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Land surface analysis by ADEOS/POLDER

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ABSTRACT: In this paper we have analyzed the ADEOS/POLDER data over Mongolia obtained in June 13, 1997. We estimated aerosol's optical thickness and Ångström exponent from both the reflectance and polarization data at 443 nm for the desert area. Using the atmospheric correction scheme based on the retrieval aerosol optical parameters, we got estimates the surface reflectance form POLDER data at 443, 670, and 865 nm. Then we got the Roujean's BRDF parameters for land surfaces.

1. INTRODUCTION

The POLDER has collected eight months global data during the ADEOS satellite's operation period (launched in August, 1996, ended in June, 1997). This sensor has an ability to measure both the directional reflectance and polarization reflected by the earth-atmosphere system. It observes target reflectances and polarizations from up to 14 different viewing directions in a single satellite pass. In addition to the reflectance measurements of the Earth's reflectance image in 8 bands, centered at 443, 490, 565, 763, 865, and 910 nm, it had a capability of measuring the polarizations in 3 bands, centered at 443, 670, and 865 nm.

The bidirectional reflectance distribution function (BRDF) is the strongly anisotropic for the atmosphere and vegetation. The atmospheric aerosol scattering plays an very important role in atmospheric effects. In atmospheric correction scheme we need aerosol optical parameters (Takemata et. al 1998). We attempt to retrieve aerosol optical parameters (i.e., optical thickness and Ångström exponent) over land surfaces by using ADEOS/POLDER's directional reflectance and polarization data before performing the atmospheric correction (Kawata et. al 1998). First, we retrieve local aerosol optical parameters for the desert area in Mongolia from both the reflectance and polarization data at 443 nm (Figure 1). Using the atmospheric correction scheme based on retrieval aerosol optical parameters, we make surface reflectance images from observed reflectance values. Then we get estimates of the Roujean's BRDF fitting parameters for land surfaces at 443, 670, and 865 nm.

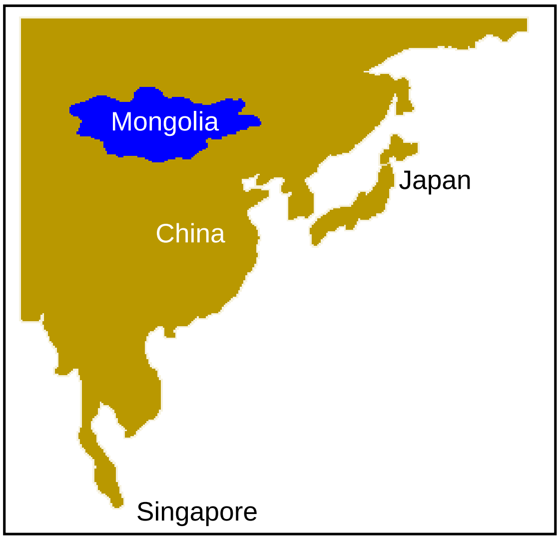

Figure1 Map of study area

2. BACKGROUND

The incident solar flux $\pi \boldsymbol{F}_0$ is given by Eq.(1) in Stokes vector representation,

$$\pi \boldsymbol{F}_0 = \pi[F\ 0\ 0\ 0]^t \qquad (1),$$

where πF is equal to the extra-terrestrial irradiance per unit area normal to the direction of solar rays, E_s[W/m^2] and a superscript t represents the matrix transposition. It illuminates a plane parallel atmosphere from the direction of (μ_0=cos$^{-1}\theta_0$, ϕ_0), where θ_0 and ϕ_0 are the solar zenith and the solar azimuth angle, respectively. The upward Stokes vector $\boldsymbol{I}(\tau, \mu, \mu_0, \phi-\phi_0) = [I\ Q\ U\ V]^t$ at the top of the atmosphere (TOA) in the direction of (μ, ϕ) can be expressed by Eq.(2) in terms of the reflection matrix of the atmosphere - ground surface system $\boldsymbol{R}_{atmos+surface}$,

$$\boldsymbol{I}(\tau, \mu, \mu_0, \phi-\phi_0) = \mu_0 \boldsymbol{R}_{atmos+surface}(\tau, \mu, \mu_0, \phi-\phi_0)\, \boldsymbol{F}_0 \qquad (2).$$

