A Relationship Between Lightning and Volcano Activity in Manizales. An Amazing Thunderstorm.

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***Abstract*—This paper presents an analysis of the thunderstorm that took place in the city of Manizales, Colombia, on March 30, 2012, and makes an evaluation of the possible relationship between the lightning activity of that thunderstorm and the high volcanological activity registered in the Nevado del Ruíz volcano at the same city. This paper uses data obtained from the Lightning Location Network (LINET), World Wide Lightning Location Network (WWLLN) and the Volcanological and Seismological Observatory of Manizales (OVSM).**

***Keywords*—lightning activity; volcanic ash; aerosols.**

I. Introduction

Lightning is one of the natural phenomena that has been and continues being studied the most, with a range of over 250 years of study so far. Even though some of the efforts have focused on the characterization of this phenomenon by associating it with meteorological conditions, little study has been conducted in order to associate the lightning activity with other phenomena, such as volcanic eruptions, for instance. Recently, this association has begun to gain some interest in the international scientific community as reported in some works like those presented in [1]–[4].

In the work presented in [2], the authors found a relationship between lightning activity and different types of eruptions in more than 55 volcanoes. In the same way, in a recent study presented in [5], the authors found that 212 eruptions in 80 volcanoes could be associated with the existence of an important lightning activity. Taking into account that the volcanic lightning are present not only near the crater [4], but also in other areas where they can cause the death of animals and humans, and can also cause problems to electrical and communication systems, it is pertinent to seek for a possible relationship between the mentioned phenomena. Some works on this topic have been already reported in the literature [2], [4].

One of the first studies conducted in order to analyze the possible relationship between lightning activity and volcanic eruption, using a lightning detection network, was the work presented in [1]. An important lightning activity was detected in eleven of the thirteen volcanic eruptions that were registered, and this lightning activity was related to the presence of volcanic ash. In some other works, like those presented in [1], [3] it has been shown the importance of using lightning location networks and data from the Volcanological Observatories, in order to be able to correlate the information and for finding possible relationships between these two phenomena. This work is an attempt to find some relationship between a particular thunderstorm and changes in volcanic activity of the Nevado del Ruíz volcano, by making observations of the information available at LINET - Colombia, World Wide Lightning Location Network - WWLLN, Ozone Monitoring Instrument (OMI) and the Colombian Geological Service (SGC).

On the other hand, Manizales a Colombian city with approximately 400000 inhabitants, is located only at 28 km away from the Nevado del Ruíz Volcano. This volcano has caused some injuries to people who live near it, some of them being more tragic than others, as for example the one that took place in the year 1985 where some cities located in areas surrounding the volcano were destroyed, and around 23000 people were killed because of this volcano eruption. Since the year 2012 the Nevado del Ruíz volcano has been showing some activity changes, as reported by the Volcanological and Seismological Observatory of Manizales (OVSM) on its website [6], and by other media as well.

On March 30, 2012 there was a thunderstorm in the city of Manizales, between the 5 and 7 hours UTC, and according to the most important local newspapers some of these lightning flashes were responsible for fires in some houses and also for associated problems of electromagnetic interference as power outages and telecommunication problems [7].

The objective of this paper is to explore whether there is any relationship between the intense thunderstorm that took place on March 30, 2012 in the city of Manizales, Colombia and the high volcanic activity registered at the Nevado del Ruíz volcano, which is very close to the city. The volcano activity was registered in days near to the day at which the thunderstorm occurred, and both the volcano and lightning activities had an unusual intensity.

II. Data and Methodology

This section describes the sources of data utilized to develop this work. The sources utilized to acquire information about lightning activity were: the LINET - Colombia network, and the World Wide Lightning Location Network - WWLLN. The information for the volcano activity was obtained from the

Colombian Geological Survey, and data about volcanic emissions of ash and gas from the Ozone Monitoring Instrument - OMI.

A. *LINET - Colombia*

LINET is a lightning detection network developed at the University of Munich, in Europe, which consists of 90 sensors located in 17 countries [8], operating in the low- and very-low-frequency (VLF/LF) ranges. This network detects cloud-to-ground (CG) and intra-cloud (IC) lightning, with errors of less than 150 m. In Colombia LINET began its operation on September, 2011, and it consists of 9 sensors located as shown in Fig. 1. The company responsible for the operation of this network in Colombia is Keraunos S.A.S. This nine-sensors network achieves a detection efficiency of 90 % [9]. In the area with the highest efficiency, they are located the Manizales city and the Nevado del Ruíz Volcano, allowing in this way to obtain an important reliability to the data obtained by means of this network.

