to be dynamic rather than static. It is hard to conceive of a quiescent electron.

William Albert Noyes

SOME RECENT CONTRIBUTIONS TO THE PHYSICS OF THE AIR. II

BAROMETRIC FLUCTUATIONS

Another meteorological phenomenon that has been the subject of numerous investigations, is the pressure of the atmosphere. This pressure undergoes many changes, and the causes of some of them, such as its variations between summer and winter, and between ocean and continent, have long been known. But the causes of certain others, notably the great changes that accompany cyclones and anticyclones, have not yet been fully determined. Neither of these classes of changes, that is, those whose causes have long been known, and those whose causes still remain partially obscure, will be discussed here, though each is important and full of interest. But there are two other classes, namely, barometric ripples, and the pressure wave of semidiurnal period, that, because of their obvious interest to physicists, will be briefly considered.

Barometric "Ripples."—Small pressure changes having amplitudes usually of 0.1 mm. to 0.3 mm. and periods of 5 minutes to 10 minutes, and continuing for hours or even days together, are very common during cold weather. They are not greatly different in magnitude from the well known wind effects on the barometer, but obviously of different origin since their amplitude has no relation to the local wind velocity.

Their explanation appears to lie in the fact that whenever layers of air that differ in density at their interface flow over each other, long billows, analogous to water waves, and generated in the same way, are produced. If, now, the under layer is colder than the upper, as it is during the radiation or surface inversions of winter, and rather shallow, 100

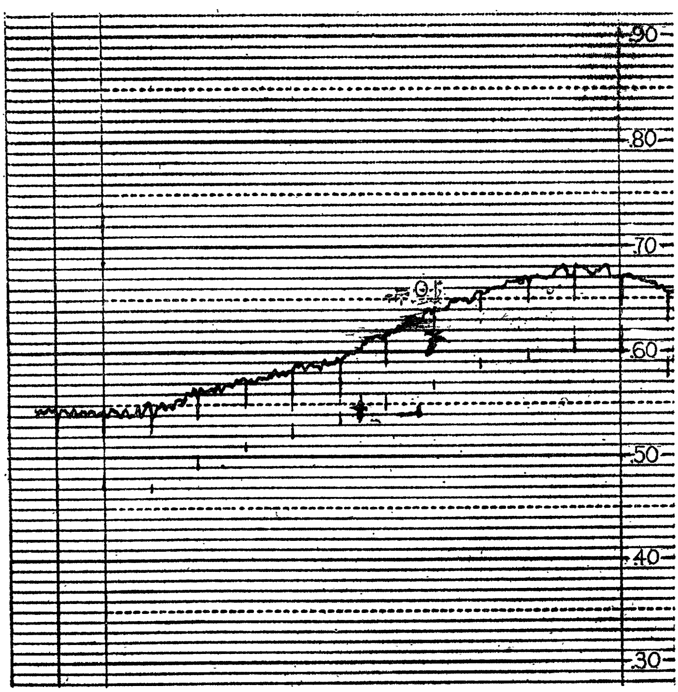

Fig. 4. Barometric Ripples.

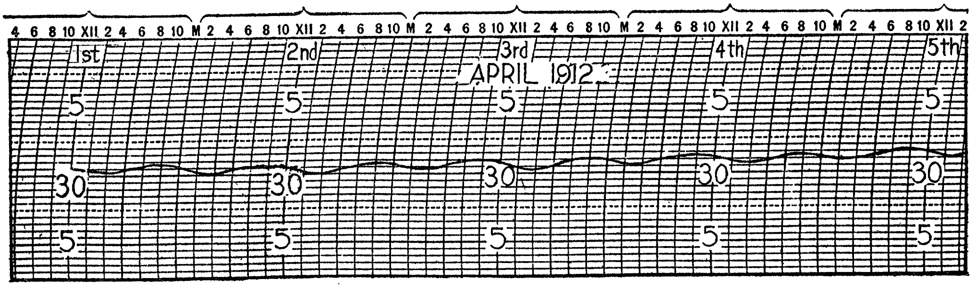

FIG. 5. Balogram, Grand Turk Island, West Indies.

meters to perhaps 500 meters thick, the passage of the air billows, like the passage of waves in shallow water, necessarily produces greater or less corresponding changes in the pressure on the bottom—changes that, as shown in Fig. 4, appear as a series of ripples in the record of a sensitive barograph.

