately?

There is a new branch of applied science that teaches farmers how to grumble right about the weather. It is called Agricultural Meteorology. As a coherent branch of knowledge, this subject is so new that the first formal textbook about it in the English language was published in the year 1920. It happens that the author of this book, Professor J. Warren Smith, of the United States Weather Bureau, began his investigations in the new field by making a careful study of the relation of weather to the yield of corn in Ohio. Let us see what light his studies shed upon the question at issue between our friends A and B.

Day after day, and year after year, the principal atmospheric conditions are observed and measured at a great number of points scattered over the State of Ohio, as they are elsewhere throughout the Union, and the records thus obtained are carefully compiled, summed up, averaged and otherwise discussed by officials of the Weather Bureau. Thus a great fund of detailed statistical information about the weather is available for comparison with the statistics gathered by other agencies concerning the yield of crops and their condition at different stages of growth.

Professor Smith's analysis of the Ohio records revealed a fact of so much practical importance that this discovery alone suffices to place agricultural meteorology among the most fruitful branches of knowledge cultivated by mankind. He discovered that the success of the Ohio corn crop depends chiefly upon the amount of rain that falls during the month of July. The normal rainfall of that month for the State is 4 inches, while the average yield of corn during the past sixty years has been 34.5 bushels per acre. Comparing the values for individual years, it is found that the yield is strikingly sensitive to variations from the normal July rainfall, and especially so when the rainfall is a little more or less than 3 inches. Near this critical rainfall point, a variation of *one-fourth inch* of rain in July means a variation in the value of the corn crop of Ohio of nearly $3,000,000, and a variation of one-half inch makes an average variation in the value of the crop of more than $7,500,000. When the rainfall for July averages over 5 inches the probable yield of corn will be more than 27,000,000 bushels greater than it will be if the rainfall averages less than 3 inches. In other words, this difference of 2 inches in the rainfall for the month of July adds $13,650,000 to the income derived by Ohio farmers from corn alone.

Variations of the temperature in July, in Ohio, have been compared with variations in the yield of corn, with the result that the temperature of the month appears to have little effect upon the crop. Thus we find Farmer A to have been right and Farmer B wrong; but both were merely expressing personal opinions based upon an insignificant sum-total of experience. Science rests upon a surer foundation.

Although the case of the Ohio corn crop is probably simpler than most of those that agricultural meteorology has to deal with, for the reason that a single meteorological element is, in this case, of decisive importance, it illustrates a rule of quite general application that has recently come to light; viz., that in the growth of any particular crop there is usually a rather brief "critical period," when it is most sensitive to the influence of weather. For corn, in a considerable area of the northern United States, this period is July, or more specifically, in Ohio, the interval from July 11 to August 10. The rainfall and temperature of other months have, however, definite though minor influences, which can be evaluated for the same regions.

With respect to the American "corn belt" in general, it is not certain how far the rules deduced for Ohio are applicable. Professor Smith has been inclined to look upon July rainfall as the dominating factor for the whole of that region; so that, for example, a difference of 1 inch in the rainfall (viz., a total for July of 4.4 inches or more, as compared with 3.4 inches or less) has been held responsible for an increase of 500,000,000 bushels of corn in the eight principal corn-growing States. It has also been stated that in the four States of Indiana, Illinois, Iowa and Missouri an increase of half an inch of rain in July meant an increase of $150,000,000 in the value of the crop. These figures have, however, been challenged, and the subject is still under discussion.

The study of the critical periods of different crops, and the determination of the amounts of heat and moisture most favorable to the success of the crop at such periods, may be regarded as the leading task of the agricultural meteorologist. The most elaborate researches of this character have been made in Russia by Professor P. Brounov, who founded in 1896 a meteorological bureau, attached to the Ministry of Agriculture, with an extensive network of stations scattered over the Russian Empire. This bureau was quite distinct from the ordinary meteorological service, under the direction of the Central Physical Observatory in St. Petersburg. Just before the war Professor Brounov had 150 stations in operation; most of them for observing the effects of weather on the leading cereal crops, though some studied the corresponding relations of horticulture or the animal industries. Each agricultural station comprised a small plot of land, on which a certain sequence of crops was grown year after year under conditions of cultivation as nearly uniform as possible, the only variable factor being the weather. Meteorological instruments were installed in the immediate proximity of the plants under investigation. Prior to 1914 Brounov had determined the critical periods of most of the crops grown in Russia, and had published a great deal of information on this subject that could be turned to practical account by Russian farmers.

It will perhaps not be immediately apparent to the reader just how such information can be utilized. Its practical applications vary, in fact, according to circumstances. First of all, a knowledge of critical periods and of the weather requirements of crops at these periods enables the farmer to select his crops and time his farming operations on the basis of climatic statistics. Brounov published a series of charts showing the probability of dry weather, as deduced from many years of observations, for each ten-day period throughout the agricultural year for every part of European Russia. With such charts at our disposal, and knowing how long after planting each crop arrives at its critical period with respect to moisture, we can readily estimate the probable success of a given crop planted at a given time and place; at least, so far as this is determined by rainfall. If temperature or other meteorological conditions are of special importance at the critical periods, we shall need additional climatic charts. Of course, the weather in any particular year may differ widely from the climatic averages; but in the long run crops will prosper in proportion as their critical periods coincide with the occurrence of favorable weather as shown by the climatic record. It will be seen that this is quite a different idea from the traditional one that a certain crop needs a "moist climate," another a "hot climate," etc. The agriculturist now asks the man of science to tell him *when*, between planting and harvesting, heat or moisture is of vital importance to the crop, and *how much* of each will produce the biggest yield.

In regions where irrigation is practiced it is obviously advantageous to the farmer to know at what stage of its growth a crop becomes sensitive to the amount of moisture received. During the greater part of its life the plant may be quite indifferent to moisture, and at such times irrigation would be wasteful. The farmer needs to know not only when the critical period has arrived, but also what the water requirements are at that period. Too much water may be as bad as too little.

Even when agricultural practice ignores the rules laid down by the agricultural meteorologist, a knowledge of these rules may be applied with great advantage to the prediction of crop yields. It is hardly necessary to tell any farmer or business man that accurate crop forecasts are an economic desideratum of the utmost importance. The United States Government maintains an army of more than 200,000 volunteer crop reporters, supervised by a staff of experts, for the purpose of determining month by month the condition of every agricultural crop and its prospective yield. With regard to the monthly announcements of the Bureau of Crop Estimates, Professor H. L. Moore, of Columbia University, says:

"The commodity markets are in a state of nervous expectancy as the time approaches for the official forecasts, because great values are at stake. It has been estimated that in the case of the cotton crop alone an error in the forecasts which should lead to a depression of one cent a pound in the price of cotton-lint would—assuming a crop equal to that of 1914—entail a loss of eighty million dollars to the farmers. The vast values at stake and the dangers when no official estimate is available of the manipulation of the markets in the interest of speculators are held to justify the large recurrent annual cost of the employment of the numerous correspondents, clerks, and experts."

Professor Moore is one of those who have pointed out that the forecasts based upon the actual condition of the growing crops can be vastly improved by a mathematical analysis of the weather reports from the various regions in which the crops are grown. In fact, he goes so far as to assert that much better forecasts can be made from the weather reports alone than from reports on the condition of the crops. Whether or not this view is unduly optimistic, it goes without saying that the precise data which agricultural meteorology is now acquiring cannot fail to enhance greatly the accuracy of crop forecasts.

Of course, the weather has always been watched with keen interest by everybody concerned with the purchase or sale of agricultural products and has been one of the chief factors determining the rise and fall of prices. At produce exchanges throughout the United States daily weather bulletins are received from the agricultural districts, and at many of them a large weather map is drawn every morning by an employee of the Weather Bureau detailed for this purpose. The Bureau has made various other arrangements for supplying the information that is so eagerly desired concerning the weather as it affects crops, as well as the animal industries. During the "growing season" in the cotton, corn, wheat, sugar, rice, broom-corn and cattle-producing areas, designated centers receive telegraphic reports of rainfall and the daily extremes of temperature from substations in the regions concerned, and these are distributed in bulletin form. Each local center, besides publishing detailed reports from its own area, issues condensed reports from all the others. The Bureau also issues every week during the agricultural season a "National Weather and Crop Bulletin," with text and charts setting forth the current conditions of moisture, temperature, etc., and the state of the crops in all parts of the country.

The use which dealers and farmers make of these weather reports is, however, very far from having been reduced to science. Some of these persons, it is true, are frequently able, by a purely instinctive process of deduction, to make successful forecasts of crop yields from a close study of the weather, and others have worked out crude rules of their own for the same purpose; but the agricultural meteorologist approaches the problem in a different way. Immense progress has been made in the past decade in applying the mathematical theory of *correlation* to this problem. This branch of mathematics, originally developed chiefly for statistical studies in biology by Galton, Pearson, and others, is now extensively used by meteorologists not only for studying the effects of weather on crops, but also for finding out what correspondences or relationships exist between variations of weather in different parts of the world, as well as between weather and sun spots, weather and vital statistics, etc.

Sometimes, when the farmers do not disagree on the subject of favorable and unfavorable weather for the crops, they hold opinions in common that agricultural meteorology is unable to substantiate. An illustration is found in the idea that a good covering of snow during the winter is favorable to the yield of winter wheat. Apparently this is one of the host of popular ideas that are based merely on the delusive foundation of "everybody says so." Smith has investigated the statistics of wheat for Ohio and C. J. Root those for Illinois. In both cases their results negative the prevailing opinion. Professor Smith finds "some evidence to indicate that wheat has a better prospect if it is not covered by snow during the month of January," while Mr. Root states that, in general, "the winters of light snowfall are followed by good wheat yields and the winters of heavy snowfall by light yields."

The study of the relations between weather and crops is really a branch of a science of broader scope, known as *phenology*. This science is devoted to the investigation of all periodic phenomena of plant and animal life that are controlled by the weather. There are, in some parts of the world, large corps of phenological observers, who maintain records year after year of the leafing, flowering, and fruiting of both wild and cultivated plants, the migrations and first songs of birds, and various other events of a biological character that recur with the seasons. In the course of time it becomes possible to compute from such records the normal dates of these events; and then, in any particular year, a comparison between the actual dates and the normal shows whether the season is early or late, and by how many days. Phenological observations on plants also make it possible to draw charts showing the normal march of the seasons over a country, expressed in terms of plant life, and such charts are often more valuable to the agriculturist or horticulturist as a guide in selecting varieties for cultivation and in timing his operations, than any charts that can be compiled from ordinary climatic data. Some admirable charts of this kind have been drawn for parts of Europe.

There are many practical applications of phenology to agriculture, and there would be more if phenological observations had been made more extensively throughout the world. Good phenological charts of different regions would, for example, greatly facilitate the work of foreign plant introduction carried on by the United States Bureau of Plant Industry. In the United States phenological observations were made systematically between 1850 and 1863, but only desultory work has been done in this line subsequently. The most comprehensive individual record is that maintained by Thomas Mikesell from 1873 to 1912, at Wauseon, Ohio, and published in full by the Weather Bureau in 1915.

The old rule of American farmers, inherited from the Indians, that the time to plant corn is when the leaf of the white oak is "the size of a mouse's ear," illustrates the use that can be made of so-called "index plants" of the native flora as guides for farming operations. Professor A. D. Hopkins writes on this subject:

"If such guide plants do not occur on the farm, they can be found among the ornamental trees and shrubs and hardy flowering plants of other localities or countries and transplanted. The periodical event of the falling of the flower catkins of the Carolina poplar has been found to be one of the best guides to the general early or late character of one season as compared with the average, while the opening of the leaf buds and unfolding of the leaves serve as reliable guides to the progress of spring. The various magnolias in their succession of flowering events serve as excellent guides to the rate of progress of spring and the time to do various kinds of work. The ornamental Spiræas, Deutzias, Diervillas, climbing roses, and Clematis among the ornamentals, and the dogwood, service tree, redbud, and oaks among the native trees of the middle and eastern regions of the United States are more or less constant in their response to prevailing local influences which are indicative of the time to plant certain field and garden crops. The opening of the leaf and flower buds and the flowering of the common fruit trees and shrubs of almost every farm serve as more or less reliable guides tothe time to spray for certain insect and plant diseases."

Dr. Hopkins has worked out an interesting rule known as the "bioclimatic law," according to which the periodical events of plant and animal life advance over the United States at the rate of 1 degree of latitude, 5 degrees of longitude, and 400 feet of altitude every four days—northward, eastward, and upward in spring, and southward, westward, and downward in autumn. Thus, when the date of any phenological occurrence is known for one locality, it may be approximately determined for any other. This law has enabled the Department of Agriculture to publish rules of general application concerning the best time to plant winter wheat in order to escape the ravages of the Hessian fly, thus saving many millions of dollars to American farmers. The same law is susceptible of various other profitable uses.

Orchard Heaters in Operation. The economical use of this method of frost protection depends upon accurate forecasts of the right time to "fire" the orchard. (*Courtesy of Hamilton Orchard Heater Co.*)

The United States Weather Bureau has been a branch of the Department of Agriculture since 1890, and a very large share of its routine work is devoted to the agricultural interests of the country. The climatological statistics that it has assembled are indispensable in many departments of agricultural research, besides furnishing varied information of practical value to farmers. The Bureau has developed a number of special types of forecasts for the rural industries; such as predictions, three or four days in advance, of favorable weather for cutting alfalfa; forecasts of weather unfavorable for sheep-shearing; notices to fruit growers of dry-weather periods in which fruit trees should be sprayed; and warnings of the occasional summer showers that would do so much damage to the great raisin-drying industry of California but for the vigilance of the forecasters and the efficient arrangements made by the industry itself for disseminating and acting upon the warnings. Of course, the ordinary daily weather forecasts, storm warnings, and cold-wave warnings are valuable in many ways to agriculturists, and the Bureau has made great efforts to give such information prompt and general distribution in the rural districts. The forecasts are generally displayed in post offices, and in many cases the rural telephone exchanges are pressed into service to distribute weather information regularly to all their subscribers. Some exchanges sound a signal every morning when the forecast is ready for distribution. Lastly, the wireless telegraph and the wireless telephone, which, in the immediate future, will form part of the equipment of every up-to-date farm, afford ideal channels for the dissemination of weather news and are already extensively used for this purpose.

A Snow Surveyor at Work. Note the cylindrical snow sampler, with its serrated cutting edge, and spring balance for weighing the sample of snow (*Photographed by J. C. Aller.*)

Snow Rollers, or Wind-Blown Snowballs on a Lawn at Potsdam, N. Y.(*Photographed by T. J. Moon.*)

There remain to be mentioned the various steps the Weather Bureau has taken to protect the rural industries from the night frosts of spring and autumn, in the shape of special forecasting arrangements, the publication of frost charts, and a wide range of scientific investigations. The Bureau's undertakings in this line are merely a part, though a leading one, of a great campaign of frost protection that is being carried on by scientific and official agencies in this country on a larger scale than anywhere else in the world.

Frosts, classified according to their severity as "light," "heavy," and "killing," are most likely to occur in spring and autumn, when an extensive area of high barometric pressure brings its usual accompaniment of clear skies and calm nights. They are predicted on a general scale from the weather map, and locally from indications of temperature and humidity and a knowledge of important topographic influences, such as those due to hills and valleys and neighboring bodies of water.

In agricultural usage the term "frost" is applied to the occurrence of a temperature low enough to kill or injure tender vegetation, such as growing vegetables or the buds, blossoms, and fruit of fruit trees. The occurrence of a frost, in this sense, is not necessarily identical with the deposit of ice crystals known as "hoarfrost." Different species and varieties of plants are, of course, susceptible in very different degrees to the effects of low temperature; i. e., they differ greatly in "hardiness." In the case of fruits and vegetables the danger point generally lies a little below the freezing point of water (32 degrees F.).

The occurrence of frost is favored by the rapid cooling, by radiation, of the earth and its plant covering, which goes on at night under a clear sky and in still air. Under these conditions a layer of stagnant, cold air forms close to the ground, with warmer air lying above it. The difference in temperature at different levels is often so pronounced that fruit on the lower branches of a tree is killed while that growing on the higher branches remains uninjured. Similarly, frost will occur in the bottom of an inclosed valley but not on the surrounding slopes. In the case of a valley the layer of cold air that forms at the bottom is commonly deepened by additional cold air draining down from the hills.

Many large orchards have their "warm spots" and their "cold islands" or "north poles," well known to the orchardist; due in some cases to the nature of the soil rather than to topography. Certain mountain regions in North Carolina are famous for their "thermal belts" or "verdant zones"; i. e., areas part way up the slopes that escape the frosts occurring both above and below them. These frostless belts, which have been the subject of numerous investigations for three-quarters of a century, seem to mark the upper level of the pool of cold air that collects in the valley by drainage from the mountainsides. A detailed temperature survey of the thermal belt region of North Carolina was made during the years 1912–1916 by the United States Weather Bureau and the North Carolina State Board of Agriculture. In some places the minimum temperature at night was found to be 15 or 20 degrees higher in the thermal belt than at the bottom of the valley, a few hundred feet below.

Clouds, by checking radiation from the earth, and wind, by mixing the colder and warmer layers of air together, both prevent frosts that would otherwise occur. Artificial methods of protection include covering plants with screens of wood, paper, or cloth, building smudge fires to provide a blanket of smoke (a method of doubtful value), and, above all, heating by means of wood fires or various types of "orchard heater," burning either oil or coal. An elaborate technique of orchard heating has been developed, having in view especially the most economical use of fuel and labor consistent with the object to be attained. In many cases orchards are provided with alarm thermometers, which ring a bell when the temperature approaches the danger point in the orchard.

The local prediction of frost from the readings of meteorological instruments is a problem that has not been fully solved. The idea formerly prevailed that the temperature of the dew point, as determined from readings of the dry-bulb and wet-bulb thermometers in the early evening, was a safe guide to the fall of temperature to be expected during the night, but this belief has not stood the test of accurate observations. At the present writing certain formulas involving data of both temperature and humidity are being used experimentally by Weather Bureau specialists for predicting the lowest temperature of the night when the general conditions indicate that frost is possible. A comprehensive discussion of this subject has been published by the Bureau as Supplement No. 16 of the "Monthly Weather Review." (Washington, 1920.)

CHAPTER XVI

COMMERCIAL METEOROLOGY

It is a significant fact that the American Meteorological Society, which was organized in 1919, has a Committee on Commercial Meteorology. The appointment of this committee was one of the earliest tokens of the fact that the applications of meteorology to business, always recognized to be important and far-reaching, had at last been segregated as a distinct field of inquiry. The time is near at hand when this field will have its corps of specialists and its textbooks. Courses in commercial meteorology will be given in business colleges, and meteorologists will be attached to the staffs of large business enterprises. The chamber of commerce of a wide-awake western city already maintains a Department of Meteorology, with a former Weather Bureau official at its head, and "consulting meteorologists," now practicing their novel profession in other parts of the country, find their principal clientele among business concerns.

Weather not only influences most kinds of business, but is the foundation of many of them. Plenty of illustrations of the latter fact will be found in every large department store. Umbrellas, rubbers, and mackintoshes are made and sold because of rain; their best market is in countries with rainy climates, and their sale from day to day fluctuates with the state of the sky. Electric and palm-leaf fans are a drug on the market or the reverse, according to the readings of the thermometer. Sleds and ice skates are sold where and when the weather is cold. This list may be prolonged *ad lib*. If we leave the department store and walk along any business thoroughfare, we shall discover other striking examples of commercial undertakings that owe their existence chiefly or entirely to the weather. Abolish cold weather and you abolish the dealer in furnaces and heating stoves, besides reducing the rank of the coal-dealer considerably below the "baronial" level. Eliminate hot weather from the meteorological program and the ice dealer will likewise tumble from his high estate.

All this is so obvious that it seems hardly worth while setting down; and yet the paradox must somehow be explained that business men have not, in general, paid much attention to meteorology, and that they have made only fragmentary use of the official meteorological establishments that were created, in part, for their benefit. Probably this paradoxical situation is merely a case of mental inertia. During the long ages of traffic before there were any weather maps, scientific weather forecasts, or climatic statistics, the weather was necessarily an unknown quantity in the mathematics of buying and selling. That it is not so to-day is a fact to which the business mind has been very slow in adjusting itself.

We have mentioned some of the obvious relations of weather to commerce, but there are others that are not so obvious. Many of these are indirect. Thus the effects of the weather on agriculture are nearly always reflected in the commercial world. It is not the farmer alone who suffers from a prolonged drought, for example. It has been asserted that every severe financial panic in our history has been closely associated with a protracted period of deficient rainfall, and that there has been no period of protracted drought without a severe financial panic except one that occurred during the Civil War. Mr. H. H. Clayton, who published this assertion in 1901, has cited the case of the wheat crop as illustrating the magnitude of the effect that rainfall exercises on economic conditions in general through its effects on agriculture.

"If," he says, "the amount of wheat raised in the United States were reduced one-half or even one-third by a year of deficient rainfall, it is easy to imagine an enormous strain on the business of the country, and with a succession of such years the effect might mean disaster. Such a deficiency in the wheat supply, with wheat at 80 cents a bushel, would mean for a single year a direct loss in wealth of more than $100,000,000; it would mean that nearly all the wheat which is usually shipped abroad would be needed at home; it would mean that thousands of railroad cars and ships which ordinarily transport this grain would lie idle, that thousands of men who usually handle this grain in transport would be out of employment, that farmers in large numbers would be unable to meet their obligations, and consequently that banks and business of all kinds would suffer." Recent prices of wheat give added force to these statements.

In contrast to such broad relations of the weather to business, it may be interesting to point out certain relations which are of so special a character that, although familiar to hosts of business men, they have generally escaped the attention of writers on economics. On this subject Mr. John Allen Murphy says:

"Retail sales are influenced tremendously by the weather. This is one factor that makes it impossible for a retailer to equalize the peaks and valleys in his sales chart. Favorable weather will bring him a rush of business. A bad day will keep patrons from his store. There is nothing he can do to prevent it. Many merchants have tried the plan of offering 'stormy day specials,' but at best such a scheme is only a makeshift that seldom works. The weather also affects the buying moods of people. A dark, dreary day in summer seems to influence humans to take on the same cast as the atmosphere. They are grouchy and hard to please. On the other hand, a cold day in winter has the opposite effect. The warmth and cheer of the store is such a pleasant contrast to the out-of-doors that shoppers like to linger over the wares and indulge themselves more readily in the luxury of buying.

"A stormy day or a series of them always helps the mail-order business. In such weather people are inclined to stay at home. In passing the time, they are likely to thumb the pages of such catalogues as they have and thus see in them articles that they want. On the farm, especially in the bleak days of winter, it is often the custom to order garden seeds, incubators, tools, and many other things that will be needed as soon as spring opens up. On a bad day traveling salesmen find it easier to get the ear of a merchant. Not being busy with customers, he is prone to be more lenient toward the 'boys with the grips.'"

Another writer on this subject, Mr. F. C. Kelly, says:

"In a large city, the business of a department store is seriously hurt by rain in the forenoon, but rain in the early afternoon is usually a big help. Most customers of a big-city department store are women, and nearly all of them live some distance from the store—at the edge of the city or in the suburbs. If it rains along about eight or nine o'clock in the morning, the woman who had planned to go shopping that day is quite likely to change her mind, even though she did not intend to go until afternoon. The rain not only suggests discomfort in getting about, but diminishes her desire or immediate need for certain articles, and drives the shopping idea out of her head. On the other hand, if it is bright and clear in the morning, but clouds up about noon for a heavy downpour which lasts most of the afternoon, it is the best thing that could happen for the department store, because shoppers get in and cannot comfortably get out. They shop all over the store, buy luncheon there, and shop some more. While the rain is thus helping the department stores, it may hurt the smaller shops, because many customers who would otherwise look around are obliged to do their buying all under one roof."

