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

Baolan Wu$^{1,2}$
Xiaopei Lin$^1$, Lisan Yu$^2$

1 Physical Oceanography Lab, Ocean University of China and Qingdao National Laboratory for Marine Science and Technology, Qingdao, China, 266100
2 Department of Physical Oceanography, Woods Hole Oceanographic Institution, Woods Hole, MA 02543, USA
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)

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.

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

Sugimoto and Kako, 2016

Alexander et al., 1995
Background

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

Aleutian Low

Intensity change – PNA(PDO)

Meridional shift - WP

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


Sugimoto and Hanawa, 2010

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.
Background

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

Intensity change – PNA(PDO)

Meridional shift - WP

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

3~5 years time lag


Sugimoto and Hanawa, 2010

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

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

Outline

- 1 Background
- 2 Data & Method
- 3 Result
Definition of the North Pacific Subtropical Mode Water

1. temperatures between 16-18 °C
2. temperature gradient < 1.5 °C/hm
3. thickness >50 m

Mean temperature, mean depth and thickness of the mode water

Mixed layer depth (MLD)
Main thermocline depth (MTD)
North Pacific Subtropical Mode Water is Controlled by the Atlantic Multi-Decadal Variability
North Pacific Subtropical Mode Water is Controlled by the Atlantic Multi-Decadal Variability

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

\textit{Hanawa and Kamada, 2001}

\textit{Sugimoto et al., 2017}
North Pacific Subtropical Mode Water is Controlled by the Atlantic Multi-Decadal Variability

Result

SST anomaly variation within the mode water formation area related to the AMV

Mixed layer depth

Main thermocline depth

Mode water thickness

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

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

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

- **anomalous easterly wind**
- northward Ekman transport of warm water
- signal propagates from surface to subsurface
- increase the mode water mean temperature
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
Upper 700m Ocean heat content in the north Pacific Ocean (black line) is related to the AMO rather than the PDO.
Fish catches around Japan exhibits strong decadal to multi-decadal variability which is likely related to the AMO rather than the PDO.
A new precursor!

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

Fish catches around Japan exhibit strong decadal to multi-decadal variability which is likely related to the AMO rather than the PDO.
Thanks for Your Time

Related References


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

Result

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 °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
**PI-Control model EXP.** pre-industrial control simulation by CESM model, in which greenhouse gases 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.
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

(a) Zonal wind anomaly and AMO index \( R = 0.82^* \)

(b) Zonal wind anomaly during 1970-1980

(c) Zonal wind anomaly during 2000-2010

(a) Climatology OLR (W/m²)

(b) OLR=260 W/m² and AMO index \( R = 0.72^* \)
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