Relevance of near-Earth magnetic field modeling in deriving SEP properties using ground-based data

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Anastasios Kanellakopoulos[1], Christina Plainaki[1,2], Helen Mavromichalaki[1], Monica Laurenza[1], Maria Gerontidou[1], Marisa Storini[2], Maria Andriopoulou[3]

[1]Nuclear and Particle Physics Section, Physics Department, National and Kapodistrian University of Athens, Zografos, 15784 Athens, Greece

[2]INAF-IAPS, Via del Fosso del Cavaliere, 00133 Rome, Italy

[3] Space Research Institute, Austrian Academy of Sciences, Graz, Austria

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Abstract: In this work we investigate how the use of different magnetospheric field models can influence the derivation of the relativistic solar energetic particles (SEP) properties when modeling Ground Level Enchantments (GLE) events. As a case study, we examine the event of 2012 May 17 (also known as GLE71), registered by ground-based Neutron Monitors (NMs). We apply the Tsyganenko-89 and the Tsyganenko-96 models in order to calculate the trajectories of the arriving SEPs in the near-Earth environment. We show that the intersection of the SEP trajectories with the atmospheric layer at 20 km from the Earth's surface (i.e. where the flux of the generated secondary particles is maximum), forms for each ground-based neutron monitor a specified viewing region that is dependent on the magnetospheric field configuration. Then, we apply the Neutron Monitor Based Anisotropic GLE Pure Power Law (NMBANGLE PPOLA) model (*Plainaki et al., 2010*), to derive the spectral properties of the related SEP event and the spatial distributions of the SEP fluxes impacting the Earth's atmosphere. We examine the dependence of the results on the used magnetic field models and evaluate their range of validity. Finally, we discuss information derived by modeling the SEP spectrum of particle acceleration scenarios.

Introduction

Ground Level Enhancements (GLEs) are short-term increases observed in cosmic ray intensity records of ground-based particle detectors such as neutron monitors (NMs) or muon detectors; they are related to the arrival of solar relativistic particles at the terrestrial environment. Hence, GLE events are related to the most energetic class of SEP events. On 2012 May 17, the first GLE of the 24th solar activity cycle, known as GLE71, was registered by the NMs of the worldwide network, starting at ∼01:51 UT (at Oulu NM) and having a maximum of about 17% (registered at South Pole NM at ∼02:13 UT).

