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Auroral Electrojet Activity Index AE and Its Universal Time Variations

by

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and

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June 1965

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Abstract

An index, denoted by AE, is derived as a measure of global electrojet activity. The basic data used are 2.5 minute readings of the H trace in the standard magnetograms from seven auroral zone observatories. The readings are referenced to a level determined for each observatory from quiet intervals. All the data from the seven observatories are then plotted against UT, and two envelopes are drawn to embrace all the points. The index AE at any epoch is defined by the distance (or separation) between the upper and lower envelopes at that epoch. When viewed as functions of UT the upper and lower envelopes themselves show development and decay of positive and negative variations. It is found that a positive excursion usually accompanies a negative (larger) variation, confirming the well-known feature of polar disturbance. The AE index for a 6-day period, February 10-15, 1958, shows that polar disturbances statistically repeat with a time interval of about 4 hours, and that the average duration of their most active phase is a little over 1 hour. It is pointed out that the repetition time of 4 hours is comparable with that of the electron flux enhancements observed by Anderson et al. (1965) in the magnetosphere tail. It is suggested that polar disturbances are directly related to Anderson's "electron islands" in the magnetosphere tail.

I Introduction

Interpretation of records taken at the magnetic observatories requires organization and analysis of the raw records which, for most purposes, are not readily amenable to simple numerical treatments. This paper presents a means, different from the conventional methods, of organizing magnetic data obtained at a network of observatories in the auroral zone. The method is adapted to digital records and modern computer techniques. While the present method is not intended to bring out all the properties of polar magnetic disturbances, it reveals some of their important features more clearly and readily than other methods commonly used in the past.

We will first describe our present view of the polar disturbance in a symbolic manner to make clear the interpretation of the results presented in this paper. The polar disturbance, represented here by Dp, varies with universal time, denoted by T, and is considered to consist of three parts:

$$Dp(T) = Dpo(T,\lambda) + Dz(T) + Dpi(T,\lambda) \qquad (1)$$

where λ is longitude with respect to the sun, or, local time. In the present idealized model the obliquity of the geomagnetic axis with reference to the rotational axis is ignored for the sake of simplicity, recognizing, however, that this obliquity plays an important role in geomagnetic phenomena. It may be thought that if the inclination of the geomagnetic axis is taken into account the variable λ should represent 'geomagnetic local time'. However, geomagnetic time is a nonlinear function of real time (Chapman and Sugiura, 1956), and in the data analysis presented in this paper the nonlinearity of geomagnetic time is not incorporated. Thus, strictly speaking, it is not correct to say that if λ is considered to be geomagnetic time the conclusions drawn below are all valid with this substitution of the meaning of λ. However, we are mainly concerned with the universal time variation, and hence the distinction between local time and geomagnetic time is for the most part irrelevant. The first term Dpo(T,λ) in equation (1) is the field due to the polar disturbance current system; the second term Dz(T) represents the uniform fields approximately parallel to the geomagnetic axis, and the third term Dpi includes irregular fields. The part Dz is the sum of the magnetic fields from the ring current in the magnetosphere, the current on the magnetosphere boundary surface, the current in the magnetosphere tail, and, if there is any, a zonal current flowing in the polar ionosphere. Because of the distortion of the magnetosphere the ring current field will not be exactly axially symmetric, but to a first approximation it may be considered to be so. The field from the neutral sheet current in the magnetosphere boundary current is, of course, not axially symmetric, but, according to Mead (1964), the lowest term of the spherical harmonic expansion of this field, which represents a uniform field, gives a good approximation near the earth. The field from the neutral sheet current in the magnetosphere tail may be taken to be uniform in the vicinity of the earth; according to Mead (1965), the orientation of the normal to the neutral [illegible] sheet depends on the direction of the geomagnetic axis relative to the earth-sun line; however, for the sake of simplicity this field is included in the term Dz.

The term Dp(T,λ) differs from DS defined by Chapman (1953) and Sugiura and Chapman (1960) in the following respect. The latter, i.e., DS(T,λ), is defined as the deviation of the total disturbance field D from axial symmetry; the axially symmetric part is designated Dst. This method of analysis is useful in low to moderate latitudes because of the particular circumstance that the ring current field, which is the main contributor to the disturbance there, is very nearly axially symmetric. Akasofu and Chapman (1964) have refuted the symmetry, but the question is not as yet definitively resolved. In the auroral zone the division of D into DS and Dst does not entail a division of the disturbance into two entities associated with different physical mechanisms. If there is any axial asymmetry in the disturbance field arising from a single physical mechanism, the field is decomposed into an axially symmetric (Dst) and an axially asymmetric (DS) part. This point was, of course, realized in defining Dst and DS. It has become a custom to refer to the polar disturbance current system as the DS (or SD) current system even though the integral of the current over each latitude circle is not zero. However, so long as the original meaning of each symbol is correctly understood there does not seem to be any harm in using various symbols such as DS, SD, Dst, Sq, etc. in a rather loose sense; they provide convenient, simple terms to various geomagnetic variations that are otherwise difficult to name.

The component Dpo in equation (1) can be expressed as

$$Dpo(T,\lambda) = K(T)\ DS^{o}(\lambda) \qquad (2)$$

where K(T) is an operator with a meaning given below and where $DS^{o}(\lambda)$ is the field from the familar polar disturbance current system (Figure 1), the symbol DS not being used in the rigorous sense explained above. The operator K(T) simply means that the intensity of the field varies with T maintaining the field pattern prescribed by $DS^{o}(\lambda)$, but K(T) may alter the phase (or the orientation) of the current pattern; the latter provision was included because the orientation of the current system is quite variable. In reality Dpo is not so simple as equation (2) indicates; however, we adopt this simplification merely for the sake of convenience in thinking. Thus what is generally called the DS current system (in a loose sense) is our Dpo current system. In the present study Sq is altogether ignored. The relative importance of DS, Dz, and Dpi components in determining Dp has remained an open question for some years. Some studies (Nagata, 1950; Sobouti, 1961; Davis and Kimball, 1962; and Fairfield, 1963) which treated the Dp variations as departures from quiet-day levels found the main features of the $Dpo(\lambda)$ pattern to be of primary importance. These features include the existence of eastward and westward electrojets at the evening and morning sectors of the auroral zone, respectively, and the tendency for currents to flow poleward at the auroral zone near local geomagnetic midnight. Other studies, including those of Fukushima (1953), Knapp (1961), and

Akasofu and Chapman (1964), treated the Dp variations as deviations from the level of whatever variation existed at the time chosen. These studies indicated that Dpi or an ionospheric component of Dz could be more important than Dpo.

II An Index, AE, of Auroral Electrojet Activity

In the first part of this study seven auroral zone observatories are used; the basis of the selection is the availabiltiy of magnetic records, latitude of the observatory, and the need to obtain an even distribution in longitude. One of the purposes of the study is to examine the variation of both the eastward and westward electrojets at, and on the equatorial side of, the auroral zone. In order to avoid complications introduced by polar cap currents, stations located clearly inside the auroral zones are rejected initially. The locations of the five Northern Hemisphere stations chosen are shown in Figure 2. This choice leaves a large gap centered on the longitude of the east coast of North America. Since the conjugacy of magnetic variations in the northern and southern auroral zones has been well demonstrated (Nagata and Kokubun, 1960; Wescott 1961; and Westcott and Mather, 1965), magnetic records from Halley Bay and Bryd Station near the southern auroral zone are used to improve the station distribution. Locations of the points conjugate to Halley Bay and Byrd Station are also shown in Figure 2. A station at slightly lower latitude than Byrd Station (or Fort Churchill, which lies near the conjugate point to Byrd Station) is preferred to provide observations near 90^{o} West Longitude but the lack of a station there and the availability of the Byrd Station records have led to the choice of that station.

Instantaneous scaling of the H tracings from each station has been made by a semi-automatic method at 2.5 minute intervals for the six UT days February 10-15, 1958. This period includes the great magnetic storm of February 11, 1958 and several quiet intervals. The instantaneous H scalings have been referenced from baselines representing the average H value measured on quiet days occurring before and after the period under study. These base-levels are assumed to represent to within about 10 γ (gamma) at each location the horizontal component of the geomagnetic field in the absence of disturbance ionospheric currents. Thus the deviations ΔH from the reference level are directly related to the magnitude of the eastward or westward currents giving rise to the Dp magnetic variations at each station. Sq variations are included in the measurement, but the effects are small, probably not often exceeding 20 γ (Nagata and Mizuno, 1955).

If the distribution of stations were infinitely dense, and if a superposition were made of all the H traces arranged by UT, these traces would define upper and lower envelopes between which all curves would lie. When the number of stations is limited as is necessarily the case in practice, such envelopes are not completely defined. Nevertheless, when the H traces for the seven stations shown in Figure 3 are superimposed on each other, an upper and lower envelope can be defined reasonably well. Two envelopes so drawn are shown in the bottom of Figure 3. In what follows we will refer to the upper and the lower envelopes by AU and AL, respectively. (For convenience, we place the second letter of the symbols AU, AL, Ao, Az, and AE on line with the first, but the second letter is to be thought of as a subscript.) In essence these envelopes are the loci of the maximum and minimum of ΔH for the seven stations. A reproduction of a machine plot of the data for the period February 10-15, 1958 with the AU and AL envelopes drawn in appears as Figure 4. This diagram shows the general trend of the Dst variations for the period (shown by Sugiura, 1965) as well as the auroral electrojet activity.

Were the station distribution more perfect the AU and AL envelopes resulting from this procedure would represent at each epoch the maximum positive and negative H deviations occurring along the auroral zone. Since the major positive and negative bay disturbances extend over an appreciable length of the auroral zone, they are reflected in the observations from a limited station distribution. We have found that a minimum of four observatories nearly equally spaced along the auroral zone provide sufficient data to reproduce the essential features displayed in Figures 3 and 4. However, such a limited station distribution will not always measure the full amplitude of the larger distrubances and might not detect small localized disturbances unless one of the stations happens to be in the disturbance region. The discussions in section VII suggest that four observatories are not quite adequate; one would wish to have a minimum of six observatories. During times of major disturbance the auroral electrojets may shift equatorward of the auroral zone and hence away from the station distribution. An example of this shift is evident in Figure 3 where in some instances deviations at Sitka are larger than those at College, whereas most of the time the reverse is true. A converse circumstance in which the maximum electrojet current shifts to the pole side of the station network can also be conceived. However, a test using the data from Barrow, Barter Island, and Murchison in conjunction with those from the stations in the auroral zone has so far revealed no serious difficulties of such nature. In summary it could be stated with these and other practical considerations that an ideal station network would be one with a spacing of roughly 30° of longitude around the entire (northern) auroral zone and with a further condition, though unlikely to be readily met in practice, that every other station be roughly 5° to the south of the auroral zone.

Consider briefly the variations shown on Figure 4. Moderate positive and negative H deviations exist at the beginning of February 10 and gradually decay into an interval with near-zero disturbance. Then at 1200 an interval of major positive and negative disturbance begins and continues until the commencement of the great magnetic storm of February 11. More-or-less continuous disturbance exists with variable amplitude into the middle of February 12. Near 1700 on February 12 a major but relatively short-lived disturbance occurs. Another long interval of disturbance extends from 0840 on February 13 to 1830 on February 14. A quiescent interval with minor short-lived disturbances then continues to the end of February 15.

Note the tendency for positive and negative deviations to occur together. An exception occurs on February 11 near 1100 where the entire envelope is negatively depressed. In view of the fact that positive and negative H deviations generally tend to occur together and that this negative depression of the envelope happens when the world-wide Dst is at a maximum, we believe that the depression results mainly from a uniform field of a 'ring current' in the magnetosphere rather than from a zonal current in the auroral ionosphere.

When axially symmetric fields from distant sources are absent the upper (AU) and lower (AL) envelopes provide a measure of the maximum eastward and westward electrojet currents at any time. At a time when zonal currents exist either in the auroral ionosphere or in the magnetosphere, these currents will displace the AU and AL envelopes so that they no longer provide a direct indication of the maximum eastward and westward current densities in the auroral electrojet. However, the separation between the AU and AL envelopes solely depends upon the maximum eastward and westward electrojet currents and is independent of zonal currents, if any, existing in the ionosphere, or, of the axially symmetric component of magnetic fields from any distant sources.

