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The updated GLE Alert system by ANEMOS

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Abstract

Ground level enhancements (GLEs) of cosmic radiation are the result of solar energetic particles (SEPs) arriving at the Earth, potentially causing major damage to technological systems, but also posing a threat for human health. Intense SEPs, such as the GLE events, can influence the radiation exposure of aircrafts and consequently increase the radiation dose on human crew, but also have an impact on satellites and affect the design of space missions, i.e electronic devices onboard the satellite platforms etc. Therefore, predicting such events is challenging and one of the most important aspects of space weather research. In this work the updated GLE Alert++ System of the Athens Neutron Monitor Station (A.Ne.Mo.S.) implemented by the Athens Cosmic Ray Group of the National and Kapodistrian University of Athens (NKUA) is being presented. Moreover, the innovations of the updated system in relation to the previous version of the GLE Alert Plus are introduced. Finally, the most recent and the first of solar cycle 25 GLE event, GLE73, is discussed. This event was registered by several stations of the worldwide ground-based neutron monitor network. An accurate alert was issued successfully by the ESA R-ESC federated product GLE Alert Plus, as well as by the updated GLE Alert++ System of the NKUA/A.Ne.Mo.S. It should be emphasized that GLE Alert++ signal by NKUA/A.Ne.Mo.S. was issued 45 minutes earlier than the one issued by GOES satellites.

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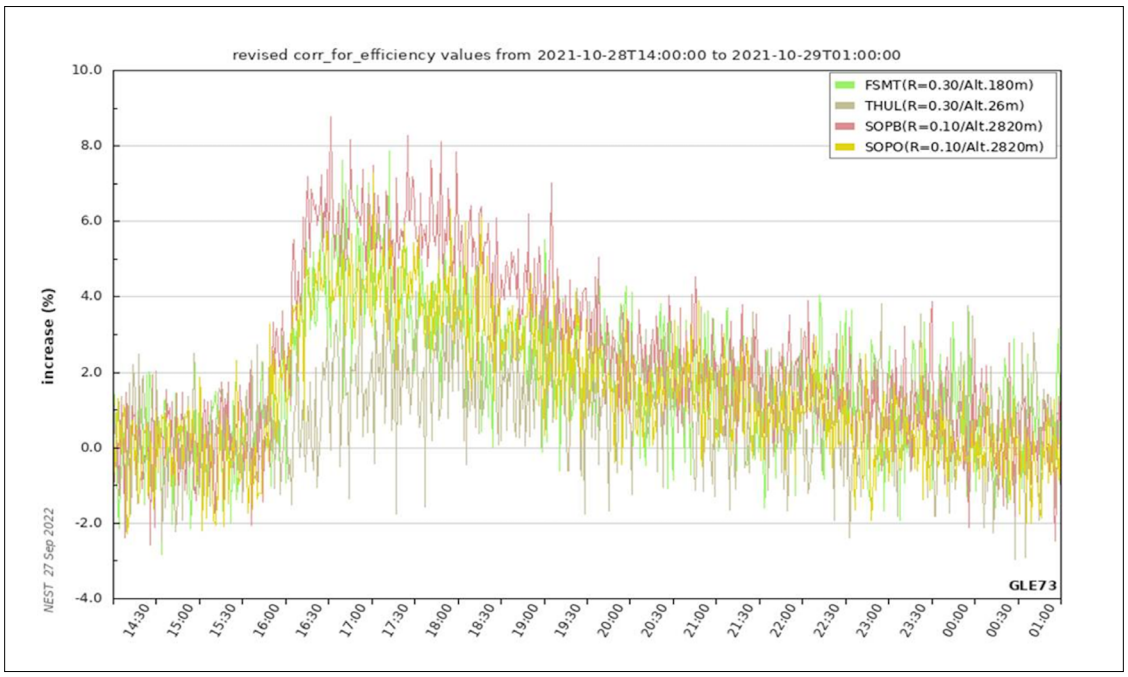

Fig. 1: The GLE73 as registered by a few neutron monitors (https://www.nmdb.eu/nest/draw_graph.php).

