A CPT for Cloud Parameterization and Aerosol Indirect Effects

Supported by

Our CPT's participating institutions:

- U. Wisconsin --- Milwaukee (Cloud parameterization: V. Larson, Lead PI)
- GFDL (GCM simulations: L. Donner, J.-C. Golaz, Y. Ming)
- NCAR (GCM simulations: A. Gettelman, H. Morrison)
- JPL (Satellite obs: G. Stephens)
- U. Washington (Aircraft obs: R. Wood)
- NOAA ESRL (LES: G. Feingold)

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 linked to vertical motions.
- Aerosol-cloud interaction: An example.

Observed dependence of cloud droplets on aerosols

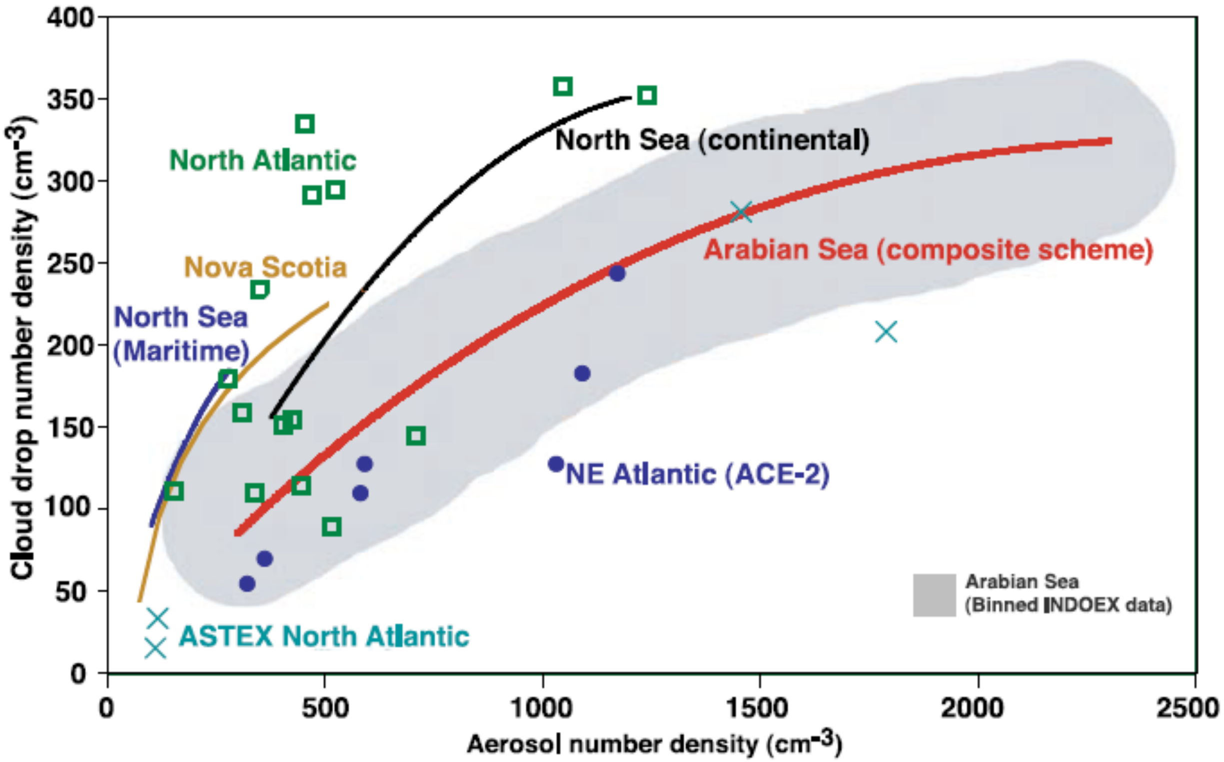
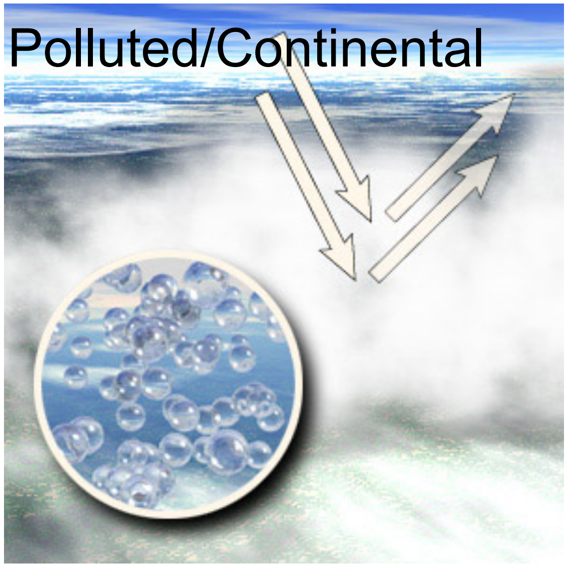


Fig. 5. Aircraft data illustrating the increase in cloud drops with aerosol number concentration. References for the data are as follows: North Sea (*28*), Nova Scotia and North Atlantic (*29*), ACE-2 (*30*), Astex (*31*), the thick red line is obtained from a composite theoretical parameterization that fits the INDOEX aircraft data for the Arabian Sea (*23*). The gray-shaded region is the INDOEX aircraft data for the Arabian Sea (*32*).



