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Geomagnetic Indices

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The purpose of this review is to outline the definition and method of derivation of the indices of geomagnetic activity that are most commonly used at present. The first part of the review presents the methods of derivation of *Kp*, *ap*, *AE*, and *Dst*; the second part involves a discussion of the strengths and weaknesses of each index. It is shown that the distribution of magnetic observatories whose data are used in the production of the indices strongly influences the quantitative reliability of the indices in varying degrees. Furthermore, it is found that, in general, indices are only capable of defining the lower limit of geomagnetic activity at any given time. It is concluded that indices should only be used in statistical studies of solar-terrestrial interactions; their use in the study of individual events is generally not advisable.

1. INTRODUCTION

In the study of solar-terrestrial relationships, it is generally desirable to have some estimate of the level of dissipation of energy within the magnetosphere at any given time. To obtain an accurate quantitative estimate is impossible at the present time, since it requires a knowledge of dissipation of energy through several available mechanisms, each of which varies in space and time. Each mechanism produces disturbances of various types, ranging from X rays to ULF emissions. The monitoring of any one of these disturbances leads to a gross estimate of the level of magnetospheric activity; however, some emissions are more difficult to monitor than others. Historically, it has been found that low-frequency ($0.01 > f > 0$ Hz) geomagnetic fluctuations can be recorded with the least difficulty, because they are unaffected by meteorological conditions and are observable at great distances from the source current system in the upper atmosphere and magnetosphere. Accordingly, most space physicists have used geomagnetic variations when they have wished to have some idea of the level of magnetospheric activity.

Since most research workers who are not involved in studies of geomagnetic activity do not wish to have to interpret magnetograms in order to estimate the level of activity, geomagnetists developed a series of indices designed to give a semiquantitative measure of the level of magnetospheric activity. Since indices were first introduced, a large number of different ones have been developed. General reviews of these different indices have already been written [*Lincoln*, 1967; *Siebert*, 1971], but detailed information about the derivations of each index tends to be scattered throughout the literature. In fact, many of the indices were used by a limited group of research workers and have, in the course of time, become almost obsolete. However, certain indices have become established and are used frequently by modern-day space physicists. The four most commonly used indices are *Kp*, *ap*, *AE*, and *Dst*. The purpose of this review is to define the origins and status of each of these indices and then to point out circumstances under which one must be careful in making use of them.

Before outlining the methods by which the indices are derived it is useful to point out that all data used in the computation of the indices are recorded on three component magnetometers. Traditionally the variations are recorded in the local magnetic coordinate system (H, D, Z) or the geographic coordinate system (X, Y, Z). In these systems, H and D and X and Y are the horizontal components, with H lying in the local magnetic meridian plane and X lying in the geographic meridian plane. The Z component is vertical and is common to both systems, and D and Y make up the respective orthogonal systems. Although low-latitude and midlatitude data are generally best ordered in the H, D, Z system, high-latitude data recorded in this coordinate system are often not easy to interpret. Accordingly, at most high-latitude stations the X, Y, Z system is used, and thus the horizontal components of the disturbance field recorded at these stations should generally be rotated in the horizontal plane to effect easy comparison with data recorded in the H, D, Z system.

2. THE Kp INDEX AND ΣKp

The *Kp* index is a 3-hour index of the level of worldwide geomagnetic activity that was first introduced by *Bartels* [1949*a*] and *Bartels and Veldkamp*, [1949]; it was discussed in some detail in a later paper [*Bartels*, 1957]. The index is derived from a statistical composite of variations at the selected group of sub-auroral-zone stations shown in Table 1.

TABLE 1. Observatories Whose Data Are Used in the Computation of *Kp*

Observatory	Geomagnetic North Latitude, deg	Geomagnetic East Longitude, deg	Comment
Sitka	60.0	275.3	
Meanook	61.8	301.0	
Agincourt	55.1	347.0	Up to 1969
Ottawa	57.0	351.5	Since 1969
Fredricksburg	49.6	349.8	
Hartland	54.6	79.0	
Eskdalemuir	58.5	82.9	
Lerwick	62.5	88.6	
Witteveen	54.1	91.2	
Wingst	54.6	94.1	
Rude Skov	55.9	98.5	
Lovö	58.1	105.8	Since 1954
Amberly	−47.7	252.5	
Toolangi	−46.7	220.8	Since 1972

The process by which Kp is derived is somewhat complex; however, it is useful to follow its progress to appreciate the significance of the index. The calculation can be broken down into three separate stages.

a. Computation of the K index. The 3-hour range index K was first introduced in 1938 [*Bartels et al.*, 1939] and was adopted internationally in September 1939. Historically, the numerical values involved in the computation of the K index were obtained by a study of data from the midlatitude station of Niemegk (54°N, 13°E geomagnetic). This later came to represent a standard station. The K index is derived from the data of each observatory for 3-hour intervals of universal time (00–03, 03–06, . . . , 21–24). For each 3-hour interval, the vertical difference δ between the absolute maximum and the absolute minimum of the component trace is measured for each component H, D, and Z (or X, Y, and Z). The maximum deviation δ_{max} of the three components is recorded (in gammas), and it is on this measurement that K is based. Each observatory has its own table for converting δ_{max} to the quasi-logarithmic index K, the values in the table being determined by the geomagnetic latitude of the observatory. The values of K range from 0 (low activity) to 9 (strong activity), so that the lower range limit for $K = 9$ is 100 times the upper range limit for $K = 0$, as is seen from Table 2. A detailed description of the method by which the K index is computed is given in *Mayaud* [1968].

