Long-term changes of marine heatwaves in the seas around the Korean Peninsula : Impacts on marine ecosystems, fisheries, and societies

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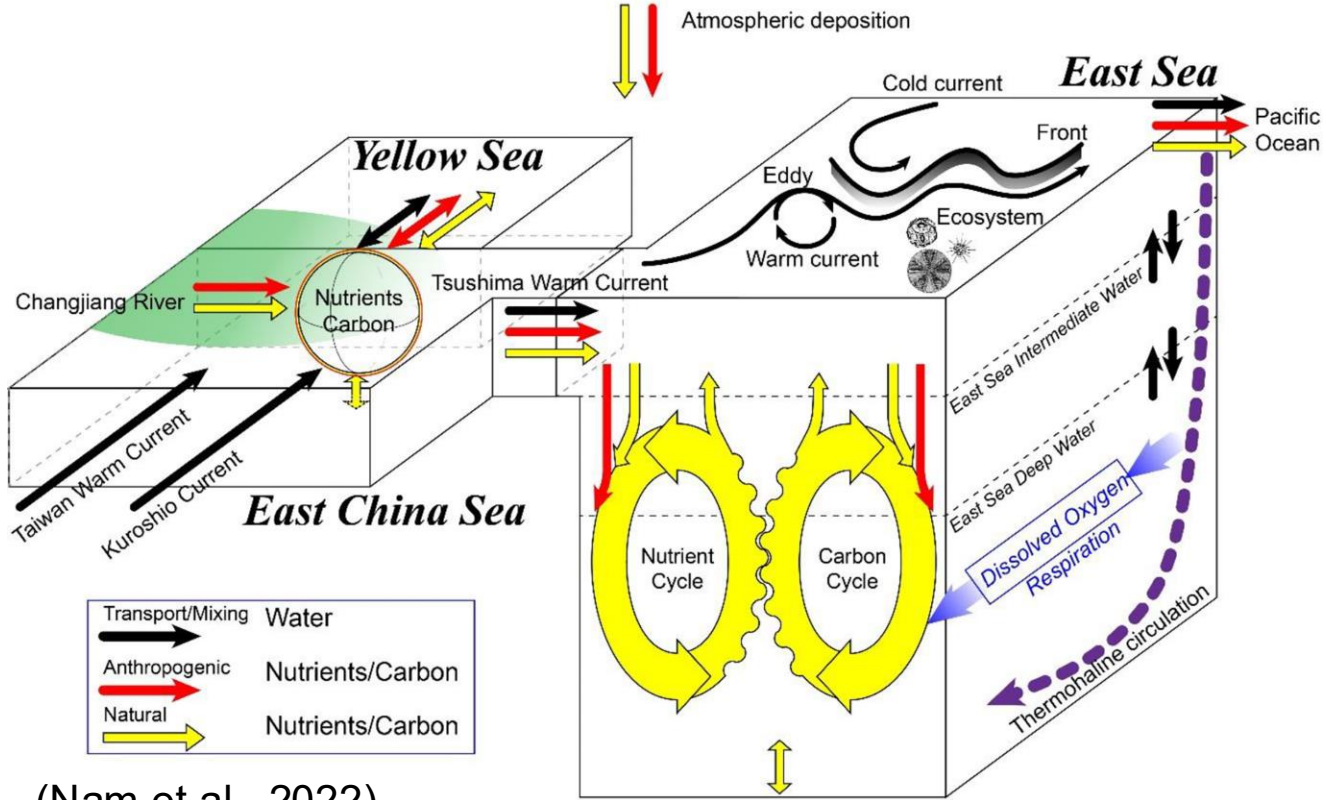
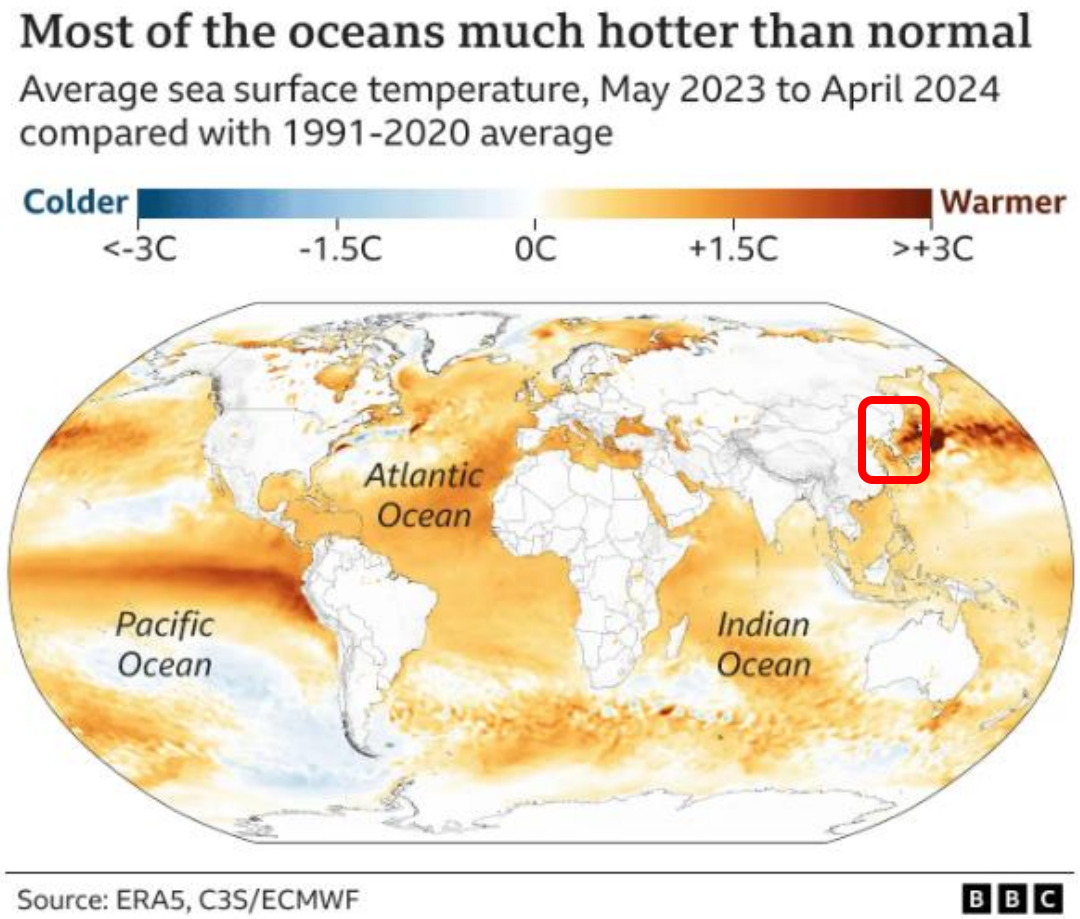
Introduction/Background



(Nam et al., 2022)



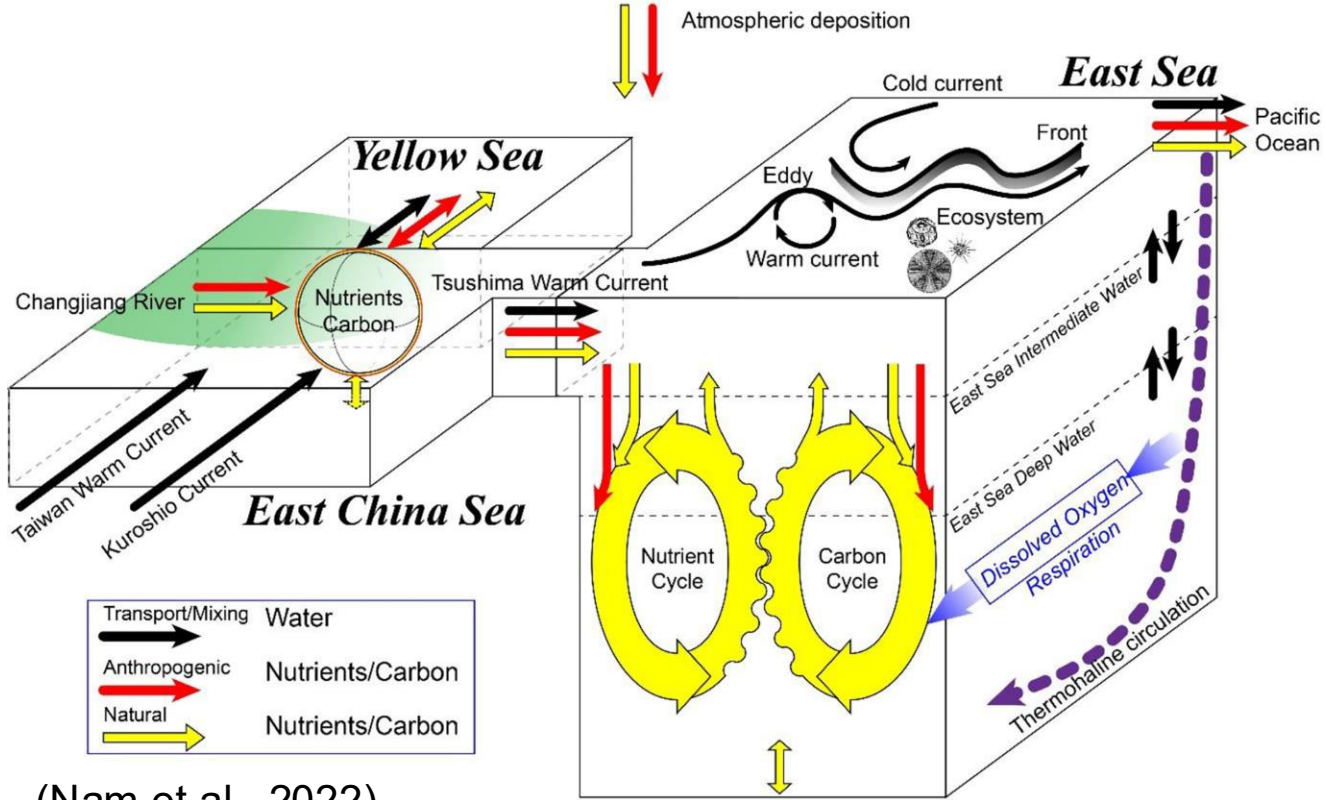
East Asian Marginal Seas at high risks

- Large rivers, both shelves and deep sea, short residence times (5~100 yrs), dynamic ocean circulation and processes, hydrographic and biogeochemical cycles

- World's most affected marginal seas

- Undergoing unprecedented transformation due to climate change and human activities

Introduction/Background



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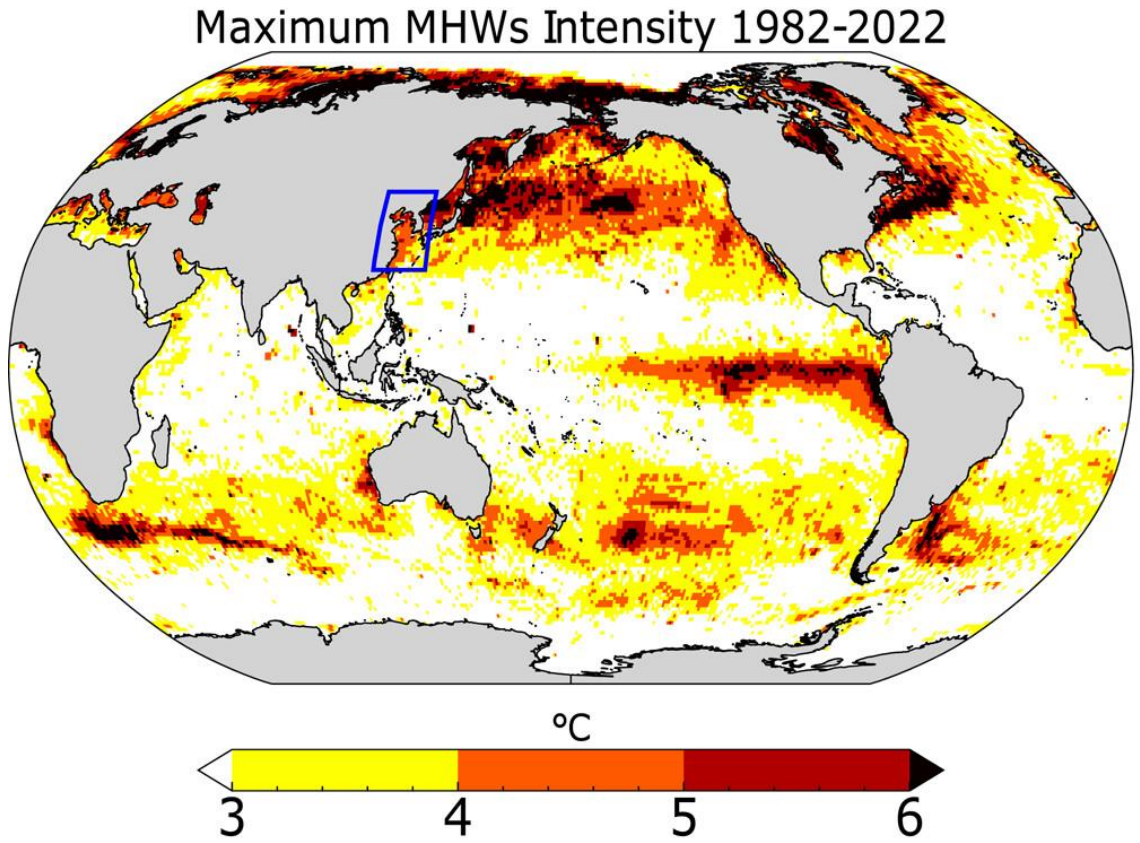


