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Measurement of aerosols and clouds with combined Raman elastic-backscatter lidar

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Abstract

For obtaining the quantitative measurement of aerosols and clouds in low atmosphere, detecting channel of Raman scattering signal has recently been added to the NIES's compact elastic lidar system (CML lidar). Using Raman and elastic scattering signals, both of the extinction and backscatter coefficient as well as lidar ratio of aerosols and clouds are retrieved, independently. In conjunction with the existed measured attenuated color ratio and total depolarization ratio, simple method for classifying of aerosols and clouds is accomplished based on the optical properties modeled by OPAC (Optical Properties of Aerosols and Clouds) soft package.

1. Introduction

Optical properties of particular atmospheric constituents, that is, water and ice cloud and aerosol particles, affect local radiative forcing, the radiation balance of the earth, and the climate[1]. These properties of cloud and aerosol particles are highly variable, both in the temporal and spatial dimensions. Thus quantitative and continuous measurements of aerosols and clouds optical properties are very important and necessary in radiation and modeling studies. Meanwhile, because these extrinsic optical properties are decided by the intrinsic microphysical properties of aerosols and clouds, and finally associated with their types, we can use measured optical properties to classify them.

Lidars are powerful tools for providing quantitative measurement of the optical properties of particles with high spatial and temporal resolution and with a high level of accuracy. Due to independent measurement of particle extinction and backscatter, the combined Raman elastic-backscatter lidar has been widely and successfully used in aerosols and clouds measurement, and is also used for operational lidar systems with automatic and continuous data analysis[2].

2. Method

The CML lidar is a two-wavelength polarization-sensitive laser sensing system; it provides simultaneously atmospheric backscatter profiles at 532 and 1064nm, and depolarization profile at 532nm in automatic and continuous operation. After reconstruction, profile of nitrogen Raman-shifted signal at 607nm is also obtained. Unfortunately, due to the weak of the return signal, Raman signal measurement is only observed at night. Through these four backscatter signals, profiles of particle lidar ratio and total depolarization ratio at 532nm, as well as attenuated color ratio from 1064nm to 532nm are retrieved finally.

Lidar ratio is defined as the ratio of particle extinction to backscatter ratio, and it is very important parameter in derivation of particle extinction from signals detected by the traditional Mie scattering lidar[3-4]. Since the lidar ratio connects two optical quantities that both depend on the wavelength of the incident light, and particle microphysical properties such as the refractive index, and the particle size distribution, it can span, in general, over 1 order of magnitude from approximately 10 to 100 Sr, and also indicate the types of particles. Depolarization ratio of lidar signal is defined as the ratio of the polarization component perpendicular to the transmitted laser polarization to the parallel component. It reflects nonsphericity of the scatterer. It is close to zero for spherical particles such as water clouds and spherical aerosols, and it is high for ice clouds and dust particles. Attenuated color ratio is the ratio of attenuated backscatter coefficient at 1064nm to the one at 532nm, and can be obtained directly from the calibrated backscatter data. It is generally high for larger particles. It can be used for characterizing aerosols and is also useful to distinguish thin clouds from aerosols. Because all of three derived optical properties are dependent on the microphysical properties of particles, and finally communicated with their types, we can use these differences to classify.

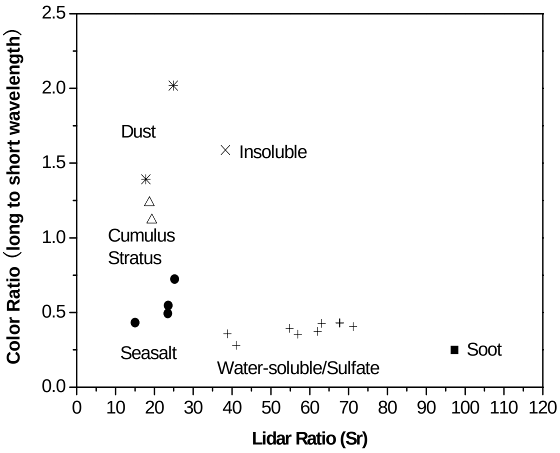

Fig.1 Example of modeled aerosols and clouds scattering properties calculated using OPAC software package.

To illustrate the general characteristics of aerosols and clouds scattering, Fig. 1 shows a plot of the 1064 to 532-nm backscatter color ratio vs. lidar ratio at 532nm derived using the OPAC software package[1]. The scattering models used are insoluble, water soluble, soot, sulfate, dust or mineral, sea salt parts of aerosol, and stratus and cumulus type clouds. Four values of relative humidity (0%, 50%, 70% and 90 %) are considered for the aerosols. From the Fig.1, it is easy to find that different types of particles are located in the different regions. Such significant difference in Fig.1 provides the basis for the simple classification of particles. According to the modeled data, the corresponding values of discrimination are listed in the table 1. Note that, the lidar ratio of dust particles in tab.1 is adopted from the practical measurements[5], and does not agree with modeled value in Fig.1. This is because the Mie theory does not well describe scattering properties of irregular dust particles, and the calculated data is also not well represent the real value of dust particles. Except to the lidar ratio and attenuated color ratio, depolarization ratio is a useful indicator to identify irregular particles and it also provides the means to discriminate ice clouds and dust aerosols[6].

