Dynamic pathway linking Pakistan flooding to East Asian heatwaves

Zheng-Hang Fu

Work with Wen Zhou and Shang-Ping Xie

2025-03-24

About me

Zheng-Hang Fu http://www.zhenghangfu.com

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Education

- **Ph.D in Climate Sciences (Fudan Elite Ph.D Program)**
  - Fudan University, 2023.09-present
- **B.S. in Atmospheric Sciences (with Highest Honor)**
  - Fudan University, 2019.09-2023.06

Research Interests

- Climate Dynamics
- Climate/Weather Extremes
- Coupled Atmosphere-Ocean Dynamics

Research experience:

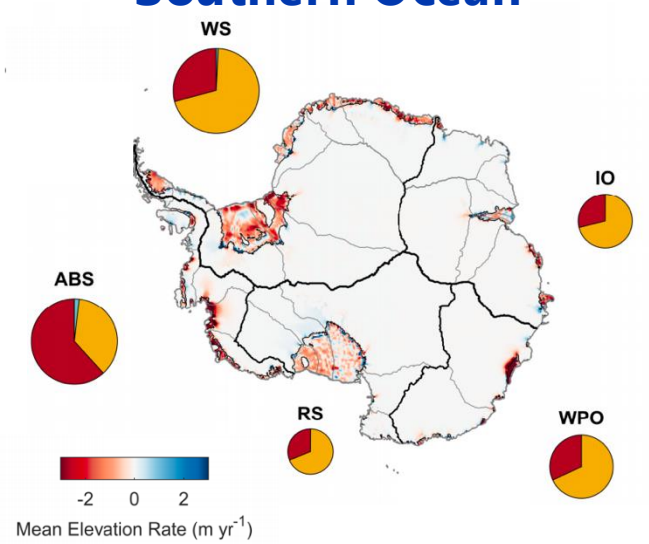
- Characteristics of Aerosol Chemistry and Acidity in Shanghai after PM2.5 Satisfied National Guideline: Insight into Future Emission Control
  (undergraduate)

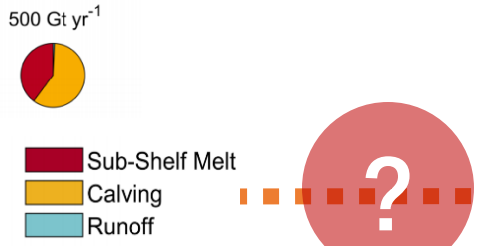
- Multiple Tropical Cyclone Events under Climate Change: Mechanisms, Projections, and the Probabilistic Modeling
  (undergraduate - graduate)

- Dynamic pathway linking Pakistan flooding to East Asian heatwaves
  (undergraduate thesis – PhD thesis)

My ongoing research

Antarctic ice melting input freshwater into the Southern Ocean





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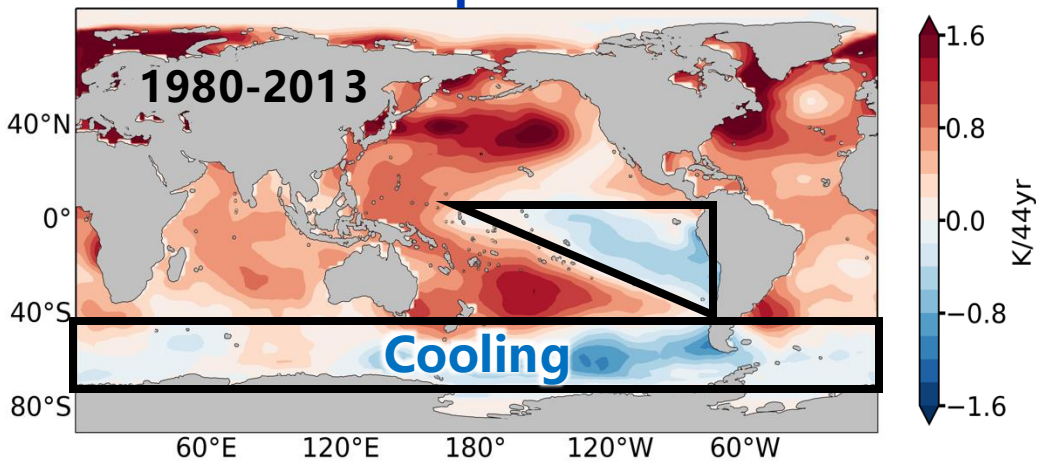
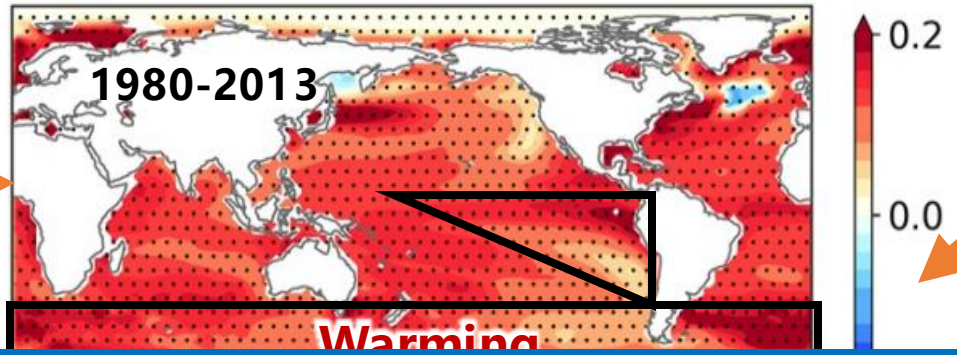
Coulon et al., 2024

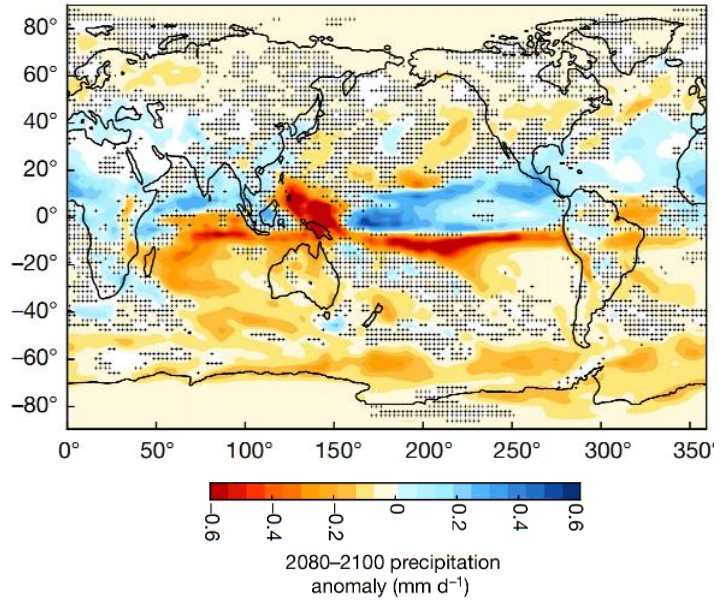
Observed cooling over the Southern Ocean and tropical Pacific



SST bias in CMIP6 models



Tropical deep convection change



Bronselaer et al., 2018

Tropical deep convection bias

Understanding the impact of freshwater forcing from Antarctic ice melting on the tropical deep convection to reduce bias in current climate models.

Science outreach in China

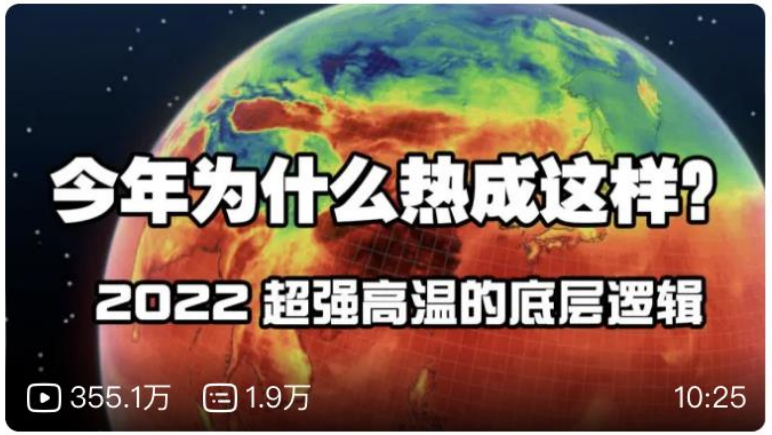
ZQA Weather Hub of China

中气爱

- Co editor-in-chief, 2023-
- Core member, 2022-2023
- Member, 2020-2022

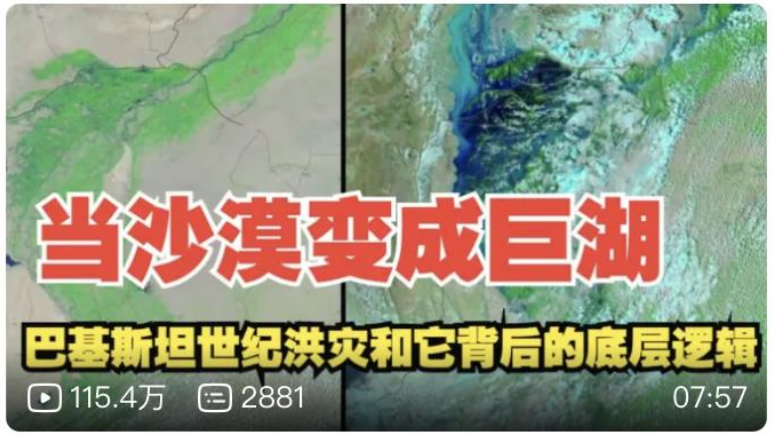
代表作 (Representative work)

Views: 3551k Comments: 19k



Why So Hot This Year? The Story of 2022 Historic Chinese Heatwaves

Views: 1154k Comments: 2.881k



When Desert Becomes Giant Lake - The Story of the Historic Pakistan Flooding

Weibo (Twitter-like platform): over 10 million followers

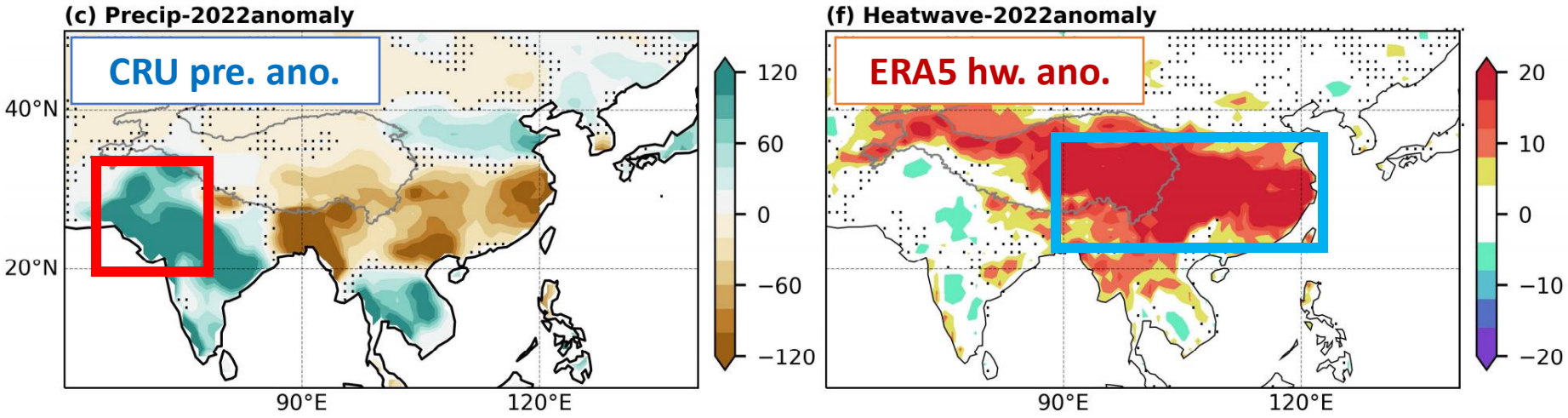
bilibili (YouTube-like platform): over 2 million followers

