North Pacific Subtropical Mode Water is Controlled by the Atlantic Multi-Decadal Variability

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North Pacific Subtropical Mode Water is Controlled by the Atlantic Multi-Decadal Variability

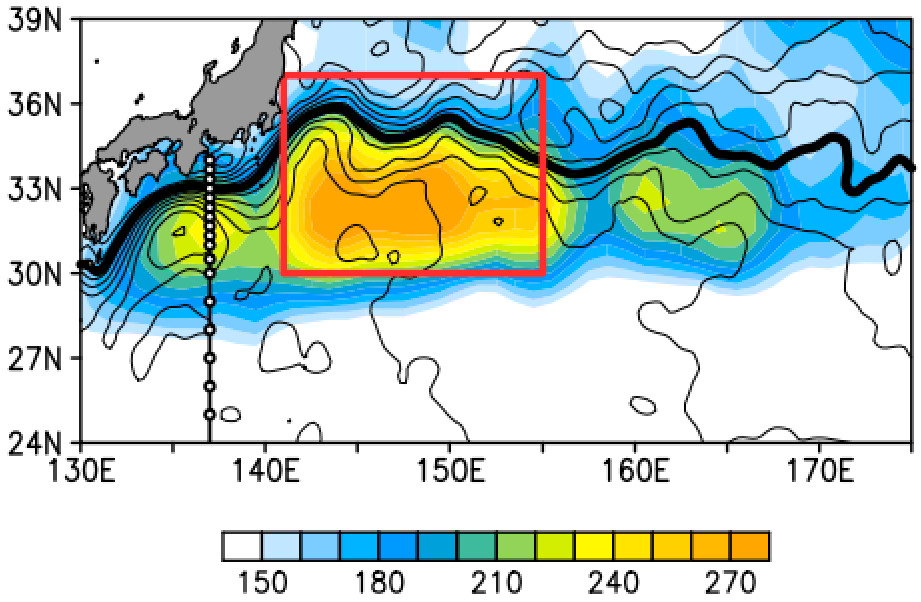
Outline

- **1 Background**
- 2 Data & Method
- 3 Result

Background

North Pacific Subtropical Mode Water is Controlled by the Atlantic Multi-Decadal Variability

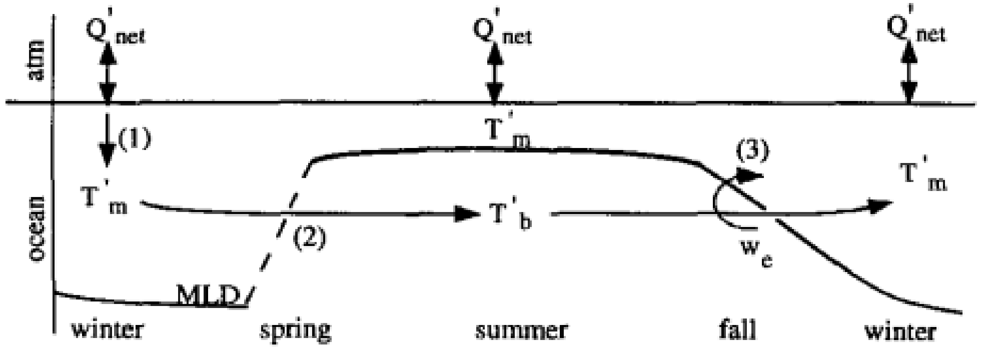
South of the Kuroshio Extension ➔ North Pacific Subtropical Mode Water (NPSTMW)



Sugimoto and Kako, 2016

Color shading: mixed layer depth
Contours: sea surface height
Thick black contour: the Kuroshio Extension axis (SSH = 90 cm)

re-emergence process



Alexander et al., 1995

North Pacific Subtropical Mode Water (mode water hereafter**)** is a vertically homogeneous thermocline water mass, occupying the whole of the subtropical Western Pacific Ocean.

It transports **mass**, **heat** and **nutrients** from the surface into the subsurface ocean and provides **memory of climate variability** for climate prediction.

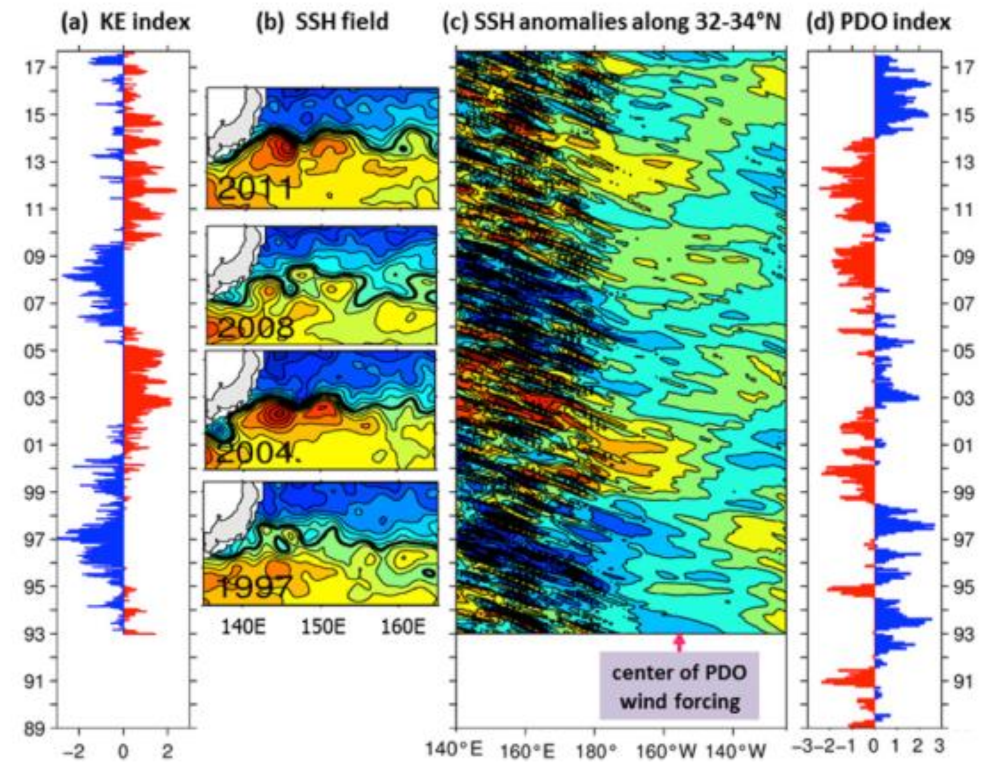
Background

North Pacific Subtropical Mode Water is Controlled by the Atlantic Multi-Decadal Variability

Aleutian Low

Intensity change – PNA(PDO)

Meridional shift - WP



Qiu et al. 2017 US CLIVAR report; Oka et al. 2012

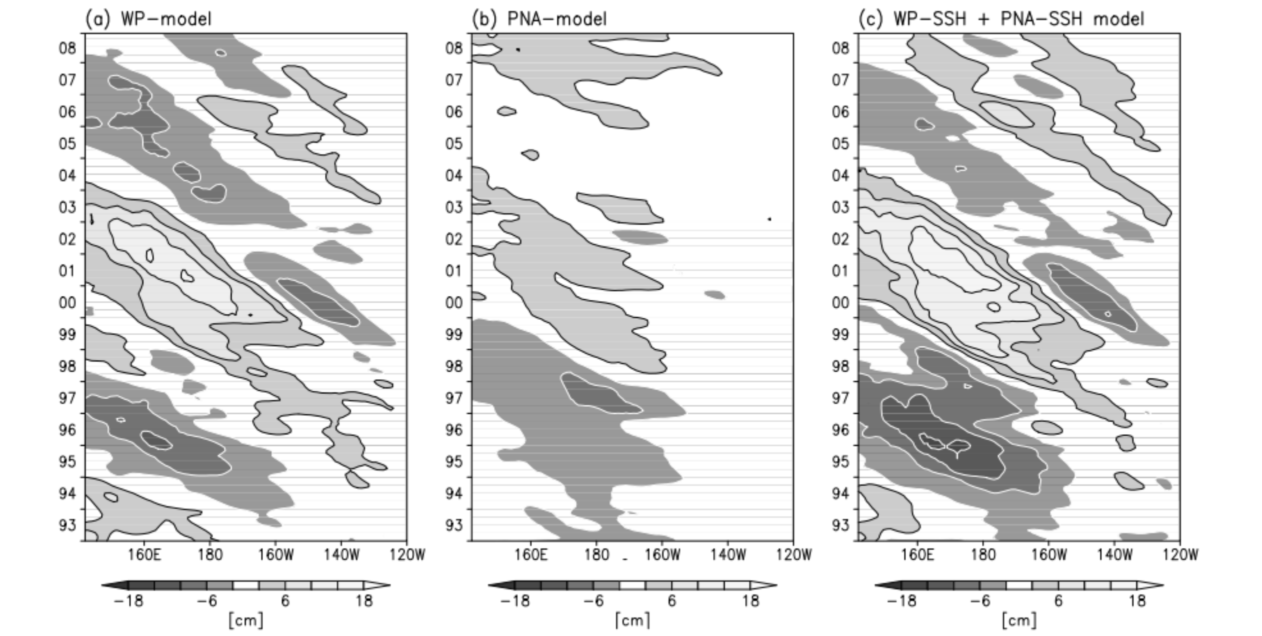


Figure 3. As in Figure 2c but for (a) WP-SSH model, (b) PNA-SSH model, and (c) sum of WP-SSH model and PNA-SSH model (cm). See the text for WP-SSH and PNA-SSH models.

Sugimoto and Hanawa, 2010

3-5 years: first-mode baroclinic Rossby waves
western midlatitude North Pacific where mode water develops

➢ Background

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Aleutian Low

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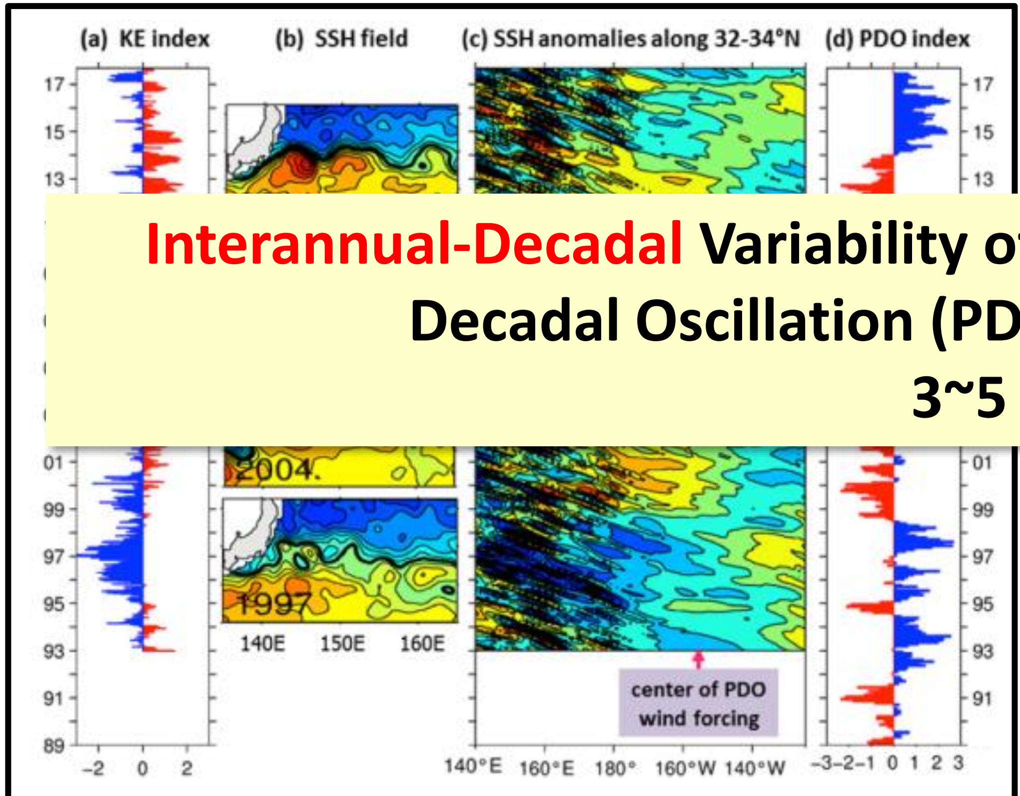

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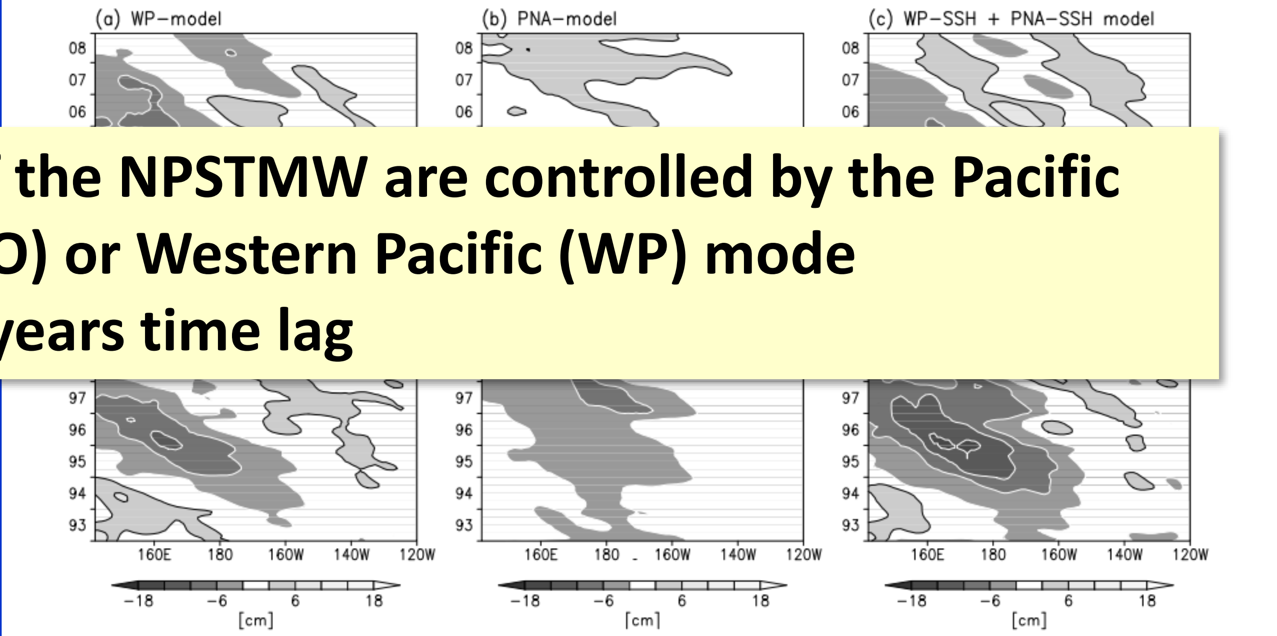

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Sugimoto and Hanawa, 2010

Interannual-Decadal Variability of the NPSTMW are controlled by the Pacific Decadal Oscillation (PDO) or Western Pacific (WP) mode

3~5 years time lag

3-5 years: first-mode baroclinic Rossby waves
western midlatitude North Pacific where mode water develops

