the Atmosphere, were prepared specially by Prof. Humphreys for this book. Chapter II, Measurement of Meteorological Elements, by S. P. Fergusson, is a brief discussion of instruments and methods of observaton. Chapter III, Atmospheric Temperature, by W. R. Gregg, is a well-illustrated discussion of the subject; which, however, would be easier to grasp if part 2 preceded part 1. The section on vertical distribution of temperature is based largely on the most recent data collected in the United States.[9] Prof. J. Warien Smith prepared the brief chapter, IX, on Secondary Circulation of the Atmosphere. Prof. A. J. Henry's chapter, X, on Forecasting the Weather, is a brief statement of the interesting subject. Chapter XI, Climate, by Prof. C. F. Talman, is likewise by necessity highly condensed. The bibliography contains classified references to the more important works on meteorological topics; though in the references on clouds, Clayton's extensive "Discussion of the Cloud Observations," made at Blue Hill Observatory,[10] and the Weather Bureau's voluminous "Report on the International Cloud Observations" have been omitted.[11]

A book of this nature, put together so rapidly, is bound to show lack of unity and unevenness of treatment. Some teachers have described *Introductory Meteorology* as uninteresting and too difficult for the elementary student. The first point, that it is uninteresting, is founded on the fact that it is practically nothing but meteorology, there being little or no mention of the human applications or effects of the elements discussed; and the second objection, that it is too difficult, is based on the necessarily condensed treatment of some of the more difficult parts. The book was not intended to be complete in itself. The authors, however, may have overestimated the meteorological knowledge of many instructors and the time available to others for preparing supplemental lectures. These objectionable features may be easily remedied if there is a call for a somewhat enlarged edition.

On the whole, the book is filling a demand for a brief book on modern meteorology.[12]—C. F. B.

### *A Manual of Aerography.*

"A Manual of Aerography," issued by the United States Navy, was compiled by Lieut. Commander Alexander McAdie.[13] The book is composed of individual chapters assembled essentially without reference to one another, several of which are taken directly from the compiler's "Principles of Aerography" (Chicago, 1917). There are chapters on fundamental units, formulæ, and tables; but most of the book is made up of brief discussions of the major branches of meteorology. Two of the chapters deal with the effects of meteorological conditions on flying: one, by Prof. W. J. Humphreys, is published here only; while the other, by Capt. C. J. P. Cave, is reprinted from the Aeronautical Journal, London, 1917.—C. F. B.

### *A Treatise on the Sun's Radiation and other Solar Phenomena.*

[In continuation of A Meteorological Treatise on the Circulation and Radiation in the Atmosphere of the Earth and of the Sun, 1915.]

Much of this work deals with the solar constant, radiation, and the application of solar data to short and long range forecasting; therefore, it is of interest to meteorologists, although they can not agree with many of the author's conclusions.[14]

Reviews of the earlier work on atmospheric circulation and radiation [15] have been published by F. W. Very, in Science, December 3, 1915 (N. S., vol. 42, pp. 800–805), by A. McAdie, in Geographical Review, October, 1916 (vol. 2, pp. 323–324), and by H. Bateman in Astro-physical Journal, December, 1916 (vol. 44, pp. 342–344).—C. F. B.

### *Meteorological Glossary.*

[Fourth Issue, London, 1918.]

This valuable publication of the British Meteorological Office constitutes a companion volume to the interesting little primer of practical meteorology known as "The Weather Map." While it contains numerous meteorological definitions, it is not primarily a lexicographic work, but rather a compend of information on various meteorological topics, arranged in alphabetical order. A more extended notice of this publication will appear in a later number of the REVIEW.—C. F. T.

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## SOME RECENT CONTRIBUTIONS TO THE PHYSICS OF THE AIR.[1]

By W. J. HUMPHREYS, Professor of Meteorological Physics, U. S. Weather Bureau.

There has come to us from ancient times the story of a foolish man who sold his birthright for a mess of pottage, and that story to-day is right applicable to us physicists, except in one important particular—we haven't even got the pottage. No department of learning has a richer birthright than has the department of physics in meteorology—the physics of the air. And yet the few institutions that even profess to teach this subject in any form offer it through the department of geology, or more frequently still, that omniverous department which, for want of a better name, is called the department of geography. Statistical meteorology, if such expression will be permitted, or climatology, is of course of great interest alike to the geologist and the geographer, and this they should teach and in a great measure do teach; but climatology is no more meteorology than descriptive geography, for instance, is geology. Its value is great and unquestioned, but its function, like the function of geography, is merely to describe and not to explain.