DOUYIN (Chinese TikTok): over 5 million followers

Concurrent extreme events over ASM regions in 2022

ASM: Asian summer monsoon

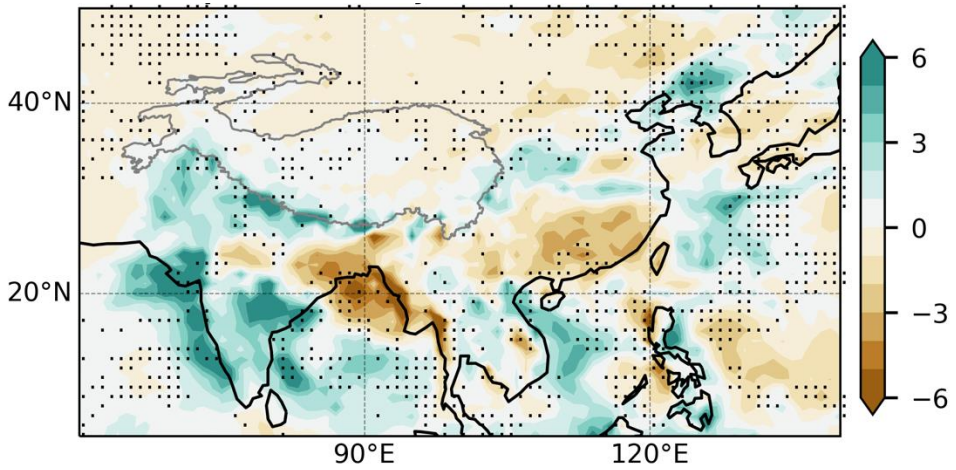
Photo Credits:
Left: TIME
Right: BBC news

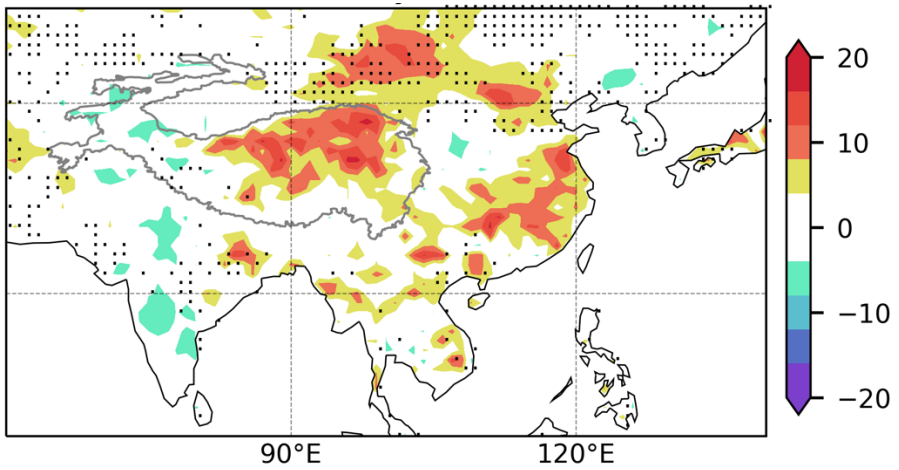


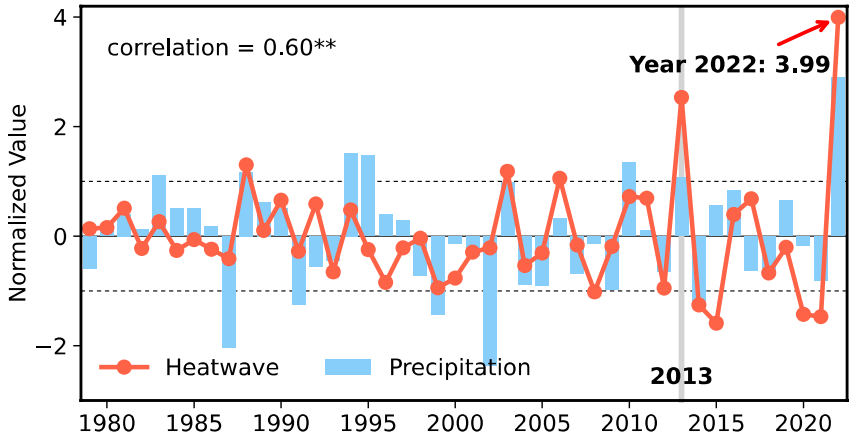
Pakistan： Devastating flooding & Southern China： Record-breaking heatwave

Recurrent Pakistan flooding-East Asian heatwaves events

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





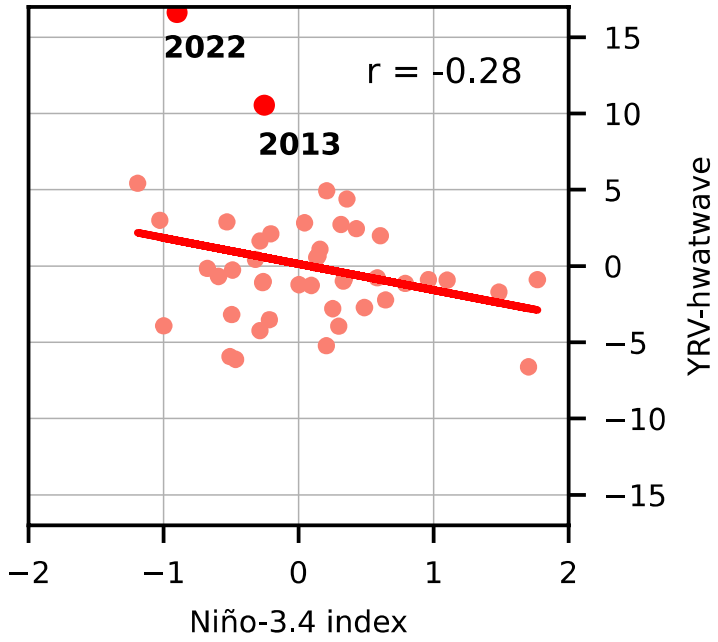


- The robust in-phase relationship between the two extreme events has been noted in several studies, **but the underlying mechanisms remain to be determined.**

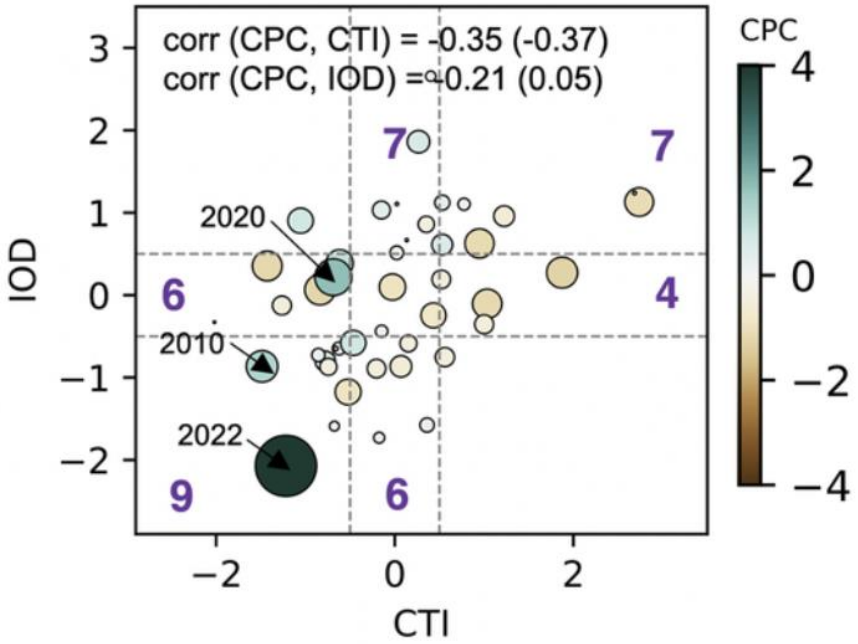
He et al. 2023; Liu et al. 2016

Two hypotheses

SST forcing could not tell the whole story



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



ENSO and Pakistan rainfall: **-0.35**

You et al. 2024

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

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)

CRU4.07： Land precipitation (1901-2022)

ERA5 total precipitation; CMAP; GPCP: for **cross-validation**

✓ **Data validation**

NOAA： Monthly OLR (1979-2019)

Berkeley Earth： Daily T-2m max (1979-2019)

✓ **Heatwave definition**

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.

Model experiments

CESM2-CAM6 AMIP simulation (10 member)

0.95°×1.25°; 70 vertical levels; forced with historical SST during 1880-2014.

