# 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)

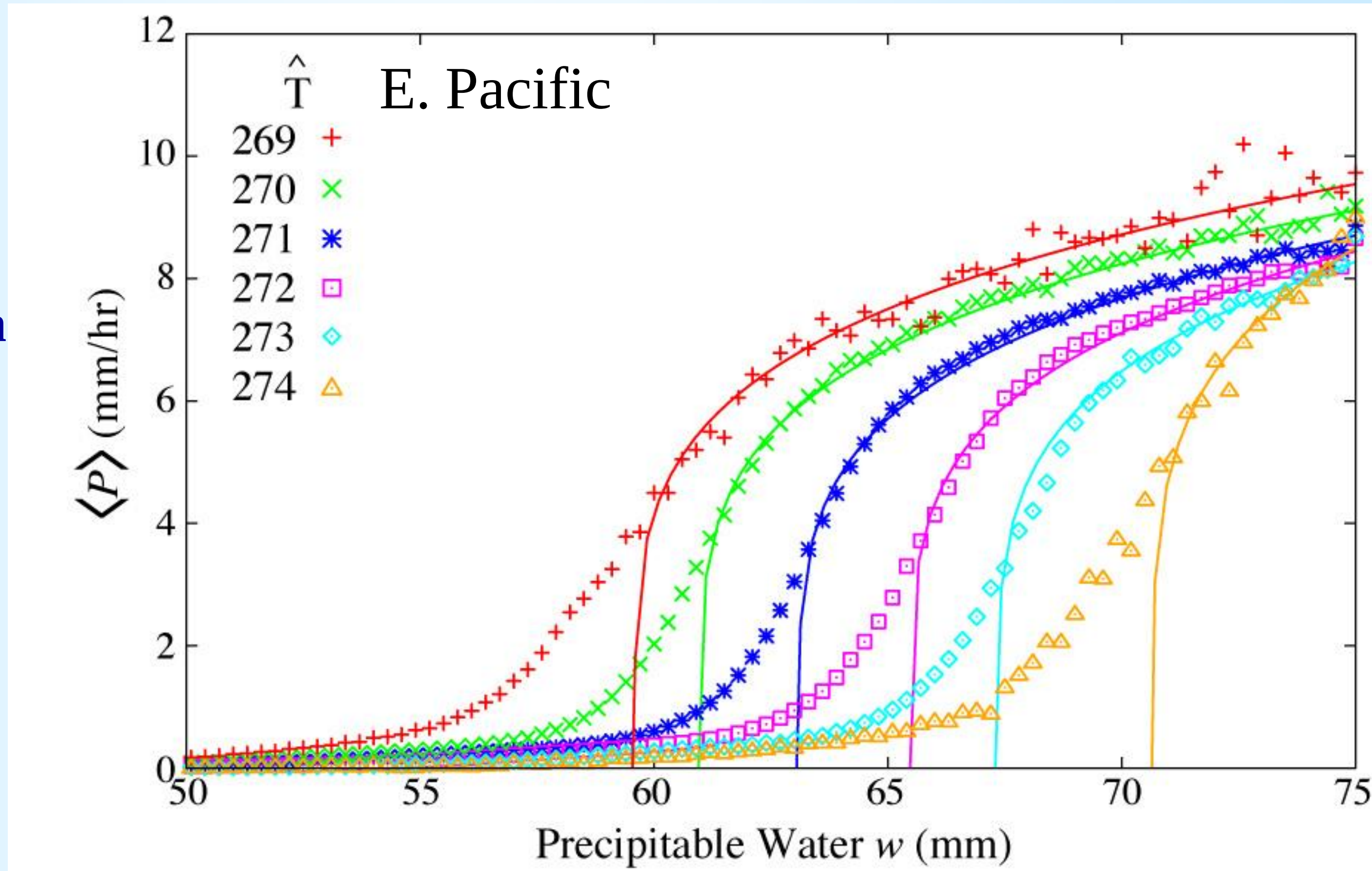
2. Precip space, time autocorrelation<<water vapor potentially consistent with stochastic plumes but try to retain power law autocorrelations?

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:**

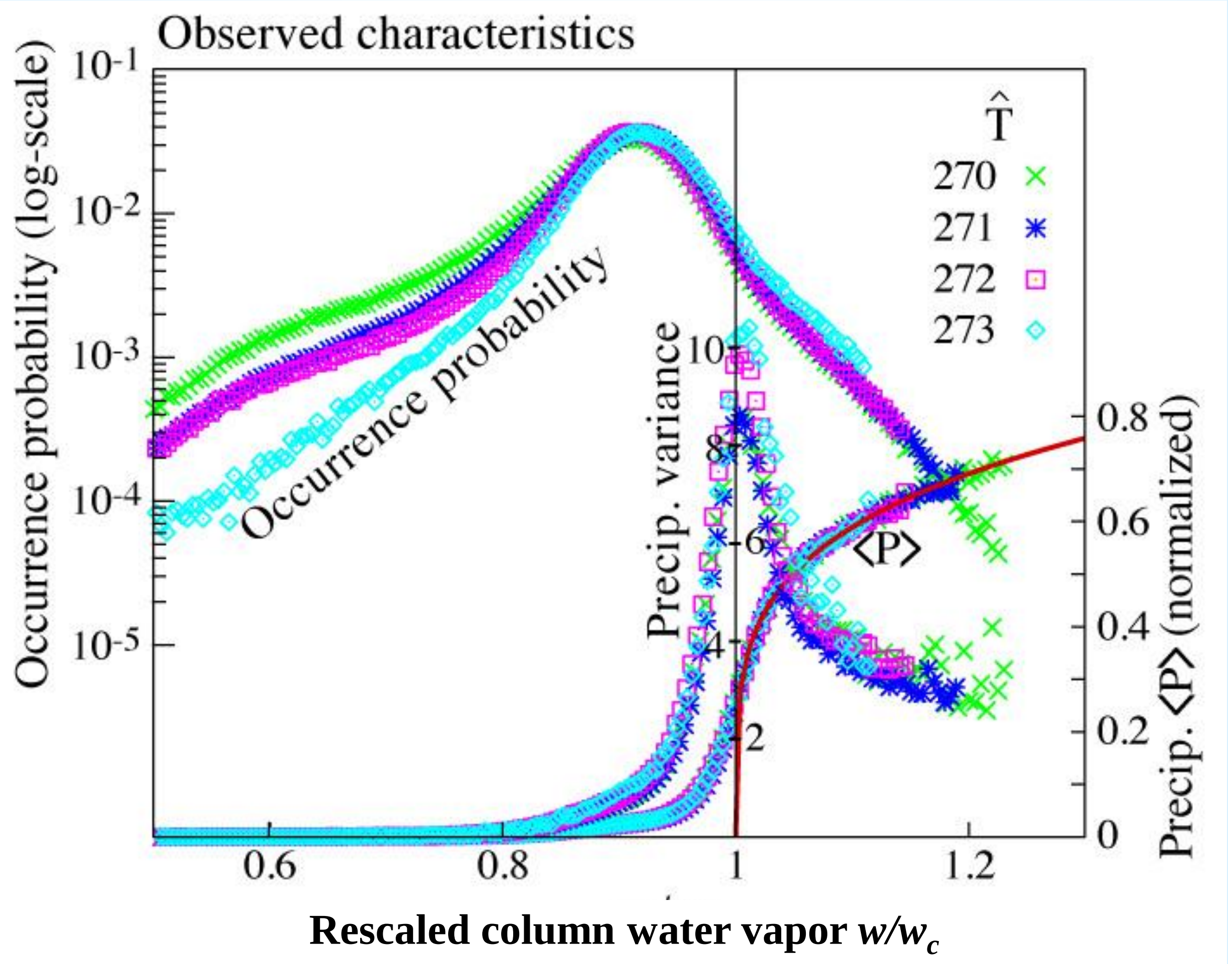
**$P(w)=a(w-w_c)^{\beta}$**
**$w_c$ changes, same $\beta$**

- **[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**

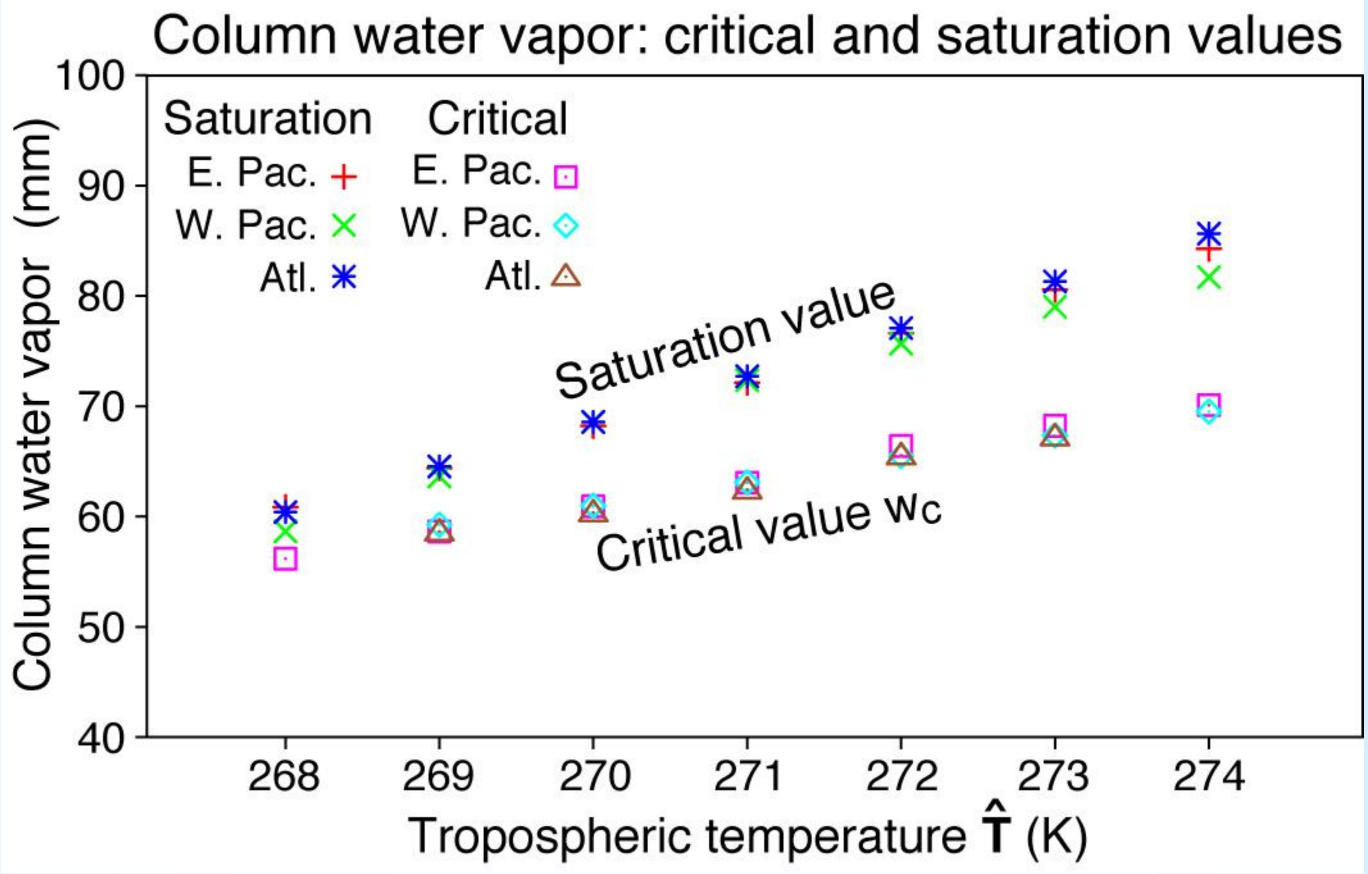
# Collapsed statistics for observed precipitation




