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Lidar in Space Technology Experiment correlative measurements by lidar in Potenza, southern Italy

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Abstract. An intensive lidar measurement campaign was carried out in Potenza (40°36′N–15°44′E, 820 m above sea level (asl)) in conjunction with the Lidar in Space Technology Experiment (LITE) mission and primarily aimed at the validation of LITE stratospheric aerosol measurements. Potenza lidar measurements in coincidence with all five nighttime overpasses near southern Italy (September 11, 12, 17, and 18, 1994) are compared with simultaneous LITE data. Potenza lidar data appear to be highly correlated with LITE data both at 355 and 532 nm. Potenza lidar versus LITE measurements of the aerosol-scattering ratio show a correlation coefficient of 0.72–0.81 at 355 nm and 0.88–0.93 at 532 nm, with an average calibration coefficient of 0.92 ± 0.19 at 355 nm and 1.02 ± 0.07 at 532 nm. Comparisons are also made in terms of the average Ångstrom coefficient, whose values are consistent with submicrometer aerosol particles. Finally, Potenza lidar measurements of the aerosol layer base and top heights, the peak aerosol-scattering ratio and peak height, as well as of the aerosol scattering ratio at the cloud base appear to be consistent with measurements performed by other ground lidar stations in Europe during the LITE campaign as well as with the LITE data.

1. Introduction

The Lidar in Space Technology Experiment (LITE) flew aboard the space shuttle during the period September 9–20, 1994, and represents the first attempt to perform global lidar measurements of the Earth atmosphere from space. The LITE was developed by the NASA Langley Research Center (LaRC) to demonstrate the utility of lidar systems in space. LITE is built around a Nd:YAG laser (1064 nm), with crystals for the generation of second and third harmonics (532 and 355 nm) and a 1 m Cassegrainian-configured receiving telescope. A full description of the system is given by *McCormick et al.* [1993].

The LITE experiment aimed to demonstrate lidar technology effectiveness in the space environment and to perform various scientific investigations concerning the Earth's atmosphere. Primary atmospheric parameters measured by LITE are clouds, tropospheric and stratospheric aerosols, characteristics of the planetary boundary layer with much greater resolution than is available from current orbiting sensors, surface albedo, and stratospheric temperature and density. These parameters are necessary to produce a global data set for the development of reliable global chemistry and climate models.

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Validation of the measurements was an essential part of the LITE experiment, and in order to be satisfactorily carried out, an extensive correlative measurements program was required in which LITE measurements could be compared with coincident measurements occurring over a variety of geographical regions [*Woods*, 1994].

The validation effort involved ground-based and airborne lidar systems, "in situ" aerosol samplers, as well as visible and infrared radiometers. In particular, about 60 ground-based lidar systems carried out comparative measurements all over the world [*Winker et al.*, 1996]. Five lidar systems were operated in Italy during the LITE mission (Firenze, Frascati, L'Aquila, Napoli, and Potenza). Our group operated the lidars in Napoli (40°50′N, 14°10′E, sea level) and Potenza (40°36′N, 15°44′E, 820 m above sea level).

The Napoli lidar is based on an excimer laser source working at 351 nm (Xe:F), while the Potenza lidar is based on a Nd:YAG laser operating both at 532 nm and at 355 nm; both systems meet the characteristics required by the correlative measurements plan, with lidar wavelengths being nearly coincident with LITE. The Potenza lidar was developed to perform nighttime measurements of both tropospheric and stratospheric parameters, while the lidar system in Napoli was optimized to perform tropospheric measurements. Although the LITE campaign was planned for the period September 11–18,

Table 1. LITE Overpasses Over Napoli (40°50′N, 14°10′E, Sea Level) and Potenza (40°36′N, 15°44′E, 820 m above sea level)

Orbit	1994	Time (Subsatellite Point)	Distance From Napoli and Potenza, Respectively
		NIGHTTIME	
33	September 11	2237 GMT (40.3°N, 30.2°E)	1300 and 1200 km eastward
34	September 12	0010 GMT (40.3°N, 7.4°E)	650 and 750 km westward
128	September 17	2023 GMT (40.3°N, 29.9°E)	1300 and 1200 km eastward
129	September 17	2156 GMT (40.3°N, 7.2°E)	650 and 750 km westward
145	September 18	2145 GMT (40.3°N, 4.4°E)	900 and 1000 km westward
		DAYTIME	
60	September 13	1439 GMT (38.2°N, 25.0°E)	950 and 850 km southwestward

1994, the ground-based measurements were made from September 10–19 in order to have a more complete statistical sample.

LITE accomplished six overpasses within 2000 km of Napoli and Potenza, five of which were nighttime. A summary of the LITE passes over southern Italy is reported in Table 1. Note that LITE data profiles are based on 30 s time averaging, corresponding to horizontal averaging of approximately 200 km along the orbital track, while Potenza and Napoli lidar data are point measurements. None of the orbits was really close to our validation stations (650–1300 km). Because of these considerable distances, lidar measurements should be compared with LITE data in terms of stratospheric aerosol parameters only, since little change is expected in stratospheric aerosols over these distances. Therefore comparisons between LITE and Potenza lidar data have been performed in terms of stratospheric aerosol parameters for all nighttime overpasses. Further, a comparison between daytime data sets in terms of stratospheric aerosols is not possible because of the limited signal-to-noise ratio of both LITE and Potenza lidar daytime measurements at stratospheric heights.

The lidar system in Potenza performed elastic backscatter measurements from one hour before to one hour after the LITE overpasses, thus giving a sense of the homogeneity of the stratospheric layer. Retrieval of aerosol backscattering ratios at 355 and 532 nm were determined as were the retrieval of aerosol size characteristics. Results of the comparison between LITE and Potenza lidar in terms of stratospheric aerosol data are discussed for all nighttime orbits.

Fourteen radiosonde launches were performed in Potenza during the correlative measurement campaign in coincidence with lidar operations and have been used in the lidar data analysis procedure.

Preliminary results concerning the LITE correlative measurement campaign in Potenza have been reported in a recent paper [*Cuomo et al.*, 1997], which was mainly devoted to the comparison between LITE and Potenza lidar measurements in coincidence with orbit 128. In this more extensive paper, the analysis has been extended to all nighttime orbits.

The organization of this paper is as follows: In section 2, we briefly describe the experimental setup in Potenza. In section 3, a brief overview of the analysis procedure for lidar data is presented as well as experimental results and their comparison with LITE measurements for all nighttime overpasses.

