P1.14   SIMULTANEOUS RETRIEVAL OF MULTIPLE AEROSOL PARAMETERS
USING A MULTI-ANGULAR APPROACH

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1. 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). Although it has been suggested that aerosols exert a net cooling influence on climate (e.g. Twomey *et al.* 1984), this effect has received less attention than the radiative forcing due to clouds and greenhouse gases. 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. 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. The best hope we have for aerosol retrievals over bright backgrounds are observations from multiple angles (Martonchik and Diner 1992), such as those provided by the MISR (Diner *et al.* 1989) and POLDER instruments (Deschamps *et al.* 1994).

In this investigation we examine the feasibility of simultaneous retrieval of multiple aerosol optical parameters using reflectances from a typical set of twelve angles observed by the French POLDER instrument (Deschamps *et al.*, 1994). The retrieved aerosol optical parameters consist of asymmetry factor, single scattering albedo, surface albedo, and optical thickness.

2. METHODOLOGY

2.1 *Radiative Transfer Simulations*

The Discrete Ordinate Model (DOM) developed by Stamnes *et al.* (1988) is used to make the radiative transfer simulations in this study. First, a regular grid system is generated for the four-dimensional

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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, an 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 observation zenith cosines and relative azimuth angles of (0.35, 15°), (0.39, 22.5°), (0.43, 30°), (0.47, 37.5°), (0.51, 45°), (0.55, 52.5°), (0.55, 60°), (0.51, 67.5°), (0.47, 75°), (0.43, 82.5°), (0.39, 90°), and (0.35, 97.5°). These angles correspond roughly to the angles in "set 3" of the Deschamps *et al.* (1994) article. Reflectance values are also obtained for the same set of angles by randomly sampling the four-dimensional parametric space; these compose of 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.

2.2 *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 $i = 1, 2, \ldots, K$, any of the optical parameter can be approximated by a dth 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 increase, 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.

3. RESULTS

It is found that using a third degree ($d = 3$) polynomial and every other angle ($K = 6$) in the set of twelve, 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 computational cost.

Figure 1 shows the retrieval results using the present polynomial fitting technique; the x-axis denotes the actual value of the parameter while the y-axis denotes the estimated value. Each point on the scatter-plot represents a case in the test runs. The root-mean-square (rms) errors are 0.101, 0.003, 0.002, and 0.211 for α, g, ω_0, and τ, respectively. It is rather interesting to find that g and ω_0 can be estimated with much higher confidence than α and τ.

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 hyper-surface 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. Figure 2 shows the results of such a retrieval for g = 0.65 and ω_0 = 0.95. It is seen that the improvement is quite negligible.

