Lidar observations of Etna volcanic aerosol

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Abstract—**Lidar observations of atmospheric aerosols have been performed at IMAA-CNR, Tito Scalo, Southern Italy, during the last two last eruptive events of Etna volcano in July-August 2001 and October-December 2002 periods. For both campaigns, some anomalous layers have been observed at 4 km of height above sea level. Anomalous values of lidar ratio, i.e. extinction to backscatter ratio, respect to those typically measured at IMAA, reveal the presence of aerosol with a different chemical composition and size distribution. Such values have been ascribed to the presence of Etna emitted aerosol.**

Keywords: lidar, aerosol, Etna

I. Introduction

Volcanoes and fumaroles are the sources of about 20% of sulphate aerosol in the atmosphere. While the stratospheric sulphate aerosols have been studied since the second half of the last century, more information are needed about tropospheric volcanic aerosols, in order to evaluate the local impact of this kind of aerosol. For these reasons, it is necessary to obtain information about the microphysical properties of volcanic aerosols.

The Raman lidar technique is a powerful tool to investigate aerosol properties. In fact a lidar in elastic-Raman configuration allows to retrieve, in independent way, aerosol extinction and backscatter profiles [1]. In the frame of the EARLINET (European Aerosol Research LIdar NETwork) project [2], the IMAA-CNR lidar station (Tito Scalo, Potenza, Southern Italy, 40°36'N, 15°44'E, 820 m above sea level) provides, since May 2000, systematic measurements of aerosol extinction and backscatter at 355 nm and backscatter measurements at 532 nm in the troposphere. In addition to routine measurements, EARLINET lidar stations perform special measurement campaigns in coincidence with particular atmospheric events. In particular, more than 100 Saharan dust special outbreaks events have been observed with our lidar system, for an amount of about 300 hours of data acquisition, in order to study this kind of aerosol. Furthermore, the IMAA lidar station is the best candidate to study Etna aerosol emission, because of the small distance, only 300 km, between IMAA and the volcano.

In the last two years a strong Etna activity has been recorded, in fact, in the summer 2001, one of the most complex and unusual eruptive event of the last 300 years occurred and after a short period of quiescence, on 28 October 2002, an intense seismic and eruptive activity started again. In correspondence of these two large eruptive events, we performed intensive measurements campaign in order to study the development and the characteristic of the volcanic aerosol layers.

II. Results

In July-August 2001, a large amount of ashes and smokes were introduced into the atmosphere by Etna eruptions. Eruptive activity started at the beginning of July with feeble eruptions, became stronger in the 17–31 July period, and decreased at the beginning of August. The eruptive activity was characterized by several eruptions accompanied by a strong seismic activity. The total volume of lava and pyroclastics, emitted during the whole period 7 July – 9 August, was approximately 40 million cubic meters (about 21 of lava and less than 20 of pyroclastics). Moreover, SO_2 emission reached a maximum value of 20000 t/d on 20 July against a typical summer mean value of 2500 t/d.

The IMAA lidar campaign devoted to observation and characterization of Etna emitted aerosols covers the whole period of interest (9 July- 13 August), for a total amount of 70 hours of measurements. Anomalous aerosol layers at about 4 km of height have been observed, in disagreement with the values typically observed during summer period in Potenza. In fact, in absence of dust events and forest fires, at our site, aerosol layers typically never exceed 3 km of height. Moreover, typical observations of diurnal cycles show aerosol planetary boundary layer heights never exceeding 3 km with the presence of a typical residual layer extending up to about 3.5 km [3]. Higher dust layers are normally observed during Saharan dust events or in presence of smokes originated by forest fires. Aerosol backscatter profiles are typically obtained with a 30 minutes average (corresponding to 36000 laser shots) and with a vertical resolution of 60 m. In particular, on 24 July, aerosol backscatter profile, at both 355 and 532 nm (Fig. 1a), shows the presence of two distinct aerosol layers: the lowest between 2 and 3.5 km a.s.l. and another one at an altitude of about 4 km. In this layer, the peak values of aerosol backscatter are $7x10^{-7}$ and $1.6x10^{-6}$ m^{-1} sr^{-1} at 355 and 532 nm respectively, values quite high if we consider that, for this day, no significant fire occurred and backtrajectory analysis provided by the German Weather Service and TOMS image show no air masses coming from the Saharan region. In the same layer, the mean value of aerosol extinction at 355 nm is about $7x10^{-5}$ m^{-1} (Fig. 1b), with an optical depth within the layer of 0.07. In Fig. 1c, the lidar ratio LR, defined as the ratio between extinction and backscatter coefficients, is reported. The mean lidar ratio value is 54 sr for 2-3.5 km layer and 55 sr inside the higher layer. It is worth noting that these values are higher than 43 sr, typically observed at IMAA in three years of measurements [4], and are also higher than lidar ratio values obtained in cases of Saharan dust intrusion (around 46 sr). This relevant discrepancy leads us to suppose the presence of a different type of aerosol, clearly correlated to Etna eruptions. In addition, an estimation of the Angstrom coefficient δ, obtained by the wavelength dependence of aerosol backscatter at 355-532 nm, provides us a mean δ value inside the two layers of 2.6, against 1.5, typically observed during this period of the year. This is a further confirmation of the different kind of observed aerosol, characterized by a smaller size.

