Using Neutron Monitors as seeders of the GLE Alert: The Space Weather Perspective

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Abstract: A significant space weather impact (i.e. risks and failures at communication and navigation systems, spacecraft electronics and operations, space power systems, manned space missions, and commercial aircraft operations) is being imposed from Ground Level Enhancements (GLEs) which are defined as significant intensity increases at neutron monitor measurements. A timely and reliable GLE Alert signal requires both the availability of actual-real time data in a continuous data flow scheme. Given the special characteristics of each neutron monitor station (cut-off rigidity, altitude, latitude, longitude), and the underlying common detection design, all NMs can be used as a unified mutli-directional detector. In this work the availability of each NM station with respect to their delivery of real-time data and their continuous data flow into NMDB as well as the characteristics of the NM stations that contributed to the establishment of timely GLE Alerts for the last 13 GLE events will be presented and discussed.

Neutron Monitors:

✓ Despite their decades of tradition, ground based **neutron monitors** (NMs) remain the state-of-the-art instrumentation for measuring cosmic rays, and they play a key role as a research tool in the field of space physics, solar-terrestrial relations, and space weather applications. They are sensitive to cosmic rays penetrating the Earth's atmosphere with energies from about **0.5-20 GeV**, i.e. in an energy range that cannot be measured with detectors in space in the same simple, inexpensive, and statistically accurate way.

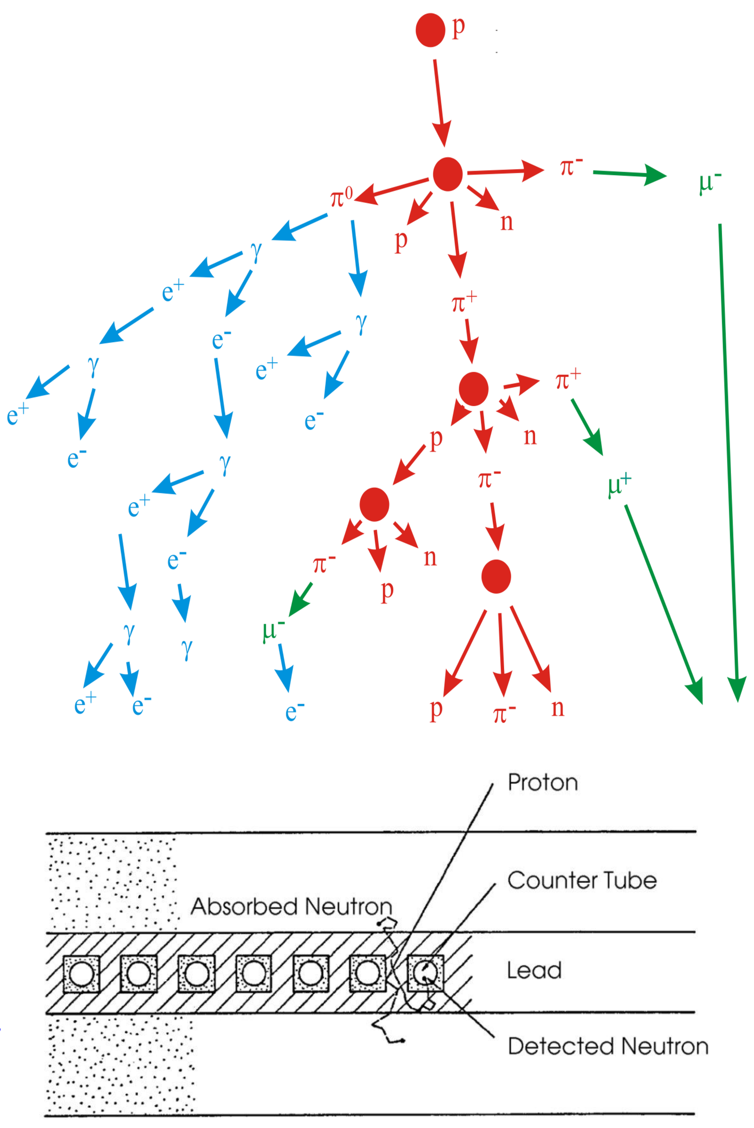

Figure 1. A schematic sketch of a cascade within the Earth's atmosphere, leading to the production of secondary neutrons which in turn are being recorded by a classical neutron monitor (from http://www.nmdb.eu/?q=node/142)

High-resolution Neutron Monitor Database (NMDB):

