Convective Vertical Velocities in GFDL AM3, Cloud Resolving Models, and Radar Retrievals

Leo Donner and Will Cooke
GFDL/NOAA, Princeton University

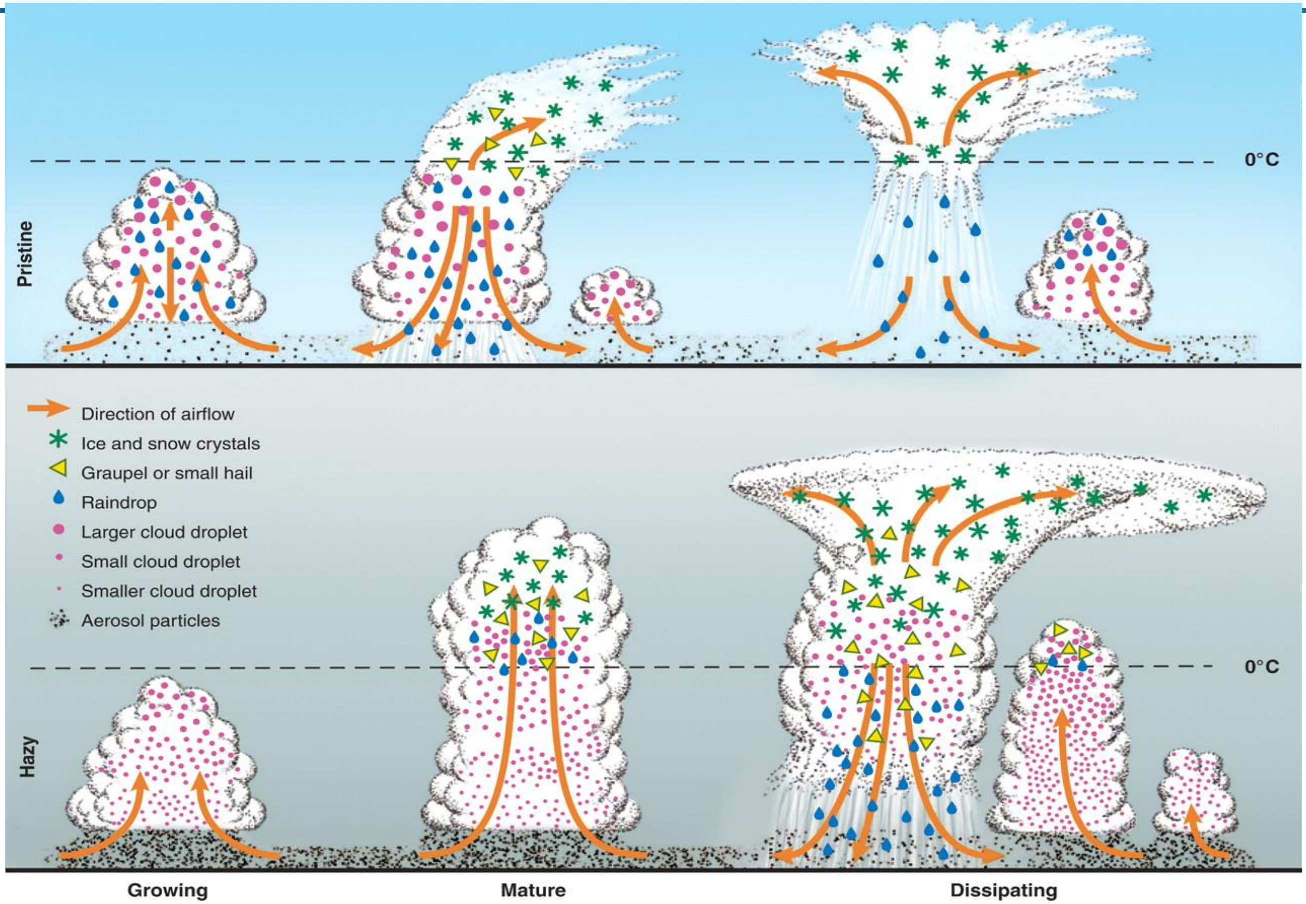
DOE ASR Meeting, Potomac, MD, 10-13 March 2013

Motivation and Approach

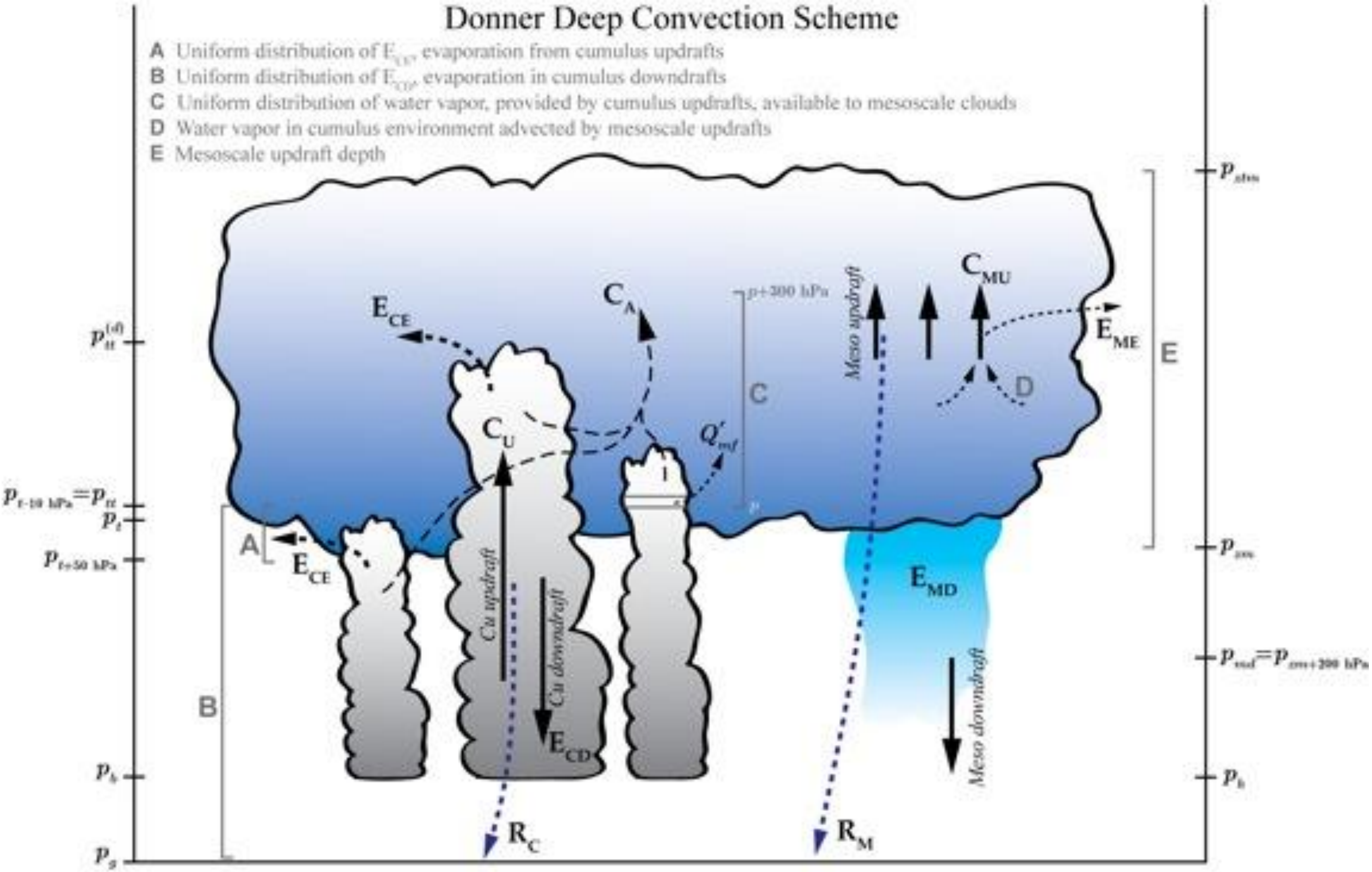
- Cloud-resolving models (CRMs) simulate processes whose representation in climate models is essential for understanding climate and climate change.
- Current CRMs struggle to represent cloud-system properties essential for understanding climate, for example, cloud updraft vertical velocities, *w.*
- Appropriate CRM resolution and sub-grid parameterizations are essential to removing current limitations on CRMs as an essential tool in understanding climate and climate change.

