WATER VAPOR AND AEROSOL LIDAR MEASUREMENTS WITHIN AN ATMOSPHERIC INSTRUMENTAL SUPER SITE TO STUDY THE AEROSOLS AND THE TROPOSPHERIC TRACE GASES IN ROME

D. Dionisi[1]*, A.M. Iannarelli[2], A. Scoccione[3], G.L. Liberti[1], M. Cacciani[3], S. Argentini[1], L. Baldini[1], F. Barnaba[1], M. Campanelli[1], G. Casasanta[1], H. Diémoz [4], L. Di Liberto[1], G.P. Gobbi[1], I. Petenko[1,5], A.M. Siani[3], J. Von Bismarck[6], S. Casadio[2]

*[1]Institute of Atmospheric Sciences and Climate, Italy, *d.dionisi@isac.cnr.it*
[2]Serco Spa, Italy
[3]Physics Department, "Sapienza" University of Rome, Italy
[4]ARPA Valle d'Aosta
[5]A.M. Obukhov Institute of Atmospheric Physics, Russia
[6]ESA-ESRIN EOP-GMQ

ABSTRACT

A joint instrumental Super Site, combining observation in urban ("Sapienza" University) and semi-rural (ESA-ESRIN and CNR-ISAC) environment, for atmospheric studies and satellites Cal/Val activities, has been set-up in the Rome area (Italy). Ground based active and passive remote sensing instruments located in both sites are operating in synergy, offering information for a wide range of atmospheric parameters. In this work, a comparison of aerosol and water vapor measurements derived by the Rayleigh-Mie-Raman (RMR) lidars, operating simultaneously in both experimental sites, is presented.

1 INTRODUCTION

The characterization of the planetary boundary layer (PBL) is important in a variety of fields such as air quality studies, weather forecasting, climate change modeling, and Earth Observation satellite Cal/Val activities. Aerosols have a significant impact on the earth radiative budget and on air pollution. Furthermore, aerosols trapped within the PBL, can be used as tracers to study the boundary layer vertical structure and its temporal variability. The water vapor is an important atmospheric variable, its mixing ratio is useful as a tracer of air parcels and in understanding energy transport within the atmosphere.

In this context, "Sapienza" University, ESA-ESRIN and CNR-ISAC decided to cooperate and to exploit the remote sensing instrumentation, located in their experimental sites, in a coordinated effort (see Figure 1):

- BAQUNIN (Boundary-layer Air Quality Using Network of INstruments) Super-Site instruments are located at "Sapienza" University, in the city centre (41.90°N, 12.51°E and 75m ASL).
- CIRAS observatory (CNR-ISAC Rome Atmospheric Supersite,) is located in the semi-rural foot area of Tor Vergata (41.88°N, 12.68°E, 107 m ASL, http://www.isac.cnr.it/en/infrastructures/ciras-cnr-isac-rome-atmospheric-supersite).

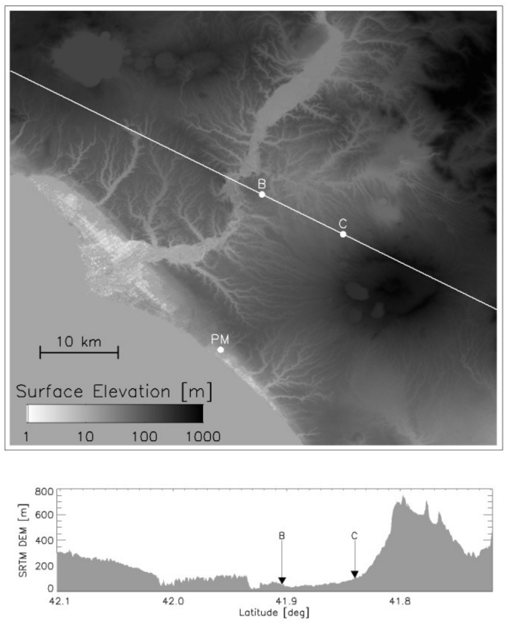

Figure 1. Upper panel: surface elevation a.s.l. of Tiber valley of the study area. Lower panel: elevation transect along with the location of two sites. B indicates the BAQUNIN site, C the CIRAS site and PM the position of the radio-sounding site of Pratica di Mare.

In figure 1, the upper panel depicts the study area, the locations and the surface elevation of the two sites. The lower panel shows the elevations transect along with the locations of BAQUNIN (B), CIRAS (C) and Pratica di Mare WMO station (PM).

