Developing and Testing Convective Parameterizations

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GCSS, Victoria, 13 June 2006

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Emerging Science Demands on Cumulus Parameterization

- More realistic cumulus-scale microphysics for cloud feedbacks and aerosol interactions
- Mass fluxes for simulating tracer transport for chemistry and carbon cycle models, including in TTL
- Mesoscale circulations for upper-troposphere cloud feedbacks
- Intensity distributions for convection

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Emerging Science I: Aerosol-Cloud Interactions

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Observed dependence of cloud droplets on aerosols

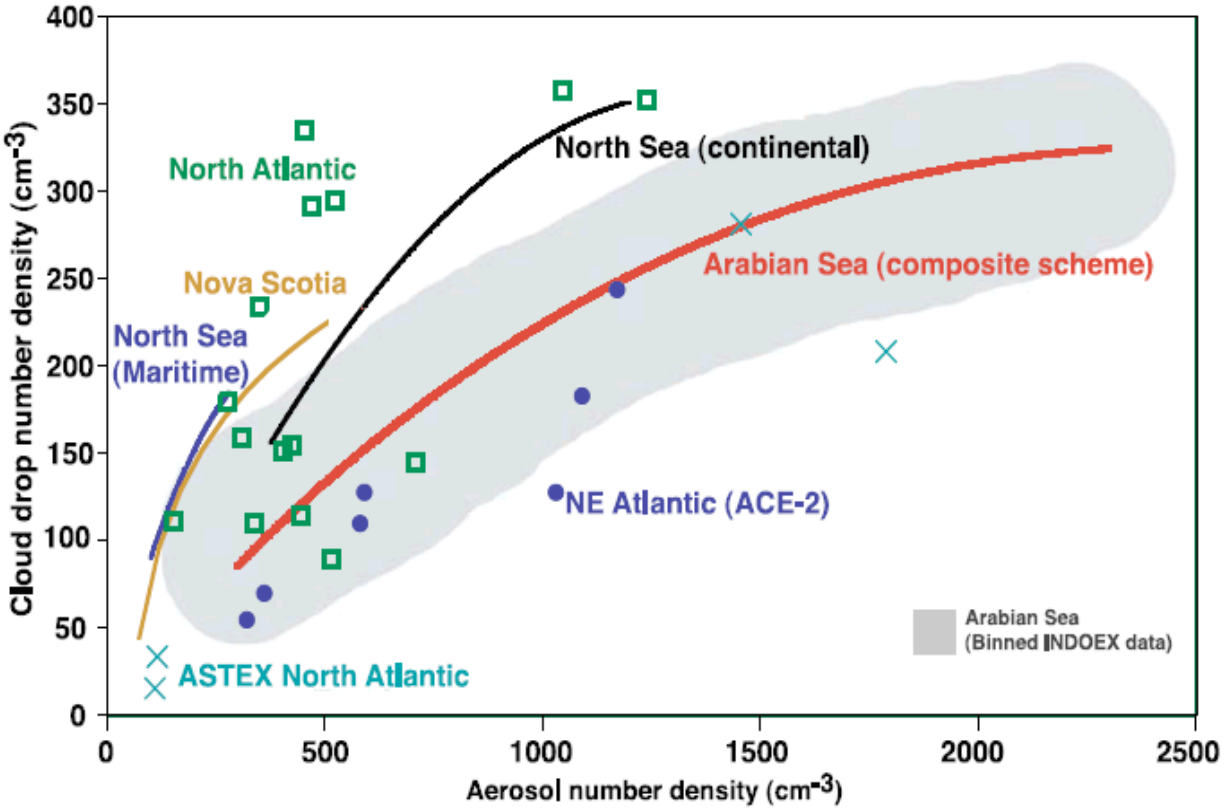
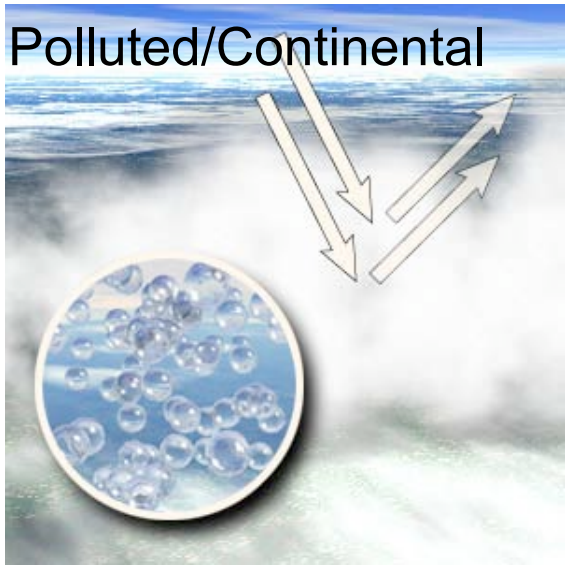
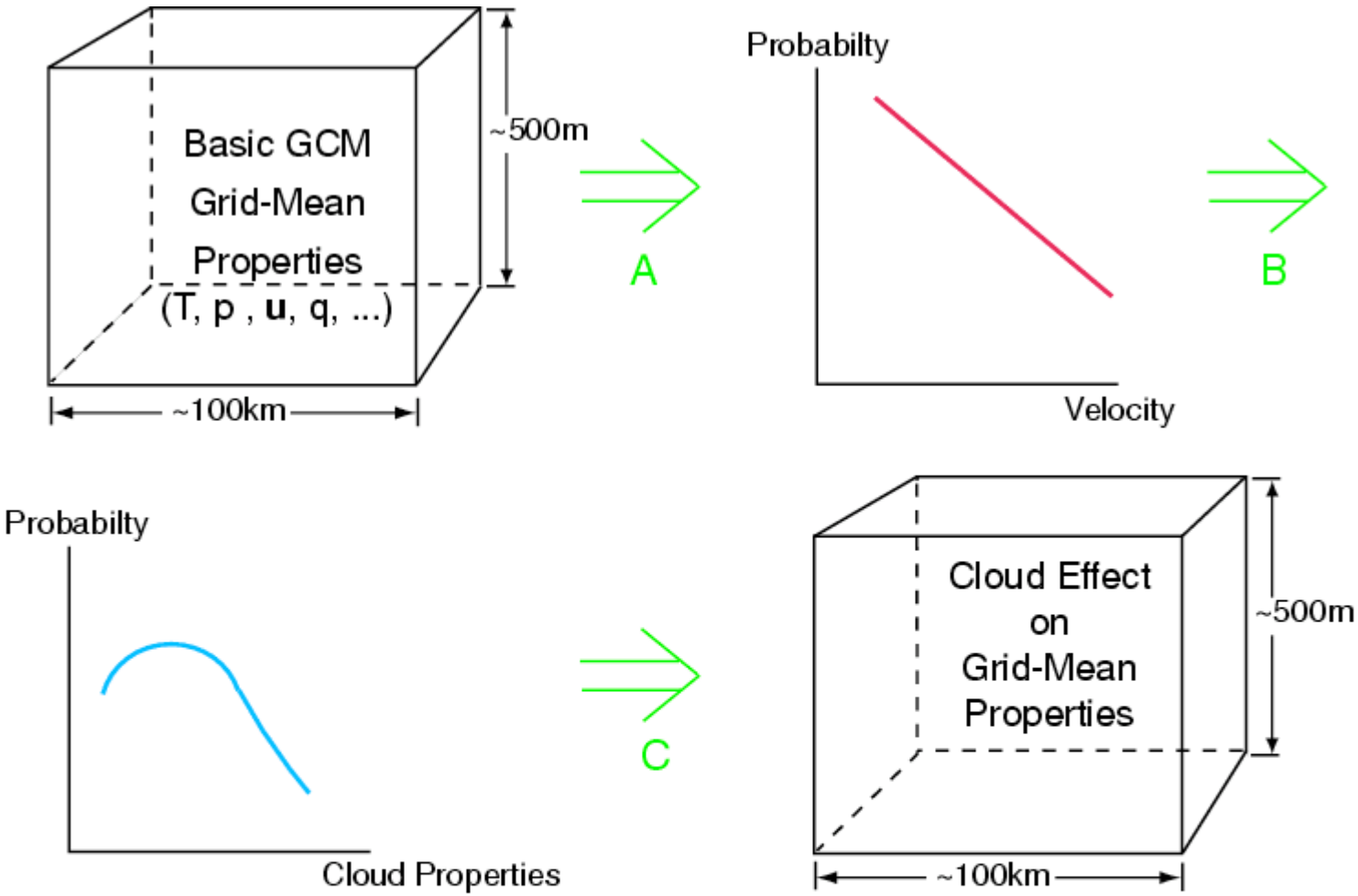


Fig. 5. Aircraft data illustrating the increase in cloud drops with aerosol number concentration. References for the data are as follows: North Sea (*28*), Nova Scotia and North Atlantic (*29*), ACE-2 (*30*), Astex (*31*), the thick red line is obtained from a composite theoretical parameterization that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



Source: Ramanathan et al., Science, 294, 2119.



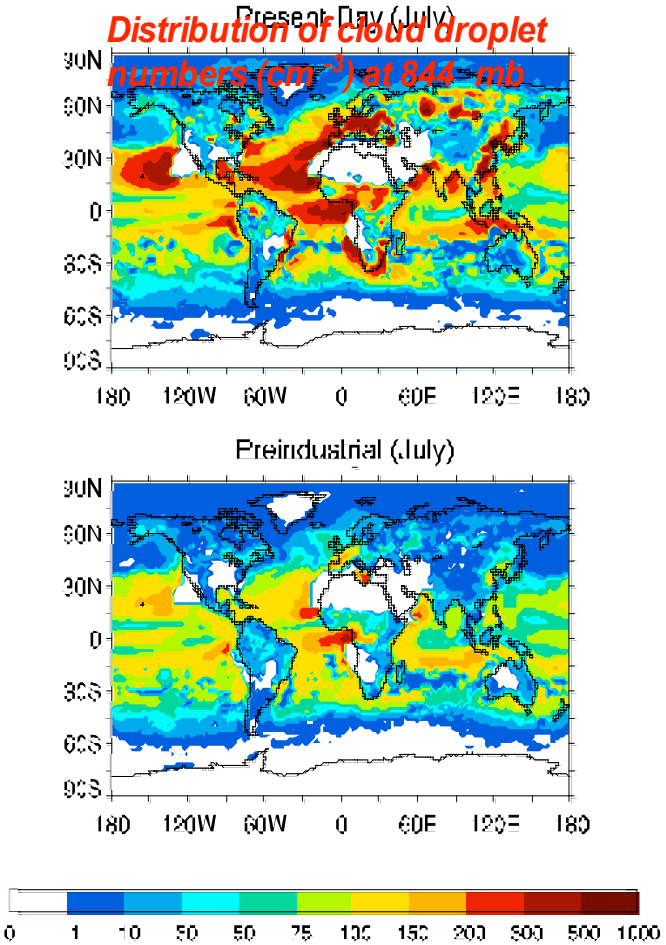
A: "Statistical" Parameterizations, e.g.
Donner (1993, *J. Atmos. Sci.*), Golaz et al. (2002, *J. Atmos. Sci.*)

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

C: Averaging

Preliminary Results: Aerosol -Warm Cloud Interactions

Distribution of cloud droplet numbers (cm^{-3}) at 844 mb



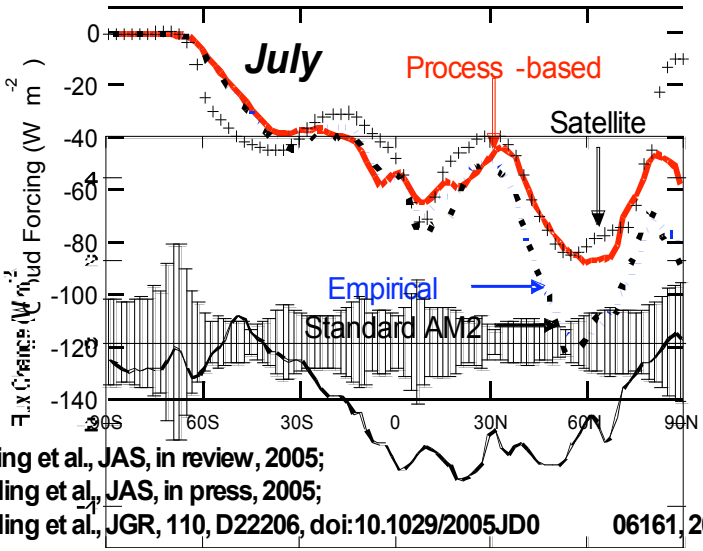
TOA flux change (W m^{-2}) from preindustrial to present -day

Annual global mean

Indirect effects: -1.8 W m^{-2}

CO_2: +1.5 W m^{-2}

Shortwave cloud forcing (W m^{-2})



Source: Ming et al., JAS, in review, 2005;
Ming et al., JAS, in press, 2005;
Ming et al., JGR, 110, D22206, doi:10.1029/2005JD0 06161, 2005.