2. Experiment

The lidar system in Potenza was developed around a Nd:YAG laser source (Continuum, model NY20) with second- (532 nm) and third- (355 nm) harmonic generation crystals. The receiver consists of two vertically pointing Cassegrainian-configured telescopes (each has a 500 mm diameter primary mirror and 5 m combined focal length), located 8 m apart. One telescope is located close to the transmitter (0.5 m apart, small off-axis bistatic configuration: telescope 1), while a second telescope is placed approximately 8 m apart (large off-axis bistatic configuration: telescope 2). Telescope 2 has one detection channel only, while the radiation collected by telescope 1 is split into two parts by means of a 90% beam splitter in order to allow water vapor Raman measurements to be made when elastic backscatter measurements are not required. Spectral selection is performed by means of monochromators (Jobin Yvon models H10 and HD10), placed in the focal plane of each telescope. The selected radiation is detected by cooled photomultipliers (Hamamatsu model R1828 and Thorn EMI models 9202QB and 9558QB), whose signals are amplified and sampled by means of both A/D conversion and photon counting. Because of the nonnegligible distance between the lidar transmitter and the receivers, raw signals below approximately 12 km are corrected through a height dependent geometrical factor in order to account for the partial superposition of the laser beam to each telescope's field of view.

In coincidence with LITE overpasses (i.e., from one hour before to one hour after the passes) the Potenza lidar system was operated to perform elastic scattering measurements only, with telescopes 1 and 2 detecting backscatter signals at 532 and 355 nm, respectively. Within ±2 hours of the LITE overpasses the two monochromators in telescope 2 were tuned to detect H_2O (407.5 nm) and N_2 (386.6 nm) Raman signals in order to accomplish atmospheric humidity and temperature measurements. The slits of the monochromators are selected to provide a 2 nm central bandwidth centered at 386.6 and 407.5 nm, respectively, together with high out of band rejection (10^8 and 10^9, respectively), thus preventing elastic backscatter contamination of the Raman signals.

Data were integrated over 12,000 laser shots corresponding to 3 min. The vertical resolution was set to 300 m. According to weather conditions, aerosol backscattering profiles are averaged over 1–2 hours. In order to allow the intercomparison between LITE data (vertical resolution of 150 m) and corresponding Potenza lidar measurements, the LITE data have been smoothed down to 300 m.

3. Data Analysis and Results

Data presented in this paper are expressed in terms of the aerosol-scattering ratio or backscattering mixing ratio $R_{A,\lambda}(z)$

Table 2. Values of $R_{A,\lambda}(z_b)$, z_b, z_t, $R_{A,\lambda}(z_{\mathrm{pk}})$, and z_{pk} as Found by Several Ground-Based Lidar Groups in Europe During the LITE Campaign

	$R_{A,355}(z_b)$	$R_{A,532}(z_b)$	z_b, km	z_t, km	$R_{A,355}(z_{\mathrm{pk}})$	$R_{A,532}(z_{\mathrm{pk}})$	z_{pk}, km
This paper	0.030 ± 0.005	0.065 ± 0.02	12–14	27–32	0.10–0.12	0.20–0.28	18–19
Gobbi et al.		0	13–14	28–30		0.2–0.25	17–18
Jager et al.		0.05–0.1	10–14	28–36		0.2–0.3	18–20
Morandi et al.	0.01	0.05	11	28	0.08	0.23	18
Rizi et al.	0.02	0.1	12	28–29	0.1	0.2	20
Steinbrecht and Claude, 353 nm	0.03–0.05		12–13	26–28	0.12		18

[*Cuomo et al.*, 1997; *Russell et al.*, 1981]; $R_{A,\lambda}(z)$ is related to the aerosol backscattering coefficient $\beta_{A,\lambda}(z)$ through the expression

$$\beta_{A,\lambda}(z) = R_{A,\lambda}(z) n(z) \sigma_{\mathrm{Ray}} \tag{1}$$

with $n(z)$ and σ_{Ray} being the atmospheric number density profile and the Rayleigh backscattering cross section, respectively. $R_{A,\lambda}(z)$ is obtained from the elastic backscattered signal $S_\lambda(z)$ through the expression

$$R_{A,\lambda}(z) = \frac{S_\lambda(z)}{S_m(z)} - 1 \tag{2}$$

$S_m(z)$ represents the molecular contribution to $S_\lambda(z)$ and takes the form

$$S_m(z) = K n(z) z^{-2} \exp\{-2[\tau_m(z) + \tau_A(z) + \tau_{\mathrm{O_3}}]\} \tag{3}$$

with $\tau_m(z)$, $\tau_A(z)$, and $\tau_{\mathrm{O_3}}(z)$ being the molecular, aerosol, and ozone contributions to the optical thickness, respectively, and K being a calibration factor; this factor can be determined by normalizing the lidar signal $S_\lambda(z)$ to $S_m(z)$ in any aerosol free region above the stratospheric aerosol layer. Both the $\tau_m(z)$ and the atmospheric number density profile $n(z)$ can be obtained either from radiosonde data or from an atmospheric model. Radiosonde launches became available in Potenza in September 1994, just before the LITE measurement campaign. For the present analysis, $\tau_m(z)$ and $n(z)$ were determined from radiosonde pressure and temperature profiles. In order to estimate the term $\tau_{\mathrm{O_3}}(z)$, an ozone profile from U.S. Standard Atmosphere (1976) was considered. Ozone absorption cross section was taken to be 1×10^{-22} cm^2 at 355 nm [*Cacciani et al.*, 1989] and 2.75×10^{-21} cm^2 at 532 nm [*Vigroux*, 1953].

