The influence of orography on monsoons:
dynamics and radiative-convective physics

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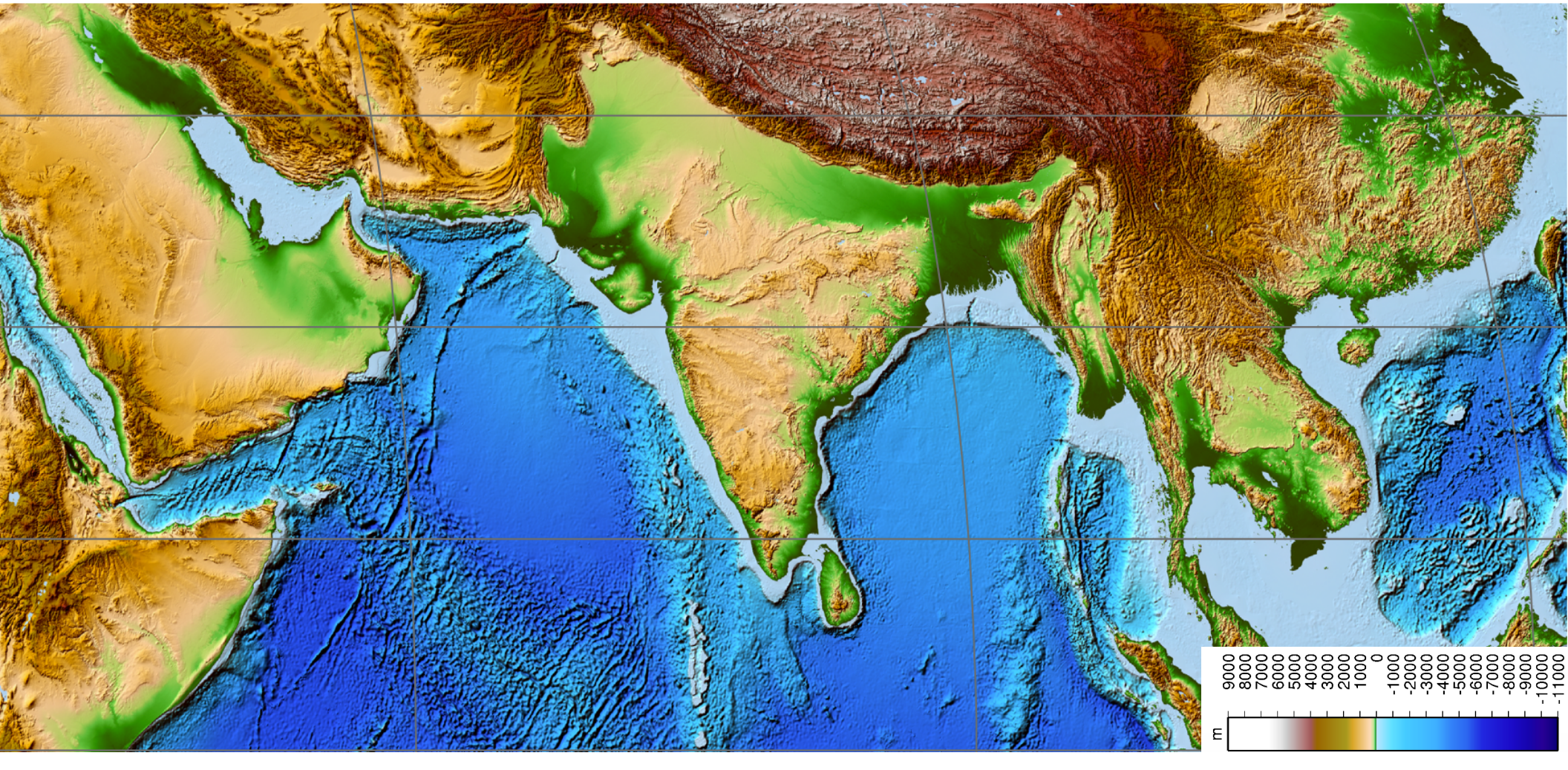
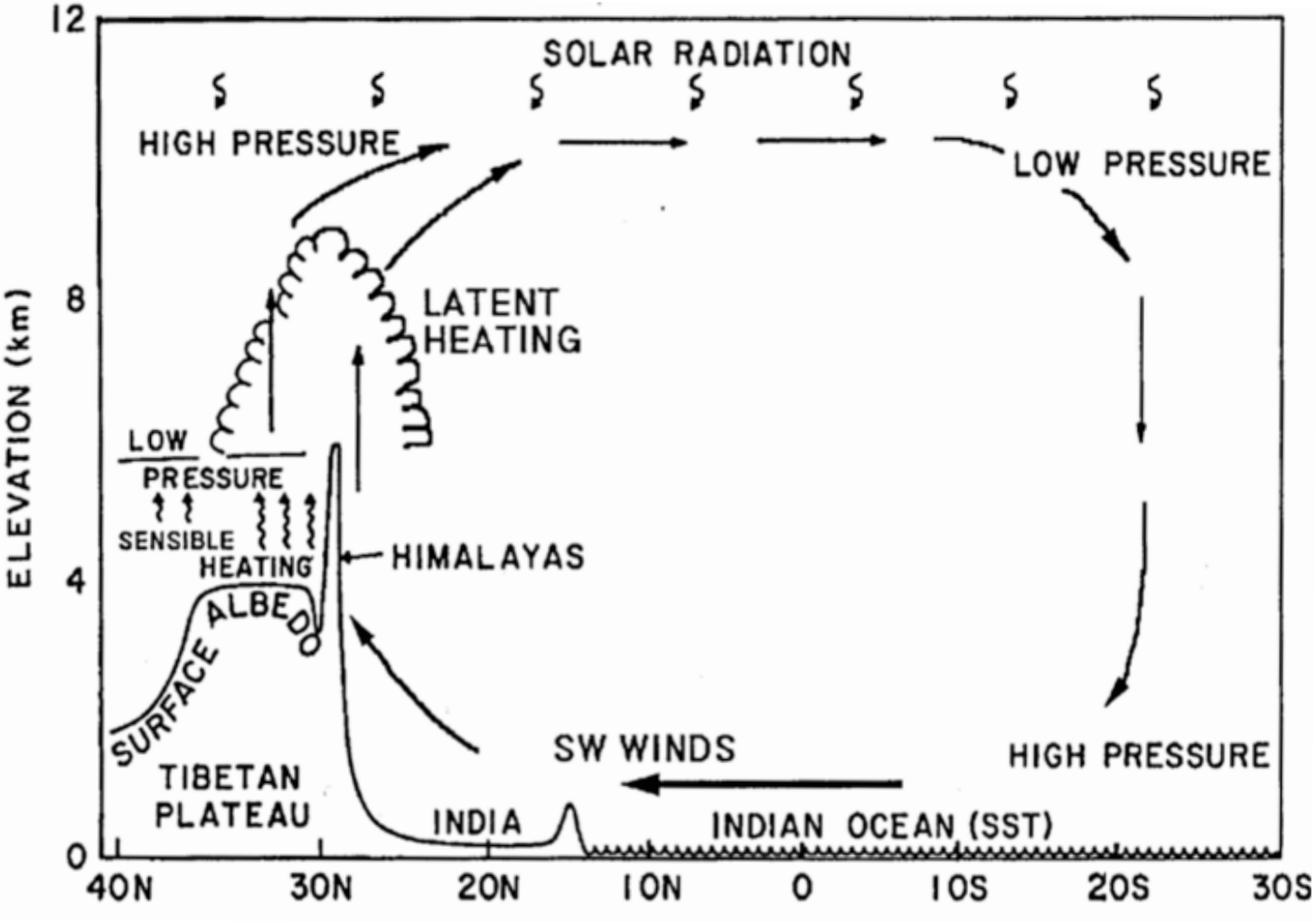