1. Introduction

A GLE of cosmic rays is the result of solar cosmic rays (with proton energies above 500 MeV) arriving at the Earth. It is observed as an abrupt and sharp increase in the counting rate of ground-based cosmic ray detectors and lasts several hours (Mavromichalaki et al. 2007; Anashin et al. 2009; Souvatzoglou et al. 2014) (Fig. 1).

In other words, GLEs are recorded when specific solar processes accelerate charged particles to energies high enough to be detectable by neutron monitors (NMs) or other particle detectors on the Earth (http://www.nmdb.eu; http://www.wdcb.ru/stp/cosmic_rays/gle.html; https://gle.oulu.fi/#/). Since these particles can possibly create a major problem (Mariatos et al. 2005) in microelectronic systems for satellites, spacecraft and airplanes, and biological effects on astronauts and air crews (Dorman et al. 2004; Souvatzoglou et al. 2009; 2014; Kuwabara et al. 2006), developing real-time warning systems using the neutron monitor network (http://www.nmdb.eu) is really important and useful.

2. Evolution of the GLE Alert system

An algorithm capable of predicting the onset of a GLE and providing an alert is created by the Athens Cosmic Ray Group. The first real-time GLE Alert system was installed and operated by Athens Neutron Monitor Data Processing (ANMODAP) Center of the Physics Department of NKUA in 2003 and was described in Mariatos et al. (2005) and Souvatzoglou et al. (2009). A few years later, in 2010, the GLE Alert system was installed and operated in the Neutron Monitor Database (NMDB) (Mavromichalaki et al. 2010).

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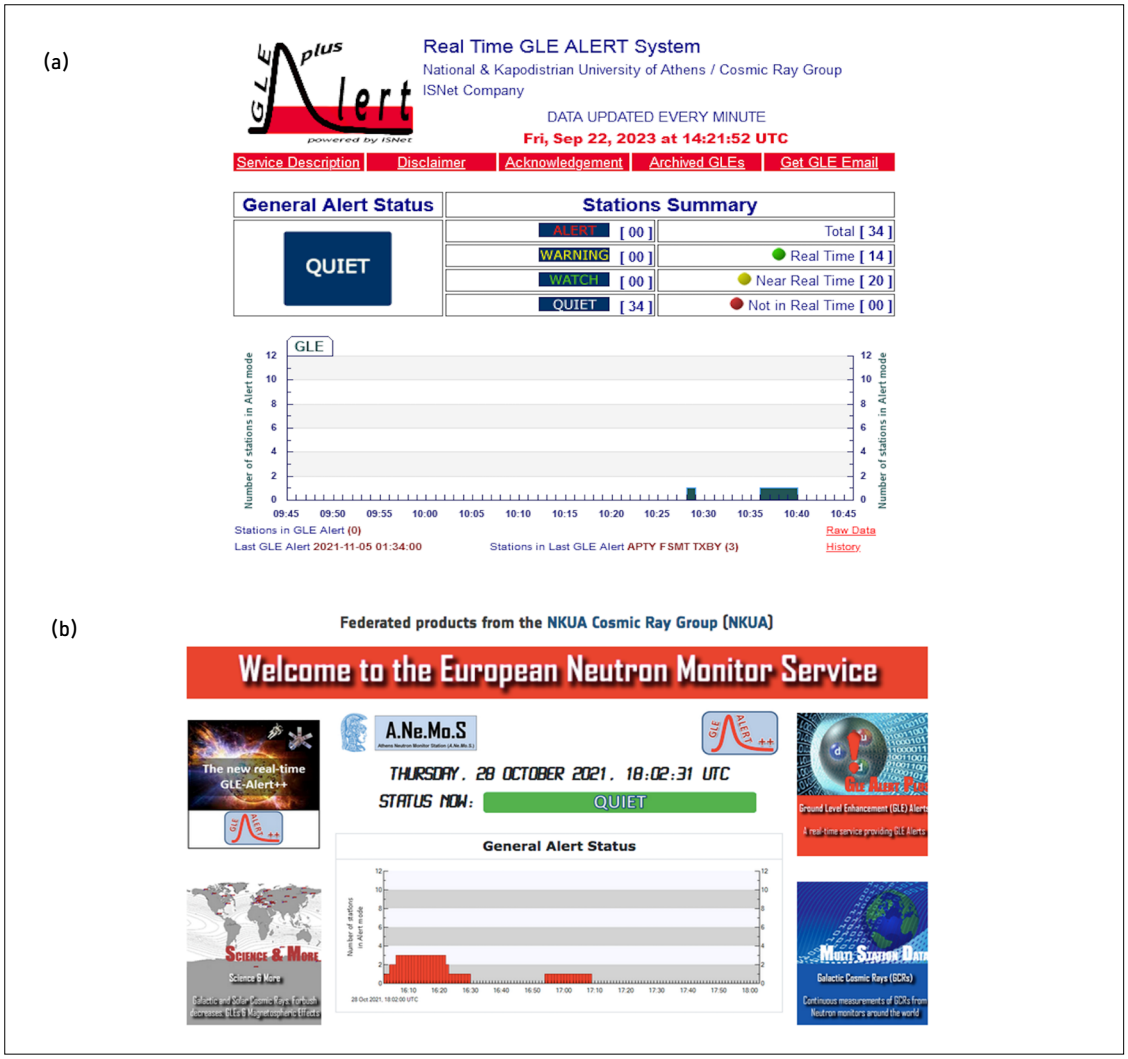

