Remote Sensing of Aerosol Over Vegetation Cover Based on Pixel Level Multi-Wavelength Polarized Measurements

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Abstract

Often the aerosol contribution is small compared to the surface covered vegetation. while, atmospheric scattering is much more polarized than the surface reflection. In essence, the polarized light is much more sensitive to atmospheric scattering than to reflection by vegetative cover surface. Using polarized information could solve the inverse problem of separating the surface and atmospheric scattering contributions. This paper presents retrieval of aerosols properties from multi-wavelength polarized measurements. The results suggest that it is feasible and possibility for discriminating the aerosol contribution from the surface in the aerosol retrieval procedure using multidirectional and multi-wavelength polarization measurements.
Keywords: Aerosol, remote sensing, polarized measurements, short wave infrared

1. Introduction

Atmospheric aerosol forcing is one of the greatest uncertainties in our understanding of the climate system. To address this issue, many scientists are using Earth observations from satellites because the information provided is both timely and global in coverage [2], [4]. Aerosol properties over land have mainly been retrieved using passive optical satellite techniques, but it is well known that this is a very complex task [1]. Often the aerosol contribution is small compared to the surface scattering, particularly over bright surfaces [5]. On the other hand, atmospheric scattering is much more polarized than ground surface reflection [3]. This paper presents a set of spectral and directional signature of the polarized

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reflectance acquired over various vegetative cover. We found that the polarization characteristics of the surface concerned with the physical and chemical properties, wavelength and the geometric structure factors. Moreover, we also found that under the same observation geometric conditions, the Change of polarization characteristics caused by the surface geometric structure could be effectively removed by computing the ratio between the short wave infrared bands (SWIR) polarized reflectance with those in the visible channels, especially over crop canopies surface. For this crop canopies studied, our results suggest that using this kind of the correlation between the SWIR polarized reflectance with those in the visible can precisely eliminate the effect of surface polarized characteristic which caused by the vegetative surface geometric structure. The algorithm of computing the ratio of polarization bands have been applied to satellite polarization datasets to solve the inverse problem of separating the surface and atmospheric scattering contributions over land surface covered vegetation. The results suggest that compared to using a typically based on theoretical modeling to represent complex ground surface, the method does not require the ground polarized reflectance and minimizes the effect of land surface. This makes it possible to accurately discriminating the aerosol contribution from the ground surface in the retrieval procedure.

2. Theory and backgrand

Polarization (Brit. polarisation) is a property of waves that describes the orientation of their oscillations. The polarization is described by specifying the direction of the wave's electric field. According to the Maxwell equations, the direction of the magnetic field is uniquely determined for a specific electric field distribution and polarization. The simplest manifestation of polarization to visualize is that of a plane wave, which is a good approximation of most light waves. For plane waves the transverse condition requires that the electric and magnetic field be perpendicular to the direction of propagation and to each other. Conventionally, when considering polarization, the electric field vector is described and the magnetic field is ignored since it is perpendicular to the electric field and proportional to it. The electric field vector of a plane wave may be arbitrarily divided into two perpendicular components labeled x (0^0) and y (90^0) (with z indicating the direction of travel). The two components have exactly the same frequency. However, these components have two other defining characteristics that can differ. First, the two components may not have the same amplitude. Second, the two components may not have the same phase. That is they may not reach their maxima and minima at the same time.

Although direct, unscattered sunlight is unpolarized, sunlight reflected by the Earth's atmosphere is generally polarized because of scattering by atmospheric gaseous molecules and aerosol particles. Linearly polarized light can be described by the Stokes parameters (The Stokes parameters are a set of values that describe the polarization state of electromagnetic radiation (including visible light). They were defined by George Gabriel Stokes in 1852) I, Q, and U, which are defined, relative to any reference plane, as follows:

$$I = I0° + I90° \tag{1}$$

$$Q = I0° - I90° \tag{2}$$

$$U=I45°-135° \tag{3}$$

where I is the total intensity and Q and U fully represent the linear polarization. In Eqs.(1)–(3) the angles denote the direction of the transmission axis of a linear polarizer relative to the reference plane. The degree of linear polarization P is given by

$$P = \frac{\sqrt{Q^2 + U^2}}{I} \tag{4}$$

and the direction of polarization x relative to the reference plane is given by

$$\tan 2x = \frac{U}{Q} \tag{5}$$

For the unique definition of x , see Figure 1.

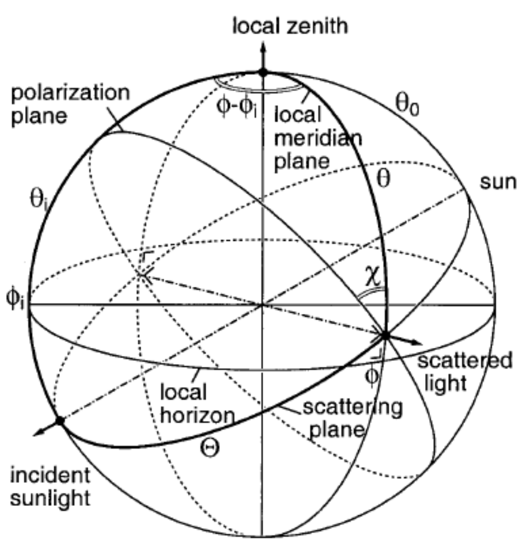

Fig. 1. Geometry of scattering by an atmospheric volume element. The volume element is located in the origin

In Figure 1 the local zenith and the incident and scattered light rays define three points on the unit circle. Applying the sine rule to this spherical triangle (thicker curves in the figure) yields.

