Convective Transition Statistics for Climate Model Diagnostics

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Context: NOAA model diagnostics task force

Convective transition background: water vapor-precipitation relation association with conditional instability $\Rightarrow$ constraints for models

Observational basis: satellite retrievals, in situ, GPS; scale dependence

Model comparisons: time slice experiments, MJO task force expts, parameter perturbation experiments

Next directions: Convective transition in θ_e coordinates; ARM site diagnostics; unorganized vs organized convection

Supported in part by: National Oceanic and Atmospheric Administration (MAPP Program), Department of Energy (RGCM Program), National Science Foundation (AGS)

Context: NOAA MAPP Model Diagnostics Task Force (MDTF)

- see talk by Dan Barrie on Thursday; poster by Eric Maloney (Chair) + talks/posters by J. Booth, A. Berg, H. Annamalai, J. Wang, X. Xu, D. Kim, X. Jiang …
- Time-slice experiment (GFDL and NCAR model versions):
  - intervals with high-frequency 3-D output, incl. 5-yr (2008-2012) with 6-hourly, 2-yr with hourly (2009-2010)
  - moist static energy budget terms (GFDL model— see poster by Ming Zhao)

+ connections to MJO task force, CMIP5, DOE ARM data

- Here we focus on a set of diagnostics for the onset of precipitation (esp. deep convective) as a function of environmental thermodynamic variables

MDTF diagnostics package

- "process-oriented diagnostic" characterizes a physical process hypothesized to be related to the ability to simulate an observed phenomenon (Eyring et al. 2005, *BAMS*; Sperber & Waliser 2008, *BAMS;* Maloney et al. 2014, *J. Clim*.; Kim et al. 2014, *J. Clim*.)
- diagnostics to be repeatable in modeling center workflow, focused on model improvement

Applications Programming Interface

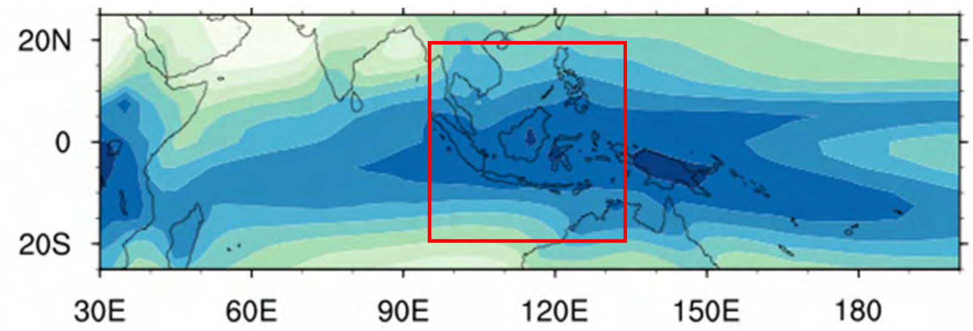
- python script:
  1. Set up paths, variable names,..
  2. Call diagnostics **contributed by various groups*** >plots
  3. Compose plots into a web page
- *open source, observational comparisons supplied; user can test a diagnostic to submit, contributed to library of diagnostics
- Currently being developed with NCAR, GFDL

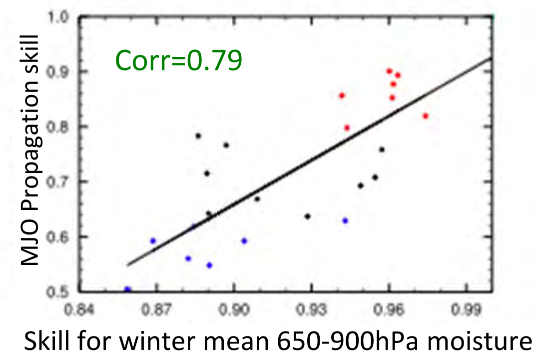
Eric Maloney (CSU), Andrew Gettelman, Jack Chen (NCAR), Yi Ming (GFDL),
Yi-Hung Kuo, JDN, + others…. (UCLA)

Example of process oriented diagnostics metric*:

Model Winter MJO Eastward Propagation and Low-Level Mean Moisture over the Maritime Continent

Winter mean 650-900hPa moisture

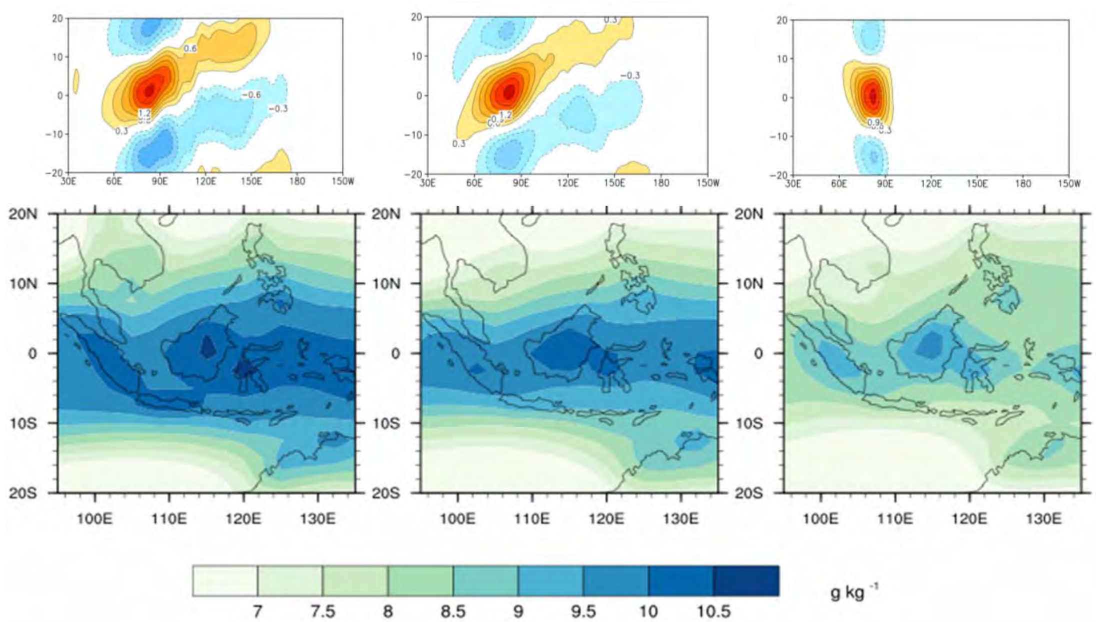




OBS

Good MJO models

Poor MJO models



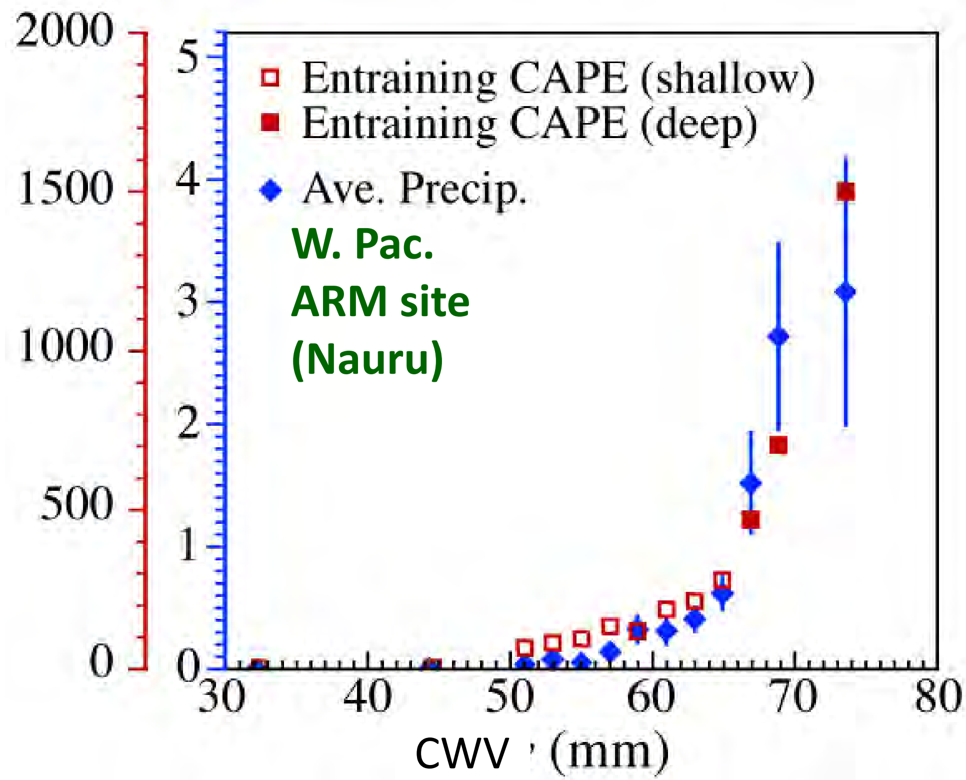
Gonzalez & Jiang 2017

Jiang 2017;
see also Jiang et al. 2015; Maloney et al. 2014; Kim et al. 2014

*that connects with MJO task force—see Friday morning schedule
& with analysis below

Convective transition background:
water vapor-precipitation relation association with conditional instability

Indications of importance of lower free tropospheric moisture: **Austin 1948; Yoneyama and Fujitani 1995; Brown and Zhang 1997; 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; Kiladis et al. 2008...**



Entraining plume: dry free troposphere kills buoyancy; non-entraining: predicts deep convection even for dry columns, instead of observed pickup

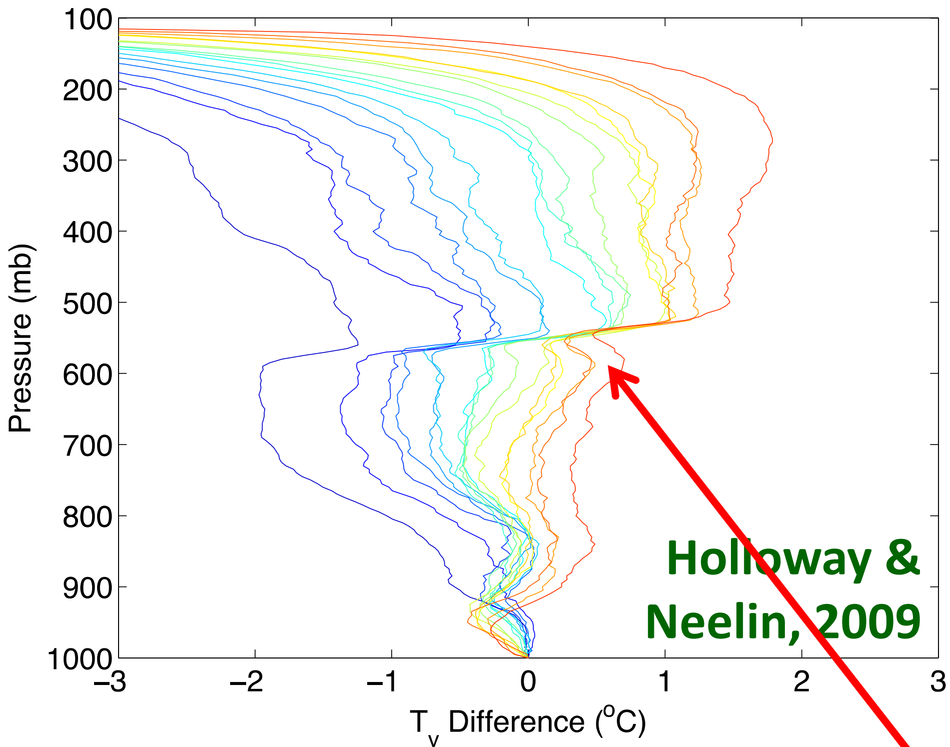
Entraining convective available potential energy and precip binned by column water vapor, CWV

Neelin et al., *Phil Trans. Roy. Soc. A*, 2008; Holloway & Neelin, *JAS*, 2009

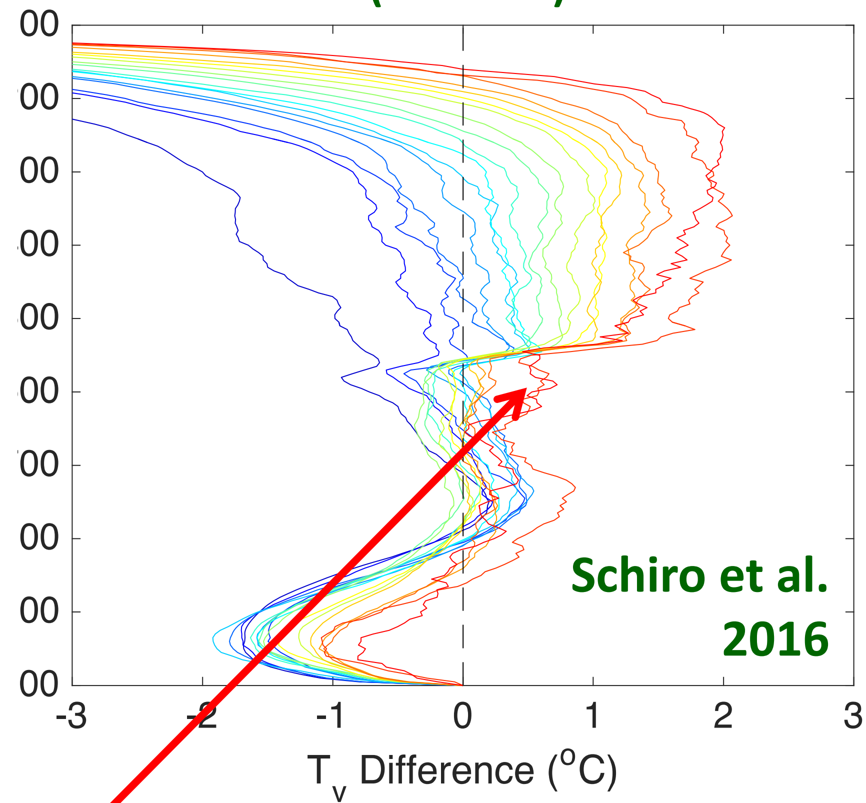
Convective transition background:

Entraining parcel buoyancy by column water vapor bins

W. Pac. Nauru (all times)



GoAmazon site (all times)



Entrainment scheme ~1/z 'Deep inflow A' (with rapid freezing)

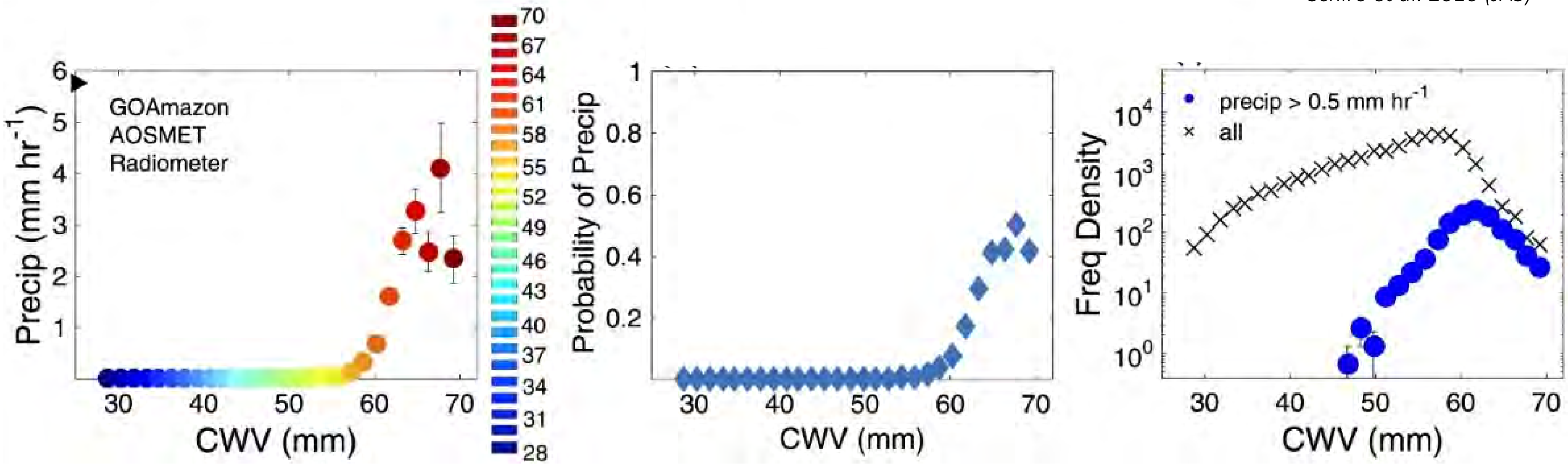
- Highest few column water vapor bins deep convective
- Over Amazon additional effects (convective inhibition, recovery from ABL cooling by precip, microphysics,…) but free tropospheric moisture via entrainment still leading effect

Observational basis:
Convective Transition Statistics at GOAmazon Site, Manacapura, BR

Previous work: satellite retrievals & ground-based measurements:
e.g., Bretherton et al. 2004 (J. Clim.), Peters and Neelin 2006 (Nature Phys.), Holloway and Neelin 2009 (JAS), Sahany et al. 2012 (JAS), Ahmed and Schumacher 2015 (GRL), …

GOAmazon Ground-based Measurements

Schiro et al. 2016 (JAS)

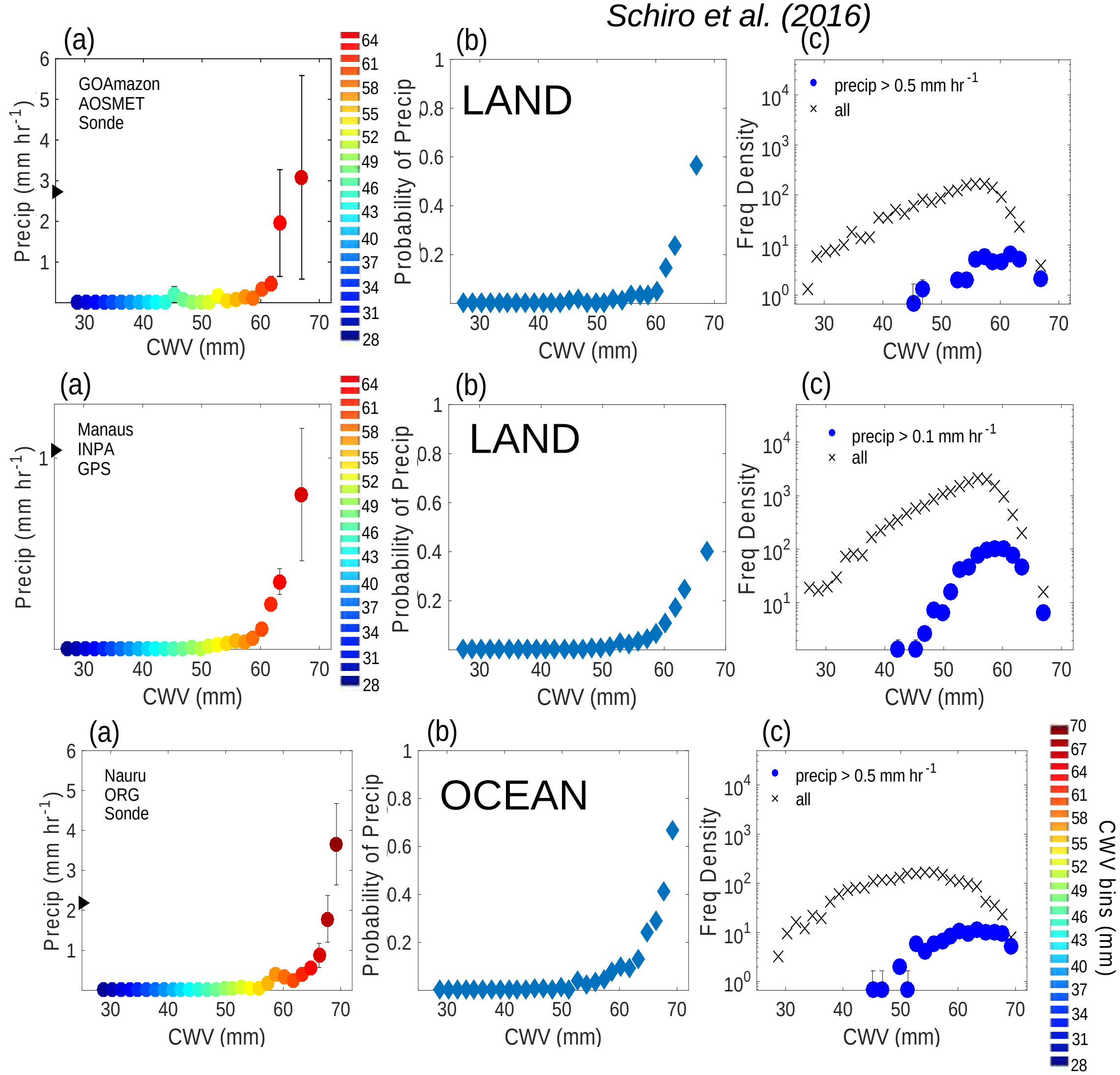


- Sharp increase in precip and probability of precip with column-integrated water vapor (CWV) above a critical threshold
- PDF of CWV for precipitating points peaks around threshold
- Robust over tropical land and ocean

Observational basis:
Convective Transition Statistics, Land vs Ocean

- Close parallels over land & ocean
  - Sharp increase in rain rate and probability of precip with increasing CWV
  - Verified using multiple CWV measurements (microwave radiometer, **radiosonde**, **GPS**)
- The peak in precipitating points near critical value, decreasing sharply at higher CWV, consistent with dissipative effects of precipitation on CWV and convection on buoyancy.
  - Onset occurs at lower CWV over land than over ocean, even wher considering temperature

Schiro et al. (2016)

