Interannual variability of the marine heat waves in the Western North Pacific Ocean and its marginal seas

Hyung-Ju Park and **Hanna Na***

Physical Oceanography Laboratory

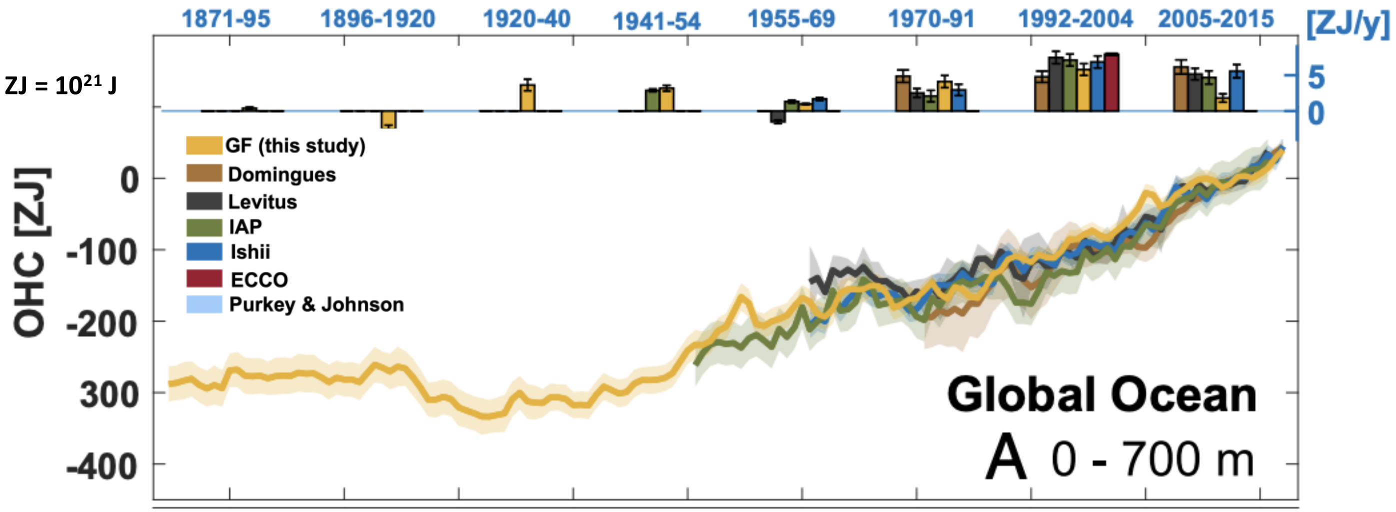
Seoul National University

S1: FUTURE/HD/POC Topic Session
Climate Extremes and Coastal Impacts in the Pacific

Introduction

- 90% of excess energy due to anthropogenic greenhouse gas emissions has been taken by the ocean, leading to sea-level rise or extreme temperature rise events (Zanna et al., 2019; *PNAS*)

1 ZJ = 10^{21} J



Zanna et al. (2019; *PNAS*)

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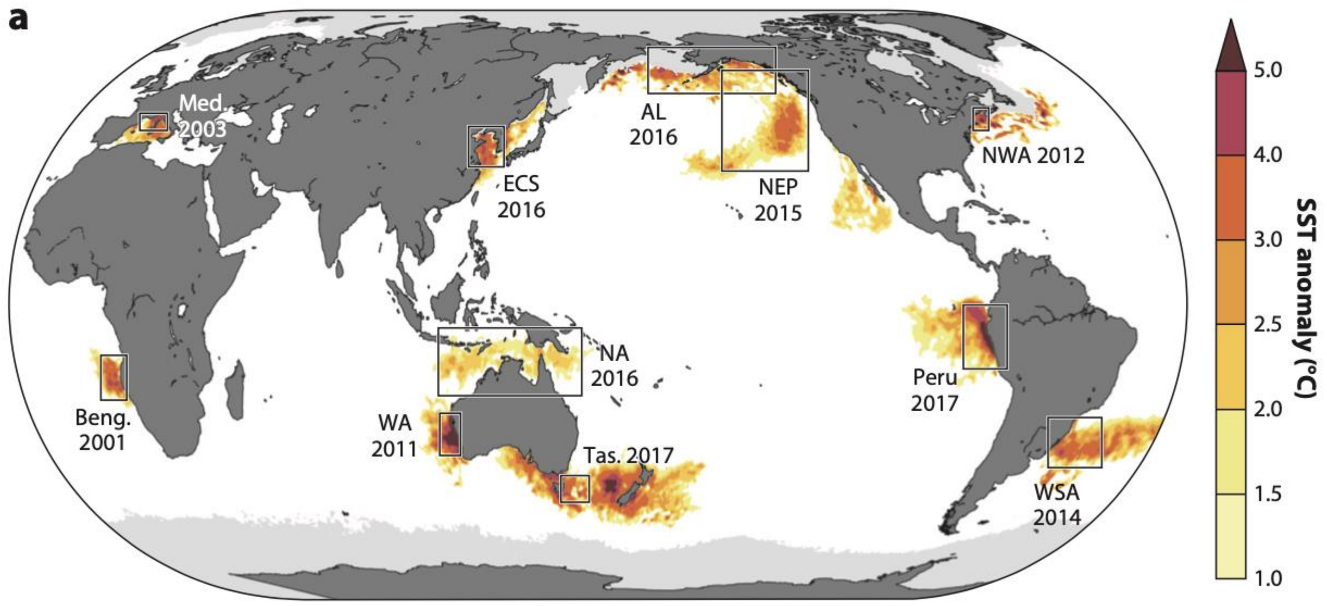
- Anomalously warm seawater events have occurred with increasing frequency and duration over the past century (Oliver et al., 2018; *Nature communication*)



Oliver et al. (2021; *Annual Reviews*)

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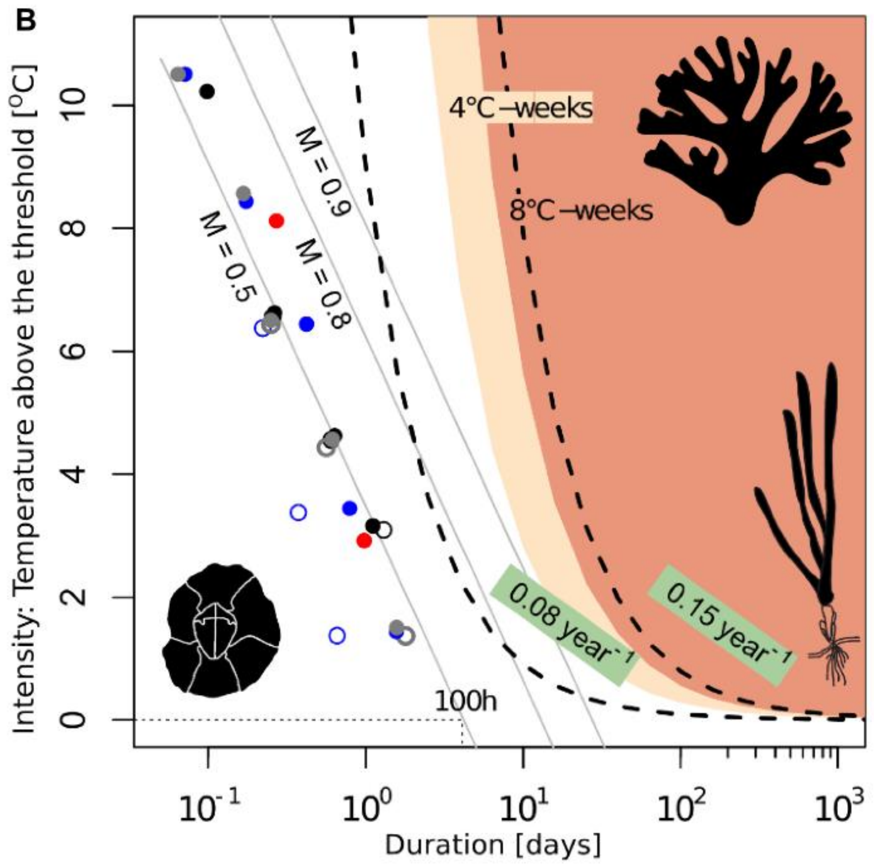
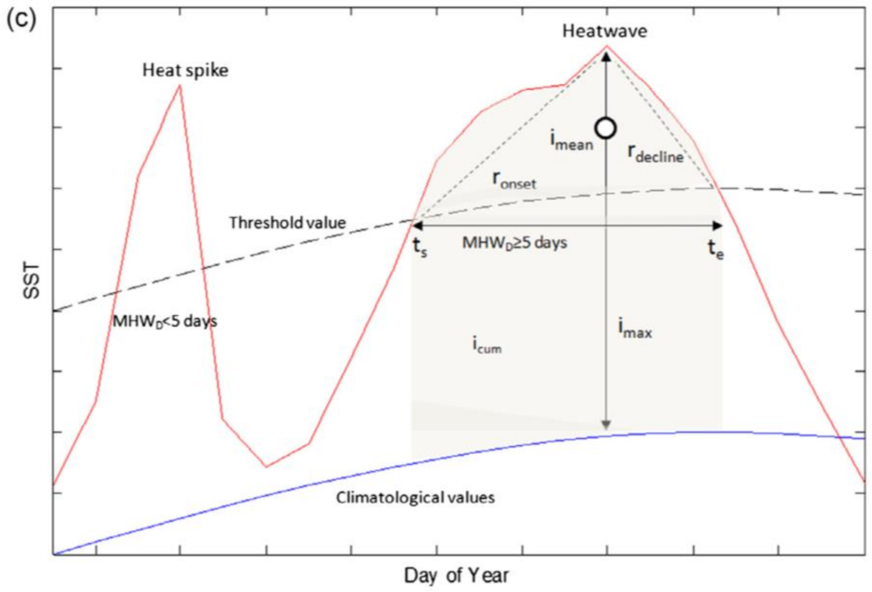
- The ecological impact depends on the characteristics of the warm seawater event, including its duration and intensity