$$\cos x = \frac{\sin\theta_i \sin(\phi - \phi_i)}{\sin\Theta} \frac{\sin(\frac{\pi}{2} + x)}{\sin\theta_i} = \frac{\sin(\phi - \phi_i)}{\sin\Theta} \tag{6}$$

Therefore polarization angle x , i.e., the angle between the polarization plane and the local meridian plane, is given by

$$\cos x = \frac{\sin\theta_i \sin(\phi - \phi_i)}{\sin\Theta} \tag{7}$$

The zenith and azimuth angles of the incident sunlight are (θ_i, ϕ_i), and the zenith and azimuth angles of the scattered light ray (the observer) are (θ, ϕ). The solar zenith angle is $\theta_0 = \pi - \theta_i$. With these definitions, scattering angle Θ is given by

$$\cos\Theta = \cos\theta\cos\theta_i + \sin\theta\sin\theta_i\cos(\phi - \phi_i),\ 0 \le \Theta \le \pi \tag{8}$$

3. Aerosol Polarization

From Mie calculation of the light scattered by spherical particles with dimensions representative of terrestrial aerosols, one can guess that polarization should be very informative about the particle size distribution and refractive index. Inversely, because polarization is very sensitive to the particle properties, this information is nearly untractable without a priori knowledge of the particle shape (Mishchenko and Travis, 1994). Over the past decades, considerable effort has been devoted to the study of aerosol polarization properties. One uses appropriate radiative transfer calculations to evaluate the contribution of aerosol polarization scattering. The aerosol's size distribution and refractive index are derived simultaneously from their scattering properties.

The simulations are performed by a successive order of scattering (SOS) code. We assume a plane-parallel atmosphere on top of a Lambertian ground surface with uniform reflectance $\rho = 0.3$ and a bi-direction reflectance with BPDF model, a typical and bi-direction reflectance value of ground reflectance at the near-infrared wavelength considered. The aerosols are mixed uniformly with the molecules. The code accounts for multiple scattering by molecules and aerosols and reflection on the surface. Polarization ellipticity is neglected. The results are expressed in terms of polarized radiance Lp, defined by

$$Lp = \sqrt{Q^2 + U^2} \tag{9}$$

3.1 Relationship between aerosol polarization phase function and particle physical properties

Aerosol polarization phase function is known to be highly sensitive to aerosol optical properties, especially aerosol absorption properties, as was shown by Vermeulen et al [6] and Li et al [7]. Polarization phase function provided important information for aerosol scattering properties. Figure 2(a) [Li et al]shows the calculated polarization phase function in the principal plane as a function of the scattering angle. The calculations correspond to those for aerosol with four types of refractive index and the size distribution given by the bimodal log-normal model for sensitivity of polarization phase function to the aerosol real (scattering) and imaginary (absorption) part of refractive index. It can be seen from

Figure 2(a) that the aerosol refractive index (including real and imaginary part) is highly sensitive to polarized phase function. Typically, we consider that the difference among polarized phase function curves of various aerosol refractive index at the range of scattering angle 30^0--90^0 is quite significant, showing a characteristic of the sensitivity of aerosol polarized phase function to refractive index. Moreover, the maximum value at the scattering angle from 30^0 to 90^0 is more accessible in the principal-plane geometry.

For the size distribution model of aerosol particle, Figure 2(b) is the curve of polarized phase function of three size distribution models with the same index of refractive. It can be seen from Figure 2(b) that the aerosol size distribution models is also highly sensitive to polarized phase function[7]. The aerosol size distribution models can significantly affect the polarization function. That is to say, the polarization phase function of aerosol can be used to be important information to retrieve the size distribution model of aerosol.

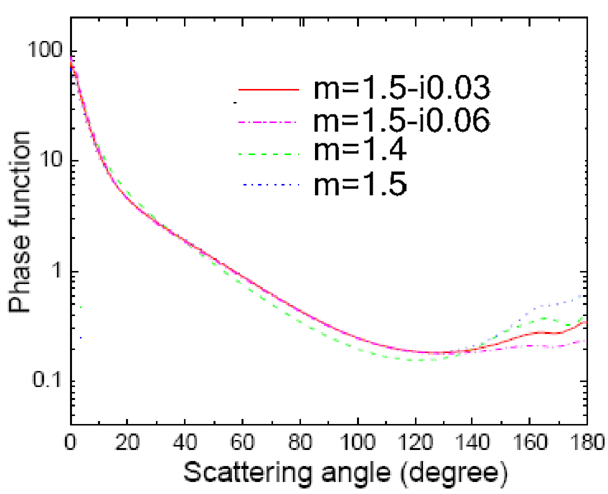

Fig. 2(a)

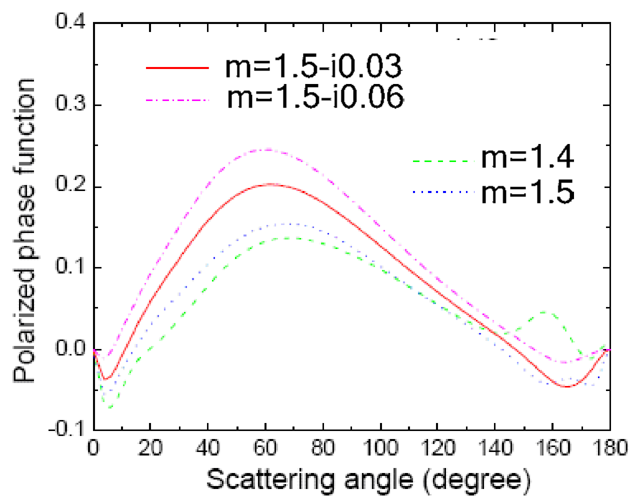

Fig. 2(b)

