Lidar Measurement of Optical Properties of Cirrus Clouds at Kwangju, Korea

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Abstract: Cirrus clouds observation was conducted using a lidar system in order to measure their height, thickness and optical depth at Kwangju (35°10`N, 126°53`), Korea in winter, December 2002, and spring March and April 2003. Cirrus clouds at high altitude can be distinguished from atmospheric aerosols location by high depolarization ratio and high altitude. Cirrus clouds were observed at 5~12km altitudes with a high depolarization ratio from 0.2 to 0.5. Optical depth of cirrus clouds had varied from 0.28 to 1.81. Radiative effect of observed cirrus cloud on climate system was estimated to be negative net flux from –0.24 to –31.04 W/m^2 .

Keywords: Cirrus cloud, Lidar, Optical depth.

1. Introduction

Cirrus clouds have been identified as one of the important factors that have been found to regulate the radiance balance in the earth-atmosphere system. They have a large influence on weather and climate [1] because they consistently cover more than 20% of the Earth's surface [2]. Accurate optical information of cirrus clouds is important for the radiative model to estimate their contribution to the radiation balance. The overall role of cirrus clouds on the energy balance of solar radiation in the earth atmosphere system depends on the optical depth, altitude and particle size of cirrus clouds.

Owing to high altitude and non-spherical shape of cirrus clouds, lidar is one of the most suitable instruments for retrieving optical properties of cirrus clouds. Lidar obtains information on physical and optical properties of clouds, such as cloud thickness and altitude as well as optical depth. In this paper, the radiation forcing effect by cirrus clouds was estimated by a radiative transfer model, SBDART(Santa Barbara DISORT Atmospheric Radiative Transfer)[3], using cirrus clouds data observed by the K-JIST lidar.

2. K-JIST LIDAR system

The K-JIST lidar system used in this observation is equipped with a Nd:YAG laser as a light source of the transmitter and a Schmidt Cassegrain telescope as a receiver. Fig. 1 shows the schematic diagram of the lidar system used in this study. Three wavelength (355, 532, 1064nm) of Nd:YAG laser are vertically transmitted into the atmosphere with a repetition rate of 20Hz. The beam diameter is set to be 10mm, so that the maximum beam divergence is less than 0.5mrad. The laser produces 8-ns pulses with energies as much as 400mJ at 1064nm. The transmitted beam is expanded by 5 times beam expander. To control the polarization state of the transmitted 532nm radiation with a high precision, a wave-plate (λ/2 plate) is inserted into the optical path of the 532nm beam. After passing the beam expander, the beam divergence is less than 0.2mrad.

In the receiving part a three-telescope configuration is used to collect the backscattered lidar signal from the atmosphere. The optical signals received by each of the telescopes are separated spectrally by dichroic mirrors and then filtered by sets of interference filters for each wavelength. Neutral-density(ND) filters are employed to adapt the light intensity of the signals to the corresponding photo-multiplier tubes (PMTs) sensitivity. In this study, 532nm backscattered signal is analyzed to observe optical depth and altitude of cirrus clouds.

3. Observation and Results

1) LIDAR Observation

Observation of cirrus clouds with this K-JIST lidar was made at Kwangju(35°10'N, 126°53'E), Korea at December 2002 and March ~ April 2003. During these periods the lidar system had been continuously operated if weather condition permitted. As a result, a dataset consisting of many different cirrus cloud cases was obtained.

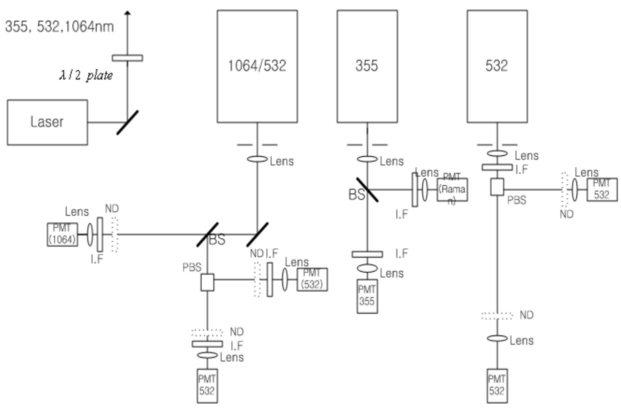

Fig. 1 The schematic diagram of lidar system

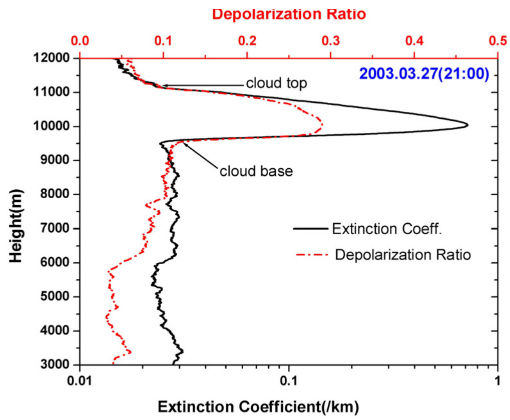

Fig. 2 Vertical profile of extinction coefficient and depolarization ratio observed March 27, 2003.

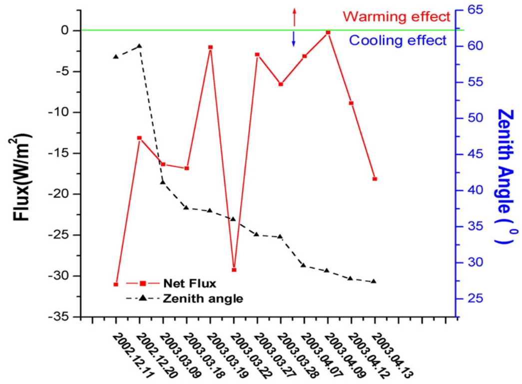

Fig. 3. Net flux according to the zenith angle change.