In Figure 3, we plot the reflectance values at every third angle in the 12-angle set by varying α and τ but at fixed values of g and ω_0. 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
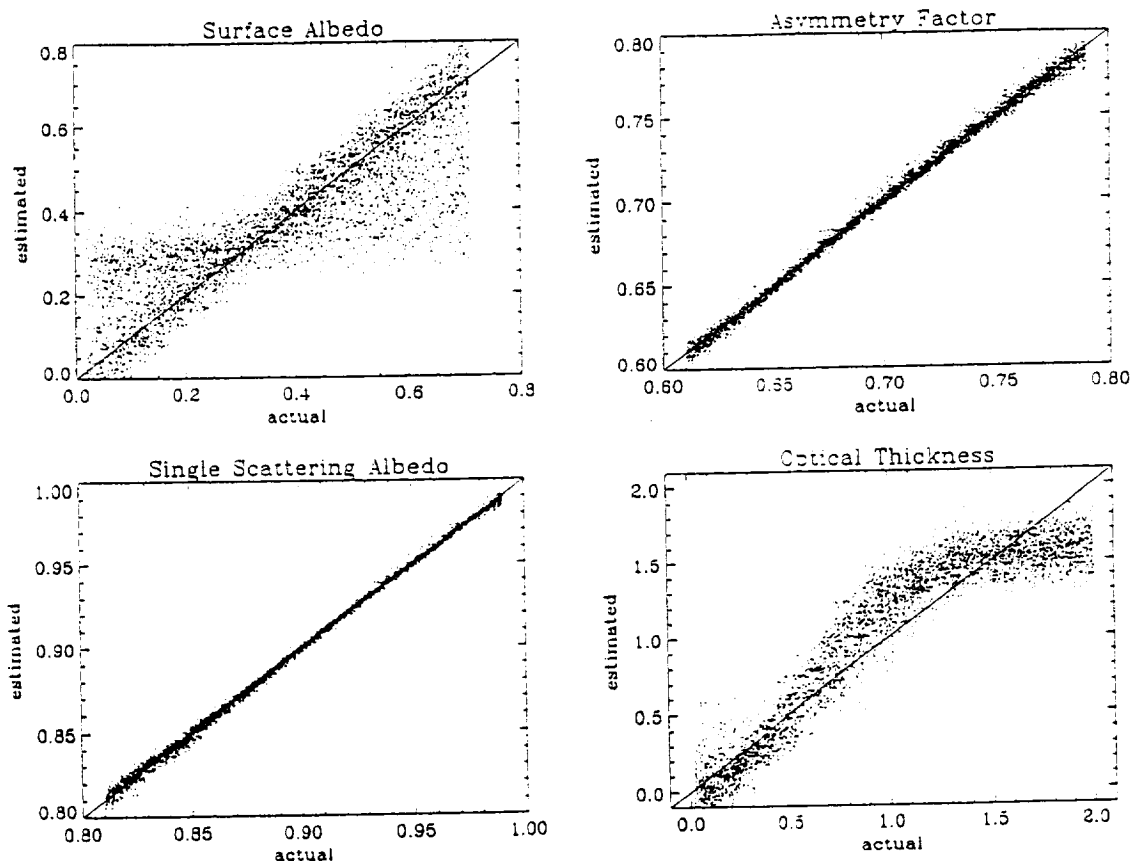

