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Comment on "Classification of aerosol properties derived from AERONET direct sun data" by Gobbi et al. (2007)

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Abstract. It is pointed out that the graphical, aerosol classification method of Gobbi et al. (2007) can be interpreted as a manifestation of fundamental analytical relations whose existance depends on the simple assumption that the optical effects of aerosols are essentially bimodal in nature. The families of contour lines in their "Ada" curvature space are essentially empirical and discretized illustrations of analytical parabolic forms in (α, α') space (the space formed by the continuously differentiable Angstrom exponent and its spectral derivative).

1 Introduction

Gobbi et al. (2007) provided a useful graphical representation of spectral curvature in sunphotometry data and an aerosol classification scheme referenced to the intensive parameters of η (fine mode fraction) and R_f (modal radius of the fine mode). While they refer to our papers on spectral curvature they neglect to relate their approach to the analytical formulations presented in these papers (O'Neill et al., 2001a, b, 2003, 2005). The most recent 2005 paper deals with the extraction of the fine mode, effective Van de Hulst phase-shift parameter ($\rho_{\mathrm{eff,f}}$[1])[2]. Taken as a whole, these analytical formulations in fact present a theoretical framework for the "Ada" classification technique of Gobbi et al. (2007)

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[1] $\rho_{\mathrm{eff,f}} = 2\frac{2\pi r_{\mathrm{eff,f}}}{\lambda}|m-1|$ where "m" is the complex refractive index.

[2] We have, only recently, begun referring to the latter technique as the FMC (fine mode curvature) algorithm.

2 Analytical representation of spectral behavior in (α, α') space

2.1 Curves of constant "t"

A polynomial of aerosol optical depth (τ_a) versus wavelength in log-log space (Eck et al., 1999) permits one to compute first order (Angstrom) and second order spectral derivatives (α, α') at a reference wavelength (usually 500 nm). The fundamental spectral curvature equations for a bi-modal aerosol size distribution of fine-mode (f) and coarse-mode (c) components is given by (O'Neill et al., 2001a);

$$\alpha = \eta\alpha_\mathrm{f} + (1-\eta)\alpha_\mathrm{c} \tag{1}$$

$$\alpha' = \eta{\alpha'}_\mathrm{f} + (1-\eta){\alpha'}_\mathrm{c} - \eta(1-\eta)(\alpha_\mathrm{f}-\alpha_\mathrm{c})^2 \tag{2}$$

where α and α' are the first and second spectral derivatives of the total optical depth τ_a (in ln τ_a and ln λ space) and the subscripted variables have the same meaning for the fine and coarse mode optical depths. The parameter η is the optical fine mode fraction ($\eta = \tau_\mathrm{f}/\tau_\mathrm{a}$). Some simple algebraic manipulation reduces Eqs. (1) and (2) to the "conservation of t" relation (Eq. (4) from O'Neill et al., 2001a);

$$t = \{\alpha-\alpha_\mathrm{c}\} - \frac{\{\alpha'-{\alpha'}_\mathrm{c}\}}{\{\alpha-\alpha_\mathrm{c}\}} = \{\alpha_\mathrm{f}-\alpha_\mathrm{c}\} - \frac{\{{\alpha'}_\mathrm{f}-{\alpha'}_\mathrm{c}\}}{\{\alpha_\mathrm{f}-\alpha_\mathrm{c}\}} \tag{3}$$

where η has been eliminated. The value of "t", independent of the actual aerosol content (i.e. independent of η), reduces to a constant value if the fine-mode aerosol type (as manifested by the rightmost curvature expression in Eq. 3) is invariant. This formulation is quite remarkable in that it represents virtually all aspects of spectral curvature in a succinct differential equation which is a function of only one universal, fine-mode variable (i.e. t). Its derivation only depends on the assumption that aerosol optics are essentially bimodal (which refers to the preeminance of Eqs. (1) and (2) where α_f and α_c are quasi constant and η generates most of the variation in α and α').

The effective Van de Hulst phase shift parameter $\rho_{\mathrm{eff,f}}$ is, in turn, a strong empirical function of α'_f and α_f (O'Neill et al., 2005) which themselves are outputs of a spectral deconvolution algorithm (SDA) whose starting point is Eq. (3) above (O'Neill et al., 2001b,2003). The validation of $\rho_{\mathrm{eff,f}}$ retrievals from SDA outputs is the objective of current investigations (Atkinson et al., 2010).

A little bit of algebra applied to Eq. (3) yields the concave-downwards, parabolic equation;

$$\alpha' - \alpha'_{\mathrm{min}} = \left[\alpha - \alpha(\alpha'_{\mathrm{min}})\right]^2 \tag{4}$$

where $\alpha'_{\mathrm{min}} = \alpha'_c - \frac{t^2}{4}$ and $\alpha(\alpha'_{\mathrm{min}}) = \alpha_c + \frac{t}{2}$ are the coordinates of the parabolic minimum in (α, α') space. The α' versus α event-equations given in Table 1 and illustrated in Fig. 2a of O'Neill et al. (2003) reduce to the more universal form of Eq. (2) with a bit of algebraic manipulation[3].