Total depolarization ratio δ of backscattered signal at 532nm separated by polarizer beam splitter as P-component and S-component was used to distinguish cirrus clouds from other aerosols like water droplet,. The total depolarization ratio δ is obtained from the linear polarization components of the Mie/Rayleigh backscatter signals at 532nm, which defined as

$$\delta(z) = \frac{P_P(z)}{P_P(z) + P_S(z)} \qquad (1)$$

where the subscript P and S denote the parallel and the perpendicular components with respect to the polarization plane of the emitted laser. Theoretically, the depolarization of the spherical particles should be zero, but the depolarization ratio of the pure molecular atmosphere and spherical particles are nonzero, because of the anisotropy of the air and multiple scattering effect. Therefore a 0.37 ~0.4% depolarization ratio of air is expected[4]. Fig. 2 shows the vertical profile of extinction coefficient and depolarization ratio of observed cirrus clouds observed March 27, 2003. Cirrus clouds layer at approximately 9.5-ll km heights can be identified clearly from depolarization ratio (dash and dotted curve). If depolarization ratio profile showed above 0.2, that region was determined as cirrus clouds in this study.

In Fig. 2. extinction coefficient showed exactly same trend with depolarization ratio in the high depolarization ratio region. In this study, extinction coefficient was calculated by the Klett method[5] using received backscattered signals. The optical depth was calculated by integrating the aerosol extinction profile of cirrus clouds.

During the observation periods, cirrus clouds were detected total 12 days. Table. 1 summarizes base height, thickness, and optical depth of the observed cirrus clouds. Observed cloud base varied from minimum 4.70km to maximum 9.85km. Cloud thickness varied from 1.34km to 5.82km. Optical depth of cirrus cloud varied from 0.28 for thin cloud to 1.81 for thick cloud.

Table 1. Observed cirrus cloud base height, thickness and optical depth.

Date	Mean cloud base height (km)	Cloud thickness(km)	Optical depth
2002			
11-Dec	5.65	4.04	1.06
20-Dec	8.75	2.37	0.38
2003			
09-Mar	5.49	3.44	1.06
18-Mar	6.28	3.46	1.19
19-Mar	8.21	2.10	0.28
22-Mar	7.32	4.00	1.81
27-Mar	9.85	1.34	0.45
28-Mar	5.57	2.44	0.79
07-Apr	8.35	3.48	0.62
09-Apr	4.70	5.82	0.34
12-Apr	7.04	4.27	1.13
13-Apr	6.35	5.65	1.71

2) Model Calculation

Radiative forcing of cirrus clouds was calculated from radiative transfer model based on the observed thickness, altitude, and optical depth of cirrus cloud. The SBDART(Santa Barbara DISORT Atmospheric Radiative Transfer) model was used which can compute plane-parallel radiative transfer in clear and cloudy conditions within the earth's atmosphere and at the surface.

The model was used to calculate difference between upwelling flux and downwelling flux at TOA(Top of the Atmosphere) and surface under the presence of cirrus clouds SBDART model used input parameters such as optical depth, altitude, zenith angle of observed cirrus clouds. Its results show temporal variations of net flux in a function of zenith angle in Fig. 3. Optical depth and altitude of cirrus clouds was observed by the K_JIST lidar and zenith angles calculated by the model are presented on Figure 3. The results show that the cirrus cloud that observed at the Kwangju, Korea(mid-latitude region) cooling effect to the radiative forcing and the value was in proportion to optical depth. Zenith angle affect the result as it decreases by seasonal change. Optical depth of 2003.03.22 and 2003.04.13 has similar value but calculated result in 2003.03.22 is two times

Table 2. Radiative forcing calculation of various aerosols.

	Study	Net flux at TOA(Wm^{-2}) [Optical depth : 1]
Volcanic aerosol[6] Model estimation result	Stowe et al, 1992	-19.2
	Chou et al, 1984	-13.0
	Minnis et al, 1993	-(11.5±4.4)-0.5
	Lacis et al, 1992	-30.0
	Hansen et al, 1997	-28.4
Asian dust	Conant et al	-30
	Nakajima et al	-26.6±3.9
Cirrus cloud	This research	-10.8±9.2

lower than in 2003.04.13 as the zenith angle is decreased.

To know the cirrus cloud radiative forcing value, comparison was conducted with other aerosol's radiative values. Table 2. shows net flux values at TOA for volcanic aerosol and Asian aerosol. Calculation method of volcanic aerosol and Asian dust was same with cirrus cloud. The value of cirrus cloud shows similar or a little smaller value than other aerosols. But, if occurrence frequency is considered, cirrus cloud is more affect than other aerosols.

4. Conclusion

Altitude, thickness, and optical depth of cirrus clouds was conducted by K-JIST lidar system at Kwangju, Korea from December 2002 through April 2003. Cirrus clouds were usually observed above 5km altitude up to 12km with varying optical depth.

The radiative forcing effect calculated by a radiative transfer model showed negative net flux from -0.24 to –34.04(Wm^{-2}) in the winter and spring. Net flux by cirrus cloud per unit optical depth was comparable to the that of volcanic aerosol and Asian dust.

The present study provided a direct measurement of optical and height of cirrus cloud that give useful information for estimating radiative effect of cirrus cloud.

Acknowledgement

This work was supported in part by the Korea Science and Engineering Foundation (KOSEF) through the Advanced Environmental Monitoring Research Center (ADEMRC) and Ministry of Education & Human Resources Development through the Brain Korea 21(BK21) at Kwangju Institute of Science and Technology.

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