Figure 1. Simultaneous retrievals of surface albedo, assymmetry factor, single scattering albedo, and optical thickness for a layer of aerosols using reflectances at multiple observation angles.
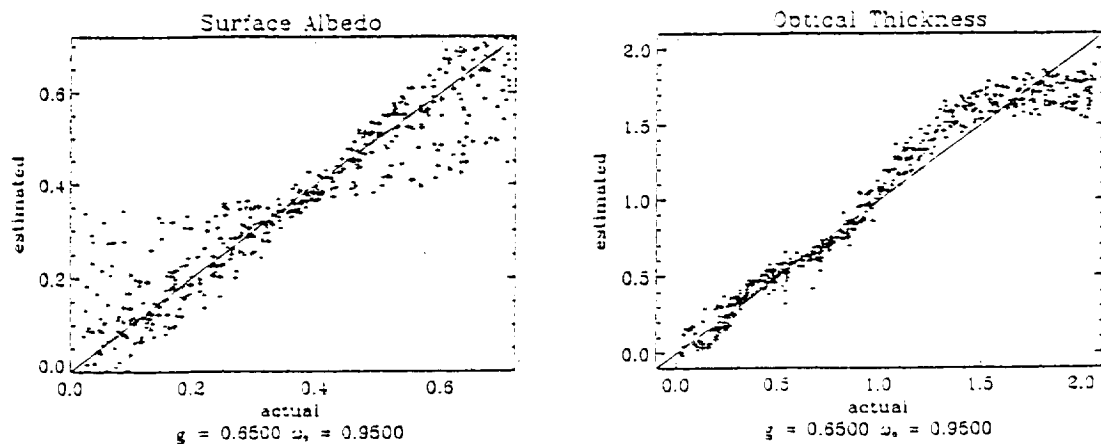
Figure 2. Simultaneous retrievals of surface albedo and aerosol optical thickness for g = 0.65 and ω_0 = 0.95 using reflectances at multiple observation angles.
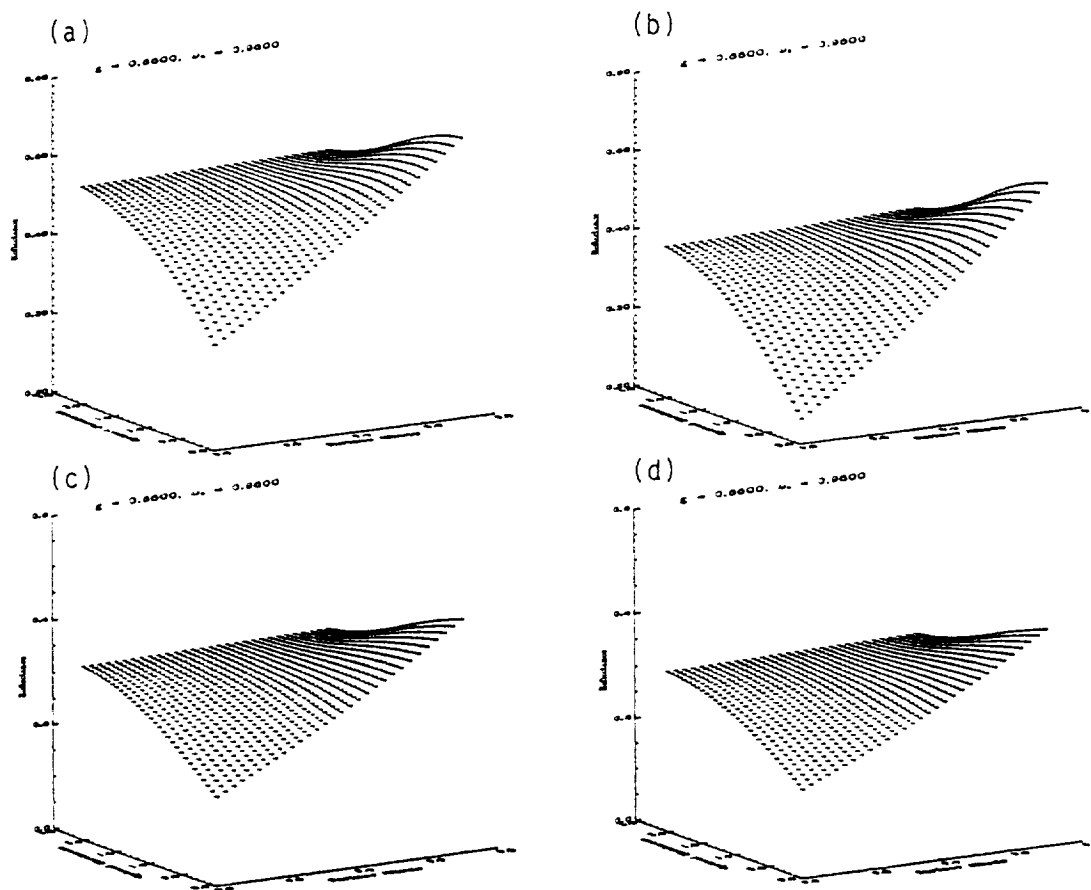

Figure 3. Reflectances as functions of surface albedo (x-axis) and aerosol optical thickness (y-axis) at
a) (0.35, 15°), b) (0.47, 37.5°), c) (0.55, 60°), and c) (0.43, 82.5°) observation angles.
The x-axis ranges from 0 to 0.8 while the y-axis ranges from 0 to 2.5.

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 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.

4. DISCUSSIONS AND CONCLUSIONS

It is found 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 combined with spectral information, our technique may still yield much better optical thickness estimates than one can derive from single-angle measurements.

Note that the present technique does not assume any *a priori* knowledge for the aerosol composition or the background albedo. Using the present technique and the current set of 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.

5. REFERENCES

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