

# The Modeled and Observed Dependence of the Precipitation Onset and Cloud Type on Layer-Moisture

Matthew R. Igel

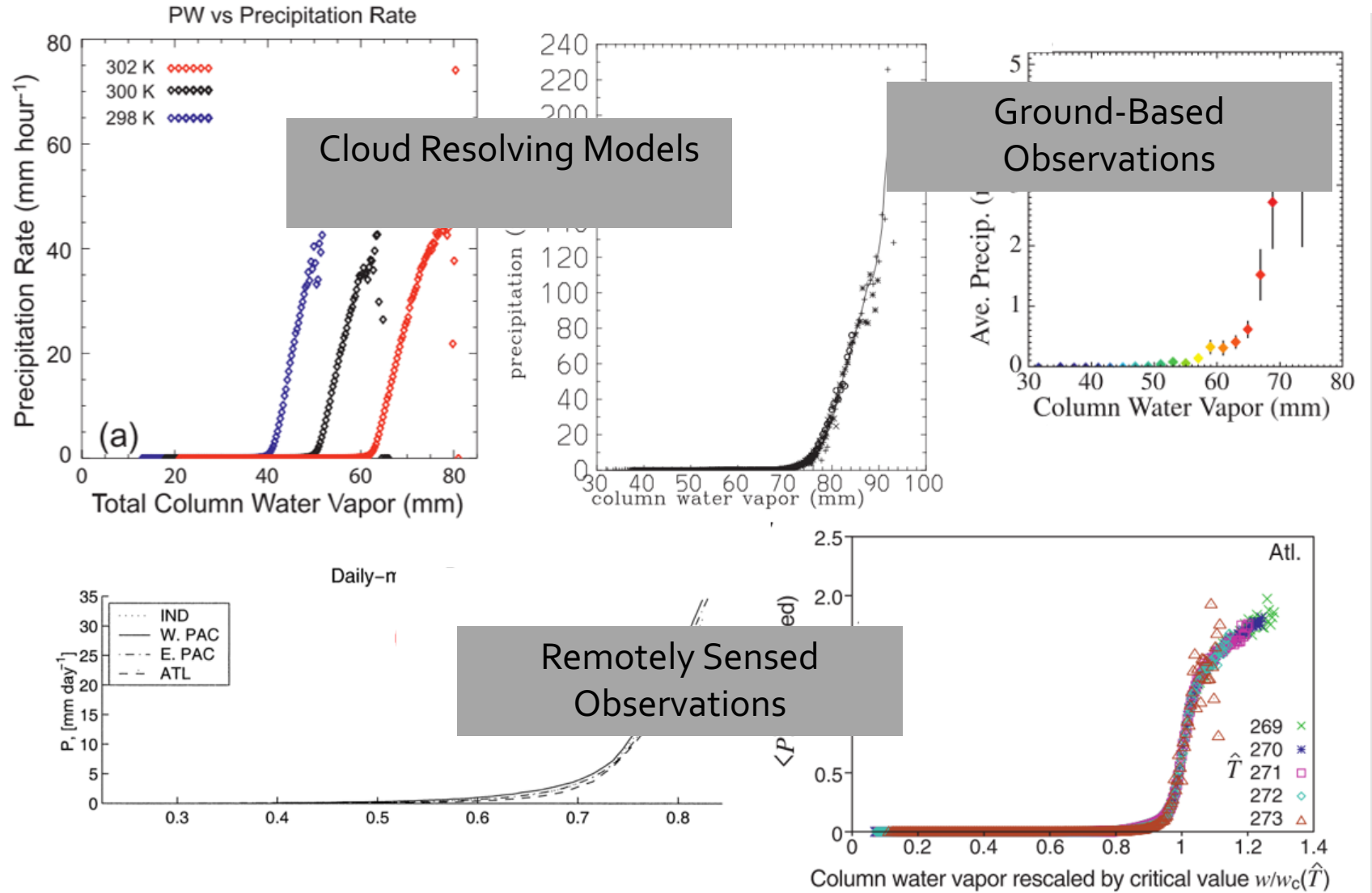
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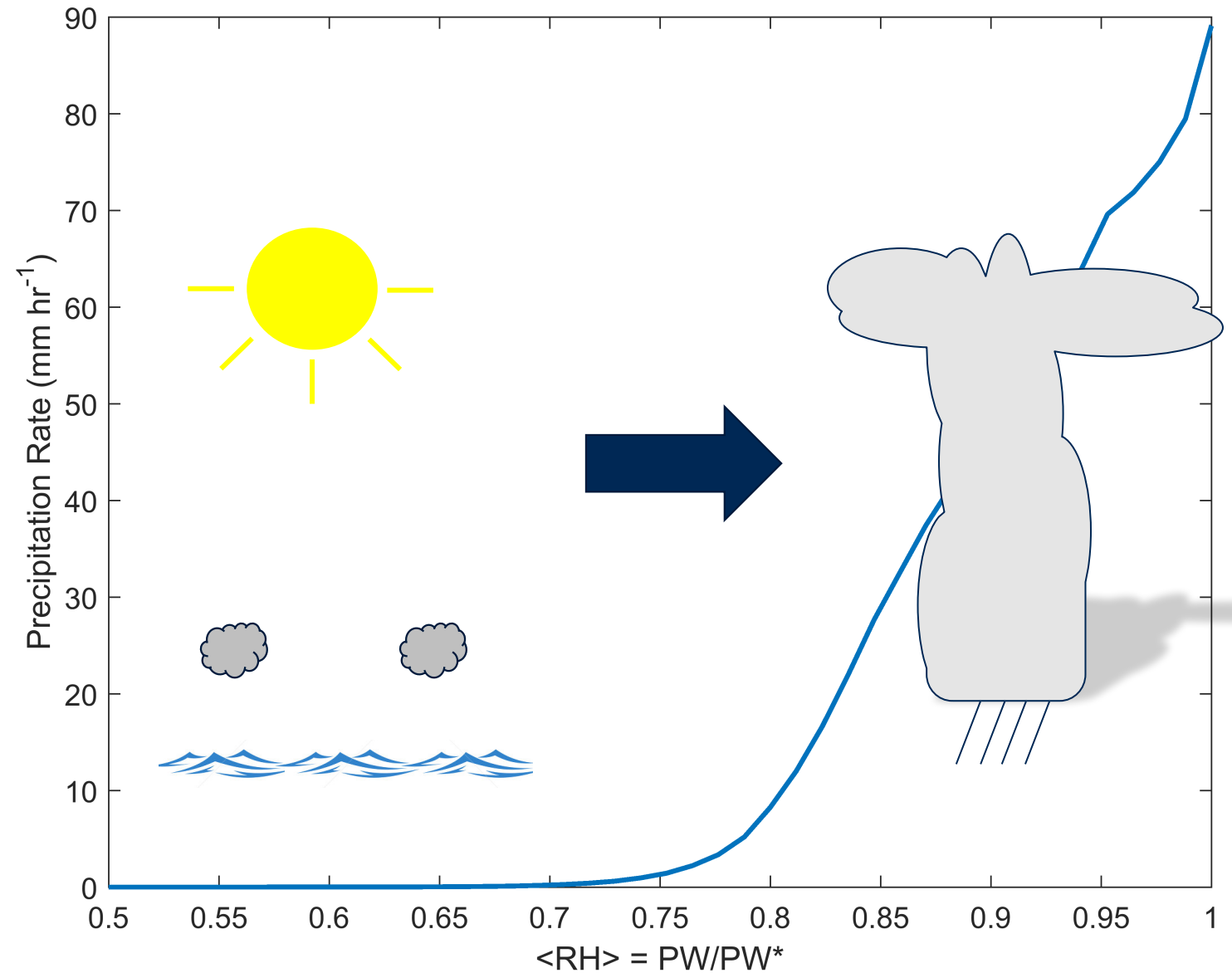
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# Mean Precipitation Grows as a Function of Column Humidity (or PW/PW<sub>S</sub>)



(a) Posselt [2012], (b) Yano et al [2012], (c) Holloway and Neelin [2009], (d) Bretherton et al [2004], and (e) Neelin et al [2009]

How has this largely been viewed in the past?  
(The Naïve Explanation)



- A two-state system: clear air ( $P=zero$ ) and cloudy ( $P>zero$ )  
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# What is missing from the Naïve Explanation?

