New Insights into Aerosol Asymmetry Parameter

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The aerosol contribution to radiative forcing is one of the more uncertain aspects of climate science. Absorption and angular scattering are both aerosol properties which influence the variability of radiative forcing efficiency (RFE). For computational efficiency, angular scattering is often represented by a single value such as backscatter fraction, upscatter fraction or asymmetry parameter. Figure 1 shows a probability distribution function for RFE based on 8 years of single-scattering albedo (SSA) and backscatter fraction (BFR) measurements at Southern Great Plains (SGP). Because SSA and BFR co-vary, the total variability in RFE is less than what would be expected based on the individual variability of SSA and BFR. While BFR can be directly measured by an integrating nephelometer with a backscatter shutter, the aerosol asymmetry parameter (g), which cannot be measured directly, is more commonly used in radiative transfer models to describe the angular distribution of scattered light. Here we describe various insights about the asymmetry parameter derived from long-term measurements, multi-platform field campaigns and literature surveys.

The aerosol asymmetry parameter (g) is defined as the cosine-weighted average of the phase function, where the phase function is the probability of radiation being scattered in a given direction. Values of g can range from -1 for 180-degrees backwards scattering to +1 for complete forward scattering, with a value of 0.7 commonly used in radiative transfer models. Unfortunately, no direct method for measuring the aerosol asymmetry parameter exists (polar nephelometers lack sensitivity to small aerosol particles), and so indirect methods must be used (Figure 2). The May 2003, Atmospheric Radiation Measurement (ARM) Program Aerosol intensive operational period (IOP) provided an excellent opportunity to compare results from a variety of the indirect methods shown in Figure 2, based on both in-situ and remote sensing measurements. The comparisons were generally favorable, and yielded

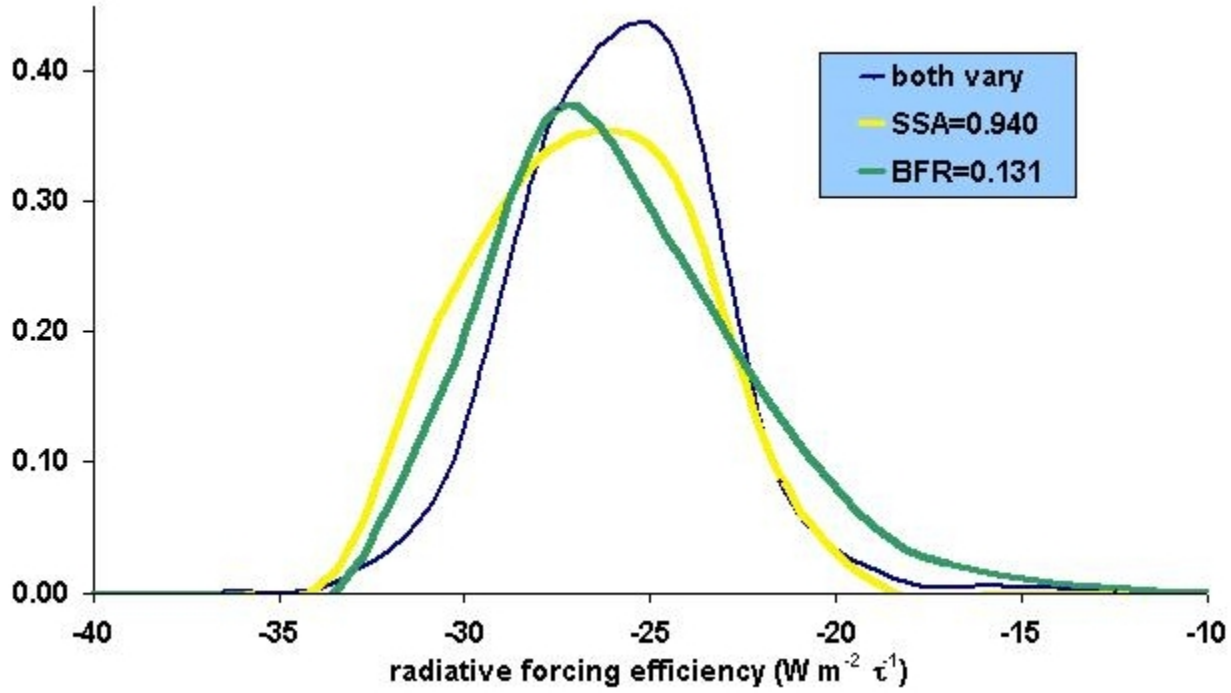

Figure 1.

