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On the Low Correlation Between Long-Term Averages of Solar Wind Speed and Geomagnetic Activity After 1976

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During solar cycle 20, the first full cycle with measurements of solar wind parameters, geomagnetic activity measured by Ap was found to correlate with the square of solar wind speed V, and activity measured by Dst was found to correlate with the product of V and the southward component of the interplanetary magnetic field, B_s. Both of these correlations break down during cycle 21. In the case of Ap, the much stronger variation of B_s in cycle 21 compared to cycle 20 makes clear that the B_s contribution to activity is important on yearly as well as shorter time scales. The product B_sV^2 gives an excellent correlation with Ap over both cycles. In the case of Dst, the stronger variation of B_s in cycle 21 causes a stronger variation in B_sV, which is not reflected in Dst, perhaps because Dst also depends upon solar wind dynamic pressure in a nonlinear way.

A high correlation between half-year averages of solar wind speed V and the mid-latitude geomagnetic activity index Ap was reported by *Crooker, Feynman, and Gosling* [1977] (hereafter referred to as CFG) for solar cycle 20. Independently, at the 1978 Solar Wind Conference, *Gringauz* [1981] reported a high correlation between yearly averages of V and the mid-latitude aa index. Since the aa index has been recorded for the past century, *Gringauz* [1981] used the regression formula between V and aa to reconstruct an equally long record of solar wind speed. He noted that its validity depends upon the high correlation between V and aa yearly averages, which may not hold for other solar cycles. This doubt is confirmed by recent data. The high correlation breaks down for cycle 21, and the breakdown continues into the present cycle 22.

The breakdown is apparent in plots of the two parameters shown in Figure 1. The Ap averages are calculated from the daily values, and the V averages are calculated from all available hourly averages in the National Space Science Data Center (NSSDC) interplanetary medium data set, compiled by J. H. King. Until 1976, the two parameters track each other quite well, as in CFG; but after 1976, the tracking is poor. The scatter plot of V^2 against Ap in Figure 2a, where the V^2 averages are approximated by the squares of the V averages, shows linearity, in agreement with CFG, but the correlation coefficient is only 0.62, compared to 0.86 found by CFG for cycle 20 alone (rayed points).

In contrast, the plot of B_sV^2 against Ap in Figure 2b shows far less scatter than Figure 2a. The parameter B_s is the southward component of the interplanetary magnetic field (IMF), where the half-year averages were calculated from the same NSSDC data set of hourly averages. (Values prior to 1975 are represented by the approximately equivalent absolute value of the north-south component, following CFG, since the distribution of this component is symmetric about zero [*e.g., Luhmann et al.*, 1992].) A linear fit of Figure 2b yields

$$Ap = 3.3 \times 10^{-5} B_sV^2 - 0.8 \qquad (1)$$

with slope and intercept close to the values 3.5×10^{-5} and -1.9 calculated by CFG. The correlation coefficient is 0.90, the same as that obtained by CFG. Figure 1 illustrates this high correlation with the superposition of Ap' on the Ap plot, where Ap' is calculated from the right side of (1) using the B_sV^2 averages. The correspondence between the two curves is particularly remarkable in view of the fact that the data sets do not match in intervals with solar wind data gaps, since the Ap averages form a continuous data set based on daily values.

What at first seems like a surprising difference in correspondence between the Ap and V plots before and after 1976 is easily explained by the variation of B_s, shown in the second panel from the top of Figure 3. As demonstrated by *Slavin et al.* [1986], the IMF was considerably stronger during cycle 21 than during cycle 20, and this trend is reflected in B_s. Although a solar cycle variation of B_s is present in cycle 20 [*e.g., Siscoe et al.*, 1978], its amplitude is less than half the amplitude of the cycle 21 variation. For cycle 20, CFG found that the correlation between Ap and V^2 remained unchanged when B_s is multiplied by V^2. This is obviously not the case for cycle 21, and the much stronger variation of B_s explains the difference.

Solar cycle 21 makes clear that B_s contributes significantly to geomagnetic activity on yearly time scales. It is well known that on time scales of hours, V varies little, and B_s variations dominate correlations with activity [*e.g., Garrett et al.*, 1974; *Burton et al.*,