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

Aerosols, CCN

↓

Local Cooling, Vertical Velocity

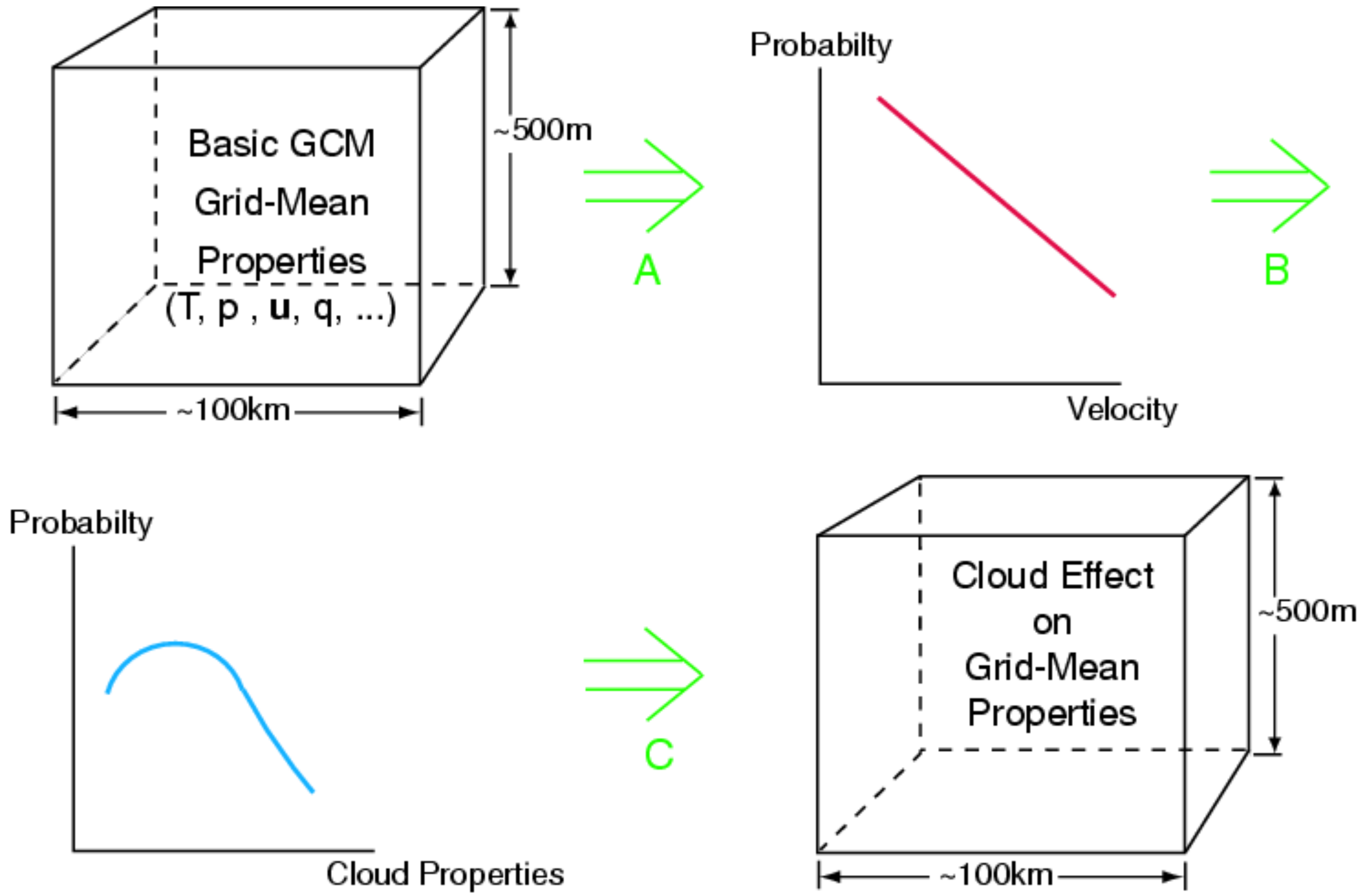
↓

Supersaturation

↓

Droplet Activation

Linking Cloud Microphysics and Macrophysics

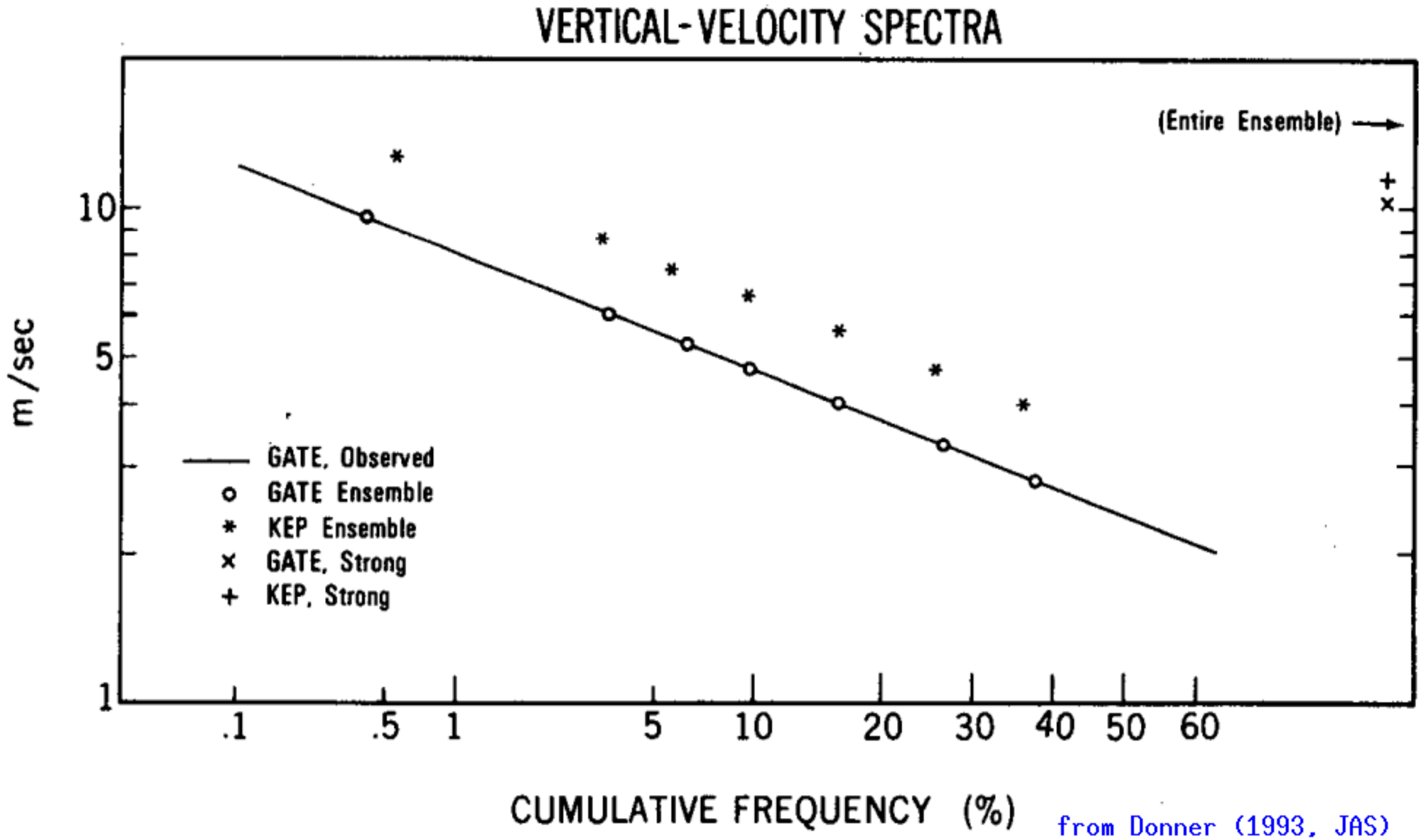


A: "Statistical" Parameterizations, e.g.
Donner (1993, *J. Atmos. Sci.*), Golaz et al. (2002, *J. Atmos. Sci.*)