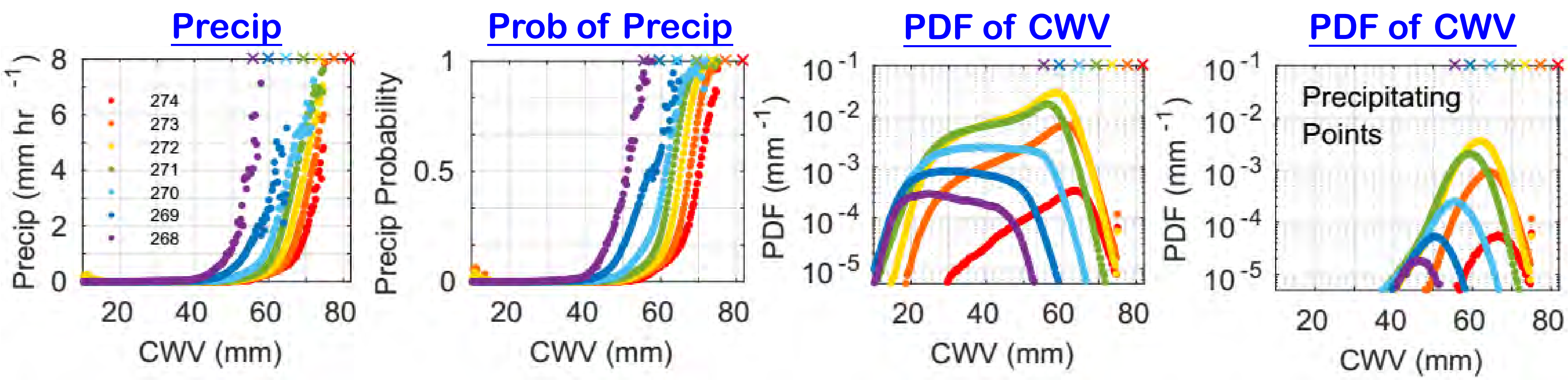


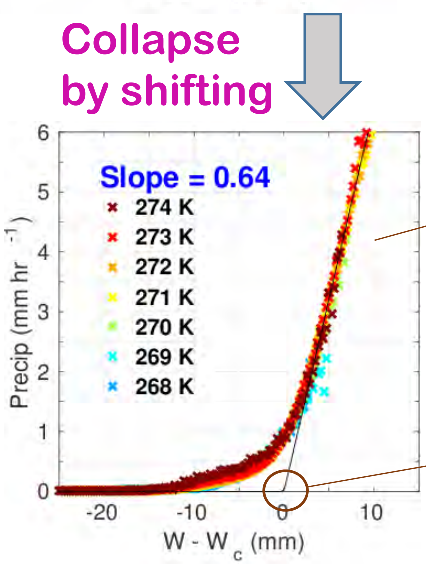
Observational basis: Convective Transition Statistics over oceans

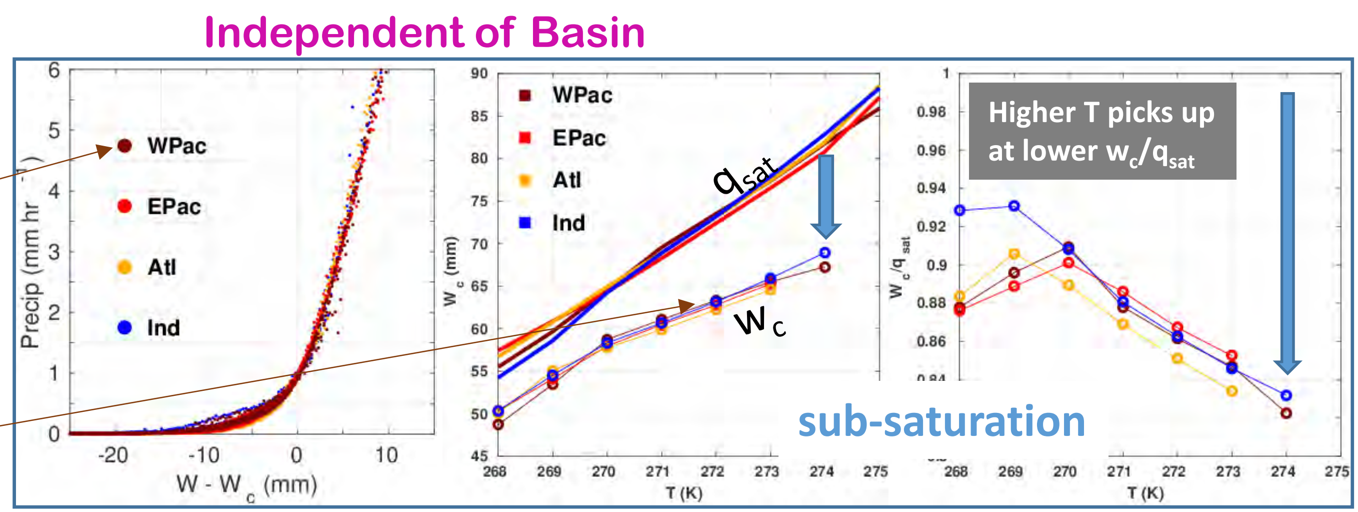
Condensing stats for Precip(CWV,*T*)

W. Pacific 20°S-20°N 2002/6-2014/5

RSS TMIv7 CWV & Precip (0.25° snapshot)
NCEP-DOE Reanalysis-2 Temperature (2° 6-hourly)
T: 1000-200 mb mass-weighted column average temperature
q_{sat}: column-integrated saturation specific humidity
Precip event (>0.75 mm/hr)
Bins with PDF<10^{-5} trimmed







Kuo et al., in prep.

Robust across instruments

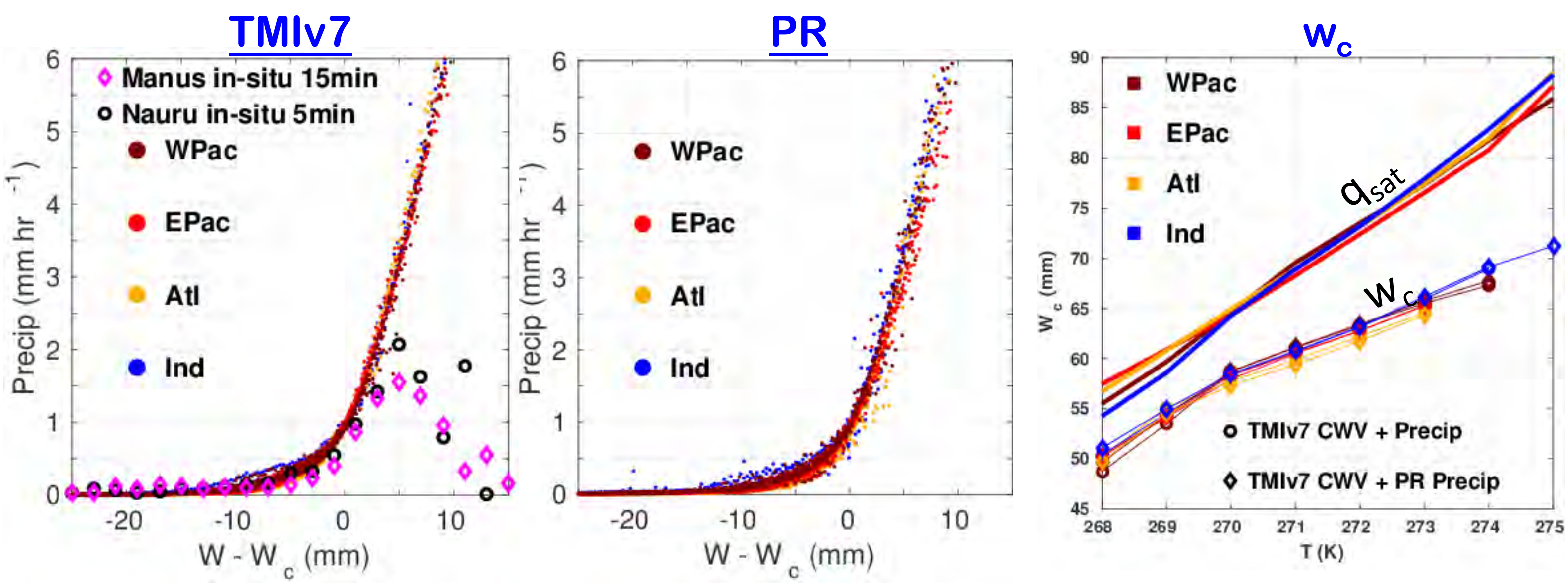
- TMI (emissivity) vs. PR (reflectivity)
- TMIv7 CWV used in both cases
- More scatter for PR
- Quantitative agreement

TMIv7 CWV & Precip (0.25° snapshot)

Reanalysis-2 Temperature (2° 6-hourly)

Bins with PDF<10^{-5} trimmed

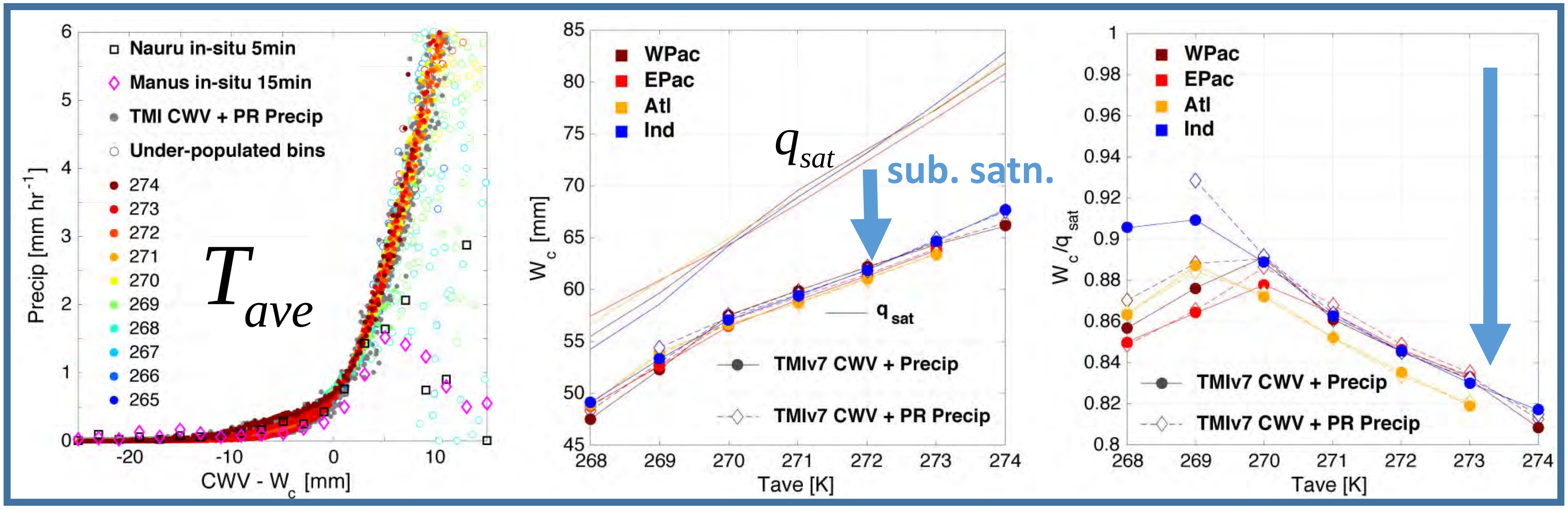
TRMM PR Precip 2A25 ver. 7.00 (0.05° instantaneous)



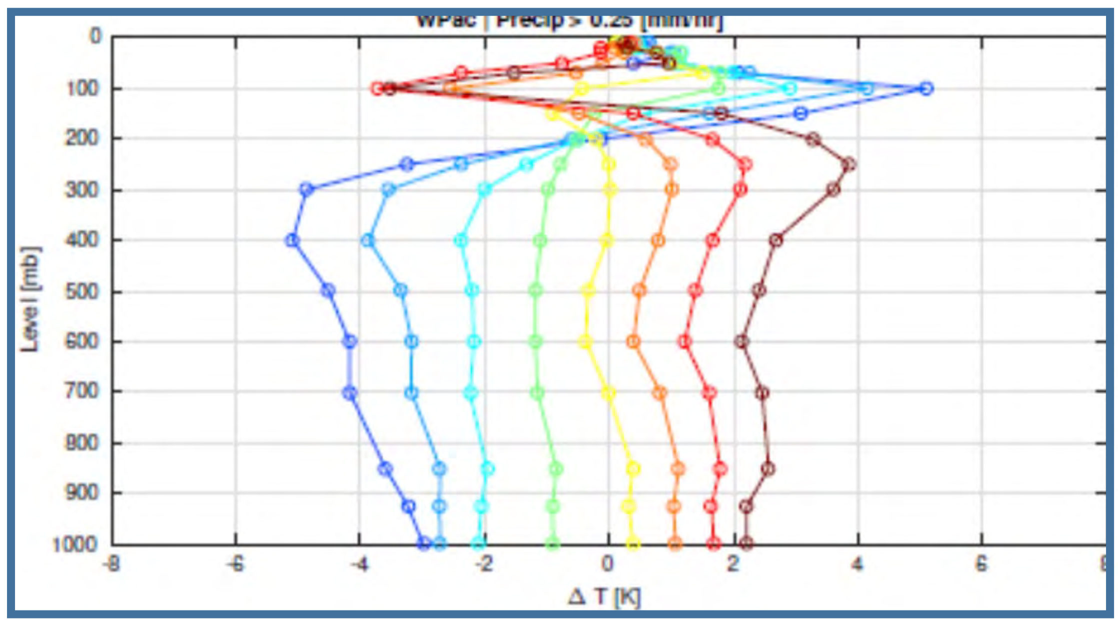
Kuo et al., in prep.

Robust to temperature measures

T_{ave}



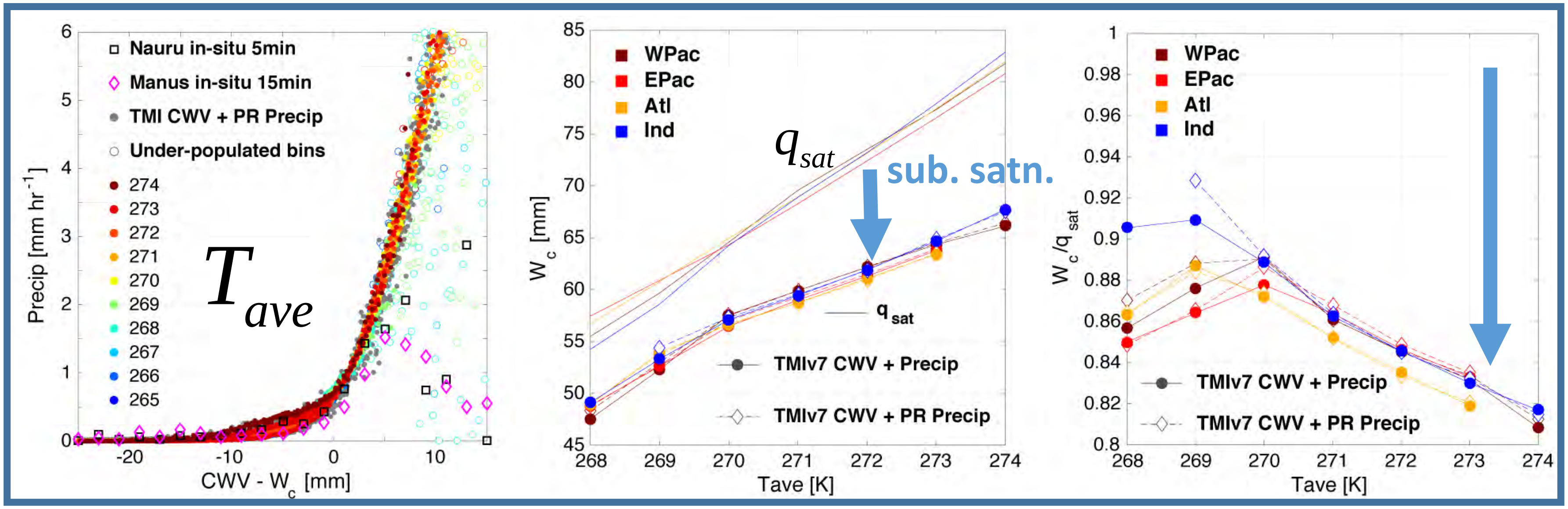
Vertical temperature profiles
for precipitating points
(P>0.25mm/hr; departure from avg)
tend to be deep through troposphere, motivating T_{ave} =avg 200-1000mb

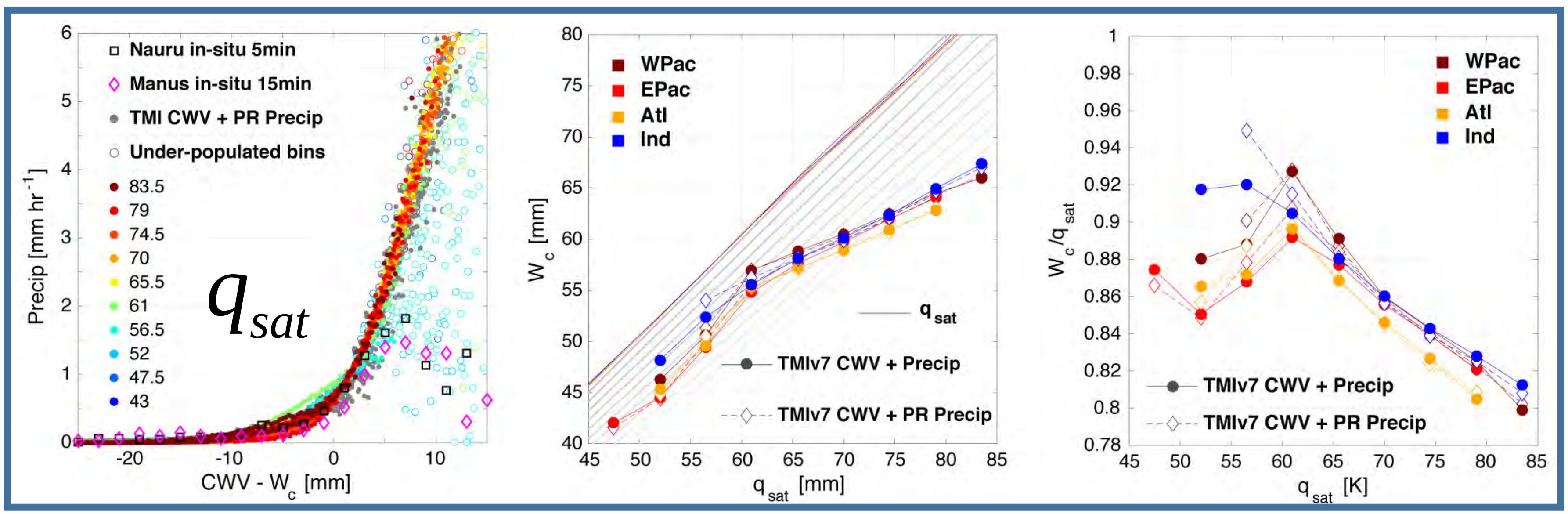


Kuo et al., in prep.

Robust to temperature measures

T_{ave} vs $\int q_{sat} dp / g$

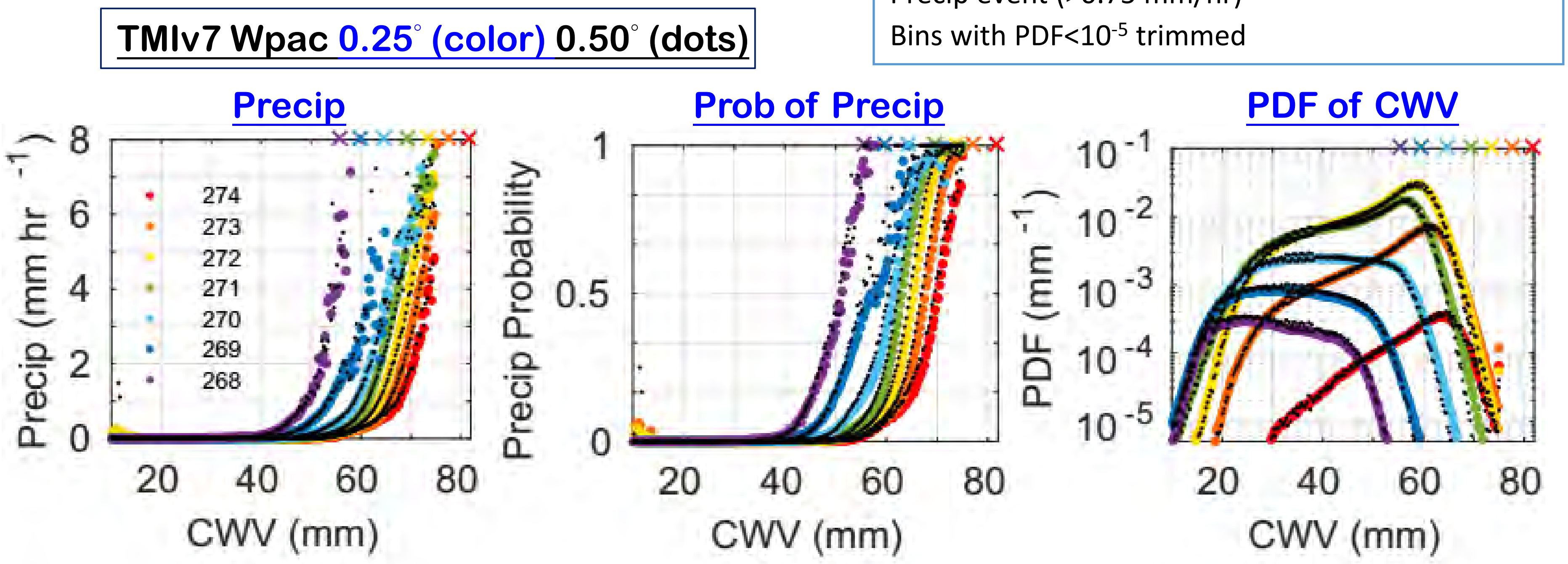




Kuo et al., in prep.

