Effects of cloud superparameterization at the land-atmosphere interface

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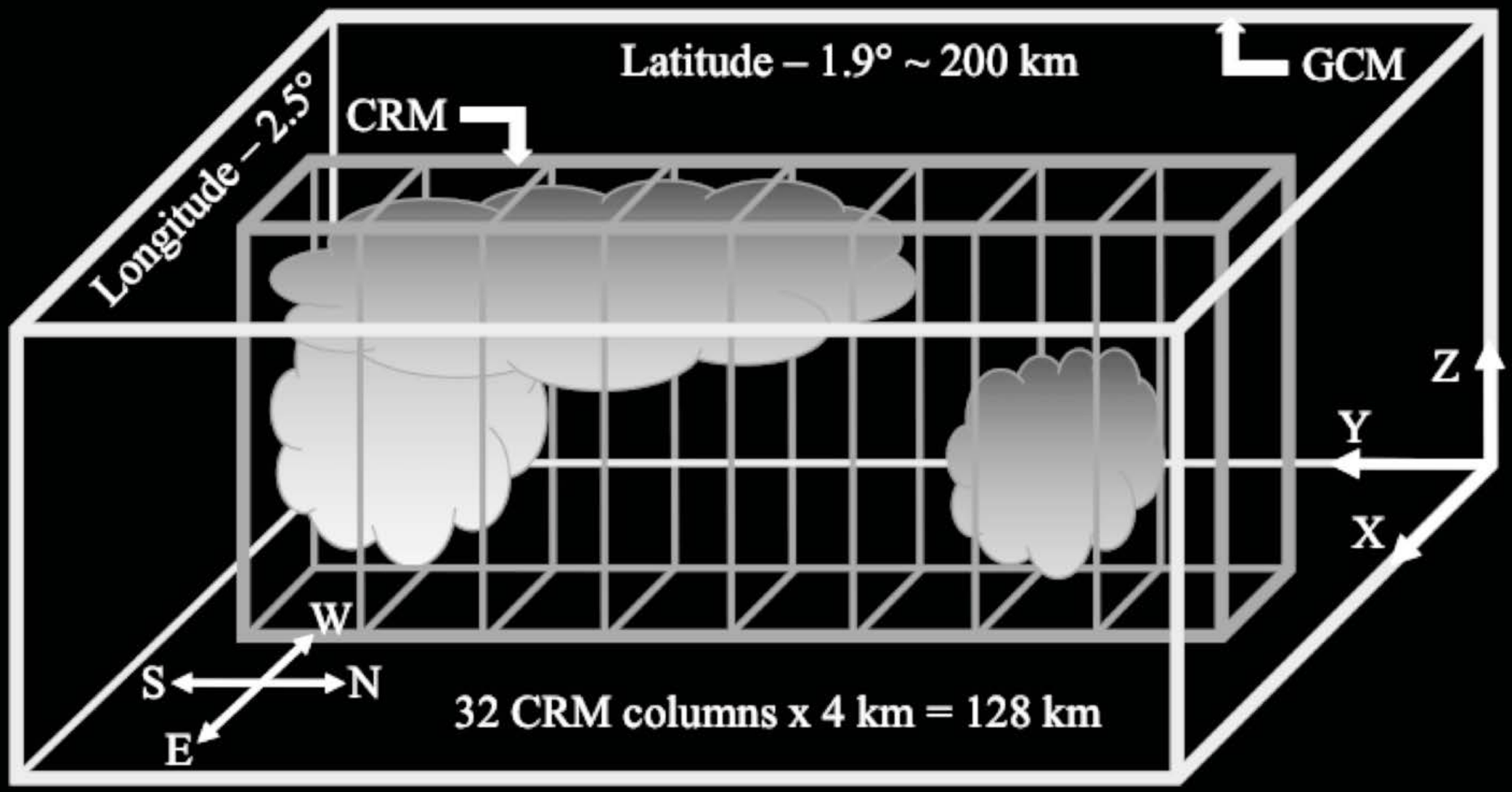
Acknowledging UCI researchers:
Jian Sun, Hossein Parishani, and Gabe Kooperman

Cloud superparameterization

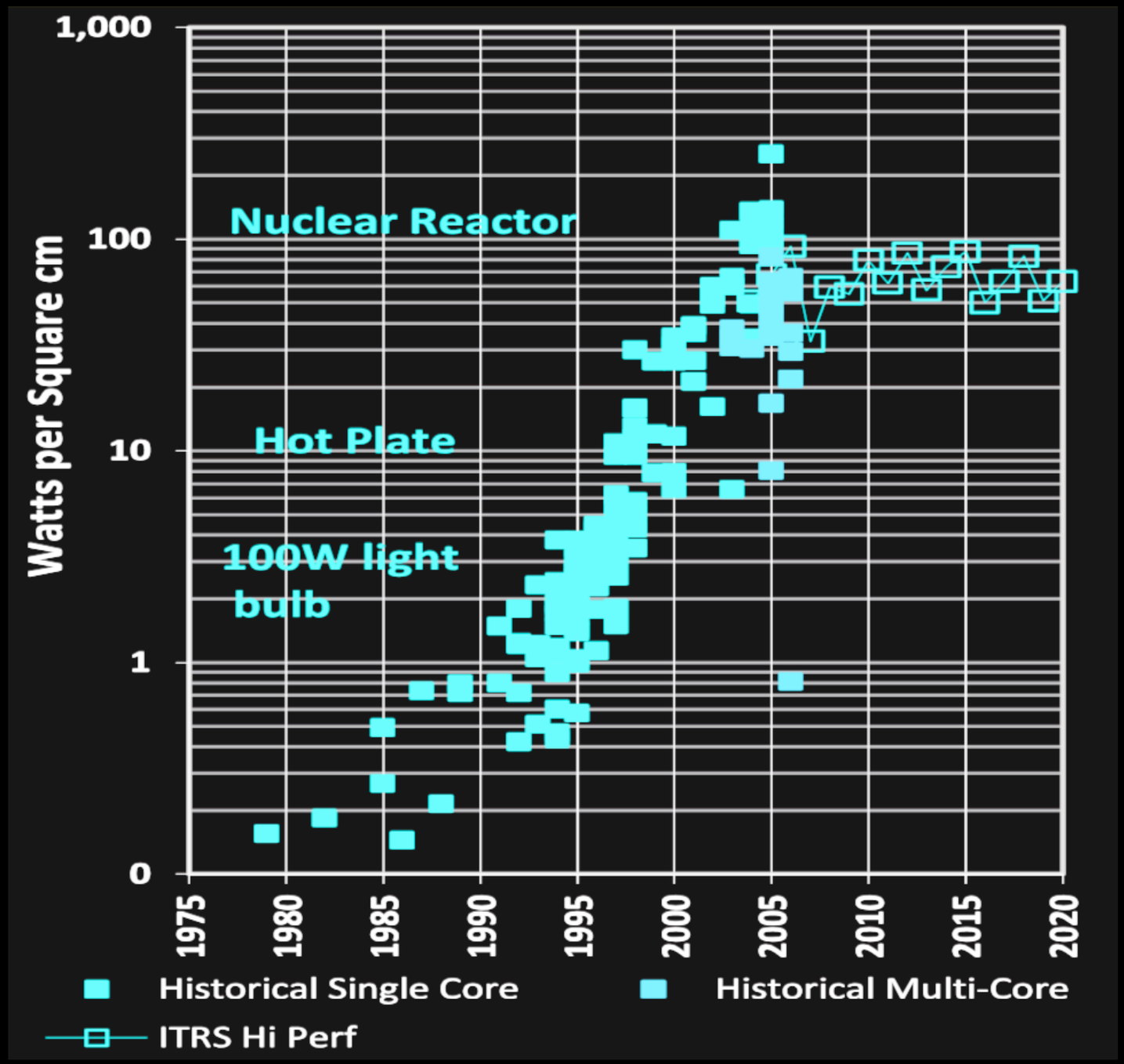


Examples of progress using superparameterized algorithms in fixing long-standing problems linked to deep convection.

- More realistic intensity distribution of rainfall
- Missing weather patterns emerge
  - Central US mesoscale convective systems
  - The Madden-Julian Oscillation

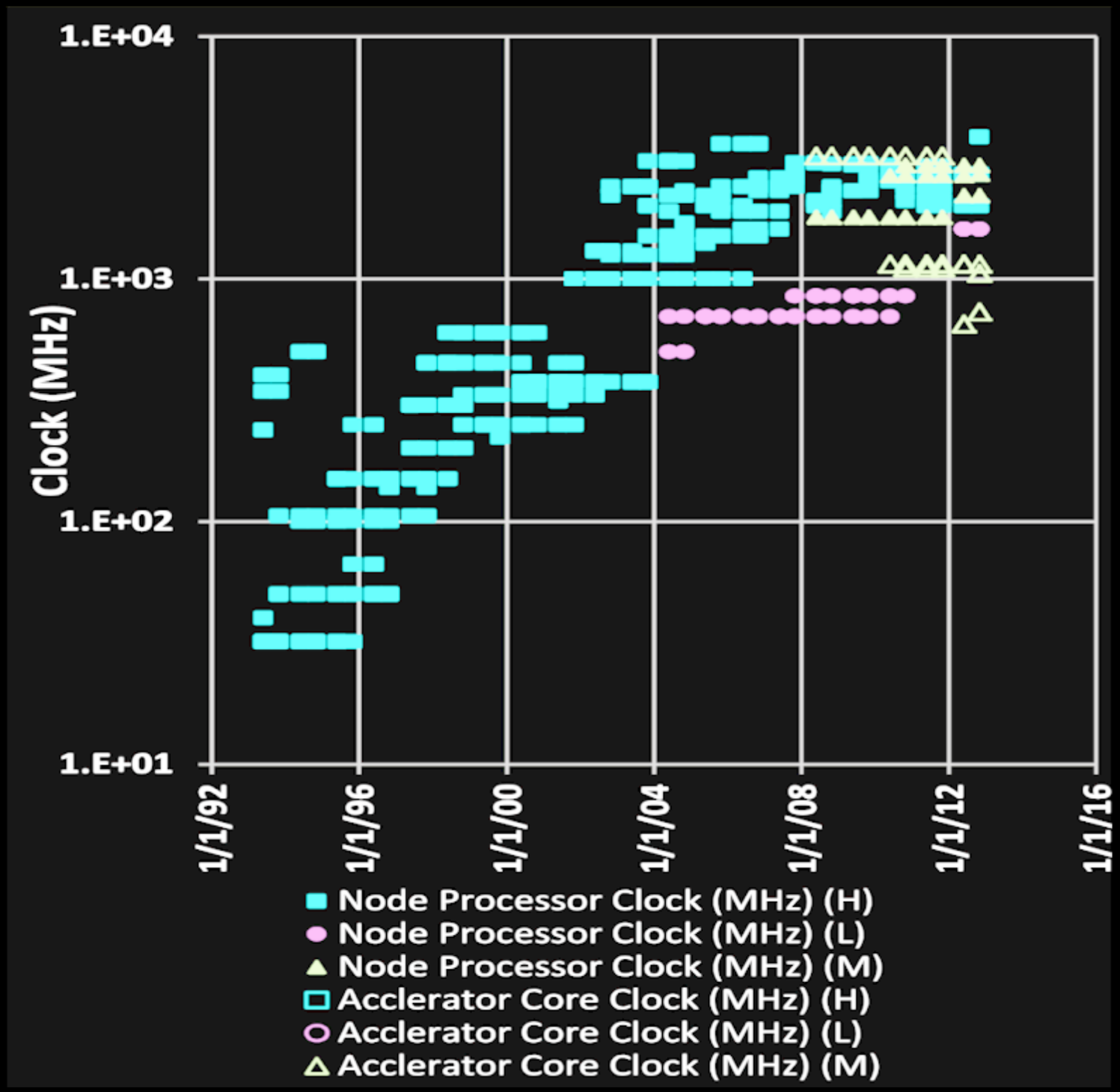
Energy limitations are morphing supercomputers in new ways.

Power density / cooling demands of multi-core systems hitting a limit.



Source: Kogge and Shalf, IEEE CISE
Courtesy of Horst Simon, LBNL

Serial CPU clock speeds are not increasing.

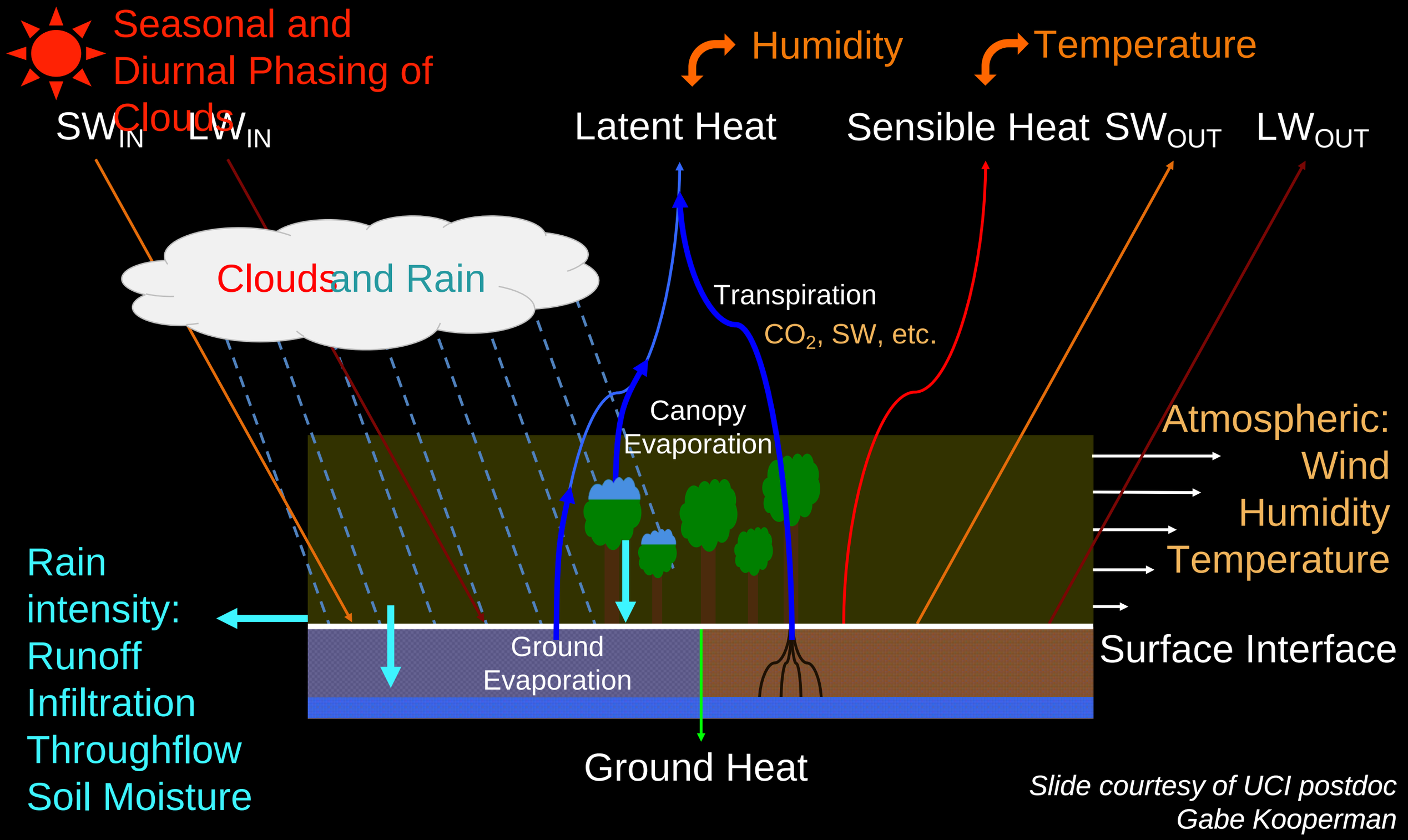


Source: Kogge and Shalf, IEEE CISE
Courtesy of Horst Simon, LBNL

Superparameterization is well situated to exploit new emerging forms of co-processor computing power.

- Communication bottlenecks often limit access to new forms of co-processor computing power.
- Especially for climate simulation, which involves a lot of communication.
- Superparameterization is an unusually low-communication algorithm.
- Serious potential to computationally expand the paradigm.

How can super-parameterization impact land-surface energy exchange?



Slide courtesy of UCI postdoc Gabe Kooperman

Part I.

Assessment of land-atmosphere coupling in SPCAM3.5 versus CAM3.5

Sun and Pritchard, in review for JAMES

Simulations

- SPCAM v3.5 versus CAM v3.5
- 20-year AMIP simulations; SSTs prescribed.
- ~2.5 degree global resolution.
- In SPCAM, embedded cloud-resolving models with 8 CRM columns spaced 4 km apart.