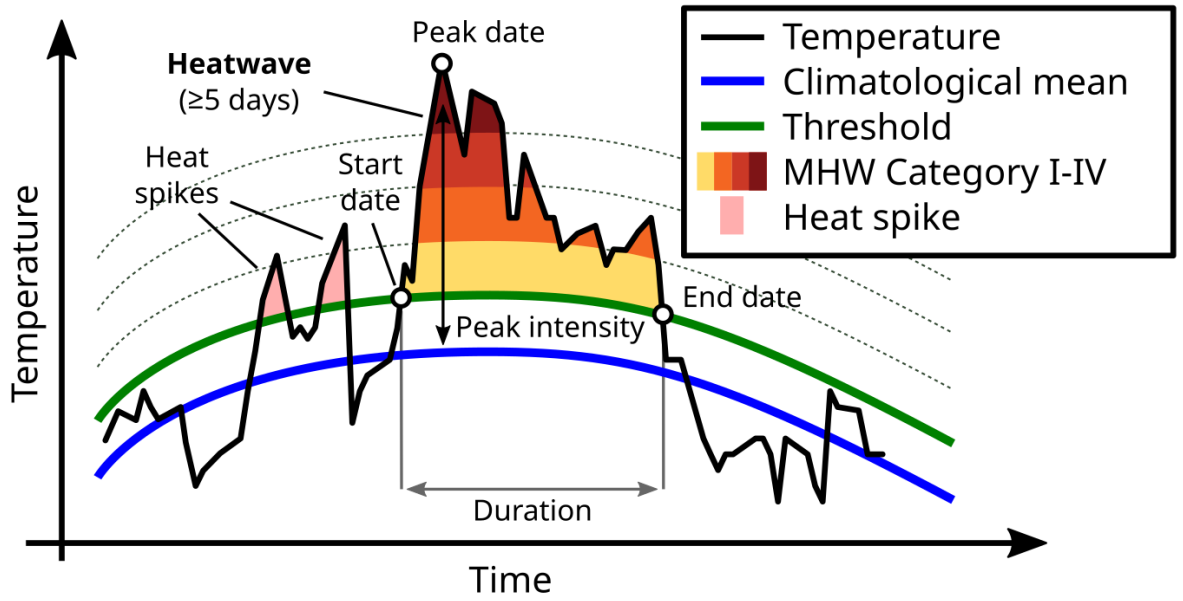
(Dasgupta et al., 2024)

East Asian Marginal Seas at high risks

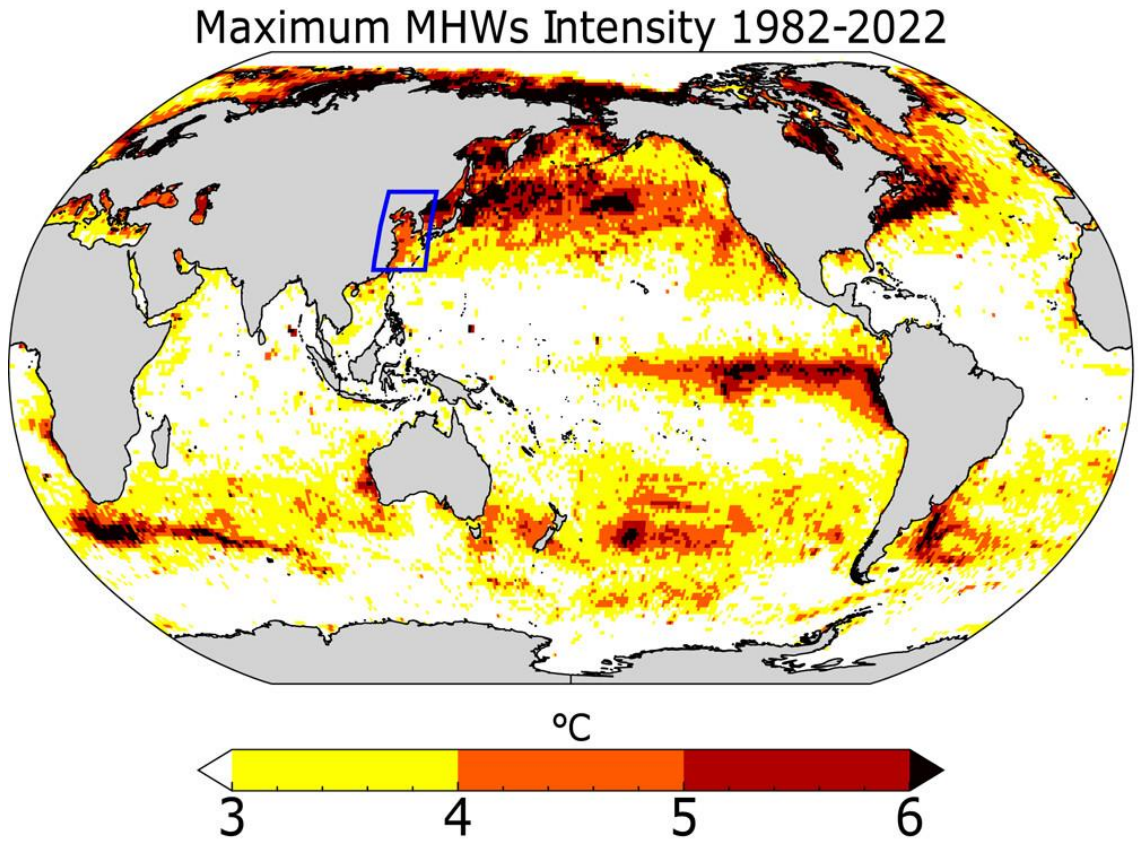
- Not only ocean warming, deoxygenation, acidification, eutrophication, and sea level rise,
- But also extreme events such as marine heatwaves, flooding/droughts, tropical storms, etc…
- Influence on geographic distribution, phenology, and growth of marine biota in species-dependent ways
- Impact on ecosystem structure and function; thus fisheries, communities, and ecosystem services

Introduction/Background

Marine heatwaves (MHWs) as a period when seawater temperatures exceed a seasonally-varying threshold for at least 5 consecutive days



(Hobday et al., 2016)



(Dasgupta et al., 2024)

East Asian Marginal Seas at high risks

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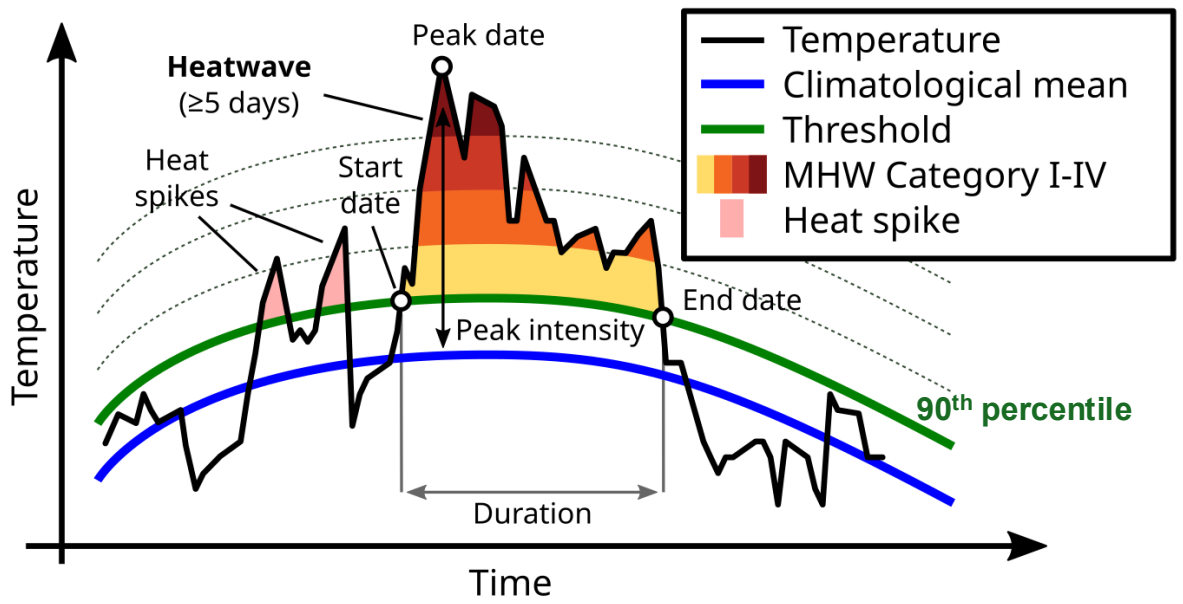
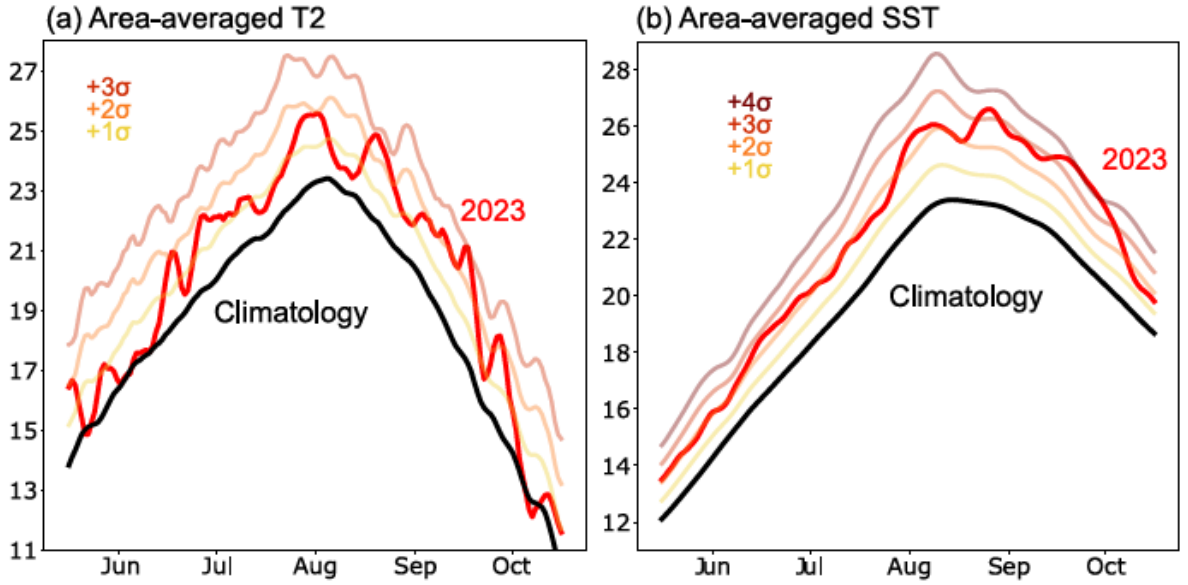
Introduction/Background

Marine heatwaves (MHWs) as a period when seawater temperatures exceed a seasonally-varying threshold for at least 5 consecutive days



(Hobday et al., 2016)



(Okajima et al., 2025)

