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MAR 80 J M WILCOX, P H SCHERRER N00014-76-C-0207
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by

J. M. Wilcox and P. H. Scherrer

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of the Vorticity Area Index to the Solar Magnetic Field

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Abstract

The apparent response of the vorticity area index to the solar magnetic field is confined to tropospheric regions of intense circulation. Discussions and calculations that include larger volumes of the troposphere would not be expected to show a significant sun-weather effect. Analysis of the effect in time intervals outside the original 1963-73 is also discussed. An assessment of this sun-weather effect at the present time is given.

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1. Introduction

We shall discuss the characteristics of tropospheric circulation that are involved in the apparent response of the vorticity area index (VAI) as the solar magnetic field is carried past the earth by the solar wind. The main point we wish to make is that the response is concentrated in the tropospheric regions of most intense circulation, i.e. the central portions of well-formed low pressure troughs. Discussions and calculations that involve tropospheric volumes larger than these regions of intense circulation involve regions at which no sun-weather effect is apparent.

We shall also discuss some factors that must be considered when assessing this sun-weather effect in the years from 1947-1978.

2. The Discussion by Shapiro (1979)

A recent discussion by Shapiro (1979) does not take proper account of the above considerations. In particular, by defining his own vorticity area index rather than analyzing the vorticity area index defined by Roberts and Olson (1973) he has attenuated out most of the apparent solar signal in the vorticity area index. The analysis in Shapiro (1979) of his vorticity area index, which we all agree has little or no solar signal, is not appropriate for assessing the statistical and physical significance of the apparent sun-weather effect discussed by Wilcox et al. (1976).

The difference between Shapiro's vorticity area index (vai) and the Roberts and Olson vorticity area index (VAI) can be seen in the following way. Figure 1 shows the response of the VAI at 500mbar to 162 interplanetary magnetic sector boundary transits past the earth during winter months from 1 November 1963 to 31 March 1976. The previously reported (Wilcox et al., 1976) minimum in VAI approximately one day after the boundary transit is clear. A measure D of the depth of this minimum is defined as the VAI around day +1 minus the average of the VAI around days -2 and +4 (day 0 is the boundary transit time). Each VAI in this relationship refers to the mean of three adjacent half-days.

In Figure 2 we show that the size of the sun-weather effect using the vai computed by Shapiro (1979) is small compared to the size obtained using the VAI of Roberts and Olson (1973). We compute several vorticity area indices using different discriminator values of vorticity, i.e. the vorticity area index is computed as the sum of the area in the northern hemisphere in which the vorticity equals or exceeds various indicated values between 14 and 24 units of vorticity ($10^{-5}s^{-1}$). For each index we then compute a superposed epoch analysis about boundary transit times. The 131 boundary transits during the winter 1963-1973 that were analysed by Wilcox et al. (1976) are used in preparing Figure 2. The ordinate of Figure 2 is the size in percent of the sun-weather effect, which is defined as the value D divided by the average vorticity area index near days -2 and +4. The abscissa is the discriminator value of the vorticity used in computing the vorticity area index.

We see in Figure 2 that the strength of the sun-weather effect increases steeply with increasing discriminator vorticity value. Shapiro (1979) has used smaller discriminator vorticity values in computing his index and has thereby attenuated out most of the effect evident with higher values.

3. Extension of the Analysis to Earlier Time Intervals

In his Figure 12 Shapiro (1979) analyzes his vai during the time period 1947-1970. Two important considerations not mentioned by Shapiro (1979) have to be recognized with regard to analysis of the effect before 1963. First, between 00Z and 12Z on 9 January 1962 the series of VAI values very abruptly and permanently increased by more than a factor of two. This is clearly not meteorologically real, and apparently resulted from the use of methods either for constructing the National Meteorological Center pressure grid heights themselves before and after that date, or for determining VAI values from the grid heights.[1] Second, before 1963 the average value of geomagnetic activity on toward days of the inferred polarity of the interplanetary magnetic field was approximately twice as large as the value of geomagnetic activity on away days. After 1963 this difference disappeared. There is some controversy as to whether this situation represents a large change in the coupling between the interplanetary magnetic field and terrestrial activity or is simply a deficiency of the inferred polarity during the early years. In any case, the response of a major terrestrial activity index to the inferred polarity of the interplanetary magnetic field changed markedly before 1963 as compared with after 1963.

Figure 3 is a plot of the Roberts and Olson (1973) VAI from 1946 to 1978. The annual variations in VAI with a peak in winter and a minimum in summer are apparent. The large change in VAI on 9 January 1962 is clearly seen. Caution is clearly indicated in analysis of the VAI before 9 January 1962, particularly in view of conditions related to the variance of the VAI to be discussed later in this paper.