b. Computation of the Ks index. One of the difficulties in doing statistical studies in which K indices are used is that there is a pronounced diurnal variation that must be taken into consideration; e.g., the 3-hour intervals near local (geomagnetic) midnight tend to be substantially more disturbed than all the other 3-hour intervals during the day. In addition, the diurnal variation exhibits a seasonal variation that must also be taken into account. Accordingly, a standardization process was developed to circumvent these difficulties, in which conversion tables were developed that subdivide the tables by season (northern winter, northern summer, and the equinoxes) and by universal-time interval. The resultant index Ks was defined as a continuous variable (as opposed to the integral K) ranging between 0.0 and 9.0 and was given in thirds of an integer. It must be pointed out that the limiting values of Ks (0o and 9o) comprise only $\frac{1}{6}$ of a full interval, and this results in the following coding for Ks:

Ks value range	0–1/6	1/6–3/6	3/6–5/6	5/6–1$\frac{1}{6}$	· · ·
Ks code	0o	0+	1−	1o	· · ·

The coded Ks symbols range from 0o to 9o, and different values of Ks are allotted to different 3-hour intervals for a given value of K, which is dependent on

TABLE 2. K and δ_{max} Values for an Observatory Situated at 50° Geomagnetic Latitude

K =	0	1	2	3	4	5	6	7	8	9
δ_{max}, γ	· · ·5	· · ·10· · ·	20· · ·	40· · ·	70	· · ·120· · ·	200· · ·	330· · ·	500· · ·	

the season of the year, as is shown in Table 3. The coded values of *Ks* form the basis for the computation of *Kp*.

c. Computation of the Kp index. The index of planetary magnetic activity *Kp* is simply derived for each 3-hour interval by averaging the *Ks* indices for the thirteen observatories listed in Table 1. As does the standardized *Ks* index, *Kp* ranges through twenty-eight grades from 0o to 9o.

In the computation of the *Kp* index the data from Rude Skov and Lovö are combined so as to simulate a single observatory. The same procedure will come into effect for Amberley and Toolangi starting in 1972 (M. Siebert, personal communication, 1972).

In typical tables of indices, the eight values of *Kp* over a universal day are summed to give an indication of the over-all level of activity during the day. The resultant quantity ΣKp should be treated with caution, since, as *Bartels* [1957] has pointed out, addition of such quasi-logarithmic quantities can provide misleading results. Thus, days whose *Kp* values are 0o 0o 0o 0o 0o 0o 0o 9o and 2o 2o 2o 1o 1o 1o 0o 0o both have a ΣKp = 9o but have characteristically altogether different types of magnetic activity.

The *Kp* index is often presented in the so-called 'musical diagrams,' such as that shown in Figure 1, so that a large number of data can be compressed into a small space.

Values of the *Kp* index for the period 1932–1961 presented in tabular form and in 'musical diagrams' are available in a booklet published under the auspices of the International Association of Geomagnetism and Aeronomy (IAGA) [*Bartels,* 1962].

d. The ap index and Ap. Very often, for the purposes of arithmetic manipulation, it is more convenient to use an index based on a linear scale rather than on a quasi-logarithmic scale. Accordingly, *Bartels* [1951] introduced the 'daily equivalent planetary amplitude' *Ap*, which is the average of the eight *ap* values computed for each 3-hour interval. The 3-hour index *ap* is obtained directly from *Kp* and hence is based only on midlatitude observations. The relation between each value of *ap* and a value of *Kp* is shown in Table 4. The actual origin of the *ap* scale is somewhat obscure, and the reasons for the choice of 400 as the highest value

TABLE 3. Conversion Table for *K* to *Ks* for Lerwick Observatory during the Northern Winter

K	UT	0–3	3–6	6–9	9–12	12–15	15–18	18–21	21–24
0	*Ks* =	0	0	0	0	0	0	0	0
1	*Ks* =	1+	2−	2−	1+	1o	1o	1o	1o
2	*Ks* =	2+	3−	3o	3o	3−	2+	2o	2o
3	*Ks* =	3+	4o	4+	4+	4o	3+	3o	3o
4	*Ks* =	4+	5o	6−	6−	5o	4+	4−	4o
5	*Ks* =	5+	6o	7−	7−	6−	5o	5−	5o
6	*Ks* =	6o	7o	7+	7+	7−	6−	6−	6−
7	*Ks* =	7o	8−	8o	8o	7+	7o	7−	7−
8	*Ks* =	8o	8+	9−	9−	8+	8o	7+	7+
9	*Ks* =	9o	9o	9o	9o	9o	9o	9o	9o

