ACTIVE-PASSIVE OPTICAL REMOTE SENSING FOR WEATHER AND CLIMATE RESEARCH

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ABSTRACT:

Studying optical properties of atmospheric aerosol is important because aerosol affects people around the world significantly. Aerosol can directly affect climate change by scattering and absorption of solar and other radiations, and also indirectly affect the radiation by affecting cloud formation. Tropospheric aerosol is associated with air pollution and adverse health effects. These effects strongly depend on the physical and optical properties of aerosol particles. In this paper, we present the method combined sunphotometer (passive measurement) and Lidar developed by Wuhan University (active remote sensing measurement) to retrieve the aerosol optical depth. The primary results show that the proposed method improved the precision of aerosol optical depth effectively. Furthermore, long-term atmospheric and aerosol data could be obtained by consecutive Lidar and sunphotometer observations. Also these data will be useful for future understanding about their environmental and climate effects.

1. INTRODUCTION

Studying climate and a changing climate is important because changing environmental conditions will affect people around the world. Aerosol is as the most important atmospheric composition as a measurement of regional air pollution and for the uncertain impact on global climate. According to the U.S. Climate Change Science Program, factors such as aerosols, land use change, and others may play important roles in climate change, although their influence is highly uncertain at the present time. However, it is affirmed that their change will alter our surrounding condition and impact human health and animal-plant ecosystem.

Aerosols can directly affect climate change by scattering and absorption of solar and other radiations, and also indirectly affect the radiation by affecting cloud formation. These aerosols have residence time of few days, and thus are distributed inhomogeneously in the atmosphere. presently, there are still many uncertainties concerning the spatial distribution, the shape of the atmospheric aerosols (Frejafon et al., 1998). AOD (aerosol optical depth) is one of the most important parameter of the aerosol optical properties to assess the the variety of the atmospheric aerosol.

For estimating more accurately the abundance and sources of aerosols and better understanding how aerosols affect global climate, various active and passive measurements have been developed to provide aerosol optical properties. Combinatin of different observations into an integrated system helps to obtain quantitative information from the lidar measurements, for which several assumptions concerning the optical properties and the composition of the aerosols are necessary (Chih-Wei Chiang et al., 2007; D.Balis et al., 2000). Aerosols are now widely monitored by using lidars, which can provide vertical profiles of backscattering coefficient. There is also a remote sensing aerosol monitoring network initiated by NASA under the name of AERONET (AErosol RObotic network). Up to now, most experiment in china is about dust aerosols for the northern region model. Further researches about emending the existing atmospheric model and aerosol type and make them more compliant for central China area application find lack of data at Wuhan. We develop the Lidar-Sunphotometer system (Active-Passive Optical Remote Sensing) for obtaining optical attribute parameters about aerosols and other atmospheric components. The combined use of the active and passive optical remote sensing is valuable when attempting to detect atmospheric transport phenomena and diffusion properties for climate change.

2. EXPERIMENTAL SETUP

2.1 Lidar system

A mobile aerosol lidar named WUML has been developed by the State Key Laboratory for Information Engineering in Surveying, Mapping and Remote Sensing (LIESMARS) at Wuhan University. It is well-known that elastic backscatter lidars have been shown to be effective tools for measuring aerosol optical properties. The mobile aerosol lidar WUML is constructed basis of elastic Mie-scattering theory of particle, which can show aerosol distribution in atmosphere in both space and time, and provide valuable information in identifying boundary layer optical depth, elevated aerosol layers, wave activity, and sources of pollution. In this section, the framework and theory of WUML system is introduced.

WUML consists of a laser pulse transmitter, an optical receiving telescope and data acquisition and processing subsystems. The Nd:YAG laser transmitter works at the wavelengths of 1064 nm and 532 nm. It operates at 20 Hz pulse repetition frequency. The receiver consists of a 25 cm telescope. The detected signals from the PMTs are fed into the amplifier. The outputs of the amplifier are connected to a PC-based data acquisition system. The system provides backscatter signal strength integrated over adjustable laser shots averaged over a corresponding time resolution of 0.05 µs at a spatial resolution of 7.5 m. A complete overlap between the laser beam and the telescope's field-of-view is obtained at a range of about 500 m.

