Search for possible relationship between volcanic ash particles and thunderstorm lightning activity

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Abstract. Explosive volcanic eruptions that eject columns of ash from the crater often generate lightning discharges strong enough to be remotely located by very low frequency radio waves. A fraction of volcanic ash particles can stay and disperse long enough to have an effect on weather phenomena days later such as thunderstorms and lightnings. In this work we report on lightning activity analysis over Europe following two recent series of volcanic eruptions in order to identify possible correlations between ash release and subsequent thunderstorm flash frequency. Our attempts gave negative results which can be related to the fact that we have limited information on local atmospheric variables of high enough resolution, however lightning frequency is apparently determined by very local circumstances.

1. Introduction

The atmosphere below 50 km is conducting because of the presence of ions created primarily by cosmic rays and background radioactivity. The contribution of free electrons in this region can be neglected due to their short lifetimes [1, 2]. Significant charge separation in the lower atmosphere appears to require strong updrafts which carry water droplets upward causing at the cloud tops the accumulating of increasing positive charge. The exact mechanism by which charge separation happens is still a subject of research [3, 4, 5, 6]. Similarly, the mechanism by which the lightning discharge begins is not well known [8, 9]. Measured electric fields in thunderclouds are typically not large enough to directly initiate a discharge [1, 2].

The explanation of lightning activities is further complicated by the fact that very similar meteorological situations, such as tropical cyclones of the same strengths and trajectories, can yield to extremely different flash rates [10, 11]. Nevertheless the increasing efficiency of remote detection on global scales provides a key to a better understanding of many aspects of related phenomena [12, 13, 14, 15].

One of the existing global collaborations is the World Wide Lightning Location Network (WWLLN, see http://wwlln.net) operating over 50 sensors at universities and research institutes. The physical basis of remote observation is the strong electromagnetic emission over a wide spectrum coupled to a lightning discharge. Radio waves in the Very Low Frequency (VLF) range (3–30 kHz) are damped very slowly in the atmosphere, therefore a network of synchronized detectors can locate remote lightning strikes when the vertical electric field exceeds the background noise [16].
It is well known that volcanic eruptions that eject columns of ash above a critical height (approximately 7 km) from the crater often generate strong lightning activity [1, 2, 17]. This observation motivated to initiate the WWLLN Ash Cloud Monitor experiment (http://wwlln.net/volcanoMonitor.html), where the lightning activity is evaluated in every minute over more than 1500 active volcanos. The primary goal of this project is to monitor volcanic activities and issue early alerts (e.g., about ash clouds endangering aviation) when it is necessary.

Besides triggering lightning discharges in the volcanic ash clouds, small aerosol particles staying longer in the troposphere can also change lightning activities over distant areas, too. In the present work we attempt to find evidences supporting this hypothesis. Two recent eruptions are analyzed over Europe. The main finding in both cases is that an apparent increase in the integrated lightning frequency over a given area cannot be explained directly by the possible presence of ash clouds, other factors appear to have stronger effects resulting in marked spatial and temporal fluctuations.

2. Data and methods

Global WWLLN lightning data are evaluated in the period of 28/10/2004 – 30/06/2010. The annual mean flash rate has a very uneven geographic distribution illustrated clearly in Fig. 1a. Approximately 70% of lightnings is located in the tropics where the majority of thunderstorms occur. In spite of the common perception, only 20-25% is the so called cloud-to-ground flash, the rest is either cloud-to-cloud or intra-cloud discharge.

In order to evaluate possible effects of volcanic ash on lightning frequency, we concentrated on a limited area over the continental Europe. The reason is clearly seen in Fig. 1a: Europe has a moderate exposure compared to the tropical regions, nevertheless the strongest lightning activity is around the Mediterranean Sea (MS) [18]. Therefore a statistical comparison is performed over two rectangles: one covers the whole geographic area of Europe, a smaller embedded region is located to the Mediterranean, see Fig. 1b.

The time series shown in Fig. 2 exhibit a marked seasonal behavior, as expected at mid-latitude climate. The most active thunderstorm period is the middle of Summer (June-July) over the continent, and a characteristic delay is apparent over the MS region (October-November). Orange ellipses in Fig. 2 indicate unusually strong lightning activity over the continent during
Figure 2. Top: time series of the lightning activity detected by the WWLLN network over the two rectangles denoted in Fig. 1b, see the legends. Bottom: the difference between daily flash numbers of the EU and MS data smoothed by a 31-day running mean procedure. Orange ellipses indicate the periods of closer analysis. (Vertical dotted lines denote the end of months.)

Autumn months in 2006 and 2007, and a very sharp increase in Spring of 2010. Here we pose the question whether this marked increase could be related to volcanic eruptions occurring shortly before these periods, or it is only an illusory temporal correlation.

3. Case study I: Mt. Etna, 2006-2007
One of the biggest producers of volcanic plumes in the world is Mount Etna in Sicily, Italy [19, 20]. In the year of 2006, a longer eruption lasted from 31 August to 15 December, and the ash spread from the source area to a distance of several kilometers away from the volcano, representing a serious danger for aviation. Andronico et al. published a very detailed analysis on ash plume dispersal by using ground based and satellite observations [19]. They introduced five plume categories and evaluated their duration, eruption typology, tephra fallout, and observable extent. Apart from class 1 (degassing plumes), all the others are characterized by light to continuous ash fallout and a limited spatial dispersion, the largest detected distances were only around 250 kilometers at moderate (3-4 km) heights.

