# Aerosol Indirect Effect Analysis: Dynamics vs. Aerosol


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# Introduction

- Recent satellite studies have shown correlations between aerosol optical depth and cloud cover (Ignatov et al. 2005; Loeb and Manalo-Smith 2005; Kaufman et al. 2005; Matheson et al. 2006).

- However, correlation does not necessarily imply cause-and-effect. Other factors that need to be considered include:
  - Cloud contamination.
  - Humidification of aerosols near clouds (i.e., dynamics).
  - Increased particle production near clouds.
  - An increase in aerosol size caused by in-cloud processing.
  - Sunlight reflected by nearby clouds enhancing the illumination of the adjacent cloud-free pixels.

- This presentation: Study aerosol-cloud interactions from satellite data and cloud resolving model simulations to separate the dynamical and aerosol impacts on cloud properties, and cloud contamination on aerorosol retrievals.

# Observational Analysis

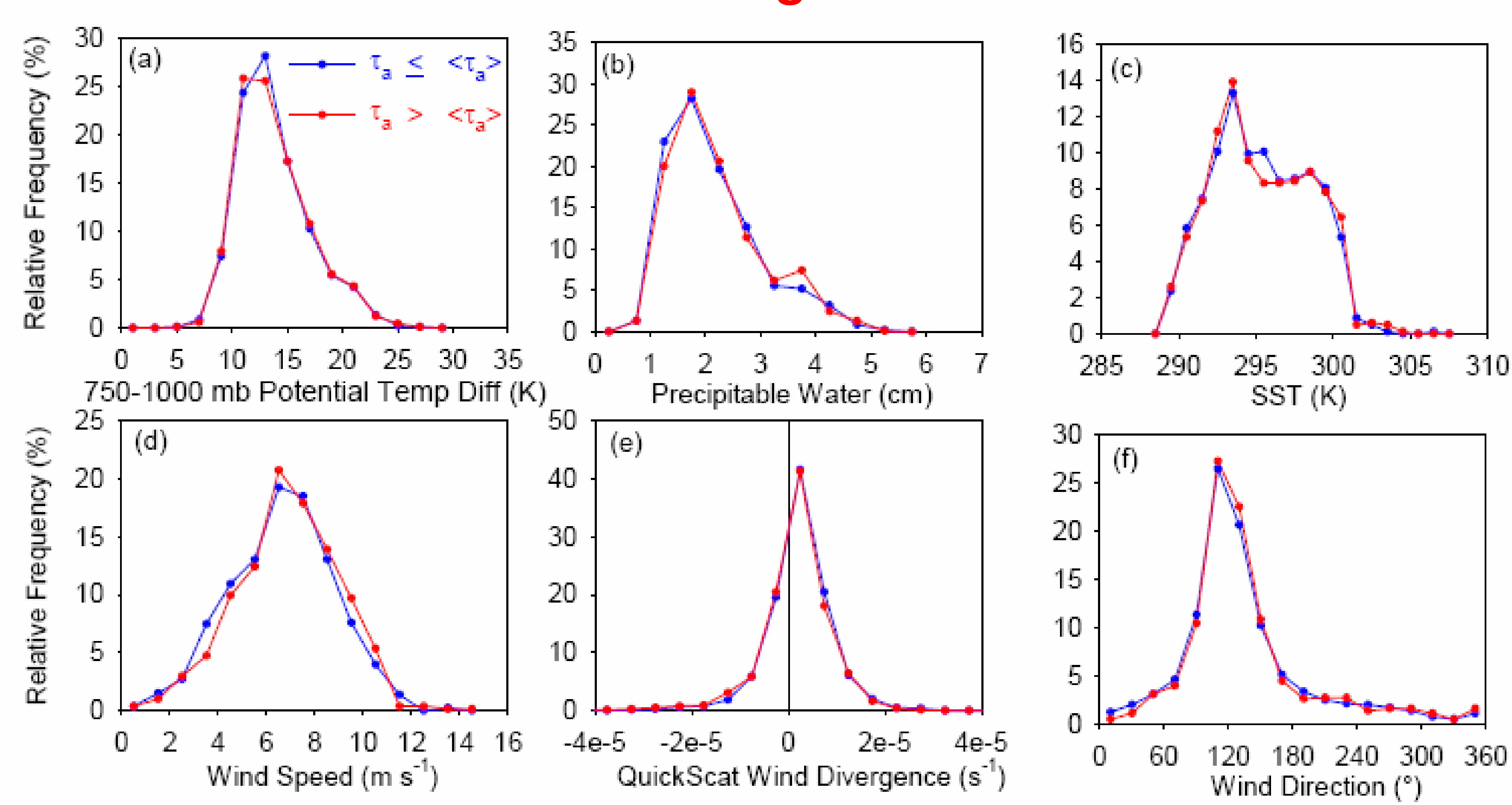
- Consider sulfate aerosols (according to MATCH) off African coast (0°S-30°S and 50°W-10°E) during September 2003.
- Consider only single-layer low clouds in 1°regions with both cloud and aerosol retrievals.
- Each day, cloud and aerosol retrievals in each 5°×5° region are separated into two distinct populations:

