strom.
T

BULLETIN

OF

The Terrestrial Electric Observatory

OF

FERNANDO SANFORD
Palo Alto, California

VOLUME VI

Observations upon Electric Repulsion between Insulated Bodies and Electric Attraction between Insulated and Uninsulated Bodies Which Are Caused by Variations in the Distribution of the Earth's Electric Charge Induced by the Electrostatic Induction of the Negative Charge of the Sun, and a Discussion of the Origin of the Twelve-hour Barometric Wave and Its Relation to the Atmospheric Potential Gradient

Palo Alto, California
March 1930

BULLETIN

OF

The Terrestrial Electric Observatory

OF

FERNANDO SANFORD
Palo Alto, California

VOLUME VI

Observations upon Electric Repulsion between Insulated Bodies and Electric Attraction between Insulated and Uninsulated Bodies Which Are Caused by Variations in the Distribution of the Earth's Electric Charge Induced by the Electrostatic Induction of the Negative Charge of the Sun, and a Discussion of the Origin of the Twelve-hour Barometric Wave and Its Relation to the Atmospheric Potential Gradient

Palo Alto, California
March 1930

STANFORD UNIVERSITY PRESS

CONTENTS

OBSERVATIONS UPON ELECTRIC REPULSION BETWEEN INSULATED BODIES AND ELECTRIC ATTRACTION BETWEEN INSULATED AND UNINSULATED BODIES WHICH ARE CAUSED BY VARIATIONS IN THE DISTRIBUTION OF THE EARTH'S ELECTRIC CHARGE INDUCED BY THE ELECTROSTATIC INDUCTION OF THE NEGATIVE CHARGE OF THE SUN, AND A DISCUSSION OF THE ORIGIN OF THE TWELVE-HOUR BAROMETRIC WAVE AND ITS RELATION TO THE ATMOSPHERIC POTENTIAL GRADIENT

Brief review of the work on the electrostatic induction of the sun.—As this is probably the last *Bulletin* which will be published from this observatory, it seems advisable to give a short review of the work which has been done here and the reason why its separate publication was necessary.

In 1911 the present writer published a paper in the Leland Stanford Junior University Series entitled *A Physical Theory of Electrification.* In this paper an attempt was made to show how all the known phenomena of static electricity could be explained without making any assumptions different from those generally believed at that time except the assumption that the earth carried a very great charge of negative electricity.

It had already been shown by Hale that the regions around sun-spots were the seats of enormous charges of negative electricity, and the later proof of the magnetic field of the sun seemed to make necessary the assumption that the whole surface of the sun was negatively electrified to the same degree as the regions about sun-spots. At least, no other possible means of accounting for the magnetic field of the sun except by the rotation of its negative charge has ever been proposed.

Upon retirement to the emeritus list of the Stanford faculty in 1919, the author decided to attempt the identification of the hypothetical negative charges of the earth and the sun. As such an investigation was regarded as unpromising by my successor and former colleagues of the Department of Physics, the university authorities declined to provide funds or facilities for carrying on the work, and it became necessary to undertake the investigation at my home in Palo Alto. Accordingly, a small building was constructed and equipped for making the intended observations; and to relieve the Department of Physics from all responsibility in the premises it was named "The Terrestrial Electric Observatory," adopting the term suggested by Sir William Thomson for the phenomena of earth-currents and atmospheric electricity.

Knowing the superiority of the leading physical journals to any private publication as a means of reaching the scientific public, the papers giving the earliest results of the investigation were offered to them, but were rejected, sometimes even contemptuously, by all the journals except *Science* to which they were sent. It accordingly became necessary to issue them as private bulletins if they were to be published at all.

Previous to beginning the investigation it seemed probable that if the negative charge of the sun were great enough to account for the observed magnetic field its inductive effect upon the earth might be susceptible of observation. Also, it did not seem impossible that the tremendous currents required to produce the magnetic fields of sun-spots might induce temporary currents in the earth during their growth and subsidence or their passage across the visible hemisphere of the sun, and in that manner account for the terrestrial magnetic disturbances which often accompany the appearance of sun-spots. So it was decided to test first for solar electrostatic induction upon the earth.

One who has given careful attention to the phenomena of the atmospheric potential gradient, the magnetic and the earth-current phenomena, with their daily and seasonal variations, will see that these phenomena are such as should appear on a conducting, electrified globe insulated in space from other bodies and acted upon inductively by another similarly electrified globe related to it in space as the sun is related to the earth. In fact, nearly all the phenomena which may be deduced from the known laws of electrostatic induction under the conditions of charge which are here assumed and the conditions in space which have been observed between the sun and the earth had been recognized before the present investigation was undertaken; but not one of them had been attributed to electrostatic induction.

However, the most direct evidence of the sun's electrostatic induction which could be deduced from the hypothesis of its enormous negative charge, namely, the induction of a positive charge on the day side and a negative charge on the night side of the earth, had not been observed. Uninsulated conductors upon or within the earth had always been taken as the zero from which electric charges have been measured, and the question of the invariability of this zero had not been raised. So it has come to be one of the tenets of physics that the earth, together with all bodies upon its surface and including its atmosphere, contains an equal number of elementary positive and negative electric charges of equal magnitude; and while it has long been known that the earth carries a negative surface charge and that bodies upon its surface are seldom, if ever, at the true zero of electrification, it has been assumed that the electropositive equivalent of this negative surface charge is in some manner diffused throughout the atmosphere above the earth. The question of a possible difference in the distribution of these charges over the day and night hemispheres of the earth seems not to have been sufficiently considered.

On a method of determining the distribution of the earth's surface charge.—In theory, it seems a simple matter to insulate a body which has been discharged to earth on the day side, to allow it to remain insulated until it is carried around to the night side, and then to determine if it is still in electrical equilibrium with the uninsulated body to which it was originally discharged; but even this simple experiment is beset with difficulties. It is difficult to say when a conductor has been discharged to earth entirely removed from the possible inductive influence of all electrified bodies. The only known method of insuring the complete discharge of an electrified conductor is to place it wholly inside of and in electrical contact with a closed hollow conductor. Experiments have shown that the electrical field of the earth is the same inside as outside a closed hollow conductor, regardless of any charge which may be on the outer surface of the hollow conductor. Accordingly it has been assumed that any conductor inside of and in contact with a closed hollow conductor is in a state of "absolute electrical neutrality," that is, that it contains an exactly equal number of positive and negative elementary electrical charges of equal magnitude.

It is plain that if such enclosed conductor, after being discharged to the outer hollow conductor, were insulated and allowed to remain inside, it would always remain in the same electrical condition that it was in while in contact with the outer conductor. This fact suggests a method of determining whether the distribution of the earth's surface charge is the same everywhere around a given parallel of latitude. Thus, if two conductors be placed inside the same hollow conductor and both be discharged to its walls at the same time, they will be in electrical equilibrium with each other and with uninsulated bodies upon the earth. If one of these conductors be now insulated while the other remains in electrical contact with the outer conductor, they will remain in electrical equilibrium with each other unless the intensity of the earth's field undergoes a change. If this occurs, the uninsulated conductor will gain or lose electrons until it is in equilibrium with the earth's field; while the insulated conductor can neither gain nor lose electrons, and hence cannot follow the change in intensity of the earth's electric field. In this event a potential difference will be developed between the two enclosed conductors.

If under the proposed conditions a potential difference does appear between the two enclosed conductors, it must be attributed to a change in the electrical charge of the uninsulated conductor, and such a change must, in turn, be attributed to a change in the distribution or the intensity of the earth's surface charge.

To find whether such a change actually occurs, a quadrant electrometer was set up inside an earthed wire cage; both pairs of quadrants were discharged to the case of the instrument and to the wire cage; one pair was then insulated and the other pair left connected to earth through the metal case of the instrument and the wire cage; the needle was charged from a battery which was enclosed in a grounded metal box, and one pole of the battery was grounded to this box and the large wire cage.

Set up in this manner the instrument showed a regular daily deflection of the needle, indicating that the insulated quadrants became electronegative to the grounded quadrants by day and electropositive to them by night. The deflection was greatly increased when the insulated quadrants were connected to an insulated conductor of considerable capacity which was suspended inside the grounded cage.

That the deflection of the needle was not caused by a change in the electromotive force of the charging battery was shown by using an electrometer with a quartz fiber suspension and charging the needle only once in two or three days. It was found that there was a slight temperature deflection of the needle when it was uncharged and all the quadrants were removed; the removal of this deflection is fully discussed in Volume III of this *Bulletin.*

Many possible and impossible explanations of this daily deflection have been proposed, and all have been found to be fallacious except the one here given. That it was not due to a variation in the ionization of the air in the cage was shown by placing a sheet of radioactive material on the pier directly below the electrometer, thereby keeping the air in the vicinity of the instrument highly ionized at all times. To show that it was not due to a daily variation in the conductivity of the air inside the electrometer case, the needle was grounded, the battery was placed between the two pairs of quadrants, and one pole of the battery and its connected quadrants were grounded. This gave a constant potential difference between the two quadrant pairs while one pair and the needle were always grounded. The deflections produced by this arrangement are shown in Volume V of this *Bulletin.*

Finally it became clear that if all electric charges upon the earth are due to a potential difference between the charged body and the earth, that is, that we know nothing about electrical charges *per se,* then if the day side of the earth becomes electropositive to the earth as a whole, all insulated bodies near the earth on this side must become more electronegative; and when the earth in their vicinity becomes more electronegative, they must all become electropositive. Consequently, if the negative charge of the sun induces a positive charge on the day side of the earth and a negative charge on the night side, *all insulated bodies near the earth must become negatively charged by day and positively charged by night.* That this simple deduction was so long in dawning upon the author is humiliating; but the vain attempts to put it across to others tend to lessen the humiliation.

