International Journal of Remote Sensing Applications Volume 3 Issue 4, December 2013 www.ijrsa.org
doi: 10.14355/ijrsa.2013.0304.11

Monitoring of Atmospheric Particles in Beijing and Dunhuang Using a Raman Lidar with Enhanced Dynamics

Pan Chao[1], Yiming Zhao[1,], Chen Lin[2] ,Yang Xiaoyu[1], Shang Yanan[1], Liu Bo[1], Wang Lidong[1],
Antonella Boselli*[3,4], Gianluca Pisani[3,5], Nicola Spinelli[3,5], Xuan Wang[3,6];

[1]China-Italy Laser Remote Sensing Joint Research Center – Beijing Research Institute for Telemetry, Beijing, P.R. China;

[2]National Satellite Meteorology Center, Beijing, P.R. China;

[3]China-Italy Laser Remote Sensing Joint Research Center – CNISM, Napoli, Italy;

[4]CNR-IMAA, Potenza, Italy;

[5]Dipartimento di Fisica, Università di Napoli "Federico II", Napoli, Italy;

[6]CNR-SPIN, Napoli, Italy;
[1]zym_bird@hotmail.com; [2]chenlin@cma.gov.cn, [3,4]boselli@imaa.cnr.it; [3,5]pisani@na.infn.it; [3,5]spinelli@na.infn.it; [3,6]wang@na.infn.it

Abstract

In high urbanized areas, the atmospheric particulate matter concentration (the so called PM) can exceeds the healthy limit values. Human activities, such as the burning of fossil fuels, industrial activities, and ground transport contribute to measured PM exceedance. Natural contribution is originated mainly from dust storms and volcanic eruptions. The Gobi desert, for instance, is the major source of mineral dust in China, that is one of the most interesting regions for aerosol study being surrounded by the main sources of anthropogenic and natural aerosol. On the base of the above considerations, the need of a new advanced scanning lidar system raised in order to better understand the formation, emission and diffusion of particulate from natural and anthropic sources and to evaluate their relative contribution, to characterize the chemical and physical properties of atmospheric aerosols, their spatial and temporal distribution and the main transport mechanisms.

To this aim, a new, versatile and portable Raman scanning lidar system has been designed and developed in the frame of the AMPLE (Aerosol Multi-wavelength Polarization Lidar Experiment) project, the first action of the recently founded China-Italy Laser Remote Sensing Joint Research Center between the National Consortium of Italian Universities for the Physical Science of the Matter (CNISM) and the Beijing Research Institute for Telemetry (BRIT).

The AMPLE lidar device has been installed at the Beijing Research Institute for Telemetry in the Beijing city area, which is strongly affected from anthropogenic pollution and sand dust from Gobi desert in order to carry out 4-D (space and time) imaging of the atmospheric aerosol distributions, their optical properties, and microphysical characterization.

A first demonstrative measurement campaign has been performed on May 2013 in Beijing, while on August 2013 AMPLE has been carried in Dunhuang close to the Gobi desert and far away from the urban area, in order to study sand dust directly at source. Results of those measurements are described in this paper.

Keywords

Lidar; Aerosol ; Gobi Desert

Introduction

In the last years, the increasing urbanization and industrialization of the Asia region made China as one of the countries more affected by atmospheric anthropogenic particles. Moreover, the Gobi desert extending from the north of the China to the south of Mongolia, acts as a natural source of dust aerosol in this area. Thus, the combination of both anthropogenic and mineral aerosol strongly influence the air quality, particularly affecting the lower troposphere. Hence, a detailed characterization of atmospheric aerosol, including dust aerosol, needs in order to improve the effectiveness of the solutions to be carried out by environmental agencies.

Dust storm monitoring is actually a binding request in the analysis of regional and global environmental changes (D. Jugder et al., 2012), and the study of the Asian dust aerosol directly at source is an essential pass, because sand dust is espected to change its optical and microphysical properties, as well as their direct and indirect radiative forcing when mixed internally with other aerosol type (YC. Song, 2013; Z. Liu et al, 2013).

