NORTH-SOUTH ASYMMETRY IN ACTIVITY ON THE SUN AND COSMIC RAY DENSITY GRADIENTS

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INTRODUCTION. One method of detecting a perpendicular cosmic ray density gradient ($\vec{\nabla} N_p$) is to make use of the contribution of the drift term $\vec{B} \times \vec{\nabla} N_p$ to the solar cosmic ray diurnal variation. This method has been described by Swinson [1970, 1976] and by Hashim and Bercovitch [1972]. The $\vec{B} \times \vec{\nabla} N_p$ term produces a flow in the ecliptic plane perpendicular to the IMF $\vec{B}$, with the sense of the flow depending upon the sense of $\vec{B}$; this field-dependent flow adds vectorially to the usual azimuthal streaming which produces a cosmic ray intensity maximum at 18 hours solar time (after correction for geomagnetic bending). In the case of a southward perpendicular gradient, when the IMF is away from the sun, the resultant diurnal variation should have a larger amplitude, and the time of maximum should occur a little earlier, whereas if the IMF is toward the sun, the resultant diurnal variation should have a smaller amplitude with a later time of maximum. Swinson and Kananen [1982] have used this method to analyze neutron monitor and underground muon data, separated according to IMF sense, from 1965 to 1975, to show that there is a perpendicular cosmic ray gradient that pointed southward prior to 1969, and a suggested northward pointing gradient after the reversal of the sun's polar magnetic field in 1969-71.

DATA. In this paper we will consider data from four underground cosmic ray telescopes, two in the northern and two in the southern hemisphere. The telescopes are Embudo Cave (35.20°N, threshold rigidity 19 GV, median rigidity 132 GV), Socorro (34.04°N, threshold rigidity 45 GV, median rigidity 305 GV), Bolivia (16.31°S, threshold rigidity 16 GV, median rigidity 125 GV) and Hobart, (42.85°S, threshold rigidity 30 GV, median rigidity 162 GV). The data presented are for the periods 1965-83, 1968-83, 1965-76 and 1965-83, respectively. The yearly average solar diurnal variation for each telescope has been determined for days when the IMF was toward (T) and away from (A) the sun. The amplitude data are presented (the A amplitude should exceed the T amplitude for a southward gradient).

In Figure 1 the annual A and T amplitudes for each station, for all available data, are plotted for 1965 to

1983. The A amplitude points are joined by solid lines and the T amplitude points by dashed lines; shading occurs when A amplitudes are greater than T amplitudes, indicating a southward perpendicular gradient. The vertical lines on the diagram indicate the end of the solar polar field reversals of 1969-71 and 1980-81. Prior to 1971 there is a consistent predominance of A amplitudes over T amplitudes in both hemispheres, which is consistent with a southward perpendicular gradient during this period. After 1971, the northern hemisphere telescopes (Embudo and Socorro) show some dominance of T-amplitudes, while the southern hemisphere telescopes (Bolivia and Hobart) show little change from the pre-reversal situation. The average annual errors for the amplitudes plotted in Figure 1 are ±.014% for Embudo, ±0.165% for Socorro, ±0.16% for Bolivia and ±0.125% for Hobart.

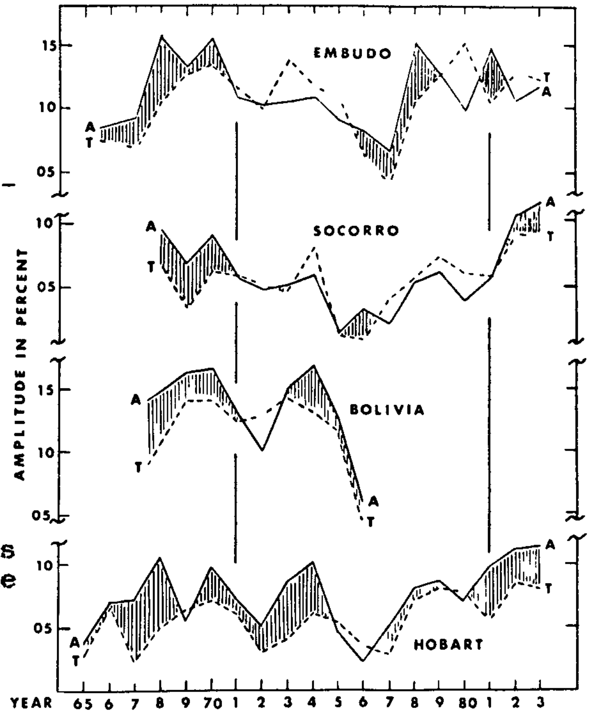

Figure 1. Yearly average amplitudes of away polar-polarity days (solid line) and toward polarity days (dashed line) for underground muon telescopes in Embudo, Socorro, Bolivia, and Hobart, 1965-1983.

The shaded areas occur when the amplitude for the away polarity exceeds that for the toward polarity.

In order to look for a possible cause for a perpendicular cosmic ray gradient we have examined data on the N-S asymmetry in activity on the sun. One might expect that when activity is greater on the sun's northern hemisphere, that activity might be more effective in sweeping cosmic rays out of the heliosphere above the ecliptic plane or in preventing galactic cosmic rays from entering, leading to a S-pointing perpendicular gradient. Here, we extend a study by Roy [1977], which used the "major" flares as defined by the comprehensive flare index, CFI, [Dodson and Hedeman, 1971] to show that between 1959 and 1970 there was a greater frequency of flares in the northern hemisphere of the sun than in the southern hemisphere; this northern hemisphere asymmetry was not evident from 1971 to 1974. This paper extends the results of Roy through 1980.

