CNR-IMAA experimental field for atmospheric research

Fabio Madonna, Gelsomina Pappalardo, Aldo Amodeo, Giuseppe D'Amico, Lucia Mona, Aldo Giunta, Antonella Boselli, Vincenzo Cuomo

Consiglio Nazionale delle Ricerche - Istituto di Metodologie per l'Analisi Ambientale (CNR-IMAA)
C.da S. Loja, 85050, Tito Scalo, Potenza, Italy
madonna@imaa.cnr.it

ABSTRACT

At the Istituto di Metodologie per l'Analisi Ambientale of the Italian National Research Council (CNR-IMAA) an advanced observatory for the ground-based remote sensing of the atmosphere is operative. This facility is equipped with several instruments including two multi-wavelength Raman lidars, one of which mobile, a microwave profiler, a 36 GHz cloud radar, two laser ceilometers, a sun-photometer, a GPS receiver, a surface radiation station and three radiosounding stations.
The CNR-IMAA observatory is located in Southern Italy in a location that offers the opportunity to study different kinds of weather and climate regimes. The CNR-IMAA observatory provides quality-controlled data with a special focus on the profiling of key atmospheric variables such as aerosol, clouds, temperature and humidity. Long-term measurements for aerosols and clouds climatology are the main topics of observatory and are currently performed following the EARLINET measurement protocols for lidar systems and using operational active and passive instruments.
In this work, a brief description of the equipment and the activities of the CNR-IMAA observatory is provided. Moreover, examples of the integrated measurements performed at the facility for the characterization of aerosol and clouds properties are presented as well as the scientific activities related to the exploitation of the synergy between ground based and satellite observations and to the evaluation of weather and climate models.

1. INTRODUCTION

The ground-based atmospheric observatory, operative at the CNR-IMAA, is located in Southern Italy on the Apennine mountains (40.60N, 15.72E, 760 m a.s.l.), less than 150 km from the West, South and East coasts. The site is in a valley surrounded by low mountains (<1100 m a.s.l.). The observatory operates in a typical mountain weather strongly influenced by Mediterranean atmospheric circulation, resulting in generally dry, hot summers and cold winters. In this location phenomena like orographically-induced effects on cloud formation can be studied. Moreover, the large number of dust and volcanic aerosols outbreaks [1], [2] observed each year at the facility along with the availability of simultaneous measurements of aerosol and clouds make the site optimal also for the long-term monitoring and for the investigation of aerosol-cloud interactions within a continental boundary layer. The expertise of the CNR-IMAA staff in atmospheric studies covers a large range from aerosols to clouds, from satellite validation to in-situ measurements. Currently, at the CNR-IMAA large attention is also paid to cloud monitoring and aerosol-clouds interaction study using both active and passive remote sensing techniques. In particular the acquisition of new profilers, described in the next section, has largely increased the observing capabilities in the field of clouds research.