Oliver et al. (2019)

Introduction

- 90% of excess energy due to anthropogenic greenhouse gas emissions has been taken by the ocean, leading to sea-level rise or extreme temperature rise events (Zanna et al., 2019; *PNAS*).
- Anomalously warm seawater events have occurred with increasing frequency and duration over the past century (Oliver et al., 2018; *Nature communication*)
- The ecological impact depends on the characteristics of the warm seawater event, including its duration and intensity
- The Hobday et al. (2016) provides the hierarchical approach to describe Marine Heat Wave (MHW) characteristics: **Discrete prolonged anomalously** warm water event in a particular location



How the interannual variation of **MHWs** in the western North Pacific Ocean and its marginal seas are related to the well-known climate variability?

Data and Method

Data	period	resolution	variable
OISSTv2	1982-2022	0.25°, daily	Sea Surface Temperature
ERA5		0.25°, daily	Surface Air Temperature, Surface net heat flux, Sea Level Pressure, Wind, Geopotential
GPCP		2.5°, monthly	precipitation
SODA 3.4.2	1982-2020	0.5°, monthly	Sea Surface Height

MHW events are defined following the **Hobday et al. (2016),**

Qualitative definition of MHW:

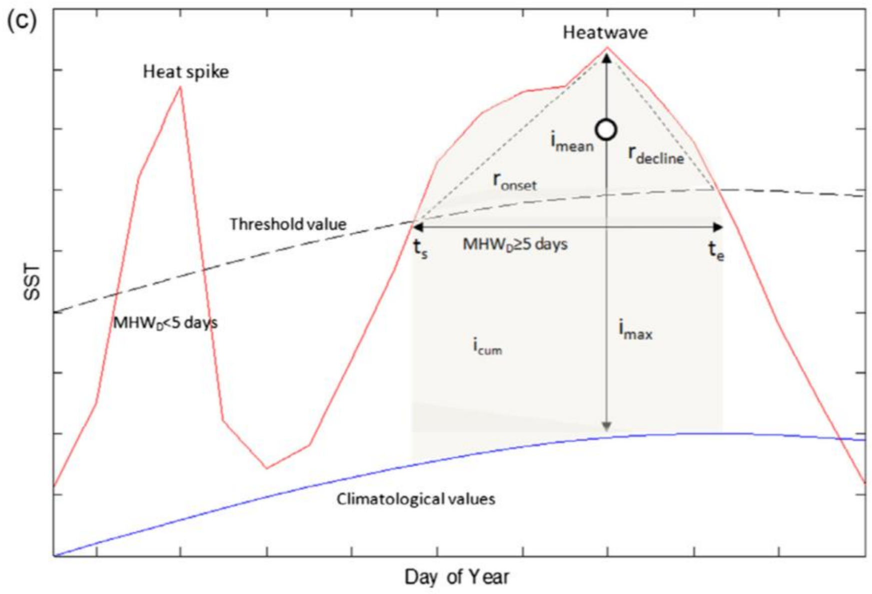
Discrete prolonged anomalously warm water event in a particular location

Quantitative definition:

Discrete: gaps between events of two days or less will be considered as a continuous event

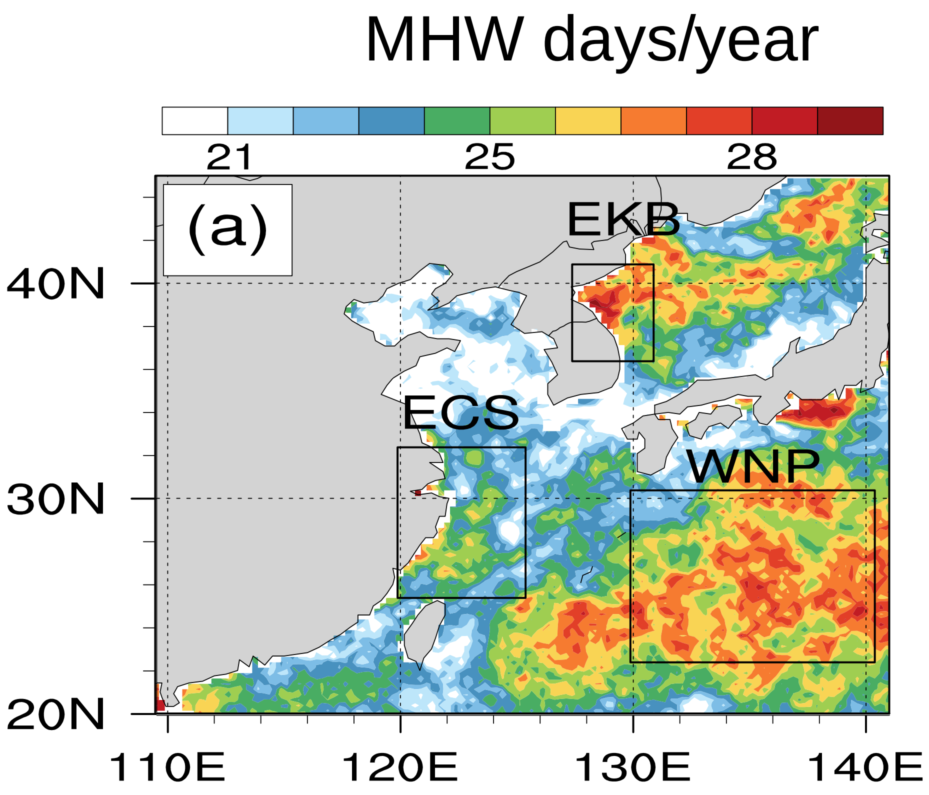
Prolonged: persistent for at least **five days**

Anomalously warm: warm temperature **higher than 90%** percentile for given calendar day