3.2 Polarization radiance response to aerosol optical thickness and wave lengths

Aerosol polarization radiance is sensitive to aerosol optical thickness. For remote sensing of aerosol, polarization radiance is nearly additive with respect to the contributions of molecules, aerosols. Figure 2(c) shows the calculated aerosol polarization radiance in the principal plane as a function of the observation zenith angle. The curves of the aerosol polarized radiance are calculated at 865nm, for different aerosol optical thickness with the size distribution given by the bimodal log-normal model for the sensitivity of aerosol polarization radiance to the aerosol optical thickness. It can be seen from Figure 2(c) that the aerosol polarization radiance is highly sensitive to aerosol optical thickness. Aerosol optical thickness can be derived from aerosol polarization radiance measurements. Aerosol polarization measurements can be used to retrieve the aerosol optical properties.

For the spectral wavelength, Figure 2(d) shows typical results for the sensitivity of aerosol polarized radiance to the spectral wavelength. The different curves correspond to different aerosol polarized radiance at 865nm, 670nm and 1640nm. It can be seen from Figure 2(d) and 3(d) that polarization will allow to retrieve aerosol key parameters concerning spectral wavelength.

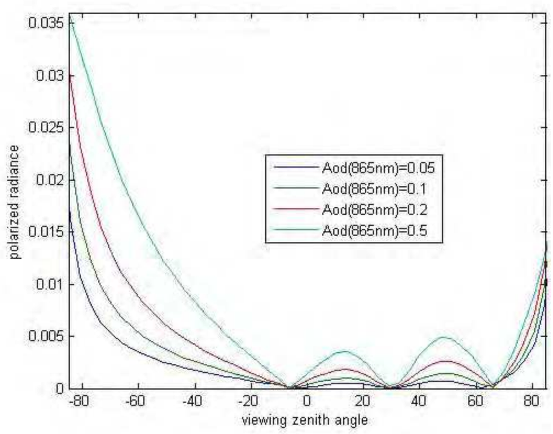

Fig. 2(c)

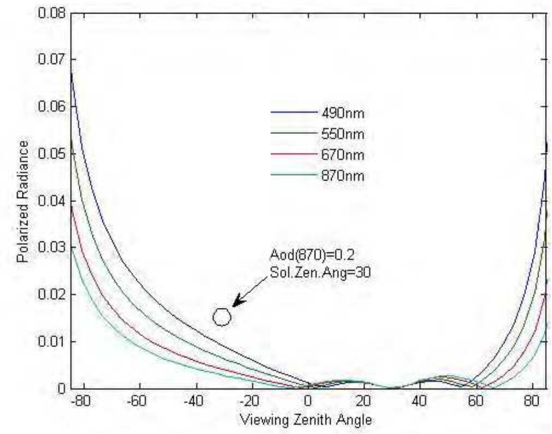

Fig. 2(d)

4. Vegetation Polarization model

In the remote sensing of aerosol over land surface, a parameterization of the surface polarized reflectance is needed for the characterization of atmospheric aerosol over land surface. Because the aerosols properties are efficient at polarizing scattered light. Whereas the surface reflectance is little polarized, that is the reason why the polarization measurements can be used to estimate the atmospheric aerosol properties over land surface [2]. Although small, the surface contribution to the top of the atmosphere (TOA) polarized reflectance cannot be neglected and some parameterization is required. In addition, the parameter of the surface is used as a boundary condition for solving vector radiative transfer (VRT) in both direct and inverse problems. In general, the bidirectional polarization distribution functions (BPDF) is used to estimate the atmospheric contribution to the TOA signal. The function will be used as a boundary condition for the estimate of atmospheric aerosol from polarization remote sensing measurements over land surface.

In most cases, measurements of linear polarization of solar radiation reflected by a plant canopy just provide a simple and relatively cheap way to obtain the characterization of a plant canopy polarized reflectance. Although it demonstrates the relationships between polarized light scattering properties and plant canopies properties, more research is needed if the complexity and diversity inherent in plant canopies is to be modeled, especially more practical BPDF model as a boundary condition for the estimate of atmospheric aerosol.

For remote sensing of aerosol over land surface including polarization information, the vector radiative transfer equation accounting for radiation polarization provides the power simulation of a satellite signal in the solar spectrum in a mixed molecular-aerosol atmosphere and surface polarized reflectance. In order to present the characterization of the TOA polarized reflectance of vegetated surface, some simulation accounting for radiation polarization in atmosphere and surface were made. In what follows, we used the method of successive orders of scattering (SOS) approximations to compute photons scattered one, two, three times, and etc. Rondeaux's , Breon's and Nadal's BPDF models were used to calculate the contribution of the land surface covered plant canopies polarized reflectance as a boundary condition to solve vector radiative transfer equation. It is noticed that:

4.1 The TOA polarized reflectance of vegetation cover depends on zenith angle of sunlight.

Upward polarization radiation at the top of the atmosphere was computed by the successive orders of scattering (SOS) approximations method for wavelengths (λ) of 443 μm . Polarization radiation at the TOA varies according to the angle of incidence. As shows in Figure 3(a) and (b).