Actually, the growing interest of the scientific community is devoted to investigate the dust transport, in order to improve measurements and data set, to increase the understanding of the involved processes and to enhance dust prediction capabilities.

The present paper aims to show the results of two measurement campaign in Beijing and Dunhuang performed to study aerosol layers properties and time evolution, by using an innovative lidar apparatus developed in the frame of a collaboration between Italy and China.

The paper is organised as follows: instrumentations and methods are discussed in section 2, the study area is described in section 3. Finally, results of performed measurements are showed in section 4.

Instruments and methods

The longstandig research collaboration between CNISM and BRIT in the field of LIDAR brought to the creation of an international joint research center for laser remote sensing. In the framework of this "China-Italy Laser Remote Sensing Joint Research Center" a new lidar apparatus, AMPLE, has been designed, developed and installed in China (Beijing).

The AMPLE system has been designed to perform volume scanning of the atmosphere and to retrieve high quality 3D map of particlulate optical properties and their time evolution. The AMPLE 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. Each detected signal is acquired by multi-channel scaler 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.

The lidar apparatus is able to detect to detect both the elastic lidar returns at 355nm and 532nm, and the N_2 and H_2O Raman lidar echoes at 386nm and 407nm.

A detailed description of the lidar apparatus is reported in Y. Zhao. et al., 2013.

Optical properties of atmospheric particlesand their spatial and temporal distributions are retrieved from lidar data. Backscattering coefficient at 355nm are determined both by Raman and Klett-Fernald methods (Fernald F. G., 1984; Klett J., 1981), giving completely compatible results. At 532nm the backscattering coefficient is determined only by Klett-Fernald method by assuming a mean value of the lidar ratio of 45 in the lower aerosol layer, while for the cirrus the lidar ratio is found by taking into account that molecular signals are expected both before and after the cirrus.

The volume depolarization ratio δ_V is obtained from the ratio between measured intensities in parallel and cross-polarized elastic channels. The particle linear depolarization, δa, is determined starting from the measured scattering ratio $R = (\beta_{aer} + \beta_{mol}) / \beta_{mol}$ (Pisani et al., 2012).

Finally, water vapour mixing ratio profiles are obtained from the ratio of the two inelastic Raman backward scattered signals from nitrogen molecules at 387 nm and water vapour particles at 407 nm (Withemann D.N., 2003).

The measurement area

The East Asia region is a unique area in terms of photochemistry and aerosol loading and therefore it represents an ideal natural laboratory to characterize aerosol particles distribution and properties.

This area is recognised as the most important source of atmospheric dust aerosol whose averaged emission has been estimated of about 10^7 t d^{-1} (Y. Shen et al., 2005). In particular, Gobi desert has been considered as the primary source of dust that is drifted from the surface and than transported over distances up to thousand of kilometres.

The city of Beijing (39.55N, 116.23E) is in the path of these desert sand outbreaks, so the air quality in this city is dramatically affected by natural dust. Furthermore, Beijing's air quality is also affected by anthropogenic factors like the increasing of car ownership, the industrial activities in the neighbouring cities and biomass burning. The air over Beijing is, hence, the result of a complex mixture of these natural and anthropogenic particles. Theresore, when natural dust and anthropic polluted aerosol are mixed together the result can be a thick haze mixture that appears like fog.

In August 2013 AMPLE has been carried in Dunhuang closeness the Gobi desert (40.8N, 94.4E), in the north-west part of the China, to perform a demonstrative measurement campaign. Due to its special location and good infrastructure, Dunhuang has been established as one of the super-sites for many international aerosol field experiments (Xia et al., 2004).

The measurement area is located in a semi-arid region, rounded by high mountains and desert area with a very dry climate with lots of direct sunshine and with very little precipitation.

Because of the combination of the earth's surface condition, as well as its dry and windy climate Dunhuang frequently feel the effect of dust storms, especially in spring and summer (Zhou, 2001).

