Leveraging observations and model experiments for constraints on tropical convection in CAM

Todd Emmenegger
INFORM Project

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Goals

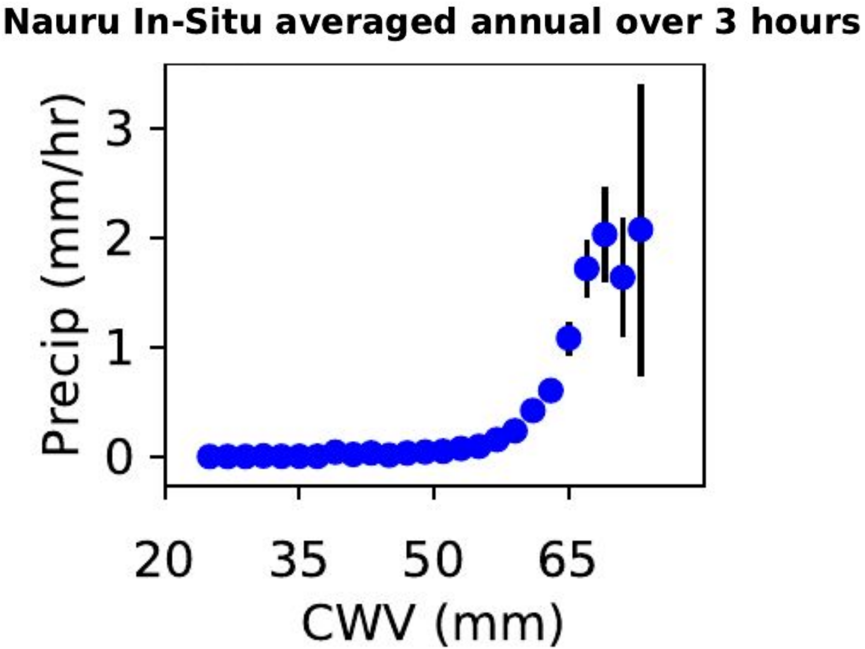
1. **Develop suite of model diagnostics to improve representation of tropical convection in CAMs**
2. **Combine simple theory, models, and a variety of observational products to build constraints**

Outline

1. **Transition to deep convection - the precip ‘pickup’ diagnostic**
2. **Bulk plume framework of buoyancy**
   a. **importance of mixing**
   b. **a new diagnostic for convective sensitivity**
3. **CAM6 PPE experiments**
   a. **importance of parameters for sensitivity**

The ‘Pickup’

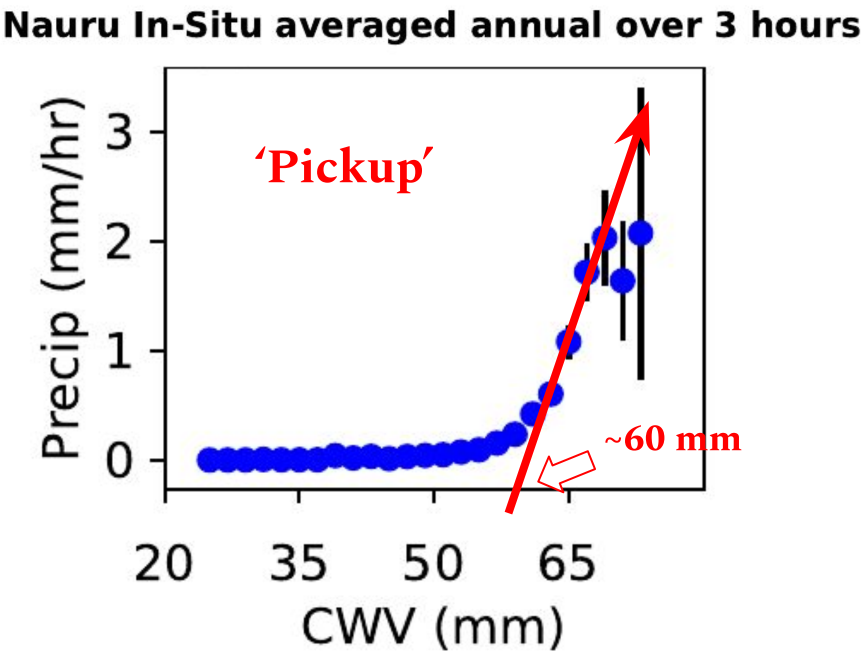
- **Robust relationship between CWV and precip: conditional-average precipitation rate picks up once a critical CWV value has been reached**
    - Identified on both short (minutes; Peters and Neelin, 2006) and daily (Bretherton et al., 2004) timescales
    - Observed over tropical land and ocean (Kuo et al. 2018, 2020; Schiro et al. 2017; Neelin et al. 2009)



Conditional-average precipitation rate from measurements taken at Nauru Island from Atmospheric Radiation Measurement field campaign (ARM)

The ‘Pickup’

- **Pickup** represents the transition to deep convection
- Linear fit provides estimation of critical value

