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Atmospheric-electric effects from volcano eruptions on Kamchatka peninsula (Russia)

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ABSTRACT

For registration of electric field strength of the atmosphere (E_Z EPA) on the peninsula of Kamchatka in points Kluchi (KLYG) and Kozyrevsk (KZYG) electrostatic flux meters of land basing operate. Thanks to wind stratification the eruptivny clouds from strong explosive volcanic eruptions on 16.12.2016 and 14.06.2017 have passed Shiveluch over these points, and we found a call on the records E_Z EPA. Considerable signal amplitude > 1.0 kV/m allowed to select surely it against the background of noises caused by the variations of meteorological values. During forming of an eruptivny cloud from eruption of 14.06.2017 within 13 minutes the flow of electromagnetic impulses from discharges ("a volcanic lightning") was registered. The studying by remote methods of electrostatic electricity in the eruptive clouds is the perspective direction for obtaining information on development the eruptive clouds and processes of their electrization.

Key words: volcano, explosive activity, volcanic lightning, atmospheric electric field, voltage gradient

1. INTRODUCTION

Long-term continuous observations of electric field potential gradient in the atmospheric near-ground layer, which determines the atmospheric electric field vertical component strength (AEF E_Z), are the experimental basis for the investigation of local electric effects in the atmosphere. Atmospheric electric field (AEF) is a sensitive indicator of high-energy processes occurring both in the atmosphere and in the ionosphere. AEF parameter variations are bounded not only by cloud structures and lightning strokes which mainly form the global electric circuit (Williams, 2009), but other relations of local atmospheric electric field with such geodynamic processes as earthquakes and volcano eruptions are known (Buzevich et al., 2003; Ponomarev et al., 2011; Cherneva, Firstov, 2018).

Explosive activity of Kamchatka volcanoes when volcanic ash is emitted into the atmosphere, forming eruptive clouds, is one more local source of air-born electric structures in which «volcanic lightning» is generated. Volcanic plumes, stretching for hundreds of kilometers in some cases, carry a powerful electric charge which can be recorded by ground-based instrumentation. When controlling the AEF E_Z in the near-ground layer, we can detect eruptive clouds even poorly saturated by aerosol particles of finely dispersed ash (Mather, Harrison, 2006).

In the paper (McNutt, Williams, 2010) a post-event analysis of lightning strokes for 212 explosive eruptions was performed and their relation with Volcanic Explosivity Index was shown (VEI51[2]). It was detected that static electricity plays an important role even during weak eruptions as long as less than 2% fell on the eruptions with VEI=6, about 10% fell on the events with VEI =3-5 and 82% fell on the eruptions with VEI=1-2. Moreover, strokes from volcanic lightning are the eruptive cloud propagation paths (Thomas et al., 2008, Firstov et. al, 2017).

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2 VEI – Volcanic Explosivity Index characterizing the erupted pyroclastics volume 0.0001<(VEI=1)<0.001 km3; 10<(VEI=6)<100 km3.

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Natural observations carried out at a Large Fissure Tolbachik Eruption (LFTE) in Kamchatka in July-October 1975 (Rulenko, Tokarev, 1979) and at Sakurajima volcano (Japan) during the eruption in 1995 (James et al., 1998; Miura et al., 2002) allowed one to make a qualitative description of eruptive cloud charge configuration (Fig. 1). AEF E_Z values could change both in sign and in magnitude. During the LFTE, the AEF E_Z maximum/minimum values reached the measuring instrumentation limit of ± 30 kV/m (Rulenko, Tokarev, 1979).

