

Integration of measurements and model simulations to characterize Eyjafjallajökull volcanic

aerosols over south eastern Italy

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Abstract

Volcanic aerosols resulting from the Eyjafjallajökull eruption have been detected in south-eastern Italy from 20 to 22 April 2010, at a distance of approximately 4000 km from the volcano, and have been characterized by lidar, sun-sky photometer, and surface *in-situ* measurements. Volcanic particles added to the pre-existing aerosol load and measurement data allow quantifying the impact of volcanic particles on the aerosol vertical distribution, lidar ratios, the aerosol size distribution, and the ground-level particulate-matter concentrations. Lidar measurements reveal that backscatter coefficients by volcanic particles were about one order of magnitude smaller over south-eastern Italy than over Central Europe. Mean lidar ratios at 355 nm were equal to 64 ± 5 sr inside the volcanic aerosol layer and were characterized by smaller values (47 ± 2 sr) in the underlying layer on April 20, 19:30 UTC. Lidar ratios and their dependence with the height reduced in the following days mainly because of the variability of the volcanic particle contributions. Size distributions from sun-sky photometer measurements reveal the presence of volcanic particles with radius $r > 0.5 \mu\text{m}$ on April 21, and that the contribution of coarse volcanic particles has increased from 20 to 22 April. The aerosol fine mode fraction from sun-sky photometer measurements varied between values of 0.85 and 0.94 on 20 April and decreased to values between 0.25 and 0.82 on 22 April. Surface measurements of particle size distributions were in good accordance with column averaged particle size distributions from sun-sky photometer measurements. PM1/PM2.5 mass concentration ratios of 0.69, 0.66, and 0.60 on 20, 21, and 22 April, respectively, support the increase of super-micron particles at ground. Measurements from the Regional Air Quality Agency show that PM10 mass concentrations on 20, 21, and 22 April, 2010 were enhanced in the entire Apulia Region. More specifically, PM10 mass concentrations have on average increased over Apulia Region of 22%, 50%, and 28% on 20, 21, and 22 April, respectively, compared to values on 19 April. Finally, the comparison of measurement data with numerical simulations by the FLEXPART dispersion model demonstrated the ability of FLEXPART to model the advection of the volcanic ash over the 4000 km from the Eyjafjallajökull volcano to Southern Italy.

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1. Introduction

The eruption of the Eyjafjallajökull volcano in Iceland entered a phase of **strong ash** ejection to the atmosphere on 14 April, 2010, which lasted for several days. **During** the initial explosive phase, the eruption ejected volcanic ash to altitudes as high as 10 km above sea level, as reported by the Institute of Earth Sciences (IES, <http://www.earthice.hi.is>). The westerly winds over Iceland transported the volcanic emissions first toward northern Europe (starting with UK and Norway) (Petersen, 2010) and then, towards Central and Southern Europe. Emeis et al. (2011) found from remote sensing data and numerical simulations that the first volcanic ash layer reached Germany on 16 April. The volcanic **ash** was detected in clear layers above Switzerland starting from 17 April (Bukowiecki et al., 2011), above southern Italy from 19 April (Madonna et al., 2010; Mona et al., 2012), and over Greece after 21 April (Papayannis et al., 2012). **The spatiotemporal distribution of the volcanic ash over Europe has been investigated extensively by EARLINET, the European Aerosol Research Lidar NETwork, which performed almost continuous measurements from 15 April to 22 May 2010 (e.g. Ansmann et al., 2010; Wiegner et al., 2011; Gasteiger et al., 2011; Groß et al. 2011; Mona et al., 2012; Papayannis et al., 2012). Lidar instruments are well suited to observe aerosol layers at higher altitudes and can provide information about their vertical structure and development with time. In addition to lidars, different ground-based, airborne and space-borne instruments have been used to characterize the physical and optical properties of the volcanic aerosols resulting from the Eyjafjallajökull eruption (e.g. Bukowiecki et al. 2011; Schäfer et al., 2011; Revuelta et al., 2012; Campanelli et al., 2012; Schumann et al., 2011, Toledano et al., 2012; Rossini et al., 2012).**

This paper focuses **firstly** on the **integration of different measurements techniques** to characterize aged volcanic aerosols at Lecce (40.4°N; 18.1°E), in south eastern Italy, approximately 4000 km away from the Eyjafjallajökull volcano. After advection over **so long distances, the volcanic ash is highly dispersed and the particle** surfaces can be modified by condensation and coagulation processes upon contact with atmospheric trace gases and aerosols (Langmann et al., 2012). **Therefore,** the use of different remote sensing and in-situ sampling devices to characterize aged volcanic particles represents **one of** the main objectives of this study. **Lidar measurements performed within EARLINET, captured the spatiotemporal evolution, of the volcanic aerosol plume over Lecce, Sun-sky photometer measurements performed within AERONET (Holben et al., 1998) at the lidar site allowed studying the volcanic aerosol effects on the main column-averaged aerosol optical and microphysical properties. Surface in-situ measurements showed how the volcanic ash influenced the particle size distribution and impacted the mass concentration of PM1 and PM2.5 particles. Finally, in situ SO₂ and PM10 measurements performed by the Regional Air Quality**

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Agency (www.arpa.puglia.it/web/guest/qariainq) have been analyzed to study the impact of volcanic aerosols on regional air quality in the entire Apulia Region. Synoptic meteorological maps and analytical back trajectories have mainly been used to infer the advection of volcanic aerosols to the monitoring site. Aerosol observations performed thousands of kilometres away from source regions are also important for the validation of volcanic ash transport models. Therefore, measurement data have been compared with results from the dispersion model FLEXPART.

An overview of the instrumentation and a brief description of the FLEXPART dispersion model are given in section 2. Results and discussion are reported in section 3. Main conclusions and caveats are presented in section 4.

2. Instrumentation and FLEXPART model

2.1 Experimental devices

Remote sensing and surface in-situ measurements were conducted at the Physics Department of the University of Salento (40.4°N; 18.1°E) which is located 6 km away from the town of Lecce, in south-eastern Italy, and approximately 4000 km away from Iceland. Measurements are regularly performed there, with a Raman lidar identified as UNILE (UNiversity of LEcce) lidar. The lidar is operative since the beginning of the European Aerosol Research Lidar NETwork (EARLINET) in May 2000 (Matthias et al., 2004) and nowadays employs an f/4 Newton telescope with a 30-cm-diameter mirror and a frequency-tripled Nd-YAG laser (355 nm) that delivers pulses of ~ 350 mJ of energy at a repetition rate of 30 Hz. The UNILE lidar has been designed to derive vertical profiles of aerosol extinction ($\alpha(z)$) and backscatter ($\beta(z)$) coefficients and lidar ratios (LR(z)) during nighttime and aerosol backscatter coefficients during day time at a wavelength of 355 nm. Details on experimental apparatus and data analysis are reported in De Tomasi and Perrone (2003) and De Tomasi et al. (2003; 2006). The statistical uncertainties of $\beta(z)$ are calculated from the error propagation law by assuming a Poisson noise on the lidar signals. The aerosol extinction coefficient is calculated by a linear fit of the derivative of the logarithm of the nitrogen Raman signal with respect to the range (Ansmann et al., 1992) and its uncertainties are set as the uncertainties associated to the slope of the fitting straight lines. Lidar ratio ($LR(z) = \alpha(z)/\beta(z)$) uncertainties are calculated using standard propagation techniques (Bevington and Robinson, 2003). The lidar system is estimated to achieve full overlap between 0.3 - 0.5 km (Matthias et al., 2004).

An AERONET sun/sky radiometer operates at the lidar site since March 2003. AERONET is a federated international network of sun/sky radiometers established in 1993 (Holben et al., 1998). Data are publicly available online in near real-time mode (<http://aeronet.gsfc.nasa.gov>). The sun-sky radiometer measures direct sun radiance in eight spectral channels between 340 and 1020

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nm (340, 380, 440,500, 670, 870, 940 and 1020 nm). Sky measurements are performed at 440, 670, 870 and 1020 nm wavelengths through a wide range of scattering angles from the Sun (Holben et al., 1998). An automated cloud-screening algorithm (Smirnov et al., 2000) is applied to AOT direct-sun measurements. Aerosol microphysical parameters are retrieved from direct sun and diffuse sky radiance measurements by a flexible inversion algorithm, developed by Dubovik and King (2000). A discussion on the accuracy of individual retrievals is reported in Dubovik et al. (2000). Quality assured (automatically cloud cleared and manually inspected) level 2 AERONET data retrieved from measurements performed between 19 April and 22 April, 2010 have been used in this study.

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For continuous aerosol size distribution measurements at about 10 m from the ground, a TSI Aerodynamic Particle Sizer (APS) 3321 with 51 channels of equal logarithmic width of 0.031 within the diameter size range of 0.54-20.0 μm , was deployed. The APS measurements started on April 21 at midday. Particulate matter (PM) samples have also been collected at ~10 m above the ground level with a low volume (2.3m³/h) HYDRA-FAI dual sampler which allowed to simultaneously collect 24-hour PM_{2.5} and PM₁ samples on 47-mm-diameter preheated filters (PALLFLEX, Tissuquartz). The filters were conditioned for 48 hours (25°C and 50% humidity) before and after sampling and PM mass concentrations have been determined by the gravimetric method. Uncertainties of the mass concentrations are below 5%.

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2.2 The FLEXPART dispersion model

The Lagrangian particle dispersion model FLEXPART (Stohl et al., 1998, 2005) was used to simulate the transport of volcanic ash. FLEXPART was run in forward mode and driven with meteorological data from the European Centre for Medium-Range Weather Forecasts (ECMWF) analyses with 0.18° x 0.18 ° horizontal resolution and 91 vertical model levels. The simulation accounted for gravitational particle settling as well as dry and wet deposition, but not for ash aggregation processes. Formation of sulphate particles was also not simulated. Ash emission rates as a function of time and height, determined previously using an inversion scheme that coupled a priori source information and FLEXPART model results with satellite data (Stohl et al., 2011), were used as a source term for this study. The ash particle size distribution included 25 particle size classes from 0.25-250 μm diameter. The model output had a horizontal resolution of 0.25 ° x 0.25 ° and a vertical resolution of 250 m.

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3 Results and discussion

3.1 The advection of volcanic aerosols to Southeastern Italy

The synoptic meteorological situation on 14-15 April, with a high located south of Iceland and a trough over northern Scandinavia, favoured the transport of ash first over Norway and later

over Southern England, Denmark and Central Europe (e.g. Peterson, 2010; Folch et al., 2012). Stagnant conditions over Central Europe during the following days favoured a long residence time of the ash over Europe, associated with slow subsidence of the ash layers and settling of larger particles. The situation changed on 20 April when north-westerly winds transported parts of the volcanic ash plume first over south-eastern Europe and then over Eastern Europe on April 23 (Fig. 1 of the paper by Folch et al., 2012). Eight-day analytical back trajectories from the Hybrid Single Particle Lagrangian Integrated Trajectory Model (HYSPLIT) (Draxler and Rolph, 2010) have been analyzed in this study to infer the arrival of volcanic particles over Lecce. We found that air masses from south-eastern Europe and north-western Africa were mainly advected over south-eastern Italy, up to ~3 km above sea level (a.s.l.) on the diurnal hours of April 19. Backtrajectories with an origin over Central Europe, arrived in south-eastern Italy up to ~3 km a.s.l. on the morning of 20 April, in accordance with the synoptic meteorological situation (Folch et al., 2012). The arrival over the monitoring site of this study of air masses which had previously travelled across Iceland started on the afternoon of April 20. Figure 1a shows the 8-day back-trajectories, ending at the Physics Department of the Salento University on April 20 at 18:00 UTC. The backtrajectory, ending at ~0.5 km a.s.l., has crossed Iceland before reaching the monitoring site. The backtrajectories ending at ~2 and 3 km a.s.l., have their origin over Central Europe. However, they have travelled over European regions known to have been affected by volcanic ash before reaching Lecce and as a consequence, may have been responsible for the advection of volcanic particles at altitudes larger than few kms a.s.l.. Figure 1b shows the pathway of the backtrajectories, arriving over Lecce on 21 April at 06:00 UTC. Both the 2 km- and the 3 km-arrival-height backtrajectories, have travelled across Iceland before reaching Lecce. Figures 1c and 1d show the pathways of backtrajectories arriving over Lecce, on 21 April at 18:00 UTC, and on 22 April at 12:00 UTC. Air masses from northern Europe at lower altitudes and from north-western Africa at higher altitudes were transported to Lecce on April 23. Thus, the transport of volcanic particles to south-eastern Italy was most likely on 20, 21, and 22 April according to HYSPLIT back trajectories. Analytical back trajectories provided by NASA (<http://croc.gsfc.nasa.gov/aeronet/index.html>) for the monitoring site of this study, which are based on a kinetic trajectory analysis using NASA GMAO assimilated gridded data, were generally similar. It is also worth noting, that from April 20, 21:00 UTC until April 22, 03:09 UTC, volcanic particles were detected in the free troposphere at the CNR-IMAA Laboratory in Potenza (40°36'N, 15°44'E, 760 m a.s.l.), which is ~250 km away from the monitoring site of this study (Mona et al., 2012).

Plots of volcanic-ash column-integrated mass concentrations over Europe from FLEXPART (Fig. 2) confirm the advection of volcanic aerosol over southeastern Italy from 20 to 22 April. The green dot in Fig. 2 represents the lidar site. Simulated ash columnar mass concentrations at Lecce are

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higher than a few mg m^{-2} after the afternoon of April 20. They reach the highest values of nearly 200 mg m^{-2} during the night of 20/21 April and subsequently decrease to rather low levels in the afternoon of 22 April. Notice that even the largest ash column loadings over Lecce are about one order of magnitude lower compared to those simulated by FLEXPART over Central Europe on 16 April (Stohl et al., 2011). Thus, while some volcanic ash reached Southeastern Italy, it is much more diluted than earlier over Central Europe. Simulations of the Eyjafjallajökull volcanic ash dispersal over Europe using COSMO-MUSCAT also revealed the advection of diluted ash over south-eastern Italy on 21 April (Fig. 4 of the paper by Heinold et al., 2012).

