SOLAR PARTICLE EVENT ANALYSIS USING THE STANDARD RADIATION ENVIRONMENT MONITORS: APPLYING THE NEUTRON MONITOR'S EXPERIENCE

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Abstract: Space weather is an environmental concept that refers to the dynamic conditions in the space contiguous to Earth, but also at interplanetary and interstellar space scale. A wide variety of physical phenomena influences space weather. This includes solar events as coronal mass ejections (CMEs) and solar flares (SFs), populations of galactic (GCRs) and solar (SCRs) cosmic rays, geomagnetic storms, ionospheric disturbances and geo-magnetically induced currents at Earth's surface. The Standard Radiation Environment Monitor (SREM) is a particle detector developed by ESA for satellite applications with the main purpose to provide radiation hazard alarms to the host spacecraft. Currently, SREM units are in operation onboard of PROBA-I, INTEGRAL, ROSETTA, GIOVE-B, HERSCHEL and PLANCK satellites. SREM units have been constructed within a radiation hardening concept and therefore are able to register extreme solar particle events (SPEs). Large SPEs are registered at Earth, by ground based detectors as neutron monitors (NMs), in the form of Ground Level Enhancements (GLEs). Over the past few years the cosmic ray community succeeded in formulating an accurate GLE Alert, which operates in real-time mode. In this work, a projection of the SREM registered SPEs to the ground based GLEs was attempted. This led to the validation of the satellite measurements, as all of the investigated events were registered both is space and on Earth. Furthermore, a feasibility study of a radiation alarm deduced by SREM meas-urements was implemented for the event of January 20, 2005 (GLE69). This event was chosen as a case study due to the fact that at the time of the SPE two satellites carrying SREM units, namely: INTEGRAL and ROSETTA, were at almost 1 AU distance and had minor angular distribution (<6°) with respect to the Sun-Earth line. Taking advantage of the NM experience, the steps of the GLE Alert algorithm were put into practice on SREM measurements. The outcome was that SREM units did register the outgoing SPE on-time and that these could serve as indicators of radiation hazards, leading to successful alarms.

The SREM unit

SREM units have been developed as a partnership of the European Space Agency (ESA), the Paul Scherrer Institute (PSI) and Contraves Space A.G. Those provide valuable data for both the near-Earth particle radiation environment (e.g. trapped particles in the radiation belts) and the interplanetary (IP) particle radiation environment with the diverse orbits of missions equipped with jointly-calibrated SREM units, offering unique opportunities for a comprehensive investigation of Solar Particle Events (SPEs) and Space Weather (SW) studies. SREM units measure both electrons with energies above 500 keV and protons with energies above 10 MeV and bins the measurements in overlapping energy channels. So far, seven units have been launched on board satellites STRV-1C, PROBA-1, INTEGRAL,ROSETTA, GIOVE-B and recently on HERSCHEL and PLANCK.

Figure 1. *Photograph of an SREM unit*

Solar Particle Events (SPEs)

Solar particle events (SPEs) are particle radiation events caused by the Sun and its extreme events as solar flares (SFs) and coronal mass ejections (CMEs). SPEs consist primarily of protons but also electrons and other heavy ions with energies ranging from a few tens of keV to GeV. The propagation of the extreme and hazardous SPEs, from the Sun to the Earth depends on their energy. The majority of SPEs are relatively short lived, usually lasting for tens of hours with an exponential decrease in flux afterwards, they can reach high values of fluxes at their peak, thus posing severe hazards for space missions, satellites and sensitive ground-based instruments. Large SPEs are registered at Earth, by ground based detectors as **Ground Level Enhancements (GLEs)**. SPEs are registered by several space-based and ground-based particle radiation monitors.

