Regional Climate Modeling to Understand Tibetan Heating Remote Impacts on East China Precipitation

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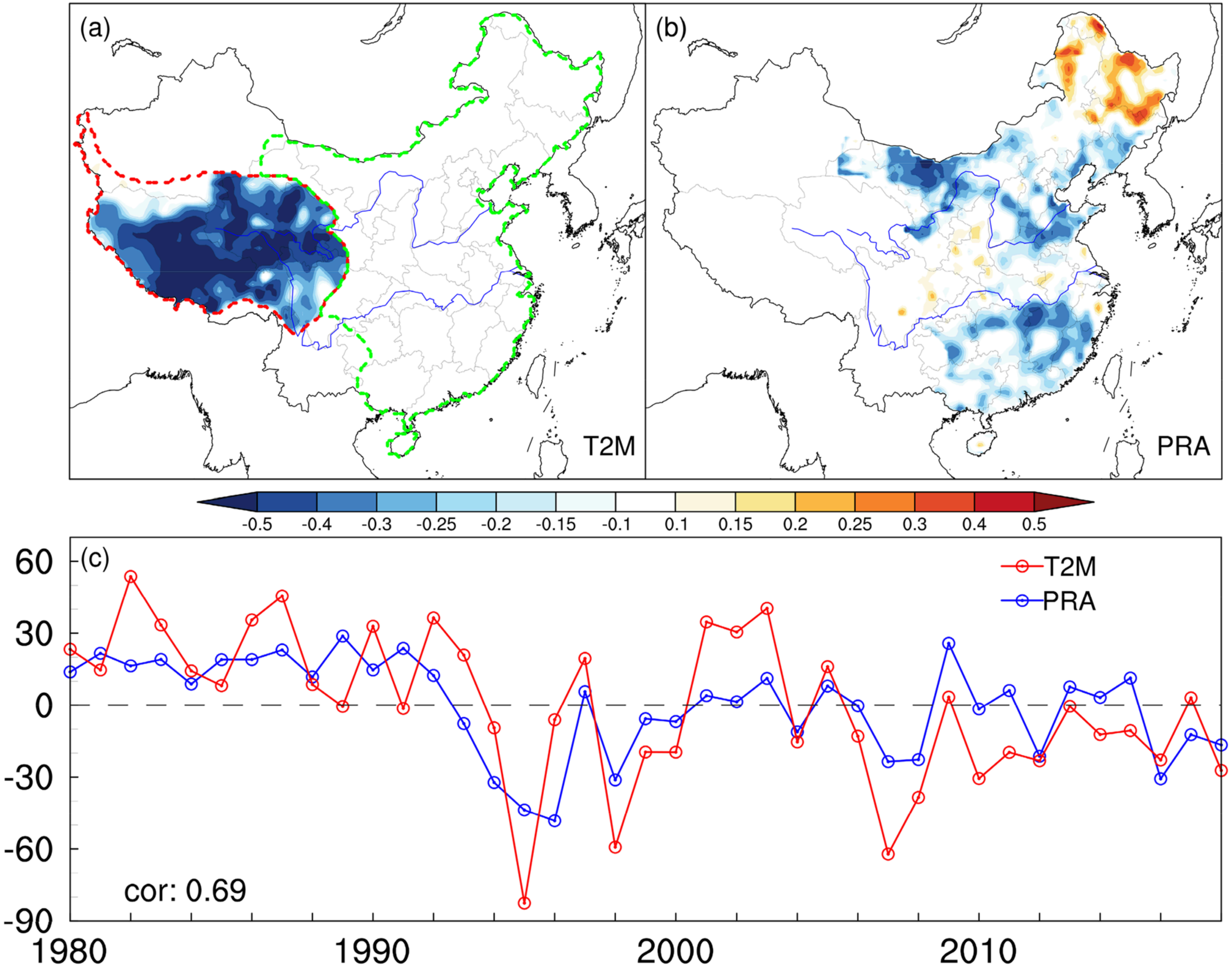
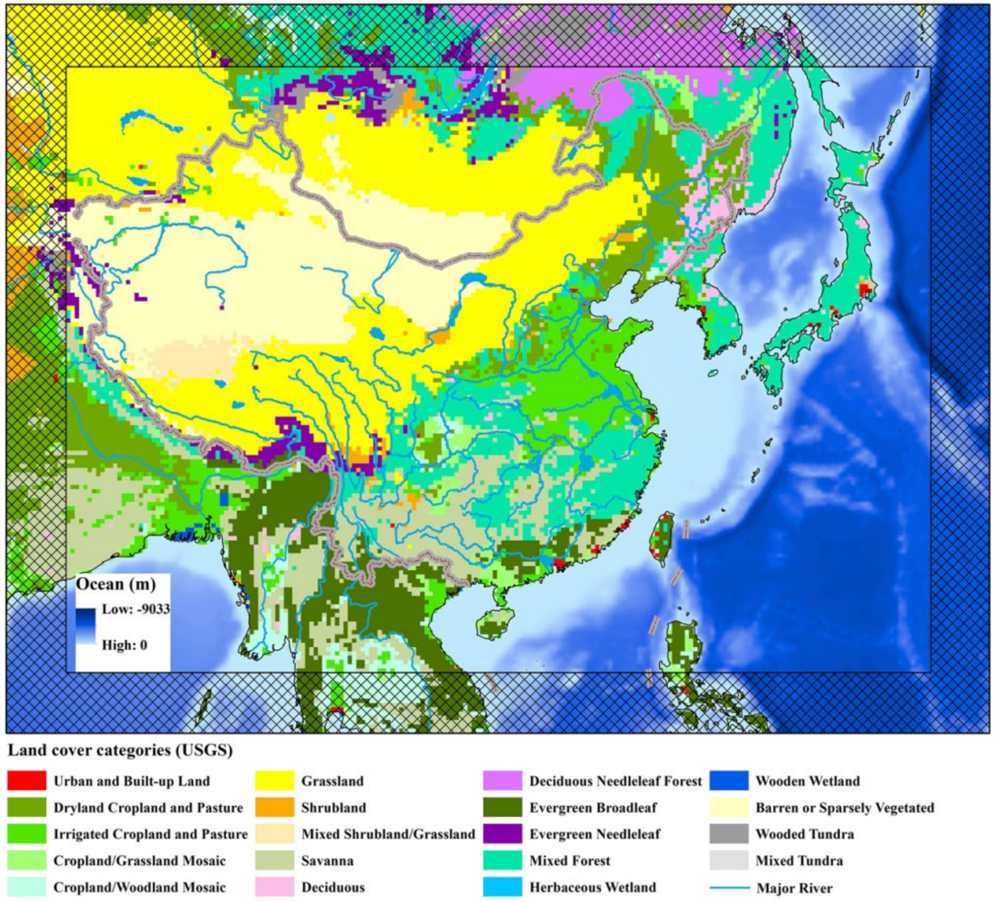
Observed Teleconnection