Figure 4 is redrawn from Russell and Rosenberg (1974) and shows yearly average values of the geomagnetic index Ap during days in which the inferred polarity of the interplanetary magnetic field was toward the sun (solid line) and away from the sun (dashed line). We see after 1963 a significant difference in the influence of the interplanetary magnetic field as measured by the inferred polarity, namely that the factor of two difference in geomagnetic activity as a function of inferred polarity seen before 1963 disappears after 1963. Again, this suggests considerable caution in analysis of the VAI using inferred transit times of sector boundaries before 1963.

1 A change of NMC analysis procedures specifically on 9 January 1962 has not yet been confirmed. Various changes of routine around that general time are, however, a matter of record at NMC.

4. Response to Two Specific Points

We respond now to the two numbered points on page 1114 of Shapiro (1979).

1) "Except for similar, but irrelevant seasonal behavior, vai (VAI) is virtually uncorrelated with the average absolute vorticity" (Shapiro, 1979). This is correct, and is exactly what would be expected since the VAI corresponds to tropospheric regions of intense circulation (low-pressure troughs) whereas the average absolute vorticity is a property of the entire troposphere. Figure 5 shows the vorticity contours corresponding to $20 \times 10^{-5} s^{-1}$ at 00Z on 26 February 1967. The contribution to the vorticity area index computed by Roberts and Olson (1973) comes from the area within these contours. The average hemispheric absolute vorticity computed by Shapiro (1979) describes predominently regions of the troposphere outside these contours in which the sun-weather effect is not apparent. On the other hand, it might be interesting to look at absolute vorticity within these contours, and we are in the process of doing this.

2) "Because VAI represents a relatively small area where the vorticity exceeds a rather sizeable threshold value, small broad scale changes in vorticity from day-to-day can produce very large day-to-day changes in VAI" (Shapiro, 1979). Shapiro has a good point here. In published work the VAI was computed by summing the areas corresponding to the NMC grid points at which the vorticity equalled or exceeded the specified value. A relatively small change in vorticity could include or exclude a given grid point, thus contributing to the day-to-day variation in computed VAI. In present work we are computing a contour of the specified value of vorticity, and then computing the area within this contour. Small changes of vorticity will then lead to only small changes in computed VAI.

5. Did the Effect Disappear in Recent Years?

Shapiro (1979) mentions the claims by Williams and Gerety (1978) that "The apparent correlation between sector boundary crossings and VAI was not evident in the more recent time period, 1974-77". As we have briefly reported (Wilcox and Scherrer, 1979), the correlation has been remarkably constant if an apparent decrease during the past few years of the intensity of tropospheric circulation is properly accounted for. This can be seen in the following way. Hines and Halevy (1977) introduced the excursion, which was defined as the difference between the maximum and minimum values of the VAI found in a 12-day interval centered on the time of boundary transit. The amplitude of the sun-weather influence was small when the excursion was small and large when the excursion was large. In the past few years the observed excursions have been considerably smaller than in the previous years.

We have defined a value of excursion such that half of the 162 boundary transits during the interval 1 November 1963 to 31 March 1976 had larger excursions and half had smaller. The sun-weather effect is examined separately for each group. Consider now the three winter interval from 1 November 1963 to 31 March 1966. Figure 6 shows for this interval (plotted at 1965), the average value of D (see Figure 1) associated with the group of boundary transits having larger excursions, and the average D for the group of boundary transits having smaller excursions. The analysis is repeated stepping one year at a time so that the final point plotted at 1977 represents the three-winter interval from 1 December 1975 to 31 March 1978, the last for which data are available. We see in Figure 6 that between 1963 and the present the size of the sun-weather effect associated with the group of boundaries having larger excursions is rather constant, while in most years the boundaries associated with smaller excursions show no significant effect.

Why then did Williams and Gerety (1978) conclude that the sun-weather effect disappeared in recent years? Figure 7 shows for each interval the number of boundary transits associated with larger excursions and with smaller excursions. In the years 1963-1973 discussed by Wilcox et al. (1976) the two numbers are approximately equal, but in recent winters the magnitude of the excursion has declined considerably such that in the last interval only 7 boundary transits had larger excursions while 31 transits did not. A decline in the value of the VAI in recent years can also be seen in Figure 3. If this decline is not an artifact of the meteorological data processing, an important change in the large-scale tropospheric circulation in the northern hemisphere is indicated to have occurred in the past few years.

6. Conclusion

In conclusion, we wish again to emphasize that the apparent sun-weather effect occurs only in regions of intense tropospheric circulation. Criticisms such as Shapiro (1979), Williams (1978), and Bhatnagar and Jakobsson (1978, for a response see Larsen, 1978) are not appropriate. Shapiro (1979) computed a vorticity area index for regions of less intense circulation, and found a smaller effect. Williams (1978) analysed the four components of the Lorenz (1955) energy cycle. Since these components describe the entire troposphere the contribution to them of the small regions of intense circulation is rather small. Nevertheless, Williams (1978) found several similarities between the response of the VAI to boundary transits and the response of the Lorenz components to boundary transits. These similarities are:

1) The Lorenz eddy kinetic eddy parameter KE showed the most significant changes. This is the Lorenz parameter most similar to the VAI.
2) The KE and VAI both have a minimum after boundary transits in winter but not in summer.
3) The minimum in KE and in VAI is seen at 500, 300 and 200mb, but not at 100mb.

