Dynamic pathway linking Pakistan flooding to East Asian heatwaves

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Motivation

In July–August 2022, Pakistan suffered historic flooding while record-breaking heatwaves swept southern China, causing severe socio-economic impacts. Similar extreme events have frequently coincided between two regions during the past 44 years, but the underlying mechanisms remain unclear.

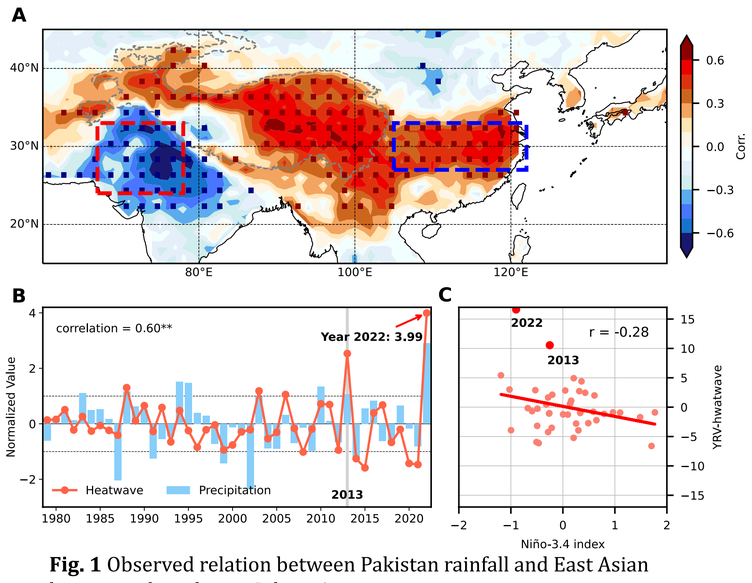

Fig. 1 Observed relation between Pakistan rainfall and East Asian heatwave days during July to August.

Two hypotheses

1. SST forcing modulates Pakistan rainfall and East Asian heatwaves at the same time.
2. The two extreme events are dynamically intrinsic to climate system.

Research questions

1. How do SST forcing, such as ENSO, and internal variability contribute to the strong co-occurring tendency between Pakistan flooding and East Asian heatwaves?
2. What is the dynamic pathway through which Pakistan rainfall exerts influence on East Asian climate, especially long-lasting heatwaves?

Co-variability of Pakistan flooding and East Asian heatwaves

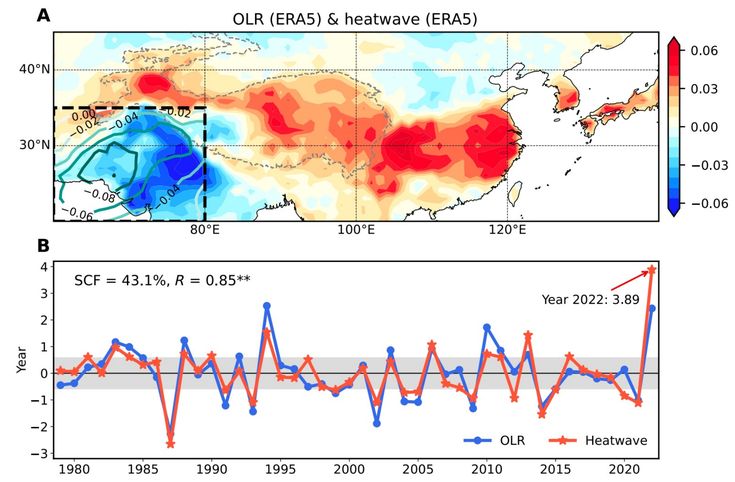

Fig. 2 Coupled pattern between July through August averaged northwestern South Asian convection and East Asian heatwaves.

The coupled mode captures the overall convection intensity (All Indian rainfall index) and interannual variability (EOF1) of Indian summer monsoon.

Similar extreme events are well-identified in 2010, 2013, and 2022.