B: "Classical" Process Studies, e.g., CPT, GCSS

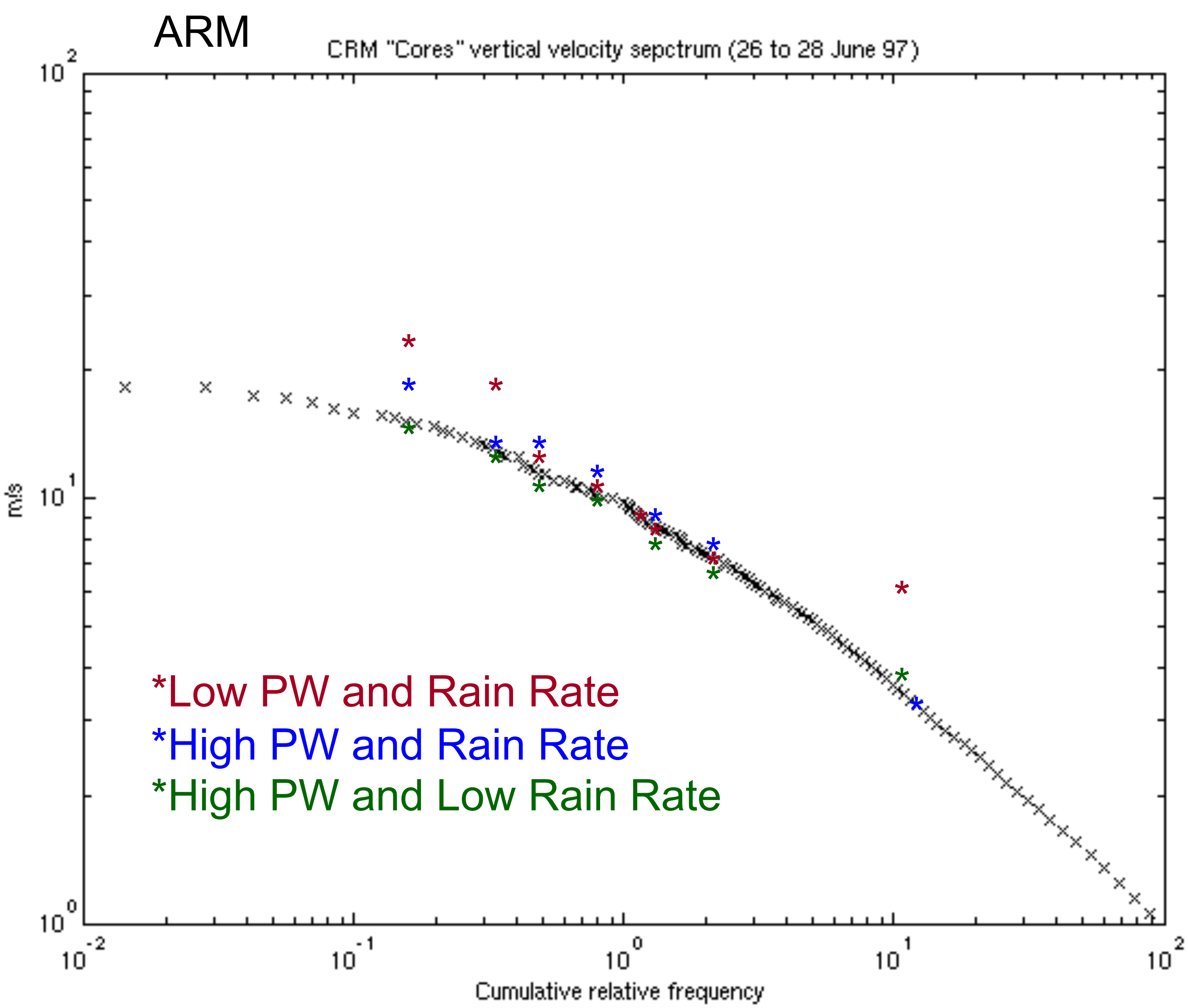
C: Averaging

A Digression from the CPT… Vertical Velocities in Parameterized Deep Convection

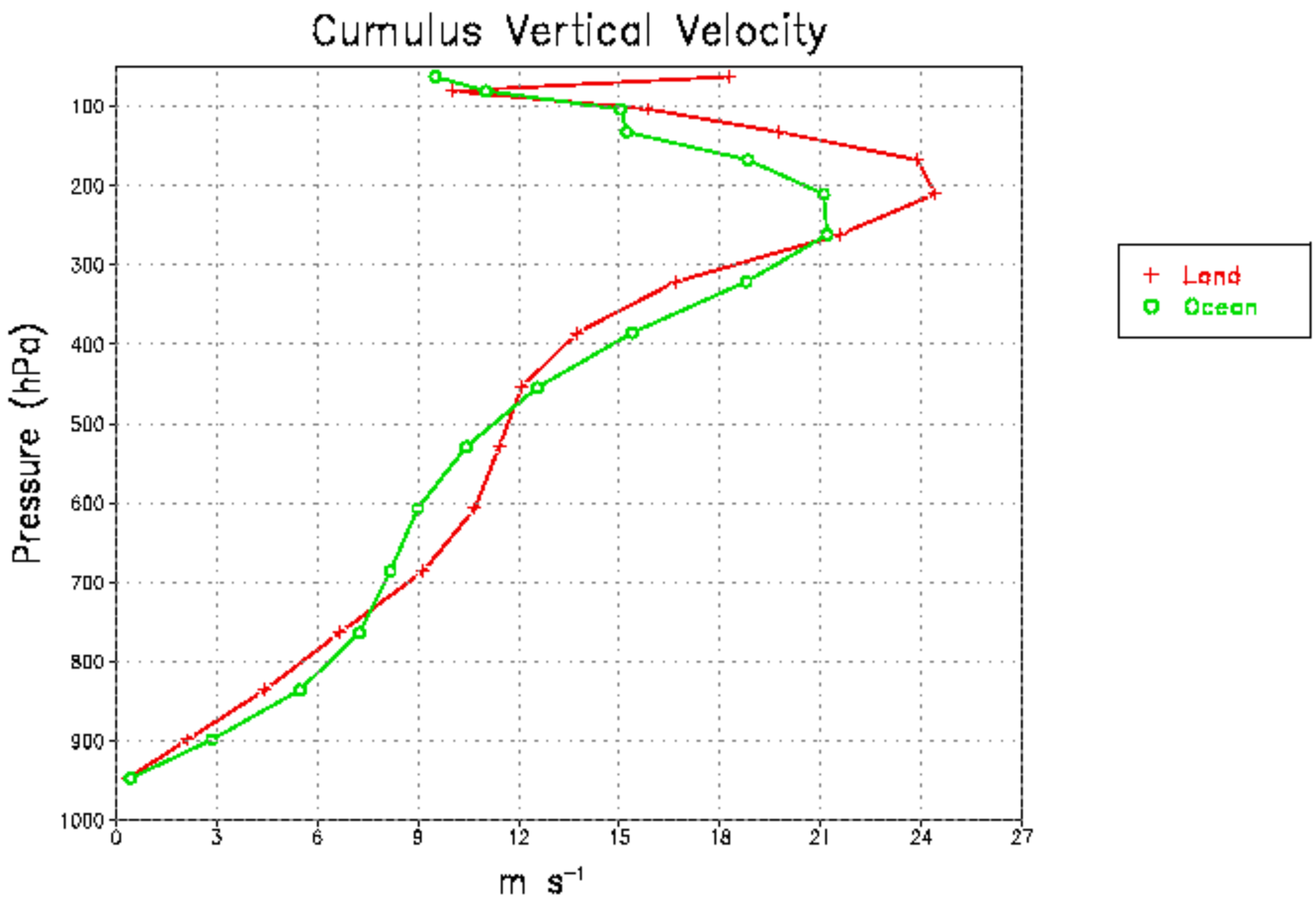


from Donner (1993, JAS)

CRM results provide independent evaluation of entrainment PDF



CRM results from Cris Batstone, CDC; *,*,* from Donner (1993) entrainment PDF



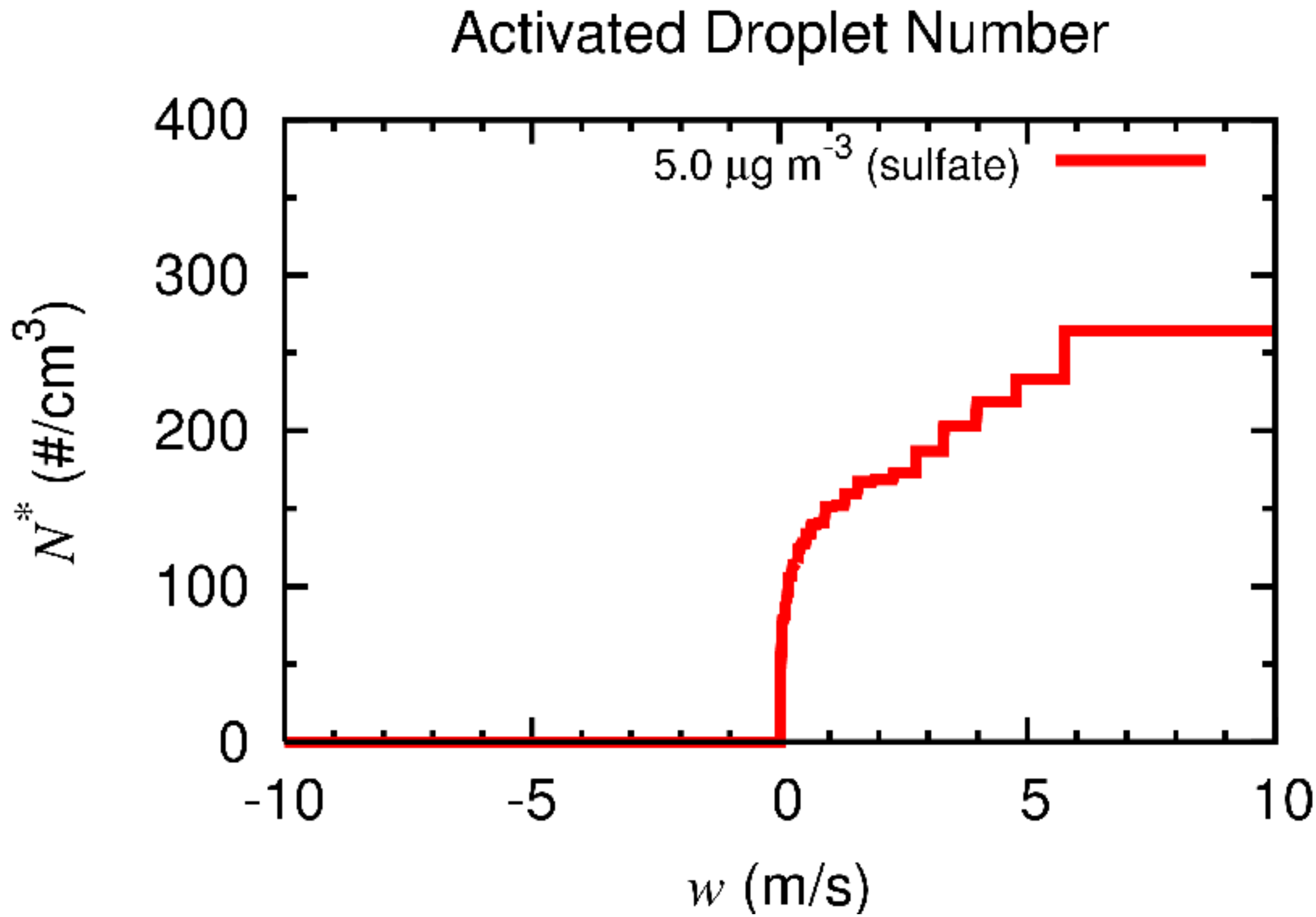
Land CAPE: 2006 J/kg; Ocean CAPE: 2002 J/kg

from Donner et al. (2001, J. Climate)