2.2 Sunphotometer

The CIMEL CE318 automatic suntracking photometer, is a solar-powered weather hardy robotically pointed sun and sky spectral radiometer. It has high degree of accuracy which have many advantages such as easy taking, easy fixed, automatic scanning, solar energy current supply and automatic data transferring.(Holben et al. 1998)

This instrument has approximately a 1.2° full angle field of view and two detectors for measurements of direct sun, aureole, and sky radiance. It mainly performs measurements of the aerosol optical depth at several wavelengths. The channels of the instrument are centred at 340, 380, 440, 500, 675, 870, 937, 1020, and 1064 nm, with bandwidths of about 10 nm. To make the direct sun measurements, the working time of the sunphotometer is restricted to sunny daytime without the presence of clouds.

3. EXPERIMENTAL SITE

Wuhan(30° N, 114° E) is the largest city in central China. Wuhan occupies a land of 8494.41 km², most of which is plain and decorated with hills and a great number of lakes and pools. Wuhan 's climate is a subtropical monsoon one with abundant rainfall and distinctive four seasons. The number of aerosol particles in the tropospheric atmosphere is larger than other area because of its population of 8.58 million, and the source of aerosol is complex.， Aerosol affects radiation, cloud formation, and environment severely. The experimental site is on the roof of the LIESMARS building at about 39m above sea level.

Figure 1. The geographical location of Wuhan

4. METHOD

4.1 Lidar system

In the earth’s atmosphere, light extinction is caused by two basic atmospheric components, molecules and particulates. For the measurements taken in the clear or moderately turbid condition, the atmosphere is assumed that it only consists two scattering properties when evaluating optical propagation (Fernald et al. 1972).

For a two-component atmosphere composed of aerosol particles and molecules, under the hypothesis of single scattering, the lidar equation is written as:

$$P(r) = C\frac{\beta_a(r)+\beta_m(r)}{(r-r_0)^2}\exp\{-2\int_{r_0}^{r}[\alpha_a(r)+\alpha_m(r)]dr\} \quad (1)$$

where $P(r)$ = the lidar return signal power
C = lidar constant
r_0 = altitude of the lidar
$\beta_a(r)$ = aerosol particle backscattering coefficient
$\beta_m(r)$ = molecular backscattering coefficient
$\alpha_a(r)$ = aerosol particle extinction coefficient
$\beta_m(r)$ = molecular extinction coefficient

In the equation, the Rayleigh scattering coefficients of atmospheric molecules can be obtained from known functions within the required accuracy (V.A. Kovalev et al. 2004; US Standard Atmosphere 1976). And the backscatter-to-extinction ratio S is assumed to be a constant:

$$\beta_a(r)/\alpha_a(r) = S\,. \quad (2)$$

However, the backscatter-to-extinction ratio depends on several parameters, its uncertain brings most systematic error. To solve this problem, the photometer will obtain the total atmosphere transmission coefficients and optical depths which will be complement measurements for Lidar to improve the precision of above aerosol parameters retrieved from Lidar.

4.2 Sunphotometer

To retrieve the aerosol total column optical depth of the atmosphere, the inversion of the direct sun measured by the sunphotometer is based on the Beer-Lambert-Bouguer law:

$$E_\lambda = E_{0,\lambda}R^{-2}\exp(-m\tau_\lambda)T_{g,\lambda} \quad (3)$$

Where E_λ = solar irradiances at the ground level
$E_{0,\lambda}$ = solar irradiances at the top of the atmosphere
R = actual Earth-Sun distance coefficient
m = optical air mass
τ_λ = total optical depth
$T_{g,\lambda}$ = transmission of absorbing gases (the ozone and water vapour absorption at 675 nm and 870 nm)

The equation are transformed to the below for the sunphotometer as a filtered detector measures the spectral extinction of direct sun radiation:

$$V_\lambda = V_{0,\lambda}R^{-2}\exp(-m\tau_\lambda)T_{g,\lambda} \quad (4)$$

where V_λ = digital voltage
$V_{0,\lambda}$ = extraterrestrial voltage

After obtain the geographical location (latitude and longitude) and time of the measurements, we can calculate R and m. There is significant water vapor absorbing at wavelength 870 nm that cannot be ignored. The extraterrestrial voltage $V_{0,\lambda}$ is a constant depends on the instruments, and it can be calculated from the Langley plot. The Langley plot is a log of V_λ against the optical air mass m between the range of 2 and 5 during the day that aerosol and irradiance is stable.

