Proceedings "International Magnetosphere Study" Tokyo 1979 p. 316.

Irregular geomagnetic activity in the northern and southern hemispheres associated with IMF sector boundary passage

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ABSTRACT:

K_n and K_s, the northern and southern hemispheric indices of geomagnetic activity, for the period 1959-1974 are analysed to examine the influence of solar magnetic sector boundary passage. It is shown that hemispheric difference in activity is a function of the type of sector boundary and that greater change is associated with a +/- boundary. Occurrence frequency of the index 0 depicts a significantly larger response in association with a +/- boundary, only for the southern hemisphere index. Ratios of occurrence frequency of K_s to K_n, as a function of sector boundary passage, show significant departures only for indices 0 and 5, indicating two regions of solar wind velocities that cause significant differences in geomagnetic activity of the two hemispheres.

INTRODUCTION

The discovery of the sector structure of the interplanetary magnetic field (IMF) and increased geomagnetic activity in the vicinity of a sector boundary (Wilcox and Ness, 1965) has added a new parameter in the study of solar-geomagnetic relations. It soon became apparent that the sector structure of the IMF is well-ordered in all phases of solar cycle (Wilcox and Colburn, 1972). Association between polar-cap geomagnetic field and the polarity of IMF provided a useful tool for inferring the

IMF direction in the ecliptic plane from ground-based data (Svalgaard, 1968). This list of inferred polarity pre-dates the satellite data by about four decades. From a study of the relation between low latitude geomagnetic activity and sector boundary, Rangarajan (1977) showed that with the passage of a +/- boundary the response was significantly larger. Similar results were earlier indicated by Shapiro (1974) who used K_p index for his analysis.

Mayaud (1967, 1968, 1970) has described in detail the derivation and the characteristics of the geomagnetic activity indices K_n and K_s of the northern and southern hemisphere, respectively. These indices represent, for each three-hour interval, the mean intensity of geomagnetic activity superposed on the regular diurnal variation along the latitude circle at a distance of about 19° from the mean position of the auroral zone in each hemisphere. While the index K_p corresponds to a measure of the nocturnal level of the activity, K_n and K_s indices are measures of true level of activity. Mayaud (1970) showed that there exists a real difference in the activity in the two hemispheres, with the northern hemisphere higher by about 10% on the average. Before the introduction of the standard indices K_n and K_s, Siebert (1968) analysed the magnetic activity difference of the two hemispheres as a function of the sector structure of the IMF. He computed the average K_n and K_s from K-indices of stations in approximately conjugate regions and showed that when nocturnal values are used, (K_n-K_s) is higher during sectors directed away from the Sun. Wilcox

(1968) found a small but significant enhancement of geomagnetic activity in the northern hemisphere in the away sector and decrease in the toward sector. According to him, when the geomagnetic field direction in the tail is anti-parallel to the IMF, they can be connected leading to greater geomagnetic activity. The effect related to polarity of IMF is an order of magnitude smaller than the seasonal change in excess geomagnetic activity in northern hemisphere relative to the southern hemisphere reported by Mayaud (1970).

Most of the studies relating IMF to geomagnetic activity have utilised the magnitude rather than the frequency of occurrence of an index as a parameter. The classic example that distinguishes the two indices $\sum$Kp and Ap (days with 3 hourly Kp 0000 0008 and 1111 1111 respectively with $\sum$Kp being same but nature of the disturbance being substantially different) suggests that the occurrence frequency may be a very meaningful parameter in some analyses. Occurrence frequency of the index with increasing magnitude will also provide useful information on the range of activity susceptible for the influence of the parameter under consideration (IMF polarity, in the present instance) and the threshold separating active and quite intervals.

In this communication we examine the occurrence of different magnitudes of the indices Kn and Ks as a function of the passage of solar magnetic sector boundary past the earth to bring out the IMF influence on the hemispheric difference in geomagnetic activity. As far as we are aware, this a first attempt to study the nature of response of the geomagnetic activity in the two hemispheres comprehensively with a long span of data, use of which reduces substantially the errors associated with average features. Hence, we also report the results of analysis when $\sum Kn$ and $\sum Ks$ are used as parameters and discuss the salient features.