Longstanding view:
Tibetan Plateau heating drives Asian monsoon



Prell et al. (1992)

Cause of Asian monsoon:

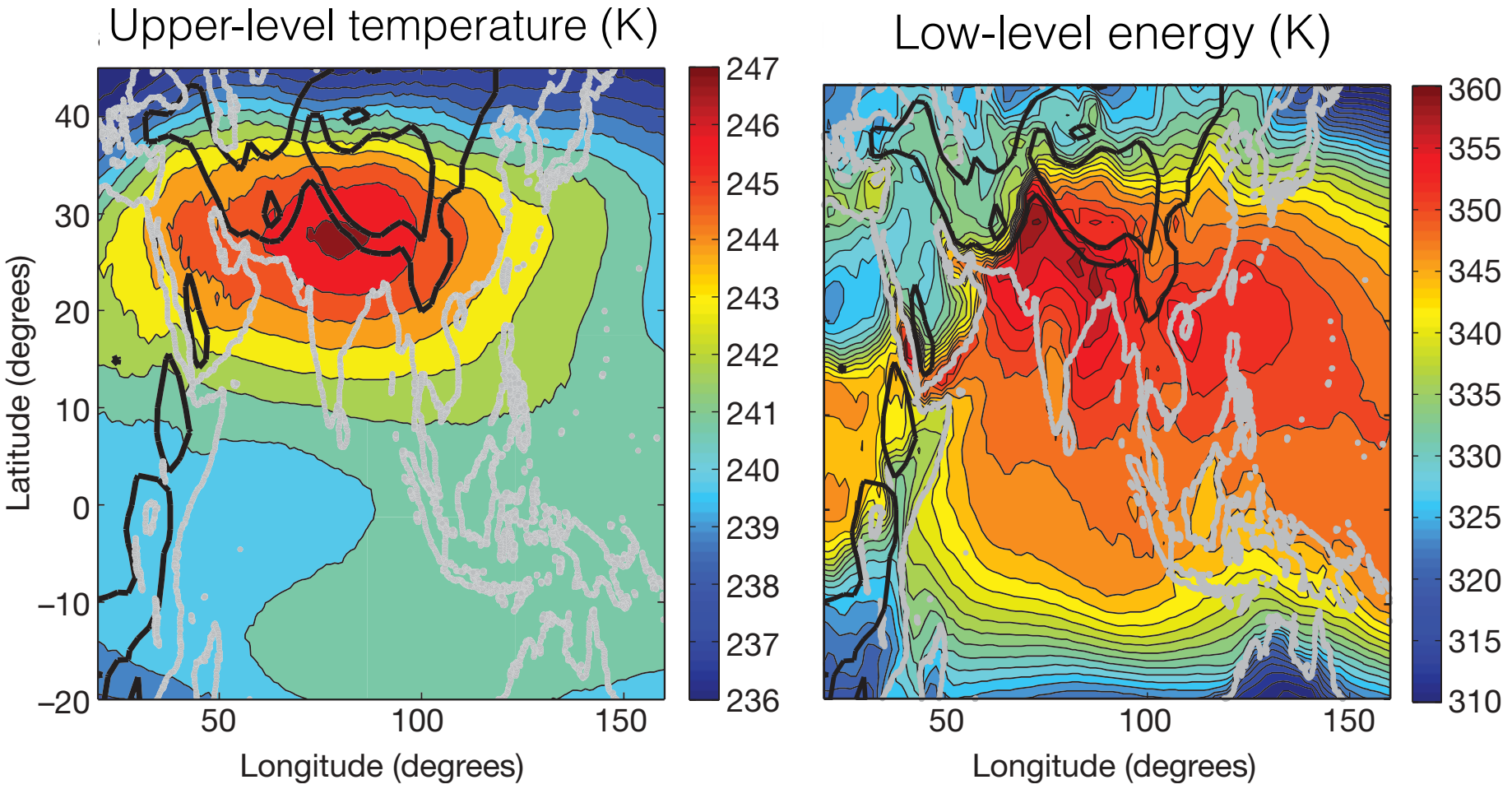
1. Insolation produces sensible heat flux from Plateau

2. This produces moisture convergence and latent heating of atmosphere above S. Asia

3. This heating drives monsoon flow, including Somali jet

see, e.g., Flohn (1974), Hahn & Manabe (1975), Li and Yanai (1996)

Observed thermal structure is inconsistent with idea of Tibet as dominant heat source

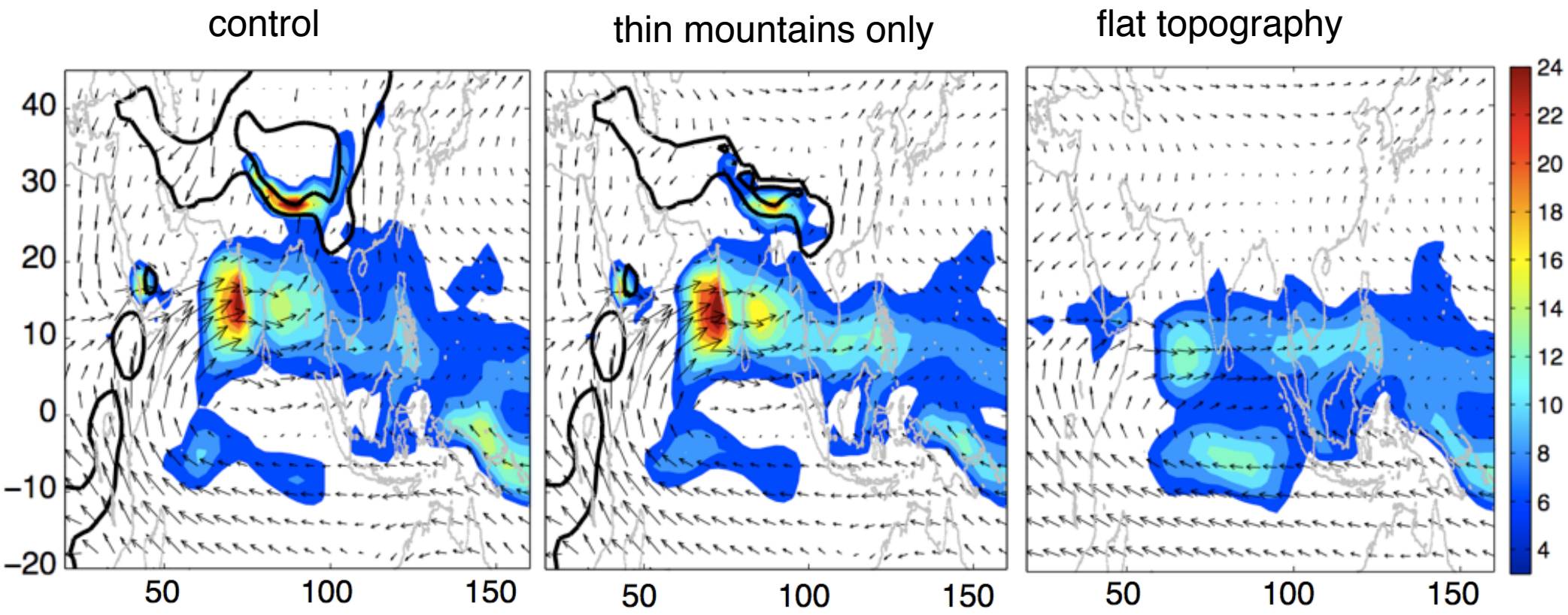


black contours mark surface pressures of 700 and 900 hPa

Boos & Kuang (2010)

Use climate model to see if we need a horizontally extensive topographic heat source or simply a narrow topographic barrier to create a strong monsoon.

