Climate change-driven evolution of East Asian summer monsoon front and frontal precipitation

Suyeon Moon[1] (symoon@apcc21.org), and Hyungjun Kim[2]

[1] Climate Services and Research Division, APEC Climate Center, Busan, South Korea

[2] Moon Soul Graduate School of Future Strategy, Korea Advanced Institute of Science and Technology, Daejeon, South Korea

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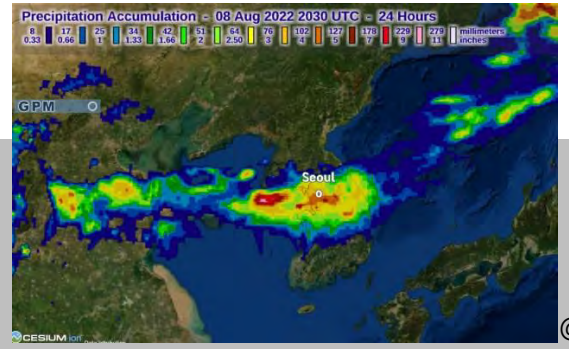
Occurrence of more back-to-back summer heavy precipitation

Record-breaking heavy rainfall in Seoul 2022:

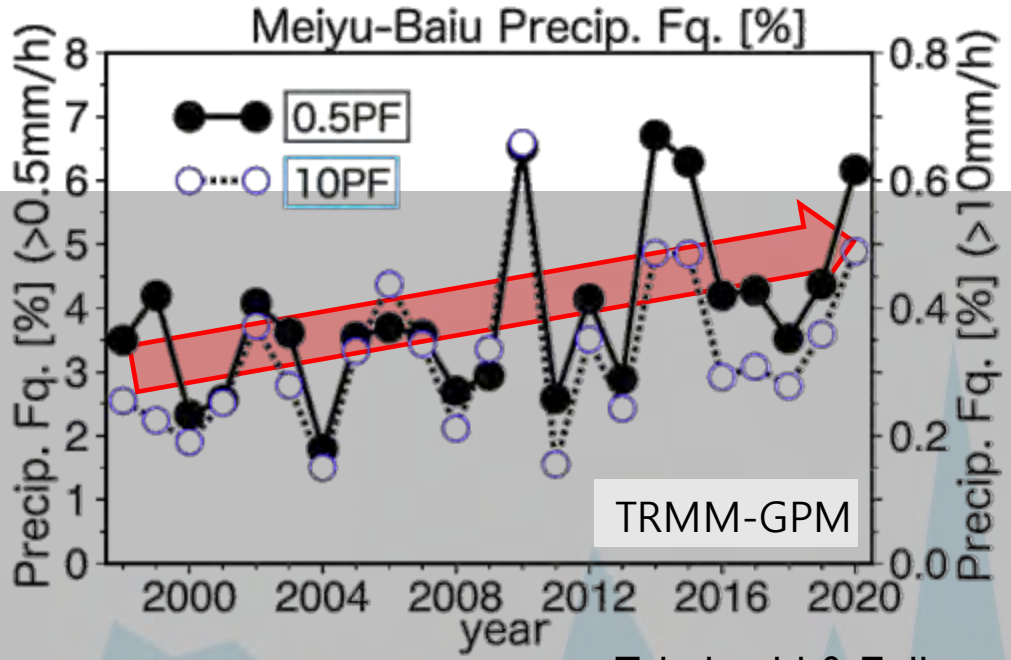


@CESIUM

South Korea's Monsoon Rains Set Off Deadly Landslides and Flooding

With at least 40 people dead, the current monsoon season is already proving to be a particularly dangerous one in South Korea, with rain forecast to continue.


@TheNewYorkTimes



Takahashi & Fujinami, 2021

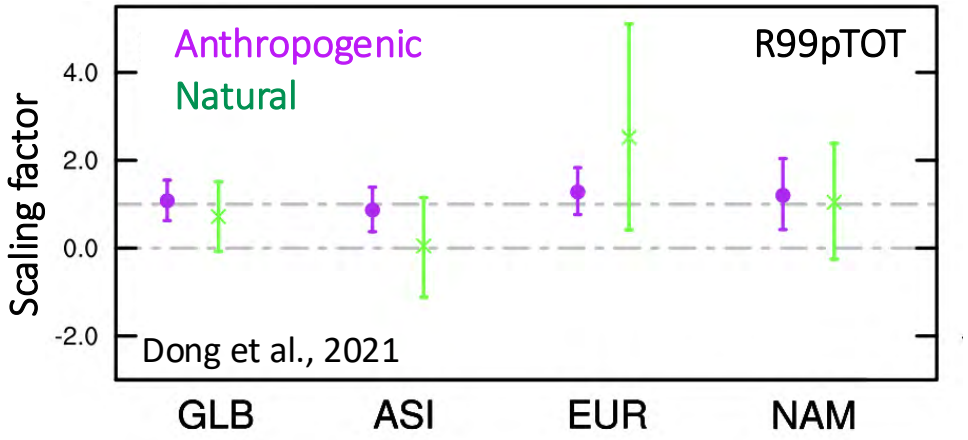
Are these increasing trends due to
natural variability or **the impact of anthropogenic warming**?

Maximum daily precipitation in summertime (JJA) over the East Asian region based on JRA55 during 1979–2022

1980 1990 2000 2010 2020

Precipitation is composed of various weather systems

Attribution study of heavy precipitation

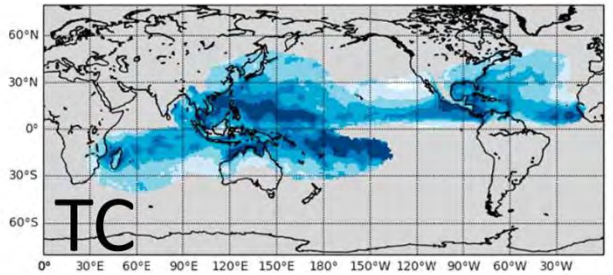


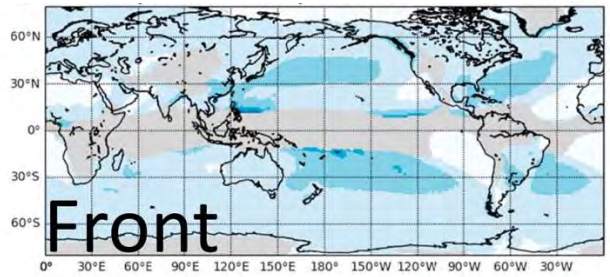
Changes in precipitation have been detected, but …

Most studies on the detection and attribution of precipitation have primarily **focused on the seasonal mean or extreme indices**, **not on process-oriented components**.