Ours aim was to study the aerosol properties directly at source in order to analyse dust optical and microphysical properties during the first stage of the aerosol motion and without modification due to mixing with other aerosol types.

As Fig.1 reports, measurement area is very close to the Gobi Desert and far away from the urban area, therefore lidar measurements allowed us to capture local natural particles didn't taking into account the contribution of sources of aerosol coming from human activities.

FIG. 1 GOOGLE MAPS OF THE AREA SURROUNDING THE OBSERVATIONAL SITE (RED MARKER)

Results

The first explorative measurement campaign was performed in Beijing on 13-14 May, 2013 with the aim to characterize the aerosol distribution and properties above the city.

Lidar measurements were performed between 12:09 UT of 2013/05/13 to 24:09 UT of 2013/05/14. Features as low altitude stratifications and cirrus cloud are clearly detailed in the colour maps of Fig. 2, showing the aerosol linear depolarization profiles. Temporal variations of aerosol vertical distribution were also observed during the measurements.

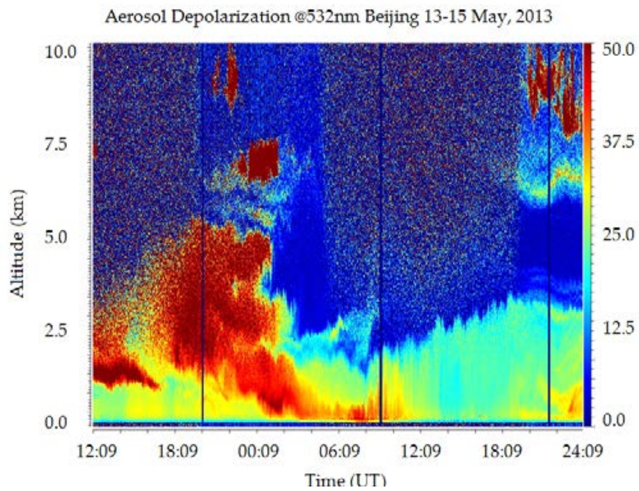


FIG. 2 COLOUR PLOT OF LIDAR PROFILES OF LINEAR PARTICLE DEPOLARIZATION FOR MEASUREMENTS PERFORMED ON 13-14 MAY 2013

Lidar measured profiles highlighted a very high aerosol load over the Beijing area at lower altitude and up to 5km. The mixing of dust presence in the atmosphere is highlighted by the high values of the linear volume depolarization ratio in the colour plot of fig.2. Clouds are also visible in the range between 7 and 10 kilometers.

Reported measurements have a spatial resolution of 15m and a temporal resolution of 60sec.

A second lidar measurement campaign was performed in Dunhuang on 19-20 August, 2013 during a dust storm event in the Gobi Desert.

The height of the dust layer is captured in the depolarization ratio profile as shown in Fig. 3, indicating as the dust particles were transported from the surface and confined below 4 km of altitude.

A very interesting feature develops around 22:00 and it is spectacularly visible in the depolarization map. It consists in an evident dynamical effects of rising of mineral particles from the soil giving rise to a stable layer at about 1.5km of altitude. Simultaneously a vertical oscillation of this "plume" and of the upper bound of the upper layer take places. A detailed analysis of this phenomenon must take into account meteorological data (wind , pressure, temperature) as well as data on the site and it is still in progress.