Ensemble mean: SST-forcing

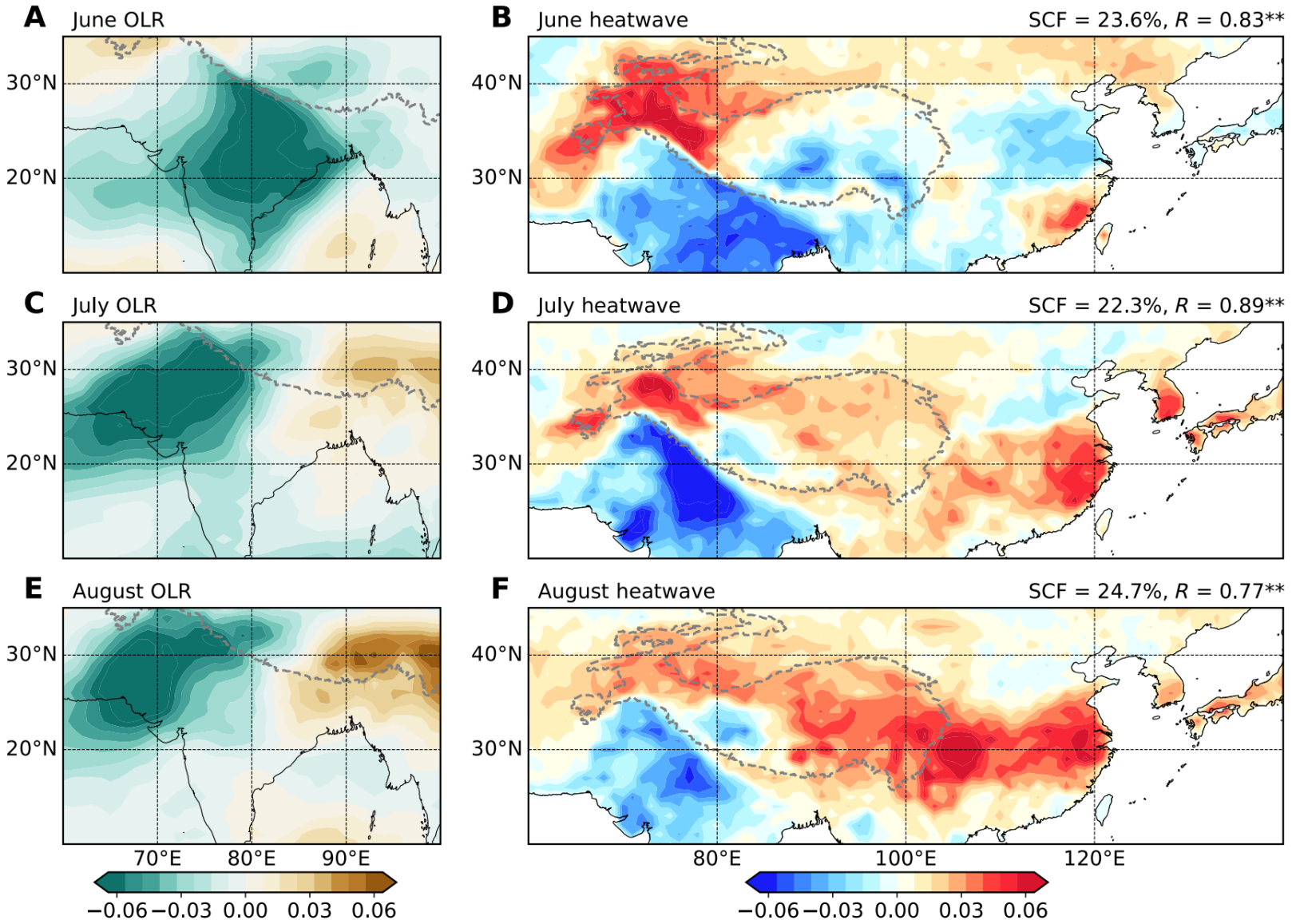
- The 10 members share the same external forcing

Ensemble spread: atmospheric internal variability

- Ensemble spread: 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 Asian heatwaves

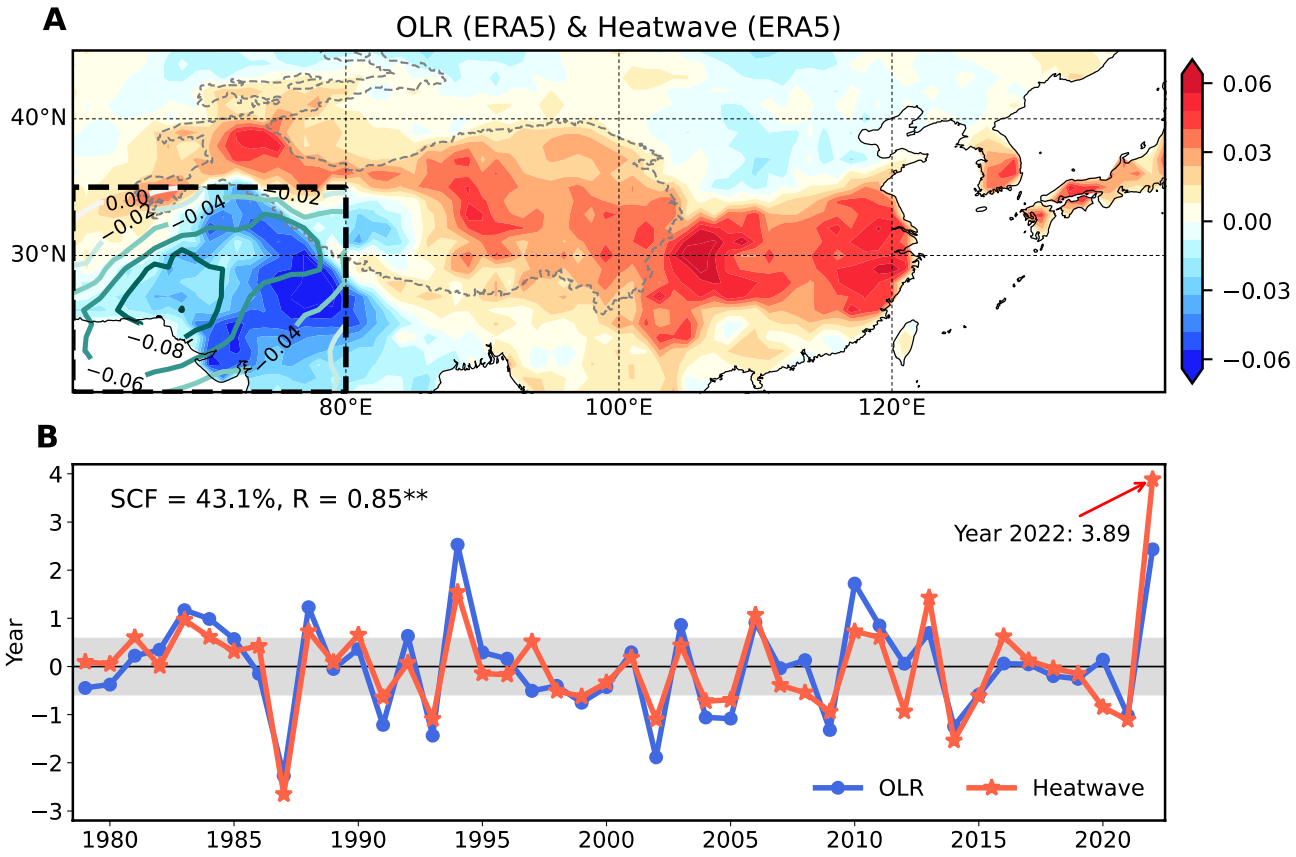


AIRI: all-Indian rainfall index

Month	June	July	August
Corr.	0.81	0.66	0.76

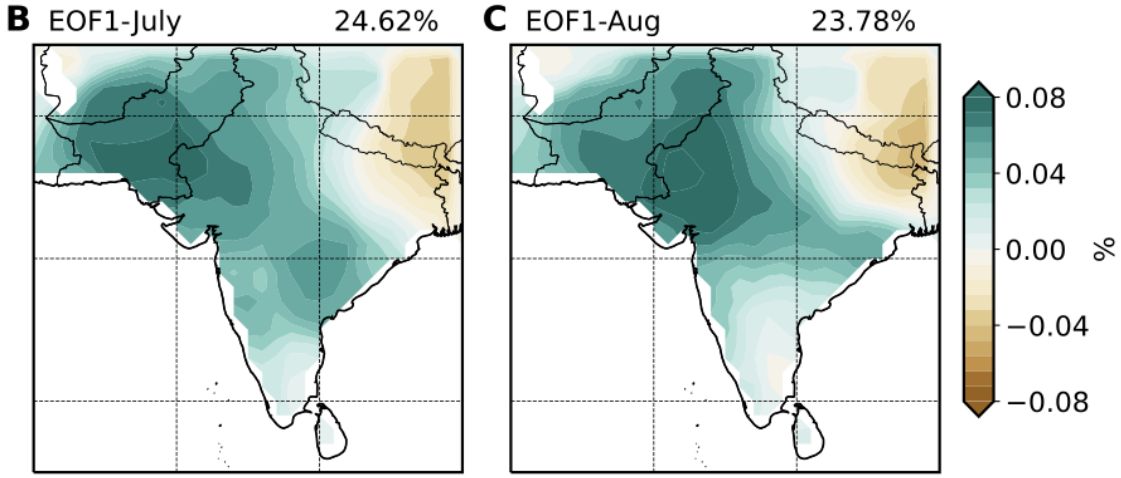
- The coupled mode from MCA captures the overall convection intensity of Indian summer monsoon.
- The MCA1 in June does not feature a simultaneously enhanced heatwave over YRV and its vicinity.

Co-variability of Pakistan flooding and East Asian heatwaves

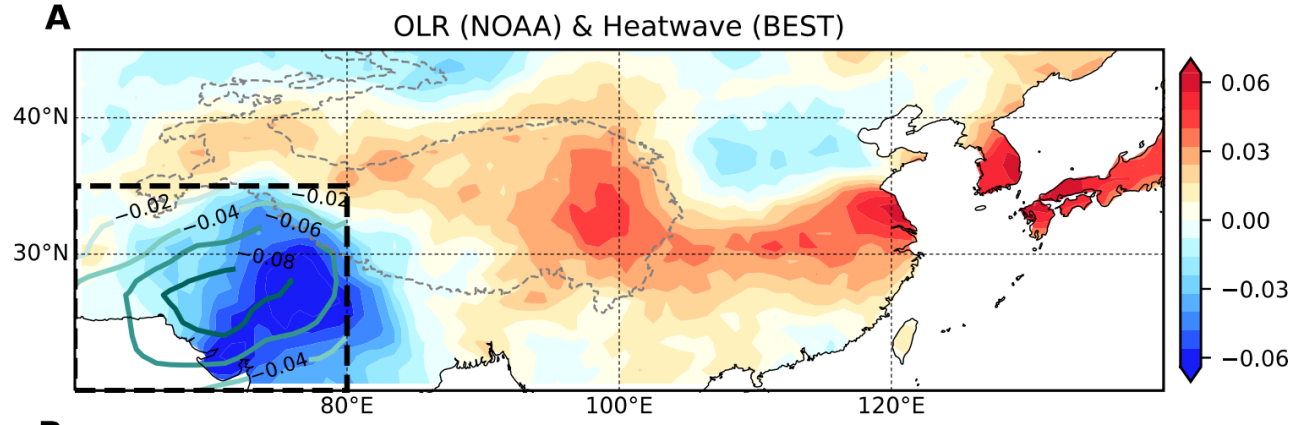


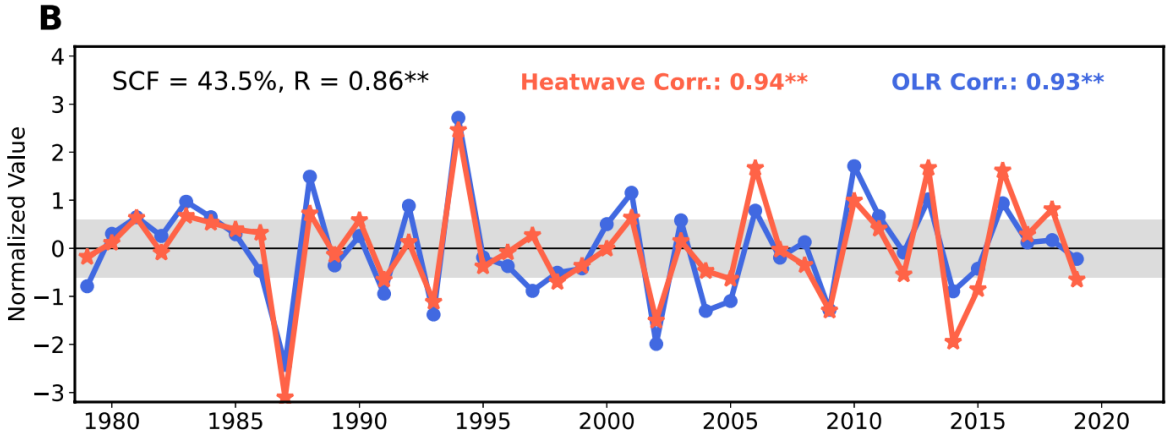
- The coupled mode from MCA captures the interannual variability of Indian summer monsoon.

