Convective Updraft Speeds: A Correlate to Climate Sensitivity?

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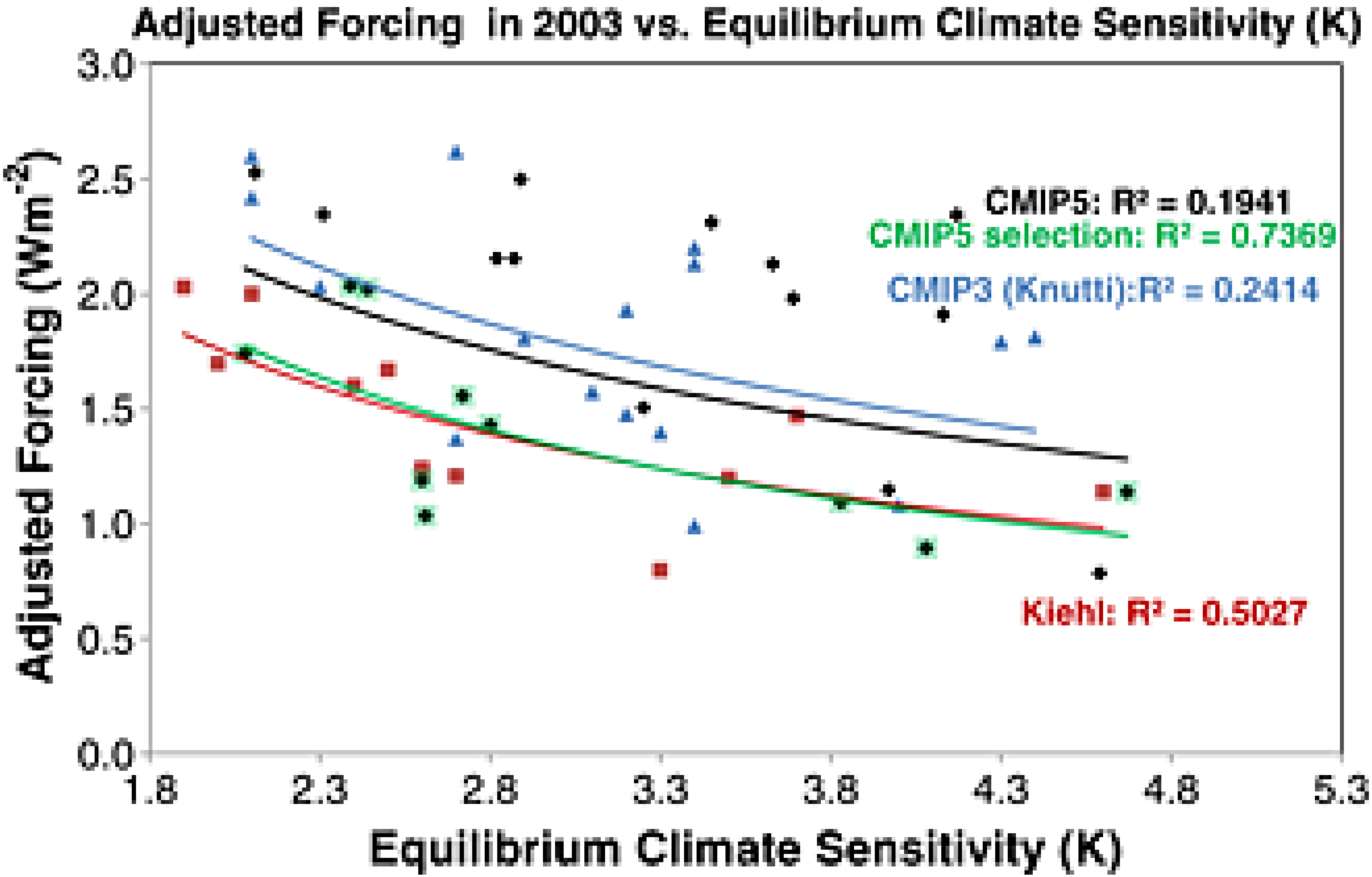
GEWEX, CUNY, 28 March 2017

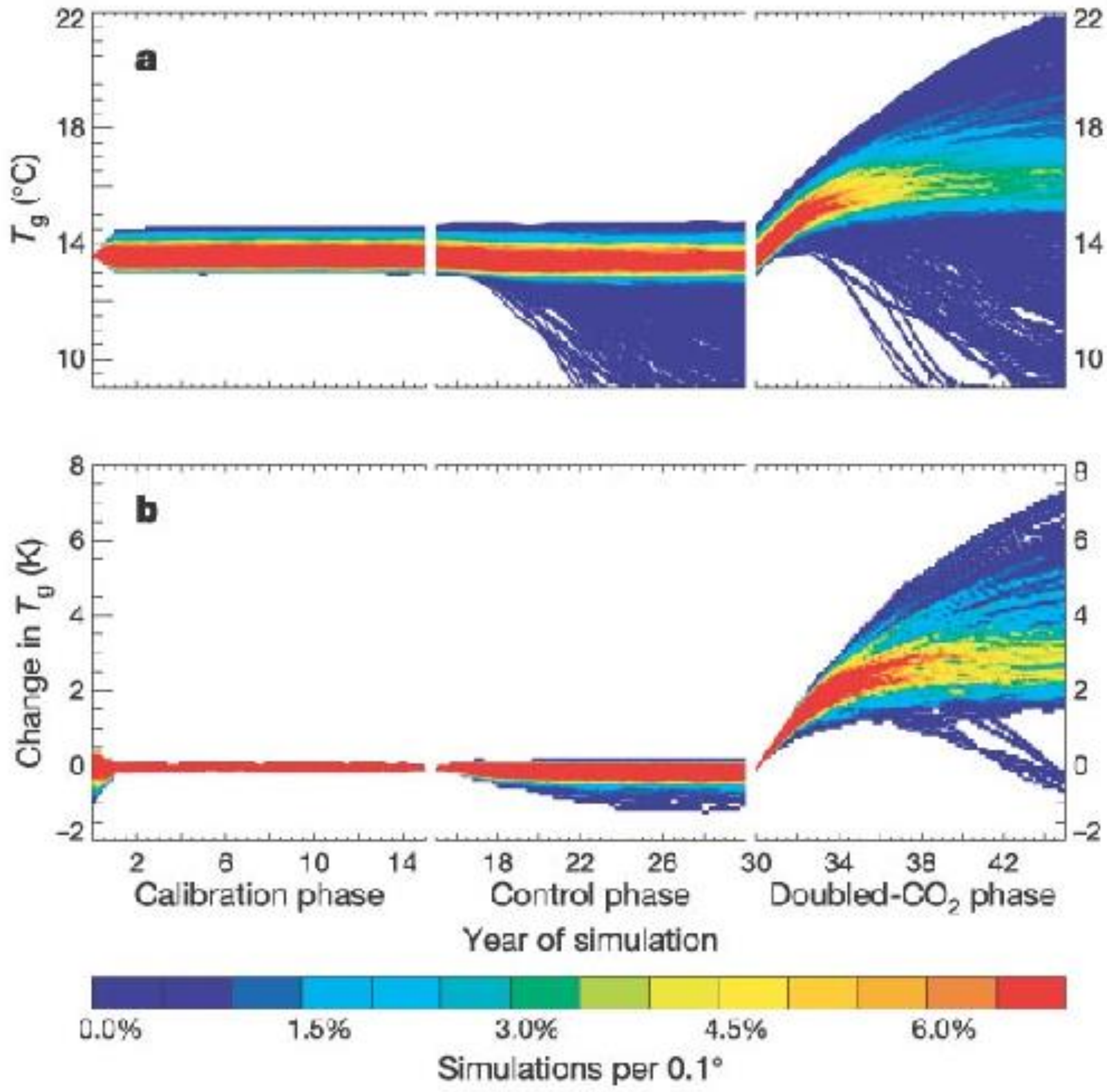
Uncertainties in anthropogenic climate forcing and sensitivity persist, limiting understanding of past climate change and future projections.



From Forster et al. in **Journal of Geophysical Research: Atmospheres**
Volume 118, Issue 3, pages 1139-1150, 6 FEB 2013 DOI: 10.1002/jgrd.50174
http://onlinelibrary.wiley.com/doi/10.1002/jgrd.50174/full#jgrd50174-fig-0007

