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AEROSOL RETRIEVAL USING SYNTHETIC POLDER MULTI-ANGULAR DATA

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Abstract -- The POLarization and Directionality of the Earth's Reflectances (POLDER) instrument onboard the Japanese ADEOS satellite offers unique possibilities for the retrieval of aerosol parameters with its polarization and multi-angular capability. In this study we examine a technique that simultaneously retrieve multiple aerosol parameters, namely asymmetry factor, single-scattering albedo, surface albedo, and optical thickness, using simulated POLDER reflectances. It is found that, over dark or bright surfaces, simultaneous retrieval of multiple parameters is indeed possible, but not over surfaces with intermediate reflectivity. Among the four parameters, the single-scattering albedo is retrieved with the best accuracy and is the least vulnerable when the reflectance value is subjected to a 0.1% white noise.

INTRODUCTION

Atmospheric aerosol particles, both natural and anthropogenic, are important to the earth's radiative balance through their direct and indirect effects. They scatter the incoming solar radiation (direct effect) and modify the shortwave reflective properties of clouds by acting as cloud condensation nuclei (indirect effect). IPCC [1] esimates the radiative forcing of its direct effect to be -0.5 W/m^2 globaly while the radiative forcing of the indirect effect ranges from 0 to -1.5 W/m^2 with much larger uncertainty. In order to understand the role that aerosols play in a changing climate, detailed and accurate observations are a prerequisite.

The retrieval of aerosol optical properties by satellite remote sensing has proven to be a difficult task, especially over land. The difficulty results mainly from the tenuous nature and variable composition of aerosols. To date, with single-angle satellite observations, we can only retrieve reliably against dark backgrounds, such as over oceans and dense vegetation. Even then, assumptions must be made concerning the chemical composition of aerosols, which may be highly variable. The best hope we have for aerosol retrievals over land surfaces are observations from multiple angles [2, such as those provided by the POLDER [3] and MISR [4] instruments.

In this investigation we examine the feasibility of simultaneous retrieval of multiple aerosol optical parameters using reflectances from three typical sets of twelve angles observed by the French POLDER instrument [3]. Specifically, angular sets 1, 2, and 3 in [3] are investigated; they correspond to, respectively, the nadir set, the backward set, and the forward set refered to in this study. The simultaneously retrieved aerosol optical parameters consist of asymmetry factor, single scattering albedo, surface albedo, and optical thickness.

METHODOLOGY

Radiative Transfer Simulations

The Discrete Ordinate Model (DOM) developed by Stamnes *et al.* [5] is used to make the radiative transfer simulations in this study. First, a regular grid system is generated for the four-dimensional parametric space of asymmetry factor (g), single scattering albedo (ω_0), surface albedo (α), and optical thickness (τ). Specifically, g is varied from 0.6 to 0.8 at an interval of 0.025, ω_0 from 0.8 to 1 at an interval of 0.025, α from 0 to 0.72 at an interval of 0.06, and τ from 0.01 to 2.1 at an interval of approximately 0.13. The coordinate of a particular grid point is therefore specified by a 4-tuple of (g, ω_0, α, τ). Using the components of the 4-tuple as inputs to DOM, model simulations are made for all grid points to obtain the *control* reflectance values at the three sets of observation angles. Reflectance values are also obtained for the same angles by randomly sampling the four-dimensional parametric space; these compose the *test* reflectance values.

The Henyey-Greenstein approximation is used to construct the phase functions from asymmetry factors for all simulations. The modeled atmosphere is assumed to contain only one homogeneous layer of aerosols. The modeled reflective surface is assumed to be Lambertian. A solar zenith angle of 45° is used in all simulations.

Polynomial Fitting

To estimate the optical parameters using the multi-angular reflectance values, we choose a least-squares polynomial fitting technique. If we denote the reflectance values at the K observational angles by r_i, where $i = 1, 2, ..., K$, any of the optical parameter can be approximated by a d^{th} degree polynomial in the K variables of r_i. The coefficients of the polynomial are chosen to minimize the squares of errors at the grid points. The polynomial hence maps a hyper-surface in the K-dimensional reflectance space to a hyperplane in the four-dimensional optical parameter space. Note that, as d or K increases, the number of terms, N, in the polynomial increases much faster than linearly. The computational complexity of the present technique is roughly N^3, therefore the computation cost increases dramatically when d or K get large.

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RESULTS

It is found that using a third degree ($d = 3$) polynomial and every other angle ($K = 6$), one already approaches the limit of the retrieval accuracy; increasing the number of angles or the degree of the polynomial does not significantly improve the accuracy to warrant the extra computational cost. This is true for all three sets of angles investigated.

Using "pure" simulated data (i.e. without noise), the root-mean-square (rms) errors for the simultaneous retrieval of all four parameters are listed in Table 1 for the three sets of angles. It is rather interesting to find that g and ω_0 can be estimated with much higher confidence than α and τ. The retrievals of α and τ are more accurate using the nadir and backward sets of angles (sets 1 and 2), while the forward set yields better retrievals of g and ω_0.

Since g and ω_0 can be accurately retrieved, a logical step to improvement is to fix g and ω_0 values and to apply the same polynomial fitting technique to α and τ. The original problem is equivalent to mapping a hypersurface in the reflectance space to a hyperplane in a four-dimensional space, while the current one maps to a straight line in a two-dimensional space. One would expect much better accuracy due to the reduced complexity of the problem. However, the results show that the improvement is quite negligible.