The coupled spatial patterns of the first SVD mode for **(a)** May air temperature with the key signals over TP (within the red dashed line, terrain height above 4000 m) and **(b)** summer precipitation with the key signals over eastern China (within the green dashed line in **a**) as well as **(c)** the time series of their respective expansion coefficients.



This coupled mode explains 42.5% of the spatial covariance between the two fields with an interannual temporal correlation of 0.69 between their expansion coefficients.

CWRF Experiment Design



Grid: 30km 36 levels
Driving: ERR-Interim

Experiment abbreviation	Control initial state (I) b=balanced, n=not	Soil temperature perturbation (T) p=perturbed, n=not	Soil water phase change (W) c=changed, n=not
InTnWn	Not (n)	Not (n)	Not (n)
InTpWn	Not (n)	Yes (p)	Not (n)
InTpWc	Not (n)	Yes (p)	Yes (c)
IbTnWn	Yes (b)	Not (n)	Not (n)
IbTpWc	Yes (b)	Yes (p)	Yes (c)

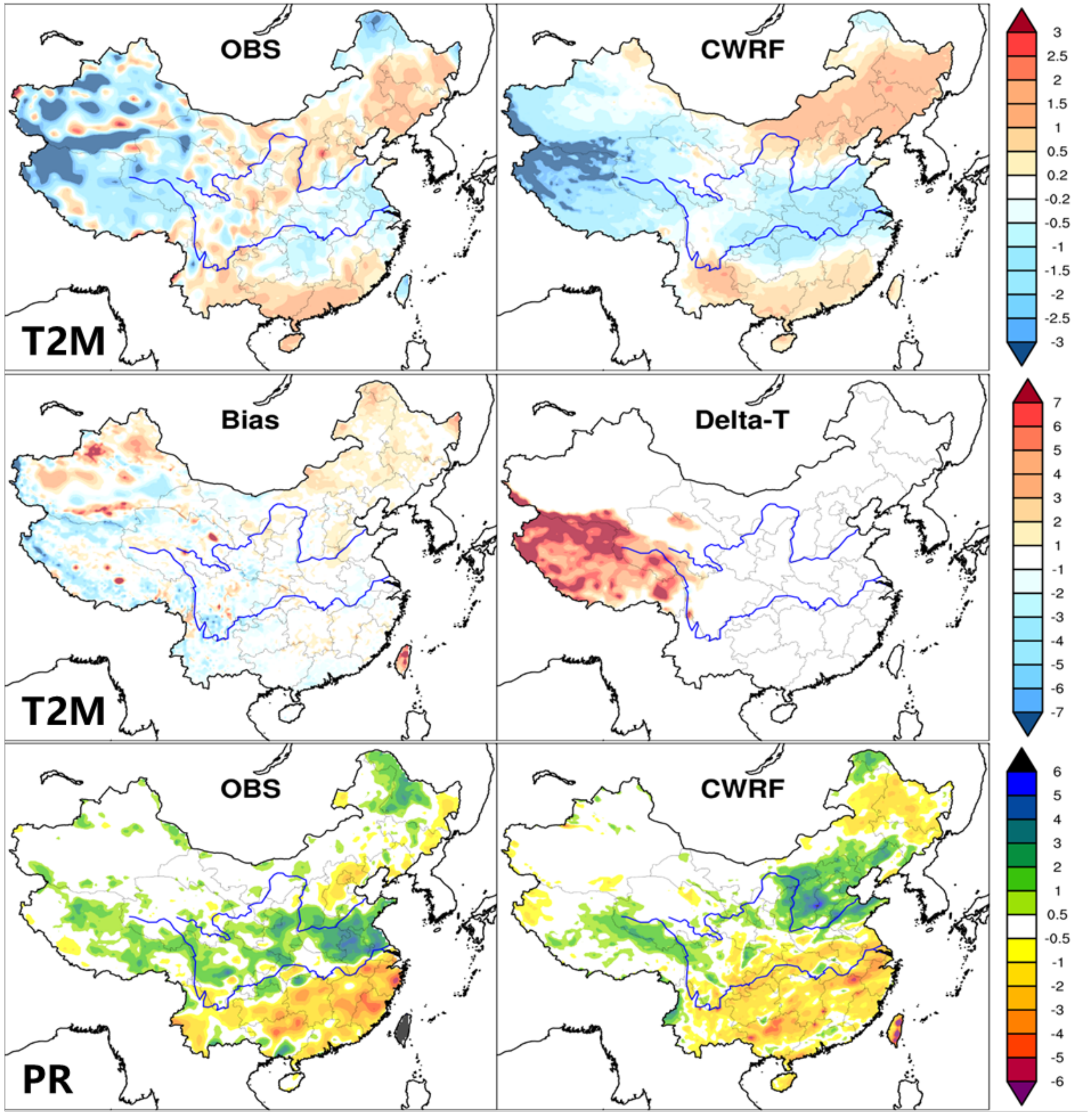
Control run:
May 1 – Dec 31, 2003
Ten IC realizations (April 22 to May 1 at a daily interval)