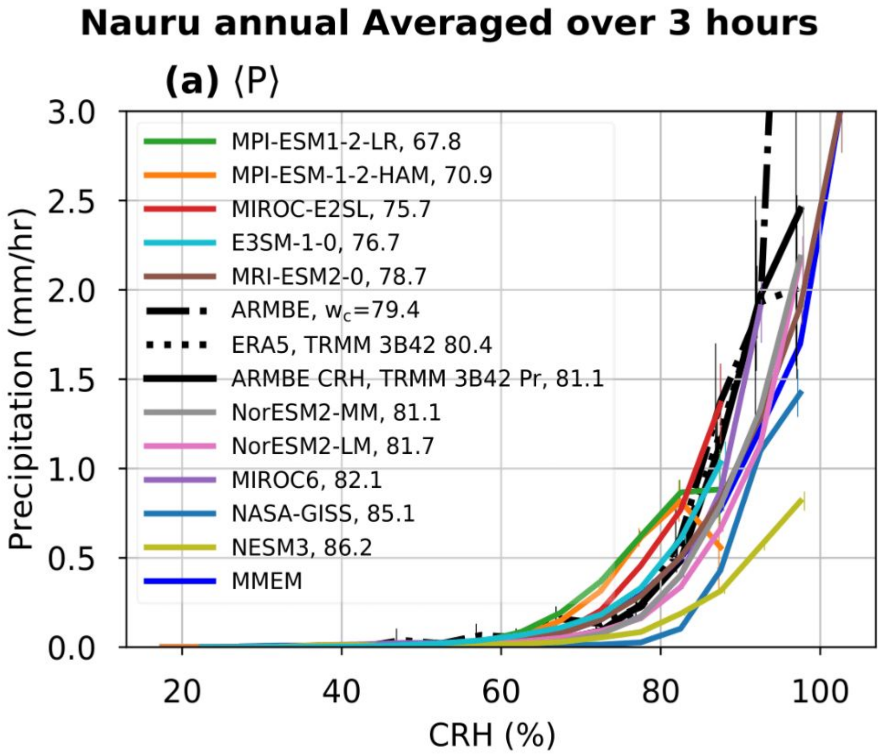


Conditional-average precipitation rate from measurements taken at Nauru Island from Atmospheric Radiation Measurement field campaign (ARM)

Pickup is a measure of model sensitivity

Higher crit values ⇒ insufficient sensitivity to moisture via entrainment (too much mixing)

- Observations: black
- Models: colored
- ERA5 reanalysis provides an additional baseline

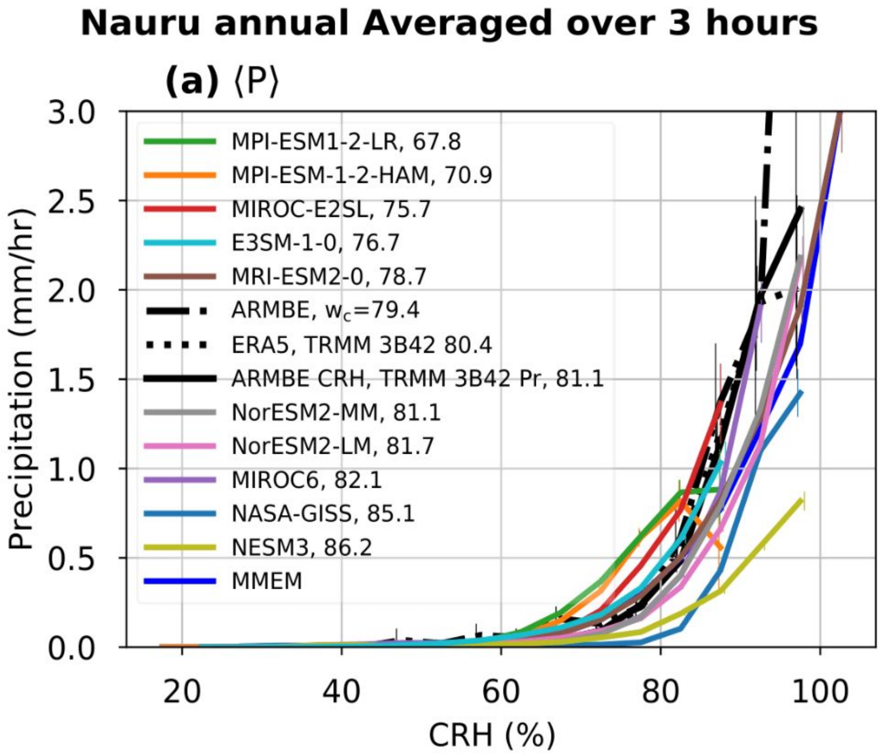


Convective transition statistics for CMIP6 model cohort. Emmenegger et al. 2022

Models are doing ok

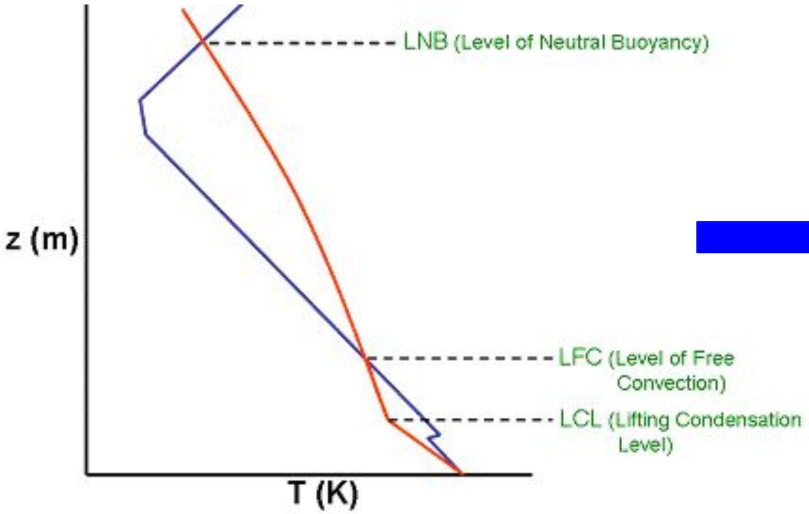
Higher crit values ⇒ insufficient sensitivity to moisture via entrainment (too much mixing)

- Observations: black
- Models: colored
- ERA5 reanalysis provides an additional baseline
- **Models perform better than CMIP5 generation (most models pickup early; Rushley et al. 2018)**

