Two Perspectives on Amplified Warming over Tropical Land

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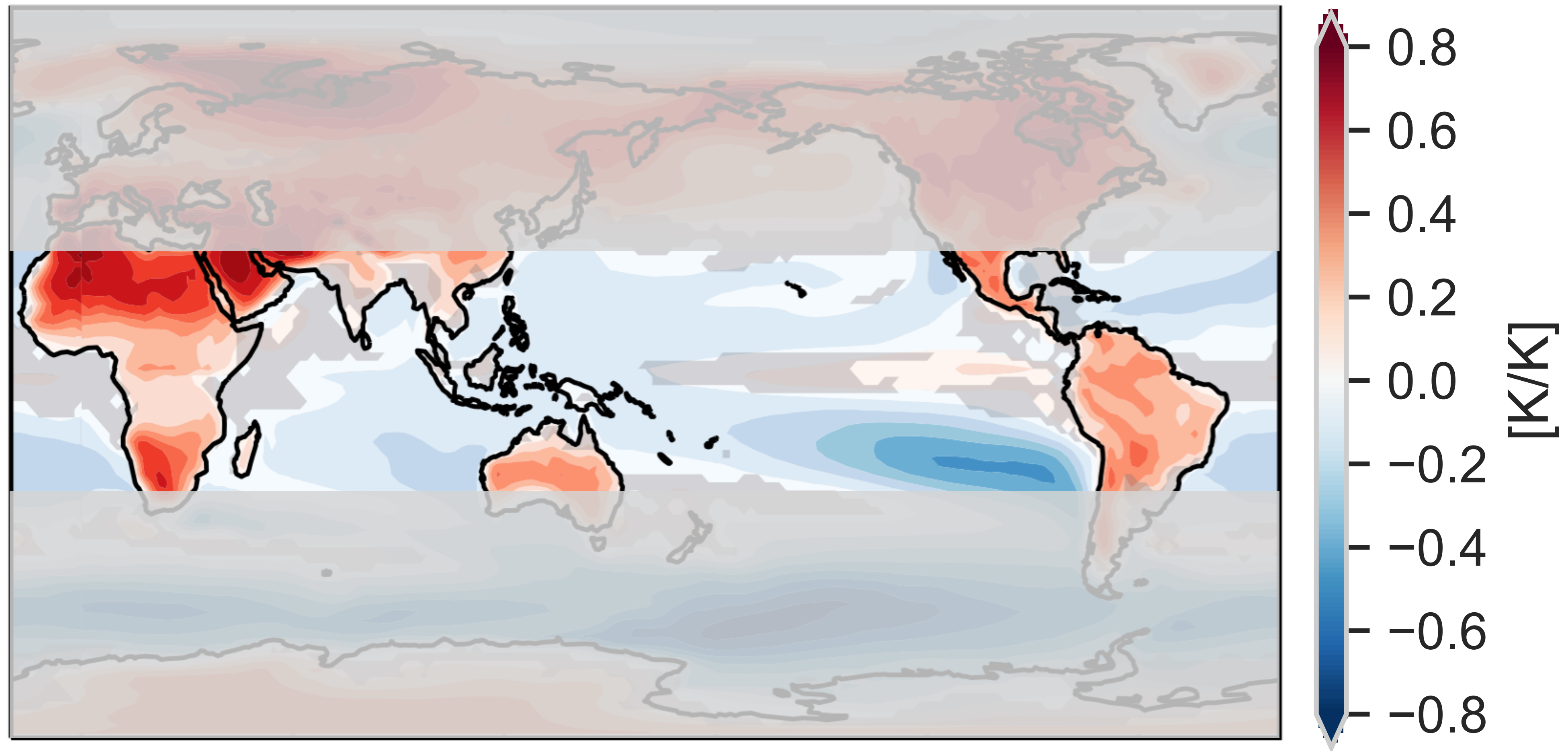
What is amplified warming over tropical land?

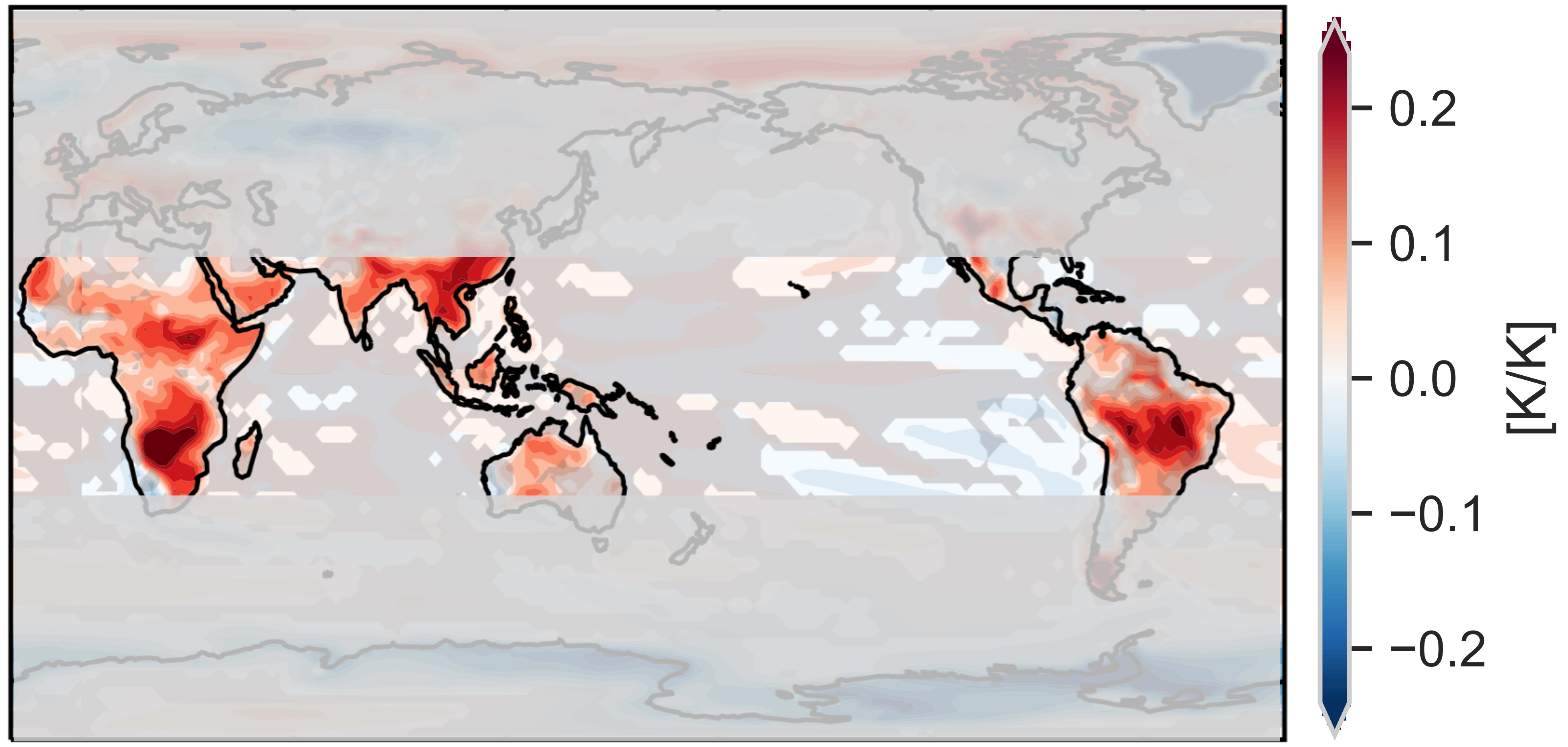
Summer mean warming (relative to global mean)



Land warms more than ocean;
Dry land warms more than moist land.

(Joshi et al., 2008, 2013; Bryne & O'Gorman et al., 2013, 2018…)

Hot tail warming (relative to local mean)



Extreme hot days warm more than the average days.

(Fischer et al., 2007, Seneviratne et al., 2013; Berg et al., 2014; Donat et al., 2017; Vogel et al., 2017; Duan et al., 2020; Dirmeyer et al., 2021…)

Duan et al., *GRL, 2020*

Explanation 1: atmospheric dynamics perspective

$$\Delta \text{MSE} \quad = \quad c_p \Delta T \quad + \quad L_v \Delta q$$

The "QE—WTG" framework

(1) Weak temperature gradient (WTG) + Quasi-equilibrium (QE)

$$\Delta \text{MSE}^L = \Delta \text{MSE}^O$$

(2) Moisture constraint

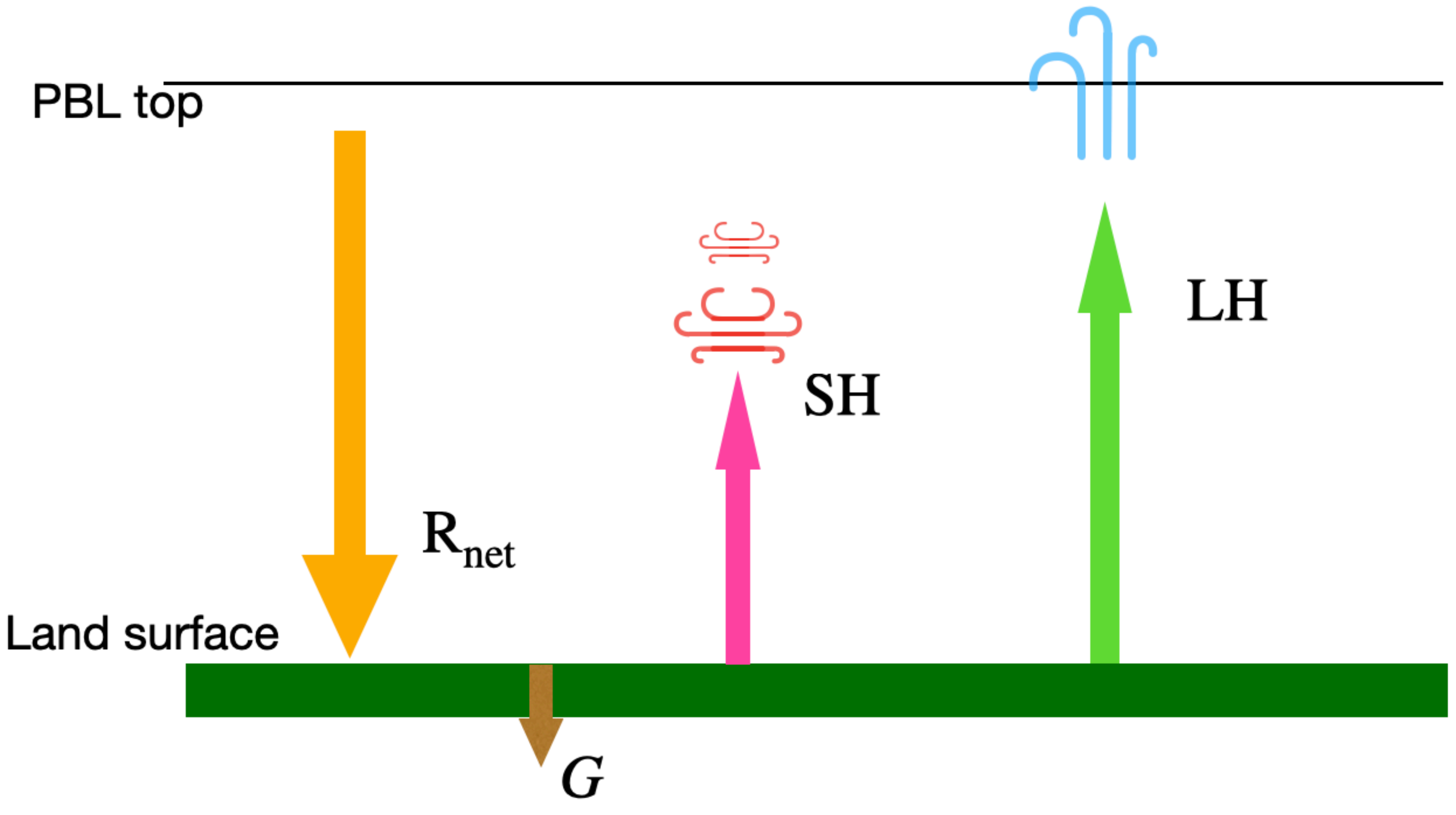
$$\Delta q^L = \gamma \Delta q^O$$

$$\Delta q^L < \Delta q^O, \text{therefore } \Delta T^L > \Delta T^O$$

(Bryne & O'Gorman, 2013, 2018; Bryne, 2021)