Tab.1 Values of optical properties of particle types used in classification

Particle Types	*Lidar Ratio (Sr)*	*Attenuated color ratio*	*Depolarization Ratio*
Ice cloud	10-30	>0.75	>0.1
Water cloud	10-30	>0.75	<0.1
Dust	30-70	>0.75	>0.1
Water-soluble	30-80	<0.75	none
Soot	80-120	<0.75	none
Insoluble	30-80	>0.75	none
Sea salt	10-30	<0.75	none
Unknown			

3. Results

Fig. 2 shows the temporal and vertical distribution of aerosols and clouds optical properties in seven typical cases obtained at Tsukuba, Japan. These optical properties include total depolarization ratio (TDR) at 532nm, attenuated color ratio (CR) at 1064nm to 532nm, particle extinction coefficient (EP), backscatter coefficient (BP) and the lidar ratio (LR) at the wavelength of 532nm. Although geometrical form factor of the lidar system is corrected, the data below 500m still may not be reliable. From the above figure, it is easy to find that the optical properties of particles vary greatly with the height and time. And the differences among these optical properties reflect the characteristics of particles itself and provide information to classify the particles.

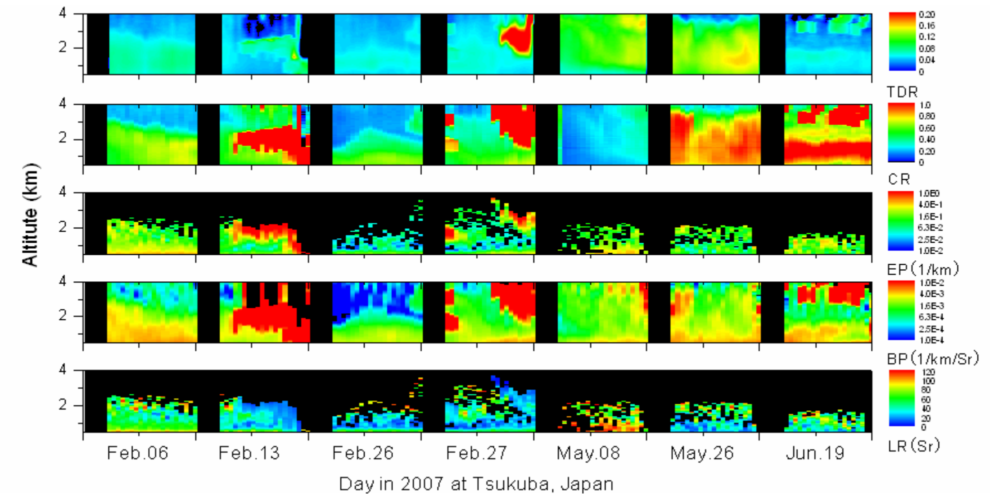

Fig.2 Temporal and vertical cross section of optical properties in typical cases.

Using the method of classification described above, different types of aerosols and clouds in the same typical cases as Fig.2 are discriminated and showed in the Fig.3. The vivid and clear description of particle types in temporal and vertical distribution provides directly information about the particles, and helps us to easily understand the particles characteristics in the atmosphere. Moreover, combined with meteorological data, the classification of aerosols and cloud can used to identify the aerosols sources. Of course, the method of classification is too simple and just applied in discriminating obvious feature of particles which has distinct optical properties. Accurate classification of particles, especially for aerosols, will be studied in the future.

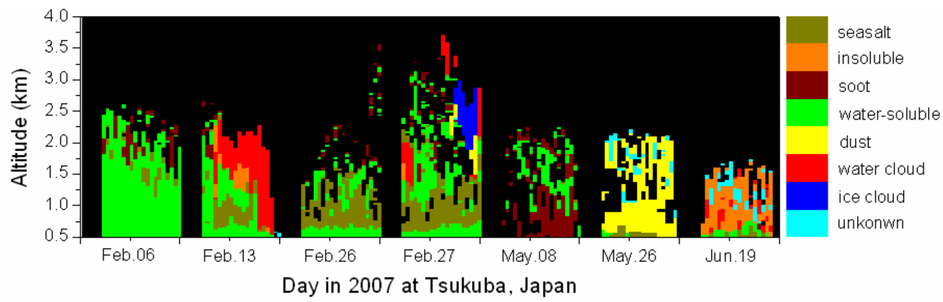

Fig.3 Classification of aerosol and cloud in the same cases as Fig.2.

4. Summary

The CML lidar system with added Raman detection channel provided quantitative measurements of aerosols and clouds in automatic and continuous operation. Temporal and vertical distribution of aerosol and cloud optical properties such as lidar ratio, attenuated color ratio and depolarization ratio were simultaneously observed and analyzed. Based on the modeled data calculated by OPAC soft package, a simple method for classifying aerosol and cloud types using the difference among these measured optical properties is described, and the result of classification in typical cases is given finally.

Reference

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