IBS Center
for Climate Physics

Recent marine heatwaves in the East China Sea: Mechanisms and future risk under climate change

2025. 11. 12.

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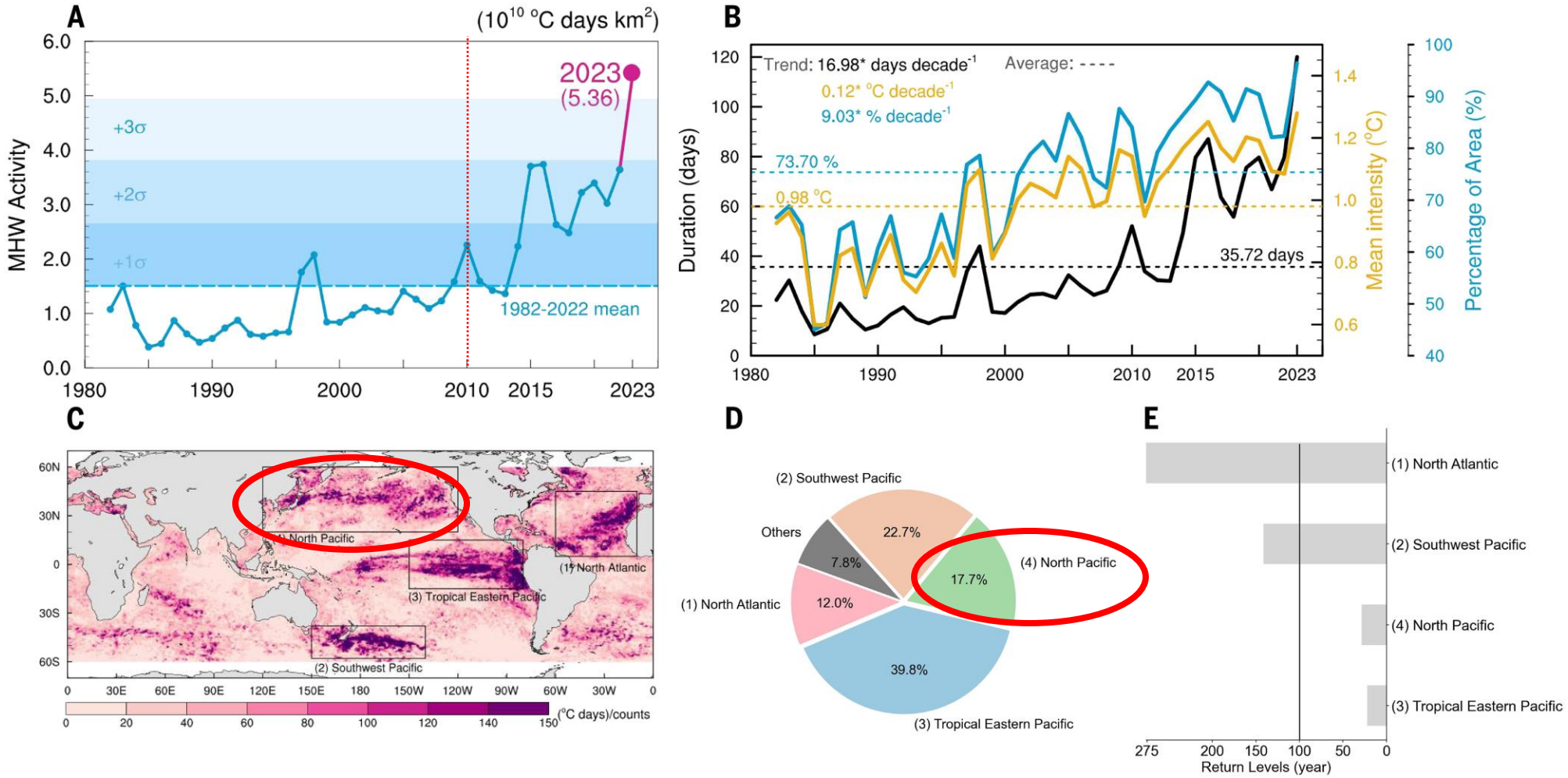
with Jung-Eun Chu, Yongchim Min, Go-Un Kim, Jongmin Jeong, Suchan Lee, Jaeik Lee, and Jin-Young Jeong

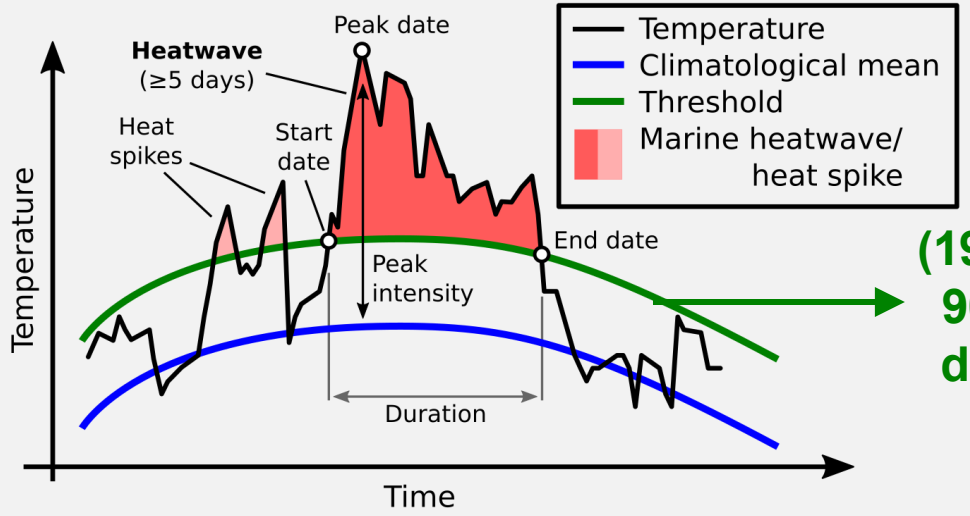
Session 5 (PICES2025)
Climate Extremes and Coastal Impacts in the Pacific

Global marine heatwave activities



Dong et al (2025)

What is marine heatwave?

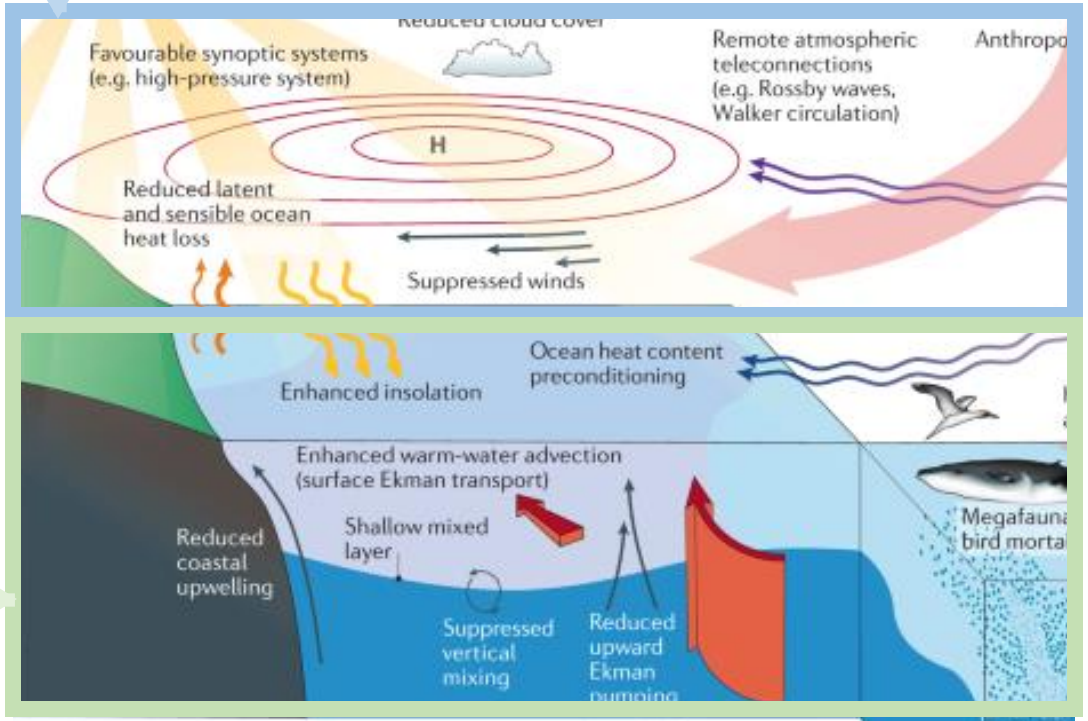


Hobday et al. (2016)

(1982-2011, 30yrs)
90th percentile
daily threshold

Atmospheric conditions

: by surface winds, cloud cover, and radiation
(Chen and Qin, 2016; Oliver et al 2007)

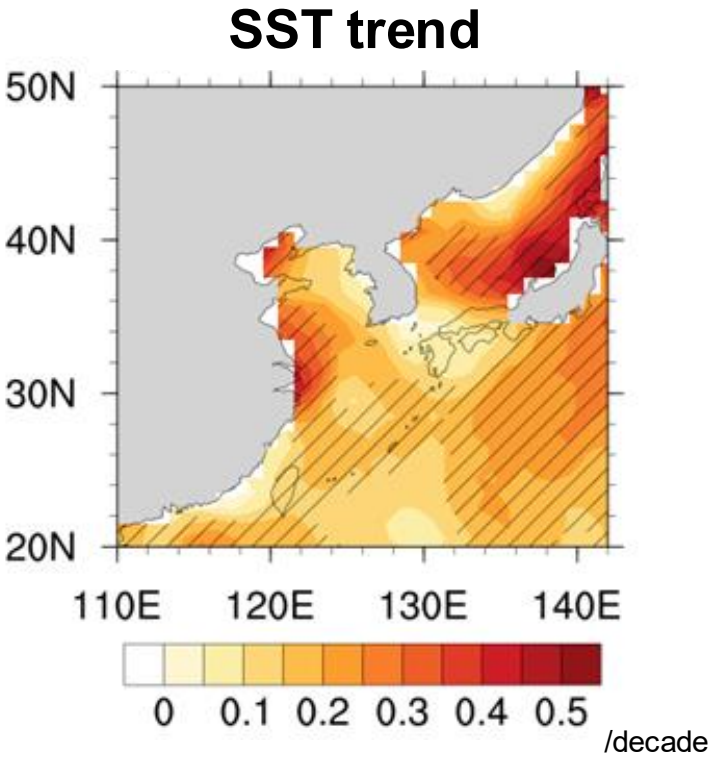


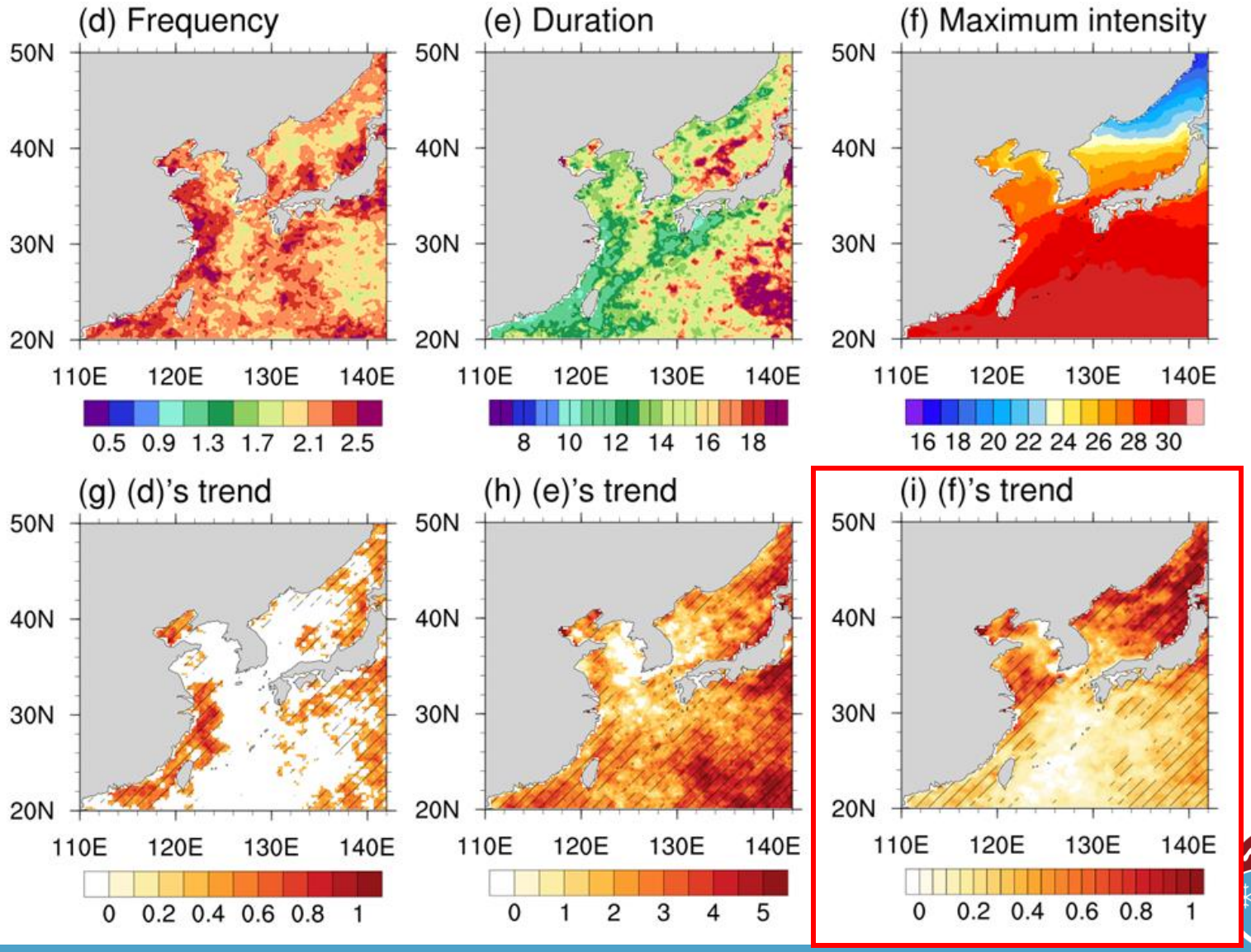
Holbrook et al. (2020)