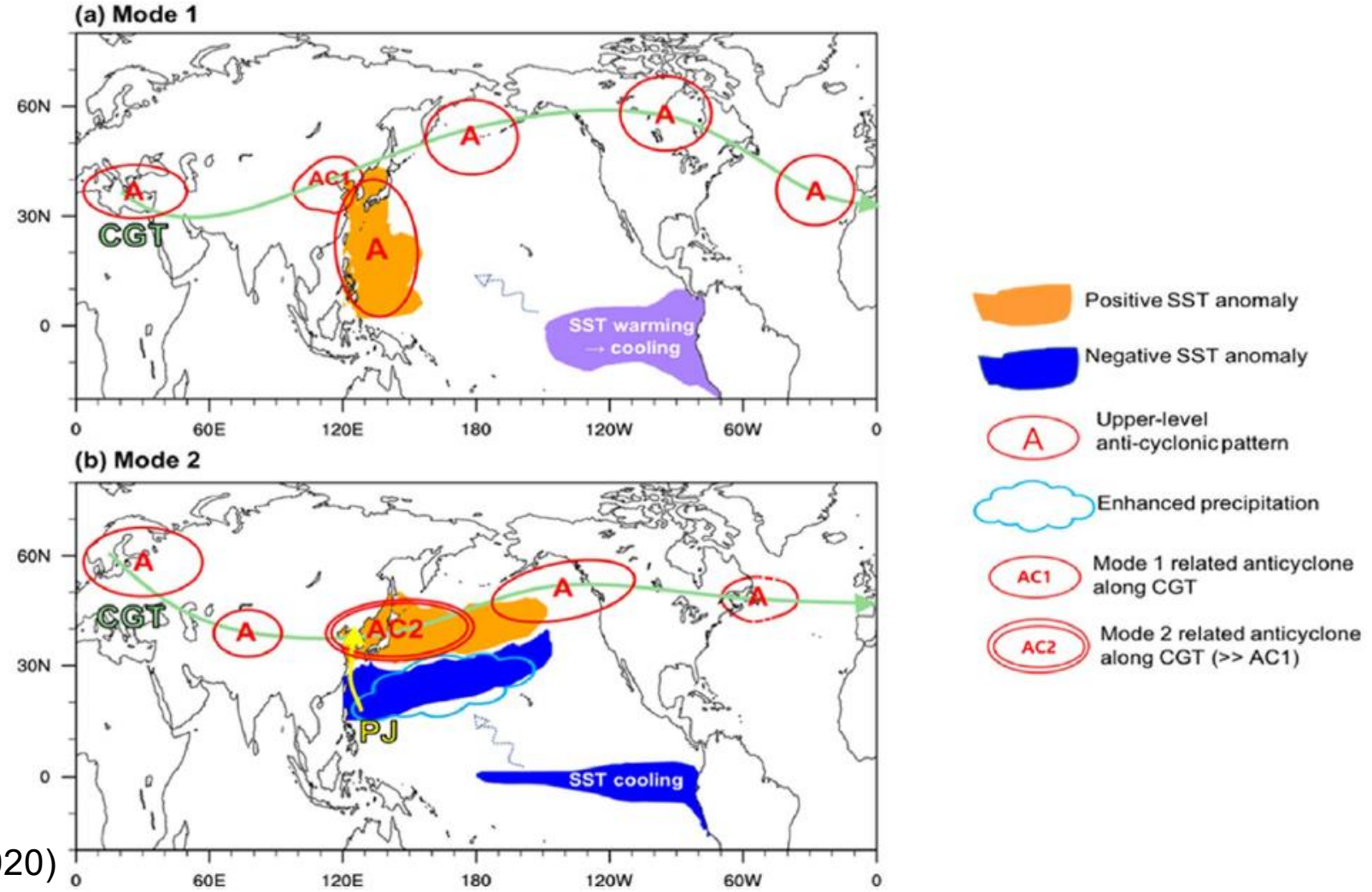
Key properties/characteristics (parameters) of MHWs as matrix components

- **Intensity (severity): instantaneous temperature anomaly [unit: degrees Celsius], strongest intensity, …**
- **Duration: length of time the event lasts [unit: days], longest duration, largest number of total days, etc.**
- **Frequency: number of distinctive MHW events in a given area over a year [unit: count per yr]**
- **Cumulative intensity: measure of the total thermal stress [unit: degree Celsius-days]**
- **Spatial extent: total area of the sea/ocean covered by the MHW [unit: square kilometers]**

Recent studies on marine heatwaves (MHWs) around KP

Two major modes of MHWs in the NW Pacific

- ✓ Two modes of East Asian MHWs associated with two contrasting SST patterns over the subtropical western NP
- ✓ First MHW mode: ocean warming over East Asia occurring along with the subtropical western NP from the earlier winter by an ENSO, intensifying to an extreme warming state around East Asia
- ✓ Second MHW mode: MHWs over East Asia occurring due to a significant intensification of a zonally elongated high-pressure zone in response to anomalous subtropical convection in addition to mid-latitude zonal waves



(Lee et al., 2020)

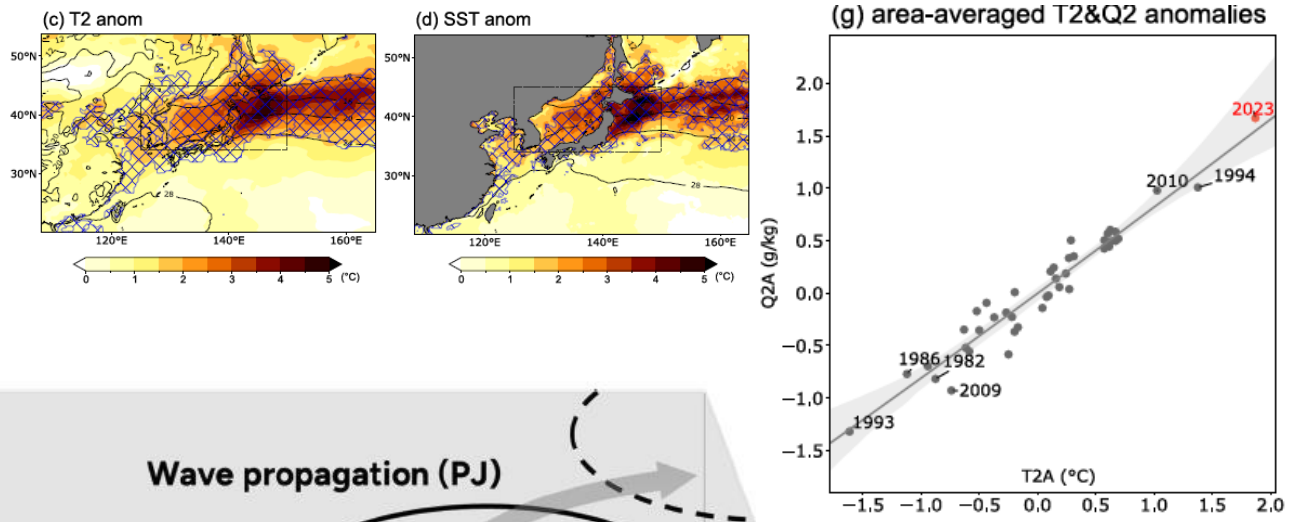
Recent studies on marine heatwaves (MHWs) around KP

Atmospheric pathway of MHWs in the NW Pacific

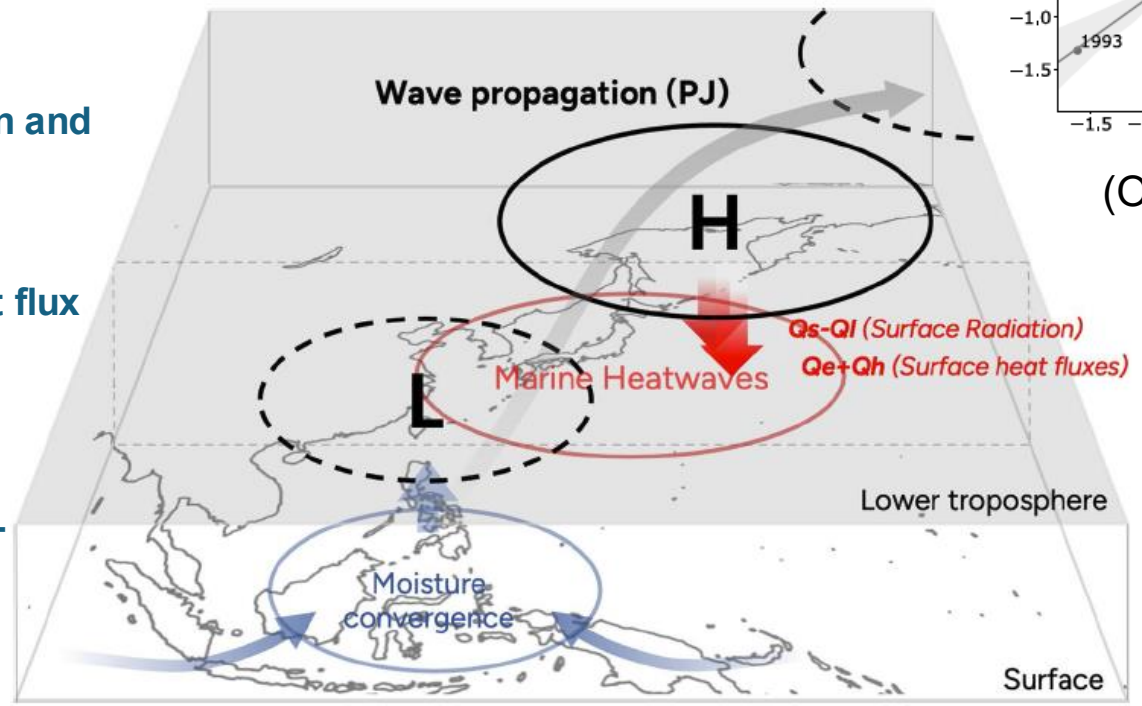
- ✓ Pacific-Japan (PJ) atmospheric teleconnection pattern* and its interaction with oceanic processes on the surface warming

*PJ pattern: thermally driven Rossby waves originating over the tropical western Pacific through deep convection and propagating toward high latitudes

- ✓ The PJ pattern induces anticyclonic circulation and the corresponding northward extension of the subtropical high over the NW Pacific
  - ➔ increasing in insolation and decreasing ocean-to-atmosphere latent heat flux
  - ➔ developing East Asian MHWs "atmospheric pathway to MHWs"
- ✓ Unprecedented summer MHWs linked to the atmospheric pathway exacerbating the record-breaking 2023 East Asian summer heatwave



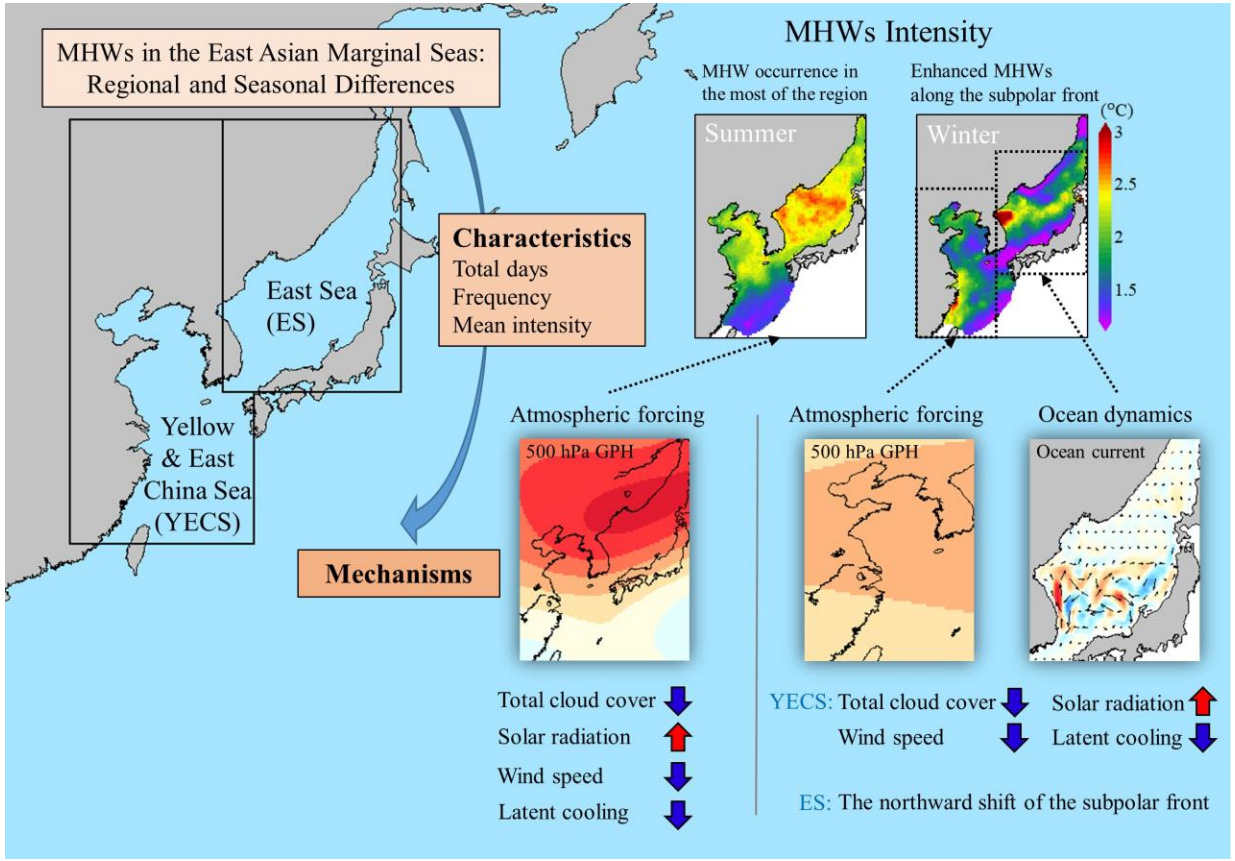
(Okajima et al., 2025)



