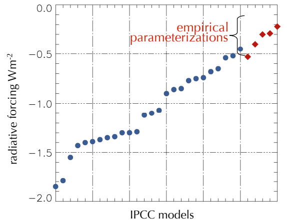
A new approach to observationally-based estimation of aerosol-cloud radiative forcing

Allison McComiskey, Cooperative Institute for Research in Environmental Sciences University of Colorado/ NOAA Earth System Research Laboratory

Graham Feingold, NOAA Earth System Research Laboratory

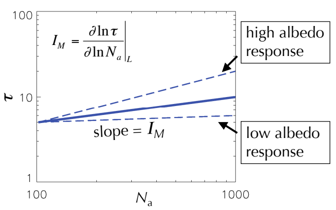
Uncertainty in radiative forcing estimates of the cloud-albedo effect is high and derived solely from modeling in the IPCC AR4. Estimates from observations are uncertain to the extent that they are not useful for validating or parameterizing models. We outline the factors that bias observations of the cloud-albedo effect and propose a new consistent approach that removes the bias. The goal is a more highly constrained estimate of the cloud-albedo effect and reduced uncertainty in climate predictions.



IPCC models that predict the weakest radiative forcing use parameterizations based on satellite observations.

Observationally-inferred estimates of radiative forcing have a range approximately three times higher than for models.

Constraints must be placed on observational approaches in order to provide useful estimates that can be used in model validation and/or parameterization.

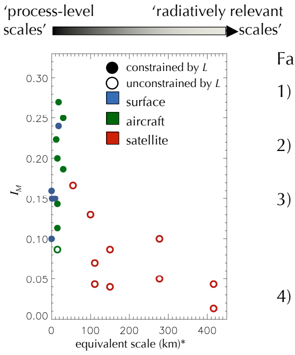


$$I_M = \left.\frac{\partial \ln \tau}{\partial \ln N_a}\right|_L$$

The cloud-albedo effect I_M is quantified as the change in cloud optical depth τ with change in aerosol concentration N_a for clouds of constant liquid water path L.

Coincident, independent measures of each of these properties must be made to accurately characterize the cloud-albedo effect. This is difficult using satellite observations, thus accurate global estimates are lacking.

The cloud-albeo effect from published studies varies systematically with observational approach and scale. An approach is required to link the radiative forcing at climatically relevant scales to processes that can only be accurately observed at the scale of the microphysical processes.



*temporal scales converted to spatial domain using 5 m s⁻¹ wind velocity

Factors that reduce the sensitivity of I_M with increasing scale are:

1) dismissing the constraint on constant L necessarily reduces sensitivity of I_M. *

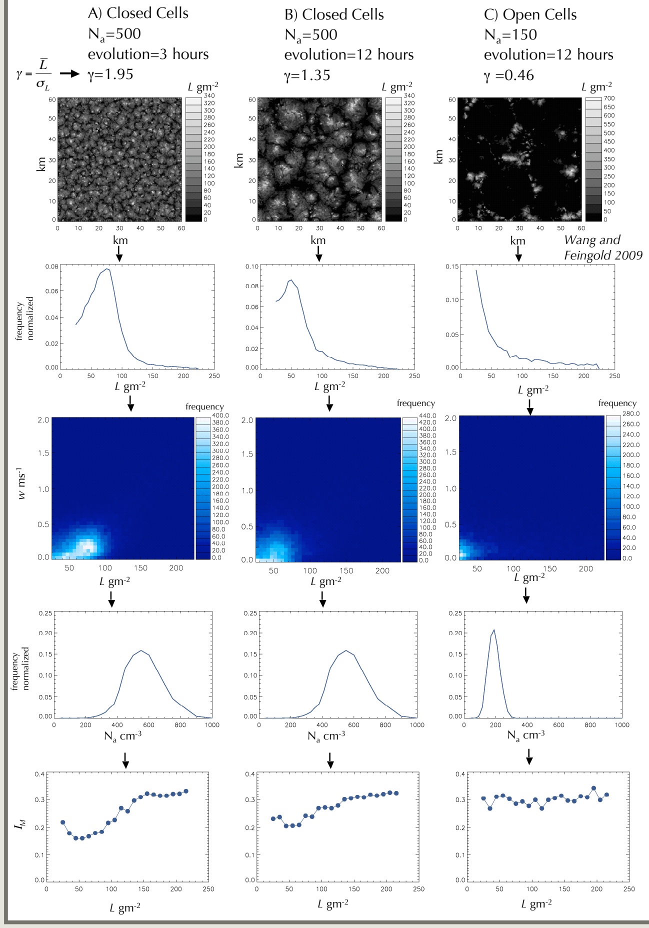
2) narrowing of both the cloud and aerosol pdfs with averaging deteriorates their relationship.