In Figure 1, we plot the reflectance values at every third angle of the twelve angles in the forward set (set 3) by varying α and τ but at fixed values of g and ω_0. In the figure, μ is the cosine of the observation zenith angle and $\Delta\phi$ is the relative azimuth between the incident and observation directions. It is seen that, when α is small (large), the reflectance values increase (decrease) with increasing τ. However, when α assumes intermediate values (around 0.6), the reflectance values stay fairly constant across a wide range of τ, especially towards the large end of it. Similarly, when τ is large (>1.2) the reflectance values show no influence by the surface albedo. It is this ambiguity that results in large errors in the retrieval of α and τ. Indeed, if we assume that the surface albedo is known *a priori* and apply the same technique to simultaneously

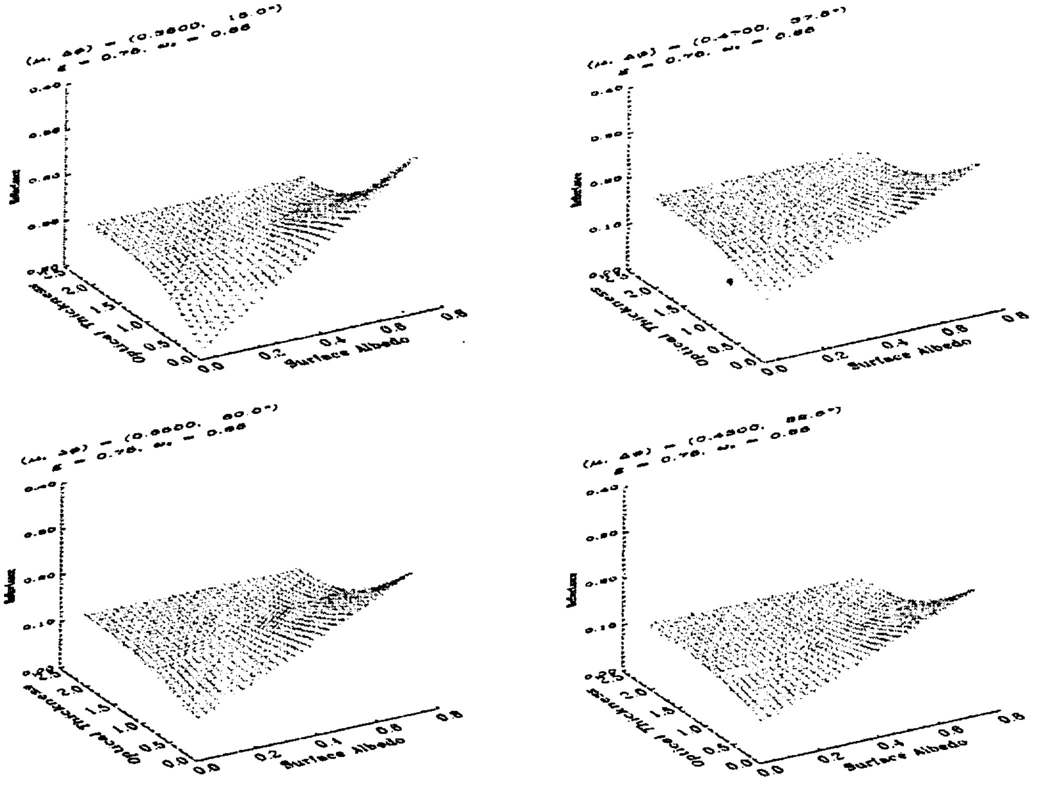

Figure 1. Reflectances (z-axis) as functions of surface albedo (x-axis) and aerosol optical thickness (y-axis) at (μ, $\Delta\phi$) of (0.35, 15°), (0.47, 37.5°), (0.43, 82.5°), and (0.55, 60°), clockwise from top left. The x-axis ranges from 0 to 0.8 while y-axis ranges from 0 to 2.5.

retrieve g, ω_0, and τ, we find that much improved accuracy can be obtained for the retrieval of τ when α is smaller than 0.1 or larger than 0.6. There is no discernible improvement, however, for in-between values of α.

With 0.1% white noise added to the simulated data the rms error for the simultaneous retrieval worsens considerably. Table 2 lists these errors. Comparing Table 1 and 2, one observes that, again surprisingly, single-scattering albedo is the most accurate and the least vulnerable to the added noise.

When simultaneously retriving g, ω_0, and τ, by assuming α is known, the rms error for the retrieval of optical thikness in the presence of noise is about 3 to 4 times of that for theoptical thickness retrieval without noise. Under no circumstance, i.e. low or high surface albedo, is the error better than 0.1.

Table 1. rms error for simultaneous retrieval from "pure" data

Set	α	g	ω_0	τ
1	0.076	0.006	0.004	0.126
2	0.085	0.008	0.004	0.166
3	0.101	0.003	0.002	0.211

Table 2. rms error for simultaneous retrieval from data with 0.1% white noise

Set	α	g	ω_0	τ
1	0.167	0.028	0.012	0.376
2	0.199	0.040	0.017	0.479
3	0.249	0.018	0.011	0.858

DISCUSSIONS AND CONCLUSIONS

We find that, using the chosen set of angles, the asymmetry factor and the single scattering albedo of an aerosol layer can be retrieved with high confidence. Due to ambiguity in the reflectance signal, surface albedo and aerosol optical thickness cannot be retrieved as accurately. However, when the surface reflectivity is low or high and its value is known, the simultaneous retrieval of the other three parameters improves.

The particular strength of the present technique is that it does not assume any *a priori* knowledge for the aerosol composition, i.e. the index of refraction. Using the present technique and the typical POLDER angles, one can retrieve single scattering albedo accurately at any wavelengths available from the instrument. The spectral dependence of single scattering albedo will no doubt give important clues to the chemical composition of aerosols. One can therefore make radiative transfer simulations with the correct chemical composition to yield better estimates of optical thickness.

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