A NEW METHOD FOR ESTIMATING AEROSOL PROPERTIES AND SURFACE REFLECTANCE FROM POLDER DATA OVER LAND

Takashi Kusaka and Ryuichi Taniguchi

Kanazawa Institute of Technology
Nonoichimachi Ishikawa, 921-8501, Japan
kusaka@neptune.kanazawa-it.ac.jp

1. INTRODUCTION

The Asian dust transported from desert areas in the northern China often covers over East Asia in the late winter and spring seasons. It is regarded as a main source of atmospheric aerosols over East Asia and has significant effects on the climate change. Moreover, fine dust particles in the air have harmful influence on our health on the local and global scales. Many authors have investigated aerosol properties over ocean [1] and over dark vegetated areas [2],[3] using satellite measurements. In these cases, the surface contribution to the radiance received by the satellite sensor is small. However, it is as yet very difficult to extract optical properties of the widely spread hazy dust from satellite data over the land surface because the radiance received by a satellite sensor strongly depends on the surface reflectance. It will be, therefore, necessary to estimate optical properties of Atmospheric aerosols and the surface reflectance simultaneously from satellite data.

The PARASOL/POLDER observes the reflectance and polarization of a target quasi-simultaneously in multi-viewing angles at wavelengths of 490nm, 670nm and 865nm, and so POLDER data provide enough information to determine optical characteristics of atmospheric aerosols and the surface reflectance. We have developed the algorithm for estimating optical properties of aerosols and the surface reflectance simultaneously from POLDER data [4],[5]. However, absorption of light ray by aerosols is not taken into account in the estimation algorithm. Therefore, we will need the improvement of the estimation process.

In this study, we describe a new method for the estimation of aerosol properties using the polarized radiance effectively. After that, we use the estimated aerosol properties to estimate the surface reflectance from the total radiance received by the POLDER. This is because the contribution of light reflected by the ground surface to the polarized radiance at the top of the atmosphere is very small. Since the ground resolution of a POLDER-measured pixel is 6x7 km^2 at nadir, the radiance and polarization at the top of the atmosphere were obtained from the numerical computation of the radiative transfer equation in a uniform plane parallel atmosphere bounded by the uniform Lambertian reflector. We used the 6SV-1.0B code developed by Vermote et al. [6] to compute values of Stokes parameters at the top of the atmosphere. In this case, it was assumed that the number size distribution of aerosols is represented by the Junge power-law (minimum radius: 0.05µm, maximum radius: 15µm) and aerosol particles are spherical.

By comparing the radiance and polarization received by the POLDER with those obtained from the radiative transfer simulation, we estimate the optical thickness of aerosols, t, the exponent of Junge power-law, a, the complex refractive index, Nr (real part) and Ni (imaginary part), and the surface reflectance, A.The contribution of light scattering by aerosols to the total radiance in the near infrared wavelength is relatively small. In the present study, the retrieval of aerosol properties and the surface reflectance from PARASOL/POLDER data at 490nm and 670nm channels taken on April 28, 2006 is taken into account.

2. ESTIMATION ALGORITHM OF AEROSOL PROPERTIES AND SURFACE REFLECTANCE

We estimate aerosol properties and surface reflectance by comparing the radiance and polarization obtained from satellite measurements with those obtained from the computation of multiple scattering light in the atmosphere-ground system.

The radiance and polarization of scattering light are completely described by the Stokes parameters (I, Q, U, V), where I is the total radiance and the other parameters have same dimension. We have V=0 in the linear polarization. The linearly polarized radiance Ip and the polarization direction χ can be derived from Q and U as follows :

$$I_p=\sqrt{Q^2+U^2} \quad (1)$$

$$\tan(2\chi) = U/Q \quad (2)$$

The degree of polarization is defined as the ratio Ip/I. The linearly polarized radiance Ip does not depend on the surface reflectance on the assumption that the ground surface is a Lambertian reflector.