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

**Neelin, Peters, Lin, Holloway & Hales, *Phil Trans. Roy. Soc. A*, 2008**

# Critical point dependence on temperature

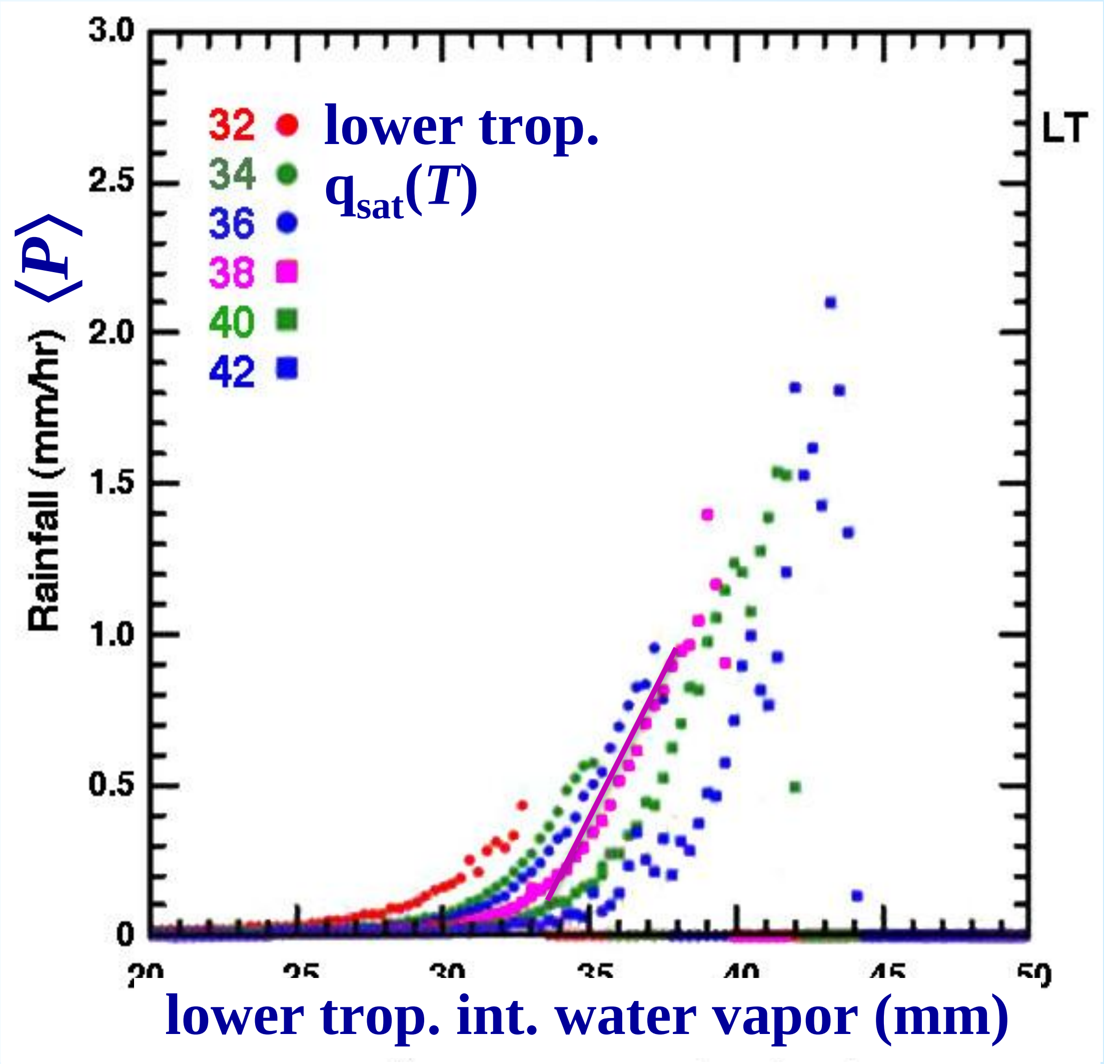



- **Find critical water vapor $w_c$ for each vert. avg. temp. $\hat{T}$**
- **Compare to vert. int. saturation vapor value binned by same $\hat{T}$**
- ***Not* e.g., a constant fraction of column saturation**
- **lower tropospheric saturation $q_{sat}(T)$ binning gives same results**

**Neelin, Peters & Hales, 2009, JAS**

# WRF W. Pac (4 km run) preliminary comparison*: Precip. dependence on lower tropospheric temperature ($q_{sat}$) & water vapor

- <*P*> averages conditioned on lower trop. layer $q_{sat}(T)$, &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:

**Quasi equilibrium mass flux closure: Zhang - McFarlane (1995) scheme modified with entraining plumes, convective momentum transport (Neale et al. 2008)**

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

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

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

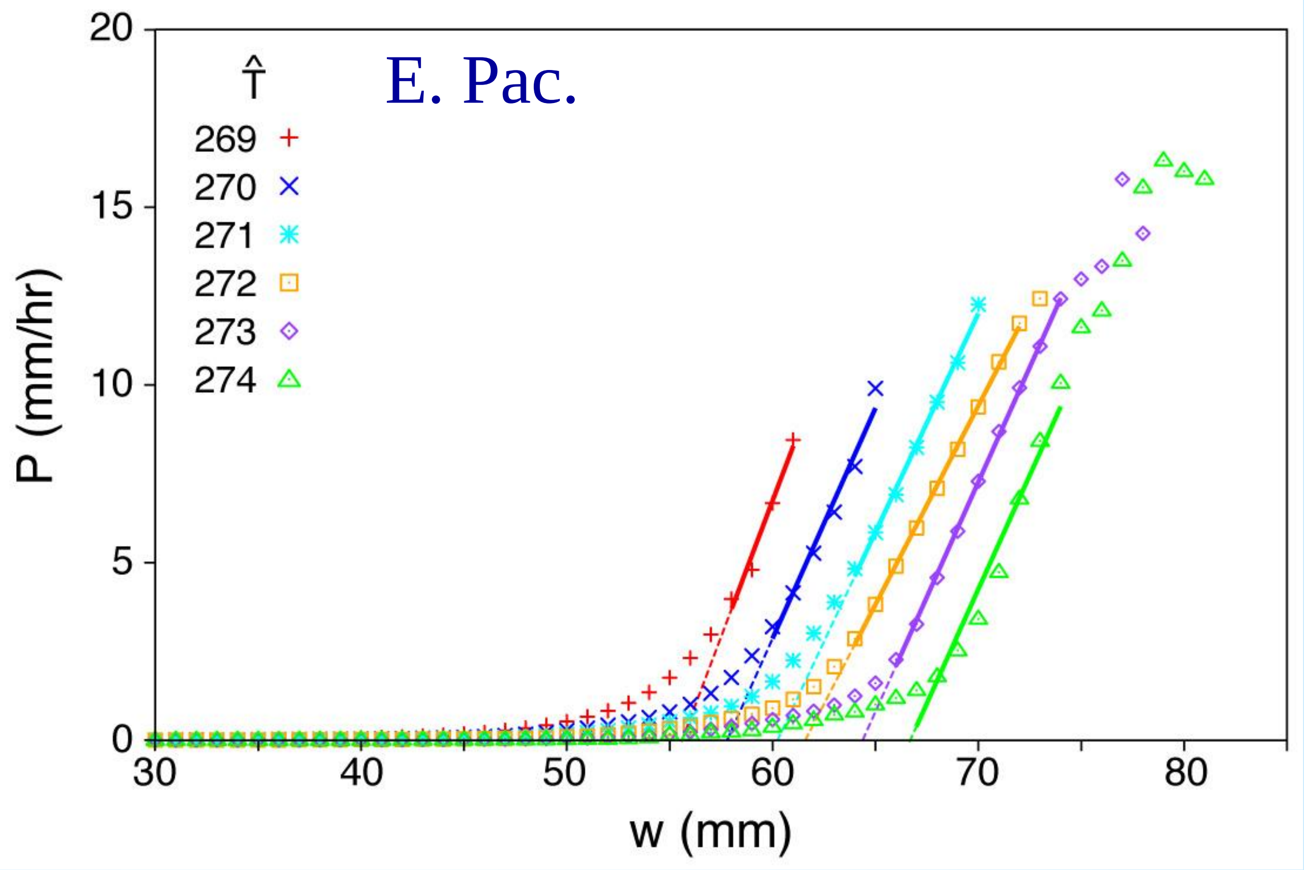
**** Convective available potential energy**