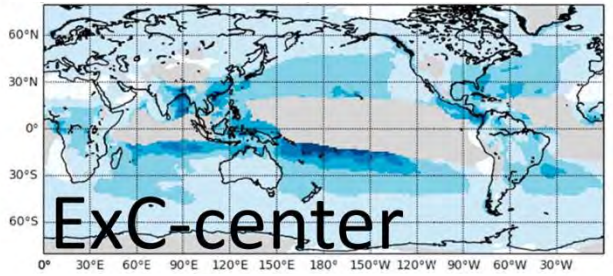
Precipitation is **composed of various weather systems!**

Total precipitation =





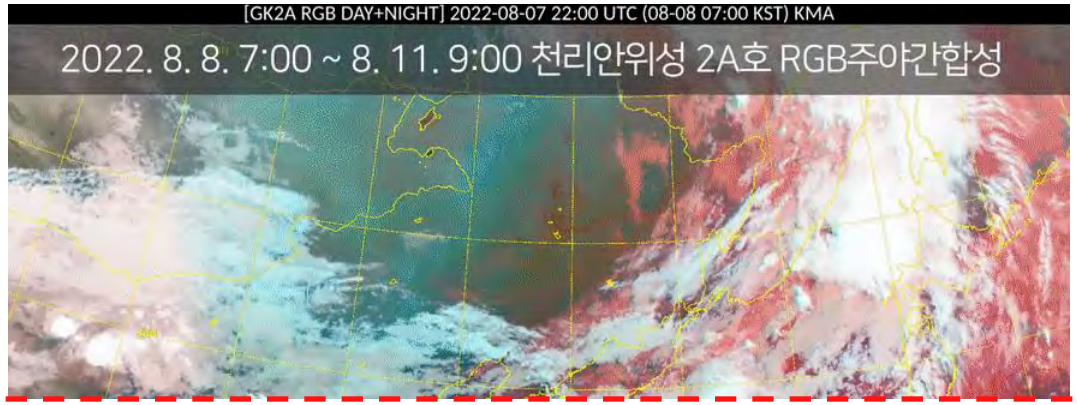
Utsumi et al., 2016

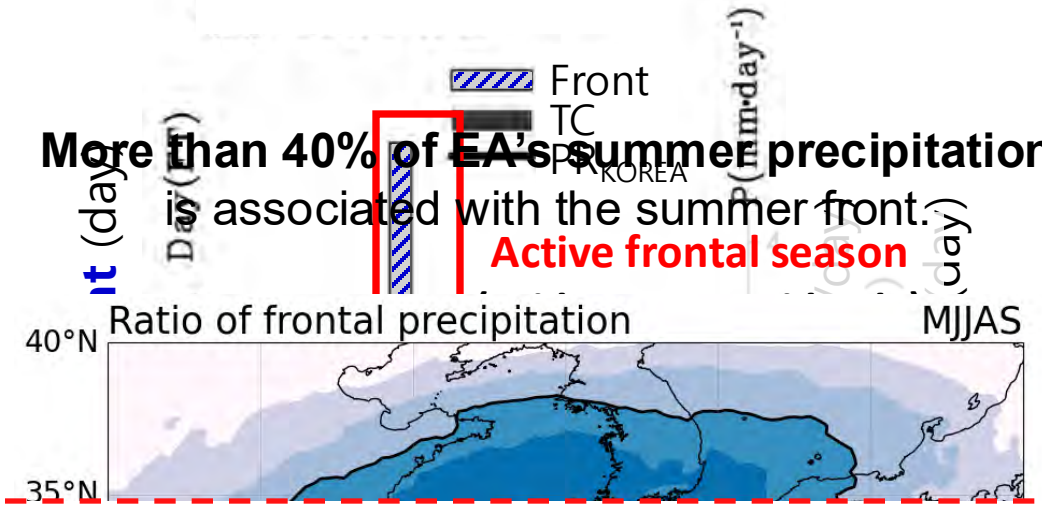


+ Others

Why do we focus on the “Frontal precipitation” ?

GK-2A Satellite [8 – 11 Aug 2022]





