Statistical analysis of Thunderstorm Ground Enhancements (TGEs) detected on Mt. Aragats

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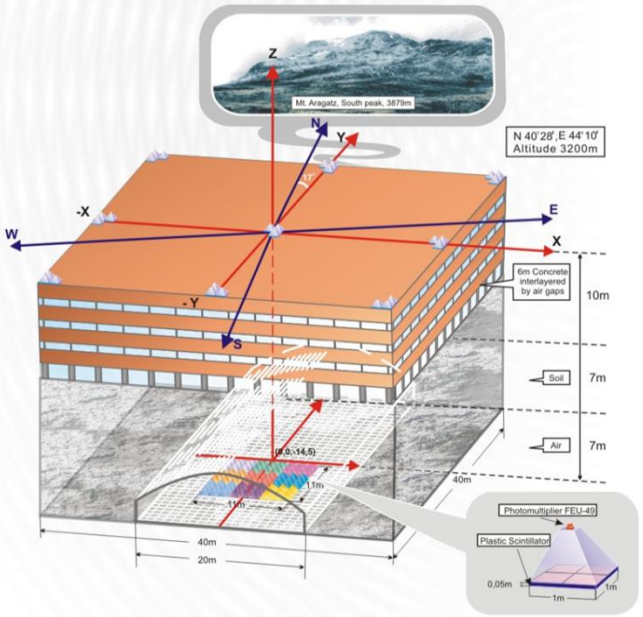
During 5 years of observation starting from 2008–2012 by particle detectors of ASEC have been registered 298 Thunderstorm Ground Enhancements (TGE). For estimating an amplitude of TGE at Aragats (3200m asl.) were used identical 5 cm thick 1 m^2 area outdoor plastic scintillators of AMMM, MAKET detectors and 3cm thick 1 m^2 area outdoor plastic scintillator of STAND1 detector. For estimating an amplitude of TGE at Nor Amberd(2000m asl.) were used 5 cm thick 0.81 m^2 area indoor plastic scintillators of NAMMM. An amplitude of TGE was measured at maximal flux minute relative to the mean value of detector minutely count rate before TGE event started. An enhancement was accepted as genuine TGE only if it was observed by as minimum with 3 independent detectors and the amplitude of signal in each detector exceeds 3 standard deviations.

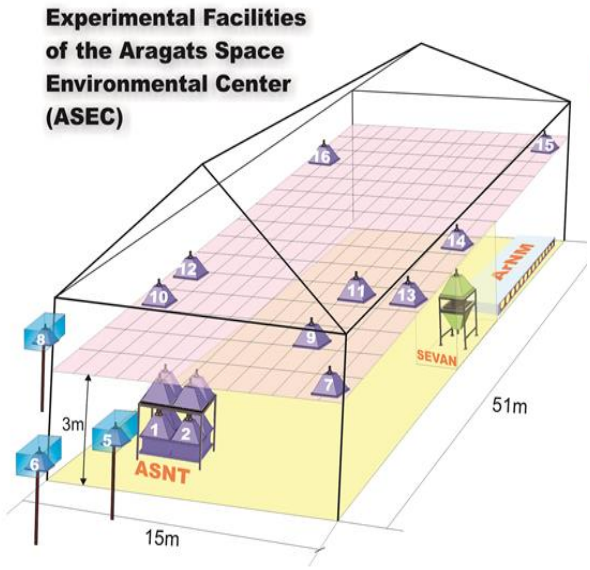
From 298 TGEs

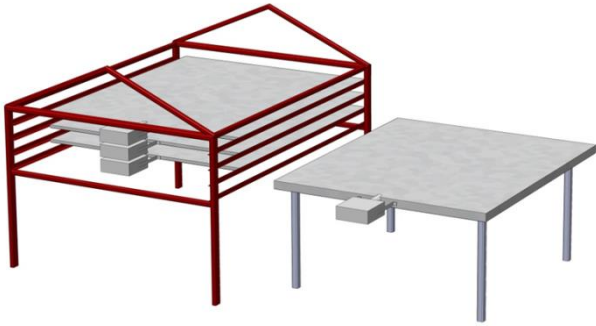
277 were registered in Aragats.

20 TGEs in Nor Amberd.

1 TGE by 3.8% amplitude was registered in Yerevan (1000m asl., measurements in Yerevan has started in 2011).





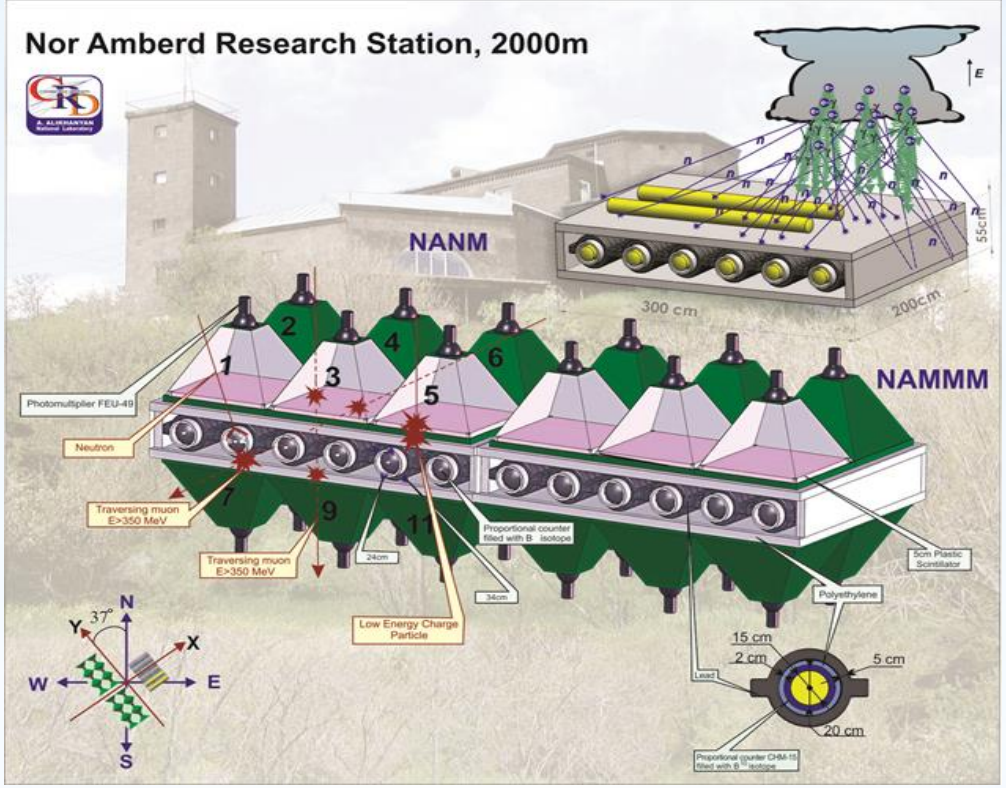


Aragats Multidirectional Muon Monitor (AMMM) consists of 5 cm thick 1 m^2 plastic scintillators located outdoors and in underground hall beneath 14 m of concrete and soil. Upper layer is composed of 29 scintillators; underground detector consists of 90 scintillators of the same type.

