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# A POSSIBLE EFFECT OF ATMOSPHERIC CIRCULATION IN THE DAILY VARIATION OF THE EARTH'S MAGNETIC FIELD. II.

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## ABSTRACT

Seasonal features that are not related in a simple way to solar declination occur in the daily variation of the horizontal intensity of the earth's magnetic field at Tucson, as at Honolulu studied previously. They are studied here in quiet-day data averaged over 11 years. The nature of these features suggests that they may arise from the seasonal variation of the large-scale air circulation in the lower ionosphere, and that they may offer the possibility of utilizing regular geomagnetic observations in meteorological research.

## 1. INTRODUCTION

There are seasonal features in the daily variation of the earth's magnetic field that are not related in a simple way to solar declination. The author believes that features of this kind may arise from large-scale air circulation (large-scale prevailing winds) in the lower ionosphere. Such circulation should modify, from day to day and from month to month, the solar-produced daily-periodic ionospheric winds which, it is generally accepted, lead to the daily variation of the earth's magnetic field. The magnetic variation is caused by the relatively small superposed magnetic fields of electric currents which these winds generate in the lower ionosphere by dynamo action as they move the electrically conducting air across the main magnetic field.

Certain such seasonal features in the daily variation of the field at Honolulu have recently been discussed by the author [11]. The present paper [1] concerns features of this kind that occur in the daily variation of the field at Tucson, Ariz. Rooney [4] earlier called attention to diurnal variation anomalies at Tucson.

Introductory to the material that follows the author would like to describe qualitatively, as they appear to him, some implications of the dynamo theory of the daily variation of the earth's magnetic field from the point of view of possible effects of atmospheric circulation.

The daily variation of the field depends essentially on three factors, the movement of the air, the electrical conductivity of the air, and the magnetic field of the earth that is cut by the moving air. The conductivity of the air depends primarily on the time of day, since the intensity of photoionizing solar radiation in the lower ionosphere, which is the main source of the conductivity, depends on solar altitude and is greatest near midday. A cap of relatively dense ionization in the lower ionosphere centered approximately under the sun moves each day from east to west around the earth with the sun, enhancing the daytime (relative to the nighttime) effects of the winds that produce the daily variation of the field. At the same time a cap of heating in the upper atmosphere due to the solar radiation absorbed there moves in the same way around the earth under the sun contributing to the daily-periodic winds of the lower ionosphere and to the winds of the atmosphere in general. The parallel of latitude around which the center of this enhanced ionization and this heating moves each day changes of course with time of year, as it does for the sun itself.

[1] The author would like to repeat the first footnote of the previous paper: Concerning the general subject of regular motions of air in the ionosphere and their geomagnetic relationships the reader is referred to an article by Chapman [1]. The reader's attention is also called to articles by van Sabben [7] and by Vestine [8].

In view of this seasonal change of latitude of the enhanced ionization and the heating under the sun, the portion of the earth's magnetic field covered by the part of the atmosphere most active in the dynamo process at any particular time of day changes with the time of year. And since the earth's field is oblique to the axis of rotation and also has marked regional irregularities, the field effectively used in dynamo action relative to a particular location may differ appreciably at different times of the year and may thus modify the average amplitude and form of the daily variation of the field from month to month. But for times of the same solar declination on opposite sides of the year, as roughly the months of April and August, for example, the field utilized in dynamo action, if the daily-periodic winds or other seasonally changeable factors [2] are not different, should be approximately the same.[3] Any major differences found at two such times in the daily variation of the field would seem probably to be caused by differences at the two times in the winds in the lower ionosphere that produce the daily variation. It is this criterion that is used here (as it was in the previous article on the daily variation of the earth's field at Honolulu [11]) to point out features in the daily variation of the field at Tucson that may arise from seasonal characteristics of the large-scale air circulation.