No aspect of business more faithfully reflects the weather, or, in a somewhat less degree, the weather forecasts, than advertising. So important is it, in many lines of business, to make advertising fit the weather that one might expect merchants to be, as a class, as weather-wise as sailors and farmers. A page of advertising in a great metropolitan newspaper is a costly investment. If, for example, it invites the public to pay a Sunday visit of inspection to some haven for homeseekers in the suburbs and Sunday turns out to be the kind of day that converts building-lots into bogs, the advertiser will perhaps be led to inquire whether there is not some means of avoiding another such fiasco; and he may thus make the surprising discovery that meteorology is not entirely a theoretical science. The conjunction of a conspicuously advertised sale of rubbers and a soppy week-day morning may be either a lucky accident or the result of studying the weather map. In the former case, supposing the business to be conducted in the northeastern United States, where dry weather is about twice as common as wet, the odds would be two to one against the occurrence even of light showers on the day the advertisement appeared, and three or four to one against the occurrence of such weather as would make the advertisement decidedly *à propos*.

These remarks about newspaper advertising are, to a great extent, applicable also to the dressing of windows and the display of goods inside the shop. In both cases a moderate amount of foresight in the matter of weather will result in placing before the customer the right goods at the right time. One of the minor ways in which the merchant can turn the science of meteorology to advantage consists of using meteorological instruments and the official weather forecasts and bulletins for the purpose of attracting attention to his windows or to his stock-in-trade. The drug-store thermometer is the illustration of this process that comes first to one's mind. There is no reason why, with the progress of civilization, this celebrated instrument should not be made a trustworthy index of temperature as well as an effective advertisement. In continental Europe weather instruments are displayed along with miscellaneous advertising matter in many of the street "weather columns" (*Wettersäulen*), which furnished the idea of the meteorological kiosks installed by the Weather Bureau in American cities.

One of the most important branches of commercial meteorology relates to the effects of weather upon transportation. This is a many-sided subject. In the first place, the railway and steamship companies, and other concerns engaged in the transport of goods and passengers have their manifold weather problems, among which one may mention, at random, that of dealing with the snow blockades of railways, precautions against the skidding of taxicabs in wet weather, the avoidance of iceberg-infested routes at sea, and the selection of climatically favorable sites for aerodromes. The shipper has a somewhat different, but overlapping set of weather problems.

"In the building of railroads," says Mr. E. L. Wells, "many phases of climate are to be considered, including the probability of floods, deep snows, high winds, sand storms, etc. It is not long since a considerable length of railroad line in one of the Western States was found to be practically worthless because of having been built too near the bed of a stream and therefore being too much subject to damage from floods, so it was replaced by a line built higher up. The writer remembers two railroads entering the same town in one of the northern plains States, one of which is seldom blockaded, while the other is sometimes closed by snow for months at a time. In the former case the cuts are parallel to the wind, while in the latter the wind blows directly across the cuts. In operating railroads a knowledge of the climate is essential. This is particularly true in the shipment of perishable products, which may require icing or ventilation as a protection against high temperature, or insulation against cold. Not only is a knowledge of climatic conditions essential in taking precaution against loss in transportation, but weather records are playing an increasingly large part in the settlement of claims for products and property damaged in transit. The claim agents of the leading transportation companies and the traffic managers of the commission houses and producers' associations keep complete files of climatological data, and a large percentage of claims for damaged goods, whether they be for a trainload of chilled bananas or for a traveling man's samples ruined by rain, are now settled out of court on the basis of the weather records. Claims for car demurrage are often settled on the basis of the weather reports."

Detailed information concerning the effects of temperature on all sorts of food products, both in transportation and in storage, was collected by the Weather Bureau some years ago and published as the Bureau's Bulletin No. 13.

While the domestic shipper can easily obtain from the Weather Bureau detailed climatic statistics for all parts of the United States, as well as the current weather reports for this country, and can profit greatly by regulating his operations in accordance therewith, it is not quite so easy for the shipper to foreign markets to obtain the corresponding data of foreign countries. With the expansion of our foreign trade, the demand for such data has grown to large proportions. The Weather Bureau, which has an unrivaled meteorological and climatological library in Washington, is naturally the place where such data are most frequently sought, but the labor entailed in extracting and digesting the information in response to individual requests is often too great to be undertaken by a Government office, where the time of the employees is absorbed in routine duties. There is, therefore, a promising field here for the private commercial meteorologist. Unofficial work in this line is already carried on to some extent. Thus a great steel company in New York has a salaried "consulting geographer" on its staff, who advises on meteorological questions. One of the problems he has been called upon to solve was to determine the proper dates for shipping steel from Atlantic and Pacific ports of the United States to various places in India, so that it would never arrive during the monsoon rains. Records of current and very recent weather in distant countries are, in a great majority of cases, unobtainable anywhere in the United States. The interchange of detailed weather reports between the different meteorological services of the world involves in the first place, with few exceptions, a painfully slow process of publication, and then distribution by mail; so that, for example, records of observations at some places in South Africa or Australia, or even many parts of Europe, do not reach the Weather Bureau Library, in Washington, until two or three years after the observations are made. Undoubtedly the time will come—and probably in the near future—when there will be a world-wide exchange of weather news by wireless telegraphy.

One kind of business wholly dependent upon the weather, which we have not yet mentioned, is weather insurance. There are several kinds, but hail insurance and tornado insurance are those extensively practiced; the former much more widely and systematically in the Old World than in the New, while the latter is confined to America. Insurance against frost is said to have been practiced in Germany, and there appears to be an excellent field for it in the United States. The insurance of outdoor events, such as games, shows, and *al fresco* parties, against rain has been carried on for a good many years by speculative underwriters at Lloyd's, in England, and has more recently been undertaken in this country. Of course the weather element enters to a considerable degree into other kinds of insurance. Ordinary marine insurance is, to a large extent, insurance against storms; fire insurance is partly insurance against lightning; window and plate glass insurance involves the risk of breakage by wind and hail; and even life insurance is greatly concerned with the effects of weather and climate.

CHAPTER XVII

MARINE METEOROLOGY

That it behooves a sailor to be weather-wise has always been admitted, but there was a time, almost within the memory of men now living, when neither seamen nor landsmen had the remotest conception of the benefits that a systematic study of the meteorology of the sea was capable of conferring upon the maritime world. The man who first grasped the importance of such a study and translated his ideas into facts was the American naval officer, Lieutenant Matthew Fontaine Maury.

During his brief career at sea Maury became impressed with the meagerness of the information then available concerning the winds and currents that aid or hinder the voyages of sailing ships. When, in consequence of an accident that incapacitated him for shipboard duties, he was assigned to service in Washington, he began to explore the old logs of naval vessels, filed in the Navy Department, for notes on meteorological conditions, and eventually developed a plan of securing regular observations from both the Navy and the merchant marine. The result of this undertaking was the publication of the famous Wind and Current Charts, which revolutionized navigation throughout the world.

The practical value of these charts, of which 200,000 copies were distributed to the masters of merchant vessels of all nationalities, was promptly recognized. By taking advantage of the favorable winds and currents shown on the charts, and avoiding those that were unfavorable, mariners were able to reduce the average time of a sailing voyage between the Atlantic and Pacific ports of the United States by forty days. The money value of the charts to vessels sailing from the United States to South America and the Far East was estimated at $2,250,000 per annum. British shipping on all seas is said to have benefited to the extent of $10,000,000 per annum. Neither was the utility of the charts limited to the saving of money. The following episode is cited in Maury's biography:

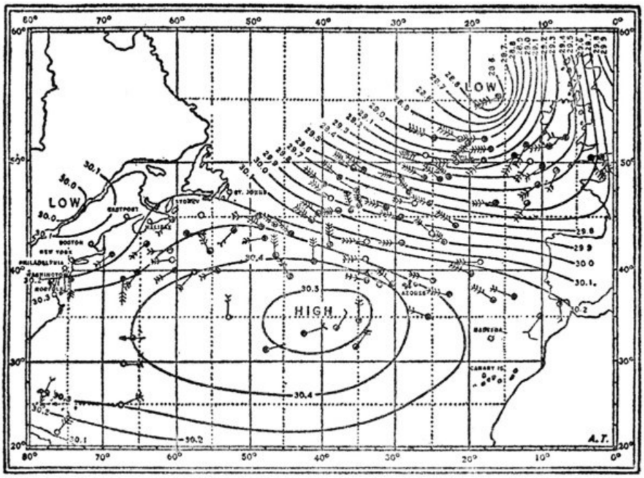
"When the *San Francisco*, with hundreds of United States troops on board, foundered in an Atlantic hurricane, and the rumor reached port that she was in need of help, everyone looked to Maury as the only man in the country who could tell where to find the drifting wreck. To him the Secretary of the Navy sent for information. He at once set to work and showed how the wind and currents acting upon a helpless wreck would combine to drift her 'just here', pointing to a spot on the chart, and making a cross mark with the blue pencil he had in his hand. Just there the relief was sent, and just there the survivors of the wreck were picked up. This was an incidental result of his study of winds and currents."

A further outcome of Maury's enterprise was the holding, at his suggestion, and by invitation of the United States Government, of an International Maritime Conference, which met in Brussels in 1853, and worked out a world-wide plan for meteorological observations at sea. The work thus begun has since been carried on by the leading maritime nations of the world. In the United States the duty of gathering weather reports on a uniform plan from vessel masters has been intrusted, at different times, to the Hydrographic Office, the Signal Service, and the Weather Bureau. It is now performed by the last-named institution, through its Marine Division, but the Pilot Charts and books of sailing directions ("Pilots") in which the compiled information is published, are issued by the Hydrographic Office of the Navy.

The modern successors of Maury's Wind and Current

Charts are, especially, the Pilot Charts for the different oceans issued monthly in Washington, and the monthly charts of similar character published by the British and German governments. Apart from these periodical publications, valuable collections of meteorological charts for oceans or smaller marine areas have been published by the British, German, Dutch, Indian, Japanese and other authorities.

The value of such publications has not been lessened by the gradual substitution of steam for sails on ocean-going vessels. While wind is no longer all-important, it is a factor in determining the speed, and hence the earning capacity, of all classes of ocean shipping, and the same is true of marine currents. Fog and drifting ice are, in general, more serious obstacles to steamers than to sailing ships. A glance at one of the Hydrographic Office Pilot Charts will suffice to show that these publications are indispensable to the mariner. On these charts we find, first of all, in the center of each five-degree square of latitude and longitude a "wind rose" showing the frequency of the winds that have been observed in that region from each of the cardinal points, and their average force from each direction. On the charts will also be found the routes recommended for full-power and low-power steamers and sailing vessels, lines of magnetic variation, tracks of storms in past years for the month in question, location and force of currents, average limits and prevalence of fog for the month, recent information about drifting ice and derelicts, descriptions of storm signals, and an abundance of other information of vital importance to the seaman.



OCEAN WEATHER MAP PREPARED FROM VESSEL REPORTS

JAN. 11, 1913, GREENWICH MEAN NOON

U. S. Weather Bureau

Solid black lines are isobars. Arrows fly with the wind, the center of the arrowhead marking the position of the vessel, and the number of feathers denoting the force of the wind on the Beaufort scale. Shading of the head shows degree of cloudiness.

Most of the material used in the preparation of the charts above described is obtained from a great corps of volunteer marine observers, who enter their observations at stated hours in forms provided for the purpose and send these records to the establishment in charge of the work at the end of each voyage. The forms furnished by the United States Weather Bureau prescribe only one regular observation a day, to be taken at Greenwich mean noon. Each observation shows the position of the ship, the direction of the wind, the force of the wind on the Beaufort scale, the height of the barometer, the readings of the dry-bulb and wet-bulb thermometers, the temperature of the water at the surface, the state of the weather, and the kind, amount, and movement of clouds. In order to check the accuracy of the barometric readings, the observer is instructed to read his barometer at prescribed hours on three successive days when in port and send the readings to the Weather Bureau. On receipt of these readings the Bureau compares them with those of the nearest meteorological station, and then mails the observer a "barometer tag," showing the results of the comparison and the error of his instrument. Besides keeping up these routine observations, the observer keeps a record of fog encountered at any hour of the day and makes detailed reports on storms. Many marine observers also report observations at stated hours by wireless telegraphy.

The enormous fund of information thus collected over the ocean is applied to several purposes besides the construction of Pilot Charts. Our Weather Bureau and certain foreign meteorological institutions prepare daily charts, showing approximately the instantaneous conditions over great oceanic areas, especially the North Atlantic. These maps are analogous to the daily weather maps published for land areas, but the drawing of each map is, necessarily, delayed for several months after the date to which it refers, in order to allow time for the receipt of as many reports as possible from ships at sea. As a rule such charts are prepared in manuscript only, but, though they cannot be distributed after the manner of ordinary weather maps, they are valuable for studies in the institution itself on the movements of storms and other atmospheric processes. They also enable the meteorological officials to answer inquiries concerning the winds and weather that have prevailed over a particular part of the ocean on any specified date. Such inquiries come from vessel owners, underwriters, and others, and the replies are frequently used as evidence in admiralty suits.

In the case of one series of such maps—viz., the daily synoptic charts of the North Atlantic, begun by Niels Hoffmeyer, of Copenhagen, and now prepared jointly by the Danish Meteorological Institute and the Deutsche Seewarte, in Hamburg—the charts have actually been published and sold, though they are so costly that the number of sets in libraries throughout the world is probably small. These remarkable charts present daily pictures of the winds and barometric pressure over the North Atlantic Ocean and the adjacent continents from 1873 to 1876, and from 1880 down to a recent date.

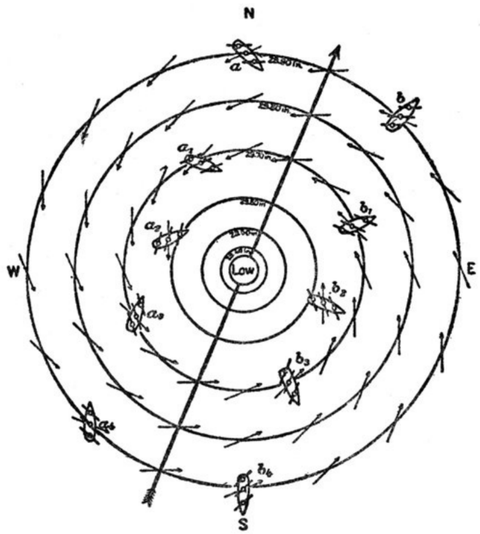
From what we have already said it will be seen that the marine observers cooperating with the United States Weather Bureau and kindred institutions abroad are all contributing toward the great task of recording the history of the weather over the oceans from day to day and assembling data that can be digested in the form of marine climatic statistics and used as the basis for many scientific investigations. This concerted undertaking does not, however, constitute the whole scope of marine meteorology. Every intelligent mariner finds it necessary to acquaint himself with the laws of the winds, indications of coming storms, means of determining the proximity of icebergs, the systems of storm signals used in different countries, the method of constructing weather maps from wireless bulletins, etc. He ought, in short, to become an accomplished meteorologist.

One of the classic problems of the navigator is that of handling his ship in a violent cyclonic storm, especially a tropical hurricane. The reader will recall that a cyclone, besides traveling as a whole at a rate of several hundred miles a day, consists of a system of winds rotating around the center. The result of this double motion is that the winds on one side of the center are not only more violent than those on the other, but they are also so directed as to drive a vessel running before the wind, across the storm track ahead of the advancing center, while those on the other side tend to drive a vessel to the rear of the storm. The two halves of the storm area are accordingly known as the "dangerous" and "navigable" semicircles, respectively. While this simple statement sets forth the fundamental facts involved, the actual problem is complicated by many features, such as the fact that the winds do not blow in circles, but more or less spirally, that the area of the storm cannot be readily determined, that two storms may occur in close proximity to each other, etc.

The accompanying diagram, published by the United States Hydrographic Office, represents a cyclonic storm in the northern hemisphere, the circles being isobars, or lines passing through places at which the same barometric pressure prevails (indicated in inches), and the arrows indicating the direction of the winds. The diagram is thus explained:

"For simplicity the area of low barometer is made perfectly circular and the center is assumed to be ten points to the right of the direction of the wind at all points within the disturbed area. Let us assume that the center is advancing about north-northeast, in the direction of the long arrow, shown in the heavy full line. The ship *a* has the wind at east-northeast; she is to the left of the storm track, or technically in the navigable semicircle. The ship *b* has the wind at east-southeast and is in the dangerous semicircle.***A vessel hove to at the position marked *b*, and being passed by the storm center, will occupy successive positions in regard to the center from *b* to *b*4, and will experience shifts of the wind, as shown by the arrows, from east through south to southwest. On the other hand, if the storm center be stationary or moving slowly and a vessel be overtaking it along the line from *b*4 to *b*, the wind will back from southwest to east, and is likely to convey an entirely wrong impression as to the location and movement of the center. Hence it is recommended that a vessel suspecting the approach of proximity of a cyclonic storm should stop for a while until the path of the center is located by observing the shifts of the wind and the behavior of the barometer."

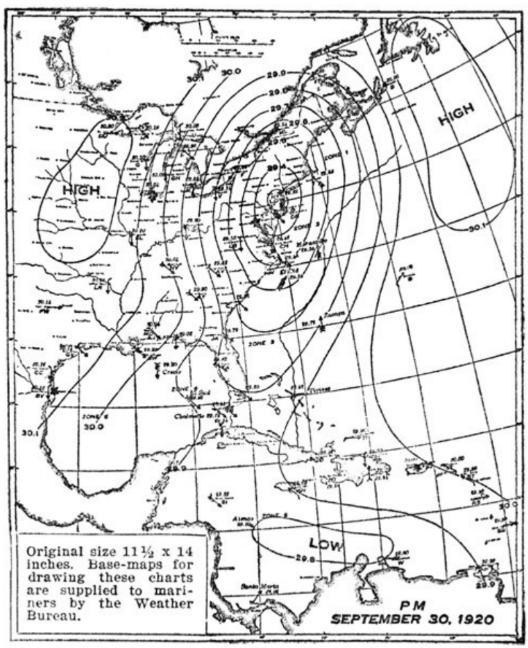
The movement of the winds around the storm center shown in this diagram is that of cyclones of the northern hemisphere; i. e., contrary to the direction of the clock hands. In the southern hemisphere they blow in the opposite direction around the center.



NAVIGATION OF A SHIP IN A CYCLONIC STORM
(*U. S. Hydrographic Office.*)

By observing the rise or fall of the barometer, the shift of the winds, and the state of the sea and sky, the experienced navigator is generally able to lay down on a chart the approximate position of the storm center and steer his vessel so as to avoid danger. Various devices, known as "storm cards," "cyclonoscopes," etc., have been used to aid in the process of locating a storm from shipboard observations. In the Far East mariners use for locating typhoons an ingenious combination of the storm card and the aneroid barometer, called the "barocyclonometer," an invention of the Rev. J. Algué, director of the Philippine Weather Bureau.

The most important development in marine meteorology in recent years has been the rapidly increasing use of radiotelegraphy, both by marine observers in transmitting reports of observations to shore and to other ships, and by meteorological institutions in issuing weather bulletins and storm warnings to vessels at sea. The first regular undertaking in this line was carried out under the auspices of the London *Daily Telegraph* in the year 1904. This newspaper arranged with some of the leading transatlantic steamship lines to furnish weather reports by wireless from their vessels, and these reports were published in its columns for several months. The following year the United States Weather Bureau began, in a tentative way, the collection of wireless weather reports from off-shore vessels, and similar undertakings were soon afterward launched in other parts of the world, but for some years such reports were of little practical value, owing to the limited range of wireless communication.



A SHIPBOARD WEATHER MAP

> Vessels off the American coast can make their own weather maps every night, using data supplied at fixed hours by high-power radio stations (shown by stars on the map), together with radio reports from other vessels. Letters near stations are the code letters used in wireless bulletins to describe the stations. Vessel reports are indicated by names. Arrows show direction of wind and the force on the Beaufort scale (shown by the number of feathers). Besides data for constructing maps, the radio stations issue forecasts and storm reports for each of the numbered zones shown off the Atlantic coast and over the Gulf.

At the present time wireless reports from ships on the Atlantic enable the forecasters on both sides of that ocean to extend the areas of the weather maps on which their predictions are based, and reports from ships are also received to a limited extent by forecasters on our Pacific coast as well as in the Far East, India, and elsewhere. In this country such reports have been especially valuable in indicating the movements of West India hurricanes, and thus have helped to solve the problem of protecting the vast tonnage that has been attracted to Caribbean waters by the opening of the Panama Canal. The reciprocal process of transmitting weather intelligence to vessels by wireless bulletins, broadcasted at certain hours every day by high-powered radio stations, has made much more progress. Such bulletins include information concerning the current and prospective weather, winds and storms over specified ocean areas, as well as reports of observations made at a number of land stations, from which it is possible for vessels at sea to construct their own weather maps. They are thus enabled to take advantage of favorable winds and to avoid unfavorable winds and storms. Wireless weather reports from other vessels help to piece out these shipboard maps.

The meteorological services of all civilized countries adjacent to the sea display signals along their coasts to announce the coming of storms dangerous to navigation. One of the earliest devices used for this purpose was the "aeroclinoscope," a form of semaphore formerly employed by the meteorological service of Holland. The position of the arm of the semaphore indicated the region in which the barometer was low; i. e., the storm center. In the British Isles, in the middle of the last century, Admiral FitzRoy introduced the use of canvas cones and "drums" (i. e., cylinders), which, seen from any direction, have the appearance of solid triangles and squares against the background of the sky. The British later abandoned the drum and used the cone only, pointing up or down for northerly or southerly gales, respectively. The American storm flag—red with a square, black center—was adopted by the United States Signal Service (the predecessor of the Weather Bureau) in 1871. This signal was subsequently amplified by the addition of red and white pennants to show the expected direction of the wind at the beginning of the approaching storm. Most countries use lanterns for night storm signals. In the year 1909 a uniform system of signals, consisting of cones by day and lanterns by night, was recommended for use in all countries by an international commission which met in London.

In spite of this recommendation some thirty or forty different systems of daytime storm signals are now in use in different parts of the world. On the China coast an elaborate system of signals, consisting of cones, balls, diamonds, and squares displayed on a mast and yardarms, indicates the existence of a typhoon anywhere in the neighboring seas, together with its location and movement.

CHAPTER XVIII

AERONAUTICAL METEOROLOGY

During the great war the British Government decided, in its wisdom, to establish a flying field in Scotland, at which aviators were to be trained in dropping bombs. The commission having this matter in hand chose a site on the shores of Loch Doon. In laying out the field a bog had to be drained; then a railway was constructed, hangars were erected, and other operations were carried out, entailing altogether an expenditure of half a million pounds. At a certain late stage in the proceedings the disconcerting discovery was made that the field could never be successfully used for the purpose intended, on account of the gusts and eddies produced by the surrounding hills. The undertaking was therefore abandoned. The authorities had presumably enlisted the skill of engineers from the outset of the work—but they had failed to consult a meteorologist!

A few such object lessons seem to be necessary to demonstrate the fact—which ought to be obvious—that meteorology is an indispensable and vital adjunct of aeronautics. This fact is now pretty well understood. Nearly all the activities of mankind are more or less influenced by weather, but few, if any, to such an extent as aeronautical enterprises. Hence a definite branch of applied science—Aeronautical Meteorology—is rapidly taking shape. Already it enters into the curriculum of aeronauts; it has profoundly modified the methods of the ordinary meteorological services of the world; and it is raising a crop of specialists, some of whom are now employed by the business firms that manufacture or operate aircraft.

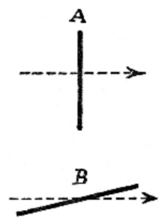
The statement has constantly been made since the war that aeronauts are becoming "independent" of the weather.