# 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)

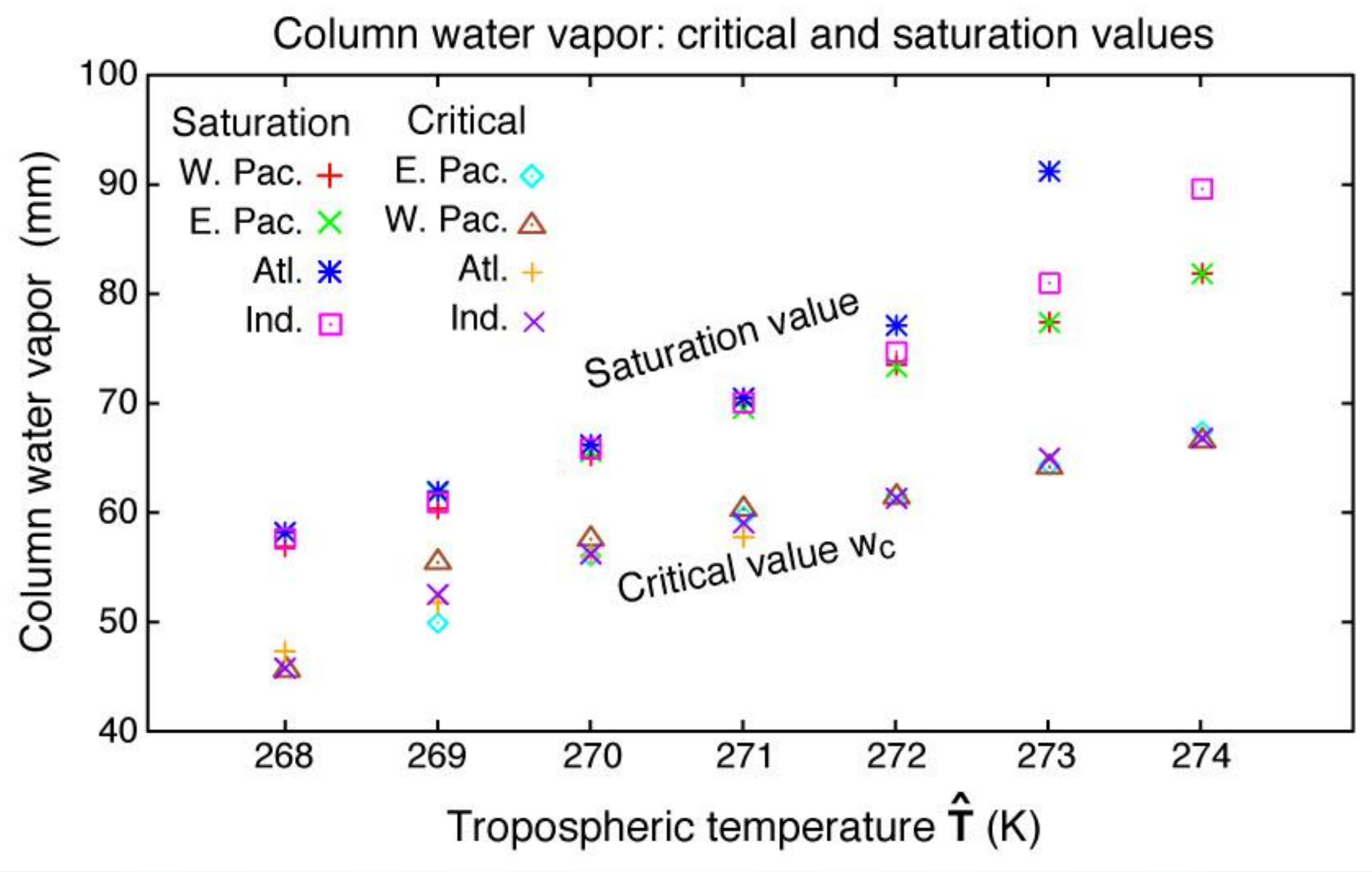
$P(w)=a(w-w_c)^{\beta}$

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

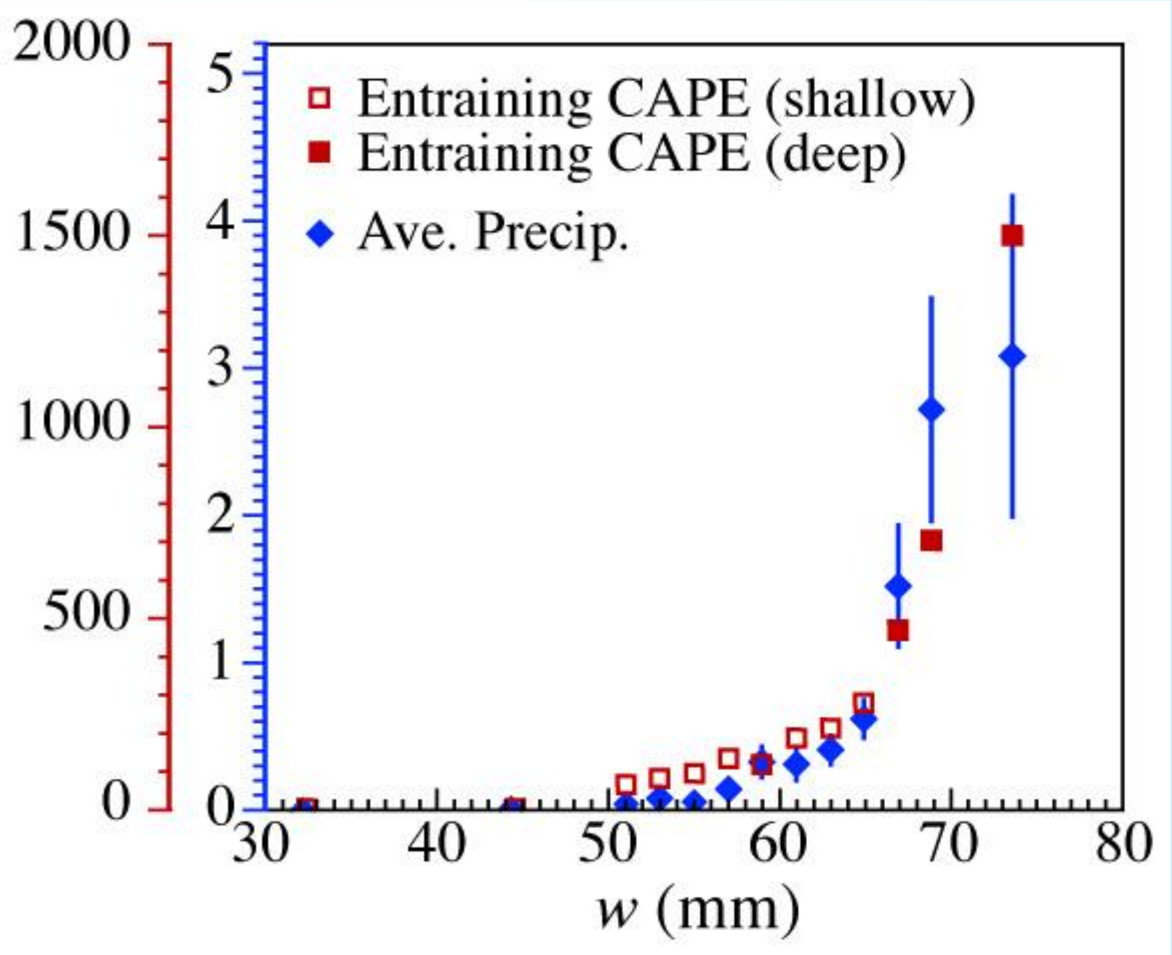



- **critical water vapor $w_c$ for each vert. avg. temp. $\hat{T}$**
- **Compare to vert. int. saturation vapor value binned by same $\hat{T}$**
- **Suggests suitable entraining plumes can capture T dependence**

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 troposph. 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)**

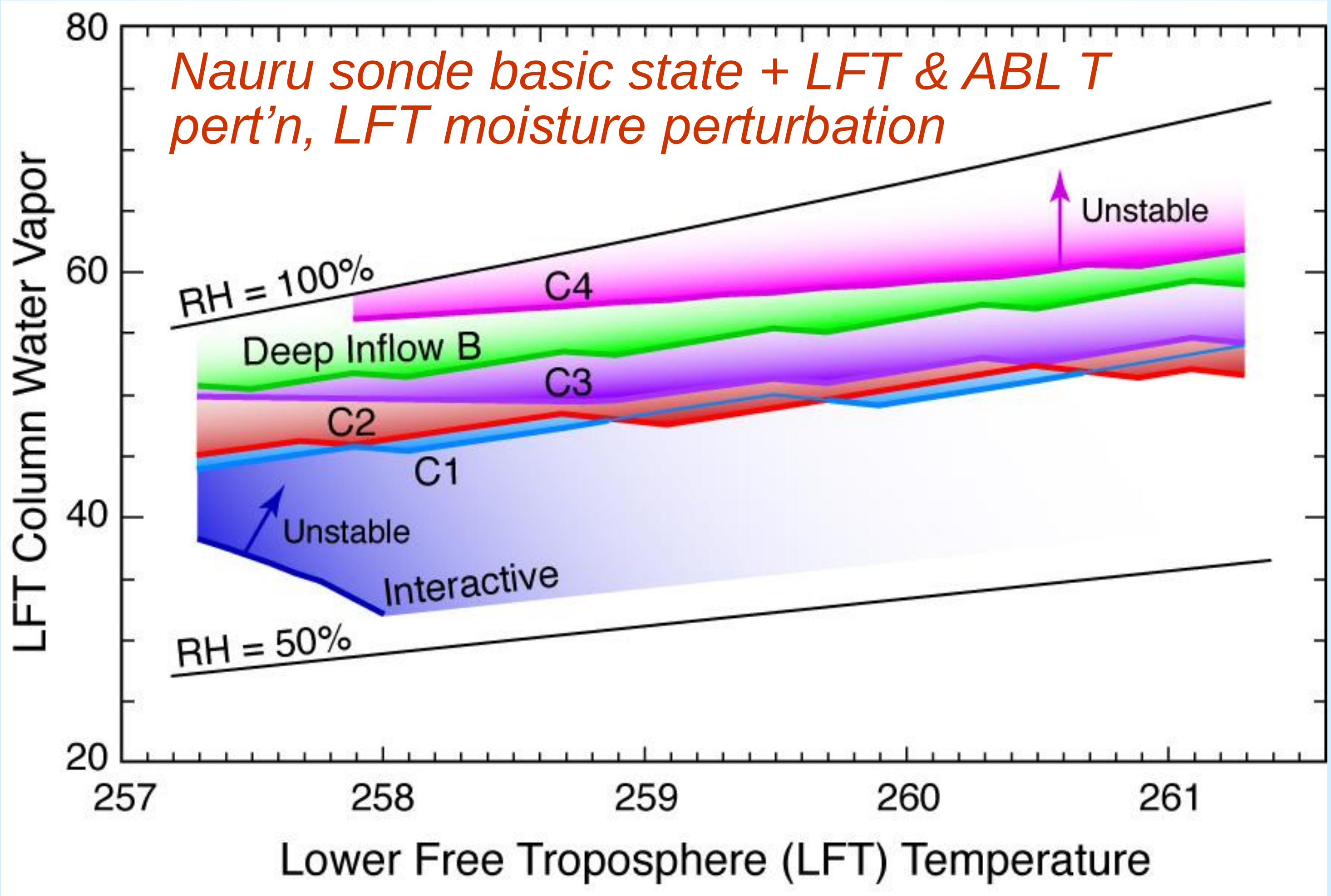



*Brown & Zhang 1997 entrainment; scheme and microphysics affect onset value, though not ordering.