3.2 UNILE lidar measurements

Figure 3 (solid lines) shows the backscatter coefficient (β) profiles at 355 nm retrieved from lidar measurements performed from 20 April until 22 April. β -profiles have been retrieved from one-hour-average lidar measurements. More specifically, the profile at 05:30 UTC was calculated by averaging lidar measurements from 05:00 to 06:00 UTC. Aerosol optical thicknesses (AOTs) at 355 nm, calculated from lidar profiles are also reported in each plot of Fig. 3. To this end, we have assumed that extinction profiles did not vary with altitude in the lowermost aerosol layer, whose height is of the order of the planetary boundary layer (PBL) height (De Tomasi and Perrone, 2006). Then, we can assume that aerosol particles are well mixed within the PBL.

Figure 3a shows that aerosol particles monitored by the lidar were mainly located below 3 km from the ground level at 5:30 UTC on 20 April. The aerosol-load-height increased with the time of the day and the comparison of Fig. 3a and Fig. 3b shows that at 17:30 UTC, backscatter coefficients were characterized by larger values ($\cong 1.5 \text{ Mm}^{-1} \text{ sr}^{-1}$) mainly within the 2.5-3.0 km altitude range. We believe that the advection of volcanic aerosol has likely contributed to the increase of β values above 2.5 km a.s.l., in accordance with backtrajectory pathways. The gradually descending layers of volcanic particles which were observed at the CNR-IMAA Laboratory (Mona et al., 2012) from 20 April, 21:00 UTC, and 21 April, 12:00 UTC between about 4 km a.s.l. and the onset of the PBL, support this. Notice that the β values at 1064 nm retrieved at the CNR-IMAA Laboratory, varied within the $0.05\text{-}2.0 \text{ Mm}^{-1} \text{ sr}^{-1}$ range within volcanic ash layers. Extinction (α) and lidar ratio (LR) profiles retrieved at Lecce from nighttime Raman lidar measurements (De Tomasi et al., 2006) are plotted in Fig. 4. The lidar ratio profile at 19:30 UTC of 20 April (Fig. 4a, dots) allows inferring two main aerosol layers: one extends up to about 1.8 km above ground level and is characterized by LRs $\cong 47 \pm 2 \text{ sr}$ and the other extends over the 2.1-3.3 km range and is characterized by lidar ratios spanning the 65-71 sr range (Table 1). The lower LR values retrieved up to 2 km a.s.l. (Fig. 4a, dots) are affected by the contribution of pre-existing aerosol particles, which are not of volcanic origin. We

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believe that the larger LR_s retrieved within the upper aerosol layer are likely due to the contribution of volcanic aerosol; air masses from Central European regions known to have been affected by volcanic ash arrived to Lecce at altitudes larger than 2 km a.s.l. on the evening of April 20. Notice that Ansmann et al. (2010) found that the volcanic ash plume monitored on 16 April (14:15-15:30 UTC) at Leipzig (Germany) was characterized by lidar ratios at 355 nm of 55-65 sr (Table 1). Papayannis et al. (2012) found lidar ratios at 355 nm of 55-76 sr in volcanic aerosol layers 2.0-4.8 km a.s.l. monitored over Greece and Turkey. Mean LR values at 355 nm retrieved at Lecce for different altitude ranges are compared in Table 1 with the corresponding ones retrieved at Potenza from 20 up to 22 April (Mona et al., 2012) and the one provided by Ansmann et al. (2010). It is worth noting, that LR values retrieved at Lecce at 23:30 UTC of 20 April are in good accordance with the ones retrieved at Potenza within the same altitude range. The lidar measurements at 02:30 on 21 April (Fig. 4c, dots) shows that LR values were less dependent on altitude than for the earlier measurements (Table 1). The mixing of volcanic aerosols with underlying aerosol particles as a consequence of particle sedimentation, subsidence, and/or the spatiotemporal variability of the volcanic aerosol contribution were likely responsible for this result.

Aerosol particles up to about 4 km a.s.l. have been detected by the lidar at 23:30 UTC of April 20 (Fig. 3c). The aerosol load and the maximum height where aerosols have been detected by the lidar decreased with time on April 21. These results are due to smaller contributions of both volcanic aerosols and non-volcanic particles. Aerosol particles were located up to ~ 3.2 km a.s.l. and lidar ratios spanned the 32-50 sr range at 02:30 UTC of April 22 (Fig. 3g and Fig. 4d). Significantly larger LR_s were retrieved on 21-22 April, 19:07-03:09 at Potenza.

Figure 5 shows the time evolution from 20 to 22 April 2010 of the aerosol optical thickness at 355 nm (open dots) retrieved from lidar measurements. Notice that non-volcanic aerosols have likely contributed to the rather high AOT_s retrieved from lidar measurements performed on the daytime hours of 20 April, if we assume that the advection of volcanic particles over south-eastern Italy has mainly occurred since the evening of 20 April, in accordance with HYSPLIT backtrajectories. AOT values vary significantly with time; they reach a peak value at ~ 15:30 UTC on 21 April, then, decrease and a peak value is again observed at about 03:00 UTC on 22 April. The advection over the monitoring site of this study of an inhomogeneous cloud of volcanic particles was likely responsible for these results. In fact, Figs. 3 and 4 show that both the aerosol backscatter coefficient and lidar ratios varied with time and height from 20 to 22 April.

3.3 AERONET sun/sky photometer measurements

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AERONET aerosol products (Version 2, Level 2 data) are lacking for the monitoring site of this study from 12 up to 19 April. In addition, only some aerosol products are available from 14:15 UTC of 20 April until 16:11 UTC of 21 April. In particular, refractive index and single scattering albedo values have not been provided for these two days. The AERONET values of the AOT at 340 nm, retrieved from sun/sky photometer measurements performed from 20 to 22 April, 2010 are plotted in Fig. 5 (full circles). We observe that the few available AERONET-AOTs at 340 nm are in satisfactory agreement with lidar AOTs at 355 nm. Figure 6 shows the evolution with time of the AOT at 500 nm (full dots) and the fine mode fraction η (open triangles) from 20 to 22 April (Spectral Deconvolution Algorithm, Version 4.1, Level 2 data). η represents the ratio of the AOT due to fine mode particles, with a radius r smaller than 0.4-0.5 μm , to the total AOT. Figure 6 shows that AOT (500 nm) values on average decrease from 20 to 22 April, in accordance with lidar-AOTs (355 nm). 500 nm-AOTs also vary significantly with time and reach a peak value at $\sim 15:30$ UTC of 21 April, in accordance with lidar-AOTs (Fig. 5, open circles). The fine mode fraction decreases from 20 to 22 April (Fig 6, open triangles), indicating that the contribution of coarse mode particles increases. The columnar volume size distribution profiles retrieved on 20 and 21 April, from AERONET sun-sky photometer measurements are plotted in Figs. 7a and 7b. No data are available for 19 and 22 April. If we assume that the differences on the aerosol load monitored on 20 and 21 April are mainly due to the contribution of volcanic particles, we can use the differences between the volume size distribution retrieved on 21 April at 14:49 UTC ($(dV(r)/d\ln r)_A$), and the one retrieved on 20 April at 14:15 UTC ($(dV(r)/d\ln r)_B$), to determine the size distribution of volcanic aerosols on 21 April, 14:49 UTC. Figure 8 (solid line) shows the mass size distribution calculated in accordance with the following relationship:

$$dM_{A-B}/d\text{Log}(r) = ((dV(r)/d\ln r)_A - (dV(r)/d\ln r)_B) \cdot \ln 10 \cdot \rho$$

where $\rho = 3.0 \text{ g/cm}^3$ represents the particle density for volcanic ash, according to Kristiansen et al. (2012). Positive $dM_{A-B}/d\text{Log}(r)$ values are found for the 0.05-0.11 μm radius range and for radii $r > 0.5 \mu\text{m}$ (Fig. 8, solid line). While the difference for the small radii can be explained by the nucleation and subsequent growth of sulphate particles from volcanic SO_2 emissions, the difference for particles with radius $r > 0.5 \mu\text{m}$ is very likely due to coarse volcanic particles. This result is consistent with measurements performed over Central Europe (e.g. Emeis et al., 2010; Petaja et al., 2012). A drastic increase of particles with diameter greater than 1 μm was observed at Augsburg, Germany, during the volcanic ash plume impact episode (Pitz et al., 2001). Moreover, size distribution measurements during aircraft flights over Central Europe also revealed the dominance of

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coarse particles to the total particulate mass in the volcanic ash plume (e.g. [Schumann et al., 2010](#); [Kristiansen et al., 2012](#)).

3.4 Surface *in situ* measurements

Figure 7c shows the volume size distributions from TSI-APS (3321) measurements performed at the lidar site (~ 10 m a.s.l.) on 21 April at 14:49 and 16:11 UTC, respectively. Volume size distributions near the ground reach minimum values at a radius $r \cong 0.46 \mu\text{m}$ and are characterized by a coarse mode peaking at $r \cong 1.4 \mu\text{m}$, in satisfactory agreement to the AERONET-volume size distributions retrieved at 14:49 and 16:11 UTC, respectively (Fig. 7b). The volume concentration of both the column-integrated and the ground-based distribution was larger at 16:11 than at 14:49 UTC. Hence, the significant contribution of particles with radius $r > 1 \mu\text{m}$ revealed by Fig. 7c was likely due to the impact of volcanic aerosol at ground. *In situ* measurements performed by Lettino et al. (2012) over southern Italy and by Rossini et al. (2012) over central Italy have also revealed the surface impact of volcanic particles with radius $r > 1 \mu\text{m}$.

PM1 (particles with an aerodynamic diameter $\leq 1 \mu\text{m}$) and PM2.5 (particles with an aerodynamic diameter $\leq 2.5 \mu\text{m}$) samples were also collected at the lidar site from 21 to 24 April. Mass concentrations of daily PM1 and PM2.5 samples revealed that the PM1/PM2.5 mass ratios were 0.69, 0.66, and 0.60 on 20, 21, and 22 April, respectively, indicating that the contribution of particles with radius $> 1 \mu\text{m}$ increased from 21 to 22 April, in accordance with the daily evolution of the AERONET fine mode fraction.

Surface *in situ* SO₂ and PM10 measurements performed by the Regional Air Quality Agency (<http://www.arpa.puglia.it/web/guest/qariainq>) have been analyzed to infer the volcanic aerosol effects on regional scale. Enhanced PM10 and SO₂ concentrations were monitored all over south eastern Italy from 20 up to 22 April 2010. Table 2 reports the daily PM10 mass concentrations monitored from 19 up to 23 April 2010, at 10 sites of the 400 km long Apulia Region (Fig. 9), in addition to the average value (avg) over all sites. Uncertainties of PM10 values are smaller than 5%. Yearly mean (Y-M) mass concentrations ± 1 standard deviation (SD) and site type definition are also provided in the last two columns of Table 2. The largest PM10 mass concentrations have been monitored on 21 April at all sites (within experimental uncertainties), with the exception of site A, the site furthest in the north, where the largest PM10 level was reached on 20 April. These results suggest that the PM10 enhancement was very likely due to a large-scale pollution event, consistent with the arrival of volcanic particles (section 3.1). PM10 levels larger than corresponding yearly-means were reached at most of the sites on 20 or 21 April. The inhomogeneous structure of the volcanic particle cloud was likely responsible for the variability of the PM10 enhancement found at

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different sites. Enhanced PM10 mass concentrations were found all over Europe when the volcanic ash cloud was present (e.g. Schäfer et al., 2011; Emeis et al., 2011). PM10 averaged values reported in Table 2 show that the mean PM10 mass concentrations in the Apulia region increased by 4, 9, and 5 $\mu\text{g}/\text{m}^3$ (or by 22, 50, and 28%) on 20, 21, and 22 April, respectively, relative to the mean PM10 level on 19 April. The PM10 enhancements at site I (~500 m away from the lidar site) were 4, 6, and 5 $\mu\text{g}/\text{m}^3$ on 20, 21, and 22 April, respectively.

Figure 10 shows the time series of PM10 and SO₂ mass concentrations at sites G and C (Fig. 9) which are approximately one hundred and two hundred kms away from the lidar site. The correlation between PM10 and SO₂ mass concentrations, especially at site C, is also suggestive of a volcanic source of the PM10 enhancements, since SO₂ is also emitted by the volcano. Correlations between particulate matter and SO₂ in the Eyjafjallajökull plume have been observed earlier both by aircraft (Schumann et al., 2010) as well as at the ground (e.g. Emeis et al., 2011). Figure 10b reveals that a fast increase of PM10 and SO₂ mass concentrations occurred at ~ 06:00 UTC on 20 April and that high peak SO₂ mass concentrations were reached earlier at site G than at site C, even though site G is further south than site C. The advection over south eastern Italy of an inhomogeneous cloud of volcanic particles has likely been responsible for these results. Volcanic particles were detected at the CNR-IMAA Laboratory which is ~ 150 km away from site G, since the night of 19 April (Madonna et al., 2010; Mona et al., 2012) and backtrajectory pathways reveal that the backtrajectory ending at site G on April 20, 06:00 UTC at 100 m a.s.l. had crossed the CNR IMAA Laboratory area before reaching site G.