Thus, the KE has a similar response to boundary transits as the VAI, but with smaller amplitude, just as would be expected from the above discussion.

Bhatnagar and Jakobsson (1978) attempted to analyse the sun-weather effect without using an index, but rather by studying kinetic energy and the square of the vorticity over the entire northern hemisphere. As already pointed out by Larsen (1978) we would not expect to see a significant boundary transit effect in these quantities when computed over the entire northern hemisphere.

Finally, we may state our view of the present situation with regard to the apparent influence of the solar magnetic field on tropospheric circulation. We feel that interesting and stimulating questions have been asked, but that final definitive answers are not yet in hand. This sun-weather research is still in an exploratory rather than a confirmatory stage.

There is general agreement (Hines and Halevy, 1977; Shapiro, 1976; and ourselves) that the effect reported in Wilcox et al. (1976) is statistically significant at about the 95% level. A more interesting and fundamental question than the significance of the results reported by Wilcox et al. (1976) is what assessment we can make at the present time with regard to the possible chain of physical causations from the solar magnetic field to tropospheric circulation. In addition to those already discussed, a number of additional effects have been reported that may be relevant here. Sector boundary transits accompanied by more active solar wind conditions appear to cause a larger VAI response (Wilcox, 1979). The role of initial conditions in the tropospheric circulation with regard to the size of the sun-weather effect has been discussed by Wilcox and Scherrer (1979).An influence of the polarity (toward or away from the sun) of the interplanetary magnetic field on the area of troughs near 180° longitude has been reported by Wilcox et al. (1979). The analysis by Larsen and Kelley (1977) of the success of forecasts in a time frame related to sector boundary transits suggests that the effect may be physically significant in the sense of having an appreciable influence on the evolution of atmospheric circulation (as reflected in numerical weather predictions that take no account of solar influence).

A physical mechanism may come from the growing body of evidence suggesting an influence of solar magnetic sector structure on the electric currents and fields in the lower atmosphere (Markson, 1971; Park, 1976; Reiter, 1977; Roble and Hays, 1979).

It seems rather unlikely that these several systematic effects can all be dismissed as statistical fluctuations, but we prefer to wait for the results of several investigations in progress before making a final assessment.

Acknowledgments

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Figure Captions

Figure 1 A superposed epoch analysis of the vorticity area index at 500mb about 162 times of interplanetary magnetic sector boundary transits during the winters in the interval 1 November 1963 to 31 March 1976 for which spacecraft observations of boundary transits are available. A typical error bar (twice the standard error of the mean) is shown for the point at day -4 (Wilcox and Scherrer, 1979).

Figure 2 The size of the sun-weather effect in percent as a function of the value of vorticity used in computing the vorticity area index. Larger values of vorticity show a larger size of the effect. The index recomputed by Shapiro (1979) has a considerably smaller effect than the original index of Roberts and Olson (1973).

Figure 3 Variation with time of the 500mb vorticity area index computed by Roberts and Olson (1973). Note the annual variation in the index, the abrupt increase by about a factor of two on 9 January 1962 (an artifact), and the decline in values of the index in recent years.

Figure 4 Yearly average of the geomagnetic activity index Ap for toward polarity days of the <u>inferred</u> interplanetary magntic field (solid line) and for away days (dashed line). Note that in the early years the toward days are approximately twice as active geomagnetically as are the away days, but that this difference disappeared near 1962.

Figure 5 Contours corresponding to vorticity of $20 \times 10^{-5} s^{-1}$ on 0 U.T. of 26 February 1967 plotted on the standard National Meteorological Center grid. The apparent sun-weather effect is concentrated in the central regions within these contours.

Figure 6 D for the groups of boundary transits having larger excursions (open circles) and for the groups of boundary transits having smaller excursions (filled circles). The total length of the error bar is twice the standard error of the mean (Wilcox and Scherrer, 1979).

Figure 7 The number of boundary transits in each three-winter interval for which the excursions are in the larger group (open circles) and in the smaller group (filled circles). Note that in the last two intervals the number of boundary transits with larger excursions is considerably decreased (Wilcox and Scherrer, 1979).

