Extreme events interaction: Pakistan sea-like flood contributes to unprecedented heatwaves in East Asia

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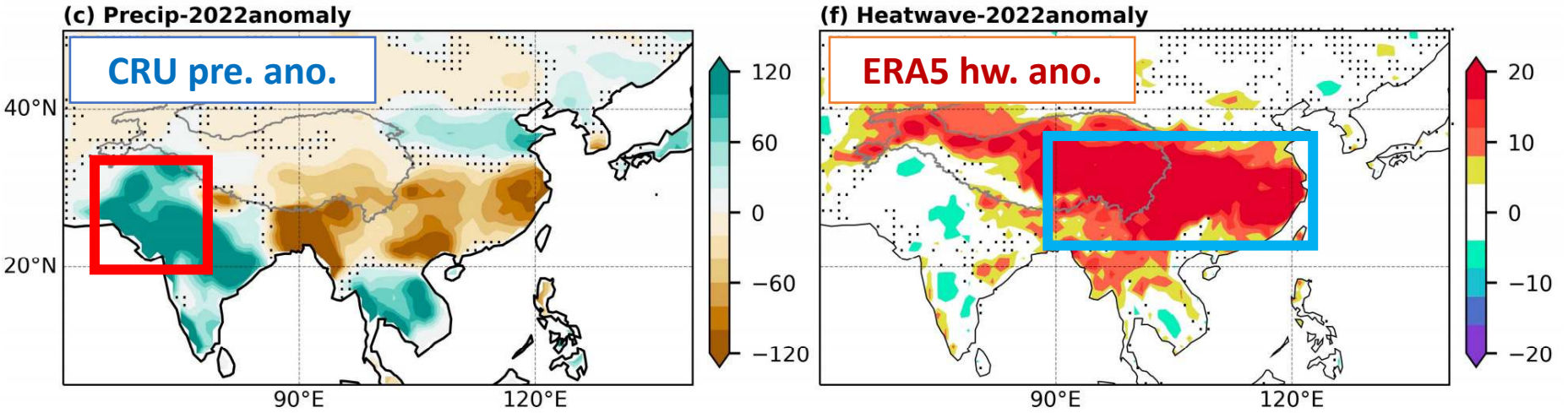
2023-12-13

Concurrent extreme events over ASM regions in 2022

ASM: Asian summer monsoon

Photo Credits:
Left: TIME
Right: BBC news

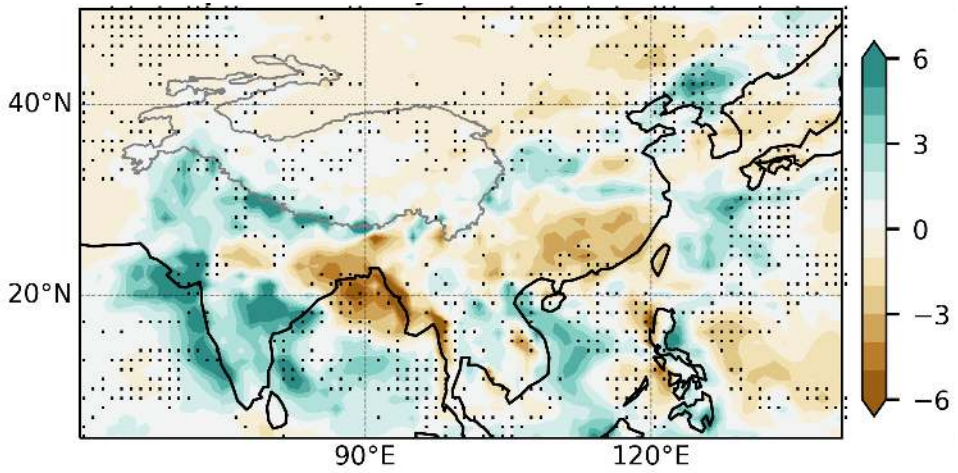


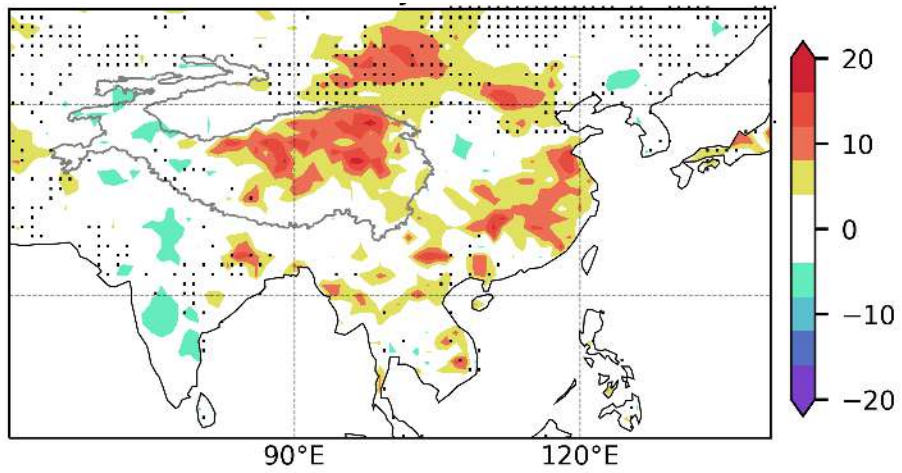
Pakistan：Devastating flooding & Southern China：Record-breaking heatwave

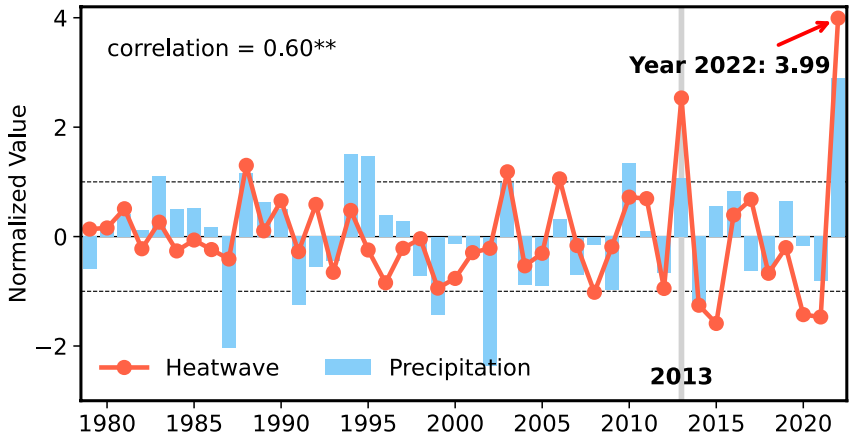
He et al. 2023; Jeong et al. 2023

Recurrent Pakistan flooding-East Asia heatwaves events

July-August 2010: mega-flooding in Pakistan & intense heatwave in southern China







- The robust in-phase relationship between the two extreme events has been noted in several studies, **but the underlying mechanisms remain to be determined.**

He et al. 2023; Liu et al. 2016

Research questions

- How do **SST forcing and internal variability** contribute to the strong co-occurring tendency between Pakistan flooding and East Asia heatwaves?

- What is the **dynamic pathway** through which Pakistan rainfall exerts influence on the climate in East Asia, especially in terms of causing long-lasting heatwaves?

Observations and reanalysis

Data

ERA5： Monthly circulations (37 vertical levels), monthly OLR, hourly T-2m max (processed to daily data) (1979-2022) Hersbach et al. 2018

CRU4.07： Land precipitation (1901-2022) Harris et al. 2020

ERA5 total precipitation; CMAP; GPCP: for **cross-validation** Xie and Arkin, 1997; Huffman et al. 1997

Data validation

NOAA： Monthly OLR (1979-2019) Liebmann et al. 1996

Berkeley Earth： Daily T-2m max (1979-2019) Rohde et al. 2020

Model experiments

CESM2-CAM6 AMIP simulation (10 member)

The CAM6 model is run at 0.95° × 1.25° horizontal resolution with 70 vertical levels, forced with historical SST during 1880-2014 from the ERSST.v5 dataset.

Ensemble mean: SST-forcing

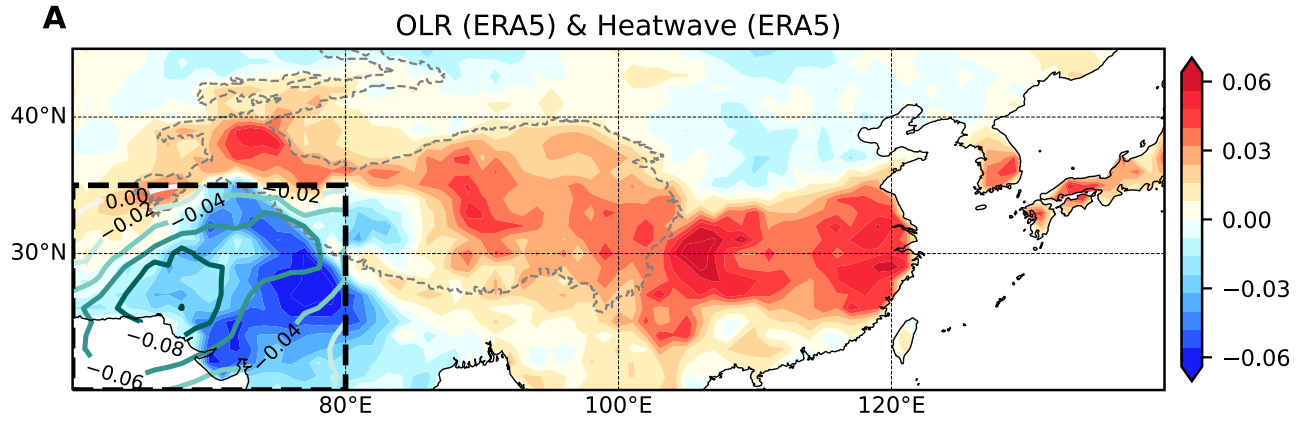
- As the 10 members share the same external forcing, the ensemble mean represents the prescribed global SST-forced variability.

