GLE alert and afterwards?

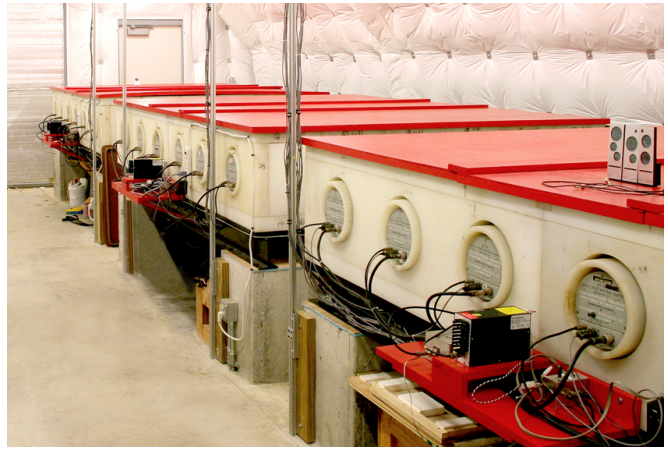
Rolf Bütikofer, Erwin Flückiger, Lukas Bäni

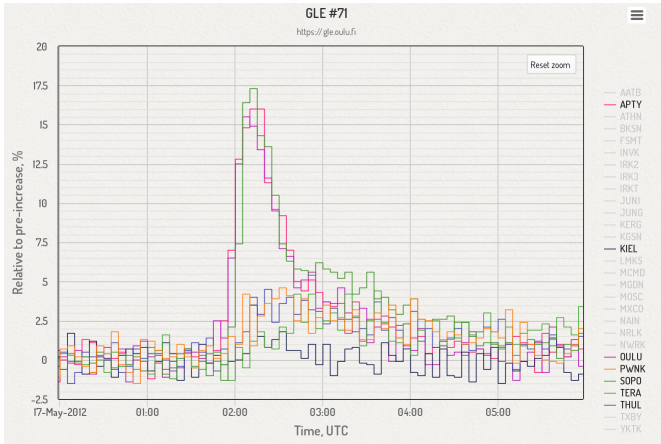
Physics Intitute, University of Bern, Switzerland

NMDB meeting, 19-21 March 2025, Athens, Greece

What information can be received from neutron monitor measurements

- Information about the spectrum of CRs near Earth in energy range from $\sim$**500 MeV to** $\sim$**15 GeV**
- Minimal proton energy to be detected by NMs at polar regions and at high altitude: $\sim$**300 MeV**
- NM stations “looking in different directions” $\rightarrow$ information about **anisotropy of CR**
- **1 minute data**, i.e. time variations of CR intensity in the range of minutes can be investigated





From GLE data base http://gle.oulu.fi/

NMs and NMDB

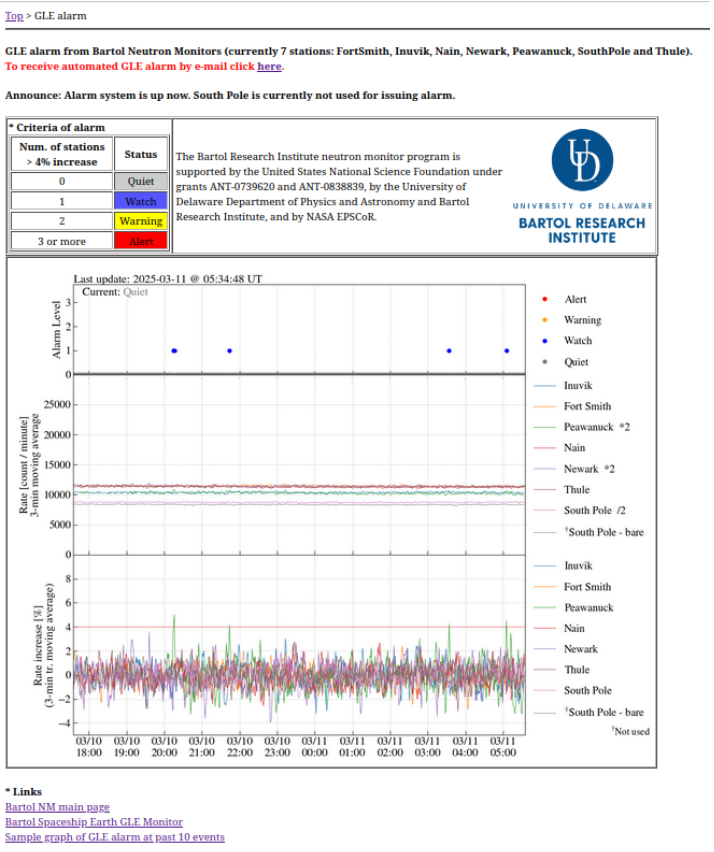
- Worldwide network of standardised NMs
- About 50 NM stations in operation
- Many NM stations send data to NMDB, $\sim$**25 in real-time**

www.nmdb.eu

$\Rightarrow$ **GLE alarm applications**

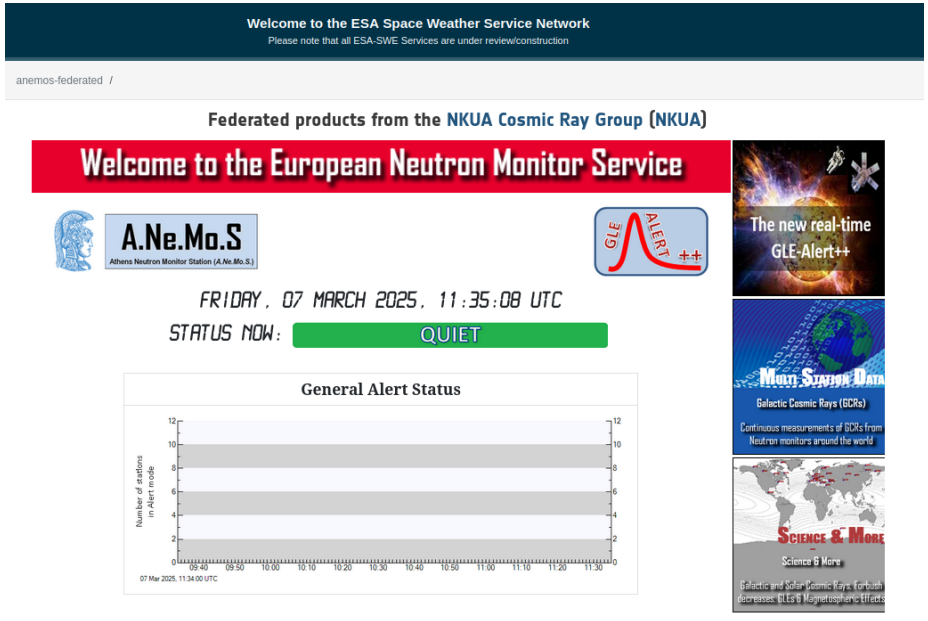
GLE alarm systems

GLE alarm from Bartol research institute



www.bartol.udel.edu/∼mangeard/glealarm/index.html

Athens Real Time GLE ALERT System



https://swe.ssa.esa.int/anemos-federated

User registration to get GLE alarm

Bartol system

Top > GLE alarm

GLE alarm from Bartol Neutron Monitors (currently 8 stations: FortSmit
To receive automated GLE alarm by e-mail click here.

Announce: Alarm system is up now. South Pole and Thule station are cur

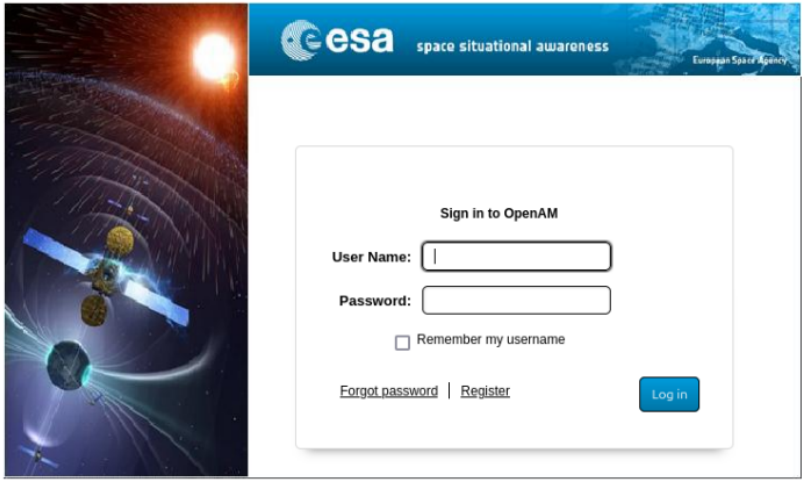
*** Criteria of alarm**

Num. of stations > 4% increase	Status
0	Quiet

Delaware Cen

Athens system

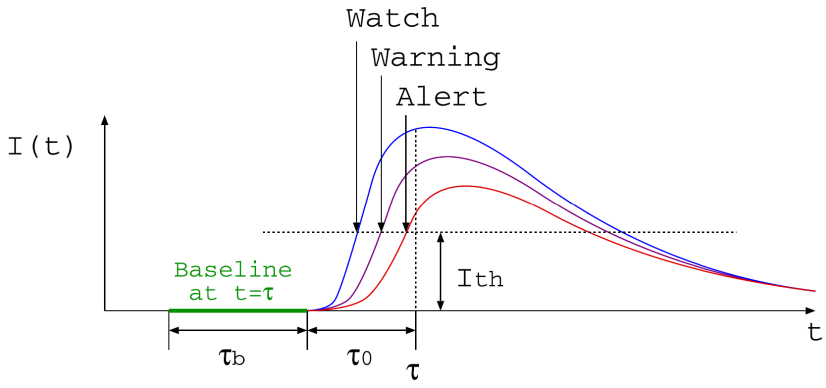
Federated products from the NKUA Cosmic Ray Group (NKUA)