Thus we can define an index AE by

$$AE = AU - AL \qquad (3)$$

which is a direct measure of the total maximum amplitude of east and west electrojet currents. AE is an instantaneous global index of the electrojet and is a function of universal time. We define another index Ao by

$$Ao = (AU + AL)/2. \tag{4}$$

Then Ao is the displacement of the midpoint of AU and AL from the reference level at a particular time. It is an approximate measure of the equivalent zonal current regardless of whether the current flows in the ionosphere or in the magnetosphere.

In this paper the changes in the fields from the surface current on the magnetosphere boundary and from the neutral sheet current in the magnetosphere tail are ignored. Rough estimates of these fields are given in Appendix. If the equatorial Dst is zero, Ao indicates the degree of asymmetry of the Dpo field. When the current flowing in the auroral zone ionosphere tends to zero, AU and AL, and hence Ao, converge to a point, the ordinate of which, measured from the quiet level, then is the effect of the ring current, say, α Dst(equator), where α is a factor expressing the variation of Dst with latitude; α may be taken to be cos θ, where θ is geomagnetic latitude. Then, referring to equation (1), the ionospheric zonal component Az, if there is any, can be written as

$$Az = Ao - \alpha\, Dst(equator). \tag{5}$$

The relations between these quantities are illustrated in Figure 5. Quantities AE and Ao can be expressed as follows:

$$AE(T) = \left[Dpo(T,\lambda) + Dpi\right] \tag{6}$$

$$Ao(T) = \left[Dz(T)\right] \tag{7}$$

where the square brackets mean that the range is to be taken of the variations inside the brackets. It is understood that all the quantities refer to the horizontal component H. In terms of AE and Ao the magnitude of Dp can be expressed as

$$[Dp] = AE + Ao \tag{8}$$

As is seen in Figure 4 and diagrams to be presented below, Ao and Az are generally non-zero but usually are small relative to AE. Therefore AE alone is a good approximation to $[Dp]$. Thus we propose AE for an index of Dp. An obvious advantage of AE as an index of the Dp variation is that AE results from direct measurement and has a directly interpretable meaning; specifically, AE is a direct measure of the world-wide maximum amplitude of the auroral electrojets. A plot of AE for the period given in Figure 4 is shown in Figure 6 together with low-latitude Dst.

AE is defined as an instantaneous index but the method can be applied to time averages. The effect of averaging over time is illustrated in Figures 7 and 8. Compared with the 2.5-minute instantaneous values shown there, envelopes AU and AL based on the 15-minute averages of the 2.5 minute values are much smoother, and there is some reduction in amplitude. Corresponding curves for the 1-hour averages are further reduced in amplitude and there is significant loss in resolution of the lesser events. The 1-hour averages still show the occurrence of the more significant variations but even these tend to become lost in the 3-hour averages.

III Locations of Maximum Electrojet Currents

Inherently the plots showing the AU and AL envelopes contain more information than the AE index since they indicate east and west current direction as well as magnitude. It is of interest to determine which stations contribute to the formation of the AU and AL envelopes at a particular time since this information gives the local time of the positions of the most intense eastward and westward electrojet currents. One-half hour average data for the period February 10-15 have been used to determine the local geomagnetic time of the locations where maximum positive and negative H excursions were observed from the network of seven stations shown in Figure 1. The result, shown in Figure 9, is that the AU envelope is determined most frequently from the contribution of stations west of the midnight meridian while stations to the east determine the AL envelope. Thus, the most intense electrojet currents at the auroral zone flow on the night side of the earth with eastward and westward currents tending to flow in the evening and morning sectors, respectively; this is a restatement of the well-known fact.

IV Temporal Relationships between Dp and Dst

As mentioned above, hourly-average data can be used to examine the more significant variations of the auroral electrojets although there results some loss of detail. Hourly-average H values are available in published form for several auroral zone observatories and these have been used to examine other periods in 1958. Data from Dombas, Halley Bay, Sitka, College, Wellen, Dixon Island, Cape Chelyuskin, Byrd and Yellowknife have been combined to form hourly-average AU and AE envelope plots, shown in Figure 10, for the three intervals February 10-15, May 24-June 11, and June 27-July 2, 1958. Although at relatively high latitude, Cape Chelyuskin has been included here to improve the longitudinal station distribution since preliminary testing indicated that the behavior of H there was similar to that at the other stations. The first interval in Figure 10 is the same as that for which the instantaneous 2.5-minute scalings are available so that the results from the two types of data are readily comparable (see Figures 4, 7, and 8). Note that the use of hourly-average data for the construction of Figure 10 results in greatly reduced envelope amplitudes. The intervals shown in Figure 10 contain magnetically quiet and active periods but are chosen because they do contain major storms. The Dp variations during the May, June, and July 1958 intervals exhibit the same characteristics as seen in the February 1958 interval: Dp is highly variable with roughly simultaneous bursts of eastward and westward auroral electrojet current developing several times each day. During magnetic storms the Dp bursts are particularly intense.

As was noted by Chapman (1956), during storm periods the auroral zone currents tend to develop well before the main phase of magnetic storms. This temporal relationship is demonstrated in Table 1 where the times of AE onset, AE maximum, onset of negative Dst, and negative Dst maximum are listed for the sudden commencement storms occurring during the intervals depicted in Figure 10. Several instances of AE and negative Dst onsets unaccompanied by storm sudden commencements (ssc) are included. The onset of AE usually occurs within one hour of the time of an ssc and builds to a maximum one-half to several hours later. In comparison, the development of the storm main phase, as indicated by increasingly negative Dst, usually does not commence until several hours later. On the average, there is a 3-hour delay between the commencement of AE activity and the onset of the storm main phase (Dst) and an equivalent delay between the time of maximum AE and maximum negative Dst. This time delay as derived from a statistical analysis is evident in Figure 28 of the paper by Sugiura and Chapman (1960).

V Temporal Relationships between Low Latitude DS, Dp and Dst

Of interest also are the temporal relationships between disturbance at the auroral zone and at low latitude. A recent study by Akasofu and Chapman (1964) suggests that while a portion of the low-latitude disturbance may be due to ionospheric return currents from the auroral electrojets, another part is due to asymmetry of the equatorial ring current in the magnetosphere; more explicitly, part of the ring current flows in the ionosphere on the night side in their interpretation.

Hourly average H data from seven observatories lying between geomagnetic latitudes 21°N and 41°N have been used to derive an index somewhat analogous to AE. At each observatory an hourly-average value of ΔH, denoted here by $\overline{\Delta H}$, is determined by

$$\overline{\Delta H} = \overline{H} - Ho \qquad (9)$$

where $\overline{H}$ is the hourly-average horizontal component and where Ho is the daily mean H component measured on quiet days. $\overline{\Delta H}$ results from Sq and disturbance variations; the disturbance variations may contain axially symmetric (Dst) and axially nonsymmetric (DS) components. We obtain the axially nonsymmetric component DS by

$$DS = \overline{\Delta H} - Sq - Dst \qquad (10)$$

where Dst is determined by hourly values given by Sugiura (1965). Using the DS values obtained from the low-latitude station distribution, the range R(DS) is determined:

$$R(DS) = DS_{max} - DS_{min} \qquad (11)$$

thus, R(DS) results from the sum of the maximum world-wide eastward and westward current measured in the latitude zone containing the station distribution after Sq and the axially symmetric field are subtracted. It represents the asymmetrical component of disturbance at low latitude as does AE at the auroral zone.

Plots of AE, R(DS) and Dst for the period February 10-15, 1958 are contained in Figure 11. As is evident from Figure 11, AE and R(DS) fluctuate much more rapidly than Dst with R(DS) tending to follow the fluctuations of AE quite well during much of the period shown. This behavior is not in disagreement with the usual interpretation that the axially nonsymmetric disturbance observed at low latitude is due largely to ionospheric return currents from the auroral electrojets. However, R(DS) is not exactly proportional to AE, and during some hours of the

February 10-15, 1958 period there is no obvious relationship either to AE or Dst. Contained in the February 10-15 period are 52 hours during which AE $<150\gamma$; if a relationship between R(DS) and Dst exists it should be most apparent during these hours when the auroral electrojets are weak. A scatter diagram of R(DS) versus Dst when AE $<150\gamma$ (Figure 12a) indicates the possibility of a dependence of R(DS) upon Dst. A least squares fit with a straight line is shown in Figure 12a. If R(DS) is assumed to be independent of AE (in the range considered), and if the asymmetric component of Dst is proportional to Dst itself, the straight line in Figure 12a shows that the Dst asymmetry is about 12% of its symmetric value. However, as is seen in Figure 12b, R(DS) evidently depends on AE even in the range considered (i.e., AE $<150\gamma$); the above percentage may be considered as the upper limit on a statistical basis. In this regard the standard deviation for the least squares fit is 7.5γ. There may be times when the degree of asymmetry exceeds the rate obtained above. In their study which indicated greater asymmetry in the ring current Akasofu and Chapman (1964) used the first half of the tenth hour of February 11, 1958 as an example. For that time they obtained a value for the axially nonsymmetric component of disturbance at low latitude about the same as indicated by our Figure 11. However, their method indicated near-zero Dp during the same interval, hence they concluded that the low-latitude disturbance resulted from asymmetry of the ring current. On February 11, 1958 between 1000 and 1030 the AE index ranged from 500 to 1000γ, indicating an intense current in the auroral zone, hence the postulation of a large ring current asymmetry is not necessarily required for the interpretation of the February 10-15, 1958 data. At least in part, the dissimilarity between our result and that of Akasofu and Chapman appears to be due to a different choice in Dp baselines in the two studies. However, the question of whether or not the DS variations in low latitudes represent the fields due to the return current of the auroral electrojets, or more precisely, to what degree the low latitude DS represents the return current, remains unanswered.

VI Relation of the AE index to Kp and ap

Kp is the mean standarized K index from twelve observatories lying in northern or southern latitudes between 48^{o} and 63^{o} geomagnetic latitude (Bartels et al., 1962). K-indices for individual stations are determined from the largest of the maximum ranges of the three components for 3-hour intervals at that station. Kp is defined by a quasi-logarithmic relation to the amplitude of disturbance in order that a wide range of activity be expressed by a one-digit number; the corresponding linear amplitude index is ap, and the daily equivalent planetary amplitude Ap is the average of the 8 ap values for one day.

Kp and ap are measures of variation in the geomagnetic field and in principle respond only to disturbance variations (Sq and lunar variations are subtracted out in the preparation of the K-indices). During periods of great magnetic activity, the auroral electrojets may move equatorward until they approach or partially overlie the higher latitude observatories used to determine Kp. Then high Kp-index values result directly from the influence of the auroral electrojets and from variation in the equatorial ring currents. Under more normal conditions the twelve observatories used to derive Kp are equatorward of the auroral electrojets and then the middle latitude DS currents and the ring currents are the primary contributors to the 3-hour Kp and ap indices. Both AE and DS are more variable within a 3-hour span than Dst (see Fig. 11) and since Kp and ap are measures of variation in 3 hours, they provide indices of Dp activity primarily. The relationships between Kp, ap and a 3-hour AE index for the period February 10-15, 1958 are shown in Figure 13.

VII Temporal Variation of Dp

A striking feature of Figures 6 and 10 and one best illustrated in Figure 14 is the almost periodic occurrence of burst-like Dp activity. Such a feature has been pointed out by Akasofu (1960) with reference to intense polar disturbances associated with magnetic storms. The Dp bursts during February 10-15, 1958 and the other intervals shown in Figure 10 occurred at an average rate of approximately 6 per day (see Fig. 15) with a tendency for the burst frequency and amplitude to increase with the level of activity. Examination of individual bursts seen in Figure 4 reveals that the typical rise time to the peak is from 20 minutes to 1 hour. The decay time is similar to the rise time or slightly longer in many instances. Such behavior is expected from the appearance of the Dp variations at individual stations, but the almost regular Dp variations are revealed only by a global index with high time resolution such as AE.

In order to illustrate the periodic occurrence of polar disturbances on a more quantitative basis, estimates of power spectral density have been made of the series of semi-hourly AE indices for the 6-day period mentioned above. The results are presented in Figure 16, where the power spectral density estimates are plotted against frequency ranging from 0 to 1.0 cph (cycle per hour), the latter frequency being the Nyquist frequency. There are two broad peaks of interest, which are marked A and B in Figure 16. The former, which lies between 0.2 and 0.4 cph, or between 2.5 and 5 hours in period, is interpreted to represent the repetition of events; the period corresponding to the center of this broad peak is 4 hours. Applying the χ^2 test (Blackman and Tukey, 1958) to the deviation of the peak value in A from a smooth background, indicated by broken lines in Figure 16, the probability that an estimate exceeds the peak value by chance is 10%. There are five points in A at which spectral density estimates were made; of these, only neighboring points are correlated, and those points not adjacent are mutually independent. The joint probability that all these points contributed to form the broad peak by chance is negligibly small. Thus the spectral peak A is considered to be significant.