Meteorology, on the other hand, is concerned with causes; it is the physics of the air—a vast subject of rapidly-growing importance upon which peace and war alike are becoming more and more dependent. Only yesterday we

"Heard the heavens fill with shouting,
And there rained a ghastly dew
From the nation's airy navies
Grappling in the central blue;"

and to-day

"Saw the heavens fill with commerce,
Argosies of magic sails,
Pilots of the purple twilight,
Dropping down with costly bales."

It is therefore no longer an opportunity, a shamefully neglected opportunity, that invites, but an imperative duty that commands our leading institutions to add to the various subjects taught, studied, and investigated in

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[9] See "Mean values of free-air barometric and vapor pressures, temperatures, and densities over the United States," by W. R. Gregg, MONTHLY WEATHER REVIEW, 1918, 46: 11–21.

[10] Ann. Ast. Obs. Harv. Coll., 1896, vol. 30, pt. 4, 4°, 500 pp., 17 pl.

[11] By F. H. Bigelow, Report of the Chief of the Weather Bureau, 1898–99, vol. 2, 1900, 4°, 787 pp.

[12] For other reviews of this book, see one by "M." in Science, Dec. 6, 1918, pp. 576–577, and another by R. De C. Ward, in Geogr. Rev., 1919. vol. 7.

[13] Government Printing Office, 1918, 165 pp. 8vo.

[14] Cf. C. G. Abbot, Pyrheliometry and solar radiation, Science, June 21, 1918, pp. 609–610 and F. H Bigelow's reply, Science, Oct. 25, 1918, pp. 417–418.

[15] A Meteorological treatise on the circulation and radiation in the atmospheres of the earth and of the sun. New York, 1915, 431 pp., 78 figs.

[1] Extracts from vice-presidential address, Physics section, A. A. A. S., Baltimore, December, 1918. Published in full, Science, Feb. 14 and 21, 1919, N. S., vol. 49, pp. 155–163, 182–186, 6 figs.

their departments of physics that eminently valuable and fascinatingly difficult branch of geophysics—the physics of the air.

No doubt the great majority of colleges and universities would find it highly impracticable to add a proper course in meteorology to their present long list of electives. Neither is it practicable nor desirable for all of them to teach anthropology, say, despite its fascination, nor even any whatever of the a-to-z kinds of engineering. But it is insisted with all possible emphasis that if taught at all it be taught right—taught as a branch of physics. It is also insisted that there is a growing need, especially in connection with both the science and the art of aviation, for young men who understand the phenomena of the atmosphere. Nor should it be forgotten that when our Army called for men trained in meteorological physics it called in vain—they did not exist. Furthermore, it would be a godsend to our national Weather Bureau if in the future it could secure a larger portion of its personnel from among university graduates highly trained in the subjects with which they have to deal. And, finally, it is insisted that the physics of the air offers many opportunities to the creative scholar, and every university must realize that its paramount duty is the fostering of research and the training of investigators, for in no other way can it meet the growing and compelling demands of a progressive civilization.

It must be admitted, however, that it is not now easy to give a connected course on atmospheric physics, for there is no suitable text, and the isolated articles upon which such a course must needs be based are scattered through the journals from Dan to Beersheba and buried under a babel of tongues. But this is only a difficulty and not, in the face of imperative needs, an excuse. A far greater and very real difficulty has, it is true, confronted most of us, for, until the last decade or less, several important lectures in such a course would of necessity have been restricted to the same brevity as characterizes Horrebow's famous chapter on snakes in his Natural History of Iceland—there aren't any.

Some of these lectures are still unwritten—tantalizing challenges to the skill of the experimentalist and acumen of the analyst—while others have been at least partially supplied, a few of which it will be interesting to review in what follows.

### *Temperature of the Free Air.*

* * * It appears, then, that the average temperature gradient (rate of decrease of temperature with elevation) of the free air is approximately that of a rising mass of saturated air; and for the reasons (*a*) that frequently the air is rising and saturated, and (*b*) that departures from the thus established saturation curve develop but slowly, as explained, and are soon eliminated by its reestablishment.