In order to estimate the term $\tau_A(z)$ to be introduced in expression (3), a Klett type modified procedure was considered [*Di Girolamo et al.*, 1996]. This iterative procedure is based on the assumption of a constant value of the extinction-to-backscattering ratio k_λ within the stratospheric aerosol cloud. In the case of stratospheric background aerosols the value of k_λ, depending on aerosol microphysical characteristics, was found to have values of 48 ± 15 and 32 ± 9 sr, at 532 and 355 nm, respectively [*Del Guasta et al.*, 1994]. Applying this procedure to a number of cases of statistical relevance corresponding to observations performed in the period after March 1994, i.e., far from any major volcanic event, we found the profiles of $R_{A,\lambda}(z)$ corresponding to the first iteration to be almost superimposed (within 2% at any height) to the first-guess estimate of $R_{A,\lambda}(z)$ obtained by neglecting the term $\tau_A(z)$ in expression (3). A similar behavior was found in Potenza lidar data during the LITE campaign and thus the first-guess estimates of $R_{A,\lambda}(z)$ were used. Measurements performed at Potenza before the LITE campaign provided values of the aerosol-scattering ratio at the cloud base, $R_{A,\lambda}(z_b)$, of 0.065 ± 0.02 and 0.030 ± 0.005 at 532 and 355 nm, respectively. Values of $R_{A,\lambda}(z_b)$ measured at Potenza during the LITE campaign are found to fall in the above mentioned range. Similar values were found by several other groups operating ground-based lidar systems in Europe during the LITE campaign and are reported, together with ours, in Table 2. *Morandi et al.* [1996] found values of $R_{A,\lambda}(z_b)$ equal to 0.05 at 532 nm and to 0.01 at 355 nm, while *Rizi et al.* [1996] measured values of $R_{A,\lambda}(z_b)$ of 0.1 and 0.02 at 532 and 355 nm, respectively. *Steinbrecht and Claude* [1996] measured values of $R_{A,353}(z_b)$ in the range 0.03–0.05, and *Jager et al.* [1996] found values of $R_{A,532}(z_b)$ of 0.05–0.1. The aerosol cloud base and top heights z_b and z_t are determined through a procedure defined by *Di Girolamo et al.* [1995], characterized by a typical uncertainty of 300–600 m.

Because of the distance between the lidar transmitter and the receivers, $S_\lambda(z)$ was corrected through a height dependent geometrical factor. Such a factor assumes different values depending on whether $S_\lambda(z)$ is collected by means of telescope 1 or telescope 2, the larger correction being needed for telescope 2 data because of its larger off-axis bistatic configuration. The correction is performed by taking into account also the alignment condition of the laser beam with respect to the telescope field of view. The height dependent geometrical factor was determined by means of a ray-tracing-based software [*Velotta et al.*, 1997]. The selection of the most accurate parameters to be considered within the geometric function has been performed through a best fit procedure applied to the data in the height range 10–12 km. This correction introduces negligible effects on the data above 12 km, and its contribution to the uncertainty affecting $R_{A,\lambda}(z)$ is included in the term $R_{A,\lambda}(z_b)$.

The error affecting $R_{A,\lambda}(z)$ is mainly dependent on the uncertainty affecting the lidar signal $S_\lambda(z)$, the atmospheric number density $n(z)$, and the molecular contribution to the optical thickness $\tau_m(z)$. For all reported data the uncertainty affecting $S_\lambda(z)$ does not exceed 2–3% at any height within the aerosol layer. The use of radiosonde data leads to an uncertainty on $n(z)$ and $\tau_m(z)$ of approximately 3% up to 30 km [*Russell*, 1979]. The uncertainty affecting $R_{A,\lambda}(z)$ is also dependent on the value of $R_{A,\lambda}(z_b)$. The overall error affecting $R_{A,\lambda}(z)$ is less than 40% at any height.

During the time of the LITE campaign the weather in southern Italy was fair, characterized by mostly clear skies. As a consequence, lidar observations were successfully carried out in Potenza in coincidence with all LITE overpasses.

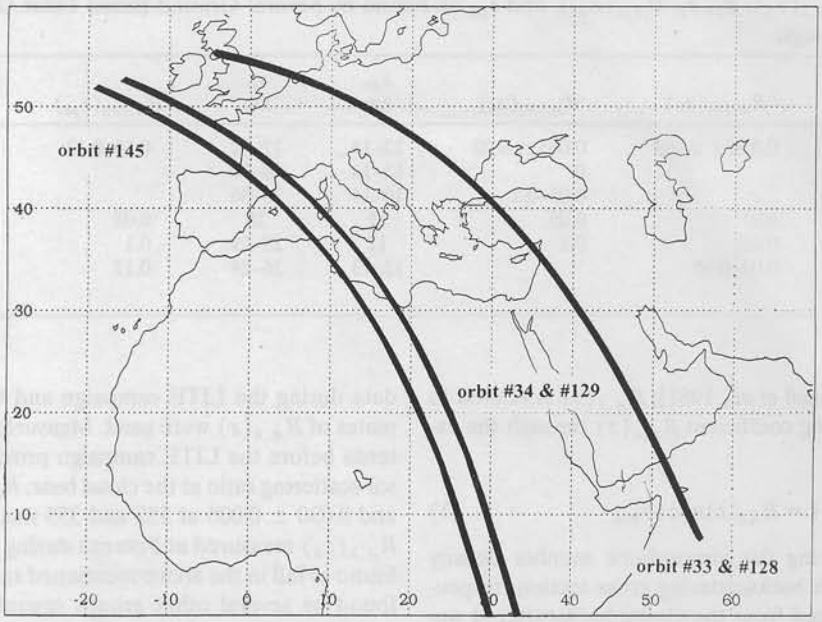

Figure 1. Shuttle ground tracks for all nighttime orbits. Orbits 33 and 128 as well as orbits 34 and 129 are almost colocated.

Figure 1 shows the shuttle ground tracks for all nighttime orbits (33, 34, 128, 129, and 145). Orbits 33 and 128 fell approximately 1200 km eastward of Potenza, at 30.2°E and 29.9°E, respectively; orbits 34 and 129 were approximately 750 km westward of Potenza (7.4°E and 7.2°E), while orbit 145 was located 1000 km westward.

Figure 2 compares Potenza lidar measurements of $R_{A,355}(z)$ and $R_{A,532}(z)$ in coincidence with all nighttime overpasses. $R_{A,355}(z)$ and $R_{A,532}(z)$ have been plotted on different amplitude scales in order to show their similarities. The good agreement between lidar data at two different laser wavelengths illustrated by Figure 2 shows the high internal consistency of Potenza lidar data. For all measurements the stratospheric aerosol layer base z_b appears to be located between 12 and 14 km, while the top z_t is at 27–32 km. $R_{A,355}(z)$ and $R_{A,532}(z)$ profiles below the stratospheric aerosol base depend on tropospheric properties and, consequently, are expected to be highly variable on the mesoscale. Therefore they are not reported in the figures. Minor structures in Figure 2 can be observed at 15, 18, and 22 km on all profiles. Features observed above 30 km have no physical significance, resulting from signal statistical noise. Observed values of z_b and z_t appear to be in good accordance with measurements performed by other lidar groups in Europe in coincidence with the LITE campaign (Table 2). All observed values of z_b are in the range 10–14 km (*Morandi et al.* [1996], 11 km; *Rizi et al.* [1996], 12 km; *Steinbrecht and Claude* [1996], 12–13 km; *Gobbi et al.* [1996], 13–14 km; *Jager et al.* [1996], 10–14 km), while all observed values of z_t are in the range 26–36 km (*Morandi et al.* [1996], 28 km; *Rizi et al.* [1996], 28–29 km; *Steinbrecht and Claude* [1996], 26–28 km; *Gobbi et al.* [1996], 28–30 km; *Jager et al.* [1996], 28–36 km).