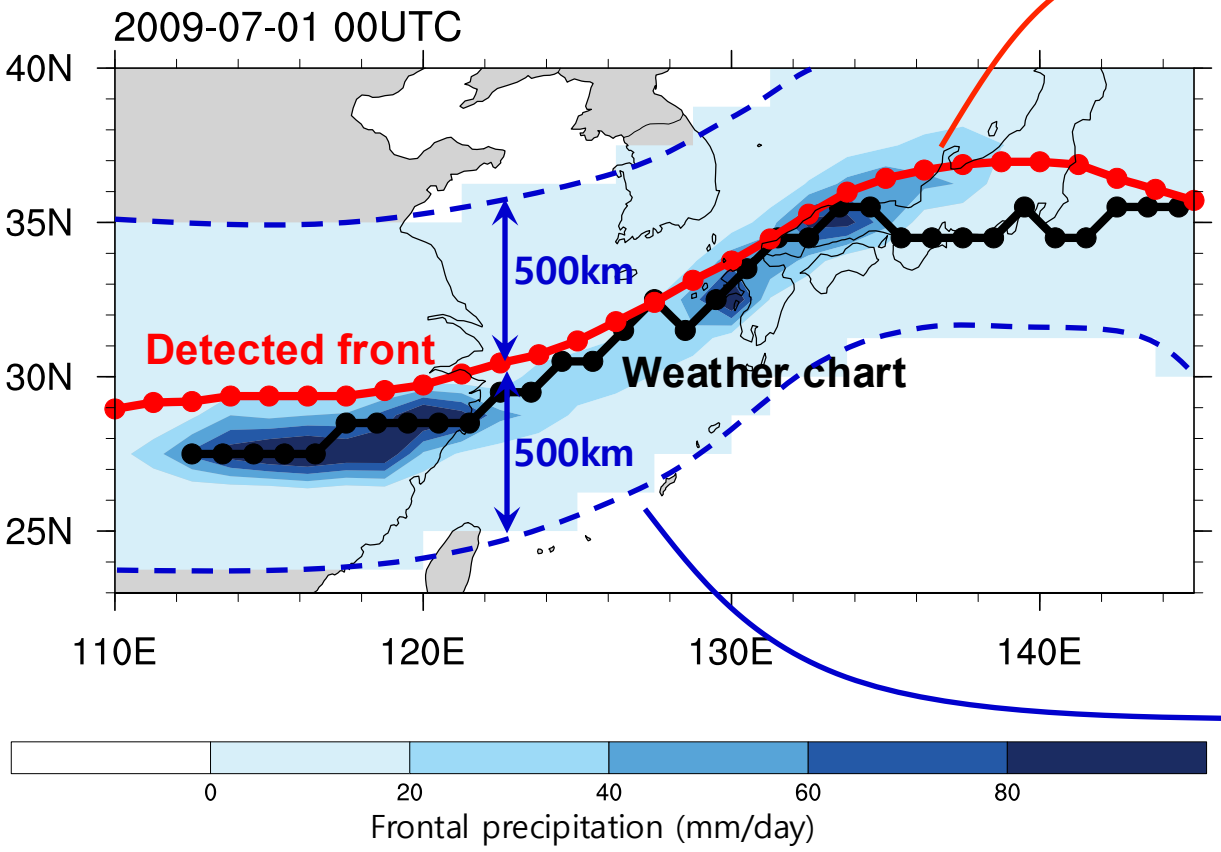
More than 40% of EA’s summer precipitation is associated with the summer front.

Research purpose

- **Detect the ‘Front’ and ‘Frontal precipitation’ with careful verification** during summertime over East Asia
- Investigate **how much of the recent change in frontal precipitation can be attributed to anthropogenic greenhouse gas forcing**.

Detection of ‘Front’ and ‘Frontal Precipitation’

Using JRA55 6hourly reanalysis data



Detection of **FRONT**

(1) $|\partial\theta_e/\partial y| > 0.04$ K/km

(2) Number of front grids

$$\frac{Number\ of\ grid\ satisfying\ condition(1)}{Total\ number\ of\ grid} \geq 0.1$$

(3) Continuity of front line

$$\overline{|LAT_{i+1} - LAT_i|} < 1.25$$

(horizontal resolution of JRA55 is 1.25°)

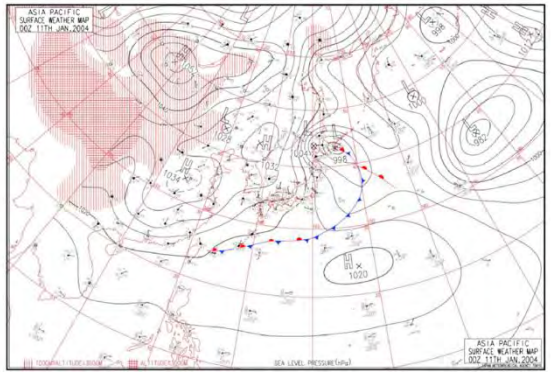
(4) Running average of LAT_i

Detection of **FRONTAL PRECIPITATION**

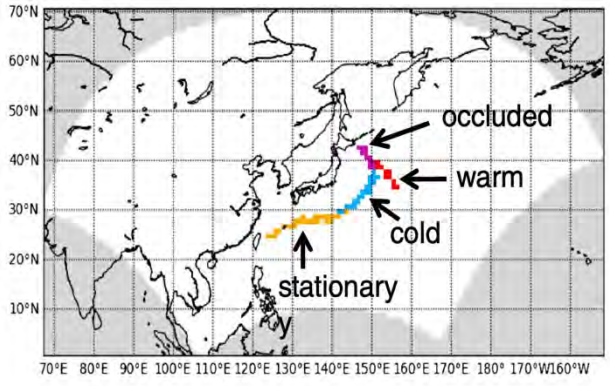
Daily precipitation within a **500 km radius** of the front line at any timestep of the day.

Carefully verified front detection

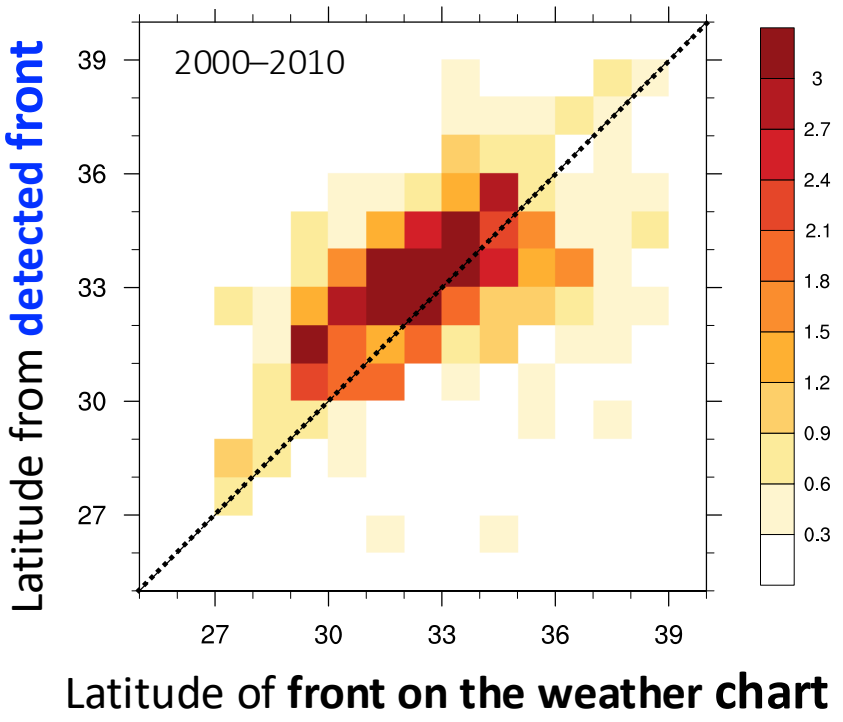
Weather chart
provided by the Japan Meteorological Agency