Ocean dynamics and physical conditions

: by current, vertical mixing, and entrainment/detrainment
(Feng et al, 2013; Gao et al., 2010)

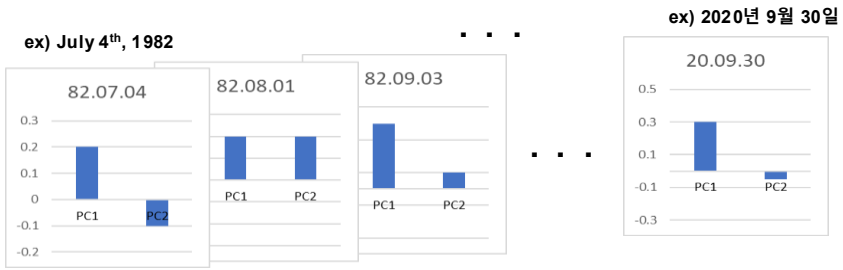
Marine heatwave in boreal summer (1982-2020)



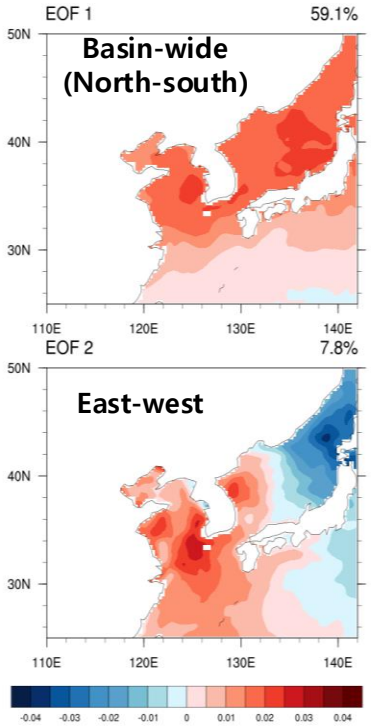


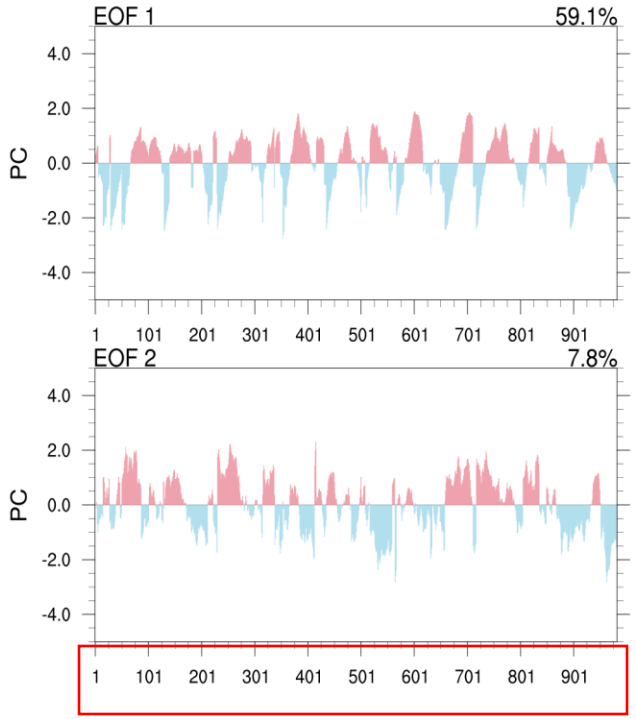
Classification into four major modes

Combination of PC1 and PC2

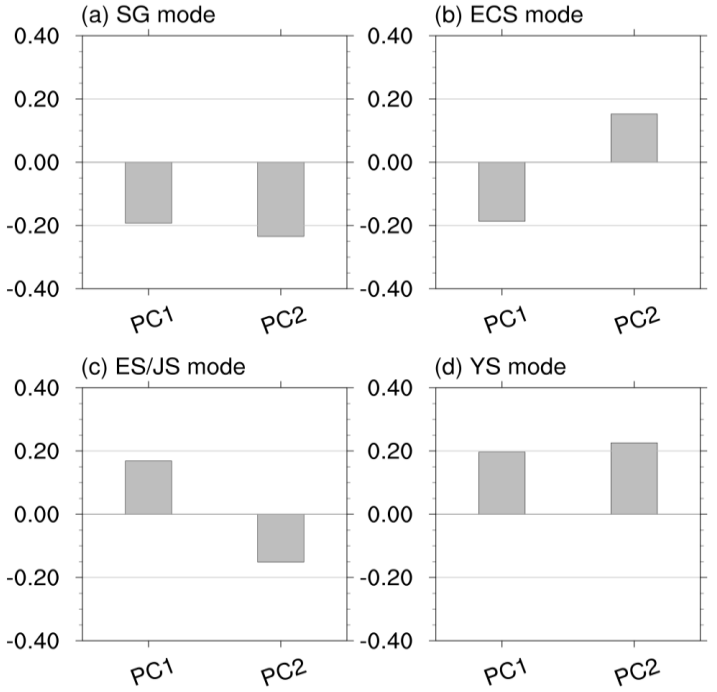


Input sample
= 982 days (1982-2020)



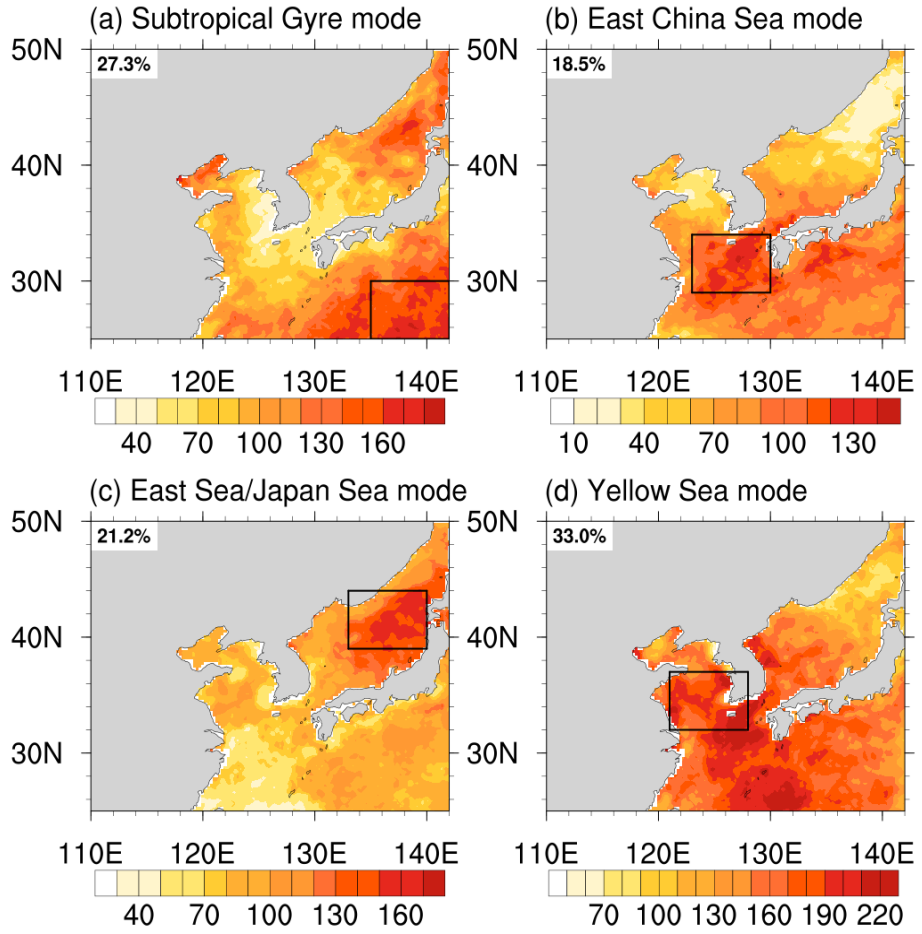


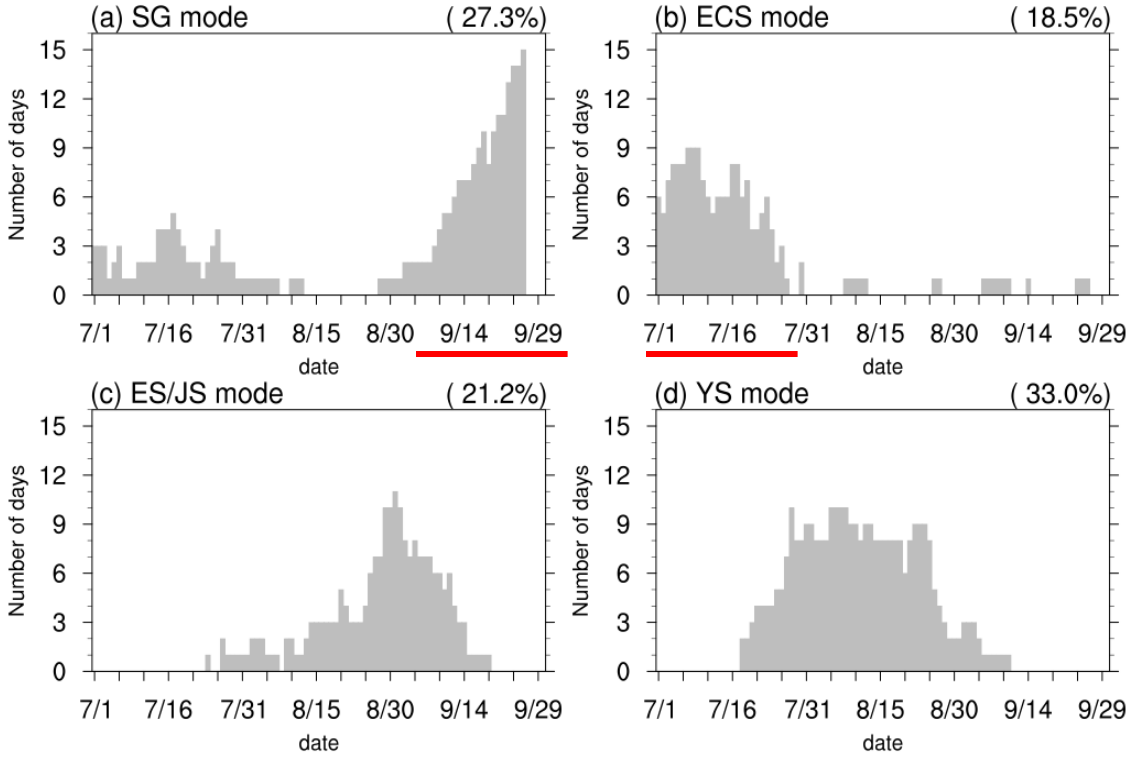
(2x2 maps)



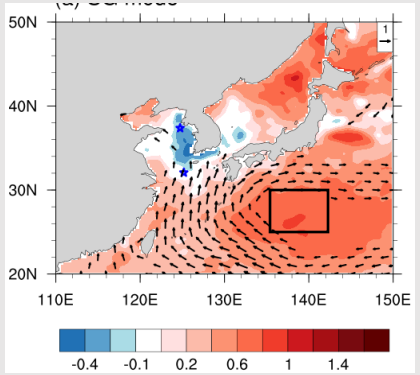
Spatial distribution and temporal information of MHWs