**Holloway & Neelin, *JAS*, 2009**

**Neelin, Peters, Lin, Holloway & Hales, *Phil Trans. Roy. Soc. A*, 2008**

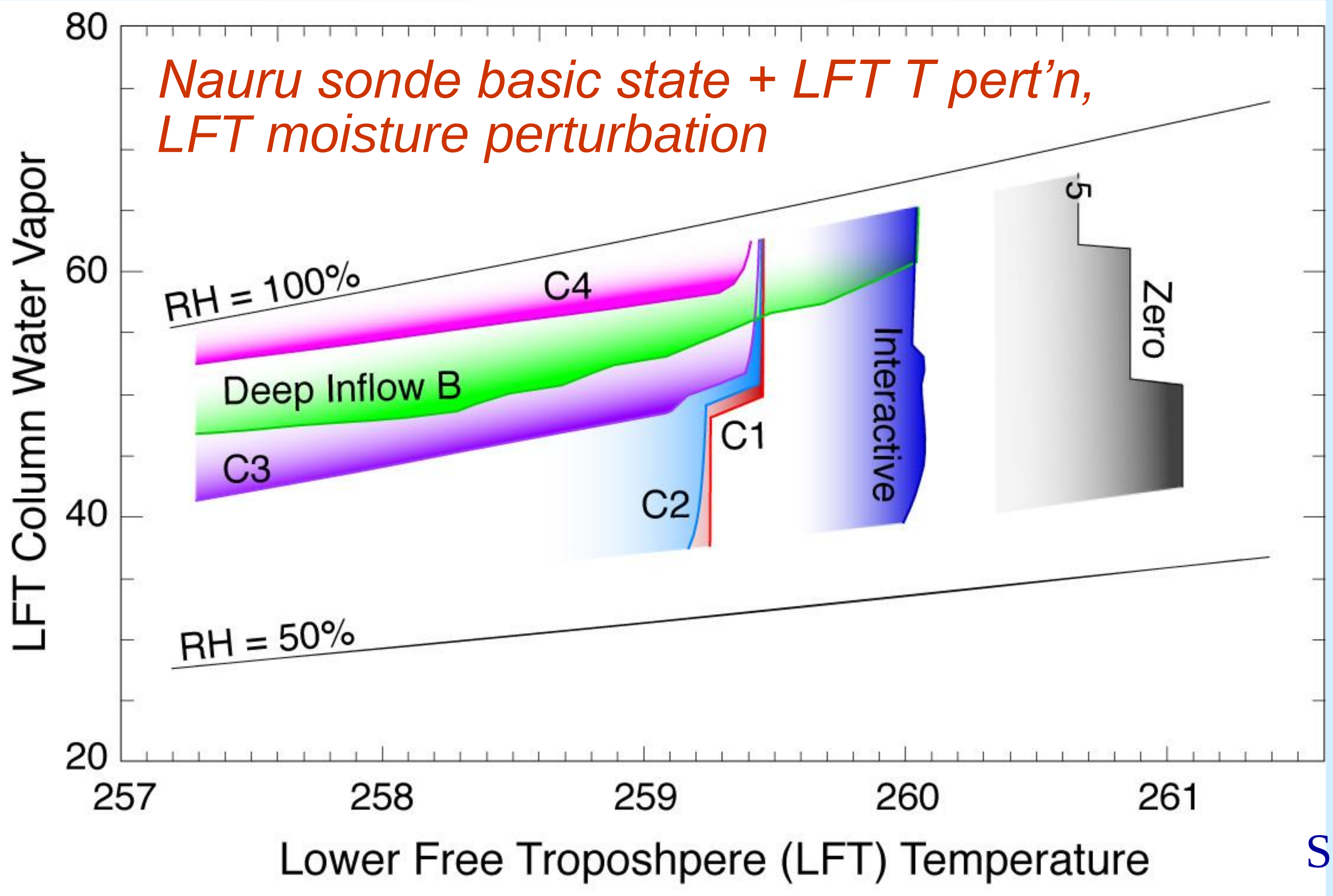
# Plume model stability boundaries (onset of vertical vel. at 175-225 hPa) for various entrainment cases




analysis
S. Sahany

C1, C2, C3, C4: free troposheric 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

# Plume model stability boundaries for various entrainment cases

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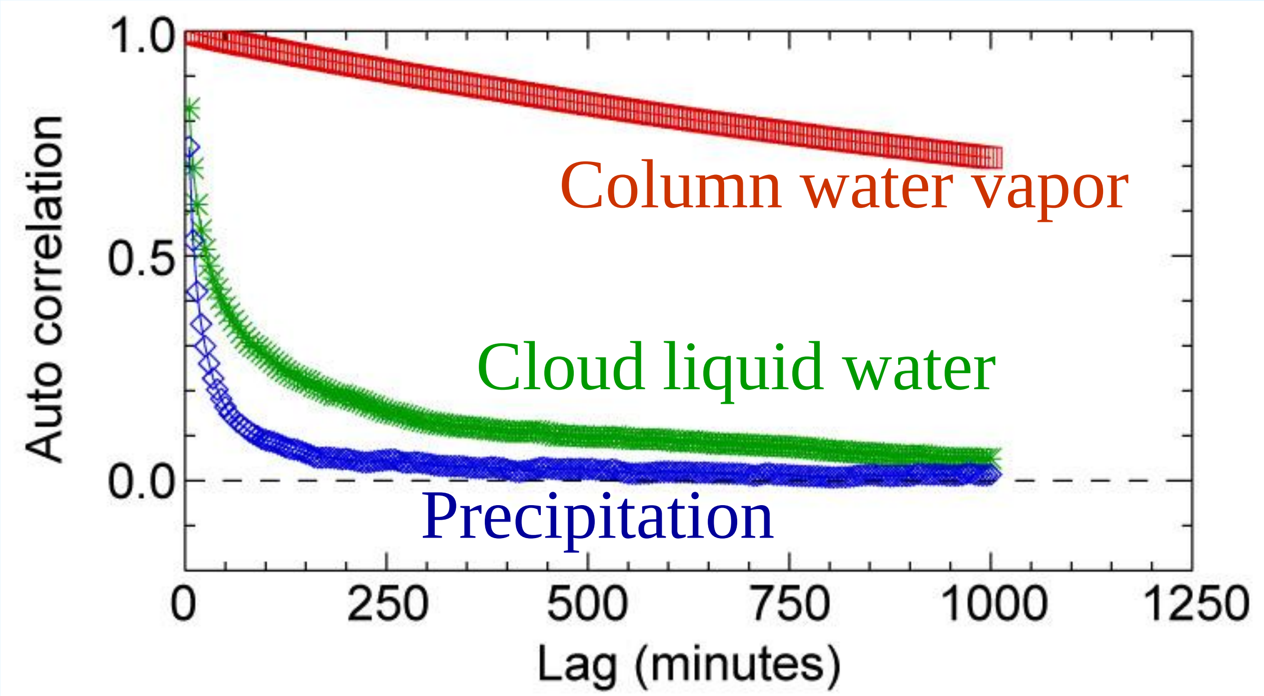
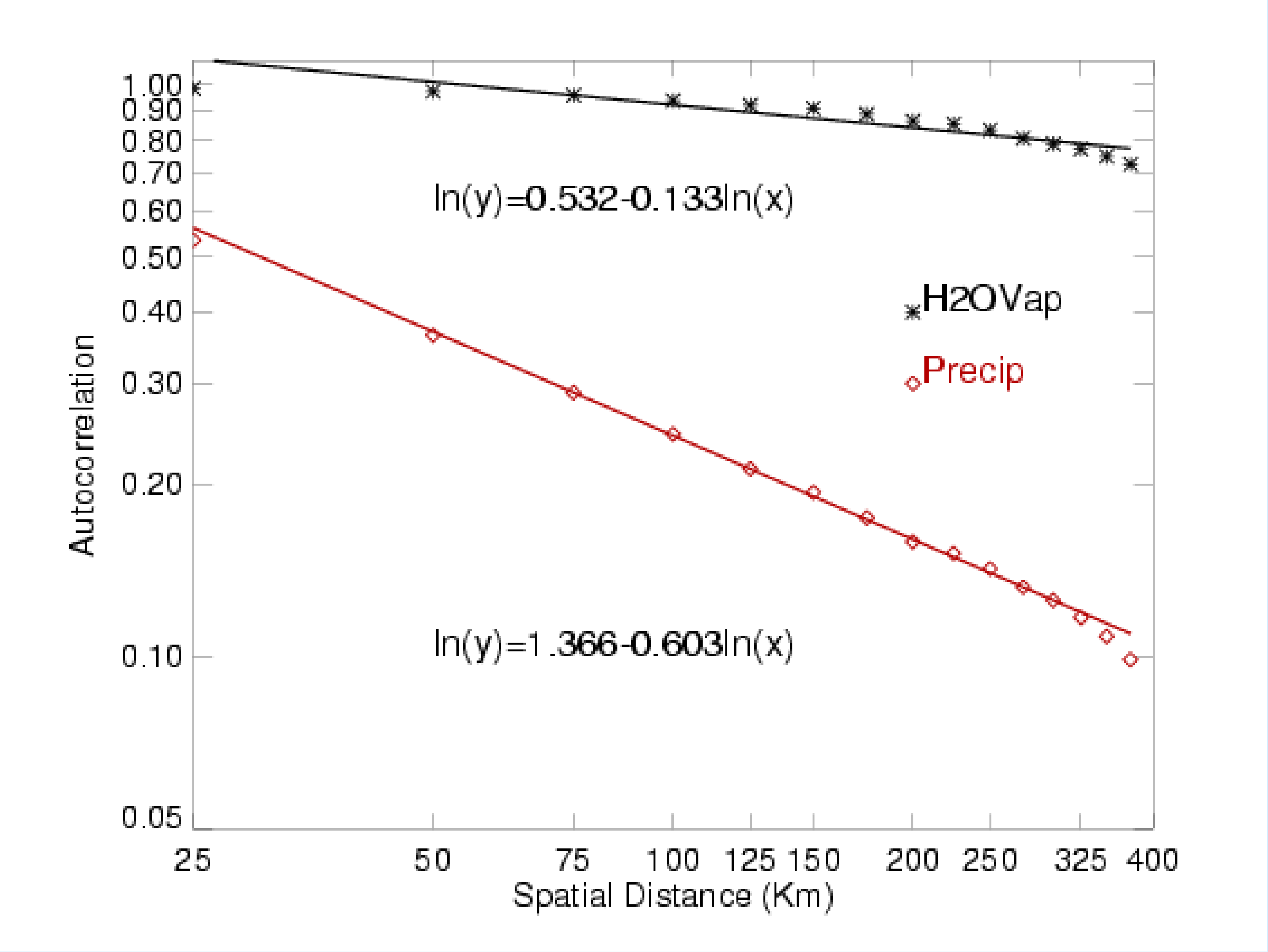
# Prec & column water vapor: autocorrelations in time