The 1.0° gridded front data
(*Utsumi et al., 2014, JGR-Atmos*)



Joint PDF of the median latitude of front

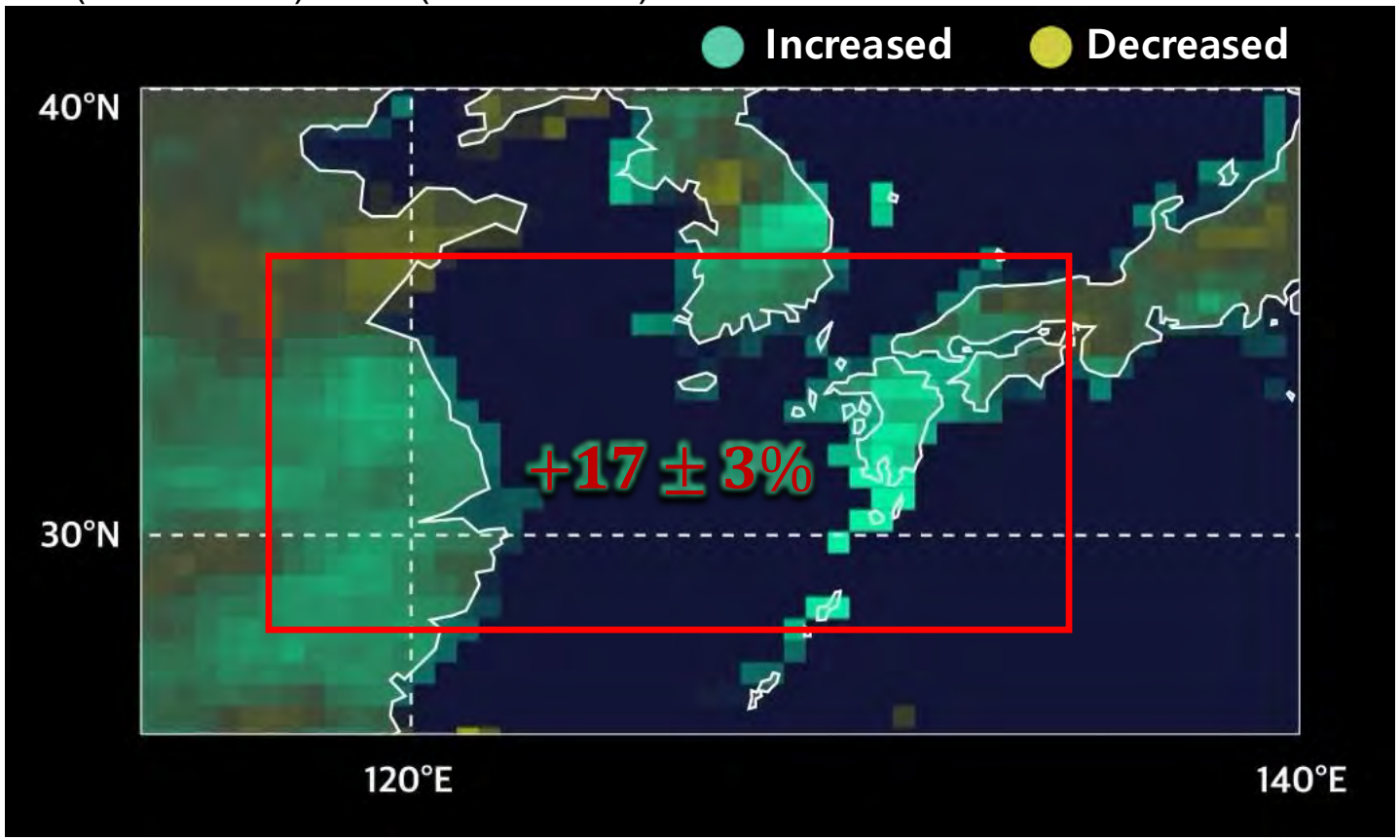


The detected fronts simulated a close match with the front observed in the weather charts.

Observed changes in frontal precipitation intensity

The intensity of frontal rainfall became enhanced by $17 \pm 3\%$ along the coastal regions of East Asia.

P2 (1991–2015) – **P1** (1958–1962)



Observation data:
daily, APHRODITE
& REGEN

Detection of anthropogenic greenhouse gas forcing impact

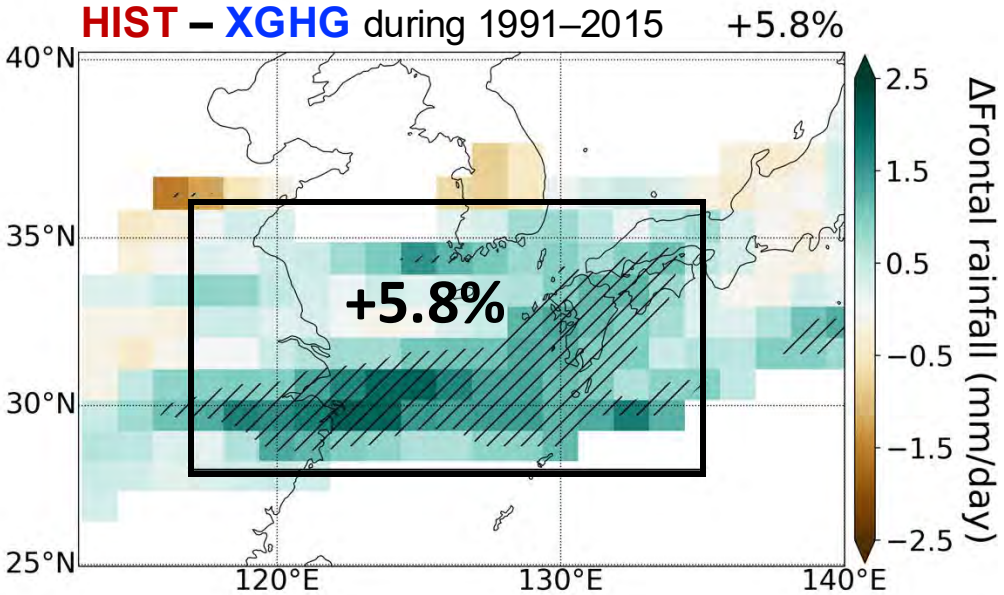
To demonstrate anthropogenic greenhouse gases forcing impacts
Daily, **CESM1 LE** historical (HIST) & All-but-greenhouse gases forcing (XGHG)