Baseline Period : 1982-2022

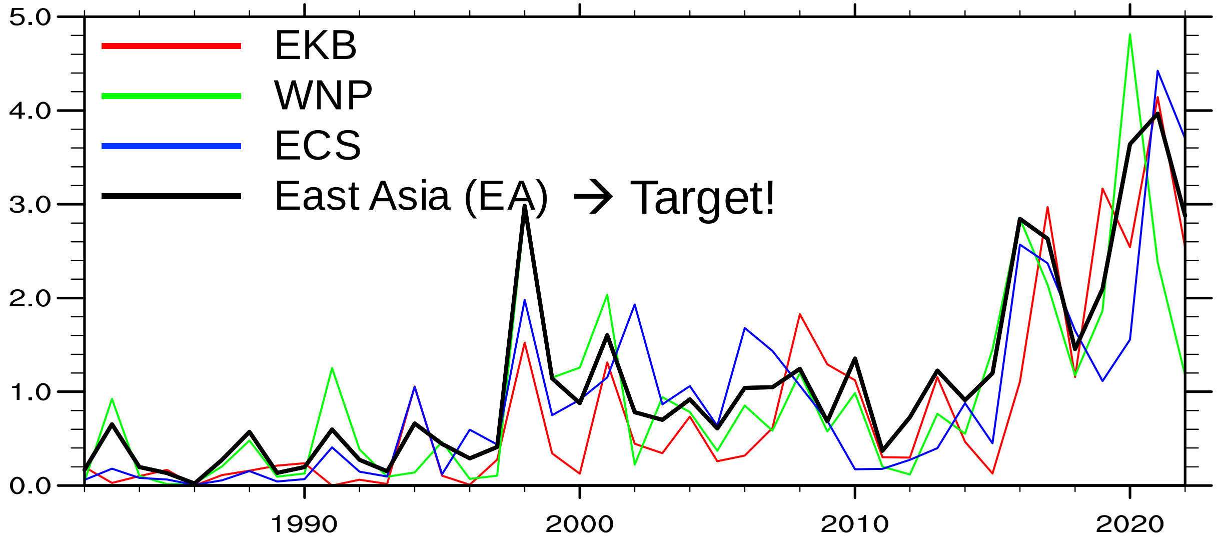
Results: Spatial Distribution of the Climatological MHWs



Hotspots for MHWs:

EKB : East Korea Bay
ECS : East China Sea
WNP: Western North Pacific

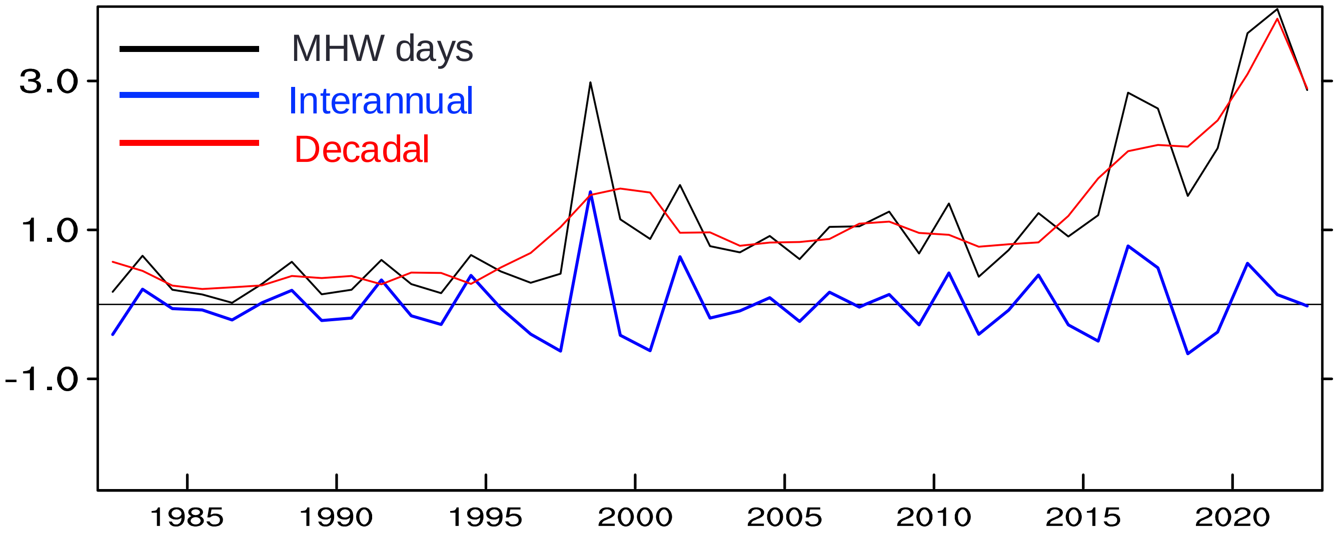
Annual MHW days divided by Std.

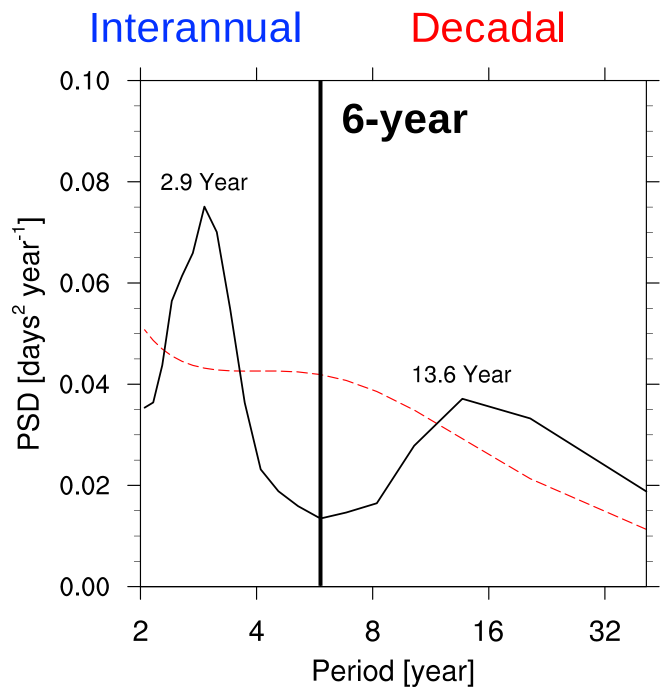


Notable features:

1. Long-term increasing trend
2. **Year-to-year variation**

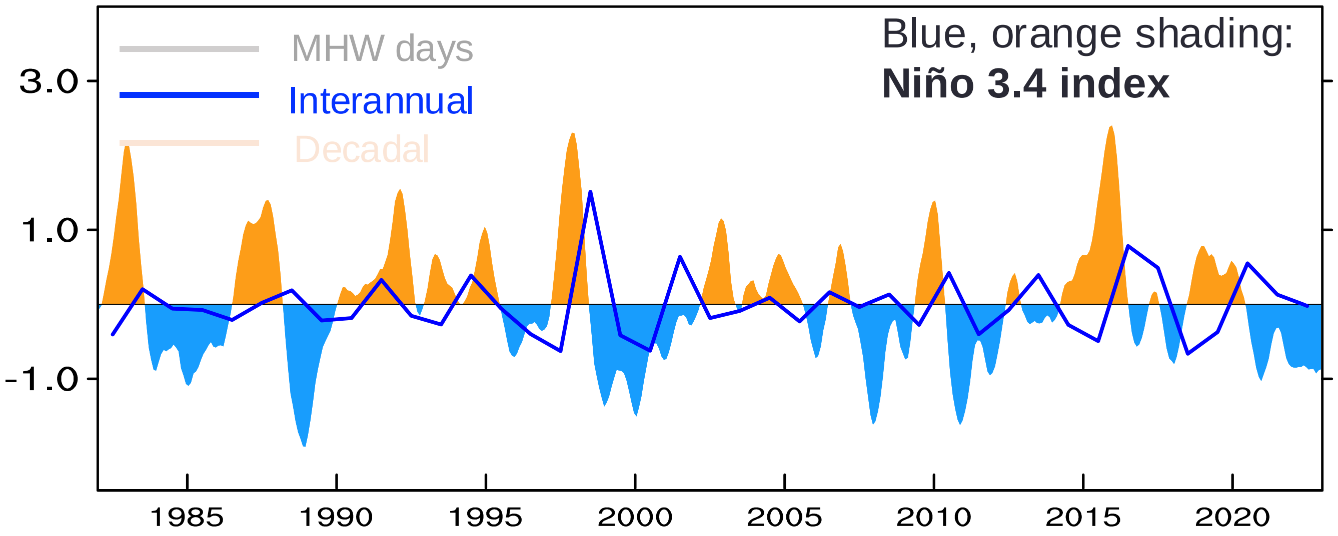
Area-averaged MHW days timeseries

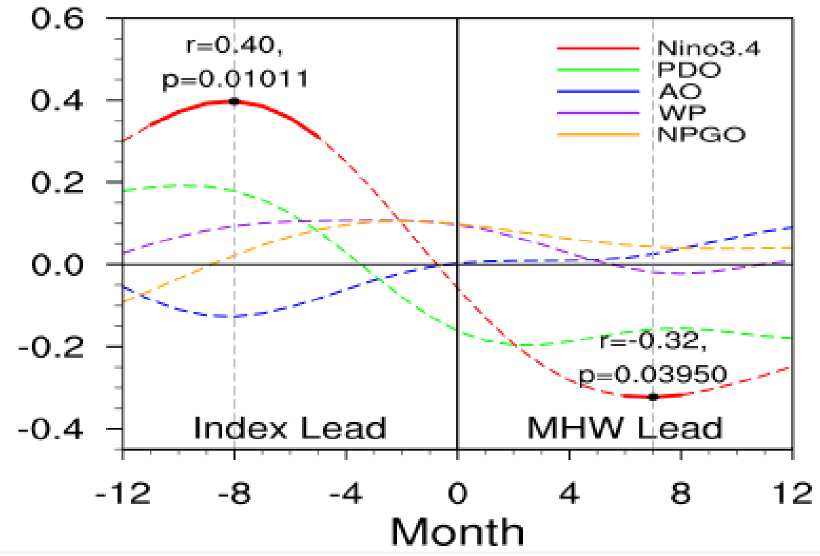




- The spectral analysis reveals a clear distinction between **interannual** and **decadal** components