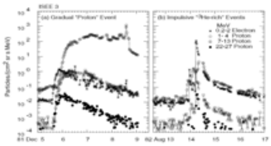

Figure 2. *'Gradual' and 'Impulsive' SPEs (taken by Reames,1999)*

Ground Level Enhancements (GLE) Alert:

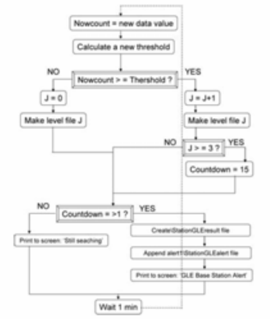

Figure 3. *Block diagram of the GLE Alert algorithm. Further info at Dorman and Zuckerman, 2003 & Souvatzoglou et al., 2009*

Steps of the GLE Alert algorithm

- Define for each NM station a moving threshold under the equation:

$$I_{th} = M + N * \sigma$$

where σ is the standard deviation, M the average of the previous 60 min measurements and N a statistical factor which characterizes every station, its value varies from 1 to 3. When I_{th} exceeds the threshold, a pre-alert point is marked. If 5 pre-alert points are marked in succession, a ***Station Alert*** Signal is being produced.

- A supervising program, with a time window of **15 min** is enabled. If three NM Stations enter the ***Station Alert*** Mode within the specific time window a ***General Alert*** will be produced.

- Service available online in real-time by the European Neutron Monitor Database (NMDB) – www.nmdb.eu.

The SPE of 20 January 2005 (GLE69)

Solar Events

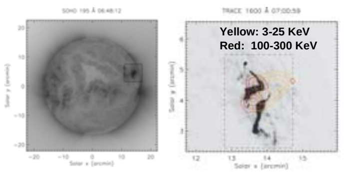

Figure 4. *SOHO/EIT image showing the X7.1 flare of January 20, 2005 (left panel) and the 1600 Å TRACE image (right panel). Both figures taken by Tziotziou et al., 2010*

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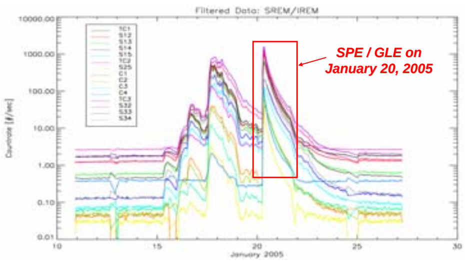
The SPE / GLE of January 20, 2005 relates with a large X7.1 flare which occurred on January 20, 2005 in AR 10720, on the western part of the solar disc (N14W61) as the SOHO/EIT image clearly indicates (see ***Figure 4*** – left panel).

The over-plotted yellow and red contours on the 1600 Å TRACE image indicate respectively the location of the soft and hard RHESSI emission (see ***Figure 4*** – right panel).

- Many papers describing the January 20, 2005 event can be reached at: https://creme96.nrl.navy.mil/20Jan05/

SREM recordings

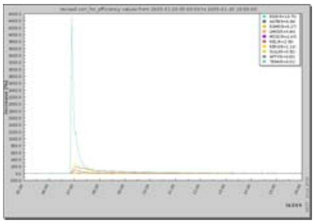


The onset phase of the SREM recorded particle flux was impulsive and it peaked within two hours after the flare, indicating a very good magnetic connectivity of the event location on the Sun to the Earth.

It is evident in ***Figure 5*** that there were a number of SPEs, registered by the SREM unit, that forehanded the event of January 20, 2005. Nevertheless, SPE / GLE69 stands out as a well defined event.

Figure 5. *SREM / INTEGRAL recordings from January 10 to 27, 2005 (taken by Tziotziou et al., 2010)*

Neutron Monitor recordings



Southern NMs (South Pole, Terre Adelie and McMurdo) recorded extremely sharp increases of more than 2000% (e.g. ***Figure 6***) whereas all the other stations recorded significantly smaller fluxes The onset of the GLE was placed at about 06:48 UT. The maximum amplitude was recorded by South Pole NM. An interesting feature of this GLE is the two-peak structure of the solar cosmic ray increase observed by several stations.

