Ground Level Enhancement Measurements with the Neutron Monitors

Pierre-Simon Mangeard[1] (mangeard@udel.edu)

[1]Bartol Research Institute, Department of Physics and Astronomy, University of Delaware, Newark DE19716, USA

UNIVERSITY OF DELAWARE
BARTOL RESEARCH INSTITUTE

Introduction

- A neutron monitor (NM) is a ground-based detector that records the nucleonic component of air showers produced by cosmic rays (CR) impinging the Earth's atmosphere [4].

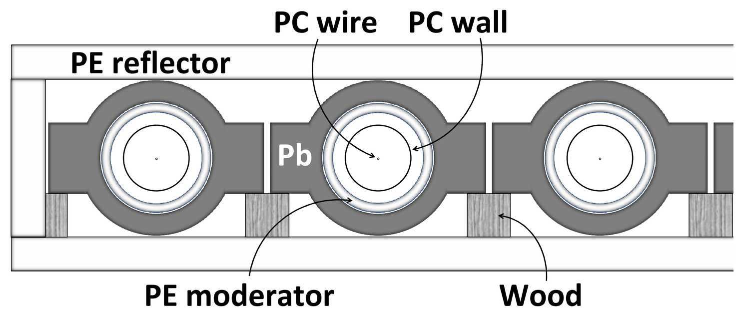

Figure 1: Example of NM64 - BF_3. Secondary particles (SP, mostly neutrons) interact with Pb-nuclei and produce tertiary neutrons that are captured in the proportional counter via the reaction $n + {}^{10}B \longrightarrow {}^{4}He + {}^{7}Li^{*}$.

- The NM response integrates the contributions of particles that exceed the maximum value between the atmospheric rigidity cutoff (∼1 GV) and the local geomagnetic rigidity cutoff (0-17 GV).
- Solar Energetic Particles (SEPs) are high-energy particles from the Sun that are accelerated during solar flares and coronal mass ejections. The most intense SEP events produce a large number of energetic particles (up to several GeV). Their interaction in the Earth's atmosphere induces a significant raise of the radiation levels on the ground that is detected by the worldwide network of the neutron monitors. Such events are called **Ground Level Enhancement** (GLE).
- *A GLE event is registered when there are near-time coincident and statistically significant enhancements of the count rates of at least two differently located neutron monitors including at least one neutron monitor near sea level and a corresponding enhancement in the proton flux measured by a space-borne instrument(s)* [7].
- The official database of neutron monitor count rates during GLE reports the data from 1956 at `https://gle.oulu.fi/`.

