Comment to: “A multi-decadal history of biomass burning plume heights identified using aerosol index measurements” by Guan et al.

The paper is an interesting study of smoke injection/plume height determined by the Aerosol Index (AI). The authors make very good use of the available long AI time series from TOMS and OMI.

I had some doubts about the assumptions made in Sect. 4, lines 20-26, which say: “We propose that most of the analyzed large-AI young plumes are sufficiently optically thick so that AI is close to or reaches an asymptote with respect to aerosol optical depth at ~360 nm, similar to the behavior suggested by Wong and Li’s calculation for a longer wavelength (2002). When this occurs, and because SSA is not expected to vary a great deal (Jeong and Hsu, 2008), plume height will determine the value of AI. That is, an increasing plume height will be associated with increasing AI, as shown in Fig. 3.”

I expected this assumption to be valid for near-unphysical aerosol optical thickness (AOT), and performed several radiative transfer model calculations to prove my point. Surprisingly (to me), my hypothesis was wrong. Below I show some figures that indicate that your assumption is valid, but only if the aerosol optical properties single-scattering albedo (SSA) and asymmetry parameter (g) remain constant. I also find an indication that AI is not influenced very much by aerosol size distribution (approximated by the Angstrom coefficient).

The simulations were performed for the wavelength pair that I use in my AI algorithm (see, e.g., [Penning de Vries et al., ACP 2009]), so $\lambda_0 = 376.5$ nm and $\lambda = 335.5$ nm, but I assume that the results can be extended to the OMI/TOMS AI, at least qualitatively. Other simulation parameters: SZA = 30°, nadir viewing geometry, surface albedo 5%.

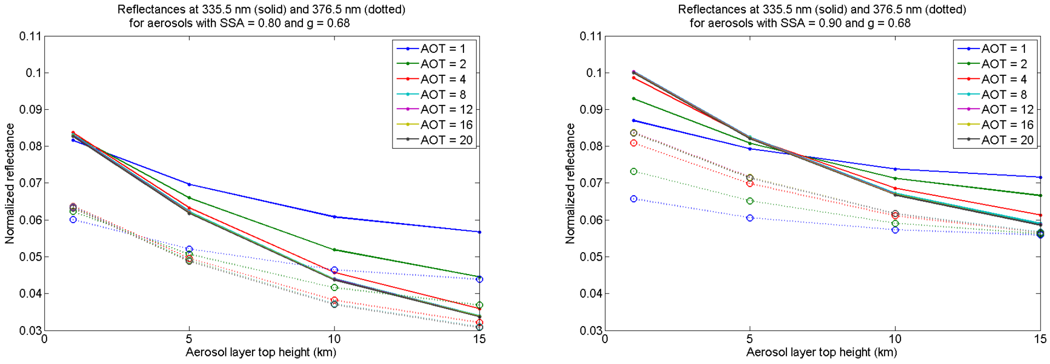

Figure 1. Reflectances at 335.5 nm (solid lines, dots) and 376.5 nm (dotted lines, circles) for 1-km thick aerosol layers with top heights 1, 5, 10, and 15 km. AOT was varied from 1 to 20 (as indicated in the figure legend). Left plot, SSA = 0.80 and g = 0.68. Right plot, SSA = 0.90 and g = 0.68.

In Fig. 1 we see that the dependence on AOT disappears (saturates) already at an AOT of approximately 5, independent of the value of SSA. For very strongly scattering particles (SSA = 0.99) the point shifts to higher AOT (8 or higher), but because the AI is much smaller and less sensitive to aerosol layer height, and anyway not of interest to this smoke study, we disregard those results here.

