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Analyzed polarized reflectance model of typical surface types over China based on the PARASOL measurements

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ABSTRACT

In this paper, the parameters of four types of polarization reflectance models (the Breon physical model, the Nadal–Breon semi-empirical model, the Maignan et al. single parameter model, and the Litvinov et al. model) were analyzed based on the PARASOL observation of three typical features in China three sites (forest, grassland, and desert). Subsequently, combined with the model analysis, the polarization reflectance characteristics of each typical feature were studied. The results reveal that 1) the imitative effect of the Litvinov et al. model about forest was the best, as the linear slope was greater than 0.9 and R^2 was better than 0.8; 2) the linear slope and R^2 of the Nadal–Breon model about all surfaces were higher than 0.8; 3) although fitting slope of the Maignan et al. model was bad under the forest ($0.15 < \mathrm{NDVI} < 0.3$) background, the fitting effect was the best for desert and grassland. The results will provide a theoretical basis for the use of multi-angle polarization remote sensing data to detect the physical properties of the surface type and provide a priori knowledge for the quantitative inversion of surface atmospheric parameters.

1. Introduction

Compared to the traditional surface bidirectional reflectance [1,2], the surface polarization reflectance has its unique advantages [3–5], such as the ability to monitor the surface properties more easily (leaf inclination distribution [6], soil moisture [7], vegetation classification [8]), and improve the accuracy of retrieval land aerosol of polarization remote sensing [9–11]. The polarization reflectance is sensitive to the different surface type, the observation angle and so on. Polarization reflectance model is a useful method to describe polarized reflectance. The polarization reflectance model can be obtained by satellite observation data and ground measurement data.

Currently, the research on surface polarization reflectance model has made some progress. Breon et al. [12] developed polarization reflectance models to apply to vegetation and bare soil. Nadal and Breon [13] proposed a semi-empirical polarization reflectance model based on the data obtained from the POLDER instrument [14,11]. Maignan et al. [15] proposed only one parameter of the polarization reflectance model by introducing the normalized difference vegetation index (NDVI) parameter. Litvinov et al. [16] proposed the improved Fresnel model based on the Research Scanning Polarimeter (RSP) [17,18]. Xie et al. [19] retrieved the polarized bidirectional reflectance of the typical features of the Pearl River Delta region in China based on the multi-angle polarized airborne data

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acquired by directional polarimetric camera (DPC) [20]. Diner et al. [21] explored of a polarized surface bidirectional reflectance model using the Ground-based Multi-angle SpectroPolarimetric Imager [22].

As the unique characteristics of China geographical region and the few polarization measurements data from ground and aerial observation, the research on properties of different polarized reflectance on the typical surfaces in China is insufficient. Therefore, in this paper, the different polarized reflectance models of the typical surfaces in China three sites were analyzed based on the PARASOL data in 2008, and the parameters of the models were fitted. Subsequently, the applicability of the models to the typical surfaces of China three sites was analyzed. The result provides a priori knowledge of the physical properties of the ground surface based on multi-angle polarization remote sensing data.

2. Description of the polarized reflectance models for surface

The polarized reflectance models assume that the surface polarization reflectance is generated by the single specular reflection of the surface, and the specular reflection can be expressed by the Fresnel equation.

$$F_p(m,\gamma)=\frac{1}{2}\left(\left(\frac{m\mu_t-\mu_r}{m\mu_t+\mu_r}\right)^2-\left(\frac{m\mu_r-\mu_t}{m\mu_r+\mu_t}\right)^2\right) \quad (1)$$

$$\mu_r=\cos\theta_r,\quad \mu_t=\cos\theta_t \quad (2)$$

$$\sin\theta_r=\mathrm{m}\sin\theta_t,\quad \theta_r=(\pi-\gamma)/2 \quad (3)$$

where $F_p(m,\gamma)$ is the Fresnel equation, m is the refractive index, γ is the scatter angle defined in the scattering plane, θ_r and θ_t are the angles of specular reflection and refraction, respectively. In most cases, to calculate the polarization reflectance for land surfaces, the refractive index m is fixed and is assumed to be equal to 1.5 [23].