Terrestrial segment.

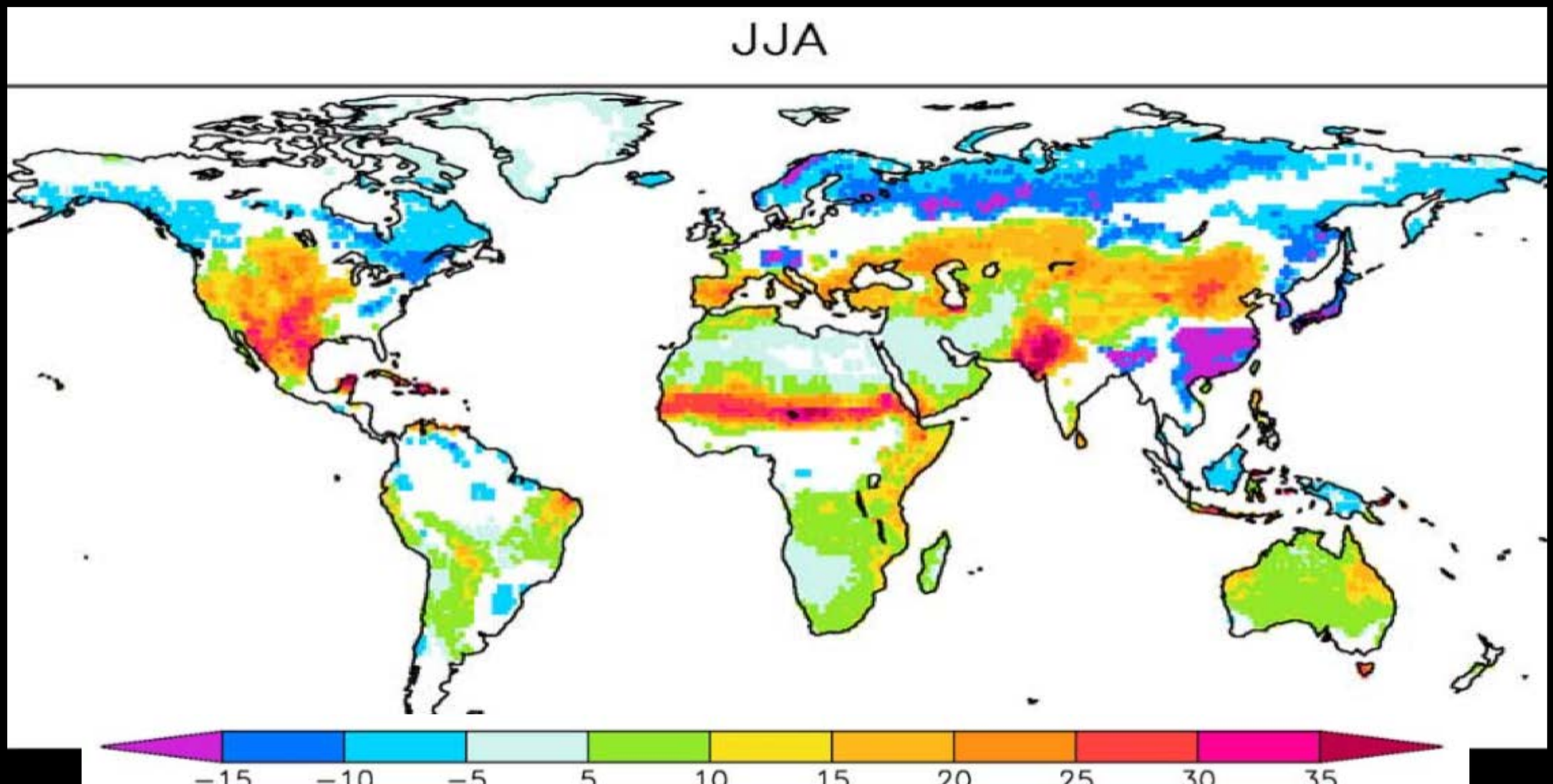
Terrestrial coupling index (Dirmeyer 2011)

$$I_\phi = s_w \beta_\phi$$

soil water variability

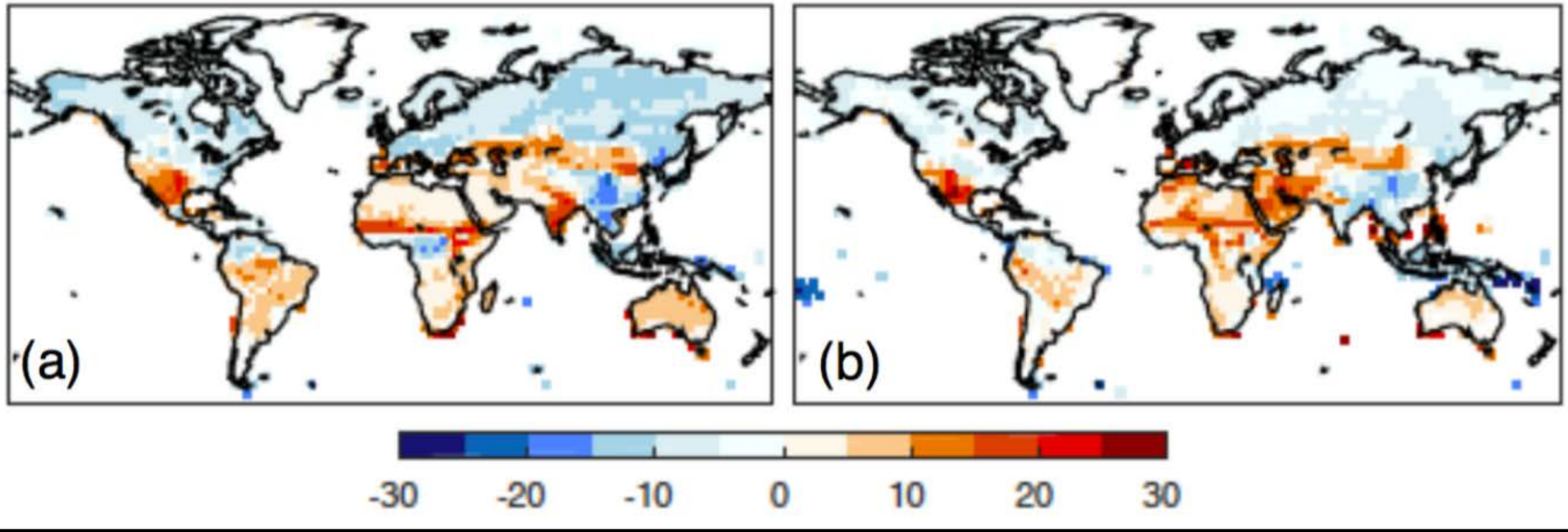
regression slope vs. soil water

JJA "I_{LH}" from the Global Soil Wetness Project GSWP-2



Effect of superparameterization on "l_{LH}" during JJA

JJA **SP-CAM** **CAM**

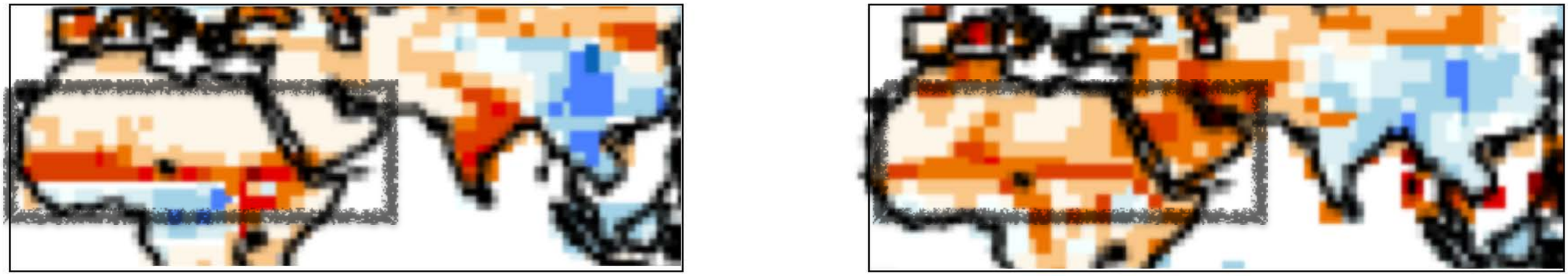


Sun and Pritchard, in review

Several favorable regional effects.

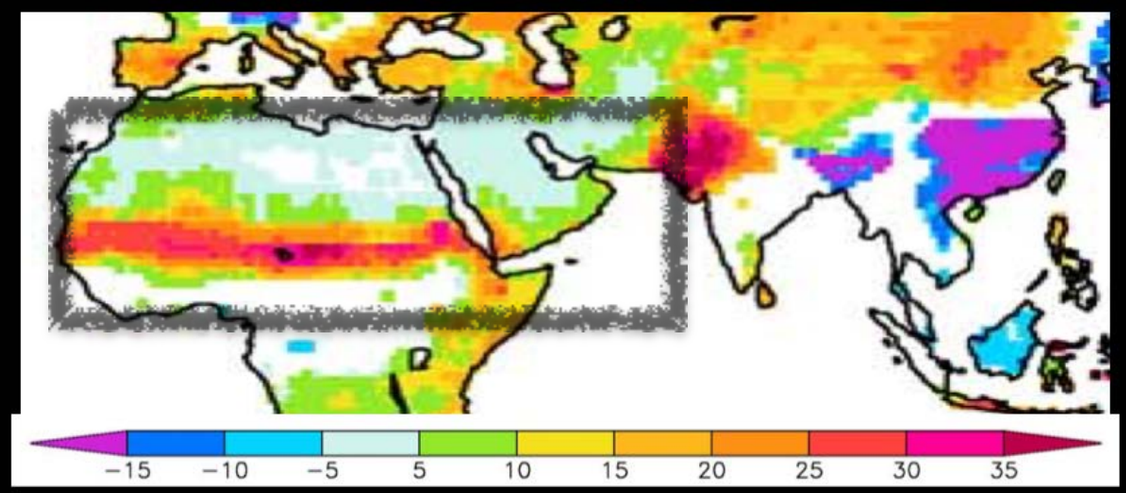
Removal of unrealistic coupling across Northern Africa, Middle East; enhanced coupling contrast across ITCZ.

JJA SP-CAM CAM



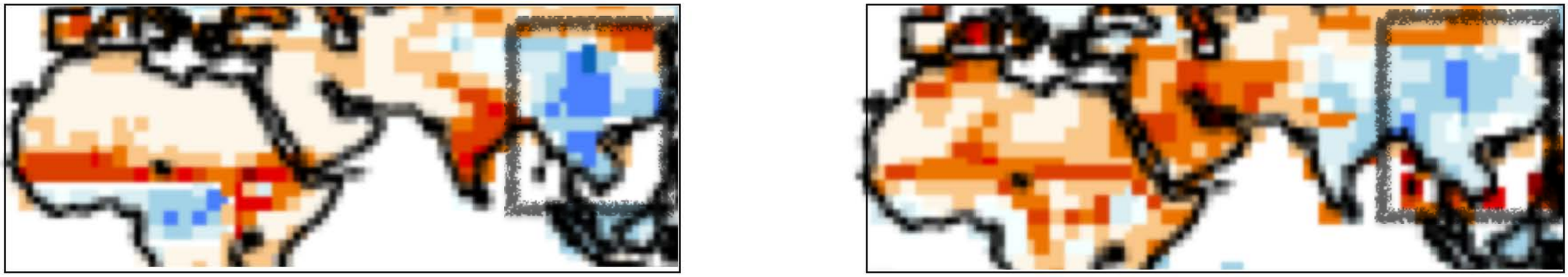
-45 -30 -15 0 15 30 45

JJA GSWP v2 Dirmeyer (2011)



Enhanced negative coupling over Central / Eastern China.

JJA SP-CAM CAM



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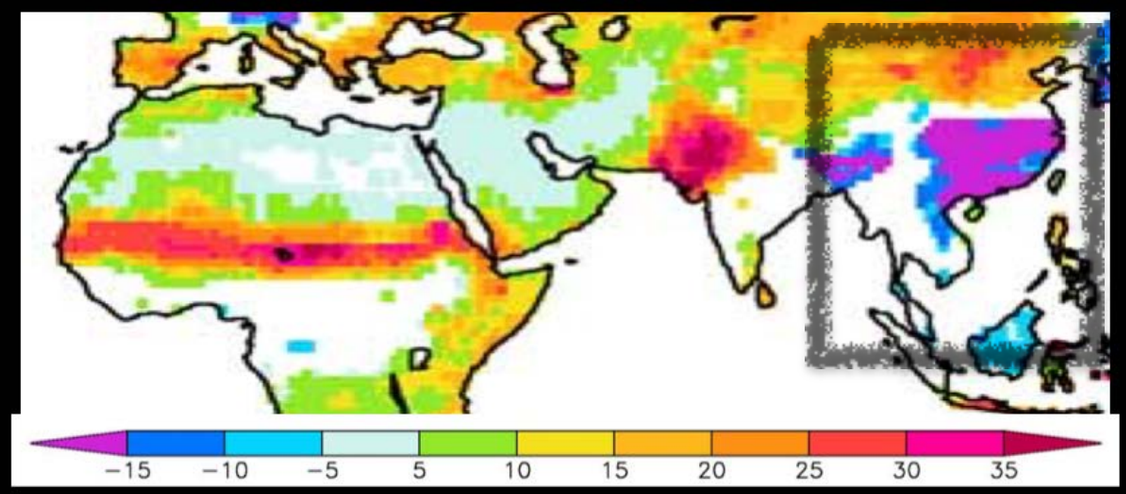
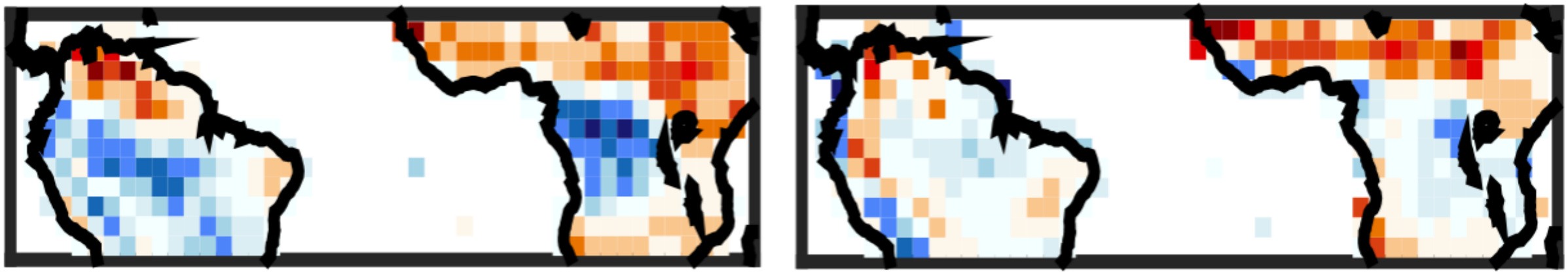
JJA GSWP v2 Dirmeyer (2011)



Enhanced wet season negative tropical rainforest coupling

DJF SP-CAM CAM



DJF GSWP v2 Dirmeyer (2011)

Atmospheric segment.

