2015
5-th International TEPA Symposium
Thunderstorms and Elementary Particle Acceleration
October 5-9 | Nor Amberd | Aragatsotn Province | Armenia

Thunderstorm ground enhancements (TGEs) abruptly terminated by negative cloud-to-ground lightnings

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Abstract. The relationship of lightnings and particle fluxes in the thunderclouds is not fully understood to date. Using the particle beams (the so-called Thunderstorm Ground Enhancements – TGEs) generated in the lower part of clouds by the strong electric fields as a probe, we investigate the characteristics of the related atmospheric discharges. The well-known effect of the TGE dynamics is the abrupt termination of the particle flux. We demonstrate that among 12 atmospheric discharges that abruptly terminated TGE all are the negative cloud-to-ground lightnings. The flux termination and lightning occurred at one and the same second.

With new precise electronics on millisecond time scales we can see that particle flux decline occurred simultaneously with abrupt increase of electrostatic field after the return stroke of the lightning. Therefore, the declining of particle flux is connected with rearranging of charge centers in the cloud involving removal of the Lower Positive Charged Region (LPCR).

1. INTRODUCTION

Thunderstorm Ground Enhancements (TGEs, Chilingarian et al., 2010, 2011) are abrupt enhancements of the secondary cosmic rays measured on the Earth's surface in correlation with thunderstorms and lasting from several seconds to several tens of minutes. The origin of TGEs are the very strong electric fields in the thunderclouds; if all electrostatic fields induced by the charge layers in the thundercloud join in a resulting field that accelerates the electrons downwards, the seeds from the ambient population of Cosmic Rays (CR) can gain energy from the field, multiply and produce bremsstrahlung gamma rays which are registered at the Earth's surface. Plenty of the seed electrons originate from the multiple Extensive Air Showers (EASs) unleashed by the galactic high-energy protons and stripped nuclei interacting with the atmosphere.

The mechanism of the acceleration and multiplication of seed electrons, namely Runaway Breakdown (RB), was suggested in (Gurevich et al., 1992) along with emphasizing its role in the lightning initiation. This mechanism recently is referred also as Relativistic Runaway Electron avalanches (RREAs, Dwyer, Smith, and Cummer, 2012; Dwyer and Uman, 2014). RB operates only at very high electric fields in the cloud and is capable to originate TGEs with energies up to 40-50 MeV and intensities tens of times exceeding the cosmic ray background (Chilingarian, et al., 2013).

In 2002 Chilingarian, Mailyan and Vanyan proposed a compatible with RB mechanism – Modification of electron energy Spectra (MOS), which can increase the secondary cosmic ray flux by a few fractions of a percent, but in a larger energy scale.

In 1999, Alex Gurevich and colleagues suggested that when the electric field in a thunderstorm cloud reaches the critical value of $E > E_C$, every cosmic ray secondary electron with "runaway" energies (0.1 – 2 MeV) initiates a micro-runaway breakdown (MRB). Usually it is very difficult to select these nanosecond-lasting showers originated in the cloud from the individual electrons (Extensive Cloud Showers – ECSs, Chilingarian et al., 2011) within the ongoing TGE of several minutes duration. ECSs (MRBs) should be distinguished from the plenty of large EASs originated high in the atmosphere and containing millions of particles. Nonetheless, at Aragats research station where clouds sometimes are "sitting" on the surface we detect several large TGEs, within which "resolve" numerous very short (< 400 nsec) showers originated in the thundercloud from a seed electron (Chilingarian et al., 2011). Furthermore, by the 2-way classification we demonstrate systematic differences of ECSs and EASs. Thus, TGEs are superposition of the multiple avalanches initiated by the individual CR electrons in thundercloud and reaching the Earth's surface.

The relation of RBs, TGEs and lightnings are not yet fully discovered. If we can definitely state that RB is capable to initiate a TGE and a lightning cannot initiate a TGE (Chilingarian, 2014), then the role of RB in lightning initiation is still dimmed.

According to the theory of a combined effect of RB-EAS (Gurevich, et al., 1999), the ionization of the atmosphere by a high-energy EAS ($E > 10^{16}$ eV) in RB conditions is growing strong enough to produce spark-type local electric breakdown that can radiate a strong local pulse of electric current and serve for lightning leader initiation.

For proving this theory we need simultaneous and synchronized on nanosecond time scales detection of EASs, TGEs and lightnings by particle detectors with fast electronics, detectors of the fast waveforms of radio emission, sensitive fast cameras, precise lightning detectors and electrostatic field sensors. Certainly, *in-situ* measurements of the electric field in the cloud will be very helpful. Unfortunately to date there are no convincing experiments for solving the lightning origination enigma.