Cloud updraft speeds are important controls on cloud-aerosol interactions and an emerging important element in cumulus parameterizations for climate models. Sherwood *et al.* (2013, *Nature*) found convective mixing to be an important control on climate sensitivity. GCM parameter studies show convective entrainment to be an important control on climate sensitivity (Stainforth *et al.,* 2005, *Nature*; Sanderson *et al.,* 2010, *Climate Dynamics*; Zhao, 2014, *J. Climate*).

Aerosol Invigoration of Deep Convection

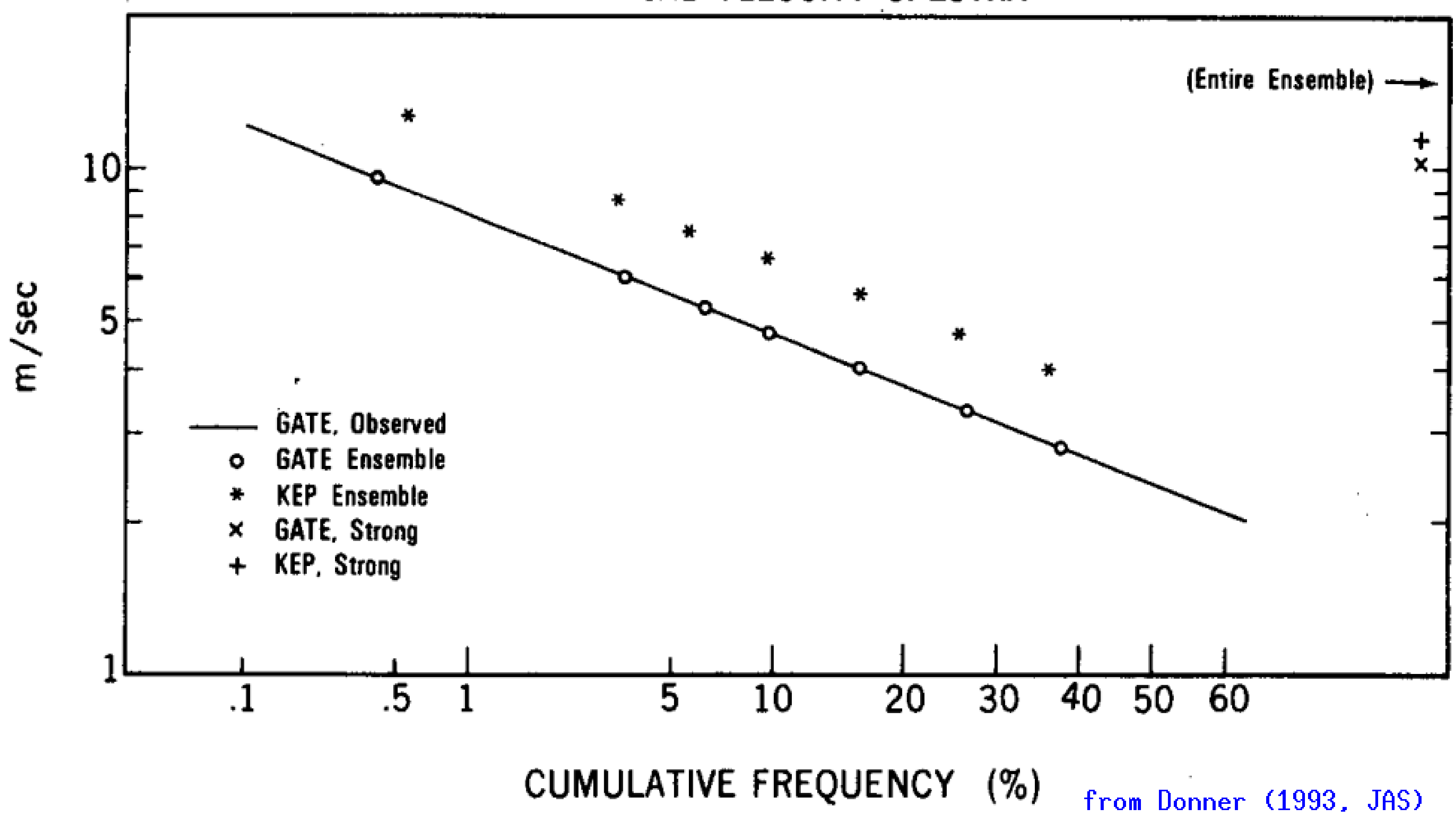


from Rosenfeld *et al.* (2008, *Science*)



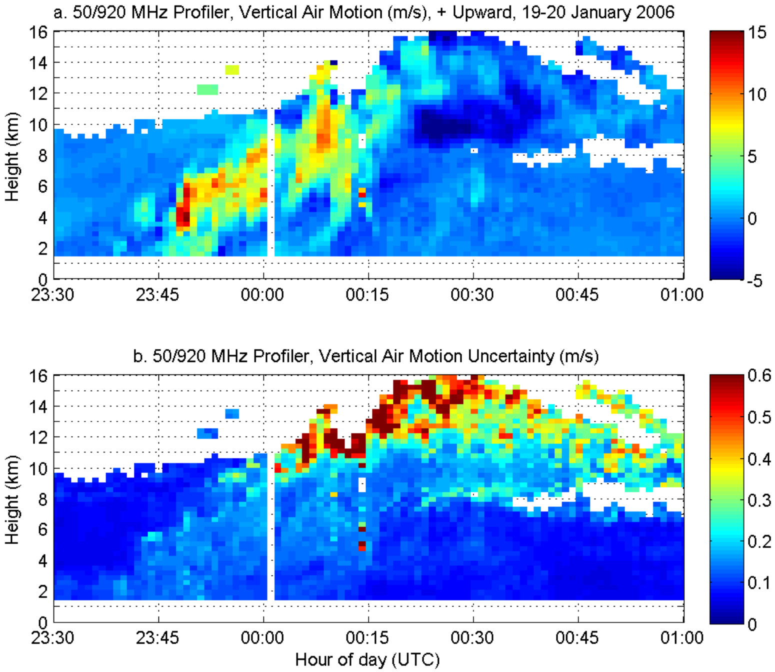
from Benedict *et al.* (2013, *J. Climate*)

VERTICAL-VELOCITY SPECTRA



from Donner (1993, JAS)