DATA ANALYSIS

Three hourly Kn and Ks for the period 1959-1974 are available on magnetic tape at the World Digital Data Centre C-2 at Bombay, India. These indices are listed as integers between 0 and 27 corresponding to magnitudes 3 Kn and 3 Ks, as the indices are computed correct to one-third of a unit. This was reduced to a more coarse scale of 0 to 9 as given below:-

3K	0-1	2-4	5-7	---------	23-25	26-27
K	0	1	2	---------	8	9

Since occurrence of Kn or Ks with magnitudes $\geqslant 6$ is rare, the indices $\geqslant 6$ were grouped together in one category. The occurrence frequencies of each of the indices with magnitudes 0,1,2,3,4,5 and $\geqslant 6$ for each day were computed. List of well-defined solar magnetic sector boundaries compiled by Svalgaard (1975) were used as key days in a superposed epoch analysis. During the 16-year period, there were 240 boundaries with -/+ and 242 boundaries with +/- polarity change. Apart from the frequency of occurrence, $\sum Kn$ and $\sum Ks$ for each day was also used in a similar analysis, for the same list of boundaries. To avoid repetitive use of +/- and -/+ boundaries, we define these as 'positive' and 'negative' boundaries.

our results show that this feature is significantly seen only in post-boundary intervals which can be ascribed to the fact that in any sector the leading part is more geoeffective than the trailing portion.

To examine the difference in nature of response dependant on the type of boundary, we have regraphed in Fig. 1c the variation in $\sum$Kn and $\sum$Ks as a function of the day of passage of either type of boundary. It is at once apparent that post-boundary difference in response is pronounced for $\sum$Ks with larger magnitude in association with a positive boundary. The concept of topological symmetry between IMF directed away from (toward) the Sun and the geomagnetic tail field of the northern (southern) hemisphere leading to greater activity appears consistent especially in regard to the southern hemispheric indices. $\sum$Kn does not show any dependence on the nature of polarity change. This implies that mere reconnection of the tail field and IMF would not be sufficient for increased geomagnetic activity and that to account for these features in responses of $\sum$Kn and $\sum$Ks, difference in the variation of IMF parameters controlling geomagnetic activity in the vicinity of a +/- and -/+ boundary will have to be invoked.

Using IMF polarity data observed by satellite and night-time K-indices of near conjugate regions for three solar rotations, Siebert (1968) showed that (Kn-Ks) decreased across a positive boundary and increased across a negative boundary. We have derived the mean difference ($\sum$Kn - $\sum$Ks) from a more extensive data base. The change in (Kn-Ks) across either type of boundary is depicted in Fig. 2. The hemisphere difference in activity is an order of magnitude less than the indices themselves and comparable to that indicated by Wilcox (1968). The anticipated decrease (increase) across a positive (negative) boundary is also clearly noticed. However, the transition across the key day, is more rapid in association with a positive boundary .

II Frequency of Occurrence of Kn and Ks and IMF sector boundary

In Fig. 3 are shown the occurrence frequencies of Kn and Ks for the indices with increasing magnitudes from 0 to 5 and $\geqslant$ 6 as a function of passage of the sector boundary separately for the +/- and -/+ boundaries. Tests of significance for difference between the means and frequencies Kn and Ks were applied to individual cases. The levels above which the differences are significant are indicated in Table I. The salient features of the figure consistent with Table I can be summarised as follows:-

1) Frequency of the index $\geqslant$ 6 depicts no dependence on the boundary. This suggests that geomagnetic disturbance with ranges greater than those characterized by index 5 are not caused by the discontinuity in solar wind across a sector boundary or in other words, moderately severe magnetic storms, in general, may not be associated with sector boundary passage though SSCs are often recorded following the boundary passage.

2) Indices 4 and 5 occur more frequently in Kn as compared to Ks after the passage of a negative boundary. This feature is again consistent with the greater probability of activity in northern hemisphere in the away sector of the IMF.