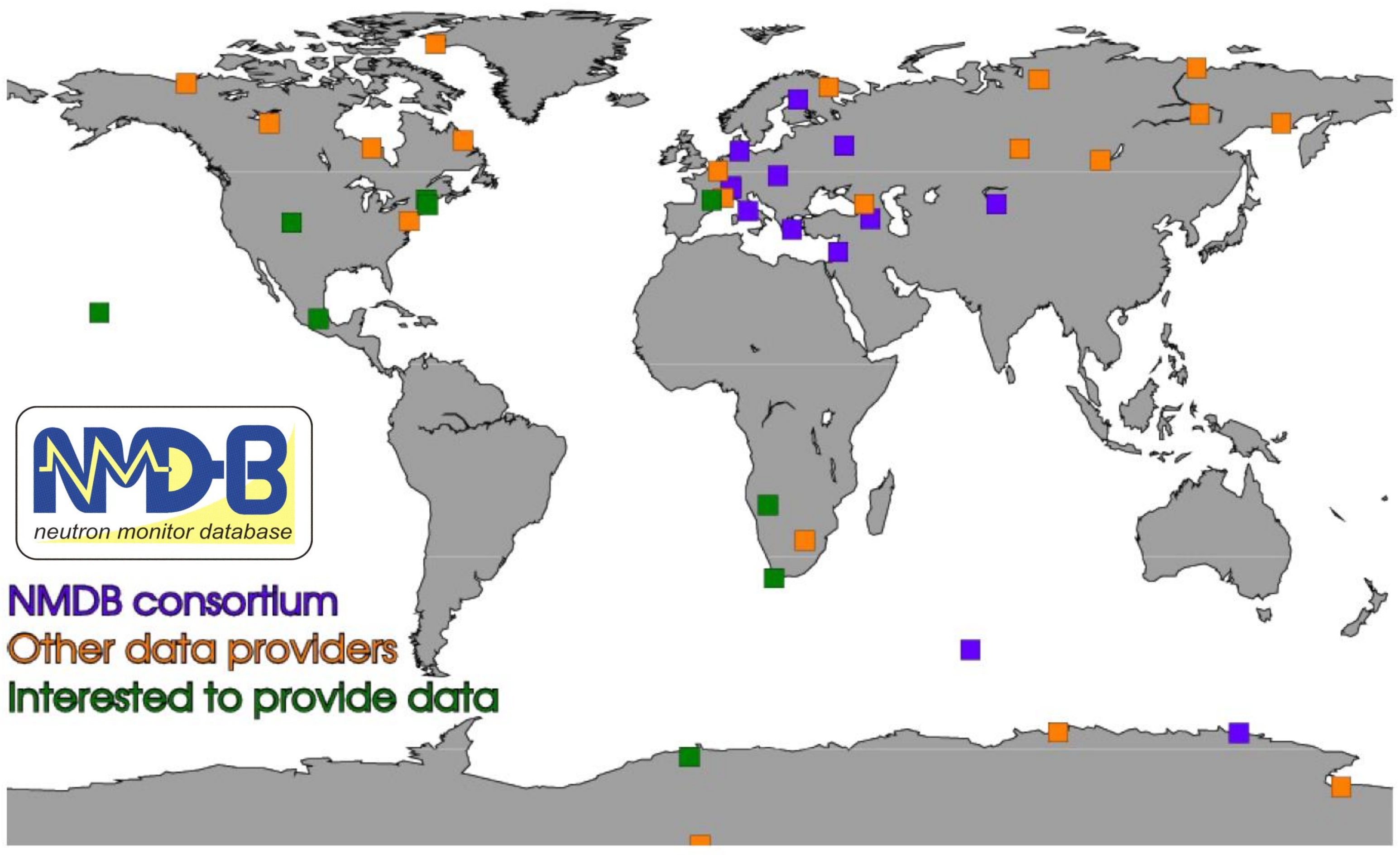

Figure 2. Worldwide distribution of the neutron monitor stations that provide data to NMDB and/or that will provide data to the database in the future (http://www.n,db.eu)

✓Today, more than 40 NMs from around the world participate to NMDB, making it the single access point for neutron monitor data.

European Neutron Monitor Service:

✓The Cosmic Ray group of the **At**hens **Ne**utron **Mo**nitor **S**tation (**A. Ne. Mo. S.**) at the National and Kapodistrian University of Athens with the contribution of the ISNet Company are working towards the establishment of a **European Neutron Monitor** Service that will be made available via the **ESA SSA SWE** portal. The **European Neutron Monitor** Service is intended to provide **[a]** Reliable and timely **GLE Alerts** and **[b]** Access to the **Neutron Monitor Data of Multiple Stations**

✓ The **ESA SSA SWE European Neutron Monitor** Service is building upon the infrastructure made available with the implementation of the **Neutron Monitor Database (NMDB)** .