As the components of the Stokes vector, I is the intensity, Q is related to the linear polarization, U to the plane of polarization, and V to the circular polarization. $\boldsymbol{R}_{\text{atmos+surface}}$ can be expressed in terms of the reflection and transmission matrices of the atmosphere, $\boldsymbol{R}_{\text{atmos}}$ and $\boldsymbol{T}_{\text{atmos}}$, and the surface reflection matrix, $\boldsymbol{R}_{\text{surface}}$. We assumed a single atmospheric layer model. These reflection and transmission matrices of the atmosphere can be computed for a given atmospheric model by using the adding and doubling method (Hansen and Travis, 1974). For a natural surface, we assume that the surface reflection matrix consists of the diffuse and specular components. Then $\boldsymbol{R}_{\text{surface}}$ can be expressed as follows,

$$\boldsymbol{R}_{\text{surface}}(\mu, \mu_0, \phi\text{-}\phi_0) = \alpha\rho_{\text{diff}} + (1\text{-}\alpha)\rho_{\text{sp}} \qquad (3),$$

where α is the mixing ratio of the specular to the diffuse components . In Eq.(3), ρ_{diff} and ρ_{sp} represent the diffuse and specular components in the polarized radiation by the target surface, respectively. The diffuse reflectance components is essentially equal to the surface reflectance of Lambertian surface. We shall adopt the simplified Rondeaux and Herman's model for the specular components (Rondeaux and Herman, 1991). It is given by Eq.(4),

$$\rho_{\text{sp}}(\mu,\mu_0,\phi\text{-}\phi_0) = [1 / 4(\mu_0+\mu)]\, \boldsymbol{R}_{sp}(2\omega) \qquad (4).$$

where,

$$\omega = 0.5\cos^{-1}[\cos\theta\cos\theta_0+\sin\theta\sin\theta_0\cos(\phi\text{-}\phi_0)]$$

The space reflectance R and degree of linear polarization P in the reflected radiation at top of atmosphere are given by Eq.(5) and Eq.(6), respectively.

$$\mathrm{R} = \frac{\pi \mathrm{I}}{\mu_0 \mathrm{E_S}} \qquad (5),$$

$$\mathrm{P} = \frac{\sqrt{\mathrm{Q}^2 + \mathrm{U}^2}}{\mathrm{I}} \qquad (6).$$

3. AEROSOL RETRIEVAL

We retrieve aerosol optical parameters (i.e., optical thickness and Ångström exponent) over land surfaces using POLDER's directional reflectance and polarization data in 443 [nm] bands.

As for aerosol size distribution models, we consider Junge type power law model and it is given by Eq.(7),

$$n(r) = \begin{cases} C\cdot 10^{\,v+1} & \text{for } 0.02\text{mm} \le r \le 0.1\text{mm} \\ C\cdot r^{-(v+1)} & \text{for } 0.1\text{mm} < r \le 10\text{mm} \\ 0 & \text{for } r < 0.02\text{mm and } r > 10\text{mm}, \end{cases} \qquad (7),$$

where n(r) is the number density whose particle size is between r and r+dr. C is a constant which is determined to satisfy of particles of radius r per unit increment in radius r.

The aerosol optical thickness τ_λ at any wavelength λ [nm] can be Eq.(8) in terms of τ_{500} .

$$\tau_\lambda \approx \tau_{500}\left(\frac{\lambda}{500}\right)^{-\beta} \qquad (8),$$

where β is Ångström exponent and it is related to Junge's index.

We consider here 5 different types of α, namely, β=0.5, 1.0, 1.5, 2.0, 2.5. As the desert dust, we adopted, m = 1.55 - i0.005 (Tanré et. al, 1988). And we use the optical thickness values of Rayleigh molecules based on the Midlatitude, Spring - Summer model of MODTRAN3.

