Recent developments and future challenges in cumulus parameterization

Tony Del Genio

NASA/GISS

AMS Meeting

1/7/15

A little over a decade ago (Randall et al., 2003, BAMS):

BREAKING THE CLOUD PARAMETERIZATION DEADLOCK

BY DAVID RANDALL, MARAT KHAIROUTDINOV, AKIO ARAKAWA, AND WOJCIECH GRABOWSKI

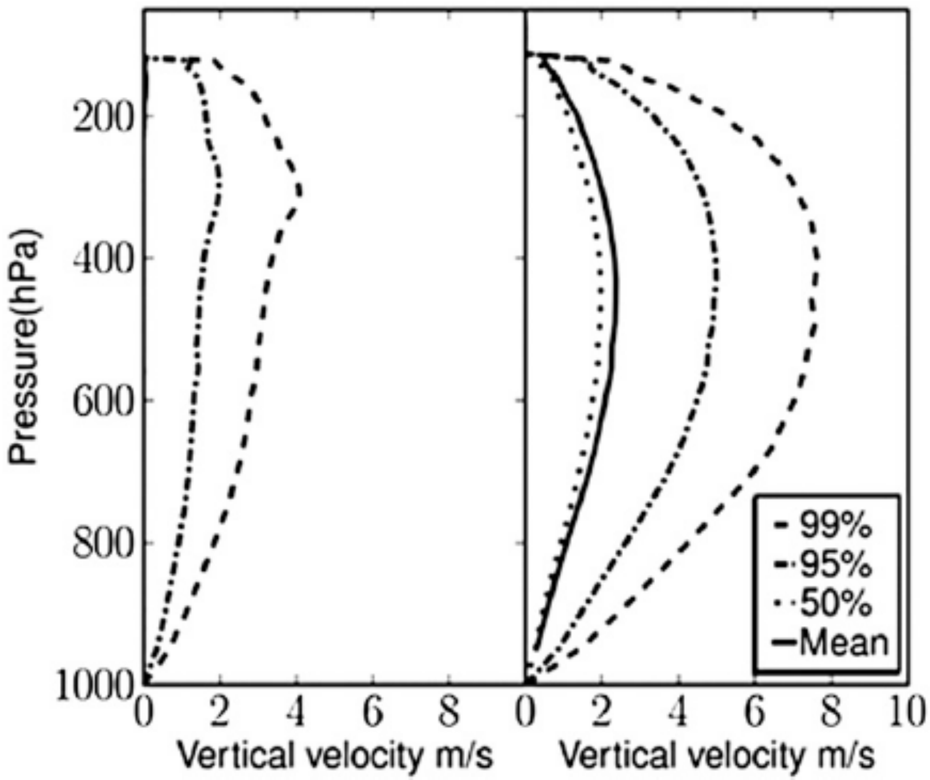
Start of the "super-parameterization" era, and eventually global cloud-permitting models

But conventional cumulus parameterization has advanced rapidly since then – with implications for atmospheric chemistry applications

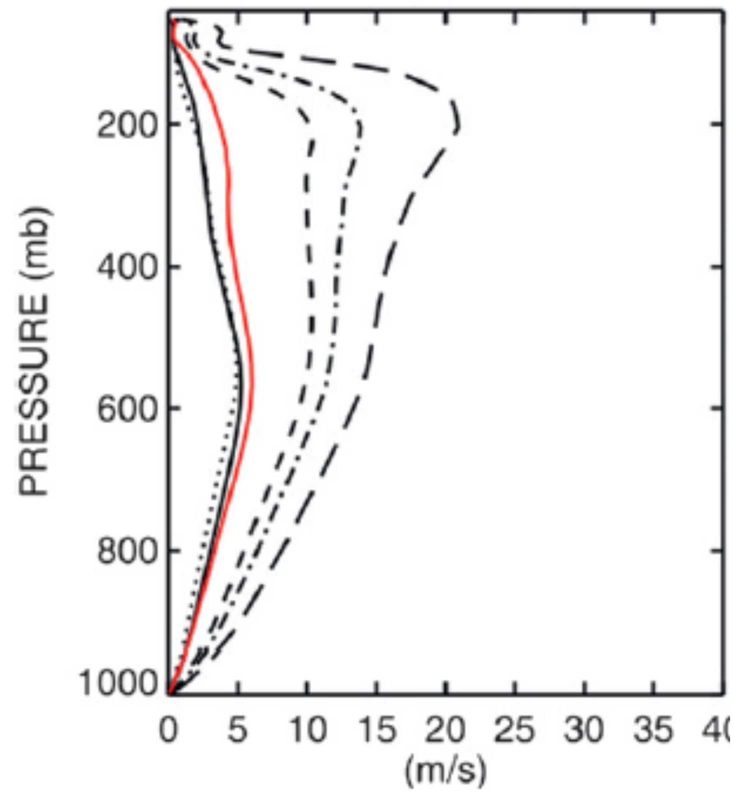
What happened?