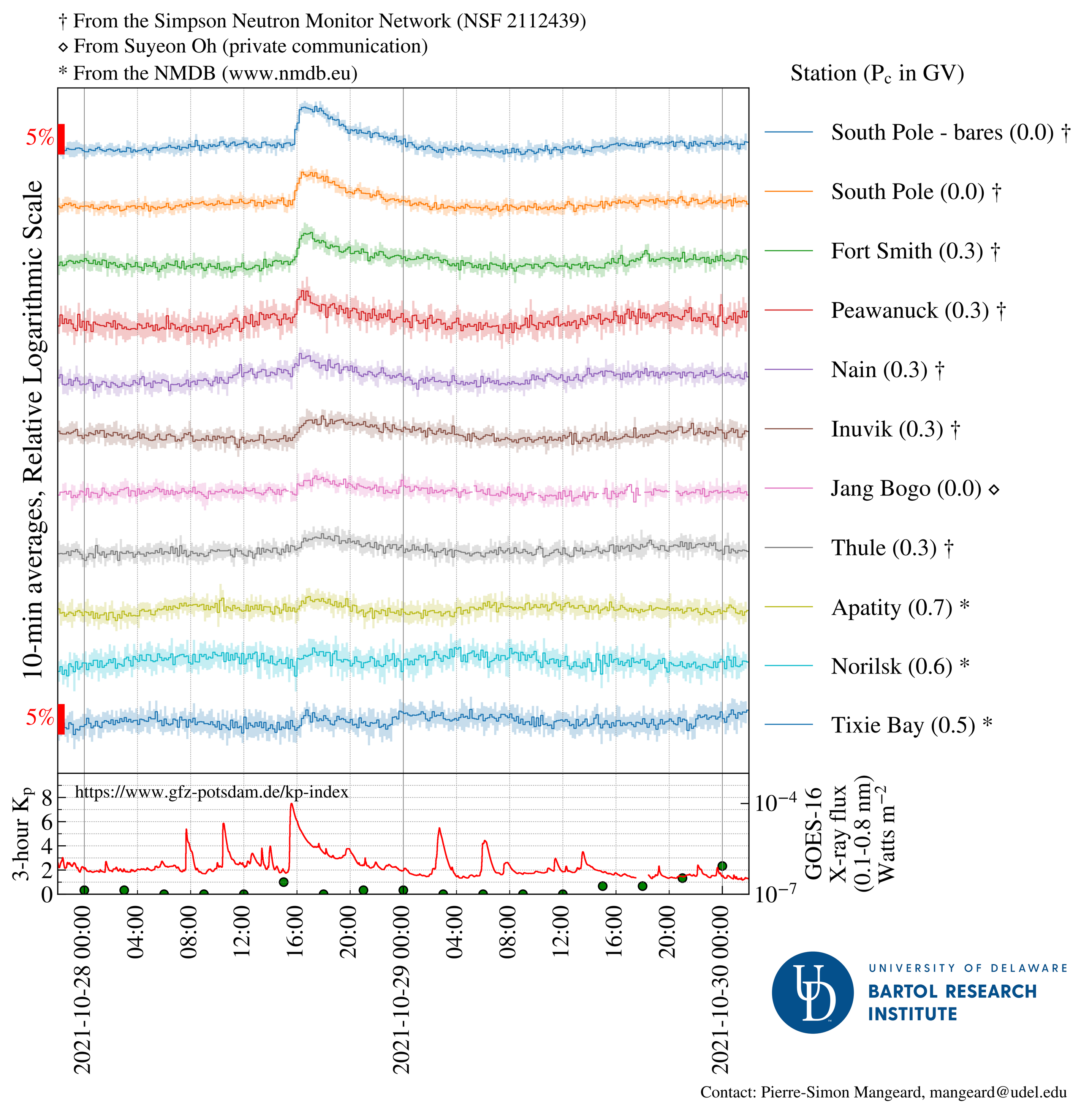

Figure 2: GLE-73 on 28 October 2021, observed by the neutron monitors of SpaceShip Earth and by the neutron detectors at the South-Pole.

Space Weather

- Depending on their source, intensity, and propagation in the inner heliosphere, solar storms can create hazardous radiation levels for orbiting spacecrafts, satellites, and commercial aircraft on polar routes. Electronics, crews, and passengers are directly affected.