Moreover, measurements carried out during the 24 July – 6 August period show aerosol layers characterized by high values of LR and δ, with an average of about 50 sr and 2.4.These anomalous values lead us to suppose the presence of aerosol of volcanic origin. In fact, even if satellite images and back-trajectory analysis do not show air masses coming from Sicily, it is possible that a diffusion mechanism spread part of the Etna emitted material on 300 km that is the small distance between IMAA and the volcano. A support of this hypothesis comes from the agreement between measured values of lidar ratio and Angstrom coefficient, and theoretical estimation calculated in the case of sulphate aerosols (δ ~ 2.4 and LR~ 50 sr) [5-6].

In the period 28 October- 16 December 2002, more than 130 hours of lidar measurements were performed at IMAA in order to study aerosol emitted by Etna eruptions. In the first days, SO_2 emission reached very high values with a maximum value of about 20000 t/d on 29 October, against a value of 990 t/d observed in the pre-eruptive phase. The total volume of ash emitted during the 2002 Etna eruption has been estimated as 20-50 million cubic meters.

Also in this case, an anomalous aerosol layer is present at about 4 km a.s.l., where no relevant aerosol load has been observed in absence of forest fires and Saharan dust. Fig. 2 reports profiles of aerosol backscatter at 355 nm and 532 nm (a), aerosol extinction (b) and lidar ratio (c) at 355 nm measured at IMAA around the midnight of 1 November 2002. In the aerosol backscatter profiles, different aerosol structures are evident below 3 km of altitude, but a very strong peak extending between 3.5 and 4.5 km is observed. In this layer, aerosol backscatter coefficient reaches value of about $5x10^{-6}$ and $1x10^{-6}$ m^{-1} sr^{-1} at 355 and 532 nm respectively. In fact, the very strong peak observed in the backscatter profiles reveals the presence of a large amount of aerosol. This behavior has been observed also in the corresponding extinction profile characterized by a peak value inside the layer of about $2x10^{-4}$ m^{-1} and an optical depth of the layer of 0.1, about 1.5 times the values observed for the Etna 2001 case. This difference is due to the presence of an aerosol amount larger than that measured in 2001. In fact, the aerosol load observed on 1 November 2002 is so large that also satellite images have been able to show air masses coming from Etna towards IMAA site. In addition, the lidar ratio profile, reported in Fig. 2c, is almost constant with the altitude between 3.5 and 4.5 km, with a mean value of 52 sr. This behaviour can be also related to a less relevant changing in the aerosol properties because of direct transport of volcanic aerosol from Etna to IMAA, that is also responsible for a more relevant aerosol load over Potenza.

During the Etna 2002 lidar measurement campaign, the evolution of aerosol layers related to the eruption has been studied. Also in this case lidar ratio values greater than 50 sr have been obtained with a LR mean value of 52 sr. In this campaign, as well as for the 2001 one, the mean value of the Angstrom coefficient, retrieved from the backscatter profiles at 355 and 532 nm, is about 2.4, value characteristic of submicrometric particles such as sulphates.