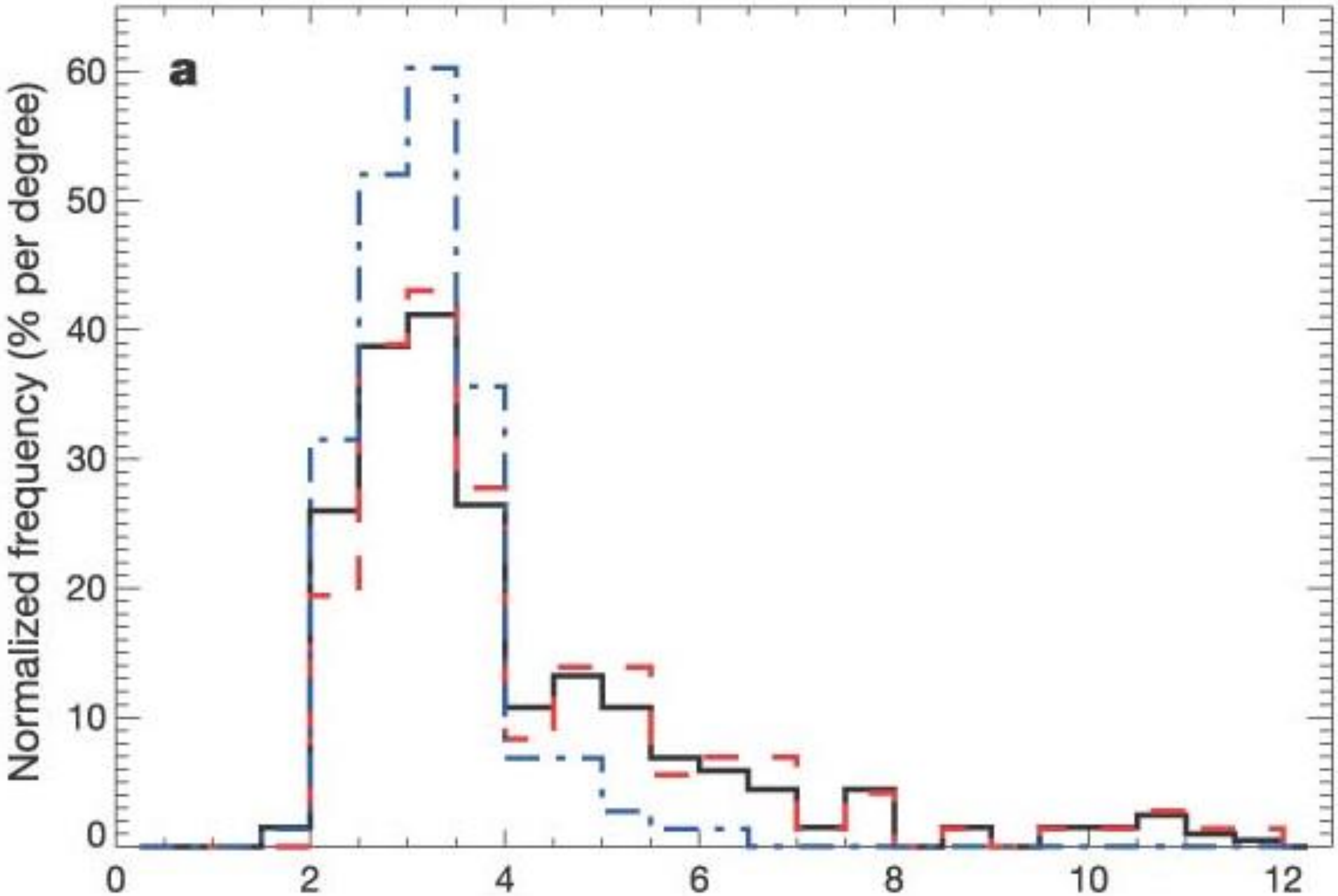
Perturbed physics studies with multiple climate models suggest convective entrainment is an important control on climate sensitivity.

Parameteric Control on Simulations without Cloud-Aerosol Interactions



From Stainforth *et al*. (2005, *Nature*)

Hadley Centre model



Global-mean temperature increase due to CO_2 doubling

from Stainforth *et al*. (2005, *Nature*) Blue: No Entrainment Variation
Red: No Autoconversion Variation

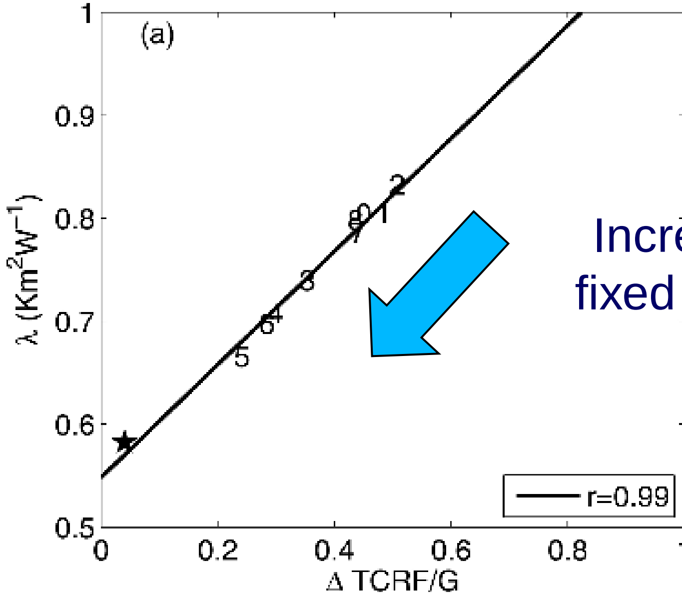
Hadley Centre model

Dependence of Climate Sensitivity on Convective Entrainment (Zhao, 2014, *J. Climate*)

jcl

GFDL model

Climate Sensitivity



Increasing Entrainment for fixed precipitation threshold, except for Exp. 2

Change in Cloud-Radiative Effect, Normalized by Energy-Balance Change

Climate sensitivity dependence on entrainment also shown by Stainforth *et al.* (2005, *Nature*), Sanderson *et al.* (2010, *Clim. Dyn.*), and for shallow but not deep convection, Klocke *et al.* (2011, *J. Climate*).

ECHAM5 Skill and Sensitivity Parameter Dependencies
(Klocke *et al.*, 2011, *J. Climate*)

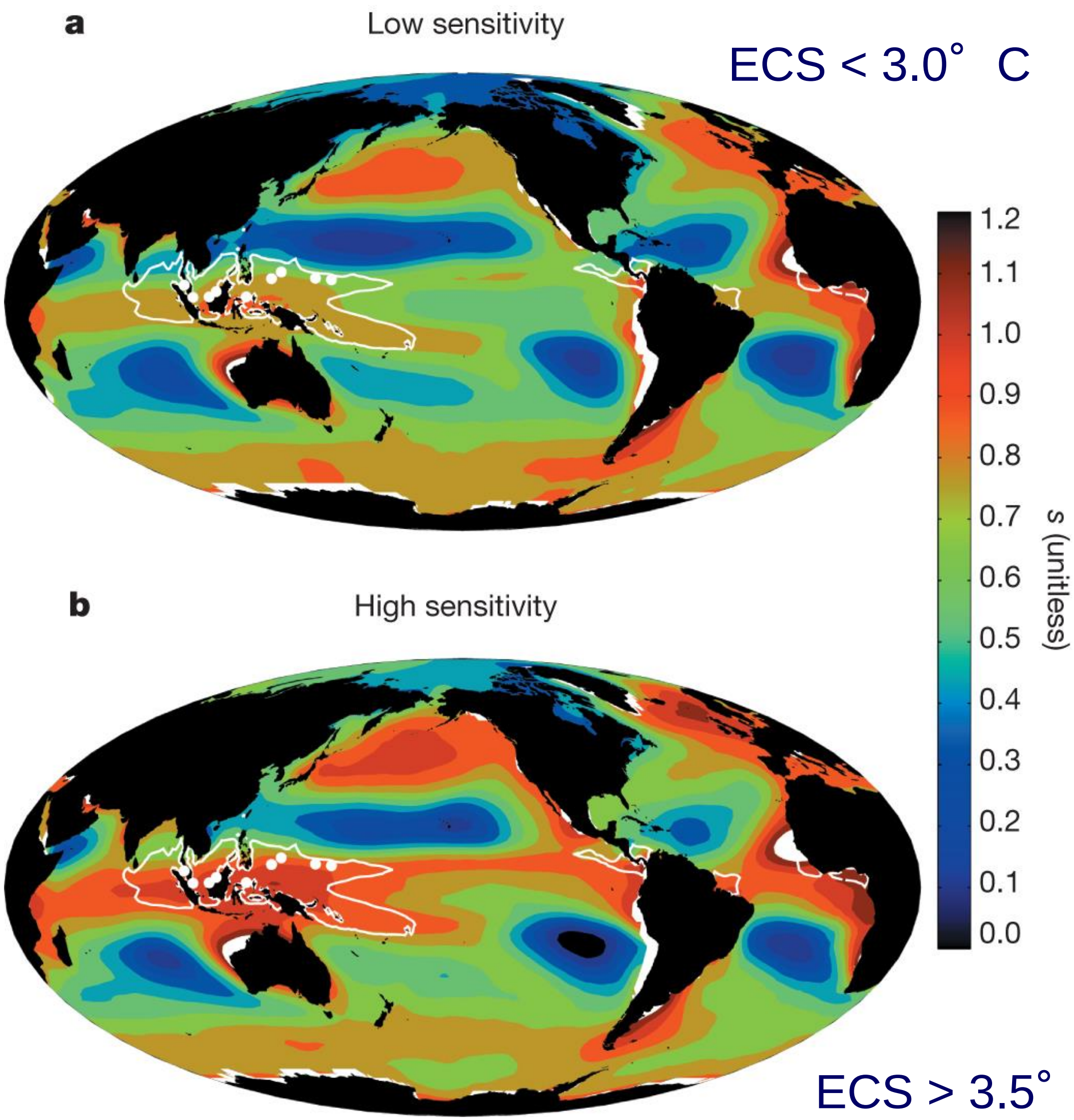
Parameter description	Default value	Range	R^2 skill (%)	R^2 sensitivity (%)
Entrainment rate for shallow convection[a] (Tiedtke 1989)	0.0003	0.0003–0.001	3	44
Cloud mass flux above level of nonbuoyancy[a] (Tiedtke 1989)	0.1[b]/0.3[c]	0.1–0.3333	3	44
Entrainment rate for penetrative convection (Tiedtke 1989)	0.0001	0.00001–0.0005	64	0
Conversion rate from cloud water to rain (Tiedtke 1989)	0.0004	0.0001–0.005	0	1
Inhomogeneity of liquid clouds (Cahalan et al. 1994)	0.7	0.65–1	4	0
Inhomogeneity of ice clouds (Cahalan et al. 1994)	0.7[b]/0.8[c]	0.65–1	20	1
Asymmetry of ice particles in clouds (Stephens et al. 1990)	0.91[b]/0.85[c]	0.75–1	0	1
Coefficient for horizontal diffusion	12	6–24	6	5
Gravity wave drag activation threshold (mean) (Lott 1999)	500	400–1000	2	0
Gravity wave drag activation threshold (std dev) (Lott 1999)	200	100–700	2	0
Albedo minimum of snow/ice	0.6/0.5	0.45–0.65	8	0
Albedo maximum of snow/ice	0.8/0.75	0.75–0.9	9	3

[a] Indicates coupled parameters, to keep top-of-atmosphere radiative fluxes close to balance.
[b] Default value in the atmosphere-only model.
[c] Default value in the coupled model.