This statement has a grain of truth in it, but no more. It is a fact that, under war conditions, aviators flew in every sort of weather, and often with impunity. Even since the war commercial aircraft have negotiated adverse atmospheric conditions with remarkable success. A spectacular feat of this sort was achieved on August 28, 1919, when a passenger-carrying aeroplane on the Paris-London route, piloted by Lieutenant Shaw, flew over this route through a hurricane blowing in gusts of from 40 to over 100 miles an hour, accompanied by a torrential rainstorm and such poor visibility that the pilot was frequently obliged to fly very low in order to pick up his landmarks and make sure that he was on his course. The flight was accomplished in 1 hour and 50 minutes—about half an hour less than schedule time. It is said that "the two passengers in the cabin of the machine emerged without any appearance at all of strain"—such as they certainly would have experienced if they had made the crossing by the Channel steamer on that boisterous day. In fact the land and sea route was seriously disorganized by the storm, and the Continental trains were arriving in London hours late.

Lest hasty conclusions should be drawn from this episode it should be stated at once that the company operating the air route in question, far from considering itself independent of weather, is not content with the detailed bulletins furnished to aeronauts by the British Meteorological Office (which specializes in aeronautical meteorology more extensively than any other official weather service in the world), but maintains an elaborate weather service of its own, with an able meteorologist at the head of it.

An accurate statement of the situation would be that wind and weather are no longer the grave dangers that they once were to the aeronaut; but they are still, and will probably always be, factors of the utmost importance in the successful and profitable operation of aircraft. In order to make this matter plain it will be necessary for us, first of all, to devote a few words to some of the fundamental principles involved in aerial navigation.

The layman who sees nothing mysterious in the ascent of a balloon is, in general, somewhat puzzled by the phenomenon of a heavier-than-air machine rising from the ground. Yet, in both cases, the ascent of the vehicle depends upon the fact that air is not just empty space, but a material substance, possessing density, weight, and other properties many of which pertain also to solids. A balloon rises not because it is light, but because the air about it is heavy. In other words, gravity pushes the air under the balloon more forcibly than it pulls the balloon downward. The ability of an aeroplane to leave the ground depends upon the fact that air offers resistance to bodies moving through it.



THE EFFECT OF AIR RESISTANCE ON AN AEROPLANE

Suppose a vertical plane (A)—such, for example, as the wind shield of an automobile—is moving horizontally through still air. The resistance of the air impedes its motion, and a part of the motive power is employed in overcoming this resistance. Now, suppose the plane (B) is nearly, but not quite, horizontal, and is propelled by a force tending to make it move in the direction indicated by the arrow. This is approximately the case of an aeroplane driven by a motor; the plane representing the wings of the machine. Only a part of the air's resistance is now effective in impeding the forward motion of the plane. The rest of it pushes the plane upward. If you hold your hand at such an angle and move it through water you will feel an analogous upward push. Moreover, you will notice that the faster you move your hand the greater is the push. Not only does this upward pressure of a fluid upon an inclined plane moving through it vary with the speed of the latter (to be exact, as the square of the speed), but it also varies with the angle which the plane presents to the fluid in its path. If the wing of an aeroplane, for example, cuts the air nearly edgewise, the upward pressure will be slight. As it departs from an edgewise position, (with the front edge higher than the rear), the upward pressure increases, but not indefinitely; beyond a certain rather small angle it begins to diminish.

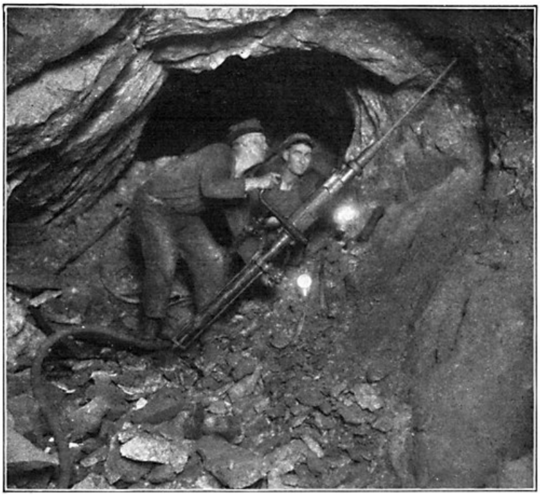
In an aeroplane the upward pressure, or "lift," is increased by giving the wings a slightly arched shape, or "camber." The air flows over the arched wings in such a way as to produce a suction above them which helps the push from below. The actual amount of lift for a given speed has been determined by experiments for wings of various shapes and sizes and set at various angles to the line of motion. If, when the machine is in the air, the lift is just sufficient to counterbalance the weight of the aeroplane, the latter flies horizontally. An increase in lift causes the machine to rise; a decrease in lift permits gravity to pull it down.

Now suppose the aviator is flying horizontally and wishes to climb. At the rear of the machine and forming part of its tail is a hinged horizontal flap called the "elevator," under the control of the pilot. By giving this flap an upward tilt he causes the air to exert a downward pressure on the tail of the machine, and hence the nose of the machine is carried upward. While the inertia of the aeroplane tends to carry it along the original path, its wings now present a greater angle to the air, the lift is increased, and the machine rises. The reverse of this operation will cause the machine to descend.

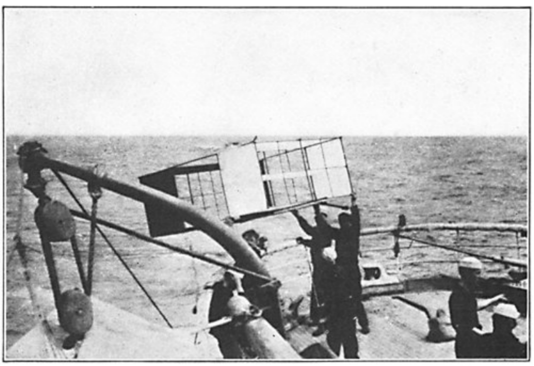
THE BED OF POTOMAC RIVER, AT WASHINGTON. From an altitude of a few hundred or a few thousand feet, submarine features are clearly revealed to great depths. Objects have thus been photographed 45 feet under water. The shoals are submerged to a depth of from 2 to 5 feet. In favorable weather, aerial photographs are valuable in making hydrographic surveys. (*Photographed from the air by Dr. W. T. Lee, U. S. Geological Survey.*)

A vertically hinged flap in the tail, acting on exactly the same principle as the rudder of a ship, enables the pilot to turn horizontally. Two or more small horizontal flaps, known as "ailerons," attached to the wings, are used to preserve the lateral balance of the machine, and to give it the proper "bank," or inclination, when making a turn.

With these few details in mind, we shall be prepared to consider, in a general way, how the behavior of an aeroplane is affected by the wind and other atmospheric phenomena.



Drilling with Compressed Air in a Copper Mine. The drill also forces a stream of water into the hole to lay the dangerous sulphur-bearing dust. (*Courtesy Sullivan Machinery Co.*)



Launching a Weather Bureau Kite from the "Seneca" During the International Ice Patrol, to Explore the Air Over the Ocean.

(*Photograph, U. S. Weather Bureau.*)

With respect to wind there is an important difference between aircraft and marine craft. Mere strength of wind is not dangerous to an aeroplane, except when starting or landing. An aviator flying above the clouds, with no landmarks in sight by which to gauge his movements, is no more conscious of the actual wind at that level, provided it is steady, than he is of the rotation of the earth on its axis. He feels the wind produced by the motion of his machine through the air—the so-called "relative wind"—but no other. The true wind may be a mere zephyr, or a hurricane blowing 150 miles an hour; the effect is the same on his machine, so far as he is able to observe. On the other hand, a strong wind has a very different effect from a light one upon the course of the aeroplane's flight with respect to the ground beneath. If a pilot, with no landmarks to guide him, steers by compass for a certain point, and if there is a strong cross-wind of which he is unaware, he will be carried far out of his course; a wind dead ahead or astern will merely affect the speed of his flight, so that he will arrive later or sooner at his destination than he expected.

One of the important problems of aeronautics, especially from the commercial point of view, is to prevent aircraft from being driven off their course by the wind when flying with no visible landmarks; i. e., over clouds, fog, the ocean, or an unmapped country. When this problem is solved, pilots will fly above the clouds much more commonly than they do now. The winds at high levels are generally both steadier and stronger than at low. The stronger wind is an advantage or a disadvantage, according to whether it is blowing in the direction of flight or the reverse; but as the winds at different levels generally blow in different directions, a pilot who is independent of landmarks can choose whatever level affords the winds most favorable for his intended journey.

Over established air routes quite elaborate measures are now adopted to keep pilots informed of the direction and speed of the wind at different levels, so that they can make due allowance for this factor in shaping their course. In clear weather this information is easily obtained by sighting the drift of a pilot balloon with a theodolite, or by observing in a specially designed graduated mirror or pair of mirrors the drift of the smoke cloud from a shell fired by an anti-aircraft gun and timed to burst at any desired altitude. In cloudy weather the smoke trails can often be successfully observed through small breaks in the clouds. When the sky is completely overcast, a succession of shells is fired at definite short intervals of time and the distances apart of the puffs of smoke and the direction of the line in which they lie are determined from an aeroplane flying above the spot. Another method, which was devised by the French military meteorological service during the war, is to send up small balloons loaded with bombs which burst after a certain time, the position of each burst being determined by sound-ranging from the ground.

These methods of providing information concerning the winds at flying levels have, however, their serious limitations, and aeronauts now look hopefully to the perfection of the existing systems of "directional wireless," whereby the pilot will receive whenever desired, or at regular intervals, a wireless signal from the terminus of his route or some other known point, the direction from which the signal comes being indicated by suitable apparatus on the aeroplane. Thus aided, he should never deviate far from his course, unless he chooses to.

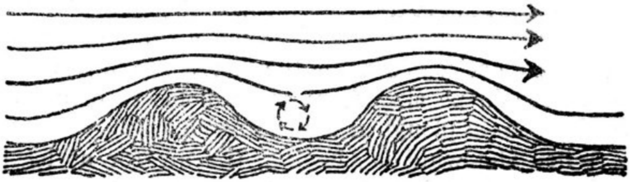
For long journeys, such as the crossing of the Atlantic, the air pilot will naturally make use of all available information concerning the great permanent or semipermanent wind systems of the earth, such as the trade winds of the lower atmosphere, the antitrades above them, and the fairly constant eastward drift of the atmosphere at high levels in middle latitudes. The dividend-earning capacity of commercial aircraft necessarily depends upon taking advantage of favorable winds, while adverse winds may mean not only a loss of money but the danger of prolonging a journey until the fuel supply is exhausted—a serious predicament over the ocean and also over lands remote from civilization. It is, however, a common error on the part of current writers to overrate the constancy and reliability of the winds in various parts of the world, and to lay too much stress on the value of permanent wind charts. What the aeronaut needs especially to know is the typical behavior of the winds with respect to the distribution of barometric pressure, as shown by a weather map, including their variations with altitude. The time will come when the information necessary for plotting the winds at various levels will be flashed at frequent intervals by high-powered radio stations to aerial navigators in all parts of the world—a system that is already in its initial stages, especially in Europe. A pilot making a long journey will thus be able to lay his course so as to utilize the winds that will speed him on his way. Even violent storms, such as the mariner seeks to avoid, will be turned to advantage by the airman.

We have now to consider another aspect of wind that is of much more interest to the airman than to the seaman, and that is the question of "wind structure." The layman usually thinks of a wind as a nearly steady horizontal flow of air. Such winds exist, but they are exceptional, especially in the lower levels of the atmosphere. A wind is generally full of gusts and eddies, upcurrents and downcurrents, and it is these eccentricities that gradually develop in the aviator a sort of sixth sense—a "feel" for atmospheric fluctuations, that enables him to adjust his machine instinctively to the forces tending to disturb its equilibrium. He also learns by experience the conditions under which irregularities of a pronounced character may be expected. He becomes well acquainted with the great mound of air that drives his machine upward when passing over a hill or mountain;

with the eddy that lurks in the lee of such an obstacle; with the downward tendency of the air over lakes, rivers, swamps and forests.

"The air is so sensitive," writes the late well-known British flyer, Gustav Hamel, "that it is affected even by the color of large patches of vegetation. Whether this be entirely due to the different heat-radiating power of different colors it is impossible to say, but invariably an aeroplane on passing from grass land to a field covered with yellow flowers experiences a certain amount of air disturbances only less noticeable than the inevitable bump experienced in passing from green fields to ploughed land, or from ploughed land to meadow."

When the wind is blowing, the air for at least a few hundred feet above the ground is nearly always in a state of turmoil. This is partly due to the friction of the moving fluid against the irregular surface of the earth, and partly to the ascending and descending currents caused by differences in temperature. The latter effect is illustrated in the rapid rise of air over a bare sunlit plain and its fall over an adjacent forest or body of water. Ascending currents are often made visible by the formation of detached cumulus clouds, each of which marks the summit of a rising column of moist air, while in the spaces between the clouds the air is generally sinking. Measurements with balloons have shown that vertical currents often attain speeds of 600 feet a minute or more, while the process of hail formation appears to indicate that in thunderstorm clouds there are violent uprushes amounting to 2,000 or 2,500 feet a minute, and possibly much more. The descending air current between clouds is sometimes so strong that an aeroplane cannot force its way up through it.



THE FLOW OF AIR OVER TWO RIDGES

(*After Dr. Franz Linke.*)

Notice the eddy in the valley to the leeward of the first ridge

A SHELTERED LANDING PLACE MAY BE DANGEROUS

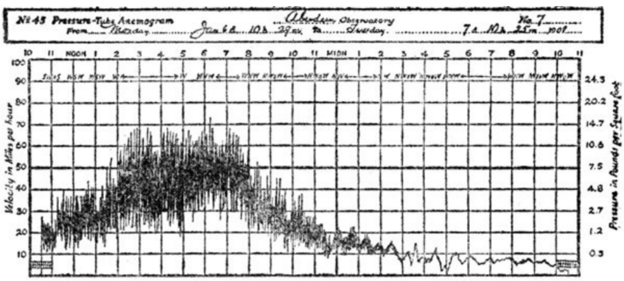
(*After Dr. Franz Linke.*)

A landing place surrounded by trees is dangerous in windy weather on account of the air waves formed between the moving air above and the calm air below.

AIR WAVES NEAR THE EARTH'S SURFACE

The waves are made visible by smoke

The turbulence of the lower air—a phenomenon that adds so much to the difficulties of starting and landing—extends to various heights, depending especially upon the strength of the wind. A rough rule, evolved by the Zeppelin pilots before the war, was to expect turbulent conditions up to an altitude equal to from ten to twenty times the force of the wind in meters per second. Thus, for a wind of 10 meters per second, the turbulent layer would be from 100 to 200 meters thick. A good picture of the atmospheric ups and downs encountered by the airman when flying low is furnished by the behavior of the smoke from a factory chimney with a moderate wind blowing, forming smoke waves.



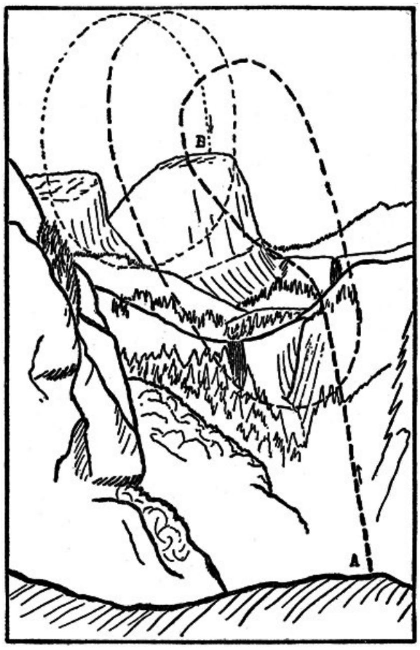
THE WIND'S AUTOGRAPH ON A GUSTY DAY, RECORDED WITH A PRESSURE-TUBE ANEMOMETER

The vertical lines are hour lines and the horizontal lines show the force of the wind in miles an hour and also in pounds a square foot.

These disturbances give rise to the very marked fluctuations in the force of the wind known as gusts. There are certain forms of anemometer especially designed to record the gustiness of the wind. A record of the wind's force is traced by a pen on a moving strip of paper, and the "anemogram" thus obtained shows a continuous series of irregularities, the extent of which increases with the strength of the wind. The puffs and lulls often alternate at intervals of a few seconds or less, and the actual force of the wind at a given instant may be many times greater than its average force for, say, five minutes. An ordinary anemometer does not indicate these rapid fluctuations, but merely shows the time required for a mile of wind to flow past the instrument. Thus when such an instrument tells us that the wind is blowing at the rate of 40 miles an hour, it may actually be varying between 20 and 60 miles an hour, or between even wider limits.

Since the matter became of practical importance on account of the needs of aviation, many interesting studies have been made of the effects of different kinds of topography upon the overlying air currents. A striking example of the eccentric winds that sometimes prevail in mountain valleys has been described by Mr. B. M. Varney, of the University of California, in the "Monthly Weather Review." From the summit of a steep cliff about 1,100 feet above the floor of Yosemite Valley the writer launched broad sheets of tissue paper, and, with the aid of powerful binoculars, followed their flight as they were carried in huge spirals, thousands of feet in diameter, finally disappearing beyond the mountains on the opposite side of the valley. The accompanying sketch shows the path of one of these papers. From its starting point at *A* until it passed behind the summit of Liberty Cap (*B*), more than a mile distant, the paper was watched for 7 minutes. The top of Liberty Cap is some 1,600 feet above the point at which the flight began. This sketch visualizes one of the ticklish problems that will some day confront the pilot of a sight-seeing or mail-carrying aeroplane in the Yosemite National Park.

Although, on an average, the air is much steadier at high levels than near the ground, very unsteady currents are sometimes found at all altitudes attainable by aircraft. Thunderclouds, thousands of feet above the earth, are always the seat of violent turmoil, but such clouds can, as a rule, be avoided by the airman. When a stratum of air glides over another differing sharply from it in density—and distinct strata of this sort are not uncommon in the atmosphere—friction between the strata sets up waves like those produced in water by wind blowing over it. If the two streams are moving in the same direction, but at different speeds, the waves are long and regular; when they are more or less crossed, the waves are short and choppy. The moisture at the crests of these waves may be cooled to such an extent as to condense into visible clouds, arranged in long continuous rolls or rows of detached patches; forms frequently assumed by cirro-cumulus and alto-cumulus. More often, however, the waves of air remain invisible, because the conditions of moisture and temperature are not right for the production of cloud.



AIR CURRENTS IN YOSEMITE VALLEY

(*Sketched by B. M. Varney.*)

The flight of a sheet of paper across the valley.

Recalling, now, what has been said above about the way in which the lift of an aeroplane varies with the angle at which the wings meet the air and also with the speed of the machine relative to the air, it will be easy to understand some of the difficulties experienced in maintaining one's equilibrium when flying in a turbulent atmosphere. Waves, eddies, vertical currents and other features of wind structure cause abrupt changes in the attitude and the speed of the machine with respect to the air stream. The sudden increases and decreases of lift thus produced have much the same effect upon the machine as if it were running over a solid obstacle on the one hand or plunging into a vacuous space in the atmosphere on the other, and hence are aptly described by aviators as "bumps" and "holes in the air," respectively. The latter term, which seems to have become firmly rooted in all languages (French, *trou d'air*; German, *Luftloch*; etc.), has had the unfortunate effect of keeping alive in the public mind the idea that the aviator occasionally runs into a vacuum or semivacuum, such as could not exist in the atmosphere. (The nearest approach to such a thing is the rarefaction in the core of a tornado or waterspout, due to the enormous centrifugal force of the vortex; something that no aviator has yet encountered.)

To make matters worse, different parts of the sustaining surface of the machine may receive different impulses. One wing, for example, may graze a violent uprush of air not encountered by the other, giving the aeroplane a tilt to one side, or the tail of the machine may be driven in one direction and the nose in the other. Again, the whole machine may suddenly enter an air current of quite different speed and direction from the one in which it has been flying. To take an extreme case, it may run into a stream of air flowing just as fast, and in the same direction, as the machine itself, with the result that the *relative* wind becomes zero, and the machine, deprived of all lift, drops like a stone until it acquires a velocity with respect to its new environment.

When such conditions prevail, the pilot is kept busy with his "controls"; now moving his elevator to adjust his fore-and-aft balance, and now his ailerons to set him on an even keel laterally, and occasionally turning his rudder to offset the effects of horizontal gusts. The elevator and the ailerons are worked with a single lever, colloquially called the "joy-stick," and the rudder with a bar which the pilot operates with his feet. Ordinary adjustments of this kind are performed automatically by the trained aviator, but violent disturbances call for the exercise of skill and judgment. Generally speaking, no amount of atmospheric turbulence causes any serious trouble to the trained pilot, except when he is flying close to the ground, as in starting and landing.

Before we leave the subject of wind it will be well to emphasize once more the fact, which the average layman has difficulty in grasping, that the only movements of the air that affect the safety and comfort of flight are the movements relative to the machine, and not those relative to the ground. To the aviator, when he is once clear of the ground, a steady wind of any speed is merely a mass of calm air. Hence an aviator will sometimes have perfectly smooth flying when the wind, as measured on the earth, is blowing 40 or 50 miles an hour; and again he will describe the air as rough and bumpy when flags are hanging limp from their staffs and dwellers on *terra firma* declare that not a breath of air is stirring. In the early days of flying aviators themselves were afraid of a strong wind. Thus Wilbur Wright, during his pioneer exhibition flights in France, would never go up unless the smoke from his cigarette rose in a straight line, and until about the end of 1909 no aviator attempted to fly in a wind of 20 miles an hour.

At the present time the only atmospheric condition that seriously hampers flying is fog or low cloud. An aviator flying in a fog or cloud is not only liable to wander far from his course, on account of the unknown leeway of his machine, but he is often in great doubt as to his proximity to the ground. One of the curious effects of such a situation is that the airman loses his sense of the vertical. On land our sense of up and down is determined by the force of gravity, pulling us toward the earth. When riding in a terrestrial vehicle, we are conscious of other pushes and pulls; such, for example, as the jolt that pitches us forward when a train stops suddenly, or the outward thrust that we feel when swinging around a curve. Again, in descending in a lift we seem to lose weight, as if gravity had suddenly grown weaker. On earth all such impressions are corrected by the sight of objects around us; but the aviator enveloped in mist has no such guides, and he often becomes quite confused about the direction of the ground. A turn, which involves banking, increases his confusion. Eventually he may be flying almost upside down without being aware of the fact. Professor Melville Jones, who has been through such experiences, says of the pilot's confusion:

"His first indication that something is wrong is, as a rule, either an increase or a decrease of speed that is not counteracted by the accustomed movements of the controls. A period of wild suspense and utter bewilderment now follows, during which the pilot makes violent efforts to recover control, but without success. The next thing that he realizes, if he realizes anything at all, is that he is either on his back or spinning, and the next thing he knows is that he is out of the clouds with the earth standing up at a ridiculous angle and spinning round like a drunken dinner plate. Happy is he that has plenty of air room under these circumstances."

Spirit-levels and similar instruments are affected by the same disturbances that mislead the pilot in his estimation of the vertical; but fortunately there are certain other devices, due to the exigencies of the war, during which cloud flying was a part of the tactics of the military aviator, which have virtually solved this problem, though their use has not yet become general.

