Lightning and Electrical Activity during the Shiveluch Volcano Eruption on November 16, 2014

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Abstract

Based on the data of the World Wide Lightning Location Network (WWLLN), a sequence of lightning discharges was detected. It occurred on the path of propagation of an eruptive ash cloud formed by the Shiveluch volcano explosive eruption on November 16, 2014 in Kamchatka. Detailed information on the motion of the eruptive cloud was received on the basis of seismic and meteorological data, satellite images and registration of atmospheric electric field potential gradient (AEF *V')* at Kosyrevsk site (KZV). The central part of the eruptive cloud was at a distance of 35 km from KZV at two heights of 10 and 12 km that manifested in AEF *V'* in the form of two anomalies with the amplitude of ~90 V/m. It was concluded that WWLLN is capable of indicating of andesitic Shiveluch volcano explosive eruptions and tracing ash clouds in the near zone when electrification processes develop the most intensively and strong discharges occur.

Key words: volcanic lightning, atmospheric electricity, explosive eruption, eruptive cloud.

Introduction

Observations of atmospheric electricity variations during volcano explosive eruptions indicate the development of electrification processes of eruptive clouds which are the consequence of magma fragmentation and formation of an eruptive column [James et al., 1998; Mather, Harrison, 2006]. Appearance of dipole electric structures during magma fragmentation and formation of an eruptive cloud are caused by a number of reasons, they are: contact charging of large and small particles by different sign charges during magma fragmentation; difference of ash large and small particle composition which is determined by the content of crystals, glass and magma-dissolved water; their spatial separation under the action of gravity [Williams and McNutt, 2005; Thomas et al., 2008].

The paper [McNutt, Williams, 2010] analyses retrospectively the occurrence of volcanic lightning at 80 world volcanoes for 212 explosive eruptions. The relation of lighting discharges with Volcanic Explosivity Index (VEI[1]) was under investigation. It was distributed as follows: less than 2% of eruptions had VEI=6, 10% had VEI=3-5, and the rest weak eruptions had VEI=1-2. This indicates a great role of static electricity during eruptive cloud formation even during weak eruptions and convincingly shows the informative value of volcanic lightning for eruptions with different VEI index. The convincing proof for tracing of eruptive clouds by lightning activity is shown in the papers [Bennett at al.,2010; Behnke, McNutt, 2014].

At present, the World Wide Lightning Location Network (WWLLN) is capable of registering lightning discharges with a time accuracy up to several microseconds that makes it possible to determine the location of discharges with the accuracy of about three kilometers [Rodger et al., 2006; Hutchins et al., 2012; Lane et al, 2011].

Eruptive cloud electrification also affects the atmospheric electric field variations V' in the near ground layer of the atmosphere. Under some circumstances, this fact may be applied to observe volcanic cloud motion [James et al., 2003, 2008].

Observation means

The Shiveluch volcano is the most northern one among the active volcanoes of Kamchatka with andesitic lava content and the height of the blister cone of 2500 m above the sea level. During the last decays, its eruptions determined by slow magma squeezing and formation of a blister cone (56.63° N, 161.32° E) are periodically accompanied by strong ash explosions. The eruptive cloud may rise up the tropopause height (10-12 km in summer and 8-10 km in winter for Kamchatka peninsular).

During the explosive eruption of andesitic Shiveluch volcano (56°47’ N, 157°56’ E, Russia) on November 16, 2014, a fluxmeter EF-4 was used to measure atmospheric electric field variations. The fluxmeter is installed at “Kozyrevsk” (KZY) seismic station of Kamchatka Branch of Geophysical Service of RAS (KB GS RAS) which is located at the height of 50 km above the sea level, 113 km to the South-West of Shiveluch volcano (Fig. 1). Meteorological parameters were registered by Vasiala wxt520 weather station. The eruption was accompanied by an explosive earthquake which was registered at seismic stations located near Shiveluch volcano.

[1] VEI is the Volcanic Explosivity Index. Ejected material range is less than 0.0001 <VEI=1<0.001km^3; 10 <VEI=6 < 100 km^3.