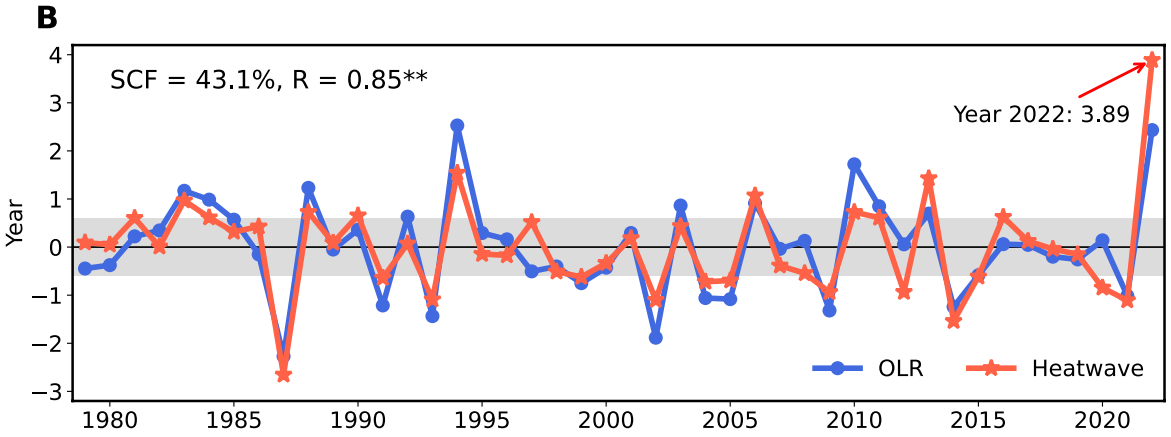
Ensemble spread: atmospheric internal variability

- We calculate the ensemble spread by subtracting the ensemble mean from each member. This will capture the atmospheric internal variability due to the randomized initial conditions of each member run.

Danabasoglu et al. 2020

Co-variability of Pakistan flooding and East Asia heatwaves

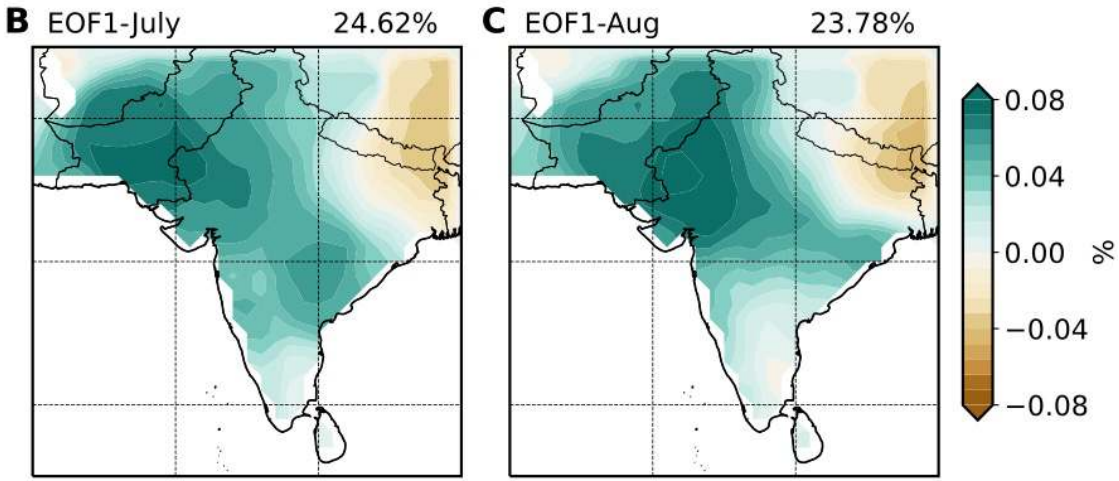




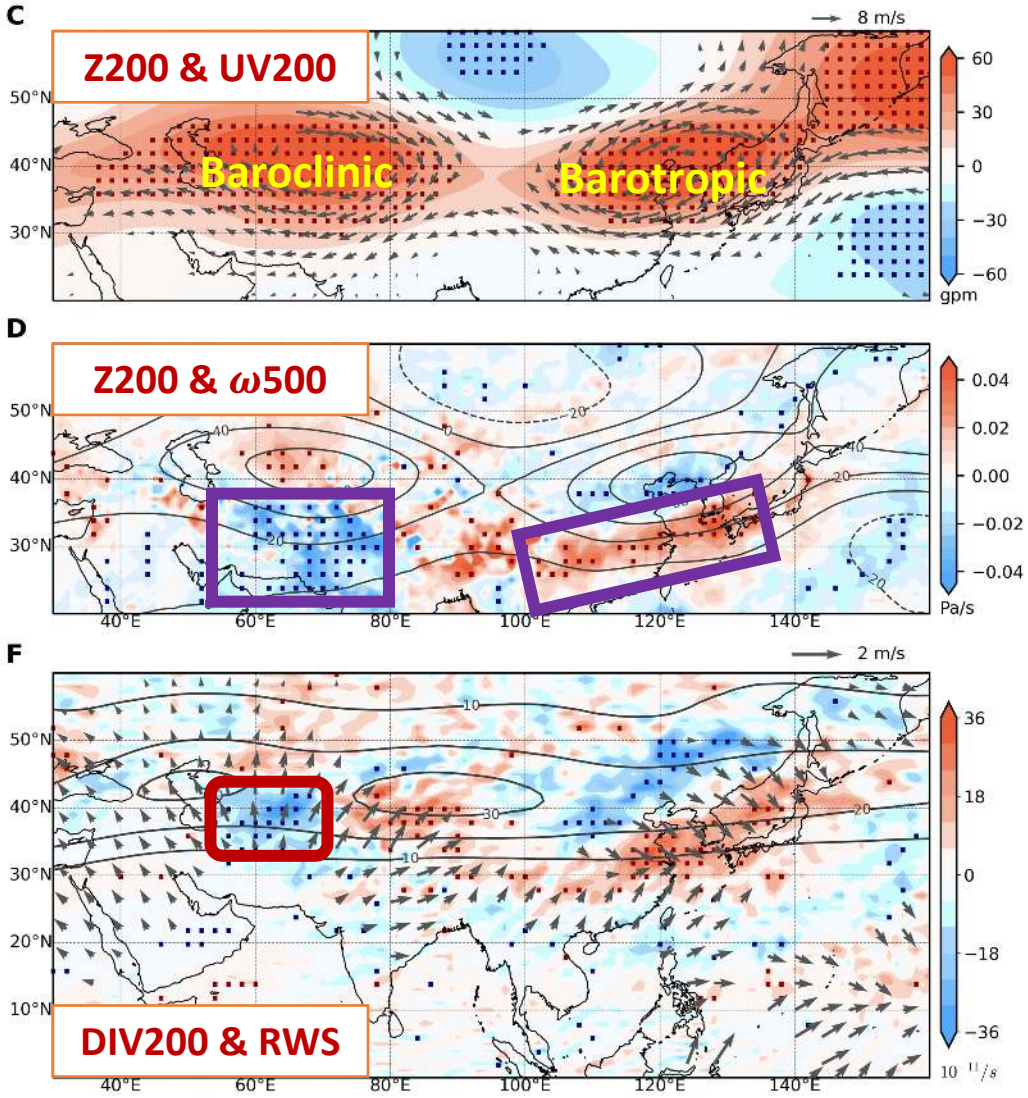
- The coupled mode from MCA captures the interannual variability and overall convection intensity of Indian summer monsoon.

- The enhanced convection over Pakistan-northwest India is coupled with increased heatwaves in the YRV and much of the Tibetan Plateau.