Triggering Feedback Strength

(Findell et al. 2011)

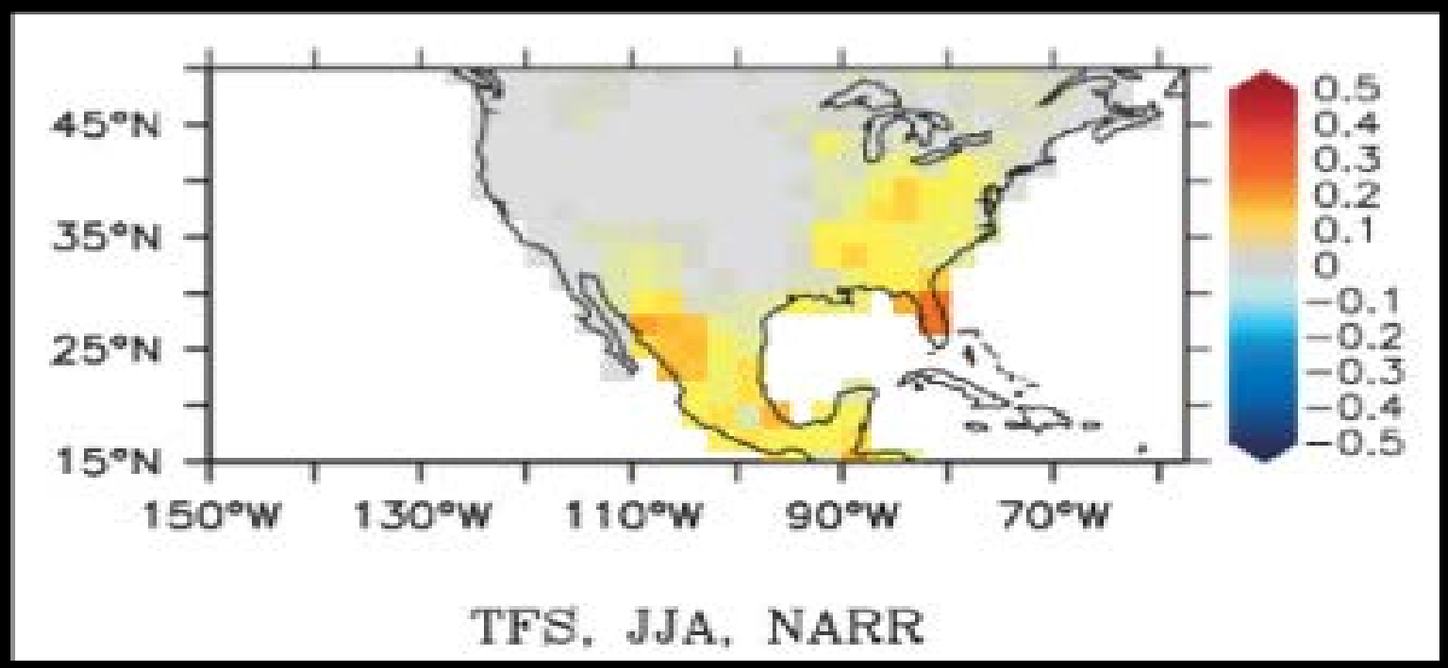
Probability of afternoon rainfall occurrence

$$TFS = \sigma_{EF} \frac{\partial \Gamma(r)}{\partial EF}$$

Evaporative Fraction variability

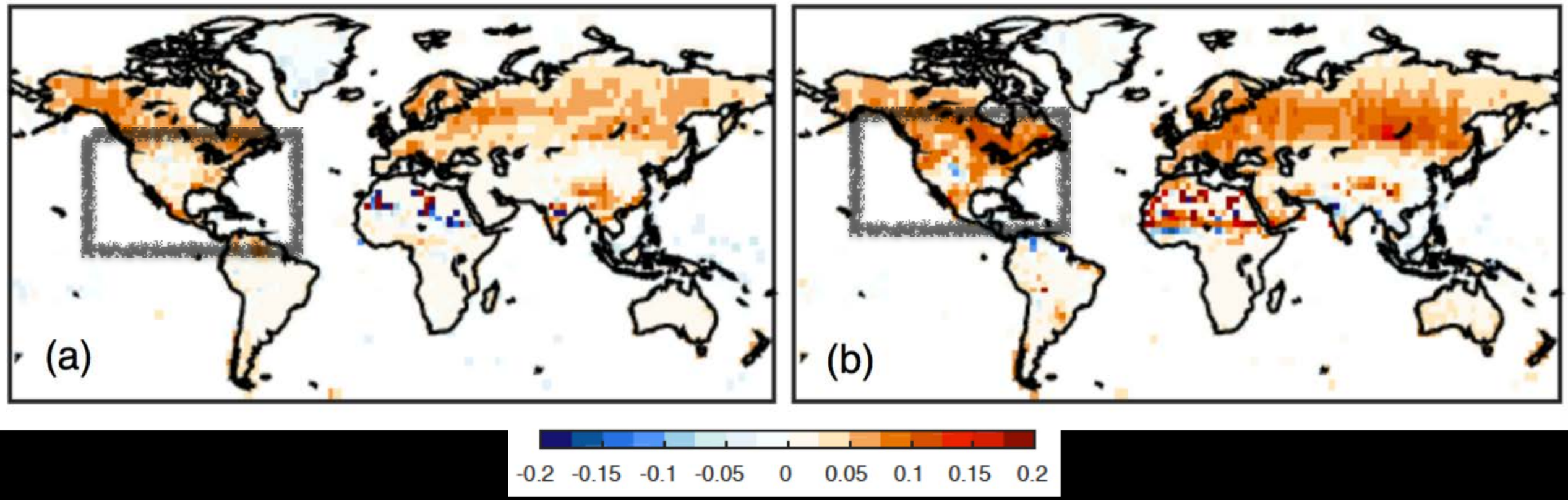
Morning evaporative fraction

“**TFS**” from the North American Regional Reanalysis:



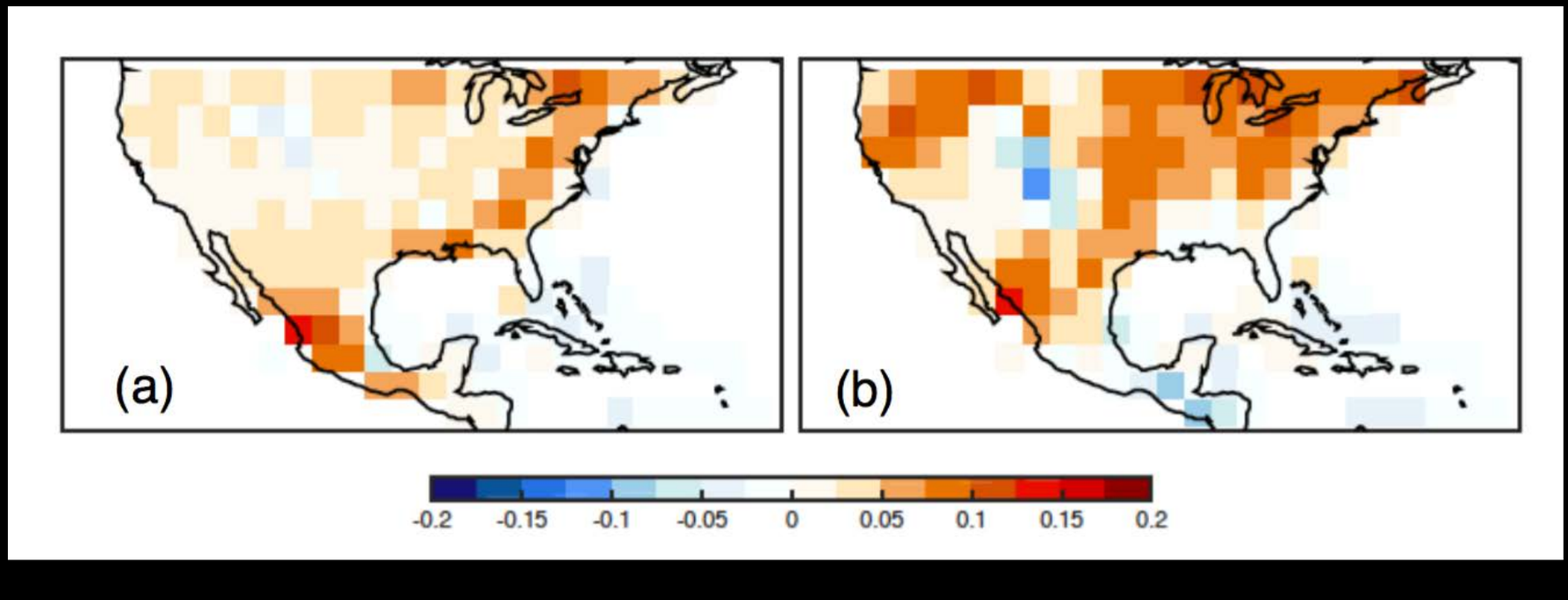
Superparameterization reduces the triggering feedback strength (TFS).

SP-CAM **CAM**

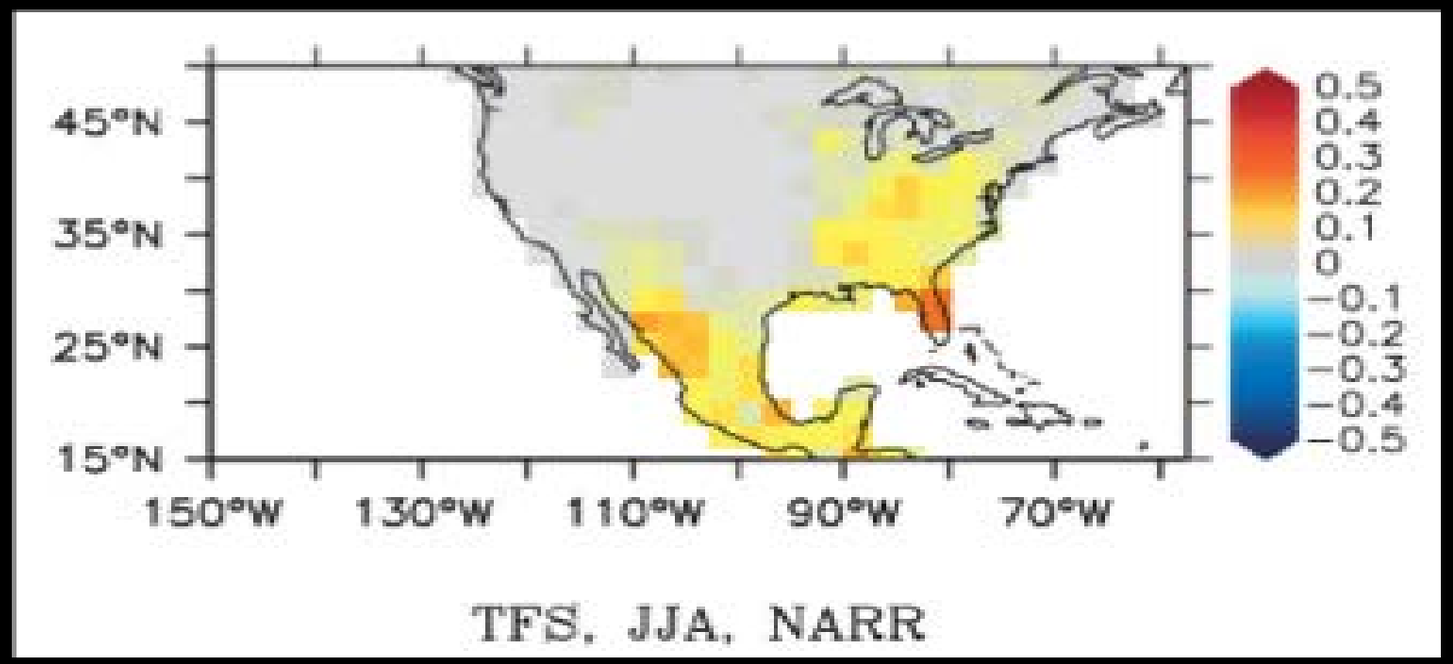


More realistic land-atmosphere triggering over US.

SP-CAM **CAM**



NARR Findell et al. 2011



Introducing:

“PBL Feedback Strength”

(Sun and Pritchard, in review)

Mean afternoon PBL height

$$PFS_{PBLH} = \sigma_{EF} \frac{PBLH}{\partial EF}$$

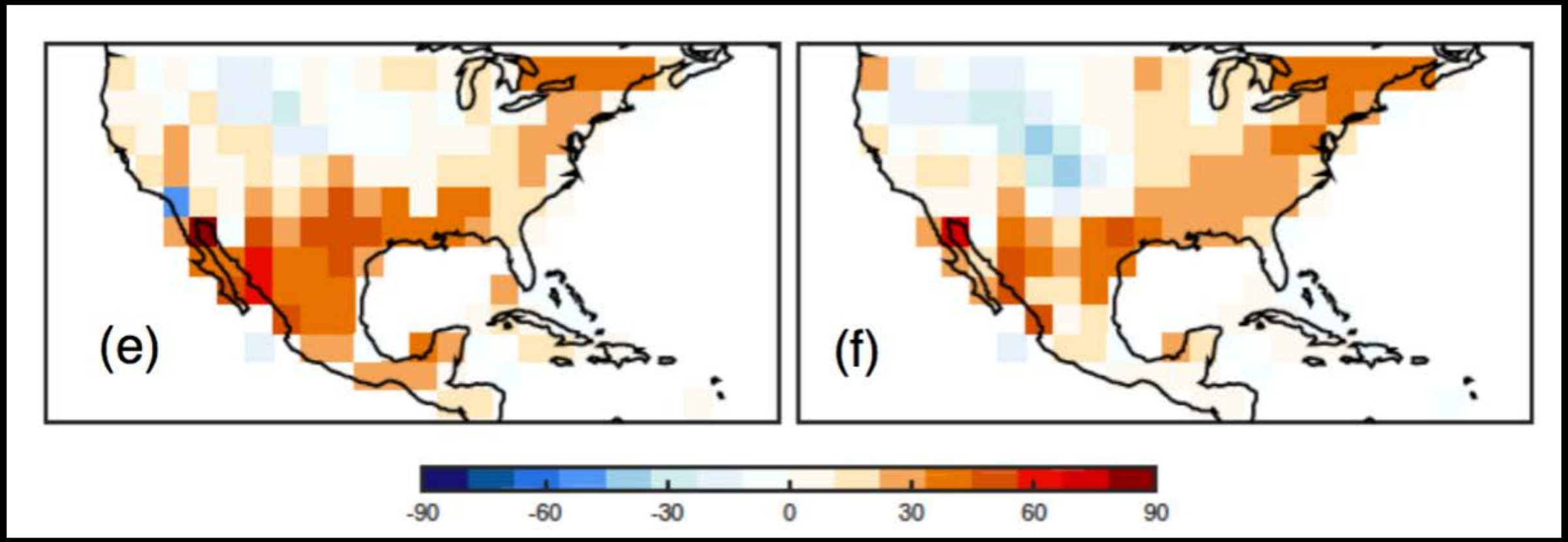
Evaporative Fraction variability

Morning evaporative fraction

PFS_{LCL}

SP-CAM

CAM



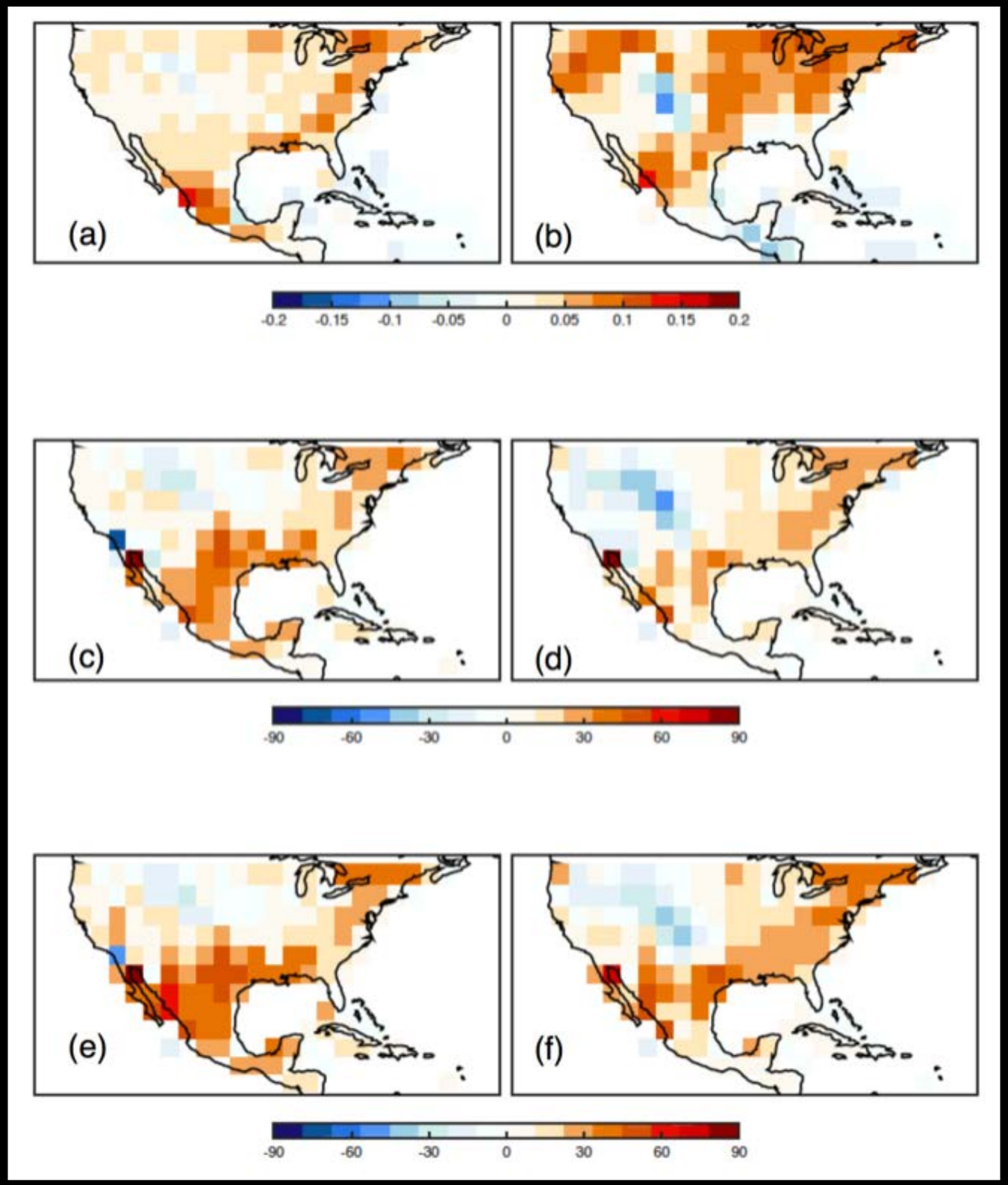
In CAM, a disconnect between convective triggering versus PBL sensitivity to morning evaporative fraction.

