SOLAR MAGNETIC SECTOR EFFECTS ON THE VERTICAL ATMOSPHERIC ELECTRIC FIELD AT VOSTOK, ANTARCTICA

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Abstract. The vertical atmospheric electric field was measured at Vostok, Antarctica (78°S, 107°E) during the period March-November 1974 using a rotating dipole antenna. It is found that the electric field is depressed by ~15% 1-3 days following the passage of solar magnetic sector boundaries. This effect is more clearly evident in the austral winter when Vostok is in continuous darkness. No significant difference is found between the away-to-toward boundaries and the toward-to-away boundaries. These results suggest the possibility that the global fair-weather atmospheric electric field is an important factor in the solar activity-weather relationships.

The purpose of this note is to report preliminary results from the analysis of vertical atmospheric electric field data obtained at Vostok, Antarctica during the period March-November 1974. Vostok is a USSR station located on a high plateau at an altitude of 3488 m above mean sea level. The thickness of the snow and ice beneath the station is estimated to be approximately 3500 m. Its geographic coordinates are 78° 28' S and 106° 48' E; magnetically, it is at the southern geomagnetic pole. Vostok offers an exceptionally good location for monitoring fair-weather electric fields associated with the global circuit, because it is relatively free from local disturbances such as electrified clouds, man-made atmospheric pollution, etc. The weather at Vostok is characterized by exceptionally low wind speeds and clear sky throughout the year. Furthermore, its location near the center of the polar cap tends to minimize the effects of electric generators in the magnetosphere and ionosphere (e.g. Park [1976]).

The vertical atmospheric electric field was measured at ~1.5 m above the snow surface with an instrument developed at Stanford University. Figure 1 shows a sketch of the instrument with approximate dimensions. The cylinder houses the electronics and a motor, which rotates the dipole antenna at approximately 1800 rpm. The AC signal induced in the antenna is first amplified and then processed through a synchronous detector and a low pass filter with upper cutoff frequency of 1 Hz. In this way, the instrument can follow electric field fluctuations up to 1 Hz. By contrast, a stationary antenna would have a response time of the order of 1/2 hour, which is the time required for the antenna to charge or discharge through the poorly conducting atmosphere. The output signal was recorded continuously on a chart recorder. All available data from March 12-November 6, 1974 were digitized every UT hour to form the data base for the present study. The average electric field was 93.7 V/m directed downward, and the polarity never reversed during the entire period of observation. The recorder saturated when the measured electric field reached 353 V/m; discarding the data from such times has the effect of filtering out strong electric fields generated during occasional wind storms by blowing snow.

Figure 2a shows the diurnal behavior of the electric field at Vostok plotted against UT. Figure 2b shows the expected thunderstorm area over major continents of the world as a function of UT [Whipple and Scrase, 1936]. The peaks occur when these continents go through the afternoon. The good agreement between these peaks and the three peaks in Figure 2a indicates that the electric field data from Vostok do in fact reflect the changes in global ionospheric potential and that the data are not significantly contaminated by local disturbances. Figure 2a is also in agreement with earlier measurements made at polar latitudes and over oceans (e.g. Kasemir [1972]; Israel [1973]).

Figure 3 shows the results of a superposed epoch analysis. Day zero marks the passage of the solar magnetic sector boundary as re-

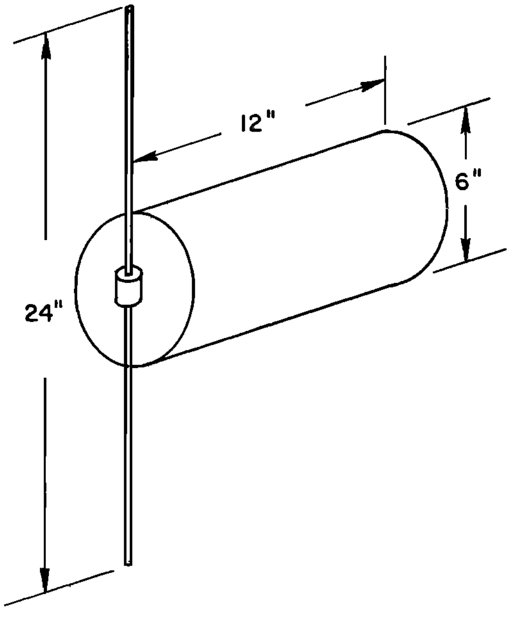

FIGURE 1. A sketch of the electric field mill used at Vostok, Antarctica with approximate dimensions.