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



Atmospheric dynamic processes

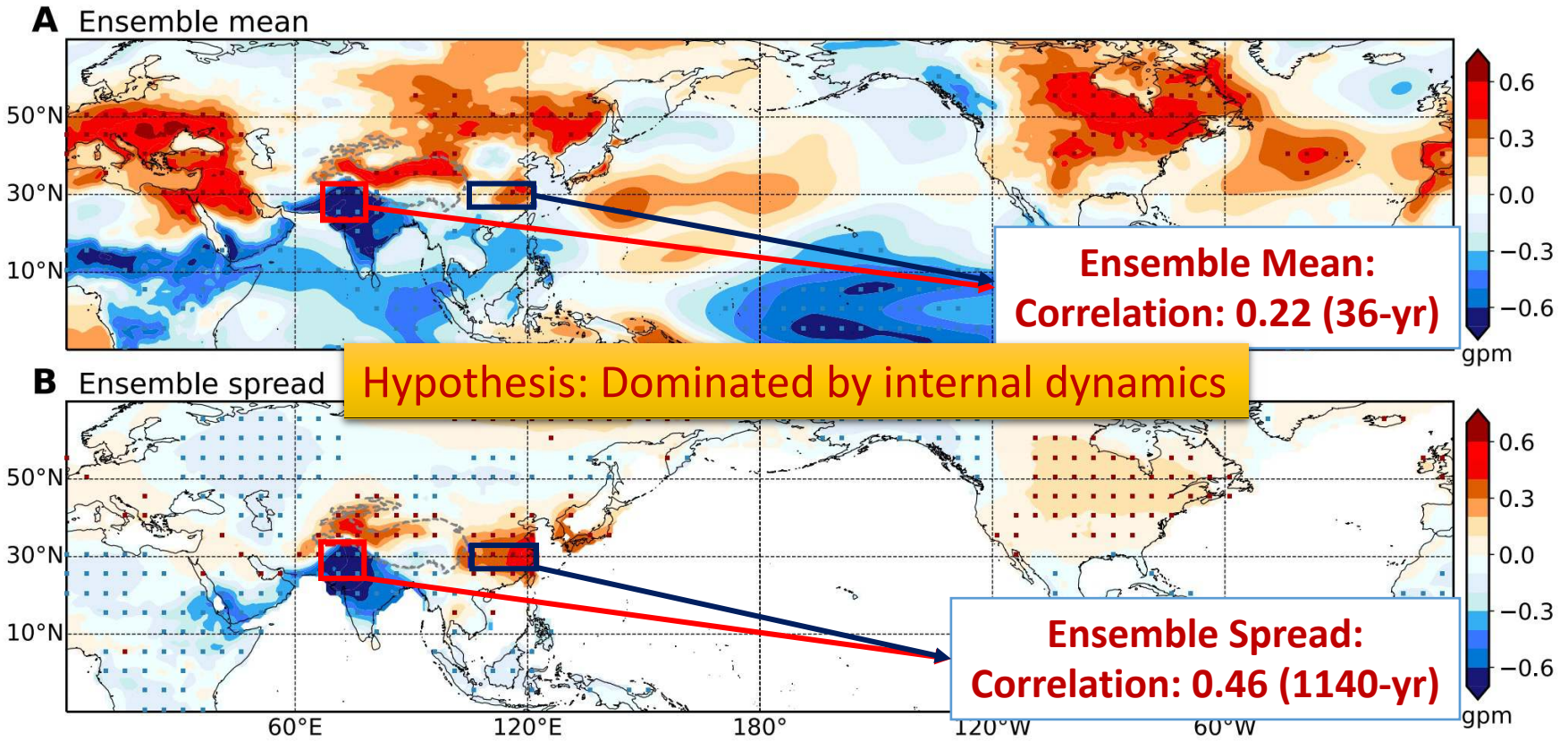


Composite analysis based on MCA series（threshold±0.6）

- Two AACs over the western and eastern of the TP, respectively, with distinctive dynamic structures.
- Upward anomalies over Pakistan are accompanied by enhanced convection, and subsequent upper-level AAC.
- Intensified heatwaves over East Asia are associated with anomalous downward motion on the south flank of the east AAC.
- **Divergent flow produces a negative Rossby wave source (RWS)** near the subtropical westerly jet over northwestern Pakistan.

Role of global SST forcing vs. atmospheric internal variability

- The SST-forced pattern is of a global scale while the internal mode is confined mostly within the ASM region.



Averaged Pakistan-northwest India OLR & gridded surface temperature

A suite of LBM experiments: Effect of convective heating

LBM experiments

Unlike other complicated atmospheric models, LBM **only includes linear processes** and thus can more accurately produce the circulation anomalies in response to diabatic heating.

Spatial resolution： T42L20 Response in Day 30 approximate as the steady solution

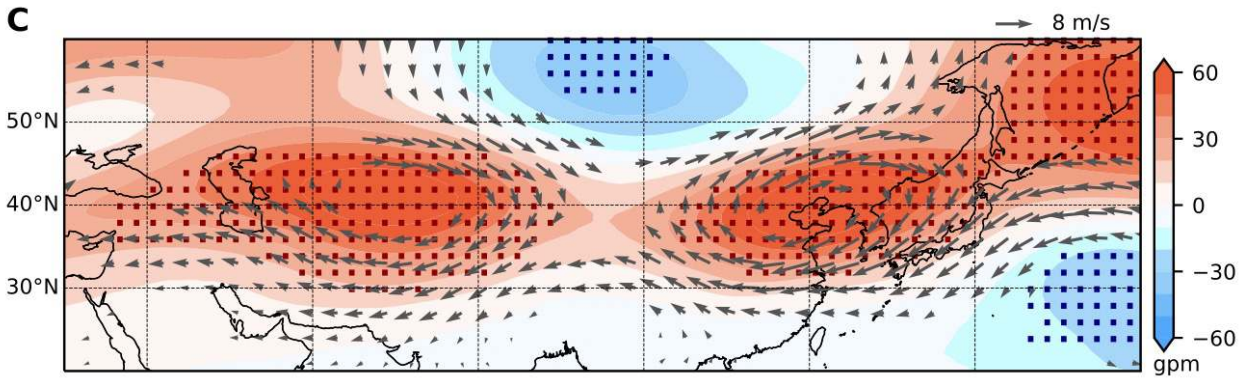
Vertical maximum heating at 450hPa with 6-7K/day (typical of deep convection)

Watanabe et al. 2000

Model Setup

No.	Heating Location	Background Climatology
1	Pakistan-northwest India	July-August
2	Pakistan-northwest India	June
3	Central India	July-August

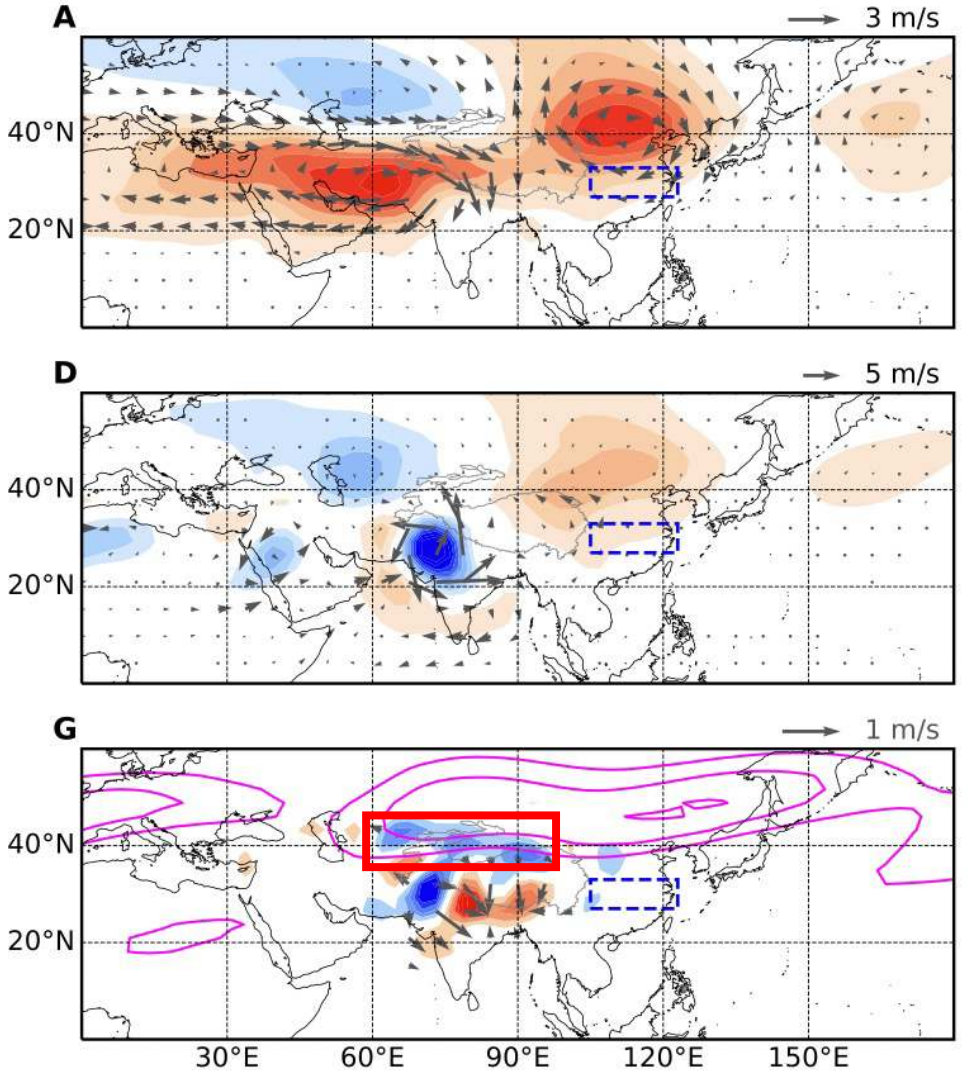
Pakistan convection stimulates two observed AACs



- The upper-tropospheric divergent flow associated with Pakistan convective heating could touch the subtropical westerly jet.