(I) 1° subregions with MODIS $\tau_a$ less than or equal to the mean 5°×5° value ($<\tau_a>$)

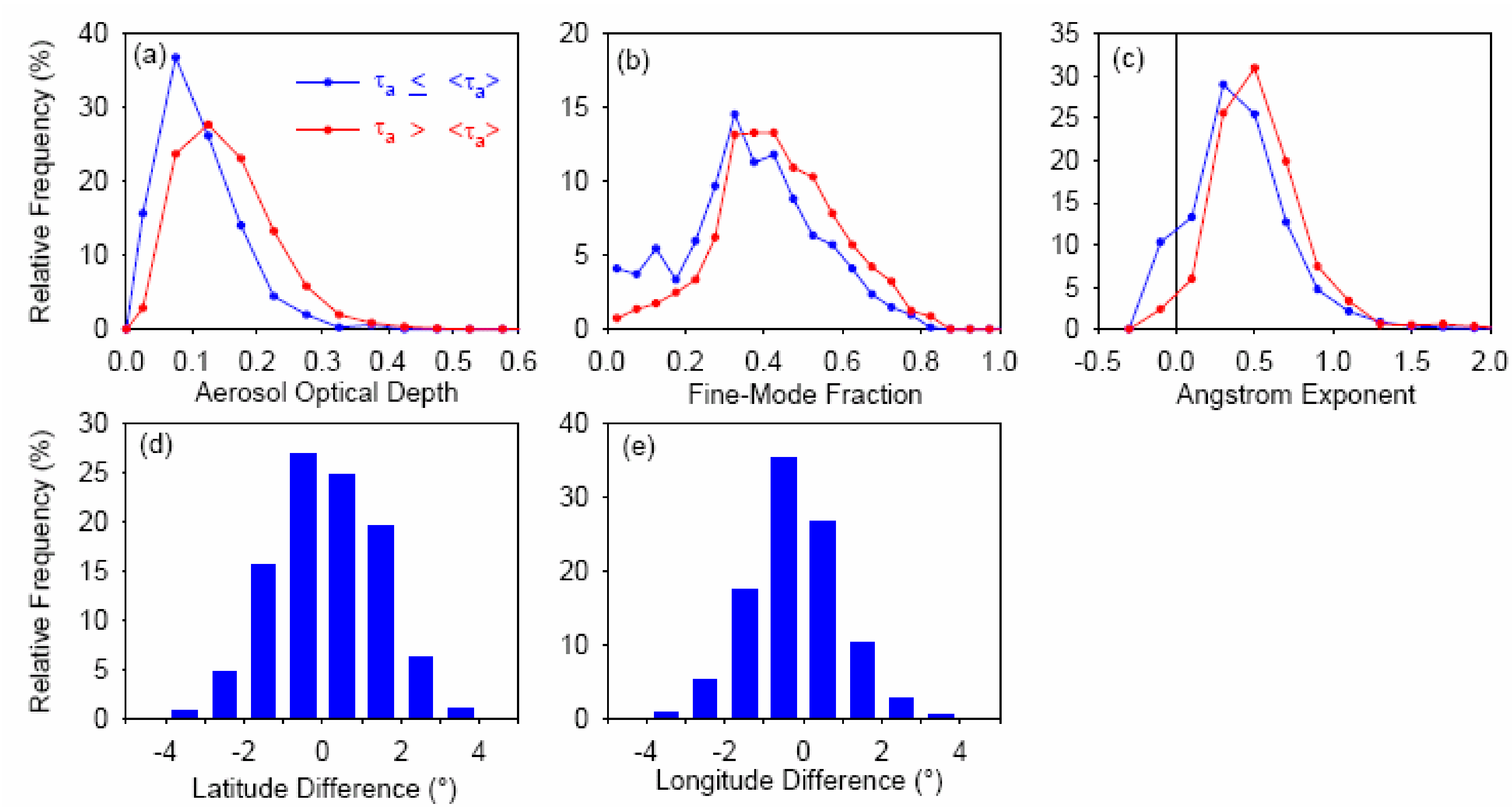
(II) 1° subregions with $\tau_a$ greater than $<\tau_a>$.

