DEVELOPMENT OF THREE-WAVELENGTH POLARIZATION-RAMAN LIDAR AND APPLICATION TO SHIPBORNE MEASUREMENTS

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ABSTRACT

A Three-Wavelength Polarization-Raman Lidar (TWPRL) system for aerosol and clouds was developed. This lidar system provides α at 532 and 355 nm, β at 355, 532 and 1064 nm, and σ at 532 nm as well as water vapor content using Raman lidar techniques. The temporal and vertical variation of aerosols and clouds could be determined. We conducted shipborne TWPRL measurements over Yellow Sea of China from August to September in 2014. The derived aerosol optical properties indicate that the developed lidar system worked very well. 24-hour continuous measurements with the shipborne TWPRL during the cruise are presented.

1. INTRODUCTION

Atmospheric aerosols have many effects on global warming and cooling, through altering the radiative properties of the atmosphere ^[1]. Knowledge of the vertical structure of cloud and aerosol scattering properties or layers from varying climate regimes is fundamental to understand their role in the atmospheric processes as well as on human health and environment.

Lidar measurements of atmospheric aerosol profiles have become important for atmospheric researchers during last decades. Since 2001, The National Institute for Environmental Studies (NIES) has been constructing ground-based lidar networks with automated dual wavelength/polarization Mie-Lidar systems to observe air quality in the Asian region ^[2]. From June 2006, CALIOP (Cloud-Aerosol Lidar with Orthogonal Polarization) has been measuring global aerosol and cloud vertical distributions continuously with very high spatial resolution ^[3]. Aerosol optical and microphysical properties by ground-based sunphotometer measurements and

aerosol vertical profiles by lidar measurements, performed within AERONET^[4] and MPLNET^[5], are used to analyze aerosols effects on radiative budget and atmospheric heating rate profiles. Within the European Aerosol Lidar Research Network (EARLINET) ^[6], now part of the Aerosols, Clouds, and Trace gases Research InfraStructure Network (ACTRIS), more than 30 lidar systems were used to monitor the aerosol vertical distribution over Europe.

In addition, ships provide a mobile platform in oceans allowing the cover of large geographical regions. Single-wavelength lidars were used during field campaign like INDEOX^[7], ACE2^[8], ACE-Asia^[9]. Dual-wavelength Mie/polarization lidar measured the aerosol in the northern west Pacific region ^[10]. Kanitz et al. ^[11] deployed a multiwavelength Raman lidar (Polly^{XT}) with a polarization-sensitive receiver channel on RV Polarsten. The cruise went from Bremerhaven, Germany to Punta Arenas, Chile from 16 October 2009 to 25 November 2009.

A Three-Wavelength Polarization-Raman Lidar (TWPRL) was designed and developed in Shandong Academy of Sciences Institute of Oceanographic Instrumentation (SDIOI) for aerosol and clouds measurement. The lidar system was tested and performed aboard the research vessel Xiangyanghong No. 8 over the Yellow Sea and Jiaozhou Bay of China from 29 Aug. to 2 Sept. 2014. The data presented here give information on the vertical distribution and optical properties of the Jiaozhou Bay and Yellow Sea of China during the lidar campaign. 24-hour continuous measurements with the shipborne TWPRL during the cruise are also presented.

2. LIDAR SYSTEM

The configuration and specifications of the

TWPRL system are presented at Figure 1 and Table 1. This is a typical lidar instrument containing Nd:YAG laser as a transmitter, Schmidt-Cassegrain telescope to collect scattered laser radiation, dichroic beam splitter to split beam of light from the telescope and set of photodetectors connected to the PC computer.

The lidar is conceived to perform vertical measurements. The transmitter emits laser pulses at 355, 532, and 1064 nm with a repetition rate of 20 Hz. All three laser beams are aligned on two optical axes: one is the 355 nm channel; another one is the 532 and 1064 nm channel. The outgoing laser beams are expanded by a 5 X beam expander to reduce the divergence angle, and then directed into the sky through a set of mirrors.

Figure 1. The three-wavelength Polarization-Raman lidar system configuration.