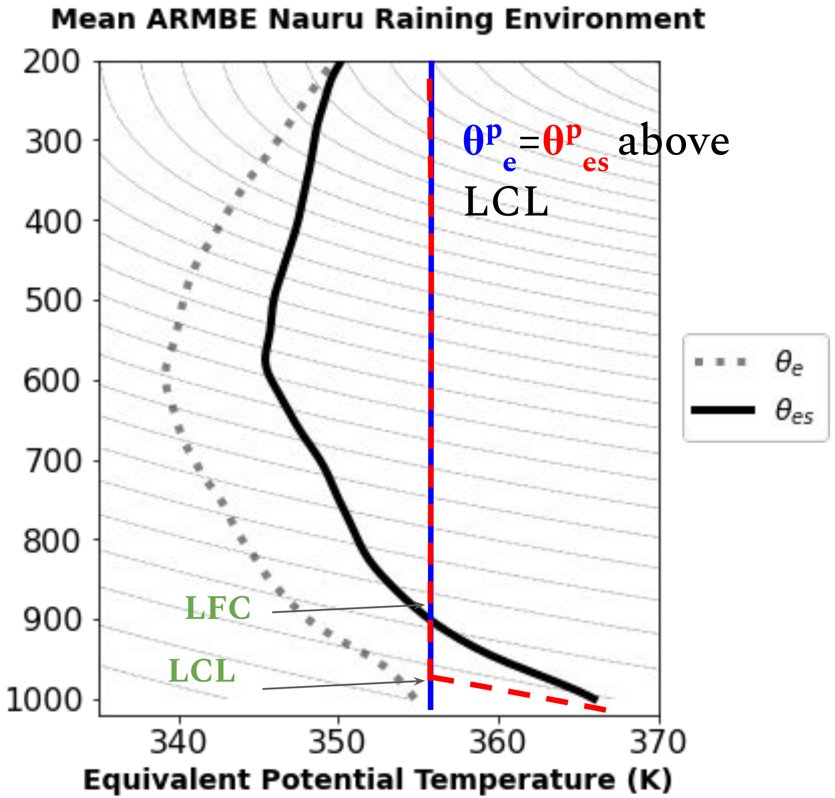


Convective transition statistics for CMIP6 model cohort. Emmenegger et al. 2022

Bulk plume framework

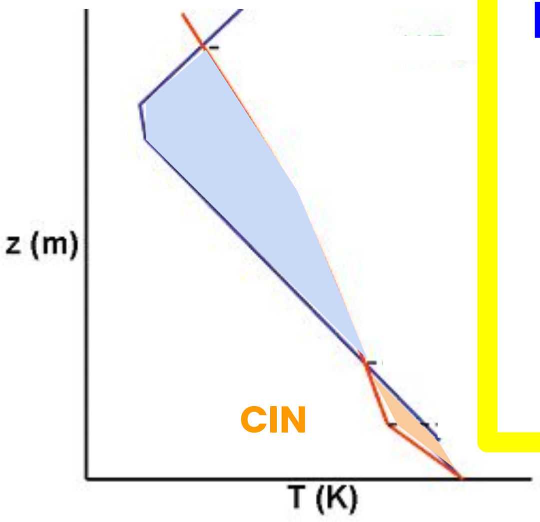


Example of conditional instability from COPS Summer School 2007



Average profiles during raining times

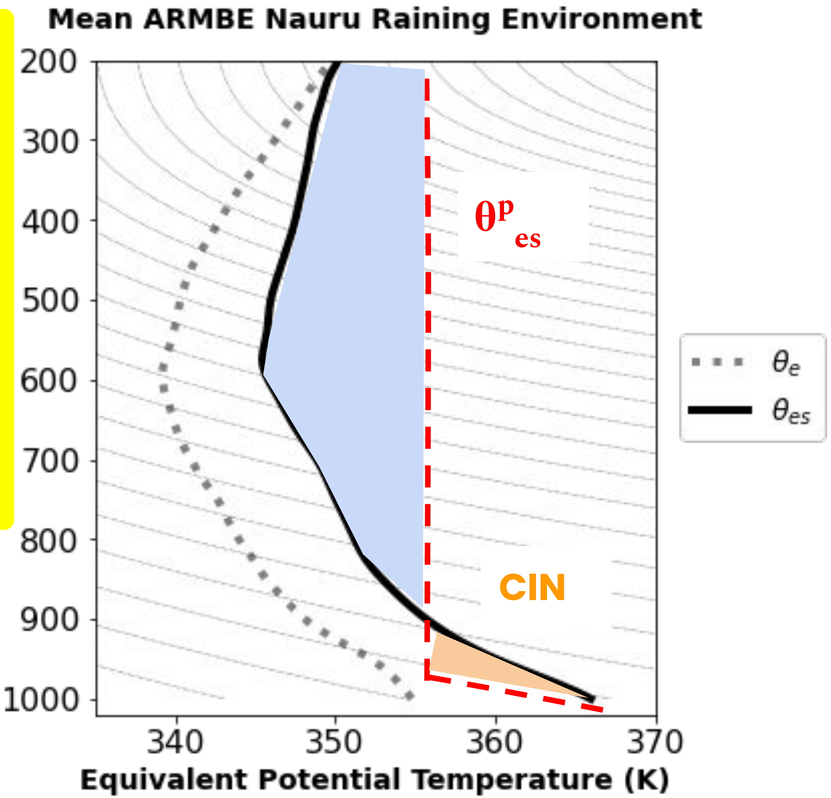
Bulk plume framework



Example of conditional instability from COPS Summer School 2007

BUOYANCY (B)