Explanation 2: surface flux perspective

$$\Delta R_n \approx \Delta \mathrm{SH} + \Delta \mathrm{LH}$$

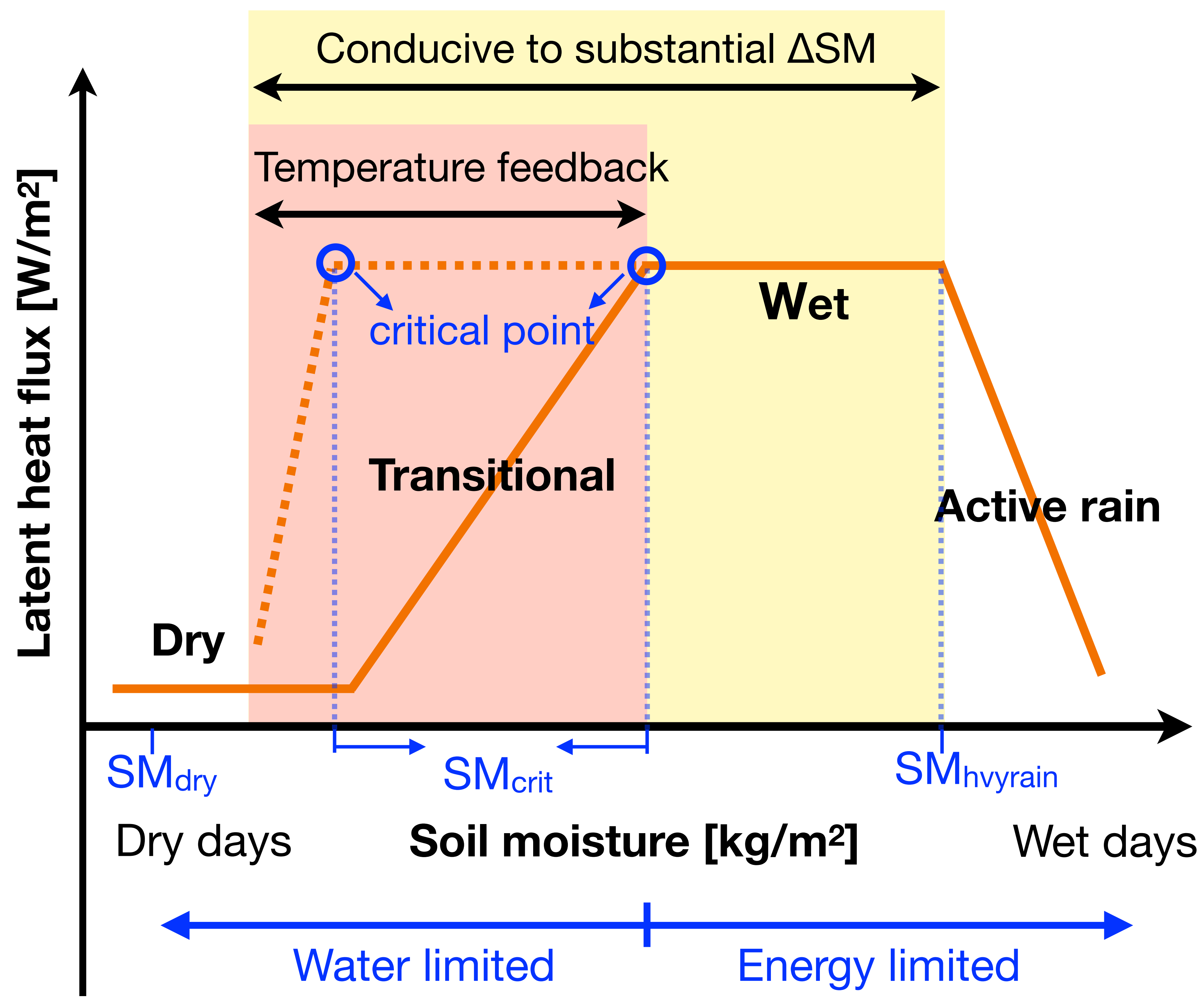


Soil dries/plants' physiology changes (stomata close),
LH decreases,
"surface flux partitions towards SH",
warming is amplified.

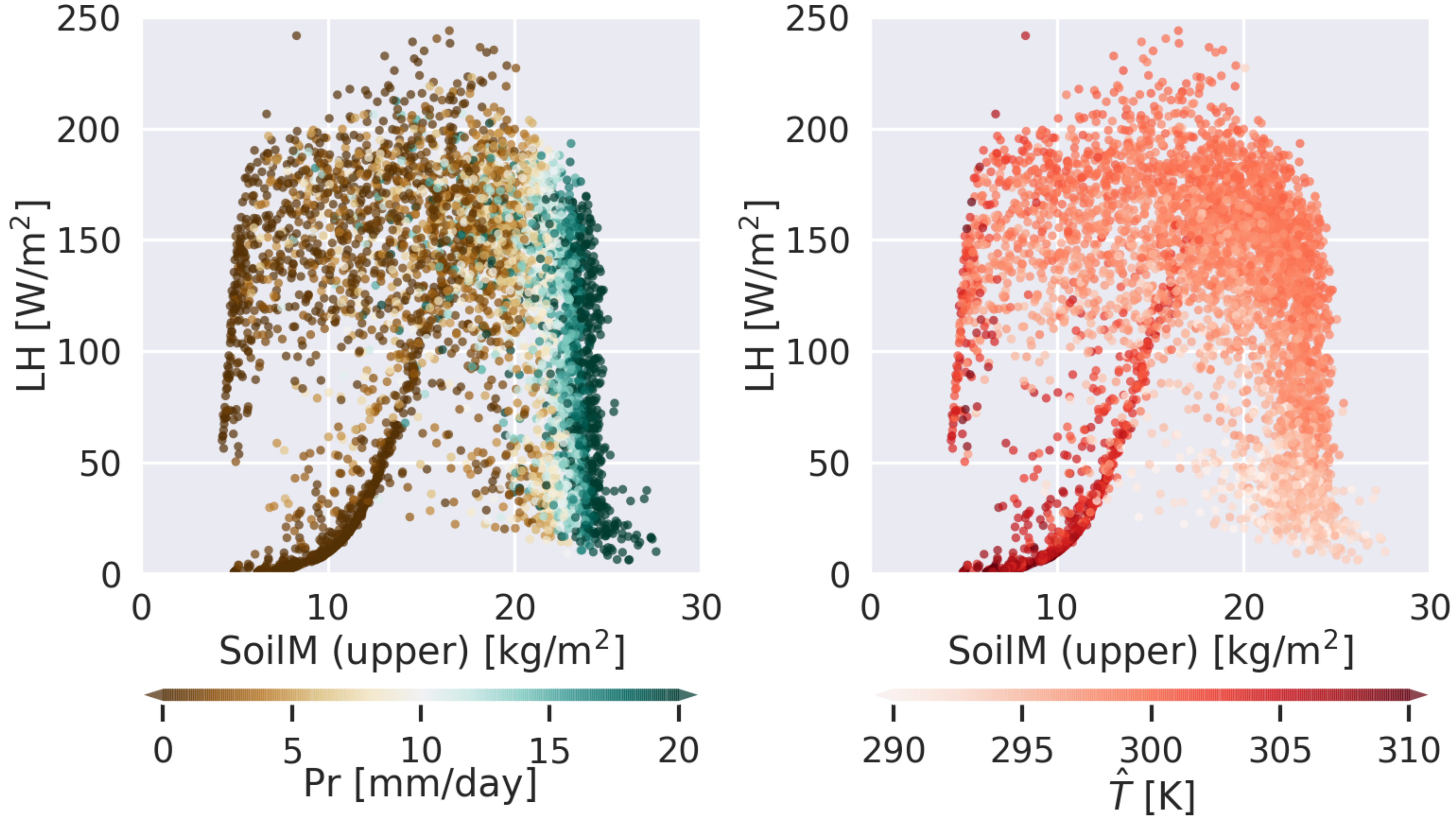
(Fischer et al., 2007, Seneviratne et al., 2013; Berg et al., 2014; Donat et al., 2017; Vogel et al., 2017; Duan et al., 2020; Dirmeyer et al., 2021…)