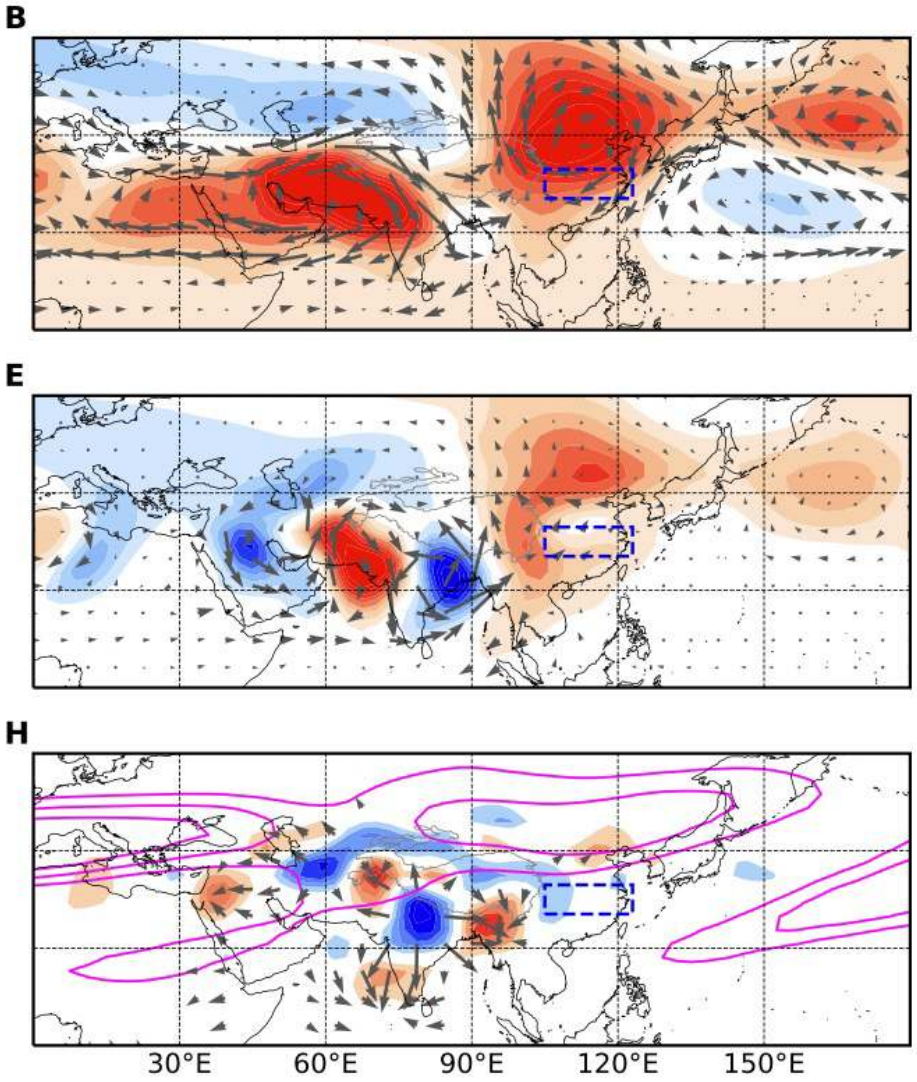
- AAC over eastern China could be directly forced by the Pakistan convection through the upper troposphere westerly.

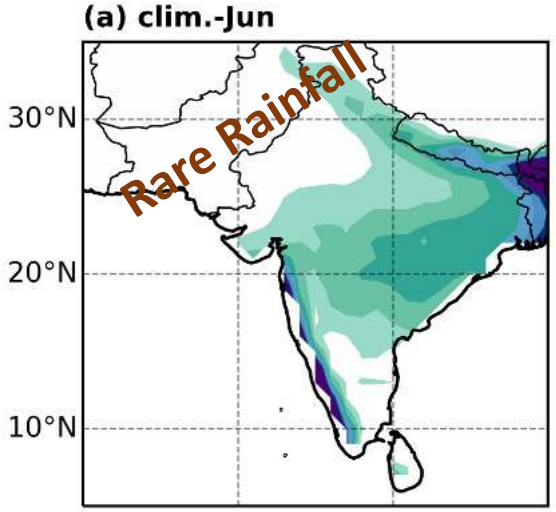
Experiment 1: Heating in Pakistan during July-August

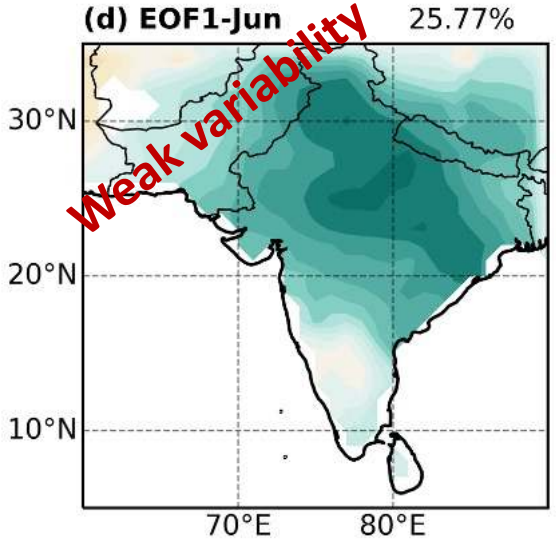


Monsoon climate variability inhibits the linkage in June

Experiment 2: Heating in Pakistan during June



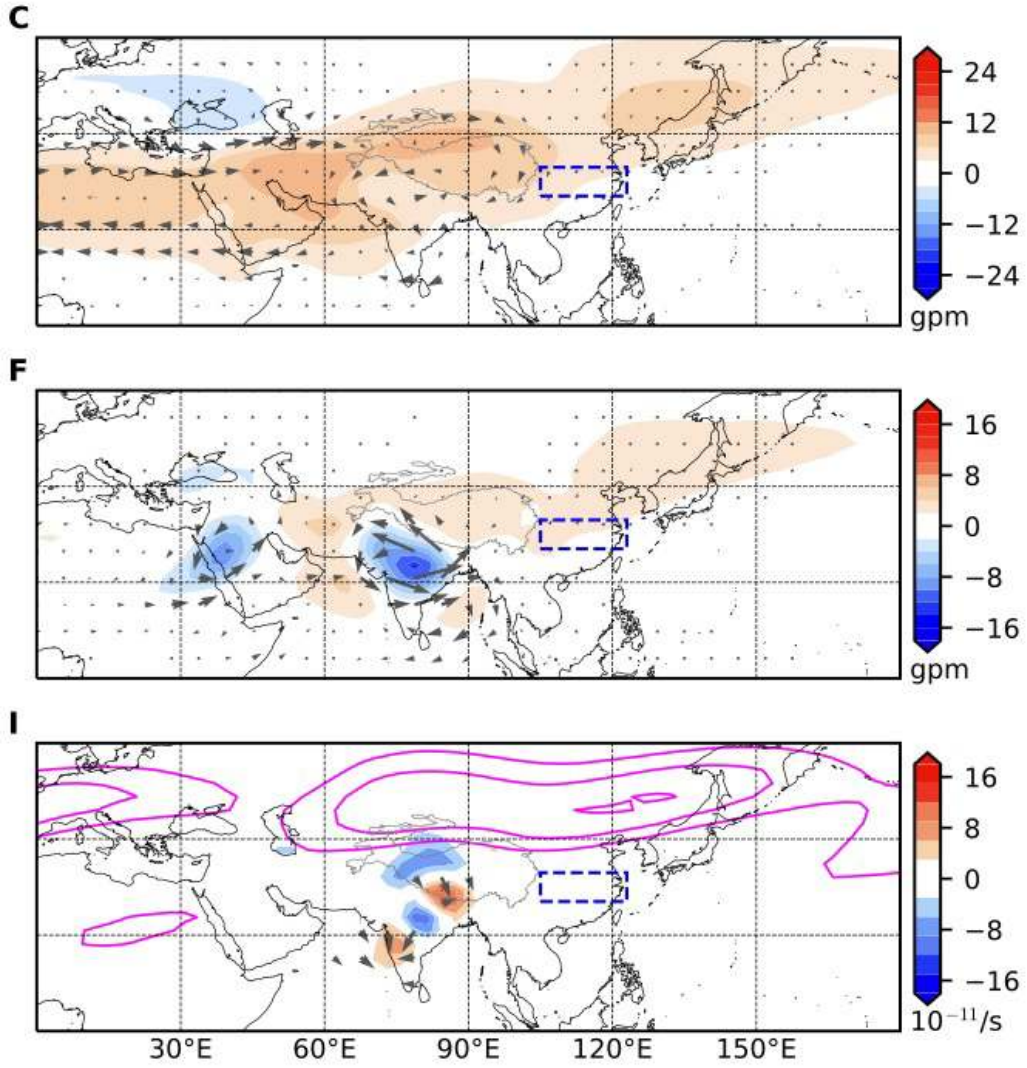




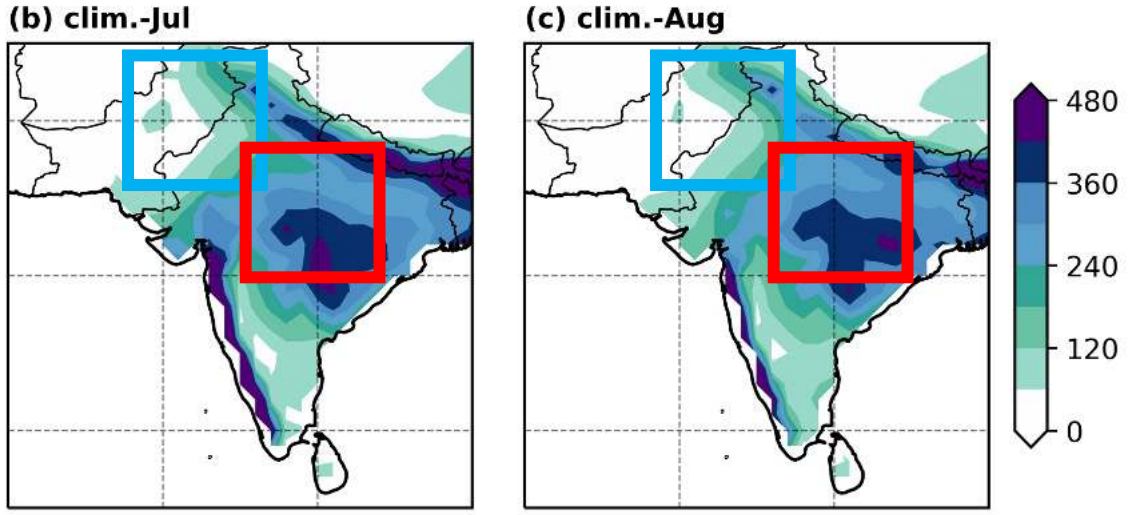
- Although Pakistan convection can force a strong Rossby wave response on a June basic state, the variability and climatology of the local monsoon system may put restrictions on this response.