(thick black contours denote 900 hPa and 750 hPa surface pressures;
arrows represent 850 hPa horizontal winds)



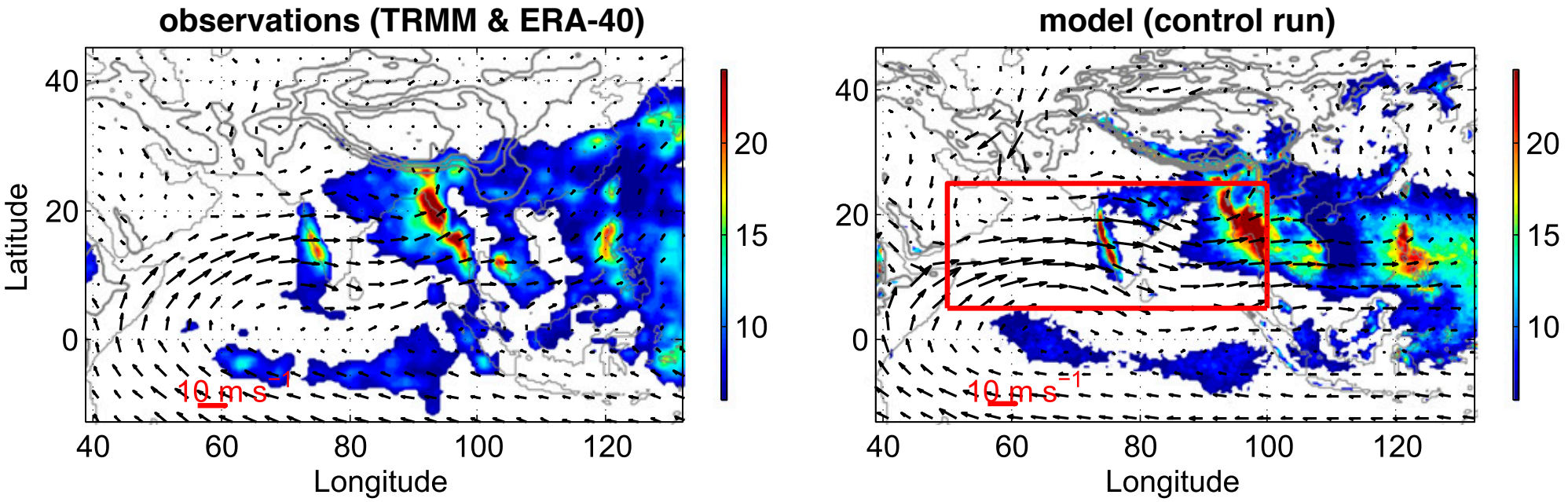
--> monsoon precipitation largely unchanged by elimination of almost all of Tibetan plateau, as long as Himalayas are preserved

Boos & Kuang (2010)

More recent test in high-resolution global model

Global WRF model integrated at 40 km horizontal resolution, prescribed SST

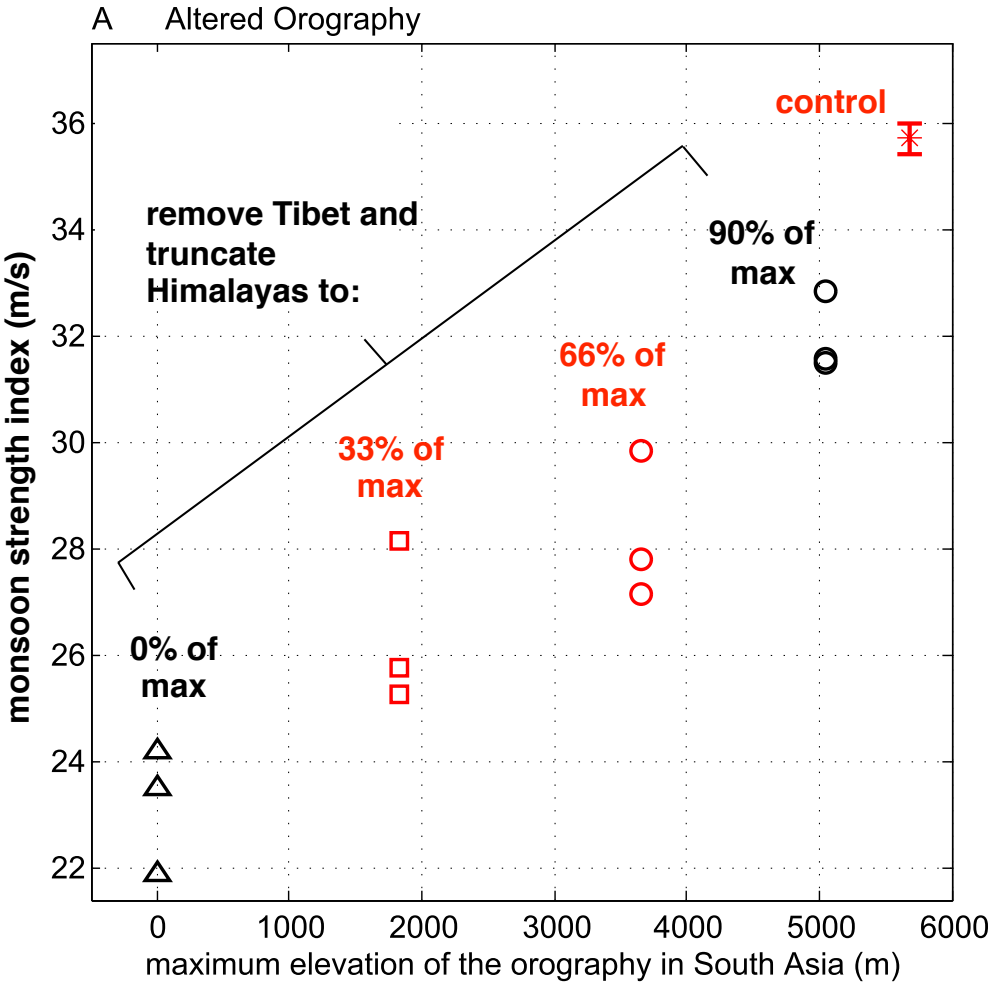
June-August climatologies of precipitation (mm/day) and 850 hPa wind