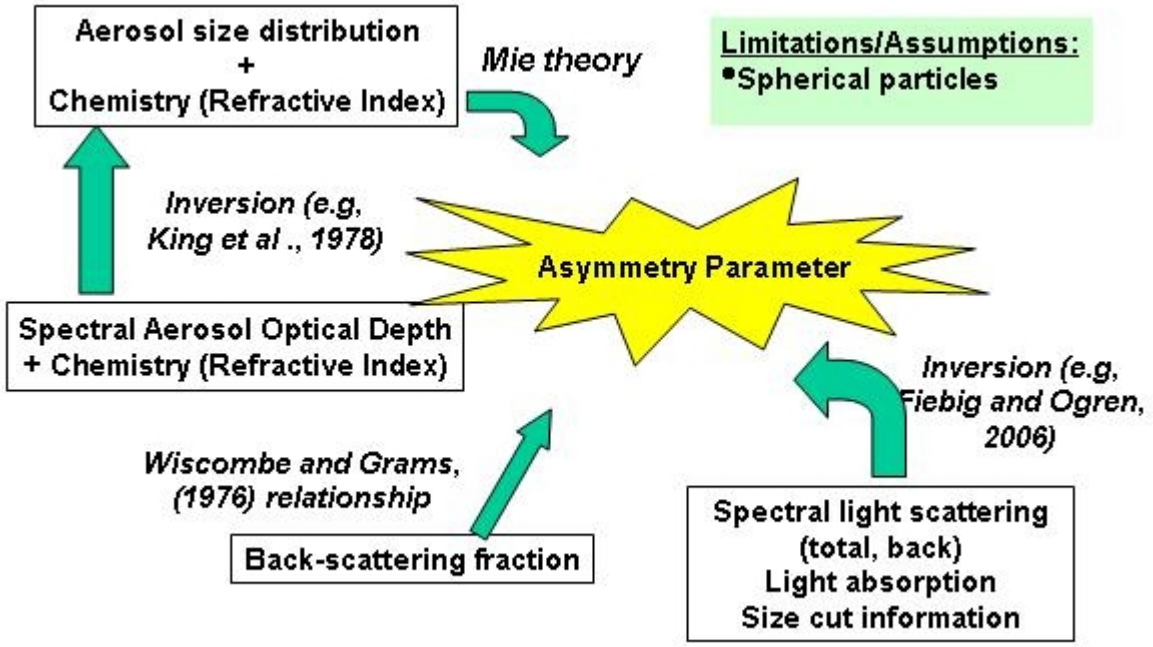

Figure 2.

values of *g* during the IOP of 0.60 ± 0.03 (low relative humidity [RH]) and 0.65 ± 0.05 (ambient RH) at a wavelength of 550 nm (Table 1). These values of *g* are on the order of 10% lower than is typically used in radiative transfer models. Results from one model (SBDART) suggest that a 10% reduction of *g* results in a 19% reduction of aerosol radiative forcing at the top of the atmosphere and a 13% reduction at the surface. Detailed results from the IOP comparisons are presented in Andrews et al. (2006).

Table 1. Results from different schemes to derive asymmetry parameter during May 2003 IOP (from Andrews et al. 2006).

Method	range (dry)	median (dry)	range (ambient)	median (ambient)
empirical fit to *bfr*	0.49-0.67	0.59	0.51-0.80	0.65
size dist. PCASP	0.61-0.65	0.65		
size dist. Climet	0.66-0.69	0.67		
size dist. TDMA	0.57-0.66	0.63	0.67-0.75	0.69
size dist. SMPS	0.52-0.65	0.60		
Fiebig inversion	0.51-0.67	0.58		
AERONET inversion			0.69-0.71	0.70

While intensive field campaigns can provide a means to evaluate and compare techniques for deriving *g*, long-term measurements can be used to gain insight into behavior such as the seasonal variability in *g*. Figure 3 shows results from an inversion of the long-term aerosol measurements at the SGP and North Slope of Alaska (NSA) ARM sites. A multi-year climatology shows median values of 0.58 at SGP and 0.63 at NSA, for low RH conditions at 550 nm wavelength. Figure 3 also shows how the spectral dependence of asymmetry parameter varies as a function of aerosol type. At SGP, where the aerosol is primarily continental in origin, the spectral dependence of *g* is larger than for the arctic marine aerosol sampled at NSA. At NSA in the summer, the aerosol is dominated by sea salt (Quinn et al. 2002) and the spectral dependence for the sub10um aerosol virtually disappears.

