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

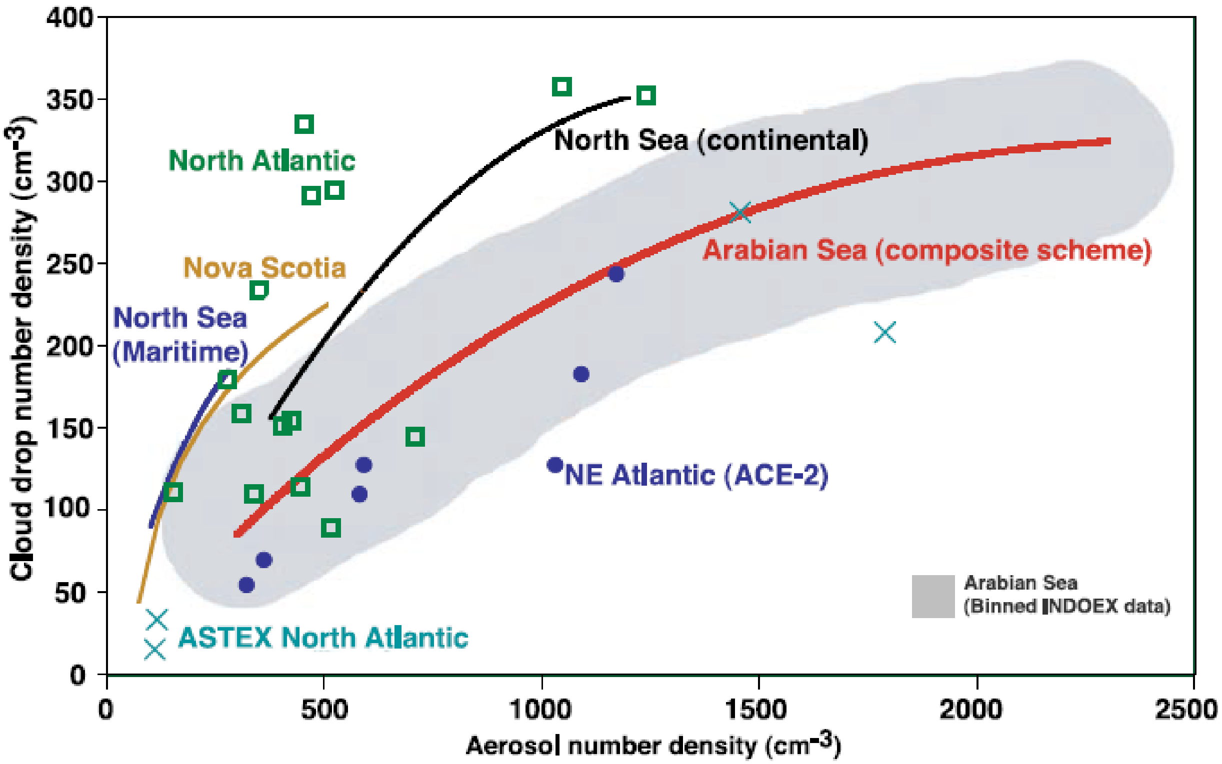
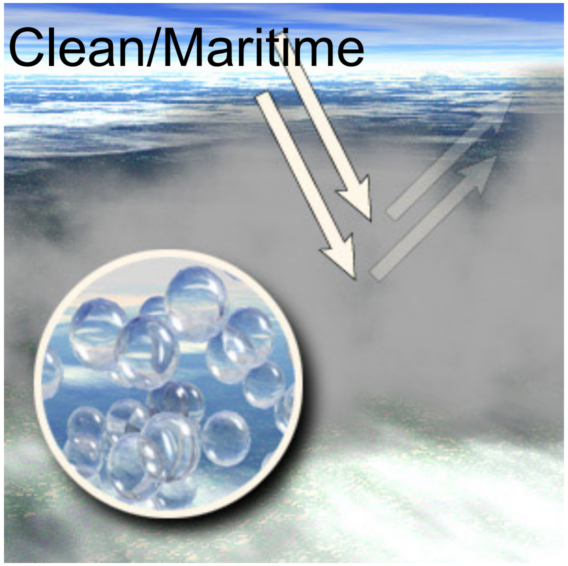
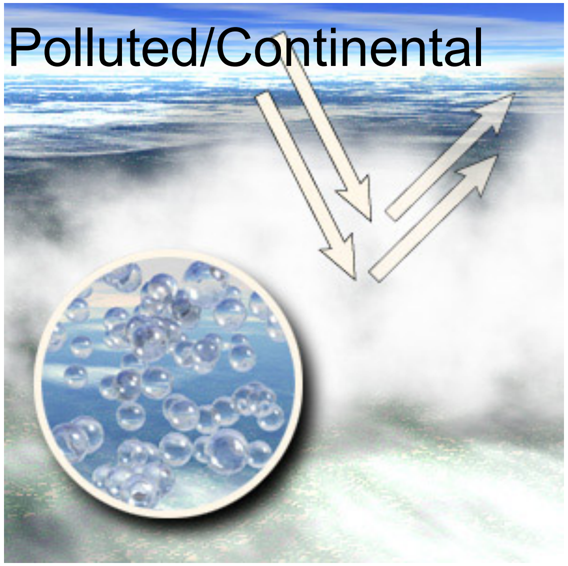
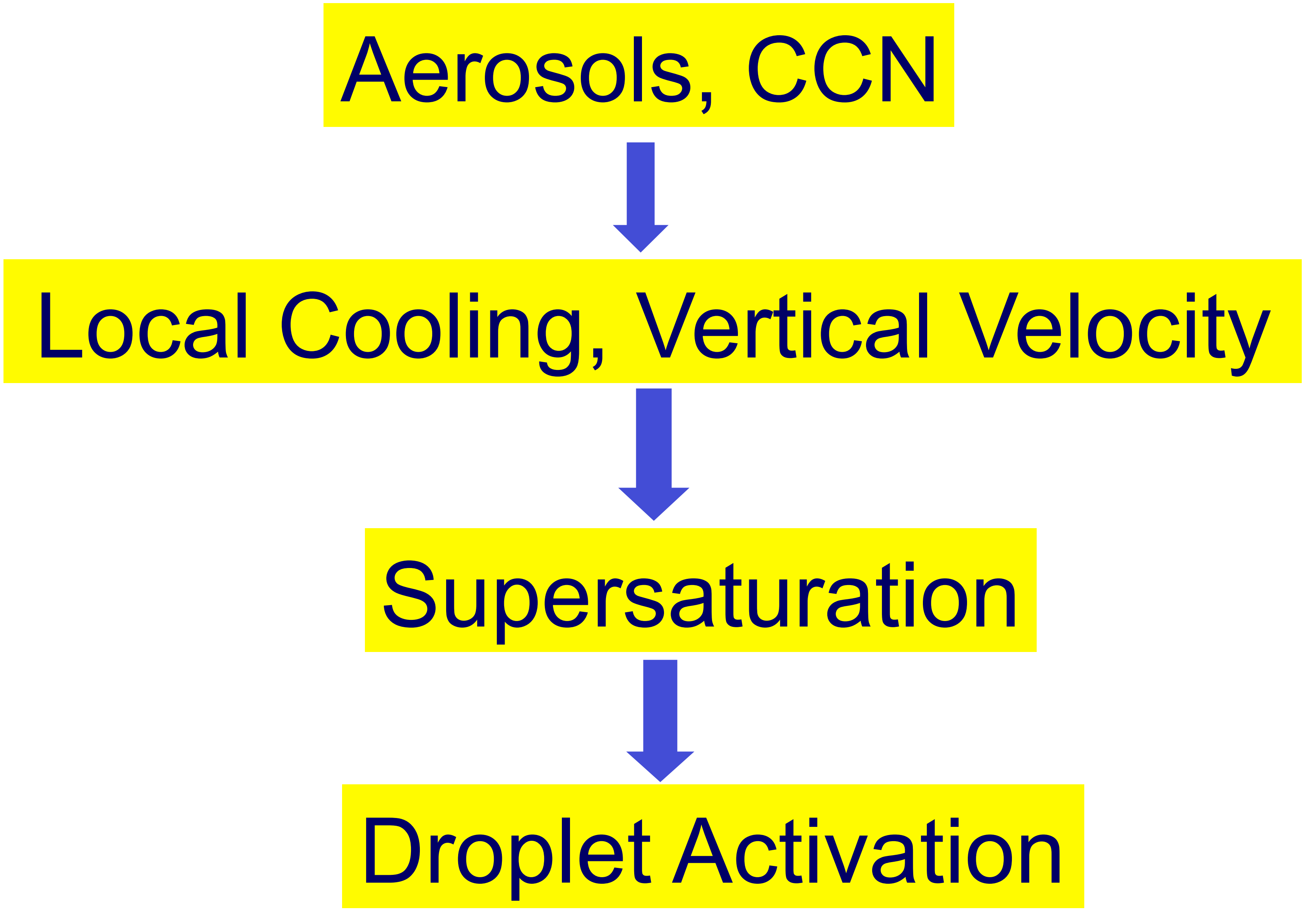