The second peak, marked B, is more pronounced than the peak A. The period corresponding to the peak is 1.15 hours. We interpret the peak B to represent the average duration of the most active phase of polar disturbances. The confidence level obtained by the χ^2 test for the peak value is 95%. There are three points in B, of which two are independent. Again the probability that all the points had by chance such deviations from the smooth background, indicated in Figure 16 by broken lines, is negligible. The following remarks are made regarding the possible effect of the second harmonic of B if it exists. The second harmonic would be near 1.74 cph, which will fall near 0.26 cph when the spectrum is folded about the Nyquist frequency. Then the latter frequency coincides with the peak A. The possibility of the peak A being the second harmonic of B is rejected on the following ground. First, the power contained in A is about 8 times that in B. Secondly, A is much broader than B. For these reasons we judge that the spectral peak A is real.

Anderson et al. (1965) and Anderson (1965) have detected "islands" of energetic electron fluxes in the magnetosphere tail. These electron islands have a sharp rise and a slower decay regardless of whether the satellite is inbound or outbound. For this reason these authors interpreted such events as being 'time variations' and not 'spatial variations'. They report that the occurrence of electron islands is time dependent. According to Anderson (private communication), when these electron islands are observed they occur with intervals of a few to several hours. We point out that the recurrence times of polar disturbances as derived from the AE index are of the same order of magnitude as those of Anderson's electron islands. Thus it is suggested that polar disturbances are directly related to electron injection into the magnetosphere tail or to acceleration of electrons in the vicinity of the neutral sheet.

VIII Summary and Conclusions

A method is described for obtaining a global index (AE) of Dp activity using the H variations measured at a station network distributed along the auroral zones. The index is a direct measure of the axially nonsymmetric component of Dp activity. Since this component is found to exceed the axially symmetric component in magnitude, AE can be considered approximately as an index of Dp.

Advantages of the AE index are as follows: (1) it is a quantitative instantaneous index and has readily interpretable physical meaning; in these two respects it is quite different from the standard Kp and ap indices; (2) the method of obtaining AE is simple and well-adapted to digital records and to modern computer techniques; and (3) the method is useful for the study of individual events and also for statistical investigations. By applying the method described here to a few selected epochs in the first half of 1958 we conclude that in several respects individual Dp events conform to the description obtained from past statistical studies; specifically, Dp develops before the magnetic storm main phase and exhibits much more rapid temporal variation; at the auroral zone, the eastward and westward electrojets develop simultaneously and have their maximum intensity in the evening and morning sectors, respectively; the axially nonsymmetric component of Dp is usually much larger than the axially symmetric component. In addition we have shown that Dp exhibits a burst-like nature with individual bursts developing and decaying with a time scale of approximately 1 hour and with an average repetition period of 4 hours.

We point out that this repetition period is comparable with that of the electron flux enhancements observed by Anderson et al. (1965), and Anderson (1965), in the magnetosphere tail, and suggest that these phenomena are directly related. It is not clear whether these electron flux enhancements in the magnetosphere tail set up electric fields that generate polar disturbances, or the two phenomena have still another common cause yet to be found.

It is our intent to extend the use of the method described here to more recent data and also to the study of Dp variations in the polar cap and elsewhere.

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APPENDIX

An estimate of the fields from the currents on the magnetosphere boundary and in the tail.

The horizontal component of the field from the surface current on the magnetosphere boundary is roughly $(0.25/r_b^3) \cos \theta$ gauss where r_b is the geocentric distance in earth-radii of the boundary on the sun-earth line (Mead, 1964). Hence, taking r_b to be 10, this field is of the order of 20γ.

If the neutral sheet current in the magnetosphere tail is approximated by a sheet current extending infinitely in the direction perpendicular to the sun-earth line, but having a finite width from r_1 to r_2 (earth-radii), then the field at the center of the earth (which is on the plane of the sheet current) is perpendicular to this plane and is given by $\Delta H = 2j \ln(r_2/r_1)$, where j is the current density (in e.m.u.); for the sheet current model, see, for instance, Williams and Mead (1965). The direction of the field near the earth is to decrease the permanent field. In the vicinity of the neutral sheet current, the current can be considered to be an infinite sheet current; thus the magnetic field H_{tail} there can be expressed as $H_{tail} = 2\pi j$. Hence, approximately $\Delta H = (H_{tail}/\pi) \ln (r_2/r_1)$. Therefore, the field of the magnetosphere tail at the earth critically depends on the extension of the sheet current. If the sheet current extends from 10 earth-radii to 100 earth-radii with a nearly equal current distribution, $\Delta H = H_{tail} \times \frac{2 \cdot 3}{\pi} \doteq 0.73 H_{tail}$. If we take H_{tail} to be 20γ, ΔH is 15γ. This is a crude estimate, and since the actual neutral sheet current does not extend infinitely this estimate may be considered to give an upper limit.

On the other hand the tail is likely to extend much beyond 100 earth-radii (Dessler, 1964; Dungey, 1965). However, regardless of the actual length of the tail, what counts here is the flux leaking through its earthward end, and thus, when the field intensity is specified in the region of the tail relatively near the earth one could define an equivalent length of the tail if one is only concerned with the near-earth region. It is in this context that we made the above estimate. The direction of the field from the tail is opposite to that due to the magnetosphere boundary current; and hence the resultant field is of the order of 10γ in the direction of enhancing the horizontal component of the permanent field. During major disturbances these fields may be increased, but since we are here concerned with the polar disturbances whose magnitudes are several hundred to a few thousand gamma, we will consider the changes in the fields from the magnetosphere boundary current and the neutral sheet current in the magnetosphere tail to be negligible in the present problem.

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TABLE I

Time Of ssc	AE Onset	AE Max.	Negative Dst Onset	Negative Dst Max.
Feb 10^d 10^h 32^m	10^d 11^h	10^d 19^h	10^d 15^h	10^d 23^h
11^d 01^h 25^m	11 01	11 02	11 04	11 12
May 25^d 15^h 17^m	25 15	25 24	25 21	26 03
No ssc	26 07	26 15	26 13	26 18
No ssc	27 09	27 11	27 12	27 13
29^d 07^h 56^m	29 06	29 10	29 10	29 15
31^d 16^h 52^m	31 16	31 19	31 19	31 24
Jun 01^d 05^h 36^m	01 03	01 05	No negative Dst development.	
No ssc	06 19	06 21	06 20	07 01
07^d 00^h 46^m	07 00	07 01	07 02	07 04
07^d 06^h 59^m	07 04	07 08	07 08	07 10
08^d 17^h 28^m	08 17	08 18	No negative Dst development.	
08^d 22^h 42^m	08 21	08 23	08 24	08 24
No ssc	09 18	10 02	09 23	10 04
No ssc	27 19	27 22	27 22	27 24
28^d 07^h 13^m	28 02	28 10	28 04	28 09
28^d 17^h 42^m	28 18	29 02	28 19	29 05
No ssc	29 08-12	29 14	29 15	29 16
No ssc	Jun 30^d 21^h- Jul 01^d 01^h	01 01	01 02	01 03

FIGURE TITLES

Fig.

1 Idealized current diagrams based on the average of forty magnetic storms, at maximum epoch in the main phase: (a) combined disturbance current, (b) Dst current, (c) DS current. The current flow between adjacent lines is 10,000A. After Chapman, 1956.

2 Map showing the northern auroral zone. Black triangles show locations of points conjugate to Byrd Station (BY) and Halley Bay (HB) and closed circles indicate locations of Sitka (SI), College (CO), Wellen (WE), Dixon Island (DI) and Kiruna (KI). Other stations used in late phases of this study are Dombas (DO), Yellowknife (YE) and Cape Chelyuskin (CC).

3 H traces from seven observatories for February 11, 1958. Dashed portions are averages drawn through fluctuating traces or, where indicated by "?", represent portions of the traces which could not be scaled with confidence. At the bottom of the diagram are the upper and lower envelopes defined by superposition of the seven H traces.

4 Reproduction of machine plot of H data from the seven observatories with upper and lower envelopes drawn in for the interval February 10-15, 1958.

5 Schematic drawing illustrating the relationships between AU, AL, AE, Ao and Az.

Fig.

6 Plot of the AE index for February 10-15, 1958, the same interval represented by Figure 4. The dashed line gives the low-latitude Dst obtained by Sugiura (1965).

7 Plot of the upper (AU) and lower (AL) envelopes obtained on February 12, 1958 using 2.5-minute scalings and 15-minute, 1-hour and 3-hour averages of the 2.5-minute scalings.

8 Plot of the upper (AU) and lower (AL) envelopes for February 15, 1958; see title to Figure 7.

9 Local geomagnetic time of locations where maximum positive and negative H excursions were observed during February 10-15, 1958. Half-hour averages with $|\Delta H| > 50\gamma$ were used to compile the diagram.

10 AU and AL envelopes compiled from hourly-average H values at nine auroral zone stations. Full circles show times of ssc's reported by five or more stations; open circles show those reported by two to four stations.

11 Plots of auroral zone AE, low latitude Dst and range R(DS) of low latitude DS for the interval February 10-15, 1958.

12 A) Plot of range R(DS) of low latitude DS vs Dst for hours when $AE<150$. The straight line fitted by least squares has a standard deviation of 7.5γ: B) Plot of R(DS) versus AE for hours when $AE<150\gamma$.

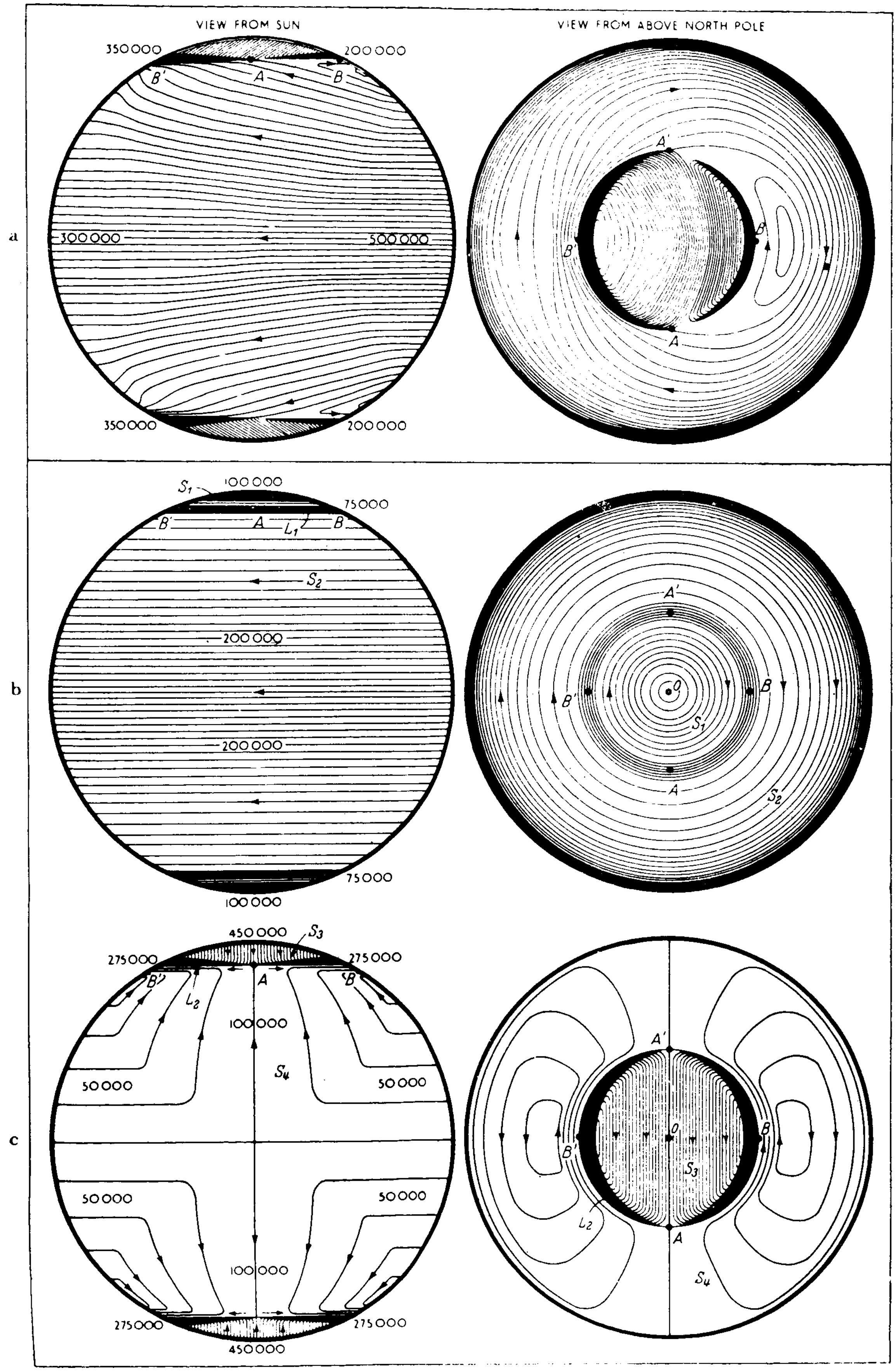
Fig.