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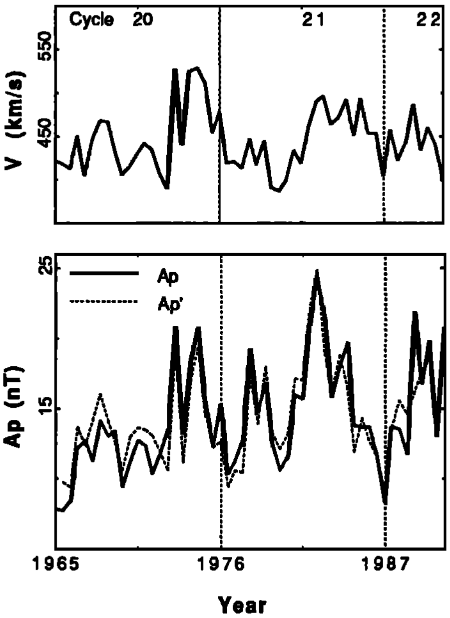

Fig. 1. Solar cycle variations of half-year averages of solar wind speed V and the mid-latitude index of geomagnetic activity, *Ap*. The superposed *Ap'* is proportional to B_sV^2, where the B_s values are half-year averages of the southward component of the interplanetary magnetic field.

1975]. For cycle 20, CFG pointed out that the opposite was true on the yearly time scale: B_s varied little, and V dominated the correlation. However, CFG anticipated that this might not be the case for other cycles by noting the better correspondence between *Ap* and B_sV^2 compared to V^2 during the years of sunspot maximum in cycle 20 (1967-1970), even though *Ap* was low then. They comment that during cycles when geomagnetic activity is higher at sunspot maximum, the strong correspondence between the *Ap* and V variations found for cycle 20 may be less striking and the contribution of B_s clearer. Cycle 21 confirms their expectation.

CFG used only the *Ap* index to measure long-term variations in geomagnetic activity, assuming that all indices are reasonably well correlated. Later *Feynman* [1980] found that yearly averages of the ring current geomagnetic activity index *Dst* track yearly averages of the mid-latitude index *aa* reasonably well from 1957 until 1972 but then diverge through 1975, the endpoint of her plot. We update her comparison with half-year averages of −*Dst* and *aa* in Figure 4 for the interval 1965-1991. The divergence noted by Feynman continues all the way through the next cycle, where *Dst* and *aa* show poor correspondence. In contrast, *aa* and *Ap* show excellent correspondence in Figure 4b; but this is to be expected since they differ only in the number of contributing observatories. Feynman proposed that the difference between *aa* and *Dst* could be explained by a different dependence of *aa* and *Dst* on the parameters B_s and V. For cycle 20, she found that while *aa*, like *Ap*, correlates well with either V^2 or B_sV^2, −*Dst* correlates better with B_sV. From her regression of B_sV on Dst we obtain

$$-Dst = 0.072\, B_sV - 55 \tag{2}$$

and calculate −*Dst'* from the right side of (2) using the B_sV averages. *Dst'* is superposed on the *Dst* plot in Figure 4a. The two curves match reasonably well during cycle 20, as Feynman illustrates. However, they diverge widely in cycle 21. The high values of B_s at the peak of cycle 21 predict *Dst* averages more than a factor of 2 too large. The correlation coefficient between *Dst* and B_sV is only 0.66.

The weak correlation between long-term averages of *Dst* and B_sV can probably be ascribed to the role of solar wind dynamic pressure, proportional to nV^2 plotted in the bottom panel of Figure 3. It shows the same upward trend displayed by *Dst* through the two cycles, a trend that the other indices as well as B_s and V lack. However, no product of B_sV and nV^2 taken to any power can improve the correlation between *Dst* and B_sV, probably because the relation between *Dst* and nV^2 is nonlinear. For example, on short time scales, *Burton et al.* [1975] find good correlation between B_sV and the rate of change of *Dst* after correcting *Dst* for Chapman-Ferraro current changes, proportional to dynamic pressure. These corrections can be as large as 90 *nT* [*Gonzalez et al.*, 1992]. On the other hand, *Murayama* [1982] finds that the correlation improves when B_sV is multiplied by $(nV^2)^{1/3}$. Thus, in the course of a storm, high dynamic pressure can cause both a large sudden commencement to high, positive *Dst* values and a sharp decline during the main phase to large negative values. Folding these factors into the long-term variations presented here is beyond the scope of this report.

The solar cycle variation of nV^2 is remarkably regular in view of the less regular variations of its components, especially n, in the third panel of Figure 3. Average n rose sharply in the middle of cycle 20, in agreement with *Feldman et al.* [1979], and then never returned to its prerise low. The higher n averages in cycle 21

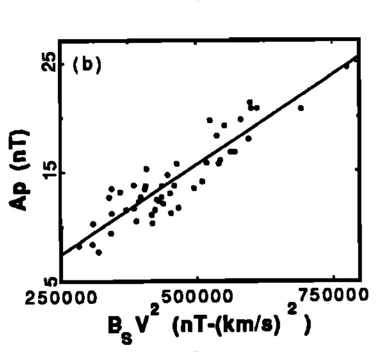

Fig. 2. Scatter plots of (a) V^2 (1964.5-1991) and (b) B_sV^2 (1965.5-1990) against *Ap*, with linear regression fits. The corresponding correlation coefficients are (a) 0.62 and (b) 0.90. Rayed points in Figure 2a mark cycle 20 (1964.5-1975.5).