3) Change in occurrence frequency of the index 3 is same for both Kn and Ks but actual frequencies are larger for Kn, throughout the 9-day interval. The dependence, on the type of boundary, of the difference between Kn and Ks noticed in the immediately higher magnitudes of 4 and 5 is absent for this range of activity.

4) While index 2 provides a clear transitory pattern between active and quiet intervals for the -/+ change both for Kn and Ks, the corresponding index appears to have a magnitude less than 2 for the other type. Index 2 in the case of +/- change depicts a response similar to that of the more active intervals. It may be noted that occurrence of at least two successive values of K = 2 after a geomagnetic disturbance is used generally as a criterion for ending of a magnetic storm/ (vide Solar Geophysical Data). For groups 2 and 3 Kn occurs more frequently than Ks, independent of sectors and especially independent of sector boundary.

5) Changes in occurrence of 1 with the passage of either boundary is same for Kn and Ks, similar to that observed for index 3.

6) While the response of occurrence of 0 to a negative boundary is same for Kn and Ks, there is a significant difference between the two in association with the passage of a positive boundary. Kn still depicts the same magnitude of response but Ks shows a pronounced change with the crossing of the boundary. Throughout the interval of 9 days centred on the key day, occurrence of 0 is more in Ks than in Kn. Also the excess frequency in Ks is significantly larger in the pre-boundary intervals of a +/- polarity change.

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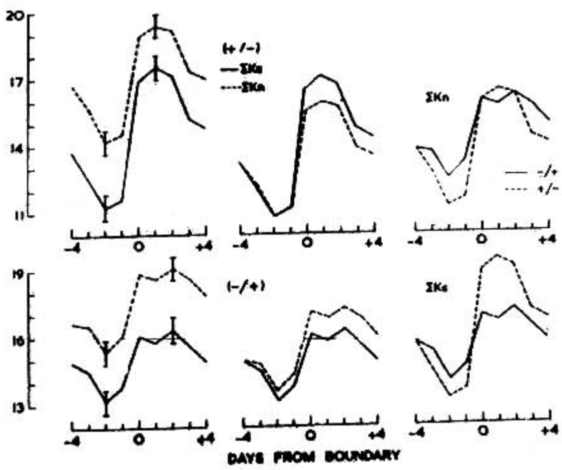