Key Issues

- Number of activated aerosols depends on supersaturation at cloud base, using Ming (2006, *J. Atmos. Sci.*)
- Base supersaturation depends on vertical velocity at cloud base
- Current AM2 approach takes account of stratiform vertical velocities (uniform within grid box) and convective vertical velocities

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Three Methods for Calculating Convective Vertical Velocity

- Estimate from cloud work function for all members of RAS ensemble with warm base, including deep convection.
- Estimate from cloud work function for shallow members of RAS ensemble only.
- Estimate from turbulent kinetic energy in planetary boundary layer.

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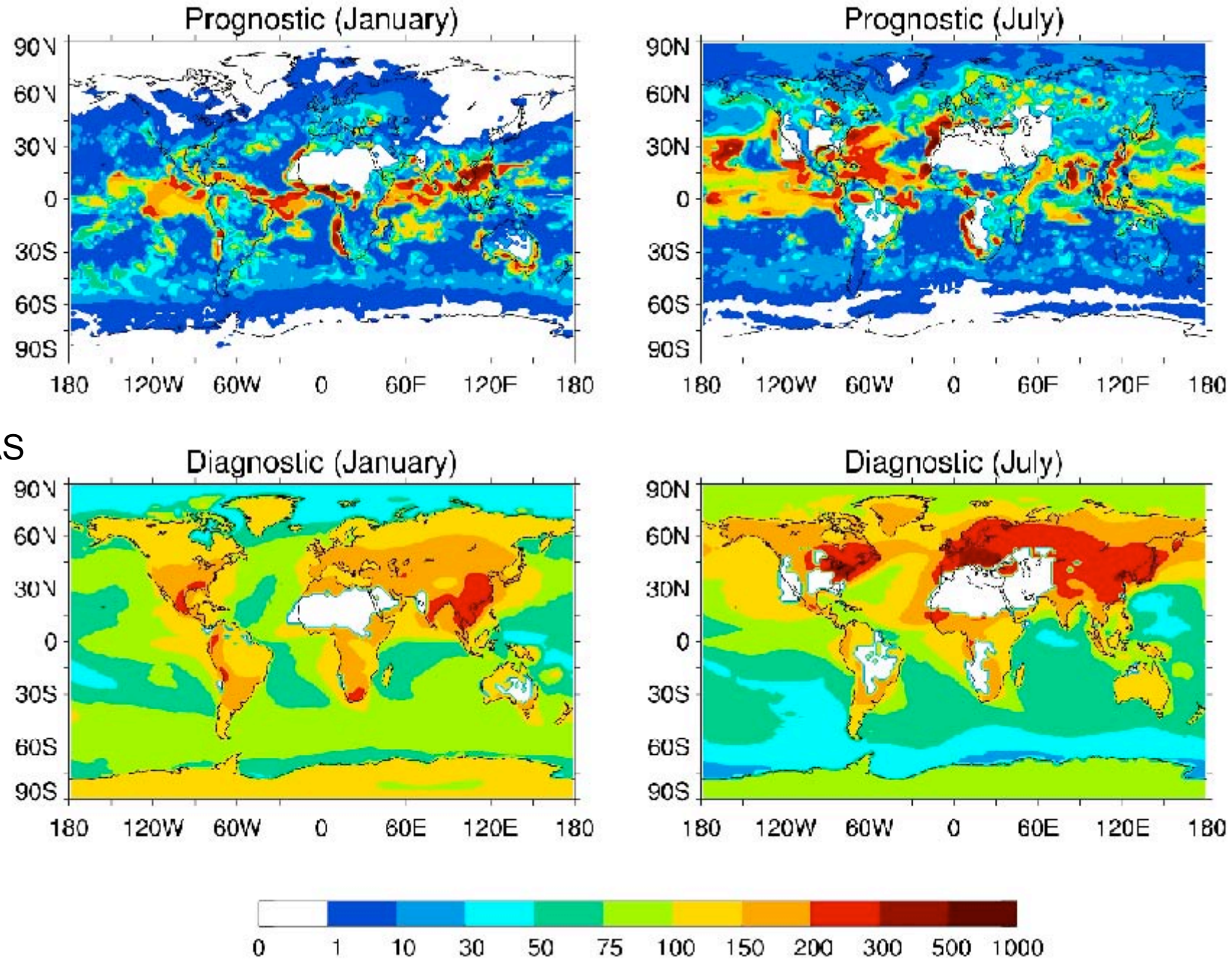
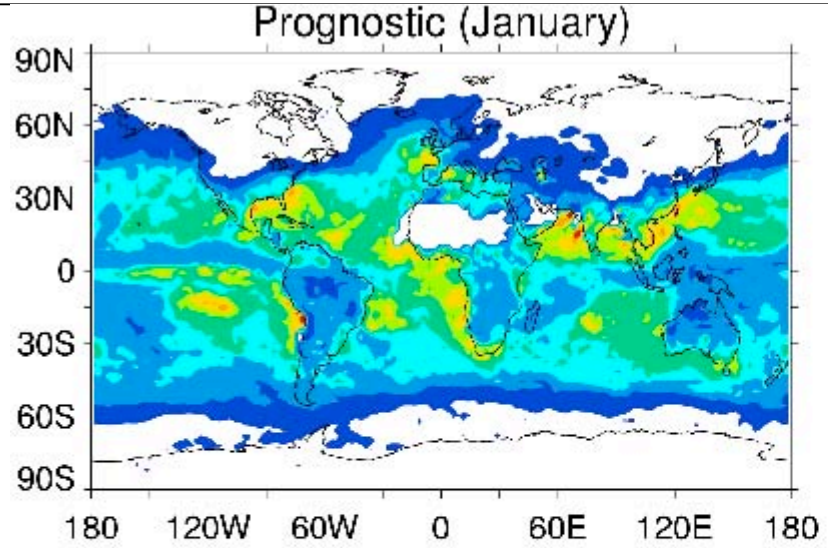
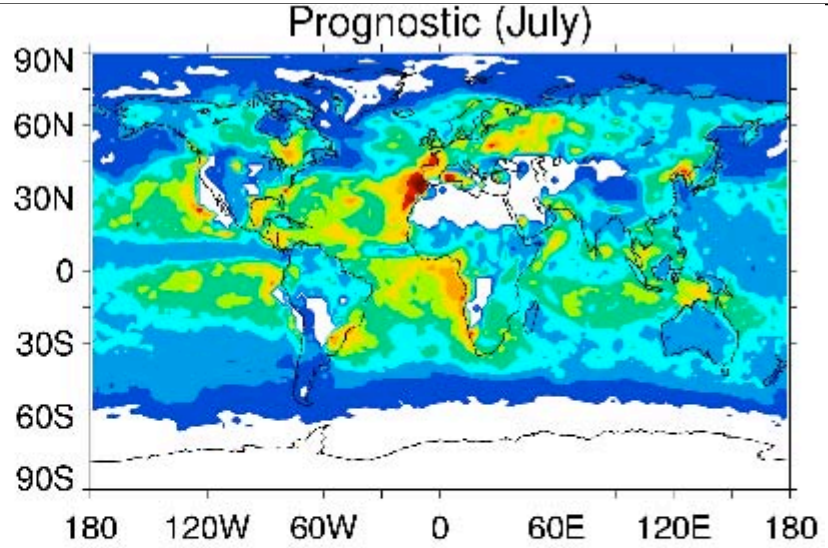
All RAS

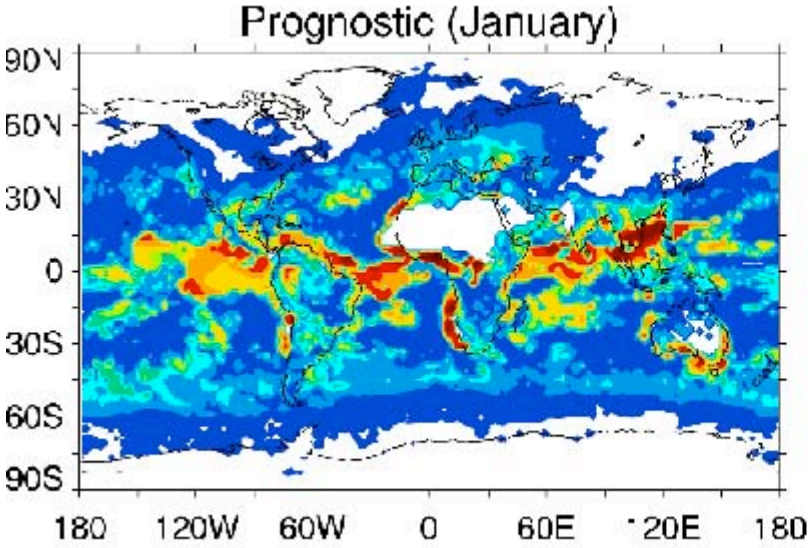

Prognostic (January)
Prognostic (July)
Diagnostic (January)
Diagnostic (July)
90N
60N
30N
0
30S
60S
90S
180
120W
60W
0
60E
120E
180
0
1
10
30
50
75
100
150
200
300
500
1000

