ENERGETIC SOLAR PARTICLE EVENTS

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1. Introduction. Studies of the arrival directions of energetic solar particles during ground level enhancements (GLE's) observed by neutron monitors have shown that, in general, in the first hour of the event most of the particles arrive with a distribution of pitch angles peaked about the garden-hose field direction in the vicinity of Earth (e.g., McCracken, 1962, Maurer et al.,1973, Duggal,1979). During the first hour some of the particles arrive from the anti-solar direction, while in later stages of the event the intensity becomes more nearly isotropic as a result of scattering of particles in interplanetary space.

In this paper an attempt is made to determine the arrival directions of the particles during the early stages of the GLE of 16 February 1984 using the data currently available to us from high latitude neutron monitors near sea level where the cut-off is essentially atmospheric ($\sim$1GV).

2. Data. In this event the first particles arrived at Earth during the interval 0905-0910 UT and the data we have used for this interval are listed in Table 1 together with the asymptotic viewing directions assumed for the neutron monitors for 2 GV particles (Shea and Smart, 1975). We also list the percentage increases observed in the next five minutes. These figures are expressed as the percentage above the level prevailing in the hour 0800-0900 UT.

TABLE 1 DATA FOR GLE OF 16 FEBRUARY 1984

STATION	ASYMPTOTIC DIRECTION AT 2GV LATITUDE	LONGITUDE, ^{0}E	PERCENTAGE INCREASE 0905-0910	0910-0915
Goose Bay	-8	0	42.4	94.2
Deep River	-22	10	39.5	71.9
Mawson	-13	56	36.6	49.3
Kerguelen	26	152	5.5	11.0
Thule	68	324	0	8.4
Terre Adelie	-53	170	0	5.0
Inuvik	16	233	0	1.5
Alert	83	8	0	0
McMurdo	-67	275	0	0

3. Analysis. It was expected that during the first five minutes virtually all the particles would arrive from the garden-hose direction or from small angles relative to that direction, since the time would not be available for receiving scattered particles, except those scattered very close to Earth.

Following earlier authors, we use the symbol δ to represent the angle between the asymptotic mean direction of arrival of the particles and the asymptotic viewing direction of a neutron monitor, calculated in most instances for 2 GV particles.

In spite of the apparent simplicity of this event, we have so far been unable fully to understand the pattern of arrival directions. At 0910 UT on 16 February 1984, the Sun was overhead at $(-12^0,42.5^0)$, implying that if the solar wind speed were such that the garden-hose angle was 45^0W of the Earth-Sun line, the mean arrival direction of the particles should have been $(-12^0,357.5^0)$. However, the fact that the increases observed in the first five minutes at Goose Bay, Deep River and Mawson were so nearly the same would appear to require a near equality of the δ values for these stations instead of the 5^0, 16^0 and 57^0 calculated for this case. By trial, we have found that if, instead, the mean arrival direction were $(5^0,25^0)$ the δ values for Goose Bay, Deep River and Mawson would have been 28^0, 31^0 and 36^0 respectively, values consistent with the progression towards slightly smaller intensity increases for these stations. This arrival direction, however, implies a garden-hose angle of less than 20^0W of the Earth-Sun line which would appear to be unacceptably small.

There is the further problem that for a mean arrival direction of $(5^0,25^0)$ Kerguelen has a δ value for 2 GV particles of 120^0 and would not therefore be expected to receive prompt particles. However, a 5.5% increase occurred in the first five minutes, and the profile has the appearance characteristic of prompt particles. If it is assumed that, say, 4 GV particles were responsible for the increase at Kerguelen, the δ value would be 74^0. Although less than 90^0, this value seems to be still too large for prompt particles. In any case Thule and Alert have δ values of 74^0 and 78^0 respectively but registered no increase in the first five minutes. At this stage, we have not found a satisfactory solution to these problems.

A similar analysis of the next five minute interval, during which scattered particles were received at several monitors, has also failed so far to yield an orderly progression of percentage increase versus δ. It is interesting to note that Pomerantz et al. (1984) found by analysing the hourly average data for this event that a smooth function of the percentage increase versus cos δ could be obtained. Whether this is due to the effect of smoothing fine structure is a matter to be investigated.

4. Comments. As with previous analyses which we have made of five minute data, e.g., the event of 7,8 December 1982 (Fenton et al., 1983), we believe that a more detailed treatment may be necessary in which the actual asymptotic directions at the time of the event are used and in which the over-simplification is eliminated of assuming that a single asymptotic direction can be used for each station. In a more detailed analysis, the responses of high altitude, as well as non-polar, monitors should also be taken into account. It should be possible to extend the analysis to one-minute data, at least for large GLE's for which accurately timed data are available, and thus obtain additional information on the scattering environment in the nearby interplanetary space.

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