Sensitivity run:
Impose perturbations to the *initial* conditions of surface and sub-surface soil temperatures in TP with or without soil moisture adjustment for freezing/melting

Observed and Simulated 2003 China Anomalies

CWRF well captures 2003 observed climate anomalies:

- Spring cold anomaly over TP, shown for T2m in May
- CWRF tends to have cold T2m biases (relative to sparse observational data) over TP
- Summer drought in the south and heavier rainfall in the north of the Yangtze River as well as above normal rainfall in the Northeast

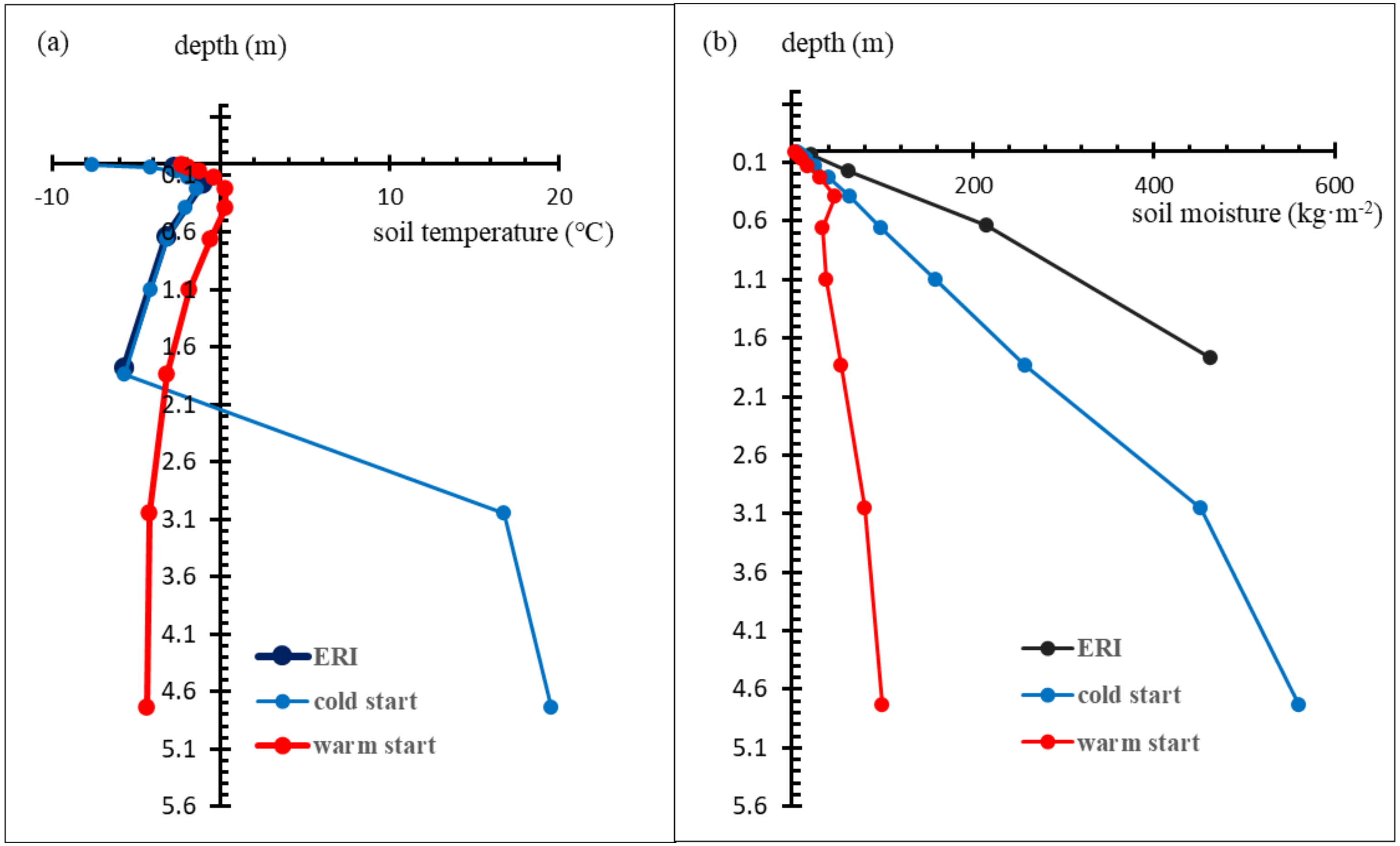


Sensitivity to Initial Conditions

Cold Start:
Initial conditions come directly from driving climate model or reanalysis data

Warm Start:
Initial conditions come from restart data of the CWRF long-term simulation