Background

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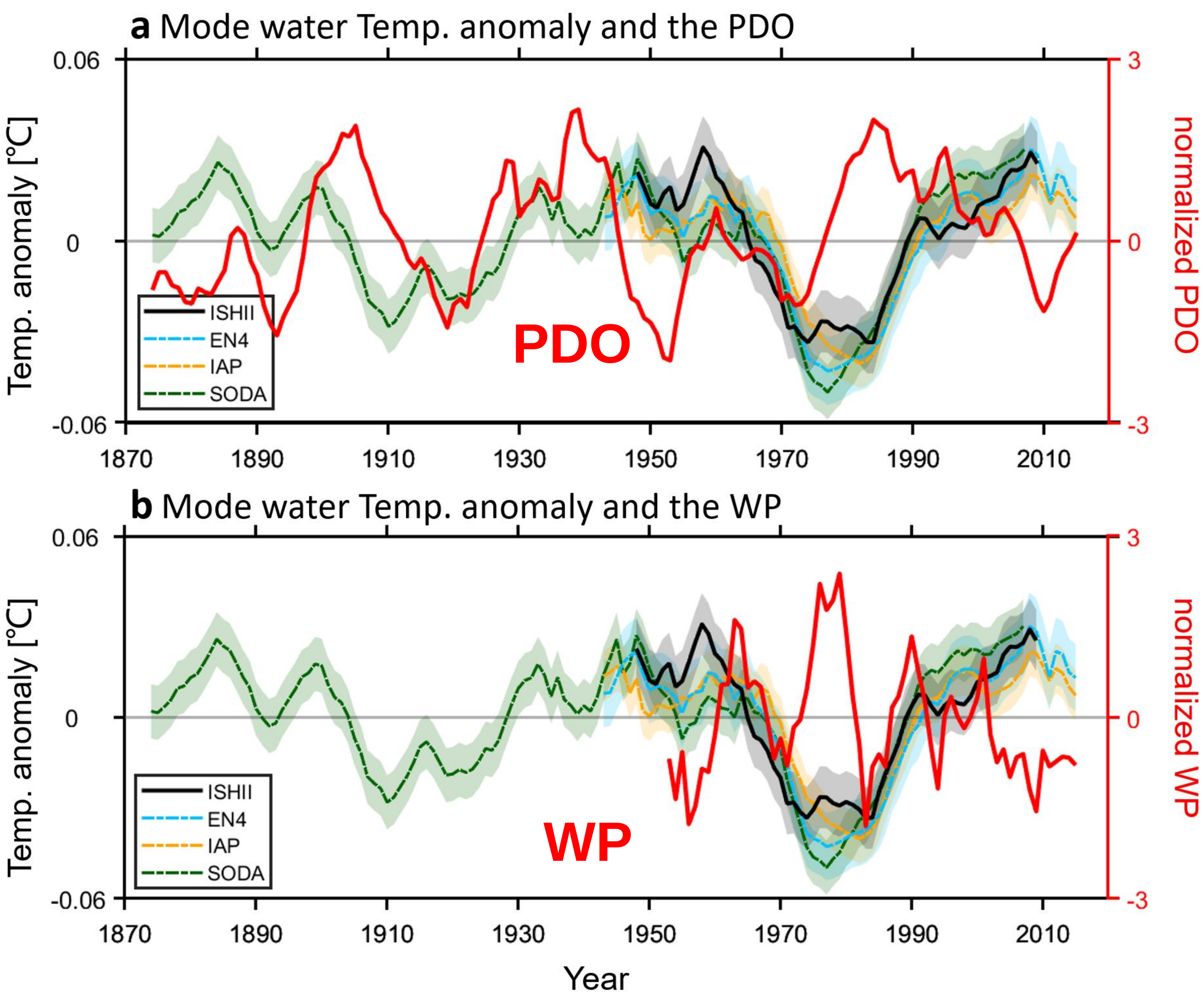
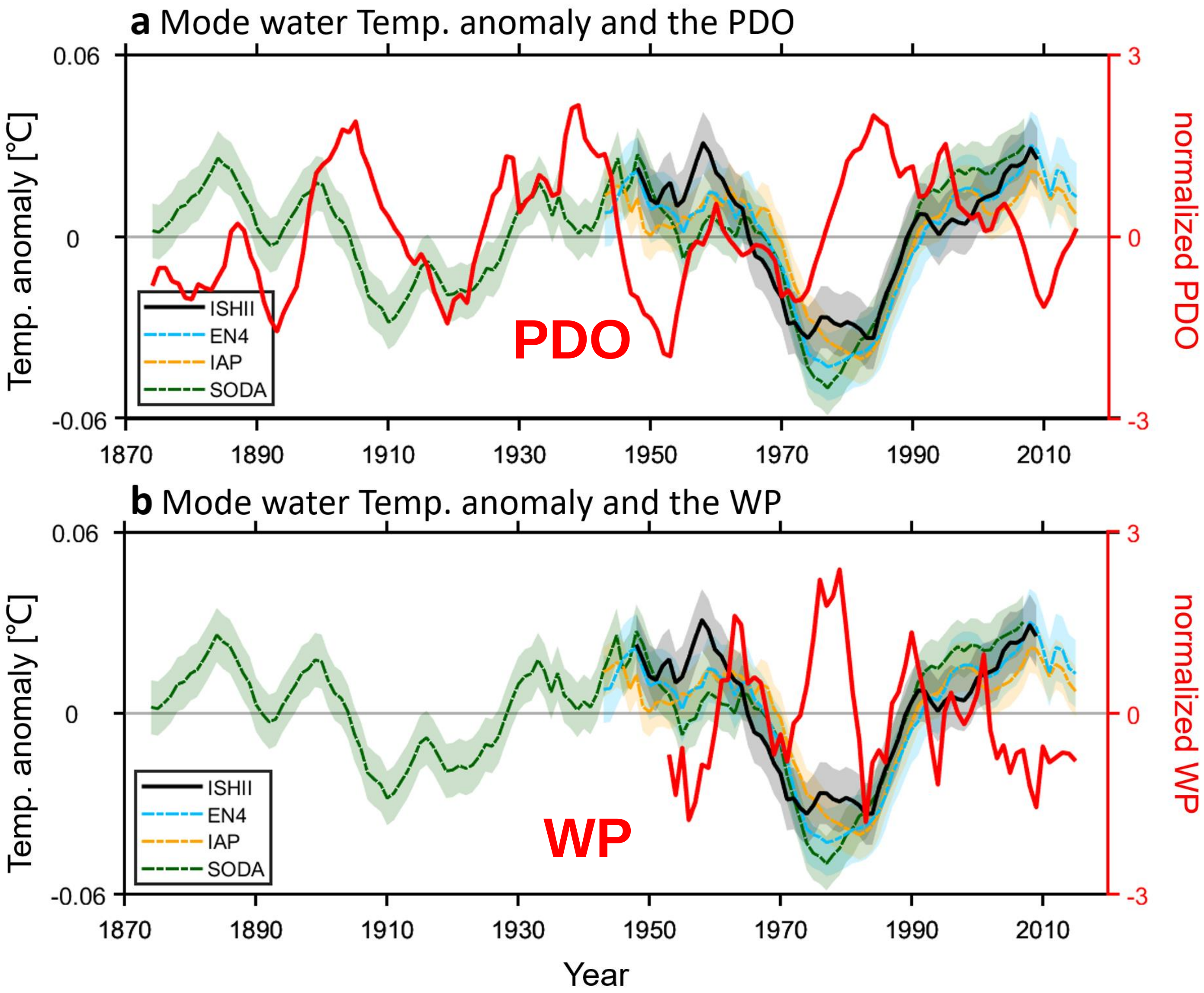


Background

North Pacific Subtropical Mode Water is Controlled by the Atlantic Multi-Decadal Variability

Decadal to multi-decadal Variability of the mode water mean temperature is neither to be controlled by the PDO nor the WP…

But by… ?



➢ Background

North Pacific Subtropical Mode Water is Controlled by the Atlantic Multi-Decadal Variability

Influence of the **Atlantic Multi-Decadal Oscillation (AMO)** on the **North Pacific** through

Atmospheric Teleconnections

Zhang and Delworth, 2007

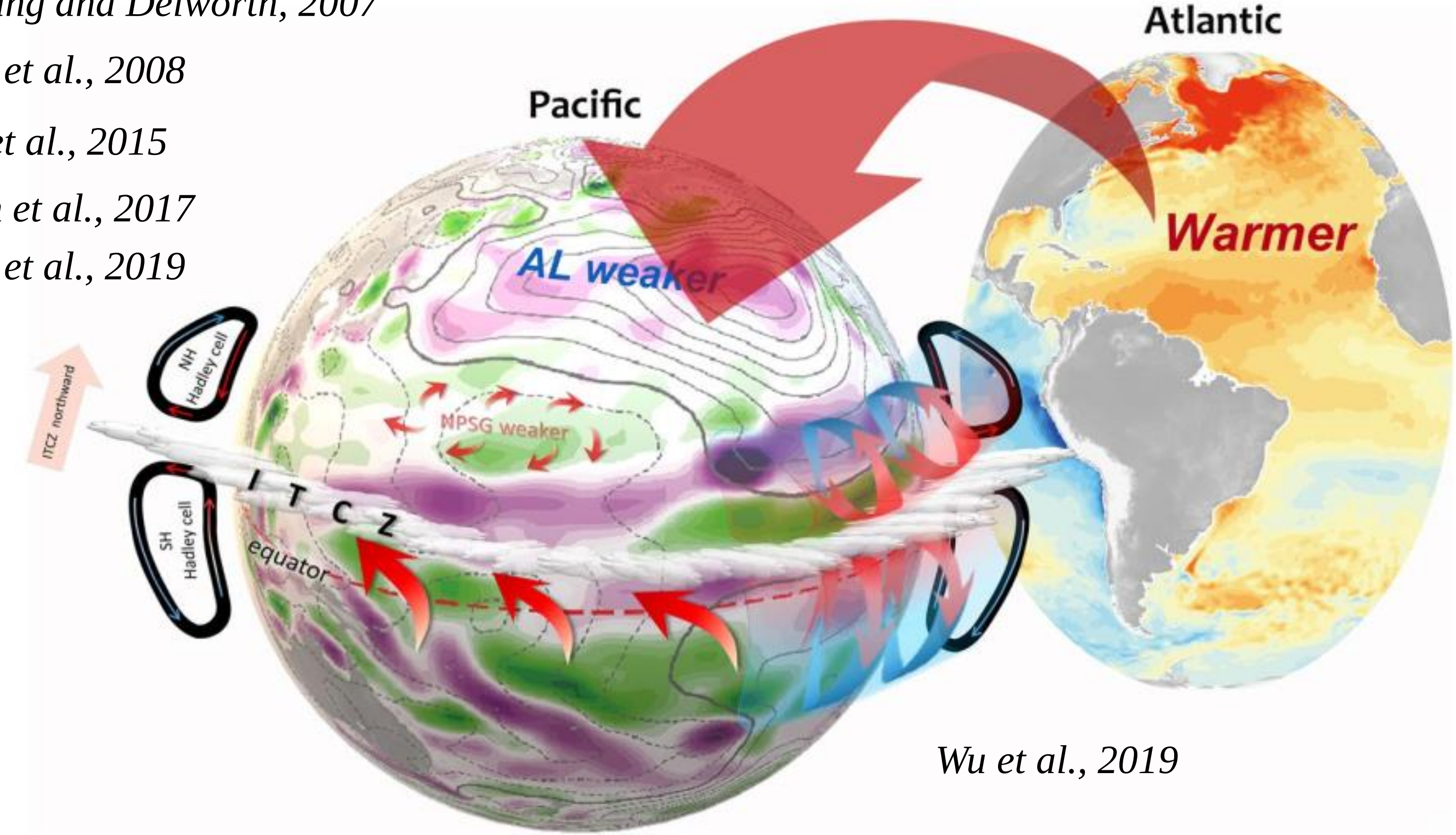
Wu et al., 2008

Li et al., 2015

Sun et al., 2017

Wu et al., 2019

…



Wu et al., 2019

The Atlantic Ocean can influence the **mid-latitude** **Pacific** directly through the **Atmospheric Stationary Rossby Wave**.

How the mode water responses to the AMO-induced surface wind variation?

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➢ Data & Method

North Pacific Subtropical Mode Water is Controlled by the Atlantic Multi-Decadal Variability

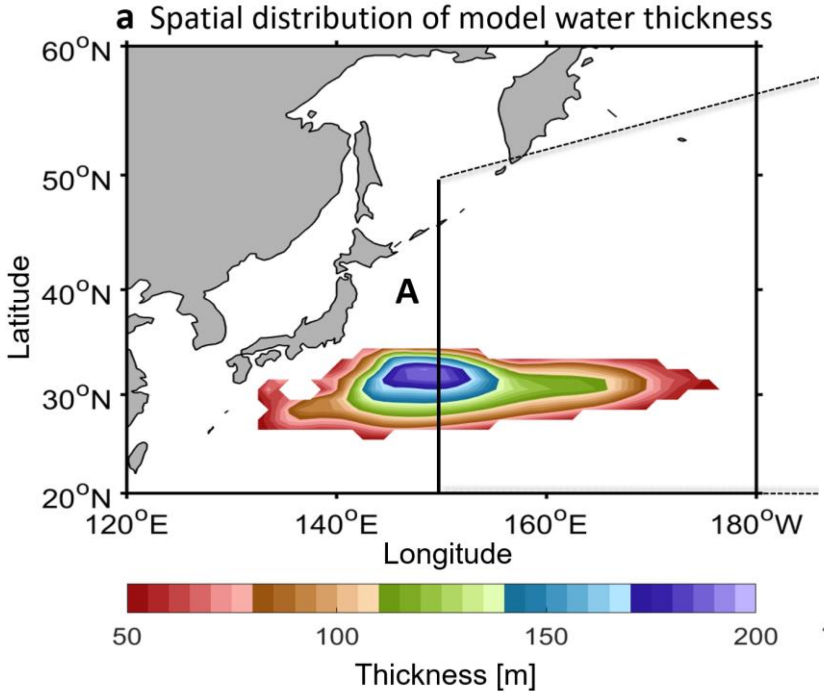
Data: **Ishii**, **EN4, IAP data**, SODA, NCEP1
Time series: 1871-2018, **1945-2012 (overlap)**
pre-processed: Apply a 7-year running mean filter to all time series
Model Experiments: PI-Control model EXP. & Pacemaker EXP.

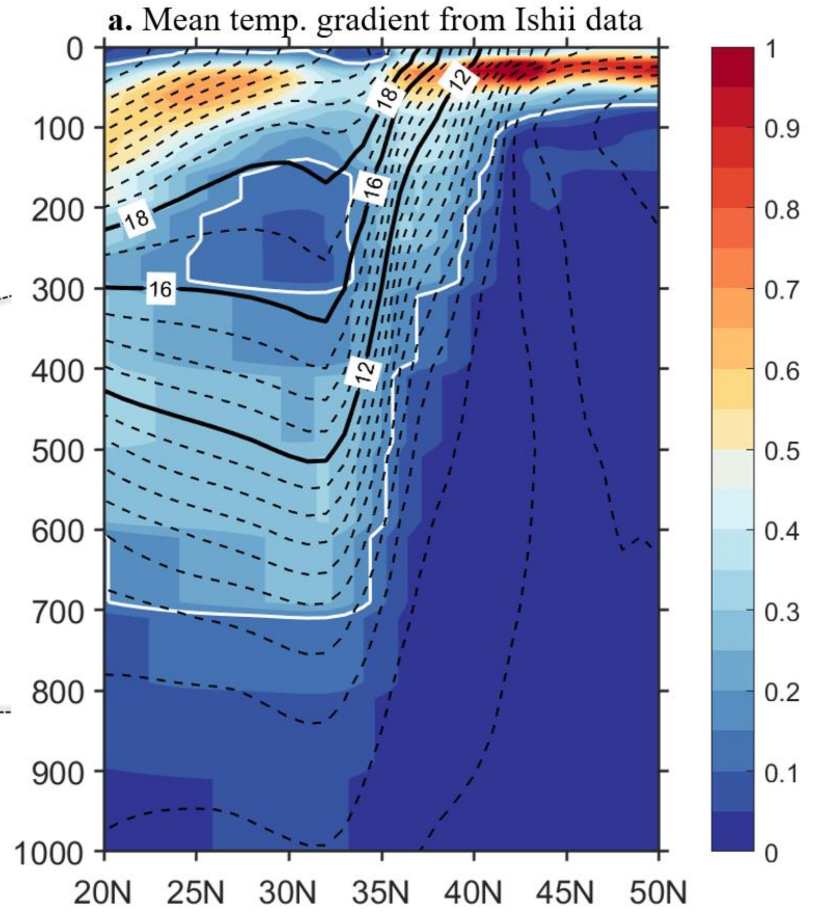
Definition of the North Pacific Subtropical Mode Water

① temperatures between 16-18 ^{o}C
② temperature gradient < 1.5 ^{o}C/hm
③ thickness >50 m

Mean temperature, mean depth and thickness of the mode water

Mixed layer depth (MLD)
Main thermocline depth (MTD)





