Proceedings of ICRC 2001: 3363 © Copernicus Gesellschaft 2001

ICRC 2001

Fine time resolution analysis of the 14 July 2000 GLE

M. L. Duldig

Australian Antarctic Division, Kingston, Tasmania, Australia 7050

Abstract. A Ground Level Enhancement occurred on 14 July 2000 and a significant response was observed by at least 18 stations in the world-wide neutron monitor network. Earliest onset was between 10.30 and 10.35 UT at several stations.

Analysis of the enhancement using the established technique described by Cramp et al. (1997) has been undertaken for every 5-minute interval from 10.30 UT to 20.00 UT using data from 25 stations (including some with no significant enhancement). The spectrum was fitted with a simple power law and initially had a slope of around -6, softening during the event to around -9. At onset the particle arrival was quite anisotropic but tended toward increasing isotropy for an hour or more. Later in the event, when only low energy protons remained, the pitch angle distribution became highly anisotropic again.

The apparent "arrival direction" of the particles also changed markedly between 11.00 and 11.10 UT but varied more slowly before and after that transition.

1 Introduction.

The GLE of 14 July 2000 is associated with an X5.8 solar flare (importance 3B) from active region 9077 that commenced at 10.03 UT, reached its peak at 10.24 UT and ended at 10.43 UT. The largest neutron monitor response was observed at South Pole with a maximum 58.3% above the pre-increase level in 1-minute data. A very small increase was observed at Lomnicky Stit which has a vertical cutoff of approximately 4 GV.

The technique for modelling the GLE response by neutron monitors has been developed over many years (Shea & Smart, 1982; Humble et al., 1991) and is described in detail in Cramp et al. (1997). The Tsyganenko (1989) geomagnetic field model is employed to determine the asymptotic viewing directions of ground-based instruments (Flückiger & Kobel 1990). The recently released IGRF 2000 field is employed and non-vertical arrival trajectories are also included in the response calculations. A least-squares fitting technique minimizing the difference between the computed and measured response for each neutron monitor is used to determine the apparent particle arrival axis of symmetry, pitch angle distribution and rigidity spectrum. In addition to accurately representing the observed cosmic ray increases, the model should produce null responses for those stations which did not record any increase. Thus it is important to include stations at many different geographic locations so that a wide range of viewing directions and cutoff rigidities will be included in the analysis.

In this analysis five minute averaged data from 25 neutron monitors were modelled for all intervals between 10.30 UT, during the rising phase of the enhancement, until 20.00 UT, late in the event when particles of only a few GV remained. Simple power law spectra were fitted and an exponential form was used for the pitch angle distribution.

The observed increases were corrected to standard sea level atmospheric pressure using the two attenuation length method (McCracken, 1962). Comparison of Mt. Wellington observations with those of Hobart and the new monitor at Kingston led to a derived attenuation length for the GLE of 110 g cm^{-2} which was used for the corrections.

2 Results and Discussion.

Figure 1 shows the observed increases at 18 neutron monitors (solid line) and the fit to those observations (dots) for all 5-minute intervals between 10.30 UT and 20.00 UT on 14 July 2000. Apatity was used as the normalization station and is not shown. Also not shown are Aragats, Haleakala, Hermanus, Potchefstroom and Rome which did not record significant increases.