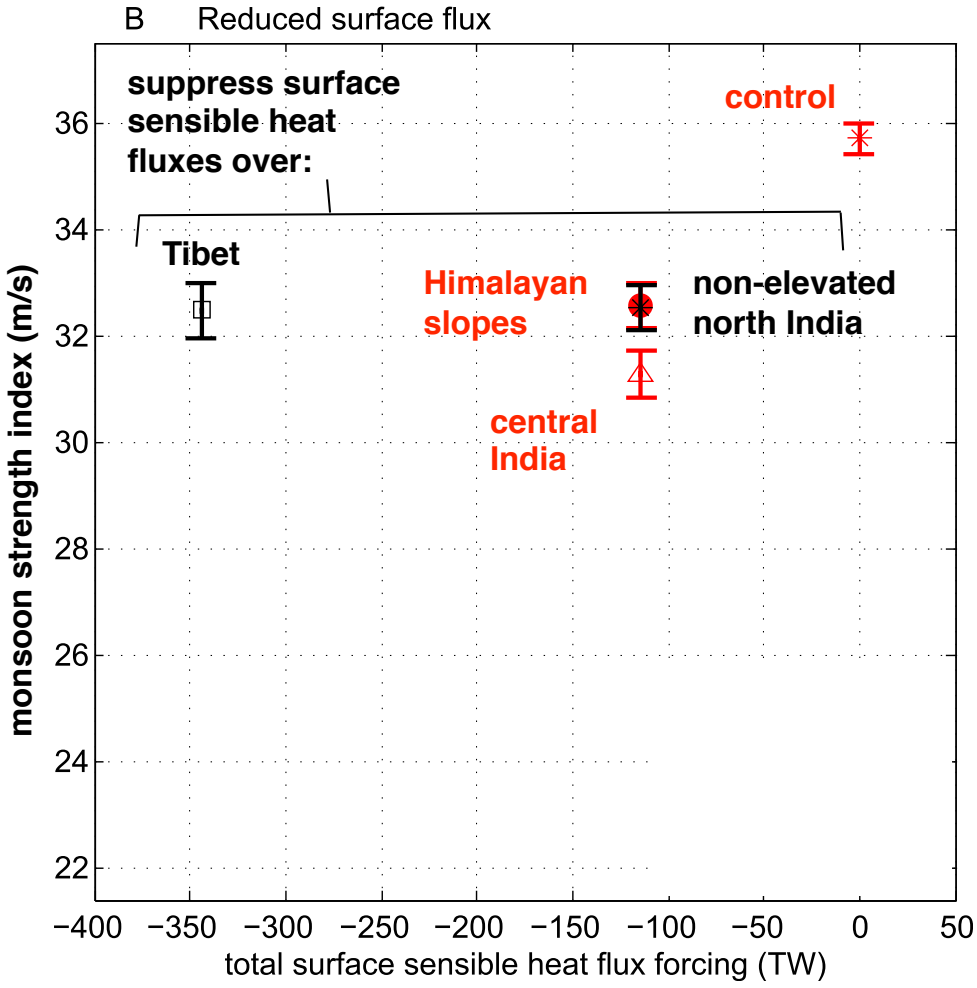


Now examine influence of topography & surface heat fluxes on monsoon circulation in **red box**

Ma, Boos & Kuang (2014)

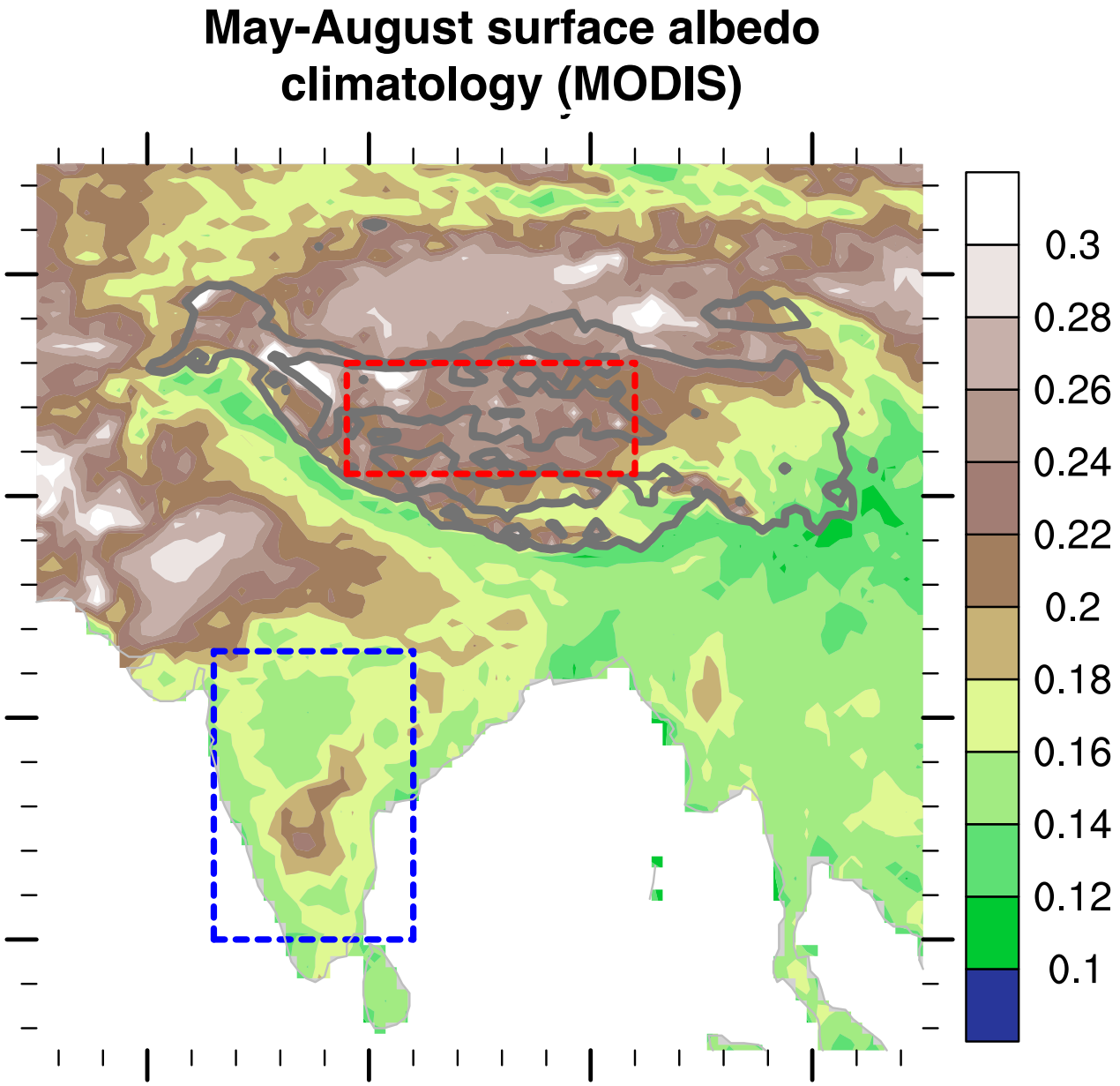
Effects of topography & surface heat fluxes





Ma, Boos & Kuang (2014)

Why doesn't Tibet act as elevated heat source?

