CLIMATE INTERPRETATION OF THE NORTH PACIFIC MARINE HEATWAVE OF 2013-2015

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QUESTION

What are the large-scale climate mechanisms linking these two patterns?
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Figure 1: Dominant patterns of winter (JFM) SST anomaly (SSTa) variability in the Northeast Pacific (blue and red bounding boxes) inferred from Empirical Orthogonal Functions (EOFs). (a) EOF2 and (b) EOF1 capture the GOA and ARC patterns observed in the evolution of the Warm Blob from JFM 2014 to JFM 2015. (c) The timeseries of the GOA SSTa pattern are strongly correlated to PC2 and exhibit an NPGO-like variability. (d) The timeseries of the ARC SSTa pattern are strongly correlated to PC1 and exhibit an NPGO-like variability. [Figure redrawn from Di Lorenzo and Mantua, 2016]
Figure 1: Dominant patterns of winter (JFM) SST anomaly variability in the Northeast Pacific (blue and red bounding boxes) inferred from Empirical Orthogonal Functions (EOFs). (a) EOF2 and (b) EOF1 capture the GOA and ARC patterns observed in the evolution of the Warm Blob from JFM 2014 to JFM 2015. (c) The timeseries of the GOA SST anomaly pattern are strongly correlated to PC2 and exhibit an NPGO-like variability. (d) The timeseries of the ARC SST anomaly pattern are strongly correlated to PC1 and exhibit an NPGO-like variability. [Figure redrawn from Di Lorenzo and Mantua, 2016]
Cross Correlation
PC2 (NPGO-like) vs. PC1 (PDO-like)

PC2 leads

PC1 leads

95% significance

Correlation

lag years

R=0.95

WINTER (JFM) 2014

WINTER (JFM) 2015

GOA Pattern

Relationship of normalized units

emerges as EOF2 JFM SSTa

GOA Pattern

emerges as EOF2 JFM SSTa

NPGO-like

Arctic Pattern

PDO-like

GOA Pattern

emerges as EOF1 JFM SSTa

ARC Pattern

GOA Pattern

emerges as EOF1 JFM SSTa

ARC Pattern

GOA Pattern

emerges as EOF1 JFM SSTa

ARC Pattern

GOA SSTa pattern are strongly correlated to PC2 and exhibit an NPGO-like variability. (EOFs). (blue and red bounding boxes) inferred from Empirical Orthogonal Functions

The timeseries of the ARC SSTa pattern are strongly correlated to PC1 and exhibit a significant positive trend towards PDO-like variability. (EOFs). (redrawn from Di Lorenzo and Mantua, 2016)

Figure 1: Dominant patterns of winter (JFM) SSTa variability in the Northeast Pacific.

Figure 5: Increasing Coupling of GOA and ARC Patterns.

The sliding correlation is computed using a backward window, so that for example the value for year 2100 is computed over the range 2080-2100. [Figure redrawn from Di Lorenzo and Mantua, 2016]

The 1-year lead relationship between PC2 with PC1 is explored as a sliding 20-year correlation in both observations between 1920-2015 (c) and ensemble mean of 30 crosscorrelations between PC1 and PC2 in the CESM-LE (b). This statistical relationship is found also in the interpretation discussed in Figure 3. This statistical relationship is found also in the CESM-LE 30 member ensemble. The observed crosscorrelation function (a) PC2 (GOA pattern) leads PC1 (ARC pattern), consistent with the mechanistic example the value for year 2100 is computed over the range 2080-2100. [Figure redrawn from Di Lorenzo and Mantua, 2016]
QUESTION
Why does winter NPGO-like variability lead to a PDO-like response the following winter?
WINTER (JFM)

SSTA

NPGO-like

SST ANOMALY

-0.5  0  +0.5  °C
WINTER (JFM)

SLPa

ATMOSPHERIC FORCING

North Pacific Oscillation

SLP ANOMALY

UNITS OF STD

-2  0  +2
Winter (JFM)

Audit [JFM]