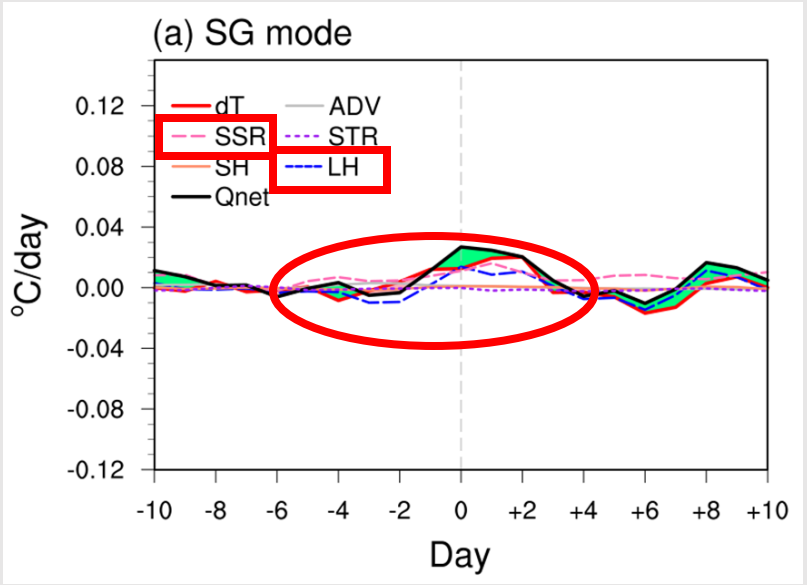
Spatial distribution of MHWs





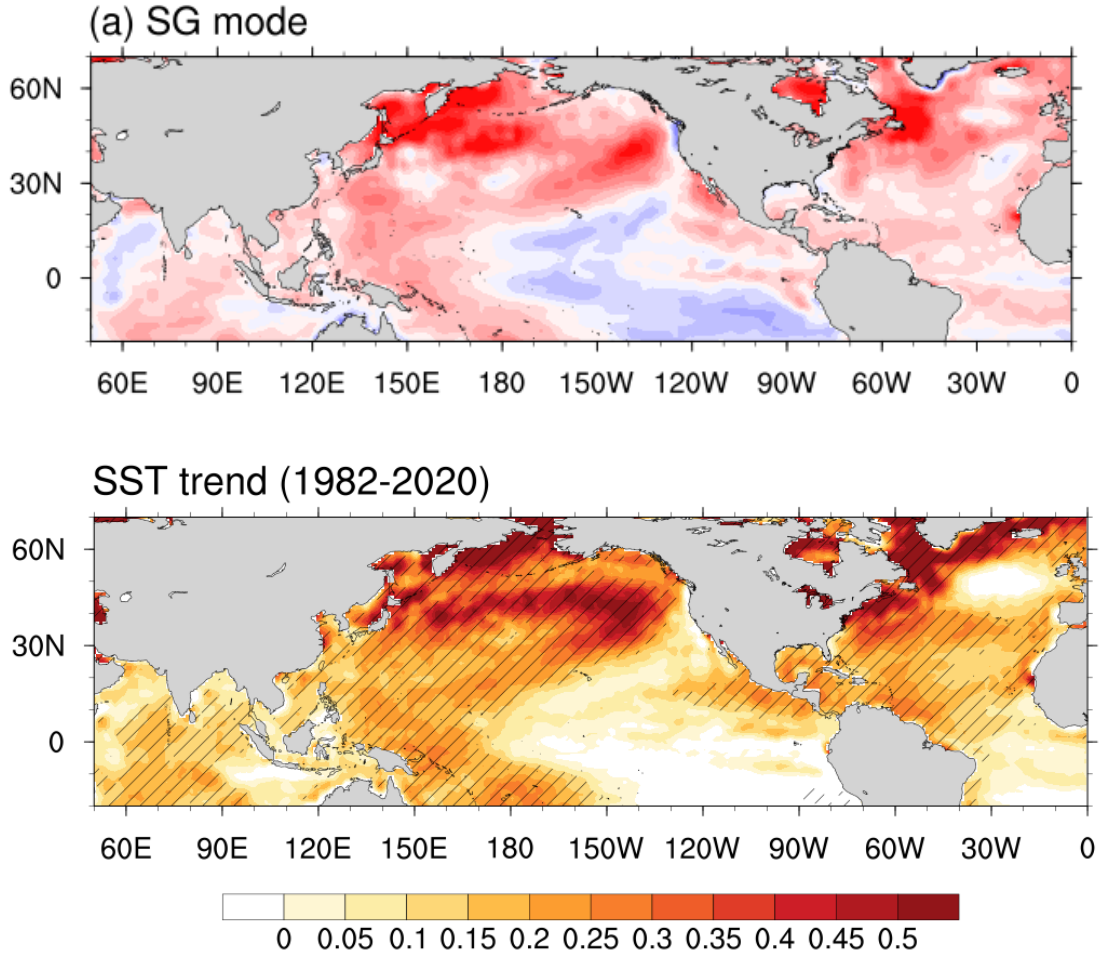
Summary: Subtropical Gyre mode



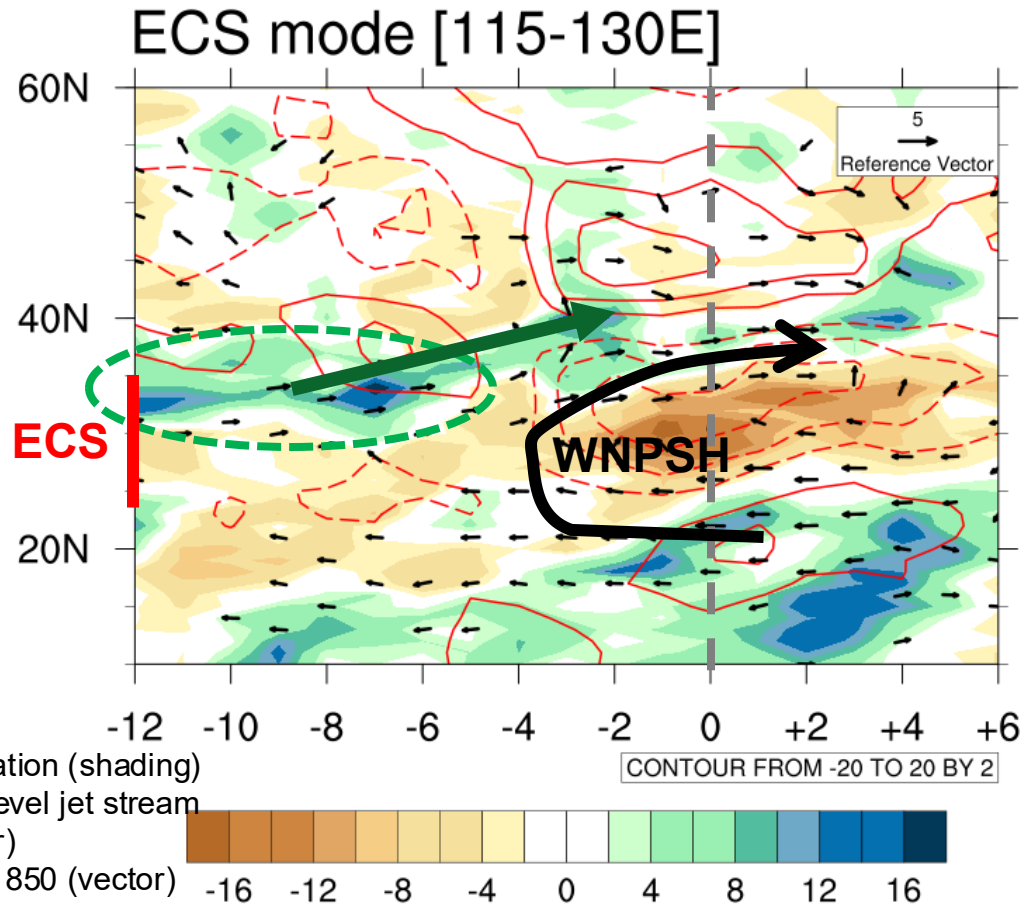


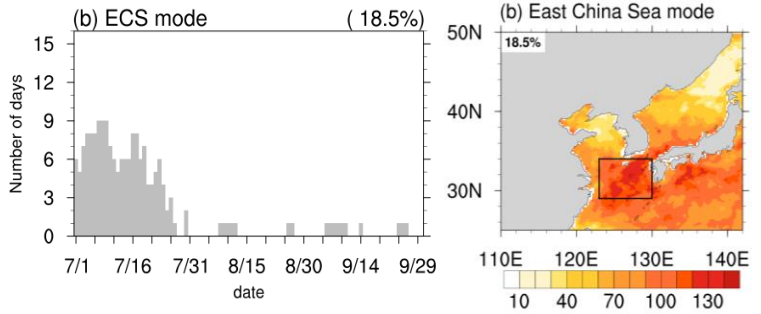
- **Shortwave radiation** seems to mainly contribute to warm water temperatures before the occurrence of MHWs, indicating that **the WNPSH has had a significant impact** on the development of the MHWs.

Spatial pattern : SST
(SOM1 vs. trend (1982-2020)



Summary: East China Sea mode





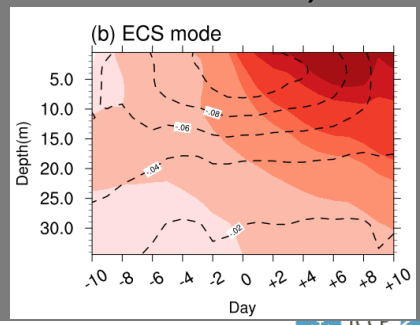
Strong monsoon

↓

Northward subtropical high & Jet stream → Enhanced shortwave radiation

↓ +

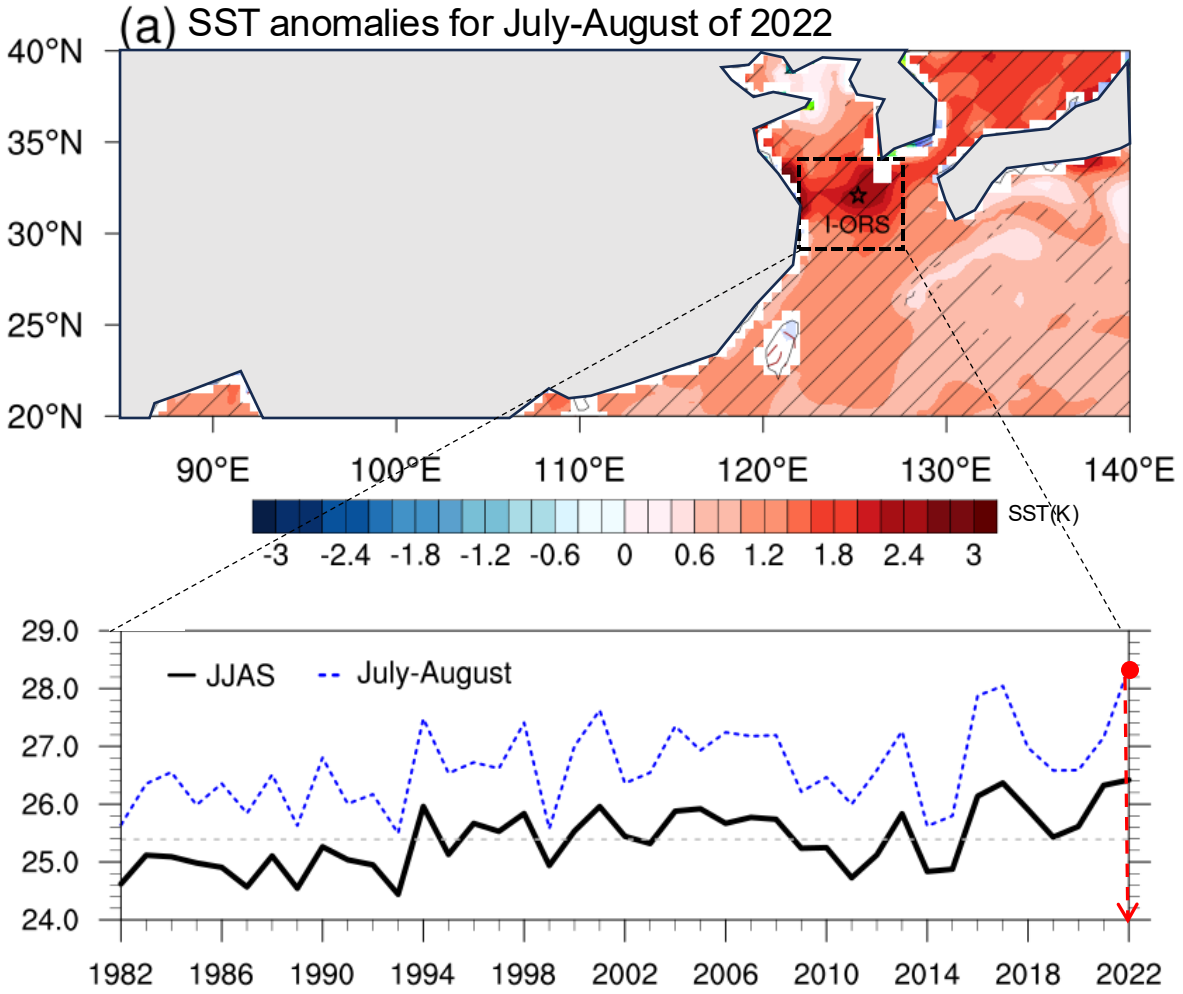
The freshwater from the Yangtze River or rainfall itself → Stratification by salinity gradient (i.e., barrier layer formation)