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➢ Result

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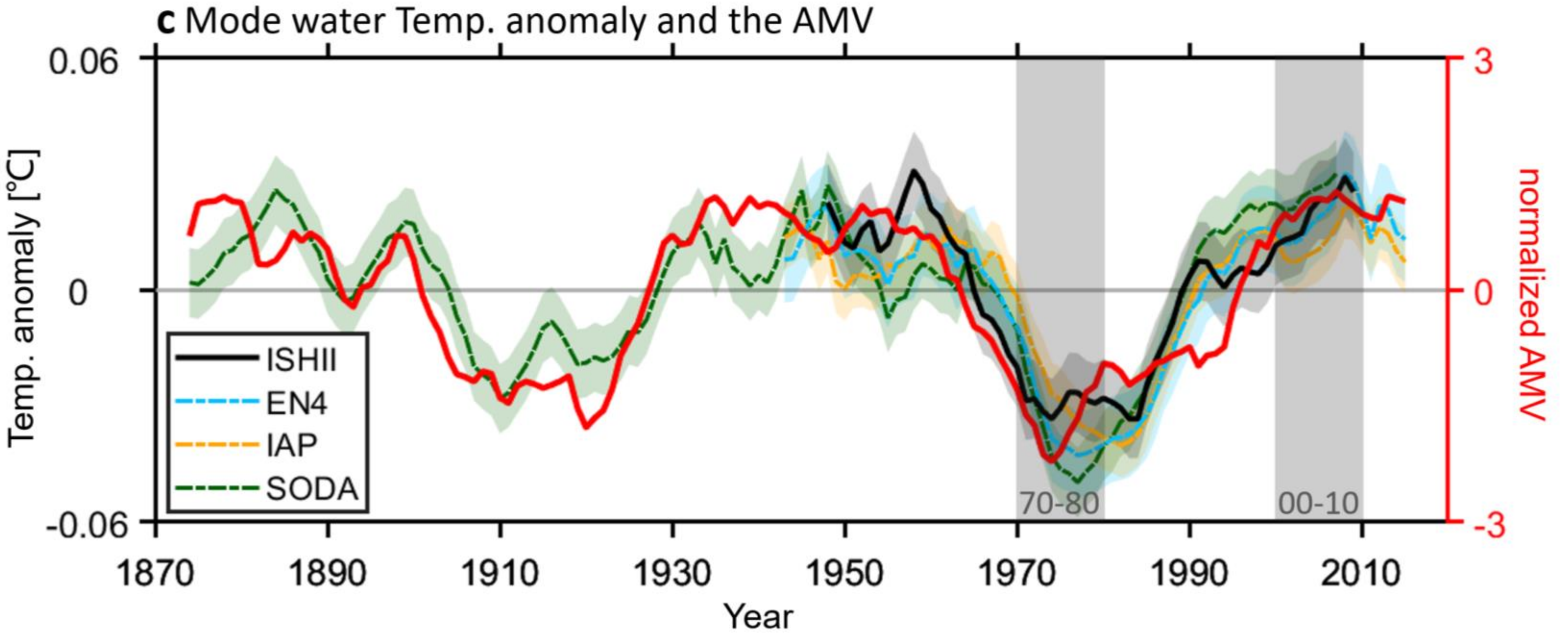
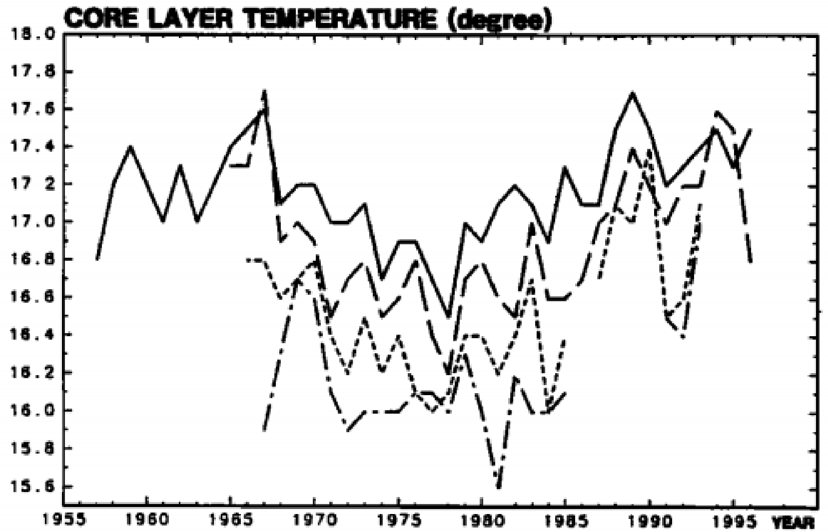
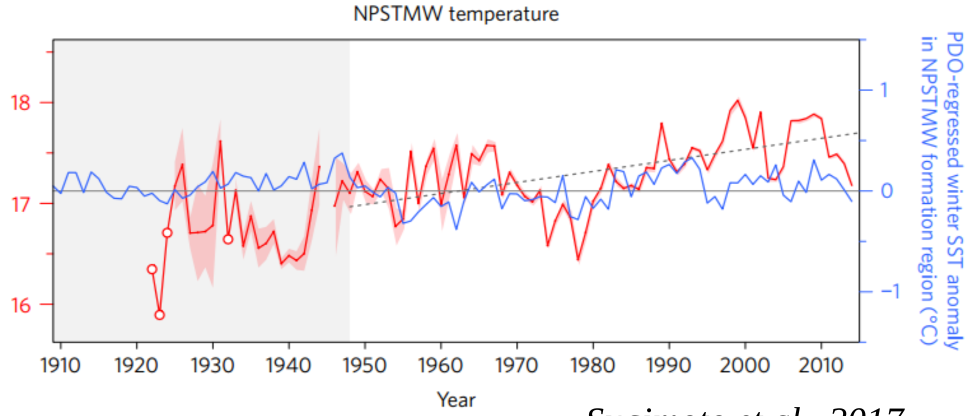




Hanawa and Kamada, 2001

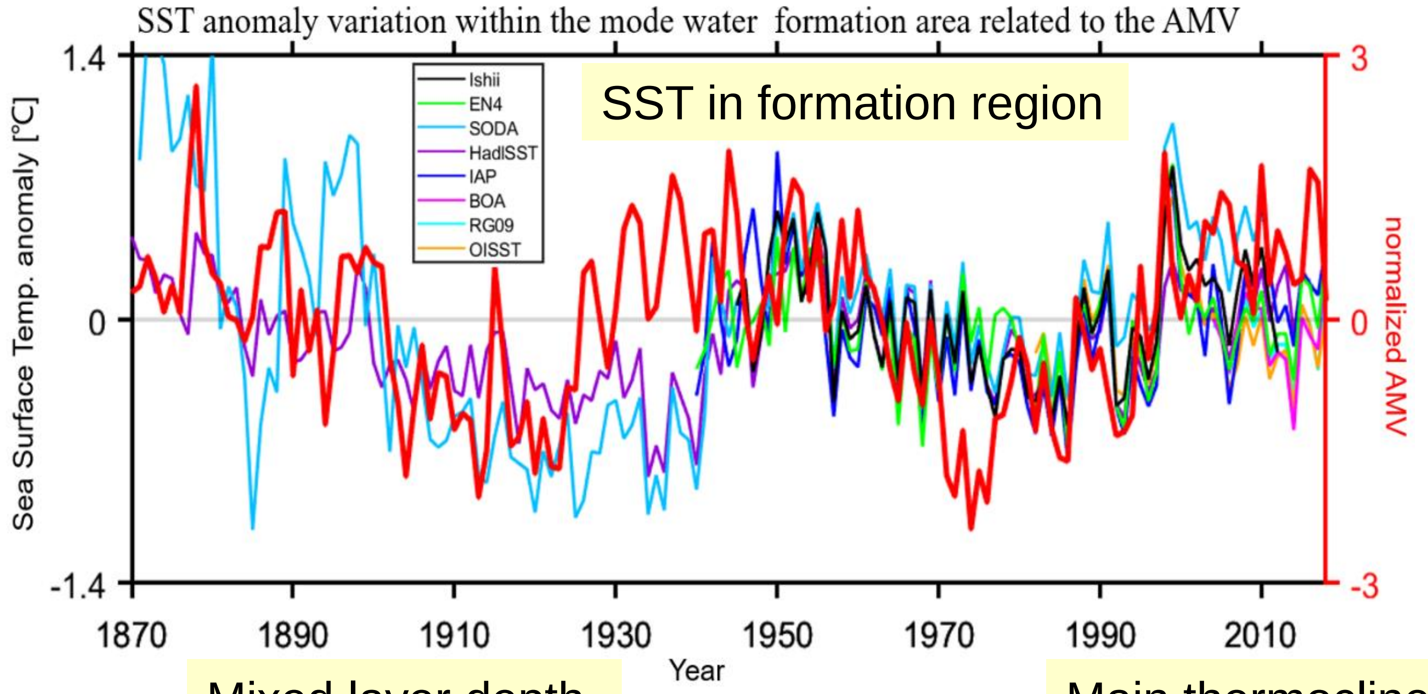


Sugimoto et al., 2017

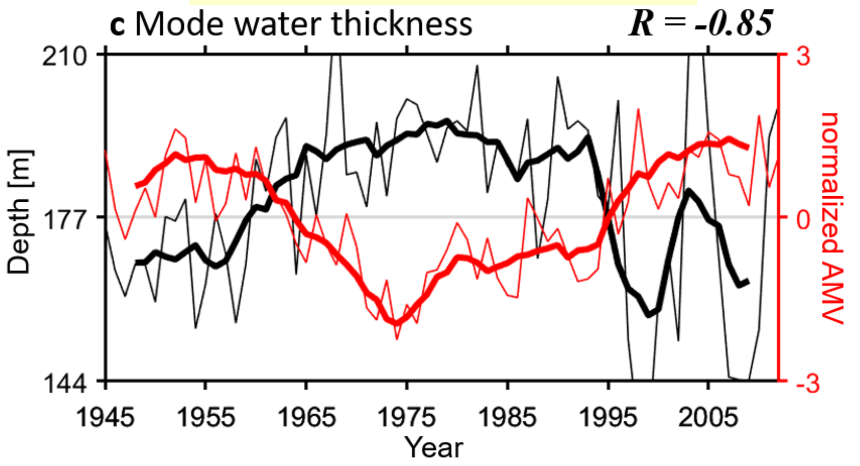
The STMW temperature varies coherently with the Atlantic Multi-Decadal Oscillation (AMO) rather than the PDO in the **decadal to multi-decadal time scales** **with zero time lag**

Result

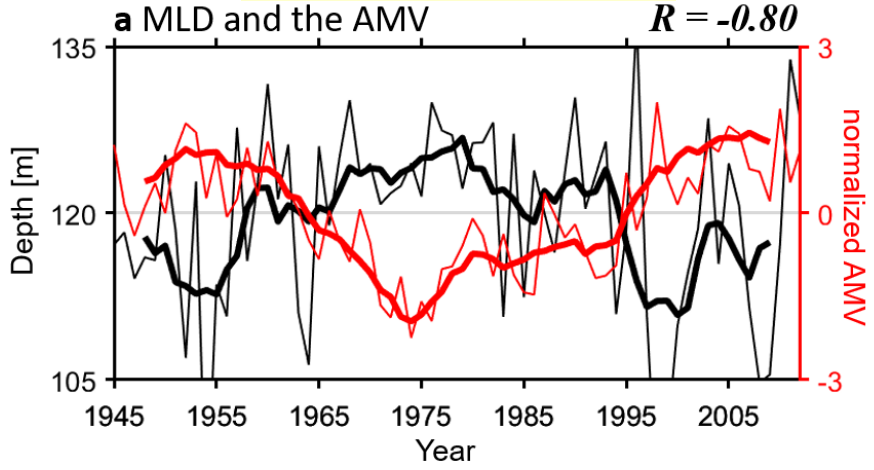
North Pacific Subtropical Mode Water is Controlled by the Atlantic Multi-Decadal Variability



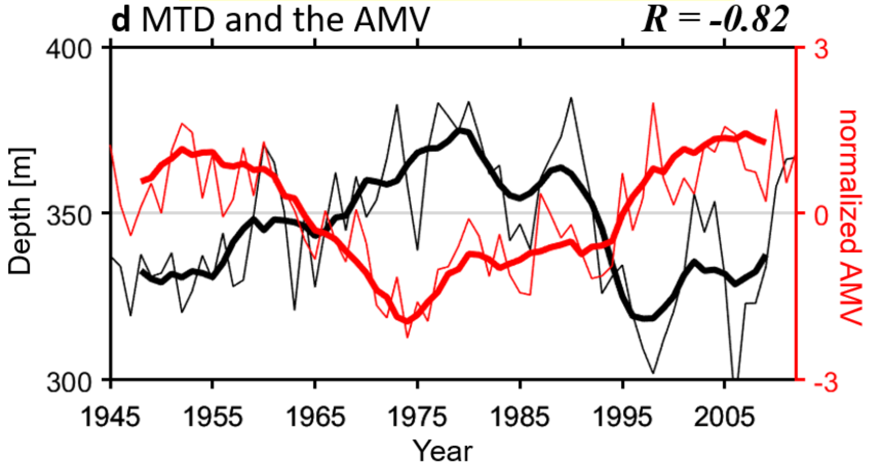
Mode water thickness



Mixed layer depth



Main thermocline depth

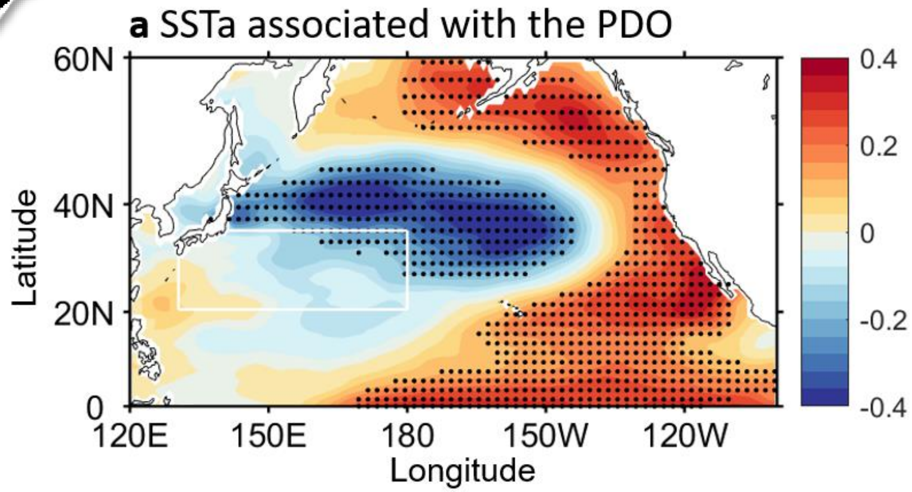


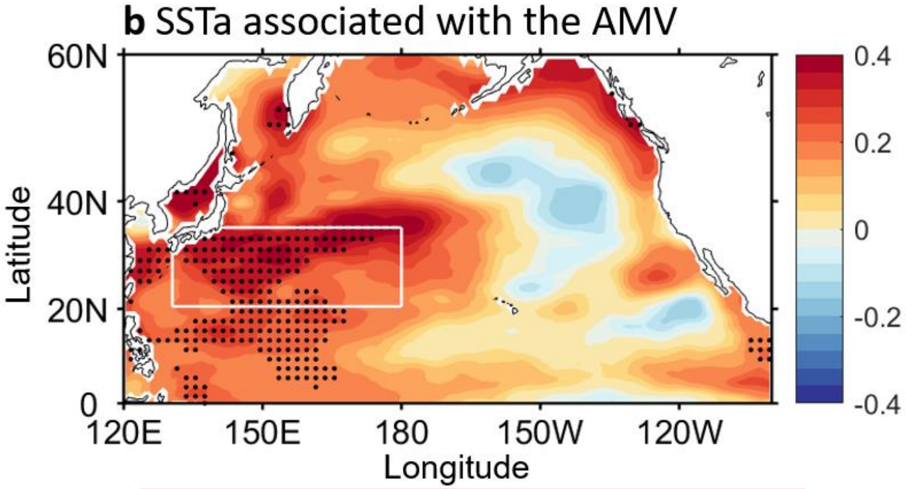
All variables consistently vary with the AMO

➢ Result

North Pacific Subtropical Mode Water is Controlled by the Atlantic Multi-Decadal Variability

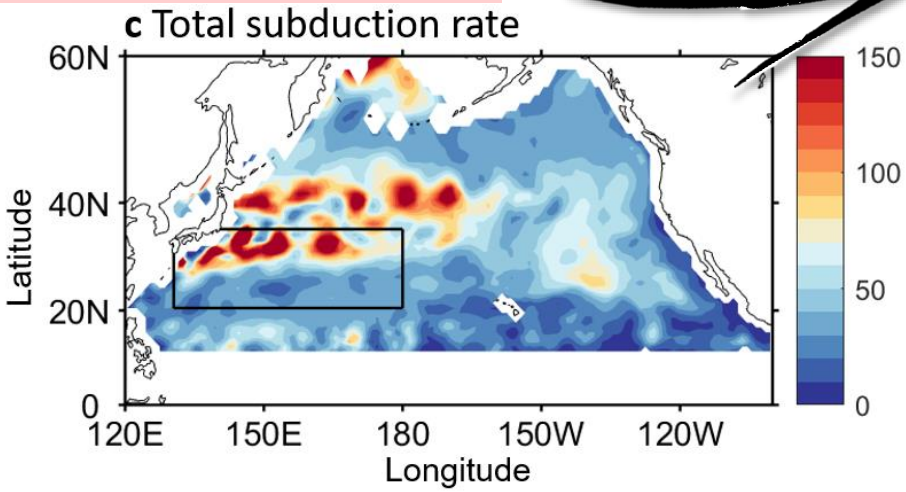
AMO has large impact on the western Pacific Ocean SST

