OPTICAL PROPERTIES OF ASIAN DUST ESTIMATED FROM GROUND BASED POLARIZATION MEASUREMENTS

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ABSTRACT :

Polarimetric measurements of the sky radiation by the PSR-1000, which is the multi-spectral polarimeter developed by the Opt Research Corporation and has the same wavelength regions (443nm, 490nm, 565nm, 670nm, 765nm and 865nm) as the ADEOSII/POLDER sensor, have been carried out at the ground station in Kanazawa city, Japan from March to May. First of all, the wavelength dependency of degrees of polarization is examined and it is shown that degrees of polarization measured under the hazy dust cloud are lower than those measured in the clear sky and decrease as the wavelength increases. Next, a new method for estimating optical properties, such as the optical thickness, the number size distribution and the refractive index, of the Asian dust and the ground reflectance from degrees of polarization measured by PSR-1000 is described. Finally, this method is applied to polarization data acquired on April 15, 2002. As a result, it is shown that our estimation algorithm provides a good result.

KEY WORDS: Polarization, Ground-based Measurement, Optical Properties of Asian Dust

1. INTRODUCTION

The Asian dust is regarded as a main source of atmospheric aerosols over East Asia in the spring season. However, it is as yet very difficult to extract optical properties of the widely spread hazy dust from satellite-level data over the land surface because the radiance received by a satellite sensor strongly depends on the surface reflectance. The structure and optical properties of a haze including the Asian dust have been studied by means of Lidar observation and sun photometer measurement from ground stations. However, ground based polarization measurements are as yet very sparse. It is expected that the polarimetric information will provide the improvement of estimating the optical properties of the hazy dust.

We have made polarimetric measurements of the sky radiation at the ground station in the Kanazawa city, Japan, which is located at the Sea of Japan, from March to May in 2000 to 2005 (Kusaka, et al., 2002). Asian dust clouds often appear together with normal clouds, and so we have only measured the degree of polarization when the Kanazawa city was covered with a thin dust cloud.

First of all, the wavelength dependency of degrees of polarization measured when the Asian dust was recognized in the Kanazawa city is examined. Next, a new method for estimating optical properties of Asian dust clouds and the ground reflectance from degrees of polarization measured by PSR-1000 (Masuda, 1997) is described. Finally, in order to evaluate the proposed algorithm, optical thickness of Asian dust estimated from the measured polarizations is compared with that obtained from the measurement result by the sun photometer.

2. POLARIZATION MEASUREMENT

The PSR-1000 measures the intensity of the sky radiation. A Glan-Thmpson prism is implemented between the hood (2 degrees field of view) and the interference filters in the PSR-1000 instrument. The prism rotates automatically by a pulse motor and the range of the rotation is 0 to 360 degrees. The measurement by the PSR-1000 is controlled by a personal computer (PC).

The optical instrument attached on the tripod is pointed manually to a desired direction to measure the intensity of the sky radiation. Since the received signals change sinusoidally against the angle of rotation of the polarizer, the maximum signal value, I_{max} and the minimum value, I_{min} can be easily obtained from the sinusoidal curve. The degree of linear polarization, L , is therefore given by

$$L = ((I_{max}-I_{dk})-(I_{min}-I_{dk}))/((I_{max}-I_{dk})+(I_{min}-I_{dk})), \quad (1)$$

where I_{dk} is the dark signal that is the signal received in no incident solar radiation.

Polarizations were measured at angles of 90 and 120 degrees from the solar direction in the principal plane in 2000 to 2002. From 2003, polarization measurements were carried out at angles of 75, 90, 105 and 120 degrees from the solar direction. Fig.1 shows degrees of polarization measured at the angle of 90 degrees when the hazy dust was recognized in the Kanazawa city. Fig.2

shows degrees of polarization measured at the angle of 90 degrees in the clear sky. Polarization measurements shown in Figs. 1 and 2 were carried out in the morning on March 22, 2001, April 13, 2003 and May 3, 2003, and another polarization data were acquired in the afternoon.