← **Frequent MHWs**

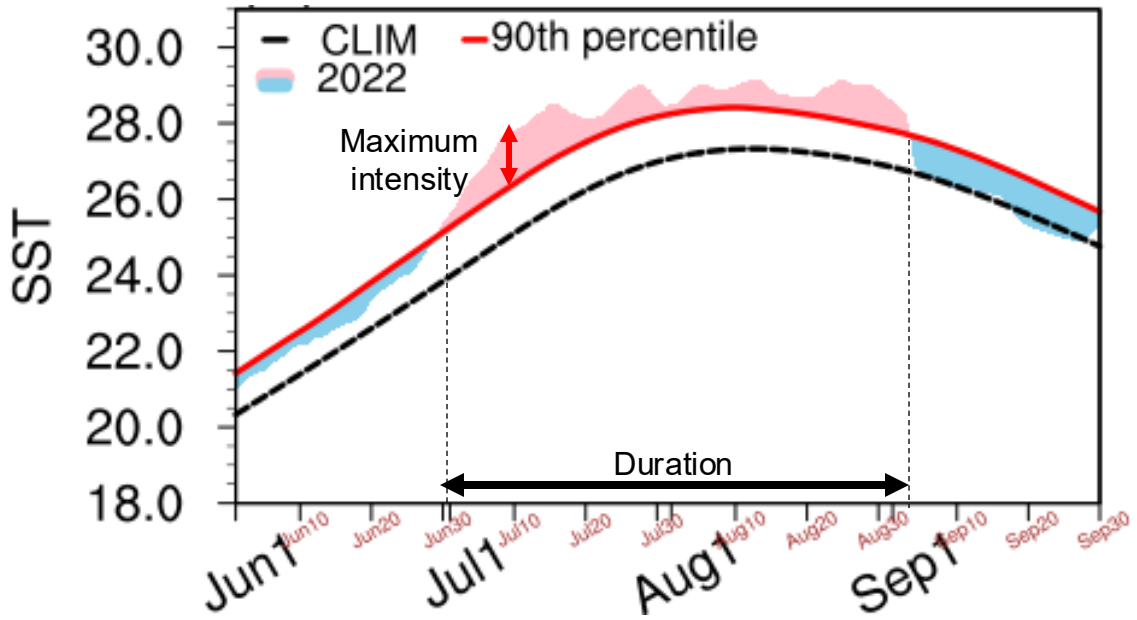
Oh et al., (2023) Classification and causes of East Asian marine heatwaves during boreal summer, Journal of Climate, 36(5), 1435-1449

Unprecedented year of 2022: Hot SST extremes



- A notable increase, reaching up to 2.4°C above the summer average (July-August)
- Furthermore, SST during the peak summer months of July and August recorded temperature above 28ºC for the first time.

Characteristics of summer Marine heatwave in 2022



Frequency	Duration	Maximum intensity
1	62 d	2.85°C

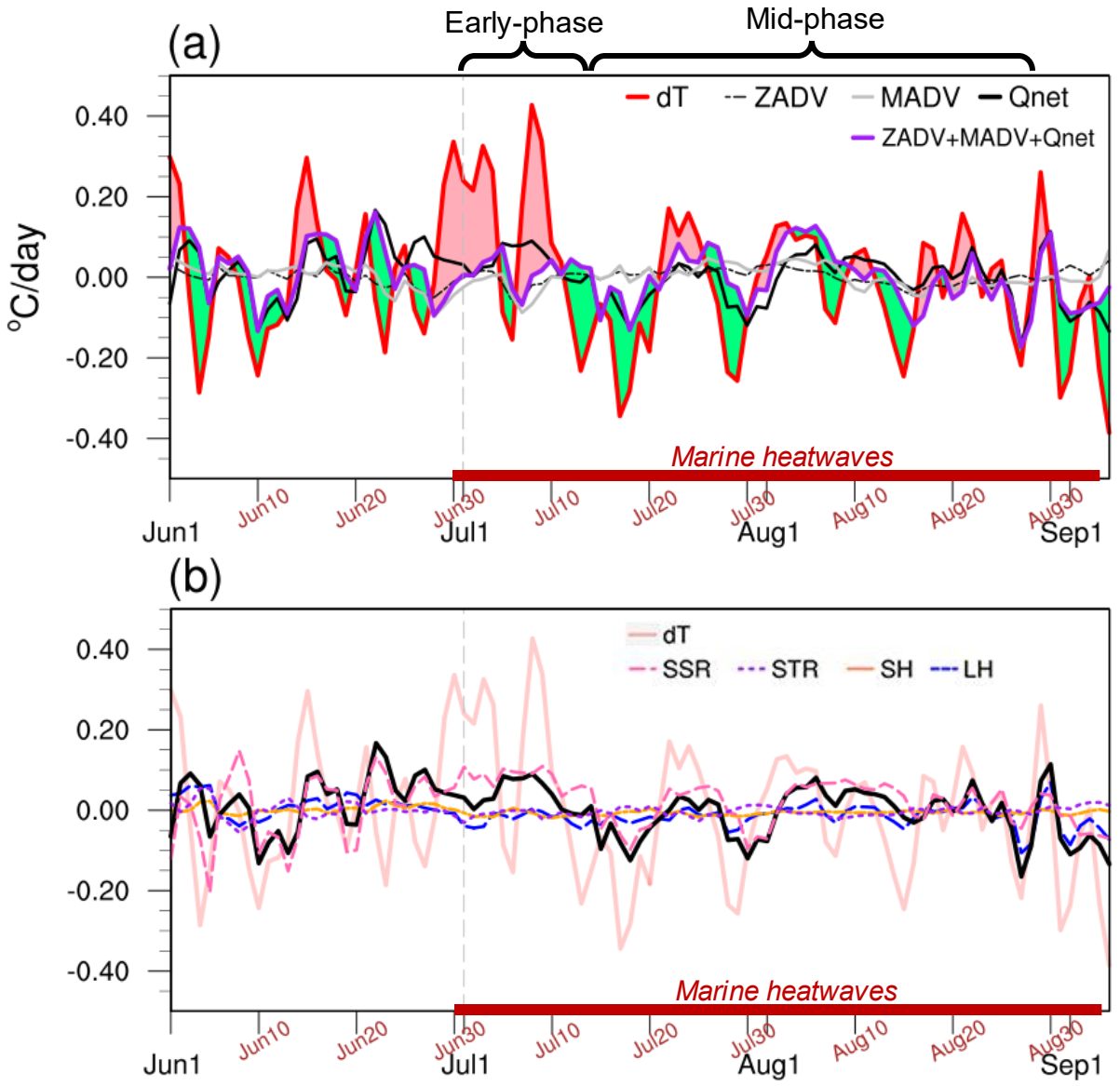
Contributing factors of the MHW in 2022

Mixed-layer heat budget equation

$$\underbrace{\frac{\partial T_m}{\partial t}}_{\text{dT}} = \underbrace{-u_m \frac{\partial T_m}{\partial x} - v_m \frac{\partial T_m}{\partial y}}_{\text{ADV (horizontal advection)}} \underbrace{- w_d \frac{(T_m - T_d)}{h_m}}_{\text{Vertical mixing}} + \underbrace{\frac{Q_{net}}{\rho C_p h_m}}_{\text{Qnet}}$$

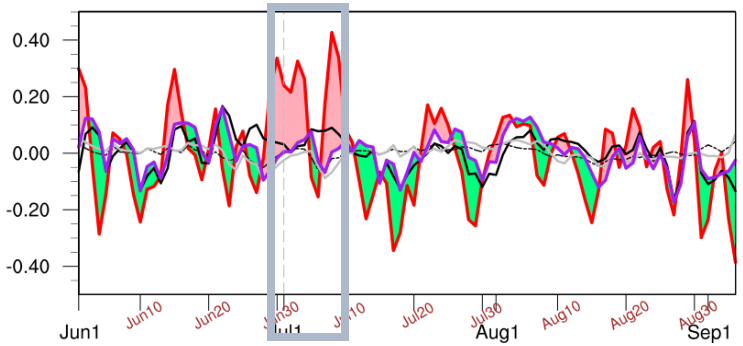
upwelling / downwelling

Qnet = SSR+STR+SH+LH



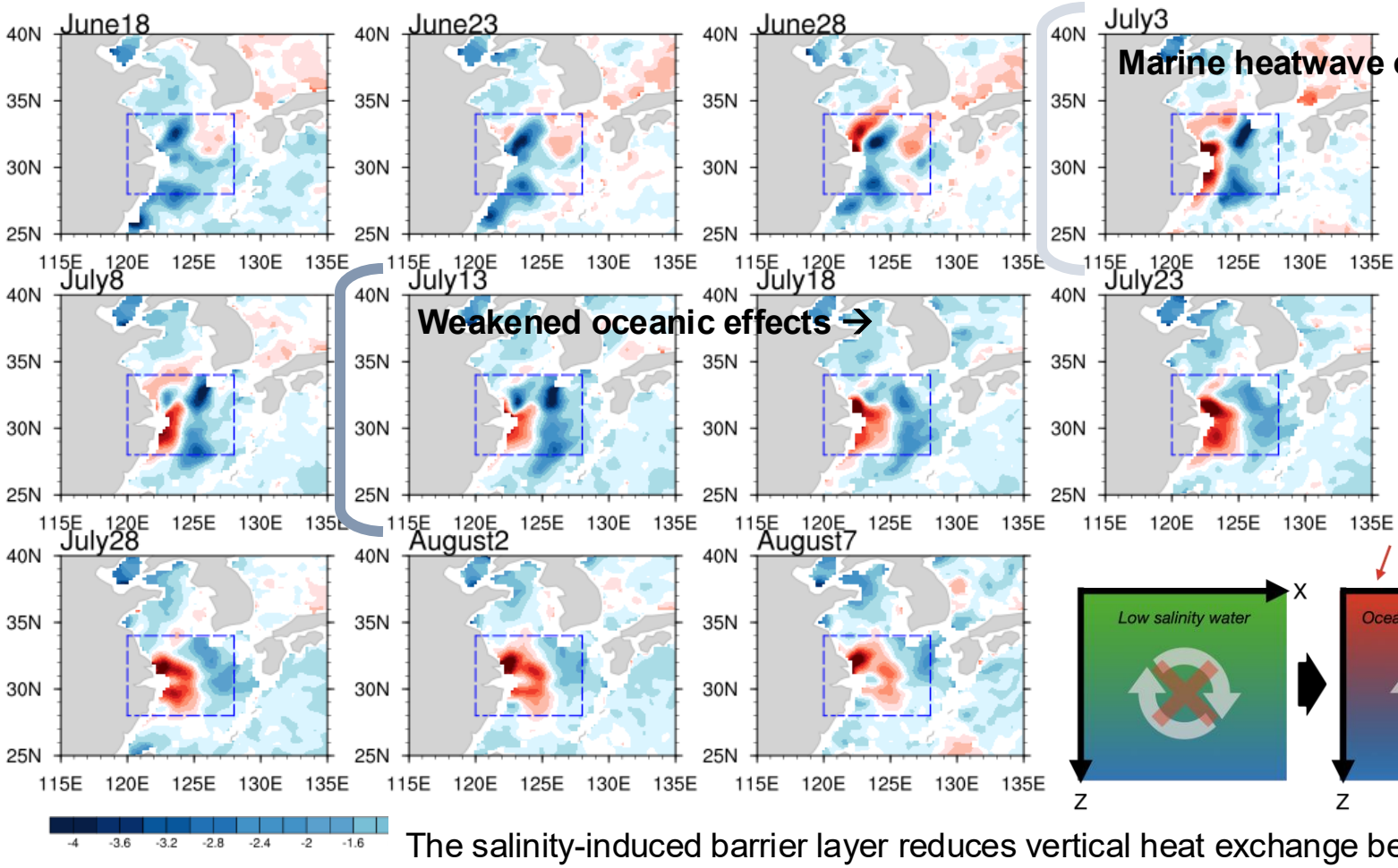
- (Early-phase of the MHWs) The positive warming tendency is generally related to ocean stratification caused by the weakening of the vertical mixing.
- (Mid-phase of the MHWs) From mid-July, the effects of the shortwave radiation on SST warming were dominant as the anticyclonic circulation persisted.