It follows from the fact that similarly electrified bodies repel each other that *all insulated bodies near the earth must repel each other at all times except twice a day.*

Results of experimental tests.—To test this deduction, one diagonal pair of quadrants was removed from the quadrant electrometer, the needle and the other pair of quadrants were connected and insulated, and the instrument was allowed to stand with the case grounded and the needle and connected quadrants amber-insulated and doubly shielded from outside induction by the instrument case and the surrounding wire cage. No charged body was in the vicinity of the wire cage, which was four feet square and eight feet high.

Set up in this way, the instrument gave a very regular daily deflection, greater than had been obtained by the previous methods of adjustment. Thus a large Günther & Tegetmeier electrometer with a light paper needle, when adjusted for highest sensitivity, gave a daily deflection of the needle through an arc of more than five degrees. To produce an equal deflection by charging the needle and attached quadrants required a charge of more than 200 volts. Accordingly there was a potential difference of 200 volts between the positive and the negative charges induced in the instrument by the changes in distribution of the earth's surface charge in twenty-four hours, though the gain or loss of electrons by the instrument during that time must have been insignificant and always in a direction to lessen the effect.

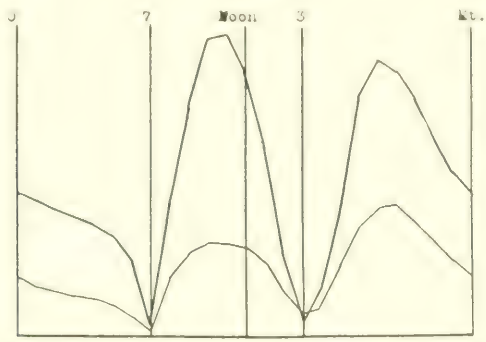
Three electrometers of very different patterns and different sensitivities were set up in the same manner upon the same pier, and their deflections were recorded photographically upon the same sheet; all gave similar curves, but of very different range of magnitudes. Figure 1 (p. 10) shows the mean daily variations for the same twenty days of two electrometers of different construction, one a large Günther & Tegetmeier instrument with a silver suspension and a paper needle, the other a home-made electrometer of the Dolezalek pattern with a phosphor-bronze suspension and a metal needle. The larger instrument was more than three times as sensitive as the smaller one. They stood side by side upon the same pier and their deflections were recorded photographically upon the same sheet. The average daily range of deflection was 77 millimeters in the case of the larger instrument and 23 millimeters in the case of the smaller, the record sheet being at a distance of approximately one meter.

The double curve in Figure 1 is interpreted as showing that the surface charge of the earth at Palo Alto passed through its position of mean intensity twice each day, once about 7:00 A.M. and once at from 3:00 to 4:00 P.M., that it attained its maximum electropositive state at from 10.00

to 11:00 A.M. and its maximum electronegative condition at from 7:00 to 8:00 P.M. This interpretation agrees with curves previously made with a charged electrometer needle which was deflected continuously in one direction from 10:00 or 11:00 A.M. to 7:00 or 8:00 P.M., after which it was deflected in the opposite direction throughout the remainder of the twenty-four hours. Similar curves, all of which are very much alike, have been obtained for seventeen months with the Dolezalek pattern electrometer. A copy of the photographic record given by this instrument for three successive days is shown on pages 16 and 17.

That the deflections are wholly due to a repulsion between the quadrants and the needle when they are connected, or when both are insulated

FIGURE 1



Curves given by two insulated, uncharged quadrant electrometers from each of which one diagonal pair of quadrants had been removed and the needle and remaining pair put into electrical contact. The deflections are caused by the repulsion of the needle by the attached quadrants.

separately, has been shown in several ways. When the needle is placed midway between the two diagonal quadrants its deflection is very small. When it is rotated in such a manner as to lie partly within the quadrants on one side it is deflected in one direction, and when it is turned so as to lie partly within the quadrants on the opposite side the directions of its daily deflection are reversed. That is, the needle is deflected farther and farther away from the nearest quadrants from 7:00 A.M. to 10:00 or 11:00 A.M., after which it gradually moves back toward its nearest position, which it reaches about 3:00 or 4:00 P.M. It then gradually moves away from the quadrants until 7:00 or 8:00 P.M., after which it slowly returns again to the position from which it started on the previous morning.

The periodicity of this daily variation has been very regular for the seventeen months for which it has been recorded, but the range of deflection has differed considerably from day to day. The daily range has been much greater in summer than in winter, but just how much of this difference is due to the relative positions of the earth and the sun is uncertain. It is very noticeable that on cloudy or foggy days the deflections are of smaller range than on clear days. Since in this climate the cloudy and foggy days practically all occur in the winter season, it is difficult to say how much of the decrease in the range of electrometer deflection is due to this cause and how much to a true seasonal variation. No careful series

TABLE I

MONTHLY MEANS OF DAILY DEFLECTIONS OF ELECTROMETER A FOR SEVENTEEN MONTHS IN 1928 AND 1929

Month	A.M. 1	A.M. 2	A.M. 3	A.M. 4	A.M. 5	A.M. 6	A.M. 7	A.M. 8	A.M. 9	A.M. 10	A.M. 11	Noon
May.......	− 4.5	− 5.9	− 6.7	− 7.7	− 9.0	−12.1	−15.5	− 3.4	+ 4.5	+ 7.2	+ 7.3	+ 5.9
July.......	− 4.4	− 7.5	−10.0	−12.2	−13.9	−16.0	−17.5	− 9.7	− 4.6	− 1.6	− 0.1	− 0.1
Aug.	− 3.7	−10.9	−12.4	−13.3	−13.2	−13.8	−17.6	−11.9	− 6.9	− 0.7	+ 0.6	+ 0.6
Sept.	− 1.4	− 5.4	− 7.8	−10.0	−11.5	−12.6	−18.2	−12.1	− 6.5	− 2.0	0	− 0.4
Nov.	+ 0.2	− 0.7	− 1.8	− 3.3	− 5.5	− 6.4	− 6.8	− 9.7	− 9.6	+ 5.6	+ 7.5	+ 4.6
Dec.	− 2.0	− 3.2	− 4.2	− 5.0	− 6.0	− 6.0	− 6.8	− 7.8	− 9.2	+ 5.5	+ 8.0	+ 7.0
Feb.	+ 2.2	0	− 3.0	− 4.6	− 5.6	− 6.1	− 7.1	−11.7	−11.3	+ 1.5	+ 4.1	+ 3.1
Mar.	− 1.0	− 4.0	− 6.8	− 8.0	− 8.7	− 9.5	−11.1	−11.6	− 4.9	0	+ 2.0	+ 2.6
Apr.	− 1.2	− 4.6	− 9.6	−12.2	−13.2	−13.5	−17.1	− 7.2	− 0.5	− 0.1	− 0.4	− 1.1
May.......	− 4.5	− 5.9	− 6.7	− 7.7	− 9.0	−12.1	−17.7	− 8.8	− 4.4	− 2.6	− 1.8	− 2.3
June.......	+ 1.2	− 2.2	− 6.0	− 8.3	−11.6	−18.7	−18.0	− 7.7	− 4.3	− 3.6	− 3.8	− 5.6
July.......	− 2.2	− 5.3	− 7.9	−10.0	−11.1	−17.0	−21.2	− 9.8	− 5.9	− 3.0	− 2.4	− 3.4
Aug.	− 3.0	− 6.0	− 8.7	−11.5	−12.8	−14.3	−19.4	− 9.2	− 4.2	− 2.0	− 0.5	− 1.1
Sept.	− 0.2	− 2.0	− 3.9	− 6.4	− 7.2	−10.1	−17.2	−12.6	− 7.2	− 5.4	− 4.6	− 4.2
Oct.	+ 1.6	− 0.6	− 3.1	− 4.6	− 5.7	− 7.0	−10.6	−15.3	− 8.0	− 4.4	− 2.6	− 3.3
Nov.	+ 7.5	+ 5.1	+ 3.5	+ 1.3	− 1.1	− 3.5	− 6.0	−16.8	−14.5	− 6.4	− 6.1	− 5.9
Dec.	+ 1.8	− 0.3	− 1.0	− 2.0	− 2.4	− 3.4	− 4.4	− 5.3	− 6.8	− 0.7	+ 1.2	+ 1.2
Av. of seventeen months...	− 0.7	− 3.5	− 5.8	− 7.6	− 8.9	−11.1	−13.9	−10.2	− 6.2	− 0.7	+ 0.5	− 0.1

