ALIVE Polarization Measurements

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Atmospheric Correction

The usual way that polarized reflectance measurements are corrected for the contribution of the surface is to assume that the contribution from the surface to the upwelling radiance at the surface or top of the atmosphere can be modeled simply as a direct beam interaction with the surface. The direct beam interaction is corrected for diffuse transmission effects by using a scaled optical depth where the scale factor is determined empirically. Figure 1 shows how well this approach works for a solar zenith angle of 45° and relative azimuth of 45°.

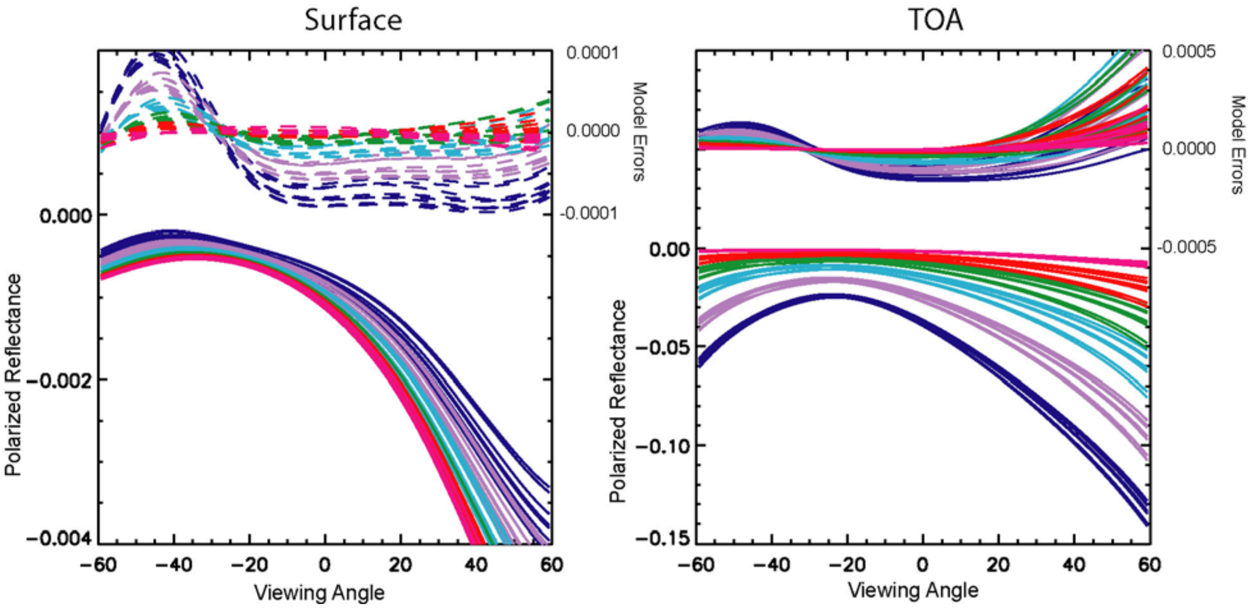

Figure 1. Spectral bands are 410, 470, 555, 670, 865, and 1590 in blue, mauve, turquoise, green, red, and cyan. Aerosol models cover optical depths from 0.05-0.2 and effective radii from 0.1-0.5 µm where the size variation is caused by mixing different fractions of fine (0.1 µm) and coarse (2.0 µm) particles.

There are three problems with this approach. (1) It is not particularly accurate. (2) The optimum scale factors for the optical depth depend on viewing geometry and in particular the relative solar azimuth. (3) The scaling is different for upwelling measurements at the surface than it is for measurements within the atmosphere, or at the top of the atmosphere.