- **Emphasis on missing process components**
  - Updraft speeds rather than just mass fluxes
  - Entrainment
  - Downdraft cold pools
- **Departures from quasi-equilibrium**
  - Triggers to delay response to unstable state
  - Memory of past events
  - Stochastic response to large-scale forcing
- **Great new datasets**
  - Active remote sensing (TRMM/GPM, CloudSat/CALIPSO, ARM)
  - Field experiments (DYNAMO, TWP-ICE,…)
  - Large-scale forcing for SCMs, GCM hindcast initialization
- **Focus on weather/climate variability and parameter dependences, rather than mean state**
  - Madden-Julian Oscillation, diurnal cycle, etc.

Dual Doppler convective updraft speed retrievals now inform cumulus parameterization (and CRM) deficiencies



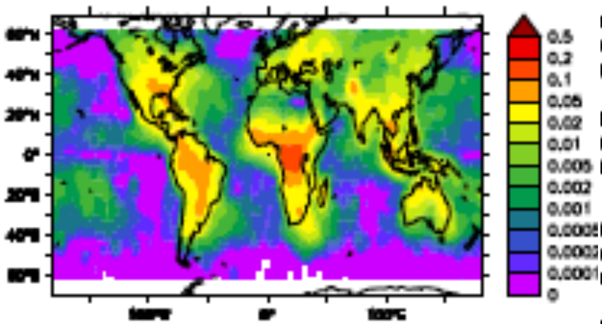
Dual Doppler, Darwin, Australia, TWP-ICE (Collis et al., 2013)