Area-averaged MHW days timeseries (Interannual)

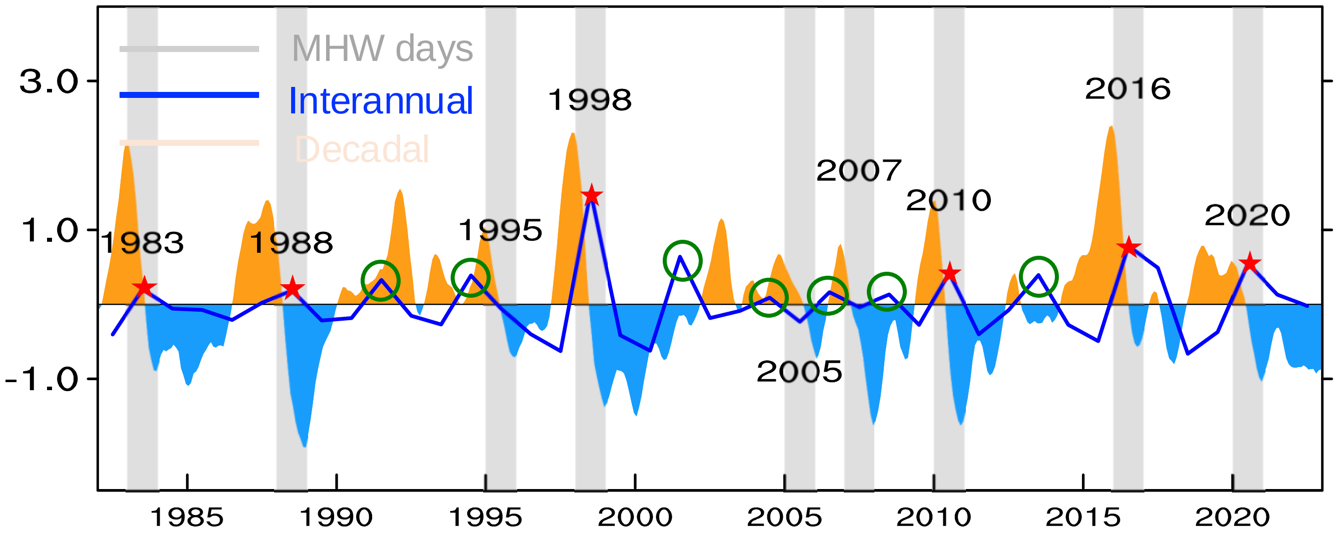




- The spectral analysis reveals a clear distinction between **interannual** and **decadal** components
- The interannual component shows significant correlation with Niño 3.4 index leading 8 months (***r*** **= 0.40, p < .05**)
  (No significant correlation with PDO, NPGO, and AO index within a 12-month window)

Q1. Relation between ENSO transitions and peaks of the interannual component?

Area-averaged MHW days timeseries (Interannual)



Blue, orange shading:
Niño 3.4 index
Gray shading:
El-Niño to **La**-Niña **T**ransition year

Q1. Relation between ENSO transitions and peaks of the interannual component?

- Within a 41-year span, there have been **nine transitions** from El Niño to La Niña, during which the interannual component **peaked six times**

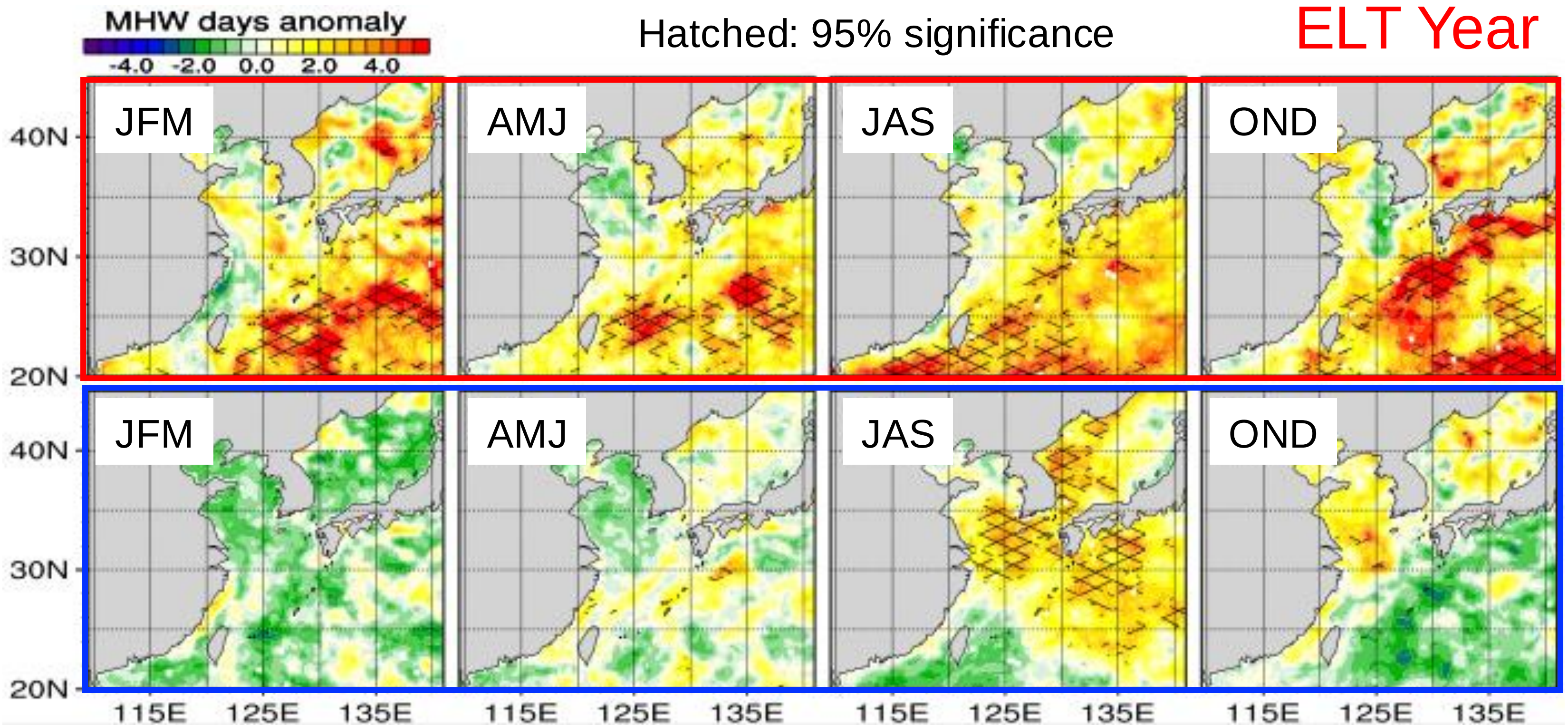
  → **El** Niño to **La** Niña **T**ransition Year (**ELT** Year) : 83, 88, 98, 10, 16, 20

- Seven peak years of the interannual component during which the Niño index did not show transitions

  → **N**on-**T**ransition Year (**NT** Year) : 91, 94, 01, 04, 06, 08, 13

Q2. Other climate drivers for the years that do not coincides with the ENSO transitions?