Kluchi meteorological observatory maintained by the Kamchatka Department on Hydrometeorology and Environment Control is located 48 km from Shiveluch volcano. The data on meteorological values registered at this station (atmospheric pressure, air temperature, humidity and balloon sounding of the atmosphere twice a day) are available on the site http://www.esrl.noaa.gov/raobs/intl/intl2000.wmo.

Data on the location of lightning discharges accompanying the eruption are available online (http://webflash.ess.washington.edu/). The WWLLN site in Kamchatka is located in Paratunka.

According to weather balloon sounding on November 16, 2014 at 12:00 (UT), temperature and wind stratification up to the height of 25 km is shown in Fig. 2. There are two inversions at the heights of 9-10 and 12 km on the temperature vertical section where wind velocities were 17 m/s and 11 m/s, respectively. At these heights, the wind direction was south-south west (azimuth is 50° and 80°, Fig. 2b). The direction is opposite to the azimuth. The height of the lower inversion corresponded to the tropopause height typical for autumn-winter period at Kamchatka peninsula.

Evolution of the eruptive plume

The seismic station network located in the area of Shiveluch volcano allowed us to detect an explosive earthquake accompanying the eruption on November 16. The beginning of the eruption was determined with the accuracy up to several seconds by the time of the first onset of the explosive earthquake registered at the nearest to the volcano seismic station, BDR, located at a distance of 10 km from the volcano crater (Table). Ascending of the thermal flow and formation of the eruptive cloud for the eruption under analysis were accompanied by lightning discharges. The WWLLN network registered a total of seven discharges, the times for which are shown in the Table and the location is illustrated in Fig. 1. Within the interval of 25-40 seconds after the onset of the eruption, three discharges were recorded near the volcano. These discharges, apparently, accompanied the ascending of the thermal flow and formation of the eruptive cloud. The subsequent three discharges occurred almost simultaneously in 8.4 minutes, supposedly, at the background of the eruptive plume carried by wind on the contact with a colder cloud structure. The last discharge was registered 17 minutes after the onset of the eruption at the distance of 20.5 km from the eruption center (Fig. 1).

A satellite image (Landsat 8), taken 22 minutes after the onset of the eruption (Fig. 3) shows the character of the eruptive cloud formation. At that time, it is quite compact and

significantly loaded with ash (dark area). In the satellite image of Modis[2] system in infrared light (the difference is 31 and 32 channels) taken at 11:45, two fronts may be distinguished with a specific degree of conditionality at the distances of 104.3 and 71.7 km from the volcano. The azimuth from the source to the first front center was 223^0 that agrees well with wind azimuth at tropopause height (48^0).

According to the data of VAAC (Volcanic Ash Advisory Center, Tokyo), obtained on the basis of the MTSAT-IR satellite image at 12:00, an eruptive cloud was recorded at the height of 9 km above the sea level, moving in the south-western direction with the velocity of ~15 м/с (http://ds.data.jma.go.jp/svd/vaac/data/TextData/2014/20141116_SHEV_0110_Text.html).

At KZY, the background value V' of AEF was relatively calm and had the value of 60 V/m (Fig. 4a) before the eruption and after it for almost 15 hours on November 16, 2014 from 01:25 to 16:25. The behavior of meteorological parameters for this period did not have strong variations (Fig. 4*c*-*e*) that shows fair weather conditions. AEF V' variations and the fixed points, marked by another kinds of observations are shown in Fig. 5a,b in detail. At 10:45 first V' weak variations of AEF can be seen, and almost in two hours after the eruption, the onsets of two anomalies are clearly distinguished on the record of AEF V' (12:04 and 13:10) with the total duration of about 1.5 hour (Fig. 4a) when the AEF V' maximum value reached 170 V/m. Fair weather conditions give justification to consider the AEF V' variations to be a consequence of electrification of the eruptive plume the trajectory of which was 25 km to the East of KZY site according to satellite images.

According to the propagation time, the time difference between the eruption onset and the time of two maxima in AEF V', we may estimate the motion velocities of eruptive cloud separate fronts, which were 17 m/s and 11 m/s.

The agreement between the velocities of atmospheric electric structure propagation and the wind velocities at definite heights shows that ash advection might occur at two heights (9-10 and 12 km) where temperature inversions were observed.