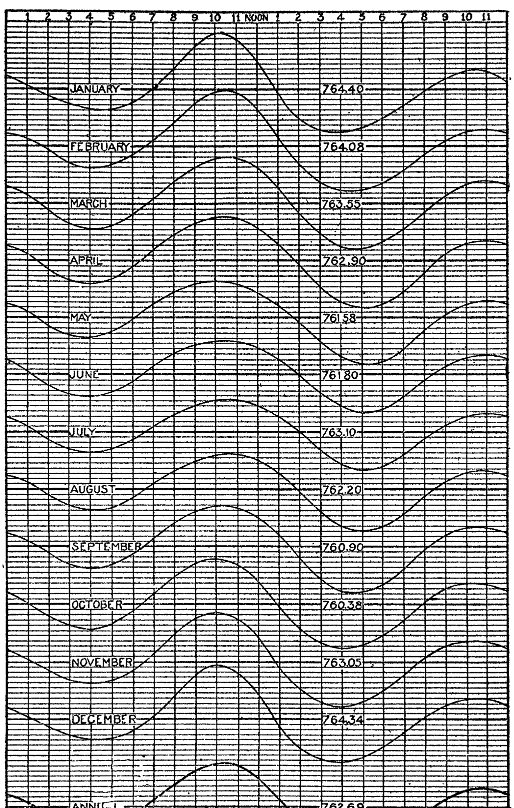

FIG. 6. Average daily barometric curves, Key West, Florida.

During the summer, when air billows rarely form near the surface, though frequently at greater altitudes, especially that of the cirrus cloud, barometric ripples do not appear. This, doubtless, is because wave disturbances in air, as in water, do not penetrate far beneath the wave level.

Semidiurnal Pressure Changes.—It has been known now for more than two and a half centuries that there are approximately regular daily variations in the height of the barometer that culminate in two maxima and two minima in the course of twenty-four hours. During particularly calm weather these fluctuations are conspicuous on the current barogram, as shown in Fig. 5, obtained at Grand Turk Island, West Indies, and always revealed by averages, no matter how masked by storm conditions, as shown by Fig. 6, based on records, covering fourteen years, at Key West, Fla.

Although, as stated, this phenomenon of the semidiurnal variation of the atmospheric pressure has been familiar almost since the invention of the mercurial barometer, and although repeatedly studied, its cause or causes remained until quite recently wholly unknown.

Some of the observed facts in regard to this twelve-hour cyclic change of pressure are:

(*a*) The maxima occur at, roughly, 10 o'clock A.M. and 10 o'clock P.M.

(*b*) The minima occur at, roughly, 4 o'clock A.M. and 4 o'clock P.M.

(*c*) The amplitude, when other things are substantially equal, varies with place approximately as the square of the cosine of the latitude.

(*d*) The amplitude is everywhere greatest on equinoxes and everywhere least on solstices.

(*e*) The amplitude is greater at perihelion than at aphelion.

(*f*) The amplitude is greater by day than by night.

(*g*) The amplitude is greatest on clear days and least on cloudy days.

(*h*) The day amplitude is greater over land than over water.

(*i*) The night amplitude is greater over oceans than over continents.

(*j*) Over the tropical Pacific Ocean the forenoon maximum is about 1 mm. above, and the afternoon minimum 1 mm. below the general average pressure.