Units of STD

SLP anomaly

Change in strength of mean atmospheric circulation
SLPa

WINTER (JFM)

ATMOSPHERIC FORCING

North Pacific Oscillation

SLP ANOMALY

-2  0  +2

UNITS OF STD
SLPa

Winter (JFM)

Atmospheric Forcing

North Pacific Oscillation

SLP Anomaly

Units of STD
SLPa

Winter (JFM)

Atmospheric Forcing

North Pacific Oscillation

SSTA in SubTropics

SLP Anomaly

-2 0 +2

Units of STD
Winter (JFM)

Atmospheric Forcing

North Pacific Oscillation

SSTa in SubTropics

Meridional Modes

Spring (JFM)

North Pacific Ocean Dynamics

Meridional Modes

WINTER (JFM)

ATMOSPHERIC FORCING

North Pacific Oscillation

SSTa IN SUBTROPICS

SLPa

Meridional Modes

SPRING (JFM)

Meridional Modes

North Pacific Oscillation

Shift in Convection Cell

SSTa Range [-1C +1C]
ENSO Teleconnection Pattern

**Winter (JFM)**
- Atmospheric Forcing
- Meridional Modes

**Spring (AMJ)**
- High
- Low

**Summer & Fall**
- SSTa Range [-1C +1C]

**Winter (JFM) Next Year**
**ENSO Teleconnection Pattern**

**Meridional Modes**

**Spring (AMJ)**

**Winter (JFM)**

**Atmospheric Forcing**

**Winter (JFM) Next Year**

**Summer & Fall**

**SLPa**

**SSTa**

**Range** [-1°C +1°C]
ENSO Teleconnection Pattern

Meridional Modes

HIGH

LOW

SSTa RANGE [-1C +1C]
ENSO Teleconnection Pattern

Meridional Modes

SST \( \text{Range} \) [-1°C, +1°C]
**Winter (JFM)**

1. SST anomaly map

2. **Meridional Modes**

   **Spring (AMJ)**: ENSO Teleconnection Pattern

3. **Winter (JFM) Next Year**

   SST anomaly range: [-1°C, +1°C]
The diagram illustrates the connection between seasonal modes of the North Pacific Ocean, specifically focusing on ENSO-like and PDO-like patterns. The cycle begins in Winter (JFM) with a NPGO-like mode, transitioning through Spring (AMJ) to a Meridional Modes pattern. In the following Winter (JFM) next year, the PDO-like pattern emerges, completing the cycle. This cycle highlights the interannual variability of the North Pacific Ocean, with connections to both ENSO and PDO teleconnection patterns.
Winter (JFM)

Winter (JFM) NEXT YEAR

Spring (AMJ)

Summer & Fall

NPGO-like

PDO-like

ENSO-like

Meridional Modes

ENSO Teleconnection Pattern

Win 2014

Win 2015

Fall 2015
QUESTION
Was the ENSO teleconnection important in persisting and intensifying the 2015 SSTa?
**Inter-European (JFM) 2014**

**Meridional Modes**

**Spring (AMJ)**

**Winter (JFM)** Next Year

**Summer & Fall**

**ENSO-like**

**PDO-like**

**ARC SSTa Index**


°C -3 -2 -1 0 1 2 3

JFM 2015 ~3 °C

Winter (JFM) 2015

Fall 2015
50 SIMULATIONS with CLIMATE MODEL
To extract the fraction of North Pacific atmospheric forcing of tropical origin
**Meridional Modes**

**Winter (JFM) 2014**

**Spring (AMJ)**

**Summer & Fall**

**Winter (JFM) NEXT YEAR**

**ENSO Teleconnection Pattern**

**PDO-like**

**ARC SSTa Index**

-3
-2
-1
 0
 1
 2
 3


*year*

**Di Lorenzo and Mantua, 2016**

**50 SIMULATIONS with CLIMATE MODEL**

To extract the fraction of North Pacific atmospheric forcing of tropical origin

**JFM 2015**

~3 °C

~1.5 °C

R=0.56

**Fall 2015**

**ENSO-like**
RESULTS

ENSO teleconnection account for ~50% of the 2015 SSTa
QUESTION
Are these type of climate event becoming more frequent?
Meridional Modes