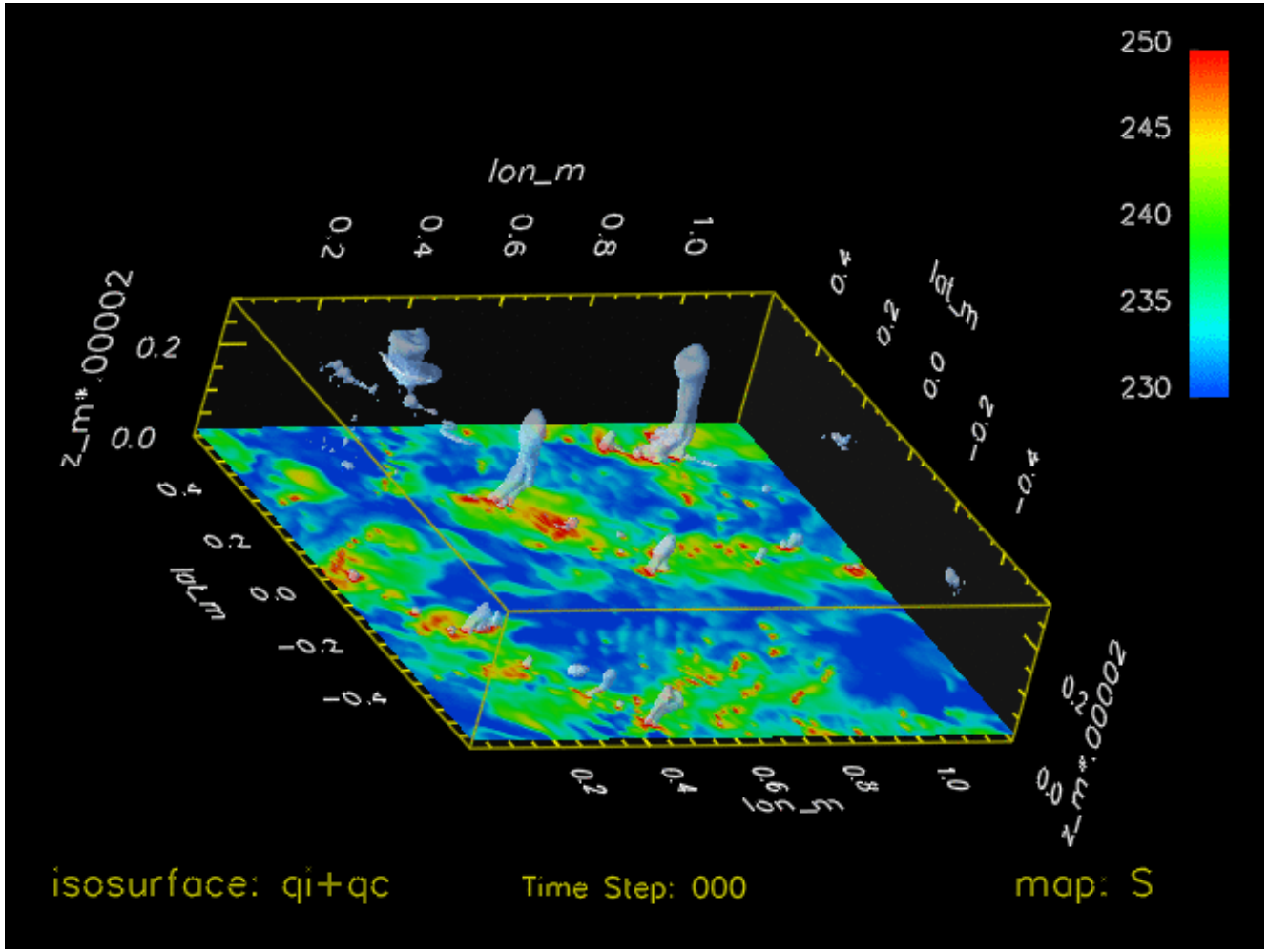


Hypothesis: Elevated heating effect is offset by high surface albedo.

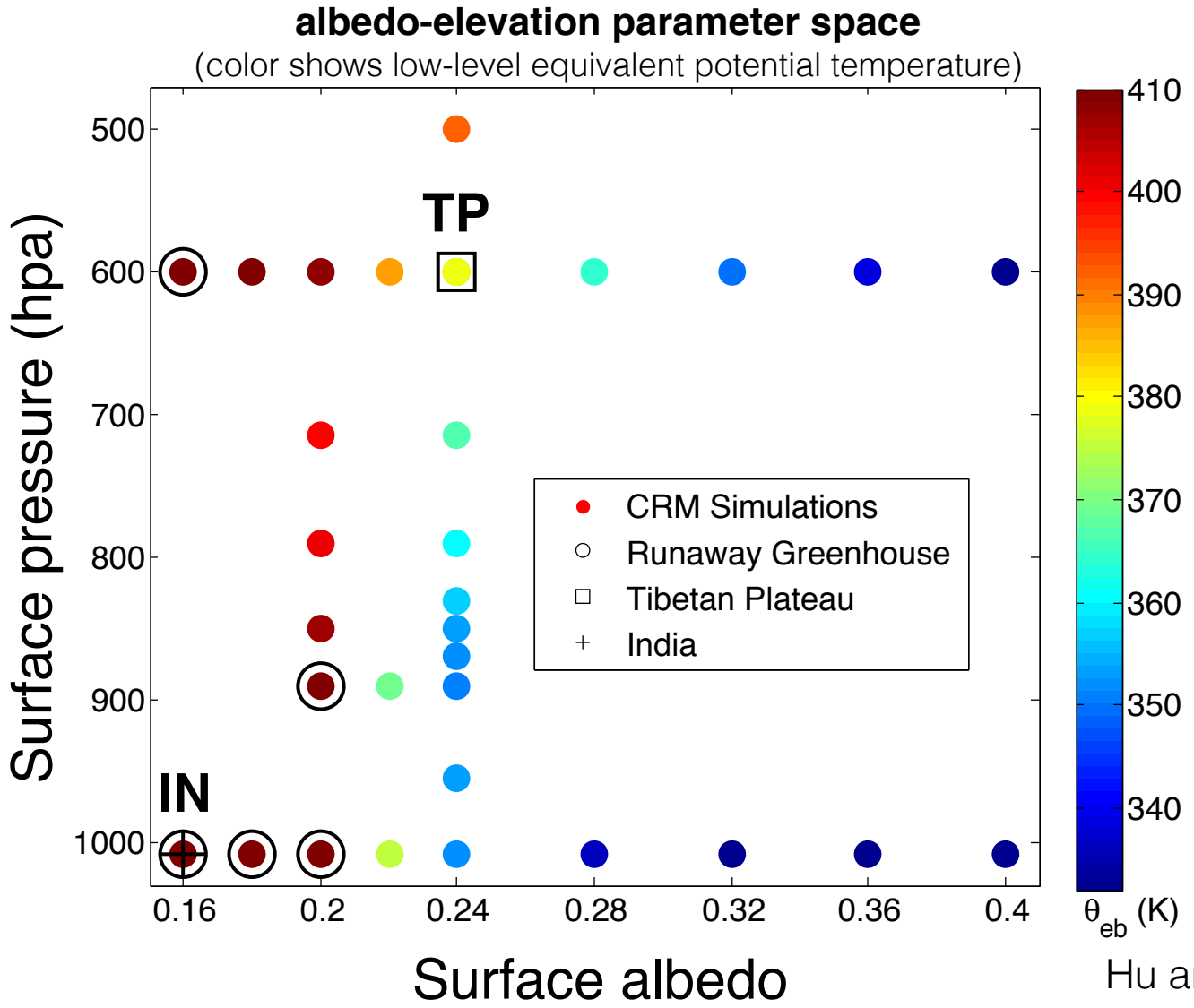
Hu and Boos (in prep.)

How much of Tibet's elevated heating is cancelled by high surface albedo?

Study this using simulations of radiative-convective equilibrium in a cloud-resolving model.



Tibet's high surface albedo more than compensates for its elevation in effects on upper-tropospheric temperature



Hu and Boos (in prep.)