Interannual component: ELT Year and NT Year



WNP: Western North Pacific
ECS : East China Sea
ES : East Sea

ELT Year:

- MHWs occurred primarily **over the WNP ocean**
- A significant **positive MHW days** anomaly is observed **throughout the year**

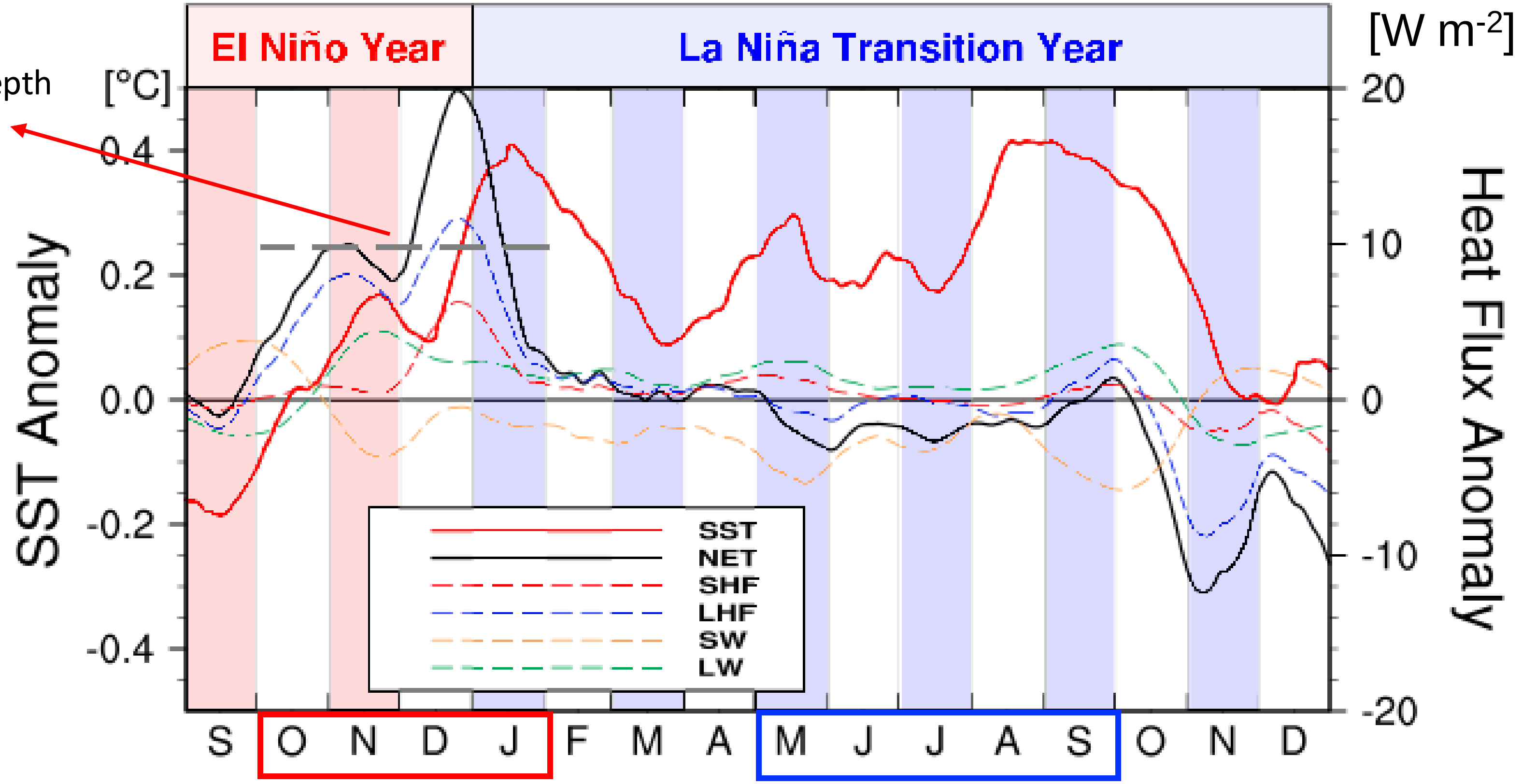
NT Year:

- MHWs occurred not only over the **WNP** but also in its marginal seas including the **ECS and ES**
- A prominent positive MHW anomaly occurs during the **summer**

Interannual component: ELT Year

Area-averaged over the target domain

10 W m^{-2} X 4-month
= 0.5°C increase of 50m-depth mixed layer temperature



Heat Flux-Driven

Ocean-Driven

Phase dependent influence of the ENSO teleconnection?

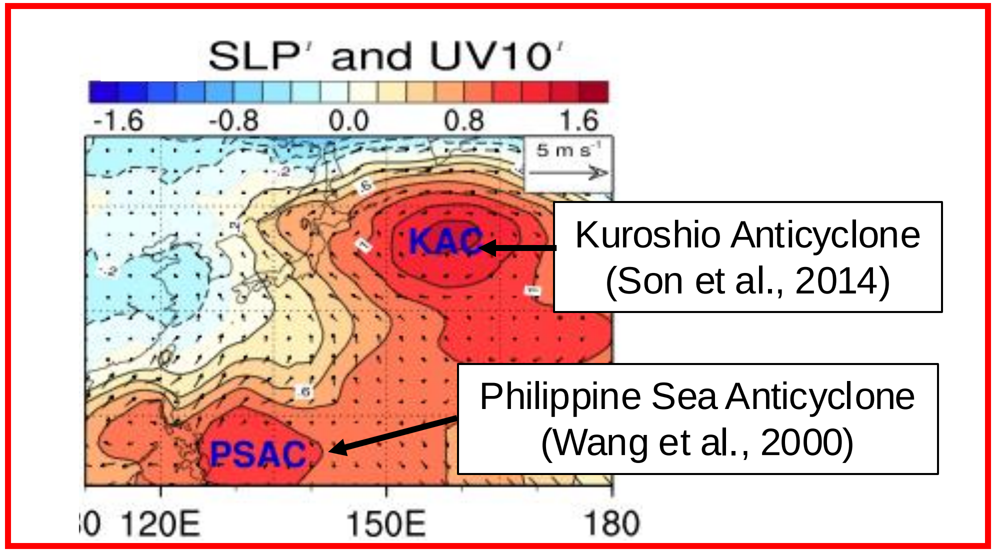
- Positive SST anomaly throughout the ELT year
- Direction of the heat flux

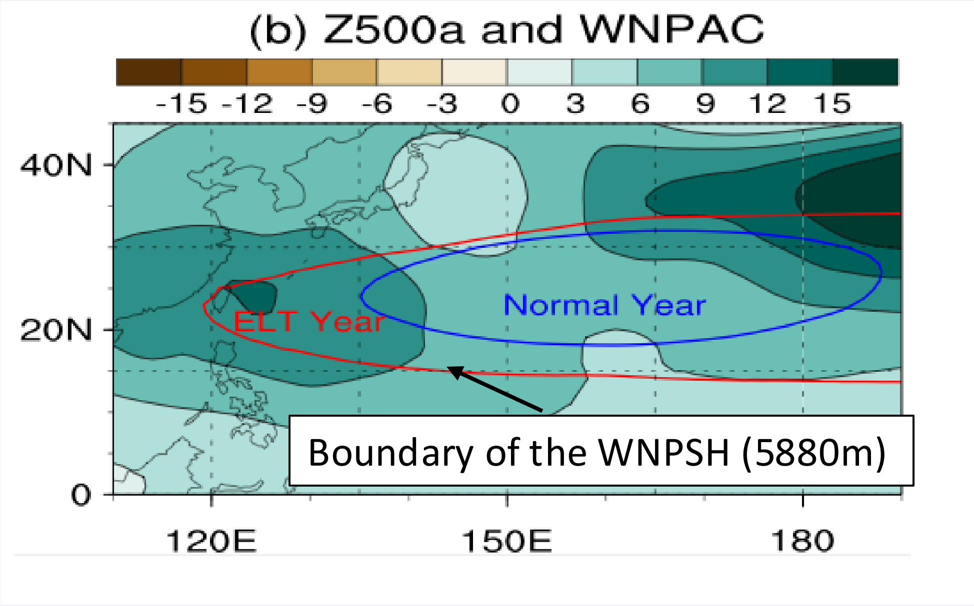
  El Niño phase: Downward heat flux aligns with the SST increase → Heat flux-driven MHWs

  Transition to La Niña phase: Upward heat flux → Ocean-driven MHWs
- Latent heat flux is the primary contributor to the net heat flux → Conditions in lower atmosphere & upper ocean?