If the large-scale air circulation does lead to such features in the daily variation of the field, it may be that, through the movement of the daytime cap of enhanced conductivity and heating (most intense under the sun) around the earth, the sun may act to disclose the presence of a feature in the large-scale wind pattern by augmenting the contribution of such a feature to the daily magnetic variation at the time that it (the sun) is passing over the longitude range of this feature of the winds. Since the convention in most maps, including those for the Southern Hemisphere, is such that north is above and the from-east-to-west direction is from right to left, it seems to the author important in the present work that the time scale used in portraying (as in the following figures) the daily variation of the earth's field be made to run from right to left, rather than from left to right as is customary. It might be, for example, that a feature of the air circulation would produce an effect in the daily geomagnetic variation when the sun is passing over the longitude of this feature of the winds that would be perceivable at more than one Observatory at the same universal time. The time scale could then be useful as a scale of longitude, indicating approximately in what longitude the feature might be (see, for example, fig. 4).

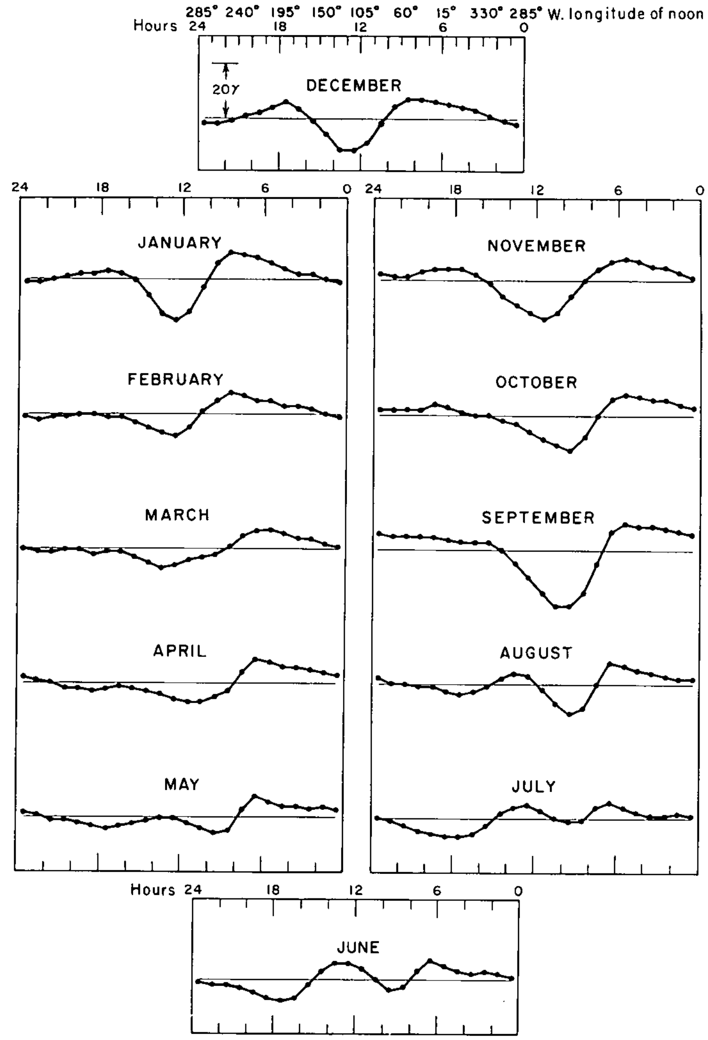


FIGURE 1.—Daily variation of horizontal intensity in gammas of the earth's magnetic field at Tucson, Ariz. Monthly averages for the five international quiet days of each month for the 11 years 1948–58. 105th west meridian time.