Spatial Resolution Dependence

RSS TMIv7 CWV & Precip (0.25° instantaneous)
NCEP-DOE Reanalysis-2 Temperature (2° 6-hourly)
T: 1000-200 mb mass-weighted column average temperature
q_{sat}: column-integrated saturation specific humidity
Precip event (>0.75 mm/hr)
Bins with PDF<10^{-5} trimmed



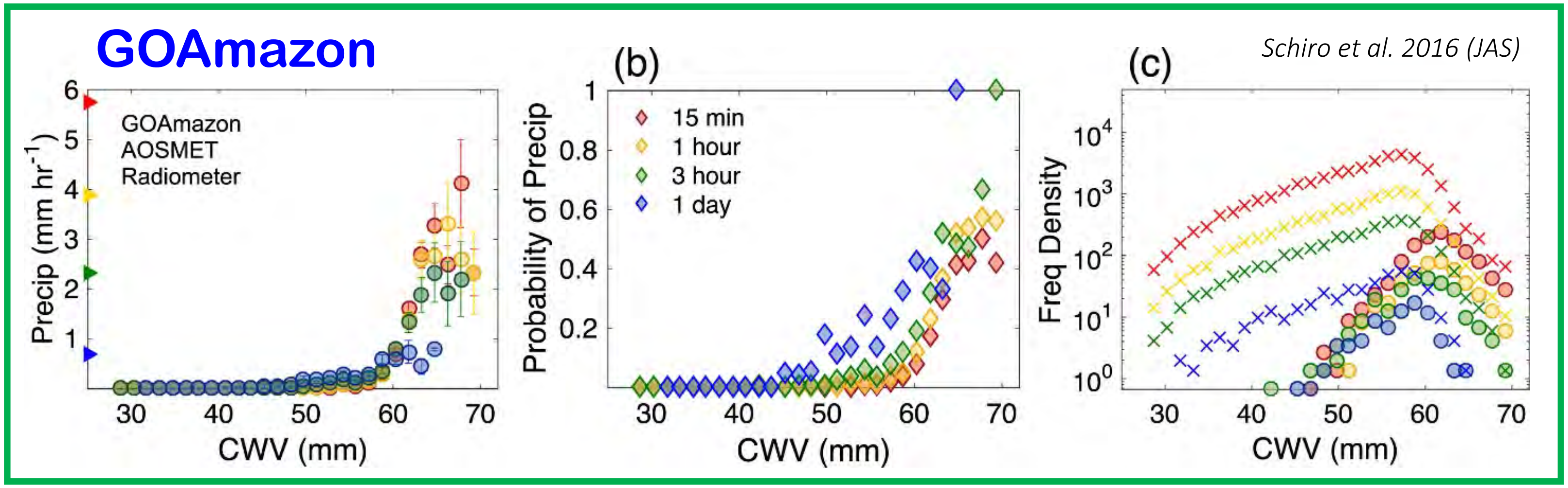
- Precip Pickup independent of spatial resolution (up to ~1.5°; 2.5° fine, slightly less sharp)
- Probability increases with coarse-graining
- PDF insensitive to resolution, except for high CWV

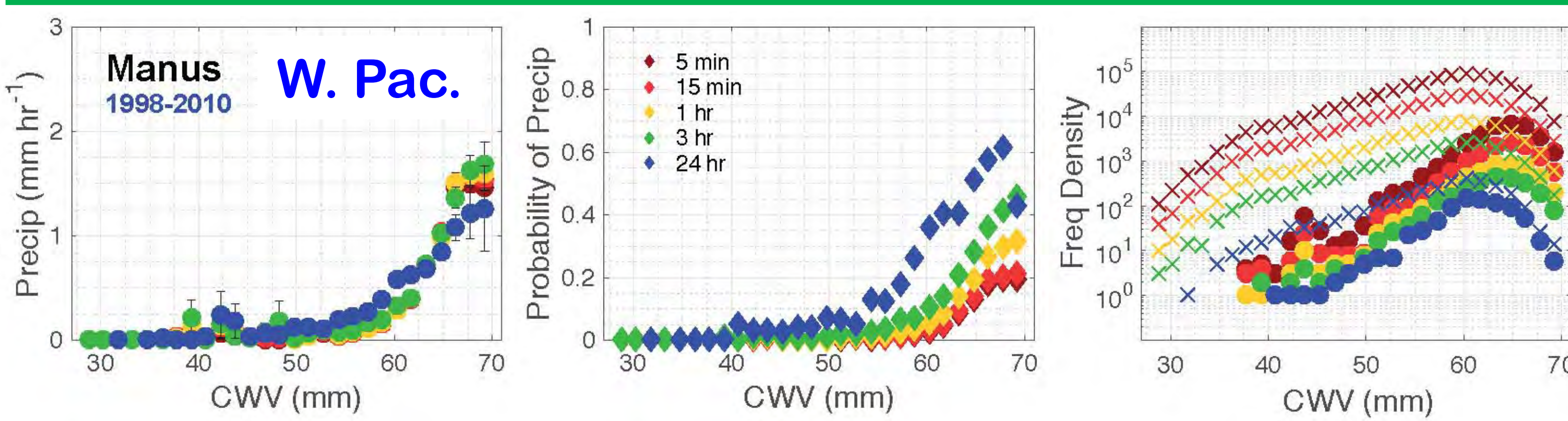
Kuo et al., in prep.

Coarse-graining in Time

- Snapshot not part of standard model output

rain gauge, radiometer





- Reasonably robust up to a few hours time-average
- daily avg. tends to smooth out fundamental pickup: related but not optimal for fast-timescale processes

Model comparisons:

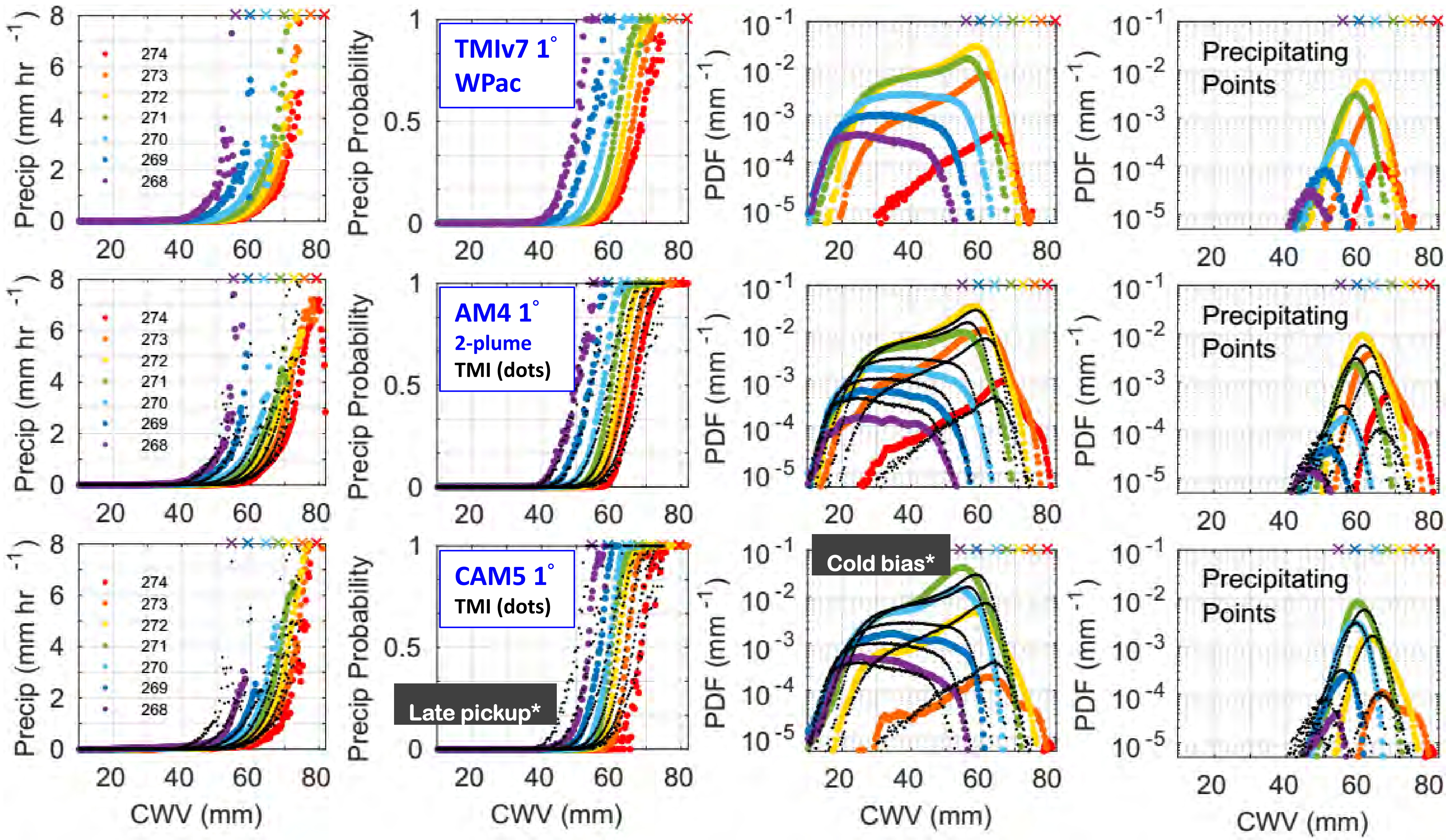
Coordinated Model Comparison in AM4 & CAM5

- Qualitatively reasonable, with quantitative discrepancies

NOAA **M**odel **D**iagnostic **T**ask **F**orce

Timeslice Experiments

1° uncoupled; 2yr of history



*slightly: see other models below!

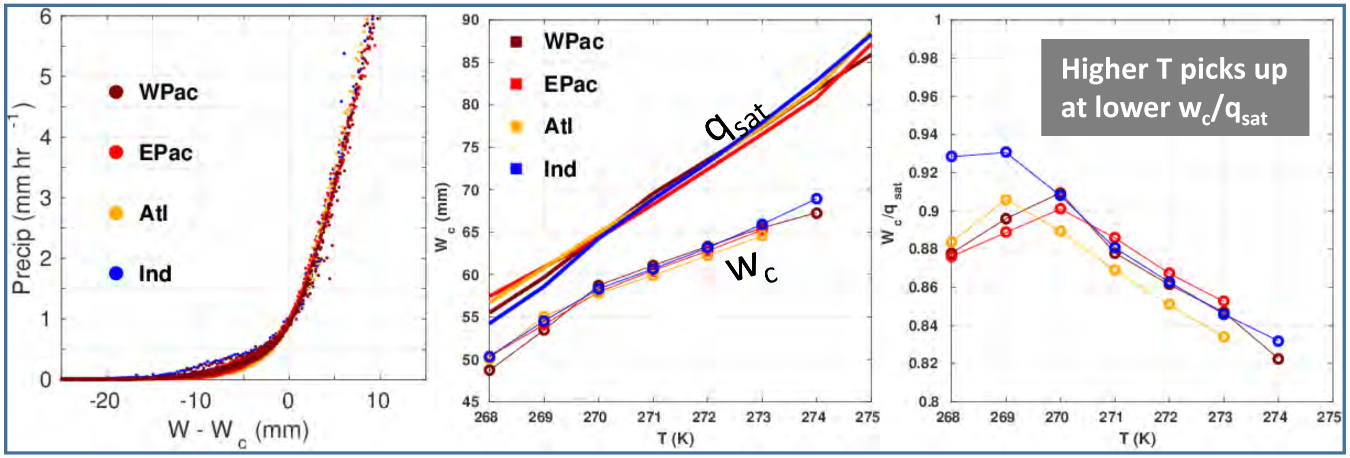
Kuo et al., in prep.

Model comparisons: **collapsed statistics**

Coordinated Model Comparison in AM4 & CAM5

- Qualitatively reasonable, but with quantitative discrepancies

Recall: observations collapsed for all basins, with onset boundaries



Model comparisons: **collapsed statistics**

Coordinated Model Comparison in AM4 & CAM5

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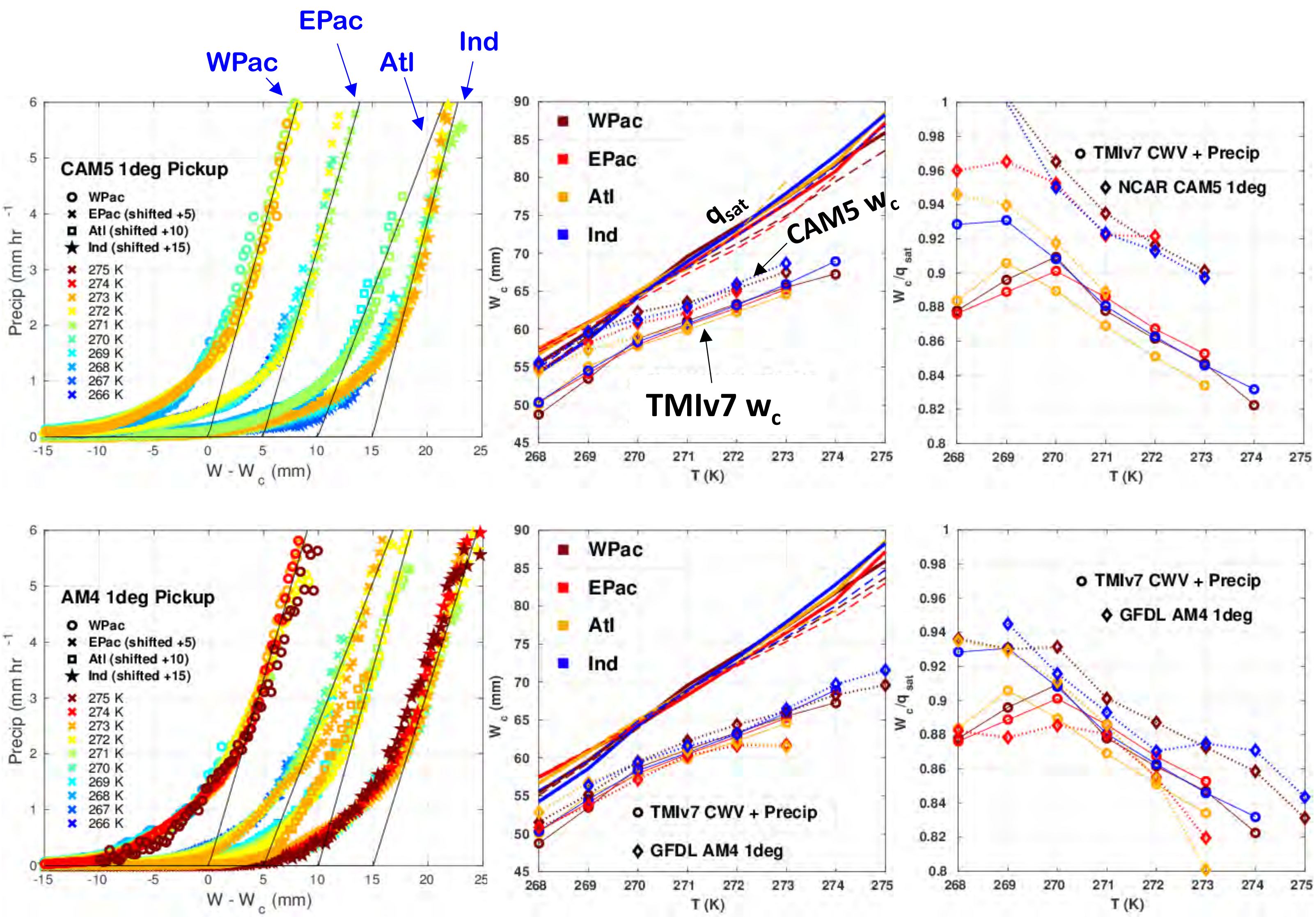
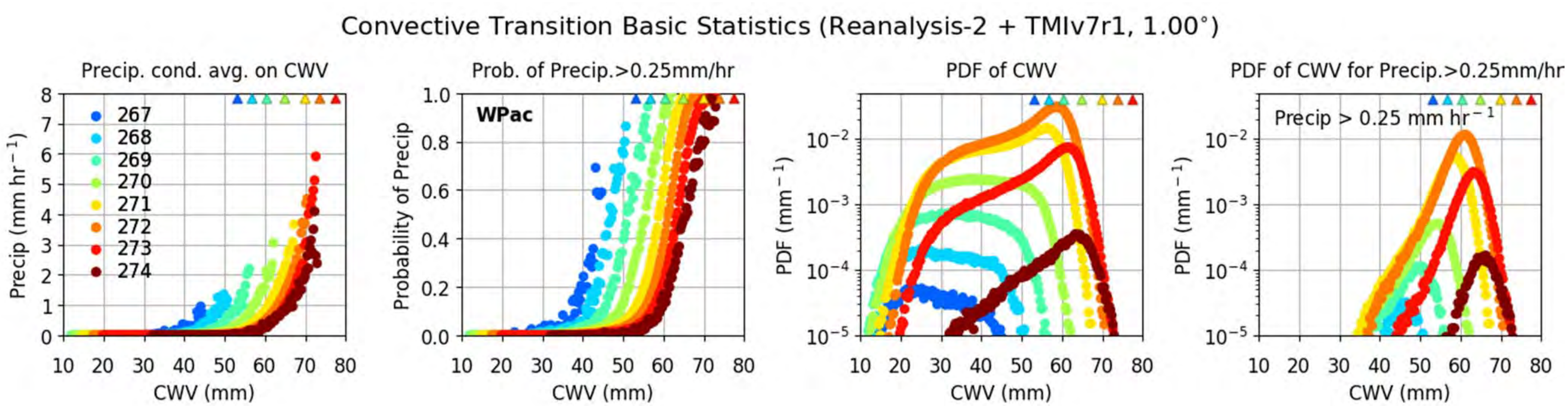


Kuo et al., in prep.

Model comparisons:

Multi-model comparison: Convective transition statistics applied to MDTF + MJOTF/GASS* models

- MJO task force MJOTF/GASS MJO project (climate simulation component, e.g., Petch et al. 2011, Jiang et al. 2015, Jiang 2017, Gonzalez and Jiang 2017)
- 20 years, AGCM or atmosphere-ocean coupled
- 20 years, 6 hourly avg., re-gridded to 2.5° × 2.5°
  http://www.ucar.edu/yotc/mjodiab.html

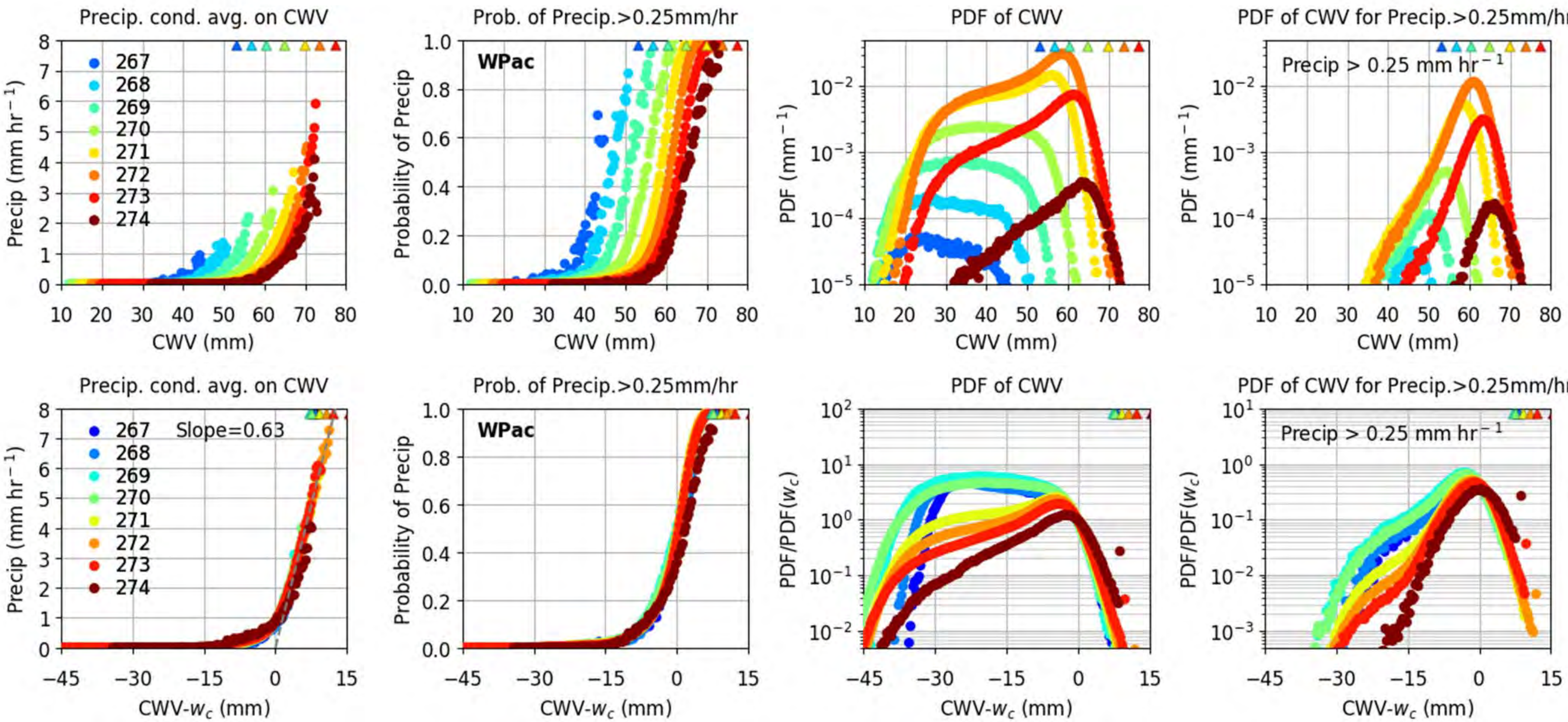


*GASS: Global Energy and Water Cycle Experiment Atmospheric System Study

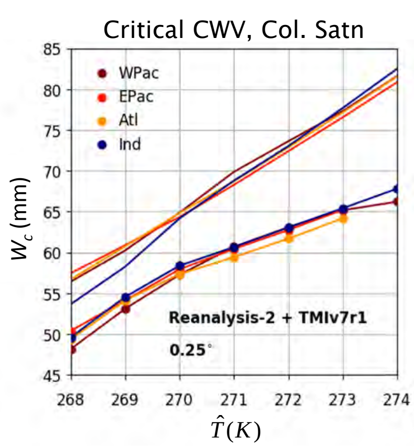
(TMIv7r1 CWV & Precip; Reanalysis-2 Temp.)