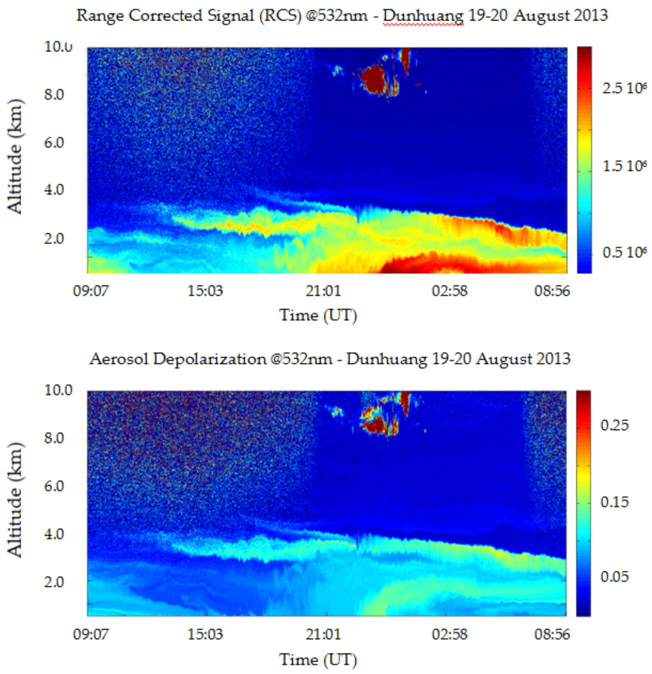


FIG. 3 COLOUR PLOT OF LIDAR PROFILES OF RANGE CORRECTED SIGNAL (RCS) AND LINEAR PARTICLE DEPOLARIZATION MEASURED ON 19-20 AUGUST 2013.

A preliminary quantitative analysis of the data relative to the time interval between 22:00 of 08/19 to 01:40 of 08/20 was performed. To this aim, and in order to reduce statistical errors, a time resolution of 10min was selected. Of course this resolution do not allow to analyze in detail the oscillation.

Maps of backscattering coefficient and aerosol linear depolarization ratio for the boundary layer and for the cirrus are reported in the Fig. 4.

Backscattering coefficient and aerosol depolarization ratio at 355nm and 532nm resulted very close each other for cirrus, as expected from large particles, but they resulted considerably different for low altitude layers, as a function of the different physical-chemical properties of particles in these layers.

We determined also the un-calibrated water vapour mixing ratio that is reported in the map of Fig. 5, where the presence of a stable moist layer extending up to 4km, with a maximum at around 3km is visible. Therefore, physical property of particles in this layer can strongly influenced by this.

From the Raman analysis, also the behaviour of the lidar ratio has been determined for the two layers 2.0-2.8km and 2.8-5.5km. These two altitude ranges have been chosen on the basis of the fact that the backscattering vertical profiles show the existence of two main internal feature of the layer. The LR of Fig. 6 clearly shows that the two layers have a different nature, being characterized by a lower value of LR at higher quotes where there is the maximum of the mixing ratio.

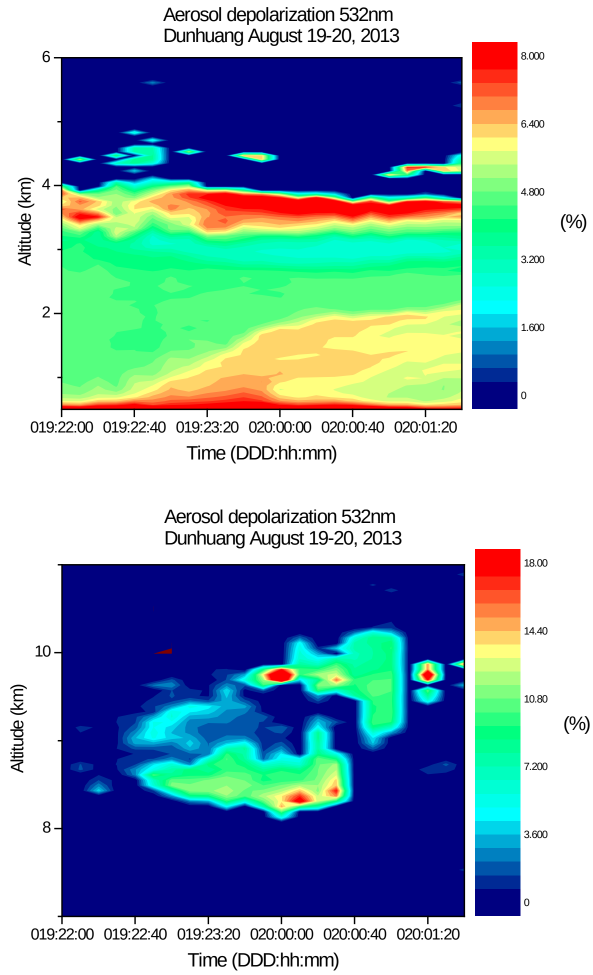


FIG. 4 COLOUR PLOT OF AEROSOL DEPOLARIZATION RATIO AT 532NM IN DIFFERENT ATMOSPHERIC RANGES (2-6 KM AND 7-11 KM) MEASURED ON 19-20 AUGUST 2013