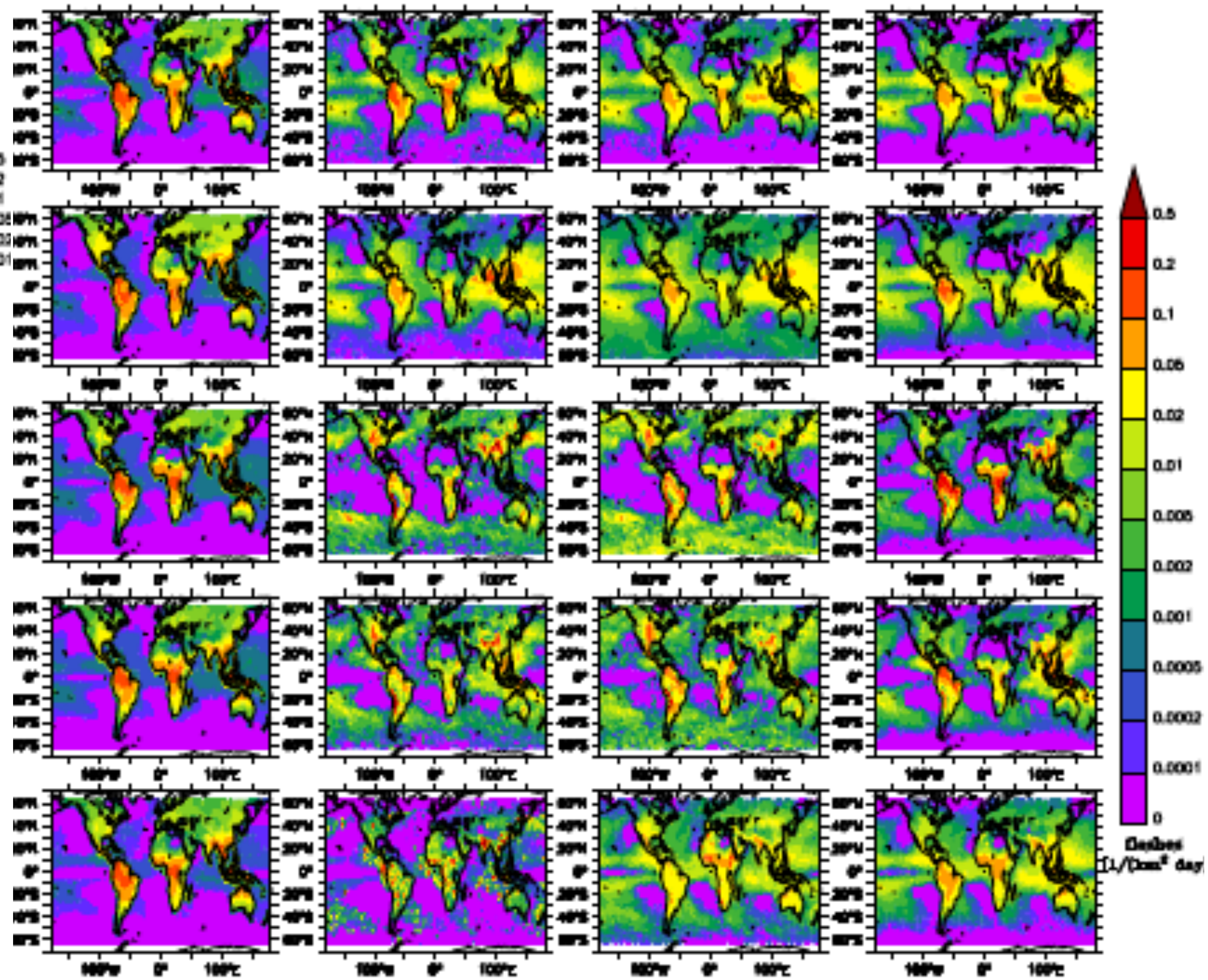


GISS SCM (Wu et al., 2009)

Why climate modelers should care: Convective cloud feedback -> ice water path -> convective detrainment -> updraft speed + particle size distribution + fall speed

Why atmospheric chemists should care: LNOx production parameterization should be based on updraft speed





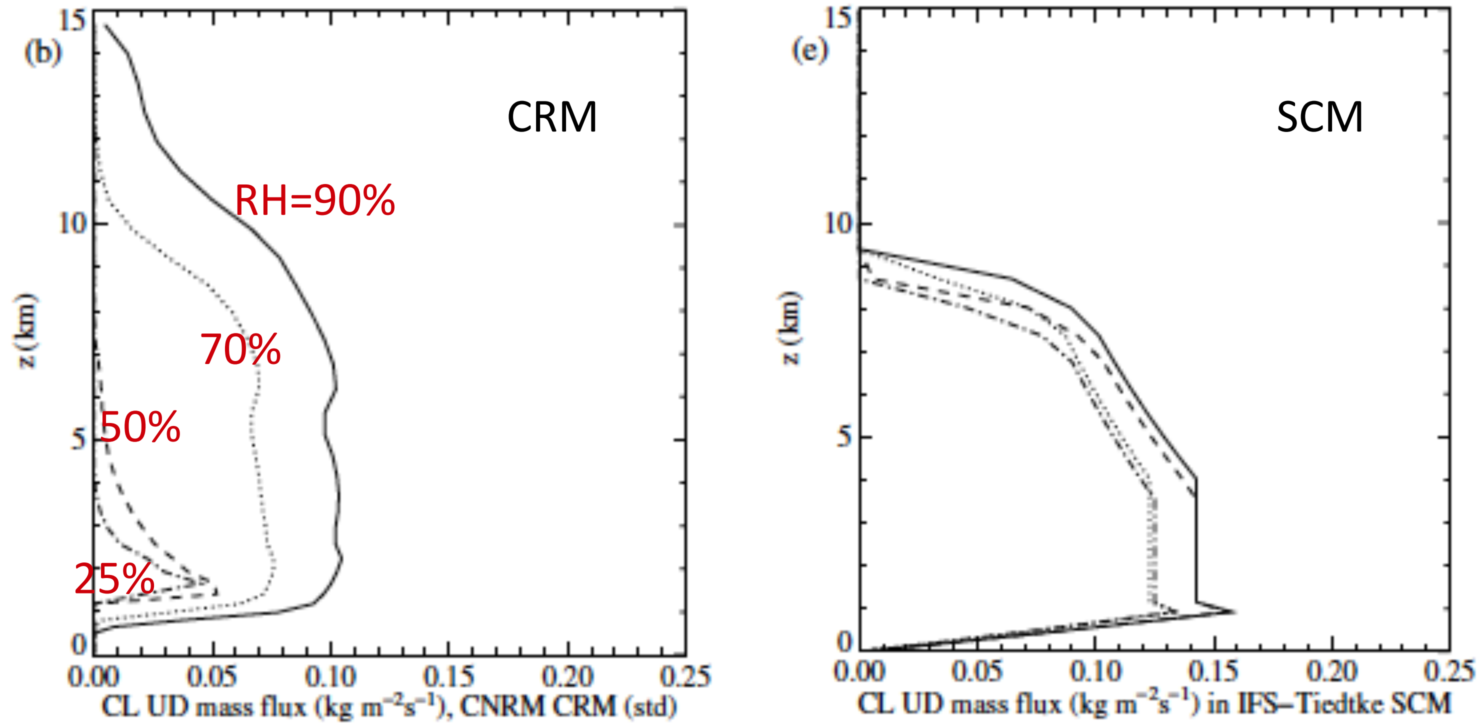
Lightning flash rate climatology:

- **Land >> ocean**
- **Africa >> other land**
- **U.S. peak in SE**

Schemes based on height, precip, mass flux have insufficient skill

Tost et al. (2007)

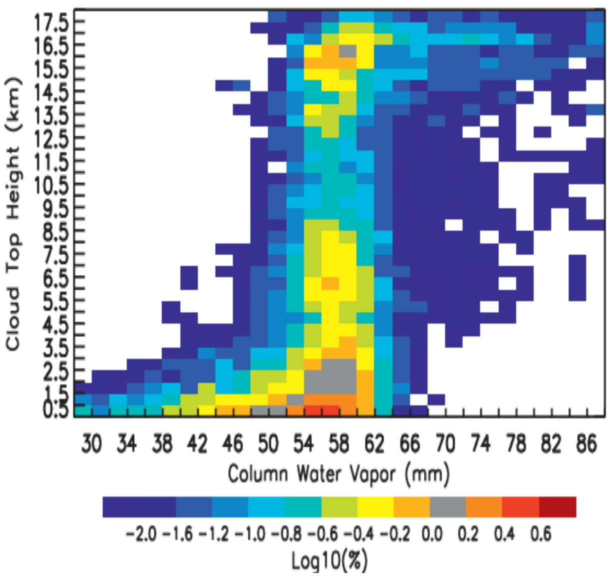
In cloud-resolving models, convection is sensitive to free troposphere humidity; in SCMs, it isn't