Spatiotemporal distribution of anomalous salinity water (SMAP)



- During onset of the MHWs, the ocean dynamics played a crucial role in the warm water conditions for approximately **10 d** since the MHWs occurred.

SMAP sea surface salinity (8-day running) from June 18th to August 8th



The salinity-induced barrier layer reduces vertical heat exchange between the surface and middle layers of the ocean.

Unprecedented year of 2022: Floods

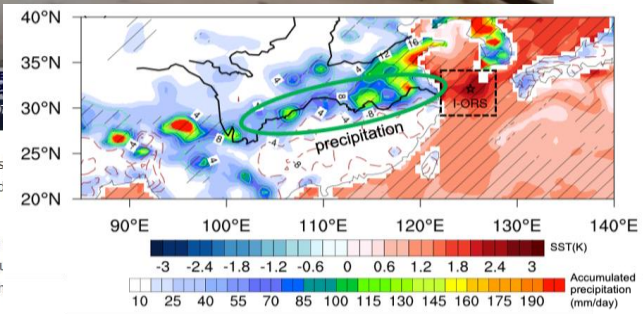
Southern China hit by severe rains, floods as 'dragon boat water' peaks

By Reuters

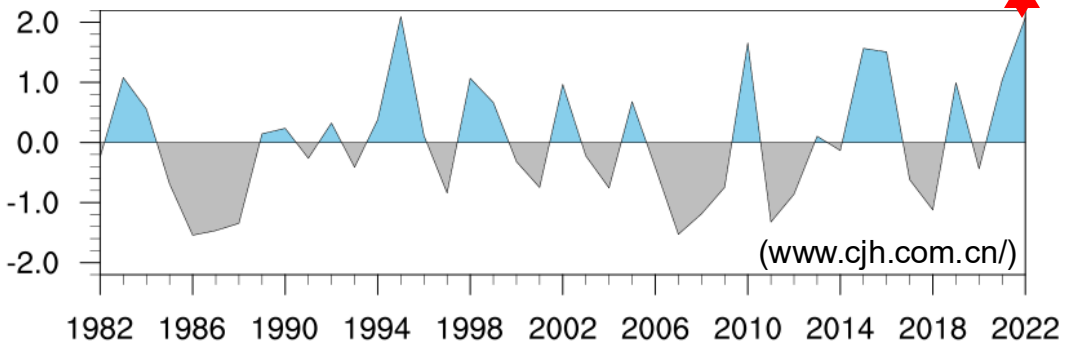
June 21, 2022 4:58 PM GMT+9 · Updated 2 years ago

BEIJING, June 19 (Reuters flooding in cities and muc power.

Streets turned to swollen in Guizhou province in sou media. The rainfall in som



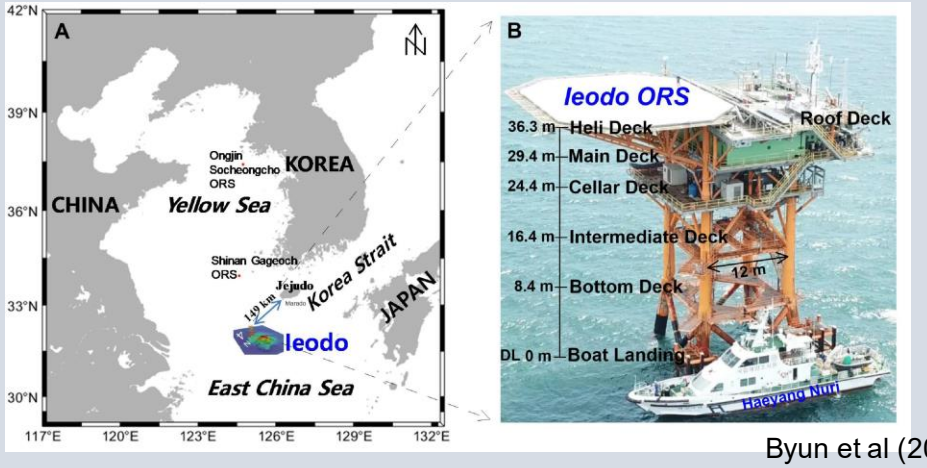
River discharge from Yangtze River (June)



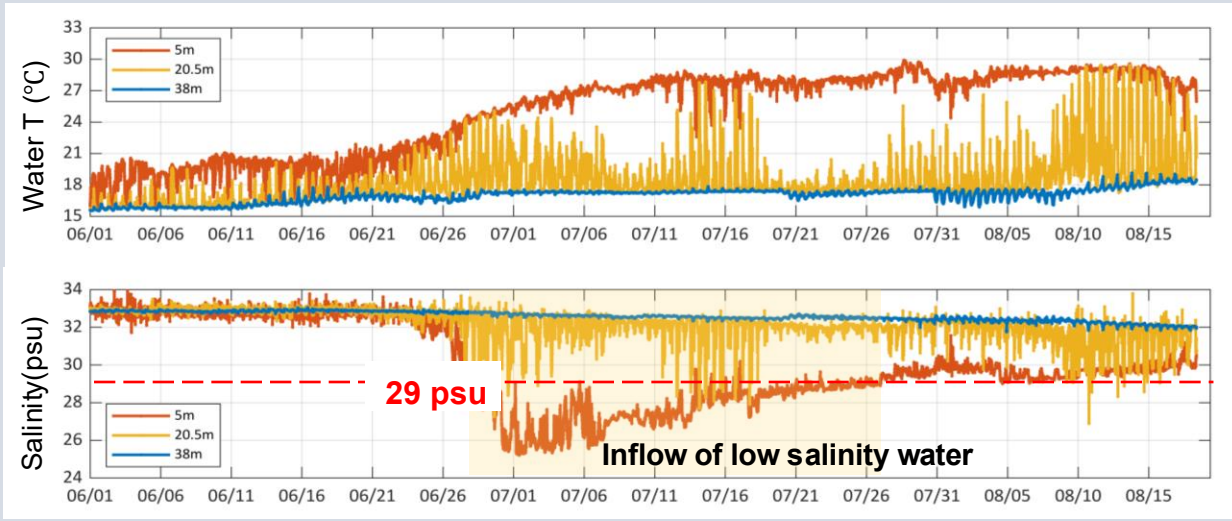
KIOST KOREA INSTITUTE OF OCEAN SCIENCE & TECHNOLOGY

From observational data

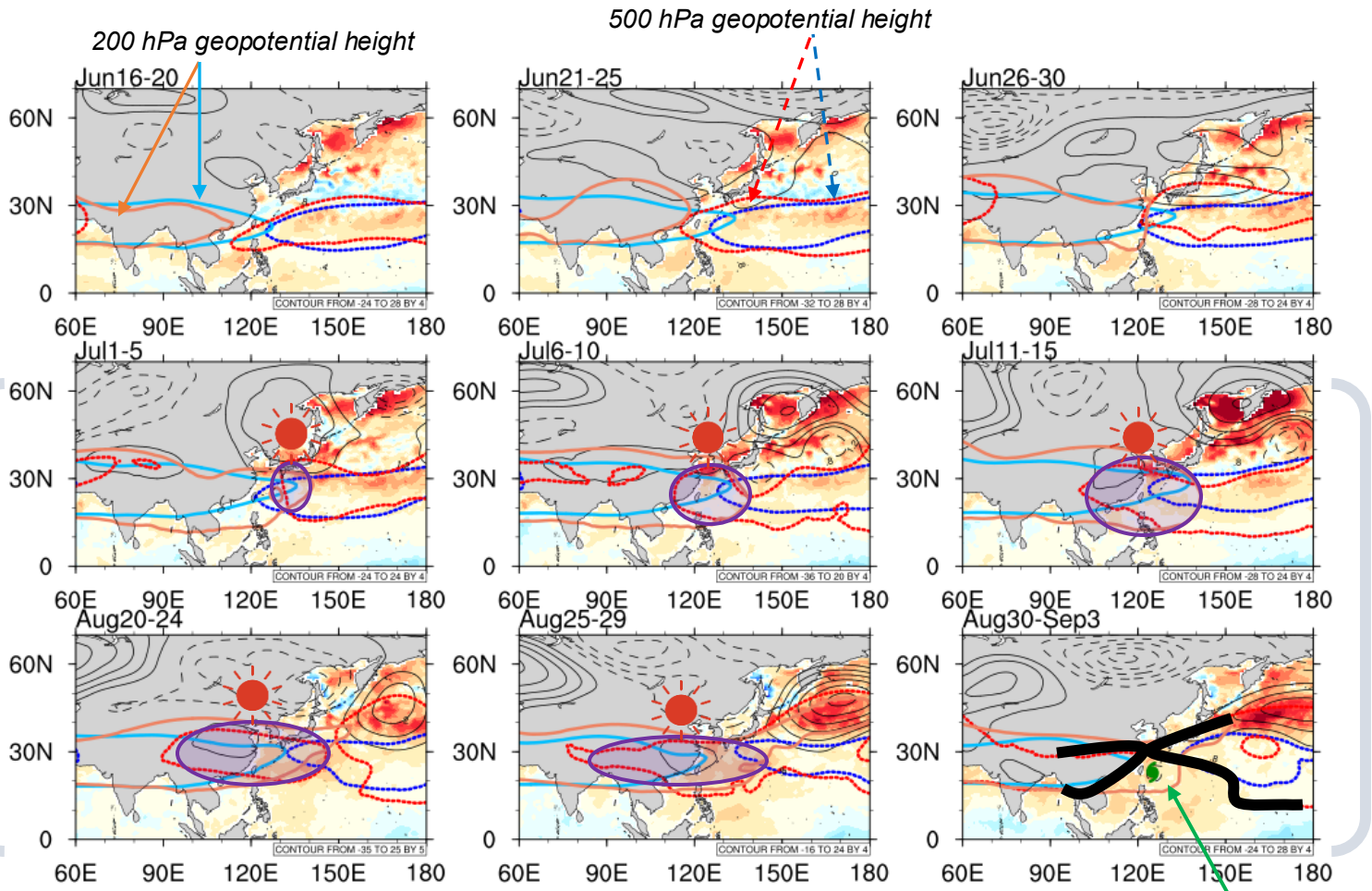
KORS Korea Ocean Research Stations

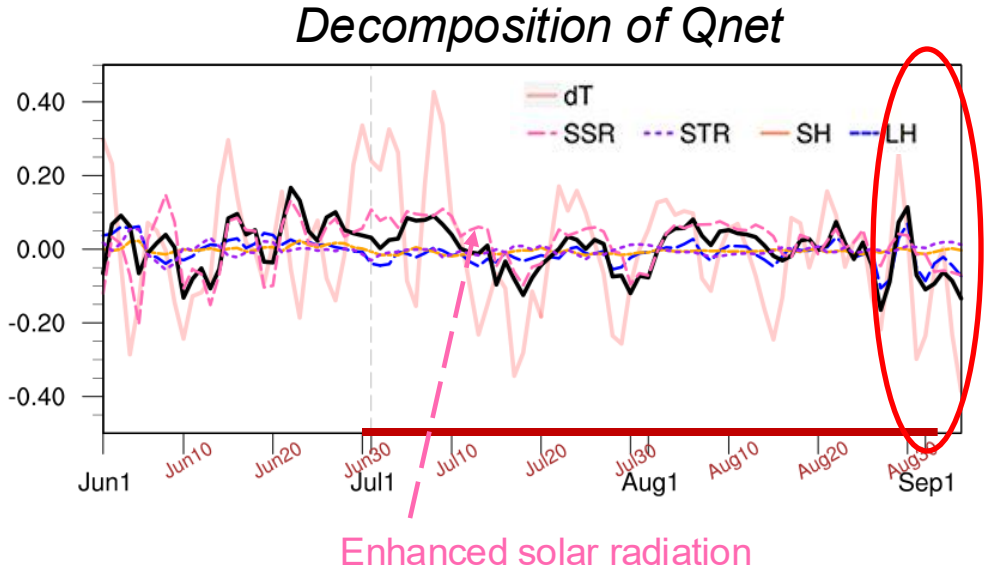


Byun et al (2021)



What caused the long-lasting MHW in 2022?





- The persistent **high-pressure systems** implies clear skies with minimal cloud cover, allowing **solar radiation** to reach the surface uninterrupted, thus sustaining the marine heatwaves.
- Finally, the MHWs declined because *Typhoon Hinnamnor* blocked the sun light and intensified the wind speed on early September.