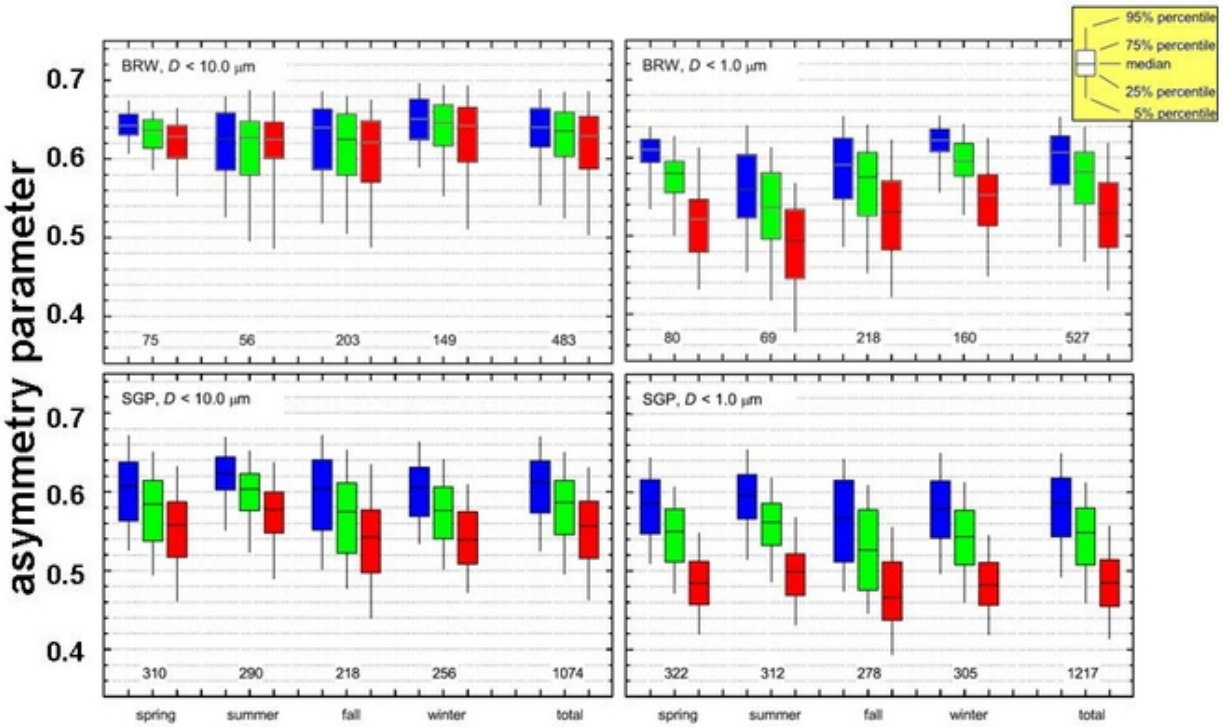

Figure 3.

Figure 4 compares asymmetry parameter values reported in the literature, calculated from National Oceanic and Atmospheric Administration-Global Monitoring Division in-situ measurements and derived from Aerosol Robotic Network (AERONET) measurements (Dubovik and King 2000) at a number of coastal and oceanic sites. The values of *g* derived from the *in-situ* measurements tend to be lower than the AERONET values. This is likely due to differences in measurement technique – the *in-situ* measurements are made at low relative humidity (RH<40%) while the AERONET measurements