13 Plots of Ap, Kp and 3-hour averages of AE versus universal time for the period February 10-15, 1958.

14 Plot of AE for the period February 10-15, 1958 with positions of peaks emphasized by vertical lines drawn to them from the abcissa.

15 Intervals between sucessive Dp bursts during the 31 days illustrated in Figure 10. Hourly-average data were used to compile the diagram.

16 Estimates of the power spectral density for polar disturbances in the frequency range 0 to 1 cycle per hour; power spectral density in units of γ^2 per cycle per hour.



VIEW FROM SUN
VIEW FROM ABOVE NORTH POLE
a
350000
200000
B'
A
B
300000
500000
350000
200000
A'
B'
B
A
b
S_1
100000
75000
B'
A
L_1
B
S_2
200000
200000
75000
100000
A'
B'
O
B
S_1
A
S_2
c
450000
S_3
275000
275000
B'
A
B
L_2
100000
S_4
50000
50000
50000
50000
100000
275000
275000
450000
A'
B'
O
B
S_3
L_2
A
S_4

FIGURE 1

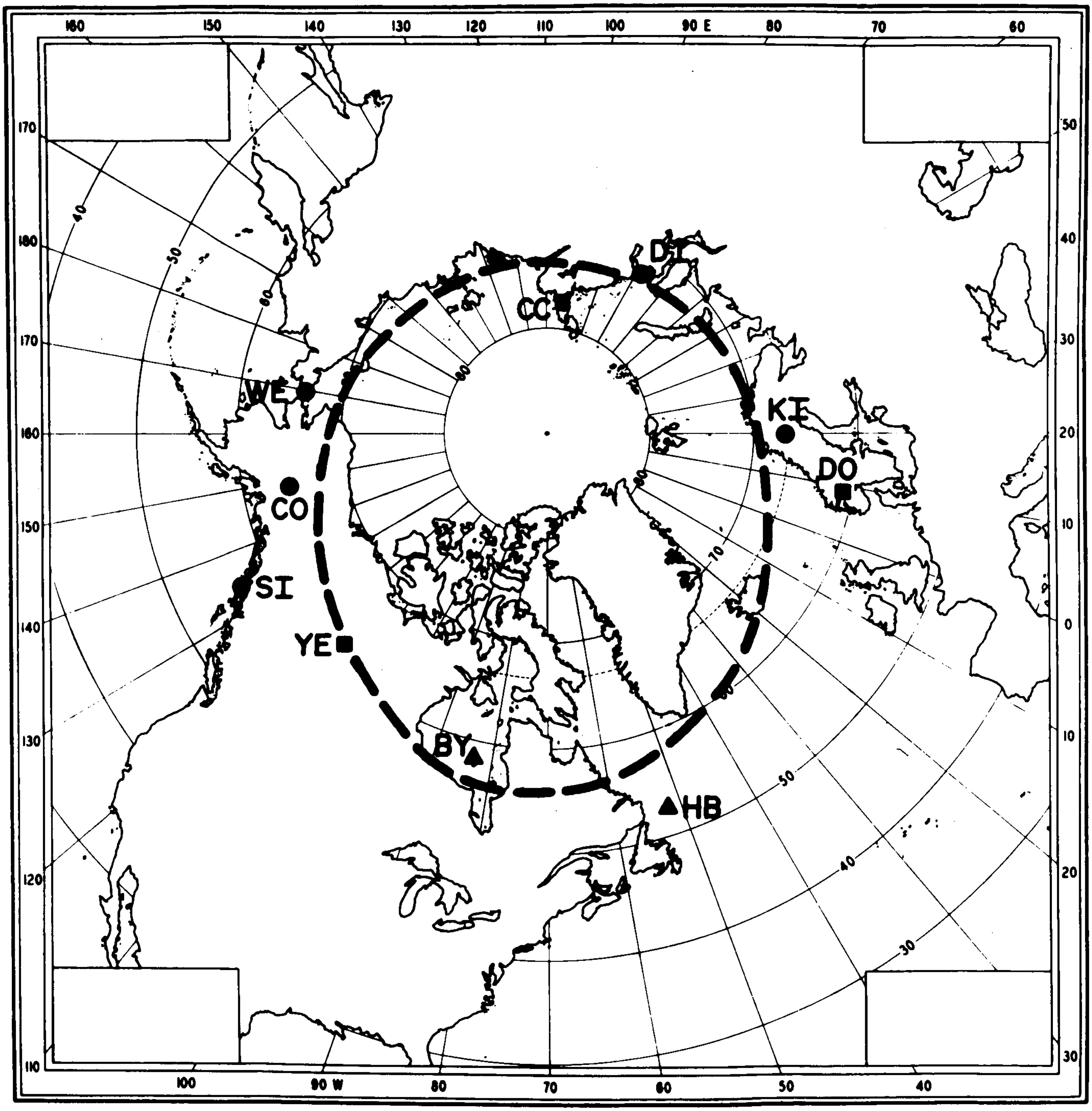


FIGURE 2

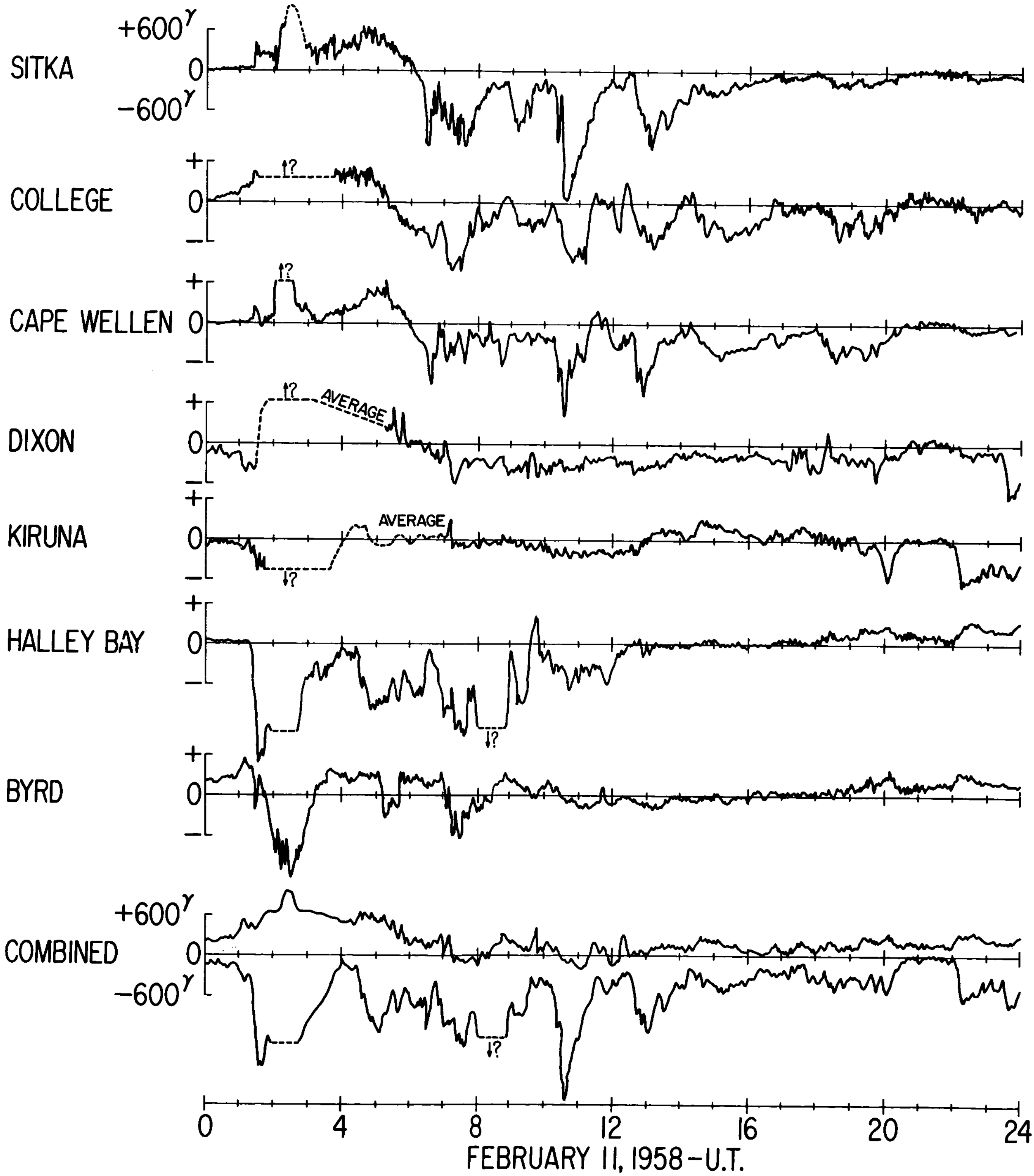

SITKA
+600γ
0
−600γ
COLLEGE
CAPE WELLEN
DIXON
AVERAGE
KIRUNA
HALLEY BAY
BYRD
COMBINED
0 4 8 12 16 20 24
FEBRUARY 11, 1958 – U.T.