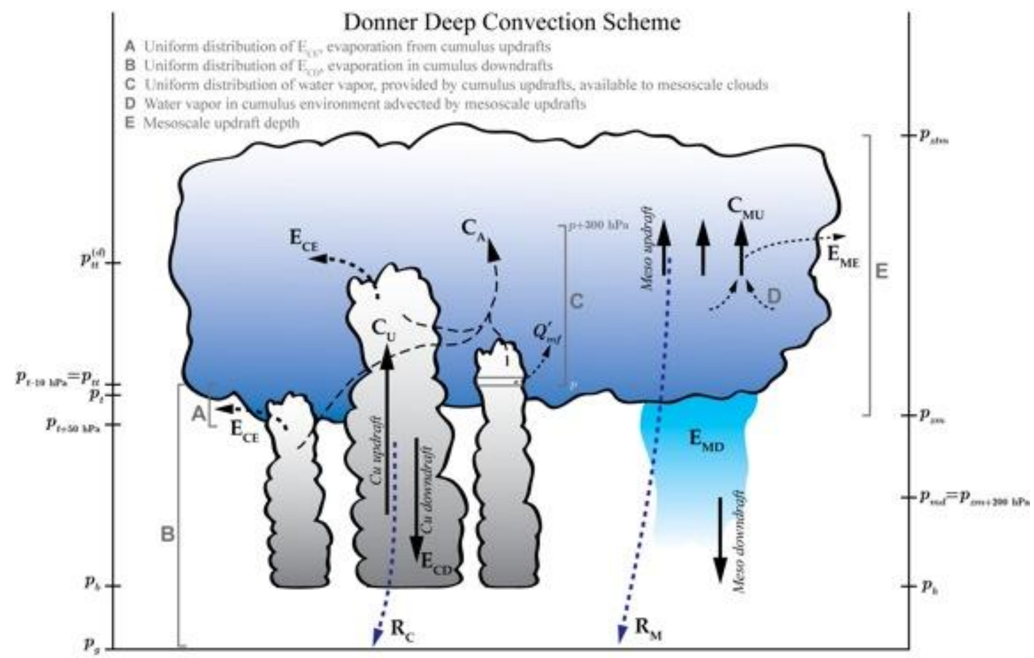
Until recently, observations of convective vertical velocities have been extremely limited, precluding evaluation of either parameterized values for climate models or CRMs. New radar observations of vertical velocity (e.g., Collis *et al.*, 2013, *J. Appl. Meteor. Climatol.*) are providing important new constraints on both. “Validated” CRMs can be used to guide further parameterization development.



fom Collis *et al.* (2013, *J. Appl. Meteor. Climatol.*)

Convective vertical velocities from radar show general structural agreement with AM3 deep convection parameterization (multiple deep updrafts with large vertical velocities, mesoscale updraft with lower vertical velocities, mesoscale downdraft).

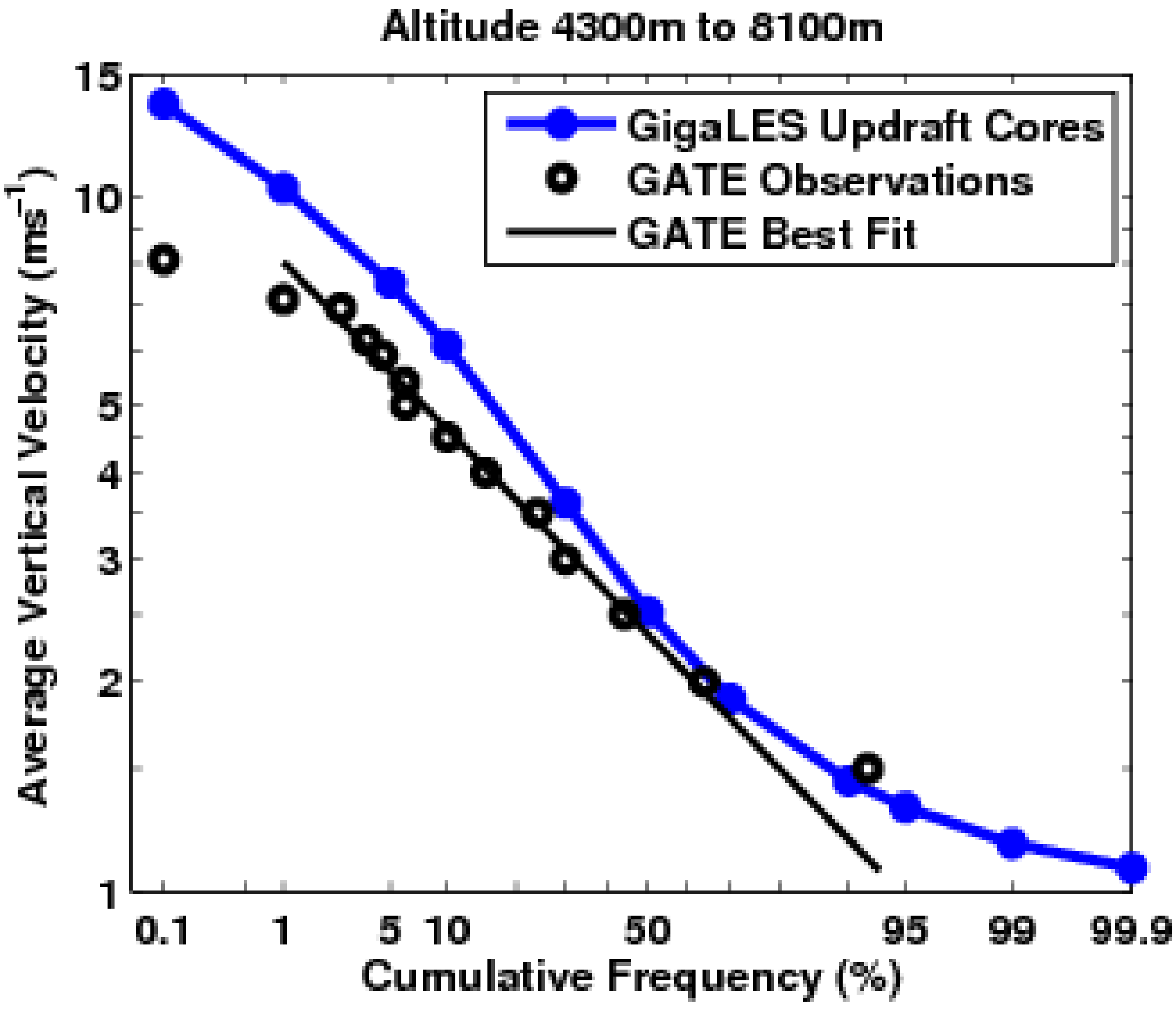
Quantitative assessment of parameterized vertical velocity PDFs using radar observations is an urgent priority.



from Benedict *et al.* (2013, *J. Climate*)