MPI Model

Mechanisms by which entrainment in convection controls climate sensitivity are not well understood and likely model-dependent.

Multi-model mean local stratification parameter



ECS < 3.0° C

ECS > 3.5° C

Global stratification parameter *S* defined within white contours. Radiosondes at white squares.

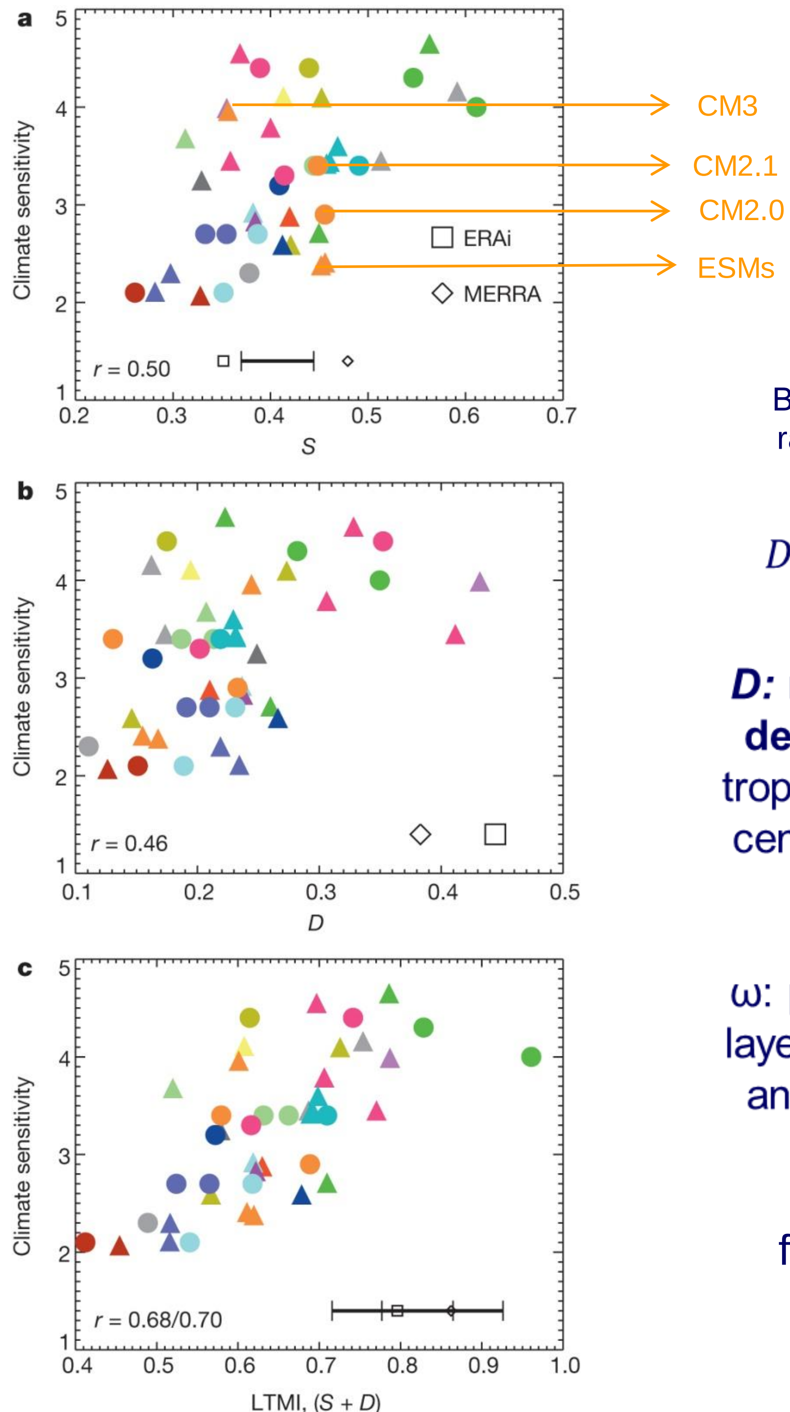
$$S = \left(\frac{\Delta RH_{700-850}}{100\%} - \frac{\Delta T_{700-850}}{9K}\right)/2$$

More Mixing at Higher *S*

from Sherwood *et al.* (2014, *Nature*)

Relation of lower-tropospheric mixing indices to ECS

LTMI explains about 50% of ECS variance



Bar indicates 2σ range of radiosonde observations

$$D = \frac{\Delta H(\Delta) H(-\omega_1)}{-\omega_2 H(-\omega_2)}$$

$$\Delta = \omega_2 - \omega_1$$

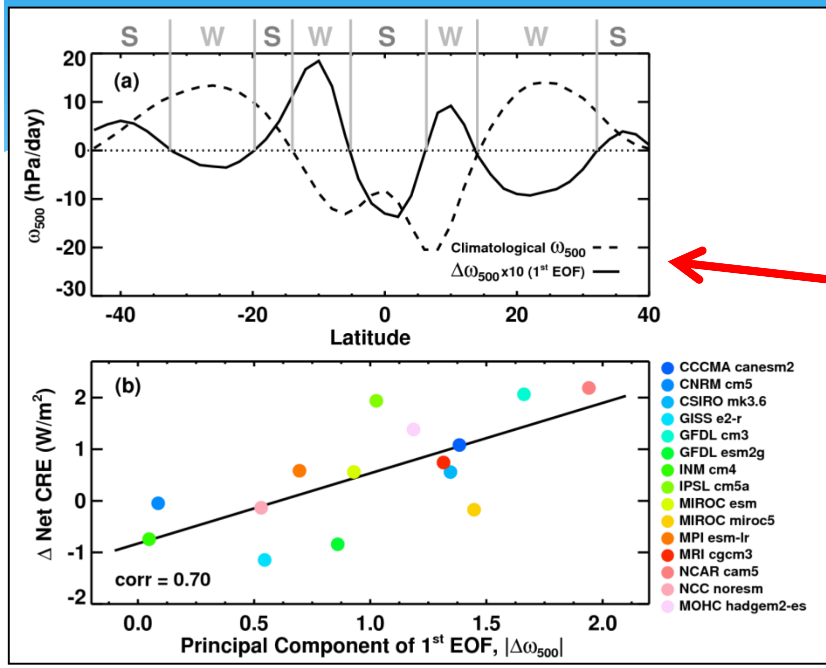
***D:* ratio of shallow to deep overturning** in tropics and sub-tropics, central Pacific through central Africa

H: step function

ω: pressure velocity in layers 2 (600-400 hPa) and 1 (800-750 hPa)

from Sherwood *et al.* (2014, *Nature*)

Quantifying the Model Differences in Circulation and Relation with Cloud Radiative Effect Changes



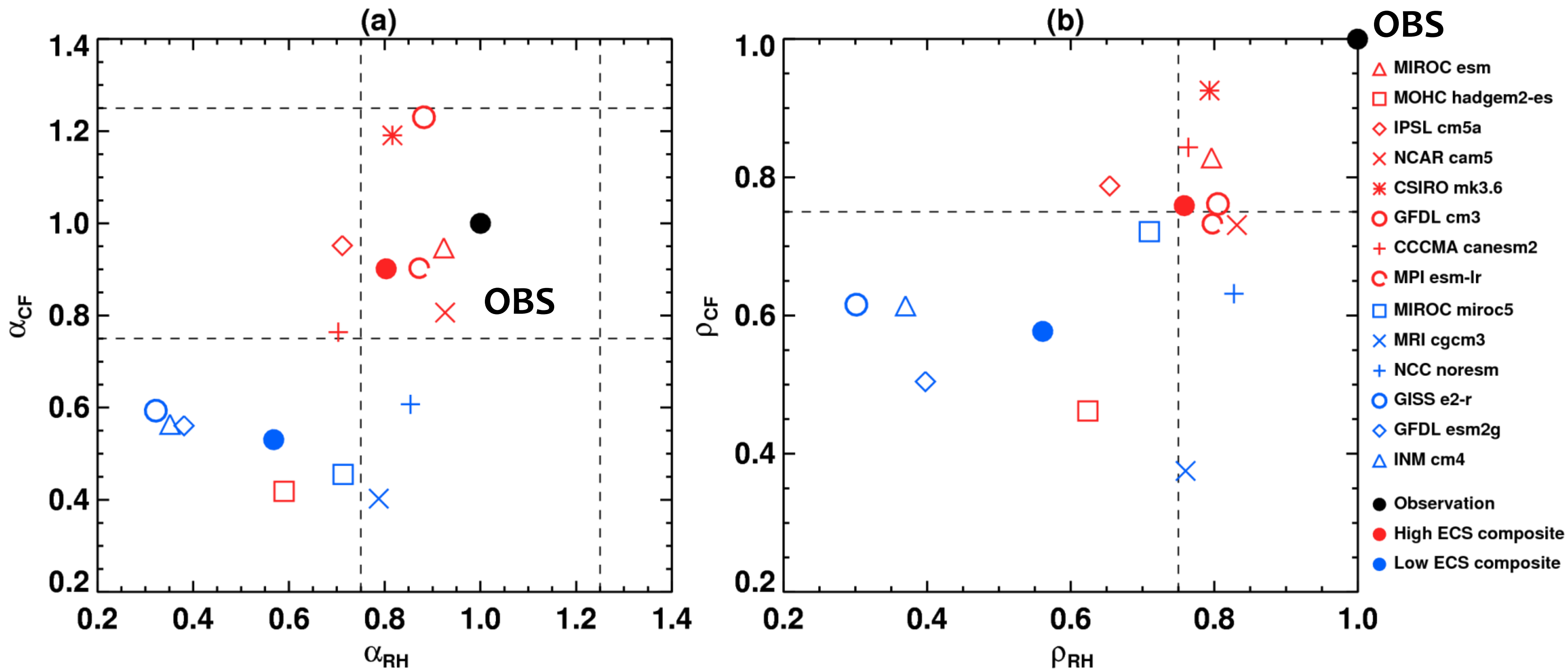
The explained variance by the 1st EOF is **57%**