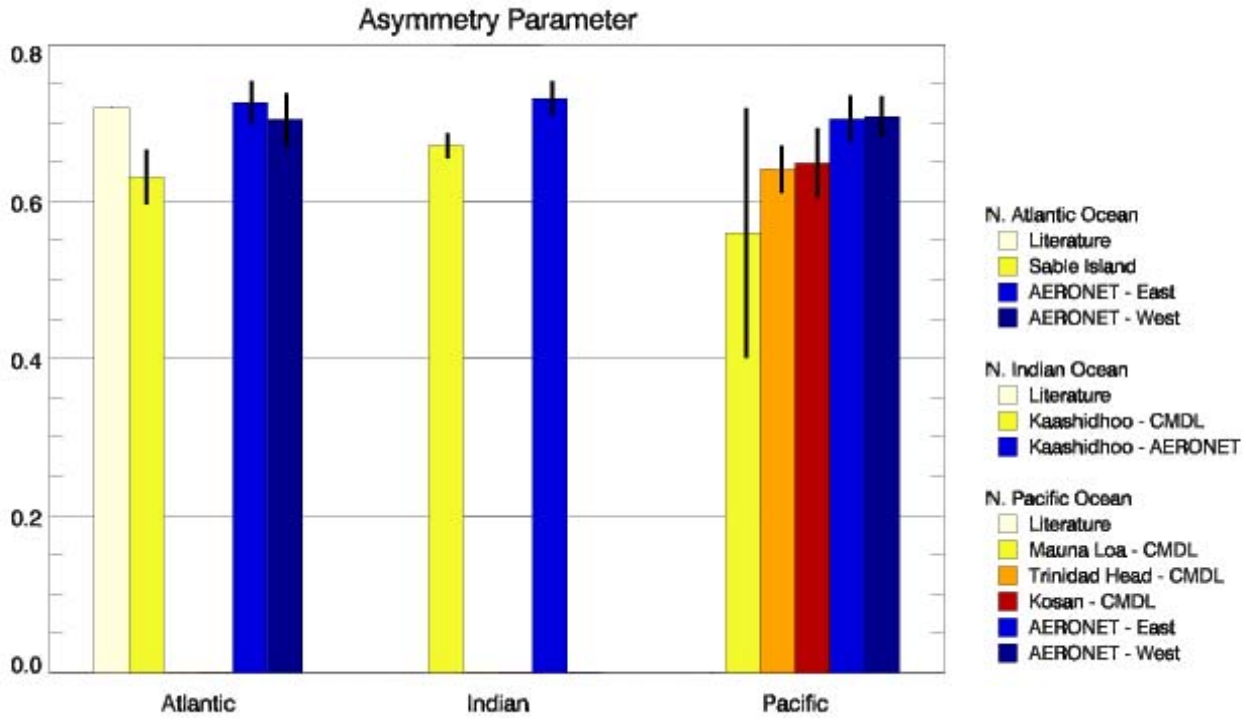

Figure 4.

are for ambient conditions. Additionally, the in-situ measurement only samples particles smaller than 10 μm aerodynamic diameter and thus might miss larger particles that AERONET would sense. The AERONET values for marine aerosol asymmetry parameter tend to be approximately 0.7 – the value frequently assumed by radiative transfer models.

The RH dependence of asymmetry parameter at SGP, derived from humidified-nephelometer measurements of scattering and backscattering, shows an increase of about 20 percent as RH increases from 40% to 85% (Figure 5). For comparison, the RH dependence of light scattering over the same humidity range increases by approximately 70 percent. Aloft over SGP, the in-situ aerosol profiling data show little systematic dependence of *g* over altitudes up to 3.7 km asl, with median values at low RH ranging from 0.58-0.60 (Figure 6a). This weak RH-dependence generates a small increase in climatological vertical profiles of *g* at ambient RH, with median values of 0.59-0.62 at the various altitudes sampled. There is little seasonal variability in the in-situ aerosol profiling -derived vertical profiles of *g* at SGP (Figure 6b), although summertime asymmetry parameter values tend to be higher than those for other times of year, perhaps indicative of flow from coastal regions and the Caribbean (Ogren et al. 2003).

