The response of the atmospheric electric potential gradient to the ash clouds of v. Shiveluch and v. Ebeko (Peninsula Kamchatka, Island Paramushir, Russia)

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Abstract. In order to introduce a new method into the complex of instrumental observations for monitoring explosive eruptions, the authors analyze response intensity of the atmospheric electric potential gradient (PG) during the passage of eruptive clouds. In the area of the volcano Shiveluch there are two observation points of PG. Two eruptions of the Shiveluch volcano of various strength that occurred on 16.12.2016 and 14.06.2017 were considered. Ebeko volcano, located near the city of Severo-Kurilsk (7.2 km). During volcanic explosions, ash emissions to a height of 4-5 km occur. Monitoring of the atmospheric electric potential gradient will allow the passage of ash plumes over the city of Severo-Kurilsk to be recorded. The results of field observations for the period October 2018-June 2019 are presented.

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Introduction

The electric field of the atmosphere (EFA) is a sensitive indicator of high-energy processes occurring both in the atmosphere and in the lithosphere. Variations of EPA parameters are limited not only by cloud structures and lightning discharges, which mainly form the global electric circuit [1], but also other connections of the local electric field of the atmosphere with geodynamic processes (earthquakes, volcanic eruptions) [2] are known. During the explosive activity of volcanoes significant volumes of volcanic material (tephra, ash, gases) are emitted into the atmosphere. Aerodynamic structures are formed - volcanic clouds, plumes that carry a powerful electrical charge. Control of PG in the atmospheric surface layer, allows detecting perturbations of EFA associated with these structures [3].

On the Kamchatka Peninsula, the Northern Volcanic Group is a unique object for studying the electrification of eruptive clouds. Four active volcanoes are located here: Shiveluch, Klyuchevskoy is the highest (4,750 m) and productive volcano in Eurasia, Bezymyanny and Plosky Tolbachik (refer with Fig. 1). Ash plumes from explosive eruptions of Shiveluch and Bezymyanny volcanoes can spread over the villages of Klyuchi, Kozyrevsk and Krutoberegovo. Electrostatic sensors are installed in these villages - observation points (OP) KZYG and KLYG, KBGG (refer with figure 1). The first results obtained from these points are given in [4; 5; 6].
Another object for research is the Ebeko volcano. Ebeko volcano (1156 m asl) is located near the city of Severo-Kurilsk (~ 7.2 km). The frequency of eruptions is one of the most active volcanoes of the Kuril island arc. In 2017, the hydrothermal eruption of this volcano began. Such eruptions last 2-4 years. Eruptive clouds of individual explosions rise to an altitude of 3-5 km. Under the action of the wind, they are often demolished in the direction of the city, which is not rarely accompanied by the fall of the ashes. The observation point SKRG was established and is continuously operating since October 1, 2018.

Instrumentation and methods of observation

Since 2013, the Kamchatka Peninsula has a network of observation points PG. Observation points are organized near the Northern group of volcanoes on the basis of the seismological stations of the Kamchatka branch of the Federal Research Center “United Geophysical Service RAS”. In Kozyrevsk (KZVG) it has been operating since 2013. In Klyuk (KLYG) it has been operating since 2016. In Krutoberegovo (KBGG) it has been operating since 2018. In 2018, the observation point PG was organized at the seismic station of the Sakhalin branch of the Federal Research Center “United Geophysical Service RAS” in the city of the North-Kurilsk (SKRG).

Figure 1a shows the network of observation points of PG.

To automate the process of collecting and preprocessing data in 2018, a software-hardware recording complex PG was developed based on the EF-4 electrostatic sensor (electric field mills) [7], ADC E-24, an L-Card company and a Thiner Board microcomputer from Asus [8] (refer with Fig. 1b). This configuration of the software and hardware complex is implemented at all existing observation points, which increases the operating efficiency of the entire observation network PG.

For accurate selection of PG signals associated with the passage of ash clouds, a comprehensive analysis of seismic, infrasound, satellite monitoring of the activity of Kamchatka volcanoes, as well as video and visual observation data was performed.

At the Institute of Volcanology and Seismology (IVS) of the Far Eastern Branch of the Russian Academy of Sciences, the KVERT group in real time, using the Uniscan-36 receiving station, conducts satellite monitoring of the explosive activity of Kamchatka volcanoes [9].