Convection in central India fails to trigger Rossby wave train

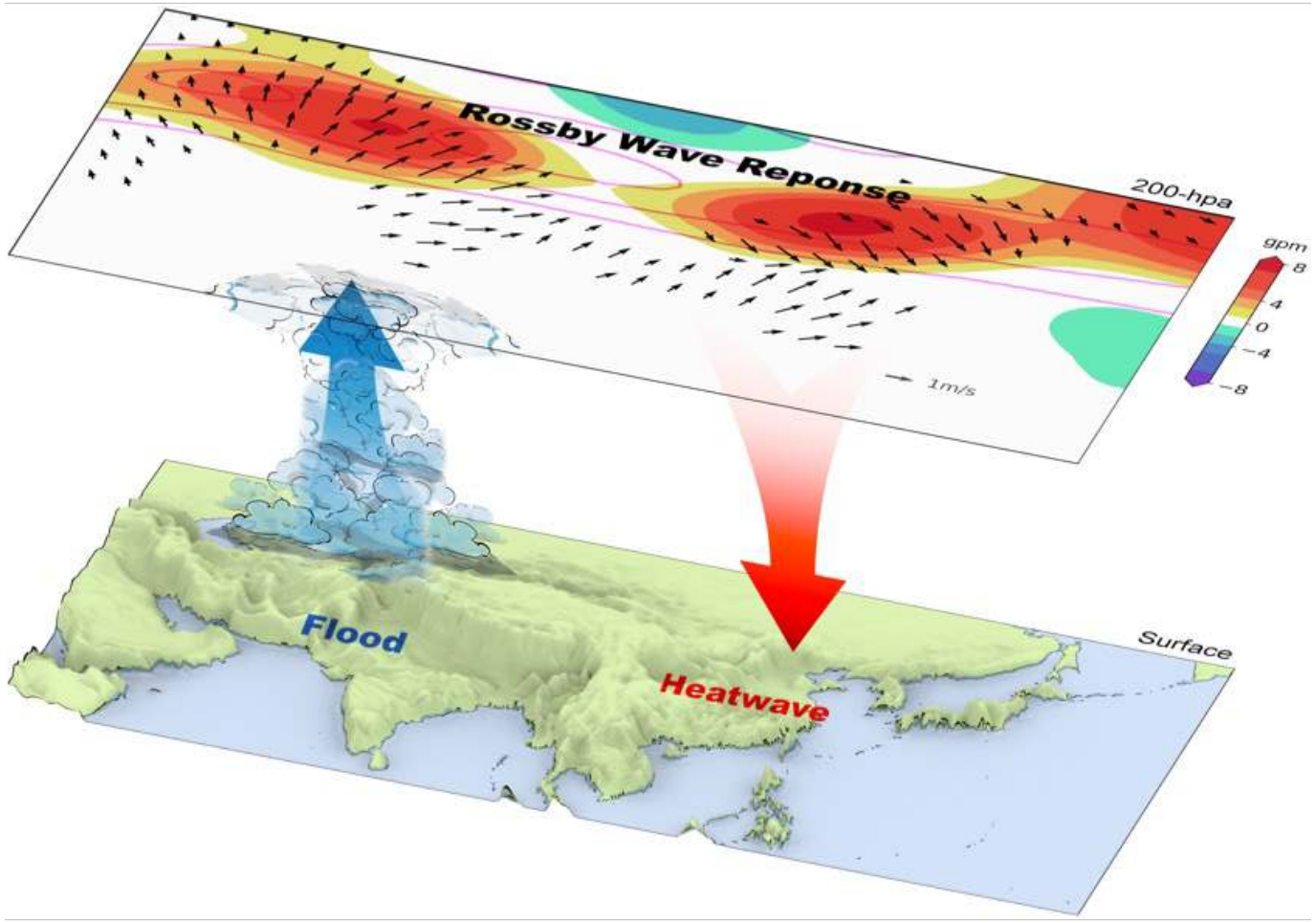
Experiment 3: Heating in central India during July-August



- 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).



Dynamic pathway linking Pakistan flooding to East Asia heatwaves



Pakistan flooding

↓

Upper troposphere divergent wind

↓ Westerly

Downstream AAC response

↓

Suppressed convection/ Increased heatwave over YRV

Reinforce

Take-Home Message

- **Dynamic pathway**: the upper-tropospheric divergent wind induced by convective heating over Pakistan excites a stationary anomalous anti-cyclone over eastern China, which further leads to persistent heatwaves.

- AMIP simulation indicates that the dynamic pathway linking Pakistan flooding and East Asia heatwaves is an atmospheric internal mode, largely independent of global SST forcing.

- Pakistan is a sweet spot for convection to perturb the Asian westerly jet, and contributes to East Asia heatwaves during July-August.

Related work:

- Fu, Z.-H., W. Zhou*, S.-P. Xie*, R. Zhang, and X. Wang, 2023: Dynamic Pathway Linking Pakistan Flooding to East Asia Heatwaves. *under review*