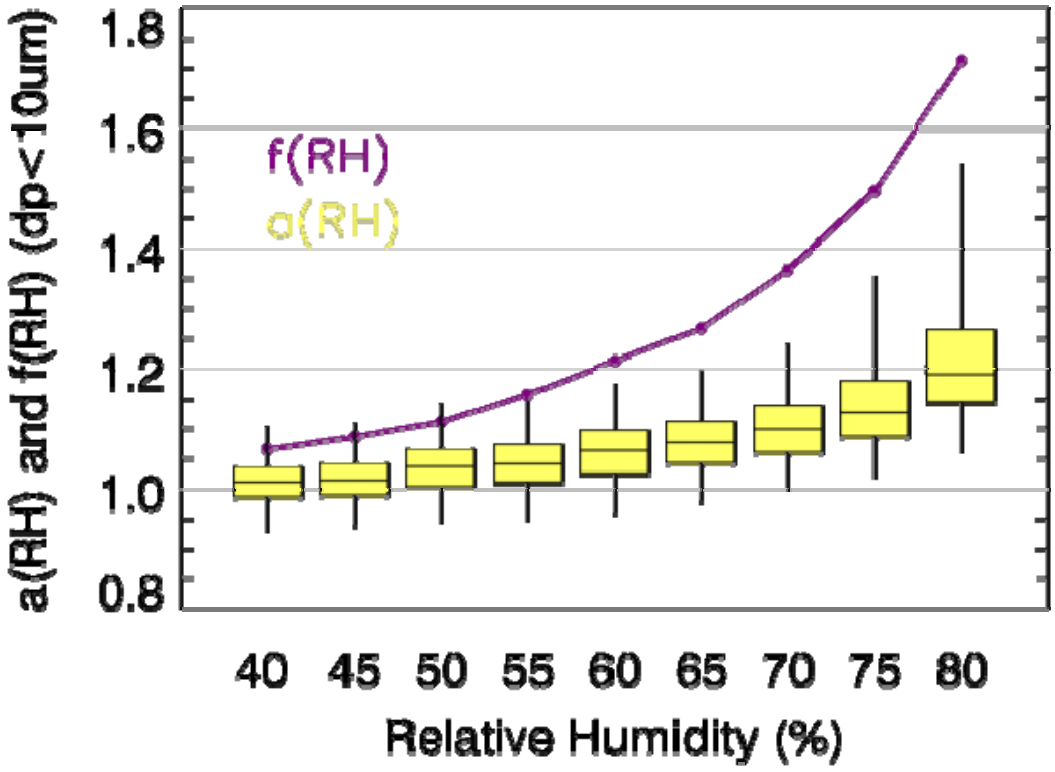

Figure 5.

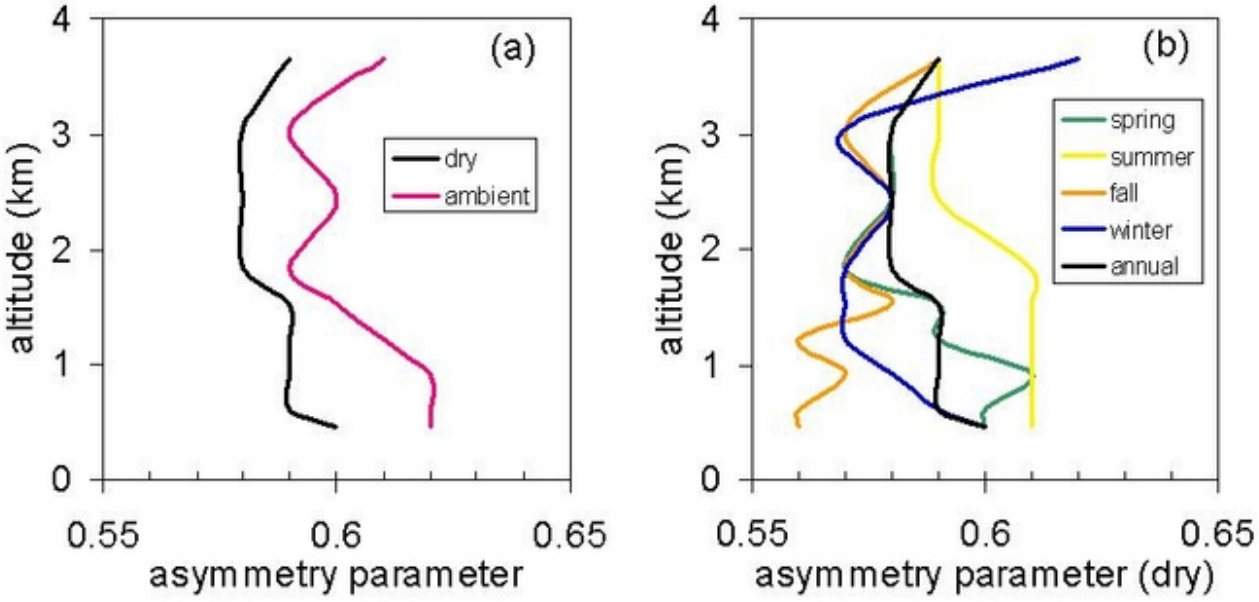

Figure 6.

Asymmetry parameter and single-scattering albedo (ω_o) are seen to co-vary systematically, possibly due to the effects of scavenging of particles by clouds (Andrews et al. 2006). The highest values of g and ω_o tend to be associated with the highest aerosol loadings at SGP, while the lowest values of these parameters are typically observed under clean conditions. Comparison of asymmetry parameter values for interstitial aerosol measured during cloud events and for aerosol when no cloud or fog was present suggests that cloud scavenging preferentially removes larger particles, leaving behind particles with systematically lower values of g in interstitial air.