Taken together these facts compel the conclusion that the daily cyclic pressure changes are somehow the results of temperature changes. Many efforts have been made to find just how the two are connected—how, for instance, a diurnal change in temperature can produce a semidiurnal change in pressure, but until recently without much success. To be sure, the diurnal temperature curve is not a simple sine curve of twenty-four hours period, and, like any other curve, can be closely duplicated by a series of superimposed sine curves of proper amplitudes and periods. But this is far from satisfying to the average physicist, and particularly so if he has not yet seen by what process the actual unanalyzed temperature changes can produce corresponding pressure variations in the open atmosphere. Of course it may be argued that there must always be a flow of air from the warmer to the colder regions, and, therefore, a pressure wave of diurnal period perpetually sweeping around the earth. Such a wave does indeed appear in the analyzed data. And as the temperature curve yields sine waves of twenty-four hours, twelve hours, eight hours and other periods, so, therefore, may the pressure curve also. But while this may be a portion of the story, it certainly is not the whole of it. There are other and important connections between temperature changes and pressure variations that must be considered; and these indeed seem to be the chief factors in producing the semidiurnal pressure wave.

One of these factors is vertical convection, first suggested, but never adequately developed, by Cleveland Abbe. Indeed, it appears to be the principal cause of the forenoon maximum as the following consideration shows:

Let the mass m of air be near the ground and have the horizontal velocity v, and let the larger mass M be at a higher elevation and have the greater velocity V in the same direction. If now these two masses should mingle in such manner as to be free from all disturbance, except their own mutual interference, the resulting final velocity, U, in the same direction, would be given by the equation

$$U = \frac{mv + MV}{m + M}$$

and there obviously would be no check in the total flow—no damming up and consequent increase of pressure. But this simple mixing of the two masses is by no means all that happens in the case of vertical convection. The rise of the mass m is simultaneously accompanied by an equivalent descent of air from a higher level, which in turn loses velocity, directly or indirectly, by surface friction. If the falling mass is also m, and if its velocity is reduced by friction to v, then from a single interchange, due to vertical convection, the total momentum becomes

$$2\,mv + (M - m)V$$

and the total flow is reduced by the amount

$$m(V - v).$$

But as this is for a single interchange, it is obvious that the more active vertical convection becomes, the greater will be its interference with the flow of the atmosphere, the more the winds will be dammed up, and the higher the barometric pressure. As convection increases, reaches a maximum, and then decreases, so, too, will the resulting interference go through the same changes.

Now the general movement of the atmosphere is from east to west within the tropics and from west to east at higher latitudes. Therefore in either case such damming up of the air as vertical convection may produce will be essentially along meridians, and thus a function of the time of day. But, in general, convection increases most rapidly during the forenoon, say eight to nine o'clock, is most active at ten to eleven o'clock, and reaches its greatest elevation about four o'clock in the afternoon. Hence the damming up of the atmosphere, due to vertical convection, and the resulting increase of barometric pressure must increase most rapidly during the forenoon, and come to a maximum about ten o'clock. After this the convectional interference decreases, while at the same time the amount of air in a vertical column of fixed cross-section diminishes as a result of expansion and overflow, until at about four o'clock in the afternoon the barometric pressure has, as a result of this overflow, reached a minimum.

To form some idea of the magnitude of the barometric change due to convectional turbulence, consider the atmosphere between two parallels of latitude near the equator. This limited quantity may be regarded as a stream flowing around the earth, having its minimum velocity and maximum depth where convectional interference is greatest, and maximum velocity with minimum depth where convection is absent. And since the linear velocity of a point on the equator is approximately 28 kilometers per minute, while during the forenoon the rate of increase of the barometric pressure at the same place is, roughly, 0.2 mm. per hour, it follows that a damming up, or check in the flow, of the given stream at the rate of 0.44 kilometers per hour would be sufficient of itself to account for the observed rise in the barometer. But if the average velocity of the wind, or flow of the stream in question, is 10 meters per second, which it may well be, the rate of decrease in velocity requisite for the given rate of pressure increase could be produced by having only 1 part in 80 of the whole superincumbent atmosphere brought to rest per hour, or the equivalent thereof, an amount that perhaps is reasonable. At any rate, the assumed velocity decrease is of the same order of magnitude as that observed to take place during, and as the result of, diurnal convection.