This synergy of sites gathers a unique ensemble of advanced instrumentation for atmospheric remote-sensing and for the validation of atmospheric composition satellite data. The list of available instruments at both sites is reported in table 1.

Table 1. Instrument suite

Instrument type	Products	BAQUNIN	CIRAS
Elastic and Raman lidars	Aerosol backscattering and extinction , H2O profiles, AOD, cloud boundaries	✓	✓
Ceilometer	Aerosol backscattering profile, cloud boundaries		✓
SODAR	Thermal turbulence, wind speed and direction profiles	✓	✓
RADAR	Precipitation		✓
MFRSR	Total column of AOD, O3, H2O	✓	
POM 01 L (PREDE)	AOD, SSA, AE, Refr. Indx, PF, VSD	✓	
Brewer	Total Column of O3, NO2 and SO2, UV Dose and UV Index	✓	
Pandora	Total Column of NO2, O3, HCHO, others	✓	✓
Meteorological sensors	Air temperature, RH, pressure, wind, SW and LW radiation	✓	✓
CIMEL	Total column of AOD and H2O, SAE, AAE, SSA, Refr. Indx, VSD	✓	✓

From the instruments in Table 1, among others, the following products are listed: Aerosol backscattering and extinction profiles, Aerosol Optical Depth (AOD), Single Scattering Albedo (SSA), Angstrom Exponent (AE), Scattering Ångström Exponent (SAE), Absorption Ångström Exponent (AAE), Real and imaginary part of Refractive Index (Refr. Indx), Phase Function (PF), and Volume size distribution (VSD).

The simultaneous employment of the advanced lidars located in both sites to study the variability of aerosol and water vapor is presented in this work.

2 Rayleigh-Mie-Raman Lidar systems

Lidar is a well-established technique for measuring both aerosols and water vapor vertical profiles [1] along the time. Furthermore having two lidars located in different environments, urban and semi-rural, gives the possibility to observe the differences of aerosol and water vapor distributions. In the following paragraphs a short description of the two Rayleigh-Mie-Raman (RMR) lidars is reported.

2.1 RMR Lidar at BAQUNIN Super Site

The transmitter is a Nd:Yag laser with 3 wavelengths 1064, 532 and 355 nm and pulse frequencies 30Hz.

The receiver is composed by 4 telescopes to detect the backscattered radiation at 5 wavelengths. A Cassegrain telescope (the diameter is 500 mm) is used to detect the elastic signal at 355 nm and to the Raman signals at 387 nm (N_2) and 407 nm (H_2O). The radiation is separated via an optical system composed by interferential filters and dichroic mirrors. The detection altitude range is 0.5 - 10 km. The elastic radiation at 532 nm is collected by two telescopes [2], the first one is reflective (60 mm diameter) and dedicated to the lowest portion of the troposphere (0.05 – 5 km), the second is a Cassegrain telescope (160 mm diameter) covering the 0.5 – 10 km altitude range. This signal is further split into two channels for each telescope in order to collect the total backscatter and backscatter-polarized parallel to the emitted radiation. For the elastic radiation at 1064 nm, a Cassegrain telescope (160 mm) is used, and the range of the altitude is 0.125-10 km.

For all channels, the vertical resolution is 7.5 m and the temporal resolution is 10 seconds which corresponds to an integration of 300 laser pulses. This system operates in both day and night-time conditions.

2.2 RMR Lidar at CIRAS Super Site

The transmitter is based on an Nd:YAG laser with 2nd (532 nm) and 3rd (355 nm) harmonic generators.

Backscattered radiation is collected and analyzed at 4 wavelengths of interest: 355 and 532 nm for the elastic backscatter and 386.7 and 407.5 nm for Raman scattering of N_2 and H_2O molecules, respectively. The receiver is in a multiple-telescope configuration [3, 4], allowing the sensing of a wide-altitude atmospheric interval. For the Raman and elastic backscatter, two different collection channels (CHs) are employed: one for the lower range (0.1 – 5 km altitude, using a 30 cm telescope and an optical fiber) and one for the upper range (2–13 km altitude, using an array of nine 50 cm aperture telescopes and an optical fiber bundle). An additional 15 cm telescope is used to collect the 532 nm elastic backscatter from the lower atmosphere (0.5–8 km).

The acquisition vertical resolution is 75 m and the signals are integrated over 60 second (600 laser pulses) and recorded. The RMR system is operated in manual mode and it provides 40 – 60 nighttime measurements per year. The system operates in both day and night-time conditions.