- 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.



Co-variability of Pakistan flooding and East Asian heatwaves

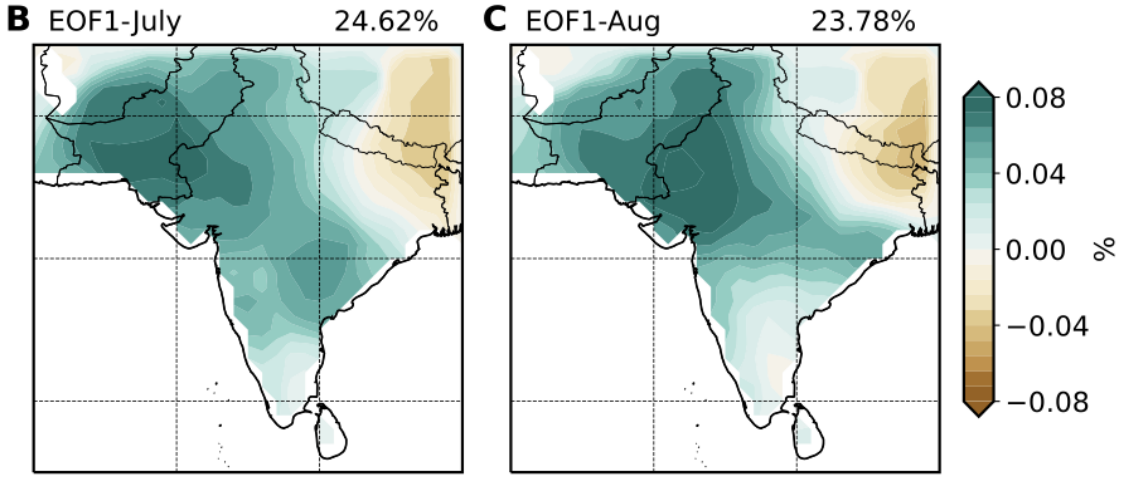




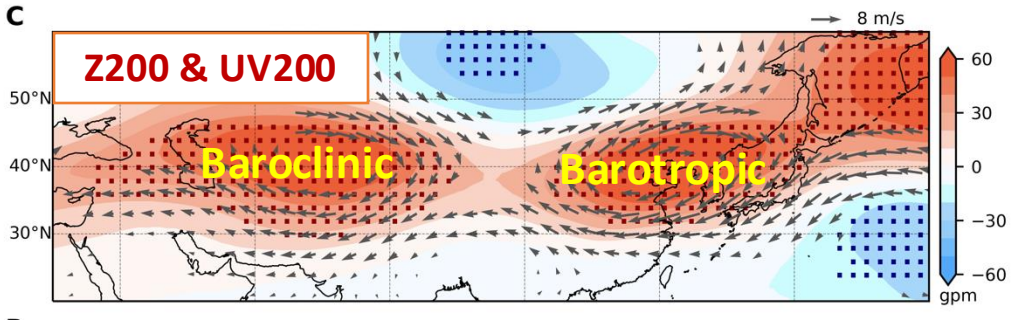
- The coupled mode from MCA is not sensitive to the dataset selection.

- 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.

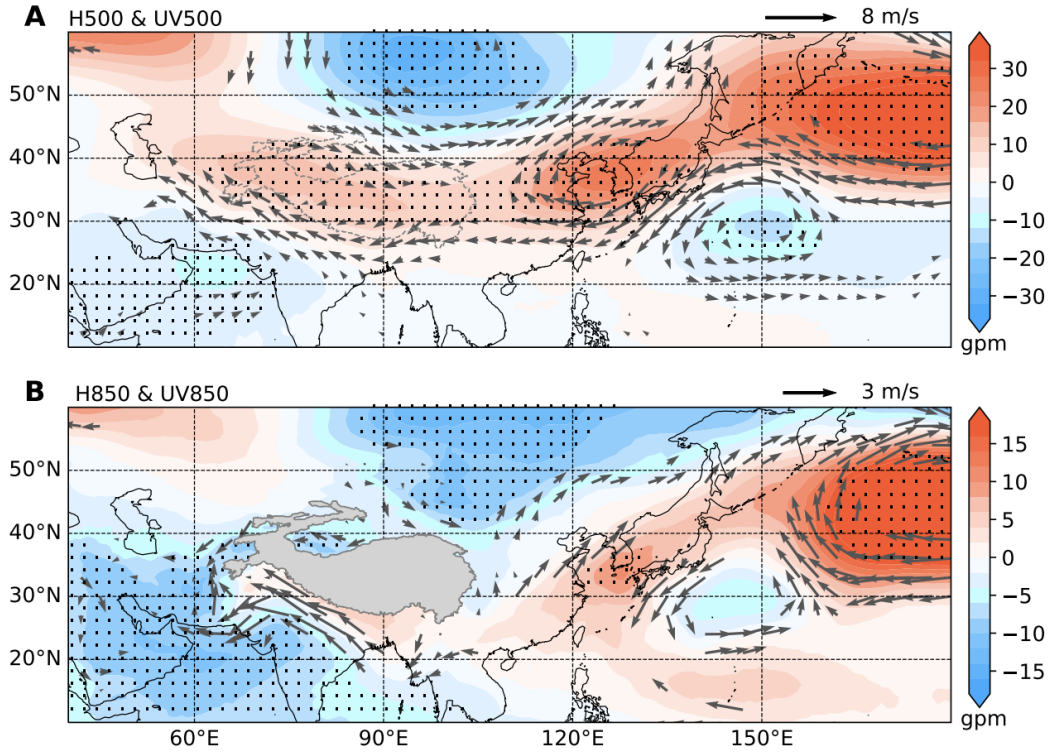


Atmospheric dynamic processes

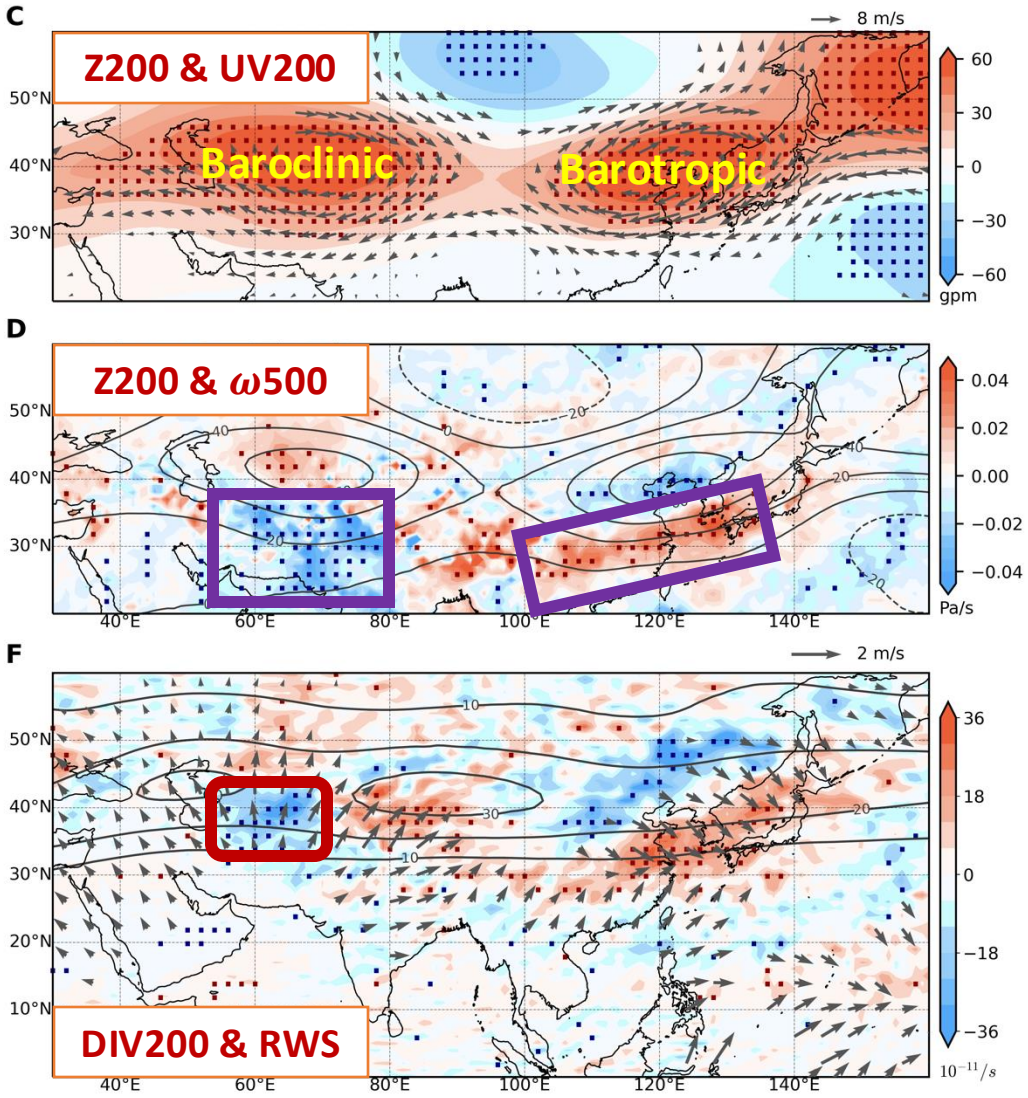


Composite analysis based on MCA series（threshold±0.6）

- Two AACs over the western and eastern of the TP, respectively, with distinctive dynamic structures.



