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Implementation of High Dynamic Raman Lidar System for 3D Map of Particulate Optical Properties and Their Time Evolution

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Abstract

Fast scanning lidar system can provide aerosol volume distribution and time evolution in atmosphere. Usually fast scanning lidar has a relative simple configuration. Multi-wavelength depolarization and Raman measurements gave us more information about the particulate shape, type and dimension. The most Raman lidars use high power laser source in order to get enough Raman scattering signal. One of a challenge for Raman lidar system is to have enough dynamic range to satisfy the measurements both for pure molecule Rayleigh scattering and high dene aerosol, such as dust storm, volcano emitted aerosol and high polluted urban aerosol. The estimation of microphysical properties requires independent measurements of both backscatter and extinction coefficient at several wavelengths (multi-wavelength Raman lidar). Additional information can be retrieved from simultaneous measurements of the depolarization signal and water vapor mixing ratio, since those measurements are particularly useful to correlate aerosol optical properties with their shape and hygroscopicity.

A multi-wavelength depolarization and Raman lidar system has been designed to perform volume scanning of the atmosphere and to retrieve high quality 3D map of particulate optical properties and their time evolution. This system is equipped with a doubled and tripled Nd:YAG diode-pumped laser that is specifically designed for this device, with a repetition rate of 1KHz and average optical power of 0.6W at 355nm, 1.5W at 532nm and 1W at 1064nm. The relative high repetition rate laser source can increase the detectable signal dynamic range. The receiving system is based on a 25cm modified Cassegrain telescope. The spectral selection of the backscatter elastic and Raman signals is made through a system of dichroic beam splitters and narrow band (0.5 nm) interferential filters. Fast single photon counting photomultipliers are used to collect the selected radiation. Each detected signal is acquired by multi-channel scalers with a raw spatial resolution varying from 30cm to 30m. Moreover, polarization purity of laser line allows to perform polarization measurements at both 355 and 532nm. This device is installed in the Beijing city area, which is strongly affected from anthropogenic pollution and sand dust from Gobi desert.

Keywords

Aerosol; Particulate; 3D scanning map;Lidar

Introduction

Atmospheric aerosols, which originate both from natural sources and from human intervention, considerably affect the Earth's radiation balance, and they are considered to be one of the major sources of uncertainty in climate forcing predictions. In addition, the natural and anthropic aerosoloutbreak events in atmosphere affect strongly the human daily life and their health.

The lidar technique is one of the most important remote sensing methods in atmospheric aerosol, particulate studies. The compact elastic backscattering, micropulse lidar is suitable for mobile system but it can only provide the aerosol, particulate qualitative profile distribution. The sophisticated Raman lidar can quantitatively measure the aerosol optical parameters and hence, with multiwavelength, can evaluate the particulate microphysics properties. While, the high powered multiwavelength Raman lidar usually is fixed and is not suitable for particulate 3D mapping measurements. Furthermore, one of the main drawback of ground-based lidar is the limitation of signal dynamic. This is more serious for the volcanic eruption plume and East Asia dust storm events.

A new, versatile prototype of polarization, Raman scanning lidar system (named AMPLE - Aerosol Multi-wavelength Polarization LIDAR Experiment) has been designed and implemented at Beijing and Napoli Research Unit of CNISM. AMPLE is a project of the scientific co-operation between CNISM and the Beijing Research Institute of Telemetry and represents the first action of the recently founded Italy-China Laser Remote Sensing Joint Research Center, involving the Universities of Napoli, Pavia, L'Aquila, and Politecnico di Milano, and two spin-off companies: Advanced LIDAR Applications, s.r.l. and Bright Solutions, s.r.l.

AMPLE Description

A high repetition rate Nd:YAG laser was used in order to reduce the lidar signal dynamic range. It is crucial for high dense aerosol measurement, such as volcanic ash and heavy dust storm events. Two wavelength (355 nm, 532 nm) depolarization measurements can give more information about the particle shapedistinguishing. Multiwavelength channel (1064 nm, 532 nm, and 355 nm)are fundamental for the particle dimension evaluation. Raman capability is essential for quantity measurement of aerosol optical parameters. A compact and fast 2 axis scanning mechanic support was designed and implemented in order to achieve3D mapping measurements.