Fig. 2: (a) The previous version: GLE Alert Plus System and (b) the current version: GLE Alert++ System (https://swe.ssa.esa.int/anemos-federated).

GLE Alert Plus is an improved version of the previous alert system in the frame of European Space Agency (ESA) SSA P2-VIII project, operating from 2013 until now (Fig. 2). GLE Alert Plus system is developed by ISNet, uses neutron monitor data from NMDB database and is supported by NKUA and ESA. The improvements of this software are described in Souvatzoglou et al. (2014).

In 2021, an updated version of the GLE Alert Plus, GLE ALERT ++, was installed by the Athens Cosmic Ray Group and evaluated by ESA and is now operated at ESA Website (Fig. 2b). This system produces every minute a General Alert Status and station graph and status for every station participating in the network (https://swe.ssa.esa.int/anemos-federated).

The main core of the GLE Alert System is presented in Figure 3. As it is shown, each neutron monitor is treated separately by the GLE Alert and the general alert status is issued according to the number of stations in alert mode. However, a more extensive description of the physical concept as well as the applied algorithm are included in Mavromichalaki et al. (2010), Souvatzoglou et al. (2014), Mavromichalaki et al. (2018) and Mavromichalaki et al. (2022).

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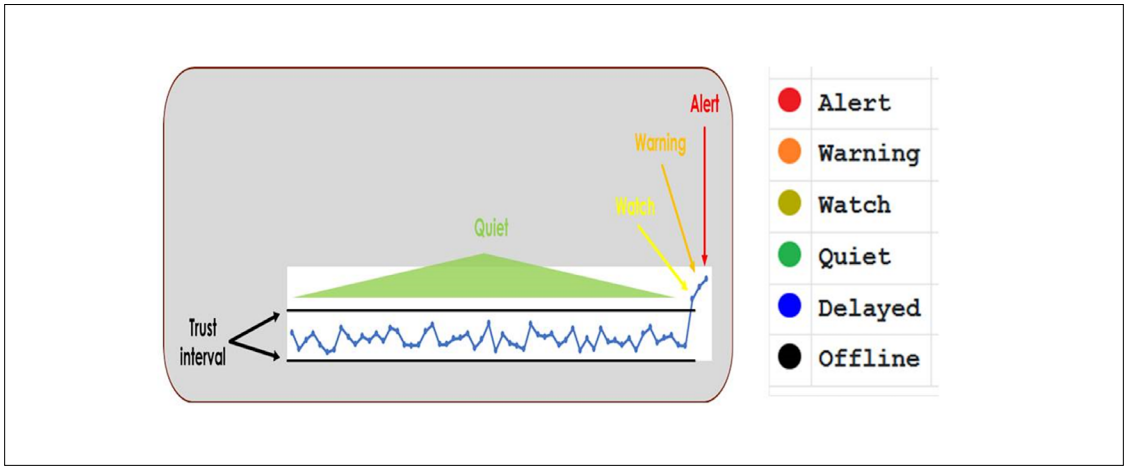

Fig. 3: GLE Alert treats each NM station separately and defines the station status. Depending on the number of stations in alert mode, GLE Alert defines the corresponding general alert status.