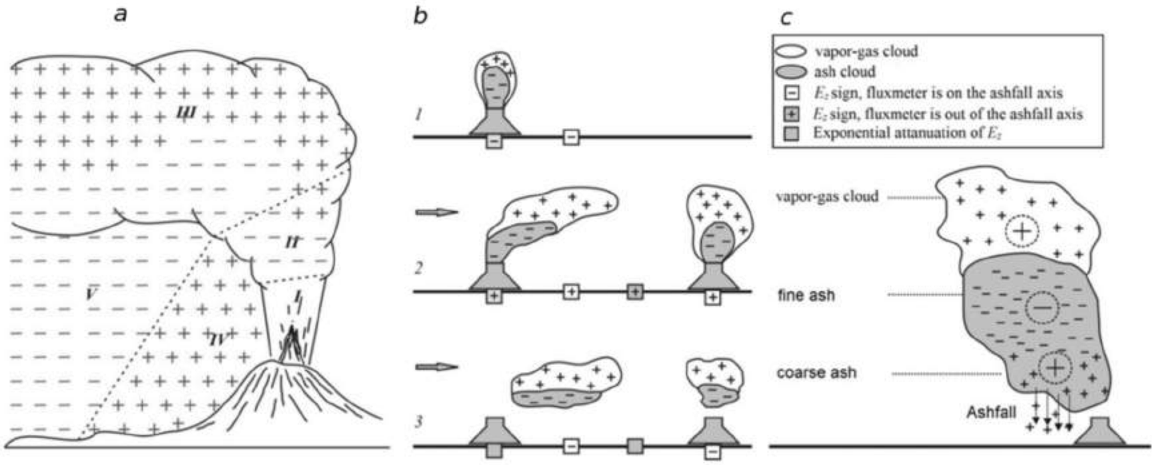

Figure 1. Schematic models of electric structure formation in an eruptive cloud. a – in the near-field zone [Rulenko, 1994]; b – schemes of charge separation during volcanic plume formation under the wind effect based on [Miura et al., 2002]; c – charge separation in eruptive clouds based on natural observations on Sakurajima volcano [James et al., 1998]. I – charge separation under the effect of gravity forces at the initial section during weak wind; II – cloud formation at the auto-modeling section under the wind effect; III – plume in the buoyancy zone; IV – coarse fraction precipitation area; V – tephra precipitation area.

It was shown in the papers (Rulenko, Tokarev, 1979; Miura et al., 2002; Mather, Harrison, 2006) that magma fragmentation (breakage) plays a major role at the first stage of eruptive cloud electrization. At the second stage, particles of different sizes are separated in the eruptive column and in the forming eruptive plume. That causes their bipolar charging and spatial charge separation in an eruptive column and in the ash fall region under an eruptive cloud plume. In the first case, the separation is determined by aerodynamic drag during gas-ash steam injection into the atmosphere. In the second case, it is the result of gravity differentiation. It is possible that among many physical and physical-chemical process of charge generation and separation in a volcanic cloud, thermoionic emission and thermoelectrics contribute significantly.

As an eruptive cloud moves away from an eruption center, ash coarse fraction is falling and aerozoles are being formed that causes its charge configuration change (Fig. 1c).

In the paper, we present some data of AEF E_Z recording during eruptive cloud passage on Kamchatka peninsula and consider the directions for future investigations of atmospheric-electric effects from volcanic eruptions on Kamchatka peninsula (Russia).

2. METHODS OF OBSERVATIONS

The Northern Group of Volcanoes on Kamchatka peninsula is a unique object for investigation of eruptive cloud electrization (Fig. 2). During appropriate wind directions, frequent explosive eruptions of andesitic Shiveluch and Bezymyanniy volcanoes increase the probability of eruptive plume passage over Klyuchi and Kozyrevsk villages where the fluxmeters (KZYG and KLYG, Fig. 2) are installed. The first results obtained from these sites data are presented in the papers (Firstov et al., 2017; Shevtsov et al., 2016).

A fluxmeter EF-4 (KZYG) and its prototype with wider dynamic range (KLYG) were used [Efimov et al., 2013]. Application of a powerful compact ac electronic motor and surface mounting allowed us to realize the device in a rectangular housing with the dimensions of 120×200×45 mm. It has low power consumption that is very important for creation of a self-contained network of AEF E_Z recording sites to monitor volcanic explosive activity in Kamchatka. To protect the equipment mechanical part from dense and very wet snow («ice snow») and volcanic ash, the fluxmeters were mounted with their shutters downwards.

The signals in AEF E_Z records from eruptive clouds were selected on the basis of data integration from seismic, infra-sound and satellite monitoring of Kamchatka volcano activity. A radiotelemetric seismic station network (RTSS) of Kamchatka Branch of the Federal Research Center «Geophysical Survey of RAS» (FRC GS RAS) is in operation in the region of Sheveluch volcano. Seismic data from RTSS «Semkorok» (SMK) were used in the paper. It is located 9 km from the Shiveluch volcano crater. At two seismic stations (KLYA, KZYA) the sensors record infra-sound in the frequency range of 0.03-10 Hz [Makhmudov et al., 2016] and video observations are carried out. Processing of digital data obtained from the RTSS and infra-sound channels is performed by DIMAS interactive software [Droznin, Droznina, 2010].

Within the «KVERT» Group of the Institute of Volcanology and Seismology (IVS) FEB RAS, satellite monitoring of Kamchatka volcano explosive activity is carried out in real time mode by Uniskan-36 receiving station [Gordeev, Girina, 2014]. The complex approach based on geophysical and satellite methods allowed them to select the signals in AEF E_Z which are determined by the passage of gas-ash clouds from Shiveluch volcano eruptions.

