Preliminary analysis of the 6 November 1997 Ground Level Enhancement

M.L. Duldig[1] and J.E. Humble[2]
[1] *Australian Antarctic Division, Kingston, Tas 7050, Australia*
[2] *University of Tasmania, Hobart, Tas 7001, Australia*

Abstract

The first significant GLE of the present Solar Cycle occurred on 6 November 1997. Earliest onset was observed around 1215 UT but up to 15 minutes later at other neutron monitor locations. The times of peak intensity also varied widely at these locations. The spectrum, pitch angle distribution and arrival directions are presented, based on an analysis of data available in the GLE database and from other sources.

1 Introduction:

The ground level enhancement (GLE) of 6 November 1997 was the first of the present (23^{rd}) solar cycle. This enhancement was observed by at least 17 neutron monitors within the worldwide network with a maximum geomagnetic cutoff of ~3.5 GV. The earliest onset appears to be in the interval 1215–1220 UT at Goose Bay. The maximum increase of 18.6% was observed at South Pole in the interval 1434–1436 UT and again in the interval 1500–1502. It should be noted that the South Pole increase remained above 14% from 1332 until 1510 UT.

A 2B/X9.4 solar flare at heliocentric coordinates 18° S, 63° W in region 8100 has been associated with this solar particle event (Lovell et al. 1999). Hα emission commenced at 1149 UT and peaked at 1155 UT. Type II and Type IV radio emission was also recorded concurrently (Solar-Geophysics Data 1997,1998). A coincident fast coronal mass ejection (CME) was identified by the LASCO instrument on the SOHO spacecraft.

The technique we employ for analysing a GLE has been fully described in Cramp et al. (1997). The Tsyganenko (1989) geomagnetic field model is used to determine the asymptotic viewing directions of each ground based neutron monitor (Flückiger & Kobel, 1990) for vertical and cardinal directions at zenith angles of 16° and 32° (a total of 9 arrival directions for each monitor). A least square technique is then used to derive the apparent particle arrival direction, pitch angle distribution and rigidity spectrum. The model must accurately reproduce the observed increases including null responses for those monitors that did not observe an increase. It is important to include data from as wide a range of geographic locations as possible to give the best possible global coverage of viewing cones and cutoff rigidities.

This analysis is an extension of the Lovell et al. (1999) study and included five-minute averages from 19 neutron monitors. Observed increases were corrected to sea level atmospheric pressure using the two-attenuation length method (McCracken, 1962) and an attenuation length of 100 g cm^{-2}. Spectra were modelled as power laws in rigidity and an exponential form of the pitch angle distribution was employed.

2 Results:

Neutron monitor responses were modeled for 10 five-minute intervals between 12:45 UT and 15:00 UT commencing on each quarter hour and for the five-minute intervals commencing at 16:00, 17:00 and 18:00 UT. Figure 1 shows observed increases and 1σ error bars for all the monitors and times considered. Also shown by the open diamond symbols are the fit responses. Three monitors, Brisbane, Darwin and Mexico City are not shown as they did not observe significant increases, but they were included in the analysis.