Temporal variability over land is complicated: SM limited; ET—SM is nonlinear

LH—SM relationship at a given location



An example grid cell in southern Africa

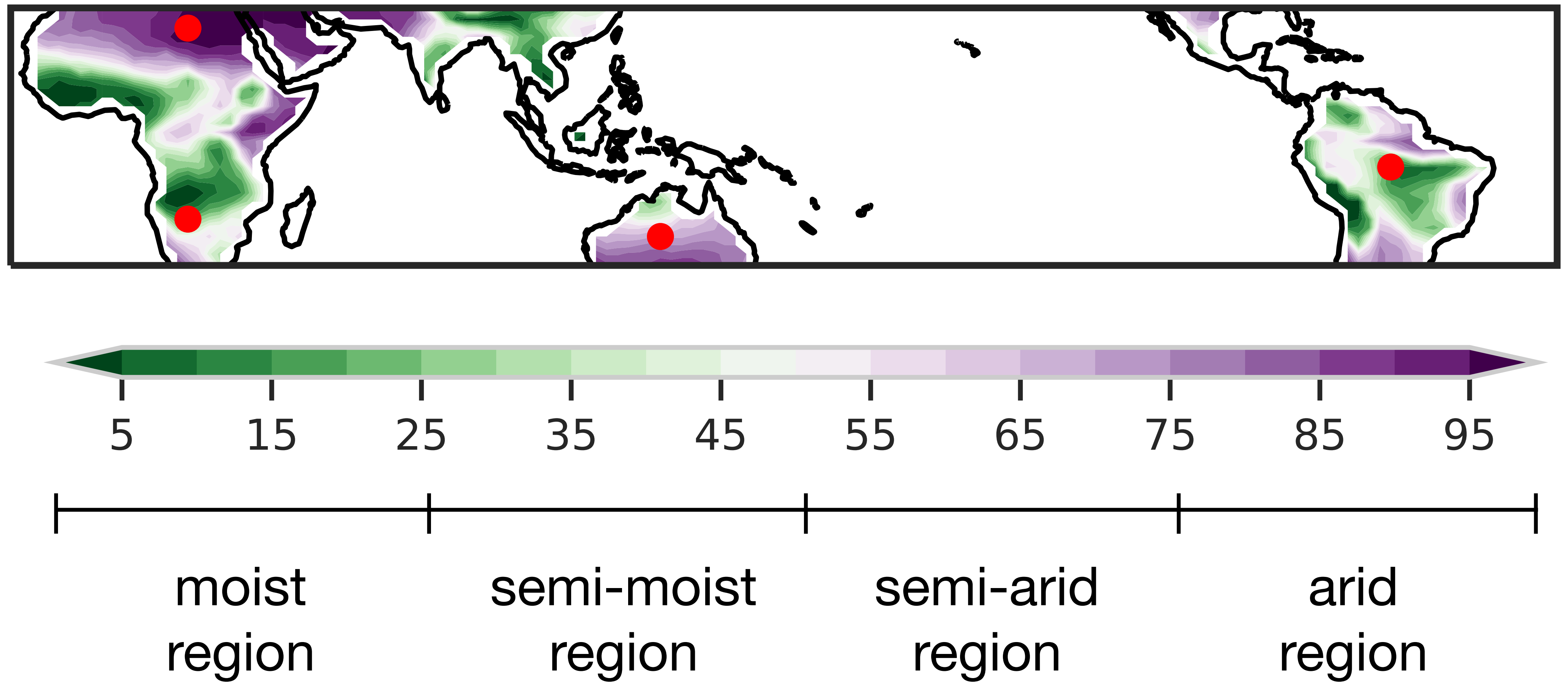


warm season, GFDL-ESM2M

Duan et al., *GRL, under review*

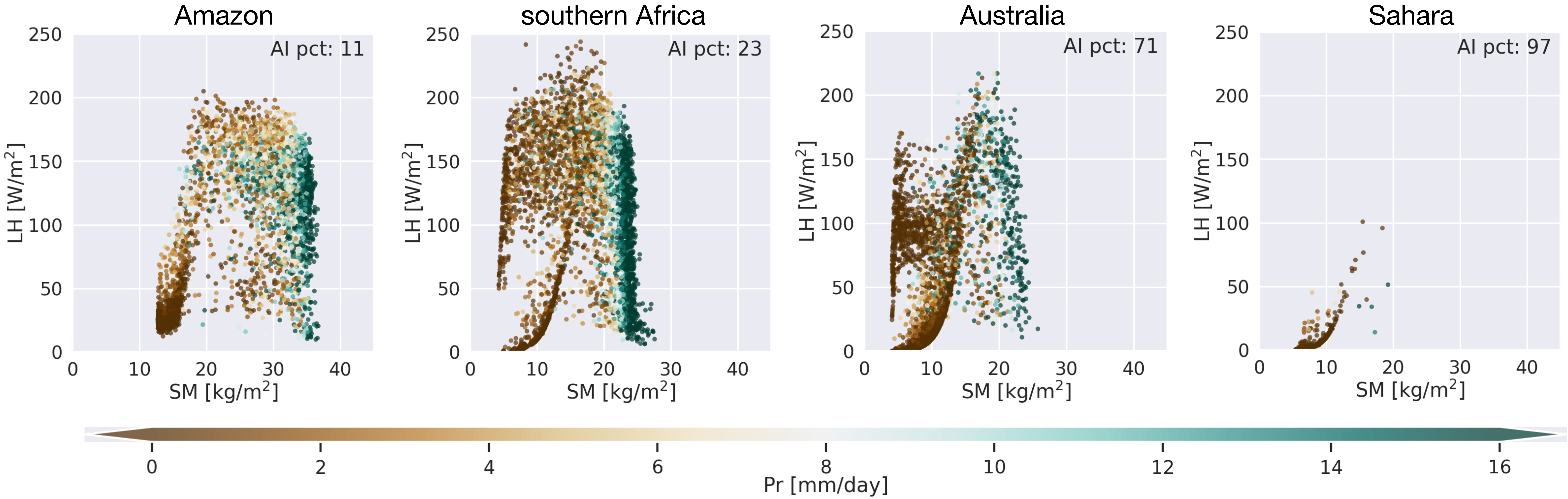
Spatial heterogeneity across land is large

Percentile of climatological warm-season Aridity Index

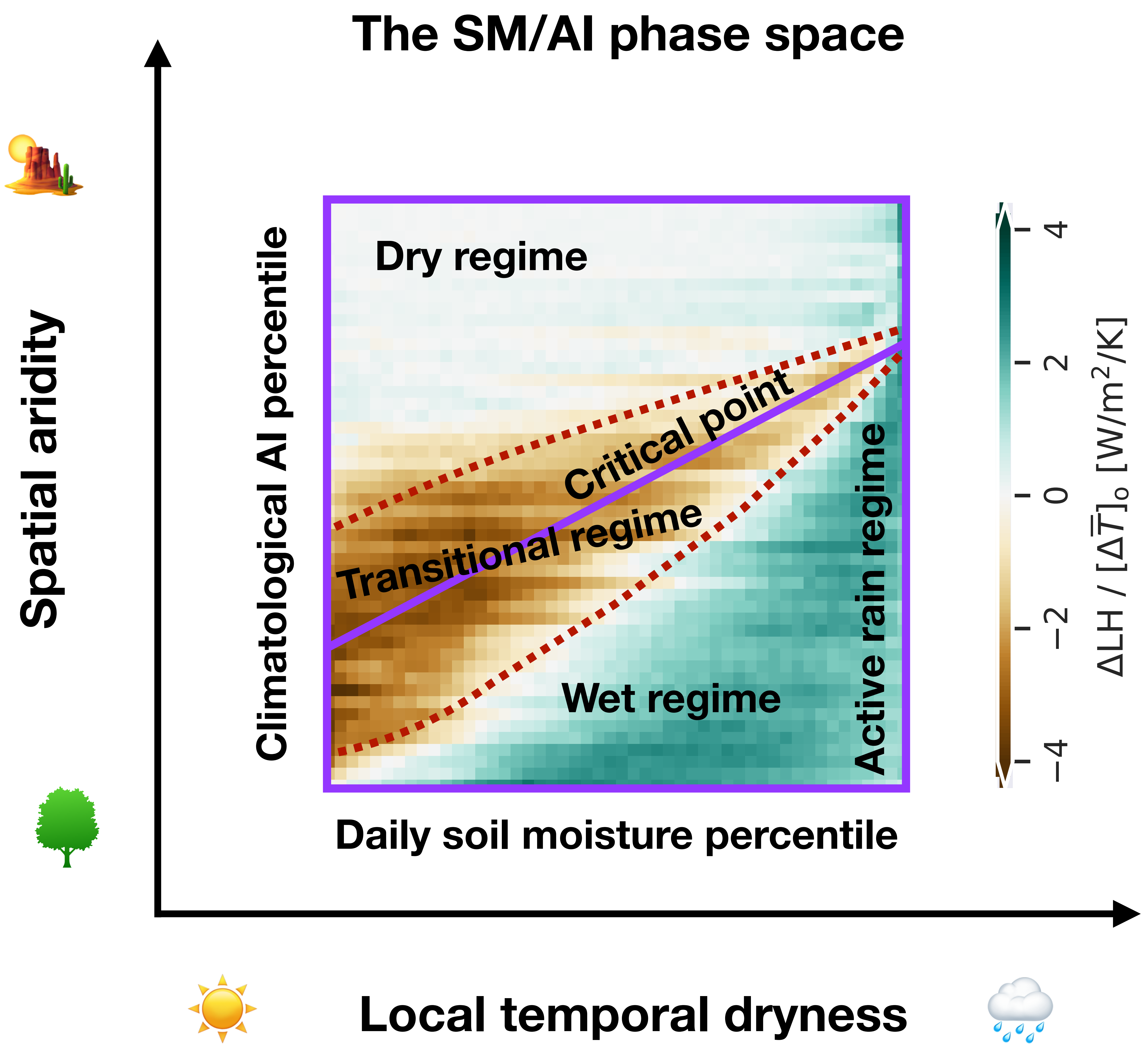


$$\text{Aridity Index} = \frac{0.8 \cdot \text{Radiation}_{\text{net}}^{\text{sfc}}}{L_v \cdot \text{Precipitation}}$$

GFDL-ESM2M



An effective way to examine the spatiotemporal distribution of key variables over land