SP-CAM CAM

TFS

PFS_{PBLH}

PFS_{LCL}

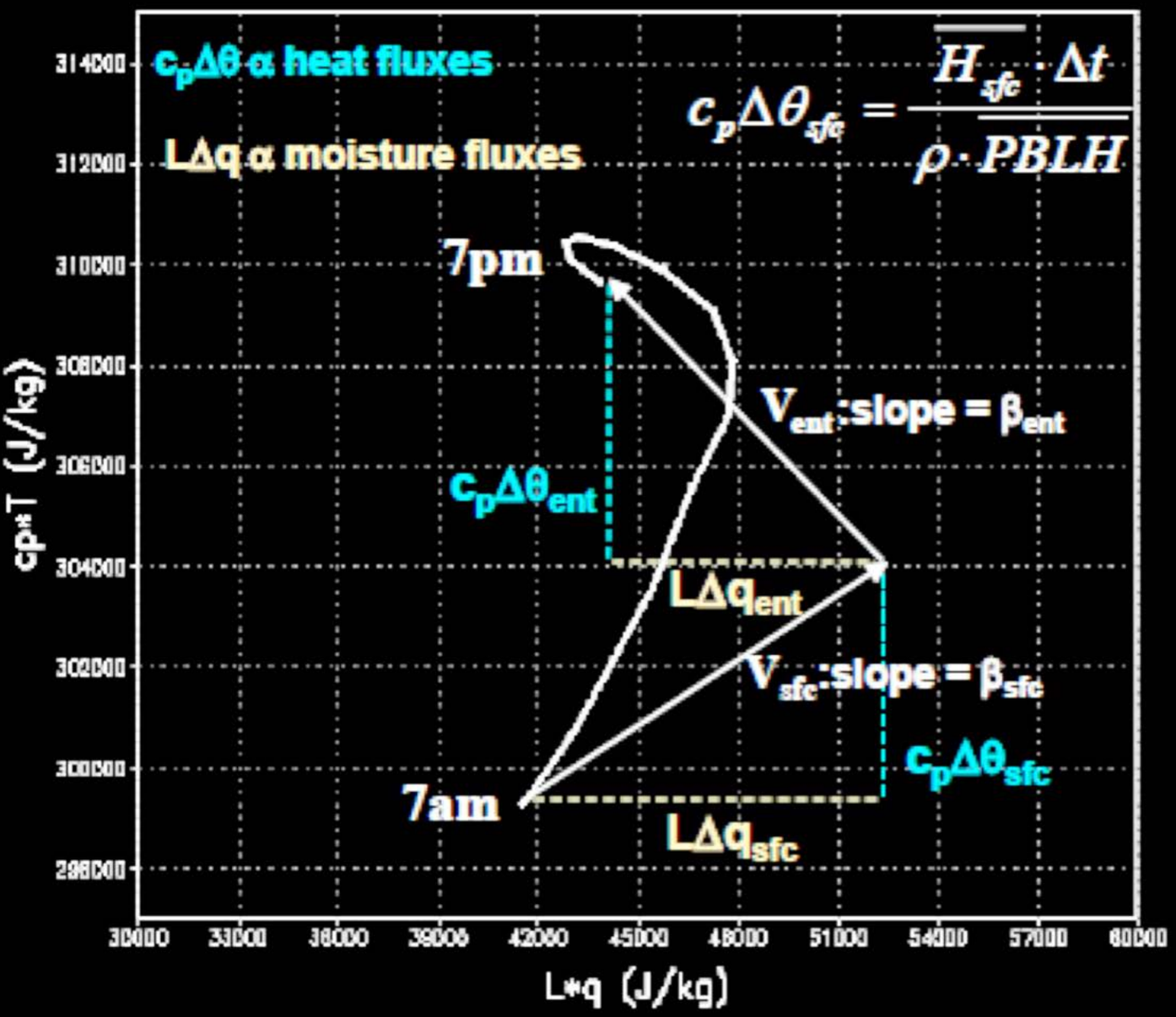


Part II.

An unintended effect of superparameterization at the land interface revealed by ARM data.

Pritchard et al, in prep

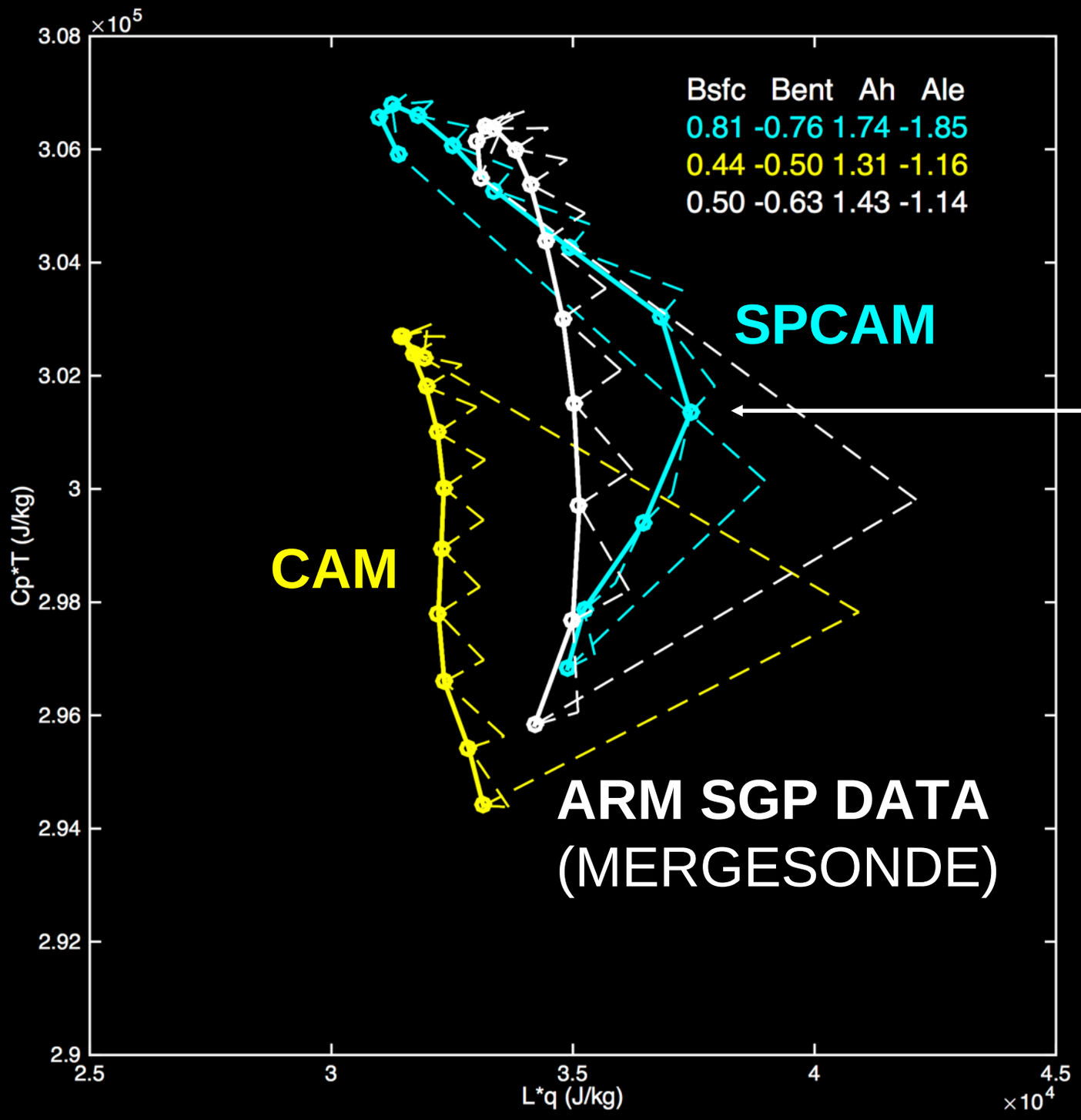
Bettsian mixing diagrams following the LoCo (“local coupling”) approach of Santanello et al.



- For a given time step, plot 2m T&Q in energy space;
- Surface vector can be calculated with PBL height, H_{sfc} and LE_{sfc};
- Residual vector then can be derived from the T-Q trajectory and surface vector, which represent the atmospheric response including entrainment, advection, etc.

Composite mixing diagrams for models versus ARM SGP.

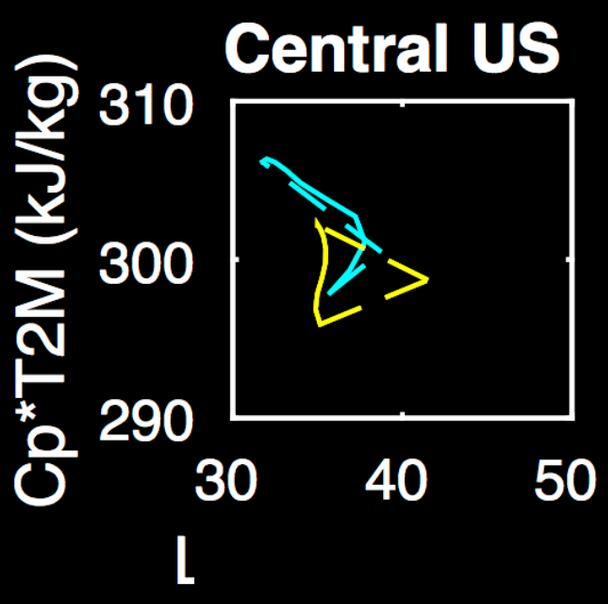
Climatological diurnal cycle from 15 independent realizations of JJA



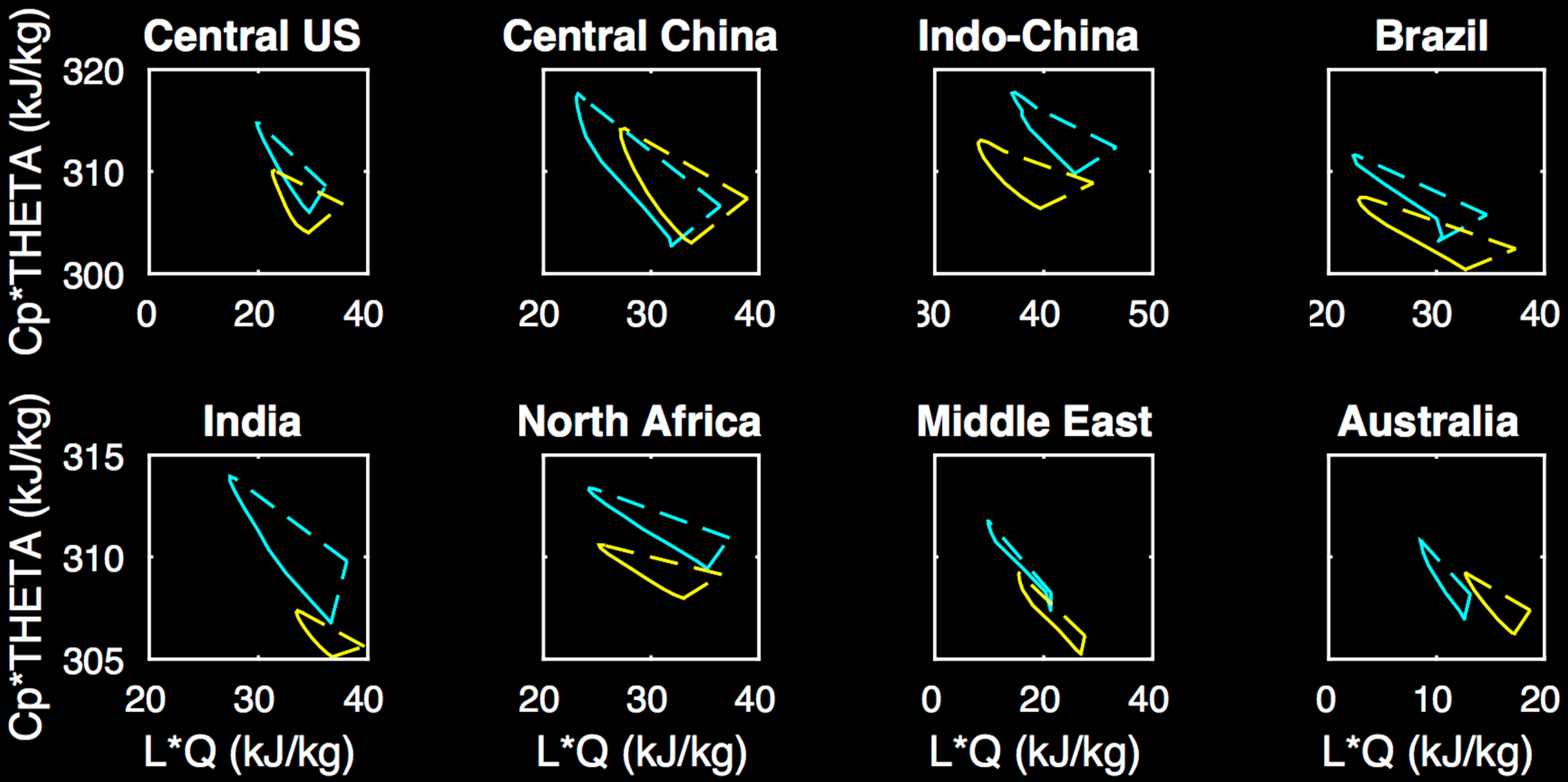
Spurious diurnal moisture cycle

The spurious 2-m moisture cycle is not unique to SGP.

SPCAM **CAM**



PBL-integrated energetics tell a different story than 2-m mixing diagrams, suggesting it is not a fundamental change in entrainment dynamics.



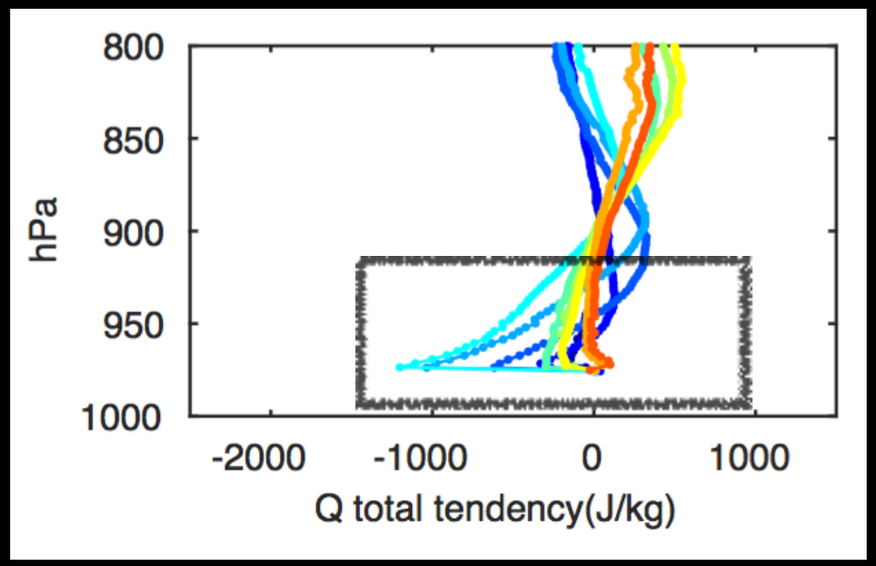
2-m state is not a robust proxy for whole-PBL model differences in LoCo mixing diagrams.

Implies problem is close to the surface.