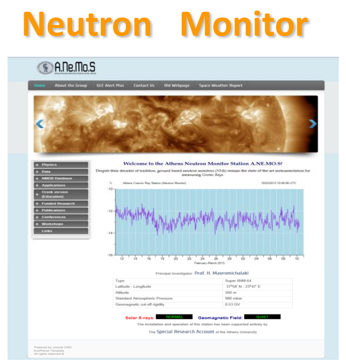

Figure 3. The new Athens Neutron Monitor Station (A. Ne. Mo. S.) Website @ http://cosray.phys.uoa.gr

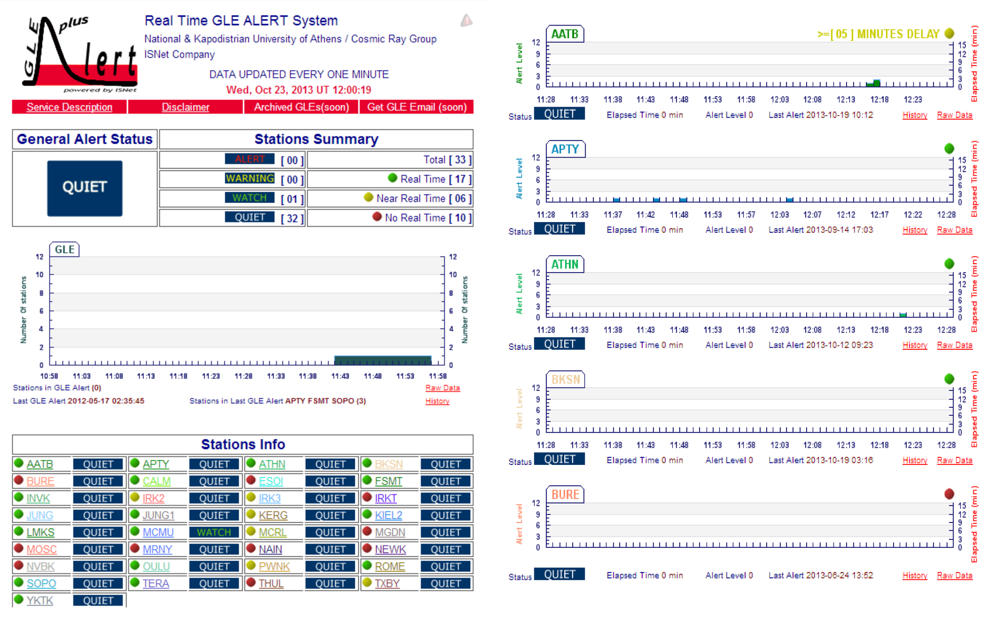

Figure 4. The Screenshot of the real time application GLE Alert Plus Website @ http://swe.ssa.esa.int/web/guest/anemos-federated

References:
> Kuwabara et al., Space Weather, 4, S10001, 2006
> Souvatzoglou et al., Adv. Space Res., 43, 728, 2009

Results:

[1] Availability of real-time neutron monitor data

✓How many minutes within the selected time frame (Jan-Aug 2013) a specific neutron monitor station was in **"Real-time"** mode, in **"Near real-time"** mode or in **"Non real-time"** mode, based on the rate with which the station provided data into NMDB.