It appears then:

(*a*) That the afternoon minimum is caused essentially by overflow from the region where the atmosphere is warmest, or better, perhaps, from the meridian along which the temperature increase has been greatest, toward that meridian along which there has been the greatest decrease in temperature.

(*b*) That vertical convection interferes with the free horizontal flow of the atmosphere and to that extent dams it up and correspondingly increases the barometric pressure; also, that the time of this interference agrees with the forenoon changes of the barometer, and that its magnitude is of about the proper order to account for the forenoon barometric maximum.

The afternoon barometric minimum and the forenoon maximum, therefore, are to be regarded as effects of temperature increase; the minimum as due to expansion and consequent overflow; the maximum as caused by vertical convection and consequent interference with the free circulation of the atmosphere.

The forced afternoon minimum would occur in an otherwise stagnant atmosphere, and substantially as at present; but not so with the forced forenoon maximum, since the interference or damming effect depends upon a flow or circulation of the atmosphere, parallel roughly to the equator.

It remains now to account for the night ten o'clock maximum and four o'clock minimum, both of which appear to depend upon the natural or free vibration of the atmosphere as a whole.

This subject has been discussed by several mathematical physicists of great eminence. The latest and most complete of these discussions is by Lamb, who concludes:

> Without pressing too far conclusions based on the hypothesis of an atmosphere uniform over the earth, and approximately in convective equilibrium, we may, I think, at least assert the existence of a free oscillation of the earth's atmosphere, of "semidiurnal" type, with a period not very dif-

ferent from, but probably somewhat less than, twelve mean solar hours.

Hence any cause of pressure change, having a semidiurnal period or approximately so, would, if of sufficient magnitude and proper phase, account for the twelve-hour barometric curve. All that is needed, apparently, to give the semidiurnal pressure curve is a pressure impulse of the same period, twelve hours, as that of the free vibration of the atmosphere as a whole. And this is furnished by the forced forenoon barometric maximum, followed six hours later at the same place by the forced afternoon barometric minimum. In other words, taken together, the forenoon and afternoon forced disturbances appear to occur with the proper time-interval necessary to set up and maintain the twelve-hour free vibrations of the atmosphere.

The course of events at each locality appears to be substantially as follows:

1. A forced forenoon compression of the atmosphere, followed by its equally forced afternoon expansion, the two together forming one complete barometric wave, with a ten o'clock maximum and a four o'clock minimum, in harmony with the free vibration of the entire atmospheric shell.

2. Non-disturbance through the night or during the time of a single free vibration.

3. Repetition the following day of the forced disturbance in synchronism with, and therefore at such time as to reenforce, the free vibrations.

The series of disturbances is continuous, forced by day and free by night, but the resulting amplitudes of the barometric changes are limited, through friction and through the absence of perfect synchronism, to comparatively small values. Each point upon the atmospheric shell receives at every alternate swing a forced impulse in phase with the free vibration, and therefore at such time and in such manner as indefinitely to maintain the vibrations of the atmosphere as a whole.

The forenoon maximum and the afternoon minimum are primary disturbances equally forced but in different ways by the daily increase of temperature, while the evening maximum and the morning minimum are secondary disturbances caused by the joint action of the forced primaries through the twelve-hour free vibration of the atmosphere. In short, the semidiurnal swing of the barometer is a result of merely fortuitous circumstances—of the fact that the mass of the atmosphere happens to be such that the period of its free vibration is approximately just one half that of the earth's rotation.

ATMOSPHERIC ELECTRICAL PHENOMENA

The selected contributions to the physics of the air just reviewed belong to the domains of mechanics and thermodynamics. But there have also been recent contributions to other branches of the subject, especially to atmospheric electricity, among them,

(*a*) The discovery in 1900 by C. T. R. Wilson and, also, by H. Geitel of spontaneous ionization in the atmosphere.