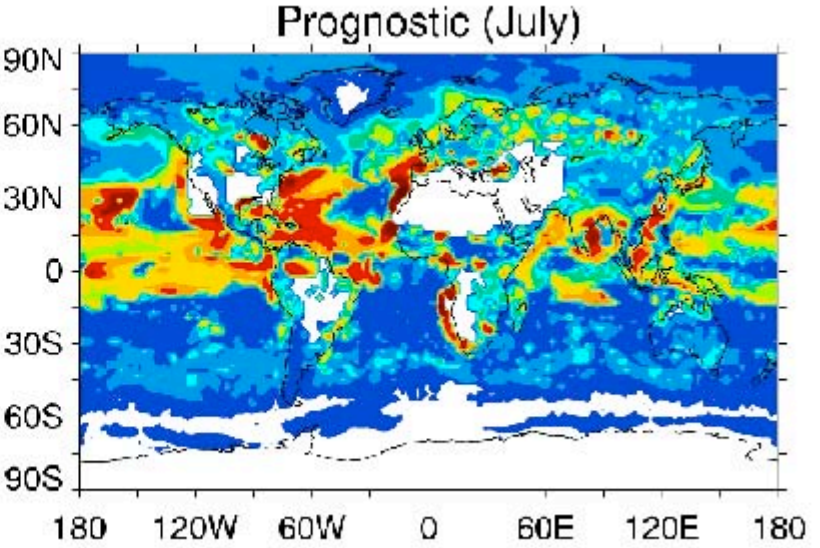


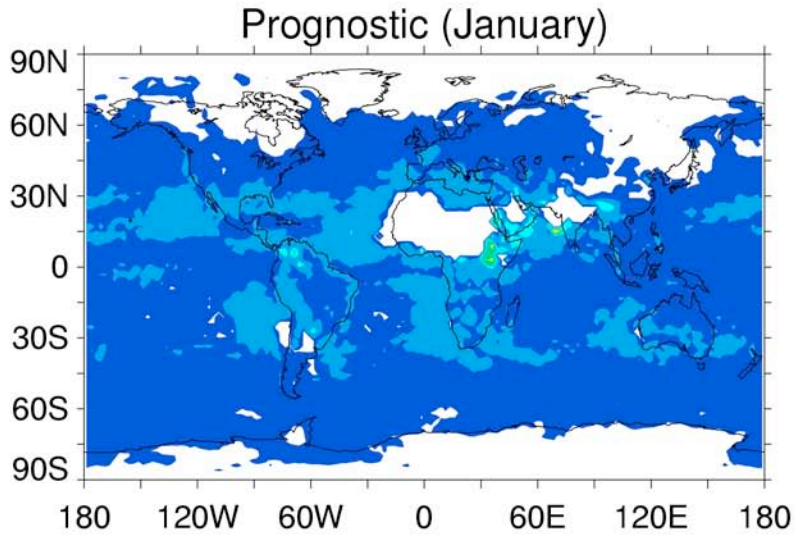


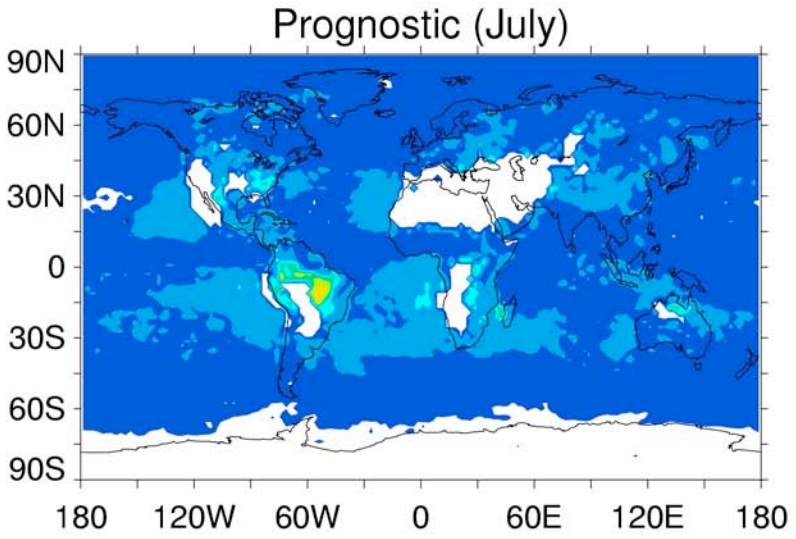
RAS Shallow

RAS All





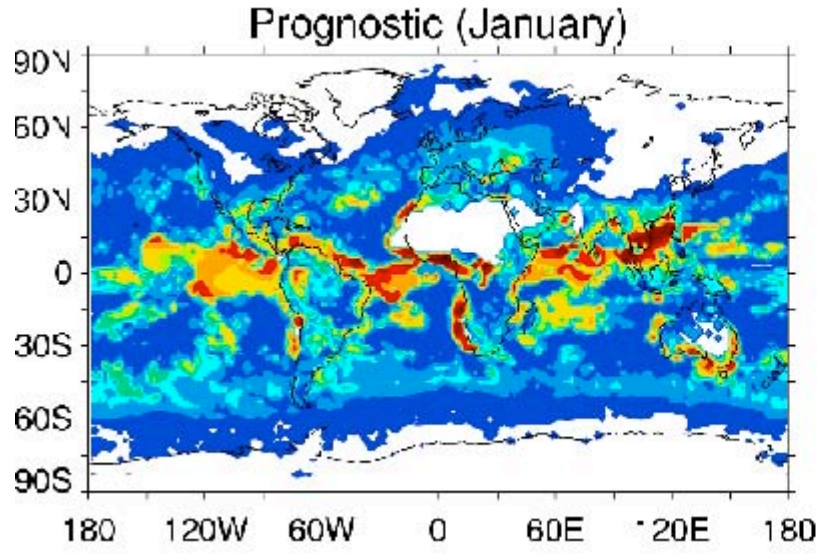

Prognostic (January)
90N
60N
30N
0
30S
60S
90S
180
120W
60W
0
60E
120E
180

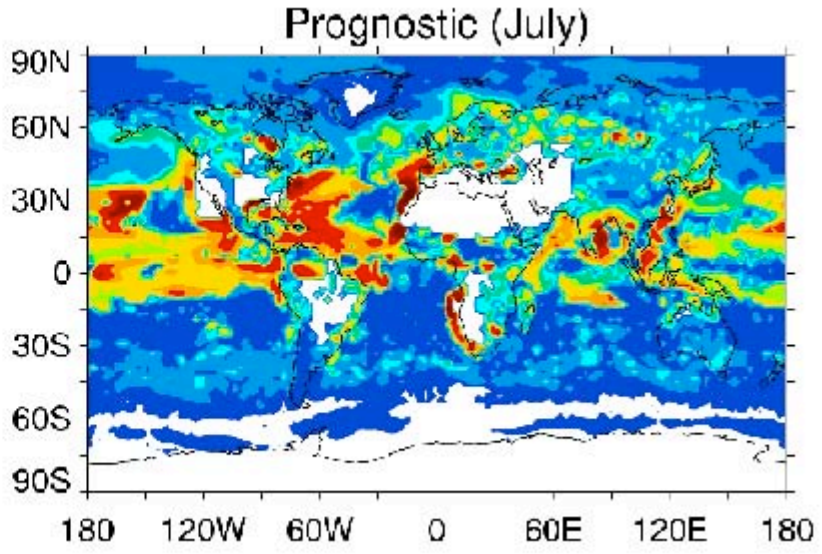

Prognostic (July)
90N
60N
30N
0
30S
60S
90S
180
120W
60W
0
60E
120E
180

TKE


0
1
10
30
50
75
100
150
200
300
500
1000

RAS All


Prognostic (January)
90N
60N
30N
0
30S
60S
90S
180
120W
60W
0
60E
120E
180


Prognostic (July)
90N
60N
30N
0
30S
60S
90S
180
120W
60W
0
60E
120E
180

Current Problems

- RAS All uses upper-cloud vertical velocities with cloud base aerosol concentrations, systemically over-estimating droplet number for deep clouds
- RAS All ignores cold-cloud microphysics in deep clouds
- TKE cloud base vertical velocities much lower than in cloud interior, systematically underestimating droplet number

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Proposed Solution

- Realistic vertical velocities for cumulus ensemble
- Supersaturation profile through full depth of cloud
- Microphysical removal mechanisms for activated aerosols
- Extend to deep convection by including ice microphysics

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Emerging Science II: Cumulus Mass Fluxes for Tracer Transport in Chemistry and Carbon Cycle Models

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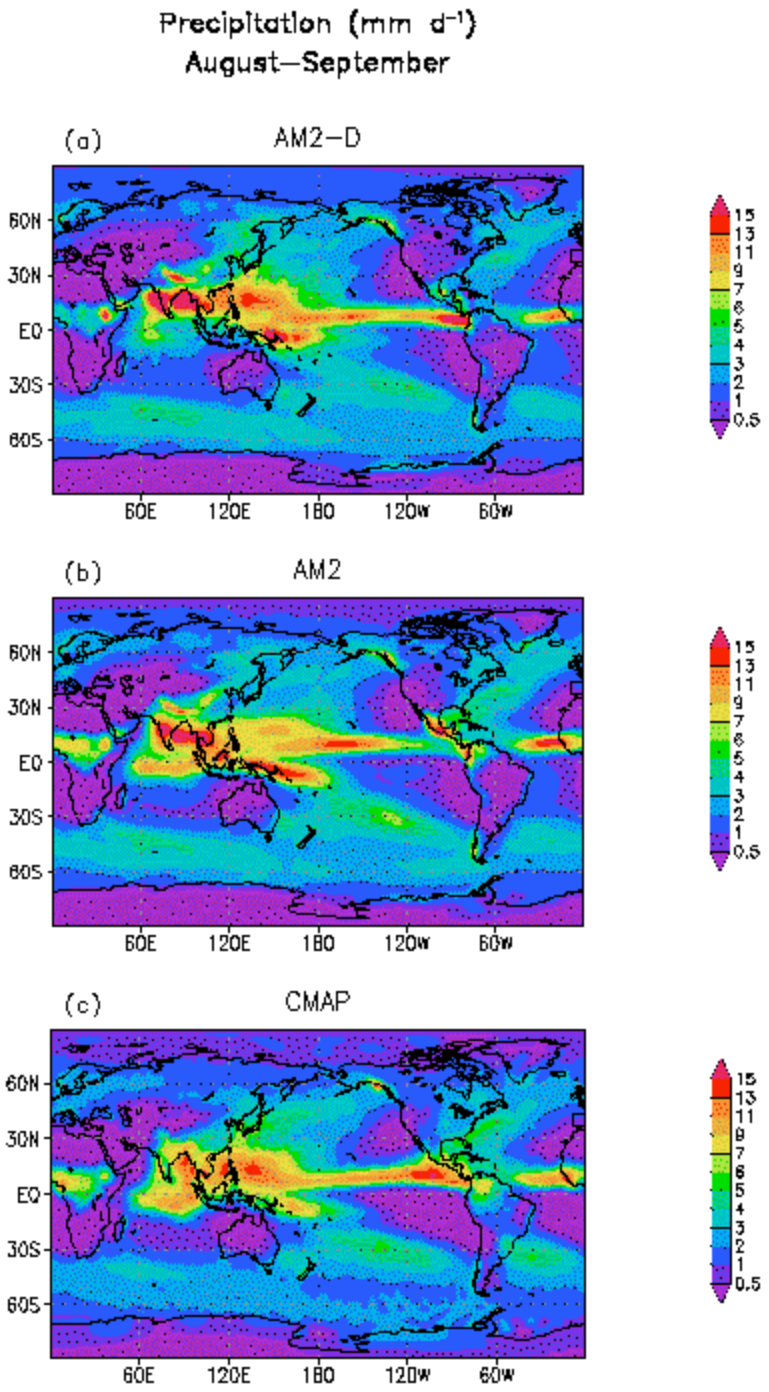
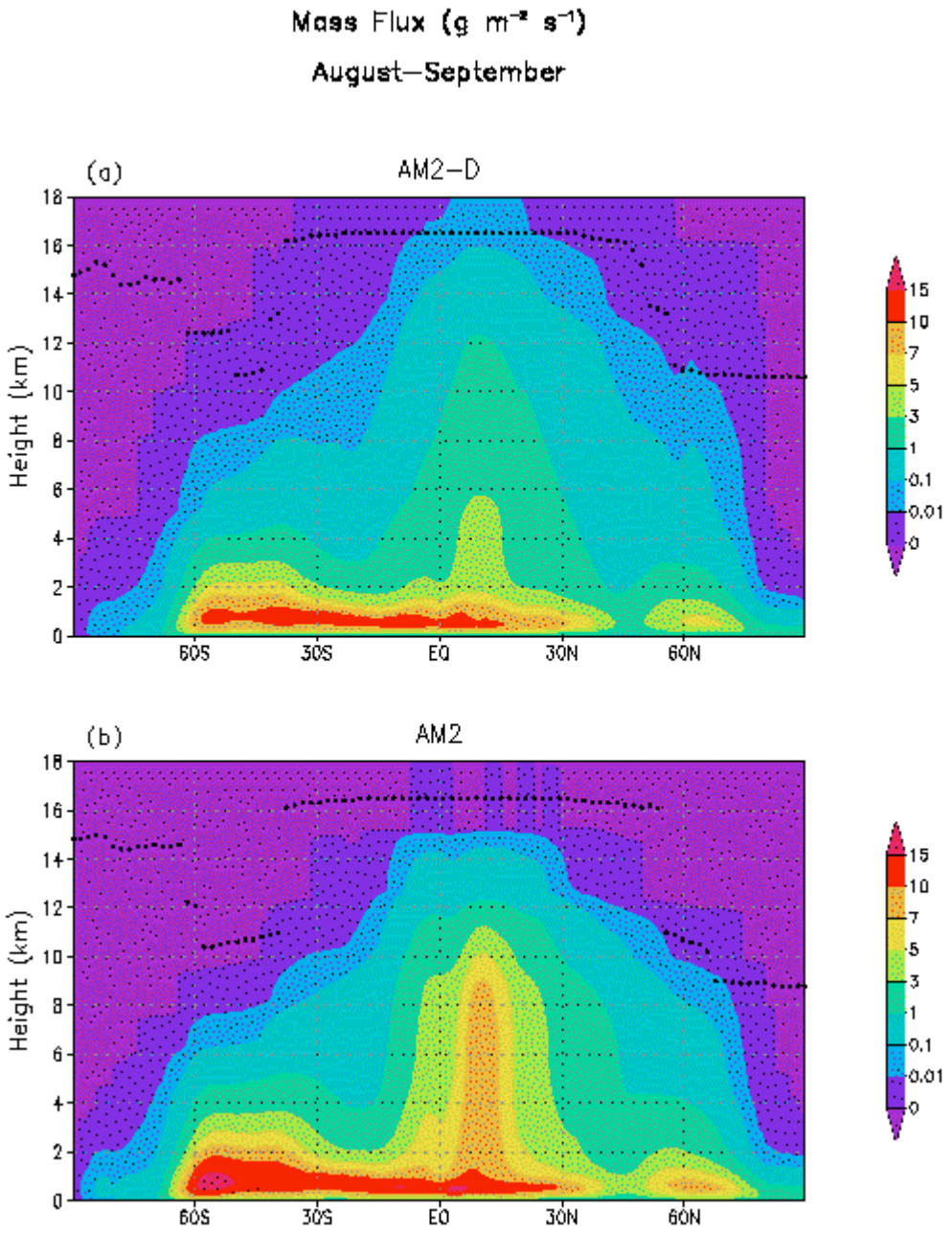
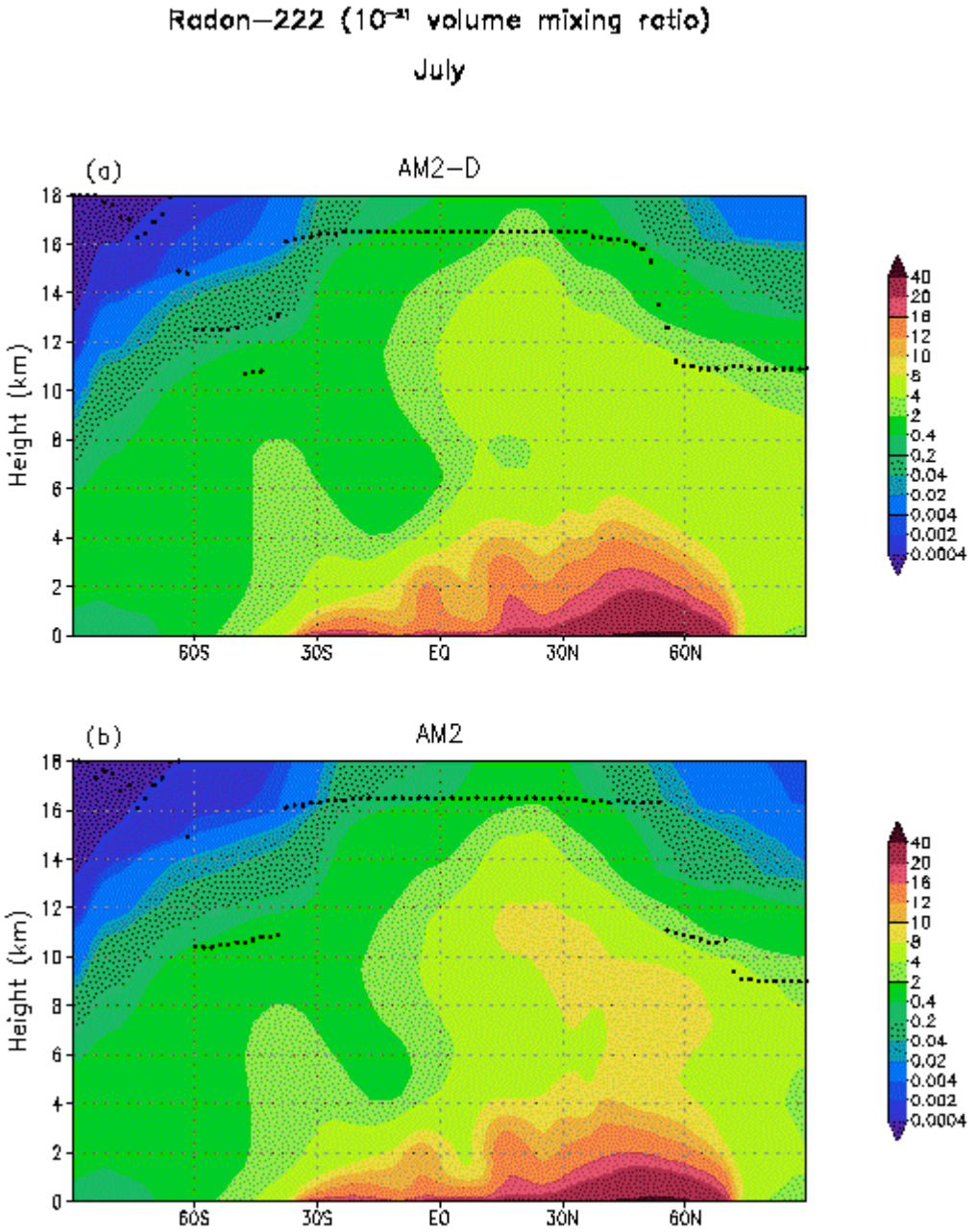
Precipitation does not differ much between AM2 and AM2-D. Between 30°S and 50°N, AM2-D precipitation is only 2% less than AM2.



