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Apparent Relationship Between Solar Sector Boundaries and 300-Millibar Vorticity: Possible Explanation in Terms of Upward Propagation of Planetary-Scale Waves

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It appears to be well established that large-scale variations of pressure fields in the troposphere are propagated up to ionospheric levels, to at least the *E*-region (Brown and Williams, 1971; Deland and Cavalieri, 1973). Correlations between large-scale stratospheric variations and ionospheric parameters are illustrated in figure 1, taken from Deland and Cavalieri (1973). It seems possible that the resulting changes in the ionosphere could cause variations in the magnetosphere, and thus cause variations in geomagnetic parameters such as the geomagnetic activity index A_p. It therefore appears likely that at least some of the observed correlations between geomagnetic variations and meteorological variations may be due to meteorological effects on the geomagnetic variables, rather than due to a common solar origin for the variations in both geomagnetic and meteorological variations, as is commonly presumed. Partly because of these considerations, the correlations between the solar sectors and large-scale atmospheric vorticity in the lower atmosphere reported by Roberts and Olson (1973) and Wilcox et al. (1973) are of great interest since the solar-sector data appear to be independent of any terrestrial influences. It is shown in this paper that even these solar data, as analyzed by Wilcox et al. (1973), may be affected by geomagnetic properties; and a method for removing such influences is suggested.

WELL-DEFINED BOUNDARIES AND THE BOW SHOCK

In their comparison of solar sectors and 300-millibar vorticity, Wilcox et al. used the times of passage of well-defined boundaries as key days in a superposed-epoch analysis. The well-defined boundaries were specified by Wilcox and Colburn (1969) as those for which the magnetic polarity was the same for at least 4 days before the boundary and of the opposite sign for at least 4 days after. According to Ness and Wilcox (1967), the gaps in the data corresponding to the satellite crossing the magnetosheath and magnetosphere were partly compensated for as follows:

> Whenever such a perigee gap has a given field polarity both before the satellite entered the magnetosphere and after the satellite returned to the interplanetary medium, the gaps have been filled with that polarity.

Autocorrelations for the magnetic field polarity obesrved by the satellite along its trajectory have been published by Ness and Wilcox (1967) and Wilcox and Colburn (1969). The autocorrelation function falls off quite rapidly for 2 or 4 days' lag, as of course it must in view of the tendency of the polarity to be repeated after 7 to 10 days, according to the characteristic sector structure described by Wilcox, Ness, and their coworkers. The observed autocorrelation at a given lag can be considered to be an estimate of the quantity

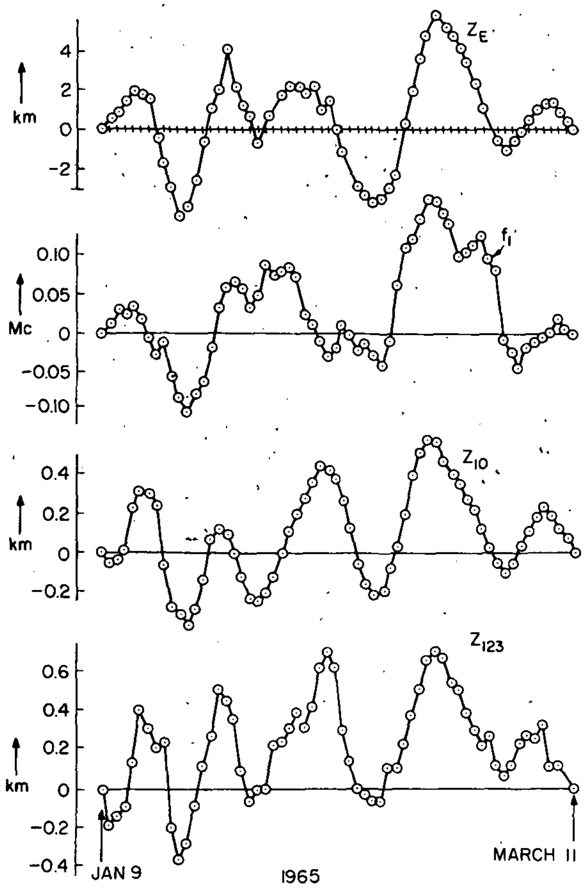

FIGURE 1.—Simultaneous variations of ionospheric and stratospheric variables over Aberystwyth from January 9 to March 11, 1965, taken from Deland and Cavalieri (1973): Z_E is the height of a constant electron density surface in the E-region (Brown and Williams, 1971); f_1 represents smoothed variations of *f*-min; Z_{10} is the height of the 10-millibar surface over Aberystwyth (Brown and Williams, 1971); and Z_{123} is the smoothed variation of 10-millibar height corresponding to the first three zonal wave numbers.