If GLE occurs ⇒ Notification by e-mail in both systems

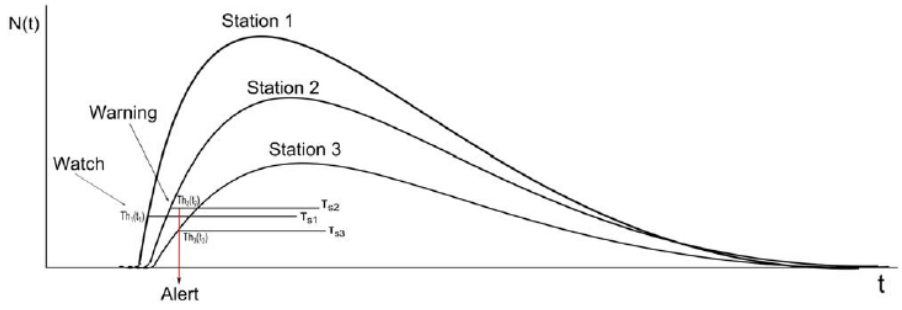
Procedure of GLE alert system

Bartol system



Kuwabara et al, 2006

Athens system



Souvatzoglou et al., 2014

NM data used for GLE alert application

Bartol system

NM stations of Spaceship Earth (currently FSMT, INVK, NAIN, NEWK, PWNK, SOPO, THUL)