(Noh et al., 2023)

Recent studies on marine heatwaves (MHWs) around KP

Seasonal changes and regional differences of MHWs in the East Asian Marginal Seas

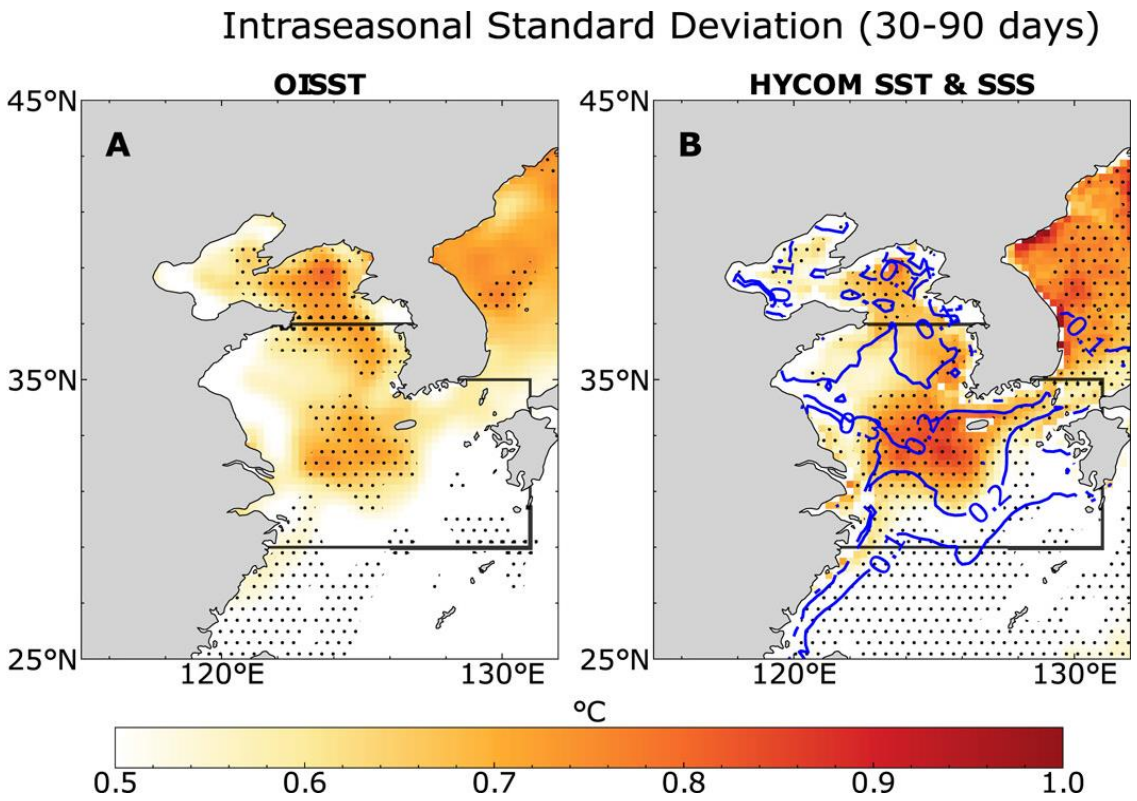


(Choi et al., 2022)

- ✓ More frequent occurrence in summer (2.7 events/decade) in a relatively wide area than in other seasons
- ✓ Strong (up to 3.7°C) and long-lasting (up to 38 days/event) winter MHWs concentrated along the subpolar front in the East Sea (ES) where the MHWs are 20% longer (2.2 days/decade) than in the Yellow & East China Sea (YECS)
- ✓ Summer MHWs primarily driven by increased solar radiation (reduced cloud cover and latent cooling from weakened wind)
  vs
  Winter MHWs driven by regionally differing mechanisms; YECS MHWs mainly due to the atmospheric processes while ES MHWs largely driven by the northward frontal shift
- ✓ Large-scale atmospheric processes (summer MHWs)
  vs
  Intensified MHW generation in limited areas (winter MHWs)

Recent studies on marine heatwaves (MHWs) around KP

MHWs in the East Asian marginal seas facilitated by BSISO



(Dasgupta et al., 2024)

- ✓ Role of the Boreal Summer Intraseasonal Oscillation (BSISO) in the genesis of MHWs in the southern YS and northern ECS

*BSISO: A dominant mode of intraseasonal (30-90 days timescale in this study) climate variability in the tropics during the Northern Hemisphere summer; a large-scale pulse of weather activity that moves slowly eastward across the Indian Ocean and western Pacific Ocean

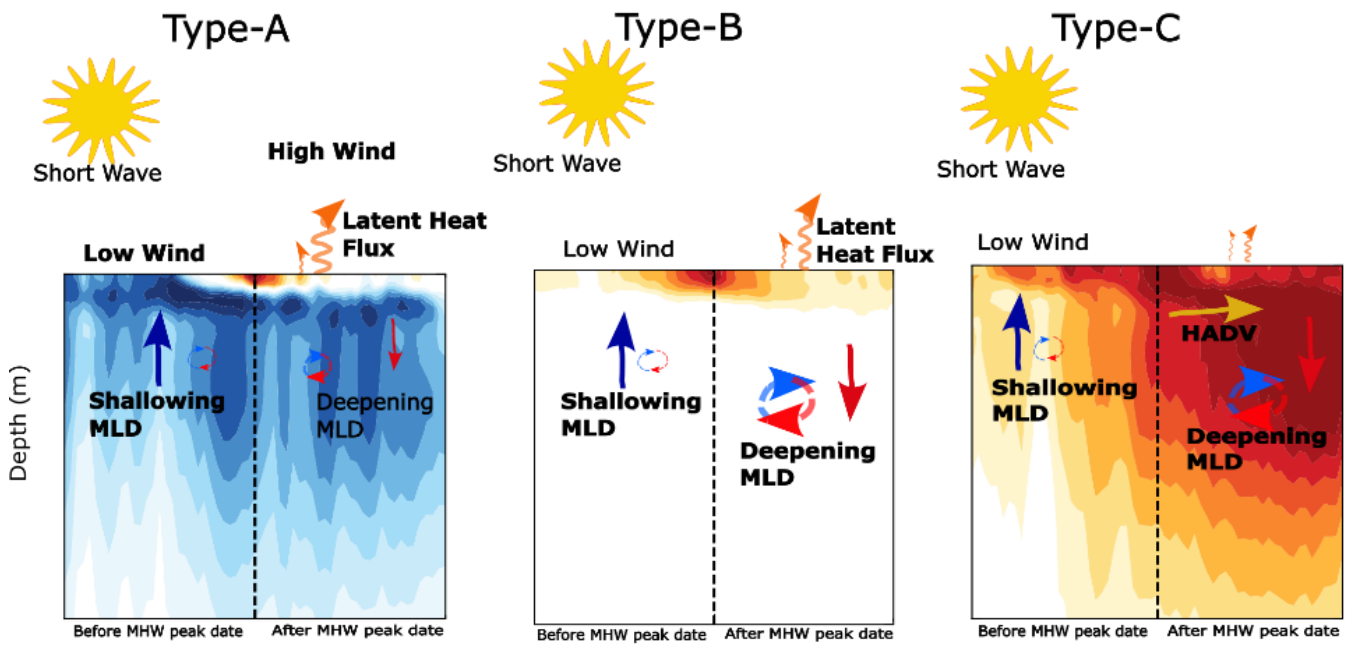
- ✓ Most severe (> 4°C) and devastating MHWs during the summer of 2016 were initiated primarily by mixed layer shoaling (more dominant role) and increasing solar influx, and facilitated with the favorable condition from northward propagating BSISO (phases 5, 6, and 7)

- ✓ Mixed layer shoaling leads SST anomalies by 1-2 days, providing a potential sub-seasonal prediction window for MHWs in the region

Recent studies on marine heatwaves (MHWs) around KP

Summer MHWs in the East Sea (Japan Sea)

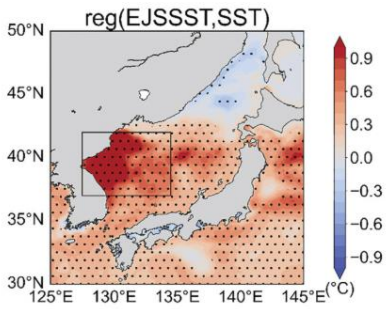
- ✓ Three types (Types A, B, and C) of subsurface evolution of summer (JJA) MHWs in the ES are identified
  - Type A: surface-confined and short-lived with anomalous warm surface & cold subsurface temperatures
  - Type B: surface-intensified warm anomalies with no subsurface anomalies
  - Type C: warm anomalies extending to deep layers at the upper 200 m
- ✓ Common mechanism contributing to the formation (increased shortwave radiation, decreased wind speed, thinned mixed layer) & dissipation (mixed layer deepening, heat release to the atmosphere, interactions btw the surface mixed layer and deeper layers) of all three types
- ✓ Significantly different mechanisms playing the relative role of the heat penetration into the layer below the mixed layer and dissipation of MHWs, e.g., significant role of horizontal advection only during the Type C MHWs

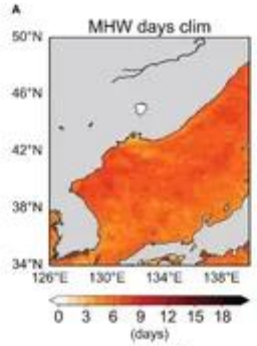


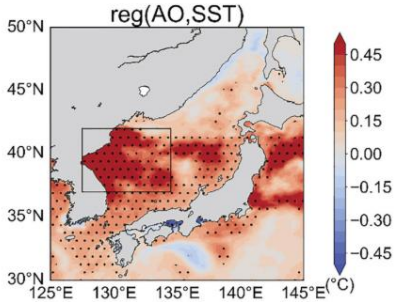
(Saranya and Nam, 2024)

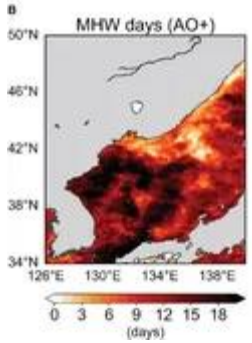
Recent studies on marine heatwaves (MHWs) around KP

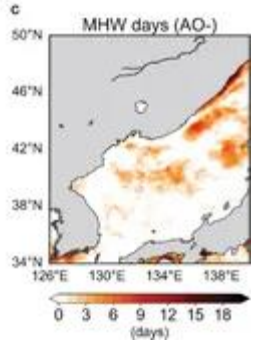
Winter MHWs in the East Sea (Japan Sea)

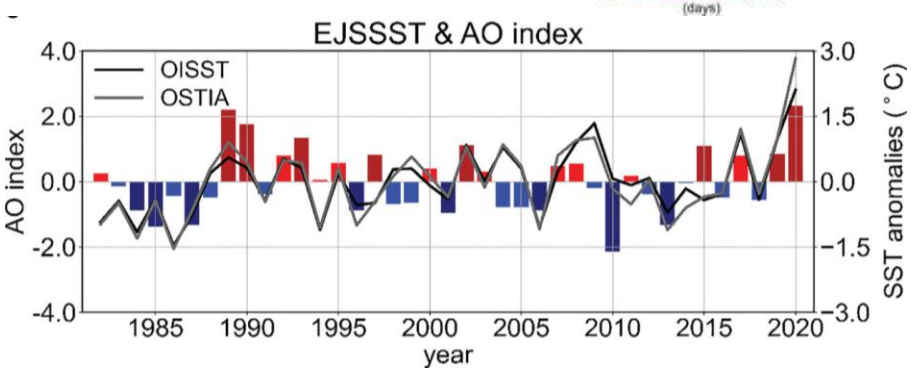






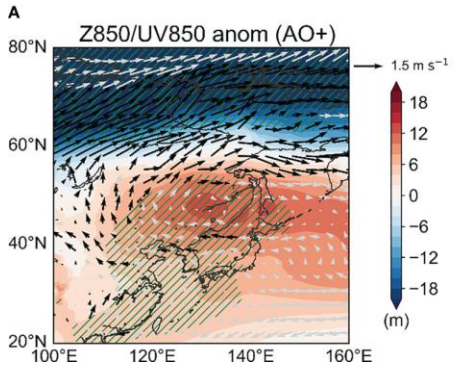


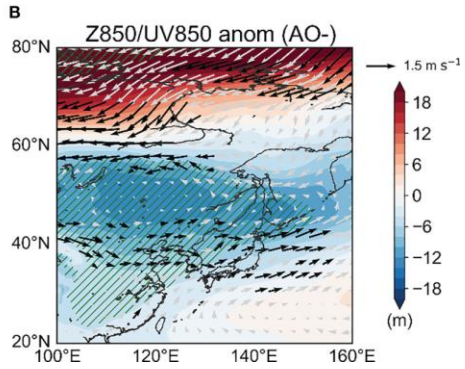




(Song et al., 2023)