2. EXPERIMENTAL FIELD

In the following, a detailed description of the equipment of the CNR-IMAA observatory is reported.
a) PEARL (Potenza EARlinet Lidar) multi-wavelength lidar for the retrieval of aerosol optical and microphysical properties. This system is the result of the upgrade of a pre-existent lidar system, operative since May 2000 in the frame of EARLINET - European Aerosol Research LIdar NETwork. PEARL is performing systematic measurements three times per week, in the frame of EARLINET regular operations, and additionally more than 6 times per month, both during night time and daytime, for the validation of CALIPSO mission.
b) a water vapor Raman lidar working at 355 nm, able to provide the high-resolution vertical profile of clouds, water vapor mixing ratio, aerosol extinction and backscattering coefficient.
c) a multi-wavelength lidar system for the retrieval of aerosol optical and microphysical properties. The system is transportable and it is one of the EARLINET reference systems.
d) a 1064 nm laser ceilometer for cloud base measurements (Jenoptik CHM15k) able to provide the cloud base of cloud layers up to 15 km above the ground with the possibility to investigate the optical properties of cirrus clouds.
e) a 905 nm laser ceilometer for cloud base measurements (CT25K type) able to provide the cloud base of cloud layers up to 7.5 km above the ground and information on the atmospheric optical properties.
f) MIRA36 meteorological Ka-Band cloud radar. It is a magnetron based pulsed Ka-Band Doppler radar for unattended long term observation of clouds properties. This system is able to provide high accurate measurements the reflectivity factor with a vertical resolution up to 15 m. The system is also equipped with a 3D scanning unit.
g) A microwave profiler (MP3014 type) for temperature water vapor and cloud profiling in the troposphere. The system is able to perform a 3D scanning of the sky and is equipped with a special system for the mitigation of rain effects.
h) CIMEL CE-318 sun photometer for measuring atmospheric aerosol columnar properties. operative within AERONET. It is able to provide the aerosol optical depth (AOD) at 340, 378, 440, 500, 613, 870, 940, 1020 and 1640 nm, along with the water vapor column content and the retreival of the microphysical aerosol properties.
i) An infrared thermometer (IRT) for measuring the zenith sky brightness temperature (Tb) within the spectral range of 9.6 to 11.5 microns. It provides useful information about the cloud base temperature,

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l) A surface radiation station equipped with high class broadband radiometers to monitor Earth's radiation field at the Earth's surface. The station includes a pyranometer and a pyrgeometer for measuring the global and diffuse solar radiation and longwave downwelling radiation, and two pyreliometers for direct solar radiation measurements.
m) Two manual radiosounding/ozonesounding stations, equipped with GPS receiver for wind measurements
n) an automatic radiosounding station able to perform up to 24 radiosoundings automatically and remotely controlled.
o) Surface meteorological sensors for measuring temperature, pressure, relative humidity, wind, visibility and rain with an high temporal resolution.
Measurements of the integrated water vapor from GPS will be implemented in the next future.

3. INTEGRATED OBSERVATIONS

In this section, examples of the measurements performed at the CNR-IMAA experimental field for atmospheric research for the characterization of aerosol and clouds properties are reported.

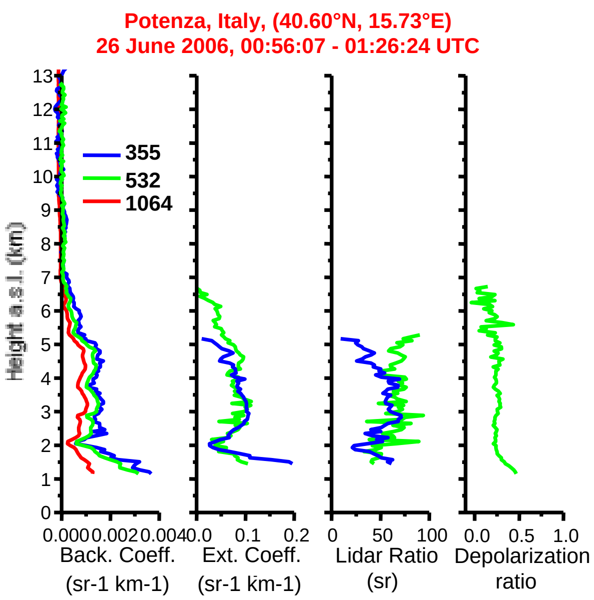

Figure 1. *Saharan dust outbreak occurred over the Mediterranean basin measured over Potenza on 26 June 2006. Shown are profiles of the particle backscatter coefficients (blue = 355nm, green = 532 nm, red = 1064), the extinction coefficients, the lidar ratios and the linear depolarization ratio.*