In the present paper we will try to approach this problem by the analysis of a special kind of TGEs, i.e. TGEs abruptly terminated by lightnings. To our knowledge, the Baksan group reported the first TGEs of this kind (Alexeenko et. al., 2002). They demonstrated that the particle count rate increased at energies of ~30 MeV then quickly returned to the background level when lightning occurred. In (Khaerdinov and Lidvansky, 2005) they correctly deduce that the detected flux enhancements are not directly related to the lightning activity; the lightnings serve rather as a switch-off for the electric field. Recently several groups report such special TGEs as well (Tsuchiya H. et al., 2013, Chilingarian et al., 2015, Kelley et al., 2015, Kollarik et al., 2016, Kuroda et al., 2016).

With installing of new fast electronics at Aragats (Pokhsraryan, 2016) it became possible to investigate time series of the near-surface electric field, fast waveforms of atmospheric discharges and particle fluxes on the millisecond time scale. Various particle detectors and field meters are now synchronized by GPS receivers providing a time stamp with an accuracy of better than a few tens of a nanosecond.

In the paper we present the analysis of a TGE event occurred on 7 October 2015 for the first time detected on a millisecond time scale. We also consider a sample of TGEs observed during 2013-2015, all of them being abruptly terminated by lightnings, in order to deduce what kind of atmospheric discharge had ceased the particle flux.

2. INSTRUMENTATION: ARAGATS SOLAR NEUTRON TELESCOPE [1]

Aragats Solar Neutron Telescope (ASNT, Fig. 1) is a part of the worldwide network coordinated by the Nagoya University and aiming primarily to measure the fluxes of the neutrons born in the violent solar flares. Now ASNT is monitoring 7/24 charged and neutral fluxes of secondary cosmic rays. ASNT observation of the ever-largest TGE detected at Aragats Space Environmental Center (ASEC, Chilingarian et al., 2005) on 19 September 2009 (Chilingarian et al., 2011) allows for the first time to measure simultaneously the energy spectra of the electrons and gamma rays and firmly establish the neutrons production in the photonuclear reactions of gamma rays in the atmosphere.

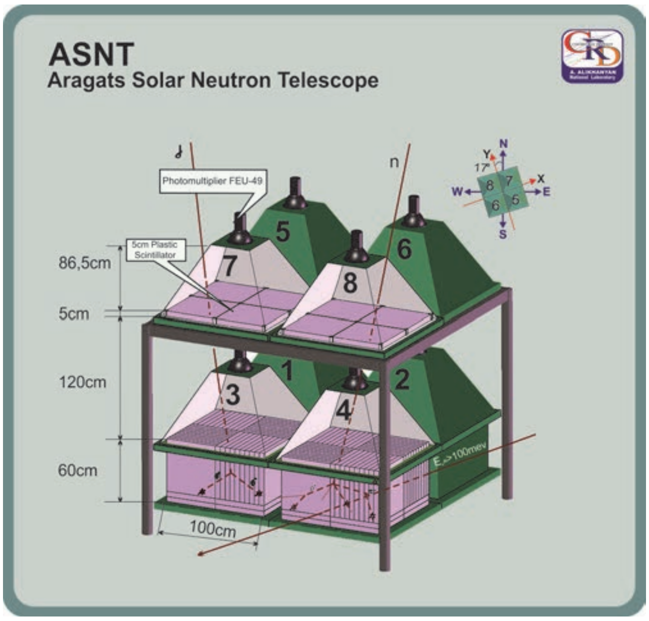

Figure 1. Setup of the Aragats Solar Neutron Telescope (ASNT)

ASNT consists of 4 upper and 4 lower scintillators, each having an area of 1m^2. The distance between the layers is ~1.2 m. The data acquisition system can register all coincidences of detector signals from the upper and lower layers, thus enabling measurements of the arrival of the particles from different directions. The signals ranging from 0.5 mV to 5 V, from each of 8 photomultipliers, are passed to the programmable threshold discriminators. The output signals are fed in parallel to the 8-channel logical OR gate triggering device and to a buffer. If there is a signal in the channel we will denote it by 1 and the channels that were not fired within the ‘‘opening’’ time of the gate (~1 μs) by 0. The ASNT trigger condition is defined by detecting at least one signal in the 8 data channels. The trigger rate of the entire detector system does not exceed 10 kHz. The duration of the entire data readout and signal processing procedure is less than 10 μs. There are 23 different possibilities of so-called ‘‘basic states’’. Sixteen of them carry information about the direction of the incident particle. For example, the state configuration 0010 for the upper layer and 0010 for the lower layer corresponds to the charged particle traversal through the third upper and third lower scintillators (zenith angle between 0 and 30). Combination 0010 and 1000 corresponds to the traversal through the third upper and the first lower scintillator (zenith angle between 20 and 40). The other 7 possibilities give additional valuable information on the particle flux incident on the detector. For instance, the combination 01, i.e., no signal in the upper and the signal in the lower layer can be attributed to the traversal of a neutral particle. However, due to small sizes of the anticoincidence shielding (see Fig. 1), several charged particles can hit the detector from the side. Nonetheless, if the particle beam is near vertical (it is just the case of a TGE hitting ASNT), we can measure the energy release spectrum of the thunderstorm-correlated gamma rays. Histograms of the energy releases in the thick scintillators are measured and stored each minute, providing the exact pattern of the energy releases during solar transient events and during thunderstorms. The top scintillators have the thickness of 5 cm (energy release for the vertical electrons is ~10 MeV) the combination 11 will select charged particles with energy greater that 20 MeV. The advanced data analysis system (ADAS) provides registration and storage of all logical combinations of the detector signals for further offline analysis and for issuing warnings and alerts on the dangerous space weather conditions.