In the first three figures the time scales (105° W. meridian hours) run from right to left, and above the scale of hours for December at the top of each figure is given the corresponding longitude of noon, that is, of the subsolar point. The map of the Northern Hemiphere on Mercator's projection with North America approximately in the middle may be imagined as underprint in each monthly diagram. To illustrate the helpfulness that is felt to lie in such a representation, the rather well known summer maximum near midday in the horizontal intensity at Tucson is seen, for example in June of figure 1, to occur mainly when the sun is passing over the longitude range of roughly 150°←90° W. The author earlier pointed

[2] The possibility that the electric currents which are induced in the earth by those flowing in the ionosphere, or some other geophysical factor such as water currents in the oceans, might be playing a major role in producing the kind of anomalous seasonal effects in the daily variation of the field being considered here seems unlikely. The changes that often occur from one day to the next in the daily variation apparently involving these seasonal effects (see, for example, fig. 4) appear to require a cause that can change rapidly, over times of the order of a day, and yet that can possess persistent seasonal characteristics. These requirements would seem to be met by large-scale atmospheric circulation. It is recognized, however, that even a cause that could not change appreciably from one day to the next might produce a seasonal effect which, modified from day to day in some other way, as for example by superposed magnetic disturbance, might lead to effects similar to those being considered here.

[3] Because of the equation of time, relatively small differences in the phase of the daily variation should be present from month to month throughout the year, but it is not believed that these are large enough to contribute importantly to the few large seasonal differences discussed below.

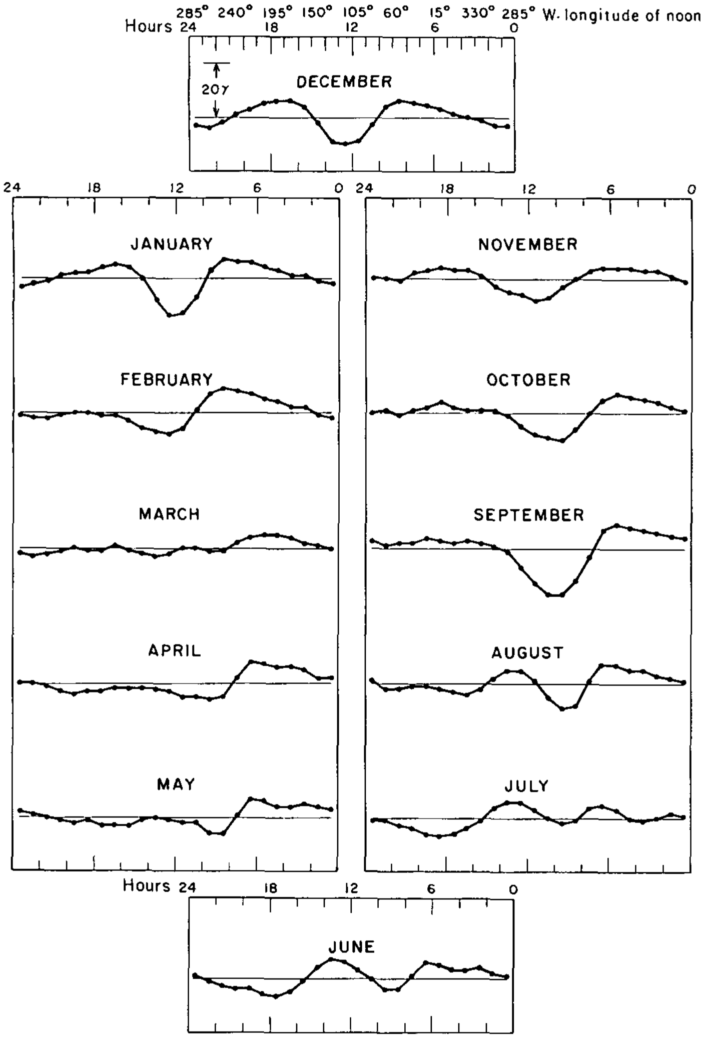


FIGURE 2.—Daily variation of horizontal intensity in gammas of the earth's magnetic field at Tucson, Ariz. Monthly averages for the five international quiet days of each month for the five years 1950–54. 105th west meridian time.