Duan et al., *GRL, under review*

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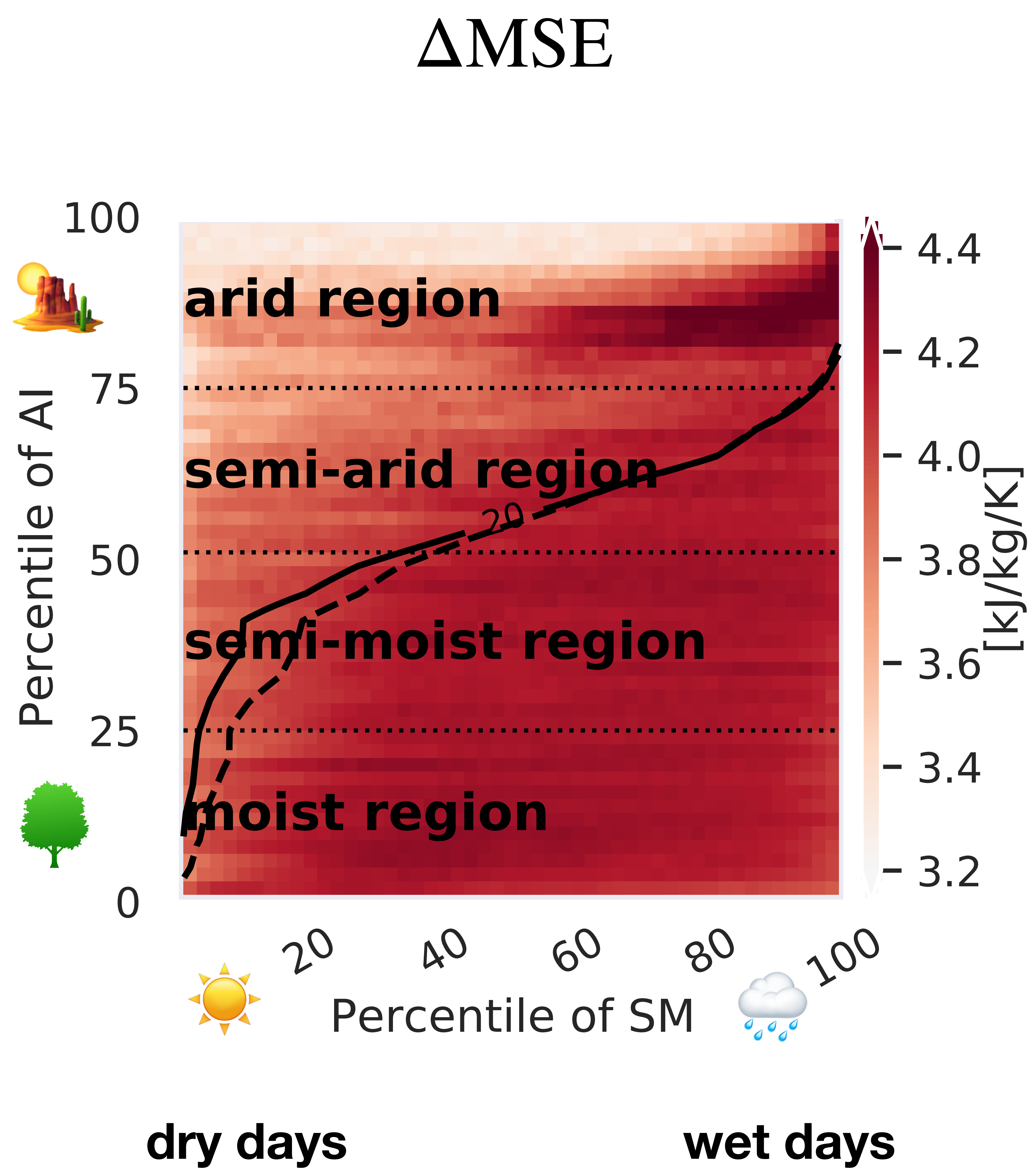
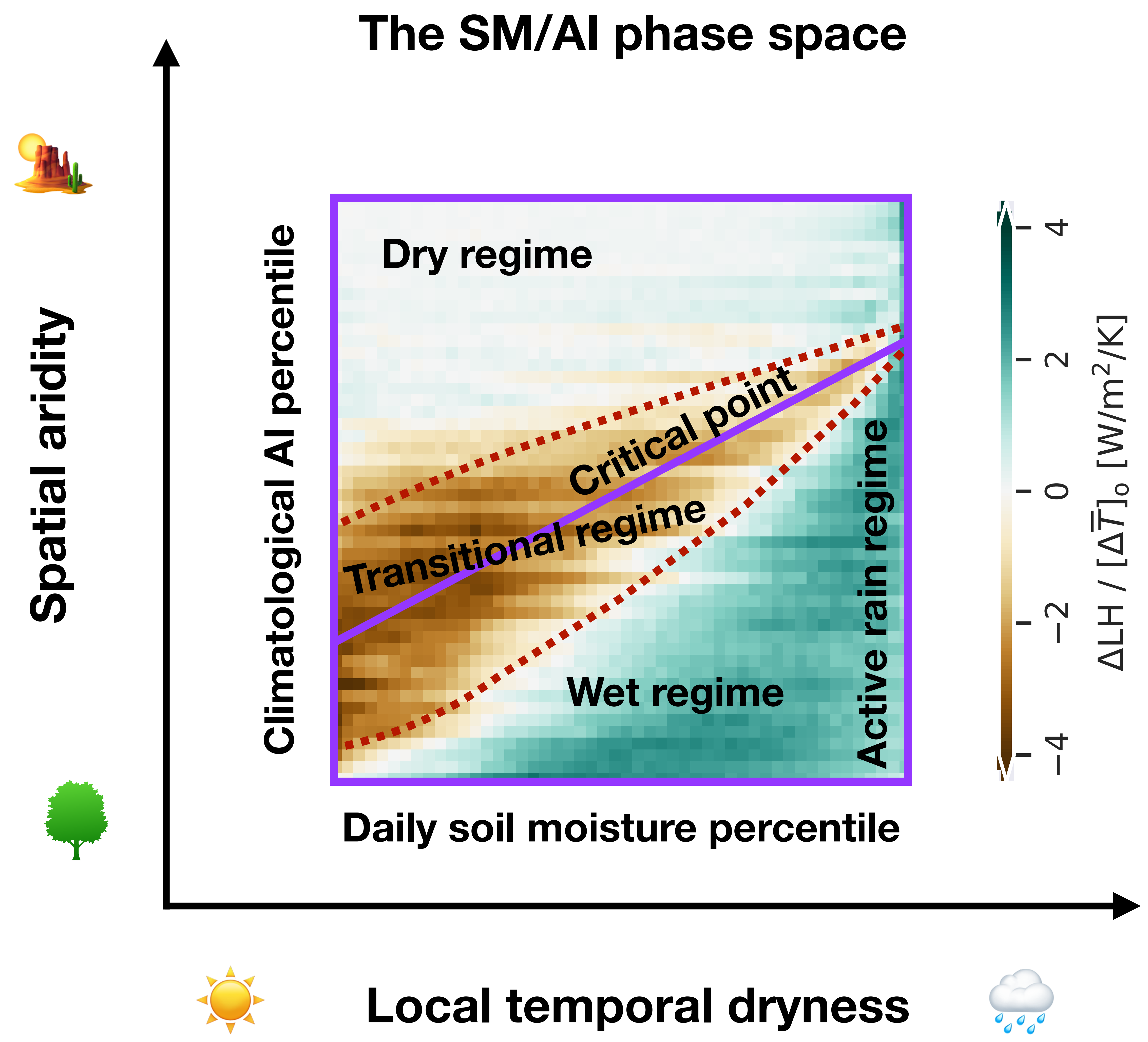
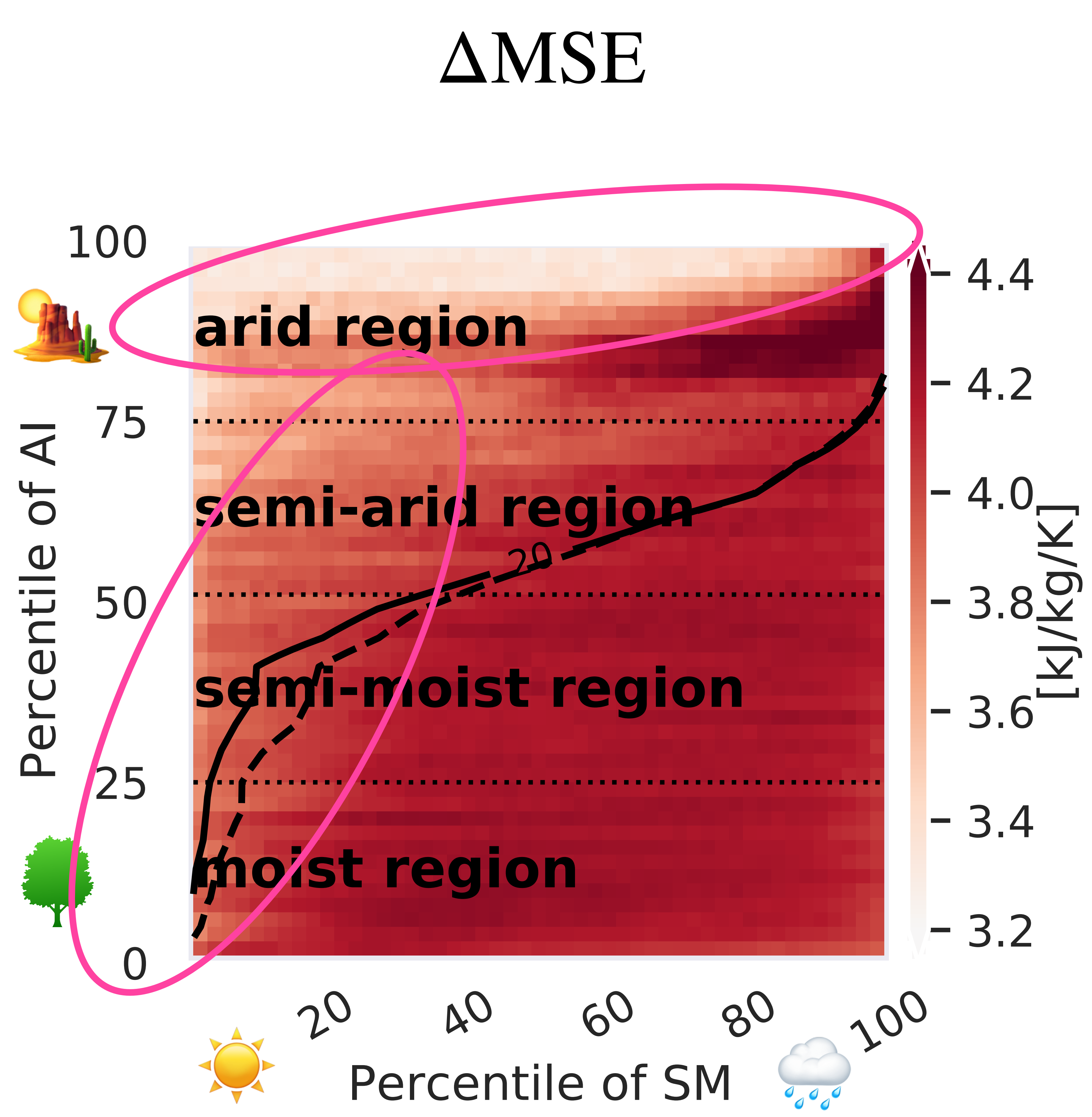




Duan et al., *GRL, under review*

Uniform ΔMSE holds in wet conditions, not dry conditions



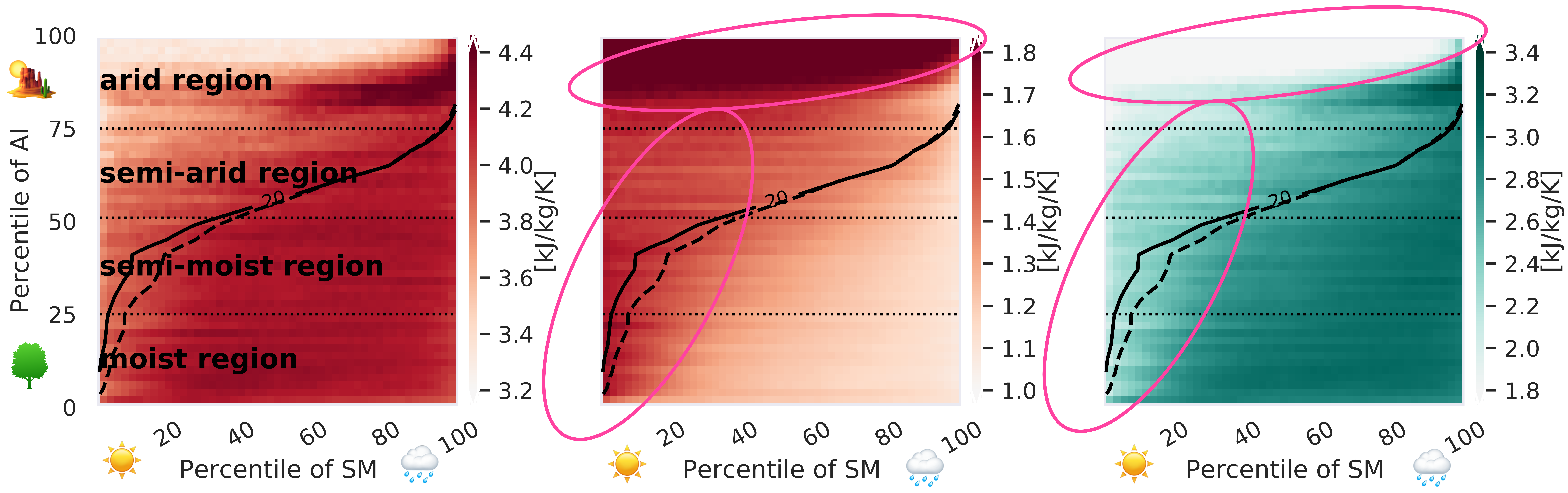
CMIP6 Multi-model mean
Δ: 4xCO2 - piControl
normalized by tropical mean ocean warming into /K
x-axis: daily timescale

It is hard to provide an "accurate" prediction for *ΔT* in non-convective conditions, e.g., deserts.

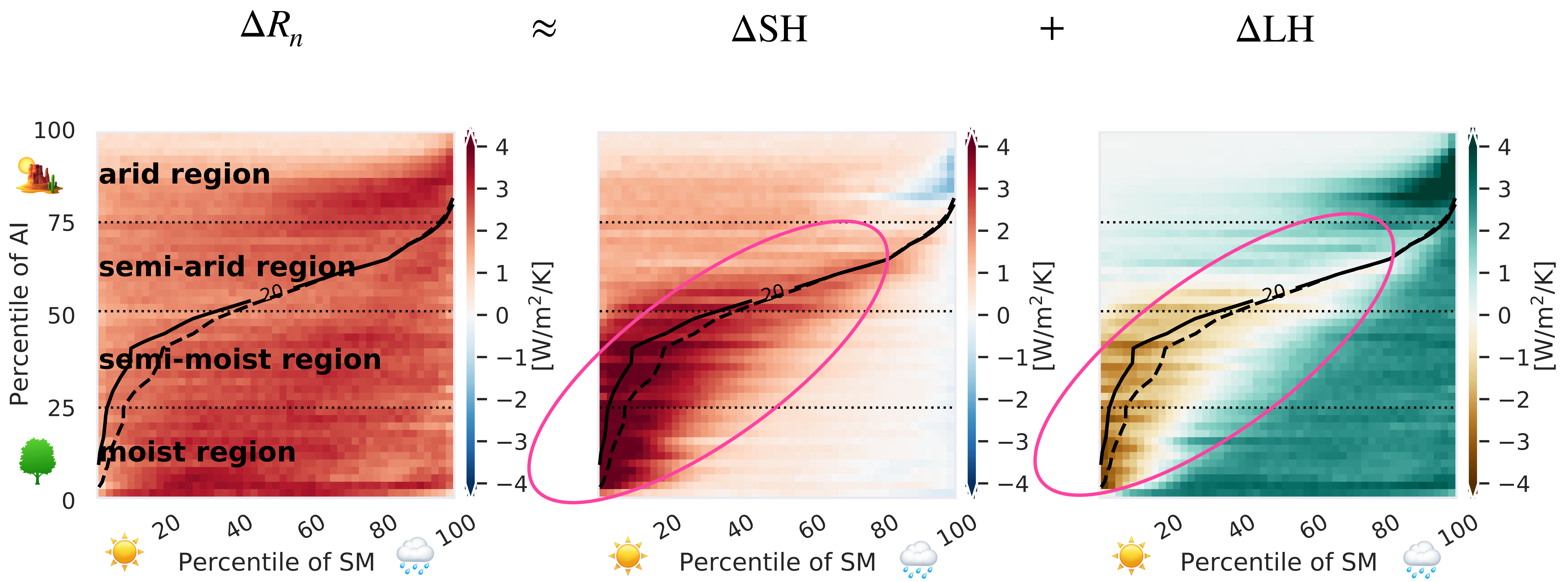
These dry conditions warm the most in *ΔT*.

