GEOMAGNETIC CUTOFF VARIATIONS DURING SOLAR ENERGETIC PARTICLE EVENTS – IMPLICATIONS FOR THE SPACE STATION

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ABSTRACT

Measurements of the time–variability of the location of the geomagnetic cutoff during the large solar energetic particle events of October and November 1992 using count rate data from the polar orbiting *SAMPEX* satellite are reviewed. Significant changes in the cutoff location of up to $\sim 5°$ in less than one day are observed, even during periods with only moderate geomagnetic disturbances. We discuss the implications of such variations for the radiation hazard at the International Space Station, and we note that real–time monitoring of the cutoff location might be used to provide a warning of the increased radiation levels, sometimes hours before the Space Station itself reaches high magnetic latitudes.

INTRODUCTION AND DATA ANALYSIS

Using the geomagnetic field, along with data from the Mass Spectrometer Telescope (MAST) on the *Solar, Anomalous, and Magnetospheric Particle Explorer* (*SAMPEX*) satellite, we have previously reported on the ionic charge states of solar particles observed during the large solar energetic particle (SEP) events of October and November 1992 (Leske et al., 1995). In the process of this earlier study, in which we used the geomagnetic cutoff as a particle rigidity indicator, it was necessary to determine and correct for the time variability of the geomagnetic cosmic–ray cutoff. For sufficiently large SEP events, we found it to be straightforward to determine the cutoff and its variation empirically, using proton and alpha particle count rates.

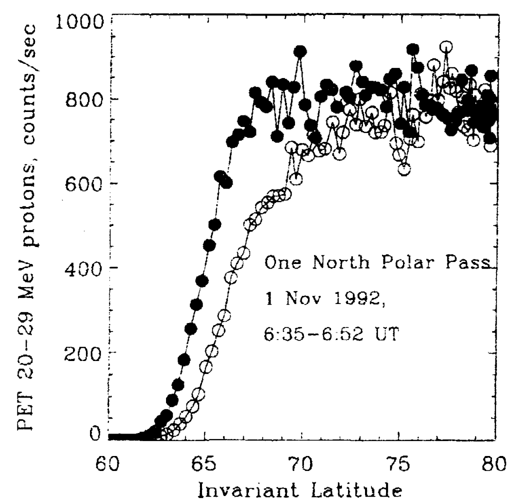

Fig. 1: Rate of $\sim$ 20–29 MeV protons from PET plotted vs. Λ for a single passage into (filled circles) and out of (open circles) the north polar cap.

Figure 1 illustrates the low energy proton rate from the Proton/Electron Telescope (PET) on *SAMPEX* for a single pass over the north polar cap during this time period. We defined the cutoff location, Λ_C, to be that invariant latitude Λ at which the count rate is half of its mean value above 70°. Note that for the example shown, the cutoff location varies by $\sim 1°$ from one side of the polar cap to the other, largely due to the day–night asymmetry in the geomagnetic field. We were able to measure Λ_C to an accuracy of $\sim 0.2°$ four times per orbit (at each polar cap entrance and exit) for several proton and alpha counting rates during a week–long period encompassing the two SEP events.

The variation of the orbit–averaged cutoff location for three proton and alpha rates measured during this time interval is shown in Figure 2, where it is compared with the geomagnetic activity index *Dst*. Geomagnetic activity was not particularly severe during this time interval (*Dst* values can drop below -200 nT in major geomagnetic storms), yet the cutoff latitude changed by $> 5°$ in less than one day. Although the variation of the cutoff shows a good correlation with *Dst*, there seem to be large differences during the passage of a shock (around day 307 in Figure 2) when *Dst* actually lags the cutoff variations. Thus, even if *Dst* were instantly available or accurately predictable, it is no substitute for a direct measurement of the cutoff location during the most critical periods of rapid change.

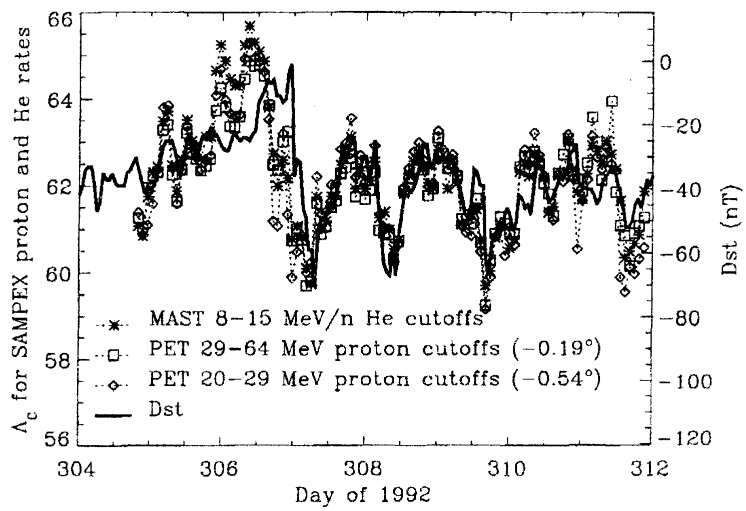

Fig. 2: The orbit–averaged cutoff invariant latitude (as determined from three SAMPEX proton and alpha rates) plotted vs. time, and compared with Dst.

