Water vapor and the transition to strong convection

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- **Issues with precip. simulation, esp. at regional scales, tropics: global warming, El Niño…, Sensitivity to convective schemes**
  e.g., IPCC 2001, 2007; Trenberth et al 2003; Maloney and Hartmann 2001; Joseph and Nigam 2006; Biasutti et al. 2006; Dai 2006; Tost et al. 2006; Neelin et al 2007; Bretherton 2007...

1. Sensitivity of convective margin zones

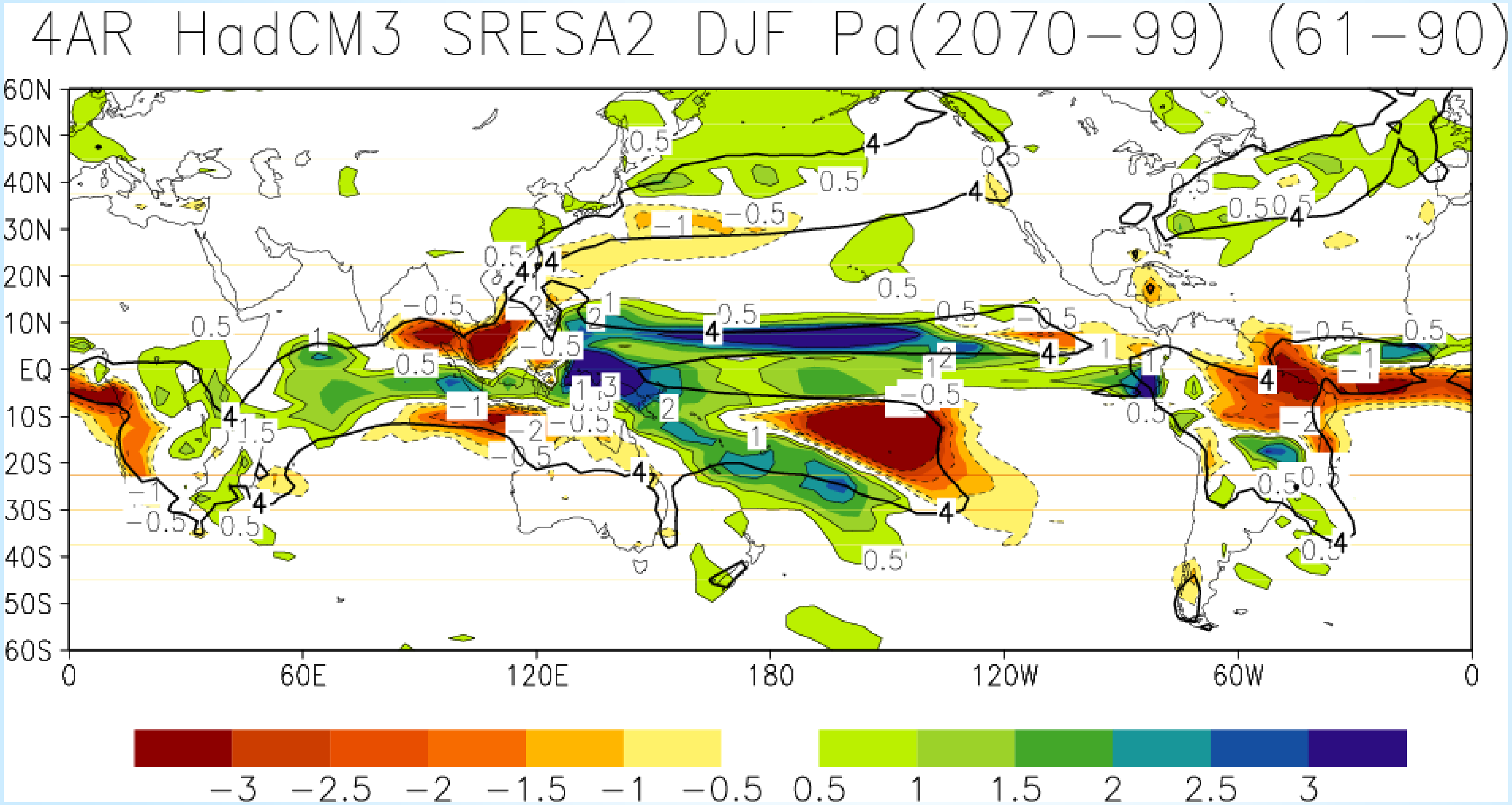
2. Characterizing transition to deep convection
  - dependence on temperature and water vapor
  - remote sensing statistics and buoyancy calculations from vertical structure

3. Long tails in distributions of column tracers

Issues with precipitation simulation, especially at regional scales, tropics: global warming, El Niño…

- **Sensitivity to convective schemes, interaction with large-scale**
- **[although some agreement on large-scale or amplitude]**

Precipitation change: HadCM3, Dec.-Feb., 2070-2099 avg minus 1961-90 avg.



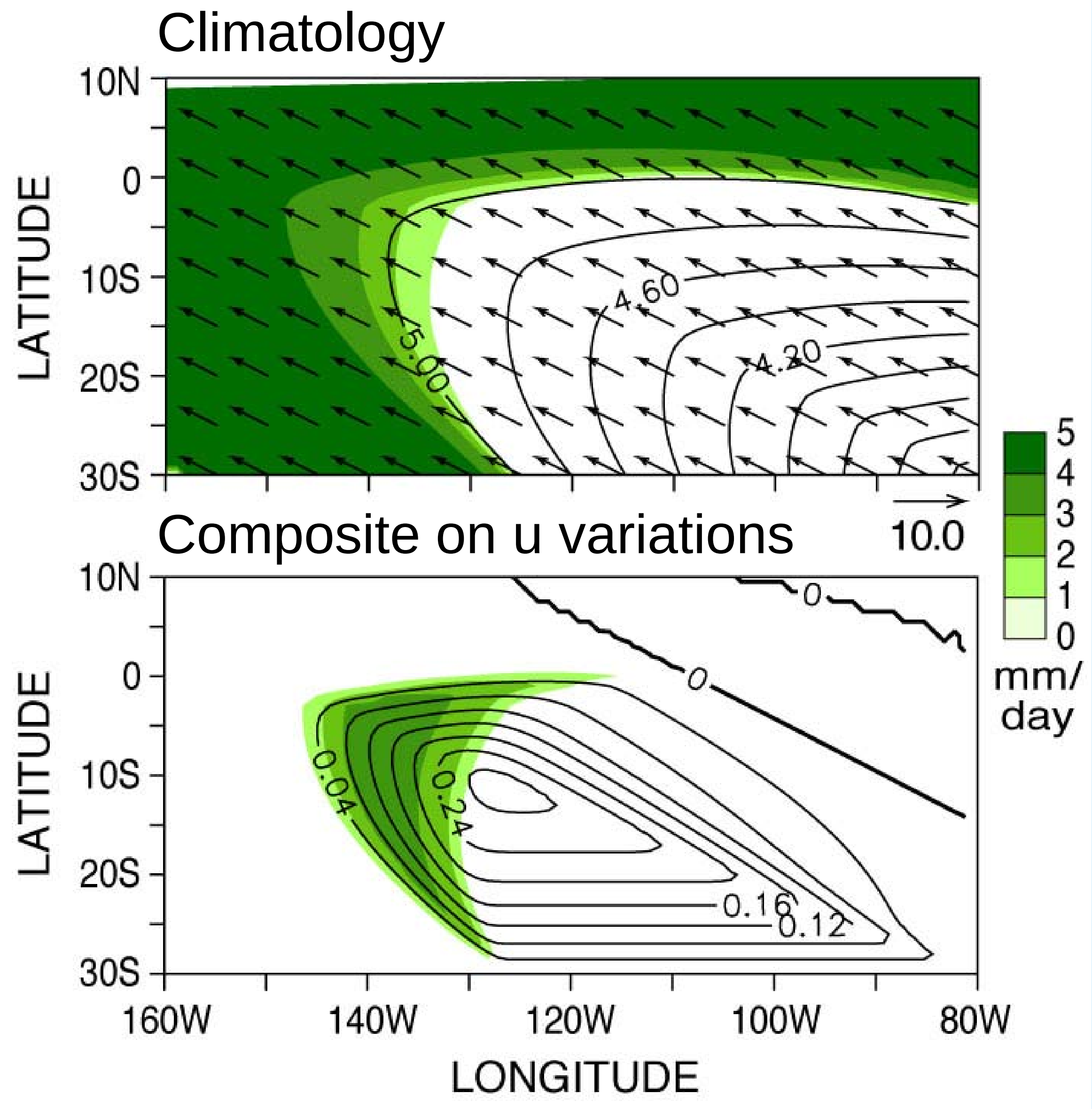
4 mm/day model climatology black contour for reference

e.g., IPCC 2001, 2007; Trenberth et al 2003; Maloney and Hartmann 2001; Joseph and Nigam 2006; Biasutti et al. 2006; Dai 2006; Tost et al. 2006; Neelin et al 2006; Bretherton 2007...

1. Sensitivity at convective margin

Prototype model*: dry advection into a precipitating region

Precipitation (green) and moisture (contours) would be constant except for trade wind inflow