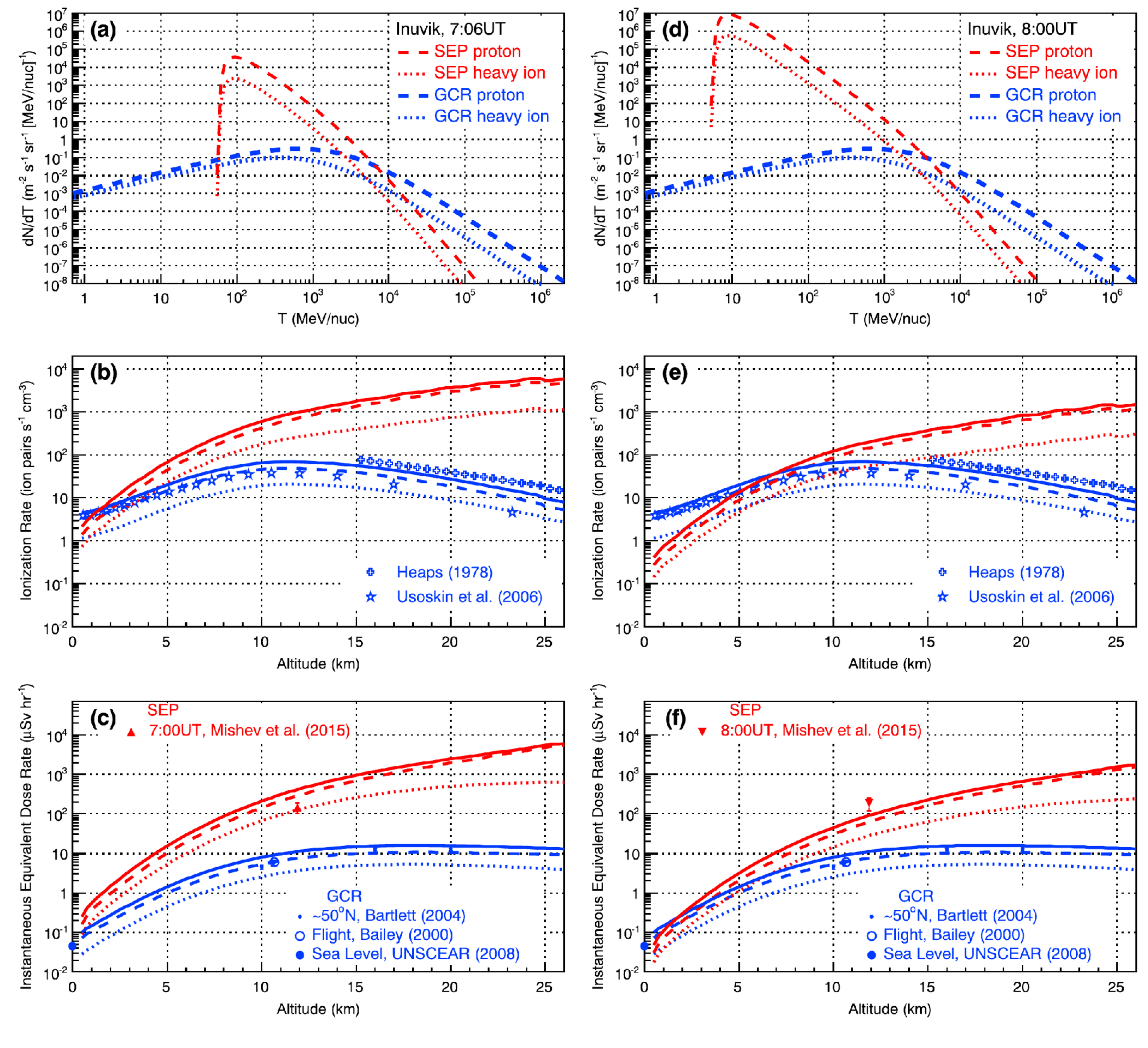

Figure 3: (a, d) Modeled cosmic ray spectra used as inputs to simulate the (b, e) atmospheric ionization production rate and (c, f) instantaneous equivalent dose rate above Inuvik (Canada) NM station at the peak time of the GLE of 20 January 2005 (a, c) and a time during the decay phase (d, f) [6].

- To help mitigate these hazardous effects, the data from the neutron monitor network serves as a real-time (within several minutes) alert system for GLE. You can subscribe to the following **real-time GLE alarm systems**:
  - Based on the signal of the neutron monitors operated by the Bartol Research Institute at `http://www.bartol.udel.edu/~mangeard/glealarm/subscribe.html` [5].
  - Based of NMDB data at `http://cosray.phys.uoa.gr/index.php/glealertplus` (Service description therein).

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Multiple ground detectors at the South-Pole

- Two types of neutron monitors are located at the South-Pole: a standard 3NM64 [4] and an unleaded array of 12 tubes. Each detector has a different response function to the SEPs. Thus, the ratio of their count rates can be used to estimate the spectral shape of the SEPs [2].
- The Cerenkov tank detectors of the cosmic ray air shower array IceTop [1] are sensitive to the most energetic components of the SEPs. The tank detectors have been tuned such that each responds differently to SEPs. It brings additional spectral information. The last three GLEs are being analyzed with a combined dataset [3].