3. LARGE TGE OCCURRED ON 7 OCTOBER 2015

On 7 October 2015 the weather at Aragats was stormy. Disturbances of the near-surface electrostatic field started around 7:00 UT and followed with several lightnings to12:00. The atmospheric pressure was 685.3 mbar; wind speed 2.5 m/sec from ~270° N direction. The solar radiation decreased from 500 W/m^2 at 10:15 down to zero at 11:45 due to thick cloud preventing solar radiation to reach the Earth’s surface. The temperature followed the decline of the solar radiation with a short delay decreasing from 2.8 C° down to 0.5 C°. The location of the cloud just above the particle detectors and developing of the Lower Positively Charged Region (LPCR) in the bottom of it assisted unleashing of the large TGE, which started at 14:40 and all the particle detectors of ASEC registered it. The relative humidity during TGE was very high – 97%. In Fig. 2 we show the two-second time series of the ASNT detector (Fig. 1). The upper blue time series correspond to the flux measured by the four 60 cm thick 1-m^2 plastic scintillators; the black time series are measured by the same scintillators conditioned on the absence of a signal in the upper (veto) scintillators; and the read one – the near-vertical flux of particles registered in both layers of detector (11-combination, mostly electrons with energies above 20 MeV).

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[1]*Particle detectors and field meters used in the present research are described in other papers of proceedings. Here we present only description of the ASNT detector.*

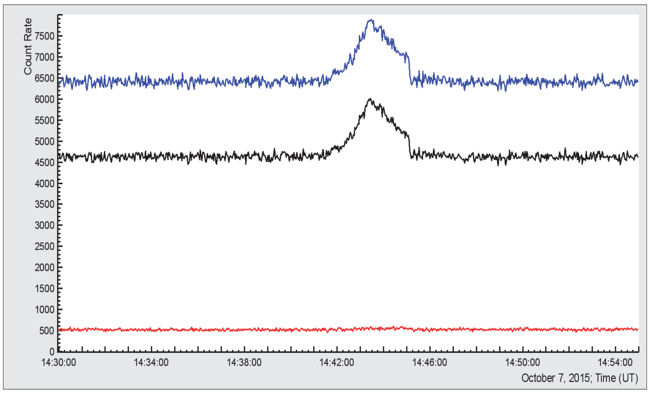

Figure 2. TGE seen in the two-second time series of the ASNT detector; blue time series – total flux; black time series – flux with veto on near-vertical charged particles; red time series – high energy particles with energies greater than 20 MeV.

In Fig. 3 we show p-values of the same two-second time series observed by ASNT detector. The significance of detecting peaks in the time series of the particle count rates is determined by the p-values of the peak significance test, i.e. by the value of the peak divided by the standard deviation of count rate (number of standard deviations contained in the peak, Nσ). The p-value is the most comprehensive measure of the reliability of detecting peaks in a time series. Large p-value corresponds to small chance probabilities that the observed peak is a background fluctuation and not a genuine signal. Therefore, we can safely reject the null hypothesis (background fluctuation) and confirm the TGE.

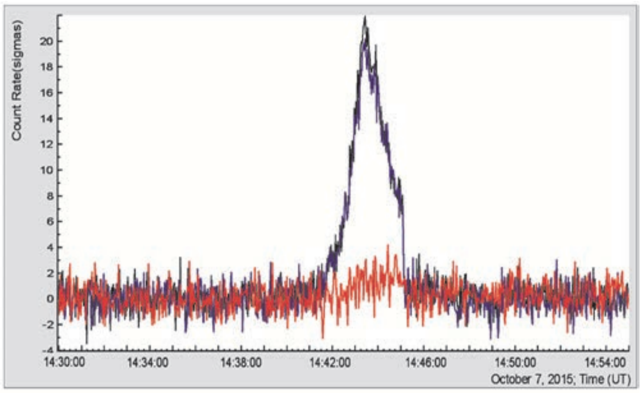

Figure 3. TGE as seen in the p-values of the two-second time series of the ASNT detector; black time series – total flux; blue time series – flux with veto on near-vertical charged particles; red time series – high energy particles with energies greater than 20 MeV.

Closeness of the particle flux with and without veto proves that most of the TGE particles were gamma rays.

The high-energy gamma ray flux was confirmed by directly measured differential energy spectrum with the network of NaI spectrometers, see Fig 4. Differential energy spectra measured by 3 NaI spectrometers extended at least up to 30 MeV (therefore the "parent" electrons have energies up to 40-50 MeV). The integral near-vertical energy spectra of the TGE event measured by the CUBE detector (energy threshold ~ 4 MeV) with capability of separating electron and gamma ray fluxes was: I_e ~ 350(min*m^2)$^{-1}$; Iγ ~ 9500(min*m^2)$^{-1}$; Ie/Iγ ~ 3.8%.

