Cloud Macrophysical Parameterization and Aerosol Indirect Effects

Supported by

State of play

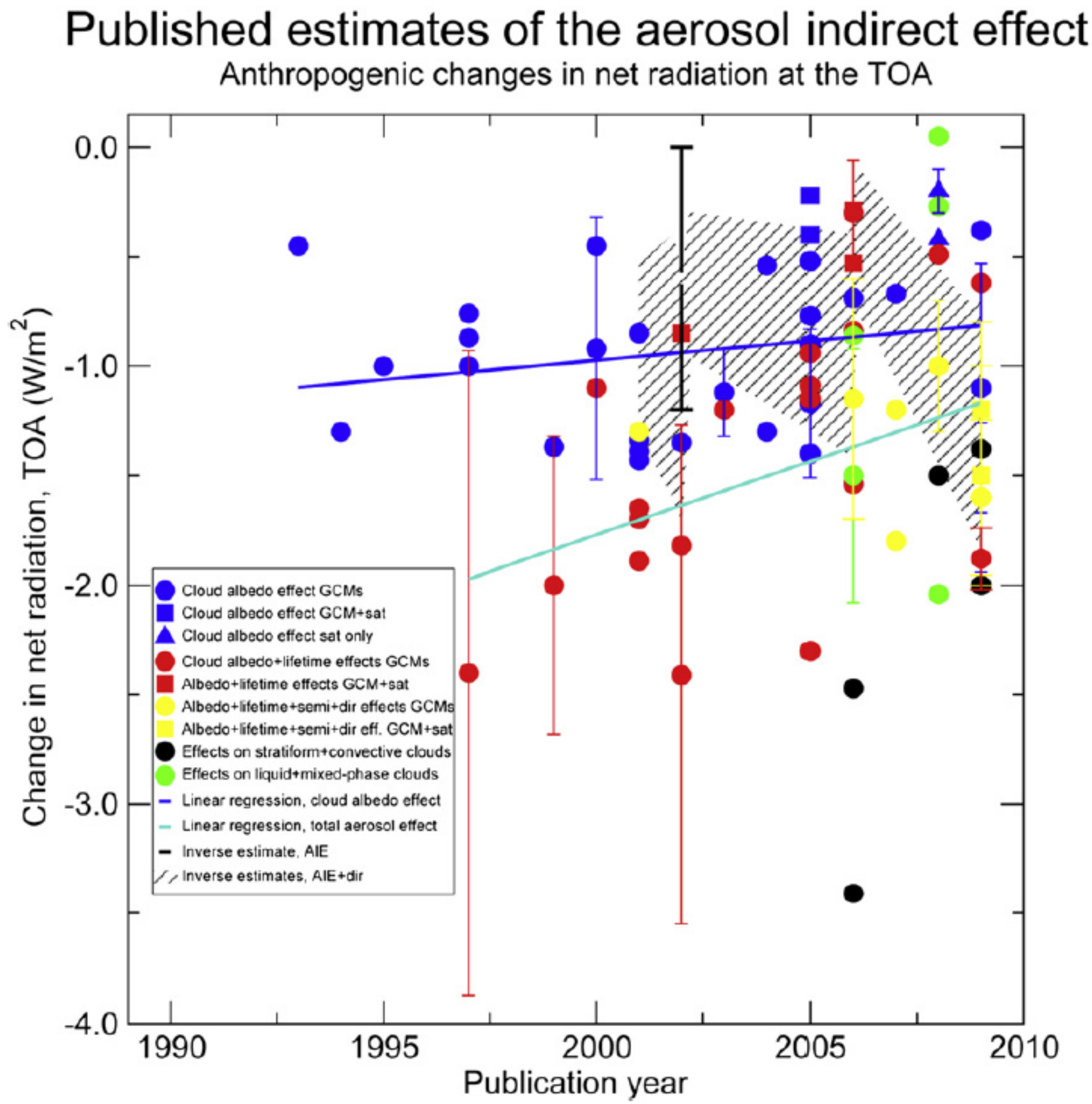


Figure from Trude Storelvmo, in Isaksen et al. (*Atmos. Env.*, 2009)

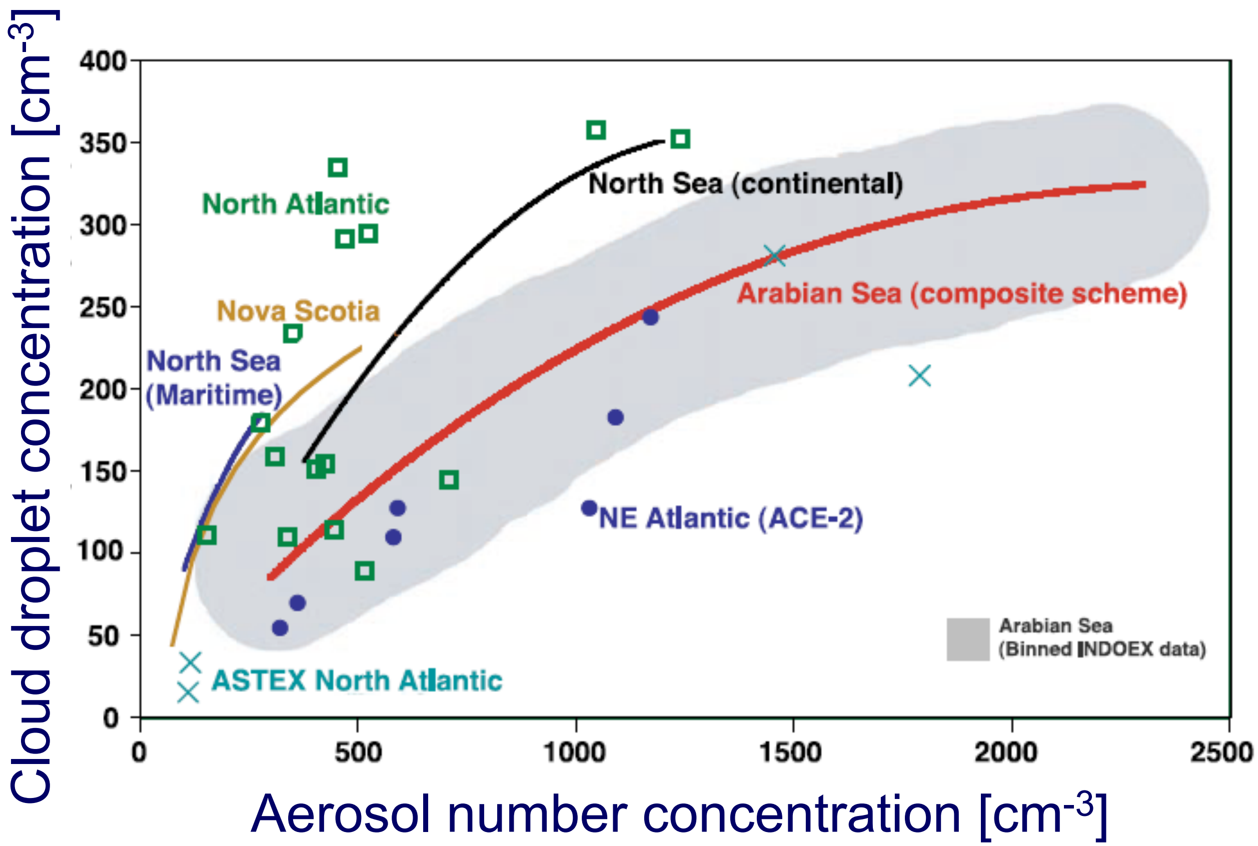
Our CPT's participating institutions:

- **U. Wisconsin, Milwaukee** (Cloud parameterization: V. Larson, Lead PI)
- **GFDL** (SCM and GCM simulations: L. Donner, J.-C. Golaz, Y. Ming, H. Guo)
- **NCAR** (SCM and GCM simulations: A. Gettelman, H. Morrison, P. Bogenschutz)
- **NOAA ESRL** (LES: G. Feingold, T. Yamaguchi, S-S. Lee)
- **JPL** (Satellite obs: G. Stephens, M. Lebsock, T. Kubar)
- **U. Washington** (Aircraft and satellite obs: R. Wood, D. Grosvenor)

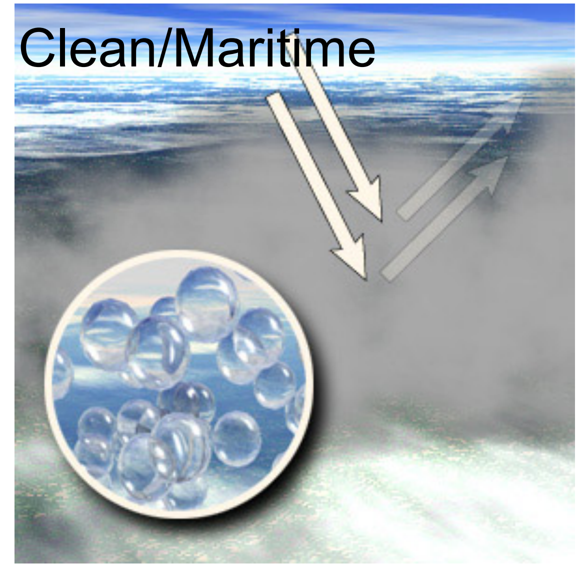
Dynamics-Based PDFs for Cloud Parameterization: Motivation

- Moisture-based PDFs are not linked to dynamics of cloud formation and dissipation.
- Key microphysical processes like droplet activation are closely linked to vertical motions.
- Aerosol-cloud interaction: An example.

Observed dependence of cloud droplets on aerosols



Source: Ramanathan et al. (*Science*, 2001)



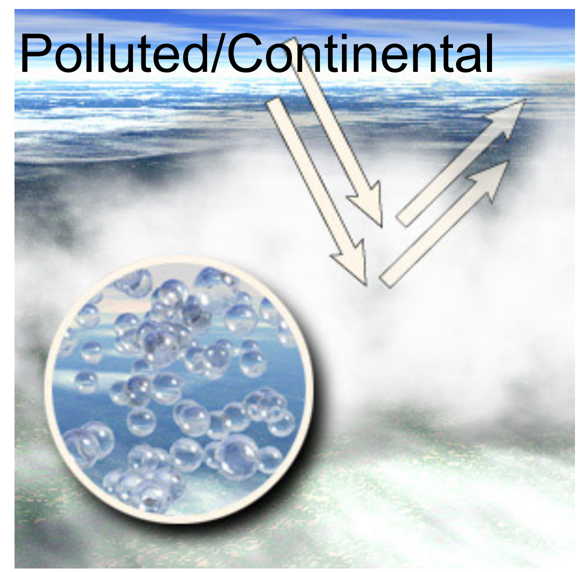
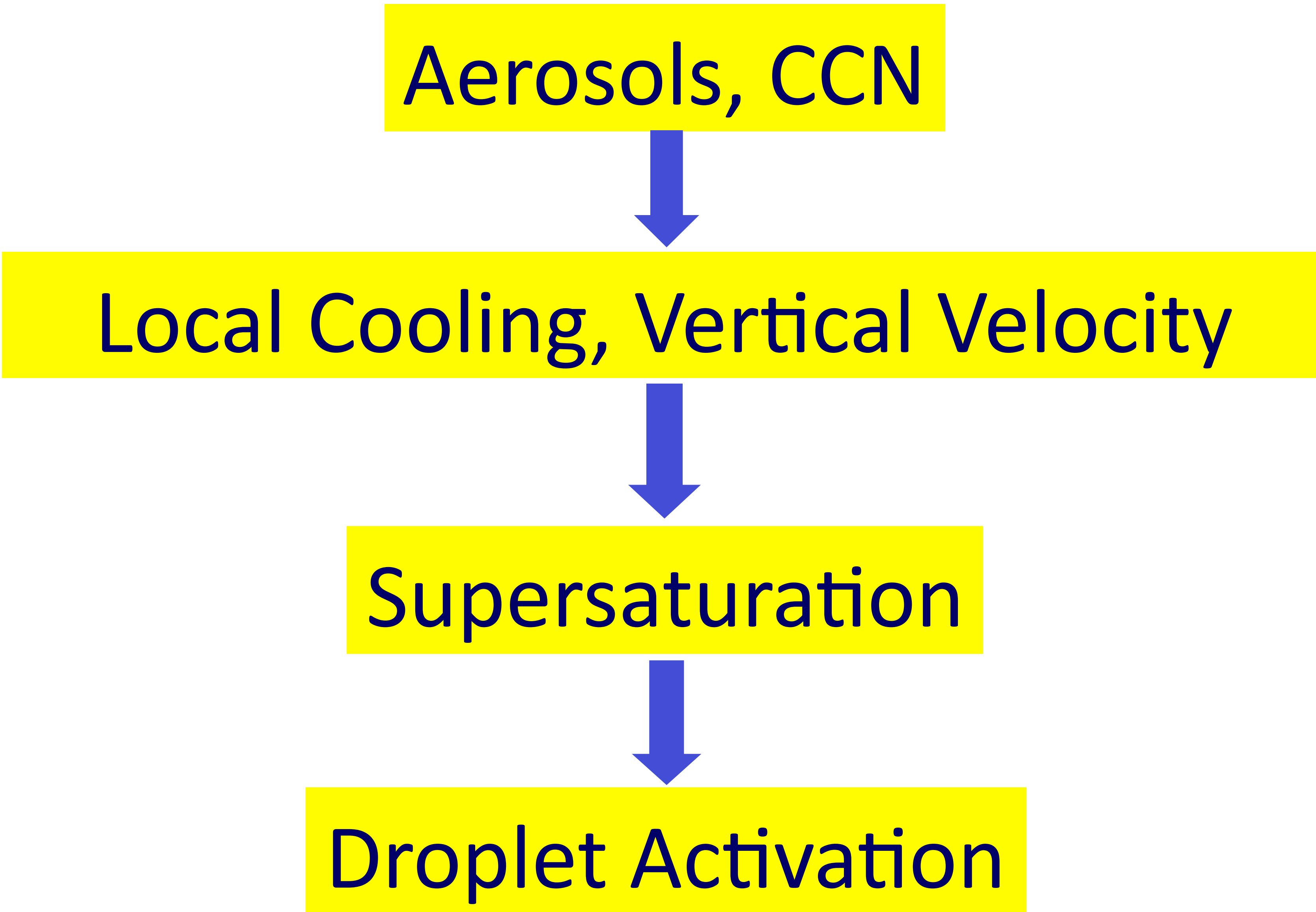
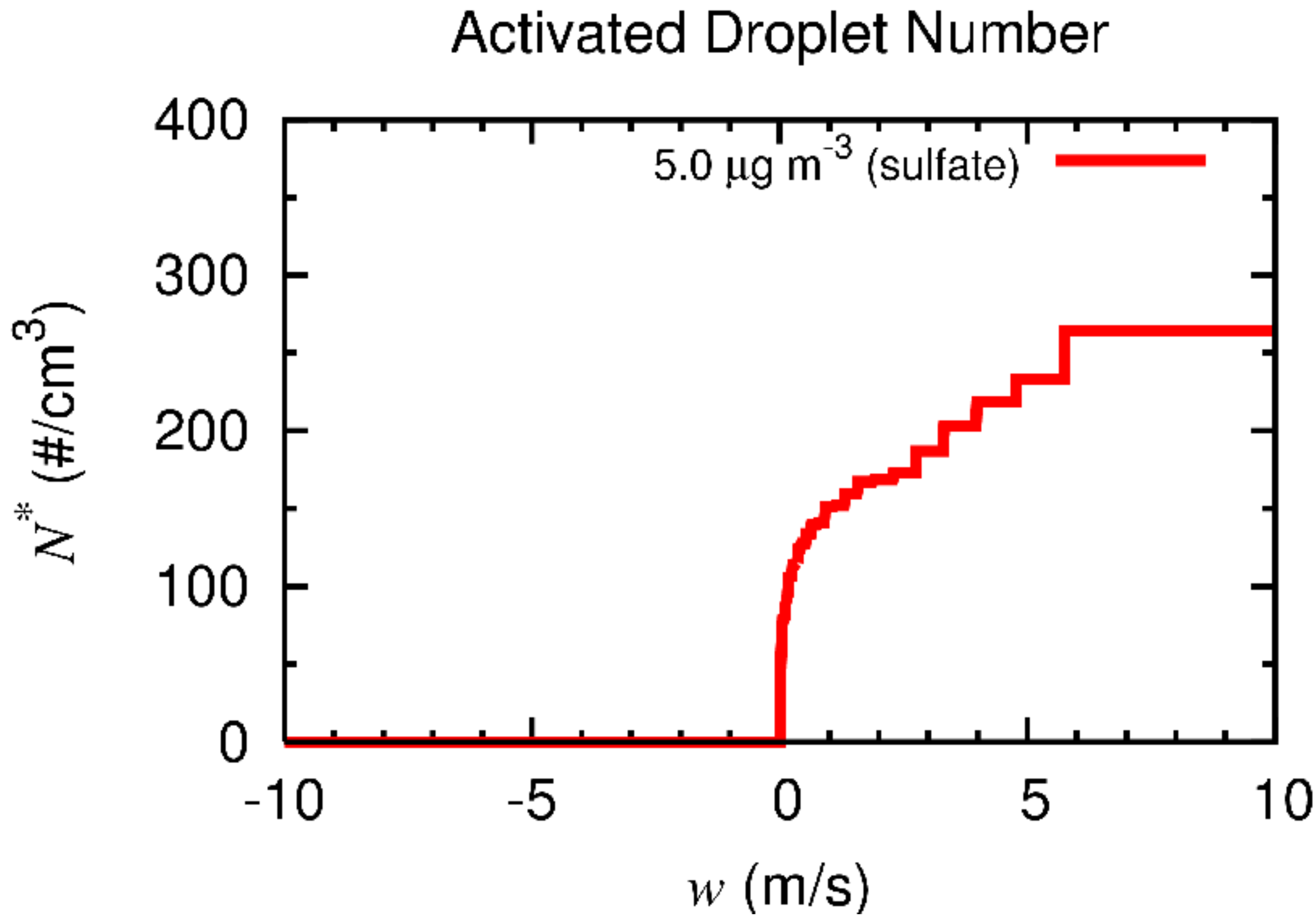