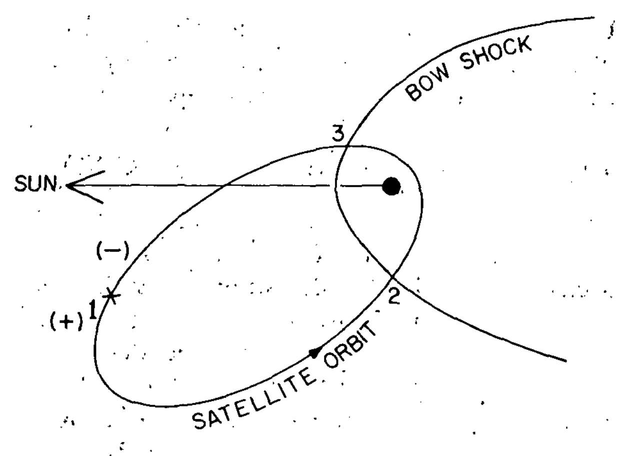

FIGURE 2.—Schematic diagram of a satellite orbit and the bow shock, showing the possibly well-defined boundary of a magnetic sector at **X**. Point *1* is just after the sector boundary, and points *2* and *3* are just before and just after, respectively, the satellite encounters the bow shock.

$(2P - 1)$, where P is the probability of observing the same polarity at a given time and at a time τ later. It follows that the probability of observing a given polarity, assuming that the same polarity was observed a few days previously, varies with the time delay.

In figure 2 a schematic diagram of Earth's bow shock and a satellite orbit such as that of IMP 3 is shown. Because the figure is schematic, it is not meant to be realistic. In the figure, *2* and *3* denote points just outside the bow shock that fall within 4 days after passing **X.** Let us assume that there is a (−, +) crossing at **X**; therefore, there is positive polarity at *1* and the previous 4 days were all negative. The probability that the boundary crossing at **X** will be recorded as well defined is then the probability that positive polarity is recorded for the following 4 days. This will depend on the probability of recording positive polarities at points *2* and *3*, conditional on positive polarity at *1*, because the polarity at both must be positive for a well-defined boundary to be recorded. These probabilities in turn will depend on the position of the bow shock because this will determine the time lags between point *1* and points *2* and *3*. For instance, the wider the bow shock, the less likely it is that the polarity at both points *2* and *3* will be positive and thus enable continuity of polarity across the gap to be recorded as specified by Ness and Wilcox (1967). It follows that the probability of a well-defined boundary being recorded will depend to some extent on the width of the perigee gap. This will be so for all the boundaries recorded by the satellites with periods of 8 days or less, and for a varying fraction of the boundaries for all other satellites. As a consequence, the well-defined boundaries may include a higher proportion of cases for which the bow shock and magnetopause were relatively close to Earth, and fewer for a relatively disturbed "pushed out" magnetosphere. If the latter occurs in part because of atmospheric influences, the possibility of bias due to a positive correlation arising from accidental selection of the data is apparent.

CONCLUSION AND RECOMMENDATIONS

The possibility that the correlations reported by Roberts and Olson (1973) may be due to accidental selection of the solar sector data is sufficiently serious that further analysis should be undertaken with special care to avoid the problems discussed in this paper. One method would be to avoid all selection; that is, include all boundary crossings in the analysis. This is difficult to do because of the perigee gap: this approach might easily lead to more boundary crossings with a smaller gap than with a larger one. The only way to be certain appears to be to use only those boundary crossings for which the satellite was some fixed distance, such as 20 Earth radii, ahead of the Earth for 4 days before and 4 days after, which would insure that the selection is not affected by the bow shock or magnetosphere.

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DISCUSSION

WILCOX: We thank Dr. Deland for his interest in our work, but I do not believe that the remarks are relevant to it. The sector pattern is well defined almost all the time, being either two or four sectors per solar rotation as seen on spacecraft going out to Venus, for example, where one will have continuous observations for several months. You simply see that within a given sector you have the field completely in one direction, except for filaments of a few hours' width, and then you have a boundary, and then you have the next sector.

I just do not see the relevance of all this. I could comment that the particular autocorrelation that you chose for 1965 was the one interval of a few months out of the 10 yr now observed in which the sector pattern was less well defined than the others. There are a number of other published autocorrelations, for example, any of which you could have chosen that would have had a considerably longer time to go down to zero. It seems to me, however, that the basic point is just that spacecraft observations away from Earth establish very clearly that one has either a two- or a four-sector pattern with a very sharp boundary.

If there is a suggestion of a selection effect, it would seem that the clearest way to remove that possibility is to have no selection at all. We worked with 54 boundaries that were well observed by spacecraft. The interplanetary field for 4 days on each side of the boundary was unidirectional. For this particular interval, I sat down and used the sector charts and counted the total possible number of boundaries during this interval, which came out to be 74. We, therefore, repeated the analysis, using all 74 boundaries, in which case I do not think there could be any selection effect. It seems to me that if you have 54 out of 74 you are not dealing with a problem of selection.

DELAND: Dr. Wilcox's point is well taken; however, I am still concerned that, even with the 74 boundaries, there is still some problem with the interpolation across the perigee gap, but I have not had time yet to look into this procedure. I still stick to my point, that if you really want to be sure of having no problem, you should essentially stay clear of Earth and any possible statistical contamination.