- **Long autocorrelation times for vertically integrated moisture (once lofted, it floats around)**
- **Nauru ARM site upward looking radiometer + optical gauge**



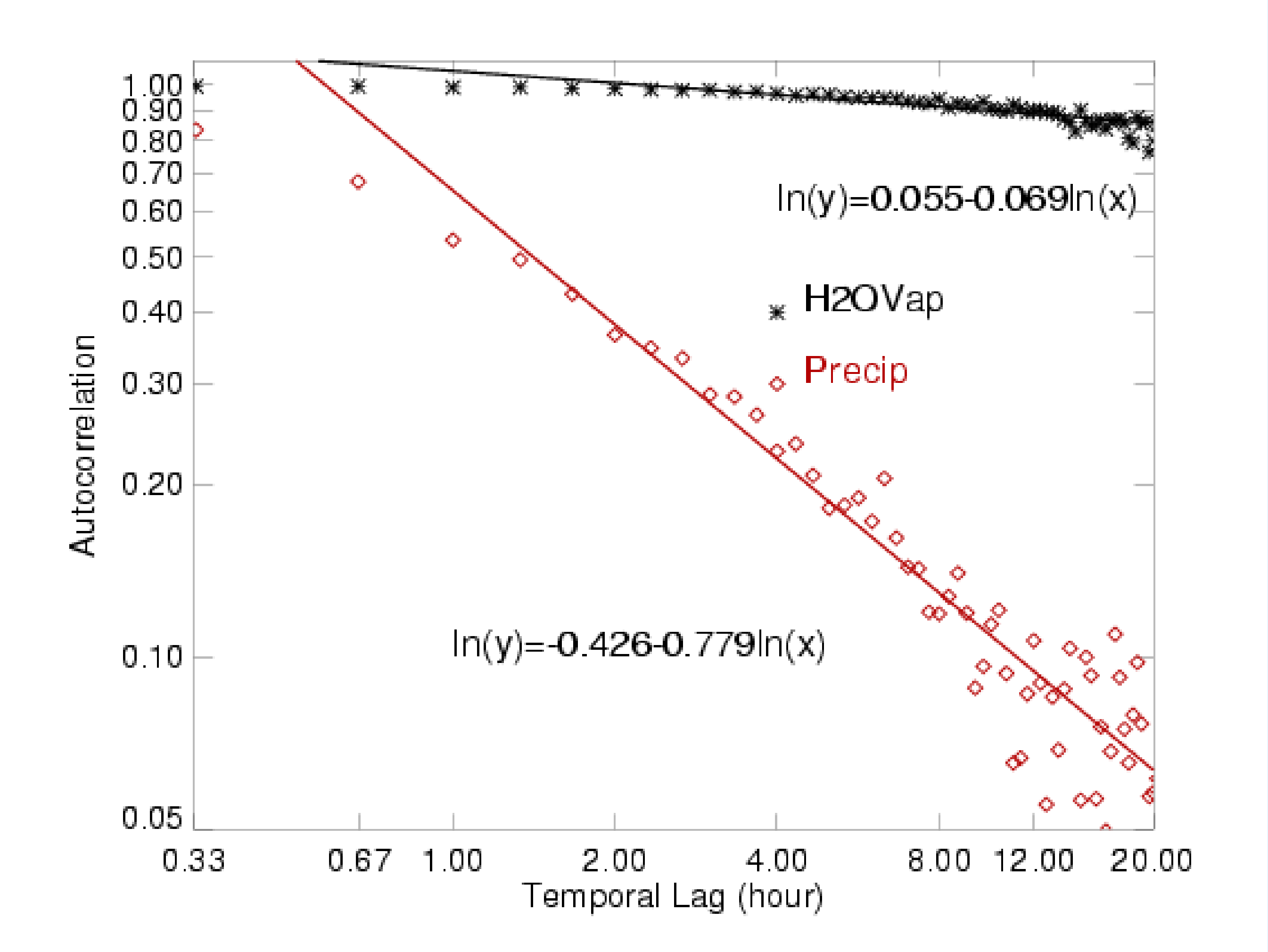

**Neelin, Peters, Lin, Holloway & Hales, 2008, *Phil Trans. Roy. Soc. A***

# TMI precipitation and column water vapor spatial correlations




analysis BaijunTian

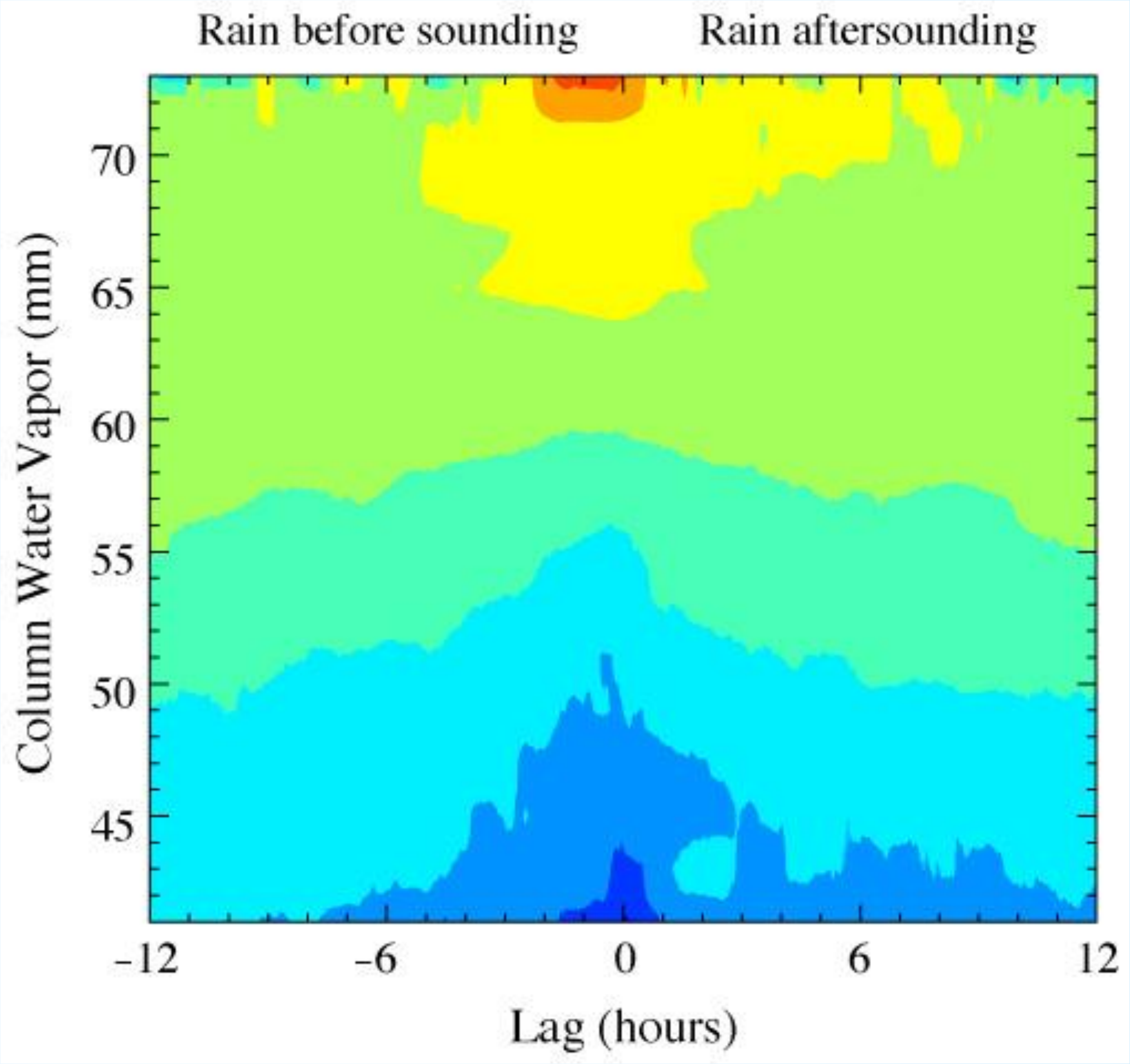
# TMI-AMSRE precipitation and column water vapor temporal correlations




analysis BaijunTian

# 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 ⇒ favorable environment, but stochastic plume
- Nauru ARM site upward looking radiometer + optical gauge