3.5 Measurements and FLEXPART simulations

Experimental results are compared in this section with numerical results from the dispersion model FLEXPART to contribute to the validation of the model abilities at a distance of approximately 4000 km from the volcano site. Dotted lines in Fig. 3 represent one-hour average vertical profiles of the volcanic ash mass concentration at the lidar site from FLEXPART simulations. The comparison of solid and dotted lines in Fig. 3 reveals the ability of the model to catch, at least in some cases, main features of the aerosol vertical distribution retrieved from lidar measurements. One must be aware that volcanic ash mass concentration profiles from FLEXPART cannot be directly compared to lidar profiles, since FLEXPART profiles are only representative of volcanic ash particles, while non-volcanic particles have also contributed to the retrieved lidar profiles.

Notice that FLEXPART predicts the arrival of ash on April 20, 17:30 UTC (Fig. 3b, dotted line) within the altitude range for which backscatter coefficient values (Fig. 3b, solid line) were ascribed

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to a larger contribution of volcanic particles, in accordance with the discussion reported in Section 3.2. Aerosol particles up to about 4 km have been detected by the lidar at 23:30 UTC of 20 April and the vertical structure of β (Fig. 3c, solid line) and LR (Fig. 4b, full dots) have allowed inferring the presence of two aerosol layers, with the upper layer (2.1-3.3 km a.s.l.) characterized by larger LR values (64 ± 5 sr) due to a larger contribution of volcanic particles (Ansmann et al., 2012). Accordingly, the FLEXPART profile at 23:30 UTC (Fig. 3c, dotted line) shows that a volcanic ash layer extends from ~ 2 km up to 3.7 km a.s.l.. The highest concentrations of about $170 \mu\text{g m}^{-3}$ at ~ 3 km a.s.l. are about a factor 7 lower than the highest values on 16 April over Leipzig (Ansmann et al., 2012). This suggests that the volcanic ash over south eastern Italy was strongly diluted. Notice that on 16 April, Asmann et al. (2010) found from lidar measurements at 355 nm performed over Leipzig, that backscatter and extinction coefficients reached peak values of $7.5 \text{ Mm}^{-1}\text{sr}^{-1}$ and 370 Mm^{-1} , respectively in the center of the ash plume. Figure 3c (solid line) and Fig. 4b (solid line) show that at 23:30 UTC on 20 April backscatter and extinction coefficients reached values up to $0.7 \text{ Mm}^{-1}\text{sr}^{-1}$ and 30 Mm^{-1} , respectively, within 3-4 km a.s.l.. We have assumed that the aerosol load located above 3 km from the ground was mainly due to volcanic aerosol. Hence, extinction and backscatter coefficients over Lecce in the volcanic aerosol layer were about a factor 10 lower than the highest values monitored at Leipzig on 16 April. This is in reasonable accordance with FLEXPART ratios of peak ash mass concentrations at Leipzig (16 April) and Lecce (20 April).

Figure 3g (dotted line) shows that the simulated volcanic ash was mainly located from the ground up to ~ 1.2 km and from 2 up to ~ 3.7 km at 23:30 UTC of April 21, in satisfactory accordance with lidar measurements which detected aerosol particles up to ~ 3.7 km a.s.l. (Fig. 3g, solid line). Both the backscatter coefficient values (solid line) and the simulated volcanic ash mass concentrations (dotted line) were characterized by rather low values at 17:30 UTC of April 22 (Fig. 3i), suggesting an end of the volcanic ash episode.

Figure 5 shows the time evolution from 20 to 22 April 2010 of the ash total column mass concentration from FLEXPART (M_a , full triangles) above the lidar site, in addition to the aerosol optical thickness at 355 nm (open dots) retrieved from lidar measurements. Ash total column mass concentration values vary significantly with time and reach rather low values after midday of 22 April. Accordingly, we have found that AOT values also were quite dependent on monitoring time and reached rather low values after midday of 22 April. M_a and AOT reach high peak values at different times. Uncertainties in the model simulations which grow as the ash cloud is transported far from its source and over complex topography (e.g., the Alps) (Kristiansen et al., 2012) are expected to lead to some discrepancies between the model and measurements for the diluted ash cloud over Southern Italy. Kristiansen et al. (2012) found a time delay between the modelled and measured

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PM10 peak values at the Jungfraujoch station (Swiss Alps). However, one must be aware that changes of the contribution by volcanic and non-volcanic particles have contributed to the variability with time of the AOT, while M_a was only due to volcanic ash.

The FLEXPART mass size distributions ($dM/d\log(r)$) for the monitoring site of this study are plotted in Figs. 11a-11c at different day hours of 20, 21, and 22 April. Mass size distribution profiles of Fig. 11 represent 1-hour-average profiles. Please note that the $dM/d\log(r)$ data points of the 20 April profile at 23:30 UTC (Fig. 11a) must be multiplied by a factor 2: volcanic ash mass concentrations reached the highest values on the night of 20 April over southeastern Italy. Figure 11 shows that modelled mass size distributions are dominated by particles with radius $r > 1 \mu\text{m}$. Dotted and dashed lines in Fig. 8 show for comparison the FLEXPART mass size distributions referring to 11:30 and 14:30 UTC, respectively of 21 April. Hence, experimentally determined $dM_{A-B}/d\log(r)$ values are in reasonable agreement with FLEXPART mass size distributions, within the model expected uncertainties. Both the experimentally determined and the FLEXPART size distributions reveal the significant contribution of particles within the $0.6 - 4 \mu\text{m}$ radius range, even though peak values are reached at different radii. Again, one must be aware that FLEXPART particle size distributions cannot be directly compared to AERONET columnar volume size distributions, since non-volcanic particles as well as sulphate particles of volcanic origin may have contributed to the retrieved AERONET profiles. It is worth noting from Fig. 11 that the modeled mass size distributions of 22 April (Fig. 11c) are shifted to larger particle sizes than the ones of 20 April (Fig. 11a). This result is in accordance with both the AERONET fine-mode-fraction means which have decreased from 20 to 22 April (Fig 6, open triangles) and the ground measurements of size segregated mass concentrations (Fig. 7c).

Figure 12 shows the time evolution of the volcanic ash mass concentrations ($\mu\text{g}/\text{m}^3$) from FLEXPART simulations at the lidar site and at $\sim 150 \text{ m a.s.l.}$. Daily means of the volcanic ash mass concentration are 0.7 , 4.5 , and $3.8 \mu\text{g}/\text{m}^3$ on 20, 21, and 22 April, respectively. These results are in reasonable accordance with the measurements at site I which is only a few hundred meters away from the lidar site. There, the PM10 enhancements were 4 , 6 , and $5 \mu\text{g}/\text{m}^3$ on 20, 21, and 22 April, respectively (Table 2).

4. Summary and conclusion

Results on the characterization of aged volcanic aerosol by lidar, sun/sky photometer, and surface *in-situ* measurements at a south eastern Italian site, which is approximately 4000 km away from the Eyjfallajökull volcano, have been reported. Meteorological synoptic maps and analytical back trajectories have revealed that southern Italy was mainly affected by volcanic ash particles

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from 20 to 22 April, 2010, in accordance with other published studies. However, the volcanic ash over southeastern Italy was strongly diluted. The extinction and backscatter coefficients retrieved in volcanic aerosol layers at Lecce were about a factor 10 lower than the highest values monitored at Leipzig on 16 April. Lidar measurements performed at the Physics Department of the University of Salento, within EARLINET, have shown that at 19:30 UTC of 20 April, volcanic particles were located near 2.1-3.3 km above ground level. Mean lidar ratios (LRs) at 355 nm were 64 ± 5 sr inside the volcanic aerosol layer, but only about 47 ± 2 sr at lower altitudes. The dependence of LR values on altitude decreased with time mainly because of the high variability of the volcanic particle contributions. In fact, the vertical structure of the lidar backscatter coefficient and of the AOT at 355 nm, varied significantly on 20, 21, and 22 April.

AERONET sun-sky photometer measurements have revealed that volcanic particles with radius $r > 0.5 \mu\text{m}$ arrived over south eastern Italy and that the contribution of coarse particles increased with time; the aerosol fine mode fraction varied from 0.85 to 0.94 on 20 April, and from 0.25 to 0.82 on 22 April. Ground-level in-situ measurements of the aerosol size distribution were in satisfactory accordance with columnar-average size distributions from sun/sky photometer measurements. Daily PM1 and PM2.5 mass concentrations have shown that the PM1/PM2.5 ratio was 0.69, 0.66, and 0.60 on 20, 21, and 22 April, again suggesting the advection of volcanic particles with aerodynamic radius $r > 0.5 \mu\text{m}$, in accordance with AERONET sun-sky photometer measurements. Enhanced PM10 and SO₂ concentrations were also found all over a 400 km long area of southern Italy from 20 up to 22 April, 2010. In particular, PM10 mass concentrations averaged over all measurements in the Apulia Region increased by 22%, 50%, and 28% on 20, 21, and 22 April, respectively compared to values on 19 April.

The comparison of experimental measurements with numerical simulations by the FLEXPART dispersion model has revealed that FLEXPART

- could capture the arrival of volcanic ash particles over south-eastern Italy from 20 up to 22 April,
- caught the high variability with altitude and time of volcanic particles advected ~ 4000 km away from the volcano site;
- was able to model the size distribution of volcanic particles and the increase of average particle size with time;
- captured the enhancement of PM10 levels at our monitoring site.

In conclusion, the paper has shown that the integrated use of different remote sensing and in situ sampling devices has allowed characterizing some optical and microphysical properties of aged volcanic particles even in a plume that was very dilute compared to the ash plume observed over Central Europe a few days earlier. The paper has also contributed to the validation of the

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FLEXPART dispersion model. It is rather important to test advanced dispersion models to better evaluate in the future the hazard to aviation due to volcanic ash and, more generally, to better evaluate the impact of volcanic ash emissions on the environment.

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The financial support of the EARLINET-ASOS Network by the European Commission under grant RICA-025991 is gratefully acknowledged. The authors would like to thank the NOAA Air Resource Laboratory for providing HYSPLIT backtrajectories and the Regional Air Quality Agency of Apulia Region for provideng PM10 and SO₂ data.

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Table 1 Mean values and standard deviations of the lidar ratios at 355 nm retrieved at Lecce, Potenza, and Leipzig on different days and hours and at different altitude ranges.

Time (UTC)	Altitude (km a.s.l.)	LR _{355 nm} (sr)
16 April, 14:15-15:30 (Ansmann et al., 2010)	2.5-4.0	60 ± 5
20 April, 19:00-20:00	0.6-1.8	47 ± 2
	2.1-3.3	64 ± 5
20 April, 23:00-24:00	0.7-1.9	40 ± 3
	2.3-2.7	57 ± 3
20 April, 21:00-23:05 (Mona et al., 2012)	2.0-3.0	42 ± 2
	3.1-4.0	38 ± 6
21 April, 02:00-03:00	0.6-2.1	45 ± 3
	2.4-3.1	53 ± 6
22 April, 02:00-03:00	0.6-2.1	35 ± 3
	2.0-3.0	45 ± 5
21-22 April, 19:07-03:09 (Mona et al., 2012)	1.6-3.4	80 ± 12

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Table 2 PM10 mass concentrations ($\mu\text{g}/\text{m}^3$) measured at different sites in the Apulia Region (shown in Fig. 9) from 19 April to 23 April, 2010. Yearly-mean (Y-M) mass concentrations ± 1 standard deviation (SD) and site type definition are provided in the last two columns.

Site	19 April ($\mu\text{g}/\text{m}^3$)	20 April ($\mu\text{g}/\text{m}^3$)	21 April ($\mu\text{g}/\text{m}^3$)	22 April ($\mu\text{g}/\text{m}^3$)	23 April ($\mu\text{g}/\text{m}^3$)	Y-M \pm SD ($\mu\text{g}/\text{m}^3$)	Site Type
A	26	33	28	22	20	19 \pm 11	rural
B	15	20	27	21	21	23 \pm 9	suburban
C	23	23	44	26	36	29 \pm 18	suburban
D	20	24	27	24	21	25 \pm 16	suburban
E	18	21	24	24	20	16 \pm 14	suburban
F	13	21	25	25	19	21 \pm 10	suburban
G	12	17	25	20	20	20 \pm 12	rural
H	18	19	24	25	22	25 \pm 13	suburban
I	18	22	24	23	19	26 \pm 13	suburban
L	15	18	20	20	19	23 \pm 15	suburban
Avg	18	22	27	23	22		

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Figure Captions

Fig. 1 8-day back trajectories from the Hybrid Single Particle Lagrangian Integrated Trajectory Model (HYSPPLIT) of air masses ending at the Physics Department of the Salento University, Lecce (Italy), (a) on 20 April at 18:00 UTC, (b) on 21 April at 06:00 UTC, (c) on 21 April at 18:00 UTC, and (d) on 22 April at 12:00 UTC.

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Fig. 2 FLEXPART simulations of the Eyjafjallajökull volcanic ash (total atmospheric columns in mg m^{-2} , integrated over all 25 particle size classes) on 20 April at (a) 06:00 UTC, (b) 18:00 UTC, (c) 24:00 UTC, on 21 April at (d) 18:00 UTC, (e) 24:00 UTC, and on 22 April at (f) 18:00 UTC. The green dot marks the monitoring site.

Fig. 3 Vertical profiles of the aerosol backscatter coefficient at 355 nm (solid line) and of the volcanic ash mass concentration simulated by FLEXPART (dotted line) at different hours of 20, 21, and 22 April 2010.

Fig. 4 Vertical profiles of the aerosol extinction coefficient (solid line) and of the lidar ratio (full dots) retrieved from nighttime lidar measurements at different hours of 20, 21, and 22 April 2010.