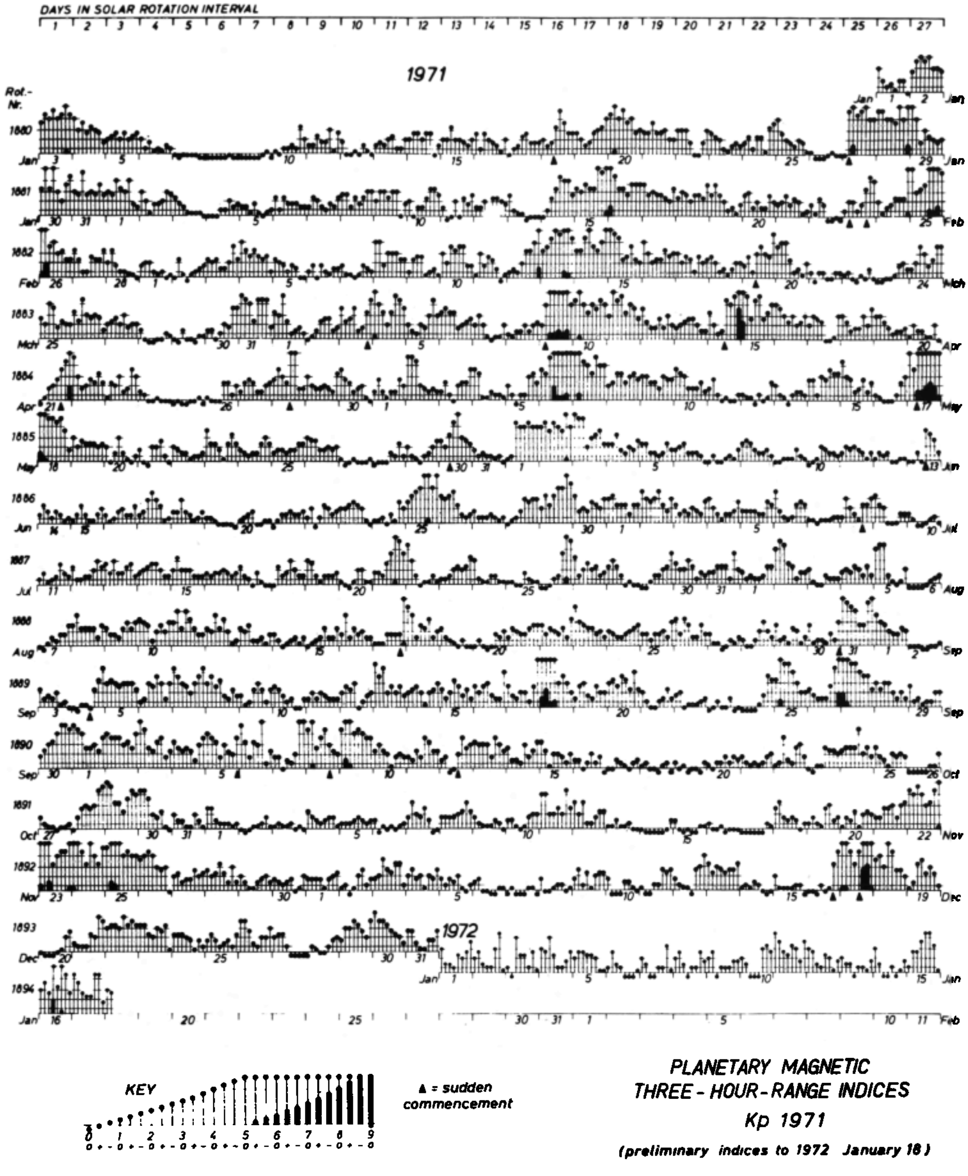

Fig. 1. Musical Kp diagram showing planetary magnetic 3-hour range indices for the year 1971.

do not appear to have been documented in the literature (M. Siebert, personal communication, 1972). The values for those ap indices that correspond to Kp = 1o, 2o, 3o, $\cdots$, 8o can be obtained from the range values for the standard mid-latitude observatory (see Table 2). One can obtain ap corresponding to $Kp = n_0$ (n = 1, 2, 3, $\cdots$, 8) by evaluating $ap \cong (\delta^{n+1}_{\max} + \delta^{n}_{\max})/4$. The values of ap corresponding to $Kp = n\pm$ are evaluated by interpolation. The values of ap for Kp = 8+, 9−, 9o are influenced by the choice of 400 as the upper value of the scale.

TABLE 4. Relationship between the Values of *Kp* and *ap*

Kp	*ap*	*Kp*	*ap*	*Kp*	*ap*	*Kp*	*ap*
0o	0	2+	9	5−	39	7o	132
0+	2	3−	12	5o	48	7+	154
1−	3	3o	15	5+	56	8−	179
1o	4	3+	18	6−	67	8o	207
1+	5	4−	22	6o	80	8+	236
2−	6	4o	27	6+	94	9−	300
2o	7	4+	32	7−	111	9o	400

The numerical values of *ap* can be related to the magnitude of the disturbance at a standard midlatitude station. The average range of the most disturbed component can be taken as 2 *ap*; i.e., for $Kp = 3+$, the average range is $(2 \times 18) = 36\ \gamma$. Thus *ap* is an equivalent amplitude in units of 2 γ.