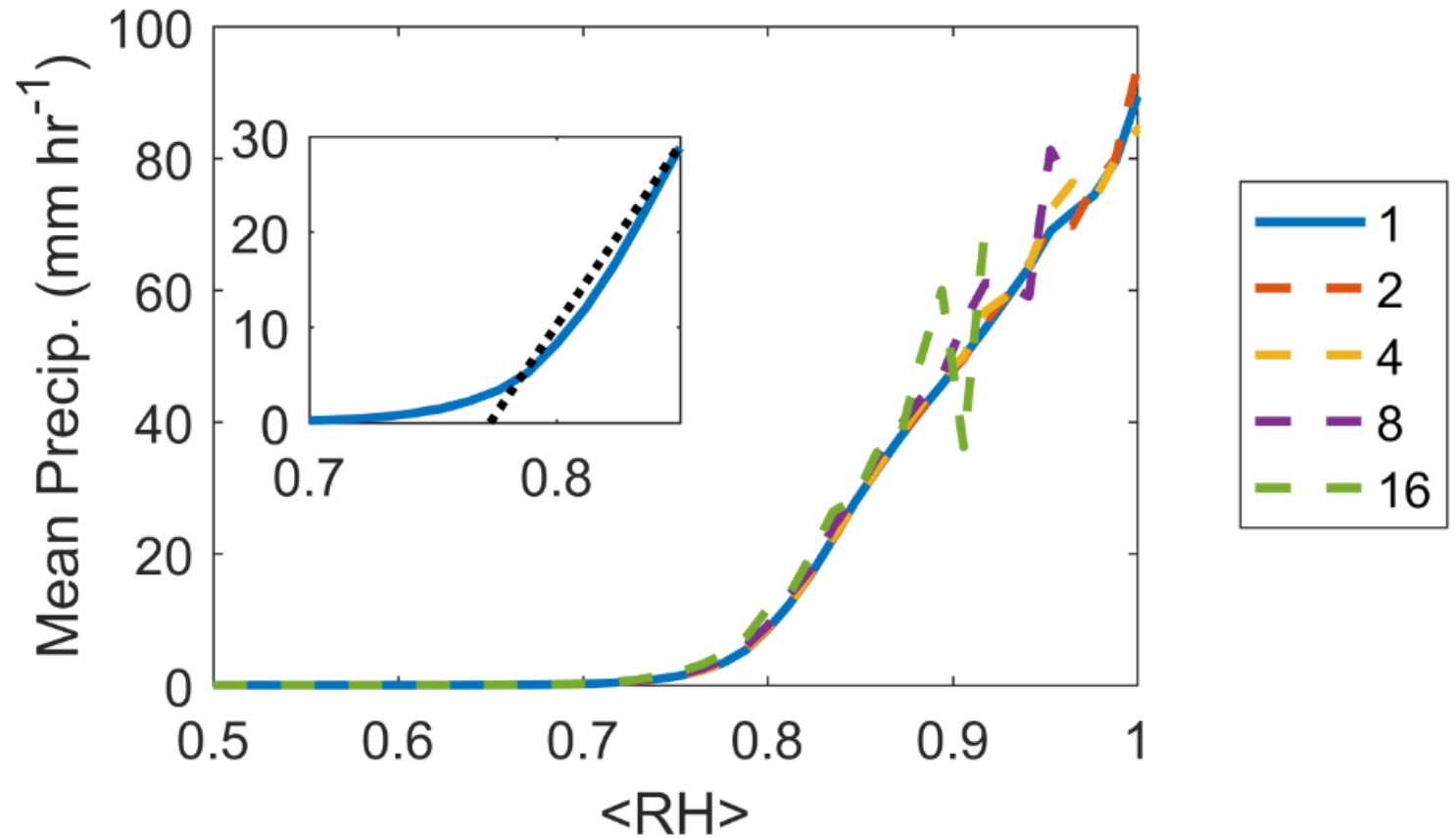


- We need to account for the entire population of tropical clouds.
- Need to explain invariance across length and time scales.

# Goal and Methods

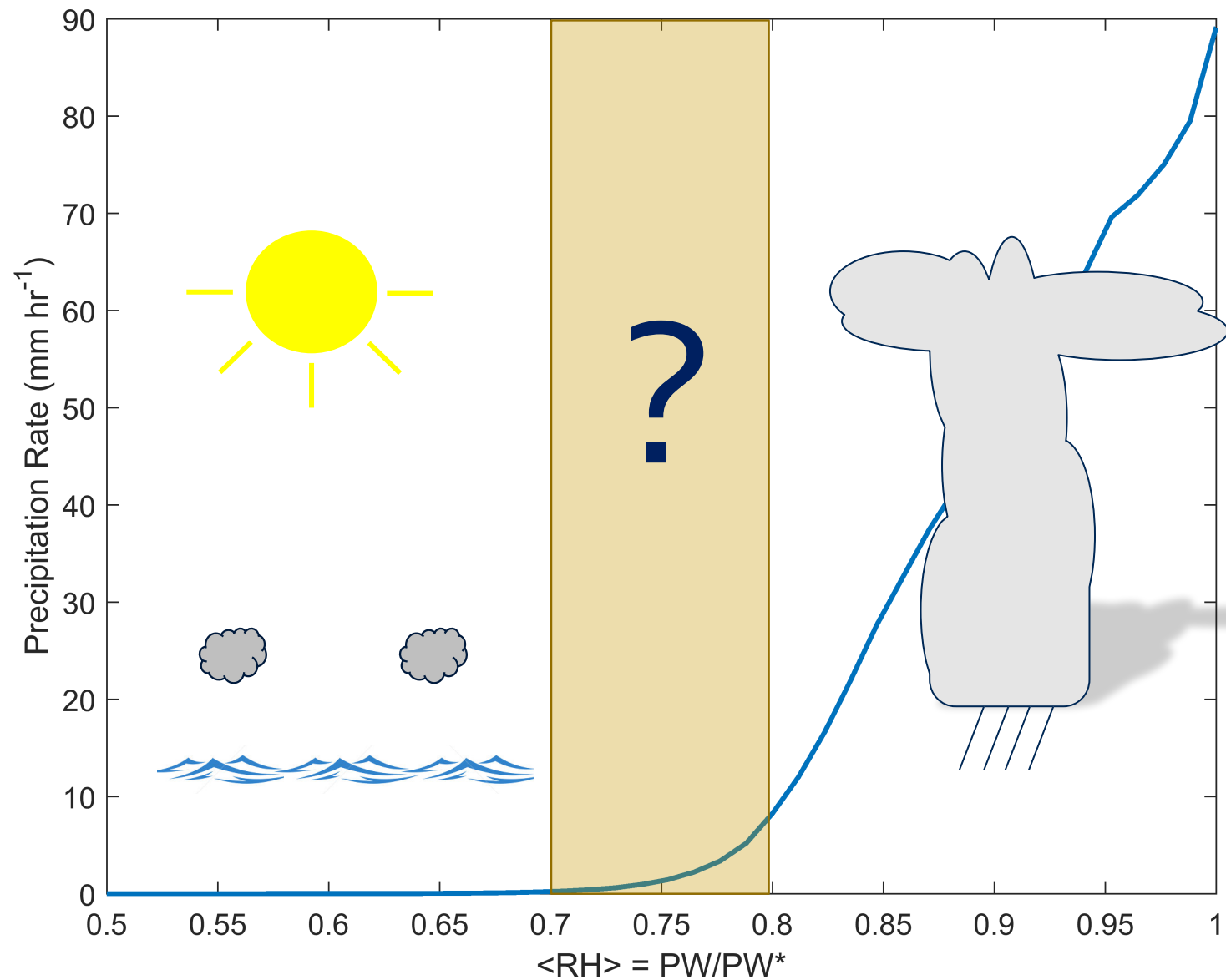
- **Goal:** Determine how the entire population of convection projects onto the mean Precipitation-Column Humidity Relationship.
- **Cloud Modeling:** Large domain (1000's of km), high resolution (1km x 1km) RCE simulation with the best possible physics packages (including 5-minute output). Used the RAMS model.
- **Observations:**
  - High resolution observations of precipitation and clouds from CloudSat.
  - Vertically resolved moisture and temperature from AIRS.
  - Augmented high resolution water vapor from OCO<sub>2</sub>

# What does the Precipitation- Column Humidity Relationship look like in the Model?



- Modeled precipitation pickups up as it does in previous studies.
- The magnitude of mean precipitation is insensitive to horizontal scaling.
- (Inset) Regression suggests a pickup of  $\langle \text{RH} \rangle = 77\%$ .

Statistics  
Suggest the  
Pickup Cannot  
be Explained  
by Deep  
Convection  
Only

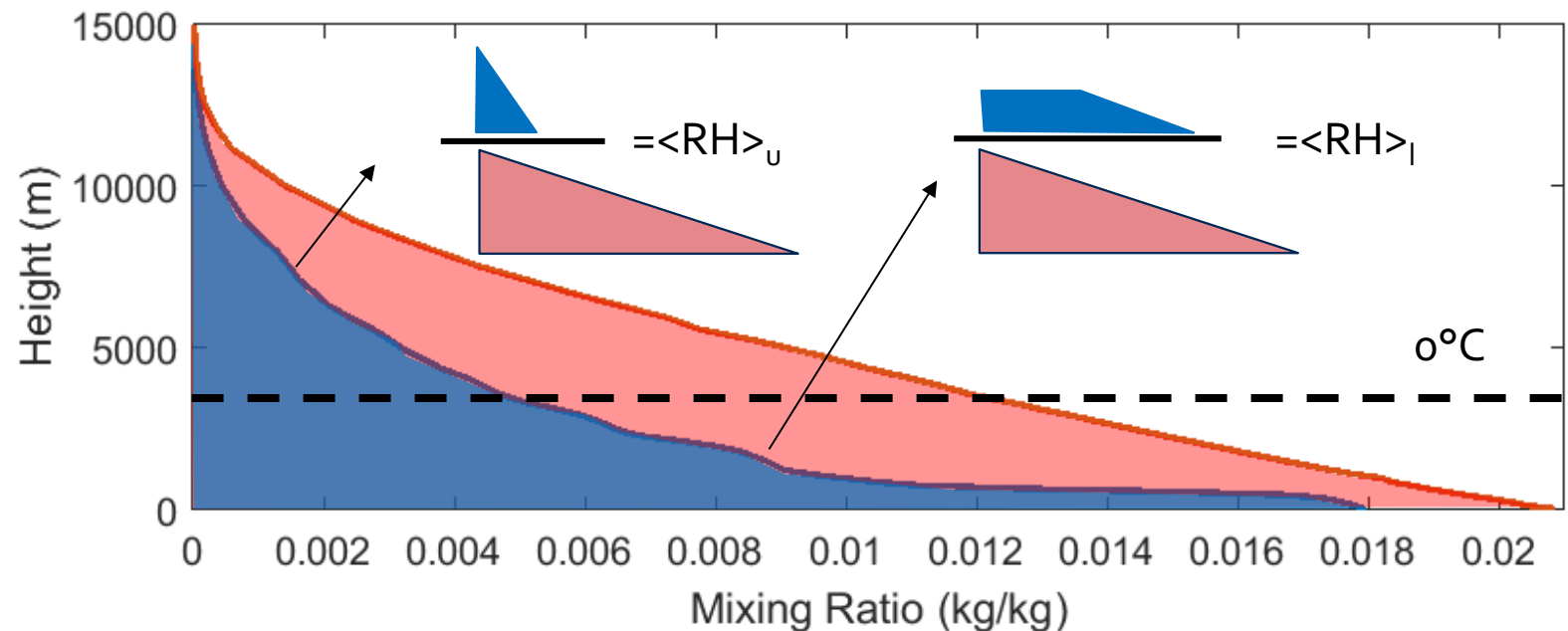


- At least a two-state system...  
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# Layer Moisture