Fig. 5. Aircraft data illustrating the increase in cloud drops with aerosol number concentration. References for the data are as follows: North Sea (*28*), Nova Scotia and North Atlantic (*29*), ACE-2 (*30*), Astex (*31*), the thick red line is obtained from a composite theoretical parameterization that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

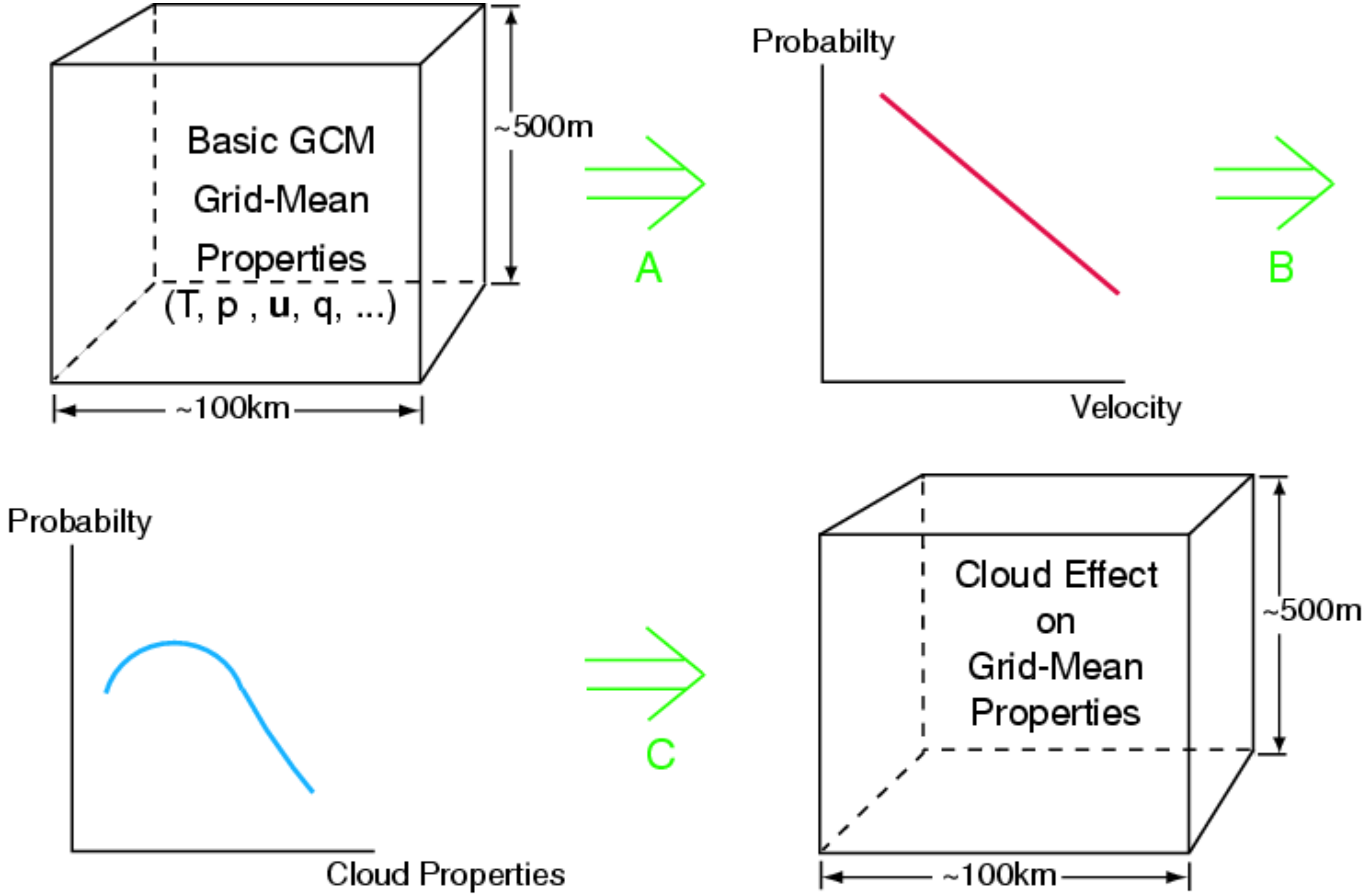




Source: Ramanathan et al. (*Science*, 2001)