Note: Stratifying each 5°×5° region each day into two groups ensures that both groups are influenced by the same large-scale meteorological influences.

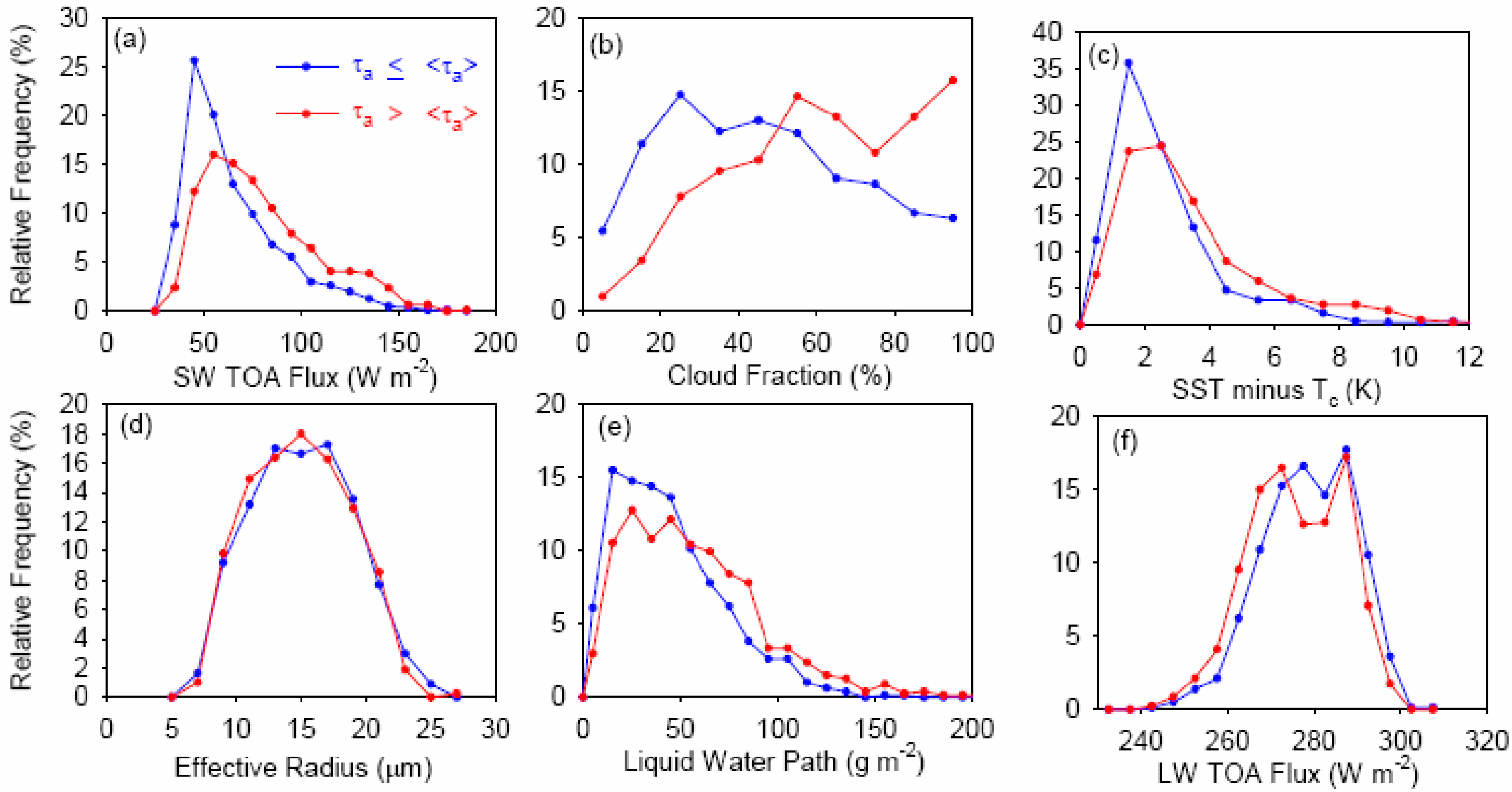
# PDFs of Meteorological Parameters



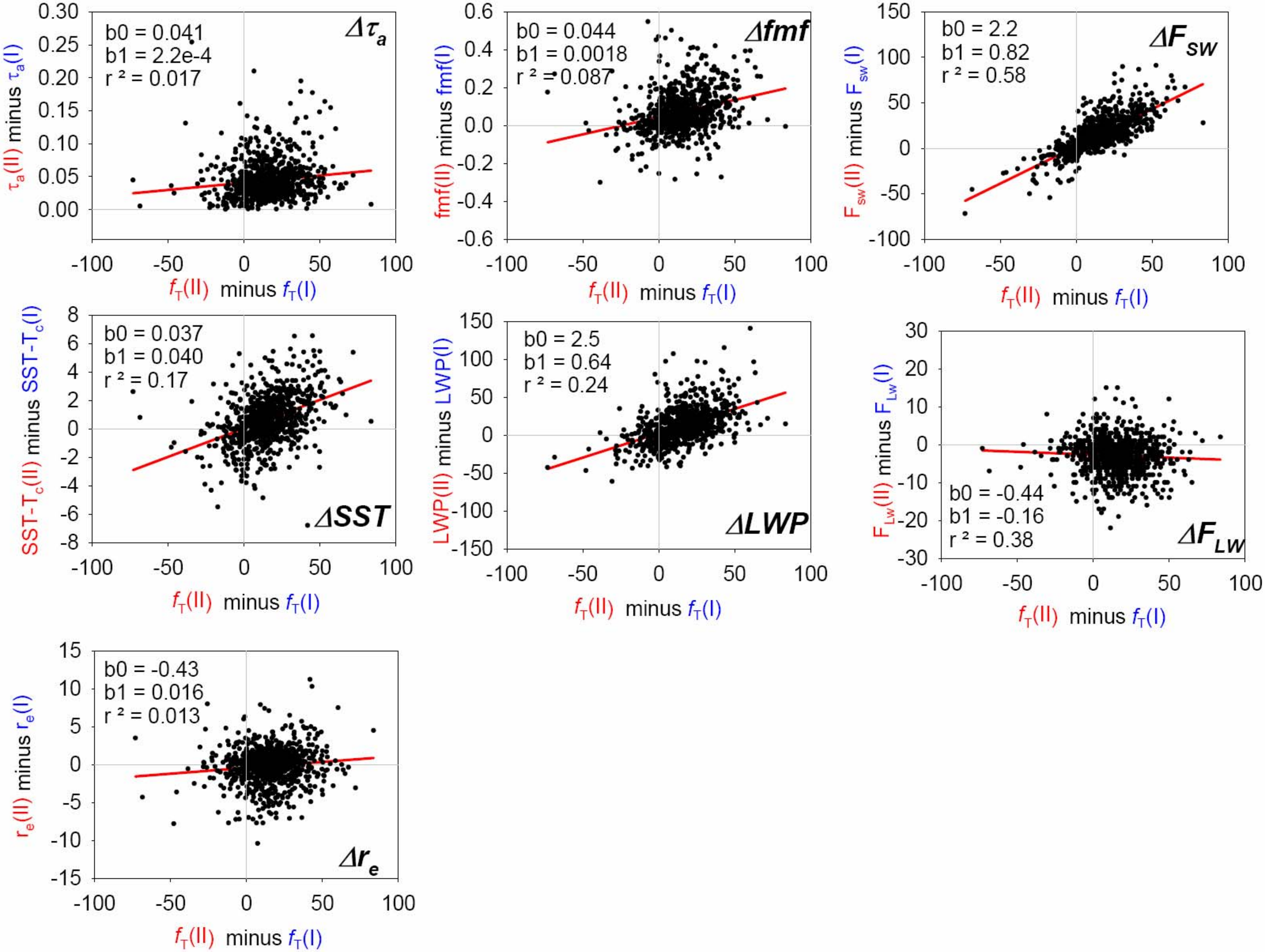
# PDFs of Aerosl Parameters



# PDFs of Cloud and Radiation Parameters



| Variable | Mean | | Mean Diff ($\Delta$) | $\Delta/\sigma_{95}$ |
|---|---|---|---|---|
| | $\tau_a \le <\tau_a>$ | $\tau_a > <\tau_a>$ | | |
| $\tau_a$ | 0.11 | 0.15 | $4.4\times10^{-2} \pm 1.2\times10^{-2}$ | **3.5** |
| $\eta_a$ | 0.37 | 0.43 | $6.7\times10^{-2} \pm 3.2\times10^{-2}$ | **2.1** |
| $\alpha$ | 0.42 | 0.62 | $-2.1\times10^{-1} \pm 7.0\times10^{-2}$ | **3.0** |
| $p_w$ | 2.2 | 2.3 | $4.3\times10^{-2} \pm 2.2\times10^{-1}$ | 0.19 |
| $w_s$ | 6.4 | 6.6 | $0.2 \pm 0.6$ | 0.38 |