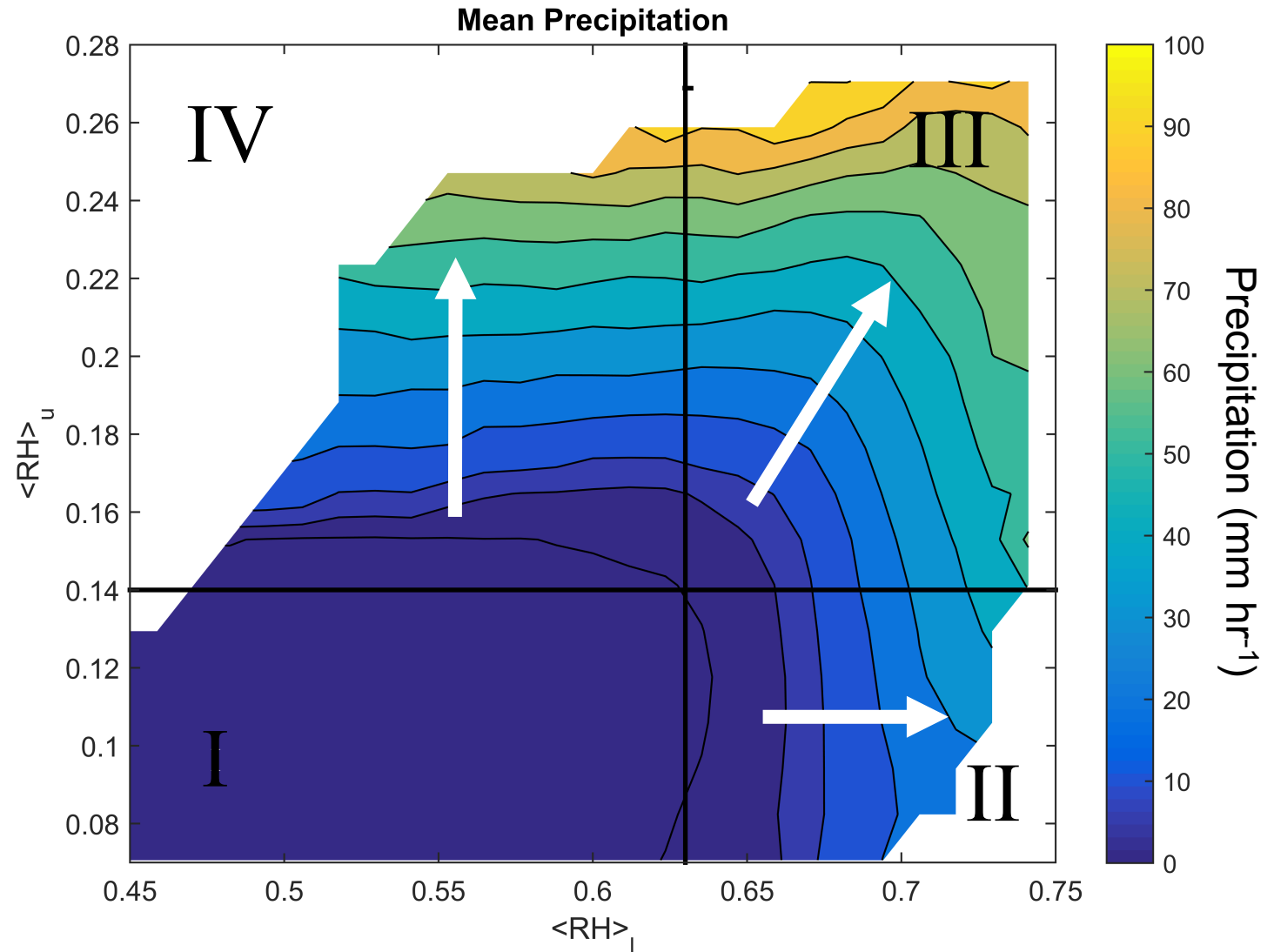
- An initial investigation of the dependence of cloud types on  $\langle RH \rangle$  was largely uninformative.
- This led to an investigation of two independent moisture layers
  - Surface to the melting layer
  - Freezing level to the TOA
- Two layers turns out to be informative without being unduly complicated.