The eruptive cloud is formed and distributed according to the stratification of the atmosphere. At the Klyuch meteorological observatory of the Kamchatka Hydrometeorology and Environmental Monitoring Department, and the Severo-Kurilsk Meteorological Observatory of the Sakhalin Hydrometeorology and Environmental Monitoring Department, balloon sounding is carried out twice.
a day. These data make it possible to determine the direction and speed of the spread of eruptive
clouds from the explosive eruptions of volcanoes of the Northern Group and the Ebeko volcano
(http://www.esrl.noaa.gov/raobs/intl/intl2000.wmo).

Characteristics of individual explosions according to remote monitoring and the study of
variations PG associated with the passage of eruptive clouds

Shiveluch Volcano Eruptions. As a result of the analysis of field data, an event catalog is formed.
A table of parameters of the registered signals is compiled (refer with Table 1). During the period of
observations in 2013–2018, 4 events associated with powerful explosive eruptions were recorded in.
Shiveluch [4, 6].

Table 1. Parameters of V’ EPA signals recorded at ground-based points during the passage of
eruptive clouds from the eruptions of Shiveluch volcano.

| №  | Date       | t₀     | KZYG | KLYG |
|----|------------|--------|------|------|
|    |            |        | polarity | V’, [V/m] | αt, [min] | polarity | V’, [V/m] | αt, [min] | δ, [g/m²] |
| 1  | 14.12.2014 | 10:17:55 | + 170 | 85 | Observation point did not work |
| 2  | 16.12.2016 | 22:31:32 | Cloud passed by | – | –1249 | 51 | 20 |
| 3  | 14.06.2017 | 16:26:37 | +1082 | 140 | –/+ | –5877 / +4820 | 40 / 34 | ~300 |
| 4  | 30.12.2018 | 00:34:46 | – | –588 | 90 | 80 |

Note. t₀ is the time of eruption, αt is the duration of the signal, δ is the amount of ash per 1 square
meter.

Let us consider in detail the events of December 16, 2016 and June 14, 2017.

Based on the FRC GS RAS data, during the Shiveluch volcano eruption at 22:311 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 (refer with Figures 2a, 2b), 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 (refer with Figure 2c).
Figure 2. Eruptive cloud propagation from Shiveluch volcano eruption at 22:31 on 16.12.2016 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 17/12/2016

In this case, ash should not have fallen in Klyuchi village. However, about two hours later, ashfall began, it intensity was ~ 20 g/m². The second eruptive cloud, involved in the ashfall, 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 (refer with Figure 2c). Such eruptive cloud is not observed on satellite images.

The reliable remote methods for volcanic explosive activity monitoring are seismic and infrasound ones. While the former gives us the information on explosive process intensity and duration, the latter indicates the degree of its instability and the intensity of ash offset into the atmosphere.

Explosive earthquake at RTSS SMK with the duration of ~15 minutes, accompanying the explosion on December 16, 2016, is rather weak ($A_{\text{max}}=4$ µm/s) and is significantly noised (refer with Figure 3a). 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 ash-gas mixture outflow.

Figure 3. Record of seismic signal vertical component at RTSS SMK (b) and the response in PG during the second eruptive cloud passage after the eruption on December 16, 2016 (b). Grey color indicates the response in PG on the eruptive cloud passage

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) (refer with Fig. 3b). Based on the form of the anomaly back edge in AEF $E_Z$ [10] 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.

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 данные 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 (refer with Figure 4a). Then, according to wind stratification, the eruptive cloud...
moved to Klyuchi village with the velocity of 12 m/s (refer with Figures 4a, 4b, 4c). 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 (refer with figure 4d). Almost one hour later, the eruptive cloud covered Klyuchi village where about 100 g/m² of ash fell (refer with Figure 4e). After that the eruptive cloud moved in the direction of Klyuchevskoy volcano (refer with Figure 4f). At 21:33 the eruptive cloud reach 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 velocity maximum amplitude but we can assume that its amplitude exceeded \( A_{\text{max}} > 400 \text{ mkm/s} \) (refer with Figure 5a).

**Figure 4.** Propagation of eruptive cloud from Sheveluch volcano eruption at 16:26 on 14/06/2017 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)

The eruption was accompanied by 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 (refer with Figure 5b).

Thus, the explosion on 14/06/2017 began with a strong burst after which the ash-gas mixture was outflowing from the volcano crater for 10 minutes.