| wind direc | 125 | 125 | $3.0\times10^{-2} \pm 2.5\times10^{1}$ | 0 |
| wind_div | $2.6\times10^{-6}$ | $1.9\times10^{-6}$ | $-6.8\times10^{-7} \pm 8.5\times10^{-7}$ | -0.80 |
| $\theta_{750}$-$\theta_{1000}$ | 13.6 | 13.6 | $-2.5\times10^{-2} \pm 6.1\times10^{-1}$ | -0.04 |
| SST | 295 | 295 | $6.0\times10^{-2} \pm 5.3\times10^{-1}$ | 0.1 |
| SST-$T_c$ | 2.6 | 3.4 | $8.1\times10^{-1} \pm 3.5\times10^{-1}$ | **2.3** |
| $F_{sw}$ | 64 | 78 | $14 \pm 4$ | **3.3** |
| $F_{LW}$ | 279 | 276 | $-2.8\times10^{1} \pm 2.0\times10^{1}$ | **-1.4** |
| *f* (%) | 45 | 59 | $14 \pm 5$ | **3.1** |
| $r_e$ ($\mu$m) | 15 | 15 | $-0.2 \pm 0.8$ | -0.23 |
| LWP ($gm^{-2}$) | 42 | 53 | $12 \pm 7$ | **1.7** |



Δτ_a
b0 = 0.041
b1 = 2.2e-4
r ² = 0.017
τ_a(II) minus τ_a(I)
Δfmf
b0 = 0.044
b1 = 0.0018
r ² = 0.087
fmf(II) minus fmf(I)
ΔF_SW
b0 = 2.2
b1 = 0.82
r ² = 0.58
F_sw(II) minus F_sw(I)
ΔSST
b0 = 0.037
b1 = 0.040
r ² = 0.17
SST-T_c(II) minus SST-T_c(I)
ΔLWP
b0 = 2.5
b1 = 0.64
r ² = 0.24
LWP(II) minus LWP(I)
ΔF_LW
b0 = -0.44
b1 = -0.16
r ² = 0.38
F_LW(II) minus F_LW(I)
Δr_e
b0 = -0.43
b1 = 0.016
r ² = 0.013
r_e(II) minus r_e(I)
f_T(II) minus f_T(I)

# Model Description

- Use LaRC CRM to study the influence of dynamics and thermo-dynamics on aerosol-cloud property correlations.

- CRM will incorporate a double-moment cloud microphysical parameterization, which
  - **predicts the mixing ratio and number concentrations of cloud droplets, cloud ice, rain, and snow (Morrison et al. 2005).**
  - **provides a detailed treatment of droplet activation and ice nucleation from a specified (or predicted) distribution of aerosol**.