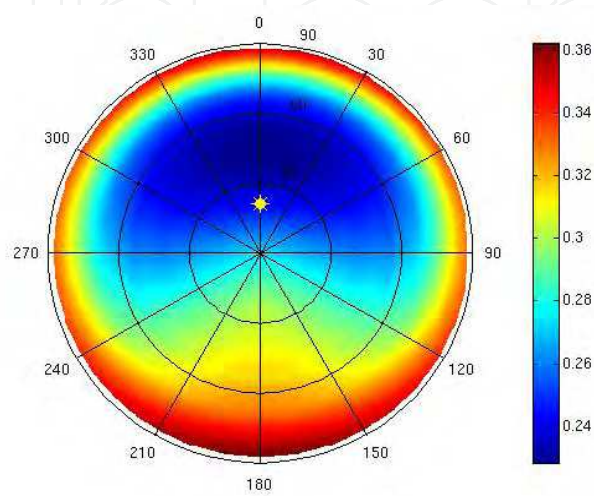

Fig. 3(a)

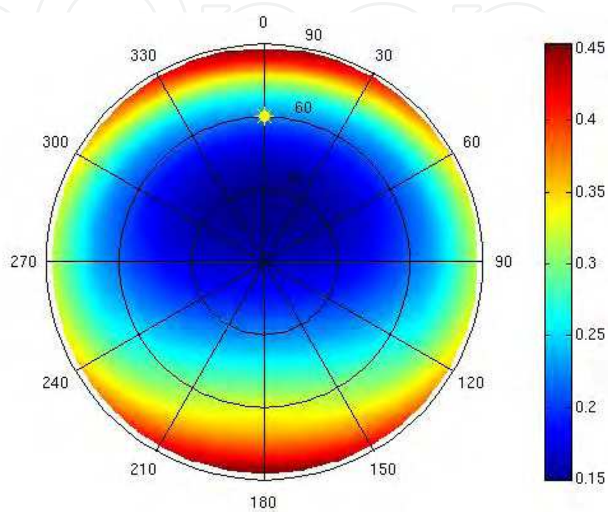

Fig. 3(b)

4.2 Surface BPDF with different land cover types or model

Characterization of the polarizing properties of land surfaces raises probably a more complicated problem than for the atmosphere, on account of the large diversity of ground targets. Concerning the underlying polarizing mechanism, it is usually admitted that land surfaces are partly composed of elementary specular reflectors (water facets, leaves, small mineral surfaces) which, according to Fresnel's law, reflect partially polarized light when illuminated by the direct sunbeam. There is convincing evidence that it is correct in the important case of vegetation cover [Vanderbilt and Grant, 1985; Vanderbilt et al., 1985; Rondeaux and herman, 1991]. By assuming this hypothesis and restricting to singly reflected light, we can anticipate that the main parameters governing the land surface bidirectional polarization distribution function (BPDF), apart from the Fresnel coefficients for reflection, should be the relative surface occupied by specular reflectors, the distribution function of the orientation of these reflectors, and the shadowing effects resulting from the medium structure [7]. Plant canopies structure is difficult to model with single BPDF.

As example of land surface canopy BPDF predicted within this context, we consider the TOA polarized radiance contribution of the model for vegetative cover depends on canopy structure, cellular pigments and refractive indices of vegetation, as the Figure 3(c) and (d) shown. It can be seen in Figure 3(c) that the polarized radiance distribution in 2π space is controlled by directions of both incidence and reflection, and by the main parameters governing the vegetative structures. Comparison of Figure 3(c) and Figure 3(d) shows that according to difference of the refractive indices, the reflective distribution of the polarized radiance varies correspondingly.

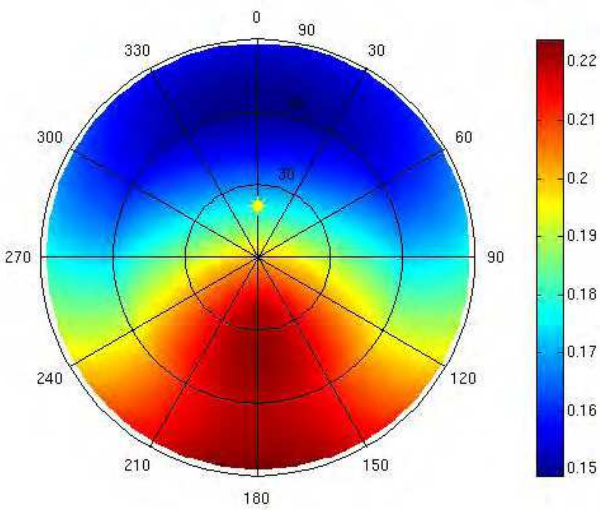

Fig. 3(c)

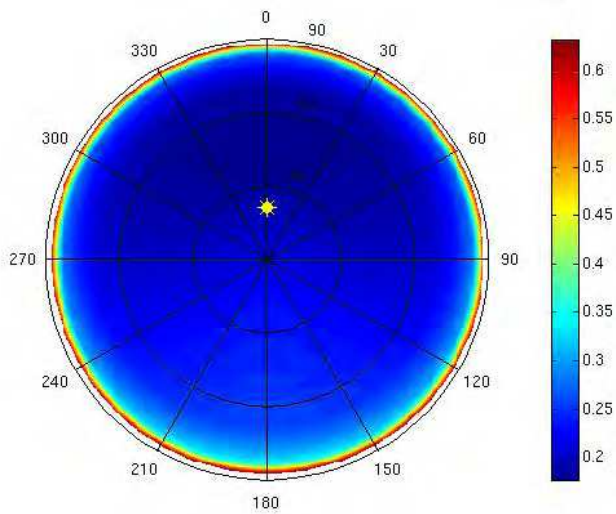

Fig. 3(d)

4.3 Retrieval of TOA contribution of aerosol and land surface polarization

The TOA measured polarized radiance is the sum of 3 contributions: aerosol scattering, Rayleigh scattering, and the reflection of sun light by the land surface, attenuated by the atmospheric transmission on the down-welling and upwelling paths. In order to find out the influence of aerosol and land surface polarization on the TOA polarized contribution, we choose different aerosol model and aerosol optical thickness at a certain land surface BPDF model condition as study parameters.