Eruptive clouds are formed and propagate by atmosphere stratification effect. Balloon sounding is carried out twice a day at the meteorological observatory «Klyuchi» of Kamchatka Office on Environment Hydrometeorology and Monitoring. These data give us the possibility to determine eruptive cloud direction and propagation velocity from the explosive eruptions of the Northern Group volcanoes (http://www.esrl.noaa.gov/raobs/intl/intl2000.wmo). The «Klyuchi» observatory is located 48 km to the south-west from Shiveluch volcano (Fig. 2).

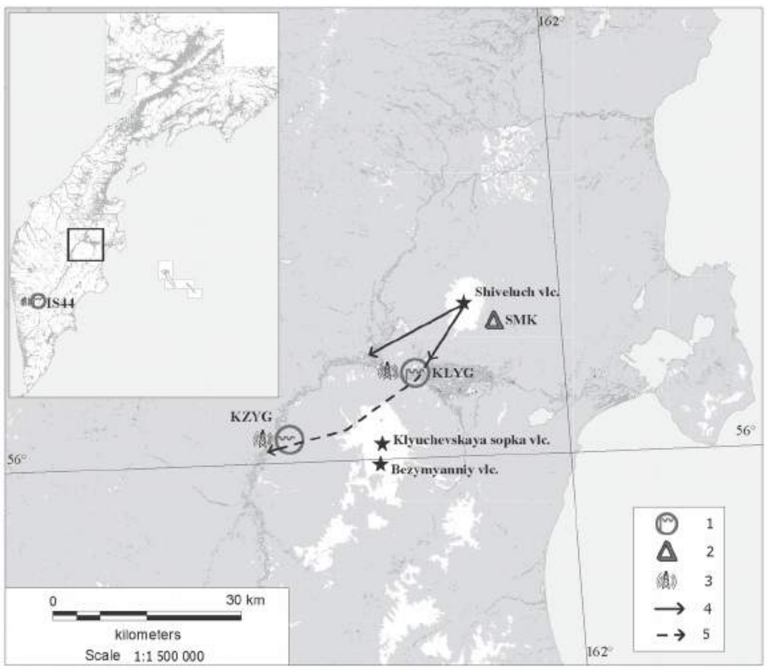

Figure 2. Locations for AEF strength and infra-sound waves observation sites in the region of the Northern Group of Volcanoes and eruptive cloud path from two eruptions of Shiveluch volcano having responses in AEF E_Z. Locations of the instrumentation: 1 – fluxmeter, 2 - radiotelemetric seismic station, 3 – microbarograph; trajectories of eruptive formations during the eruptions on 4 – December 16, 2016 and 5 – June 14, 2017. The inset illustrates the location of the Northern Group of Volcanoes and «Paratunka» observatory on Kamchatka peninsula.

At present, the World Wide Lightning Location Network (WWLLN) is widely used to observe lightning. It allows us to record electromagnetic pulses (EMP) from lightning strokes over the globe [Rodger et al., 2006]. As long as WWLLN network sites are located at large distances from Kamchatka and record only powerful lightning strokes, it observes ~10% of lightning strokes recorded at the same region by a electromagnetic signal direction-finder in the very low frequency range (VLF) [Druzhin et al., 2011]. Lightning strokes are monitored by a VLF direction finder, included into the WWLLN network, at «Paratunka» observatory of the Institute of Cosmophysical Research and Radio Wave Propagation (IKIR) FEB RAS. The direction finder consists of two perpendicularly arranged frame antennas, oriented in the north-southern and east-western directions, and a rod antenna. The frame 100-coil antennas have the dimensions of

4x8 m, and the rod antenna is 5 m high and is mounted on a building roof. Electromagnetic pulses are recorded in the range of 0.5-60 kHz exceeding the threshold level of 1 V/m. The VLF direction finder allows us to record electromagnetic radiation from regional thunderstorms and to locate the azimuths of their arrivals.

3. RESPONSE IN AEF EZ DURING ERUPTIVE CLOUD PASSAGE FROM EXPLOSIVE ERUPTIONS OF SHIVELUCH VOLCANO

Based on the FRC GS RAS data, during the Shiveluch volcano eruption at 22:31[3] on December 16, 2016 (http://www.emsd.ru/~ssl/monitoring/main.htm), the eruptive cloud height was 5.6 km. It was estimated from the seismic signal intensity. On satellite images (Fig. 3a, 3b), the eruptive cloud moved under the wind effect with the azimuth of ~ 75° and with the velocity of ~17 m/s that corresponded to the wind azimuth and velocity at the height interval of 6.5-8.0 km according to atmosphere stratification (Fig. 3b).