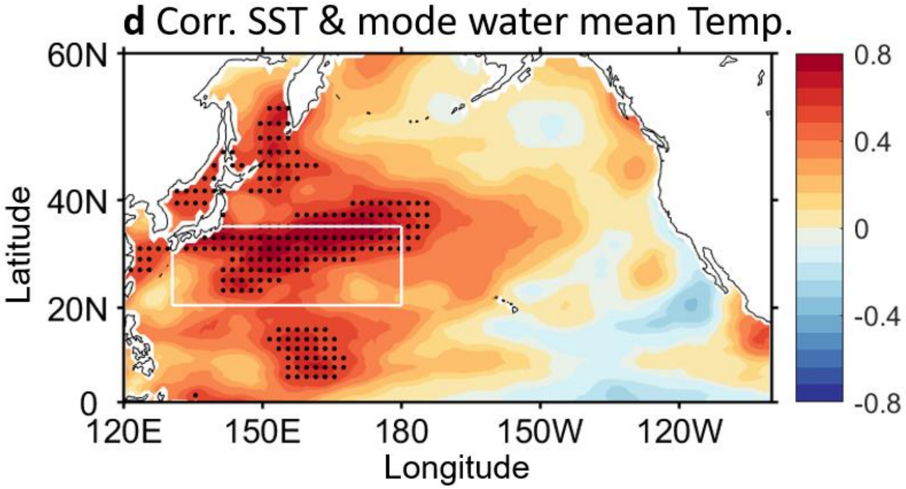




subduction process

mode water variability





Result

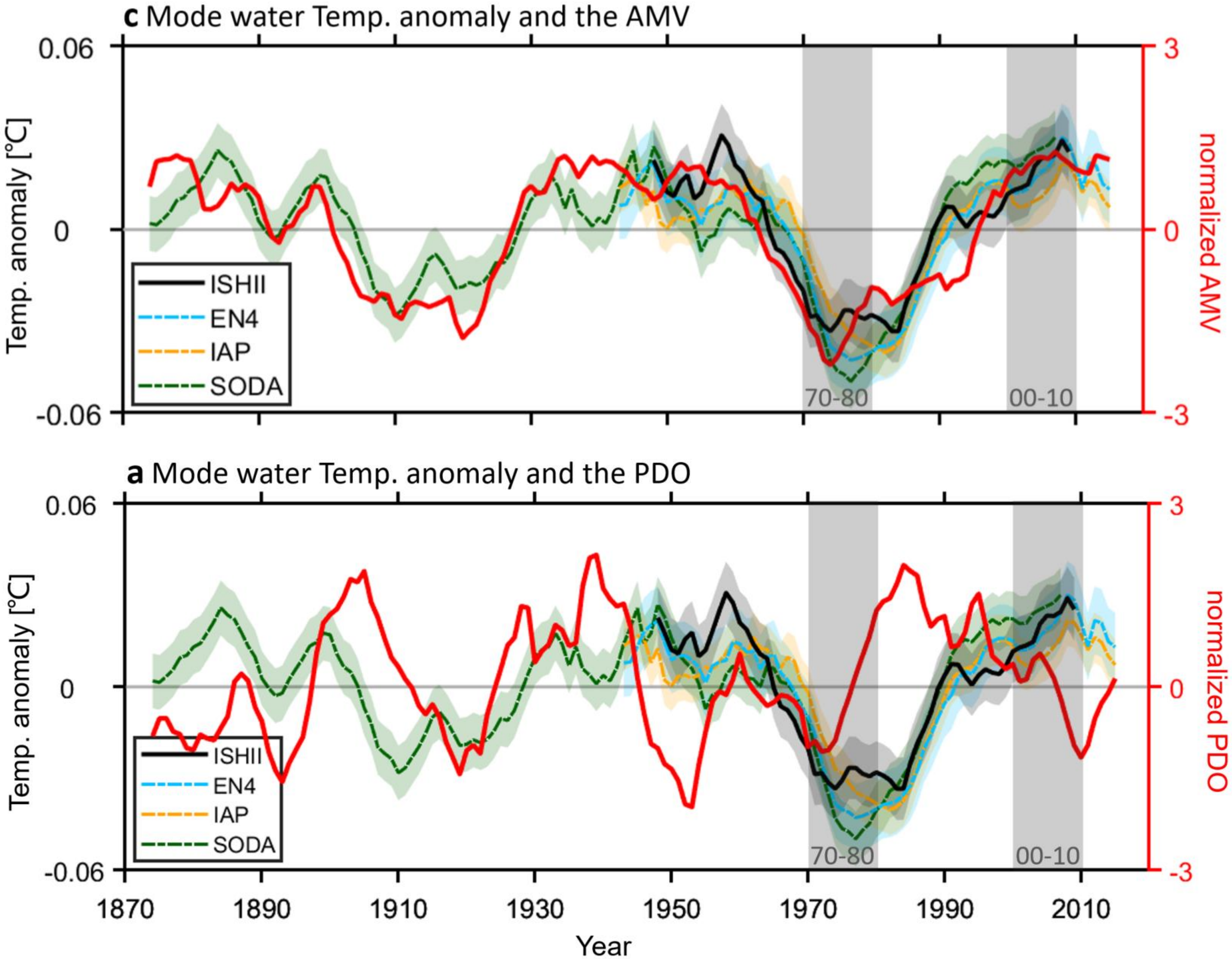
North Pacific Subtropical Mode Water is Controlled by the Atlantic Multi-Decadal Variability

Two decadal changes

Cold Period
(1970-1980)

Warm Period
(2000-2010)

PDO has no effect on the two decadal time periods



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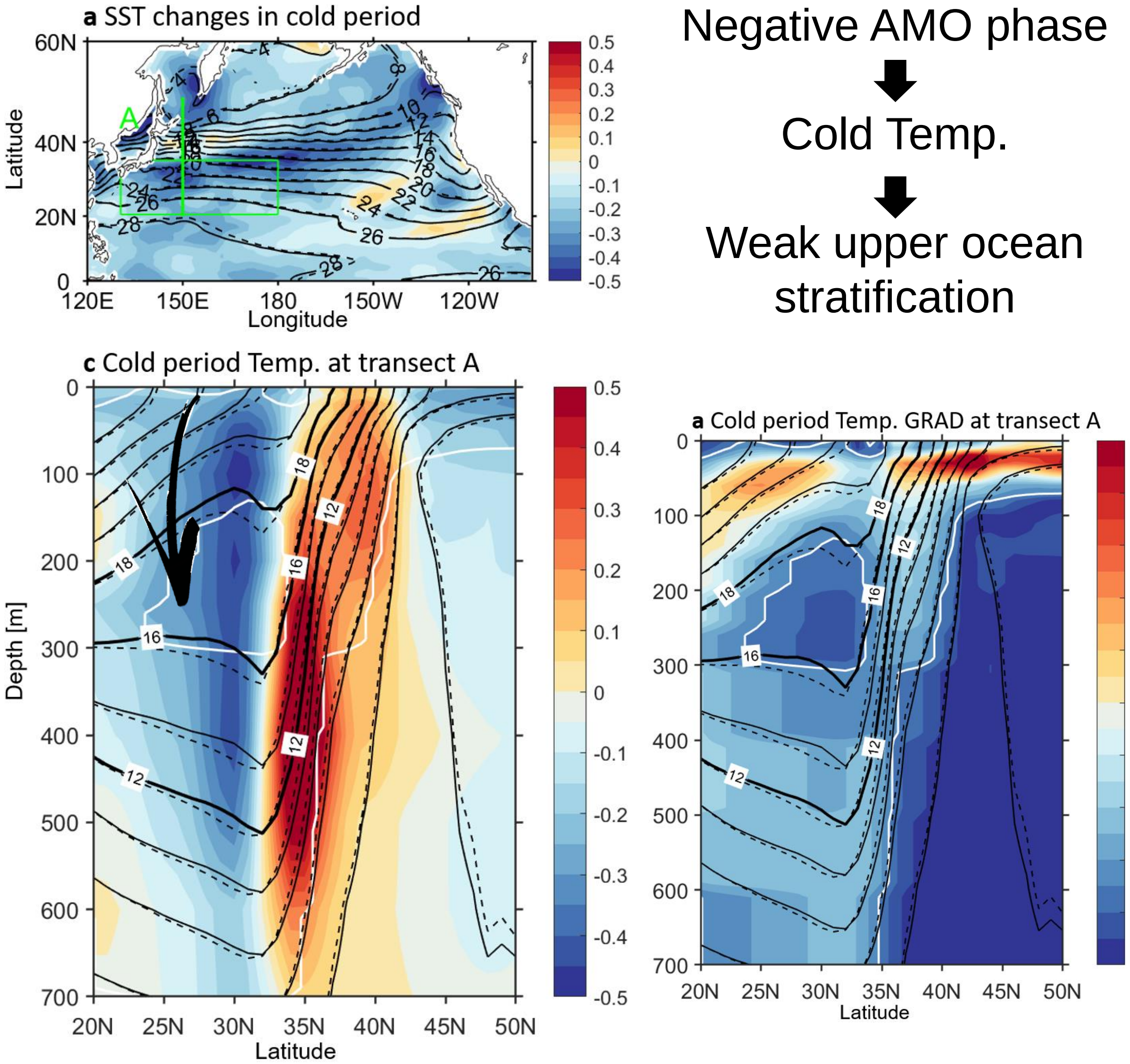
Cold Period (1970-1980)

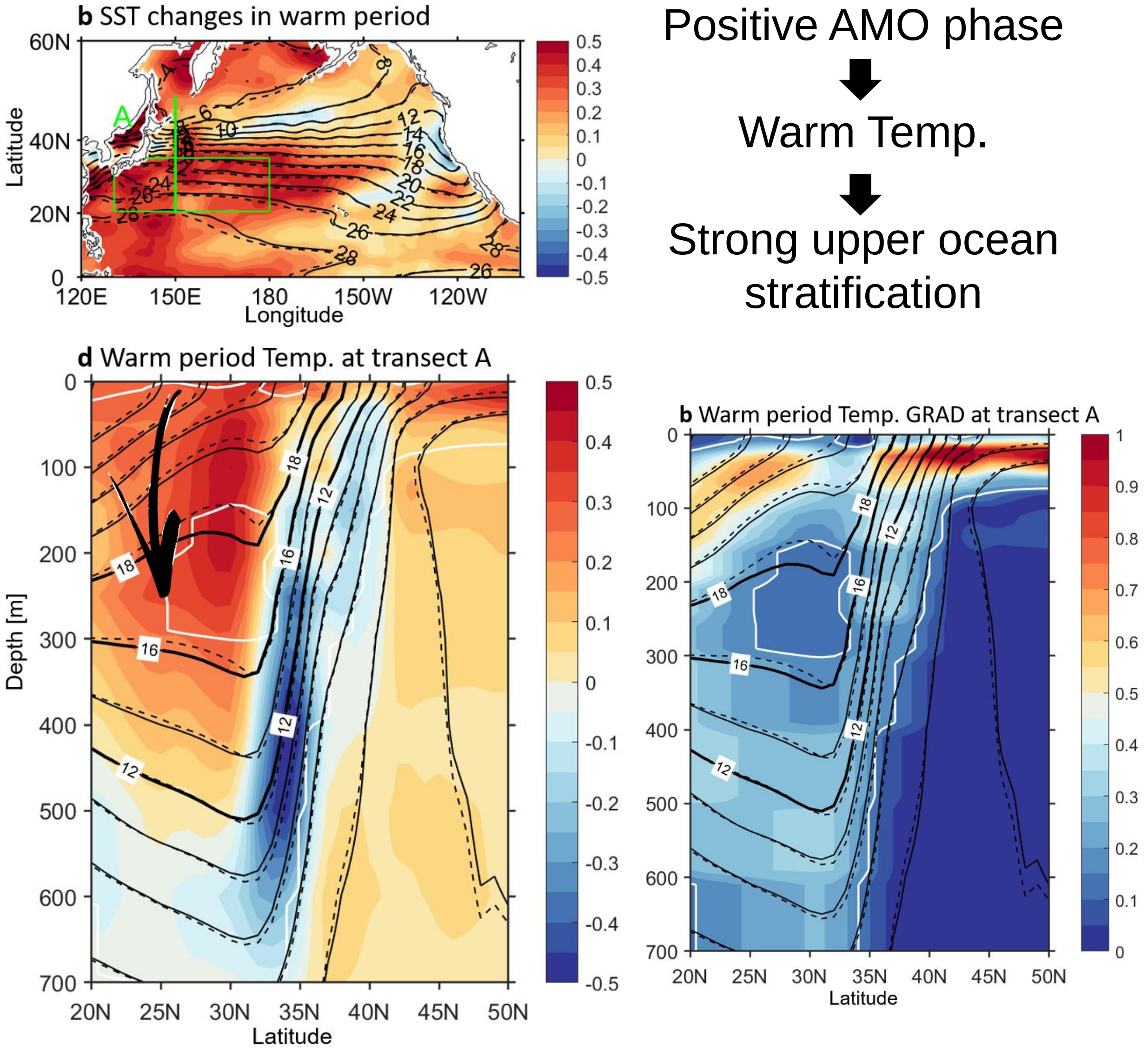


Negative AMO phase

Cold Temp.

Weak upper ocean stratification

Warm Period (2000-2010)



Positive AMO phase

Warm Temp.

Strong upper ocean stratification

➤ Result

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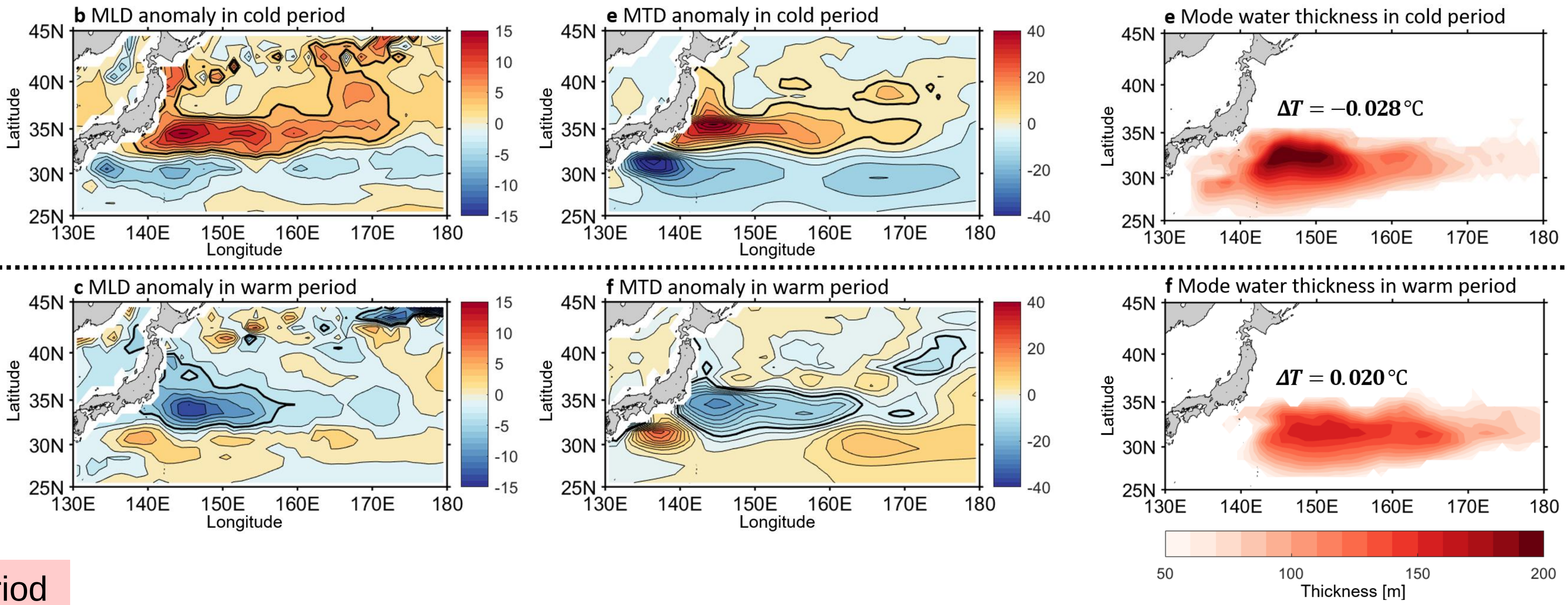
Cold Period (1970-1980) … ➔ Weak upper ocean stratification ➔ deep MLD ➔ deep MTD ➔ more mode water



Warm Period (2000-2010) … ➔ Strong upper ocean stratification ➔ shallow MLD ➔ shallow MTD ➔ less mode water

➢ Result

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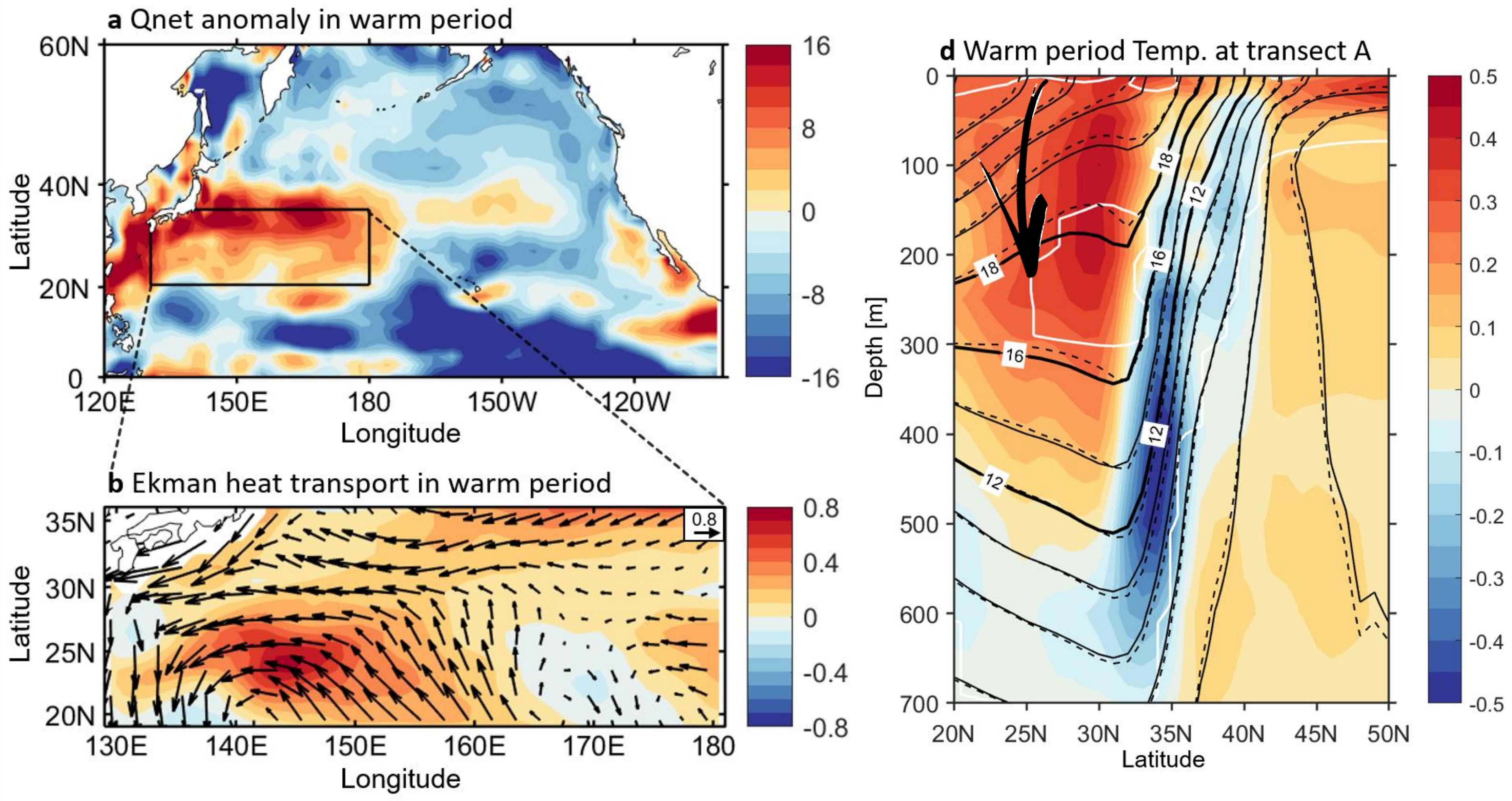
SST variability in the mode water formation area are not determined by the air-sea heat flux. In fact, the air-sea interaction here is ocean driving atmosphere.