The particle flux reached the maximum at ~14:44 and on the declined phase at 14:45:07 the negative lightning "killed" it (see Fig. 5). The disturbances of the near-surface field started at 14:45:07, reaching the maximum at 14:45:07.10; the amplitude was ~70 kV/m and the distance to lightning was ~7 km.

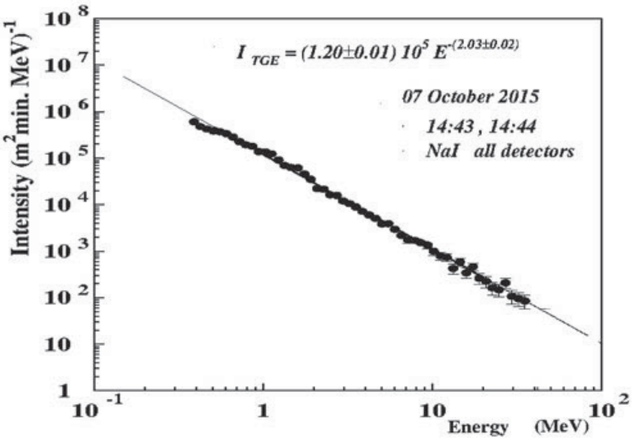

Figure 4. Differential energy spectrum of the TGE measured by the NaI spectrometer with energy threshold 0.4 MeV

After the shaping of the LPCR in the bottom of the cloud, the emerged strong electric field accelerated the electrons downward in the direction to the ground. The LPCR is usually small as compared to the main negative charge; so it can influence only the electrostatic field locally beneath the cloud. LPCR, as well, can control the development of the downward negative leader starting above in the cloud. The main negative charge region in the middle of the cloud and its image charge of the opposite sign (under the assumption of perfectly conducting ground) form much more extended field also accelerated electrons downward. The superposition of these two fields and electrostatic field induced by the main upper positively charged region is changing fast, dependent on the wind speed that moves LPCR above the particle detector location. Deposition of the negative charge to the ground by lightning leads to an abrupt increase of the positive charge overhead, resulting in the particle flux decay. We note that the "atmospheric electricity" sign convention (a downward-directed electric field or field change vector is considered positive) is used throughout this paper. Therefore, negative lightning depositing negative charge to the ground produces positive electrostatic field change as indicated in the Figure 5 (see the discussion on the atmospheric electricity sign convention in (Krehbiel et al., 2014).

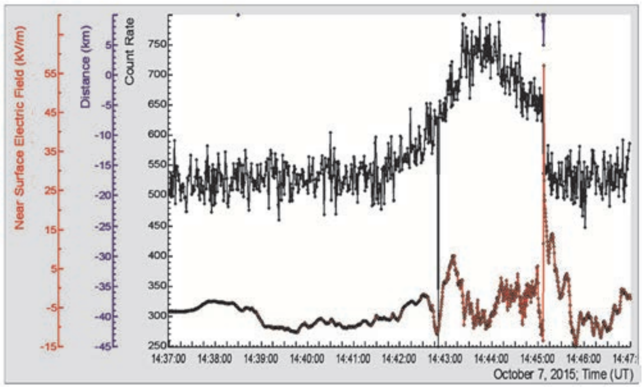

Figure 5. TGE abruptly terminated by the negative lightning; in the bottom are shown electric field disturbances detected by the electric mill EFM-100; in the middle – 1-sec time series of count rate of 3 cm thick outdoor plastic scintillator, on the top – distance to lightning; Lightning occurred at 14:45:07 coinciding with decline of particle flux by 14.4%.

In our previous paper (Chilingarian et al., 2015) we compared the 50 msec time series of the near-surface electrostatic field measurements with the 1-sec time series of the count rates of particle detectors. This, 20-fold inconsistency in the time series prevents definite inference on start of the particle decline relative to lightning time. With installing of the new fast electronics (Pokhsraryan, 2016) it becomes possible to compare lightning and particle fluxes on the same temporal scale.

In Fig. 6 we demonstrate five seconds of the 50-ms time series of the count rates including abrupt increase of the near-surface electrostatic field and particle flux termination. Visible decline of the particle flux occurred within 100 ms from (14:45:07.175 to 14:45:07.275) of the abrupt increase of the near-surface electrostatic field that is manifestation of the negative lightning strike. It is expected that the maximum of electrostatic field change is reached later than the maximum of electromagnetic pulse from the lightning. Our statistics of the time difference between WWLLN time stamps and EFM-100 field maximum time stamps (137 coinciding detections, see Fig. 5 in Chilingarian et.al., 2016) shows a delay of electrostatic field maximal value of ~ 185 ms. Thus, the decline of the particle flux detected at ~14:45:07.175 was simultaneously with abrupt increase of the near-surface electrostatic field after the return stroke which deposited the negative charge on the ground. This is further supported by the fact that detection of the fast electric field waveform was triggered at 14:45:06.995 that is 180 ms prior to the abrupt termination of TGE.