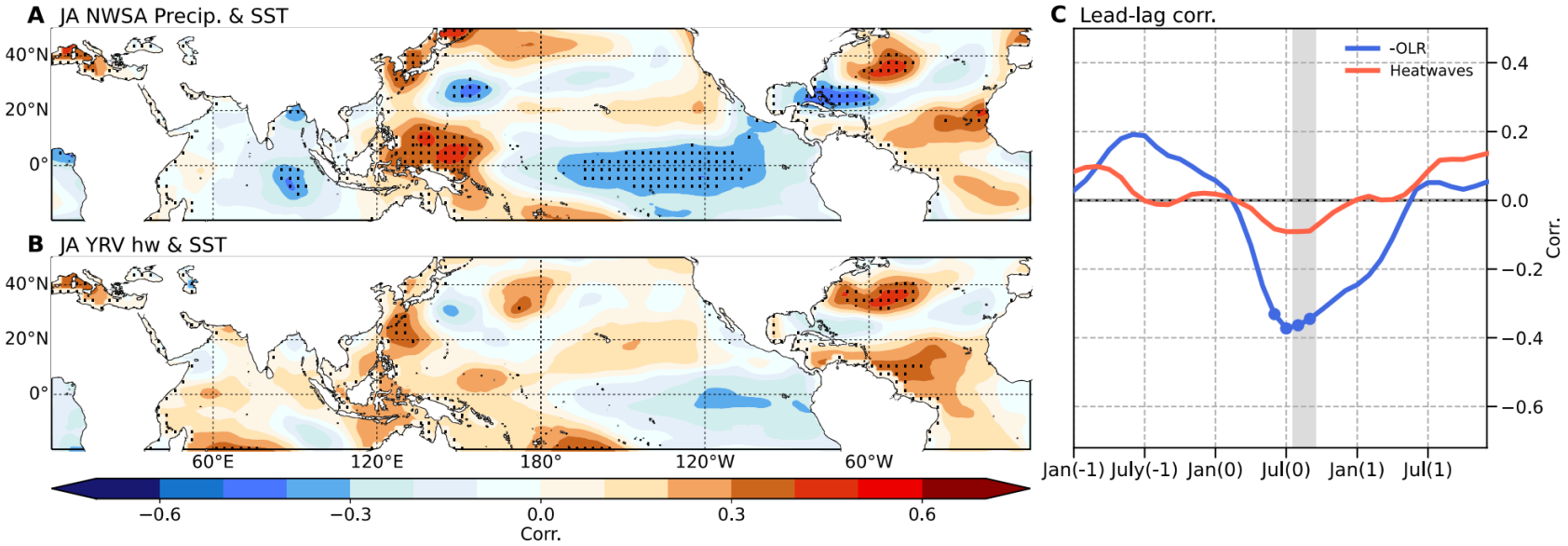
Atmospheric dynamic processes



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.

Observed correlations indicate weak SST forcings

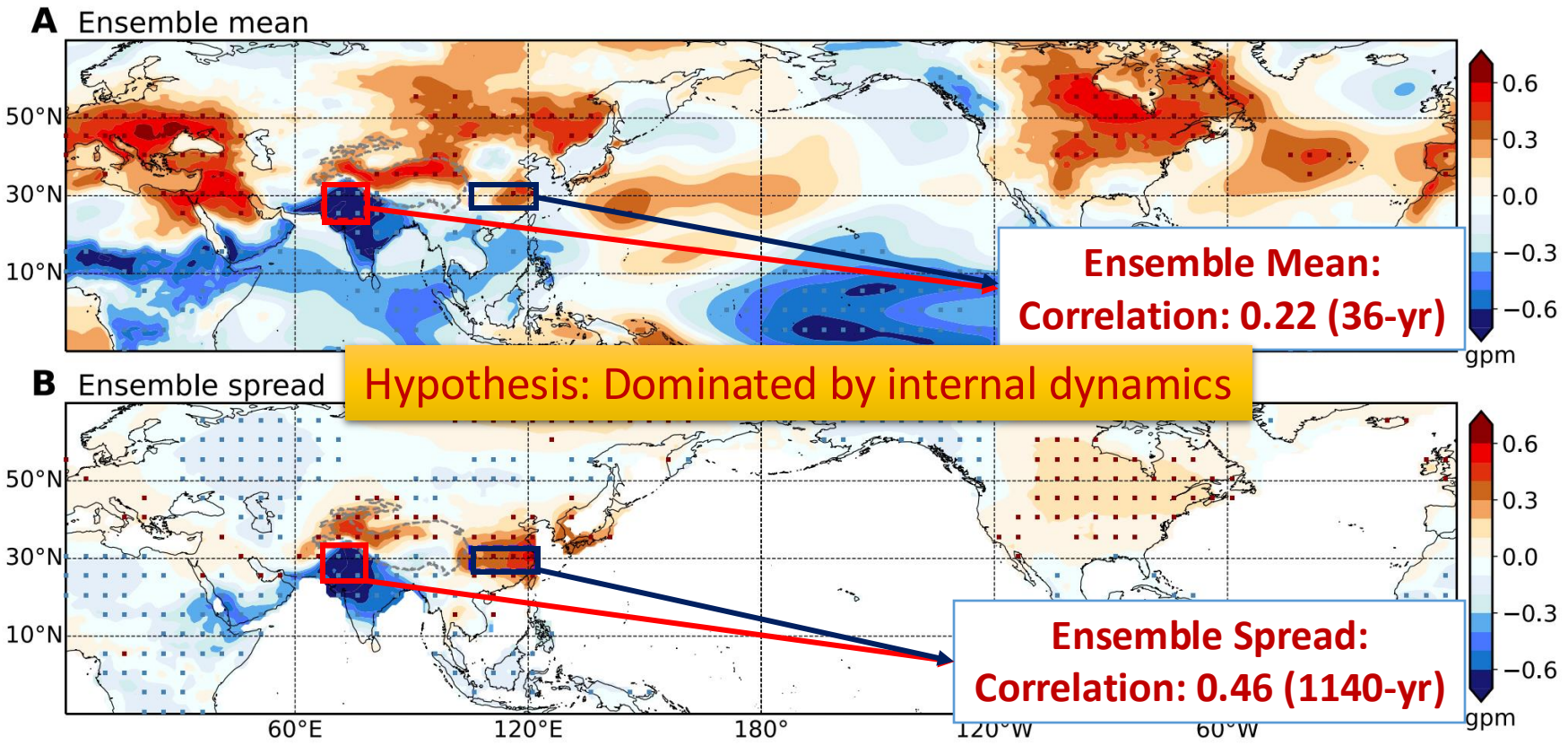


- The most prominent SST pattern is the cooling over the eastern tropical Pacific.

	YRV heatwaves				
PNWI precipitation	**ERA5**	**ERA5 (no ENSO)**	**BEST**	**BEST (no ENSO)**	**ENSO**
CRU	0.57	0.58	0.47	0.52	−0.35
ERA5	0.58	0.59	0.53	0.58	−0.31
CMAP	0.62	0.62	0.53	0.57	−0.24
GPCP	0.60	0.61	0.50	0.54	−0.30

Role of global SST forcing vs. atmospheric internal variability

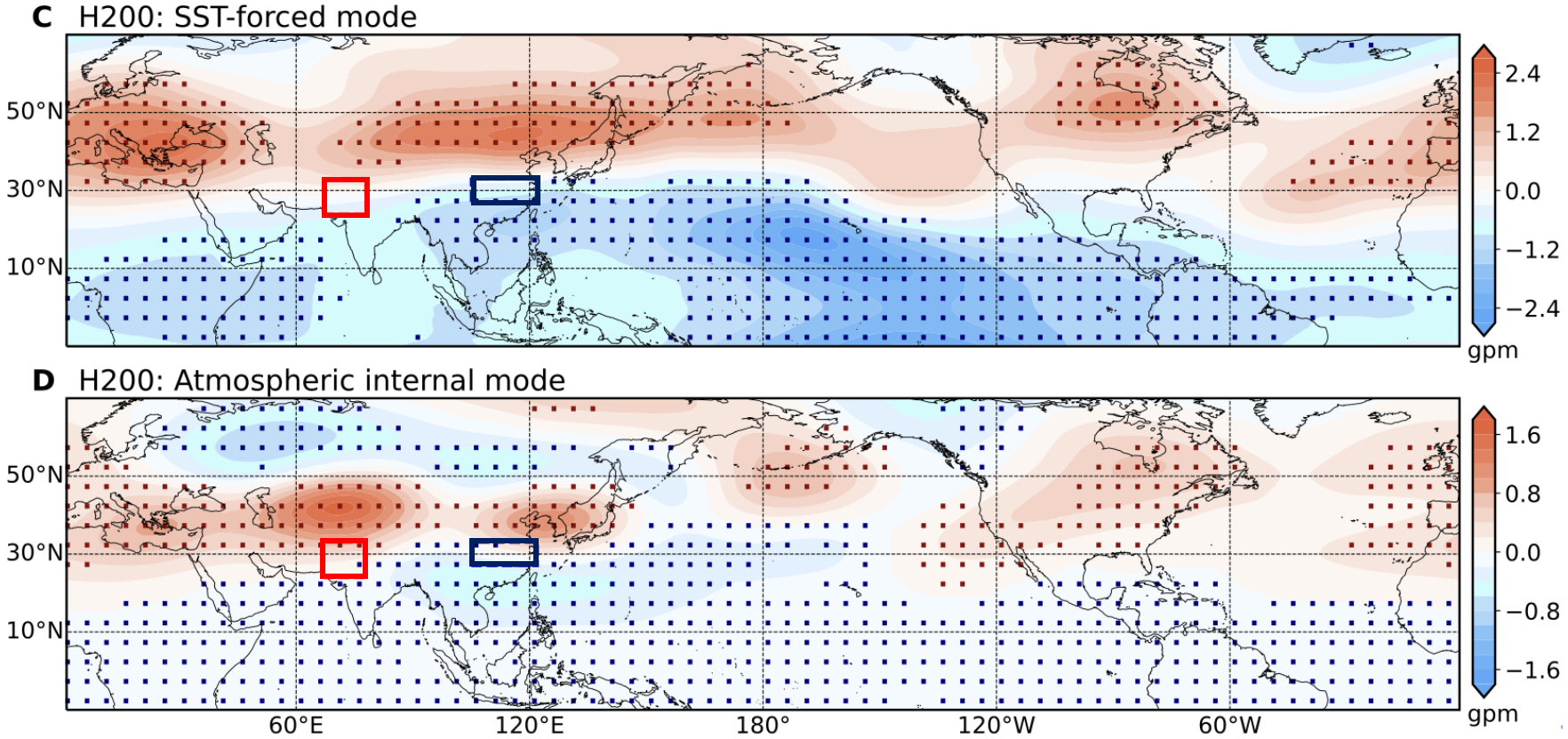
- The SST-forced pattern is of a global scale while the internal mode is confined mostly within the ASM region.



Averaged Pakistan-northwest India OLR & gridded surface temperature

Atmospheric internal variability dominates the coupled mode

- 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

A suite of LBM experiments: Effect of convective heating

LBM experiments

Circulation anomalies in response to diabatic heating.