3. THE AE INDEX

Although the *Kp* index is capable of describing the general state of planetary geomagnetic activity, it contains contributions from at least two major sources, the auroral electrojet and the ring current. To study auroral-zone activity it is desirable to maximize the auroral electrojet contribution. This has been accomplished by the development of the *AE* index, which was first proposed by *Davis and Sugiura* [1966]. To obtain this index of geomagnetic activity, only slightly subauroral-zone stations are employed for the most part, and they are chosen so as to provide uniformly spaced coverage around the auroral zone. In some cases this necessitates the use of southern hemisphere stations to take advantage of the apparent conjugacy of magnetic variations of a substorm nature [*Wescott,* 1961; *Boyd,* 1963]. The stations used in the computation of the *AE* index, over the interval 1957–1964, inclusive, are listed in Table 5.

The *AE* index is constructed by using only the *H* component of the perturbation field. The *H* component at each observatory is scaled at 2.5-min intervals; the average quiet-time baseline is used as a reference level. These baseline levels are assumed to be within ~10 γ of the undisturbed *H* component, and thus the actual scaled values of ΔH include S_q contributions in addition to those from the auroral current system.

All the scaled values from the various observatories are superimposed in a magnetogram format. This composite drawing, shown in Figure 2, is enclosed by upper and lower envelopes representing the maximum positive and negative values of ΔH for all observatories at each given time. The amplitude of the upper envelope at any instant is denoted by *AU*, and the amplitude of the lower envelope is designated by *AL*. If the station distribution were closely enough knit, *AU* and *AL* would represent the maximum positive and negative deviations occurring along the auroral zone.

Physically speaking, *AU* gives a good representation of the maximum magnetic perturbation generated by the eastward electrojet usually found in the after-

TABLE 5. Observatories Whose Data Are Used in the Computation of the *AE* Index over the Interval 1957–1964

Observatory	Geomagnetic North Latitude, deg	Geomagnetic East Longitude, deg
Halley Bay	−65.8	24.3
Norway Station*	−63.8	43.9
Lerwick†	62.5	88.6
Dombås‡	62.3	100.1
Sodankylä	63.8	120.0
Dixon Island	63.0	161.6
Tixie Bay	60.4	191.4
Cape Wellen	61.8	237.1
College	64.6	256.5
Sitka	60.0	275.3
Meanook	61.8	301.0
Byrd	−70.6	336.0

* 1961 only.
† 1957–1963.
‡ All years except 1961.

noon sector. Similarly, *AL* represents the maximum magnetic perturbation generated by the westward electrojet in the morning and midnight sectors. At the present time it appears as though the eastward and westward electrojets may fluctuate independently of one another [*Rostoker*, 1972], so that it may often be useful to treat *AU* and *AL* as independent indices. However, at the present time it is customary to combine these indices to give a direct measure of the total

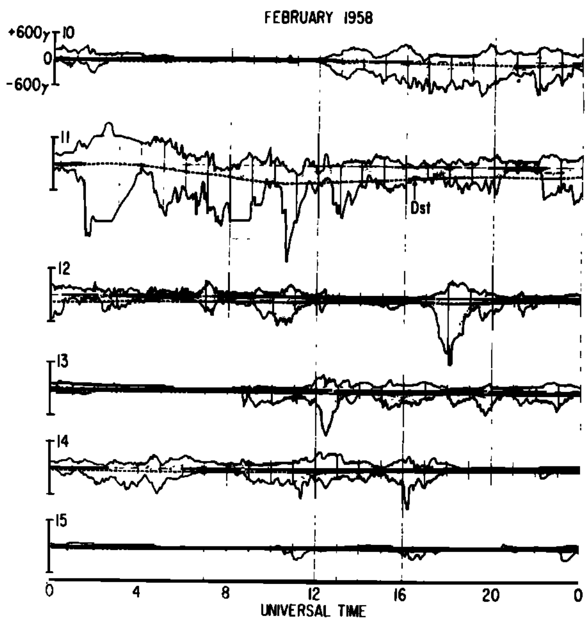

Fig. 2. Superposition of *H* components of auroral-zone magnetograms such that the amplitude of the upper and lower envelopes define *AU* and *AL*, respectively. [After *Davis and Sugiura*, 1966.]

maximum amplitude of the eastward and westward electrojet currents. Hence the index *AE* is defined by $AE = AU - AL$. Thus *AE* represents the difference in levels (measured in gammas) between the upper and lower envelopes at any given instant in time.

Although *AE* is generally calculated at 2.5-min intervals and is available in this form from the World Data Center, hourly average values of *AE* are also available for the period 1957–1964, inclusive (University of Alaska Reports UAG R-192–UAG R-200).

It should be noted that the values of *AE* have been computed for periods after 1964, although the station coverage varies irregularly because of the difficulty in obtaining recent data from the Soviet stations. However, it is customary to update the *AE* index when data from additional stations become available. Thus, after 1964, the contributing stations tend to differ from year to year. More recent *AE* index values are made available by the National Space Science Data Center.

