The Estimation of Aerosol Optical Parameters from ADEOS / POLDER Data

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ABSTRACT

We have analyzed the reflectance and polarization data acquired by POLDER on board ADEOS satellite. The ADEOS/POLDER's reflectance and polarization data at 865nm over the Arabian Sea near Indian Continent, taken on Nov. 18, 1996, were investigated by using typical aerosol size distribution models, namely, Oceanic, Water-Soluble and Junge models. We made multiple scattering simulations for these models by assuming a tropical atmosphere. A single atmospheric layer model with an isotropic Gaussian type ocean surface (Cox-Munk model) was considered in this study.

The main results of this study were summarized as follows:

1) We found that Junge model with n=4.0 - 4.5 and m=1.50-i[0.0 - 0.01] and Water-Soluble model can satisfy the observed reflectance data , as well as the observed polarization data by assuming the typical ocean aerosol optical thickness values .

2) Oceanic aerosol model was rejected on the ground that it failed to explain the observed polarization features.

3) The image construction for both reflectance and linear polarization was made, using estimated aerosol optical parameters. Simulated images showed that most of characteristic features in the observed images can be theoretically reconstructed.

4) Furthermore, the ocean wind speed at the time of POLDER observation was estimated to be V= 4.0 ~ 6.0 m/sec from the analysis of the observed reflectance data.

1. INTRODUCTION

Let us assume an incident solar flux $\pi \overline{F_0}$ illuminates a plane parallel atmosphere with the optical thickness of τ_{at} from the direction of (μ_0, ϕ_0), where μ_0 and ϕ_0 are the cosine of the solar zenith angle and the solar azimuthal angle, respectively. The incident solar flux is given by Eq.(1) in a Stokes vector representation.

$$\pi \overline{F_0} = \pi [F \quad 0 \quad 0 \quad 0]^t \qquad (1),$$

where a superscript t represents the matrix transposition. The upwelling Stokes vector $\bar{I}\left(\tau_{at}, \mu, \mu_0, \phi - \phi_0\right) = [I \quad Q \quad U \quad V]^t$ at the top of the atmosphere in the direction of (μ, ϕ) can be expressed by Eq.(2) in terms of the reflection matrix of the atmosphere-ocean system $\overline{R}_{at+sf}$.

$$\overline{I}\left(\tau_{at},\mu,\mu_0,\phi-\phi_0\right)=\mu_0\overline{R}_{at+sf}\left(\tau_{at},\mu,\mu_0,\phi-\phi_0\right)\overline{F}_0 \qquad (2).$$

As for the components of the Stokes vector, I is the intensity, Q is related to linear polarization, U to the plane of polarization, and V to circular polarization. By using the adding method [1], $\overline{R}_{at+sf}$ can be expressed in terms of the reflection matrix, $\overline{R}_{at}$, the transmission matrix, $\overline{T}_{at}$, of the atmosphere and the reflection matrix, $\overline{R}_{sf}$, of the sea surface. Since the basic formulations of these matrices were given for a single atmospheric layer with a Gaussian type ocean surface (Cox-Munk model[2]) in our previous paper [3], we will not repeat them here. The degree of linear polarization in the upwelling radiation is given by

$$LP=\frac{\sqrt{Q^2+U^2}}{I} \qquad (3).$$

For simplicity, we shall call it the linear polarization in this paper.

