GeV Cosmic and Solar Energetic Particle Observation from Ground Based Detectors

Paul Evenson[1]

[1]*University of Delaware Department of Physics and Astronomy*

Only three Ground Level Enhancements (GLEs) produced by GeV solar energetic particles have been confirmed in the present solar cycle, and those have been quite small by historical standards. At the same time direct observations of high energy solar particles from spacecraft have become available. This has resulted in some discussion as to whether the definition of a GLE as an event detectable on the ground (as opposed to a statement about the spectral form of the event) is an appropriate scientific classification. The combination of instruments at the Amundsen – Scott Station at the geographic South Pole offers an opportunity to span the two worlds (Abbasi *et al.* 2008). Operating at high altitude and low geomagnetic cutoff the neutron monitor at Pole has nevertheless traditionally been accepted as making a "ground level" observation. An enhanced array of bare neutron detectors and IceTop (the surface component of the IceCube Neutrino Observatory) now allow spectral information to be extracted from events that are too small to use geomagnetic techniques to obtain spectra. I discuss our spectral measurements for the event of 17 May 2012, the largest confirmed GLE (The IceCube Collaboration 2013) and compare them to other available data on the event.

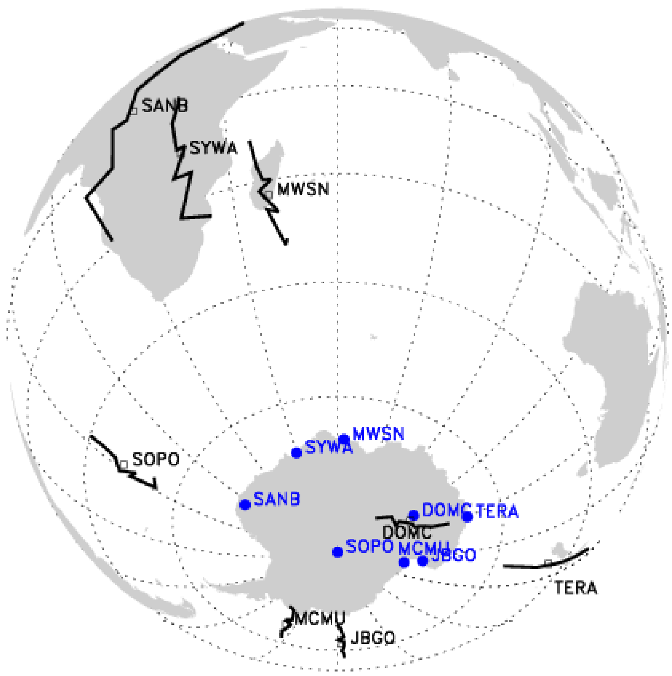

Figure 1. Asymptotic viewing directions for solar energetic particles entering vertically at various Antarctic stations. Station locations are indicated in blue and the range of viewing directions is given by the black lines. (Plot courtesy of W. Nuntiyakul)

The magnetic field of the Earth limits the viewing or "asymptotic" direction of a ground based station to a small range of angles in interplanetary space (Figure 1). Neutron monitor locations are shown in blue: Mawson, Terre Adelie, Mcmurdo, Jang Bogo, SANAE, and the proposed Syowa are near the coast, with South Pole and Dome C in the interior. The asymptotic directions are represented by black lines. In this representation the interplanetary arrival direction is parallel to a line connecting the center of the Earth to a point on the surface. The arrival direction depends somewhat on particle rigidity, with the line showing the range of arrival directions for a typical solar energetic event spectrum.