4. THE Dst INDEX

Although *Kp* and *AE* indices are primarily indicators of magnetospheric substorm activity, the *Dst* index was developed to give an indication of ring current strength alone. The *Dst* index has been in use for some time and is found in the definition of the storm variation *D*, i.e., $D = Dst + DS$ where *DS* can be thought of as being due to auroral electrojet activity.

The *Dst* index acquired its acceptance after the International Geophysical Year through the work of *Sugiura* [1964], and it has been commonly used in one form or another since then. The original IGY *Dst* index was obtained by using the array of eight low-latitude observatories listed in Table 6. The observatory locations were chosen so as to be uniformly distributed in longitude and far from the influence of both the auroral and equatorial electrojets. As with the *AE* index, only the *H* component of the magnetic variation is used in the preparation of *Dst* indices. The details of the preparation of *Dst* have been described by *Sugiura* [1964], and a brief account is given in the appendix of this paper.

The *Dst* values for the IGY data are given in *Sugiura* [1964]; however, more recently a new set of *Dst* tables that covers the period 1957–1970, inclusive, has

TABLE 6. Observatories Whose Data Are Used in the Computation of Equatorial *Dst*

Station	Geomagnetic North Latitude, deg	Geomagnetic East Longitude, deg	Comment
Hermanus	−33.3	80.3	IGY and up to 1963
Alibag	9.5	143.7	IGY only
Kakioka	26.0	206.0	IGY and after 1963
Apia	−16.0	260.2	IGY only
Honolulu	21.0	266.4	IGY and to present
San Juan	29.9	3.2	IGY and to present
Pilar	−20.3	4.6	IGY only
M'Bour	21.2	55.1	IGY only

been compiled by M. Sugiura and D. J. Poros (unpublished manuscript, 1971). This list of *Dst* values supersedes the previous provisional *Dst* values calculated by Sugiura and his colleagues and published in a series of NASA technical reports. The most recent *Dst* values are calculated by using only three observatories. From 1957 to 1963, Honolulu, San Juan, and Hermanus were used, and after 1963 Hermanus was replaced by Kakioka. These revised *Dst* values are computed by using the same techniques as were used to derive the IGY values, except in the evaluation of the reference level and S_q at each observatory. Thus there are two sets of *Dst* values in existence for the IGY, and differences in hourly values range as high as several tens of gammas, as can be seen from Table 7. M. Sugiura and D. J. Poros (unpublished manuscript, 1971) recommend usage of the revised values when data from the IGY are to be compared with more recent data. However, because of the nonuniform station coverage, *Dst* is now being revised with data from four stations and with an updated version of the baseline level (M. Sugiura, personal communication, 1972). Thus it is anticipated that a further updated version of equatorial *Dst* will be available in the near future.

5. POSSIBLE ERRORS ARISING FROM THE USE OF GEOMAGNETIC INDICES

The inadequate distribution of magnetic observatories over the earth's surface causes great difficulty in the interpretation of geomagnetic indices. Each of the indices described in the previous section is defined in terms of some ideally uniform distribution of observatories. The net result of the nonuniform distribution of observatories is that the magnitude of disturbances whose region of maximum perturbation lies in the gap between stations will be underestimated. Thus it is safe to say that the indices of geomagnetic activity give only a lower limit of the level of geomagnetic activity. Situations under which indices may provide an incorrect estimate of the level of geomagnetic activity are discussed in this section.

a. The Kp index. As with all the indices discussed in this review, *Kp* is derived from data from an array of observatories. To derive such an index, it is desirable that there should be a uniform spacing of observatories around the world. Unfortunately this is not true for the *Kp* index observatories. Although there is a large concentration of stations in western Europe, there is no coverage in the whole of the Soviet sector (105.8°E to 252.5°E) and in the sector containing the Atlantic Ocean (351.0°E to 79.0°E). As a result, substorms occurring in these sectors may produce rather small perturbations at those observatories whose

TABLE 7. Comparison of *Dst* Values for IGY Data by Using the Two Methods of Computation of Equatorial *Dst*

	September 13, 1957, UT															
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
New	8	44	2	−59	−131	−130	−180	−300	−319	−349	−405	−352	−314	−281	−269	
Old	−1	36	−9	−51	−123	−125	−173	−283	−326	−364	−434	−395	−351	−299	−272	

data are used to formulate *Kp*. In addition, substorms originating to the north of the average auroral zone may produce such a small perturbation at a *Kp* observatory due south of the region of maximum disturbance that only a small value of *Kp* will arise. An example of such a case is shown in Figure 3, where a strong substorm originating near 71°N results in a quite small *Kp* value of 1+. It should then be clear that it is not correct to claim a lack of substorm activity just because *Kp* was small during the interval in question. However, a large value of *Kp* (greater than ~2+) is generally a guarantee of substorm activity, although the fact that *Kp* is a 3-hour index makes it impossible to identify the time of onset of substorm activity using *Kp* alone.

A second problem with *Kp* arises from the dynamic motion of the auroral oval during magnetic-storm activity. It is well known that with an increasing level of magnetospheric-storm activity the auroral oval tends to expand equatorward [*Akasofu and Chapman*, 1963]. Thus an increase in *Kp* may result from (1) an actual increase in the current flowing in the auroral electrojet, (2) the movement of the auroral electrojet closer to the *Kp* observatories, or (3) a combination of (1) and (2). Thus it can be seen that *Kp* is not a good quantitative indicator of the intensity of a given substorm or level of substorm activity.