anomalous easterly wind

⬇

northward Ekman transport of warm water

⬇

signal propagates from surface to subsurface

⬇

increase the mode water mean temperature

Result

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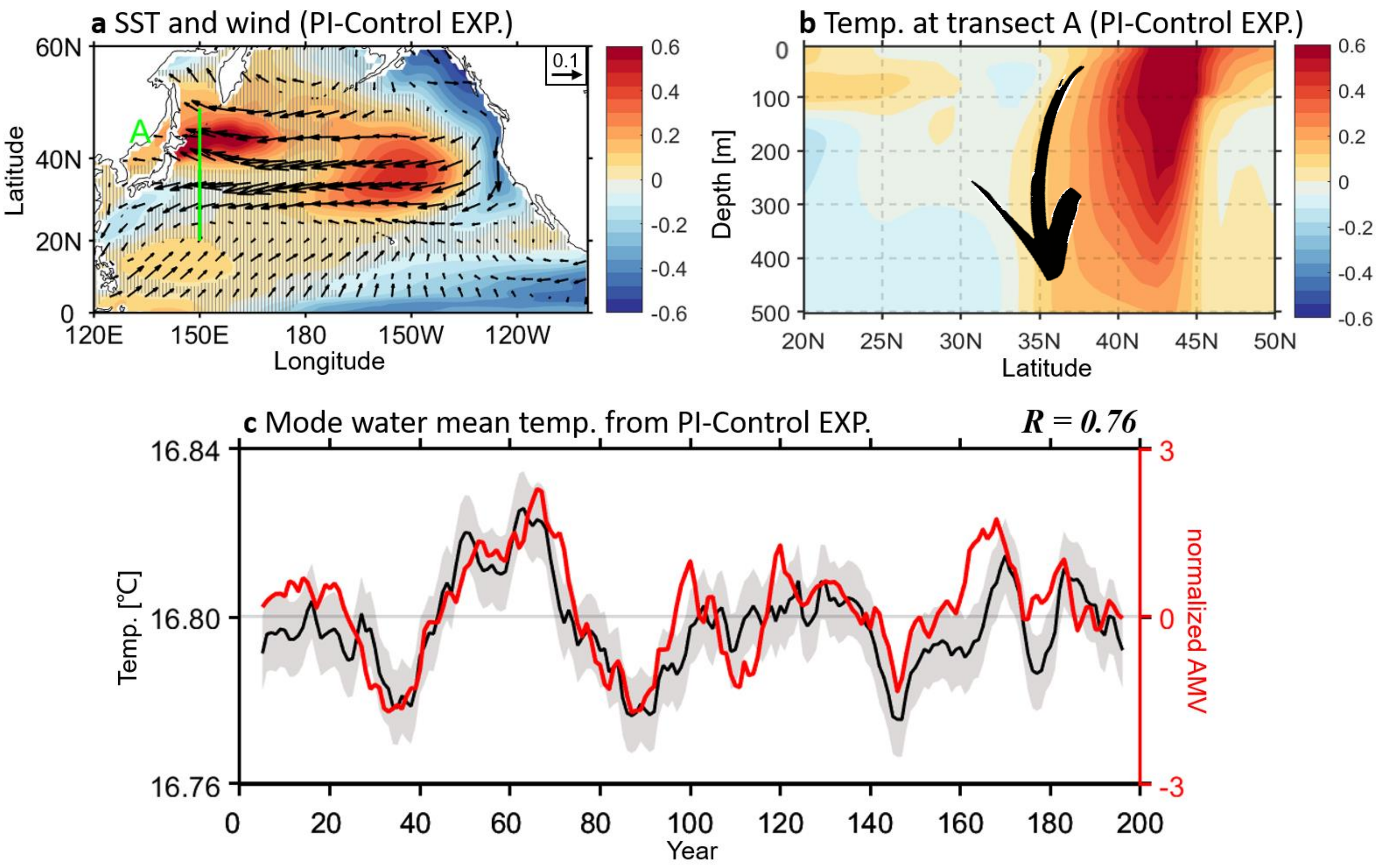
The long-term PI-Control model simulation: **multiple AMO cycles**

Model SST and wind vectors regressed upon the model AMO index.



signal propagates from surface to subsurface

Result

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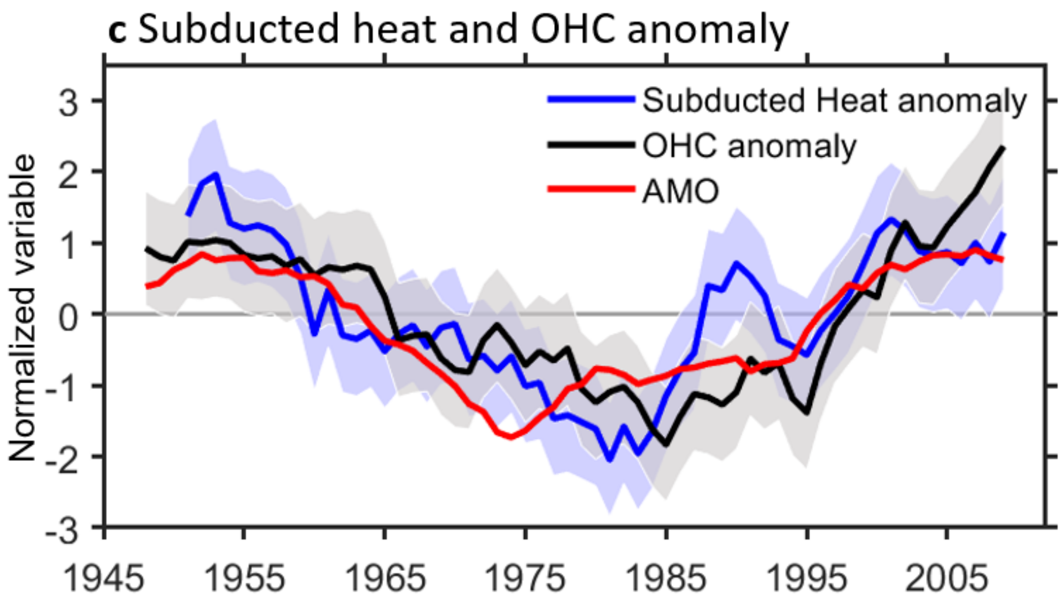
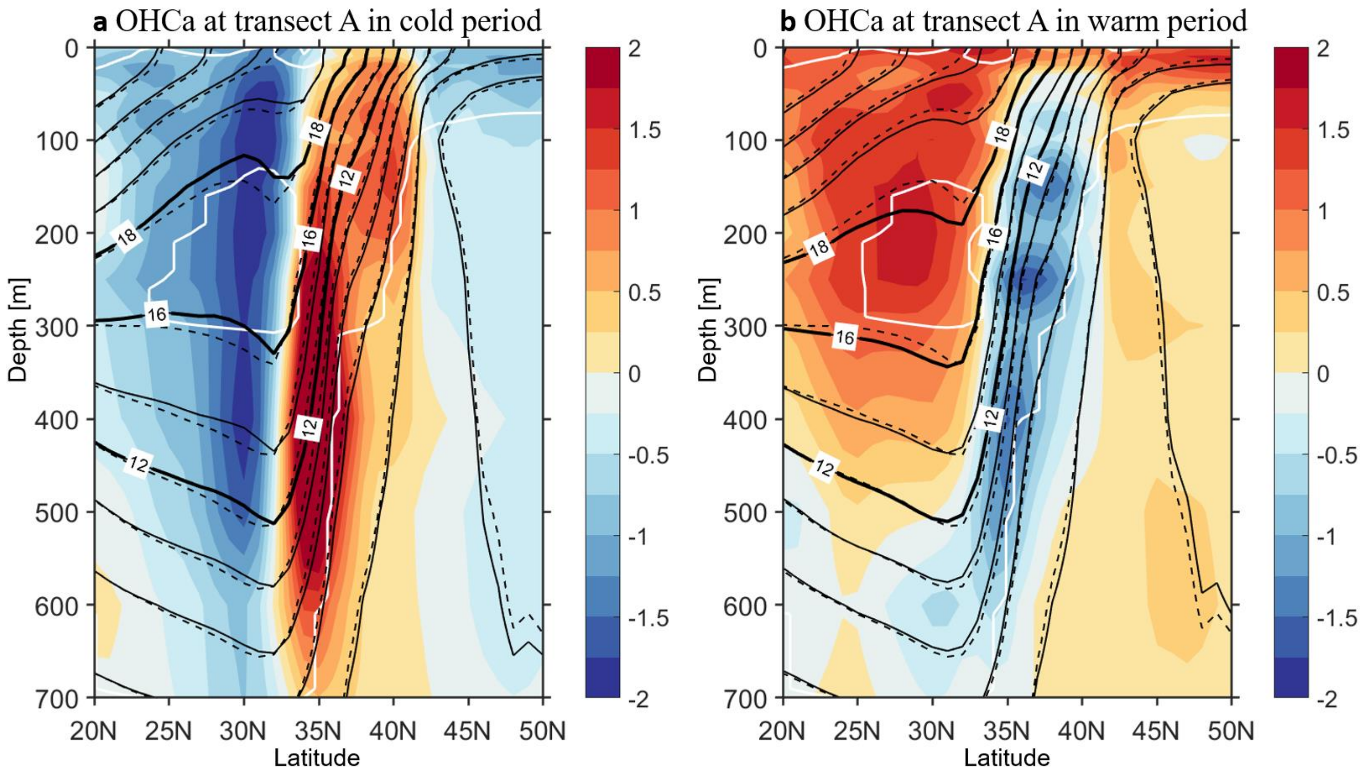


Upper 700m **Ocean heat content** in the north Pacific Ocean (black line) is related to the **AMO** rather than the PDO.

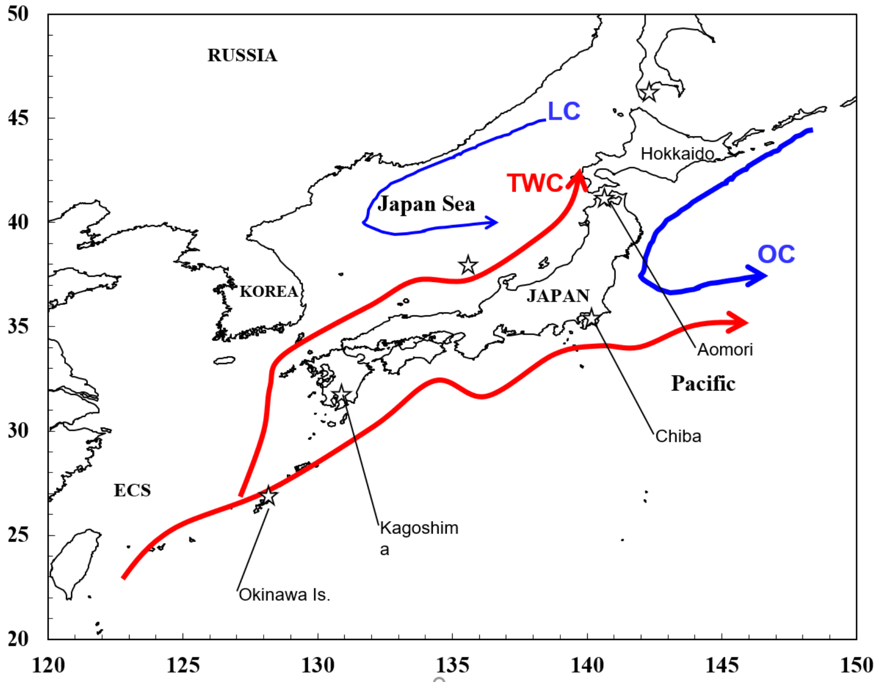
Ocean heat content vertical structure

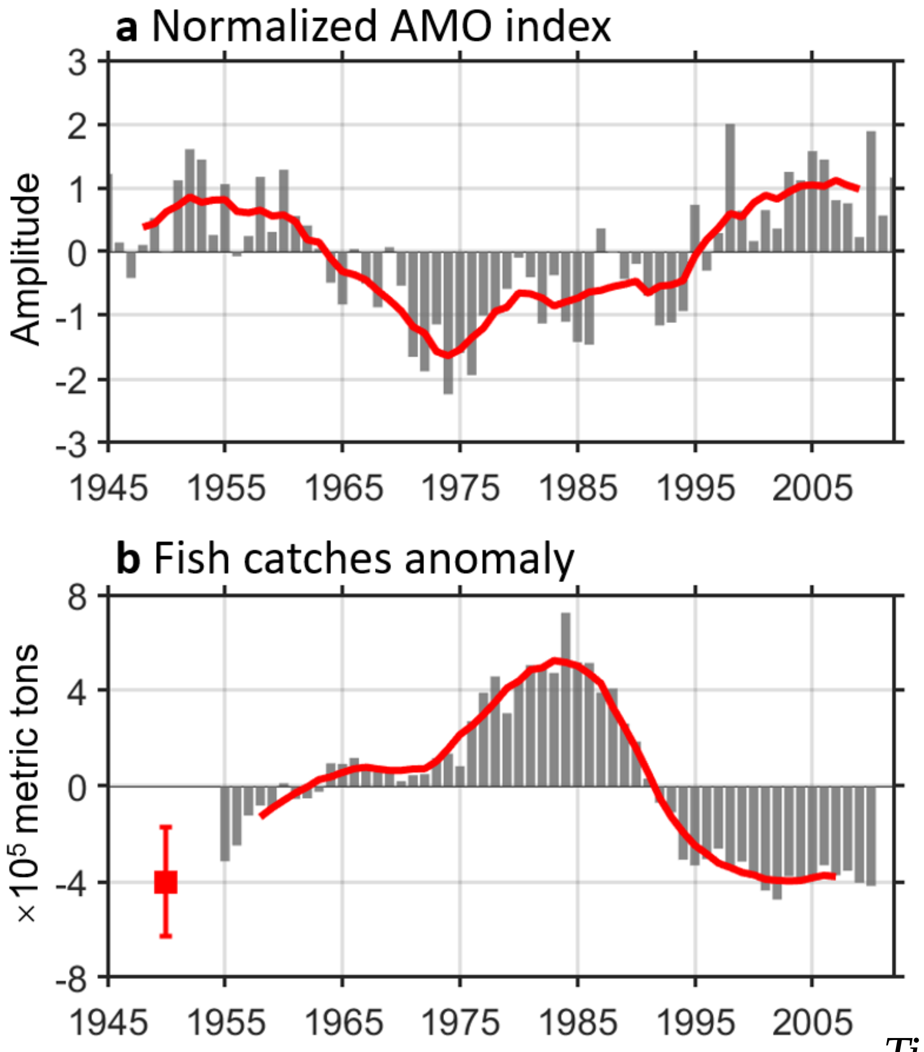


➢ Result

North Pacific Subtropical Mode Water is Controlled by the Atlantic Multi-Decadal Variability

Fish catches around Japan exhibits strong decadal to multi-decadal variability which is likely related to the **AMO** rather than the PDO.