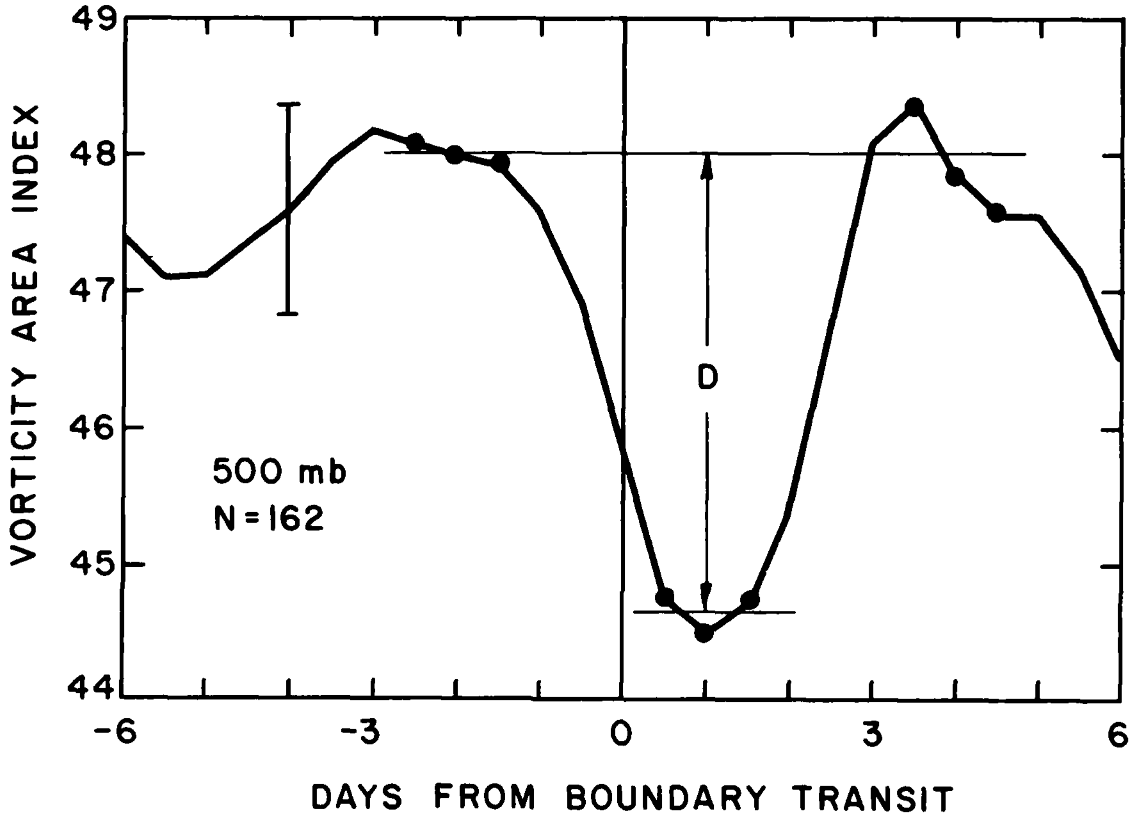
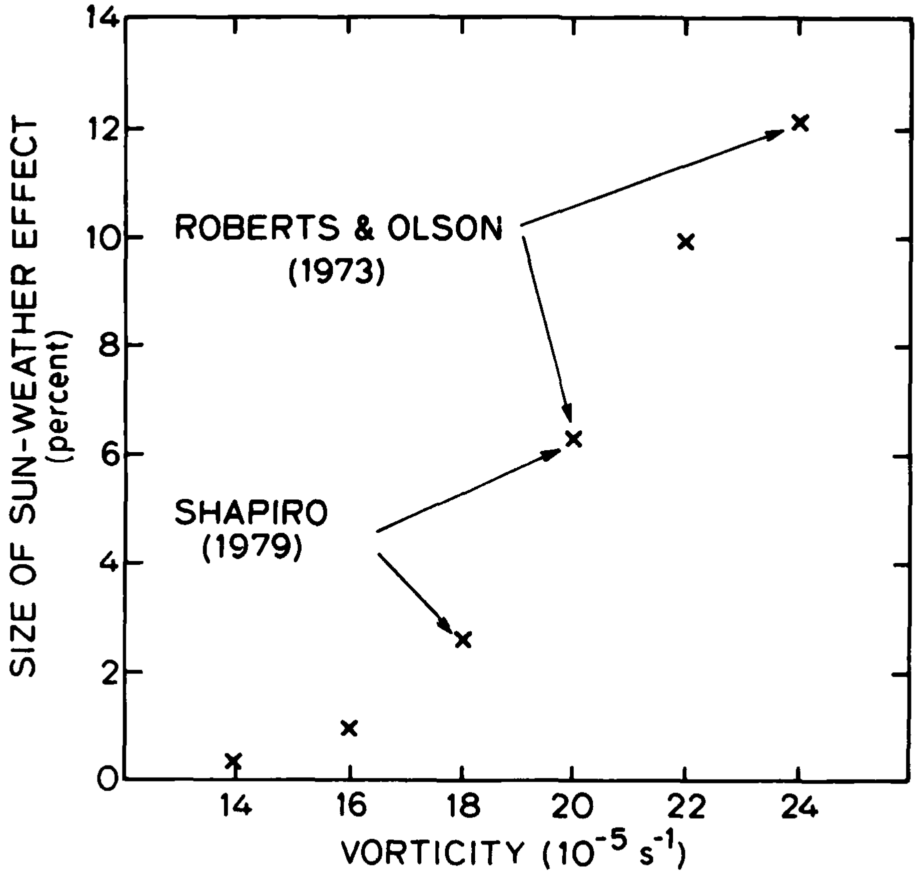