Month	P.M. 1	P.M. 2	P.M. 3	P.M. 4	P.M. 5	P.M. 6	P.M. 7	P.M. 8	P.M. 9	P.M. 10	P.M. 11	Mid-night
May.......	+ 2.3	− 5.5	−11.2	− 9.9	0	+10.5	+15.9	+17.1	+13.1	+ 7.4	+ 2.3	− 2.1
July.......	− 3.8	− 8.2	−12.5	− 9.2	+ 4.9	+20.8	+26.4	+26.7	+24.2	+16.5	+ 9.4	+ 2.6
Aug.	− 2.1	− 8.9	−12.8	− 9.7	+ 7.1	+23.1	+29.6	+28.9	+23.6	+17.1	+ 8.2	+ 1.8
Sept.	− 3.0	− 8.9	−13.3	−13.2	+ 2.9	+19.3	+28.0	+25.0	+19.4	+13.0	+ 8.2	+ 3.4
Nov.	− 2.9	− 6.4	− 8.0	− 9.5	− 4.0	+11.5	+13.4	+10.6	+ 8.7	+ 7.3	+ 4.0	+ 1.7
Dec.	+ 0.5	− 3.5	− 5.5	− 8.0	− 5.2	+ 7.8	+11.2	+11.0	+ 9.8	+ 9.2	+ 3.2	− 1.2
Feb.	− 3.0	−11.1	− 9.8	−11.2	− 9.0	+ 9.3	+21.4	+18.1	+13.0	+ 9.4	+ 6.6	+ 5.1
Mar.	+ 0.2	− 6.6	− 8.5	− 9.8	− 3.4	+13.0	+22.4	+19.8	+15.6	+11.1	+ 7.0	+ 2.3
Apr.	− 4.0	−10.0	−15.4	−12.0	+ 2.1	+19.2	+29.1	+28.4	+21.4	+14.1	+ 7.0	+ 2.4
May.......	− 6.2	−11.2	−15.5	−13.0	+ 3.9	+22.1	+30.4	+31.2	+25.5	+15.0	+ 6.5	+ 0.9
June.......	−10.2	−14.7	−18.7	−13.3	+ 3.3	+18.8	+30.4	+32.2	+26.2	+18.0	+11.8	+ 6.2
July.......	− 3.4	−12.7	−17.4	−14.5	+ 3.6	+21.4	+33.8	+35.0	+28.2	+17.6	+ 9.4	+ 2.7
Aug.	− 4.4	−11.1	−16.0	−11.7	+ 4.4	+24.7	+31.0	+30.6	+20.7	+13.5	+ 8.3	+ 2.1
Sept.	− 7.0	−13.8	−16.6	−14.0	+ 4.7	+23.1	+31.2	+26.7	+19.4	+15.0	+ 8.1	+ 2.8
Oct.	− 4.4	−13.3	−13.9	−14.6	+ 2.4	+22.2	+24.8	+21.8	+16.7	+12.6	+ 7.4	+ 4.1
Nov.	−10.2	−14.0	−15.5	−16.7	+ 0.7	+16.4	+18.4	+16.5	+14.4	+13.2	+12.3	+10.0
Dec.	− 2.6	− 4.4	− 5.3	− 6.5	− 2.4	+ 7.1	+10.3	+ 9.2	+ 6.0	+ 5.4	+ 4.4	+ 3.3
Av. of seventeen months...	− 3.8	− 9.8	−12.9	−11.6	+ 1.5	+17.4	+24.4	+23.3	+18.3	+12.9	+ 7.4	+ 2.8

of records of cloudiness have been made, and such observations as have been made seem to indicate that apart from disturbances caused by clouds and fog there is considerable seasonal variation in the range of electrometer deflection.

Table I (p. 11) gives the monthly means of daily electrometer deflections for seventeen months, the instrument used being the Dolezalek pattern electrometer which gave the smaller range in Figure 1. During this period, the month of December, 1929, was unusually foggy for this climate, the fogs frequently being dense and of long duration. The mean daily range of deflection for the twenty-five days of December for which records were measured was only seventeen millimeters, while the average daily range for the seventeen months was thirty-eight millimeters. On one very foggy

TABLE II

Daily Variation of Deflection of Needle of Electrometer A for Month of May, 1929

Date	A.M. 1	A.M. 2	A.M. 3	A.M. 4	A.M. 5	A.M. 6	A.M. 7	A.M. 8	A.M. 9	A.M. 10	A.M. 11	Noon
1.......	+ 2	— 2	— 5	— 9	—11	—14	—19	— 8	— 4	— 4	— 4	— 6
2.......	+ 1	— 4	— 6	— 8	—10	—13	—19	— 8	— 5	— 8	—13	—19
3.......	— 2	— 3	— 4	— 4	— 3	— 4	—20	— 6	— 3	— 2	— 3	— 4
4.......	0	— 5	— 8	— 9	— 9	—14	—16	— 6	— 4	— 9	—10	— 7
5.......	— 6	— 6	— 9	— 9	— 7	—11	—14	— 4	— 2	— 1	— 1	— 4
6.......	+ 1	— 3	— 7	— 9	—12	—13	—26	—10	— 7	— 7	— 7	— 8
7.......	+ 5	+ 3	— 3	— 6	— 9	—13	—20	—10	— 7	— 6	— 6	— 7
8.......	— 5	— 4	— 5	— 6	— 8	—17	—20	— 9	— 6	— 5	— 4	— 6
9.......	— 1	— 5	—12	—17	—21	—21	—16	— 5	— 2	— 2	— 1	— 3
10.......	+ 4	0	— 3	— 3	— 5	—12	—15	— 3	0	0	+ 1	— 5
11.......	+ 2	0	— 3	— 9	—11	—17	—24	—11	— 9	— 8	— 8	— 8
12.......	+ 5	— 3	— 8	—14	—16	—29	—27	—17	—13	— 7	— 7	— 6
13.......	+ 3	— 1	—12	—17	—18	—18	—14	—10	— 3	+ 1	+ 1	+ 3
14.......	+ 2	— 5	—13	—17	—14	—17	—14	— 9	— 3	— 4	— 3	— 2
15.......	—13	—14	—15	—15	—14	—15	—18	—11	— 2	+ 2	+ 2	0
16.......	—13	—12	— 9	— 1	— 2	—14	—19	— 8	— 1	0	0	— 1
17.......	—10	—15	—17	—18	—18	—18	—18	—15	—12	+ 2	+ 3	+ 1
18.......	— 8	— 9	— 9	—10	—10	—13	—15	—13	— 5	— 5	+ 3	+ 5
19.......	— 7	— 7	— 8	— 8	— 8	— 9	—12	—13	—10	+ 3	+ 7	+ 6
20.......	— 5	— 5	0	+ 1	— 5	—14	—15	— 4	0	— 8	— 5	— 1
21.......	—11	—11	—10	—12	—14	—17	—17	—10	0	+ 1	+ 3	+ 3
22.......	—11	—13	—14	—15	—15	—15	—17	—15	— 6	+ 3	+ 3	+ 2
23.......	—11	—11	—12	—12	—13	—14	—14	— 8	+ 4	0	+ 1	+ 4
24.......	— 3	— 5	— 8	— 9	—12	—19	—18	— 9	— 2	0	0	— 2
25.......	+ 1	— 1	— 3	— 5	— 7	—15	—20	— 9	— 5	— 3	— 2	— 3
26.......	— 1	— 3	— 5	— 7	— 9	—17	—16	— 6	— 4	— 3	— 2	— 3
27.......	— 1	— 2	— 3	— 4	— 7	—13	—15	— 4	— 2	— 2	— 2	— 3
28.......	+ 1	— 2	— 3	— 3	— 7	—17	—21	—11	— 8	— 6	— 6	— 7
29.......	— 4	—11	—16	—10	— 8	—14	—20	— 7	— 5	— 4	— 4	— 4
30.......	— 4	0	— 8	—15	—20	—22	—20	—15	—13	— 2	— 1	— 2
31.......	+ 5	— 4	—11	—11	— 5	— 7	— 9	+ 2	+ 2	— 1	+ 2	+ 1

TABLE II (*Continued*)