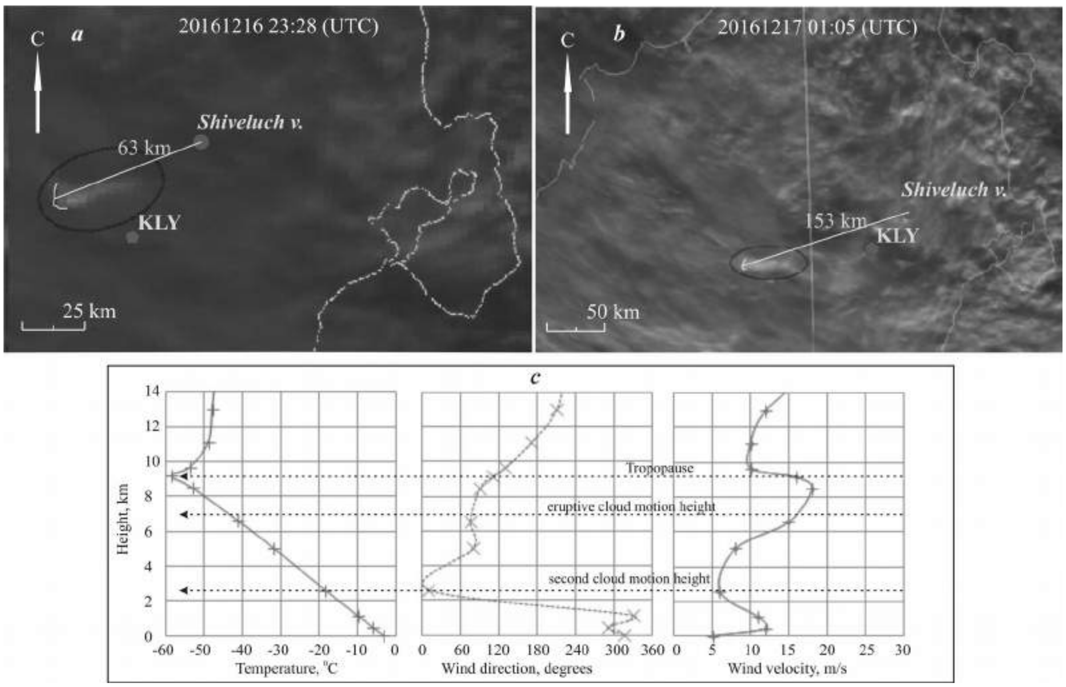

Figure 3. Eruptive cloud propagation from Shiveluch volcano eruption at 22:31 on December 16, 2016 and atmosphere stratification according to the data of balloon sounding at Klyuchi meteorological station. a, b – satellite images (TerraMODIS) of eruptive cloud obtained in real time mode at Uniskan-36 receiving station (IVS FEB); c – temperature and wind stratification of the atmosphere at 00:00 on December 17, 2016.

In this case, ash should not have fallen in Klyuchi village. However, about two hours later, ash fall began. Its intensity was ~ 20 g/m2. The second eruptive cloud, involved in the ash fall, should have been carried by the wind with the azimuth of ~ 45° and velocity of ~ 5 m/s that corresponds to the atmosphere stratification at the height of 2.5 km (Fig. 3c). Such an eruptive cloud is not observed on satellite images.

Reliable remote methods for volcanic explosive activity monitoring are seismic and infra-sound ones. While the former gives us the information on explosive process intensity and duration, the latter indicates the degree of its nonstationarity and the intensity of ash release into the atmosphere.

Explosive earthquake (EE) at RTSS SMK with the duration of ~15 minutes, accompanying the explosion on December 16, 2016, is rather weak (Amax=4 µm/s) and is significantly noised (Fig. 4a). The acoustic signal was not observed on the microbarograph records at the nearest KLYA site. On the whole, this explosion may be characterized as a «blowdown» that means longtime ash-gas mixture outflow.

The ash fall at Klyuchi village was accompanied by a negative single-pole anomaly in AEF with the minimum value of -1.23 kV/m and total duration of ~45 minutes (15 minute leading edge and 30 minute back edge). Based on the form of

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the anomaly back edge in AEF E_Z [Cherneva et al., 2007], we can assume that the eruptive cloud was a thin aero-electric formation moving horizontally at the height of 2.5 km. Owing to the eolian differentiation, the cloud gained significant horizontal size of ~9 km, which was estimated by the AEF E_Z anomaly back edge duration and wind velocity at the height of 2.5 km.