The outstanding difficulty of a fog is the problem of landing. In the case of a forced landing, at a distance from a regular landing-ground, the pilot must simply trust to luck. He may descend in the water or the treetops, or on rough ground that will wreck his machine, but he has no choice. The only solution of this difficulty is the installation of a reserve engine, or some other expedient that will obviate the necessity of forced landings. The task of finding a landing ground in a fog and descending to it in safety will, in the near future, be comparatively simple. Most fogs, though by no means all, are so shallow that it is possible to tether a kite-balloon so that it will float above the fog and indicate the position of the aerial harbor. Several such balloons, flying tandem, would afford sufficient lift to support a series of electric lanterns along the cable, for use at night. Searchlights and "star shells" have been employed for the same purpose. Directional wireless and the wireless telephone seem likely, however, to be the chief dependence of the future aeronaut seeking port in a fog. These devices will also be the means of averting collisions in a fog or cloud along crowded airways, and especially in the congestion that will prevail in the vicinity of important air ports. Last but not least, the artificial dispersion of fog by means of electrical discharges, although still in the experimental stage, holds out possibilities of being the ultimate solution of the fog problem, not only for the aeronaut, but also for the mariner, the railway manager, and everybody else who is incommoded by a misty atmosphere.

Even when he is not flying in clouds or fog the aviator by no means always enjoys a clear view of distant objects. A slight haze impairs visibility, while a heavy rainstorm or snowstorm may obstruct the aeronaut's view as badly as a fog.

Of the meteorological elements that affect aeronautics, other than those we have mentioned, the most important is the density of the atmosphere—generally expressed in terms of barometric pressure. The air diminishes in density upward, and the rarefied atmosphere of high levels has several effects on aircraft. Its decreased buoyancy imposes a limit upon the ascent of balloons; its decreased resistance makes it necessary for an aeroplane to fly at greater speed in order to get the same lift; it diminishes the power of gasoline engines, on account of the reduced supply of air; and it has various unpleasant and even dangerous effects on the aeronaut, similar to "mountain sickness." The level that a given aeroplane cannot exceed owing to the combined effect of reduced lift and reduced engine power is known as its "ceiling." Different types of aeroplane have very different ceilings.

At great altitudes the air is always very cold, summer and winter. The low temperature may interfere with the efficient working of the engine, and it is, of course, a source of discomfort to the pilot. The formation of ice and heavy deposits of snow lead to inconveniences in both aeroplanes and airships. The pelting of hail is sometimes a painful experience for aeronauts. Lastly, lightning has hitherto left aviators unscathed, but has caused numerous disasters among balloonists.

The recent rapid development of aeronautics has laid a heavy burden of additional labor upon the meteorological services of the world, and is producing something like a revolution in their methods. The history of these changes is interesting. From the beginning of the twentieth century until a few years before the World War meteorologists were engaged in a great campaign of upper-air research, utilizing kites, captive balloons, pilot balloons, and sounding balloons to measure the winds, temperature, humidity and pressure at various levels in the atmosphere. In other words, aeronautical methods were employed in the service of meteorology, but the investigators hardly entertained the idea of reversing the relation and making meteorology the handmaiden of aeronautics. The point of view prevailing in those days is well indicated by the fact that the organization that had charge of the upper-air explorations throughout the world was known as the "International Commission for Scientific Aeronautics," a name that it bore until the year 1919.

The plan for providing regular weather reports for the benefit of aeronauts began with some small-scale enterprises in Germany about 1909. In the summer of that year Dr. Franz Linke organized a storm-warning service in connection with the International Aeronautical Exposition at Frankfort, and at the beginning of the year 1911 an aeronautical weather bureau for the whole of Germany was established, with headquarters at the Observatory of Lindenberg. Shortly before the war a similar undertaking was launched in Italy, under Dr. Matteucci, whose service was the first one in the world to publish daily charts, based on telegraphic reports, of the winds at various levels over an entire country.

During the war the regular meteorological services of the belligerent countries and the meteorological units attached to the armies and navies maintained an almost continuous service of weather information for the great fleets of fighting aircraft. Bulletins, distributed chiefly by wireless telegraphy, supplied particulars of the current and prospective winds at the flying levels, the prevalence of fog, the degree of visibility, etc. New telegraphic weather codes, far more elaborate than those in use before the war, were devised for transmitting such information, and the whole business of observing and reporting weather became immensely more arduous than it had been in the days when the only interests served by practical meteorology were those of the land and the water.

Since the close of hostilities great efforts have been made to maintain these new operations of the meteorological establishments at something like the level attained during the war. The task is, however, beset with difficulties, on account of the great expense involved. It is being accomplished with different degrees of success in different countries.

CHAPTER XIX

MILITARY METEOROLOGY

One of the most astonishing paradoxes connected with the misapplication of human brains and energy glorified with the name of the "art of war" is this—that, while weather has always played an important part, and often a decisive one, in military operations, no attempt was ever made until a few years ago to include meteorology in the purview of military science or to utilize the services of meteorologists at the battle front.

The most casual survey of the history of warfare reveals the fact that atmospheric conditions rank high among the "controls" of fighting. From a military point of view, weather and climate bear a certain analogy to topography. They are a part of the physical environment with which a commander has to reckon. Weather, however, differs from topography in the fact that it is subject to rapid changes, and is therefore doubly worthy of attention on the part of an army, which must not only take account of the weather as observed and in progress, but must also, as far as possible, anticipate that which is to follow.

Everybody will recall the ruin that overtook the French army in Russia in 1812 on account of untoward weather conditions, but it is less well known that Napoleon, with his usual sagacity, obtained from his scientific advisers a report on the Russian climate before he planned his campaign; that the winter set in much earlier than usual in that fatal year; and, most interesting of all, that it was actually a brief period of thawing weather, rather than the intense cold that preceded and followed it, which, by turning the roads into bogs and breaking up the ice in the Beresina, brought about the culminating disaster.

Another fateful spell of weather ushered in the battle of Waterloo. It is described in a well-known passage of "Les Misérables," which contains enough truth mingled with hyperbole to be worth quoting:

"S'il n'avait pas plu dans la nuit du 17 au 18 janvier, 1815, l'avenir de l'Europe était changé. Quelques gouttes de plus ou de moins out fait pencher Napoléon. Pour que Waterloo fût la fin d'Austerlitz, la Providence n'a eu besoin que d'un peu de pluie, et un nuage traversant le ciel à contre-sens de la saison a suffi pour l'écroulement d'un monde."

The rains and floods that led to the annihilation of the Roman legions under Varus in A. D. 9 and the great tempests that helped English seamen defeat the Spanish Armada furnish additional well-known examples of the immense importance of weather as a factor in warfare. We need not, however, look farther back than to the recent world conflict to find similar examples in profusion. Leaving out of consideration the indirect effects of the weather upon the progress of the war as exercised through its control of crops, transportation, and other features in the economic life of the belligerent and neutral nations, we need only examine war-time newspapers to see how the armies themselves were helped or harassed by meteorological conditions at every turn. The war was a great popular teacher of climatography, just as it was of geography. The drenching misery of Flemish winters, as formidable to the soldiers in the trenches as the bullets of the enemy, became as familiar to the present generation of Americans as did somewhat similar conditions in Virginia to Americans of the Civil War period.

The British campaigns in Mesopotamia were as much a conflict with climate as with human foes. Marches were made when the temperature stood at 110 degrees Fahrenheit and over. The temperature in the hospital tents is said to have reached 130 degrees. The disaster at Kutel-Amara was due to the rains and floods that prevented reenforcements from reaching the beleaguered garrison. The failure of the Dardanelles expedition was partly due to the fact that the extreme dryness of the country was not realized—as it would have been if the War Office had called climatologists into council—and totally inadequate provision was made for the water supply.

The new engines of war brought forth by the recent struggle were peculiarly susceptible to the effects of weather. The larger guns and heavy motor trucks were difficult to move over muddy roads. The aircraft, though they managed to fly in all kinds of weather, suffered innumerable disasters for which atmospheric conditions—chiefly storms and fog—were responsible, and their operations were conspicuously affected by favorable and unfavorable winds. Shells were fired to unprecedented heights, and their trajectories were modified by unknown conditions in the upper air. Last but not least, the use of poisonous gases, especially in the period before gas clouds were largely replaced by gas shells, was dependent upon the occurrence of appropriate winds; and a slight miscalculation in this respect sometimes brought disaster to the troops using the gas.

It is not surprising that professional meteorologists played a part in the World War, but it is difficult to understand why meteorological units were not attached to all armies, at least when on active service, several decades before the year 1914. Meteorologists did, indeed, take a hand in one earlier conflict, but not as enrolled soldiers. During the Spanish-American War a special service was organized by the United States Weather Bureau to protect the American fleet in southern waters from unpleasant surprises in the shape of West India hurricanes. In the summer of 1898 a chain of observation stations was established by the Bureau around the Caribbean Sea. The service then inaugurated in consequence of the exigencies of war proved so valuable to shipping in time of peace that it has continued to operate, with some intermissions, down to the present day.

When the World War broke out, the only country that immediately put meteorologists, as such, into the field was Germany. The Germans were fortunate in having a far greater number of trained meteorologists at their disposal than had their enemies. There were chairs of meteorology in several German universities and high schools, and the numerous meteorological observatories and institutes of the Empire had provided occupation for a large amount of professional talent in this line. One of the first acts of the army that invaded Belgium was to establish an aerological service in that country.

The Entente countries were slow in adding meteorological units to their armies, but their civilian meteorological services were utilized to the utmost for military purposes from the beginning of the war. They at first worked under difficulties arising from the cessation of the customary weather reports from central Europe, but, to offset this disadvantage, the weather map was expanded in other directions, the number of daily hours of observation was increased, and eventually the forecasters in London and Paris acquired much better facilities for making their predictions than they had enjoyed in time of peace. The supply of weather information to the public was suspended, and great precautions were taken to prevent the reports of the Allied services from being utilized by the enemy. The German meteorologists were seriously hampered by the lack of reports from the westward. It has been asserted that such reports were sometimes obtained by radio from submarines stationed off the coast of Ireland, but such a service, if it existed, must have been fragmentary and unsatisfactory. That the Germans made many mistakes in their attempts to infer the atmospheric conditions over the British Isles from the limited weather map at their disposal is proved by the fact that their airships frequently crossed the Channel when, with an ampler knowledge of impending weather, they would certainly have remained at home. Several Zeppelins came to grief in the course of these ill-timed raids. One of the interesting routine duties of the British Meteorological Office during the war was to draw the weather map for a given moment as the Germans would probably draw it, with their curtailed set of telegraphic reports, and then predict the German prediction!

In the spring of 1915 a small meteorological section was organised in the British Army, and attached to the Royal Engineers. This force was afterward enlarged, and provided units for service on several battle fronts. The British also developed a naval meteorological service, which had existed in embryo before the war, and, eventually, a special meteorological service for the Royal Air Force. Analogous services were organized by the French and the Italians.

The United States Army and the United States Navy both established meteorological services not long after this country entered the war. The former was attached to the Signal Corps, and was partly officered and recruited from the Weather Bureau. A training school for army meteorologists was opened at College Station, Texas. Upward of 300 men were given instruction in this school, and most of them were sent overseas. The naval meteorological service was headed by the director of Blue Hill Observatory, and the junior officers received special training at that institution.

The varied activities carried on by these war-time units were so different from the traditional duties of meteorologists that they may be said to mark the advent of a new branch of applied science—Military Meteorology. They were, moreover, as we shall see, extremely fruitful of effects upon the science of meteorology in general.

In the principal battle zones the military weather men maintained a dense network of observation stations, the reports from which, combined with those received from the regular peace-time weather stations of the Allied and neutral countries, enabled the forecasters at headquarters to keep closely in touch with atmospheric changes. Observations of both surface and upper-air conditions were made at frequent intervals, and radiotelegraphy was largely used to insure prompt transmission of the reports. In general, weather maps were drawn four times a day. Information was distributed locally to the fighting units by telephone and otherwise.

The vast fleet of aircraft called into being by the war would, of itself, have imposed upon the military meteorologists the necessity of paying a great amount of attention to the upper air. Pilot balloons were sent up so frequently and at so many points that the aviators generally knew just what winds they would encounter aloft. Special arrangements were made to follow the progress across the country of the thundersqualls which constituted a serious danger to the "sausages," or observation balloons, as well as to aeroplanes on the ground, and to hangars.

There was, however, another urgent reason for keeping a close watch of the winds and other atmospheric conditions at various levels above the earth's surface. Experience acquired early in the war proved that old-fashioned methods of correcting the aim of artillery for meteorological disturbances were extremely inadequate for modern guns, the projectiles of which rise to altitudes of from 10,000 to 20,000 feet and encounter conditions quite different from those prevailing at the surface. The flight of a projectile is affected by the force and direction of the wind, and the density of the air through which it passes. Some modern projectiles remain in the air as long as 70 seconds, and a moderate wind blowing across the path of such a projectile may easily cause it to fall half a mile away from the point at which it would strike if fired in still air. One of the routine duties of the army weather service was to observe the winds and compute the air-densities at different heights wherever such information was required by the artillery.

In order to facilitate the application of such data by the gunners ingenious methods were developed for computing what is known as the "ballistic wind." This is a fictitious wind which, if affecting the projectile throughout its flight, would produce the same total deflective effect and effect on range as the various winds that the projectile actually encounters.

Meteorological observations were also of great importance in connection with the new process of locating distant guns known as "sound-ranging." This process consists, briefly, in determining the exact instant of arrival at several points of the sound waves propagated through the air from the gun that is being located. If sound traveled at a uniform speed, these observations would show the exact distance of each of the observing points from the gun, and a simple geometrical construction would indicate the position of the latter. The speed of sound waves in the air is, however, affected by both wind and temperature. Accordingly, allowance had to be made for these varying factors, and the necessary data were supplied by the meteorological units.

The observation and prediction of winds favoring the use of poisonous gases by friend or foe was one of the most delicate tasks allotted to the army meteorologists. The flow of such gases is determined by the winds close to the surface of the earth, and these are greatly affected by topography. Local air currents controlled by the slope of the ground were especially utilized for gas attacks. Strong winds were unfavorable, because they quickly dissipated the gas cloud. The meteorologists not only advised their own troops when to use gas, but also gave warning when the atmospheric conditions were such that gas was likely to be used by the enemy. The use of gas shells was less dependent for its success upon the wind than the liberation of gas clouds, but even when shells were used the wind and weather at the objective point were factors of importance.

The exigencies of warfare developed several new features of meteorological practice, the utility of which did not cease with the war. Thus it became customary to measure the degree of "visibility" of distant objects, for the benefit of aviators and gunners, and this element was included in the routine weather reports. Scales of visibility, ranging from "very bad" to "excellent," etc., were adopted, and eventually certain forms of apparatus ("visibility meters") were devised for getting fairly precise measurements of this weather factor.

Another novel practice that deserves to be perpetuated was the plan adopted by the military forecasters of adding to their predictions a statement as to their probable accuracy; this was expressed on a numerical scale of "odds," instead of by use of the vague terms "probably" and "possibly," which have generally served the purpose of the dubious forecaster.

The war brought about many improvements in the instruments and methods used in sounding the upper air; and the intensive campaign of pilot-balloon observations carried out at the military stations provided a body of data for study quite unparalleled in the history of meteorology.

Lastly, the war revolutionized weather telegraphy in Europe. Before the war the European forecasters were hampered by exasperating delays in the collection of reports over the telegraph lines, especially in the international exchange of observations. Wireless telegraphy had been extensively used for gathering reports from vessels and supplying vessels with forecasts, but not for the interchange of meteorological information on land. The war changed all this. Radiotelegraphic weather messages became the rule, and the advantages of the new system were so obvious that the tendency has been to retain it as far as possible since the war.

CHAPTER XX

MEDICAL AND PHYSIOLOGICAL METEOROLOGY

The starting point in any study of the physiological effects of weather and climate upon humanity is the remarkable fact that, on the hottest days of summer and the coldest of winter, in tropical deserts and amid polar snows, the temperature within the body of a healthy man remains constant to a fraction of a degree. There are slight temperature differences between different parts of the body; there is a periodic daily variation of about half a degree; and there are other slight changes, due to eating and exercise; but an internal temperature of about 98.6 degrees F. is maintained with little or no regard to fluctuations in the temperature of the air.

The body has often been compared to a building in which the temperature is regulated by a thermostat, but the comparison is not exact. The thermostat controls the temperature merely by regulating the combustion of fuel; and with the advent of mild weather we let the fires go out altogether. In the body the fires are always burning, the briskness with which they burn—or, to drop the metaphor, the rate at which bodily heat is generated—depending, above all, upon muscular activity, but also upon other causes. It is true that we possess a nervous mechanism, analogous to the thermostat, which tends to adjust the production of animal heat in such a manner as to offset the cooling effect of our environment; but this mechanism appears to be less important in maintaining our constant temperature than another, which regulates the loss of heat from the body. According to M. J. Rosenau:

"Heat is lost from the body chiefly in two ways; (1)

by *heat transfer*, or loss by radiation, conduction, and convection; (2) by *evaporation*, chiefly by the evaporation of the water of perspiration. Pettenkofer and Voit estimated the loss of water by the lungs at 286 grams, and from the skin at from 500 to 1,700 grams daily. This will give some idea of the effects here concerned. The loss by heat transfer diminishes as the temperature of the surrounding air rises. The temperature of the body would rise when the atmospheric temperature goes above 70 degrees F. were not perspiration then secreted. So long as the perspiration can evaporate freely the heat production and heat loss are balanced. With a high humidity evaporation is lessened and the balance is maintained by rushing blood to the skin, which causes an elevation of the temperature of the surface, and thus the loss of heat by radiation, conduction, and convection is facilitated."

Human sensations of temperature are paradoxical. We talk of being "hot" and "cold," as if we belonged to the class of cold-blooded animals—the fishes and the reptiles—that actually undergo great variations of temperature, with variations in the temperature of their environment. We hear people say, for example, that they are most comfortable at a temperature of 65; yet we know that their temperature is always 98½, except just at the surface of the body.

The human body is, in fact, a poor thermometer. Our sensations do not register the temperature of the air, but they do, in a way, register the cooling power of the air, which depends upon temperature, humidity, and air movement, and they register, especially, changes in this cooling power, for within certain limits the body soon adapts itself to a constant rate of cooling, so as to lose any impression of heat or cold. When a steady outflow of heat from the body has been set up and the external cooling power is suddenly increased, we become conscious of a difference between the temperature at the surface of the body and the "blood temperature" beneath. The action of the nerves at the surface and the nerves underneath, under these circumstances, has been compared to that of a thermo-junction, in which an electric current is produced by differences of temperature. The rate of evaporation from the skin, also, has a marked effect upon our sensations of comfort and discomfort.

The common thermometer was long ago discredited as a means of measuring atmospheric comfort. Then, for a time, the wet-bulb thermometer had its day, and its indications were once published on a large scale in this country as representing the "sensible temperature," or temperature that we actually feel. The wet-bulb thermometer is cooled by evaporation below the air temperature, except when the air is saturated with moisture, and may therefore give a rough indication of the temperature acquired by the skin when moistened with perspiration. The temperature of the skin is not, however, an accurate indication of our feelings of heat or cold, nor is it a satisfactory guide to the physiological effects of atmospheric conditions.

Several instruments have been devised for the purpose of measuring the cooling power of the air, to which the bodily mechanism must respond in order to maintain a uniform temperature within. One of these was invented nearly half a century ago by J. W. Osborne. A porous cylinder was filled with warm water, and an agitator, driven by clockwork, kept the water in the cylinder at uniform temperature at any given moment. The rate at which heat was lost from the wet surface of the cylinder was determined by a thermometer, having its bulb immersed in the water, and a stop watch. A different plan was adopted by A. Piche, in an instrument which he called the *deperditometer*, and which was supposed to imitate more closely the behavior of the body. A porous vessel is filled with water, the temperature of which is kept constantly at "blood heat" (98.6 degrees F.) by a gas jet provided with an automatic regulator. The amount of gas burned in a given time is then supposed to measure the cooling power of the atmosphere as it affects humanity. J. R. Milne's *psuchrainometer* is constructed on the same principle, but heat is supplied and measured electrically.

Among many other instruments of this class, one that now enjoys special favor is the *katathermometer*, devised by Prof. Leonard Hill, in England. This consists of a pair of large-bulbed spirit thermometers, one of which has its bulb covered with fine cotton mesh. To use the instrument, the bulbs are immersed in water at about 150 degrees F. until the spirit rises to the top of the thermometer tubes. The excess of water is then jerked off the wet bulb, and the other bulb is dried. The instruments are finally suspended in the air, and the rate of cooling from 110 to 100 degrees, or from 100 to 90 degrees, is taken with a stop watch. The dry-bulb measurements are supposed to show how fast the human body loses heat at its surface by radiation and convection, while the wet-bulb measurements also take account of evaporation.

In order to connect the readings of this device with human sensations, Hill and his collaborators have used the instrument under a great variety of atmospheric conditions, both indoors and out, and compared the readings with independent estimates of comfort and discomfort. On an ideal summer day the "wet kata" fell from 110 to 100 in 25 seconds, and the "dry kata" in 85 seconds. Indoors at the seaside in summer, under comfortable conditions, the readings were 50 seconds and 140 seconds, respectively. A large number of other readings, taken under different conditions in various parts of the word, have been published. The katathermometer is now used in both Great Britain and the United States in the study of ventilation problems, and has acquired a rather extensive literature. According to its inventor, "the heating and ventilation of rooms should be arranged so that the wet-bulb falls from 100 to 90 degrees in about one minute, and the dry-bulb in about three minutes."

A Weather Bureau Kiosk, in Union Square, San Francisco.
(*Photograph, U. S. Weather Bureau.*)

The United States Weather Bureau Station, Observatory Type, at Peoria, Illinois. (*Photograph, U. S. Weather Bureau.*)

Regardless of the merits of these particular instruments, it is certain that the cooling power of the air—which is quite a different thing from the temperature of the air—is a very important factor in determining our comfort and our health. Within certain limits the body can easily adjust itself to changes in the cooling power of the air; within wider limits the adjustment is effected with difficulty, and we experience discomfort and possibly suffer in health; and finally there are extreme conditions, in either direction, to which adjustment is not possible; the internal temperature is then either lowered or raised, as the case may be, and a comparatively small change of this sort is fatal; i. e., death results by chilling or by heat stroke.

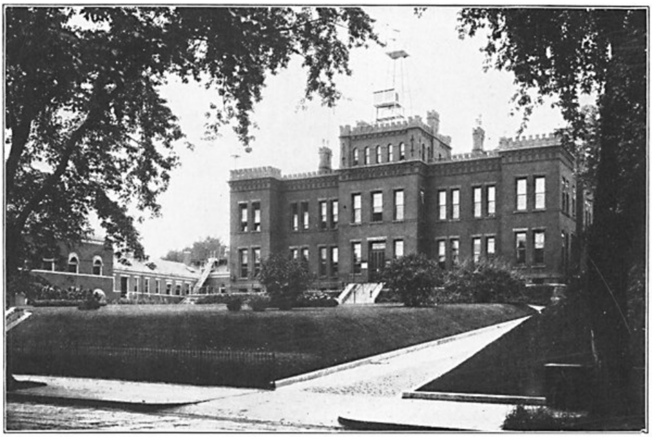
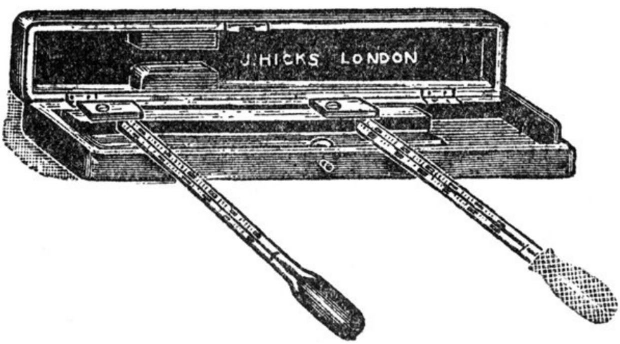


Photo U. S. Weather Bureau

THE CENTRAL OFFICE OF THE UNITED STATES WEATHER BUREAU IN WASHINGTON

One interesting result of recent inquiries on this subject is the discovery that the bad effects of crowded, "stuffy" rooms are not generally due to impurities in the air, but to heat, humidity, and especially lack of air movement. It seems to be now demonstrated that there is no such thing as "crowd-poisoning," and that the bad smells of confined places are no indication that the air is deleterious. Professor Hill, who has done more than anybody else to upset traditional ideas with regard to ventilation, tells us that "the deaths in the Black Hole of Calcutta, the depression, headache, etc., experienced in close rooms are alike due to heat stagnation; the victims of the Black Hole died of heat stroke." Most recent writers on physiology also discredit the time-honored methods of testing the purity of the air by measuring the percentage of carbon dioxide it contains. The amount of this gas normally present in the free air is about three-hundredths of one per cent, but experiments have shown that thirty times this amount—a percentage higher than is found in the worst ventilated rooms—may be breathed for hours together without detrimental effects. A further departure from old-fashioned views is seen in the assertion of recent authorities that a deficiency of oxygen, unless far more pronounced than ever actually occurs in buildings, mines, etc., where the supply of this gas has been the subject of so much solicitude, has no physiological significance whatever. In support of this assertion it is pointed out that at mountain health resorts the concentration of oxygen out-of-doors is much less than that found in the worst ventilated rooms at sea-level. In mines an ample supply of oxygen may be positively dangerous, as favoring the occurrence of explosions. These were rare before the enactment of laws requiring a high percentage of oxygen in mine air.