Date	P.M. 1	P.M. 2	P.M. 3	P.M. 4	P.M. 5	P.M. 6	P.M. 7	P.M. 8	P.M. 9	P.M. 10	P.M. 11	Midnight
1.......	— 9	—15	—21	—17	+ 4	+25	+35	+32	+25	+20	+10	+ 5
2.......	— 8	—13	—19	—21	— 6	+11	+26	+37	+35	+26	+19	+ 9
3.......	— 9	—16	—18	—12	+ 2	+21	+25	+26	+22	+12	+ 2	+ 3
4.......	—11	—19	—21	—12	+ 7	+26	+31	+32	+29	+22	+14	+ 6
5.......	— 9	—18	—18	—12	+21	+32	+35	+29	+13	+ 5	— 1	— 3
6.......	—12	—19	—24	—17	+ 3	+25	+35	+32	+30	+22	+14	+ 6
7.......	—10	—17	—23	—22	— 2	+20	+28	+31	+27	+21	+16	+11
8.......	— 9	—16	—23	—18	+ 8	+27	+37	+32	+25	+15	+ 5	— 3
9.......	— 8	—17	—16	—17	+ 4	+32	+37	+34	+30	+23	+12	+ 2
10.......	—16	—13	—15	—18	—15	+ 6	+23	+29	+26	+19	+11	+ 8
11.......	—10	—15	—23	—23	— 4	+31	+39	+37	+27	+21	+14	+ 6
12.......	— 9	—14	—20	—24	+ 1	+31	+39	+41	+33	+27	+19	+13
13.......	— 8	— 4	— 9	—14	— 3	+ 2	+20	+32	+31	+23	+14	+ 7
14.......	— 4	—13	—18	—11	+14	+34	+31	+25	+21	+ 8	+ 1	+ 3
15.......	— 6	— 9	— 9	—14	+ 1	+25	+40	+39	+30	+18	— 2	—10
16.......	— 5	—11	—15	—16	+ 8	+25	+31	+30	+24	+15	— 4	—11
17.......	— 6	—13	—13	— 2	+14	+24	+34	+36	+39	+18	+12	+ 3
18.......	+ 5	+ 1	— 6	—10	+ 6	+19	+31	+33	+19	+ 1	— 4	— 7
19.......	— 1	— 2	— 6	— 3	+ 8	+14	+23	+27	+22	+ 4	— 4	— 7
20.......	+ 1	+ 3	+ 1	— 6	—11	— 3	+16	+32	+28	+ 9	— 1	— 5
21.......	— 1	— 6	—11	—12	+12	+26	+30	+32	+25	+12	+ 5	— 5
22.......	— 2	— 8	—12	—10	+10	+34	+37	+33	+26	+16	— 1	— 7
23.......	+ 4	— 2	— 9	— 8	+10	+22	+26	+30	+18	+13	— 2	— 9
24.......	— 6	—11	—17	— 8	+ 4	+20	+32	+32	+23	+13	+ 9	+ 2
25.......	— 7	—13	—20	—12	0	+14	+27	+32	+28	+19	+10	+ 4
26.......	— 7	—14	—17	—11	— 1	+23	+34	+31	+21	+11	+ 7	+ 2
27.......	— 7	—16	—18	—10	+ 8	+23	+29	+25	+15	+ 4	+ 3	+ 1
28.......	—10	—15	—22	— 7	+ 4	+22	+31	+33	+28	+18	+ 7	+ 4
29.......	— 7	—14	—19	—13	+ 6	+27	+34	+33	+27	+16	+ 8	0
30.......	— 7	—13	—18	—15	+ 5	+34	+37	+33	+23	+16	+13	+ 5
31.......	+ 3	+ 4	— 2	—10	+ 2	+10	+12	+10	+ 5	0	— 3	— 4

day, December 19, the total range was only five millimeters. This is the smallest range yet observed on any day.

In order to show the uniformity of variation from day to day, Table II gives the hourly deflection in millimeters from the mean for the day of the electrometer needle as photographed upon a record sheet at a distance of one meter from the instrument. This month is chosen because the daily variations were approximately a mean for the year, and because it is the only month of the seventeen for which a record was obtained for every day.

In Table III (p. 14) the same data are given for the month of December, 1929, which is the most anomalous of the seventeen months under consideration.

It has been assumed that the mean potential of the earth at Palo Alto occurs about 7:00 A.M. and about 3:00 or 4:00 P.M., the time when the electrometer needle is in its position of nearest approach to the quadrants, and that its deflection from this position is due to both it and the quadrants becoming charged relative to the earth. It cannot be assumed that this condition of mean potential is of the same magnitude at all seasons of the year, since the negative charge of the earth must always be greater on the hemisphere which is turned from the sun; but it has been observed that its time of occurrence does not vary greatly with the season. Accordingly, the deflections of the electrometer needle have been measured from the mean of these two positions of no deflection. In Figure 2, the mean daily deflections for the months of May and December, 1929, are shown in this manner. The continuous curve shows the mean daily deflection for May and the dashed curve that for December.

The effect of rainy, as distinct from foggy, days upon the electrometer deflection may be seen in the June, 1929, records. In this month there were eight days upon which there was some precipitation, though at no time was there an important rainfall. In Figure 3 (p. 18) the mean daily electrom-

TABLE III

DAILY VARIATION IN DEFLECTION OF ELECTROMETER A FOR DECEMBER, 1929

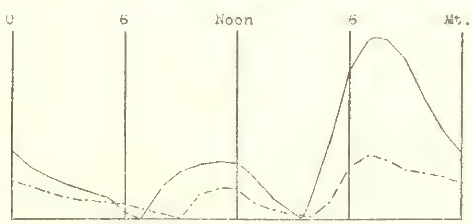
Date	A.M. 1	A.M. 2	A.M. 3	A.M. 4	A.M. 5	A.M. 6	A.M. 7	A.M. 8	A.M. 9	A.M. 10	A.M. 11	Noon
7.......	— 8	— 9	— 9	— 9	— 9	— 9	— 8	— 8	— 9	+ 4	+ 5	+ 4
8.......	— 4	— 4	— 4	— 4	— 4	— 3	— 3	— 3	— 3	— 3	— 1	+ 4
9.......	— 3	— 3	— 3	— 1	— 1	+ 4	— 2	— 3	— 1	+ 4	+ 8	+ 8
10.......	0	0	0	0	0	0	0	+ 2	+ 1	+ 4	+ 4	+ 2
11.......	+ 4	+ 5	+ 4	+ 5	— 1	— 5	— 5	— 4	— 1	— 4	— 5	— 5
12.......	— 2	— 2	— 2	— 2	— 2	— 2	— 2	— 2	— 1	+ 7	+ 6	+ 7
13.......	+ 3	+ 2	— 3	0	+ 8	+ 7	+ 3	+ 2	— 3	— 1	0	0
14.......	— 1	0	— 8	— 9	— 9	— 8	— 7	— 8	— 6	+ 5	+ 5	— 1
15.......	+ 4	+ 5	— 1	— 5	— 7	— 7	— 7	— 7	— 7	— 1	0	0
16.......	— 3	— 2	— 2	— 2	— 3	— 3	— 2	— 2	— 3	— 3	— 1	+ 5
17.......	— 2	— 2	— 3	— 3	— 3	— 3	— 3	— 3	— 2	0	+ 5	+ 6
18.......	— 1	— 2	— 1	— 1	— 1	— 2	— 2	— 1	— 2	+ 2	+ 5	+ 4
19.......	0	0	0	0	0	0	0	0	0	—10	— 6	— 3
20.......	+ 3	+ 2	+ 1	0	+ 2	+ 3	+ 4	— 4	—12	0	+ 1	0
21.......	— 6	— 5	+ 4	0	+ 5	+ 2	0	— 3	—13	— 5	— 2	— 1
22.......	+ 7	+ 4	+ 3	— 4	+ 2	0	—13	—13	—11	0	+ 4	+ 3
23.......	+ 4	—10	— 9	— 7	— 4	— 9	— 9	—10	— 7	0	+ 2	+ 3
24.......	+14	— 6	— 8	— 7	— 7	— 5	— 7	— 7	— 7	+ 2	+ 4	+ 2
25.......	+ 5	0	— 6	— 8	— 8	— 8	— 9	— 8	— 7	— 3	0	+ 3
26.......	— 8	— 8	— 3	+ 4	+ 4	+ 1	+ 1	— 1	— 7	— 3	0	+ 3
27.......	+11	+ 4	+ 6	— 7	—14	—14	—14	—14	—15	— 3	— 2	— 5
28.......	+ 3	+ 3	+ 2	+ 1	— 1	— 3	— 3	— 8	—18	— 7	— 6	— 7
29.......	+12	+10	+ 9	+ 5	+ 7	+ 5	+ 2	— 2	—14	— 3	— 2	— 3
30.......	+ 8	+ 6	+ 6	+ 6	— 1	—13	—14	—14	—14	— 2	— 1	— 3
31.......	+ 8	+ 6	+ 2	— 2	—12	—13	—11	—11	— 9	— 2	0	0

TABLE III (*Continued*)