Only NM stations at **high geomagnetic latitudes**

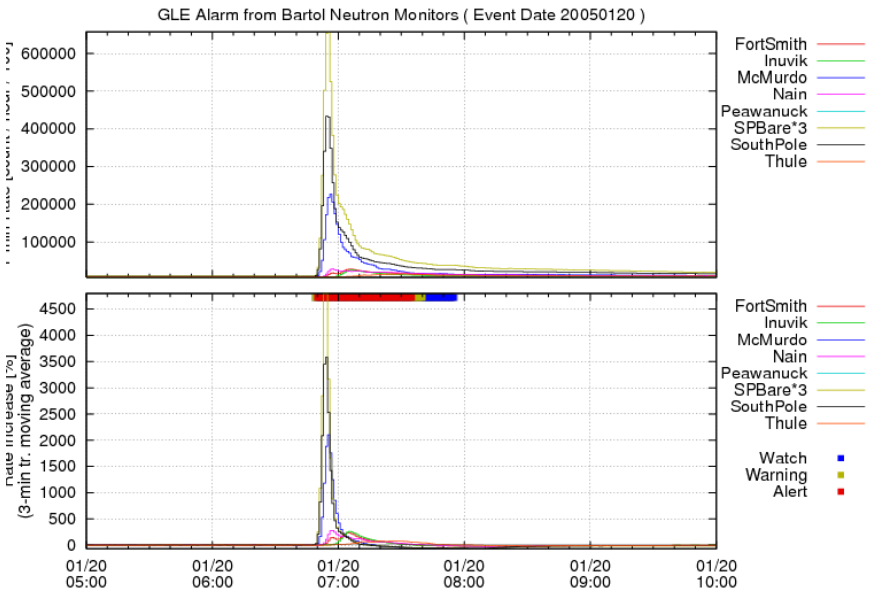
Athens system

All NM stations available in near real-time from NMDB

NM stations at **all geomagnetic latitudes**

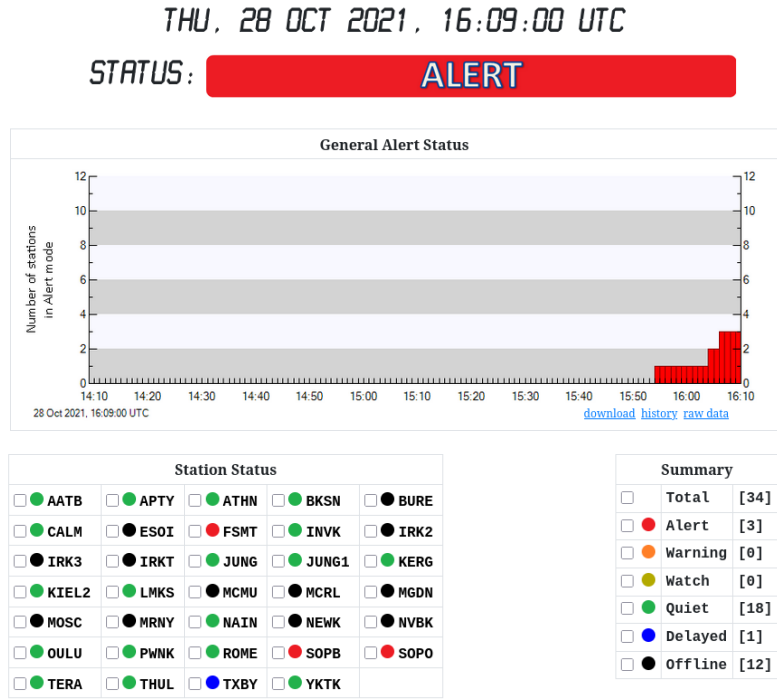
Webpage GLE alarm occurence

Bartol system



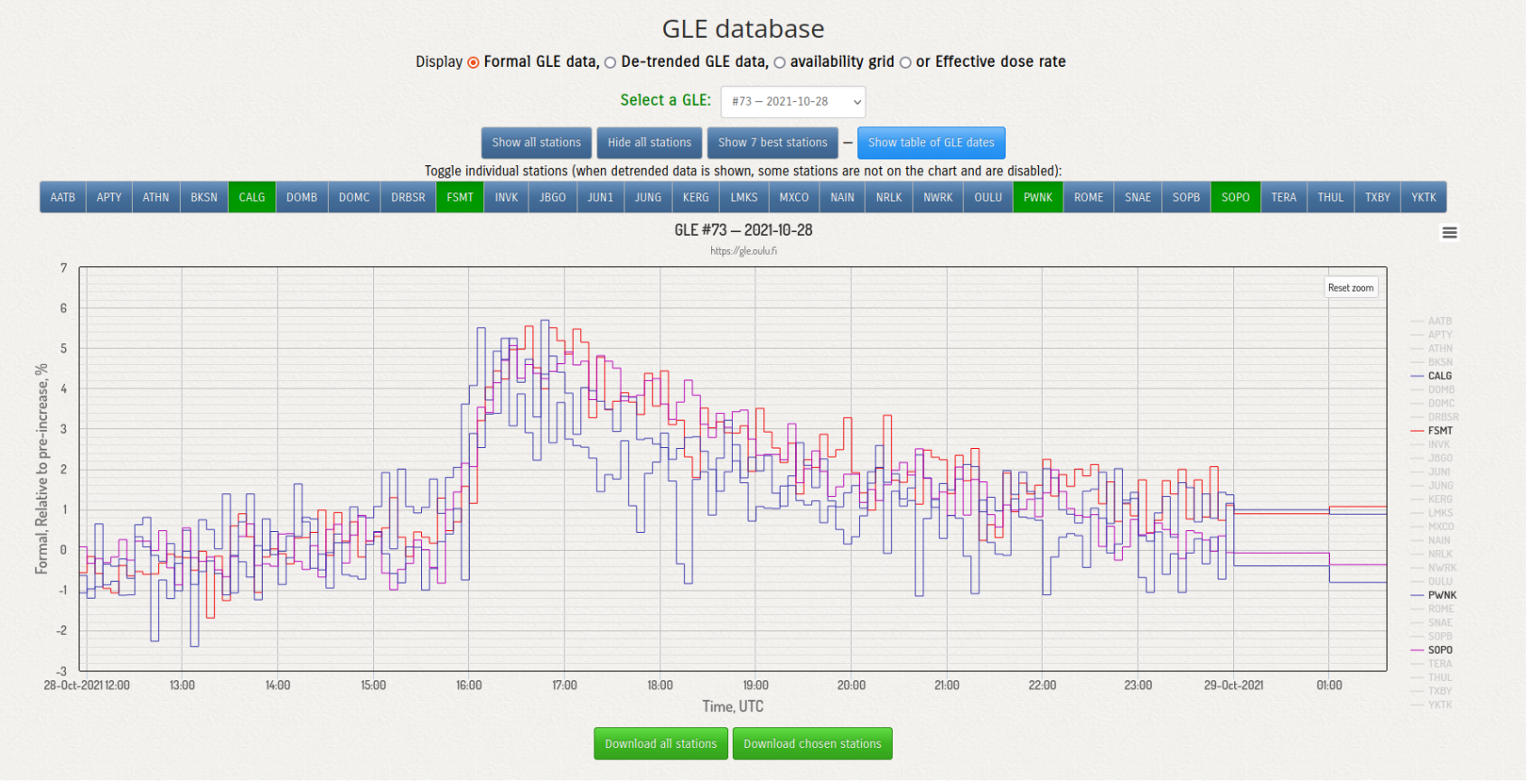
GLE#69 on 20 January 2005

Athens system



GLE#73 on 28 October 2021

GLE#73: 2021-10-28



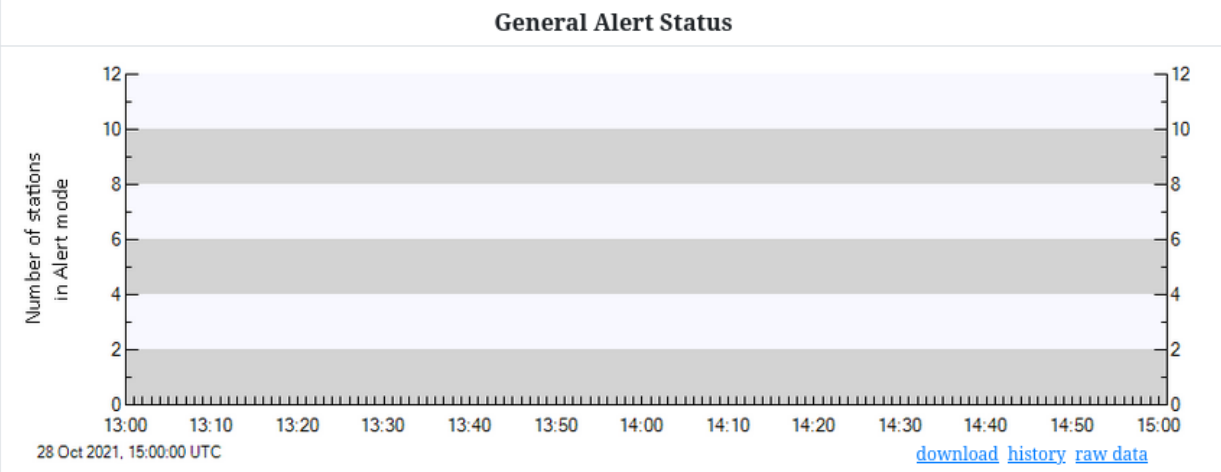
GLE data base, https://gle.oulu.fi/

Time from onset to peak: almost one hour → gradual GLE

Athens during GLE#73 on 2021-10-28

THU, 28 OCT 2021, 15:00:00 UTC

STATUS: QUIET



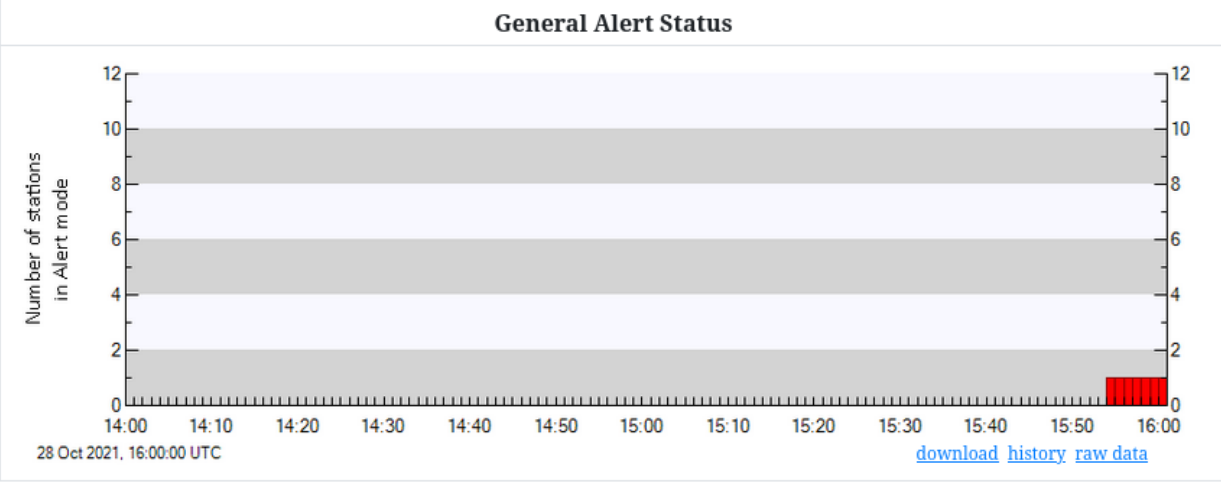
Station Status				
AATB	APTY	ATHN	BKSN	BURE
CALM	ESOI	FSMT	INVK	IRK2
IRK3	IRKT	JUNG	JUNG1	KERG
KIEL2	LMKS	MCMU	MCRL	MGDN
MOSC	MRNY	NAIN	NEWK	NVBK
OULU	PWNK	ROME	SOPB	SOPO
TERA	THUL	TXBY	YKTK	

Summary	
Total	[34]
Alert	[0]
Warning	[0]
Watch	[2]
Quiet	[20]
Delayed	[1]
Offline	[11]

Athens during GLE#73 on 2021-10-28

THU, 28 OCT 2021, 16:00:00 UTC

STATUS: WATCH



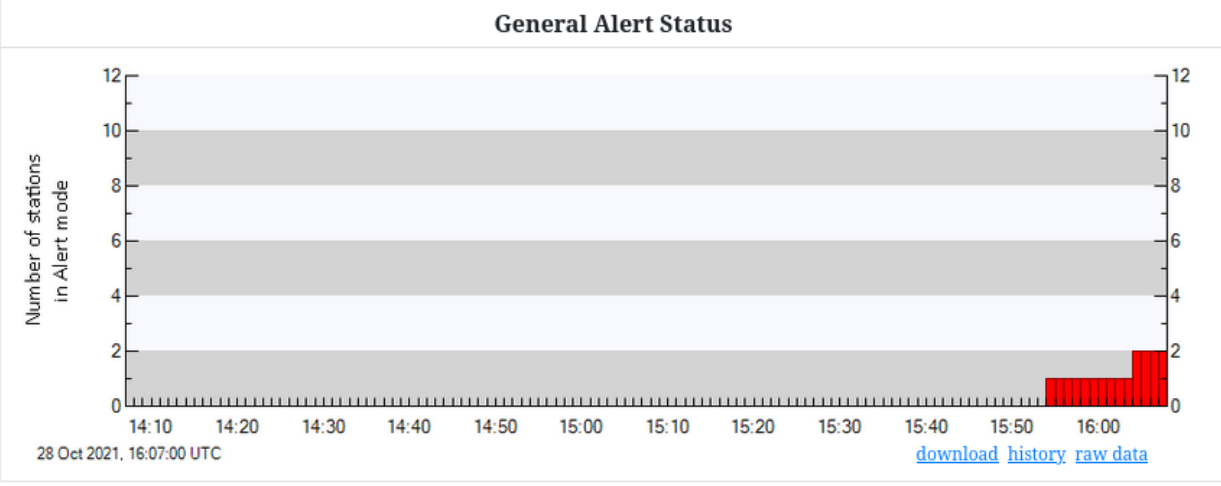
Station Status				
AATB	APTY	ATHN	BKSN	BURE
CALM	ESOI	FSMT	INVK	IRK2
IRK3	IRKT	JUNG	JUNG1	KERG
KIEL2	LMKS	MCMU	MCRL	MGDN
MOSC	MRNY	NAIN	NEWK	NVBK
OULU	PWNK	ROME	SOPB	SOPO
TERA	THUL	TXBY	YKTK	

Summary	
Total	[34]
Alert	[1]
Warning	[0]
Watch	[0]
Quiet	[21]
Delayed	[0]
Offline	[12]

Athens during GLE#73 on 2021-10-28

THU, 28 OCT 2021, 16:07:00 UTC

STATUS: WARNING



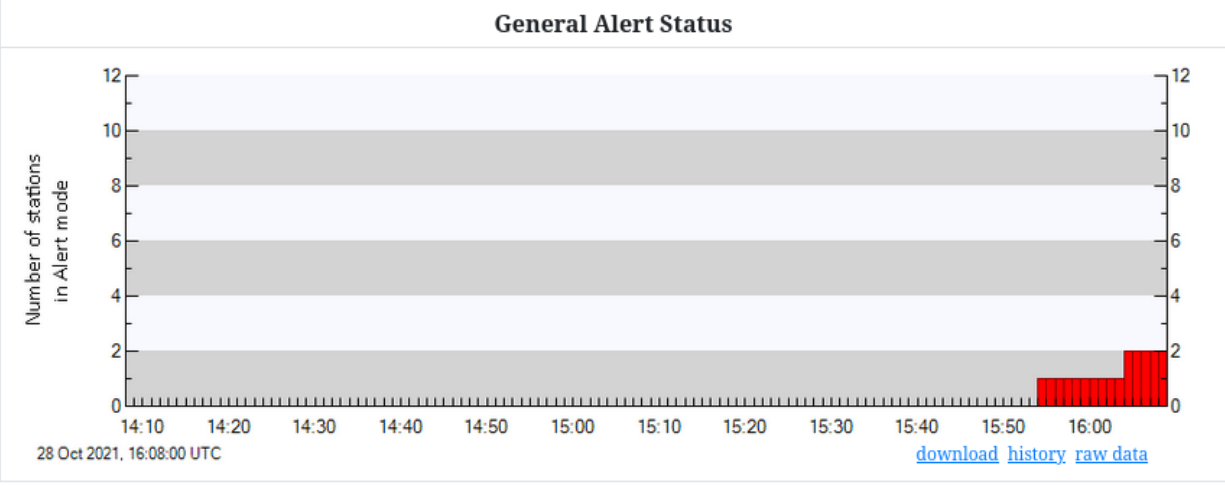
Station Status				
AATB	APTY	ATHN	BKSN	BURE
CALM	ESOI	FSMT	INVK	IRK2
IRK3	IRKT	JUNG	JUNG1	KERG
KIEL2	LMKS	MCMU	MCRL	MGDN
MOSC	MRNY	NAIN	NEWK	NVBK
OULU	PWNK	ROME	SOPB	SOPO
TERA	THUL	TXBY	YKTK	

