Tongtong Xu

Dillon Amaya

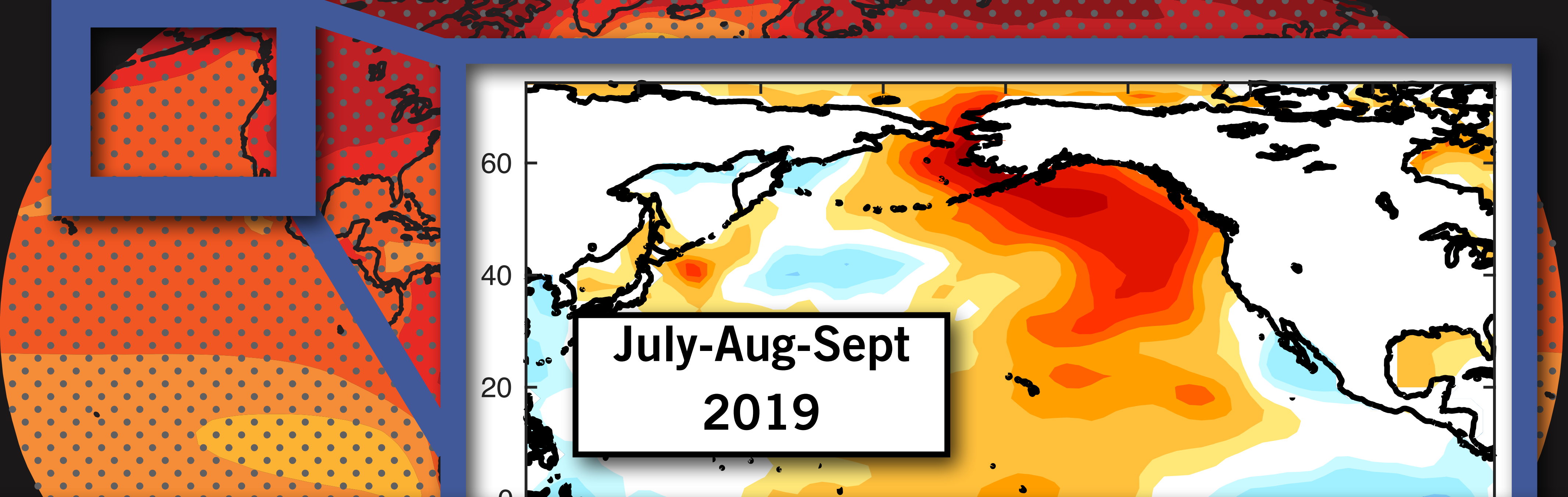
Alaska Marine Heatwave 2019

Hot Off the Press

Georgia Tech | Ocean Science & Engineering

Emanuele Di Lorenzo

PICES, October, 2019



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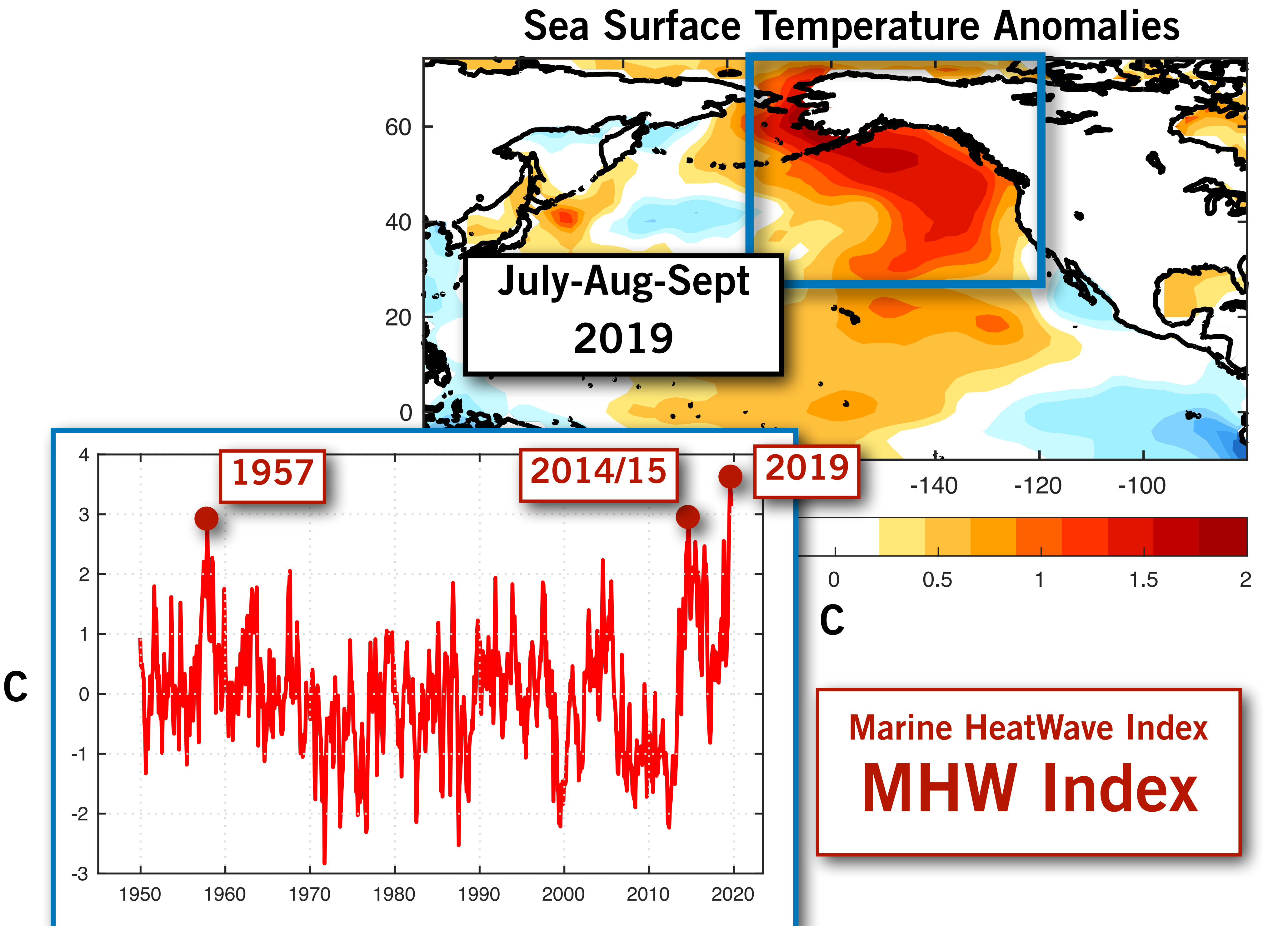
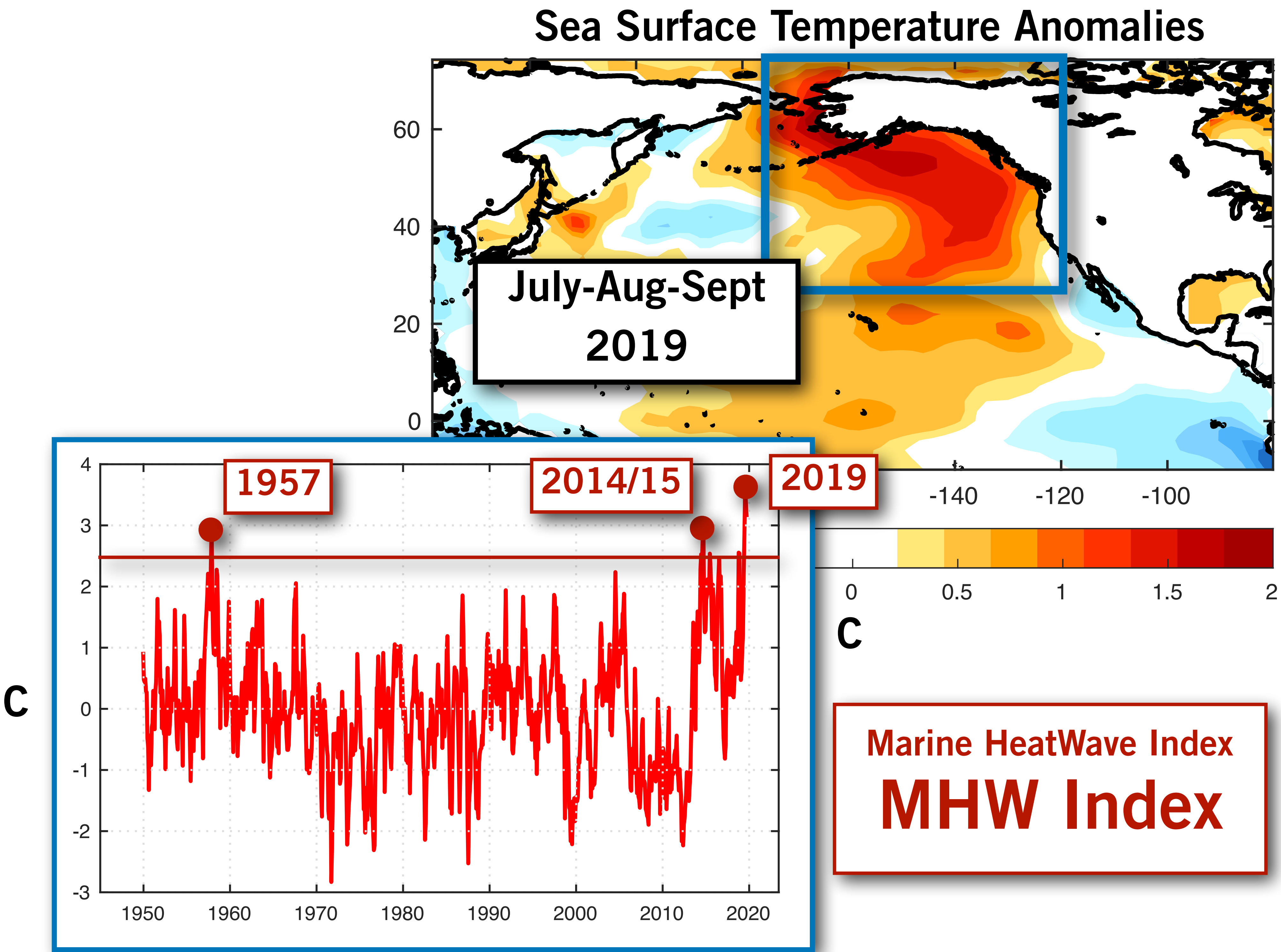
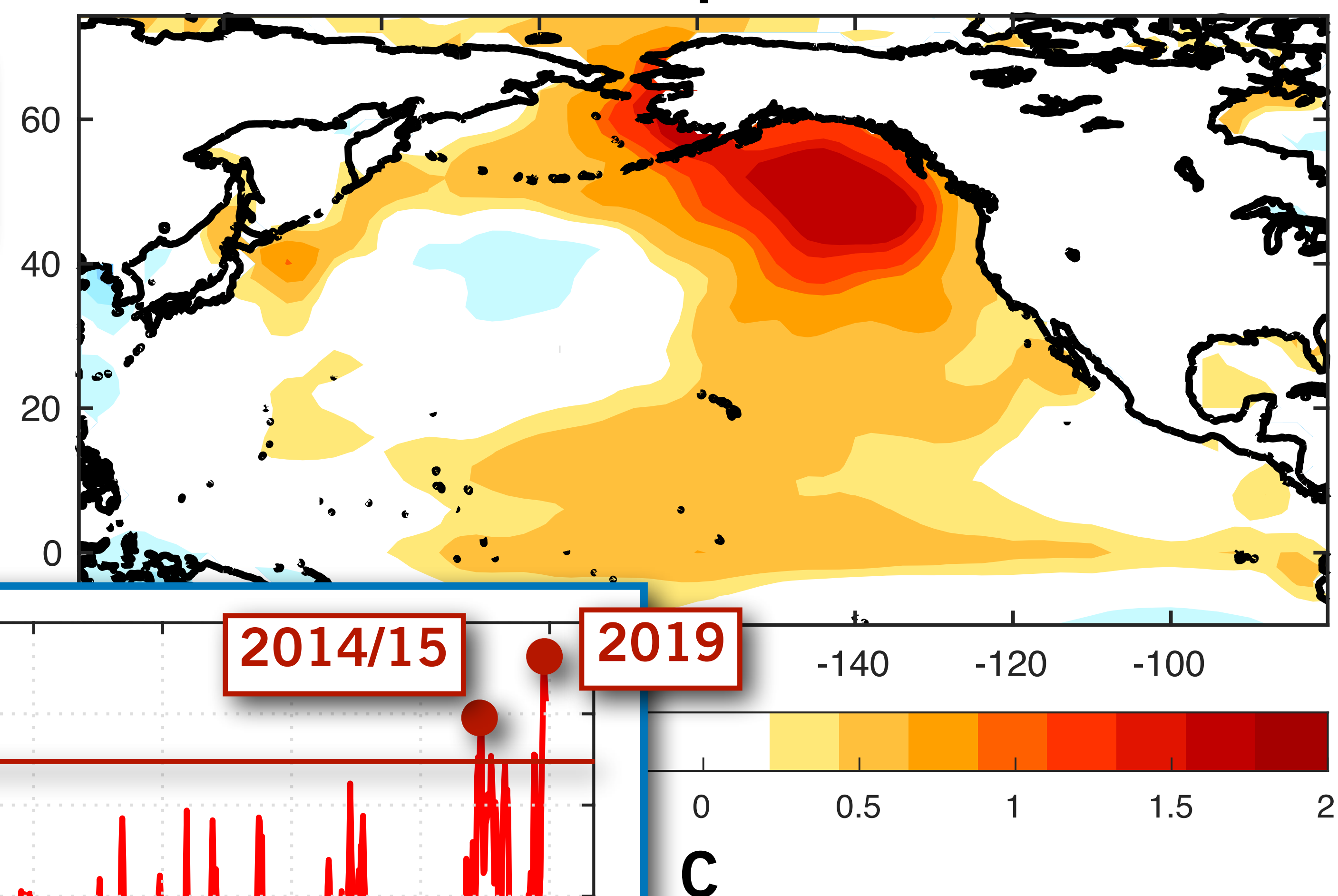

Sea Surface Temperature Anomalies
July-Aug-Sept
2019
60
40
20
0
-140
-120
-100
0
0.5
1
1.5
2
C
1957
2014/15
2019
4
3
2
1
0
-1
-2
-3
C
1950
1960
1970
1980
1990
2000
2010
2020
Marine HeatWave Index
MHW Index

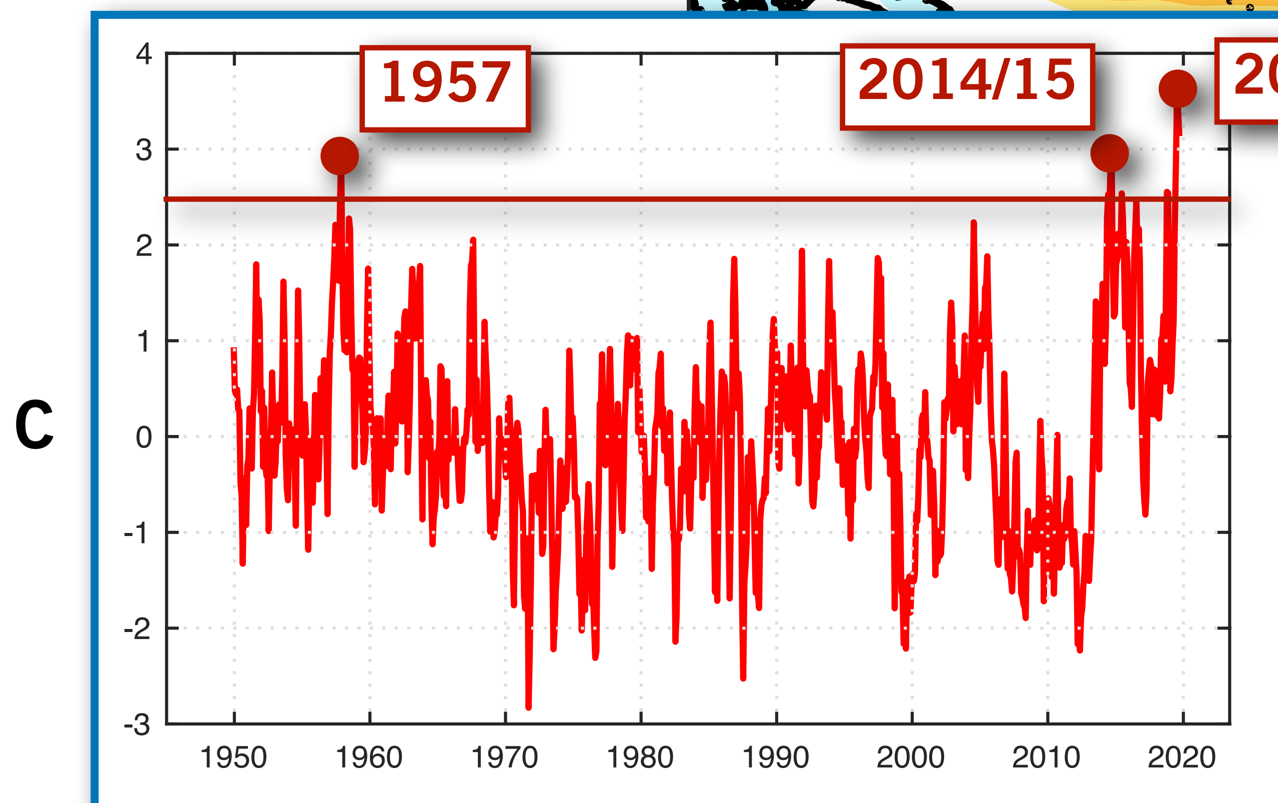


Sea Surface Temperature Anomalies
July-Aug-Sept
2019
60
40
20
0
-140
-120
-100
0
0.5
1
1.5
2
C
1957
2014/15
2019
4
3
2
1
0
-1
-2
-3
C
1950
1960
1970
1980
1990
2000
2010
2020
Marine HeatWave Index
MHW Index

Sea Surface Temperature Anomalies

Average of Extremes

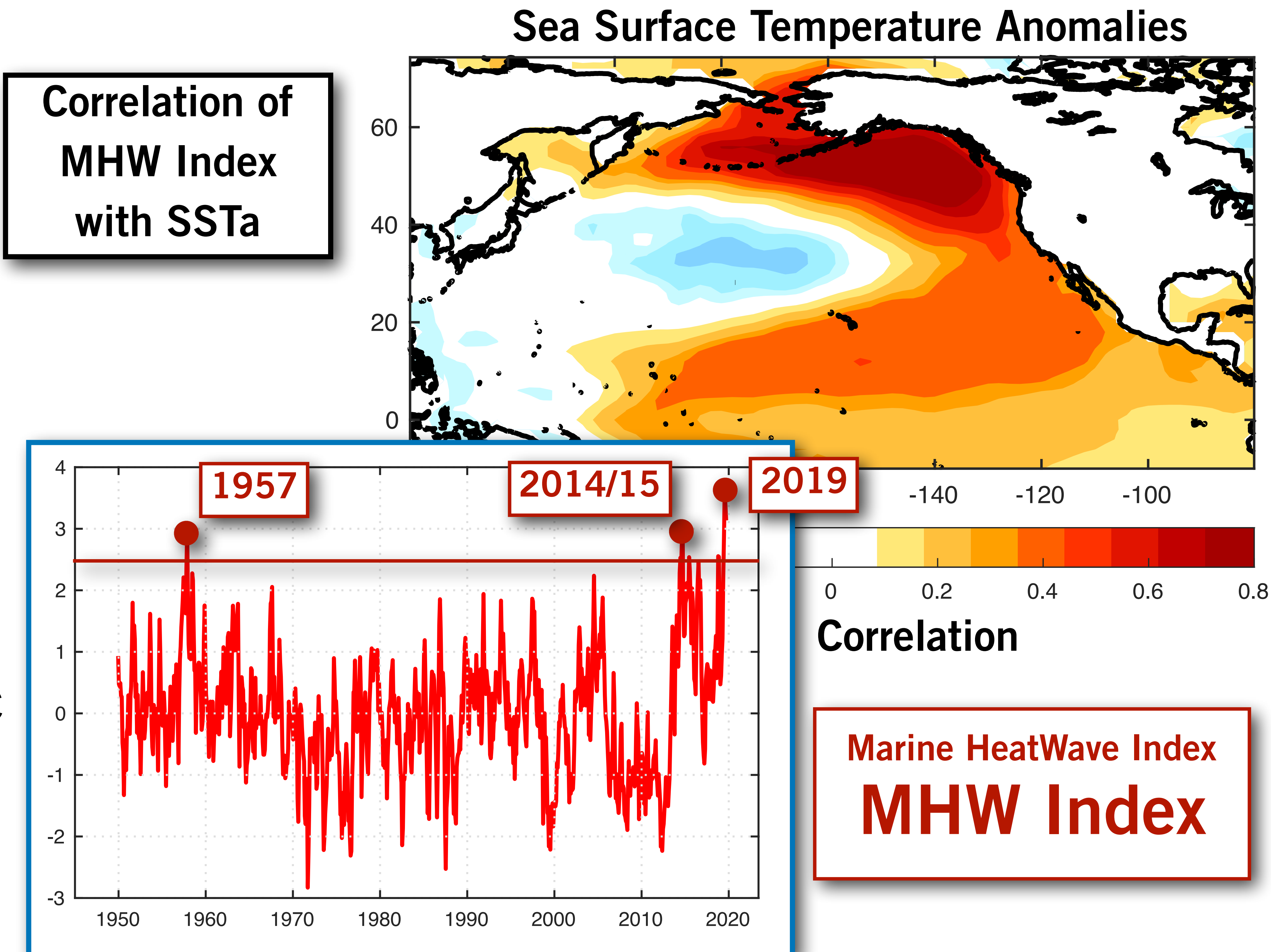




Marine HeatWave Index

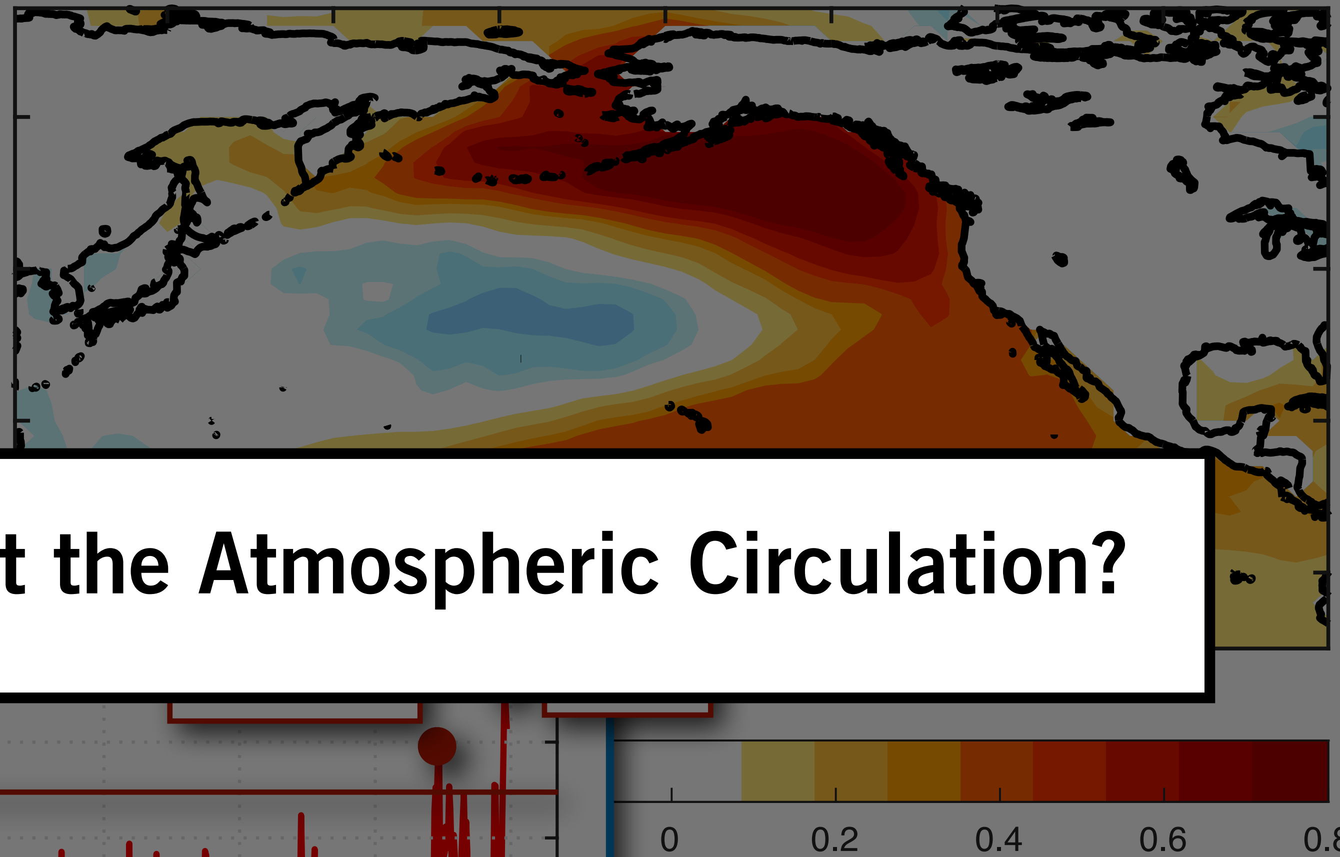
MHW Index

C


Sea Surface Temperature Anomalies
Correlation of MHW Index with SSTa
60
40
20
0
-140
-120
-100
0
0.2
0.4
0.6
0.8
Correlation
1957
2014/15
2019
4
3
2
1
0
-1
-2
-3
1950
1960
1970
1980
1990
2000
2010
2020
Marine HeatWave Index
MHW Index

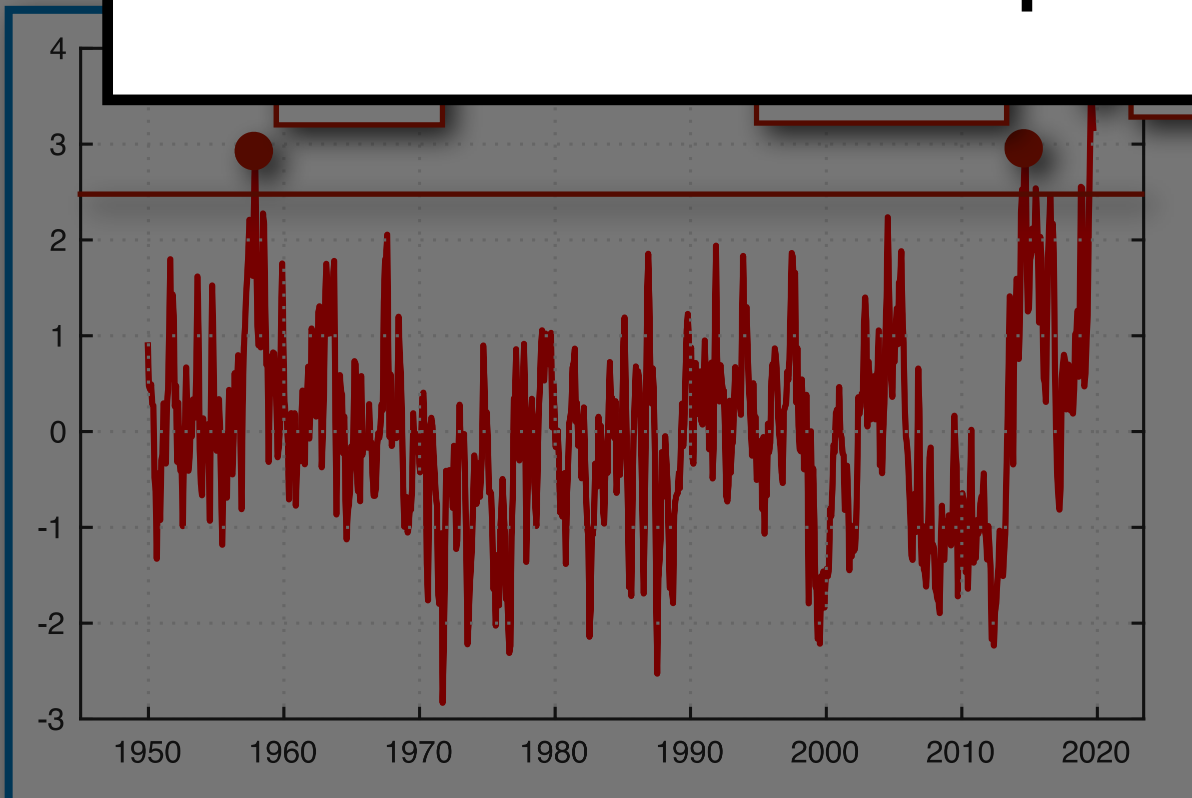
Correlation of MHW Index with SSTa

Sea Surface Temperature Anomalies



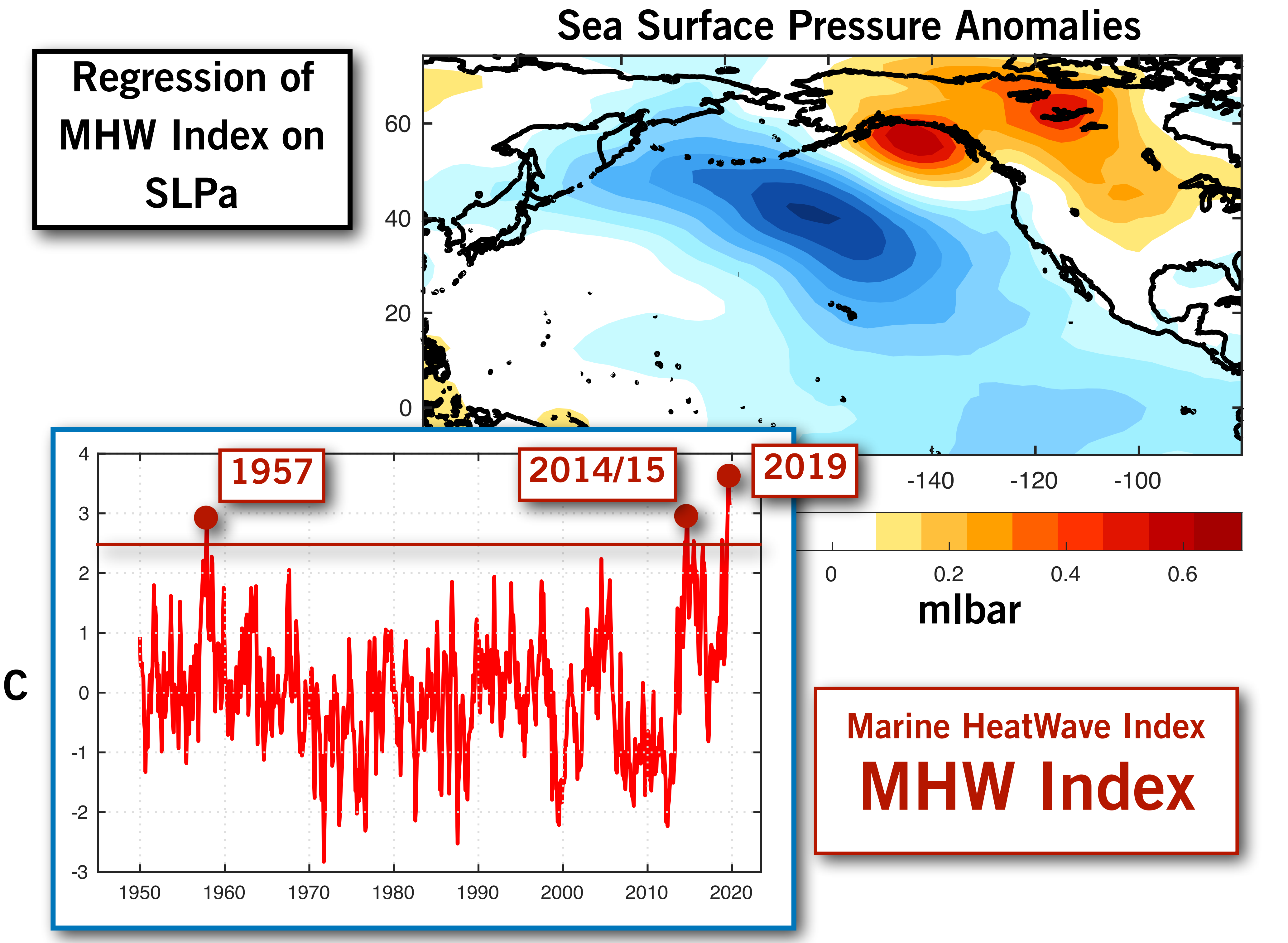
What about the Atmospheric Circulation?

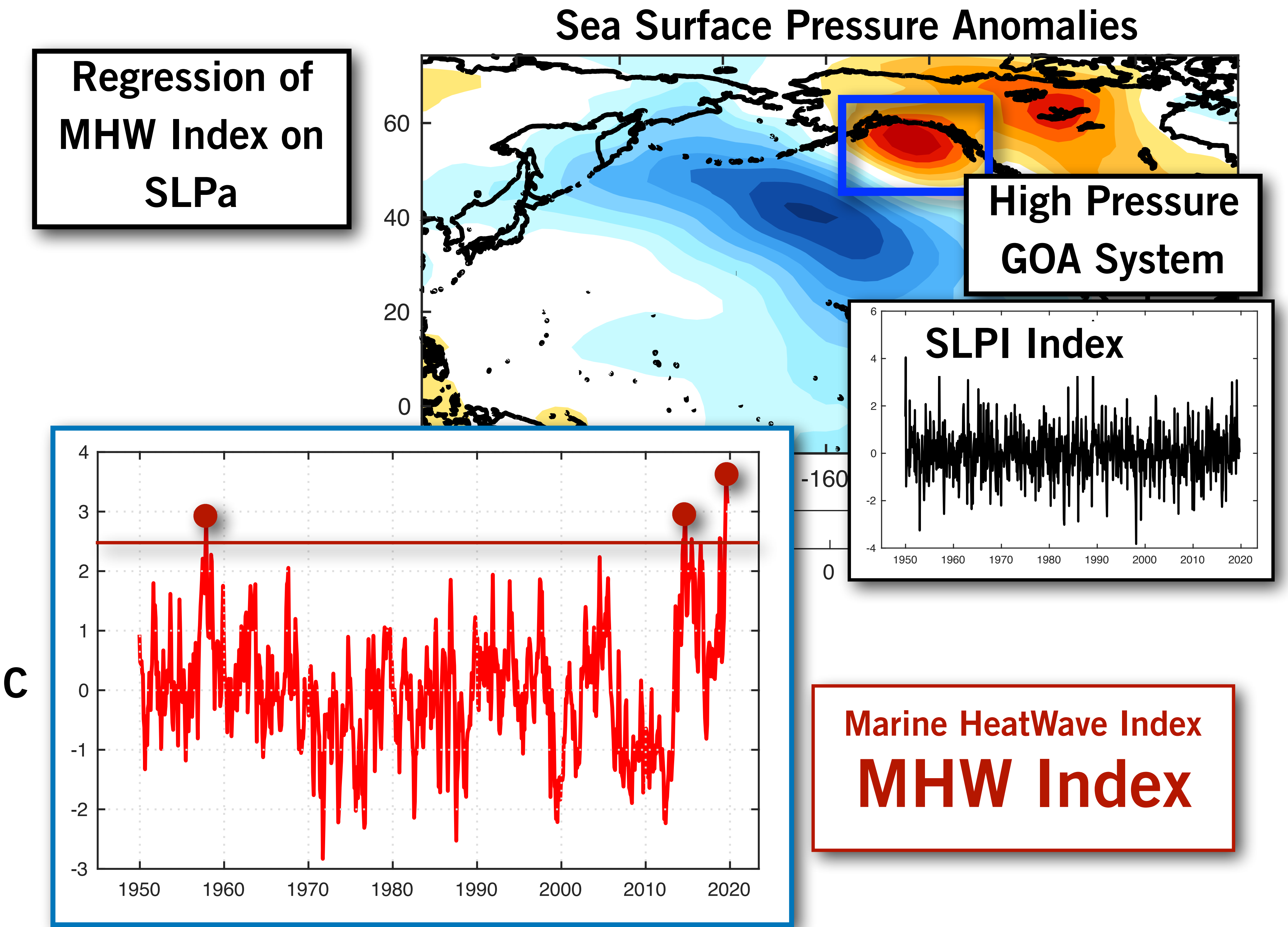
C



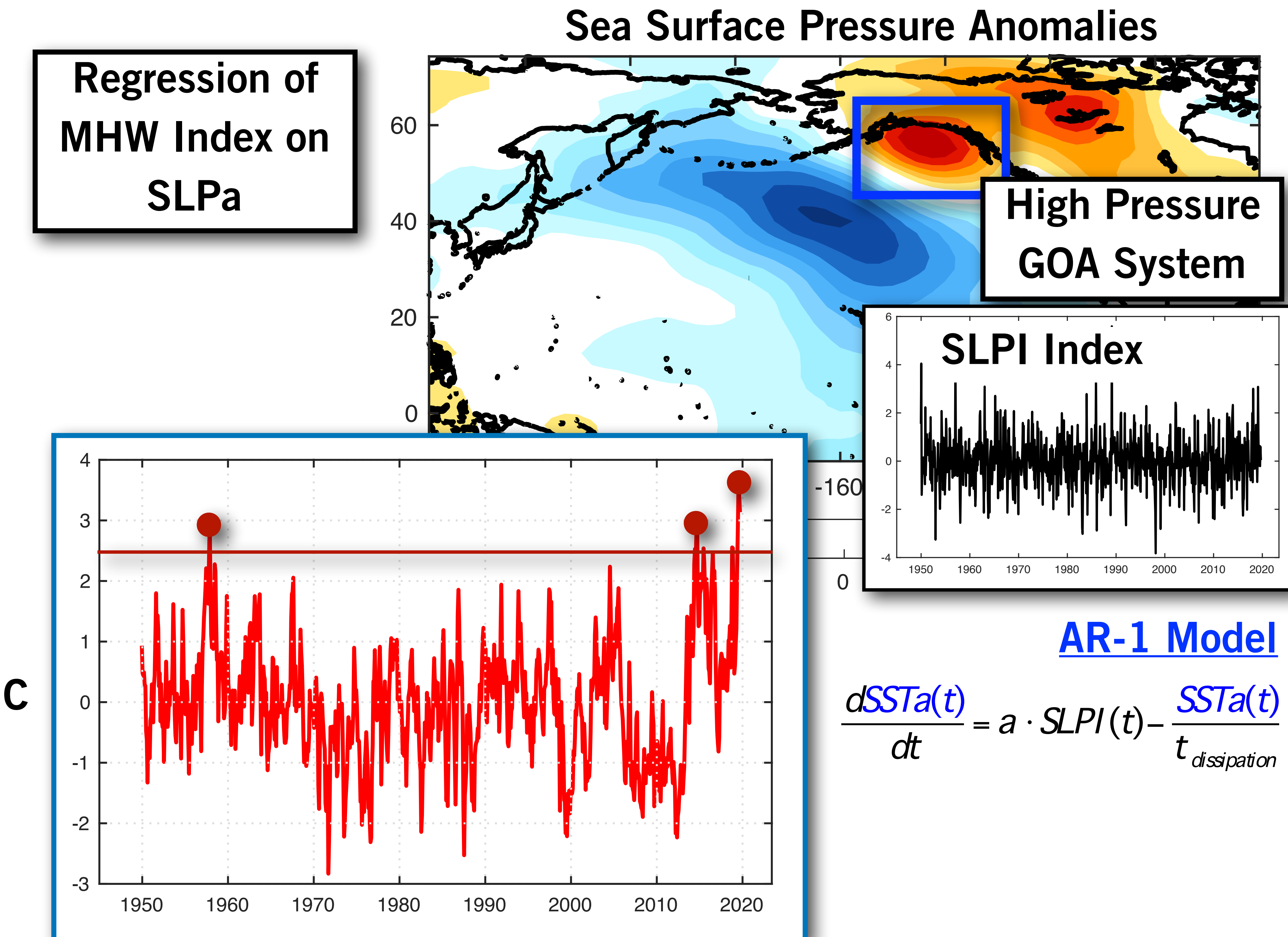
Marine HeatWave Index

MHW Index

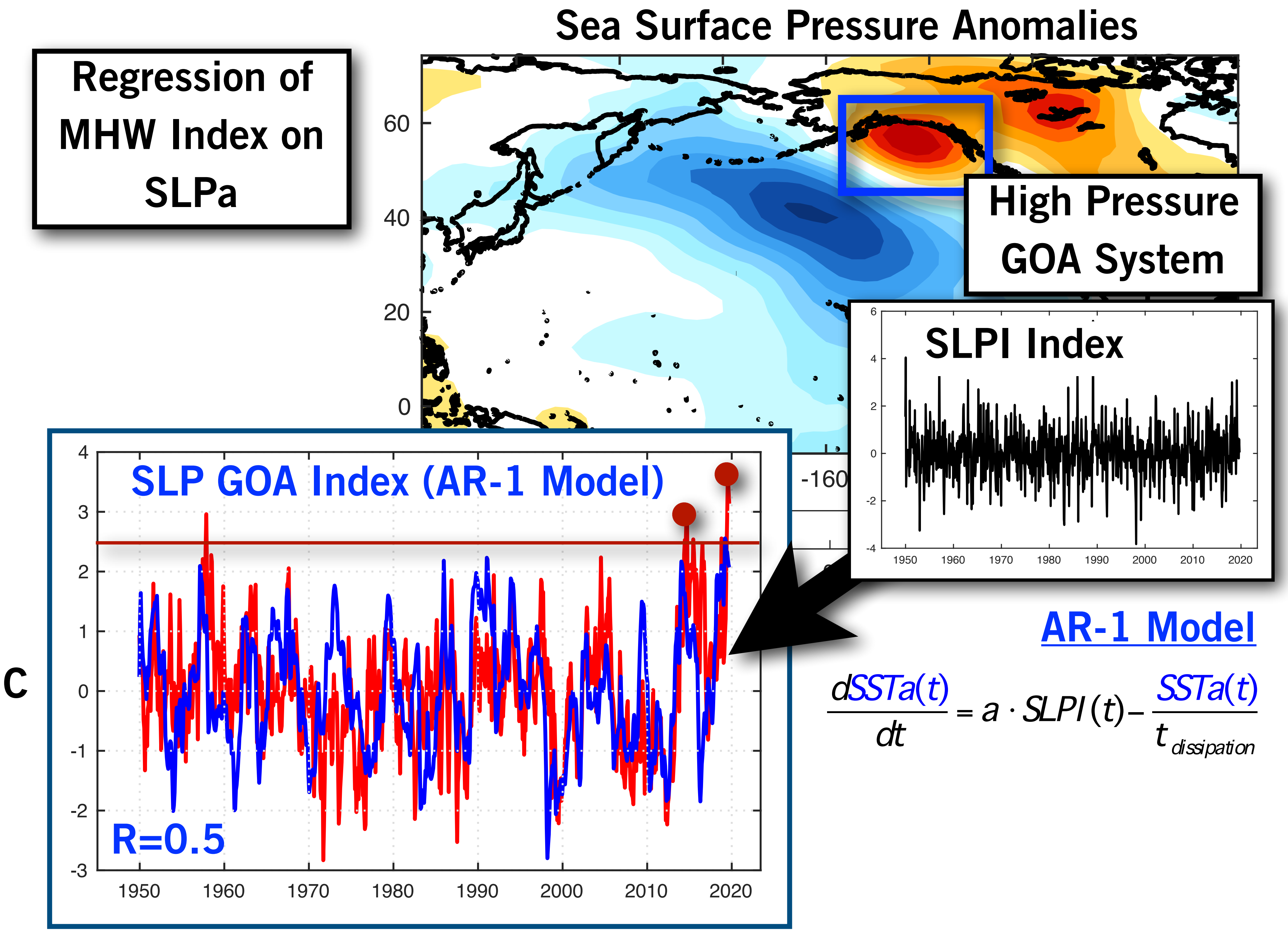

Sea Surface Pressure Anomalies
Regression of MHW Index on SLPa
60
40
20
0
-140
-120
-100
0
0.2
0.4
0.6
mlbar
C
1957
2014/15
2019
4
3
2
1
0
-1
-2
-3
1950
1960
1970
1980
1990
2000
2010
2020
Marine HeatWave Index
MHW Index



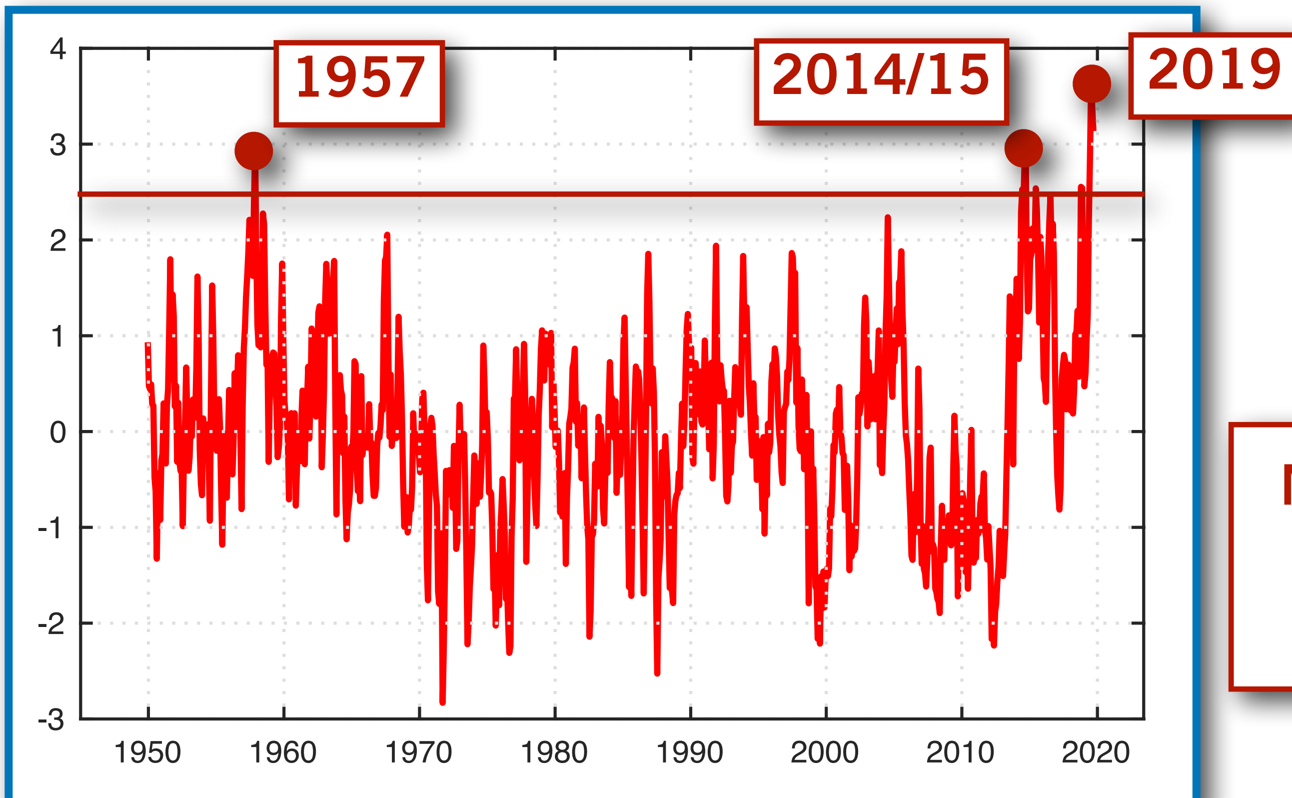
Sea Surface Pressure Anomalies
Regression of MHW Index on SLPa
High Pressure GOA System
SLPI Index
C
Marine HeatWave Index
MHW Index



Sea Surface Pressure Anomalies
Regression of MHW Index on SLPa
60
40
20
0
-160
0
High Pressure GOA System
SLPI Index
6 4 2 0 -2 -4
1950 1960 1970 1980 1990 2000 2010 2020
C
4 3 2 1 0 -1 -2 -3
1950 1960 1970 1980 1990 2000 2010 2020
AR-1 Model
$\frac{dSSTa(t)}{dt} = a \cdot SLPI(t) - \frac{SSTa(t)}{t_{dissipation}}$

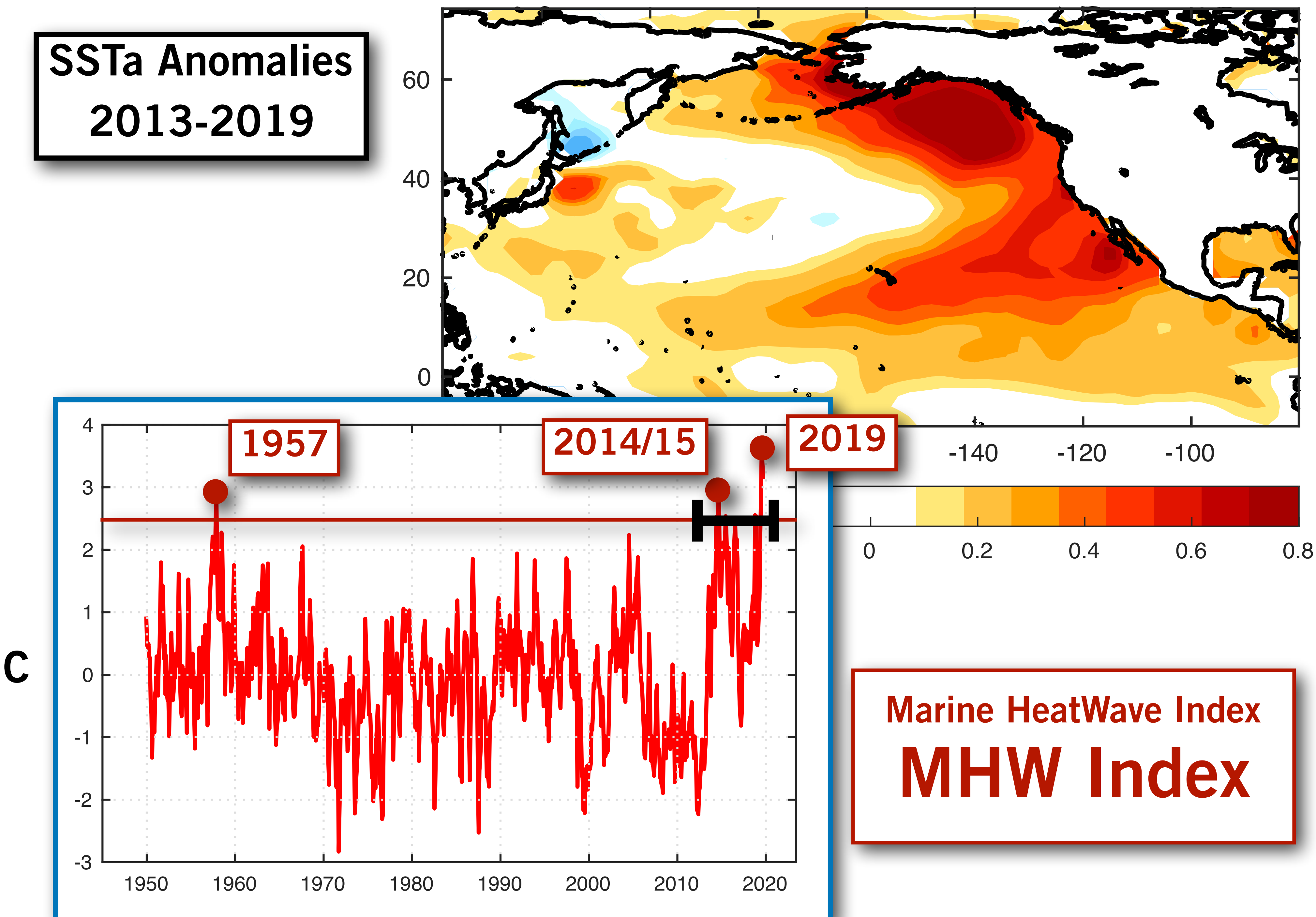

Sea Surface Pressure Anomalies
Regression of MHW Index on SLPa
High Pressure GOA System
SLPI Index
SLP GOA Index (AR-1 Model)
R=0.5
C
AR-1 Model
$\frac{dSSTa(t)}{dt} = a \cdot SLPI(t) - \frac{SSTa(t)}{t_{dissipation}}$

C

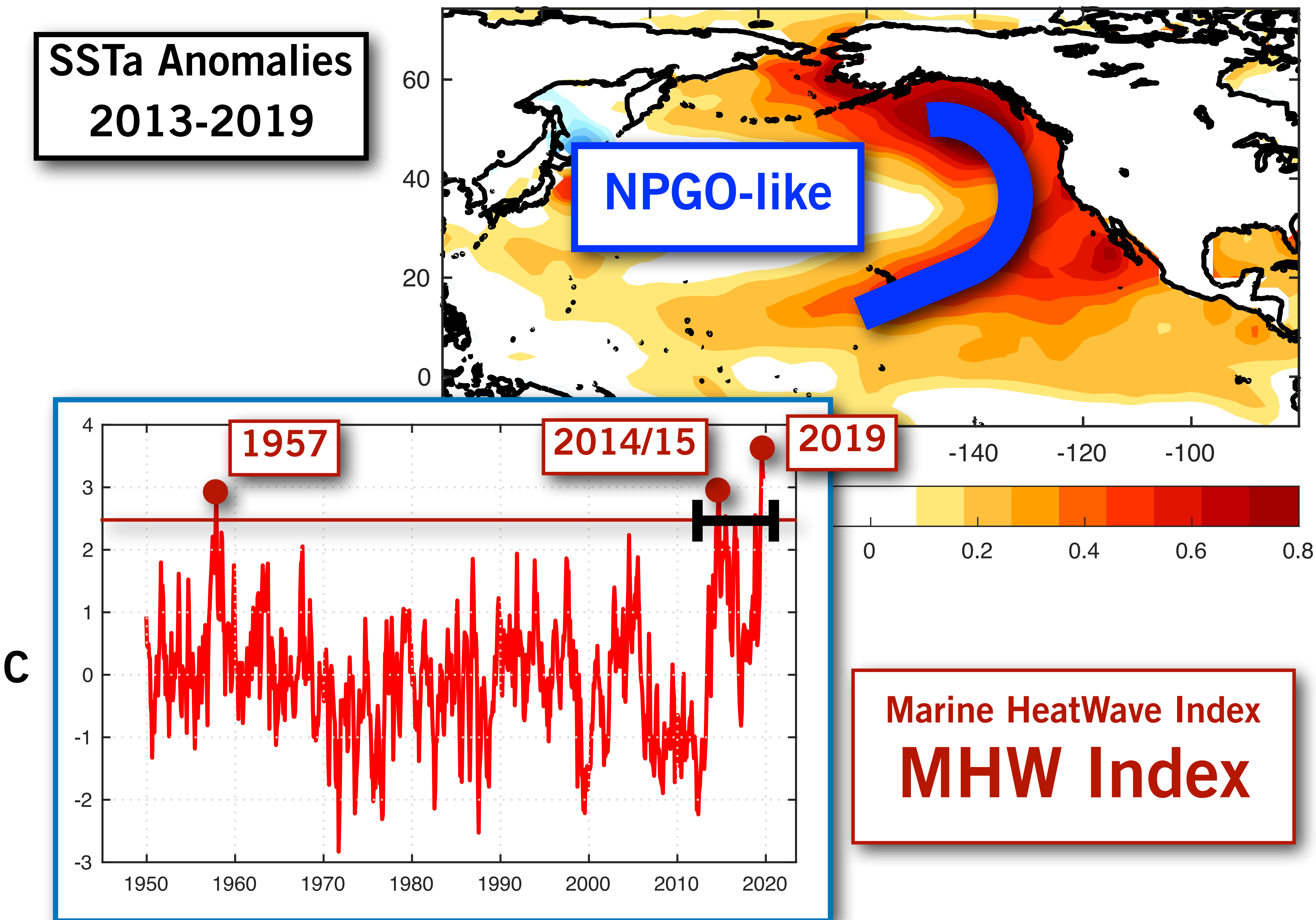


Marine HeatWave Index

MHW Index



SSTa Anomalies
2013-2019
60
40
20
0
-140
-120
-100
0
0.2
0.4
0.6
0.8
C
4
3
2
1
0
-1
-2
-3
1950
1960
1970
1980
1990
2000
2010
2020
1957
2014/15
2019
Marine HeatWave Index
MHW Index


SSTa Anomalies
2013-2019
NPGO-like
60
40
20
0
-140
-120
-100
0
0.2
0.4
0.6
0.8
C
1957
2014/15
2019
4
3
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1
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-1
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1950
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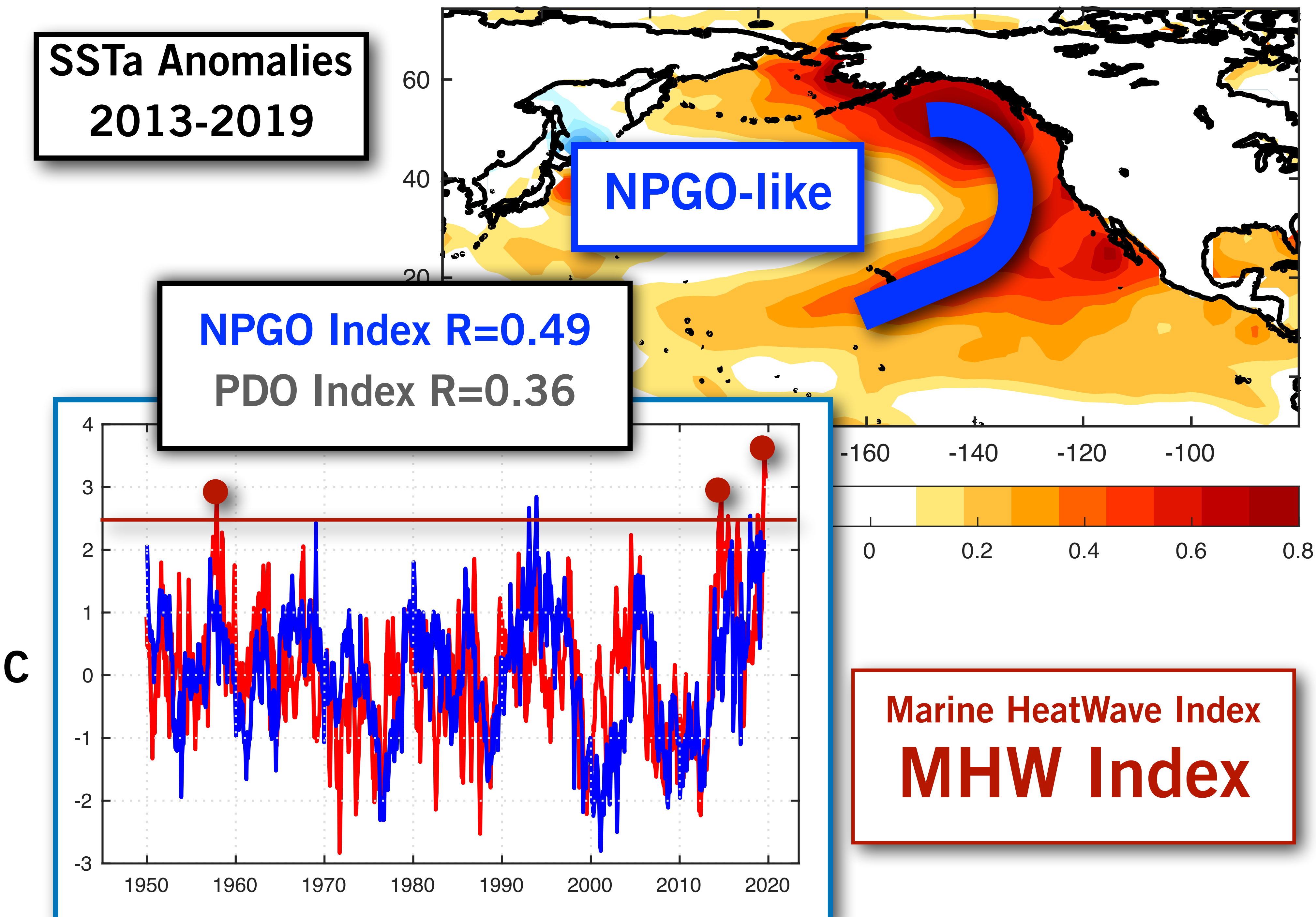
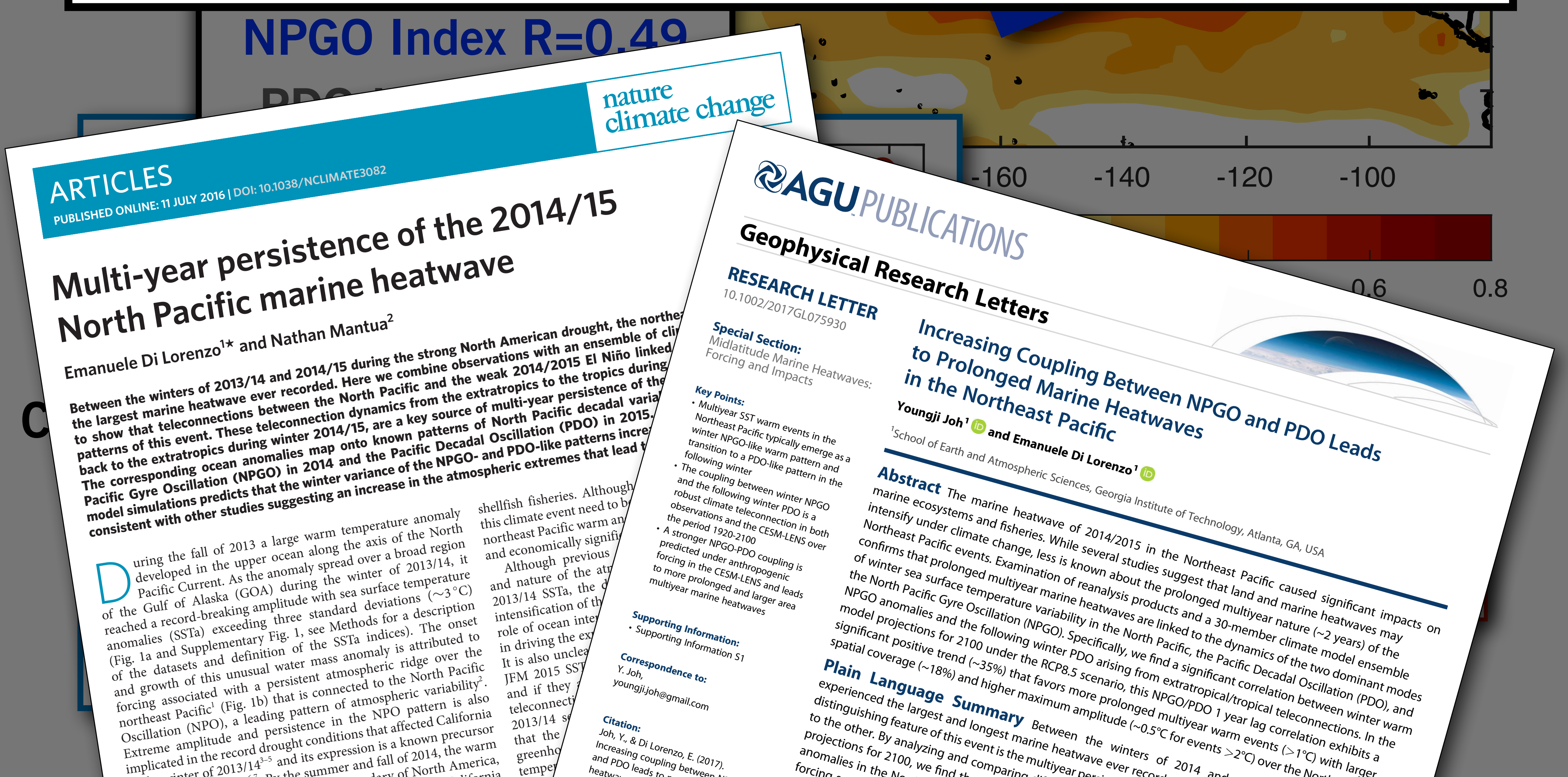
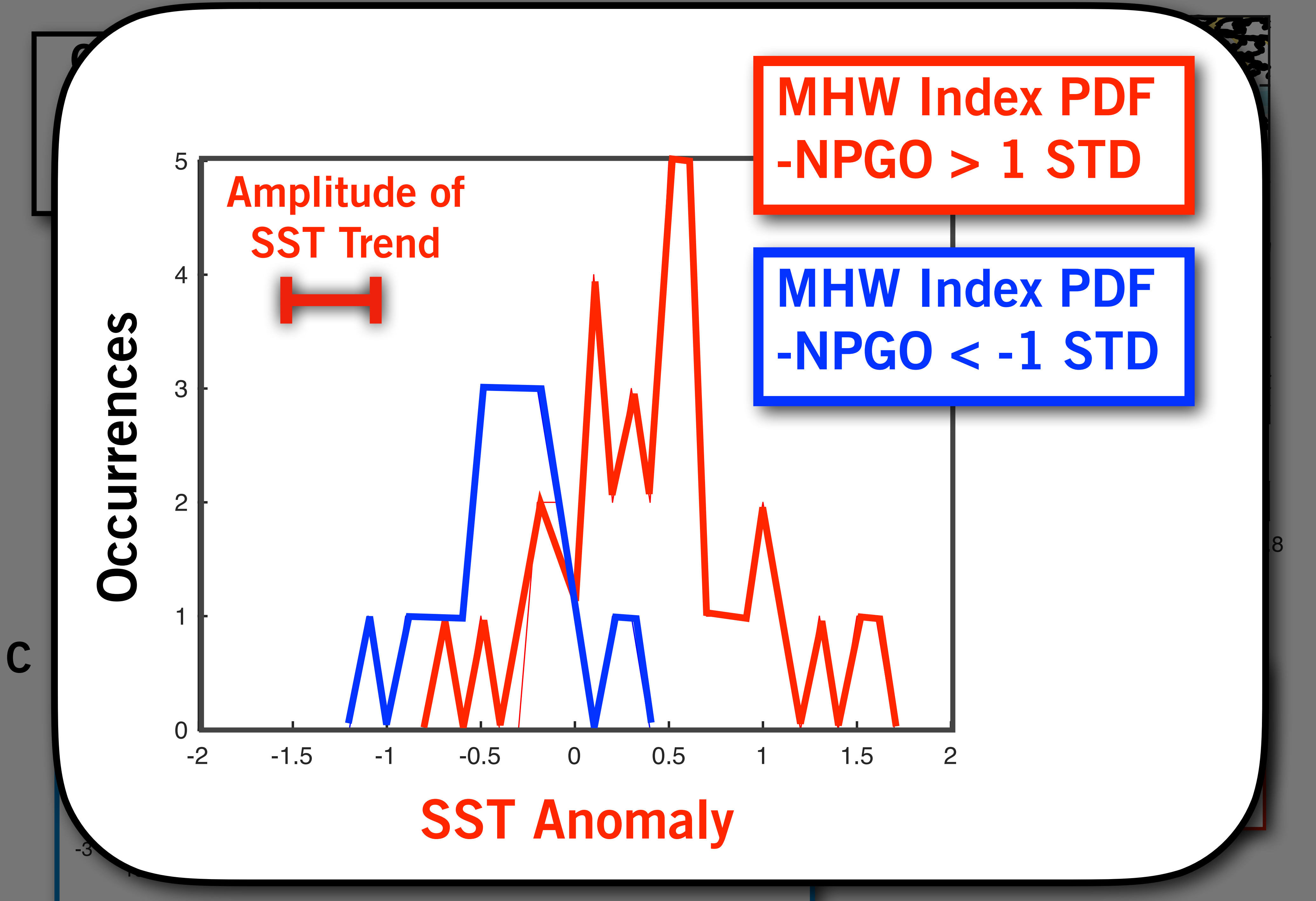
2000
2010
2020
Marine HeatWave Index
MHW Index

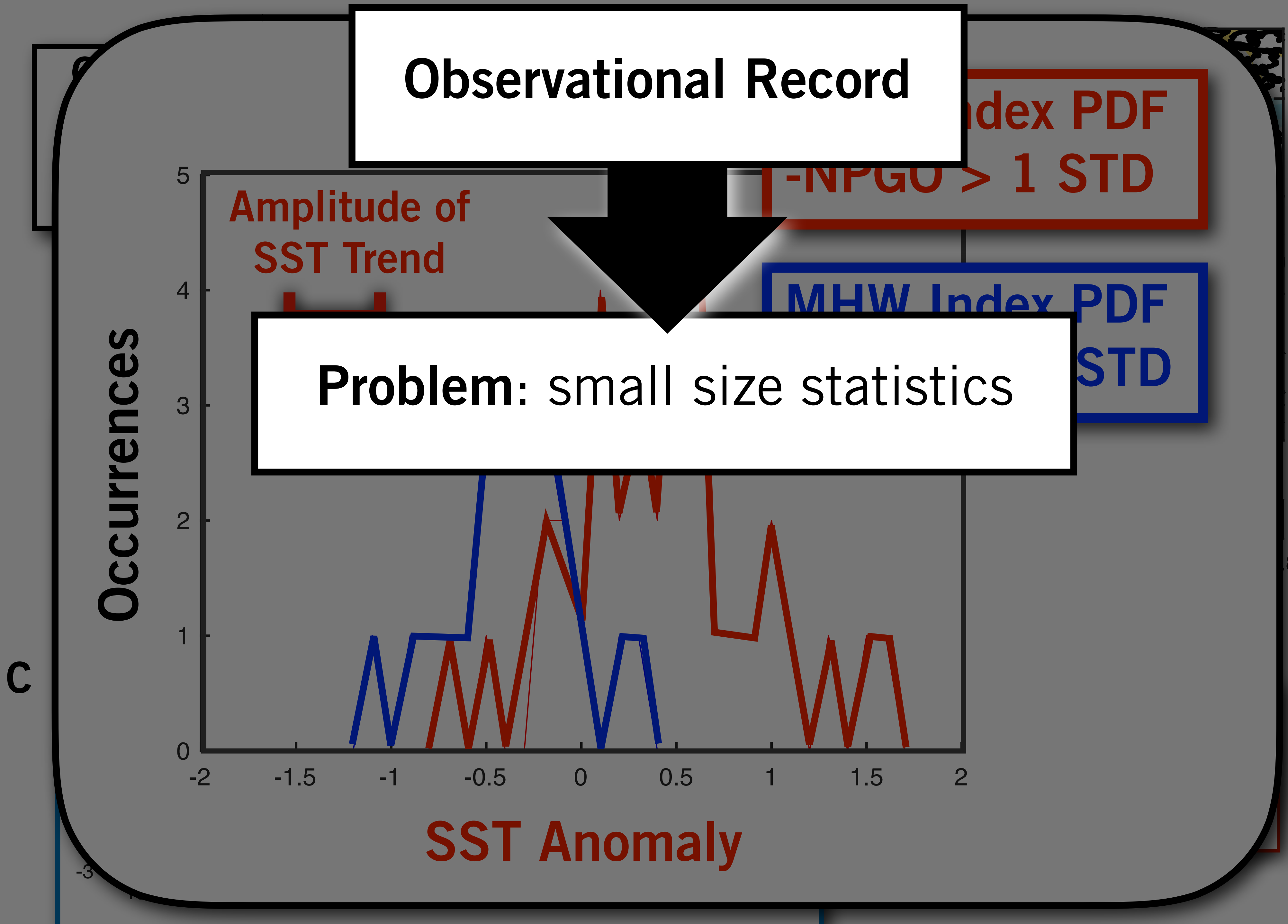

SSTa Anomalies
2013-2019
60
40
20
NPGO-like
NPGO Index R=0.49
PDO Index R=0.36
-160
-140
-120
-100
0
0.2
0.4
0.6
0.8
4
3
2
1
0
-1
-2
-3
1950
1960
1970
1980
1990
2000
2010
2020
C
Marine HeatWave Index
MHW Index

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





MHW Index PDF
-NPGO > 1 STD
MHW Index PDF
-NPGO < -1 STD
Amplitude of
SST Trend
Occurrences
SST Anomaly
0
1
2
3
4
5
-2
-1.5
-1
-0.5
0
0.5
1
1.5
2
C


Observational Record
Problem: small size statistics
Amplitude of SST Trend
-NPGO > 1 STD
MHW Index PDF
Occurrences
SST Anomaly
C
0
1
2
3
4
5
-2
-1.5
-1
-0.5
0
0.5
1
1.5
2

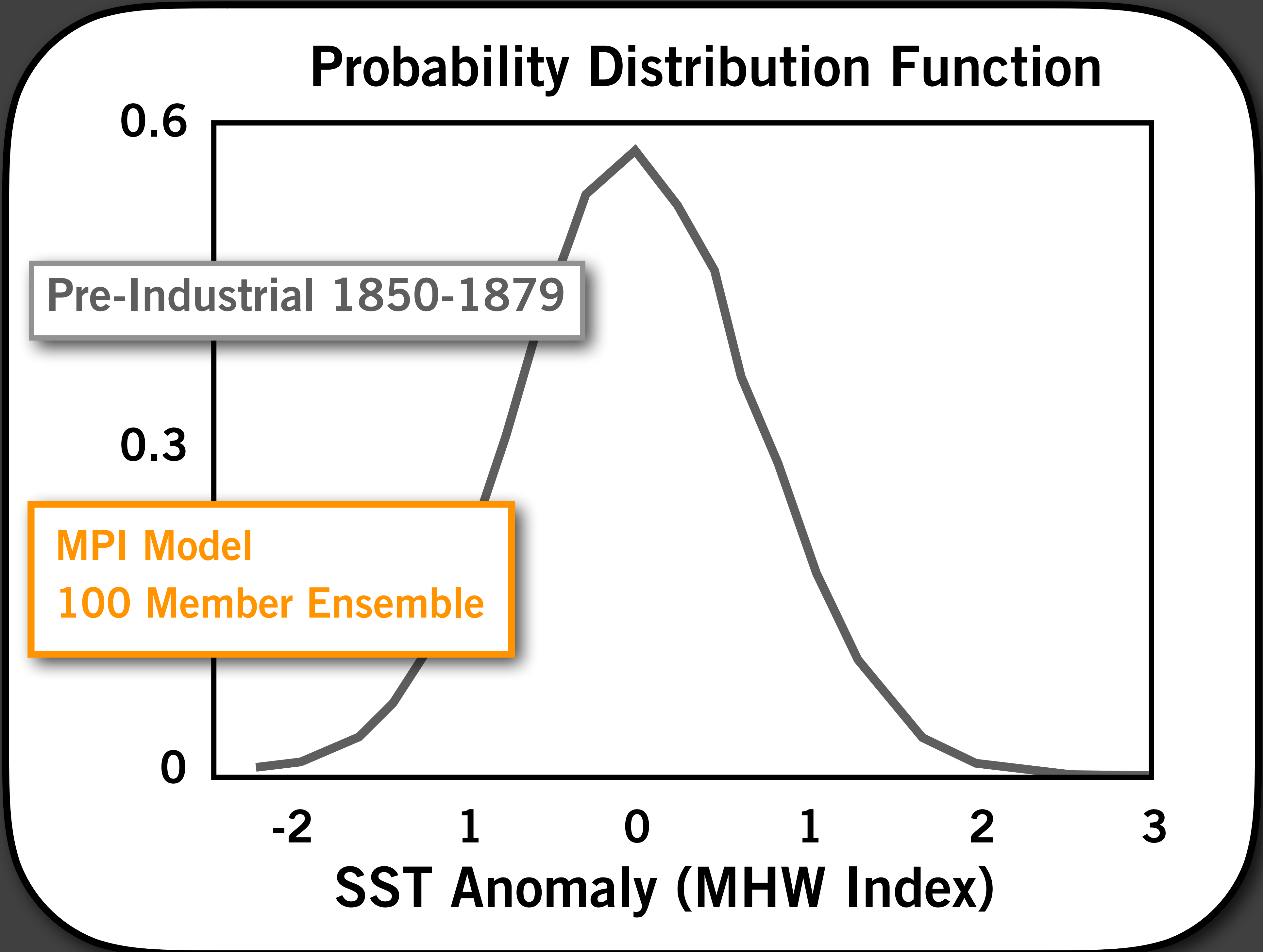
Observational Record

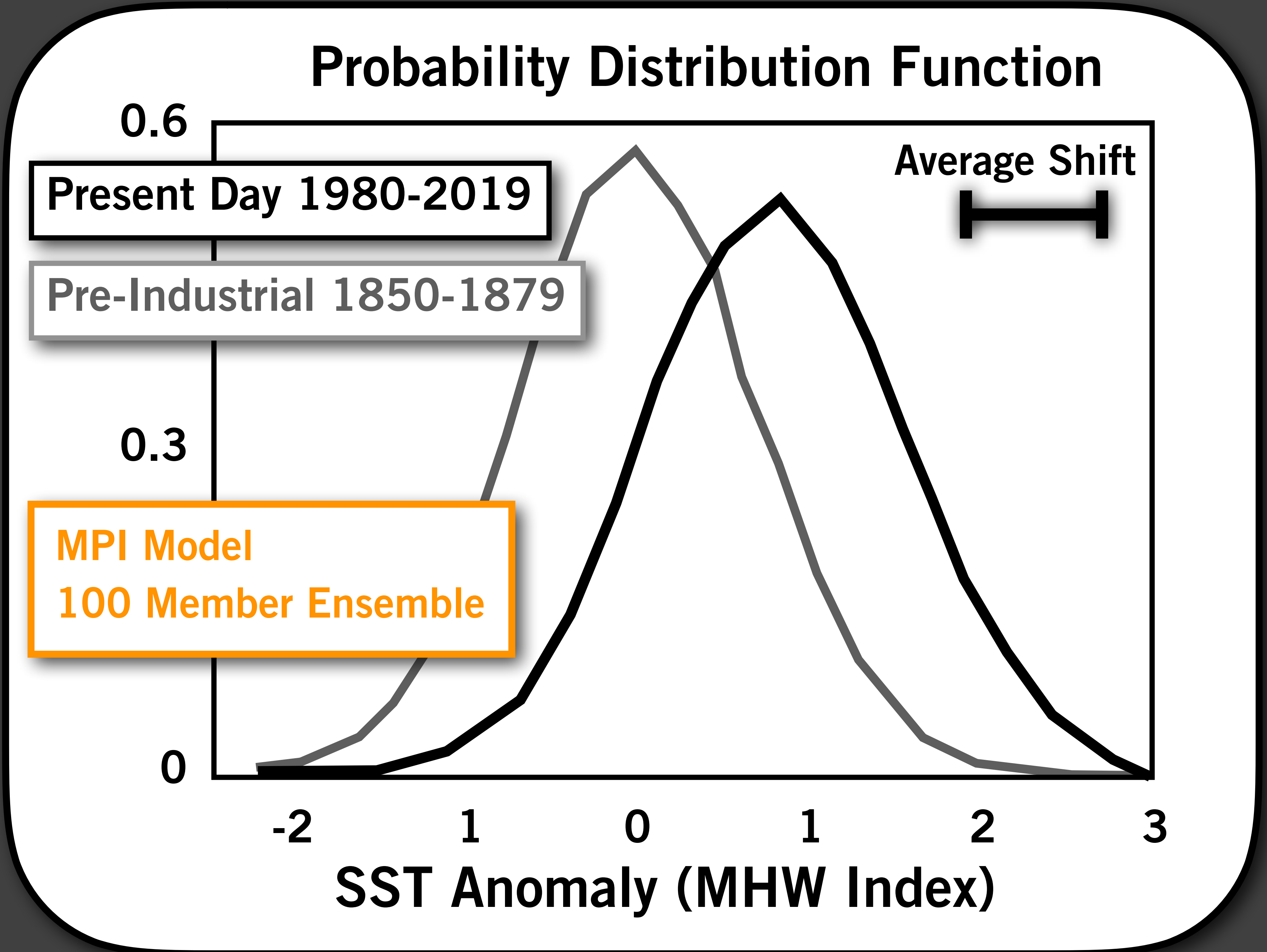
Problem: small size statistics

MPI-Grand Ensemble: **100 ensemble members**

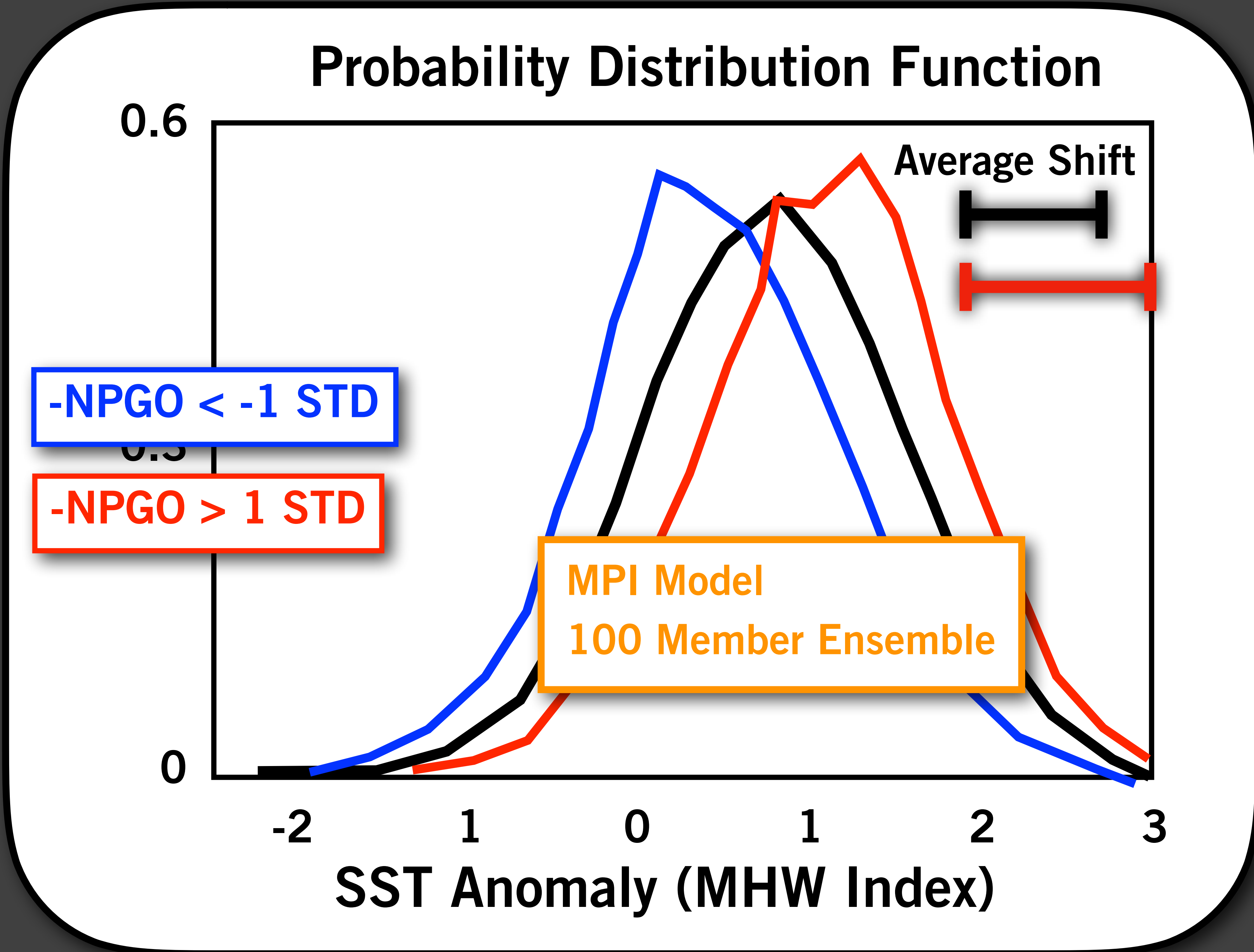
1850-2005 with historical radiative forcing

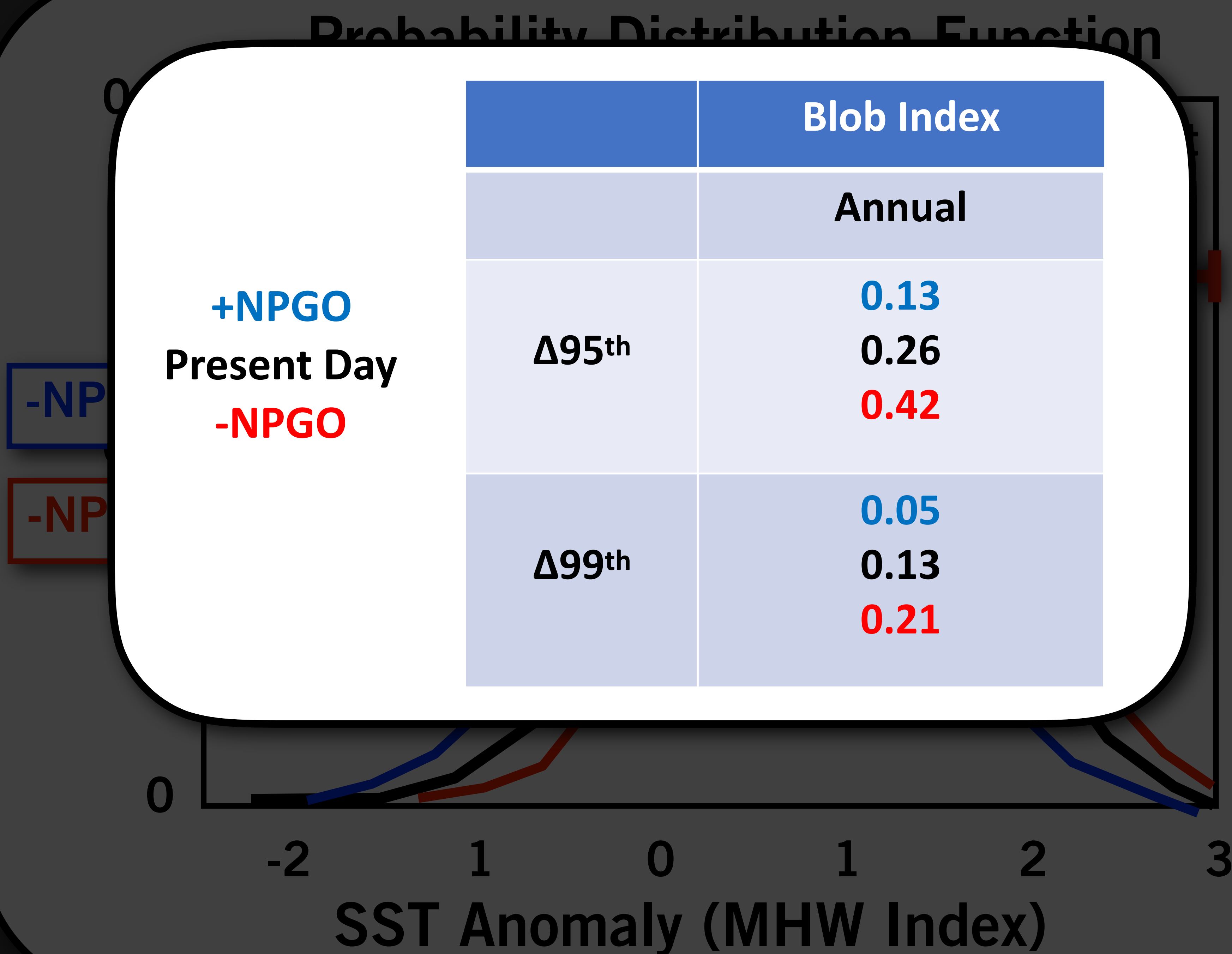
2006-2100 with RCP8.5


Probability Distribution Function
0.6
0.3
0
Pre-Industrial 1850-1879
MPI Model
100 Member Ensemble
-2
1
0
1
2
3
SST Anomaly (MHW Index)



Probability Distribution Function
0.6
0.3
0
Present Day 1980-2019
Pre-Industrial 1850-1879
Average Shift
MPI Model
100 Member Ensemble
-2
1
0
1
2
3
SST Anomaly (MHW Index)


Probability Distribution Function
0.6
0.3
0
Average Shift
-NPGO < -1 STD
-NPGO > 1 STD
MPI Model
100 Member Ensemble
-2
1
0
1
2
3
SST Anomaly (MHW Index)



+NPGO
Present Day
-NPGO

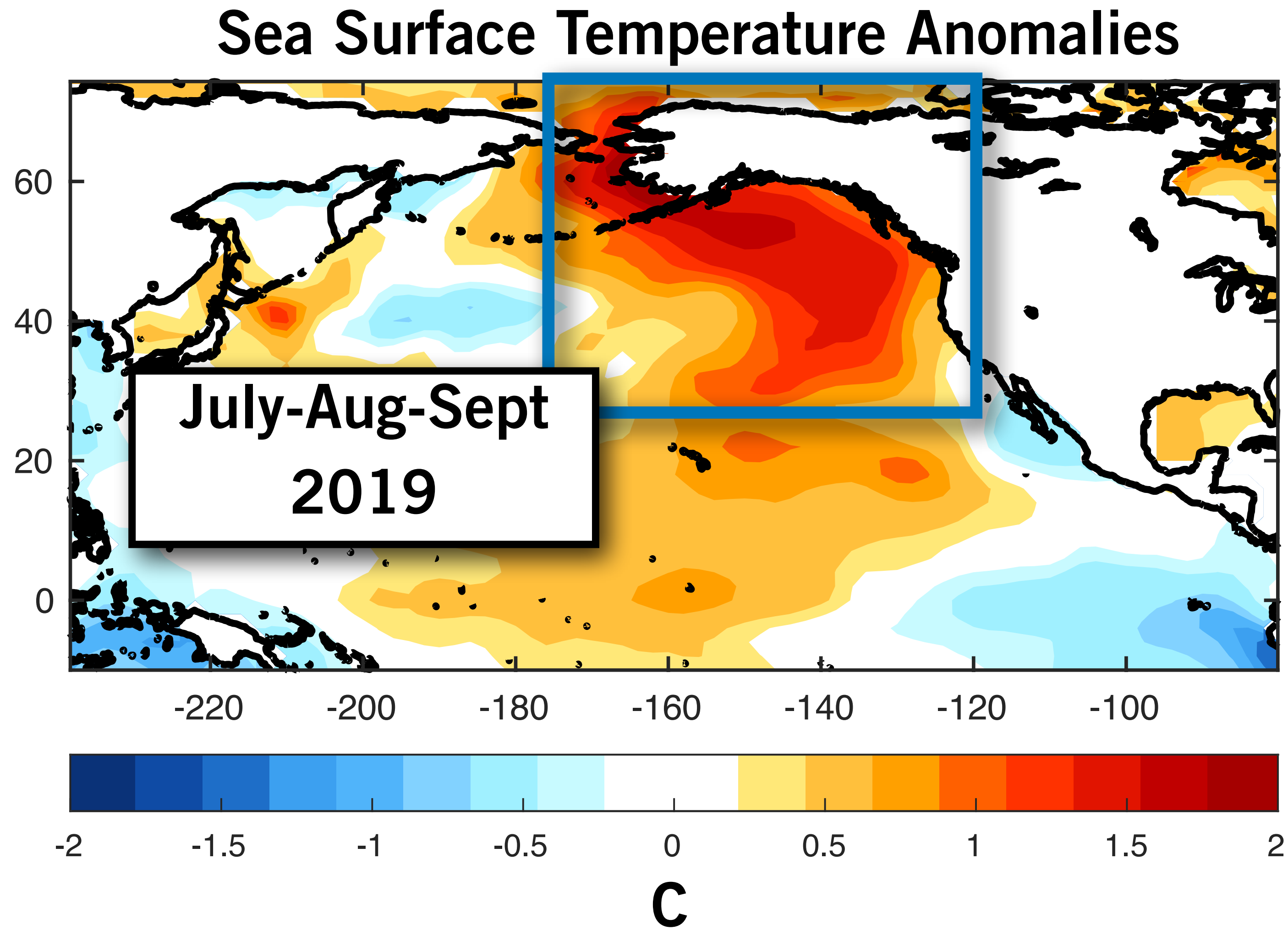
	Blob Index
	Annual
Δ95th	0.13 0.26 0.42
Δ99th	0.05 0.13 0.21

Probability Distribution Function

+NPGO
Present Day
-NPGO

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

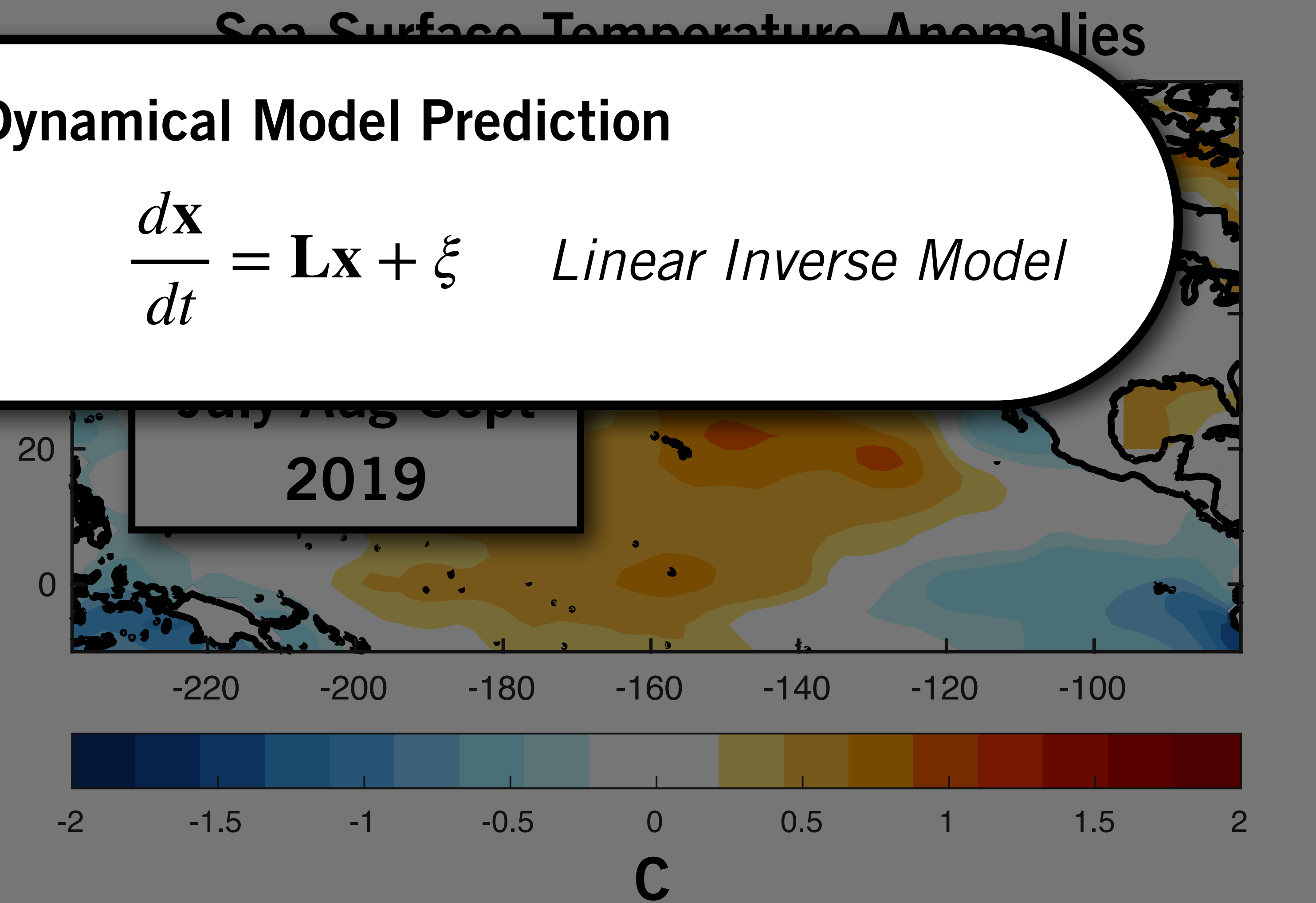
Changes in Extremes associated with trend is comparable to that of the phases of the decadal modes



Question: Is the Blob going to continue this winter?

Empirical Dynamical Model Prediction

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



Question: Is the Blob going to continue this winter?

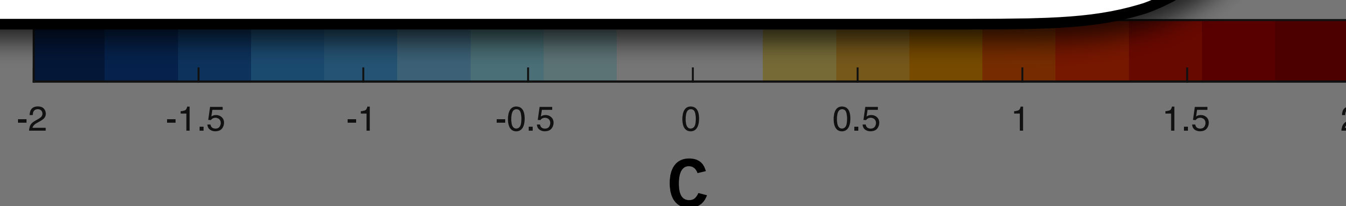
Sea Surface Temperature Anomalies

Empirical Dynamical Model Prediction

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

By solving the LIM system, we obtain

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



Question: Is the Blob going to continue this winter?

Sea Surface Temperature Anomalies

Empirical Dynamical Model Prediction

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

By solving the LIM system, we obtain

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

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

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

Sea Surface Temperature Anomalies

Empirical Dynamical Model Prediction

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

By solving the LIM system, we obtain

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

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

$$\begin{bmatrix} \hat{\mathbf{s}}(t+\tau) \\ \hat{\mathbf{p}}(t+\tau) \end{bmatrix} = \mathbf{G}(\tau = 6months) \begin{bmatrix} \mathbf{s}(t) \\ \mathbf{p}(t) \end{bmatrix} \begin{matrix} \longleftarrow \textbf{SSTA} \\ \longleftarrow \textbf{SLPA} \end{matrix}$$