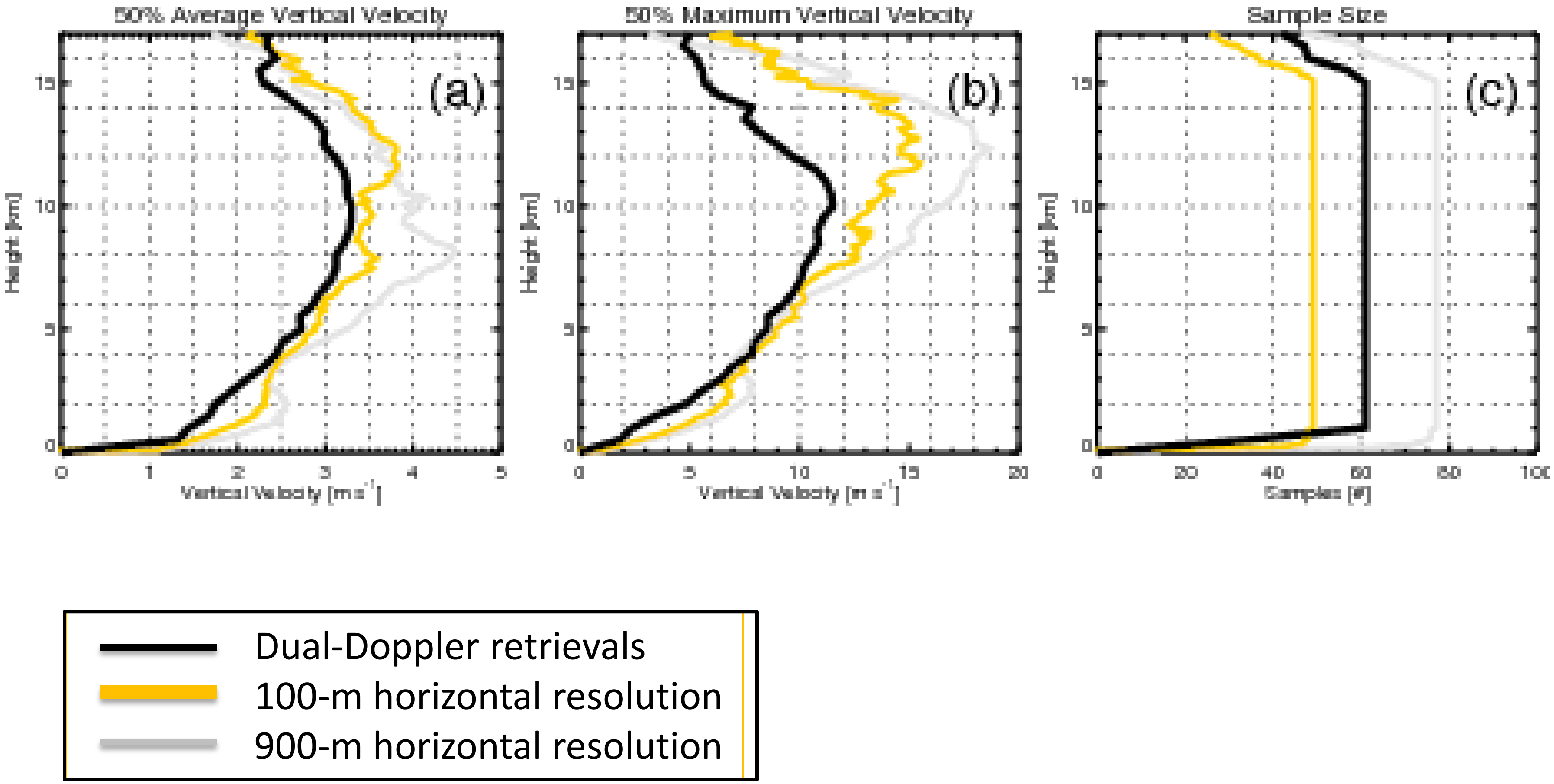
Realism of vertical velocities in current CRMs can be limited by resolution and their treatments of sub-grid turbulence and microphysics. Appropriate treatments of sub-grid processes in CRMs offer prospect of realistic simulation of vertical velocities.

100-m horizontal resolution *w* PDFs from giga-LES agree reasonably well with observations.

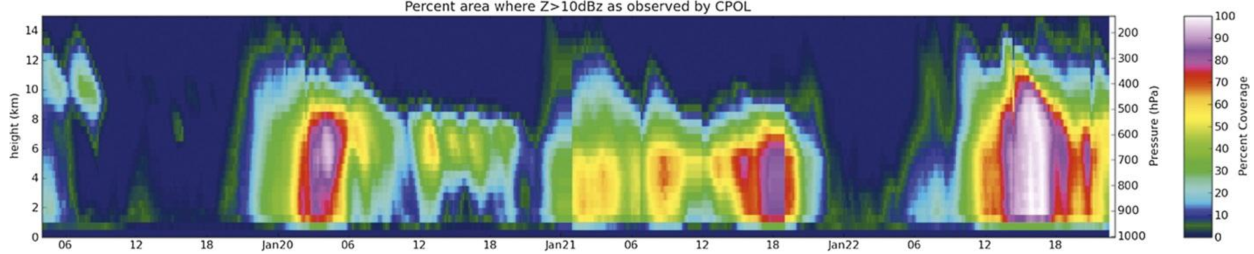


Analysis by Ian Glenn and Steve Krueger, University of Utah

TWP-ICE, 23 January 2006: Vertical Velocities from DHARMA CRM with Double-Moment Microphysics



DHARMA integrations by Ann Fridlind, NASA GISS
Analysis by Adam Varble, University of Utah