Aerosols, CCN
Local Cooling, Vertical Velocity
Supersaturation
Droplet Activation

Linking Cloud Microphysics and Macrophysics

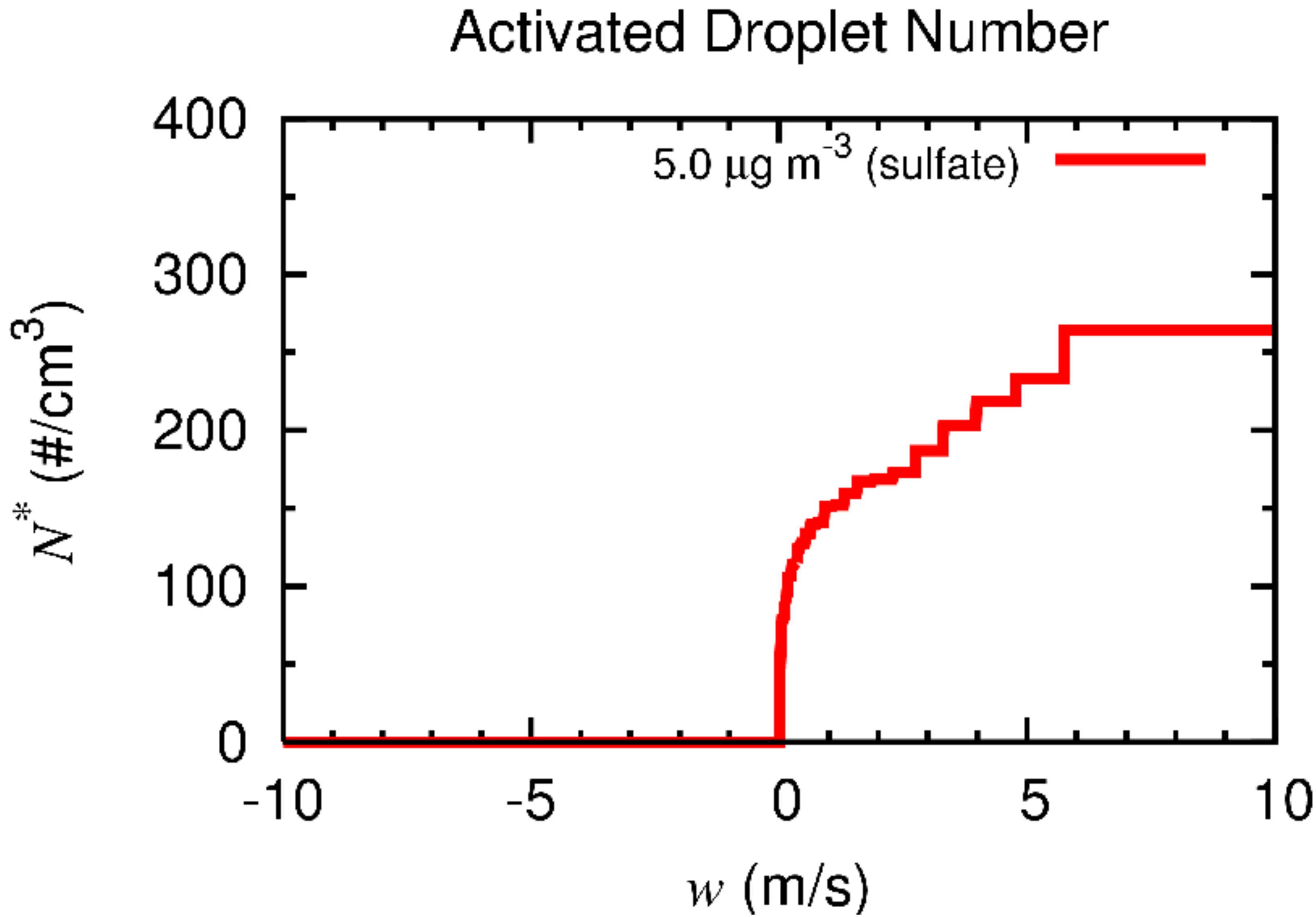


A: "Statistical" Parameterizations, e.g.
Donner (1993, *J. Atmos. Sci.*), Golaz et al. (2002, *J. Atmos. Sci.*)

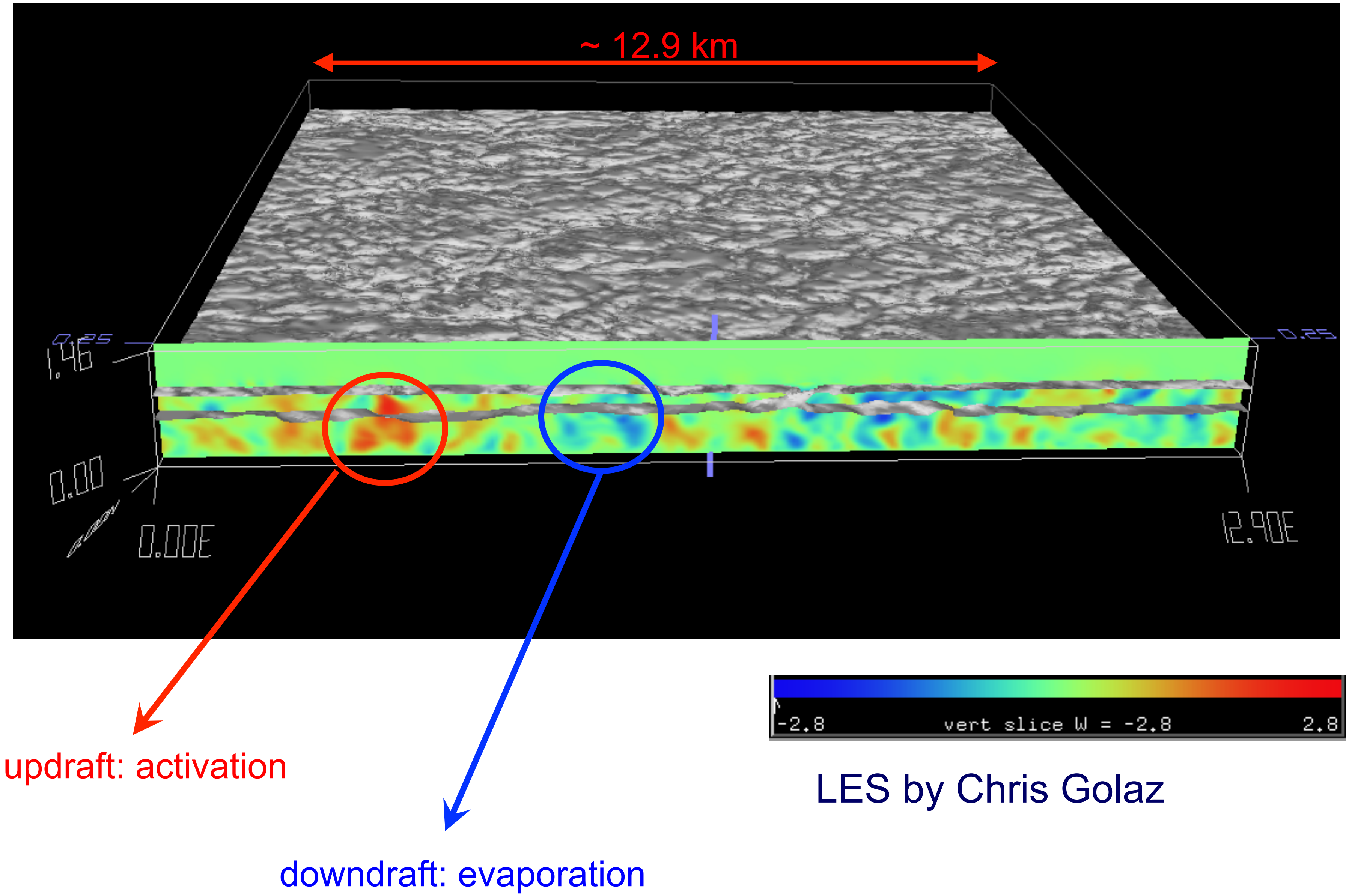
B: "Classical" Process Studies, e.g., CPT, GCSS