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Fig. 5 Time series of the aerosol optical thickness (AOT) at 355 nm from lidar measurements (open dots) and of the ash total column (Ma) simulated by FLEXPART at the lidar site (full triangles). Full dots represent the aerosol optical thickness at 340 nm from AERONET sun-sky photometer measurements.

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Fig. 6 Time evolution from 20 to 22 April, 2010 of the aerosol optical thickness (AOT) at 500 nm (full dots) and of the fine mode fraction (open triangles) from AERONET sun-sky photometer measurements.

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Fig. 7 Volume size distributions retrieved from AERONET sun-sky photometer measurements performed at different day hours of (a) 20 and (b) 21 April, 2010. (c) Volume size distributions retrieved at the ground level from Aerodynamic Particle Sizer (APS 3321, TSI) measurements performed on 21 April, 2010 at different day hours.

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Fig. 8 Columnar mass size distribution of volcanic particles inferred from the AERONET volume size distribution retrieved at 14:49 UTC of 21 April, by setting the particle mass density for volcanic particles $\rho = 3.0 \text{ g/cm}^3$ (solid line). Columnar mass size distribution of volcanic ash from FLEXPART simulations at 11:30 UTC (dotted line) and 14:30 UTC (dashed line) of 21 April, 2010.

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Fig. 9 Geographical locations of selected sites of the Air Quality Agency of the Apulia Region in south eastern Italy and of the lidar site.

Eliminato: Fig. 9 Columnar mass size distribution of volcanic ash from FLEXPART simulations at selected hours on (a) 20, (b) 21, and (c) 22 April, 2010.¶

Fig. 10 Time series of PM₁₀ and SO₂ mass concentrations at sites C and G (locations are shown in Fig. 9).

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Fig. 11 Columnar mass size distribution of volcanic ash from FLEXPART simulations at different hours on (a) 20, (b) 21, and (c) 22 April, 2010.

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Fig. 12 Time evolution at the lidar site of the volcanic ash mass concentration ($\mu\text{g/m}^3$) at ~150 m a.s.l. from FLEXPART simulations. Daily means on 20, 21, and 22 April are also provided.

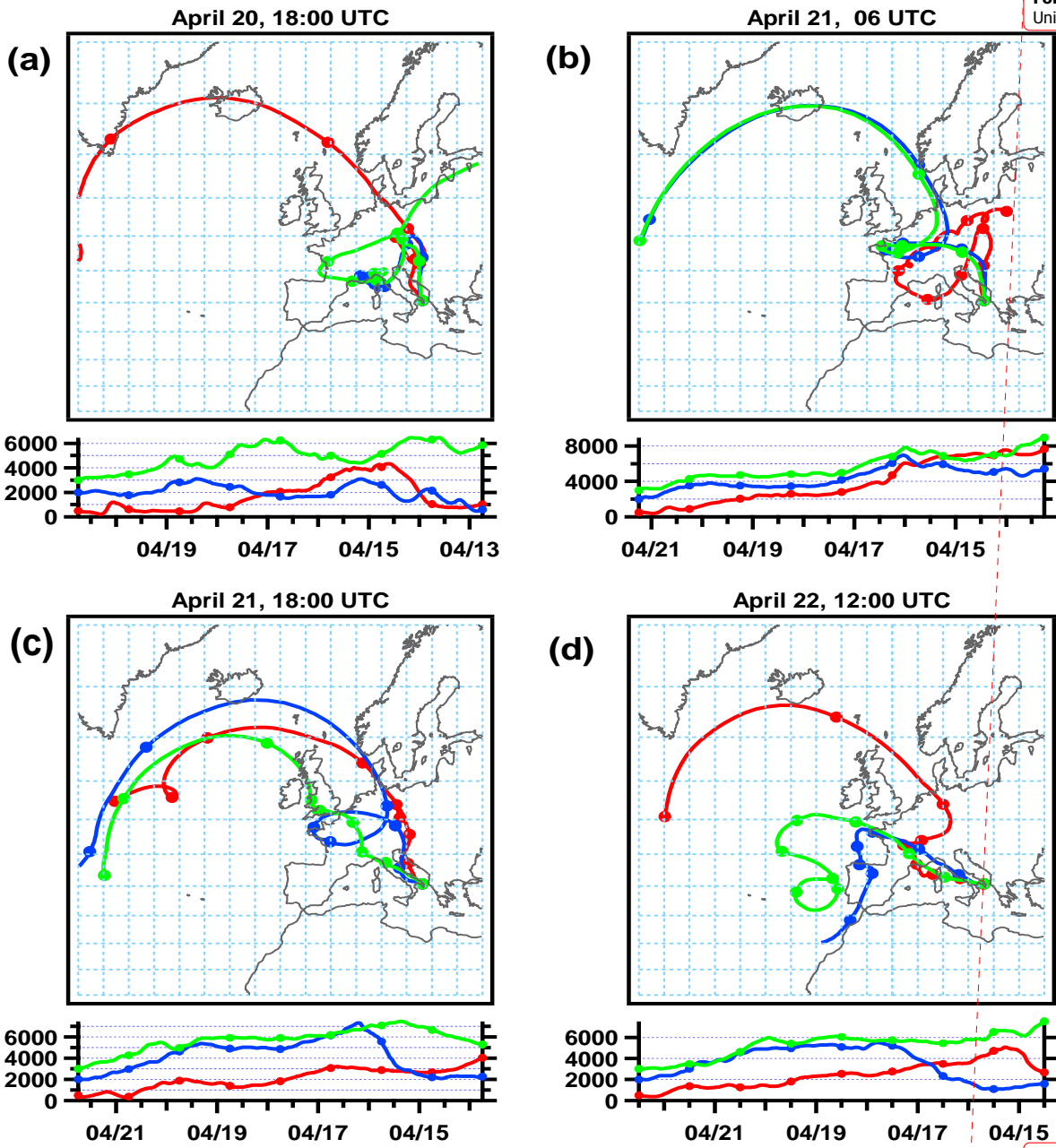


Figure 1 (M. R. Perrone et al.)

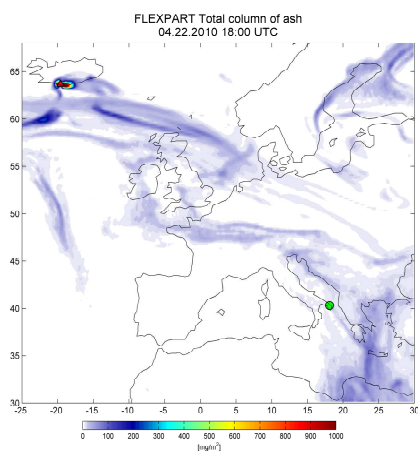
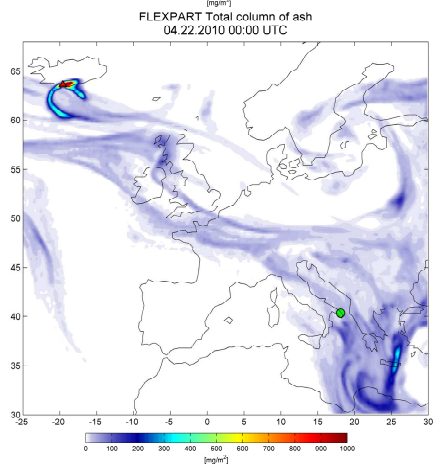
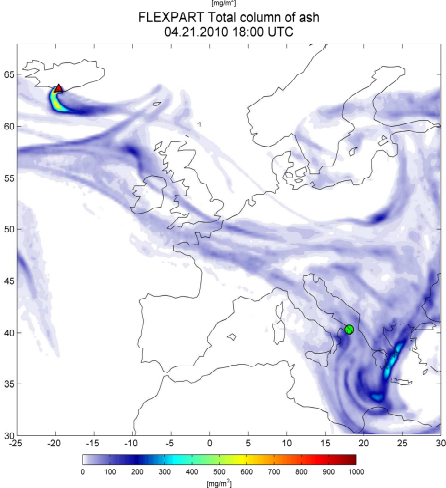
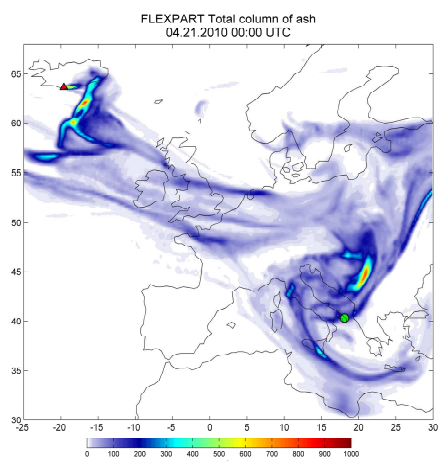
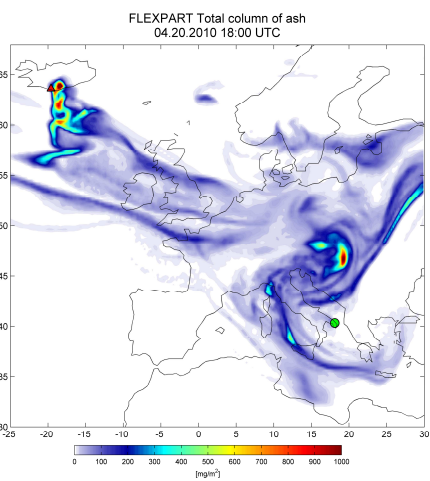
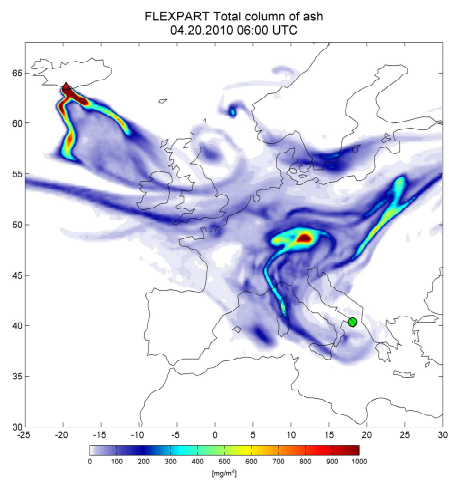


Figure 2 (M. R. Perrone et al.)

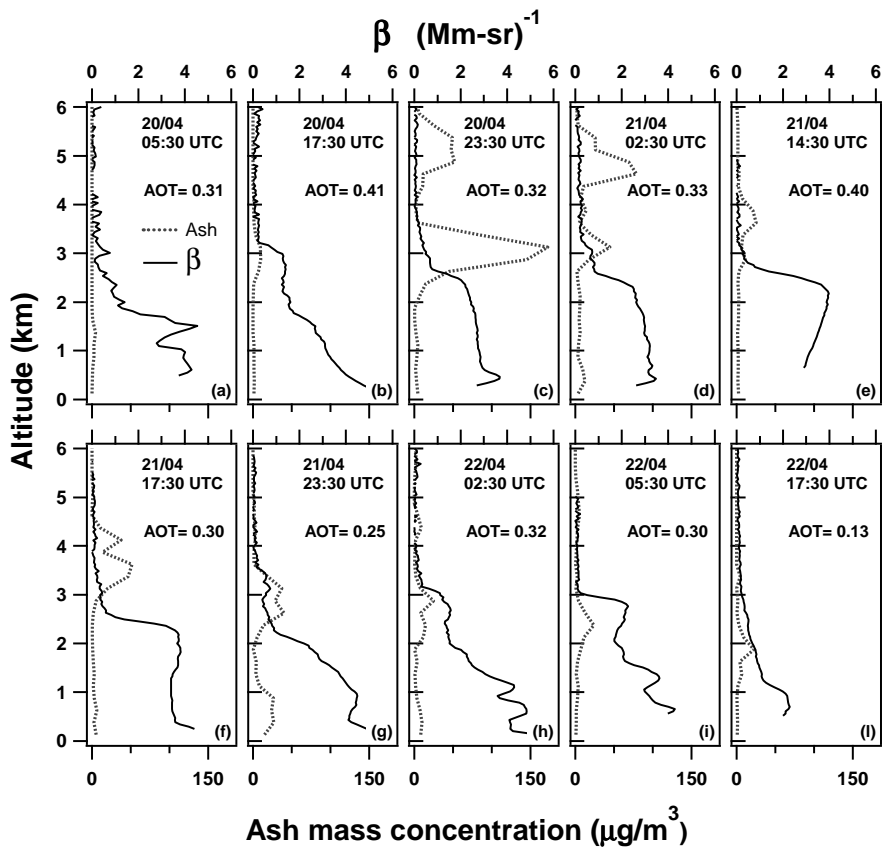


Figure 3 (M. R. Perrone et al.)

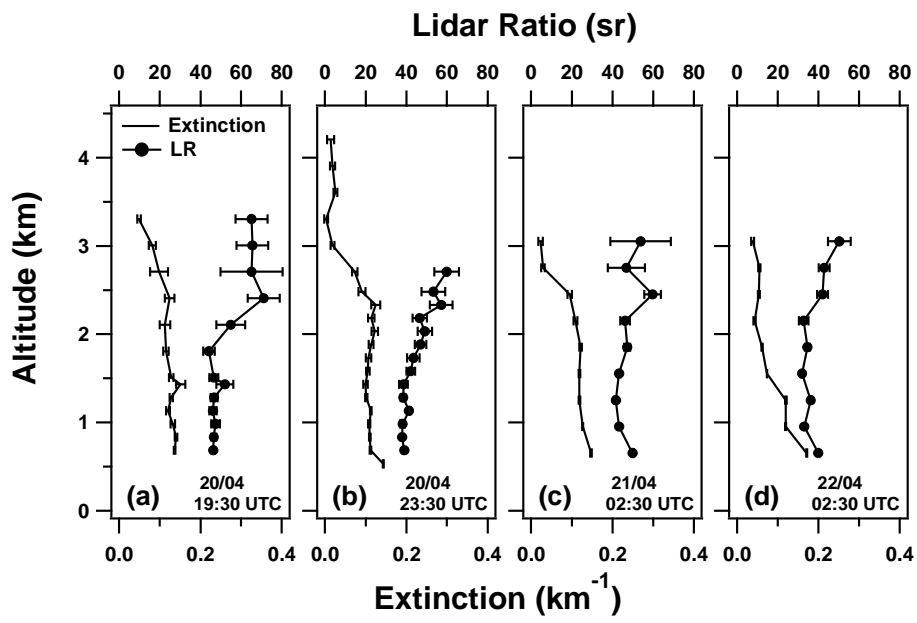


Figure 4 (M. R. Perrone et al.)