MAKET array consists of four 60 cm thick plastic scintillators and 12 of 5 cm thick ones from which 3 are located outside of the main building.

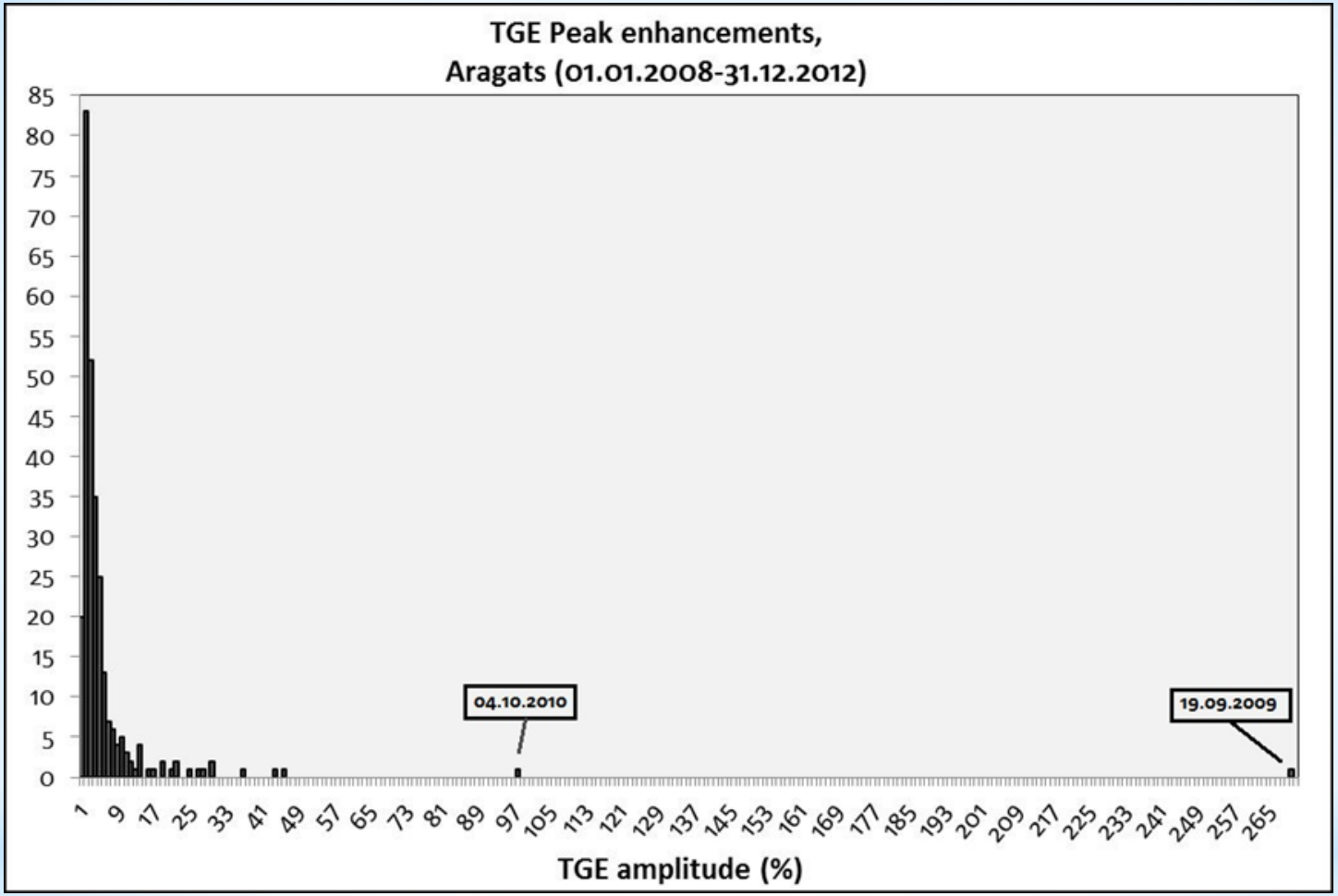
The STAND1 detector exclusively designed for the TGE research comprise of three-layers of 1 cm thick and 1m^2 sensitive area plastic scintillators one above the other and 3cm thick scintillator located aside. Outdoor location, 1 cm thickness and three-layer design allow to measure flux of TGE electrons with 3 different energy thresholds starting from 1.5 MeV. The energy threshold of 3 cm thick scintillator is about ~5 MeV.

The distance between AMMM and MAKET detectors is ~ 400 m, detectors operate with fully independent cabling and data acquisition electronics (DAQ), and demonstrate very similar time-coherent patterns of flux enhancements;