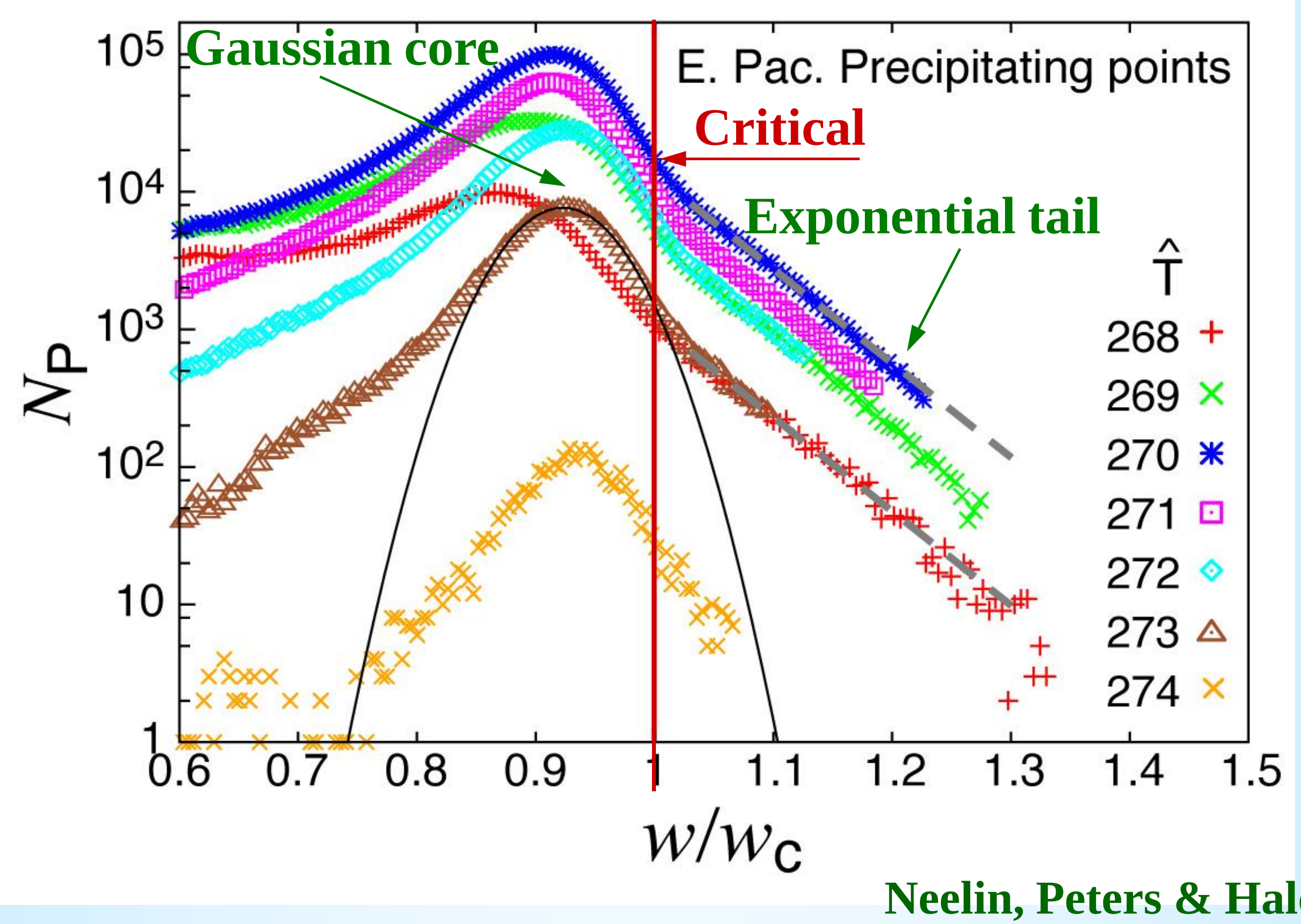

Holloway and Neelin 2010, *JAS*

# 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)

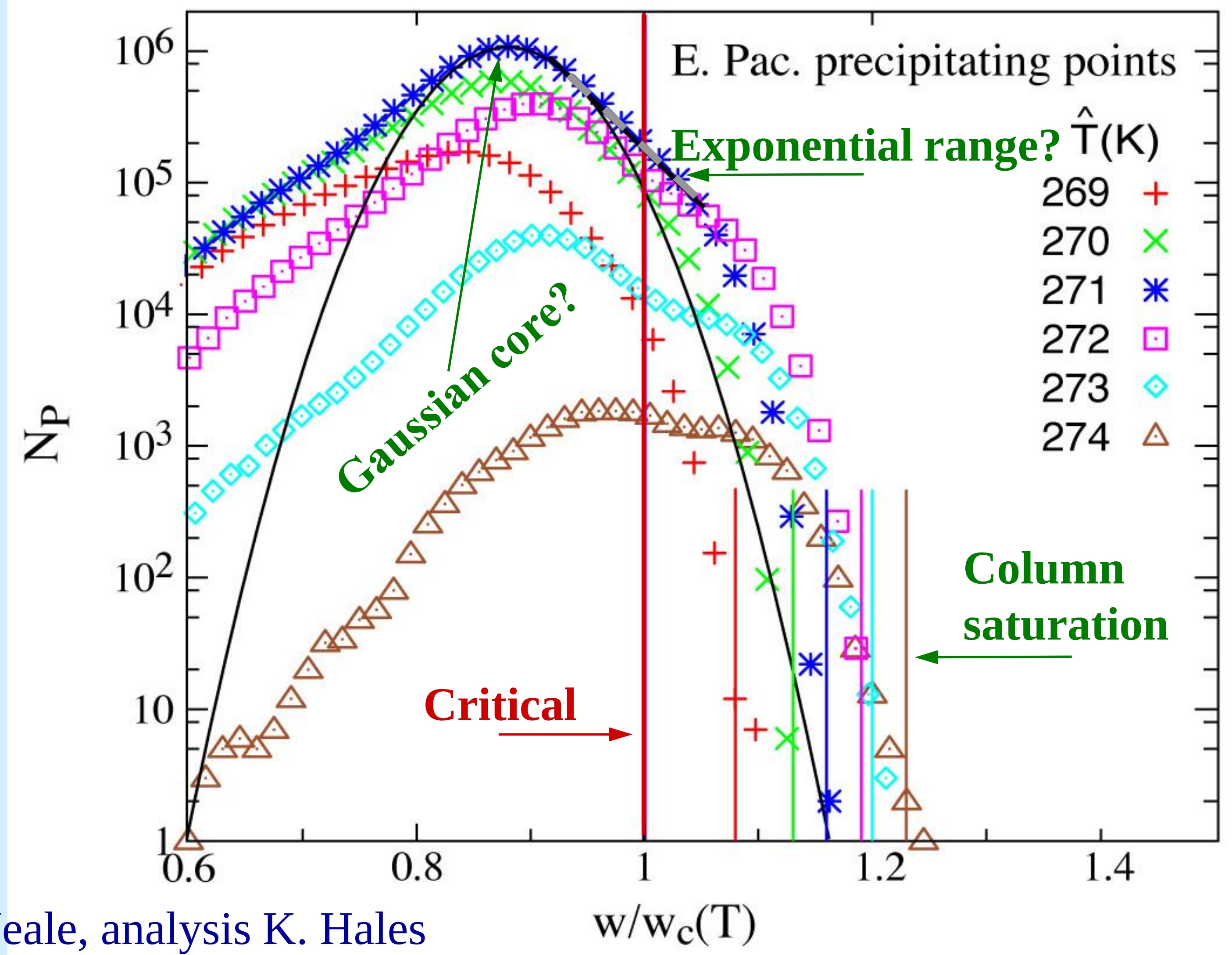



Neelin, Peters & Hales, 2009, JAS

# Precipitating freq. of occurrence vs. $w/w_c$

## Eastern Pacific for various tropospheric temperatures

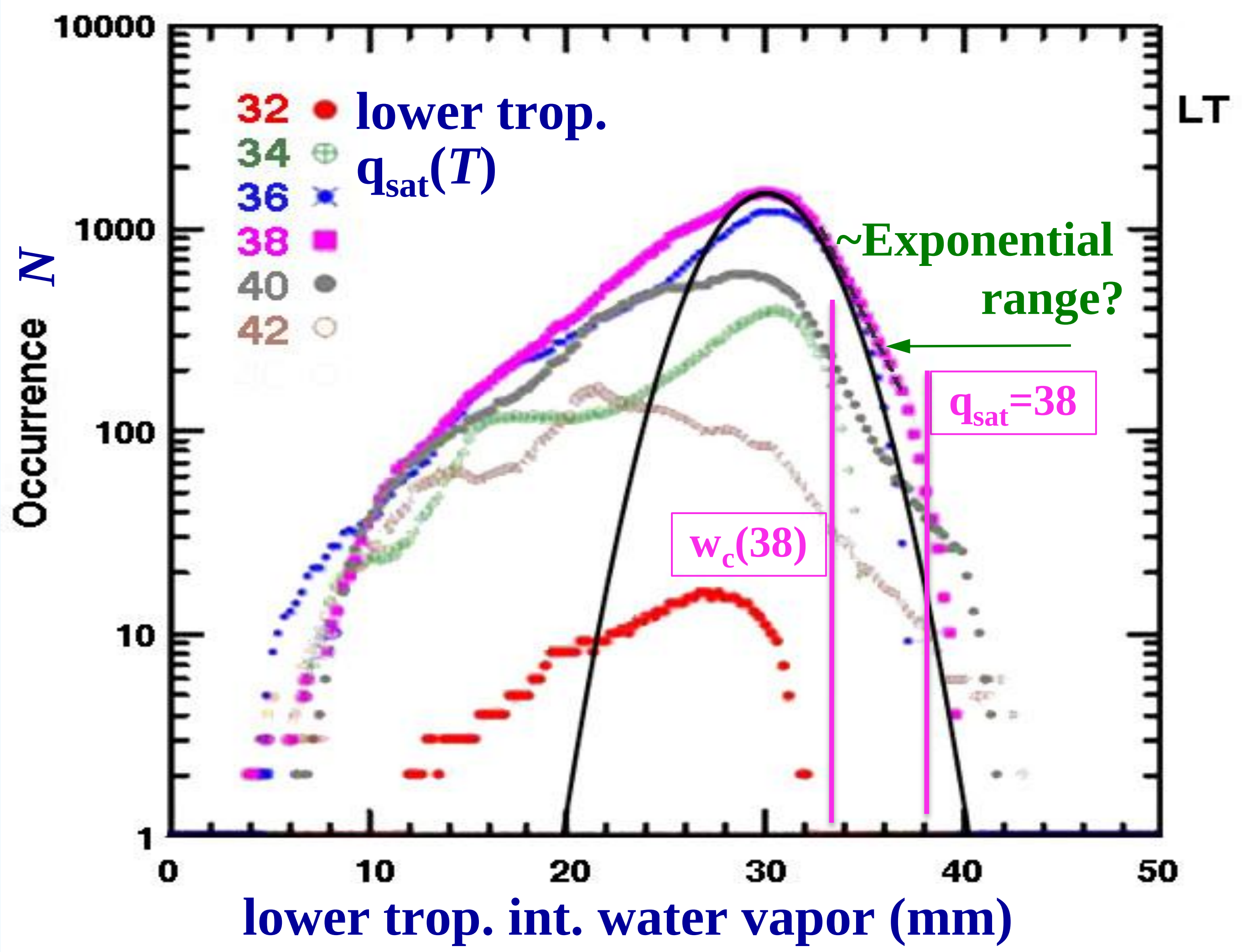
- CAM3.5 preliminary comparison
- Includes super-Gaussian ~exponential range above critical pt.