GCMs do not entrain enough environmental air

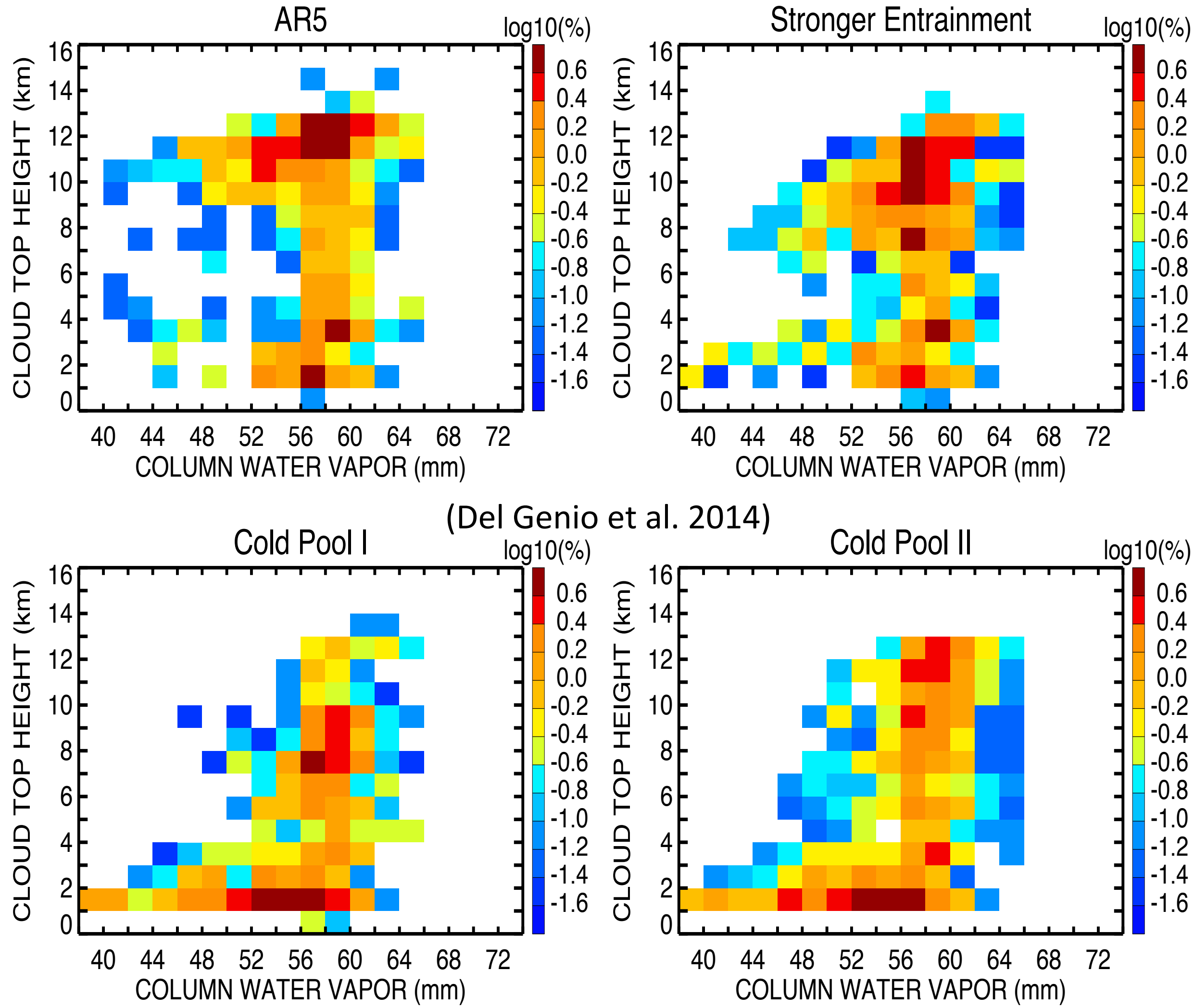
(Derbyshire et al., 2004)

Convection depth vs. column water vapor during the MJO



CloudSat/CALIPSO + AMSR-E

(Del Genio et al. 2012)



(Del Genio et al. 2014)

GISS SCM versions during DYNAMO

(Del Genio et al., 2014)