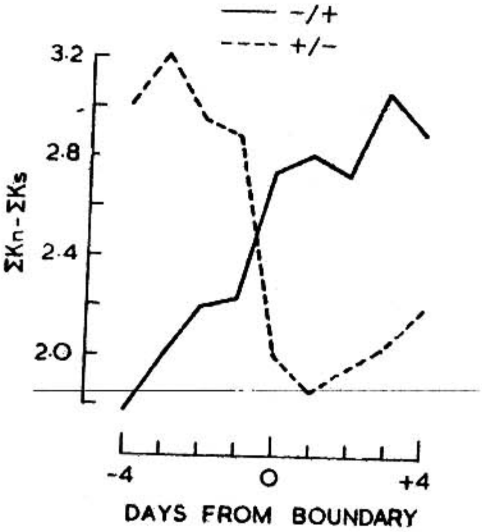

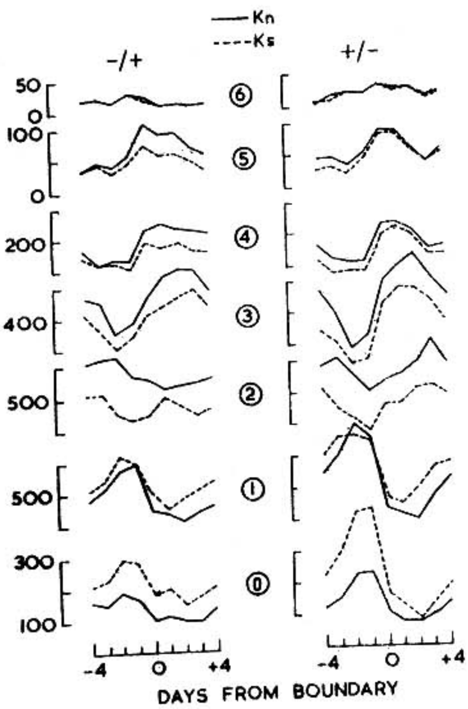

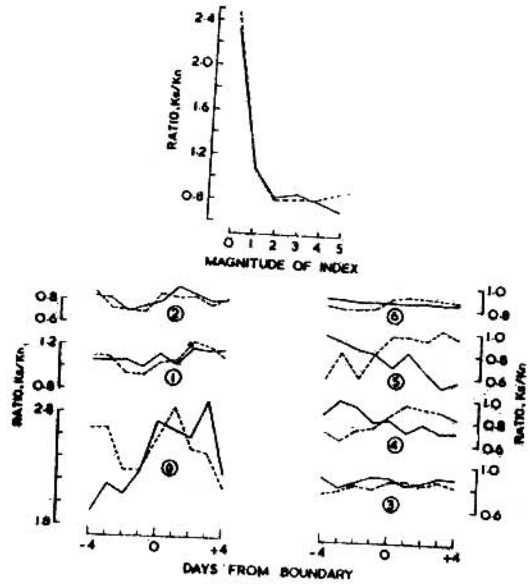

TABLE I

Level of significance (percent) of difference

K	Ks and Kn (-/+) -4	-3	-2	-1	0	+1	+2	+3	+4	K	Ks and Kn (+/-) -4	-3	-2	-1	0	+1	+2	+3	+4
0	99	99	99	99	99	99	99	99	79	0	99	99	99	99	99	99	99	99	99
1	-	-	-	-	-	90	90	90	90	1	-	-	-	-	-	-	95	95	-
2	99	79	99	99	99	-	90	99	75	2	90	99	99	99	90	95	95	99	99
3	-	95	-	-	-	95	95	-	-	3	99	99	90	95	95	90	99	90	95
4	-	-	-	-	-	95	90	95	95	4	-	-	-	-	-	-	-	-	-
5	-	-	-	-	90	-	90	95	90	5	-	-	-	-	-	-	-	-	-
ΣK	95	99	99	99	99	99	99	99	99	ΣK	99	99	99	99	99	99	99	99	99

	Ks (+/-) and Ks(-/+) -4	-3	-2	-1	0	+1	+2	+3	+4		Kn (+/-) and Kn (-/+) -4	-3	-2	-1	0	+1	+2	+3	+4
0	-	-	99	99	-	95	90	-	-	0	-	-	-	95	-	-	-	-	-
1	95	99	-	-	-	-	-	-	-	1	-	95	99	95	-	-	-	-	-
2	-	90	-	95	-	-	-	90	-	2	-	-	90	90	-	-	-	99	-
3	90	-	95	99	-	-	-	-	-	3	-	-	95	90	-	-	-	-	-
4	-	95	95	-	-	-	-	-	-	4	-	-	-	-	-	-	-	99	90
5	-	-	-	-	-	-	-	-	90	5	-	-	-	-	-	-	90	95	-
ΣKs	-	99	95	99	-	95	-	-	-	ΣKn	-	-	90	95	-	-	-	95	-

frequency of the indices and is prevalent in the vicinity of the sector boundaries, we computed the ratio of occurrence of Ks and Kn for 0,1,2,3,4 and 5, using for this purpose the cumulative sum for 9 days centred on the sector boundary. The variations in the ratio with increasing magnitude of the index, separately for the two types of boundaries, are shown in Fig. 4a. We find that the ratio corresponding to 0 is about 2.4 whereas for the next higher index, the ratio falls close to unity followed by a nearly constant value of about 0.8 for 2,3 and 4. This basic pattern is same whether the nine days considered is centred on +/- or -/+ sector change. However, the occurrence ratios of 0 and 5 show a noticeably larger magnitude for the group of days centred on a positive boundary. To further examine if the ratio has any dependence on the passage of the boundary as the occurrence of the indices themselves we computed Ks/Kn for each of the 9 days for the indices 0,1,2,3,4 and 5. The changes in ratio with the passage of the boundaries are shown in Fig. 4b. For K = 5, there is a distinct anti-symmetry with larger ratios in preboundary intervals followed by smaller ratios for the -/+ polarity change and vice-versa for the opposite type of change of sectors. Group 4 has a pattern similar to 5. In other words for 4 and 5, it may be concluded that frequency of Ks is larger than that of Kn in the negative sectors, irrespective of the boundary. For the intermediate range of activity, with index 1,2 or 3, there is no significant change in Ks/Kn and the magnitudes of the ratios are comparable for the two types of boundaries. For group 0 large difference in the ratios between the two types of polarity change is noticed well away from the key days. Also, the range of variation in the ratio is perceptibly larger in association with a negative boundary.