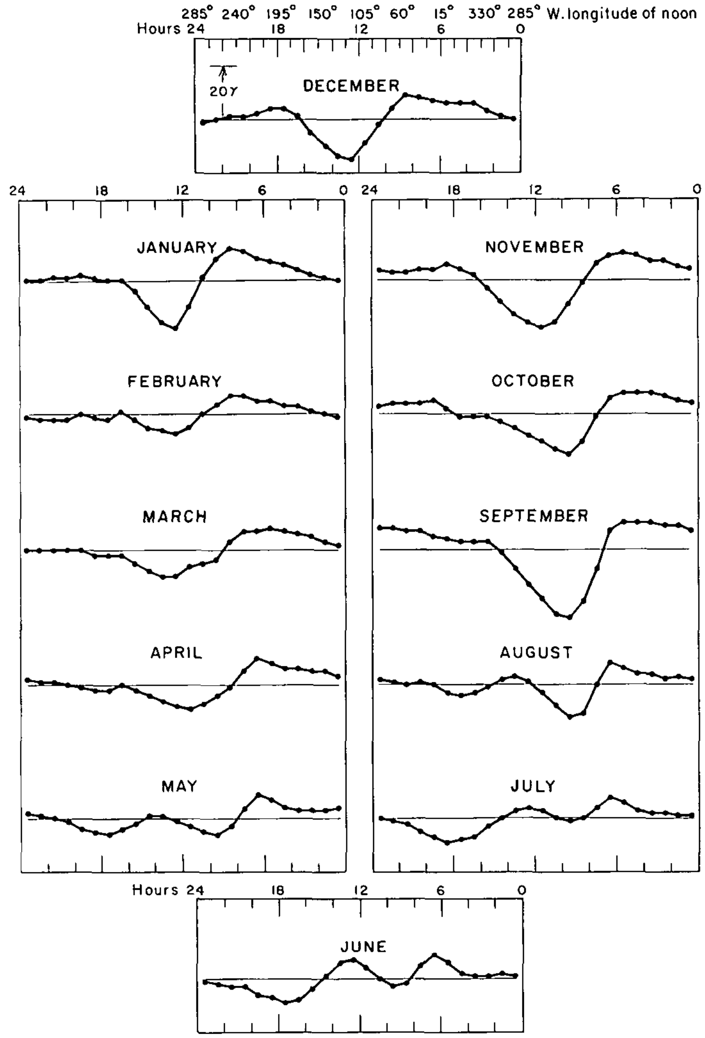


FIGURE 3.—Daily variation of horizontal intensity in gammas of the earth's magnetic field at Tucson, Ariz. Monthly averages for the five international quiet days of each month for the six years 1948, 1949, 1955–58. 105th west meridian time.

out [10] that this feature in average data also appears to occur at Honolulu and at Cheltenham, Md., at the same universal time.

## 2. PRESENTATION OF DATA

In figure 1 are shown, for the five international quiet days of each month, the 12 monthly averages of the daily variation of the horizontal intensity at Tucson for the 11 years 1948–58. These years follow the sunspot maximum of 1947, contain the sunspot minimum of 1954, and extend through the maximum of 1957. They include several years of unusually high sunspot numbers.

For each year, for each month separately, the hourly departures of the horizontal intensity were determined from the row for the mean of the five quiet days in the table of hourly values for the particular month in the corresponding yearbook for the Tucson Magnetic Observatory issued by the U.S. Coast and Geodetic Survey. For each month, the 11 values for each hour were averaged, rounding the results to one gamma. These were corrected approximately for non-cyclic change and the values plotted in figure 1.

The figure is so arranged that the results for months having roughly the same average solar declination are horizontally adjacent to one another. This was done in the previous article [11], and the approximations involved were discussed there. It can be seen that, as in the results for Honolulu [11], there are differences of range and of form in the daily variation that do not follow solar declination in a simple way. The results for these years may be compared with those for earlier years given by Vestine, Laporte, Lange, and Scott [9].