$$\langle RH \rangle_u + \langle RH \rangle_l = \langle RH \rangle$$



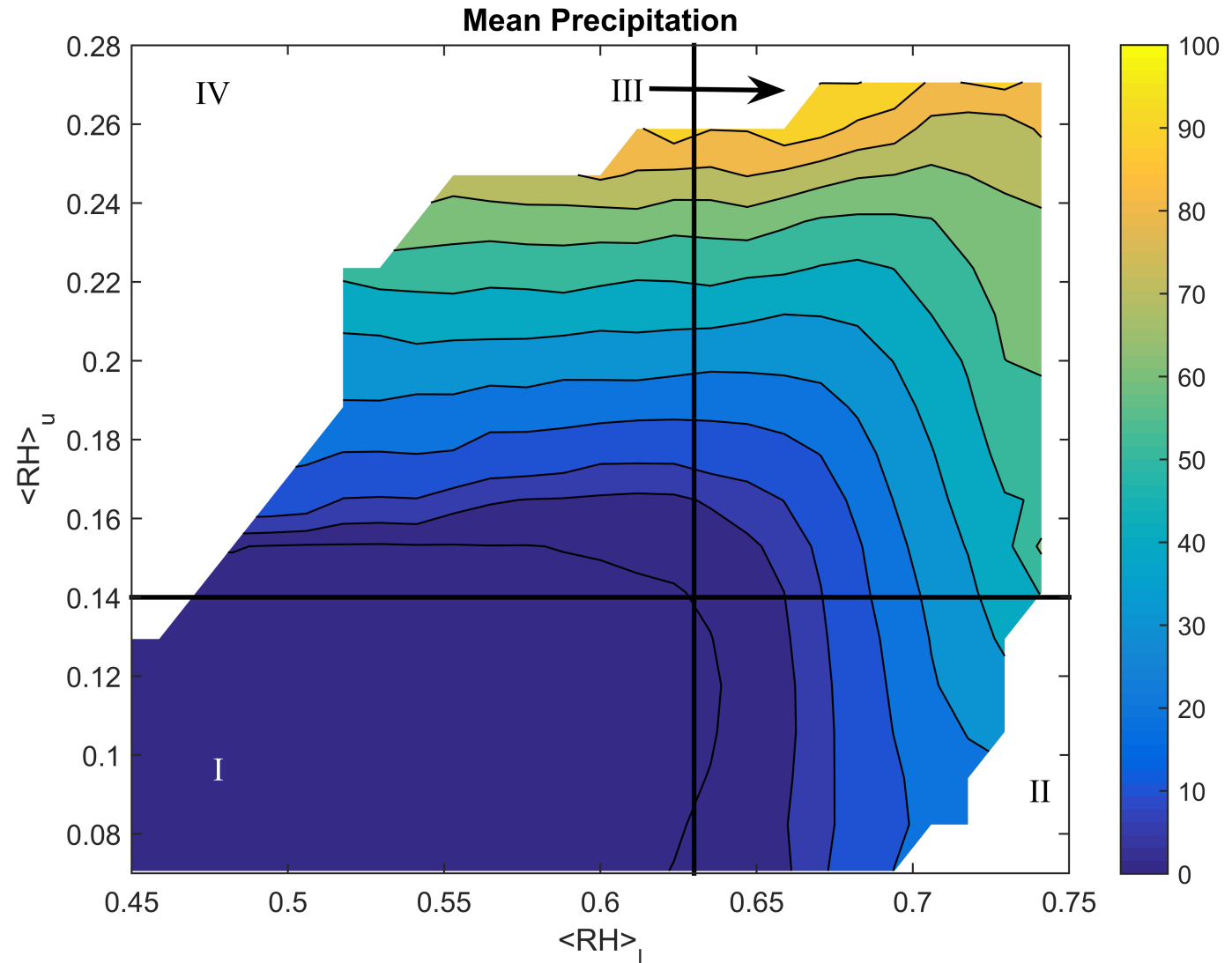


# Mean Precipitation as a Function of Layer-Contributions to Column Humidity



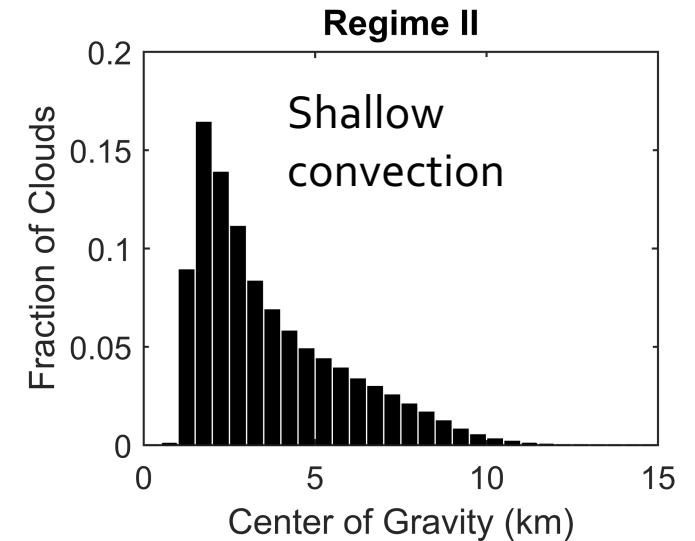
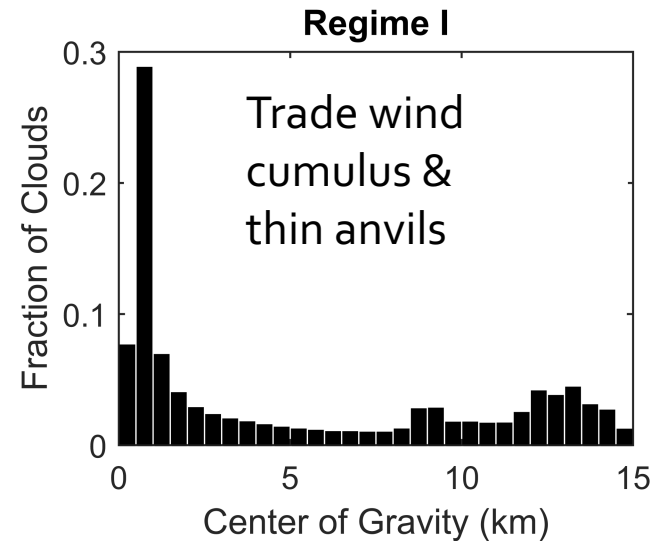
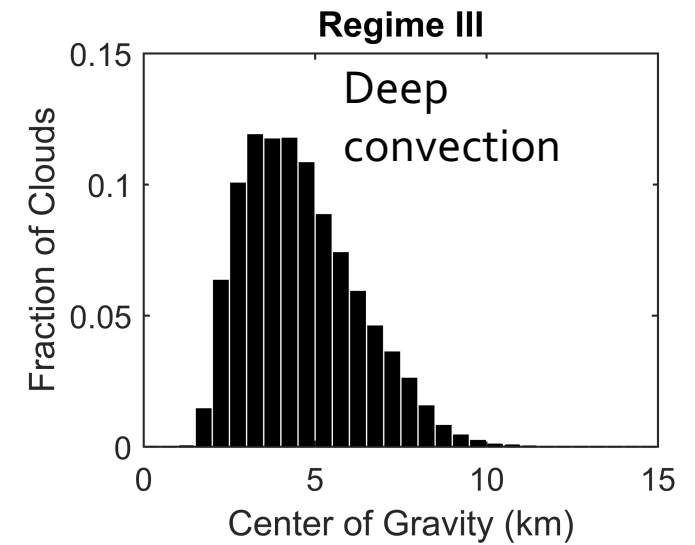
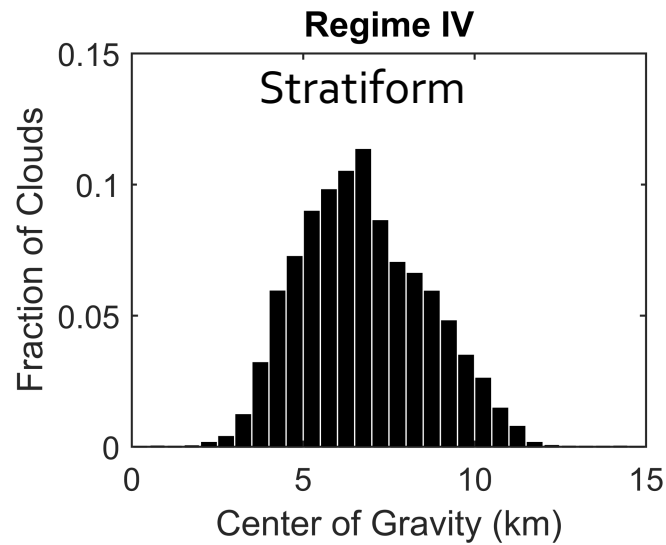
- Mean Precipitation Separates out into 4 distinct regimes that depend largely on either  $\langle RH \rangle_l$  or  $\langle RH \rangle_u$ .

# Modeled Cloud Types Separated by Layer-Moisture Regimes



- Layer-contributions to column humidity can statistically separate cloud types.

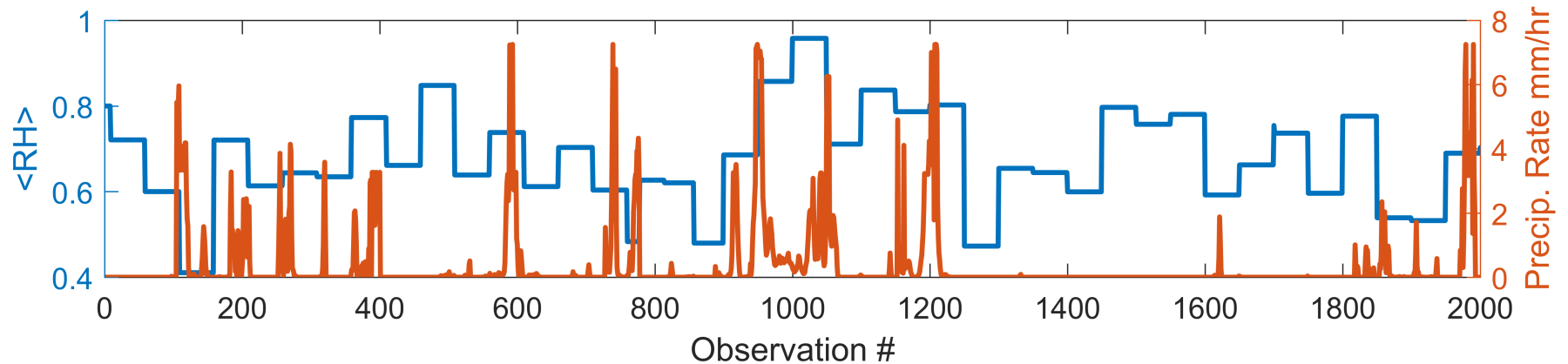
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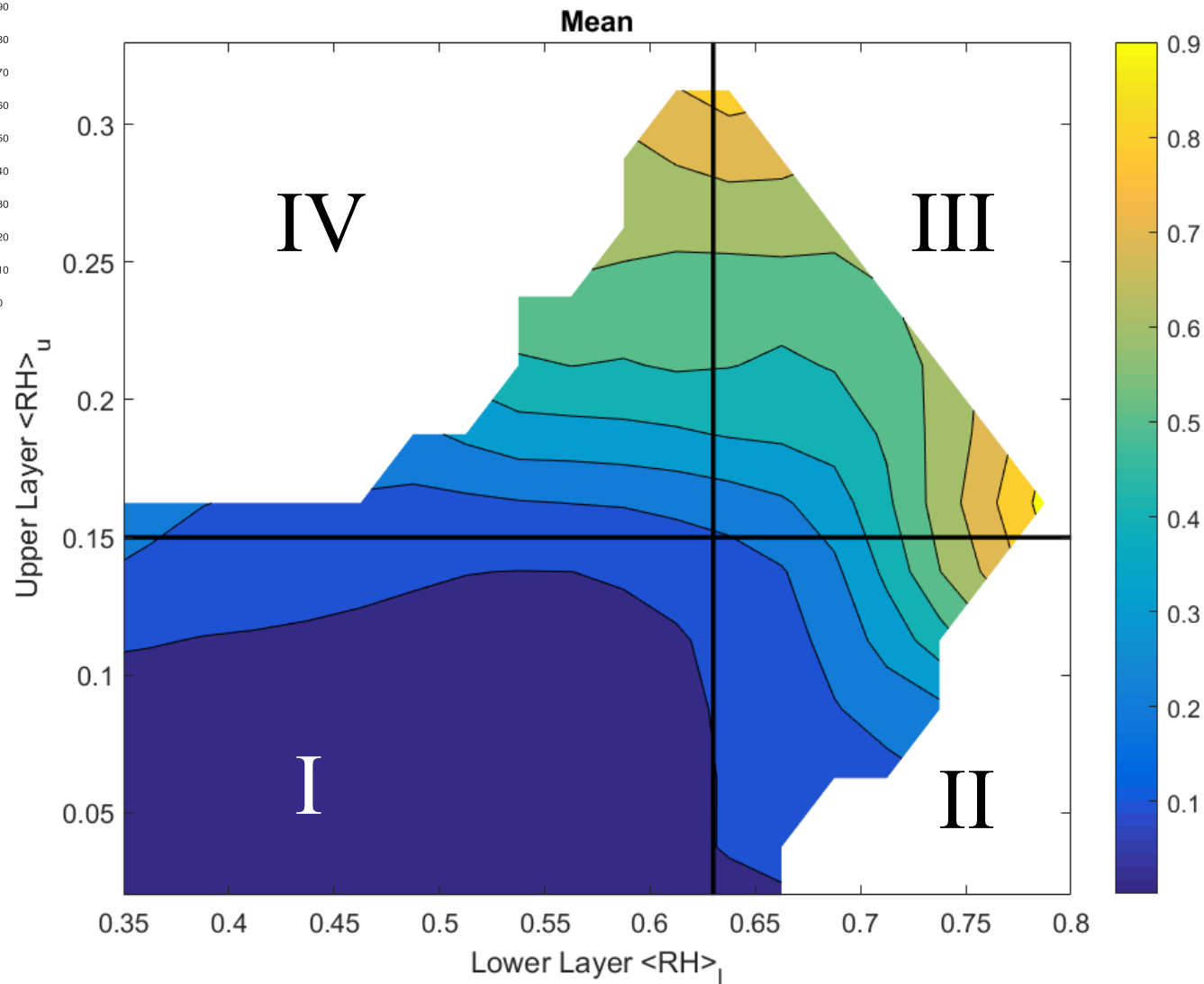
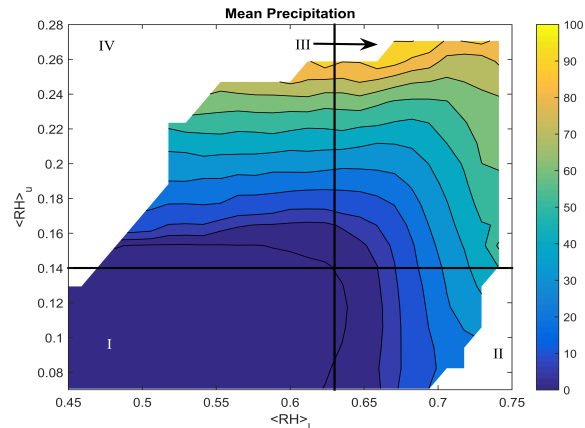
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# Observational Analysis