The number of flares in each hemisphere was counted as a function of month and year, using observations from the worldwide network of solar optical and radio patrol stations. From these data, an annual average for the per-

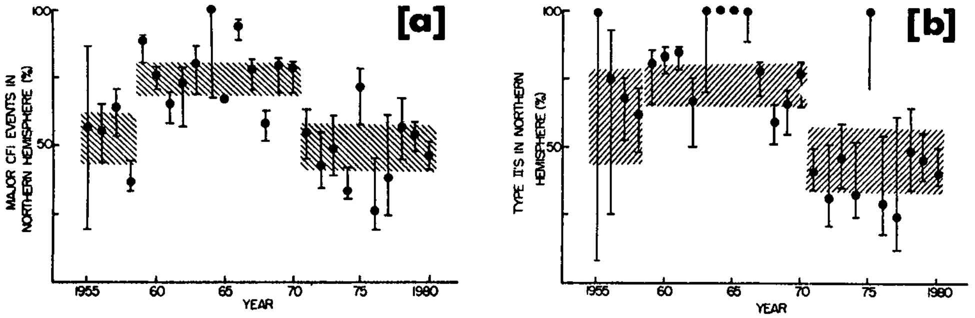

Figure 2(a) The percentage of "major" flares, as defined by the comprehensive flare index, that occurred in the northern hemisphere of the sun from 1955 through 1980, and (b) the percentage of flares with Type II radio emission that occurred in the northern hemisphere of the sun from 1955 through 1980. See text for further explanation.

centage of major events in the northern solar hemisphere was determined, and these annual averages are displayed as solid dots in Figure 2(a). The data have also been arranged into groups of years, and the average for each group of years falls within the shaded regions in Figure 2(a). It is clear that there is a strong, statistically significant dominance of solar northern hemisphere activity from 1959 to 1970, with an essentially even distribution of activity between the two solar hemispheres before and after that period.

This same method was applied to a sub-set of these "major" events -- the events for which metric Type II solar radio emission has been associated. These events were selected primarily because a Type II radio burst is indicative of a shock passing through the corona between 1.5 and 2 solar radii, which could subsequently effect the cosmic ray intensity in the inner heliosphere, particularly at that latitude. This sub-set of Type II events is displayed in Figure 2(b), where the results are comparable to those in Figure 2(a). Data in Figure 2 are preliminary; a complete analysis will be published later.

DISCUSSION AND CONCLUSION: The marked N-S asymmetry in solar activity (with predominant activity in the sun's northern hemisphere) during the 1960's could certainly account for a S-pointing cosmic ray gradient. It is also clear from the data in Figure 1 that the response to this change in solar activity asymmetry, and the related change in the perpendicular cosmic ray density gradient, is different for cosmic ray telescopes in the earth's northern and southern hemispheres. Northern hemisphere detectors see a S-pointing gradient in the 60's and a N-pointing gradient after 1971, while southern hemisphere telescopes see a S-pointing gradient both before and after the reversal.

These results can be accounted for by a combination of a

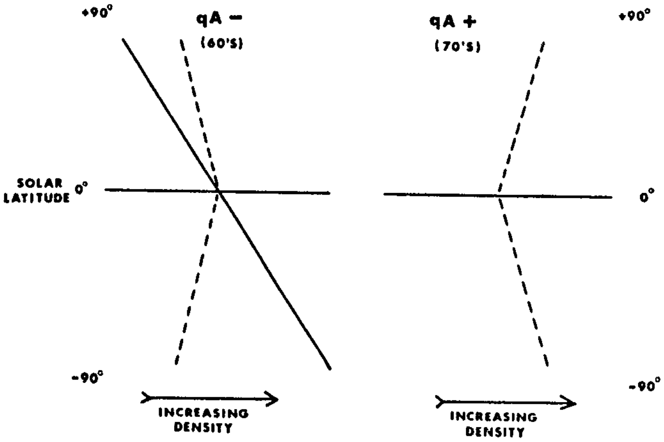

Figure 3. Schematic representation of perpendicular cosmic ray density gradients. North-South symmetrical (dashed lines) and North-South asymmetrical (solid lines) are shown for the two IMF configuration qA- and qA+.

N-S symmetrical gradient, and a significantly larger N-S asymmetrical gradient that is present only during the 1960's (dashed lines and solid lines, respectively, in Figure 3). The N-S symmetrical gradient arises naturally as the result of cosmic ray trajectories in the heliosphere [Erdos and Kota, 1981; Kota and Jokipii, 1983]; for these symmetric gradients, the cosmic ray intensity decreases with increasing heliolatitude before the 1969-71 reversal, and increases with increasing heliolatitude after the reversal as shown schematically in Figure 3. The N-S asymmetrical gradient is greater in magnitude than the symmetrical gradients, and is S-pointing above and below the equator before the reversal, as shown schematically by the solid line in Figure 3; the asymmetrical gradient is attributed to the N-S asymmetry in solar activity demonstrated in Figure 2. After the reversal there is no N-S solar activity asymmetry and therfore no N-S asymmetrical cosmic ray density gradient. Cosmic ray telescopes in the northern hemisphere therefore see a density gradient above the ecliptic plane that is S-pointing before the reversal and N-pointing after it, while telescopes in the southern hemisphere see a gradient below the ecliptic plane whose resultant effect is S-pointing before and after the reversal, leading to the cosmic ray effects seen in Figure 1.

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