2.2 Curves of constant η (FMF)

Equations (1) and (2) above can be slightly rearranged to yield;

$$\alpha - \alpha_c = \eta(\alpha_f - \alpha_c), \tag{5}$$

$$\alpha' - \alpha'_c = \eta\left(\alpha'_f - \alpha'_c\right) - \eta[1-\eta](\alpha_f - \alpha_c)^2 \tag{6}$$

The fine mode curvature parameters are approximately related by the relationship given in O'Neill et al. (2001b);

$$\alpha'_f \cong a\alpha_f^2 + b\alpha_f + c \tag{7a}$$

which can be more conveniently rewritten as;

$$\alpha'_f - \alpha'_c = a(\alpha_f - \alpha_c)^2 + b*(\alpha_f - \alpha_c) + c* \tag{7b}$$

where[4] $b* = b + 2\alpha_c a$ and $c* = c + (b + a\alpha_c)\alpha_c - \alpha'_c$.

Substituting for $\alpha_f - \alpha_c$ and $\alpha'_f - \alpha'_c$ in Eq. (4) yields, after a little algebra;

$$\alpha' - \alpha'_c = \frac{[a-(1-\eta)]}{\eta}(\alpha - \alpha_c)^2 + b*(\alpha - \alpha_c) + c*\eta \tag{8}$$

an expression which represents concave-downwards parabolic curves of constant η on the (α, α') plane.

[3]Coarse mode event; $\alpha(\alpha'_{\mathrm{min}}) = \alpha_c - \frac{b_f}{2a_f} = \alpha_c + \frac{t}{2}$ and $\alpha'_{\mathrm{min}} = \alpha'_c - \left(\frac{b_f}{2a_f}\right)^2 = \alpha'_c - \frac{t^2}{4}$
Fine mode event; $\alpha(\alpha'_{\mathrm{min}}) = \alpha_f + \frac{b_c}{2a_c} = \alpha_c + \frac{t}{2}$ and $\alpha'_{\mathrm{min}} = \alpha'_f - \left(\frac{b_c}{2a_c}\right)^2 = \alpha'_c - \frac{t^2}{4}$
The α' versus α parabola under the "Coarse Mode Event" heading had a sign error; the 3rd term within the right hand brackets should have read – $b_f/(2a_f)$ rather than + $b_f/(2a_f)$.

[4]It is noted that the expression for $b*$ is corrected for an error in O'Neill et al. (2001).

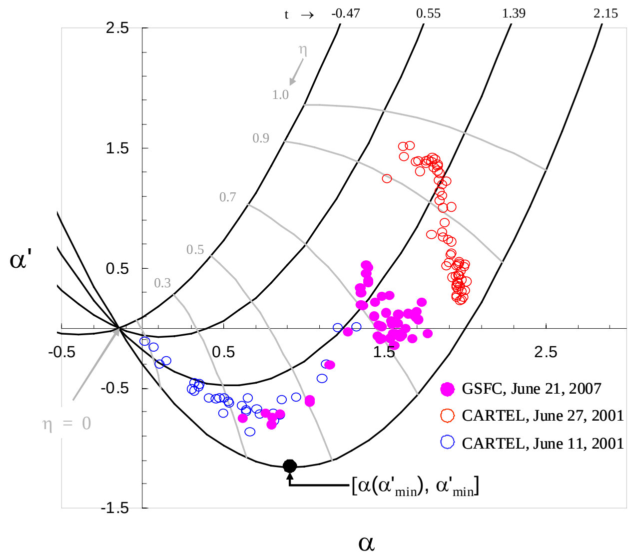

Fig. 1. Contours of constant "t" (black curves) and η (grey curves) superimposed on an (α, α') grid (reference wavelength of 500 nm). Some illustrative data for the coarse mode and fine mode events of 11 and 27 June 2001 at the CARTEL AERONET (AEROCAN) site (O'Neill et al., 2003) and a mixed fine-mode, coarse-mode event on 21 June 2007 at the GSFC AERONET site (red circles) are superimposed on the non-linear (t, η) grid.

2.3 Graphical representation of constant "t" and η curves in (α, α') space

Figure 1 shows families of α' versus α curves generated by Eqs. (4) and (8) (at a reference wavelength of 500 nm) along with some sample data points for the two cases mentioned in O'Neill et al. (2003) and a third case generated from AERONET data acquired at the NASA/GSFC site.

This figure is analogous to the empirical $\delta\alpha$ vs. α figures presented in Gobbi et al. (2007) except that their axes represent variables that are discrete rather than differentially continuous and our α' is taken as positive if α increases with increasing wavelength ("differentially continuous" in the sense of true derivatives applied to a spectral polynomial). The blue circles show a coarse mode event (most likely thin cloud) associated with an extensive increase in coarse mode optical depth (and relatively little variation in "t" or hence fine mode size) while the red circles show a fine mode event for which "t" and thus the fine mode particle size appear to change substantially. The GSFC data shows a combination of these two cases.

3 Summary

The objective of this comment was to demonstrate that the empirical graphical method of Gobbi et al. (2007) could be represented by analytical functions in (α, α') space. The general applicability of these analytical functions depends fundamentally on the simple assumption that the optical effects of aerosols are generally bimodal in nature. The outputs of Gobbi et al.'s graphical technique (η and the modal radius of the fine mode distribution) are virtually a subset of the products retrieved from the SDA combined with the FMC algorithm (η, α_{f} and $\rho_{\mathrm{eff,f}}$). The families of analytical curves which were presented above are in fact a consequence of the theoretical framework which permits the retrieval of these parameters.

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