GLE69 was the largest GLE in half a century and was successfully recorded by NMs all over the world. It has been thoroughly analyzed by the cosmic ray community.

Figure 6. *GLE69 – taken by NEST tool of the European Neutron Monitor Database (NMDB) / www.nmdb.eu*

Positioning of satellites carrying SREM

As a case study for this work, the extreme SPE event of January 20, 2005 (ranked as GLE69 for the Cosmic Ray Community) was chosen. Further above, a description of the event is furnished.

At this point, it is important to note that the January 20, 2005 event constitutes a valuable case for SREM measurements, as two satellites which carry SREM units, namely INTEGRAL and Rosetta, where at a distance of ~ 1 AU and in a very narrow angular distribution from the Sun – Earth line, therefore comparable to other satellites operating at 1 AU and to ground based recordings.

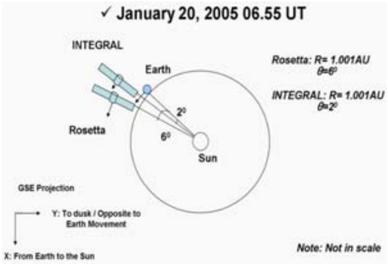


Figure 7. *Positioning of the INTEGRAL and Rosetta satellites on January 20, 2005 with respect to Sun-Earth line*

Applying the GLE Alert algorithm

Table I. *Results of the GLE Alert algorithm on SREM recordings*

INTEGRAL		Rosetta	
Unit / Energy band	Time (UT)	Unit / Energy band	Time (UT)
C1: 43<Ep[MeV]<86	07:05	C1: 43<Ep[MeV]<86	07:16
C2: 52<Ep[MeV]<278	07:00	C2: 52<Ep[MeV]<278	07:05
C3: 76<Ep[MeV]<450	07:00	C3: 76<Ep[MeV]<450	07:05
C4: 164<Ep[MeV]<∞	06:59	C4: 164<Ep[MeV]<∞	07:05

In this approach only step one of the GLE Alert algorithm has been used. Therefore, the results of ***Table I*** display the times of the ***Station Alert*** onset for each SREM channel

- The only SREM channel that records protons with E > 500 MeV, is C4. From ***Table I*** it is evident that INTEGAL issues a ***Station Alert*** on 06:59 UT, while Rosetta on 07:05 UT.
- Neutron Monitors issued a ***General Alert*** on 06:52 UT (*Souvatzoglou et al., 2009*)

Results

- Both satellites carrying SREM units issued Alerts very close to the one issued by NM measurements.

Single use of the C4 SREM channel

- In order to establish a ***General Alert***, it is necessary to have at least three 'Stations' in ***Station Alert*** mode, therefore it is probably impossible to issue an Alert (in the sense of warning) by **using only C4 SREM channel**. More likely, as an alternative definition, SREM units could issue Alarms, meaning that at this moment the specific channel registers an on-going SPE. Every satellite carries only one C4 channel, thus, it can only point out the time that the greater energy particles are registered. This could serve as an indicator of SPE arrival and therefore issue an Alarm.

Parallel use of all SREM channels

- A realistic approach could be to use the SPE Alert algorithm taking as input all four channels, which will be used as different 'Stations' operating in parallel mode. In this approach, it is possible to apply all steps of the algorithm and issue a ***General Alert***. The main drawback of this procedure is that the issued Alert will be delayed from the first high energy registration on C4, but at the same time the main advantage would be a stronger and better defined Alert. Moreover, the overlap of the energy bands could serve well the necessities of the Alert algorithm due to the fact that it can make the delay be minor (e.g. at Table ***Table I*** it is evident that INTEGRAL would enter at ***General Alert*** mode at 07:00 UT, only 1 minute after the C4 single onset).

- It is evident that SREM units are capable for accurate and precise SW applications. Follow-up work will include a quantitative analysis following both aforementioned approaches (**Single** and **Parallel** use).

Acknowledgement:

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References:

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