The electric field measurements are fed to the myRio board by the TCP-IP connection (WiFi) scaled ~ 5 times less than the firmware application provided by Boltek via Internet cable (Pokhsraryan, 2016). It explains ~5-fold decrease of the electrostatic field strength of myRio output.

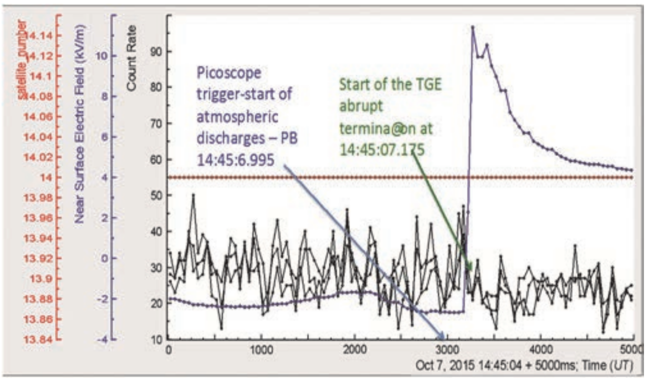

Figure 6. Five seconds of 50 ms time series of all 3 layers of the STAND1 detector (located near SKL hall) before and after sharp decline of particle flux at 14:45:07.225. The flux decline coincides with an abrupt increase (100 ms rise time) of the near-surface electrostatic field. 14 GPS satellites participate in the precise time synchronization.

4. TYPE OF ATMOSPHERIC DISCHARGE ABRUPTLY TERMINATING TGE

We add to the already published 5 TGE events terminated by lightning that occurred in 2014 (Chilingarian et al., 2015) 5 new TGE events observed in 2015 and 2 old events from 2013 and 2012 found in the databases. The goal of our analysis is the identification of the discharge type for all 12 TGEs.

First of all we can claim that only negative discharges terminate TGEs (see for instance, Chilingarian, Hovsepyan and Mnatsakanyan, 2016). However the question still to be answered is: are these discharges intracloud ones (IC-), or cloud-to ground (CG-)? In our analysis we will use the data from the network of near-surface electric field sensors, photographs from lightning monitoring cameras and data from the World Wide Lightning Locating Network (WWLLN).

All 12 TGE events terminated by an atmospheric discharge are shown in the Fig. 7. The abrupt decline of TGE is shown in the 1-second time series of count rates of 3-cm thick outdoor plastic scintillator of STAND1 detector. In 2012-2014 years the data from STAND1 near MAKET experimental hall was used (Fig 7 e-h); in 2015 – the data from STAND1 detector near SKL experimental hall (Fig 7 a-d). For all 12 TGEs the disturbances of electrostatic field and distances to lightning performed by the EFM-100 electric mill located on the roof of MAKET hall were used.

In the Tab. 1 we summarize characteristics of TGE events interrupted by lightnings. As we can see from Fig. 7 lightning occurred in the same second with the count rate decline. Negative lightning in the disturbances of near-surface electrostatic field is seen as abrupt positive change of the field with subsequent slow recovering.

Table 1 contains essential parameters of the selected TGEs. In the first column we put the date of the event, in the second – time of start of the abrupt change of electric field and corresponding value of the electrostatic field. In the third column we put the time and value of the reached maximal electric field. The fourth and fifth columns show the rise time (from start to maximum) and recovery time (Full width at half maximum - FWHM) of the measured disturbed electrostatic field respectively. In the sixth column we show the drop of the particle detector count rate. The seventh column shows the drop of electric field (difference between maximal and start values). The next two columns show the distance to lightning estimated by electric field mill EFM-100 and WWLLN, respectively. The WWLLN time stamp of detected lightning is shown in the last column. In the last 2 rows of the Table we show calculated values of measurements means and mean standard deviations (MSD). The typical features of the negative cloud-to-ground (-IC) lightnings terminated TGE are:

1. Mean rise time of the near-surface electrostatic field ~ 242 ± 88 ms;
2. Mean field recovery time (FWHM) ~ 4.3 ± 2.3 sec;
3. Mean particle flux drop – 37 ± 23%;
4. Mean field surge –60 ± 19 kV/m;
5. Mean distance to lightning ~ 5.3 ± 2.9 km.

Very large amplitude of the negative lightning field changes (~60 kV/m) achieved in very short time (~242 ms) and large recovery time of electric field (4.3 sec) indicate strong discharge processes at nearby distances (up to10 km) in the thunderclouds above Aragats.