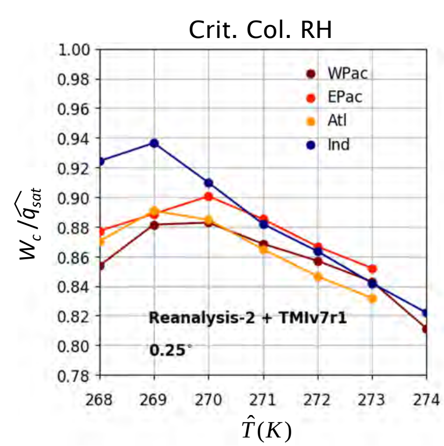
1.00°

0.25°



Recall: observations
0.25 & 1 deg.;
dependence on column water vapor
(orig. & collapsed)

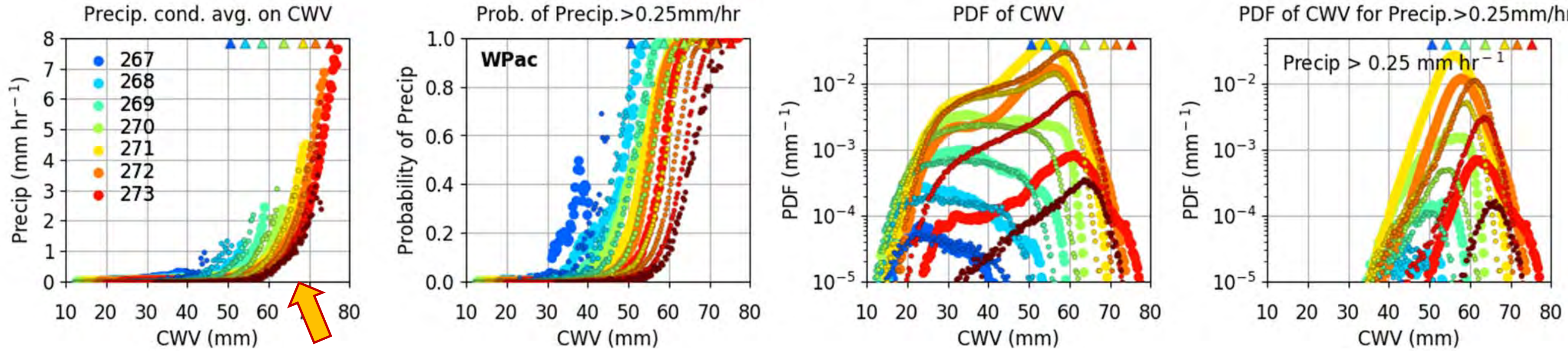




Critical CWV, Col. Satn, & Critical Col. RH

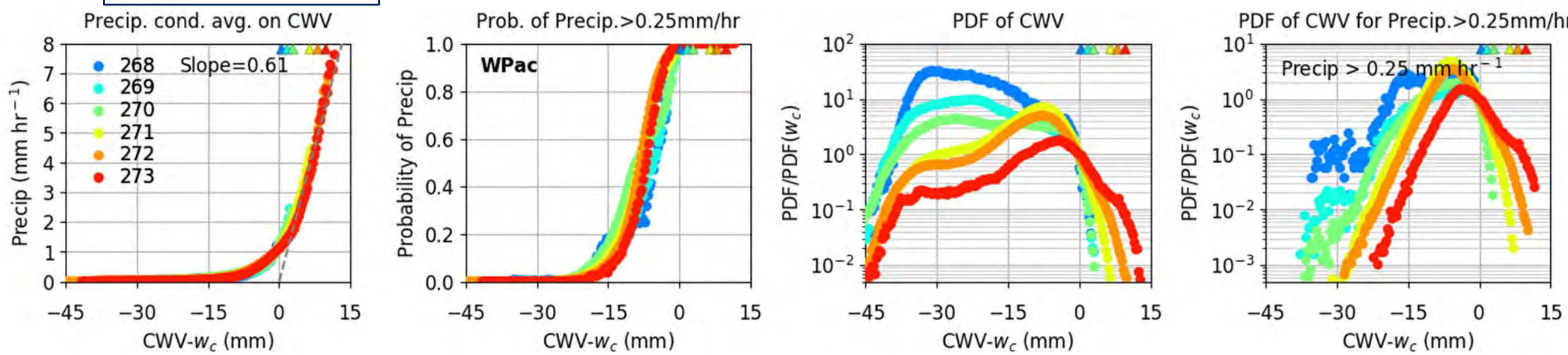
Kuo et al., in prep.

Convective transition: Basic statistics

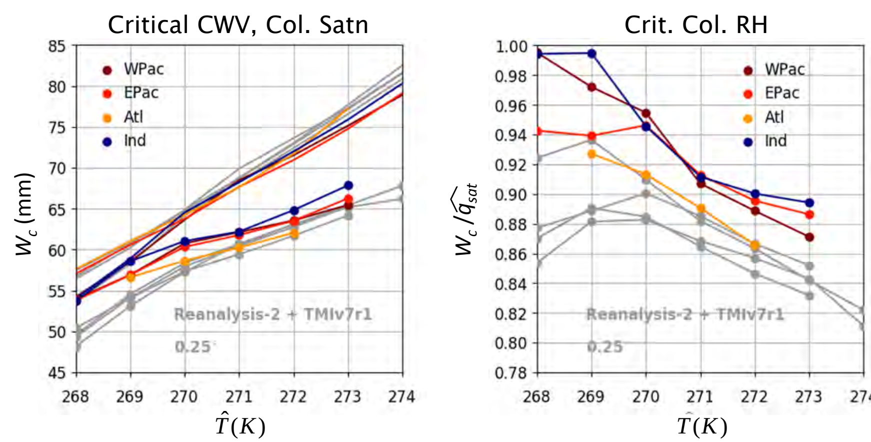


Small dots: obs

Convective transition: Collapsed statistics



Critical CWV, Column saturation & Critical column relative humidity

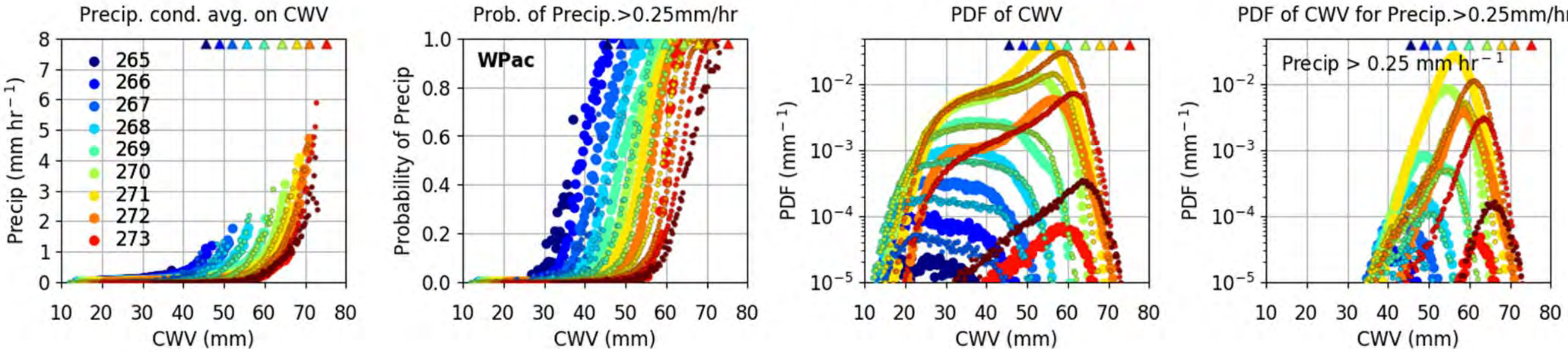


Recall: MDTF Timeslice Exp. Hourly, 1° CAM5.3

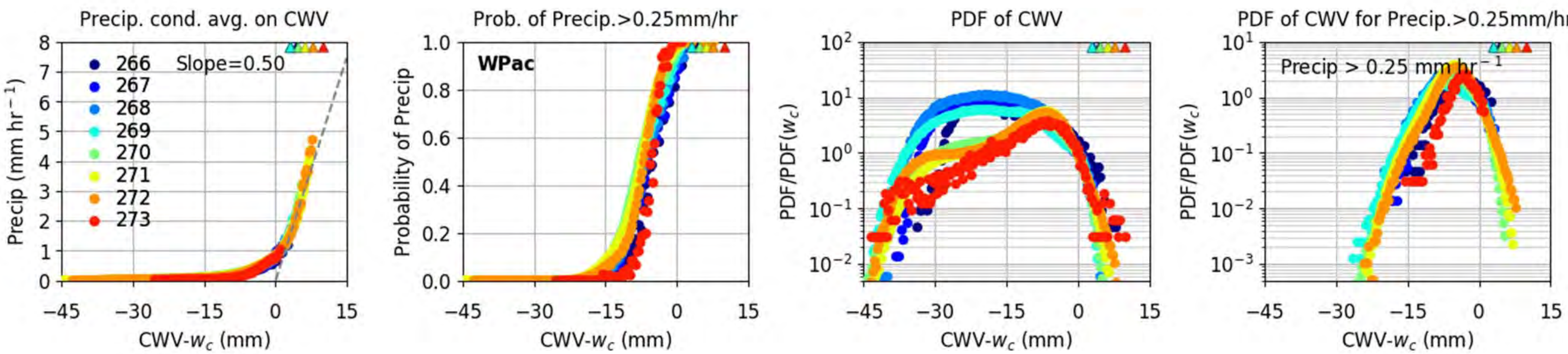
Pickup good, slightly high critical CWV; good PDFs

Kuo et al., in prep.

Convective transition: Basic statistics

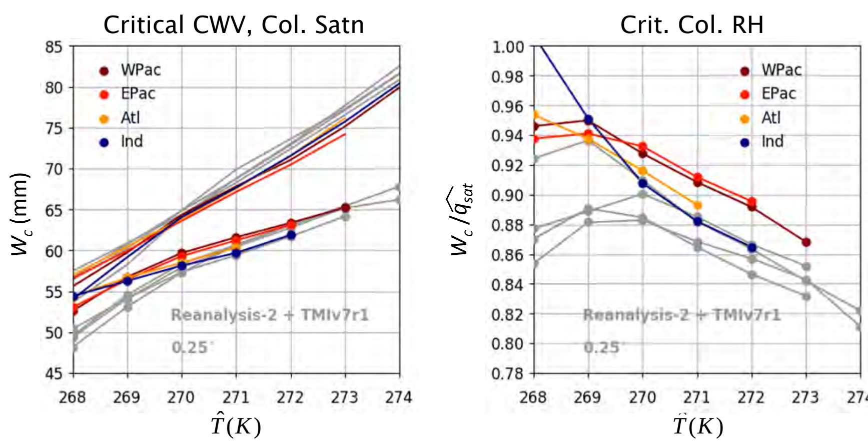


Convective transition: Collapsed statistics



Critical CWV, Column saturation & Critical column relative humidity

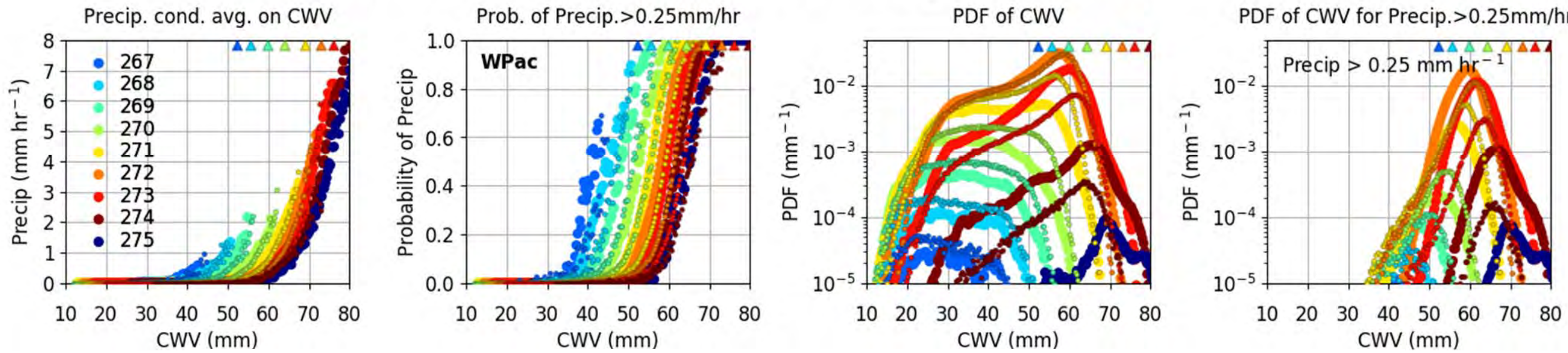
MJOTF
6-Hourly,2.5°
CAM5 (NCAR)



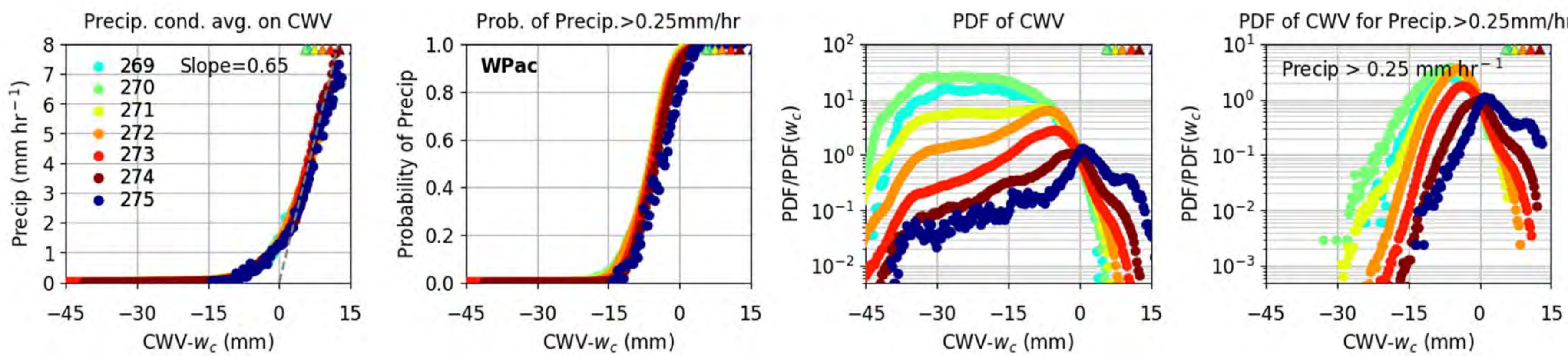
Highly consistent between hourly and 6-hourly

Kuo et al., in prep.

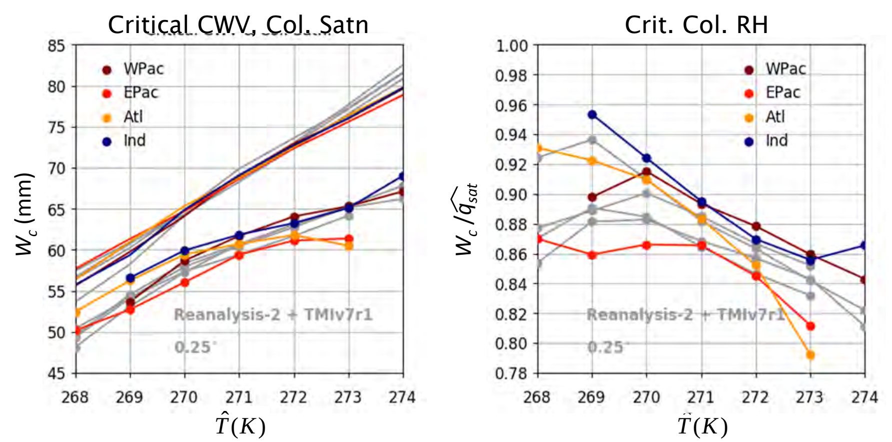
Convective transition: Basic statistics



Convective transition: Collapsed statistics



Critical CWV, Column saturation & Critical column relative humidity

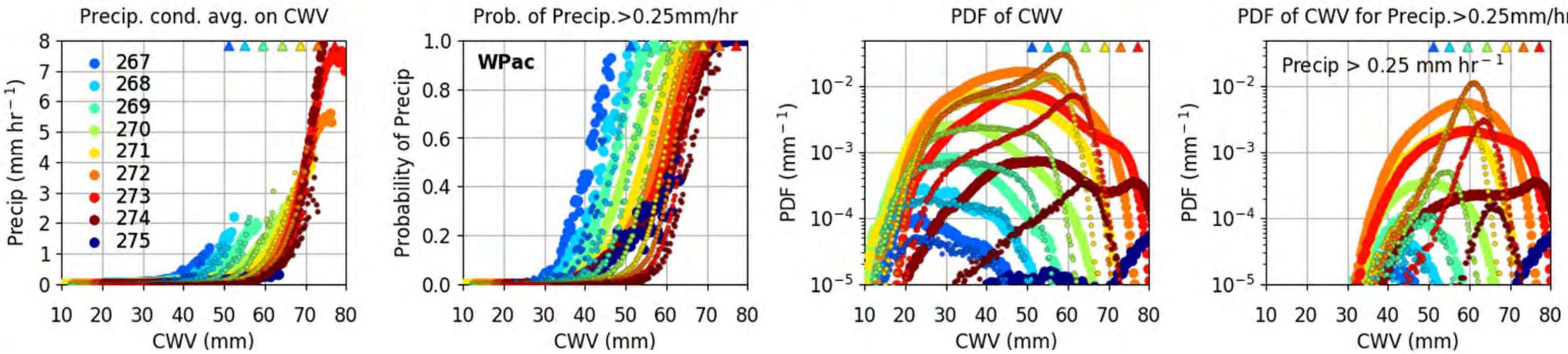


Recall: MDTF Timeslice Exp. Hourly, 1° GFDL AM4 2-plume

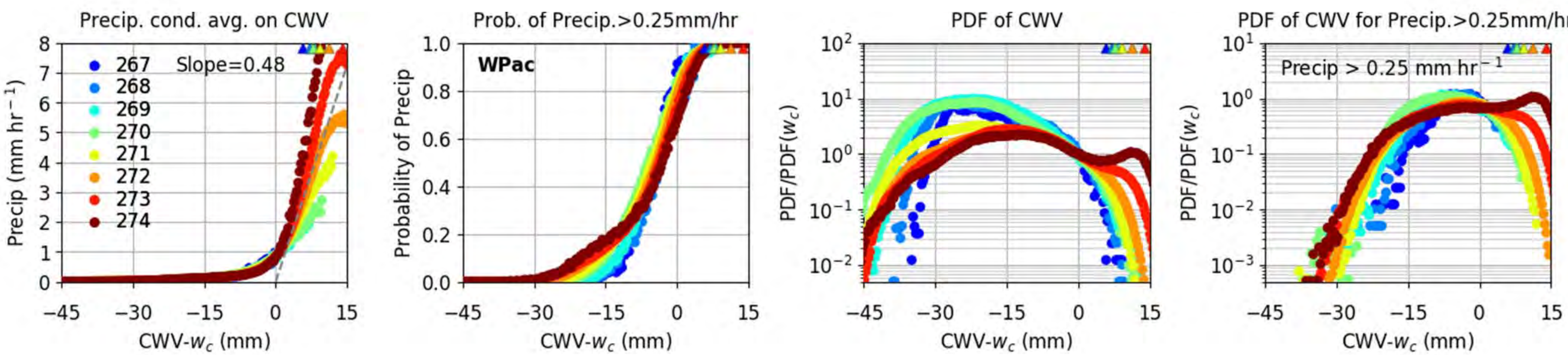
Quant. match with obs; higher PDF for high CWV & T_{ave}

Kuo et al., in prep.