FIGURE 3

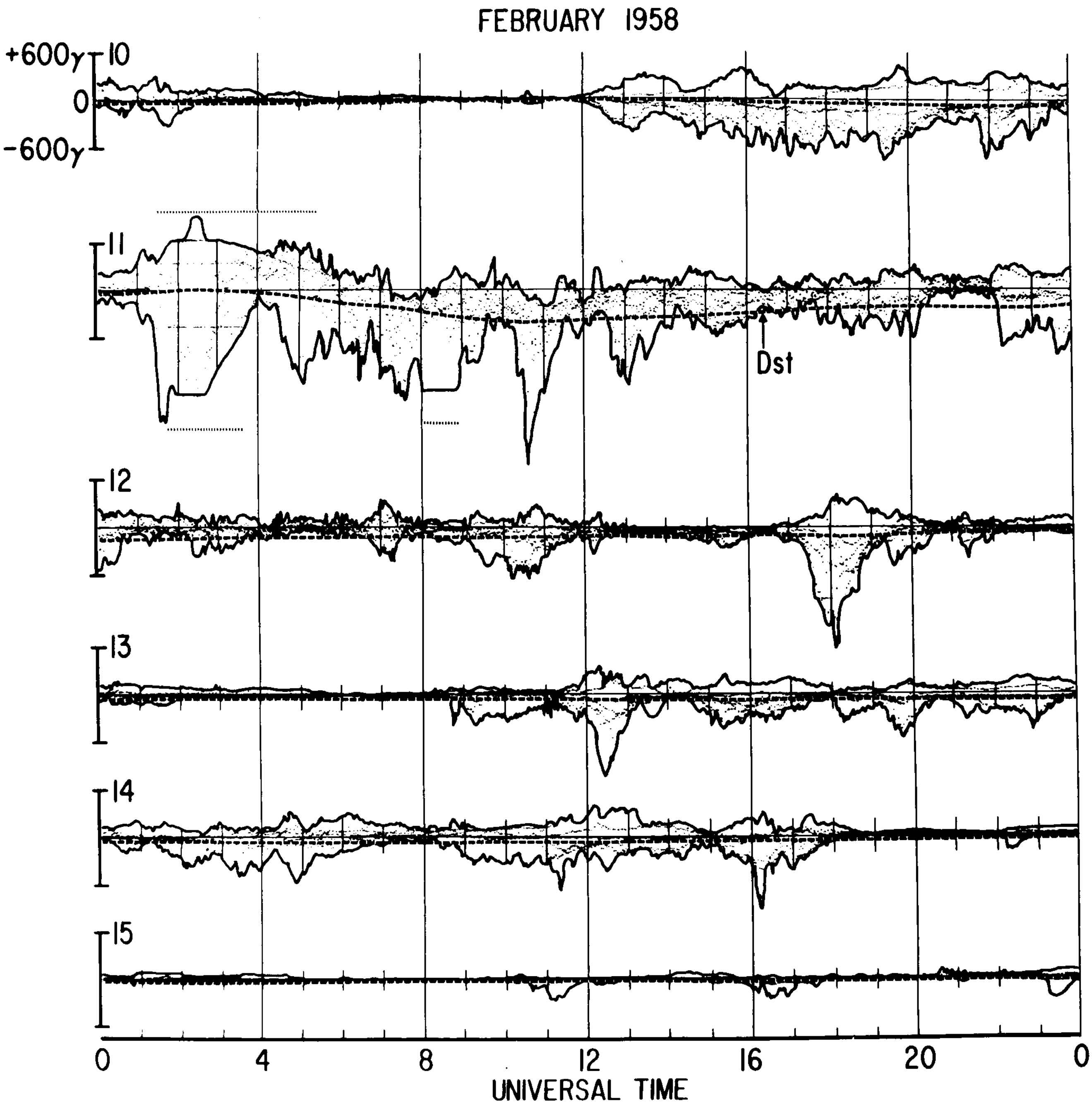

FEBRUARY 1958
+600γ
0
-600γ
10
11
12
13
14
15
Dst
0
4
8
12
16
20
0
UNIVERSAL TIME

FIGURE 4

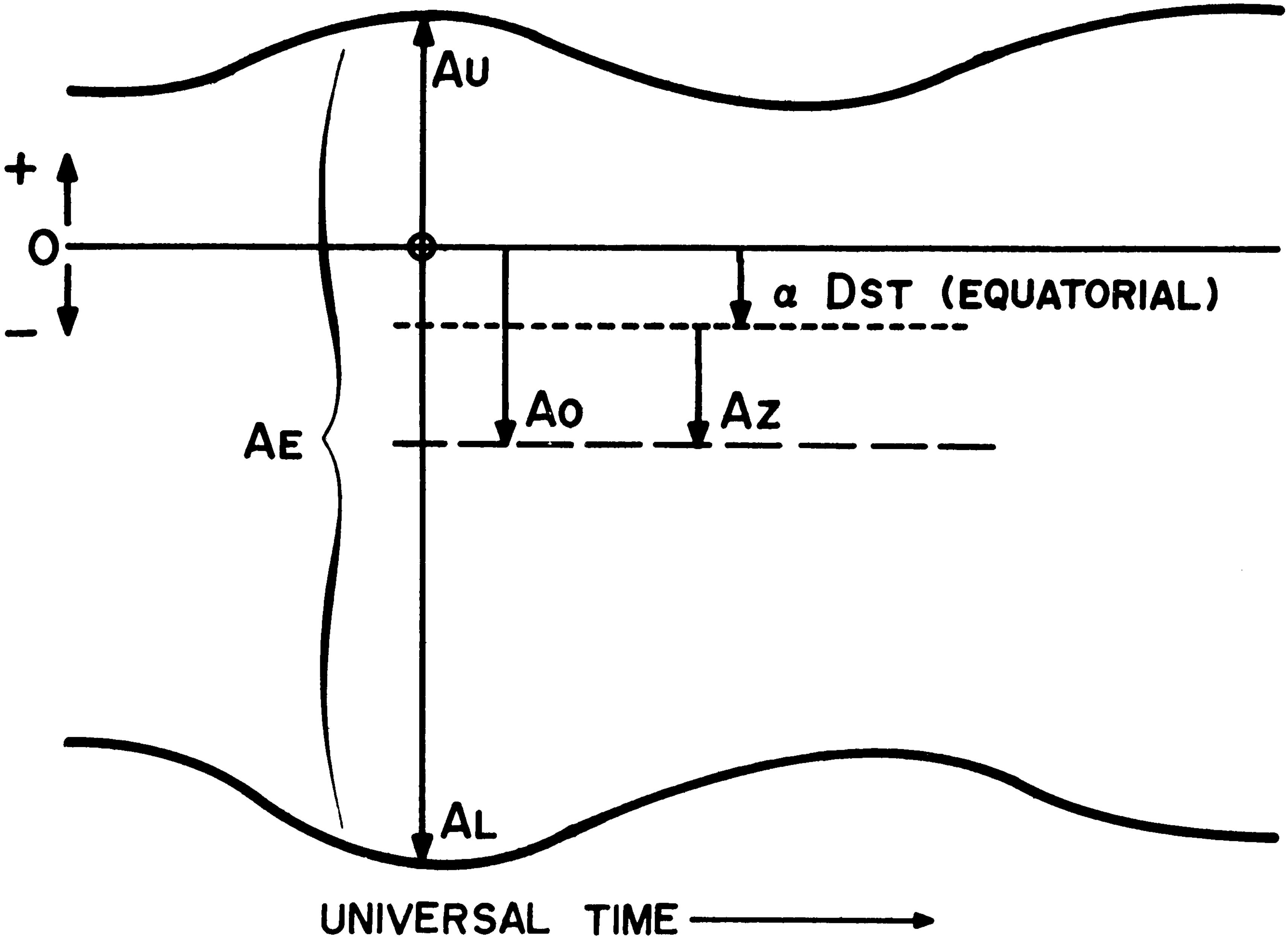


FIGURE 5

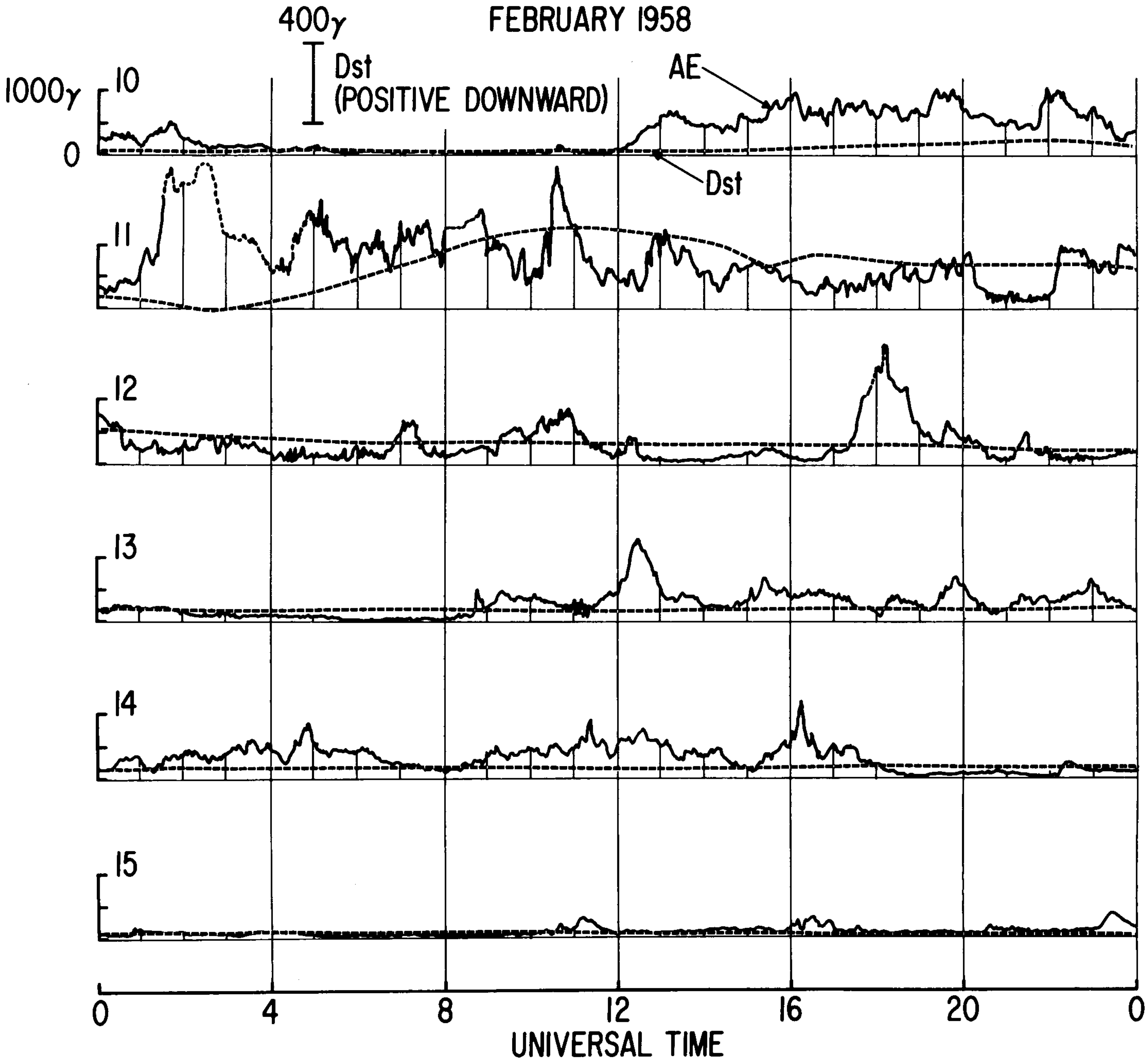

400γ
FEBRUARY 1958
Dst
(POSITIVE DOWNWARD)
1000γ
0
AE
Dst
10
11
12
13
14
15
0
4
8
12
16
20
0
UNIVERSAL TIME

FIGURE 6

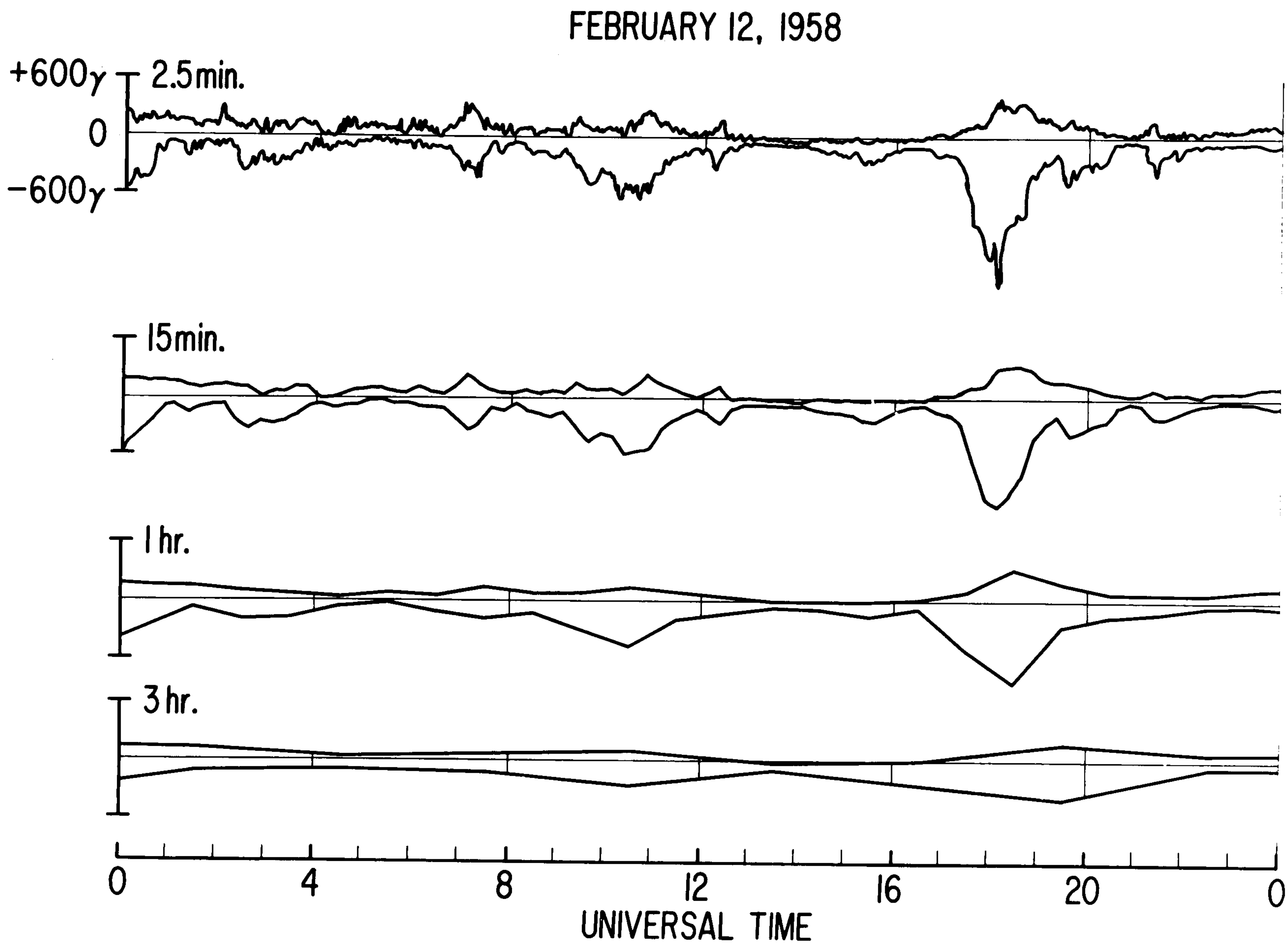

FEBRUARY 12, 1958
+600γ
0
-600γ
2.5min.
15min.
1hr.
3hr.
0
4
8
12
16
20
0
UNIVERSAL TIME