(*b*) The discovery in 1902 independently by Rutherford and Cook, and by McLennon and Burton, of a penetrating radiation in the lower atmosphere, presumably from radioactive substances near the surface of the earth.

(*c*) The discovery in 1905 by Langevin of slow moving or large ions in the atmosphere.

(*d*) The discovery by Simpson in 1908 and 1909 that the electric charge on thunderstorm rain, and precipitation generally, is prevailingly positive.

(*e*) The discovery in 1908, also by Simpson, of the probable origin of the electric charge of the thunderstorm.

(*f*) The discovery by Kolhörster in 1914 of an extremely hard or penetrating radiation in the atmosphere that seems to be of extra terrestrial origin.

Each of these several discoveries has its own peculiar interest, but the origin of the electric charge of the thunderstorm involves more meteorological phenomena than does any of the others, and, therefore, it is selected for further remarks.

Many have supposed that, whatever the genesis of the thunderstorm, the lightning, at least, is a product or manifestation of the free electricity always present in the atmosphere—normal atmospheric electricity. Observations, however, seem definitely to exclude this assumption. Thus, while the difference in electrical potential between the surface of the earth and a point at constant elevation is, roughly, the same at all parts of the world, the number and intensity of thunderstorms vary greatly from place to place. Further, while the potential gradient at any given place is greatest in winter, the number of thunderstorms is most frequent in summer, and while the gradient in the lower layer of the atmosphere, at many places, usually is greatest from 8 to 10 o'clock, both morning and evening, and least at 2 to 3 o'clock P.M. and 3 to 4 o'clock A.M., no closely analogous relations hold for the thunderstorm.

But how, then, is the great amount of electricity incident to a thunderstorm generated? Fortunately an answer to this question based on careful experiments and numerous observations, and that greatly aids our understanding of the interrelations between the various thunderstorm phenomena, has been given by Dr. G. C. Simpson, of the Indian Meteorological Department.

The chief conclusions drawn by Simpson from his observational data, and supported by numerous subsequent observations by other persons at widely separated places, are:

(*a*) That the charge on thunderstorm rain, amounting often to 5 to 10 electrostatic units per cubic centimeter, usually is positive.

(*b*) That, on the whole, the quantity of positive electricity brought down is more than three times greater than the negative.

While these observations were being secured a number of well-devised experiments were made to determine the electrical effects of each obvious process that takes place in the thunderstorm.

Freezing and thawing, air friction, and other things were tried, but none produced any electrification. Finally, on allowing drops of distilled water to fall through a vertical blast of air of sufficient strength to produce some spray, positive and important results were found, showing: (1) That breaking of drops of water is accompanied by the production of both positive and negative ions. (2) That three times as many negative ions as positive ions are released.

Now, a strong upward current of air is one of the most conspicuous features of the thunderstorm. It is always evident in the turbulent cauliflower heads of the cumulus cloud—the parent, presumably, of all thunderstorms. Besides, its inference is compelled by the occurence of hail, a frequent thunderstorm phenomenon, whose formation requires the carrying of raindrops and the growing hailstones repeatedly to cold and therefore high, altitudes. And from the existence of hail it is further inferred that an updraft of at least 8 meters per second must often occur within the body of the storm, since, as experiment shows, air of normal density must have approximately this upward velocity to support the larger drops, those of 4 mm. or more in diameter, and, because of its greater weight, even a stronger updraft to support the average hailstone.