Convective transition: Basic statistics

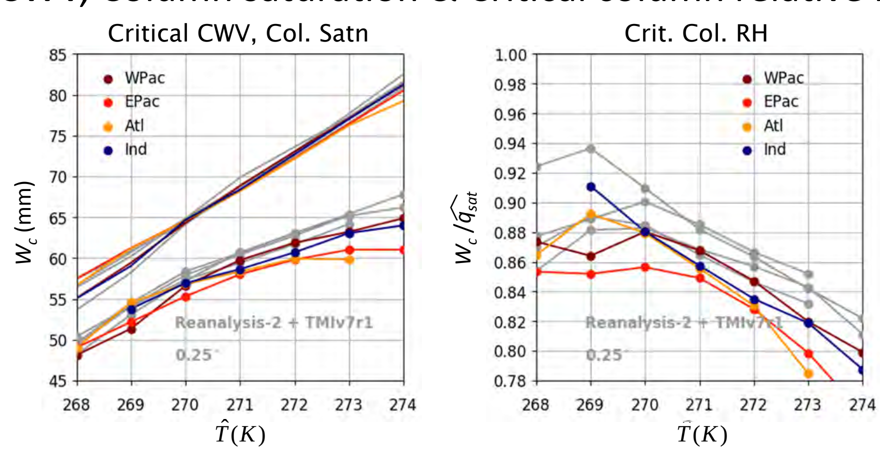


Convective transition: Collapsed statistics



Critical CWV, Column saturation & Critical column relative humidity

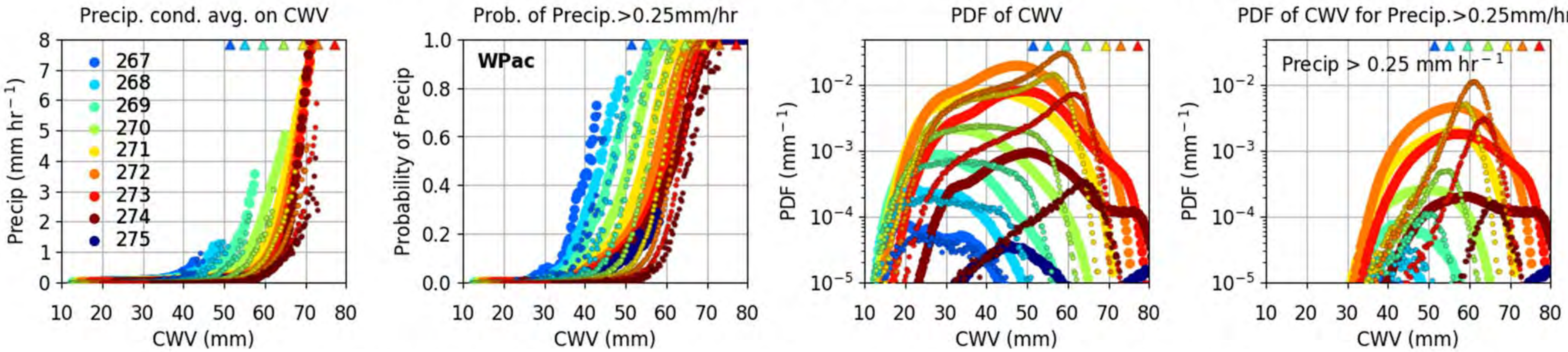
MDTF Timeslice Exp. Hourly, 1° GFDL AM4 Donner



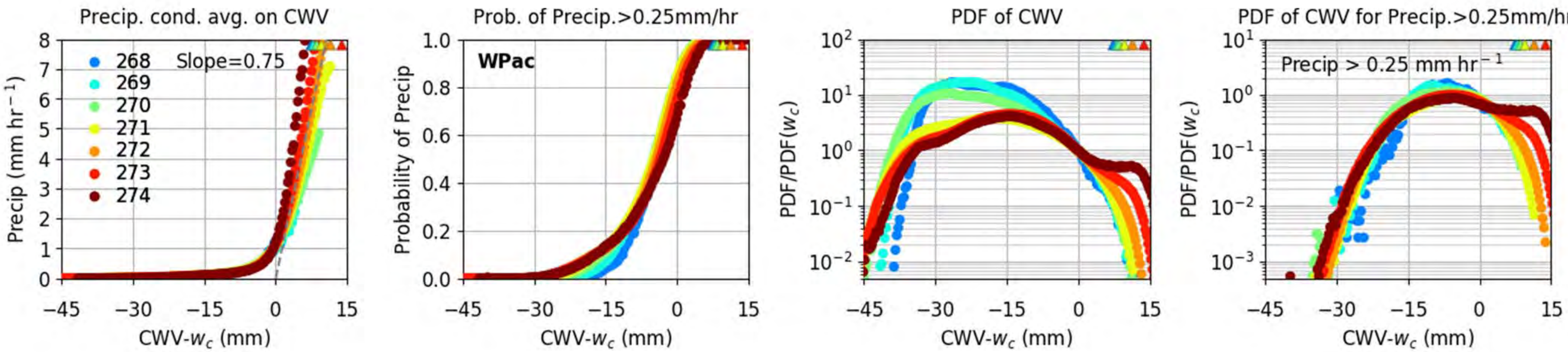
Pickup good; but PDFs too wide

Kuo et al., in prep.

Convective transition: Basic statistics

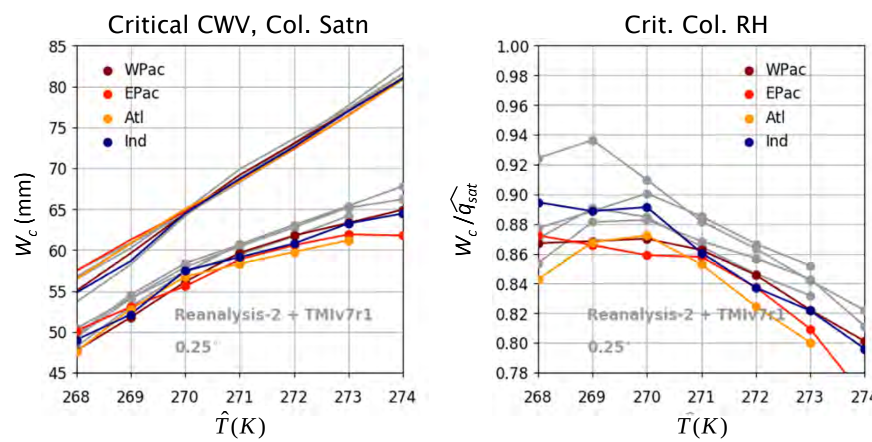


Convective transition: Collapsed statistics



Critical CWV, Column saturation & Critical column relative humidity

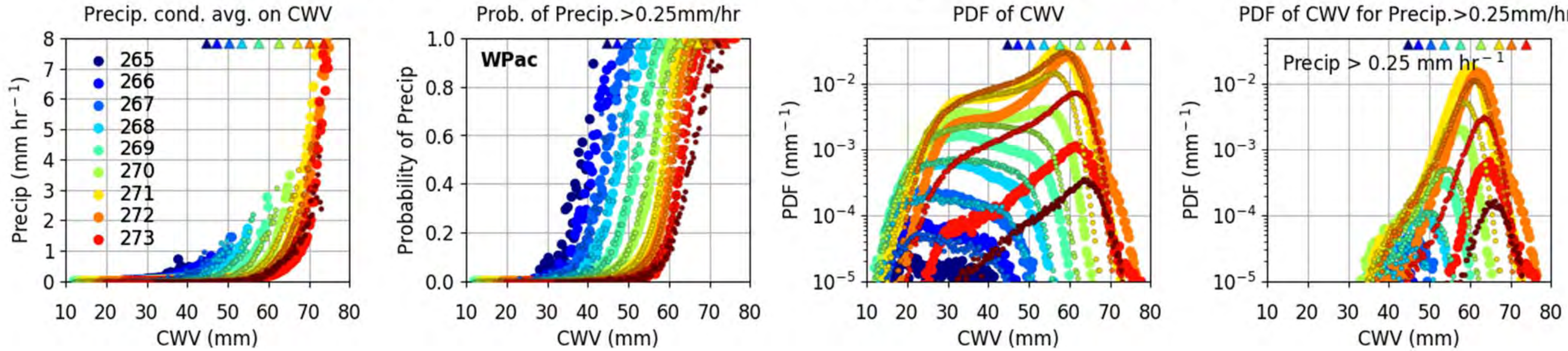
MDTF Timeslice Exp. Hourly,0.5° GFDL AM4 Donner



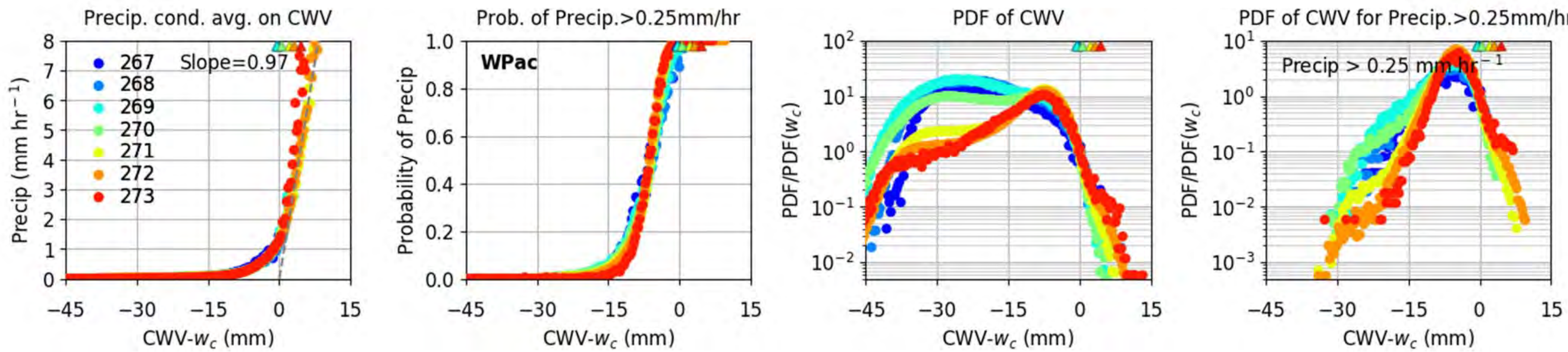
PDFs too wide; consistent between 0.5° & 1°

Kuo et al., in prep.

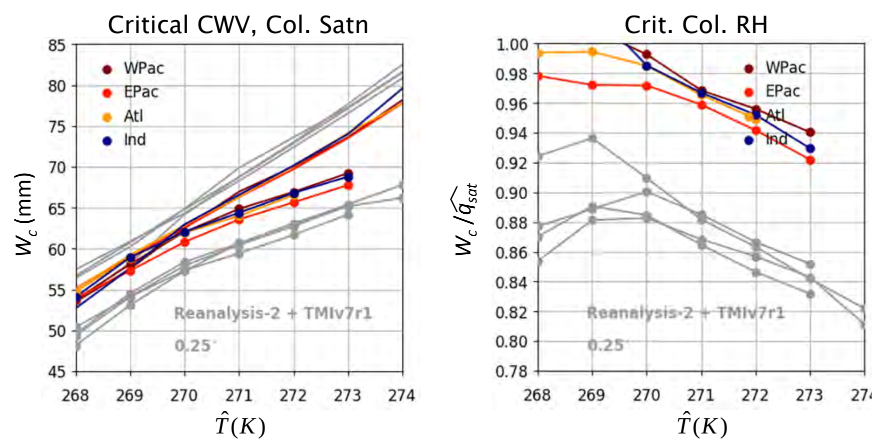
Convective transition: Basic statistics



Convective transition: Collapsed statistics



Critical CWV, Column saturation & Critical column relative humidity

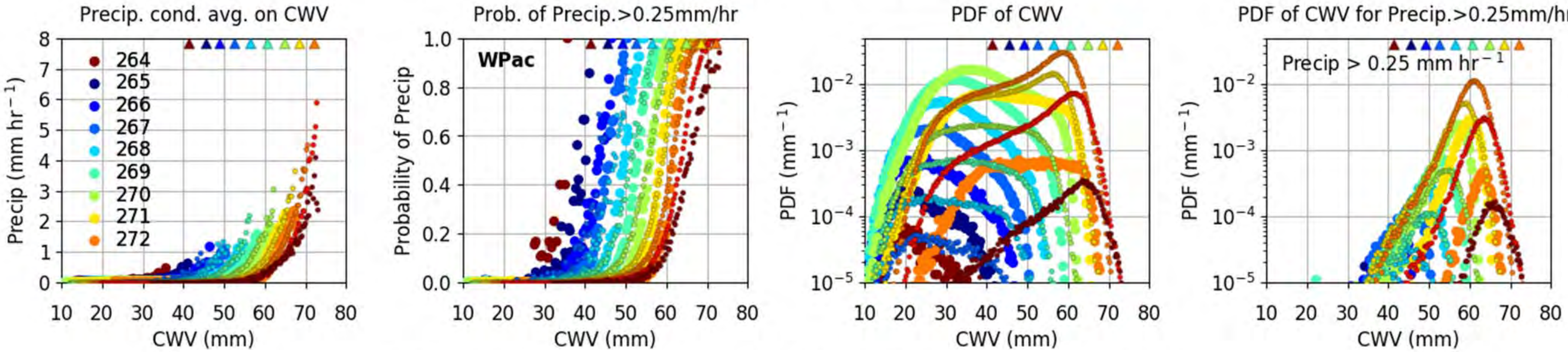


MJOTF
6-Hourly,2.5°
GEOS5

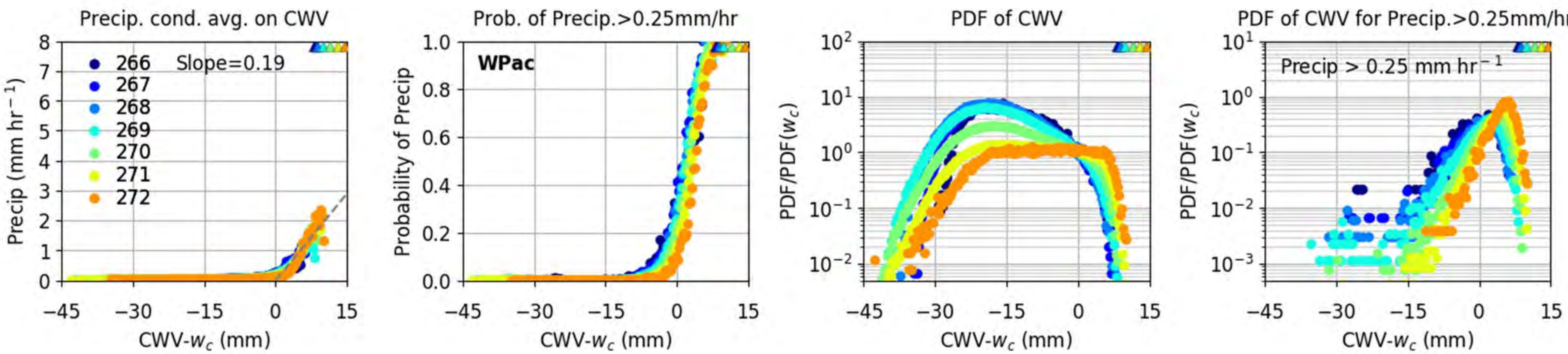
Pickup good but too high; good PDFs

Kuo et al., in prep.

Convective transition: Basic statistics

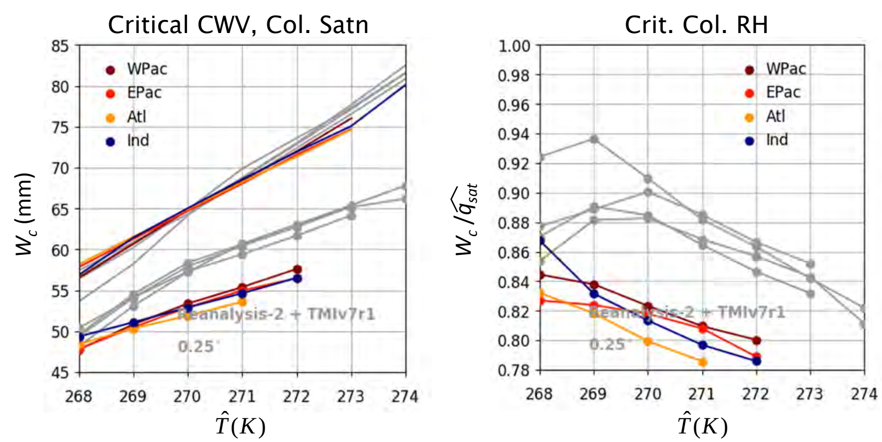


Convective transition: Collapsed statistics



Critical CWV, Column saturation & Critical column relative humidity

MJOTF 6-Hourly, 2.5° GISS-E2

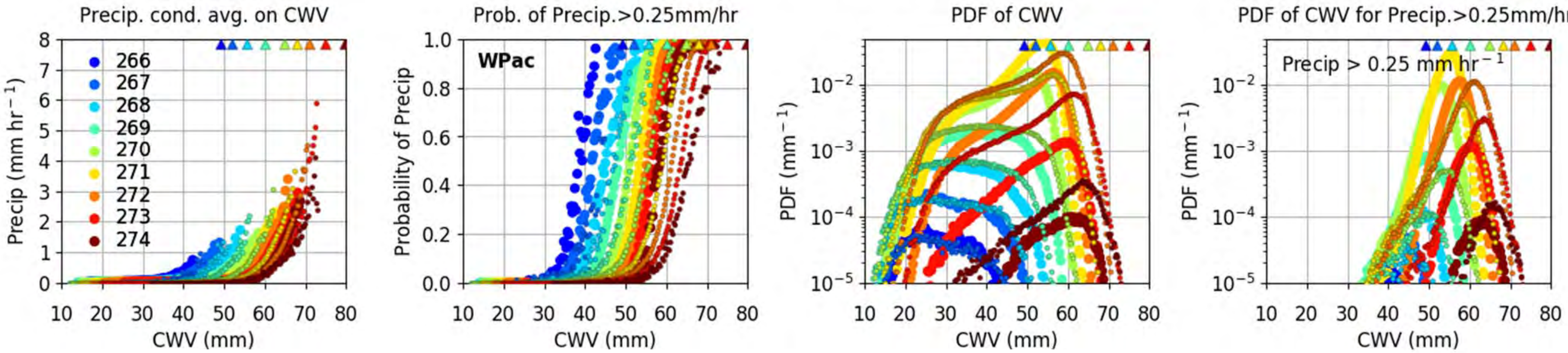


Pickup good but too low; good PDFs$|_{P>.25}$ cold bias

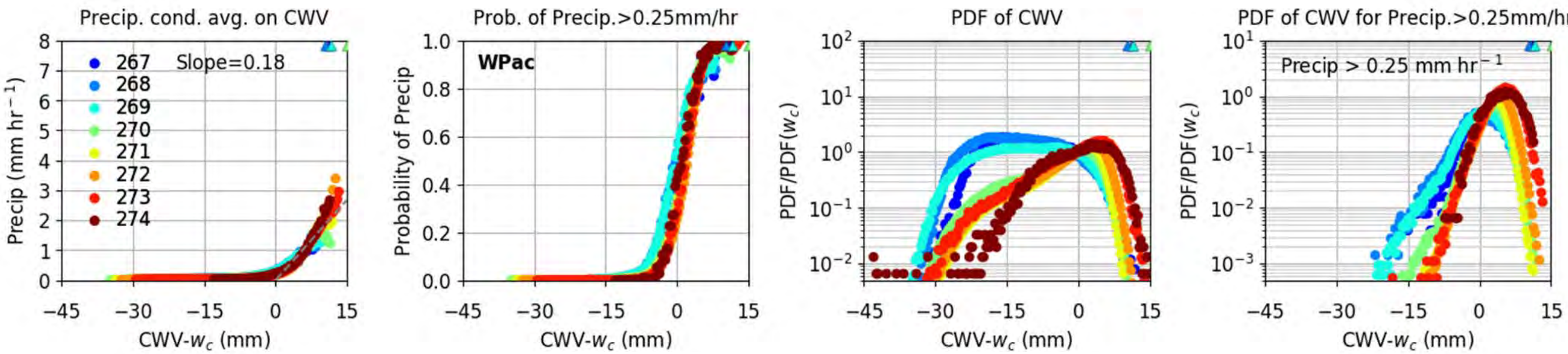
Good MJO (Gonzalez & Jiang 2017)

Kuo et al., in prep.

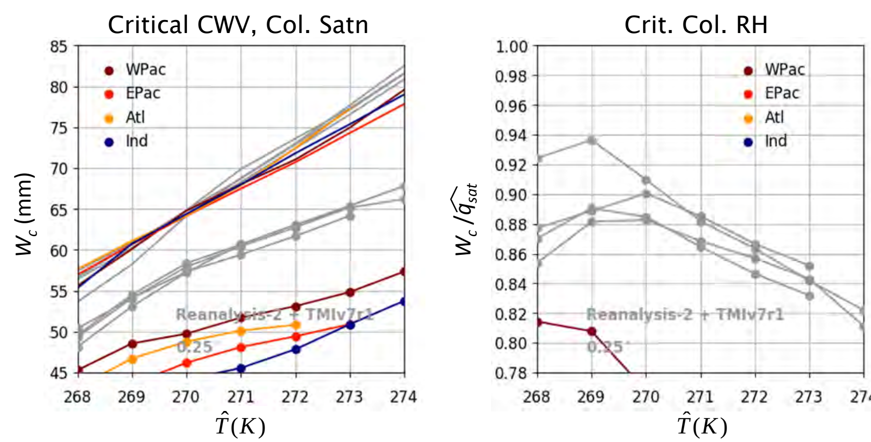
Convective transition: Basic statistics



Convective transition: Collapsed statistics



Critical CWV, Column saturation & Critical column relative humidity



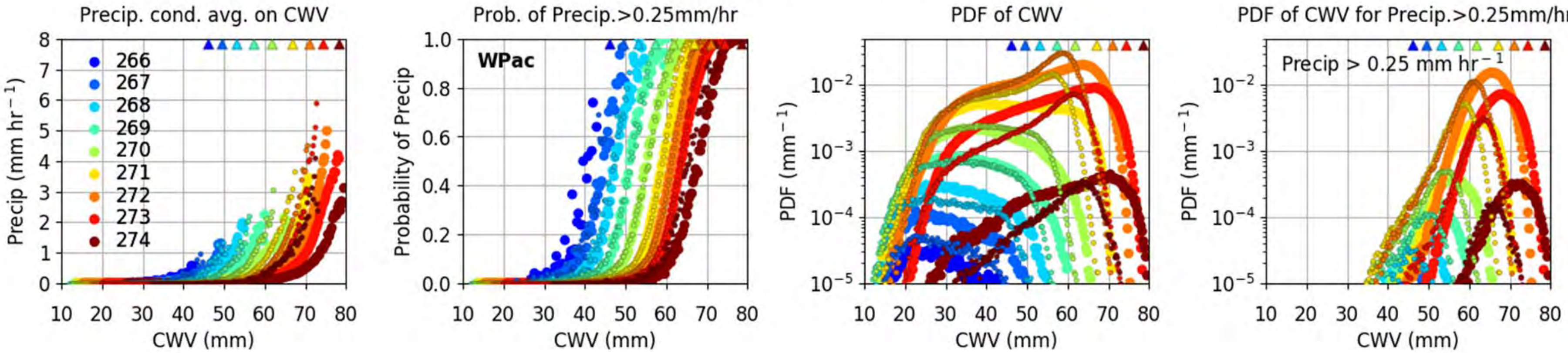
MJOTF 6-Hourly,2.5° MIROC5

Pickup OK but too low; good PDFs$|_{P>.25}$

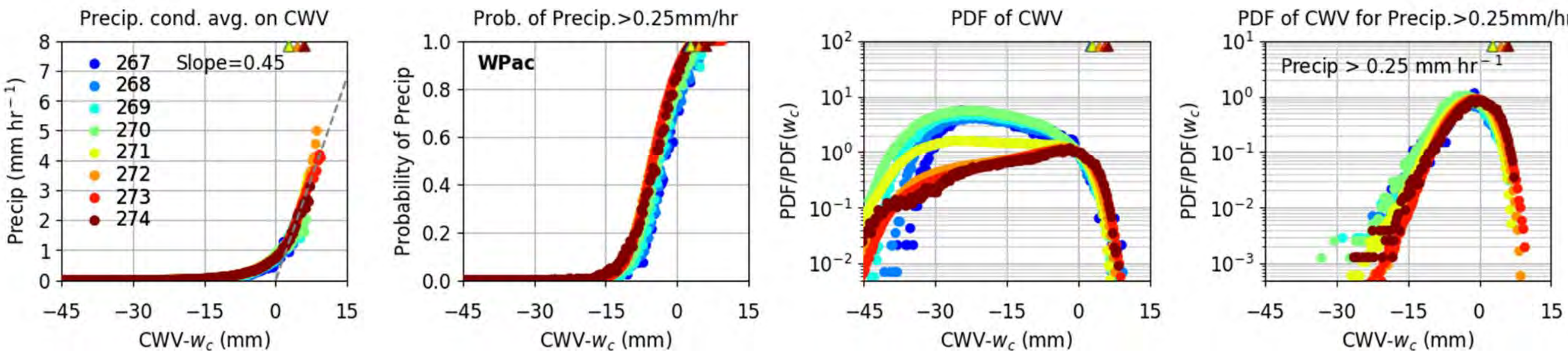
Bad MJO (Gonzalez & Jiang 2017)

Kuo et al., in prep.