figure Robert Simmon, NASA

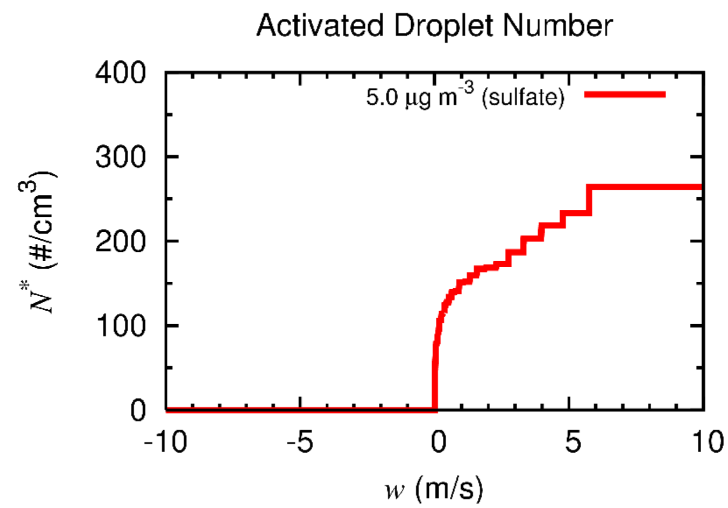

Aerosols, CCN
Local Cooling, Vertical Velocity
Supersaturation
Droplet Activation

Linking Cloud Macrophysics and Microphysics in Stratiform Clouds



cf., Ming *et al.* (*J. Atmos. Sci.*, 2006)

Large-scale CCN activation



Layer-averaged activation:

$$\overline{N}_{\text{activation}} = \int N^* \left(w, p, T\right) \, dx \, dy$$

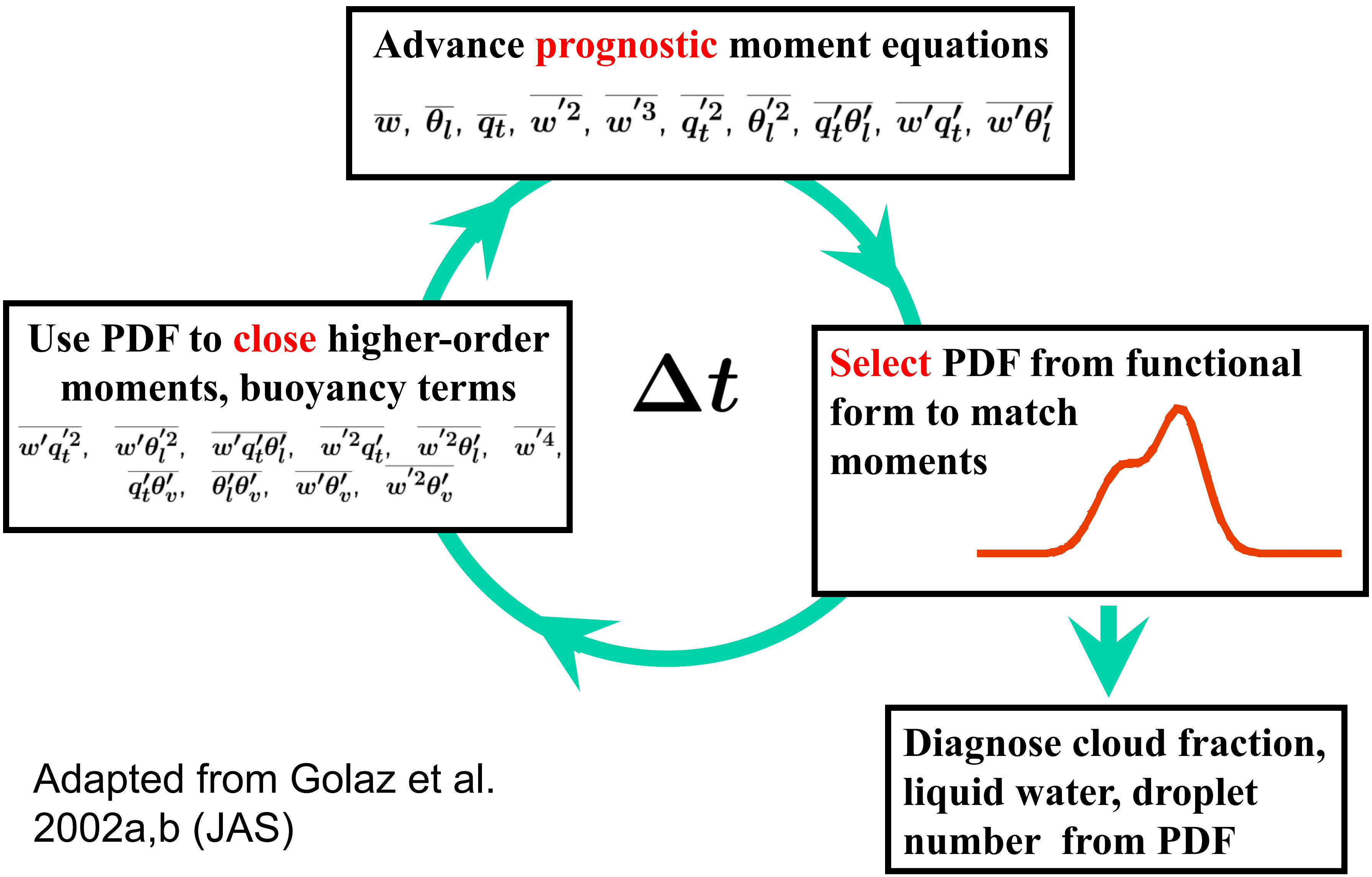
Because *N** is non-linear

$$\overline{N}_{\text{activation}} \neq N^* \left(\bar{w}, \bar{p}, \bar{T}\right)$$

However,

$$\overline{N}_{\text{activation}} \cong \int N^* \left(w, \bar{p}, \bar{T}\right) pdf\left(w\right) dw$$

Building a PDF-based parameterization



Adapted from Golaz et al.
2002a,b (JAS)

Dynamics-PDF Cloud Parameterization: Overview

- Based on Golaz et al. (2002, *J. Atmos. Sci.*): "CLUBB" (Cumulus Layers Unified by Bi-Normals)
- Joint PDFs for vertical velocity, liquid potential temperature, and total water mixing ratio
- Single-column model tests for BOMEX and DYCOMS-II field programs

Dynamics PDF Parameterization for Stratiform Clouds and Turbulence

- Fit liquid potential temperature, total water, vertical velocity PDFs for range of Cu and Sc PBLs to LES simulations
- LES evaluated using GCSS WG 1 cases (ARM, ATEX, BOMEX, DYCOMS-II RF01 & RF02, FIRE, RICO)
- Prognostic equations for higher-order moments
- Seamlessly select PDF forms based on evolution of higher-order moments
- Diagnose cloud macrophysics (fraction, liquid content, etc.) from PDFs

CPT Goals

- Chief deliverable: implementation of CLUBB within NCAR and GFDL GCMs
- Couple CLUBB with microphysics scheme
- Investigate aerosol indirect effects (AIEs) in sensitivity studies using large eddy simulation, aircraft/satellite data, and CLUBB => use to improve PDF scheme representation of AIEs
- Develop toolkit for testing GCM based on relevant satellite datasets

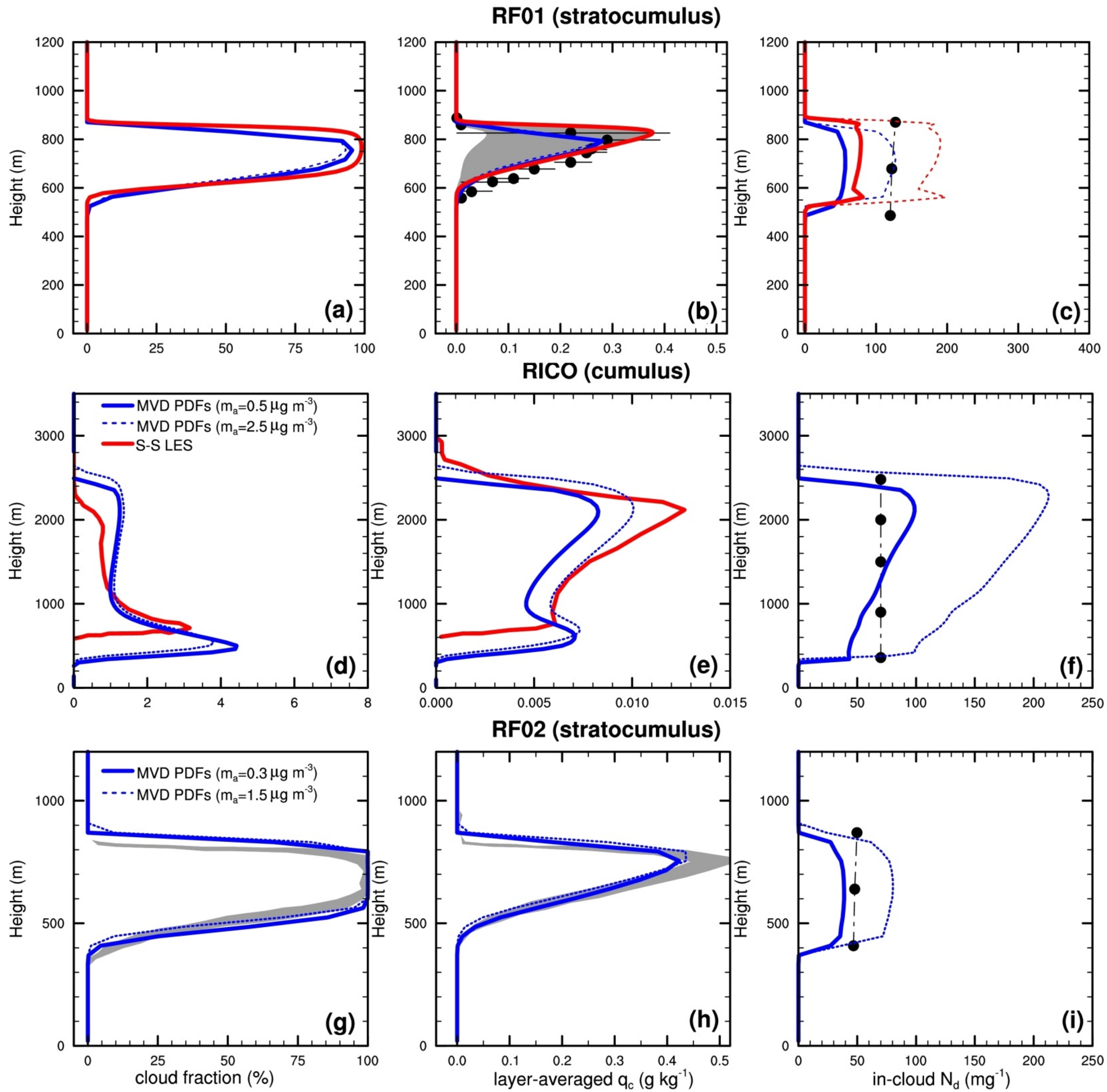
Activities during first year – CLUBB SCM