C: Averaging

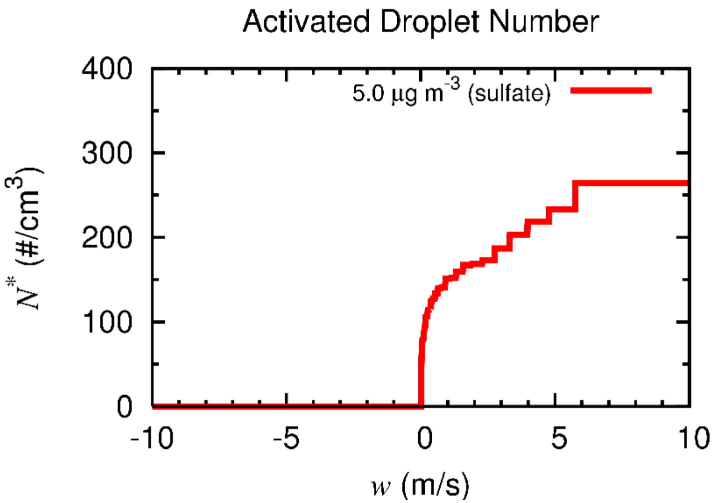
Linking Cloud Macrophysics and Microphysics in Stratiform Clouds



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


~ 12.9 km
0.25
1.46
0.00
0.00E
12.90E
0.25
-2.8
vert slice W = -2.8
2.8
updraft: activation
downdraft: evaporation
LES by Chris Golaz

Large-scale CCN activation



Layer-averaged activation:

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

Because *N** is non-linear

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

However,

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

Dynamics-PDF Cloud Parameterization: Overview

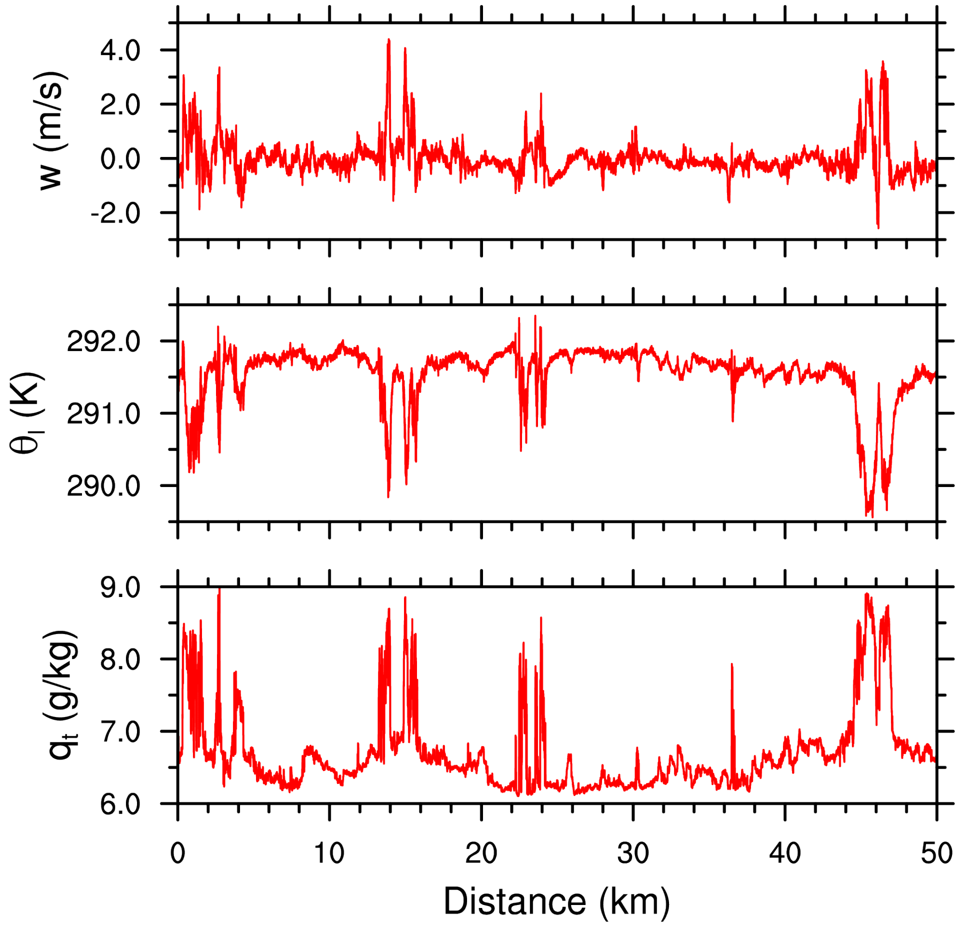
- Based on Golaz et al. (2002, *J. Atmos. Sci.*): “CLUBB” (Cumulus Layers Unified by Bi-Normals)
- Joint PDFs for vertical velocity, liquid potential temperature, and total water mixing ratio
- Single-column model tests for BOMEX and DYCOMS-II field programs