FIGURE 7

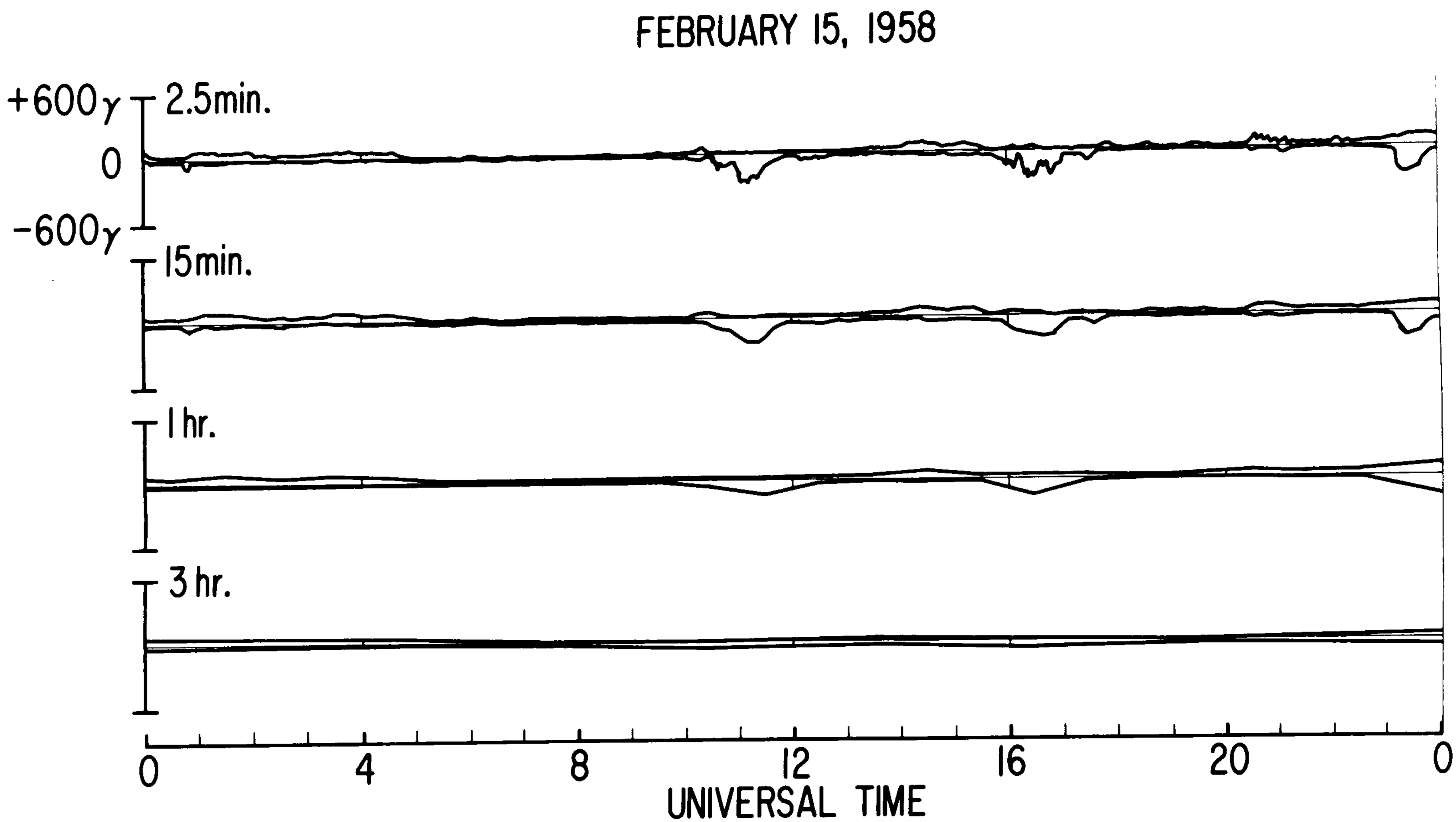
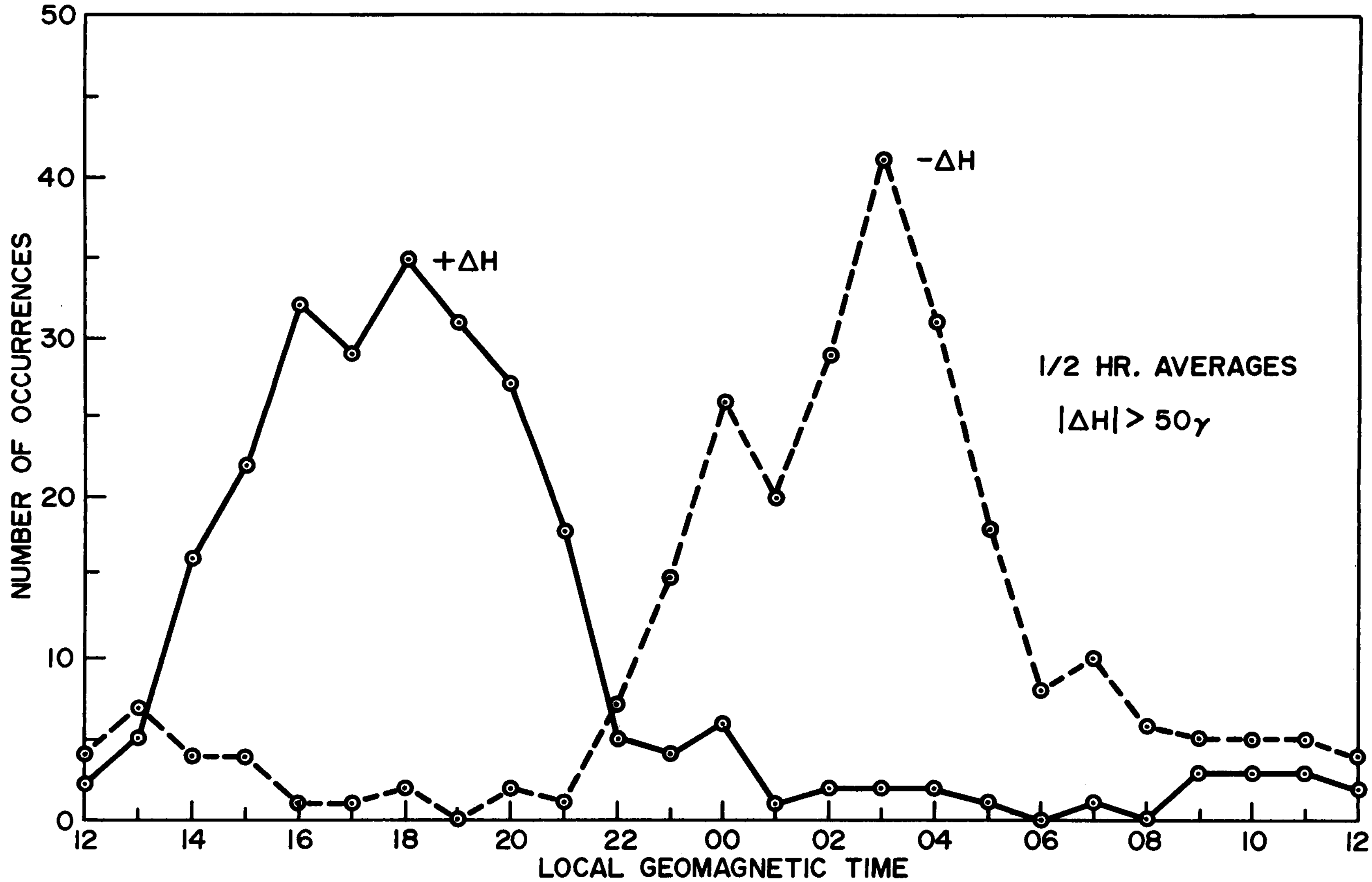

FEBRUARY 15, 1958
+600γ
0
-600γ
2.5min.
15min.
1hr.
3hr.
0
4
8
12
16
20
0
UNIVERSAL TIME

FIGURE 8



50
40
30
20
10
0
NUMBER OF OCCURRENCES
12
14
16
18
20
22
00
02
04
06
08
10
12
LOCAL GEOMAGNETIC TIME
+ΔH
-ΔH
1/2 HR. AVERAGES
|ΔH| > 50γ

FIGURE 9

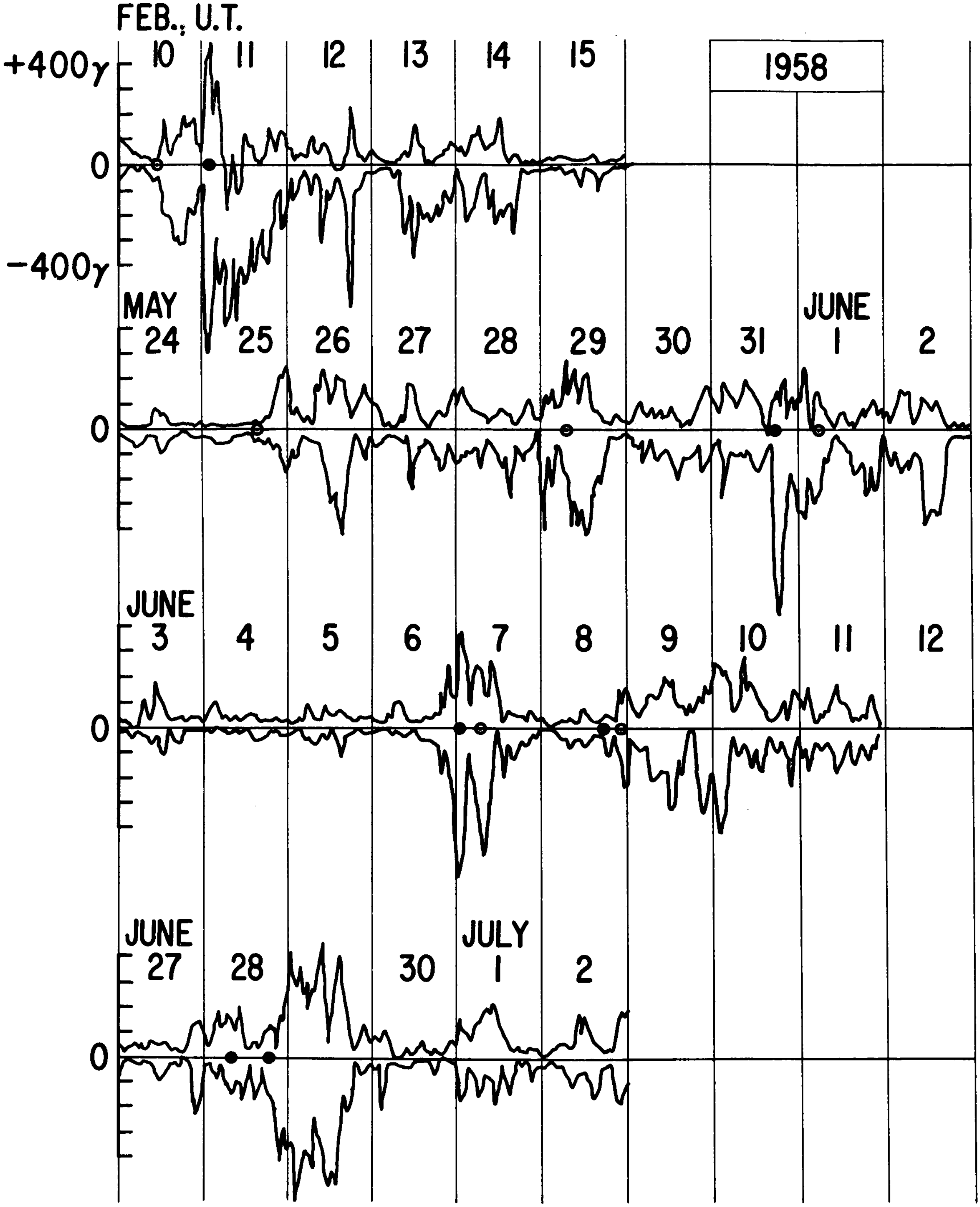

FEB., U.T.
10
11
12
13
14
15
1958
+400γ
0
-400γ
MAY
24
25
26
27
28
29
30
31
JUNE
1
2
0
JUNE
3
4
5
6
7
8
9
10
11
12
0
JUNE
27
28
30
JULY
1
2
0