HILL'S KATATHERMOMETER

Excessive dryness of the skin, which is a common cause of discomfort, is not very closely related to the humidity of the air. "In winter," says Hill, "if there be a wind the rate of evaporation is so accelerated that the skin feels dry, because in order to check the loss of body heat the sweat glands are inactive and the blood vessels of the chilled skin are constricted." There has been a great deal of discussion about the dry air of American buildings in winter, and startling figures have been adduced to show that the air of such buildings is dryer than that of deserts. So far as measurements of relative humidity go, this is perfectly true; but, as Dr. G. T. Palmer, of the New York State Commission on Ventilation, has pointed out, there is an important difference between dryness and "dryingness." The latter depends upon the movement of the air, as well as the relative humidity. The circulation of the air in a desert is generally much more active than that of the air in a building with the windows shut, and therefore much more conducive to rapid evaporation. There are systems of ventilation in which the air is kept in steady and rapid motion, and it is probably only in such cases that the air of our heated houses can be compared to that of a desert. From the European point of view American buildings are notoriously overheated, but this is probably due to the fact that our hot summers—much hotter than those of Europe—have adapted us to a tropical climate.

It is natural to inquire whether the atmospheric conditions that affect the comfort of man do not also exercise a marked influence upon his muscular efficiency and his mental powers. This question has been answered in the affirmative by a number of ingenious writers, who have sought to establish definite quantitative relations between certain states of the atmosphere and the output of work in factories, the grades attained by school children, etc. Thus, Dr. Ellsworth Huntington, a well-known worker in this field, declares that the most favorable daily mean temperature for mental activity (the temperature being measured out-of-doors) is about 40 degrees F., and for physical activity about 60 degrees F. Contrary to the common opinion, he holds that our general efficiency is at low ebb in midwinter and fairly high in summer. Variability in temperature, within certain limits, he finds to be stimulating; equable temperature the reverse. He has drawn charts showing the distribution of what he calls "climatic energy"—i. e., the combination of certain weather factors supposed to control human efficiency—throughout the world, and other charts showing a more or less similar distribution of "civilization." He has also made an ambitious attempt to interpret the history of mankind in terms of weather and climate.

Another fruitful worker along similar lines is Dr. Griffith Taylor, of Australia, who has made interesting studies of the control of settlement in his own country and elsewhere by temperature and humidity, and has introduced some novel graphic methods ("climographs") for comparing climates with respect to their effects on humanity.

There has, in short, arisen a new school of climatologists whose aim is to develop exact mathematical formulæ whereby we shall be able to adjust the economic arrangements of mankind on an intelligent basis as regards climate. The success of their efforts is a question for the future to decide, but there is no doubt that their work is profoundly suggestive. These undertakings, it may be noted, bear a striking analogy to those of the present generation of agricultural meteorologists, who are applying climatic statistics to the problem of selecting crops and to the improvement of agricultural methods.

A certain number of specialists are engaged in studying the physiological effects of sunlight and other special kinds of solar radiation, the distribution of which varies greatly from place to place and from time to time, especially on account of differences in the selective absorption of such rays by the atmosphere. The chemical action of sunshine that causes sunburn—even at very low temperatures, as, for example, on high mountains—may have far-reaching effects on the human organism (as it certainly has on plants), and there is great need of collecting more data of "photochemical climate" than we now possess, in order that this subject may be thoroughly investigated. One of the few institutions in the world at which a large amount of work has been done in this line is the private observatory of Dr. C. Dorno, at Davos, the well-known health resort in the Alps. Dorno's studies throw a good deal of light upon the therapeutic effects of sunshine in a mountain climate.

Many forms of dust in the atmosphere are capable of producing pronounced physiological and pathological effects. There is a long list of "dusty trades" in which the production of excessive dust has notoriously evil effects upon the health of workmen, leading especially to pulmonary diseases; sometimes to various kinds of poisoning. These harmful dusts are by no means confined to factories, mines, quarries, and the like. The air of the average city street abounds in them. Dr. J. G. Ogden states that 61 per cent of the dust found in the air of the New York subways consists of jagged splinters of steel, resulting from the wearing away of brake shoes, wheels, and rails.

The amount of danger to human health incurred through the presence of disease germs in the atmosphere has been the subject of much controversy. The present tendency is to regard this danger as very slight, under ordinary conditions. Thus, Dr. F. S. Lee writes:

"Evidence that disease germs pass through the air from room to room of a house or from a hospital to its immediate surroundings always breaks down when examined critically. It is indeed not rare now to treat cases of different infectious diseases in the same hospital ward. The one place of possible danger is in the immediate vicinity of a person suffering from a disease affecting the air passages, the mouth, throat, or lungs, such as a 'cold' or tuberculosis. Such a person may give out the characteristic microbe for a distance of a few feet from his body, not in quiet expiration, for simple expired air is sterile, but attached to droplets that may be expelled in coughing, sneezing, or forcible speaking. In this manner infection may, and probably does, occur, the evidence being perhaps strongest in the case of tuberculosis. But apart from this source there appears to be little danger of contracting an infectious disease from germs that float in the air."

In regard to sewer gas, which still inspires so much dread in the popular mind, Dr. Lee says:

"Workmen in sewers are notoriously strong, vigorous, healthy men, with a low death rate among them. The specter of an invisible monster entering our homes surreptitiously from our plumbing pipes and sapping our lives and the lives of our children must be laid aside; we need no longer leave saucers of so-called 'chlorides' standing about our floors to neutralize in an impossible manner mysterious effluvia that do not exist; and when we return to our town houses in the autumn we may enter them with no fears that we are risking our lives by coming into a toxic, germ-infected, sewer gas-laden, deadly atmosphere."

Present-day knowledge on the subject of infectious diseases discredits many ideas that once prevailed with regard to the effects of tropical climates on health. The remarkable results accomplished by vigorous sanitary measures in such places as Havana, the Isthmus of Panama and Guayaquil have aroused hopes—perhaps too sanguine—that eventually all parts of the tropics will be made healthful for the white race. In the Canal Zone the death rate of the large population of American men, women, and children is not higher than prevails in many cities of the United States; whereas, a generation ago, when the French were at work on the canal, the "climate" of this region was regarded as one of the most unhealthful in the world. Some authorities go so far as to assert that the deterioration in the general health and efficiency of white people in the tropics, so far as it actually occurs, is due entirely to preventable diseases. It would seem more rational, however, to assume that there are climates both in and out of the tropics which, on account of their heat, humidity, and other purely physical factors, are not so suitable for habitation for any race of humanity as others. How far acclimatization can go toward offsetting the effects of these atmospheric conditions is problematical.

The changes in the barometer that occur from day to day in regions where these changes are most pronounced are, on an average, not greater than those encountered in going from the bottom to the top of a good-sized hill, and are probably not directly of physiological importance. Certain European investigators, however, ascribe pathological effects to the minute and rapid barometric fluctuations—too small to be detected with an ordinary barometer—that occur, for example, when the foehn wind isblowing. Whether this is the cause, or a contributory cause, of "foehn-sickness," of which one hears in Switzerland, is still uncertain.

The physiological effects of a rarefied atmosphere, as experienced in mountain climbing, ballooning, and aviation, are not yet well understood, despite the large amount of study that has been devoted to this subject. Recent views are thus summarized by Rosenau:

"The symptoms produced by a marked diminution in atmospheric pressure vary with circumstances. The effects are increased by cold, active muscular exertion, or improper clothing. The noticeable symptoms are increased rapidity of respiration and acceleration of the circulation, noises in the head and dizziness, impairment of the senses of sight, hearing, and touch, dullness of the intellectual faculties, and a strong desire to sleep. Sudden changes to a rarefied atmosphere cause syncope, weakness, dyspnœa, dizziness, and nausea. These threatening symptoms go by the name of 'mountain sickness,' Bert and Journet believe this condition is due to lack of oxygen, and the symptoms may, in fact, be relieved by adding oxygen to the air inspired. Kronecker concludes that mountain sickness is caused by a congestion of the lungs, impeding the flow of blood through them. Mosso and his followers attribute the physical disturbances of a reduced atmospheric pressure to the fact that the blood loses carbon dioxide more quickly than it loses oxygen, and they ascribe mountain sickness to this decrease of carbon dioxide in the blood. Cohnheim believes there is a concentration of the blood at high altitudes; in fact, insignificant increases have been found by competent observers."

Divers and workers in caissons are subjected to high barometric pressure, amounting, at the maximum, to about 4½ atmospheres. According to Rosenau:

"The physiological effects of an increased atmospheric pressure are mainly due to an increase in the amount of atmospheric gases (especially nitrogen) which are taken up by the blood, and also to an increase in the chemical absorption of oxygen by the blood. The serious consequences usually result from too rapid decompression. As the pressure is released gas bubbles form. Gradual decompression gives a chance for the gas to escape from the lungs and be expelled without the production of bubbles."

The health and comfort of many people seem to be affected, in a rather striking way, by the passage of the barometric depressions and areas of high pressure that alternate at intervals of a few days in the temperate zones. These effects should not be ascribed to changes of pressure, but rather to the accompanying changes in the other meteorological conditions. The late Dr. Weir Mitchell, who was a pioneer student of such phenomena, wrote of "a neuralgic belt, within which, as it sweeps along in advance of the storm, prevail in the hurt and maimed limbs of men, in the tender nerves and rheumatic joints, renewed torments called into existence by the stir and perturbation of the elements." Victims of neuralgia and rheumatism are probably quite justified in regarding themselves as human barometers, capable of predicting with considerable accuracy the advent of stormy and rainy weather.

The fluctuations of temperature, humidity, and wind that attend the passage of barometric highs and lows would seem, in virtue of their effects on the heat-regulating mechanism of the body and consequent reactions upon the nervous system in general, to supply an ample explanation of the unpleasant symptoms above noted in the case of sensitive people; conditions to which the collective name of "cyclonopathy" has been given by European investigators, and which are extensively discussed in the works of Hellpach, Frankenhäuser, and Berliner. Some authorities have, however, invoked in this connection the possible effects of atmospheric electricity, and pointed to the extreme sensitiveness of many persons to the approach of thunderstorms; a condition which Dr. G. M. Beard named "astraphobia." It is stated that the passage of a low-pressure area favors the emission of radioactive emanations from the ground, that the ionization of the atmosphere, and hence its electrical conductivity, is thus increased, and that the electric charge of the body is carried away more rapidly than usual. Here we enter upon a debatable subject, but one that thoroughly merits investigation. The human organism is the seat of various electrical phenomena, and these certainly cannot be independent of changes in the electrical state of the atmosphere.

Apart from possible direct effects of atmospheric electricity upon the human system, it has been suggested that electrical changes in the atmosphere affect the rate of reproduction of bacteria, and may therefore have some influence on the spread of infectious diseases.

The weather has many subtle influences upon the human mind, producing moods of cheerfulness and depression, and manifesting themselves in the records of the behavior of school children, in statistics of crime, insanity, suicide, drunkenness, etc. An interesting account of these manifestations is given by Dr. E. G. Dexter in his book "Weather Influences" (New York, 1904).

Finally, the aspect of meteorology that has thus far acquired the most definite shape in medical circles and given rise to the most coherent body of literature is Medical Climatology, which is designed to be applied in the climatic treatment of disease (climatotherapy). Thus many compilations have been made of the climatic statistics of health resorts, and these resorts have been classified with respect to their supposed climatic effects upon various diseases. From the point of view of the physical climatologist, the statistics found in such books seem, in general, both meager and ill adapted to bring out important features of the climates discussed; to say nothing of the fact that the whole subject of climatotherapy is fraught with controversy—whereof the history of the treatment of tuberculosis furnishes a shining example!

CHAPTER XXI

WEATHER-MAKING

METEOROLOGISTS, in their candid moments, have been heard to express disappointment over the amount of progress made in the art of weather forecasting during the past half-century. “Shall we ever,” they ask, “be able to predict the weather with mathematical certainty, as the astronomer predicts an eclipse of the sun or moon?”

Perhaps even within the meteorological fold there are unorthodox optimists who would answer such a question thus: “Yes, because some day we shall *control* the weather. It is inconceivable that man, who is every day achieving new miracles in the conquest of nature, should not eventually find a way of regulating the rainfall and sunshine that are of such vital importance to his crops, the winds that must be reckoned with in his voyages by sea and air, and the various other elements of weather that have so much to do with his happiness and welfare. The attainment of this object is so tremendously desirable that it cannot forever baffle human ingenuity.”

In support of such a bold assertion it might be pointed out that we already control the weather to a certain limited extent. When the horticulturist burns orchard heaters to protect his fruit from frost he certainly alters the weather for a few hours over a small area of the earth. If there were any practical justification of the process, the temperature of the air over an entire State, for example, could be raised throughout the winter, with appreciable effects on agriculture. The difference between heating a single orchard for a night and heating a State for a season is one of degree, and not of principle.

The climate of a city is, through causes dependent upon man, materially different from the natural climate of the surrounding country. Every dwelling provided with heating arrangements enjoys an artificial summer amid the blasts of winter. Local control of the winds is exemplified in the planting of thousands of miles of trees as windbreaks in the prairie regions of our Middle West. By moderating the winds this process has a marked effect on temperature and evaporation and is so beneficial to crops that in the aggregate it furnishes a striking example of successful "weather-making" by mankind. Analogous methods, perfectly feasible with means already at our disposal, would change the whole climatic aspect of large areas of the earth's surface.

The question "Can we make it rain?" may be answered in the affirmative by those who are neither impostors nor victims of self-delusion. The deposit of spray from the spout of a teakettle might, without much stretching of terms, be described as a miniature artificial rainstorm; but much bigger showers, in nowise different from those occurring in nature, can also be produced artificially. Huge clouds have often been observed to form over forest fires and other great conflagrations. These clouds, composed of water drops, tower far above the smoke cloud, and are identical in character and mode of origin with the cumulus and cumulo-nimbus clouds formed by currents of moist air rising from the heated ground on a summer day. There are several well-authenticated cases in which rain has been seen to fall from such clouds, and these showers have sometimes been so heavy as to extinguish the fires that generated them. Hence, given favorable conditions of humidity, temperature and wind, mankind can certainly produce a rainstorm (and perhaps a thunderstorm into the bargain) by the relatively simple process of building a big fire.

Unfortunately the vast majority of methods whereby man has attempted to regulate the weather have no such rational foundation as those we have just mentioned.

Some are wholly superstitious, others are purely empirical, and yet others are based upon ideas that their promoters suppose or pretend to be scientific, but that are actually fallacious.

In the history of superstitious practices weather-making plays a prominent part. Sir J. G. Frazer, in that great storehouse of myth and folklore, "The Golden Bough," says: "Of the things which the public magician sets himself to do for the good of the tribe, one of the chief is to control the weather and especially to insure an adequate fall of rain. In savage communities the rain-maker is a very important personage; and often a special class of magicians exists for the purpose of regulating the heavenly water supply." Frazer devotes ninety pages of his work to a rapid survey of the superstitious methods of controlling the weather that have found credence among the various races of mankind. These range all the way from the most complicated ceremonies to the summary expedient of throwing a passing stranger into a river to bring rain.

The sailor who whistles or scratches the mast to raise a wind is merely keeping up a quaint custom, in the efficacy of which he may or may not put some lingering faith, but which the world at large long since ceased to take seriously. When, however, a vessel master attempts to disperse a waterspout by firing a cannon at it, he is doing what nine educated persons out of ten would probably do under the circumstances. Yet one process is no more futile than the other, and both are based on superstition. Ages ago sailors sought to frighten waterspouts away by pointing knives at them, or by shouts and the clashing of swords, and the use of cannon originally embodied the same idea of terrifying the watery monster. It is our purpose in the present chapter to describe especially several processes of weather-making which, while not obviously chimerical from the point of view of the layman, have been more or less positively discredited through the scrutiny of men of science.

The efforts of modern weather-makers have been directed especially to two objects; viz., the production of rain and the prevention of hailstorms. In the United States a certain amount of ingenuity has also been devoted to the task of dispelling tornadoes. Some years ago a device for the latter purpose was patented, consisting of a box, containing explosives, mounted on a pole and erected a mile or so to the southwestward of the village to be protected from these unwelcome visitors. The force of the wind was expected to detonate the explosives by driving a movable board against percussion caps. The inventor believed that a violent explosion would disperse the passing tornado funnel. Apart from the fact that a single installation of this character, or even several of them, would seldom happen to be at exactly the right spot to explode close to the relatively small vortex of a tornado, the effect of the explosion, even in the very heart of the storm, would certainly be negligible. The energy that keeps the tornado in action is supplied continuously from a level far above the earth, while the disturbance due to the explosion would be only momentary. Above all, the energy developed in any discharge of explosives that the community could afford to pay for would be quite insignificant compared with that which prodigal nature supplies to the tornado.

The same disproportion between the giant forces at work in the atmosphere and the pygmy forces at the disposal of mankind is a point that is overlooked in most attempts at weather-making.

The widespread belief that rain can be produced by explosions rises so far above the level of ordinary popular delusions that it has sometimes led to large expenditures of money on the part of drought-ridden communities and even of national governments. Perhaps the most remarkable example of official confidence in the efficacy of this process was that furnished some years ago by the Volksraad, or legislative assembly, of the Transvaal, which passed a law forbidding the bombardment of the clouds to produce rain, on the ground that the rain-makers were thwarting the will of the Almighty!

One manifestation of the belief in question is found in the common assertion that rain is the usual sequel of battles. This idea originated, however, long before the invention of gunpowder. It is mentioned by Plutarch and other writers of antiquity. Whatever superstition or crude process of reasoning may have first given support to this notion in the popular mind, the explanation now commonly advanced is that the condensation of moisture is promoted by the concussion due to cannonading, or that the drops already condensed and constituting the clouds are jostled together by the same disturbance, with the result that they coalesce and fall as rain. There is no ground for such assumptions. As was once pointed out by the late Professor Simon Newcomb, the effect of a violent explosion upon a body of moist air a quarter of a mile distant is about the same as that which the clapping of one's hands would produce upon the moist air of the room in which the experiment is performed. Again, if we stand in the steam escaping from a teakettle and clap our hands we shall not produce a shower, though we jostle the water drops much more than the explosion does at a distance of a quarter of a mile.

In recent years another explanation has been offered for the alleged production of rain by explosions; viz., that the smoke and gases arising from an explosion increase condensation by increasing the number of "nuclei" in the atmosphere. As we have seen, however, in considering the natural formation of rain, the number of condensation nuclei normally present in the atmosphere is so great that it must be diminished, rather than increased, before drops as large as raindrops can be formed. Moreover, the nuclei required for the condensation of water vapor, including molecules of highly hygroscopic gases, are given forth in abundance by great manufacturing centers, yet these places do not have a heavier rainfall than the surrounding country. Pittsburgh, for example, is actually one of the driest places in Pennsylvania.

One obvious reason why rain often follows a battle is that battles are frequently fought in regions where rain normally occurs every two or three days, on an average, whether in peace or war. In northern France, for example, where the battles of the World War were plenteously interspersed with showers, meteorological records show that the average number of rainy days per annum is upward of 150. The drenching rains that made “Virginia mud” a byword during the American Civil War gave great currency to the belief in “rain after battles,” Here, again, we have accurate weather records to help us dispel a fallacy. Thus at Richmond rain falls on 122 days in an average year, at Lynchburg on 124 days, and at Petersburg on 105 days.

There is, however, a particular reason why rain is rather more likely to occur soon after a battle than shortly before one; viz., the fact that intervals of fair weather, with consequent dry roads, are used by commanders in carrying out the movement of troops that precede an engagement. By the time such arrangements, often occupying several days, are completed, the “spell” of fine weather is likely to be over, and a rainstorm is due in accordance with the normal program of nature.

The most famous undertaking in the history of rain-making—and one which has had an incalculable effect in fostering the credulity of the public with respect to similar enterprises—was that carried out by General Robert Dyrenforth on behalf of the United States Government in 1891. Congress voted appropriations amounting to $9,000 for these experiments, and Dyrenforth was appointed a “special agent” of the Department of Agriculture to direct them. After some preliminary trials in the suburbs of Washington, the experimenters proceeded to a ranch near

Midland, Texas. Here a few balloons filled with a mixture of oxygen and hydrogen, as well as several sticks of dynamite carried up by kites, were exploded in the air, but the only explosions of considerable magnitude were set off on the ground. The experiments continued over a period of three weeks and in some cases showers fell within a few hours after an explosion, but, in spite of the somewhat favorable tone of the official report, the consensus of scientific opinion was that the undertaking was a failure, while the views of the public at large were divided. The attitude of the Government is sufficiently indicated by the fact that it has never since undertaken experiments in this line. The one tangible outcome of this affair was that a crop of private rain-makers sprang up all over the country, and to this day the example set by the official experimenters is cited in support of every sort of harebrained scheme for juggling with the weather.

In 1911 and 1912 the late C. W. Post, of breakfast-food fame, expended many thousand pounds of dynamite in efforts to produce rain in Texas and Michigan. Showers undoubtedly occurred in conjunction with Post's experiments, but conditions favoring their occurrence were plainly indicated on the current daily weather maps, and they had been duly forecast by the Weather Bureau.

The professional rain-maker does not generally resort to the expensive process of bombarding the clouds. His methods most frequently involve the use of chemicals, and the details are shrouded in mystery. For example, about a quarter of a century ago one Frank Melbourne, known as "the Australian rain-maker," enjoyed great celebrity and coined money by his exploits in this field. His plan was to shut himself up in a barn, freight car, or other structure, and manipulate his chemicals and electric batteries for hours or days. Naturally rain sometimes came after these operations, but as often it did not.

Several of the methods that have been suggested from time to time for producing rain are sufficiently discredited by the fact that the expense of putting them into execution would more than offset any benefits derived from the rain, if the experiments proved successful. Thus one genius, observing the deposit of water on the outside of an ice pitcher in a warm room, proposed to set up a barrier packed with ice in the path of moisture-bearing winds. Another plan occasionally suggested is to sprinkle the atmosphere aloft with liquid air or liquid carbon dioxide, in order to lower the temperature, by the rapid evaporation of these substances, below the point of condensation. A third proposal is to create a local updraft of air by means of powerful fans or blowers, thus imitating the convectional process by which clouds and rain are formed in nature.

Lastly, various plans have been suggested for altering the electrical condition of the upper atmosphere—for example, by electrical discharges from balloons—on the assumption that rainfall might thus be promoted. This assumption, however, is not consistent with known facts as to the relation between atmospheric electricity and the condensation of atmospheric water vapor.