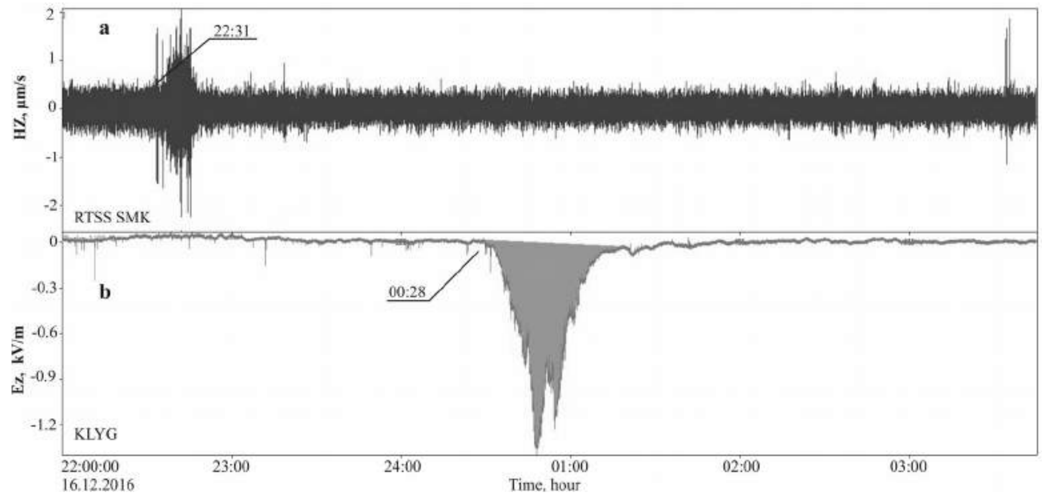

Figure 4. Record of seismic signal vertical component at RTSS SMK (b) and the response in AEF E_Z during the eruptive cloud passage (c). Grey color indicates the response in AEF E_Z on the second eruptive cloud passage.

Based on the FRC GS RAS data, during the Shiveluch volcano eruption at 16:26 on June 14, 2017 (http://www.emsd.ru/~ssl/monitoring/main.htm), the eruptive cloud height, estimated by the seismic signal intensity, was ~12 km. It is clear from the satellite images (HIMAWARI-8 data from Regional and Mesoscale Meteorology Branch NOAA/NESDIS, http://rammb.cira.colostate.edu/) that 34 minutes after the eruption, almost round eruptive cloud with the diameter of ~70 km was formed at the height of 9 km (Fig. 5a). Then, according to wind stratification, the eruptive cloud moved to Klyuchi village with the velocity of 12 m/s (Fig. 5a, 5b, 5c). Formation of an eruptive cloud during the first minutes after the explosive eruption beginning was recorded at KLYG station by a video camera which monitors Shiveluch volcano activity (Fig. 5d). Almost one hour later, the eruptive cloud covered Klyuchi village where about 100 g/m^2 of ash fell (Fig. 5e). After that the eruptive cloud moved in the direction of Klyuchevskoy volcano (Fig. 5f). At 21:33 the eruptive cloud reached Kozyrevsk village where finely dispersed ash fall was observed.

At RTSS SMK, an explosive earthquake accompanying this eruption lasted for about ten minutes. The equipment bounded by the dynamic range could not record the ground vibration rate maximum amplitude but we can assume that its amplitude exceeded Amax> 400 µm/s (Fig. 6a).

The eruption was accompanied by an air shock wave (ASW) which developed into an infra-sound one with distance and was recorded by all microbarographic channels on Kamchatka peninsula. The delay time relatively the seismic channel at RTSS SMK, which can be considered as the eruption beginning, was 2.19 minutes for KLYA (Fig. 6b).

Thus, the explosion on June 14, 2017 began with a strong burst after which the ash-gas mixture was outflowing from the volcano crater for 10 minutes.

The successful combination of «fair weather conditions» with wind direction during the eruption on June 14, 2017 allowed us to record the AEF E_Z response when eruptive cloud passed over Klyuchi and Kozyrevsk villages. AEF E_Z decrease to -6 kV/m began from the time of ash fall at Klyuchi which was followed by a sharp increase of AEF E_Z to +5 kV/m (Fig. 6c). Significantly larger amplitude of the negative phase compared to the first case agrees with significant amount of ash (~100 g/m2) which fell out at Klyuchi village.

In the paper [Cherneva et al., 2007] the authors calculated the response in AEF E_Z from bulk charges with simple configuration transported by wind and located over the conducting surface and presented model curves in dimensionless quantities. The form of the anomaly under consideration reminds the change of AEF of horizontal dipole the axis of which is oriented along the motion and which passes recording site. Evidently, the dipole is formed owing to the eolian differentiation when ash coarse particles were negatively charged in the front part of the eruptive cloud and the rest aerosol part of the cloud was positively charged.