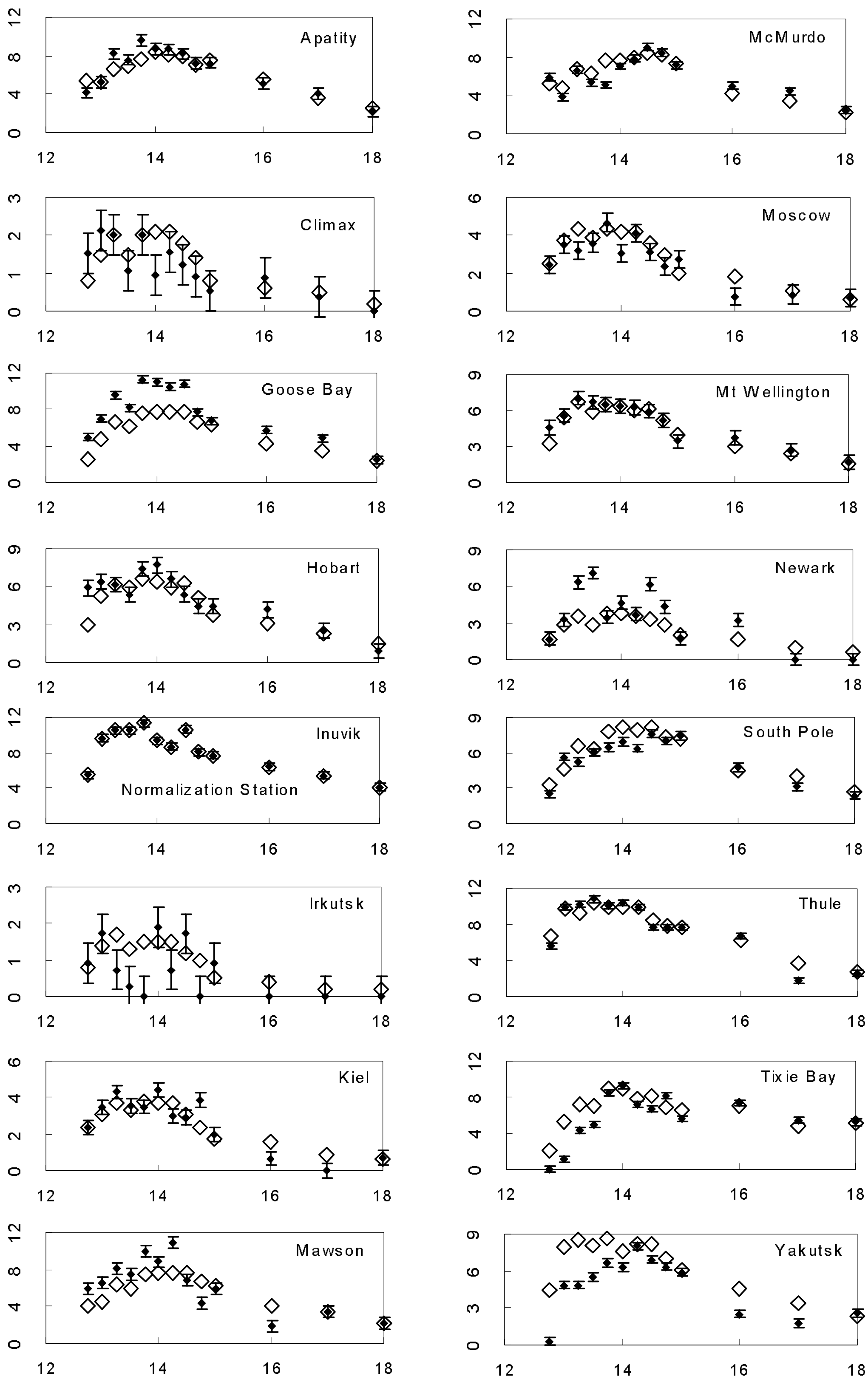

Figure 1: Five-minute average neutron monitor data corrected to sea level with 1σ errors and the fit to the observations (diamonds). Times are UT, 6 November 1997 and the vertical scales are in percent.

The modeling technique requires one station to be used for normalization to determine the spectral intensity at 1 GV. The chosen station was Inuvik for all time intervals. Clearly particles of rigidities up to ~4 GV were present during the enhancement. Figure 2 presents the derived pitch angle distributions for the enhancement. There was slight anisotropy early in the enhancement. The isotropic component was significant throughout the enhancement and increased later in the event.

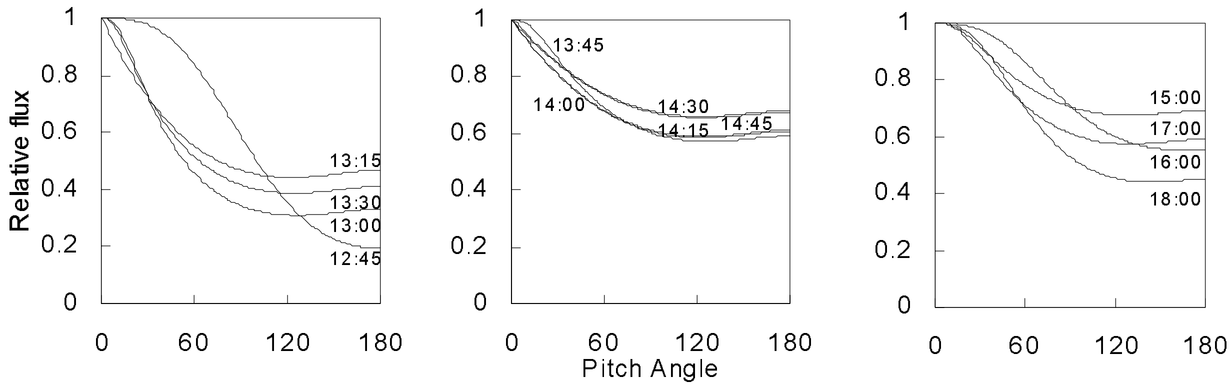

Figure 2: Derived pitch angle distributions for the 6 November 1997 GLE. Times shown are UT.

The differential rigidity spectrum was well fit by a pure power law. Initially the spectrum had a spectral index of ~ –6 and this softened progressively to a spectral index of ~ –7.7 by 18:00 UT. The spectral parameters are given in Table 1 below.