- We attempt to recreate the high-resolution modeling results with observational data.
- Data must:
  - Be plentiful: Modeling results produce >200 million samples
  - Be high resolution: Modeling results at 1km
  - Be approximately contemporaneous (...A-Train)
- Precipitation: Version 5 of the 2C-Precip (precip. rates up to 40mm/hr)
- Vertically resolved humidity: Version 6 of AIRS (large footprint)
- Augment with OCO<sub>2</sub> to rescale the AIRS TCWV (not presented, but preliminary data looks promising) and TRMM (future)

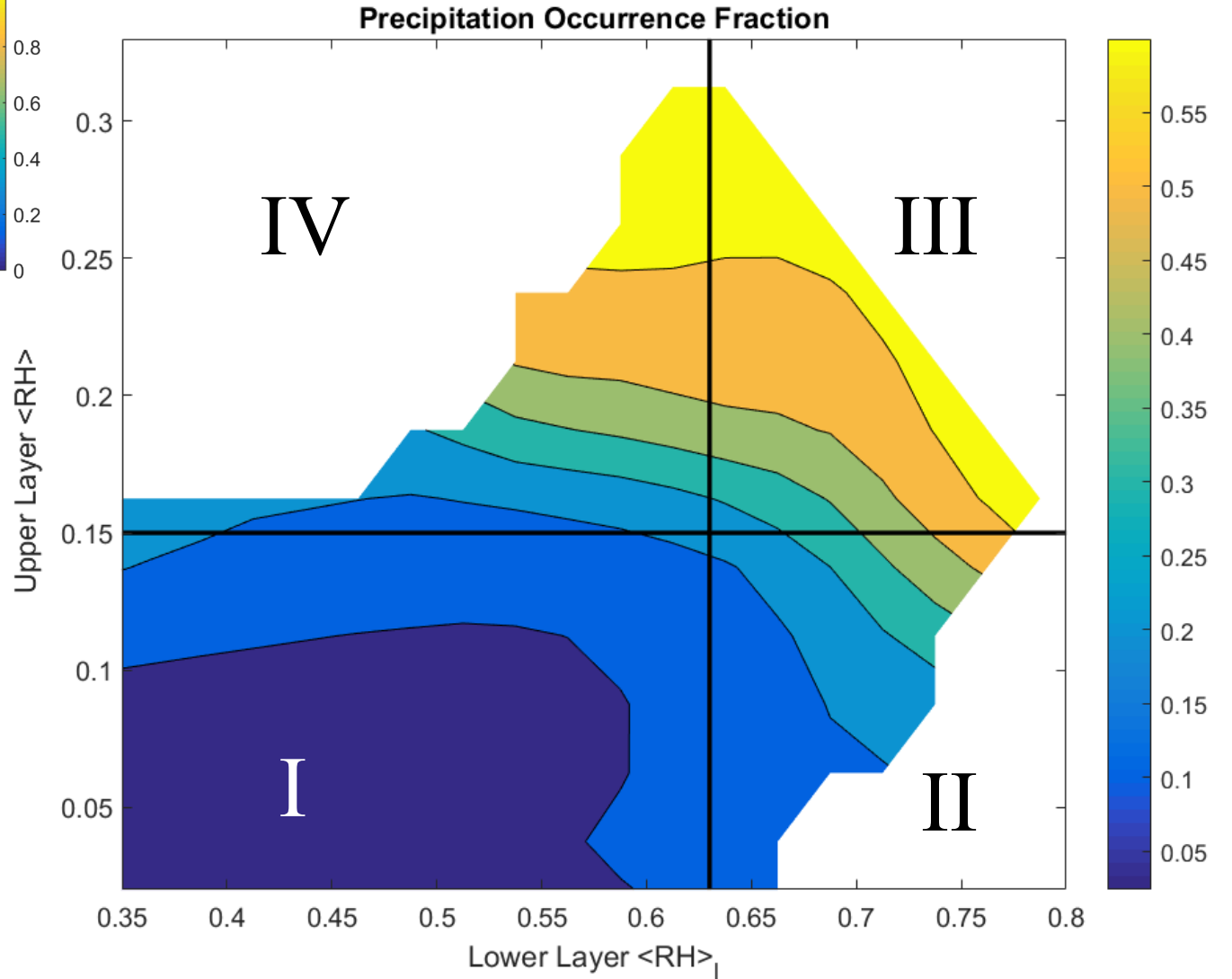
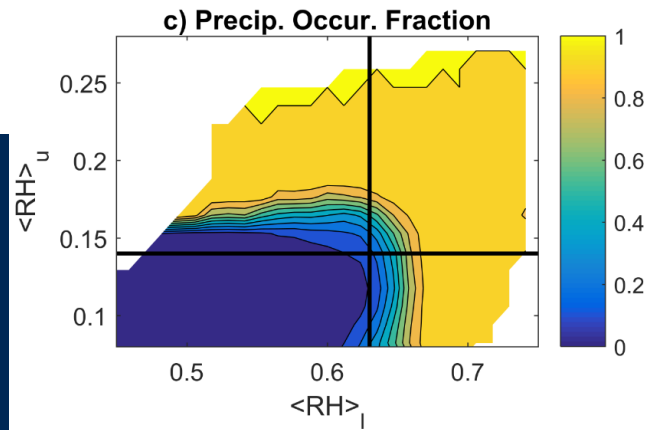


# Mean Precipitation as a Function of Layer-Contributions to Column Humidity



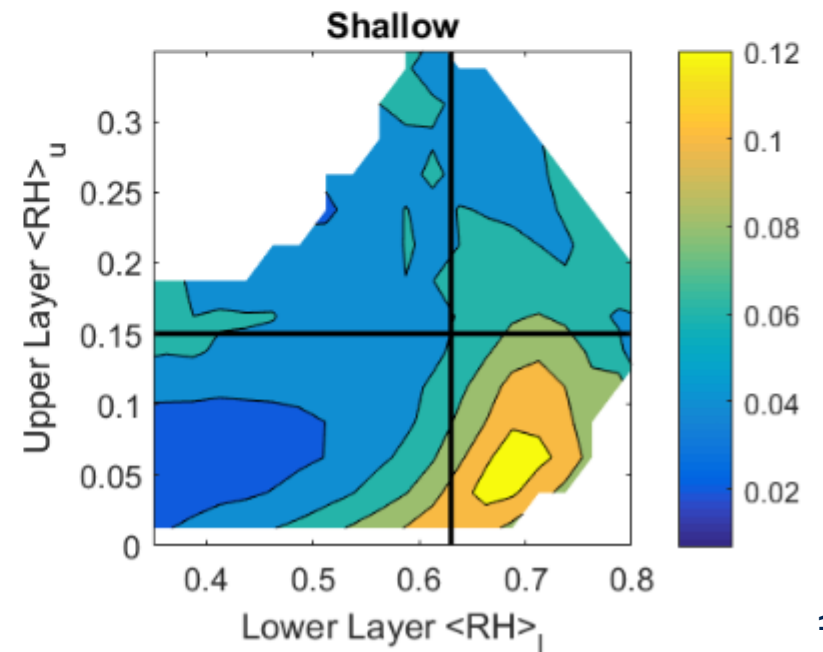
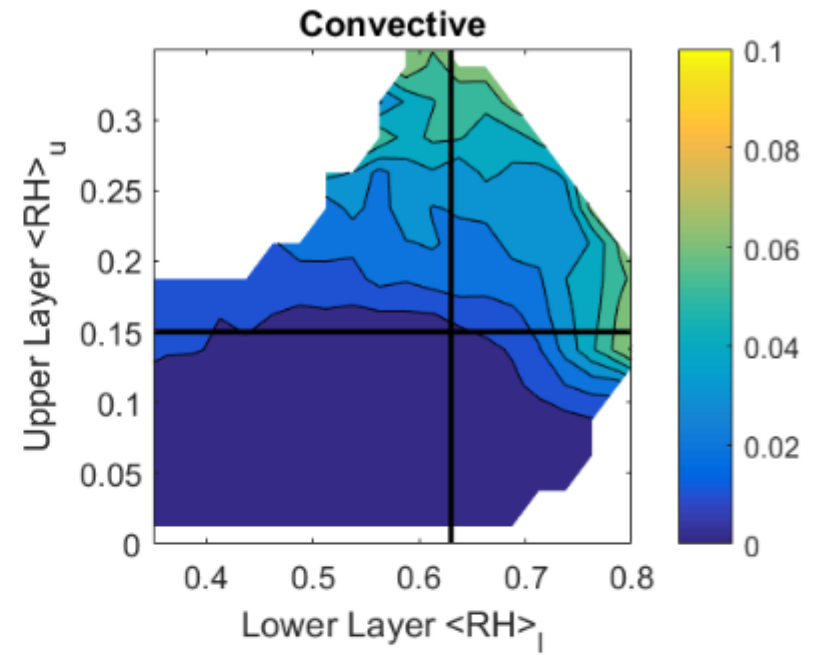
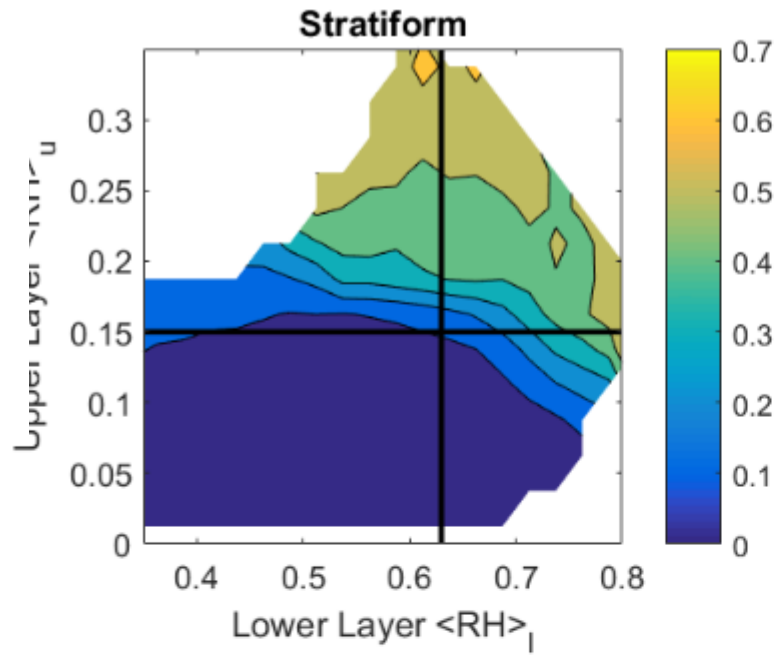
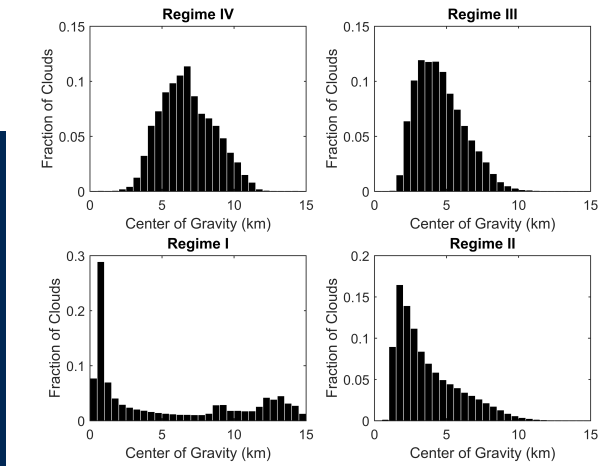
- Mean Precipitation Separates out into 4 distinct regimes that depend largely on either  $\langle RH \rangle_l$  or  $\langle RH \rangle_u$ .