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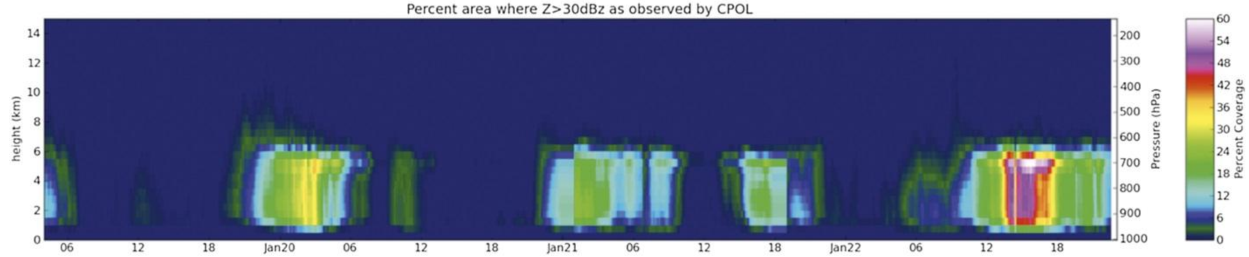
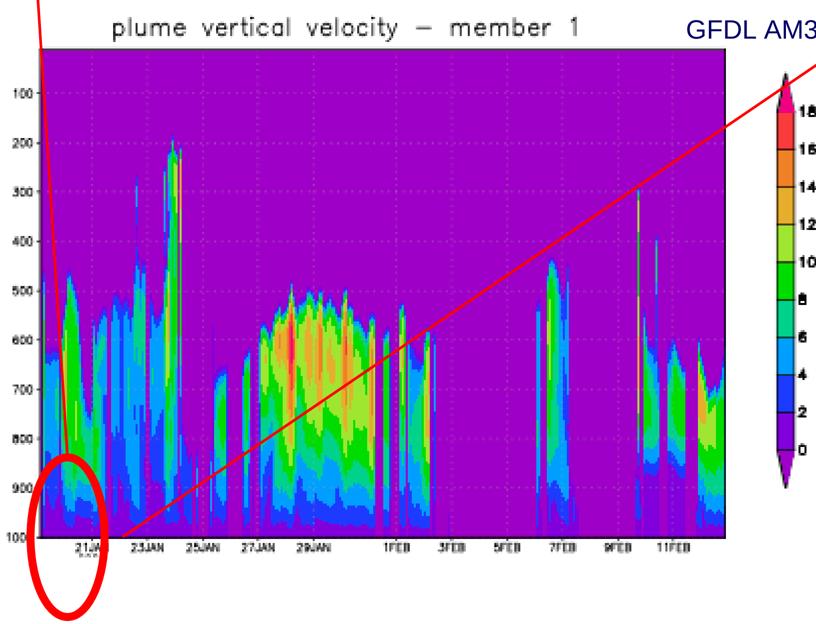
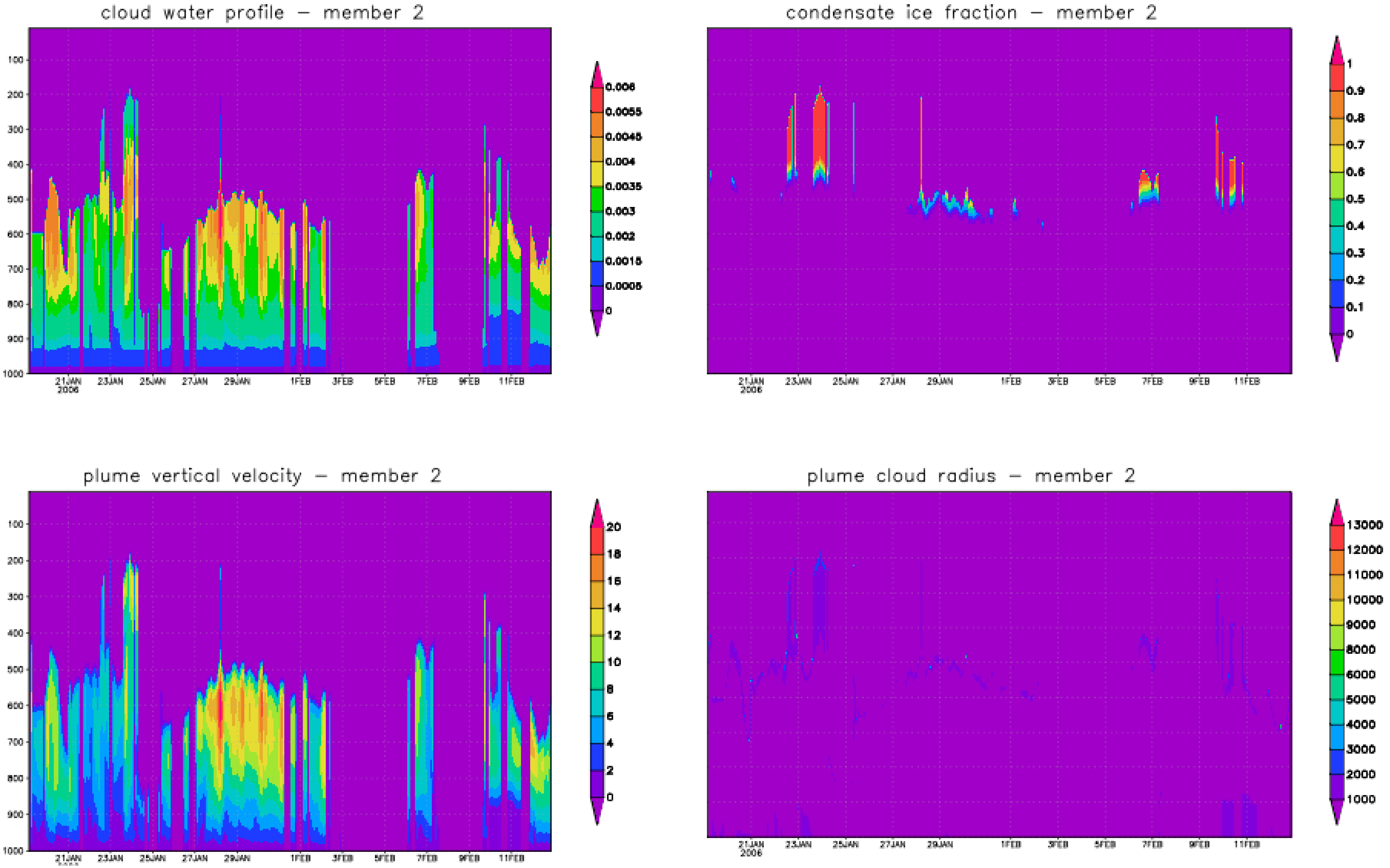


b

From Collis *et al.* (2013, *J. Appl. Meteor. and Climatol.)*



TWP ICE


cloud water profile – member 2
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0.0045
0.004
0.0035
0.003
0.002
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0.0005
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condensate ice fraction – member 2
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0.8
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0.6
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plume vertical velocity – member 2
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plume cloud radius – member 2
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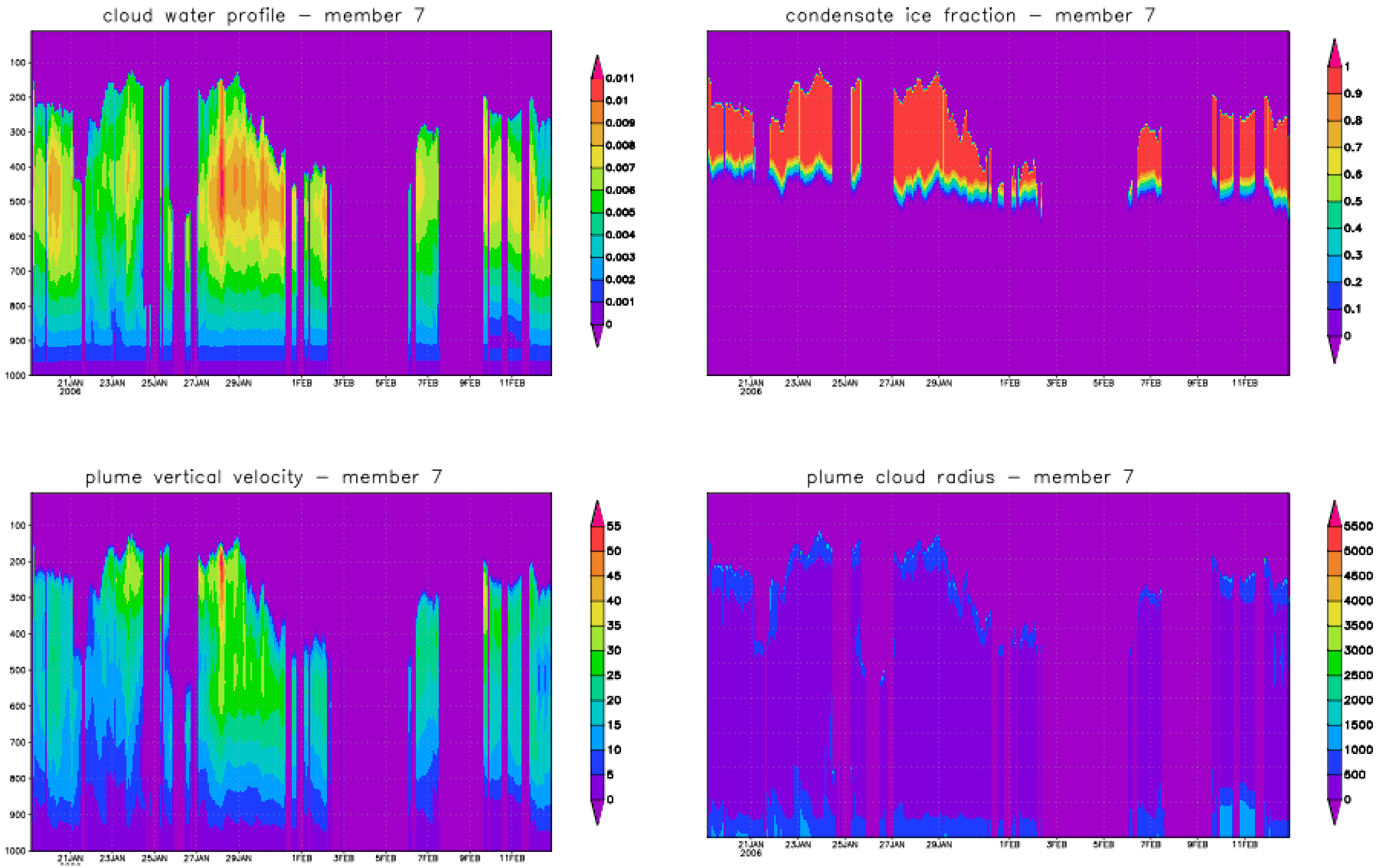