From the above discussion it is clear that it is not correct to use the *Kp* index for a study of individual events. The value of *Kp* as an index lies in its use in statistical analyses of long periods of magnetospheric activity for the purpose of

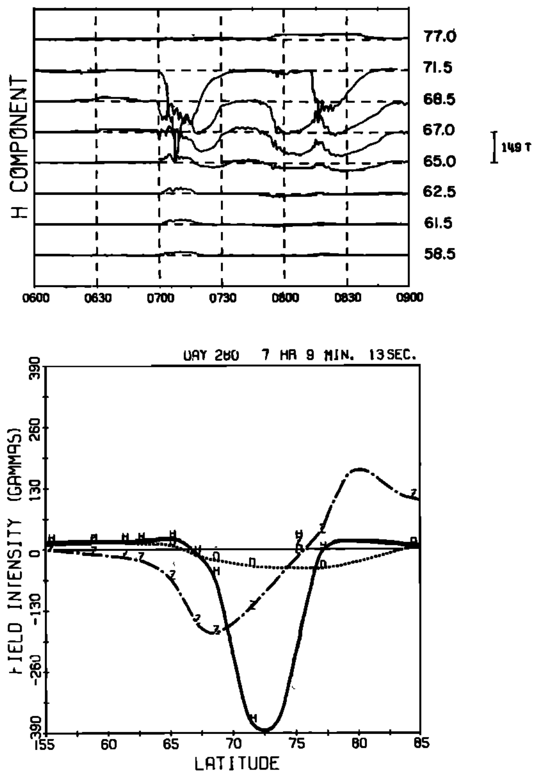

Fig. 3. Substorm sequence that occurred on October 7, 1970, at high latitudes, as indicated by the normal magnetograms from a group of observatories at different latitudes but on a common meridian. The latitude profile shows the magnetic field perturbation at 0709 UT during the expansive phase of the initial substorm of the sequence and shows that the current system peaks near 75°N. The *Kp* index that represents the 3-hour interval containing the substorm activity is 1+ (0600–0900 UT), which indicates a low level of magnetic activity.

determining long-term trends. Some of the important information gained through the statistical study of *Kp* indices has been discussed by *Siebert* [1971].

b. The AE index. Since the *AE* index is computed from auroral-zone data, this index should be superior to *Kp* as an indicator of substorm activity. However, it turns out that *AE* is subject to many of the same problems that plague the *Kp* index. The major difficulty stems from the inadequate distribution of observatories around the world. There are large gaps in the sectors containing eastern North America (336.0°E to 24.3°E) and the central Soviet Union (191.4°E to 237.1°E) at the best of times. Since substorm current systems are sometimes quite localized in spatial extent, well-defined substorms may be lost in the 'noise level' of the *AE* values. Such circumstances could arise under the following conditions.

1. The substorm current system is localized in longitudinal extent.
2. The intensified portion of the electrojet is located at high latitudes, well poleward of the *AE* stations [*Akasofu and Snyder*, 1972].
3. During intense storms the oval may move far south, away from the *AE* observatories.

The first two effects are probably most important for a study of individual events. They point to the fact that, as with *Kp*, one cannot rule out the presence of substorm activity on the basis of a low *AE* index. However, a large value of *AE* can generally be used to infer the presence of substorm activity.

Another problem involved with the use of *AE* centers around a pronounced UT variation in the level of activity inferred from the *AE* values. The effect is due to the combination of two effects: the latitudinal scatter in the locations of the observatories and their irregular spacing in longitude (see Table 5). The effect is most pronounced in the interval 0300–0600 UT, where there is a well-defined minimum in activity, and around 0900–1200 UT, where there is a clear maximum (see Figure 4). The minimum occurs in a sector where geomagnetic midnight is covered only by Byrd station. This station is at a very high latitude (~70.6°S), and during storms the auroral oval would be far equatorward, making Byrd a polar-cap station. The maximum occurs because of concentrated coverage in a confined longitudinal sector by both low- and high-latitude observatories. Average auroral-zone activity is covered by College; during storm activity the oval expands in the latitudinal regime covered by Sitka. The major UT effect, coupled with a well-defined solar-cycle dependence (see Figure 4) and seasonal effect, makes it risky to use *AE* for quantitative statistical studies of long time intervals. In this instance *Kp*, which has incorporated within it weighting factors for each station, is superior for statistical studies, even though there is a weak residual UT dependence due to the lack of contributing stations in the Soviet sector [*Michel*, 1964].