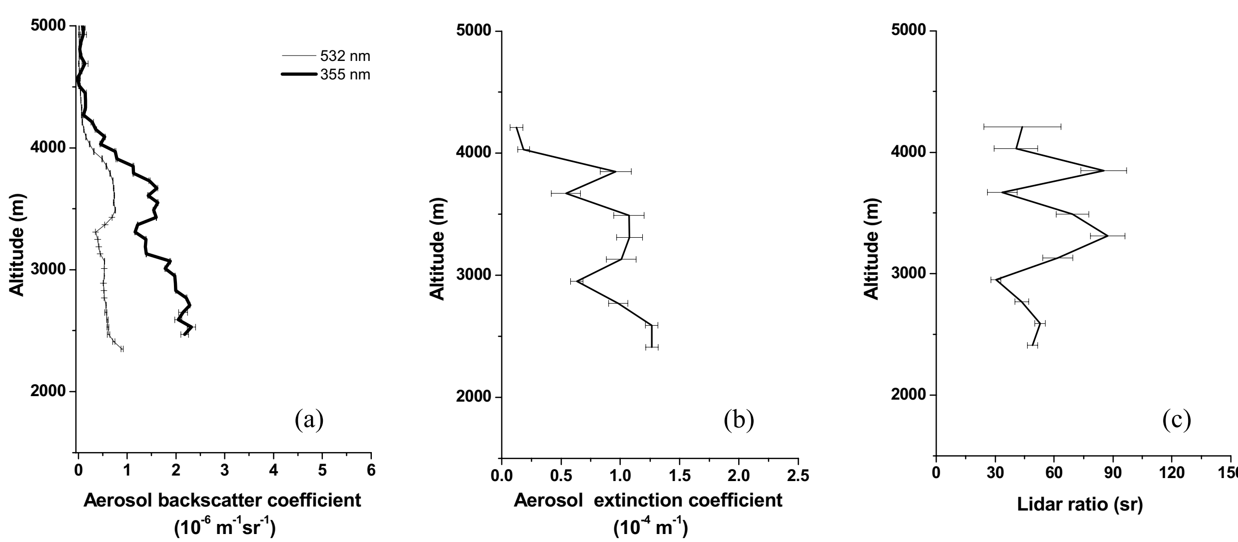

Figure 1. Backscatter coefficient at 355 and 532 nm (a), extinction at 355 nm (b) and lidar ratio at 355 nm (c), measured on 24 July 2001, 19:55-20:26 UT.

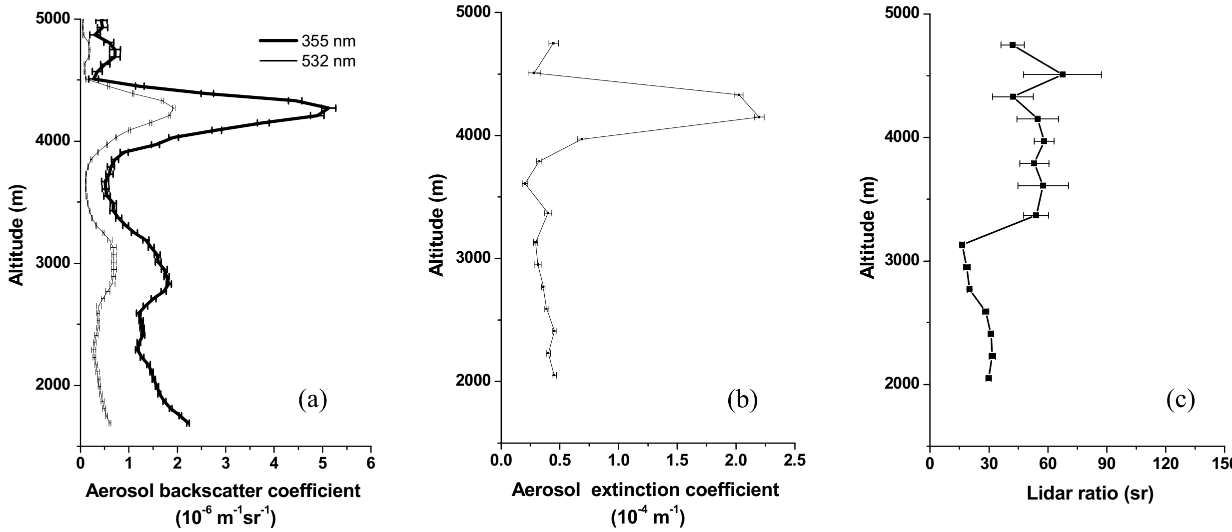

Figure 2. Backscatter coefficient at 355 and 532 nm (a), extinction (b) and lidar ratio at 355 nm (c), measured on 1 November 2002, 23:20-23:50 UT.

III. CONCLUSIONS

Etna is one of the most studied volcanoes all around the world. Numerous studies have been carried out in order to increase the knowledge about mechanisms that rule seismic and eruptive activities. Many detailed measurements campaigns have been performed to retrieve chemical composition of the emitted gases and to study dimension and composition of pyroclasts. For what concerns aerosol emitted during Etna eruptions, this is the first time that Etna aerosol emissions have been investigated by using lidar techniques and characterized in terms of lidar ratio.

Both in 2001 and 2002, IMAA lidar measurement campaign related to Etna eruptions, aerosol layers at about 4 km of altitude have been observed. These layers are characterized by a mean lidar ratio value of 52 sr, value anomalous respect to those typically observed in Potenza. Also the Angstrom coefficient estimation gives an anomalous mean value (around 2.4). These mean values are in perfect agreement with values theoretically expected for sulphates sub-micrometric particles.

In 2002, a direct volcanic aerosol transport to IMAA was observed and consequently aerosol volcanic amount was larger than in 2001 case. The agreement between values observed in the two campaigns is a further support to our hypothesis about the presence over Potenza of a volcanic aerosol layer also in the late July 2001.

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