- Constrain model simulations with advanced dynamic state and improved aerosol assimilation data.
  - **Aerosol information from MODIS, CALIPSO, and improved aerosol assimilation data (with several enhancements over MATCH).**
  - **High-resolution RTG SST data.**
  - **CALIPSO boundary layer thickness information and SST to construct temperature and humidity profiles.**
  - **AMSR-E microwave column vapor data to constrain the column humidity.**
  - **QuikSCAT surface divergence data to give more accurate large-scale subsidence information.**

# Model Sensitivity to Initial Conditions and Advective Forcing Data

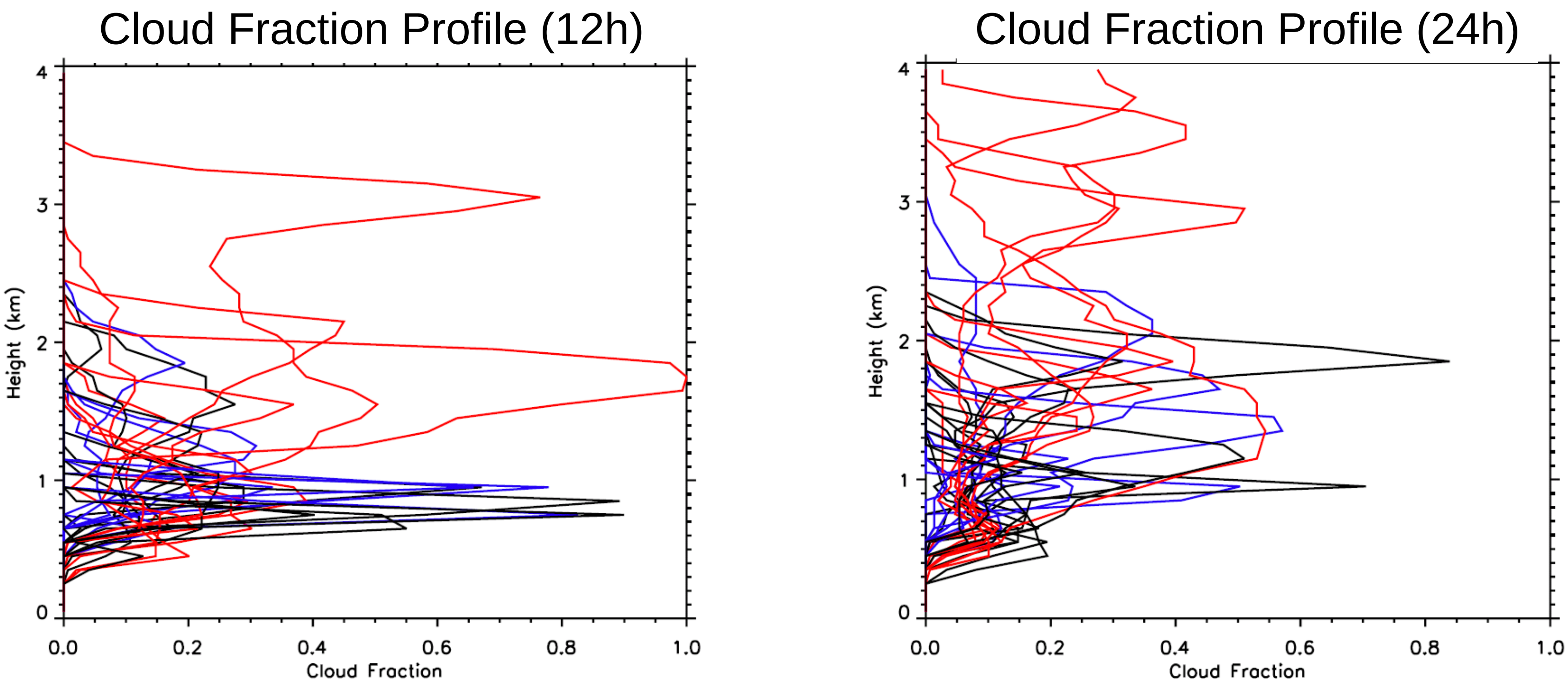
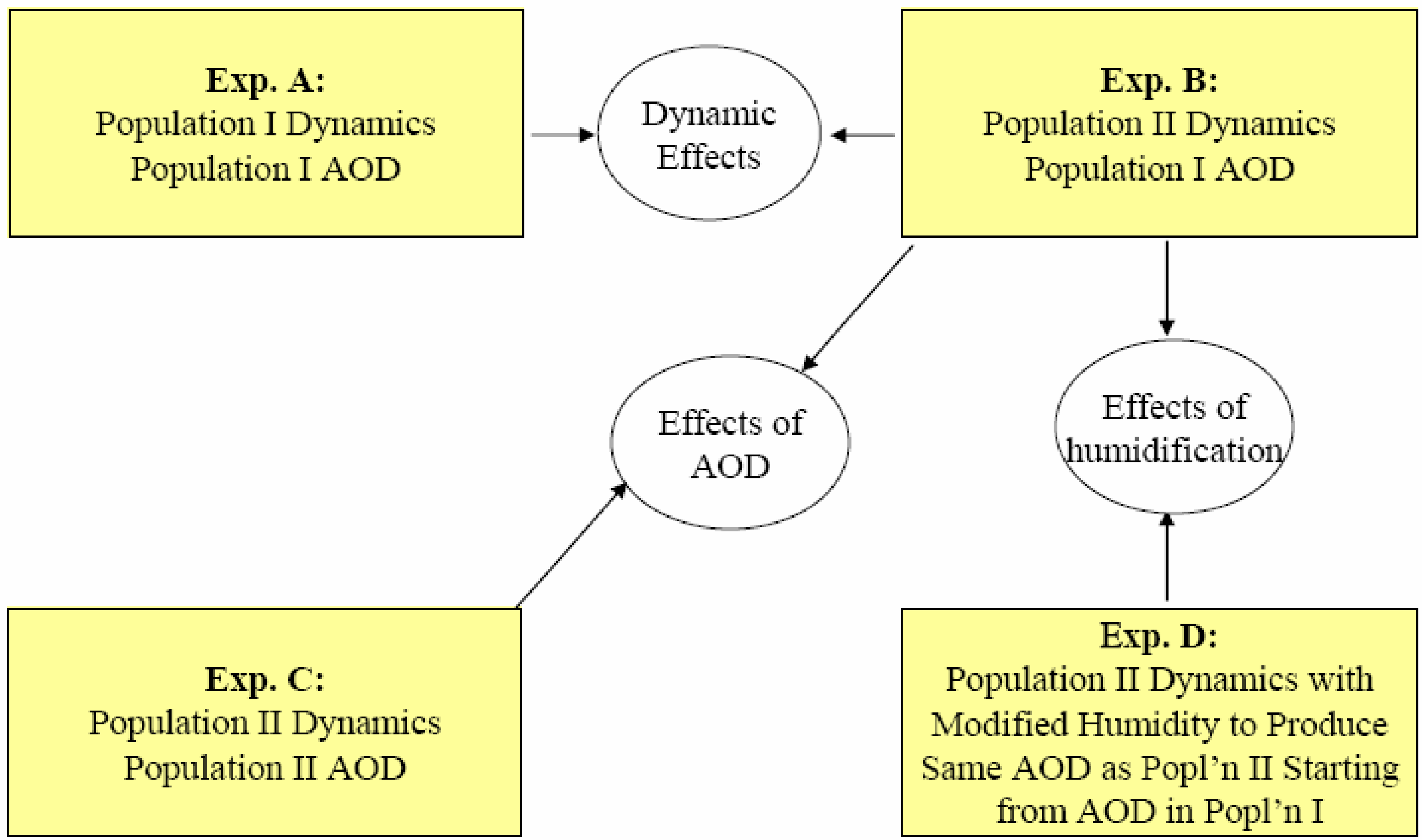



Fig. 5: Simulation of observed stratus cloud systems with equivalent diameters of 150-300 km during March 2000, initialized and driven by ECMWF data assimilation products. The advective forcing was time-invariant between 12 and 24 h. The domain size is 300 km, the horizontal grid size is 2 km, and the vertical spacing is 100 m. Red lines indicate cloud systems with SST greater than 300 K, blues lines with SST less than 297 K and black lines with SST between 297 and 300 K.