This problem can be overcome by noting that when we look at the polarized reflectance of the surface we find that its functional variation with viewing and illumination angles is similar to reflectance from surface facets (Fresnel reflection) whether the surface is a bare soil, or vegetated. It is also the case that to a good degree of approximation the polarized reflectance for a model surface with one refractive index is proportional to that with a different refractive index. This is useful in terms of algorithms for aerosol retrievals and atmospheric correction because it means that at least for treating the interaction of the surface with diffuse radiation we do not need to calculate the detailed surface reflectance matrices for multiple refractive indices. Instead, we can use one surface polarized reflectance model with a fixed refractive index that is multiplied by a suitable scale factor. Thus, when atmospherically correcting polarized reflectance measurements we can use the following iterative process:

$$\begin{aligned} \hat{\mathbf{R}}^{0}_{Srf} &= \mathbf{U} \\ \alpha^{i} &= median(\mathbf{R}^{i}_{Srf} / \mathbf{R}_{Srf,Model}) \\ \hat{\mathbf{R}}^{i+1}_{Srf} &= (\mathbf{U} - \alpha^{i}\mathbf{R}_{Srf,Model}\mathbf{T}_{Dif}) / T_{Dir} \end{aligned} \tag{1}$$

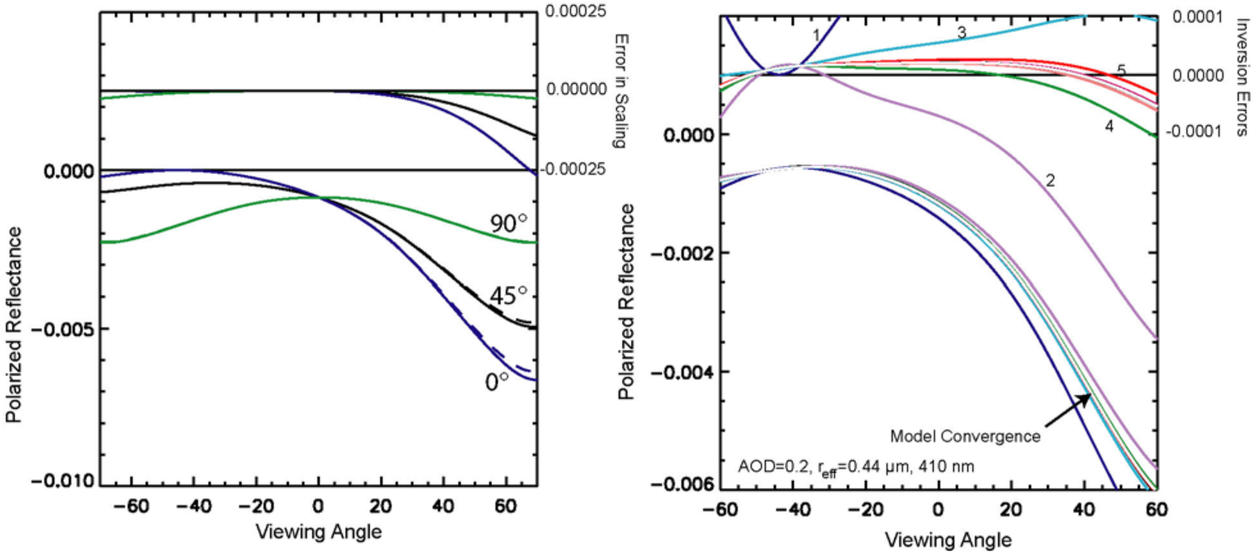

Figure 2. a) Comparison of Fresnel reflectance calculations for a refractive index 1.5 when it is scaled to that for a refractive index of 1.4 by a factor that matches the median polarized reflectance, together with residual differences. b) Atmospheric correction process outlined above showing convergence is achieved after 6 iterations even for an aerosol optical depth of 0.2.