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

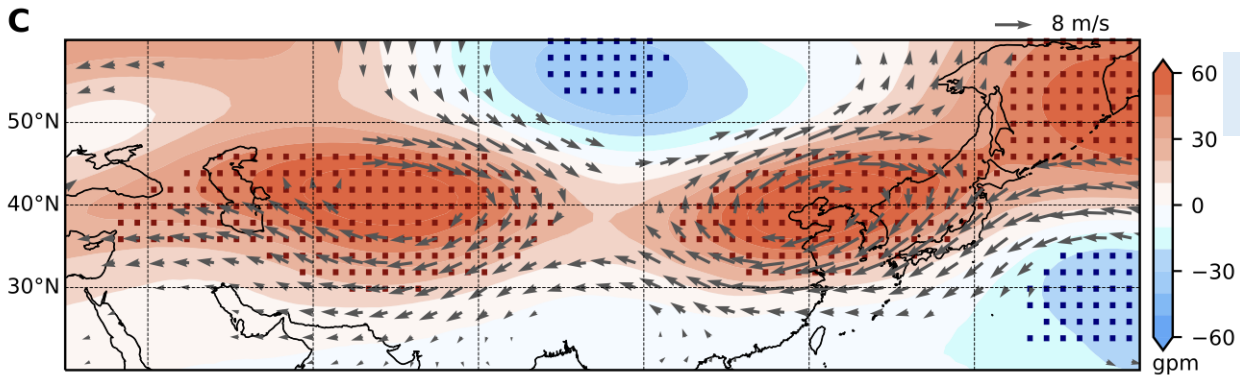
Vertical maximum heating at 450hPa with 6-7K/day (typical of deep convection)

Watanabe et al. 2000

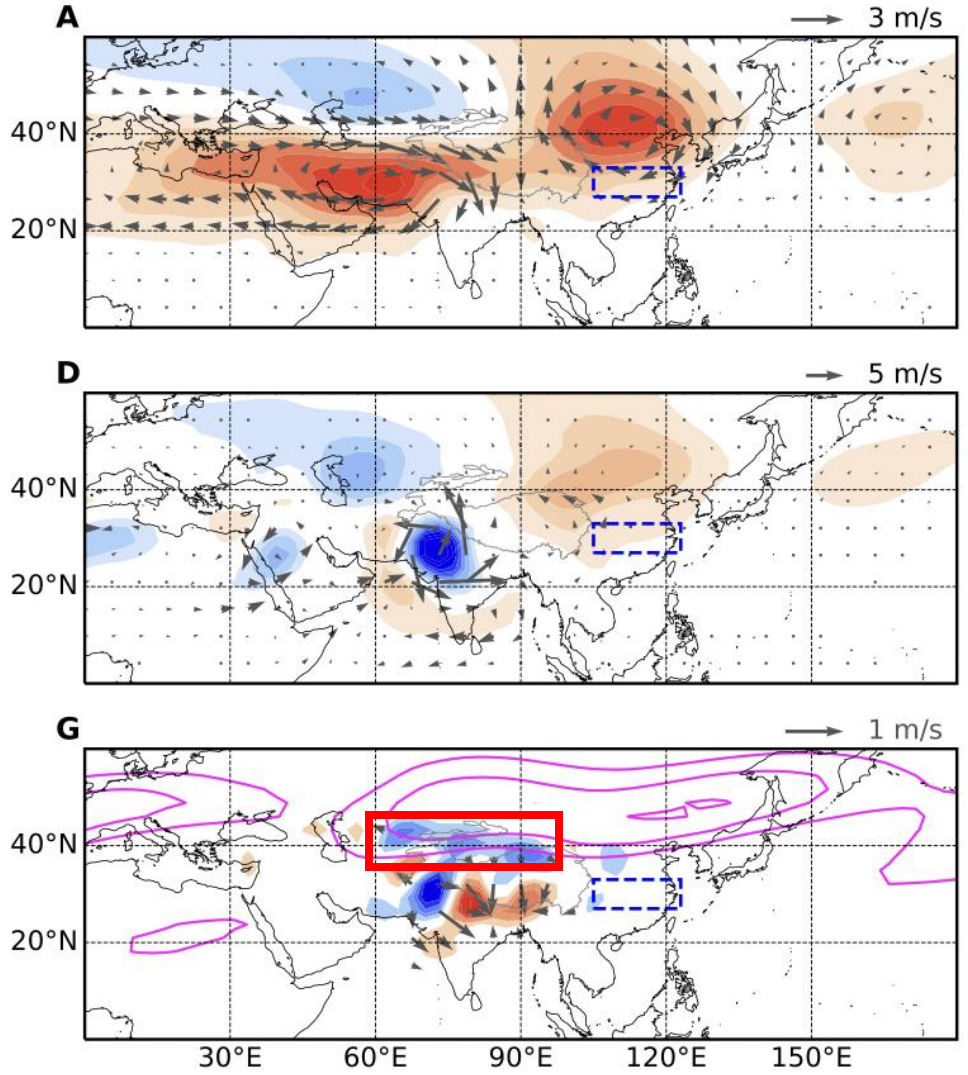
Model Setup

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



Experiment 1: Heating in Pakistan during July-August

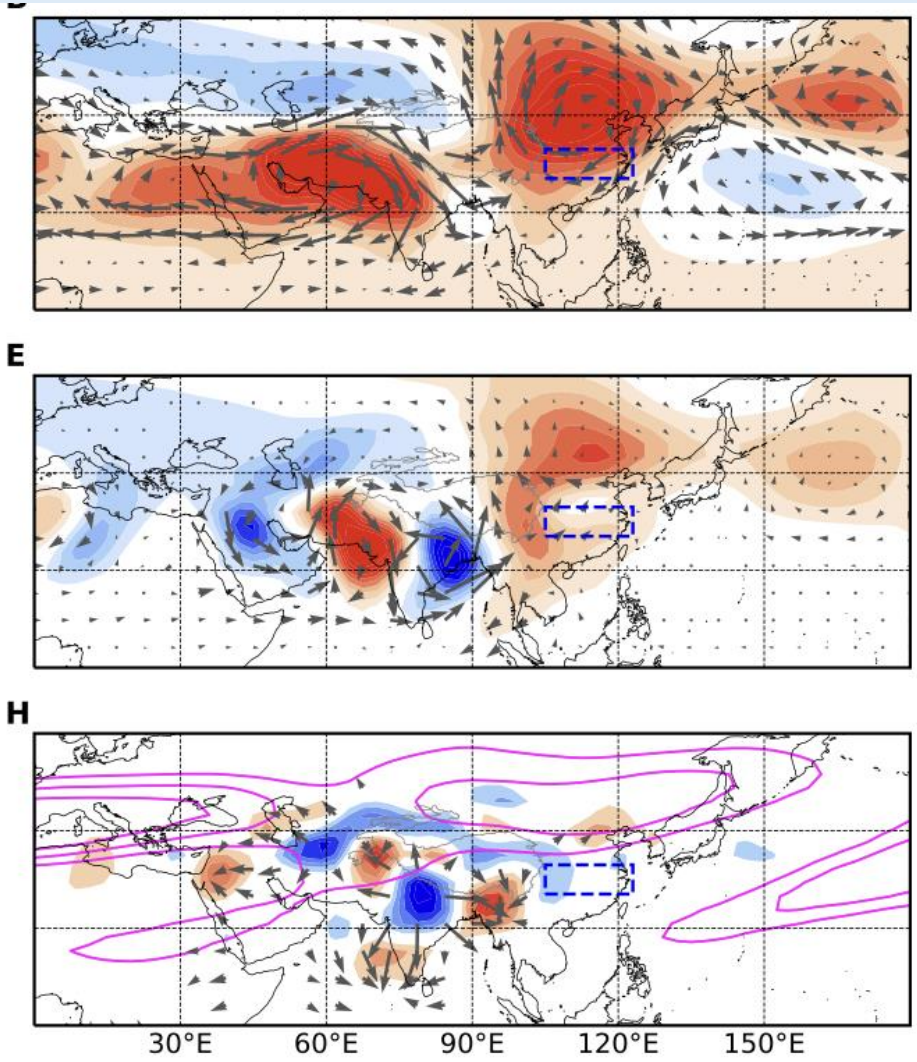


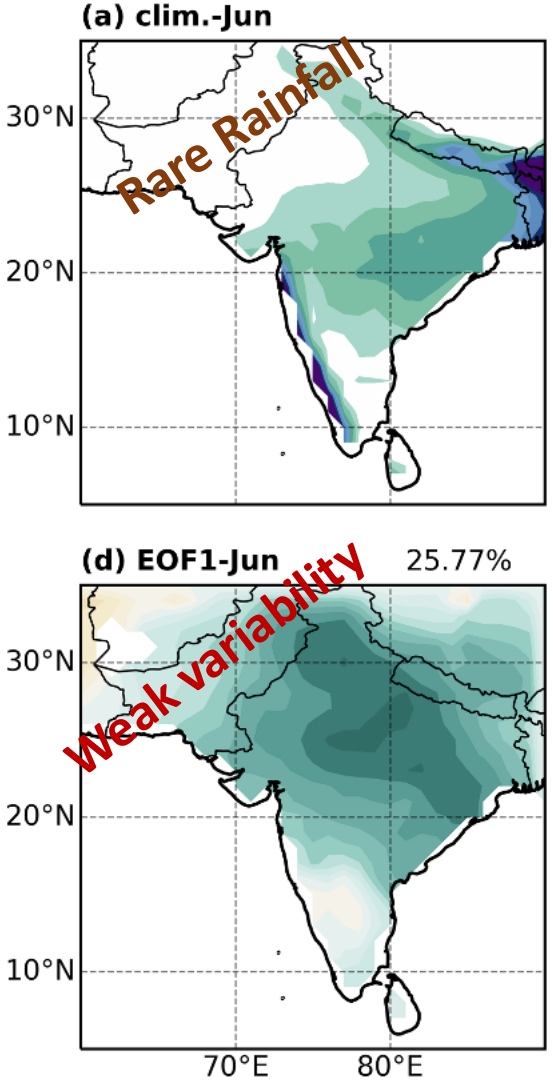
- The upper-tropospheric divergent flow associated with Pakistan convective heating could touch the subtropical westerly jet.

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

Monsoon climate variability inhibits the linkage in June

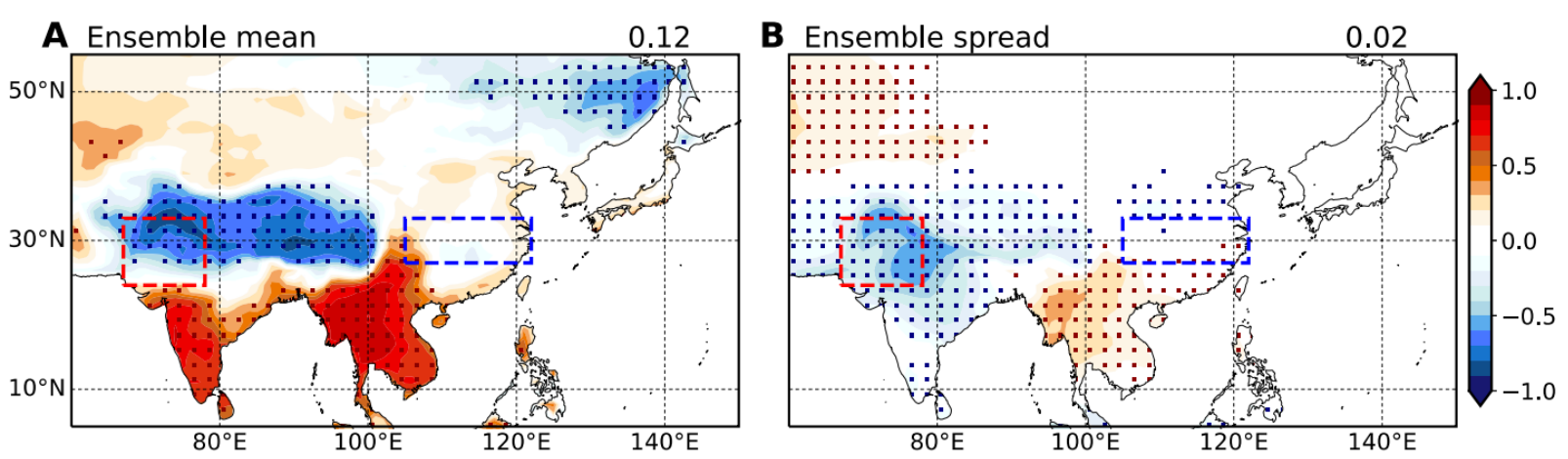
Experiment 2: Heating in Pakistan during June