Summary	
Total	[34]
Alert	[2]
Warning	[0]
Watch	[1]
Quiet	[19]
Delayed	[0]
Offline	[12]

Athens during GLE#73 on 2021-10-28

THU, 28 OCT 2021, 16:08:00 UTC

STATUS: WARNING



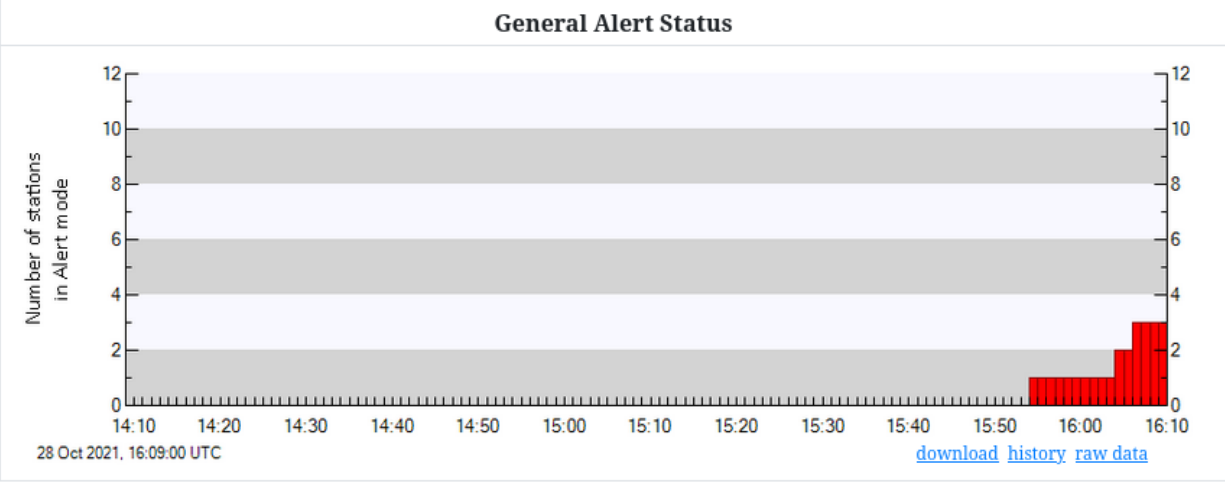
Station Status				
AATB	APTY	ATHN	BKSN	BURE
CALM	ESOI	FSMT	INVK	IRK2
IRK3	IRKT	JUNG	JUNG1	KERG
KIEL2	LMKS	MCMU	MCRL	MGDN
MOSC	MRNY	NAIN	NEWK	NVBK
OULU	PWNK	ROME	SOPB	SOPO
TERA	THUL	TXBY	YKTK	

Summary	
Total	[34]
Alert	[2]
Warning	[0]
Watch	[2]
Quiet	[18]
Delayed	[0]
Offline	[12]

Athens during GLE#73 on 2021-10-28

THU, 28 OCT 2021, 16:09:00 UTC

STATUS: ALERT



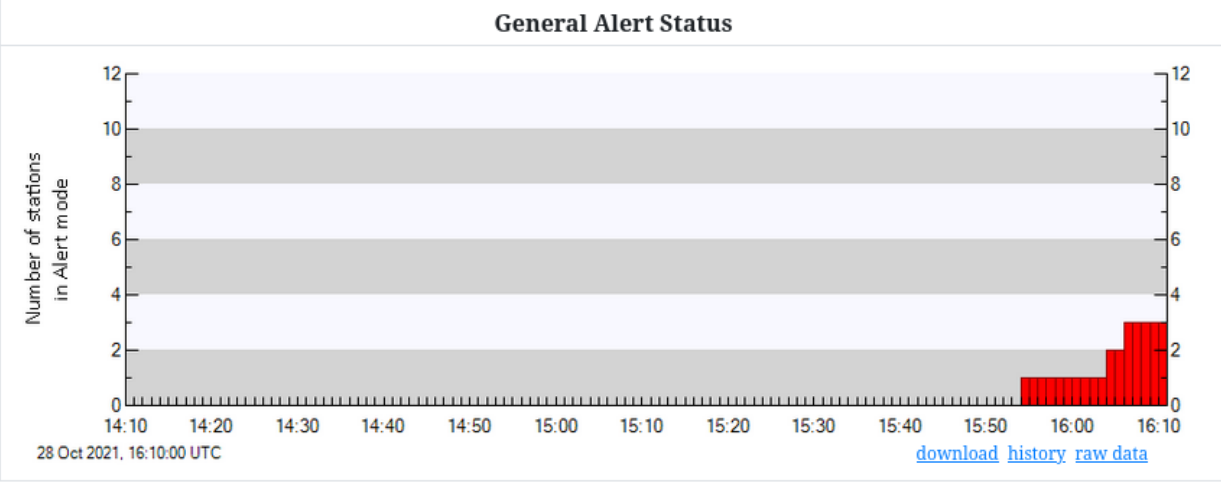
Station Status				
AATB	APTY	ATHN	BKSN	BURE
CALM	ESOI	FSMT	INVK	IRK2
IRK3	IRKT	JUNG	JUNG1	KERG
KIEL2	LMKS	MCMU	MCRL	MGDN
MOSC	MRNY	NAIN	NEWK	NVBK
OULU	PWNK	ROME	SOPB	SOPO
TERA	THUL	TXBY	YKTK	

Summary	
Total	[34]
Alert	[3]
Warning	[0]
Watch	[0]
Quiet	[18]
Delayed	[1]
Offline	[12]

Athens during GLE#73 on 2021-10-28

THU, 28 OCT 2021, 16:10:00 UTC

STATUS: ALERT



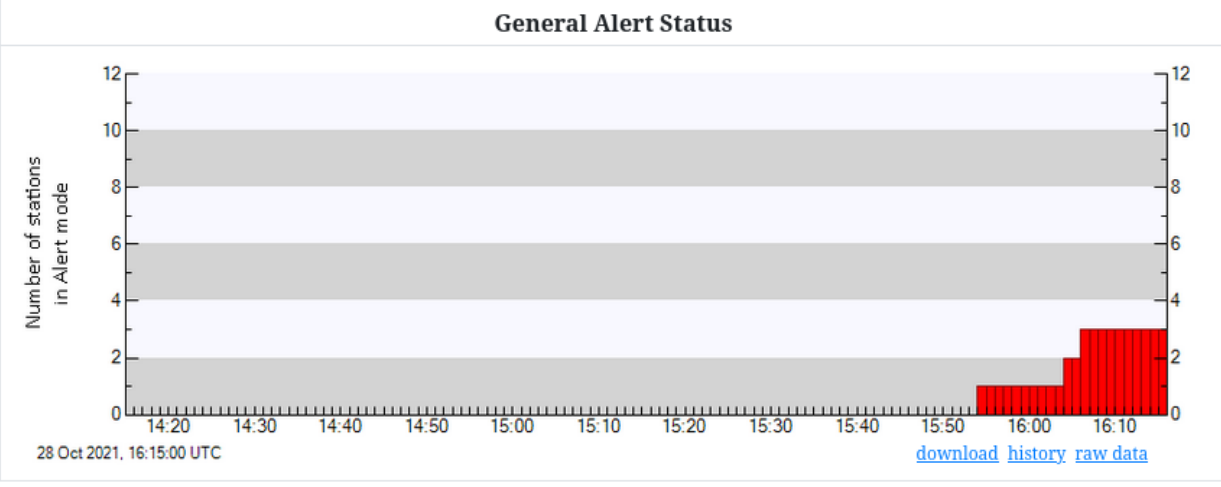
Station Status				
AATB	APTY	ATHN	BKSN	BURE
CALM	ESOI	FSMT	INVK	IRK2
IRK3	IRKT	JUNG	JUNG1	KERG
KIEL2	LMKS	MCMU	MCRL	MGDN
MOSC	MRNY	NAIN	NEWK	NVBK
OULU	PWNK	ROME	SOPB	SOPO
TERA	THUL	TXBY	YKTK	

Summary	
Total	[34]
Alert	[3]
Warning	[0]
Watch	[1]
Quiet	[16]
Delayed	[2]
Offline	[12]