- Continued testing and refinement of single column (SCM) version of CLUBB using observational cases
  - Existing case studies (DYCOMS, ATEX, BOMEX, RICO). Paper published by Guo et al. (2010, *GMD*)
  - VOCALS RF06 case study prepared and simulated with LES (Wang et al. 2010)
  - VOCALS ship-observed cases being prepared
- Exploration of CLUBB-SCM responses to aerosol perturbations
  - Ability to reproduce complex responses (LWP increasing and decreasing depending upon meteorological conditions)
  - Guo et al. (2010, and 2011: *Geophys. Res. Lett.*, submitted)

Five warm cloud cases

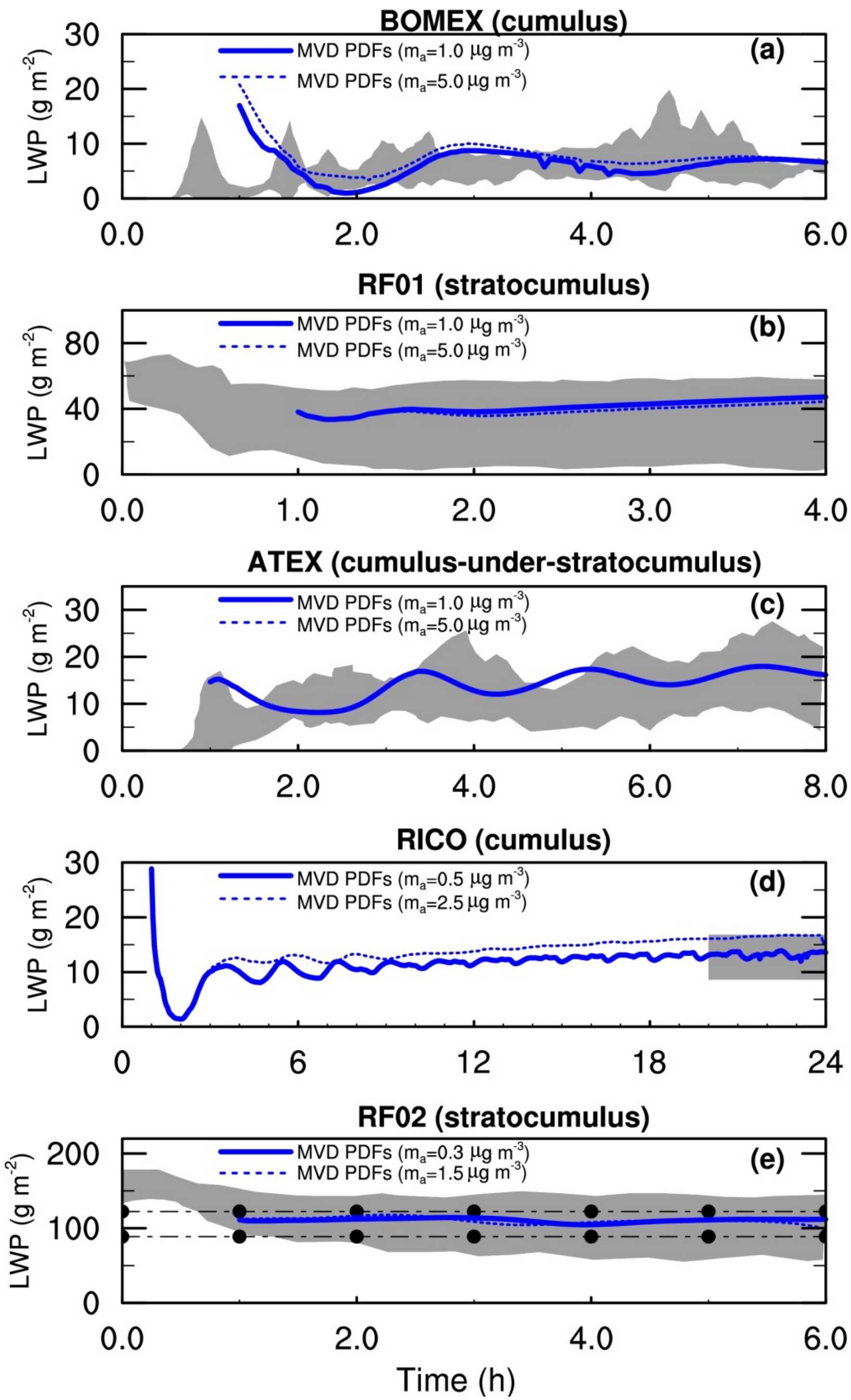
Non-precipitating
- BOMEX (cumulus)
- DYCOMS-RF01 (stratocumulus)
- ATEX (cumulus-under-stratocumulus)

Precipitating
- RICO (cumulus)
- DYCOMS-RF02 (stratocumulus)
- VOCALS RF06 (stratocumulus, open cells)



From Guo *et al.* (2010, *Geosci. Model Dev.*)

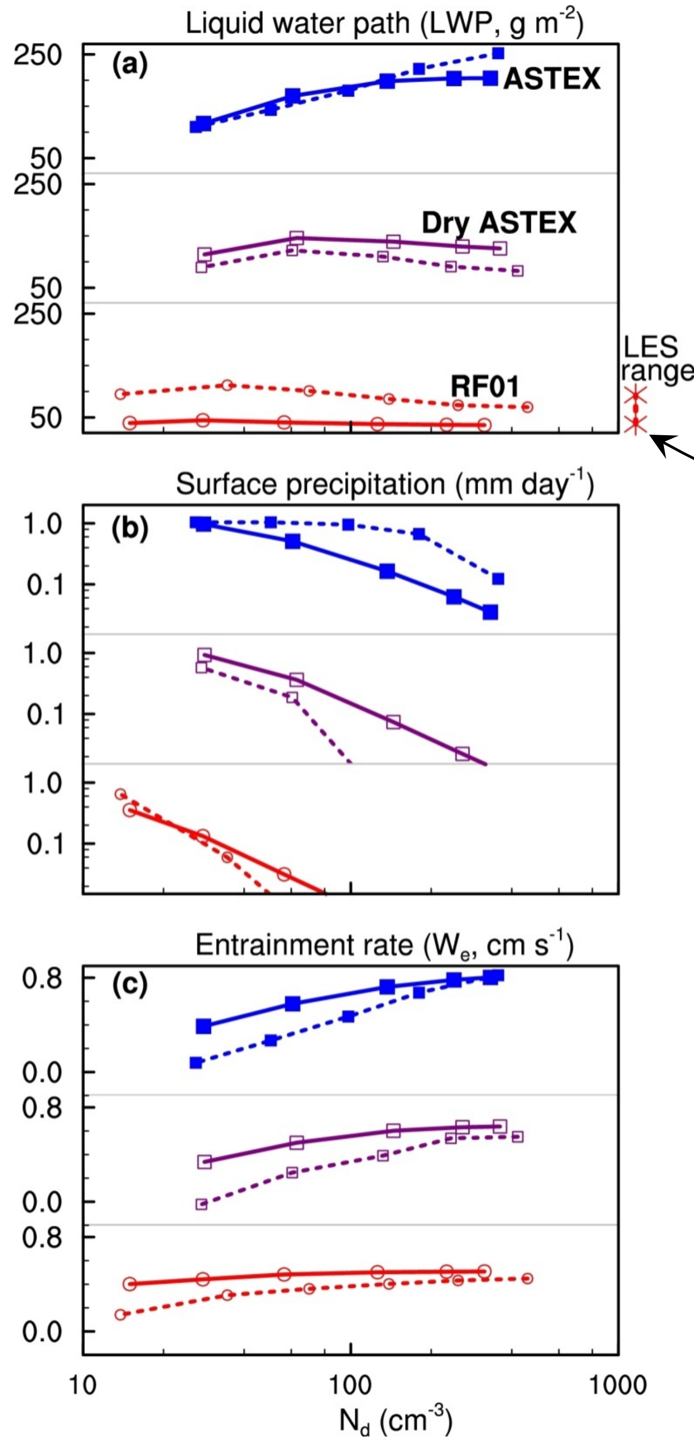
AM3 SCM using multivariate PDF with dynamics, aerosol activation, and double-moment microphysics