3 PRELIMINARY RESULTS

An example of simultaneous lidar RMR measurements is presented in this section. Figure 2 shows the logarithm of the Range Corrected Signal (RCS) at the wavelength of 532 nm acquired by the BAQUNIN Lidar (upper panel) and CIRAS Lidar (lover panel) on October 10, 2015 between 16.30 and 18.00 UT.

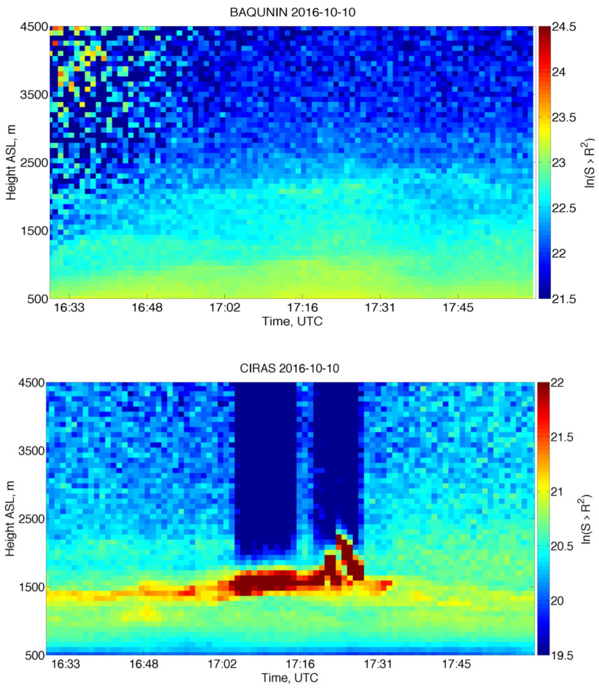

Figure 2. Time-height cross-section of the logarithm of the range corrected signal at 532 nm derived by the Baqunin and Ciras RMR lidar measurements (upper and lower panel, respectively) acquired on October 10, 2015 between 16:30 and 18:00 UT.

Both measurements have been re-gridded on the same temporal and spatial resolution (1 min and 75 m, respectively). Taking into account the different characteristics of two instruments, the ranges of the value scales of the plots are optimized for each system, in order to better appreciate the atmospheric structures. At both sites, aerosol layers are present up to 2000-2300 m, but the CIRAS lidar shows also a high backscattering layer around 1300-1500 m, which correspond to the passage, in temporal sequence, of aerosols, cloud and, again, aerosol. In terms of the aerosol load, the AOD values measured at the two sites seems to agree quite well. The values of simultaneous measurements are reported in table 2.

Table 2. AOD values derived by measurements at the two site, using Lidars at 532 nm, MultiFilter Rotating Shadowband Radiometer at 496 nm (BAQUNIN) and Cimel sun photometer at 500 nm (CIRAS)

	Lidar (17:00 UTC)	**Passive sensor (15:30 UTC)**
BAQUNIN	0.14±0.02	0.12±0.01
CIRAS	0.14±0.05	0.11±0.01

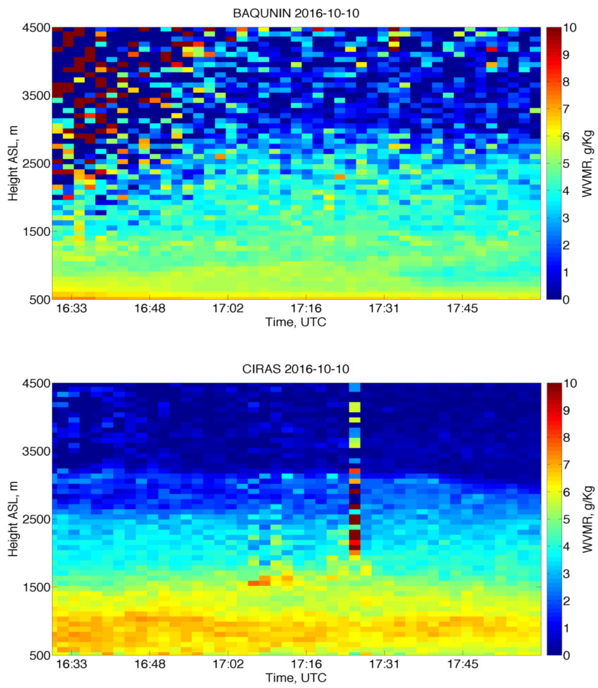

Figure 3. Time-height cross-section of the water vapor mixing ratio (WVMR) derived by the Baqunin and Ciras RMR lidar measurements (upper and lower panel, respectively) acquired on October 10, 2015 between 16:30 and 18:00 UT.