Large attention is paid at the CNR-IMAA observatory to the aerosol study. Aerosol optical properties are well characterised by the multiwavelength Raman lidar observations that also allows to retrieve the aerosol microphysical properties. Advances in multi-wavelength Raman aerosol lidar techniques have been also demonstrated to be the unique technique able of providing range-resolved aerosol microphysical properties[3], [4]. In figure 1, an example of advanced multi-wavelength Raman aerosol lidar measurements relative the observation of Saharan dust outbreak occurred over the Mediterranean basin is reported. Raman lidar allows for direct measurements of the particle lidar ratio because extinction and backscattering coefficient are independently determined; particle types can be roughly distinguished from the lidar ratio at one wavelength. In addition, the particle depolarization ratio allow us to strongly improve the identification of the different aerosol types.
Moreover, the integration of advanced Raman lidar measurements and sun photometer measurements is essential for an improved characterization of particles, in particular of non-spherical dust particles whose retrieval of microphysical properties represent an extreme challenge.
Automated sun photometer data, provided automatically by the sun photometer, as a product of AERONET network, can also be used for internal check when contemporary aerosol extinction profiles are obtained with Raman (or high spectral resolution) lidar.
The development of special techniques able to integrate measurements provided by different ground-based profilers is a powerful solution for the achievement of a synergic analysis of the atmospheric variables and to provide continuous high-resolution measurements. In the last years, many techniques have been elaborated to improve the atmospheric ground-based profiling combining data provided by different sensors. In particular, Raman lidar and microwave techniques are two of the most powerful approaches to study the atmospheric water vapor and their synergy shows special potentialities. Each technique has strengths and weaknesses: nevertheless lidar and microwave looks complementary[5].
An algorithm for the integration of lidar and microwave measurements based on the use of the Kalman filter is currently used for improving the water vapor capability in nearly all weather conditions.
The algorithm[6] integrates the lidar water vapor mixing ratio profiles and the microwave brightness temperatures, plus the infrared temperature provided by the IRT. The Kalman retrieval has been applied to the database from February 2004 to May 2005, the most interesting cases of which are related to the presence of clouds or to lidar daytime measurements. These situations are representative of lidar data unable to cover the full troposphere, because of the cloud or solar background influence. To show the performances of the algorithm, it has been selected a case study (26-27/02/2006) relative to night-time measurement with an high variability in the water vapor field and cloud base height. The lidar measurements for the selected case study, shown in figure 2, have a vertical resolution of 15 m and a temporal resolution of 10 minutes: they provide a fine description of the water vapor field, penetrating the cloud above its base. Unfortunately, the extinction due to the clouds does not allow to profile the clouds up to the top and cover the full range up to 10 km. The integration of lidar and microwave observations allow to provide an estimation of the water vapor mixing ratio profile up to 10 km above the station and to better define the cloud structure up to the top. Though the description of the water vapor field is coarser with respect to the lidar vertical resolution, the Kalman algorithm provides an operational product that allows to overrun possible limitations in the Raman lidar measurements and to provide reliable estimation of the tropospheric water vapor field. A final merging of the profiles retrieved using the Kalman integration with the lidar data can also preserve the high-resolution of the measurements performed with the lidar up to a maximum level where measurement accuracy is below an established threshold.