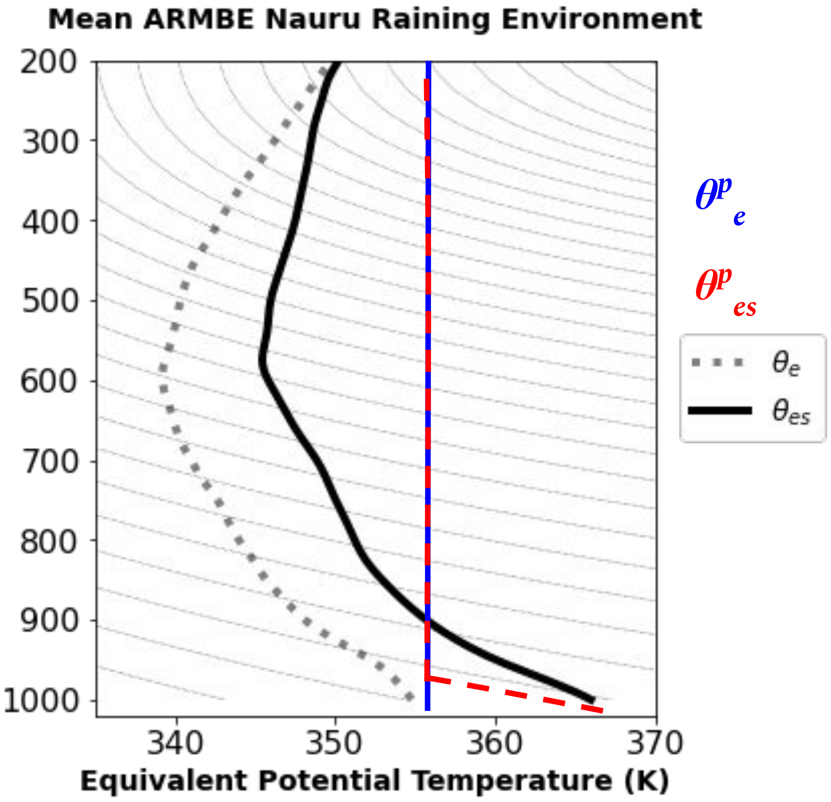
$$\frac{\delta T}{T} = \frac{\delta \theta_{es}}{\kappa \theta_{es}}$$



Average profiles during raining times

Bulk plume framework

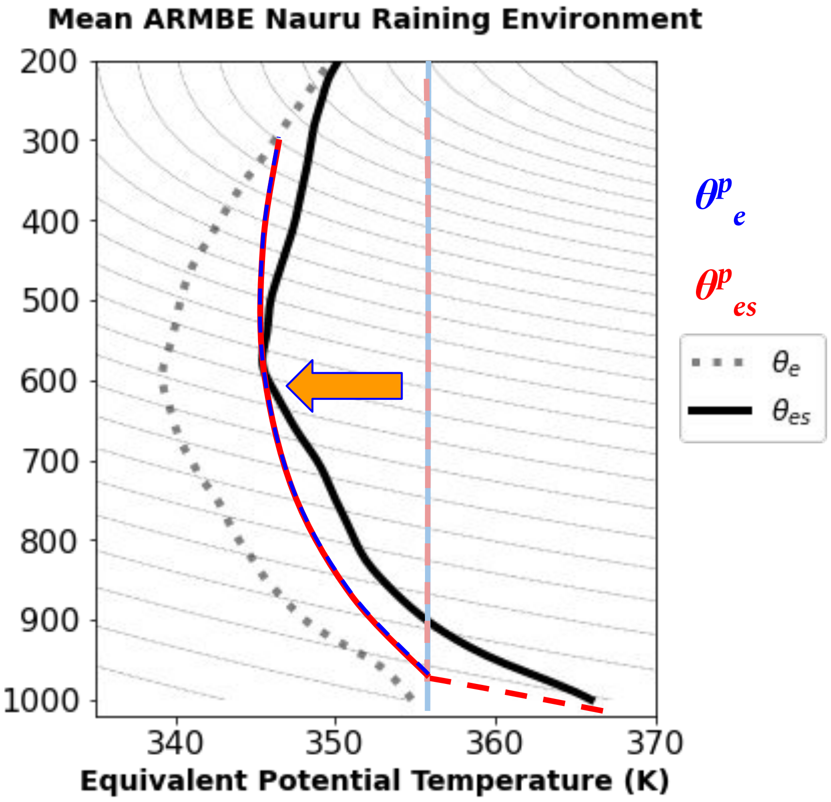
- Plume equivalent pot temp, θ^p_e , conserved



Average profiles during raining times

Bulk plume framework

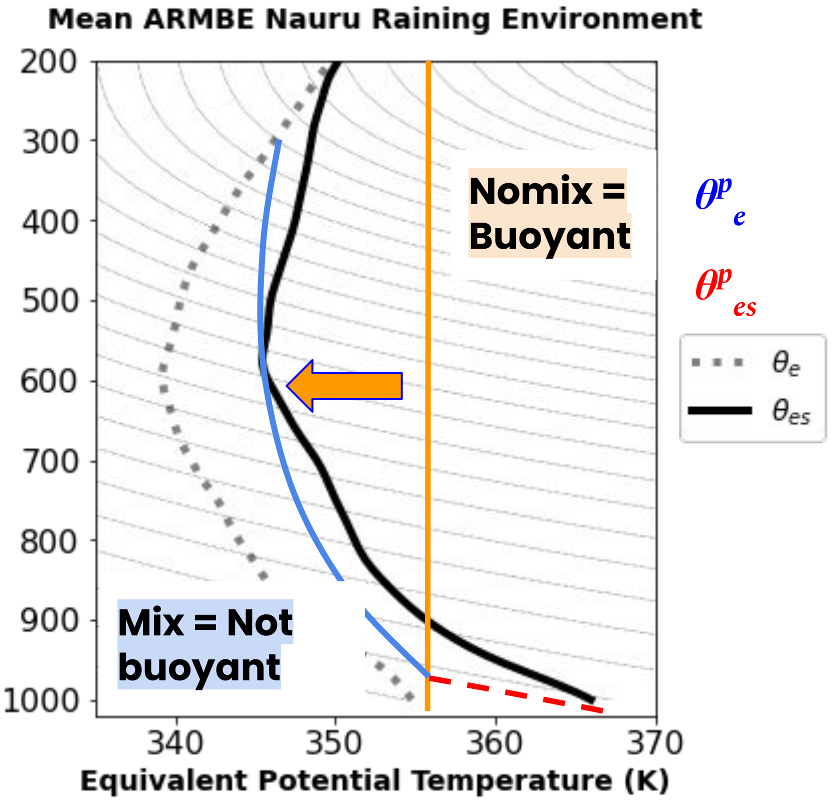
- Plume equivalent pot temp, θ^p_e , conserved
- Mixes with env θ_e **(dilutes)**