Convective transition: Basic statistics

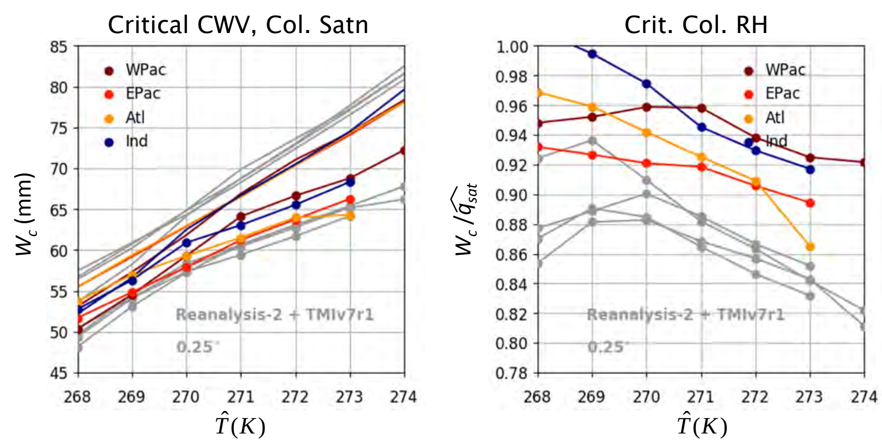


Convective transition: Collapsed statistics



Critical CWV, Column saturation & Critical column relative humidity

MJOTF
6-Hourly, 2.5°
MRI AGCM

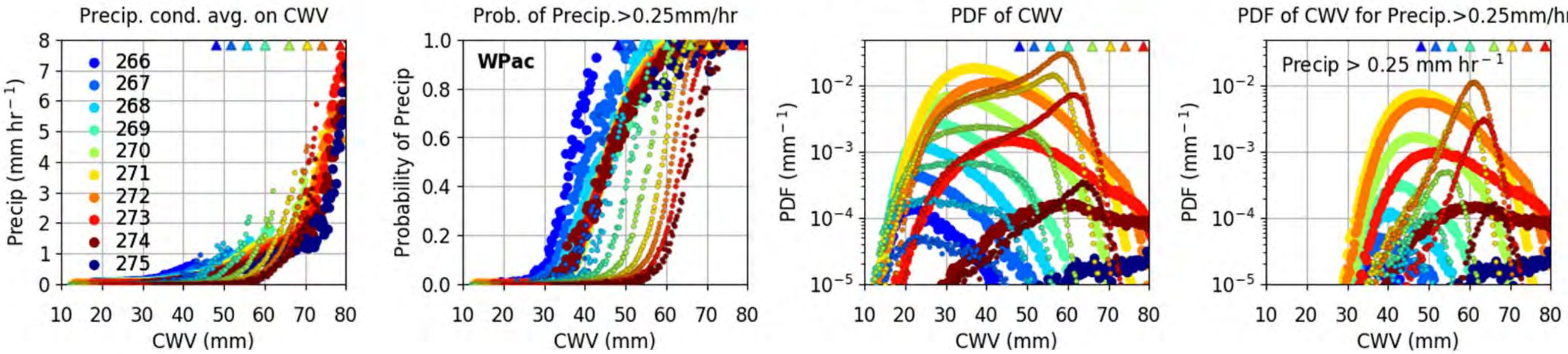


Pickup good but too high; good PDFs$|_{P>.25}$

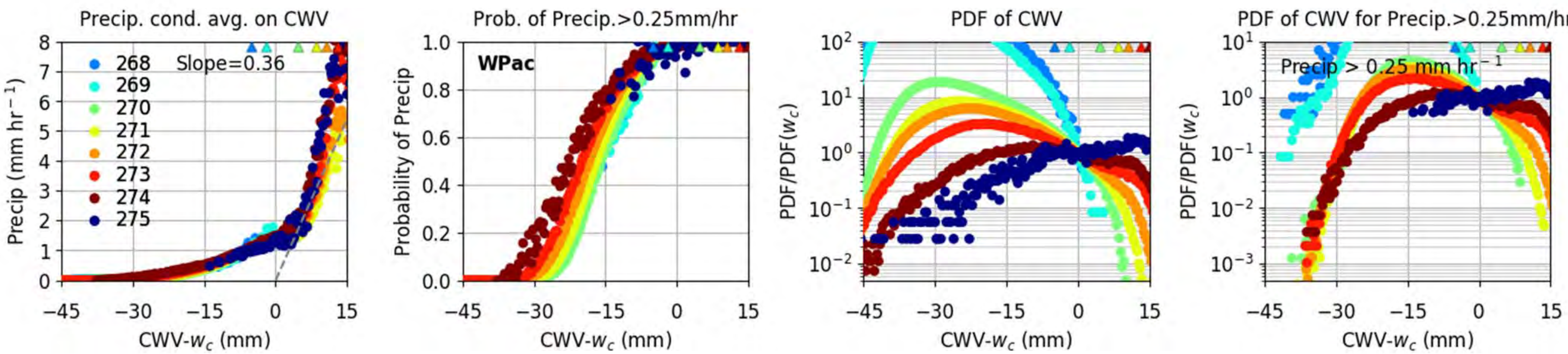
Good MJO (Gonzalez & Jiang 2017)

Kuo et al., in prep.

Convective transition: Basic statistics

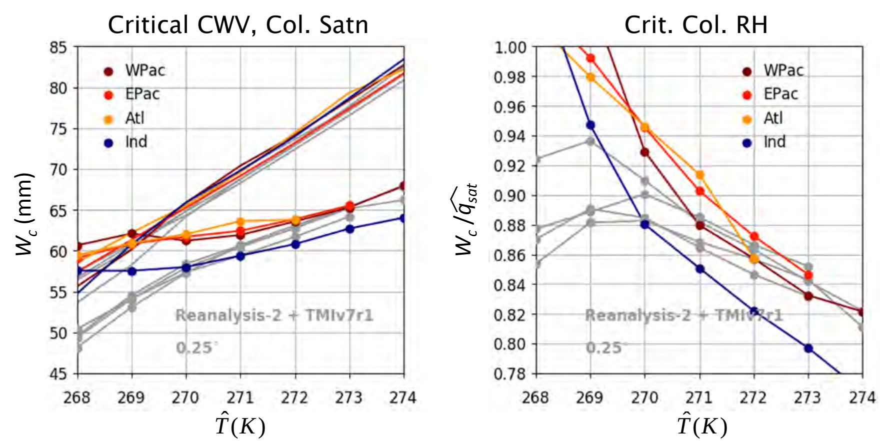


Convective transition: Collapsed statistics



Critical CWV, Column saturation & Critical column relative humidity

MJOTF
6-Hourly,2.5°
CWB (Taiwan)
GFS

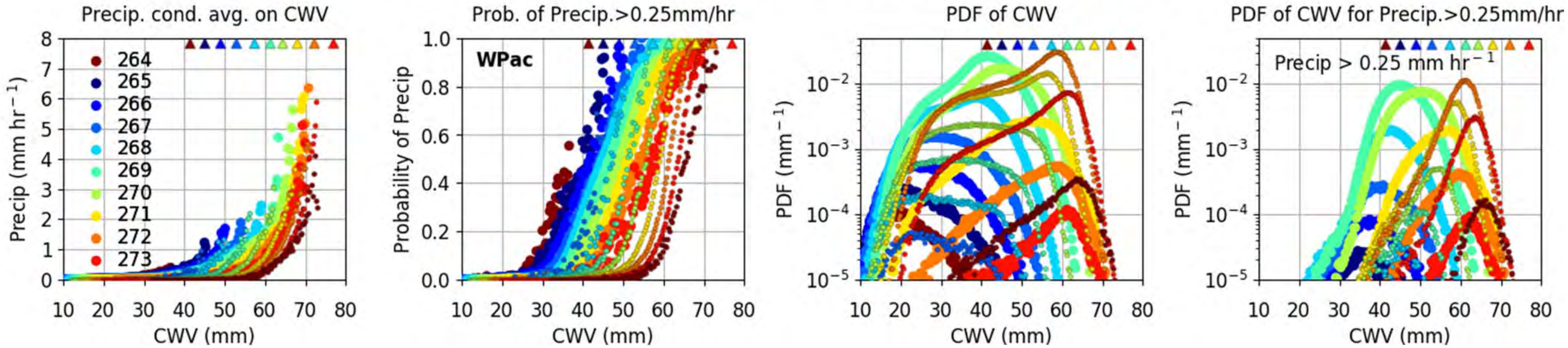


Bad: 2-step pickup pb.; poor PDFs & PDFs$|_{P>.25}$

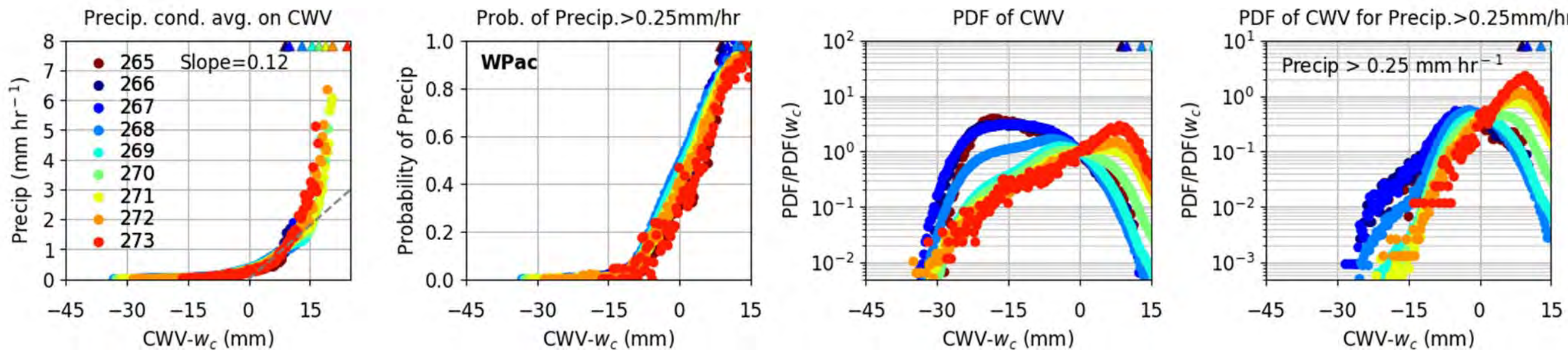
Bad MJO (Gonzalez & Jiang 2017)

Kuo et al., in prep.

Convective transition: Basic statistics

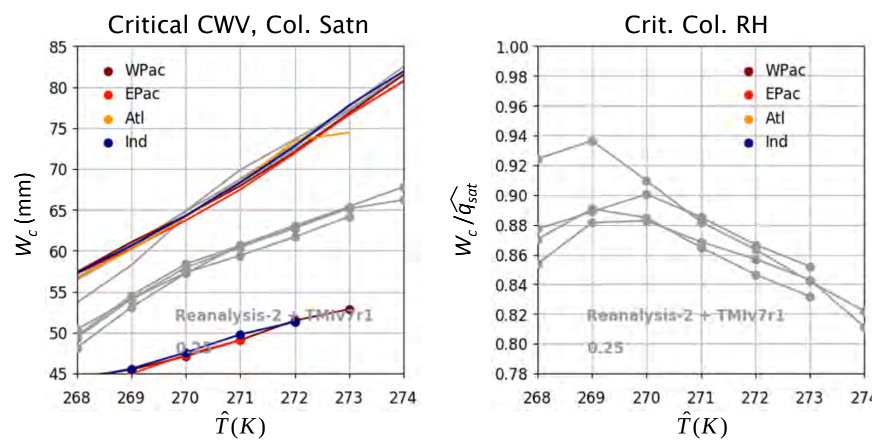


Convective transition: Collapsed statistics



Critical CWV, Column saturation & Critical column relative humidity

MJOTF
6-Hourly,2.5°
NRL NavGEMv1

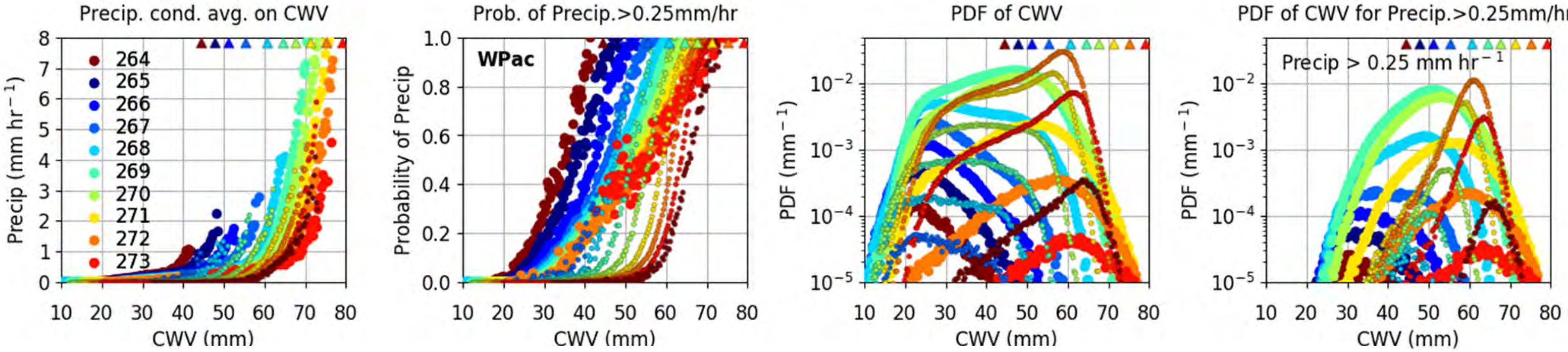


Pickup good but too low;
ok PDFs$|_{P>.25}$
cold bias

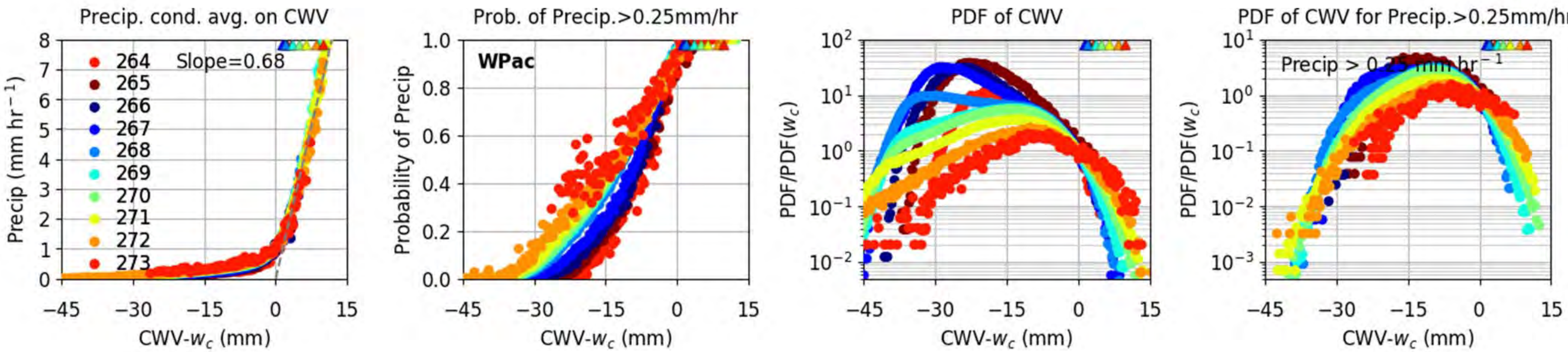
Bad MJO (Gonzalez & Jiang 2017)

Kuo et al., in prep.

Convective transition: Basic statistics

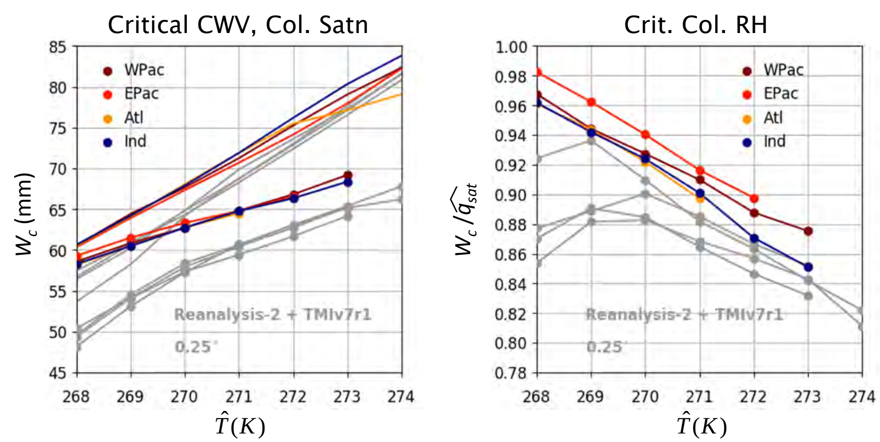


Convective transition: Collapsed statistics



Critical CWV, Column saturation & Critical column relative humidity

MJOTF
6-Hourly,2.5°
CNRM CM

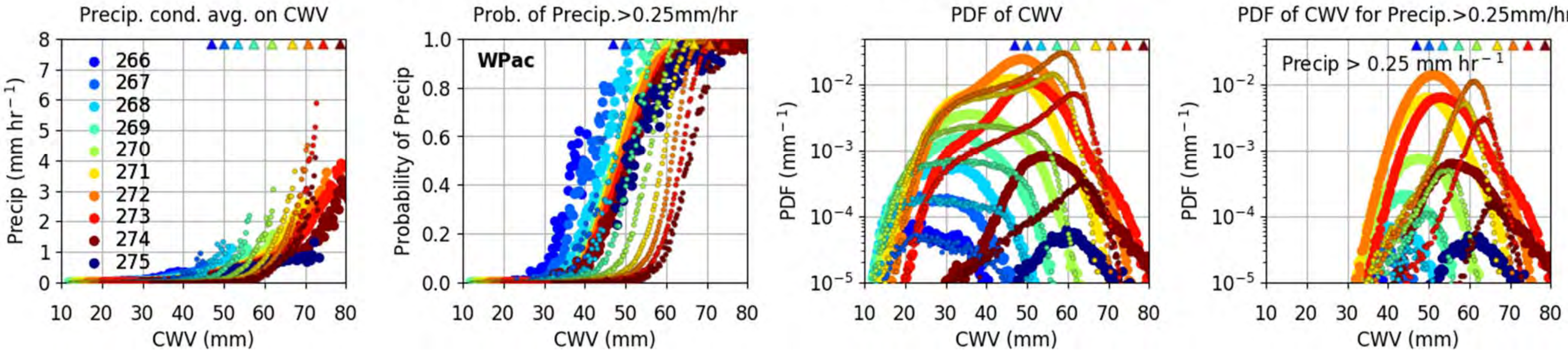


Pickup good but too high, slight 2-step; broad PDFs$|_{P>.25}$

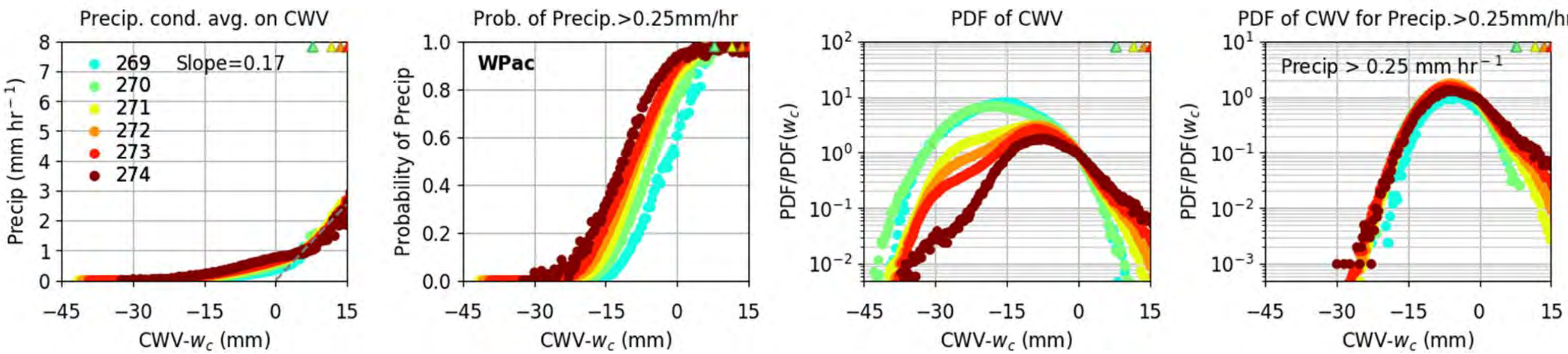
Good MJO (Gonzalez & Jiang 2017)

Kuo et al., in prep.