2.1 Estimation method at 670nm

Using the 6SV-1.0B code, we computed in advance the total radiance RAD , the polarized radiance POL and the polarization direction PD at the top of the atmosphere for many different combinations of the optical thickness of aerosols at 550nm, t(550), the refractive index of aerosols, Nr, the index of Junge power-law, a and the ground reflectance, A under some different observation conditions such as solar zenith angle, SZA, viewing zenith angle, VZA, and relative azimuth angle, RAZ, and saved the values of RAD, POL and PD in the Look-up table, U670. In this computation, the midlatitude winter model given in the 6SV-1.0B code was adopted as the atmospheric model. Moreover, we assumed that the imaginary part of complex refractive index, Ni, is zero at 670nm because there is very little absorption for dust particles at 670nm.

First of all, the values of the observed Stokes parameters in different N geometrical conditions, each of which consists of a 3-tuple of (SZA, VZA, RAZ), were extracted from POLDER data at a target pixel, and the polarized radiances OPL observed by the POLDER were computed by Eq. (1). The values of POL that correspond to all of viewing conditions, $(SZA, VZA, RAZ)_i$, (i=1, …,N) were interpolated in all combinations of Nr, a and t(550) given in U670. Next, we used the least square method to estimate optimum values of Nr, a ant t(550). To do that, the objective function was defined as the sum of square errors between the observed values and the computed ones, Q ($=\Sigma(OPL_i-POL_i)^2$, where i shows the i-th geometric condition.), and then the values of Nr, a and t(550) were estimated by minimizing the value of Q. In this case, we used the modified hill climbing algorithm adopted by Kusaka, et al. [4] in which the partial derivatives of Q are not used, to get the minimum of Q. Finally, we estimate the surface reflectance A using the estimated aerosol properties such as Nr, a and t(550). The total radiance at the top of the atmosphere is easily computed for a given surface refrectance if aerosol properties in the atmosphere are known. Therefore, using the estimated values of Nr, a and t(550), we compute the total radiance RAD for surface reflectances given in U670 in each of geomeric conditions. After that, the surface reflectance A was determined by minimizing the sum of squared residuals between the observed total radiance and the computed one for different geometric conditions in the same way as the estimation of aerosol properties.

2.2 Estimation method at 490nm

In general, the refractive index, Nr, of aerosols including the Asian dust slightly increases as the wavelength is shorter, but we have not so much experimental results for the wavelength dependency of Nr. In the present study, we assume that the refractive index, Nr, at 490nm is the same as that at 670nm. However, absorption of light by aerosols will be taken into account. As a matter of course, the number size distribution of aerosols at this wavelength is the same as that estimated at 670nm. Therefore, optical parameters of aerosols to be estimated at 490nm are the imaginary part, Ni, of complex refractive index and optical thickness of aerosols.

We first used the 6SV-1.0B code to generate the Look-up table, U490, of RAD, POL and PD for typical values of Nr, Ni, a, t(550), A, SZA, VZA and RAZ. Then, the values of RAD, POL and PD in each of geometric conditions that correspond to the Nr and the index of Junge-power law, a, estimated at 670nm were interpolated from U490 and were saved in a new Look-up table, nU490. Next, we estimated the optimum value of Ni and t(550) from the polarized radiances given in POLDER data and the Look-up table, nU490 and then obtained the surface reflectance, A, from total radiances in the same way as the case at 670nm.

3. RESULTS

The method described at the present study was applied to PARASOL/POLDER data (P3L1TBG1032192JD) taken on April 28, 2006. Fig. 1 shows the POLDER image over Japan (B: 490nm, G: 670nm, R: 865nm).
We estimated aerosol properties and the surface reflectance at pixels including the symbol + shown in Fig.1, and obtained the mean values of t, Nr, Ni, a and A. In this case, the polarized radiances observed with RAZ>180 degrees at a target pixel were used. As a result, it was found that t(670)=0.38, Nr=1.34, a=4.51 and A=0.092 at the 670nm channel, and t(490)=0.814, (Nr, Ni)=(1.34, 0.03), a=4.51, A=0.1 at the 490nm channel. Using the values of t, Nr, a and A estimated from POLDER data at 670nm, we computed degrees of polarization (Ip/I) at the pixel shown by the symbol + in Fig.1. The result is shown in Fig.2. In Fig.2, degrees of polarization observed by the POLDER are shown to compare with the estimated degrees of polarization. The observed and estimated degrees of polarization at 490nm are also shown in Fig.3. We can see from Figs.2 and 3 that the estimated degrees of polarizations are close to the observed ones at 670nm and 490nm channels. This indicates that we have reasonable estimation values for aerosol properties and the surface reflectance.