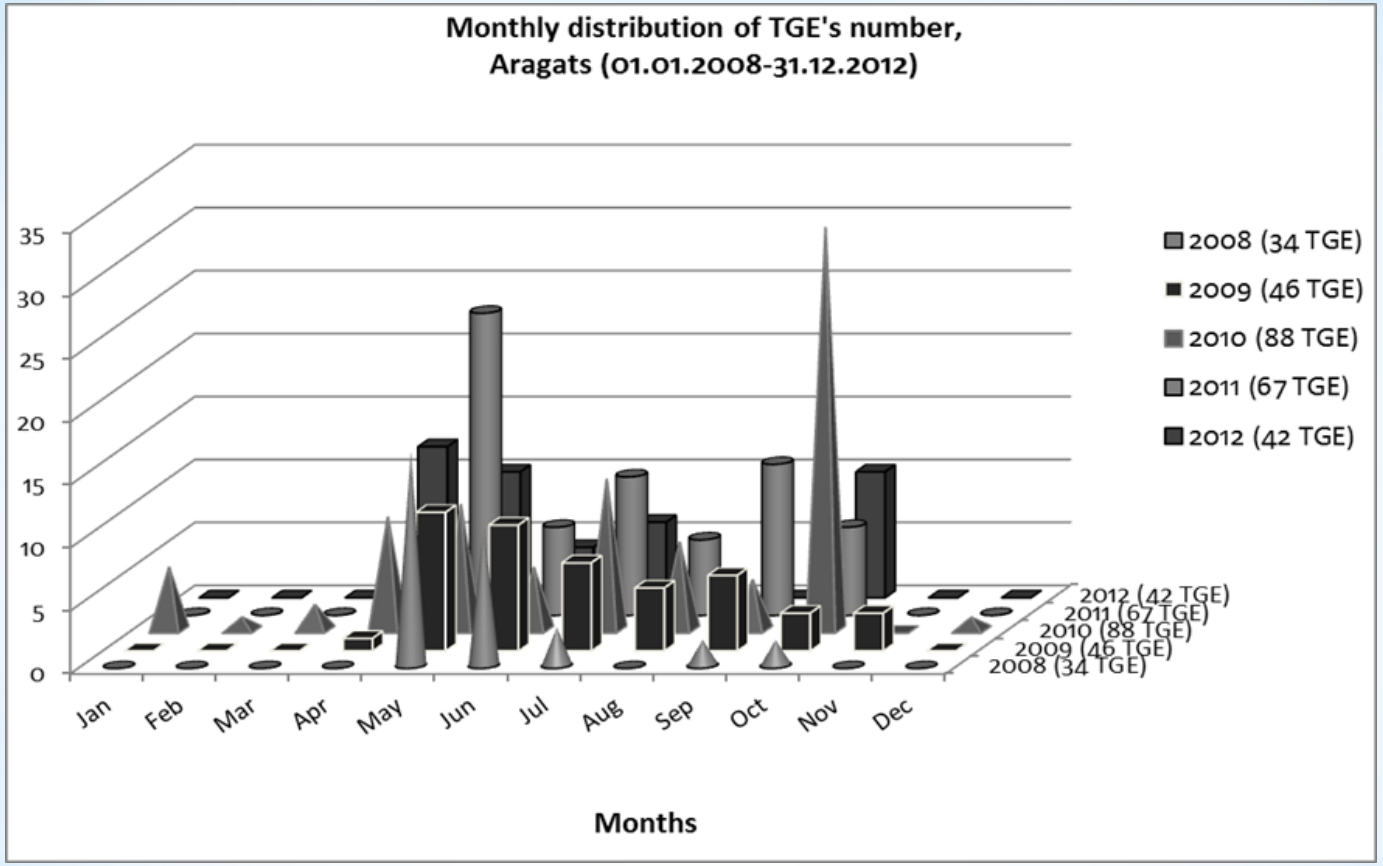
The NAMMM consists of two layers of 5 cm thick plastic scintillators above and below two of the three sections of the Nor Amberd Neutron Monitor (NANM) 18NM64. The lead filter of NANM absorbs electrons and low energy muons. The distance between layers is 1 m. Each layer consists of 6 detectors, each having area of 0.81 m^2. The DAQ system of NAMMM allow to register muons from different directions. NAMMM is hybrid detector measuring neutral and charged CR fluxes. The energy threshold of the upper scintillators is approximately equal to 10 MeV. The lower layer scintillators of NAMMM is sensitive to high-energy muons, since the lead filter absorbs low energy muons and electrons. The energy threshold of the lower scintillators is equal approximately to 250 MeV.

The histogram of TGE amplitudes registered at Aragats in 2008-2012.



190 TGEs from 277 have amplitude less than 5%, 55 TGEs have amplitude between 5 and 10% and 32 TGEs have amplitude greater than 10%. Only 13 TGEs have amplitude exceeding 20%. The maximal value of observed enhancements was 271% (September 19, 2009)

The monthly distribution of TGE events registered at Aragats in 2008-2012.

