
The Twomey Effect

Twomey effect

- The paper(s) that "started it all"
  - Precursor papers
    - Physical basis for growth of cloud droplets dates back to equations for diffusional growth from Maxwell (1800s). Applied to cloud droplet growth by Kraus and Smith (1949), Howell (1949), Squires (1952).
    - Influence of composition of aerosol particles by Köhler (1921)
    - Twomey's own prior work (e.g. Twomey 1959, Twomey and Warner 1967) provided a clear influence of the concentration of aerosol particles on the concentration of cloud droplets
    - Theoretical basis covered in ATMS 535

Comparison of Measurements of Cloud Droplets and Cloud Nuclei

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(Manuscript received 30 June 1967)

ABSTRACT

Samplings of cloud droplets were compared with airborne cloud nuclei measurements in air below cloud base. The number concentration of the cloud droplets agreed closely with the number obtained from the nuclei measurements.

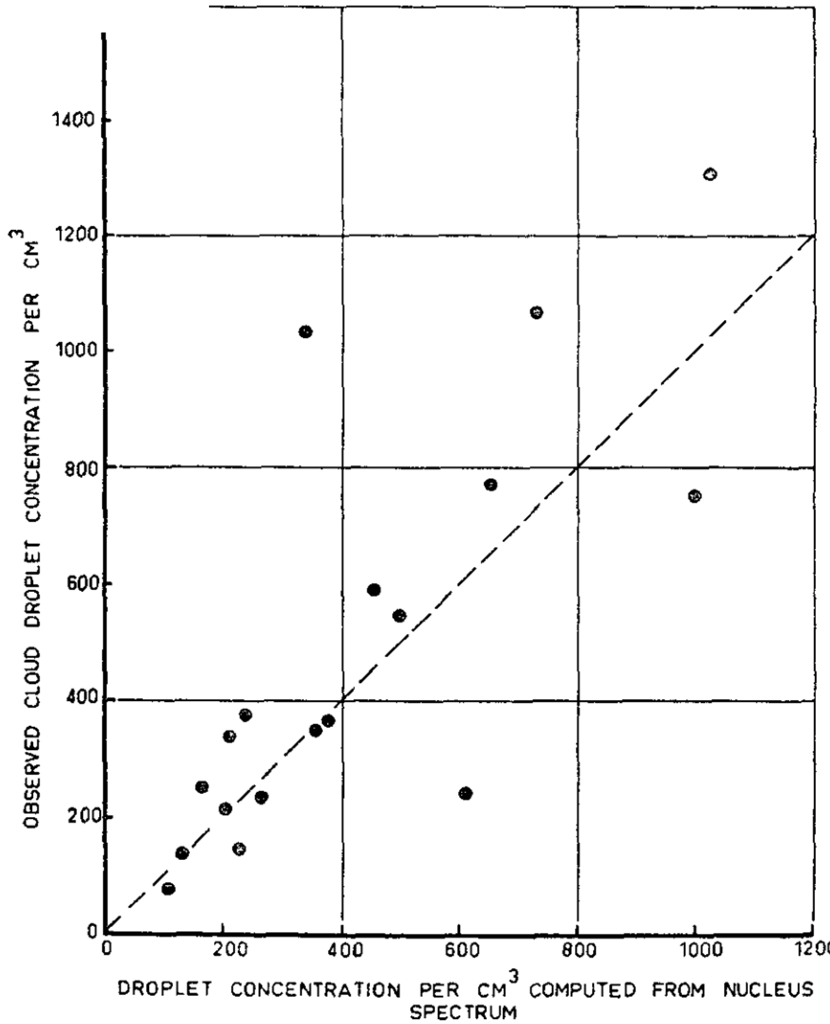

Fig. 1. Comparison of mean droplet concentration observed in cloud with the concentration computed from the observed spectra of cloud nuclei for an updraft of 3 m sec^{-1}. The dashed line represents exact agreement between observed and computed values.