Average profiles during raining times

Bulk plume framework

- Plume equivalent pot temp, θ^p_e , conserved
- Mixes with env θ_e **(dilutes)**
- **Mixing has large impact on buoyancy of plumes**



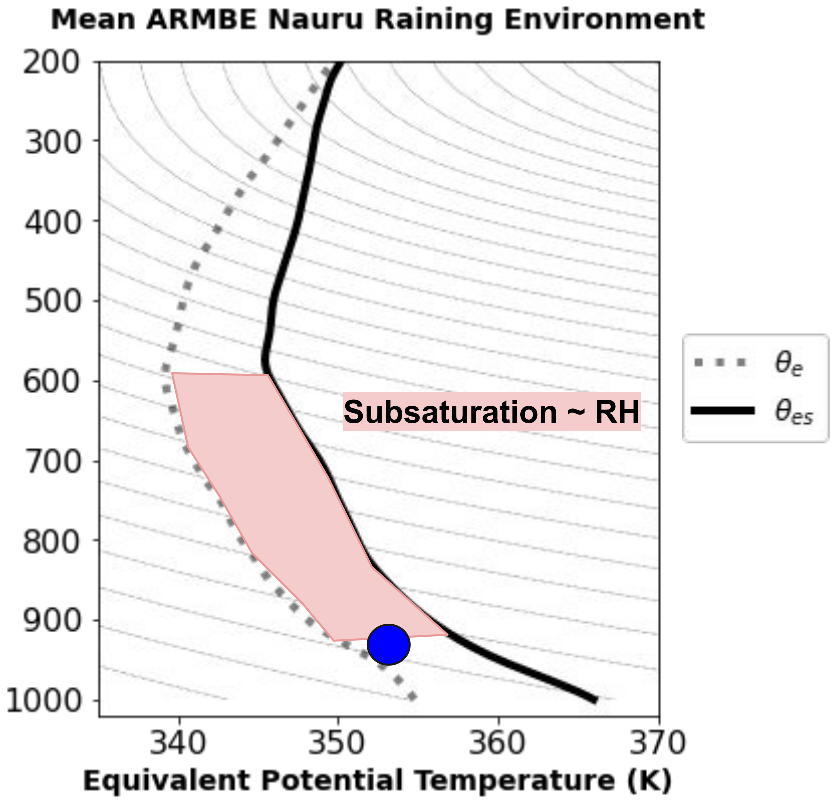
Average profiles during raining times

Simple two-layer approach

Plume eqn

$$\frac{d\theta_e^p}{dp} = \epsilon[\theta_e - \theta_e^p]$$

mixing rate



Average profiles during raining times

Simple two-layer approach

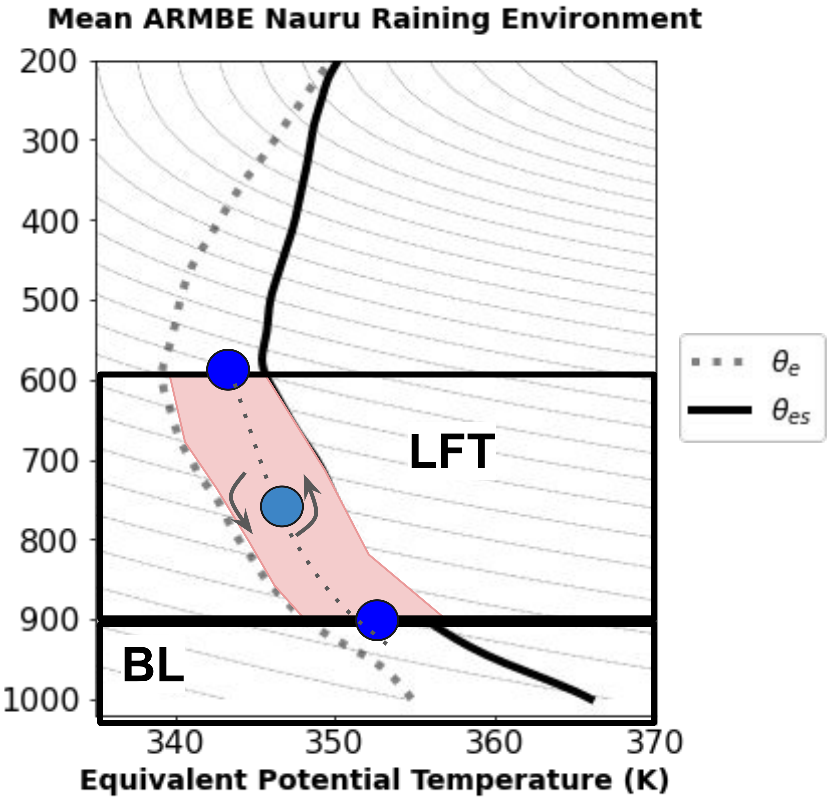
Plume eqn with linear mass flux

$$\frac{d\theta_e^p}{dp} = \epsilon[\theta_e - \theta_e^p]$$

mixing rate

Casts plume as combination between BL and dilution (D) from LFT

$\theta^p_e(LFT) \approx \theta^p_e(BL) + D \times SUBSAT(LFT)$



Average profiles during raining times

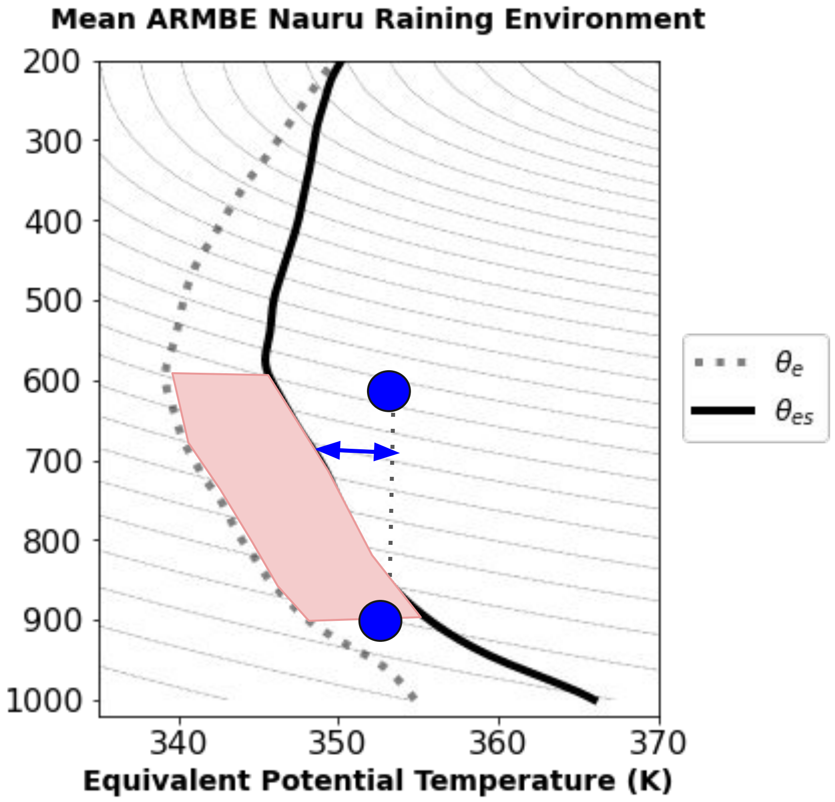
Simple two-layer approach

$$\theta^p_e(LFT) \approx \theta^p_e(BL) + D \times SUBSAT(LFT)$$