- ✓ Winter (JFM) MHWs in the northwestern ES, occurrence linked to a large-scale mode of climate variability such as the Arctic Oscillation (AO)
- ✓ The AO-related wind forcing modulates the SST variability via the oceanic dynamic adjustment processes.
- ✓ High SST variability and frequent MHWs found during boreal winter, associated with the AO; ocean dynamic adjustment processes; anomalous anticyclonic eddy-like circulation and Ekman downwelling during a positive AO phase driving positive SST anomalies
- ✓ The physical linkage btw a positive AO and the abnormally warm SST could be conductive to MHW occurrences in the ES, e.g., during the winter of 2020 (AO+)

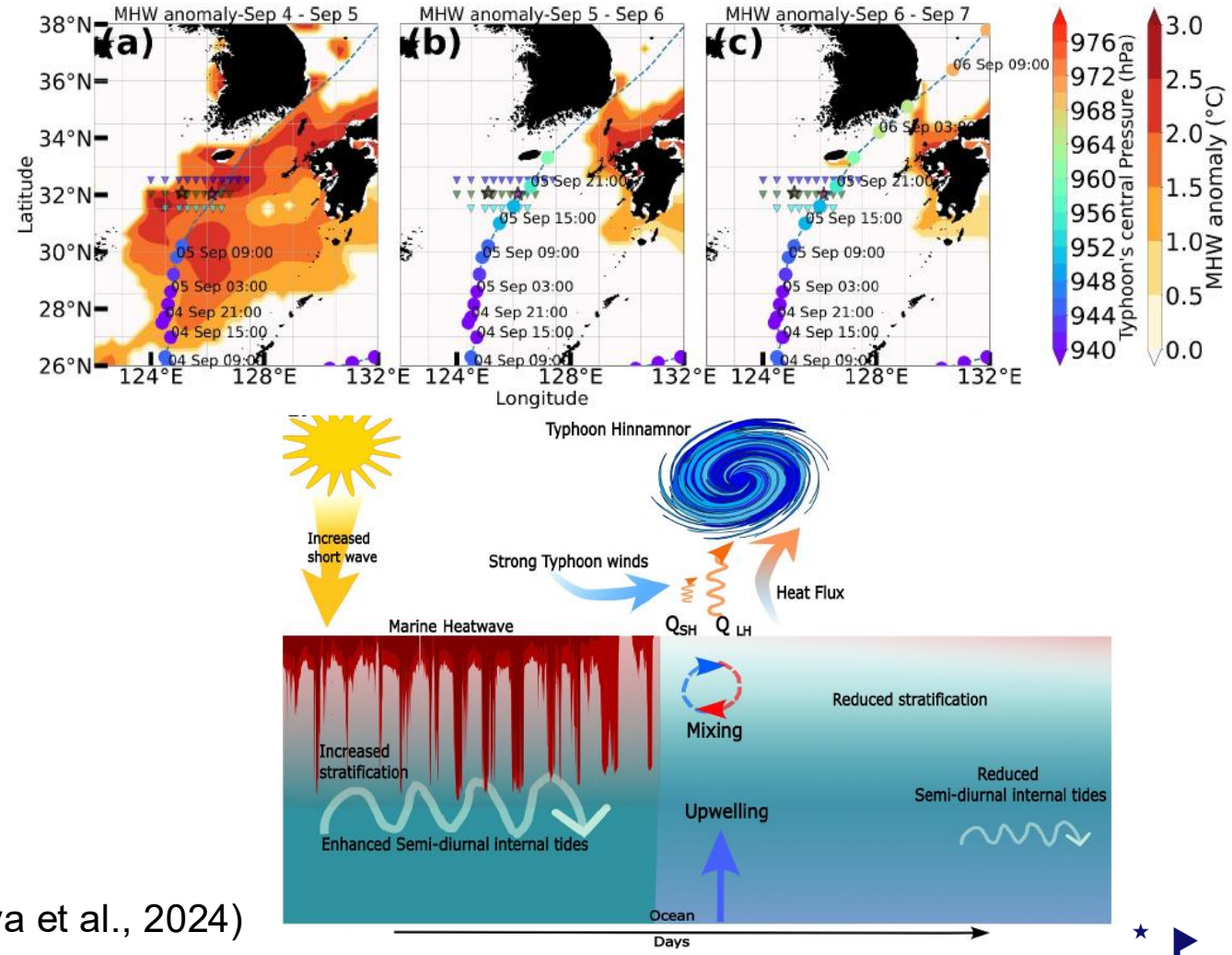




Recent studies on marine heatwaves (MHWs) around KP

Interactions of MHWs with typhoons and internal tides

- ✓ Typhoon Hinnamnor (2022) weakened and re-intensified interacting with an underlying MHW (contribution of latent heat loss from the northern ECS)
- ✓ Strong sea surface wind forcing with the typhoon enhanced vertical mixing and upwelling, resulting in sea surface cooling & disappearance of MHW
- ✓ Increased stratification during the MHW enhanced semidiurnal oscillations of water temperature (internal tides) which also weakened during post-typhoon period due to unfavorable conditions for internal tide generation from a nearby source
- ✓ This study highlights the importance of continuous time-series observations to monitor interactions among extremes (MHWs, typhoons, and internal waves/tides)

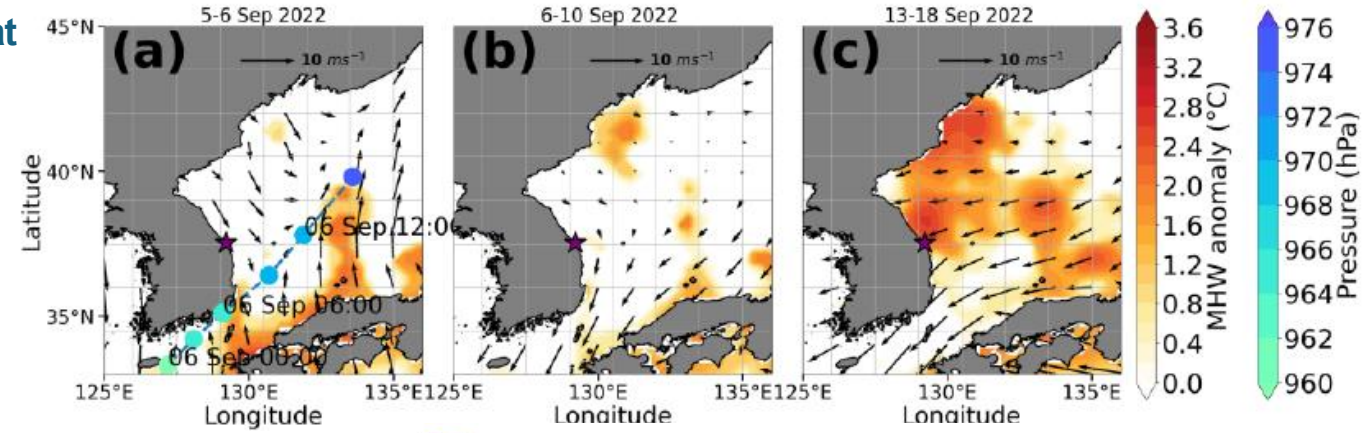


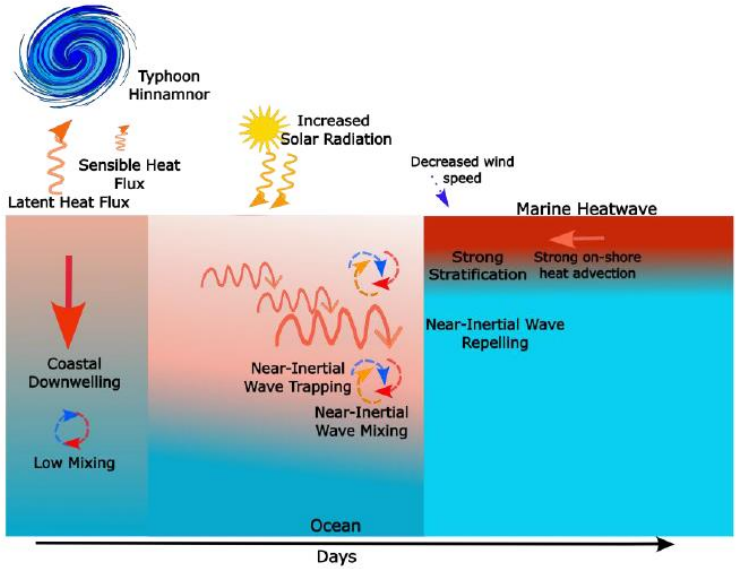
(Saranya et al., 2024)

Recent studies on marine heatwaves (MHWs) around KP

Interactions of MHWs with typhoons and near-inertial internal waves

- ✓ Typhoon Hinnamnor (2022) weakened over the ES generating post-typhoon MHWs (contribution of local heat uptake by anomalously cold SST overlying an anomalously warmer subsurface)
- ✓ This study provides the first detailed analysis of MHW formation on the western side of typhoon path off the Korean east coast, ~ 1 week after the typhoon passage.
- ✓ Near-inertial internal waves, enhanced by typhoon winds and influenced by subinertial background conditions, prevented the MHW onset during the week despite favorable conditions (coastal downwelling, increased surface net heat gain from atmosphere, and higher upper ocean heat content)