Date	P.M. 1	P.M. 2	P.M. 3	P.M. 4	P.M. 5	P.M. 6	P.M. 7	P.M. 8	P.M. 9	P.M. 10	P.M. 11	Mid-night
7.......	0	— 3	— 5	— 8	+12	+19	+21	+14	+15	+ 9	— 9	— 9
8.......	+ 4	+ 1	— 2	— 3	+ 2	+ 9	+17	+ 9	+ 3	+ 4	— 4	— 3
9.......	+ 5	+ 5	+ 4	— 1	— 3	+ 1	+ 1	— 2	— 3	— 3	— 3	— 3
10.......	0	— 1	0	0	0	0	0	— 1	— 1	— 1	— 1	0
11.......	— 5	— 3	— 2	— 3	— 4	— 2	+ 3	+ 4	+10	+ 6	+ 6	+ 6
12.......	+ 6	+ 4	+ 2	— 2	— 1	+ 2	+ 1	— 2	— 2	— 2	— 2	— 2
13.......	+ 2	+ 2	0	— 3	— 3	— 1	+ 1	0	— 3	— 2	— 3	— 3
14.......	— 7	— 6	— 8	— 3	+13	+17	+15	+13	+ 5	— 5	0	+ 2
15.......	— 1	— 3	— 4	— 6	— 3	+ 8	+10	+16	— 3	0	+10	+ 9
16.......	+ 6	+ 3	+ 1	— 2	— 1	+ 7	+11	+ 9	— 2	— 3	— 3	— 2
17.......	+ 1	— 2	— 3	— 2	+ 1	+10	+10	+ 6	+ 1	— 1	0	— 2
18.......	+ 4	+ 2	+ 1	— 1	— 1	+ 1	+ 1	0	— 1	— 1	— 1	— 1
19.......	+ 3	+ 4	+ 2	0	0	+ 2	+ 4	+ 2	0	0	0	0
20.......	—10	—12	—10	—10	— 2	+ 8	+10	+10	+11	+10	+ 5	+ 5
21.......	— 9	—12	—12	—12	— 1	+17	+16	+ 9	+ 8	+ 9	0	— 6
22.......	— 6	— 9	—12	—13	— 8	+12	+13	+14	+12	+10	+11	+ 9
23.......	— 5	— 8	— 9	— 9	— 1	+ 9	+13	+14	+12	+13	+12	+13
24.......	+ 2	— 1	— 6	— 7	— 7	— 5	+ 4	+11	+13	+13	+14	+13
25.......	— 7	— 9	— 6	— 4	+ 8	+ 9	+ 8	+13	+12	+10	+ 6	+ 7
26.......	+ 1	— 2	— 3	— 5	— 7	+10	+ 5	+ 5	+ 7	+ 5	+ 6	— 6
27.......	—13	—13	—13	—16	+ 2	+21	+21	+16	+15	+15	+17	+14
28.......	— 9	—12	—16	—19	—14	+19	+24	+18	+15	+13	+10	+ 7
29.......	— 9	—13	—11	—13	—15	+13	+16	+13	— 8	0	+12	+14
30.......	—12	—13	—10	— 9	—14	0	+17	+18	+17	+15	+13	+12
31.......	— 5	—10	—12	—13	—13	— 9	+16	+21	+18	+18	+13	+ 9

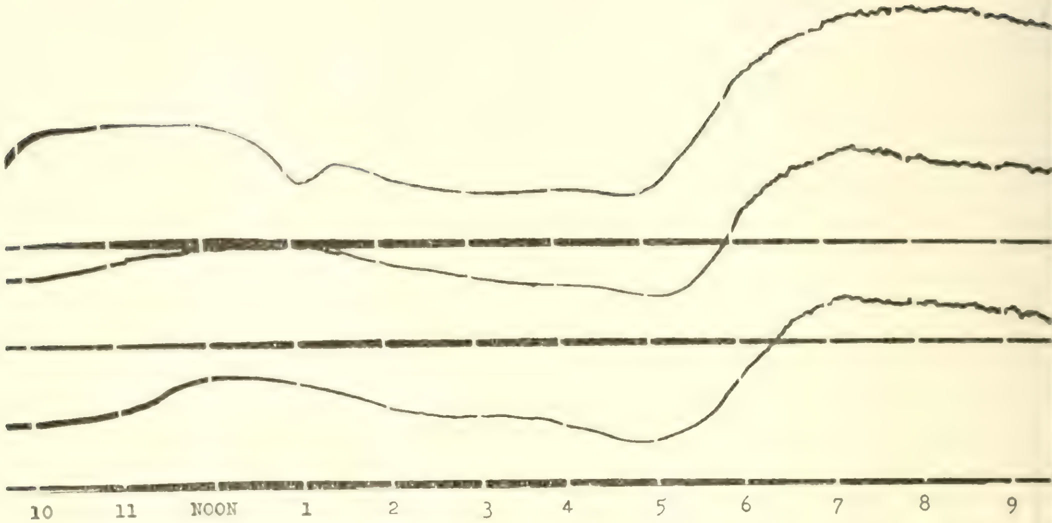
eter variation for the eight days upon which there was observable precipitation is shown by the dashed curve, and the mean variation for eighteen days without precipitation is shown by the continuous curve.

FIGURE 2

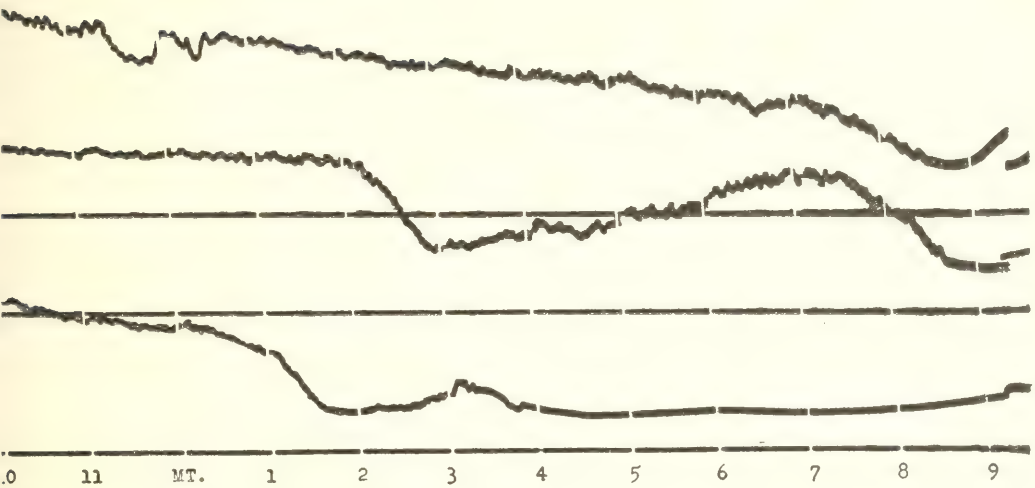


Relative magnitudes of the deflections of the needle of Electrometer A for the months of May and December, 1929. The continuous curve shows the mean daily range of deflection for May, and the dashed curve the range for December.

Lunar electrostatic induction.—In previous volumes of this *Bulletin* attention has been called to the effect of the moon's electrostatic induction

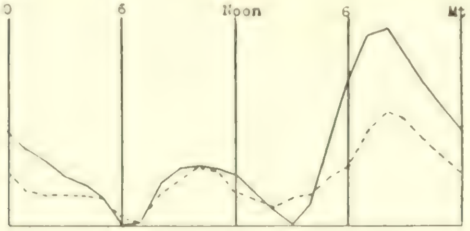


Copy of photographic record for three successive days of
and the remaining pair and needle connected, uncharged and
the copy three-fifths of the original.



ections of electrometer A with one pair of quadrants removed
ated inside a metal case in a grounded wire cage. Scale of

FIGURE 3



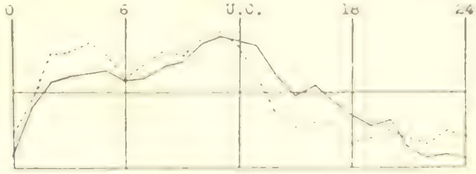
The continuous curve shows the mean daily electrometer deflection for eighteen days without precipitation, and the dashed curve shows the mean deflection of the same instrument for eight days upon which there was noticeable precipitation, both in June, 1929.

upon the earth. This effect is also shown by the present arrangement of apparatus; but less plainly than by the earlier methods, and the daily range of deflection due to the moon's induction seems to bear a smaller ratio to that of the sun than it has in past experiments when a charged electrometer needle was used.

In order to test for the lunar effect, the deflections which have been measured at hourly periods throughout the solar day must be distributed according to lunar hours. For this purpose the measurement which was made nearest the time of the moon's upper culmination is taken as the mid-hour of the lunar day. The time of this measurement may vary as much as thirty minutes on either side of the time of upper culmination. Then, unless every hour of a synodical period is used in the determination of the mean daily deflection, a considerable error is introduced, due to the much greater magnitude of the solar than of the lunar deflection. Unfortunately, it was difficult to find complete synodic periods without any missing days.

In Figure 4 the continuous line gives the mean lunar diurnal variation

FIGURE 4



Lunar diurnal variation of Electrometer A. The continuous curve shows the mean lunar daily electrometer deflection for three synodic periods, and the dashed curve shows the mean deflection for one hundred and ninety-six lunar days taken without regard to synodic periods.

for three synodic periods, and the dashed curve gives the mean lunar diurnal variation for one hundred and ninety-six days taken without reference to synodic periods. The mean range of daily variation for the continuous curve is four and three-tenths millimeters.