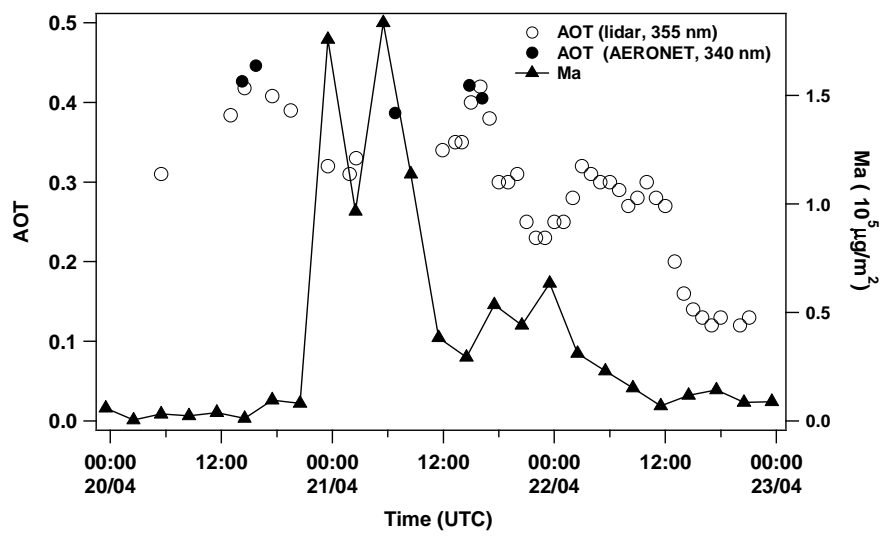


Figure 5 (M. R. Perrone et al.)

Formattato: Inglese (Regno Unito)

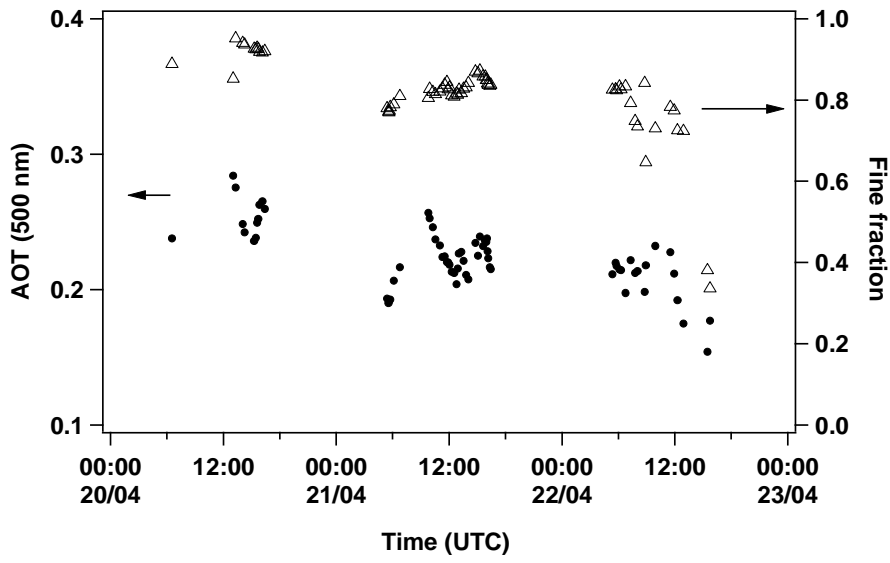


Figure 6 (M. R. Perrone)

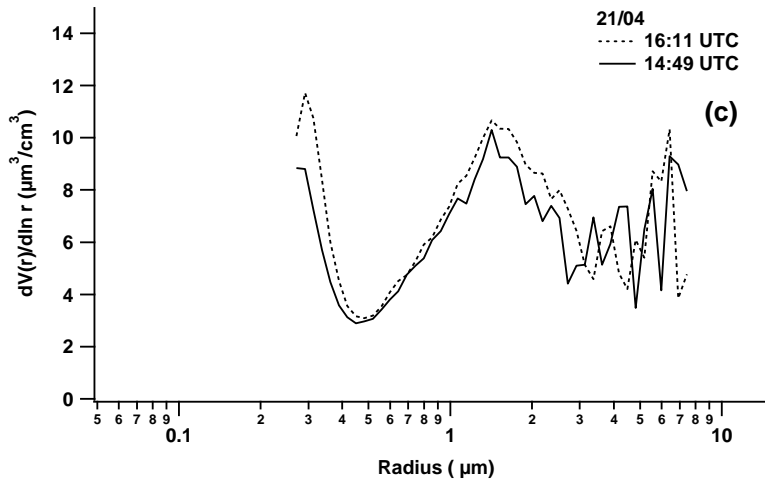
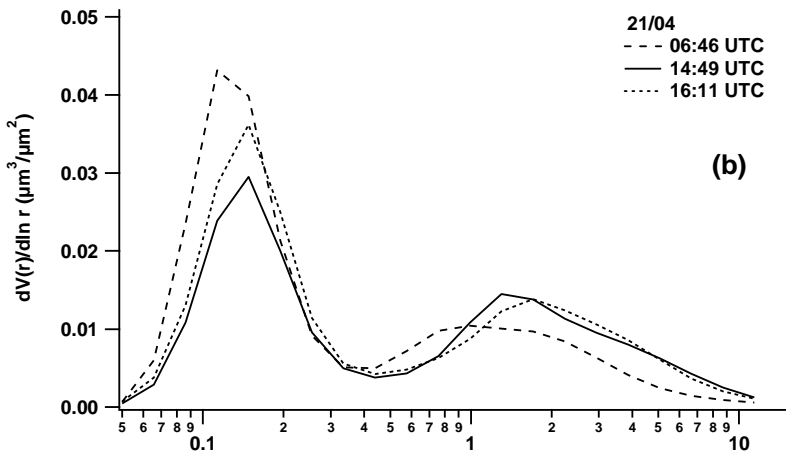
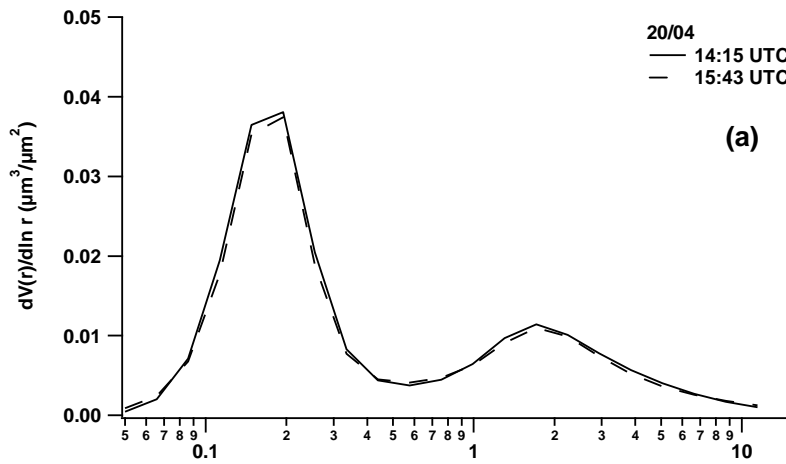
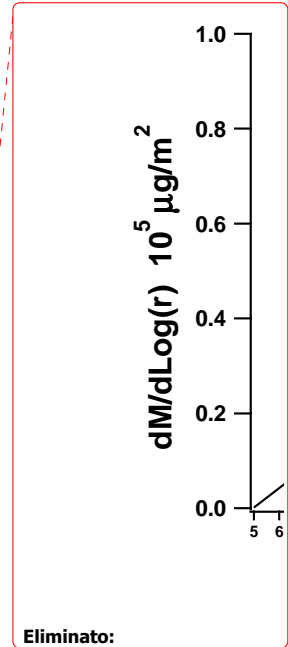


Figure 7 (M. R. Perrone et al.)



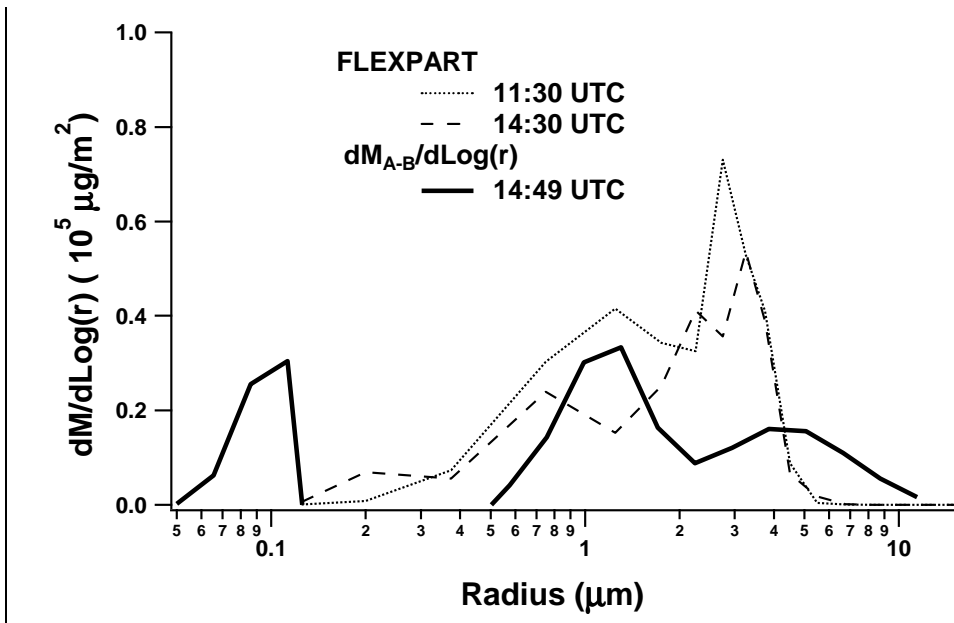


Figure 8 (M. R. Perrone et al.)

