What Exactly Do Metrics for Aerosol-Cloud Interactions Represent?

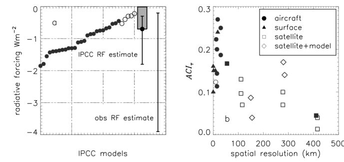
Research Highlight

The interaction of aerosols and clouds engenders a large measure of uncertainty in climate sensitivity and climate change. Metrics that quantify these interactions and associated radiative forcing estimates span a range that is too wide to be definitive for climate studies. We argue that a component of this uncertainty derives from the use of a wide range of observational scales and platforms. A common metric used to quantify the first aerosol indirect effect, or albedo effect, is ACI, the change in cloud microphysical properties with a change in aerosol concentration. This metric was intended to describe the microphysical processes that are the underlying mechanism for the albedo effect and require inputs from observations made at the "process scale." However, observations from which ACI is calculated are often made of bulk properties (e.g., cloud optical depth) over a wide range of resolutions, or "analysis scales." Differences between the process scale and analysis scale can produce a wide range of results due to the impact that data aggregation and computational approach have on statistical properties of the aerosol or cloud variable and their covariance. Further, values along this range of results are often treated as equivalent when, in fact, they may have physically different interpretations. This leads to error and larger uncertainty ranges when quantifying the radiative forcing of aerosol indirect effects.

Using data from satellite, the ARM AMF, and WRF model output, we show that as observations become coarser in resolution, variance in the property being measured is lost. This loss of variance can have an appreciable impact on the statistics that are used to represent ACI and other metrics for aerosol-cloud interactions. Therefore, maintaining statistics of the variability in the observations becomes more important as coarser resolution measurements are employed. This is especially true as aerosol and cloud properties have different inherent scales of variability, and averaging will have different effects on each and, hence, the magnitude of regression slopes between the two.

Issues associated with the coarsening of observational resolution particular to quantifying the albedo effect are also discussed. Specifically, the omission of the constraint on cloud liquid water path L and the separation in space of cloud and aerosol properties from passive, space-based remote sensors tend to dampen the measured strength of the albedo effect. Based on our understanding of these biases we propose a new observationally based and process-model-constrained method for estimating aerosol-cloud interactions utilizing PDFs of aerosol and cloud variables to retain information on their variability. This approach will generate an observationally based method for assessment of aerosol-cloud forcing and provide data for evaluation of GCM cloud properties and their variability.

This work eliminates some confusion over the existing range of values that have been published and raises the question: what does ACI represent? At the core, process level, ACI represents the activation process. However, when calculated using bulk properties over larger scales (e.g., global-scale satellite products or 1° GCM grid cells) it must, ipso facto, include other cloud microphysical processes whose contributions vary from one cloud regime to another. We argue that many of these values labeled ACI are in fact more representative of the full range of aerosol-cloud interactions and their associated feedbacks. Since the albedo effect only attempts to address instantaneous impacts of aerosol on cloud albedo without the complications of feedbacks to cloud fraction or L, it becomes particularly hard to justify continued use of empirical measures of ACI as a means of assessing the albedo effect over large scales. Instead, the full range of aerosol effects on cloud microphysics should be addressed using process-scale measures of ACI, unconstrained by L, that have been aggregated to the climate model scale. Moreover, if the measures of ACI have been aggregated appropriately, e.g., using the model-based method proposed, then



a) Radiative forcing by each IPCC model and the overall IPCC radiative forcing in comparison to an observational estimate for the cloud albedo effect resulting from the values in 1b. b) Values from the literature quantifying the albedo effect (ACI#) and plotted as a function of scale (resolution) of the study. Closed symbols are those that calculate the original variant of ACI with constraint on cloud water, and open symbols are those that ignore the constraint on cloud water.

they are more likely to embody causality rather than unphysical correlation induced by large-scale averaging.

Reference(s)

McComiskey A and G Feingold. 2012. "The scale problem in quantifying aerosol indirect effects." Atmospheric Chemistry and Physics, 12, doi:10.5194/acp-12-1031-2012.

Contributors

Allison C. McComiskey, *NOAA*

Working Group(s)

Aerosol Life Cycle, Cloud-Aerosol-Precipitation Interactions