Conclusions

The Kamchatka volcano group is located near international air routes. As a result, eruptions are serious threats for communication security. To decrease the risks, effective systems for detection of eruptions are necessary. Weak lightning activity of Kamchatka peninsular give ground to monitor strong explosive eruptions by satellite monitoring and by WWLLN system simultaneously in real time. During the development of regional WWLLN segment, the

[2] Image from VolSatView information system [21] was granted by Girina O.A.

observation resolution may be increased. The undeniable advantage of WWLLN method is its operativeness and the possibility to use in the conditions of poor visibility.

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Table. Chronology of evolution of the plume from Shiveluch volcano (56.63° N, 161.32° E) eruption on November 16, 2014.

			Time, UT	Coordinates		R, km	V, m/s	Notes
				φ, N	λ, E			
1		Arrival of a seismic wave at BDR	10:17:55.3					
2	1	Volcanic lightning	10:19:16.1	56.58	161.31	2.7		
	2		10:19:26.7	56.67	161.38	4.5		
	3		10:19:33.8	56.82	161.31	8.9		
	4		10:26:22.6	56.56	161.23	10.9		
	5		10:26:22.6	56.60	161.17	10.8		
	6		10:26:22.6	56.64	161.13	11.9		
	7		10:36:10.2	56.53	161.31	20.5		
3		Satellite image	10:40					Landsat 8
			11:45					Modis, difference is 31 and 32 channels
			12:00					VAAC data, MTSAT-1R
4		Electric field disturbances at KZY site	12:04			113.0	17,7	
			13:10			113.0	10,9	

Note: R is the distance passed by the cloud from the volcano crater, V is the average velocity of cloud front.

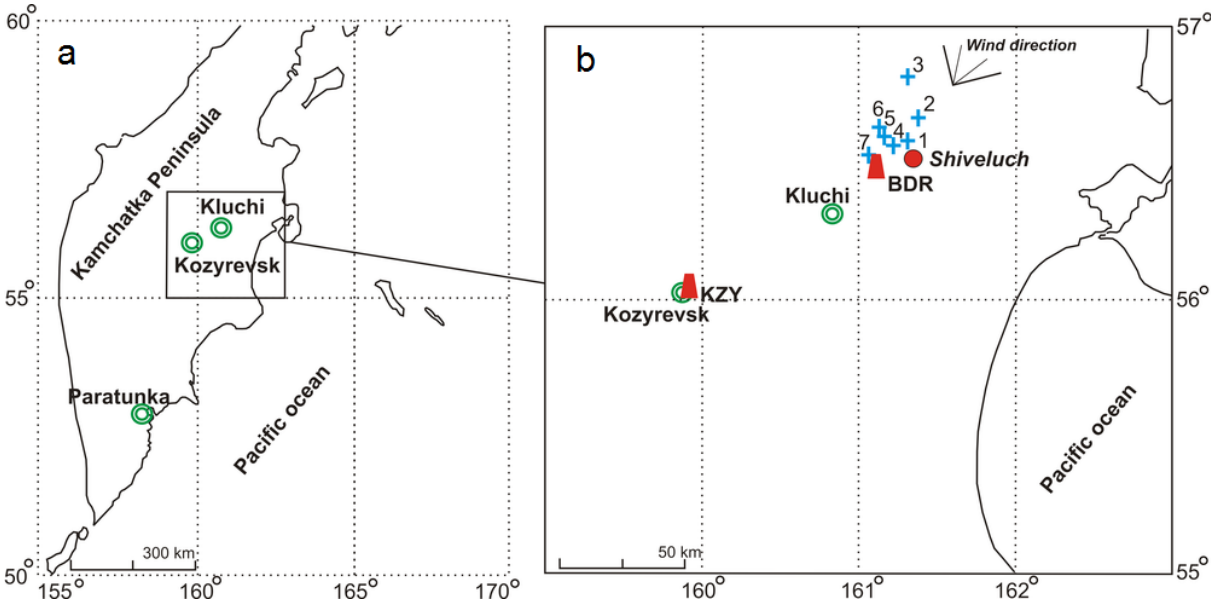

Fig. 1. The northern group of Kamchatka volcanoes, observation sites and locations of discharges from the lightning of Shiveluch volcano eruption on November 16, 2014.