Figure 2 also shows that Potenza lidar measurements of $R_{A,532}(z)$ display a larger time variability with respect to corresponding measurements of $R_{A,355}(z)$, as a result of the larger sensitivity of the former parameter to aerosol microphysical changes ($R_{A,\lambda}(z)$ scales approximately as λ^3). Values of the peak aerosol scattering ratio at 355 nm, $R_{A,355}(z_{\text{pk}})$ are found to range from 0.10 to 0.12, while $R_{A,532}(z_{\text{pk}})$ displays values in the range 0.20–0.28, with the peak height z_{pk} ranging from 18 to 19 km at both wavelengths. Such values are in agreement with measurements performed by other ground lidar groups in Europe during the LITE campaign, reported, together with ours, in Table 2. All observed values of $R_{A,532}(z_{\text{pk}})$ are in the range 0.2–0.3 (*Morandi et al.* [1996], 0.23; *Rizi et al.* [1996], 0.2; *Gobbi et al.* [1996], 0.2–0.25; *Jager et al.* [1996], 0.2–0.3), while all observed values of $R_{A,355}(z_{\text{pk}})$ are in the range 0.08–0.1 (*Morandi et al.* [1996], 0.08; *Rizi et al.* [1996], 0.1). *Steinbrecht and Claude* [1996] measured values of $R_{A,\lambda}(z_{\text{pk}})$ at 353 nm of 0.12. Reported measurements of the peak aerosol height z_{pk} are found to have values in the range 17–20 km (*Morandi et al.* [1996], 18 km; *Rizi et al.* [1996], 20 km; *Steinbrecht and Claude* [1996], 18 km; *Gobbi et al.* [1996], 17–18 km; *Jager et al.* [1996], 18–20 km).

Figures 3, 4, 5, 6, and 7 illustrate the comparison between simultaneous LITE and Potenza lidar measurements of $R_{A,\lambda}(z)$ for orbits 33, 34, 128, 129, and 145, respectively; Figures 3a, 4a, 5a, 6a, and 7a represent the comparison in terms of $R_{A,355}(z)$, while Figures 3b, 4b, 5b, 6b, and 7b represent the comparison in terms of $R_{A,532}(z)$. Accounting for the measurement uncertainty, the profiles of $R_{A,355}(z)$ measured at Potenza compare very well with corresponding LITE data, with few exceptions. In coincidence with the shuttle orbit 33, Potenza lidar values of $R_{A,532}(z)$ measured around the stratospheric aerosol cloud base are lower than corresponding LITE measurements (Figure 3b). The Potenza lidar profile of $R_{A,355}(z)$ for orbit 34 (Figure 4a) shows values somewhat higher than LITE data, below approximately 20 km, while a better agreement is present between LITE and Potenza lidar measurements of $R_{A,532}(z)$ for the same orbit. Furthermore, Figures 7a and 7b, representing the LITE versus Potenza data comparison for orbit 145 in terms of $R_{A,355}(z)$ and $R_{A,532}(z)$, respectively, evidence the presence of a vertical shift between LITE and Potenza data.