**The simulations are driven by advective forcings from the ECWMF data assimilation products. If the pre-scribed SST, advective forcings and initial sounding were perfect, the CRM would produce overcast conditions for all 32 cases.**

# Model Simulations



# Influence of Cloud Contamination on Aerosol-Cloud Property Correlations

- Compare MODIS Aqua and CALIPSO cloud/clear-sky masks

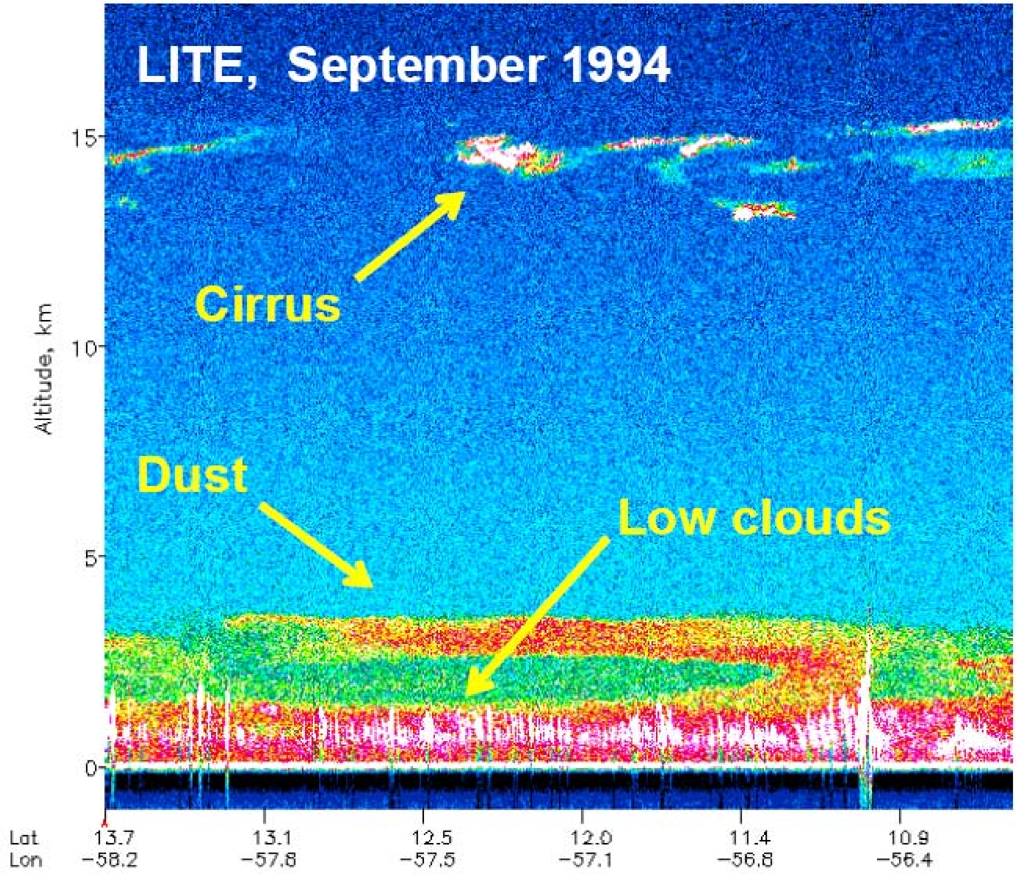



Fig. 8: 532-nm night-time data from LITE showing Saharan dust over the Atlantic Ocean on 17 September 1994. A layer of dust (below 5 km) is located above a cloud-capped marine boundary layer (~1 km). At the right, a layer of cirrus is seen at an altitude of 15 km. Image is centered at 12°N, 57°W.

# Summary

- Early satellite results suggest impressive aerosol-cloud correlations:
  - Cloud cover increases with aerosol optical depth and fine-mode fraction.
  - Need to assess role of cloud contamination in aerosol retrievals.

  - No apparent dependence on large-scale meteorological conditions.
    - Need higher-resolution meteo. data to verify this.

- Plan to conduct similar analysis using LaRC CRM to isolate influence of changes in thermodynamics and dynamics vs real indirect effect of aerosols.