- **Area-weighted CRE changes for the weakening and strengthening segments account for 54% and 46% of the total CRE change within the HC.**
- **The amplitudes of the 1st EOF mode differ by two orders of magnitude in models.**
- **Model differences in the HC change explains ~50% of model spread in CRE change.**

cf., Su *et al.* (2014, *JGR*)

Quantitative Model Performance Metrics to Represent the Hadley Circulation Structure

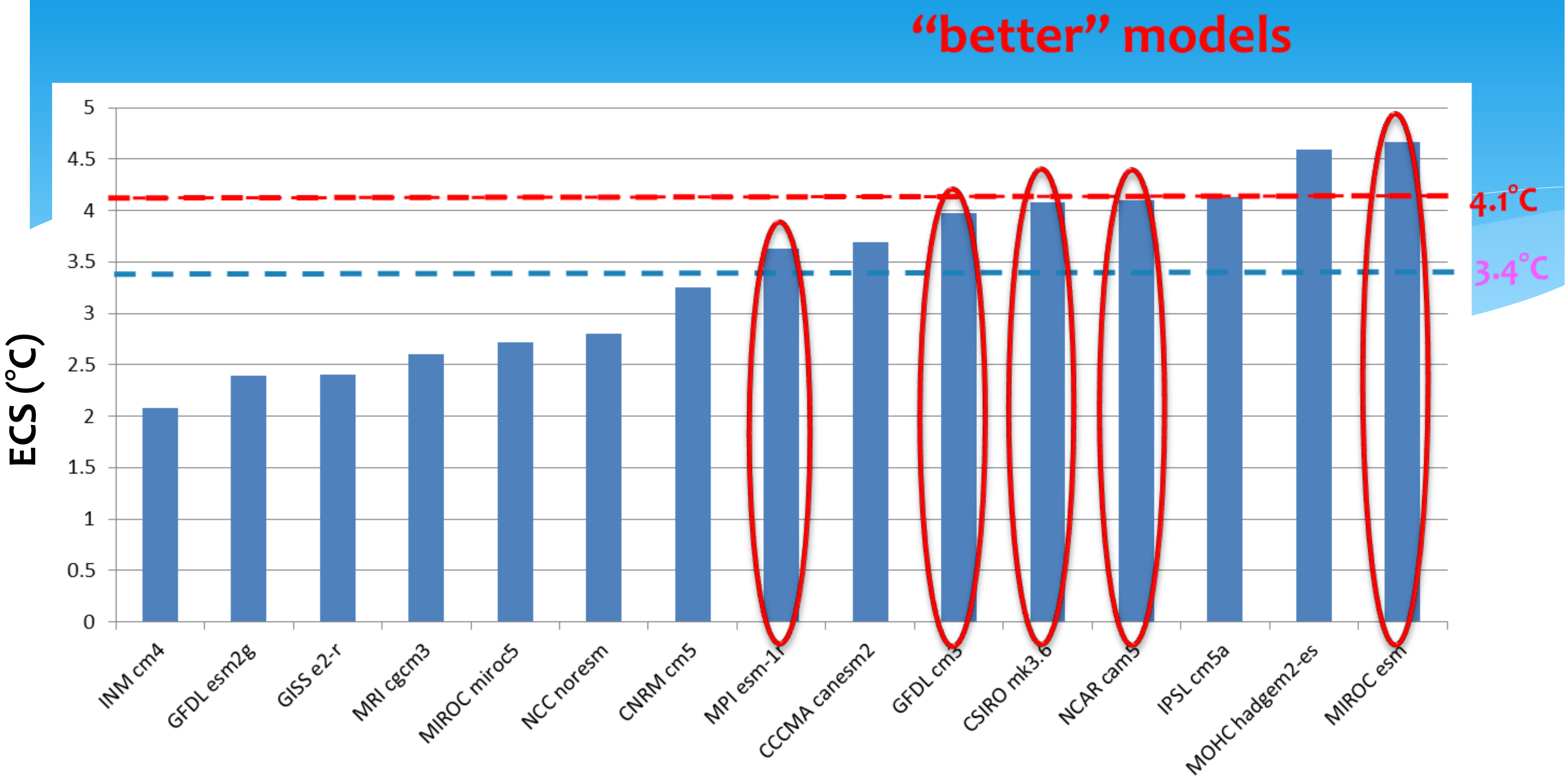
cf., Su *et al.* (2014, *JGR*)



α_{CF}, α_{RH}: regression slopes of model-mean zonal CF, RH profiles on CloudSat-CALIPSO CF, AIRS/MLS RH

ρ_{CF}, ρ_{RH}: spatial correlations between model and observed cloud fraction (CF) and relative humidity

Satellite-based "Best Estimates" of ECS

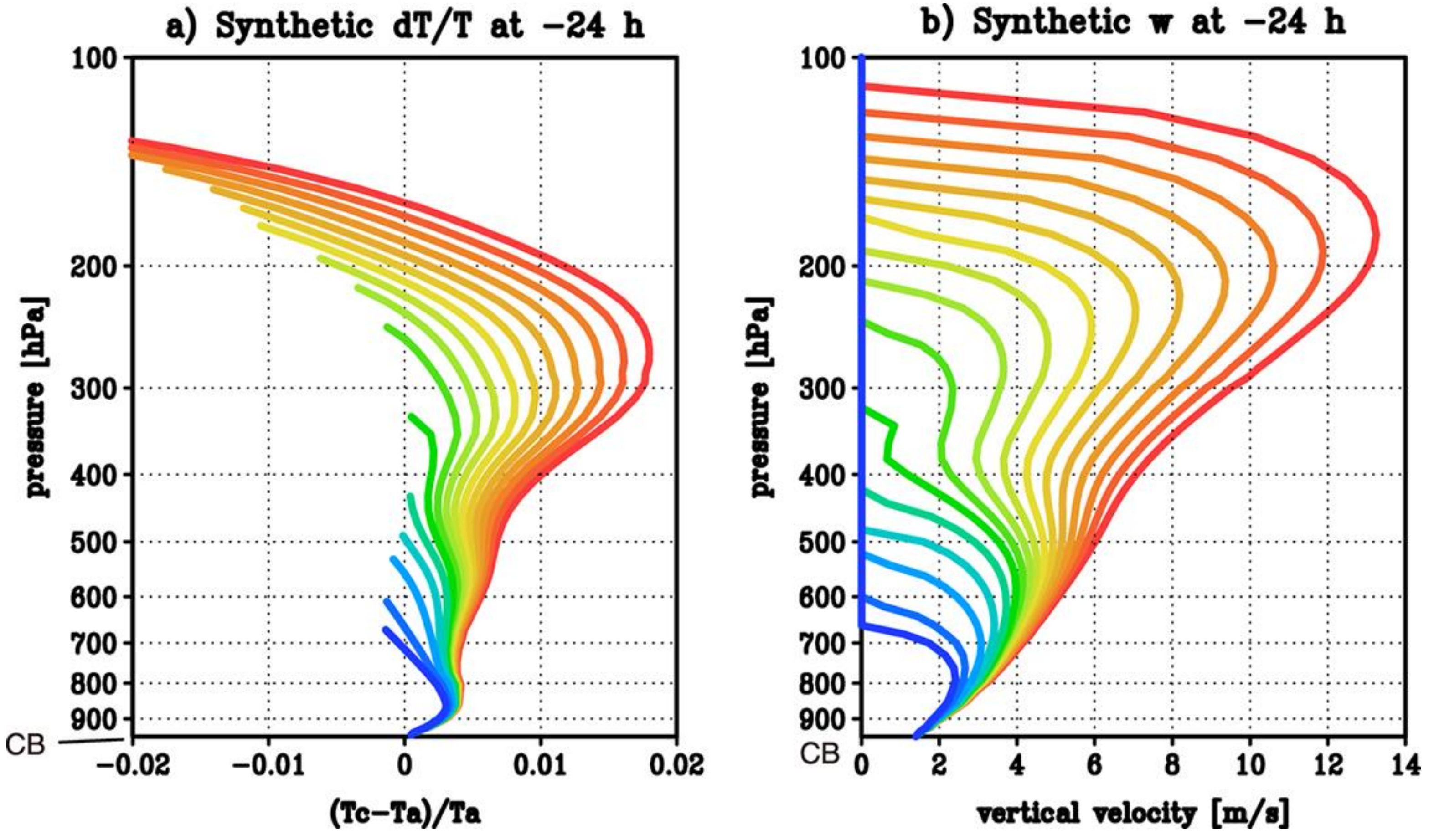


The best estimates of ECS range from 3.6 to 4.7°C, with a mean of **4.1**°C and a standard deviation of **0.4**°C, compared to the multi-model-mean of **3.4**°C and a standard deviation of **0.9**°C.