from *Guo et al.* (2010, *Geosci. Model Dev.*)

Solid: CLUBB

Dashed: LES from Ackerman *et al.* (2004, *Nature*)

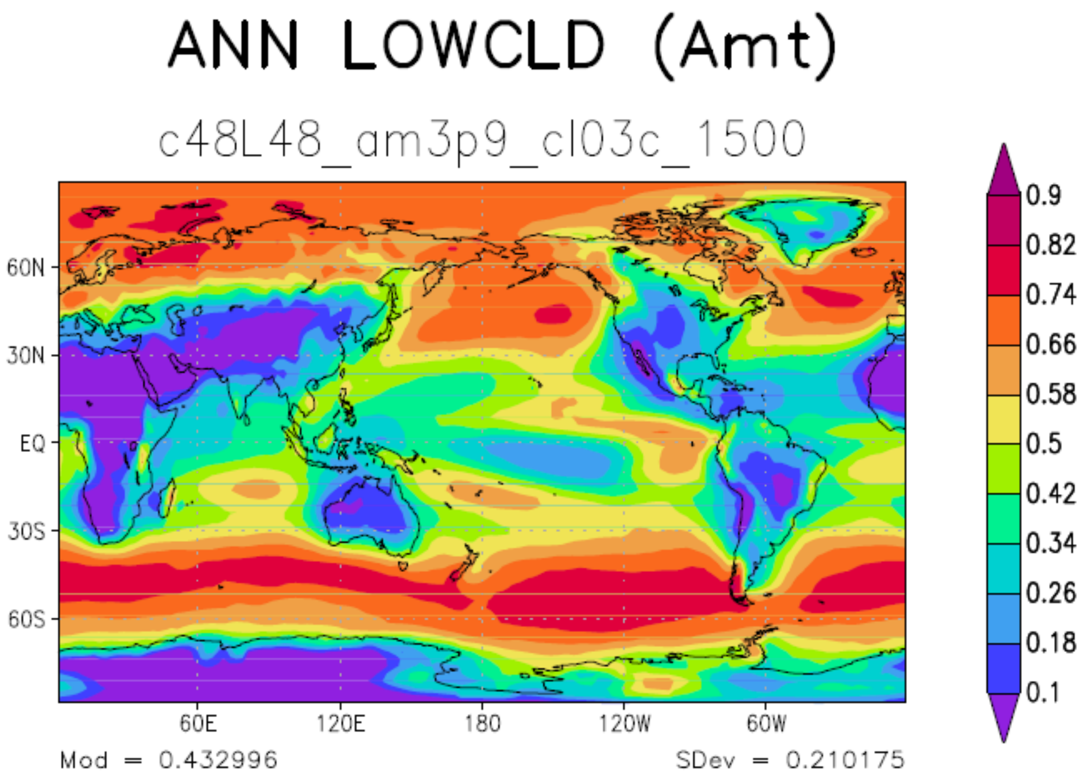


LES range from Guo *et al.* (2010, *GMD*)

Guo *et al.* (2011, *GRL,* submitted)

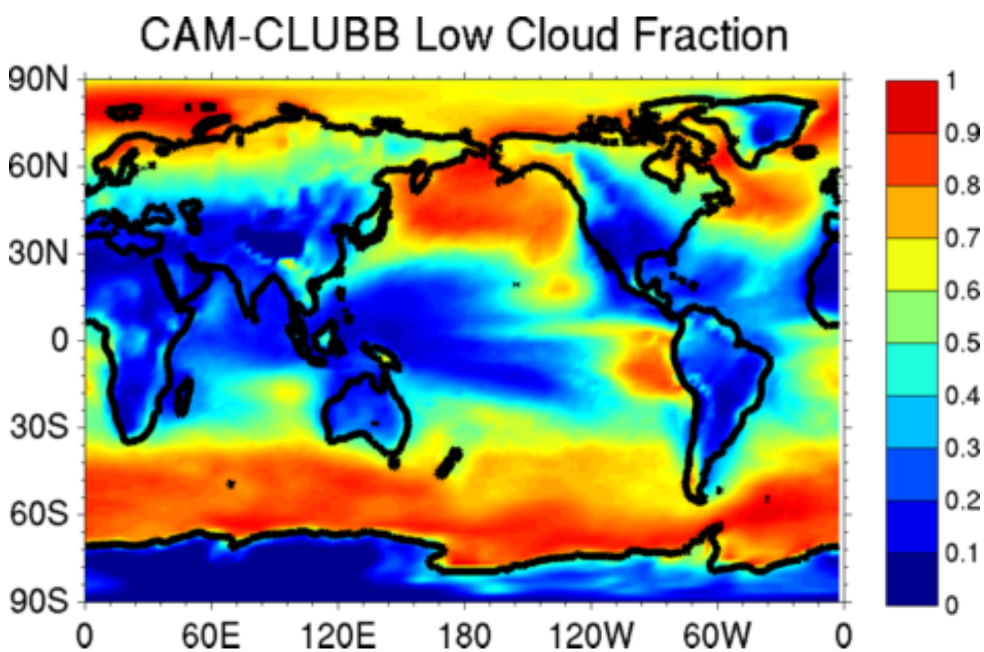
Activities during first year – CLUBB GCM

GFDL CPT Progress: AM3-CLUBB



- CLUBB incorporated into GFDL GCM (AM3)
  - CLUBB replaces AM3 large-scale cloud, PBL and shallow convection schemes.
  - Initial results in April
  - Performed several two decade-long AMIP experiments
  - Computational cost of CLUBB is relatively modest (10-15% of total CPU time)
  - Working on improving coupling with other physics parameterizations (deep convection, micro-physics)