Some bearings of the observations upon electrical theory.—It seems that the observations described above are conclusive as to the electrostatic induction of the sun upon the earth, and that no more direct proof of the electrical charge of the sun can be hoped for. They likewise show conclusively that *what we call electrification is a condition depending upon the electrical state of the body relative to the earth,* and that we know nothing whatever regarding a condition known as "absolute electrical neutrality." Our modern atomic theories which are based upon the assumption of perfect equality in the number and magnitude of two kinds of elementary electric particles in every complete atom has no basis in experimental fact. An atom which is "neutral" upon the earth might be a highly charged atom upon some other planet or sun, and vice versa. Attention has been called in earlier volumes of this *Bulletin** to evidence that atoms which are highly charged upon the earth may be uncharged in some of the stars and nebulae, and even upon our own sun. It is the hope of the author to discuss these matters further in a monograph on the subject of "Terrestrial Electricity," upon which considerable work has already been done.

Daily variation in atmospheric pressure and the distribution of the earth's surface charge.—In a paper published in *Science* for April 19, 1929, the question is raised as to a possible influence of the variation of the earth's surface charge upon atmospheric pressure. We have seen that one of the necessary conclusions resulting from the observations described in the foregoing pages is that every body insulated from the earth in lower or middle latitudes necessarily becomes electrically charged twice each day, once positively and once negatively. This statement must apply to the gases of the air as well as to small particles floating in the atmosphere.

The charges acquired by the molecules of the air do not involve any physical change in them, but result wholly from the changes which take place in the earth's electrostatic field. Hence, without any change in their electron or proton content, every so-called neutral molecule in the earth's atmosphere must be attracted toward the earth twice daily. Also, every such molecule in the earth's atmosphere must repel every other similar molecule in its vicinity twice each day. Can these conclusions be further verified by observing any results of the molecular charges?

There are two phenomena in connection with the daily variation of atmospheric pressure which have never been satisfactorily explained; namely, the times of occurrence of the morning and evening maxima and the cause of the twelve-hour pressure wave. Both phenomena are very uniform over the earth. Regarding this uniformity, Hann tells us:

---

* Volume IV, page 22.

No other meteorological element has so regular a daily period as the atmospheric pressure; and this in spite of the fact that the amplitude of this daily variation is relatively small, ranging from two or three millimeters in the tropics to a few tenths of a millimeter at 60° latitude. The daily period is double; the atmospheric pressure reaches twice daily a maximum and twice a minimum, and, where the daily atmospheric pressure is least disturbed, both maxima and minima are very much alike. This is very different from the daily range of other meteorological elements, and suggests the ebb and flow of the sea, for which reason these waves have been called atmospheric tides. In spite of their resemblance in form, an important difference in the two phenomena appears in that the atmospheric ebb and flow follows the sun and occurs according to true local time, and that no lunar influence is perceptible in it. Accordingly it can not be a gravitation phenomenon, since in that case the lunar period would be much more strongly marked than that of the sun.

The phenomenon has, accordingly, a much greater theoretical interest than the daily periods of the other meteorological elements, which, although much less simple and locally much more variable, yet can be definitely shown to depend upon the conditions of insolation. Practically, on the contrary, the daily barometric variation, on account of its minuteness, is of little significance and can scarcely be related to any consequences, while the daily period of temperature, for example, is regarded as of great importance and occupies a very conspicuous place in the domain of meteorology.*

A remarkable characteristic of the semi-diurnal barometric variation is the regularity of the occurrence of the maxima and minima and their uniformity in time of day in all latitudes. While the amplitude of these waves may vary greatly with latitude, with elevation, and with location, whether over the sea or over the land, the local times of maxima and minima are very constant. This is true also for the different periods of the year, though the amplitude of variation is everywhere greatest at the equinoxes and least at the solstices.

In this regular daily variation of atmospheric pressure there is a forenoon maximum which occurs quite uniformly from nine to ten o'clock wherever it has been recorded. This is a time of day when we should expect a low, instead of a high, barometer. It is customary to attribute a falling barometer over a given region to vertical atmospheric convection caused by the heating of the air over that region. Since the temperature of the lower air depends principally upon that of the surface of the earth beneath it, we look for a low barometer over the warmer regions of the earth.

The lowest temperature of the air over the land occurs about four o'clock in the morning and over the sea it occurs about midnight, or a little later. From this time forward the temperature of the air rises until nine or ten o'clock in the forenoon. Both the temperature and the barometric pressure rise most rapidly about seven or eight o'clock in the morning. During this time convection becomes well established. So it follows that over regions where the atmosphere near the surface is lighter the barometric pressure is greater than over surrounding regions where the surface

* Hann, *Lehrbuch der Meteorologie*, page 177. Translation by the present writer.

atmosphere is heavier. We know it is heavier, because it is displacing the air over the regions where the barometer stands higher, otherwise there could be no convection over these regions.

One attempt to explain this paradox which had the approval of a number of well-known meteorologists seems to have been first proposed by Espy, in 1840. It is based upon the assumption of a manometric effect of the heated air near the ground, which was supposed to be hindered in its expansion by the heavier air above it and could not, for that reason, distribute its pressure to the higher air, and hence caused the barometer to register a higher pressure than it would if the compression could be distributed to the whole vertical column of air. This seems to assume that the air resting upon the heated volume below must all be forced upward as a rigid body, and that it does not diffuse into the surrounding air as a result of its compression but can only spread out at the top of the atmosphere. Then, while the expanding volume below is giving an acceleration against gravity to the cooler mass above it, it is supposed to react upon the earth and thus increase the barometric pressure.

Now it is well known that the distinguishing characteristic of an elastic body is that it reacts to a stress in such a manner as to distribute the stress uniformly throughout the whole body. The rate at which a stress is distributed is the rate at which an elastic wave will travel through the medium. In the case of a gaseous body, the rate at which a compression will be distributed throughout the whole volume is the rate at which a compressional wave will travel through the gas. This rate for an isothermal compression is given by the equation $V^2 = \frac{E}{D}$. Accordingly, a compression set up in our atmosphere, even at a temperature of $-20°C.$, will be distributed throughout the whole atmosphere at a speed of a little more than eight hundred feet in a second, more than nine miles in a minute.

At a height of twenty-four miles above the earth the atmospheric pressure is only one six-hundredth as great as it is at the ground. A compression at the ground would be distributed through a vertical column twenty-four miles high in two and seven-tenths minutes, even at the low temperature specified.

The rate of temperature change in the lower atmosphere is, in equatorial regions, generally less than two degrees an hour. If a complete vertical column of air were confined and heated at this rate, its pressure would increase by about five millimeters an hour, or by about one-fourth of a millimeter in the time which would be required for the pressure to be uniformly distributed from the lower end of the column.

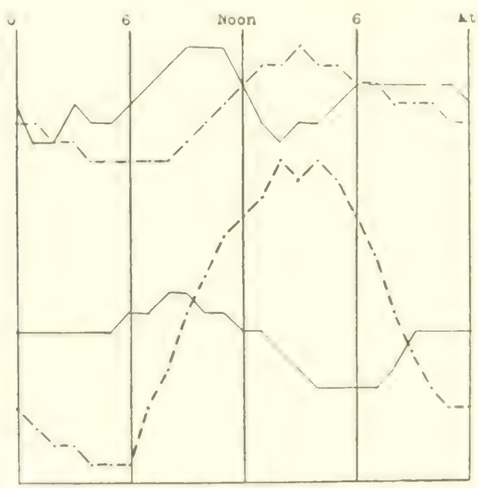
Untenable though the proposed explanation is seen to be, it crops out in a slightly modified form in our most important American textbook on Meteorology. In this case, it is assumed that the surface winds on the earth are dammed up whenever they flow into a region of vertical convection, and thus set up an excessive barometric pressure due to their decrease of speed. Thus the author says:

> It is obvious that the more active vertical convection becomes, the greater will be its interference with the flow of the atmosphere, the more 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.*

As a proof of this "obvious" statement, the author shows that if air which is moving slowly over the earth should rise and be replaced by higher air which is moving more rapidly in the same direction, and if the colder air after settling down to earth should have its velocity decreased by ground friction, the resultant velocity of the whole volume of air under consideration would be less than it was before. This is supposed to slow down the surface air which was following, and to cause it to be compressed, although from the premises the exchange of positions of the slower volume below with the faster volume above should increase the velocity of the surface winds.

It is not profitable to spend time on the discussion of these explanations of the ten o'clock barometric maximum. Both of them are based upon the assumption that this maximum is, in some manner, brought about by the

FIGURE 5



The upper pair of curves show the mean daily range of temperature and barometric pressure at Toronto for the month of January, 1927, and the lower pair show the same data for the month of July, 1927. The continuous curves represent the barometric variation and the dashed curves the temperature.

* Humphreys, *Physics of the Air,* page 236.