These results suggests that the response of Ks and Kn differ significantly only either during conditions of exceptional calm (K = 0) or during moderate disturbances (K = 5). Thus using a suitable linear relationship between Kn (or Ks) and solar wind velocity, similar to that derived between Kp and velocity (Snyder et al., 1963) we may infer the two possible regions of solar wind velocity that can be associated with perceptibly different geo-magnetic activity in the northern and southern hemispheres of the earth. If we assume $\Sigma Kp \approx \Sigma Kn$ or ΣKs and substitute $\Sigma Kp = 0$ or 40 in the relation V (Kn/Sec) = $8.44\ \Sigma Kp + 330$ of Snyder et al. (1963), we get the two velocities to be in the region of 330 km and 670 km.

These values compare favourably with the solar wind velocities associated with the average minimum during quiet intervals and that of fast streams. Bame et al. (1977) compared the plasma characteristics of slow and high-speed solar wind flows measured by Imp 6-8. The mean velocities of low speed and high speed solar wind computed by them are 327 km/sec and 702 km/sec which are very close to the range of velocities indicated above suggesting that for these velocities of solar wind geomagnetic activity in the two hemispheres tends to differ significantly.

Acknowledgement : The author is grateful to Prof. B.N. Bhargava, Director, Indian Institute of Geomagnetism and to Dr. R. Rajaram for useful discussions.

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TABLE I

Level of significance (Percent) of difference

Ks and Kn (-/+)

K	-4	-3	-2	-1	0	+1	+2	+3	+4
0	99	99	99	99	99	99	99	99	99
1	-	-	-	-	-	90	90	90	90
2	99	99	99	99	99	-	90	99	95
3	-	95	-	-	-	95	95	-	-
4	-	-	-	-	-	95	90	95	95
5	-	-	-	-	90	-	90	95	90
ΣK	95	99	99	99	99	99	99	99	99

Ks and Kn (+/-)

K	-4	-3	-2	-1	0	+1	+2	+3	+4
0	99	99	99	99	99	99	99	99	99
1	-	-	-	-	-	-	95	95	-
2	90	99	99	99	90	95	95	99	99
3	99	99	90	95	95	90	99	90	95
4	-	-	-	-	-	-	-	-	-
5	-	-	-	-	-	-	-	-	-
ΣK	99	99	99	99	99	99	99	99	99

Ks (+/-) and Ks(-/+)

	-4	-3	-2	-1	0	+1	+2	+3	+4	
	-	-	99	99	-	95	90	-	-	0
	95	99	-	-	-	-	-	-	-	1
	-	90	-	95	-	-	-	90	-	2
	90	-	95	99	-	-	-	-	-	3
	-	95	95	-	-	-	-	-	-	4
	-	-	-	-	-	-	-	-	90	5
s	-	99	95	99	-	95	-	-	-	ΣKn

Kn (+/-) and Kn (-/+)

	-4	-3	-2	-1	0	+1	+2	+3	+4
0	-	-	-	95	-	-	-	-	-
1	-	95	99	95	-	-	-	-	-
2	-	-	90	90	-	-	-	99	-
3	-	-	95	90	-	-	-	-	-
4	-	-	-	-	-	-	-	99	90
5	-	-	-	-	-	-	90	95	-
ΣKn	-	-	90	95	-	-	-	95	-