NCAR CPT Progress: CAM-CLUBB



Vertically integrated low cloud fraction from a one year simulation of CAM-CLUBB

- CLUBB implemented into CAM5
  - Replaces existing UW eddy scheme, shallow convection, and macrophysics
  - Single-column tests on several GCSS cases yields promising results compared to LES
  - Preliminary one-year simulation produces encouraging results in the representation of boundary layer clouds, but more progress is needed to match CAM-5

Activities during first year – Large eddy modeling

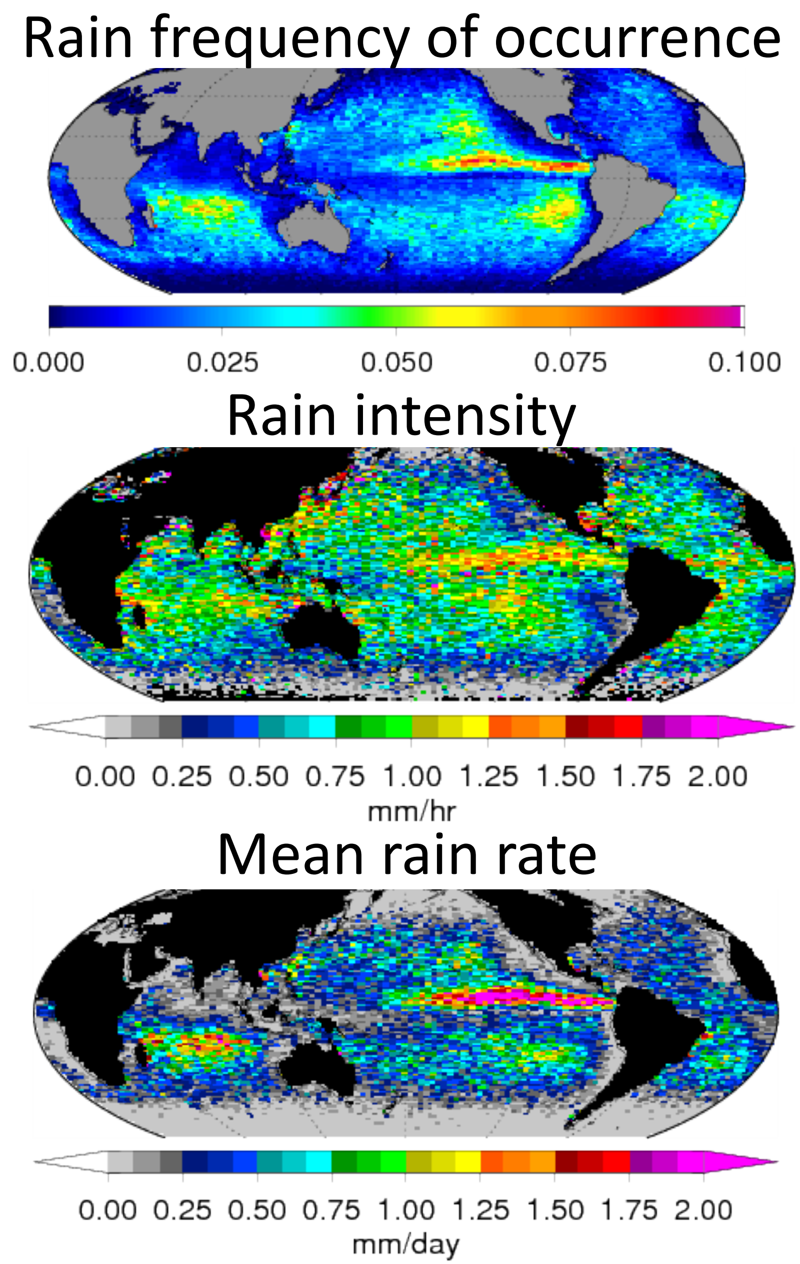
- Assessment and development of WRF as a large eddy model
  - Model initialization and equilibration for soundings that include clouds
  - Sensitivity of solutions to acoustic time-stepping
  - Statistical package for WRF-LES output
- Simulation of aerosol influences on trade cumulus clouds (RICO)
  - The role of aerosol on preconditioning
- Simulation of stratocumulus clouds (VOCALS)
  - Initialization with ship-based soundings

Activities during first year – Satellites

- Warm cloud precipitation retrievals from CloudSat nearing completion
  - First climatology of warm rain assembled for comparison with GCMs
- MODIS cloud droplet concentration (N_d) climatology
  - Evaluation of MODIS N_d estimates against observations
  - Produced quality-controlled climatology
  - Preliminary comparisons with CAM-5

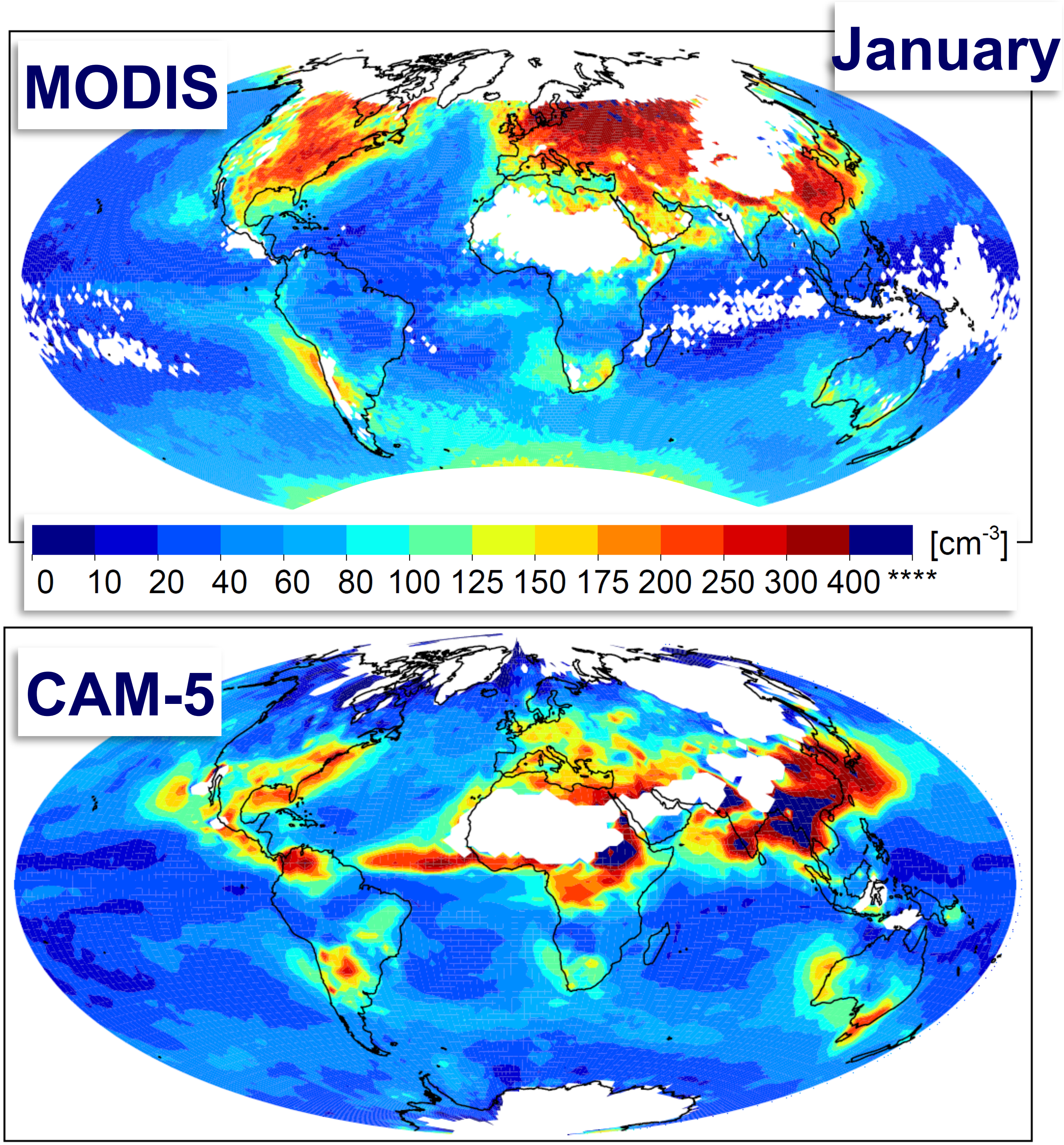
Distribution of Warm Rain from CloudSat (JPL)