Athens during GLE#73 on 2021-10-28

THU, 28 OCT 2021, 16:15:00 UTC

STATUS: ALERT



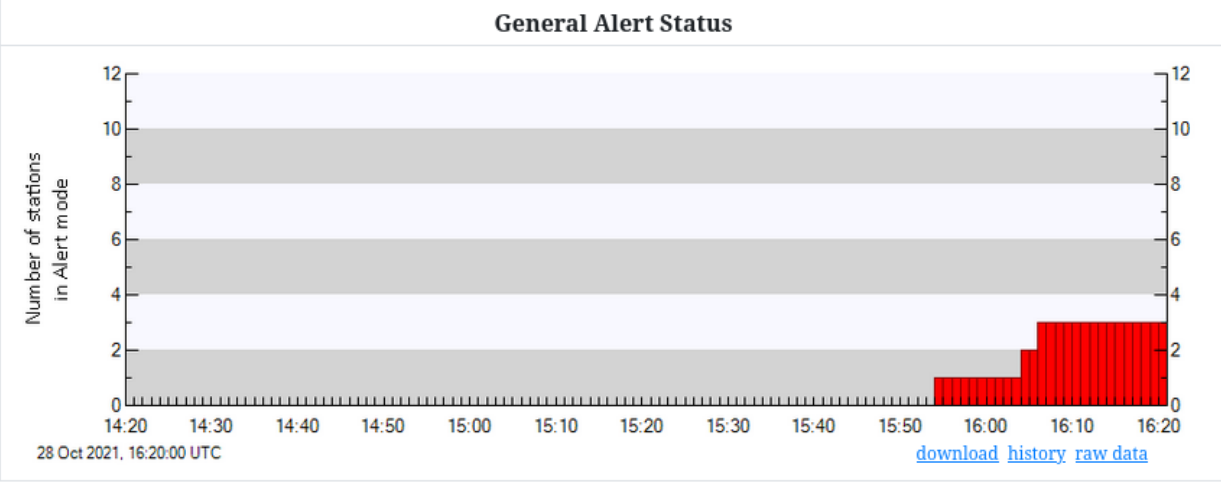
Station Status				
AATB	APTY	ATHN	BKSN	BURE
CALM	ESOI	FSMT	INVK	IRK2
IRK3	IRKT	JUNG	JUNG1	KERG
KIEL2	LMKS	MCMU	MCRL	MGDN
MOSC	MRNY	NAIN	NEWK	NVBK
OULU	PWNK	ROME	SOPB	SOPO
TERA	THUL	TXBY	YKTK	

Summary	
Total	[34]
Alert	[3]
Warning	[0]
Watch	[1]
Quiet	[18]
Delayed	[0]
Offline	[12]

Athens during GLE#73 on 2021-10-28

THU, 28 OCT 2021, 16:20:00 UTC

STATUS: ALERT



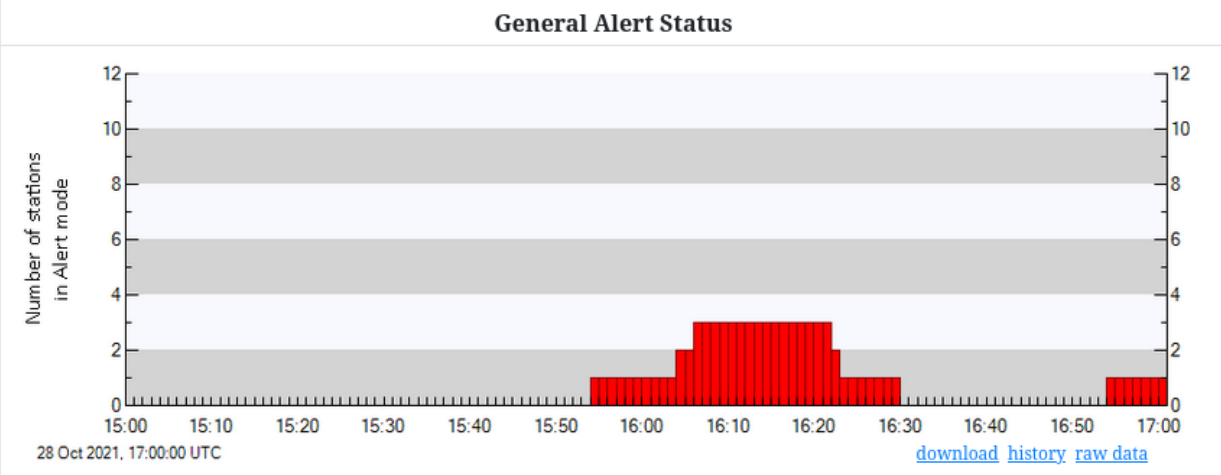
Station Status				
AATB	APTY	ATHN	BKSN	BURE
CALM	ESOI	FSMT	INVK	IRK2
IRK3	IRKT	JUNG	JUNG1	KERG
KIEL2	LMKS	MCMU	MCRL	MGDN
MOSC	MRNY	NAIN	NEWK	NVBK
OULU	PWNK	ROME	SOPB	SOPO
TERA	THUL	TXBY	YKTK	

Summary	
Total	[34]
Alert	[3]
Warning	[0]
Watch	[1]
Quiet	[18]
Delayed	[0]
Offline	[12]

Athens during GLE#73 on 2021-10-28

THU, 28 OCT 2021, 17:00:00 UTC

STATUS: WATCH



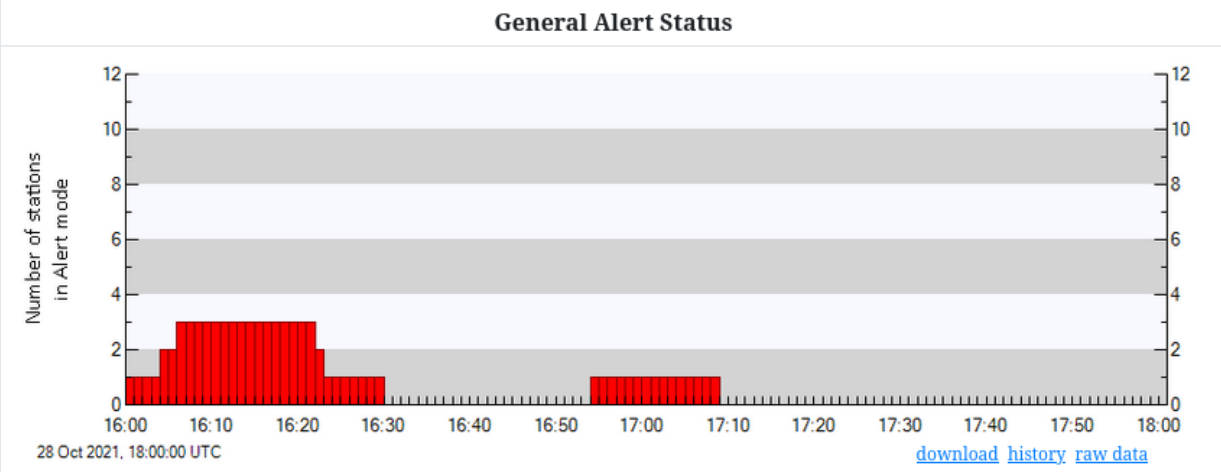
Station Status				
AATB	APTY	ATHN	BKSN	BURE
CALM	ESOI	FSMT	INVK	IRK2
IRK3	IRKT	JUNG	JUNG1	KERG
KIEL2	LMKS	MCMU	MCRL	MGDN
MOSC	MRNY	NAIN	NEWK	NVBK
OULU	PWNK	ROME	SOPB	SOPO
TERA	THUL	TXBY	YKTK	

Summary	
Total	[34]
Alert	[1]
Warning	[0]
Watch	[1]
Quiet	[21]
Delayed	[0]
Offline	[11]

Athens during GLE#73 on 2021-10-28

THU, 28 OCT 2021, 18:00:00 UTC

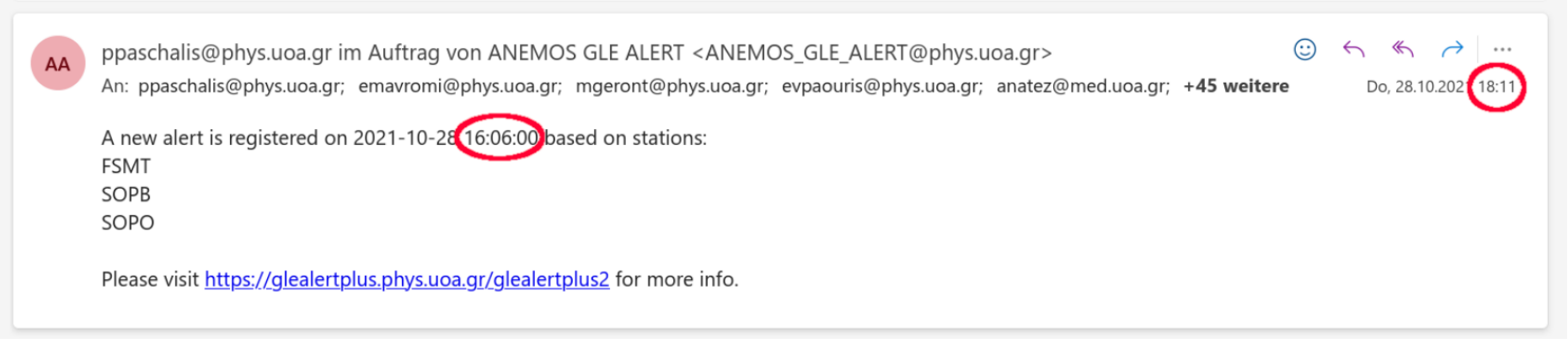
STATUS: QUIET



Station Status				
AATB	APTY	ATHN	BKSN	BURE
CALM	ESOI	FSMT	INVK	IRK2
IRK3	IRKT	JUNG	JUNG1	KERG
KIEL2	LMKS	MCMU	MCRL	MGDN
MOSC	MRNY	NAIN	NEWK	NVBK
OULU	PWNK	ROME	SOPB	SOPO
TERA	THUL	TXBY	YKTK	

Summary	
Total	[34]
Alert	[0]
Warning	[0]
Watch	[0]
Quiet	[23]
Delayed	[0]
Offline	[11]

E-mail sent by Athens application during GLE#73



AA

ppaschalis@phys.uoa.gr im Auftrag von ANEMOS GLE ALERT <ANEMOS_GLE_ALERT@phys.uoa.gr>

An: ppaschalis@phys.uoa.gr; emavromi@phys.uoa.gr; mgeront@phys.uoa.gr; evpaouris@phys.uoa.gr; anatez@med.uoa.gr; **+45 weitere**

Do, 28.10.202 18:11

A new alert is registered on 2021-10-28 16:06:00 based on stations:
FSMT
SOPB
SOPO

Please visit https://glealertplus.phys.uoa.gr/glealertplus2 for more info.