2. ADEOS / POLDER DATA

In this analysis we used the ADEOS / POLDER data set (Path No. 164; Level-1) over Arabian Sea, acquired on Nov. 18, 1996. We selected a particular scene(SceneSequence No. 35) for this study, because of small amount of cloud covers. The observed reflectance and polarization images of Sequence No. 35 at 865[nm] are shown in Fig. 1 -(a) and -(b) , respectively. The definition of reflectance at the top of the atmosphere is given by $\pi I/\mu_0 E_s=\pi I/\mu_0(\pi F)=I/\mu_0$, where E_s is the extraterrestrial solar irradiance. In these images bright tone represents either high reflectance value or high polarization value. The sun glitter is located at right bottom of the reflectance image in Fig.1. The intersecting line between the principal plane and the ocean surface is indicated by a line conecting between two azimuth angles of 0° and 180° , measured from the solar azimuth direction. The principal plane is a plane containing the solar direction, target point, and the viewing direction. The observed reflectance and polarization curves along the principal plane are shown by thin dotted line in Fig. 2-(a) and -(b), respectively. A few of sharp peaks near the viewing zenith angle $\theta=40^\circ$ in the reflectance curve occured due to the presence of clouds in Fig. 2 -(a). The same clouds make polarization decreases in Fig. 2 -(b). The location of the specular reflection occurs at a point where the solar zenith angle θ_0 is equal to the viewing zenith angle θ. In Fig. 2 and 4 such specular point occurs at $\theta_0=\theta=38^\circ$.

3. THE RESULTS

As for aerosol size distribution models, we examined ten typical aerosol models, namely, the Water-Soluble, Oceanic and Junge type power law models with the index of $\nu=3.0$, 3.5, 4.0 and 4.5. The Junge model is given by Eq.(12) [4].

$$n(r) = \begin{cases} C \cdot 10^{\nu+1} & 0.02\mu m \le r \le 0.1\mu m \\ C \cdot r^{-(\nu+1)} & 0.1\mu m \le r \le 10\mu m \\ 0 & r < 0.02\mu m, r > 10\mu m \end{cases} \quad (12)$$

where C is a normalized constant satisfying , $\int_{r_{min}}^{r_{max}} n(r)dr = 1$ and $r_{min} = 0.02\mu m$, $r_{max} = 10\mu m$.

The Water-Soluble and Oceanic model are defined by a Log-normal distribution function. The Maritime model is composed of Water-Soluble (95%) and Oceanic(5%) aerosols. The Continental model is composed of Dust-like(70%), Water-Soluble(29%) and Soot(1%) aerosols. The specific refractive indices, m=1.52-i 1.20×10^{-2}, and m=1.372-i 1.09×10^{-6} are adopted for the Water-Soluble , and the Oceanic models[5]. The 4 cases of refractive index for Junge model are also examined: m= 1.33 -i0.0, m= 1.50-i0.0, m= 1.55-i0.01, and m= 1.55-i0.05. We found that Junge model with n=4.0 - 4.5 and m=1.50-i[0.0 - 0.01] and Water-Soluble model can satisfy the observed reflectance data , as well as the observed polarization data by assuming the aerosol optical thickness of τ_a=0.05. We also found that Junge model with ν=3.5 and m=1.50-i0.05 and that with ν=4.0 and m=1.50-i0.01 are the candidate models when τ_a=0.1 is assumed. These aerosol optical thickness values are within a measured value range of typical ocean aerosols [6], [7].
We also found that Oceanic aerosol model is rejected on the ground that it failed to explain the observed polarization features. In addition, we demonstrated that the simulated reflectance and polarization images, based on the estimated aerosol optical parameters, can explain most of characteristic features in the observed images (see Fig.1-(c) and -(d)). Furthermore, the ocean wind speed at the time of POLDER observation was estimated to be V= 4.0 ~ 6.0 m/sec from the analysis of the observed reflectance data. .

These findings basicly agree with our previous results on the airborne POLDER data[3]. In this preliminary study, other atmospheric parameters, such as the optical thickness values of molecular s and aerosol were adopted from Modtran Code, assuming a tropical atmospheric model with the surface visibility of 23[km]. Furthermore, we assumed an isotropic Gaussian sea surface model and no water column reflectance and no foam coverage.

4. CONCLUSIONS

In this paper we have made an analysis of the space POLDER data over Arabian Sea by the multiple scattering model. Our conclusions based on a single scene analysis are summarized as follows:

1) We found that Junge model with n=4.0 - 4.5 and m=1.50-i[0.0 - 0.01] and Water-Soluble model can satisfy the observed reflectance data , as well as the observed polarization data by assuming the typical ocean aerosol optical thickness values .

2) Oceanic aerosol model was rejected on the ground that it failed to explain the observed polarization features.