Twomey, S., and J. Warner, 1967: Comparison of Measurements of Cloud Droplets and Cloud Nuclei. *J. Atmos. Sci.*, 24, 702–3

Twomey effect

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  - Actually, Twomey (1974) was the first paper suggesting anthropogenic aerosol impacts on cloud albedo:

POLLUTION AND THE PLANETARY ALBEDO

S. TWOMEY

Institute of Atmospheric Physics, The University of Arizona, Tucson, Arizona 85721, U.S.A.

(*First received* 27 *February* 1974 *and in final form* 17 *May* 1974)

Abstract—Addition of cloud nuclei by pollution can lead to an increase in the solar radiation reflected by clouds. The reflection of solar energy by clouds already may have been increased by the addition of man-made cloud nuclei. The albedo of a cloud is proportional to optical thickness for thin clouds, but changes more slowly with increasing thickness. The optical thickness is increased when the number of cloud nuclei is increased. Although the changes are small, the long-term effect on climate can be profound.

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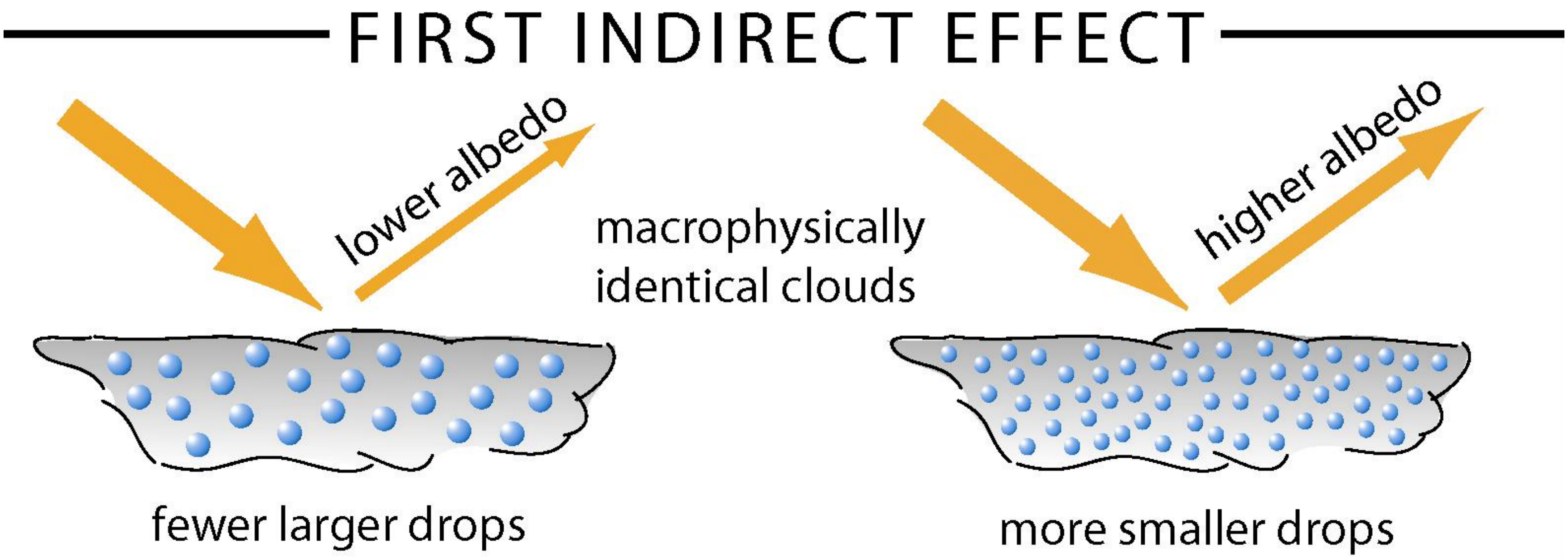
Twomey effect
a.k.a. the *first aerosol indirect effect*