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THANK YOU

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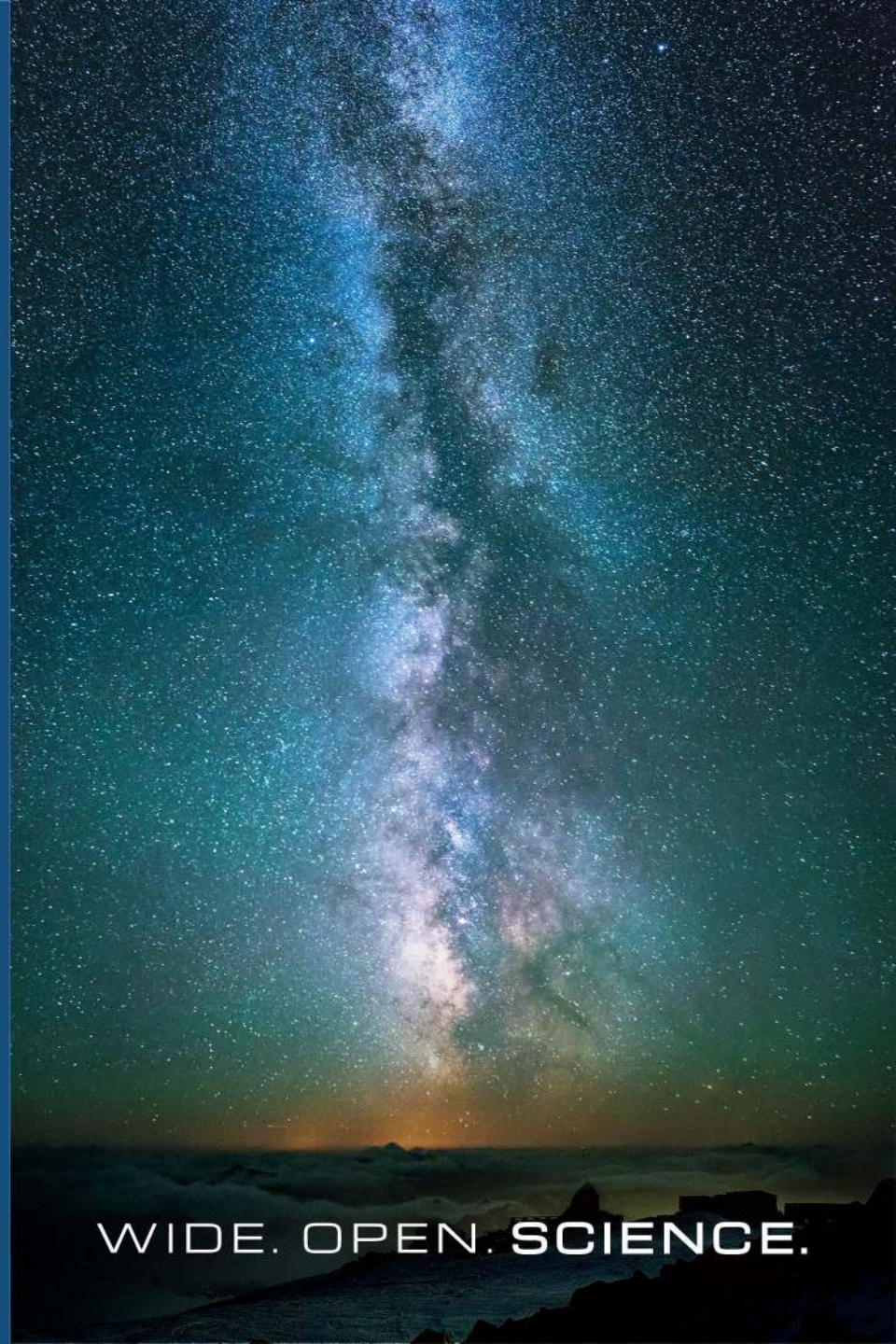
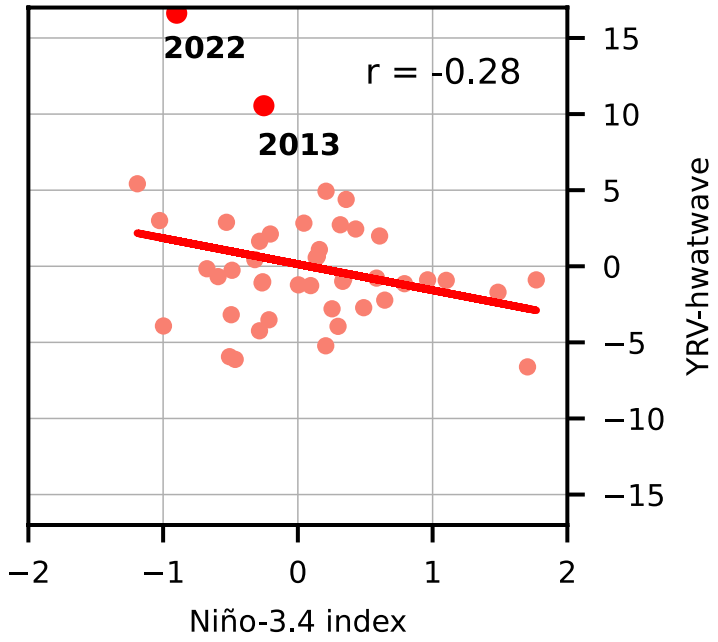
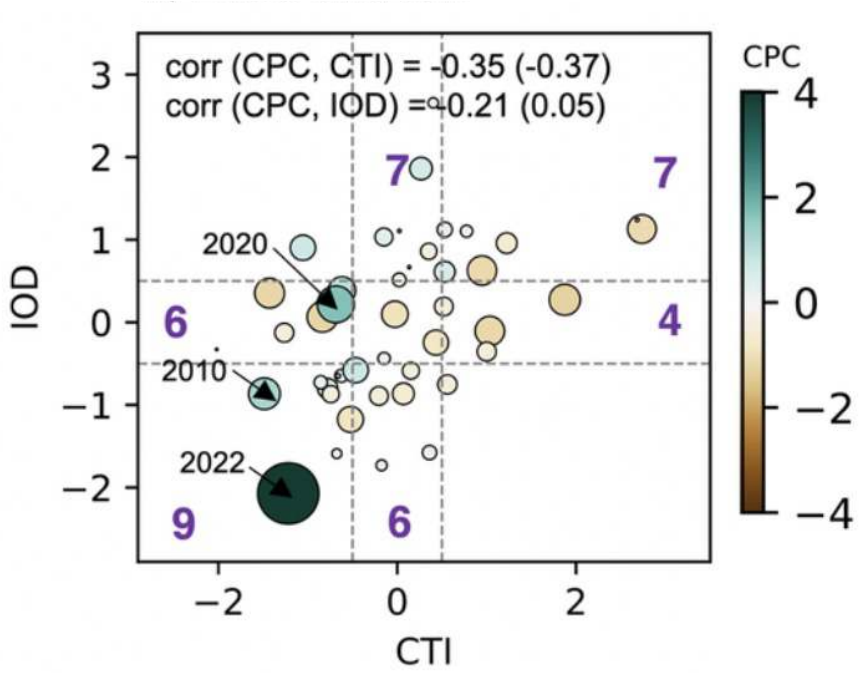


Supporting Information



ENSO and YRV-heatwave: **-0.28**



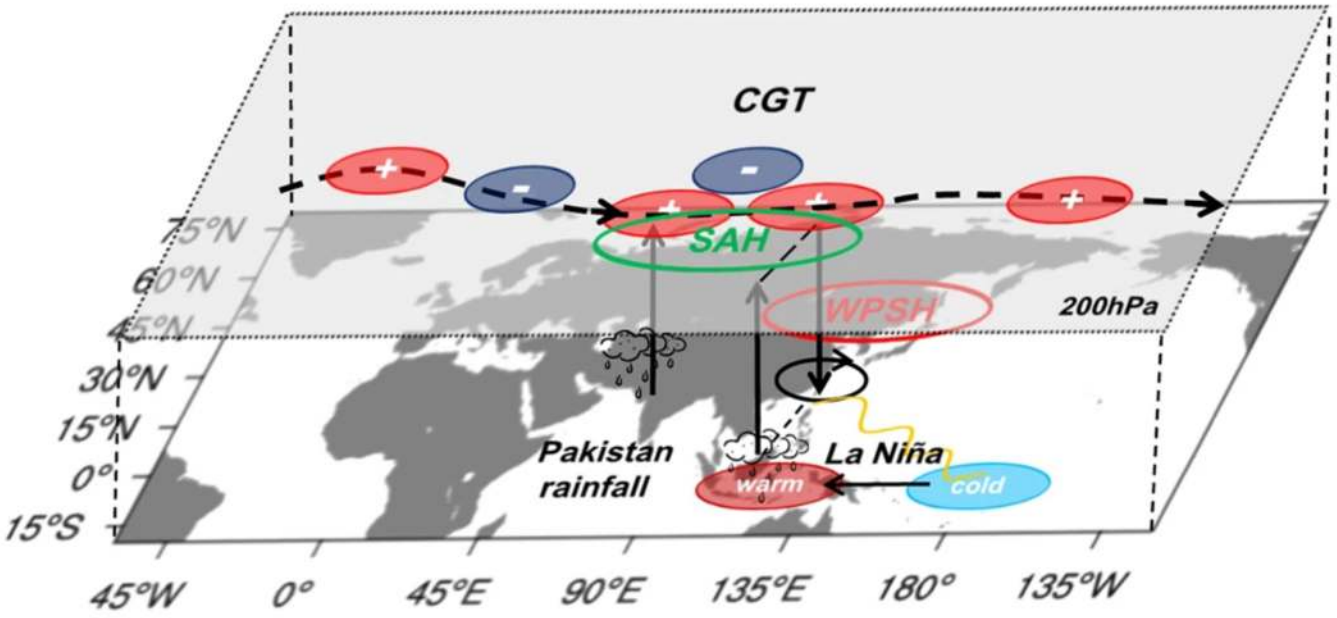
ENSO and Pakistan rainfall: **-0.35**

You et al. 2023

- The solely SST-forced pattern in Jeong et al. 2023 **underestimates** the precipitation anomalies of the two extreme events in July-August 2022.

Supporting Information

CGT: circum-global teleconnection



- Tang et al. (2023) attributed the record-breaking heatwaves over the YRV to Pakistan flooding-reinforced CGT and La Niña-forced WNP subtropical high in the summer of 2022

- Tropical SST forcing also simultaneously modulates the Pakistan rainfall and CGT pattern, its role remains to be isolated and quantified in **atmospheric simulations**.