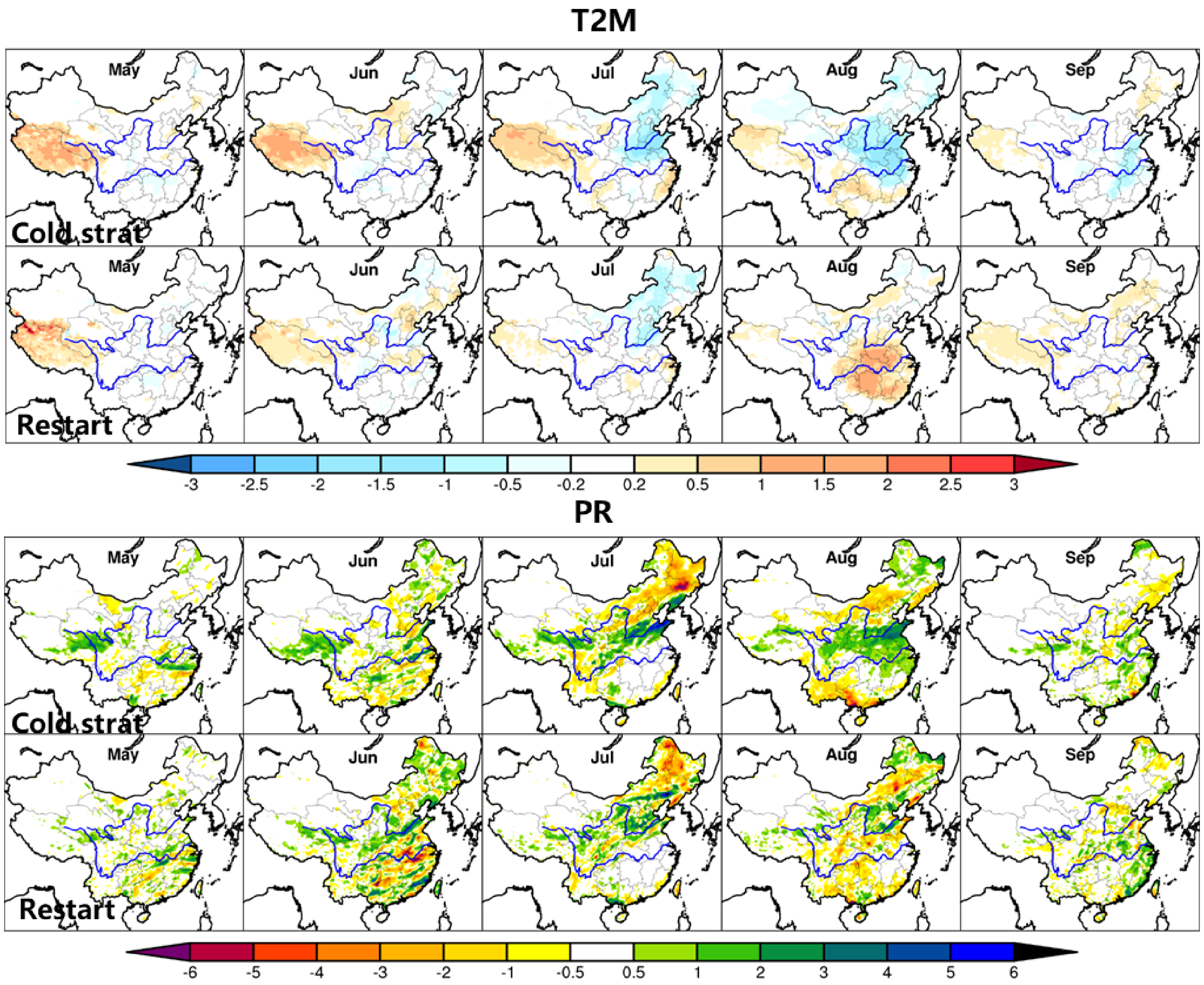
- It's critical to incorporate into the initial perturbation the **soil water phase change** according to the soil temperature change because the latent heat of melting ice is ~ 78 times the specific heat of liquid water per K.
- Otherwise, the initial perturbation would dissipate rapidly during the first few days because the imposed temperature forcing makes most grids in TP rise from below to above the freezing point and that extra heat is quickly consumed to melt the existing ice.



Initial conditions on May 1st of 2003 from ERI data and CWRF cold and warm start for **(a)** soil temperature (ºC) and **(b)** soil moisture (kg m^{-2}).

Sensitivity to Initial Conditions

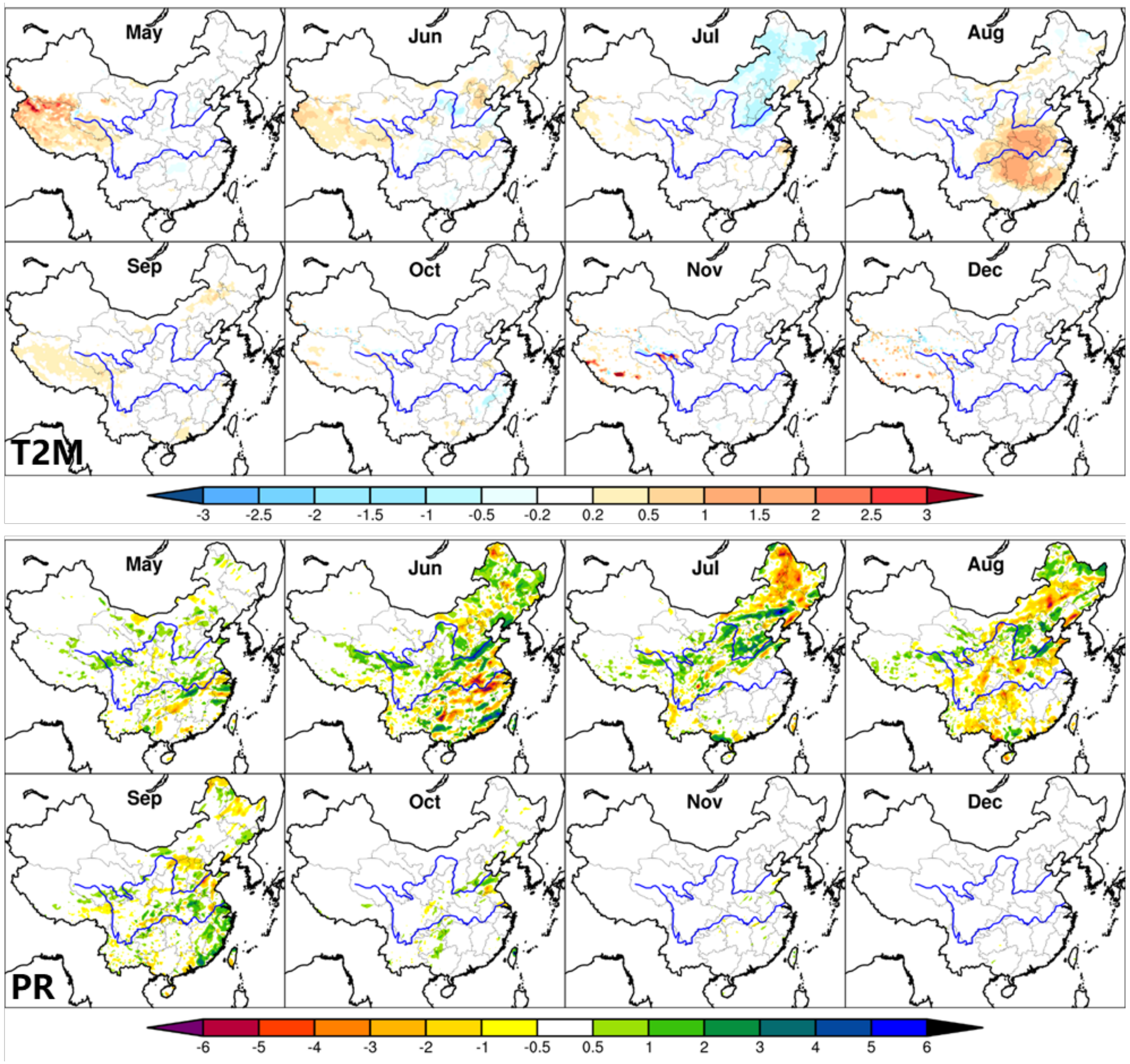
- Different ICs have great effects, especially temperature in August and precipitation throughout June to August
- Consistently, the Tibetan plateau heating effects can continue beyond summer
- ERI provides no soil ice content, which makes the CWRF cold start even more arbitrary as soil temperature crosses the freezing point
- Most climate models do not explicitly predict frozen or ice soil moisture and thus may not directly encounter such water phase change issues
- The warm start from CWRF's 36-years (1980–2015) continuous integration offers a more realistic initial state where soil temperature and moisture in both liquid and ice phases are fully balanced