IMPLICATIONS

Figure 3 shows the location of > 16 MeV/nuc oxygen events observed by MAST during these same SEP events. The median energy is about 22 MeV/nuc, which has the same rigidity as 110 MeV protons for an oxygen charge state of +7 (Leske et al., 1995). Also plotted in figure 3 is the ground track for a 400 km altitude, 51.6° inclination orbit, such as the International Space Station (ISS) will occupy. This orbit crosses the nominal boundary of the polar cap region at certain longitudes. During a large SEP event, the radiation dose in this polar region can far exceed that in the radiation belts, posing a potential risk to both astronauts and their equipment that can be mitigated if adequate warning is available. Note that since the ISS orbit is nearly tangential to the polar cap, the amount of time the station spends in the polar cap is very sensitive to the location of the cutoff.

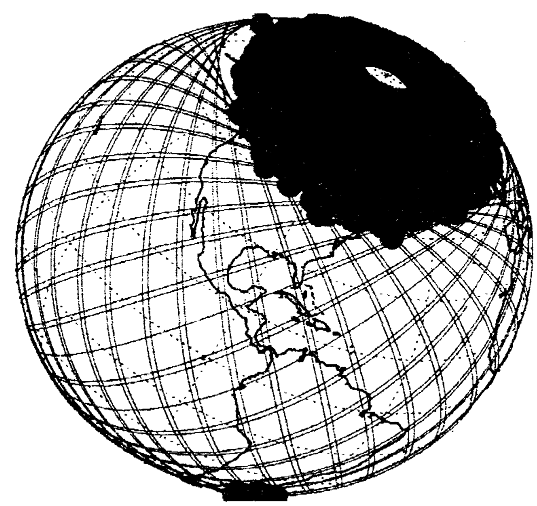

Fig. 3: The location of oxygen events (shaded region) observed by MAST during the Oct/Nov 1992 SEP events, and the ground track of the International Space Station.

The effect of cutoff variations on the radiation dose received at the ISS orbit is shown more quantitatively in Figure 4. Magnetic field quantities using the IGRF 1995 field model were calculated with the BILCAL program, available from the NSSDC (http://fdd.gsfc.nasa.gov/IGRF.html). For illustration purposes, we assume that the geomagnetic cutoff for 30 MeV protons is constant for three consecutive 2–day intervals, at either the nominal cutoff to determine the cutoff location four times per orbit, or about once every 15–30 minutes, during high rate periods. If the data were telemetered in real–time, such a monitor could provide a warning of up to several hours to the Space Station of a cutoff suppression in progress, since only several ISS orbits per day will cross into the polar caps (figures 3 and 4). Even during those times when the phase of the ISS and *SAMPEX* orbits relative to latitude are the same, the fact that *SAMPEX* enters the polar cap on every orbit means that the polar region will have been sampled at most a half orbit before the ISS is vulnerable (figure 5). A cutoff suppression which commences *while* the ISS is at high latitudes would be impossible to detect with any advance warning, however station personnel or sensitive equipment would only be exposed for the duration of that single polar crossing.

Already a small sample of rates is transmitted from *SAMPEX* in near real time, at a reduced time resolution of 192 seconds. It may be possible to increase the time resolution to the ~ 15 seconds or less required to measure the cutoff latitude to an accuracy of ~ 1°. Additional data dumps would be required, at least during forecast periods of high solar activity, which might be accomplished using inexpensive, autonomous ground stations. The feasibility of implementing such a scheme could be studied during the *SAMPEX* extended mission.

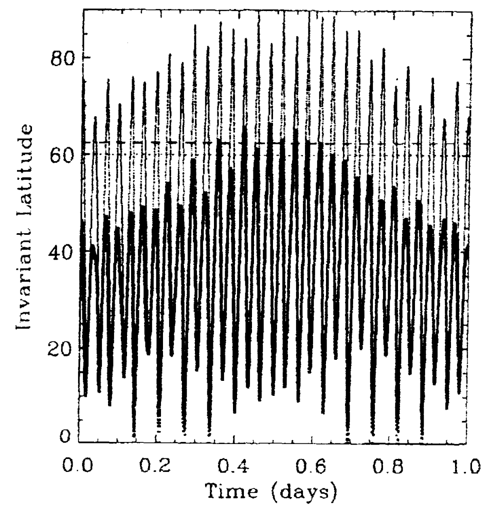

Fig. 5: Invariant latitude vs. time for the ISS (heavy curve) and SAMPEX (thin curve) when the relative phases of the orbits are such that both satellites reach high latitudes at the same time. The nominal average cutoffs for 30 MeV protons (dashed line) and 100 MeV protons (dotted line) are also shown.