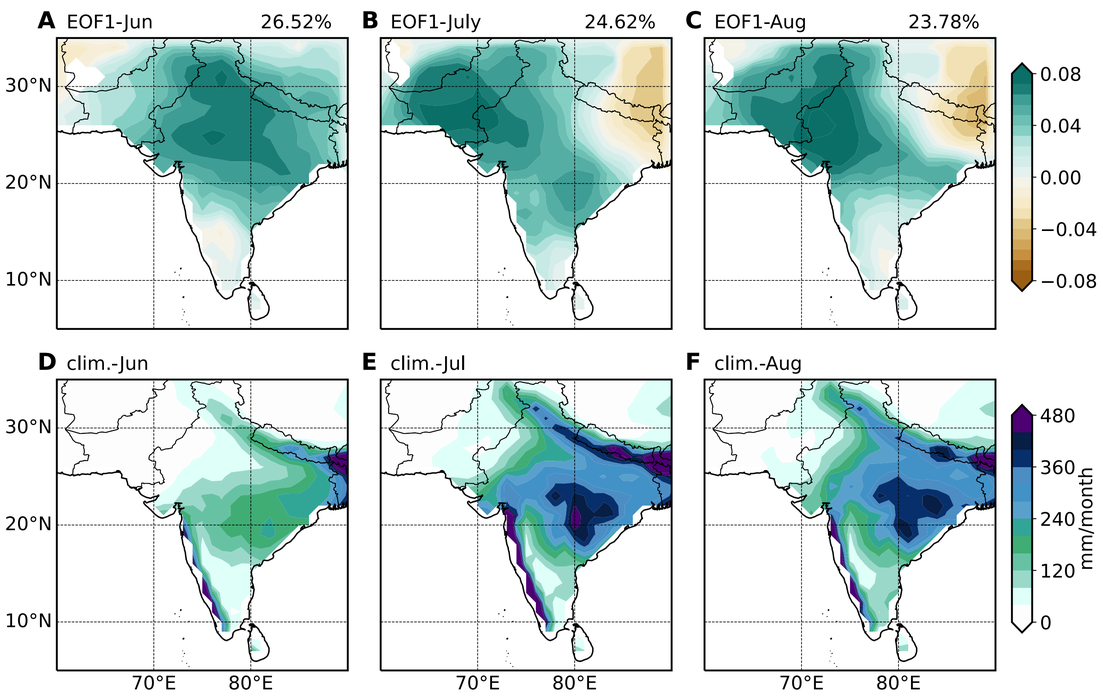

Fig. 3 Variability and climatology of Indian summer monsoon rainfall.

Atmospheric dynamic processes

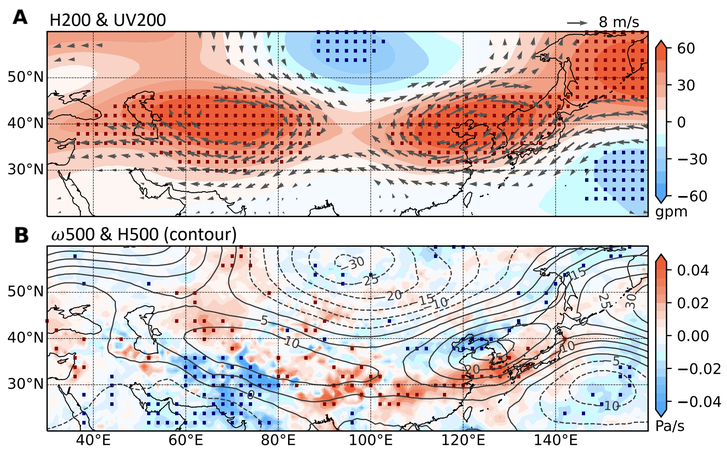

Fig. 4 Atmospheric circulations associated with the coupled mode of Pakistan flooding and East Asian heatwaves.

Two anti-cyclones (AACs) over the western (baroclinic) and eastern (barotropic) of the Tibetan Plateau, respectively.

Upward anomalies over Pakistan and downward anomalies over East Asia on the south flank of the AACs.

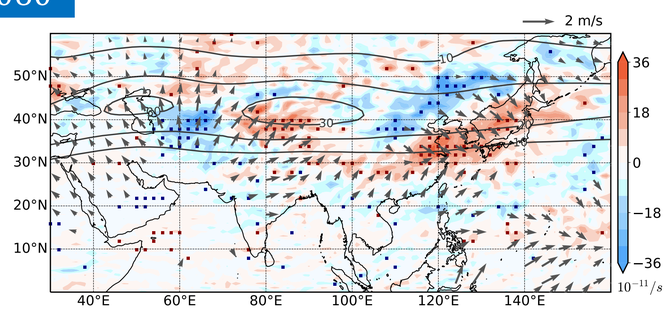

Fig. 5 Rossby wave source (RWS; shading) and divergent wind (vectors) anomalies at 200 hPa. The climatology of the mean zonal wind (contours) is overlaid.

Divergent flow produces a negative Rossby wave source (RWS) near the subtropical westerly jet over northwestern Pakistan.

The positive RWS over the East Asia is possibly due to the strong convergence induced by locally suppressed convection

Global SST forcing versus atmospheric internal variability

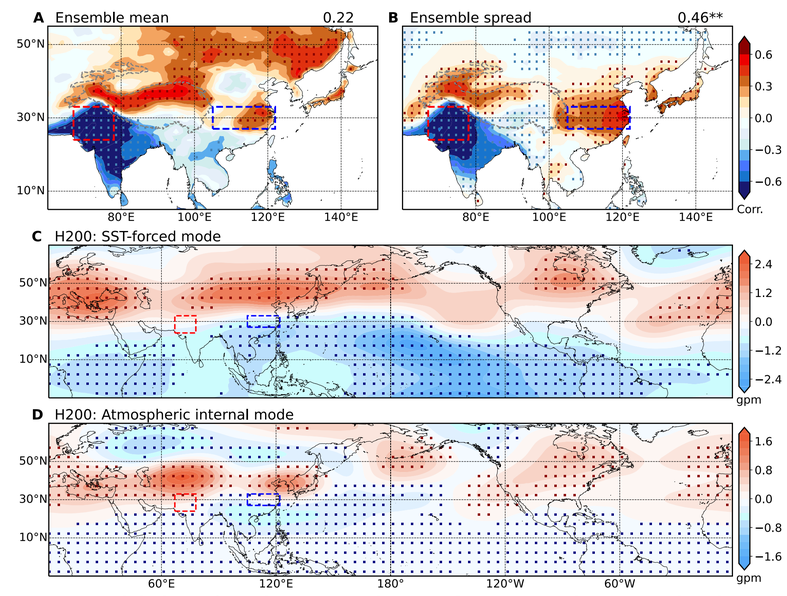

Fig. 6 Global SST-forced pattern and atmospheric internal pattern related to Pakistan convection in AMIP simulation.