Interannual component: ELT Year

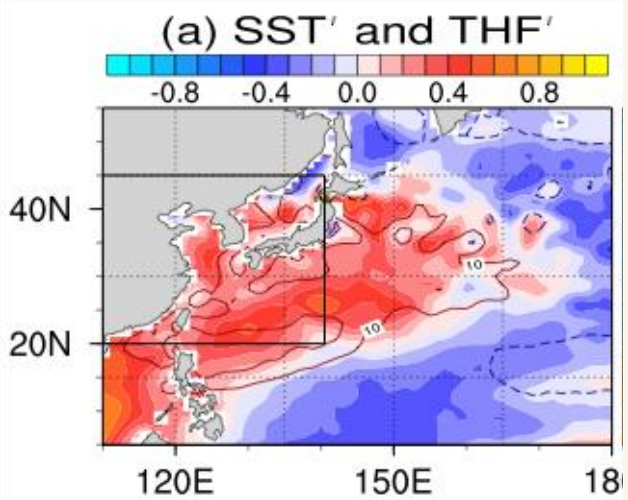
Mature Phase of El Niño (ONDJ)





Developing Phase of La Niña (MJJAS)

- **Anticyclonic circulations** over the Kuroshio Extension and Philippine Sea supplies the warm and moist **southerly wind** over the East Asia



(Shading and Contour)

- Positive SST anomaly in the WNP Ocean and East Asian marginal seas
- **Downward turbulent heat flux** anomaly

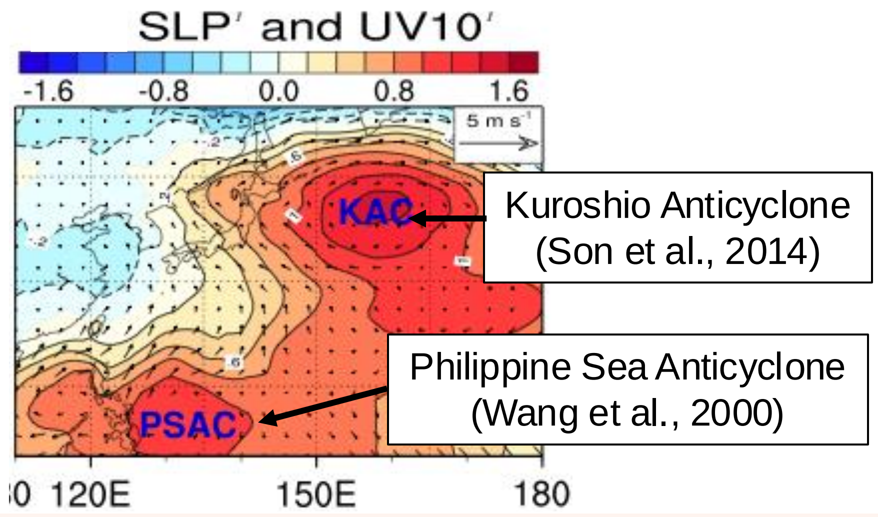
Relationship with El Niño?

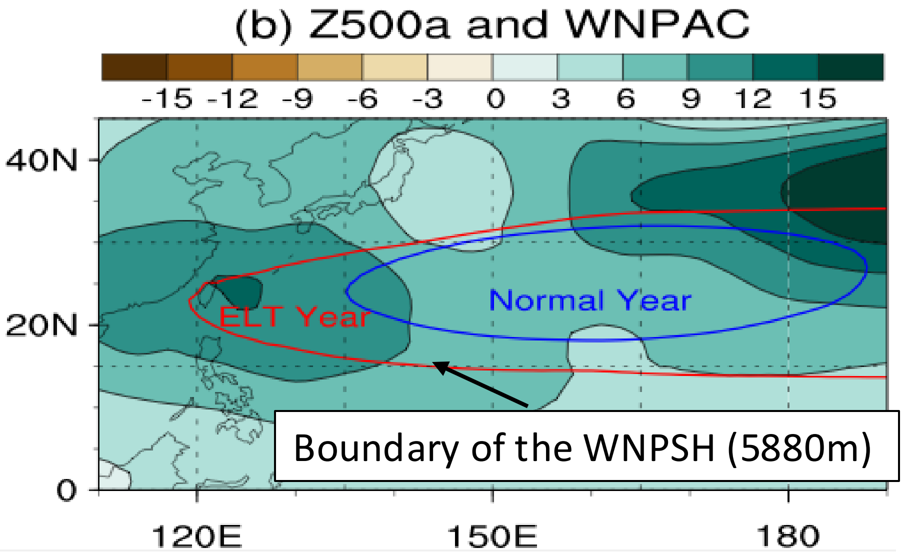
PSAC: Thermodynamic coupling of the low-level atmospheric Rossby waves and the oceanic mixed layer (Wang et al., 2000)

KAC: Response of the competing forcings from precipitation anomaly in Central Pacific and Western North Pacific (Kim et al., 2018)

Interannual component: ELT Year

Mature Phase of El Niño (ONDJ)

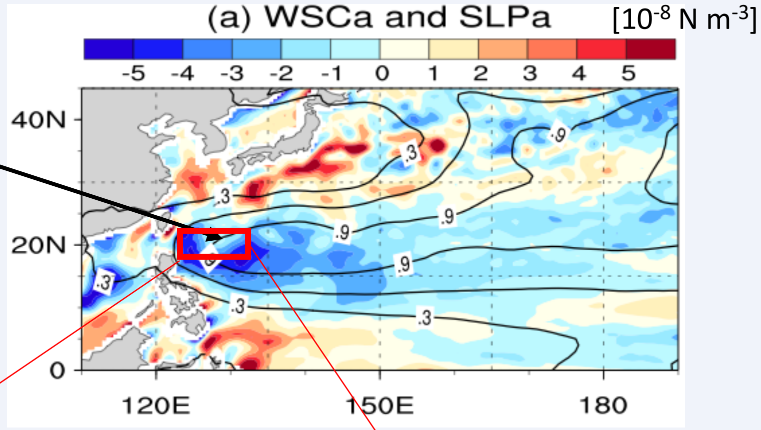




Developing Phase of La Niña (MJJAS)

- The WNPSH is stronger, more prolonged, and extends further west in the ELT year than in a normal year.

The **positive SLPa** accompanies the **negative WSCa**



Ekman downwelling

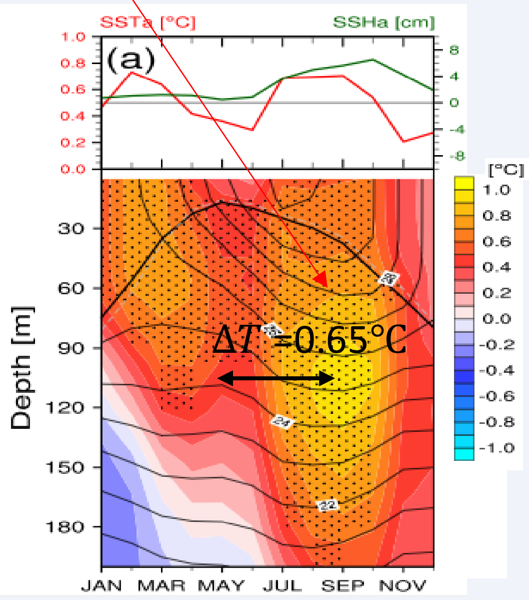
$$w_e = \frac{1}{\rho f}\nabla \times \vec{\tau} = -5.8 \pm 2.8 \times 10^{-7}\,\mathrm{m\,s^{-1}}$$

Temperature increase

$$\Delta T \sim \int_{May}^{Sep} -w_e \frac{\partial T}{\partial z}\, dt \sim 0.38 \pm 0.18^{\circ}\mathrm{C}$$

$$\left(\frac{\partial T}{\partial z} \sim \frac{10^{\circ}\mathrm{C}}{200\mathrm{m}}\right)$$