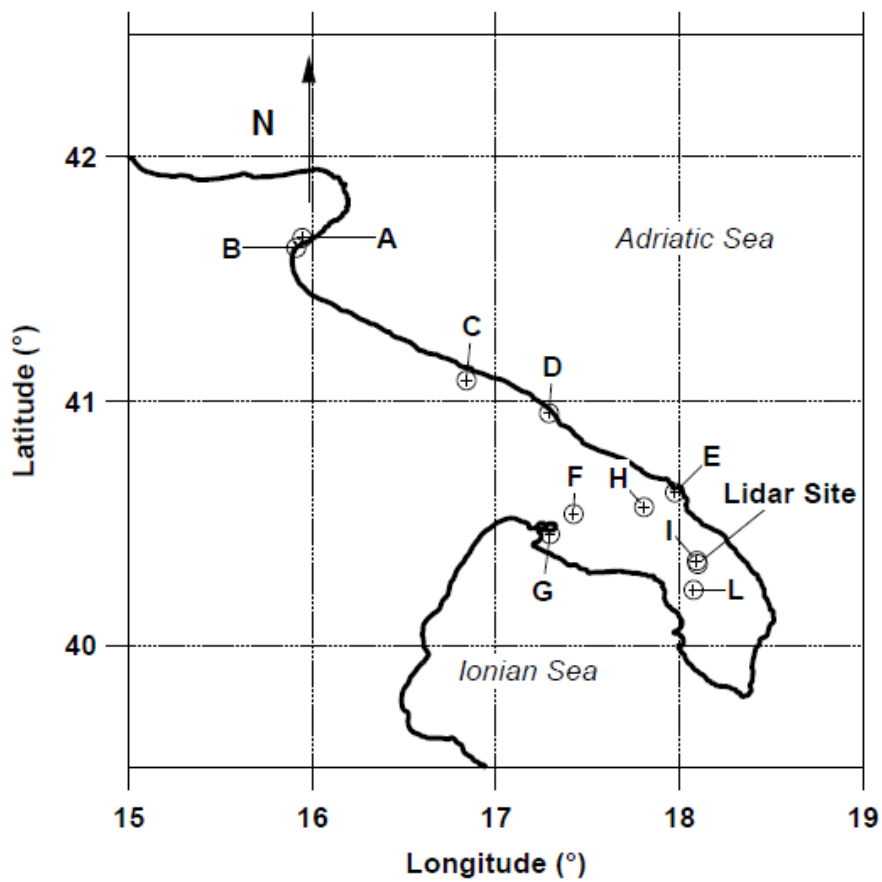


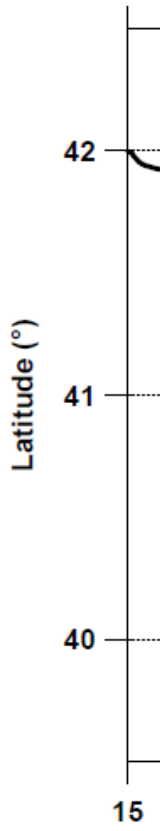
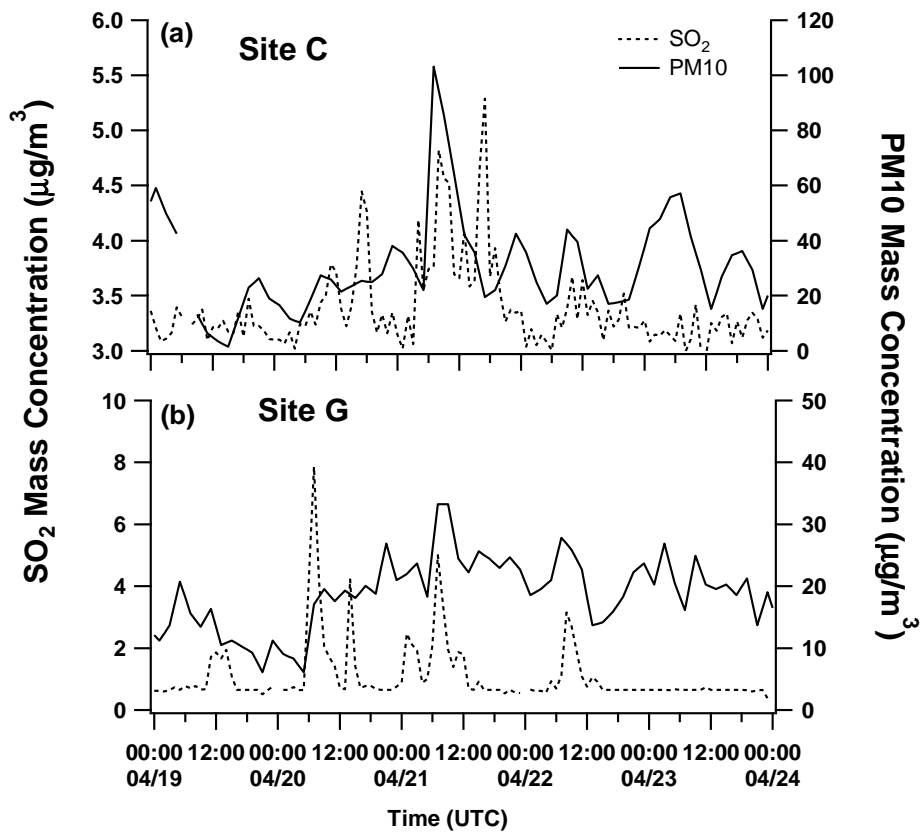
Figure 9 (M. R. Perrone et al.)

Formattato: Inglese (Regno Unito)

$dM/d\text{Log}(D) 10^5 \mu\text{g}/\text{m}^2$

Eliminato:

Formattato: Inglese (Regno Unito), Controllo ortografia e grammatica



Eliminato:

Formattato: Inglese (Regno Unito)

Formattato: Inglese (Regno Unito), Controllo ortografia e grammatica

Figure 10 (M. R. Perrone et al.)

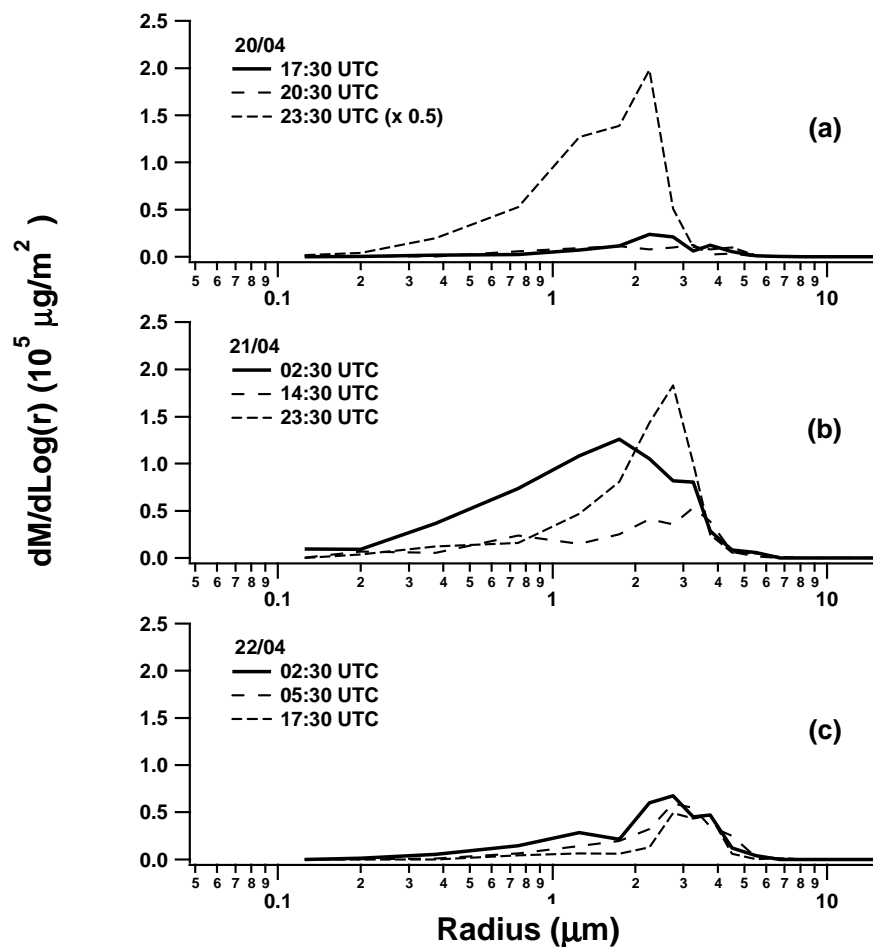


Figura 11 (M. R. Perrone et al.)

Ash Mass Concentration ($\mu\text{g}/\text{m}^3$)

Eliminato:

$dM/d\text{Log}(D) 10^5 \mu\text{g}/\text{m}^2$

Eliminato:

Formattato: Inglese (Regno Unito), Controllo ortografia e grammatica

Formattato: Controllo ortografia e grammatica

Formattato: Inglese (Regno Unito), Controllo ortografia e grammatica

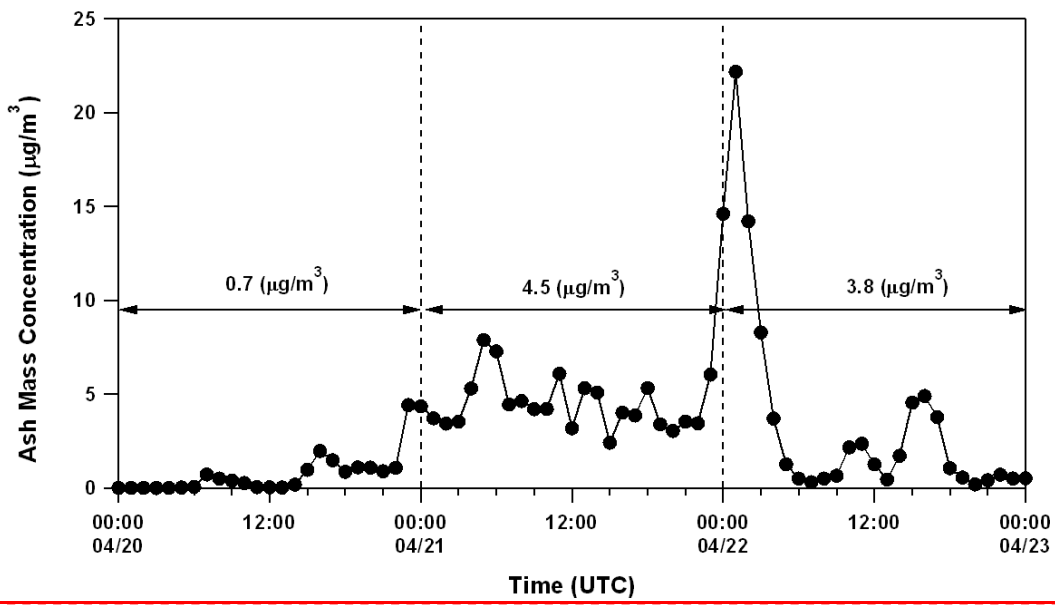


Figure 12 (M. R. Perrone et al.)

SO₂ Mass Concentration (µg/m³)

6.0
5.5
5.0
4.5
4.0
3.5
3.0
10
8
6
4
2
0

Eliminato:

Formattato: Inglese (Regno Unito)

Pagina 1: [1] Formattato	Blanco	24/09/2012 20.01.00
Tipo di carattere: Grassetto, Inglese (Regno Unito)		
Pagina 1: [1] Formattato	Blanco	24/09/2012 20.01.00
Inglese (Regno Unito)		
Pagina 1: [1] Formattato	Blanco	24/09/2012 20.01.00
Tipo di carattere: Grassetto, Inglese (Regno Unito)		
Pagina 1: [1] Formattato	Blanco	24/09/2012 20.01.00
Inglese (Regno Unito)		
Pagina 1: [2] Eliminato	Blanco	24/09/2012 17.34.00
site		
Pagina 1: [2] Eliminato	Blanco	17/09/2012 16.51.00
/		
Pagina 1: [3] Eliminato	Blanco	17/09/2012 20.07.00
eteorological synoptic maps,		
Pagina 1: [4] Eliminato	Blanco	17/09/2012 20.07.00
analytical backtrajectories, and published studies confirm the advection of volcanic aerosols to the monitoring site.		
Pagina 1: [5] Eliminato	Blanco	17/09/2012 20.07.00
lidar measurements have revealed that the		
Pagina 1: [6] Eliminato	Blanco	19/09/2012 17.21.00
both the peak concentrations as well as the total column loadings of volcanic ash simulated by FLEXPART were about one order of magnitude lower than corresponding values simulated over Central Europe on 16 April. This suggests that the		
Pagina 1: [7] Eliminato	Blanco	19/09/2012 17.21.00
volcanic particle impact was weaker		
Pagina 1: [8] Eliminato	Blanco	19/09/2012 17.21.00
over southeastern Italy than over Central Europe. Nevertheless,		
Pagina 1: [8] Eliminato	Blanco	17/09/2012 16.24.00
v		
Pagina 1: [9] Eliminato	perrone	17/09/2012 12.16.00
and the integrated use of FLEXPART simulations and		
Pagina 1: [10] Eliminato	Blanco	24/09/2012 17.39.00
experimental		
Pagina 1: [10] Eliminato	Blanco	24/09/2012 17.36.00
ed to clearly		
Pagina 1: [10] Eliminato	Blanco	24/09/2012 17.37.00
identifying		
Pagina 1: [10] Eliminato	Blanco	24/09/2012 18.00.00

Pagina 1: [10] Eliminato	Blanco	17/09/2012 16.29.00
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Lidar measurements performed at the Physics Department of the University of Salento (40.4°N; 18.1°E) within EARLINET (European Aerosol Research Lidar NETWORK EARLINET) have revealed the first arrival of volcanic aerosols on the afternoon of 20 April. L

Pagina 1: [11] Eliminato	Blanco	19/09/2012 17.28.00
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lidar measurements have shown that at 18:30 UTC of 20 April, lidar ratios (LRs) at 355 nm varied from 65 to 71

Pagina 1: [11] Eliminato	Blanco	19/09/2012 17.29.00
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located between 2.1

Pagina 1: [12] Eliminato	Blanco	19/09/2012 17.29.00
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km from the ground level

Pagina 1: [13] Eliminato	perrone	18/09/2012 12.18.00
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≅

Pagina 1: [13] Eliminato	perrone	18/09/2012 12.18.00
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5

Pagina 1: [14] Eliminato	Blanco	26/09/2012 18.13.00
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s

Pagina 1: [14] Eliminato	Blanco	19/09/2012 17.59.00
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The LR dependence on altitude has decreased with time as volcanic particles also reached ground level.

Pagina 1: [15] Eliminato	perrone	18/09/2012 12.19.00
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Then, LRs varied between 41 and 60 sr all over the aerosol column at 02:30 UTC of 21 April.

Pagina 1: [16] Eliminato	Blanco	17/09/2012 16.31.00
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The time evolution of the aerosol optical depth from lidar measurements was similar to that of the ash-total-column mass concentration from FLEXPART simulations after midday of 21 April, for the larger contribution of volcanic particles to the whole aerosol load.

Pagina 1: [17] Eliminato	Blanco	24/09/2012 18.01.00
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Pagina 1: [17] Eliminato	Blanco	17/09/2012 16.33.00
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performed within AERONET, have

Pagina 1: [17] Eliminato	Blanco	24/09/2012 18.01.00
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ed that

Pagina 1: [17] Eliminato	Blanco	17/09/2012 16.33.00
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the mass size distribution of volcanic particles retrieved from measurements performed on 21 April was in reasonable accordance with the volcanic-ash mass size distribution from FLEXPART simulations.