The primary strength of *AE* is that it describes the level of magnetic activity over relatively short intervals of time. The *AE* index is available for hourly intervals. However, it is also computed every 2.5 minutes, and such data can be obtained through the World Data Center. This time resolution is to be contrasted with that of *Kp* and *ap*, which are indicative of the level of activity over

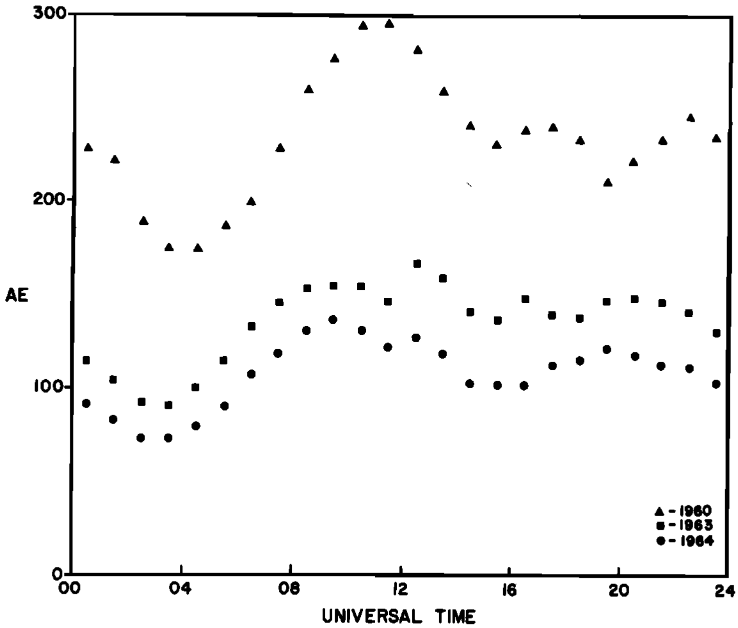

Fig. 4. Average *AE* values in each of the 24-hourly UT intervals for the years 1960, 1963, and 1964. A pronounced UT variation is apparent with a minimum in the range 0300–0500 UT and a maximum in the range 0900–1200 UT. (This UT variation is, of course, merely an artifact of the data-gathering process; see text.) The solar-cycle variation is also apparent in the decreased values of *AE* moving toward solar minimum.

intervals of three hours. In addition, the optimum *AE* values (incorporating data from the maximum number of available observatories) include coverage over the Soviet Union, and therefore the *AE* index may indicate substorm activity not easily identifiable by *Kp*. Finally, *AE* values are easily manipulated by digital computers, which facilitate statistical studies that use a large number of data.

c. The Dst index. The *Dst* index, as an indicator of the strength of large-scale current systems, does not describe the level of localized auroral electrojet activity. In this manner it differs considerably from the *Kp* and *AE* indices. According to the definition of *Dst*, it describes only the ring current intensity and thus the level of magnetic-storm activity.

Davis and Parthasarathy [1967] have suggested that the ring current *Dst* reacts to substorm activity *Dp* with a delay of one or more hours. *Davis* [1969] has interpreted this correlation between *Dst* and *Dp* as an indication that energy is injected into the ring current during the course of substorm activity. However, for individual events the asymmetric character of the ring current may lead to magnetic variations that can be at the noise level of the index. Figure 5 shows an example of a substorm of great intensity during which *Dst* shows no tendency to react. Thus *Dst* cannot be used to identify individual substorm events, although the results of Davis and Parthasarathy would tend to indicate a statistical relationship between substorms and ring current intensity.

A major problem concerning the present *Dst* index is its inability to describe quantitatively the strength of the equatorial ring current. This inability stems from the paucity of stations (as few as three) from which the index is computed, coupled with the tendency of the ring current to be asymmetric during all but the recovery phase of magnetic storms [*Akasofu and Chapman*, 1964; *Cummings*, 1966; *Akasofu and Meng*, 1969].

The strength of *Dst* lies in its ability to detect all magnetic storms. This stems from the fact that the ring current is world wide in nature, and thus there is little or no possibility of *Dst* not reacting to the growth of the ring current. Furthermore, within about two hours, the *Dst* index should be able to identify the onset and termination of the main phase of a magnetic storm (during which time the major portion of the energy of the storm is dissipated in the magnetosphere). Thus the *Dst* index gives a good qualitative description of the gross level of magnetospheric activity at any time, although it cannot be used to reveal the presence of individual substorms.

6. CONCLUSIONS

This paper has dealt with the methods by which the most commonly used indices of geomagnetic activity are derived and with the conclusions that one is able to draw by using these indices. For all the indices the following conclusions apply.

1. Indices are of great use in statistical studies of solar-terrestrial interactions, where qualitative correlations between different parameters are being sought. Of those indices described in this review, *Kp* and *ap* show the most promise for quantitative studies because of careful weighting procedures used in their computation.