$$\Rightarrow B \sim \delta\theta_{es} \approx \theta^p_e(BL) - \theta_{es}(LFT) + D\times SUBSAT(LFT)$$

Instability

Recast B as some weighting***, w,*** between subsat and instability



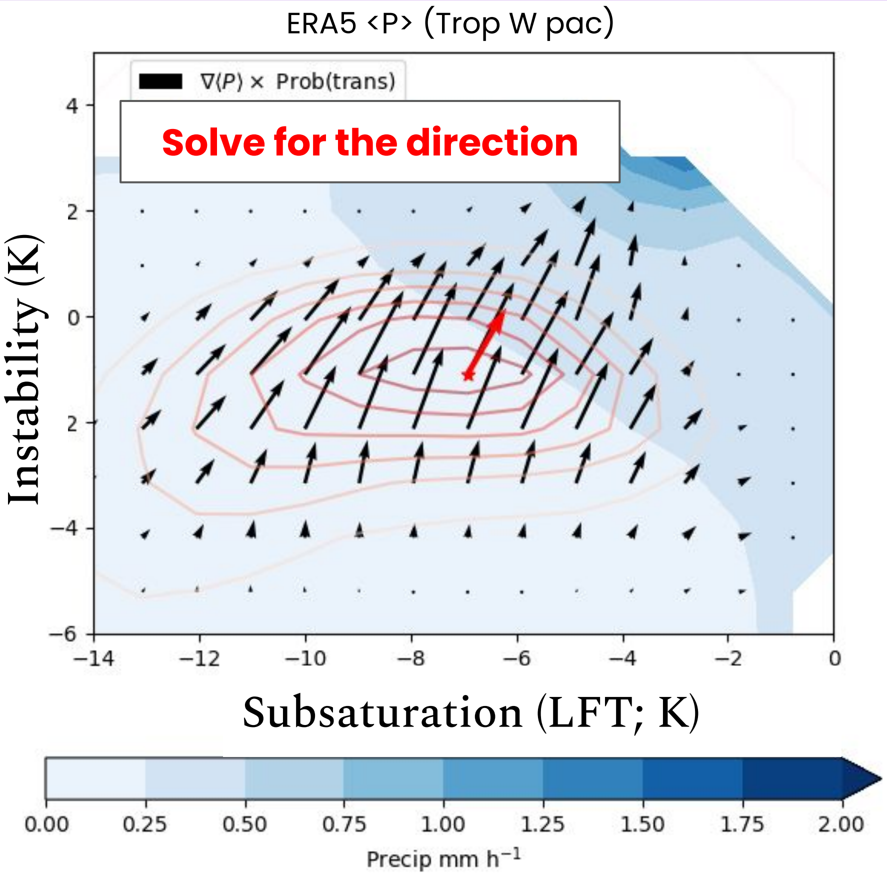
Average profiles during raining times

Find weighting

B ~ *w*×***INSTABILITY*** + (*1-w*)×***SUBSAT(LFT)***

- use precipitation as proxy for B
- 2D conditional-avg precipitation shows sensitivity of B to instability or subsat
- **Weight the gradient field (arrows) by probability of precip (red contours)**

This is a 2D pickup!



Sensitivity Metric (supplemental)

$$S = \frac{\sum_i \sum_j D_{\vec{u}} \langle P \rangle_{ij} \times \text{Prob(trans)}_{ij}}{\sum_i \sum_j ||\nabla \langle P \rangle_{ij}|| \times \text{Prob(trans)}_{ij}}$$

S is a scoring function which assigns a probability-weighted value between 0 and 1 to correlation of single direction in <P>

How well can the gradient of <P> be described by one direction?