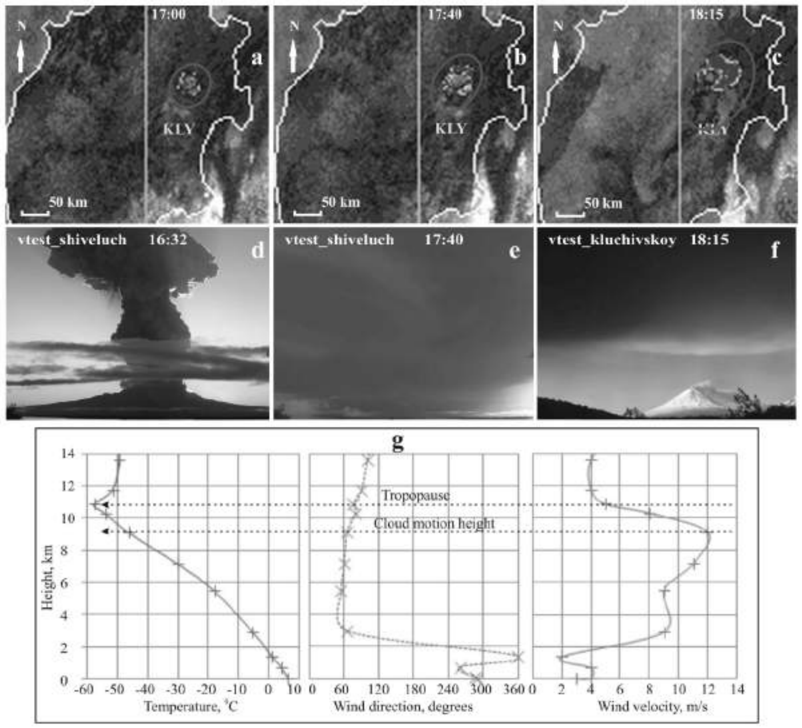

Figure 5. Propagation of eruptive cloud from Sheveluch volcano eruption at 16:26 on June 14, 2017 according to satellite HIMAWARI-8 image data (a, b, c) (http://rammb.cira.colostate.edu); eruptive cloud development recorded by a video camera (d, e, f); temperature and wind stratification of the atmosphere according to the data of balloon sounding (g).

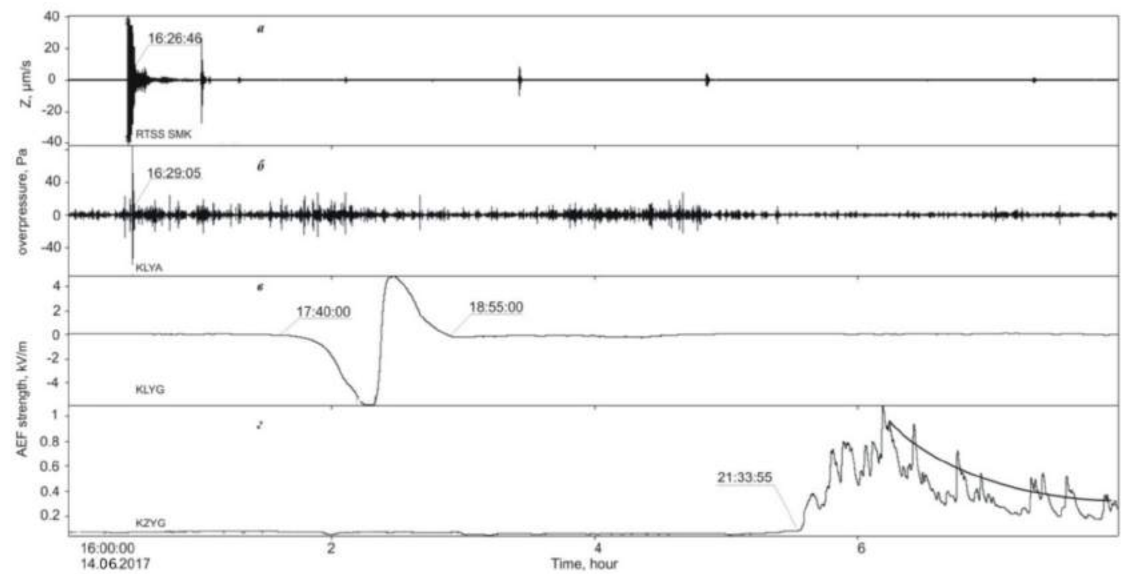

Figure 6. Record fragments: ground shift velocity of the vertical component at RTSS SMK (a); overpressure in the atmosphere at KLYA (b), AEF strength at ELYG (b) and KZYG (d) in time vicinity of Shiveluch volcano eruption on June 14, 2017.