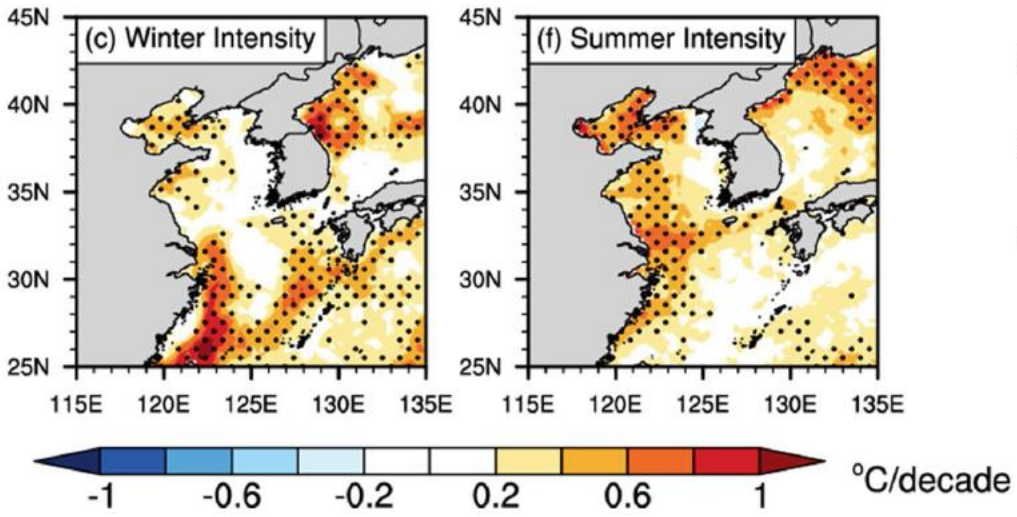


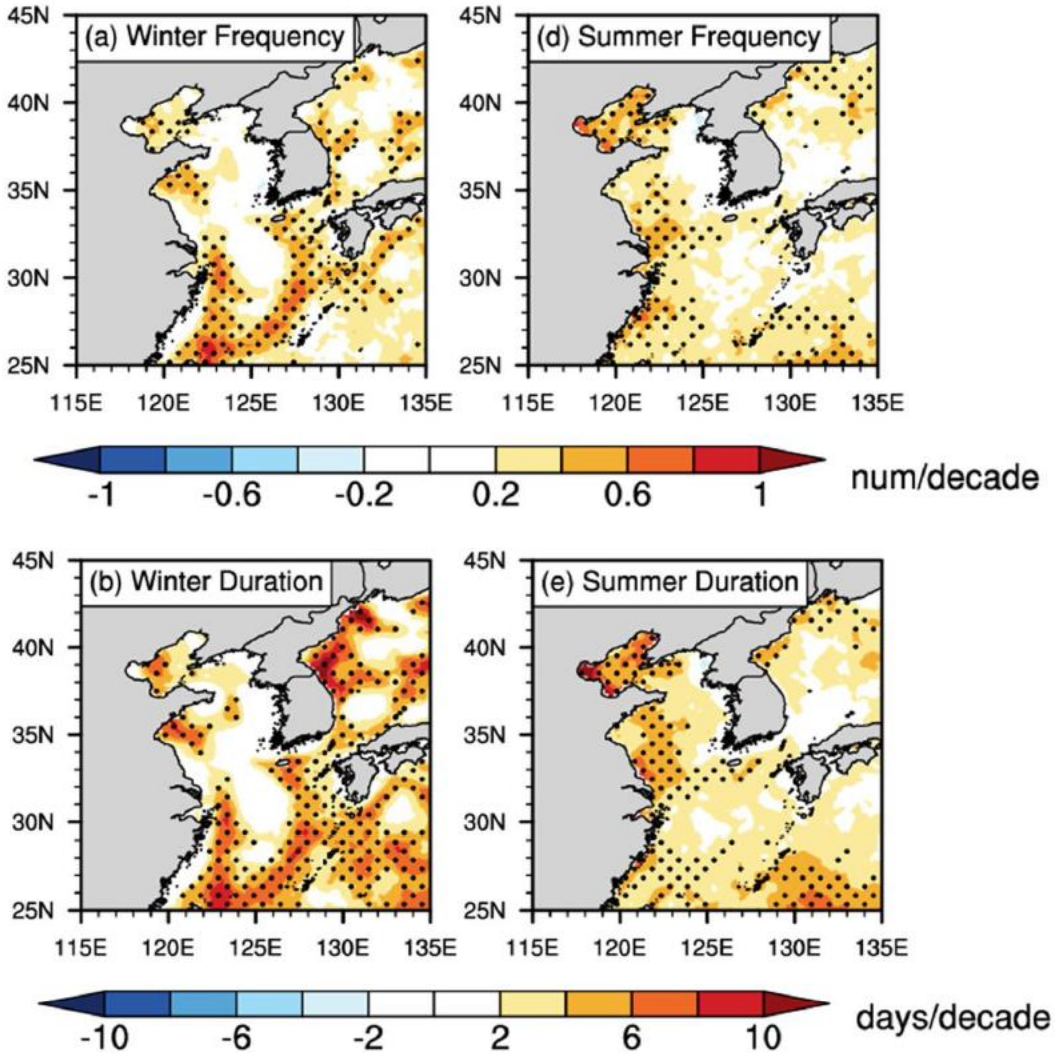
(Saranya et al., in revision)

Long-term changes in MHW matrix and their impacts

Long-term trends of MHWs in the East Asian Marginal Seas

- ✓ Long-term trends (1982-2020) of EAMS MHWs & relationship btw MHW trends and mean SST warming trends
- ✓ Duration and intensity of EAMS MHWs increased over the past four decades (+4 days/decade & +0.3°C/decade)
- ✓ In summer, the positive trend of MHWs is the highest in the ECS primarily due to the rapidly increasing mean SST
- ✓ In winter, northern ES reveals remarkably rapid increases in MHW properties in the last two decades, with increasing rates of ~6.2 & ~4.9 times longer total duration & stronger intensity than global average

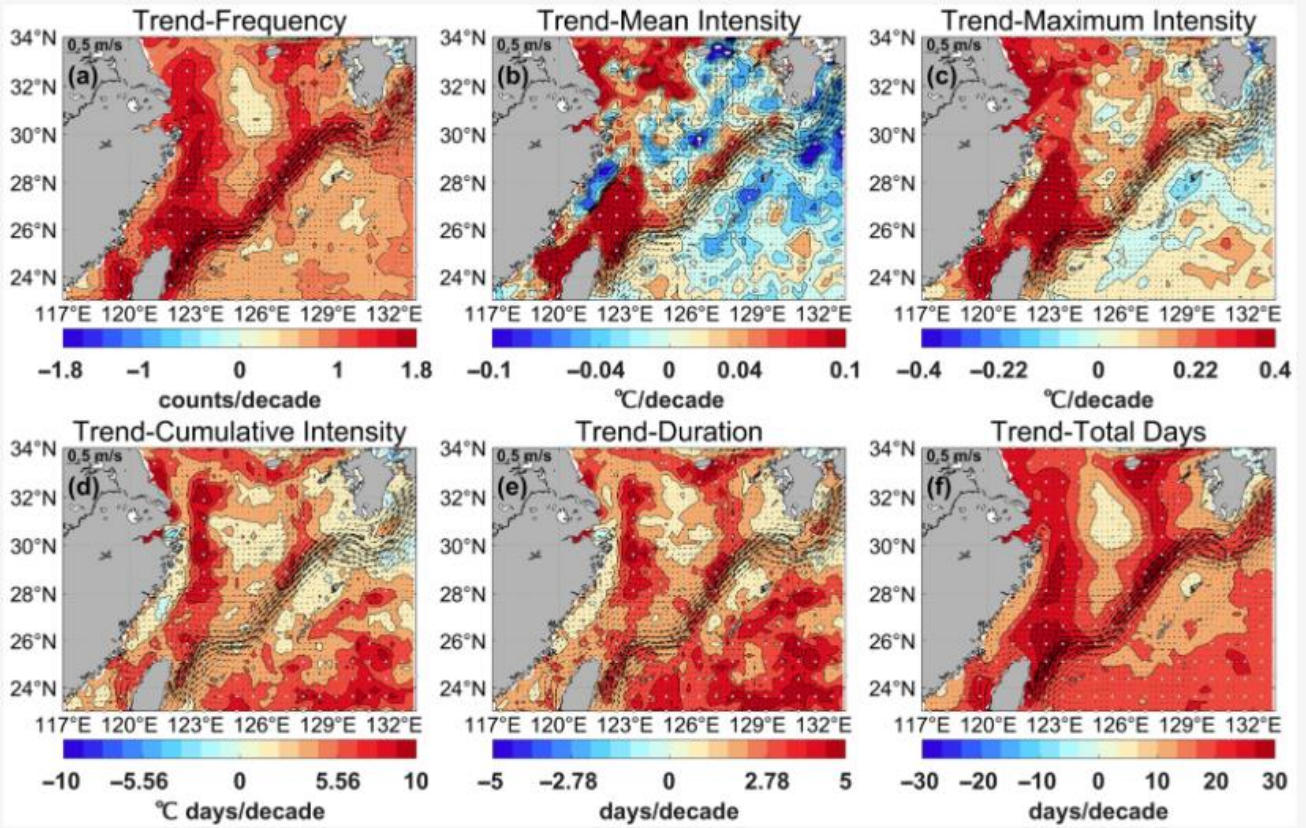




(Lee et al., 2023)

Long-term changes in MHW matrix and their impacts

Long-term trends of MHWs in the East Asian Marginal Seas – ECS



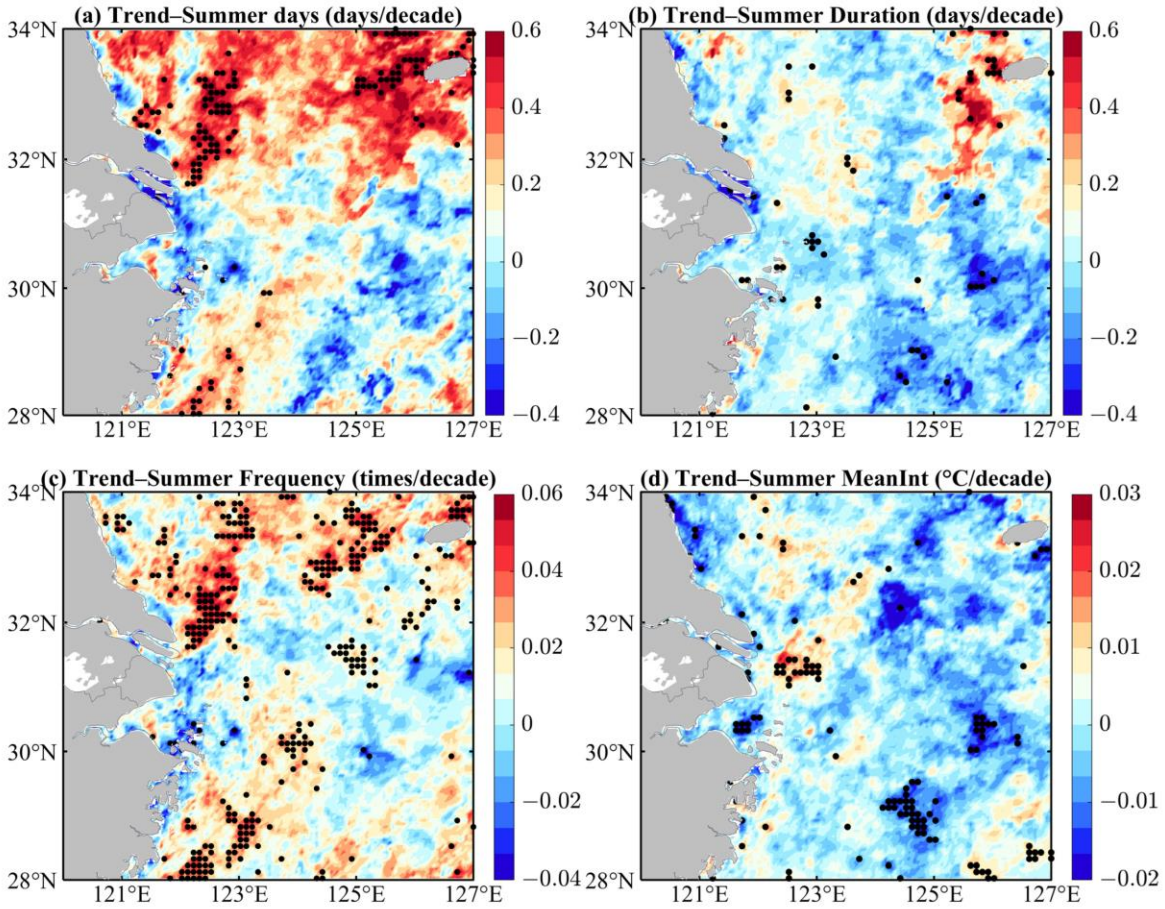
(Ma et al., 2025)

< Regional divergence in long-term trends (1982-2023) >

- ✓ **Relatively high annual average frequency, longest duration, largest number of total days, strongest intensity, and most pronounced seasonal signals in the coastal areas near China (from Jiangsu coast to northeast of Taiwan Island)**
- ✓ **Significant levels of frequency, duration, and total days, but with comparatively weak intensity in the areas along the Kuroshio path**
- ✓ **MHW indices generally showing a positive trend in the ECS from 1982 to 2023; significantly positive/increasing trends found in the region with high annual average MHW indices**

Long-term changes in MHW matrix and their impacts

Long-term trends of MHWs in the East Asian Marginal Seas – ECS



(Xie et al., 2024)

< Trends of summer MHW characteristics (1982-2021) in the Changjiang River estuary and its surrounding coastal regions >

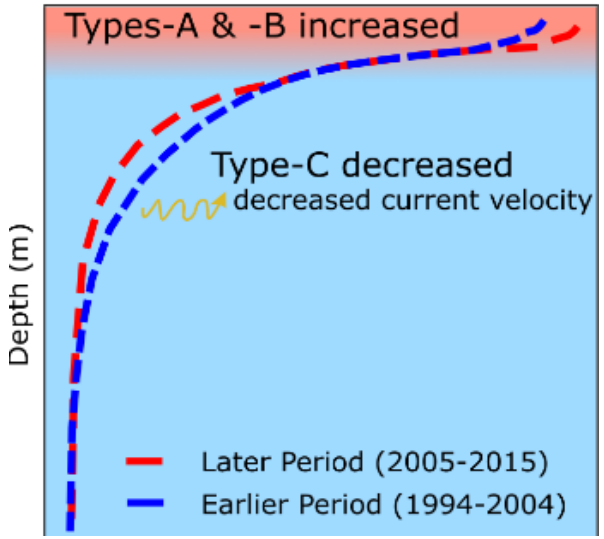
- ✓ Total days and frequency of summer MHWs increased more along the Jiangsu coast, but a negative trend off the Changjiang river mouth
- ✓ Duration and mean intensity of summer MHWs do not change significantly (increase in summer duration of ~0.1 days per decade and a mean intensity of ~0.01°C per decade).
- ✓ Fastest linear increase in duration experienced in the south the Jeju Island & larger increase in mean intensity occurring along the east coast of Sanghai