49
48
47
46
45
44
VORTICITY AREA INDEX
500 mb
N = 162
D
-6
-3
0
3
6
DAYS FROM BOUNDARY TRANSIT

Figure 1



SIZE OF SUN-WEATHER EFFECT (percent)
ROBERTS & OLSON (1973)
SHAPIRO (1979)
VORTICITY (10^{-5} s^{-1})
0
2
4
6
8
10
12
14
16
18
20
22
24

Figure 2

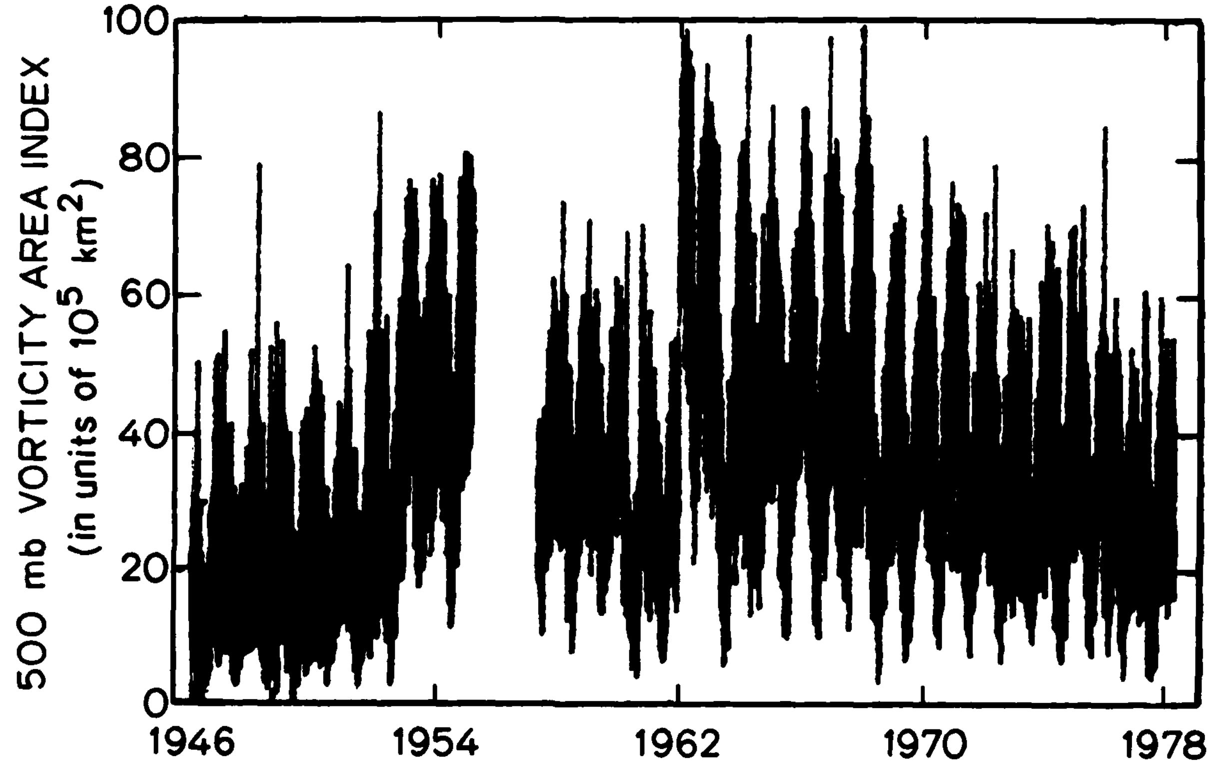
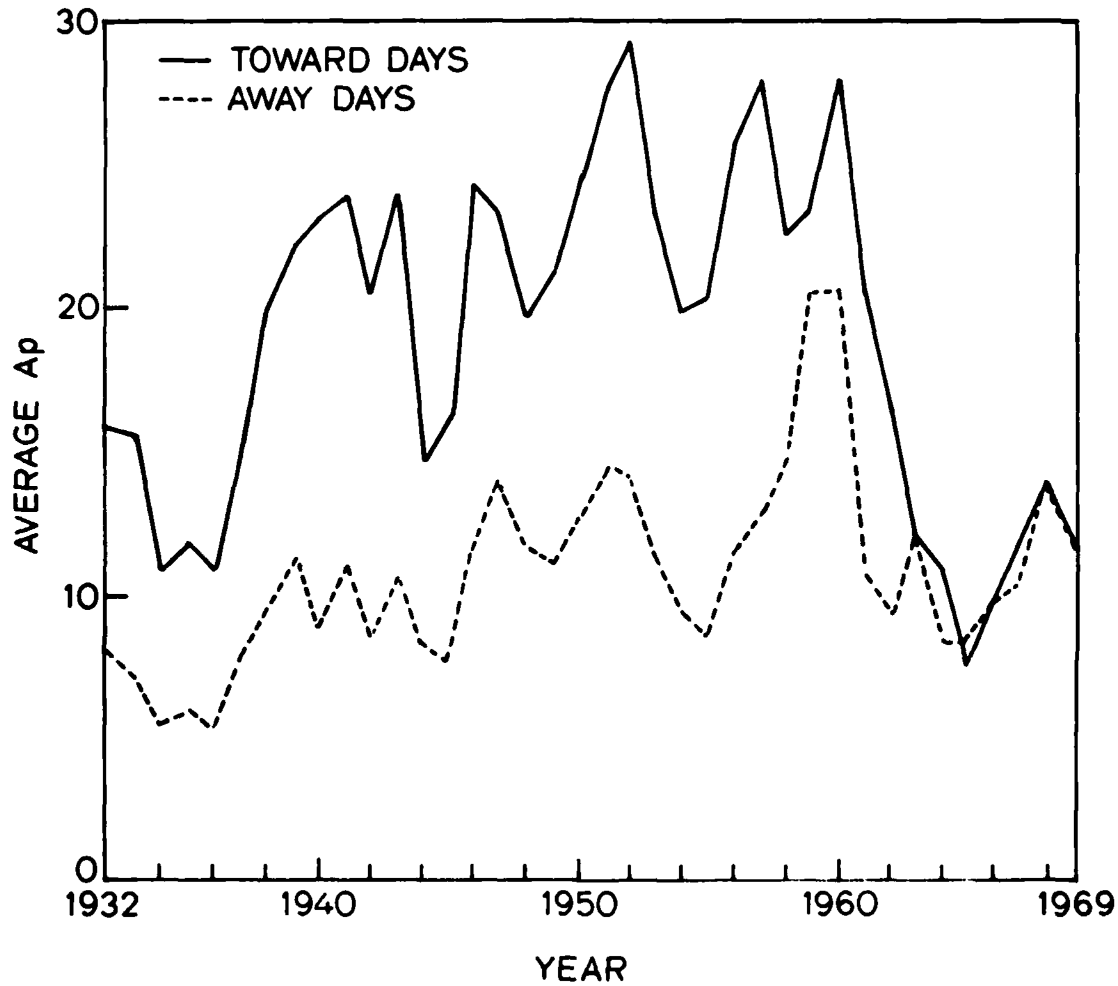