**Strength**
of tropical/extra-tropical coupling

Wang et al. 2014; Yoon et al., 2015

ENSO-like

WINTER (JFM) 2014

NPGO-like

WINTER (JFM) NEXT YEAR

SPRING (AMJ) 2014

FALL 2015
The diagram illustrates the teleconnection patterns of tropical/extra-tropical coupling. It shows two main modes: NPGO-like and ENSO-like. The strength of these coupling patterns is depicted over time, with observed and modeled data compared. The NPGO-like pattern is observed in winter (JFM) 2014, and the ENSO-like pattern is expected in fall (SON) 2015.
**Strength**

of tropical/extra-tropical coupling

- NPGO-like
- ENSO-like

**Winter (JFM)**

**Spring (AMJ)**

**Observed**

**Natural**

**Wang et al. 2014; Yoon et al., 2015**

**Greenhouse Forcing**

(Model)

**Fall 2015**
**Hypothesis:**
Thermodynamic ocean-atmosphere coupling is stronger

*Di Lorenzo et al. 2015, GRL*

- **Winter (JFM) 2014**
  - **NPGO-like**
  - **Meridional Modes**

- **Spring (AMJ)**
  - **ENSO-like**

- **Summer & Fall**

- **Strength of tropical/extra-tropical coupling**

- **Greenhouse Forcing (Model)**

- **Observed Natural (Model)**

- **Wang et al. 2014; Yoon et al., 2015**
QUESTION
Is the variance of the North Pacific climate modes increasing?
Community Earth System Model

30 members Large Ensemble (CESM-LE)

Forced with RCP8.5 greenhouse scenario

1920-2100
**WARM BLOB JFM PATTERNS under GREENHOUSE FORCING**

**GOA Pattern in CESM-LE**
- **EOF2**
  - NPGO-like
- **SFM Pattern**

**ARC Pattern in CESM-LE**
- **EOF1**
  - PDO-like

**THE CESM-LE DOMINANT EOFs OF JFM SSTa CAPTURE THE WARM BLOB PATTERNS**

**JFM SSTa [°C]**

-0.6 -0.3 0 0.3 0.6

**CO2 INCREASE UNDER GREENHOUSE FORCING**

**ENSO-LIKE**

**FIGURES**

**SPRING (AMJ)**
**WARM BLOB JFM PATTERNS under GREENHOUSE FORCING**

### Changes in Variance of GOA Pattern

- **16%** increase in variance of the GOA pattern.
- **1950** to **2100** under RCP8.5 greenhouse scenario.

- **CESM-LE** predicts an intensification of the GOA pattern in the 21st century.

### Changes in Variance of ARC Pattern

- **7%** increase in variance of the ARC pattern.
- **CESM-LE** provides an ensemble mean trend.

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**Figure 4**: Dominant patterns of winter (JFM) SSTa (ºC) variability in the Northeast Pacific from the CESM-LE (blue and red bounding boxes) inferred the two dominant EOFs from 1920-2100 under the RCP8.5 greenhouse scenario. (a) EOF2 and (b) EOF1 capture the warm blob GOA and ARC patterns. The SFM and ENSO pattern in the CESM-LE are shifted to the west, a known bias of climate models. The 20-year running variance of the PCs show an increase in variance. (c) The PC2 shows an increase of 16% in the variance of the GOA SSTa pattern, while PC1 an increase in 7% of the ARC pattern. EOF1 and EOF2 explain ~67% and ~22% of the winter SSTa variance. [Figure redrawn from Di Lorenzo and Mantua, 2016]
ENSO Teleconnection Pattern

Meridional Modes

Winter (JFM) 2014
NPGO-like

Winter (JFM) 2015
PDO-like

Spring (AMJ)