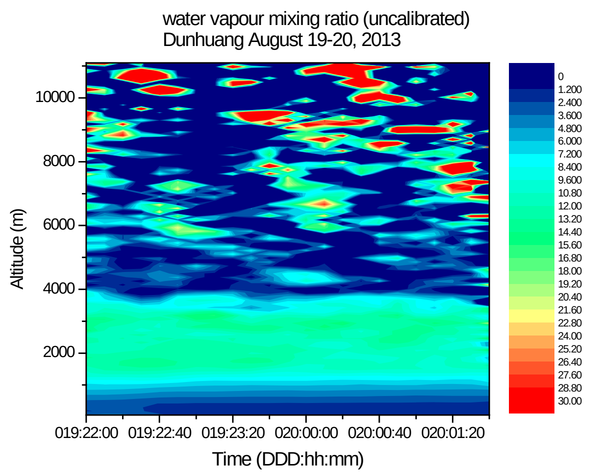


FIG. 5 WATER VAPOUR MIXING RATIO COLOUR MAPS FOR MEASUREMENTS PERFORMED ON 19-20 AUGUST 2013

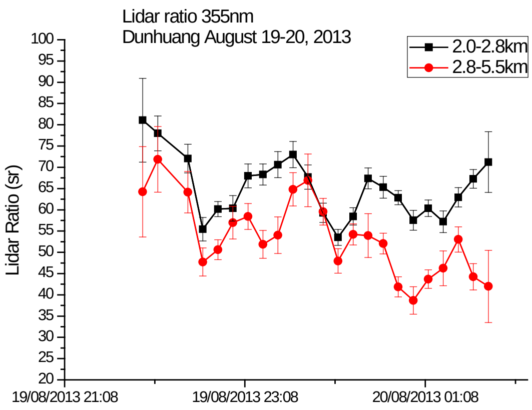


FIG. 6 LIDAR RATIO VALUES CORRESPONDING TO DIFFERENT ATMOSPHERIC RANGE 2.0-2.8KM AND 2.8-5.5KM, FOR MEASUREMENTS PERFORMED ON 19-20 AUGUST 2013

Conclusions

A new, versatile and portable multiwavelengts Elastic/Raman lidar system has been designed and developed in the frame of the AMPLE (Aerosol Multi-wavelength Polarization Lidar Experiment) project, the first action of the recently founded China-Italy Laser Remote Sensing Joint Research Center between the National Consortium of Italian Universities for the Physical Science of the Matter (CNISM) and the Beijing Research Institute for Telemetry (BRIT).

Lidar measurements were performed in two key locations of the China: Beijing city and close to Gobi desert. Geometrical and optical properties of detected aerosol layers were analised discriminating different nature of the particles. Depolarization profiles allowed us to distinguish dust particles and cloud in the observed layers. The mean optical properties of the aerosol layers and their variability with height were studied.

A very interesting feature was captured by long time lidar measurements performed close to the Gobi desert. It consists in an evident dynamical effect of rising of mineral particles from the soil giving rise to a stable layer at about 1.5km of altitude. Physical property of particles in this layer resulted strongly influenced by water vapour mixing ratio values and differs from particles contained at higher altitude, according to measured lidar ratio values.

REFERENCES

Ansmann A., U. Wandinger. Combined Raman Elastic Backscatter LIDAR for vertical profiling of moisture, aerosol extinction, backscatter and lidar ratio. Appl. Phys.B, 55,18-28, 1992.