3. The GLE Alert ++ system

In the following a small description of the innovations in this upgraded version of the GLE Alert is presented. They refer not only to functionality but also to the web interface. Regarding functionality, the novelties are:

- Lightweight architecture that makes the process of raising an Alert faster, while at the same time the data are available in real- or near real- time.
- mySQL databases to store the one-minute measurements of the stations and the webpage content.
- SQL databases to store the GLE Alert algorithm data in daily base preventing the generation of huge databases.
- Full parameterization regarding the interface.
- Execution of the algorithm for all NM stations in only 3-4 seconds.
- Keeping history data to reproduce any past condition.

Regarding the web interface, the novelties are:

- A more user-friendly interface
- The alert status extended to a 2-hour timeslot
- Providing graphs for each NM station
- Making available raw and history data
- Providing data in CSV format

Moreover, regarding the web interface the 4 levels of real-time status have remained as in the previous version (Quiet: number of stations in ›Station Alert‹ mode = 0; Watch: number of stations in ›Station Alert‹ mode = 1; Warning: number of stations in ›Station Alert‹ mode = 2; Alert: number of stations in ›Station Alert‹ mode > 3) as is shown in Figure 4.

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SERVER TIMESTAMP	STATIONS TIMESTAMP	STATIONS COUNT	STATIONS NAMES	GLE STATUS
2022-09-29 11:00:02	2022-09-29 09:00:00	0		QUIET
2022-09-29 11:00:02	2022-09-29 09:01:00	0		QUIET
2022-09-29 11:00:02	2022-09-29 09:02:00	0		QUIET
2022-09-29 11:00:02	2022-09-29 09:03:00	0		QUIET
2022-09-29 11:00:02	2022-09-29 09:04:00	0		QUIET
2022-09-29 11:00:02	2022-09-29 09:05:00	0		QUIET
2022-09-29 11:00:02	2022-09-29 09:06:00	0		QUIET
2022-09-29 11:00:02	2022-09-29 09:07:00	0		QUIET
2022-09-29 11:00:02	2022-09-29 09:08:00	0		QUIET
2022-09-29 11:00:02	2022-09-29 09:09:00	0		QUIET
2022-09-29 11:00:02	2022-09-29 09:10:00	0		QUIET
2022-09-29 11:00:02	2022-09-29 09:11:00	0		QUIET
2022-09-29 11:00:02	2022-09-29 09:12:00	0		QUIET
2022-09-29 11:00:02	2022-09-29 09:13:00	0		QUIET
2022-09-29 11:00:02	2022-09-29 09:14:00	0		QUIET
2022-09-29 11:00:02	2022-09-29 09:15:00	0		QUIET
2022-09-29 11:00:02	2022-09-29 09:16:00	0		QUIET

Fig. 4 : (a) The station status of the NMs used in the GLE Alert ++ interface and (b) the corresponding history data.