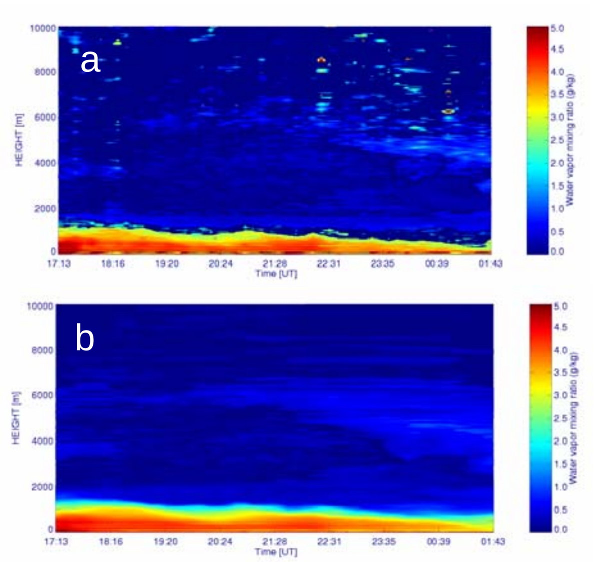

Figure 2. *Time series of the water vapor mixing ratio profile as measured by the water vapor Raman lidar operational at the CNR-IMAA on the 26-27/02/2006 (a); time series of the water vapor mixing ratio profile obtained using the integration algorithm based on the Kalman filtering algorithm (b).*

Further example of integrated measurements are related to the use of the retrieval of the cloud base height from the elastic/Raman lidar observations to improve the retrieval of the LWC obtained by applying a neural network retrieval to the microwave brightness temperatures. This integration has shown to enhance the sensitivity of the neural retrieval in particular in the detection of supercooled layers inside cirrus clouds, that are extremely important both for climate and weather studies[9]. This combination allows to optimize the product to use for the assimilation and the validation of weather models.

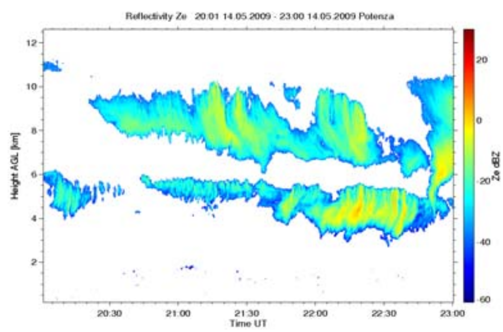

Figure 3. Time series of reflectivity factor measured by the CNR-IMAA MIRA-36 cloud radar on the 14/05/2009 from 20:00 to 23:00 UTC.

It is currently under evaluation the impact on the estimation of the melting layer retrieved by the cloud radar of the temperature profile retrieved by the microwave profiler, instead of the use of a standard atmosphere calibrated on the surface meteorological data. An example of the reflectivity factor measured by the CNR-IMAA cloud radar is reported in figure 3. Moreover, the use of forward models combining lidar, microwave and infrared radiometer data are under development with the objective to improve the retrieval of the liquid and ice water paths as well as of the water vapor integrated content.

4. SATELLITE VALIDATION

Along with the long expertise gained in lidar remote sensing and more recently also in using passive techniques, the CNR-IMAA also coordinates scientific activities related to the definition of suitable strategy for the satellite CAL/VAL as well as for the evaluation of the parameterization of numerical mesoscale models.
The satellite validation activities are both related to the direct validation of satellite observations (MIPAS, AQUA, MODIS) and to the definition of suitable strategies for using data from ground based lidar network, such as EARLINET, to support the fully exploitation of the information from present and future satellite missions (CALIPSO, ADM-Aeolus, EarthCARE) [7], [8].

In particular, the CNR-IMAA participates in an integrated study of CALIPSO and EARLINET correlative measurements. This study opens new possibilities for spatial (both horizontal and vertical) and temporal representativeness investigation of polar-orbit satellite measurements also in terms of revisit time. Since April 2008, the European Space Agency supports the EARLINET-CALIPSO correlative measurements program, with two main goals: providing conversion factors in dependence of aerosol and cloud type, and investigating representativeness of CALIPSO data in describing aerosol and cloud fields through correlation analysis with EARLINET measurements. Moreover, this investigation is contributing to the establishment of a statistical database for providing conversion factors for comparing present and future satellite mission and for investigating the representativeness of CALIPSO observations.

5. MODEL EVALUATION

Aerosol, water vapour and clouds play a vital role in weather and climate. Difficulties over their representation within numerical models are responsible for much of the uncertainty of future global warming. Therefore, there is a strong need for evaluating model capabilities to reproduce the behaviour of these key parameters in the atmosphere.