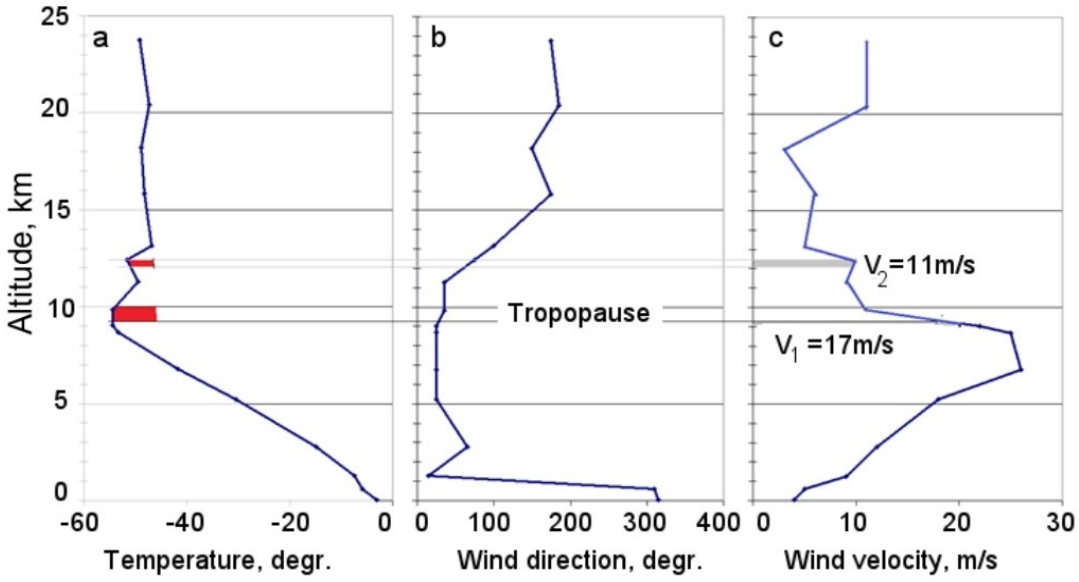

Fig. 2. Vertical sections of temperature (a), wind direction (b) and velocity (c) according to the data of Kluchi meteorological observatory at 12:00 on November 16, 2014 (UT).

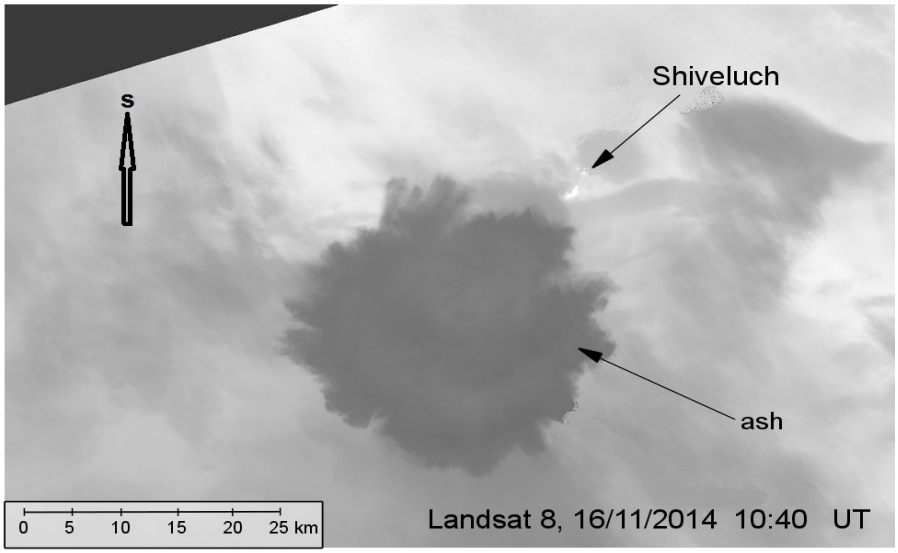

Fig. 3. Satellite image (Landsat 8) of the eruptive cloud from Shiveluch volcano, taken at 10:40 on November 16, 2014. (UT).