× 40ens — × 20ens = Greenhouse gas forcing impacts

WITH anthropogenic greenhouse gas forcing impact

WITHOUT anthropogenic greenhouse gas forcing impact

Fixed greenhouse gas forcing at 1920 condition



In the recent period, **the intensification of frontal rainfall has been influenced by greenhouse gas forcing.**

Anthropogenic greenhouse gas impact on frontal precipitation

We cannot experience the increasing frontal precipitation intensity without the greenhouse gas forcing effect.

Human-induced warming has already altered the frontal precipitation intensity over East Asia.

Non-optimized version
of the fingerprint analysis technique

Frontal rainfall intensity

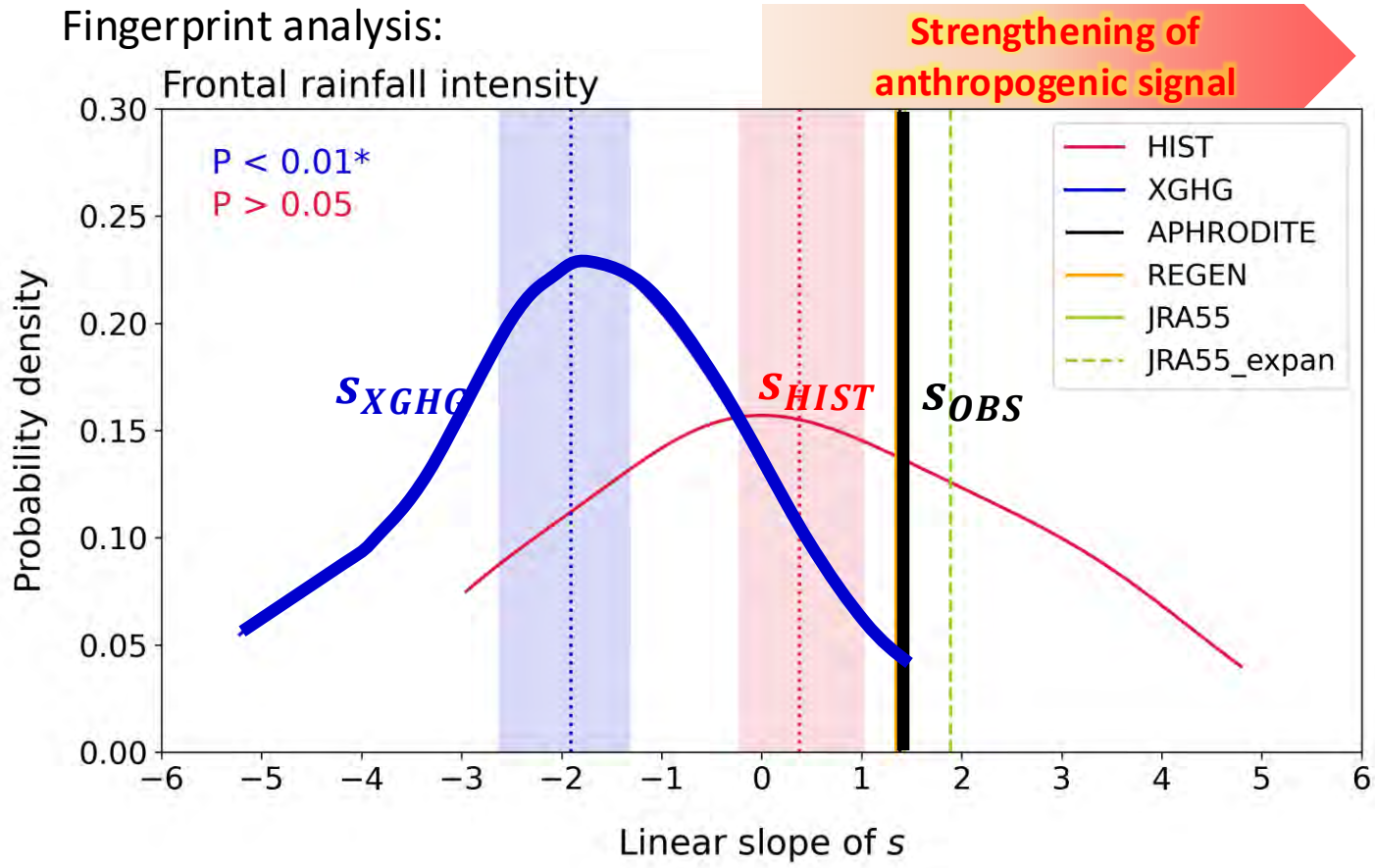
$$s(t) = FRI(t) \cdot f$$

Detection signal — Fingerprint

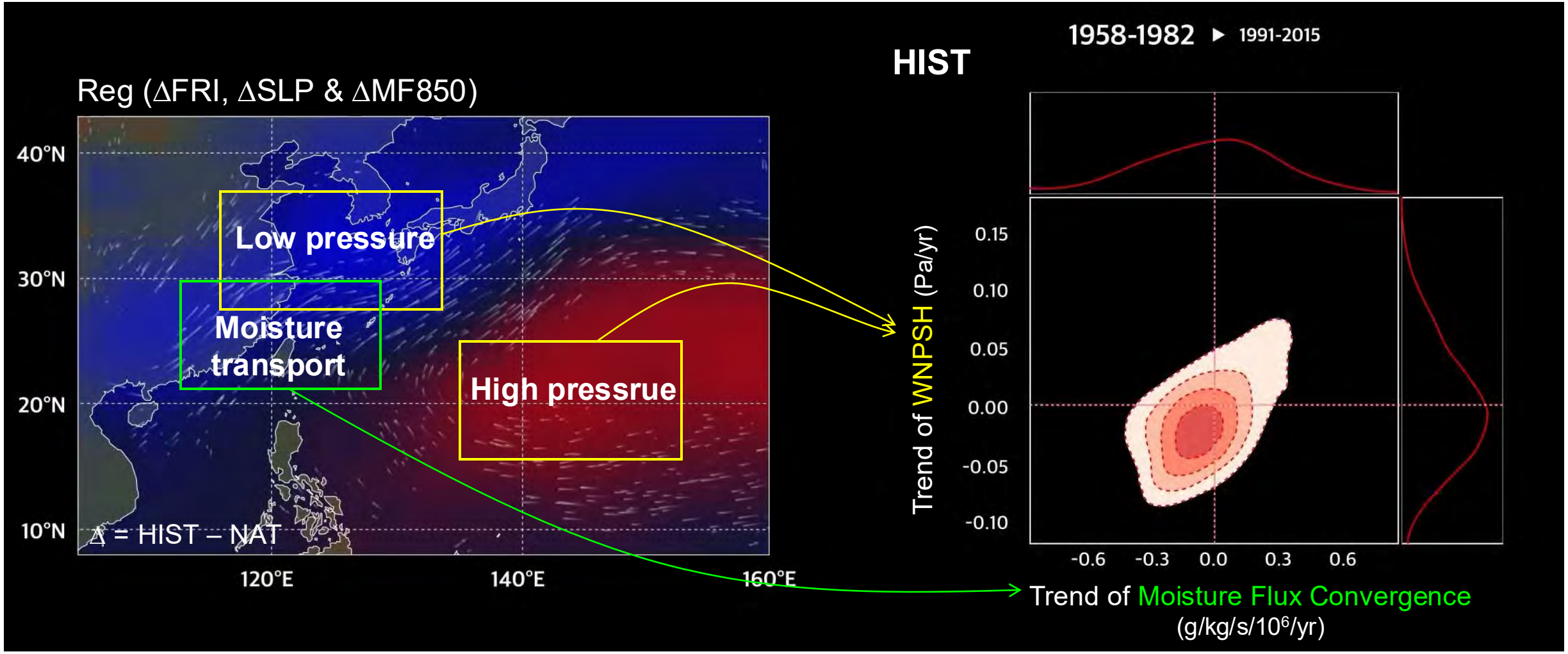
$$f = \frac{f'}{|f'|}$$

f': Difference (HIST – XGHG) in frontal rainfall intensity during 1991–2015

Fingerprint analysis:

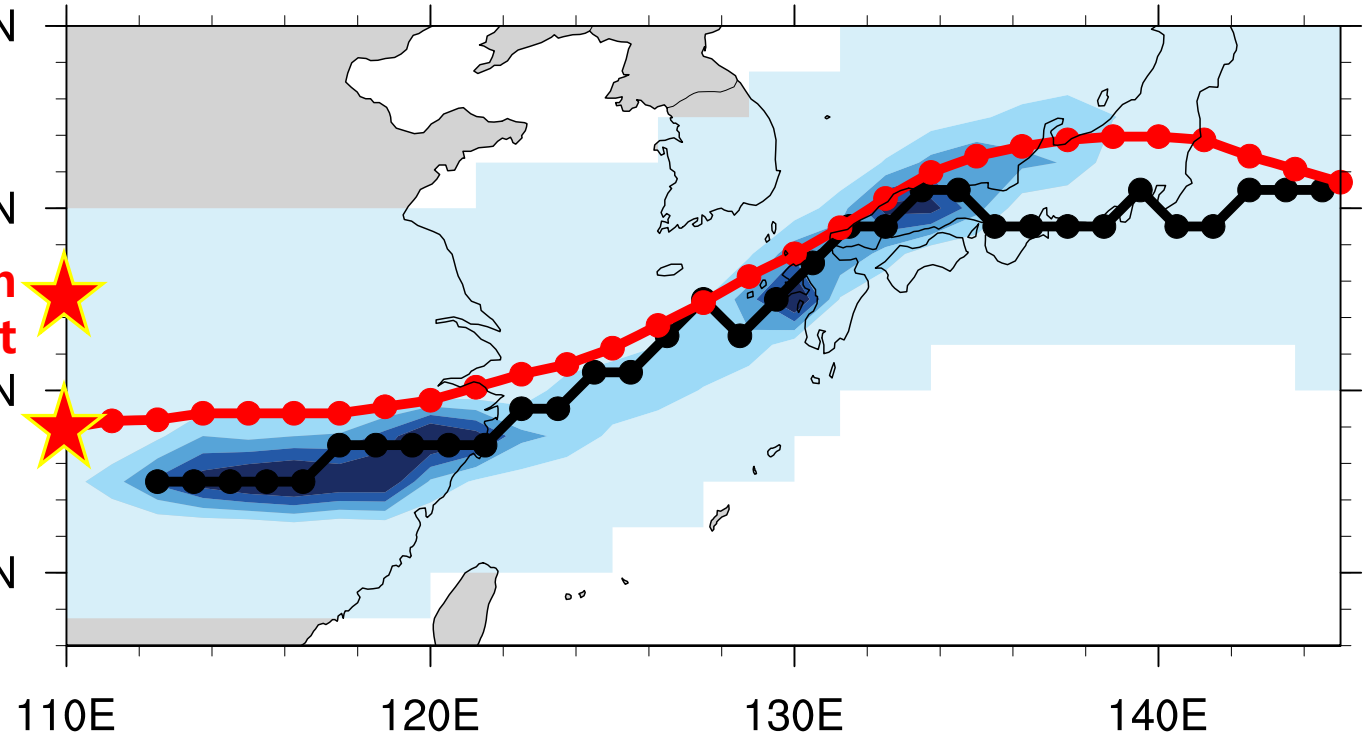


Physical mechanisms of intensified frontal precipitation

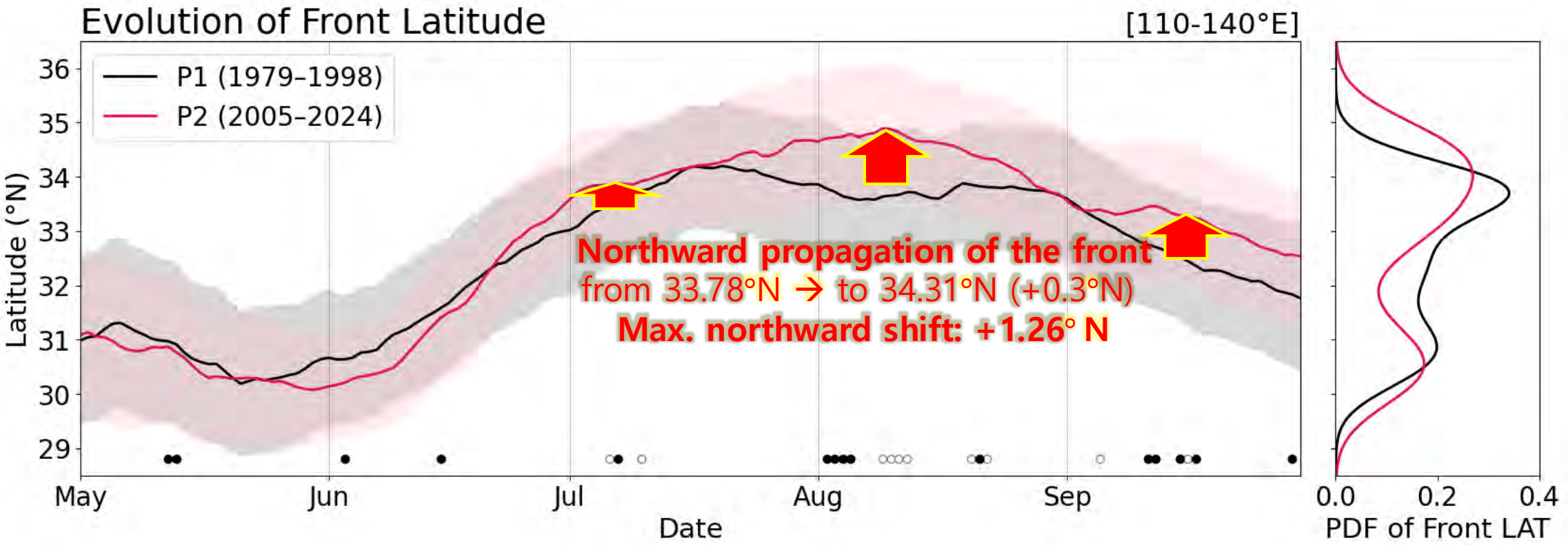