An essential point is that the volcanic activity during the eruptive period (31/09 - 15/12) was more or less continuous with the emission of relatively weak and localized plumes [19]. However, the lightning activity exhibits very large fluctuations in the same period. As an example, we show the flash locations (Fig. 3) recorded by the WWLLN on four consecutive days, where a very large positive fluctuation occurred on 30 October 2006. According to Table 1 in Ref. [19], the whole month of October was rather quiet, only a few and very small (3-40 km long) plumes were recorded, which hardly explains the large temporal fluctuations in lightning activity.

Etna’s activity was limited to the volcano’s summit area in 2007-2008 [21]. While three of the four summit craters were quiescent during the entire period, the mild passive degassing activity of the Southeast crater has been repeatedly interrupted by a sequence of explosive–effusive eruptive episodes. Two remarkable events are listed in Ref. [21] in the Autumn period of 2007: both episodes (4-5 September, and 23-24 November 2007) started with mild discontinuous ash emissions (rich in lithic fragments), which after a few days (hours) were followed by mild
Figure 3. Lightning activity on four consecutive days over the rectangle EU (see Fig. 1), 28-31 October, 2006. Note the large isolated peak at the same time in Fig. 2, top curve. The total number of recorded events on 30 October was 66354 flashes.

Figure 4. Lightning activity on four consecutive days around the MS region (see Fig. 1), 26-29 November, 2007. Note the large isolated peak in Fig. 2 top curve on the same days. The total number of recorded events on 29 November was 16755 flashes.

Strombolian explosions.

It is tempting to suggest that the localized and intense lightning activity shown in Fig. 4 has a causal link with the volcanic eruption on 23-24 November. Unfortunately, the figure sequence clearly shows that the thunderstorm zone on 26-29 November had a definite tendency to move from West to East, and it is difficult to imagine that the volcano ash cloud could do the opposite a few days earlier and contribute to triggering lightning discharges.

4. Case study II: Eyjafjallajökull 2010

On 26 February 2010, unusually strong seismic activity and rapid expansion of the Earth’s crust were registered by the Meteorological Institute of Iceland [22, 23]. This gave strong indication that magma was pouring from underneath the crust into the magma chamber of
Figure 5. Lightning activity on four days over Europe (see Fig. 1), April and May 2010, when airport closures are reported.

the Eyjafjallajökull volcano. On 14 April 2010, a strong explosive eruption series occurred in the central crater causing meltwater floods and requiring over 800 people to be evacuated. The eruptions threw volcanic ash several kilometers up in the atmosphere which led to air travel disruption in northwest Europe for days in April and in May 2010.

Recent detailed numerical analysis [24] showed that a rapid spread of volcanic ash is possible, with all countries in Europe facing the possibility of an airborne ash concentration exceeding security limits within 24 hours of an eruption. Probabilities of significant concentrations of ash are highest to the east of Iceland, with probabilities exceeding 20 % in most countries north of 50°N. Deposition probabilities were highest at Scottish and Scandinavian airports. Ash concentrations usually remain higher for longer periods during Summer when the mean wind speeds are lower.

Haszpra and Tél report numerical studies on volcanic ash dispersal by using reanalysis wind-field data for the critical time period [25]. In spite of the fact that the overall lightning activity exhibits a quick increase after the main eruption on 14-15 April 2010 (see Fig. 2), the maps determined for the same days as shown in Fig. 2 in [25] exhibit very weak spatial correlations with Fig. 5 here.

5. Discussion
We are fully aware of the fact that the presence of volcanic ash or other aerosols at elevated concentrations would mean only a single factor contributing to trigger lightnings. Thunderstorms and other forms of intense atmospheric convection depend on so many local factors that a detection of direct connection is expected to be extremely difficult. As a last attempt to explain flash number variability, we show the result of correlation analysis between the lightning activity in the Mediterranean region (MS in Fig. 1b) and a daily index of North Atlantic Oscillation.

The North Atlantic oscillation (NAO) is the fluctuations in the difference of atmospheric
pressure at sea level between the Icelandic low and the Azores high. A large positive difference between the pressure at the stations in Reykjavik and Lisbon implies increased westerlies, cool summers and mild and wet winters in Central Europe. In the opposite case (negative NAO phase), westerlies are suppressed, these areas suffer cold winters and storm tracks tend to move toward the Mediterranean Sea. The motivation for checking possible correlations is given by two recent papers where the authors claim to find an increased lightning frequency at low NAO index values [26, 27].

The NAO index is originally represented by monthly or seasonal mean patterns (and also used in this representation in [26, 27]). However, it is increasingly becoming evident that its dynamics is associated with shorter (intraseasonal) time scales. NAO pressure differences at daily resolution are available from 1948 (http://www.lasg.ac.cn/staff/ljp/) [28], therefore a direct comparison with WWLLN statistics is not difficult.

A clear technical problem at the proper comparison is that the lightning activity over the MS area has a marked seasonality (see Fig. 2), while the NAO signals lacks this feature. The standard way is to compute anomalies based on climatological mean values, however the limited length of WWLLN records and the changing detection efficiency are sources of large inaccuracies. (Changing detection efficiency is a consequence of the fact that the WWLLN project is in a developing phase and different stations operate at different periods.) Therefore we made an attempt to define daily anomalies by determining differences between the original signals and their 31-day running means. The result is shown in Fig. 6.

Figure 6c shows no sign of any significant correlation between the NAO signal and lightning
rate over the MS region. It is not presented here, but we tested the correlations between WWLLN time series over Europe and NAO with negative result as well, also other related quantities such as running standard deviation or “volatilities” determined by different methods and different window lengths.

The negative results here do not mean that there is no relationship between aerosol concentrations, cloud formation and lightning discharges [29, 30, 31]. A proper understanding probably requires to collect more detailed local information about the atmospheric variables, such as local pressure, wind speed, vertical wind component, humidity, temperature, various gradients, etc.

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