We have a theory for “elevated heating”; its magnitude depends on radiative-convective physics

$$\frac{dR}{dz_s} \equiv \frac{dISR}{dz_s} - \frac{dOLR}{dz_s}$$

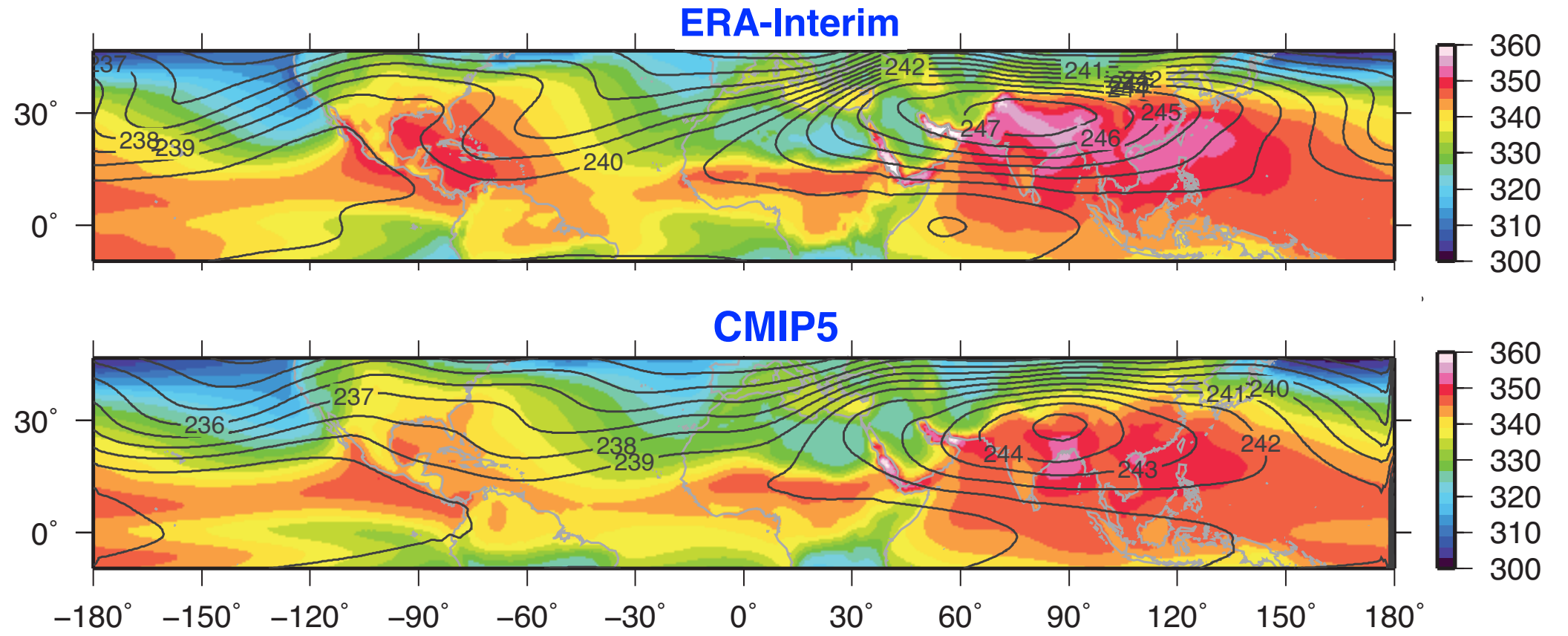
$$\approx \frac{dISR}{dz_s} - \left(\frac{\partial OLR}{\partial \tau_{co_2}}\right)_{T,\tau_{H_2O}} \left(\frac{d\tau_{co_2}}{dz_s}\right) - \left(\frac{\partial OLR}{\partial \tau_{H_2O}}\right)_{T,\tau_{CO_2}} \left(\frac{\partial \tau_{H_2O}}{\partial z_s}\right)_T - \left(\frac{\partial OLR}{\partial T}\right)_{\tau_{CO_2}} \left(\frac{dT}{dz_s}\right)$$

$$= \text{SW} - \text{LW}_{\text{CO2}} - \text{LW}_{\text{H2O}} - \text{LW}_{\text{LAPSE}}.$$

correctly representing “elevated heating” in a model requires accurate simulation of radiative transfer and moist adiabats

How well do climate models represent monsoon thermodynamic state?

(Contours: 200-400 hPa temperature; Colors: surface air moist static energy)



--> Asian thermal maximum too oceanic and too weak

--> Asian upper-level temperature maximum doesn't penetrate far enough into Africa

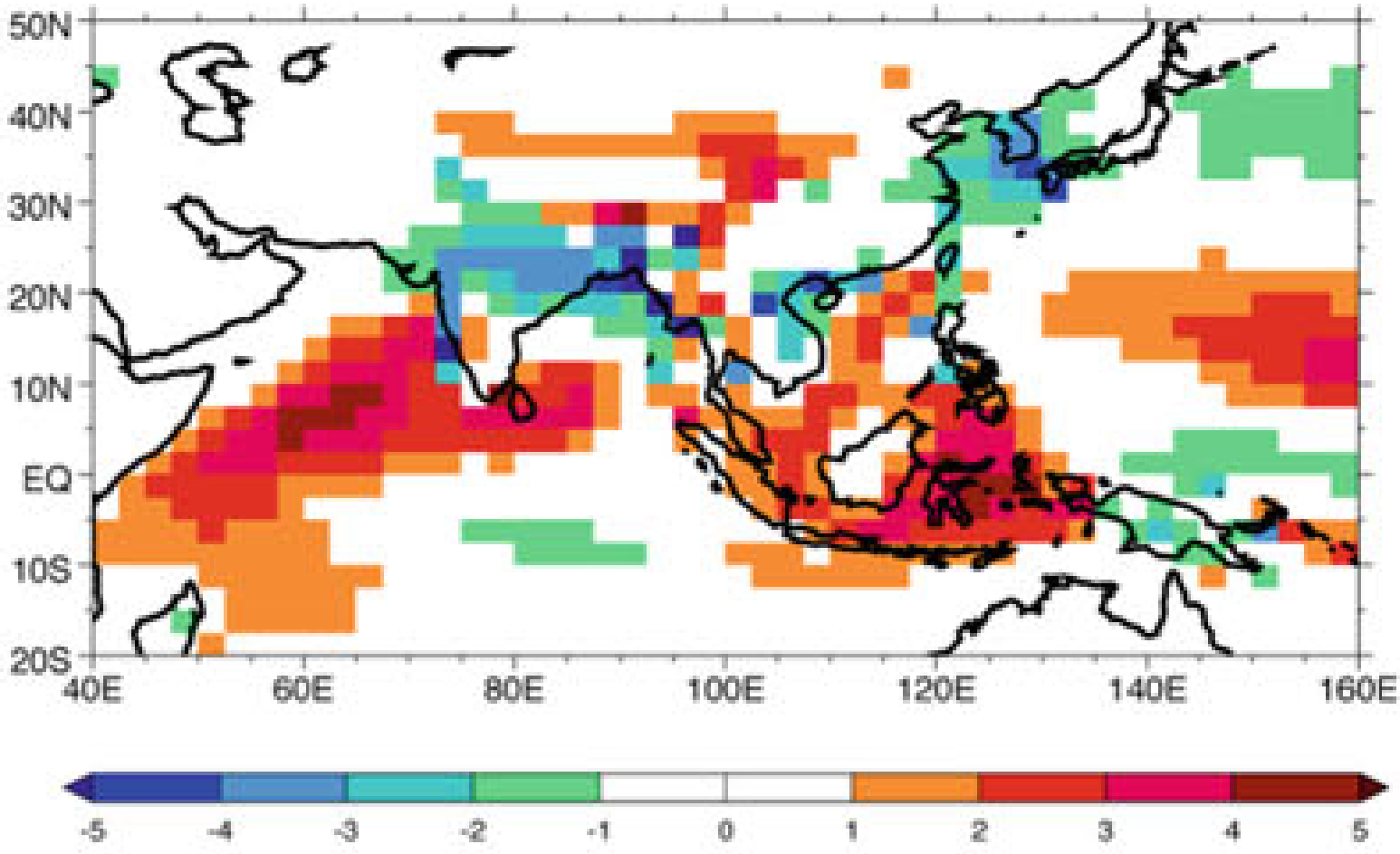
--> North American "ridge" too weak

--> Model upper-level temperature too cool

Boos & Hurley (2013)

