Cosmic ray observations at Syowa Station in Antarctica for space weather study

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A solar disturbance propagating away from the Sun affects the pre-existing population of galactic cosmic rays (GCRs) in interplanetary space in a number of ways. Using Parker's transport equation of GCRs in the heliosphere, we can infer, from the observed anisotropy (or the streaming) of high energy GCR intensity, the spatial gradient of GCR density (or isotropic component of GCR intensity) which reflects the large-scale magnetic structure such as interplanetary shocks and magnetic flux ropes in the Interplanetary Coronal Mass Ejection (ICME) (Kuawabara *et al.* 2009). While the relationship between the magnetic structure and the GCR density is now better established, it is less recognized that GCR density variations are often accompanied by strong enhancements of the cosmic-ray anisotropy, some of which extend into the region upstream of the approaching shock. Because high-energy cosmic-rays travel in interplanetary space nearly at the speed of light, ~300 times faster than ICMEs, this information is carried rapidly to the Earth before the arrival of ICMEs and can be useful for space weather forecasting. Precursory anisotropies (sometimes termed the "loss-cone" precursors) have generally been interpreted as kinetic effects related to interaction of ambient cosmic-rays with the approaching shock (Fushishita *et al.* 2010, Rockenbach *et al.* 2011).

Ground-based observations of cosmic rays (CRs) with energies between ~1 and ~100 GeV have been performed by using neutron monitors (NMs) and muon detectors (MDs). Only a global network of detectors can measure the dynamic variation of the anisotropy (and the density gradient) accurately and separately from the temporal variation of the GCR density. An example of global networks using NMs is the Space Ship Earth (SSE) network constructed by a group of University of Delaware, USA, while an example using MDs is the Global Muon Detector Network (GMDN) operated by a group of Shinshu University, Japan (Bieber and Evenson 1995, Okazaki *et al.* 2008) (for the SSE, see also an invited paper by Paul Evenson in this symposium). The GMDN was established for accurate measurement of the anisotropy in March 2006, when a hodoscope type cosmic ray detector using proportional counter tubes was installed in Kuwait and added to the previous network composed of muon detectors (MDs) using plastic scintillators at Nagoya in Japan, Hobart in Australia and São Martinho da Serra in Brazil. The detection areas of MDs, except one at Nagoya which has an area of 6 m×6 m, have been enlarged in several steps and are currently 4 m×4 m at Hobart, 4 m×8 m at São Martinho da Serra, respectively. Recently, the detection area of Kuwait MD has been also expanded to 5 m×5 m in March, 2016 (Figure 1). The SSE and GMDN have been operating continuously and automatically sending the real-time data through the internet (Rockenbach *et al.* 2014). The SSE and GMDN data are available on the following Web-sites.

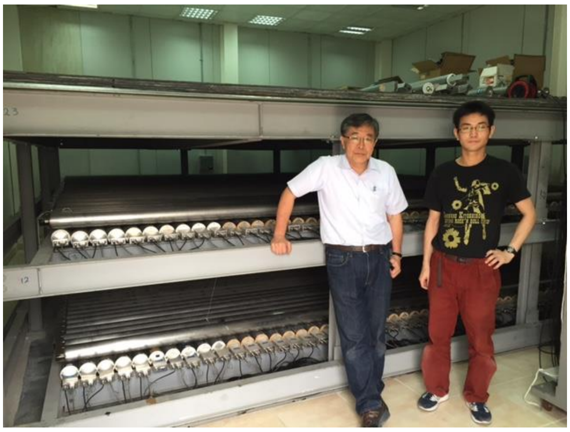

Figure 1. The Kuwait MD with a detection area expanded to 5 m×5 m. We plan to install similar (but smaller) MD consisting of proportional counter tubes at Syowa station.

Figure 2. NM equipment arrived at the NIPR.