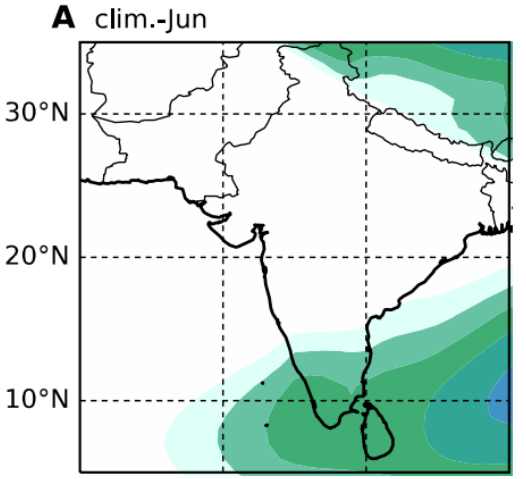


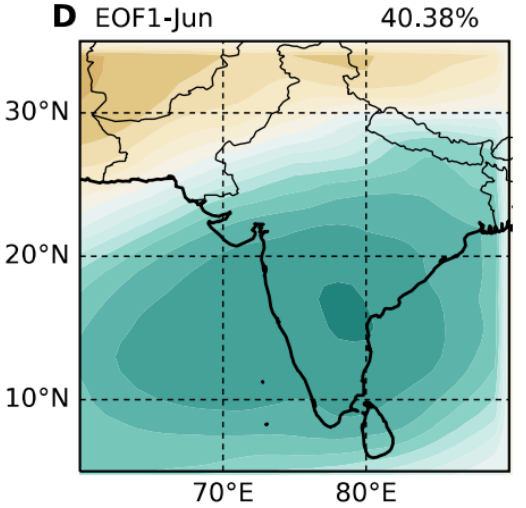


- Although Pakistan convection can force a strong Rossby wave response on a June basic state, the variability and climatology of the local monsoon system may put restrictions on this response.

Disappearing linkages in June in CESM2 simulations



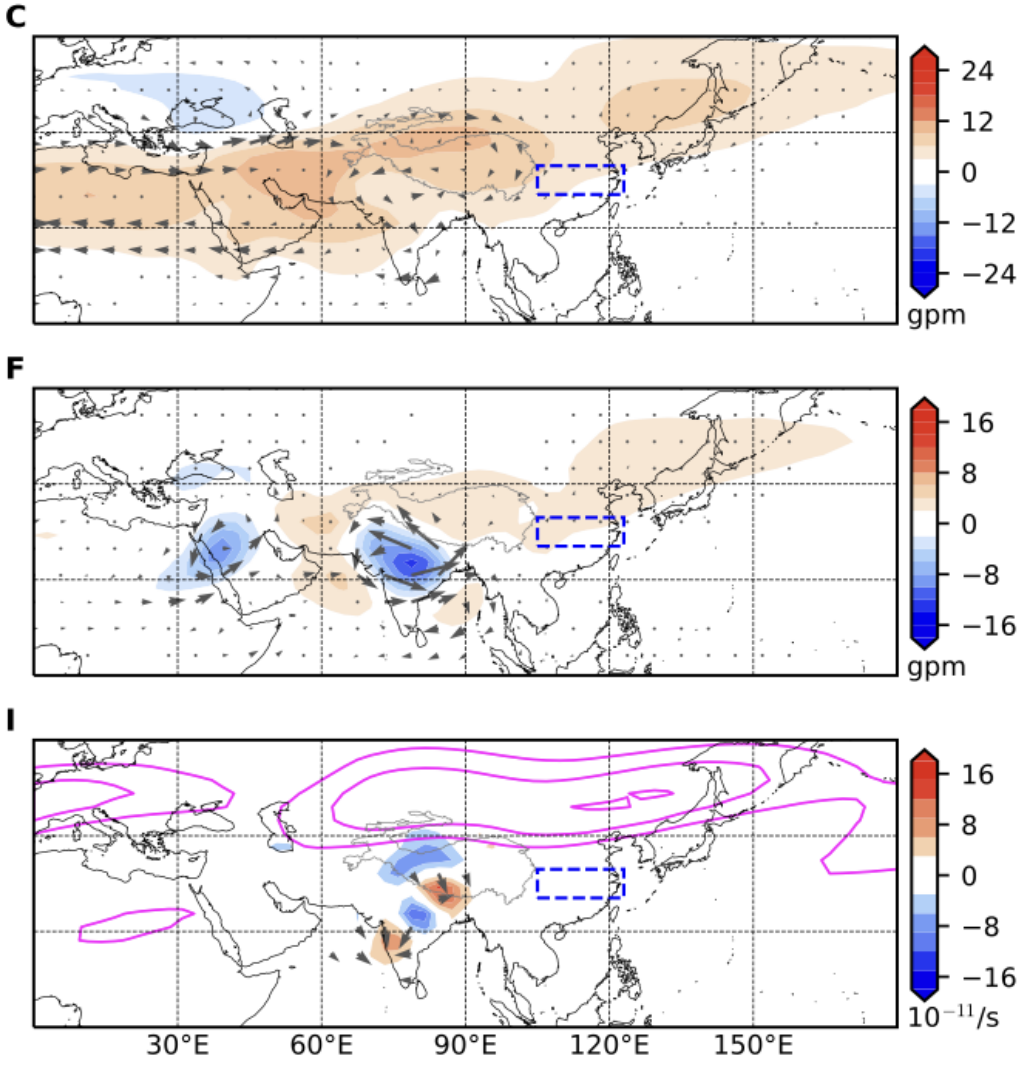




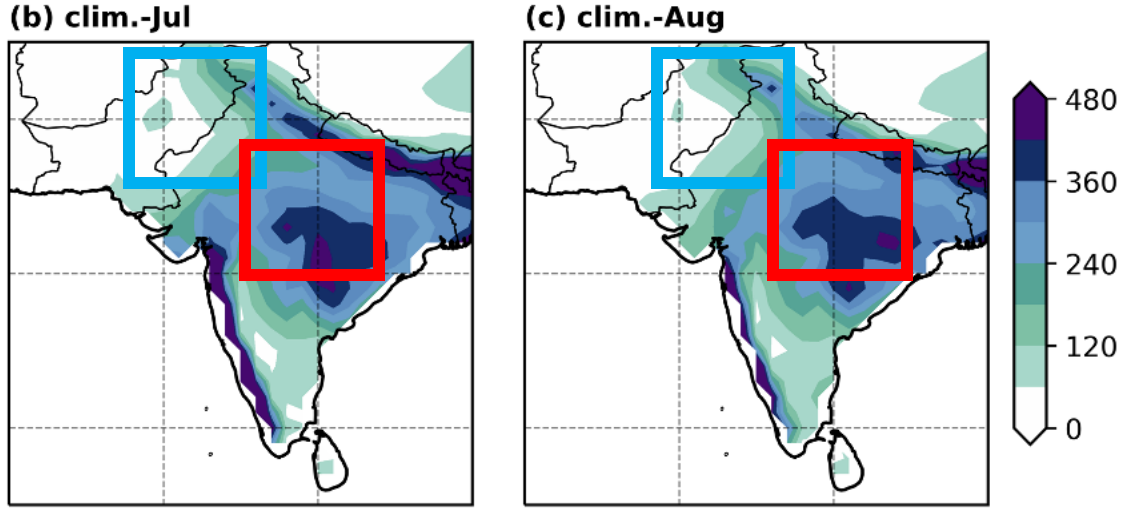
- Consistent with observations, the wave train connecting PNWI convection and East Asian heatwaves disappears in June in model simulations
- This connection is inherent to wave dynamics of the upper-level Asian westerly jet.

Convection in central India fails to trigger Rossby wave train

Experiment 3: Heating in central India during July-August

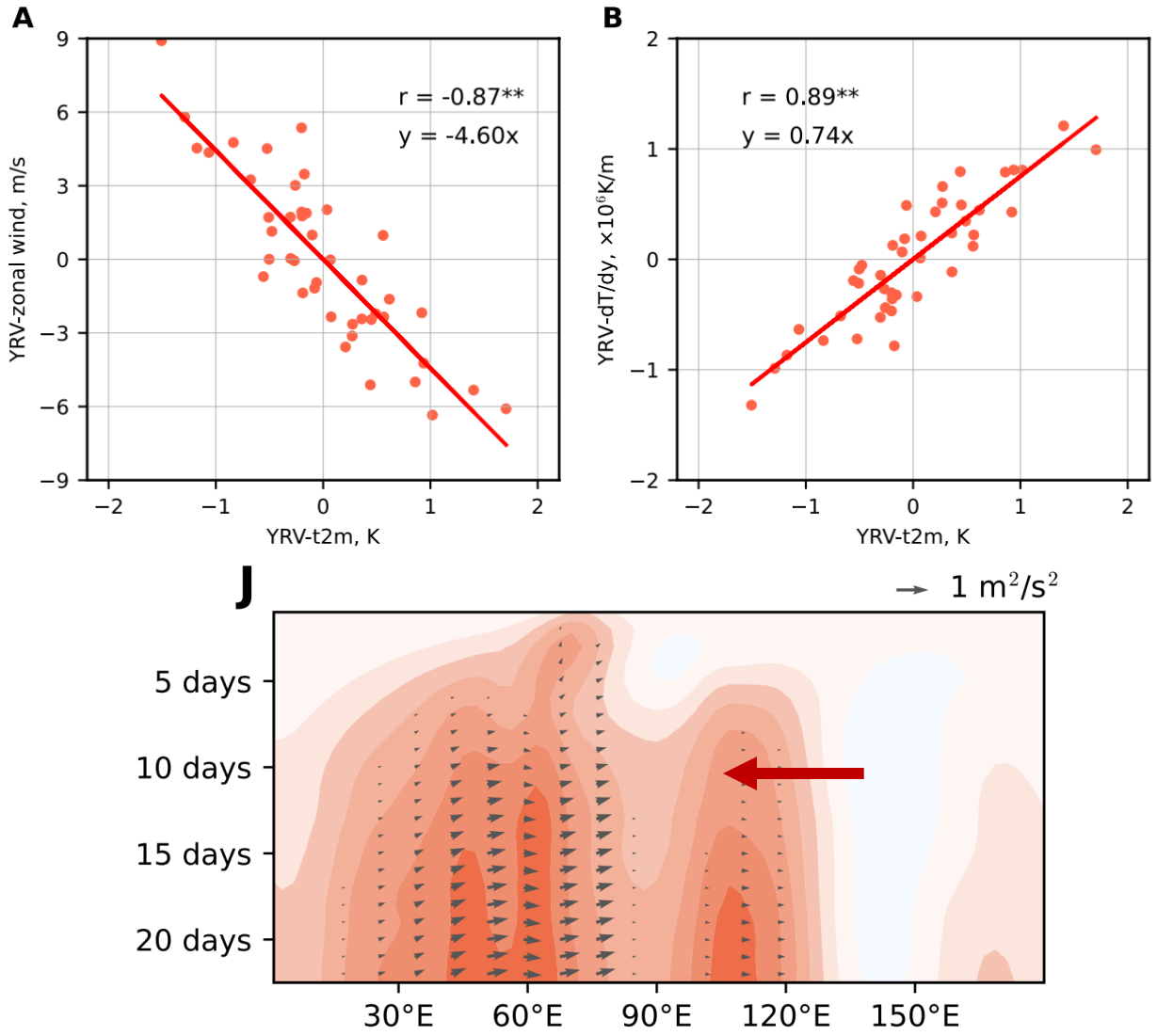


- Although rainfall variability is large in midsummer over central India, it does not effectively excite the Rossby wave response due to dynamic limitations (lower-latitude and long distance from the westerly).