The bias of energy content being too low over continental India is accompanied by too little rain there

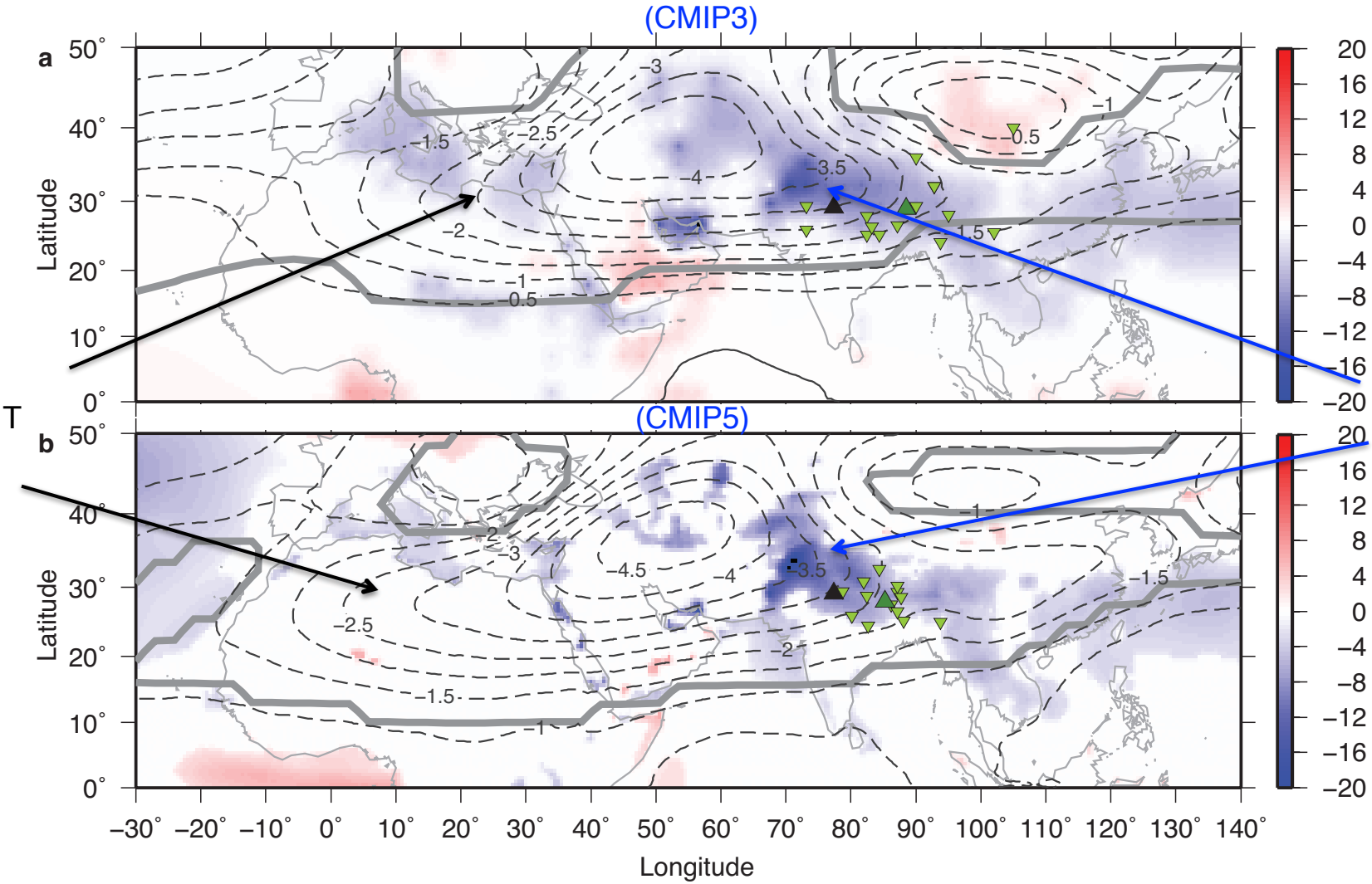
CMIP5 multi-model mean precip bias (relative to GPCP, mm/day)



Sperber et al. (2013)

Strongest bias over South Asia

Bias in multi-model mean surface h (colors, K) and
upper-tropospheric T (contours, negative dashed, K), all relative to ERA-Interim.
Thick grey contour surrounds statistically significant upper-tropospheric T bias