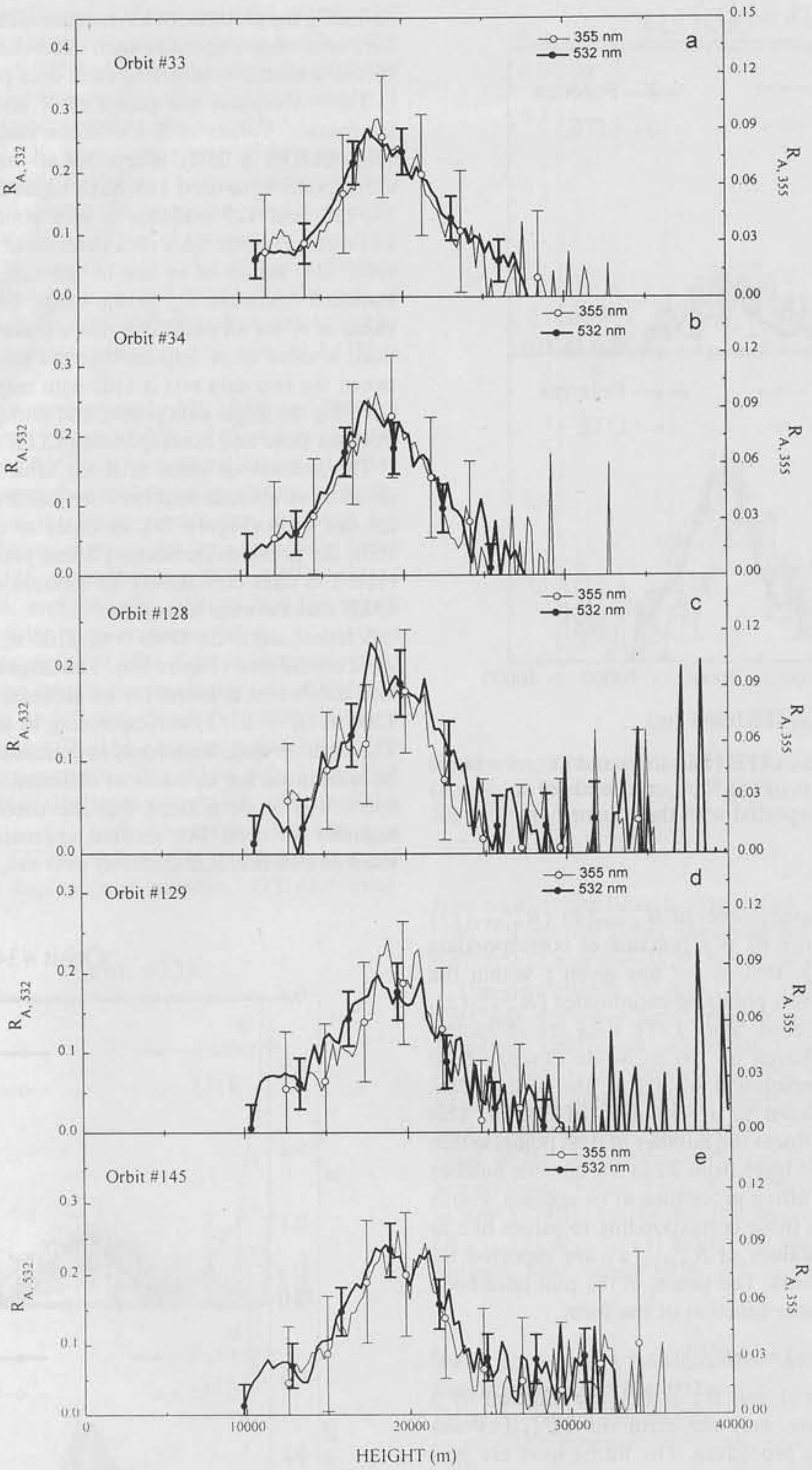

Figure 2. Potenza lidar measurements of $R_{A,\lambda}(z)$ at 355 (thin line) and 532 nm (solid line) in coincidence with all nighttime overpasses: (a) orbit 33, (b) orbit 34, (c) orbit 128, (d) orbit 129, (e) orbit 145). Data are reported with their error bars. $R_{A,355}(z)$ and $R_{A,532}(z)$ are displayed on different amplitude scales in order to show their similarities and to verify an internal consistency in the data.

Using the hypothesis that data points at different altitudes for both Potenza lidar and LITE data are uncorrelated, it is possible to perform a statistical analysis of the two data sets in order to quantify the degree of agreement between LITE and Potenza lidar measurements. For what concerns Potenza lidar data of $R_{A,\lambda}(z)$ the validity of the above mentioned hypothesis has been verified through the application of a covariance analysis to the elastic signal $S_{\lambda}(z)$.

The following procedure was considered in order to quantify the degree of agreement between LITE and Potenza lidar

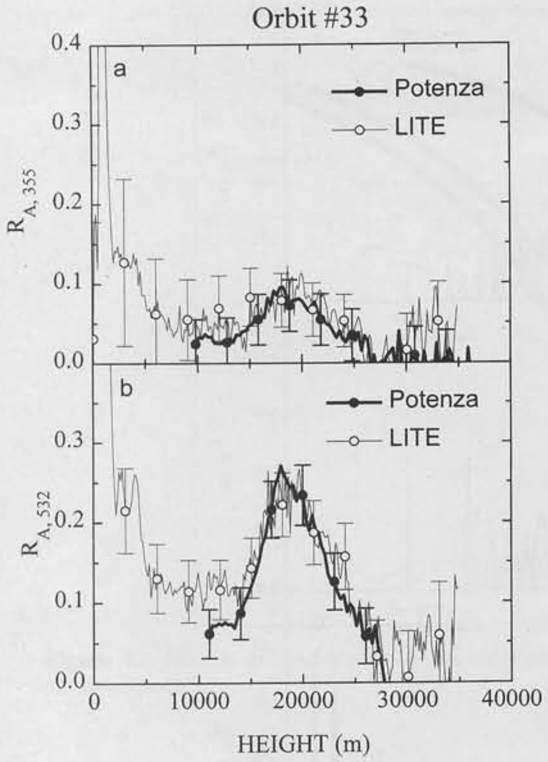

Figure 3. Simultaneous LITE (thin line) and Potenza (solid line) lidar measurements of (a) $R_{A,355}(z)$ and (b) $R_{A,532}(z)$ for orbit 33. Data are reported with their error bars.

data. Potenza lidar measurements of $R_{A,532}(z)$ ($R^{\mathrm{Pz}}_{A,532}(z)$) have been plotted (Figure 8) as a function of corresponding LITE data ($R^{\mathrm{LITE}}_{A,532}(z)$); that is, for any given z within the stratospheric aerosol layer, points of coordinates ($R^{\mathrm{LITE}}_{A,532}(z)$, $R^{\mathrm{Pz}}_{A,532}(z)$) were considered. Since LITE data are characterized by a vertical resolution of 150 m, while Potenza lidar measurements have a resolution of 300 m, the former data have been smoothed down to a resolution of 300 m. This smoothing procedure reduces the number of data points within the stratospheric aerosol layer from 70 to 35, but this number is large enough for the fitting procedure to be applied. Points reported in the plot are those corresponding to values of z in the range 16–26 km. Values of $R^{\mathrm{Pz}}_{A,532}(z)$ are reported together with their error bars. The points in the plot have been least squares fit by a linear function of the form

$$R^{\mathrm{Pz}}_{A,532}(z) = mR^{\mathrm{LITE}}_{A,532}(z) + c \tag{4}$$

Even if both $R^{\mathrm{Pz}}_{A,532}(z)$ and $R^{\mathrm{LITE}}_{A,532}(z)$ are affected by a nonnegligible uncertainty, only the error on $R^{\mathrm{Pz}}_{A,532}(z)$ was considered in the fitting procedure. The fitting lines are presented in Figure 8.

The correlation coefficient of the fit, R, equal to 1 for perfect correlation, quantifies the degree of correlation between LITE and Potenza lidar data. If the data analysis procedure is properly performed, values of the fitting parameter c are expected to be equal to zero; values of c determined through the fitting procedure are found to have an average value of -0.001. The parameter m gets the significance of a normalization coefficient to calibrate data: $m > 1$ implies $R^{\mathrm{Pz}}_{A,532}(z)$ is overestimating $R^{\mathrm{LITE}}_{A,532}(z)$, while $m < 1$ implies $R^{\mathrm{Pz}}_{A,532}(z)$ is underestimating $R^{\mathrm{LITE}}_{A,532}(z)$ values. This statistical analysis is capable of finding the presence of a systematic difference between the two data sets, also in the case such difference is small with respect to the uncertainty affecting each data point to be compared.

Table 3 reports the values of R and m for all nighttime overpasses. Values of R are in the range 0.88–0.93 (average value of 0.90 ± 0.02), except for an anomalous value of 0.37 corresponding to orbit 145. Such high values of R for orbits 33, 34, 128, and 129 evidence a very good correlation between LITE and Potenza lidar data in terms of $R_{A,532}(z)$. Except for orbit 145, values of m are in the range 0.96–1.08, with the standard deviation σ_m in the range 0.08–0.09. The average value of m for all nighttime orbits (except 145) is 1.02 ± 0.07. Such a value of m implies that the systematic difference between the two data sets is little with respect to the uncertainty affecting the single data points, and thus the agreement between Potenza lidar and corresponding LITE data is very good.