To determine the type of lightning we incorporate in our analysis another type of evidence from the network of electric mills. Since our network is rather lengthy, extending from top of Aragats to Yerevan (~ 40 km) for the classification of the discharge types we can use the criterion described by (MacGorman and Rust, 1998), see also (Krehbiel et al., 2014). When measuring the disturbances of the electrostatic field by network of sensors, the electrostatic field can reverse polarity with distance from the lightning in case of the intracloud discharges (IC), whereas for the CG ones the polarity remain constant. All 12 lightnings (with exception of one not reliably classified event) did not reverse the polarity in the domain of electric mill network. Examples of IC lightning changing polarity with distance and confirming the type by the simultaneous photographs are shown in Figs. 8 and 9. Therefore we conclude that only – CG lightnings terminate the TGE.

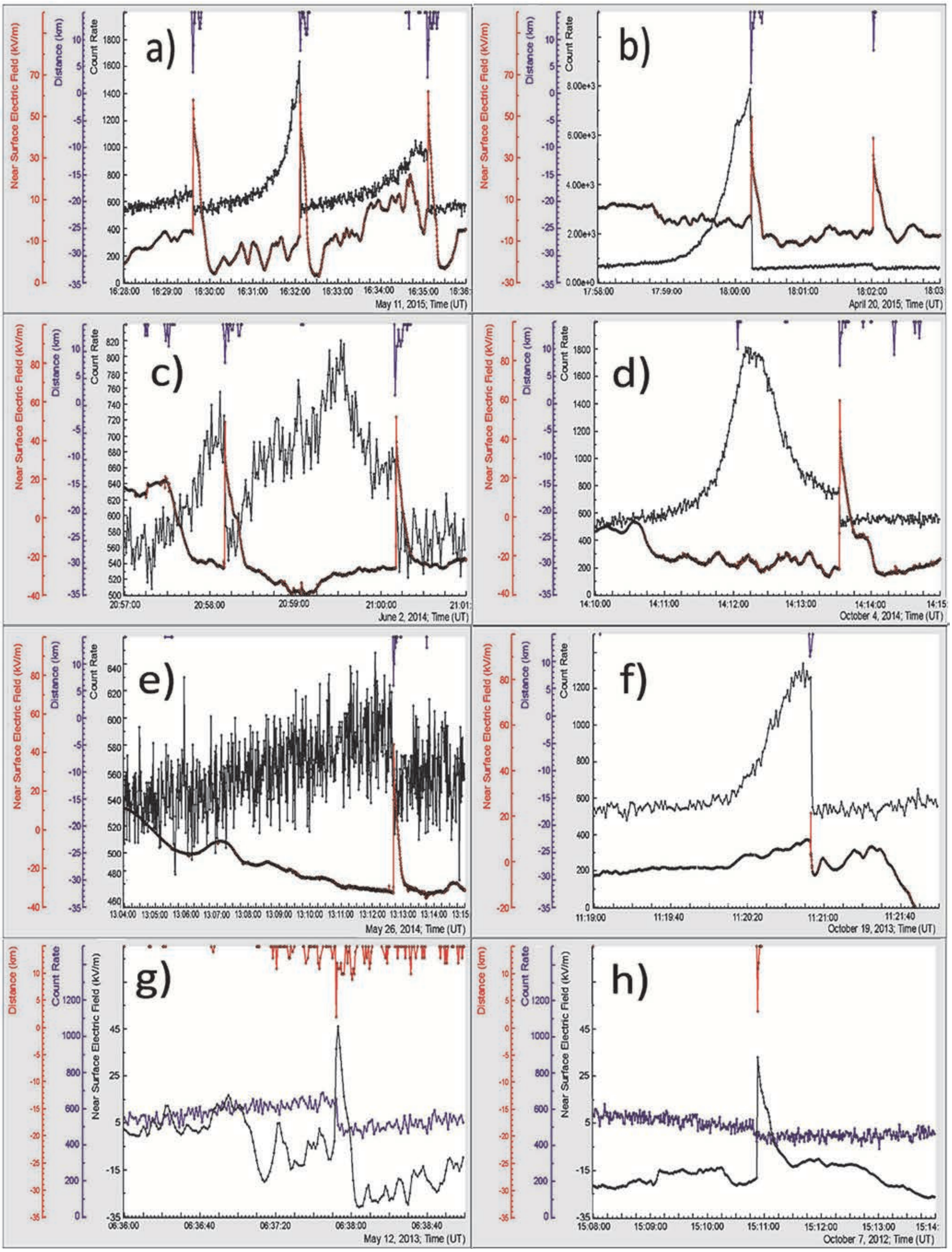

Figure 7. Time series of the 1 second count rates of the outdoor 3 cm thick scintillator sharply terminated by the lightning and disturbances of the near-surface electric field; in the top of figures the distance to lightning from particle detectors is shown. Electrostatic field and distance to lightning are measured by the EFM-100 electric mill located on roof of the MAKET experimental hall. Particle count rate was measured by the 3-cm thick scintillator of STAND1 detector located outdoors the SKL experimental hall and(a-d) and MAKET experimental hall (e-h).