  Sikka, D.R. 1980; Ding et al. 2011

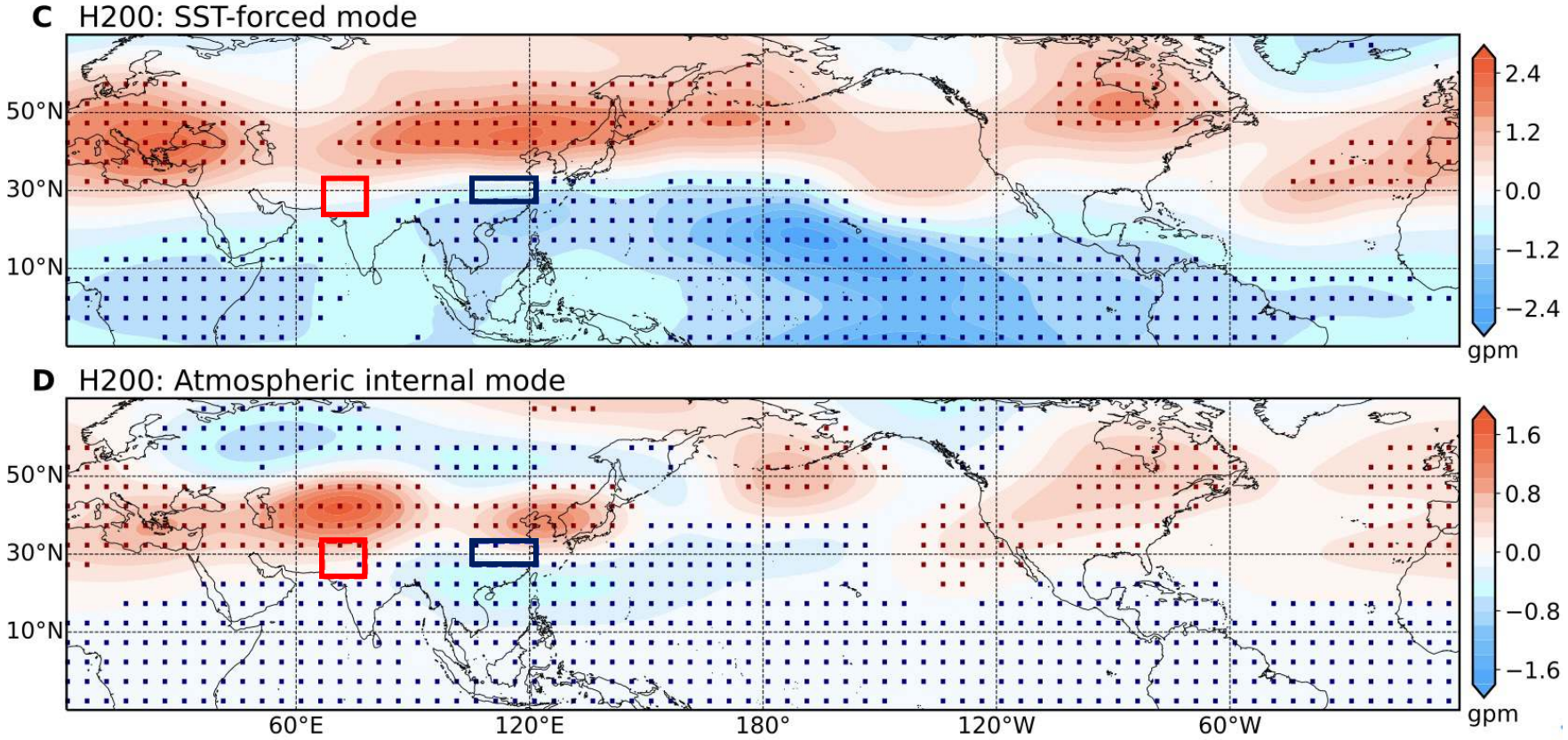
- The low-pressure systems from the tropics seem to be more important for Indian summer rainfall extremes.

- Challenge the idea that CGT plays an initiation role.

  You and Ting, 2019; You et al. 2023

Supporting Information

- The SST-forced circulation pattern closely resembles the developing ENSO-forced pattern.
- The atmospheric internal mode is reminiscent of the observed MCA mode (with two prominent AACs within 30°N–50°N).



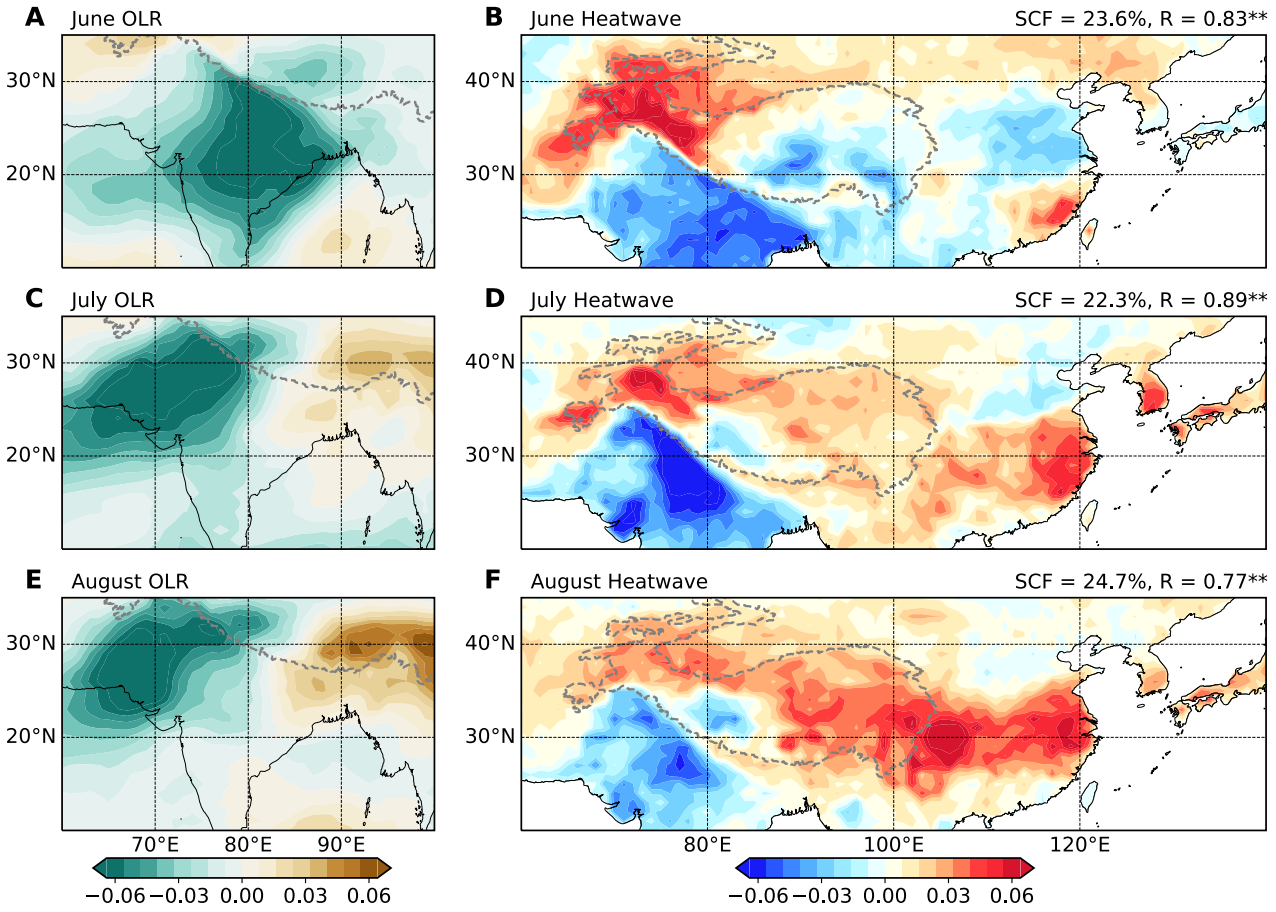
Geopotential height at 200 hPa regressed against averaged Pakistan-northwest India OLR

Supporting Information

Heatwave

An event is defined as daily T-2m max reaches or exceeds the threshold temperature for at least 3 consecutive days. We calculate the accumulative days in this study.

Perkins et al. 2013



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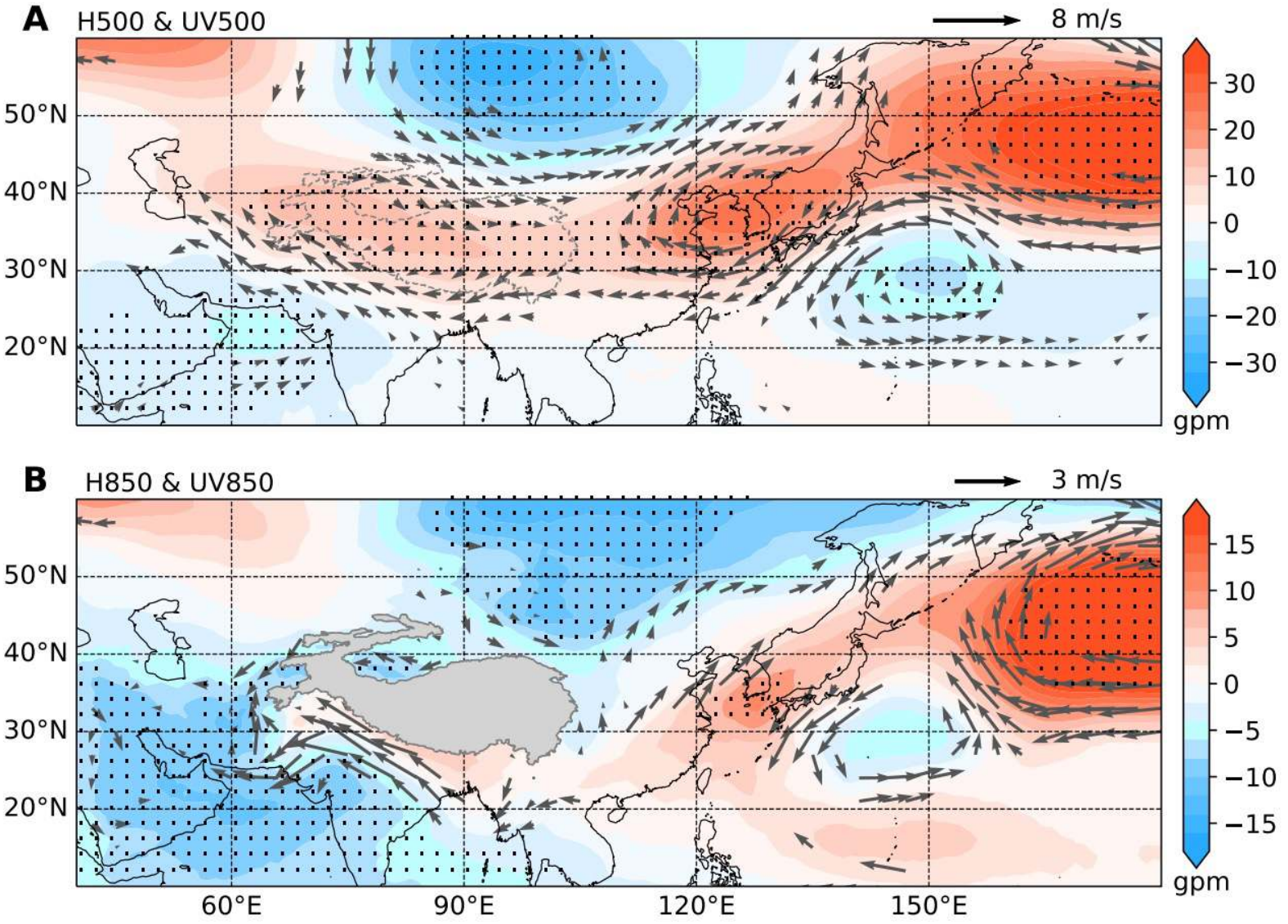