# Precipitation Occurrence as a Function of Layer-Contributions to Column Humidity



- The likelihood of precipitation is lower in nature than the model. It's increase is more gradual than in the model.

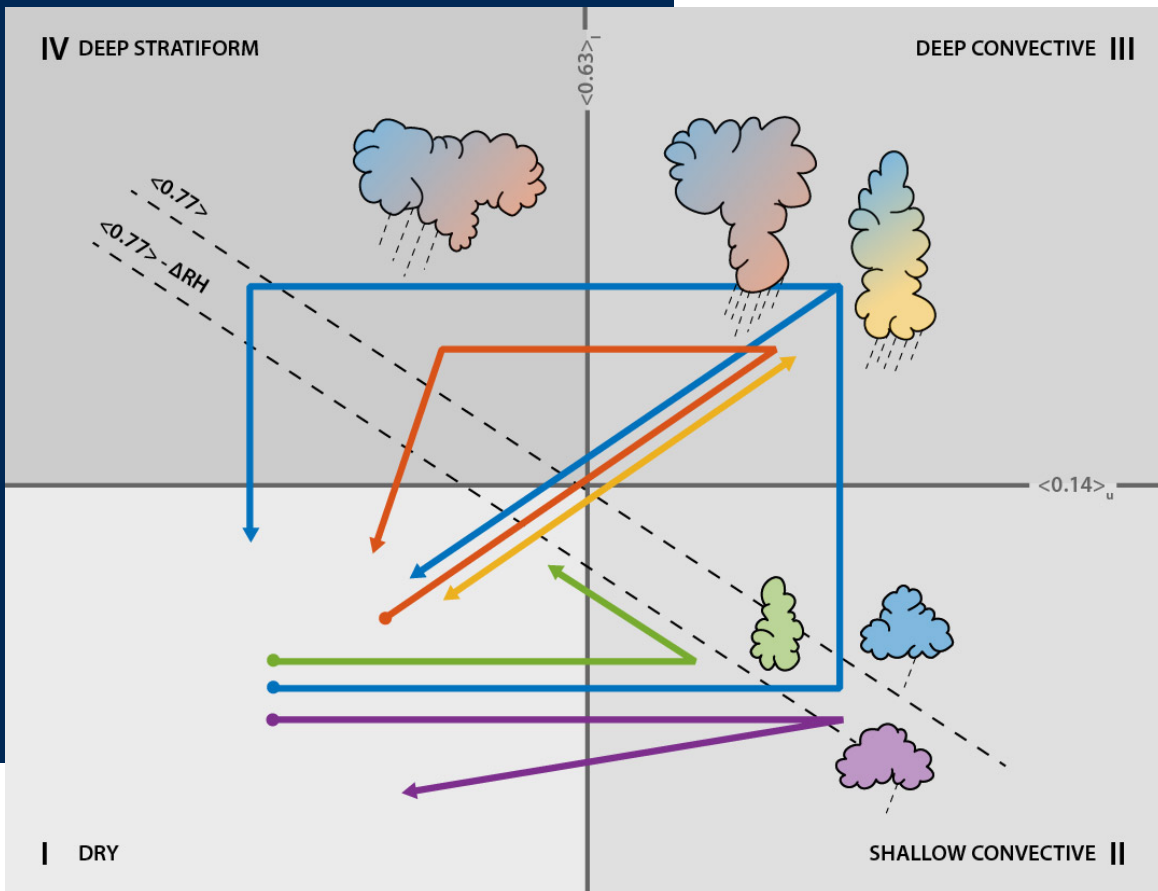
# CloudSat Precipitation Retrieval Method -> Observational Typing



- The CloudSat rainfall retrieval method can be used to assess the relative likelihood of 3 main cloud types as a function of layer moisture.
- Shallow in Regime II, Convective and Stratiform in Regimes III and IV

# Summary

- The Column Humidity-Precipitation relationship is scale-invariant across the sub-mesoscale.
- Column Humidity can be meaningfully divided into two contributions from moisture above and below the melting layer.



- In an RCE model, this division naturally separates clouds (and cloud processes) into 4 Regimes: no cloud, 'Congestus', deep convection, and stratiform.
- CloudSat/AIRS data suggest nature exhibits similar behavior as the model but that nature is less tightly coupled with bulk moisture than the model.
- The layer-moisture thinking helps to explain the behavior of mean precipitation near the pickup.



# So What?

- For the first time, we can connect the “precipitation-moisture” relationship to the entire population of tropical clouds which us past previous conceptual models based on parameterized deep convection.
- This  $\langle RH \rangle_1 - \langle RH \rangle_0$  framework can be used to show how each of the major cloud types pushes the atmosphere toward  $\langle RH \rangle = 77\%$  (the location of the pickup in precipitation).
- The  $\langle RH \rangle_1 - \langle RH \rangle_0$  framework maintains simplicity, but is much more physically useful than just  $\langle RH \rangle$ .
- Observations and a cloud resolving model produce qualitatively similar results which means we can feel comfortable inferring processes from the CRM (moisture and rain-water budgets, 4D cloud tracking).
- Two-layer moisture could form the basis of a physically-based simple, convective parameterization of clouds and precipitation.

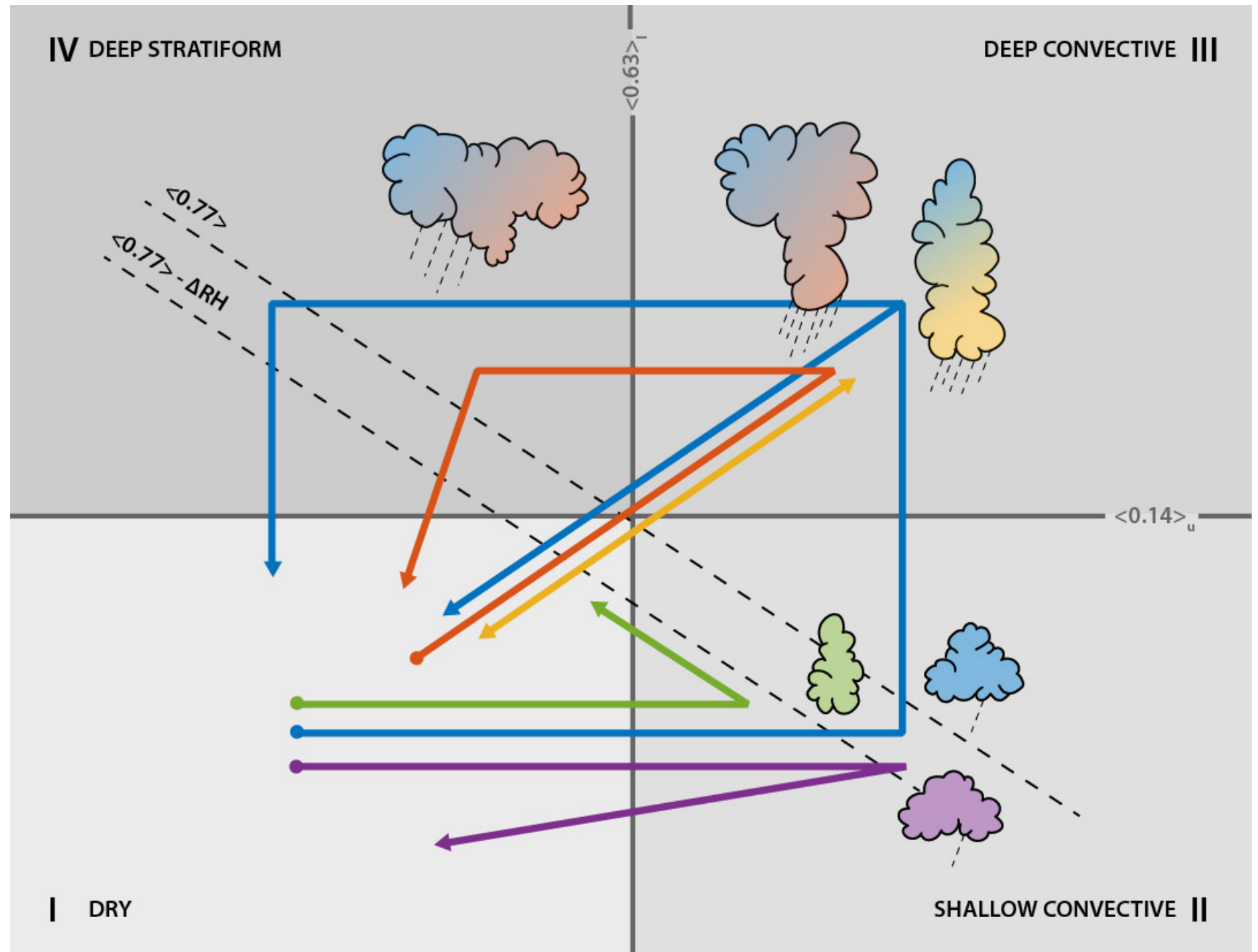
# Thanks!