Runs R. Neale, analysis K. Hales

# WRF W. Pac (4 km run) preliminary comparison*: frequency of occurrence *N* of lower tropospheric water vapor by $q_{sat}(T)$

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




*analysis Hsiao-ming Hsu

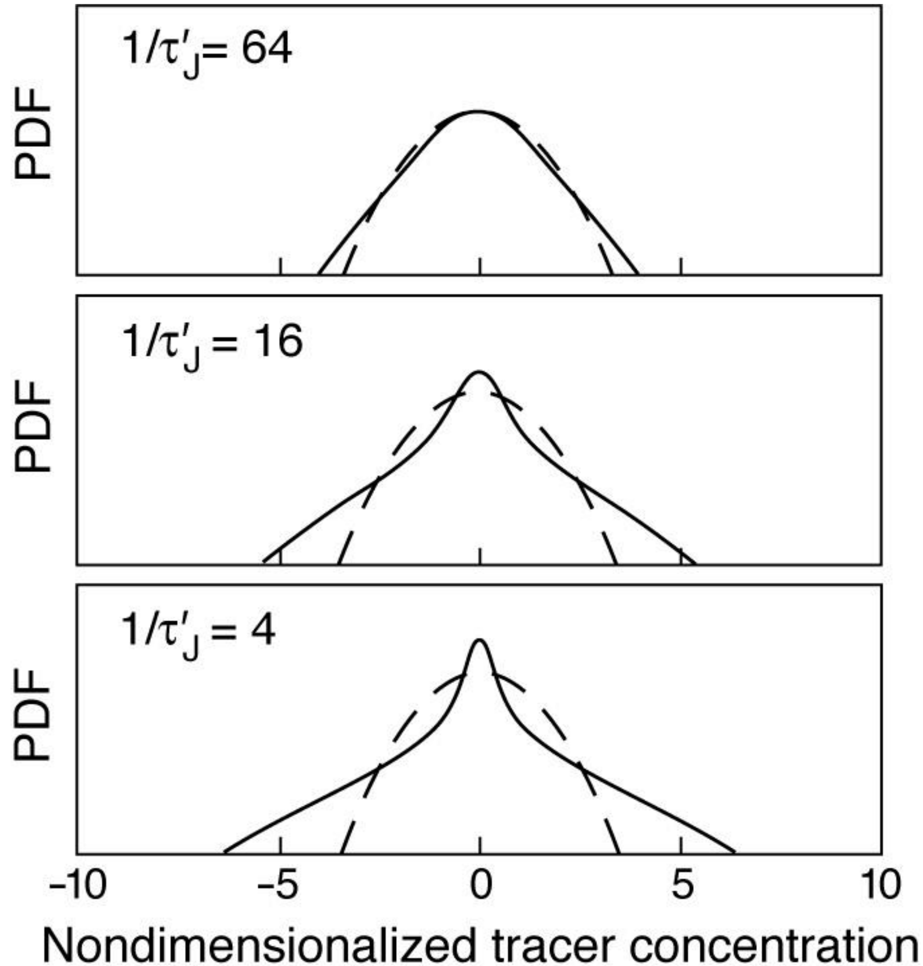
# Passive tracer advection-diffusion---probability density function from simple flow configuration

"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**

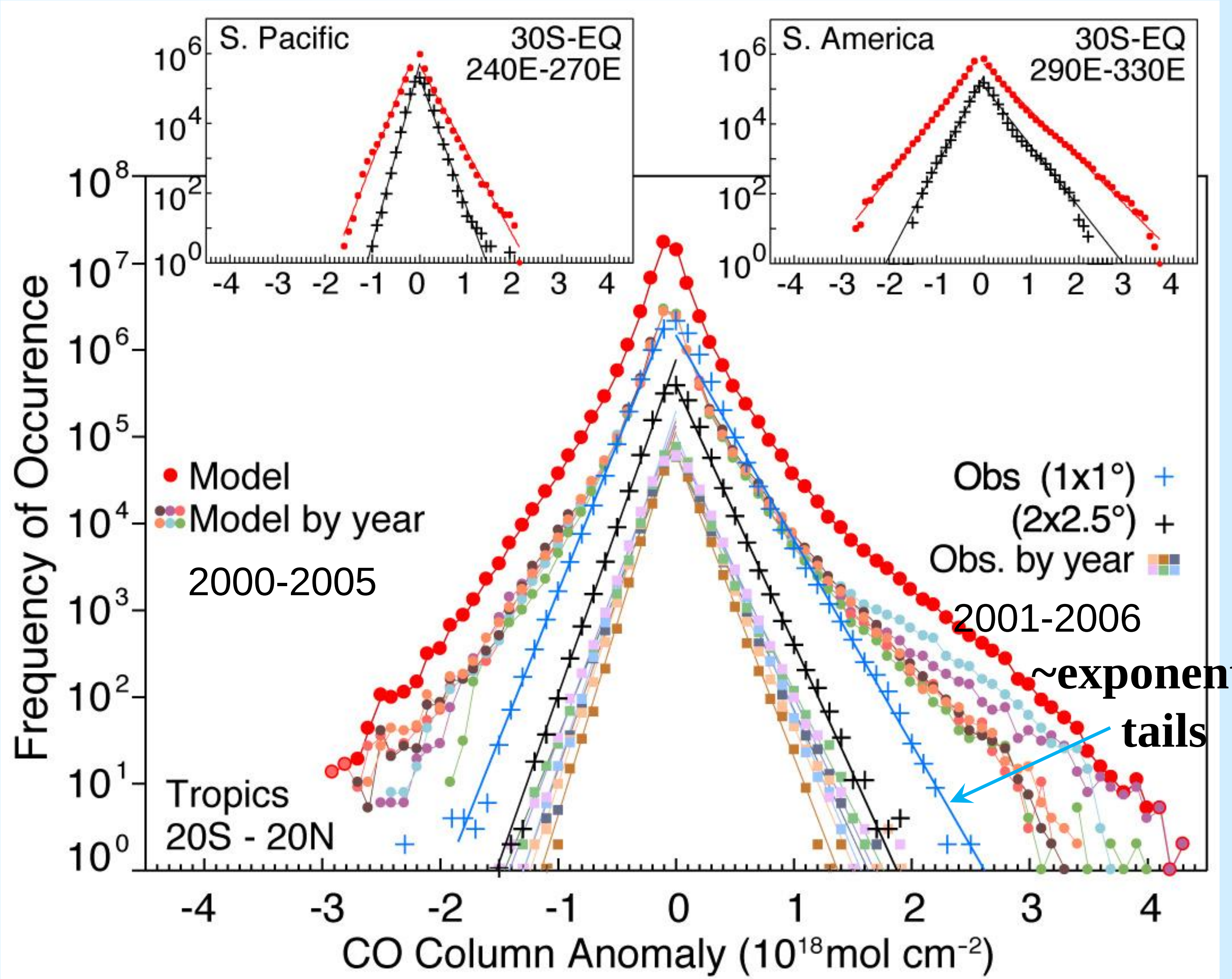
**Prototype applicable to tropospheric tracers? Incl. CWV??**