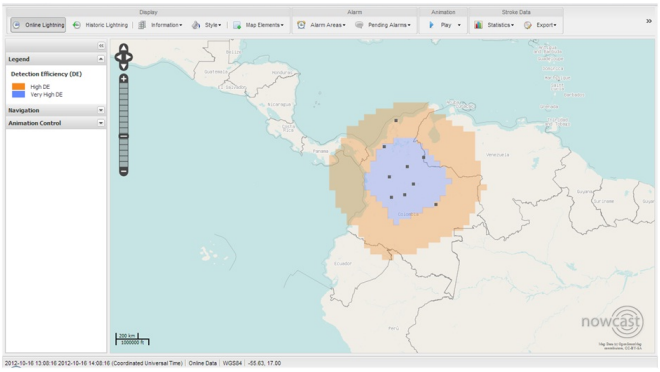

Figure 1. LINET - Colombia. Location of the nine sensors (black points) and depiction of the area with the highest detection efficiency (violet color). Adapted from [9]

B. *World Wide Lightning Location Network - WWLLN*

The WWLLN is a network with more than fifteen sensors installed around the world and working in the very-low-frequency (VLF) range. This network is administrated by the Washington University. The WWLLN Ash Cloud Monitor is an experimental research project, supported in part by a U.S. Geological Survey - USGS granted to the University of Washington. The WWLLN is continuously monitoring 1563 volcanoes around the world, every minute this network examines all the global volcanoes in the vicinity to lightning detected by itself. The lightning data used from the total strokes detected are those in the central area within 20 km of the volcano caldera, and also in an outer ring out to 100 km from the caldera. Furthermore, WWLLN also records all the major events at VEI 4 (Volcanic Explosivity Index) and half of them by the VEI 3 [10]. On March 30, 2012, the WWLLN volcano monitor reported some data for the Nevado del Ruíz volcano, which were used to look for a possible relationship with the high lightning activity presented in the same date in the city of Manizales.

C. *Ozono Monitoring Instrument - OMI*

OMI is a measuring instrument that is part of the AURA satellite, which was launched on July 2004. OMI is a contribution of the Netherland's Agency for Aerospace Programs (NIVR) in collaboration with the Finnish Meteorological Institute (FMI). OMI can recognize smoke, dust and sulfates, and also different aerosols, using the technique of Hyperspectral Imaging. The data from OMI are utilized to show activity in the Nevado del Ruíz volcano related to the emission of gas and ash. For more information regarding the operation of OMI it can be consulted [11], [12].

D. *Colombian Geological Service - SGC*

The Colombian Geological Service is a government agency which is responsible for conducting research related to the Colombia's mineral potential, this agency is also in charge of monitoring the volcanoes of Colombia, in order to achieve this task, they have three volcanological observatories, which are located in the cities of Manizales, Popayán and Pasto. The volcano observatories generate weekly and monthly reports of each of the volcanoes in Colombia. This study uses the information issued by the Volcanological and Seismological Observatory of Manizales (OVSM) for the month of March, 2012, and for the the Nevado del Ruíz volcano, where the seismic activity, gas column and the level of risk of explosion were recorded [13], [14].

III. Results

This section presents the results of the observations made, based on the data and information collected from the lightning detection networks, the OVSM and the OMI. A few days before dawn on March 30, the Nevado del Ruíz volcano presented some changes in its seismic activity, and its emissions of gas and ash, according to the OVSM [13], [14]. In a technical report issued by the OVMS [13], a number of 11727 earthquakes were reported for the month of March, 2012, and a significant increase in the height of the gas column, usually directed towards the northwest was reported as well. Fig. 2 shows one of the many events that occurred during the month of March, 2012. This events were associated with gas and ash emissions.

Fig. 3 shows four satellite images recorded by the OMI for March 20th, 21st, 27th and 29th, 2012, between the 18:00 and 19:00 UTC. This image shows the spatial distribution of the gas column made by Nevado del Ruíz volcano, corroborating the information provided by the OVSM about emissions of ash and gases from the volcano during the month of March. On March 29th, 2012, a few hours before the lightning activity, the OMI detected some activity in the Nevado del Ruiz volcano, related to gas and ash emissions, as it is shown in the last image of Fig. 3.