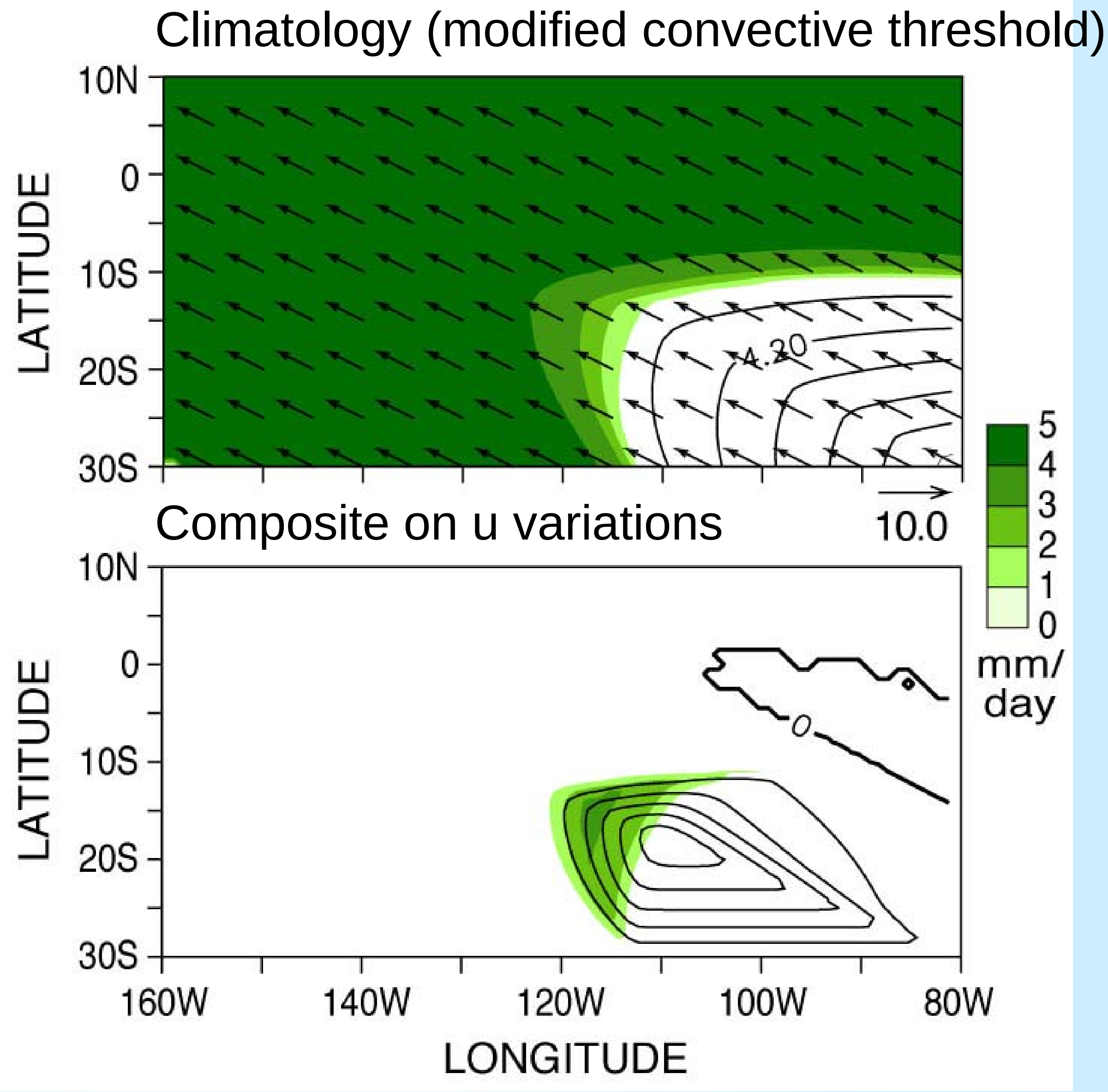
- temp. & moisture equations, specified wind + Gaussian variations;
- Analytic solutions for interplay with local thermodynamics and convective threshold

Lintner &Neelin 2008, GRL

Prototype model: change in threshold for convection

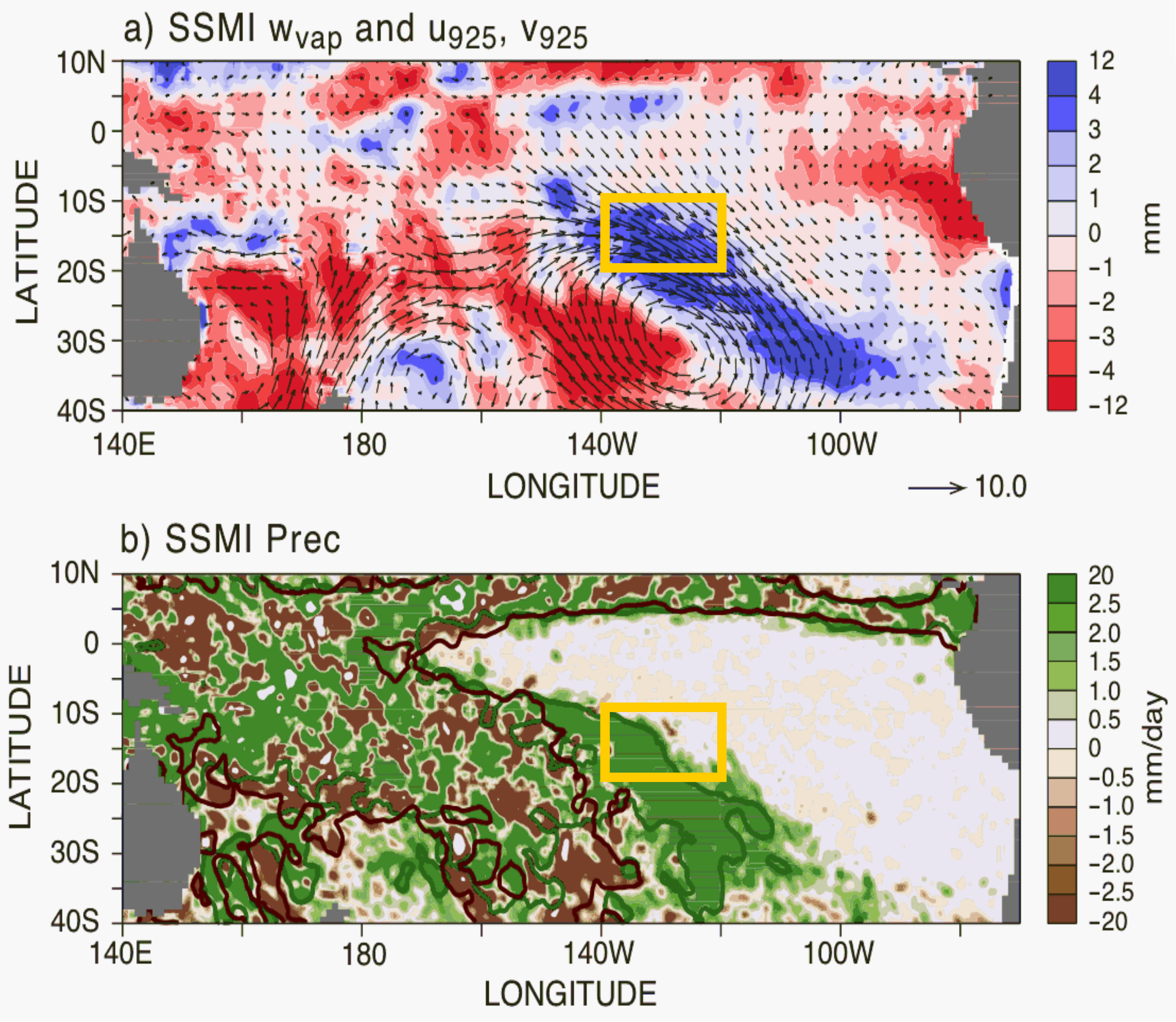
Precipitation (green) and moisture (contours)

Substantial impact of a poorly constrained aspect of convective schemes



Lintner &Neelin 2008, GRL

South Pacific Convergence Zone (SPCZ) composites: SSMI precip, column water vapor on wind variations



Daily SSMI

Composites on u925 mb avgd 140ºW-120ºW, 20ºS-10ºS.

4 mm day^{-1} (weaker trades/less low-level dry air inflow)

4 mm day^{-1} (stronger trades/more low-level dry air inflow)

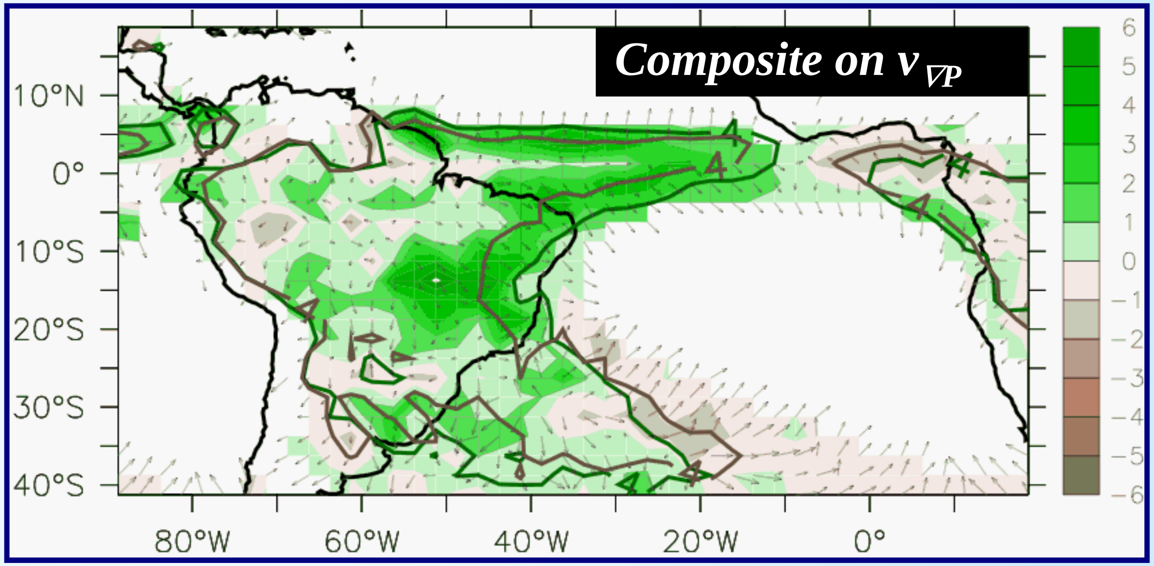
Lintner & Neelin (2008)

Precip. composite on local inflow wind anomaly

Inflow wind $v_{\nabla P}$ across gradient of mean precipitation

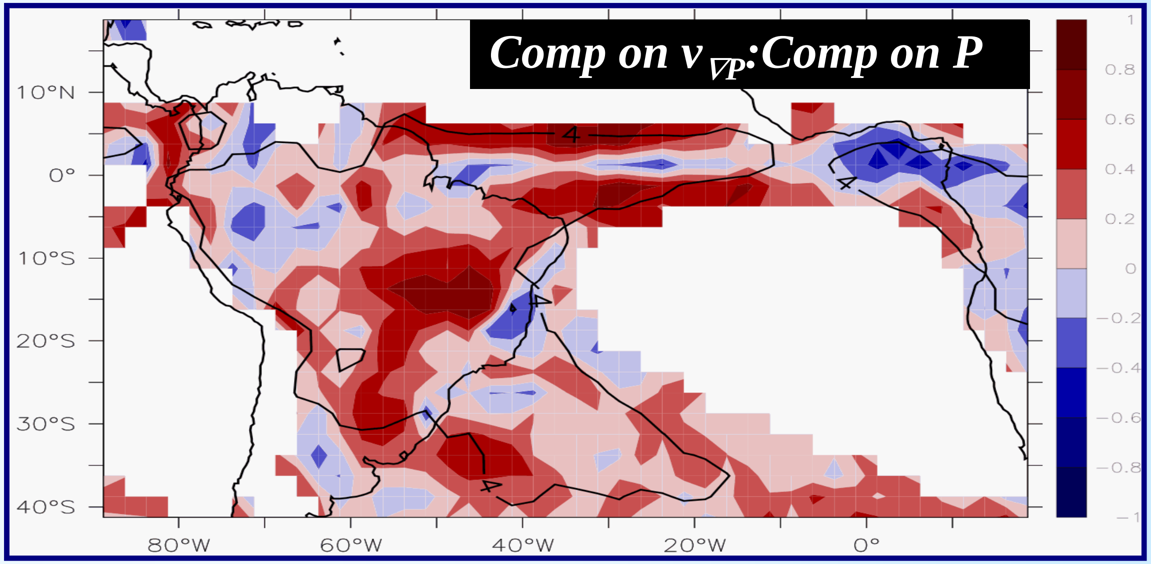
Atmospheric boundary layer (ABL) wind

Large sensitivity at margin



Ratio to composite on precipitation

Locally, monthly composite precipitation differences associated with inflow represent 80-90% of total composite-differenced precipitation