Possible causes: Stagnant atmospheric circulation

Circumglobal teleconnection (CGT)

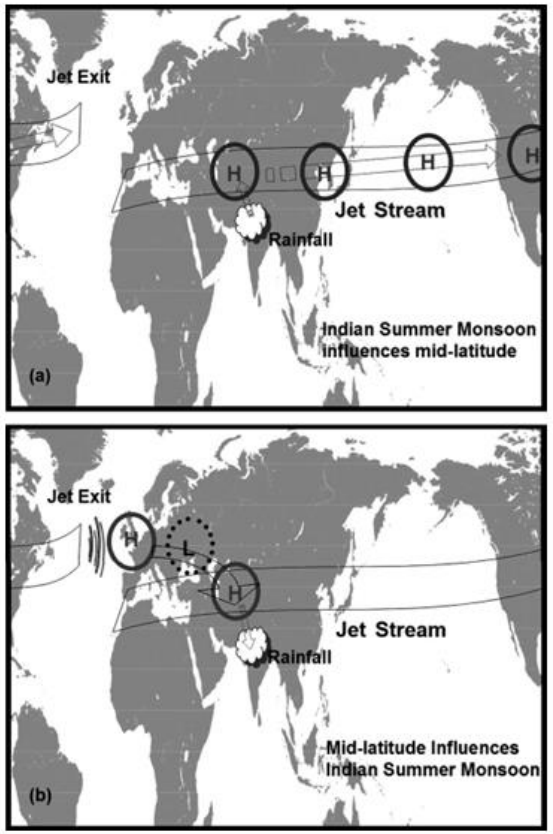
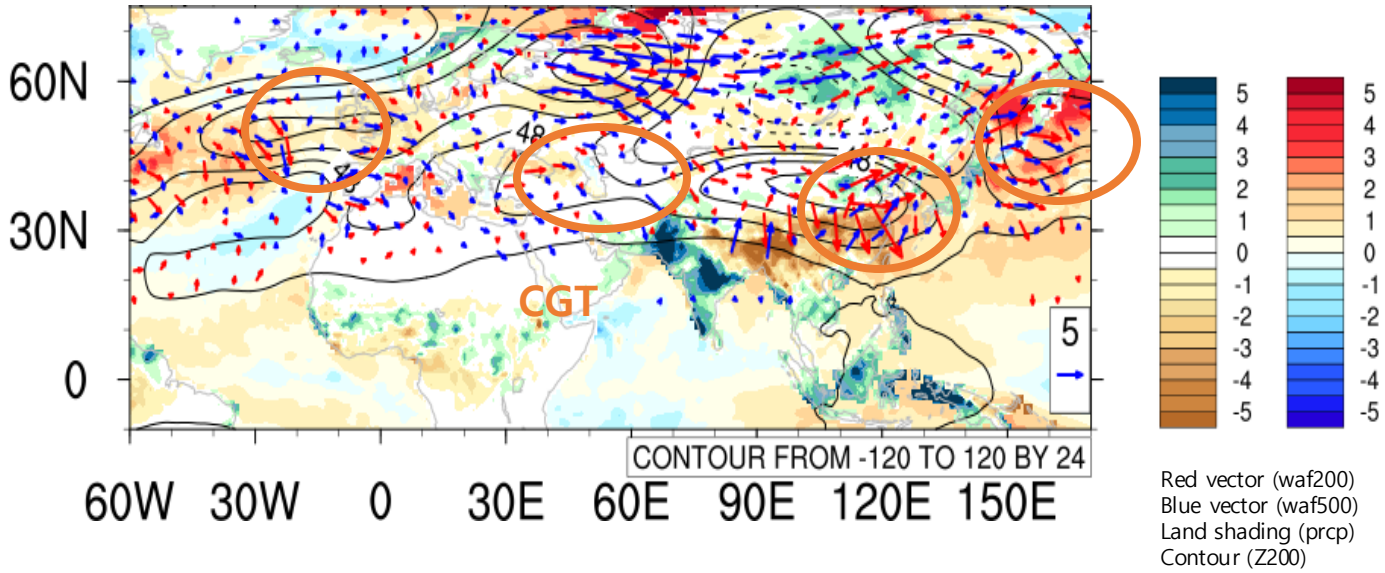


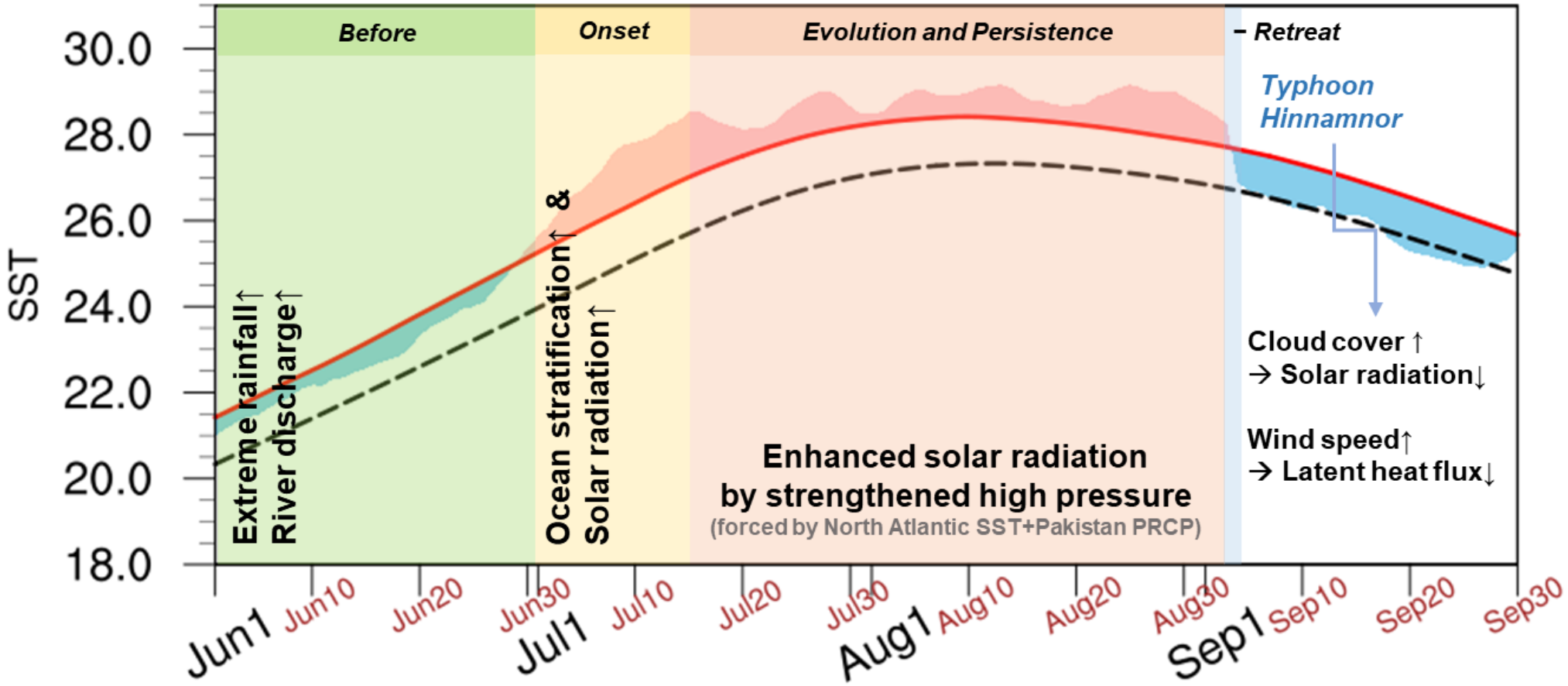
FIG. 15. Schematic diagram illustrating the entire mechanism of the CGT consisting of two scenarios during the positive phase of CGTI. The cloud denotes the strong ISM and the circles represent the CGT in the upper level.

2022 JA anomaly



- The CGT pattern can contribute to **the convective activity over the Pakistan**, and it can enhance the wave pattern to the far east to the East China Sea.

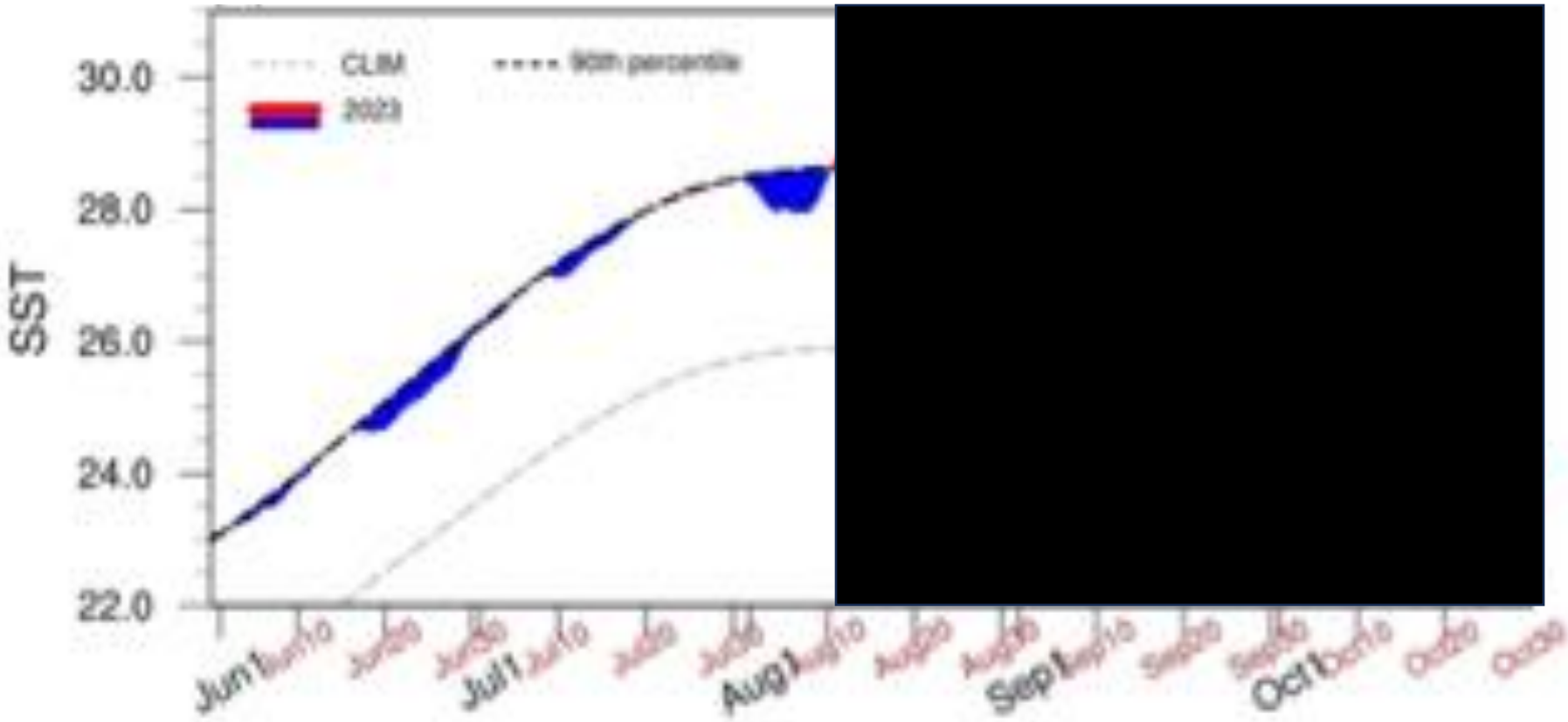
Summary of the record-breaking 2022 long-lasting marine heatwave



Oh et al. (2023) The record-breaking 2022 long-lasting marine heatwaves in the East China Sea, Environmental Research Letters, 18, 064015