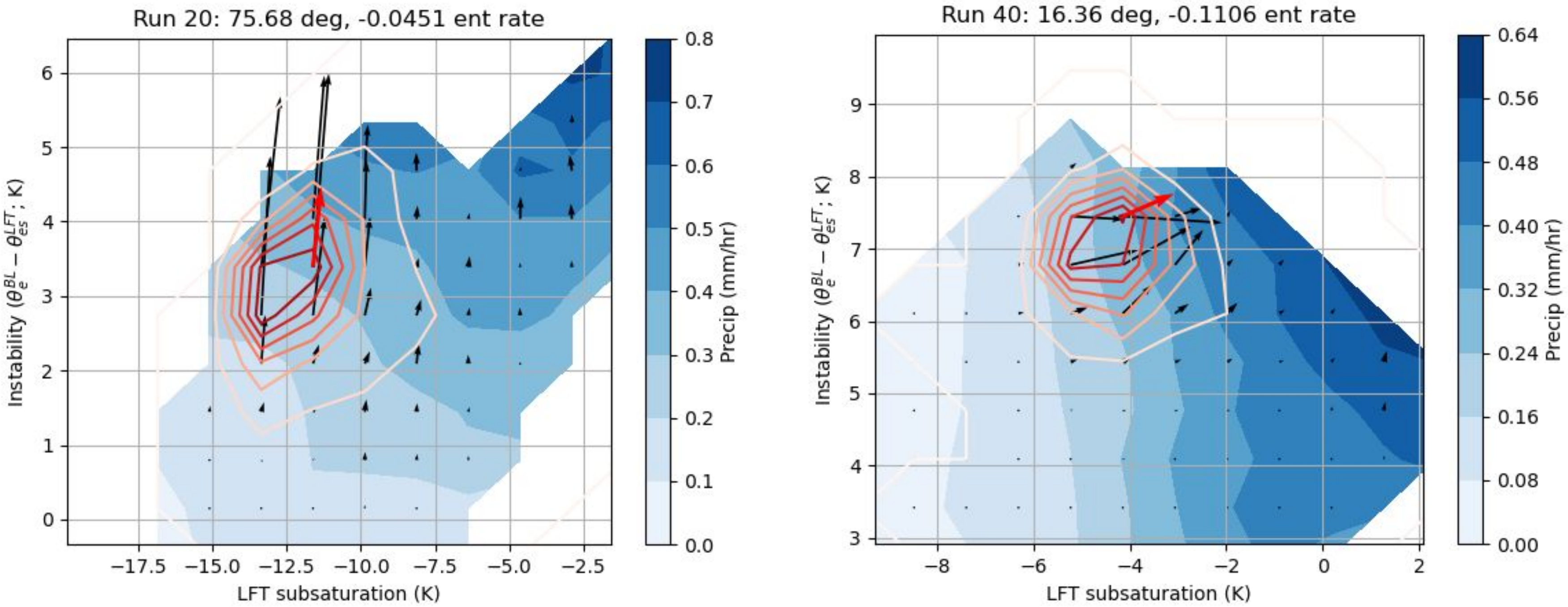
$$1 = \sum_i \sum_j \text{Prob}(trans)_{ij}$$

Weighting is a PDF that sums to 1

CAM6 PPE (Eidhammer et al. 2024)

- 262 CAM6 runs with perturbed parameters
- Params are **all** randomly perturbed for each run
- Monthly output for three years (climatological analysis)
- Analysis over west trop pac ocean (120E - 180 , -10 S - 10 N)

CAM6 PPE <P> sample

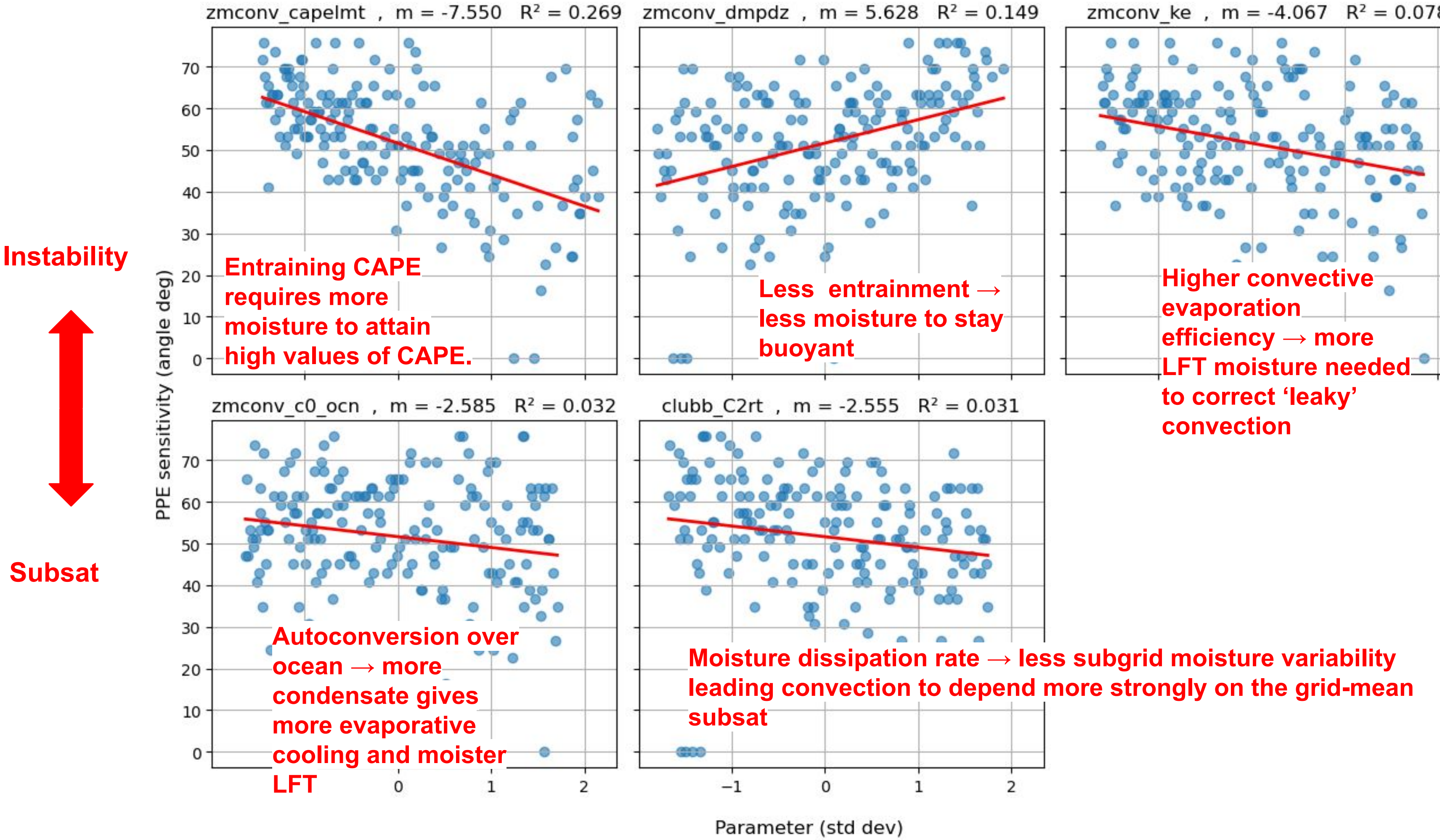


Each run gives a measure (angle) that measures sensitivity. Now we find leading params