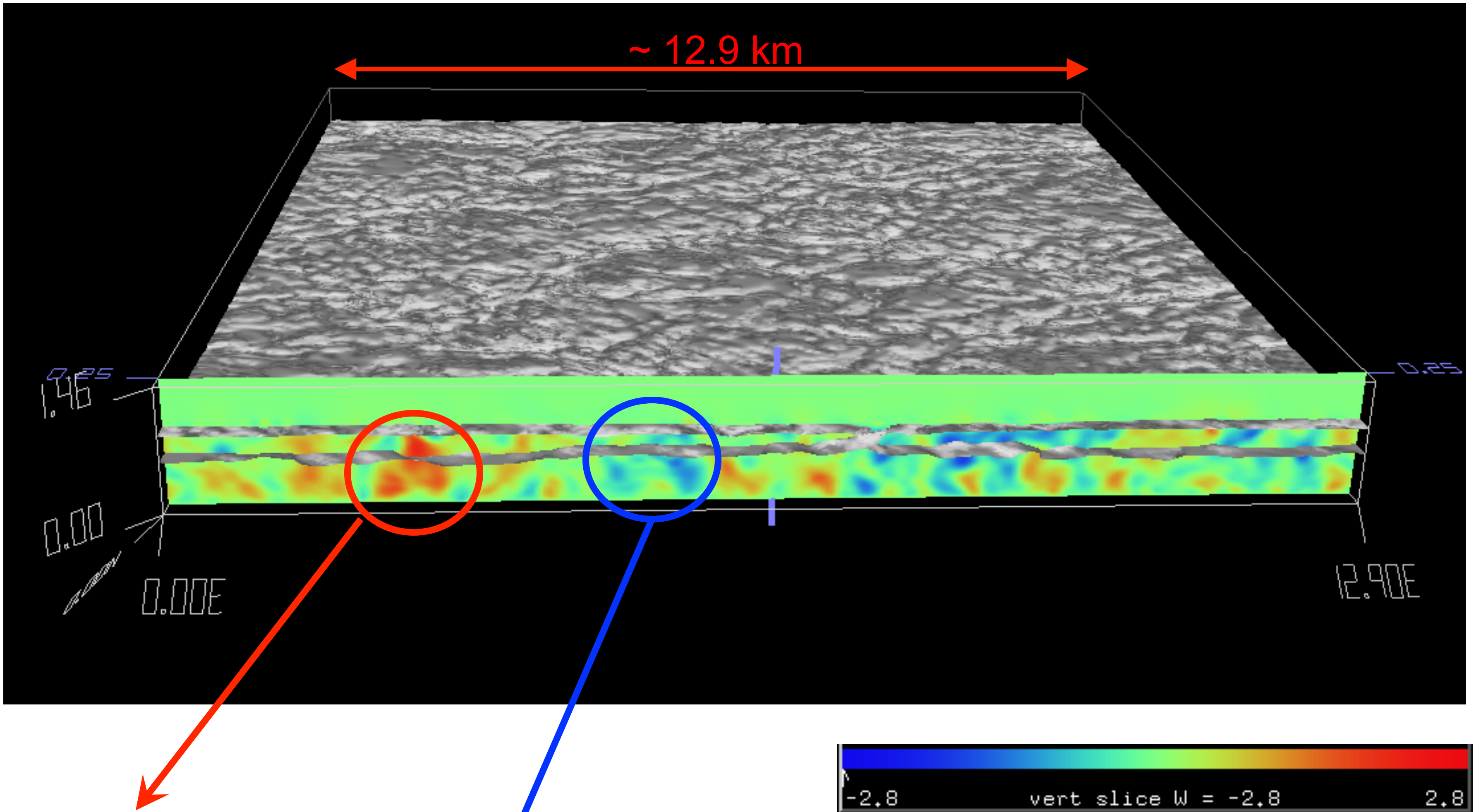
CMMAP Studies

- How do sub-grid vertical velocity PDFs for deep convection in GFDL AM3 compare with corresponding explicit PDFs in CAM-SP?
- Do explicit CAM-SP vertical velocity PDFs agree well with giga-LES for GATE? Giga-LES agrees well with GATE observations.

Linking Cloud Macrophysics and Microphysics in Stratiform Clouds



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

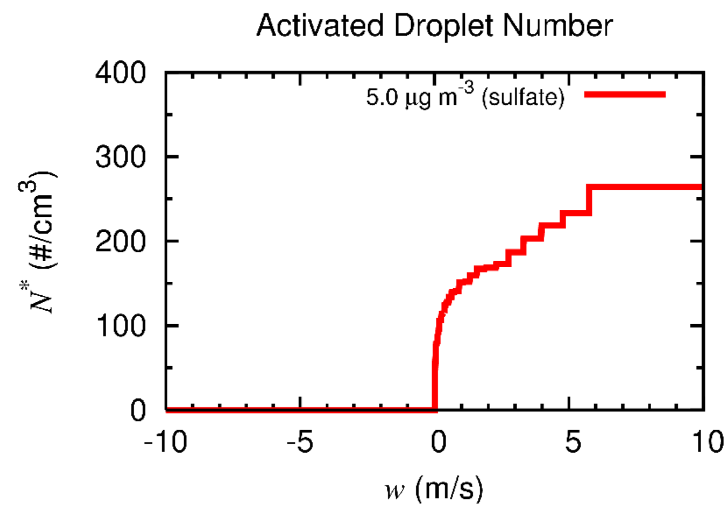


updraft: activation

downdraft: evaporation

LES by Chris Golaz

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,

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

Dynamics-PDF Cloud Parameterization: Overview

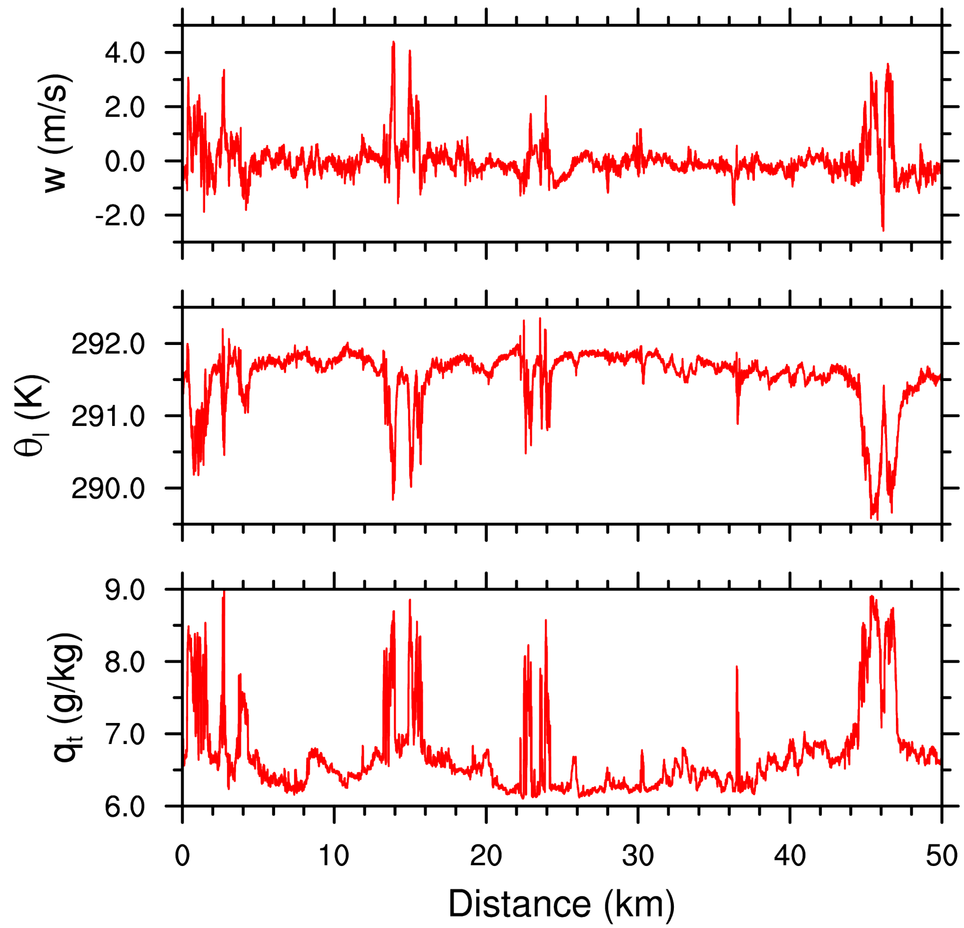
- Based on Golaz et al. (2002, *J. Atmos. Sci.*): "CLUBB" (Cumulus Layers Unified by Bi-Normals)
- Joint PDFs for vertical velocity, liquid potential temperature, and total water mixing ratio
- Single-column model tests for BOMEX and DYCOMS-II field programs