Based on the atmosphere stratification and anomaly traveltime parameters, we can estimate dipole parameters: the motion begins 40 km from KLYG; dipole motion velocity is 36 km/h; height of the dipole center above the ground is z=9 km; distance between the charges is 2.5 km. By reference to these parameters, we calculated the dipole charge q in first approximation by the formula:

$E_Z=2q/4\pi\varepsilon_0 z^2,\ \ q\approx 40\ C,$

where $\varepsilon_0= 8.85\cdot 10^{-12}\ C\cdot V^{-1}\cdot m^{-1}$ is the electrical constant.

The eruptive cloud reached Kozyrevsk village almost in 5 hours. Insignificant finely dispersed ash fall was observed there. The fluxmeter at KZYG recorded an anomaly with $E_{ZMAX}\approx 1$ kV/m. Based on the record form, the anomaly back edge corresponds to a positively charged cloud [Cherneva et al., 2007]. This phenomenon indicates the fact that during the propagation at large distances within the process of eolian differentiation, eruptive cloud develops into an aerosol cloud with insignificant amount of very fine ash.

4. LIGHTNING ACTIVITY ACCOMPANYING SHIVELUCH VOLCANO ERUPTIONS

To detect the lightning activity generated during Shiveluch volcano eruptions, we analyzed the data of WWLLN network and VLF direction finder of «Paratunka» observatory for the period June 14-19, 2017. Besides the eruption on June 14, another eruption occurred on June 18 at 16:26 within the same period. During that eruption the eruptive cloud, carried by wind in east-south-eastern direction, ascended to the tropopause height (11 km). At 19:50 the plume from the cloud was 30 km from the volcano and covered the area of 130×60 km (http://www.emsd.ru/~ssl/monitoring/main.htm). As long as the plume moved quite far from KLYG, a response in AEF E_Z was not observed.

Fig. 7 shows the sources of lightning strokes based on WWLLN data for the period under consideration. According to WWLLN data, we did not record any EMP during the eruptive cloud formation on June 14 and only 5 strokes during the eruption on June 18.

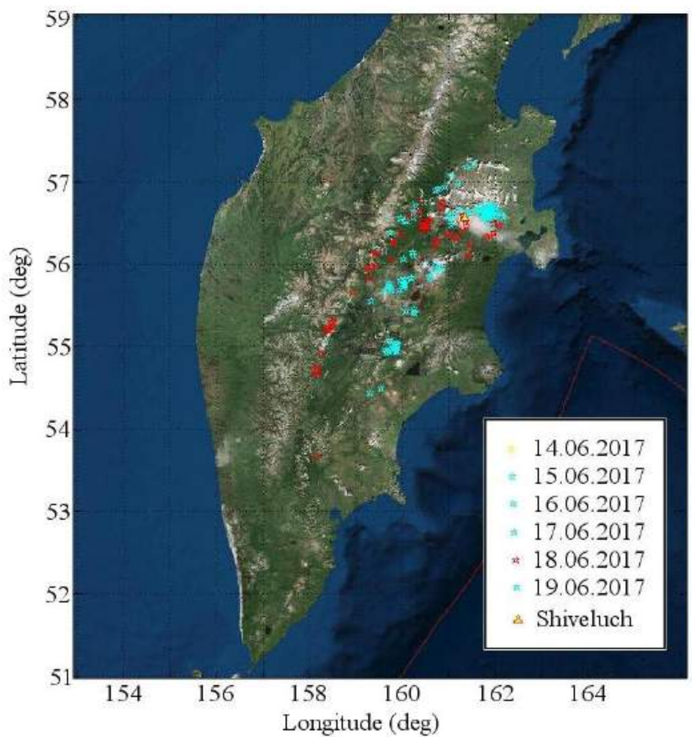

Figure 7. Lightning stroke sources on Kamchatka peninsula for the period June 14-19, 2017 based on WWLLN data.

According to the data of VLF direction finder from 16:26 to 16:52, EMP bursts were observed in the sector with the azimuths of 14.6°-32.7° on June 14 and 18. The maximum counting rate in both cases was observed from the azimuth to Shiveluch volcano (25.6°). Moreover, the duration and the peculiarities of the burst time structure are not characteristic for EMP of atmospheric-lightning origin. In spite of the fact that thunderstorm duration varies in a wide range, the average life time of atmospheric thunderstorm is more than 30 minutes, as a rule. During the eruption on June 14, 68 EMPs were recorded for 26 minutes from the azimuthal direction to Shiveluch volcano region (25.6°± 10°). Electromagnetic pulses had a form of a balanced bipolar pulse typical for close lightning. Thus, with great probability we can assume that the mentioned lightning activity is determined by eruptive cloud formation and development that means that it is «volcanic lightning» (Fig. 8a).