Long-term changes in MHW matrix and their impacts

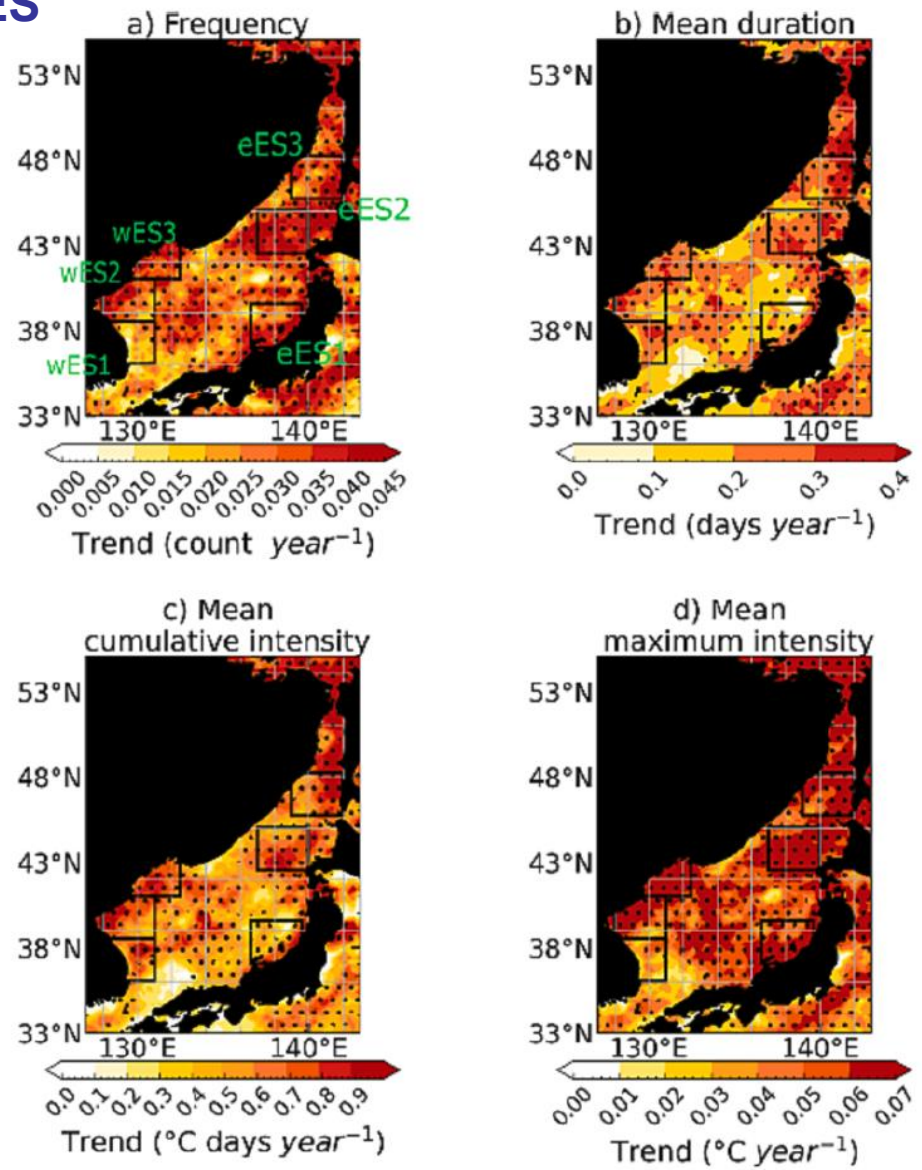
Long-term trends of MHWs in the East Asian Marginal Seas – ES

< Summer MHWs in the East Sea >

- ✓ **Long-term trends in frequency, cumulative intensity and duration of type-A, B, and C MHWs in the ES were discussed along with surface warming and subsurface cooling, and weakening currents in six sub-regions (wES1, wES2, wES3, eES1, eES2, eES3)**
- ✓ **Mean increase in number of ES MHWs (1-2 over the last 40 years)**
- ✓ **Type-B MHWs has increased whereas Type-C decreased**



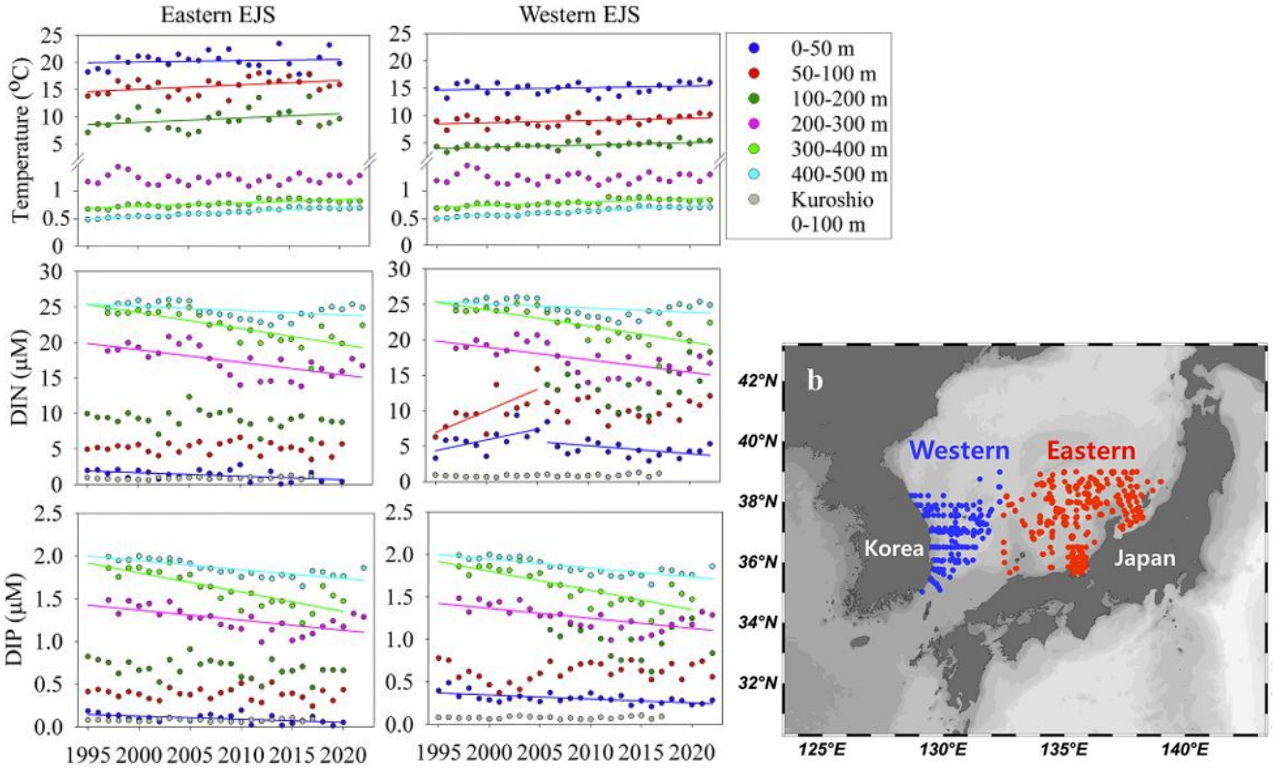
(Saranya and Nam, 2024)



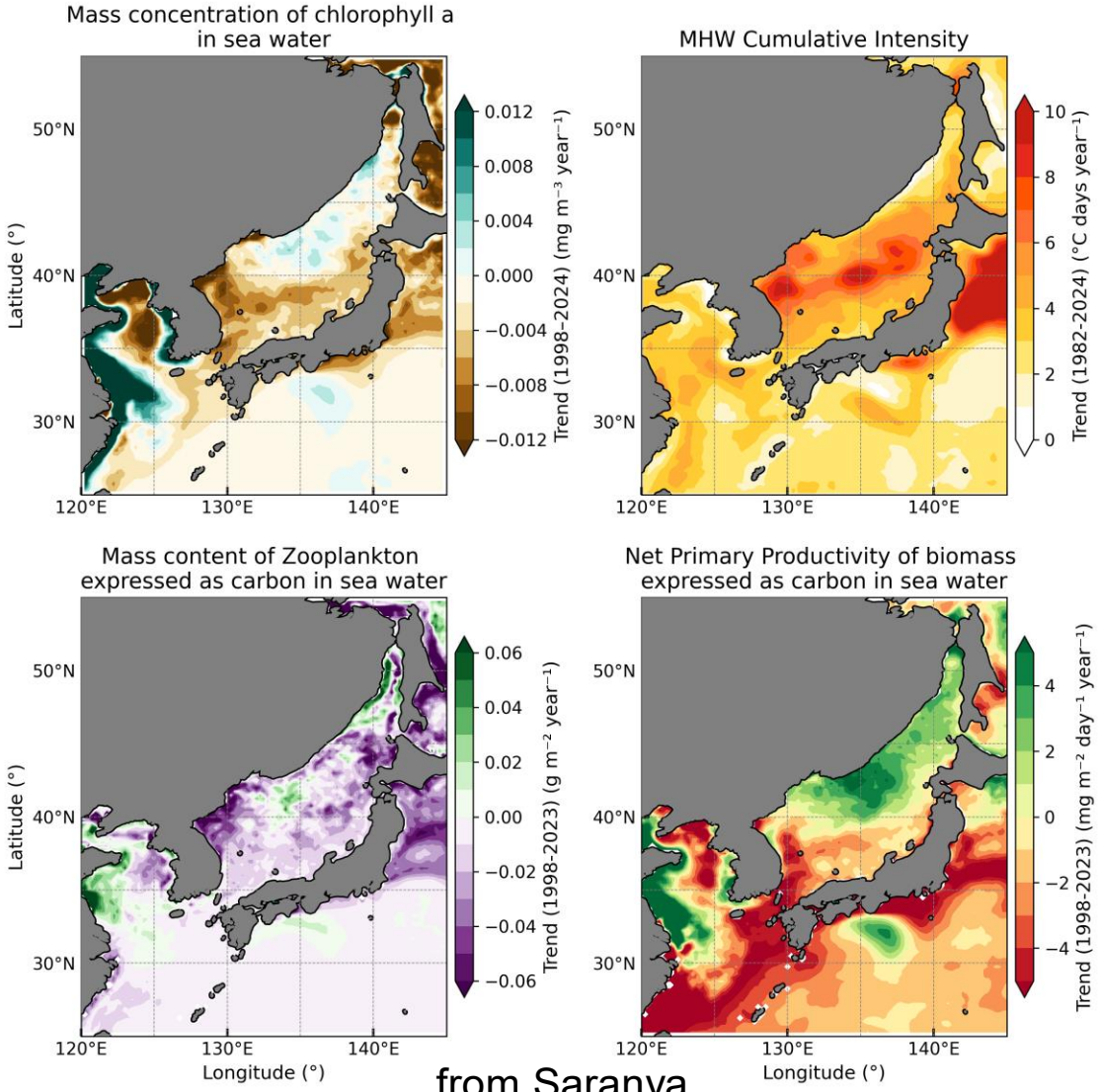
Long-term changes in MHW matrix and their impacts

Potential impacts of the East Asian Marginal Seas MHWs on marine ecosystems, fisheries, and societies

- ✓ **Rapidly increasing trends in MHW cumulative intensity (1982-2024) along the subpolar front including the East Korean Bay**
  - ➔ **Intensified thermal stress in recent decades**
  - ➔ **along with nutrient declining as well as warming**



(Park et al., 2025)