cf., Su *et al.* (2014, *JGR*)

Convective entrainment is a strong control on convective vertical velocity

Convective and large-scale mass flux profiles over tropical oceans determined from synergistic analysis of a suite of satellite observations



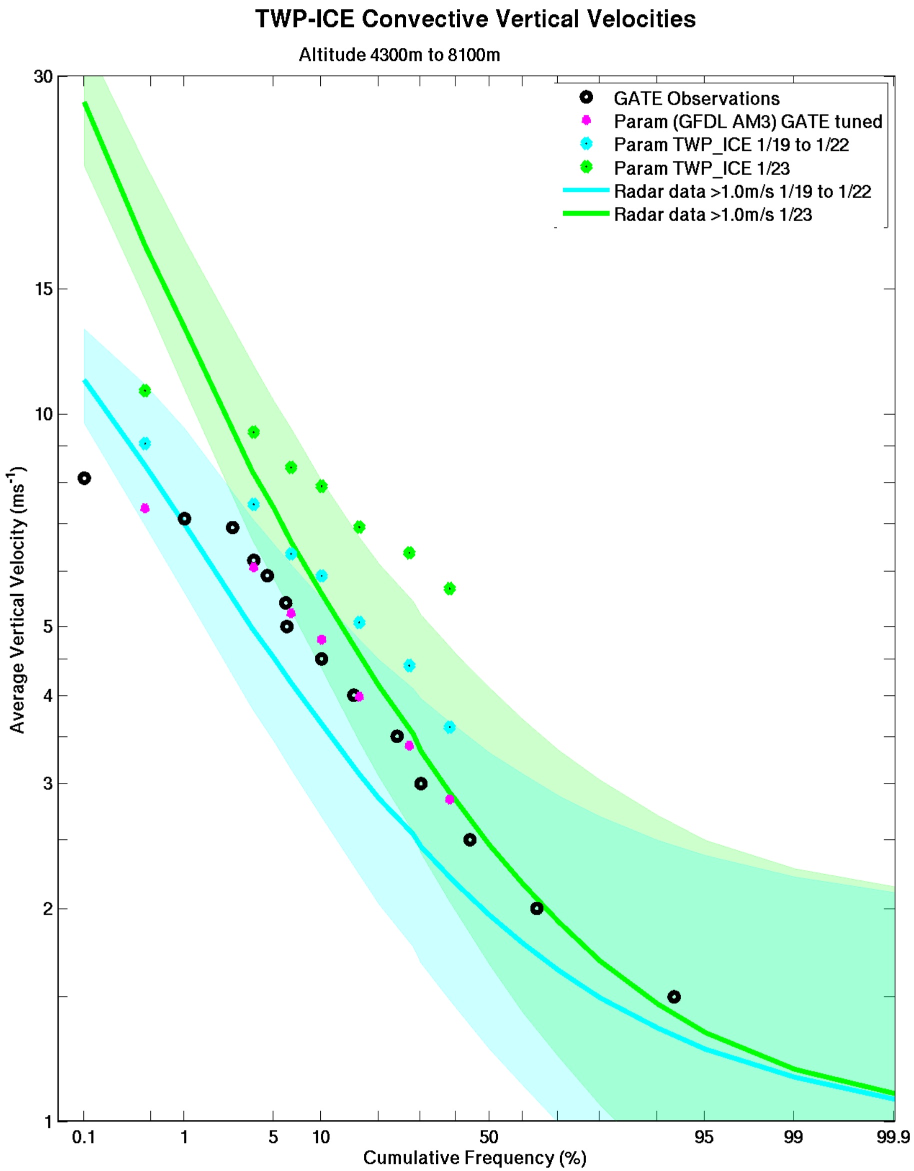
Plume entrainment rates from 0 to 0.4 km^{-1} as red goes to blue.

Journal of Geophysical Research: Atmospheres
Volume 121, Issue 13, pages 7958-7974, 12 JUL 2016 DOI: 10.1002/2016JD024753
http://onlinelibrary.wiley.com/doi/10.1002/2016JD024753/full#jgrd53104-fig-0002

from Masunaga and Luo (2016, *JGR*)

Recently obtained local and global measurements of convective vertical velocity may constrain entrainment and climate sensitivity.

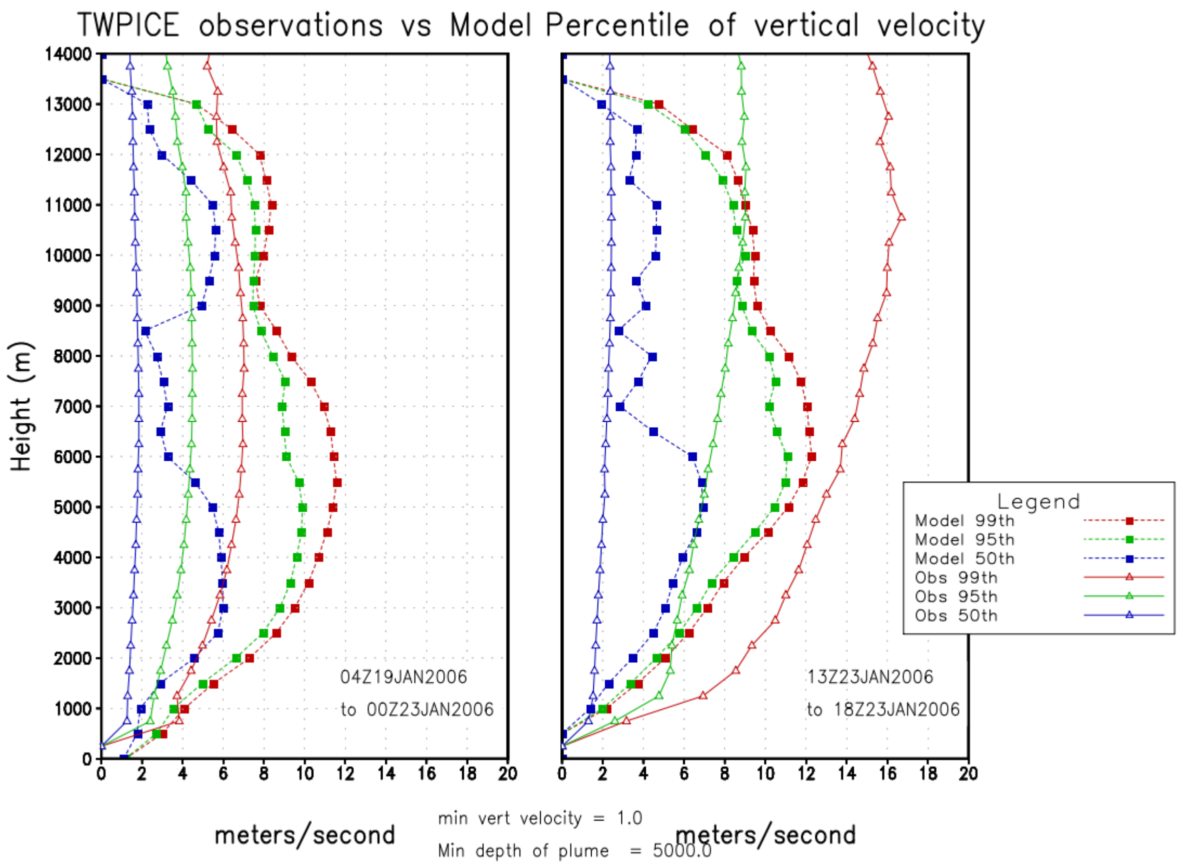
Convective Vertical Velocities from GFDL AM3 (Donner *et al.*, 2011) and TWP ICE dual-Doppler (Collis *et al.*, 2013, *J. Appl. Meteor. Climatol.*)



Shading shows ranges of radar observations with lower cut-off from 0.5 to 2.0 m s^{-1} over 5-km layer. 95th percentile by extrapolating AM3 ensembles ~ 1 m s^{-1} for GATE, 1.5 m s^{-1} for TWP ICE 1/19-22, and 2.0 m s^{-1} for TWP ICE 1.23.