UT	12:45	13:00	13:15	13:30	13:45	14:00	14:15	14:30	14:45	15:00	16:00	17:00	18:00
Flux	11.5	16.8	15.1	21.9	18.9	16.6	15.6	18.9	19.8	27.0	19.9	17.9	17.8
γ	-6.2	-6.0	-6.0	-6.3	-6.2	-6.1	-6.2	-6.4	-6.6	-7.3	-7.1	-7.4	-7.7

Table 1: Derived spectra for the 6 November 1997 GLE. The flux at 1GV is in units of $(cm^2\ s\ GV)^{-1}$.

3 Discussion:

The interplanetary magnetic field (IMF) during the enhancement was highly variable. In figure 3, IMP-8 observations of the IMF direction are shown as dark gray diamonds and the anti-field directions are shown as light gray diamonds. The black squares show the derived pitch angle axis of symmetry (or particle arrival direction) of the solar particles. The fit for particle arrival direction had large uncertainties due to the substantial isotropic component in the pitch angle distributions. It was possible to obtain satisfactory fits over extended ranges of arrival direction with small changes in the pitch angle distributions. The additional data included in this analysis have resulted in a smaller anisotropic component to the pitch angle distribution and thus greater uncertainty regarding the particle arrival direction than was presented by Lovell et al. (1999). Variations of arrival direction of 30°–50° in latitude and longitude were found to give acceptable fits at some modeled times. Conversely, the derived spectral parameters were quite robust and have an estimated uncertainty of ±0.1. For the earlier times, the derived spectra were softer than those found by Lovell et al. (1999) but they are similar late in the event.

There does not appear to be any consistency between the field direction and the particle arrival direction. Late in the event the small anisotropy appears to be aligned with the anti-field direction. The field lines observed by IMP-8 for the period of the enhancement are oriented from the east of the Sun-Earth line. This is not the typical IMF geometry, where the field would normally intersect the Earth from ~45° W. The derived arrival directions between 12:45 and 16:00 UT were beyond 90° W of the Sun-Earth line indicating particle propagation toward the Sun. The arrival directions at 17:00 and 18:00 UT were from east of the Sun-Earth line, opposite from the earlier times.

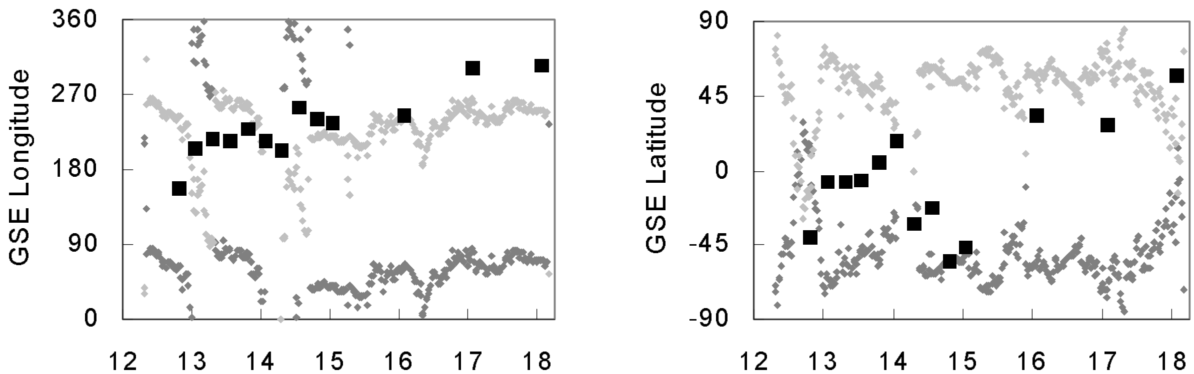

Figure 3: Interplanetary magnetic field direction (dark gray diamonds) and anti-field direction (light gray diamonds) as observed by IMP-8 for 6 November 1997. Black squares show the derived GLE particle arrival direction. Times are in UT.

A coronal mass ejection (CME) that left the Sun on 4 November 1997 was approaching the Earth during the enhancement. It passed the Earth at about 18:00 UT on 6 November 1997. It is possible that a looped field structure existed. Solar particles may then have propagated from the flare site on the western solar sector around the CME following the field lines. The loop in the field would then allow particle arrival from the reverse direction. The arrival of solar particles from east of the Sun-Earth line late in the event could be due to propagation along other arm of the loop. Such an interpretation must remain speculative at this time due to the large range of possible arrival directions giving an acceptable fit to the observations.

An attempt was made to model possible bi-directional particle flow and some greatly improved fits were obtained (additional parameters improve the fit, of course). However, at some times no physically realistic bi-directional solution could be found. Clearly further analysis is required with observations from a greater number of neutron monitor stations with better viewing cone coverage. Null observations would also prove valuable.

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