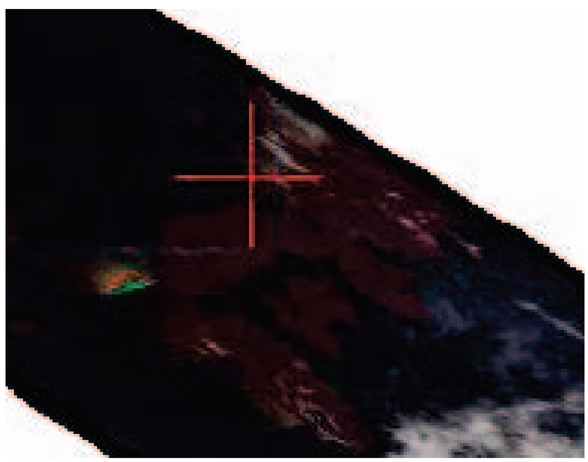

Fig.1 POLDER image taken on April 28, 2006

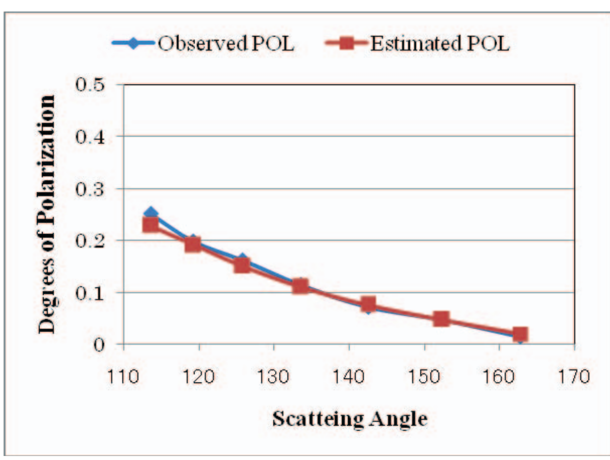

Fig.2 Observed degrees of polarization and Estimated ones at 670nm

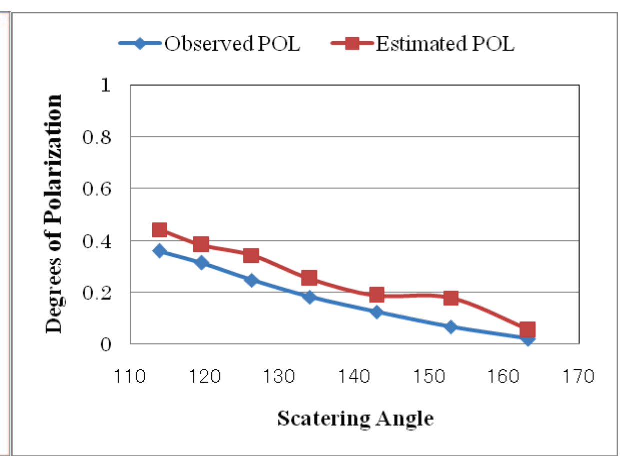

Fig.3 Observed degrees of polarization and Estimated ones at 490nm

4. CONCLUSIONS

The new method for estimating optical properties of atmospheric aerosols and the surface reflectance from PARASOL/POLDER data over the land surface was proposed. It was shown that aerosol properties over land are successfully estimated from the polarized radiance measured by the POLDER on the assumption that the ground surface is the Lambertian reflector. Once we have determined aerosol properties over land by using the polarized radiance, we can easily estimate the surface reflectance from the total radiance.
We now undertake to develop the computing system for estimating aerosol properties and the surface reflectance from POLDER data over land on the global scale.

5. REFERENCES

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