As seen from Figs. 1 and 2, degrees of polarization measured under the hazy dust cloud were lower than those measured in the clear sky and depend on the observed wavelengths. The wavelength dependency of degrees of polarization is slightly different in the observation date. We can also see that when the Asian dust was transferred to Kanazawa, Japan, the degree of polarization decreases as the wavelength increases.

3. ESTIMATION OF OPTICAL PROPERTIES OF HAZY DUST

The measured intensity of the sky radiation includes the component of the radiation reflected by the background surface. Therefore, the radiance and polarization at the bottom of the atmosphere were computed by means of the Monte Carlo integration of the radiative transfer equation in a uniform plane parallel atmosphere bounded by the uniform Lambertian reflector (Ishimoto, et al. 2002; O'Brien, 1998). In the radiative transfer simulation, it was assumed that the size distribution of Asian dust is represented by the Junge power-law, $dN/dr=cr^{-a}$, (minimum radius: 0.05μm, maximum radius: 15μm) and the dust particle is spherical, non-absorption matter. The computed linear polarization, Lp, is defined as

$$Lp=\sqrt{Q^2+U^2}/I, \qquad (2)$$

where Q and U are Stokes parameters and I is the total intensity. As seen from Eq.(2), the linear polarization Lp includes the intensity I and the intensity I depends on the background reflectance. It is, therefore, necessary to estimate optical properties of the Asian dust and the background reflectance simultaneously from the measured degrees of polarization.

Parameters to be estimated from the measured polarizations are the optical thickness of the haze, t, exponent of Junge power-law, a, refractive index of Asian dust, Nr, and the background reflectance, A, at each channel. We have polarization data measured in four directions at the almost same time and so can estimate theoretically the values of four parameters from the measured polarizations.

We determined the values of t, a, Nr and A using the following algorithm:

(1) Polarizations, Lp, at the bottom of the atmosphere were computed for typical values of t(550), Nr, a, in the dust layer and A at each channel under different solar zenith angles. In this study, only polarizations at angles of 75, 90, 105 and 120 degrees from the solar direction in the principal plane were computed. The optical thickness of dust layer, t, at the wavelength, λ, was obtained from $t(\lambda)=t(550nm)(\lambda/550)^{-\alpha}$, where α is determined from extinction coefficients at λ and 550nm.

(2) The values of t(550), Nr, a and A were chosen such that the sum of the square errors between the measured polarizations and the computed ones in four directions at the wavelength λ is minimum.

4. RESULTS

Fig.3 shows degrees of polarization measured at angles of 75, 90, 105 and 120 degrees in the afternoon on April 15, 2003. The thick dust cloud has passed over the Kanazawa city in the early morning on April 15. Degrees of polarization shown in Fig.3 provide measurement results in the air with the low concentration of Asian dust. At 443nm and 490nm channels, the radiance transmitted to the ground surface not so much depends on the ground reflectance of urban and suburban area and the degree of polarization is larger than that of another channels in the case of the hazy dust (see Fig.1). Therefore, we used only the polarization at 490nm channel to estimate optical parameters and the background reflectance.

We computed the values of Lp against all combinations of t(550), Nr, a and A given below.

Nr: 1.35 to 1.65 (interval: 0.1), a: 3 to 6 (1), t(550): 0.1 to 0.5 (0.05) and A: 0.05, 0.1, 0.15.

After that, we obtained the combination of t(550), Nr, a and A that minimizes the sum of square errors between the measured polarizations and the computed ones using the procedure (2) given in the previous section. As a result, it was found that t(550)=0.3, Nr=1.35, a=4, and A=0.1. The computed polarizations in this case are also shown in Table 1. As seen from Table 1, the computed polarizations are very close to the measured ones.

Table 1 The estimated polarizations and measured ones at the 490nm on April 15, 2003

angle	Measured Pol	Estimated Pol
75	0.341	0.337
90	0.399	0.391
105	0.354	0.352
120	0.241	0.247

We also compared the estimated optical thickness of hazy dust with that obtained from the aerosol measurement by the sun photometer. The optical thickness of aerosols by the sun photometer is 0.44 at the wavelength of 500nm. On the other hand, optical thickness of hazy dust at the 490nm channel estimated from our algorithm is 0.5. This indicates that our estimation algorithm will provide a good result. However, in order to estimate optical properties of Asian dust more accurately, we will need the improvement of the minimization process described in the previous section.