FIGURE 10

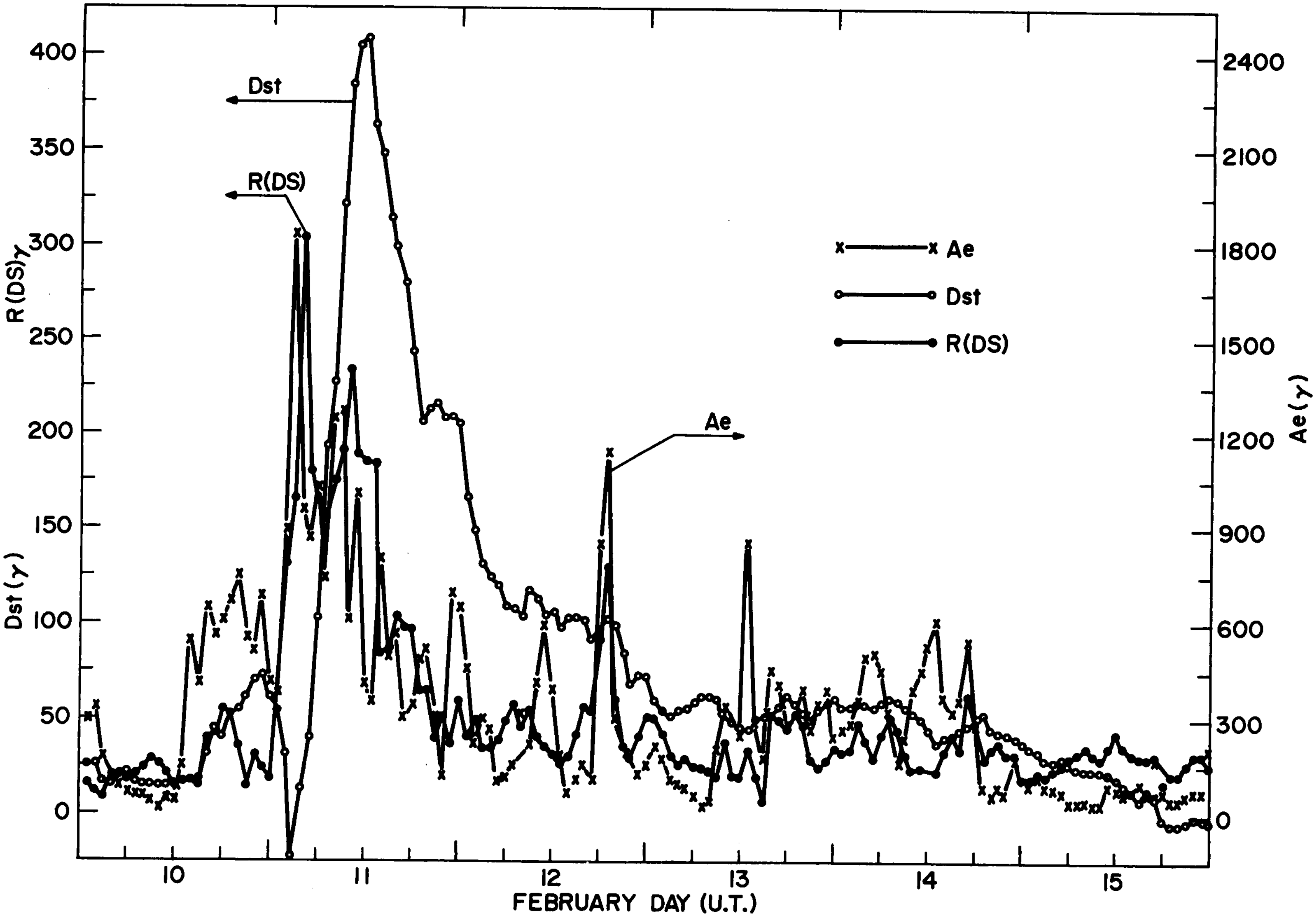

400
350
300
250
200
150
100
50
0
R(DS)γ
Dst (γ)
2400
2100
1800
1500
1200
900
600
300
0
Ae(γ)
Dst
R(DS)
Ae
Ae
Dst
R(DS)
10
11
12
13
14
15
FEBRUARY DAY (U.T.)

FIGURE 11

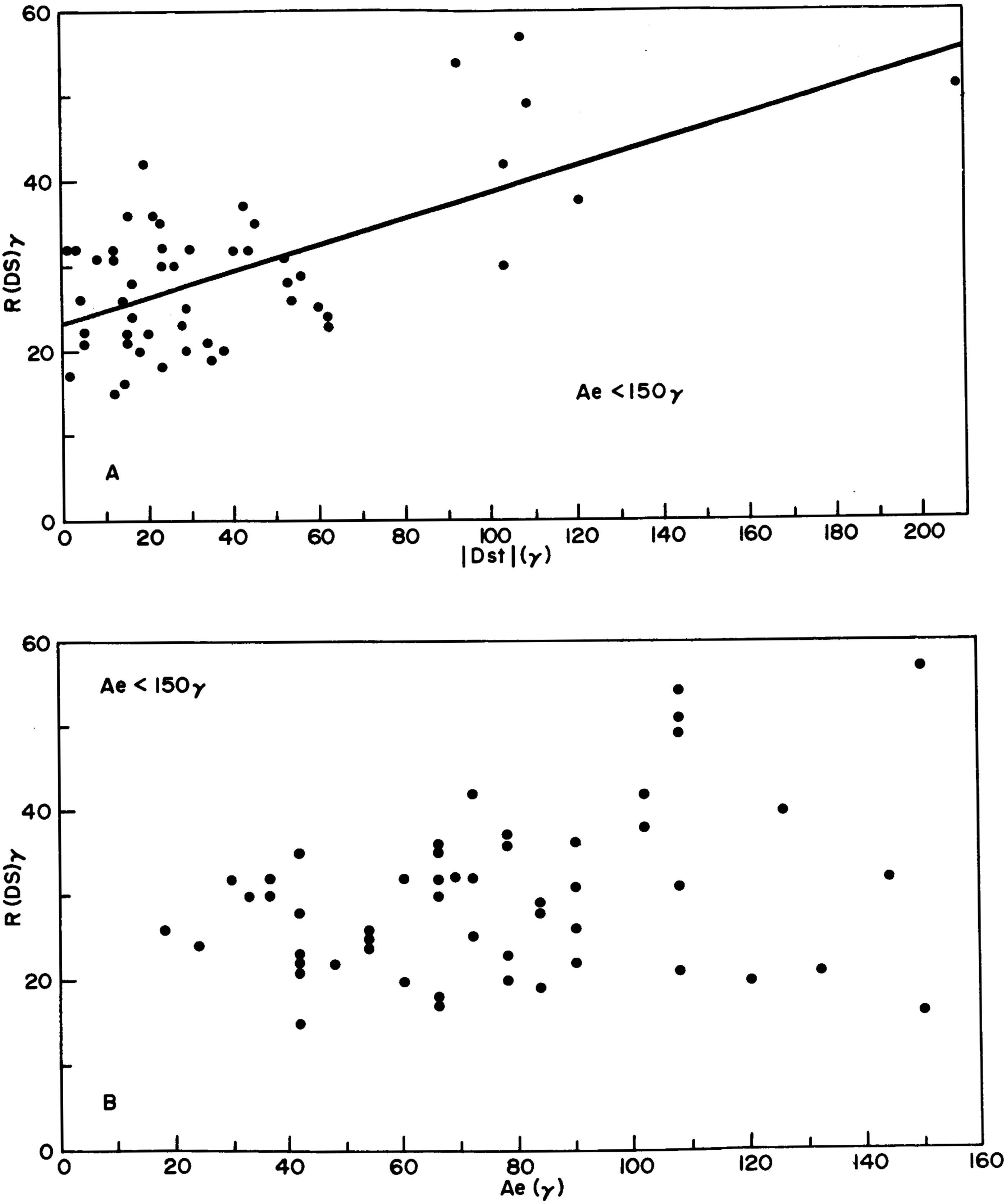


FIGURE 12

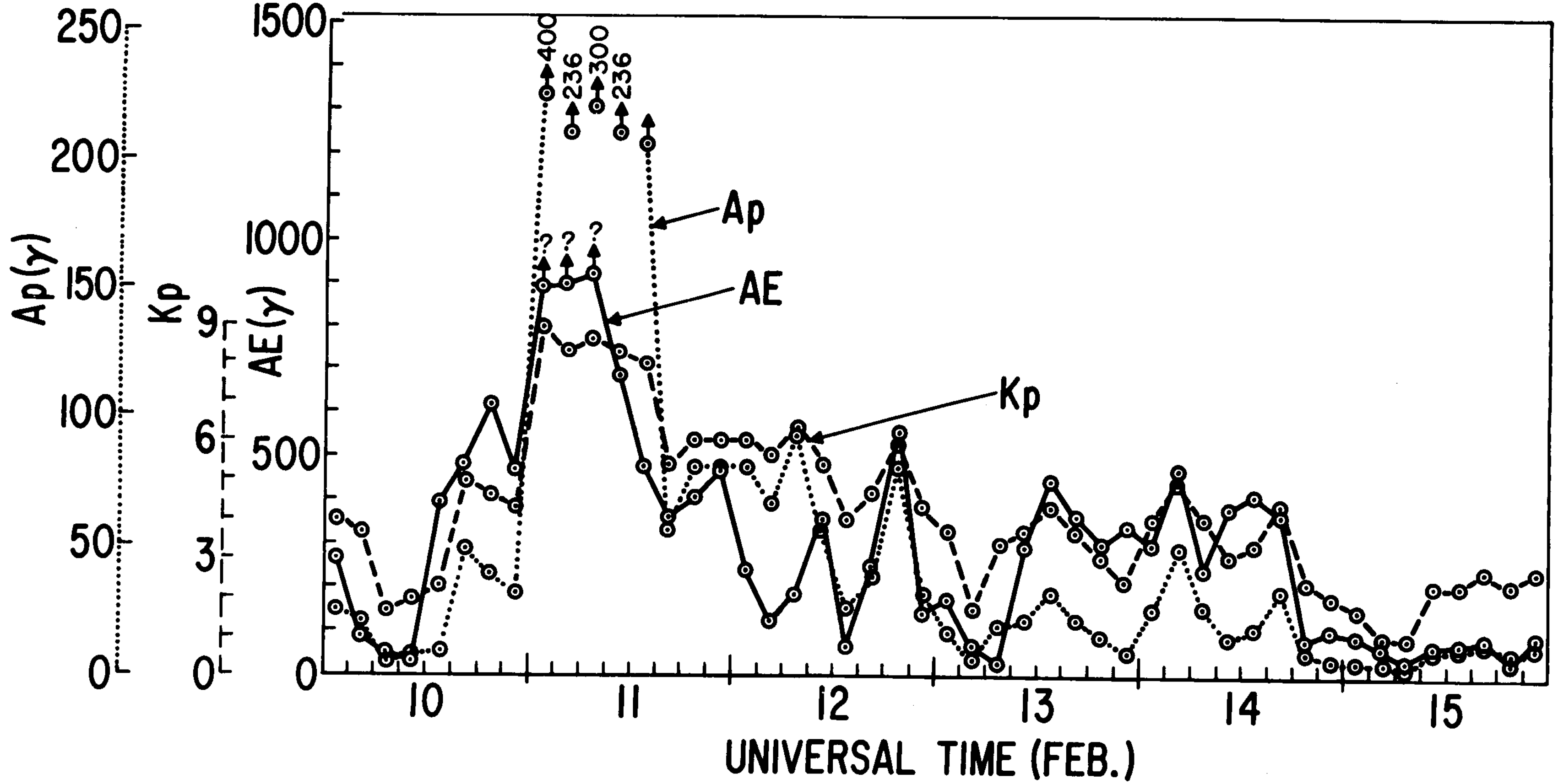

Ap(γ)
250
200
150
100
50
0
Kp
9
6
3
0
AE(γ)
1500
1000
500
0
400
236
300
236
?
?
?
Ap
AE
Kp
10
11
12
13
14
15
UNIVERSAL TIME (FEB.)