cloud water profile – member 7
condensate ice fraction – member 7
plume vertical velocity – member 7
plume cloud radius – member 7
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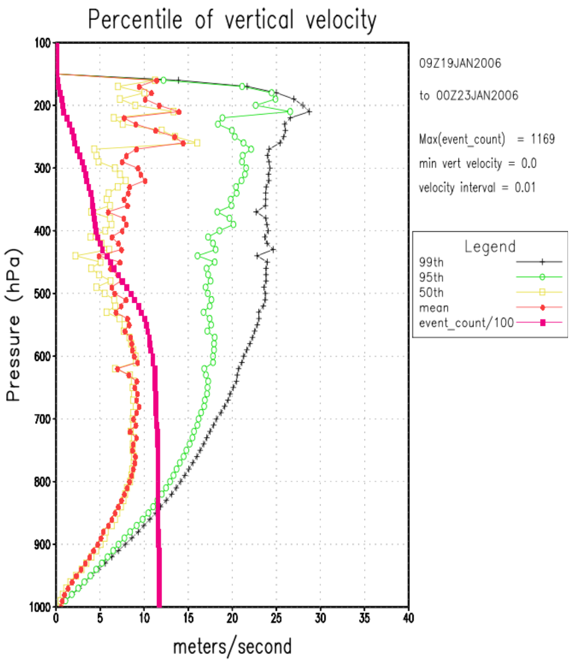
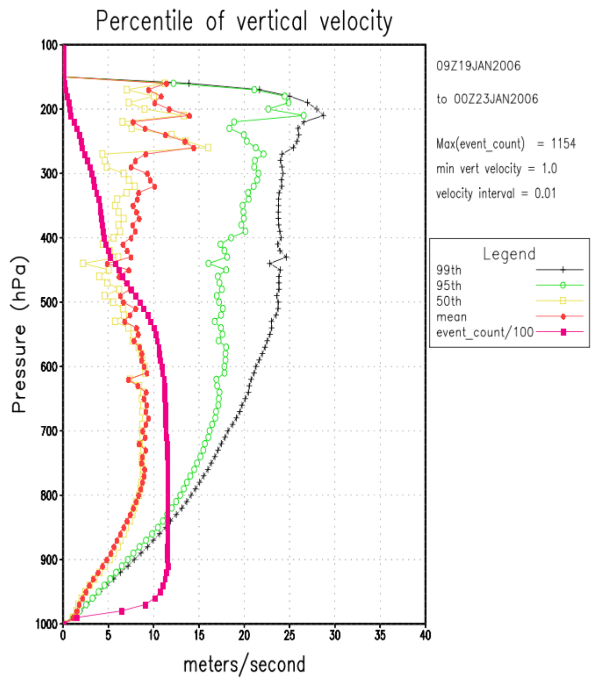
TWP ICE

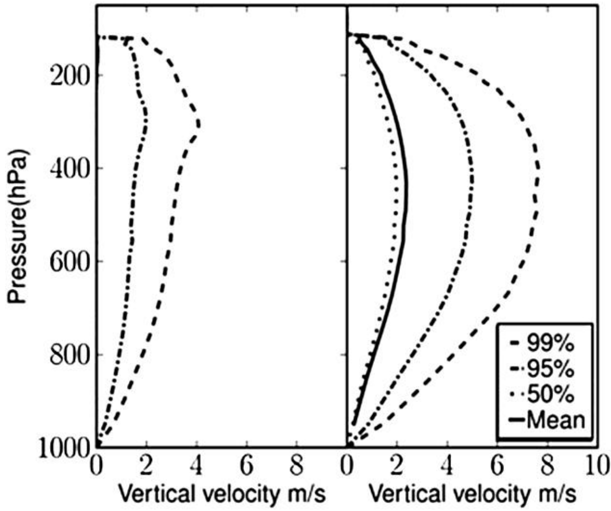
AM3

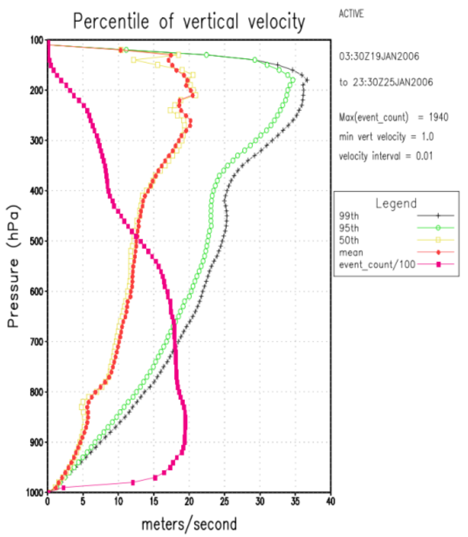


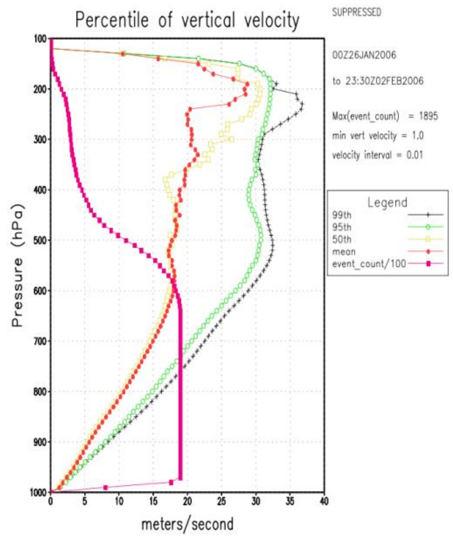
AM3

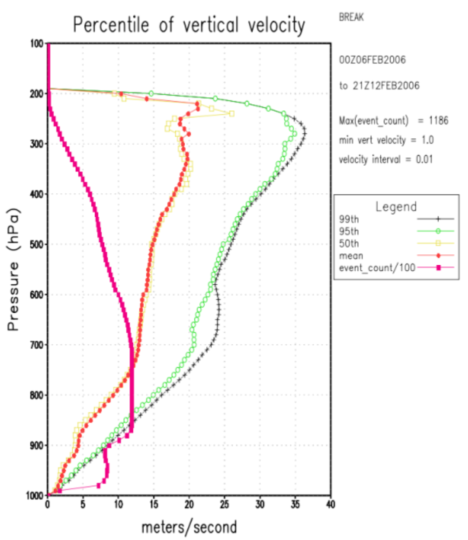


From Collis *et al.* (2013, *J. Appl. Meteor. and Climatol.*)