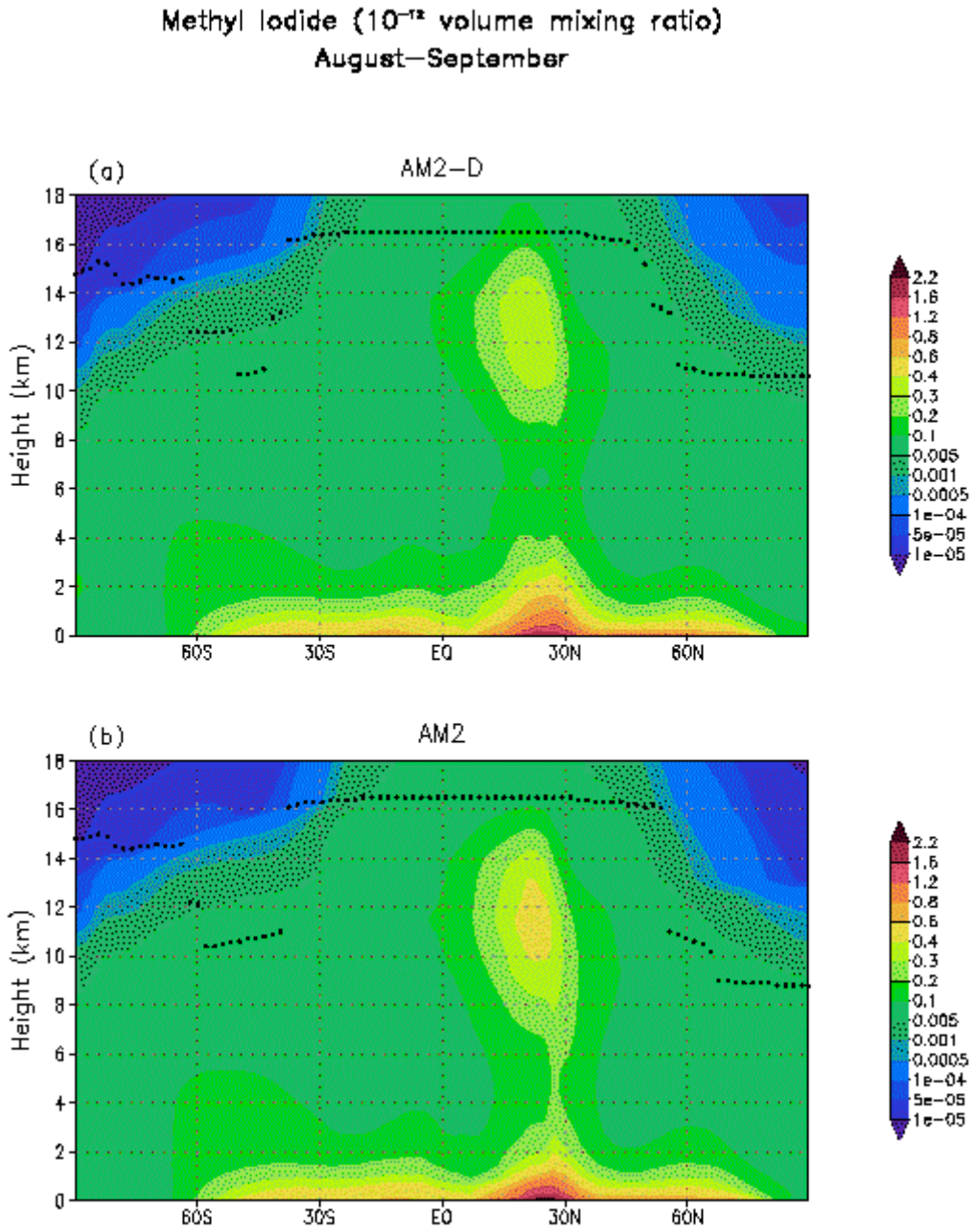
Mass fluxes differ sharply between AM2-D and AM2 and are consistent with tracer differences. Between 30° and 50°N, mass fluxes are 40% less in AM2-D.



Radon-222 concentrations are higher in the middle- to upper troposphere in AM2 (no mesoscale) but lower near the tropopause (no overshooting).



Methyl iodide concentrations are higher in the middle- to upper-troposphere in AM2 (no mesoscale) but lower near the tropical tropopause.



Developing and Testing a Cumulus Parameterization with Vertical Velocity PDFs and Advanced Microphysics

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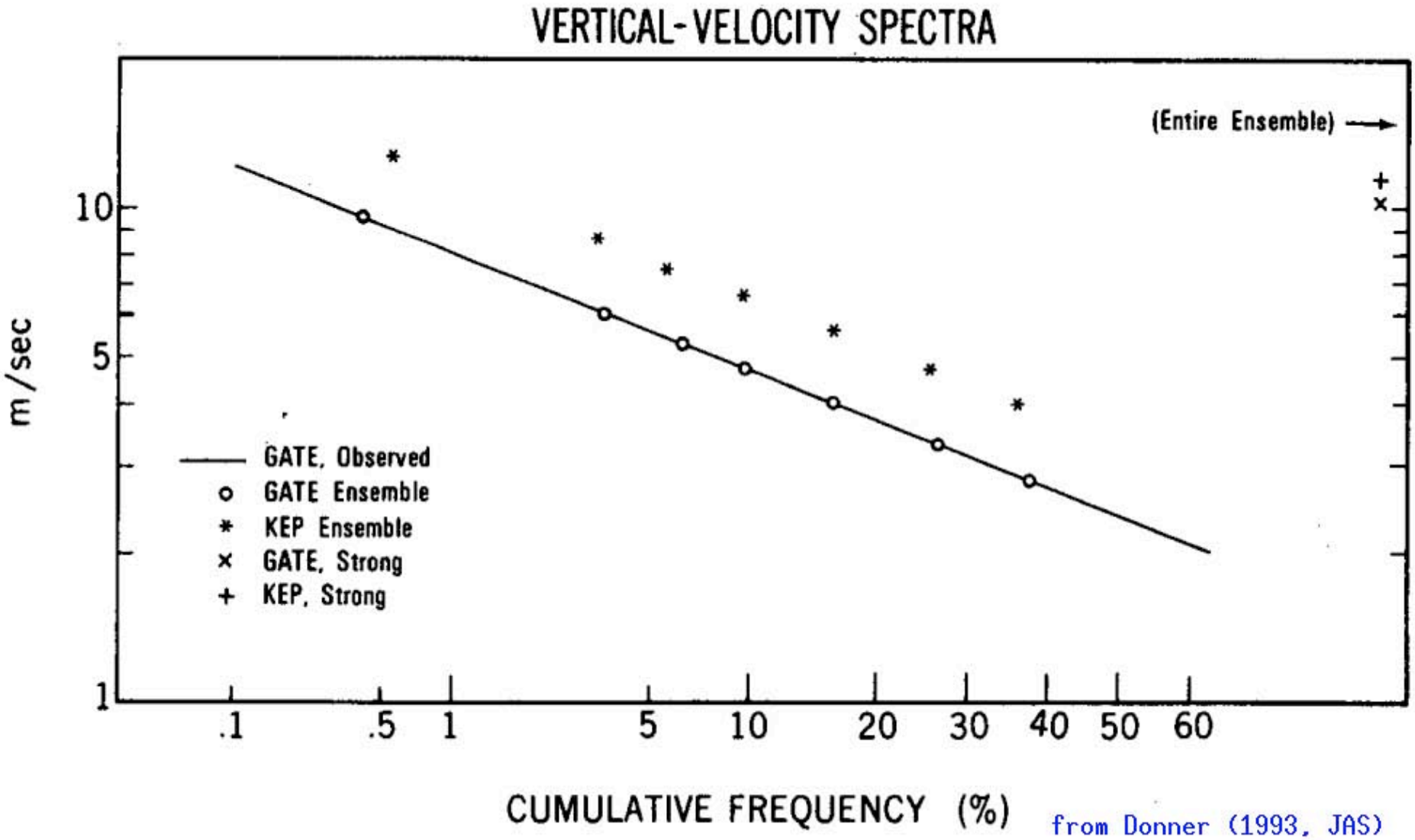
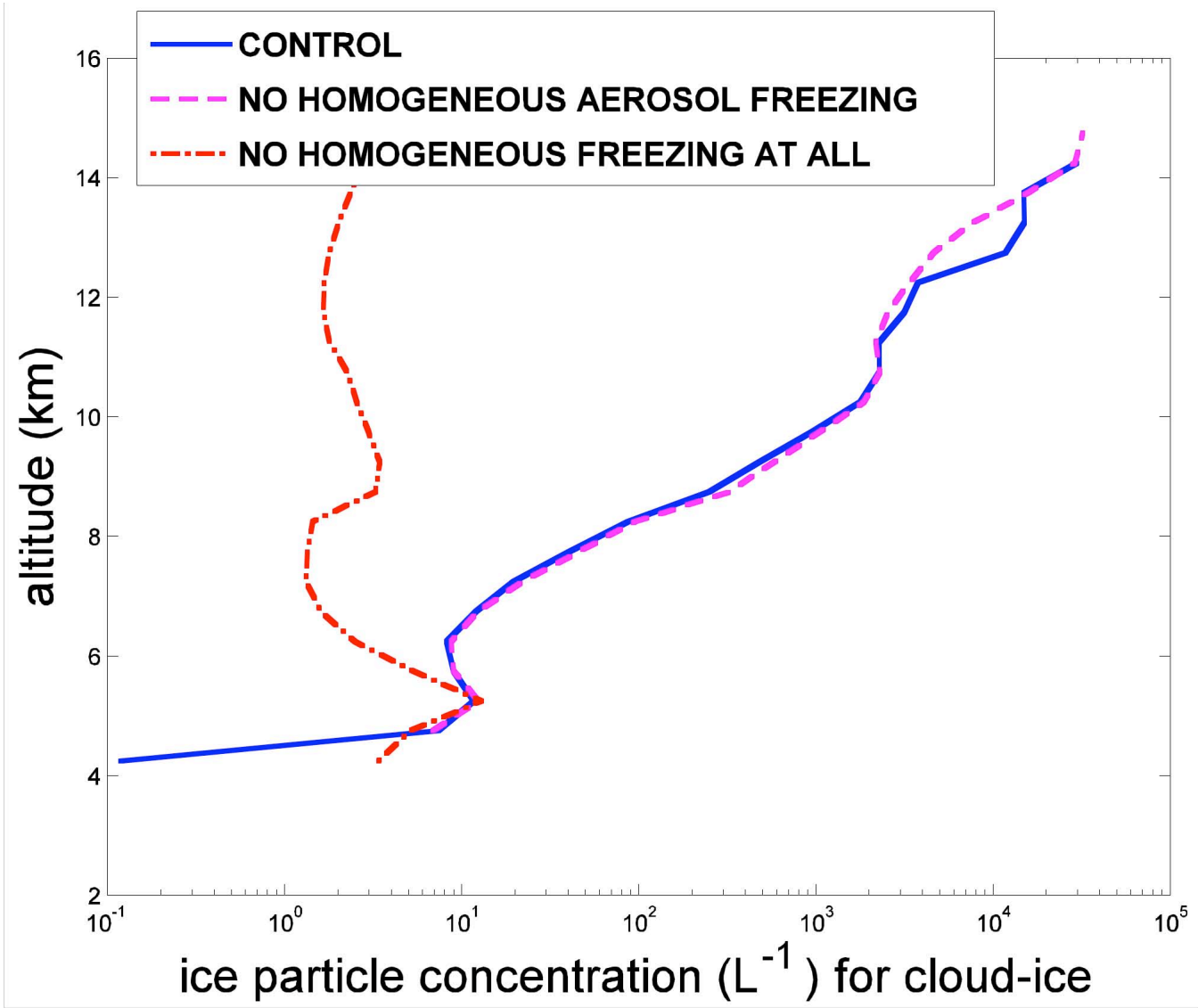
GATE observations used to infer entrainment PDF