It has been observed that volcanic ash contains particulate matter, PM_{10}, and recent studies have shown that an increase in the concentration of these kind of particles can cause important changes in the atmospheric activity. In different studies carried out in Brazil, the concentration levels of PM_{10}

Figure 2. Photography for March 8th, 2012. Arenas crater - Nevado del Ruíz volcano, showing the gas column and the ash layer on the glacier. Adapted from [13]

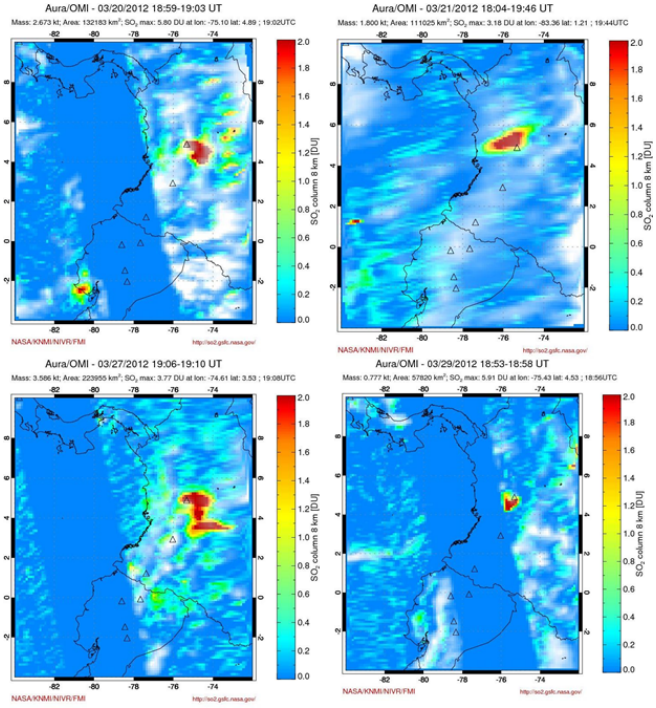

Figure 3. OMI - Gas emission from the Nevado del Ruíz volcano. Adapted from [15]

and SO_2, due to anthropogenic emissions, were correlated [16]–[18]. The principal findings showed that there exists a direct relationship between the increase in the concentration of PM_{10} and the number of cloud-to-ground flashes. It was also shown that in weekdays where the PM_{10} levels are higher, there was a greater number of flashes. Despite of the fact that those studies considered only man-made emissions, the result could lead to a possible relationship between the thunderstorm registered on March 30th in the city of Manizales and the Nevado del Ruíz volcano activity, because as said before, the volcanic ash contains high amount of PM_{10}.

On March 30th, 2012, the WWLLN Global Volcanic Lightning Monitor detected an event associated to a possible eruption of the Nevado del Ruíz volcano. A total number of 3087 strokes were detected between the 0 h and 14 h UTC inside a radius of 100 km with center in the volcano crater. Of this total number of strokes, 31 of them were located around the crater, with distances ranging between 0 km and 20 km from it, and the rest of them were located between radii ranging from 20 km to 100 km. Fig. 4 shows the spatial distribution of the 3087 strokes, where those in red color represent the events occurred between the 5 h and 7 h UTC, the time at which the thunderstorm reached the most intense peak in the city of Manizales, registering a total number of 991 strokes during this time. Furthermore it is also possible to observe that the thunderstorm was directed towards the northwest, the same direction reported by the OVSM for the column of gases and ash [13]. Using the information provided by the WWLLN it was possible to find a relationship between the thunderstorm and the volcano activity in the city of Manizales, as in the same way, in the year 2011 the WWLLN registered a lightning activity associated to activity in the Puyehue volcano [19]. In the work presented in [20], the information provided by the WWLLN was used in order to search for a relationship between the increase in the atmospheric discharges of two events registered between the emissions of ash from the Etna volcano, Italy, between the years 2006 - 2007, and the Eyjafjallajökull volcano in the year 2010 in Iceland.

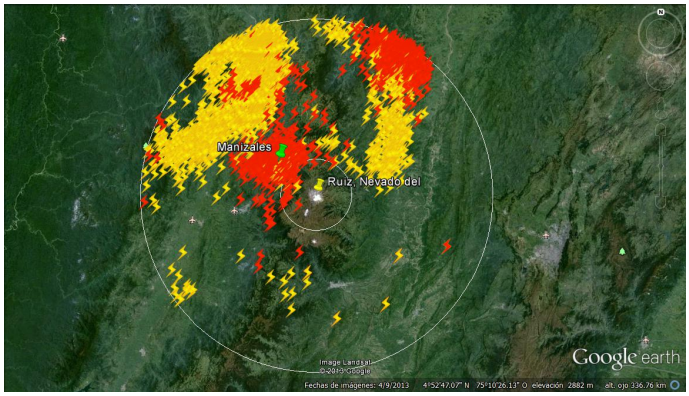

Figure 4. Lightning strokes from the WWLLN. Data seen at 20km and 100km from the volcano. Red color: strokes between the 5h and 7h, Yellow color: strokes before the 5h and after the 7h.