A major difference is apparent between March and September, though solar declination is approximately the same at these times. The range of the daily variation in March [4] in the 11-yr. averages of figure 1 is conspicuously small but large in September. Again, the form of the June daily variation occurs in considerable measure in July and in August, but is less apparent in May and April. The change in the range from January to March [4] recalls a change (though of opposite sign) that appears to occur at about this time of year at Honolulu. The average form of the daily variation of the horizontal intensity is different at Tucson than at Honolulu [3, 9], but there seems in general to be a similarity in the times of anomalous seasonal behavior indicated in the two sets of results.

To inquire in how far the monthly averages of figure 1 are representative of the 11 years, the data were divided into two sets of five and six years, though this is working with rather small amounts of data. The division chosen was the five years prior to and including sunspot minimum 1950–54, and the remaining six years 1948, 1949, 1955–58, as was done in [11]. The results, arranged in the same form as those in figure 1, are shown in figures 2 and 3, respectively. They have been corrected approximately for non-cyclic change.

The results for the two sets of years are in general similar, giving support to the reality of the seasonal characteristics pointed out in figure 1. Incidentally, several of the months show a greater range in the average of the six years (fig. 3) than in the average of the five (fig. 2), in accord with the general tendency for the range of the daily variation to be greater in years of greater sunspot number. The average yearly sunspot number for the six years was 138, while that for the five years was 41.

In summary, the daily variation of the horizontal intensity of the earth's field at Tucson, as at Honolulu, shows seasonal features that are not related in a simple way to solar declination. Something more than the seasonally changing intensity of photoionizing solar radiation is apparently involved, and some seasonally changing property of the lower ionosphere itself, probably the large-scale winds there, seems to be the most likely cause.

The results presented above have had to do with the averages of many days. In view of the changes that occur from day to day in the daily variation of the field it is of interest to study the character of the daily variation for individual days in order to determine the manner in which a particular feature, such as one of those discussed in connection with figure 1, appears in the monthly average of many days. The summer maximum near midday in the horizontal intensity at Tucson, evident in figure 1, affords an interesting example.

In figure 4 the daily variation of the horizontal intensity of the field (departures of hourly values from the daily mean) is shown for four days of June 1954 (magnetically a relatively quiet month at sunspot minimum) for the three observatories of Cheltenham, Md., Tucson, Ariz., and Honolulu, Hawaii. These days among others were felt to be illustrative of this feature. (The 16th and 24th are two of the five quiet days (Greenwich days) of this month.) The data extend in each case over the 24 hours of the respective Observatory's day, but they are plotted on universal time progressing from right to left, and with the longitude of noon shown above the time scale. The small arrows indicate noon approximately at each observatory. Again, here, the map of the Northern Hemisphere on Mercator's projection with North America approximately in the middle may helpfully be imagined as an underprint in each daily diagram.[4]

The maximum near midday at Tucson is evident, but there is also a maximum at Cheltenham, and a tendency at least toward one at Honolulu, at about the same time, that is, the same universal time, in the afternoon at Cheltenham, and in the forenoon at Honolulu where in average results for a number of years it probably appears as a shoulder on the midday maximum [10]. (Concerning the average character of the daily variation at these Observatories see, for example, Vestine, Laporte, Lange, and Scott [9] and Nelson, Hurwitz, and Knapp [3].) From figure 4 it seems probable that the maximum in average data (as that in June or July of figure 1) may be somewhat broadened by appreciable fluctuation from one day to another in the time at which the maximum is reached.

It is of interest to consider ways in which conditions in the lower ionosphere might lead, at the same, or at nearly the same, time at all three Observatories, to a change of overhead electric current and thereby to the presence of such a salient, here a maximum, in the daily variation of the field. A change of overhead current might be caused by a corresponding change of the conductivity of the air, or of the electromotive force driving the current, or of both. The first might be occasioned by a large-scale change (associated with the large-scale circulation) of the air density in the ionosphere through its effect on the photoionization equilibria there. The second might arise from a change of the winds in the ionosphere and thereby of the dynamo action.