ACKNOWLEDGEMENTS

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Leske, R. A., Cummings, J. R., Mewaldt, R. A., et al., ApJL, 452, L149 (1995).

value, suppressed by 5° from nominal, or suppressed by 15°. This cutoff is shown as a solid line overlaid on the invariant latitude vs. time plot for the ISS orbit in the top panel of Figure 4. For cutoff variations of less than one day duration, the amount of increased radiation exposure at the Space Station, if any, depends critically on the maximum invariant latitudes reached by the Station during the suppression. For example, a suppression of 5°, if limited to a half day duration, would have little or no effect if it occurred when the Station never reached extreme invariant latitudes (i.e., if centered on day 1 in Figure 4). Taking constant cutoffs for a 2–day period serves to illustrate the average effects that might be expected.

Assuming a power law differential spectrum with an index of −3, and using the cutoff–rigidity relation derived empirically in Leske et al. (1995), we calculate the total fluence of > 30 MeV protons illustrated in the middle panel of Figure 4 for the three time periods. This fluence is arbitrarily normalized to be equal to unity after 2 days at the nominal cutoff. Note that a cutoff suppression of only 5° below its nominal location, similar to that observed in Figure 2, increases the average exposure time of the station by more than a factor of 2.5, while a 15° suppression (as might be seen in a major geomagnetic storm) increases the exposure by more than a factor of 8. Finally, in the lower panel of Figure 4, we show the orbit–averaged flux of > 30 MeV protons, normalized to a maximum of unity for the nominal cutoff case. As would be expected from the other two panels, both the flux per orbit and the number of orbits exposed to > 30 MeV protons increases as the cutoff suppression becomes greater, with some high energy protons seen on every orbit with a 15° suppression.

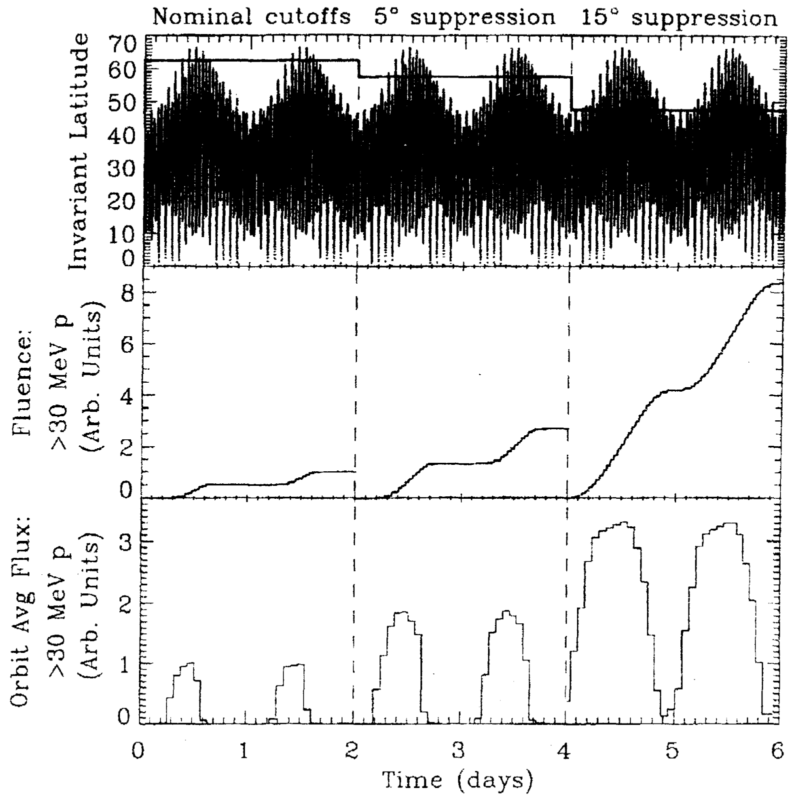

Fig. 4: Calculated quantities plotted vs. time for the ISS orbit, assuming nominal cutoffs (left), 5° cutoff suppression (center), or 15° cutoff suppression (right). Top: assumed cutoff superposed on Λ for ISS orbit; middle: fluence of > 30 MeV protons; bottom: orbit-averaged flux of > 30 MeV protons observed by the ISS.

Recall that this is only the *additional* radiation exposure due to the suppression of the cutoff, over and above any dose received from the SEP–associated flux increase itself. Thus, while solar observations or upstream particle detector monitors would be useful to warn of an approaching coronal mass ejection and would allow predictions of arrival time and intensity, the response of the magnetosphere could change the anticipated radiation dose at the Space Station by nearly an order of magnitude and should be independently measured.

A polar-orbiting spacecraft such as *SAMPEX* which crosses the caps on each orbit could be used