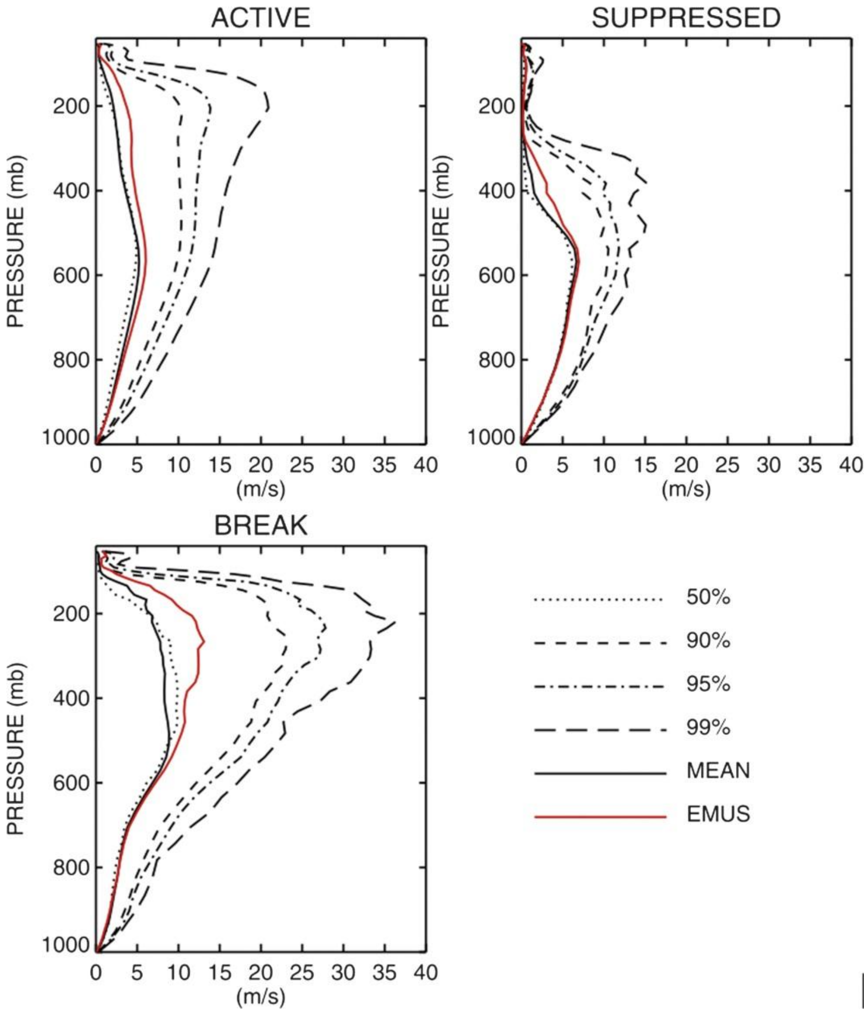






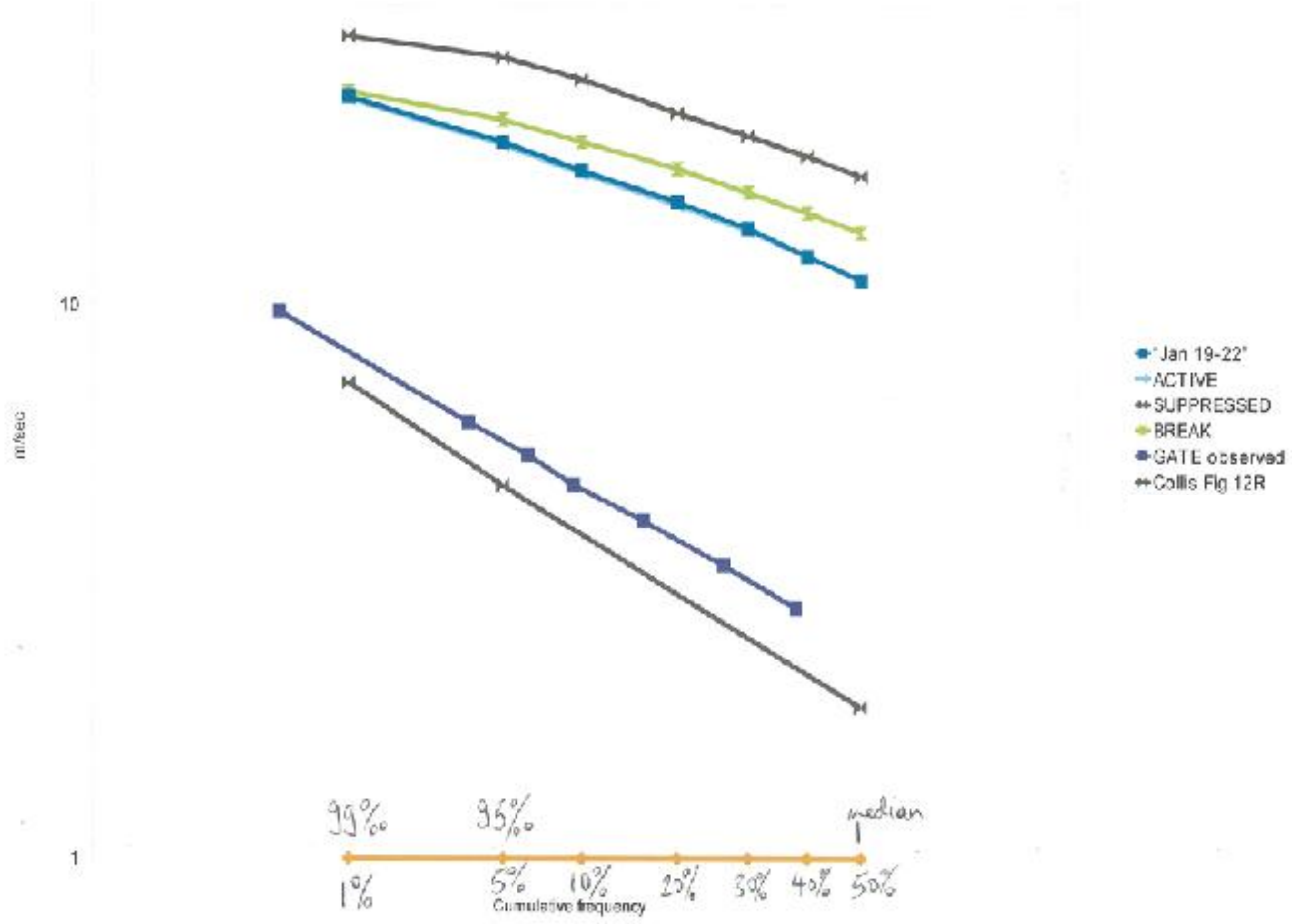
AM3

TWP ICE



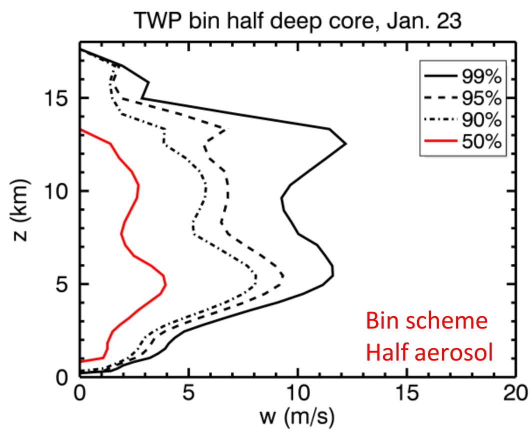
from Xu *et al.* (2009, *J. Geophys. Res.*)