It seems unlikely that such a density fluctuation would occur over the relatively short interval of a few hours at nearly the same time on many days over so large an area as to include all three of these Observatories. More likely would seem a change of the electromotive force driving the ionospheric electric current in a circuit that includes these three Observatories, and it would appear that such might be occasioned by large-scale winds.

However, the relative narrowness of the maximum frequently exhibited on individual days would seem to preclude an explanation based simply on a daytime enhancement of the dynamo effect of a favorable, and temporarily stable, pattern of the winds.

[4] In general, the magnetograms for the days of figure 4 show small amounts of minor disturbance that can be seen by studying the reduced size reproductions of the daily magnetograms themselves which are contained in the Observatories' yearbooks. Such a study of the original magnetograms adds considerably, of course, to an appraisal of the graphs of hourly departures shown in figure 4.

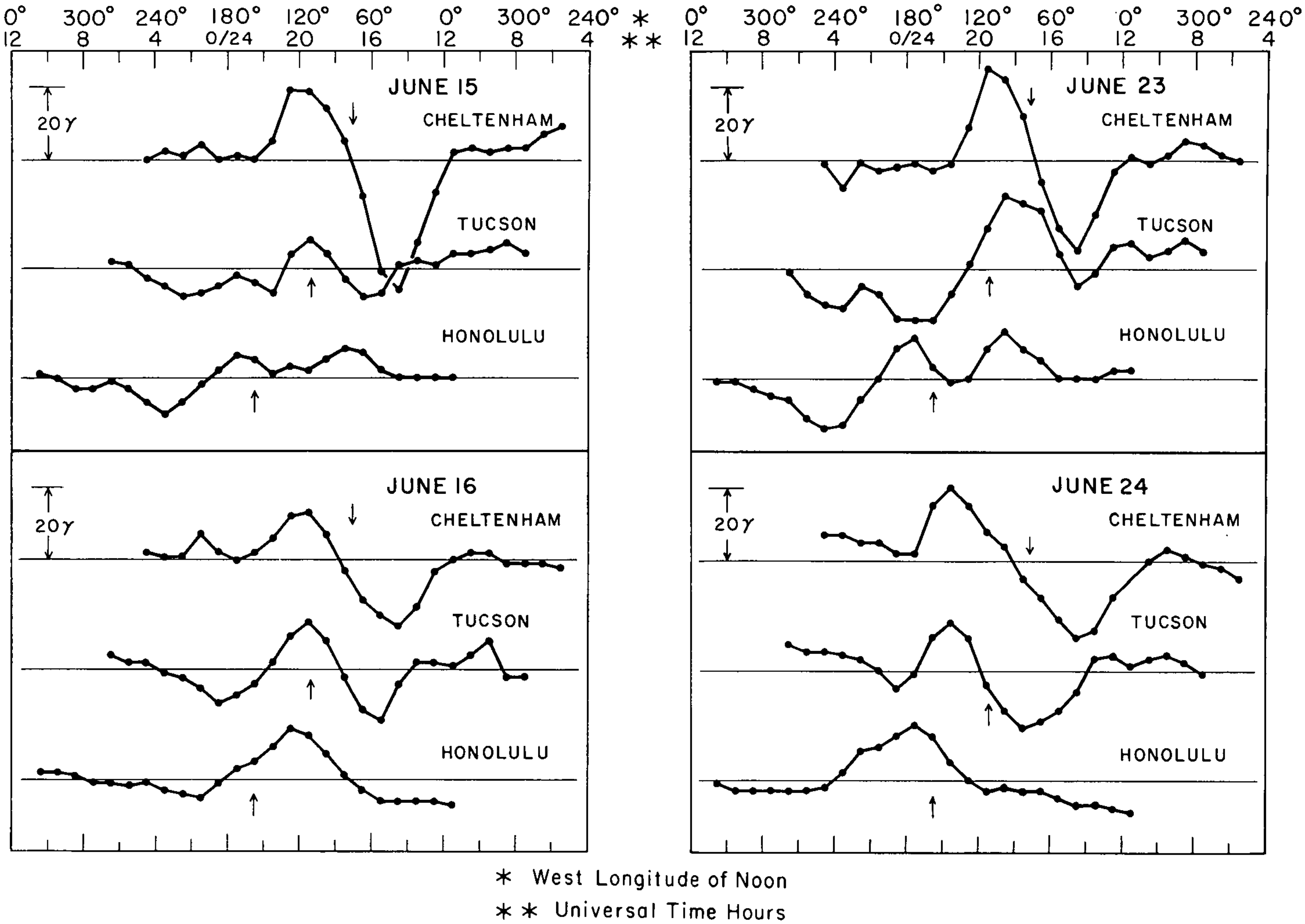


FIGURE 4.—Daily variation of horizontal intensity in gammas of the earth's magnetic field (departures of hourly values from daily mean) for four days of June 1954 at the three indicated Observatories. Double asterisk—Universal time hours. Single asterisk—West longitude of noon corresponding to the time scale. The small arrows indicate approximately noon at the three respective Observatories.

Rather, there might be in the large-scale circulation of the atmosphere in the majority of the days of summer, a pattern of air flow over the North American portion of the hemisphere that responds to the sun's daily heating [5] by a large but transitory fluctuation of the winds in the lower ionosphere as the sun passes over the interval of longitude of this pattern, the fluctuation being of sufficiently large scale and of sufficient intensity that its contribution to the total electromotive force is dominant in the daily variation over this time interval. Occurring at a time when the subsolar point is traversing the longitude range approximately 150°←90° W., there would seem to be the suggestion that the North American mountain range might be involved in the existence at this time of year of a large-scale pattern of air circulation that would exhibit this fluctuation.

[5] As, for example, to heating in the ozone region.