As is shown above, climatologies of g derived from in-situ measurements reveal values of g tend to be lower than the value of 0.7 that is frequently assumed in radiative transfer models. Agreement between models and measurements of diffuse broadband irradiances is greatly improved when the lower values of g are used (Michalsky et al. 2006). Figure 7 shows an example of the difference between down-welling irradiance when 0.7 is used versus values of asymmetry parameter that might be seen at SGP. The difference increases for higher aerosol loadings.

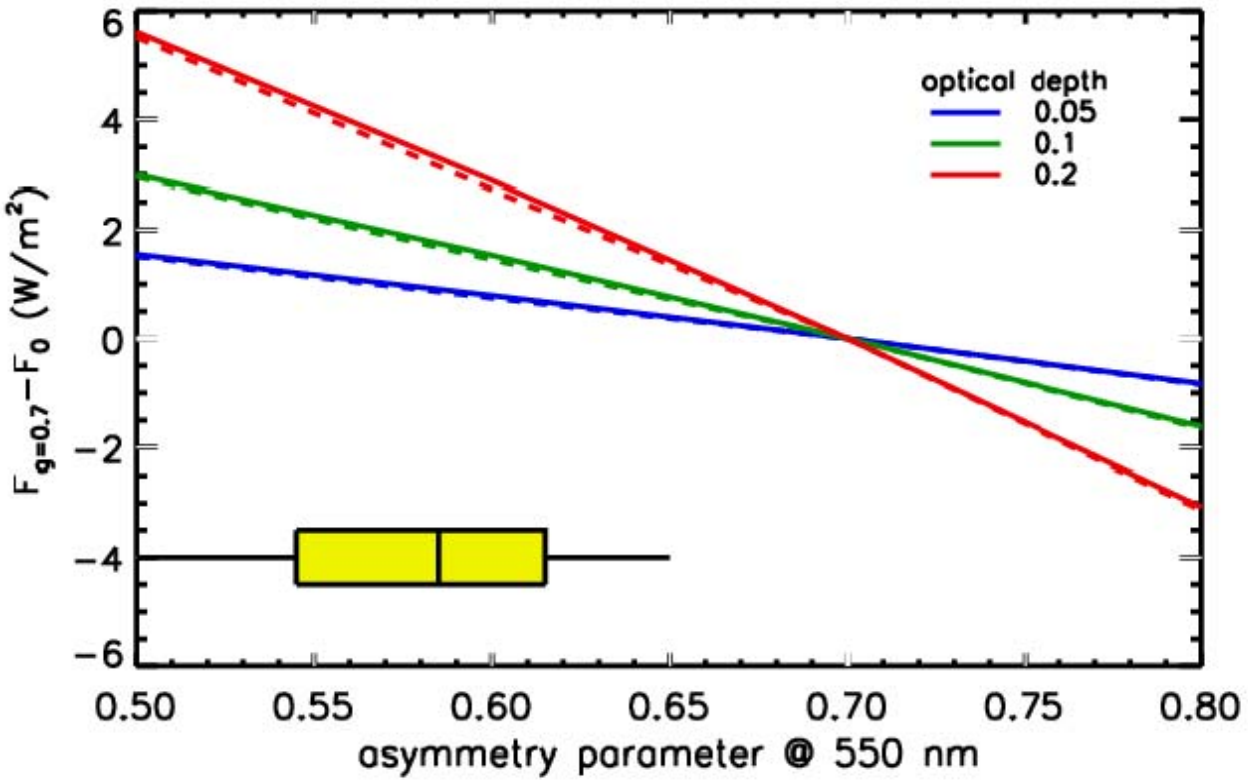

Figure 7.

In summary, while there is currently no method for directly measuring asymmetry parameter, there are several approaches to deriving g from various measurements of aerosols and radiation. While there are systematic differences in the estimated value g among the various methods, most approaches suggest that the value frequently used in radiative transfer models (0.7) may be too high. Derivations of g from

long-term measurements of aerosol optical properties show that there is a large range in asymmetry parameter, some of which is due to natural atmospheric variability (e.g., aerosol size distribution) and some of which may be due to measurement and derivation uncertainties. It is important to pursue process-level research to reconcile the differences among the various approaches for determining asymmetry parameter because aerosol radiative forcing is sensitive to the variability of *g*. Finally, development of an instrument to measure *g* would also go a long way towards furthering our understanding of what current measurements are telling us.

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