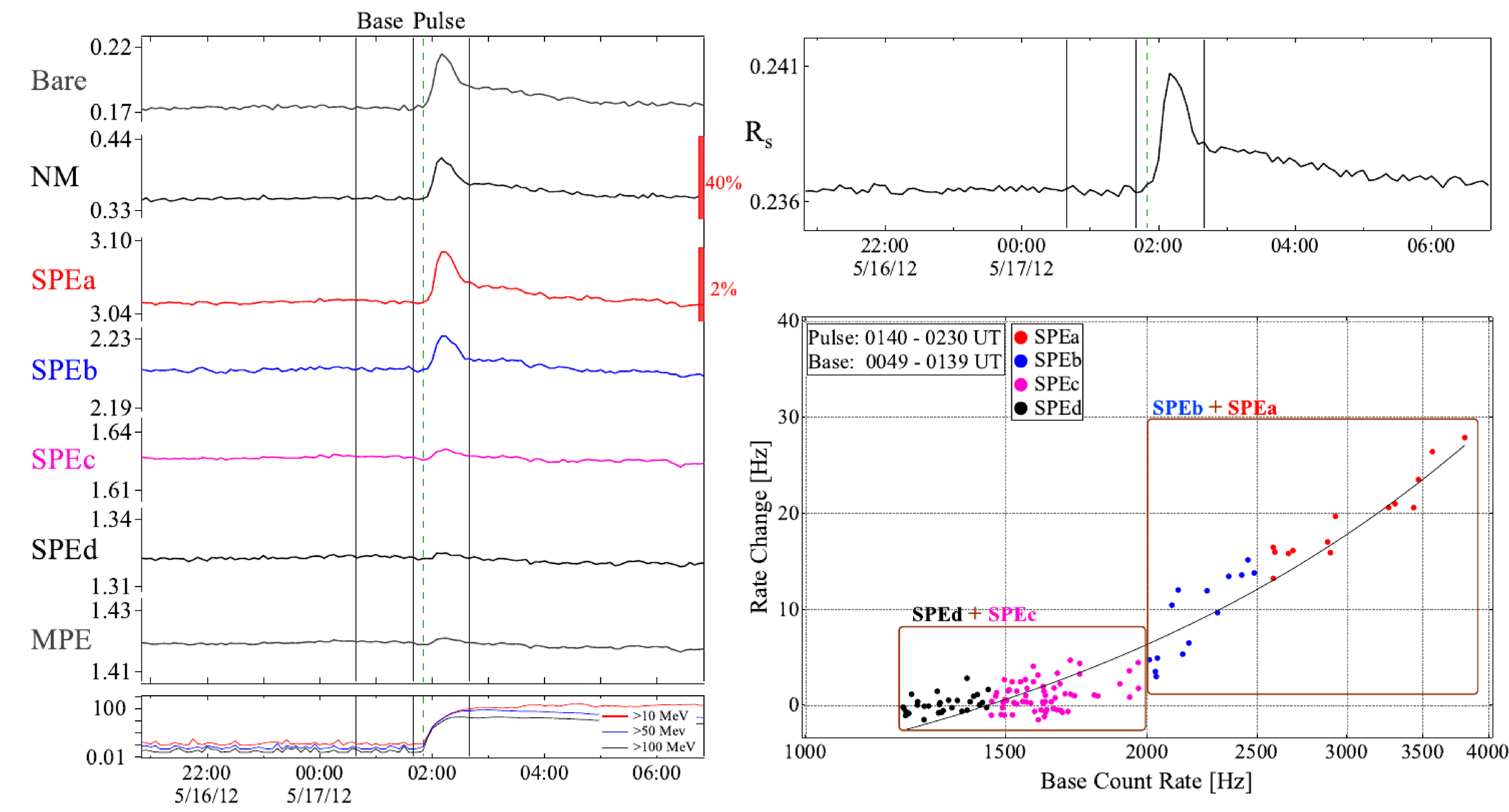

Figure 4: The GLE-71 on 17 May 2012. Left: Observations at the South-Pole and GOES Spacecraft. Right Top: Ratio of increases. Right Bottom: Rate change as a function of tank rates. (Horizontal axis on log scale and vertical axis on linear scale) [3].