**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

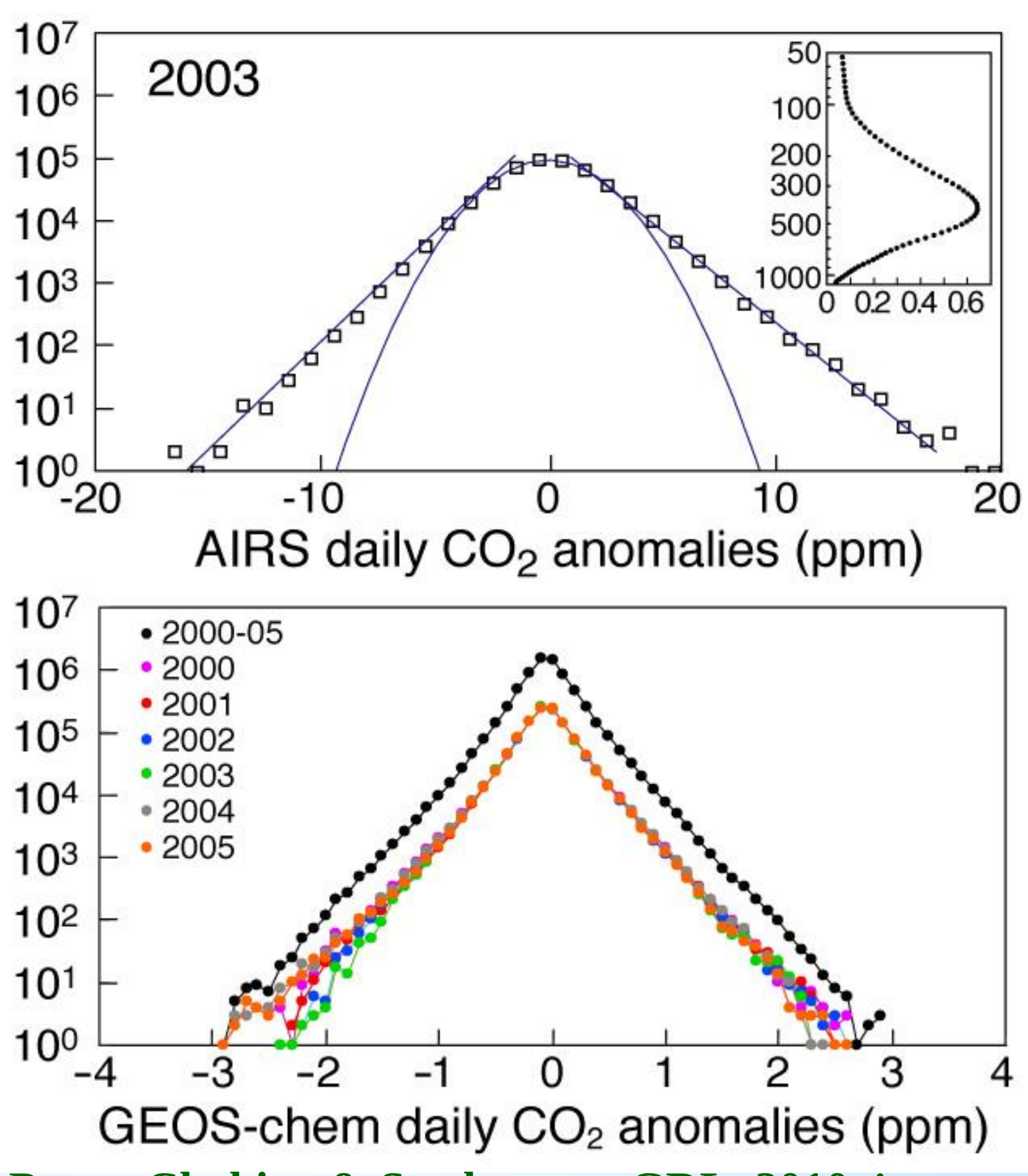
- **AIRS retrievals**

**(Chahine et al 2005, 2008)**

**(Analysis: Ben Lintner)**

- **GEOS-Chem simulations projected on AIRS weighting functions**

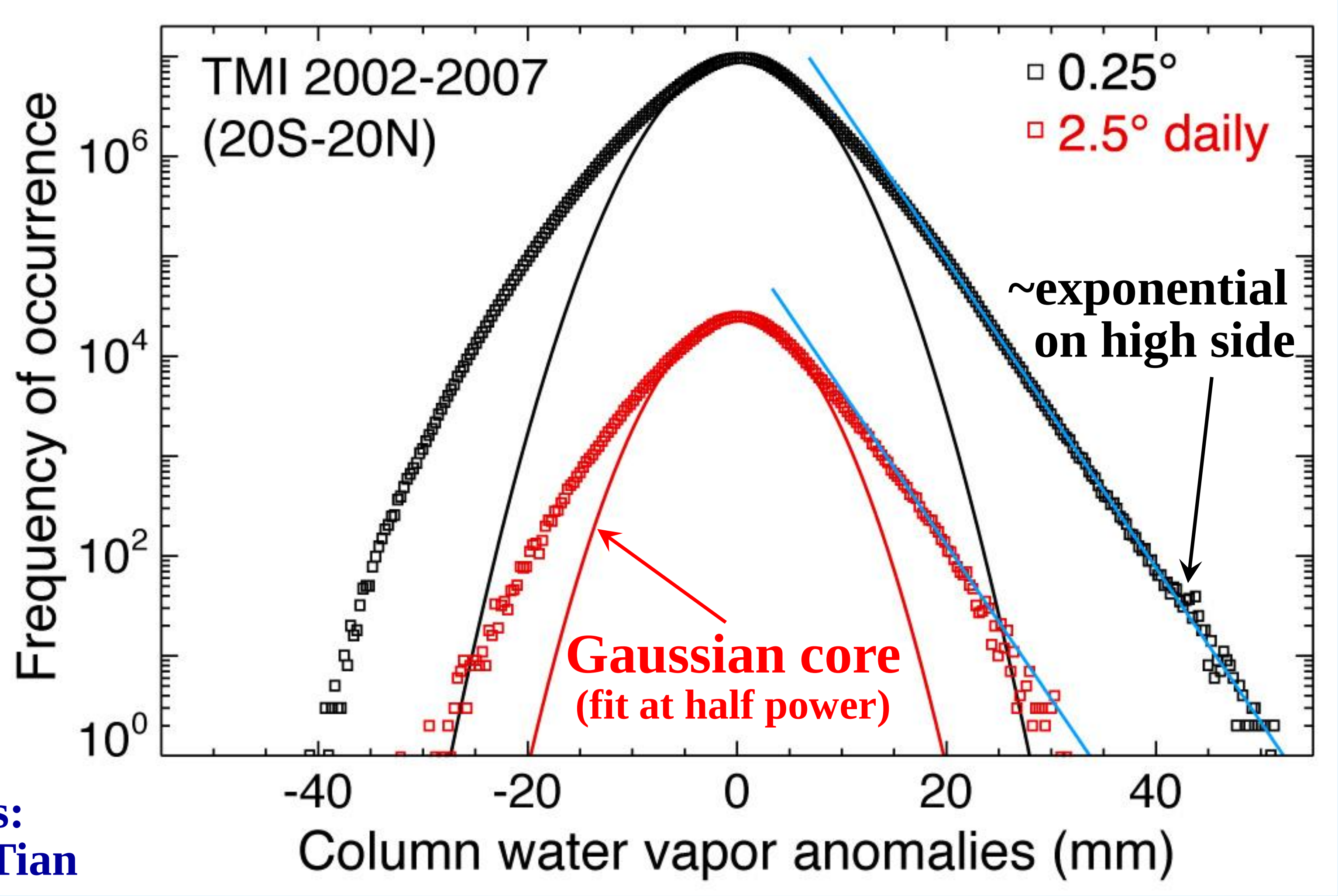
**(Analysis: Qinbin Li, Li Zhang)**




**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

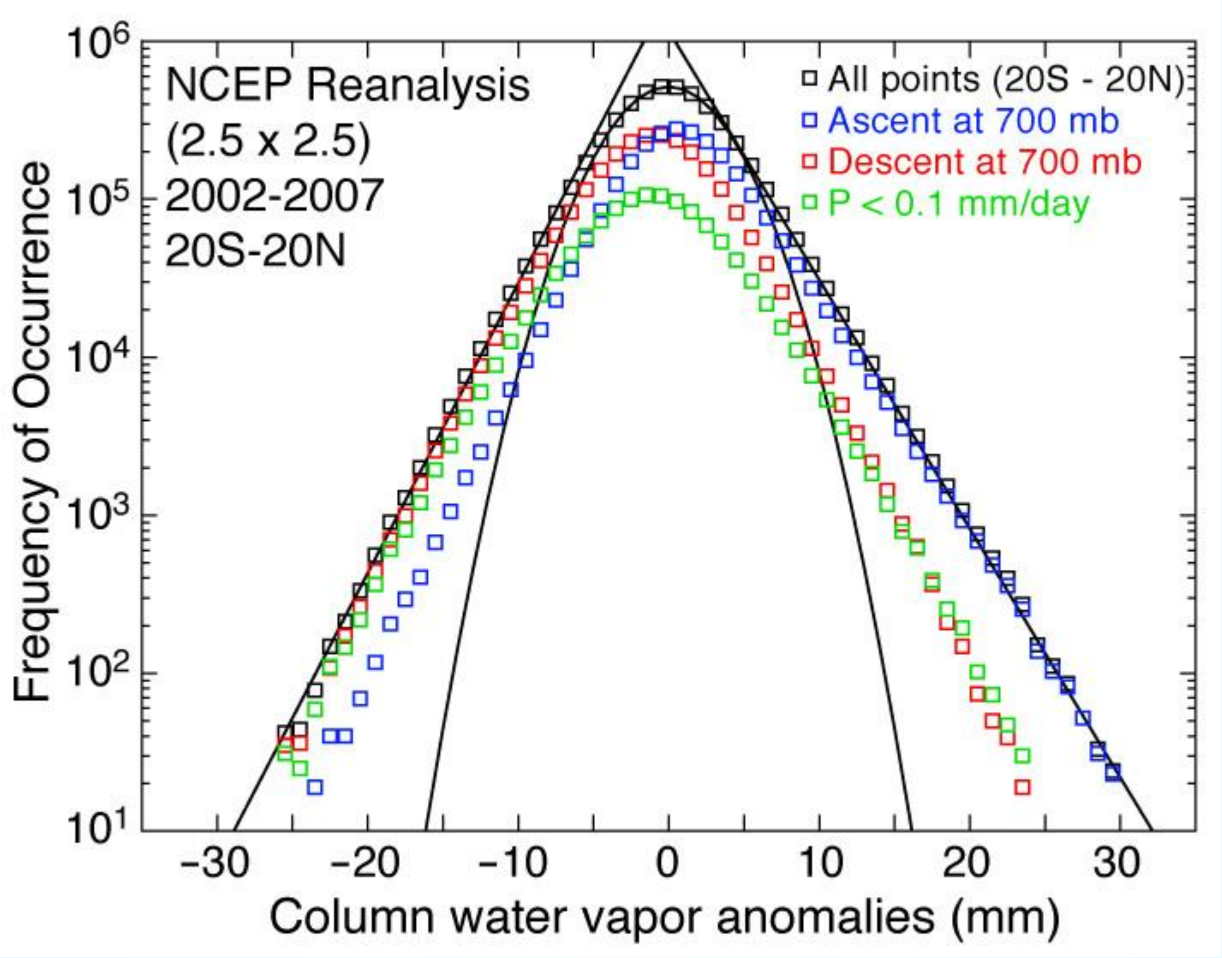



**Analysis:**
**Baijun Tian**

**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**

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