Igel, Saleeby, and Herbener (2017): The Tropical Precipitation Pickup Threshold and Clouds in a Radiative Convective Equilibrium Model. Part I: Column Moisture. *JGR: Atmos.*

Igel (2017): The Tropical Precipitation Pickup Threshold and Clouds in a Radiative Convective Equilibrium Model. Part II: Two-Layer Moisture. *JGR: Atmos.*

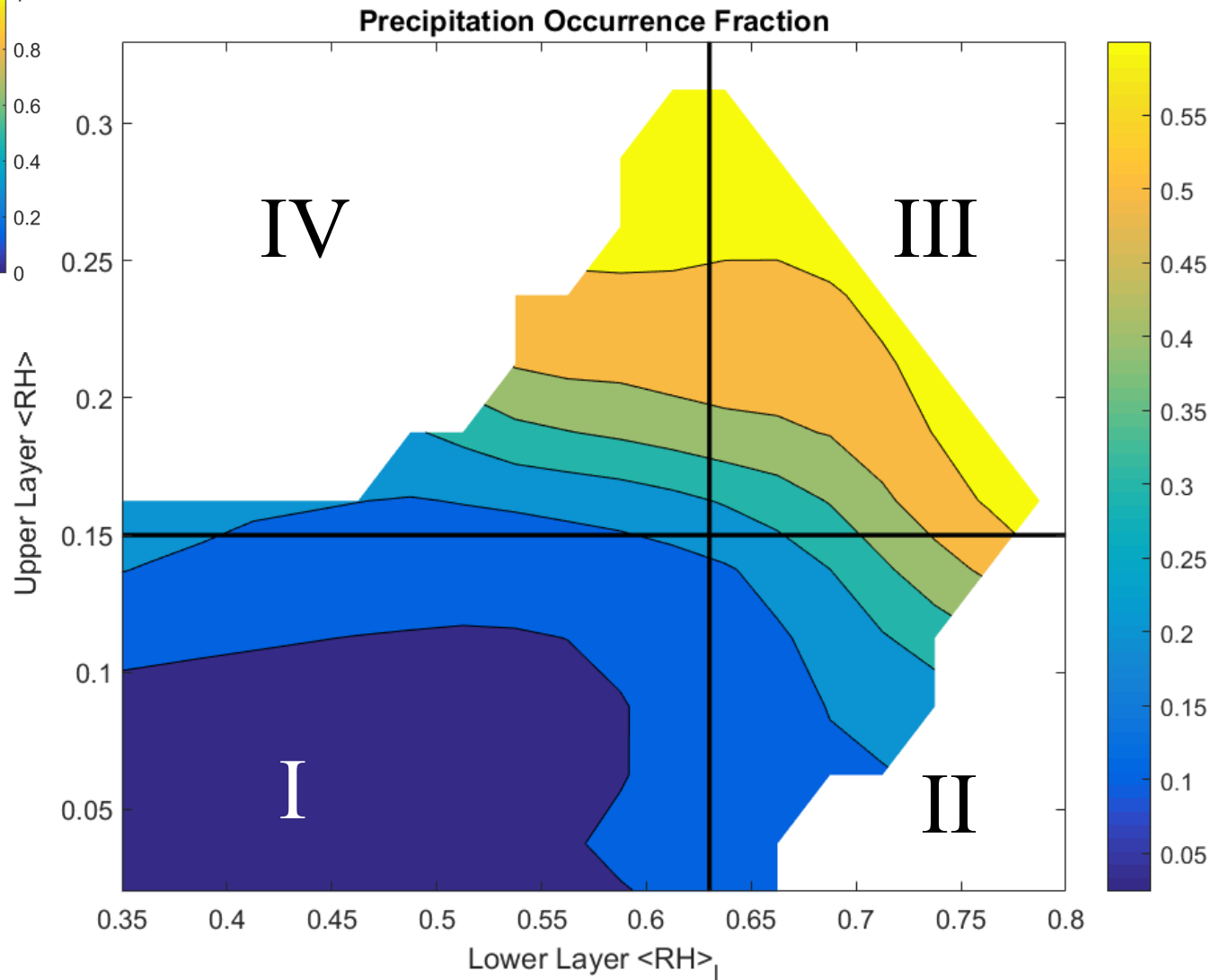
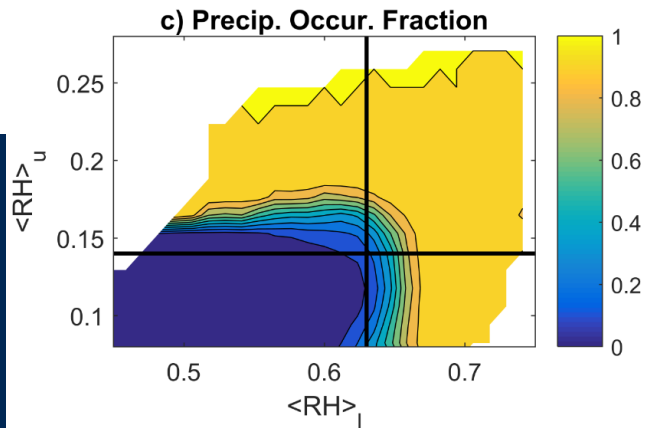
Igel (submitted): Lagrangian Clouds and the Precipitation-Column Humidity Relationship. *JGR: Atmos.*

Igel (in preparation): Observations of the Precipitation-Layer Moisture Relationship. *JGR: Atmos.*



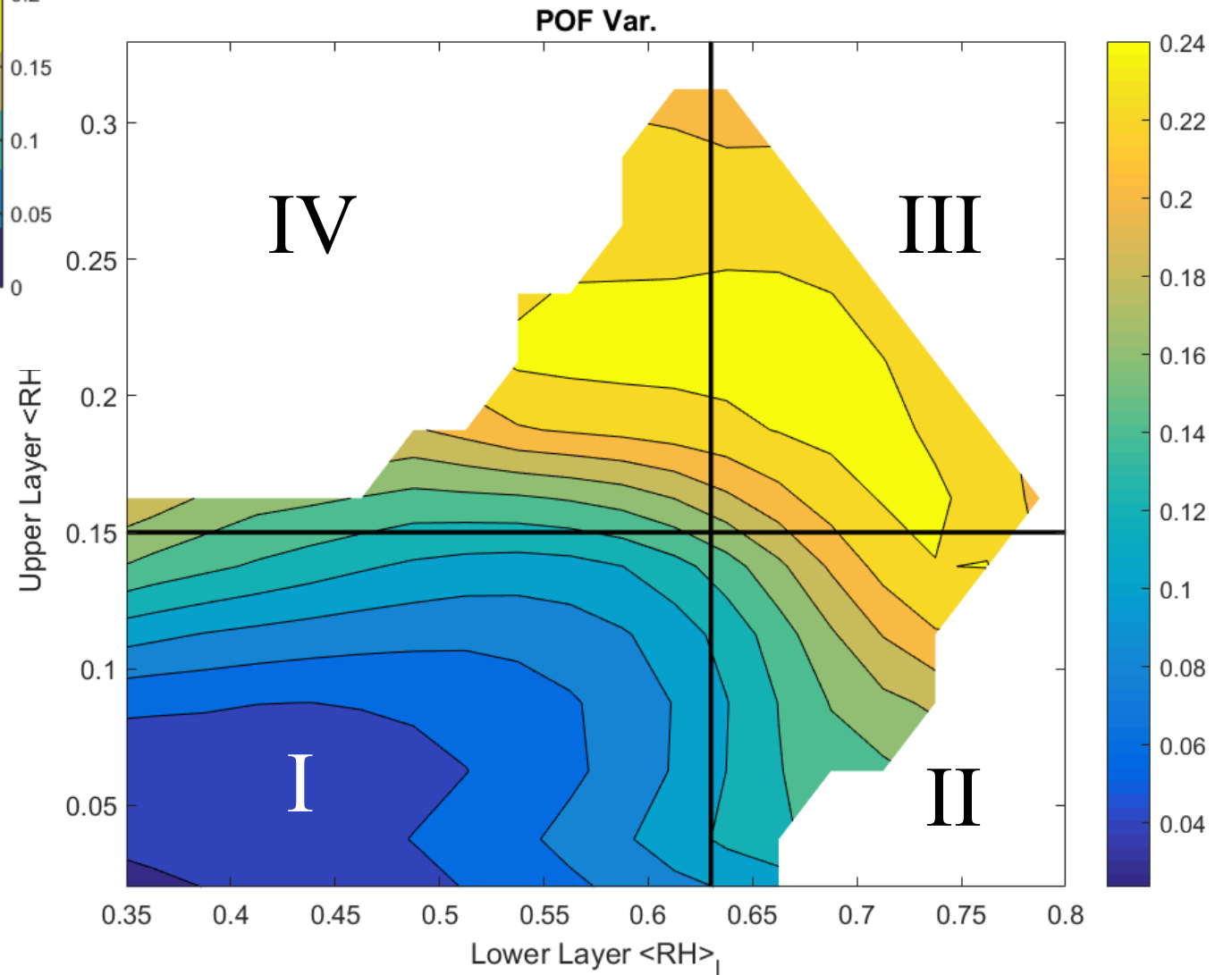
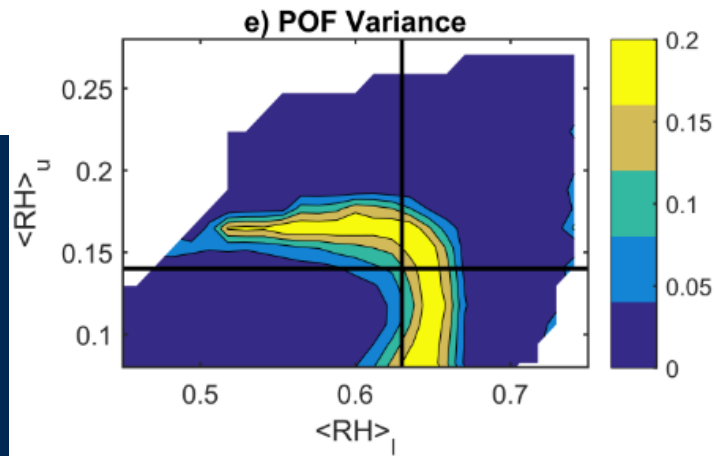
# Extra Slides