While in America a vast amount of money has been wasted on futile experiments in rain-making, far more has been spent in Europe on schemes for averting hailstorms. Methods of accomplishing this purpose have varied from age to age. In antiquity it was the custom to shoot arrows or hurl javelins toward the gathering clouds in the hope of frightening them away. In the Middle Ages ecclesiastical or occult agencies were invoked; "hail crosses" (such as are still seen in the Tyrol) were erected; and the ringing of church bells was considered efficacious against both hail and lightning, as is shown by the inscriptions found on many old bells.

The custom of firing cannon at the clouds to avert hail began centuries ago in Styria and northern Italy, and it was well established in France before the Revolution. Toward the end of the eighteenth century, however, another method of hail protection was introduced in France, whence it spread over the rest of Europe. This consisted in setting up tall, metal-tipped poles, imitated from lightning rods. It was supposed that these poles, which were known as *paragrêles*, would draw the electric charge from the clouds and thereby (though nobody could say why) would prevent the formation of hailstones. This device, though reported on unfavorably by the French Academy of Sciences, gained great popularity. One of its advocates, writing in 1827, states that more than a million *paragrêles* were at that time in use in France, Switzerland, Italy, Austria, Bavaria, and the Rhine country. The vogue enjoyed by these contrivances is said to have come to a sudden end when a tremendous hailstorm not only devastated the fields and vineyards they were supposed to protect, but also knocked down a great number of the rods themselves.

In recent times both the hail cannon and the *paragrêle* have been revived. The new era of "hail-shooting," as the process of cannonading the hail clouds is called, dates from the year 1896, when a number of cannon of a new type were installed in the vine-growing district of Windisch-Feistritz, in Styria. The success claimed for them in this region led to their introduction on a vast scale over the greater part of southern and central Europe. The cannon employed were small mortars, to the muzzles of which were attached sheet-iron funnels. No projectile was used, but the explosion of the charge sent aloft a curious whirling ring of smoke and gas, powerful enough to splinter sticks and kill small birds several hundred feet from the cannon. By the year 1900 at least 10,000 hail cannon were in use in Italy alone. Several modifications of the device were introduced, such as the use of acetylene in place of gunpowder; and eventually certain forms of rocket and bomb were adopted, for concentrating the effects of the explosion at as high a level as possible.

About the year 1899 a new form of hail rod was introduced in France, and this has become the favorite means of protection against hail in that country. It is essentially a very large lightning rod of pure copper, grounded by means of a broad copper conductor. Such rods have been installed, in some cases, on church steeples and other tall edifices, including the Eiffel Tower, in Paris, and in other cases on tall steel towers erected for this purpose. This device is called fantastically an "electric Niagara," because, according to the claims of its promoters, it draws down "torrents" of electricity from the clouds. Hundreds of these "Niagaras" have been constructed in France. Some of them are set up in rows, or so-called *barrages*, across the habitual paths of hailstorms. The French Government was induced to appoint a "Comité de Défense contre la Grêle" (Hail-protection Committee), which before the war had made elaborate plans for "protecting" not only the whole of France, but also Algeria and Tunis, with these devices. Similar rods have been erected in Argentina, and plans for introducing them in South Africa were near consummation at the time the World War broke out.

In order to understand the extraordinary hold that the various hail-protecting devices have taken upon the minds of European cultivators it should be remembered that the intensive cultivation of the soil is the rule over the greater part of Europe, so that a hailstorm of relatively small extent often does enormous damage. Vineyards are especially subject to injury from this cause, and many of the richest vine-growing districts of the Old World are notoriously afflicted with hailstorms.

Scientific commissions appointed by the Austrian and Italian governments conducted long series of tests of the methods of bombarding the clouds with mortars, bombs, and rockets, and declared them to be of no value. The erection of hail rods, though it has received a certain amount of official encouragement in France, is also strongly discountenanced by the majority of scientific men, as well as by a large proportion of intelligent agriculturists. Reports on the actual operation of the rods support conflicting opinions—as might be expected from the fact that the hailstorm is a decidedly erratic phenomenon. Thus, some observers claim that the storm clouds change conspicuously in appearance as they approach a "Niagara," and if they shed hail upon the spot it is in a soft and harmless form. Others deny the accuracy of these observations, and point to the stubborn fact that ordinary hail has fallen on several of the rods themselves, including the one on the Eiffel Tower. In the suburbs of Clermont-Ferrand a "Niagara" is installed on an iron tower, 100 feet high. This rod was pelted with hail twice in 1912 and four times in 1913, and in one case the hailstones attained the size of hen's eggs! Nobody has ever offered any plausible scientific hypothesis to explain why these rods should have an effect upon hail, even if they are able, as seems unlikely, to reduce the electrical charge of the clouds; since the formation of hail is due to movements of the air, which, in turn, are the cause and not the result of the charge in question.

Fortunately for the farmer and the horticulturist—especially in Europe—a method of averting the losses due to hailstorms is available in the shape of insurance, and its cost is decidedly less than that entailed in systematic hail-shooting or in the general erection of hail rods. Hailstorm insurance has been extensively practiced in the Old World since the end of the eighteenth century. In some countries it has been conducted or subsidized by the government. Generally each country is divided into a number of zones, according to the recorded frequency of hailstorms, and the premiums vary proportionately. Premiums also vary for different crops, since some are better able to withstand the effects of hail than others. The amount of insurance of this kind carried in Germany, alone, shortly before the World War, was more than $800,000,000.

Hailstorm insurance is fairly common in the United States, especially in the Middle West, but still lacks an adequate statistical basis in the shape of detailed records of hail frequency. In 1919 growing crops in this country were insured against hail to the extent of $559,134,000. Much information on this subject will be found in V. N. Valgren's "Hail Insurance on Farm Crops in the United States" (U. S. Dept. of Agriculture, Bulletin 912), published in 1920.

Besides the weather-making schemes already noted, mention should be made of certain more ambitious projects of this character that have been bruited from time to time, and that have found plenty of credulous supporters. In the year 1845 an American meteorologist of undoubted ability, but much inclined to the riding of hobbies—viz., James P. Espy—proposed the building of great fires in the western part of the United States in order to regulate the winds and rainfall to the eastward. The fires were to extend in a line of six or seven hundred miles from north to south, and were to be set off once a week throughout the summer. Another genius, of less celebrity, proposed to destroy blizzards by means of a line of coal stoves along the northern boundary of the country. A favorite idea of those who aspire to produce wholesale changes of climate is to alter the course of ocean currents for this purpose. One early plan contemplated the damming of the Strait of Belle Isle in order to improve the climate of New England and the Canadian provinces; while, a few years since, a proposal to build an immense jetty eastward from Newfoundland for the purpose of "protecting the warm north-flowing Gulf Stream from the onslaughts of the ice-cold, south-flowing Labrador Current" actually received, serious attention from the Congress of the United States.

CHAPTER XXII

ATMOSPHERIC BYWAYS

1. IGNIS FATUUS, OR WILL-O'-THE-WISP

Will-o'-the-wisp is proverbially elusive. It has thus far escaped the fate of the rainbow, deplored by Keats. We do not know its woof and texture, and it is not given in the dull catalogue of common things.

A strong argument in favor of the reality of this phenomenon is found in the great number of names that have been applied to it. There are forty or fifty in the British dialects alone. A myth generally carries its nomenclature with it, as it spreads from one community to another, while a fact of nature may give rise to a variety of local names.

It is certain, however, that a great many different phenomena have been described as will-o'-the-wisp. Some of these are: (1) The phosphorescence of decaying wood ("fox fire") and other vegetable matter. This is due to luminous fungi. According to H. Molisch there are some forty-five species of fungi, including twenty species of bacteria, that have the property of luminosity. Sometimes the ground under a forest is illuminated on all sides with a soft, white light from decaying leaves. (2) Fireflies, including glowworms (the wingless females of the firefly and the larvæ). (3) Luminous birds and animals. Their luminosity is supposed to be due to parasitic fungi. Certainspecies of skunk have been described as giving off in the darkness a continuous flame, the head being fiery red, which blends into a bright blue at the tail. (4) Ball lightning. (5) St. Elmo's fire. (6) Moving lanterns, distant lights of houses, and other lights due to human agency. (7) Burning gas ascending from marshes, stagnant pools, and the like. Marsh gas and other inflammable gases commonly rise from such places, and are often ignited by man, or by lightning, etc. Such fires are sometimes seen by day as well as by night. (8) Burning naphtha springs.

Excluding the numerous reported cases of will-o'-the-wisp in which the phenomenon may be plausibly identified with one of those mentioned above, there remain several cases, some of them reported by very careful observers, which appear to belong to a different category. The reports in question differ somewhat in details, but yield the following composite description:

Small luminous bodies, "about as large as your fist," or "the size of a candle flame," are seen hovering a few feet above the ground; not only over marshes and pools, but also over dry land. Sometimes they are stationary; at other times they appear to drift with the wind, or even to move independently. They appear and disappear, after the manner of fireflies. They do not set fire to objects with which they come in contact, and are believed to be without sensible heat. Their color is most often described as bluish, but may be yellow, purple, green, etc.; rarely pure white. They are without odor and without smoke. Traditionally they are associated with graveyards, but in very few of the cases heretofore recorded were they actually seen in such places. The popular idea that they flee from the traveler who tries to approach them and follow him when he seeks to avoid them is also unsupported by the evidence thus far adduced.

One of the most circumstantial accounts of these objects is that published in the Belgian journal "Ciel et Terre" for July-August, 1920, by a retired army surgeon, Jules Rossignol, who observed them repeatedly in the autumn of 1908 in and about some marshy woods near Grupont. They were generally seen to rise from the ground, at first in the shape of little white clouds, which changed to luminous globes on attaining an altitude of a dozen yards, and returned by a circular path toward the ground. They lasted from one to several minutes before disappearing in the air.

It is astonishing that the phenomenon of *ignis fatuus*, though reported from so many parts of the world, has not yet been made the subject of direct scientific examination. Nobody has ever studied its light with the spectroscope, for example. Chemists have, indeed, attempted to reproduce the phenomenon, yet the chemical explanations of it that have appeared in reference books down to a recent date are quite untenable. It has sometimes been attributed to marsh gas (methane, CH_4), and sometimes to phosphureted hydrogen (phosphine, PH_3). But marsh gas, besides not being spontaneously combustible, diffuses too rapidly in the air to produce the effects described, while phosphureted hydrogen, though it takes fire spontaneously in the air, produces thick wreaths of smoke when burning and has a powerful odor—features never reported in connection with will-o'-the-wisp.

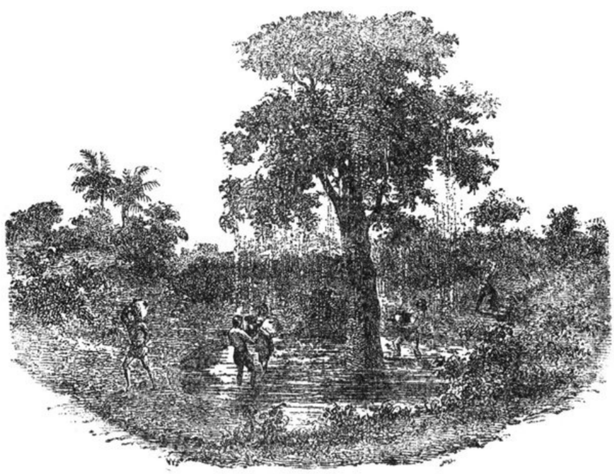
At least two more plausible explanations of *ignis fatuus* have been offered in the last few years. Mr. F. Sanford ("Scientific Monthly," Oct., 1919) believes that it is due to "swarms of luminous bacteria which are carried up from the bottom of the marsh by rising bubbles of gas." A Belgian chemist, M. Léon Dumas ("La Nature," Dec. 11, 1909), claims to have produced little luminous clouds, corresponding to the traditional descriptions of will-o'-the-wisp, by combining the two gases sulphureted hydrogen and phosphine. Both these substances are produced in the decay of animal matter, especially of the brain and spinal cord. The body of an animal, buried in some wet place, would accumulate the two gases under pressure in the skull and spinal canal, and their escape, simultaneously, would fulfill the conditions of M. Dumas' experiments.

(At the request of the present writer, these experiments were repeated at the Bureau of Standards, in Washington, with only partial success. Further trials with these and other gases due to putrefaction are desirable.)

2. THE RAIN TREE

From time to time the newspapers publish accounts of a wonderful tree, said to grow wild in Peru or elsewhere, from the leaves of which falls a continuous shower of rain, even in the driest weather. The writers generally urge the introduction of this tree in regions where the rainfall is deficient, and a so-called "rain tree" has actually been sold for this purpose by nurserymen.

The story of this tree is very old. Early voyagers reported finding it in the East Indies, Guinea, Brazil, and especially the island of Ferro, in the Canaries. Nowadays the name "rain tree" is applied especially to a magnificent tree of tropical America generally known to botanists as *Pithecolobium* (or *Enterolobium*) *saman*. One of its common names is "guango."



THE RAIN TREE
From "Voyageurs anciens et modernes"
(*By E. T. Charton*)

A legendary scene in the island of Ferro

That many plants spontaneously exude moisture under suitable conditions is well known. The phenomenon is called "guttation." The moisture drawn up from the roots is usually transpired from the leaves in the form of invisible water vapor; i. e., it is evaporated on passing into the air. If, however, the humidity of the surrounding air is sufficiently high, or its temperature sufficiently low, to check evaporation, the water will collect on the surface of the plant in liquid form, and may ultimately trickle to the ground in considerable quantities. Guttation occurs chiefly at night, or in cloudy or foggy weather. In a very dry climate it does not occur at all; and for this reason, even if the so-called rain tree could be successfully introduced in such a climate, it would not help solve the problem of irrigation.

The dripping of moisture deposited on plants by drifting fog is another common process that may have contributed to the legend of the rain tree. A classic example of this process—technically called "fog drip"—is that described by Dr. R. Marloth, who has made actual measurements of the abundant moisture captured by the vegetation of Table Mountain, South Africa, from the driving clouds of the southeast trade winds during the nearly rainless summer months. Mr. Madison Grant, writing of a similar phenomenon witnessed in the redwood forests of California, tells us that "these forests are sometimes so wet that the dripping from the high crowns is like a thin rain, and in summer it is oftentimes hard to tell whether it is raining or not, so saturated with moisture are the foliage and the trunks when the fog darkens the forest."

A copious production of "honeydew" by plant lice, scale insects, etc., may be at the bottom of some of the rain-tree stories. F. E. Lutz, in his "Field Book of Insects," writes of "weeping trees," which drip fluid of insect origin, and he says of the honeydew secreted by the pear psylla (*Psylla pyricola*): "When the psyllas are numerous theleaves and fruit become coated with this sticky substance and it even drops from them like rain and runs down the trunk."

The following account of the Peruvian rain tree, quoted from the traveler Spruce, was published in "Nature" of Feb. 28, 1878, by Prof. Thiselton Dyer:

"The Tamia-caspi, or rain tree of the eastern Peruvian Andes, is not a myth, but a fact, although not exactly in the way popular rumor has presented it. I first witnessed the phenomenon in September, 1855, when residing at Tarapoto. I had gone one morning at daybreak, with two assistants, into the adjacent wooded hills to botanize. A little after seven o'clock we came under a lowish spreading tree, from which with a perfectly clear sky over-head a smart rain was falling. A glance upward showed a multitude of cicadas, sucking the juices of the tender young branches and leaves and squirting forth slender streams of limpid fluid."

3. DEW PONDS

The Down country of southern England is one of the few places in the world where the people go to the hilltops to seek water in dry weather. On the summits of the Downs are found many artificial shallow ponds, most of them very old. Some, indeed, date back to prehistoric times. The bottom of these ponds consists of a layer of puddled chalk or clay and is impervious to water, so that there is no loss by seepage. As the ponds are not fed by springs or surface drainage, and as lack of rain does not cause them to dry up, it is popularly believed that their maintenance depends upon dew. Hence they are called "dew ponds."

Kipling mentions them in his poetical description of Sussex:

> We have no waters to delight
> Our broad and brookless vales—
> Only the dew pond on the height
> Unfed, that never fails.

The leading authority on dew ponds is Mr. Edward A. Martin, who has written a book about them. Mr. Martin's experiments have demonstrated that dew can make no important contribution to the water supply of these ponds. The rainfall on the hilltops is somewhat higher than in the valleys, and the greater part of the water in the ponds is undoubtedly derived from this source. The real key to the mystery, however, is found in the wet fogs that drift in from the sea. The process of "fog drip," which we have mentioned in connection with the rain tree, supplies the deficiencies of the rainfall, and the name "mist ponds," occasionally applied to these bodies of water, is more appropriate than "dew ponds."

It remains, however, an interesting paradox that, in time of drought, the farmers of the Downs drive their cattle to the hilltops to be watered and send their carts uphill to procure water for household use in the valleys below. Was it, perhaps, in this topsy-turvy region—where uplands are called "downs"—that Jack and Jill went "up the hill" on their ill-starred water quest?

4. BLOWING WELLS

Wells that predict weather changes are local curiosities in many parts of the world. Such wells are not uncommon in the United States. If the well is open at the top, its manifestations consist of occasional disturbance of the water and the discharge of numerous bubbles. If it is covered, a strong current of air is, at times, emitted from any small orifice in the cover. This may be strong enough to lift and blow away light objects placed over the aperture. Its emission is frequently accompanied by a loud whistling or roaring sound. Such occurrences are supposed to betoken an approaching storm. These wells are called "blowing wells"; sometimes "weather wells" or "barometer wells."

In certain cases an indraft of air is sometimes observed; i. e., the well alternately "sucks" and "blows."

As a rule these phenomena correspond to fluctuations in barometric pressure, and therefore are, in a rough way, indicative of changes in weather. It is obvious that a body of air inclosed in the earth and communicating by one or a few small openings with the air above will set up outdrafts and indrafts in adjusting its tension to that of the latter. The amount of air contained in the well itself would not suffice to produce the violent effects observed and it is therefore assumed that the typical blowing well taps a subterranean reservoir of air, probably filling the interstices of sand and gravel beds. When the pressure of the external air is diminished, some of the imprisoned air escapes. For a given body of inclosed air, the smaller the channel or channels by which it emerges, the stronger the outdraft. When the barometric pressure outside increases, the current of air flows in the reverse direction. In winter the indraft of cold air in such a well sometimes causes the water to freeze, even at a depth of 100 feet or more below the surface of the ground, and is therefore a source of inconvenience to the owner.

Various other circumstances may give rise to the bubbling and blowing of wells. Carbon dioxide and other gases dissolved in the well water account for the bubbling of many wells, and this process is more active at times of low barometric pressure, because at a given temperature, the amount of gas that the water can hold in solution varies with the pressure.

Another cause of the blowing of a well is, in some cases, a sudden rise in the water level ("water table") in the surrounding ground, as after a heavy rainstorm. If the ground is overlain by an impervious stratum, the air imprisoned between this stratum and the surface of the ground water over an extensive area will escape with violence through any available channel, such as that supplied by the well.

Lastly, cases have been described in which subterranean air currents arise from the friction of rapidly flowing underground streams, setting up permanent indrafts or outdrafts through wells communicating with such streams.

5. CURIOUS SHOWERS.

Showers of blood, sulphur, manna, frogs, fishes, and what not figure in all the old chronicles, and are still frequently reported. Many occurrences of this kind are recorded in Camille Flammarion's book "The Atmosphere," Dr. E. E. Free's "Movement of Soil Material by the Wind" (U. S. Bureau of Soils, Bulletin 68), and Mr. W. L. McAtee's article "Showers of Organic Matter" in the "Monthly Weather Review" for May, 1917.

The power of the wind to whirl objects aloft is a matter of familiar observation. McAtee tells of seeing a silk hat lifted from its owner's head and blown over a ten-story building in the city of Washington. The vortex of a tornado or a waterspout furnishes the most favorable skyward route for things that belong on *terra firma*. Objects weighing scores or even hundreds of pounds are lifted by these whirls. Within a mile or so of a tornado a shower of cart wheels or cook stoves would not necessarily constitute a "prodigy." A chicken coop weighing 75 pounds has been carried four miles and a church spire seventeen miles. Oersted tells of a waterspout at Christiansö, on the Baltic, that emptied the harbor to such an extent that the greater part of the bottom was uncovered, while McAtee says that "waterspouts have been observed to accomplish the comparatively insignificant feat of emptying fish ponds and scattering their occupants."

There is, in fact, no mystery about the way in which terrestrial objects of many sorts get into the air; nor, considering the force of the winds and their occasional strong vertical components, is it strange that such objects sometimes travel a long way from home before they return to earth.

There are, however, a great many cases of reported showers in which the objects did not really fall, as supposed. McAtee gives the following account of these spurious showers in the "Monthly Weather Review":

"*Insect larvæ.*—The rains of insect larvæ that have been investigated have proved to be merely the appearance in large numbers on the surface of the ground or upon snow of the larvæ of soldier beetles (*Telephorus*), or sometimes caterpillars, which have been driven from their hibernating quarters by the saturation of the soil by heavy rains or melting snow.

"*Ants.*—Accounts of showers of ants have usually been founded on incursions of large numbers of winged ants, which of course needs no assistance from the elements to follow out their habit of swarming forth periodically in immense numbers.

"*Honey; sugar.*—Showers of honey and of sugar are popular names for what scientists know are exudations of certain plants, or of plant lice which feed on a great variety of plants and whose product is often known also as honeydew.

"*Grains.*—Showers of grain, usually considered miraculous, have in most cases been determined to be merely the accumulation by washing during heavy rains of either the seeds or root tubercles of plants of the immediate neighborhood.

"*Manna.*—An account of manna 'rains' certainly pertains to the discussion of showers of vegetable matter, for the substance manna consists of lichens of the genus *Lecanora* but in none of the numerous recorded instances of manna 'rains' is there any direct evidence that the substance really fell from the sky. These lichens form small, round bodies that are easily blown over the surface of the ground and accumulate in depressions; they are very buoyant also and hence easily drifted into masses during the run-off of rain water. Manna 'rains' have not occurred except in countries where these lichens are common, and as for statements of their falling down upon roofs or upon people, or for any other proofs that they really rained down, I have seen none.

"*Blood rains.*—The most frequently reported showers that are spurious, at least in name, are the so-called blood rains. In all times the phenomena going under this name have frightened the people and have been taken as portents of terrific calamities. One of the famous plagues of Egypt was a bloody rain which prevailed throughout the whole land, continuing three days and three nights. Homer and Virgil both allude to blood rains, and, in fact, the general subject of preternatural rains was a favorite with the older writers.

"But scientific investigation has done away with the element of mystery in these phenomena and has explained, with the others, the rains of blood. Some blood rains have been found to be the meconial fluid ejected by large numbers of certain lepidoptera simultaneously emerging from their chrysalides; other red rains are due to the rapid multiplication in rain pools of algæ and of rotifers containing red coloring matter; "red snow" results from the presence of similar organisms. But in no case have they rained down, except in the sense that their spores or eggs have at some time been transported, probably by the wind. The precipitation of moisture furnishes favorable conditions for their rapid development and multiplication."

Most of the reported showers of blood, however, have probably been rainstorms in which the rain was colored with reddish dust. The occurrence of such dust in the atmosphere is very common in some parts of the world, as we have stated in a previous chapter. It has been asserted that rain which fell at Oppido Mamertina, Italy, May 15, 1890, actually contained blood, believed to be from birds.

Showers of supposed "sulphur" are due to pollen, chiefly from pine trees. The air in the vicinity of pine forests is sometimes filled with clouds of this material and the wind carries it for many miles. It is reported that a pollen shower at Pictou, Nova Scotia, in June, 1841, was so heavy that bucketfuls were swept up on a ship.