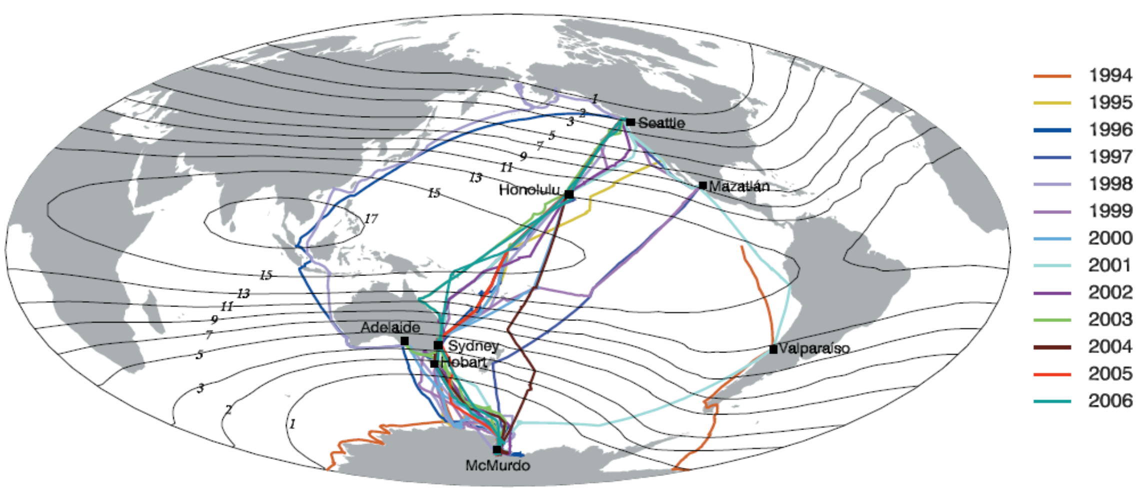

Figure 2. Tracks of the ship-borne neutron monitor latitude surveys for 1994–2007, superimposed on contours of the vertical cutoff rigidity in GV. (Nuntiyakul et al. 2014)

Fluxes of solar energetic particles are highly anisotropic, therefore networks of ground based detectors are necessary to understand this angular dependence. One such network is *Spaceship Earth* (Bieber and Evenson 1995) which is specifically optimized to study the angular distribution of solar particles by giving global coverage with neutron monitors having similar energy response. The energy spectrum can also be estimated by using a property of the Earth's magnetic field termed the "geomagnetic cutoff" whereby particles below a certain rigidity (momentum per unit charge) are prevented from entering the atmosphere at a given location. This cutoff is high near the geomagnetic equator and low near the magnetic poles. Since the magnetic field of the Earth is only crudely approximated as a dipole the actual dependence of the cutoff on geographic locations is rather complex. Figure 2 shows calculated contours of geomagnetic cutoff (expressed in GV). By locating detectors at different cutoffs an approximate energy spectrum can be deduced.

Installation of a neutron monitor at Syowa would be important in two ways. The viewing direction is similar to that of SANAE, but SANAE is located at approximatly 800 meters altitude whereas Syowa is near sea level. The two neutron monitors therefore have somewhat different energy response which can be used to estimate the energy spectrum of the incoming particles. The Syowa viewing direction also fits nicely between Mawson and SANAE. This will produce the worlds most closely spaced triad of neutron monitors, enabling study of small scale anisotropy with increased precision.

The variation in geomagnetic cutoff can also be used in different ways with a transportable detector and the ever present flux of galactic cosmic rays. This flux is often approximately constant in time on a scale of months. By considering the difference in measurements taken in locations with cutoffs that vary by a small amount the response of the detector to a narrow range of energetic particle rigidity can be determined. The best way to take such data is to use a ship-borne detector on what is termed a "latitude survey" since even a very massive detector can be moved relatively over a large range of geomagnetic cutoffs. In the coming years it will be particularly important to conduct such surveys to understand the response of a new generation of ground based detectors.

Figure 3. : Tasvan at NIPR

By repeating latitude surveys with the same instrument one can also study details of the change of the galactic cosmic ray spectrum with time. Figure 2 also shows the travels of the so called "Tasvan" transportable monitor from 1994 to 2007 (Nuntiyakul et al. 2014). The Tasvan monitor has been moved to NIPR (Figure 3) to support the installation of the planned neutron monitor at Syowa station.

References

Abbasi, R., et al. (The IceCube Collaboration): Solar Energetic Particle Spectrum On 2006 December 13 Determined By Icetop, Astrophys. J., 689: L65–L68, 2008.

Bieber, J. W., and P. Evenson: Spaceship Earth – An optimized network of neutron monitors, Proc. 24th Internat. Cosmic Ray Conf. (Rome), 4, 1316-1319, 1995.

The IceCube Collaboration, M.G. Aartsen, R. Abbasi, Y. Abdou, M. Ackermann, J. Adams, et al.: Ground level enhancement of May 17, 2012 observed at South Pole (paper 0368) [arXiv:1309.7006v2, astro-ph.HE], 2013.

Nuntiyakul, W., P. Evenson, D. Ruffolo, A. Saiz1, J. W. Bieber, J. Clem, R. Pyle, M. L. Duldig, and J. E. Humble: Latitude Survey Investigation Of Galactic Cosmic Ray Solar Modulation During 1994–2007, The Astrophysical Journal, 795:11 (13pp), doi:10.1088/0004-637X/795/1/11, 2014.