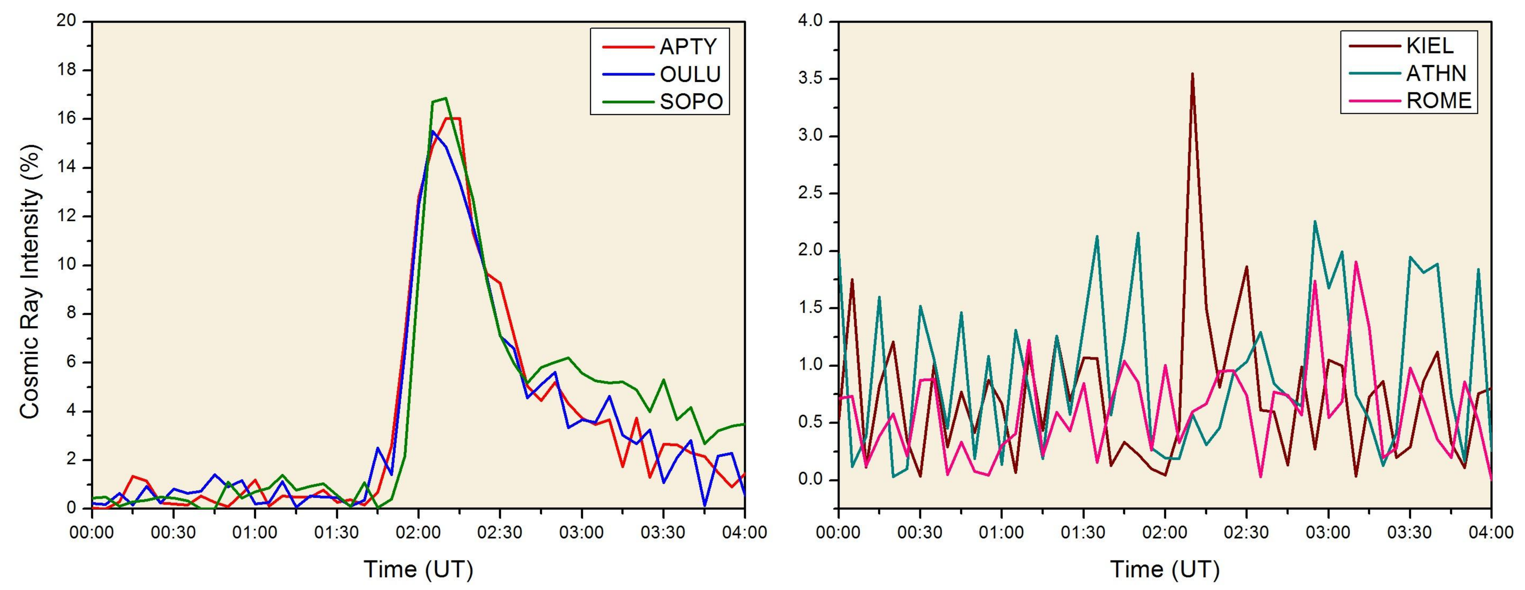

Figure 1. *GLE of 2012 May 17 as observed by the polar NMs Apatty (APTY, R_c=0.65 GV), Oulu (OULU, R_c=0.8 GV), South Pole (SOPO, R_c=0.1 GV), and by the mid-latitude NMs Kiel (KIEL, R_c = 2.36 GV), Athens (ATHN, R_c=8.53 GV) and Rome (ROME, R_c=6.27 GV)*

Why is it important to model GLE events assuming an accurate representation of the Earth's magnetospheric field ?

- the trajectories of solar protons are an important input for GLE models; their accurate derivation for protons with energies covering the complete Solar Cosmic Ray (SCR) spectrum, contributes in deriving information about the ***acceleration mechanism*** in different energy ranges
- the interpretation of the ground-level observations urges for an inter-connection between secondary cosmic rays registered at NMs and intensity spatial distribution of the primary SCR; the latter cannot be accurately assessed if the primary protons trajectories are not taken into account (*Cane et al., 2010; Lee et al., 2013*)
- quantitative information on the main direction of the anisotropic flux arrival and the primary SCR intensity during a GLE can be precisely calculated only if firstly the solar proton trajectories are simulated.

Scope of current work

- to examine the dependence of some modeled SEP properties (e.g. the location of the anisotropic SCR flux) on the assumed magnetic field models
- to define the contribution of the assumed magnetic field configuration in the differences between the NM intensity profiles, while modeling a GLE of cosmic ray intensity

Data Analysis

First step:

Applying Tsynganenko-89 (T89) and Tsynganenko-96 (T96) models (*Belov et al., 2005*), we calculate:

- the trajectories of the arriving SEPs in the near-Earth environment
- the asymptotic directions of viewing for three polar NMs

For an analytical description of the method see *Belov et al. (2005)* or *Plainaki et al. (2009)*.

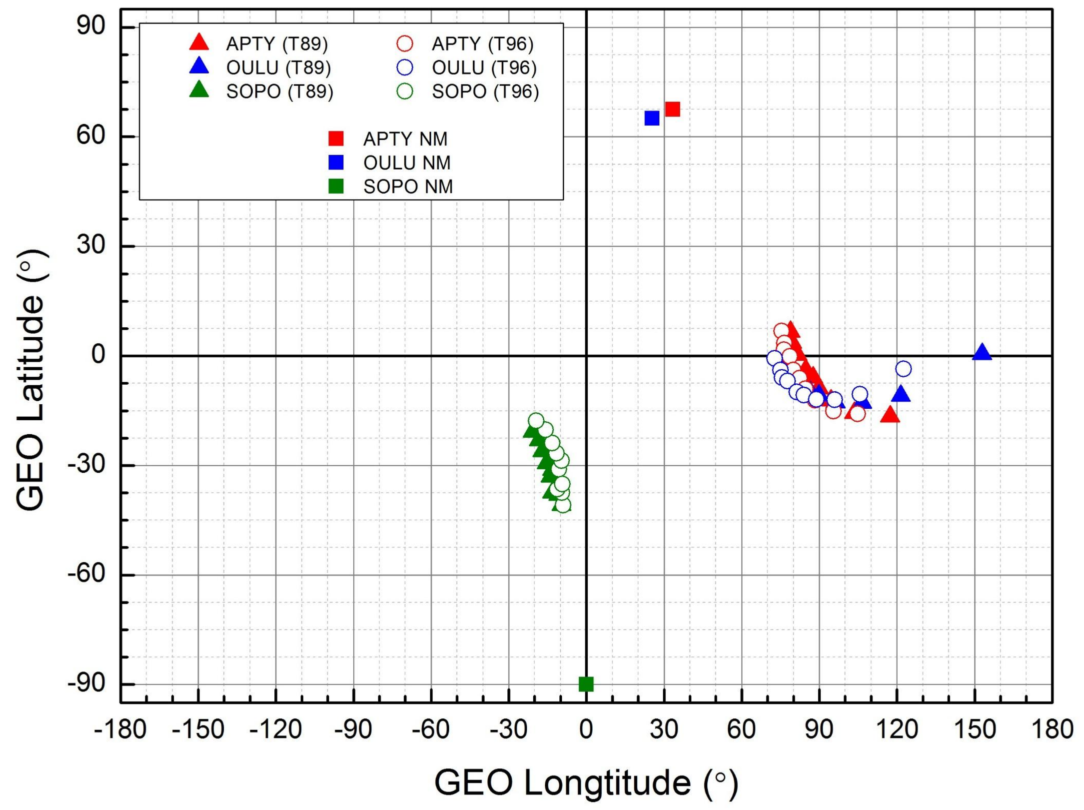

Figure 2. *The position and the asymptotic cones of the APTY, OULU and SOPO Neutron Monitors using both T89 & T96 magnetospheric models, are illustrated.*