3) instances of aerosol and cloud properties are sufficiently separated in space or time and likely to be physically unrelated on the process-level scales that drive the actual changes in cloud microphysics.

4) as spatial scale increases, cloud processes such as entrainment-mixing, collision-coalescence, drizzle, and aerosol scavenging cause aerosol or droplet concentrations to vary from those due to activation.

Observations must be standardized with respect to scale and approach and performed globally by distinct cloud regimes for useful observationally-based radiative forcing estimates. The process outlined below allows for the conservation of variability in aerosol and cloud across larger spatial domains in determining I_M rather than determining I_M from the large-scale averages. The latter produces flatter slopes and lower radiative forcing estimates.

An observationally-based estimate of the cloud albedo effect from statistically robust pdfs collected globally for distinct cloud regimes is illustrated using WRF simulations.



$$\gamma = \frac{\overline{L}}{\sigma_L}$$

Wang and Feingold 2009

WRF simulations at high temporal and spatial resolution simulate a range of conditions in which aerosol-cloud interactions occur. Varying degrees of homogeneity γ in the cloud liquid water path L field are driven by varying aerosol concentrations. Higher aerosol concentrations result in closed cells with a greater degree of homogeneity.

The shape of the L pdf changes with cloud spatial pattern and resolution of the observation. This shape has a large influence on the slope of I_M and must be well defined.

An independent measure of L is necessary for imposing constraints on I_M *calculations.*

There is an inherent coupling between L and w and thus, the observed I_M will be a function of both. Naturally, the shape of these distributions changes with cloud structure.

Joint distributions for L and w in each cloud regime must be known.

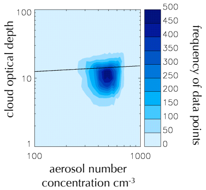
A parcel model using inputs from the above WRF runs (pdf of liquid water path L, updraft velocity w, and aerosol number concentration N_a) produces outputs of cloud properties (drop number concentrations N_d, drop effective radius r_e, and optical depth τ from which I_M can be determined.

Once I_M *is defined in this manner for different cloud regimes it can be applied using known pdfs of L and* N_a*.*

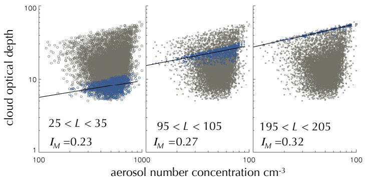
* dismissing the constraint on constant L necessarily reduces sensitivity of I_M with dependence on the homogeneity of the cloud regime

this constraint is often ignored in satellite-based analyses due the difficulty in achieving an independent measure of L

The contour plot shows I_M for Scene B (above right), calculated with no constraint on L. The slope is relatively flat.



The plots at right show a sample of L bins from the same data and the tighter correlation among data points.



The values reported in the table are the average of the values binned by L (as shown in the sample plots at left). Slopes unconstrained by L are low as the variability in L caused by variation in meteorological conditions masks the effect of aerosol on cloud drop activation. As the homogeneity of the cloud decreases the difference between the constrained and unconstrained calculations increases.

	homogeneity parameter	I_M unconstrained	I_M constrained
A	1.95	0.13	0.25
B	1.35	0.08	0.27
C	0.46	0.01	0.30