500 mb VORTICITY AREA INDEX
(in units of 10^5 km^2)
100
80
60
40
20
0
1946
1954
1962
1970
1978

Figure 3



TOWARD DAYS
AWAY DAYS
30
20
10
0
AVERAGE Ap
1932
1940
1950
1960
1969
YEAR

Figure 4

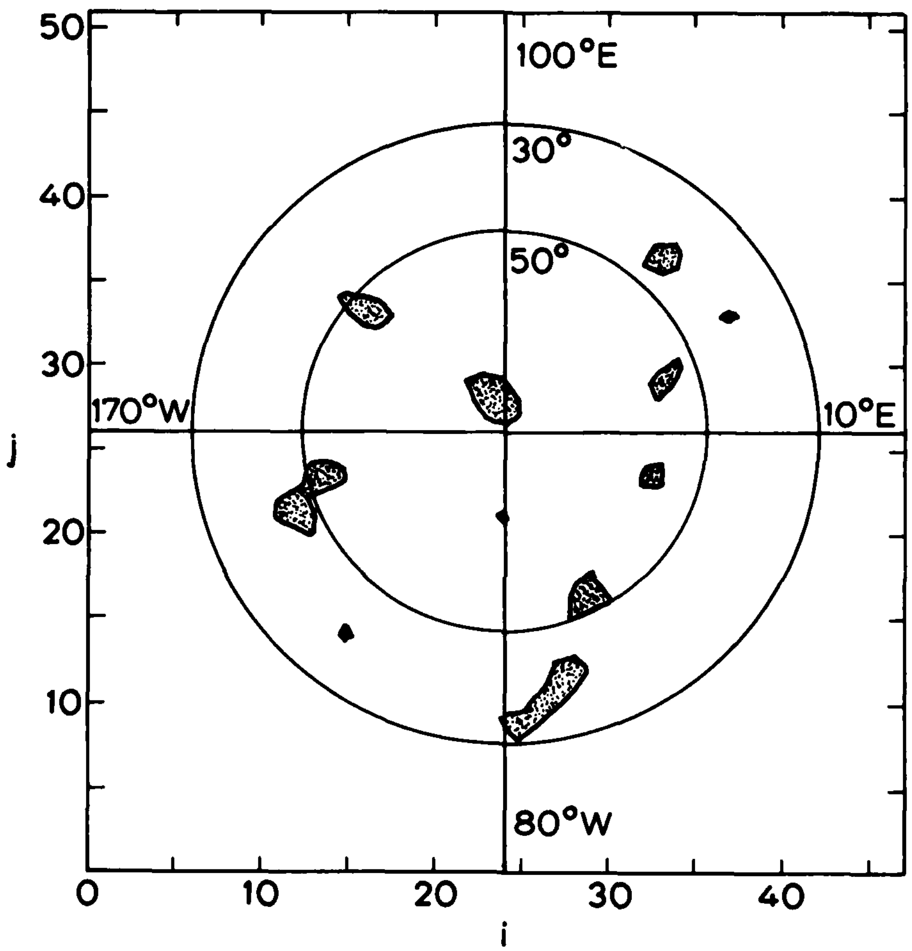
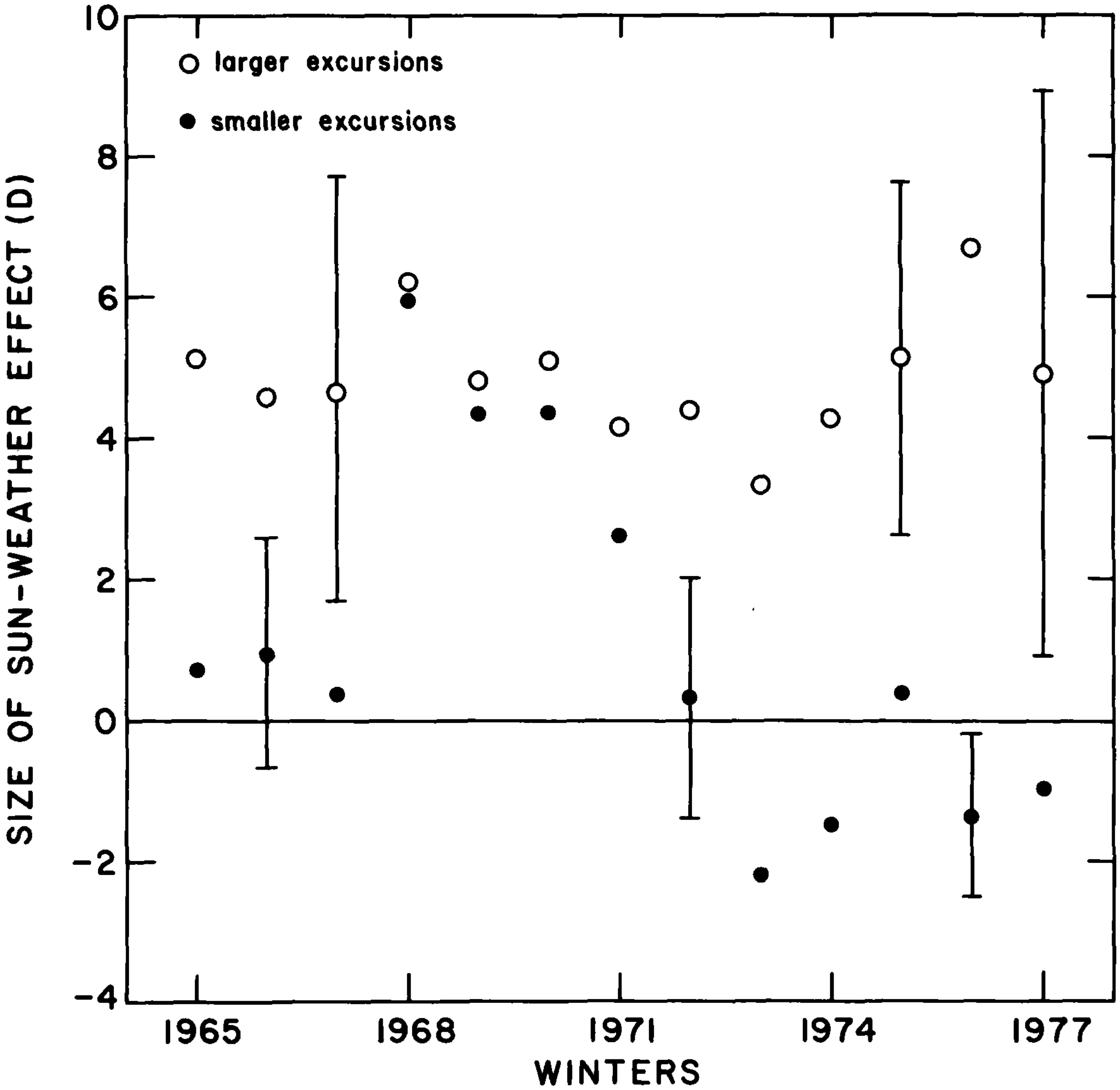