In this study, the contribution of land surface was calculated by BPDF derived from ground-based measurements for vegetative cover [Rondeaux and herman, 1991], for the atmospheric aerosol, an externally mixed model of these aerosol components is assumed [15]. The size distribution for each aerosol model is expressed by the log-normal function,

$$\frac{dn(r)}{d\ln r} = \frac{1}{\sqrt{2\pi}\ln\sigma}\exp\left(-\frac{(\ln r - \ln r_m)^2}{2\ln^2\sigma}\right) \tag{10}$$

Where rm is the median radius and ln r is the standard deviation. The rm and r values are 0.3 μm and 2.51 μm for the OC model [5], the refractive indices at $\lambda = 443\mu m$ is 1.38±i8.01 for the OC model, and 1.53±i0.005 and 1.52±i0.012 for the WS model. The scattering matrices are computed by the Mie scattering theory for radii ranging from 0.001 to 10.0 μm assuming the shape of aerosol particles to be spherical. We can see from the experiment result that the TOA polarized radiance in 2π space is obvious difference, varying according to the aerosol optical thickness Figure 3(e) and 3(f). Comparison of Figure 3(g) and 3(h) also shows that this difference in aerosol model implies influence on polarized radiance distribution in 2π space. Clearly, different assumptions about the aerosol model have large difference in the TOA polarized radiance.