The Year 2023: A Short Relief…

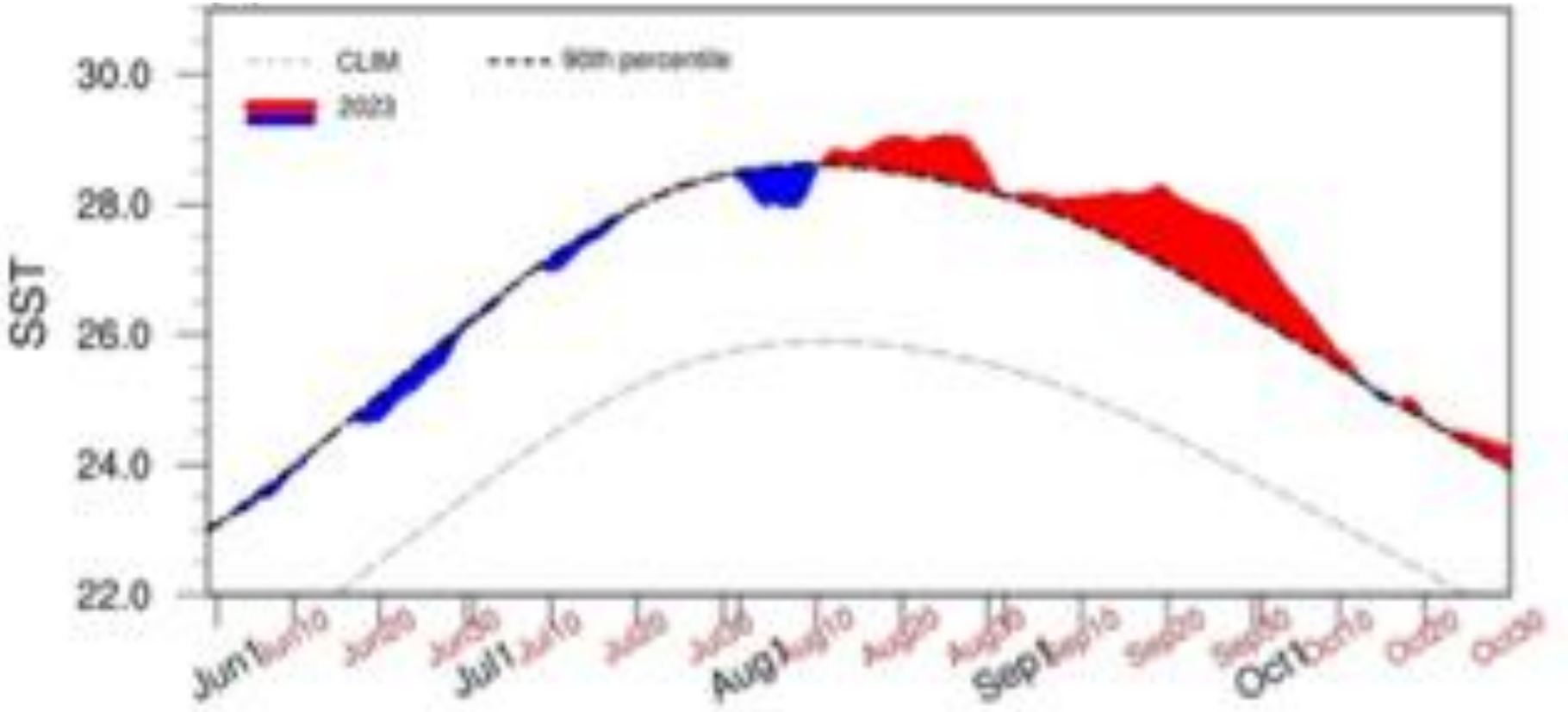
East China Sea
[25° − 34°N, 120° − 128°E]



- After several consecutive warm years, 2023 initially appeared somewhat cooler — even slightly below the marine heatwave threshold in the East China Sea.

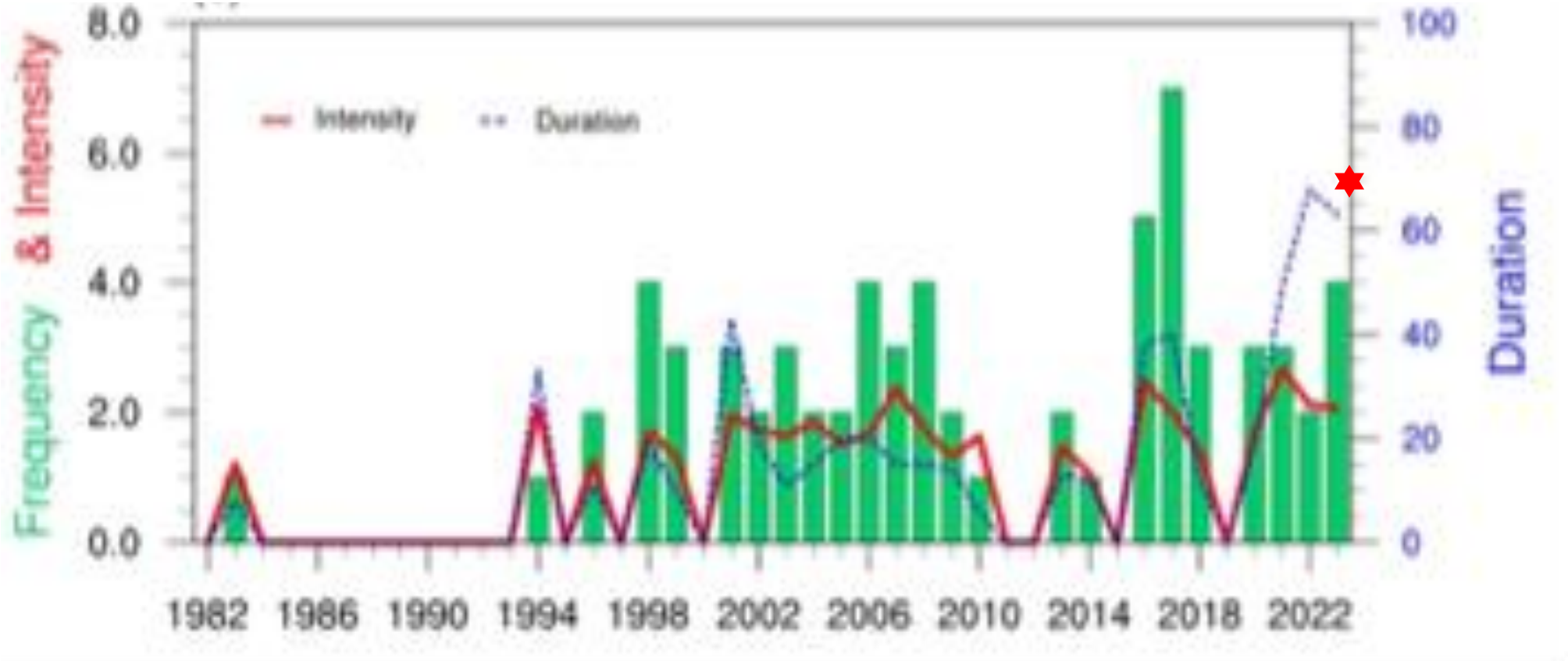
The Year 2023: A Short Relief… and Another Surprise

East China Sea
[25° − 34°N, 120° − 128°E]



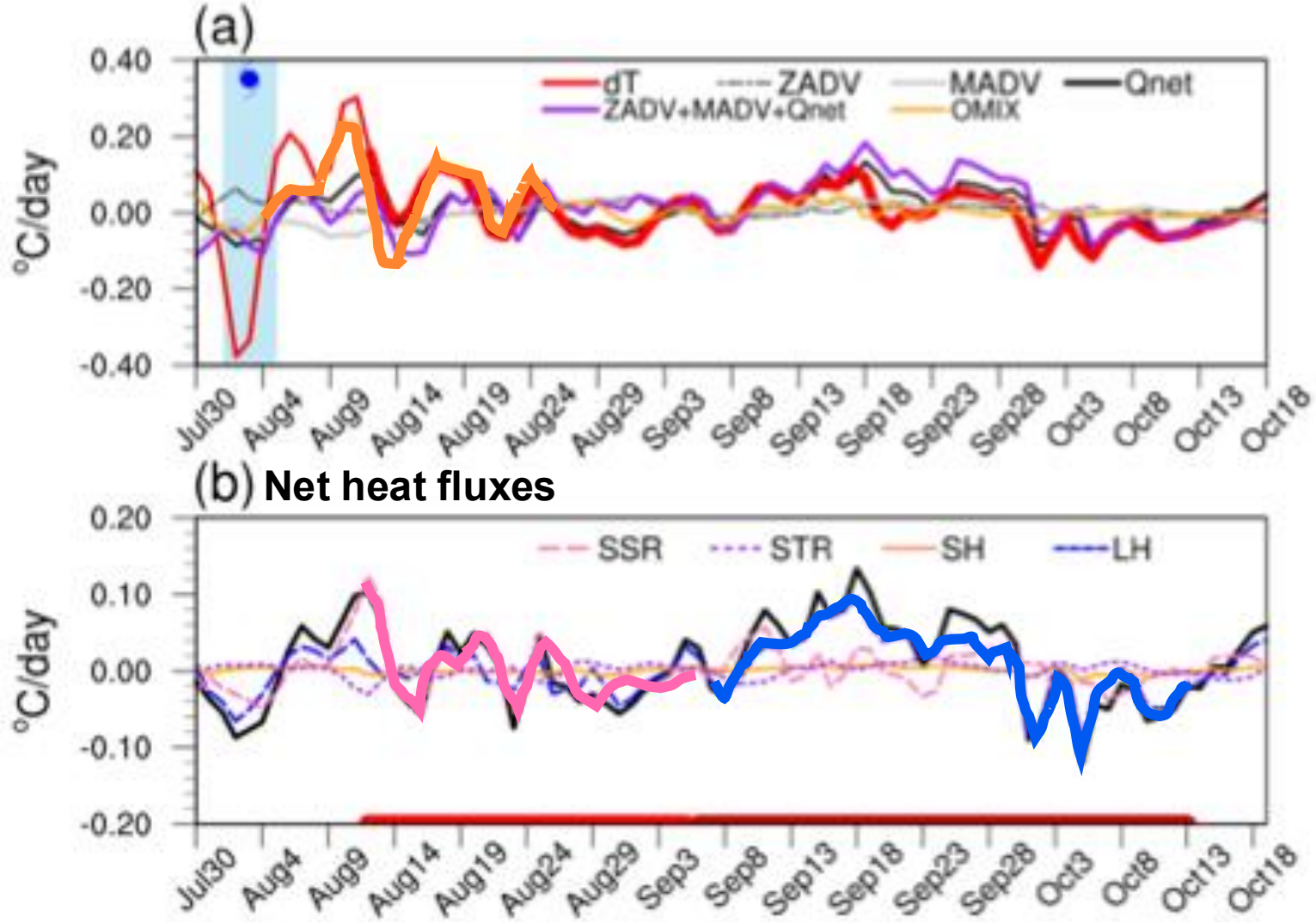
- Although it **began later than usual**, it **persisted for more than 60 days** — nearly **two months of continuous anomalous warming** over the region.

Unusual Persistence of the 2023 Marine Heatwave



- The **intensity and frequency** of the 2023 event were **similar to, or slightly strong er than**, the 10-year average.

Why Did It Happen? (Mixed-Layer Heat Budget Analysis)

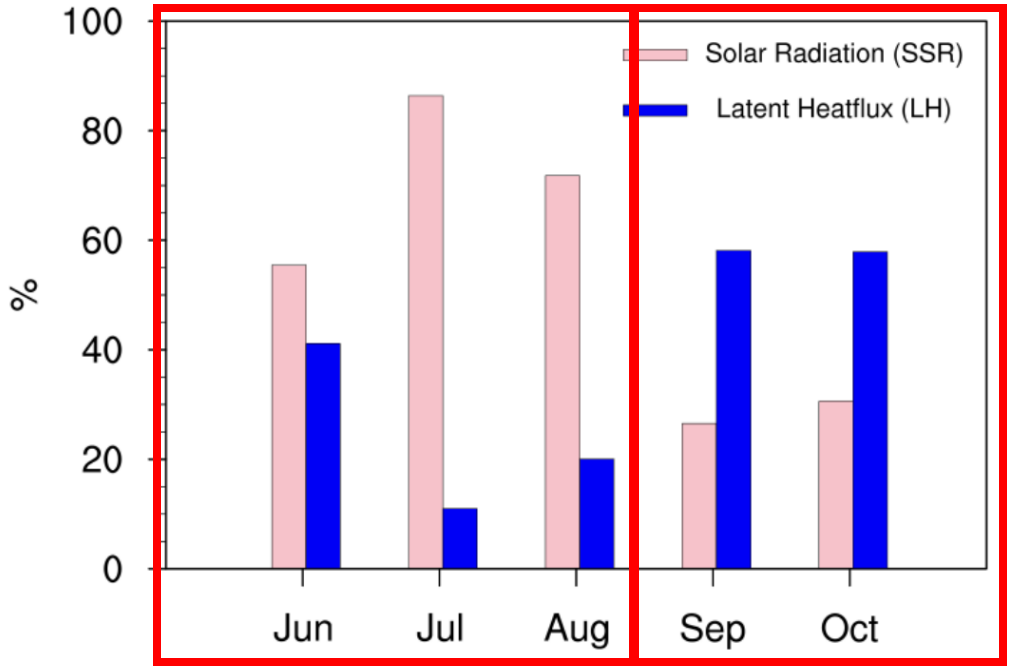


- **In the early phase**
  – **Warm subsurface water mixed upward**, triggered the warming event with **strong shortwave radiation**.