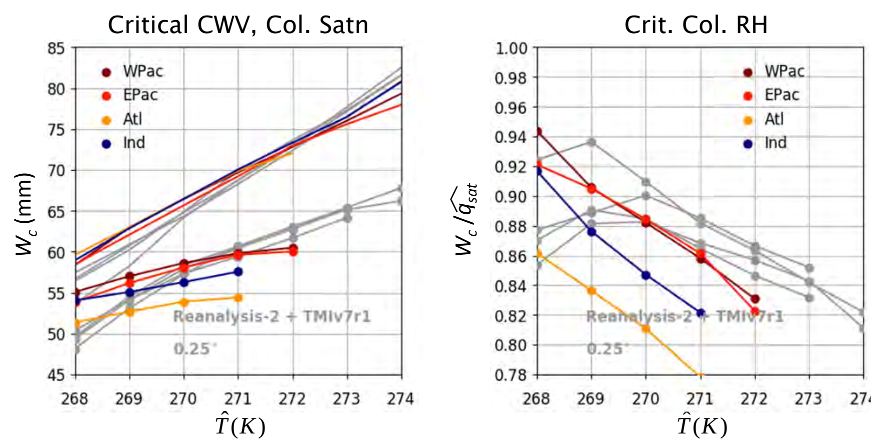
Convective transition: Basic statistics



Convective transition: Collapsed statistics



Critical CWV, Column saturation & Critical column relative humidity

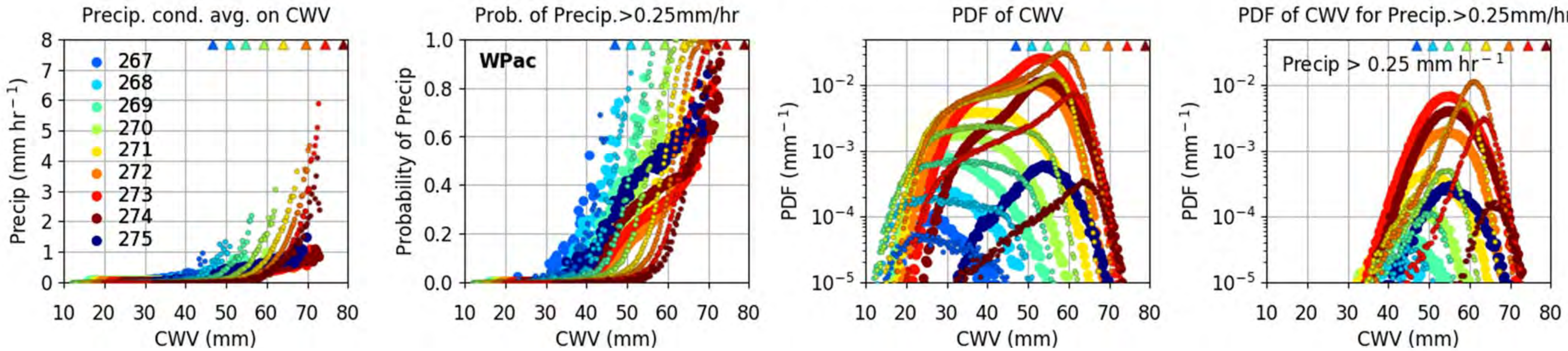


MJOTF
6-Hourly,2.5°
CanCM4

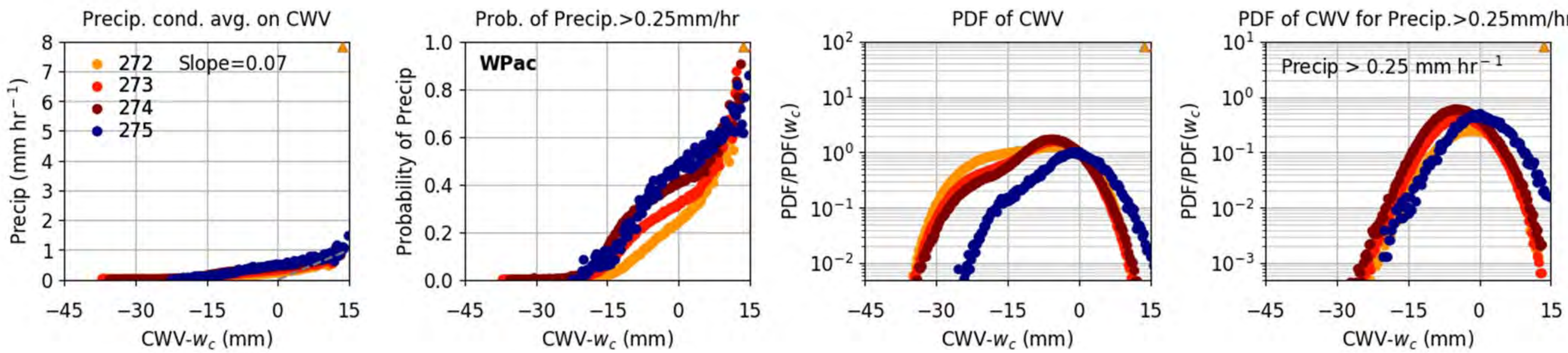
Bad: 2-step pickup; broad PDFs$|_{P>.25}$

Bad MJO (Gonzalez & Jiang 2017)

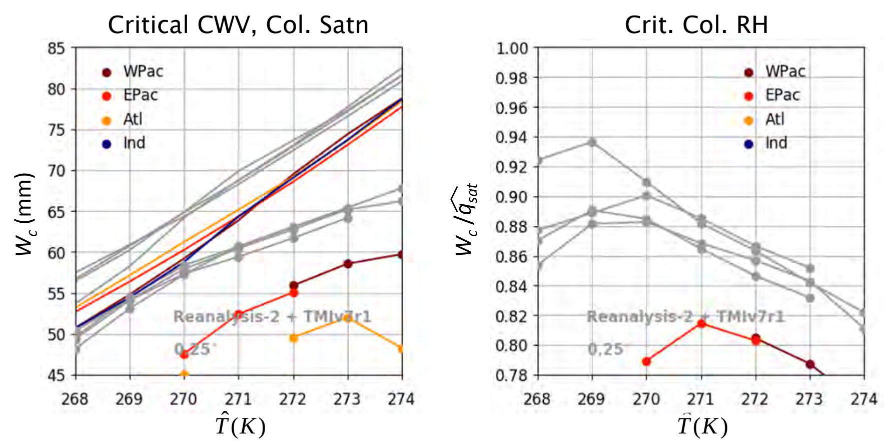
Convective transition: Basic statistics



Convective transition: Collapsed statistics



Critical CWV, Column saturation & Critical column relative humidity



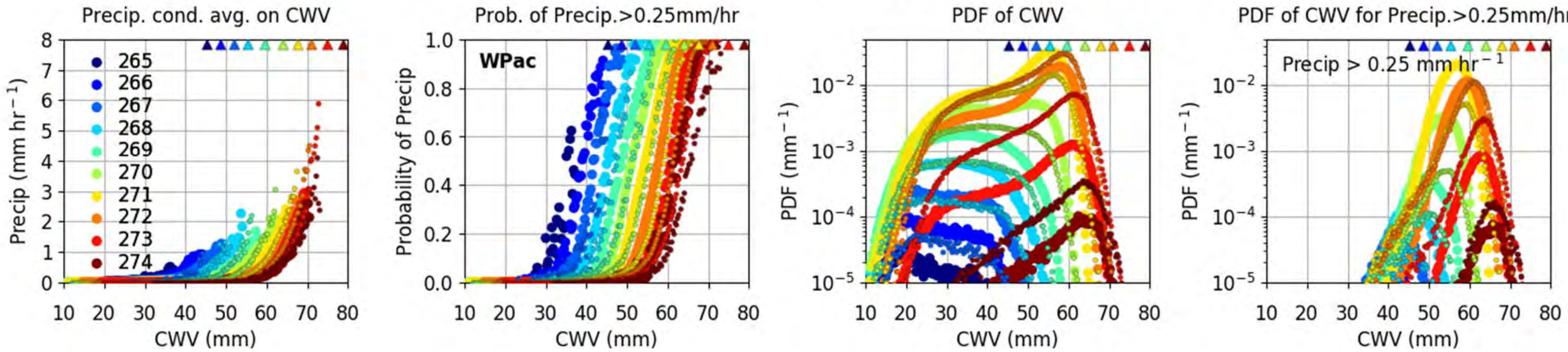
MJOTF 6-Hourly,2.5° ISUGCM

Bad: weak, broad pickup; broad PDFs$|_{P>.25}$

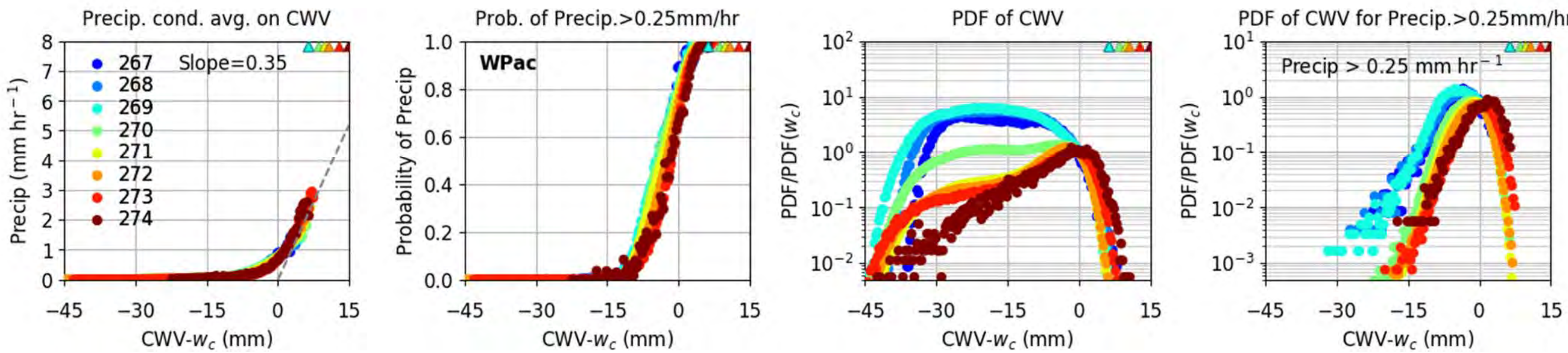
Bad MJO (Gonzalez & Jiang 2017)

Kuo et al., in prep.

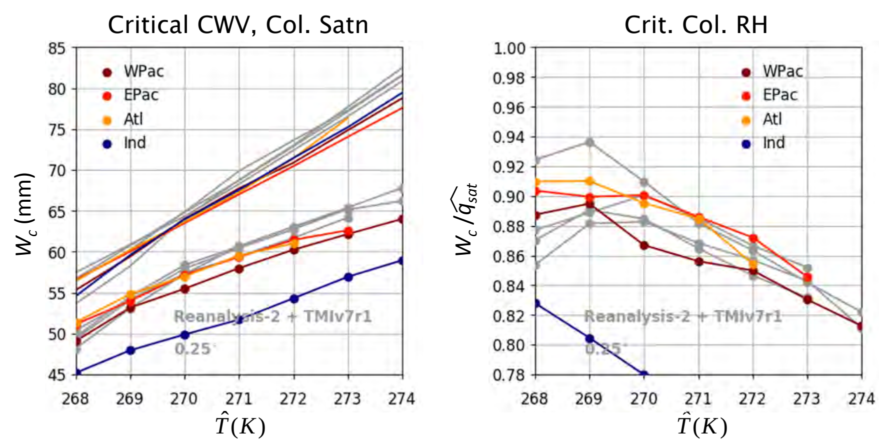
Convective transition: Basic statistics



Convective transition: Collapsed statistics



Critical CWV, Column saturation & Critical column relative humidity



MJOTF
6-Hourly,2.5°
EC-Earth

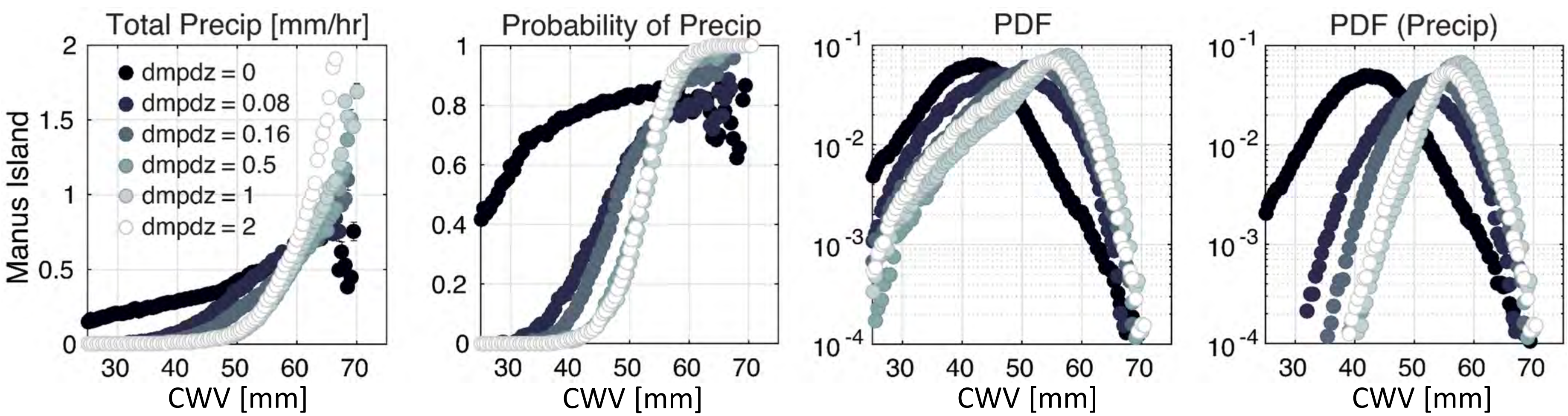
Pickup good; good PDFs & PDFs$|_{P>.25}$

Good MJO (Gonzalez & Jiang 2017)

Kuo et al., in prep.

Parameter dependence: Dependence on deep convective parameters in CESM1*

Entrainment (dmpdz)



- CESM reproduces pickup with substantial entrainment (dmpdz)
- PDFs broaden as dmpdz decreases
- Pickup collapses for no-entrainment
- Corroboration of leading causal pathway via buoyancy impact

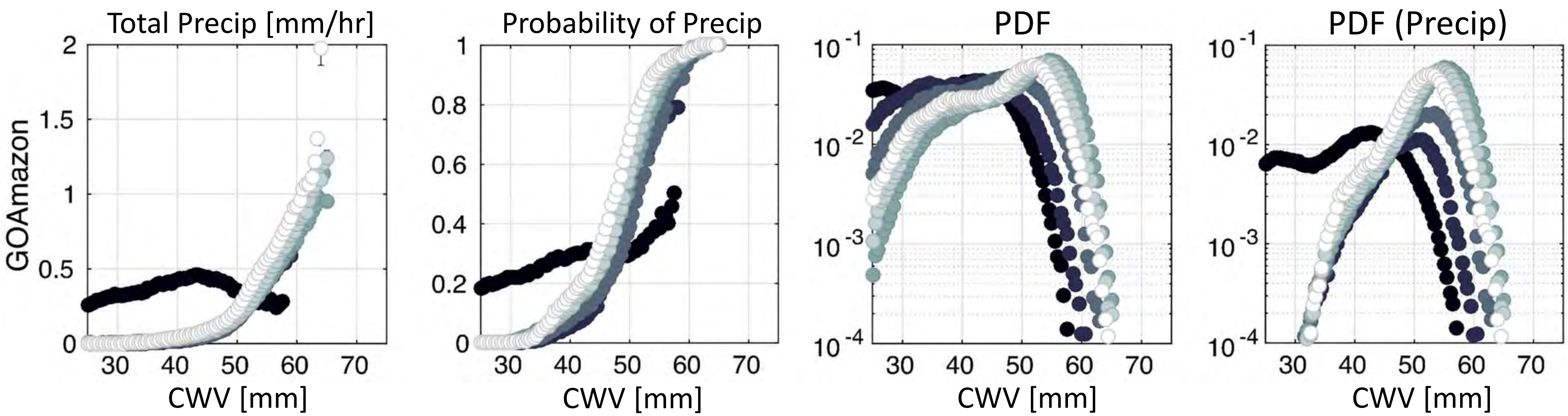
Instantaneous Precip, Column Water Vapor (CWV)
At Manus Island (W. Pacific) ARM Site (3 grid points).

Kuo et al. (2017)

*Community Earth System Model 2°; 1975-2005 historical radiative & aerosol forcing

Parameter dependence: Dependence on deep convective parameters in CESM1*

Entrainment (dmpdz)



- CESM reproduces pickup with substantial entrainment (dmpdz)
- PDFs broaden as dmpdz decreases
- Pickup collapses for no-entrainment
- Similar dependence over land & ocean

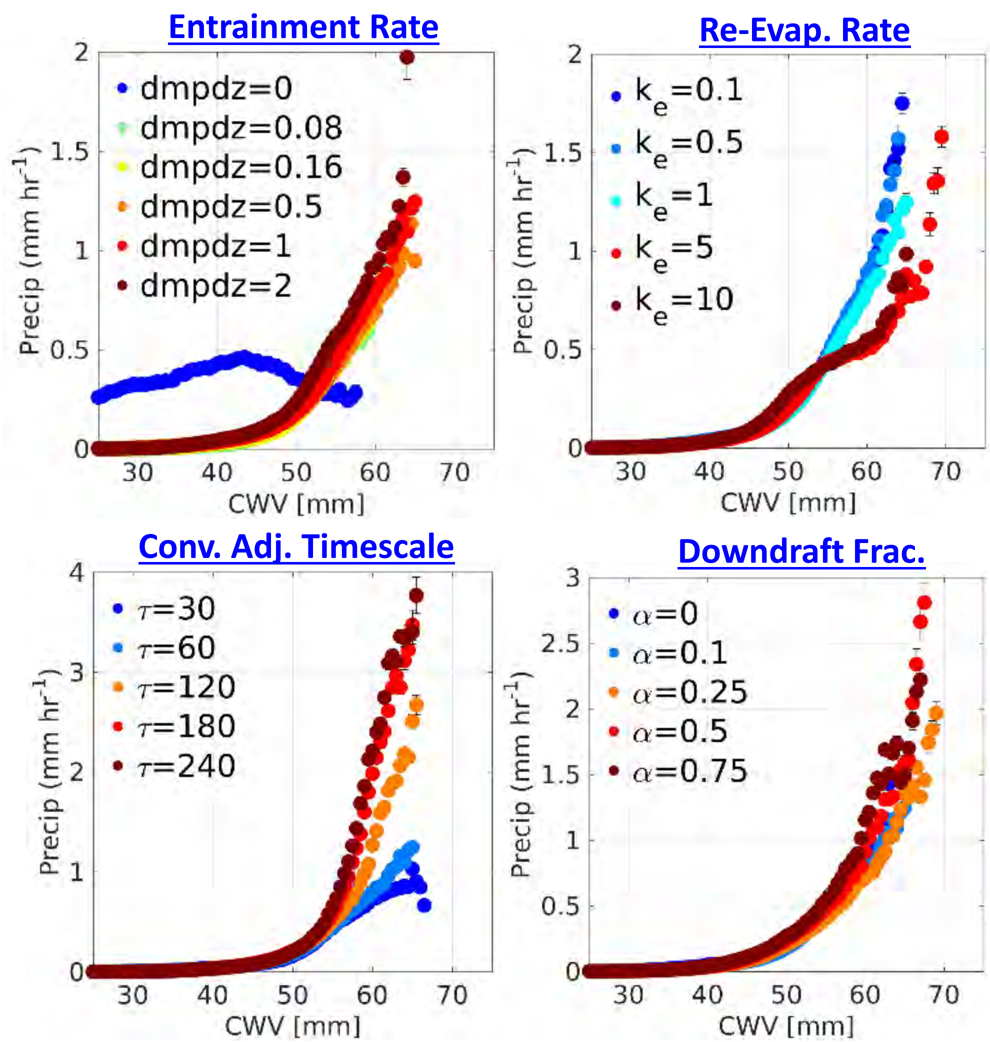
Instantaneous Precip, Column Water Vapor (CWV)
At Manaus GoAmazon ARM Site (3 grid points).
Kuo et al. (2017)

*Community Earth System Model 2°; 1975-2005 historical radiative & aerosol forcing

Parameter dependence: Dependence on deep convective parameters in CESM1*

At GoAmazon site

- No pickup with low entrainment (dmpdz)
- Steeper pickup with longer convective adjustment timescale (τ)
- Re-evaporation of hydrometeor (k_e) is inconsequential to pickup, though it affects pickup quantitatively, esp. over land
- Pickup insensitive to downdraft fraction (α)
- Similar dependence over ocean



Kuo et al. (2017)

Directions: **ongoing…**

- Pareto fronts; stochastic modeling (not today)
- Convective transition in θ_e coordinates
- Connection to the DOE ARM diagnostics package
- unorganized vs organized convection

Convective transition in θ_e variables: deep-inflow mass flux framework

Mass flux form for inflow of equivalent potential temp. θ_e into convective plume

$$\frac{\partial (M\theta_e)}{\partial z} = \frac{\partial M}{\partial z}\left(\overline{\theta}_e^{\,*} - \overline{\theta}_e^{\,+}\right)$$

Piecewise M $\Rightarrow$ layer avg. variables

θ_{ebl} bdy.-layer

$\theta_e{}^*{}_{deep}$ saturation θ_e for free trop. env.