Surface Polarized Reflectance Color

One persistent feature of the surface polarized reflectance is its absence of color. This is justified theoretically on the basis that the polarization is generated by reflection at the front surface and is therefore dependent on the real refractive index of the material, which does not generally show strong spectral variation. Although there have been several observations that have shown this spectral invariance, the approach to atmospheric correction used and the availability of coincident aerosol and water vapor measurements has left significant uncertainties as to just how "grey" the surface is. In Figure 3, it can be seen that the surface polarized reflectance shows little color (±0.001) over a huge spectral range, 410-2250 nm. This fact can be used to retrieve aerosols over land from polarization measurements, where we use the observations at 2250 nm as a proxy for the surface as outlined in the next section.

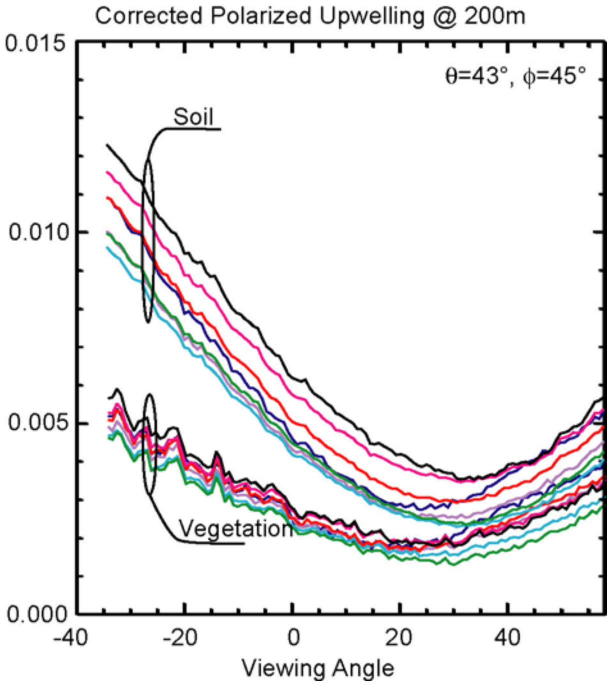

Figure 3. The atmospherically corrected surface polarized reflectance is shown here for soil and vegetated surfaces.

Aerosol Retrievals

The aerosol retrievals are implemented by using the measurements at 2250 nm as a proxy for the surface polarized reflectance and only calculating diffuse interactions between surface and atmosphere using a standard Fresnel reflectance model. The following equations indicate how the surface contribution to the polarized reflectance is handled viz.

$$
\begin{aligned}
&\hat{\mathbf{R}}^{0}_{Srf} = \mathbf{R}(\lambda = 2250nm)/T^{\downarrow\uparrow}_{Dir}(\mathbf{x}=0)\\
&\alpha^{i} = median(\hat{\mathbf{R}}^{i}_{Srf}/\mathbf{R}_{Srf,Model})\\
&\mathbf{R}(\mathbf{x},\lambda) = \mathbf{R}_{Atm}(\mathbf{x}) + T^{\downarrow\uparrow}_{Dir}(\mathbf{x})\hat{\mathbf{R}}^{i}_{Srf} + \alpha^{i}\mathbf{Q}(\mathbf{x},\lambda)\\
&\mathbf{Q}(\mathbf{x},\lambda) = T^{\uparrow}_{Dir}(\mathbf{x})\mathbf{R}_{Srf,Model}\mathbf{T}_{Dif}(\mathbf{x}) + \mathbf{T}_{Dif}(\mathbf{x})\mathbf{R}_{Srf,Model}T^{\downarrow}_{Dir}(\mathbf{x}) + \mathbf{T}_{Dif}(\mathbf{x})\mathbf{R}_{Srf,Model}\mathbf{T}_{Dif}(\mathbf{x})\\
&\hat{\mathbf{R}}^{i+1}_{Srf} = \Big[\mathbf{R}(\lambda = 2250nm) - \mathbf{R}_{Atm}(\mathbf{x}) - \alpha^{i}\mathbf{Q}(\mathbf{x},\lambda)\Big]/T^{\downarrow\uparrow}_{Dir}(\mathbf{x})
\end{aligned}
\tag{2}
$$