We compute Look Up Table (LUTs) of the space reflectance and polarization for a given aerosol model with 5 different parametrized aerosol optical thickness at 500 nm, from τ_{500} = 0.0 to τ_{500} = 0.4 with an increment of $\Delta\tau_{500}$=0.1, for 33 different zenith angles of the incident and viewing direction and 72 different azimuthal angle of $\phi\text{-}\phi_0$. In the computation, we assumed a homogeneous atmosphere bounded by a desert surface α=1.0 (i.e., Lambertian surface). The surface was assumed as a dry sand target with a surface reflectance A = 0.05 at 443 nm (Bowker et. al, 1985).

In this study we use sequential POLDER scenes from No.22 to No.41 over Mongolia on June 13, 1997 (Pass No.246; Level-1 data). We can estimate an appropriate set of (τ_{500}, α) which satisfies the observed reflectance and polarization at 443 nm, by using a diagram of theoretical polarization and space reflectances in 443 nm for a given angular condition. Figure 2 shows parametrized Polarization - Space reflectance (P-SR) diagram at the viewing condition of (Scene 30 : θ_0=22.03, θ = 47.54, ϕ-ϕ_0 = 305.18, scattering angle Θ = 117.80). In this diagram, we can find an appropriate solution of (τ_{500} = 0.303, α=1.541) from a location point (marked by $\times$). This target category is "sand", which are identified by the AARS global 4-minute land cover data sets (Tateishi, 1997).

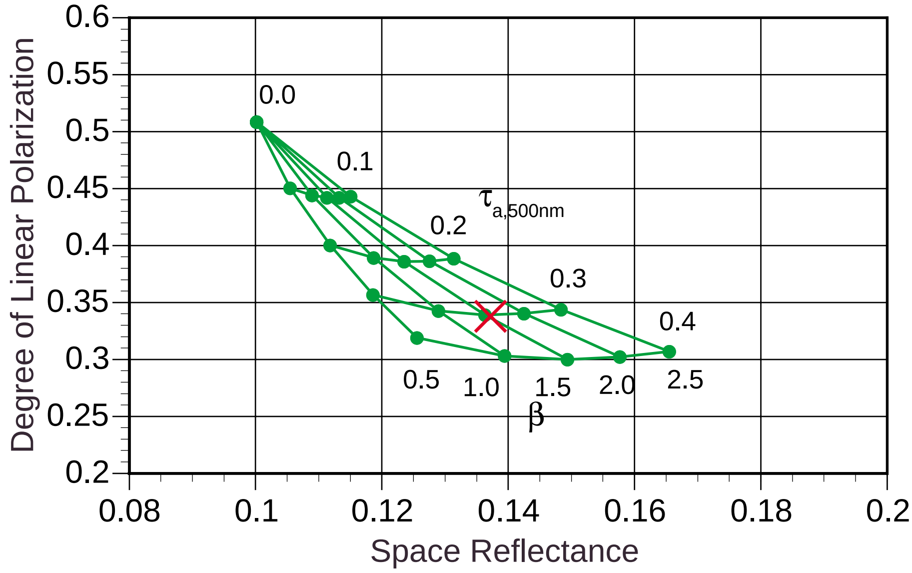

Figure2 Diagrams used by parameterized directional polarization - space reflectance in a single band; "$\times$" represents a target area with observed reflectance and degree of linear polarization values over the desert (sand) area.

4. Surface Reflectance Analysis

In this study we use the POLDER level - 1 data at 443, 670, and 865 nm. Previous results (P-SR diagram) for aerosol optical thickness τ_a and Junge's index ν are used in the atmospheric correction for POLDER Level - 1 data. The optical thicknesses of Rayleigh molecules are used values based on MODTRAN3. The total optical thickness τ is 0.598, 0.241, 0.163 at 443, 670, and 865 nm, respectively. The scattering albedo of the atmosphere ω is 0.964, 0.936, and 0.851 at each wavelength. The molecule gas - aerosol mixing ration f_r for each layer is 0.391, 0.184, and 0.108 at each wavelength.