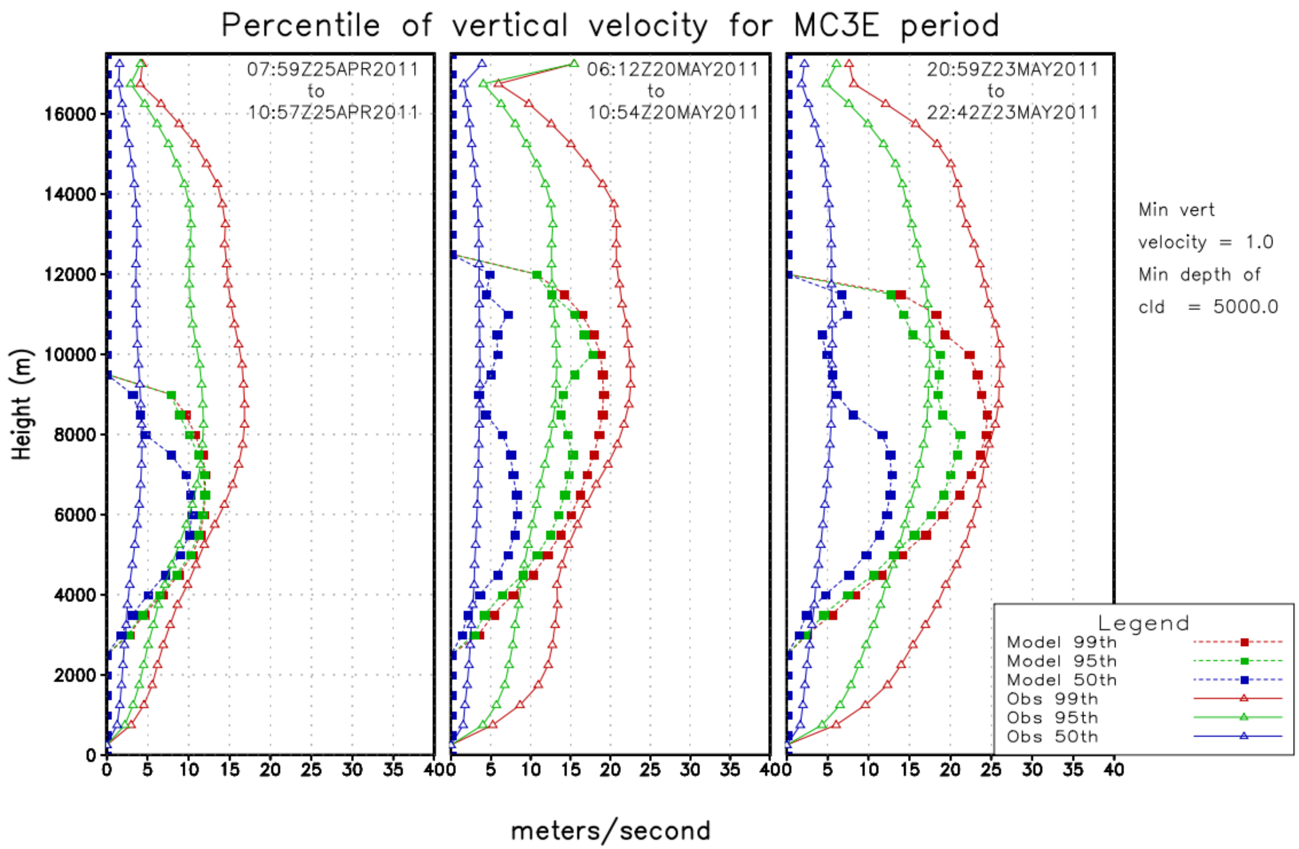
Analysis by Will Cooke, GFDL; GATE observations provided by Ian Glenn, U. Utah.

TWP-ICE PDFs of Cumulus Vertical Velocity in GFDL AM3 and Radar Observations: Prospects for Sub-Grid Parameterization



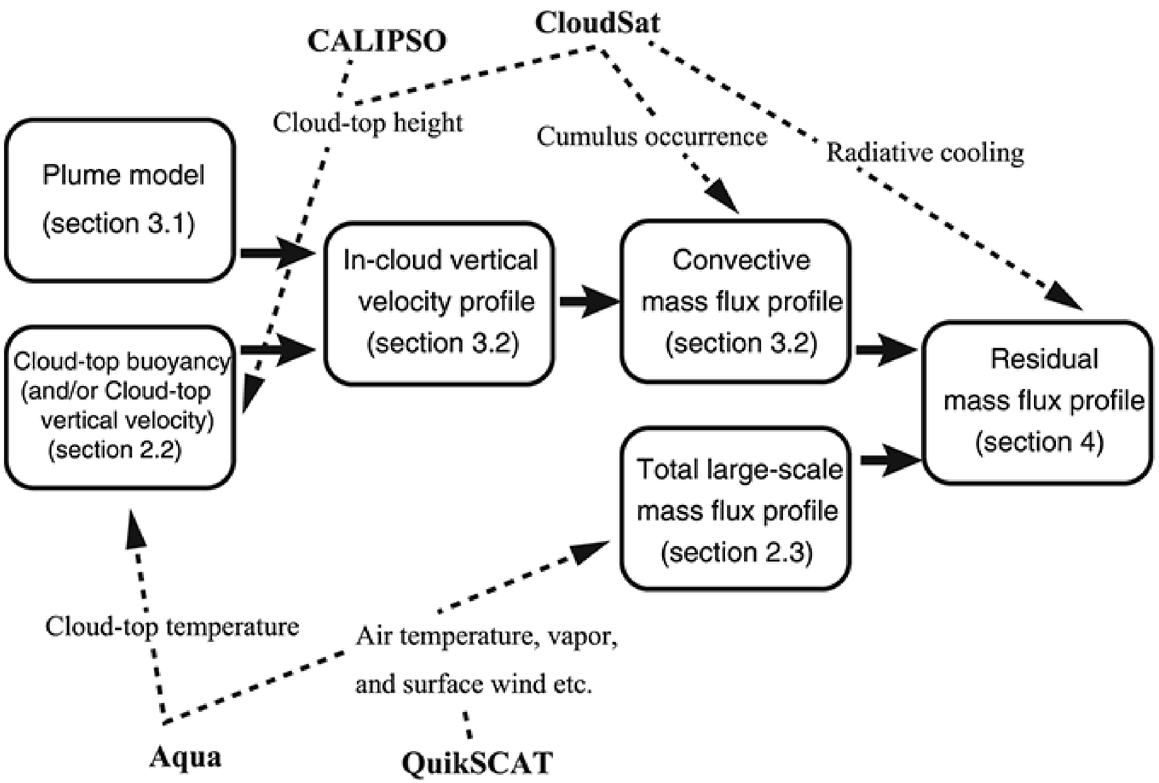
PDFs of cumulus vertical velocities at TWP-ICE from GFDL AM3 (Donner *et al.*, 2011, *J. Climate*) and dual-Doppler radar (Collis *et al.*, 2013, *J. Appl. Meteor. Climatol.*) show AM3 vertical velocity values often, but not always, larger than observed. (Donner *et al.*, 2016, *Atmos. Chem. Phys.*)

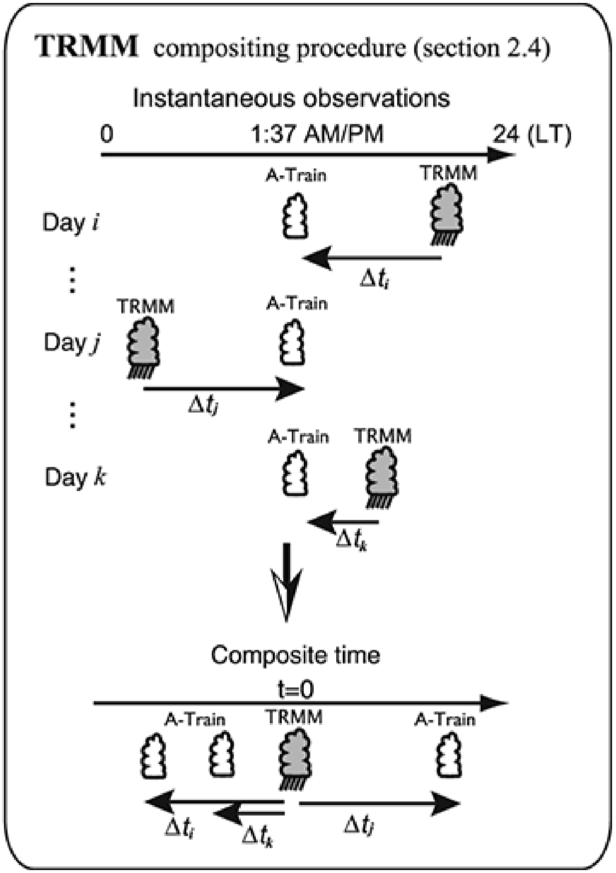
MC3E PDFs of Cumulus Vertical Velocity in GFDL AM3 and Radar Observations



PDFs of cumulus vertical velocities at MC3E from GFDL AM3 (Donner *et al.* (2011, *J. Climate*) and dual-Doppler radar (Collis *et al.,* 2013, *J. Appl. Meteor. Climatol.*) show AM3 vertical velocity values often, but not always, larger than observed. Analysis by Will Cooke, GFDL.

Convective and large-scale mass flux profiles over tropical oceans determined from synergistic analysis of a suite of satellite observations





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Volume 121, Issue 13, pages 7958-7974, 12 JUL 2016 DOI: 10.1002/2016JD024753
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from Masunaga and Luo (2016, *JGR*)