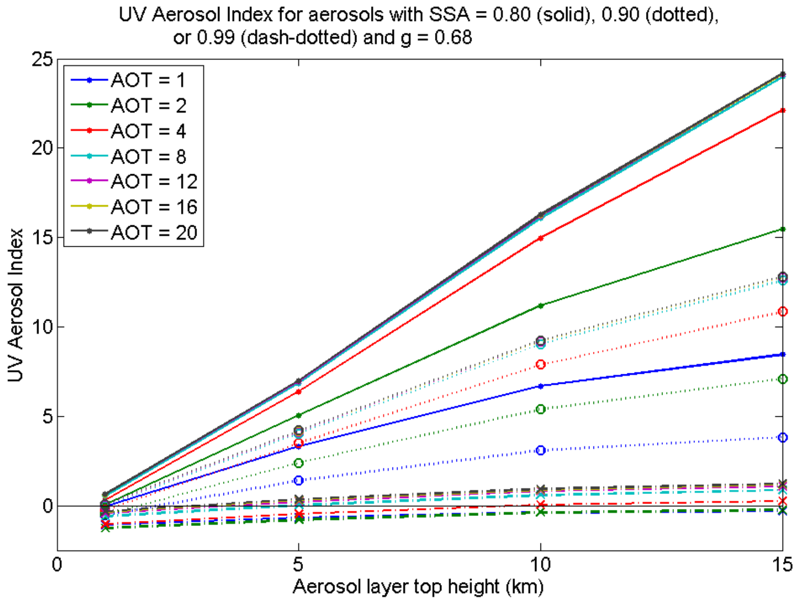

Figure 2. Aerosol Index values for 1-km thick aerosol layers with top heights 1, 5, 10, and 15 km. AOT was varied from 1 to 20 (as indicated in the figure legend). Asymmetry parameter of all aerosol scenarios was 0.68; SSA varied from 0.80 (solid line, dots) to 0.90 (dotted lines, circles) and 0.99 (dash-dotted lines, crosses).

Figure 2 confirms that the asymptotic behavior of reflectances with respect to AOT is reflected in the value of AI. But it also shows the sensitivity of AI to SSA, especially for elevated layers.

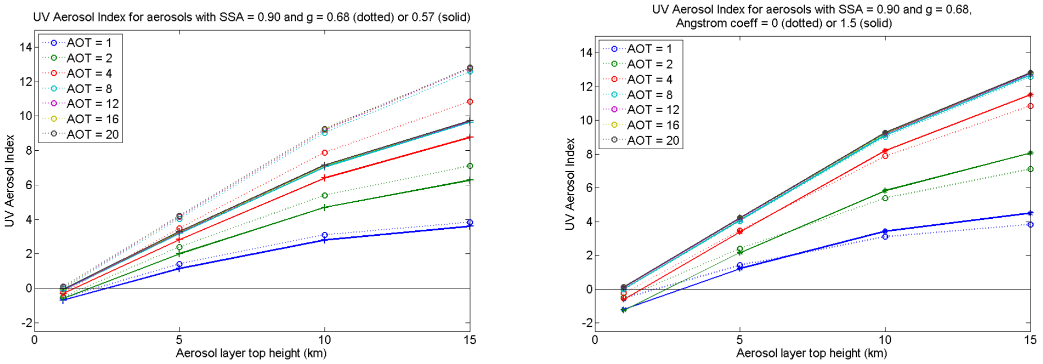

Figure 3. Aerosol Index values for 1-km thick aerosol layers with top heights 1, 5, 10, and 15 km. AOT was varied from 1 to 20 (as indicated in the figure legend). Left plot, aerosols have SSA = 0.90 and asymmetry parameter g either 0.68 (dotted line, circles) or 0.57 (solid line, pluses). Right plot, aerosols have SSA = 0.90, g = 0.68 and Angström coefficient either 0 (dotted lines, circles) or 1.5 (solid lines, asterisks).
Please note that the y-axis is different from the y-axis in Fig. 2.

The two plots in Fig. 3 show the sensitivity of AI to the asymmetry parameter (left), and the relative insensitivity to the Angström coefficient (right), which is generally used as an indication of aerosol particle size. The values chosen for g represent spherical particles (0.68) and the particle shape assumed by Wong and Li (2001). This clearly has a large impact on AI, and should be borne in mind, in particular when aged aerosols are observed (shape may change by, e.g., hydration or coagulation).
An Angström coefficient of 0 means that the AOT is independent of wavelength, so AOT(335.5) = AOT(376.5) in this study. The Angström coefficient of 1.5 used here means that AOT(335.5) = 1.19*AOT(376.5). For small AOT and aerosol layer height the Angström coefficient plays an important role for AI, but at large AOT the dependence (naturally) disappears. Interestingly, the (relative) difference in AI for the two assumed Angström coefficient values is not very large for small AOT and large layer heights, either.

To conclude: Fig. 2 shows that the assumption that AI only depends on altitude is valid for smoke clouds with AOT greater than 4-5, independent of SSA (for mildly to strongly absorbing aerosols). However, AI depends very strongly on SSA and g, hence these values need to be quite accurately known (or assumed).

The cited reference can be found at:
http://www.atmos-chem-phys.net/9/9555/2009/acp-9-9555-2009.pdf