3) The image construction for both reflectance and linear polarization was made, using estimated aerosol optical parameters. Simulated images showed that most of characteristic features in the observed images can be theoretically reconstructed.

4) Furthermore, the ocean wind speed at the time of POLDER observation was estimated to be V= 4.0 ~ 6.0 m/sec from the analysis of the observed reflectance data.

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REFERENCES

[1] J. E. Hansen and L. D. Travis, "Light Scattering in Planetary Atmospheres", *Space Sci. Review* , vol.16, pp. 527-610, 1974.

[2] Cox,C. and Munk,W. , "Measurement of the Roughness of the Sea Surface from Photographs of the Sun's Glitter", J. Opt.Soc.Amer. vol. 44, pp. 838-850, 1954.

[3] Kawata, Y., and Yamazaki,A., "Multiple Scattering Analysis of Airborne Polder Image Data over the Sea", IEEE Trans. on GRS. vol.36, No.1, pp.51-60, 1998.

[4] Junge,T., "Aerosols" in Handbook of Geophysics. (Eds. Campen et al.), Macmillan, New York, 1960.

[5] "A Preliminary Cloudless Standard Atmosphere for Radiation Computation," *Radiation Commission, IAMAP, WCP-112, WMO/TD-No.24,* 1986.

[6]Villevalde,Yu. V. et al., "Measurements of Aerosol Optical Depth in the Pacific Ocean and the North Atlantic", J. Geophysical Research, Vol. 99, No. D10, pp.20983-20988 , 1994.

[7] Hoppel, W. A. et al., "Aerosol Size Distribution and Optical Properties Found in the Marine Boundary Layer over the Atlantic Ocean", J. Geophysical Research, Vol. 99, No. D4, pp.3659-3686 , 1990.