AMPLE lidar system is compact and suitable for mobile measurements.

FIG. 1 AMPLE lidar system illustration

AMPLE specification:

Laser source:

- Diode pumped Nd:YAG
- Fundamental (1064 nm), 2nd (532 nm) and 3th (355 nm) harmonics
- Pulse rep.rate: 1000 Hz
- Output power: 0.6 W @ 355nm; 1.5 W @ 532nm; 1 W @ 1064nm
- Pulse width ~ 1 ns
- Linear polarization > 100:1

Receiver system:

- Elastic channels @ 355nm, 532nm and 1064nm
- Raman channels @ 386nm (N_2), 407nm (H_2O) and 607nm (N_2)
- Depolarization @ 355nm and 532nm

Telescope: 20 cm Cassegrain; Field of View: 1 mrad

Scanning system:

- Elevation range: from -10°to 100°;
- Azimuth range: from -110°to 110°;
- Scanning speed: 20°/smax;
- Scanning angle error: < 0.2°

Total Weight < 100 kg

Power consumption < 700 W

Output:

- Aerosol backscattering coefficient @ 355nm, 532nm and 1064nm (day and night);
- Aerosol extinction coefficient @ 355nm, 532nm (night);
- Aerosol depolarization ratio @ 355nm and 532nm (day and night);
- Water vapor mixing ratio (night);
- Spatial resolution: 15m (raw), 60-180m (final);
- Temporal resolution: 2s (raw), 1-30 min (final)

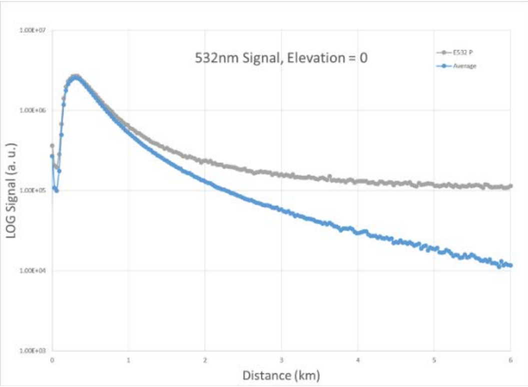
Calibration and Test

Two AMPLE lidar systems were implemented, calibrated, and tested together with the lidar system in Napoli EARLINET lidar station (Matthais et al. 2004).

Overlap Function Determination

One of the major uncertainty of lidar measurement for troposphere aerosol is the overlap function determination. It is crucial for the urban area aerosol, PM10 and PM2.5 measurements.

One of easy way to determinate the overlap function is to do a horizontal measurement under the atmosphere horizontal homogeneous condition. Fig.2 is an example of horizontal measurement result.



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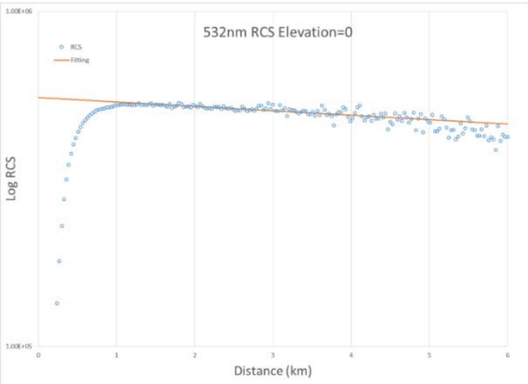

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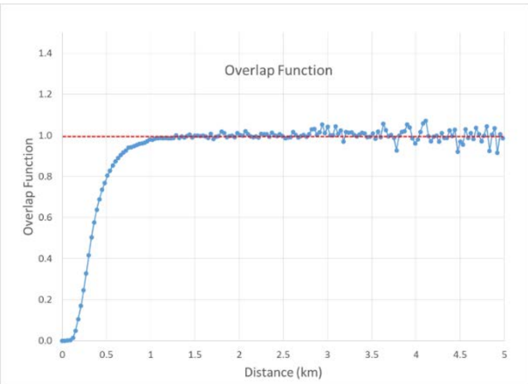