Tian et al., 2014

➢ Result

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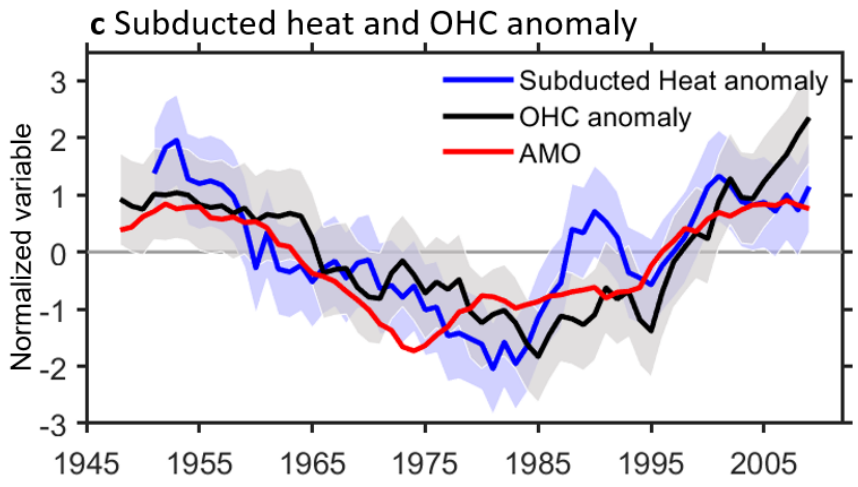
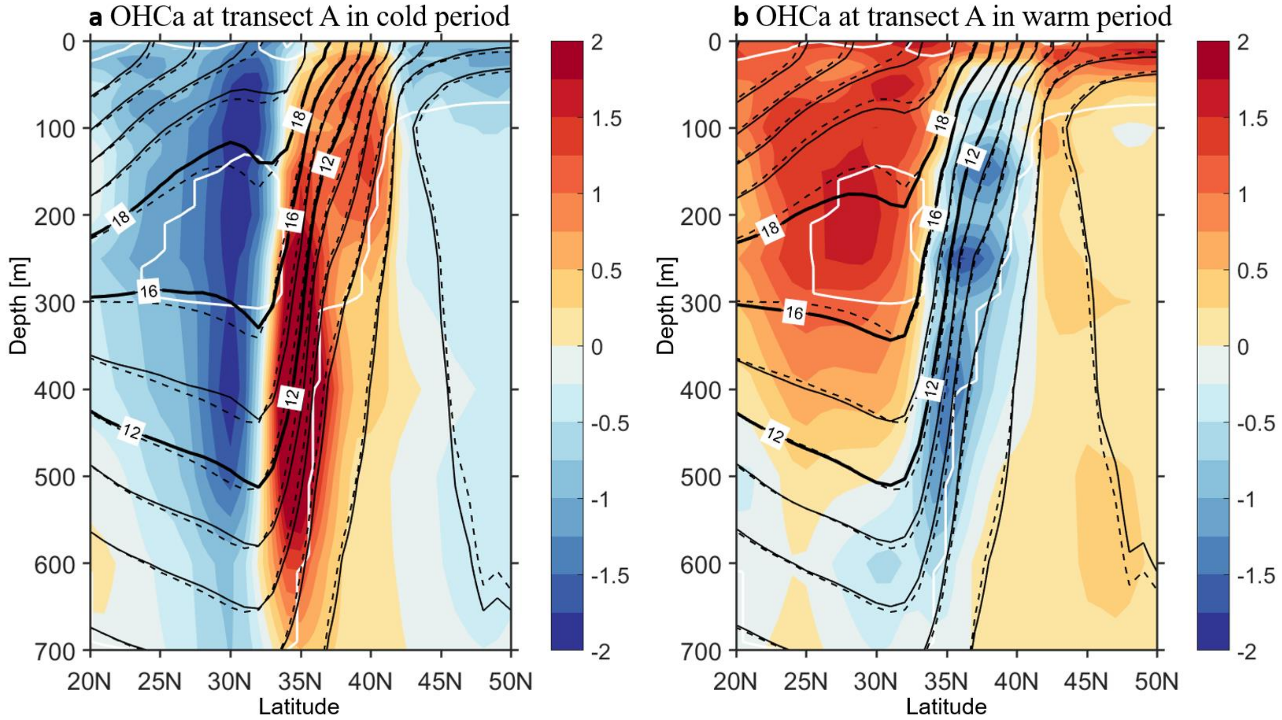


A new precursor !

Upper 700m **Ocean heat content** in the north Pacific Ocean (black line) is related to the AMO rather than the PDO.



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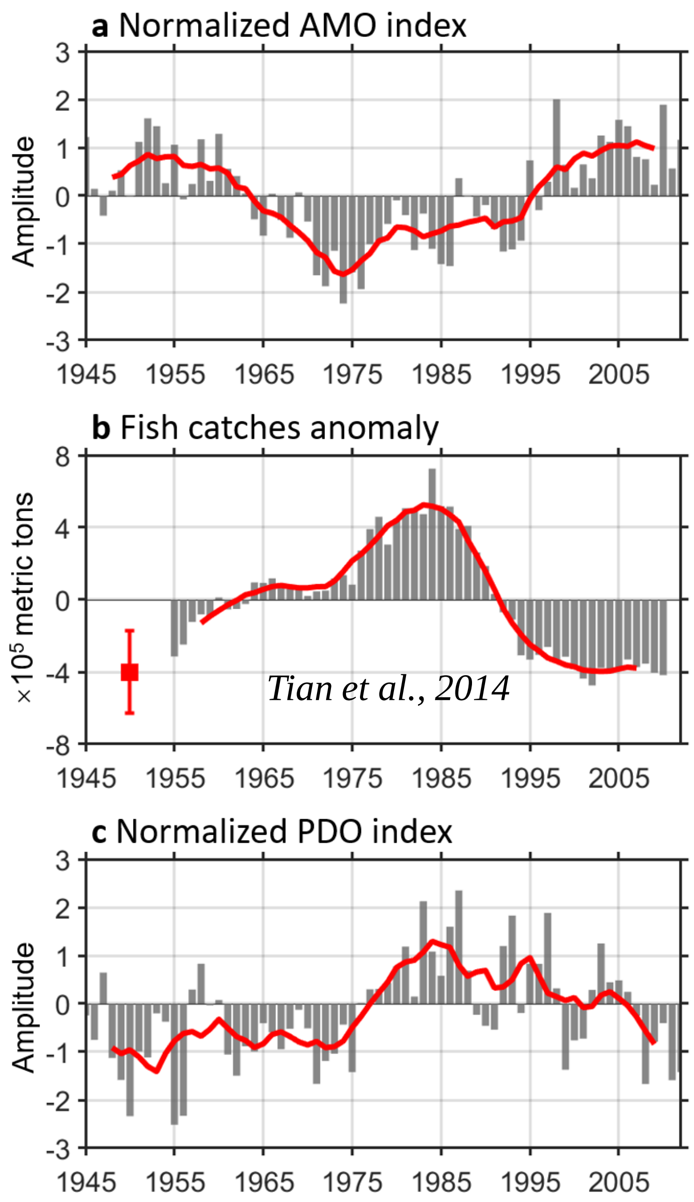

Acknowledge

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Thanks for Your Time

Related References

- Wu, B., X. Lin, and B. Qiu, 2018: Meridional shift of the Oyashio Extension front in the past 36 years. *Geophys. Res. Lett.* **45**, 9042-9048.
- Wu, B., X. Lin, and B. Qiu, 2019: On the seasonal variability of the Oyashio Extension fronts. *Clim. Dynam.* **53,** 7011-7025.
- Wu, B., X. Lin, and L. Yu, 2020: North Pacific Subtropical Mode Water Controlled by the Atlantic Multi-Decadal Variability. *Nature Climate Change*. **10**, 238-243.

➢ Result

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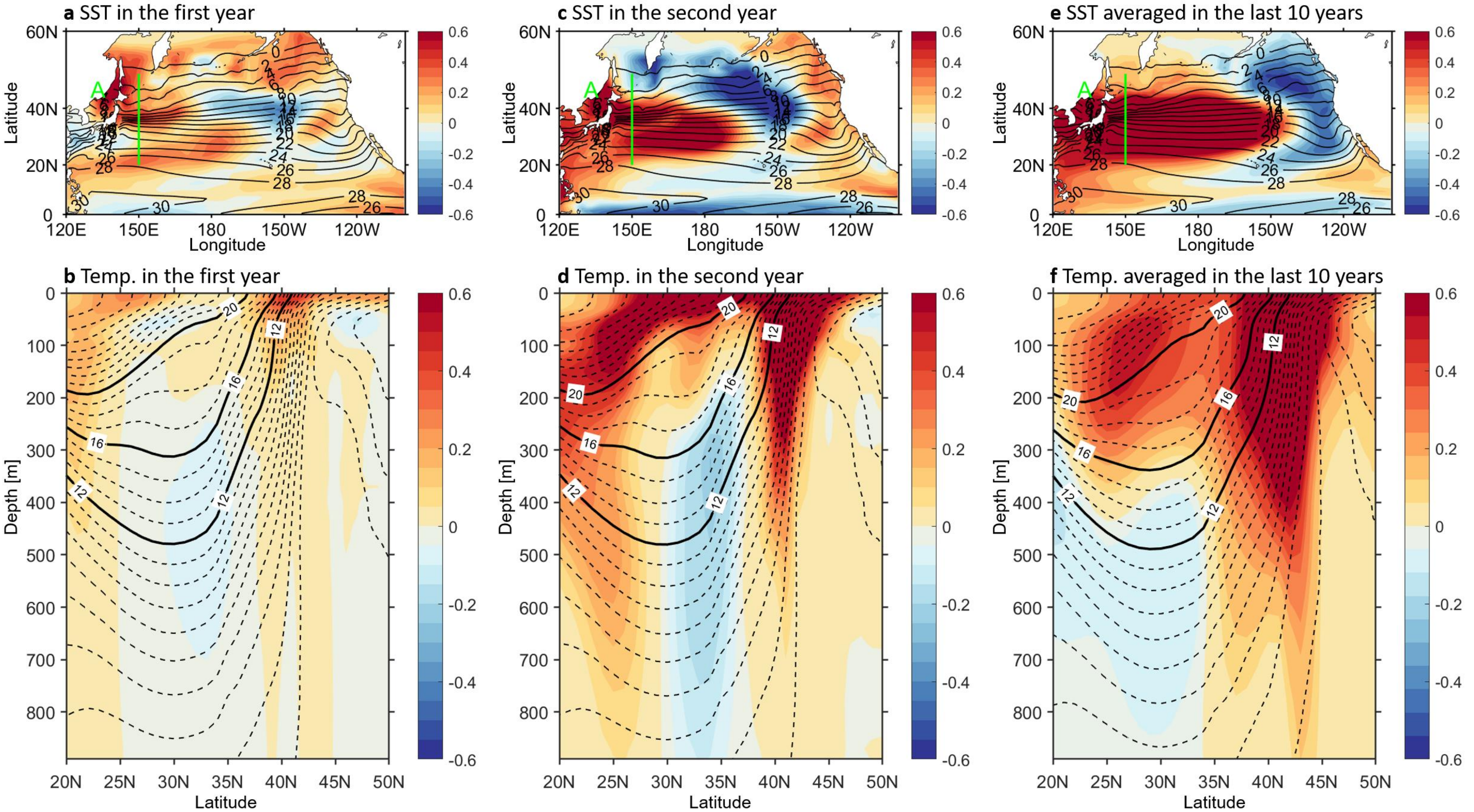
Transient simulation: Pacemaker EXP.

The whole transient processes take less than one year.

Just after we put the AMV like SST anomaly in the Atlantic Ocean



Steady state of the modelling.

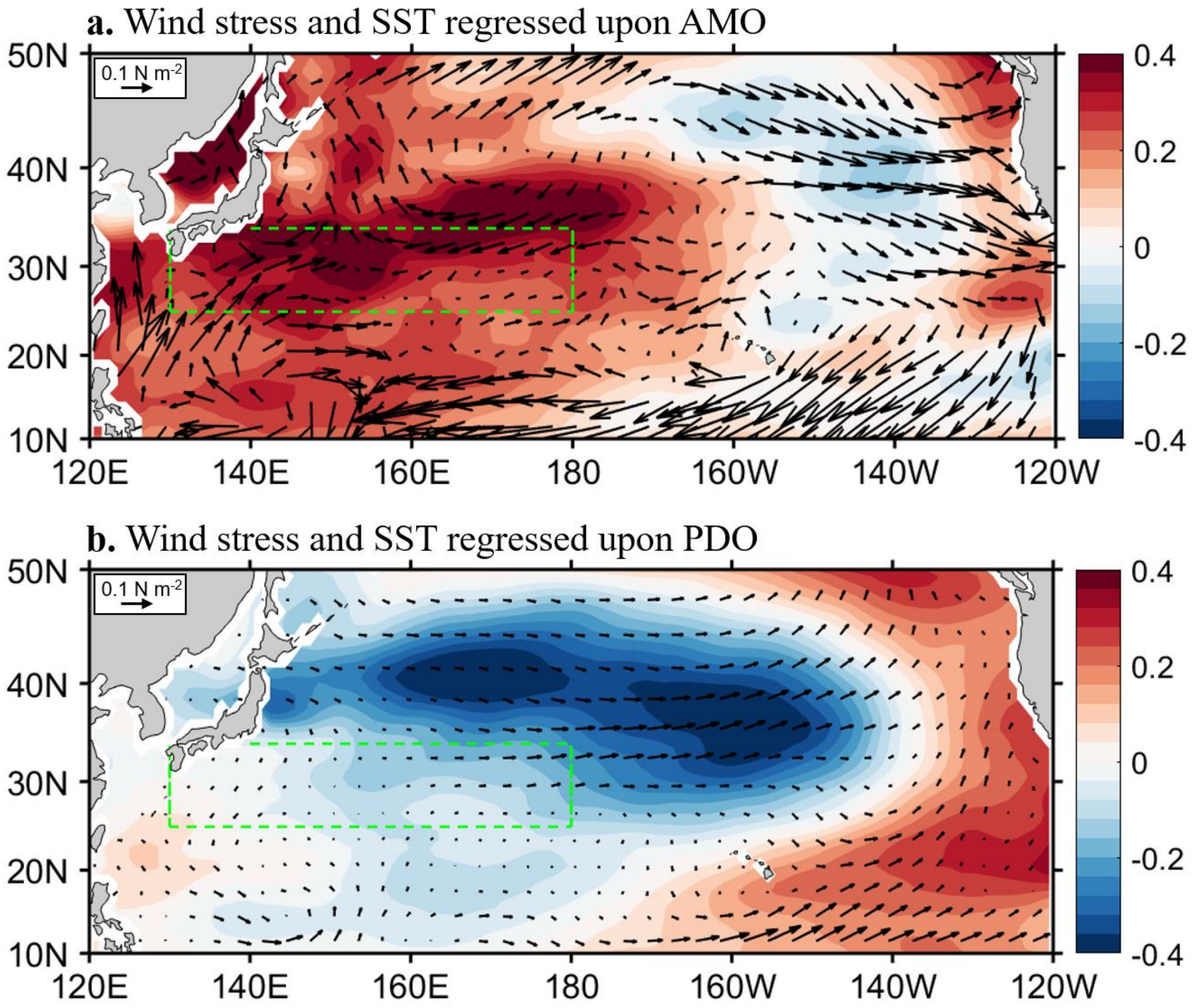


FIG. 12. (a) Regressions of the surface wind stress (vector, unit in N/m^2) and SST (shading, unit in ^{o}C) with respect to the AMO index during 1948-2012. (b) as in (a), but for the PDO index. Green dashed lines in the figures indicate the analysis basin (130°E-180°, 25°N-35°N).

Wu et al., 2020 *under review*

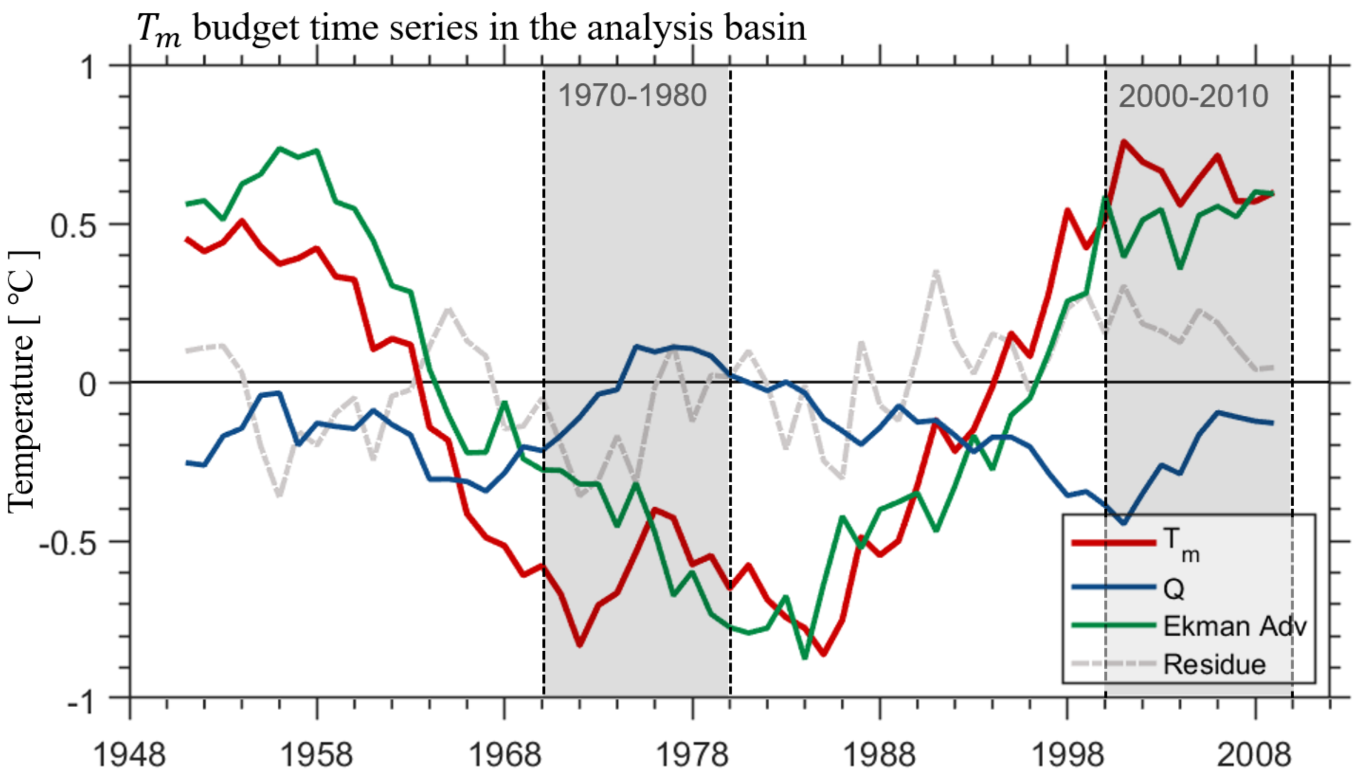


FIG. 7. Time series of time-integrated 7-year running mean mixed layer temperature (T_m) budget equations in the analysis basin (130°E-180°, 25°N-35°N, as shown in Fig. 1). Red line denotes T_m, blue line denotes the time-integrated Q_{net} forcing, green line denotes the time-integrated Ekman advective flux convergence, and gray dashed lines denotes the time-integrated residual term.