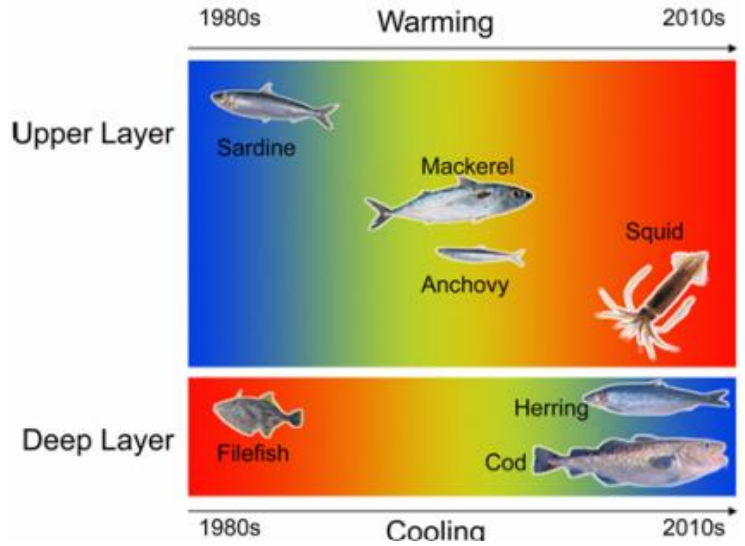
from Saranya

Long-term changes in MHW matrix and their impacts

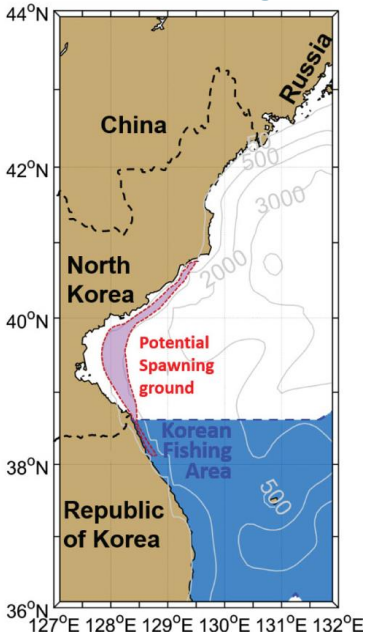
Potential impacts of the East Asian Marginal Seas MHWs on marine ecosystems, fisheries, and societies

- ✓ Rapidly increasing trends in MHW cumulative intensity (1982-2024) along the subpolar front including the East Korean Bay
  - ➔ Intensified thermal stress in recent decades
  - ➔ significant decrease in surface chlorophyll-a concentration
  - ➔ reduced phytoplankton biomass/primary productivity
  - ➔ declined zooplankton biomass
  - ➔ altered habitats of fishes/shift of fish assemblage structure

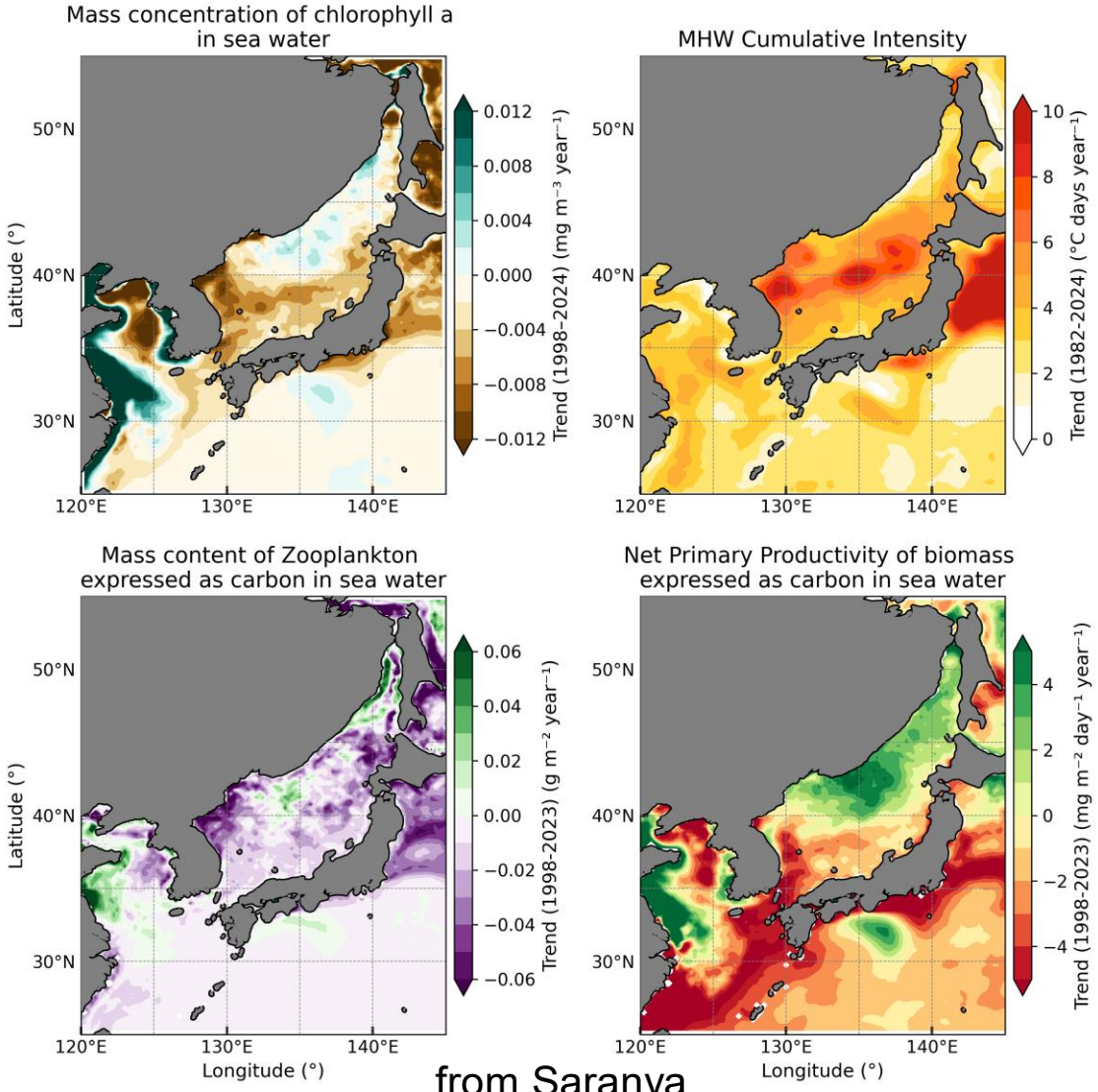
(e.g., Pollock catch in Korean waters declined sharply in the late 1980s coinciding with a ~2°C rise of SST in their spawning area)



(Jung, 2014)



(Kim et al., 2022)



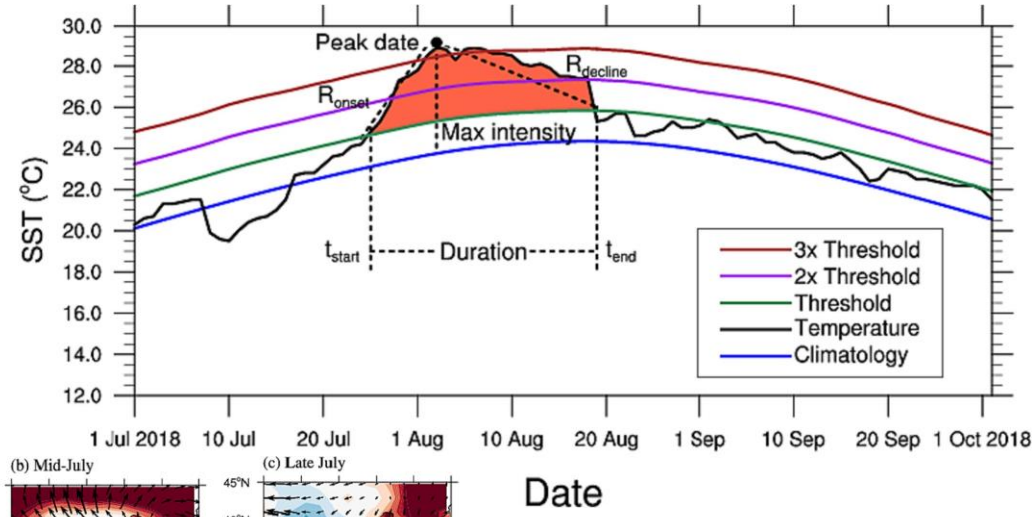
from Saranya

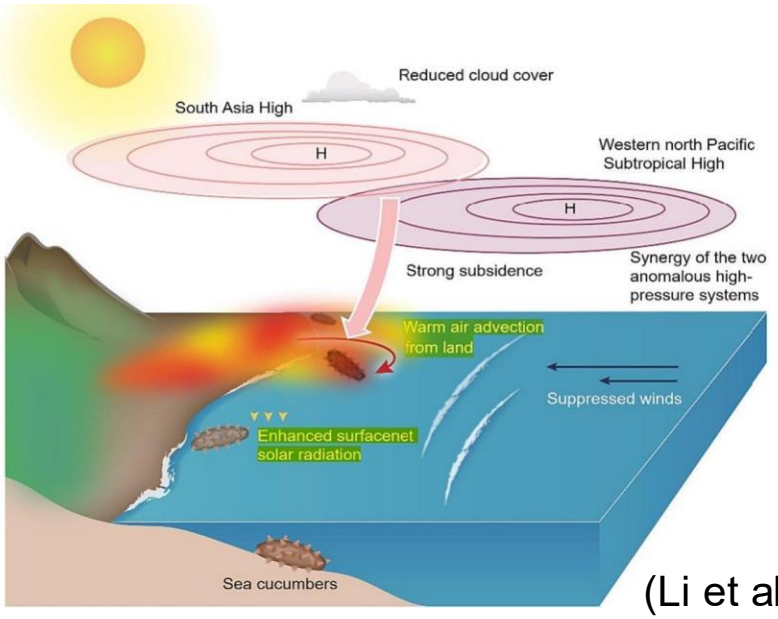
Long-term changes in MHW matrix and their impacts

Potential impacts of the East Asian Marginal Seas MHWs on marine ecosystems, fisheries, and societies

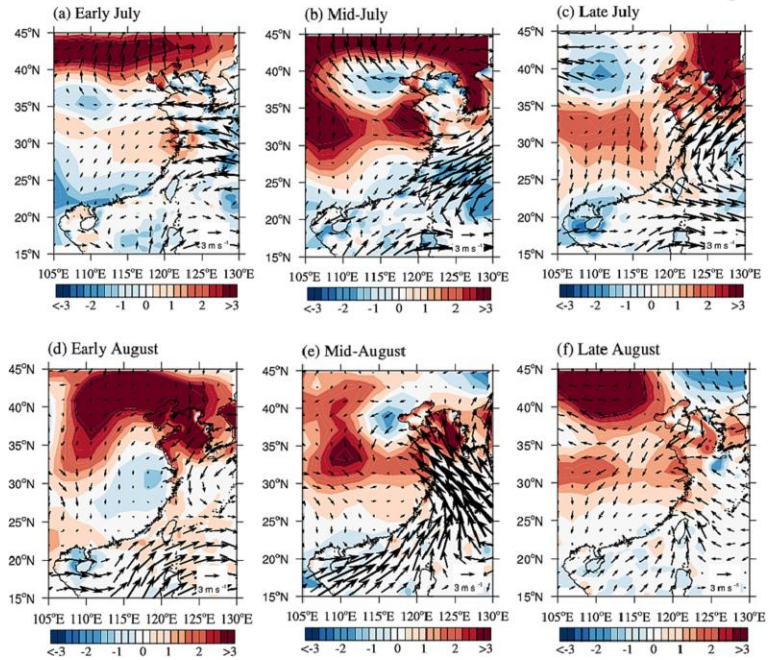
- ✓ Record-breaking (> 5°C) MHWs in the northern YS (2018)
  - ➔ Intensified thermal stress in recent decades
  - ➔ significant decrease in surface chlorophyll-a concentration
  - ➔ reduced phytoplankton biomass/primary productivity
  - ➔ declined zooplankton biomass
  - ➔ altered habitats of fishes/shift of fish assemblage structure

(e.g., Sea cucumber die-off: mass mortality in shallow farms during summer 2018)





(Li et al., 2023)



Summary and suggestions

Recent studies on Marine Heatwaves (MHWs) in the East Asian Marginal Seas (EAMS)

- Highlights intensifying characteristics and crucial role in exacerbating regional climate extremes

- Confirms that formation and dissipation of EAMS MHWs are highly dependent on region/area and season: Summer MHWs are widespread, primarily driven by large-scale atmospheric processes (increased solar radiation with reduced cloud cover, weakened cooling with reduced wind speed, evaporative cooling, and vertical mixing), and facilitated by BSISO
vs
Winter MHWs are usually stronger and longer-lasting, often concentrated in limited areas, and more affected by oceanic processes

- Suggests mechanisms underlying interaction processes among MHWs, tropical cyclones (typhoons), internal waves/tides, and major climate modes (ENSO, AO, etc.)

- Underscores the escalating threat posed by these events with intensifying trends (significant positive trends in MHW frequency, duration, intensity, etc.) and ecological threat such as fisheries damage (altered habitats & shift of fish assemblage structure)

**** Long-term and continuous monitoring of key climate extremes such as MHWs for sustainable management of marine ecosystems & climate adaptation**

- **Thank you!**

- **Any question or comment?**
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