4. CONCLUSIONS

A new method for estimating optical characteristics of thin Asian dust and the background reflectance from polarizations measured at the ground station was described. It was found that the method described here provides the reasonable optical thickness of aerosols including Asian dust. It was also shown that degrees of polarization measured under the hazy dust cloud are lower than those measured in the clear sky and degrees of polarization decrease as the wavelength increases.

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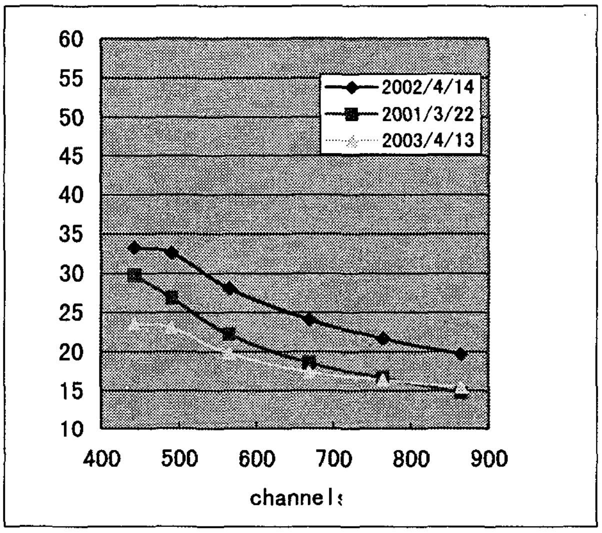

Figure 1 Polarizations at the angle 90 degrees measured when Asian dust was recognized.

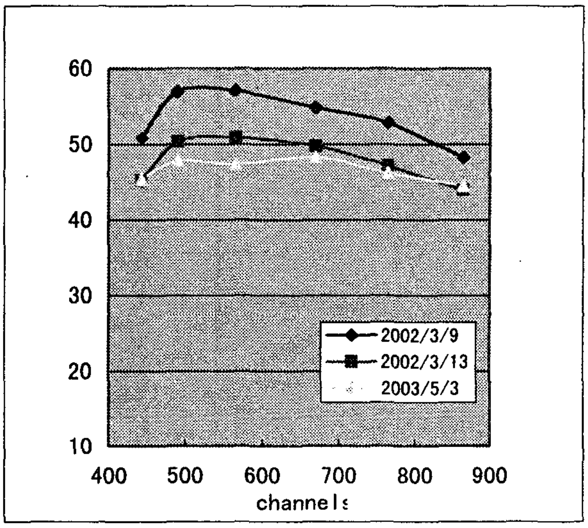

Figure 2 Polarizations at the angle 90 degrees measured in the clear sky

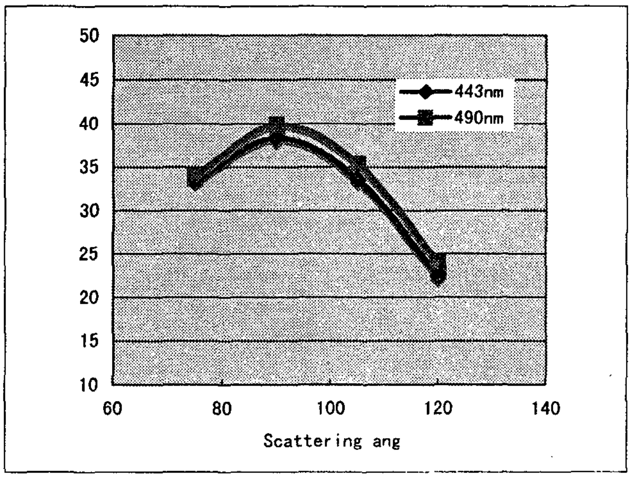

Figure 3 Measurement polarizations at angles of 75, 90, 105 and 120 at 443nm and 490nm channels in the aftenoon on April 15, 2003