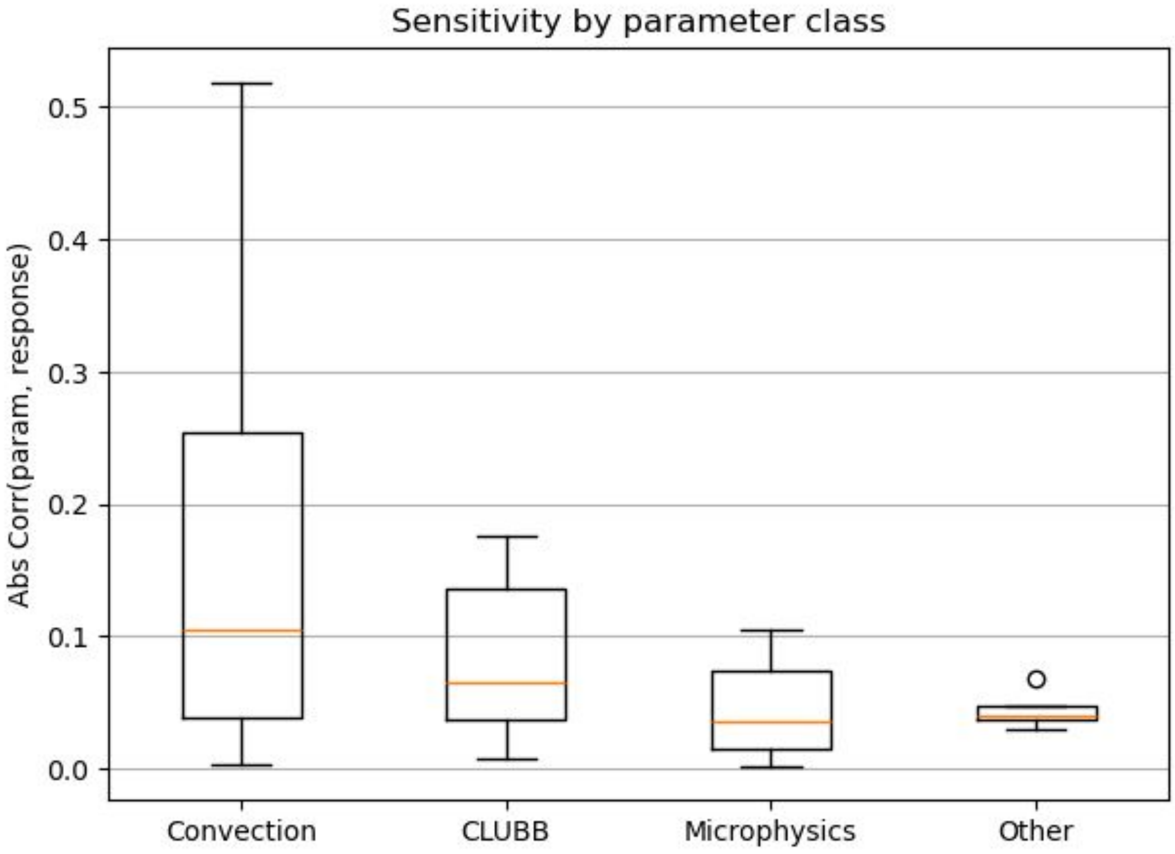
CAM6 PPE correlations

Parameter	corr(param, conv_sens)
zmconv_capelmt	0.518689
zmconv_dmpdz	0.386634
zmconv_ke	0.279404
zmconv_c0_ocn	0.177609
clubb_C2rt	0.175519
cldfrc_dp2	0.166473
clubb_C6thl	0.156406
clubb_C6rt	0.156406
zmconv_c0_lnd	0.127115
clubb_c_K10	0.114778
microp_aero_wsub_scale	0.105156
clubb_wpxp_L_thresh	0.094238
micro_mg_autocon_nd_exp	0.093259
micro_mg_autocon_fact	0.088624
micro_mg_iaccr_factor	0.082808

zmconv look to dominate variance of sensitivity



Instability
Subsat
PPE sensitivity (angle deg)
zmconv_capelmt , m = -7.550 R^2 = 0.269
zmconv_dmpdz , m = 5.628 R^2 = 0.149
zmconv_ke , m = -4.067 R^2 = 0.078
zmconv_c0_ocn , m = -2.585 R^2 = 0.032
clubb_C2rt , m = -2.555 R^2 = 0.031
Entraining CAPE requires more moisture to attain high values of CAPE.
Less entrainment → less moisture to stay buoyant
Higher convective evaporation efficiency → more LFT moisture needed to correct 'leaky' convection
Autoconversion over ocean → more condensate gives more evaporative cooling and moister LFT
Moisture dissipation rate → less subgrid moisture variability leading convection to depend more strongly on the grid-mean subsat
Parameter (std dev)



The climatological PPE response is dominated by convective parameters, with secondary contributions from shallow convection/turbulence (CLUBB) and weak marginal sensitivity to microphysics params

Future Work

- SCAM runs to zoom in on parameter classes
  - what params matter more for extremes?
  - develop time dependent measures such as convective onset
- What variability do we wish to capture and how do we build constraints for these params?

Thank You

temmen@ucar.edu