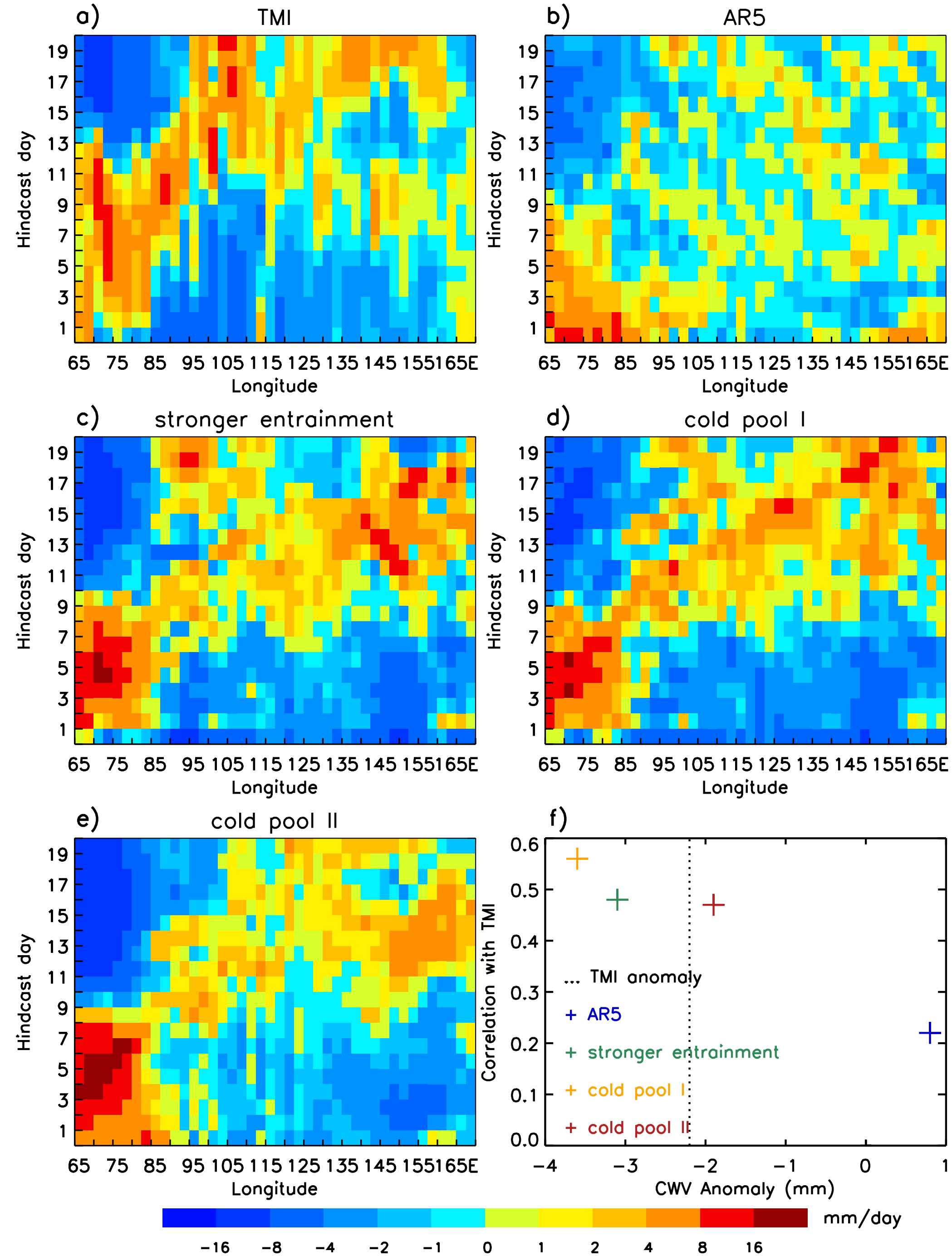
A-Train data identify model versions with improved transition from shallow to deep convection in equatorial warm pool

Hovmöller diagrams of TRMM TMI MJO precipitation anomalies during YOTC vs. 20-day hindcasts for different versions of GISS GCM:

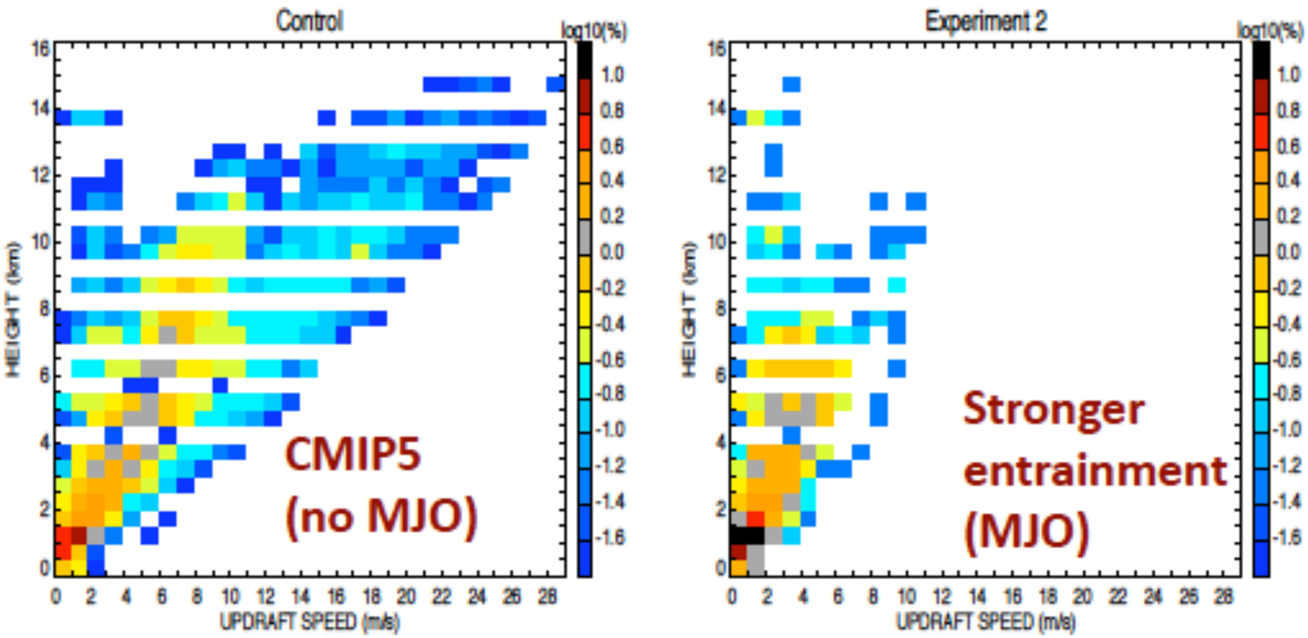
Model versions with better shallow-to-deep convection transition have more realistic MJO