Figure 3 shows the time-height cross sections of the water vapor mixing ratio (WVMR) derived by both lidars. In this case, the temporal and spatial resolution of both measurements is 2 min and 75 m, respectively. The WVMR lidar data have been calibrated using, as reference, the radiosounding launched at the WMO station # 16245 (Pratica di Mare, see figure 1) by the Italian Meteorological Service of Military Aeronautics on October 10, 2015 at 12 UTC.

The comparison between the plots of figure 3 highlights, over the CIRAS site, the presence of a moist layer between 500 and 1500 m, which seems bounded by the observed aerosol/cloud layer. This humid layer is not observed over the BAQUNIN site. This feature is well seen in Figure 4, where the temporal evolution of the WVMR lidar profiles integrated for 30 minutes (blue and red lines for BAQUNIN and CIRAS lidar measurements, respectively) are plotted together with the radiosonde WVMR profile (green line). Below 1500 m, the atmosphere is moister at the CIRAS site of (the mean difference is around 0.78 g/Kg). An opposed behavior seems to occur above 1500 m, where the BAQUNIN lidar measures slightly higher values of WVMR compared to CIRAS lidar (the mean difference is around 0.12 g/Kg).

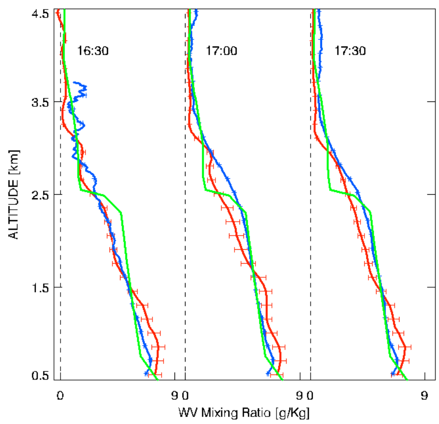

Figure 4. Temporal evolution of the 30-min integrated WVMR profiles derived by BAQUNIN and CIRAS lidars (blue and red lines, respectively) for the October 10, 2015. As reference, the radiosonde WVMR profile is also plotted (green line).

4 CONCLUSIONS

With the objective of providing independent and high-quality atmospheric composition ground-based data, which are required to accurately validate the upcoming European Earth Observation (EO) missions and payloads (e.g. S3, S5p, S5, S4, ADM-Aeolus, EarthCARE, METOP-SG, MTG), a coordinated instrumental Super site located in both urban (BAQUNIN) and semi-rural (CIRAS) environment of Rome has been setup. In this work, an example of the employment of RMR lidars located at both sites to study the temporal and spatial variability of aerosol and water vapor is presented. In the near future, the development of synergistic and coordinated ground-based measurement techniques and algorithms is planned to provide validation products that combine different atmospheric parameters (e.g. the combination of atmospheric chemistry and aerosol profiles). Within this frame, the Neural network Aerosol Typing Algorithm based on LIdar data (NATALI, http://natali.inoe.ro/) will be applied to both lidar datasets to classify aerosols.

ACKNOWLEDGEMENTS

Part of this activity has been funded by ESA Sensor Performance, Product and Algorithms Maintenance and Operations of the Earth Observation Payload Data System (IDEAS+ Contract NO.: VEGA/AG/14/01713 with SERCO S.P.A., WP-3360).

References

[1] Casadio, S., et al., 1996: Convective characteristics of nocturnal urban boundary layer as observed with Doppler sodar and Raman lidar. Boundary-Layer Meteorol., 79, 375-391.

[2] Di Girolamo, P., et al., 2017: Characterisation of boundary layer turbulent processes by the Raman lidar BASIL in the frame of HD(CP)^2 Observational Prototype Experiment. Atmos. Chem. Phys, 17, 745-767.

[3] Congeduti, F., et al., 1999: The multiple-mirror lidar '9-eyes.' *J. Opt.*, **1A**, 185–191.

[4] Dionisi D., F. Congeduti, G.L. Liberti, F. Cardillo, 2010: Calibration of a Multichannel Water Vapor Raman Lidar through Noncollocated Operational Soundings: Optimization and Characterization of Accuracy and Variability. J. Atm. Ocean. Tech., **27**, 108–121.