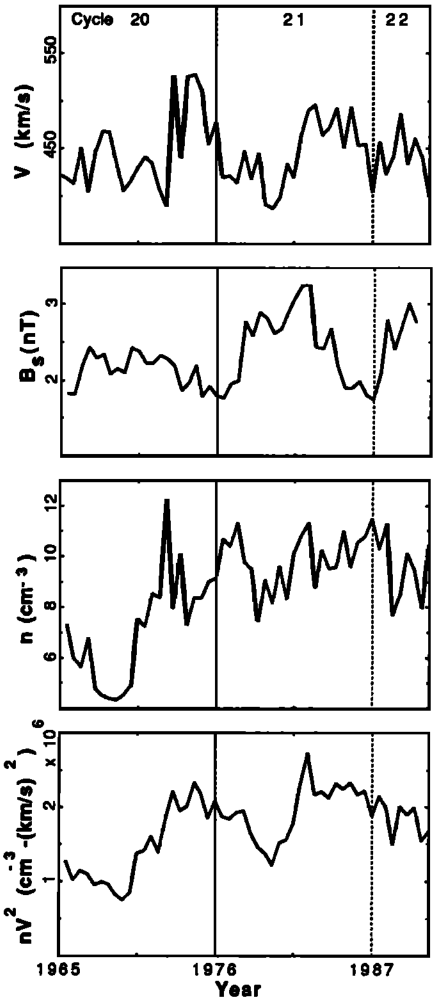

Fig. 3. Solar cycle variations of solar wind speed V, southward magnetic field component B_s , particle density n, and nV^2, proportional to dynamic pressure.

account for the higher nV^2 averages. The solar cycle variations of V are more regular, with high speed in the second half of both cycles. But n and V together, in the product nV^2, have a smoother, repeatable solar cycle variation, with a minimum just prior to the middle of the cycle and a maximum just prior to the end.

As a final note, we add that the breakdown of the correlation between Ap or aa and V^2 alone during recent cycles precludes reconstruction of long-term variations of V during the past century based on the long-term records of aa [*Gringauz,* 1981]. One can estimate the extremes of V only within the range allowed by estimated extremes of B_s [*Feynman and Crooker,* 1978].

CONCLUSIONS

1. The high correlation between Ap and V during solar cycle 20 breaks down for cycle 21.

2. Ap correlates well with B_sV^2 for both cycles.

3. The strong solar cycle variation of B_s during cycle 21 makes clear the necessity for its inclusion as a correlation factor.

4. The solar cycle variation of Dst is different from that of Ap and aa. During cycle 20, it correlates with B_sV rather than B_sV^2, as demonstrated by *Feynman* [1980]; but the correlation breaks down after cycle 20. The breakdown may be related to a dependence on solar wind dynamic pressure, but not in a linear way.

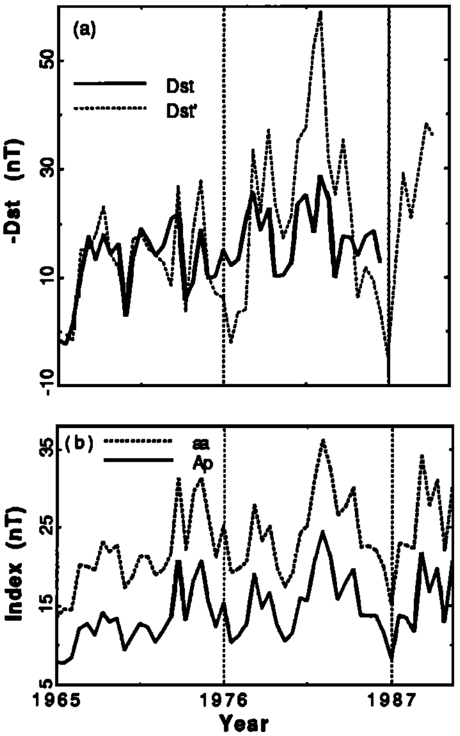

Fig. 4. Solar cycle variations of geomagnetic activity indices (a) Dst and Dst' compared with (b) aa and Ap, where Dst' is proportional to B_sV.

5. The solar cycle variation of dynamic pressure is remarkably regular during cycles 20 and 21. It reaches a minimum prior to midcycle and a maximum prior to the end of the cycle, with an overall upward trend throughout both cycles.

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