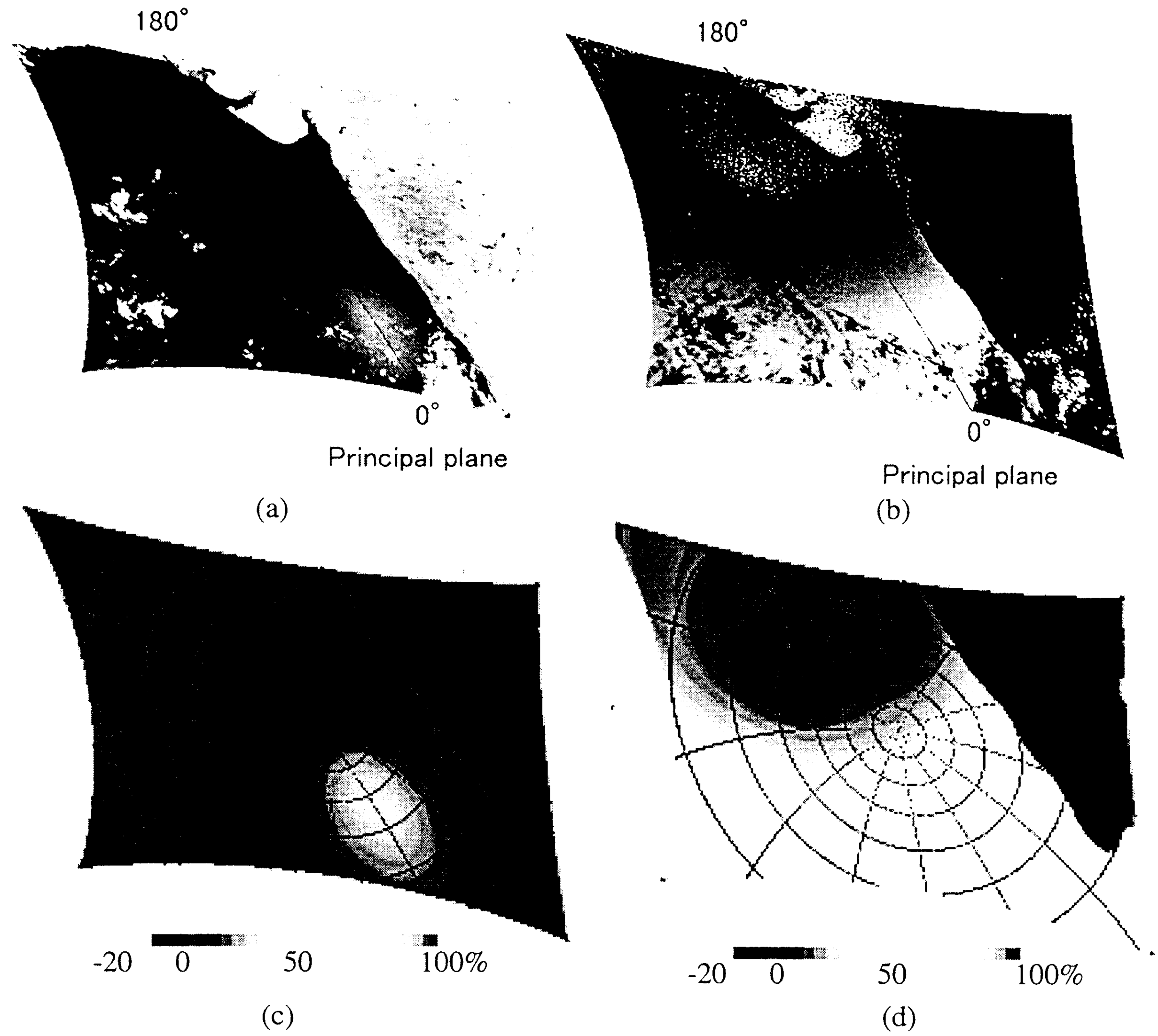

Fig. 1 The observed reflectance (a) and polarization (b) images at 865nm by ADEOS / POLDER. Scene sequence No.35, on Nov. 18, 1996. The simulated reflectance (c) and polarization (d) images, based on Junge aerosol model (ν=4.0 and m=1.50-i0.01) with $\tau_{aerosol}$ = 0.05 and surface wind speed V=5.0 m/sec.

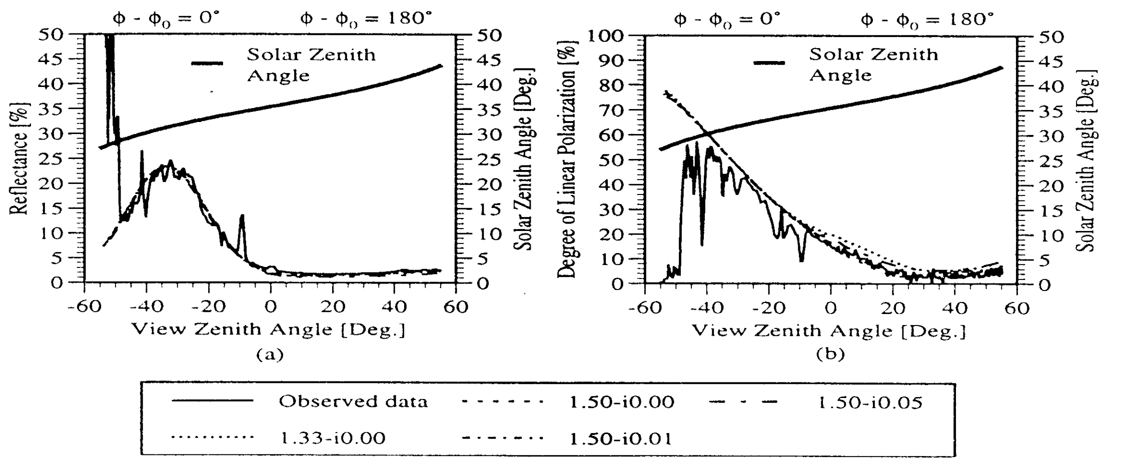

Fig.2 The sensitivity test of complex refractive index m for Junge aerosol model (ν=4.0) in the principal plane at 865nm in the case of $\tau_{aerosol}$ =0.05 and surface wind speed of V=5.0 m/sec.

(a) Reflectance, (b) Degree of linear polarization.