The anomalous value of R for orbit 145 appears to be the result of an altitude shift between LITE and Potenza lidar data for this orbit (Figure 7b). In order to determine this vertical shift, the previous mentioned fitting procedure was applied to orbit 145 data considering an altitude displacement between LITE and Potenza lidar data.

Vertical shifts Δz from 0 to 2100 m, with steps of 300 m, were considered (Figure 9b). The largest value of the correlation coefficient is found for an altitude shift of approximately 1200 m ($R = 0.73$, corresponding to a value of $m = 1.18$). The altitude shift, found only in coincidence with orbit 145, can be accounted for in terms of different air masses. In this respect, it is to be noticed that the considered 200 km length segment for orbit 145, located approximately 1000 km westward of Potenza, is completely over sea, while all other passes

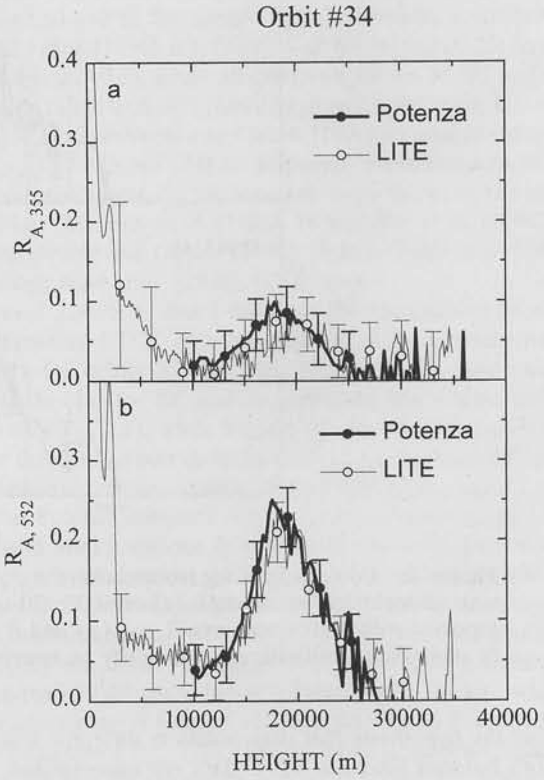

Figure 4. Simultaneous LITE (thin line) and Potenza (solid line) lidar measurements of (a) $R_{A,355}(z)$ and (b) $R_{A,532}(z)$ for orbit 34.

are continental (orbits 33 and 128) or partially continental (orbits 34 and 129). Furthermore, the tropopause height at the location of the orbit 145 LITE overpass, as obtained from the National Meteorological Center analysis, is approximately 11 km, while it has an almost constant value around 15 km for orbits 33, 34, 128, and 129; such values have to be compared with the tropopause height in Potenza having an almost constant height (12–14 km) during the campaign, as evidenced by the little time-variability for all orbits of the aerosol layer base height. Therefore in the case of orbit 145, LITE and Potenza lidar are observing different air masses (marine in the case of LITE and continental in the case of Potenza) characterized by different tropopause heights, which in the case of LITE is probably 1–2 km lower.

The fitting procedure was also applied to LITE and Potenza lidar data at $\lambda = 355$ nm. Values of $R^{\mathrm{Pz}}_{A,355}(z)$ as a function of corresponding values of $R^{\mathrm{LITE}}_{A,355}(z)$ for all nighttime orbits are reported in Figure 10, together with the fitting lines, while the corresponding values of the fitting parameters R and m are reported in Table 3. Values of m, except for a somewhat lower value of 0.64 for orbit 145, are in the range 0.79–1.19 (standard deviation of 0.11–0.14, average value of 0.92 ± 0.19), which means that Potenza lidar measurements of $R_{A,355}(z)$ are lower than the corresponding LITE data by approximately 10%. The values of the correlation coefficient R of Potenza lidar versus LITE data at 355 nm, except for orbit 145 ($R = 0.65$), are in the range 0.72–0.81 (average value of 0.77 ± 0.04) and are lower than corresponding values at 532 nm (13% on average), as a result of the larger uncertainty affecting lidar measurements of $R_{A,355}(z)$ with respect to that affecting $R_{A,532}(z)$ data. As at 532 nm, values of m and R for orbit 145 increase if an altitude displacement between LITE and simultaneous Potenza lidar is considered, the maximum value for both parameters being observed for $\Delta z = 1200$ m ($m = 0.87 \pm 0.12$ and $R = 0.79$, Figure 9d).

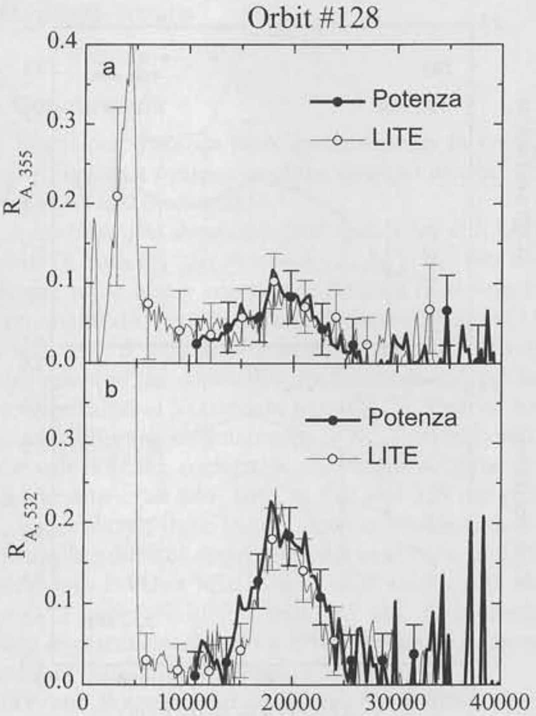

Figure 5. Simultaneous LITE (thin line) and Potenza (solid line) lidar measurements of (a) $R_{A,355}(z)$ and (b) $R_{A,532}(z)$ for orbit 128.