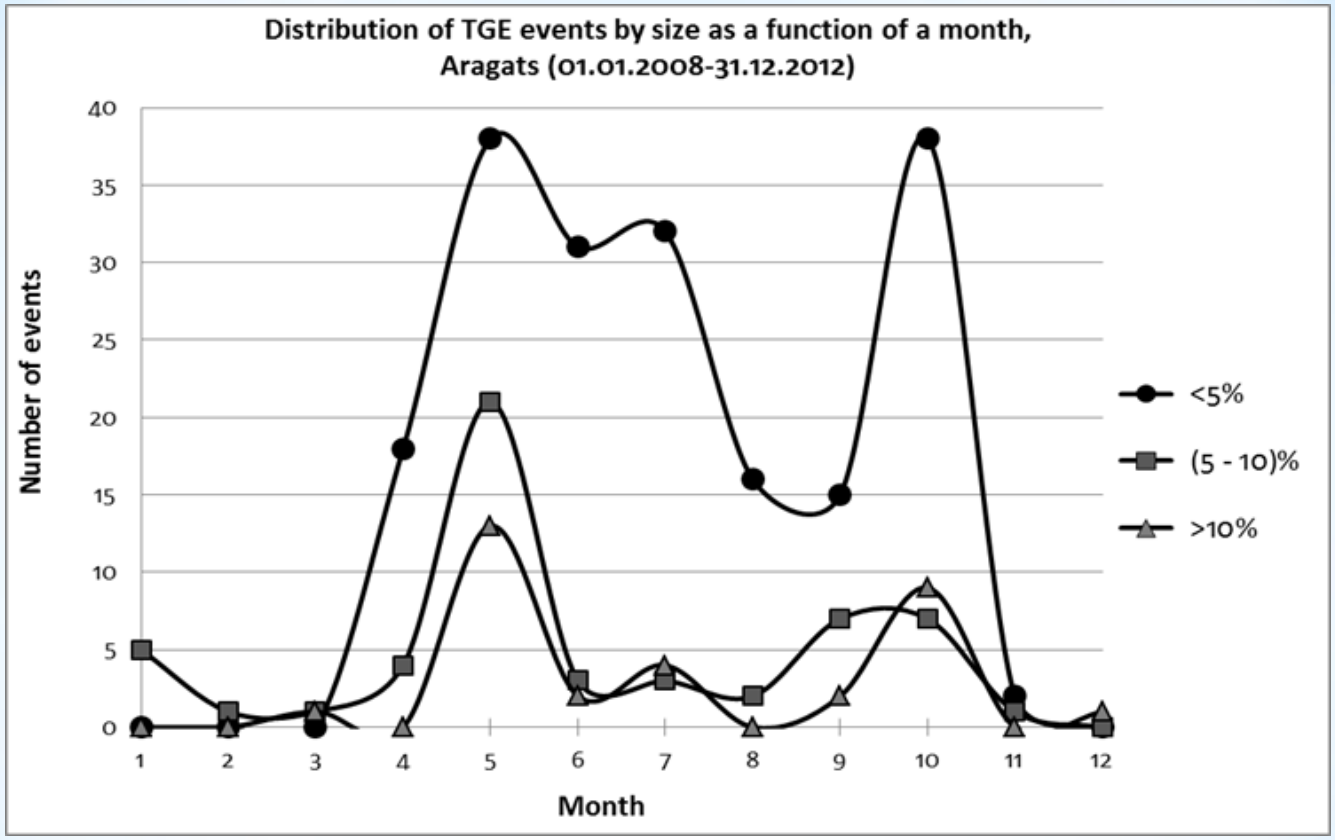


From 277 TGE's at Aragats

- 34 TGEs were registered in 2008
- 46 TGEs in 2009
- 88 TGEs in 2010
- 67 TGEs in 2011
- 42 TGEs in 2012.

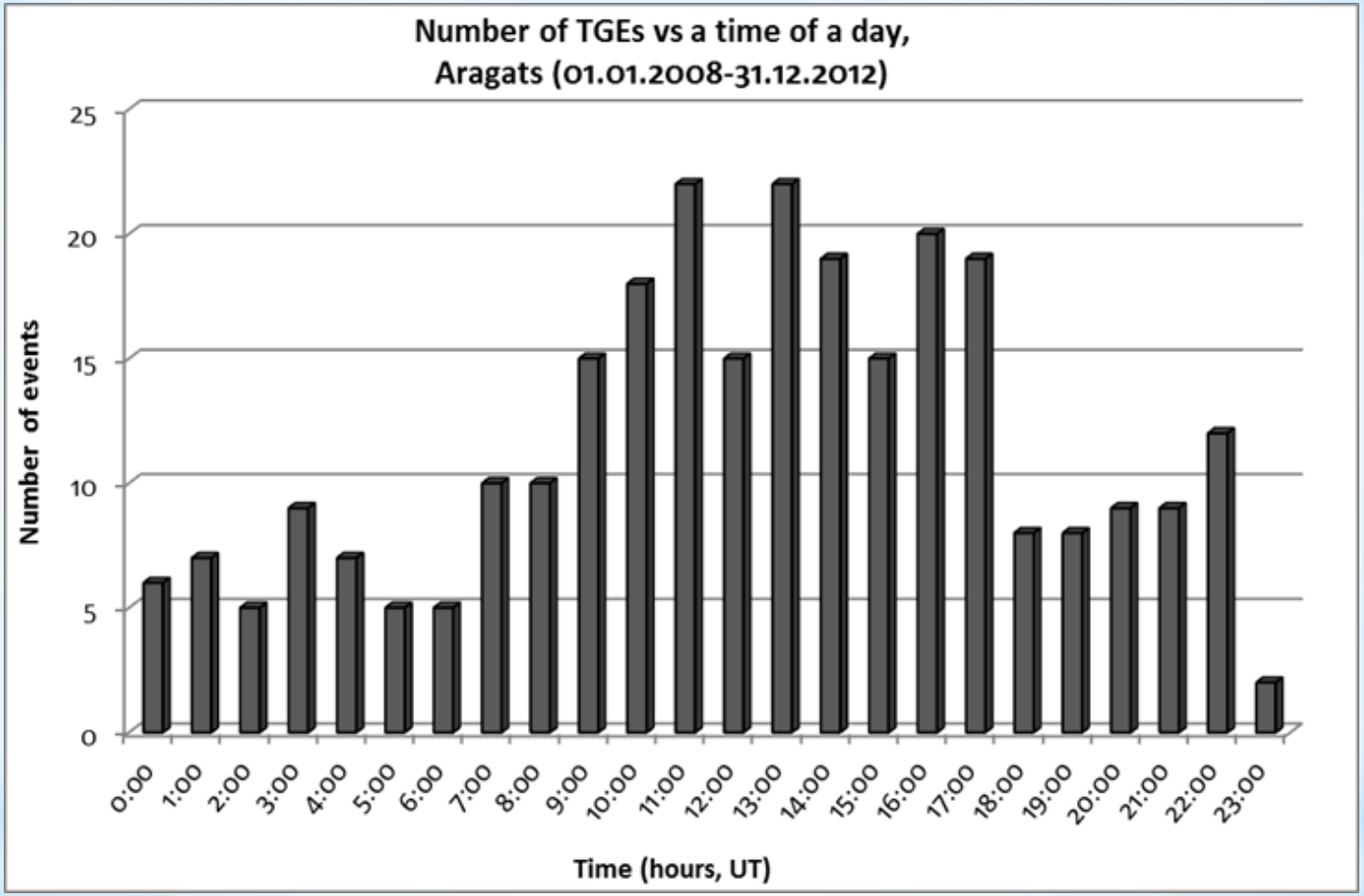
TGEs at Aragats are frequently occur on April-May and October. These months coincide with maximum of thunderstorm activity at Aragats. However, even in January there were detected particle fluxes from thunderclouds.

The distribution of TGE events by enhancement size at Aragats in 2008-2012.