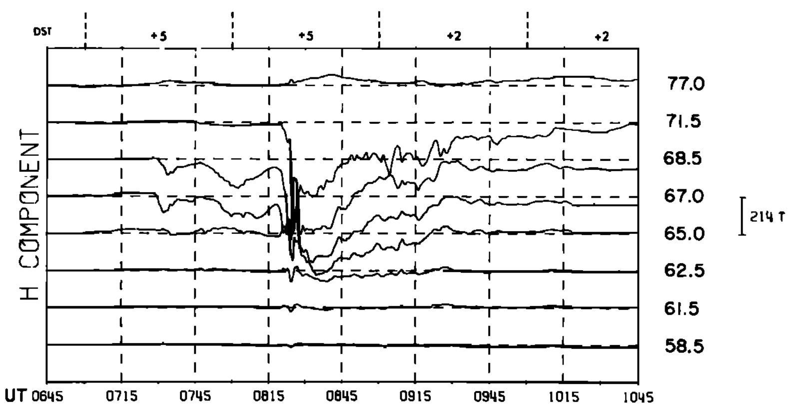

Fig. 5. *H*-component variations associated with a substorm that occurred on July 14, 1970, during which *Dst* shows no identifiable response. The magnetograms are recorded at a set of observatories at varying latitudes (shown at the right-hand side of the figure) but on a common meridian. The *Dst* values are shown across the top of the figure.

2. It is not advisable to use indices in a study of individual events, particularly where one wishes to rule out the possibility of substorm activity. It may, in fact, be impossible with the existing network of observatories to rule out the possibility of substorm activity. However, research workers are duty-bound to use all available magnetograms in a study of individual events to provide the maximum probability of the correct evaluation of the level of magnetospheric activity.

At present there is considerable controversy centering around the advisability of the adoption of new indices. However, it would appear that the nonuniform observatory distribution militates against any efforts to define new indices. Until the observatory network is improved so as to provide uniformly and closely spaced stations around the world, it will be difficult to devise new indices that will improve the level of information that can be obtained from the indices described in this paper.

APPENDIX

The derivation of the *Dst* index, which describes ring current variations, has been outlined in detail in *Sugiura* [1964]. The method used for the analyses of IGY data is discussed in the following section. Initially, the disturbance $H^{(i)}(t)$ in the H component for the ith station was broken down into

$$H^{(i)}(t) = H_o^{(i)}(t) + S_q^{(i)}(t) + L^{(i)}(t) + D^{(i)}(t)$$

where $H_o^{(i)}$ is the permanent field (including secular variation), $S_q^{(i)}$ is the solar daily variation, $L^{(i)}$ is the lunar daily variation, and $D^{(i)}$ is the disturbance. The lunar variation was considered to be small and was subsequently ignored. The mean value of $H^{(i)}(t)$ is calculated over each year and is called $H_{oo}^{(i)}$. The permanent field contribution $H_o^{(i)}(t)$ for the IGY data [*Sugiura*, 1964] was then written

$$H_o^{(i)}(t) = H_{oo}^{(i)} + \Delta H_o^{(i)}(t)$$

By taking the deviation of the observed $H^{(i)}(t)$ from $H_{oo}^{(i)}$ to be

$$\Delta H^{(i)}(t) = H^{(i)}(t) - H_{oo}^{(i)}$$

and taking the mean of each parameter over all stations

$$\langle \Delta H(t) \rangle = \langle \Delta H_o(t) \rangle + \langle S_q(t) \rangle + \langle D(t) \rangle$$

The evaluation of $\langle S_q(t) \rangle$ was carried out in the following fashion. At each station, for the five international quiet days of each month, the mean daily variation from universal midnight to universal midnight was subtracted from each of the 25 hourly mean values; the trend between the two midnight values was assumed to be linear. The altered 25 hourly mean values represent the S_q variation at each station, and the hourly values were averaged over all stations to produce a mean S_q. This mean S_q was expanded in a double Fourier series with month number M and universal time T as variables:

$$\sum_{n=1}^{6} \sum_{m=1}^{6} A_n^m \cos (mT + \alpha_m) \cos (nM + \beta_n)$$

and for each day a mean S_q was synthesized from this series. At any given time the value of S_q so obtained defined $\langle S_q(t) \rangle$.

For the IGY data, all quiet periods in which two or more successive days had $Ap < 7$ were selected, and the quantity

$$\langle \Delta H(t) \rangle - \langle S_q(t) \rangle \qquad (= \langle \Delta H_o \rangle + \langle D(t) \rangle)$$

was averaged over these quiet days. The average was 31 γ, and this was the value given to the constant $\langle \Delta H_o \rangle$. Then $\langle D(t) \rangle$ was equated to $Dst(t)$ and was defined as

$$Dst(t) = \langle \Delta H(t) \rangle - \langle S_q(t) \rangle - \langle \Delta H_o \rangle$$

Finally, these values were normalized to the magnetic equator by multiplying by sec θ_m, where θ_m is the average geomagnetic latitude of the magnetic observatories whose data are used for the IGY data $\theta_m = 22°$.

It should be pointed out that different techniques are now being used in the evaluation of the baseline reference level and the S_q variation used in the computation of Dst. At present the reference level is obtained by expanding the baseline value in a power series in time, where the coefficients for the terms up to the quadratic are determined by the method of least squares, and annual means of H are used for the five international quiet days of each month. In this manner the effect of secular variations is removed through the computation of the annual mean value of H. In addition to this modification, the S_q contribution is now determined for each station, as is described in the IGY method; however, the subtraction of S_q is made for each station separately before averaging over the contributing stations. Furthermore, the noncyclic change in S_q is now removed by assuming it to be linear from local midnight to local midnight over the international quiet days (as opposed to the assumption of linearity over a universal day used in the original treatment of the IGY data).

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