58 ± 28% @ 100m



Shading : Ta
Contour : T

Black Line:
Mixed layer depth

Negative WSCa

→ positive SSH and temperature anomaly

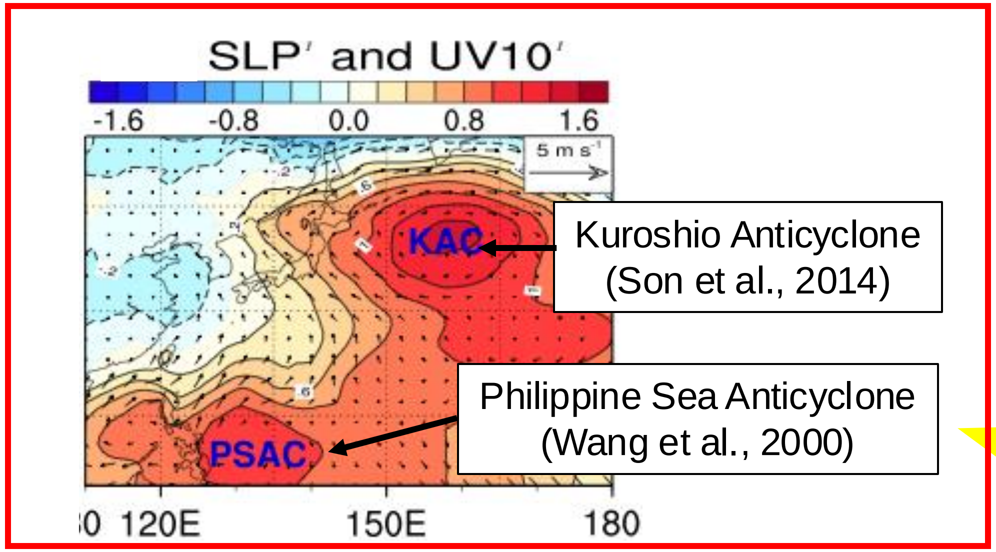
Deepening of mixed layer

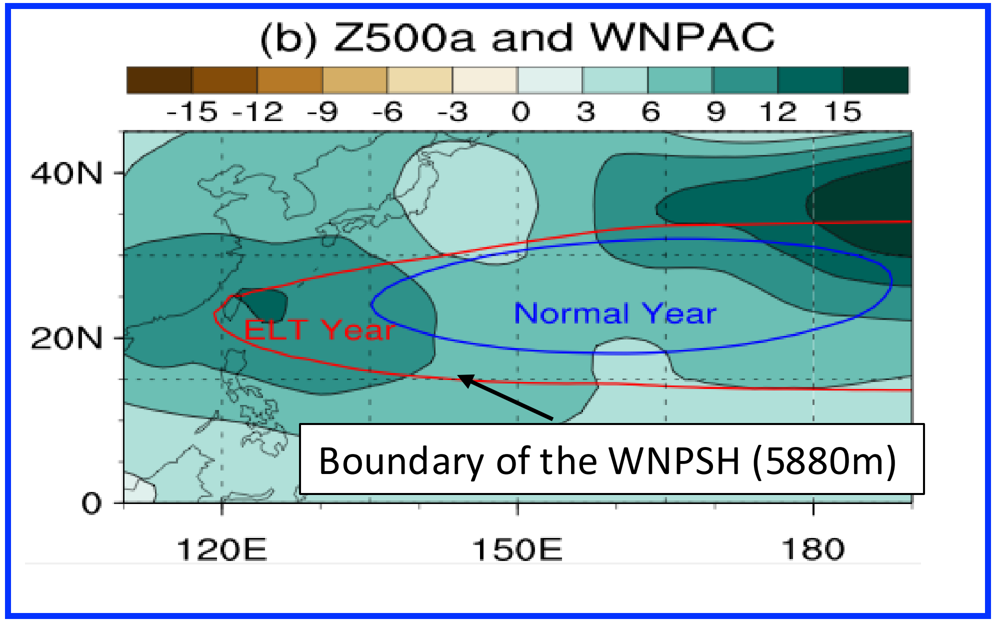
→ emergence of the temperature from thermocline to the surface

- The WNPSH is maintained by the combined effect of Indian Ocean warming and Eastern Pacific cooling via Kelvin and Rossby wave responses (Chen et al., 2016).

Interannual component: ELT Year

Mature Phase of El Niño (ONDJ)

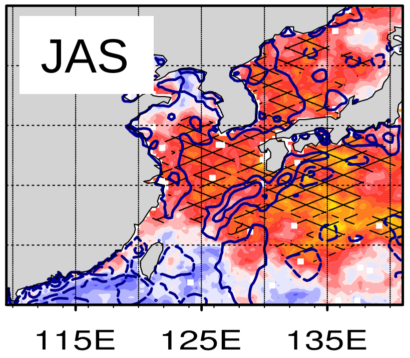


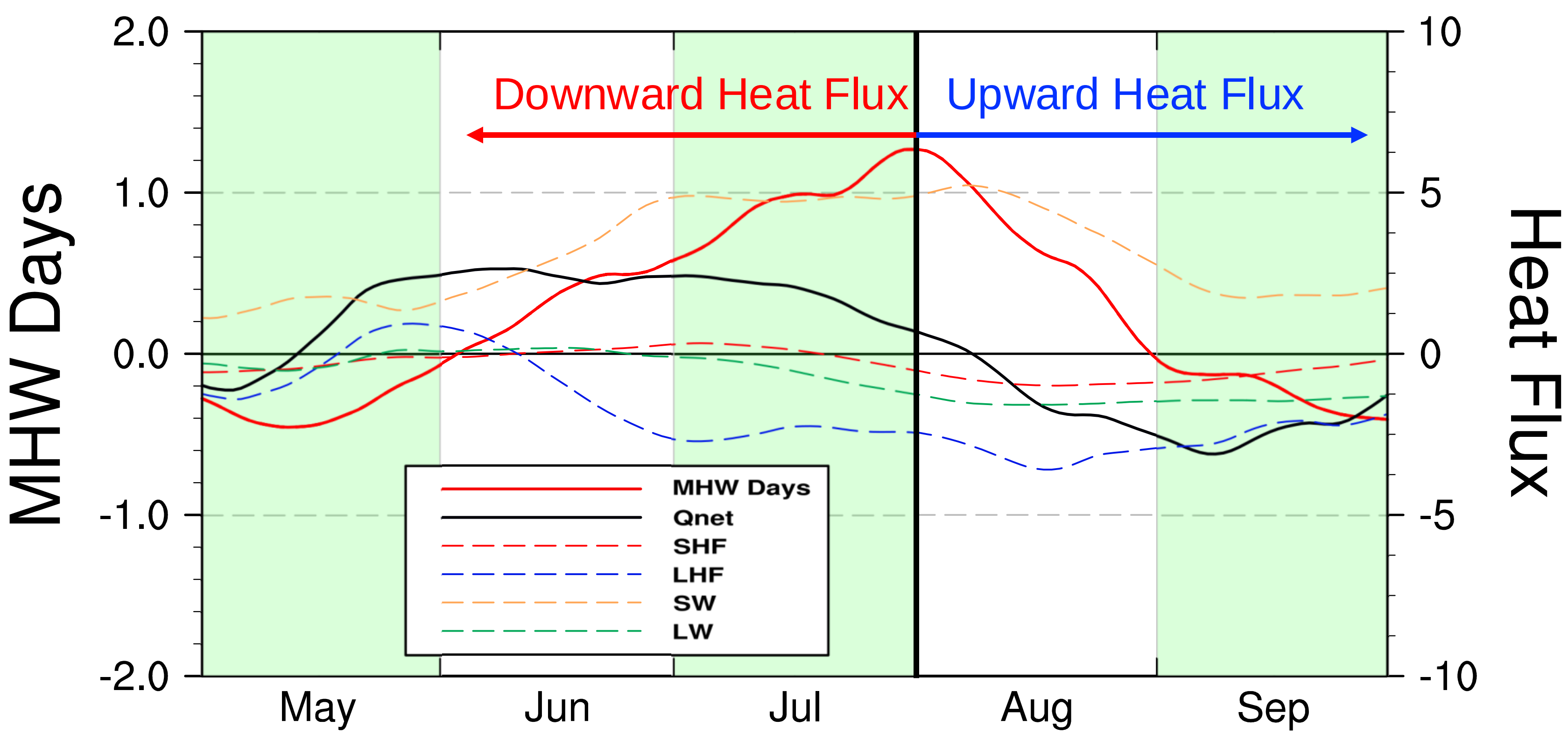


Developing Phase of La Niña (MJJAS)

Distinct pathways of the ENSO teleconnection!