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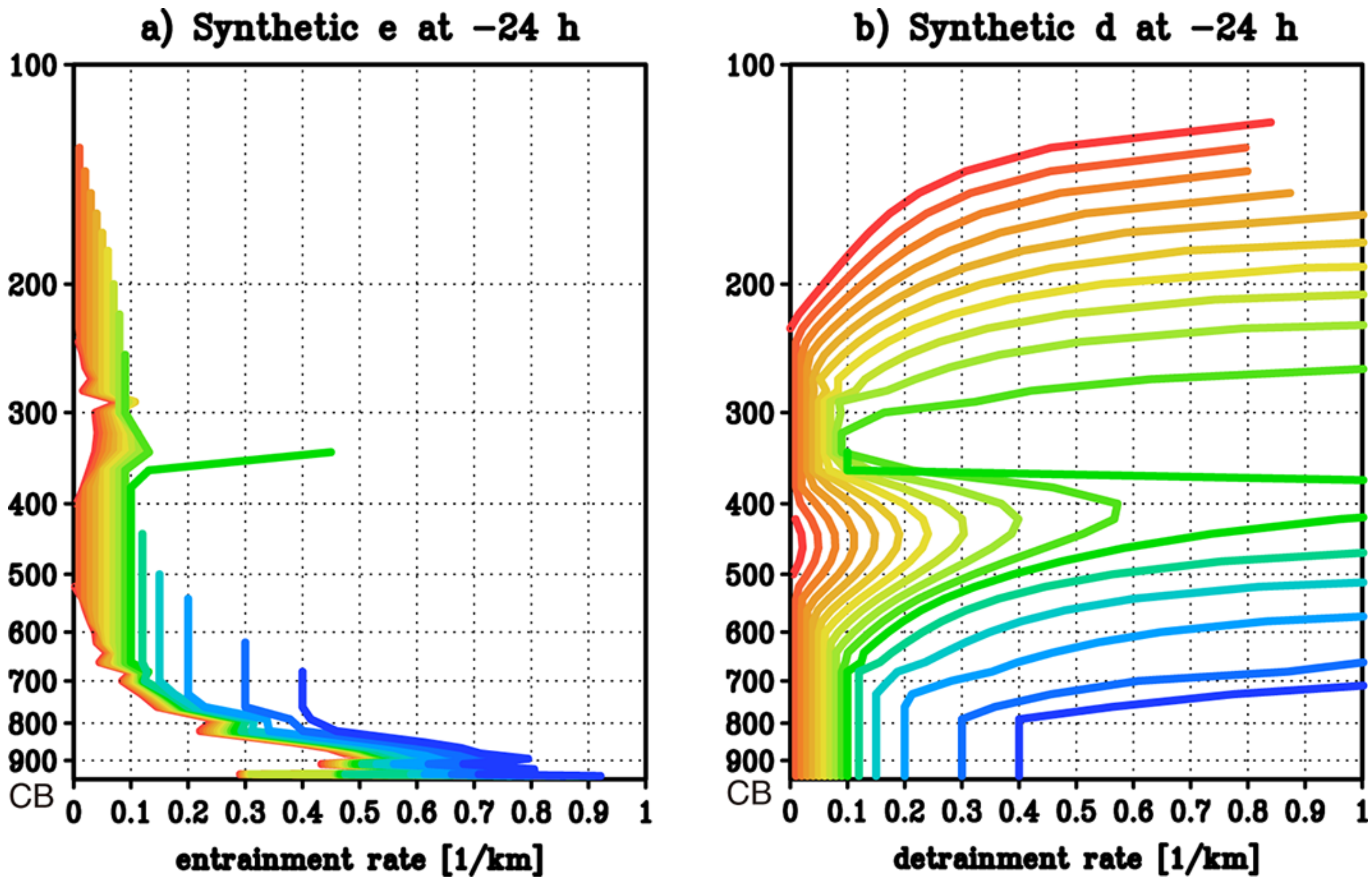

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http://onlinelibrary.wiley.com/doi/10.1002/2016JD024753/full#jgrd53104-fig-0003

from Masunaga and Luo (2016, *JGR*)

Observed (Solid Black) & CRM Vertical Velocities (Varble *et al.*, 2014, *JGR*)

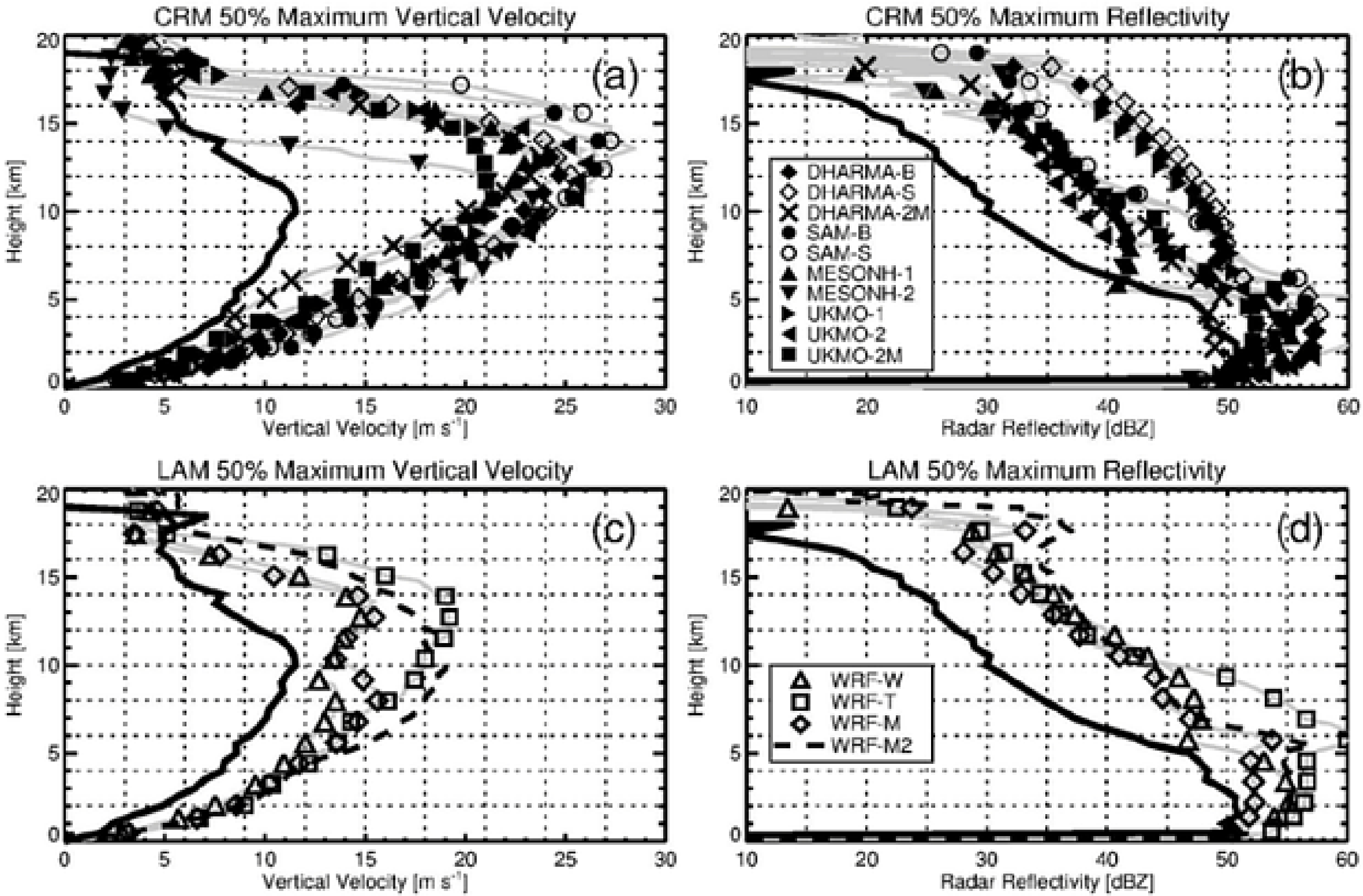
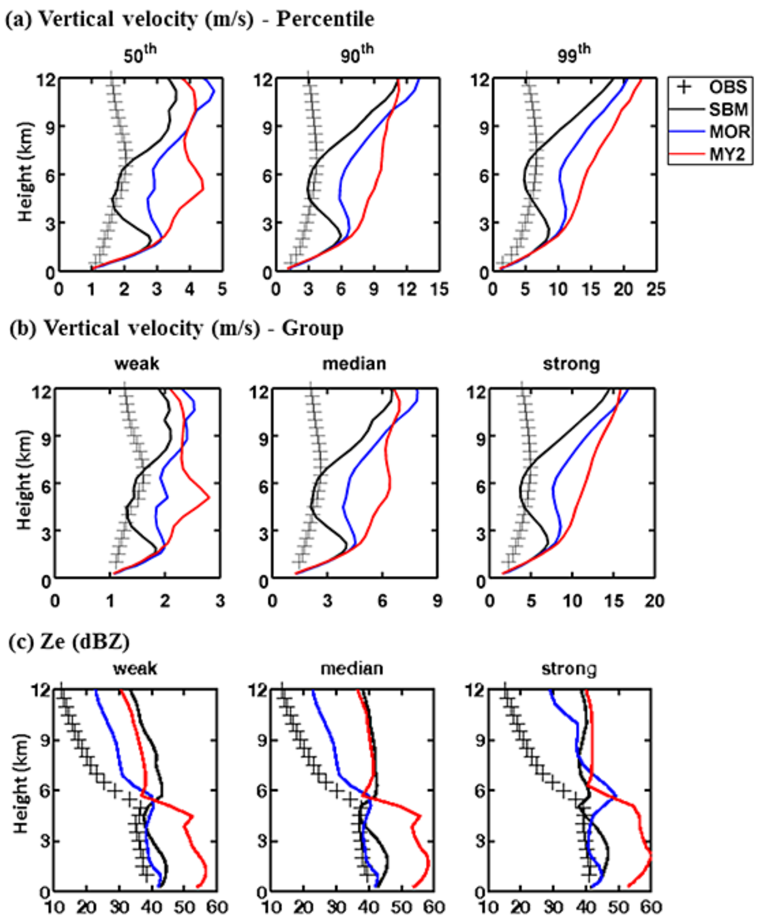


Figure 9: Median profiles of maximum vertical velocity (a,c) and radar reflectivity (b,d) for three-dimensionally defined convective updrafts beginning below 1 km and ending above 15 km for the period of 1310Z to 1750Z on 23 January 2006. CRM statistics are shown in (a-b) and LAM statistics are shown in (c-d). Gray lines with symbols and the dashed black lines represent simulations. Observations are represented by solid black lines.