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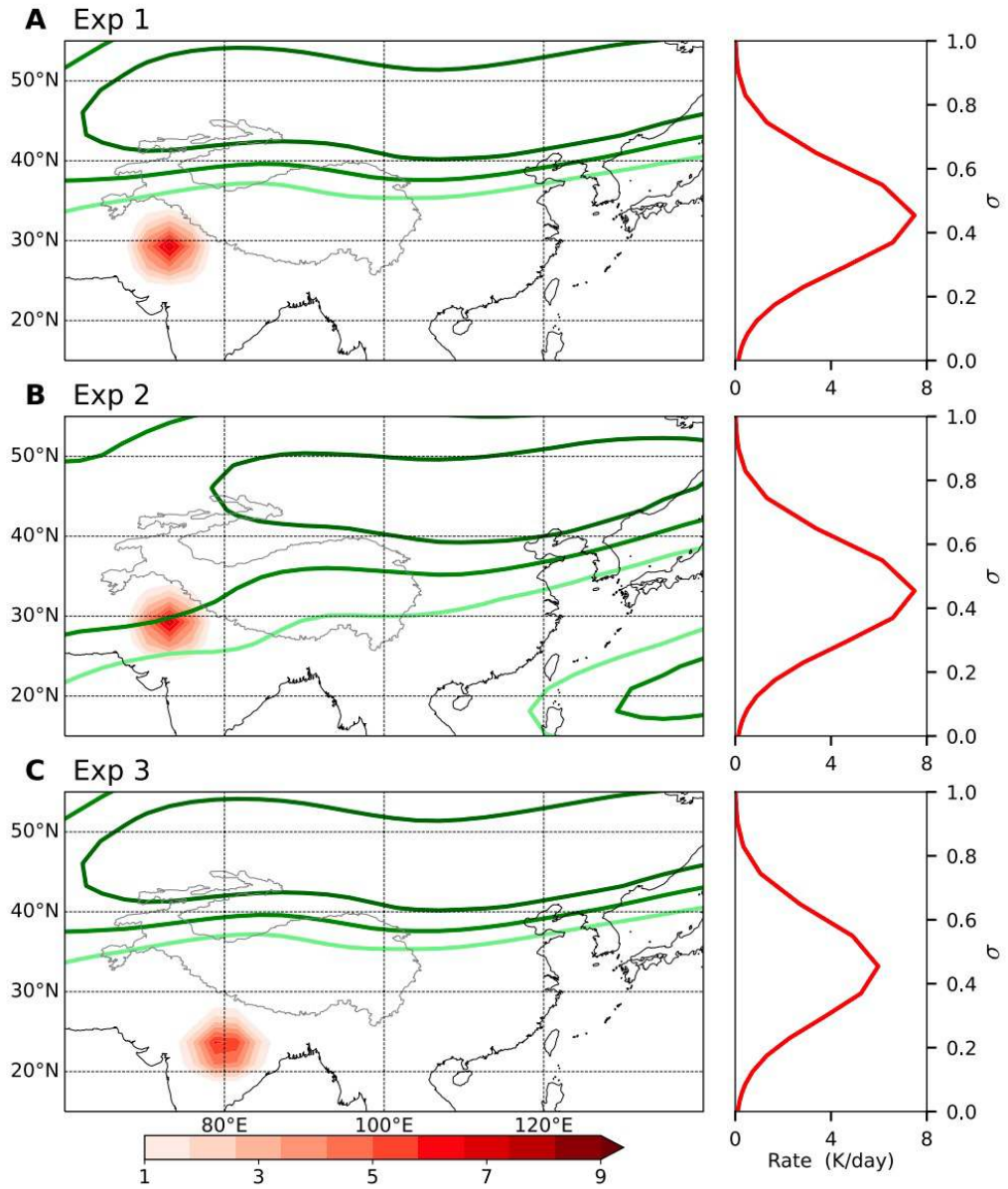

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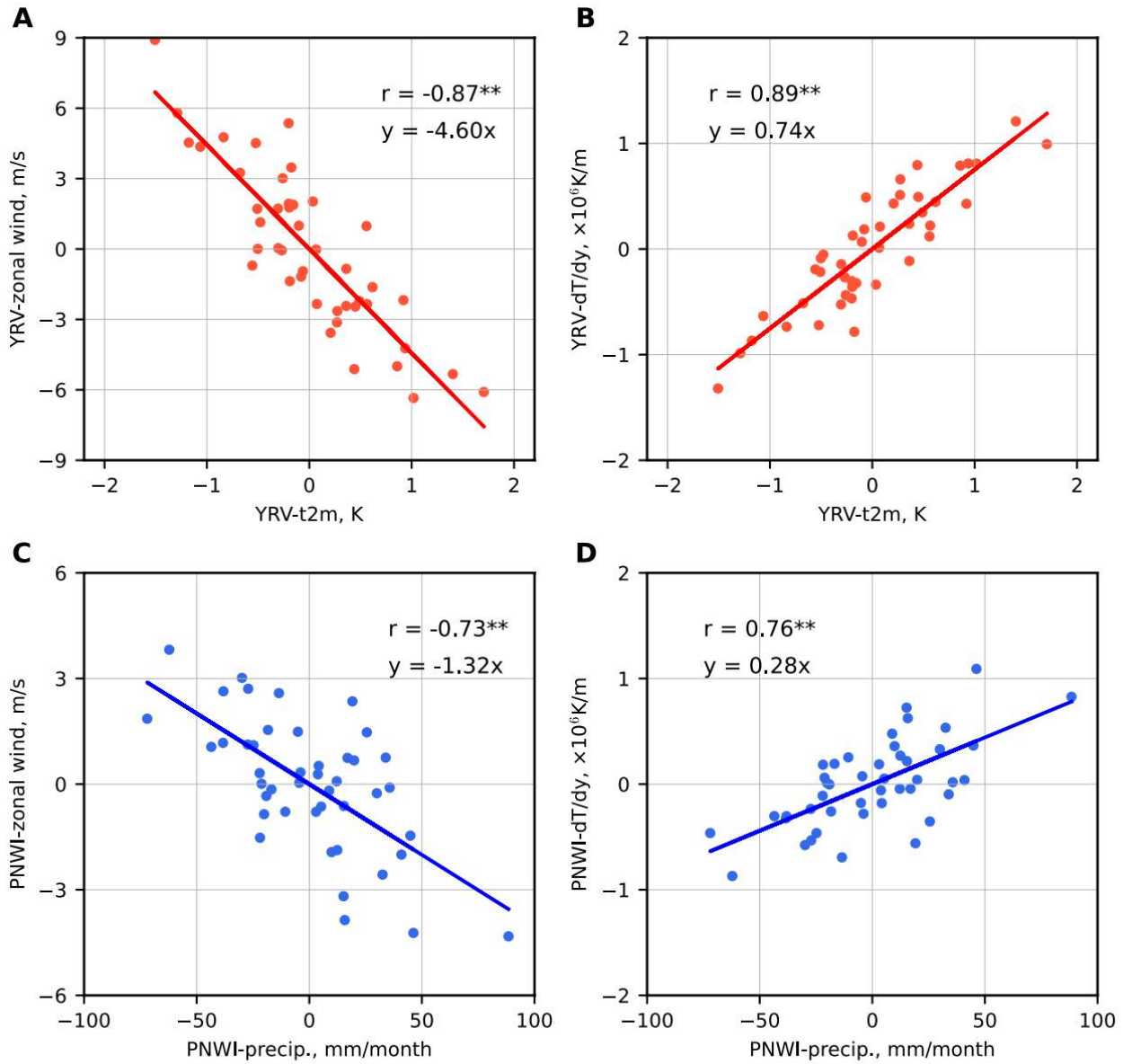

Supporting Information

Years included to the positive and negative groups in the composite analysis.

Group	Year
Positive	1983, 1984, 1988, 1994, 2006, 2010, 2011, 2013, 2022
Negative	1987, 1991, 1993, 1999, 2002, 2004, 2005, 2009, 2014, 2021

Observed correlations and partial correlations after removal of the signal of PNWI rainfall between El Niño–Southern Oscillation (ENSO) and YRV heatwaves for 1979–2014. Four precipitation datasets (see Methods) are used for validation. The correlations reaching ±0.33/±0.39 in Table 1 are at a 95%/99% confidence interval.

	YRV heatwaves	ENSO
	ERA5	Berkeley
ENSO	-0.09	0.05
ENSO (no CRU)	0.14	0.26
ENSO (no ERA5)	0.12	0.27
ENSO (no CMAP)	0.08	0.22
ENSO (no GPCP)	0.13	0.25