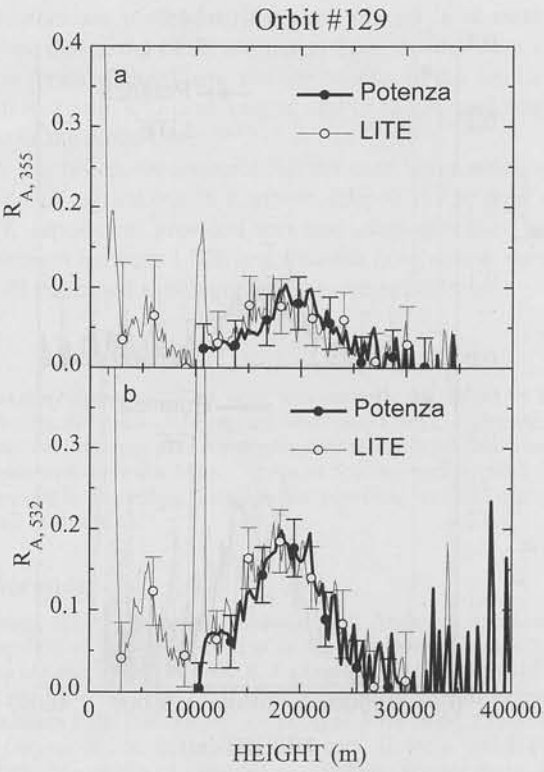

Figure 6. Simultaneous LITE (thin line) and Potenza (solid line) lidar measurements of (a) $R_{A,355}(z)$ and (b) $R_{A,532}(z)$ for orbit 129.

The dependence of $R_{A,355}(z)$ and $R_{A,532}(z)$ on aerosol sizes was discussed by *Cuomo et al.* [1997] in terms of the Ångstrom coefficient. Assuming that aerosol microphysical characteristics are slowly changing with height within the stratospheric aerosol layer, information can be obtained on aerosol average size characteristics considering the average value of the Ångstrom coefficient δ within the stratospheric aerosol layer. Value δ is given by the expression: $\delta = 4 + 2.5 \ln(m')$, with m' being the average value of the ratio $(R_{A,355}(z)/R_{A,532}(z))$ within the stratospheric aerosol layer. Potenza lidar values of δ, δ^{Pz}, measured during the LITE

Table 3. Value of the Calibration and Correlation Coefficients m and R at 532 and 355 nm as Resulting From the Fitting Procedure

Orbit	m_{532}	R_{532}	m_{355}	R_{355}
33	1.08 ± 0.08	0.93	0.79 ± 0.12	0.77
34	1.08 ± 0.08	0.92	0.91 ± 0.13	0.78
128	0.96 ± 0.09	0.88	1.19 ± 0.14	0.81
129	0.97 ± 0.09	0.89	0.79 ± 0.14	0.72
145	0.47 ± 0.021	0.37	0.64 ± 0.11	0.65

$\langle m_{532}\rangle$	$\langle R_{532}\rangle$	$\langle m_{355}\rangle$	$\langle R_{355}\rangle$
1.02 ± 0.07 (145 not included)	0.90 ± 0.02 (145 not included)	0.92 ± 0.19 (145 not included)	0.77 ± 0.04 (145 not included)

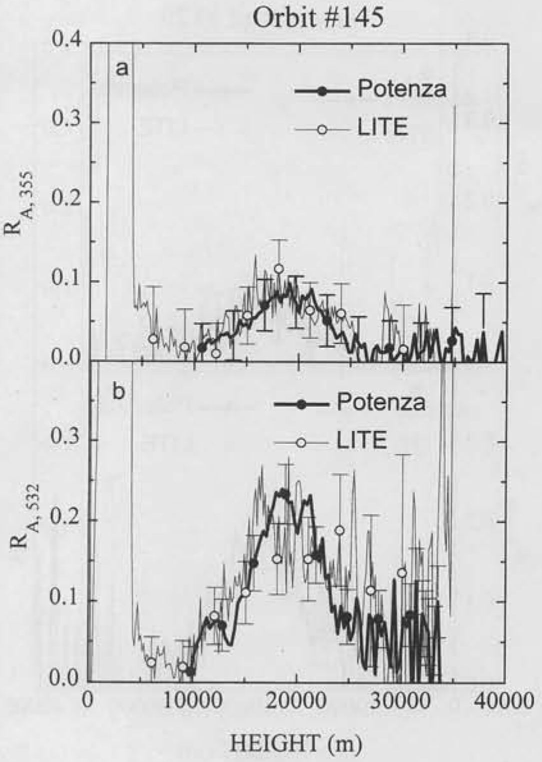

Figure 7. Simultaneous LITE (thin line) and Potenza (solid line) lidar measurements of (a) $R_{A,355}(z)$ and (b) $R_{A,532}(z)$ for orbit 145.

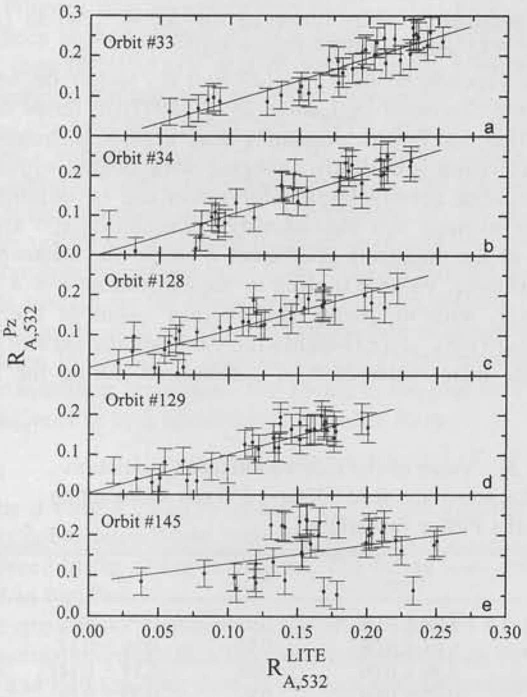

Figure 8. $R^{\mathrm{Pz}}_{A,532}(z)$ versus $R^{\mathrm{LITE}}_{A,532}(z)$ for all data points within the stratospheric aerosol layer: (a) orbit 33, (b) orbit 34, (c) orbit 128, (d) orbit 129, and (e) orbit 145. Values of $R^{\mathrm{Pz}}_{A,532}(z)$ are reported together with their error bars. Also reported is the best fit linear function defined in expression (4). Only the error affecting $R^{\mathrm{Pz}}_{A,532}(z)$ was considered in the fitting procedure.