What about the migration of the EA summer front?

Representative position of the front



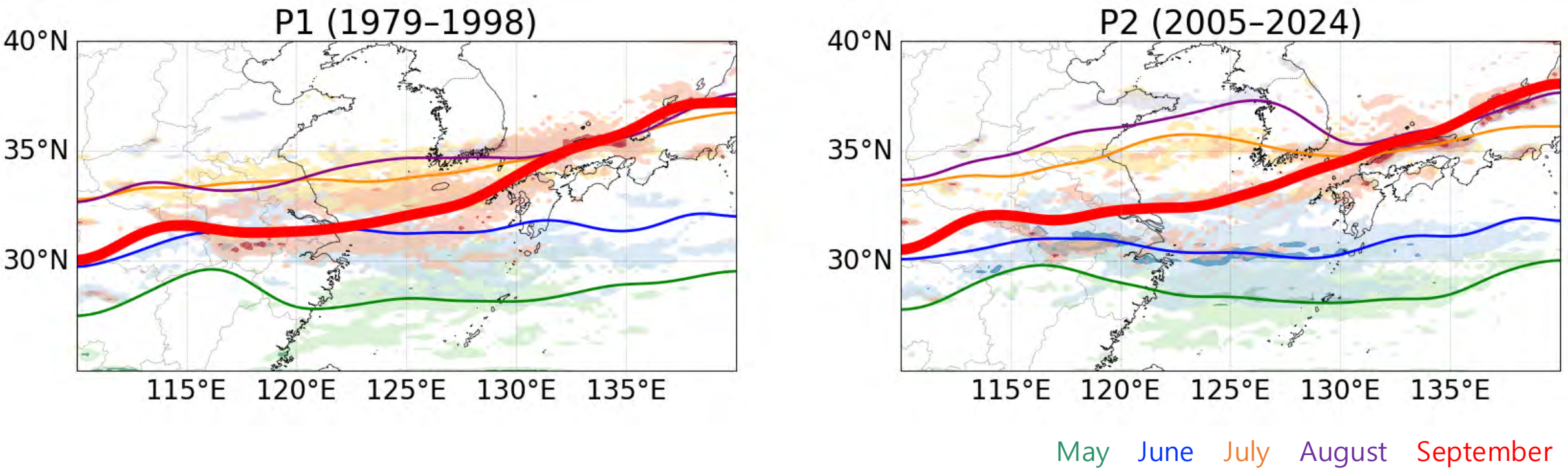
Northward migration of the EA summer front