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

In the paper [10] the authors calculated the response in PG from bulk charges with simple configuration transported by wind and located of the conducting surface and present model curves in dimensionless quantities. The form of the anomaly under consideration reminds the change of PG of horizontal dipole the axis of which is oriented along the motion and which passes a 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](image_url)

*Figure 5.* 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 14/07/2017

Comparison of the parameters of the registered PG signals from the 2016 and 2017 explosions gives some idea of the possibilities of these methods. In addition, we consider the chemical (refer with Table 2) and particle size (refer with Fig. 6) composition of the ashes that fell in the village of Klyuchi from these explosions.

### Table 2. The chemical composition of the ash eruptions of the volcano Shiveluch

| Date         | SiO₂ | TiO₂ | Al₂O₃ | Fe₂O₃ | FeO | MnO | CaO | MgO | Na₂O | K₂O | P₂O₅ | mm  | Sun   | Fe₂O₃/FeO |
|--------------|------|------|-------|-------|-----|-----|-----|-----|------|-----|------|-----|-------|-----------|
| 16.12.2016   | 65.80| 0.44 | 15.40 | 1.24  | 2.38| 0.08| 5.14| 2.60| 4.87 | 1.43| 0.14 | 0.29| 99.82 | 0.52      |
| 14.06.2017   | 64.20| 0.59 | 15.30 | 2.35  | 2.44| 0.09| 5.50| 3.30| 4.43 | 1.22| 0.14 | 0.37| 99.95 | 0.96      |

Note. Analysts A.A. Kuzmina, N.Yu. Kurnosova, V.M. Ragulina (Institute of Volcanology and Seismology).

Ash, which fell on 12/16/2016, has a fresh, juvenile appearance, is represented mainly by light transparent unpainted particles of plagioclase with a small fraction of dark-colored minerals. In the ashes that fell on 06/14/2017, in addition, there is a noticeable amount of oxidized fragments of the same rust-brown minerals, which indicates the presence of a certain fraction of the resurgent material. This is confirmed by the results of chemical analysis of ashes. By chemical composition, the ashes are almost identical and are medium-potassium dacites of the calc-alkaline series. However, the ash of 2017 compared to the ash of 2016 has a slightly less acidic composition and a significantly higher degree of oxidation, as follows from the ratio Fe₂O₃ / FeO: 0.96 and 0.52, respectively.

The granulometric composition of the ashes is shown in Figure 6. Both ashes (2016 and 2017) selected in Klyuchi village have a similar distribution pattern, but the ashes of 2017 are somewhat coarse-grained (refer with Figure 6). For comparison, the size distribution of ash in 2017, which is
selected in the upper river Baidarnay. Naturally, the ashes, collected at 7 km from the crater, are significantly coarser in comparison with the ashes transported by the wind to a distance of 48 km.

From the results of the particle size and chemical analysis of the ashes, it follows that the ash that fell in 2016 is associated with a collapse on the volcano dome or the descent of hot avalanches. In turn, the trigger for the collapse was not a very strong explosion event on the volcano.

The ash of 2017 reflects the result of a more powerful, than in 2016, explosive event that captured a significant proportion of the external, oxidized parts of extrusion. At the same time, the ash that fell in the Klyuchi settlement underwent aeolian differentiation with respect to the ash collected in the near zone of the volcano (refer with Figure 6).

Despite the insignificant differences in the particle size and chemical composition of the ashes, the eruption clouds for the cases considered had different aeroelectric structures. This indicates that the physical processes associated with the formation of eruption clouds, determine their electrification. If in the first case the ash-air cloud was “dry”, therefore, an aeroelectric structure of a “type of charged cloud” was formed. In the second case, as a result of a strong explosion, a large amount of ash and volcanic gases were emitted into the atmosphere, in which more than 90% falls on water vapor [11]. Therefore, in the near zone (KLYG, R = 48 km), as a result of aeolian differentiation, a dipole aeroelectric structure was formed (refer with Figure 5).