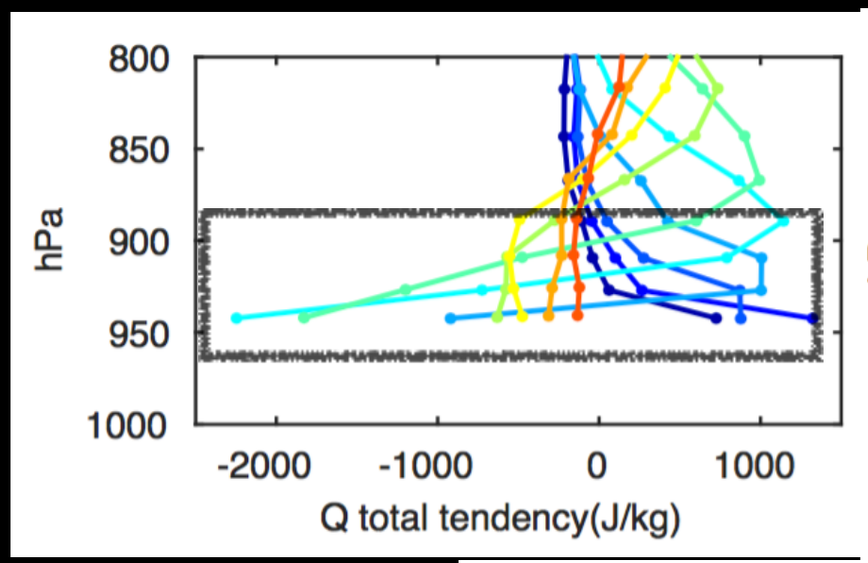
Vertically resolved humidity tendency vs. data highlights key **symptom**:

- Unobserved early morning surface moistening.
- Followed by strong late morning drying

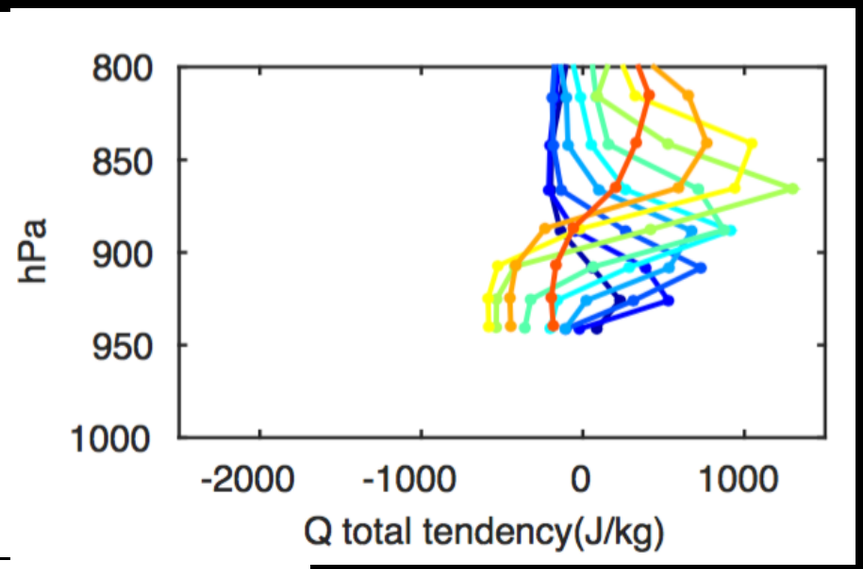
ARM SGP DATA

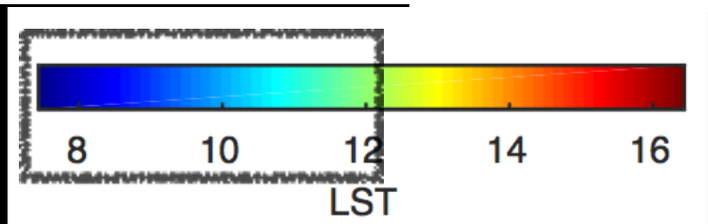


SP-CAM

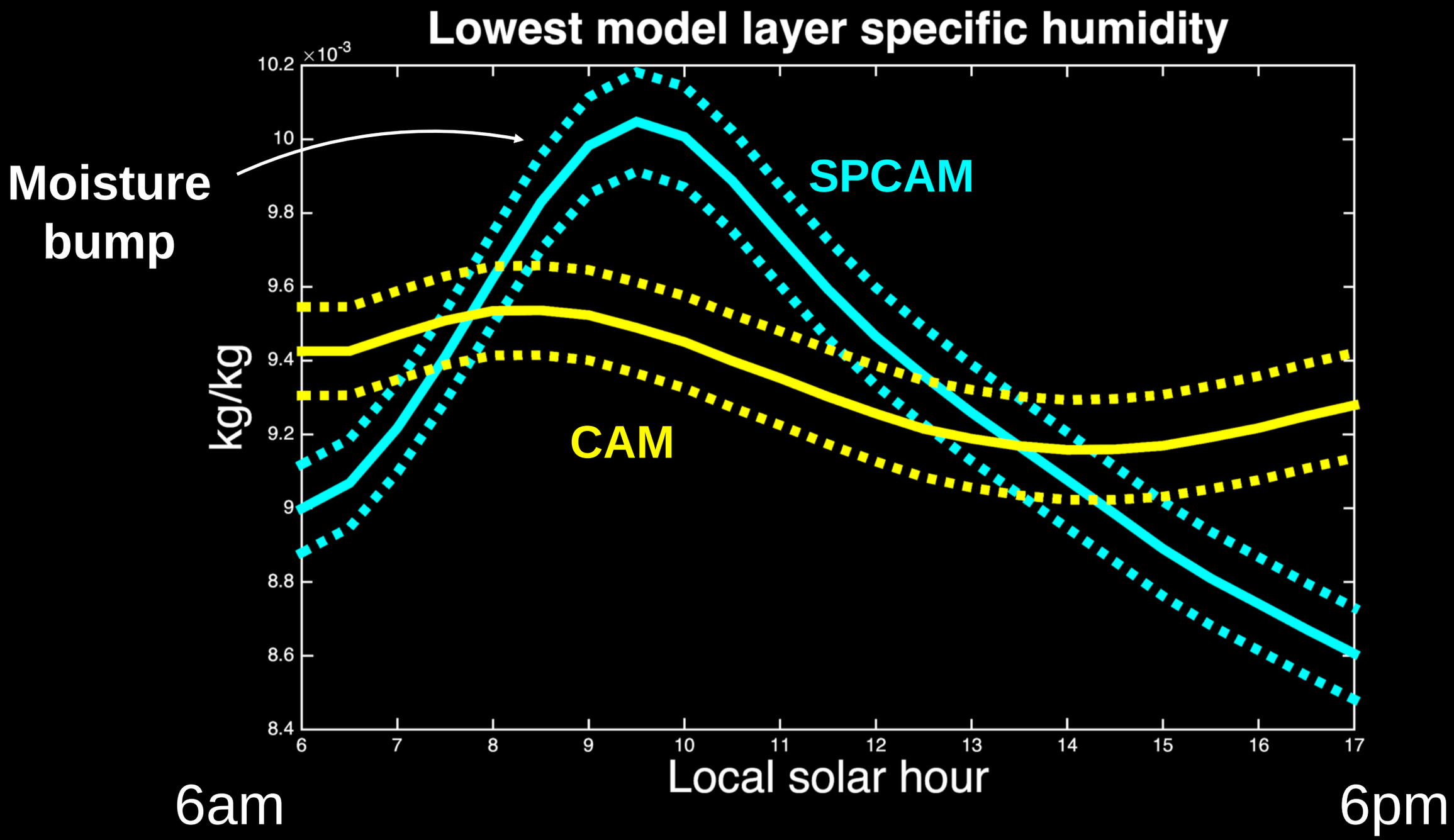


CAM





The essence of the bias can be reproduced in short hindcast simulations, which opens the door to understanding it.



(5-day 6/20/1997 hindcast, all land grid points 20S-60N)

What causes the spurious moisture bump?

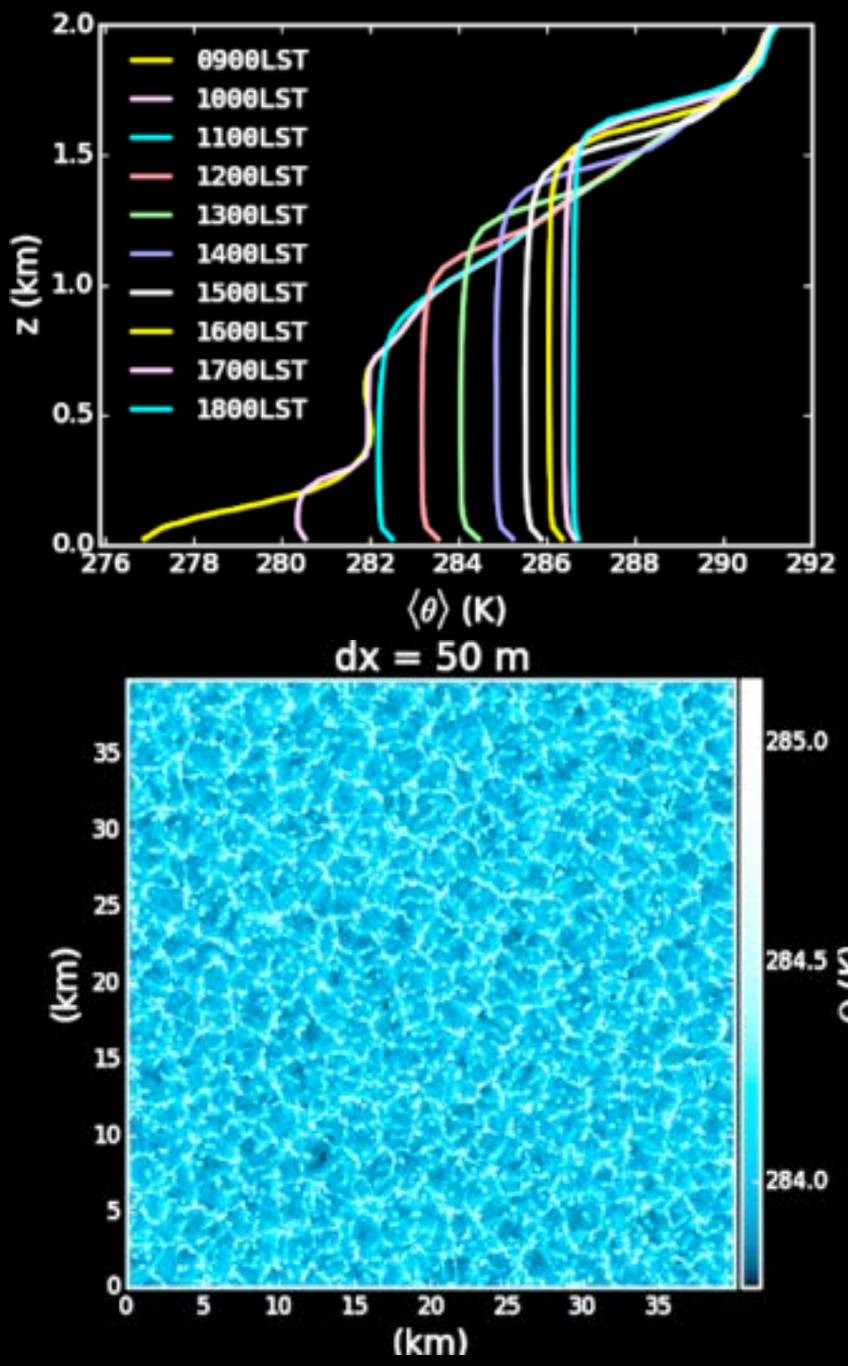
H1: Insufficient CRM resolution

Motivation:

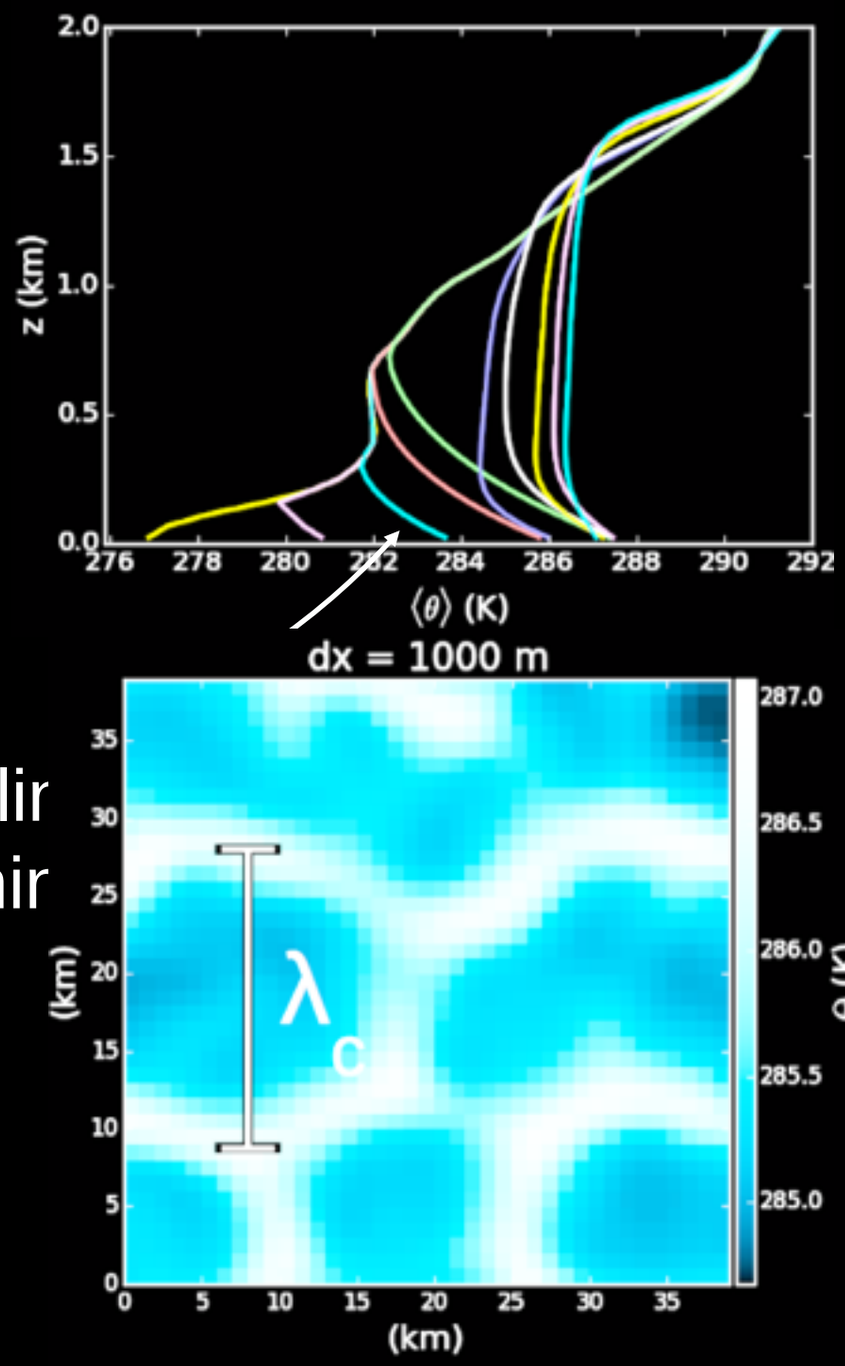
Known artifacts of coarse cloud resolving resolution.

WRF-LES convergence tests of continental PBL development a

LES (50-m dx)



CRM (1 km dx)



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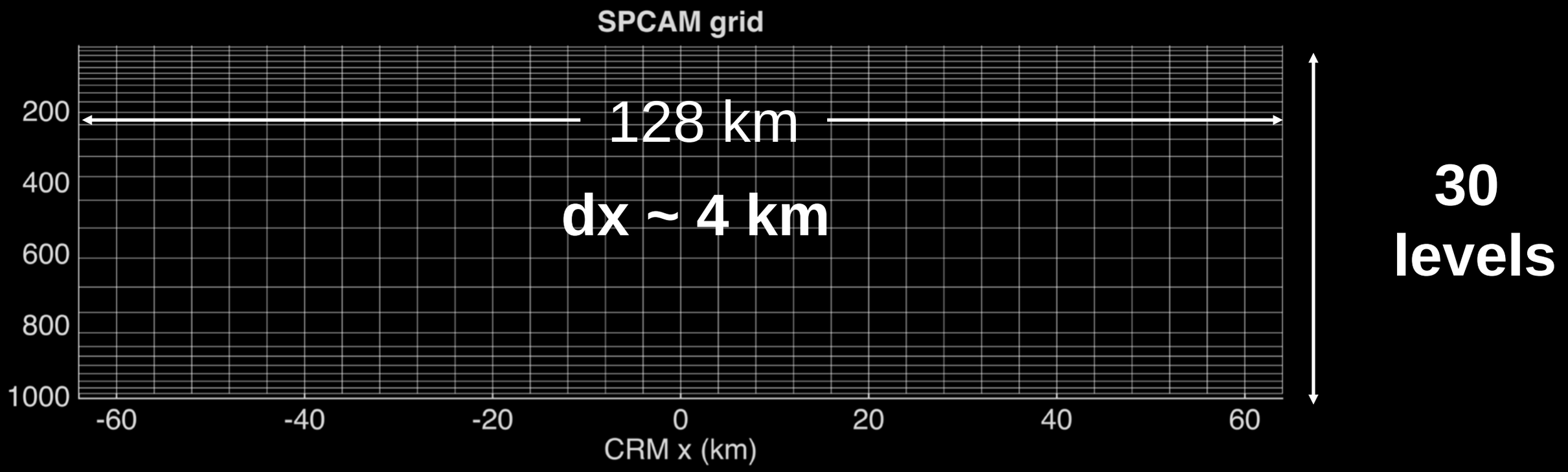
Figures from Jason Simon, Civil Engineering, Berkeley — AGU 2015 poster.