A general T/q partition - Drier gets Warmer

$$\Delta \text{MSE} = c_p \Delta T + L_v \Delta q$$



Surface flux perspective manifests strongly in the transitional regime



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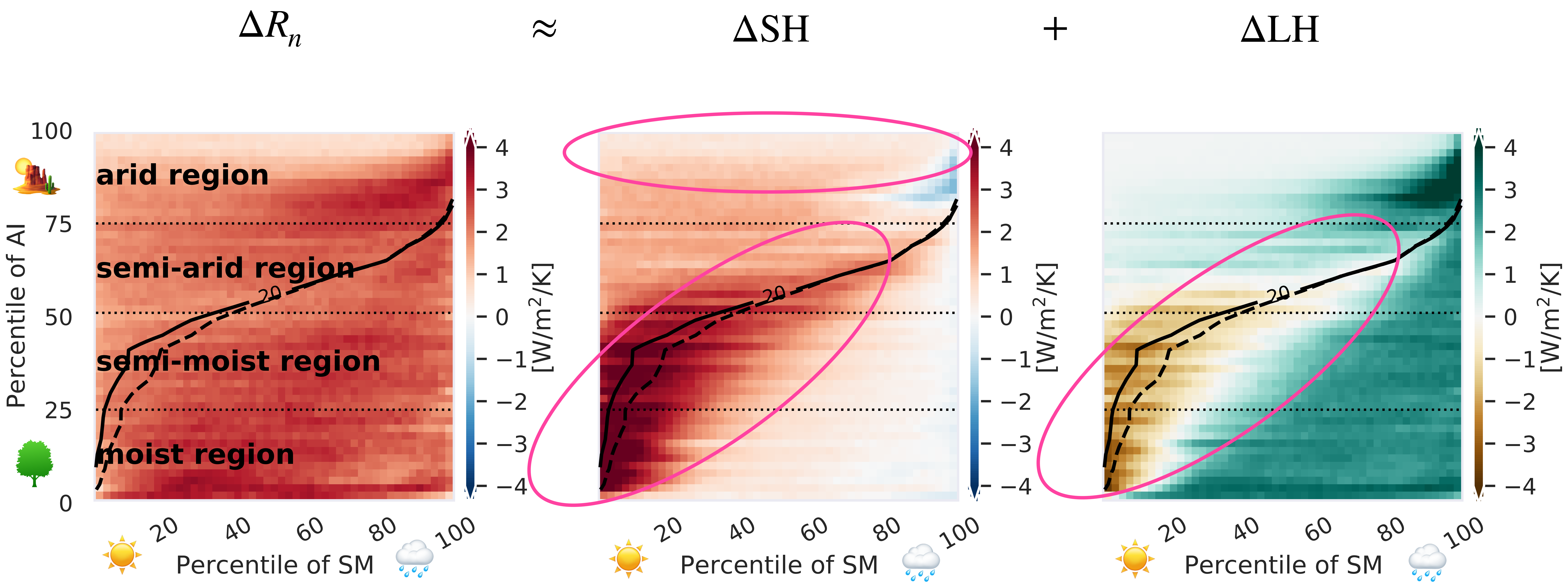

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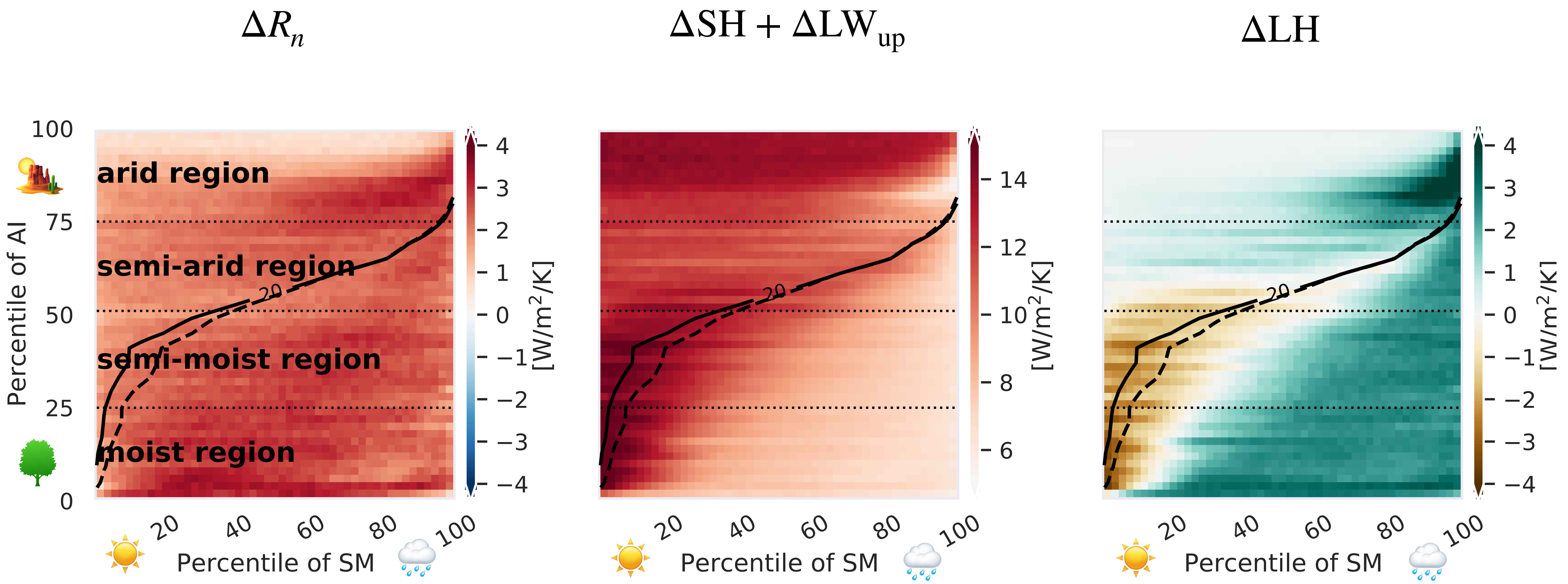
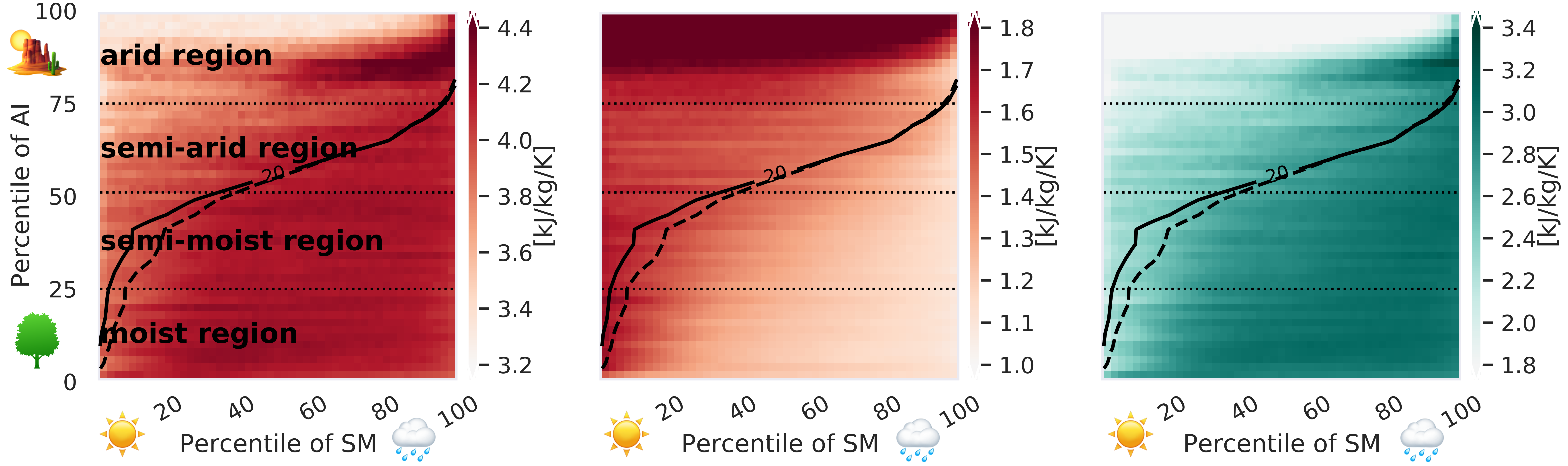


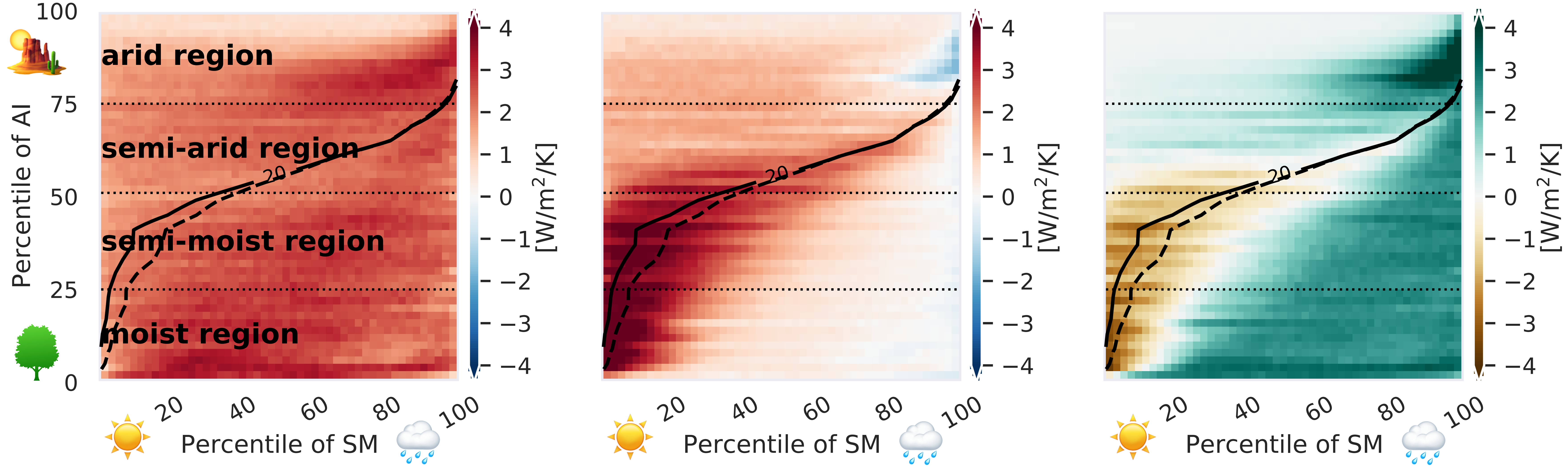
A general correspondence between the two perspectives

Atmospheric: $\Delta \mathrm{MSE} = c_p \Delta T + L_v \Delta q$



- General principle on T/q partition; not explicitly coupled to the surface.

