Measures of aerosol-cloud interactions and their uncertainties: A case study from the AMF Pt. Reyes deployment

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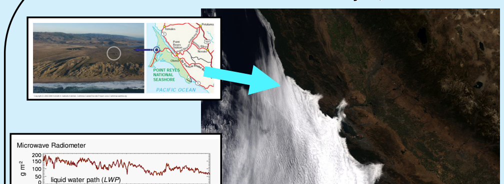
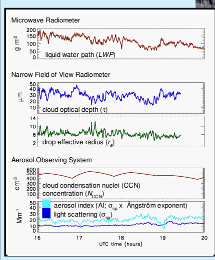
1. Introduction

Measures of aerosol-cloud interactions (ACI), derived from a range of instruments and platforms, vary widely. As these measures are used in GCM parameterizations, understanding the causes and nature of this variability is essential to understanding and improving resulting uncertainty in calculated radiative forcing. Using data from the AMF Pt. Reyes deployment in 2005, we demonstrate the nature of aerosol-cloud interactions, specifically the first aerosol indirect effect, and variability in ACI measures for marine stratocumulus over the California coast.

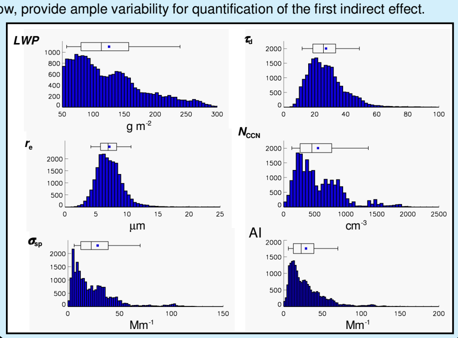
2. Aerosol/Cloud Observations at Pt. Reyes, CA 2005





The Pt. Reyes AMF deployment ran from May through September 2005. Observations used in this analysis from ground-based remote sensing and surface *in situ* monitoring are shown at left. Measurements of cloud properties are made at a temporal resolution of 20 seconds, aerosol light scattering at one minute, and CCN concentrations at 30 minutes. All observations are interpolated to 20 second temporal resolution. The subset of data used in this analysis includes observations for which all variables are available and *LWP* values fall between 50-300 g m^{-2}.

A portion of the time series for September 2, 2005 shown above reveals little variability in aerosol concentrations and cloud properties making it difficult to quantify the first indirect effect in this environment from daily observations. However, statistics for the full deployment, shown in the frequency histograms below, provide ample variability for quantification of the first indirect effect.

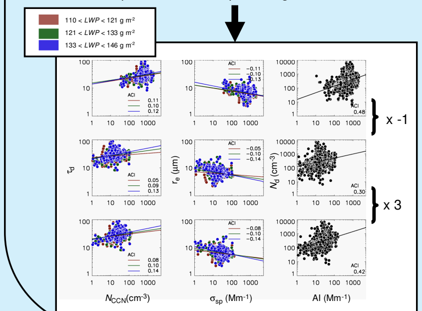


3. Aerosol-cloud interaction (ACI) Measures

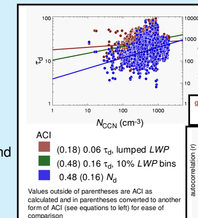
Twomey (1974) defined the first aerosol indirect effect as the change in cloud optical depth with change in aerosol concentration for cloud of constant liquid water. We use the following definitions of ACI as measures of the first indirect effect with α representing the various aerosol proxies presented at left and N_d the cloud drop number derived from observed variables [$N_d = f(\tau_d, LWP, T, P)$] :

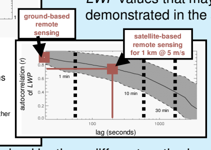
$$ACI = \left.\frac{\partial \ln \tau_d}{\partial \ln \alpha}\right|_{LWP} = -\left.\frac{\partial \ln r_e}{\partial \ln \alpha}\right|_{LWP} = \frac{1}{3}\frac{d \ln N_d}{d \ln \alpha}$$

ACI values for the Pt. Reyes deployment are given for three *LWP* bins. Drop number calculations are dependent on *LWP* and do not require sorting by cloud water content. Observations are consistent with theory and maintain the expected relationships among the three different measures.