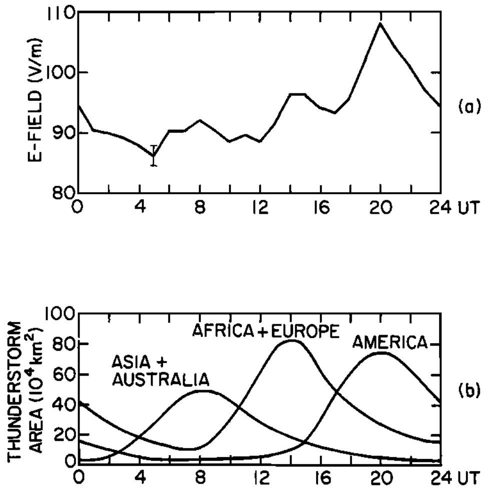

FIGURE 2. (a) Vertical electric field measured at Vostok vs. UT. Positive electric field is directed downward. The vertical bar at 5 UT shows the standard error of the mean. (b) Estimated thunderstorm area in major continents of the world plotted against UT (reproduced from Whipple and Scrase [1936]).

ported by Svalgaard [1975]. The sector structure was inferred from polar cap magnetograms, and the time of boundary crossing was specified to the nearest 00 UT. The electric field data were first averaged over each UT day, and the resulting daily values were averaged over all boundary encounters to obtain the composite picture of Figure 3. The total number of boundary encounters was 17. (In 1974, the solar magnetic field had only 2 sectors instead of the usual 4-sector structure, so the earth encountered only 17 boundaries during the approximately 8-month period of observation.) The electric field is depressed by about 15% 1-3 days after sector boundary crossing. This depression appears to be statistically significant when compared to the standard error of the mean. However, any statistical result of this nature can be questioned when it is based on only 17 cases. Therefore, it is worthwhile to examine the data in more detail, even though the data base is not large enough to allow extensive statistical tests to be applied.

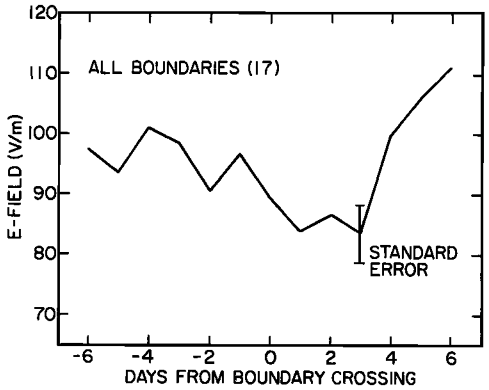

FIGURE 3. Average behavior of the Vostok electric field about the times of solar magnetic sector boundary crossing. The number in parenthesis indicates the number of cases.

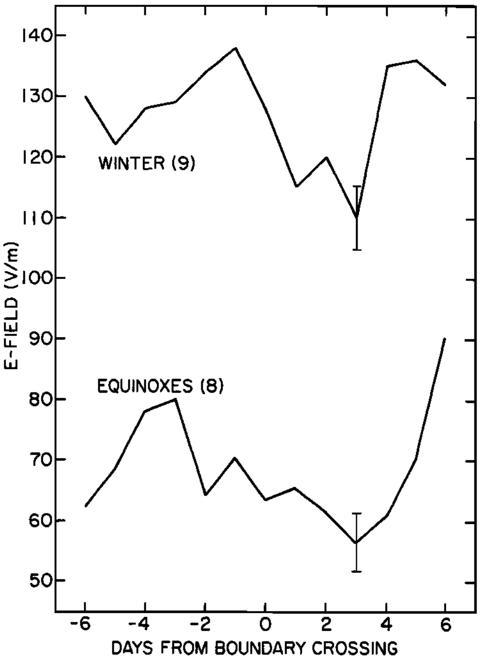

FIGURE 4. Same as Figure 3 except that the winter data (April-August) are separated from the rest.