from Donner (1993, JAS)

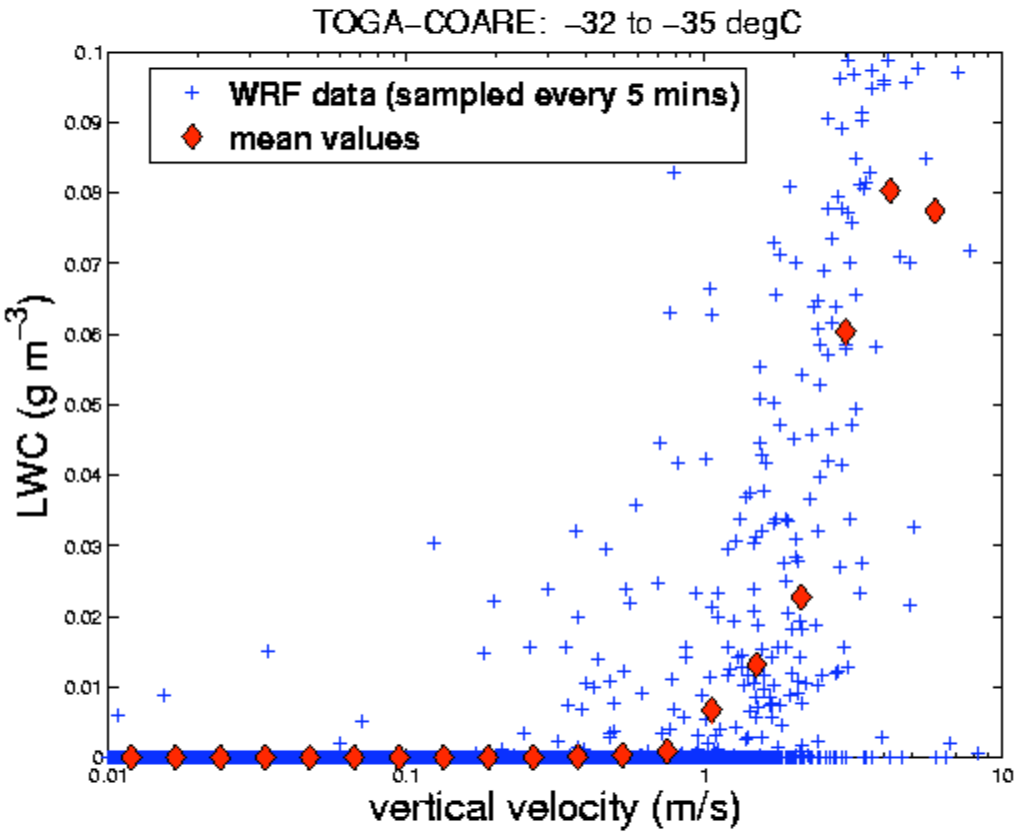
Begin with observations…very limited.

Extract fundamental properties…NOT vertical velocities…possibly entrainment?



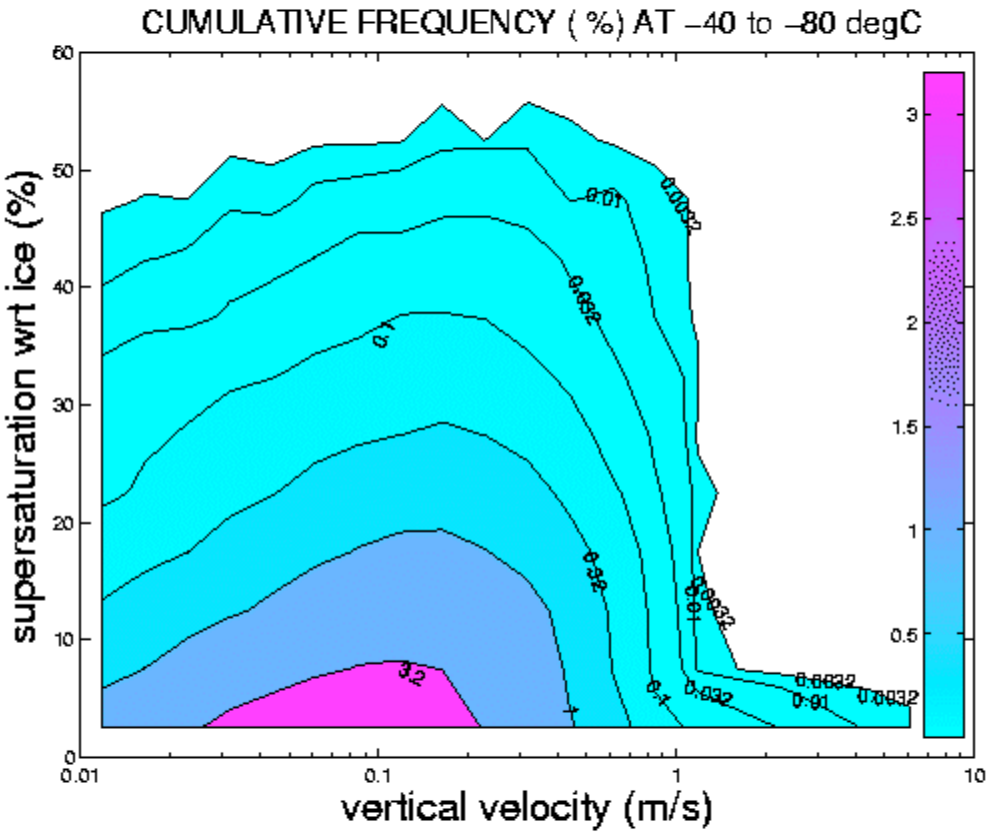
Homogeneous freezing of droplets is the key process determining ice particle concentration.

WRF liquid water content has vertical velocity threshold

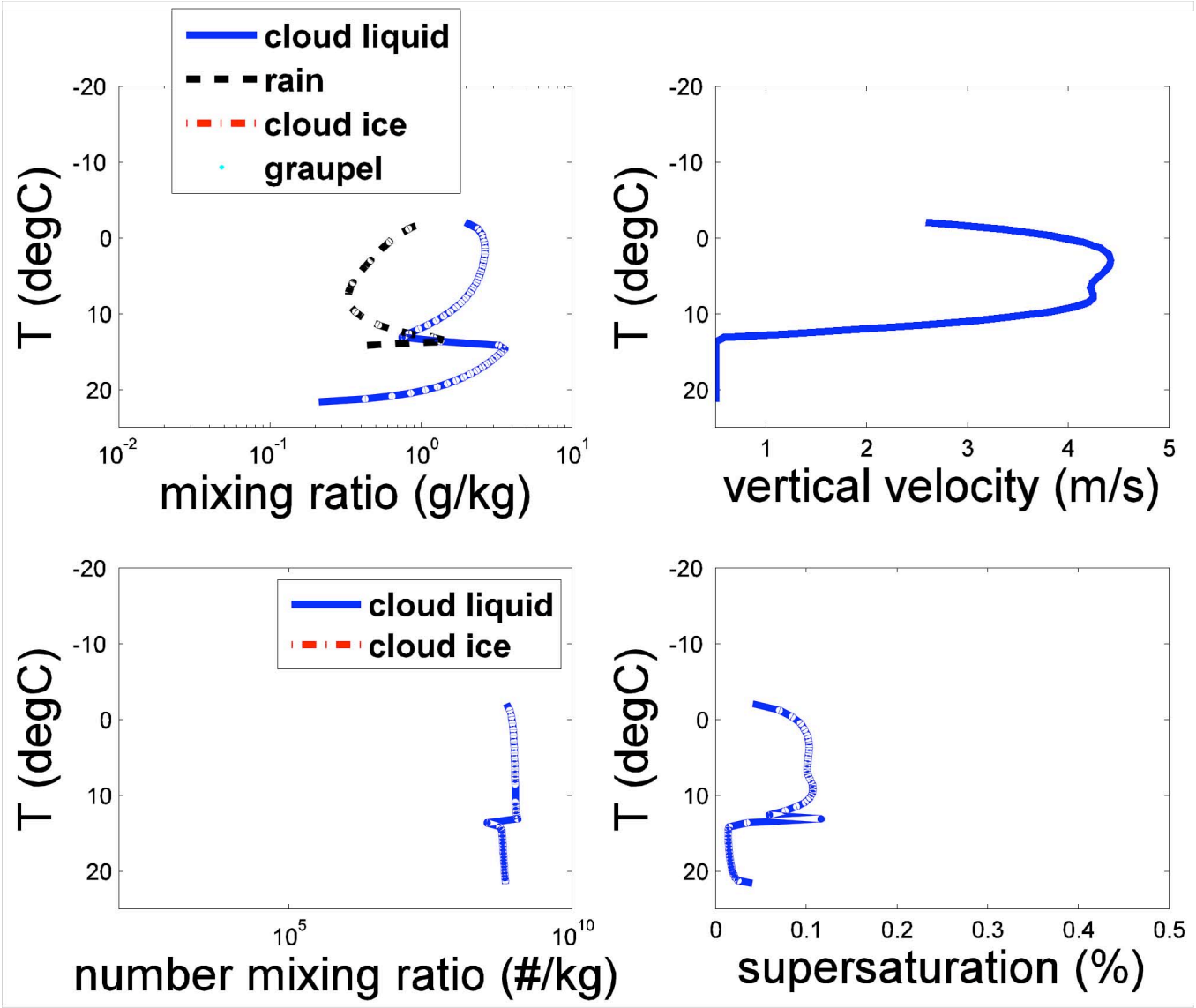


See also Heymsfield *et al.* (2005, *J. Atmos. Sci.*)