GLE onset: a few minutes before 16:00 UTC

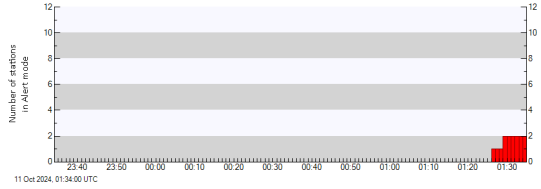
GLE alert: 16:09 UTC (at least 3 NM stations are in status *Station Alert*)

E-Mail became available in mail box at University of Bern: 16:11 UTC,
i.e. 2 minutes after GLE alert and ∼10 minutes after GLE onset

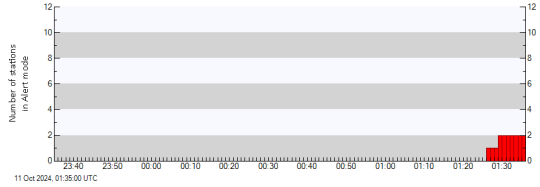
For comparison: Time from onset to peak during impulsive GLEs:
∼5 – ∼15 minutes

GLE alert on 2024-10-11

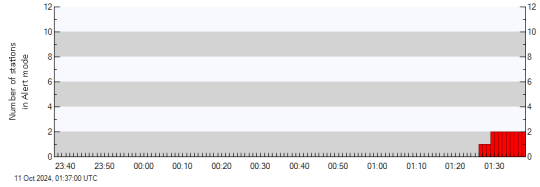
01:34 UTC:



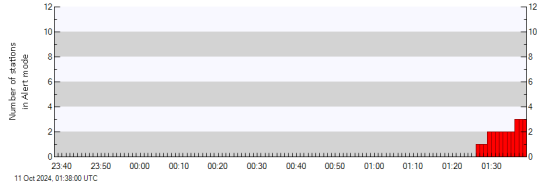
01:35 UTC:



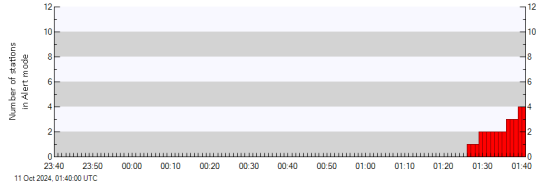
01:37 UTC



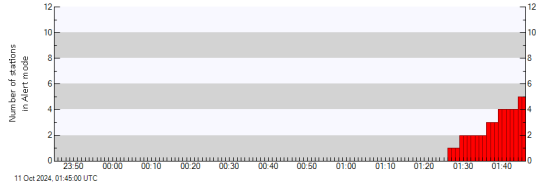
01:38 UTC:



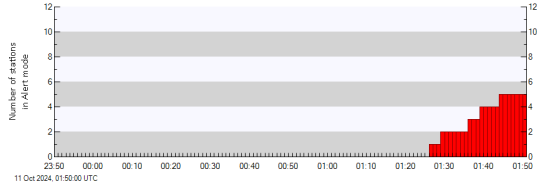
01:40 UTC:



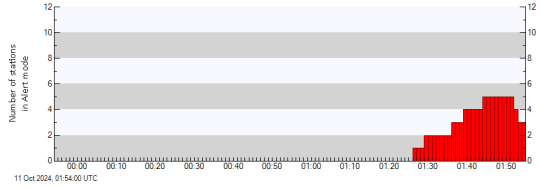
01:45 UTC



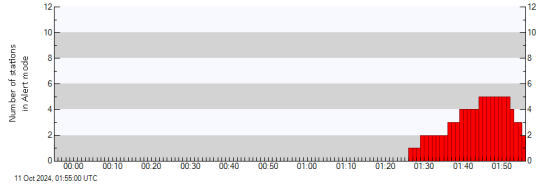
01:50 UTC:



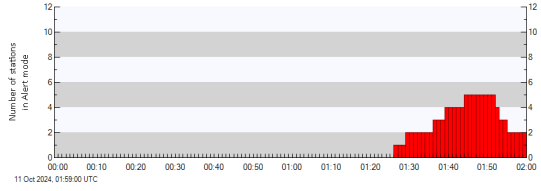
01:54 UTC:



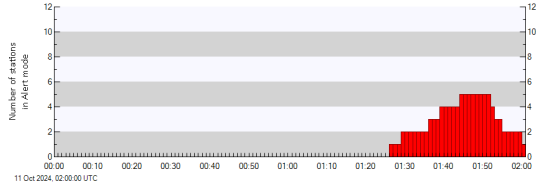
01:55 UTC



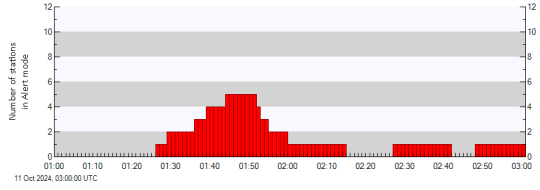
01:59 UTC:



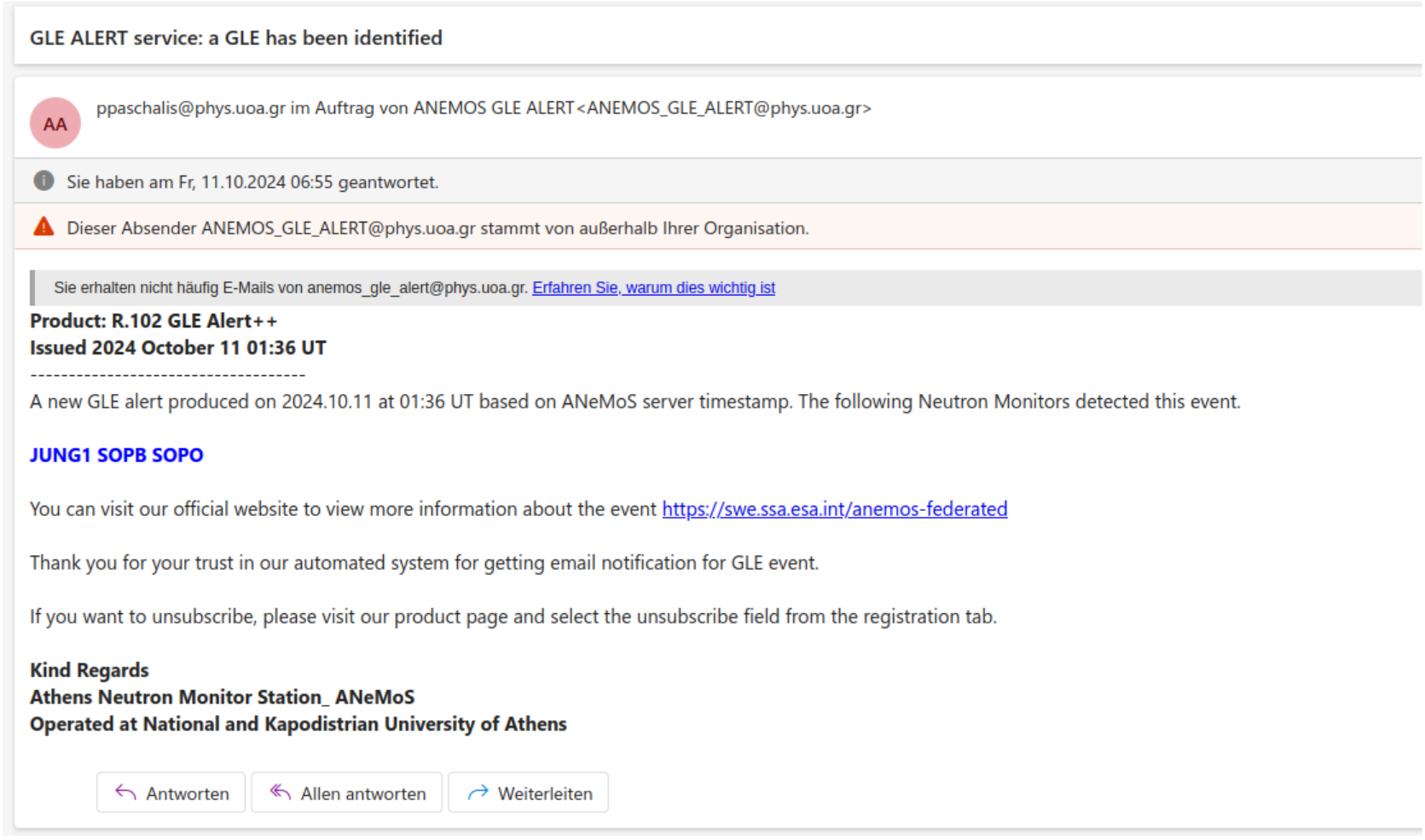
02:00 UTC:



03:00 UTC



GLE alert on 2024-10-11



GLE ALERT service: a GLE has been identified

AA ppaschalis@phys.uoa.gr im Auftrag von ANEMOS GLE ALERT<ANEMOS_GLE_ALERT@phys.uoa.gr>

Sie haben am Fr, 11.10.2024 06:55 geantwortet.

