Aerosol-Cloud Interactions and Radiative Forcing: Modeling and Observations

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Introduction

The effect of aerosol on cloud microphysics ≠ aerosol indirect effect !!

The indirect effect involves radiative forcing and depends on
- cloud microphysical response,
- macroscale properties (cloud fraction, cloud depth, distances between clouds)
- aerosol between clouds

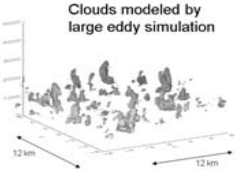
We demonstrate this via:

1. comparisons between measured irradiance fields for a field of cumulus clouds, and irradiance fields calculated based on large eddy simulations of these clouds;
2. calculations of the relative contributions of the microphysical and macrophysical responses to an aerosol perturbation for modeled cloud fields;
3. demonstrations of how sensitive the representation of aerosol-cloud interactions is to the representation of entrainment-mixing, and;
4. simulations of the transition from closed cell convection to pockets of open cells provide an example of how aerosol, through its effect on precipitation, can very effectively change radiative forcing;

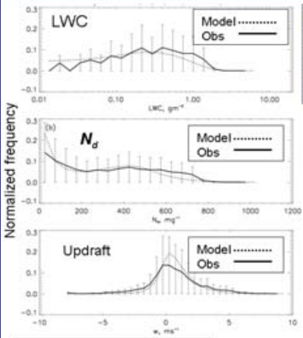
1. Comparison between Model and In-situ Observations

Clouds in Houston sampled by aircraft; CIRPAS/CalTech/NOAA

Clouds modeled by large eddy simulation

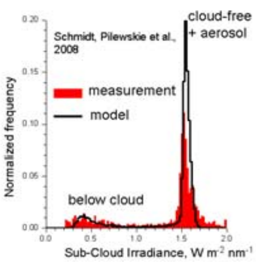


Jiang, Feingold, et al. 2008



***Generally good comparison between model and in-situ measurements: LWC, N_d, updraft; Irradiance** (aerosol + cloud)*

Comparison of 100s of clouds



Conclusions

1. *Statistical sampling of shallow cumulus allowed comparison with LES output. Good comparison for LWP, drop concentration, updraft Irradiance field below cloud compares well provided aerosol between clouds is accounted for.*
2. *In small cumulus, microphysical responses to aerosol perturbations may counteract morphological responses (cloud fraction, LWP). This reduces indirect effect response and albedo susceptibility may be non-monotonic.*
3. *Drizzle in stratocumulus is shown using LES to result in the formation of open cellular structure.*
4. *LWP is shown to decrease with increasing aerosol in non-precipitating stratocumulus as a result of an evaporation-entrainment feedback*

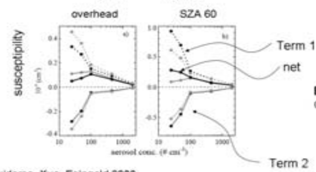
2. Susceptibility calculations based on 3-D RTM for LES simulated cloud fields

$$A_{dom} = CF \times A_{cld}$$

$$\frac{\partial A_{dom}}{\partial N_d} = \underbrace{CF\frac{\partial A_{cld}}{\partial N_d}}_{\text{Term 1}} + \underbrace{A_{cld}\frac{\partial CF}{\partial N_d}}_{\text{Term 2}}$$

$$S_o = \left.\frac{\partial A_{cld}}{\partial N_d}\right|_{\text{Const LWP}}$$

$$S_o = \frac{A_{cld}(1 - A_{cld})}{3N_d}$$



Zuidema, Xue, Feingold 2008

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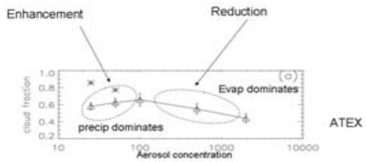
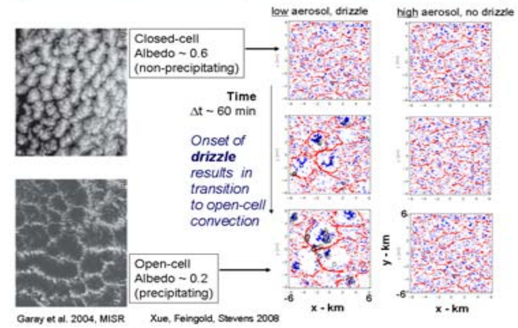


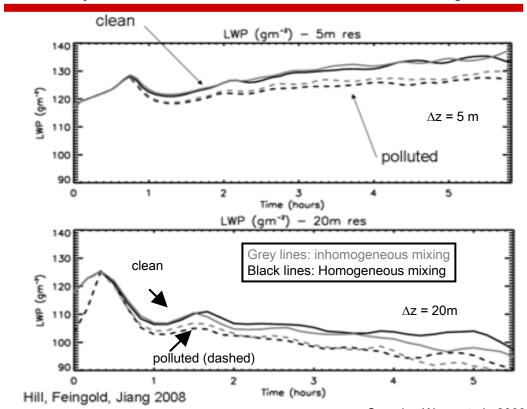
Non-monotonic response of cloud fraction to increases in aerosol

3. Aerosol Effects on Cloud Morphology via Drizzle



Drizzle transforms closed cellular convection to open cellular convection

4. Sensitivity of Aerosol-Cloud interactions to Entrainment-Mixing: LWP



Hill, Feingold, Jiang 2008

See also Wang et al., 2003

Aerosol perturbations result in a decrease in LWP in non-precipitating warm clouds Entrainment-mixing affects the magnitude of the response

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References

Hill, A., G. Feingold, H. Jiang: The influence of mixing on the climate forcing of non-precipitating marine stratocumulus, 2008: J. Atmos. Sci., submitted.

Jiang, H., G. Feingold, et al., 2008: Comparison of statistical properties of simulated and observed cumulus clouds in the vicinity of Houston during the Gulf of Mexico Atmospheric Composition and Climate Study (GoMACCS). J. Geophys. Res., in press.

Schmidt, K. S., P. Pilewskie, G. Feingold, and H. Jiang, 2008: Irradiance from fields of shallow cumulus clouds: Measurements vs. radiative transfer modeling based on clouds generated by a large eddy simulation. In preparation.

Wang, S., Q. Wang, and G. Feingold, 2003: Turbulence, condensation and liquid water transport in numerically simulated nonprecipitating stratocumulus clouds. J. Atmos. Sci., 60, 262-278.

Xue, H., G. Feingold, and B. Stevens, 2008: Aerosol effects on clouds, precipitation, and the organization of shallow cumulus convection. J. Atmos. Sci., 65, 392-406.

Zuidema, P., H. Xue, and G. Feingold, 2008: Shortwave radiative impacts from aerosol effects on marine shallow cumuli. J. Atmos. Sci., in press.