Strength of dry anomaly on day 1 east of disturbed region is diagnostic of quality of future hindcast

(Del Genio et al., 2014)

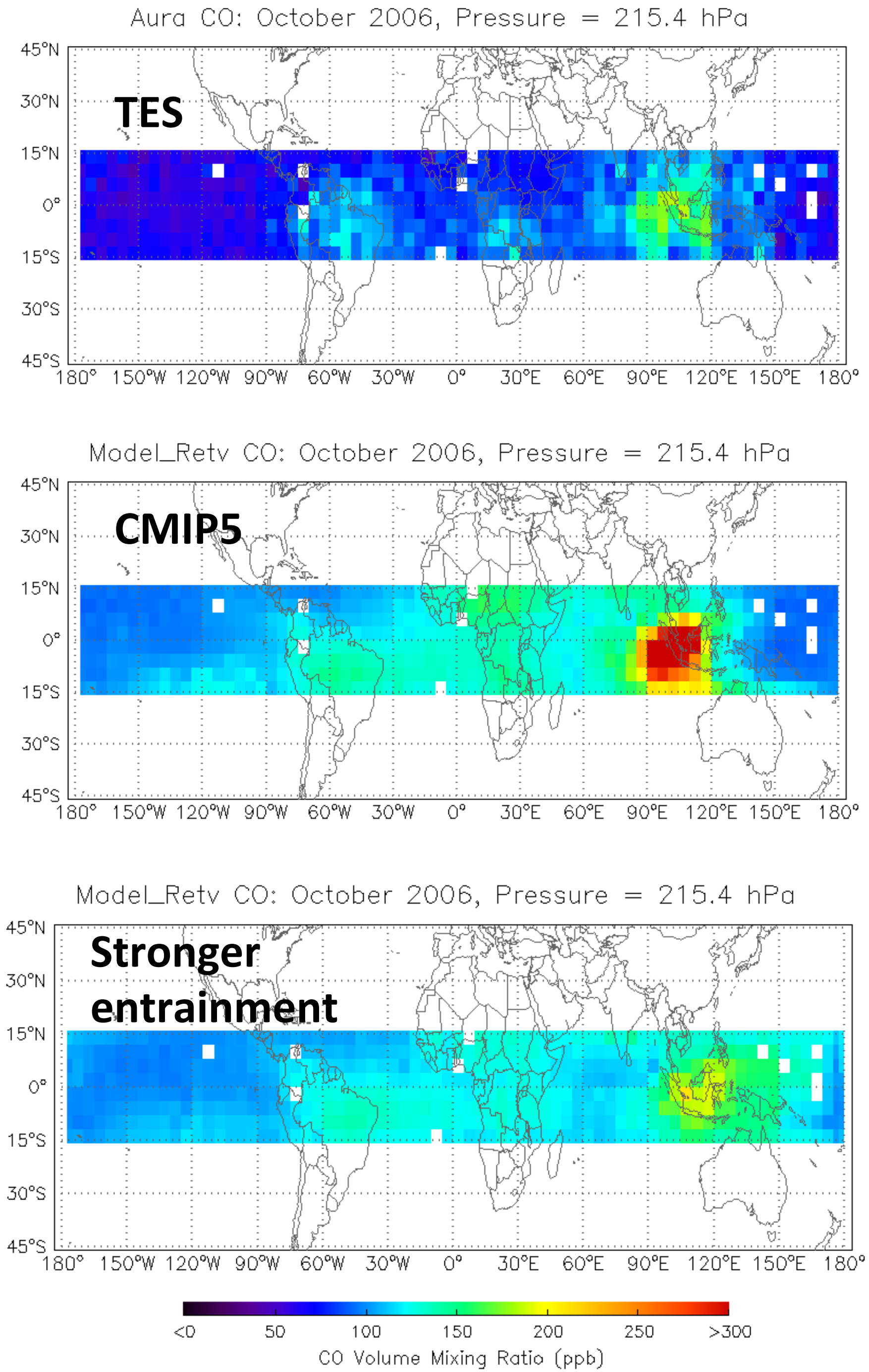


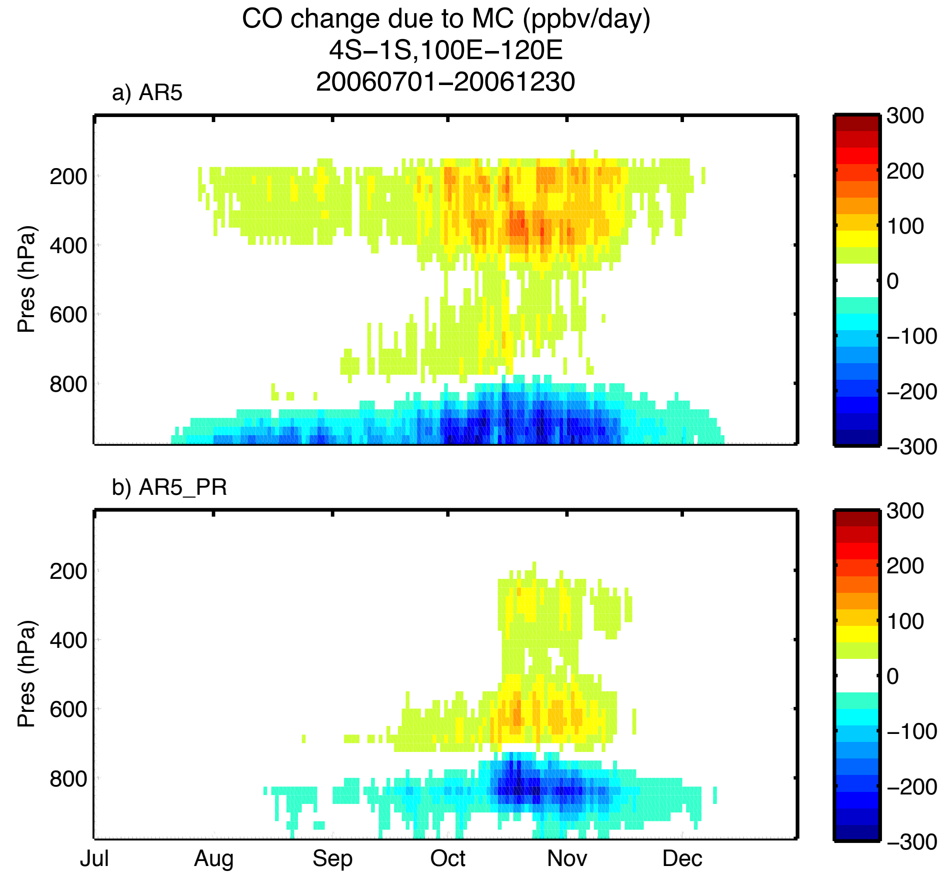
Side benefit: Stronger entrainment weakens the convective updraft speed profile at upper levels



Semi-prognostic SCM tests at AMIE-Gan

2006 Indonesian biomass burning event CO profile, GCM vs. Aura TES: Stronger entrainment improves upper level CO





(courtesy Robert Field)

Looking to the future

- Despite super-parameterization and global CPMs, CMIP GCMs will use conventional cumulus parameterizations for the foreseeable future
- Process-based and weather/climate variability metrics must become the primary tools of model assessment
- Increasingly, direct observations of convective components are available; but chemical tracers provide an independent check
- We now realize how to suppress deep convection and strong updrafts in dry environments; the challenge is how to correctly predict the transition from strongly to weakly entraining convection (cold pools?), the transition from isolated cellular to mesoscale organized convection, and the link between convective dynamics and mixed-phase microphysics