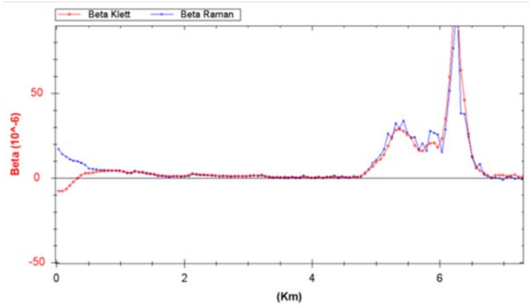
(c)

FIG. 2Overlap function determination. (a) Horizontal measurement lidar signal; (b) Measured range corrected signal compared with the ideal horizontal homogeneous condition; (c) Evaluated overlap function

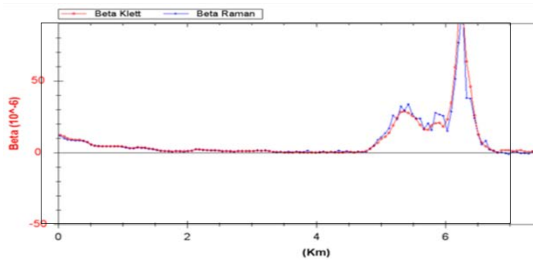
Under the ideal atmosphere horizontal homogeneous condition, lidar signal variation depends only on lidar system overlay function and distance. It will remain unchanged on atmosphere aerosol backscattering and extinction because they are constant. If the ideal condition is not met, the averaged profile of several measurements can be used.

Another practical way to evaluate the overlap function is to compare the aerosol backscattering retrieved from only elastic signal (Klett 1985) and from both elastic and Raman (Ansmann 1992) measurements (Wandinger and Ansmann 2002).

In fact, overlap function affects directly the backscattering coefficient retrieved by Klett method. While, for Raman method, backscattering coefficient is retrieved from the ratio of elastic and Raman signals. The overlap function affects much less on backscattering coefficient result. By comparing this two results, an iterative procedure can be used for overlap function evaluation.



(a)



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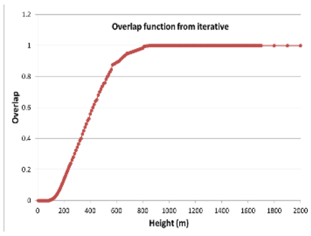

(c)

FIG. 3Iterative determination of the lidar overlap profile with Raman lidar. (a) Backscattering coefficient before iterative; (b) Backscattering coefficient after5 times iterative; (c) Evaluated overlap function

Fig. 3 gives an example of iterative determination of the lidar overlap profile with Raman lidar.

Depolarization Calibration

The measurement of depolarization of the backscattered return, allows us to discriminate of aerosol shape and the identification of the presence of non-spherical particulate. There are several papers suggesting different method for depolarization calibration (Sassen 1991; Freudenthaler 2009; Zhao 2013). AMPLE lidar system use depolarizer plate plus molecule calibration.

Water Vapor Mixing Ratio Calibration

The water vapor Raman channel (407 nm) of AMPLE allow us to measure the water vapor mixing ratio in atmosphere. The calibration was done by comparing the lidar measurement with the radio sounder at the same place in the same time interval, shown in Fig. 4.