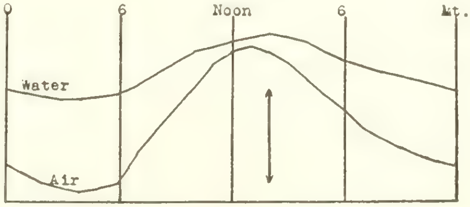
rapid convection of the air at this time of day, while it is possible to show that this particular barometric maximum is wholly independent of convection and is, in fact, most plainly marked in regions where convection is least.

For example, the Meteorological Service of Canada has published monthly statements of the hourly variations of barometric pressure and of temperature for every day in the year and for a number of stations. The curves in Figure 5 give these data for the months of January and July, 1927, at Toronto. The upper pair of curves show the mean daily variation of barometric pressure and temperature for thirty-one days in January, and the lower pair of curves show the same data for thirty-one days in July. Both sets of curves are drawn to the same scale. The continuous curves show the barometric pressure and the dashed curves show the temperature. The mean daily temperature for January was twenty-two degrees Fahrenheit, and for July it was sixty-eight degrees.

It will be seen from these data that while the mean daily range of temperature was nearly three times as great in July as in January, the ten o'clock barometric maximum was higher in January than in July. Half the forenoon barometric rise in both months occurred while the temperature was at the lowest point for the day, and, consequently, before convection could have begun. The same phenomenon is shown in the data for the coldest day in January, when the highest barometric pressure for the day occurred at ten o'clock in the morning while the temperature was six degrees below zero.

On page 61 of Hann's *Lehrbuch der Meteorologie* are given tables showing the mean daily variations of summer temperature of the water and the air at 0°–10° N. and at 30° N. over the Atlantic, as taken from the records of the Challenger Expedition. In Figure 6, the curves for daily variation of water and air temperatures at 4°.5N. are shown. The vertical line drawn at two o'clock P.M. represents one degree Centigrade, showing that the maximum difference in temperature of the air and water was approximately one degree, the water being always warmer than the air. Since this maximum temperature difference occurred at four o'clock in

FIGURE 6

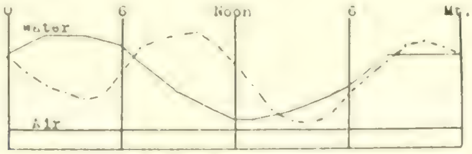


Mean daily relation of air temperature to water temperature over the ocean at 4°.5 N. latitude. The vertical line at 2:00 P.M. represents one degree Centigrade.

the morning, whatever convection there was should have been greatest at this time.

The same temperature difference between the air and the water is shown in a different manner in Figure 7, the air temperature being taken

FIGURE 7



Excess of water temperature over air temperature compared with the daily range of barometric pressure over the ocean at 4°.5 N. The continuous curve indicates the temperature and the dashed curve, the barometric variation.

as the base line from which the water temperature is measured. The same scale is used as in Figure 6. The dashed curve in Figure 7 shows the daily variation in barometric pressure in summer over the same region, taken from page 178 of Hann's *Lehrbuch.* It will be seen that the barometric pressure has no appreciable relation to whatever convection may be caused by the temperature difference between the air and the water.

A comparison of the barometric data over this region and over inland regions farther north shows that the morning barometric maximum is as high over the ocean in equatorial regions as it is over the land where the daily temperature variation is ten times as great and where the maximum temperature for the day occurs more than twelve hours later. These facts seem to suggest some other agency than convection as the cause of the morning barometric maximum and of the twelve-hour variation in barometric pressure as observed over the ocean in equatorial regions.

Hann says:

> The daily range of temperature of the air over the ocean is practically independent of temperature changes in the surface of the water. The air can give off no heat to the water at night which it has absorbed from the water during the day. The daily range of air temperature over the ocean must depend, in the main, upon the absorption of the sun's rays and the radiation to the sky. It is easily to be seen that under these conditions the temperature range must be very small.*

Convection depends upon the heating of the air by the earth below it. If there is any convection over the ocean, it must be principally in the early morning hours, and the low barometer which occurs at this time suggests such a possibility. There seems no reason to doubt that the vertical convection caused by heating the air near the ground does cause a decrease in barometric pressure; hence there must be a daily variation

* *Loc. cit.*, page 61.

in barometric pressure due to the daily change in temperature of the air near the ground. Such a variation should produce a twenty-four-hour wave, and not a twelve-hour wave such as is observed over the ocean in low latitudes. This fact has long been recognized, and there have been various attempts to separate the twenty-four-hour convectional wave from the total barometric wave for the day. These attempts have hitherto been unsuccessful. Hann says, in discussing the two systems of waves:

> The whole day wave is subject to very great local disturbances, so that it is very difficult to separate the universal terrestrial remainder of the same from these disturbances. . . . .
>
> The half-daily wave is the principal phenomenon, and has a very regular course, such as is not to be found in any other meteorological phenomenon. For this reason, an unknown cosmical cause has sometimes been assumed as its explanation.*

The twelve-hour barometric wave is, then, a hitherto unexplained phenomenon. The one attempted explanation which has acquired some standing among meteorologists is based upon a surmise by Lord Kelvin that the atmosphere as a whole may have a natural twelve-hour period of oscillation, and that this might cause the twelve-hour wave to be set up by the twenty-four-hour wave. A number of learned mathematical papers have been written on this subject, and some meteorologists seem to find a satisfactory explanation in it; but it would seem not to require any excursion into higher mathematics to decide that the twelve-hour barometric fluctuation is not due to a natural oscillation of the atmosphere. In the first place, such an oscillation would have fixed nodes ninety degrees apart upon the earth. The atmosphere cannot oscillate as an elastic sphere, since it forms a very thin compressible skin over the surface of an incompressible globe. Any compression set up in a part of this elastic layer must travel around the earth as a compressional wave at a speed of less than ten miles a minute, and would require more than forty hours to travel around the earth at the Equator.

Again, a compressional wave would not follow the parallels of latitude, but would spread out in all directions with equal speed so long as it was in a region of uniform temperature; hence places on the same meridian would not be in the region of maximum pressure at the same time. As it is, all places on a given meridian from one polar circle to the other have maximum barometric pressure at the same actual time, and a similar pressure belt extends in the same way along the meridian 180° distant. The barometric pressure belt, whatever its cause, extends entirely around the earth in a meridional direction. But it does not rotate with the earth, but remains fixed relative to the sun, while the earth rotates under it. As the earth rotates from west to east the barometric pressure wave moves around it from east to west.

* *Loc. cit.*, page 192.

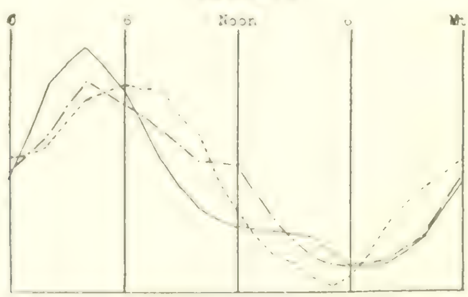
Although the twelve-hour wave and the twenty-four-hour wave have not hitherto been separated, if it be true that we have a region over the ocean where the barometric variations are independent of convection, it would seem that the inland convectional wave in the same latitude might be determined by subtracting the oceanic barometric wave from the total barometric wave inland. Unfortunately, land and sea curves for barometric variation in lower latitudes are not at hand at the time of this writing. Hann gives data on the barometric variation over the ocean at 33°N. and at Zurich, Switzerland, which is more than ten degrees farther north. If the oceanic curve be subtracted from the Zurich curve we should have left a curve approximating that due to convection at Zurich. The resulting curve is a twenty-four-hour curve, showing a maximum barometric pressure at 4:00 A.M., the coldest part of the day, and a minimum pressure at 6:00 P.M. The maximum rate of decrease of pressure occurs between 6:00 A.M. and 8:00 A.M., the period of maximum rate of increase of temperature.

Hann also gives data on two other pairs of curves which may be used to throw light on our problem. In order to compare inland and oceanic stations in nearly the same latitude he selects the Island of Jersey and the station at Kalocsa on the Danube Plain in Hungary. When the curve showing the barometric variation at Jersey is subtracted from the Kalocsa curve, a twenty-four-hour curve is obtained similar to the one obtained by subtracting the ocean curve from the Zurich curve, the maximum and minimum pressures occurring at the same time in both cases.

Another curve showing the difference between inland and coast stations may be had by subtracting the curve showing the daily variation of barometric pressure at Valentia Island, on the coast of Ireland, from the corresponding curve at Greenwich.

The three twenty-four-hour curves formed in this manner are shown in Figure 8. The continuous curve represents the Zurich–ocean curve, the

FIGURE 8



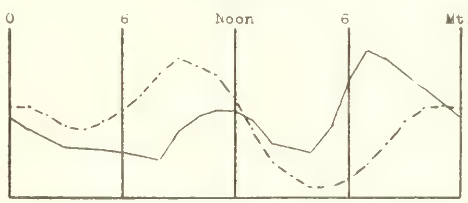
Three twenty-four-hour barometric curves derived by subtracting oceanic barometer curves from inland curves.

long-dashed curve represents the Kalocsa–Jersey curve, and the short-dashed curve the one for Greenwich–Valentia. Each probably represents with some degree of approximation the twenty-four-hour convection curve at the respective inland station, but none of them is probably a very accurate representation of this curve. However, it seems probable that if true oceanic curves could be compared with inland curves for the same latitude a close approximation to the true convection curves could be obtained.