2.1. Breon model

Breon et al. [12] developed two surfaces polarization reflectance models based on the different characteristics of vegetation and bare soil surfaces. The models can be written as follows:

$$R_p^{\mathrm{veg}}=\frac{F_p(m,\gamma)}{4(\mu_s+\mu_v)} \quad (4)$$

$$R_p^{\mathrm{soil}}=\frac{F_p(m,\gamma)}{4\mu_s\mu_v} \quad (5)$$

where R_p is the surface polarization reflectance, μ_s and μ_v are the cosine of the solar zenith angle $\theta_s$and the view zenith angle θ_v, respectively. In the application, If the NDVI value is less than 0.15, the bare soil model is used, if the NDVI value is greater than 0.3, the vegetation model is adopted, and if the NDVI value is between 0.15 and 0.3, the polarization reflectance of surface types can be expressed by the weighted combination of the two models of vegetation and bare soil.

2.2. The Nadal–Breon model

Nadal and Breon [13] proposed a semi-empirical polarization reflectance model based on the data from November 1996 and June 1997 obtained from the POLDER, and the model had been applied successfully to the POLDER and PARASOL aerosol inversion algorithm [10]. The Nadal–Breon model for polarized reflectance can be written as follows:

$$R_p^{\mathrm{surf}}(\theta_s,\theta_v,\varphi_r)=\alpha\left[1-\exp\left(-\beta\frac{F_p(\gamma)}{\mu_s+\mu_v}\right)\right] \quad (6)$$

Where φ_r is relative azimuth angle, α and β are the parameters of the model. The values of these parameters are determined by the surface NDVI and the surface classification model provided by the International Geosphere and Biosphere Project (IGBP) [24].

2.3. Linear one-parametric model

A linear one-parameter surface polarized reflectance model was introduced by Maignan et al. [15] based on the assumption of Fresnel reflection from vegetation and bare soil. The model is written as follows:

$$R_p(\theta_s,\theta_v,\varphi_r)=\frac{\alpha\exp(-\tan\theta_r)\exp(-\upsilon)F_p(m,\gamma)}{4(\cos\theta_s+\cos\theta_v)} \quad (7)$$

where α is the only parameter of the model and ν is NDVI. A damping term is introduced, as the equation accounts for the fact that the general polarization reflectance decreases with an increase in NDVI. The larger the incident angle θ_r, the greater the attenuation caused by the roughness of the polarization reflectance, thus the necessity to add the term $\exp(-\tan\theta_r)$ to reflect the influence of the surface roughness.

2.4. Modified Fresnel models

Litvinov et al. [16] introduced a new model for surface polarized reflectance based on the RSP polarimetric data. The model is based on a Fresnel reflection model from Gaussian random rough surface [25] and introduces a shadowing function with maximum in backscattering direction [26]. The modified Fresnel model for polarized reflectance can be written as follows:

$$Rp(\theta_v,\theta_0,\phi)=\frac{\alpha\pi Fp(m,\gamma)}{4\mu_n(\cos\theta_v+\cos\theta_0)}f(\mathbf{n}_v,\mathbf{n}_0)f_{sh}(\gamma) \quad (8)$$

$$f(n_v,n_0)=\frac{1}{\pi\mu_n^3 2\sigma^2}\exp\left(-\frac{1-\mu_n^2}{\mu_n^2 2\sigma^2}\right) \quad (9)$$

$$f_{sh}(\gamma)=\left(\frac{1+\cos k_\gamma(\pi-\gamma)}{2}\right)^3 \quad (10)$$

$$\mu_n=\frac{n_v^z+n_0^z}{|\mathbf{n}_v+\mathbf{n}_0|} \quad (11)$$

$$\mathbf{n}_0=(\sin\theta_0\cos\varphi_0;\sin\theta_0\sin\varphi_0;\cos\theta_0) \quad (12)$$

$$\mathbf{n}_v=(\sin|\theta_v|\cos\varphi_v;\sin|\theta_v|\sin\varphi_v;\cos\theta_v) \quad (13)$$

where α, σ, and k_γ are the three parameters of the model,