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

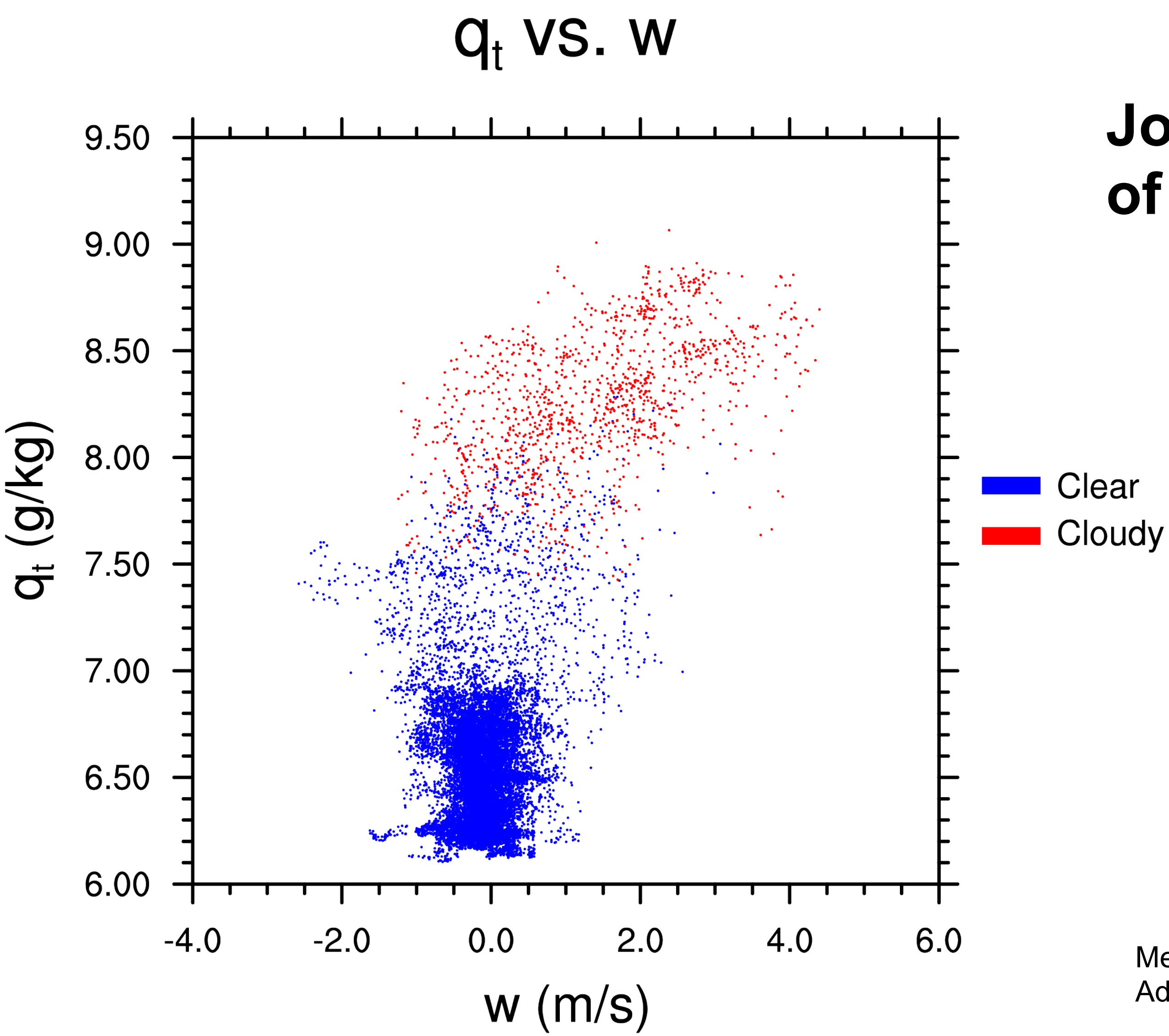
Observed cumulus case from ASTEX

Aircraft transect through a cumulus layer during ASTEX



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

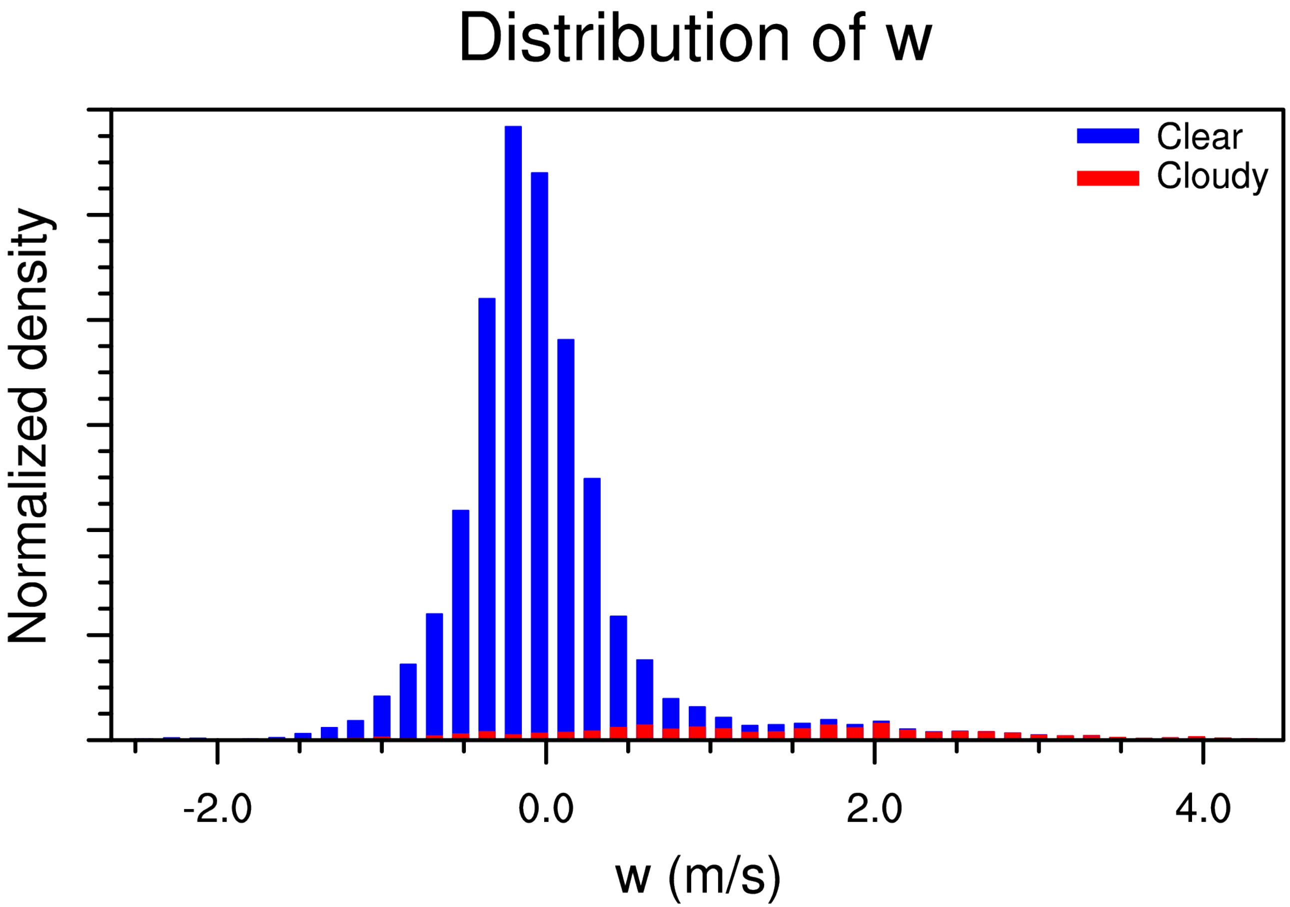
Observed cumulus case from ASTEX



Joint distribution of q_t and w

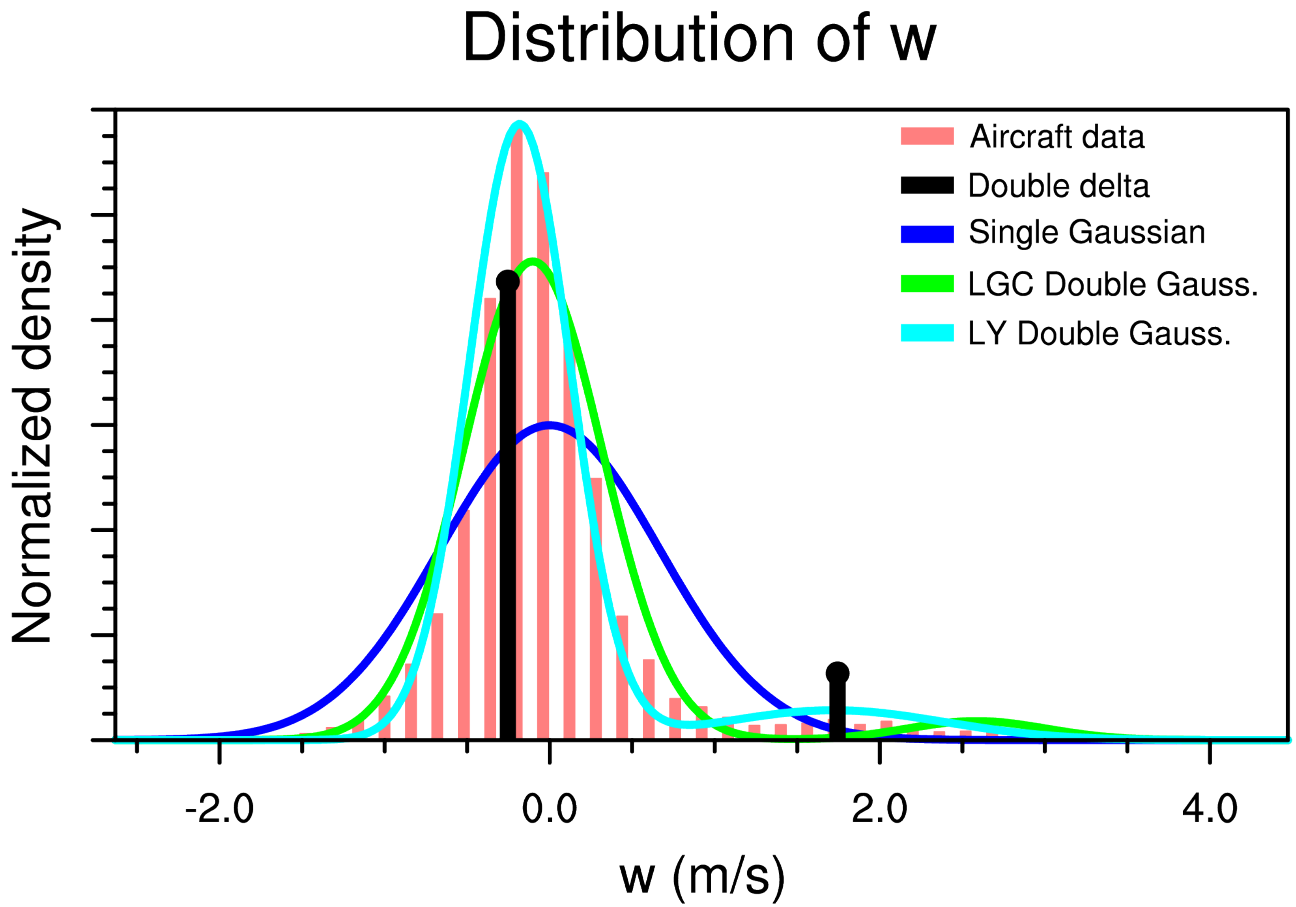
Met Office C-130 Flight a215r6.4 data
Adapted from Larson et al. 2002 (JAS)

Observed cumulus case from ASTEX



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

ASTEX Example of PDF fits to the data



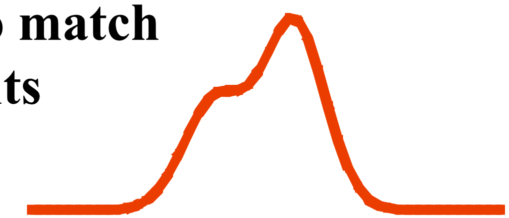
Met Office C-130 Flight a215r6.4 data
Adapted from Larson et al. 2002 (JAS)

Building a PDF-based parameterization

Advance prognostic moment equations

$$\overline{w},\ \overline{\theta_l},\ \overline{q_t},\ \overline{w'^2},\ \overline{w'^3},\ \overline{q_t'^2},\ \overline{\theta_l'^2},\ \overline{q_t'\theta_l'},\ \overline{w'q_t'},\ \overline{w'\theta_l'}$$