Experiment also shows that raindrops of whatever size can not fall through air of normal density whose upward velocity is greater than about 8 meters per second, nor themselves fall with greater velocity through still air; that drops large enough, 4.5 mm. in diameter and up, if kept intact, to attain through the action of gravity a greater velocity than 8 meters per second with reference to the air, whether still or in motion, are so blown to pieces that the increased ratio of supporting area to total mass causes the resulting spray to be carried aloft or, at least, left behind, together with, of course, all original smaller drops. Clearly, then, the updrafts within a cumulus cloud frequently must be strong and therefore break up at about the same level, that of maximum rain accumulation, innumerable drops which, through coalescence, have grown beyond the critical size; and thereby, according to Simpson's experiments produce electrical separation within the cloud itself. Obviously, under the turmoil of a thunderstorm, such drops may be forced through the cycle of union (facilitated by any charges they may carry) and division, of coalescence and disruption, from one to many times, with the formation on each at every disruption again *according to experiment*, of a correspondingly increased electrical charge. The turmoil compels mechanical contact between the drops, whereupon the disruptive equalization of their electrical potentials breaks down their surface tensions and insures coalescence. Hence, once started, the electricity of a thunderstorm rapidly grows to a considerable maximum.

After a time the larger drops reach, here and there, places below which the updraft is small—the air can not be rushing up everywhere—and then fall as positively charged rain, because of the processes just explained. The negative electrons, in the meantime, are carried up into the higher portions of the cumulus, where they unite with the cloud particles and thereby facilitate their coalescence into negatively charged drops. Hence the heavy rain of a thunderstorm should be positively charged, as it almost always is, and the gentler portions negatively charged, which also very frequently is the case.

Such in brief is Dr. Simpson's theory of the origin of the electricity in thunderstorms, a theory that fully accounts for the facts of observation and in turn is itself abundantly supported by laboratory tests and imitative experiments.

. . . .

The foregoing are only a selected few of the many recent contributions to the physics of the air, but they are sufficient, it is hoped, to show that meteorology is indeed a progressive branch of physics, and one eminently suitable to every type of scientific talent. The close observer, the clever experimentalist, and the keen analyst all can find in the phenomena of the atmosphere inexhaustible material and endless opportunities. But in science opportunity is only a synonym for duty, and of all words duty is the noblest.

W. J. Humphreys

U. S. Weather Bureau

SCIENTIFIC EVENTS

THE HISTORY OF MEDIEVAL INSTITUTIONS

Professor David Eugene Smith, of Teachers College, Columbia University, writes:

The Société de Scolastique Médiévale, founded by M. François Picavet, professor in and secretary of the Collège de France, was changed into the Société d' Histoire Générale et Comparée des Philosophies Médiévales in 1906. This society is interested in the study of the history of dogma and religion, the history of law, the history of letters, the history of philosophy, and the history of science. Monographs have been issued in all these several lines and others are in the course of preparation.

It may seem that this is not an opportune moment for scholars to be considering such a line of work. Upon this point a letter from M. Picavet, written just before the armistice, has this to say: "En ce moment ou nous ne pouvons, en raison de notre âge, que faire des voeux, pour les combattants ou venir en aide aux prisonniers, aux soldats et aux évacués des pays envahis, j'ai pensé que nous pourrions nous rendre utiles en préparant les moyens de nous suffire sur le terrain scientifique et universitaire, entre nous gens de l'entente et amis de l'entente."

Few scholars have been called upon to make a greater sacrifice in this war than M. Picavet, and his determination to continue his great work in the field in which he has done so much will doubtless appeal to all scholars in this country as in Europe.

M. Picavet would be glad to hear from American scholars who are interested in the work of the society and to have their names enrolled as sympathetic with its work. If they should later become so interested as to contribute in any way to the support of the society, this would be a welcome decision; but this is not the immediate purpose. It would be a helpful act if those interested in this line of work were to write to M. François Picavet, Collège de France, Paris, expressing their interest in the society.

If America could in some way secure an endowment of $24,000 for maintaining for ten years the chair which M. Picavet fills with such distinction in the Collège de France, a great impetus would thereby be given to this work.

ACTIVITY OF KILAUEA VOLCANO

Professor Vaughan MacCaughey, of the College of Hawaii, Honolulu, writes under date of January 22: