

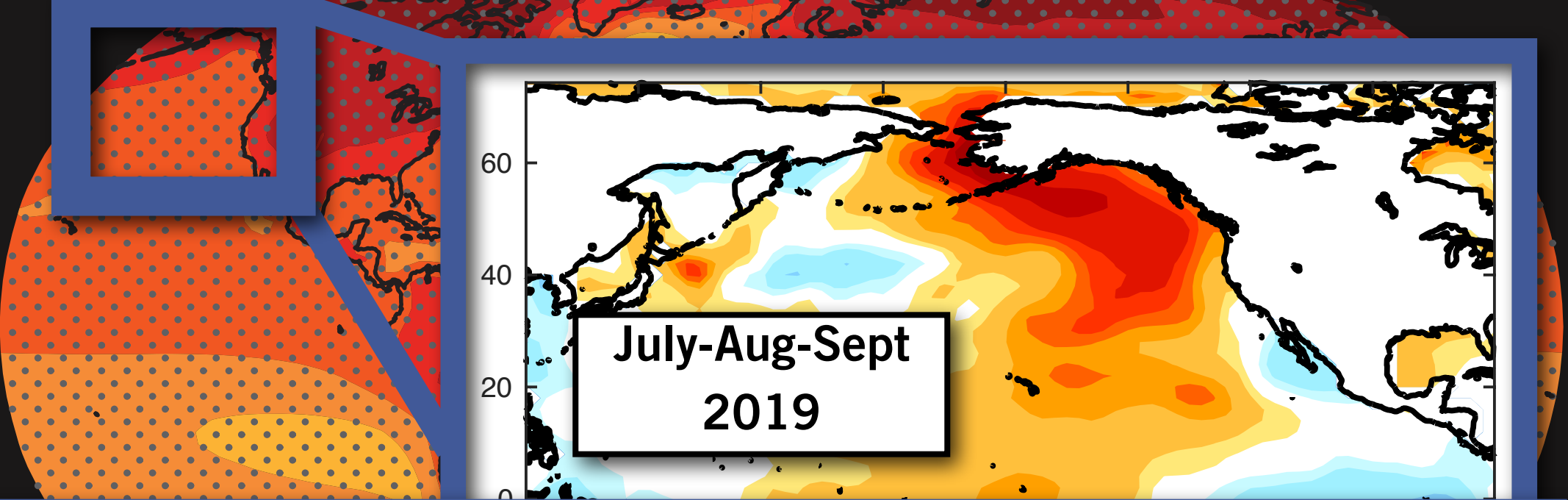
Tongtong Xu



Dillon Amaya

# ALASKA MARINE HEATWAVE 2019

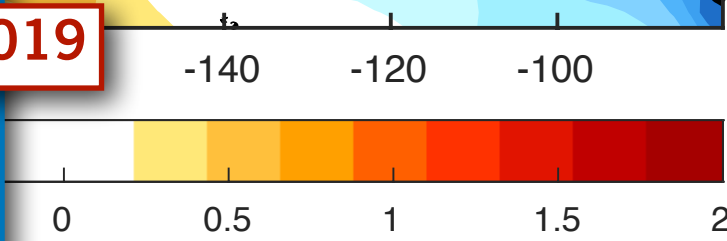
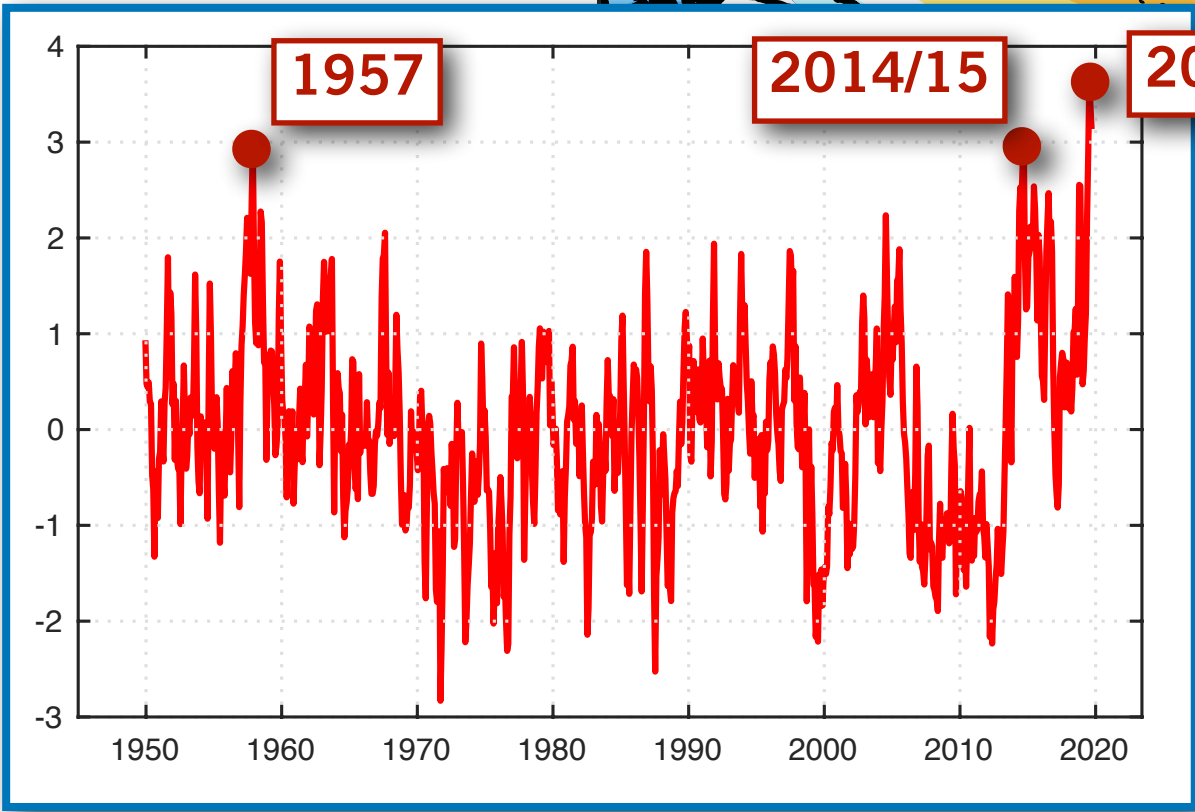
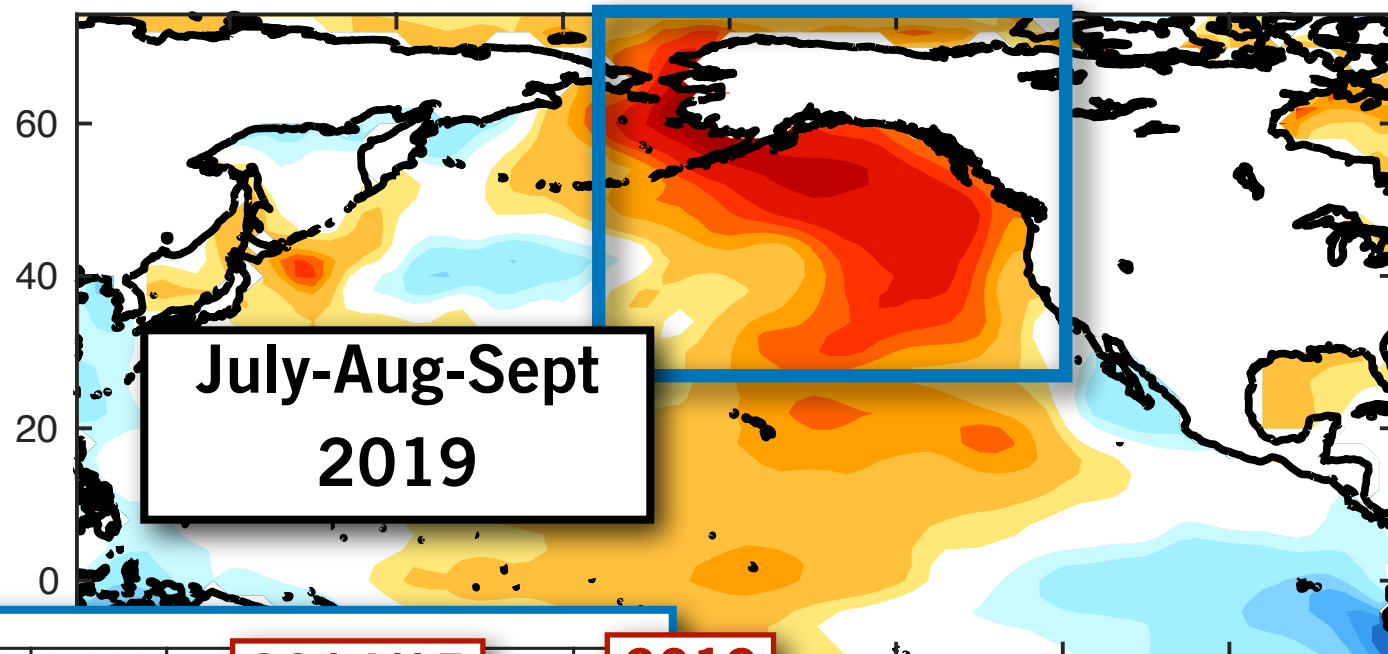
## HOT OFF THE PRESS



# ALASKA MARINE HEATWAVE 2019

HOT OFF THE PRESS

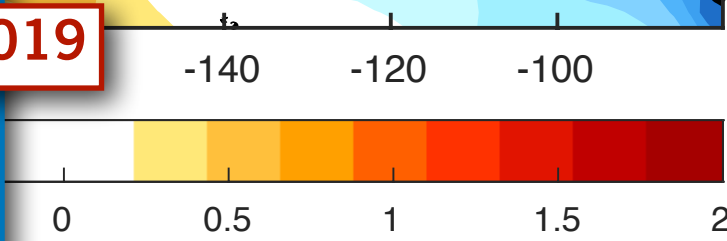
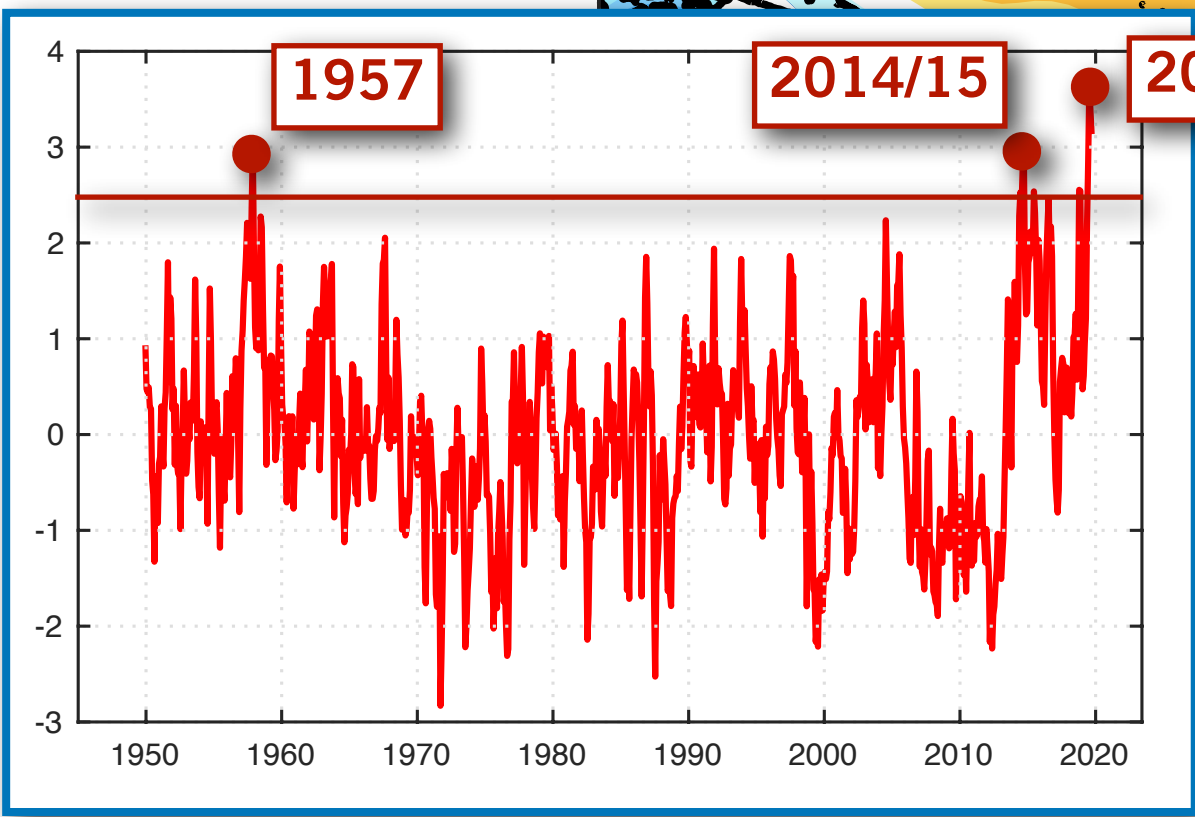
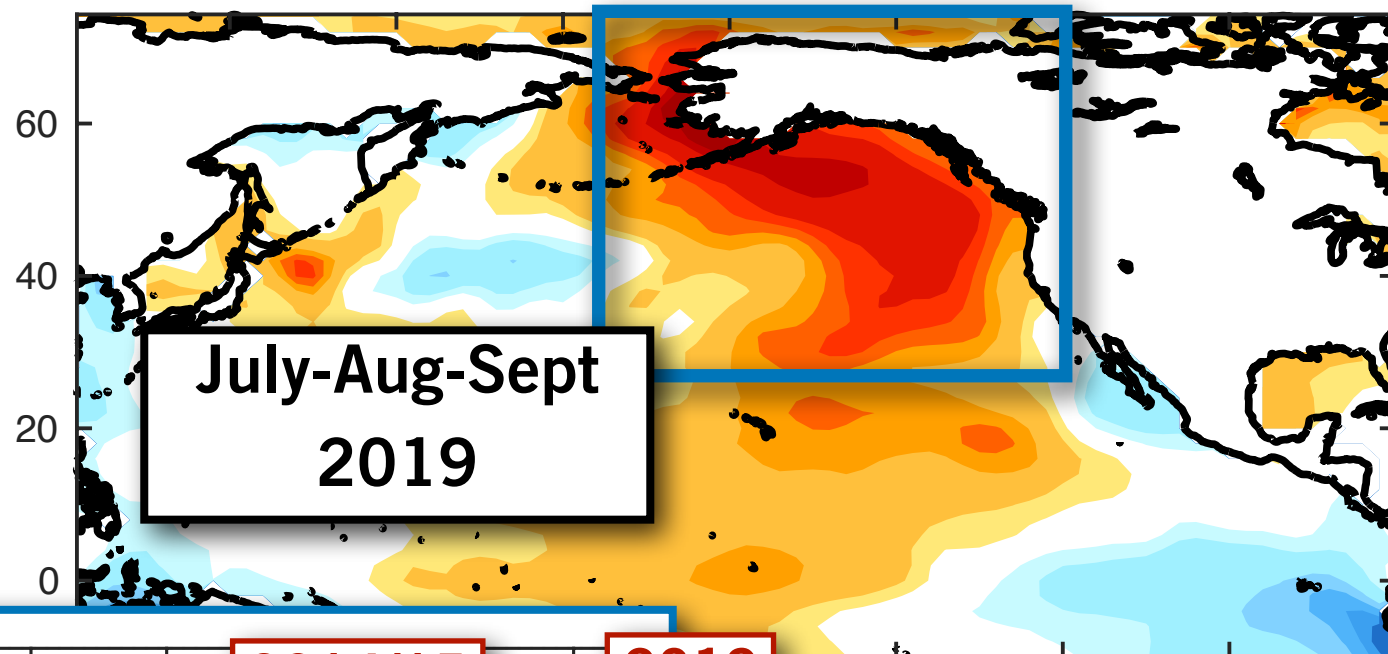
# Sea Surface Temperature Anomalies



C

Marine HeatWave Index  
**MHW Index**

# Sea Surface Temperature Anomalies

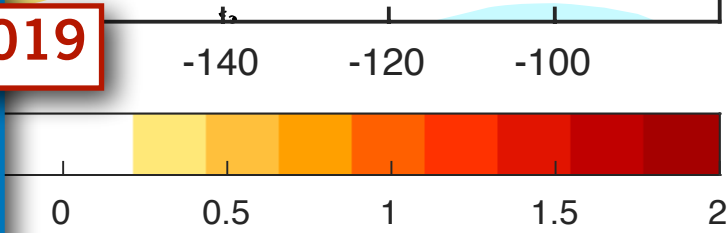
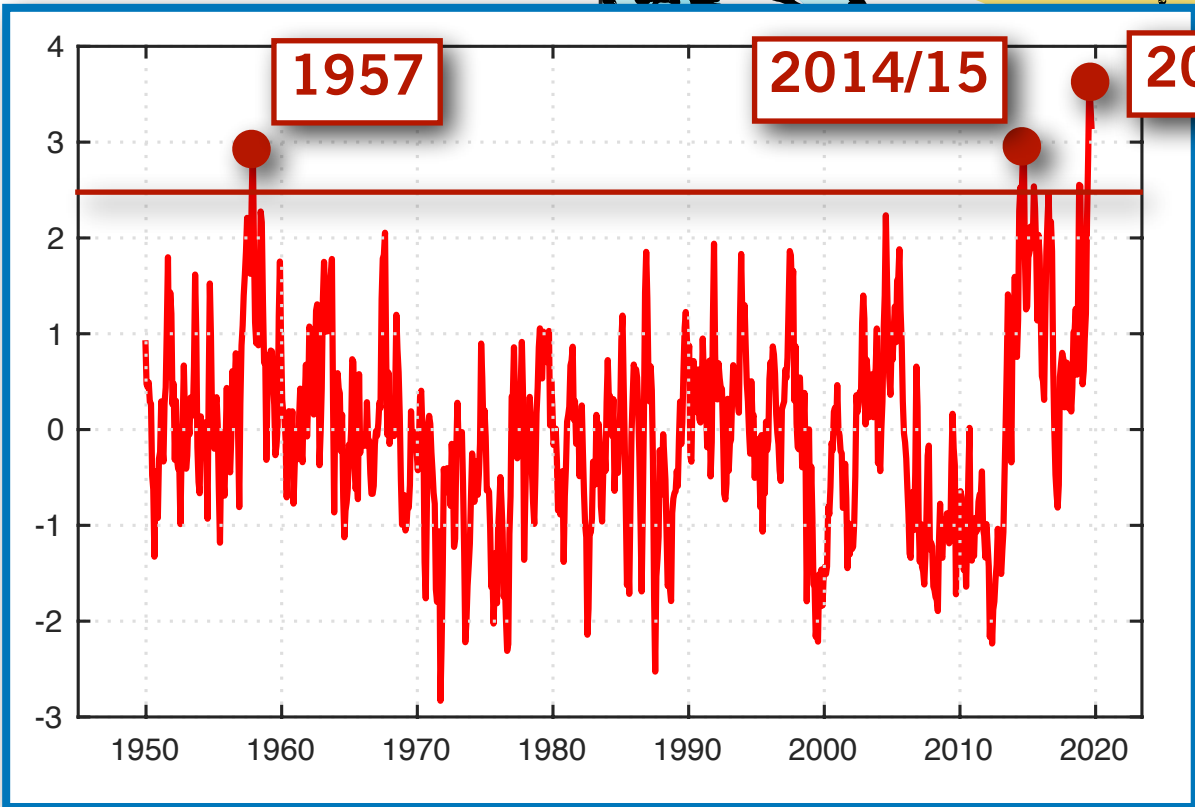
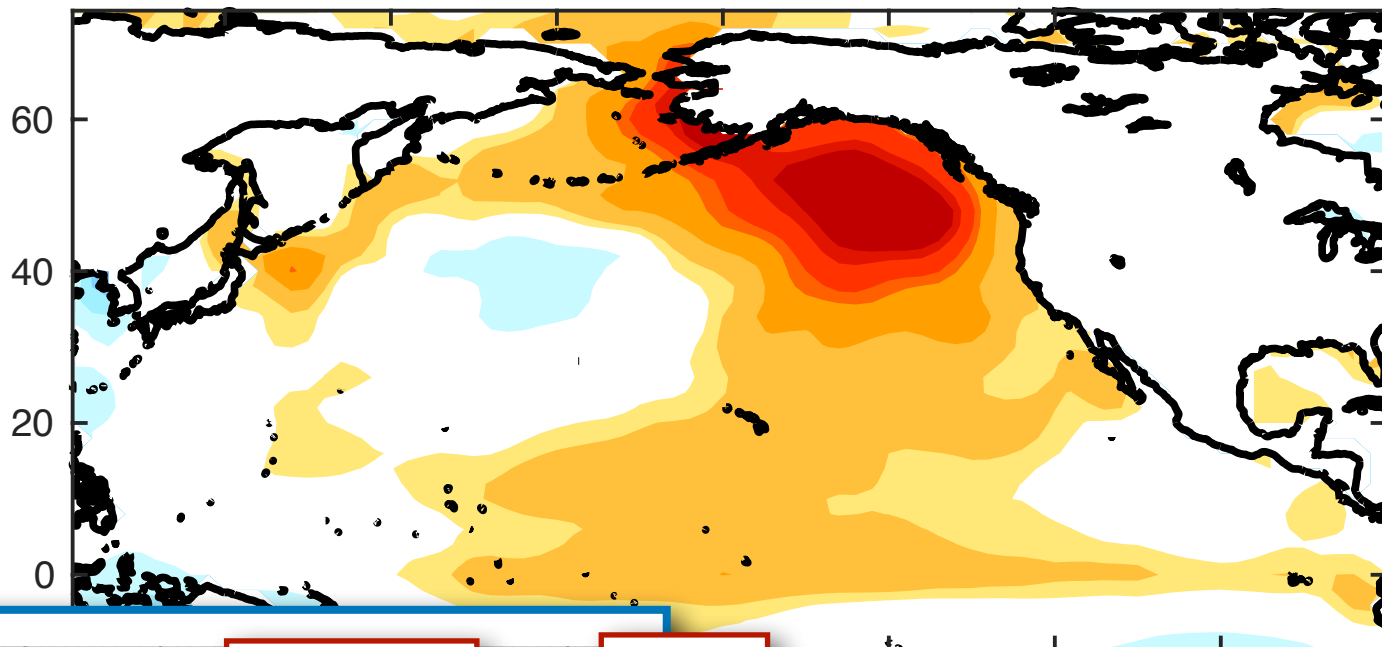


**C**

Marine HeatWave Index  
**MHW Index**

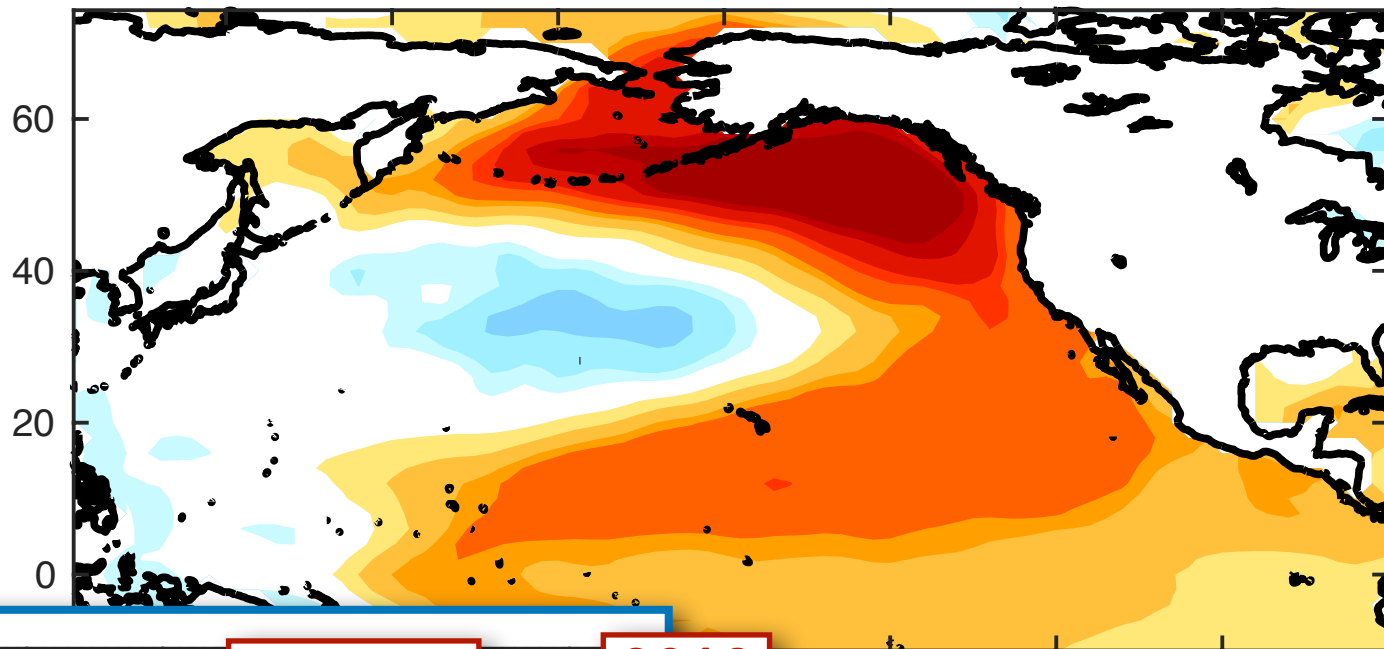
# Sea Surface Temperature Anomalies

Average of  
Extremes

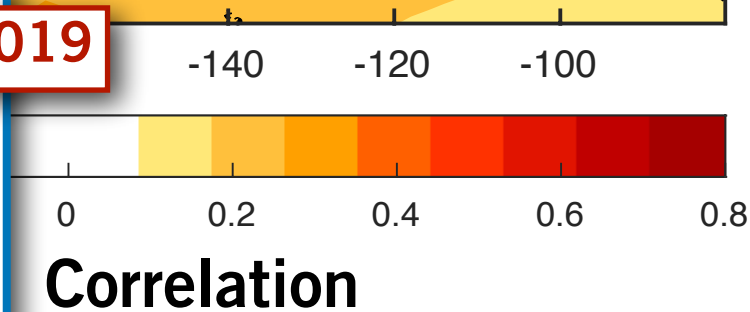
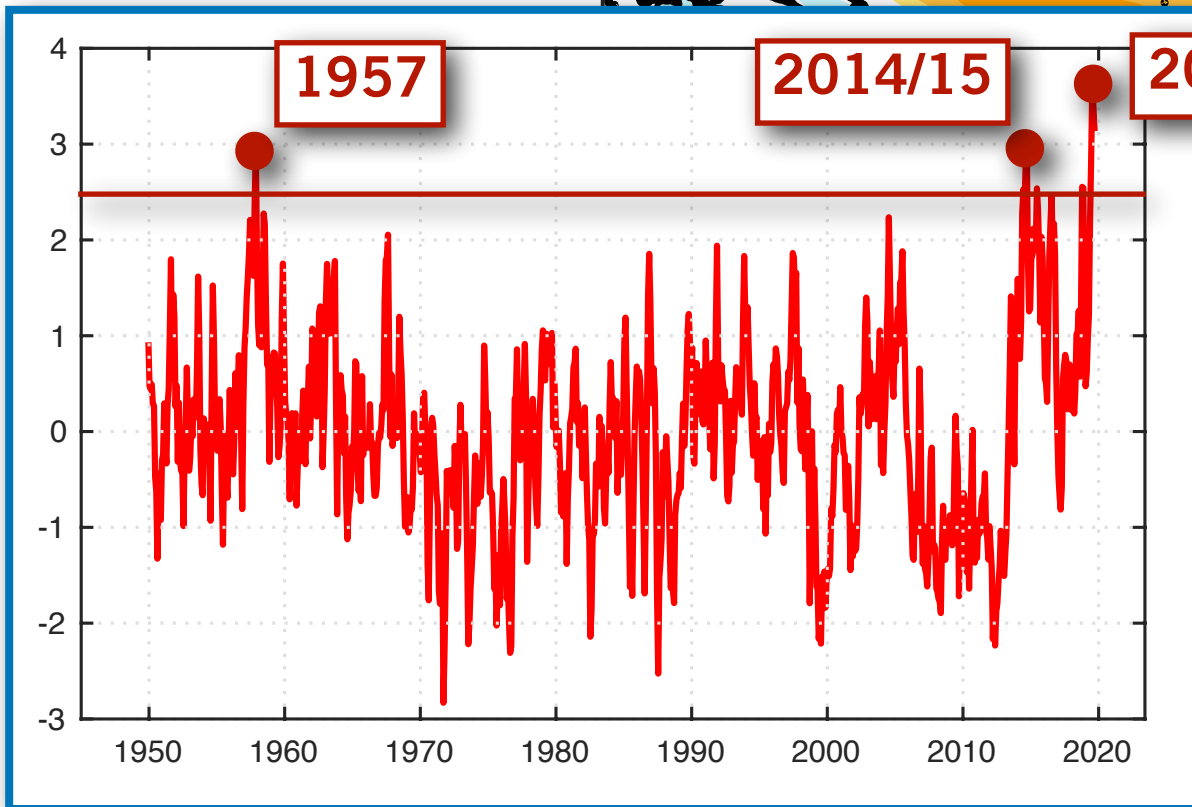


Marine HeatWave Index  
**MHW Index**

# Sea Surface Temperature Anomalies



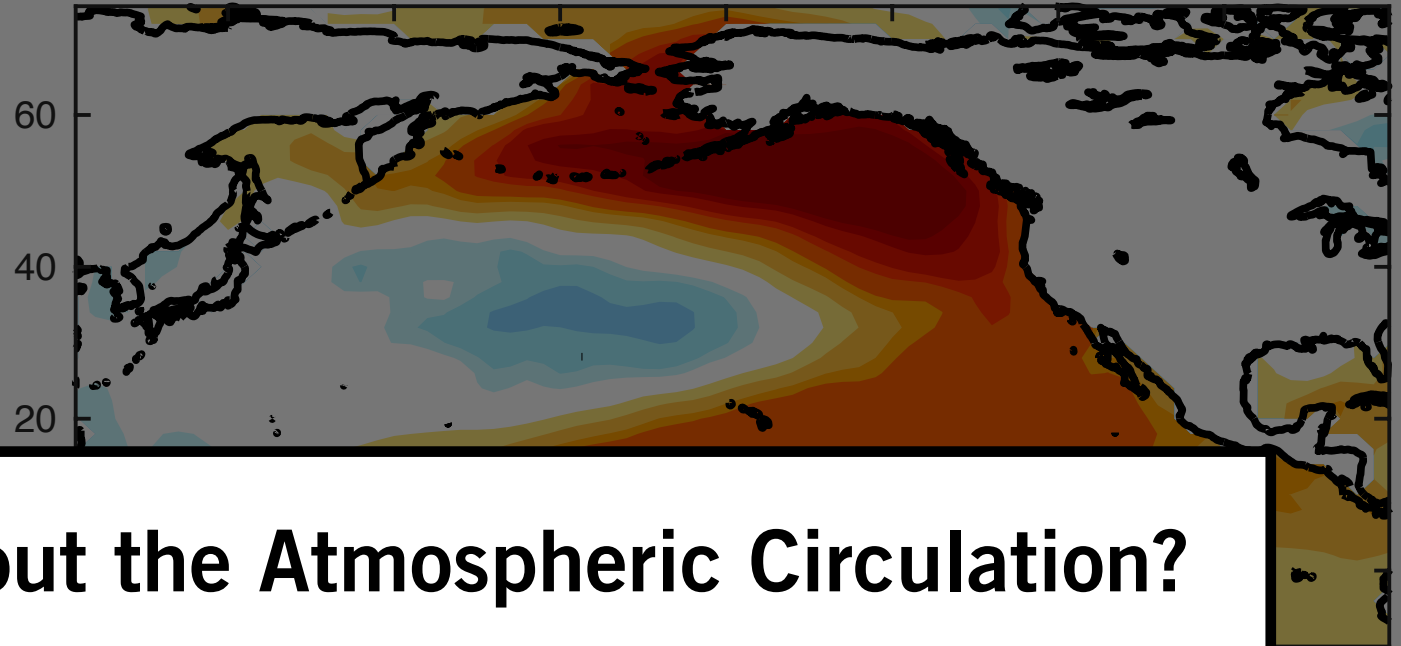
**Correlation of  
MHW Index  
with SSTa**



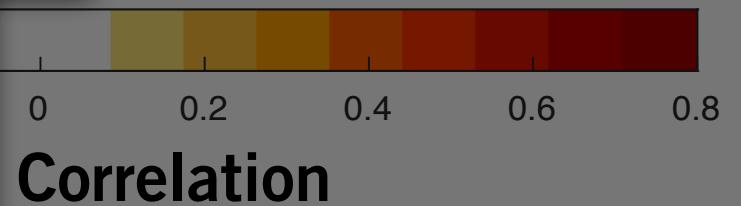
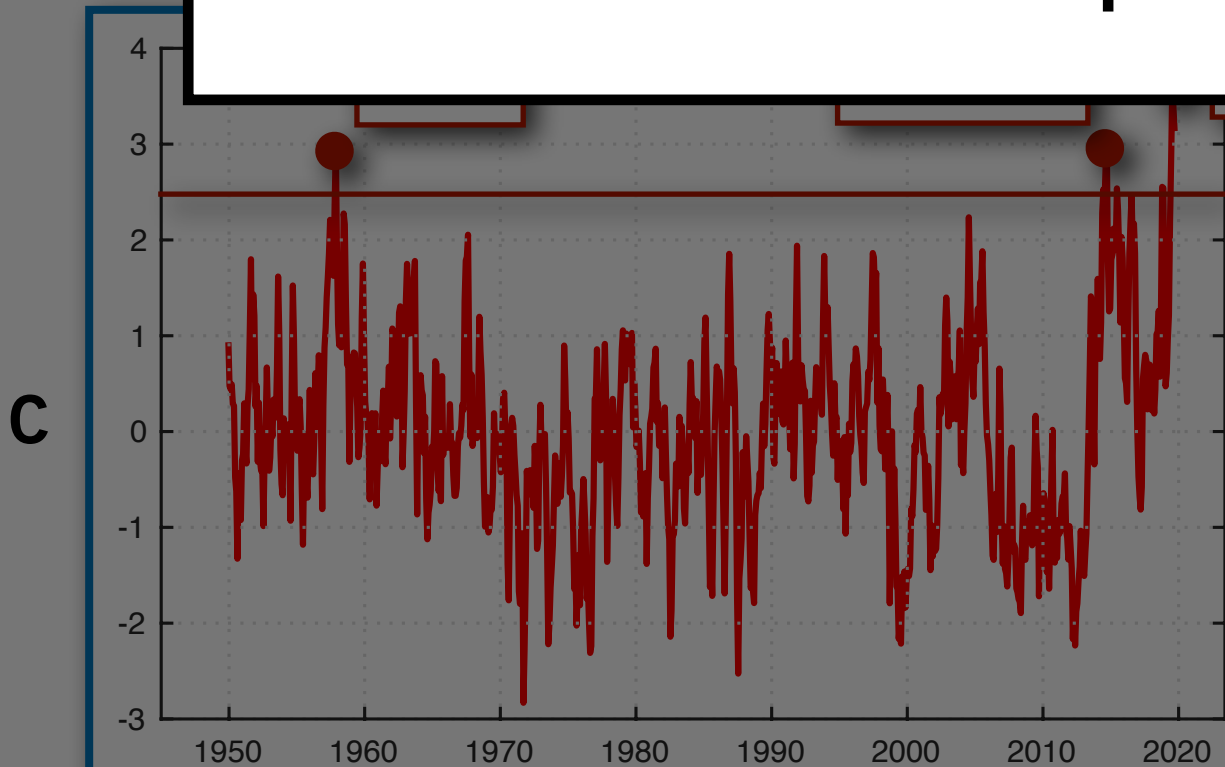
**Marine HeatWave Index  
MHW Index**

# Sea Surface Temperature Anomalies

Correlation of  
MHW Index  
with SSTa



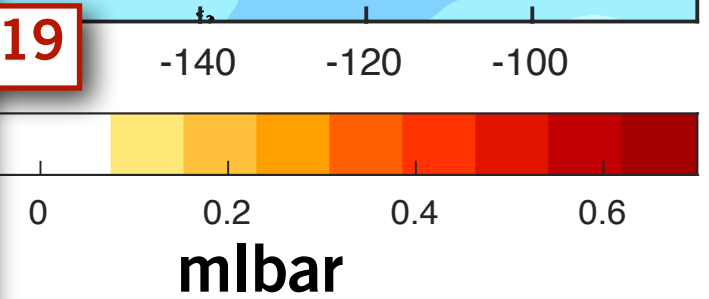
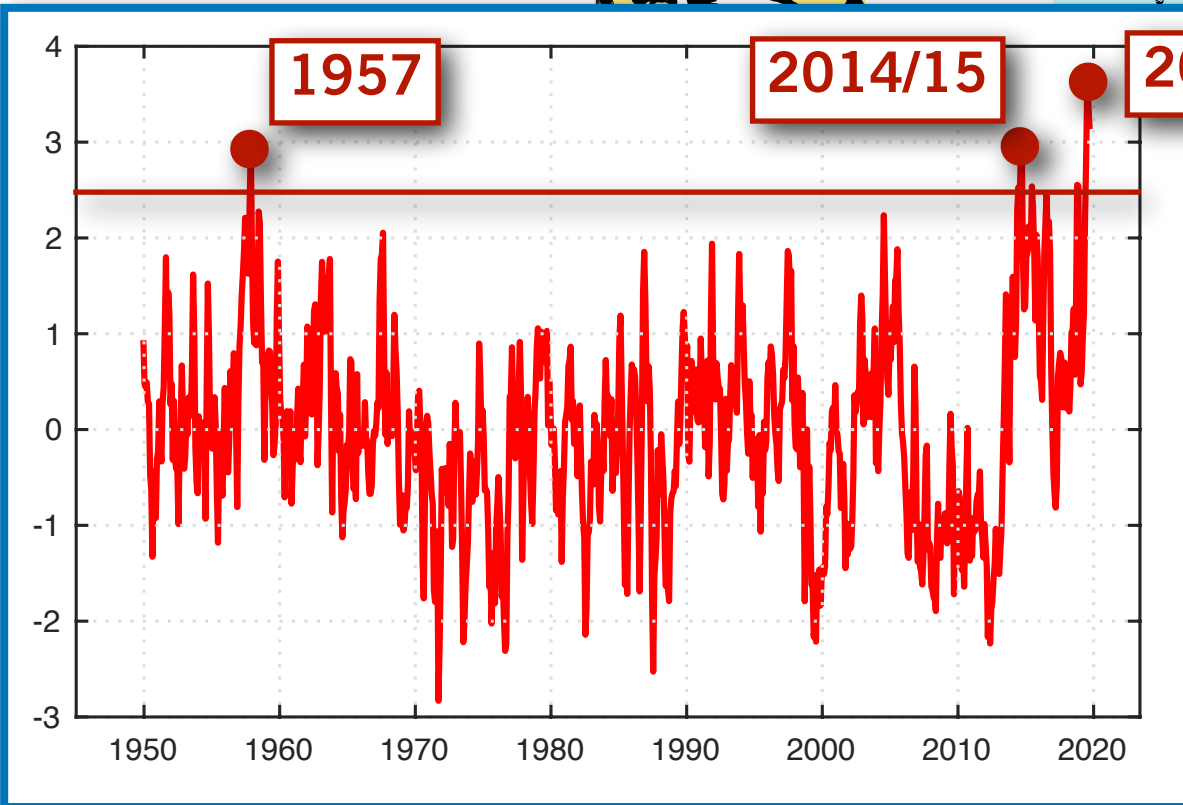
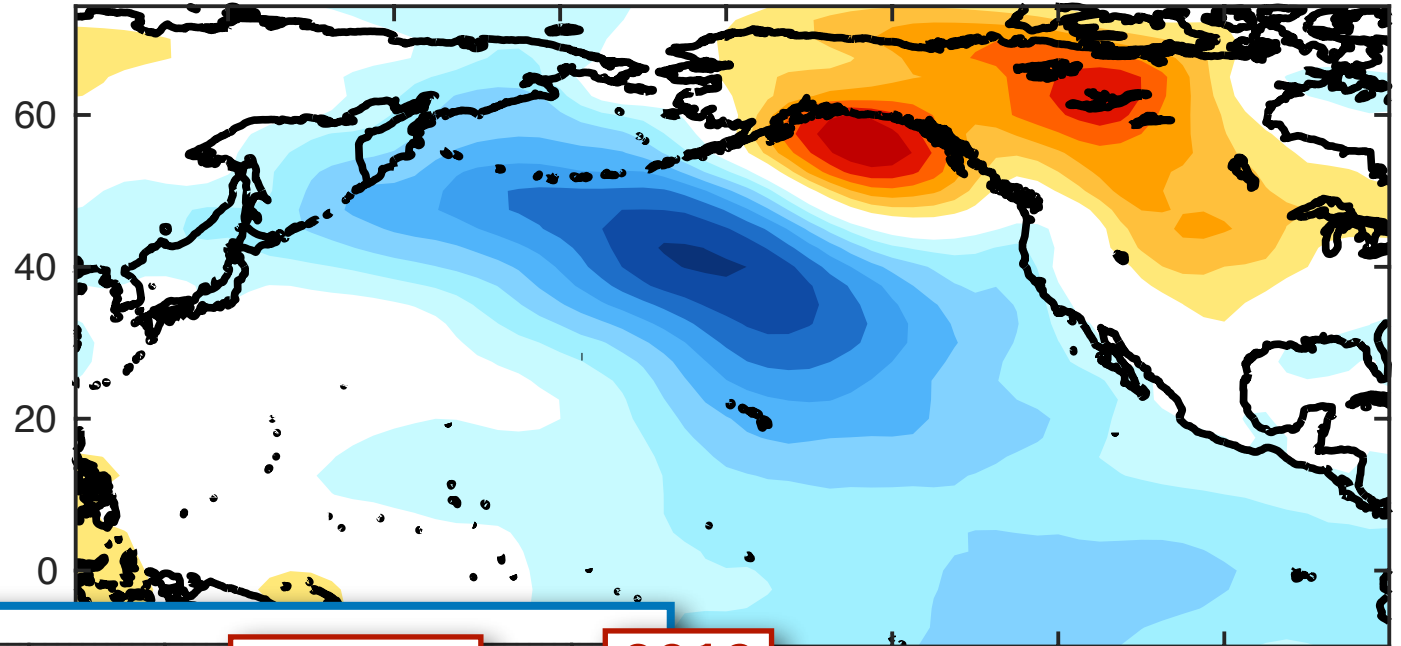
What about the Atmospheric Circulation?



Marine HeatWave Index  
**MHW Index**

# Sea Surface Pressure Anomalies

Regression of  
MHW Index on  
SLPa



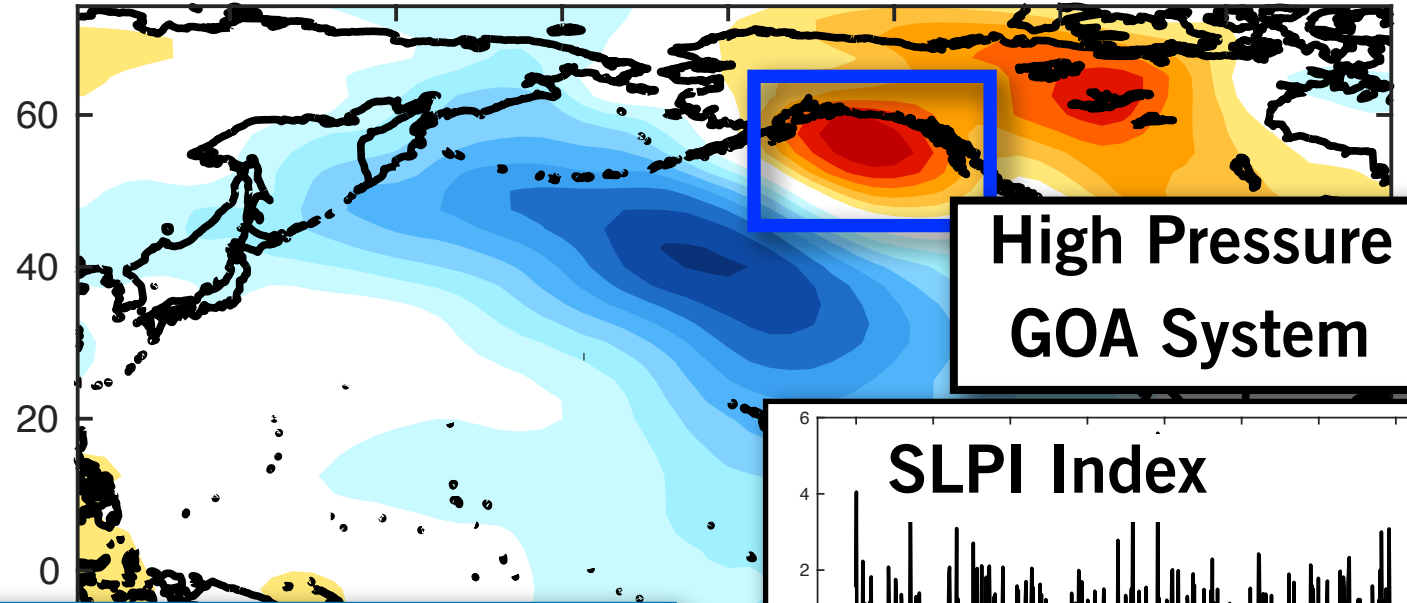
Marine HeatWave Index  
**MHW Index**

C

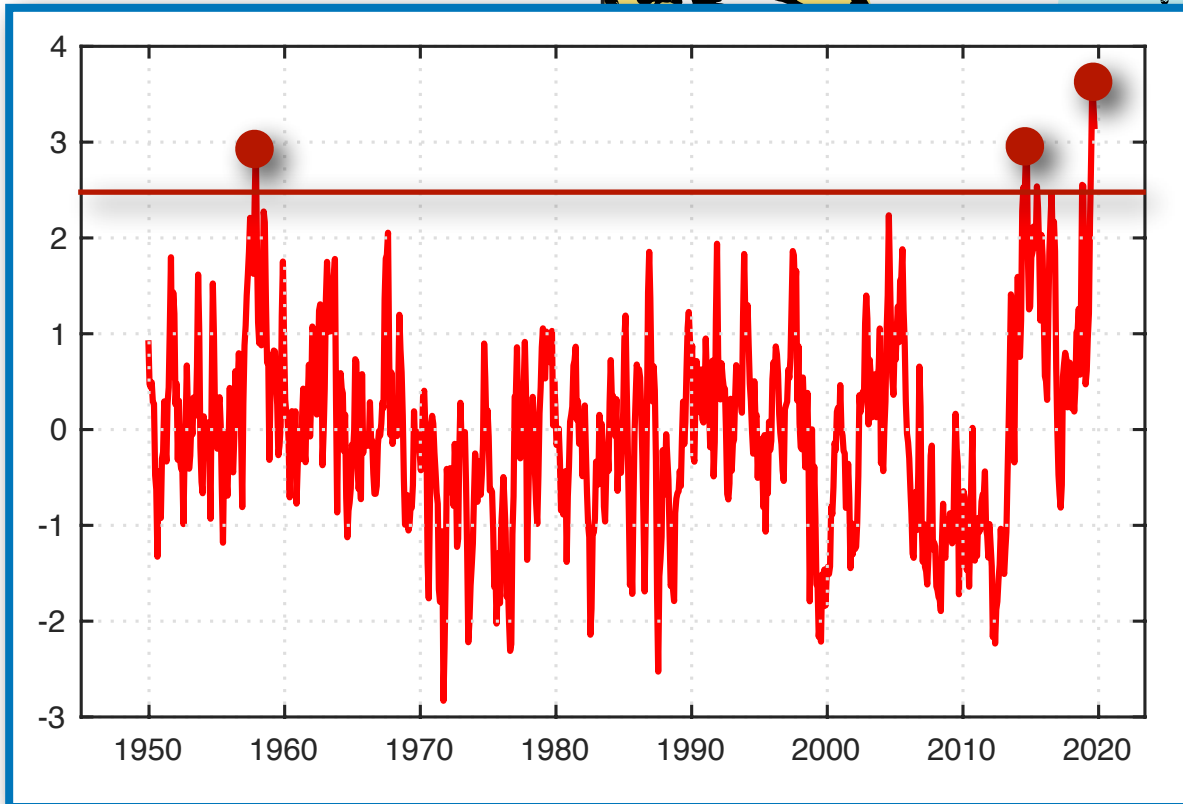
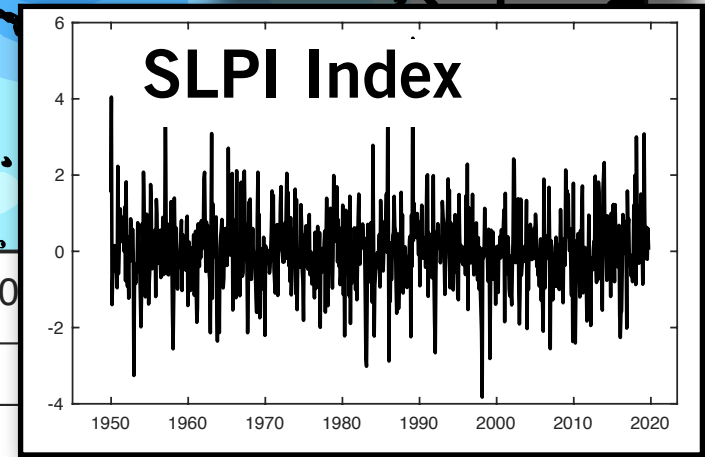


# Sea Surface Pressure Anomalies

Regression of  
MHW Index on  
SLPa



High Pressure  
GOA System

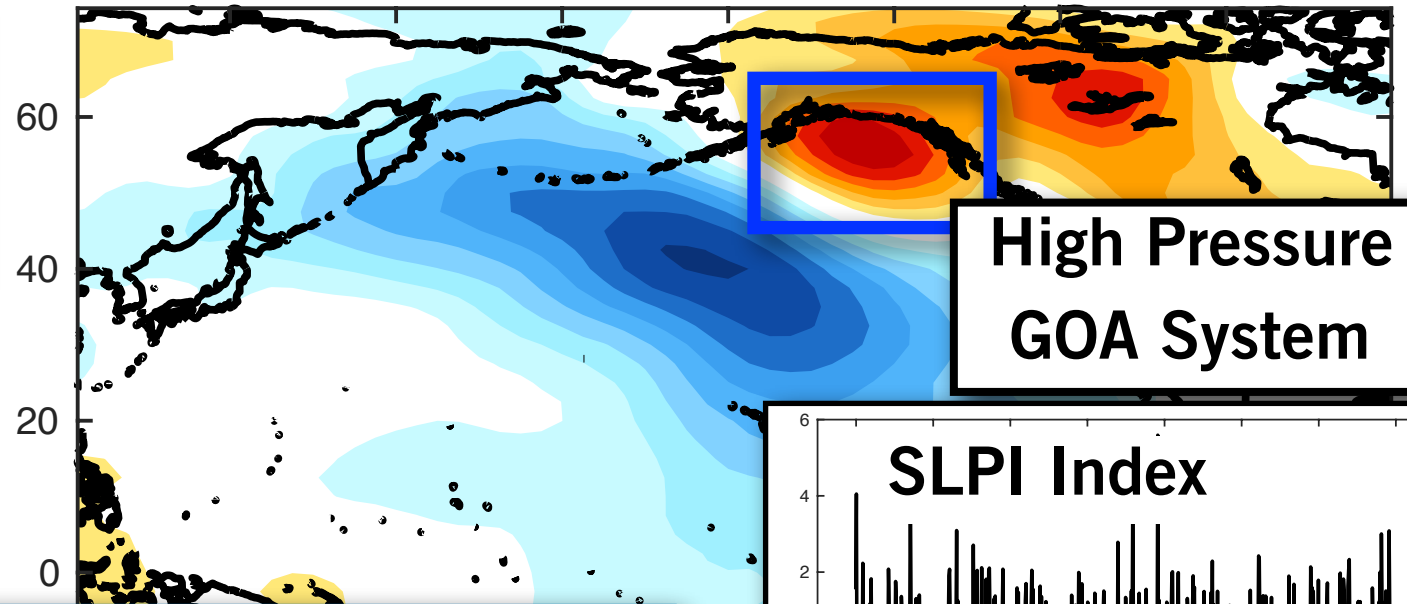


Marine HeatWave Index  
**MHW Index**

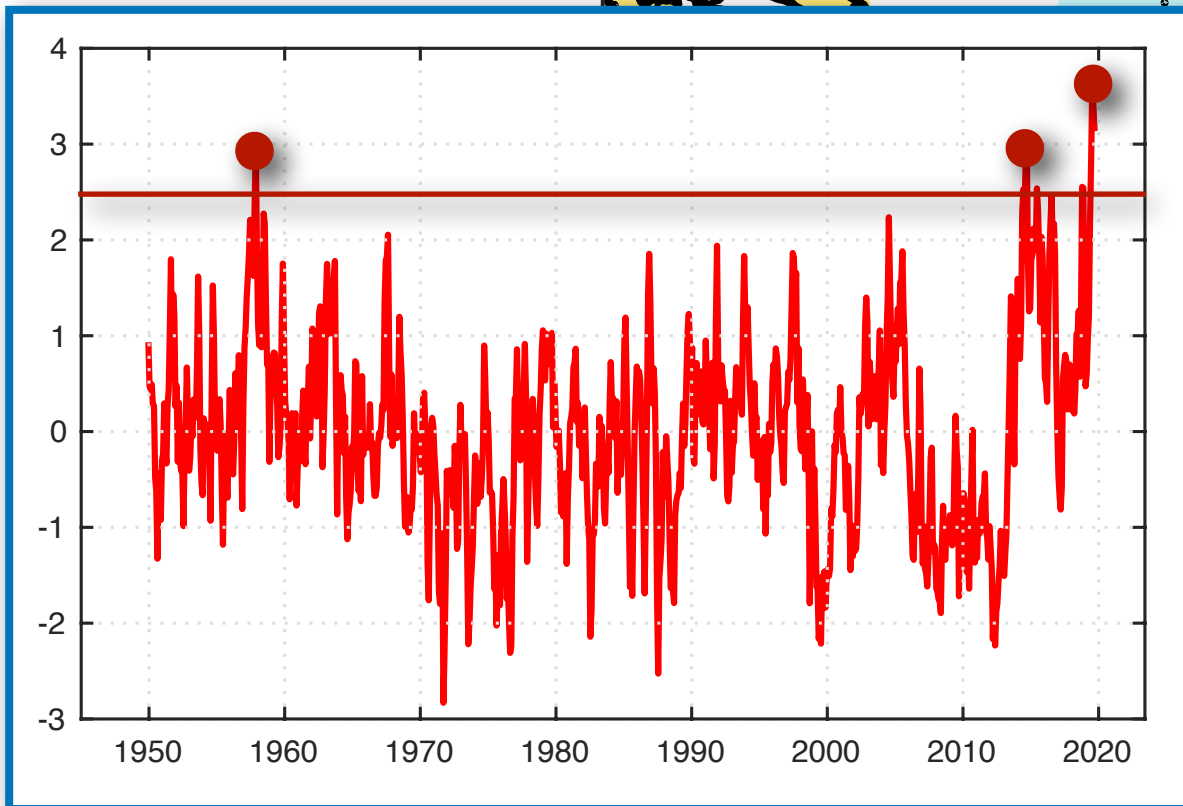
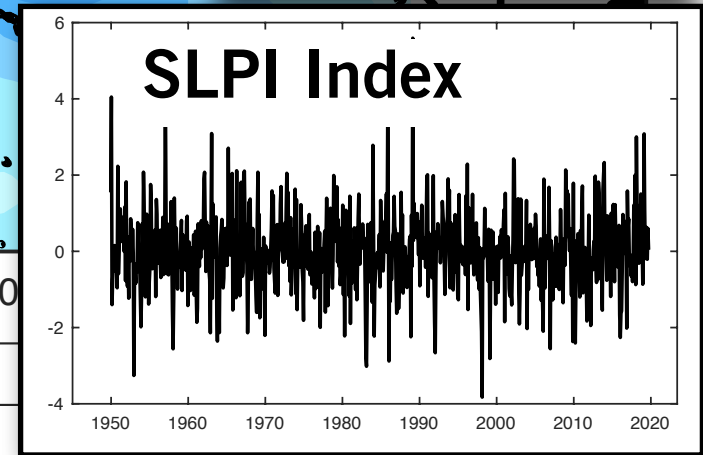
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# Sea Surface Pressure Anomalies

Regression of  
MHW Index on  
SLPa



High Pressure  
GOA System



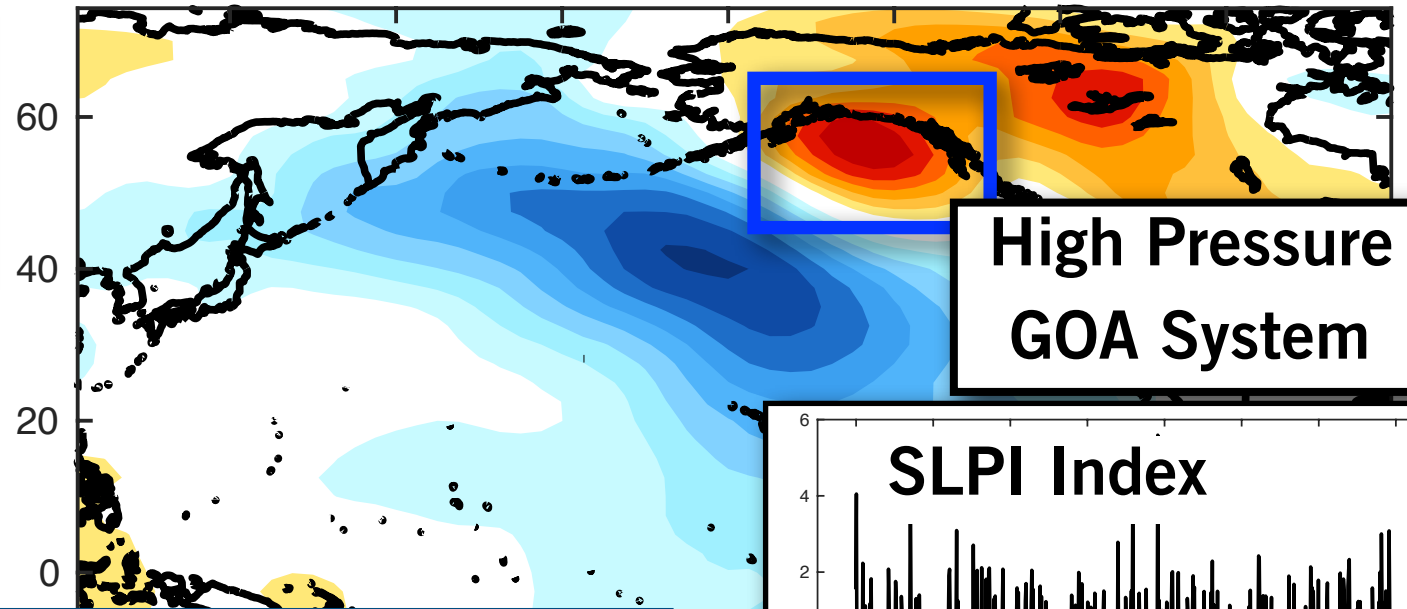
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AR-1 Model

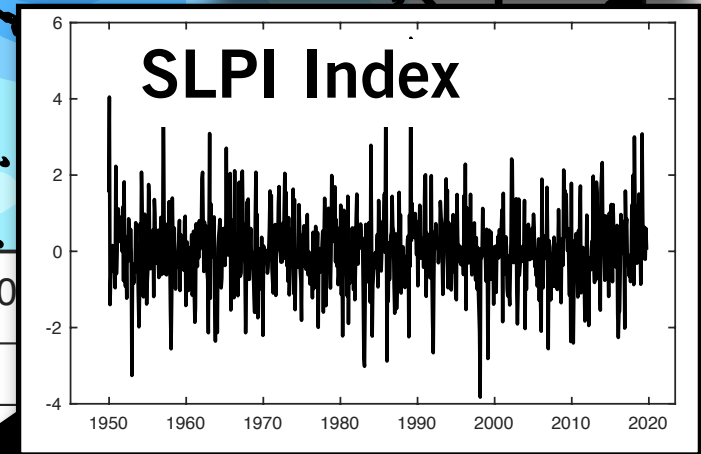
$$\frac{dSSTa(t)}{dt} = a \cdot SLPI(t) - \frac{SSTa(t)}{t_{dissipation}}$$

# Sea Surface Pressure Anomalies

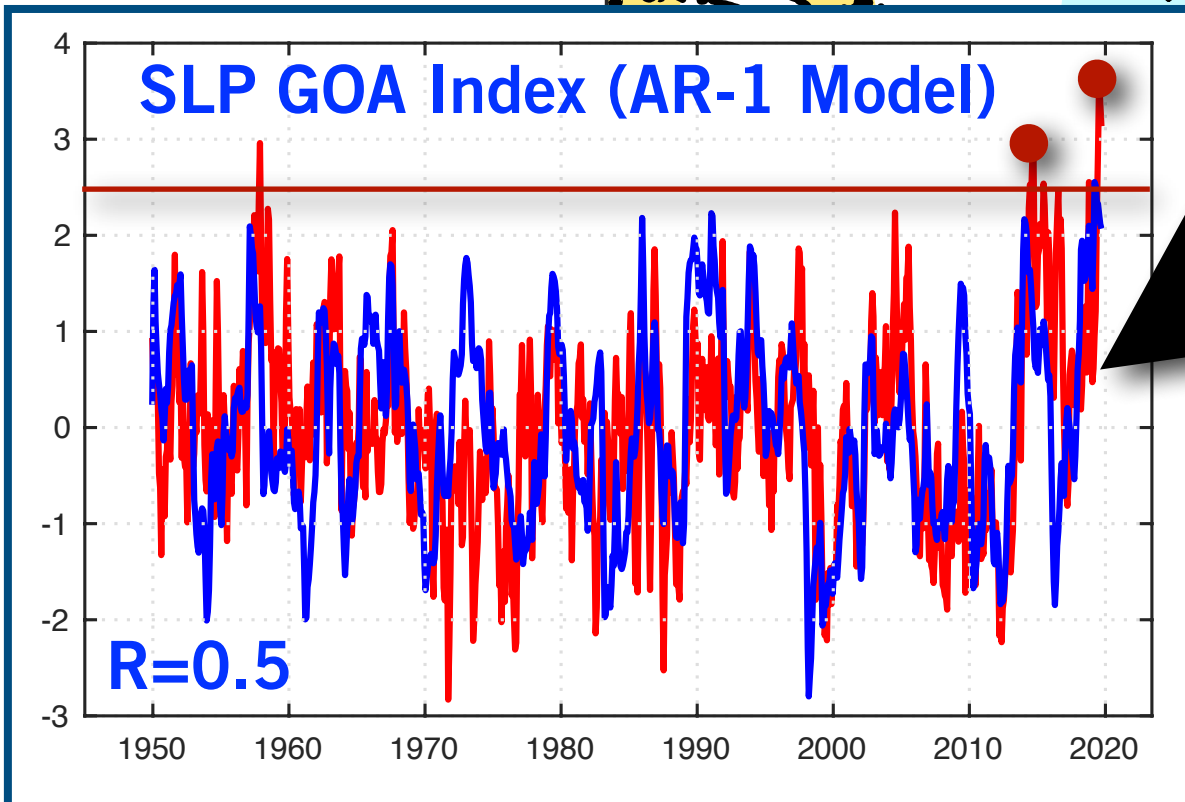
Regression of  
MHW Index on  
SLPa



High Pressure  
GOA System



SLPI Index



SLP GOA Index (AR-1 Model)

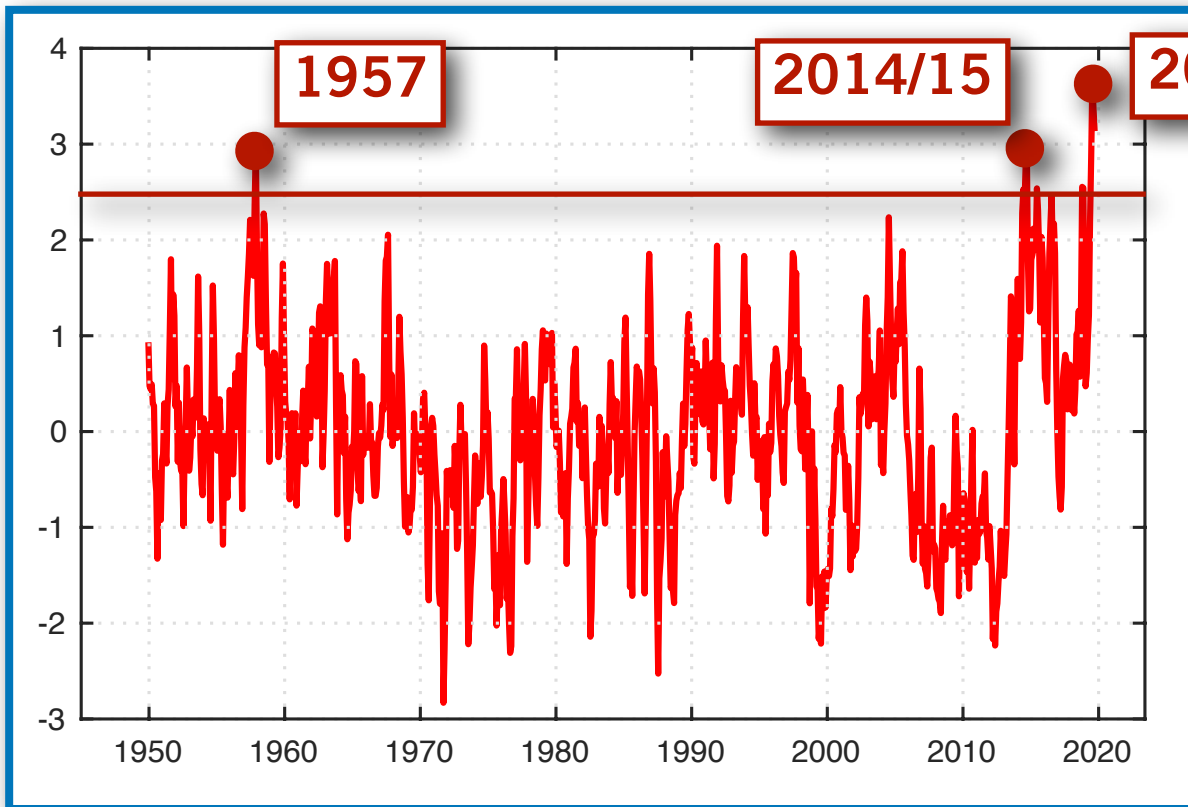
R=0.5

AR-1 Model

$$\frac{dSSTa(t)}{dt} = a \cdot SLPI(t) - \frac{SSTa(t)}{t_{dissipation}}$$

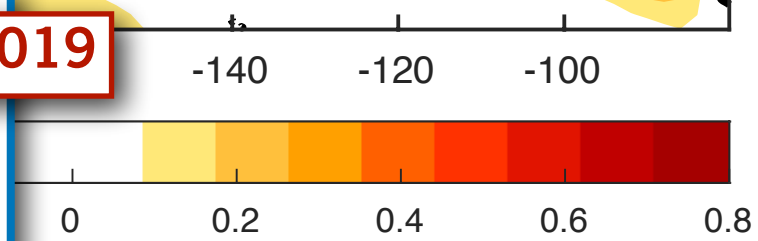
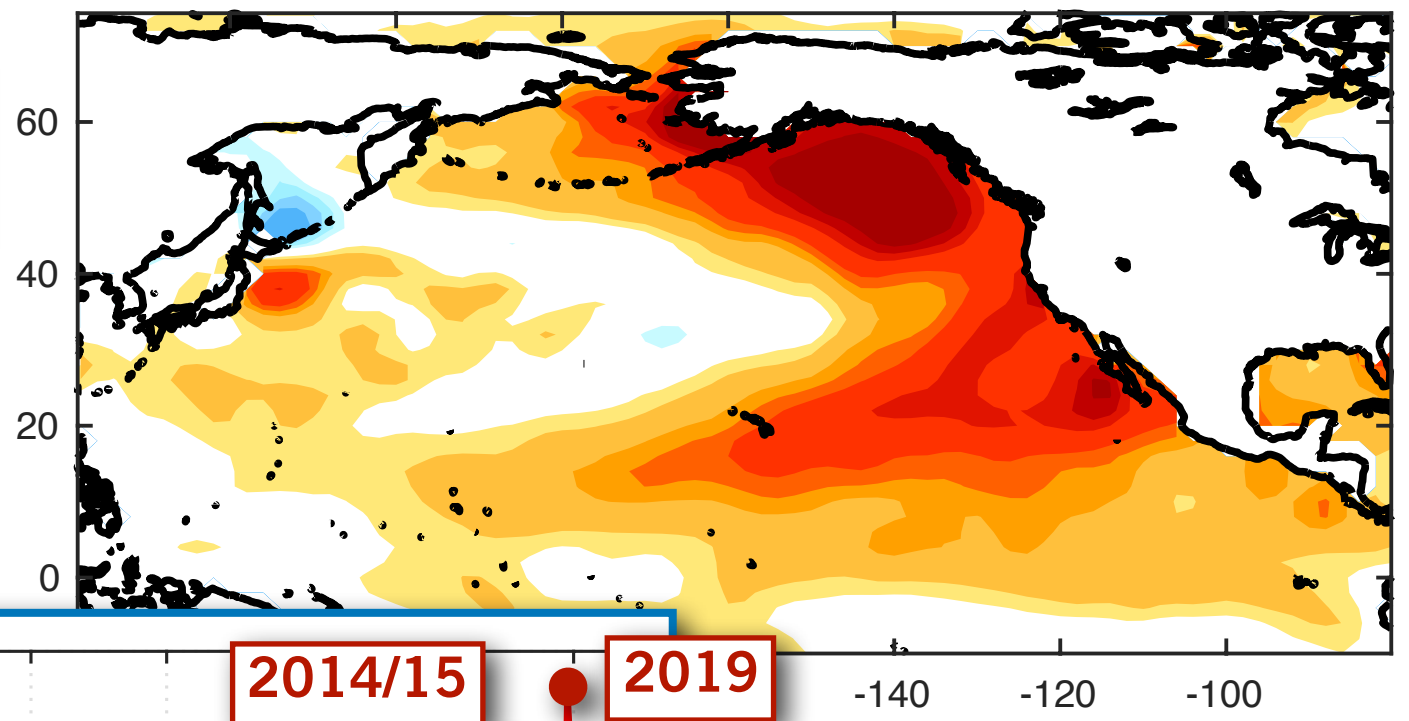
C

C

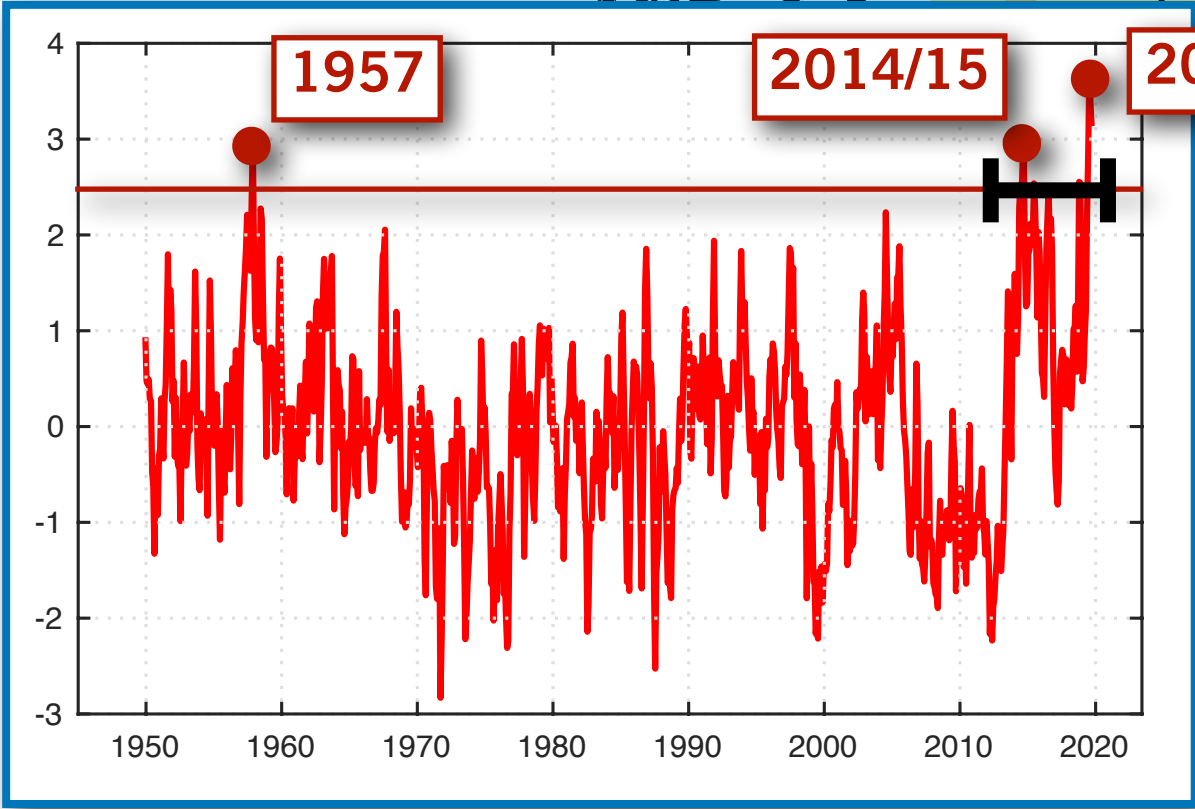


Marine HeatWave Index  
**MHW Index**

# SSTa Anomalies 2013-2019

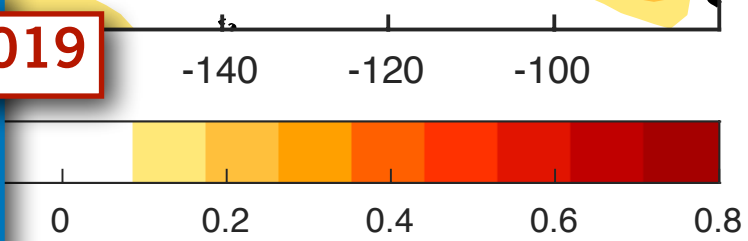
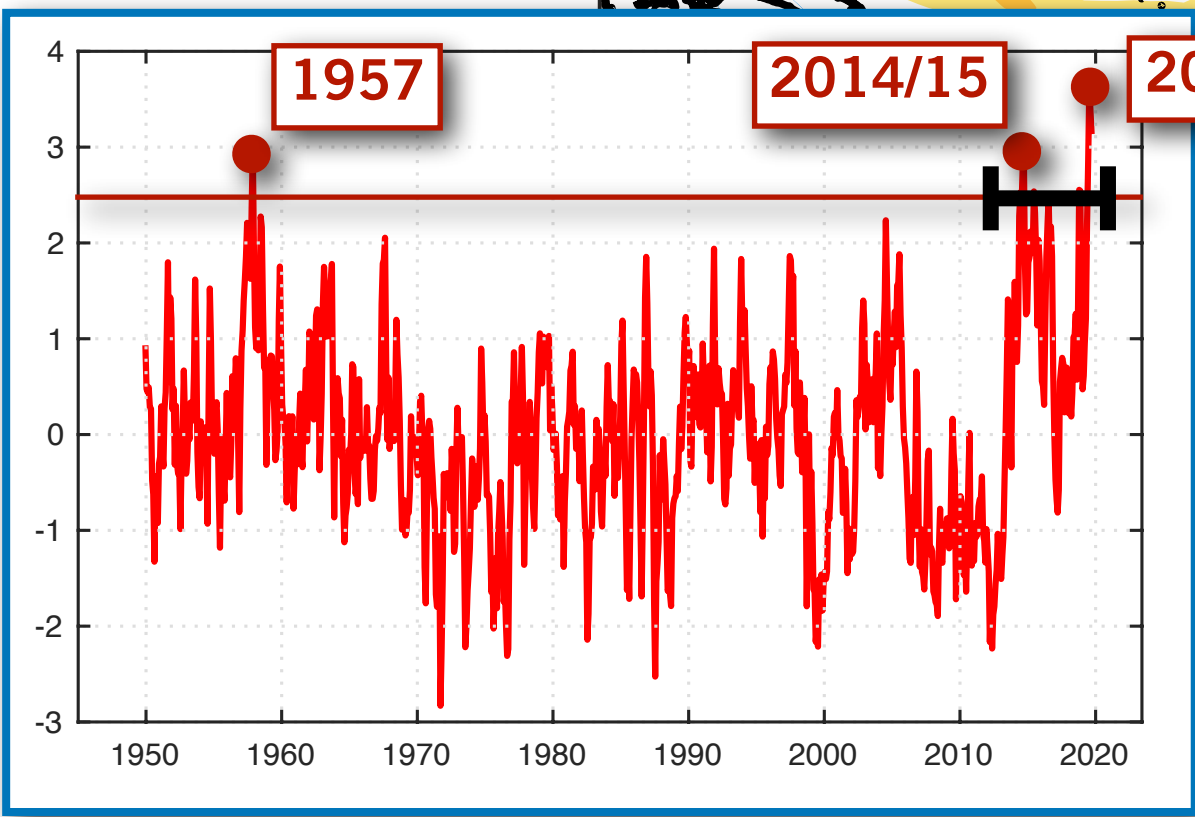
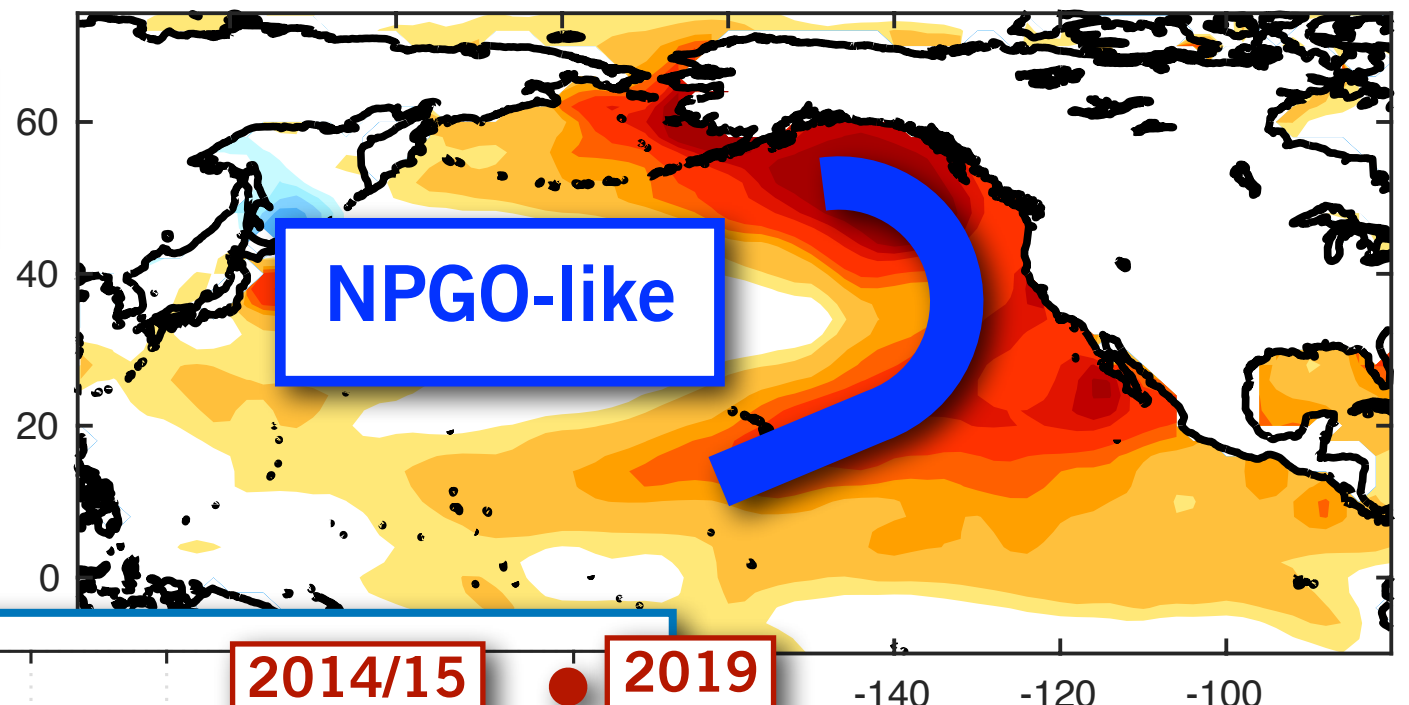


C



Marine HeatWave Index  
**MHW Index**

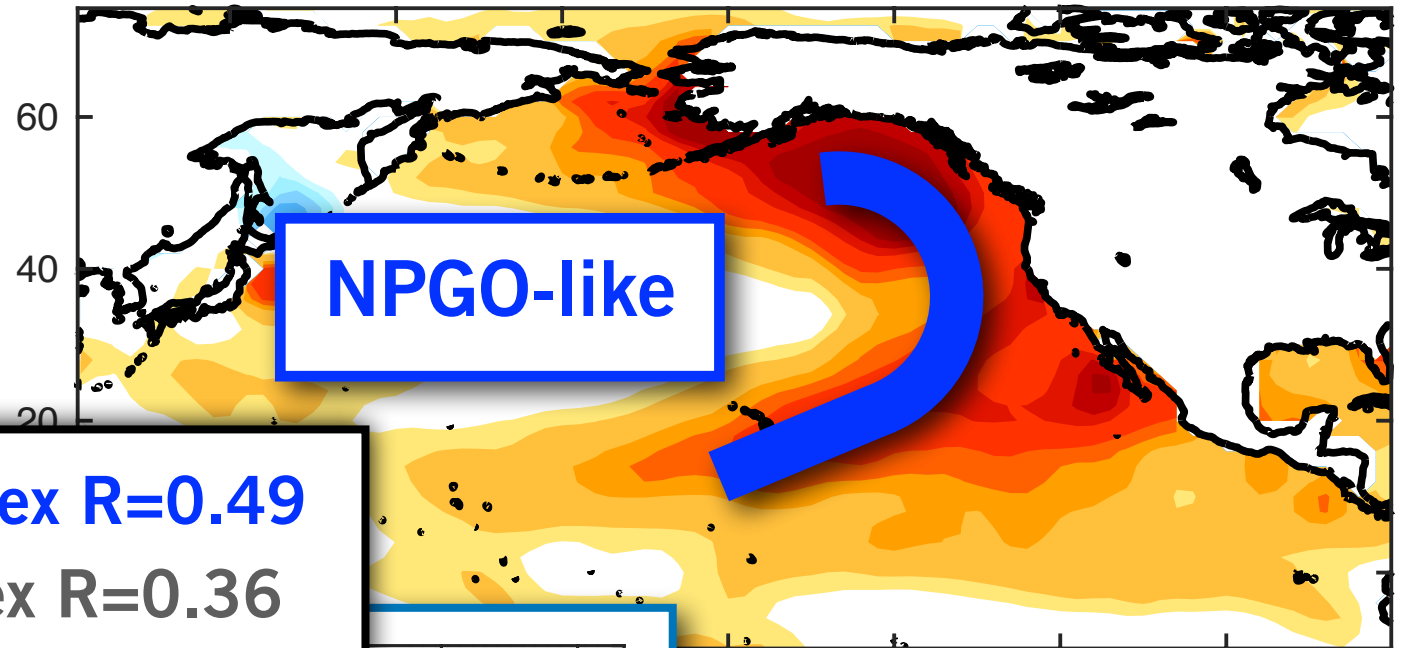
# SSTa Anomalies 2013-2019



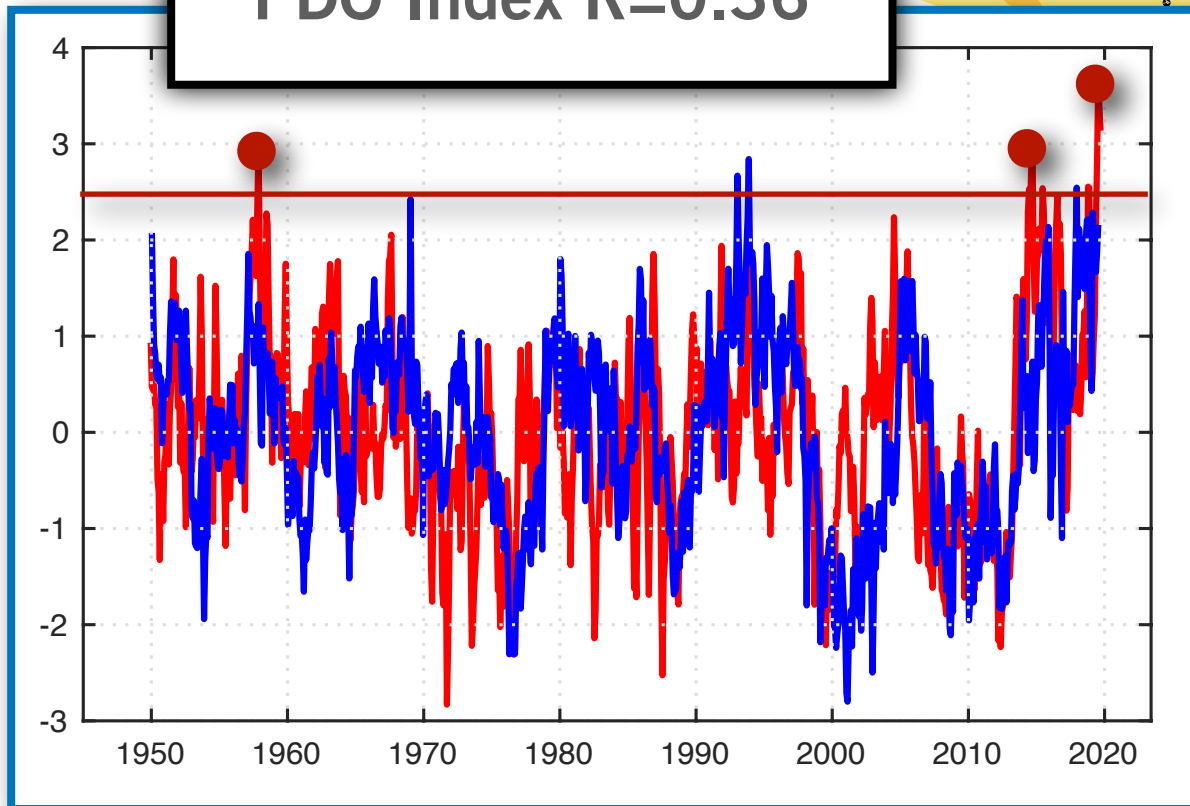
Marine HeatWave Index  
**MHW Index**

C

**SSTa Anomalies  
2013-2019**



**NPGO Index  $R=0.49$   
PDO Index  $R=0.36$**



**Marine HeatWave Index  
MHW Index**

# The dynamics of Marine HeatWave are not independent of the North Pacific climate modes

NPGO Index  $R=0.49$

nature  
climate change

ARTICLES

PUBLISHED ONLINE: 11 JULY 2016 | DOI: 10.1038/NCLIMATE3082

## Multi-year persistence of the 2014/15 North Pacific marine heatwave

Emanuele Di Lorenzo<sup>1\*</sup> and Nathan Mantua<sup>2</sup>

Between the winters of 2013/14 and 2014/15 during the strong North American drought, the northeast Pacific experienced the largest marine heatwave ever recorded. Here we combine observations with an ensemble of climate model simulations to show that teleconnections between the North Pacific and the tropics during the 2014/15 event are consistent with patterns of this event. These teleconnection dynamics from the extratropics to the tropics during the 2014/15 event are consistent with patterns of this event. The corresponding ocean anomalies map onto known patterns of North Pacific decadal variability (PDO) and the Pacific Decadal Oscillation (PDO) in 2014 and 2015. The corresponding ocean anomalies map onto known patterns of North Pacific decadal variability (PDO) and the Pacific Decadal Oscillation (PDO) in 2014 and 2015. The corresponding ocean anomalies map onto known patterns of North Pacific decadal variability (PDO) and the Pacific Decadal Oscillation (PDO) in 2014 and 2015. The corresponding ocean anomalies map onto known patterns of North Pacific decadal variability (PDO) and the Pacific Decadal Oscillation (PDO) in 2014 and 2015.

During the fall of 2013 a large warm temperature anomaly developed in the upper ocean along the axis of the North Pacific Current. As the anomaly spread over a broad region of the Gulf of Alaska (GOA) during the winter of 2013/14, it reached a record-breaking amplitude with sea surface temperature anomalies (SSTa) exceeding three standard deviations ( $\sim 3^\circ\text{C}$ ) (Fig. 1a and Supplementary Fig. 1, see Methods for a description of the datasets and definition of the SSTa indices). The onset and growth of this unusual water mass anomaly is attributed to forcing associated with a persistent atmospheric ridge over the northeast Pacific<sup>1</sup> (Fig. 1b) that is connected to the North Pacific Oscillation (NPO), a leading pattern of atmospheric variability<sup>2</sup>. Extreme amplitude and persistence in the NPO pattern is also implicated in the record drought conditions that affected California during the winter of 2013/14<sup>3-5</sup> and its expression is a known precursor to the summer and fall of 2014, the warmest on record in the history of North America, and the onset of the 2014/15 marine heatwave.

shellfish fisheries. Although this climate event need to be understood in the context of the northeast Pacific warm anomaly and economically significant and nature of the atmosphere-ocean coupling in 2013/14 SSTA, the intensification of the role of ocean internal variability in driving the extreme event is also unclear. It is also unclear whether the 2013/14 SSTA and if they teleconnect to the 2014/15 event. The 2013/14 SSTA and if they teleconnect to the 2014/15 event. The 2013/14 SSTA and if they teleconnect to the 2014/15 event.

AGU PUBLICATIONS

## Geophysical Research Letters

RESEARCH LETTER  
10.1002/2017GL075930

Special Section:  
Midlatitude Marine Heatwaves:  
Forcing and Impacts

### Key Points:

- Multiyear SST warm events in the northeast Pacific typically emerge as a transition to a PDO-like pattern and following winter
- The coupling between winter NPGO and the following winter PDO is a robust climate teleconnection in both observations and the CESM-LENS over the period 1920-2100
- A stronger NPGO-PDO coupling is predicted under anthropogenic forcing in the CESM-LENS and leads to more prolonged and larger area multiyear marine heatwaves

Supporting Information:  
• Supporting Information S1

Correspondence to:  
Y. Joh,  
youngji.joh@gmail.com

### Citation:

Joh, Y., & Di Lorenzo, E. (2017). Increasing coupling between NPGO and PDO leads to more prolonged and larger area multiyear marine heatwaves.

## Increasing Coupling Between NPGO and PDO Leads to Prolonged Marine Heatwaves in the Northeast Pacific

Youngji Joh<sup>1</sup> and Emanuele Di Lorenzo<sup>1</sup>

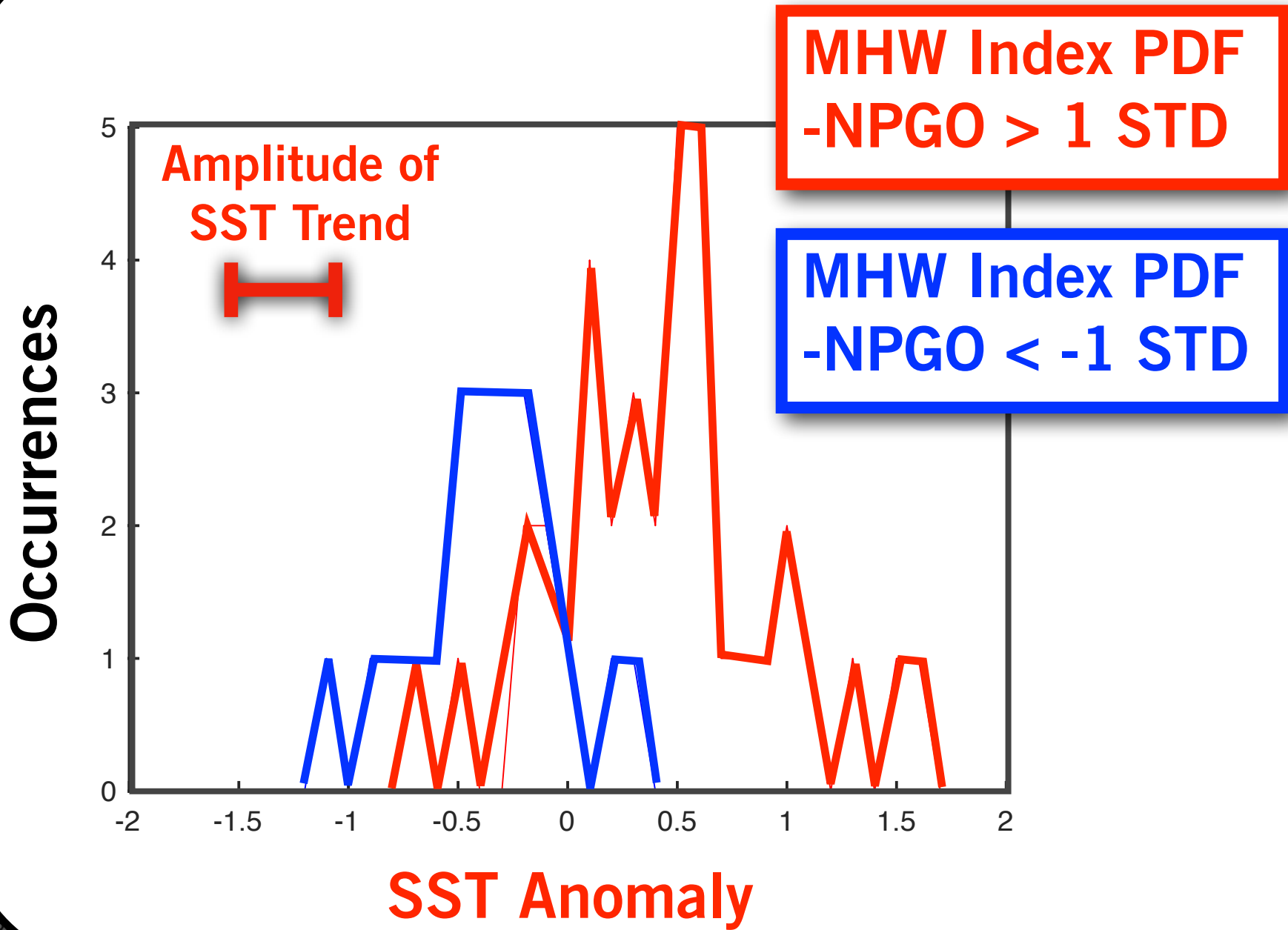
<sup>1</sup>School of Earth and Atmospheric Sciences, Georgia Institute of Technology, Atlanta, GA, USA

**Abstract** The marine heatwave of 2014/2015 in the Northeast Pacific caused significant impacts on marine ecosystems and fisheries. While several studies suggest that land and marine heatwaves may intensify under climate change, less is known about the prolonged multiyear nature ( $\sim 2$  years) of the Northeast Pacific events. Examination of reanalysis products and a 30-member climate model ensemble confirms that prolonged multiyear marine heatwaves are linked to the dynamics of the two dominant modes of winter sea surface temperature variability in the North Pacific, the Pacific Decadal Oscillation (PDO), and the North Pacific Gyre Oscillation (NPGO). Specifically, we find a significant correlation between winter warm NPGO anomalies and the following winter PDO arising from extratropical/tropical teleconnections. In the model projections for 2100 under the RCP8.5 scenario, this NPGO/PDO 1 year lag correlation exhibits a significant positive trend ( $\sim 35\%$ ) that favors more prolonged multiyear warm events ( $\geq 1^\circ\text{C}$ ) with larger spatial coverage ( $\sim 18\%$ ) and higher maximum amplitude ( $\sim 0.5^\circ\text{C}$  for events  $> 2^\circ\text{C}$ ) over the Northeast Pacific.

**Plain Language Summary** Between the winters of 2014 and 2015, the Northeast Pacific experienced the largest and longest marine heatwave ever recorded. This event is linked to the dynamics of two dominant modes of winter sea surface temperature variability in the North Pacific, the Pacific Decadal Oscillation (PDO) and the North Pacific Gyre Oscillation (NPGO). By analyzing and comparing the 2014/15 event to model projections for 2100, we find that the coupling between NPGO and PDO leads to more prolonged and larger area multiyear marine heatwaves.



C



8

-3

# Observational Record

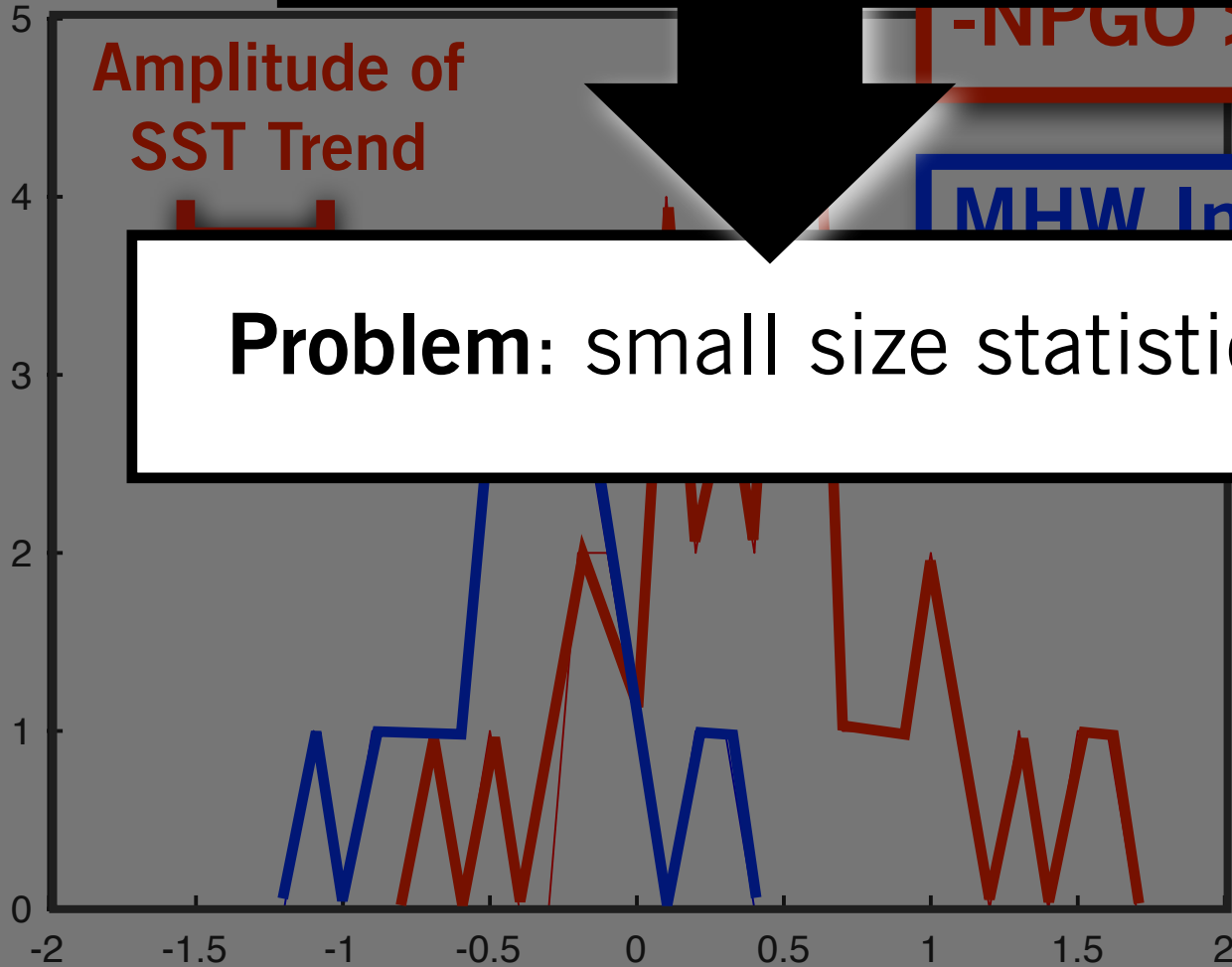
Amplitude of  
SST Trend

MHW Index PDF  
 $-NPGO > 1 \text{ STD}$

MHW Index PDF  
STD

Problem: small size statistics

Occurrences



SST Anomaly

C

-3

8

# Observational Record

Amplitude of  
SST Trend

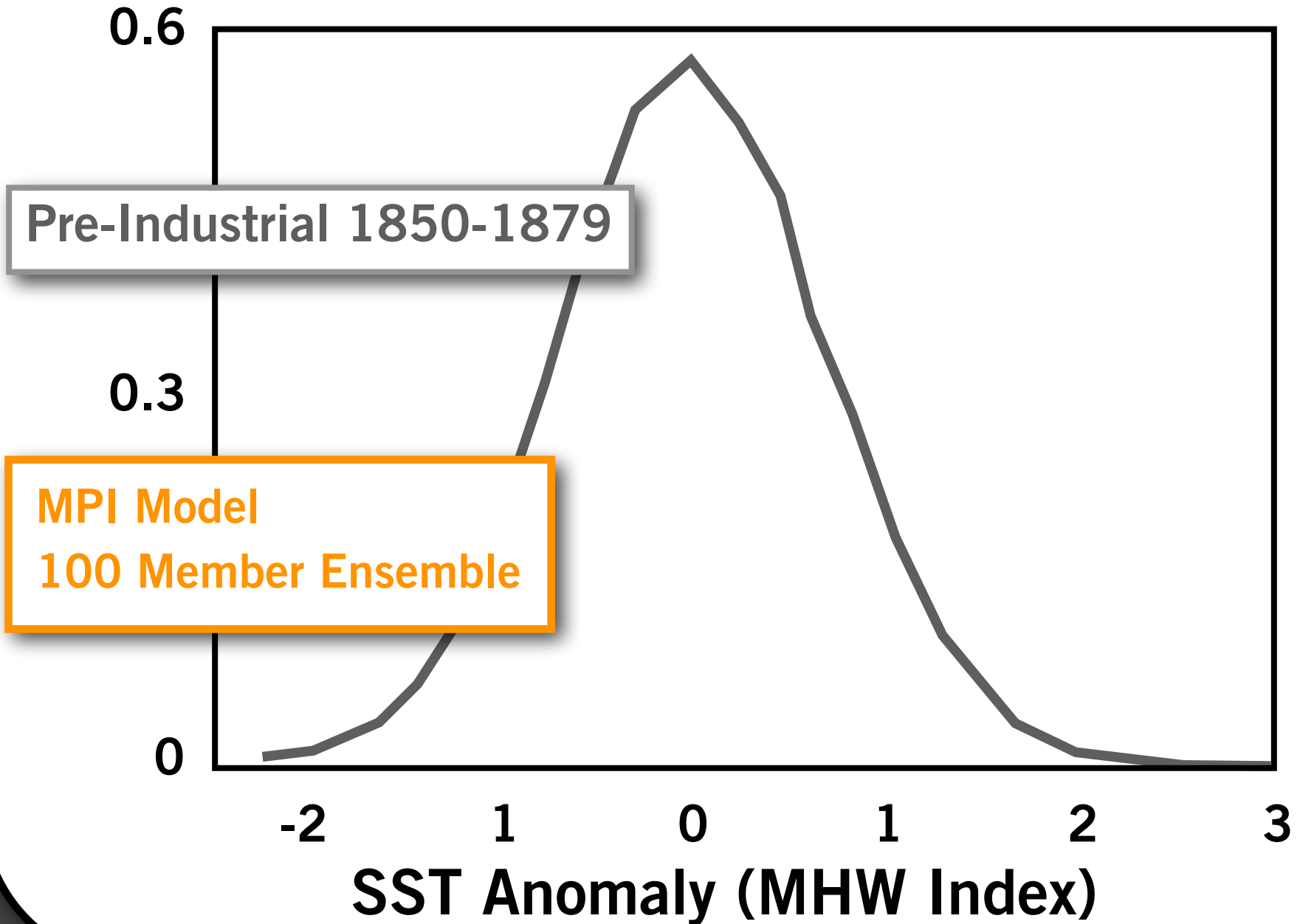
-NPGO > 1 STD

MHW Index PDF  
STD

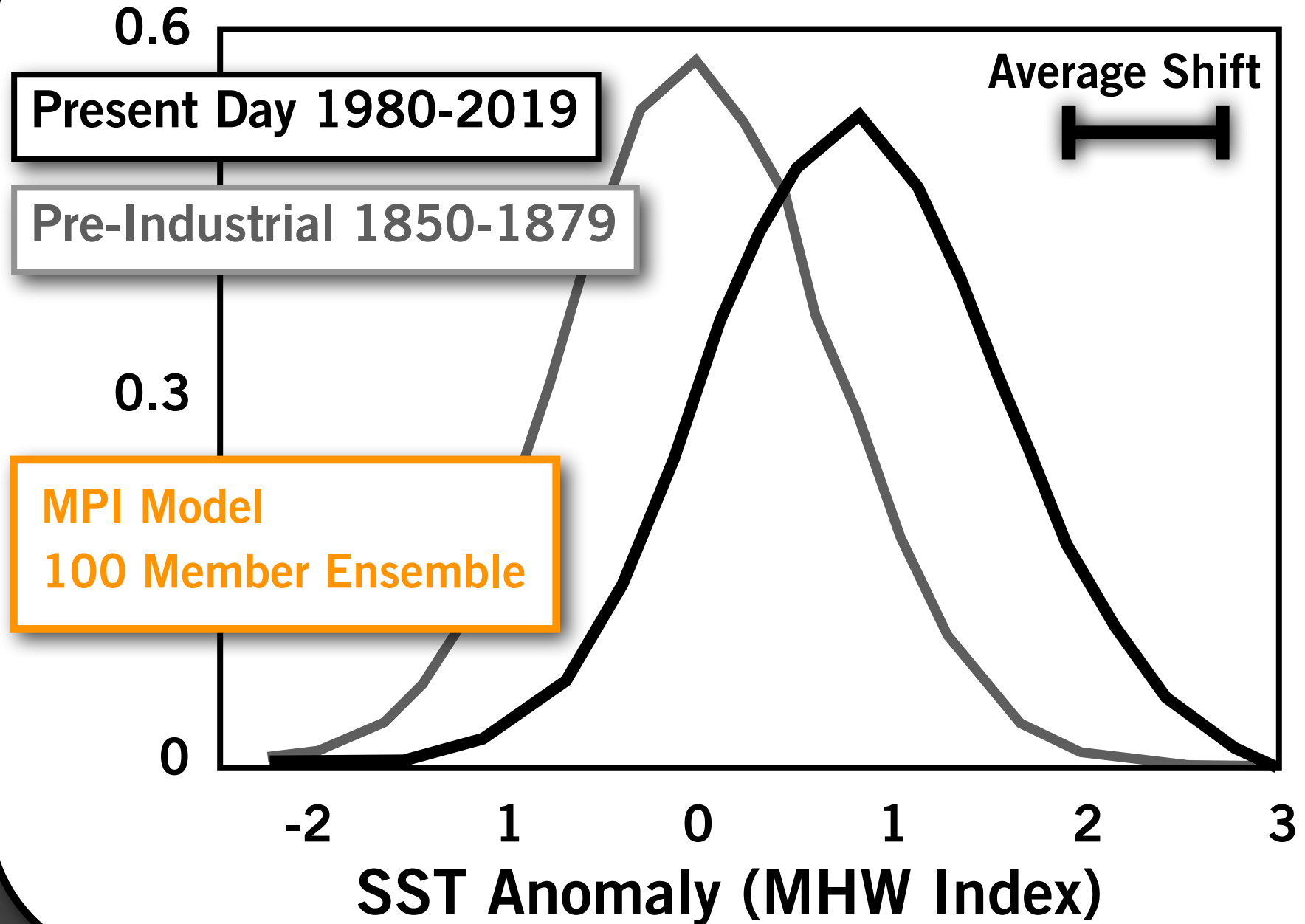
**Problem:** small size statistics

**MPI-Grand Ensemble:** 100 ensemble members  
1850-2005 with historical radiative forcing  
2006-2100 with RCP8.5

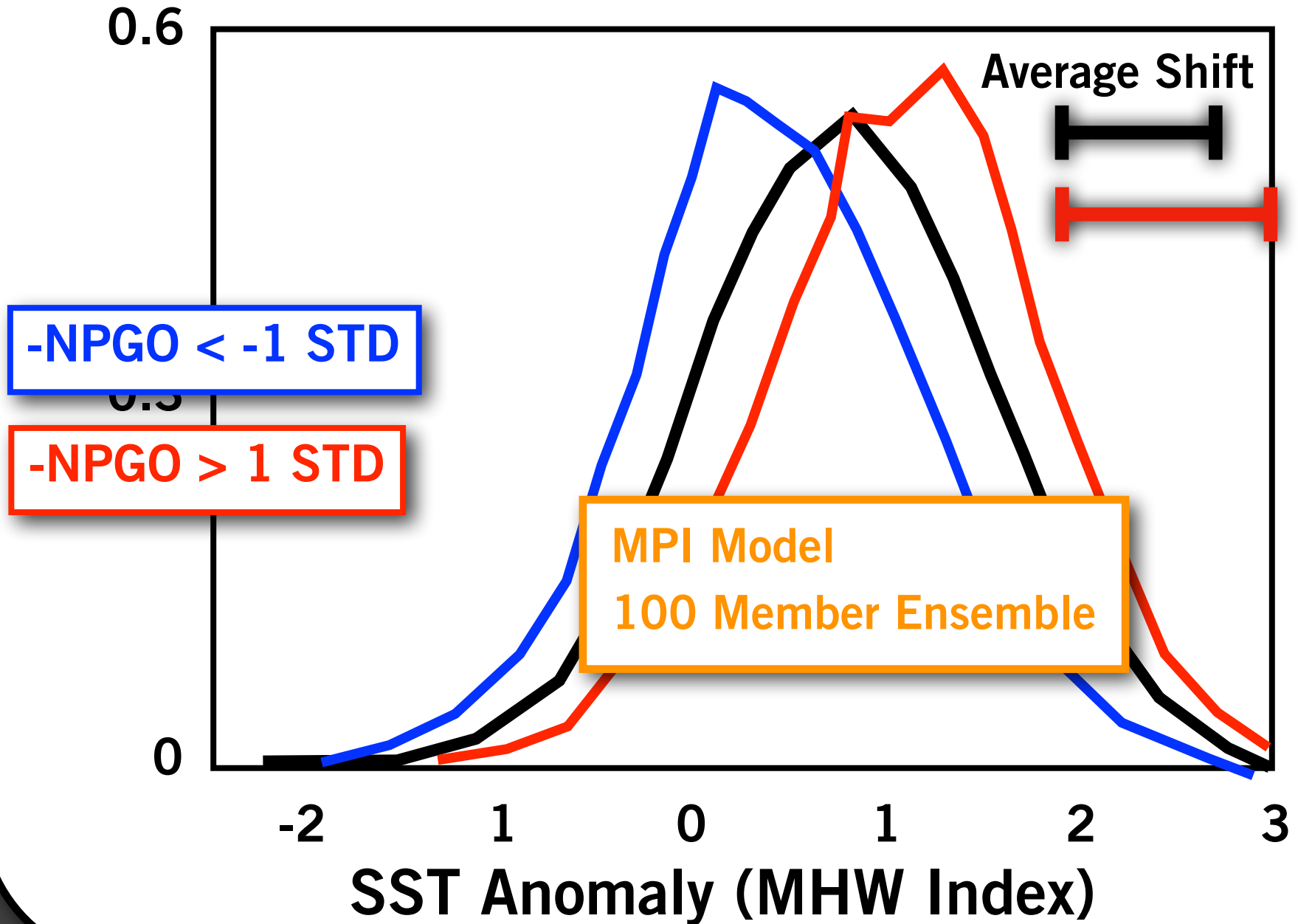
# Probability Distribution Function



# Probability Distribution Function



# Probability Distribution Function

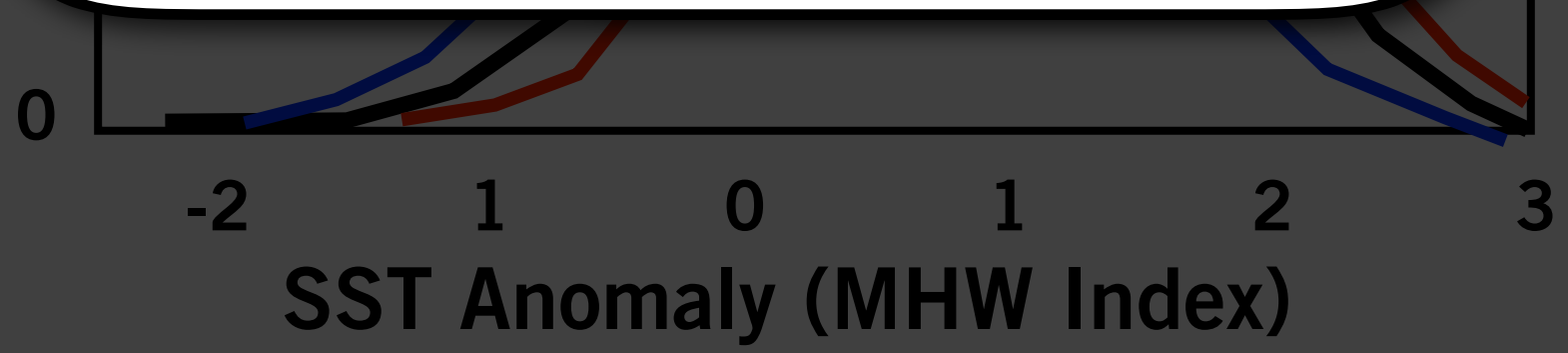


# Probability Distribution Function

		Blob Index	
		Annual	
<b>+NPGO</b> Present Day <b>-NPGO</b>	$\Delta 95^{\text{th}}$	0.13	0.42
	$\Delta 99^{\text{th}}$	0.05	0.21

-NP

-NP



# Probability Distribution Function

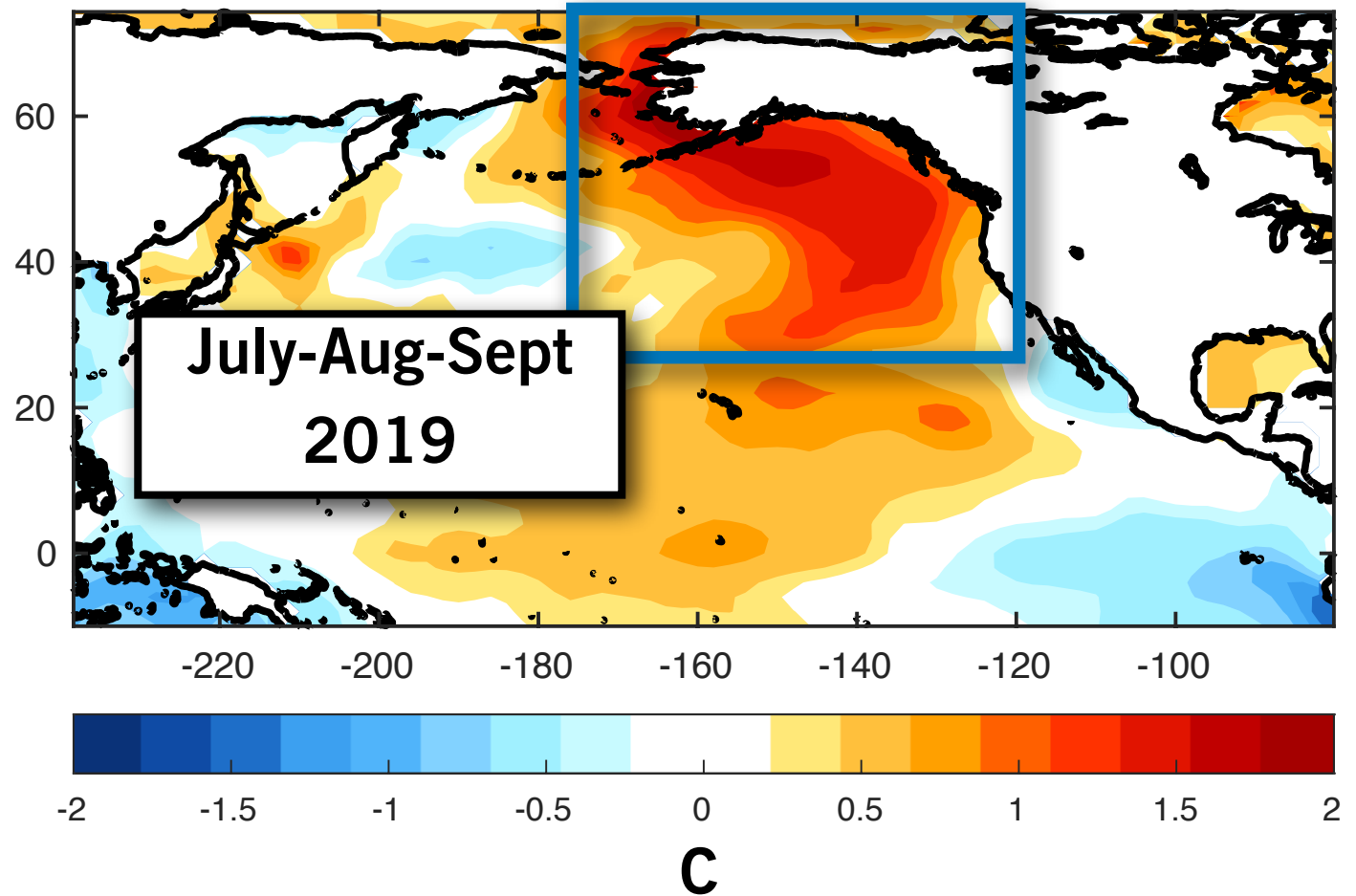
**+NPGO**  
Present Day  
**-NPGO**

	Blob Index
	Annual
$\Delta 95^{\text{th}}$	0.13 0.26 0.42
$\Delta 99^{\text{th}}$	0.05 0.13 0.21

Changes in Extremes associated with trend is comparable to that of the phases of the decadal modes



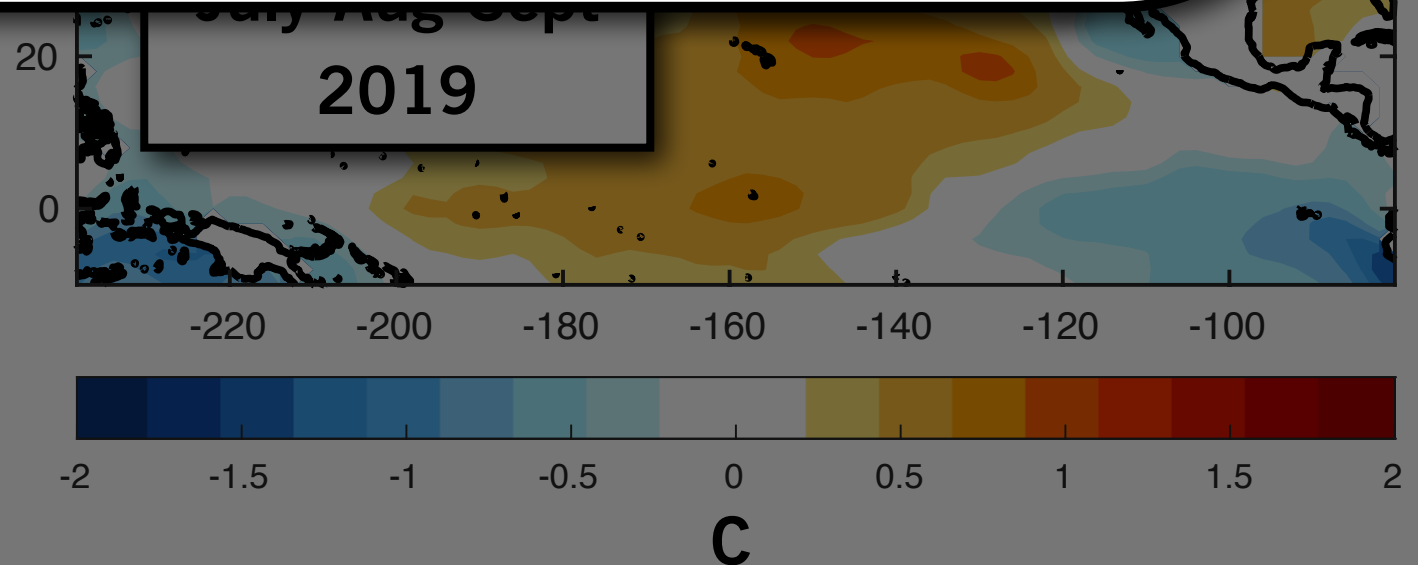
# Sea Surface Temperature Anomalies



**Question:** Is the Blob going to continue this winter?

## Empirical Dynamical Model Prediction

$$\frac{d\mathbf{x}}{dt} = \mathbf{L}\mathbf{x} + \xi \quad \text{Linear Inverse Model}$$



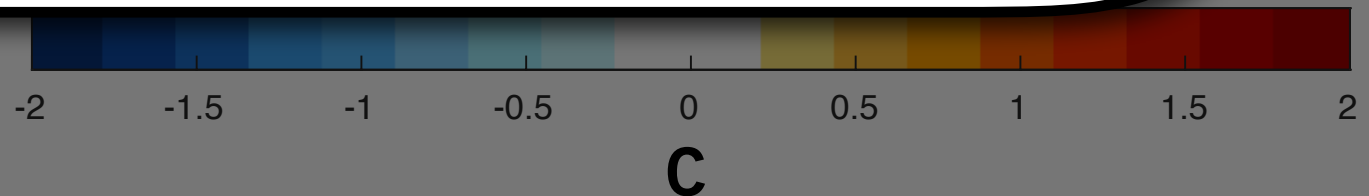
**Question:** Is the Blob going to continue this winter?

## Empirical Dynamical Model Prediction

$$\frac{d\mathbf{x}}{dt} = \mathbf{L}\mathbf{x} + \xi \quad \text{Linear Inverse Model}$$

By solving the LIM system, we obtain

$$\hat{\mathbf{x}}(t + \tau) = \exp(\mathbf{L}\tau)\mathbf{x}(t) = \mathbf{G}(\tau)\mathbf{x}(t)$$



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As data consist of SSTA and SLPA, our model system is

$$\begin{bmatrix} \hat{\mathbf{s}}(t + \tau) \\ \hat{\mathbf{p}}(t + \tau) \end{bmatrix} = \mathbf{G}(\tau = 6\text{months}) \begin{bmatrix} \mathbf{s}(t) \\ \mathbf{p}(t) \end{bmatrix} \begin{array}{l} \leftarrow \text{SSTA} \\ \leftarrow \text{SLPA} \end{array}$$

## Empirical Dynamical Model Prediction

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**Forecast**  
**March**

Jan-Feb-March



6 Months Prediction

**Initialize**  
**September**

# Sea Surface Temperature Anomalies

## Empirical Dynamical Model Prediction

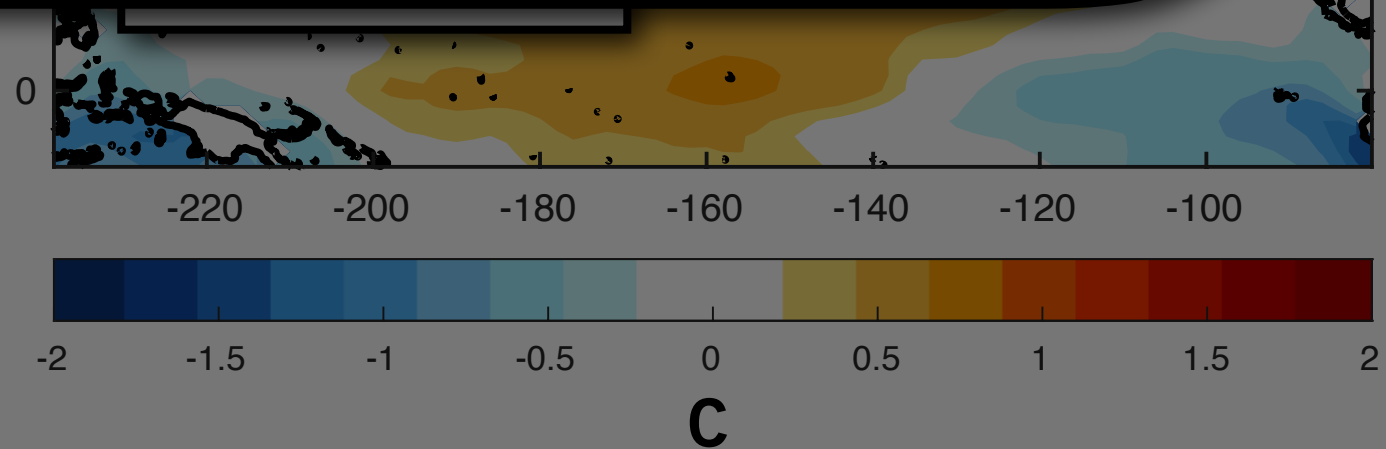
**Forecast  
March**

Jan-Feb-March



6 Months Prediction

**Initialize  
September**



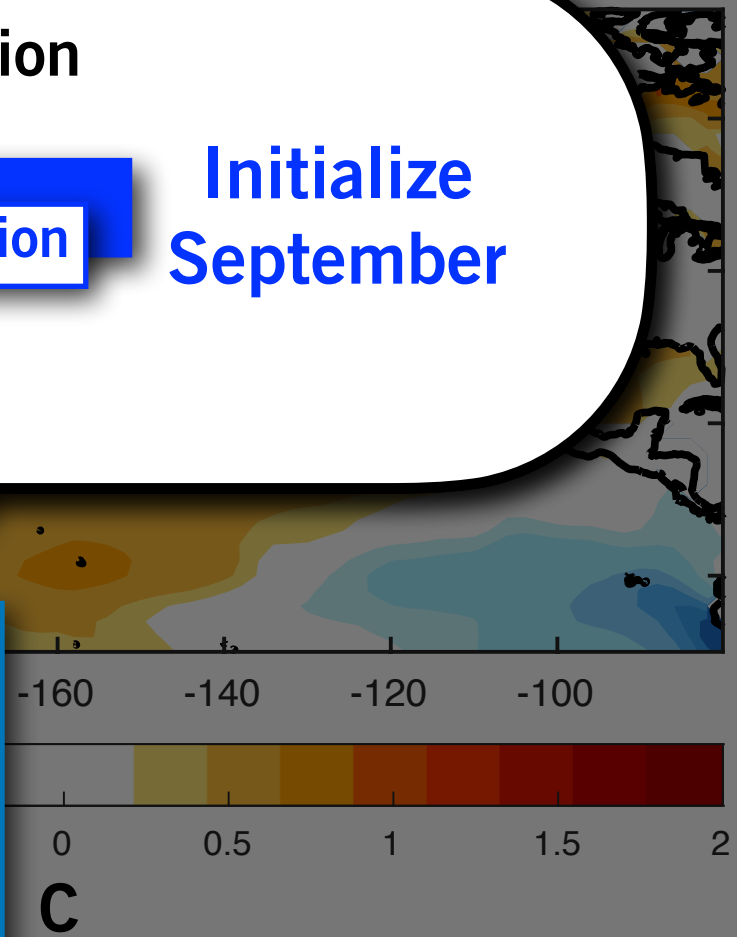
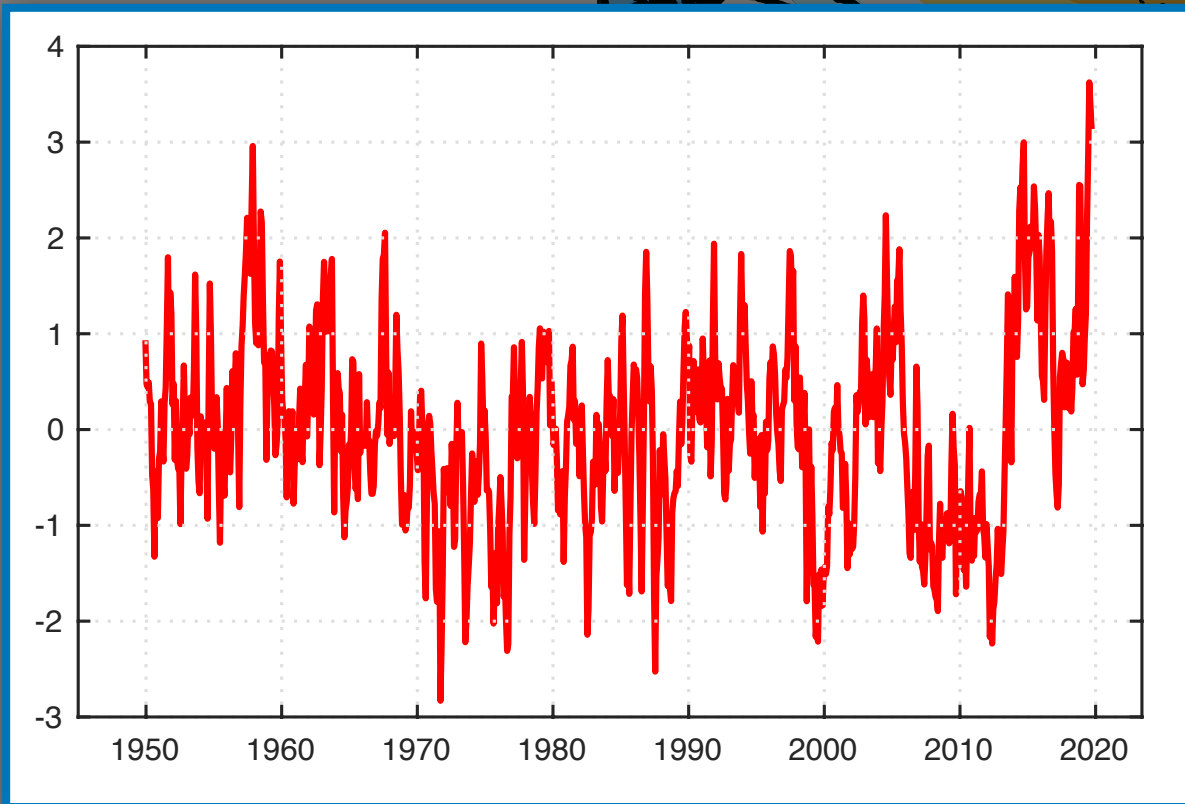
# Empirical Dynamical Model Prediction

**Forecast  
March**

Jan-Feb-March



**Initialize  
September**



Marine HeatWave Index  
**MHW Index**

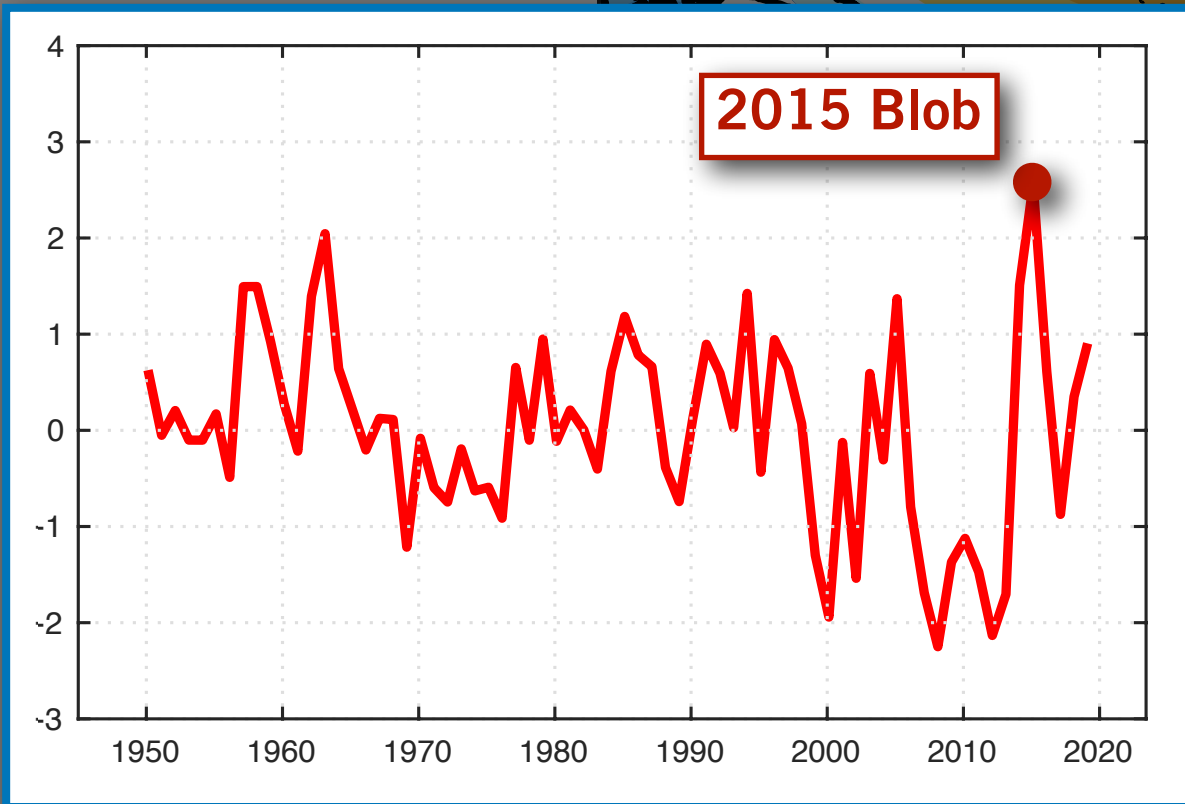
# Empirical Dynamical Model Prediction

**Forecast  
March**

Jan-Feb-March



**Initialize  
September**



-160 -140 -120 -100

**Winter Average**  
Jan-Feb-March

Marine HeatWave Index  
**MHW Index**



Empirical Dynamical Model Prediction

Forecast  
March

Jan-Feb-March

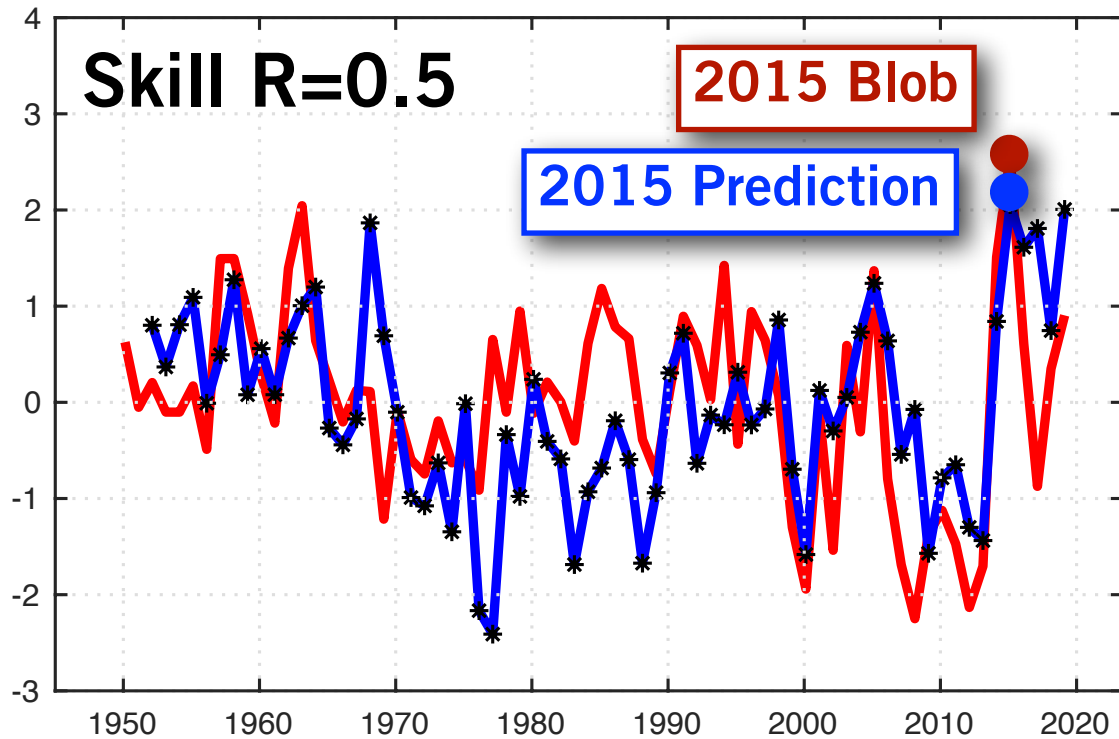


6 Months Prediction

Cross-Validation

Initialize  
September

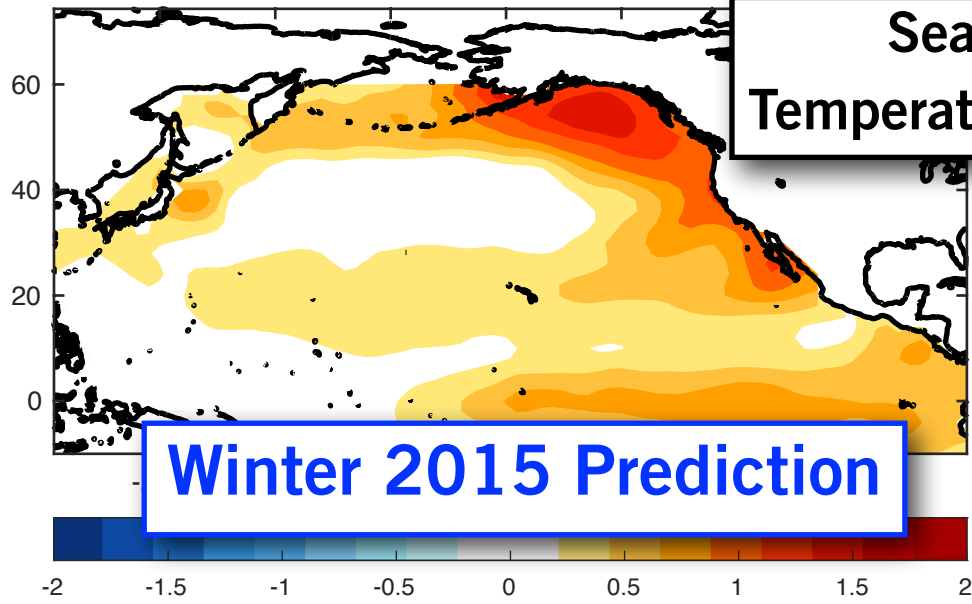
Skill  $R=0.5$



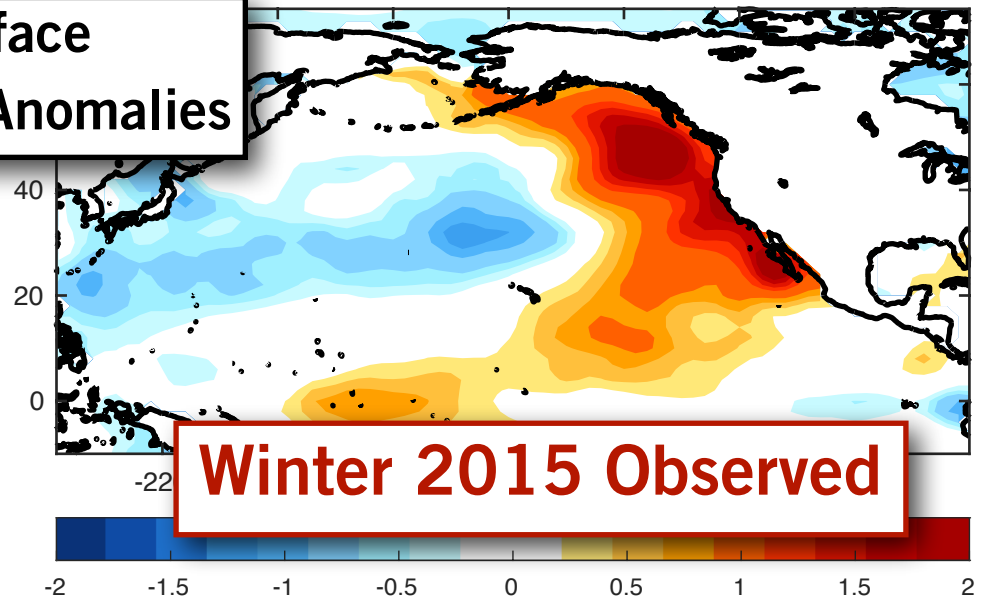
Winter Average  
Jan-Feb-March

Marine HeatWave Index  
**MHW Index**

# Sea Surface Temperature Anomalies

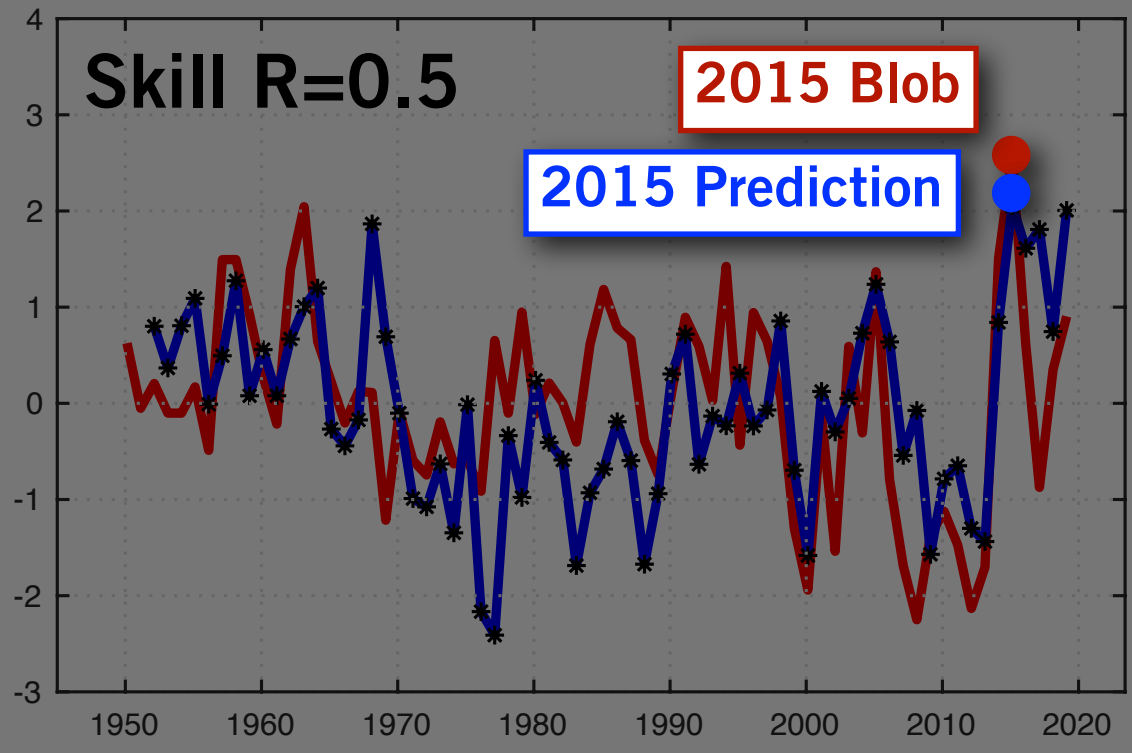


Winter 2015 Prediction



Winter 2015 Observed

Skill  $R=0.5$



2015 Blob

2015 Prediction

Winter Average  
Jan-Feb-March

Marine HeatWave Index  
MHW Index

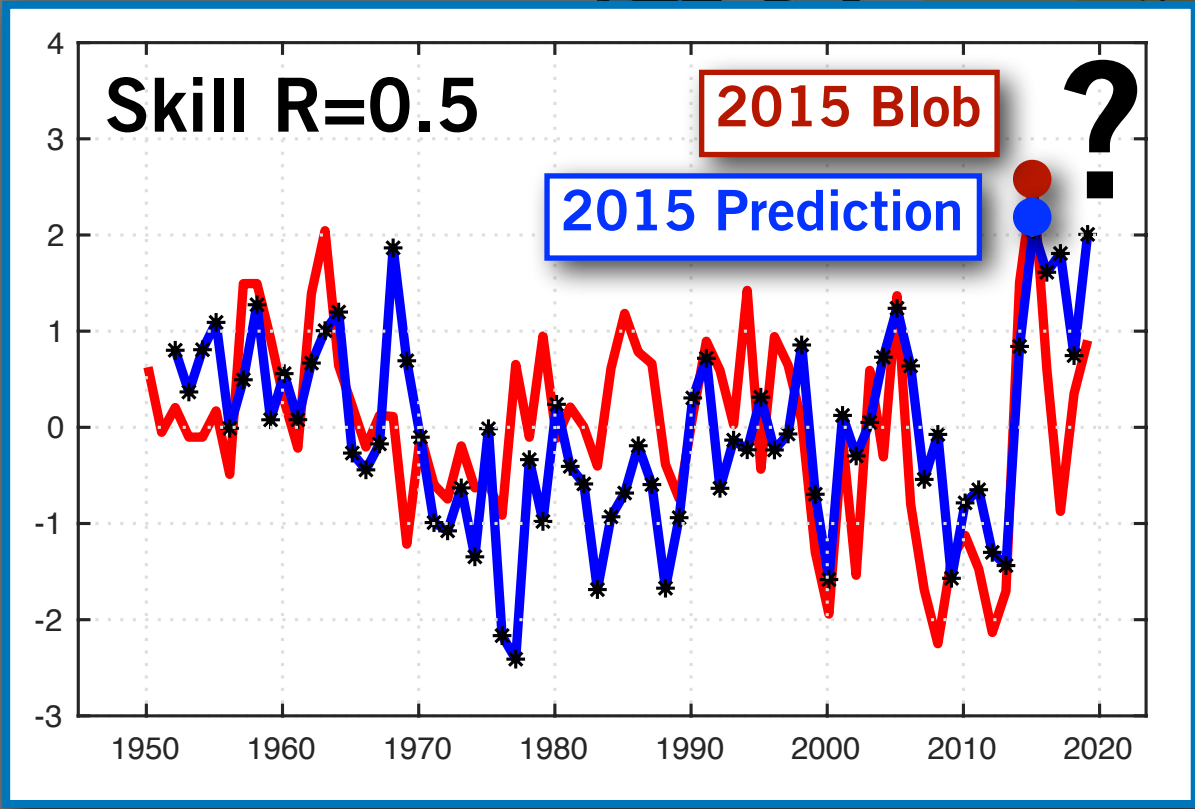
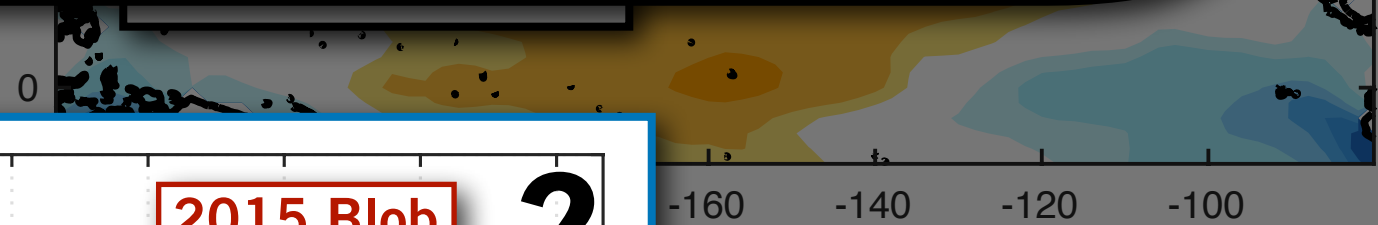
# Empirical Dynamical Model Prediction

