Precipitation and humidity relationships in observations and models

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Onset of tropical deep convection: background

- Convective quasi-equilibrium (QE) assumptions for convective parameterizations: Above onset threshold, convection/precip. increase keeps system close to onset  
  Arakawa & Schubert 1974; Betts & Miller 1986; Moorthi & Suarez 1992; Randall & Pan 1993; Zhang & McFarlane 1995; Emanuel 1993; Emanuel et al 1994; Bretherton et al. 2004; …

- Need to better characterize the transition to deep convection as a function of buoyancy-related fields – temperature $T$ & moisture (here column water vapor $w$)

- Useful guidance – properties of continuous phase transition with critical phenomena*  
  Peters & Neelin 2006, Nature Physics; mesoscale implications  
  Peters, Neelin & Nesbitt 2009, JAS
**Summary (preview)**

1. CAM 3.5 at 0.5° qualitatively captures onset of deep convection (from microwave retrievals) in Temp- column water vapor plane (WRF too?). Plume models suggest obs onset a constraint on entrainment.
   - **Background:** CWV a useful variable for characterizing onset of convection (sharp pickup at critical value; large datasets)

2. Precip space, time autocorrelation<< water vapor potentially consistent with stochastic plumes but try to retain power law autocorrelations?

3. Characteristic CWV distribution above critical more variable in models than obs---real? Hypothesized mechanism implies long tails in other tropospheric tracers---confirmed.
   - **Background:** CWV distribution: Gaussian core below critical but exponential tail above. High precip rates freq >> Gaussian.
Precip. dependence on tropospheric temperature & column water vapor from TMI*

• Averages conditioned on vert. avg. temp. $\hat{T}$, as well as $w$ ($T$ 200-1000mb from ERA40 reanalysis)

• Power law fits above critical: $P(w) = a (w - w_c)^\beta$

$w_c$ changes, same $\beta$

• [note more data points at 270, 271]

*TMI: Tropical Rainfall Measuring Mission Microwave Imager (Hilburn and Wentz 2008), 20N-20S

Neelin, Peters & Hales, 2009, JAS
Collapsed statistics for observed precipitation

- Precip. mean & variance dependence on $w$ normalized by critical value $w_c$ (for 4 $T$ values)
- Occurrence probability for precipitating points

Critical point dependence on temperature

- Find critical water vapor $w_c$ for each vert. avg. temp. $T$
- Compare to vert. int. saturation vapor value binned by same $T$
- *Not* e.g., a constant fraction of column saturation
- lower tropospheric saturation $q_{sat}(T)$ binning gives same results

Neelin, Peters & Hales, 2009, JAS
WRF W. Pac (4 km run) preliminary comparison*: Precip. dependence on lower tropospheric temperature ($q_{\text{sat}}(T)$) & water vapor

• <P> averages conditioned on lower trop. layer $q_{\text{sat}}(T)$, & water vapor
• coarse-grained to 24km grid
• so far Jan 1997, 1hr av P, each 3hr
• T dependence ~as expected; small curvature above critical

*analysis Hsiao-ming Hsu
CAM3.5 * preliminary comparison:


**Mass flux** $M_b \propto$ entraining CAPE**, $A$, due to large-scale forcing, $F$

$$M_b = A / (\tau_c F) \quad \text{(for } M_b > 0)$$

*Community Atmosphere Model 3.5: 0.5 degree short term climate projection experiment (Gent et al. 2009, Clim. Dyn.)*

** Convective available potential energy
CAM3.5 (0.5 degree run) preliminary comparison*: Precip. dependence on tropospheric temperature & column water vapor

- Averages conditioned on vert. avg. temp. $T$, as well as column water vapor $w$
- Linear fits above critical (motivated by parameterizn) $P(w)=a(w-w_c)^\beta$ as obs. but $\beta=1$ : to estimate $w_c$

*Runs, data R. Neale, analysis K. Hales
Critical point dependence on temperature

CAM3.5 preliminary comparison

- critical water vapor $w_c$ for each vert. avg. temp. $T$
- Compare to vert. int. saturation vapor value binned by same $T$
- Suggests suitable entraining plumes can capture $T$ dependence

Runs, data R. Neale, analysis K. Hales
Entraining convective available potential energy and precipitation binned by column water vapor, $w$

- buoyancy & precip. pickup at high $w$
- boundary layer and lower free tropospheric moisture contribute comparably*

*consistent with importance of lower free tropospheric moisture (Austin 1948; Yoneyama and Fujitani 1995; Wei et al. 1998; Raymond et al. 1998; Sherwood 1999; Parsons et al. 2000; Raymond 2000; Tompkins 2001; Redelsperger et al. 2002; Derbyshire et al. 2004; Sobel et al. 2004; Tian et al. 2006)

*Brown & Zhang 1997 entrainment; scheme and microphysics affect onset value, though not ordering.  
Holloway & Neelin, *JAS*, 2009
Plume model stability boundaries (onset of vertical vel. at 175-225 hPa) for various entrainment cases