Summer & Fall

Fall 2015
ENSO-like
**CLIMATE HYPOTHESIS for the WARM BLOB in 2014/15**

- **Spring (AMJ)**: Meridional Modes
- **Winter 2014**: NPGO-like
- **Summer & Fall**: ENSO Teleconnection Pattern
- **Winter 2015**: PDO-like
- **Fall 2015**: ENSO-like
CLIMATE HYPOTHESIS for the WARM BLOB in 2014/15

1. ATMOSPHERIC RIDGE GENERATES WARM BLOB WINTER

- **WIN 2014**
  - NPGO-like

2. ENSO Teleconnection Pattern

- **SUMMER & FALL**
  - PDO-like

3. MERIDIONAL MODES

- **SPRING (AMJ)**
  - ENSO-like

- **FALL 2015**
CLIMATE HYPOTHESIS for the WARM BLOB in 2014/15

1. ATMOSPHERIC RIDGE generates WARM BLOB WINTER
   - NPGO-like

2. ENSO TELECONNECTIONS reinforce and add persistence to BLOB NEXT WINTER
   - PDO-like

MERIDIONAL MODES

SPRING (AMJ)

ENSOMO-like

SUMMER & FALL

WIN 2014

WIN 2015

FALL 2015
**CLIMATE HYPOTHESIS for the WARM BLOB in 2014/15**

1. **Atmospheric Ridge** generates Warm Blob Winter
   - **NPGO-like**

2. **ENSO Teleconnections** reinforce and add persistence to Blob Next Winter
   - **PDO-like**

3. **Thermodynamic Feedbacks** may amplify under Greenhouse Forcing
   - **ENSO-like**
CLIMATE HYPOTHESIS for the WARM BLOB in 2014/15

1. ATMOSPHERIC RIDGE generates WARM BLOB WINTER

   WIN 2014

   NPGO-like

   Meridional Modes

2. ENSO TELECONNECTIONS REINFORCE AND ADD PERSISTENCE

   WIN 2015

   PDO-like

3. THERMODYNAMIC FEEDBACKS MAY AMPLIFY UNDER GREENHOUSE FORCING

   20-year Running Correlation between Winter SSTa PC2 (YEAR 0) WITH PC1 (YEAR +1)

   Correlation

   1940 1960 1980 2000 2020

   year

   95% significance
1. Atmospheric Ridge generates Warm Blob Winter

2. ENSO Teleconnections reinforce and add persistence to Blob Next Winter

3. Thermodynamic Feedbacks may amplify under Greenhouse Forcing

Climate Hypothesis for the Warm Blob in 2014/15

- NPGO-like
- PDO-like
- ENSO-like

Meridional Modes

ENSO Teleconnection Pattern

Summer & Fall

Win 2014

Win 2015

Fall 2015
References

References


References


A brief primer on North Pacific climate variability

Mean Winter Atmospheric Circulation
Sea Level Pressure (SLP)
2 dominant types of changes
2 dominant types of changes
2 dominant types of changes
Change in Location

SLPa

PDO-type

SSTa

NPGO-type

Change in Strength
Aleutian
Low
North
Pacific High

Change in Location

PDO-type
ARC Pattern

SLPa

Aleutian
Low
North
Pacific High

Change in Strength

NPGO-type
GOA Pattern

SSTa
Aleutian Low
North Pacific High

Change in Location

Arctic

Change in Strength

ENSO

SSTa

PDO-type ARC Pattern

NPGO-type GOA Pattern
Aleutian Low
North Pacific High

Change in Location

Warm Blob
Winter 2015

PDO-type
ARC Pattern

Warm Blob
Winter 2014

NPGO-type
GOA Pattern

SLPa

SSTa

Change in Strength
DISCUSS

- Atmospheric forcing of warm blob patterns
DISCUSS

- Atmospheric forcing of warm blob patterns
- Mechanisms linking 2014/15 patterns & multi-year persistence
DISCUSS

- Atmospheric forcing of warm blob patterns
- Mechanisms linking 2014/15 patterns & multi-year persistence
- Increase in variance and coupling of North Pacific modes