### *Isothermal State of the Upper Air.*

* * * If the surface temperature of the earth is maintained, as we know it is, by the absorption of solar radiation, it is equally certain that in turn the temperatures of objects in the full flood of the necessarily equivalent terrestrial radiation can not drop to zero; nor, therefore, can the air, generally, cool by convection to a lower temperature than that which this radiation can maintain. These ideas, so simple that they seem hardly worth expressing, embody the fundamental explanation of why the upper air is essentially isothermal.

In addition to being exposed all the time to earth radiation the upper air is also exposed much of the time to solar radiation; but there is abundant evidence that the atmosphere at all levels is far more absorptive of the relatively long wave-length terrestrial radiation than of the much shorter wave-length solar radiation. Hence, in computing from *a priori* considerations, the probable temperature of the isothermal region, or statosphere, as it generally is called, it is sufficient, as a first approximation, to consider the effect of only the outgoing radiation, which, according to the work of Abbot and Fowle of the Smithsonian Institution, is approximately equal in quantity and kind to that which would be emitted by a black surface coincident with the surface of the earth and at the temperature of 259° A. * * * Hence, the problem, as an approximation, is to find the temperature to which an object, assumed infinitesimally small, to fit the case of a gas, will come when exposed to the radiation of a single black plane at a given temperature and of infinite extent. * * * Whatever the nature of the object, since it is exposed to twice as much radiation when between two planes as it is when facing but one, it must, in the former case, both absorb and emit twice as much energy as in the latter. * * * $T_2 = T_1 \sqrt[n]{2}$ * * *. As already explained, the value of $T_2$ [temperature of the radiating plane] is roughly 259° A., and if [the radiation exponent] $n=4$, the value for a full radiator, it follows that [the temperature of the object exposed to this radiation] $T_1=218°$ A., substantially the value found by observation.

### *Storm Effects on Temperature Gradients.*

* * * Quite contrary to familiar ideas about convection, the ascending air [in cyclones] * * * is relatively cold and the descending air [in anticyclones] comparatively warm. And the stratosphere * * * but further confounds this confusion, for here the temperature relations are again reversed, the warmer air being now over cyclones and the colder above anticyclones.

The relation of the temperatures [of cyclones and anticyclones] to each other, level for level up to the stratosphere, is just the reverse of that which it would have to be if their circulations were of immediate thermal origin. Presumably, therefore, their circulations are largely driven and their temperatures in part mechanically determined.

* * * Now, whatever the origin of the migratory anticyclone, a subject that still requires further investigation, one of its chief features is deep winds from higher latitudes in its eastern portions. These winds, because of the rotation of the earth, necessarily lose more or less of such west-to-east velocity as they previously may have had. They lag in the midst of the general circulation. Hence the prevailing westerlies flow over them as over a mountain barrier. But by this overflow the westerlies produce at least three different effects: (*a*) They load the atmosphere over which they pass and thus increase the pressure from the surface up to near the base of the stratosphere. This increase of pressure in turn forces the loaded air to descend, warming on the way according to the adiabatic gradient of 1° C. per 103 meters (if free from clouds) and thereby raising the temperature at all levels through which it passes. (*b*) They bodily lift the stratosphere, whose pressure thereupon tends to decrease at every level in proportion to the initial pressure at that level—a result that would produce dynamically an equal drop in temperature through-

out the stratosphere. (c) By their own dynamical cooling, and at least until the pressure of the upper atmosphere has become readjusted, they establish at the base of the stratosphere a layer of minimum temperature. * * *

Similarly, whatever the origin of the migratory cyclone, another of the many meteorological problems that needs further investigation, one of its chief features is a deep wind in its eastern portions from lower to higher latitudes. In this case the rotation of the earth leads to a speeding up of the eastward component of the velocity. Hence this air may be expected to run forward and up and thus to produce a low pressure to its rear. Because of the upward trend thus given to much of the air in the cyclone, that portion of it below the stratosphere is more or less dynamically cooled. At the same time, the stratosphere bodily drops to lower levels wherever air has been removed from beneath it. Hence its pressure is increased at every level in proportion to the initial pressure at that level and its temperature thereby raised by an equal amount throughout.

Radiation and absorption probably also have some part in determining the temperature conditions and interrelations of migrant cyclones and anticyclones, but the chief cause appears to be purely mechanical, as above explained.