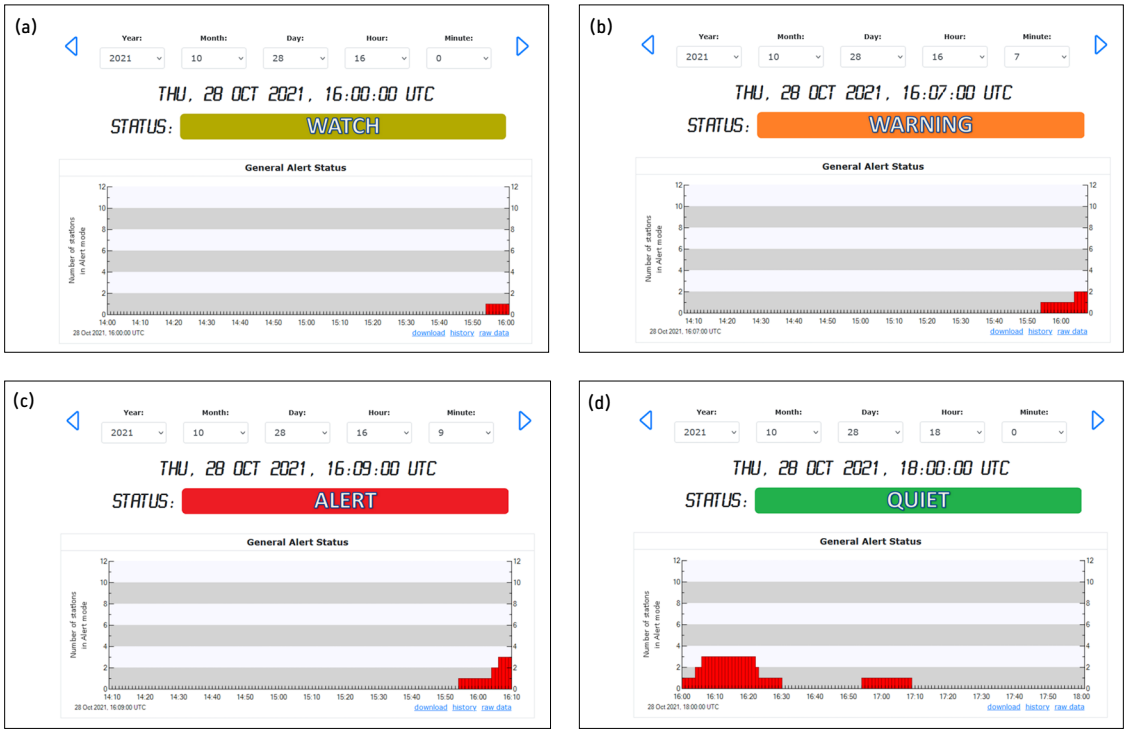

Fig. 5: The evolution of the GLE73 by the GLE Alert ++ system.

4. The first GLE Alert notification

GLE73 was detected on 28 October 2021 and was associated with the active region AR12887 on the central part of the solar disk, which produced an X1.0 solar flare. The event was registered by several stations of the worldwide ground-based neutron monitor network. The three stations that triggered the alert were Fort Smith (FSMT) Canada, South Pole Bares (SOPB), Antarctica and South Pole (SOPO) Antarctica. An accurate alert was issued successfully by the ESA R-ESC federated product GLE Alert Plus, as well as the updated GLE Alert++ System of the A.Ne.Mo.S. An overview of GLE73, the first of

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solar cycle 25, as well as a post-event analysis is presented in Papaioannou et al. (2022) and in Mavromichalaki et al. (2022).

The GLE Alert ++ application produced an email notification that was sent to all subscribed users on 28 October 2021 at 16:09 UT. The GLE Alert ++ signal by NKUA/A.Ne.Mo.S. was issued 45 min earlier than the one issued by GOES. In Figure 5 the evolution of GLE73 by the GLE Alert ++ point of view is being presented.

5. Conclusions

Summarizing it can be claimed that the neutron monitors continue to be the state of the art instrumentation and a unique asset for Space Weather predictions and applications. Both of the GLE Alert Plus, as well as the updated GLE Alert ++, detected recently the first GLE of solar cycle 25, i.e. GLE73 on 28 October 2021, in real time, sending notification emails to the registered users. It should be highlighted that forecasting of the upcoming energetic particles by GLE Alert ++ precedes the alerts based on satellites' data. As it was also mentioned above, many novelties of the upgraded GLE ALERT ++ concerning the functionality as well as the web interface will help to its continuous and uninterrupted operation, providing accurate and timely signals.

Furthermore, it is underlined that the GLE Alert ++ service needs timely and reliable real time data. For this reason the need for recording assessment and a real time assessment index of data provided by the neutron monitor community is crucial for the cosmic ray studies. The assessment of the real-time availability of the NM data has to be repeated periodically, in order to update the set of the NMs used in GLE Alert ++. It is necessary, as operating issues of the stations could be raised. The next step is to incorporate to this updated system satellite data in order to avoid possible false alerts.

Acknowledgements

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