SSE data: http://neutronm.bartol.udel.edu/~pyle/bri_table.html
GMDN data: http://cosray.shinshu-u.ac.jp/crest/DB/Public/main.php

In this paper, we propose a new CR observation at Syowa station in Antarctica. The new plan is to observe CRs with NMs and MDs simultaneously at the same lcation, which is Syowa Station in Antarctica. The second-handed equipment for NMs has arrived from Tasmania at the NIPR in "Tasvans" which had been used for the "latitude survey" using NMs on a ship (Figure 2) (for the latitude survey, see also an invited paper by Paul Evenson in this symposium). An advantage of making simultaneous observations with NM and MD at Syowa Station is that CR anisotropy can be measured in a wider energy range, because the median energy of primary CRs observed with MDs is about 5 times higher than that with NMs. Syowa Station is one of the best places for this simultaneous observations with the relatively small geomagnetic deflection of CR orbits at the polar station. Figure 3 shows asymptotic viewing directions of the Syowa NM (×) and a vertical (■) and inclined (•) directional channels of a multi-directional MD at Syowa, together with viewing directions of other multi-directional MDs in the GMDN. It is clear that the viewing direction of a NM (×) is well contained within the field of view of MD (•) and a pair of NM and MD can monitor CRs arriving from the same direction with different energies. This is important to measure the energy dependence of the anisotropy separately from the angular distribution of the CR intensity. It is also important for inter-callibrating the GMDN that asymptotic directions of Syowa MD (•) well overlap with those of other detectors in the GMDN (●● and •). Deriving new findings on space weather study from this new observation, such as magnetic structures of Interplanetary Coronal Mass Ejection (ICME) and/or the possible space weather forecast using the loss-cone precursors, are expected. It is also noted that a stable observation over a long term is required to study space weather events which are still difficult to predict accurately.

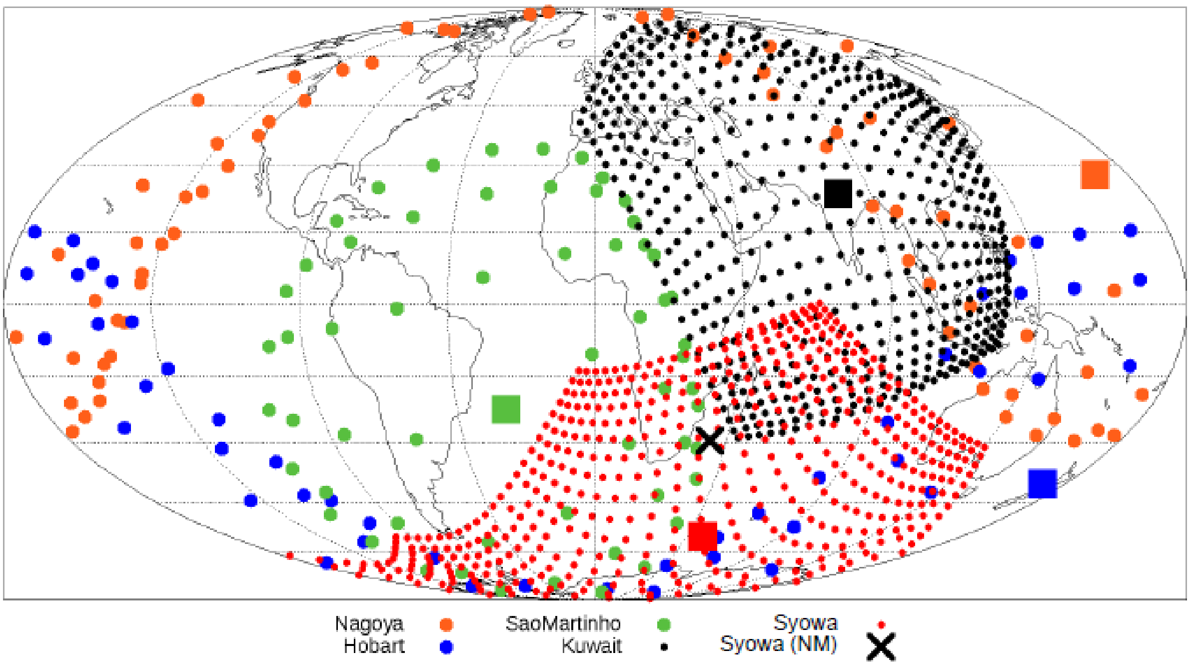

Figure 3. Asymptotic viewing directions of GMDN and the planned NM and MD at Syowa Station after correcting for the deflection of cosmic ray orbits in the geomagnetic field. A black cross (✕) shows the viewing direction of the Syowa NM, while a red solid square (■) and red dots (•) show viewing directions of vertical and inclined directional channels of Syowa MD, respectively. Solid squares (■■■ and ■) and circles (●●● and •) display viewing directions for the vertical and inclined channels of the GMDN, respectively, as indicated below the figure.

References

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