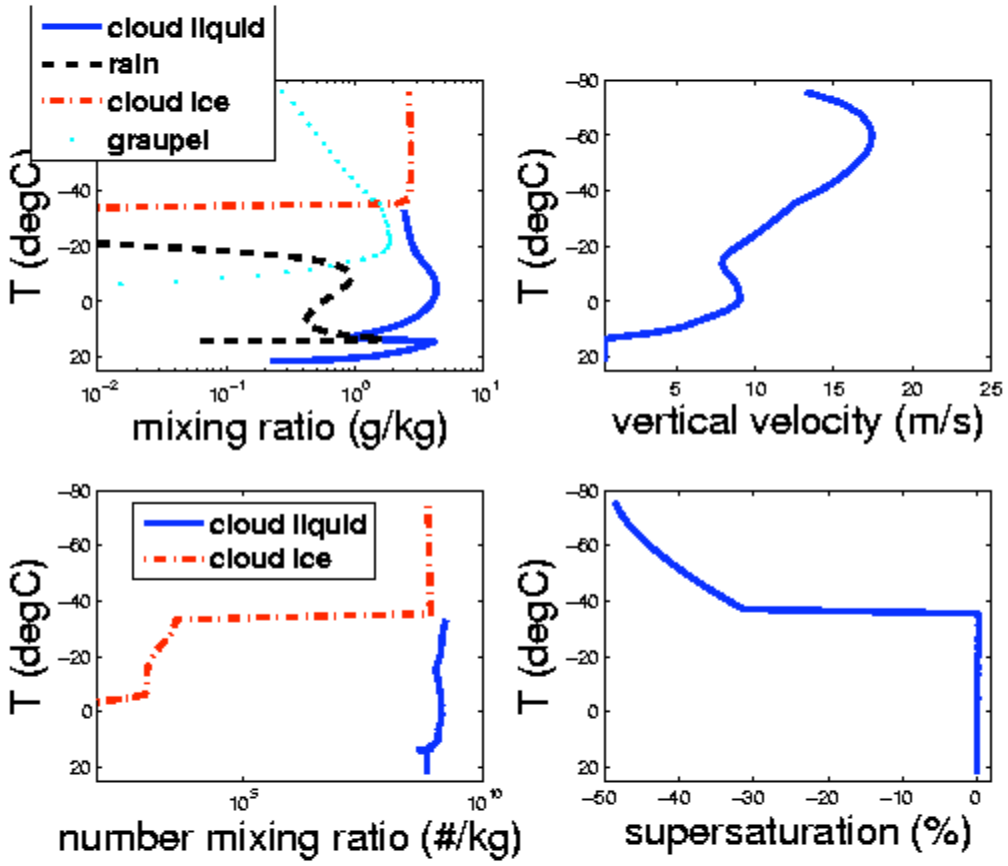
Vertical velocity is critical because it is a major control on supersaturation.



Highly entraining ensemble member (TOGA-COARE)



Weakly entraining ensemble member



Evaluating Parameterizations: Comparison of Process Model with Field Observations

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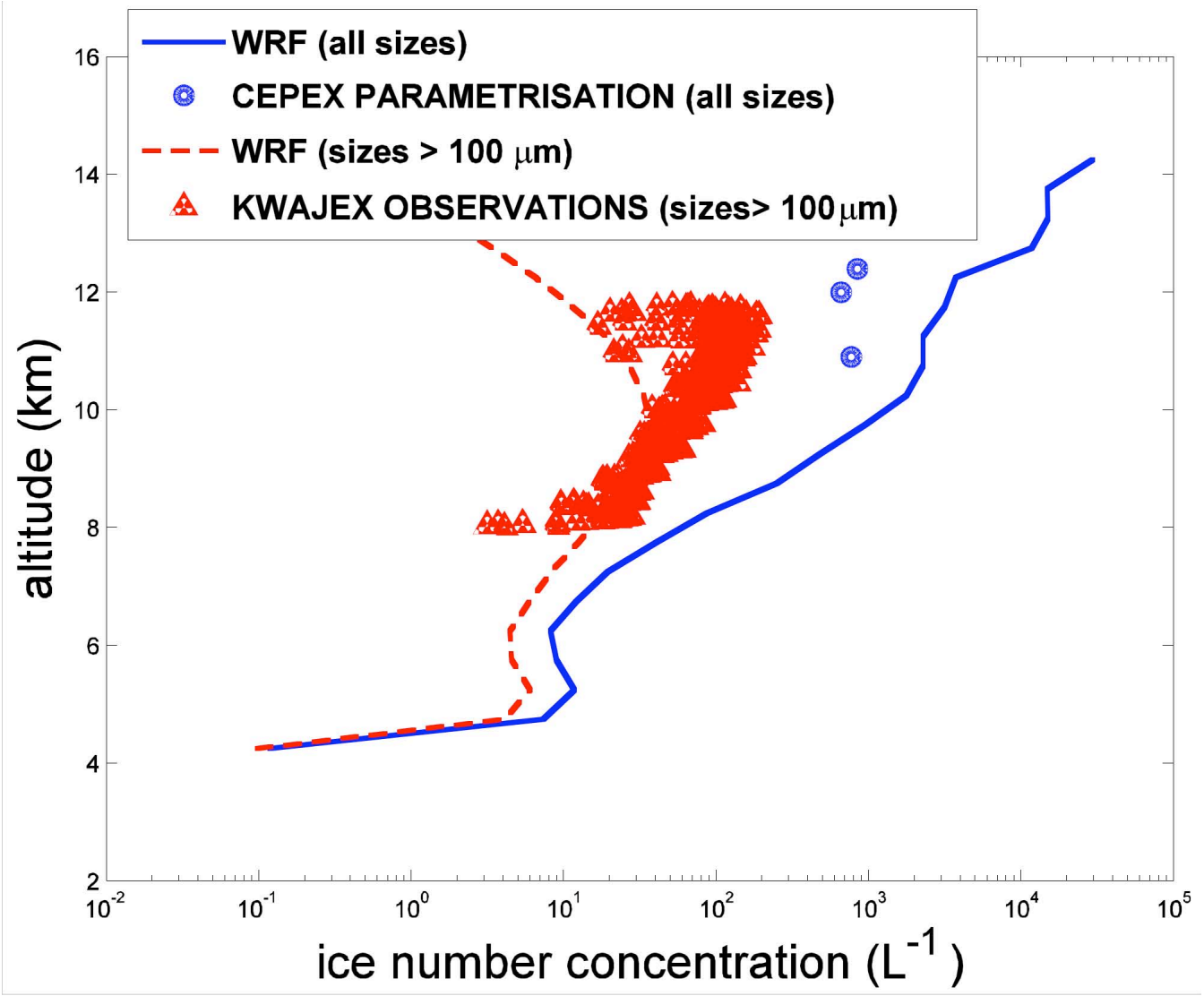
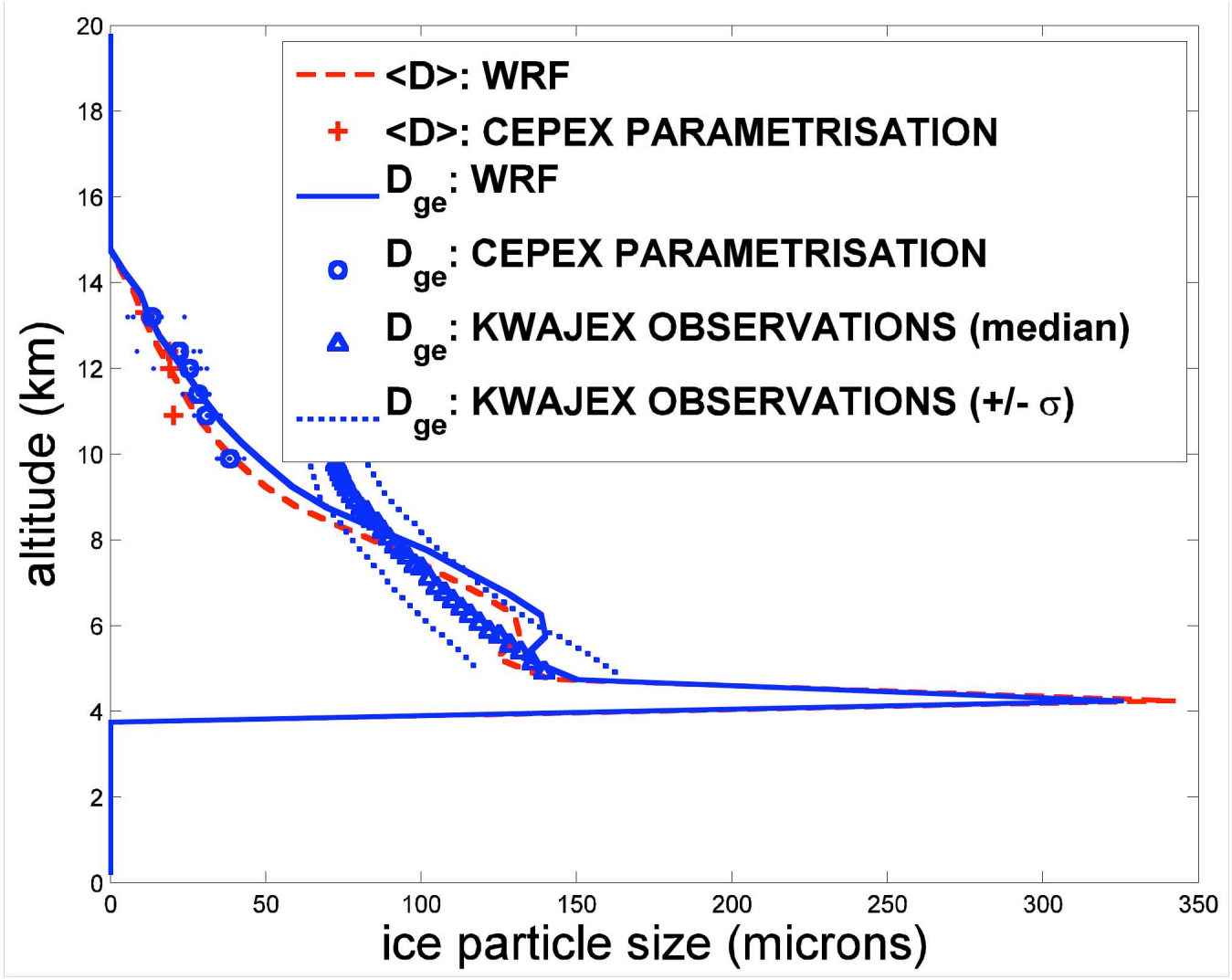


KWAJEX observations from Heymsfield *et al.* (2002, *J. Atmos. Sci.*)
CEPEX observations from McFarquhar (1999, *J. Geophys. Res.*)



<D >: number-weighted mean size;

D_{ge} : radiatively weighted mean size (Fu and Liou, 1993, *JAS*)

Evaluating Parameterizations: Compare GCM parameterizations with "trusted" process model

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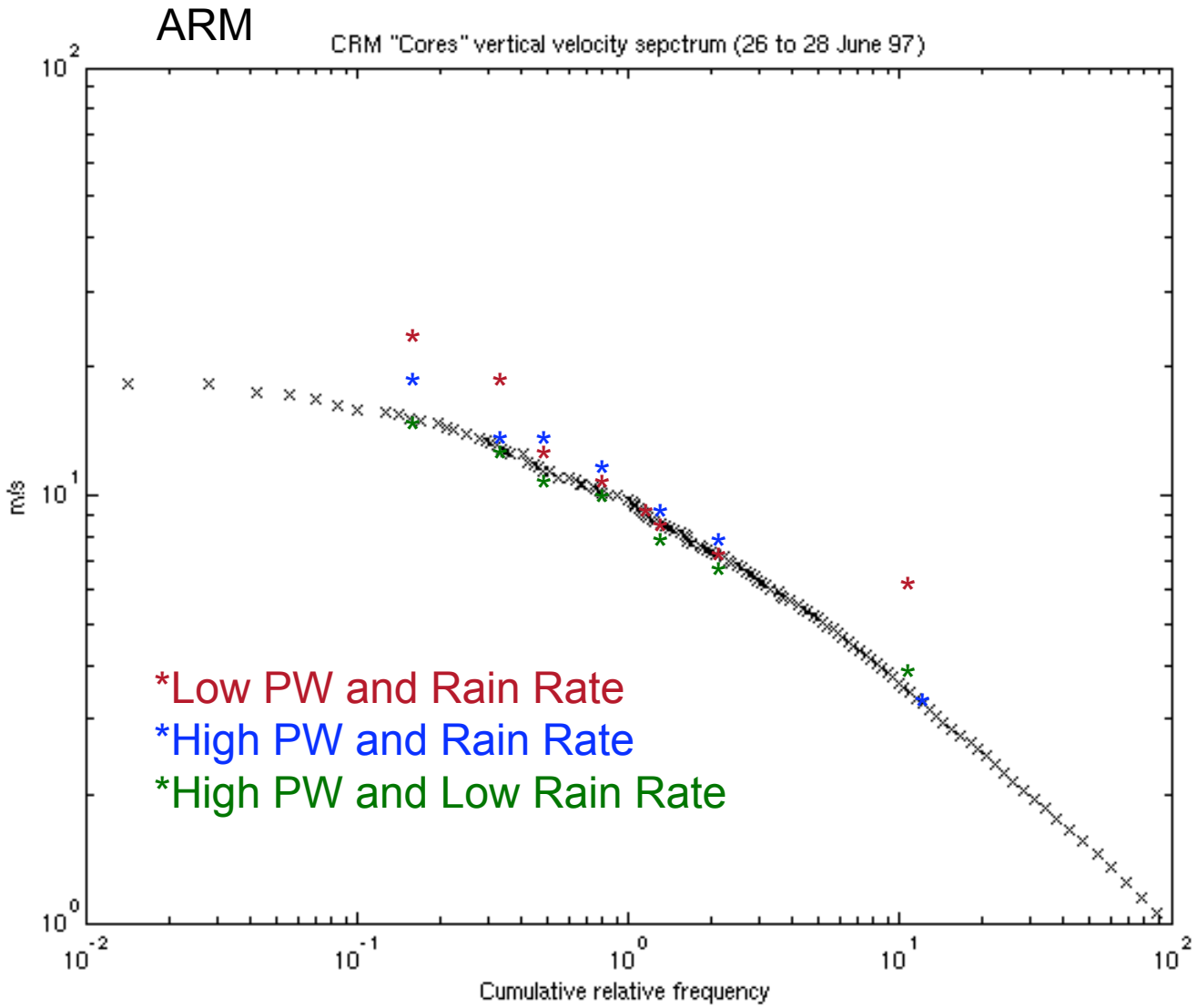
CRM results provide independent evaluation of entrainment PDF.
Multi-scale Modeling offers potential to vastly expand this database!