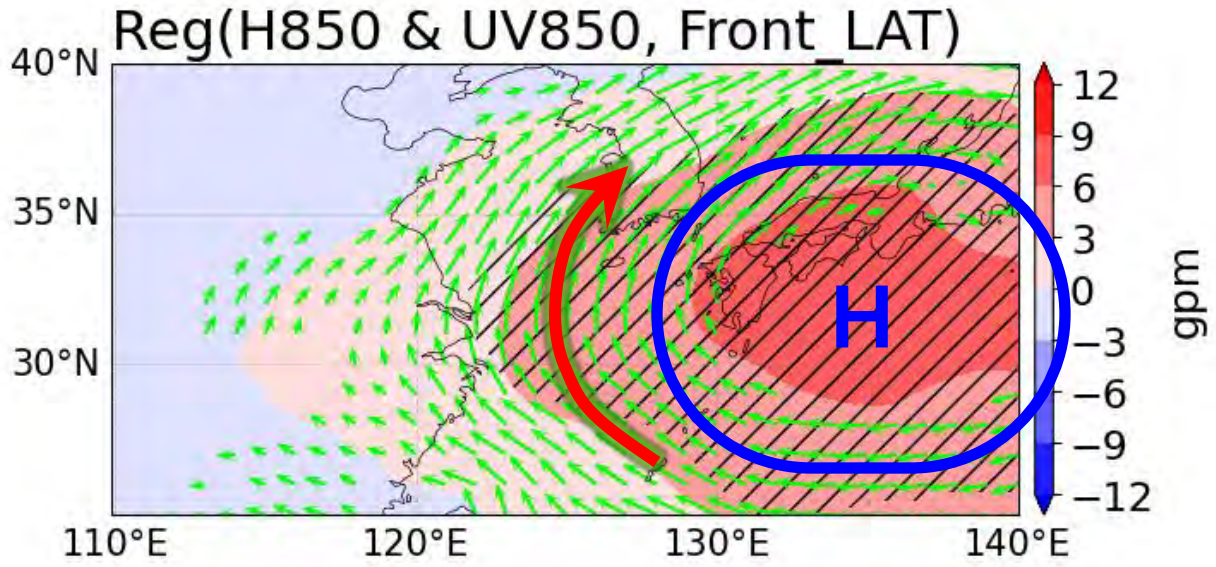
ERA5 (1979–2024), Horizontal resolution: 0.25° × 0.25°

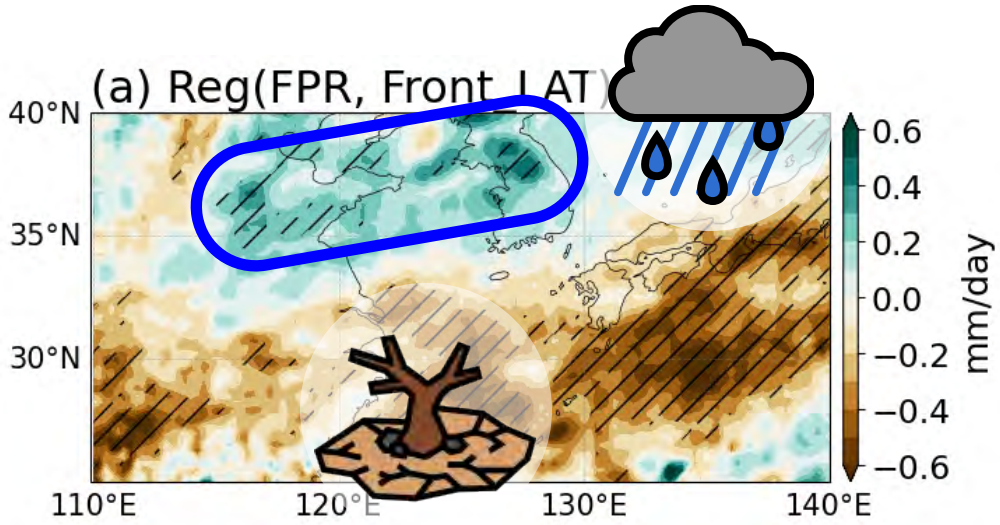
Northward migration of the EA summer front

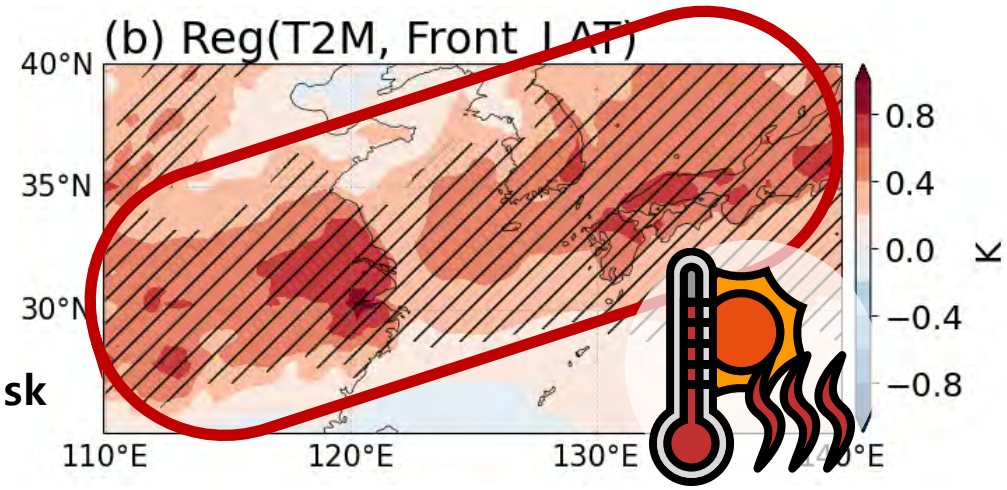
The East Asian summer front has shifted northward, especially in **July (+0.64°N)**, **August(+1.38°N)**, and **September(+0.62°N)**.



Drivers and impacts of the northward shift of the front







Northward Shift of the summer front :

Northward expansion and intensification of the WNPSH

→ **Southerly winds** along the edge of WNPSH

→ **Resulting in:**

Increased precipitation over central Korea → **(+)Heavy rainfall risk**

Rising temperature in East Asia → **(+)Heatwave risk**

Summary

- This study focuses on **process-oriented detection and attribution** to understand the anthropogenic greenhouse gas impact on East Asian summer precipitation.
- It is the first to demonstrate **the influence of anthropogenic greenhouse gas forcing on frontal precipitation** in East Asia.
- Frontal precipitation has intensified due to **stronger pressure gradients and increased moisture transport into East Asia.**
- **The northward shift of the summer front** leads to changes in both frontal precipitation and temperature in East Asia.
- The findings provide scientific evidence to support **regional risk management for extreme summer weather** in East Asia.

Thank you for your attention :)

symoon@apcc21.org

Moon, S., Utsumi, N., Jeong, J. H., Yoon, J. H., Wang, S. Y. S., Shiogama, H., & Kim, H. (2023). Anthropogenic warming induced intensification of summer monsoon frontal precipitation over East Asia. *Science Advances*, *9*(47), eadh4195. DOI: 10.1126/sciadv.adh4195