The counting rate burst form for «volcanic lightning» has two clearly defined maxima in both cases (Fig. 8b). Under the effect of gas pressure and eruptive product uplifting at the beginning of the eruption, eruptive column is formed and lightning strokes occur which form the first maximum with the duration of ~ 3 minutes. Intensity of this segment is determined by the process which is also characterized by seismic and acoustic radiation. During the eruption on June 18, an infra-sound wave was not observed and the maximum value of the counting rate was 12 pul/min against 17 pul/min during the eruption on June 14.

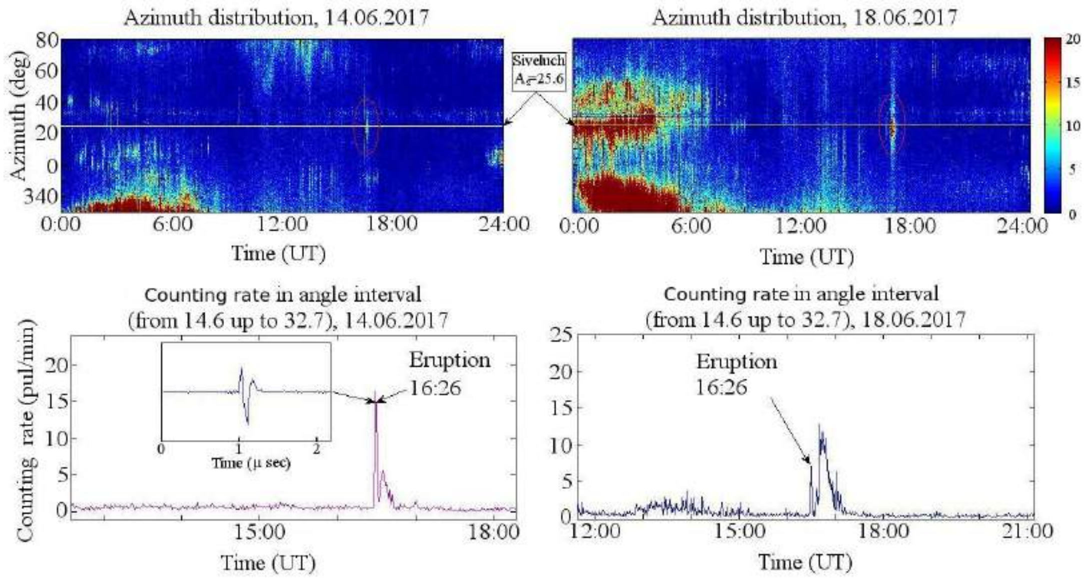

Figure 8. EMP counting rate in the angle interval of 0.1° which arrived from the sector with the azimuth of 340°-80° (a), and EMP counting rage from the azimuth to Sheveluch volcano region (14.3°-32.7°) (b).

The second part has a sharp increase of the leading edge and almost exponential decrease of the back one. Evidently, this part is an indicator of lightning activity in a cloud which reached a buoyancy zone and is moving under wind effect. Its intensity is determined by the total amount of blasted-out pyroclastics followed by blowdown during long explosions. Explosive earthquake duration which characterizes the process of pyroclastics release into the atmosphere, was 10 minutes and the maximum counting rate was 6 pul/min in the first case, and about 20 minutes and 12 pul/min in the second case, respectively.

5. CONCLUSIONS

Formation of a new extrusive dome has been observed in Molodoy Shiveluch volcano caldera since 1980. Such a long cycle of volcanic activity gives us the opportunity to study regularly the eruption dynamics. Together with the direct methods for investigation of dome morphology changes, determination of its growth and size changes, other methods are also important. One of such methods may be the investigation of eruptive cloud electization during eruption explosive stages. It has been shown in the paper that atmospheric electric field strength during eruptive cloud passage over KLYG site, which occurred during the explosive eruptions on December 16, 2016 and on June 14, 2017, was -1.2 and -6.0 kV/m, respectively. Such values of AEF E_Z are quite confidently distinguished at the nois background associated with meteorological value variations.

Investigation of EMP from «volcanic lightning» in time vicinity of an eruption is a perspective method for investigation of volcanic cloud electrization processes and determination of its propagation under wind effect.

We should particularly note that electric field strength is recorded remotely that is a positive factor in the research of such volcanoes as Shiveluch on which powerful catastrophic eruptions of «directed explosion» type are possible.

ACKNOWLEDGEMENTS

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