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
- Select PDFs based on evolution of higher-order moments
- Extract cloud macrophysics (fraction, liquid content, etc.) from PDFs

Observed cumulus case from ASTEX

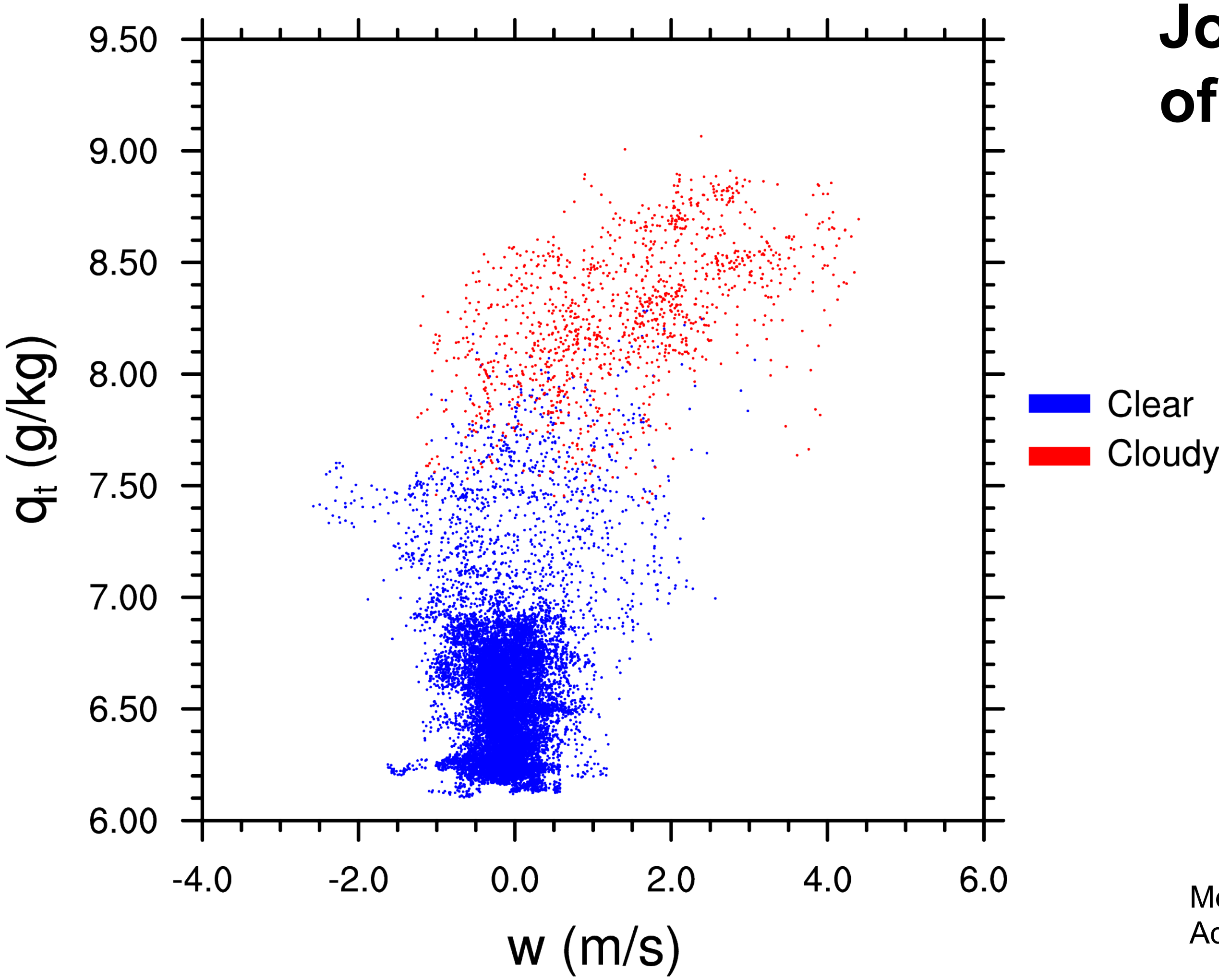
Aircraft transect through a cumulus layer during ASTEX



Met Office C-130 Flight a215r6.4 data
Adapted from Larson et al. 2002 (JAS)