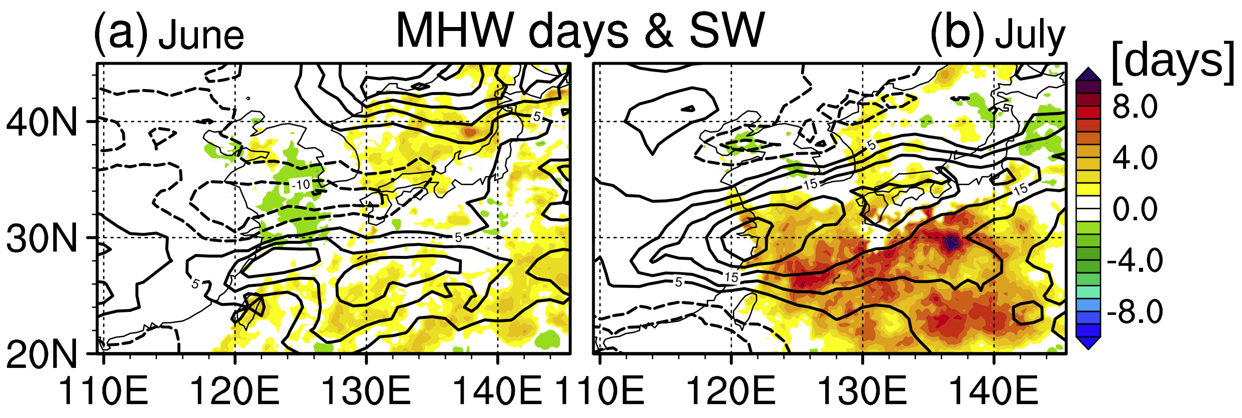
Interannual component: NT Year



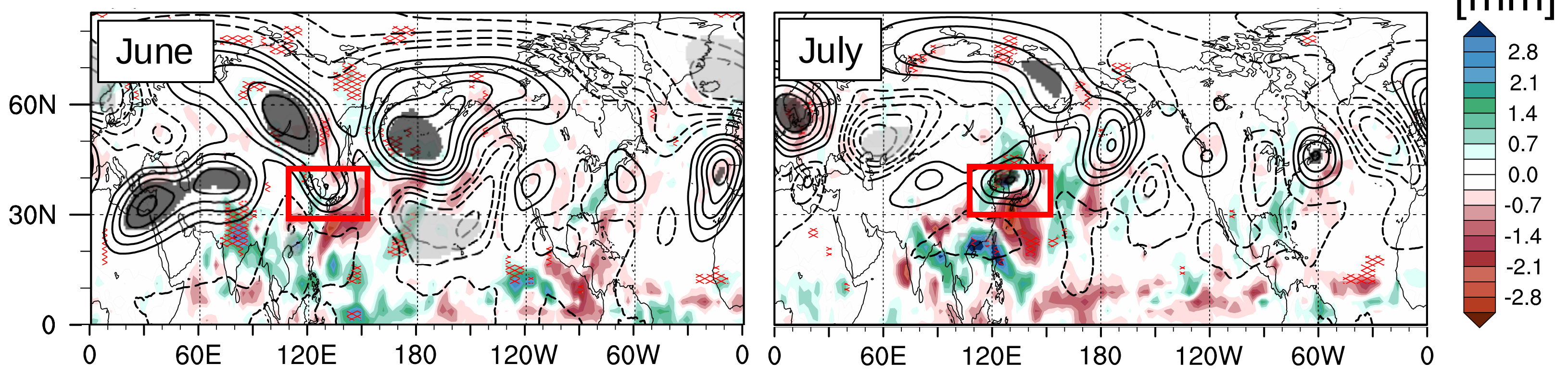


- Heat flux drives the MHW days variability
- Downward SW radiation anomaly during the summer

Interannual component: NT Year



Shading: Precipitation [mm]
Contour: 200hPa Geopotential [m^2 s^{-2}]



Circum-Global Teleconnection (CGT) pattern (Ding and Wang, 2005)

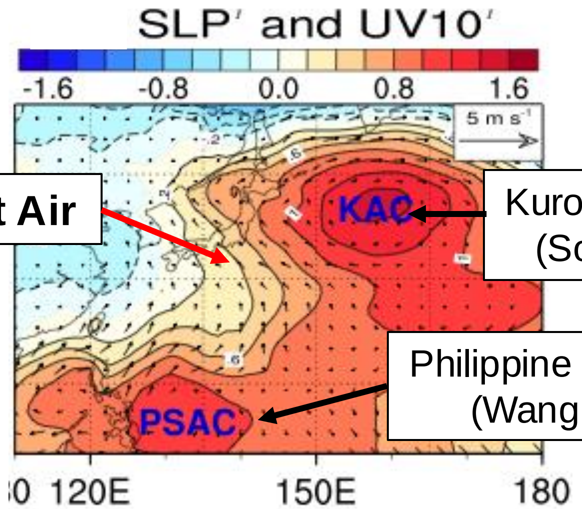
- The enhanced downward SW radiation by suppressed convective activity
- The anticyclonic circulation over the East Asia embedded on the CGT pattern

Conclusion

Q1. Relation between ENSO transitions and peaks of the interannual component?

El Niño mature phase

Warm and Moist Air

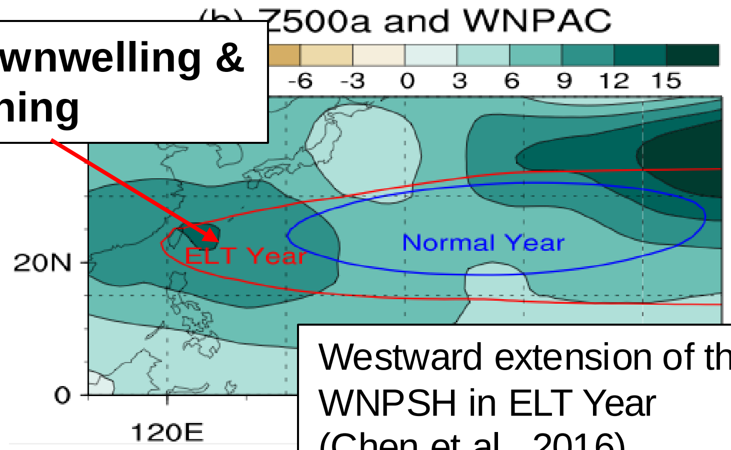


Kuroshio Anticyclone (Son et al., 2014)

Philippine Sea Anticyclone (Wang et al., 2000)

La Niña developing phase

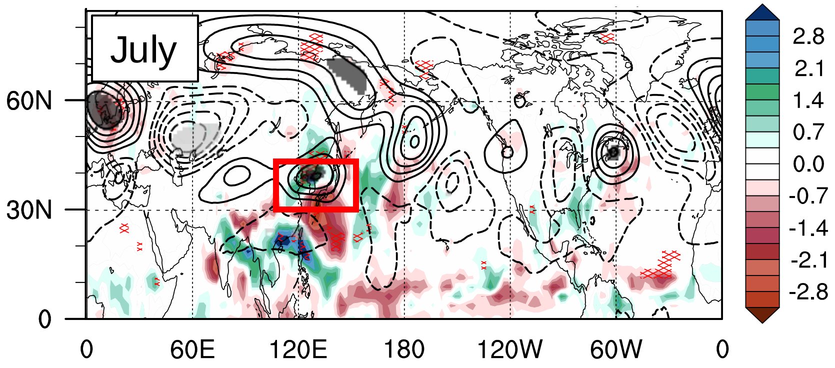
Ekman downwelling & ML deepening



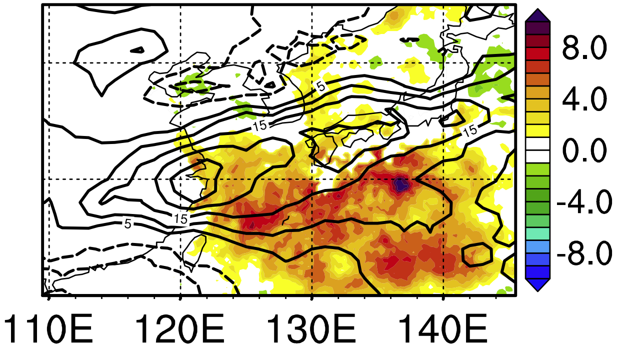
Westward extension of the WNPSH in ELT Year (Chen et al., 2016)

Q2. Other climate drivers for the years that do not coincides with the ENSO transitions?

CGT-like upper-level pattern



Shading : PRCP
Contour : GP200



Shading : MHW days
Contour : SW radiation

Thank you!