Tibetan Plateau Heating Effects on Climate

- Soil ΔT IC perturbations induce significant effects on 2m temperature and precipitation *locally* and *remotely*, which can persist for up to five months

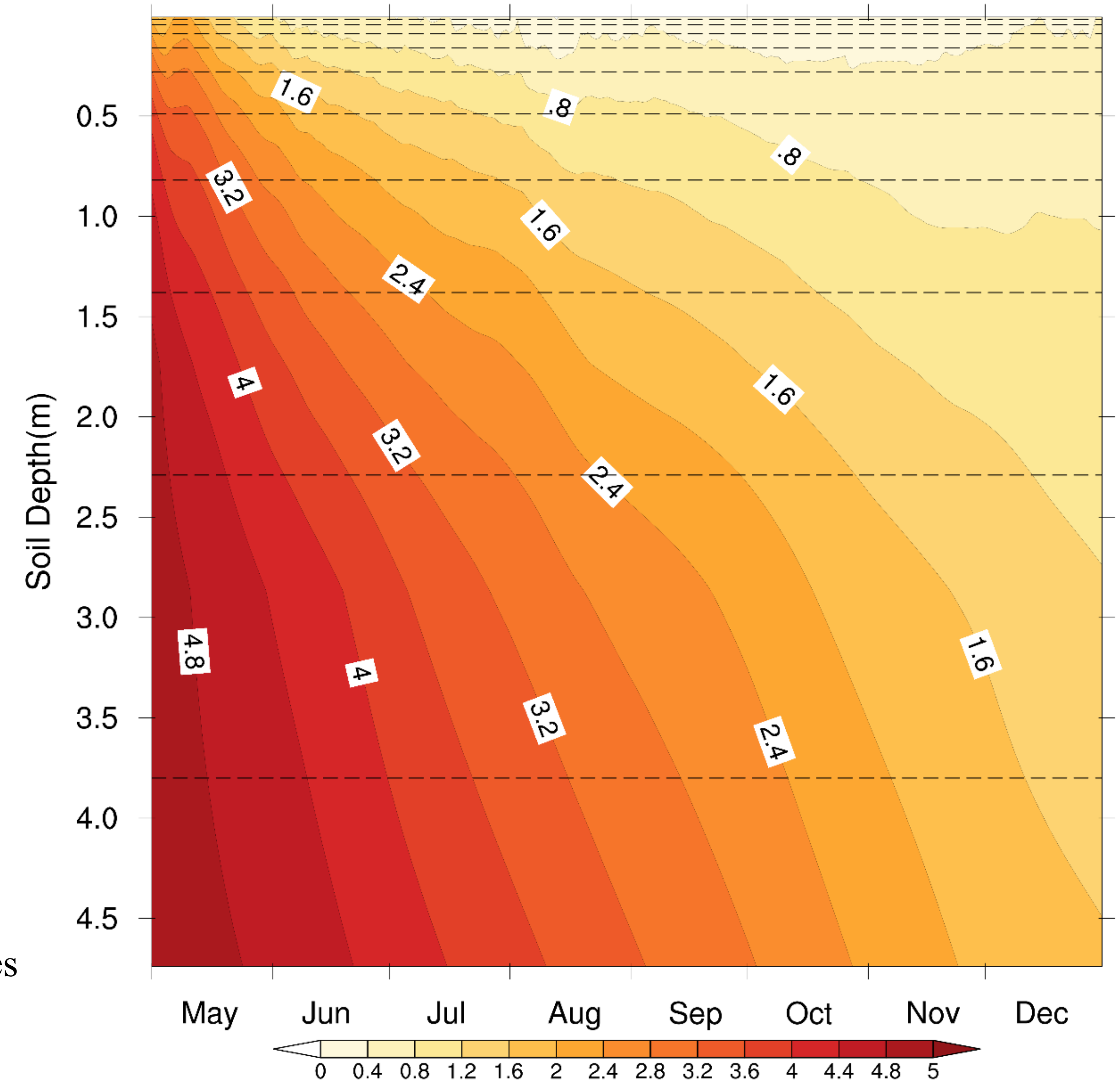
- CWRF retains a portion of the initial forcing to reduce the systematic cold bias in the May air temperature anomaly by almost half (-0.73 versus -1.41°C)