Cross Calibration of AMS-02 and the NM network

- The space-borne detectors PAMELA and AMS-02 provided high quality spectral data of Cosmic Rays since 2006.

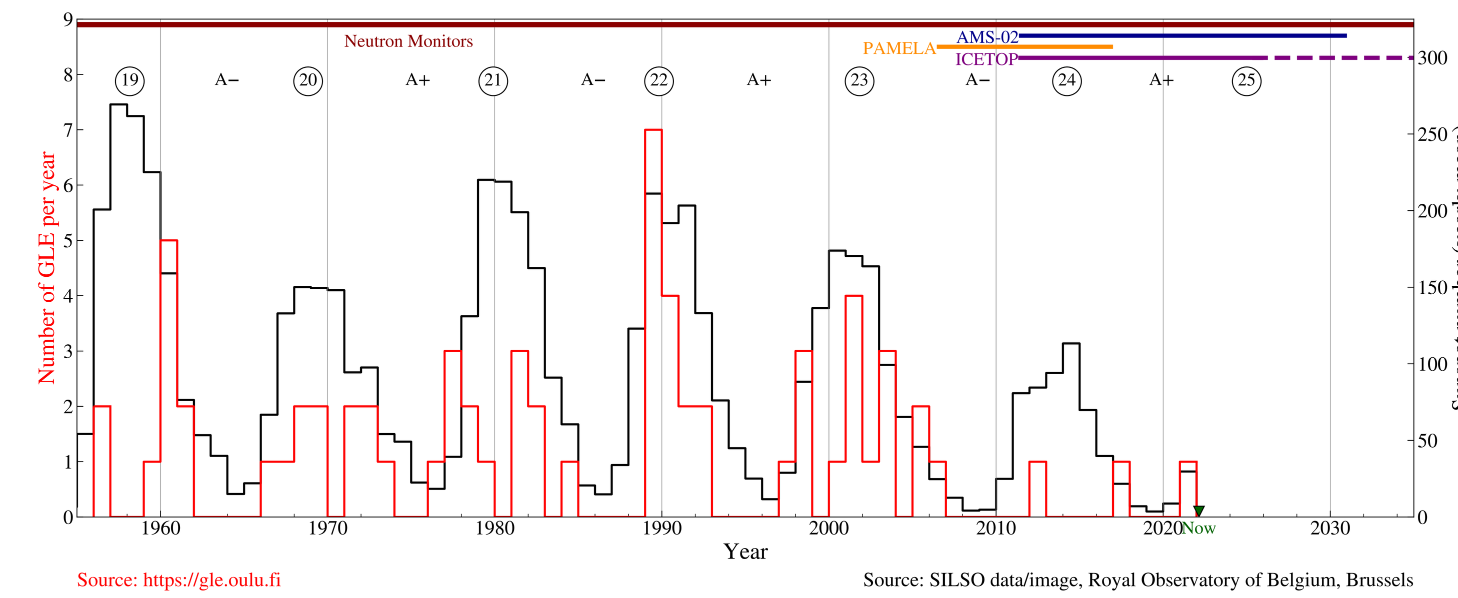

Figure 5: Number of GLE per year recorded by the NM network since 1954 (Solar cycles 19-24).

- The concomitance of neutron monitor data with direct spectral data from the top of the atmosphere should improve the determination of the neutron monitor yield functions, especially around the 1 GeV region where the determination from latitude survey data is challenging.
- Unfortunately, only two weak GLEs were recorded during the solar cycle 24
- The GLEs of cycle 25 will hopefully provide a unique opportunity to realize a precise cross calibration between the neutron monitor data and the differential energy spectrum from AMS-02 below a few GeV. This calibration will be very useful beyond the end of operation of AMS-02.