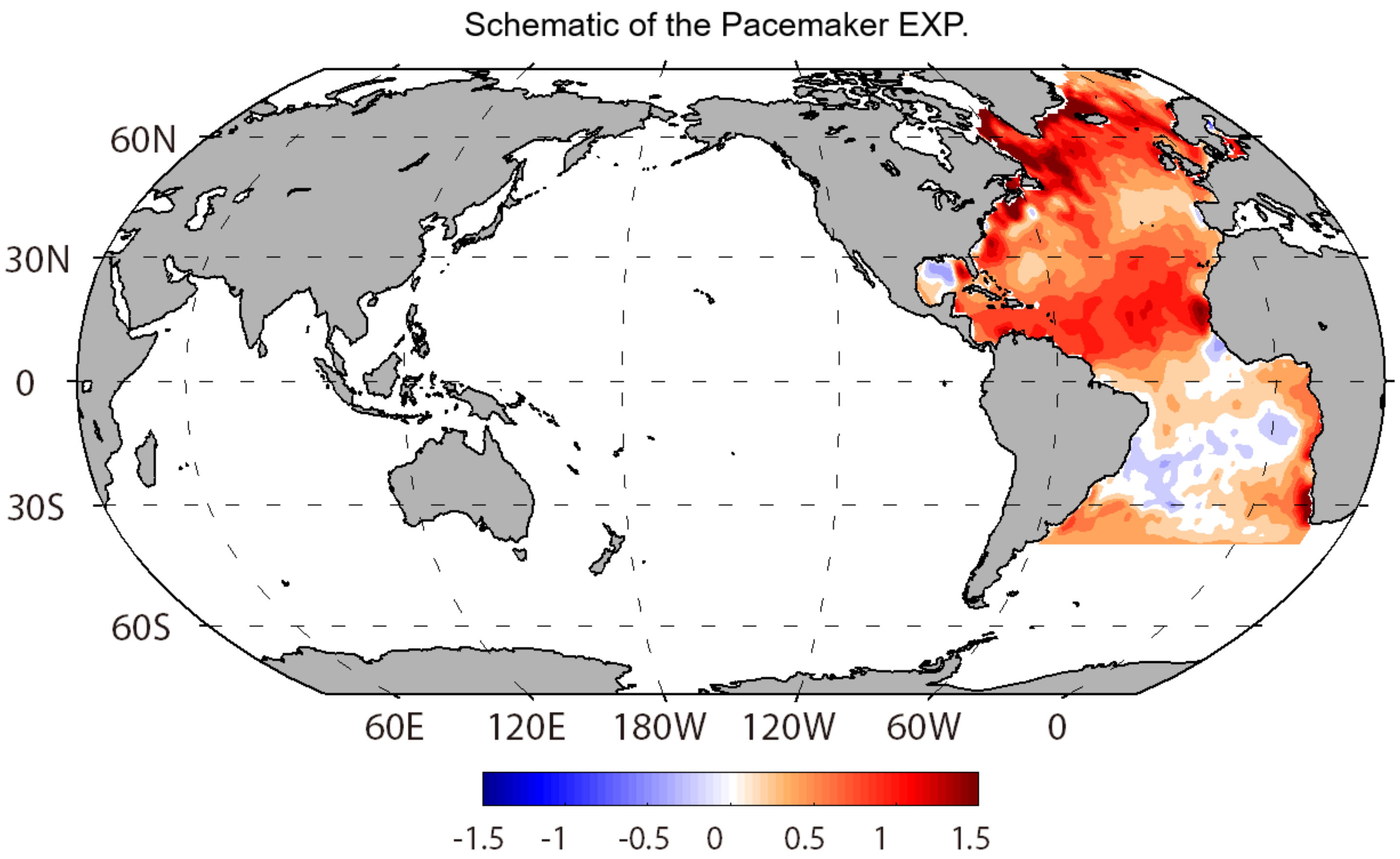
Wu et al., 2020 *under review*

➢ Supplementary

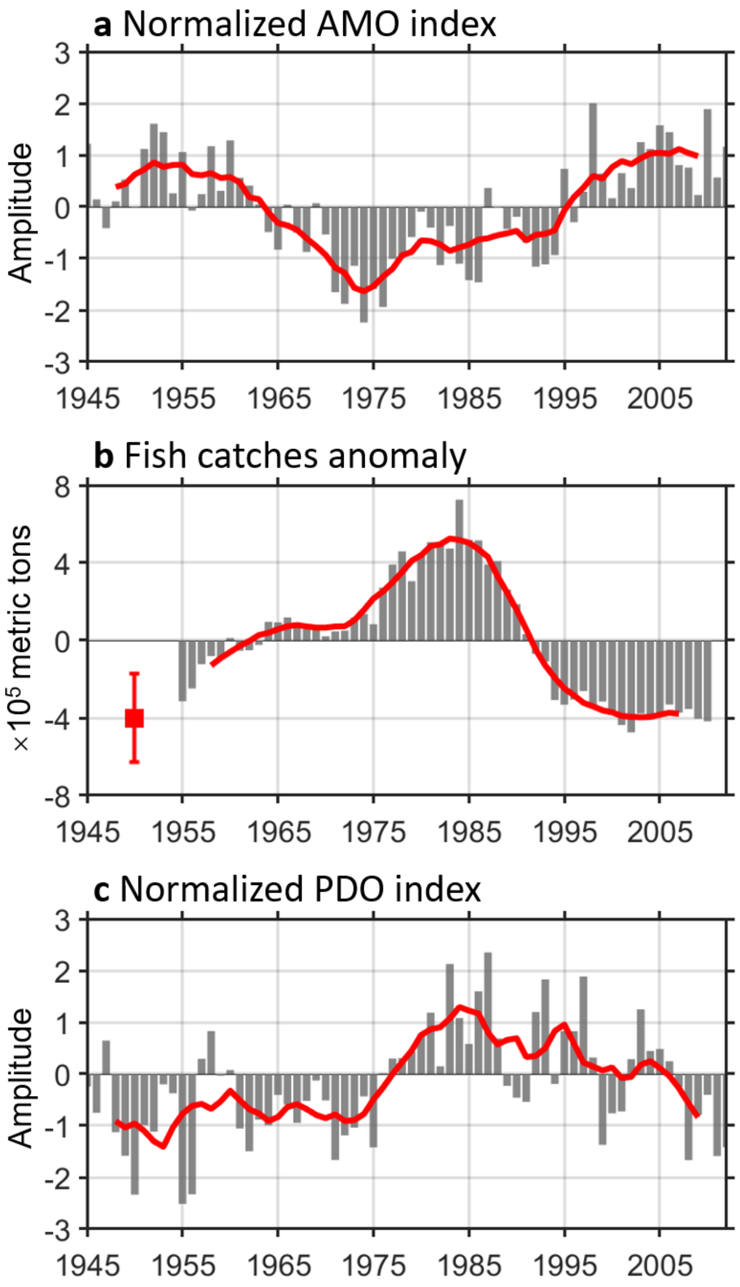
North Pacific Subtropical Mode Water is Controlled by the Atlantic Multi-Decadal Variability

PI-Control model EXP. pre-industrial control simulation by CESM model, in which greenhouse gasses are held at a constant level of 1850

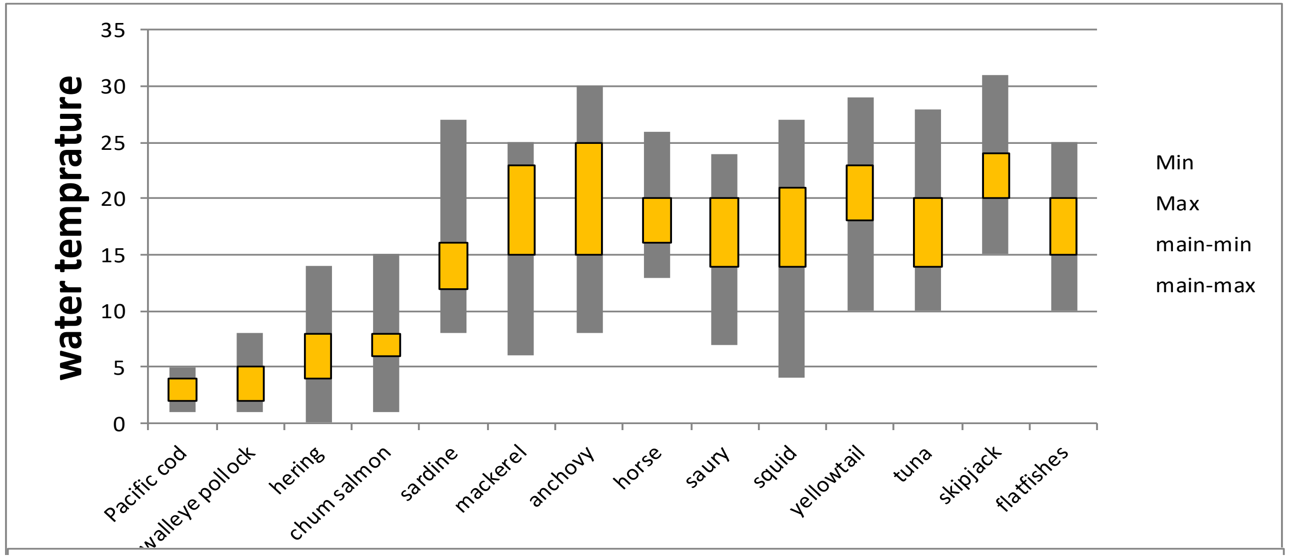
Pacemaker EXP. in which full coupling is permitted everywhere except in the Atlantic, where the observed evolution of SSTs during the positive AMO period from 1979 to 2014 is prescribed into CESM model



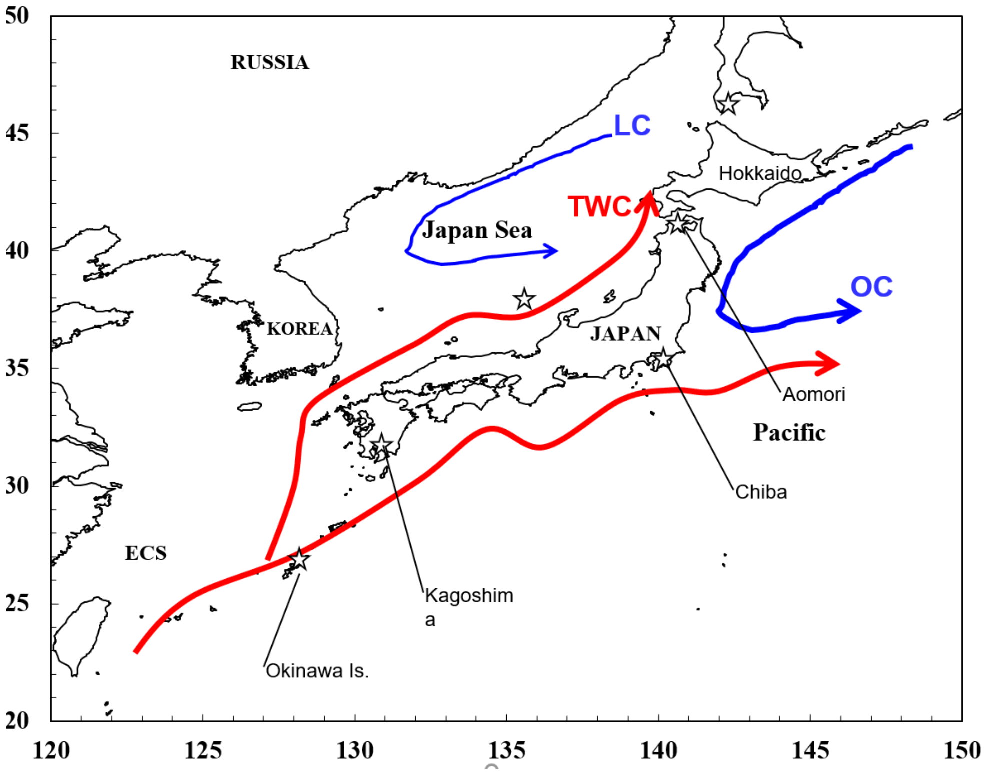
Pacemaker model experiment forced by the positive AMV SSTs. In the Atlantic Ocean, observed SST trend (unit in °C/36 yr) from 1979-2014 was added in the modelled mixed layer temperature in the restoring forcing. In the other areas, the mixed-layer temperature was restored to the model climatology. Then the climate response to the restored ocean temperature was calculated by the difference between the Pacemaker experiment and a control experiment, in which the mixed-layer temperature was restored to the model climatology.



a Normalized AMO index
Amplitude
b Fish catches anomaly
×10^5 metric tons
c Normalized PDO index
Amplitude
1945
1955
1965
1975
1985
1995
2005

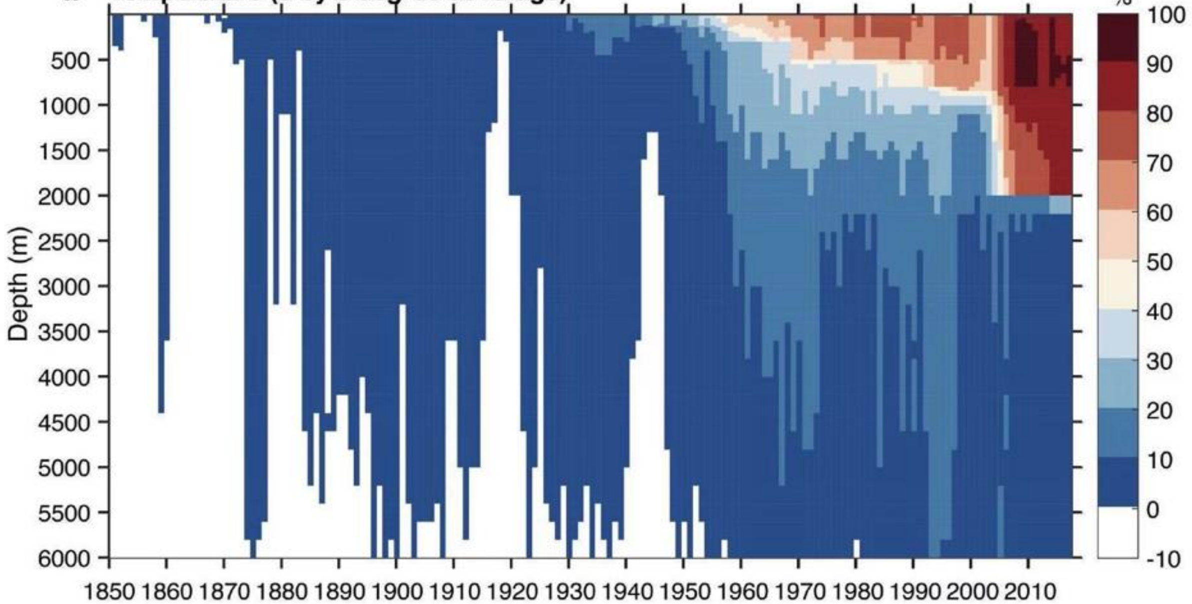


water temprature
Min
Max
main-min
main-max
Pacific cod
walleye pollock
hering
chum salmon
sardine
mackerel
anchovy
horse
saury
squid
yellowtail
tuna
skipjack
flatfishes

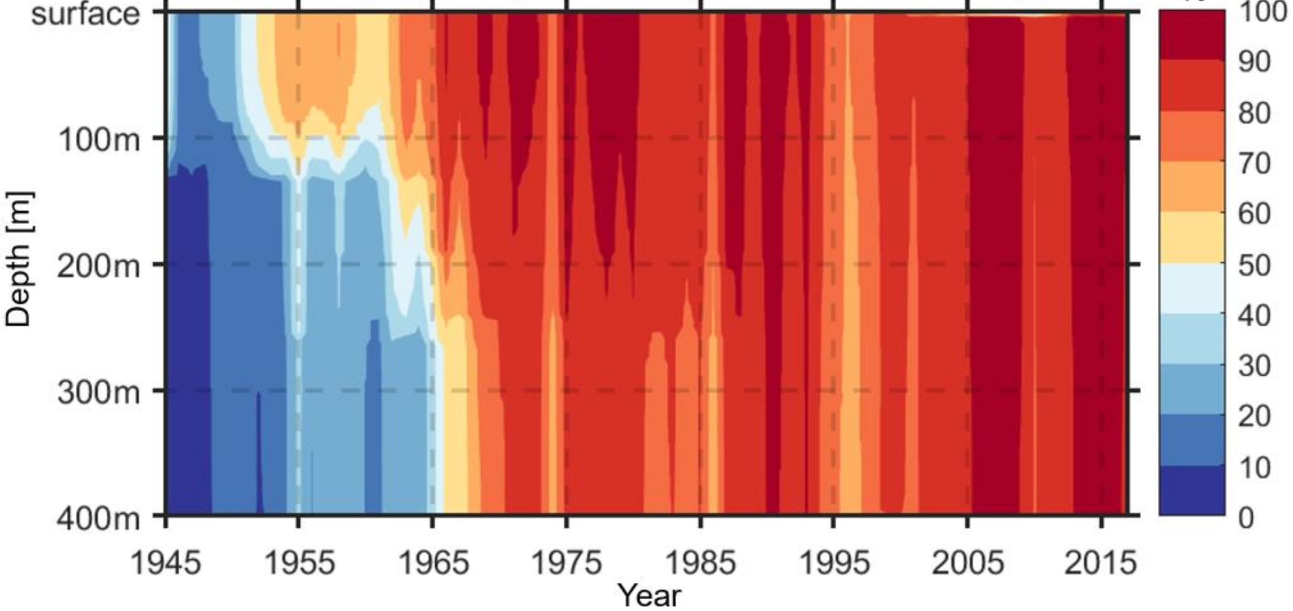


RUSSIA
LC
Hokkaido
TWC
Japan Sea
OC
KOREA
JAPAN
Aomori
Pacific
Chiba
ECS
Kagoshim
a
Okinawa Is.