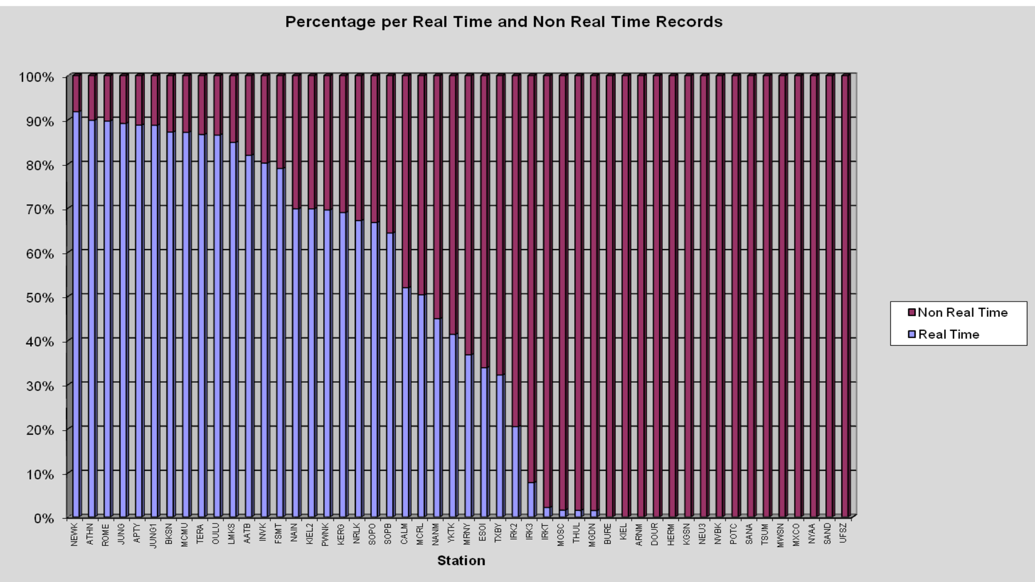

*Figure 5. Percentage per neutron monitor station per **real-time records***

[2] Data flow of a single neutron monitor

✓The data flow of the measurements is being defined as the time difference of the neutron monitor measurement clock to the clock of the GLE Alert Server. The smaller this time difference is the closer to the robust behavior of the neutron monitor station in terms of its data flow.

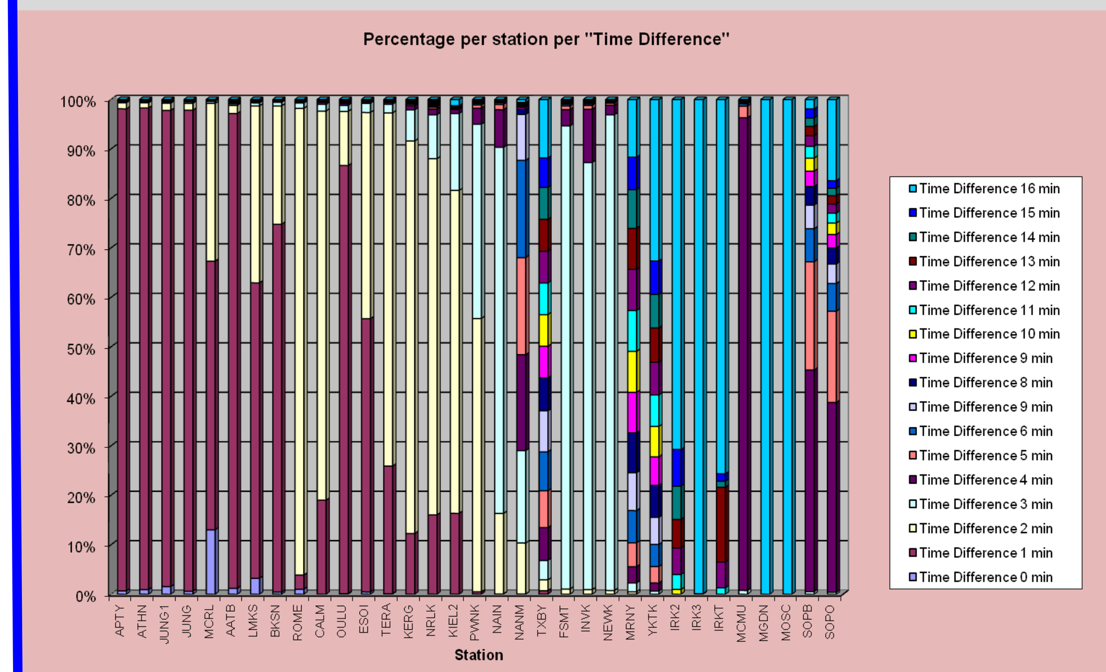

*Figure 6. Percentage per neutron monitor station per **Time-Difference***

[3] The need for the Go-Back-N algorithm

✓The basic advantage of **Go-Back-N** is that we define a time window within which the algorithm goes back N minutes in time in order to take into account delayed measurements of a specific NM station. The application of this algorithm leads to both the usage of plenty more data measurements of a single neutron monitor station and to the usage of more (previously discarded) neutron monitor stations into the establishment of a GLE Alert.