Pagina 1: [17] Eliminato	Blanco	17/09/2012 16.33.00
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V

Pagina 1: [17] Eliminato	Blanco	24/09/2012 18.02.00
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have mainly been advected over south eastern Italy

Pagina 1: [17] Eliminato	Blanco	17/09/2012 16.50.00
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, but

Pagina 1: [18] Eliminato	perrone	18/09/2012 12.20.00
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the advection of coarse volcanic particles up to ground. Then

Pagina 1: [19] Eliminato	perrone	18/09/2012 12.20.00
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m

Pagina 1: [19] Eliminato	perrone	18/09/2012 12.20.00
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s

Pagina 1: [20] Eliminato	Blanco	24/09/2012 18.11.00
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daily PM1 and PM2.5 samples which

Pagina 1: [21] Eliminato	perrone	18/09/2012 12.23.00
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revealed that the PM1/PM2.5 mass ratios

Pagina 1: [22] Eliminato	Blanco	24/09/2012 18.11.00
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were equal to

Pagina 1: [22] Eliminato	Blanco	19/09/2012 17.43.00
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, have further more

Pagina 1: [23] Eliminato	perrone	18/09/2012 12.23.00
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,

Pagina 1: [23] Eliminato	perrone	18/09/2012 12.24.00
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indicating an

Pagina 1: [23] Eliminato	perrone	18/09/2012 12.24.00
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ing fraction

Pagina 1: [24] Eliminato	Blanco	24/09/2012 18.15.00
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Finally, measurements from the Regional Air Quality Agency have revealed enhan

Pagina 1: [25] Eliminato	Blanco	24/09/2012 18.15.00
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ced

Pagina 1: [25] Eliminato	Blanco	24/09/2012 18.17.00
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and SO₂

Pagina 1: [26] Eliminato	Blanco	19/09/2012 17.45.00
22 April, 2010 all over the ~400 km long		
Pagina 1: [26] Eliminato	Blanco	17/09/2012 16.54.00
The estimated enhancement of PM10 from volcanic particles was ~ 6 µg/m ³ on 21 April at		
Pagina 1: [26] Eliminato	Blanco	17/09/2012 16.54.00
the monitoring site of this study, in satisfactory accordance with FLEXPART simulations.		
Pagina 1: [26] Eliminato	Blanco	17/09/2012 16.55.00
Pagina 5: [27] Formattato	Blanco	24/09/2012 20.01.00
Inglese (Regno Unito)		
Pagina 5: [27] Formattato	Blanco	24/09/2012 20.01.00
Inglese (Regno Unito)		
Pagina 5: [28] Eliminato	Blanco	24/09/2012 20.03.00
south		
Pagina 5: [28] Eliminato	Blanco	24/09/2012 20.04.00
dvection		
Pagina 5: [29] Eliminato	Blanco	16/09/2012 18.17.00
have		
Pagina 5: [29] Eliminato	Blanco	16/09/2012 18.17.00
been		
Pagina 5: [29] Eliminato	Blanco	16/09/2012 18.22.00
on the diurnal hours of April 19,19		
Pagina 5: [29] Eliminato	Blanco	12/09/2012 17.15.00
ground		
Pagina 5: [29] Eliminato	Blanco	11/09/2012 15.59.00
a.g.l.		
Pagina 5: [30] Formattato	Blanco	24/09/2012 20.01.00
Inglese (Regno Unito)		
Pagina 5: [31] Formattato	Blanco	24/09/2012 20.01.00
Inglese (Regno Unito)		
Pagina 5: [32] Eliminato	Blanco	11/09/2012 16.00.00
a.g.l., was mainly over Central Europe		
Pagina 5: [33] Formattato	Blanco	24/09/2012 20.01.00
Inglese (Regno Unito)		
Pagina 5: [34] Formattato	Blanco	24/09/2012 20.01.00
Inglese (Regno Unito)		
Pagina 5: [35] Eliminato	Blanco	16/09/2012 18.23.00
of the air masses		
Pagina 5: [35] Eliminato	Blanco	14/09/2012 16.06.00

Pagina 5: [35] Eliminato	Blanco	14/09/2012 16.06.00
30		
Pagina 5: [35] Eliminato	Blanco	24/09/2012 20.06.00
We observe that t		
Pagina 5: [36] Formattato	Blanco	24/09/2012 20.01.00
Inglese (Regno Unito)		
Pagina 5: [37] Eliminato	Blanco	16/09/2012 18.24.00
air masses		
Pagina 5: [37] Eliminato	Blanco	11/09/2012 16.01.00
a.g.l.		
Pagina 5: [37] Eliminato	Blanco	16/09/2012 18.24.00
ve		
Pagina 5: [37] Eliminato	Blanco	24/09/2012 20.06.00
s		
Pagina 5: [38] Formattato	Blanco	24/09/2012 20.01.00
Inglese (Regno Unito)		
Pagina 5: [39] Eliminato	Blanco	16/09/2012 18.24.00
air masses		
Pagina 5: [39] Eliminato	Blanco	11/09/2012 16.01.00
a.g.l.		
Pagina 5: [40] Formattato	Blanco	24/09/2012 20.01.00
Inglese (Regno Unito)		
Pagina 5: [40] Formattato	Blanco	24/09/2012 20.01.00
Inglese (Regno Unito)		
Pagina 5: [41] Eliminato	Blanco	11/09/2012 16.03.00
air masses		
Pagina 5: [41] Eliminato	Blanco	24/09/2012 20.08.00
ed		
Pagina 5: [42] Formattato	Blanco	24/09/2012 20.01.00
Inglese (Regno Unito)		
Pagina 5: [43] Formattato	Blanco	24/09/2012 20.01.00
Inglese (Regno Unito)		
Pagina 5: [44] Eliminato	perrone	12/09/2012 11.35.00
over		
Pagina 5: [44] Eliminato	perrone	11/09/2012 11.32.00
20 (Fig. 1a),		
Pagina 5: [45] Eliminato	Blanco	14/09/2012 16.22.00
5		

Pagina 5: [45] Eliminato	Blanco	14/09/2012 16.22.00
3		
Pagina 5: [46] Formattato	Blanco	24/09/2012 20.01.00
Inglese (Regno Unito)		
Pagina 5: [47] Formattato	Blanco	24/09/2012 20.01.00
Inglese (Regno Unito)		
Pagina 5: [47] Formattato	Blanco	24/09/2012 20.01.00
Inglese (Regno Unito)		
Pagina 5: [48] Eliminato	perrone	11/09/2012 11.35.00
, c) and		
Pagina 5: [48] Eliminato	perrone	11/09/2012 11.36.00
2		
Pagina 5: [49] Eliminato	Blanco	14/09/2012 16.34.00
7		
Pagina 5: [49] Eliminato	Blanco	14/09/2012 16.34.00
3		
Pagina 5: [49] Eliminato	Blanco	14/09/2012 16.34.00
(Fig. 1c),		
Pagina 5: [49] Eliminato	Blanco	24/09/2012 20.11.00
have been advected		
Pagina 5: [50] Formattato	Blanco	24/09/2012 20.01.00
Inglese (Regno Unito)		
Pagina 5: [50] Formattato	Blanco	24/09/2012 20.01.00
Inglese (Regno Unito)		
Pagina 5: [50] Formattato	Blanco	24/09/2012 20.01.00
Inglese (Regno Unito)		
Pagina 5: [50] Formattato	Blanco	24/09/2012 20.01.00
Inglese (Regno Unito)		
Pagina 5: [50] Formattato	Blanco	24/09/2012 20.01.00
Inglese (Regno Unito)		
Pagina 5: [50] Formattato	Blanco	24/09/2012 20.01.00
Inglese (Regno Unito)		
Pagina 5: [51] Eliminato	Blanco	24/09/2012 20.15.00
up to		
Pagina 5: [51] Eliminato	Blanco	19/09/2012 18.10.00
also		
Pagina 5: [51] Eliminato	Blanco	16/09/2012 18.27.00
above sea level		
Pagina 5: [52] Formattato	Blanco	24/09/2012 20.01.00
Inglese (Regno Unito)		

Pagina 5: [53] Eliminato	perrone	11/09/2012 11.40.00
had previously travelled across Iceland.		
Pagina 5: [54] Formattato	perrone	11/09/2012 12.25.00
Rientro: Prima riga: 0,63 cm		
Pagina 5: [55] Formattato	Blanco	24/09/2012 20.01.00
Inglese (Regno Unito)		
Pagina 5: [56] Eliminato	Blanco	24/09/2012 20.18.00
In particular, we observe that		
Pagina 5: [57] Formattato	Blanco	24/09/2012 20.01.00
Inglese (Regno Unito)		
Pagina 6: [58] Formattato	Blanco	24/09/2012 20.01.00
Inglese (Regno Unito)		
Pagina 6: [59] Eliminato	perrone	11/09/2012 13.03.00
The simulated volcanic ash was mainly located between 2.5-3.5 km above the ground level (AGL) at 17:30 UTC (Fig. 3b, dotted line) and the simulated concentrations at this altitude have increased by orders of magnitude six hours later (Fig. 3c, dotted line).		
Pagina 6: [60] Formattato	Blanco	24/09/2012 20.01.00
Inglese (Regno Unito)		
Pagina 6: [61] Formattato	Blanco	24/09/2012 20.01.00
Inglese (Regno Unito)		
Pagina 6: [62] Formattato	Blanco	24/09/2012 20.01.00
Inglese (Regno Unito), Non Evidenziato		
Pagina 6: [63] Formattato	Blanco	24/09/2012 20.01.00
Inglese (Regno Unito)		
Pagina 6: [64] Formattato	Blanco	24/09/2012 20.01.00
Inglese (Regno Unito)		
Pagina 7: [65] Formattato	Blanco	24/09/2012 20.01.00
Inglese (Regno Unito)		
Pagina 7: [65] Formattato	Blanco	24/09/2012 20.01.00
Inglese (Regno Unito)		
Pagina 7: [65] Formattato	Blanco	24/09/2012 20.01.00
Inglese (Regno Unito)		
Pagina 7: [65] Formattato	Blanco	24/09/2012 20.01.00
Inglese (Regno Unito)		
Pagina 7: [65] Formattato	Blanco	24/09/2012 20.01.00
Inglese (Regno Unito)		
Pagina 7: [66] Eliminato	Blanco	12/09/2012 17.25.00

Aerosol particles up to about 4.5 km AGL have been detected by the lidar at 23:30 UTC (Fig. 3c and Fig. 4b). Accordingly, the FLEXPART profile at 23:30 UTC (Fig. 3c) shows that the volcanic ash extends up to 6 km AGL. The highest concentrations of about $170 \mu\text{g m}^{-3}$ at ~ 3 km AGL are about a factor 7 lower than the highest values simulated on 16 April over Leipzig. This suggests that the

volcanic ash over south eastern Italy was strongly diluted. Notice that on 16 April, Asmann et al. (2010) found from lidar measurements at 355 nm performed over Leipzig, that backscatter and extinction coefficients reached peak values of $7.5 \text{ Mm}^{-1}\text{sr}^{-1}$ and 370 Mm^{-1} , respectively in the center of the ash plume located from ~ 2.7 up to ~ 4.2 km AGL. Figure 3b (solid line) and Fig. 4b (solid line) of this study show that at 23:30 UTC of 20 April backscatter and extinction coefficients varied up to $0.7 \text{ Mm}^{-1}\text{sr}^{-1}$ and 30 Mm^{-1} , respectively, within 3-4 km AGL. If we assume that the aerosol load located above 3 km from the ground was mainly due to volcanic aerosol in accordance with the above reported discussion, we obtain that extinction and backscatter coefficients mainly due to volcanic aerosol were over Lecce about a factor 10 lower than the highest values monitored at Leipzig on 16 April. These last findings which are in reasonable accordance with FLEXPART results relating peak ash levels at Leipzig (16 April) and Lecce (20 April), further more support the arrival of dilute ash over Lecce. Notice that the comparison of Fig. 3c and Fig. 3a indicates that non-volcanic, pre-existing particles were mainly responsible for the larger backscatter and extinction coefficients retrieved below 3 km from the ground level.

Pagina 7: [67] Formattato Inglese (Regno Unito)	Blanco	24/09/2012 20.01.00
Pagina 7: [67] Formattato Inglese (Regno Unito)	Blanco	24/09/2012 20.01.00
Pagina 7: [68] Formattato Inglese (Regno Unito)	Blanco	24/09/2012 20.01.00
Pagina 7: [69] Formattato Inglese (Regno Unito)	Blanco	24/09/2012 20.01.00
Pagina 7: [70] Eliminato s	perrone	18/09/2012 13.30.00
Pagina 7: [70] Eliminato b-4	perrone	18/09/2012 13.31.00
Pagina 7: [71] Formattato Inglese (Regno Unito)	Blanco	24/09/2012 20.01.00
Pagina 7: [72] Eliminato spanned the 38-60 sr range below 3 km and	perrone	18/09/2012 13.31.00
Pagina 7: [72] Eliminato at 23:30 UTC of 20 April and	perrone	18/09/2012 13.31.00
Pagina 7: [73] Formattato Inglese (Regno Unito)	Blanco	24/09/2012 20.01.00
Pagina 7: [73] Formattato Inglese (Regno Unito)	Blanco	24/09/2012 20.01.00
Pagina 7: [73] Formattato Inglese (Regno Unito)	Blanco	24/09/2012 20.01.00
Pagina 7: [73] Formattato	Blanco	24/09/2012 20.01.00

Inglese (Regno Unito)

Pagina 7: [74] Eliminato	Blanco	14/09/2012 17.22.00
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The mixing of volcanic aerosols with underlying aerosol particles as a consequence of sedimentation processes and/or the advection of volcanic aerosol also at lower altitudes were likely responsible for this result. FLEXPART numerical simulations show that volcanic ash also arrived at lower altitudes for the later profiles (Fig. 3c, d, dotted lines).

Pagina 7: [74] Eliminato	Blanco	14/09/2012 17.23.00
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Pagina 7: [75] Formattato	Blanco	24/09/2012 20.01.00
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Inglese (Regno Unito)

Pagina 7: [75] Formattato	Blanco	24/09/2012 20.01.00
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Inglese (Regno Unito)

Pagina 7: [75] Formattato	Blanco	24/09/2012 20.01.00
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Inglese (Regno Unito)

Pagina 7: [76] Eliminato	Blanco	11/09/2012 18.36.00
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(Fig. 3) as FLEXPART volcanic ash profiles indicate,

Pagina 7: [76] Eliminato	Blanco	24/09/2012 20.44.00
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the lower contribution of

Pagina 7: [76] Eliminato	Blanco	24/09/2012 20.50.00
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mainly located up to about 3 km

Pagina 7: [76] Eliminato	Blanco	11/09/2012 18.39.00
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Figure 3g (dotted line) shows that the simulated volcanic ash was mainly located from the ground up to ~1.2 km and from 2 up to ~3.7 km at 23:30 UTC of April 21, in satisfactory accordance with lidar measurements which detected aerosol particles up to ~3.7 km AGL (Fig. 3g, solid line).