The electric field shows large seasonal variations, the field being much stronger in the winter compared to the equinoxes. This can be seen in Figure 4 where the same analysis was performed as in Figure 3 except that the data were divided into two groups. The top curve represents the winter data including 9 key days that fall between April 16 and August 2. Vostok is in continuous darkness during this period. The lower curve represents the rest of the observing period involving 8 boundary crossings. The sector boundary effect appears to be more pronounced in the austral winter when the electric field is stronger.

In Figure 3 the data were averaged over all boundary crossings with no consideration given to seasonal or other systematic long-term variations. In order to remove these long-term variations, the daily values were normalized in such a way that the 13-day average centered on each key day would have the same value as the average of the entire data set. The result of a superposed epoch analysis of the normalized data is shown in Figure 5, where the electric field variation is expressed in terms of percentages. It shows the same general behavior as in Figure 3, but the standard error is significantly reduced.

If we apply the same procedure as in Figure 5 but separate the toward-to-away (-/+) boundaries from the away-to-toward (+/-) boundaries, we obtain the results shown in Figure 6. The curves become less well behaved as the data base is reduced, but they both show decreases in electric field following boundary encounters. No significant differences between the two different types of boundaries are apparent.

Although the limited amount of data available

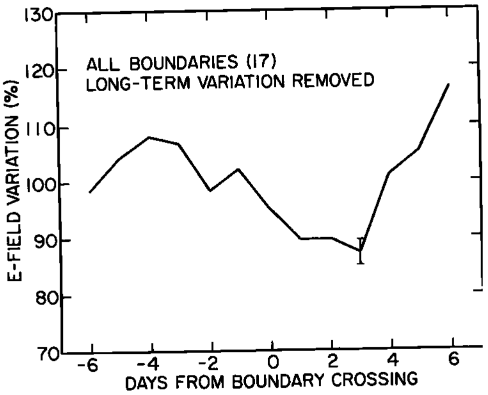

FIGURE 5. Same as Figure 3 except that long-term variations have been removed (see text).

for this study does not allow firm conclusions to be drawn, it appears very likely that the interplanetary sector effects shown here are real. If these effects are real, then they may have important implications in regard to possible solar activity-weather relationships that have received increasing attention in recent years (e.g. Roberts and Olson [1973]; King [1975]; Wilcox [1975, 1976]). Of particular interest is the similarity between the electric field variations shown here and the vorticity area index curve obtained by Wilcox et al. [1973] and reproduced in Figure 7. This curve is based on northern hemisphere winter data for 53 sector boundary crossings. These results may simply reflect the fact that both the Vostok electric field and the vorticity area index are related to worldwide thunderstorm activity. For example, if thunderstorm activity decreases following a sector boundary crossing through some unknown mechanism, one would expect to see corresponding decreases in fair-weather electric fields as well as in the vorticity area index. There is also a possibility that the fair weather electric field plays an important role in modifying the weather. According to some theories, a pre-existing fair-weather electric field is an important initial condition for the formation of thunderstorms (e.g. Vonnegut [1963], Sartor [1965], Moore [1976]). Once a thunderstorm is initiated, strong electric fields that result from charge separation can induce or increase precipitation by increasing coalescence between rain droplets (see, for example, Dayan and Gallily [1975] and the references therein). This line of thought would suggest that the global electric circuit may have an important influence on atmospheric dynamics. However, the role of atmospheric electricity and its overall importance in the weather and climate are not well understood at present. This is obviously an important area of research that needs to be investigated more vigorously.