Lintner & Neelin (2009, subm)

2. Transition to strong convection

- **Convective quasi-equilibrium assumptions: 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; …
- **Pick up a function of buoyancy-related fields – temperature *T* & moisture (here column integrated moisture *w*)**
- **Elsewhere: Onset of strong convection conforms to list of properties for continuous phase transition with critical phenomena** (Peters & Neelin 2006, Nature Physics)**; mesoscale implications** (Peters, Neelin & Nesbitt 2009, JAS)
- **Stochastic convective schemes (and old-fashioned schemes too) need to better characterize the transition to deep convection**

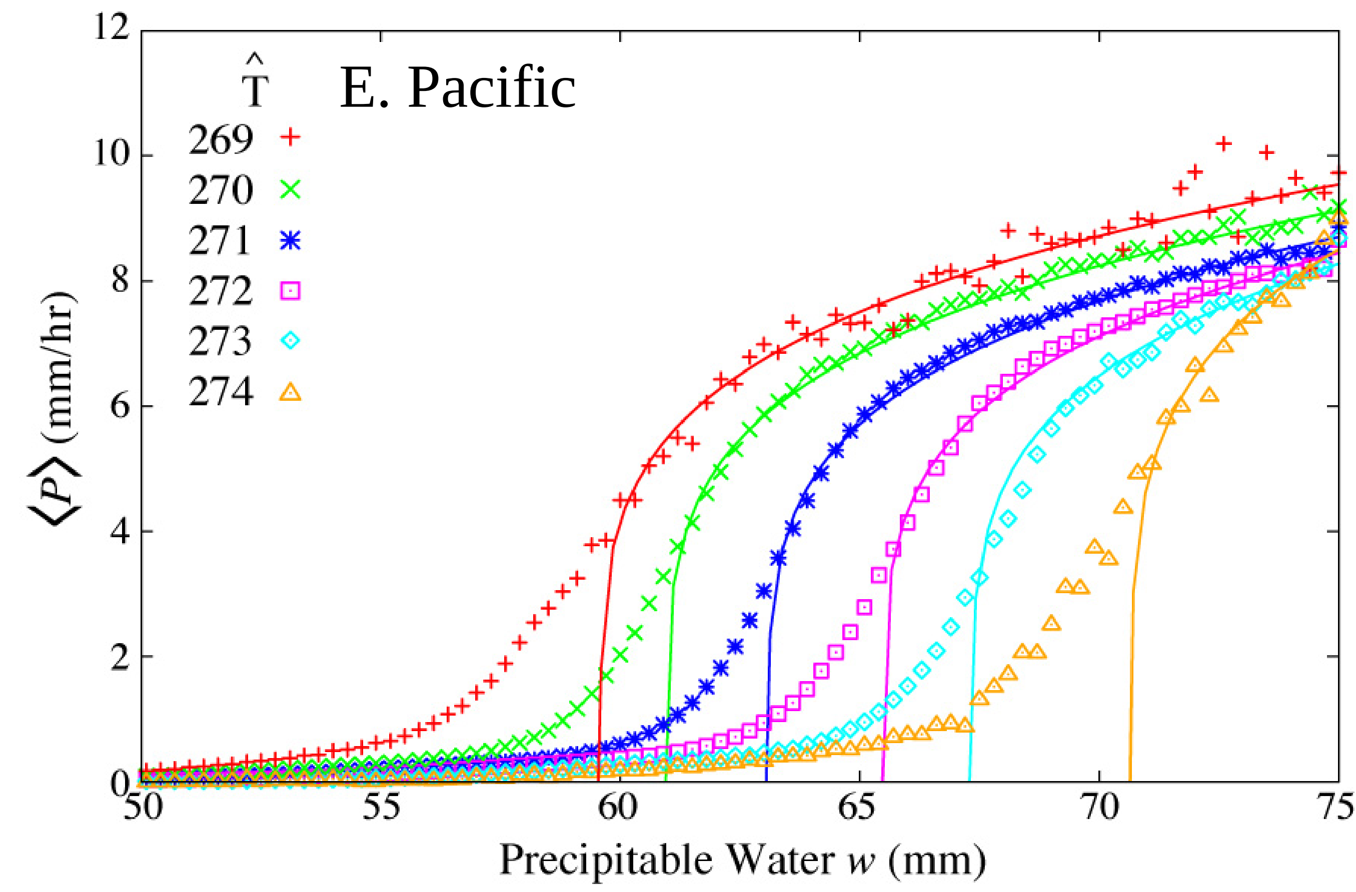
Precip. dependence on tropospheric temperature & column water vapor from TMI*

- **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 β

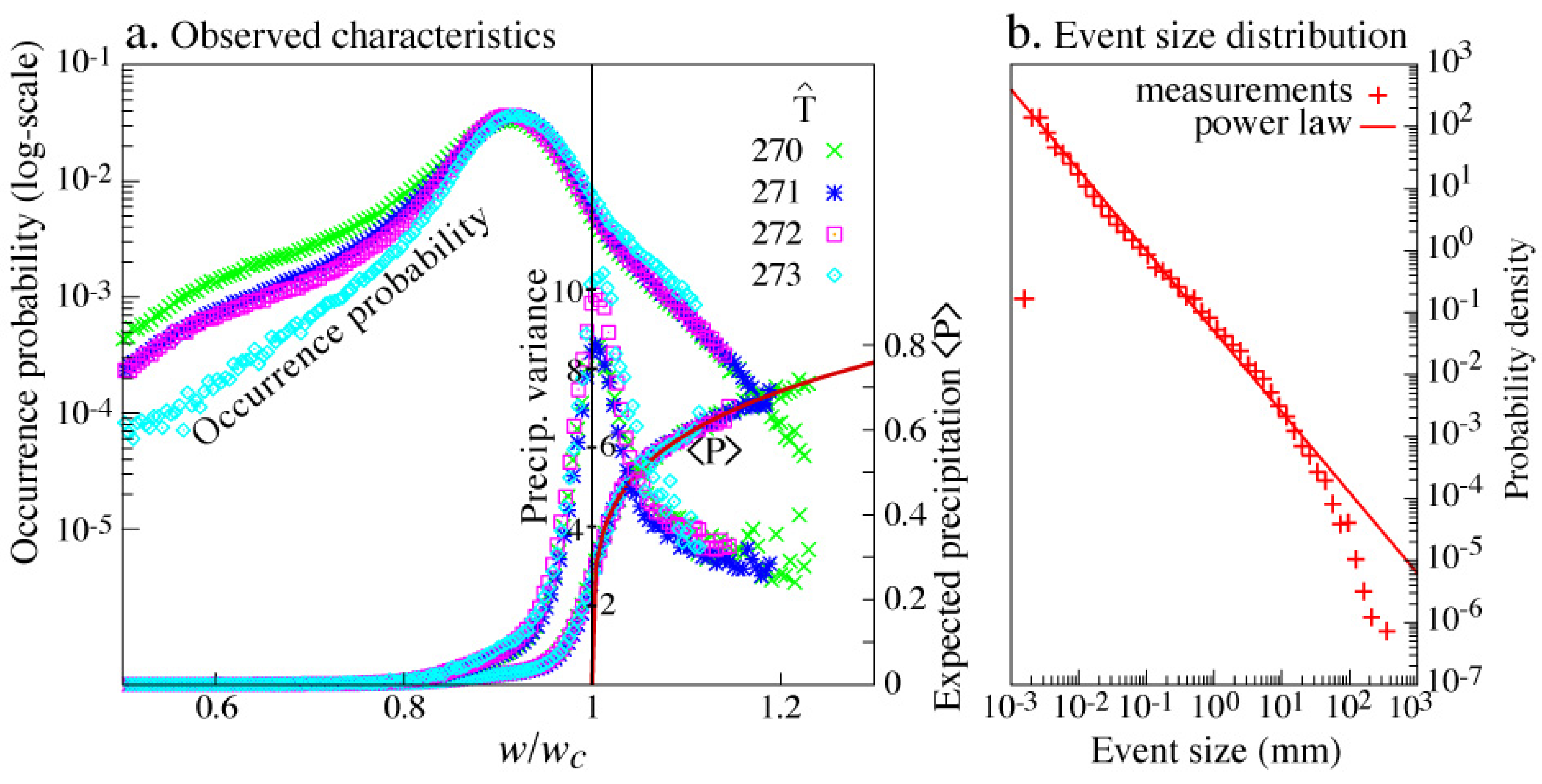
- **[note more data points at 270, 271]**