### *The Law of Wind Increase with Elevation.*

The fact that wind velocity generally increases with elevation has long been known * * *. [At levels above the influence of surface disturbances and below the stratosphere] the velocity of the wind varies inversely with its density, or, in other words, * * * the mass flow is a constant. [This] * * * mass flow * * * is directly proportional to the horizontal pressure gradient. * * * From the height of 3 or 4 kilometers above sea level up to that of 8 or 9, the density of the atmosphere is roughly inversely proportional to the altitude. Hence, to this same crude approximation [the horizontal pressure gradient] $G$ is also constant through the given range of levels. Hence the horizontal gradient and, therefore, the mass flow must be roughly constant between the given limiting levels * * *.

### *Barometric Fluctuations.*

*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 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 * * * appear as a series of ripples in the record of a sensitive barograph.

During 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 24 hours. During particularly calm weather these fluctuations are conspicuous on the current barogram, * * * and always revealed by averages, no matter how masked by storm conditions * * *. * * * [It is evident from the times of maxima and minima, and from the stronger occurrence in the tropics and in summer than in extra-tropical latitudes and in winter] that the daily cyclic pressure changes are somehow the results of temperature changes * * *.

It appears * * *:

(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 [about 10 a. m.] barometric maximum.

It remains now to account for the night 10 o'clock maximum and 4 o'clock minimum, both of which appear to depend upon the natural or free vibration of the atmosphere as a whole. * * * All that is needed, apparently, to give the semidiurnal pressure curve is a pressure impulse of the same period, 12 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. * * *

### *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 * * *. * * * The origin of the electric charge of the thunderstorm involves more meteorological phenomena than does any of the others. * * *

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 analagous relations hold for the thunderstorm. * * *

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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. 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 millimeters 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. * * * [The larger drops] 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 Doctor 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.

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## SUBJECTS FOR RESEARCH IN METEOROLOGY.

It seems well at the present time for the Weather Bureau to take the lead in suggesting fundamental problems for research in meteorology—problems the solution of which, in part at least, may be undertaken by university post-graduate students in meteorology and by others who have opportunity for research. With this in view, the following subjects are proposed by the staff of the Central Office of the Weather Bureau.

### *Instruments and Observations.*

1. Apparatus for recording the total radiation received from the sun and sky.

2. The measurement of the intensity of daylight.

A campaign to determine the intensity of daylight illumination in different latitudes under different atmospheric conditions is contemplated. Suitable apparatus for recording light intensities is highly desirable, but not yet available.

3. Methods of obtaining the directions and velocities of the winds at different elevations: (a) By direct observation with various forms of anemometers; (b) by observations of pilot and other balloons with one or two theodolites; (c) by observation of the movements of clouds by triangulation, or possibly by observations of the form, direction, and size of cloud waves.

4. Development of apparatus for determining soil temperature, soil moisture, and intensity of solar radiation as affecting plant growth.

### *Physical Properties of the Atmosphere.*

5. Origin and maintenance of the outgoing current of negative electricity.

6. Source and effects of the penetrating radiation in the upper atmosphere.

7. The absorptive power of water vapor for long-wave-length radiation.

8. The absorption and radiation properties of the different constituents of the atmosphere.

### *Temperature.*

9. A theoretical study of the cause of the altitude to latitude relation of the height of the stratosphere.

10. Diurnal variation in height and intensity of nocturnal inversions of temperature and their relation to "air drainage" and other phenomena.

This could be studied by means of frequent nocturnal soundings of the air in valleys with a small captive balloon carrying a meteorograph. Data of this kind will be of use in forecasting frost.

### *Atmospheric Pressure.*

11. Reduction of surface pressures to those of stated levels in the free air.

Such reduced pressures would make possible the construction of fairly accurate weather maps for different levels. To obtain as nearly as possible the pressures aloft without direct observations at the required levels requires a close study of the vertical temperature gradient at each place, in order that for any type of weather at any time of day and season a proper temperature factor may be used in the hypsometric formula.

12. Diurnal temperature changes in the free air and their relation to the surface semidiurnal variations of pressure.

### *Winds.*

13. Over- and under-running of differing winds, and attending phenomena.

14. Studies of atmospheric turbulence.

This may be done directly and indirectly in several ways; smoke movements, sound irregularities, irregular movements of balloons, internal movements in clouds, gustiness, cloud waves, temperature oscillations, temperature contrasts between neighboring fields.