The laser beam is coupled from side into the field-of-view (FOV) of the receiver telescope. Behind the pinhole, a collimating lens (L) collimates and transmits the light to six channels. The beam is separated according to wavelength with beam splitters and transmitted to photomultipliers. The Dichroic Beam Splitters (DBSs) were selected to reflect light with shorter wavelengths and transmit light with longer wavelengths because it is easier to produce DBS with higher transmission values at the longer wavelengths than at the shorter wavelengths. The signals are acquired using Licel transient recorder with 6 modules. Narrow band interference filter is used to suppress the sky background radiation in order to increase the signal-to-noise ratio (SNR) in each channel.

Table 1. Specifications of the TWPRL system

Size	1.7 m (H)*1.25 m (W)*0.7 m (D) (Container: 2 m *2 m*2 m)
Weight	300 kg (without container)
Transmitter	
Laser type	Flash-Lamp pumped Nd:YAG laser
Wavelength	355, 532 and 1064 nm
Single Pulse Energy	80 mJ@355 nm, 50 mJ@532 nm, 100 mJ@1064 nm
Repetition Rate	20 Hz
Divergence Angle	0.15 mrad (using a 5x expander)
Receiver	
Telescope	Schmidt-Cassegrain, D=30 cm
Field of View	0.3 mrad
Interference Filter	1 nm (FWHM) for each wavelength
Detectors	APD for 1064 nm PMT for 355, 532, 407 and 607 nm
Data Acquisition and Control system	
Data acquisition	Licel Transient recorder (40 MHz, 12 bit)
Height resolution	3.75 m
Maximum altitude	40 km
Angles of the ship	MTi-G-700 (0.2°)

From the elastically backscattered signals, and signals inelastically (Raman) scattered from nitrogen and water vapor molecules, we determine particle volume backscatter coefficients at 355, 532, and 1064 nm (3β), and particle volume extinction coefficients at 355 nm and 532 nm (2α), depolarization ratio (σ), and water vapor mixing ratio at 407 nm. In order to deploy it on the Xiangyanghong No.8, the lidar system was housed in a constant temperature and constant humidity container.

3. RESULTS

Figure 2 shows the cruise line of the Xiangyanghong No.8 during the campaign, which started on 29 Aug. and ended on 2 Sept. 2014.

The cruises went from the Black Point (120.2967° E, 36.0510° N) at 8:00 to Blue Point (120.5652° E, 35.9601° N) at 10:00 on 30 August 2014. Then we did measurement more than 24 hours in Blue Point. The second cruise started in the Blue Point in the Yellow Sea of China at 18:00 on 31 August 2014 towards the Purple Point in the Jiaozhou Bay and a further day-night observation was made.

The signals are recorded up to 50 km with 3.75 m resolutions and every 1000 pulse. In the analysis, the signals are averaged over 2.5 minute in time and 30 m in range. We conducted 24-hour continuous measurements and fixed position observations with the developed TWPRP during the cruise.

Figure 2. The cruise of the Xiangyanghong No.8

Figure 3. Time-Height display of the range-corrected signal measured in fixed position.

Figure 4. Time-Height display of the range-corrected signal measured along the sea route.

Two examples of the measurement results are depicted in Figure 3 and Figure 4. Figure 3 shows the 27-hour continuous measurements from 23:00 on 31 Aug. to 02:00 on 02 Sept. over the Jiaozhou

Bay (120.2649° E, 36.0939° N). The height of clouds decreases from 13 km at 16:00 to 3.5 km at 02:00 on 02 Sept., then it is raining. Figure 4 presents the latitude-longitude-dependent aerosol

vertical distribution observed at 532 nm along the sea route from (120.5652 ° E, 35.9601 ° N) to (120.2649 ° E, 36.0939° N).

4. CONCLUSIONS

A three-wavelength Polarization-Raman lidar was developed and conducted aboard the Xiangyanghong No. 8 from August to September 2014. The lidar system works very well during this campaign. The vertical distribution of marine aerosol over Yellow Sea was measured in fixed position for more than 24 hours. Furthermore, it is planning to do another two lidar campaign in May 2015 and September 2015 over the Yellow Sea of China.

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