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

Neelin, Peters & Hales, 2009, JAS

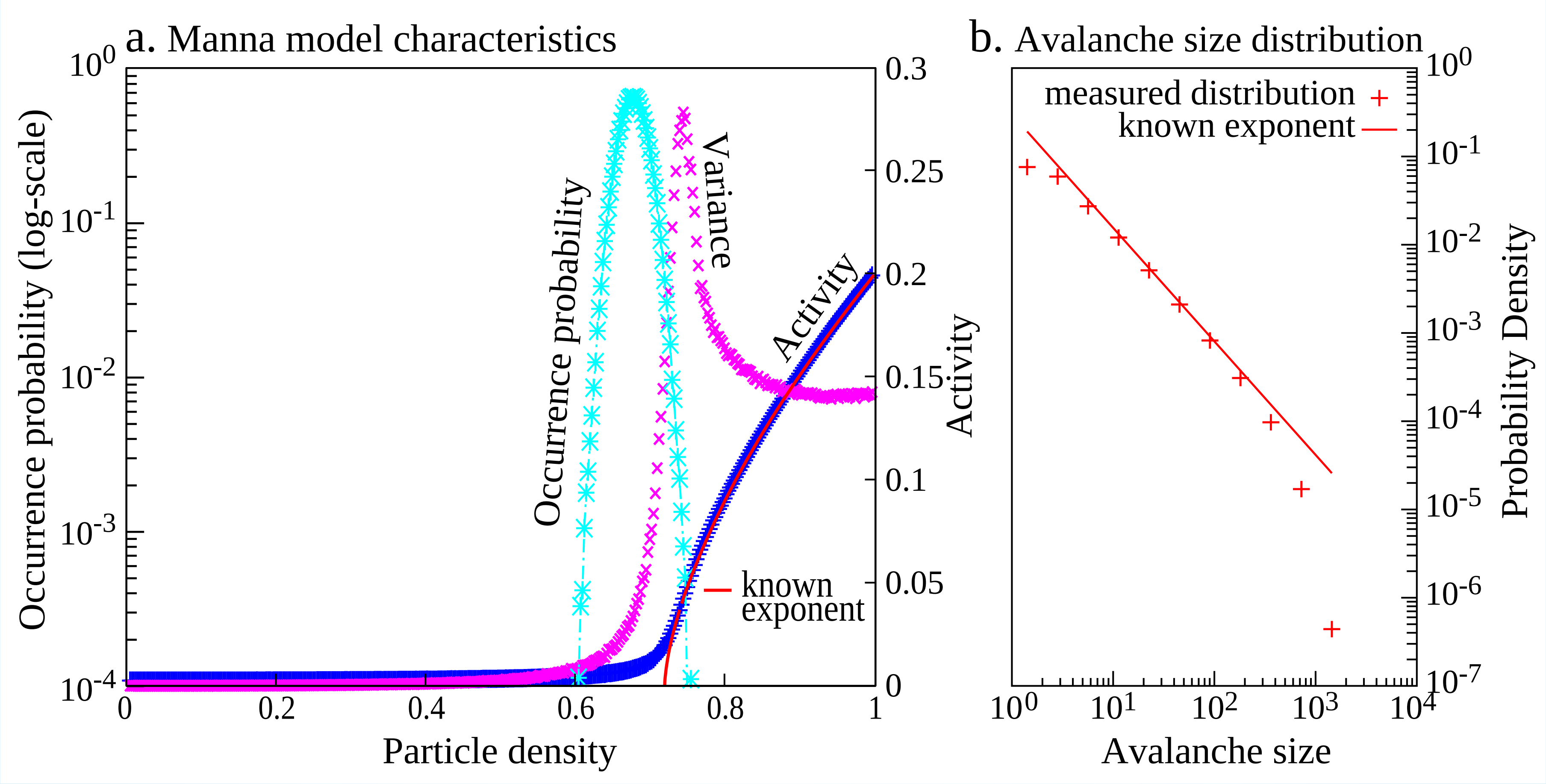
Collapsed statistics for observed precipitation



- **Precip. mean & variance dependence on *w* normalized by critical value w_c; occurrence probability for precipitating points (for 4 *T* values); Event size distribution at Nauru**

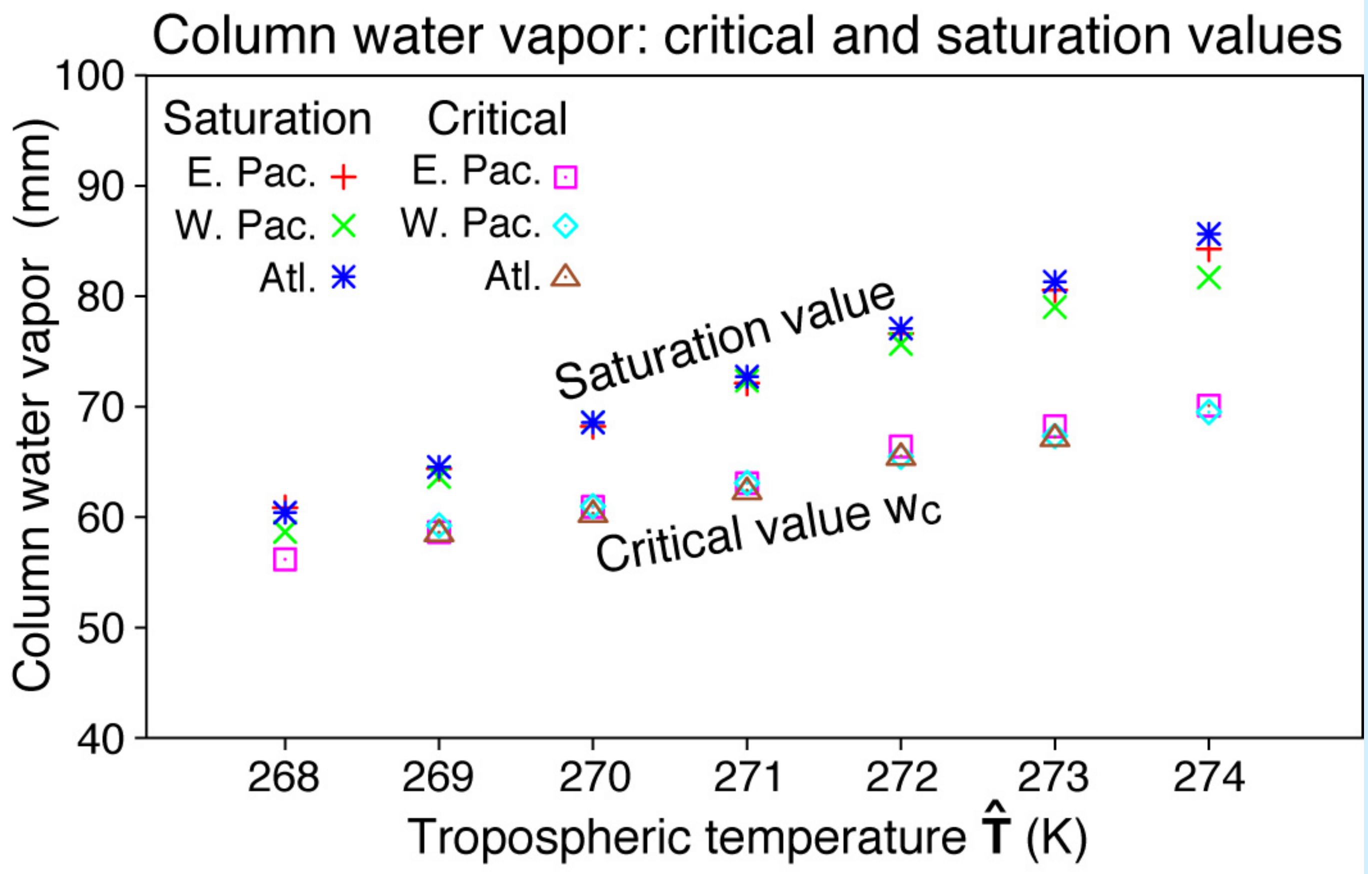
Example from Manna (1991) lattice model

(hopping particles—not a model of convection! 20x20 grid shown)



- **Activity (order parameter) & variance dependence on particle density (tuning parameter) [conserving case]**
- **Occurrence probability (log scale; very Gaussian) & event size distribution [self organizing case]**

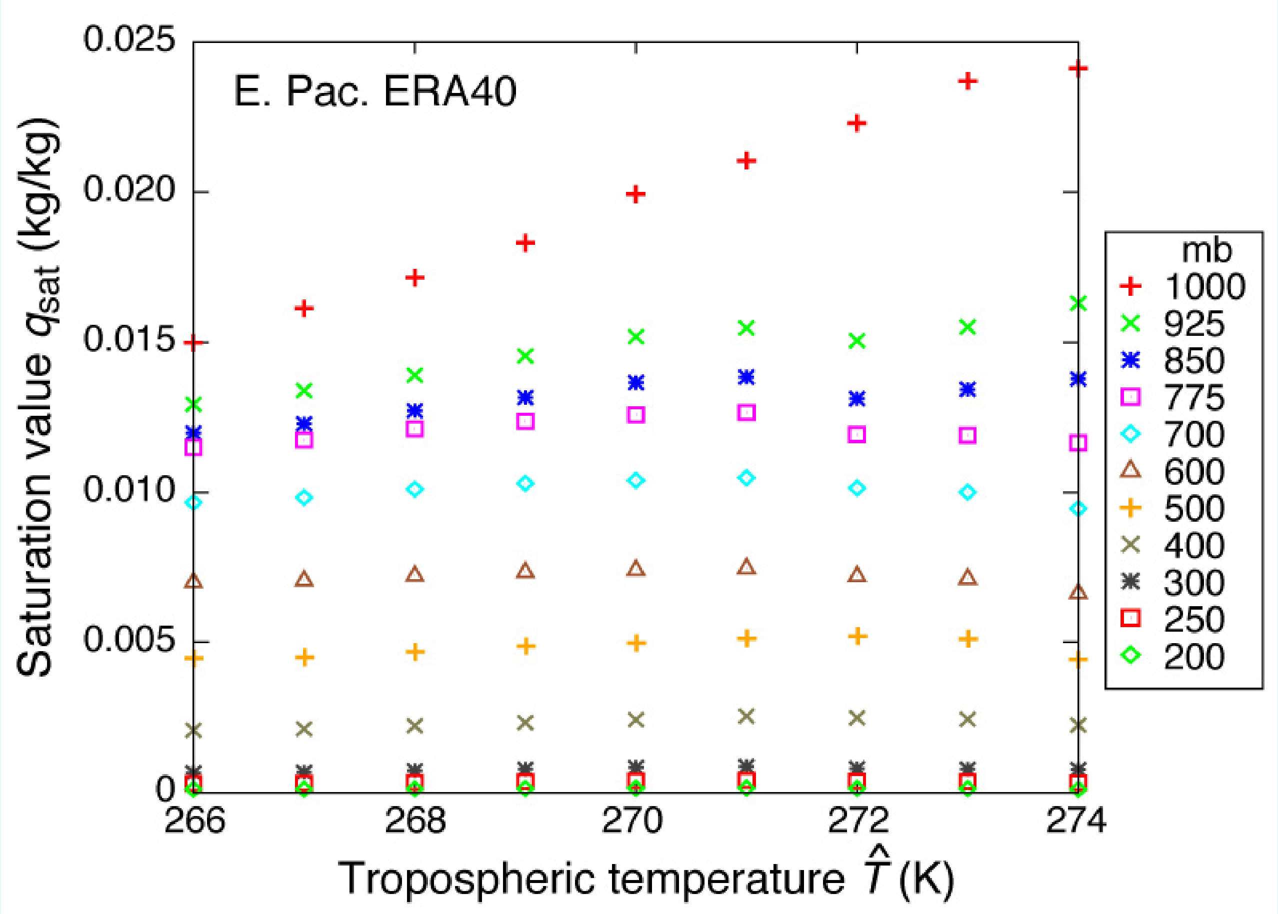
Critical point dependence on temperature