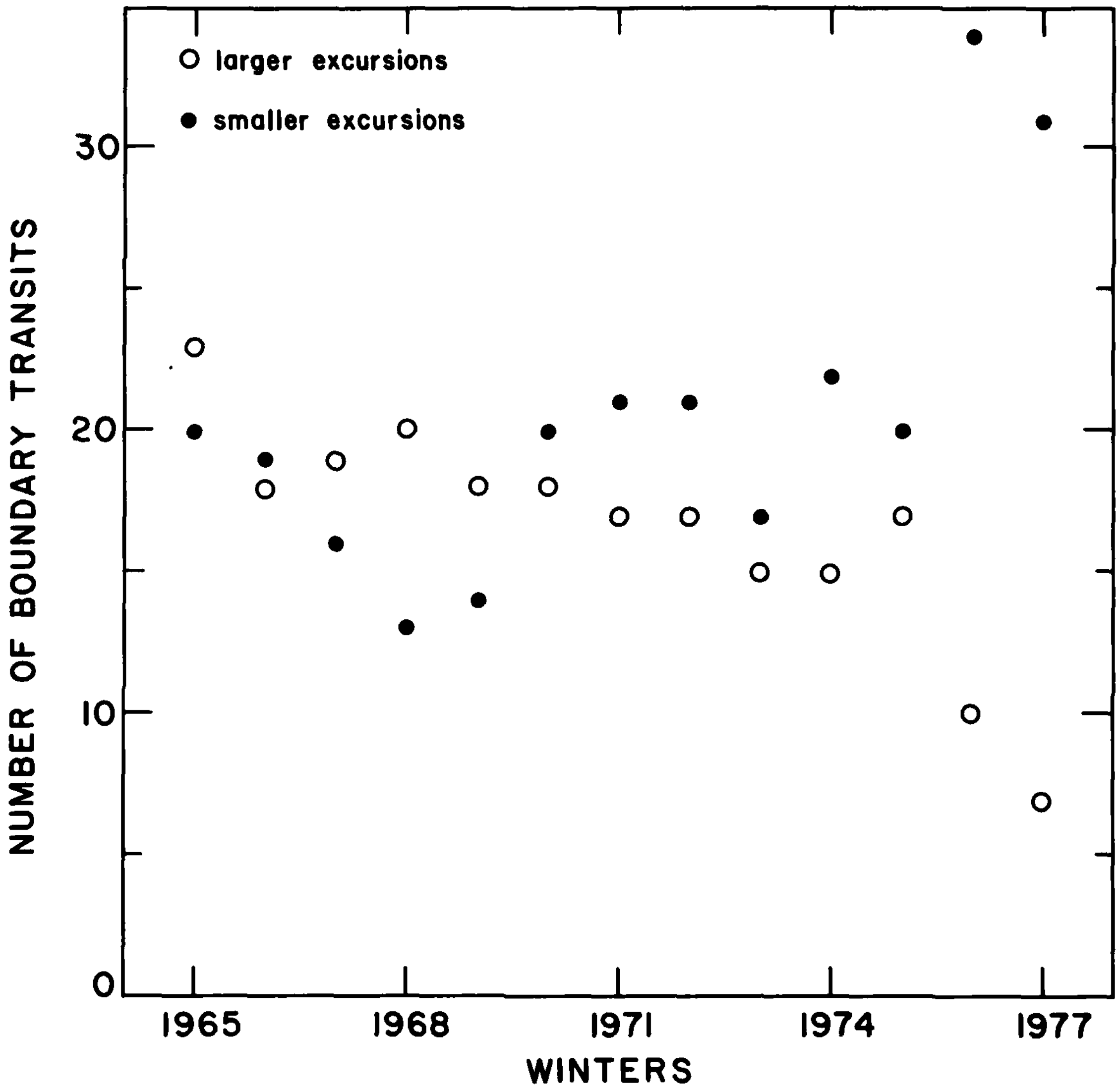


Figure 5



10
8
6
4
2
0
-2
-4
○ larger excursions
● smaller excursions
SIZE OF SUN-WEATHER EFFECT (D)
1965
1968
1971
1974
1977
WINTERS

Figure 6



larger excursions
smaller excursions
NUMBER OF BOUNDARY TRANSITS
0
10
20
30
1965
1968
1971
1974
1977
WINTERS

Figure 7