Colored are significant by *t-test* at the 95% confidence

Longer Temperature Memory in Deeper Soil

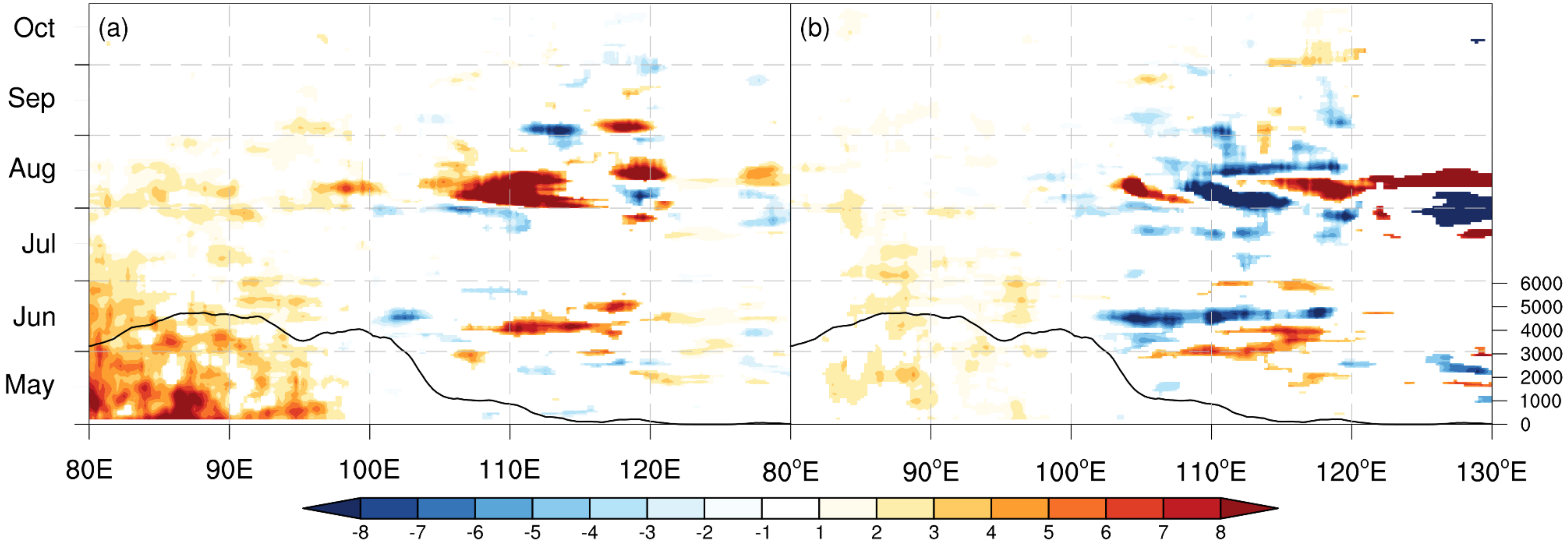
- Initial perturbations can be preserved in the soil and the ability of soil to remember temperature perturbation increases with depth
- The continuous temperature gradient makes the heat transfer to the surface and the atmosphere, which makes the impcat of perturbations last for a long time, beyond 6-8 months



Depth-day variations of the TP-averaged soil temperature differences between the warm start IbTpWc and IbTnWn. The dashed lines depict interfaces between model soil layers.

Surface-Atmosphere Interaction Response

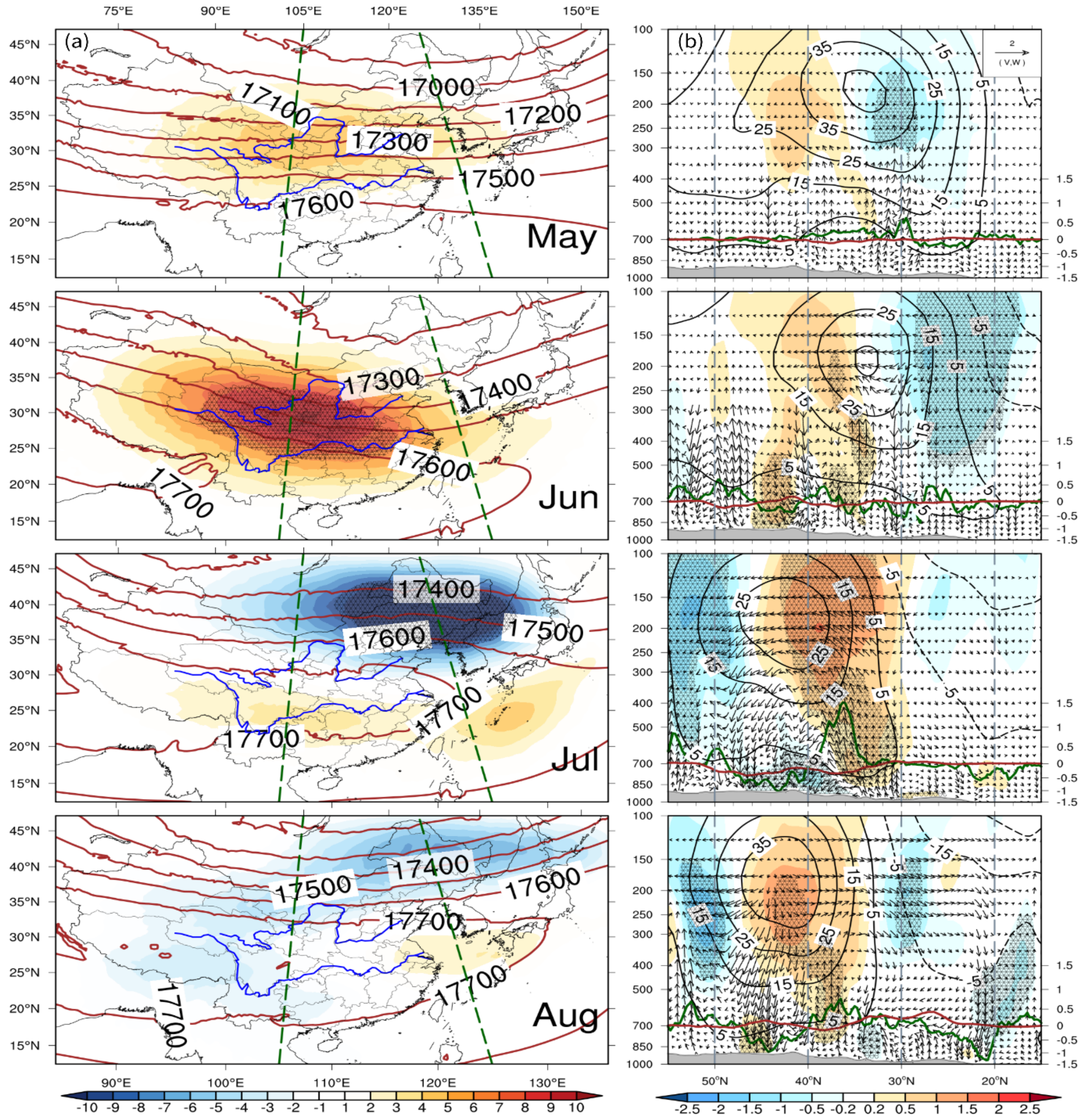
The soil temperature evolution reveals a robust energy transfer path through the surface sensible and latent heat fluxes, affecting surface-atmosphere interaction and circulation