Correspondence to: Marc.Duldig@utas.edu.au

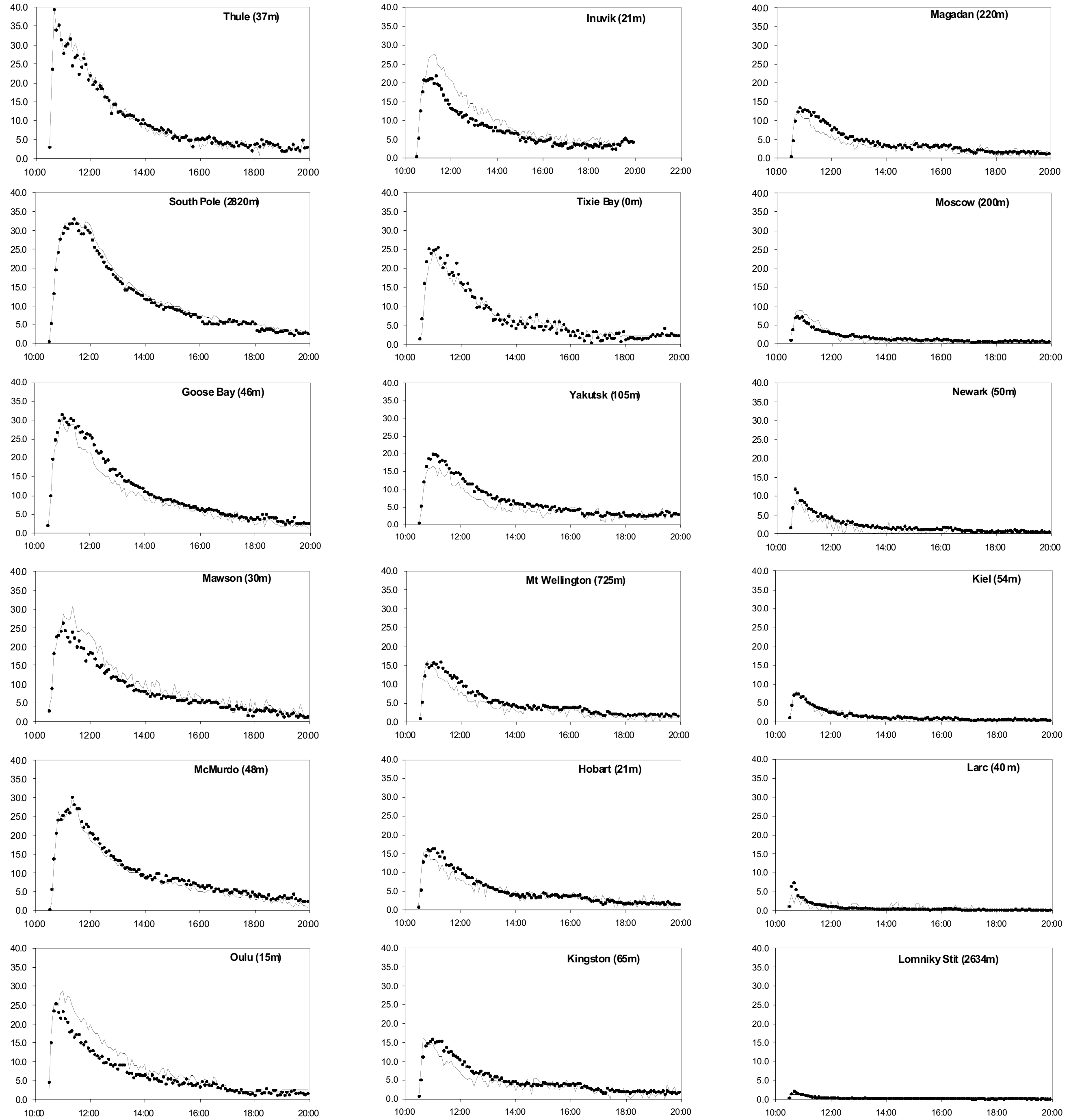

Fig. 1 Observed (line) and fitted (dots) responses to the GLE of 14 July 2000. Times are UT. The Apatity neutron monitor (used for normalisation) and monitors which did not observe a statistically significant increase are not shown.

Excellent fits to all observations were achieved during the rising phase. Similarly, the fits to observations after about 14.00 UT were very good. A few monitor responses were not as well fit in the interval between the peak and 14.00 UT. Notably, the model underestimated Mawson, Oulu and Inuvik whilst Yakutsk, Magadan and the three monitors around Hobart were overestimated. More data from additional stations and further modelling will be needed to address these relatively small discrepancies.

The fitted spectrum throughout the enhancement was unremarkable. A simple power law was fitted throughout but attempts to fit more complex spectra, like the shock acceleration spectrum of Ellison & Ramaty (1985), did not give any improvement to the fits. The spectral slope during the rising phase was typically –6. The spectrum softened progressively from that time. The slope was –7 by 11.00 UT and –8 by 12.00 UT. The slope then generally remained between –8 and –9 until 20.00 UT. It should be remembered that the parameter determinations are less accurate later in the event when the increase above background levels are small.