Strongly positive correlations (0.46 for 1140-yr) in ensemble spread indicate the dominant role played by atmospheric internal variability.

The atmospheric internal mode is reminiscent of the MCA mode of Pakistan convection and East Asian heatwaves.

A suite of LBM experiments: effect of convective heating

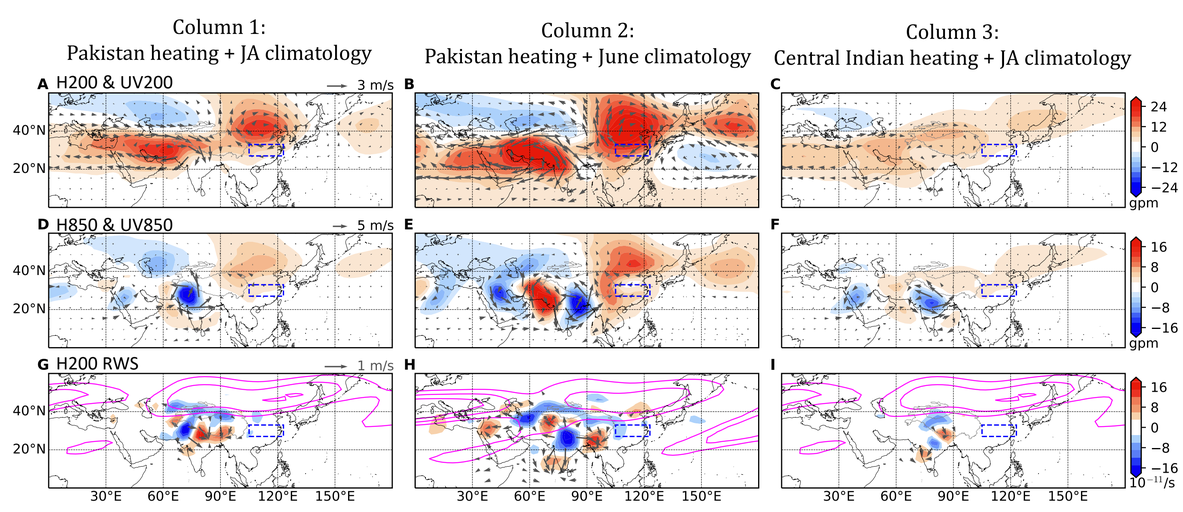

Fig. 7 Atmospheric responses to deep heating over Pakistan and central India in LBM experiments.

1. Pakistan convection could directly stimulate two observed AACs.
2. Although Pakistan convection can force a strong Rossby wave response on a June basic state, the variability and climatology of the local monsoon system may put restrictions on this response.
3. Although rainfall variability is large in midsummer over central India, it does not effectively excite the Rossby wave response due to dynamic limitations (lower-latitude and long distance from the westerly).
4. This robust waveguide and the time delay offer hopes for improved sub-seasonal prediction of extreme events in East Asia.

Take-home message

1. **Dynamic pathway:** the upper-tropospheric divergent wind induced by convective heating over Pakistan excites a stationary AAC over eastern China, which further leads to persistent heatwaves.
2. AMIP simulation indicates that this dynamic pathway is an atmospheric internal mode, largely independent of global SST forcing.
3. Pakistan is **a sweet spot** for convection to perturb the Asian westerly jet, and contributes to East Asian heatwaves during July to August.

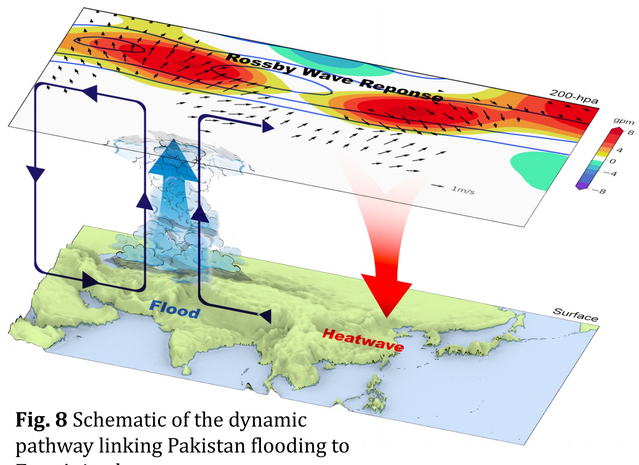

Fig. 8 Schematic of the dynamic pathway linking Pakistan flooding to East Asian heatwaves.

Publication

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