What causes the spurious moisture bump?

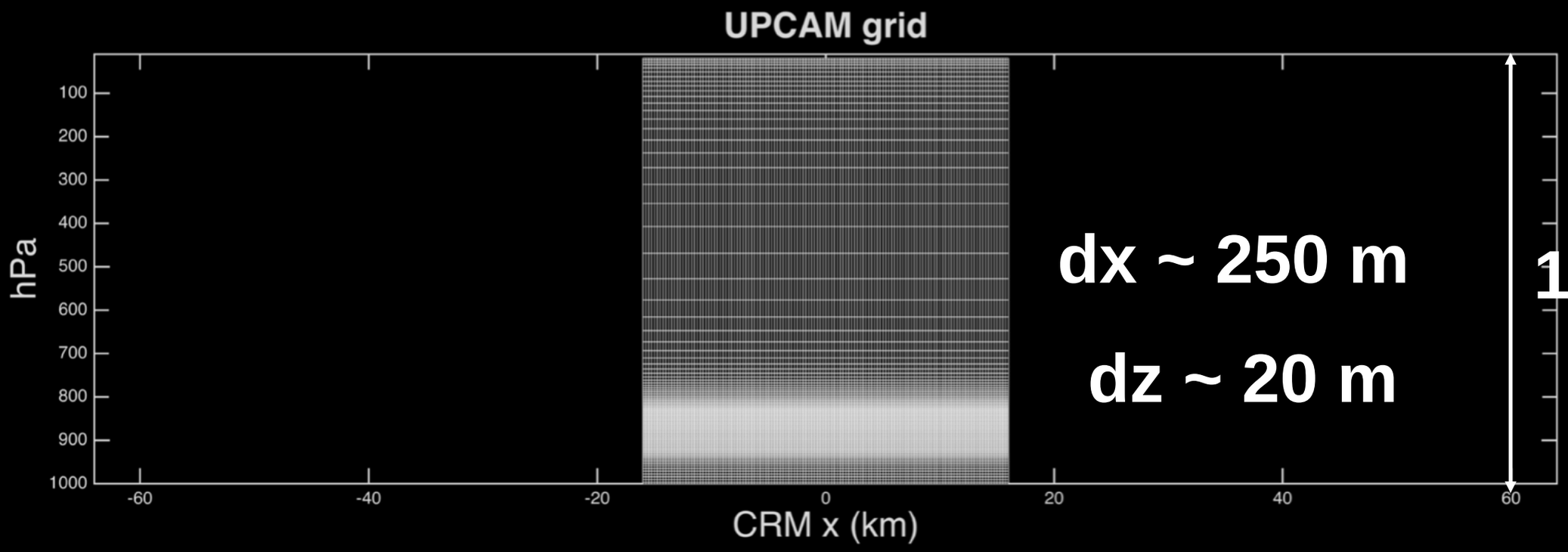
H1: Insufficient CRM resolution

Expect: Radically higher CRM resolution removes the bump.

Standard superparameterization grid structure

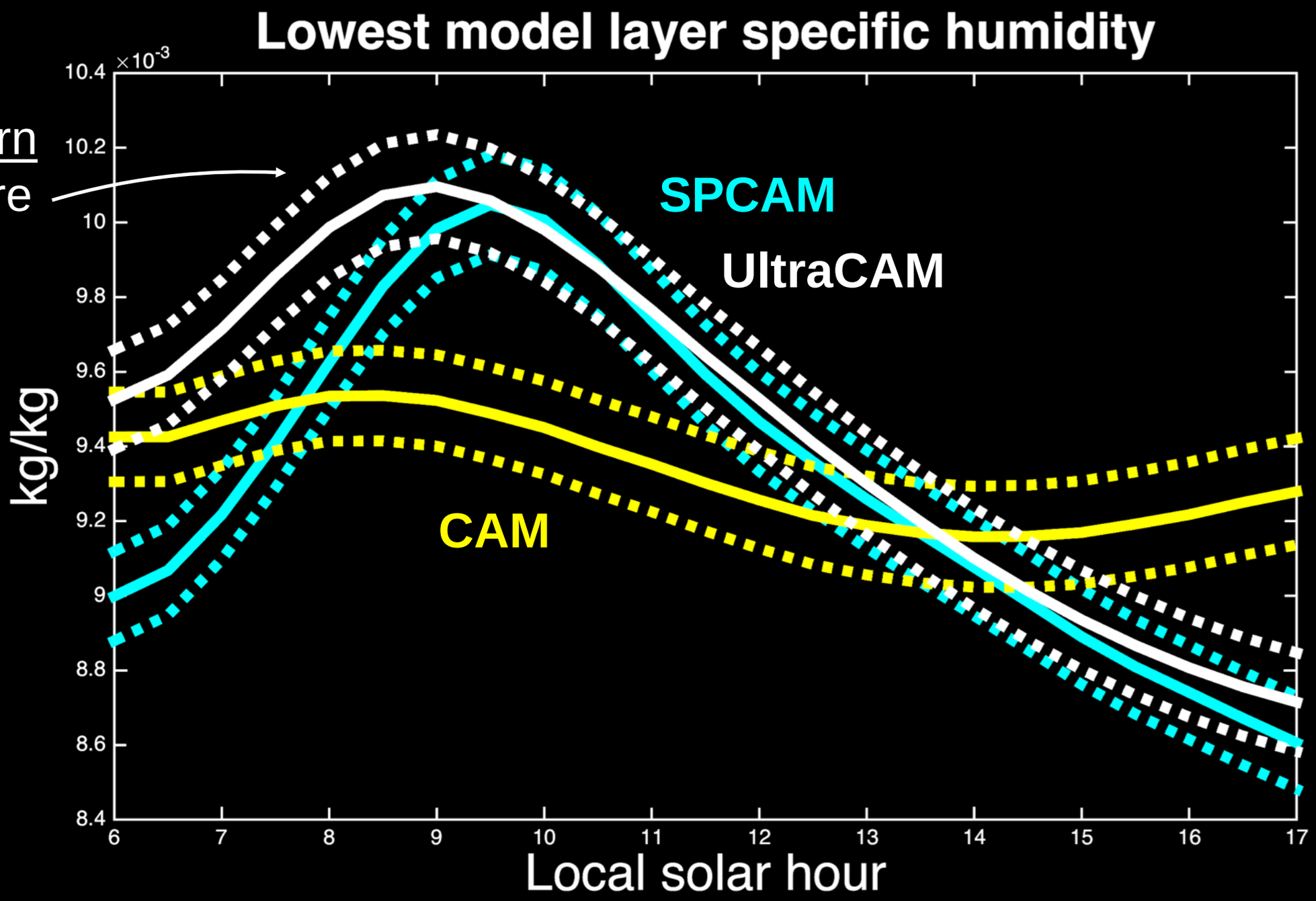


“Ultraparameterization”



(Now affordable for 5-day hindcasts)

Insensitivity to cloud-resolving resolution.

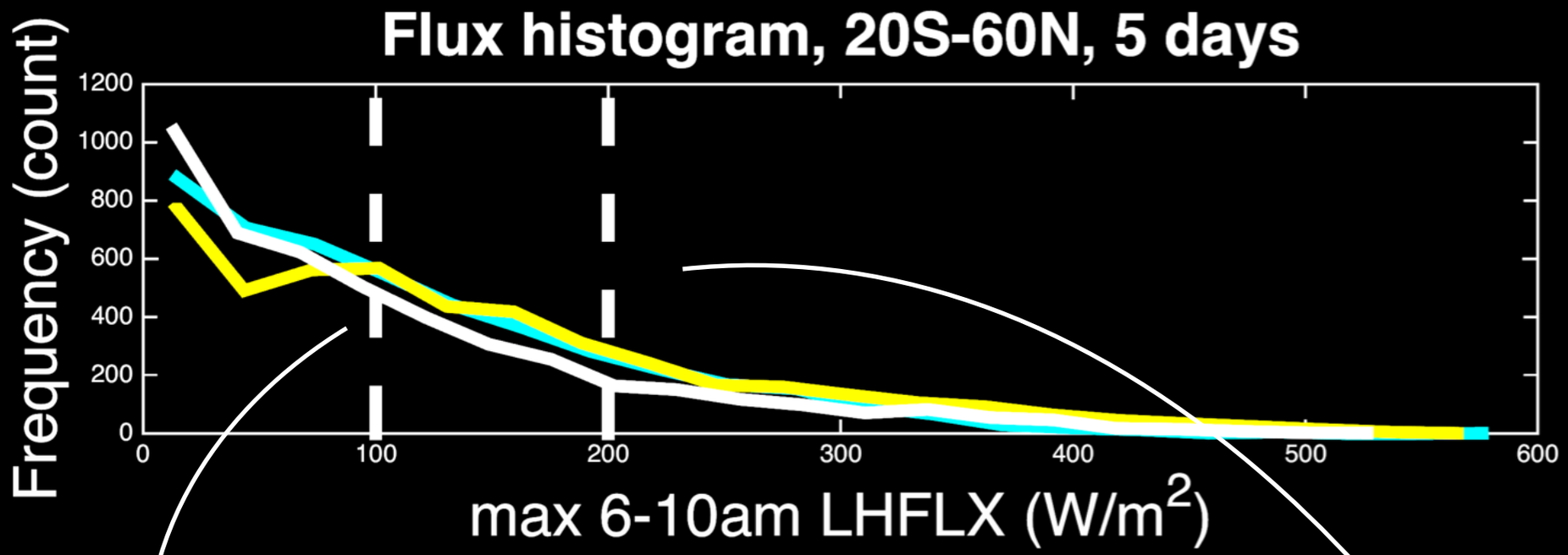


What causes the spurious moisture bump?

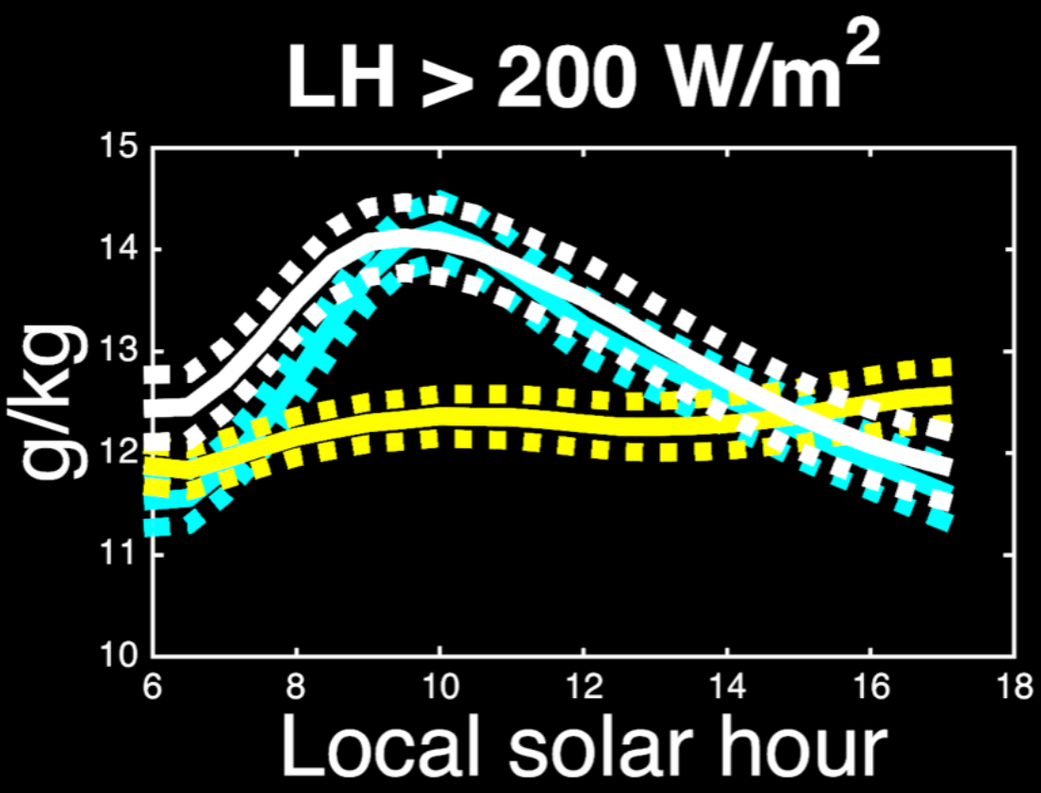
H1: Insufficient CRM resolution

X

Clue: bump is associated with surface flux magnitude.



Reduced bump



What causes the spurious moisture bump?