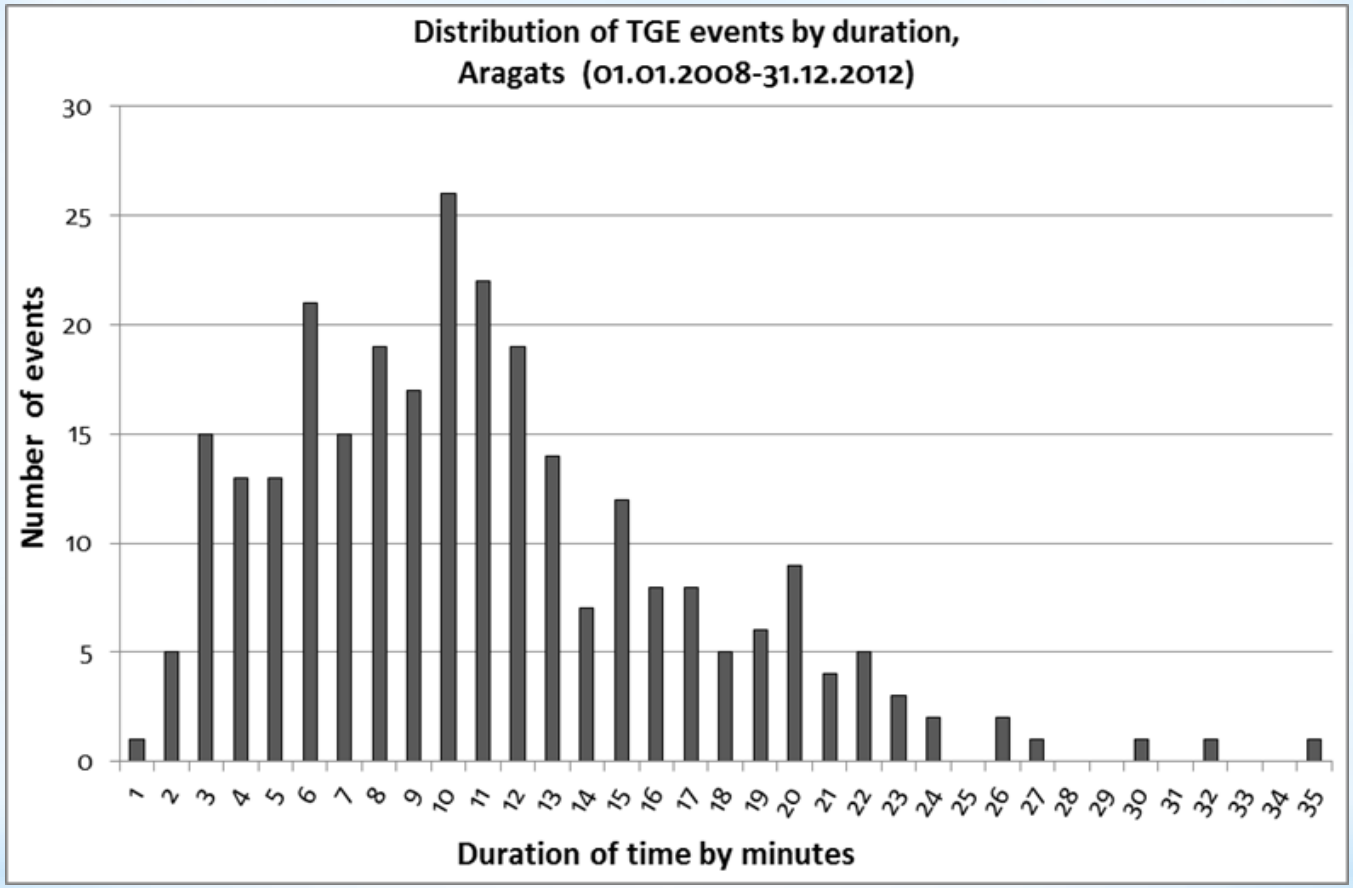
The distribution of TGEs by amplitude also demonstrates maximums in April-May and October.

The distribution of TGE events as a function of a time of a day at Aragats in 2008-2012.



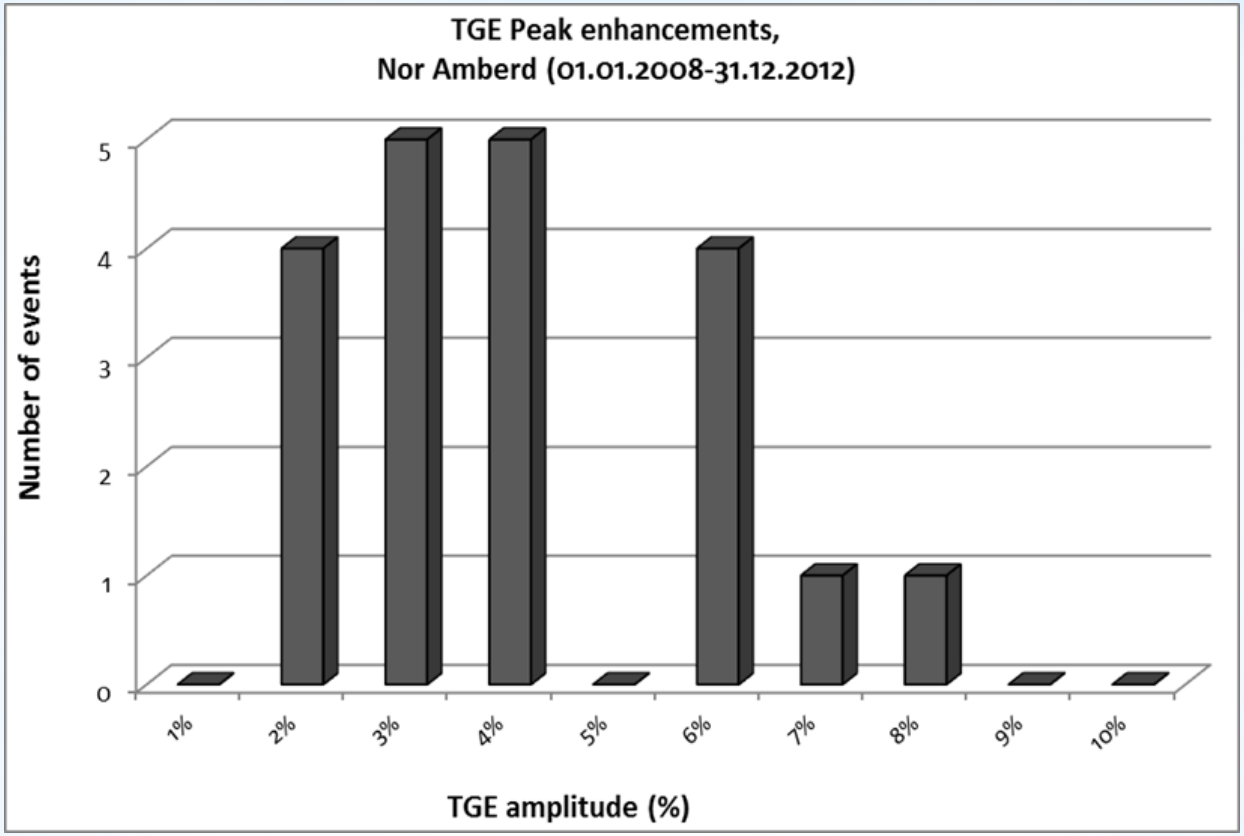
TGEs at Aragats mostly happen in day-evening time: from 9 till 17 UT (13-21) local time.

The distribution of TGE events by duration at Aragats in 2008 – 2012.