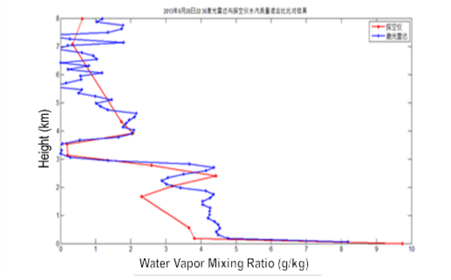

FIG. 4. Water vapor mixing ratio calibration

Preliminary Test Results

A second unit of AMPLE lidar system has been realized for the National Institute for Geophysics and Volcanology (section of Catania) to be installed on the slope of Mt. Etna. This second system is configured as polarized scanning lidar. It will allow to monitor the ash emission during Mt. Etna explosive activity so that the plume mapping and the estimated particulate mass concentrations will be retrieved. An example of depolarization measurement in Mt. Etna area is shown in Fig. 5.

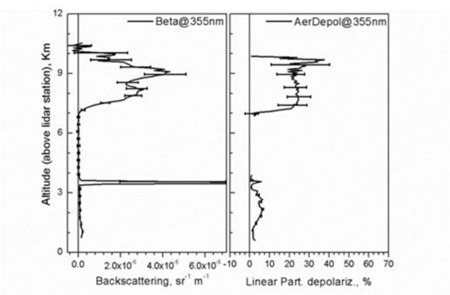

FIG. 5. An example of depolarization measurement in Mt. Etna area

Conclusions

A new, versatile prototype of polarization, Raman scanning lidar system (named AMPLE - Aerosol Multi-wavelength Polarization LIDAR Experiment) has been designed and implemented.

Special, unusual design allow it to preform Raman measurements for high dense aerosol load thanks its high dynamic signal range.

Preliminary results show that AMPLE lidar system is suitable to quantity monitoring and 3D mapping for high polluted unban aerosol and volcanic ash plume.

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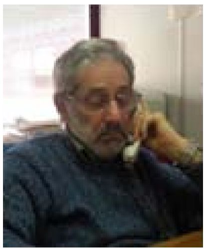
Yiming Zhao was born in Taiyuan, China, in 1983. She received the B.S. degree in electrical science & technology from Shanxi University in 2004, and Ph.D. degree in physical electronics from Beijing University of Aeronautics and Astronautics in 2009. She is currently a senior engineer at Beijing Research Institute for Telemetry (BRIT). Her main research interests are in the field of application of laser technology, include development of laser radar, atmospheric and ocean environmental monitoring.



Nicola Spinelli was born in 1947, he received the Laurea degree in physics from the University of Rome in 1971. From 1971 to 1974 he was postgraduate fellow at the Istituto di Fisica Sperimentale University of Naples. From 1974 until 1982 Assistant of General Physics and teacher on annual contract of experimental physics From 1982 to 1994 he was associate professor of General Physics and from 1994 he has been full professor of Experimental Physics at University of Basilicata and then at University of Naples "Federico II. He has been member of the scientific committees of several Italian institutions and president of the National Interuniversity Consortium for the Physical Sciences of Matter.

He has been active on atomic and molecular physics: electron collision induced ionisation-dissociation of molecules, mass spectroscopy, translational spectroscopy and multiphoton ionisation spectroscopy. Its work has been dealing with the experimental characterisation and modelling of plasma produced by laser ablation of metallic and superconductive targets. Mass spectrometry and electron spectroscopy have been applied to the study of charged species and of their evolution in the laser generated plume and combustion generated particles. His main research interests regard the environmental applications of laser spectroscopy and remote sensing of the atmosphere by active optical methods. He was responsible of the development of several lidar apparatuses using different spectral regions (UV, VIS and NIR) and techniques (Elastic scattering, Raman scattering and Differential absorption).

AntonellaBoselliwas born in Naples, Italy, on 1966. She received the Laurea degree in physics from the at University of Naples "FedericoII" on 1994. She is permanent researcher at the Institute of Methodologies for Environmental Analysis (IMAA) of the National Research Council since December 2001.

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Xuan Wangwas born in Kaifeng, Henan, China in 1962. He received his B.S. and M.S. degree in Physics, in 1984 and 1987, respectively, from Nankai University, China. In 2001, he got his Ph.D in Physics from University of Naples "Federico II", Napoli, Italy. Currently, he is permanent researcher in Italian National Research Council (CNR) – SPIN Institute.

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