The development of the pitch angle distribution is presented in Fig. 2. The earliest particle arrival (10.30–10.35 UT) was strongly anisotropic but surprisingly the anisotropy became even more extreme by 10.35 UT. From then until 10.55 UT the particle arrival tended to become increasingly isotropic. The distribution remained relatively unchanged until around 12.15 UT when the particles arriving from >90º dropped markedly. Presumably, local scattering had dominated the distribution prior to this time and over the next 10 minutes the local interplanetary magnetic field (IMF) conditions changed substantially, reducing the local scattering of the relativistic solar protons. By 12.25 to 12.30 the pitch angle distribution stabilised remaining the same until about 18.30 UT. After 18.30 UT the pitch angle distribution becomes highly anisotropic once again. At this stage there are only lower rigidity particles remaining. They may be the result of continuous shock acceleration and a well-ordered field between the Earth and the shock causing adiabatic focussing of the distribution. Detailed assessment of the pitch angle distribution, which will be undertaken in the near future, will require careful comparison with available IMF measurements. ACE satellite measurements are available from the L1 Lagrange point between the Earth and the Sun at about 30 Earth radii. IMF measurements closer to the Earth at the time of the event appear to be scarce.

The particle pitch angle axis of symmetry, or the "arrival direction" is also usually associated with the local IMF orientation. The arrival direction was initially from mid-northern latitudes and well east of the nominal garden hose direction. In fact the arrival direction prior to 10.55 (still during the rising phase) was east of the Sun-Earth line! Between 10.50 and 11.05 UT the arrival direction jumped dramatically to within 20º (but sunward) of the nominal IMF direction. The movement of the arrival direction is shown in Fig. 3.

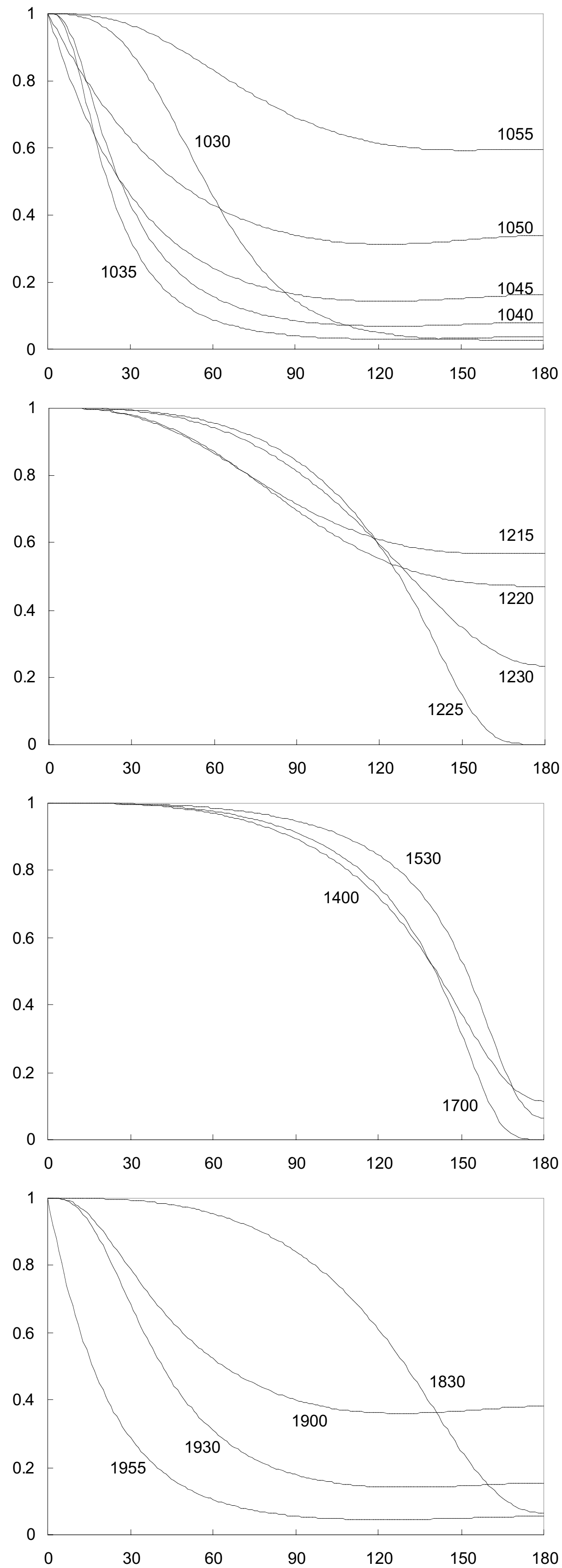

Fig. 2. Derived pitch angle distributions during the 14 July 2000 GLE. The response is normalised and pitch angles are in degrees.