## 3. DISCUSSION AND CONCLUSIONS

The discussion and conclusions of the previous paper [11] are applicable here. There appears to be considerable evidence suggesting that the large-scale prevailing winds in the lower ionosphere may be playing an important part in the production of the daily variation of the earth's magnetic field, and that with sufficient study the daily magnetic records might contribute information concerning changes in the large-scale circulation in the lower ionosphere. It seems possible to follow in a fairly satisfactory manner often from day to day [6] several rather clearly delineated seasonal changes in the character of the daily geomagnetic variation that may arise from changes in the large-scale circulation in the lower ionosphere. In sufficiently large-scale features of the atmospheric circulation it does not seem to the author unreasonable that some correlation

[6] Concerning the effect of magnetic disturbance see Discussion and Conclusions in [11].

should exist between changes in the 100-km. region and those in the high stratosphere. It appears that an empirical study of the principal seasonal changes in the daily variation of the field at two or more Observatories separated by a few hours of longitude against seasonal changes in the large-scale stratospheric circulation, such as those described by Teweles and Finger [5], by Teweles, Rothenburg, and Finger [6], and by Finger, Mason, and Corzine [2], might discover relationships between changes occurring in the circulation in the two regions. The geomagnetic daily variation by its nature should be responsive to large-scale air movement in the upper region including the prevailing winds. These circumstances suggest that a study of the daily variation of the earth's magnetic field against synoptic charts of the large-scale atmospheric circulation as high in the stratosphere as possible would constitute a research of considerable importance.

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## CORRECTION

Vol. 93, No. 1, January 1965:

p. 23, equation (A2): right side should be multiplied by $1/\Delta^2$.

p. 24, equations (A6) and (A7): Insert the number 2 before $ij$ and $kl$ respectively in the second term of the second parenthesis of each equation.

p. 24, The first sentence following (A7) should read: "Upon substitution of (A6) and (A7) into (A2) and equating coefficients of terms to the second order in $\Delta$ with those of the analytic Jacobian, a new relation . . . ."

p. 24, equation (A8): right side should be 1/4.