The automatic sun/sky CIMEL radiometer CE-318 acquires data regardless of sky conditions. To retrieve AOD from the direct sun measurements, we need to perform the cloud-screening procedure. It includes data quality checks, triplet stability criterion, diurnal stability check, and two major criteria : smoothness criteria, and three standard deviation criteria. (A.Smirnov et al, 2000)

The aerosol optical depth at relevant wavelength can be derived from the measurements in several channels of the photometer(Angström, 1964). Nevertheless, the Angström exponent is related to the aerosol size distribution (Junge, 1963).

$$\tau_a(\lambda) = k\lambda^{-\alpha} \quad (5)$$

where λ = the wavelength
$\tau_a(\lambda)$ = aerosol optical depth at λ
k = Angström turbidity coefficient,
α = Angström wavelength exponent

For the relevant study, the channels used are centred at 1020, 870, 675, 440, 500 nm. The aerosol optical depth at 532 can be calculated by nonlinear regression.

5. RESULTS AND DISCUSSION

In this section, the experimental results is exhibited and discussed. The measurements cover the period from December 2007 to April 2008. The sunphotometer measurements were performed automatically during this period without rainy, snowy, or cloudy days. And there are limited results retrieved from these measurements due to bad weather conditions. The lidar was not operated in February 2008 due to maintenance purpose.

As shown in Fig.2, AOD derived from lidar extinction data is different from that retrieved from sunphotometer. On December 13 and April 16, AOD from lidar measurements is a little smaller because the lack of lidar measurements below 500 m. It indicates that the lidar optical thickness matches with the AOD derived from sunphotometer, and the backscatter-to-extinction ratio used in the inversion of lidar equation is appropriate for the measurements. On January 9 and April 6, the results show a different situation. Considering the lack of some lidar signals, it is mainly affected by clouds. There are cloud-screening and quality control for the AOD derived from sunphotometer. For better result, it requires the absence of clouds.

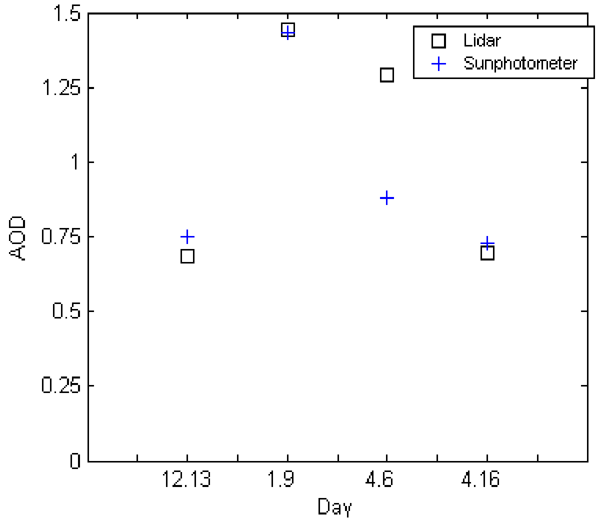

Figure 2. The optical depth derived from lidar and sunphotometer

6. CONCLUSIONS

The primary results show that the synergy of lidar and sunphotometer measurements is a useful and accurate approach to acquire atmospheric aerosol optical properties, and these parameters obtained through long-term and continuous observation will ultimately contribute to improved forecasts of air quality and predictions of climate change.

Moreover, the ground-based Lidar-Photometer system can make simultaneous observation when the space-based CALIPSO satellite flies over; and the results will provide the ground-based validation for the CALIPSO data. Furthermore, these data will also be used for emending the existing climate model and make it more compliant for China area application.

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