Observed cumulus case from ASTEX

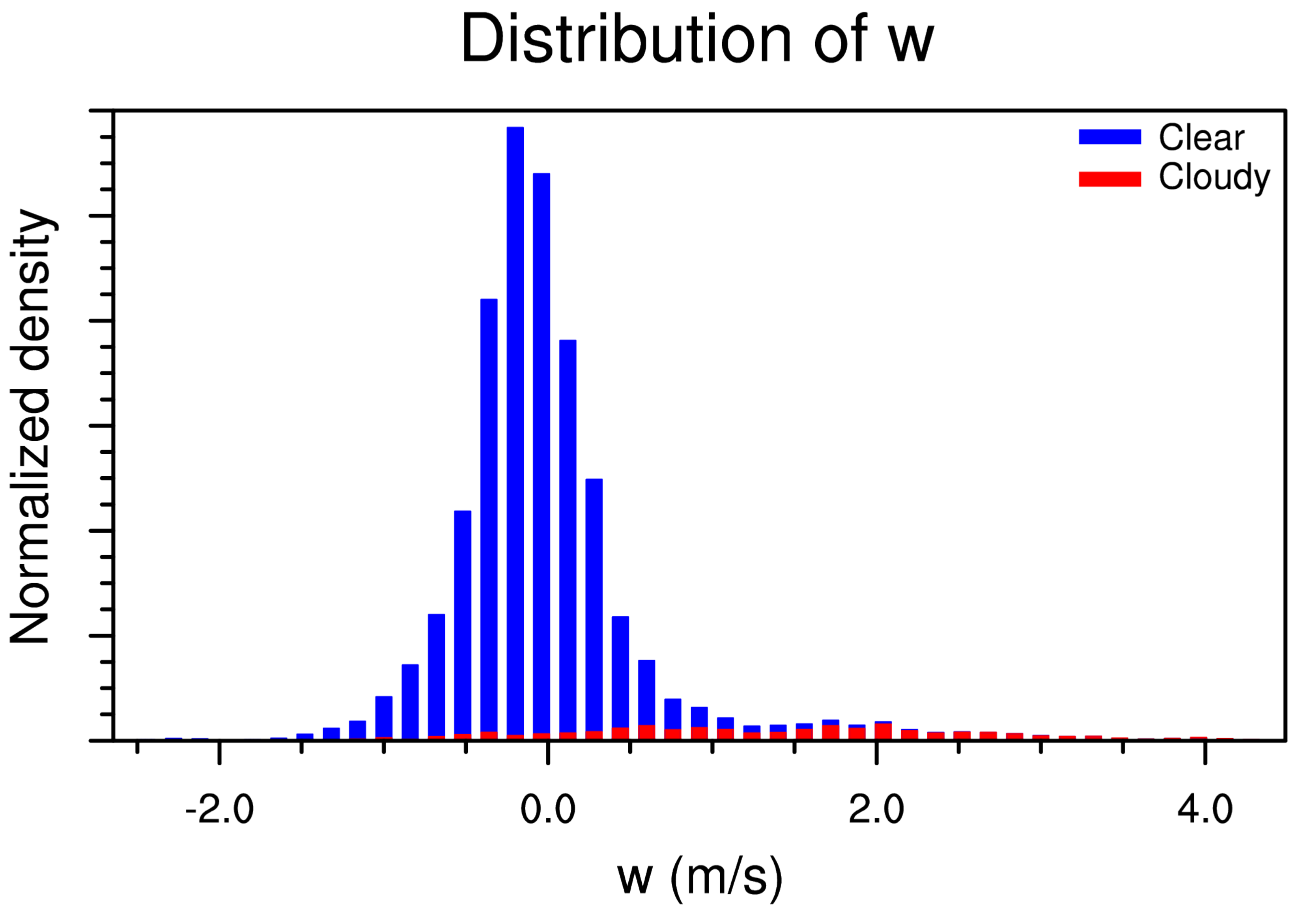
q_t vs. w



Joint distribution of q_t and w

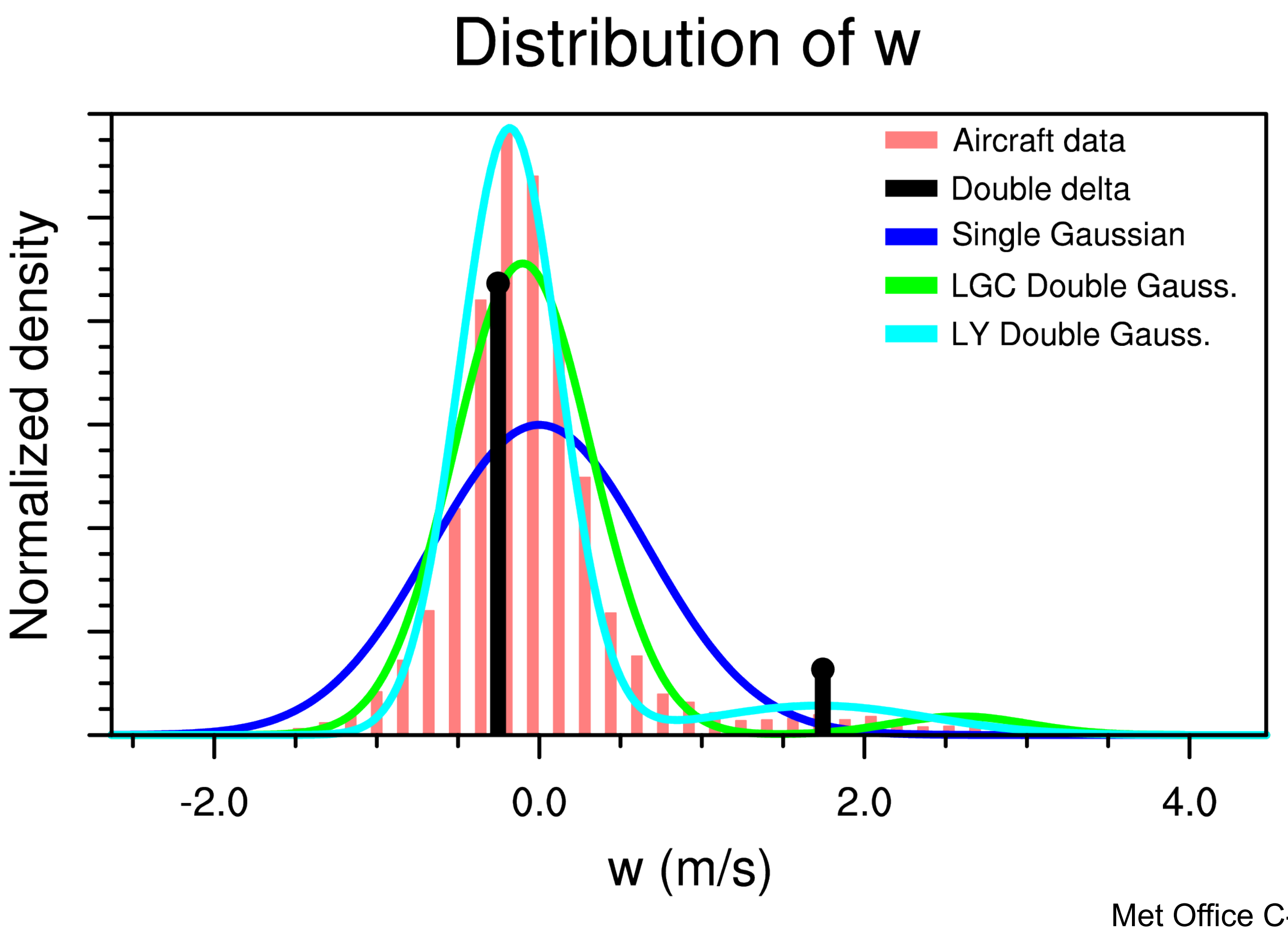
Met Office C-130 Flight a215r6.4 data
Adapted from Larson et al. 2002 (JAS)

Observed cumulus case from ASTEX



Met Office C-130 Flight a215r6.4 data
Adapted from Larson et al. 2002 (JAS)

Observed cumulus case from ASTEX
Example of PDF fits to the data



Met Office C-130 Flight a215r6.4 data
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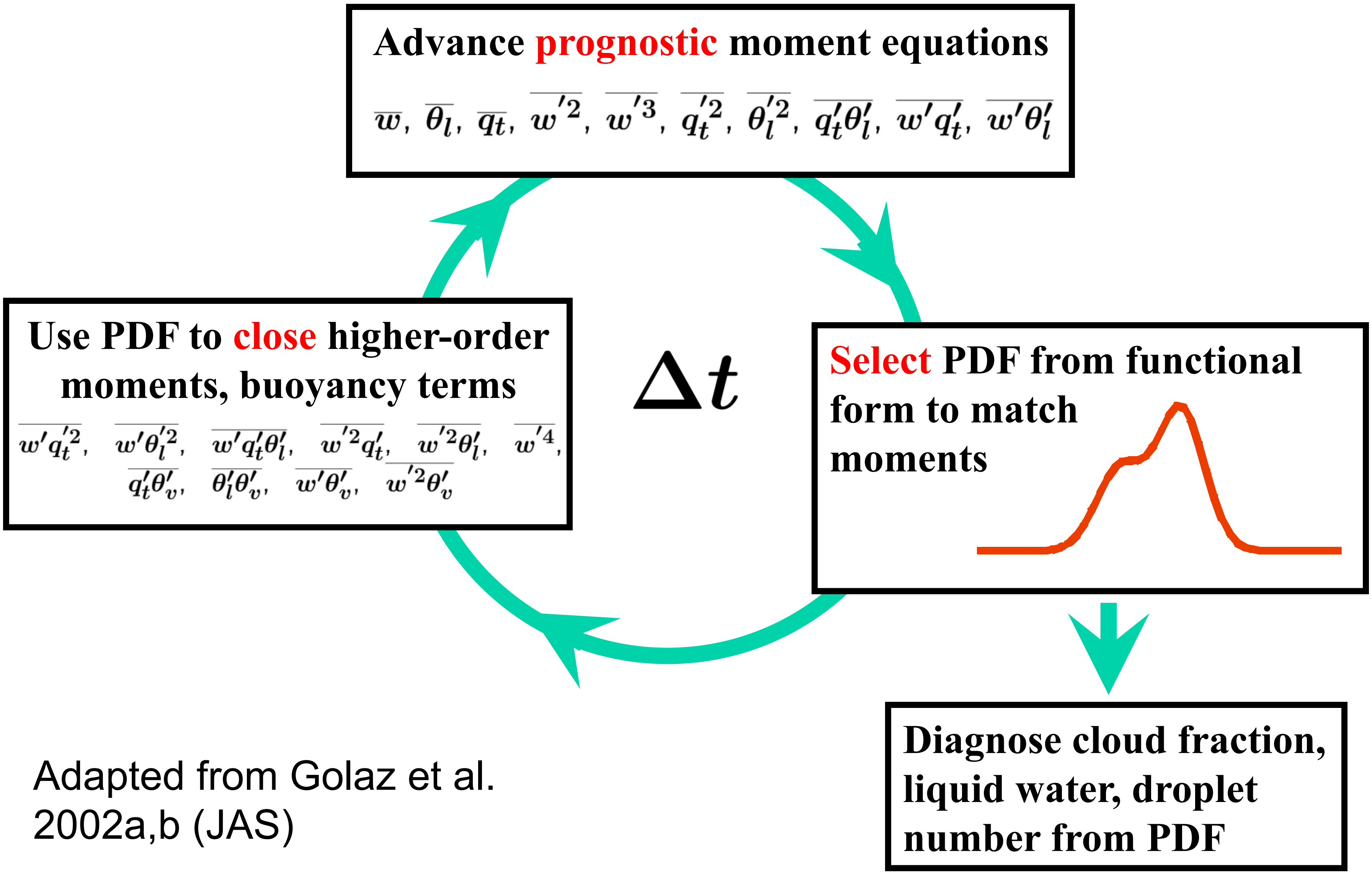
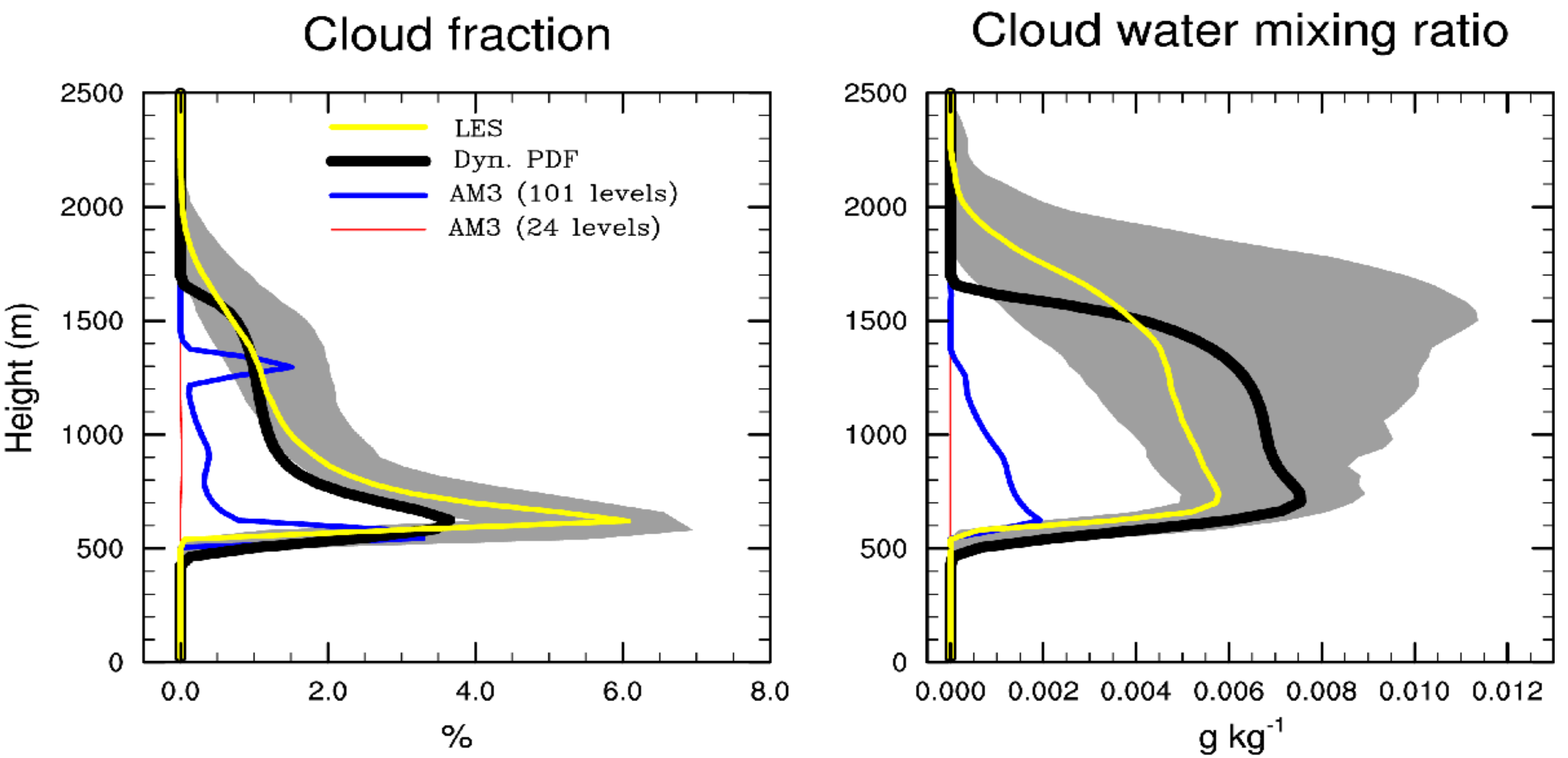
Building a PDF-based parameterization