The mean duration of TGEs is ~10 min

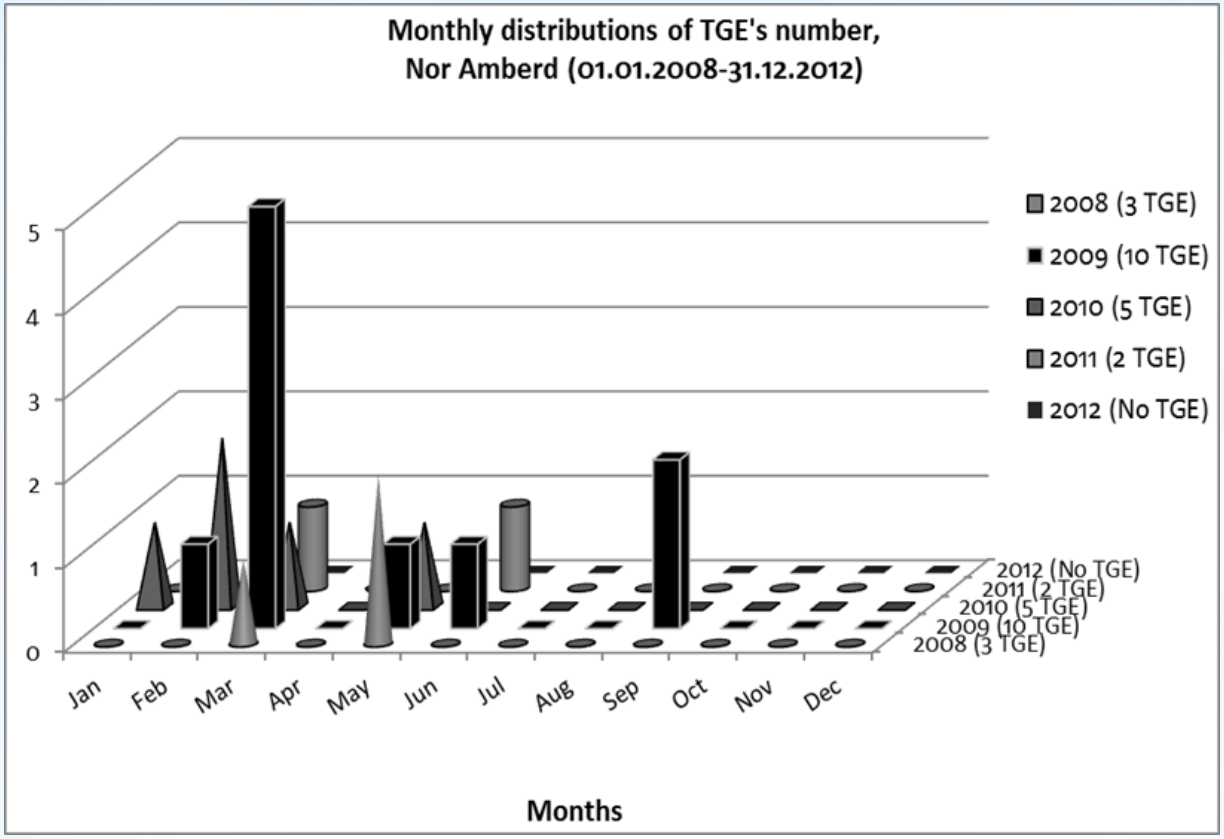
The histogram of TGE amplitudes registered at Nor Amberd in 2008 -2012.



Although thunderstorm activity in both locations is about the same, the topography of Nor Amberd destination doesn't allow thunderclouds to descend down near to detectors. Nor Amberd station is located near sharp uprising of mountain preventing low location of clouds.

14 TGEs from 20 have amplitude lower than <5%, and 6 TGEs have amplitude above 5%. The maximal value of observed enhancements is 8.6%.

The monthly distribution of TGE events registered at Nor Amberd in 2008-2012.