Forecast March

Jan-Feb-March

6 Months Prediction

Initialize September

Sea Surface Temperature Anomalies

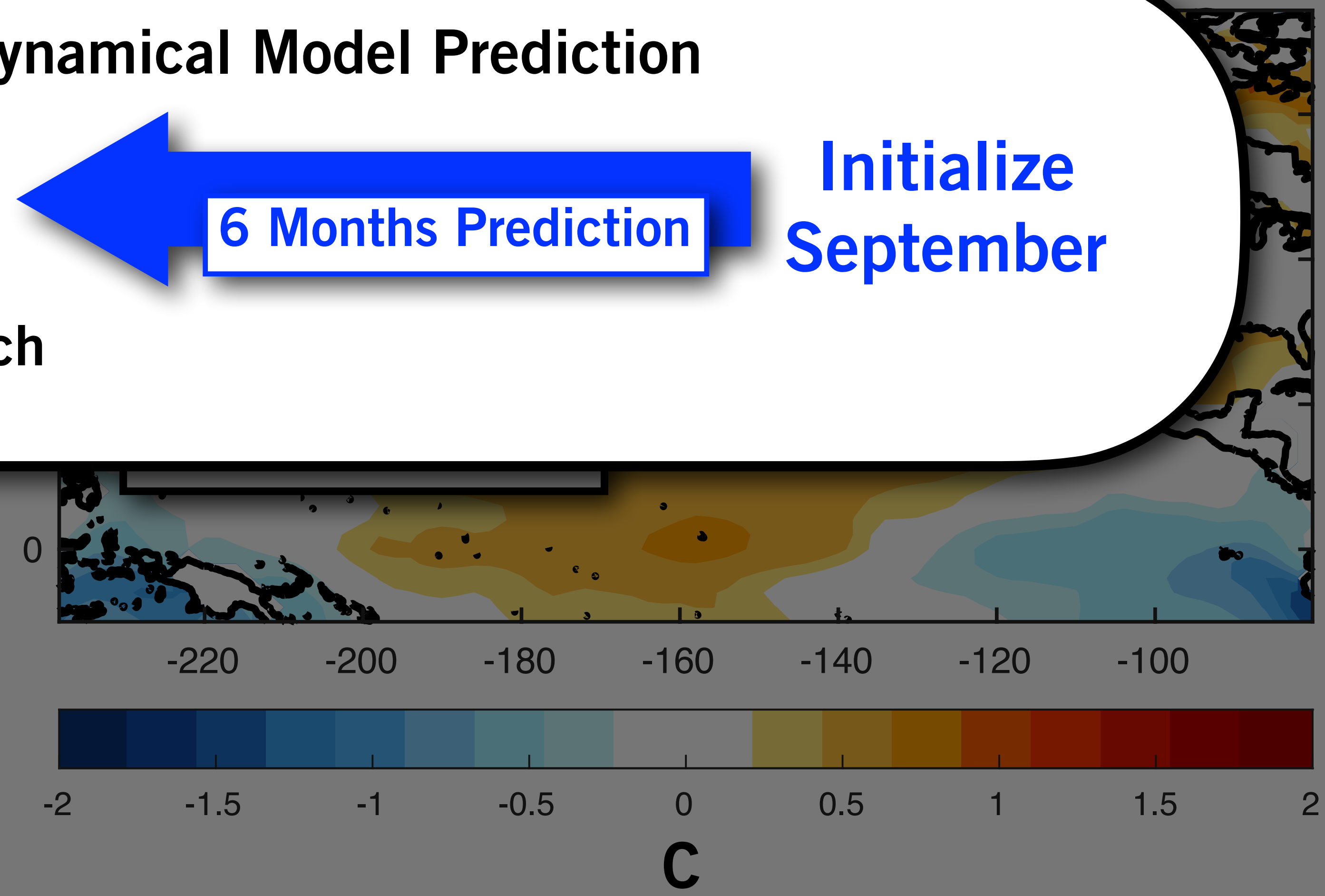
Empirical Dynamical Model Prediction

Forecast March

Jan-Feb-March

6 Months Prediction

Initialize September



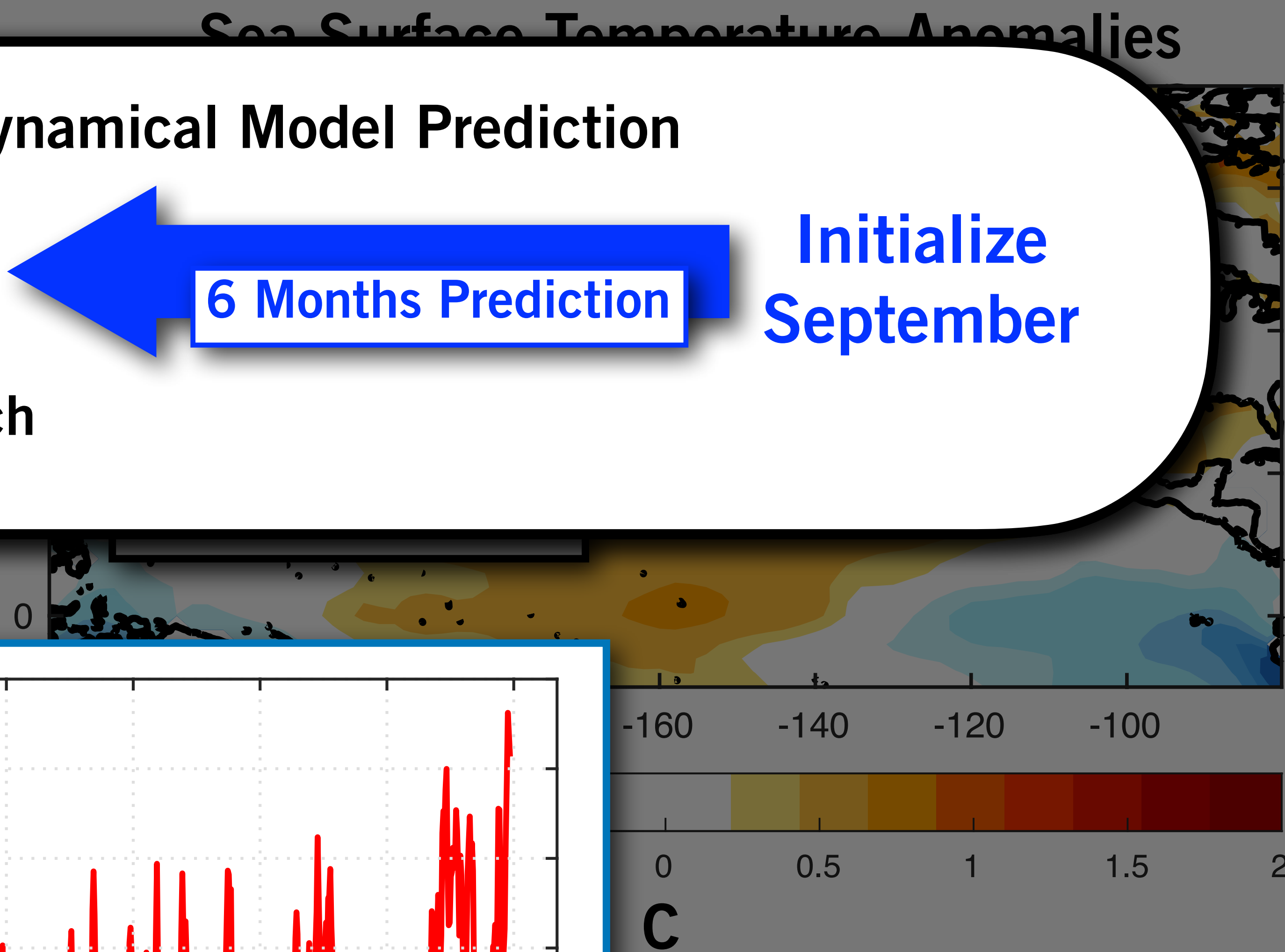
Empirical Dynamical Model Prediction

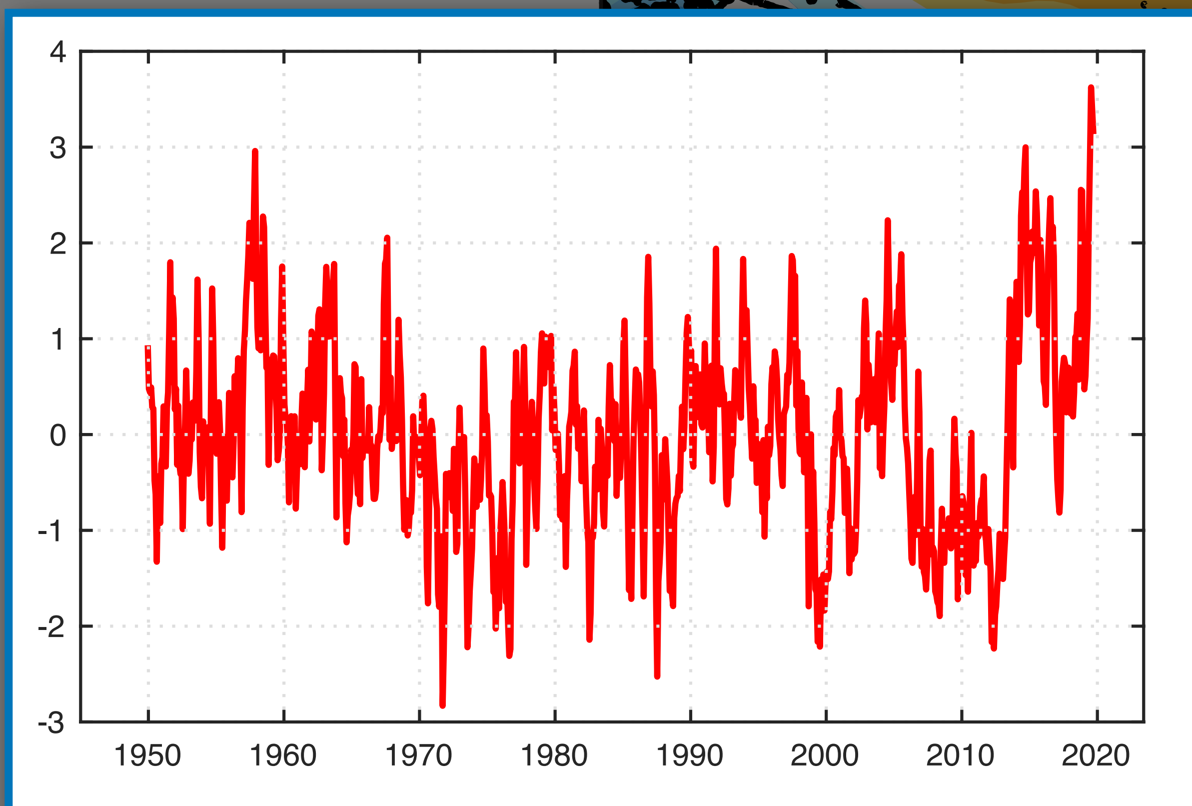
Forecast March

Jan-Feb-March

6 Months Prediction

Initialize September





Marine HeatWave Index

MHW Index

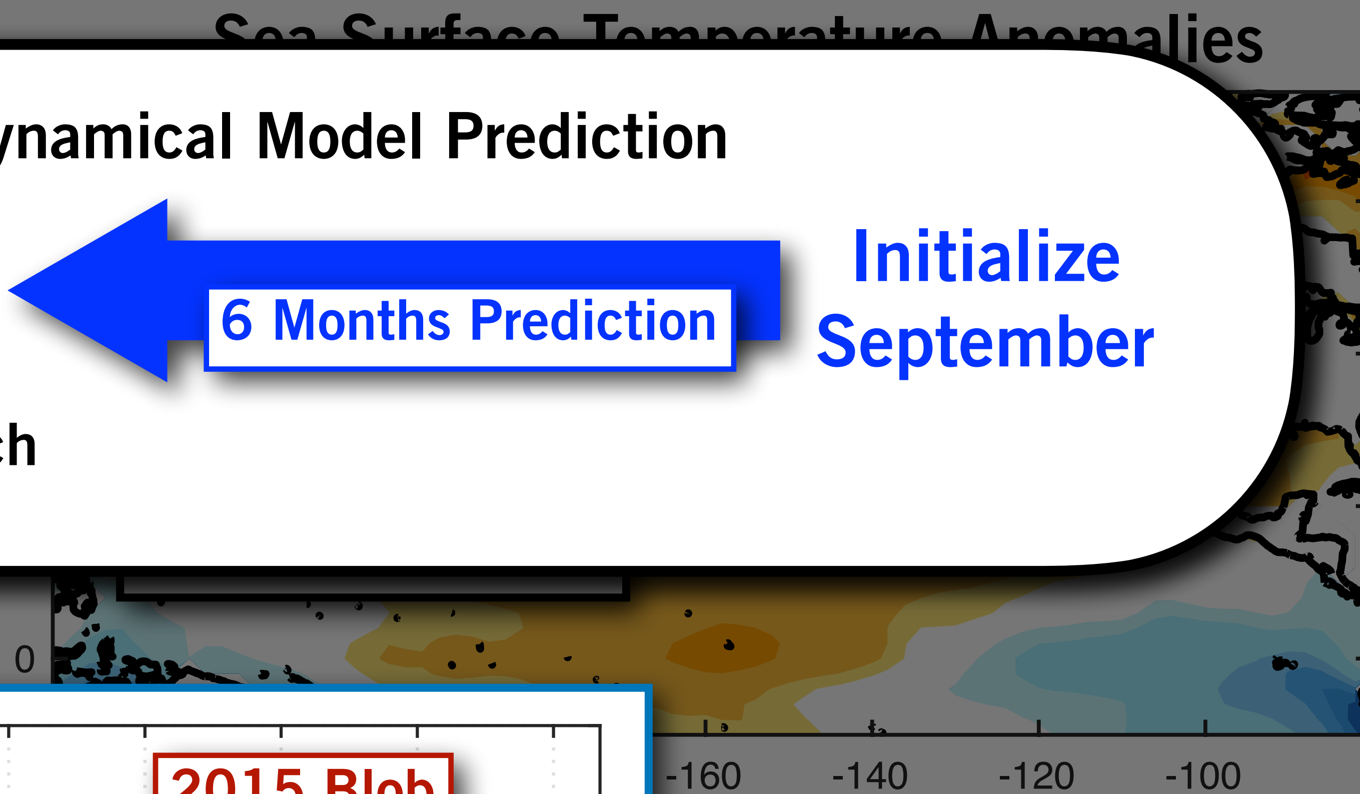
Empirical Dynamical Model Prediction