![Figure 6. The granulometric composition of the ash of the Shiveluch volcano, selections: 1, 2 - in p. Klyuch on 12/16/2016 and 06/14/2017, respectively; 3 – 14/06/2017 - in the upper reaches of the r. Baydarnoy (selected A. B. Belousov)](image)

**Ebeko volcano eruptions.** A great success was the installation of the equipment complex in the city of Severo-Kurilsk. During the period from October 1 to December 31, 2018, 33 cases were recorded in the SKRG (refer with Table 3) when eruption clouds spread over the observation point. Naturally, the explosions occurred under various meteorological conditions. Reported cases occurred both in good weather conditions, when a clear response of the PG was recorded, and in adverse meteorological conditions. In addition, it is worth noting that there were also cases when, in conditions of good weather and when the ash cloud passed close to the observation point, the response PG was absent. During the observation period, anomalies of both polarities were recorded. The duration of the anomalies varies from 10 to 30 minutes. The maximum values exceeded the sensitivity threshold of the EF-4 sensor (more than ± 2 kV / m). The second sensor with an expanded sensitivity threshold (± 8 kV / m) was installed on November 3, 2018. The maximum value of the registered anomaly is 3.0 kV / m.
Figure 7. Fragment of the acoustic signal recording (a) and the PG anomaly on two channels at point SKRG (b, c) during the passage of an eruptive cloud from the eruption of the Ebeko volcano on November 11, 2018, the formation of which is shown in (d).

In Figure 7 shows an example of the response of V′EPA to the passage of a gas-ash cloud over SKRG. A negative anomaly was registered with a maximum PG value of −102 and −120 V / m (at the observation point, two electrostatic sensors were installed at different heights from the ground surface, 10 and 15 m).

Table 3. Parameters of signals V′EPA recorded in SKRG during the passage of eruption clouds from the eruptions of the Ebeko volcano for the period from October 1 to December 31.

| №  | Date         | t₀   | polarity | PG, [V/m] (EF-4) | PG, [V/m] (EF-1) | Δt, [min] |
|----|--------------|------|----------|------------------|------------------|-----------|
| 1  | 05.10.2018   | 04:34| +        | 1335             |                  | 9         |
| 2  | 08.10.2018   | 02:38| +        | 1031             |                  | 9         |
| 3  | 06.10.2018   | 04:31| -        | -1044            |                  | 21        |
| 4  | 08.10.2018   | 04:31| -        | -1044            |                  | 21        |
| 5  | 10.10.2018   | 08:38| -        | -801             |                  | 17        |
| 6  | 21:17        | ±    | 1960     | -1596            |                  | 20        |
| 7  | 22:13        | +    | 1089     |                  |                  | 7         |
| 8  | 23:00        | -    | -876     |                  |                  | 22        |
| 9  | 19:32        | +    | 679      |                  |                  | 10        |
| 10 | 22:13        | +    | 1594     |                  |                  | 15        |
| 11 | 06:32        | -    | -935     |                  |                  | 20        |
| 12 | 21:07        | ±    | 638      | -867             |                  | 17        |
| 13 | 23:00        | -    | -876     |                  |                  | 22        |
| 14 | 23:28        | -    | -846     |                  |                  | 16        |
| 15 | 22:56        | -    | -1528    |                  |                  | 21        |
| 16 | 06:12        | ±    | -283     | 2773             |                  | 11        |
| 17 | 21:20        | +    | 2393     |                  |                  | 25        |
| 18 | 17:17        | +    | 2075     |                  |                  | 26        |
|     |     |     |     |     |     |     |
|-----|-----|-----|-----|-----|-----|-----|
| 19  | 24.10.2018 | 01:49 | - | -1409 | 29  |
| 20  | 20.09 | 03:20 | - | -2074 | 30  |
| 21  | 04:16 | - | -2091 | 20  |
| 22  | 29.10.2018 | 05:20 | ± | -240 | 135  | 12  |
| 23  | 07.11.2018 | 19:30 | + | 308 | 665  | 15  |
| 24  | 08.11.2018 | 03:25 | - | -637 | -1955 | 21  |
| 25  | 09.11.2018 | 10:22 | + | 237 | 563  | 10  |
| 26  | 13:35 | - | -41 | -147 | 11  |
| 27  | 10.11.2018 | 00:16 | - | -99 | -137 | 17  |
| 28  | 05:18 | - | -351 | -455 | 21  |
| 29  | 04.12.2018 | 01:38 | + | 252 | 435  | 13  |
| 30  | 12.12.2018 | 21:48 | - | -887 | -1689 | 9  |
| 31  | 32  | 14.12.2018 | 01:34 | ± | 890 | -405 | 2888 | -712 | 24  |
| 32  | 15.12.2018 | 02:20 | + | 844 | 2702  | 17  |

Note. $t_0$ is the time of eruption, $\Delta t$ signal duration.

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