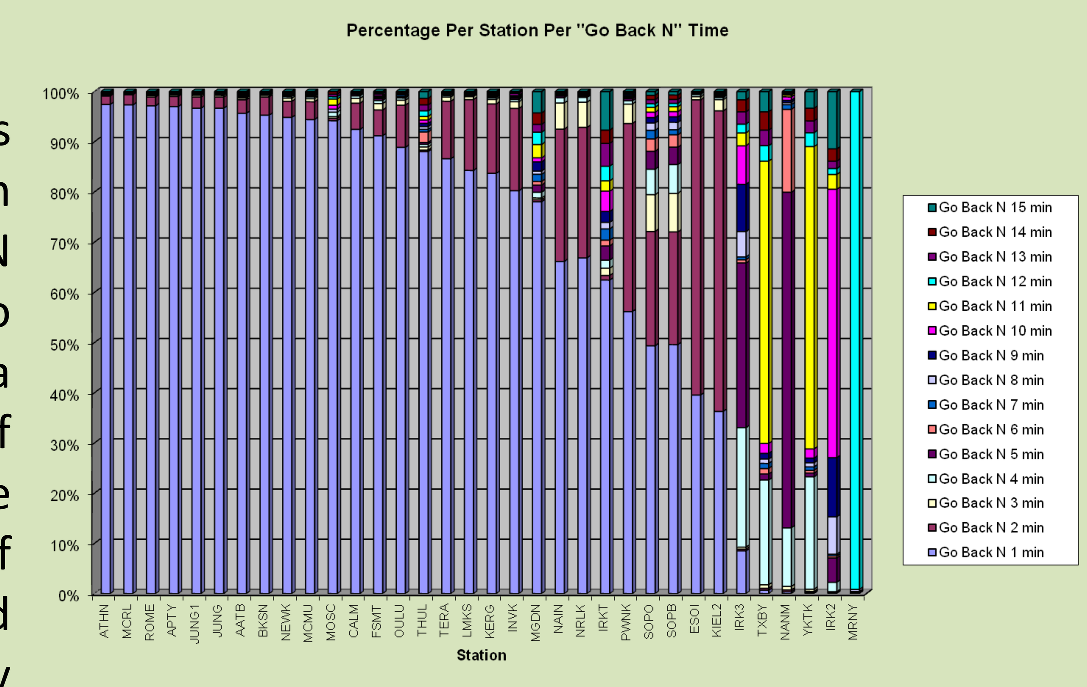

*Figure 7. Percentage per neutron monitor station per the need for the **Go-Back-N algorithm***

[4] Neutron Monitors that participated in the establishment of the GLE Alert

Neutron Monitor Stations

GLE No	59	60	61	62	63	64	65	66	67	68	69	70	71
Date	14.07.2000	15.4.2001	18.4.2001	4.11.2001	26.12.2001	24.8.2002	28.10.2003	29.10.2003	2.11.2003	17.1.2005	20.1.2005	13.12.2006	17.5.2012
NEWK												√	
ATHN													
ROME													
JUNG													
APTY	√	√	√		√	√	√		√		√	√	√
JUNG1													
BKSN													
MCMU											√	√	
TERA	√	√									√	√	
OULU	√	√	√		√		√		√		√	√	√
LMKS		√					√				√	√	
AATB		√									√		
INVK				√			√		√		√	√	
FSMT		√		√		√	√	√	√		√	√	√
NAIN		√	√		√	√					√	√	
KIEL2													√
PWNK		√		√		√			√			√	
KERG	√	√									√	√	
SOPO											√		√
CALM													
MCRL													
NANM													
YKTK											√	√	
MRNY													
ESOI													
TXBY											√		
IRK2													
IRK3													
IRKT													
MOSC	√	√	√				√				√	√	
THUL							√				√	√	
MGDN													
ARNM													
BURE													
DOUR													
KIEL	√	√	√				√	√			√	√	√
MXCO													
NVBK													
SANA													
TSUM													
UFSZ													
NRLK		√					√	√			√	√	
SOPB											√	√	√

✓Using the continuous measurements of NMs from **2000** to **2013 GLE Alert Plus** was able to spot ***all GLE events from GLE59 to GLE71, close to their actual onset/initiation***. It should be noted that NMDB is not complete in terms of archival data. Therefore we were obliged to use all records of NMDB plus data downloaded from other sources making one concatenated database of archival neutron monitor data including the whole NMDB

Table I. Neutron Monitors that participated in the establishment of the GLE Alert for each event from GLE59-GLE71

Conclusions:

○ Given the analysis that has been furnished further above, the assessment that has been based upon the availability of real-time data per station, its data flow in real-time mode, the need for the Go-Back-N algorithm (again in real-time mode) and the contribution to the establishment of a GLE Alert (based upon the archived data of the stations) underlined the fact that Neutron Monitor data are valuable for Space Weather Forecasting (i.e. establishing a timely GLE Alert) and that the underlying infrastructure (i.e. NMDB) leads to Space Weather Services (e.g. European Neutron Monitor Service).

○ GLE Alert Plus is in need of high cadence real-time data send to NMDB, in order to issue a reliable and timely alert.

10TH EUROPEAN SPACE WEATHER WEEK 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 NOVEMBER 18-22 2013, ANTWERP, BELGIUM

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