Surface: $\Delta R_n \approx \Delta \mathrm{SH} + \Delta \mathrm{LH}$



- Process-based; local and not coupled to broader atmospheric dynamics.

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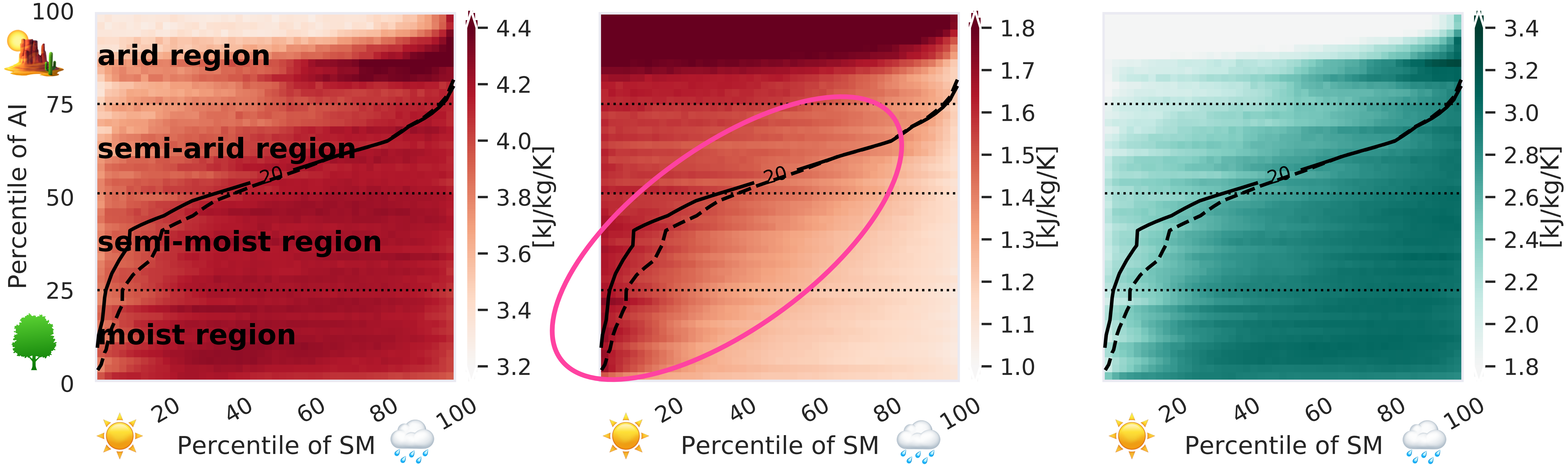

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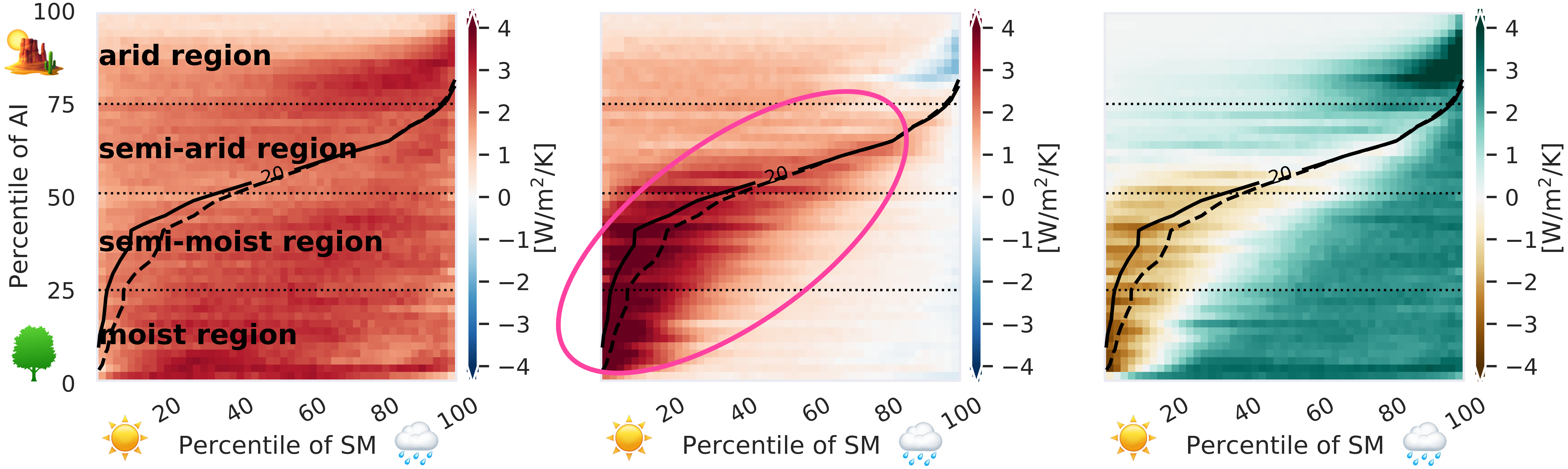

- Process-based;
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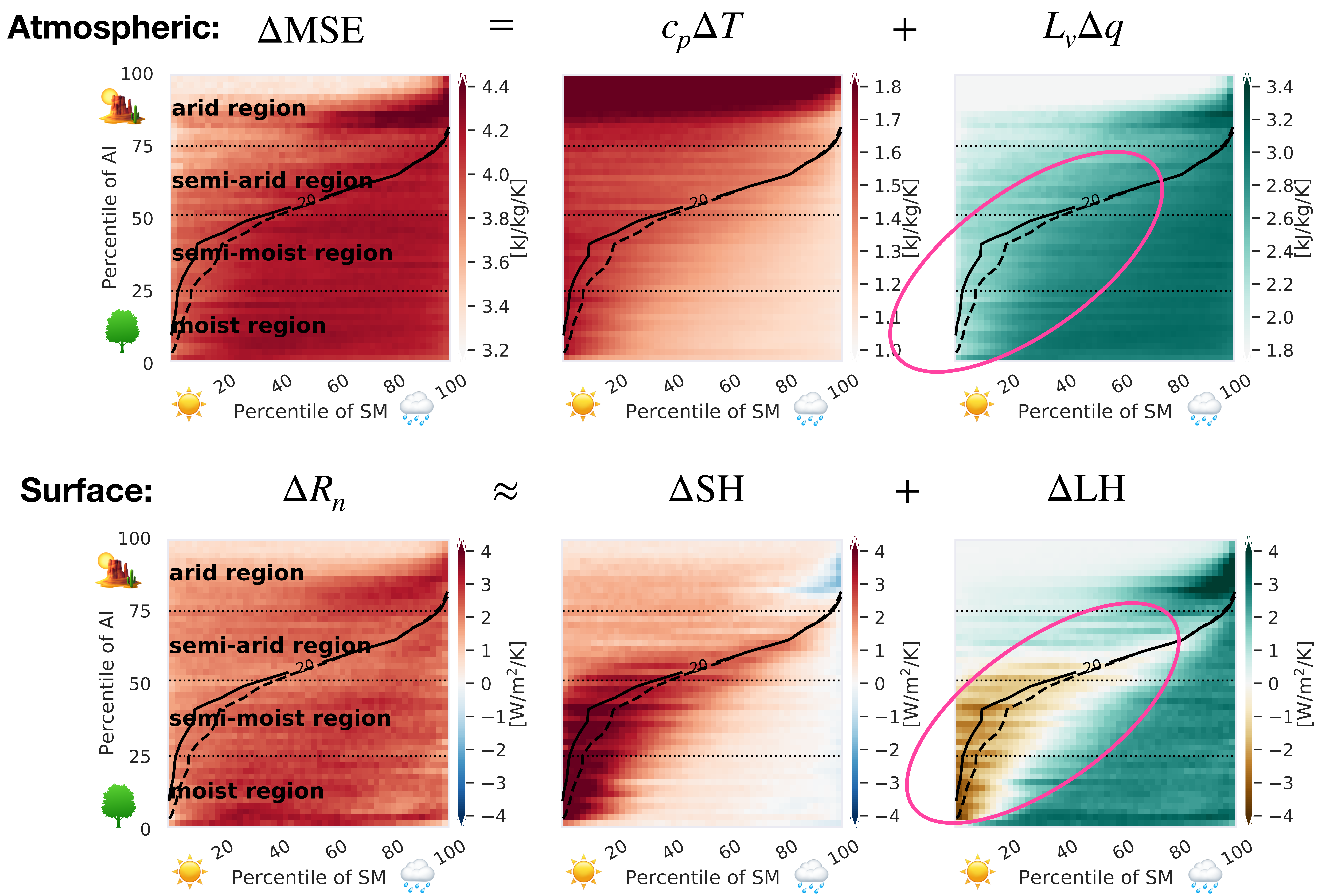
A general correspondence between the two, with a discrepancy in moistening

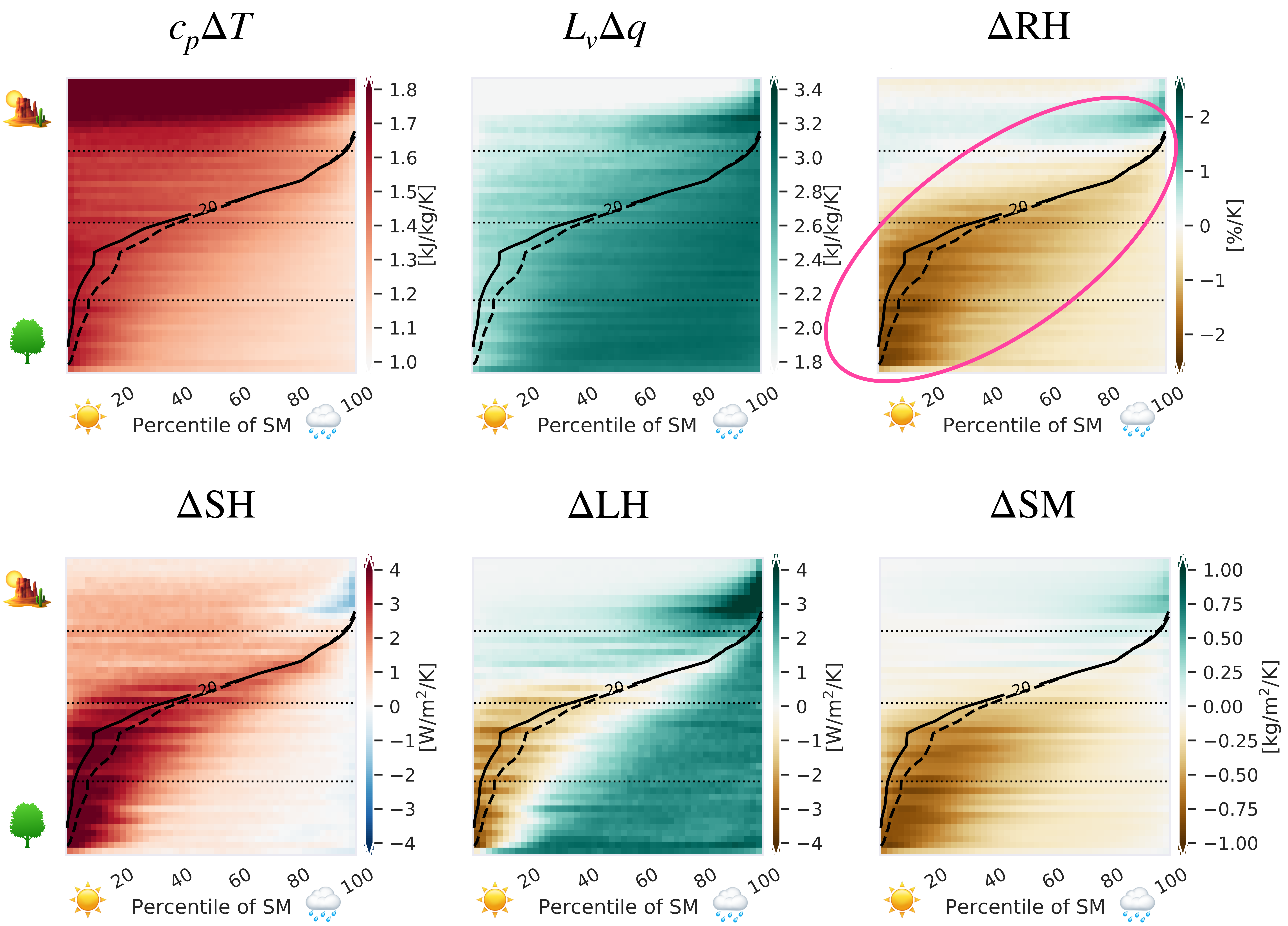


- LH **decreases** in the transitional regime.
- *q* **increases** for all conditions.
  ➡ *q* has other sources and sinks besides ET.