Attempted explanation of the twelve-hour barometric wave.—It seems evident that the inland barometric wave consists of a twenty-four-hour wave due to convection and a twelve-hour wave which is independent of convection. This twelve-hour wave is hitherto unexplained, and the main purpose of the present discussion is to inquire if it may be due to the semi-diurnal attraction by the earth's charge of the air molecules and the floating particles of water and dust in the air, combined, perhaps, with the repulsion of these particles for each other.

The daily electrometer and barometer curves do not closely resemble each other, as may be seen from Figure 9, in which the continuous curve

FIGURE 9

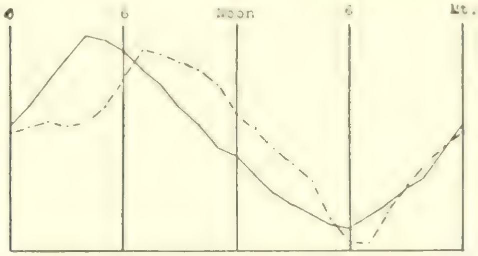


Comparison of electrometer and barometer curves at Palo Alto for March, 1929. The continuous curve shows the electrometer deflection, and the dashed curve shows the mean daily barometer range for the same days.

represents the diurnal electrometer deflections and the dashed curve shows the daily barometer variations at Palo Alto for the same period, March, 1929. However, when it is recalled that the electrometer deflections indicate a decrease of the mean surface charge of the earth between 8:00 A.M. and 4:00 P.M., it will be seen that during this time the barometer is falling, while it is rising during the whole time of increase of the earth's negative charge. This seems to indicate that the atmosphere near the earth is, on the whole, electropositive to the earth, a fact which has long been known. When the earth becomes less electronegative and the atmosphere becomes less electropositive, the barometric pressure is correspondingly decreased.

In Figure 10 (p. 28) the continuous curve gives the mean of the three twenty-four-hour curves shown in Figure 8 and the dashed curve shows a twenty-four-hour curve given by subtracting the mean daily electrometer curve for five months from the mean daily barometer curve at Palo Alto for the same period.

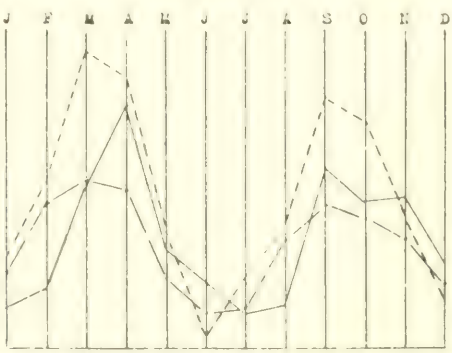
FIGURE 10



Comparison of the mean of the three twenty-four-hour barometer curves of Figure 8 with a curve derived by subtracting the mean daily electrometer curve for five months from the mean daily barometer curve for the same period. The continuous curve is the mean of the three curves of Figure 8, and the dashed curve is the Palo Alto curve.

There are, no doubt, many other resemblances between the daily electrometer curve and the twelve-hour barometer curve which will be observed when the two curves are better known. On page 234 of *Physics of the Air,* Humphreys mentions a number of characteristics of the semidiurnal barometric variation. Among them is the fact that the barometric variations are less on cloudy days than on clear days, which we have also seen to be true of the electrometer variations. Another statement is that the amplitude of the barometric variations is everywhere greatest at the equinoxes and least at the solstices. That the same is true of the amplitude of the earth-potential variations was shown in Volume V of this *Bulletin.* In Figure 11 the curve there given for the monthly mean daily ranges of

FIGURE 11

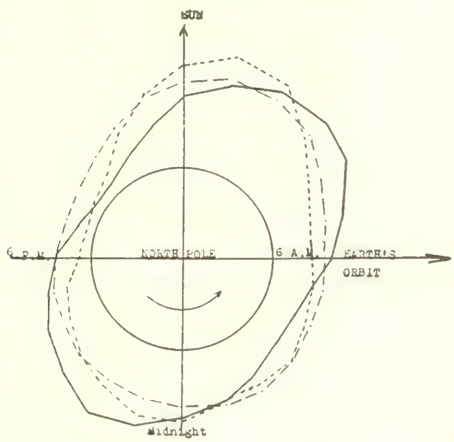


The monthly mean daily range of electrometer deflections for 1927 compared with two curves showing the monthly ranges of daily barometer variation for stations in Europe. The continuous curve shows the electrometer deflections.

electrometer deviations for the year 1927 is compared with two curves for monthly range of daily barometric variations. The continuous curve is for the monthly mean daily range of electrometer deflection for 1927, the long-dashed curve is the monthly range of the twelve-hour barometric wave for the four stations, Milan, Turin, Modena, and Rome, as given by Hann (page 190), and the short-dashed curve is the mean daily range of barometric pressure for the different months for eight stations in Europe, as given by Arrhenius, *Kosmische Physik,* page 603.

Relation of barometric wave to earth-currents.—In the Bidlingmaier diagram of Figure 12 the continuous curve represents the mean continuous

FIGURE 12



The continuous curve represents the mean continuous distribution of atmospheric pressure around the earth in equatorial latitudes, the long-dashed curve represents the mean intensity of the W–E earth-current around the parallel of Berlin, and the short-dashed curve represents the mean intensity of the total resultant earth-current around the parallel of Tortosa, Spain.

distribution of barometric pressure around the earth in equatorial regions, the long-dashed curve represents the intensity of the W–E earth-current around the parallel of Berlin for four years, as given by Weinstein,* and the short-dashed curve shows the mean distribution of intensity of the total resultant earth-current at Tortosa, Spain, for the years 1910–26, as given by Puig.† The resemblance of the three curves seems close enough to indicate a physical relation between the phenomena which they represent.

Atmospheric potential gradient and barometric pressure. — Resemblances between the daily variations in barometric pressure and the atmospheric potential gradient have frequently been observed, and attempts have

* *Die Erdströme, Tafel 1.*

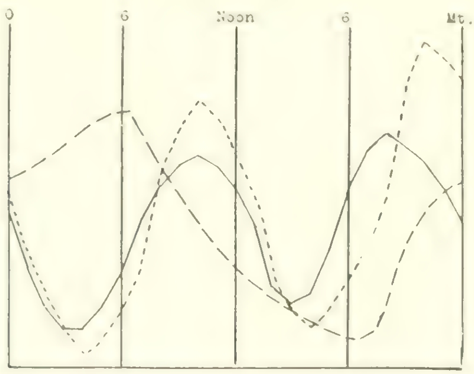
† Puig, *Las corrientes teluricas en Tortosa,* page 72.

been made to explain the potential gradient variations by the movements of atmospheric ions caused by vertical convection. The comparisons which have hitherto been made between these two phenomena have always taken into consideration the total barometric variation, which was assumed as due to convection.

It has been shown in the preceding pages that the convectional barometric variation gives a twenty-four-hour wave, while it is well known that at low altitudes the potential gradient variation gives a double wave in twenty-four hours. This would seem to indicate that if the potential gradient variation is related to either of the barometric waves it must be to the twelve-hour wave, which is not due to convection.

This is shown very clearly when the two barometer waves are compared with the potential gradient wave. In Figure 13 the continuous curve shows

FIGURE 13



Comparison of the daily variation of air-potential gradient at Kew with the twelve-hour and twenty-four-hour barometric curves. The continuous curve represents the mean daily variation of air-potential gradient at Kew. The short-dashed curve gives the mean daily variation of barometric pressure at Jersey, and the long-dashed curve shows the twenty-four-hour curve derived by subtracting the Jersey barometric curve from the barometric curve at Kew.

the mean daily variation in atmospheric potential gradient at Kew* for the year. The nearest ocean station to Kew for which data are at hand is the Island of Jersey. The short-dashed line shows the mean daily variation of the barometer at Jersey, and the long-dashed line shows the convectional barometer wave at Kew as nearly as it can be determined by subtracting the Jersey curve from the total barometer curve at Kew. Attention is called to the agreement of this curve with the three convectional barometer curves shown in Figure 8. It is readily seen that the potential gradient curve bears no appreciable relation to the convectional barometric curve.

* Mache und von Schweidler, *Die Atmosphärische Elektrizität*, page 30.

On the other hand, it bears much the same relation to the twelve-hour Jersey curve that the latter does to the earth-potential curve. The relation of the earth-potential and air-potential gradient curves has been considered on pages 16–17 of Volume II and on page 17 of Volume III of this *Bulletin.*

Funds for the publication of this volume have been provided by the Committee on University Publications, Stanford University.