In this study we selected 9 targets area (each consisting of 3 $\times$ 3 pixels) in Mongolia, i.e. Forest1-3, Grassland1-3, and Desert1-3, which are identified by the AARS global 4-minute land cover data sets. We estimate the Roujean's BRDF parameters for targets at 443 , 670 , and 865 nm (Roujean et al., 1992). This model is given by Eq.(9) and it expressed by the sum of a diffuse reflection component with shadowing effects (f_1) and a volume scattering contribution (f_2),

$$\hat{A}_t(\mu, \mu_0, f) = k_0 + f_1 \cdot k_1 + f_2 \cdot k_2 \tag{9}$$

where ,

$$f_1 = \frac{1}{2\pi}\left[(\pi - \phi)\cos\phi + \sin\phi\right]\tan\theta\tan\theta_0$$

$$-\frac{1}{\pi}\left(\tan\theta + \tan\theta_0 + \sqrt{\tan\theta_0^2 + \tan\theta^2 - 2\tan\theta_0\tan\theta\cos\phi}\right)$$

$$f_2 = \frac{4}{3\pi}\frac{1}{\cos\theta_0 + \cos\theta}\left[\left(\frac{\pi}{2} - \Theta\right)\cos\Theta + \sin\Theta\right] - \frac{1}{3}$$

and $\hat{A}_i$ is the model surface reflectance, Θ is a scattering angle. The coefficients k_0, k_1 and k_2 are obtained with a least square fit on estimated target reflectance values for different viewing angles. The k_0 parameter represents the surface reflectance when both sun and sensor are at nadir. Figure 3 shows the k_0 values of "Forest1-3", "Grassland1-3" and "Desert1-3" at 443, 670, and 865 nm. We found that surface reflectances in "Grassland1-3" and "Desert1-3" show a monotonous increase for the wave length. Then we found that the one for "Forest1-3" show a slight increase in visible wavelength and a steep increase at the near infrared band. It seems that "Grassland 1-3" consists of low vegetated surfaces.

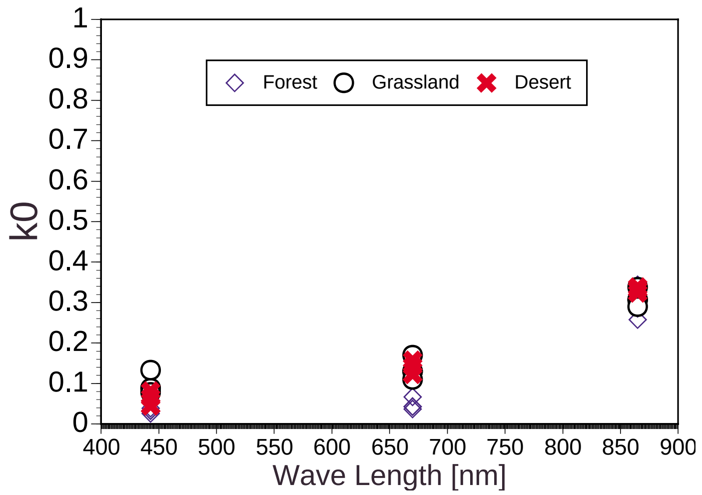

Figure 3 The k_0 variation at 443, 675 and 865 nm for "Forest1-3", "Grassland1-3" and "Deser1-3".

5. CONCLUSIONS

In this study our major work was the retrieval of continental aerosol optical parameters and the atmospheric correction for POLDER data. We can summarize as follows: (1) aerosol's optical parameters over the desert (sand area) are retrieved by using both directional reflectance and polarization data. (2) We got the atmospheric corrected POLDER reflectance data using our atmospheric correction scheme based on the result of (1). (3) Finally, we got preliminary results for surface BRDF parameter retrievals. We certainly need further studies for the atmospheric correction scheme using multidirectional remote sensing data.

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