It has been reported by several authors that the thunderstorm frequency in certain areas is correlated with the solar magnetic sectors. For example, Bossolasco et al. [1973] examined 10 years' data on the daytime lightning frequency in the Mediterranean area and found that the lightning frequency decreased by 15% when the earth was near the away-to-toward sector boundaries. The toward-to-away boundaries showed no correlation with the lightning frequency. On the other hand, Markson [1971] examined about 14 months of thunderstorm data in the United States and found that the thunderstorm activity maximized near the away-to-toward boundaries. Again, the toward-to-away boundaries showed no correlation. It should be recalled that the Vostok electric field data as well as the vorticity area index show similar correlations with both types of boundaries. These discrepancies may be due to the fact that only regional thunderstorm data were used. What is needed is a study of worldwide thunderstorm statistics, preferably during periods when simultaneous electric field data are available from polar cap stations.

Several authors who examined the energetics of solar activity-weather relationships concluded that the energies involved in solar-terrestrial processes are insufficient to influence the weather directly (e.g. Dessler [1975]; Willis [1976]). It appears that any reasonable explanation must be based on some 'trigger' mechanisms through which small signals from the upper atmosphere can control large amounts of energy available within the troposphere. If the atmospheric electric field plays a critical role in initiating thunderstorms under marginal conditions, this provides a means of controlling extremely energetic processes with very little expenditure in energy. Another difficulty lies in explaining how disturbances in the upper atmosphere are transmitted down to the lower troposphere. It should be noted that large scale (> 1000 km) variations in ionospheric potential can have a direct influence on atmospheric electric field down to the ground, unimpeded by the intervening medium [Park, 1976]. Thus it appears that the electric field deserves serious consideration as a possible agent linking solar-terrestrial phenomena with the weather.

In conclusion, about 8 months' electric field data from Vostok, Antarctica show significant and interesting relationships to the solar magnetic sector structure. These results should be checked by more measurements

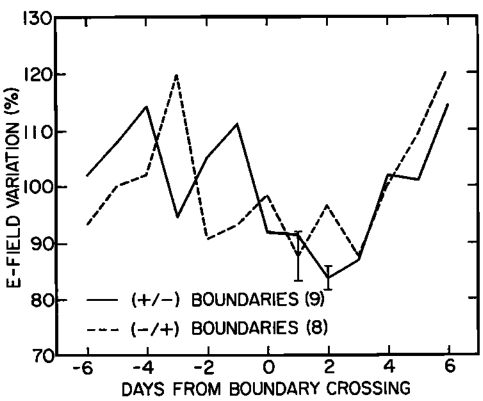

FIGURE 6. Same as Figure 5 except that the two different types of boundaries are shown separately.

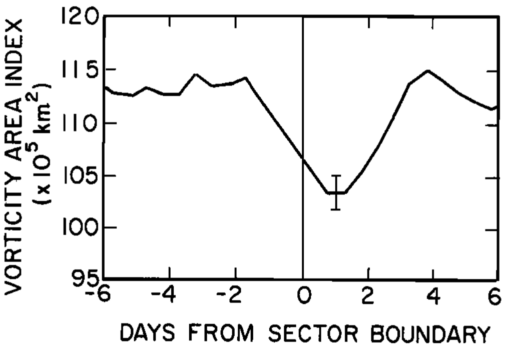

FIGURE 7. Average response of the vorticity area index to the solar magnetic sector structure (reproduced from Wilcox et al. [1973], copyright 1973 by the American Association for the Advancement of Science).

and also perhaps by analyzing other existing data. If the correlations reported here are confirmed, this would suggest that the global fair-weather electric field is an important factor in the coupling between the upper atmosphere and the lower troposphere.

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Note: Dr. R. Reiter communicated to me that the atmospheric electric field and air-earth current measured at Zugospitze Peak, Germany increase by ~20% immediately following the passage of solar magnetic sector boundaries. His results will be reported in a paper entitled "The electric potential of the ionosphere as controlled by the solar magnetic sector structure: result of a study over the period of a solar cycle," in press, J. of Atmos. and Terr. Phys., 1976.

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