$\theta_e{}^+{}_L$ subsaturation $=\theta_e{}^*-\theta_e$ lower free trop.

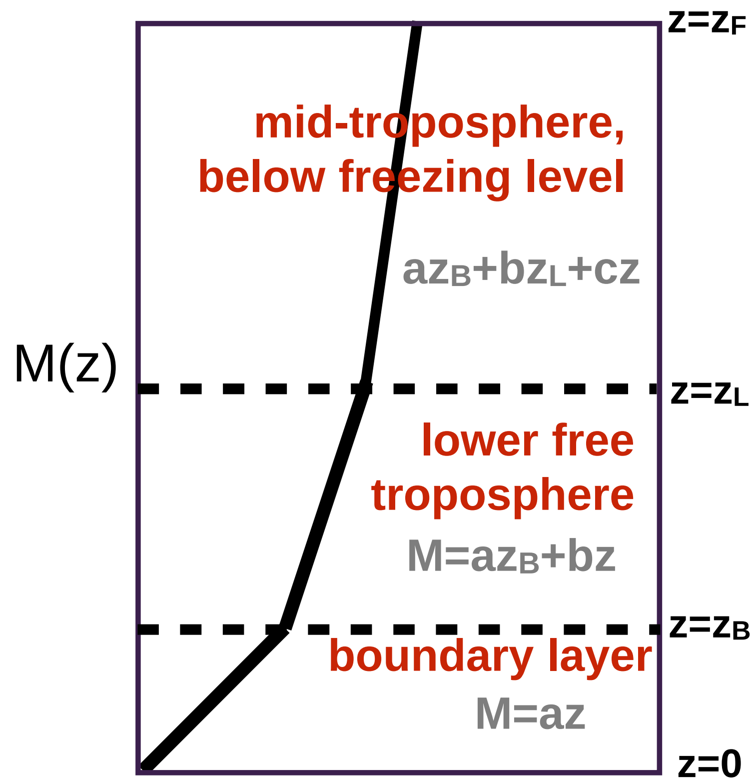
$\theta_e{}^+{}_M$ *subsaturation mid-trop.*

Buoyancy

$$B(z) \propto \frac{\left(a\hat{\theta}_{ebl} - b\hat{\theta}_{eL}^{+} - c\hat{\theta}_{eM}^{+} - d\hat{\theta}_{e\,\mathrm{deep}}^{*}\right)}{M(z)\overline{\theta}_e^{\,*}(z)} - 1$$

a, b c , like entrainment coefficients: weights for mid-level buoyancy

Piecewise deep inflow mass flux profile



$$B(z) = g\left(\frac{\theta_e - \overline{\theta}_e^{\,*}}{\overline{\theta}_e^{\,*}}\right)$$

Ahmed & Neelin, in prep.

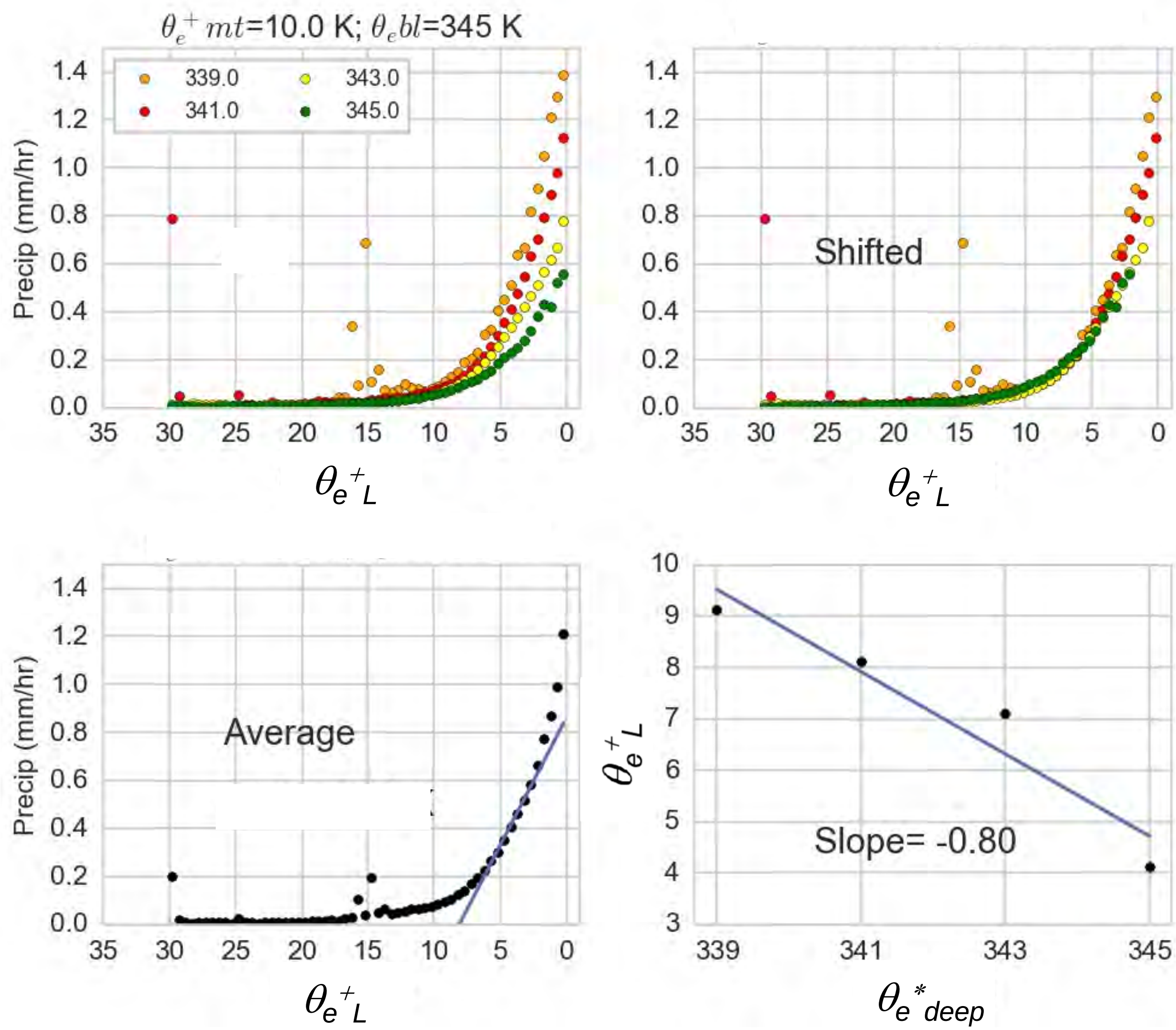
Convective transition in θ_e variables: buoyancy dependence & empirical inflow mixing coefficients

Precip pickup as function of **lower free trop. sub-saturation $\theta_e{}^+{}_L$**
(axis reversed so like CWV)

Colors: Free trop. temp. as $\theta_e{}^*{}_{deep}$

Collapse gives rel. coefficients in buoyancy eqn
($\theta_e{}^+{}_M$, θ_{ebl} fixed)

Microwave Precip, Era-interim θ_e



Ahmed & Neelin, in prep.

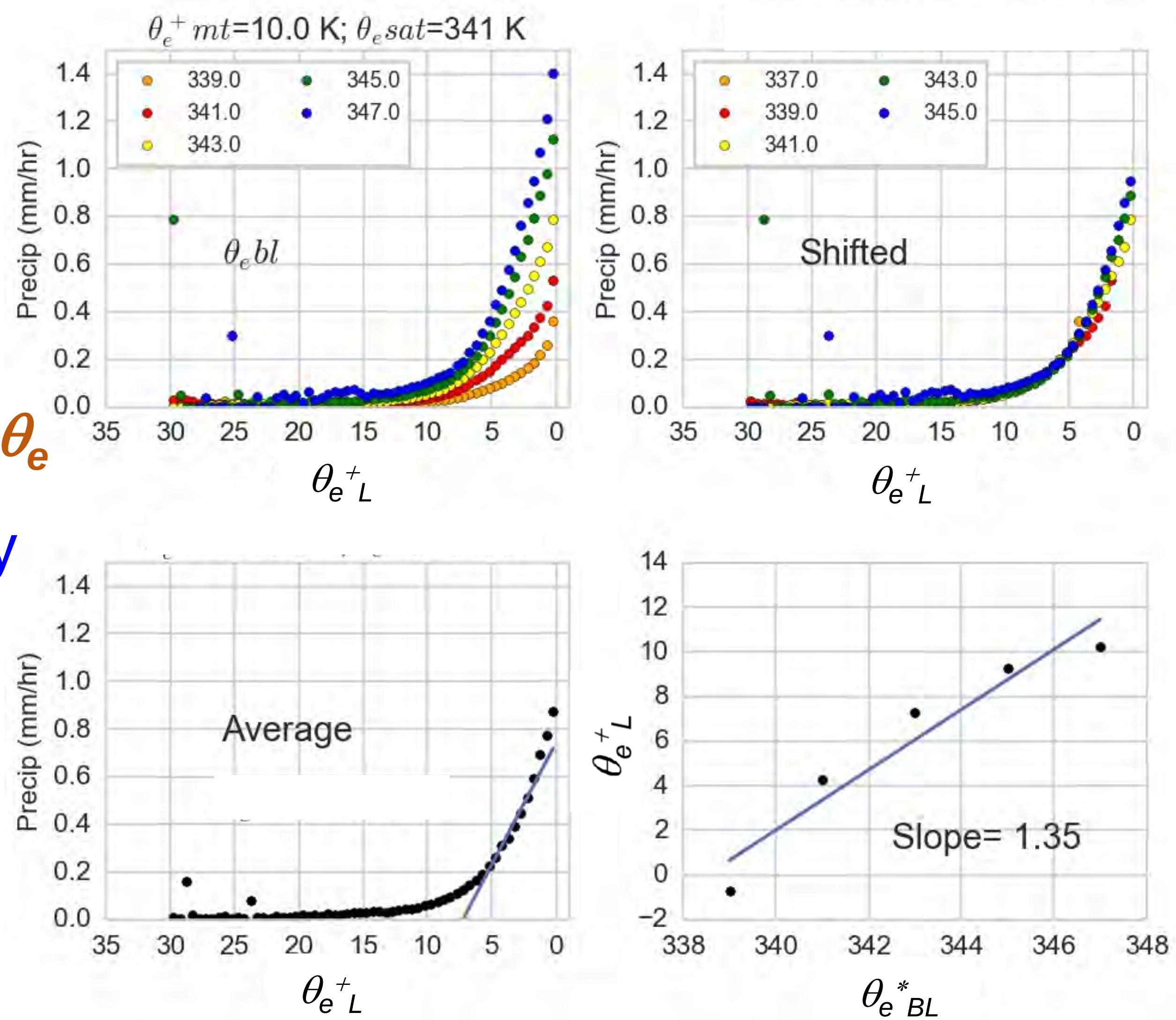
Convective transition in θ_e variables: buoyancy dependence & empirical inflow mixing coefficients

Precip pickup as function of **lower free trop. sub-saturation $\theta_e{}^+{}_L$**
(axis reversed so like CWV)
Colors: Bdy layer θ_e

$\Rightarrow$ Precip buoyancy dependence

P=f(B)

in variables directly related to parameterizations



Ahmed & Neelin, in prep.

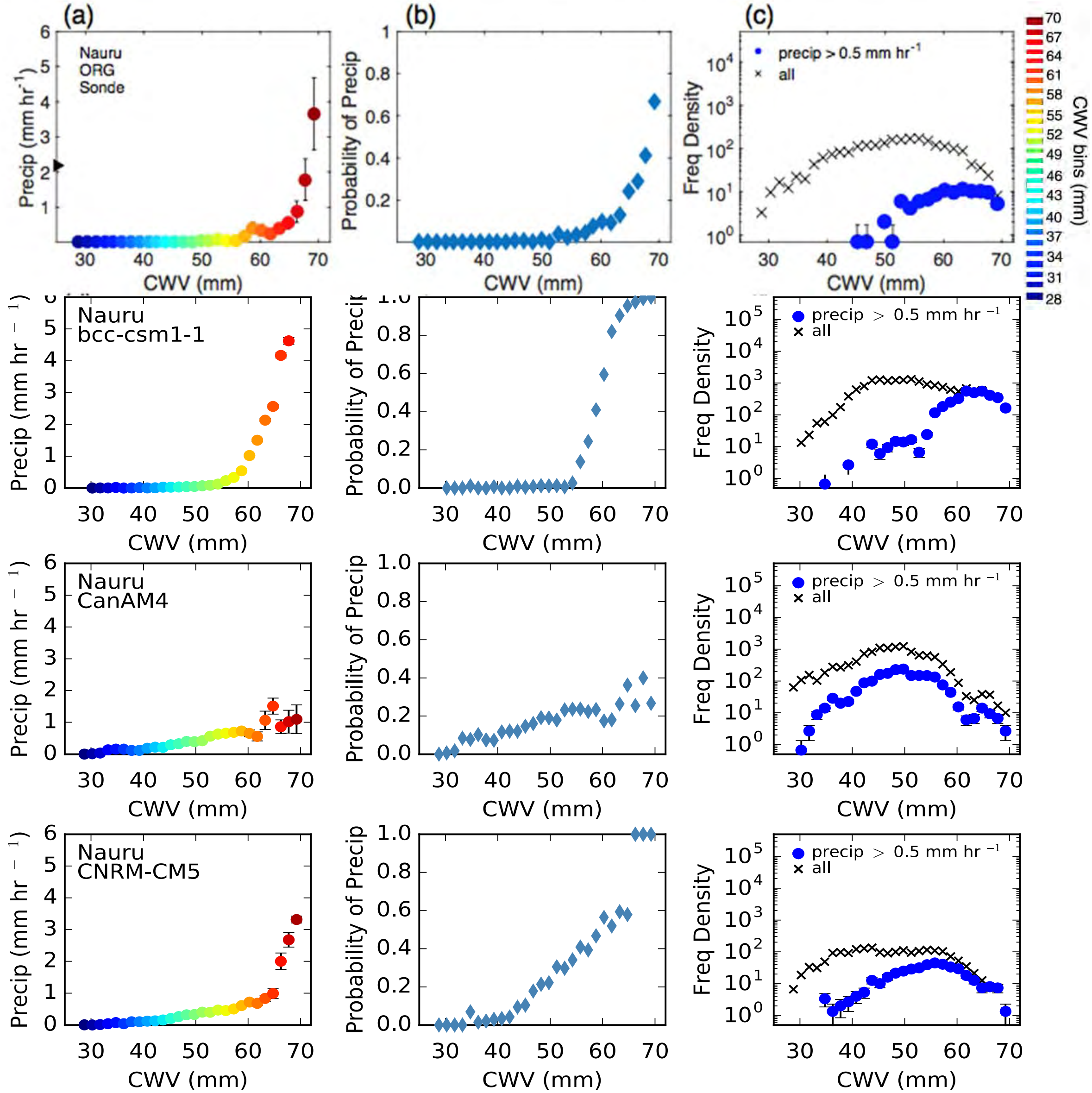
Contributions to ARM site diagnostics package*

Convective transition statistics at DOE ARM sites (Nauru, top) compared to 3 models (CMIP5 CFMIP output)

Consistent with behavior across broader regions shown earlier

Potential to leverage broader ARM observational suite (e.g., DelGenio et al. 2015; Giangrande et al. 2016)

*see talk by Peter Gleckler for more on ARM diagnostics



Chengzhu (Jill) Zhang, Kathleen Schiro, Shaocheng Xie, Peter Gleckler, JDN

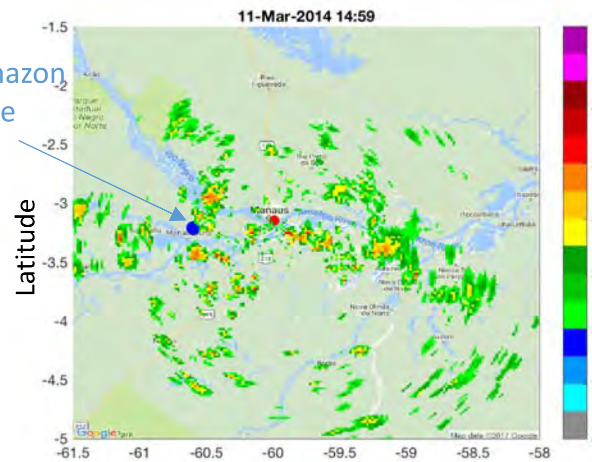
Directions: do related statistics apply when convection exhibits organization?

Probability of precipitation divided
cal, cellular
ed systems
(>100km)

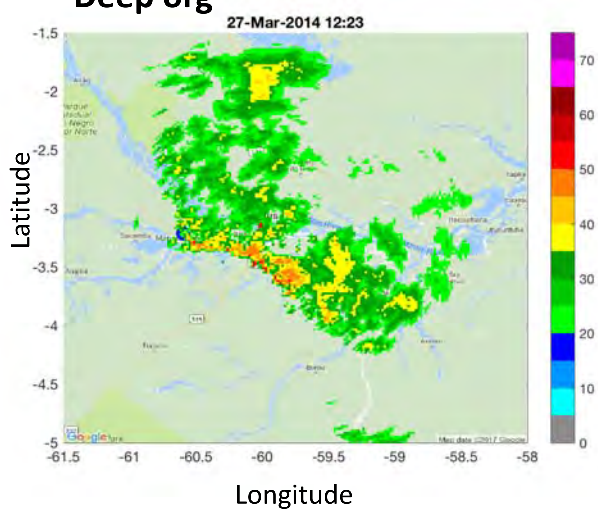
Composite radar reflectivity from SIPAM S-Band Radar at GOAmazon, Manaus, BR (red dot).

GOAmazon site

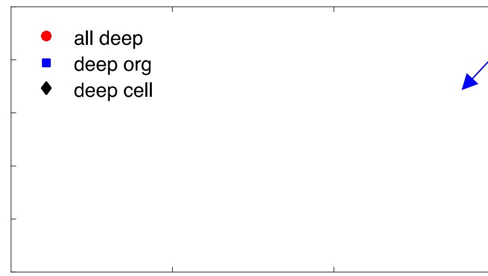
Deep cellular



Deep org

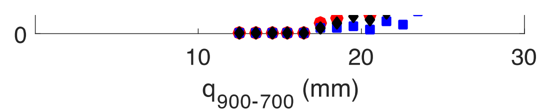


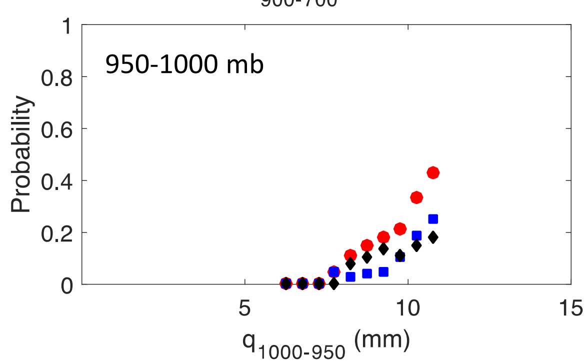
GOAmazon



Pickup as a function of column water vapor

Pickup as a function of lower free troposphere water vapor





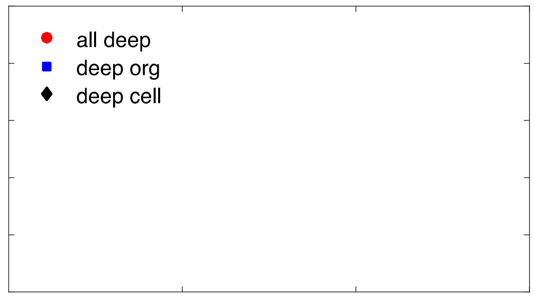
Pickup as a function of boundary layer water vapor

Schiro and Neelin (2017, in prep)

Directions: can testing these statistics as a function of buoyancy help infer typical profiles of mixing? Including when there is organization?

<u>Deep Inflow Mixing</u>

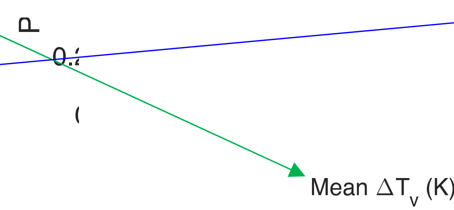
- z^{-1} mixing corresponds tc weighting of inflow at ea through lower free tropo and boundary layer



Pickup as a function of buoyancy est. with Constant Mixing

Constant entrainmen
Deep inflow mixing y
clear pickup of p
probability as a functi
bulk buoyancy measure
organized & unorganized convection
(also land/ocean, diurnal/seasonal cycles)
Stronger weighting above ABL

GOAmazon
all times



Pickup as a function of buoyancy est. with Deep Inflow Mixing

Schiro and Neelin (2017, in prep)

Concluding remarks

- Convection transition statistics…
  - Now quantified for robustness across a range of instrumentation, averaging scales
  - caveats: requires reasonably short time averages; care in treating observational products at highest Precip, CWV
  - not scalar metrics (yet) but process oriented
- Considerable range among models in simulating these fast-process diagnostics
- Parameter dependence can help identify both causal pathways and parameterization constraints
- With vertical layer information indications that can reverse engineer key aspects of deep convection dependence on environment (even for organized)
- Time-slice experiments: potential to serve as prototype for augmenting CMIP standard output for process-oriented diagnostics