Select PDF from functional form to match moments



Diagnose cloud fraction, liquid water, droplet number from PDF

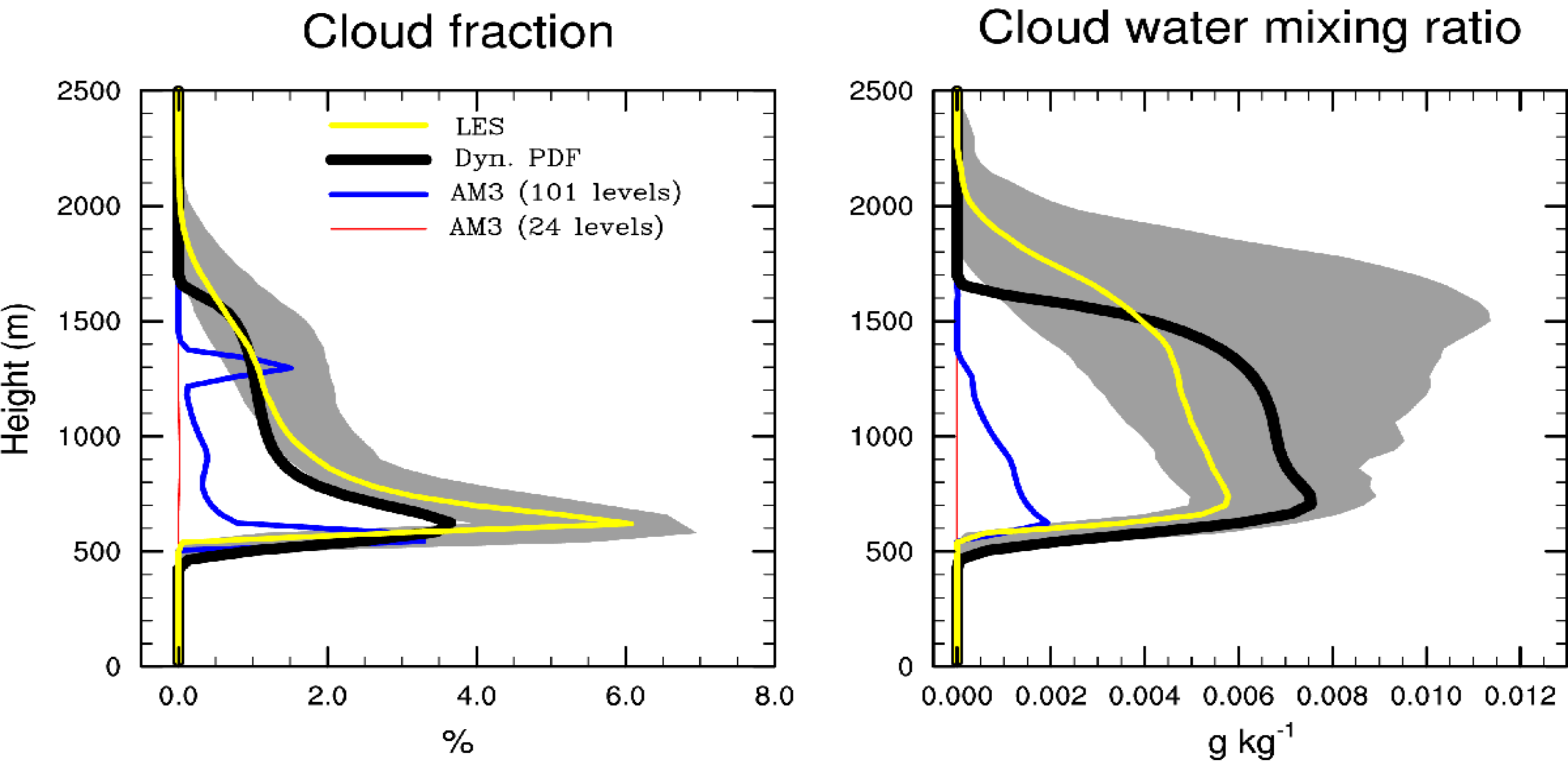
Use PDF to close higher-order moments, buoyancy terms

$$\overline{w'q_t'^2},\ \overline{w'\theta_l'^2},\ \overline{w'q_t'\theta_l'},\ \overline{w'^2q_t'},\ \overline{w'^2\theta_l'},\ \overline{w'^4},\ \overline{q_t'\theta_v'},\ \overline{\theta_l'\theta_v'},\ \overline{w'\theta_v'},\ \overline{w'^2\theta_v'}$$

Δt

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

BOMEX (cumulus)