Dieser Absender ANEMOS_GLE_ALERT@phys.uoa.gr stammt von außerhalb Ihrer Organisation.

Sie erhalten nicht häufig E-Mails von anemos_gle_alert@phys.uoa.gr. Erfahren Sie, warum dies wichtig ist

Product: R.102 GLE Alert++
Issued 2024 October 11 01:36 UT

A new GLE alert produced on 2024.10.11 at 01:36 UT based on ANeMoS server timestamp. The following Neutron Monitors detected this event.

JUNG1 SOPB SOPO

You can visit our official website to view more information about the event https://swe.ssa.esa.int/anemos-federated

Thank you for your trust in our automated system for getting email notification for GLE event.

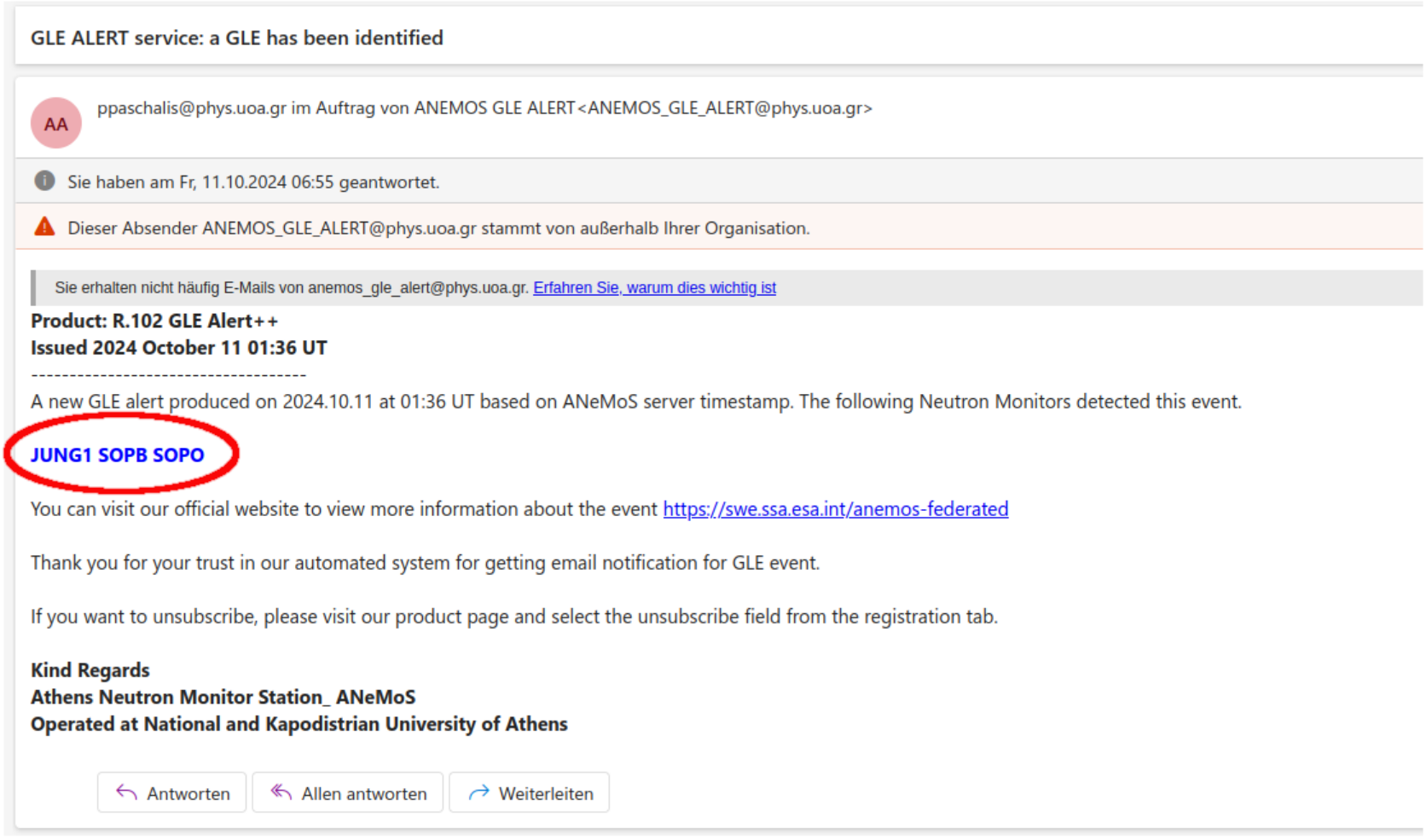
If you want to unsubscribe, please visit our product page and select the unsubscribe field from the registration tab.

Kind Regards
Athens Neutron Monitor Station_ ANeMoS
Operated at National and Kapodistrian University of Athens

Antworten | Allen antworten | Weiterleiten

E-mail was available in mail box at the University of Bern at 01:40 UT

GLE alert on 2024-10-11



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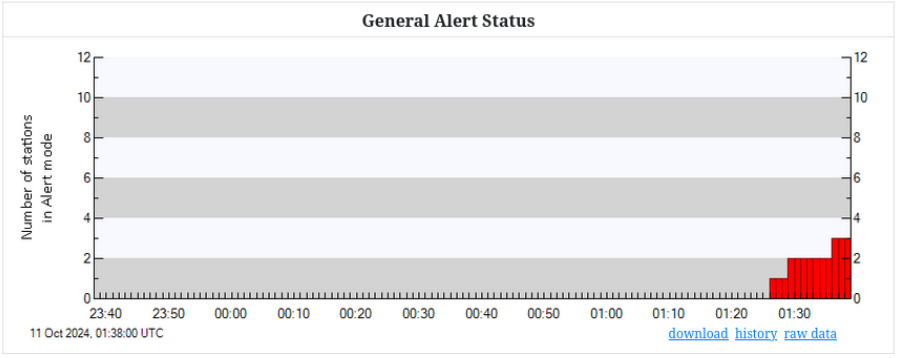
GLE alert on 2024-10-11

FRI, 11 OCT 2024, 01:38:00 UTC

STATUS: ALERT

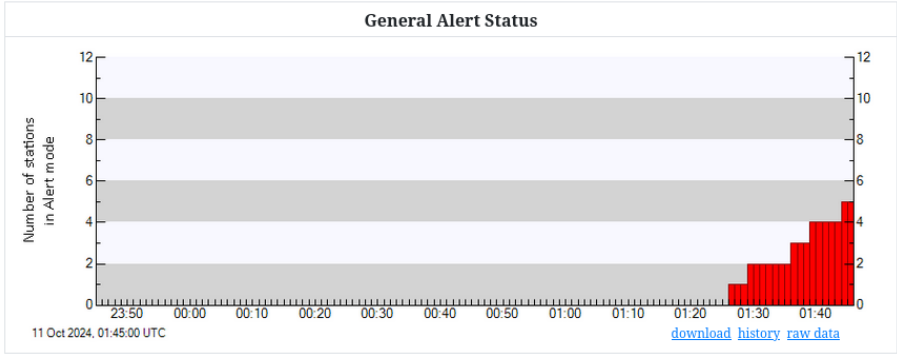


Station Status				
AATB	APTY	ATHN	BKSN	CALM
DRBS	FSMT	INVK	IRK2	IRK3
IRKT	JUNG	JUNG1	KERG	KIEL2
LMKS	NAIN	NEWK	OULU	PWNK
ROME	SOPB	SOPO	TERA	THUL
TXBY	YKTK			

Summary	
Total	[27]
Alert	[3]
Warning	[0]
Watch	[2]
Quiet	[19]
Delayed	[1]
Offline	[2]

FRI, 11 OCT 2024, 01:45:00 UTC

STATUS: ALERT



Station Status				
AATB	APTY	ATHN	BKSN	CALM
DRBS	FSMT	INVK	IRK2	IRK3
IRKT	JUNG	JUNG1	KERG	KIEL2
LMKS	NAIN	NEWK	OULU	PWNK
ROME	SOPB	SOPO	TERA	THUL
TXBY	YKTK			

Summary	
Total	[27]
Alert	[5]
Warning	[0]
Watch	[2]
Quiet	[17]
Delayed	[1]
Offline	[2]

$R_c^{BKSN} = 5.7$ GV, $R_c^{JUNG1} = 4.5$ GV, $R_c^{LMKS} = 3.7$ GV

$\Rightarrow$ **no GLE**

Who are potential stakeholders of GLE alarm systems?