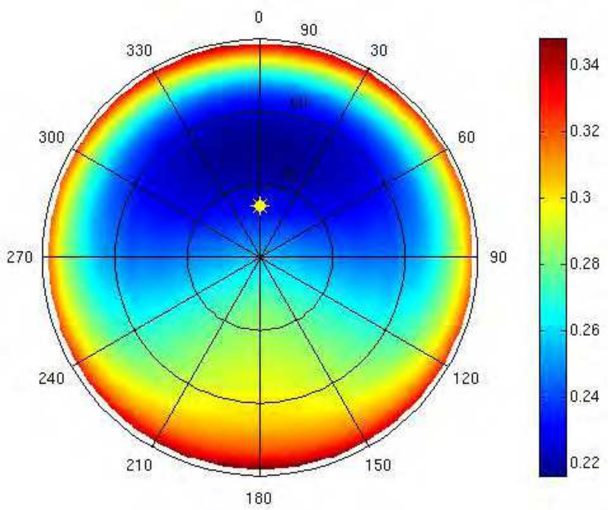

Fig. 3(e) aerosol optical depth is 0.2

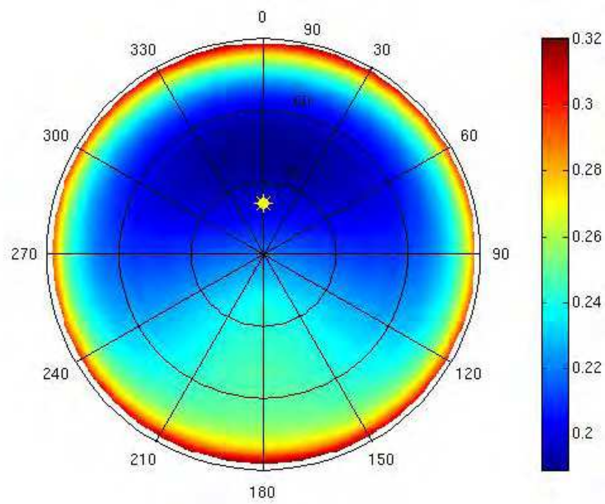

Fig. 3(f) aerosol optical depth is 0.5

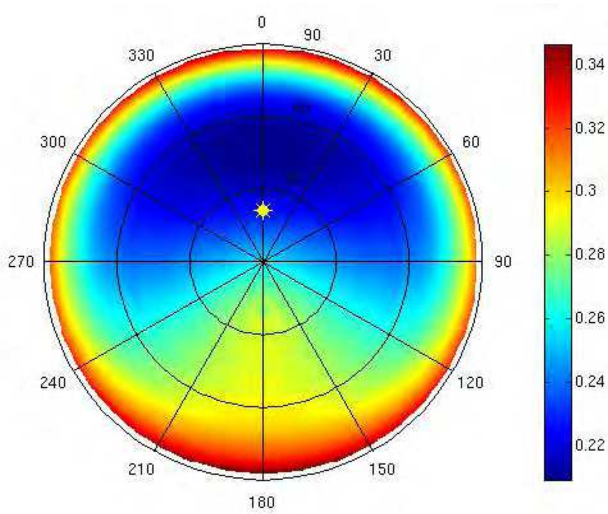

Fig. 3(g) Aerosol model is Jung model

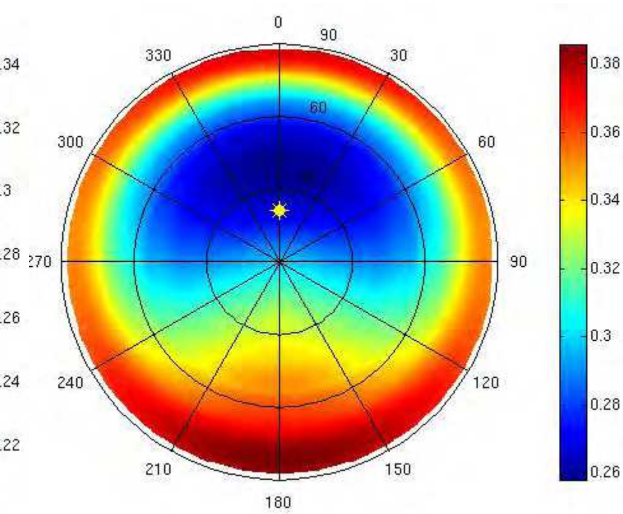

Fig. 3(h) aerosol model is WMO

4. Based on short-wave infrared band polarized model

Solar light reflected by natural surfaces is partly polarized. The degree of polarization, and the polarization direction, may yield some information about the surface such as its roughness, its water content, or the leaf inclination distribution. It is believed that polarized light is generated at the surface by specular reflection on the leaf surfaces. This hypothesis has been used to elaborate analytical models for the polarized reflectance of vegetation. Because of this fact and because the refractive index of natural targets (e.g. leaf of vegetation) varies little within the spectral domain of interest (visible and near IR), the surface polarized reflectance is spectrally neutral, in contrast with the total reflectance. Based on this polarization information and the requirement of the surface polarized reflectance, we can choose to study space-borne polarized reflectance with multi-wavelengths and multi-direction measurements.
The observations of the earth from space that have included polarization measurements are those in an exploratory project aboard the space Shuttle (Coulson et at. ,1986). By the nature

of the problem, however, solar radiation directed to space at the level of the Shuttle and other spacecraft contains a significant component due to scattering by the atmosphere, meanwhile that due to surface reflection. For atmospheric characterization and discrimination, however, such surface reflection contamination of the radiation field should be minimized or corrected for by use of radiative transfer models applicable to the conditions of observation. For maximum information content, of course, both intensity and state of polarization of the scattering by the atmosphere should be included.

Light would consist of components $E_{\perp}$ and $E_{=}$, normal and parallel, respectively, to the principal plane. Fresnel's laws of reflection give the reflected electric intensity components.

$$E'_{\perp} = -\frac{\sin(\alpha-\beta)}{\sin(\alpha+\beta)} E_{\perp} \tag{11}$$

$$E'_{=} = \frac{tg(\alpha-\beta)}{tg(\alpha+\beta)} E_{=} \tag{12}$$

Thus from the definition of the Fresnel degree of polarization, we have

$$P = \frac{E'^2_{\perp} - E'^2_{=}}{E'^2_{\perp} + E'^2_{=}} = \frac{E_{\perp}^2 \frac{\sin^2(\alpha-\beta)}{\sin^2(\alpha+\beta)} - E_{=}^2 \frac{tg^2(\alpha-\beta)}{tg^2(\alpha+\beta)}}{E_{\perp}^2 \frac{\sin^2(\alpha-\beta)}{\sin^2(\alpha+\beta)} + E_{=}^2 \frac{tg^2(\alpha-\beta)}{tg^2(\alpha+\beta)}} \tag{13}$$

Since Fresnel's laws of refraction, in which case Eq. (11) and Eq. (12) reduces to

$$\frac{E'_{\perp}}{E_{\perp}} = -\frac{\sqrt{N^2 - \sin^2\alpha} - \cos\alpha}{\sqrt{N^2 - \sin^2\alpha} + \cos\alpha} \tag{14}$$

$$\frac{E'_{=}}{E_{=}} = \frac{N^2\cos\alpha - \sqrt{N^2 - \sin^2\alpha}}{N^2\cos\alpha + \sqrt{N^2 - \sin^2\alpha}} \tag{15}$$

Obviously, for unpolarized light $E_{\perp}^2 = E_{=}^2$, for convenience, we summarize the relations Eq.(13) and Eq. (14) as follows:

$$P = \frac{2\cos\alpha\sqrt{1 - \frac{\sin^2\alpha}{N^2}}\sin\alpha\frac{\sin\alpha}{N}}{\cos^2\alpha\frac{N^2 - \sin^2\alpha}{N^2} + \sin^2\alpha\frac{\sin^2\alpha}{N^2}} = \frac{2\sin\alpha tg\alpha\sqrt{N^2 - \sin^2\alpha}}{N^2 - \sin^2\alpha + \sin^2\alpha tg^2\alpha} \tag{16}$$

Here N is the index of refraction of the medium, and α is the angle of incidence or reflection. The index of refraction N is related to the wavelength.

This shows that the degree of polarization is related to the wavelength and the angle of incidence or reflection Figure 4(a). Furthermore, under the same observation geometric conditions, this important relationship also shows that the degree of polarization of the SWIR (short wave infrared band) is related to that of the visible rang Figure 4(b).

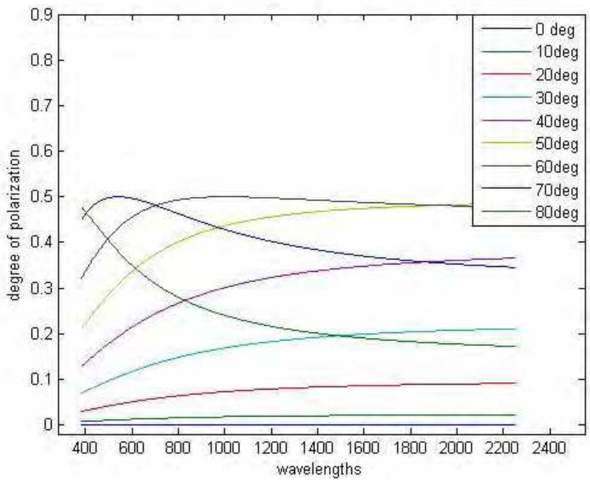

Fig. 4(a)