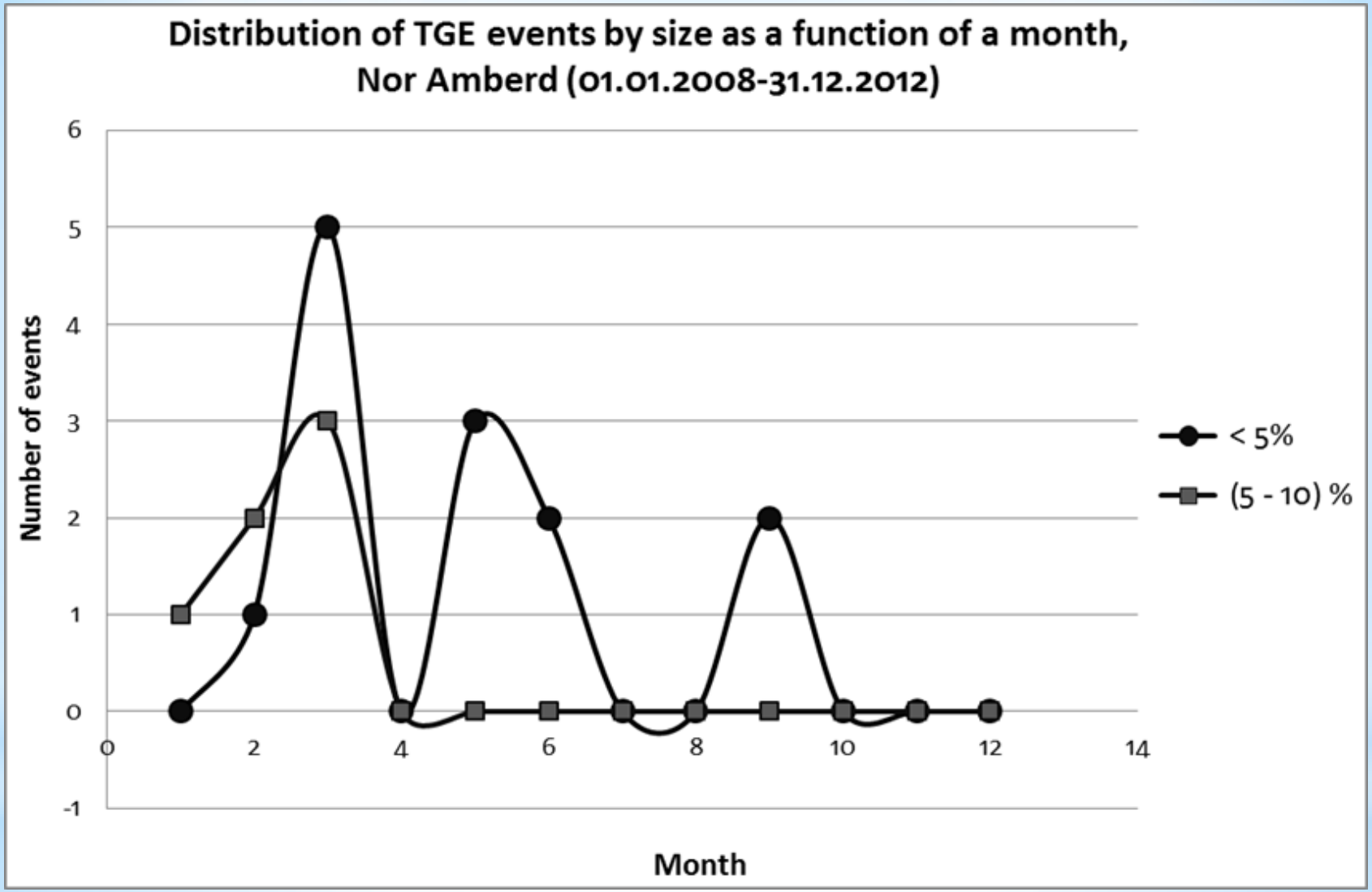


From 20 TGE's at Nor Amberd

- 3 TGEs were registered in 2008
- 10 TGEs in 2009
- 5 TGEs in 2010
- 2 TGEs in 2011
- No TGEs in 2012.

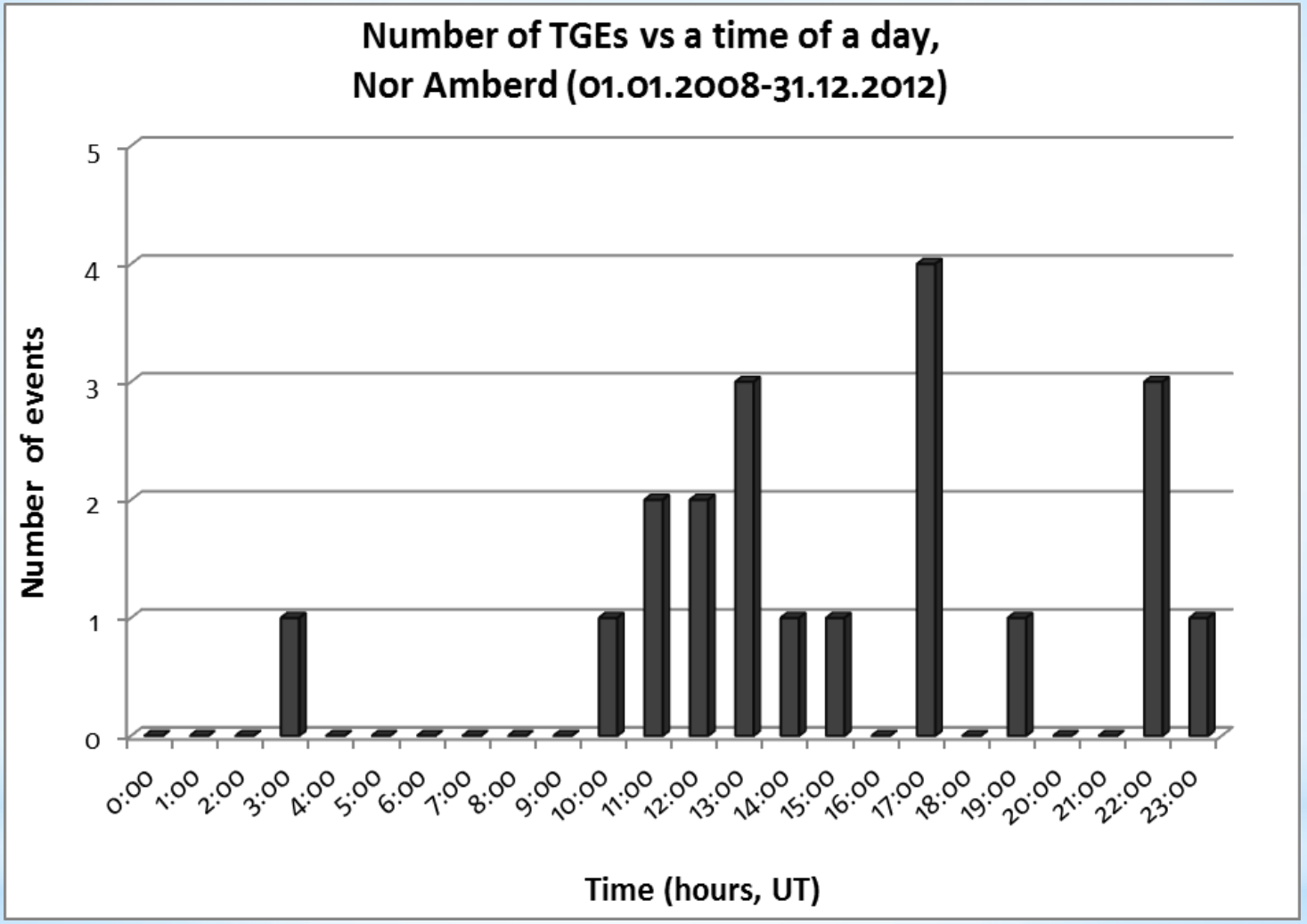
TGEs at Nor Amberd are frequently occur on March. This month coincide with strong thunderstorm activity at Nor Amberd. However, even in January there were detected particle fluxes from thunderclouds.

The distribution of TGE events by enhancement size at Nor Amberd in 2008-2012.