Table 1. Main parameters of the TGE events terminated by lightnings

Date	Start of lightning (UT) and el. field value kV/m	Time of max-imum (UT) and el. field max value kV/m	Rise time (ms)	Decay time fwhm sec	Drop of flux %	Surge of el. field kV/m	EFM Dist. km	WWLLN Dist km	WWLLN time (UT)
11/05 2015	16:29:36.380 -5.7	16:29:36.580 57.3	200	8	24	63	4.0	0.6	16:29:36.337
11/05 2015	16:32:06.550 -6.5	16:32:06.800 60	250	6	70	66.5	7.9	13.7	16:32:06.521
11/05 2015	16:35:06.550 5.5	16:35:06.800 61.5	250	5	44	56	2.9	4.2	16:35:06.534
20/04 2015	18:00:14.1001.2	18:00:14.350 49.2	250	1.1	91	48	2	6.7	18:00:14.757
20/04 2015	18:02:01.100 -3.4	18:02:01.300 39.2	200	1.2	25	42.6	7.8	N/A	N/A
4/10 2014	14:13:32.400 -25.5	14:13:32.550 58.5	150	5	32	84	6.8	N/A	N/A
2/06 2014	20:58:10.050 -25.2	20:58:10.350 48.8	300	4	24	74	7.8	N/A	N/A
2/06 2014	21:00:11.000 -23.2	21:00:11.000 52.2	350	4	22	75.4	2	N/A	N/A
26/05 2014	13:12:41.500 -32	13:12:41.800 43.6	300	7	13	75.6	6.3	N/A	N/A
19/10* 2013	11:20:53.000 9.3	11:20:53.050 21.1	50	0.05	58	11.8	11	4.9	11:20:53.392
12/05 2013	06:37:52.000 -10	06:37:53.000 45.6	400	4	20	55.6	2	N/A	N/A
7/10 2012	15:10:53.000 -17.9	15:10:53.000 50.2	200	6	22	68.1	2.9	N/A	N/A
Mean	-11.1	49	242	4.3	37	60.0	5.3		
MSD	12.8	11	88	2.3	23	19	2.9		

**According to measurements of the electric mill located near GAMMA array the lightning was much closer and amplitude of near-surface electric field disturbances was much larger. Unfortunately, lightning kills this electric mill and it is another evidence along with staff reports that lightning was much closer than 11 km.*

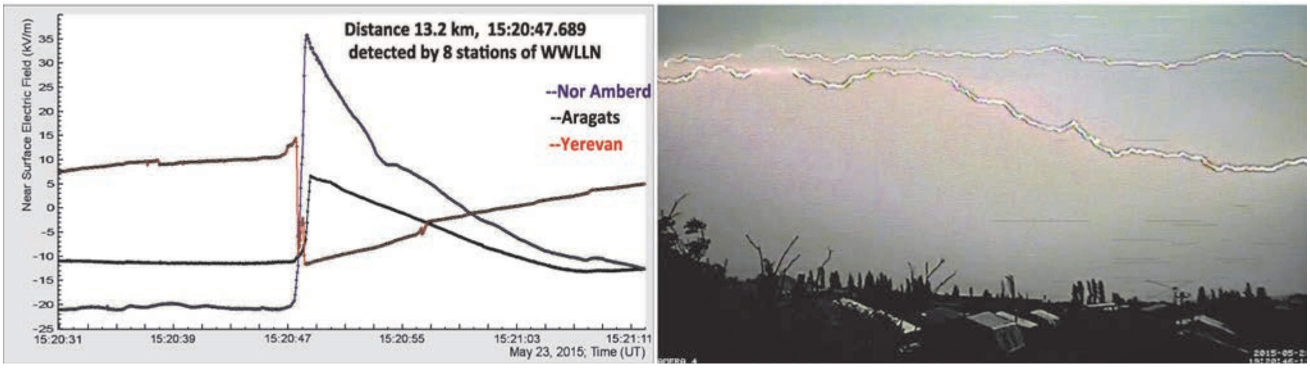

Figure 8. The disturbances of the near-surface electric field due to intracloud lightning shown on the photograph shot at Burakan village in direction of Mt. Ararat. On the top are shown the measurements of the near-surface electric field performed by the EFM-100 electric mills located at Aragats, Nor Amberd and Yerevan. Polarity reversal of electrostatic field change for the negative IC flash is apparent.