- **In the late phase (September/October):**
  – **Latent heat flux** became more dominant
  – Indicates stronger **air–sea coupling** sustaining the event.
  – **Air temperature/humidity > SST** → suppressed evaporation → Ocean retained heat longer → prolonged marine heatwave

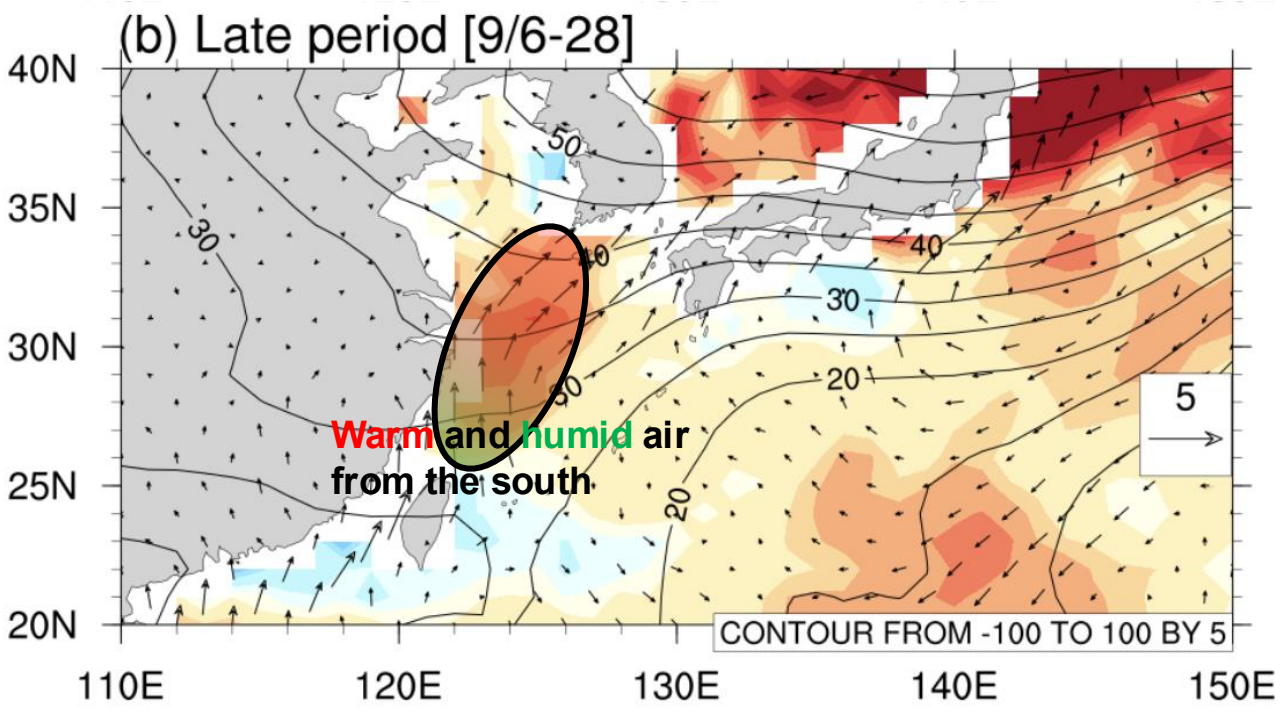
Atmospheric Control of Late-Summer MHW Persistence

Solar radiation vs. Latent heatflux



$$L_h = \rho_a L_v C_E \boldsymbol{U}(q_{sea} - q_{air})$$

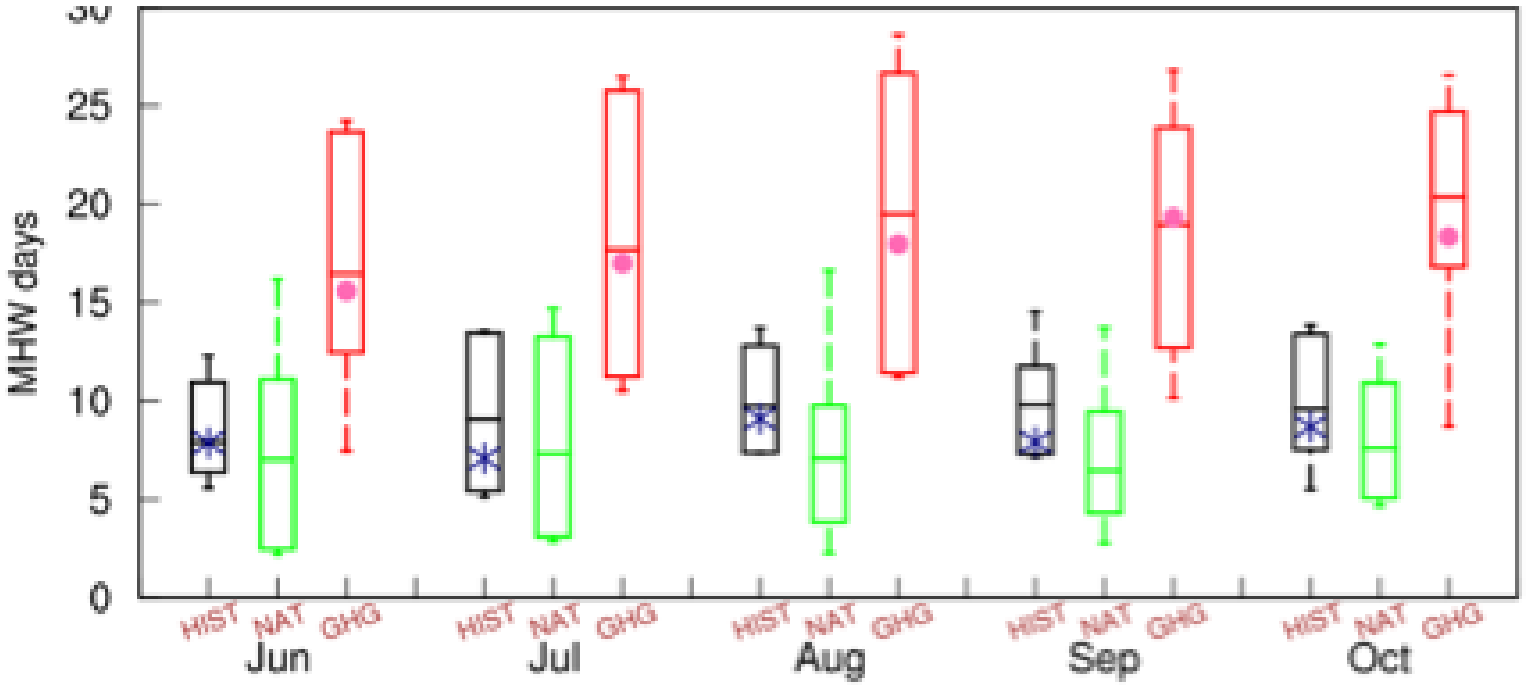
- In late summer, the latent heat flux became increasingly important, controlled by **wind speed** and **the humidity difference between the air and the ocean**.



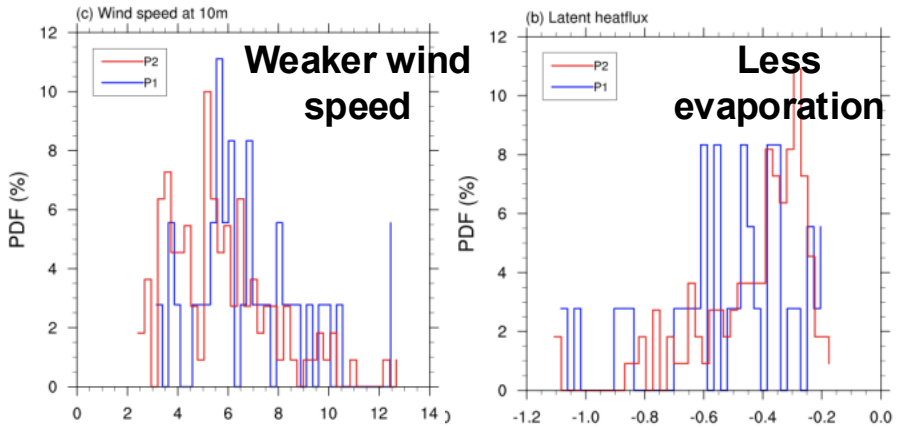
- During this period, the **Western North Pacific Subtropical High (WNPSH)** remained **strong and stationary**, which suppresses the usual seasonal shift to northerlies.

- As a result, **warm and humid air masses** persisted over the East China Sea, reducing evaporation and **prolonging the MHW into late summer.**

Future changes in MHW days in the ECS



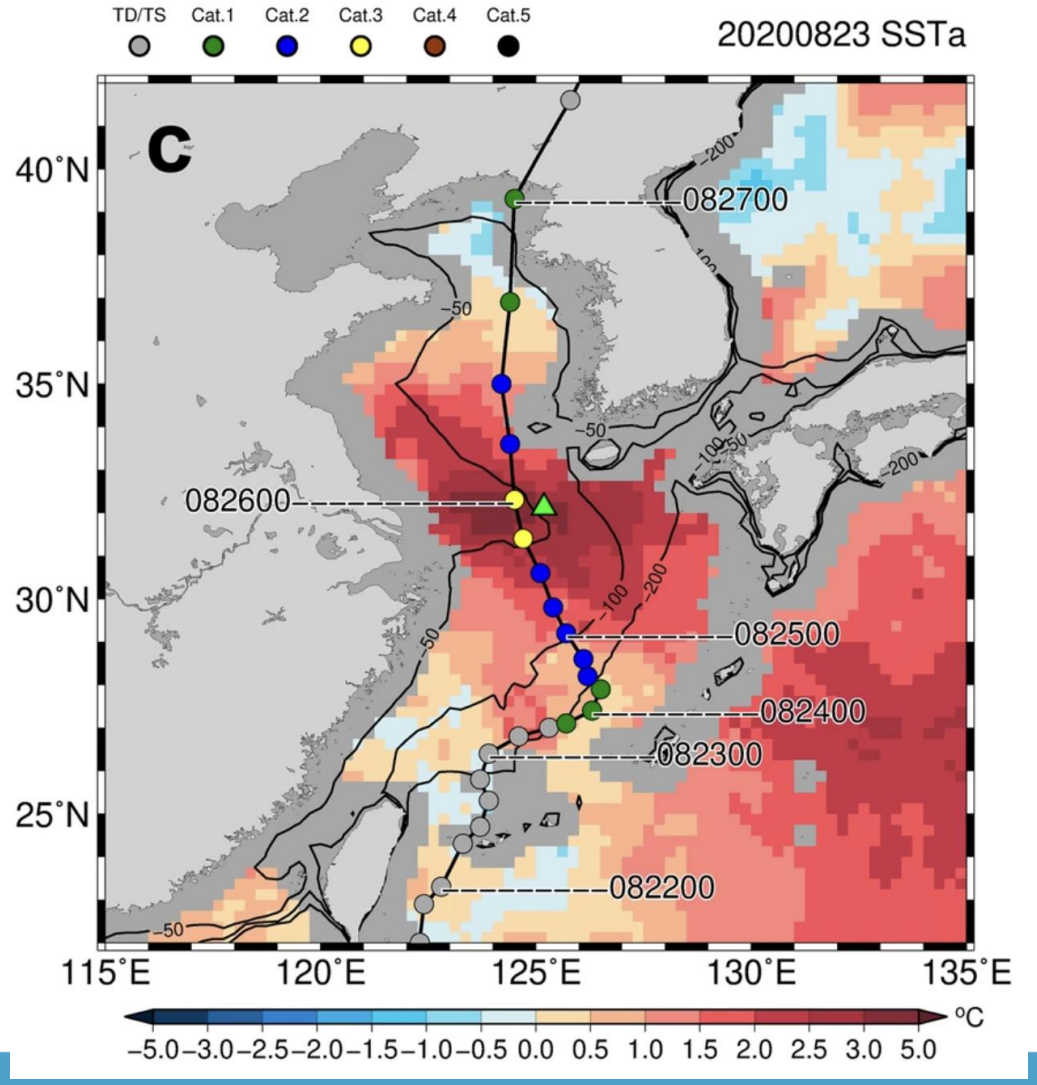
✱:ERA5
Historical period: 2001-2020
●: SSP-2.4.5 scenario: 2021-2040



- Under the **hist-GHG scenario**, representing **greenhouse forcing**, the number of marine heatwave days **inc reased by more than twofold** compared with the historical run.
- **Weaker wind speeds and a less evaporation in late summer** can be found, which created favorable conditions for the development of marine heatwaves.
- Our results suggest that **late-summer marine heatwaves** in the East China Sea are **expected to become more frequent** under future climate warming.

Oh et al. (2024) Late-arriving 2023 summer marine heatwave in the East China Sea and implications for global warming, npj Climate and Atmospheric Science, 7(1), 294

Implication: A Case of Typhoon Bavi (August 2020) from Pun et al. (2023)



- The East China Sea may play an even greater role in fueling stronger and longer-lived typhoons acros s East Asia under a warming climate.

Thank you for your attention ☺