In the case of alleged showers of "paper" the material has been found to be the crusts of dried algæ, which form on the surface of the ground exposed by the evaporation of the water of shallow ponds.

6. THE YEAR WITHOUT A SUMMER

The Weather Bureau is a bureau of information, and one of the ways in which it strives to give a good account of itself is by answering endless questions about "the year without a summer." This title has been given to the year 1816.

Blodget, in his "Climatology of the United States," tells us that all the summers from 1811 to 1817 were cold in this country, and that in every month of the summers of both 1812 and 1816 snows and frosts occurred in the Northern States. It is the latter summer, however, that has lived in popular tradition. The year 1816 is known further as "poverty year," or "eighteen hundred and froze to death." It acquired the name of "mackerel year" in New Hampshire, where people ate mackerel as a substitute for pork, little of which was fattened on account of the extreme scarcity of corn. Western Europe, also, had a cold summer in 1816, and the year as a whole seems to have been a cold one over a great part of the world.

Sources of information about the cold summer in this country, besides Blodget's book above mentioned, include Perley's "Historic Storms of New England," which devotes a whole chapter to the subject, and Charles Peirce's "Weather in Philadelphia." Peirce tells us that at Philadelphia "there was ice during every month of the year, not excepting June, July, and August, There was scarcely a vegetable came to perfection north and east of the Potomac." According to the "Monthly Weather Review," citing the recollections of James Winchester, of Vermont: "It is said that in June of that year snow fell to the depth of three inches in New York, Pennsylvania, and New Jersey on the 17th; five inches in all the New England States, except three inches in Vermont. There was snow and ice in every month of this year. The storm of June 17 was as severe as any that ever occurred in the depth of winter; it began about noon, increasing in fury until night, by which time the roads were impassable by reason of snowdrifts; many were bewildered in the blinding storm and frozen to death.... There was a heavy snowstorm August 30th.... The year 1816 had neither spring, summer, nor autumn. The only crop of corn raised in that part of Vermont that summer was saved by keeping bonfires burning around the cornfield night and day."

At the time of its occurrence the frigid weather of the summer of 1816 was popularly attributed to sun spots, which were big enough to be seen with the naked eye in May and June. A present-day hypothesis on the subject has been mentioned in our chapter on atmospheric dust. The dust cloud from the eruption of Tomboro, in 1815, was so vast that for three days there was darkness at a distance of 300 miles from the volcano.

A proximate cause of the cold summer is perhaps to be sought in an unusual intensity and extent of the area of low barometric pressure which is more or less permanently located in the vicinity of Iceland and, as one of the principal atmospheric "centers of action," has a great deal to say about the weather of the countries adjacent to the North Atlantic. Dr. C. F. Brooks has called attention to the fact that the Arctic navigator, Scoresby, found unusually mild and open weather that summer in the seas east of Greenland. This would be explained by strong southerly winds, forming part of the "counter-clockwise" circulation around the Iceland low; and if the same pressure system extended its influence to our shores, persistent cold northwest winds might be expected to result over the northeastern United States.

7. INDIAN SUMMER AND THE ICE SAINTS

Indian summer *weather* is an undeniable fact. Every inhabitant of the northern United States and southern Canada is familiar with the mild, calm, hazy state of the atmosphere that frequently occurs in the autumn, sometimes following a brief period of unseasonable cold known as "squaw winter." It is, however, one thing to recognize the existence of a certain type of weather as characteristic of our autumns, and quite another to admit that one definite spell of such weather occurs more or less regularly from year to year. One true summer, and only one, comes to pass each year, and occupies an approximately fixed place in the calendar. Even the so-called "year without a summer," which we have just described, was merely a year in which the regular annual rise of the temperature curve was less marked than usual. Indian summer, on the contrary, has never been tied down to a particular part of a particular month. In his notes on the meteorological conditions at Concord, Massachusetts, during the ten years, 1851–1860, Thoreau records the occurrence of Indian summer weather on dates all the way from September 27 to December 13; a range of 77 days.

The belief in the definite occurrence, year after year, of what has sometimes been called the "after-summer" is not peculiar to America. It prevails also in Europe, where this supposed period of renewed warmth has been assigned to certain dates, owing in part to its association with the names of particular saints in the calendar. These dates vary widely, however, from one region to another, ranging from August 15 (Julian calendar), the beginning of the "young women's summer" of Russia, to November 15, St. Martin's day, a date popularly associated with after-summer in Germany, Holland, France, Italy, and sometimes England.

The supposed tendency of particular types of weather to occur at about the same period every year, independently of and often in sharp contrast to the regular march of the seasons, has been described by R. Abercromby under the name of "recurrence," and there is a large literature on the subject; especially in connection with periods of unseasonable temperature. While Indian summer is the most discussed example of recurrence in the American weather calendar, in the Old World more attention, both popular and scientific, has been devoted to a frosty period supposed to recur in May. With the elaboration of the ecclesiastical calendar, the frosts in question became definitely associated with the days dedicated to Saints Mamertus, Pancras, and Servatius (May 11, 12, 13), or, in south-central Europe, Saints Pancras, Servatius, and Boniface (May 12, 13, 14), hence known as the Ice Saints. These saints and their days are called in French *saints de glace*, and in German *Eisheiligen*, *Eismänner*, or *gestrenge Herren*.

Yet other examples of the elusive phenomenon of recurrence are the "January thaw" of New England, the April "blackthorn winter" of England, and the June "sheep-cold" (*Schafkälte*) of Germany, dangerous to newly shorn sheep.

In the middle of the last century the cold weather of the Ice Saints was variously ascribed to the melting of the ice and snow of high latitudes, the passage of periodic meteor showers between the earth and the sun, and other far-reaching terrestrial or cosmical causes. FitzRoy believed that the liberation of latent heat in autumn during the formation of ice in the circumpolar regions was accountable for Indian summer. A review of the whole body of literature concerning supposed recurrent irregularities in the annual march of temperature will be found in the "Monthly Weather Review"

(Washington) for August, 1919.

Whether recurrence, in Abercromby's sense of the term, is a real phenomenon is still an unsettled question. Many periods of unseasonable weather occur in the course of each year, and it is easy for the uncritical observer to identify one of them with the Ice Saints, another with Indian summer, and so on. About the best that meteorologists can do at present is to explain each particular instance of such weather by reference to barometric and other conditions shown on the daily weather map.

GLOSSARY

The vast vocabulary of meteorology is very inadequately represented in ordinary dictionaries, and has never been made the subject of a comprehensive special glossary. The writer of this book has been gathering material toward such a glossary for some years, and from the material now in hand it appears that an approximately complete English meteorological dictionary, embracing both scientific and nonscientific terms relating to the atmosphere and its phenomena, would contain upward of fifteen thousand definitions.

From this statement it will be evident that the brief glossary herewith appended is of the most fragmentary character. It includes only a selection of the *meteorological*terms found in the present book. It does not, in general, include terms pertaining primarily to physics, chemistry, astronomy, physiology, etc., even though they figure to some extent in meteorology, as all such terms used in the book are more or less satisfactorily defined in the latest editions of the large American dictionaries.

Absolute Extremes.—The highest and lowest values of a meteorological element (especially temperature) that have ever been recorded at a station; known, respectively, as the*absolute maximum* and the *absolute minimum*.

(The term is sometimes improperly applied to the highest and lowest values for a specified year.)

Aeroclinoscope.—A semaphore formerly used in Holland for displaying weather signals.

Aerology.—The branch of meteorology dealing with the "free" atmosphere; i. e., all parts of the atmosphere not near the earth's surface. Aerological investigations are made with kites and balloons, and also include observations of clouds, meteor trails, the aurora, etc.

Afterglow.—1. The glow in the western sky after sunset. 2. A renewal of rosy light on mountain peaks after the first sunset illumination has faded; also called *recoloration*. This is one stage of the *Alpenglow*.

After-summer.—A renewal of mild weather in the autumn; called Indian summer in America, St. Martin's summer, etc., in Europe.

Alpenglow.—Successive appearances and disappearances of rosy light sometimes seen on mountain peaks in clear weather after sunset or before sunrise.

Altimeter.—A barometer used for measuring altitude.

Alto-cumulus; *Alto-stratus*.—Forms of cloud. (See Chapter VI.)

Anemogram.—The record traced by a self-registering anemometer.

Anemometer.—An instrument for measuring the force or speed of the wind.

Aneroid Barometer.—A barometer consisting of a thin-walled metal vacuum-box, which changes its shape with changes of atmospheric pressure. The movements of the box are communicated, by levers, to an index or (in the barograph) to a recording pen.

Anthelion.—A rare species of halo, consisting of a brilliant, usually white image of the sun opposite the latter in azimuth. (This term has also been applied to the *glory*, q. v.)

Anticrepuscular Rays.—The continuation of the crepuscular rays converging toward a point in the sky opposite to the sun.

Anticyclone.—An area of high barometric pressure and its attendant system of winds. (Cf. *cyclone*.)

Antitrades.—Term formerly applied to the prevailing westerly winds of middle latitudes, but now more frequently applied to the westerly return-currents lying over the trade winds. Some writers prefer to call the former the *antitrades* and the latter the *countertrades*.

Antitwilight Arch.—The pink or purplish zone of illumination bordering the shadow of the earth (*dark segment*) in the part of the sky opposite the sun after sunset and before sunrise.

Arcs of Lowitz.—A pair of rare halo phenomena. These arcs are directed obliquely downward from the parhelia of 22 degrees on either side of the sun toward the halo of 22 degrees.

Astraphobia.—A pathological condition experienced by certain persons before and during thunderstorms.

Atmometer.—An instrument for measuring evaporation; also called *atmidometer*, *evaporimeter*, etc.

Aureole.—(See *corona*. 1).

Aurora.—A luminous phenomenon due to electrical discharges in the atmosphere; probably confined to the tenuous air of high altitudes. It is most commonly seen in sub-Arctic and sub-Antarctic latitudes. Called *aurora borealis* or *aurora australis*, according to the hemisphere in which it occurs. Observations with the spectroscope seem to indicate that a faint "permanent aurora" is a normal feature of the sky in all parts of the world.

"*Backstays of the Sun.*"—A sailor's name for crepuscular rays extending downward from the sun.

Baguio.—The name current in the Philippines for a tropical cyclone.

Ballistic Wind.—A military term applied to a fictitious wind which, if affecting a projectile throughout its flight, would produce the same total effect in deflecting it from its course and altering its range as do the various winds that it actually encounters.

Ballon-sonde.—A sounding-balloon.

Bar.—A unit of pressure equal to 1,000,000 dynes per square centimeter. A bar = 100 *centibars* = 1,000 *millibars*. A barometric pressure of one bar is sometimes called a "C. G. S. atmosphere," and is equivalent to a pressure of 29.531 inches of mercury at 32 degree F. and in latitude 45 degrees.

Barisal Gun.—Same as *brontide*.

Barocyclonometer.—One of several instruments that have been devised for locating tropical hurricanes without the aid of a weather map.

Barograph.—A self-registering barometer.

Barometer.—An instrument for measuring the pressure of the atmosphere. The two principal types are the *mercurial* and the *aneroid*. The *microbarometer* is used to show minute changes of pressure. Certain forms of hygroscope are popularly miscalled "barometers."

Barometer Well.—Same as *blowing well*.

Barometric Tendency.—The change of barometric pressure within a specified time (usually three hours) before one of the regular observations.

Beaufort Scale.—A scale of wind force, originally devised for use at sea, but now used also on land. The scale runs from 0 = calm to = hurricane. Many other scales are similarly employed in the noninstrumental observation of wind force.

Bioclimatic Law.—A phenological law, announced by Dr.

A. D. Hopkins, according to which periodical events of plant and animal life advance over the United States at the rate of 1 degree of latitude, 5 degrees of longitude, and 400 feet of altitude every four days—northward, eastward, and up-ward in spring, and southward, westward, and downward in autumn.

Bishop's Ring.—A large corona due to fine dust in the atmosphere. It has been seen after certain great volcanic eruptions, especially that of Krakatoa, in 1883.

Blizzard.—A violent, intensely cold wind, laden with snow.

Blowing Well.—A well which emits a strong current of air from any small opening in its cover during a fall of barometric pressure. During a rise of barometric pressure such wells are sometimes observed to "suck." Wells that are thus responsive to barometric changes are sometimes called "barometer wells" or "weather wells."

Bora.—A cold wind of the northern Adriatic, blowing down from the high plateaus to the northward. Also, a similar wind on the northeastern coast of the Black Sea.

Brave West Winds.—The boisterous westerly winds blowing over the ocean between latitudes 40 and 50 degrees S. This region is known as the "roaring forties."

Bright Segment.—The broad band of golden light that, in clear weather, borders the western horizon just after sunset and the eastern just before sunrise.

Brontide.—A sound resembling a distant muffled detonation, usually indefinite as to direction. Brontides are rather common in certain parts of the world. They are called *mistpoeffers* on the Belgian coast, *Barisal guns* in the Ganges delta, *bulldag*, *desert sounds*, or *Hanley's guns* in parts of Australia, *gouffre* in Haiti, *Moodus noises* at Moodus, Connecticut, *Nebelzerteiler*, *Seedonner*, *Seeschiessen*, etc., in Germany, *baturlio*, *boniti*, *bombiti*, etc., in Italy. These sounds are probably of subterranean origin in most cases.

Bump.—An upward jolt experienced by an aviator, as if running over an obstruction. A bump may be caused by any condition that suddenly increases the lift of the machine, but is perhaps most frequently due to rising air currents. Air in which bumps are experienced is said to be "bumpy." (Cf. *hole in the air*.)

Callina.—A Spanish name for dry fog.

Calms of Cancer; *Calms of Capricorn*.—The belts of high pressure lying north of the northeast trade winds and south of the southeast trade winds, respectively.

Center of Action.—Any one of several large areas of high and low barometric pressure, changing little in location, and persisting through a season or through the whole year; e. g., the Iceland low, the Siberian winter high, etc. Changes in the intensity and positions of these pressure systems are associated with widespread weather changes.

Ceraunograph.—A self-registering thunderstorm recorder.

Chinook, or *Chinook Wind*.—A foehn blowing down the eastern slopes of the Rocky Mountains over the adjacent plains, in the United States and Canada. In winter, this warm, dry wind causes snow to disappear with remarkable rapidity, and hence it has been nicknamed the "snow-eater." (Cf. *foehn*.) The "wet chinook" is a wind of a different character, blowing from the Pacific Ocean over the northwestern United States.

Circumscribed Halo.—A halo formed by the junction of the upper and lower tangent arcs of the halo of 22 degrees, when the luminary is about 40 degrees or more above the horizon. As the altitude of the luminary increases, the circumscribed halo gradually assumes an elliptical form and finally merges into the halo of 22 degrees.

Circumzenithal Arc.—A rainbow-tinted halo, often very bright, convex to the luminary and 46 degrees or a little more above it. It is sometimes called the *upper quasi-tangent arc of the halo of 46 degrees*, but the circumzenithal arc and the halo of 46 degrees are rarely seen at the same time.

Cirro-cumulus; *Cirro-stratus*; *Cirrus*.—Forms of cloud. (See Chapter VI.)

Cistern.—The cup, containing mercury, at the base of a mercurial barometer.

Climatography.—1. Descriptive and statistical climatology. 2. An account of the climate of a particular place or region.

Climatology.—1. The science of climate. 2. A body of knowledge concerning the climate of any place or region; as, "the climatology of Panama."

Climograph.—A diagram introduced by Dr. Griffith Taylor, of Australia, for showing the mean monthly values of wet-bulb temperature and relative humidity at any place, and for comparing such data as recorded at different places throughout the world; especially with reference to the effects of climate on mankind. Other pairs of elements can be used in constructing climographs: e. g., the dry-bulb temperature and the relative humidity.

Cloud-banner.—A bannerlike cloud streaming off from a mountain peak.

Cloud-burst.—A sudden and extremely heavy downpour of rain; especially one in which the water falls in a continuous stream rather than in drops. The term has been most commonly applied to downpours in mountainous regions.

Cloud-cap.—A caplike cloud crowning (1) a mountain summit, or (2) another cloud, especially a mass of cumulo-nimbus.

Col.—The neck of low pressure between two anticyclones; also called a *saddle*.

Cold Wave.—A rapid and marked fall of temperature during the cold season of the year. The United States

Weather Bureau applies this term to a fall of temperature in 24 hours equaling or exceeding a specified number of degrees and reaching a specified temperature or lower; the specifications varying for different parts of the country and for different periods of the year.

Collector.—A device used in measurements of atmospheric electricity for determining the potential gradient.

Continental Climate.—The type of climate characteristic of the interior of a continent. As compared with a marine climate, a continental climate has a large annual and daily range of temperature.

Corona.—1. A colored luminous circular area formed, by diffraction; around the sun, moon, or other source of light seen through clouds or dust haze. Coronas invariably show a brownish-red inner ring, which, together with the bluish-white inner field between the ring and the luminary, forms the so-called *aureole*. Most frequently the aureole alone is visible. Well developed coronas show one or more series of spectral colors outside the aureole. 2. A luminous circle formed by the apparent convergence of auroral beams about the place in the sky toward which the dipping-needle points.

Corposant.—(See *St. Elmo's fire*.)

Countertrades.—(See *antitrades*.)

Crepuscular Rays.—Beams of light radiating from the sun, seen both before and after sunrise and sunset. The beams are made visible by the presence of water-drops or dust in the atmosphere, and the intervening dark spaces are the shadows of clouds. The beams are actually parallel; their apparent divergence is the result of perspective.

Critical Period.—A period in the growth of a plant when it is especially susceptible to the effects of atmospheric conditions.

Cumulo-nimbus; *Cumulus*.—Forms of cloud. (See Chapter VI.)

Cyclone.—An area of low barometric pressure with its attendant system of winds. The cyclones of the region within the tropics (*tropical cyclones*) are violent storms; those of higher latitudes (*extra-tropical cyclones*) may be stormy or otherwise. Tropical cyclones are also called *hurricanes*, *typhoons* or *baguios*. Extra-tropical cyclones are commonly known as *lows* or *barometric depressions*.

Cyclonopathy.—The abnormal sensitiveness of certain persons to the weather changes attending the passage of barometric depressions.

Cyclonoscope.—A pasteboard dial formerly used in the West Indies for locating cyclones.

Dark Segment.—The shadow of the earth which, in clear weather, rises from the eastern horizon at sunset and sinks below the western horizon at sunrise.

Deperditometer.—An instrument devised by A. Piche for measuring the cooling power of the atmosphere, with reference to its physiological effects.

Depression.—A cyclonic area, or low.

Desert Sounds.—(See *brontide*.)

Devil.—The name applied to a dust whirlwind in India. The term is also current in South Africa.

Dew.—Atmospheric moisture condensed, in liquid form, upon objects cooler than the air, especially at night.

Dew-point.—The temperature at which, under ordinary conditions, condensation of water vapor begins in a cooling mass of air. It varies with the absolute humidity.

Dew Pond.—The name applied in southern England to certain artificial ponds on the uplands. They contain water in the driest weather, and are popularly supposed to be fed by dew.

"*Doctor.*"—A colloquial name for the sea breeze in tropical climates. The name is sometimes applied to other cool, invigorating breezes.

Doldrums.—The equatorial belt of calms or light, variable winds, lying between the two trade-wind belts.

Drought.—A protracted period of dry weather. In the United States a drought has been defined as a period of thirty or more consecutive days during which precipitation to the amount of 0.25 inch does not occur in twenty-four hours. Other quantitative definitions have been used in other countries.

Dry Fog.—A haze due to the presence of dust or smoke in the air.

Dust-counter.—An instrument for determining approximately the number of dust particles or condensation nuclei per unit volume in a sample of air.

Dynamic Meteorology.—The branch of meteorology that treats of the motions of the atmosphere and their relations to other meteorological phenomena.

Earth-air Current.—The electrical current that passes between the earth and the air on account of their difference of potential.

Eddy.—A more or less fully developed vortex in the atmosphere, constituting a local irregularity in a wind. All winds near the earth's surface contain eddies, which at any given place, produce "gusts" and "lulls." Air containing numerous eddies is said to be "turbulent."

Electric Niagara.—(See *hail rod*.)

Evaporimeter.—(See *atmometer*.)

Eye of the Storm.—A calm region at the center of a tropical cyclone, or a break in the clouds marking its location.

Fall Wind.—A wind blowing down a mountain-side; or any wind having a strong downward component. Fall Winds include the foehn, mistral, bora, etc.

False Cirrus.—Cirruslike clouds at the summit of a thundercloud; probably identical in structure with true cirrus, or cirro-stratus. Sometimes more appropriately called "thunderstorm cirrus."

Fata Morgana.—A complex form of mirage, characterized by marked distortion of images.

Festoon Cloud.—Mammato-cumulus.

Flashing Arcs.—Visible atmospheric sound waves, or explosion waves.

Flat.—Featureless; said of weather maps.

Foehn.—A dry fall wind warm for the season, characteristic of many mountainous regions. The air is cooled dynamically in ascending the mountains, but this leads to condensation, which checks the fall in temperature through the liberation of latent heat. The wind deposits its moisture as rain or snow. In descending the opposite slope it is strongly heated dynamically and arrives in the valleys beyond as a warm and very dry wind. Some writers apply this term to any wind that is dynamically heated by descent; e. g., the sinking air of an anticyclone.

Foehn-sickness.—Headache, lassitude, depression, etc., attributed, in the Alpine valleys, to the blowing of the foehn.

Foehn-wall (German: *Föhnmauer*).—A wall of cloud that forms along the crest of a mountain ridge over which the foehn is blowing.

Fog.—A cloud at or near the earth's surface. A fog and a cloud are identical in structure, though the former is due to thermal conditions of the earth's surface, while the latter is most frequently clue to the dynamic cooling of ascending air. In ordinary speech, the term "fog" generally implies an obscurity of the atmosphere sufficiently great to interfere with navigation or locomotion. (Cf. *dry fog.*)

Fogbow.—A rainbow, colorless or nearly so, formed in a fog.

Fog-drip.—Moisture that is deposited on terrestrial objects by fog, and drips from them to the ground.

Fracto-cumulus; *Fracto-nimbus*; *Fracto-stratus*.—Forms of cloud. (See Chapter VI.)

Freeze.—1. Freezing of plants without deposit of hoarfrost. 2. Freezing temperatures prevailing generally over a region; not exclusively nocturnal and not confined to the air close to the earth's surface. (Cf. *frost*.)

Frost.—1. The act or state of freezing. In America, a "frost" generally means the occurrence, near the beginning or end of the growing season, of nocturnal temperatures low enough to be injurious to vegetation; distinguished from a "freeze," which is more general and severe. The Weather Bureau classifies frosts, according to their effects, as "light," "heavy," and "killing." 2. Atmospheric moisture condensed upon terrestrial objects in the form of ice; sometimes frozen dew. Also called *hoarfrost*.

Frost-smoke.—Frozen fog rising from the water.

Fulgurite.—A glassy tube formed in sandy soil or in rock by the passage of lightning.

Garúa.—A wet fog of the west coast of South America.

Geocoronium.—The name applied by Dr. A. Wegener to a hypothetical atmospheric gas, supposed to be much lighter than any gas now known to chemists.

Glaze.—Term applied by the U. S. Weather Bureau to a smooth coating of ice on terrestrial objects due to the freezing of rain; often popularly called "sleet." In Great Britain such a deposit is called *glazed frost*. A deposit of glaze on an extensive scale constitutes an "ice storm."

Glory.—A series of concentric colored rings seen around the shadow of the observer, or of his head only, cast upon a cloud or fog bank. It is due to the diffraction of reflected light.

Gouffre.—(See *brontide*.)