CWRF simulated day-longitude variations of 27°-37°N latitudinal mean surface (a) sensible and (b) latent heat flux (W m-2) differences between the warm start IbTpWc and IbTnWn. The black lines depict the latitudinal mean terrain elevation (m), using the scale on the right.

Atmospheric Circulation Response

- The condensation latent heat and vertical energy transport by the enhanced moist convection as well as the induced stronger subsidence and adiabatic heating collaborate to produce widespread warming in the mid-upper troposphere beyond the TP forcing area
- The South Asian High (SAH) pressure system and its counterpart trough over northeast China is intensified in summer, transporting more momentum of northerly & westerly wind to strengthen the East Asian westerly jet

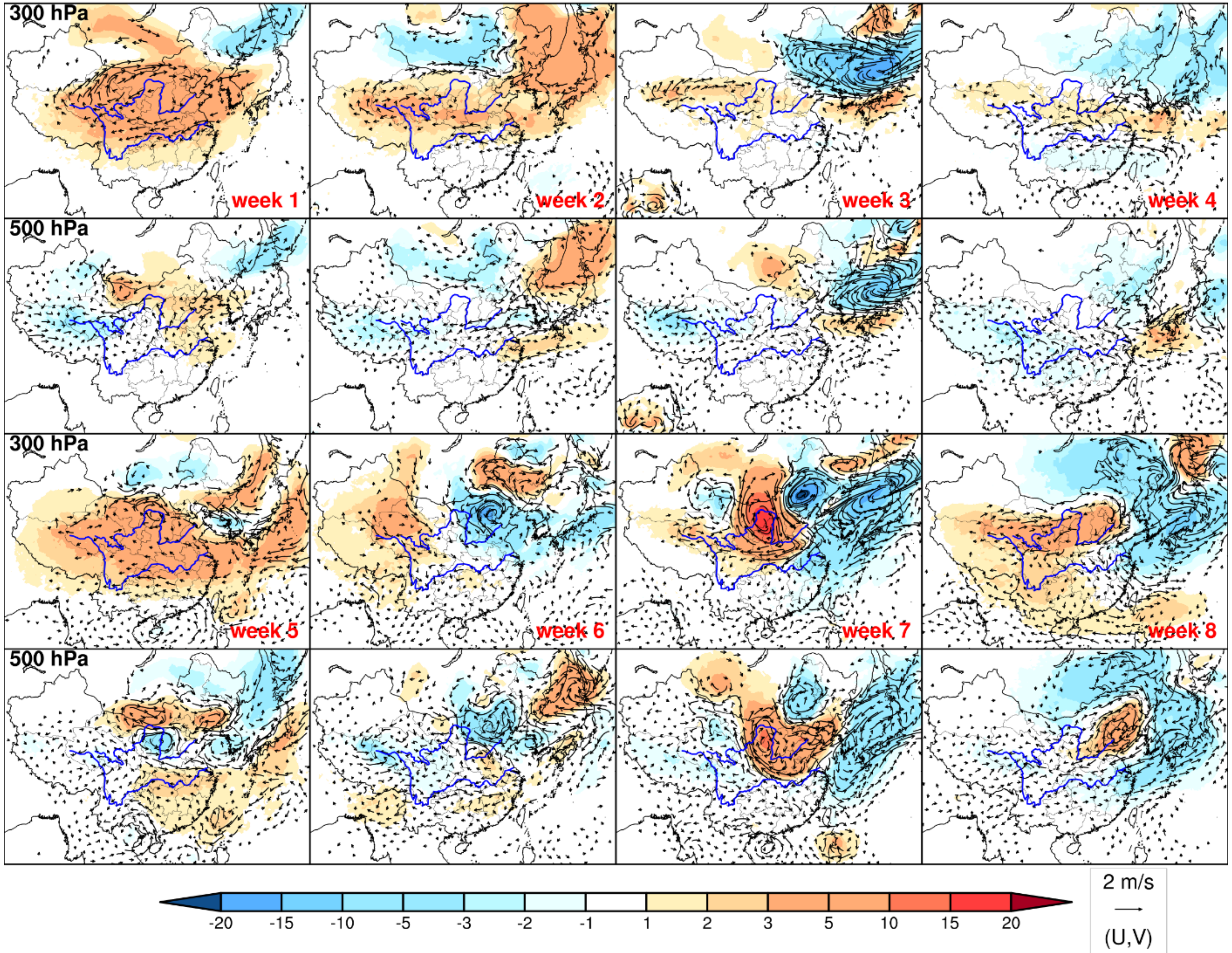


(a) 100-hPa geopotential height (colors, m) differences and control values (red contours, m); **(b)** the zonal (m s^{-1}) and meridional (m s^{-1})/vertical (10^{-4} hPa s^{-1}) wind components are represented by contours and vectors, respectively