where the third equation gives the form of our model calculated polarized reflectances, which are used in an optimal estimation process that fits the model to the observed polarized reflectance for all spectral bands, other than 2250 nm, and all angles. The estimate of the surface polarized reflectance is updated on each iteration as the set of retrieved aerosol parameters **x** is searched for but is not itself corrected using an iteration similar to Eq. (1). This is because in general the atmospheric correction of the 2250 nm measurements is primarily a correction for the effects of absorbing gases (i.e., the nomenclature **x**=0 denotes an atmosphere with no aerosols but all well mixed gases present).

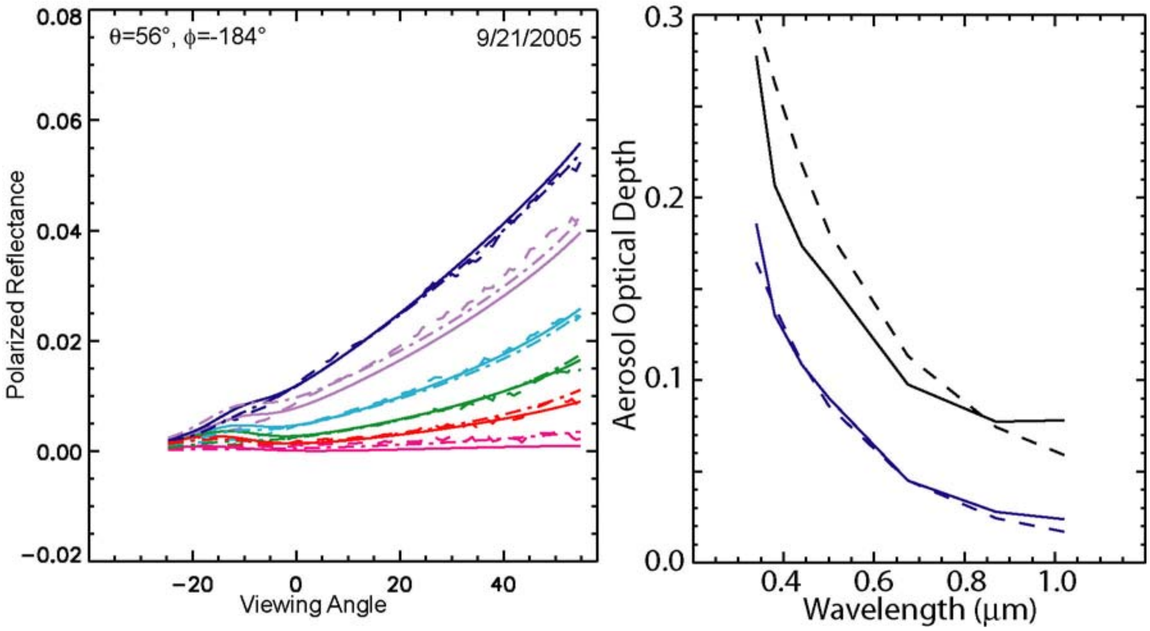

Figure 4. a) Fit between model (dashed and dot dashed lines) and measurements (solid line) for the 21 September 2005. b) Comparison of research scanning polarimeter retrieved (dashed lines) and Aerosol Robotic Network retrieved (solid lines) spectral optical depths on 21 September (black lines) and the 16th September 2005 (blue lines).

Conclusions

We recently implemented an improved approach for dealing with diffuse interactions with the surface that are important to account for properly when using the shortest wavelength bands to retrieve aerosol properties. Initial spectral optical depth estimates are within the range of expected errors. We are currently in the process of running the retrieval scheme on the entire data set to evaluate the robustness of the retrieval approach over a wider range of viewing geometries. Netcdf versions of the data have been made available in the Archive. Data in xdr format is available from the authors on request. (bcairns@giss.nasa.gov)

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