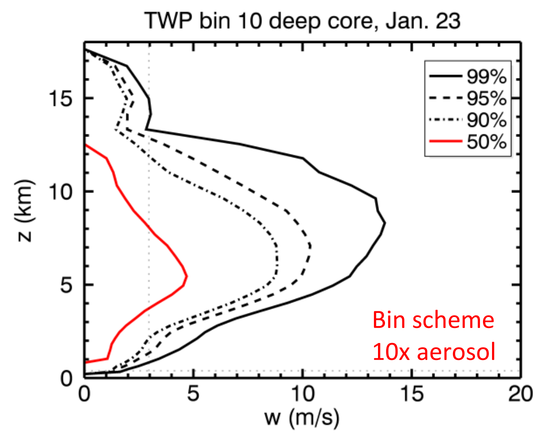
Vertical Velocity PDFs for Deep Convective Cores

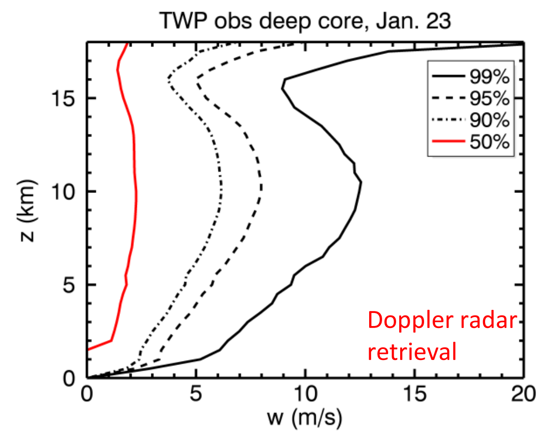


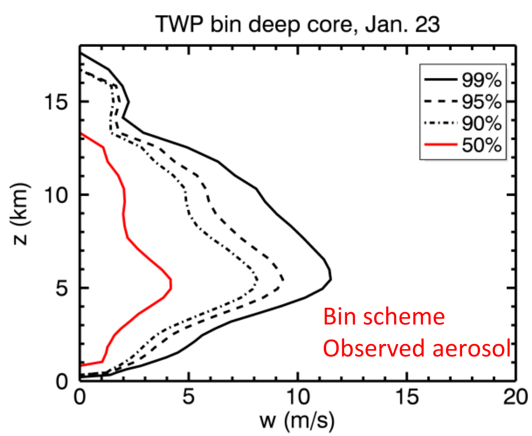
Vertical Velocity in Convective Cores: Sensitivities to Aerosol and Microphysics

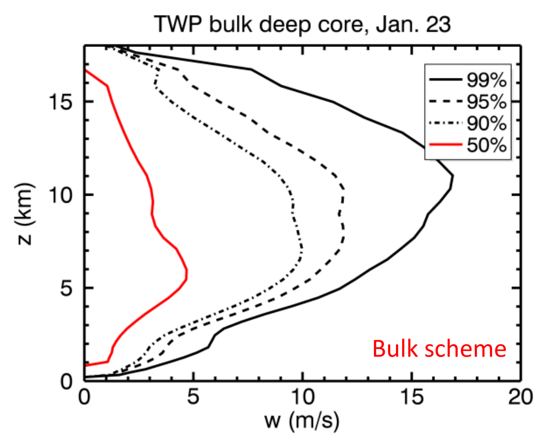
TWP-ICE case study











A convective core is defined as a column where w exceeds 1m/s for at least 4 km continuously.

By Xiaowen Li and Wei-Kuo Tao, NASA GSFC

CRM integrations by Jiwen Fan also show vertical velocities can depend on bin vs. bulk treatment, with stronger vertical velocities with bulk microphysics.
Pete Bogenschutz and Steve Krueger have found strong dependence on treatment of sub-grid turbulence in CRMs.

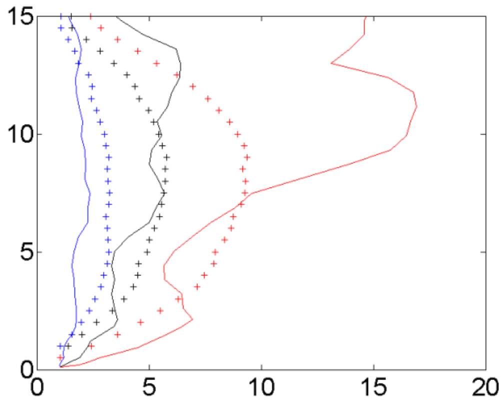
Conclusions

- GCM parameterization for vertical velocity PDF in deep convection has been developed, critical for microphysics, radiation, CAPI in deep convection.
- Convective parameterization likely to remain important even in high-resolution (10 km horizontal), cf., Arakawa and Wu (2013, *J. Atmos. Sci.*).
- CRMs and LES provide climate-critical cloud properties and could serve as references to guide climate-model development, if confidence sufficient in CRMs and LES.
- Basic climate-critical properties of state-of-science CRMs and LES depend on their resolution and sub-grid parameterizations, especially microphysics and turbulence.
- New observations promise guidance in CRM and LES development.
- Activity centered on reducing discrepancies between CRMs, LES, and observations recommended, would also provide guidance for dealing with similar issues in GCM representation of PDFs of vertical velocity.

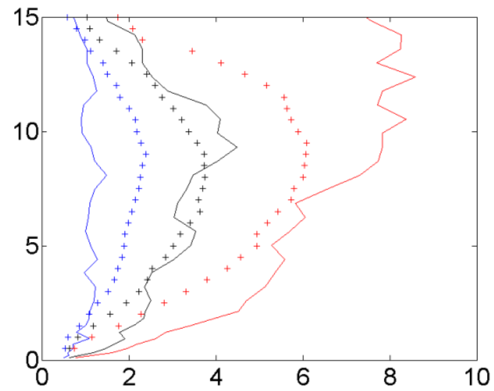
TWP-ICE

0600 UTC ~ 2300 UTC January 22 (Event B)

Percentiles of all W> 1 m/s in convective cores



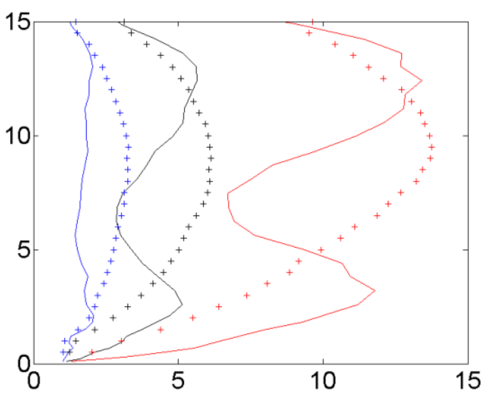
Percentiles of averaged w with W> 0.5 m/s over the radar domain



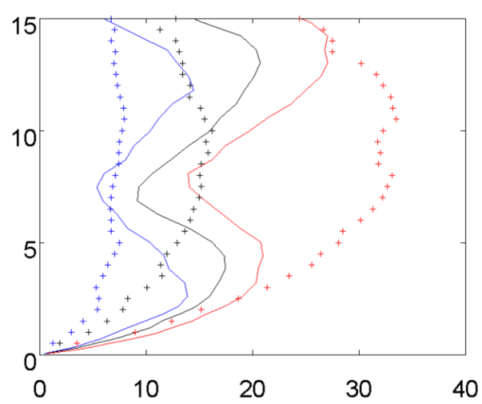
- Case Dependence: CRM vertical velocities (solid) vs. Doppler retrieval (crosses)

1310 UTC ~ 1750 UTC January 23 (Event C)

Percentiles of all W> 1 m/s in convective cores



Percentiles of the averaged max w over the radar domain



- This model, with bin microphysics, under-estimates Doppler velocities. DHARMA model, with bulk microphysics, over-estimated vertical velocities.
- Analysis by Jiwen Fan (PNNL).