Colored are significant by *t-test* at the 95% confidence

Rossby Waves Response & Propagation

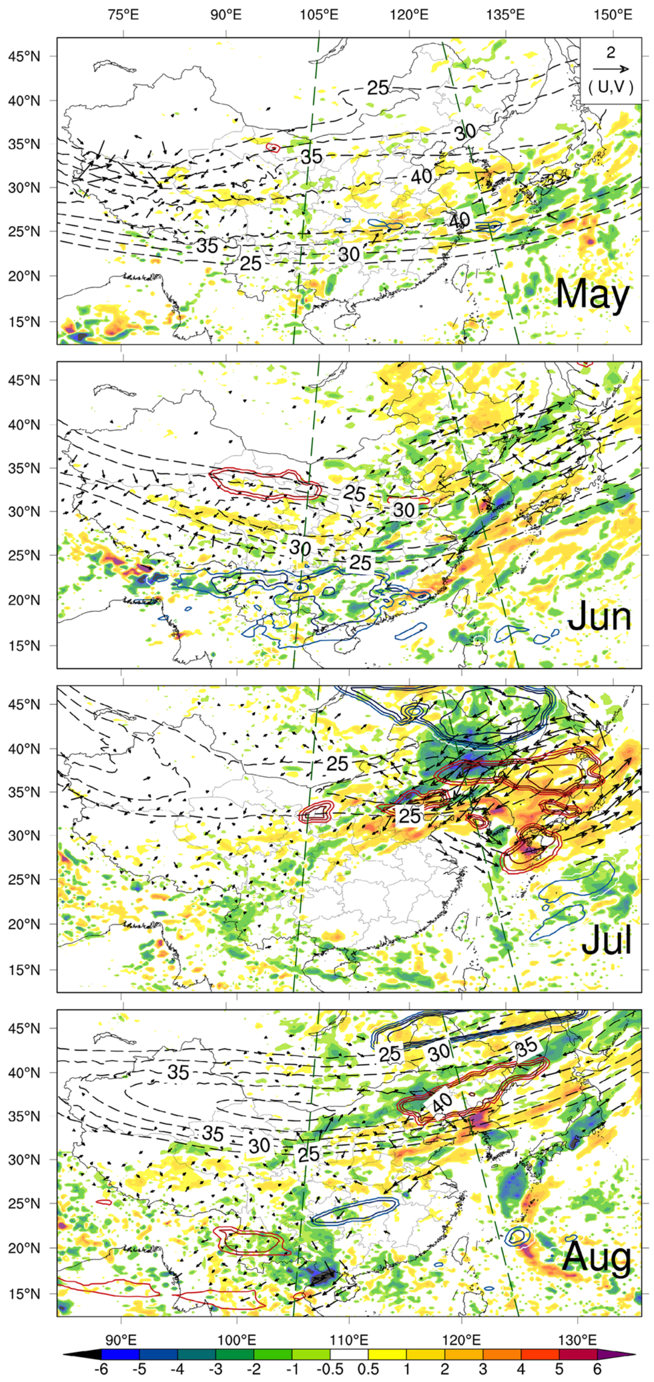
- The energy and momentum transports are accomplished through Rossby waves with significant vorticity anomalies induced by the TP heating
- These waves are initially propagating downstream and eventually become stationary, causing important circulation anomalies over the ULJ exit



CWRF simulated 300-hPa and 500-hPa geopotential height (color, gpm) and horizontal wind (vector, m s^{-1}) differences between the warm start IbTpWc and IbTnWn initiated on May 1 for the following weeks 1 to 8.

East Asian Jet Shift & Precipitation Change

- A major signal occurs in July when the mean ULJ core locates right above the Northeast and is accompanied by significant positive (negative) perturbations to its right (left) exit. This indicates the ULJ is shifted southward, which is associated with a strong low-level cyclonic circulation anomaly across the Northeast coasts, Yellow Sea, Korean Peninsula, Sea of Japan, and Japan
- A south shift of the ULJ induces a secondary circulation across the jet exit region with upward (downward) motions to the right (left). Consequently, a pronounced cooling and drier center occurs over the Northeast, whereas a heavier rainfall center appears in North China and across the Yellow Sea, Korea to Japan
- These anomalous changes weaken in August



CWRF simulated monthly (May–August) mean differences between the warm start IbTpWc and IbTnWn in 850-hPa horizontal wind (vector, m s^{-1}), 200-hPa zonal wind (contour, ±{0.5, 1.0, 1.5} m s^{-1}) and precipitation (color, mm day^{-1}), overlaid with IbTnWn 200-hPa zonal wind speeds in dashed contours (staring from 25 at an interval of 5).

Conclusion

- A positive temperature forcing imposed over the Tibetan Plateau on the surface and subsurface soil layers only at the initial conditions quickly induces positive perturbations in local air temperature and maintains its signal in local soil, especially deep layers, from spring through summer
- The energy and momentum transports are accomplished through Rossby waves with significant vorticity anomalies induced by the TP heating, which initially propagate downstream and finally become stationary
- The primary mechanism that keeps the long memory outside the TP forcing area is likely preserved in the atmospheric circulation anomalies, and the altered SAH and ULJ circulation features are responsible for the summer temperature and precipitation changes in East China