- New retrievals focused on precipitation from boundary layer clouds
- Rain rate dominated by frequency of occurrence, not intensity
- Accumulation maxima:
  - East-Pac ITCZ
  - Trade Cumulus regions

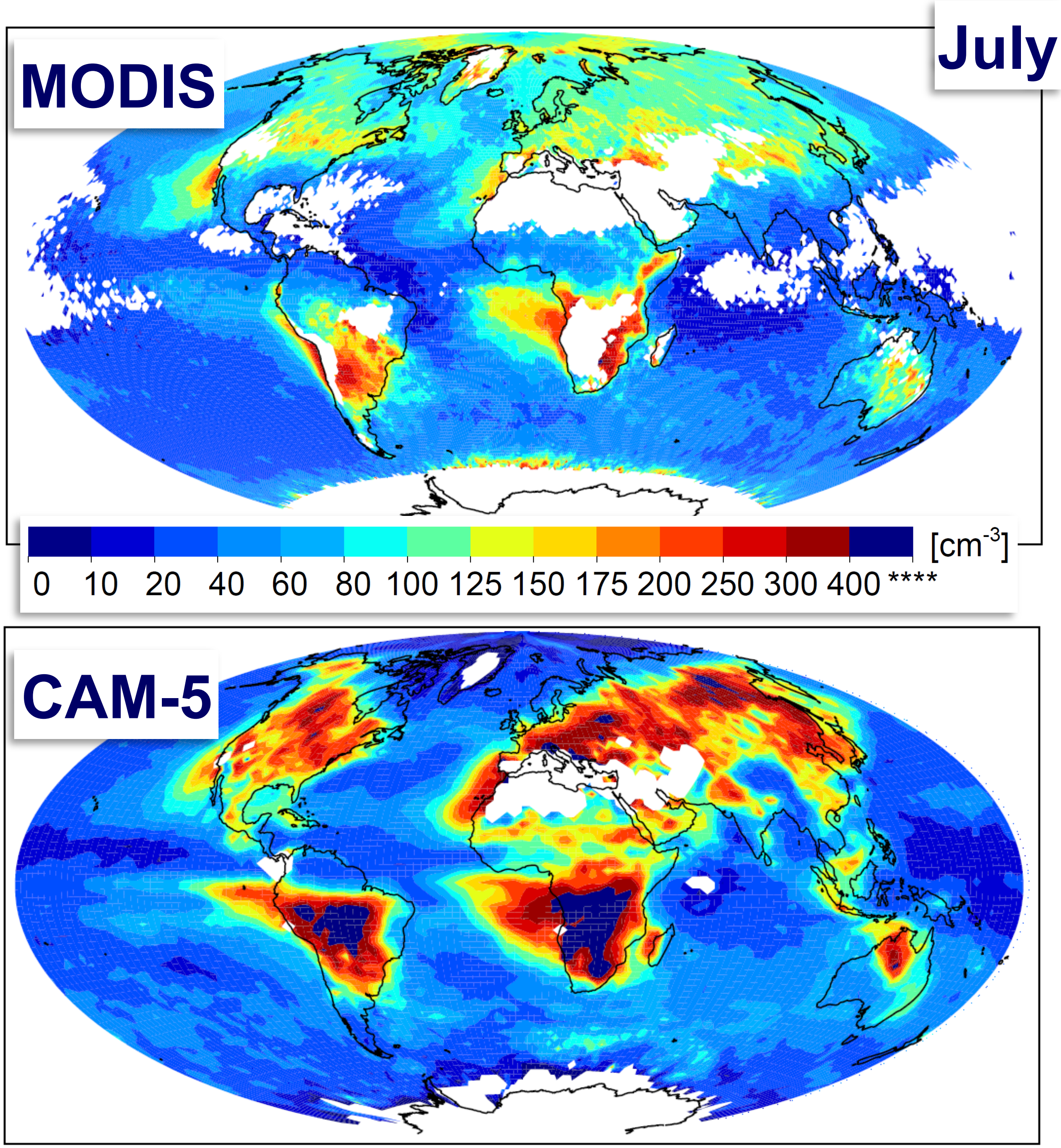


Using MODIS cloud droplet concentration to constrain GCM microphysics (U Washington)

- Use method of Boers and Mitchell (1996), applied by Bennartz (2007)
- Screen to remove heterogeneous clouds by insisting on $CF_{liq}>0.6$ in daily L3
- Cloud top droplet concentration in warm clouds from CAM-5



- CAM-5 *broadly* captures land-ocean contrasts in N_d
- Opposite sign of seasonal cycle over NH land (MODIS>CAM in winter; MODIS<CAM in summer)
- Clear evidence of S. African and S. American biomass burning in MODIS and CAM



Plans for Year 2

- CLUBB SCM and LES work
  - Through collaboration with DoE FASTER, extensive SCM comparisons with ARM field observations (GFDL).
  - Development CLUBB microphysics including prognostic rain treatment and sub-column generation (NCAR, UWM, GFDL)
  - Simulation of VOCALS stratocumulus clouds and comparison with ship-based observations including radar, Doppler-lidar (ESRL)
  - Investigation of invigoration in mixed-phase convective clouds to identify key microphysical processes responsible for aerosol-induced changes in precipitation and its distribution under different meteorological forcings (ESRL)

Plans for Year 2

- AM3-CLUBB GCM Development and analysis
  - Allow deep convection to interact fully with CLUBB.
  - Model optimization via parameter adjustments.
  - Evaluation of AM3 with field and process models using VOCALS Model Assessment (GFDL, UW)
  - Global diagnostics development
  - Improve prediction of low level clouds compared to standard AM3
  - Continued development of microphysics, especially ice, (NCAR collaboration)
  - Analysis of climate regimes where cloud simulation is deficient (GFDL, UW, JPL).

Plans for Year 2 - continued

- CAM-CLUBB GCM Development and analysis
  - continue progress in running CAM-CLUBB
  - check in code, perform extensive evaluation (single column model & global)
  - Key issues: mixed phase processes, general cloud microphysics, aerosol interactions.
- Satellite toolkit and model evaluation:
  - Add colocated water path, cloud fraction and radiation observations from Aqua to CloudSat precipitation climatology with a focus on parameter co-variability (JPL)
  - Complete study comparing pre-CLUBB models with MODIS cloud droplet concentration (UW)