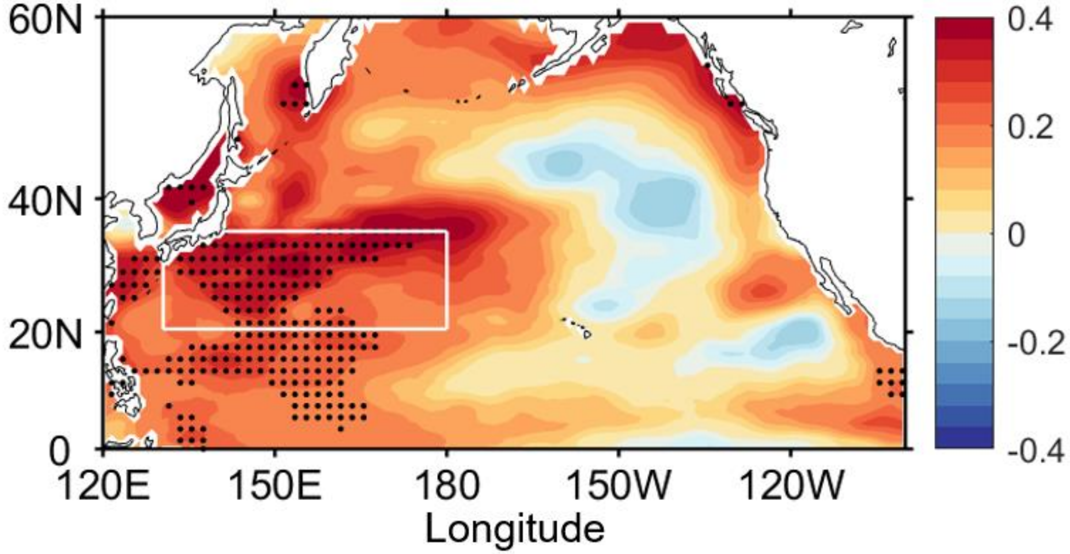
a Temperature (3 by 3 degree coverage)



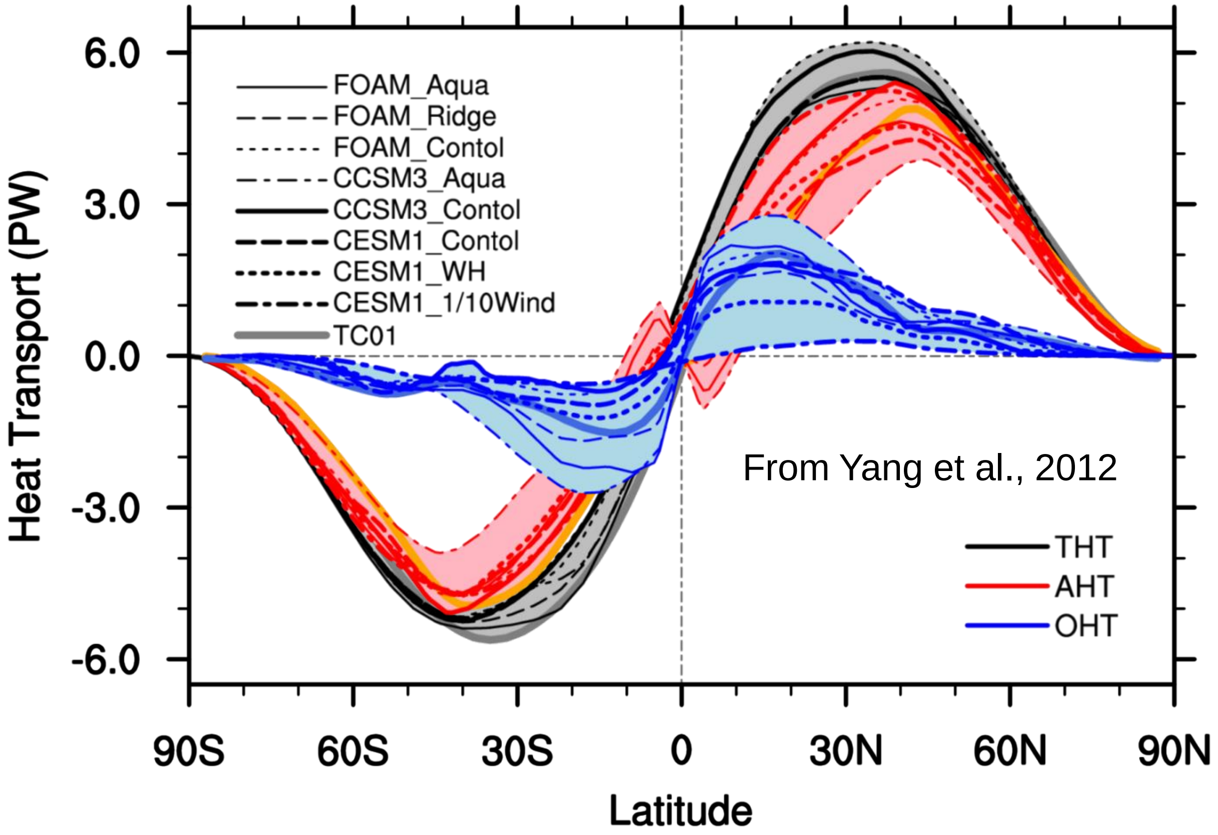
b Temperature (1 by 1 degree coverage in mode water area)



b SSTa associated with the AMV

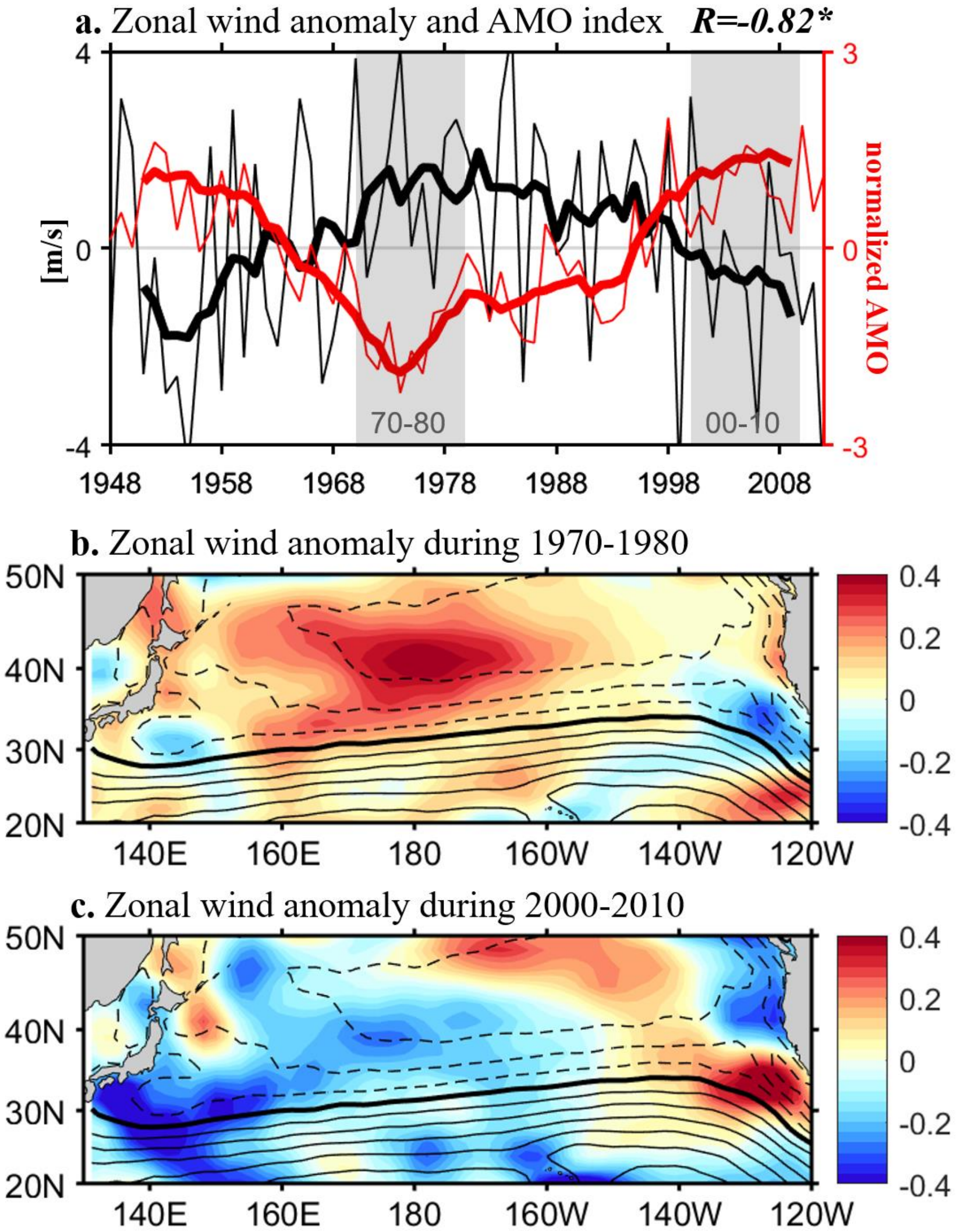


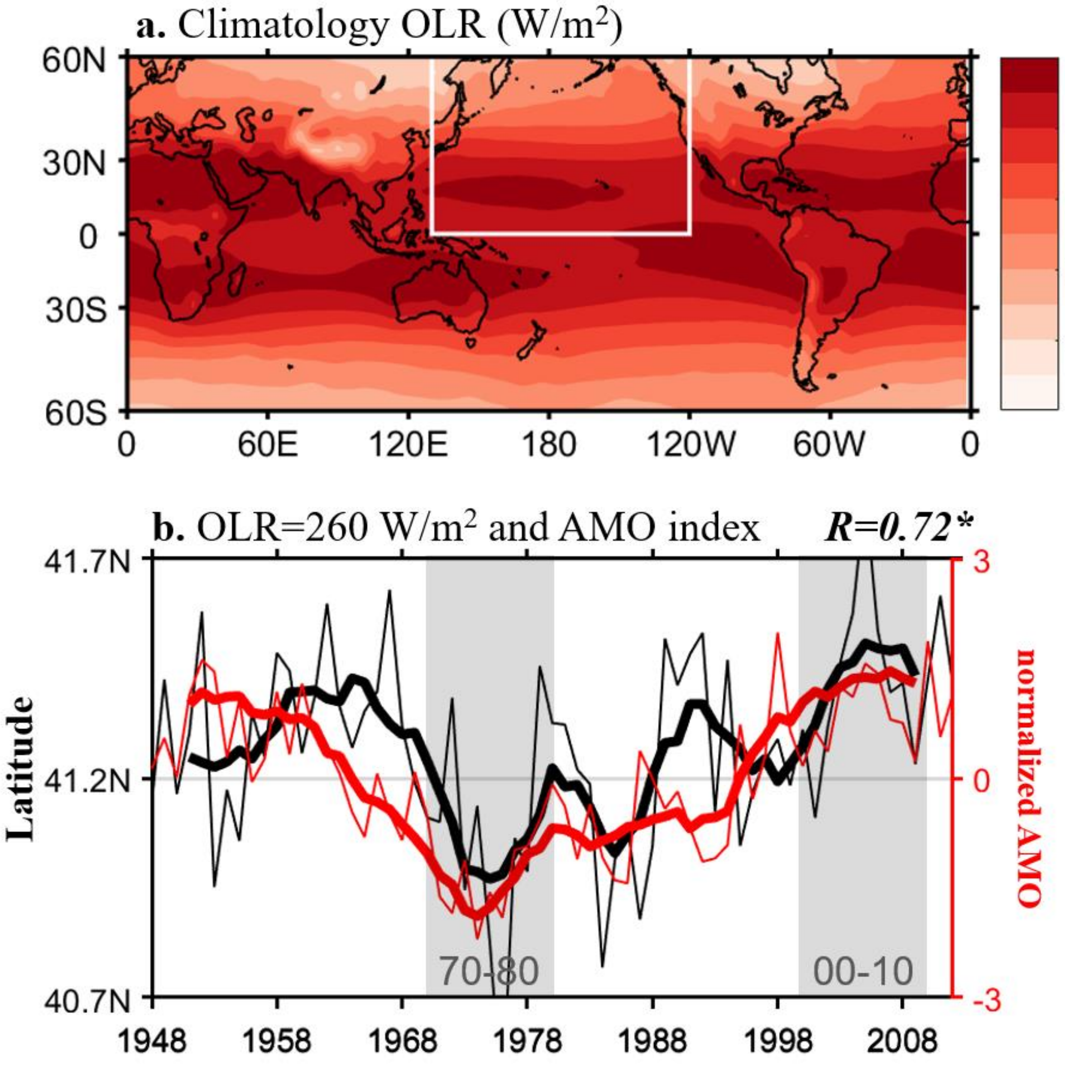
Why AMOC Shutdown Increase Westerly and Strom?



Meridional Heat Transport: Total, Atmosphere and Ocean

Bjerknes Compensation $\Delta HT_{total} = \Delta AHT + \Delta OHT = 0$





Wu et al., 2020 *submitted*

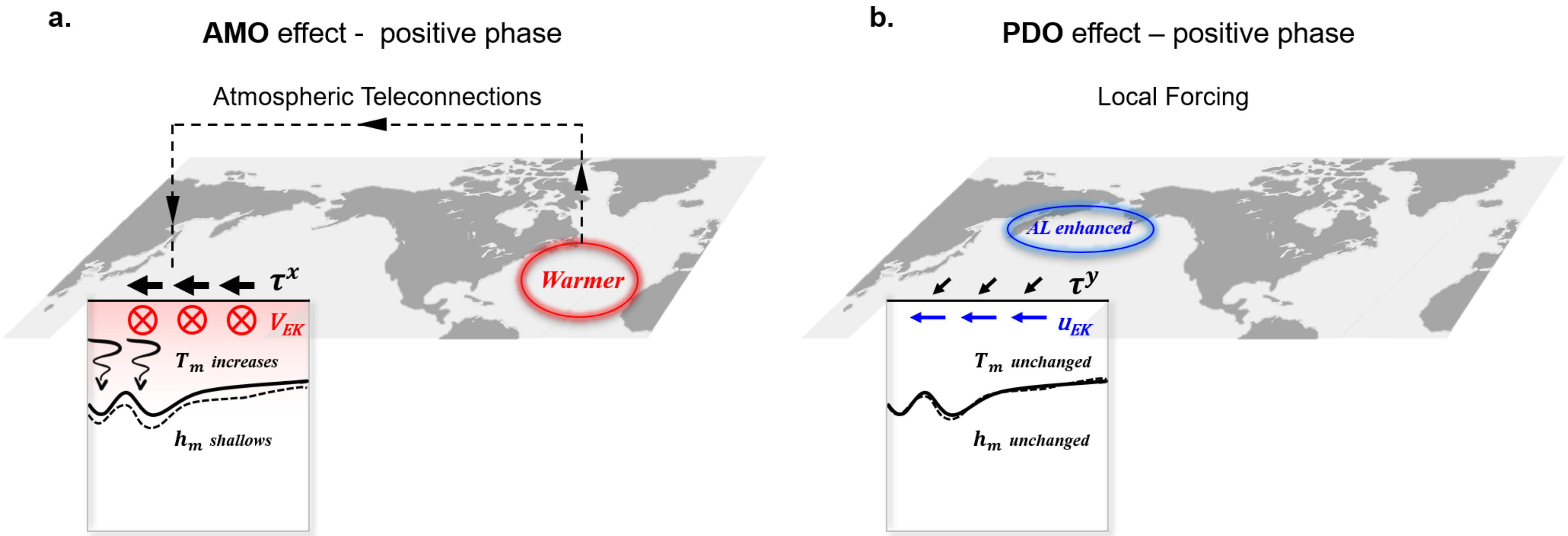


FIG. 13. Schematic diagram for the different effect from AMO (a, atmospheric teleconnection) and PDO (b, local forcing) on the mixed layer variability in the south of Kuroshio region. (a) During the AMO positive phase (2000-2010, warm period of the)The AMO warm SST anomaly (the red circle over North Atlantic) would influence the western North Pacific through the atmospheric teleconnections and induce the easterly wind anomaly (black arrows) which results in warm Ekman transport. The warm temperature anomaly would propagate into the subsurface, increasing the T_m and upper ocean stratification intensity and shallowing the h_m, in the south of Kuroshio. The vice versa for the cold period (1970-1980). The transect is along 32°N and the black solid contour indicates h_m during the warm period and dashed contour is its climatology.

Wu et al., 2020 *under review*