A note for RH:

- RH is often regarded as an indicator for atmospheric dryness, but depends on both *q* and *T*.

- *Δ*RH is associated with *Δ*SM and *Δ*LH.
  ➡(Temperature feedback is important, but hard to claim the causal chain.)



Climatological dryness vs changes in dryness

Atmospheric:

Moisture constraint: $\Delta q^L = \gamma \Delta q^O$

$\gamma = q^L / q^O$

determined by the base-climate dryness only

Surface:

Emphasizes soil drying/changes in plants' physiology and changes in surface-flux partition

Define a partition factor to relate the *T* component to the total

Atmospheric:

$$\mathrm{MSE} - gz = c_p T + L_v q = \psi c_p T$$

$$\frac{1}{\psi} = \frac{c_p T}{\mathrm{MSE} - gz}$$

Surface:

$$R_n - G = \mathrm{SH} + \mathrm{LH} = \Psi \mathrm{SH}$$

$$\frac{1}{\Psi} = \frac{\mathrm{SH}}{R_n - G}$$

Decompose climate change: base partition + changes in partition

Atmospheric:

base partition changes in partition

$$\Delta\mathrm{MSE} = \Delta(\psi c_p T) \approx \psi c_p \Delta T + c_p T \Delta\psi$$

Surface:

$$\Delta R_n \approx \Delta(\Psi \mathrm{SH}) \approx \Psi \Delta \mathrm{SH} + \mathrm{SH} \Delta \Psi$$

$$\approx \Psi \kappa \Delta T + \mathrm{SH} \Delta \Psi$$

(parameterize $\Delta\mathrm{SH} \approx \kappa \Delta T$)

Relate ΔT to (1) changes in total, (2) sensitivity (base partition), (3) changes in partition

Surface:

Changes in total: "forcing"

$$\Delta T \approx \frac{1}{\kappa \Psi}(\Delta R_n - \mathrm{SH}\Delta\Psi)$$

Changes in partition

Sensitivity: base-climate dryness

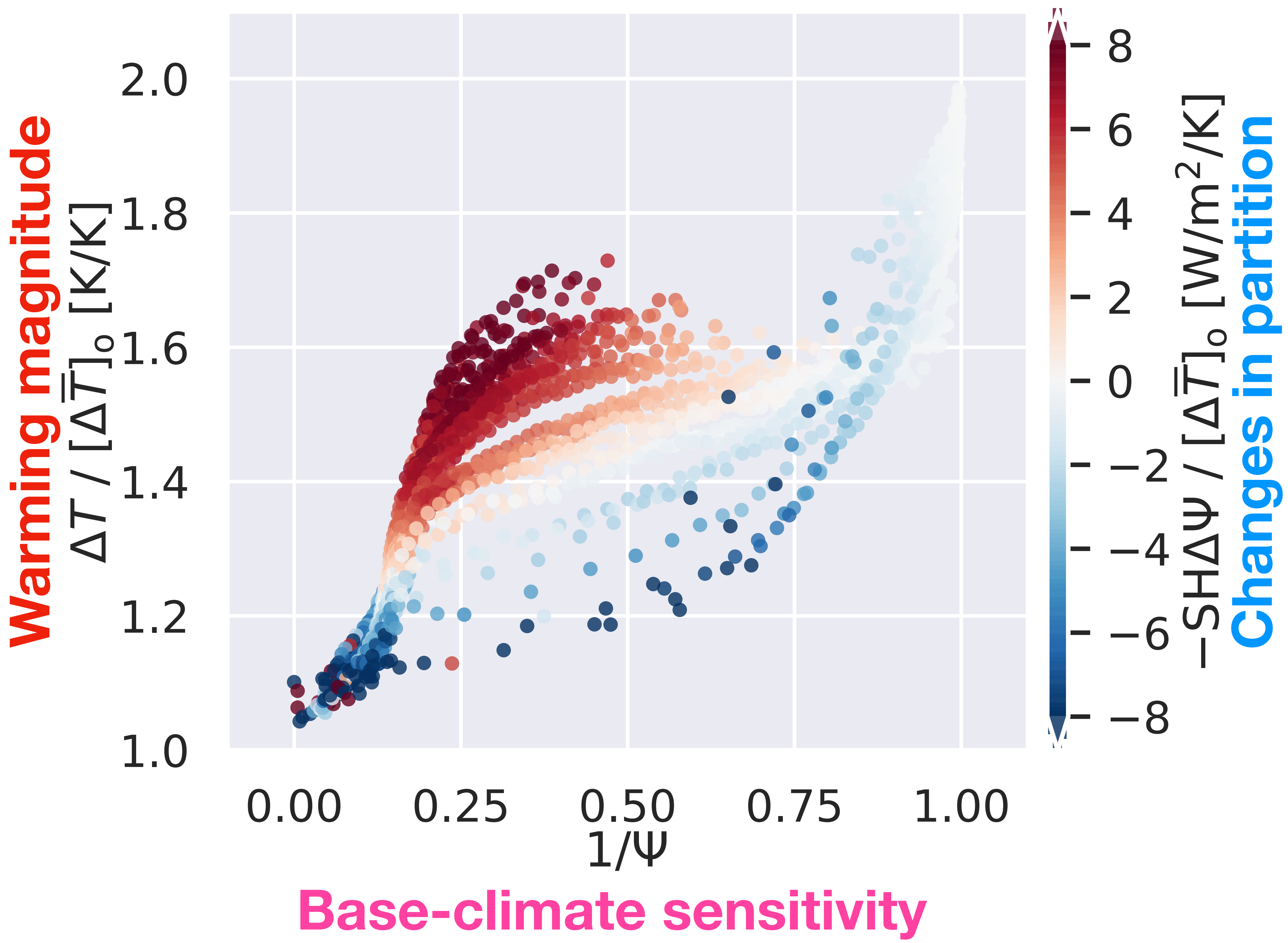
Atmospheric:

$$\Delta T \approx \frac{1}{c_p \psi}(\Delta \mathrm{MSE} - c_p T \Delta \psi)$$

Warming magnitude against base-climate sensitivity and changes in partition

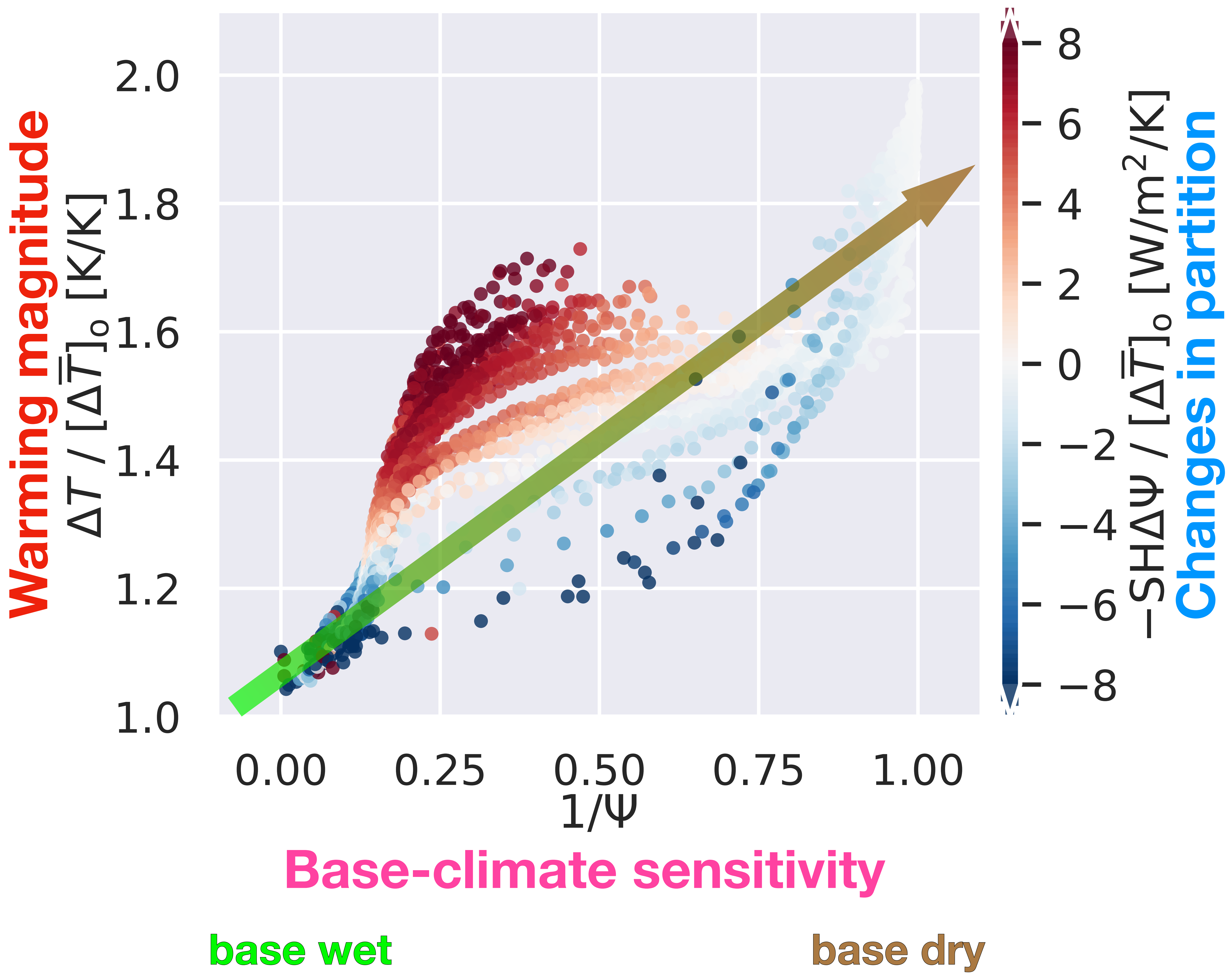
Surface:

Each dot: one of the 50 temporal bins x 50 spatial bins



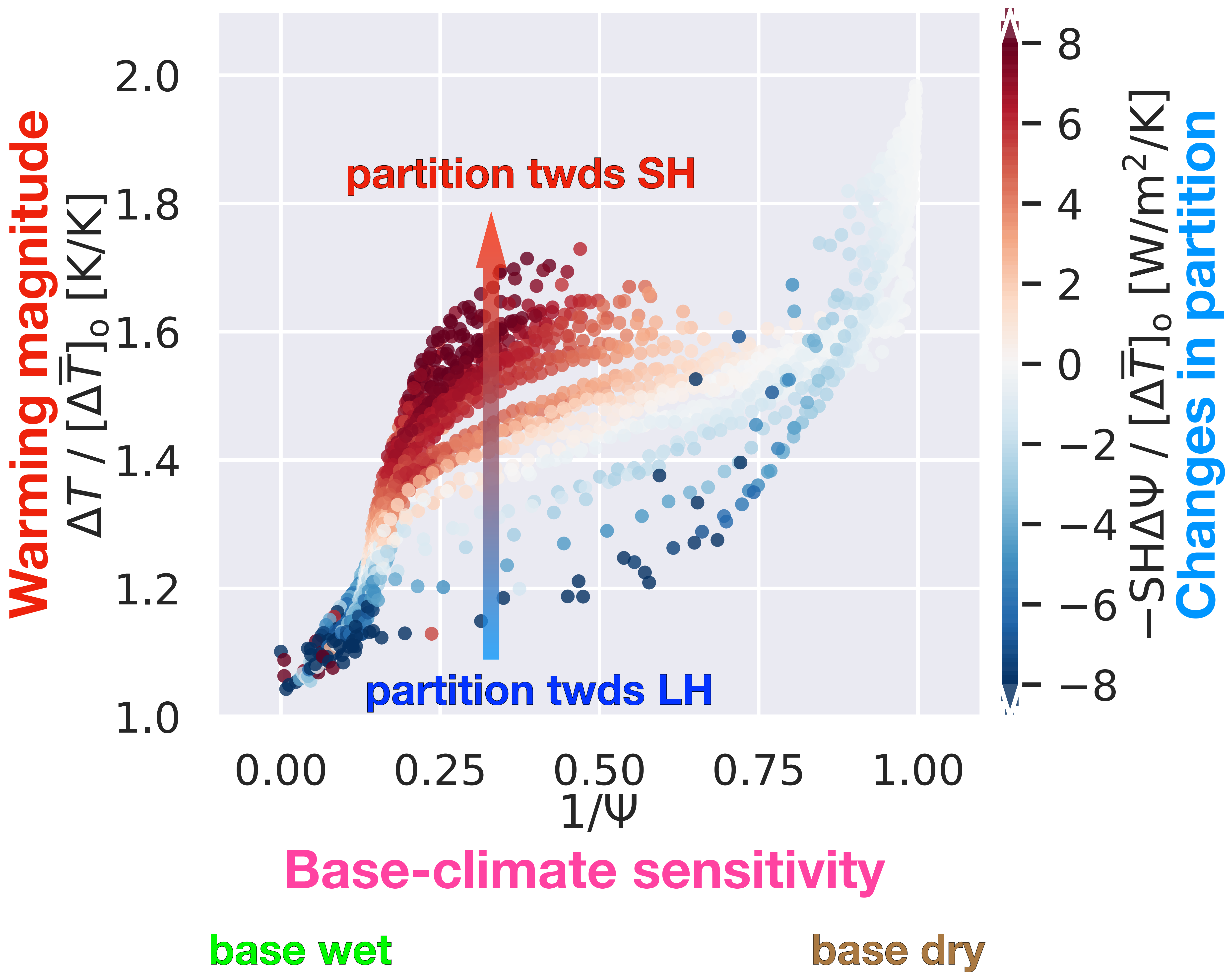
Larger base-climate sensitivity, larger warming magnitude

Surface:



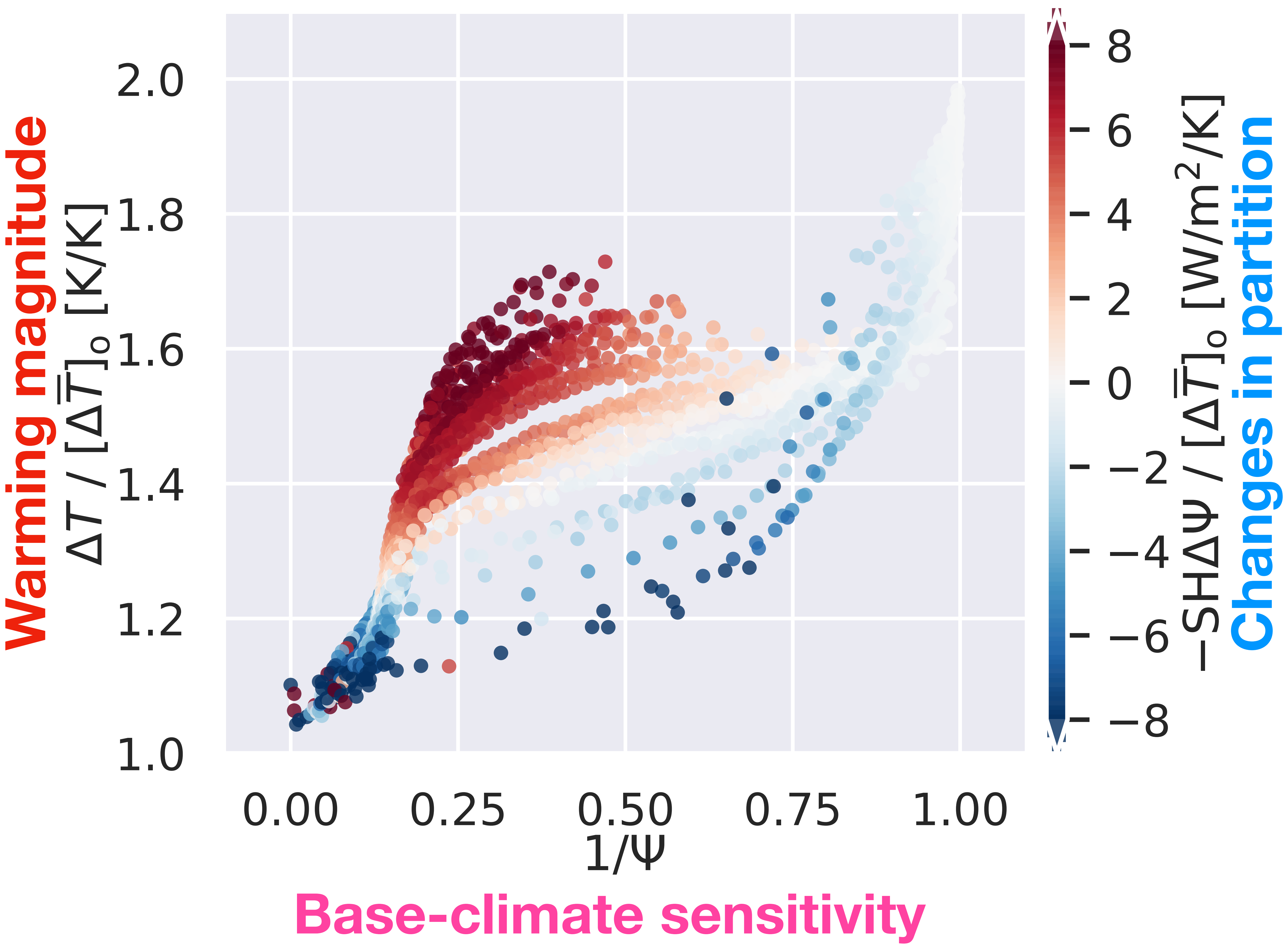
Changes in partition in intermediate conditions further enhances/dampens warming

Surface:

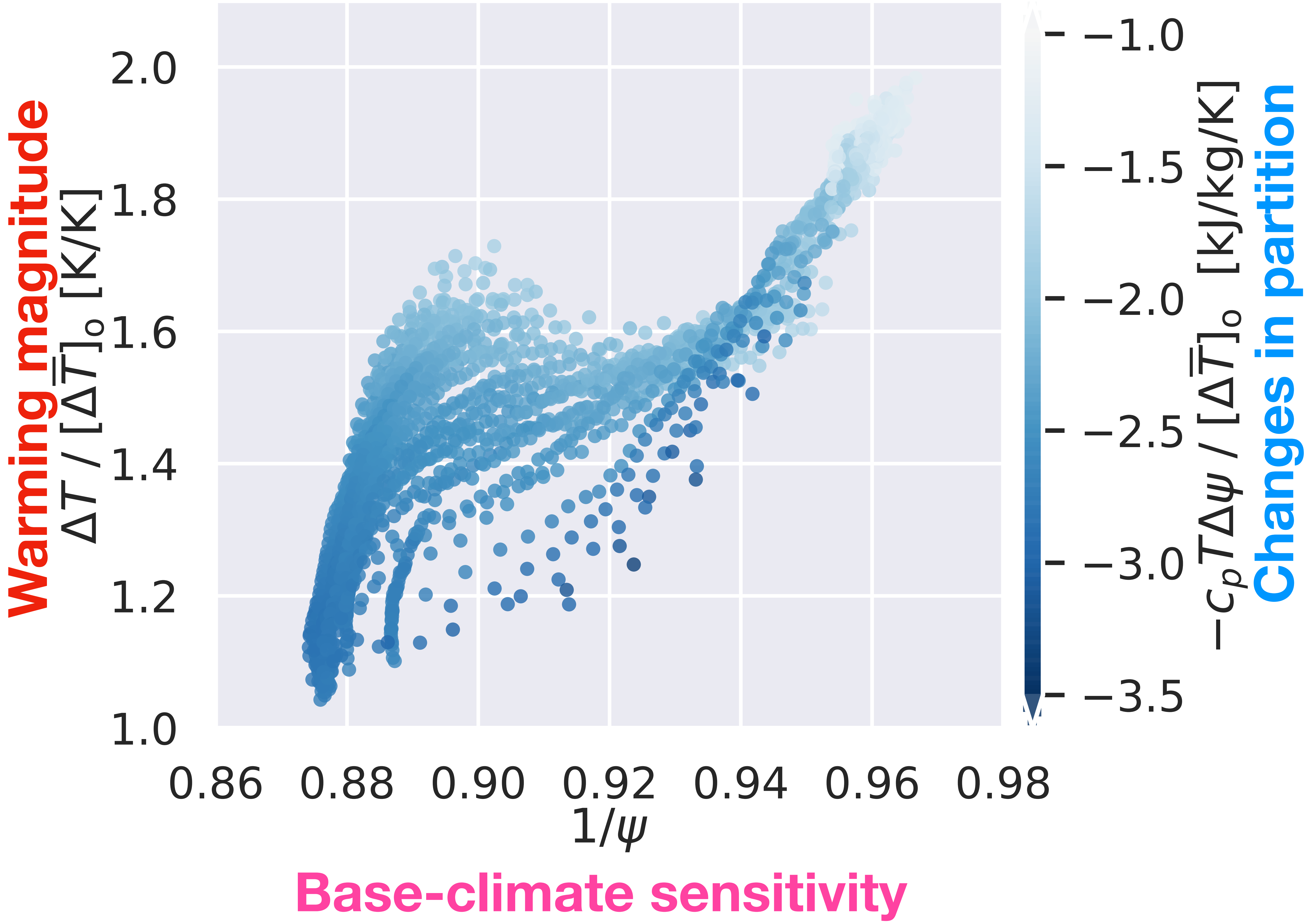


Similar relationship with the base-climate sensitivity, different in the change of partition

Surface:



Atmospheric:



Atmospheric T/q partition changes towards moistening for all conditions.

Summary

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- The two perspectives show a general correspondence (i.e., elements in the atmospheric argument carry strong surface information), with a discrepancy in moistening resulting from atmospheric sources and sinks for *q* besides ET.

- We show base-climate dryness largely explains the warming magnitude; during intermediate conditions, changes in the partition between warming and moistening further generate variability in the warming magnitude.

Duan, S. Q., McKinnon, K. A., & Simpson, I. R. Two perspectives on amplified warming over tropical land, *JCLI, under review.*

Thanks!