H1: Insufficient CRM resolution

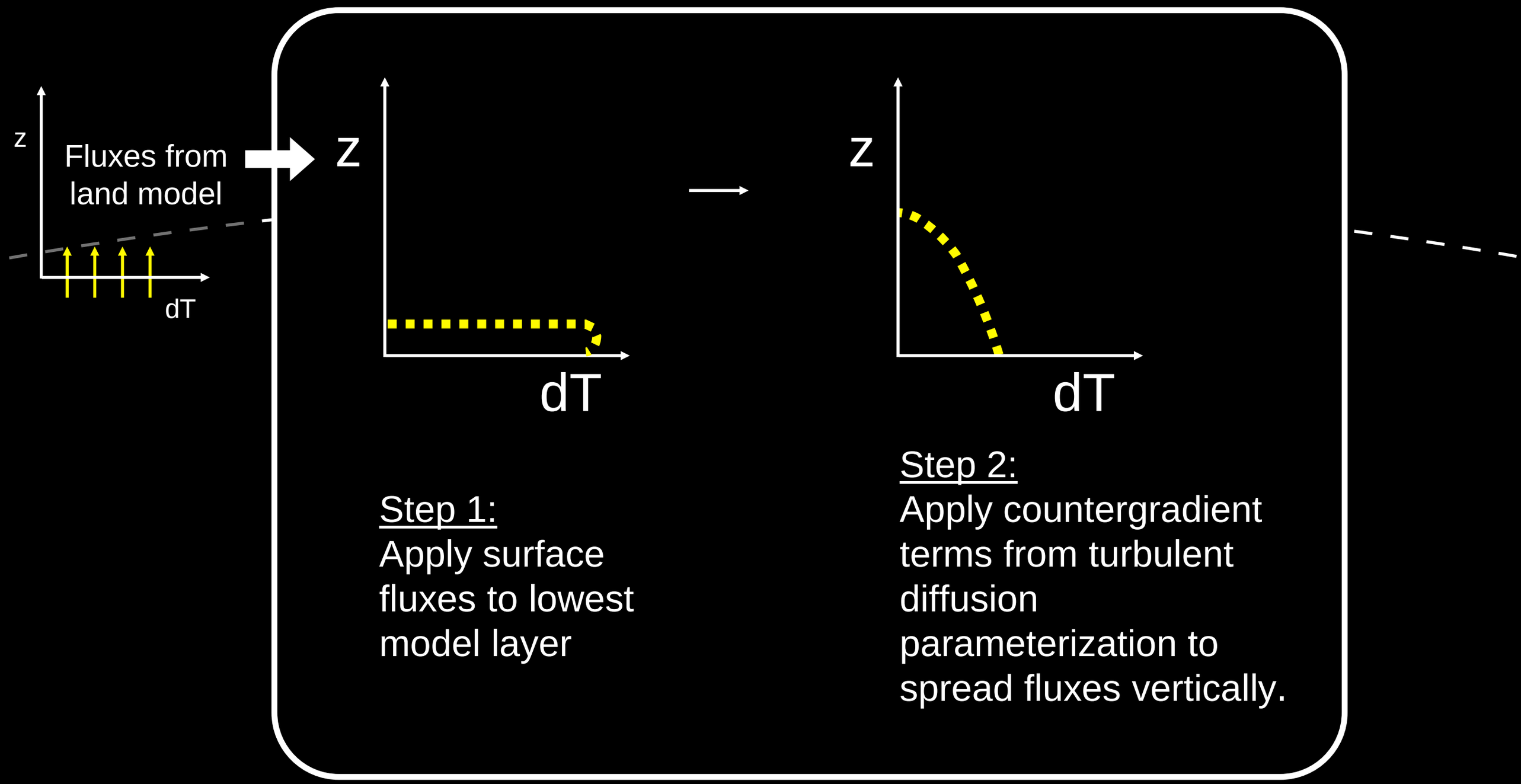
X

Sensitive to surface flux screening

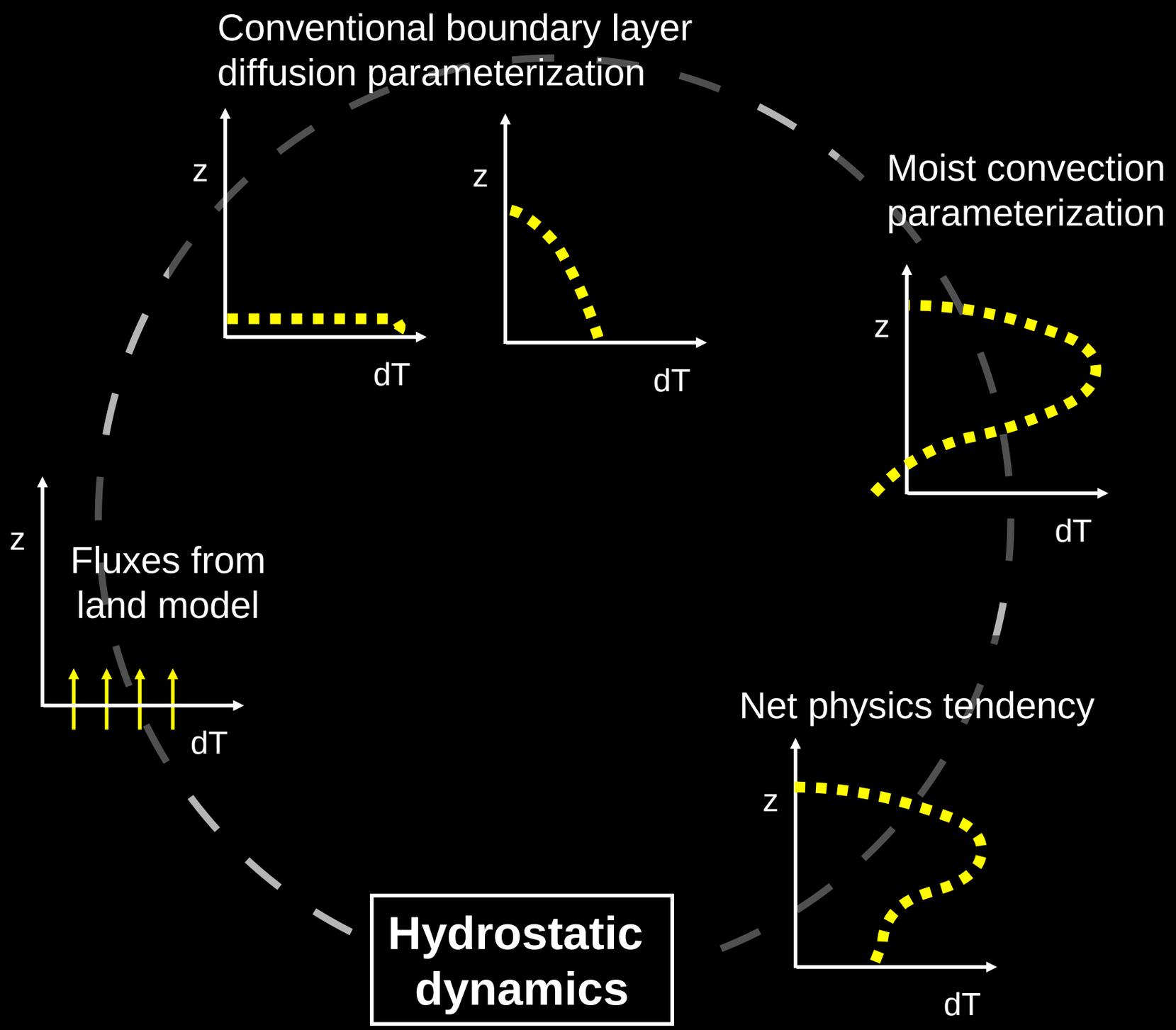
H2: Something is wrong with the way surface fluxes are transmitted to the CRM

Context.

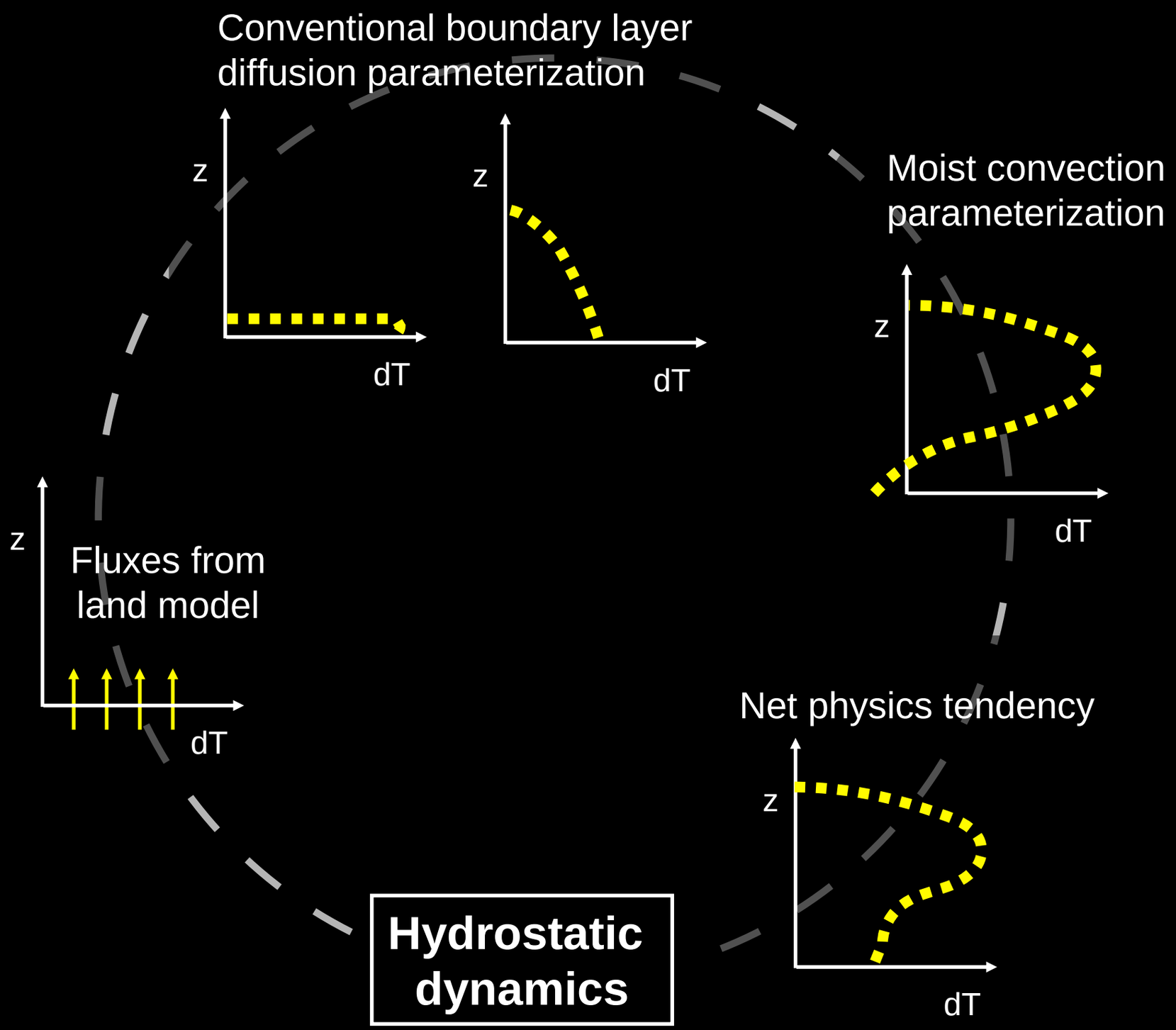
Standard CAM boundary layer parameterization:



In the context of the greater integration circuit.



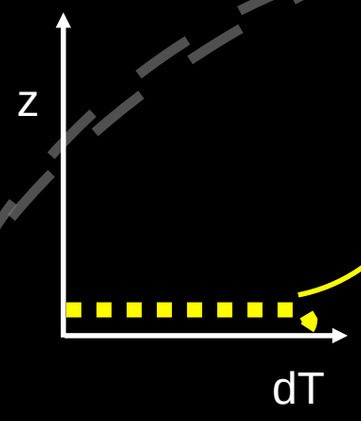
In the context of the greater integration circuit.

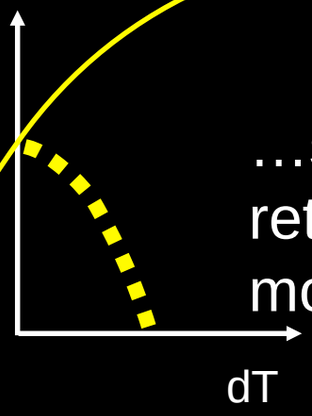


When superparameterization is used…

… cloud resolving models replace PBL and moist convection parameterizations.

Conventional boundary layer diffusion parameterization

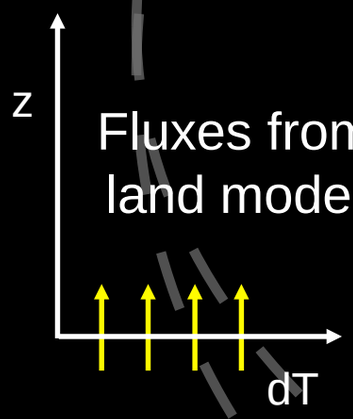


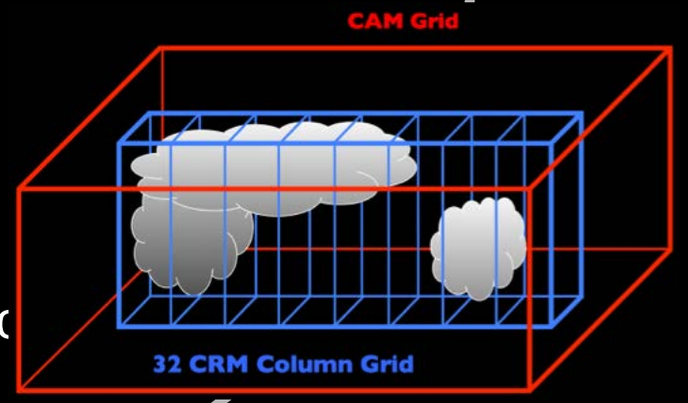


Moist convection parameterization

…surface fluxes felt by GRM via. retained initial perturbation on lowest model layer in BL scheme.

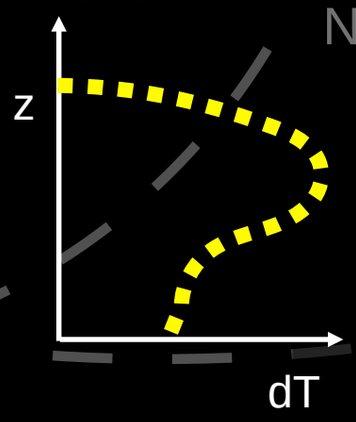
This would be fine **except that**…



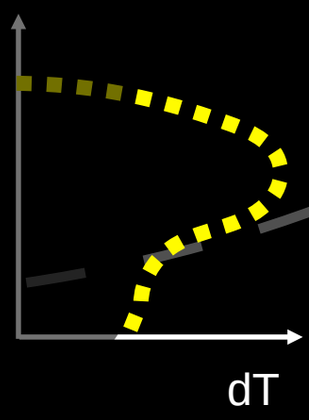


Hydrostatic dynamics

Net physics tendency



Net physics tendenc

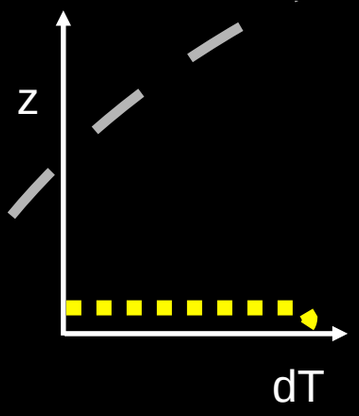


Problem: Dynamics is called in between PBL and superparameterization in SPCAM.

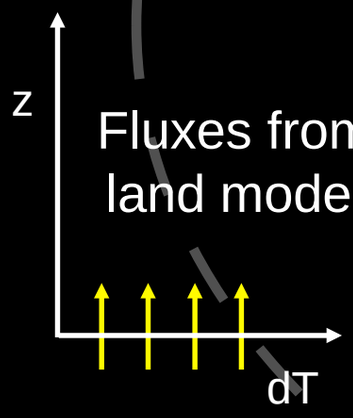
Consistent with a near-surface **symptom**

output

Conventional boundary layer diffusion parameterization

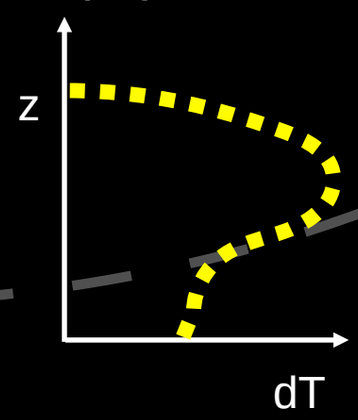


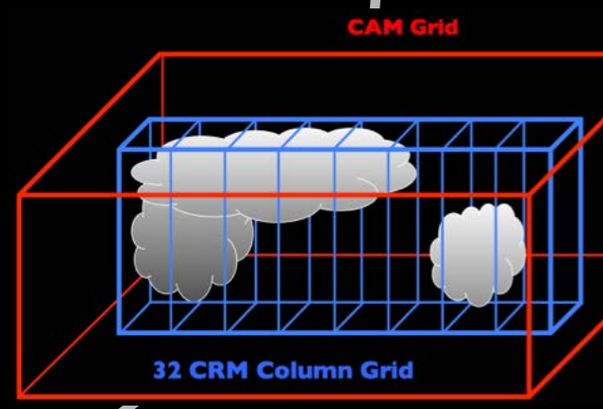
Underlying problem: Hydrostatic dycore feels undesirable tendency.



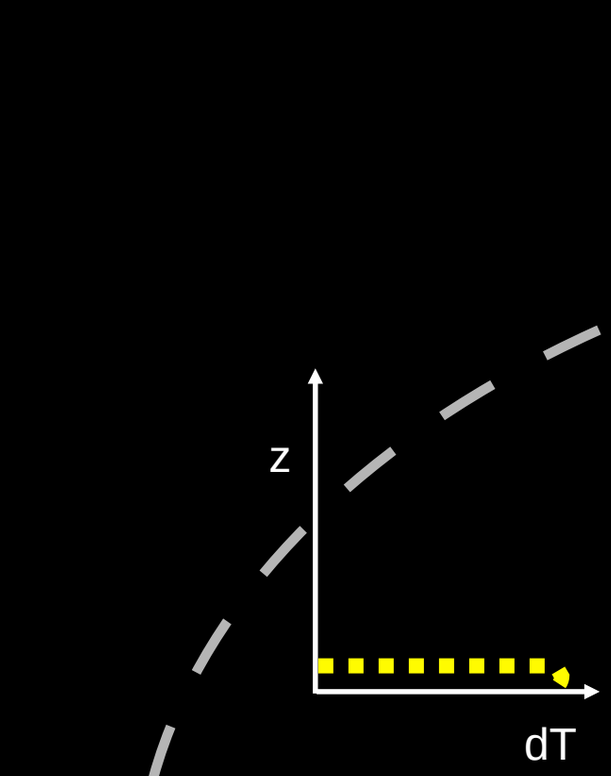
Hydrostatic dynamics

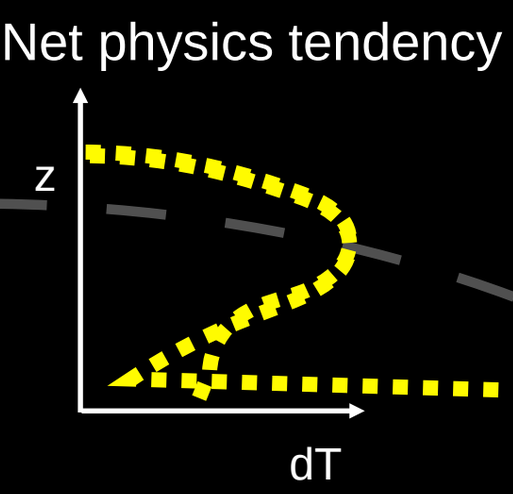
Net physics tendency





Potential fix: Wait to apply surface fluxes.