Table 4. Values of the Ångstrom Coefficient for Potenza Lidar, δ^{Pz}, and the LITE Experiment, δ^{LITE}, for All Orbit, Together With the Values of the Deviation $(\delta^{Pz} - \delta^{LITE}/\delta^{LITE})$

Orbit	δ^{Pz}	δ^{LITE}	$(\delta^{Pz} - \delta^{LITE}/\delta^{LITE})$, %
33	1.38 ± 0.04	1.51 ± 0.07	9
34	1.58 ± 0.06	1.38 ± 0.08	14
128	2.16 ± 0.07	1.89 ± 0.10	14
129	1.62 ± 0.08	1.89 ± 0.06	14
145	1.58 ± 0.05	1.65 ± 0.11	4
	$\langle\delta^{Pz}\rangle$	$\langle\delta^{LITE}\rangle$	
	1.70 ± 0.27	1.64 ± 0.25	

campaign are in the range for 1.38–2.16 (1.70 ± 0.27), while values of δ obtained from LITE data, δ^{LITE}, are in the range for 1.38–1.89 (1.64 ± 0.25). Values of δ^{Pz} and δ^{LITE} for all orbit are reported in Table 4, together with the values of the deviation $(\delta^{Pz} - \delta^{LITE}/\delta^{LITE})$. Accounting for the error associated with the measurement, LITE-derived values of δ show a good agreement with simultaneous Potenza lidar values. LITE and Potenza lidar measurements of δ are also in good agreement with measurements performed by other ground-based lidar groups in Europe during the LITE campaign. In coincidence with orbits 33 and 34, *Rizi et al.* [1996] reported values of δ of 1.67, 2.14, and 1.25 at 18, 20, and 25 km, respectively, while *Morandi et al.* [1996], for orbit 34, measured values of δ of 1.2 and 1.7 at 18 and 25 km, respectively. Theoretical computations performed by *Cuomo et al.* [1997], based on the assump-

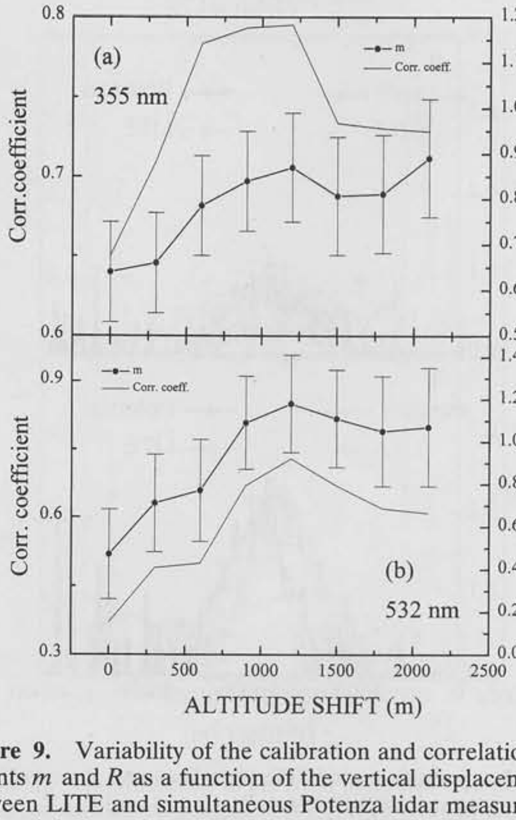

Figure 9. Variability of the calibration and correlation coefficients m and R as a function of the vertical displacement Δz between LITE and simultaneous Potenza lidar measurements of $R_{A,\lambda}(z)$ for orbit 145: (a) 355 nm and (b) 532 nm.

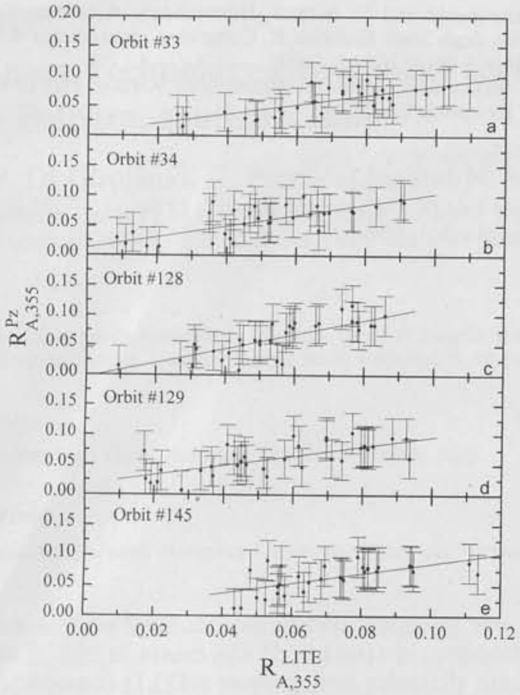

Figure 10. $R^{Pz}_{A,532}(z)$ versus $R^{LITE}_{A,532}(z)$ for all data points within the stratospheric aerosol: (a) orbit 33, (b) orbit 34, (c) orbit 128, (d) orbit 129, and (e) orbit 145, together with the best fit linear function defined in expression (4).

tions of the aerosol to be composed of a 75% H_2SO_4 water solution by mass and to follow a single-mode lognormal aerosol distribution (width = 1.8), suggest that values of δ^{Pz} and δ^{LITE} reported in Table 4 are consistent with an aerosol mean radius of 0.02–0.1 μm.

4. Conclusions

In this paper, Potenza lidar measurements in coincidence with five nighttime overpasses of the space-shuttle-borne LITE are reported and discussed.

Potenza lidar data show very good agreement with LITE data in terms of both $R_{A,355}(z)$ and $R_{A,532}(z)$, the two data sets appearing to be highly correlated. Potenza lidar versus LITE measurements display a mean correlation coefficient of 0.77 ± 0.04 and 0.90 ± 0.02 at 355 and 532 nm, respectively. The smaller values of the correlation coefficient at 355 nm, with respect to the values at 532 nm, are probably the result of the larger uncertainty affecting measurements of $R_{A,355}(z)$ by both lidars.

Low values of the correlation coefficient were found in coincidence with orbit 145, both at 532 and 355 nm (0.37 and 0.65, respectively); these values increase significantly if an altitude displacement of about 1200 m is used between LITE and simultaneous Potenza lidar. Correlation coefficients then become 0.73 and 0.79 at 532 and 355 nm, respectively. The altitude displacement found for orbit 145 can be accounted for in terms of different air masses.

LITE and Potenza lidar data have been also compared in terms of the average Ångstrom coefficient δ. Measured values of δ are in agreement with measurements performed by other groups and are consistent with submicrometer aerosol particles (mean radius = 0.02–0.1 μm).

Potenza lidar measurements appear to be consistent with measurements performed by other ground lidar stations in Europe during the LITE campaign. Comparisons were carried out in terms of cloud base and top heights, of the peak aerosol scattering ratio and peak height, and of the aerosol scattering ratio at the cloud base.

In conclusion, we can state that the correlative measurement campaign carried out in southern Italy in the context of the LITE experiment provided very encouraging results, and the agreement between LITE and Potenza lidar data is very good for all examined simultaneous measurements.

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