FIGURE 13

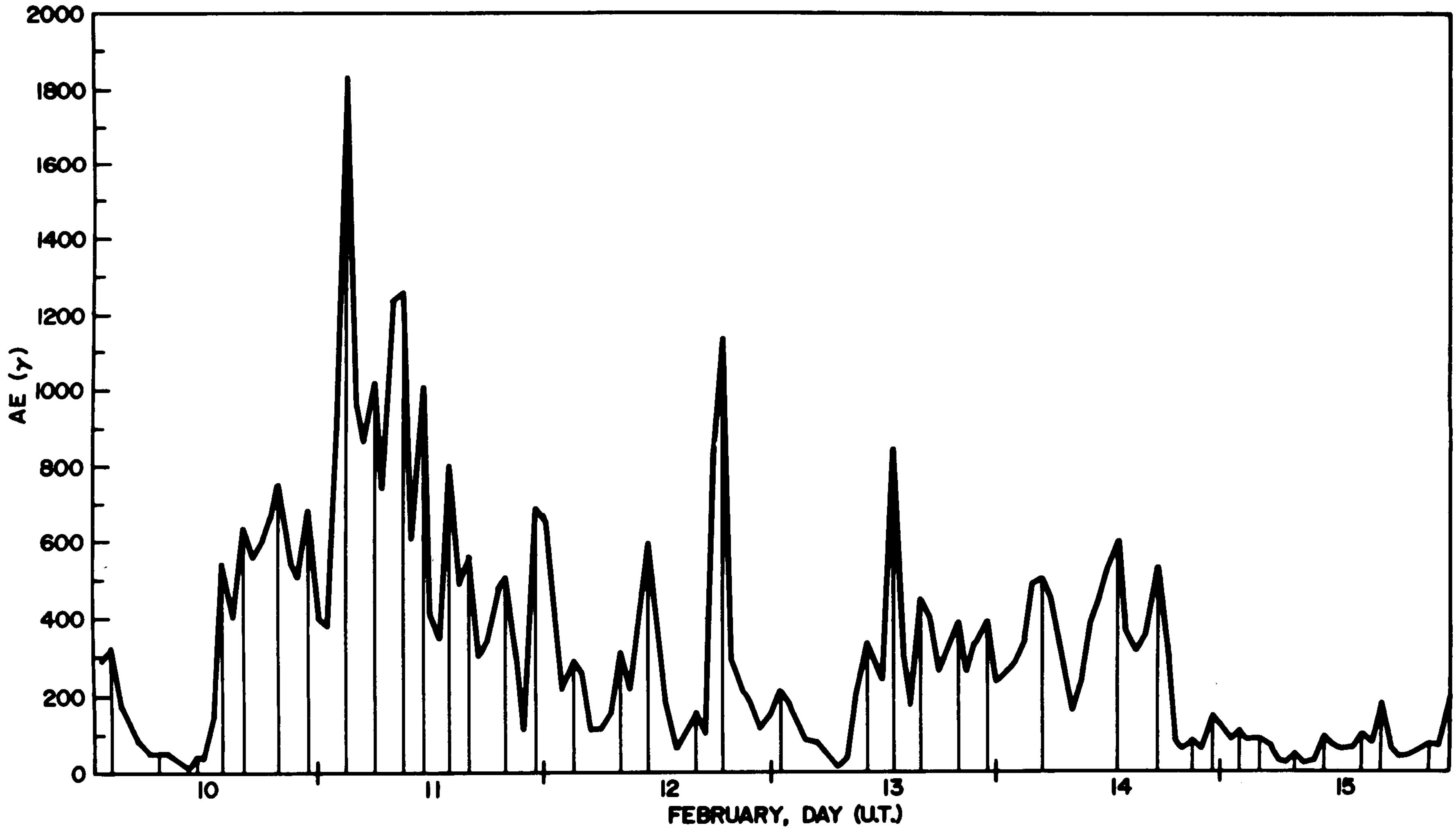

2000
1800
1600
1400
1200
1000
800
600
400
200
0
AE (γ)
10
11
12
13
14
15
FEBRUARY, DAY (U.T.)

FIGURE 14

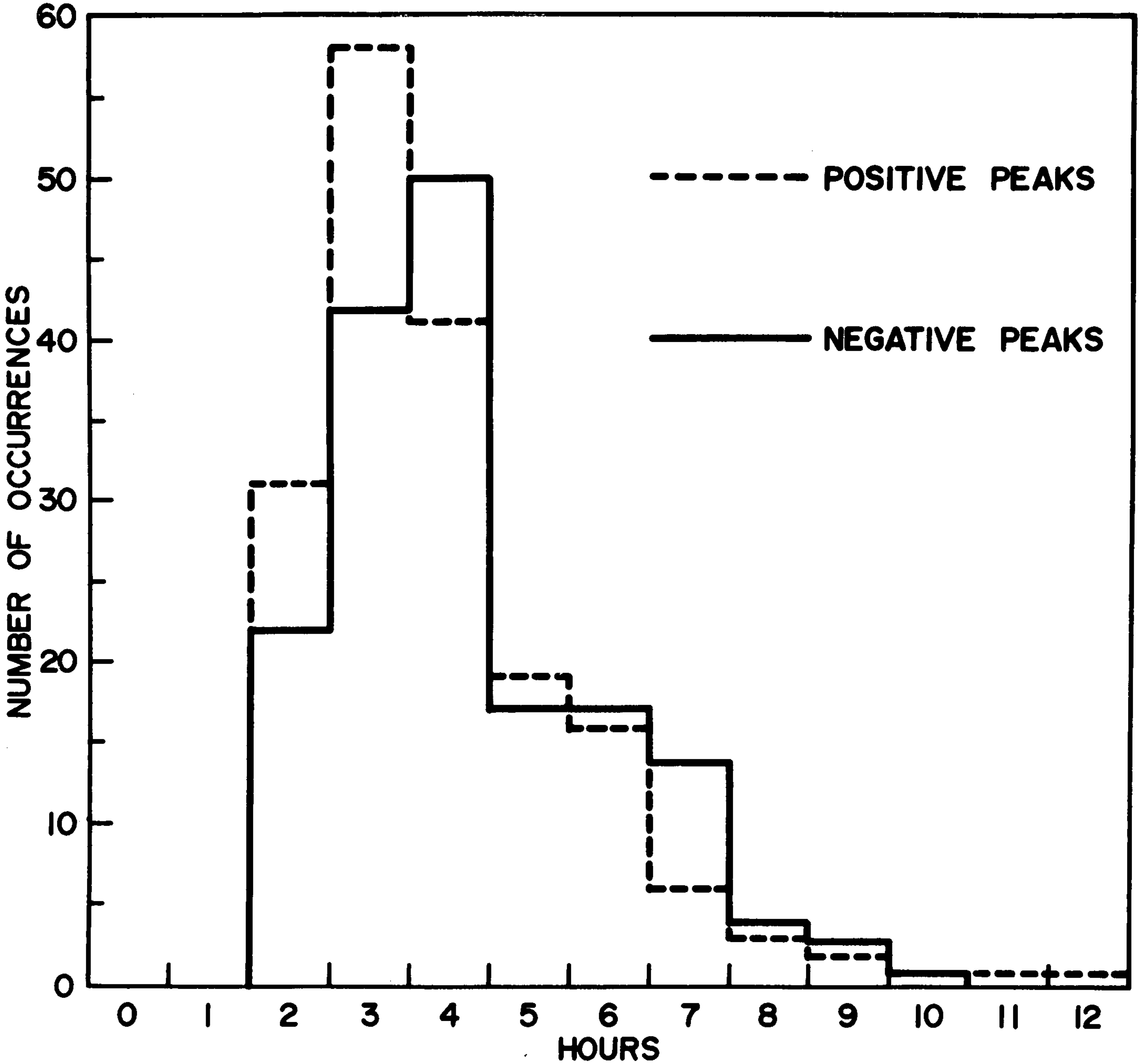
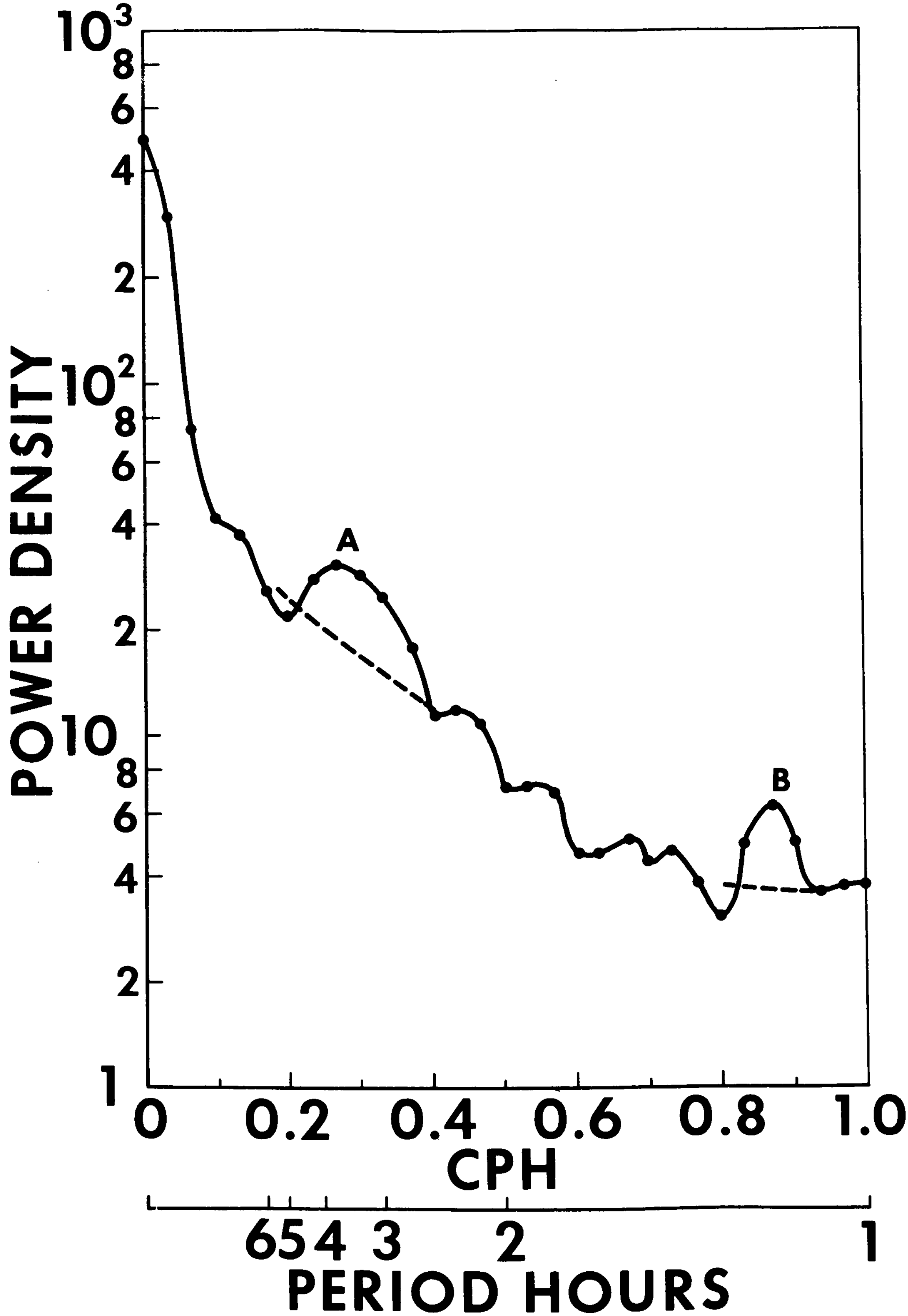

POSITIVE PEAKS
NEGATIVE PEAKS
NUMBER OF OCCURRENCES
0
10
20
30
40
50
60
0 1 2 3 4 5 6 7 8 9 10 11 12
HOURS

FIGURE 15



POWER DENSITY
10^3
8
6
4
2
10^2
8
6
4
2
10
8
6
4
2
1
A
B
0
0.2
0.4
0.6
0.8
1.0
CPH
6
5
4
3
2
1
PERIOD HOURS

FIGURE 16