- 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

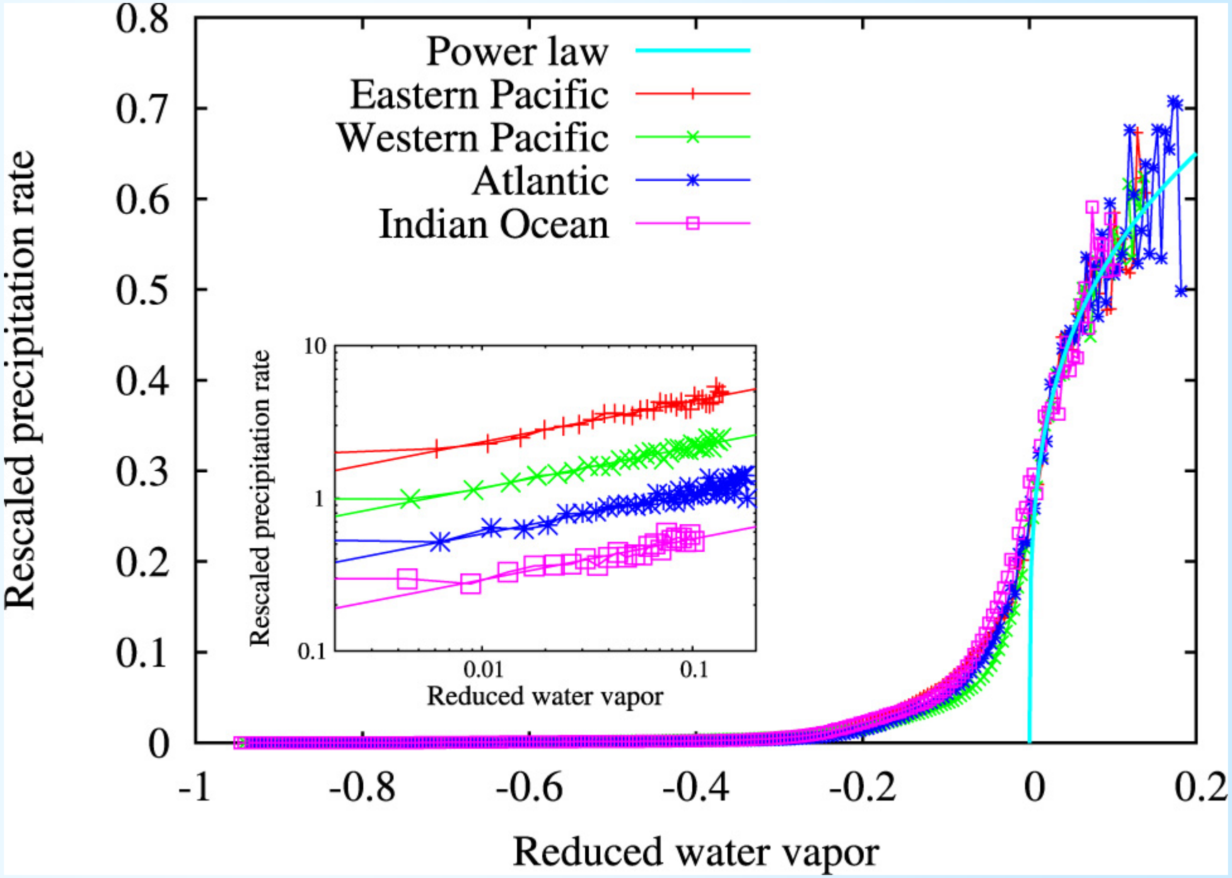
Saturation value q_{sat} (T) by level



- Saturation mixing ratio by level binned by vert. avg. temp. $\hat{T}$
- Compare to critical value & vert. int. saturation value vs. $\hat{T}$
- Appears consistent with substantial control by lower free troposphere proximity to saturation

Check pick-up with radar precip data

- **TRMM radar data for precipitation**
- **4 Regions collapse again with w_c scaling**
- **Power law fit above critical even has roughly same exponent as from TMI microwave rain estimate**
- **(2A25 product, averaged to the TMI water vapor grid)**

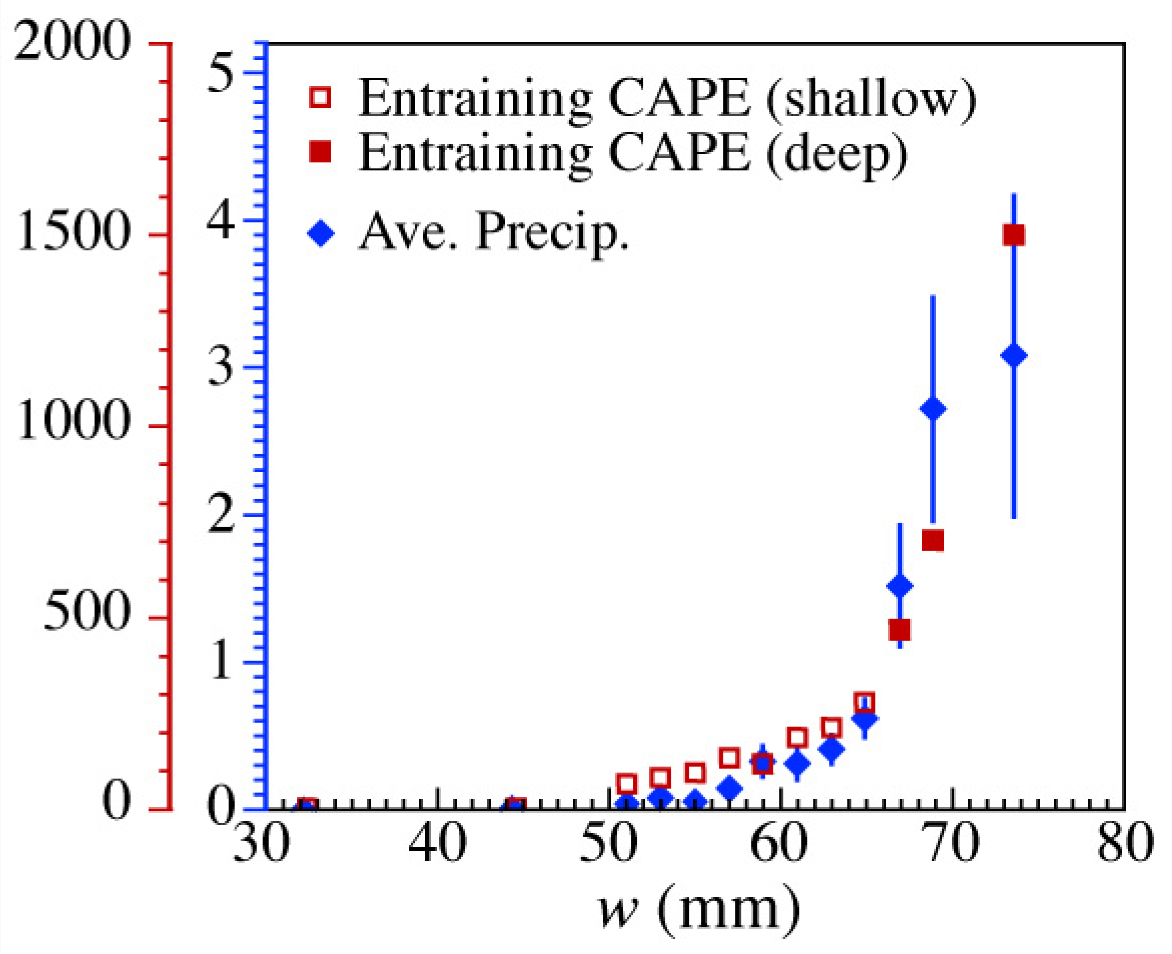


$(w-w_c)/w_c$

Peters, Neelin & Nesbitt, *JAS*, 2009

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

Binning *q*, precip. on vert. int. water vapor

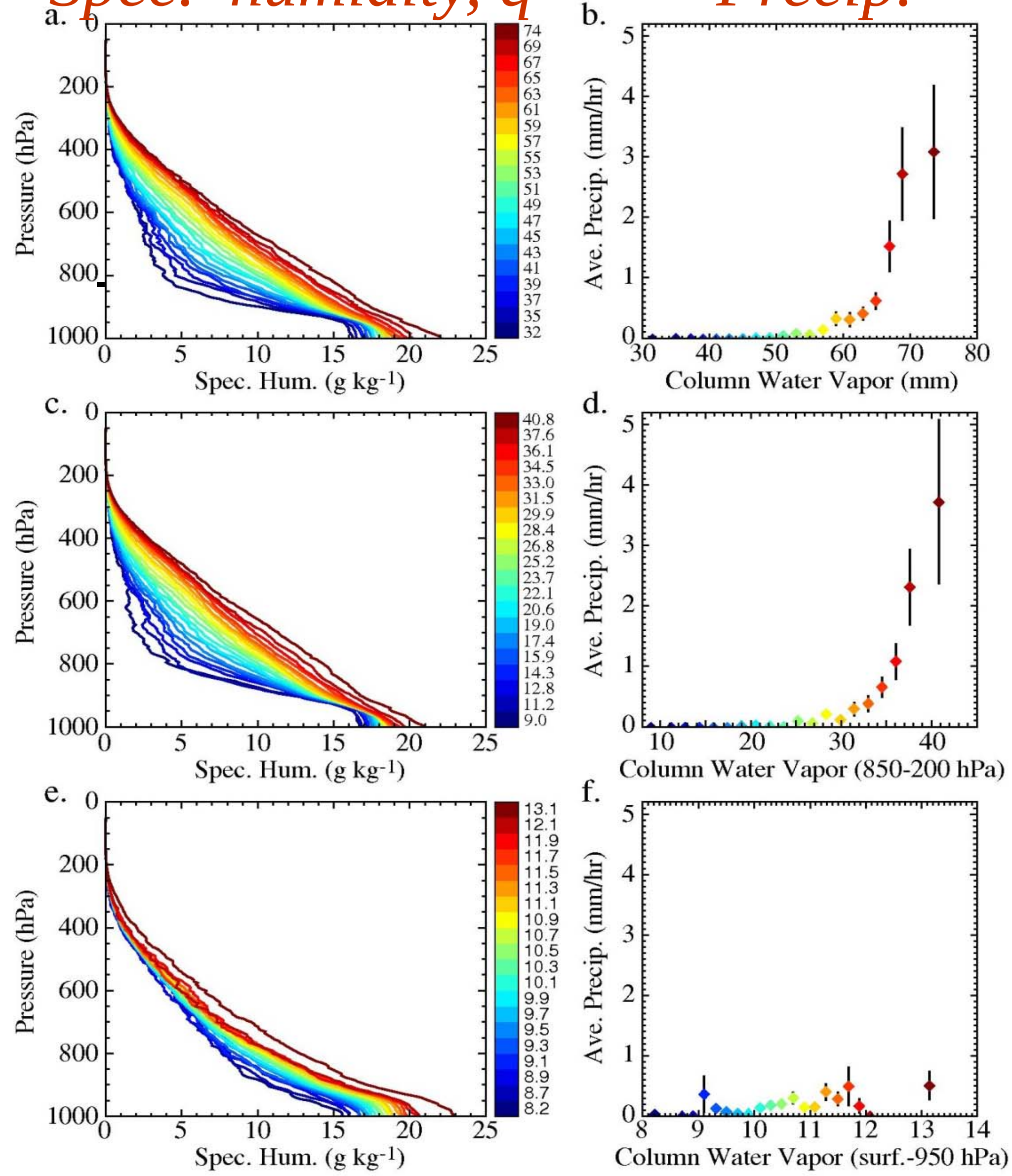
Spec. humidity, q

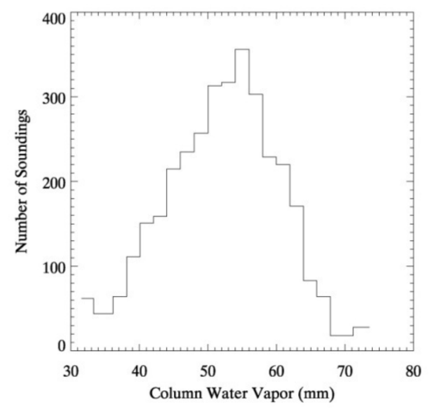
Precip.