**Forecast  
March**

Jan-Feb-March



**Initialize  
September**



**Winter Average**  
Jan-Feb-March

**Marine HeatWave Index**  
**MHW Index**

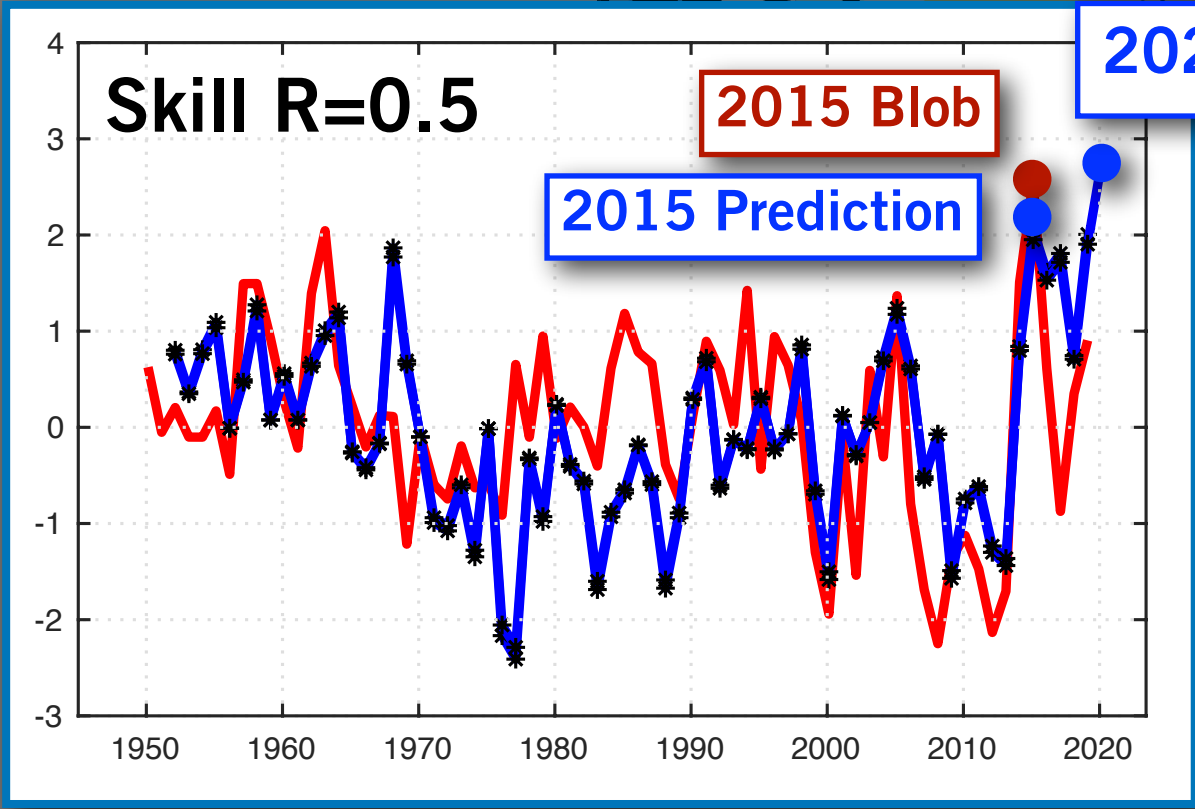
# Empirical Dynamical Model Prediction

**Forecast  
March**

Jan-Feb-March



**Initialize  
September**



**2020 Prediction**

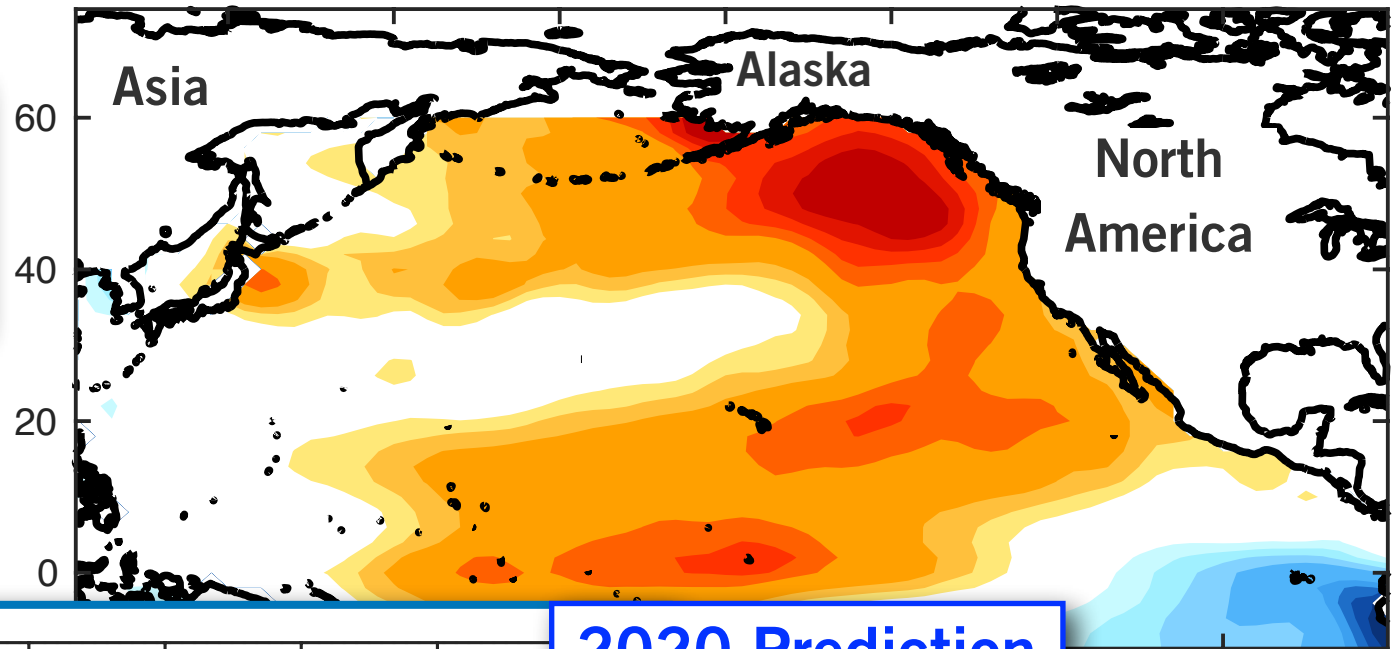
**Winter Average  
Jan-Feb-March**

**Marine HeatWave Index  
MHW Index**

# Prediction

WINTER  
2020

## Sea Surface Temperature Anomalies



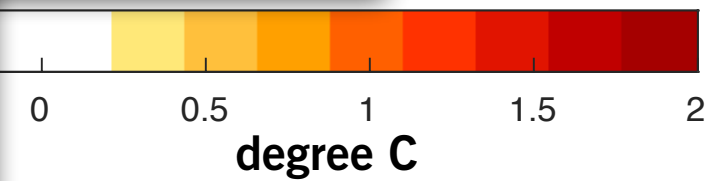
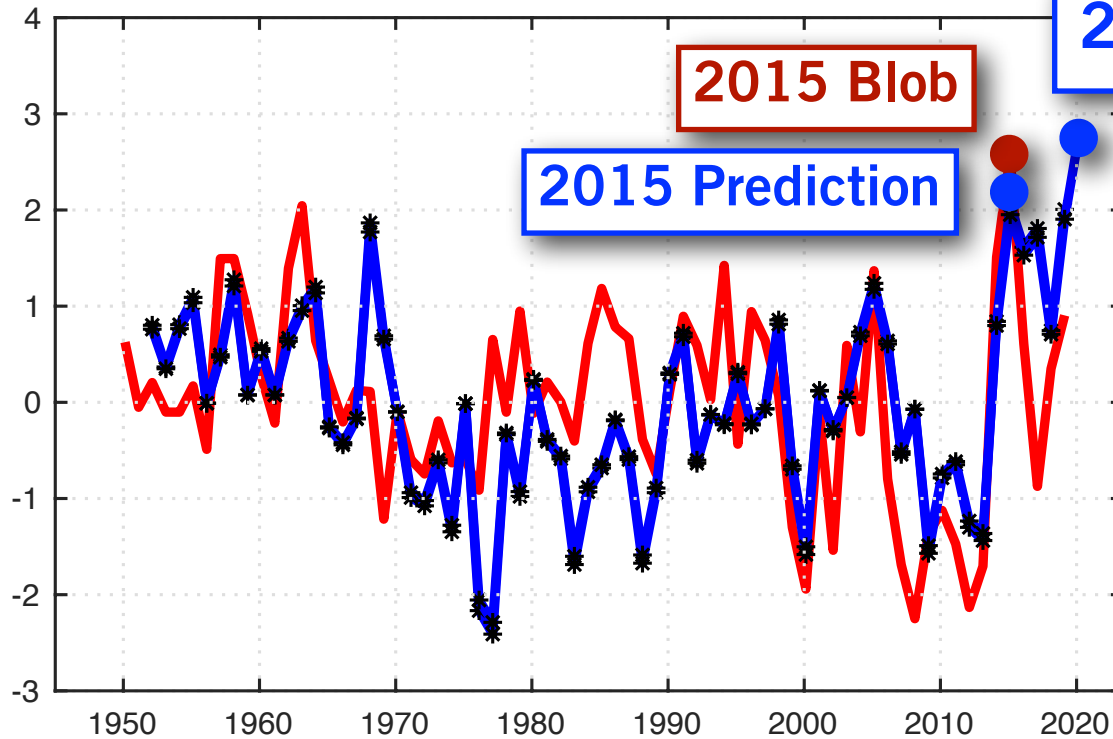
Prediction R=0.5

2020 Prediction

2015 Blob

2015 Prediction

C



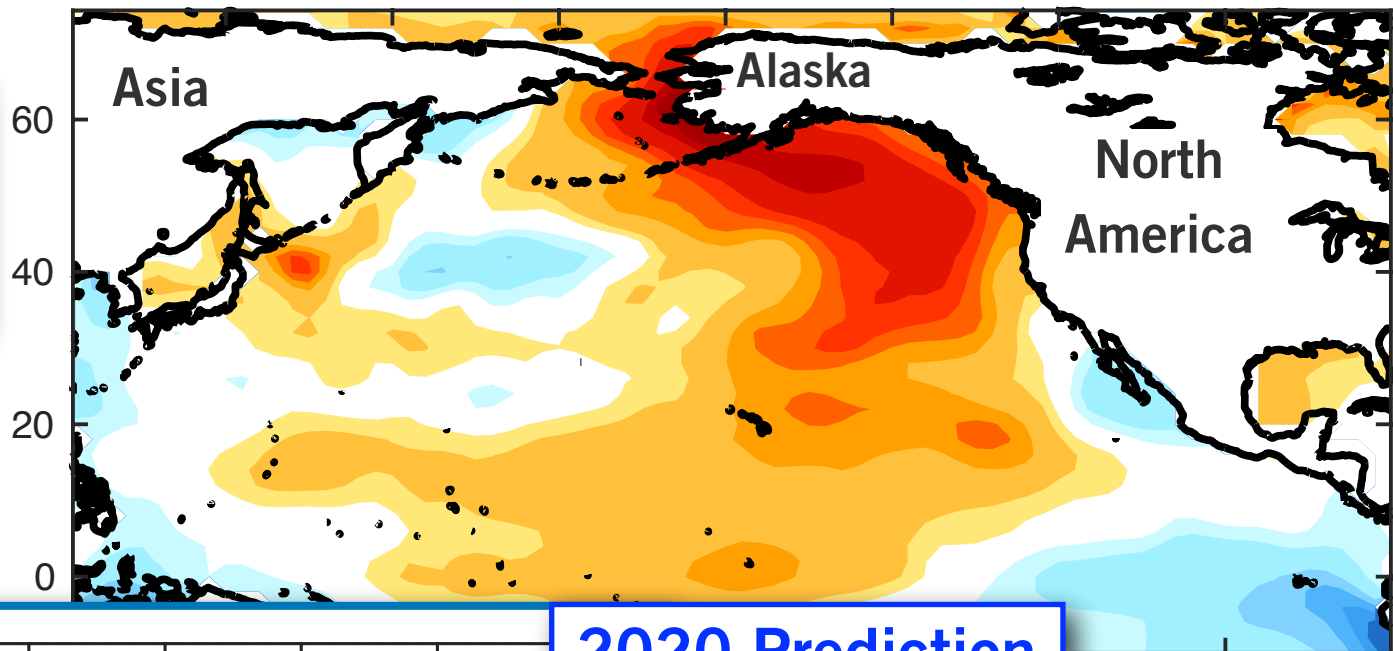
Marine HeatWave Index

Observed

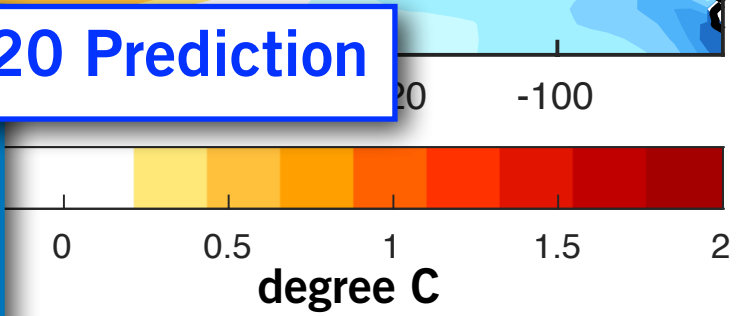
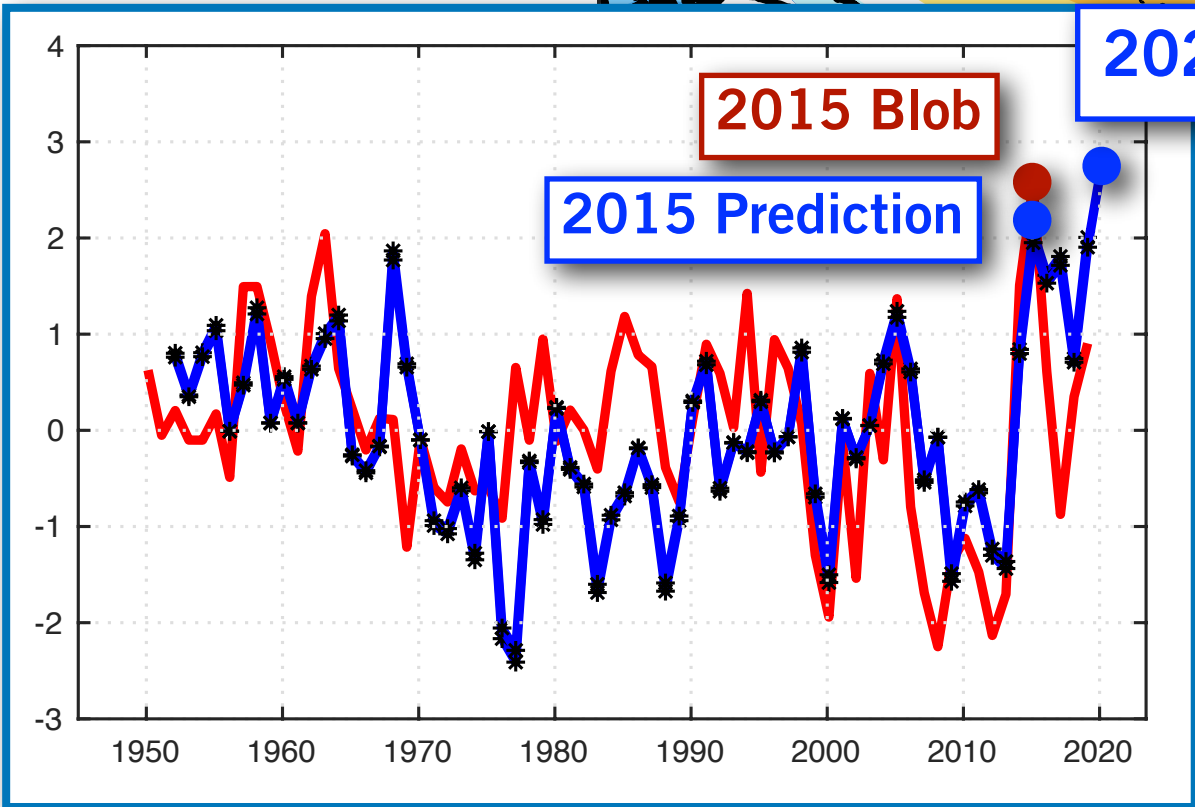
6m Prediction

# Sea Surface Temperature Anomalies

**SUMMER  
2019**



Prediction R=0.5

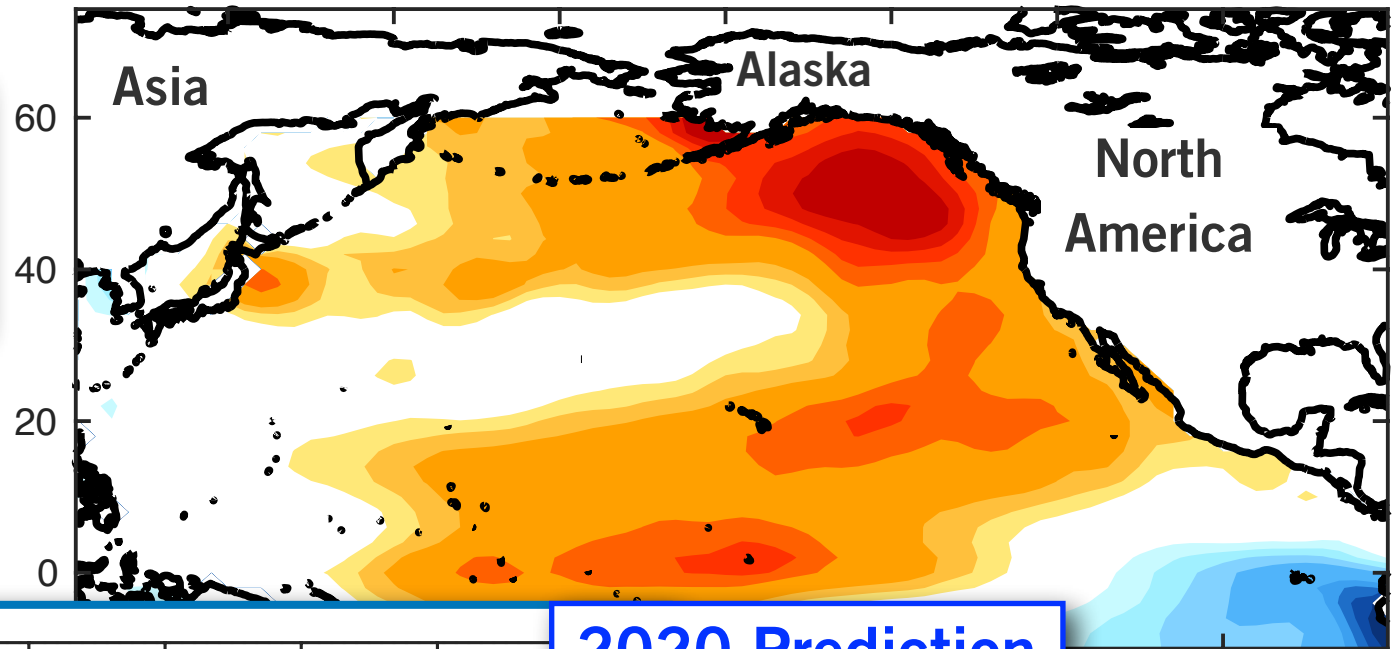


Marine HeatWave Index  
**Observed**  
**6m Prediction**

# Prediction

WINTER  
2020

## Sea Surface Temperature Anomalies



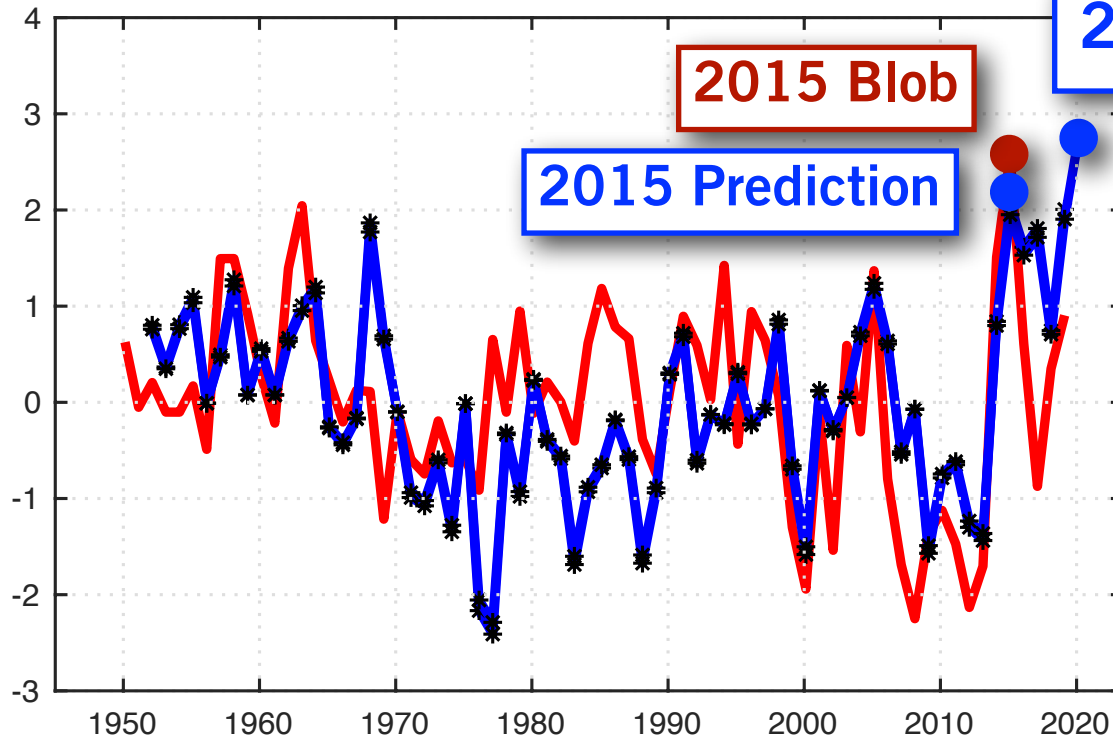
Prediction R=0.5

2020 Prediction

2015 Blob

2015 Prediction

C



Marine HeatWave Index  
**Observed**  
**6m Prediction**