# Precipitation Occurrence as a Function of Layer-Contributions to Column Humidity



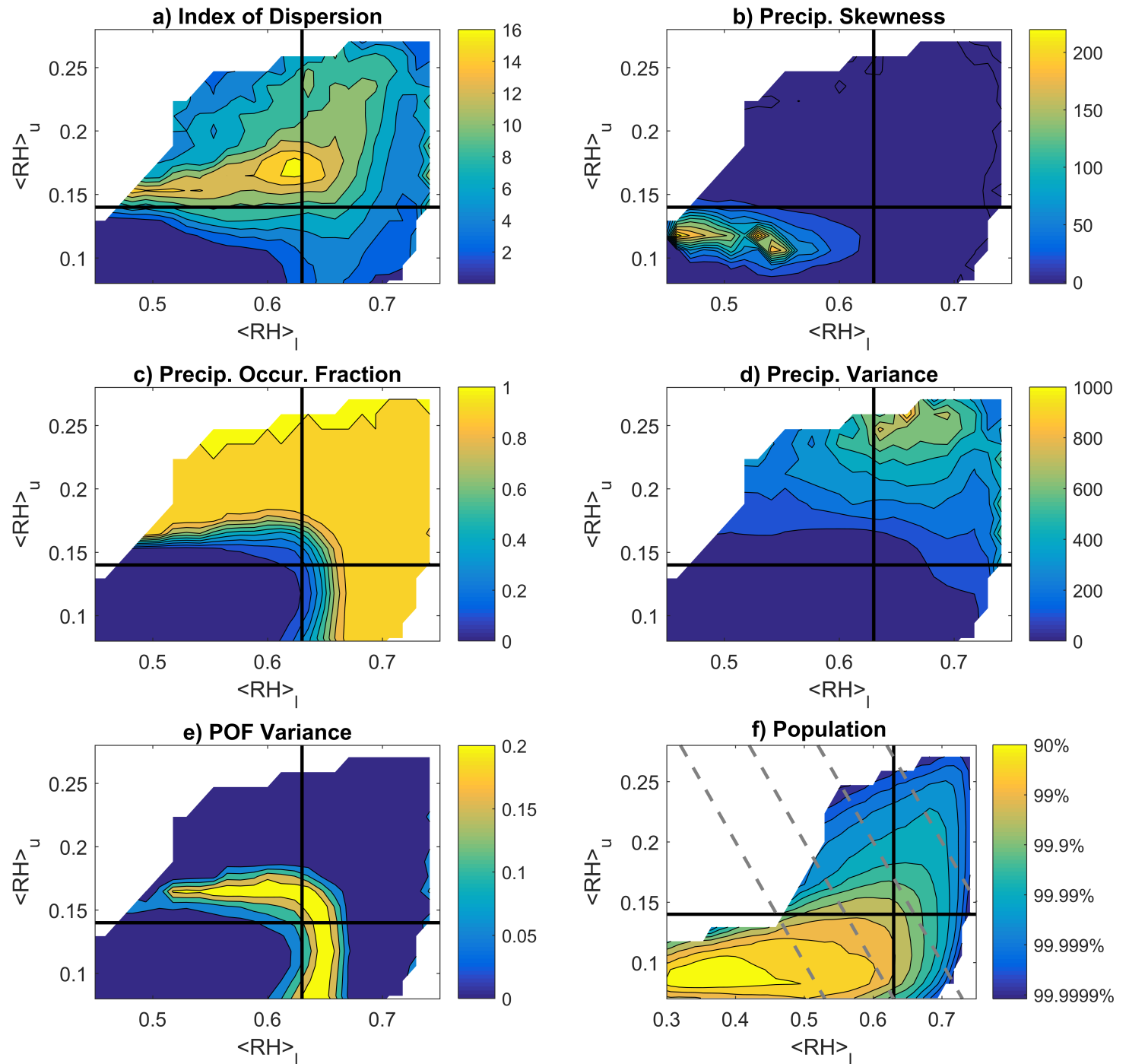
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# Precipitation Occurrence Variance as a Function of Layer-Contributions to Column Humidity

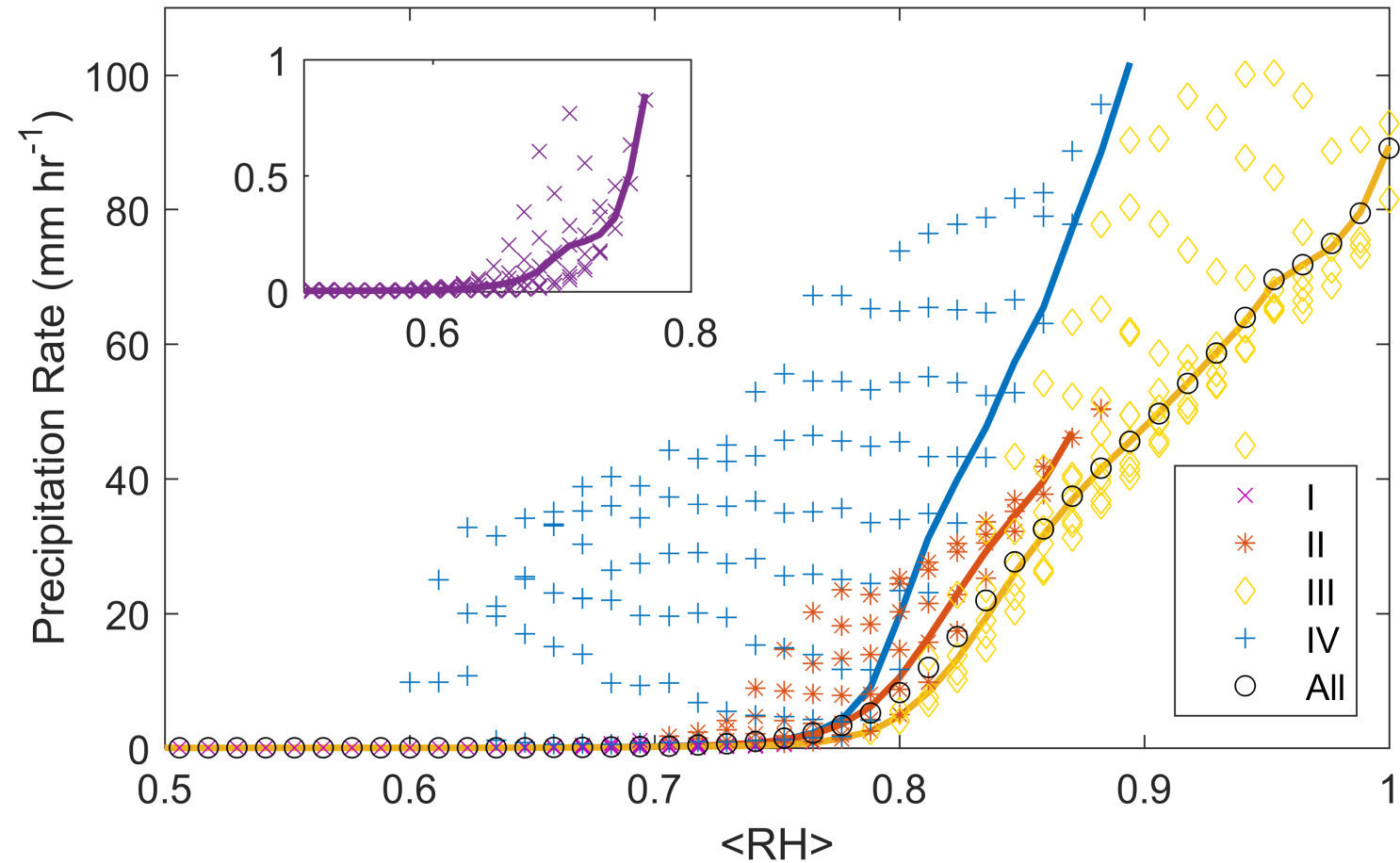


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# More Statistics



# Regime Precipitation per Column Humidity



# Tendency of moisture through layer $\langle RH \rangle$ -phase space