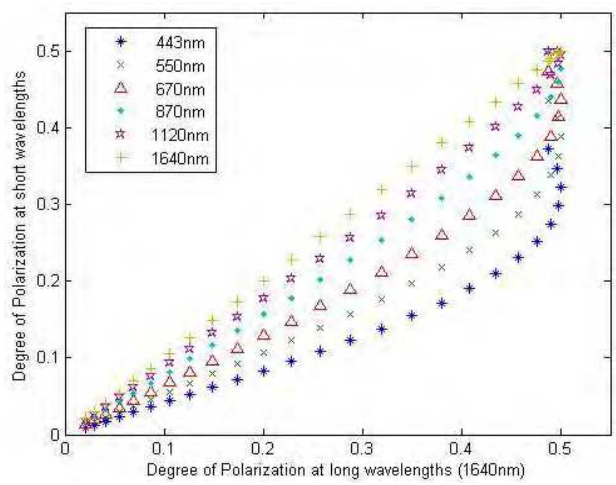

Fig. 4(b)

Figure 4(a) shows the relationship between degree of polarization and wavelengths and the angle of incidence or reflection and (b) between degree of polarization at long wavelengths 1640nm and that at short wavelengths

In Figure 4(b), we found that the SWIR is similar to the visible channels by polarized. That is, the polarized reflectance in SWIR could be used similarly to quantify that in the visible wavelength. This fact would find important applications in solving the inverse problem of separating the surface and atmospheric scattering contributions.

With these and atmospheric conditions, we find, after some algebraic manipulation that

$$\frac{L_{\lambda swir}}{L_{\lambda vi}} = \frac{R_p(\omega, \lambda_{swir}) * e^{-\tau_s(\lambda_{swir})/u_s}}{R_p(\omega, \lambda_{vi}) * e^{-\tau_s(\lambda_{vi})/u_s}} = \frac{R_p(\omega, \lambda_{swir})}{R_p(\omega, \lambda_{vi})} * e^{-(\tau_1 - \tau_2)/u_s} \tag{17}$$

Where $R_P(\omega, \lambda)$ is given by

$$R_p(\omega, \lambda) = \frac{1}{2}\left[\frac{\sqrt{N^2 - \sin^2\omega} - \cos\omega}{\sqrt{N^2 - \sin^2\omega} + \cos\omega}\right]^2 - \left[\frac{N^2\cos\omega - \sqrt{N^2 - \sin^2\omega}}{N^2\cos\omega + \sqrt{N^2 - \sin^2\omega}}\right]^2 \tag{18}$$

Where $L_{\lambda swir}$ and $L_{\lambda vi}$ are the polarized reflected radiance at long wavelengths and that at short wavelengths, respectively, ω is the scattering angle, and τ is atmospheric optical thickness.

The principle of the algorithm can be seen in Eq. (17). The relationship of the degree of polarization between two wavelengths (the visible rang and short wave infrared band) from the radiative transfer calculation is shown as a function of the aerosol optical thickness at the visible rang and the short wave infrared band.

5. Based on pixel-level multi-angle remote sensing of aerosol

The first space-based polarization measurements were undertaken by ADEOS/POLDER. The POLDER has supplied the observed data not only in the multi-wavelength bands but also at the multi-viewing angles. These directional measurements include significant information of atmospheric aerosols. This work is a feasibility study of multi-directional data for the retrieval of aerosols characteristics. The basic algorithm for aerosol retrieval is based on light scattering simulations of polarization field, where the heterogeneous aerosol model according to Maxwell-Garnett mixing rule is considered. It is shown that polarization data observed at multi-angles is a powerful tool to retrieve aerosol characteristics.

The information provided polarization space-borne sensor permit the development of a new approach to retrieving the aerosol loading at a global scale. The main contribution to the TOA polarized radiance at short wavelengths is due to the aerosols and molecules of the atmosphere, while the contribution of the surface is generally smaller than that of the aerosols. The contribution of atmospheric molecules, although significant at short wavelengths, is nearly invariant and can be easily modeled. That of the surface is more variable but the Eq. (17) and Eq. (18) show that it can be modeled with the polarized reflectance in SWIR, since the contribution of atmospheric aerosol at long wavelengths is generally small and always possible to be negligible. The contribution of the surface at long wavelengths could be used similarly to quantify that at short wavelength. Thus, the aerosol contribution to the polarized radiance can in principle be extracted from the measurement with computing the ratio between the SWIR ground polarized reflectance and those in the visible channels.

The measured polarized radiance L_{pol} is modeled as

$$L_{pol} = L_{aer} + L_{mol} + L_{surf} \tag{19}$$

that is, the sum of 3 contributions : L_{aer}, generated by aerosol single scattering, L_{mol}, by Rayleigh scattering, and L_{surf}, due to the reflection of sun light by the surface, attenuated by the atmospheric transmission on the down-welling and upwelling paths. These terms are expressed as:

$$L_{aer}(\lambda, \theta_s, \theta_v, \phi) = \frac{\tau_a(\lambda)}{4\cos\theta_v} \frac{E_s}{\pi} Q_a(\lambda, \omega, n) \tag{20}$$

$$L_{mol}(\lambda, \theta_s, \theta_v, \phi) = \frac{\tau_m(\lambda)}{4\cos\theta_v} \frac{E_s}{\pi} Q_m(\lambda, \omega) \tag{21}$$

$$L_{surf}(\lambda, \theta_s, \theta_v, \phi) = \cos\theta_s \frac{E_s}{\pi} R_p(\omega, \lambda) * \exp(\tau_m(\lambda)(\frac{1}{\cos\theta_v} + \frac{1}{\cos\theta_s})) \tag{22}$$