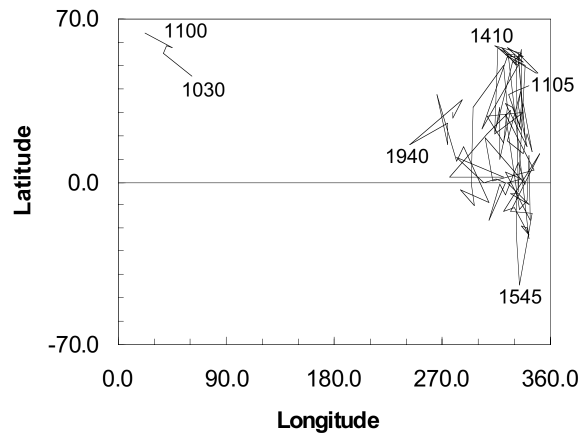

Fig. 3. The apparent axis of symmetry of arriving particles during the 14 July 2000 GLE between 10.30 and 20.00 UT.

The longitude of arrival remained between the nominal garden hose direction and the Sun-Earth line until about 14.50 UT when it returned to relative directions similar to the rising phase of the enhancement.

As is clear from figure 3 the arrival direction is generally northern as would be expected for a July event when the sub-solar point is at its most northern extreme. During the period 15.00–16.10 UT the arrival direction changed to be significantly southern, moving back to equatorial regions after that time. It remained within about 15º of the equator until about 18.00 UT when it moved further north again, briefly returning to equatorial regions in the period 18.55–19.20 UT.

The changes in particle arrival axis of symmetry would also be expected to reflect the IMF orientation near Earth. Again further study is underway to compare available IMF measurements with these results in the hope of linking the sudden changes in fit parameters to changes in the field.

We should not place too much emphasis on the model fit late in the event when the enhancement is quite small but it is worth noting that the least square quality of fit parameters were extremely good from 13.45 UT onward with χ^2 per degree of freedom values of 2 or less. Even earlier in the enhancement the quality of the fits was very high.

3. Conclusion.

For the first time a ground level enhancement has been modelled continuously throughout the event. Rapid changes have been found in the particle arrival axis of symmetry and in the particle pitch angle distribution. The changes in the two properties were not coincident in time indicating that different mechanisms are responsible. In the case of the arrival direction it is likely to be the local IMF orientation whilst the changes in pitch angle distributions is probably related to local scattering (or lack of it) related to the orderliness or turbulence of the local IMF. The steady spectral development together with the anisotropy late in the event may support continuous shock acceleration for this GLE.

It is clear from this analysis that further detailed study of these results in comparison with available IMF measurements is needed. This work is currently underway and will be reported elsewhere.

Acknowledgments. The author thanks all researchers who made GLE data available for this analysis. The Bartol Research Institute provided data from McMurdo, Newark, South Pole and Thule with support by NSF grants OPP-9528122, ATM-9616610, OPP-9724293, and OPP-9805780

References.

Cramp, J.L., Duldig, M.L., Flückiger, E.O., Humble, J.E., Shea, M.A., and Smart, D.F. (1997) The October 22, 1989 solar cosmic ray enhancement: An analysis of the anisotropy and spectral characteristics. *J. Geophys. Res. 102*, 24237–24248

Ellison, D.C. and Ramaty, R. (1985) Shock acceleration of electrons and ions in solar flares. *Ap. J. 298*, 400–408

Flückiger, E.O. and Kobel, E. (1990) Aspects of combining models of the Earth's internal and external magnetic fields. *J. Geomag. Geoelect. 42*, 1123–1128

Humble, J.E., Duldig, M.L., Shea, M.A., and Smart, D.F. (1991) Detection of 0.5-15 GeV solar protons on 29 September 1989 at Australian stations. *Geophys. Res. Lett. 18*, 737–740

Shea, M.A. and Smart, D.F. (1982) Possible evidence for a rigidity dependent release of relativistic protons from the solar corona. *Space Sci. Rev. 32*, 251–271

Tsyganenko, N.A. (1989) A megnetospheric magnetic field model with a warped tail current sheet. *Planet. Sp. Sci. 37*, 5–20