The First Aerosol Indirect Effect: Beyond Twomey

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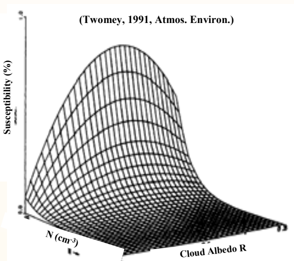
Summary

The traditional first aerosol indirect effect or the Twomey effect involves several fundamental assumptions. Some of the assumptions (e.g., constant liquid water content) are explicitly stated in studies of the Twomey effect whereas others are only implicitly embedded in the quantitative formulation. This work focuses on examining the implicit assumptions. In particular, we will show that anthropogenic pollution not only increases aerosol loading and droplet concentrations but also alters the relative dispersions of both the aerosol and subsequent droplet size distributions. The indirect effects resulting from the two altered relative dispersions (aerosol dispersion effect and droplet dispersion effect) are likely opposite in sign and proportional in magnitude to the conventional Twomey effect. This result suggests that the outstanding problems of the Twomey effect (i.e., large uncertainty and overestimation reported in literature) may lie with violation of the constant spectral shapes of aerosol and droplet size distributions implicitly assumed in evaluation of the Twomey effect, and therefore, further progress in understanding and quantification of the first aerosol indirect effect demands moving beyond the traditional paradigm originally conceived by Twomey.

1. Twomey Effect and Problems

Twomey (1974, Atmos. Environ): "it is suggested that pollution gives rise to whiter (not darker) clouds ----- by increasing the droplet concentrations and thereby the optical thickness (and cloud albedo) of clouds."



Cloud Susceptibility:

$$S \equiv \left(\frac{dR}{dN}\right)_x = \frac{R(1-R)}{3N}$$

- **R = Cloud albedo**
- **N = Droplet Concentration**

Figure 1. Dependence of cloud susceptibility on droplet concentration and cloud albedo (adapted from Twomey 1991, Atmos. Environ.). Later work links R (or other cloud properties) with aerosols using a relationship of N to aerosol loading (e.g., Kaufman and Fraser 1997, Science).

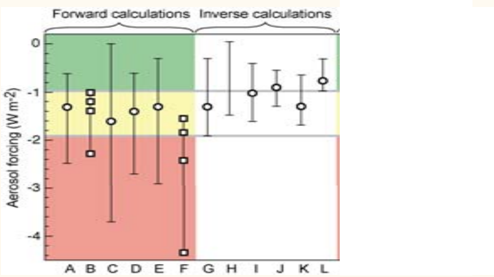


Figure 2 shows (1) the forward GCM estimates suffer from a large uncertainty and likely overestimates the cooling effect (esp. at the higher end); (2) there is a large discrepancy between forward and inverse estimates. This figure is adapted from Anderson et al. (2003).

Besides the uncertainty in the relationship of droplet concentration to aerosol concentration, the uncertainty and discrepancy as illustrated in Fig. 2 may arises from the assumptions regarding the Twomey effect, esp., those implicit ones. This work examines two about the spectral shapes of droplet and aerosol size distributions.

2. Droplet Dispersion Effect

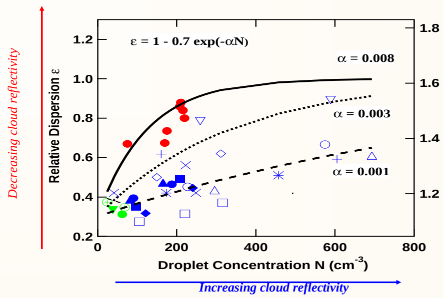


Figure 3 shows the concurrent increases of the droplet concentration and droplet relative dispersion. The warming effect from the enhanced droplet dispersion offsets the cooling of the Twomey effect due to enhanced droplet concentration. The droplet concentration shown here can also considered a proxy of aerosol loading (adapted from Liu and Daum 2002, Nature).

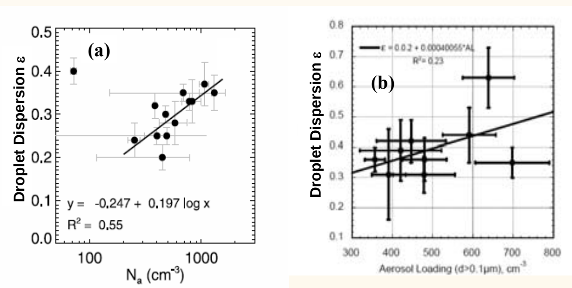


Figure 4 shows the recent results from the 2005 MASE experiments that directly relate droplet dispersion to aerosol loading. Figure (a) derives from the measurements with the CIPRAS Twin Otter aircraft and is adapted from Lu et al. (JGR, 2007). Figure (b) derives from the measurements with the DOE-G-1 aircraft. Note the interesting differences between the two data sets.

In addition to warming effect, the droplet dispersion effect also has the feature that its magnitude is proportional to that of the Twomey effect; therefore, consideration of droplet dispersion effect works to reduce both the uncertainty and the discrepancy. However, the droplet dispersion effect alone is not enough to account for the problem.

3. Aerosol Dispersion Effect

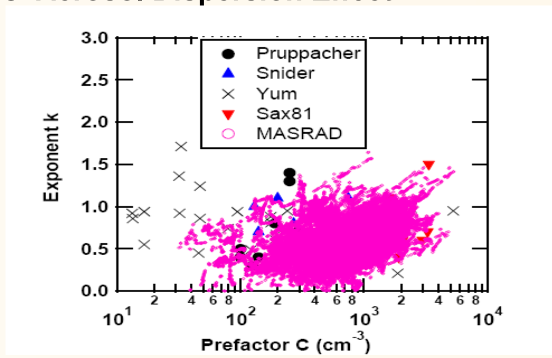


Figure 5 shows that the exponent K and the prefactor C in the CCN spectrum CCN = CS^K (s is supersaturation), are not independent of each other. Instead, K increases with increasing C (especially the MASRAD data points), supporting the notion that anthropogenic pollution increases both C and K because of the increase of aerosol particles of relatively small sizes. The MASRAD measurements were taken from July to Sep. 2005.

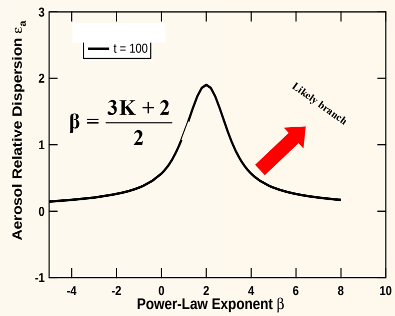


Figure 6 shows that the exponent K is related to the relative dispersion of the aerosol size distribution ε_a, and most likely decreases with increasing aerosol dispersion. Therefore, pollution likely increases aerosol concentration but decrease aerosol relative dispersion. The decreased aerosol dispersion (aerosol dispersion effect) work to offset the Twomey effect. It can also be shown that the aerosol dispersion effect is proportional to the Twomey effect in magnitude squared; its consideration reduces both uncertainty and discrepancy.

4. Future Work

To further quantify the two dispersion effects and their relative importance in determining the first aerosol indirect effect.