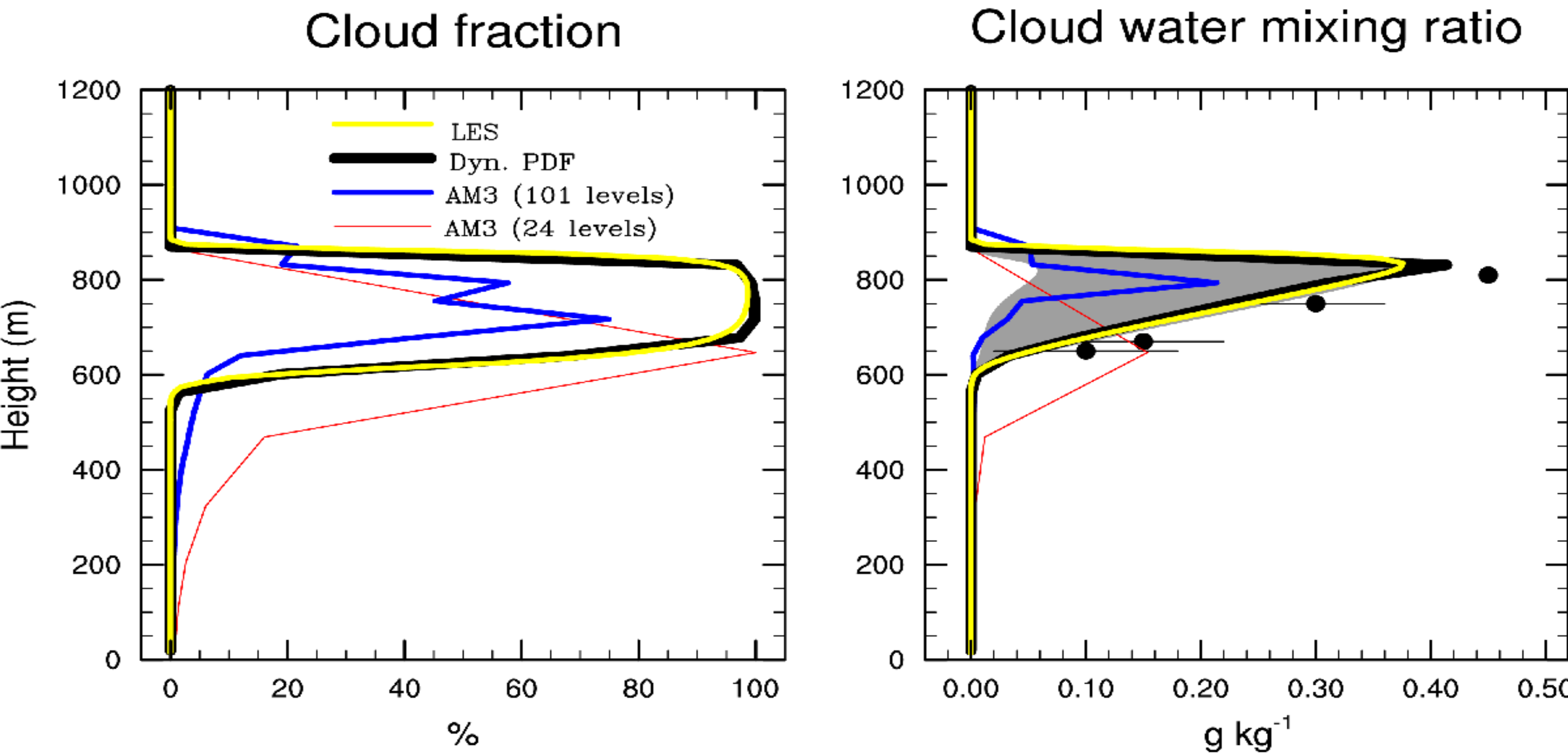


Note: 1. shaded areas indicate the range (Min. and Max. bounds) of GCSS LES intercomparisons

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

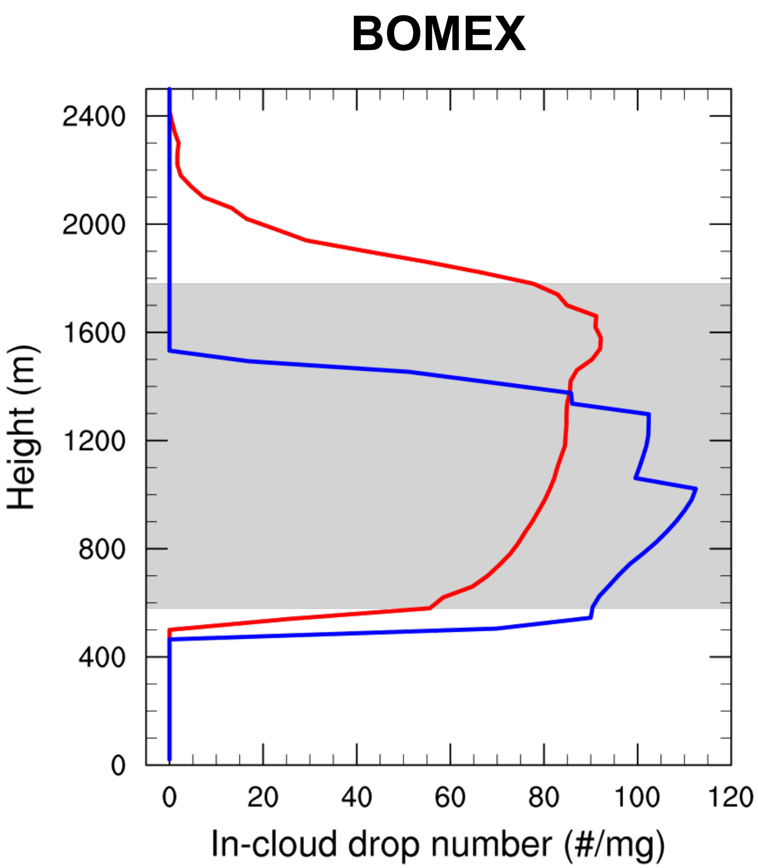
2. dots and horizontal bars indicate the obs. (Stevens et al., 2005 MWR)

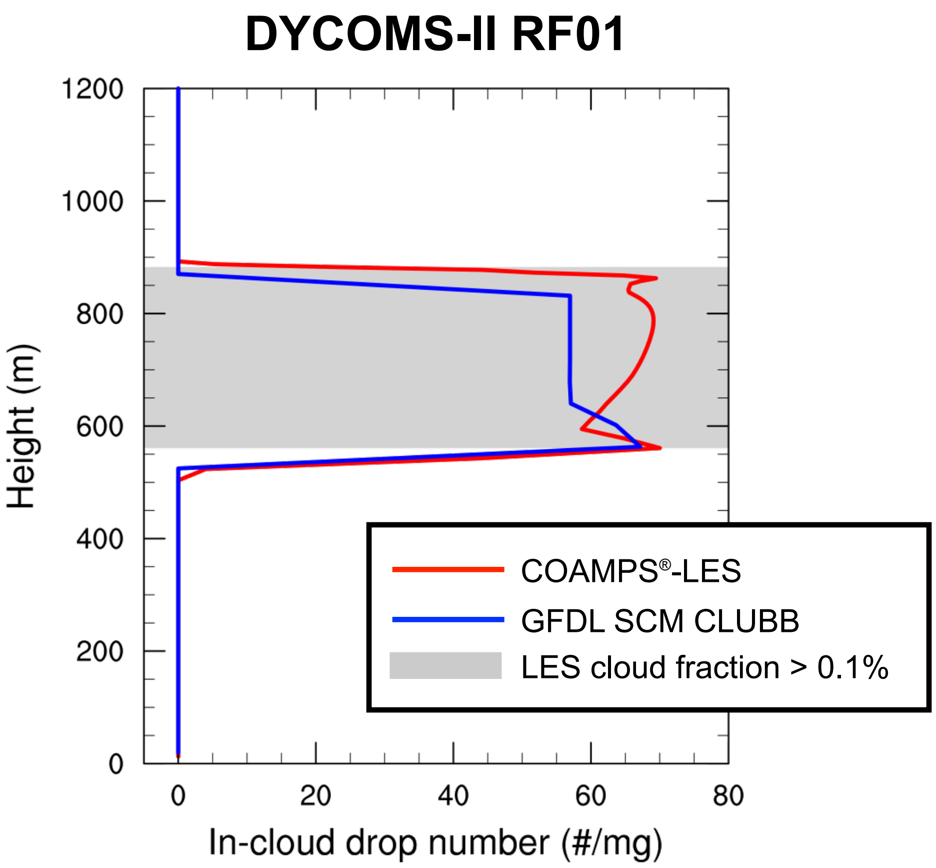
AM3 uses Tiedkte (1993, *Mon. Wea. Rev.*)

(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.