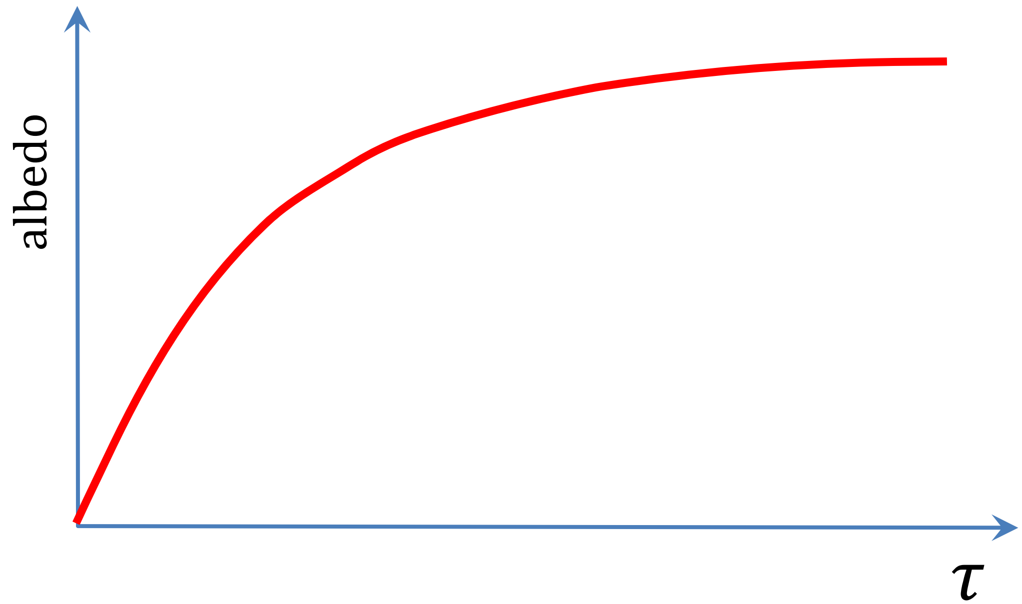


A little math

- In the geometric limit where the drop size is larger than the wavelength of light ($r > \lambda$), scattering of light is proportional to the total droplet surface area per volume [Q_{ext}=2 in Twomey's Eqn. (1)]
- In the visible (where solar energy is most intense), λ=0.4-0.8 micron, *r* for cloud drops typically 5-15 microns.
- Surface area of one drop: $A_{drop} = 4\pi r^2$
- Surface area of *N* drops per unit volume = $4\pi N r^2$
- Optical thickness $\tau = Q_{ext}\pi N r^2 h = 2\pi N r^2 h$ [Twomey Eqn. 2]
- Liquid water content *L* = $(4/3)\pi \rho_w N r^3$ [kg m^{-3}]
- Substitute for *L* into expression for optical thickness: $\tau = \frac{3Lh}{2\rho_w r}$
- Or, eliminating *r* and retaining *N*, we can write $\tau \propto N^{1/3} L^{2/3} h$
- <u>**Twomey's key result**: For fixed liquid water content and cloud thickness, optical thickness increases with $N^{1/3}$</u>

Relationship between solar reflectance and optical thickness

- Albedo increase with optical thickness, but is a concave function:



Beyond Twomey

Combine Twomey's expression for optical thickness:

$$\tau = kN^{1/3}L^{2/3}h$$

with simple expression for albedo, $\alpha \approx \tau/(\tau + 7)$, to estimate the rate of change of albedo with *N* (termed the albedo susceptibility, *Platnick and Twomey 1994*), to obtain:

$$\frac{d\alpha}{dN} = \frac{\alpha(1-\alpha)}{3N}$$

This form, although not in the original Twomey (1974,77) papers, is the most instructive way to visualize the key results:

- Clouds with low *N* are most susceptible to an increase in *N*
- Clouds with albedos ~ 0.5 are more susceptible to increases in *N* than clouds with either lower or higher albedo.

Platnick, S., and S. Twomey, 1994: Determining the Susceptibility of Cloud Albedo to Changes in Droplet Concentration with the Advanced Very High Resolution Radiometer. *Journal of Applied Meteorology* 33, 334–47.