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

Evaluating Parameterizations: Using Field Data to Test Fundamental Assumptions

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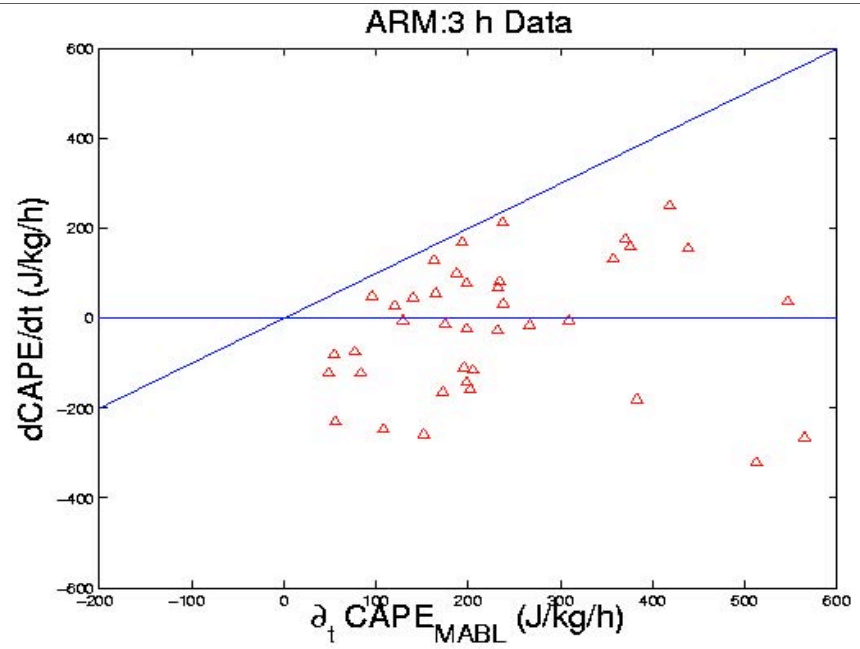

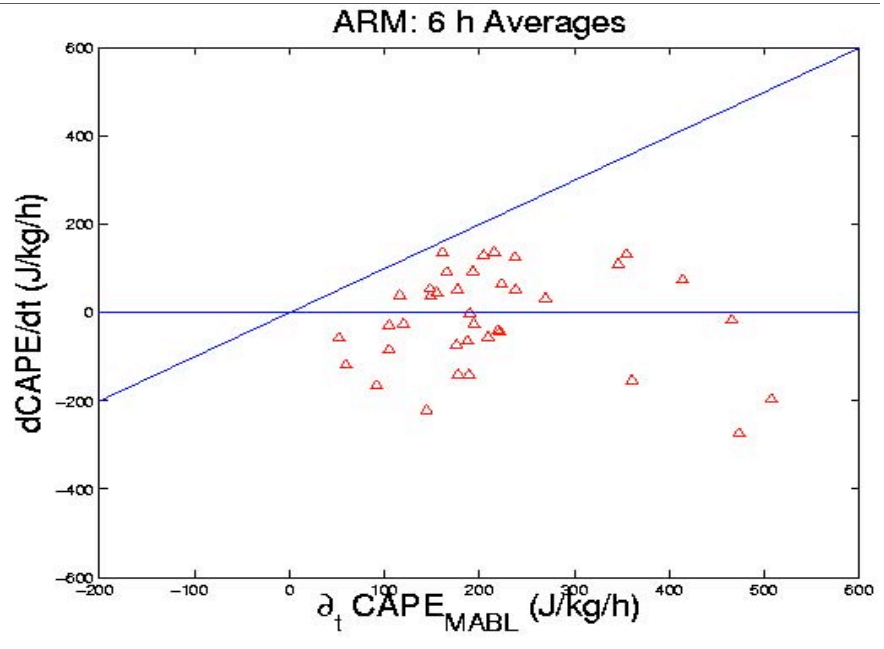

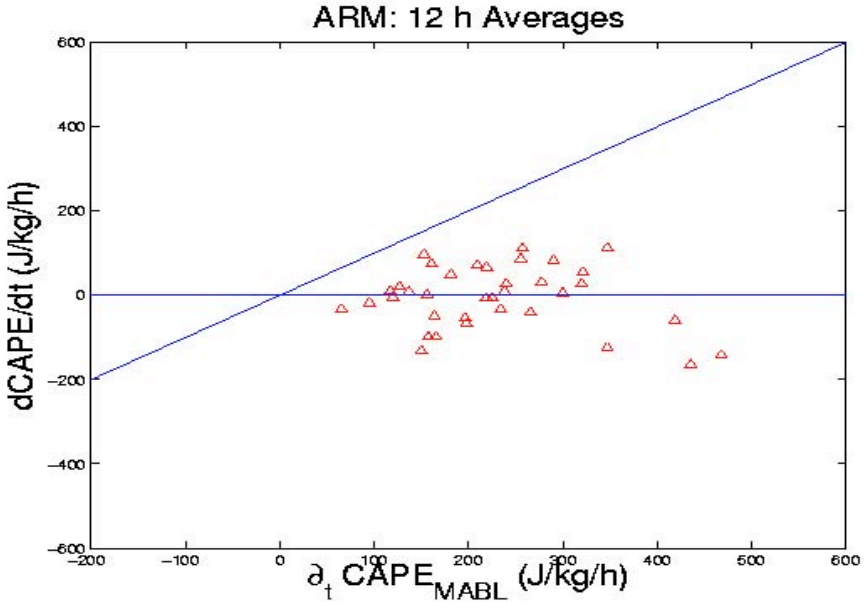

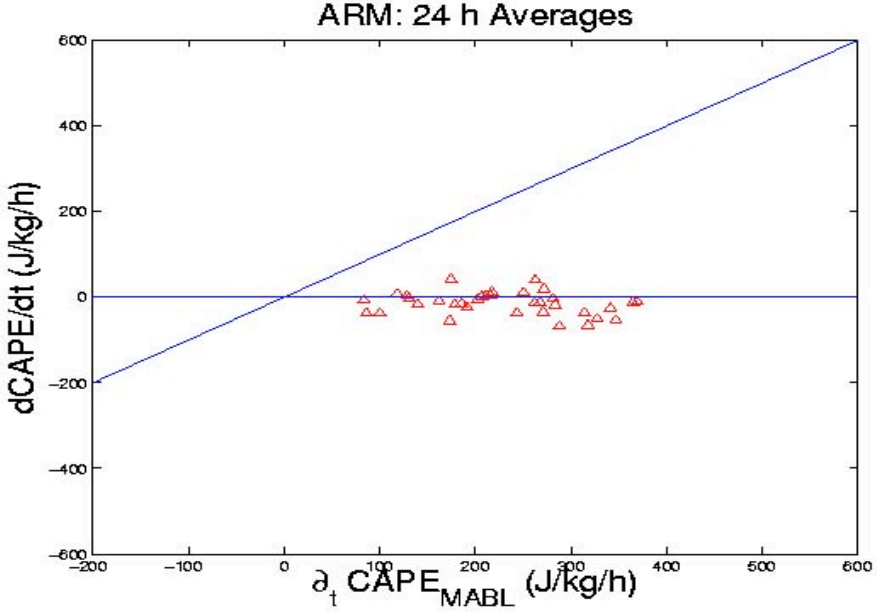

from Donner and Phillips (2003, *JGR*) Quasi-equilibrium closure

Evaluating Parameterizations: Compare with New Observing Systems and Tracer Distributions

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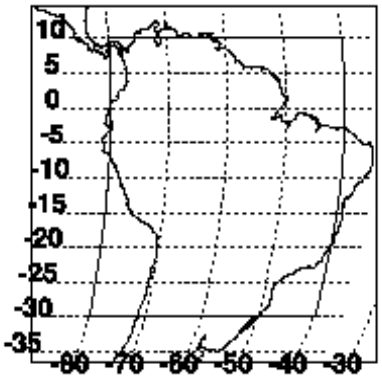
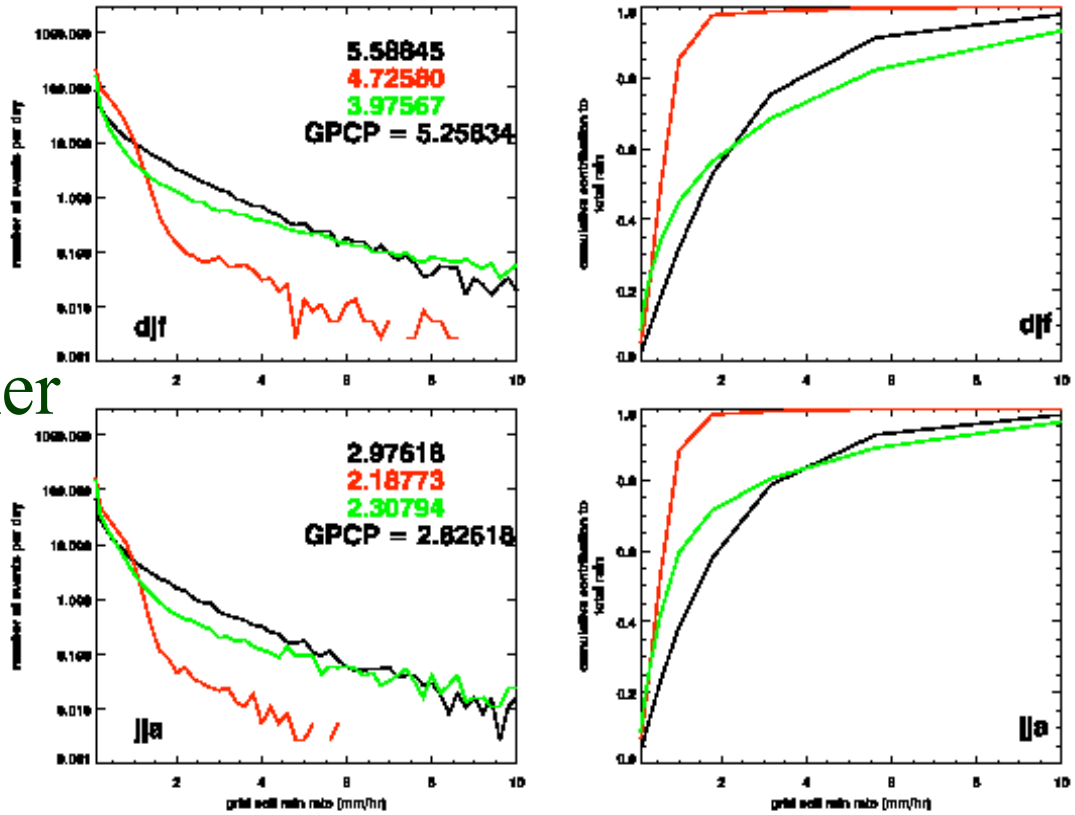
Intensity Distribution of Precipitation Events