Binned by:
Column
water vapor

850-
200 mb

Surface-
950mb



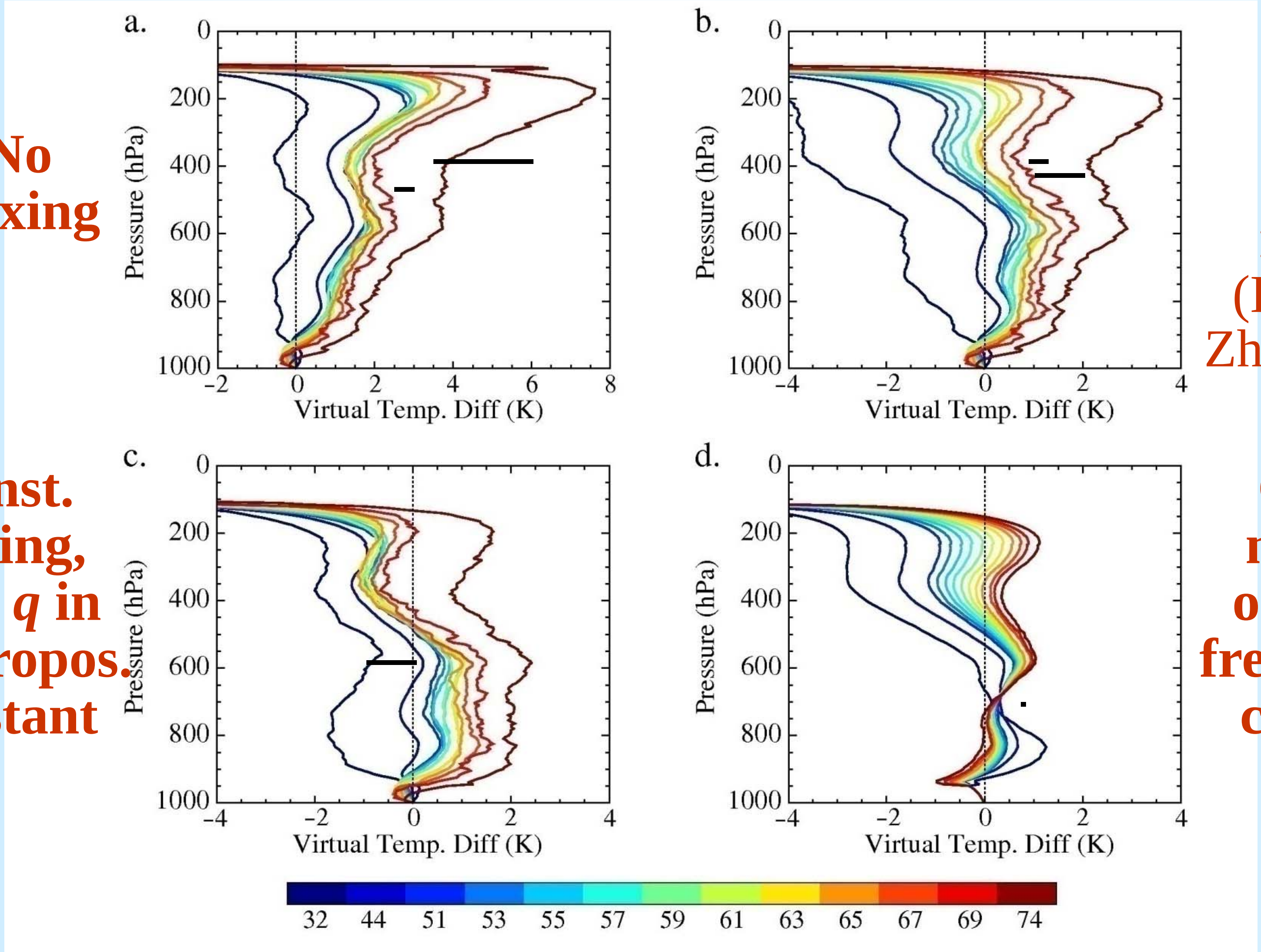


[Note fewer
soundings
in high bins]

Nauru ARM
site observations

Holloway & Neelin, *JAS*, 2009

Lifted parcel buoyancy by column water vapor bins



No mixing

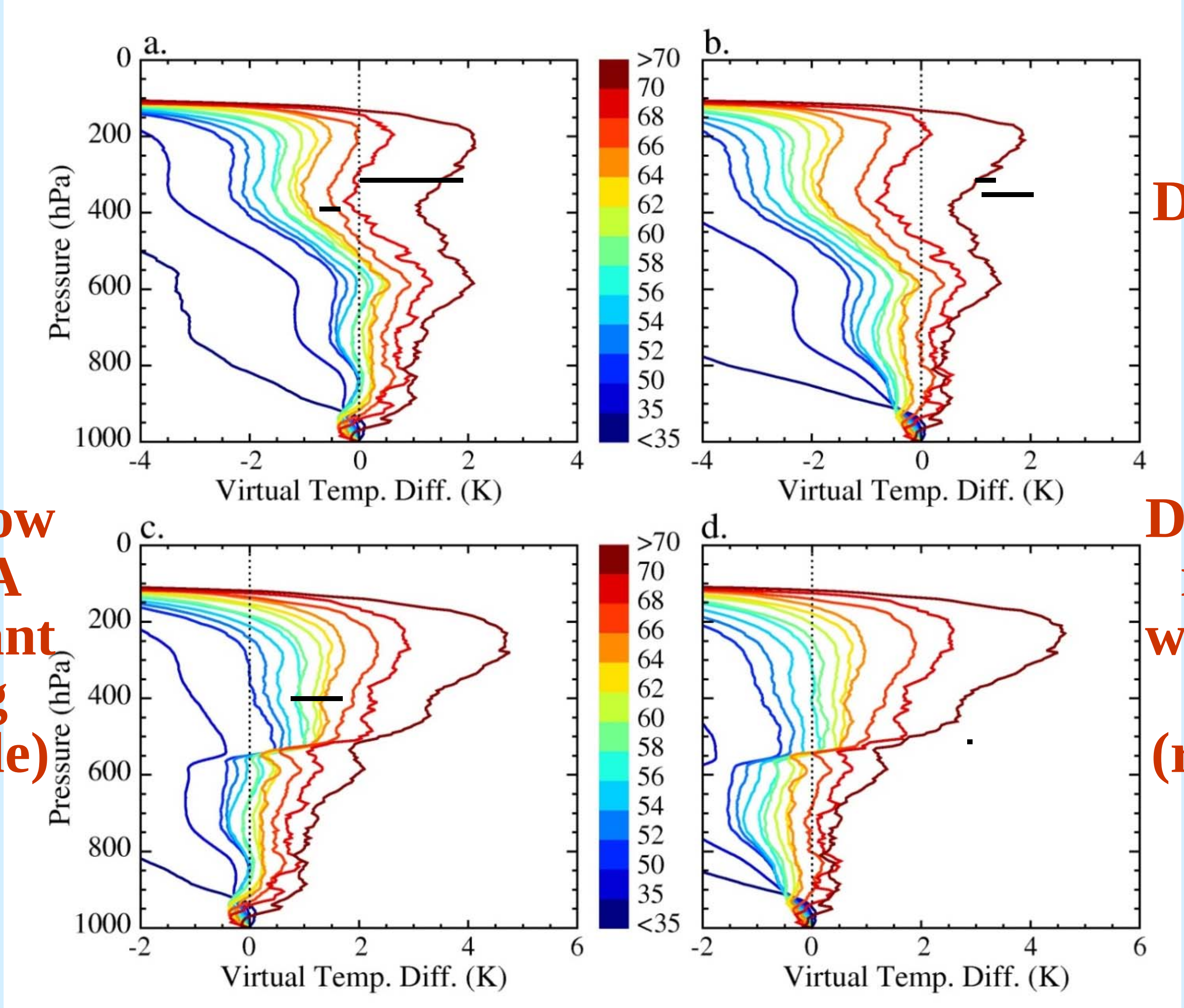
Const. mixing
(Brown & Zhang 1997)

Const. mixing, with *q* in free tropos. constant

Const. mixing, only *q* in free tropos. changes

- **Highest column water vapor bins most buoyant**
- **Both boundary layer and lower free troposphere contribute**

Lifted parcel buoyancy by column water vapor bins



Deep inflow mixing A

Deep inflow mixing B

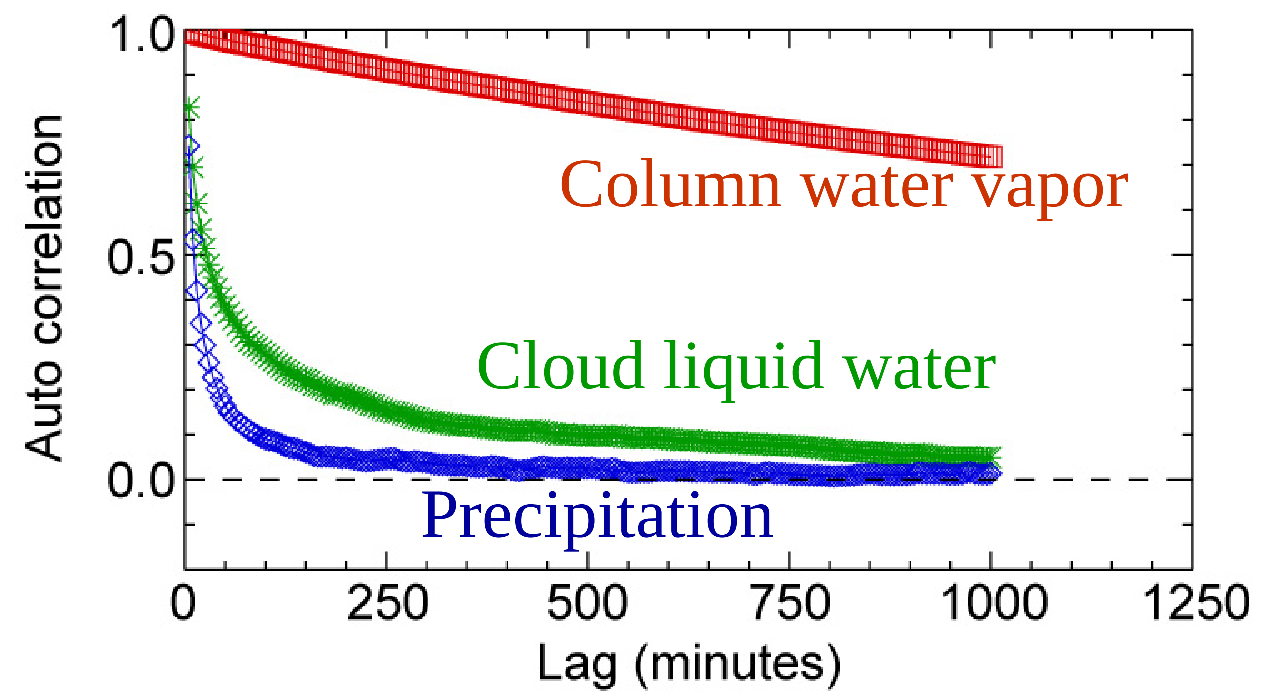
Deep inflow mixing A with instant freezing (reversible)