Albedo susceptibility estimates from space

- MODIS instrument (multi-spectral radiometer) can estimate cloud optical thickness and effective radius to estimate $\frac{d\alpha}{dN}$

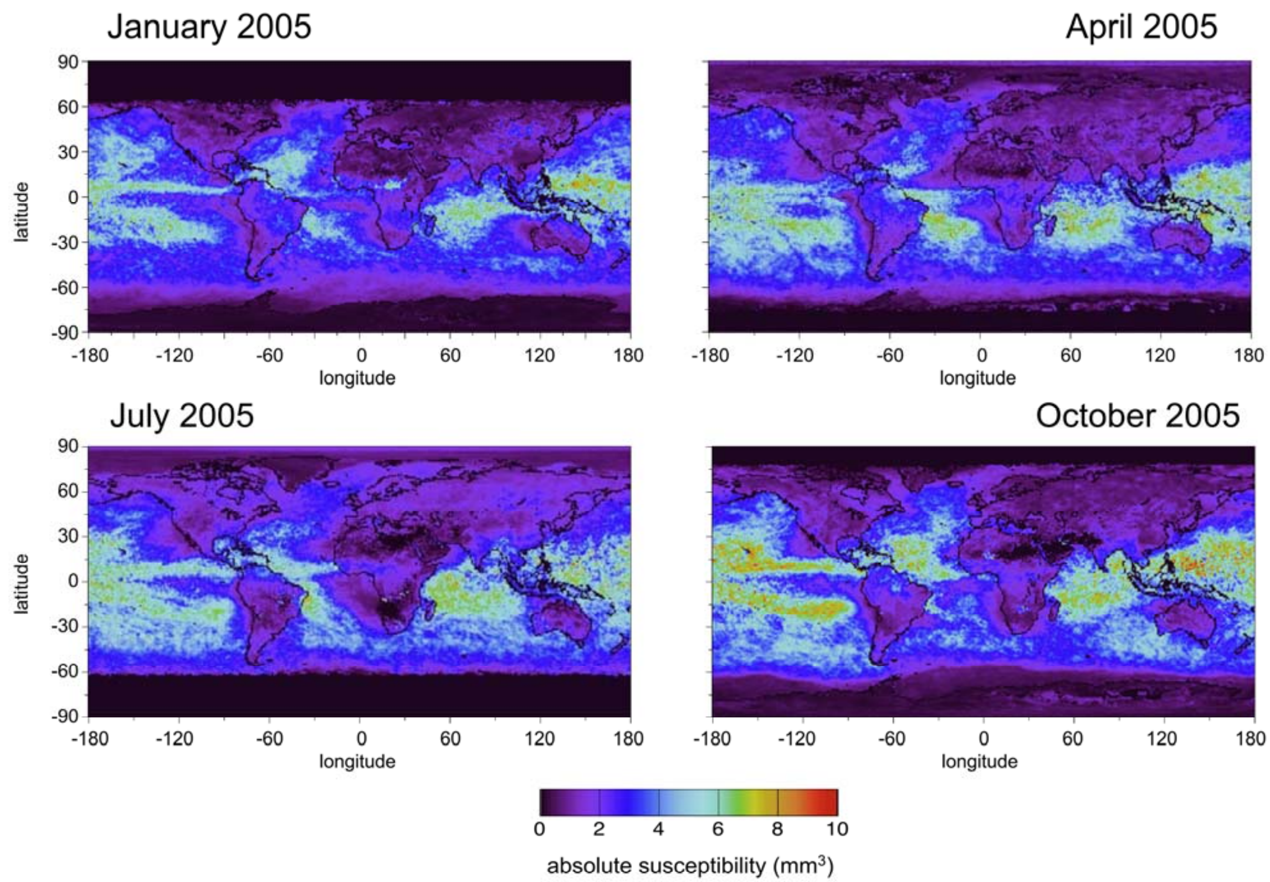


Figure 4a. Monthly averages of absolute susceptibility ($\Delta N = 1\ \text{cm}^{-3}$, $w = 0.3\ \text{gm}^{-3}$) from MODIS Terra Level 3 τ-r_e joint histograms for January, April, July, and October 2005.

Oreopoulos, L., and S. Platnick, 2008: Radiative Susceptibility of Cloudy Atmospheres to Droplet Number Perturbations: 2. Global Analysis from MODIS. *Journal of Geophysical Research* 113, doi:10.1029/2007JD009655.