Pagina 7: [76] Eliminato	Blanco	11/09/2012 18.39.00
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AGL

Pagina 7: [77] Eliminato	Blanco	11/09/2012 19.00.00
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ash total column mass concentration from FLEXPART (Ma, full triangles) above the lidar site and the

Pagina 7: [77] Eliminato	Blanco	11/09/2012 19.01.00
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The time evolution of the AOT is similar to that of the ash total column mass concentration mainly after midday of 21 April. AOTs are quite dependent on aerosol optical and microphysical properties. So, the similarity between the AOT and the Ma time evolution (Fig. 5) likely indicates that the contribution of volcanic particles all over the aerosol column was more significant since midday of 21 April. Volcanic ash, lidar and lidar ratio profiles (Fig. 4, full dots) support last comment, as it is demonstrated below. The comparison of Fig. 3a to Fig. 3b reveals

Pagina 7: [78] Eliminato	Blanco	16/09/2012 18.46.00
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located up to 3 km AGL

Pagina 7: [78] Eliminato	Blanco	12/09/2012 19.18.00
were mainly responsible for the		
Pagina 7: [79] Eliminato	perrone	17/09/2012 9.53.00
.		
Pagina 7: [79] Eliminato	perrone	17/09/2012 9.53.00
It		
Pagina 7: [79] Eliminato	perrone	17/09/2012 9.53.00
es		
Pagina 7: [80] Eliminato	perrone	17/09/2012 9.54.00
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Pagina 7: [80] Eliminato	perrone	17/09/2012 9.54.00
T		
Pagina 7: [80] Eliminato	perrone	17/09/2012 9.53.00
it		
Pagina 7: [80] Eliminato	perrone	17/09/2012 9.54.00
s		
Pagina 7: [81] Formattato	Blanco	24/09/2012 20.01.00
Inglese (Regno Unito), Non Evidenziato		
Pagina 7: [81] Formattato	Blanco	24/09/2012 20.01.00
Inglese (Regno Unito)		
Pagina 7: [81] Formattato	Blanco	24/09/2012 20.01.00
Inglese (Regno Unito), Non Evidenziato		
Pagina 7: [81] Formattato	Blanco	24/09/2012 20.01.00
Inglese (Regno Unito)		
Pagina 7: [81] Formattato	Blanco	24/09/2012 20.01.00
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Pagina 7: [81] Formattato	Blanco	24/09/2012 20.01.00
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Pagina 7: [81] Formattato	Blanco	24/09/2012 20.01.00
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Pagina 7: [81] Formattato	Blanco	24/09/2012 20.01.00
Inglese (Regno Unito)		
Pagina 7: [82] Eliminato	Blanco	11/09/2012 19.05.00

Then, the comparison of Fig. 3c to Fig. 3b shows that the aerosol load up to ~ 1.5 km AGL, which is mainly due to non-volcanic aerosol, has decreased on the night of 20-21 April as AOT

values ~ 0.3 demonstrate (Fig. 5). A significant increase of the aerosol load leading to AOTs $\cong 0.4$ was detected by the lidar within 14:00-16:00 UTC of April 21 (Fig. 5). The increase of the aerosol load at altitudes within 1-3 km AGL was responsible for this result, in accordance to Fig. 3e and likely volcanic particles have significantly contributed to the AOT increase. FLEXPART numerical simulations show that ash concentrations were larger at these altitudes and at larger altitudes. Thus, changes of the contribution by volcanic and non-volcanic particles have contributed to the larger variability of the aerosol load revealed by Fig. 3 and as a consequence, it has not been possible to obtain a proper estimate of the AOT due to volcanic particles by integrating lidar measurements and FLEXPART simulations.

Pagina 7: [83] Eliminato and FLEXPART simulations	Blanco	11/09/2012 19.40.00
Pagina 7: [84] Formattato Inglese (Regno Unito)	Blanco	24/09/2012 20.01.00
Pagina 8: [85] Formattato Inglese (Regno Unito)	Blanco	24/09/2012 20.01.00
Pagina 8: [86] Eliminato (Version 2, Level 2 data)	Blanco	11/09/2012 19.57.00
Pagina 8: [87] Formattato Inglese (Regno Unito)	Blanco	24/09/2012 20.01.00
Pagina 8: [88] Formattato Inglese (Regno Unito)	Blanco	24/09/2012 20.01.00
Pagina 8: [89] Formattato Inglese (Regno Unito)	Blanco	24/09/2012 20.01.00
Pagina 8: [90] Formattato Inglese (Regno Unito)	Blanco	24/09/2012 20.01.00
Pagina 8: [91] Eliminato by all aerosol particles	Blanco	24/09/2012 20.58.00
Pagina 8: [92] Formattato Inglese (Regno Unito), Non Evidenziato	Blanco	24/09/2012 20.01.00
Pagina 8: [93] Formattato Inglese (Regno Unito)	Blanco	24/09/2012 20.01.00
Pagina 8: [94] Eliminato The volume size distributions retrieved on 20 April at 14:15 and 15:45 UTC are probably not or only weakly affected by the contribution of volcanic aerosols, as discussed previously.	Blanco	12/09/2012 20.04.00
Pagina 8: [95] Formattato Inglese (Regno Unito), Pedice	Blanco	24/09/2012 20.01.00
Pagina 8: [96] Formattato Inglese (Regno Unito)	Blanco	24/09/2012 20.01.00
Pagina 8: [97] Formattato Pedice	perrone	26/09/2012 13.27.00

Pagina 8: [98] Formattato	Blanco	24/09/2012 20.01.00
Inglese (Regno Unito)		
Pagina 8: [99] Formattato	Blanco	24/09/2012 20.01.00
Inglese (Regno Unito)		
Pagina 8: [100] Formattato	Blanco	24/09/2012 20.01.00
Inglese (Regno Unito)		
Pagina 8: [101] Formattato	Blanco	24/09/2012 20.01.00
Inglese (Regno Unito)		
Pagina 8: [102] Formattato	Blanco	24/09/2012 20.01.00
Inglese (Regno Unito)		
Pagina 8: [103] Formattato	Blanco	24/09/2012 20.01.00
Inglese (Regno Unito)		
Pagina 8: [104] Formattato	Blanco	24/09/2012 20.01.00
Inglese (Regno Unito)		
Pagina 8: [105] Formattato	Blanco	24/09/2012 20.01.00
Inglese (Regno Unito)		
Pagina 9: [106] Formattato	Blanco	26/09/2012 18.18.00
Tipo di carattere: Corsivo, Inglese (Regno Unito)		
Pagina 9: [106] Formattato	Blanco	24/09/2012 20.01.00
Inglese (Regno Unito)		
Pagina 9: [107] Eliminato	perrone	13/09/2012 11.41.00
AGL		
Pagina 9: [107] Eliminato	perrone	13/09/2012 11.53.00
The comparison of Fig. 7b and 7c reveals that the		
Pagina 9: [107] Eliminato	perrone	13/09/2012 10.07.00
were similar to the columnar size distributions retrieved from AERONET sun-sky photometer measurements at the same time. In both cases, there is a		
Pagina 9: [107] Eliminato	perrone	13/09/2012 11.35.00
about		
Pagina 9: [108] Formattato	Blanco	24/09/2012 20.01.00
Inglese (Regno Unito), Non Evidenziato		
Pagina 9: [108] Formattato	Blanco	24/09/2012 20.01.00
Inglese (Regno Unito)		
Pagina 9: [109] Formattato	Blanco	24/09/2012 20.01.00
Inglese (Regno Unito)		
Pagina 9: [109] Formattato	Blanco	24/09/2012 20.01.00
Inglese (Regno Unito), Non Evidenziato		
Pagina 9: [109] Formattato	Blanco	24/09/2012 20.01.00
Inglese (Regno Unito)		
Pagina 9: [109] Formattato	Blanco	24/09/2012 20.01.00
Inglese (Regno Unito), Non Evidenziato		
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Pagina 9: [109] Formattato	Blanco	24/09/2012 20.01.00
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Inglese (Regno Unito)

Pagina 9: [110] Formattato	Blanco	24/09/2012 20.01.00
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Inglese (Regno Unito)

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and also agrees with the FLEXPART simulations, which show presence of volcanic ash in the boundary layer, albeit at lower concentrations than aloft.

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Inglese (Regno Unito)

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Inglese (Regno Unito)

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Inglese (Regno Unito)

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Pagina 9: [117] Eliminato	Blanco	24/09/2012 21.09.00
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, in accordance with measurements by the Regional Air Quality Agency (ww.arpa.puglia.it/web/guest/qariainq) of Apulia Region

Pagina 9: [118] Eliminato	Blanco	14/09/2012 18.27.00
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Pagina 9: [118] Eliminato	Blanco	18/09/2012 17.49.00
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Pagina 9: [118] Eliminato	Blanco	24/09/2012 21.10.00
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level

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Pagina 9: [119] Eliminato	perrone	13/09/2012 13.16.00
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Pagina 9: [120] Eliminato and/or 22	Blanco	14/09/2012 18.37.00
Pagina 9: [121] Eliminato is	Blanco	13/09/2012 16.39.00
Pagina 9: [121] Eliminato s	Blanco	13/09/2012 16.39.00
Pagina 9: [121] Eliminato not of local origin, but	Blanco	19/09/2012 18.27.00
Pagina 9: [121] Eliminato i	Blanco	18/09/2012 17.57.00
Pagina 9: [122] Eliminato	perrone	17/09/2012 10.26.00
Pagina 9: [122] Eliminato have mainly been caused by the	perrone	13/09/2012 13.19.00
Pagina 10: [123] Eliminato Figure 11 shows the volcanic ash mass concentrations ($\mu\text{g}/\text{m}^3$) from FLEXPART simulations at 150 m above ground level at the lidar site. Daily means of the volcanic ash mass concentration were 0.7, 4.5, and 3.8 $\mu\text{g}/\text{m}^3$ on 20, 21, and 22 April, respectively. Site I daily PM10 levels and daily PM10 mass concentrations averaged over all sites (Table 1) are also reported in Fig. 11 by dotted and dashed lines, respectively. At site I, only a few hundred meters away from the lidar monitoring site, the daily levels of PM10 were on 20, 21, and 22 April, 4, 6, and 5 $\mu\text{g}/\text{m}^3$, respectively larger than the daily mean on 19 April, a day not yet affected by volcanic particles (Table 1). These enhancements are quite consistent with the values simulated by FLEXPART. Sites H and Site L are only a few tens of kilometres away from the lidar site (Fig. 11) and Table 1 shows that the enhancements of the PM10 levels on 20, 21, and 22 April, respectively, are at both sites rather similar to those observed at Site I. Finally, Table 1 and Fig. 11 (dashed line) shows that the daily PM10 mean levels were on 20, 21, and 22 April, 4, 9, and 5 $\mu\text{g}/\text{m}^3$, respectively larger than the daily PM10 mean level on 19 April.	Blanco	13/09/2012 17.06.00
Pagina 13: [124] Eliminato also arrived in the boundary layer	perrone	26/09/2012 13.50.00
Pagina 13: [125] Eliminato (as also simulated ash profiles by FLEXPART), but	Blanco	17/09/2012 17.22.00
Pagina 13: [126] Eliminato	perrone	26/09/2012 13.49.00

the high variability of the contribution of

Pagina 13: [127] Eliminato	Blanco	17/09/2012 17.26.00
We have also found that the time series of the aerosol optical depth by lidar measurements were similar to the simulated ash-total-column mass concentration after midday of 21 April likely for the more significant contribution of volcanic particles to the whole aerosol load.		
Pagina 13: [128] Eliminato	Blanco	17/09/2012 17.28.00
. In fact, the estimated mass size distribution of volcanic particles from sun-sky photometer measurements was in reasonable accordance with the mass size distribution for volcanic ash by FLEXPART simulations at 14:15 UTC of 21 April. Sun-sky photometer measurements have also revealed		
Pagina 13: [129] Eliminato	Blanco	17/09/2012 17.28.00
during the arrival of the volcanic ash plume. In fact,		
Pagina 13: [130] Eliminato	Blanco	17/09/2012 17.29.00
, before the arrival of volcanic ash,		
Pagina 13: [131] Eliminato	Blanco	17/09/2012 17.29.00
, when the ash cloud had arrived		
Pagina 13: [132] Eliminato	Blanco	18/09/2012 19.26.00
and with size segregated measurements of ground PM mass concentrations.		
Pagina 13: [133] Formattato	Blanco	17/09/2012 18.01.00
Rientro: Prima riga: 0 cm		
Pagina 13: [134] Eliminato	Blanco	17/09/2012 17.33.00
the estimated enhancement of PM10 from volcanic particles was ~ 4, 6, and 5 $\mu\text{g}/\text{m}^3$ on 20, 21, and 22 April, respectively at the lidar site.		
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Pagina 13: [136] Eliminato	Blanco	17/09/2012 17.36.00
integrated use of model and experimental data was prerequisite to clearly identify signatures and impact levels of volcanic particle at a distance of 4000 km from the volcano site. Hence, the		
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Pagina 18: [138] Formattato	Blanco	24/09/2012 20.01.00
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Giustificato, Interlinea 1,5 righe		
Pagina 18: [141] Formattato	Blanco	24/09/2012 20.01.00
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Pagina 18: [148] Formattato	Blanco	24/09/2012 20.01.00
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