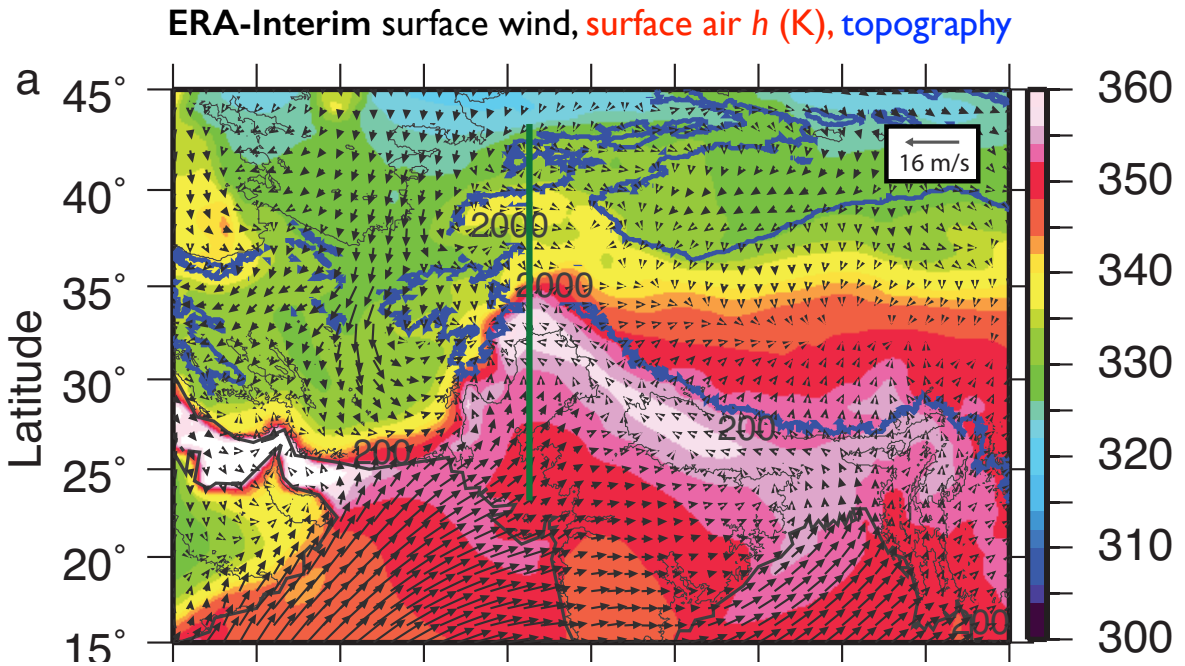


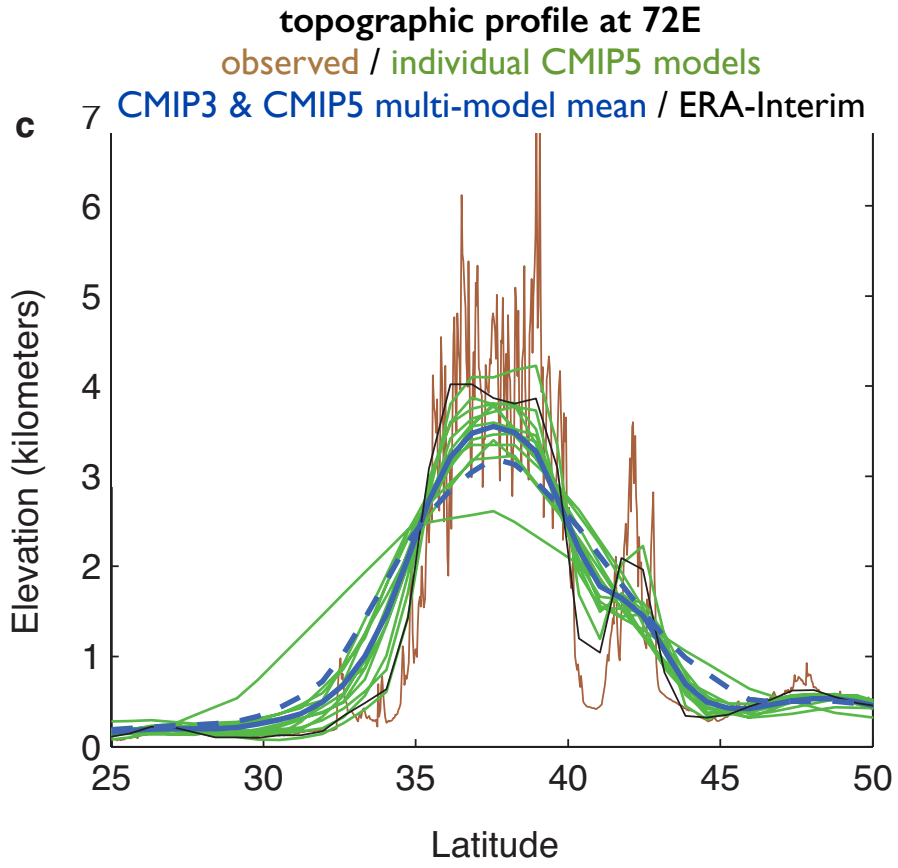
Negative upper-level T anomaly spreads westward

Negative h anomaly over northern India & Pakistan

Boos & Hurley (2013)

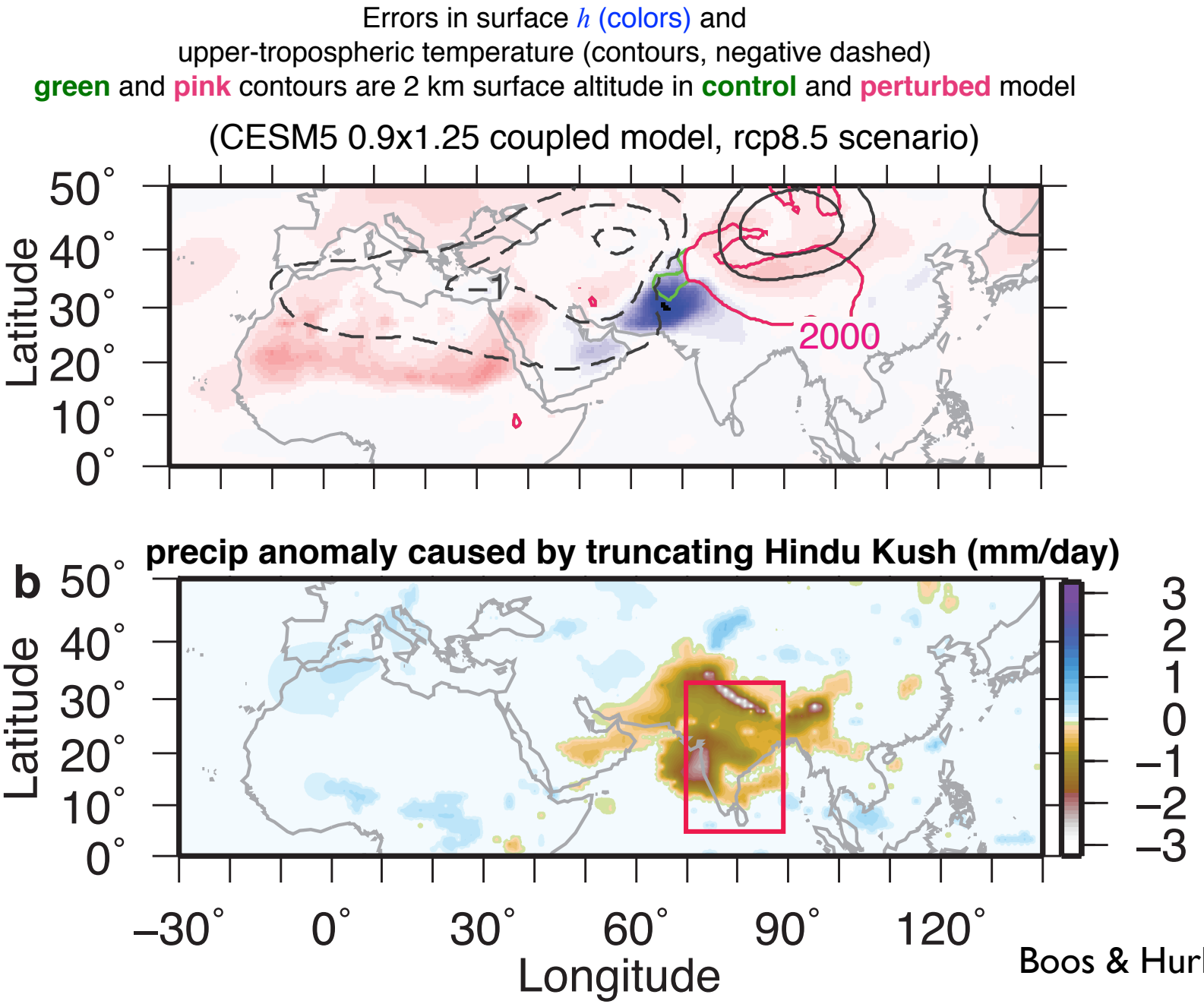
Structure of bias suggests ventilation from overly smoothed topography





Boos & Hurley (2013)

Relatively small truncation of topography west of Tibet creates large dry bias over India



Boos & Hurley (2013)

Summary

- Topography influences multiple regional monsoons in multiple ways, but obviously increases monsoon strength greatly in South Asia.

- Tibet is not the dominant thermal forcing for the South Asian monsoon. “Elevated heating” operates, but is overcompensated by surface albedo so that India would be warmer than Tibet in radiative-convective equilibrium.

- Topography instead creates a strong monsoon by preventing dry air intrusions into the moist monsoon domain. Coarse resolution models will likely allow too much ventilation of the monsoon by dry desert air unless there are compensating errors (e.g. in surface albedo) or some subgrid-scale topographic blocking scheme.