Gradient.—Change of value of a meteorological element per unit of distance. The gradients commonly discussed in meteorology are the horizontal gradient of barometric pressure, the vertical gradient of temperature, and the vertical gradient of electric potential. British meteorologists now prefer the term *lapse-rate* to *vertical gradient*.

Graupel.—A kind of granular snow, sometimes called *soft hail*.

Green Flash.—A bright green coloration of the upper edge of the sun's disk, sometimes seen when the rest of the disk is below the horizon, at sunrise or sunset.

Growing Season.—In agricultural meteorology, the interval between the last killing frost in spring and the first killing frost in autumn.

Gust.—A sudden brief increase in the force of the wind. Most winds near the earth's surface are made up of alternate gusts and *lulls*, the majority of which are too brief to be registered by an ordinary anemometer.

Hail.—Balls or irregular lumps of ice, often of considerable size, having a complex structure; large hailstones generally have a snowlike center, surrounded by layers of ice, which may be alternately clear and cloudy. Hail falls al-most exclusively in connection with thunderstorms. For so-called "soft hail" see *graupel*. (Cf. *sleet*.)

Hail Rod.—A device analogous to a lightning rod, supposed to have the property of averting the fall of hail. Hail rods have been especially popular in France, where they are called *paragrêles*. Large hail rods of recent construction are known as "electric Niagaras."

Hail-shooting.—Bombarding the clouds to prevent the fall of hail.

Halo.—A generic name for a large group of optical phenomena caused by ice crystals in the atmosphere. The commonest of these phenomena is the *halo of 22 degrees* (i. e., of 22 degrees radius) surrounding the sun or moon. The *halo of 46 degrees* and the rare *halo of 90 degrees*, or *halo of Hevelius*, also surround the luminary. Other forms of halo are the *tangent arcs*, *parhelia* (*or paraselenæ*), *parhelic* (or *paraselenic*) *circle*, *anthelion*, etc.

Harmattan.—A dry, dusty wind of the west coast of Africa, blowing from the deserts.

Haze.—A lack of transparency in the atmosphere; sometimes due to irregularities in the density of the air (*optical haze*), sometimes to dust (*dust haze*, which when dense constitutes *dry fog*), sometimes to fine particles of water or ice (grading into true *fog*).

Helm and Bar.—A pair of clouds seen when the "helm wind" is blowing over Crossfell, an English mountain; the "helm" capping the mountain and the "bar" lying to leeward of it.

High.—An area of high barometric pressure; an anticyclone.

Hoarfrost.—(See *frost*.)

Hole in the Air.—A colloquial name for any condition in the atmosphere that suddenly decreases the lift of an aeroplane. (Cf. *bump*.)

Horse Latitudes.—The regions of calms and variable winds coinciding with the subtropical high-pressure belts lying on the poleward sides of the trade winds. (The term has generally been applied only to the northern of these two regions, in the North Atlantic Ocean, or to the portion of it near Bermuda.)

Hot Wave.—A period of abnormally high temperatures. It has sometimes been defined, in the United States, as a period of three or more consecutive days during each of which the maximum temperature is 90 degrees F. or over.

Hot Wind.—A hot, parching wind characteristic of certain continental interiors; especially Australia, northern India and the prairie region of the United States.

Humidity.—The degree to which the air is charged with water vapor; viz., the actual amount of water vapor present (*absolute humidity*, which may be expressed in terms of weight per unit volume or as vapor pressure), or the ratio which this amount bears to the maximum amount the air can contain at the prevailing temperature (*relative humidity*, expressed in percentage).

Hurricane.—A tropical cyclone; especially one of the West Indies region. (A cyclone originating in this region and passing northward into the temperate zone is still called a "West India hurricane," even after it has assumed the character of an extratropical cyclone, and, if sufficiently severe, justifies the display of "hurricane warnings" at ports of the United States. "Hurricane" is also the designation of the highest wind force on the Beaufort scale, and is thus applied to any wind exceeding about seventy-five miles an hour.)

Hygrograph.—A self-registering hygrometer.

Hygrometer.—Any instrument for measuring the humidity of the air.

Hygroscope.—A device that gives a rough indication of the relative humidity of the air. Most hygroscopes are mere toys.

Ice Rain.—1. A rain that causes a deposit of glaze. 2. Falling pellets of clear ice (called *sleet* by the U. S. Weather Bureau).

Ice Saints.—A period of cold weather popularly reputed in Europe to occur yearly about May 11–13 (or, in south-central Europe, May 12–14); also, the saints whose days in the ecclesiastical calendar fall on these dates.

Ice Storm.—(See glaze.)

Ignis Fatuus.—Will-o'-the-wisp. (See Chapter XXII.)

Indian Summer.—A period of mild, calm, hazy weather occurring in autumn or early winter, especially in the United States and Canada; popularly regarded as a definite event in the calendar, but weather of this type is really of irregular and intermittent occurrence. (Cf. *St. Martin's Summer*.)

Instrument-shelter.—The American name of the cage or screen in which thermometers are exposed at meteorological stations. Called *thermometer-screen* in Great Britain.

Inversion.—More fully *temperature inversion*; an increase of air temperature with increase of altitude, instead of the normal decrease.

Ion-counter.—An instrument for determining the number of ions present, per unit volume, in a sample of air.

Isobar.—A line of equal barometric pressure. (Isobars are generally drawn on maps to show the horizontal distribution of pressure reduced to sea level, or the pressure at some specified altitude; but in a broader sense any line on a chart or diagram drawn through places of equal pressure is an isobar.)

Isohyet.—A line of equal rainfall.

Isotherm.—A line of equal temperature.

Isothermal Layer.—(See *stratosphere*.)

January Thaw.—A period of mild weather popularly supposed to recur each January, especially in New England.

Katathermometer.—A device consisting of a dry-bulb and a wet-bulb thermometer, designed for measuring the cooling power of the atmosphere, with reference to its physiological effects. It was invented by Leonard Hill.

Kiosk.—The name given by the U. S. Weather Bureau to a small street pavilion in which are displayed meteorological instruments, maps, tables, etc.

Land and Sea Breezes. Land and Lake Breezes.—The breezes that, on certain coasts and under certain conditions, blow from the land by night and from the water by day.

Lenticular Cloud.—A cloud having approximately the form of a double-convex lens, marking the position of a standing wave in the atmosphere. (See Chapter VI.)

Lightning.—A disruptive electrical discharge in the atmosphere, or, generally, the luminous phenomena attending such a discharge. The various forms of lightning are named and described in Chapter IX.

Lightning Print.—A collection of marks, often treelike in form, sometimes found on the body of a person or animal that has been struck by lightning.

Lightning Rod.—A metallic rod, connected with a suitable "ground," in earth or water, set up for the purpose of protecting some structure from lightning.

Light-pillar.—A form of halo, consisting of a column of light, vertical or nearly so, extending from or through the sun or moon. Called a *sun-pillar*, or a *moon-pillar*, as the case may be.

Line-squall.—A more or less continuous line of squalls and thunderstorms traveling broadside over the country.

Looming.—An apparent elevation of distant objects by mirage.

Low.—An area of low barometric pressure, with its attendant system of winds. Also called a *barometric depression* or *cyclone*.

Mackerel Sky.—An area of sky covered with cirro-cumulus clouds; especially when the clouds resemble the patterns seen on the backs of mackerel.

Mammato-cumulus.—A form of cloud showing pendulous sacklike protuberances. (See Chapter VI.)

March.—The variation of a meteorological element in the course of a day, year, or other interval of time; e. g., the diurnal march of temperature; the annual march of barometric pressure.

Mares'-tails.—Cirrus in long slender streaks.

Marine Climate.—A type of climate characteristic of the ocean and oceanic islands. Its most prominent feature is equability of temperature.

Meteorograph.—Autographic apparatus for recording simultaneously two or more meteorological elements. Certain types of meteorograph are connected, electrically or otherwise, with some of the instruments at meteorological stations; others are sent aloft attached to kites and balloons.

Meteorology.—The science of the atmosphere.

Millibar.—(See *bar*.)

Mirage.—An apparent displacement or distortion of distant objects by abnormal atmospheric refraction. Sometimes the images of objects are inverted, multiplied, etc.

Mist.—Generally, a wet fog or a very fine drizzle of rain; hence the expression, "it is misting." The "Scotch mist" of mountainous or hilly regions is a combination of thick fog and heavy drizzle; it has been suggested that this occurs when the rain clouds actually rest on the earth.

Mistpoeffer.—(See *brontide*.)

Mistral.—Along the Mediterranean coast, from the mouth of the Ebro to the Gulf of Genoa, a stormy, cold northerly wind, blowing down from the mountains of the interior. (The name is sometimes applied to northerly winds on the Adriatic, in Greece, and in Algeria.)

Monsoon.—A wind that reverses its direction with the season, blowing more or less steadily from the interior of a continent toward the sea in winter, and in the opposite direction in the summer.

Moon Dog.—A paraselene.

Mountain and Valley Breezes.—The breezes that, in mountainous regions, normally blow up the slopes by day (*valley breeze*) and down the slopes by night (*mountain breeze*).

Nephoscope.—An instrument for measuring the movements of clouds.

Nieve Penitente.—Fields of pinnacled snow found on certain high mountains in tropical or subtropical regions.

Nimbus.—The rain cloud. (See Chapter VI.)

Noctilucent Clouds.—Luminous, cirruslike clouds sometimes visible throughout the short nights of summer; supposed to be clouds of dust at great altitudes shining with reflected sunlight. Such clouds were observed during several summers after the eruption of Krakatoa (1883) and are still occasionally reported.

Normal.—The average value which, in the course of years, any meteorological element is found to have on a specified date or during a specified month or other portion of the year, or during the year as a whole. Also used as an adjective in such expressions as "normal temperature," etc. Thus, for any station at which records have been maintained for many years, we may compute the normal temperature of January 1, the normal pressure of February, the normal rainfall of the year, etc. The normal serves as a standard with which values occurring in a particular year may be compared in order to determine the *departure from the normal*.

Nucleus.—A particle upon which condensation of water vapor occurs in the free atmosphere in the form of a water drop or an ice crystal.

Oblique Arcs of the Anthelion.—A rare form of halo, consisting of intersecting arcs, usually white, passing through the anthelion or the place where the anthelion would occur if visible.

Ozone.—An allotropic form of oxygen, which occurs transiently in small quantities in the lower atmosphere, and is supposed to be permanently present and relatively abundant at high atmospheric levels.

Painter.—A dirty fog frequently experienced on the coast of Peru. The brownish deposit from it is sometimes called "Peruvian paint."

Paragrêle.—A hail rod.

Paranthelion.—A halo phenomenon similar to a parhelion, but occurring at a distance of 90 degrees or more in azimuth from the sun. The solar distance of the ordinary paranthelia is 120 degrees. (Analogous phenomena produced by the moon as source of light are called *parantiselenæ*.)

Paraselene.—(Plu. *paraselenæ*.) (See *parhelion*.)

Paraselenic Circle.—(See *parhelic circle*.)

Parasitic Clouds.—The name formerly given to clouds capping the summits of mountains.

Parhelic Circle.—A halo consisting of a white circle passing through the sun and parallel to the horizon. A similar phenomenon in connection with the moon is called a *paraselenic circle*.

Parhelion.—A mock sun, or sun dog; a form of halo consisting of a more or less distinctly colored image of the sun at the same altitude as the latter above the horizon, and hence lying on the parhelic circle, if present. The ordinary parhelia are 22 degrees from the sun in azimuth, or a little more, according to the altitude of the luminary. Parhelia have occasionally been seen about 46 degrees from the sun. Analogous phenomena seen in connection with the moon are called *paraselenæ*, *mock moons*, *or moon dogs*.

Penetrating Radiation.—A form of radiation that has the property of passing through a great extent of air without being absorbed and of ionizing the air inside hermetically sealed metal vessels. It is supposed to consist of a special kind of Gamma rays and to come from the higher levels of the atmosphere.

Phenology.—The study of the periodic phenomena of animal and plant life and their relations to weather and climate.

Photochemical Climate.—The chemical activity of sunlight characteristic of any place or region. The variations of this feature of solar radiation are more or less strikingly different from those of solar heat and the brightness of solar light. Certain types of "chemical actinometer" are used in its measurement.

Pilot Balloon.—A small free balloon the drift of which, as observed from the ground, indicates the movements of the air aloft.

Pocky Cloud.—Mammato-cumulus.

Pogonip.—A fog, composed of fine needles of ice, which occurs in mountainous regions of the western United States and is reputed to be very injurious to the lungs.

Pollution Gauge.—A gauge for measuring soot and other impurities found in the atmosphere.

Pontias.—A wind that blows by night from a narrow valley at Nyons, France.

Potential Gradient.—(See *gradient*.)

Precipitation.—The collective name for deposits of atmospheric moisture in liquid and solid form, including rain, snow, hail, dew, hoarfrost, etc.

Pressure.—An elliptical expression, current in meteorological literature, for *atmospheric pressure*, or *barometric pressure*.

Prevailing Westerlies.—The belts of winds lying on the poleward sides of the subtropical high-pressure belts.

Psuchrainometer.—An instrument devised by J. R. Milne for measuring the cooling power of the atmosphere with reference to physiological effects.

Psychrometer.—An instrument for measuring atmospheric humidity, consisting usually of a *dry-bulb thermometer* and a *wet-bulb thermometer*. The former is an ordinary mercurial thermometer. The latter has its bulb covered with muslin or other fabric, which is either permanently wet or is wetted before use. In some psychrometers there is only one thermometer, readings being taken both before and after moistening the bulb.

Purple Light.—The purple or rosy glow observed over a large area of the western sky after sunset and the eastern sky before sunrise; it lies above the *bright segment* that borders the horizon.

Pyrheliometer.—An instrument that measures solar radiation by its heating effects.

Qobar.—A dry fog or heat haze of the upper Nile region. (Also spelled *kobar* and *gobar* and occasionally applied to a hazy condition of the atmosphere in other parts of the world.)

Rain Balls.—Mammato-cumulus.

Rainbow.—A luminous arc formed by the refraction and reflection of light in drops of water. (See Chapter X.)

Rainfall.—A term sometimes synonymous with *rain*, but most frequently used in reference to amounts of precipitation (including snow, hail, etc.).

Rain Gauge.—An instrument for measuring rainfall.

Rain Tree.—A mythical tree which is alleged to exude copious showers of water even in the driest weather. ("Rain tree" is also the common name of an ornamental tree variously known to botanists as *Albizzia saman*, *Pithecolobium saman*, *Enterolobium saman*, and *Samanea saman*.)

Recoloration.—(See afterglow.)

Recurrence.—The alleged tendency of any particular type of weather to occur at about the same period every year, independently of and generally in contrast to the regular march of the seasons.

Refraction.—*Astronomical refraction.* Change in the apparent position of a heavenly body, due to atmospheric refraction. *Terrestrial refraction.* Change in the apparent position of distant terrestrial objects, due to the same cause.

Relative Wind.—In aeronautics, the motion of the air with reference to an aeroplane or airship moving through it.

Réseau.—A collection of meteorological stations operating under a common direction, or in the same territory. An *international réseau* is a group of stations in different countries cooperating for any purpose. The *Réseau mondial* is a world-wide system of selected stations, the observations of which may be utilized in studies of the meteorology of the globe.

Rime.—1. Hoarfrost. 2. A rough or feathery coating of ice deposited on terrestrial objects by fog. (The second meaning is the one now used in technical literature.)

Roaring Forties.—(See brave west winds.)

Saddle.—(See col.)

Saint Elmo's Fire.—A luminous brush discharge of electricity from elevated objects, such as the masts and yardarms of ships, lightning rods, steeples, etc., occurring in stormy weather. Also called corposant.

St. Martin's Summer.—One of several names given in Europe to a mild period in autumn, corresponding approximately to the Indian summer of North America.

Scarf Cloud.—A thin cirruslike cloud which often drapes the summits of tall cumulo-nimbus clouds.

Scotch Mist.—(See mist.)

Scud.—Shreds or small detached masses of cloud moving rapidly below a rain cloud or other heavy clouds.

Sea Breeze.—(See *land and sea breezes*.)

Secondary.—A small cyclone developed, or tending to develop, on the border of a large one.

Sensible Temperature.—The temperature felt at the surface of the human body; formerly identified, by some authorities, with the temperature indicated by the wet-bulb thermometer.

Silence, Areas, Zones, or Regions of.—Regions within which a sound is not heard, though heard in regions more distant from the source.

Silver Thaw.—A term variously applied to rime, glaze, and a thin coating of ice deposited on cold objects by a damp wind.

Simoom.—An intensely hot and dry wind of Asian and African deserts; often described as a sand storm or dust storm, but certain authorities state that the typical simoom is free from sand or dust.

Sirocco.—A name applied to various types of warm wind in the Mediterranean region. Some of these siroccos are foehns. The term is also used as the generic name for winds blowing from a warm region toward an area of low pressure in a normally colder region.

Sleet.—1. Frozen or partly frozen rain; frozen raindrops in the form of particles of clear ice. 2. Snow and rain falling together. (Other definitions have been proposed and the proper technical application of this term is still a subject of controversy. In popular and engineering use the word is often applied to a coating of glaze on trees, wires, rails, etc.)

Snow Bin.—A large receptacle for collecting the snowfall of an entire winter, or other long period, for measurement at one time.

Snow Garland.—An elongated mass of snow suspended at the ends and sagging in the middle.

Snow Mushroom.—An overhanging cap of snow resting on a tree stump, post, or the like.

Snow Roller.—A mass of snow rolled by the wind; generally muff-shaped.

Snow Sampler.—A device for collecting a sample of snow, cut vertically through a snowfield, for the purpose of determining the depth and density of the snow.

Snow Survey.—A measurement of the total amount of snow lying over a particular area, especially with a view to determining the total amount of water it will yield, when melted, for purposes of irrigation, etc.

Soft Hail.—Graupel.

Sounding Balloon.—A free, unmanned balloon carrying a set of self-registering meteorological instruments.

Specter of the Brocken.—The shadow of an observer and of objects in his immediate vicinity cast upon a cloud or fog bank; sometimes attended by a series of colored rings, called the *glory* or *Brocken-bow*.

Squall.—1. A sudden storm of brief duration; closely akin to a thunderstorm but not necessarily attended by thunder and lightning. 2. A sudden brief blast of wind, of longer duration than a gust.

Squaw Winter.—In North America, a brief cold spell popularly reputed to precede Indian summer.

Static.—(See *stray*.)

Storm Card.—A device intended for use on shipboard in determining the direction of a storm center from the ship.

Storm Water.—The water resulting from a heavy and rapid fall of rain; especially the portion that occurs as run-off. (The term has been used mainly in connection with the subject of sewers.)

Strato-cumulus.—A form of cloud. (See Chapter VI.)

Stratosphere.—The upper region of the atmosphere, formerly called the *isothermal layer*, in which there is no marked or systematic decrease of temperature with altitude. The stratosphere is free from clouds (except occasional dust clouds) and from strong vertical air currents, and its circulation appears to be more or less independent of that of the lower atmosphere. The height of its base, which varies with latitude and otherwise, averages between 6 and 7 miles. (Cf. *troposphere*.)

Stray.—A natural electromagnetic wave in the ether. The term is used in reference to the effects of such waves in producing erratic signals in radiotelegraphic receivers. Strays are known collectively as *static*.

Summer Day.—A day in which the temperature reaches or exceeds 77 degrees F.

Sun Dog.—A mock sun or parhelion.

"*Sun Drawing Water.*"—The sun popularly said to be "drawing water" when crepuscular rays extend down from it toward the horizon.

Sunshine Recorder.—An instrument for recording the duration of sunshine; certain types also record the intensity of sunshine.

Synchronous Chart.—A form of synoptic chart, such as the ordinary weather map, which shows the meteorological conditions prevailing over any area at a given moment of time.

Synoptic Chart.—A chart showing the distribution of meteorological conditions over an area at a given moment or the average conditions during a given period of time, such as a month or a year.

Table-cloth.—A sheet of cloud that sometimes spreads over the flat top of Table Mountain, near Cape Town.

Tangent Arc.—Any halo that occurs as an arc tangent to one of the heliocentric halos.

Term Hours.—Prescribed hours for taking meteorological observations.

Thermal Belt.—A well-defined zone, found on some mountain-sides, in which vegetation is particularly exempt from frosts in spring and autumn. Also called *verdant zone*.

Thermograph.—A self-registering thermometer.

Thermometer.—An instrument for measuring temperature; in meteorology, generally the temperature of the air. *Maximum* and *minimum thermometers* indicate, respectively, the highest and lowest temperatures occurring between the times of setting the instruments. A *wet-bulb thermometer* is used in measuring humidity. (See *psychrometer*.)

Thermometer Screen.—A cage, or sometimes merely a roof, for protecting thermometers from direct sunshine and other radiation that would cause the readings to indicate a temperature different from that of the air. In the United States generally called an *instrument shelter*.

Thunder.—The sound produced by a lightning discharge.

Thunderstorm.—A storm attended by thunder and lightning. Thunderstorms are local disturbances, often occurring as episodes of cyclones, and, in common with squalls, are marked by abrupt variations in pressure, temperature, and wind.

Thunderstorm Recorder.—Any device that furnishes a record of thunderstorms, either near or distant. Most thunderstorm recorders register, by radiotelegraphy, the strays set up by lightning discharges.

Tornado.—1. A violent vortex in the atmosphere, usually attended by a pendulous, more or less funnel-shaped cloud. 2. In West Africa: A violent thundersquall.

Totalizer.—A form of snow gauge used chiefly in the Alps, designed to be read only once a year. (French, *totalisateur*.)

Trade Winds.—Two belts of winds, one on either side of the equatorial doldrums, in which the winds blow almost constantly from easterly quadrants.

Troposphere.—The part of the atmosphere lying below the stratosphere.

Trough.—1. A line drawn at right angles to the path of a cyclonic area through all points at which the pressure has reached a minimum and is about to rise. 2. An elongated area of low barometric pressure.

Twilight.—*Astronomical twilight* is the interval between sunrise or sunset and the total darkness of night. *Civil twilight* is the period of time before sunrise and after sunset during which there is enough daylight for ordinary outdoor occupations.

"*Twister.*"—A tornado; also, a small whirling dust storm.

Typhoon.—The name applied in the Far East to a tropical cyclone.

Ulloa's Ring.—1. A glory. 2. A halo (also called *Bouguer's halo*) surrounding a point in the sky diametrically opposite the sun; sometimes described as a "white rainbow."

Vane.—A device that shows which way the wind blows; also called *weather vane* or *wind vane*.

Variability.—*Interdiurnal variability* is the mean difference between successive daily means of a meteorological element.

Verdant Zone.—(See *thermal belt*.)

Visibility.—The transparency and illumination of the atmosphere as affecting the distance at which objects can be seen. It is often expressed on a numerical scale. (This term was formerly applied by British meteorologists to a state of unusual clearness of the atmosphere, regarded as a weather prognostic.)

V-shaped Depression.—A trough of low barometric pressure bounded on the weather map by V-shaped isobars.

Waterspout.—A tornadolike vortex and cloud occurring over a body of water.

Weather Well.—(See *blowing well*.)

Wedge.—A wedge-shaped area of high barometric pressure.

Wet-bulb thermometer.—(See *psychrometer*.)

Wind.—Moving air; especially a mass of air having a common direction of motion. The term is generally limited to air moving horizontally, or nearly so; vertical streams of air are usually called "currents."

Wind Aloft.—The wind blowing at high levels as distinguished from that near the earth's surface.

Wind Rose.—1. A diagram showing the relative frequency and sometimes also the average strength of the winds blowing from different directions in a specified region. 2. A diagram showing the average relation between winds from different directions and the occurrence of other meteorological phenomena.

Winter Day.—A day on which the temperature does not at any time rise above the freezing point.

Wool-pack Cloud.—Cumulus.