Deep inflow mixing B with instant freezing (reversible)

- Highest few column water vapor bins deep convective
- microphysics between these cases; large potential impact

Prec & column water vapor: autocorrelations in time

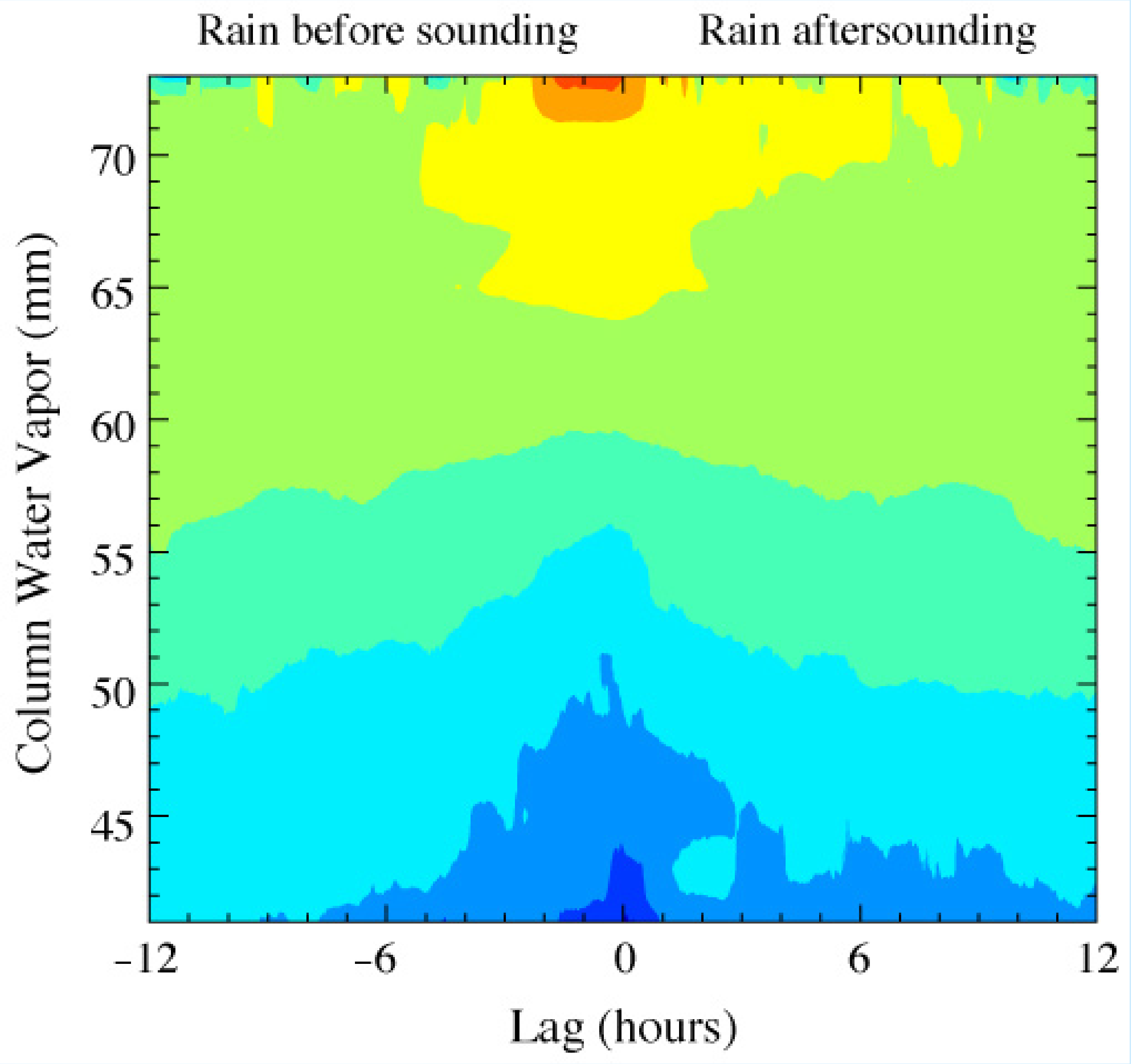
- **Long autocorrelation times for vertically integrated moisture (once lofted, it floats around)**
- **Nauru ARM site upward looking radiometer + optical gauge**



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

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**



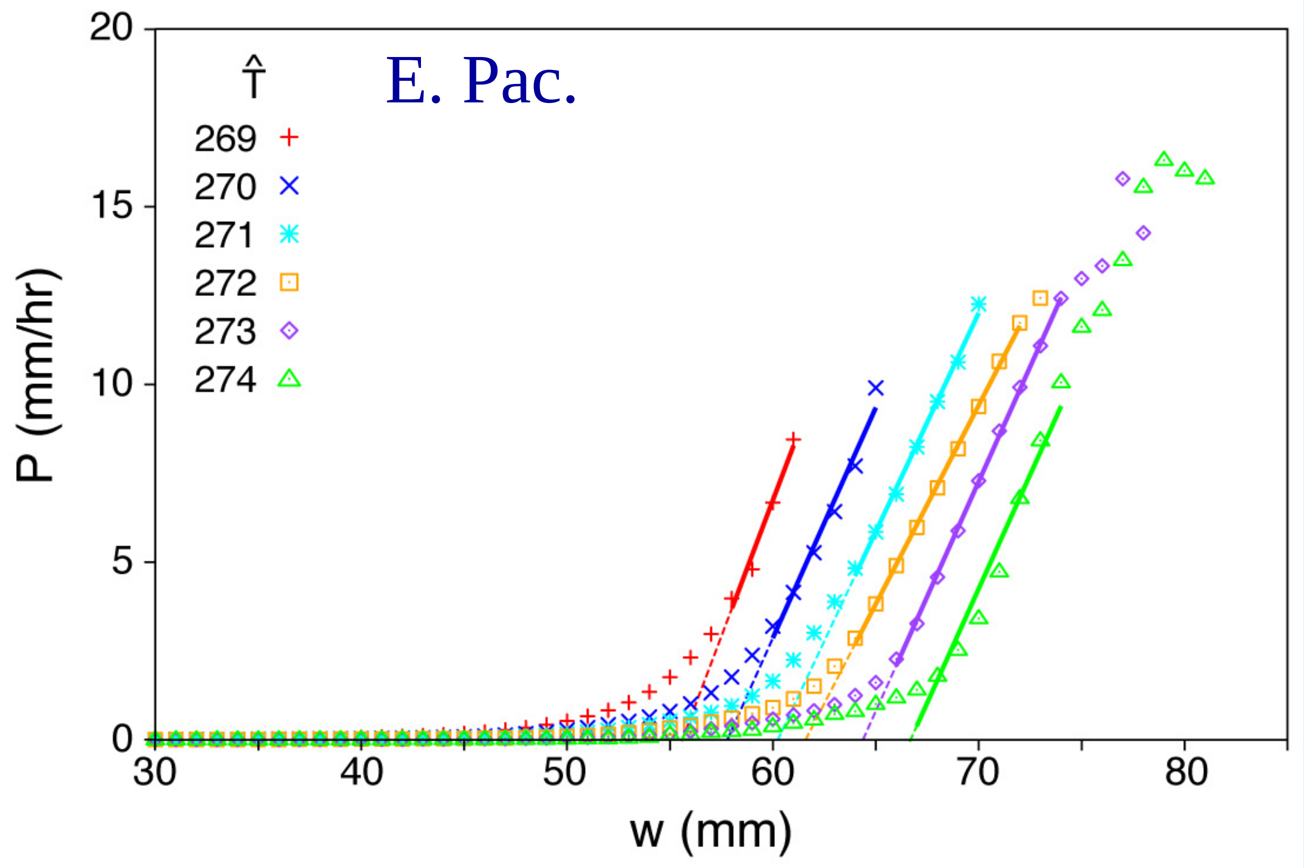
Holloway& Neelin JAS subm.

How do models do? CAM3.5 (0.5 degree run)[*]: 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