The CNR-IMAA observatory is working on the evaluation of aerosol models, such as the DREAM (Dust REgional Atmospheric Model) dust forecast model. In this context, the CNR-IMAA is performing first systematic quantitative comparisons with the have been carried out for selected stations with large number of dust observations. In the next future, the use of all EARLINET data for aerosol models evaluation is foreseen.

A strong interest is also related to the water vapor because of its high variability that makes necessary a long-term comparison between accurate and high resolution observations and operational forecast models. The EU CloudNET project offers an extended database of water vapor profiles provided by four operational forecast models of ECMWF, the MetOffice, MeteoFrance and KNMI. On the other hand, at CNR-IMAA accurate vertical profiles of water vapor mixing ratio are provided with very high resolution in a systematic way since May 2002[10].

A direct comparison between lidar and model data is provided in figure 4 where are reported the time series of the WVMR profiles measured with the Raman lidar and obtained from the analysis of the Met Office Global model relative to the case of a stratospheric intrusion observed over Potenza in the period from 1 October at 16:25 UTC to 3 October 2005 at 01:34 UTC. The white stripe in the lidar measurements indicates a time window where no lidar measurements are available because of a temporary technical problem.

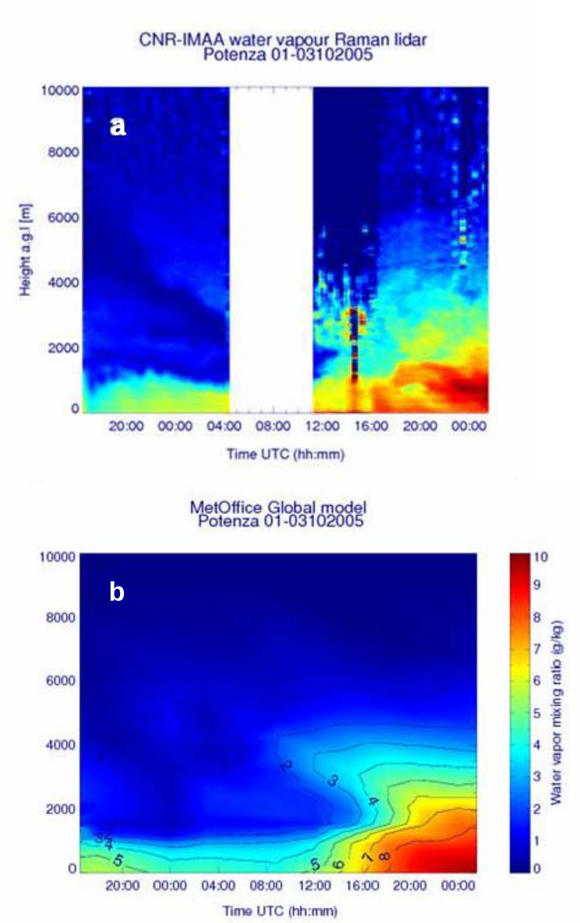

Figure 4. *Comparison of the time series of the vertical profile of the water vapour mixing ratio as measured by the CNR-IMAA water vapor Raman lidar (a) and as retrieved by the MetOffice Global model (b) on the period from 1 October at 16:25 UTC to 3 October 2005 at 01:34 UTC*

The application to the approach described above this case study shows that, even though the models do not capture details in the evolution of water vapor fields, a good agreement is found in term of vertical structure and water vapor content. A study for evaluating the capability of the model to capture mean aspects of the water vapor field as well as the possible discrepancies between observations and models is still in progress.

6. CONCLUSIONS AND OUTLOOK

This paper shows the increased observing capabilities achievable by performing integrated measurement using active and passive sensors. This allows us to provide a continuous high-resolution description of the atmospheric key variables. The database collected with the systematic measurements carried out at the CNR-IMAA observatory represents the ideal basis to study the synergy between different sensor and to use the integration approaches for the long-term monitoring and the study aerosol-clouds-radiation interactions.

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