Second step:

The results applied to the NMBANGLE PPOLA model to GLE 71 (*Plainaki et al., 2014*) in order to obtain the locations of the main anisotropic SCR flux arrival at ~20 km above the Earth's surface for:

- the initial time interval of the event (01:55-02:00 UT)
- the main phase (02:15-02:20 UT),

Third step:

For two different time intervals of the event, we calculate the angular distance, Ω, of each viewing direction from the SCR main arrival direction, using the equation:

$$\cos\Omega = \sin\lambda\,\sin\lambda_o + \cos\lambda\,\cos\lambda_o\cos(\varphi - \varphi_o)$$

where λ_o, φ_o latitude and longitude, respectively, of the SCR main arrival direction, while λ, φ are the latitude and longitude, respectively, of the asymptotic direction of viewing for every station.

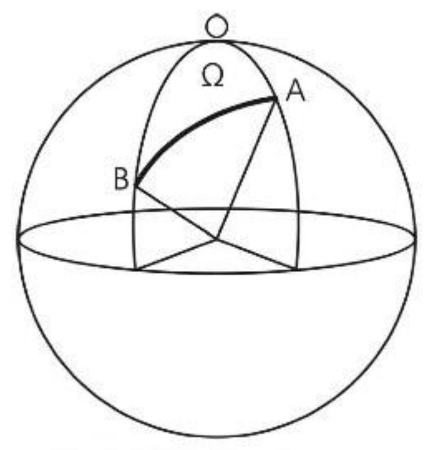

Figure 3. *Definition of the angular distance Ω*

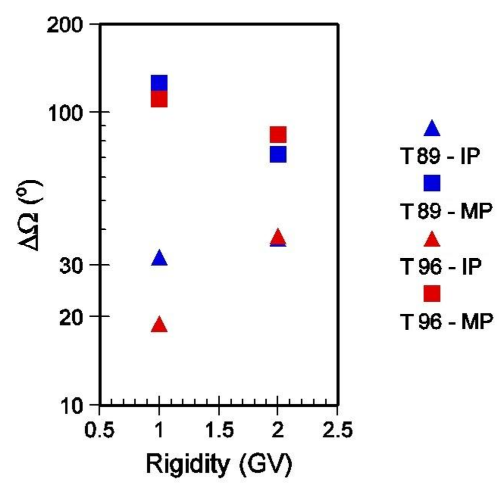

Figure 4. *Maximum difference between the angular distances of the stations as a function of rigidity.*

Results

The results from the application of the T89 and T96 models, are presented in Tables I and II and Figure 4.

Table I: Angular distance of each viewing direction from the SCR main arrival direction using T89

NM station	1 GV solar protons		2 GV solar protons	
	Ω (°), at 01:55 – 02:00 UT	Ω (°), at 02:15 – 02:20 UT	Ω (°), at 01:55 – 02:00 UT	Ω (°), at 02:15 – 02:20 UT
Apatty	68	44	47	66
Oulu	86	27	46	66
South Pole	54	153	83	138

Table II: Angular distance of each viewing direction from the SCR main arrival direction using T96

NM station	1 GV solar protons		2 GV solar protons	
	Ω (°), at 01:55 – 02:00 UT	Ω (°), at 02:15 – 02:20 UT	Ω (°), at 01:55 – 02:00 UT	Ω (°), at 02:15 – 02:20 UT
Apatty	60	52	44	68
Oulu	70	42	42	69
South Pole	51	153	80	153

Conclusions

- **In the initial phase (IP: 01:55-02:00 UT) of the event:**
  - The South Pole station was the magnetically mostly favored NM station (smaller angular distance) for registering secondary SCR corresponding to 1 GV solar protons, while Oulu and Apatity stations were the magnetically mostly favored NMs for registering secondary SCR corresponding to 2 GV solar protons.
  - From the above and the high rates of Oulu and Apatity NMs it is concluded that the flux of 2 GV solar protons was dominated against the flux of 1 GV and support the scenario that the flux of 2 GV particles may have been highly anisotropic.
- **In the main phase (MP: 02:15-02:20 UT) of the event:**
  - The more homogeneously distributed primary SCR flux results in a less significant dependence of the secondary registration on the primary SCR main arrival direction.
- **The two models T89 and T96** show that solar protons accelerated to rigidities of at least ~2 GV have a different spatial distribution only at low rigidity. When the T96 is used inside the GLE model, the location of the maximum anisotropic flux seems to be less dependent on the acceleration/transport mechanisms for 1 GV particles, since the maximum difference (ΔΩ, shown in Figure 4) between the angular distances of the stations is ~19° (for T89 the same quantity is ~32°), during the IP. Figure 4 also shows that for the 2 GV particles, both models give similar results. We conclude that the use of T96 model tend to reduce the 1 GV primary flux anisotropies, due to the magnetic configuration between the source location and the NMs asymptotic direction of viewing.

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