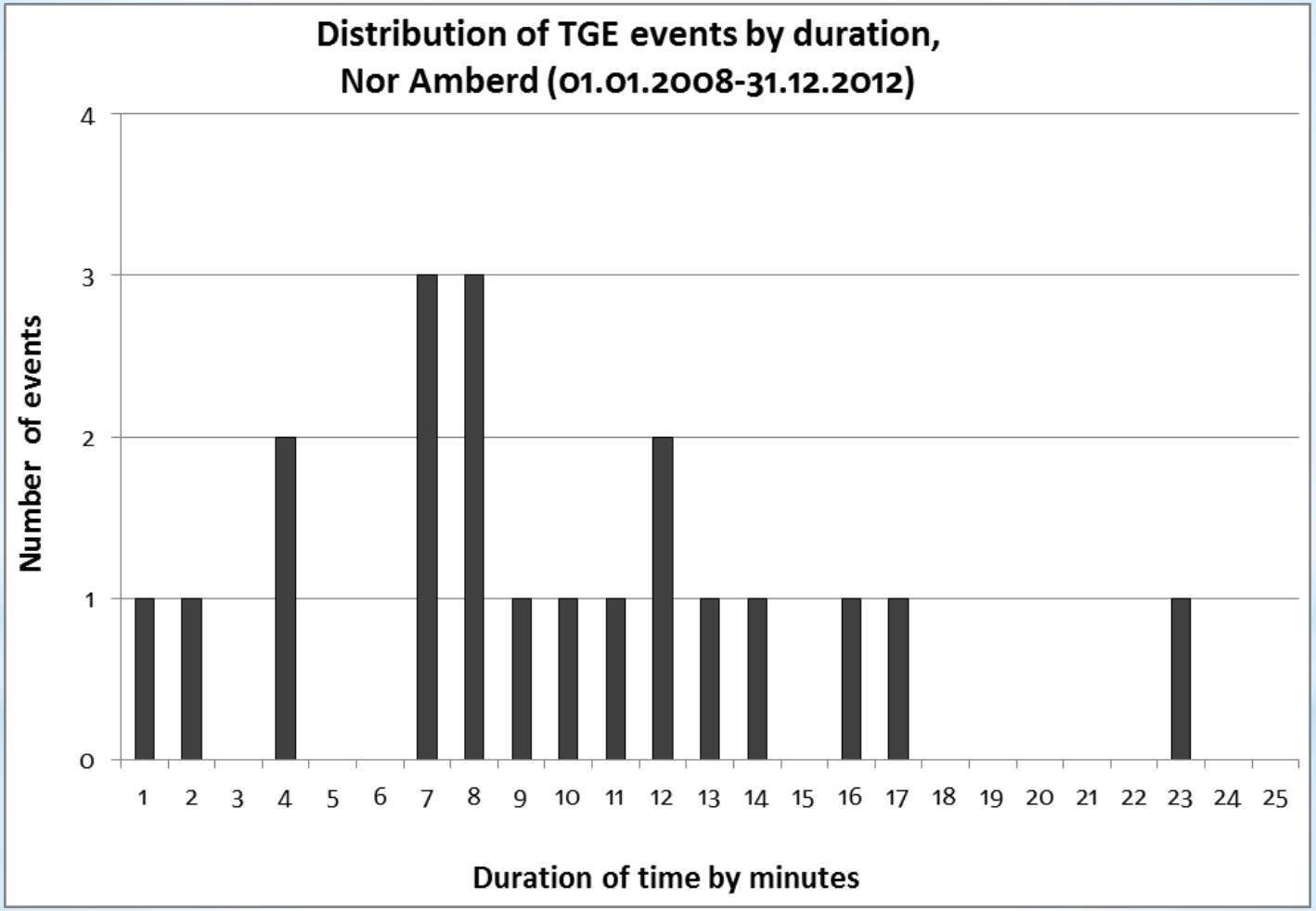
The distribution of TGEs by amplitude also demonstrates maximum in March

The distribution of TGE events as a function of a time of a day at Nor Amberd in 2008-2012.



The distribution of TGEs as a function of a time of a day at Nor Amberd demonstrates that the most probable time is evening-night by local time.

The distribution of TGE events by duration at Nor Amberd in 2008 – 2012



The mean duration of TGEs is ~10 min compatible with duration of Aragats TGEs.

Conclusion

In years of low solar activity 2008–2012 by Aragats Space Environmental Center (ASEC) particle detectors located at Aragats, Nor Amberd and Yerevan have been registered 298 Thunderstorm Ground Enhancements (TGEs).

190 events from 277 at Aragats, have amplitude less than 5%, 55 events have amplitude between 5% and 10% and 32 events have amplitude greater than 10%. Only 13 TGEs have amplitude exceeding 20%. The maximal value of observed enhancement was 271% (September 19, 2009) and the minimal registered 0.8%. In the observed years the most productive months were: May and June in 2008, May-July in 2009. The maximum number of TGE events was detected in October 2010. TGEs at Aragats mostly happen in day-evening time: from 9 till 17 UT (13-21) local time. The mean duration of TGE is ~10 min; sometimes it prolonged up to half-an-hour and more. 14 events from 20 at Nor-Amberd, have amplitude lower than <5%, and 6 events - amplitude above 5%. The maximal value of observed enhancement was 8.6% and minimal value was 1.33%. In the observed years the most productive months were March and May. The maximum number of TGE events was detected in March 2009. The most probable time is evening-night by local time and the mean duration of TGE is ~10 minutes compatible with duration of Aragats TGEs. Amplitude of only one event registered at Yerevan was 3.8%. The duration of TGE was 14 min.

To be sure of that enhancements in time series of our particle detectors are not electromagnetic inferences, we performed in-depth analysis and for each TGE collect evidence demonstrating the existence of the indisputable additional particle fluxes responsible for the detected peaks.

* An enhancement was accepted as genuine TGE only if it was observed by as minimum with 3 independent detectors and the amplitude of signal in each detector exceeds 3 standard deviations.
* The distance between AMMM and MAKET detectors is ~ 400 m, detectors operate with fully independent cabling and data acquisition electronics (DAQ), and demonstrate very similar time-coherent patterns of flux enhancements;
* The ASNT detector also measures the incoming directions of the detected particles. The count rates of the near vertical and inclined particles are dramatically different. If we observe huge enhancement in the near vertical direction (expected arrival direction of the TGE particles), in the same time the same detector using the same DAQ electronics and analysis software do not measure any enhancement in the inclined particle flux;
* Along with count rates the ASNT DAQ electronics also register energy deposit spectra of PM signals. The TGEs are concentrated only in the region of the small energy deposits. The large energy deposits due to cosmic rays remain unchanged;
* SEVAN particle detector measures 3 types of particle fluxes: low energy charged particles, neutral particles and high-energy muons (E_{μ} > 250 MeV). During several TGEs we measured deficit of muons and huge peaks in time series of neutral particles and low energy charged particles. All 3 types of particle fluxes are detected by SEVAN detector with one and the same cabling and DAQ electronics.

Lightning induced signals have very specific shape and fallow the pattern of the lightning activity. Due to strictly different duration of TGEs which last tens of minutes and atmospheric discharges lasting hundreds of milliseconds, it is easy to outline fake peaks in the time series of particle detectors.