C1, C2, C3, C4: free tropospheric entrainment 0, 1, 2, 4 x 10^{-3} hPa^{-1} (ABL entrainment 0.18 hPa^{-1})

Deep inflow B entrainment ~ z^{-1} in lower troposphere

Interactive: plume w equation, entrainment \( \frac{1}{m} \frac{\partial m}{\partial z} \), no detrainment

Nauru sonde basic state + LFT & ABL T pert’n, LFT moisture perturbation

analysis S. Sahany
C1, C2, C3, C4: free tropospheric entrainment 0, 1, 2, 4 x 10^{-3} \text{ hPa}^{-1} (ABL entrainment 0.18 \text{ hPa})

Deep inflow B entrainment \sim z^{-1} in lower troposphere

Interactive: plume w equation, entrainment \frac{1}{m} \frac{\partial m}{\partial z}, no detrainment
Prec & column water vapor: autocorrelations in time

• Long autocorrelation times for vertically integrated moisture (once lofted, it floats around)

• Nauru ARM site upward looking radiometer + optical gauge

TMI precipitation and column water vapor spatial correlations

*bH2OVap*

\[
\ln(y) = 0.532 - 0.133 \ln(x)
\]

*Precip*

\[
\ln(y) = 1.366 - 0.603 \ln(x)
\]
TMI-AMSRE precipitation and column water vapor temporal correlations

\[ \ln(y) = 0.055 - 0.069 \ln(x) \]

\[ \ln(y) = -0.426 - 0.779 \ln(x) \]
Precip conditioned on lag/lead column water vapor

- High water vapor several hours ahead still useful for pickup in precipitation
- Consistent with high water vapor $\Rightarrow$ favorable environment, but stochastic plume
- Nauru ARM site upward looking radiometer + optical gauge

Holloway and Neelin 2010, *JAS*
Obs. Freq. of occurrence of $w/w_c$ (precipitating pts)

Eastern Pacific for various tropospheric temperatures

- Peak just below critical pt. ⇒ self-organization toward $w_c$
- But exponential tail above critical pt. ⇒ more large events

• with Gaussian core, akin to forced tracer advection- diffusion problems
  (e.g. Shraiman & Siggia 1994, Pierrehumbert 2000, Bourlioux & Majda 2002)

Neelin, Peters & Hales, 2009, JAS
Precipitating freq. of occurrence vs. $w/w_c$
Eastern Pacific for various tropospheric temperatures
- CAM3.5 preliminary comparison
- Includes super-Gaussian ~exponential range above critical pt.

Exponential range?

$\hat{T}(K)$
- 269
- 270
- 271
- 272
- 273
- 274

Gaussian core?

Critical

Column saturation

Runs R. Neale, analysis K. Hales
WRF W. Pac (4 km run) preliminary comparison*: frequency of occurrence $N$ of lower tropospheric water vapor by $q_{\text{sat}}(T)$

- coarse-grained to 24km grid
- so far Jan 1997 (not conditioned on precipitation)
- exponential range (?) small; faster drop above $q_{\text{sat}}$

*analysis Hsiao-ming Hsu
Passive tracer advection-diffusion---probability density function from simple flow configuration

“Vertical” flow (across gradient) const in vertical, sinusoidal in horizontal, stoch. (Gaussian) in time; horizontal flow constant in space, sinusoid in time

Varying
autocorrelation-time $\tau'_j$ of flow

Prototype applicable
to tropospheric tracers? Incl. CWV??

High Peclet number
(low diffusivity)
$Pe=10^4$

Adapted from Bourlioux & Majda 2002 *Phys. Fluids*
Distribution of Column-int. MOPITT CO obs. & GEOS-Chem simulations 20S-20N & subregions

Analysis: B. Tian, Q. Li, L. Zhang

Neelin et al., GRL, 2010, in press
Distribution of daily CO$_2$ anomalies

- AIRS retrievals
  (Chahine et al 2005, 2008)
  (Analysis: Ben Lintner)

- GEOS-Chem simulations projected on AIRS weighting functions
  (Analysis: Qinbin Li, Li Zhang)

Neelin, Lintner, Tian, Li, Zhang, Patra, Chahine & Stechmann, GRL, 2010, in press
TMI probability density function for observed column water vapor

Anomalies relative to monthly mean, tropical oceans 20S-20N

Analysis:
Baijun Tian

Neelin, Lintner, Tian, Li, Zhang, Patra, Chahine & Stechmann, GRL, 2010, in press
NCEP reanalysis daily column water vapor probability density function

- Anomalies relative to 30-day running mean
- Asymmetric exponential tails, assoc. with ascent/descent
- Low precip.: symmetric exponential tails

Analysis: Ben Lintner

Neelin, Lintner, Tian, Li, Zhang, Patra, Chahine & Stechmann, GRL, 2010, in press
Summary

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