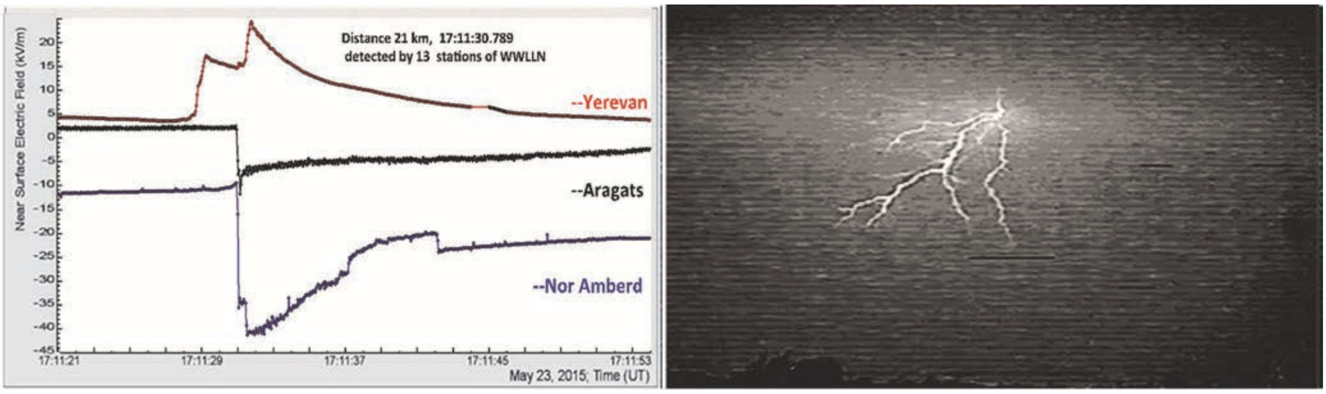

Figure 9. The disturbances of the near-surface electric field due to intracloud lightning shown on the photograph shot at Burakan village in direction of Mt. Ararat. On the top are shown the measurements of the near-surface electric field performed by the EFM-100 electric mills located at Aragats, Nor Amberd and Yerevan. Polarity reversal of electrostatic field change for the negative IC flash is apparent.

5. DISCUSSION AND CONCLUSIONS

We analysed TGE events abruptly terminated by the lightning discharge. The new fast electronics recently installed at Aragats allowed synchronization of particle fluxes, measurements of the near-surface electrostatic field and electric field waveforms on the millisecond time scale. By examining 13 TGE events, we have found that the atmospheric discharges that terminated the TGE at Aragats all are cloud-to-ground negative lightnings.

On 7 October 2015, ASEC particle detectors fixed a large TGE event. One-minute time series of low-threshold detectors demonstrate a huge enhancement equivalent to ~ 100 standard deviations. The differential energy spectrum of gamma rays extends till 30 MeV and more. The strong negative lightning seen as an abrupt enlarging of the near-surface electrostatic field with an amplitude of ~ 70 kV/m terminates the particle flux. On the 50 ms time scales we can see that the TGE decay started simultaneously with abrupt increase of the near-surface electrostatic field. Therefore, the initiation and termination of TGE is directly connected with rearranging of charged structures in the thundercloud, the most important of which is development and decay of the LPCR.

In (Chilinarian et al., 2016) we demonstrate that 3 electrostatic fields from the tripole structure of the electrified thundercloud contribute to the resulting field that accelerates electrons downward. The LPCR, as the nearest to the Earth positively charged layer has the biggest impact on the development of the resulting accelerating field and hence, on the TGE initiation.

We assume that the magnitude of accelerating field and hence, the particle flux intensity depend on the matureness (thickness) of LPCR. At the maximum of particle flux the LPCR is mature and thick, whereas at the beginning and at the decay phase the LPCR is thin.

12 TGEs terminated by lightning (Fig. 7) were equally distributed by 3 categories: terminated in the beginning, at maximum and on decaying phase (four TGEs in each category). It contradicts the model of the LPCR development and decay presented in (Nag and Rakov, 2009). According to their model, the negative lightning leader can penetrate LPCR only on its decaying phase. The mature LPCR do not allow the negative leader to punch throw and change it to intracloud lightning. Thus, maybe there are another players that influence the lightning initiation much more than the thickness of LPCR; i.e. the very large EAS occasionally hitting the cloud and unleashing –CG by the RB-EAS mechanism (Gurevich et al., 1999).

Based on TGE events detected on Aragats we conclude that only negative cloud-to-ground lightnings terminate TGEs and the particle flux decline starts after lightning strikes and rearrangement of the electric field in the cloud took place. Lightning can terminate TGE in the beginning, on the decaying phase or at maximum of development with equal frequencies. Only nearby lightnings (within 10 km) can terminate TGE.

ACKNOWLEDGEMENT

The authors thank the staff of the Aragats Space Environmental Center for the uninterruptible operation of Aragats research station facilities. The data for this paper are available via the multivariate visualization software ADEI on the WEB page of the Cosmic Ray Division (CRD) of the Yerevan Physics Institute, http://adei.crd.yerphi.am/adei. The first large TGEs were observed with renewed ASEC facilities in the beginning of October 2015 during the 5-th annual workshop TEPA-2015 (Thunderstorms and elementary particle acceleration). The natural "electron accelerator" on Aragats provided several interesting events during the conference time, which became the subject of intensive discussions among the participants. Authors thank the workshop participants E.Mareev, H.Gemmeke, M.Briggs, N. Kelley and others for useful discussions and valuable comments. The authors wish to thank the World Wide Lightning Location Network (http://wwlln.net), collaboration among over 50 universities and institutions, for providing the lightning location data used in this paper. The expedition to Aragats high altitude station was supported by the Armenian government grant N13-1C275.

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