Fernald F. G., Analysis of atmospheric lidar observations: some comments. Appl. Opt., vol. 23, No. 5, 1984.

Jugder Dulam, Nobuo Sugimoto, Masato Shinoda, Reiji Kimura, Ichiro Matsu, Masataka Nishikawa, Dust, biomass burning smoke, and anthropogenic aerosol detected by polarization-sensitive Mie lidar measurements in Mongolia Atmospheric Environment Volume 54, July 2012, Pages 231–241.

Klett J. Stable analytic inversion solution for processing lidar returns. Appl. Opt., vol. 20, No.2, 1981.

Liu Z. et al. / Journal of Quantitative Spectroscopy & Radiative Transfer 116 (2013) 24–33.

Pisani G., A. Boselli, M. Coltelli, G. Leto, G. Pica, S. Scollo, N. Spinelli, and X. Wang Lidar depolarization measurement of fresh volcanic ash from Mt. Etna, Italy", Atmospheric Environment 62, 34-40, 2012.

Shen YB., Shen, ZB. Du, MY., Wang WF., Dust emission over different land surface in the arid region of northwest China, Journal of the Meteorological Society of Japan Volume: 83 Issue: 6 Pages: 935-942 DOI: 10.2151/jmsj.83.935.

Song YC, Eom HJ, Jung HJ, Malek MA, Kim HK, Ro CU. Observations of chemical modification of Asian dust particles during long-range transport by the combined use of quantitative ED-EPMA and ATR FT-IR imaging. Atmos Chem Phys Discuss 2012;12:27297–331.

Whiteman, D.N. (2003), Examination of the traditional Raman lidar technique. II. Evaluating the ratios for water vapor and aerosols, Appl. Optics 42, 15, 2593-2608, DOI: 10.1364/AO.42.002593.

Xia Xiangao, Chen Hongbin, Wang Pucai, Aerosol properties in a Chinese semiarid regionAtmospheric Environment 38 (2004) 4571–4581.

Zhao Yiming, Yong Yu, Lianghai Li, Yanhua Li, Antonella Boselli, Giuseppe Passeggio, Gianluca Pisani, Nicola Spinelli, Xuan Wang, Implementation of High Dynamic Raman Lidar System for 3D Map of Particulate Optical Properties and Their Time Evolution, International Conference on Mapping and Remote Sensing (ICMRS 2013) 13-15 December, 2013, Sanya, Hainan, China.2013.

Nicola Spinelli was born in 1947, hee 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).

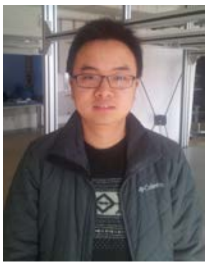
Antonella Boselli was born in Naples, Italy, on 1966. She received the Laurea degree in physics from the university of Naples "FedericoII" on 1994. She is permanent researcher at the Institute of Methodologies for Environmental Analysis (IMAA) of the National Research Council since December 2001.

Her main research interests are in the field of chemical and physical characterization of the atmosphere with laser remote-sensing systems (LIDAR). Her research activity included optical and microphysical characterization of atmospheric aerosol also rising from large scale transport phenomena, with particular reference to Saharan dust and volcanic ash transport events, analysis of multiple scattering processes and depolarization effects on lidar signals, validation of satellite data with lidar data and their integration with model results and in-situ measurement. She was involved in developing several advanced lidar systems for research purpose.

Xuan Wang was 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.

His main scientific activity is laser application, including lidar, laser remote sening, and laser ablation.

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.



Pan Chao was born in Hubei, China, in 1981. He received the B.S. degree in Electronic Engineering (2003) and M.S. degree in Signal and Information Processing(2006) from University of Electronic Science and Technology of China(UESTC). He is currently a senior engineer at Beijing Research Institute for Telemetry (BRIT). His main research interests are in the field of application of laser technology, include development of laser radar, atmospheric and ocean environmental monitoring.