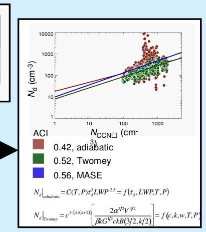
ACI may be sensitive to factors such as natural variability in aerosol and meteorological parameters or methodologies for deriving cloud and aerosol properties. Comparisons of measures of ACI from different instruments, platforms, and incorporating different methodologies should take into account these sensitivities.

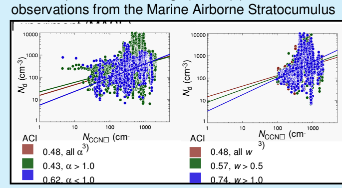




ACI at left shows that failure to account for constant *LWP* may result in low ACI due to averaging over a wider range of cloud microphysical or aerosol properties. Averaging over space or time lumps *LWP* values that may not be well correlated, demonstrated in the autocorrelation function below.

Variation in ACI for N_d derived by three different methods is shown at right. Ground-based remote sensing observations are used to calculate N_d using (1) the assumption of adiabaticity, (2) Twomey's empirical function (both defined at right), and (3) *in situ* observations from the Marine Airborne Stratocumulus

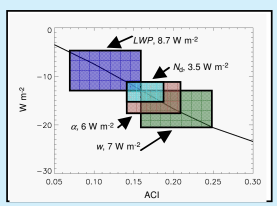




A subset of observations based on thresholds for aerosol Ångström exponent (a proxy for aerosol size distribution) and updraft velocity results in differences in calculated ACI.

4. Uncertainty in Radiative Forcing

When used as a parameterization in GCMs, variability in ACI will result in uncertainty in cloud radiative forcing. Uncertainty for the variability in ACI from the cases above is illustrated here:



Top of the Atmosphere Radiative Forcing (F)

F = f(N_CCN 500) - f(N_CCN 100)

LWP = 120 g m^{-2}

local forcing (100% cloud cover)

45° solar zenith angle

diurnal average of the equinox

surface albedo = 0.15

cloud base height ~ 300 m

(Input values are near means for Pt. Reyes and represent a neutral solar geometry.)

Failure to consider drivers of variability in ACI may result in errors in radiative forcing of up to ~9 W m^{-2}, for the coastal stratocumulus examined here. In a similar study, McComiskey and Feingold (2008) showed that error in ACI measures of 0.05 can translate to a range in calculated radiative forcing from -3 to -10 W m^{-2} per 0.05 unit ACI (0-0.33 scale) for a range of CCN concentrations from 300-2500 cm^{-3} and *LWP* from 50-300 g m^{-2}.

5. In Summary

- GCMs use ACI to parameterize aerosol-cloud interactions.
- Variability in observed ACI is high.
  - attribution to physical processes and/or measurement uncertainties is unclear
- Empirical measures of ACI, explored for California coastal stratocumulus show:
  - consistency among various ACI representations
  - ground-based measures consistent with *in situ* airborne measures
  - variability in ACI with dependence on (1) assumption of constant *LWP*, (2) methods for retrieving N_d (3) particle size, and (4) updraft velocity
- Variability in ACI is presented in the context of local cloud radiative forcing.
  - for CA coastal stratocumulus from ~ -3 to -9 W m^{-2}
  - for a range of *LWP* and aerosol concentrations from ~ -3 to -10 W m^{-2} for each 0.05 increment error in ACI

References

McComiskey, A and G. Feingold (2008), Quantifying error in the radiative forcing of the first aerosol indirect effect, *Geophys. Res. Lett.*, 35, L02810, doi:10.1029/2007GL032667.

Twomey, S. (1974), Pollution and the Plantetary Albedo, *Atmos. Env.*, v.8, pp. 1251-1256.

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