Black: SSMI

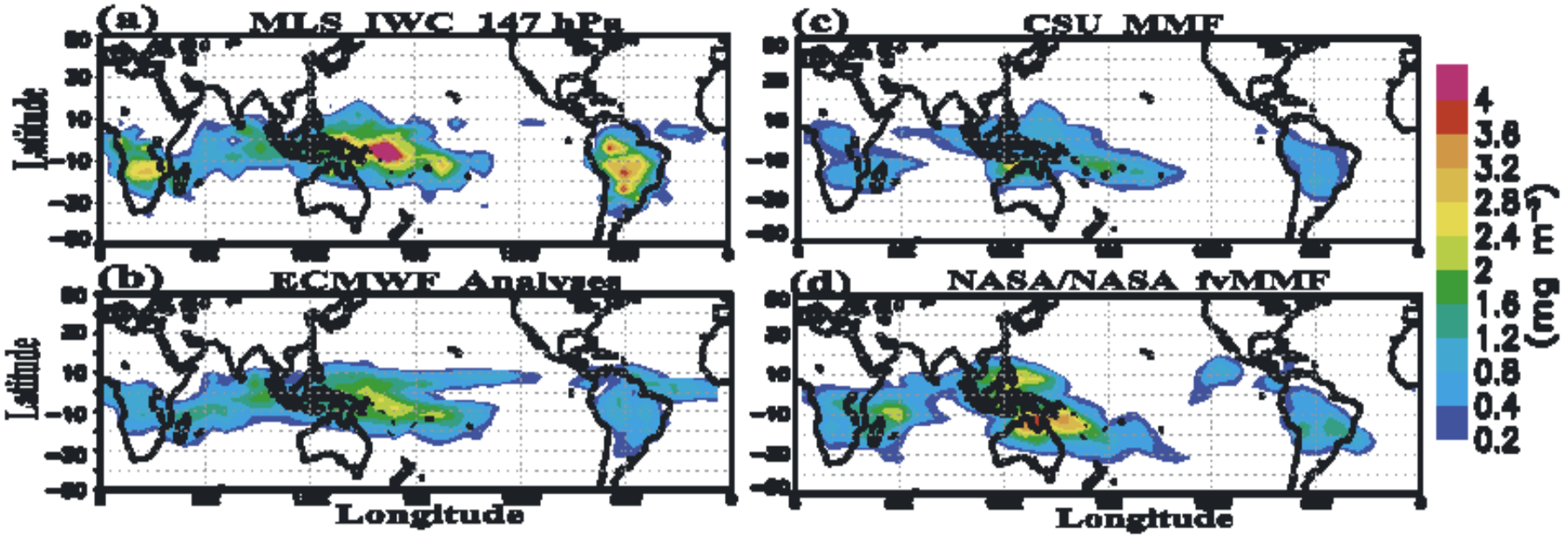
Red: RAS

Green: Donner

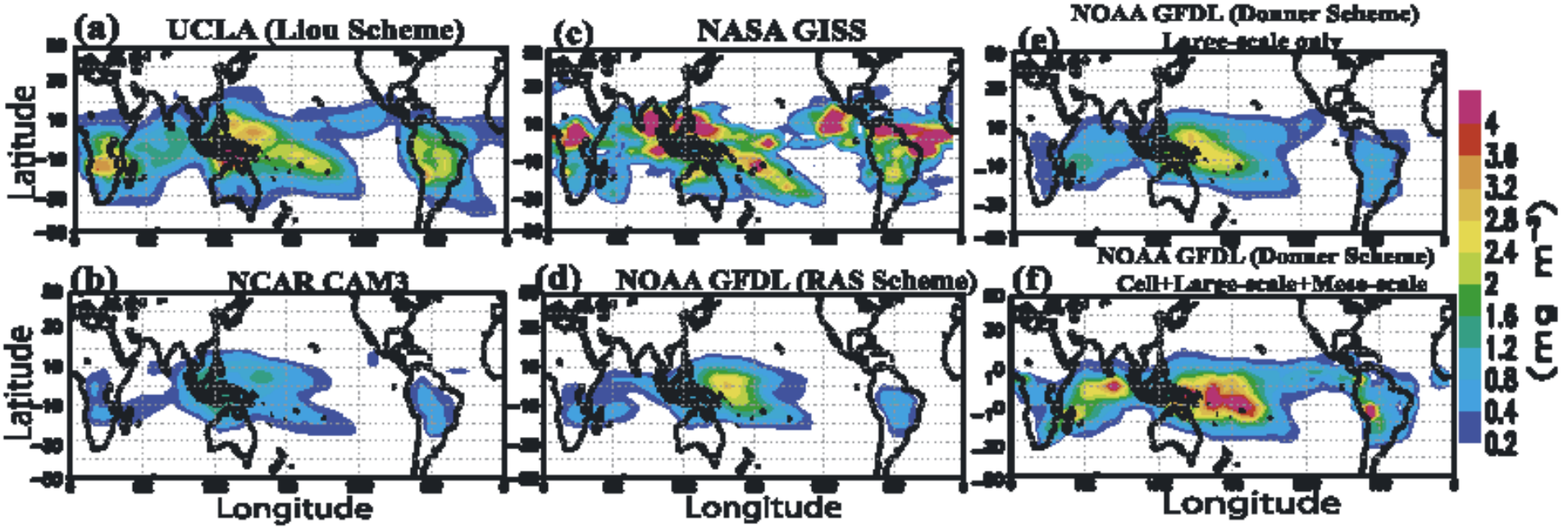


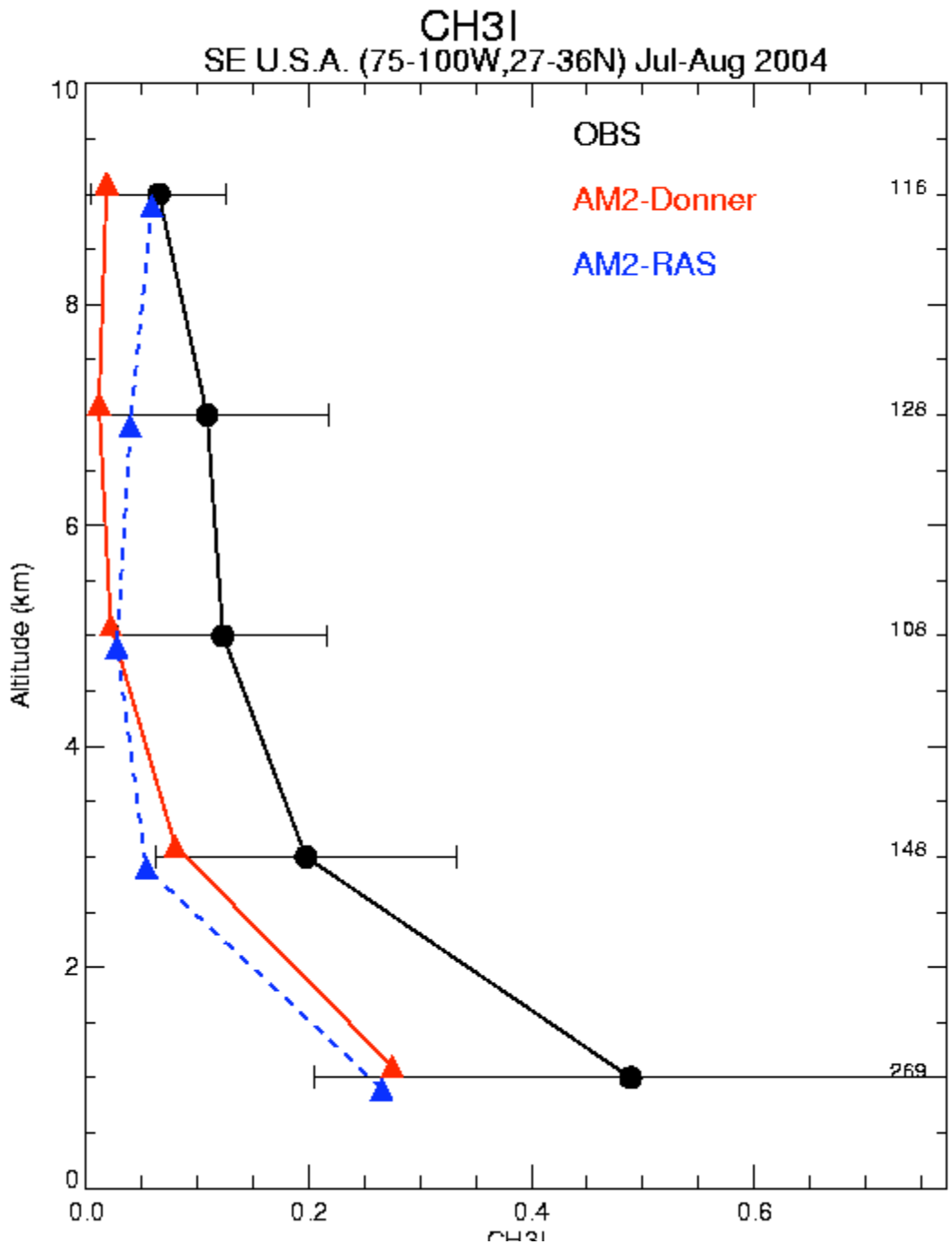
Wilcox and Donner (2006, ***J. Climate***)

January 2005 Ice Water Contents:
Microwave Sounder,
Analysis, and Multi-Model Framework
(Li *et al., GRL,* 2005)



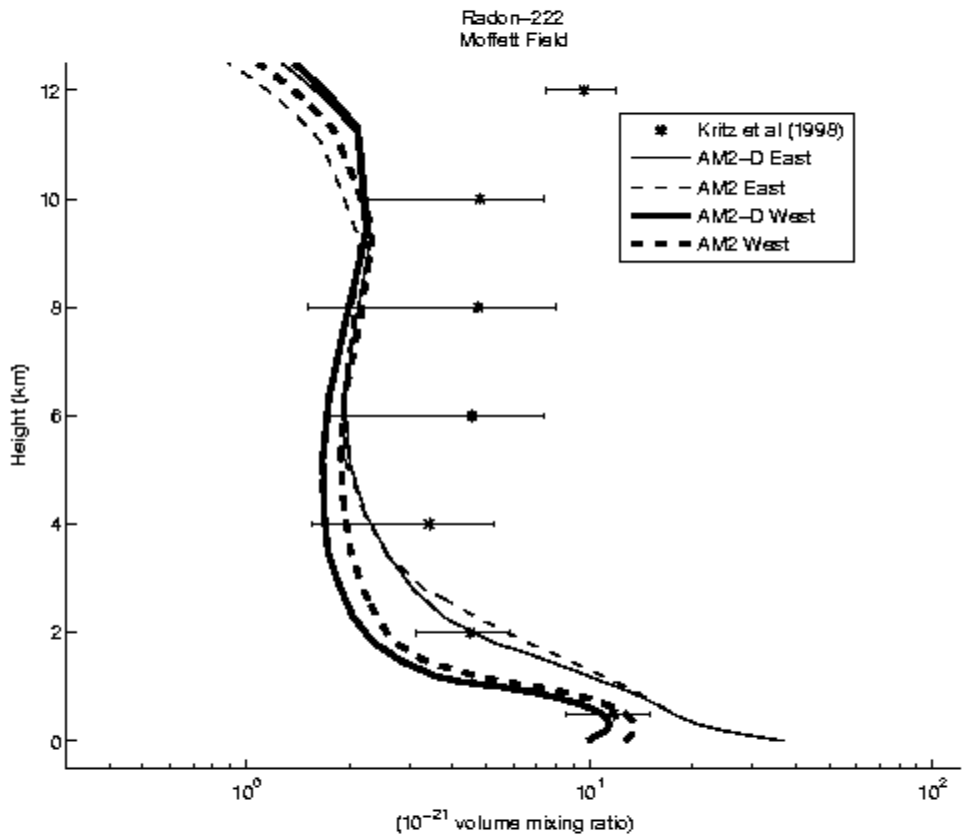
January 2005 Ice Water Contents: GCMs
(Li *et al., GRL,* 2005)




CH3I
SE U.S.A. (75-100W,27-36N) Jul-Aug 2004
OBS
AM2-Donner
AM2-RAS
Altitude (km)
CH3I
0
2
4
6
8
10
0.0
0.2
0.4
0.6
116
128
108
148
269

Methyl Iodide Convective Index August-September

REGION	*Observed Bell et al. (2002, JGR)*	*AM2-D*	*AM2*
N. Pacific	0.22	0.21	0.37
Hawaii	0.20	0.19	0.38
Christmas I.	0.24	0.28	0.43
Fiji	0.16	0.18	0.26
Tahiti	0.23	0.21	0.26


Radon–222
Moffett Field
Kritz et al (1998)
AM2–D East
AM2 East
AM2–D West
AM2 West
Height (km)
0
2
4
6
8
10
12
10^0
10^1
10^2
(10^{-21} volume mixing ratio)

Summary

- Most of the traditional demands of cumulus parameterization remain, along with many new challenges.
- MMF/Super-parameterization and classical parameterization development both can provide w PDFs for microphysics.
- Evaluation requires careful evaluation of process models against field observations and microphysical theory.
- Evaluation requires comparison with new observations-chemical, satellite, new interpretations of field data.

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