- Researchers in the field of cosmic rays
- Operators of space missions
- Airlines who have to assess the radiation dose exposure of crew members and passengers along the flight routes

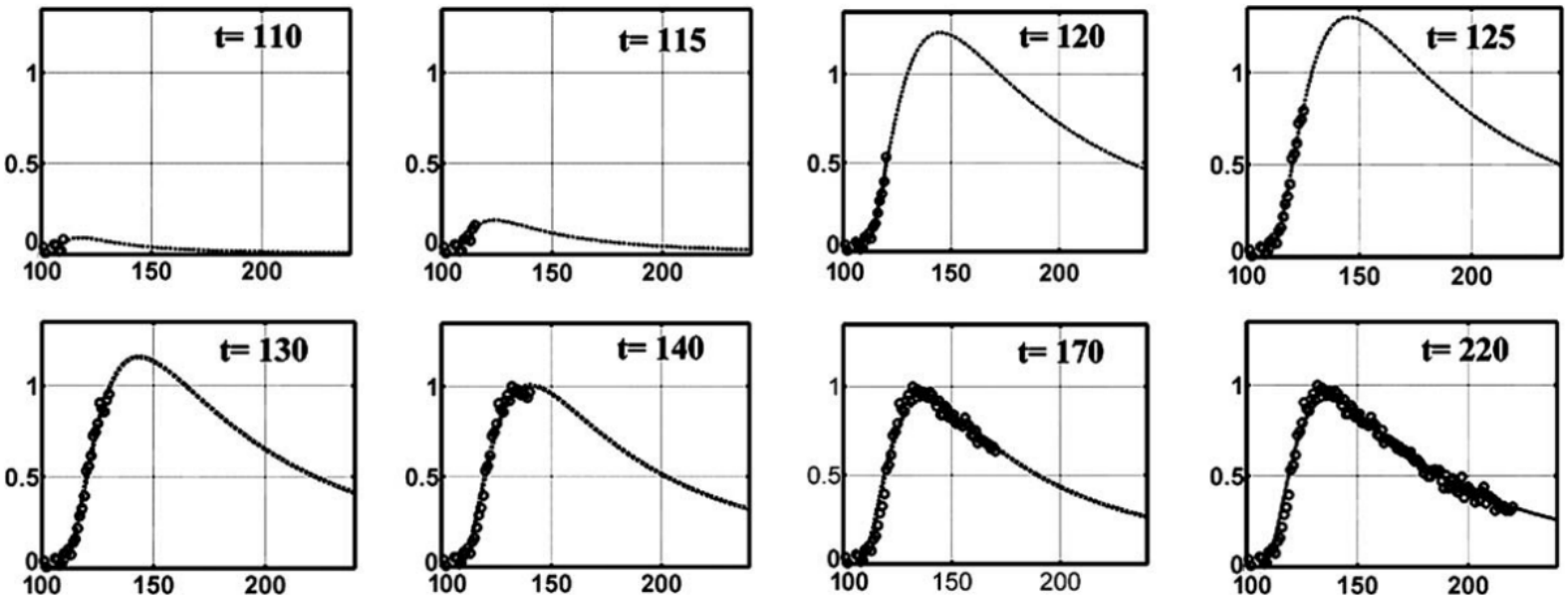
Airlines are interested to know if the expected additional radiation dose rates by SEPs is very large and that the flight route should be changed (flight altitude, flight route to lower geomagnetic latitudes or simply stay on the ground)

What additional information is desired after a GLE alert?

- Was it really a GLE or was it a false alarm?
- Amount of maximal NM count rate increases at polar and mid-latitude stations
- Time of GLE onset
- Duration and shape of onset and decay phase

A live ticker on the web page of the GLE alert sites could give the desired information

Forecasting of SEP development based on NM data

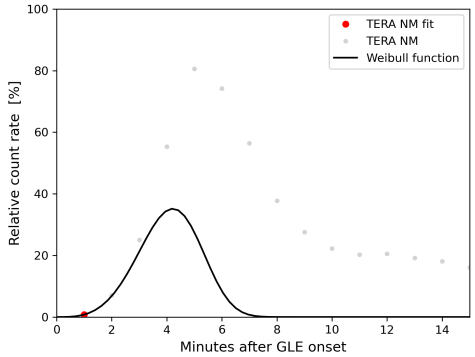


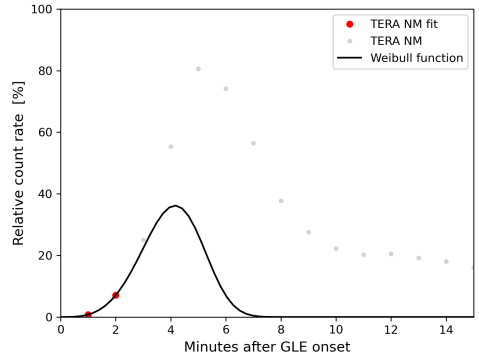
Time t is in minutes after 10:00 UTC on 29 September 1989

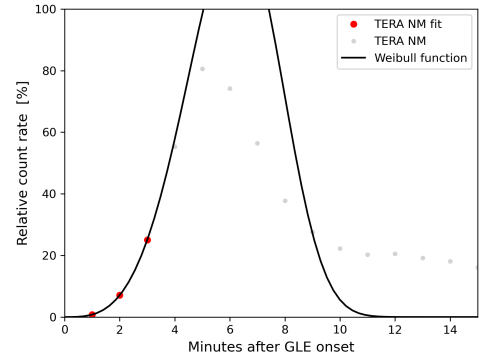
Dorman et al., 2006, Advances in Space Research, **37**, 1134-1140

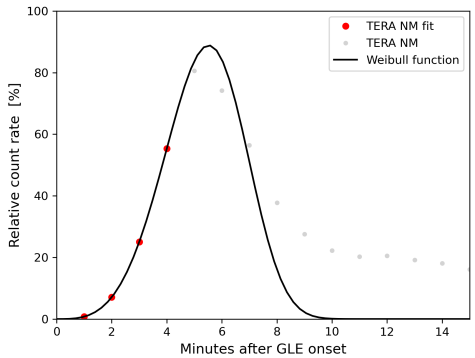
Time from onset to peak $\sim$40 minutes, i.e. diffusive GLE

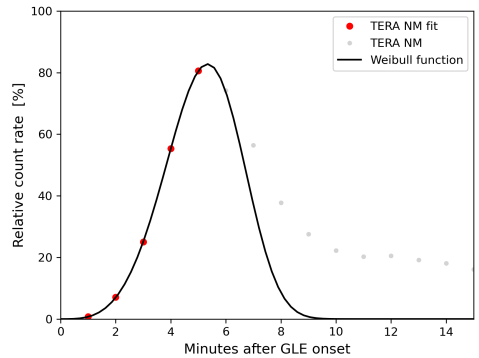
Evolution of GLE#70: Fit with Weibull function

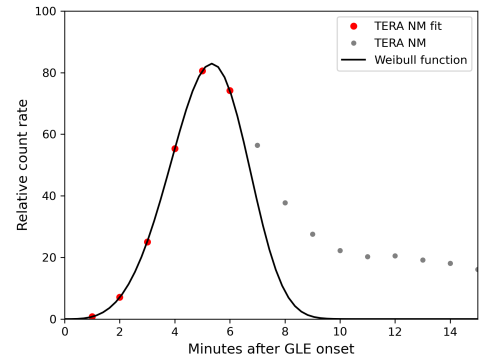


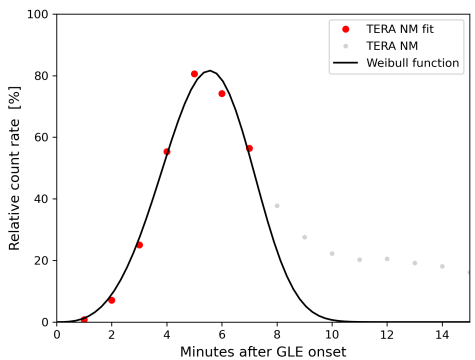


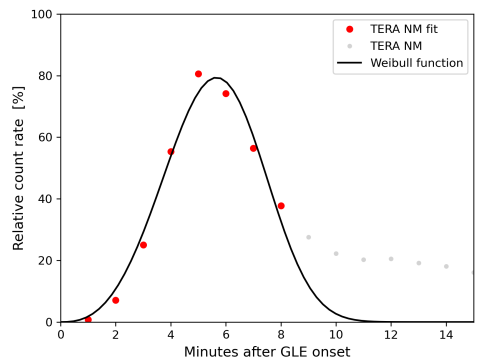


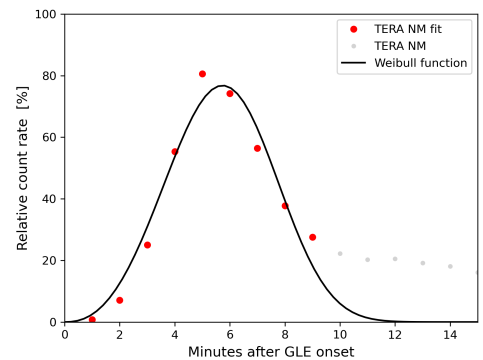












Conclusions

- In addition to the GLE alarm the stakeholders are interested in:
  - prompt information in case of a false alarm
  - predicting the development of a GLE (onset time, amplitude, characteristics of SEP flux)
- Improve GLE alert procedure to reduce false GLE alerts
- Notification by e-mail is obviously not suitable
- Further development of the GLE alarm applications would be highly welcome