Finally, taking into account the evidences obtained from OMI, OVSM and WWLLN it can be observed a possible cause for a relationship between the thunderstorm in the city of Manizales city and the volcano activity in the same city, this possible cause is related to the emission of ash and gas, which can change the atmospheric conditions, generating a possible increase in the lightning activity. By exploiting the data obtained from LINET - Colombia, the conclusion about a possible relationship could be reinforced, classifying the quantity, the time of major occurrence, the polarity and peak

current of the strokes that took place in the city of Manizales for the date mentioned before. It is important to notice that the LINET network has an efficiency of 90% in the area of study [9].

For the realization of this analysis, only the strokes that struck inside an area of 30 km $\times$ 30 km are taken into account, taking as the central point the city of Manizales. Fig. 5 shows the number of strokes per hour, a total number of 1019 strokes were registered. Table I shows the percentage of positive and negative strokes for both IC and CG lightning.

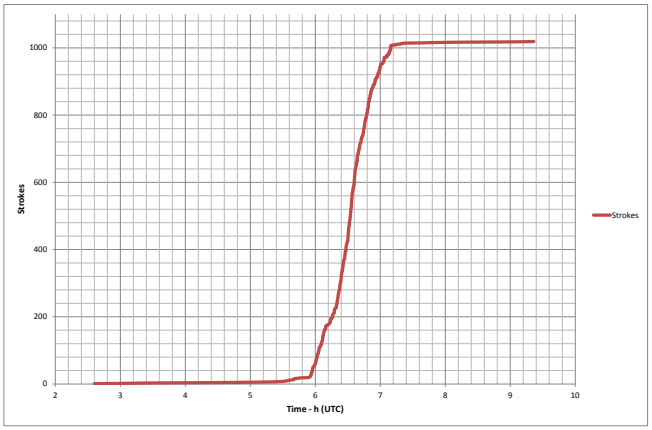

Figure 5. Temporal distribution of lightning strokes

TABLE I
POLARITY AND TYPE OF LIGHTNING.

Strokes	Positive	Negative	IC	CG
%	11.48	88.52	5.89	94.11

Fig. 5 shows that the storm had its major intensity between the 6h and 7h UTC, with a total number of 884 strokes. It means, 87% of the total events. Table II shows the type, polarity and current peak value of the cloud-to-ground lightning.

TABLE II
PERCENT: TYPE OF LIGHTNING, POLARITY. CURRENT PEAK VALUE OF CLOUD-TO-GROUND LIGHTNING

Lightning Strikes between 6h - 7h UTC		
Intra-Cloud	40	5%
Cloud-to-Ground	884	95%
Polarity of Cloud-to-Ground		
Negative	787	89%
Positive	97	11%
Current Peak Value of Cloud-to-Ground - kA		
Positive	43.1	
Negative	-127.1	

IV. CONCLUSIONS

Manizales is a city that historically has had low atmospheric activity per year [21], [22], for this reason, events like the one analyzed here are of great importance and therefore are relevant to this study. Based on available information from OVSM, WWLLN, OMI and LINET, it was found that the thunderstorm occurred on March 30, 2012 was probably related with the activity of the Nevado del Ruíz volcano, since the volcanic ash and gas emissions as SO_2 and water vapor, can change the conditions of the atmosphere, generating favorable conditions for the production of lightning [4]. It is possible to observe that the thunderstorms associated with volcanic eruptions can have long periods of time and a large amount of strokes, and these strokes can also have bigger current peak values than the ones usually reported. It is also important to note that volcanic lightning not only occurs at the site of the eruption but tens of kilometers away from the crater. In the case of the city of Manizales, it is located just 28 km away from the Nevado del Ruíz volcano and also in Katla, Iceland where people and livestock have been hit and have died because of volcanic lightning at distances of 30 km from the crater [4].

Finally, although the observations suggest that the thunderstorm is probably related to the volcanic activity, it is necessary to have more information of the meteorological variables of the area, as for example pressure, and wind speed, according to [20]. Analyzing a greater number of cases to enable a better understanding of these events is of great importance, because Colombia is located in the tropics, and as it is well known, the tropical region has one of the most highly intense lightning activities in the world.

ACKNOWLEDGMENT

The authors would like to thank COLCIENCIAS and the Universidad Nacional de Colombia, for their support in conducting this research. The authors would also thank Keraunos S.A.S for the information provided and the World Wide Lightning Location Network (http://wwlln.net), a collaboration among over 50 universities and institutions, for providing the lightning location data used in this paper.

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