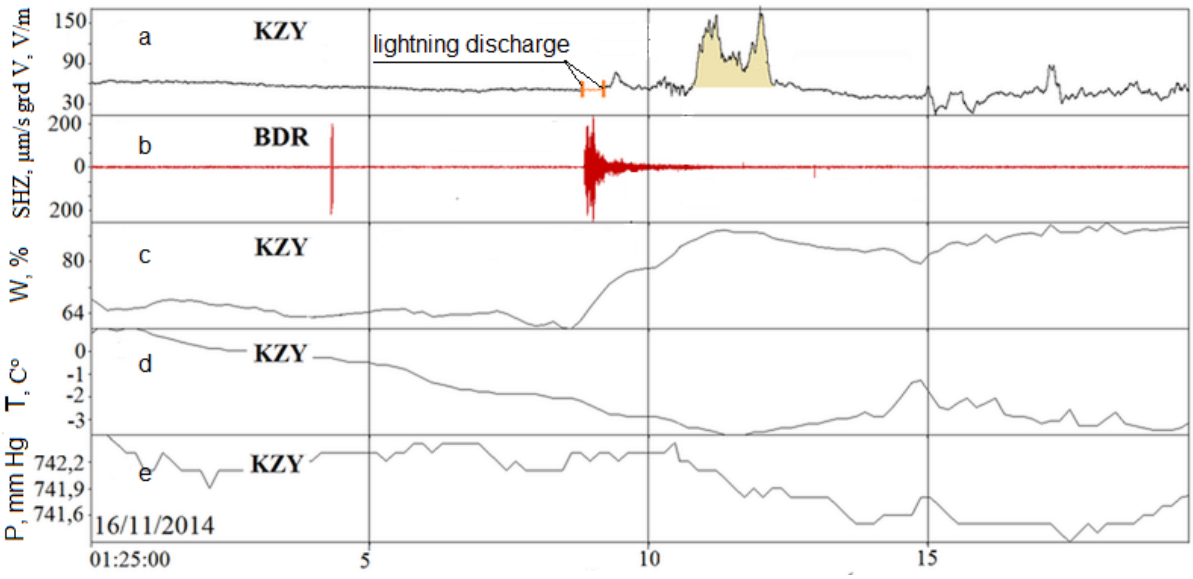

Fig. 4. Electric field at KZY site (a); seismic signal at BDR site accompanying the Shiveluch volcano eruption on November 16, 2014 (b); meteorological parameters at KZY site (c, d, e). Zero reading is 01:25:00 UT.

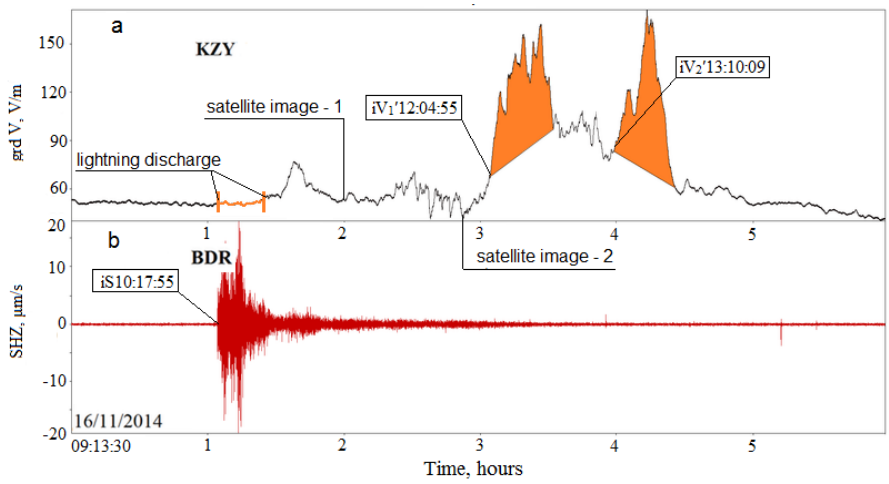

Fig. 5. Potential gradient at KZY (a), seismic signal at BDR, accompanying the Shiveluch volcano eruption on November 16, 2014. Fixed points of other kinds of observations are shown. Zero reading is 09:13:39.