Where $\tau_a(\lambda)$ and $\tau_m(\lambda)$ are the optical thickness of the aerosols and of the molecules, respectively. E_s is the TOA solar irradiance. $Q_m(\lambda, \omega)$ and $Q_a(\lambda, \omega, n)$ are pre-calculated functions, which depend on the geometric angles θ_s ,θ_v , ϕ only through the scattering angle ω . By performing some algebraic manipulation from Eq. (17)-(22), it is seen that the contribution of the surface at short wavelengths could be quantified with that at long wavelengths.
Inversions were performed with this important relationship. The TOA Polarized reflectance measurements were screened for cloud contamination and corrected for gas absorption. Based on lookup tables composed of optical contributions from mono-modal lognormal aerosol size distributions with fixed standard deviations, but with several values of the modal radius and refractive index, we made use of one week of space-borne POLDER acquisition on from November 7 to 12 , 2007 Beijing China, (latitude $39^0 58'37''$, longitude $116^0 22'51''$). The retrieval method described above for AOD from POLDER yields the AOD composite images of Figure 5a.

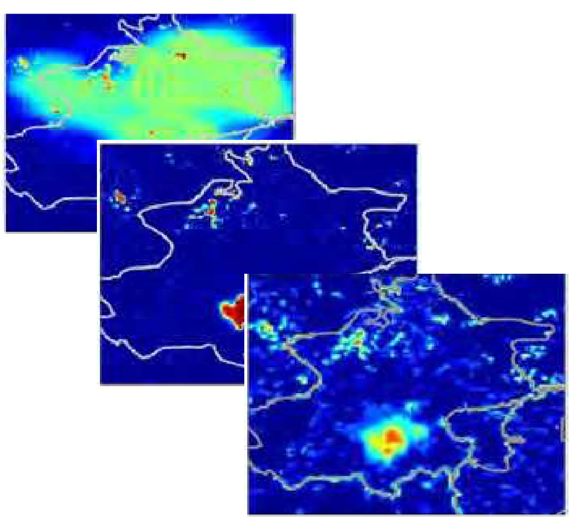

Fig. 6a the composite images of aerosol optical thickness

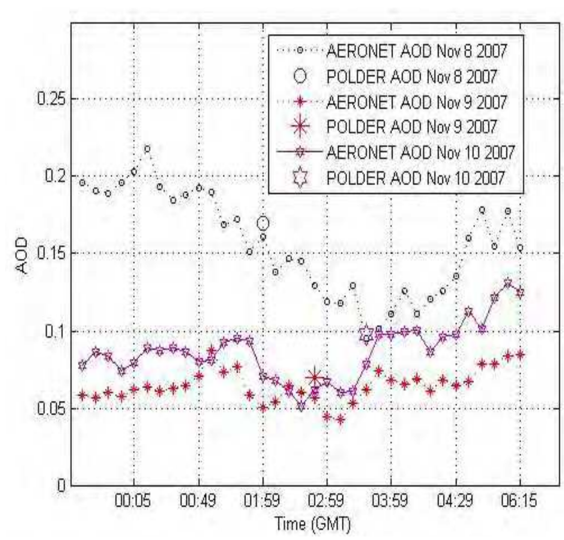

Fig. 6b compared AOD derived from POLDER and AERONET

In order to analyze the accuracy of aerosol inversion, we interpolated the AERONET AOD corresponding to time of the satellite overpass. We used the data provided by Beijing AERONET stations to analyze the accuracy of aerosol inversion from POLDER. Figure 5b shows the results. The validation shown in Figure 5b compares the AOD at 865nm derived from POLDER and AERONET instruments. As the result shows (Figure 5b), the retrieval method for the AOD from POLDER yields a nearly closer values compared with that from AERONET.

6. Summary

In this paper, the accuracy of AOD retrieved from the POLDER multi-wavelengths-based inversion scheme for the sample studied over Beijing remain relatively closer compared to ground-based sun-photometer measurements. The comparisons between the AERONET AOD and the POLDER-derived AOD using the relations between the polarized reflectance of the surface at long wavelengths and that at short wavelengths show an agreement in most cases. The agreement is much better than when using the physical functions which were derived for bare soils and vegetation. Some effect caused by the surface geometric structure can precisely eliminate for dense vegetation cover or for bare soils at least.

The results suggest that the algorithm, the contribution of the surface at short wavelengths could be quantified with that at long wavelengths in pixel level, can be used as an alternative method in the aerosol retrieval procedure from Multi-wavelength polarization space-borne sensors.

The POLDER results also provide convincing evidence that remote sensing of the terrestrial aerosols over land surfaces by way of polarization measurements is feasible and possibility for discriminating the aerosol contribution from the surface and show the potential of measurements of polarized light scattered by aerosols to retrieve optical depth.

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Our planet is nowadays continuously monitored by powerful remote sensors operating in wide portions of the electromagnetic spectrum. Our capability of acquiring detailed information on the environment has been revolutionized by revealing its inner structure, morphology and dynamical changes. The way we now observe and study the evolution of the Earth's status has even radically influenced our perception and conception of the world we live in. The aim of this book is to bring together contributions from experts to present new research results and prospects of the future developments in the area of geosciences and remote sensing; emerging research directions are discussed. The volume consists of twenty-six chapters, encompassing both theoretical aspects and application-oriented studies. An unfolding perspective on various current trends in this extremely rich area is offered. The book chapters can be categorized along different perspectives, among others, use of active or passive sensors, employed technologies and configurations, considered scenario on the Earth, scientific research area involved in the studies.