Rainfall climatology

Implications for sub-seasonal prediction



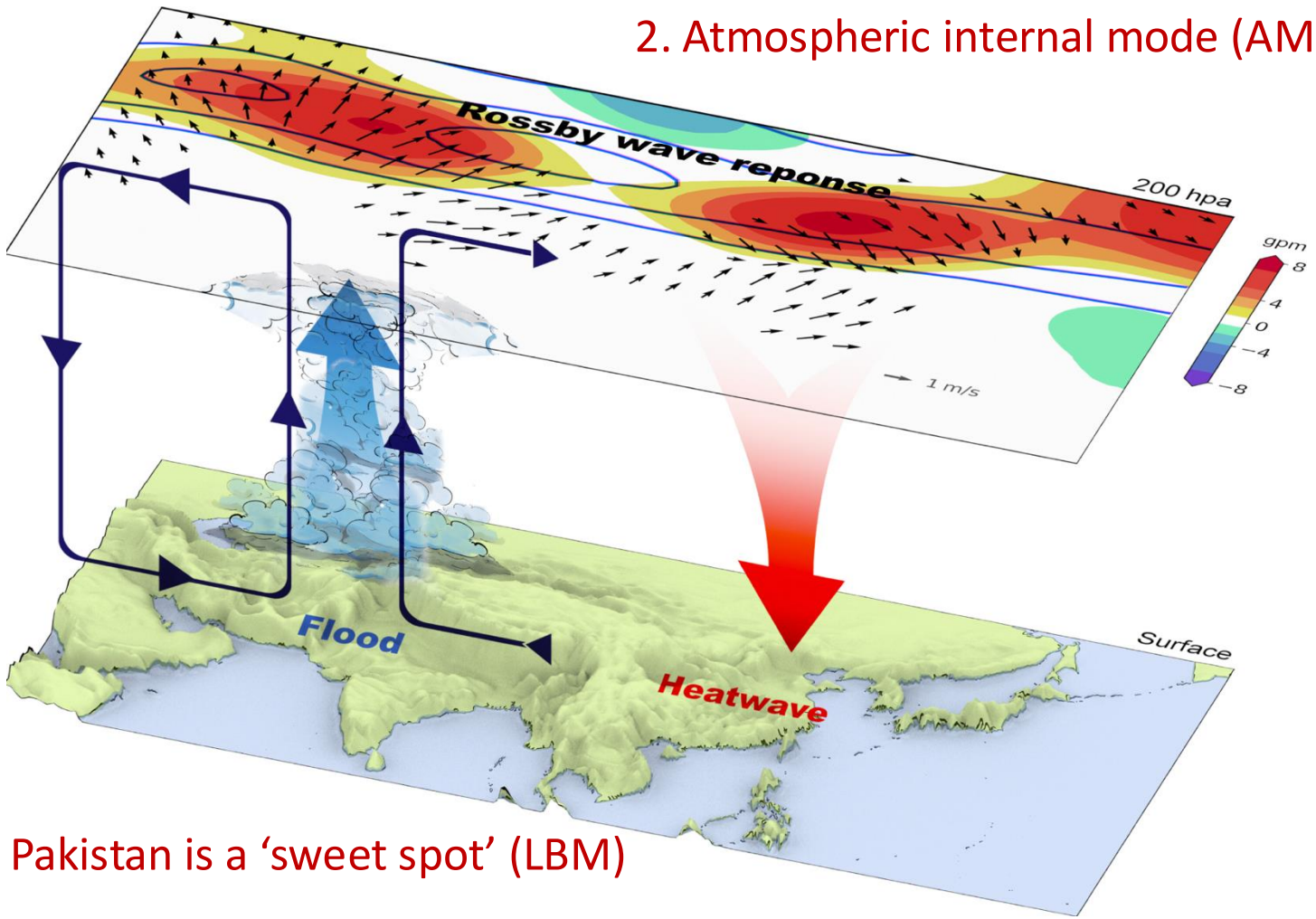
- The downstream anti-cyclone over East Asia is well-established **at least 10 days after** the initial convection perturbations.
- The delayed response in East Asia is important for subseasonal prediction

"The ISM diabatic heating triggers a strong regional CGT wave train that propagates toward East Asia along the westerlies in June but not in July to September."

--from Li et al. 2023

Dynamic pathway linking Pakistan flooding to East Asian heatwaves

2. Atmospheric internal mode (AMIP)



3. Pakistan is a 'sweet spot' (LBM)

Pakistan flooding

↓

Upper troposphere divergent wind

↓ Westerly

Downstream AAC response

↓

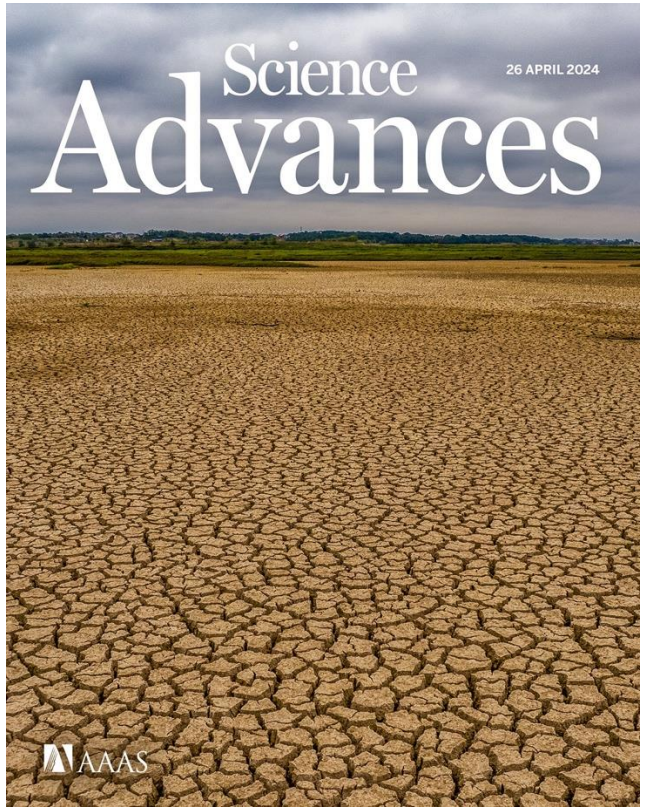
Suppressed convection/ Increased heatwave over YRV

Reinforce

1. Dynamic Pathway (Observations)

Discussion

Credit: Dike Su/**ZQA Weather Hub of China**



- The forcing of the dynamic pathway across **timescales**
- Is there a similar mechanism working in other regions near the westerly jet? -**Why Pakistan?**
- What is the role of the Tibetan Plateau? Does **air-land coupling** over High Mountain Asia enhance the dynamic linkage? (ongoing…)
- ……

- Fu, Z.-H., W. Zhou*, S.-P. Xie*, R. Zhang, and X. Wang, 2024: Dynamic Pathway Linking Pakistan Flooding to East Asian Heatwaves. *Science Advances*, 10, eadk9250.

Thank you!

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Paper Web

Group Web

Personal Web

Thank you!

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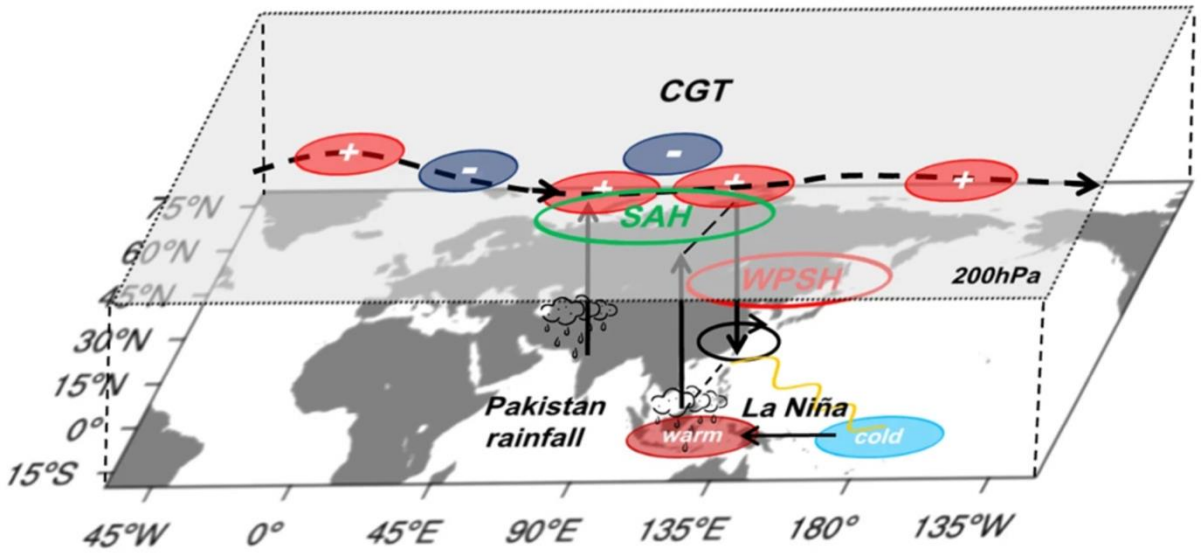
Roles of SST-forcing and CGT remain contradictory

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, the relative roles of SST forcing and atmospheric internal variability remain to be quantified to resolve contradictions among recent studies.

  Jeong et al. 2023; Tang et al 2023; Hong et al. 2023; Li et al. 2023

- 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. 2024

Performance in AMIP simulations

CESM2-CAM6 member	-OLR & Temp.	-OLR & Temp. (no ENSO)	-OLR & ENSO	Temp. & ENSO	Temp. & ENSO (no -OLR)
1	0.69	0.68	-0.09	-0.08	-0.02
2	0.20	0.21	-0.12	0.07	0.09
3	0.46	0.42	-0.35	-0.22	-0.07
4	0.47	0.50	-0.21	0.10	0.23
5	0.31	0.31	-0.23	-0.07	0.01
6	0.48	0.48	0.00	0.14	0.15
7	0.29	0.30	0.10	0.05	0.07
8	0.52	0.56	-0.19	0.14	0.28
9	0.29	0.30	-0.33	-0.03	0.07
10	0.52	0.51	-0.17	-0.15	-0.07
Observations	0.50 ~ 0.62	0.52 ~ 0.62	-0.35 ~ -0.24	-0.09 ~ 0.05	0.08 ~ 0.27