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

BOMEX (cumulus)

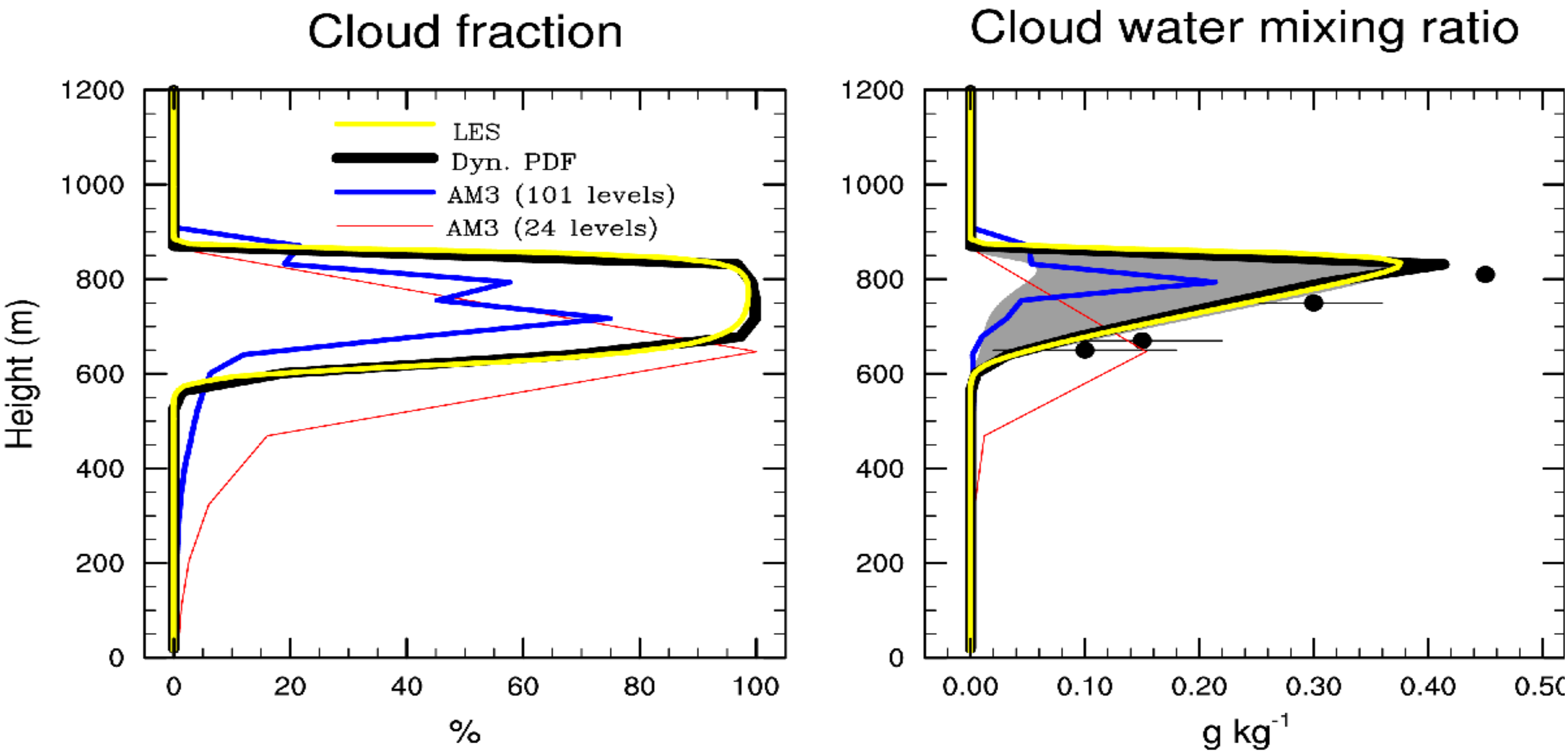


Note: 1. shaded areas indicate the range (Min. and Max. bounds) of GCSS LES intercomparisons

AM3 uses Tiedtke (1993, *Mon. Wea. Rev.*)

(Source: Huan Guo, GFDL)

DYCOMS-II Research Flight 1 (stratocumulus)



Note: 1. shaded areas indicate the range (Min. and Max. bounds) of GCSS LES intercomparisons