Improving representation of convective transport for scale-aware parameterization: 1. Convection and cloud properties simulated with spectral bin and bulk microphysics



TWP-ICE, 22 Jan 2006
SBM: spectral microphysics
MOR, MY2: bulk microphysics (from Fan *et al.*, 2015, *JGR-Atmos.*)

Journal of Geophysical Research: Atmospheres
2014JD022142, 29 APR 2015 DOI: 10.1002/2014JD022142
http://onlinelibrary.wiley.com/doi/10.1002/2014JD022142/full#jgrd52099-fig-0009

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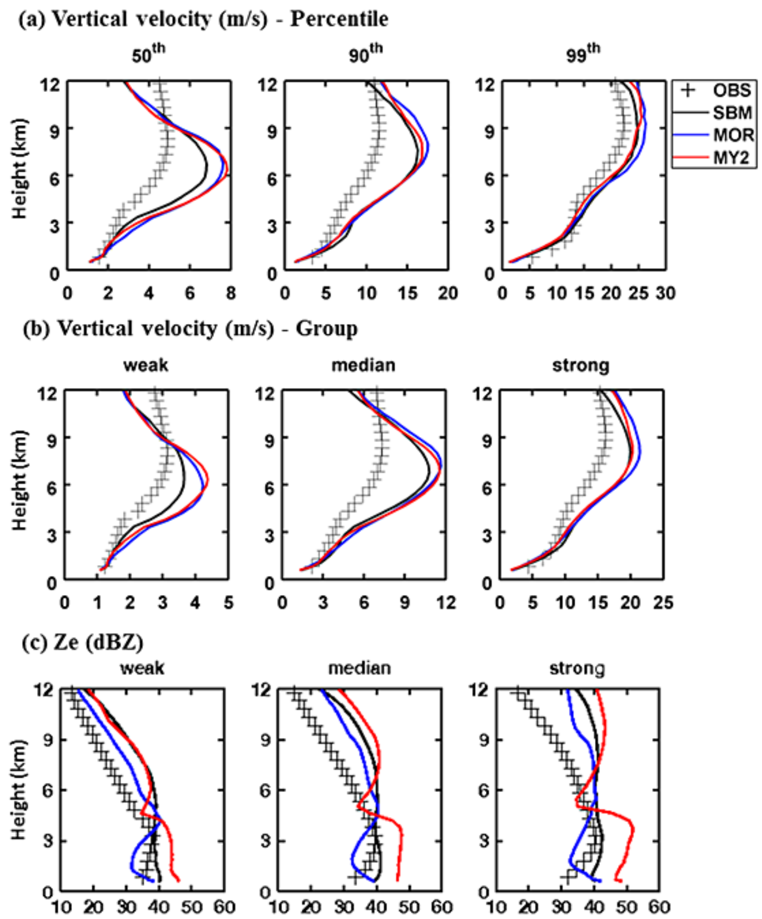

MC3E, 20 May 2011 SBM: spectral microphysics; MOR, MY2: bulk microphysics (from Fan *et al.*, 2015, *JGR-Atmos.*)

Journal of Geophysical Research: Atmospheres
2014JD022142, 29 APR 2015 DOI: 10.1002/2014JD022142
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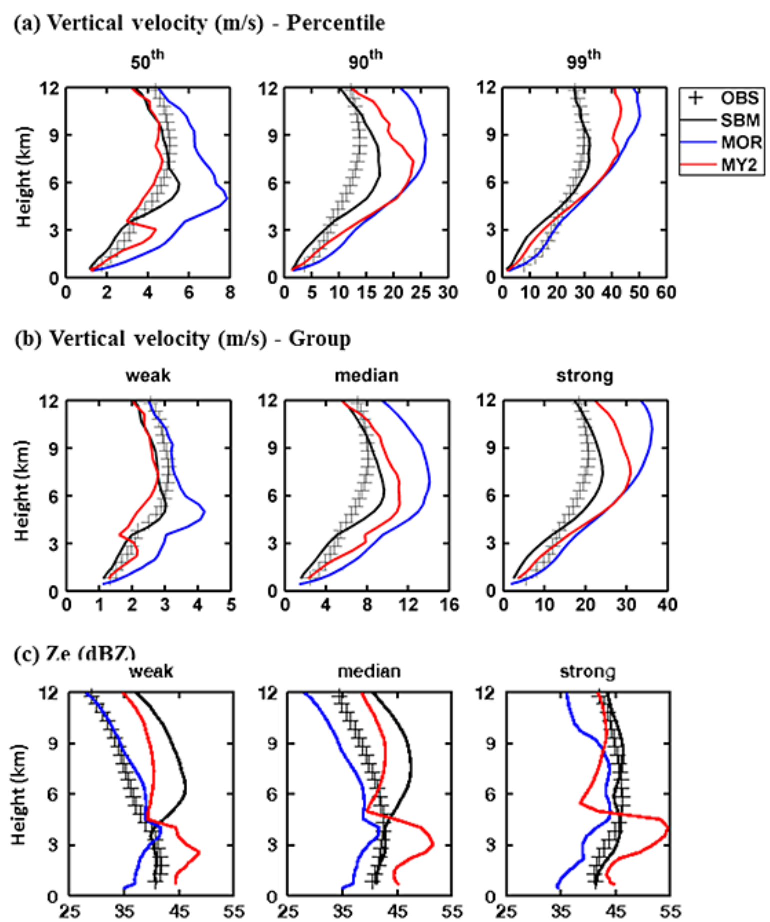
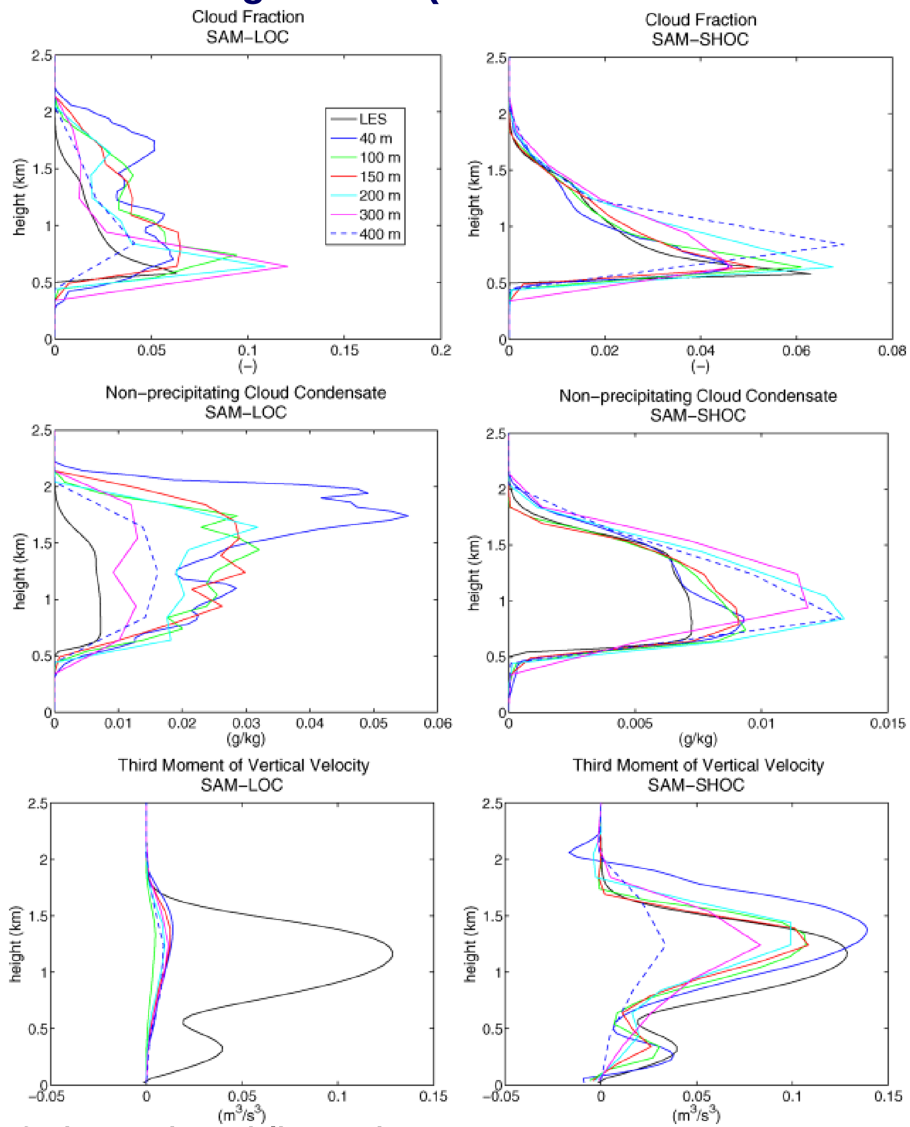


MC3E, 23 May 2011, SBM: spectral bin microphysics; MOR and MY2: bulk microphysics, from Fan *et al.* (2015, *JGR-Atmos.*)

Journal of Geophysical Research: Atmospheres
2014JD022142, 29 APR 2015 DOI: 10.1002/2014JD022142
http://onlinelibrary.wiley.com/doi/10.1002/2014JD022142/full#jgrd52099-fig-0007

A simplified PDF parameterization of subgrid-scale clouds and turbulence for cloud-resolving models (horizontal resolution 3.2 km)

BOMEX



LES
Horizontal resolution: 100m
Vertical resolution: 40m

Local turbulence unsuccessful even at 40m vertical resolution.

Higher-order, assumed distribution turbulence approaches LES even at 200m vertical resolution.

Journal of Advances in Modeling Earth Systems
Volume 5, Issue 2, pages 195-211, 18 APR 2013 DOI: 10.1002/jame.20018
http://onlinelibrary.wiley.com/doi/10.1002/jame.20018/full#jame20018-fig-0003

Bogenschutz and Krueger (2013)

Key Points

- Uncertainties in anthropogenic climate forcing and sensitivity persist, limiting understanding of past climate change and future projections.
- Perturbed physics studies with multiple climate models suggest convective entrainment is an important control on climate sensitivity.
- Mechanisms by which entrainment in convection controls climate sensitivity are not well understood and likely model-dependent.
- Convective entrainment is a strong control on convective vertical velocity.
- Recently obtained local and global measurements of convective vertical velocity may constrain entrainment and climate sensitivity.