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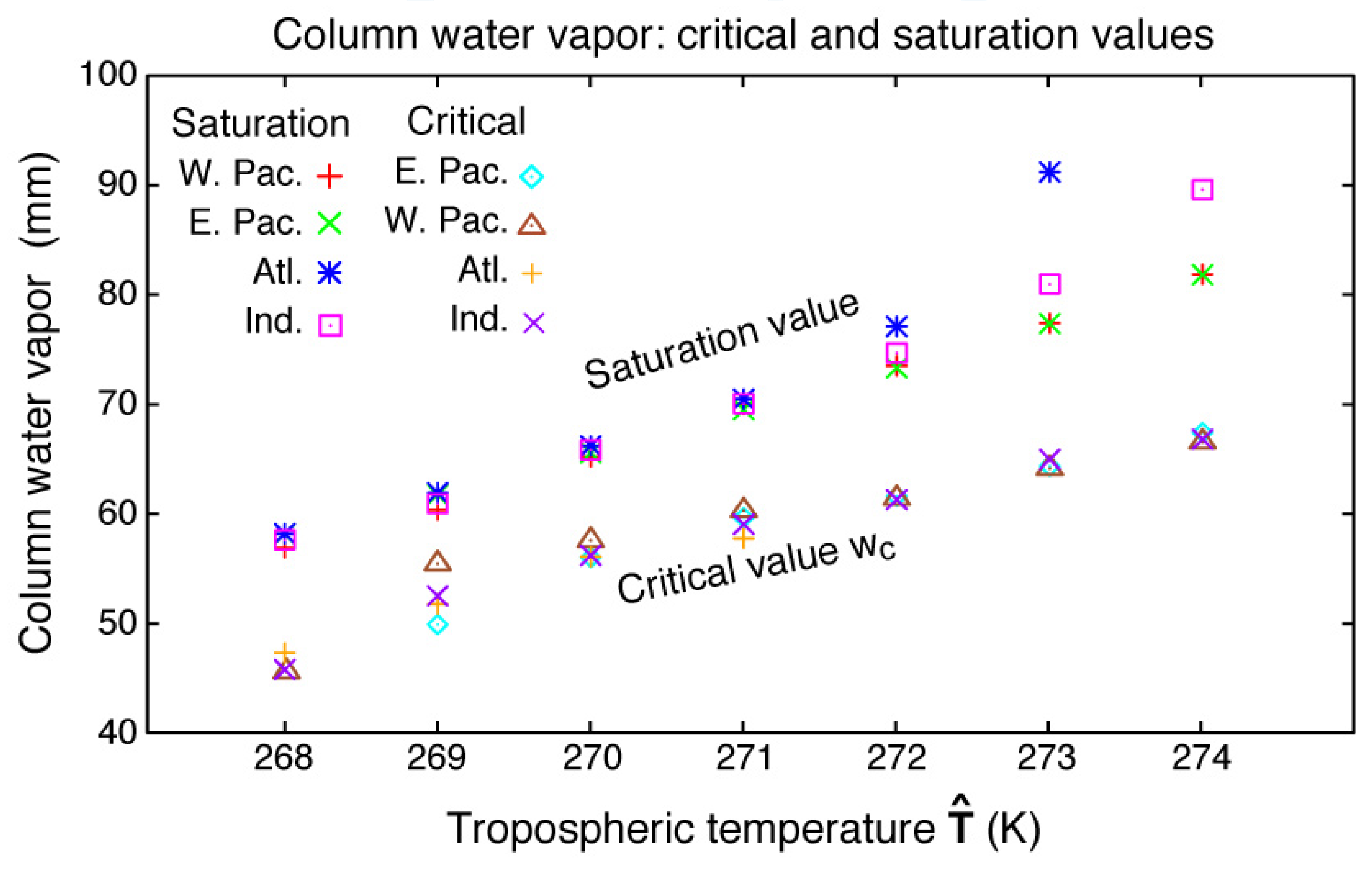
[*] Runs, data R. Neale, analysis K. Hales

Critical point dependence on temperature

CAM3.5 preliminary comparison



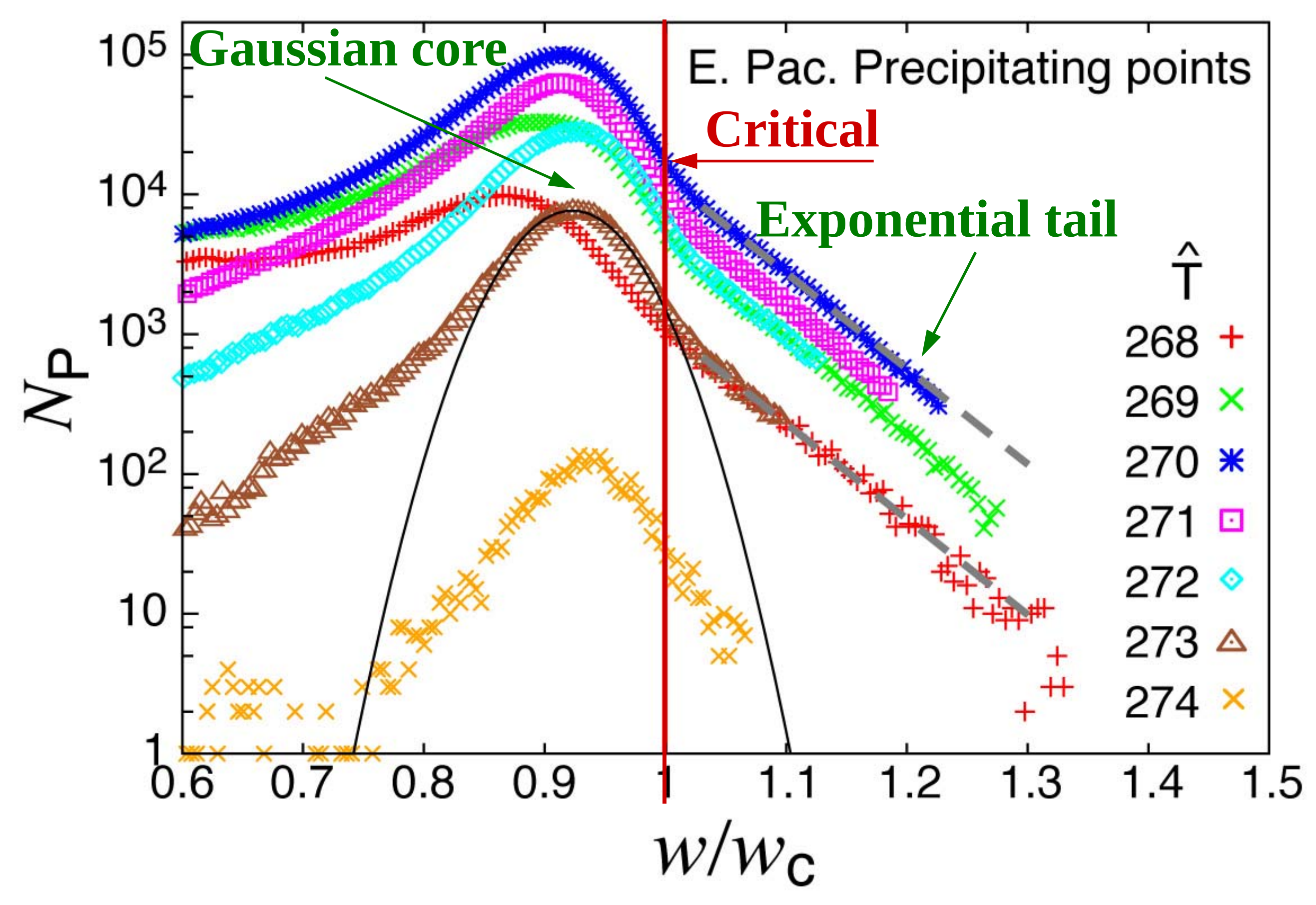
- critical water vapor w_c for each vert. avg. temp. $\hat{T}$
- Compare to vert. int. saturation vapor value binned by same $\hat{T}$
- Suggests suitable entraining plumes can capture T dependence

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

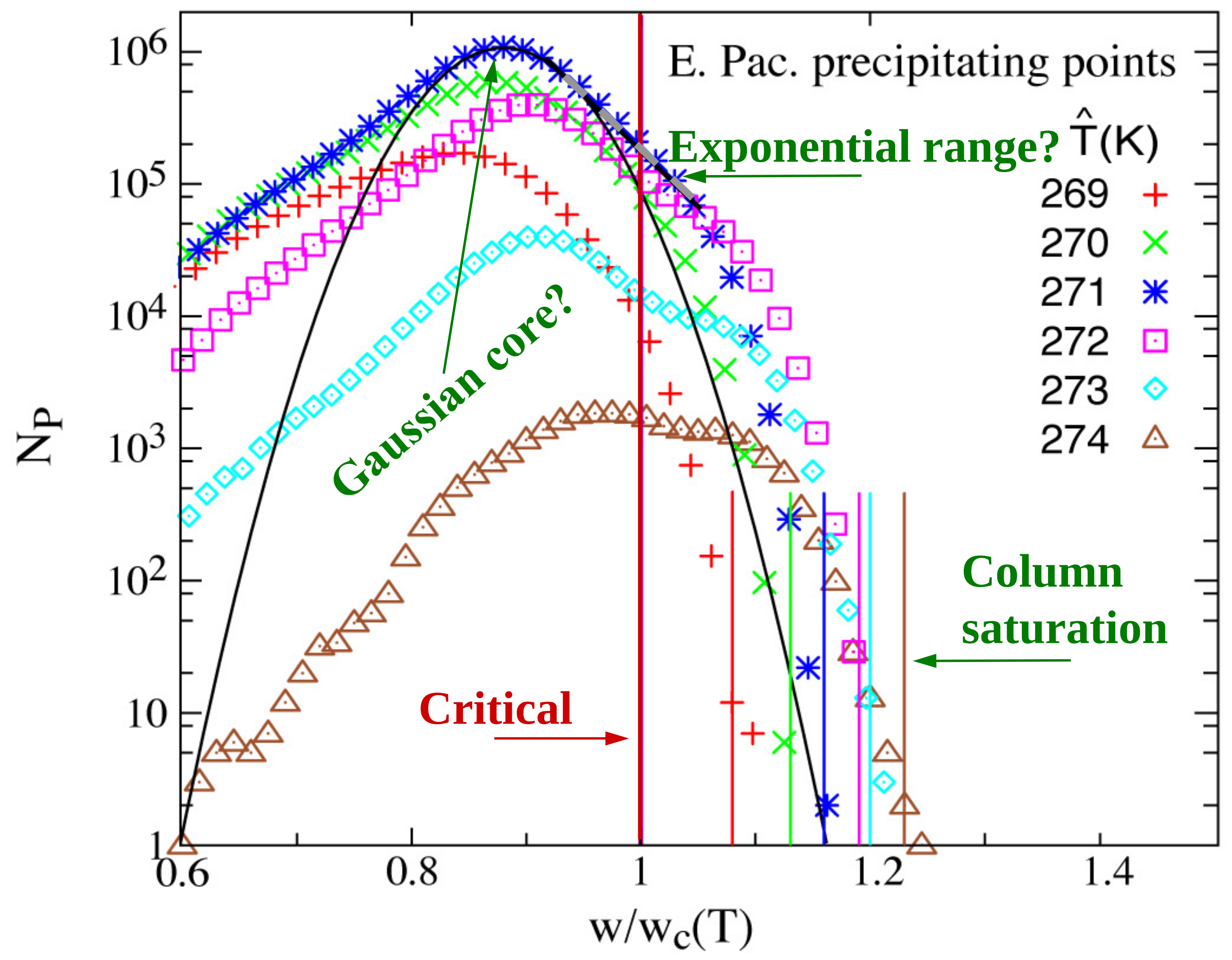
(e.g. Shraiman & Siggia 1994, Pierrehumbert 2000, Bourlioux & Majda 2002)



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.



Summary

- These statistics for precipitation and buoyancy related variables at short time scales provide new ways to quantify the transition to tropical deep convection as needed for models

- Tracer distributions consistent with simple prototypes; core with stretched exponential tails ubiquitous

Current retrievals are great but could sure use

- vertical dependence on temperature and water vapor

in deep convective regions, land,…

- Coordinated observations of condensate loading, freezing
- huge number of observations allow statistics to the computed consistently through range with large events

- Multiple tracers promising