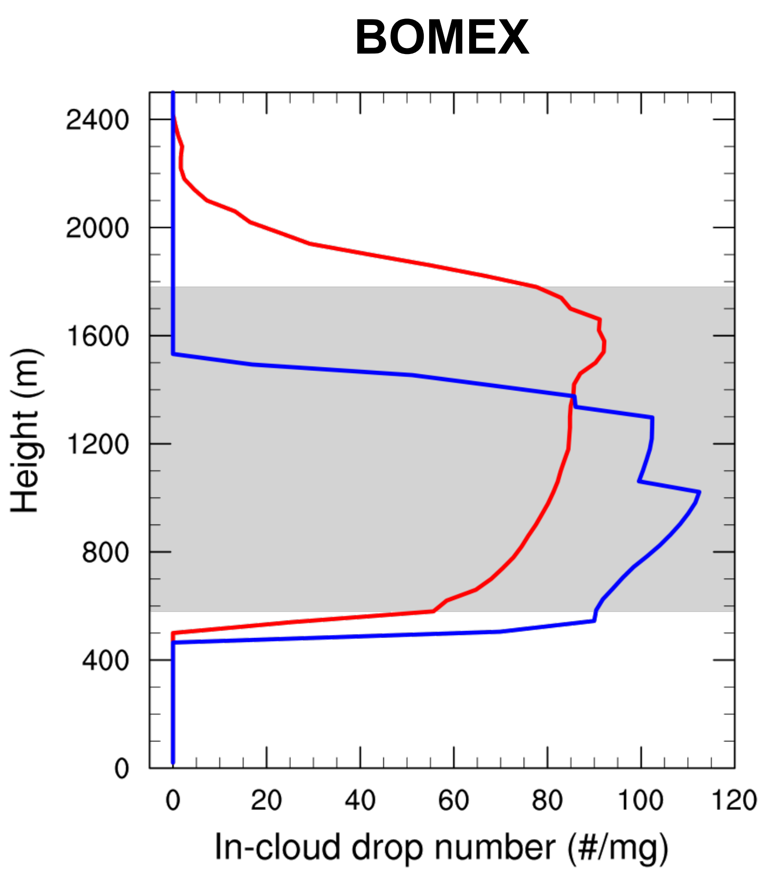
2. dots and horizontal bars indicate the obs. (Stevens et al., 2005 MWR)

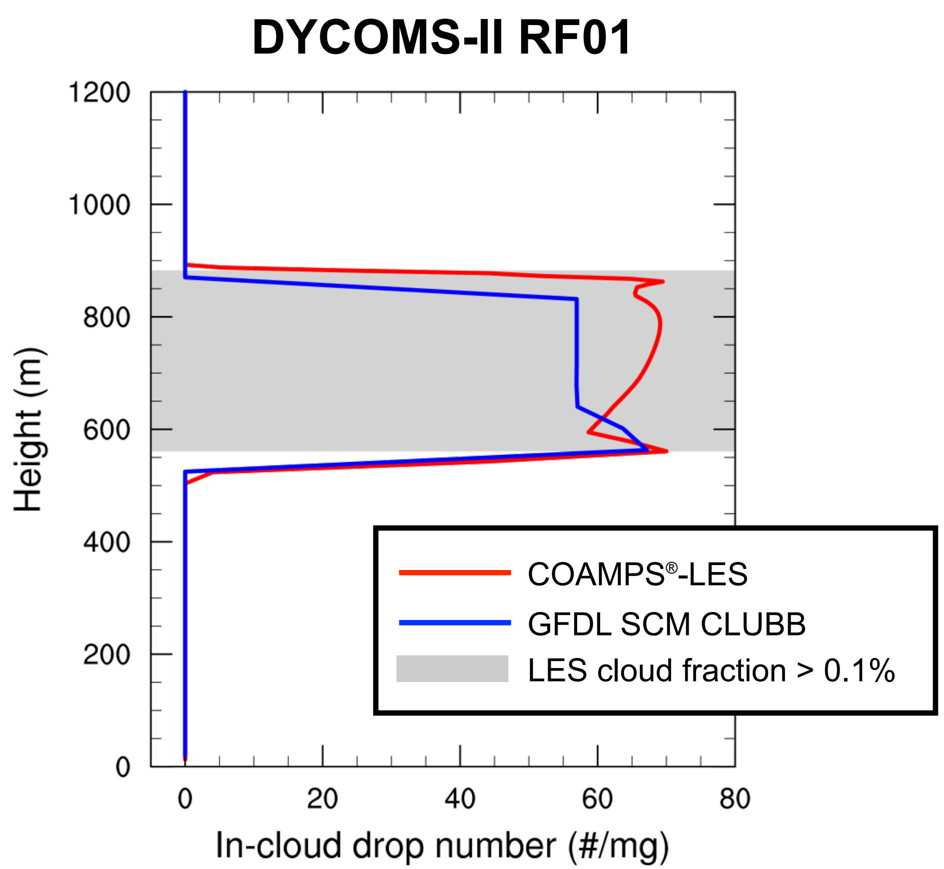
AM3 uses Tiedkte (1993, *Mon. Wea. Rev.*)

(Source: Huan Guo, GFDL)

Prediction of cloud drop number: Preliminary results (Guo et al., 2010, *GMDD)*

- Added predictive equation for cloud drop number:
  activation, evaporation and turbulence transport.
- Uniform background aerosol mass concentration.





Summary

- Most current state-of-science cloud parameterizations built around moisture PDFs.
- Cloud microphysical processes "see" dynamics, suggesting next-generation cloud parameterizations should also include dynamics PDFs.
- Cloud macrophysics and microphysics have been simulated using proto-application with dynamics PDFs.

Our CPT project: "Cloud macrophysical parameterization and its application to aerosol indirect effects"

- We will implement CLUBB in GFDL's GCM (AM) and NCAR's GCM (CAM).
- We will test the models versus LES, aircraft observations, and satellite observations.
- The goal is to improve low clouds in the GCMs.
- A particular focus is the effects of aerosols on clouds.
- SP-CAM requires parameterizations for PBL and clouds smaller than deep convection-Interaction?

Update on Book Project

Leo Donner
GFDL/NOAA, Princeton University

CMMAP, 3-5 August 2010, Fort Collins

Book Status

- Cambridge University Press copyediting
- Proofs to authors this month
- Book advertised on CUP web-site
- Price not final, expected around $80
- Available for sale February 2011
- Many thanks to Rodger Ames for editorial and technical assistance

THE DEVELOPMENT OF

Atmospheric General Circulation Models

Over the last 50 years, models that predict the state of the atmosphere have evolved from conceptual frameworks to advanced computational tools for short- and medium-range weather prediction and climate simulation. This book presents a comprehensive discussion of general circulation models of the atmosphere – covering their historical and contemporary development, their societal context, and current efforts to integrate these models into wider earth-system models. Leading researchers provide unique perspectives on the scientific breakthroughs, overarching themes, critical applications, and future prospects for atmospheric general circulation models. Key interdisciplinary links to other subject areas such as chemistry, oceanography, and ecology are also highlighted.

This book is a core reference for academic researchers and professionals involved in atmospheric physics, meteorology, and climate science, and can be used as a resource for graduate-level courses in climate modeling and numerical weather prediction. Given the critical role that atmospheric general circulation models are playing in the intense public discourse on climate change, it is also a valuable resource for policy makers and all those concerned with the scientific basis for the ongoing public-policy debate.

Cover illustration: this illustration shows how general circulation models decompose the atmosphere into discrete volumes, which in turn include parameterizations of smaller-scale processes, like clouds, which interact with the larger-scale processes. Such models are powerful tools for simulating climate and predicting weather. Image developed by Dr. Lisa Gardiner at the UCAR Office of Education and Outreach for the Center for Multi-Scale Modeling of Atmospheric Processes (CMMAP), a National Science Foundation Science and Technology Center.

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THE DEVELOPMENT OF Atmospheric General Circulation Models
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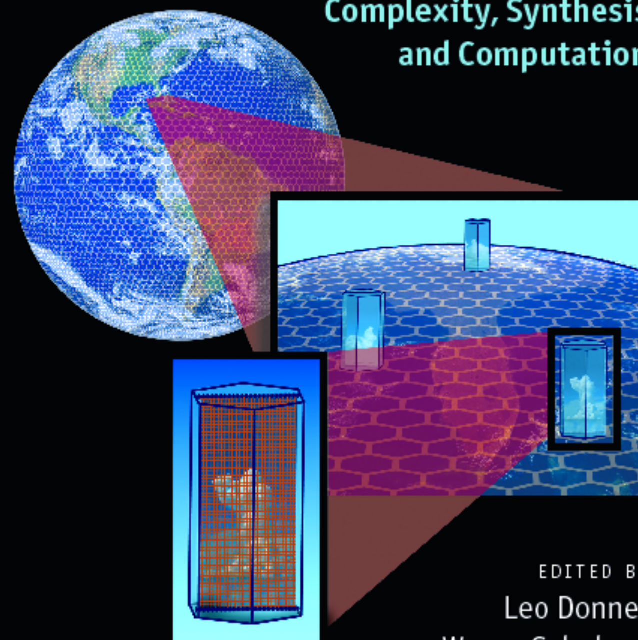
THE DEVELOPMENT OF
Atmospheric General Circulation Models

Complexity, Synthesis and Computation



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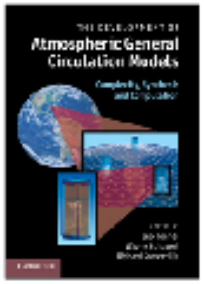

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