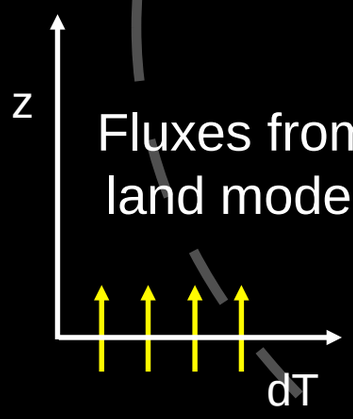


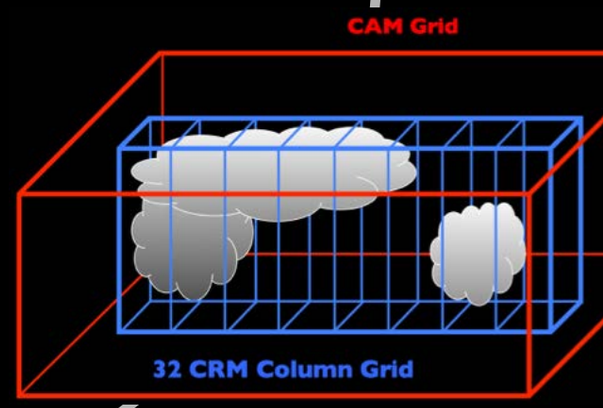
The spurious bump disappears

expect

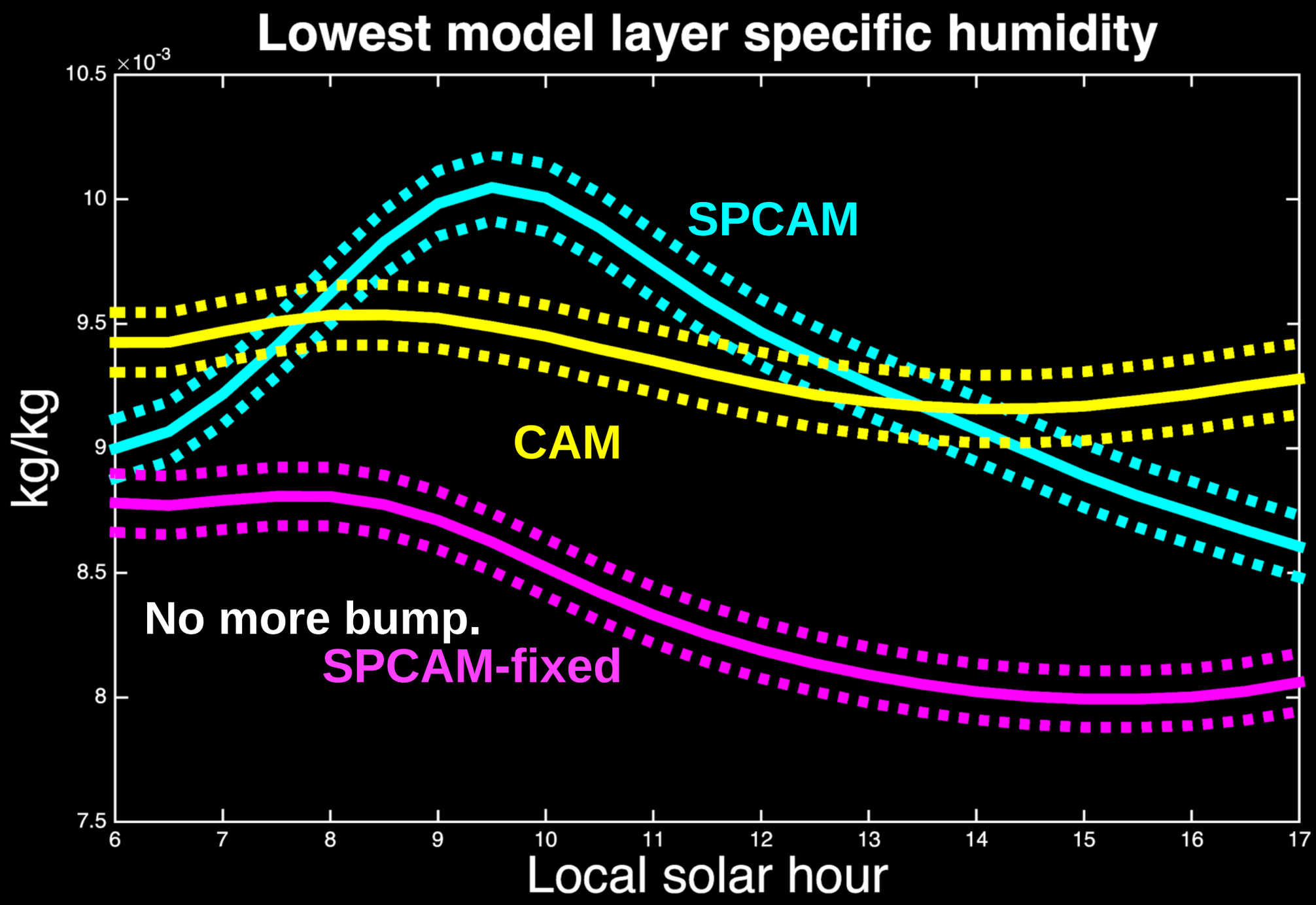
Ensures dycore receives a complete physics tendency

Hydrostatic dynamics





Consistent with expectation, bump disappears.



What causes the spurious moisture bump?

H1: Insufficient CRM resolution

✗

H2: Something is wrong with the way surface fluxes are transmitted to the CRM

✓

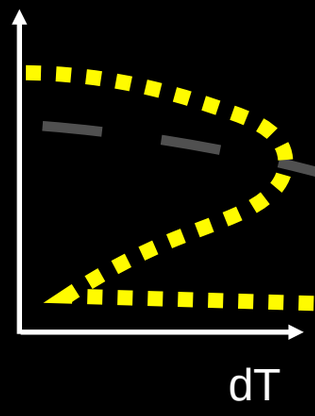
Unintended order of flux / dynamic adjustment operations found

✓

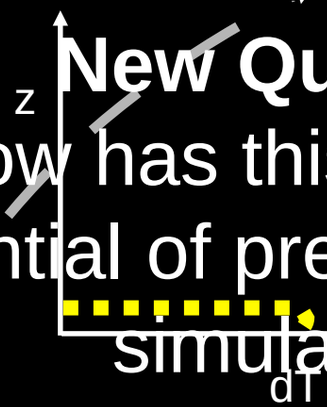
Correcting it removes the moisture bump symptom

✓

Net physics tendency



Conventional boundary layer diffusion parameterization



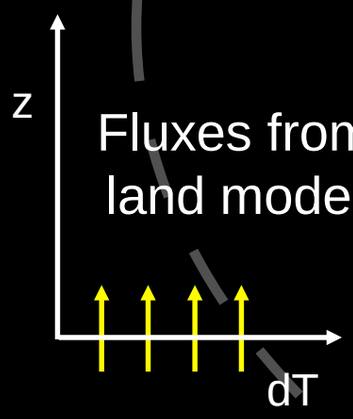
New Question:

How has this limited the potential of previous SPCAM simulations?

Underlying problem in SPCAM:
Hydrostatic dycore feels undesirable tendency

Hydrostatic dynamics

How does correcting the problem impact

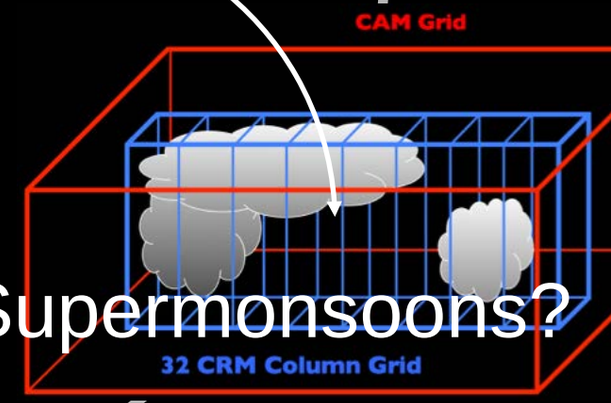


Fluxes from land model

The daily cycle of rainfall?

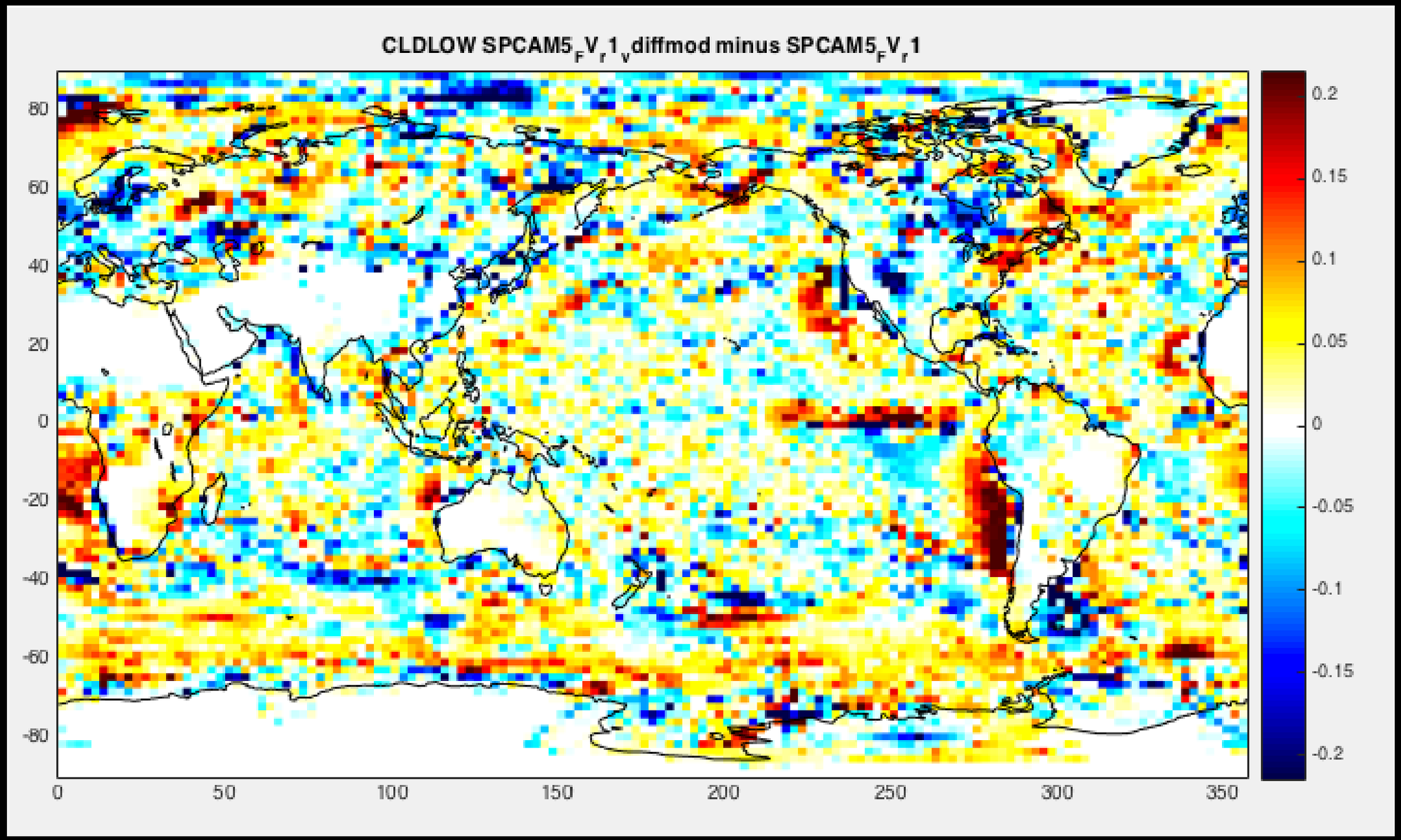
The MJO?

The Great Red Spot?



Supermonsoons?

Promising changes in coastal low cloud fraction



Stay tuned!

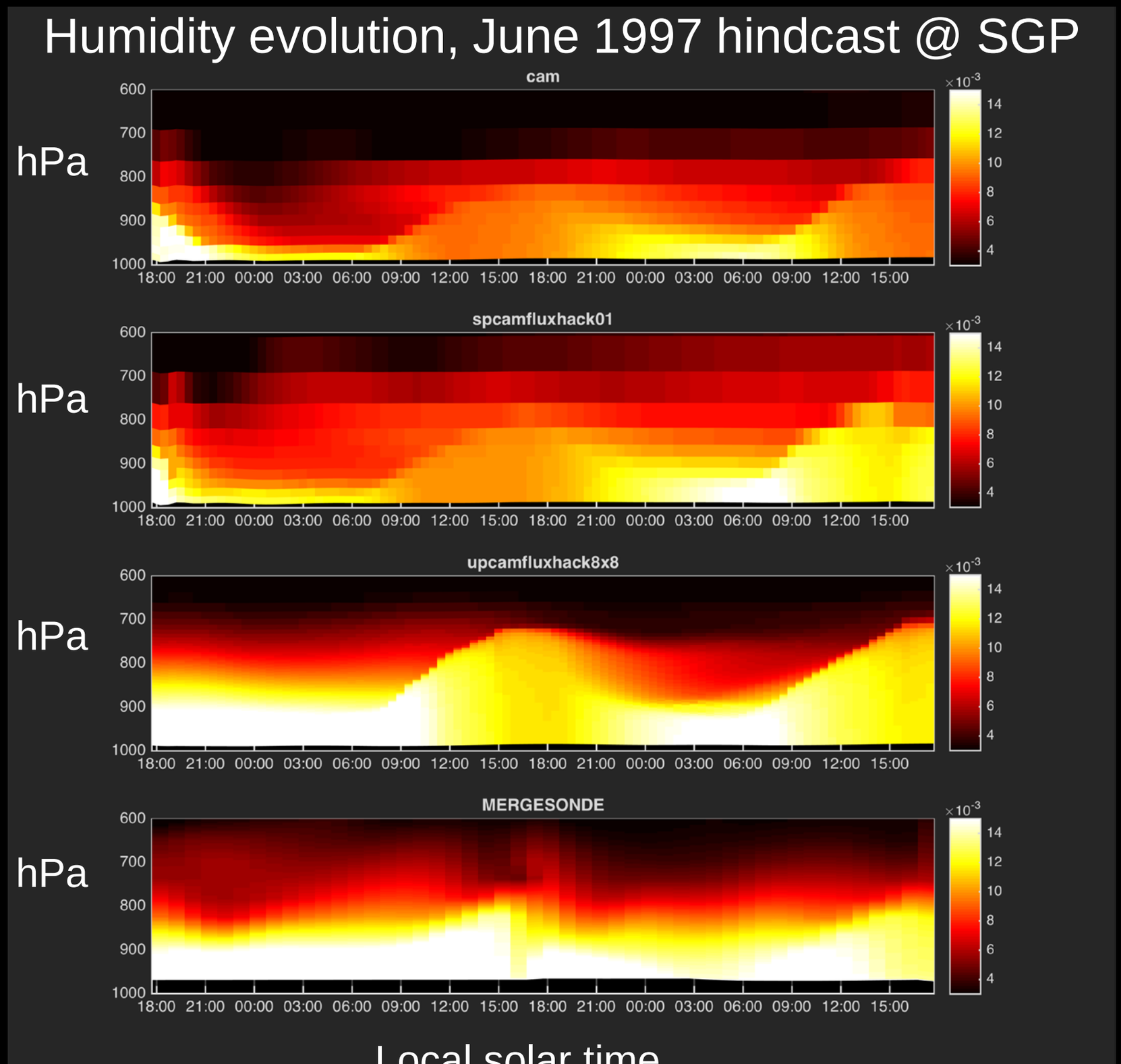
Meanwhile, ARM data & CAPT hindcasts point to value of vertical resolution and issues of chronic daytime overentrainment.

CAM

SPCAM 8x1

UltraCAM 8x8
(*hi-res helps*)

MERGESONDE DATA



Summary.

Favorable effects of super parameterization on land-atmosphere coupling.

- **Terrestrial segment:**
  - Reduced N. African, Middle-East positive JJA coupling; enhanced cross-ITCZ contrast; enhanced E. China JJA negative coupling; enhanced DJF rainforest negative coupling.
- **Atmospheric segment:**
  - Probability of afternoon rainfall less sensitive to surface state in inappropriate regions.
  - Synchrony emerges across rainfall triggering, PBL height and LCL sensitivities to surface wetness.

ARM data is proving quite useful for improving superparameterized climate models.

- Mixing diagram analysis at the SGP site turned up a spurious near-surface moisture cycle in SPCAM.
- Symptom of underlying issue in how surface fluxes are transmitted to its cloud resolving models.
- Inadvertently exposes the dynamical core to an incompletely adjusted subgrid physics tendency.
- This may have limited the potential of all previous SPCAM simulations.

Thanks.