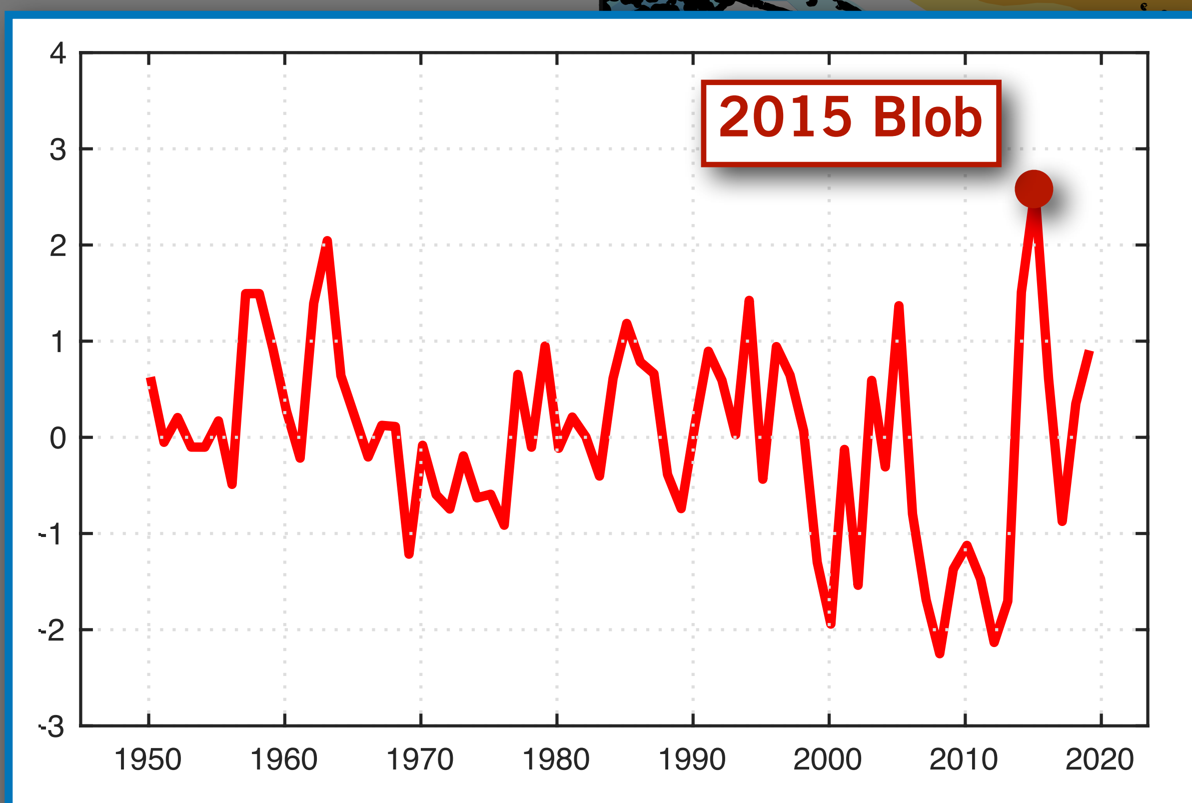
Forecast March

Jan-Feb-March

← 6 Months Prediction

Initialize September





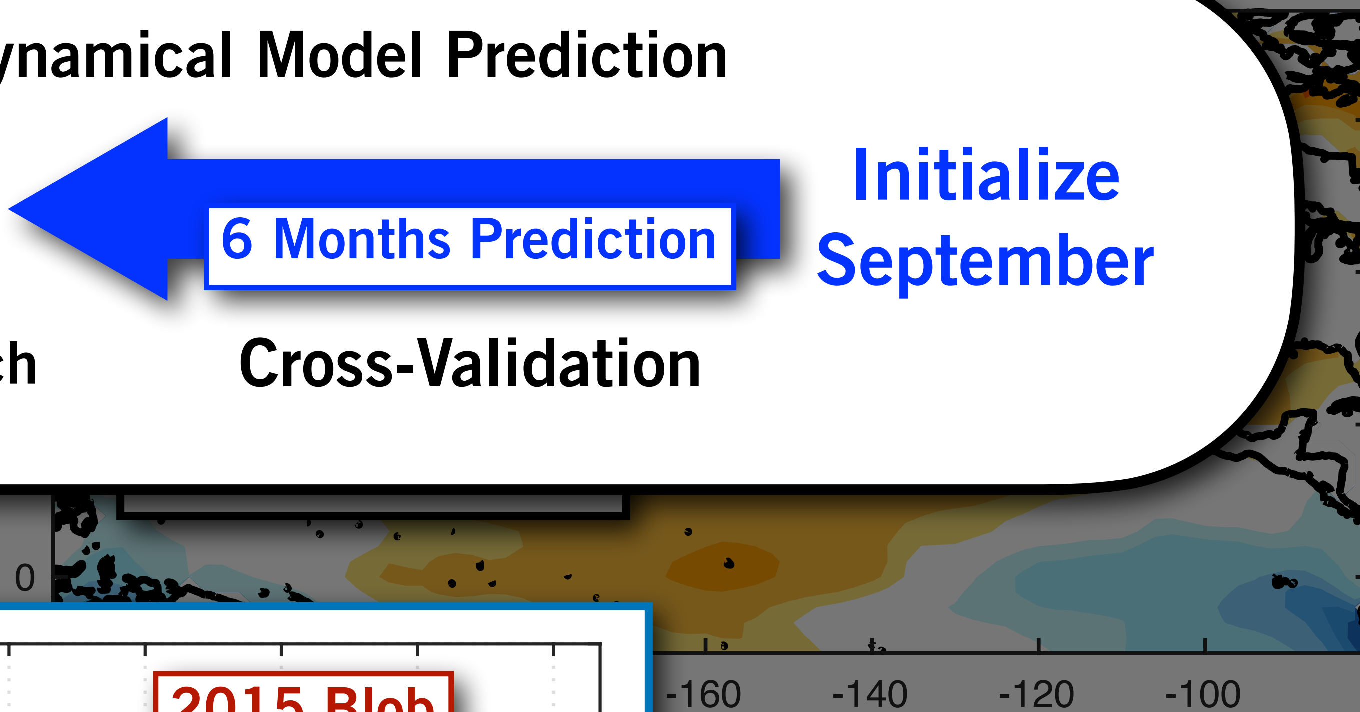
Winter Average

Jan-Feb-March

Marine HeatWave Index

MHW Index

Sea Surface Temperature Anomalies



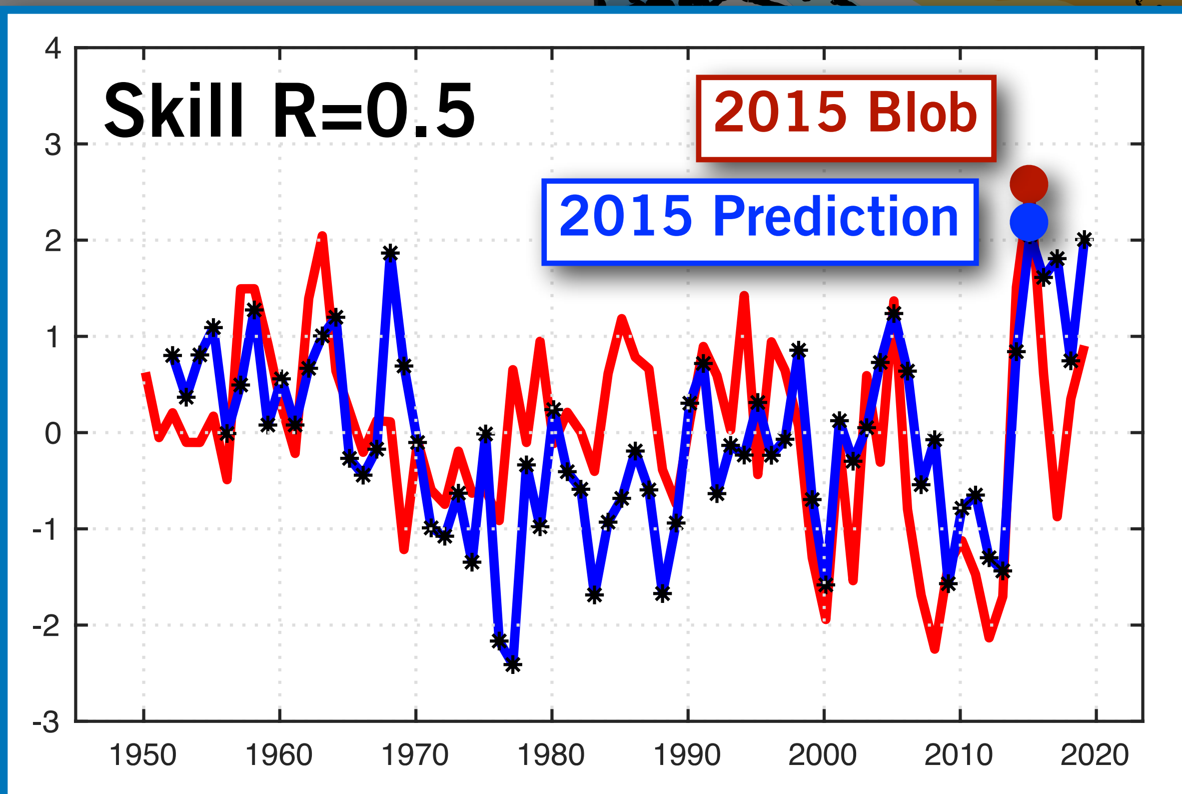
Empirical Dynamical Model Prediction

Forecast March
Jan-Feb-March

6 Months Prediction

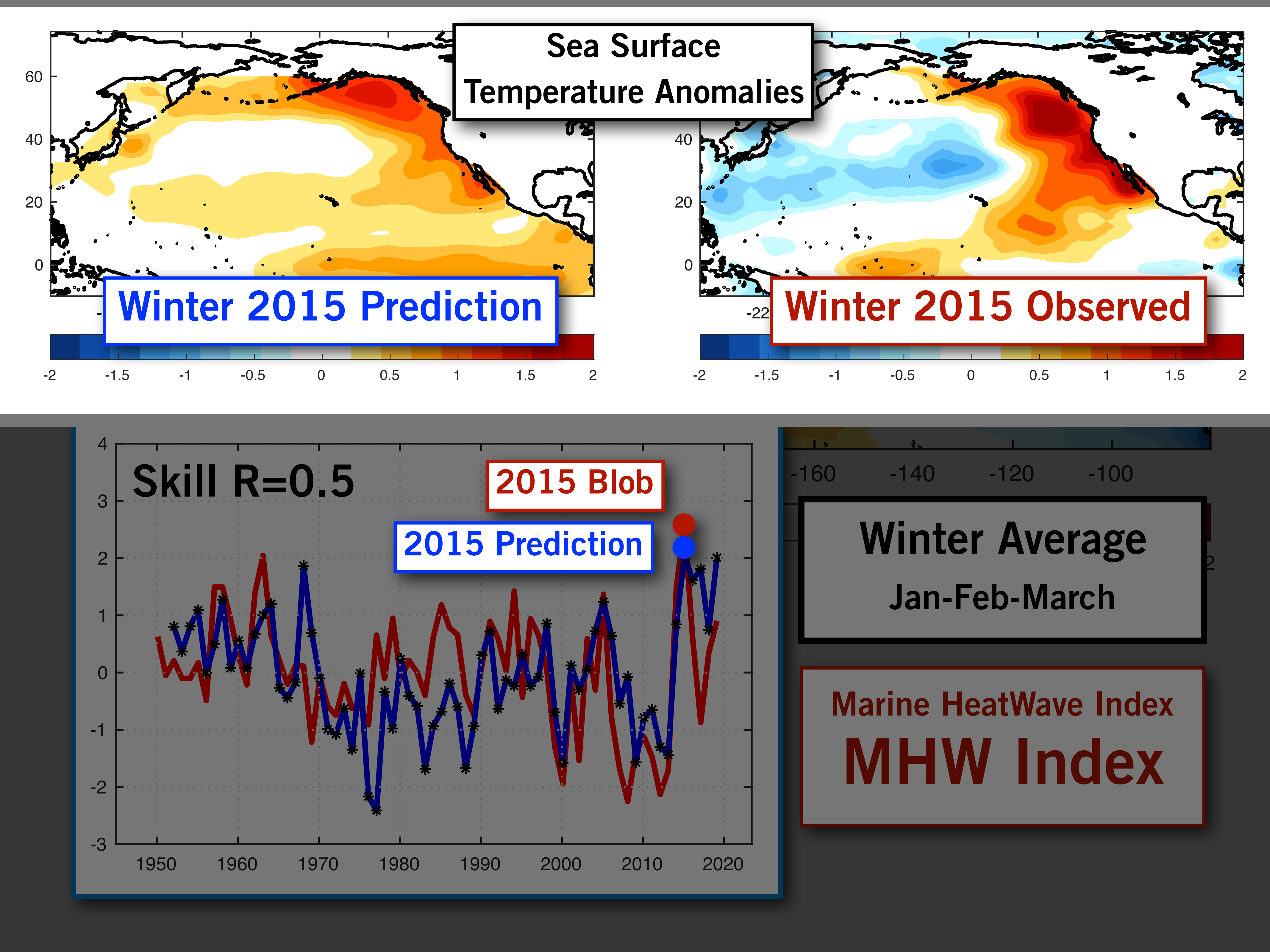
Initialize September

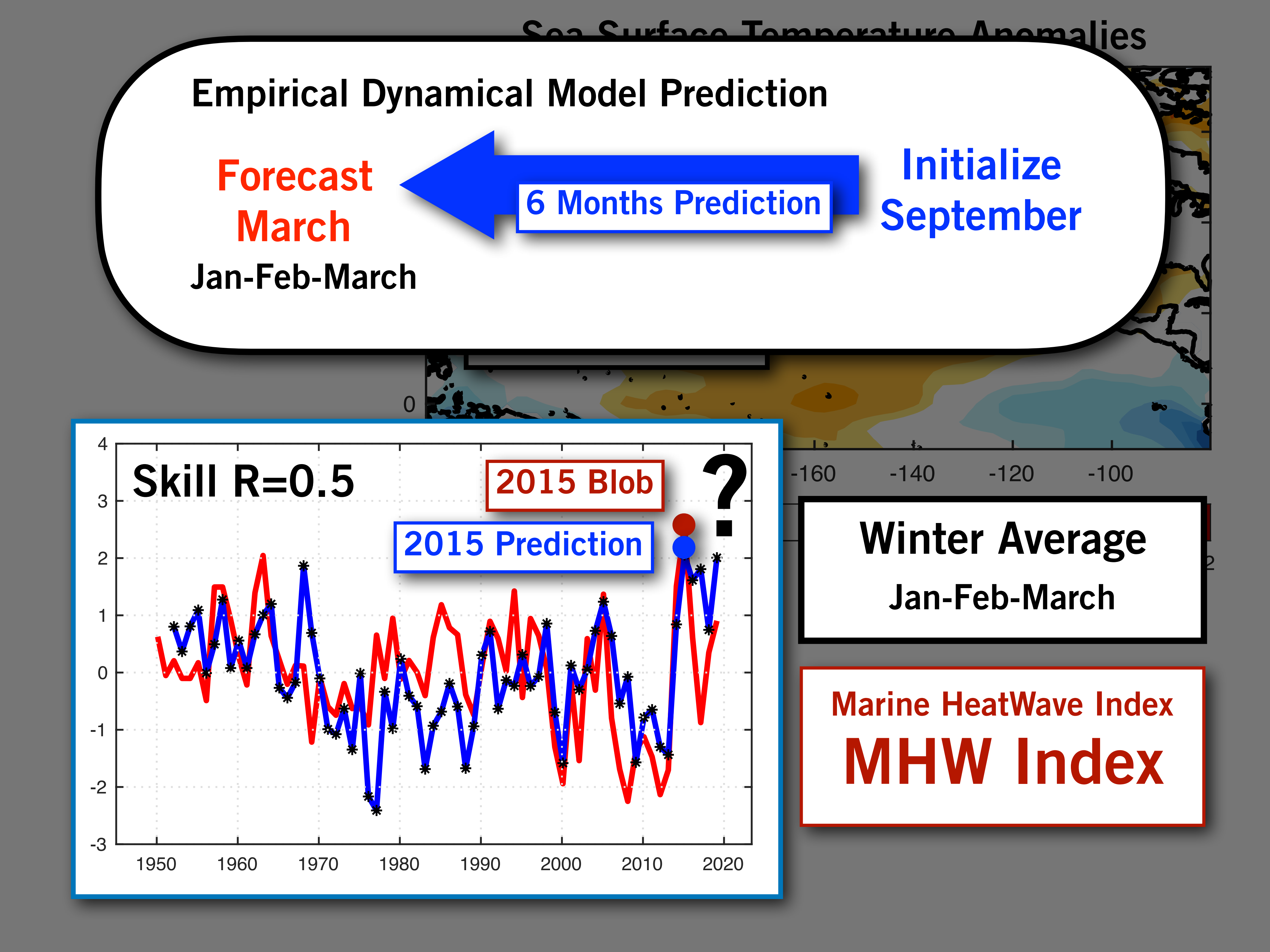
Cross-Validation

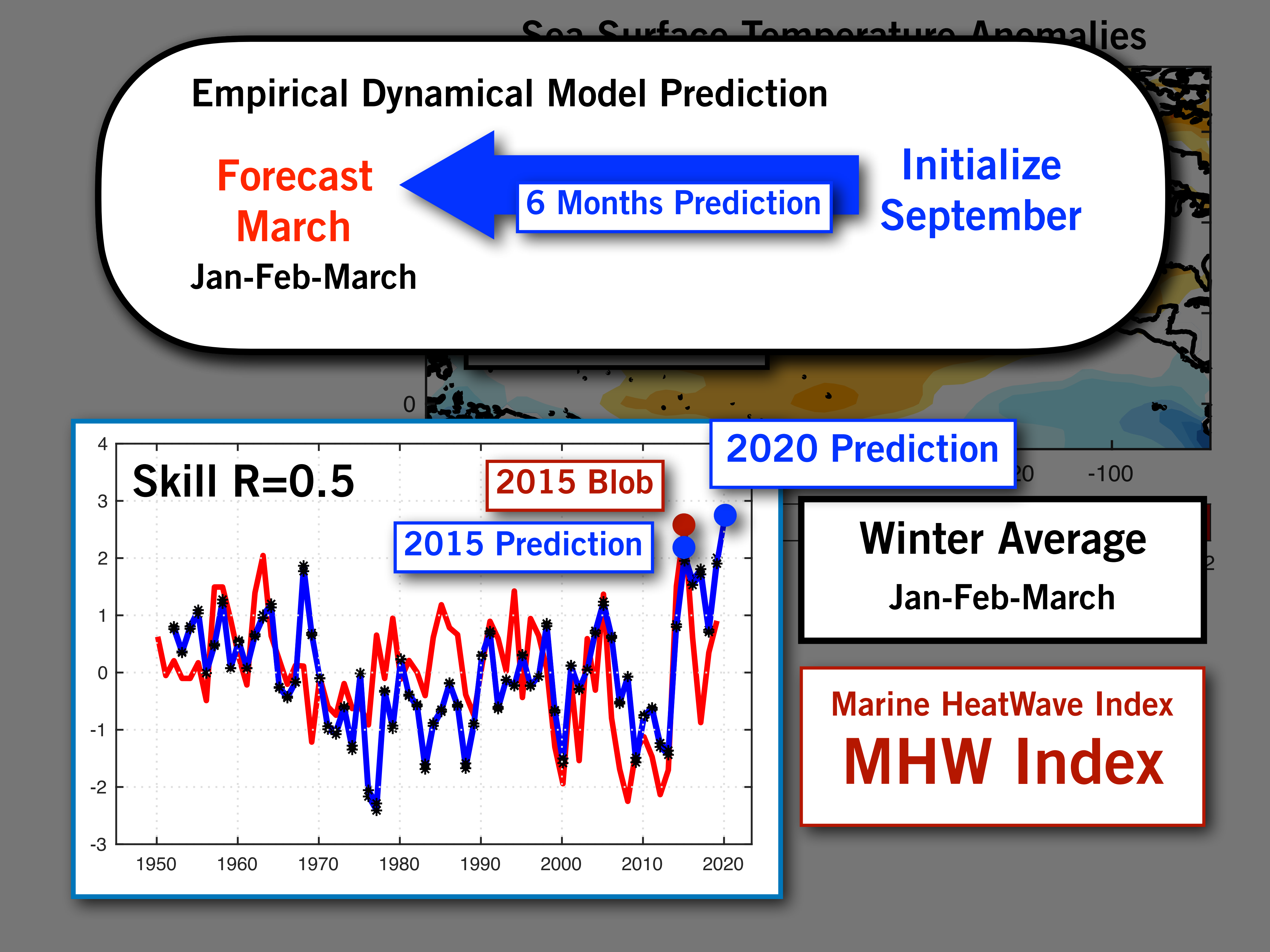


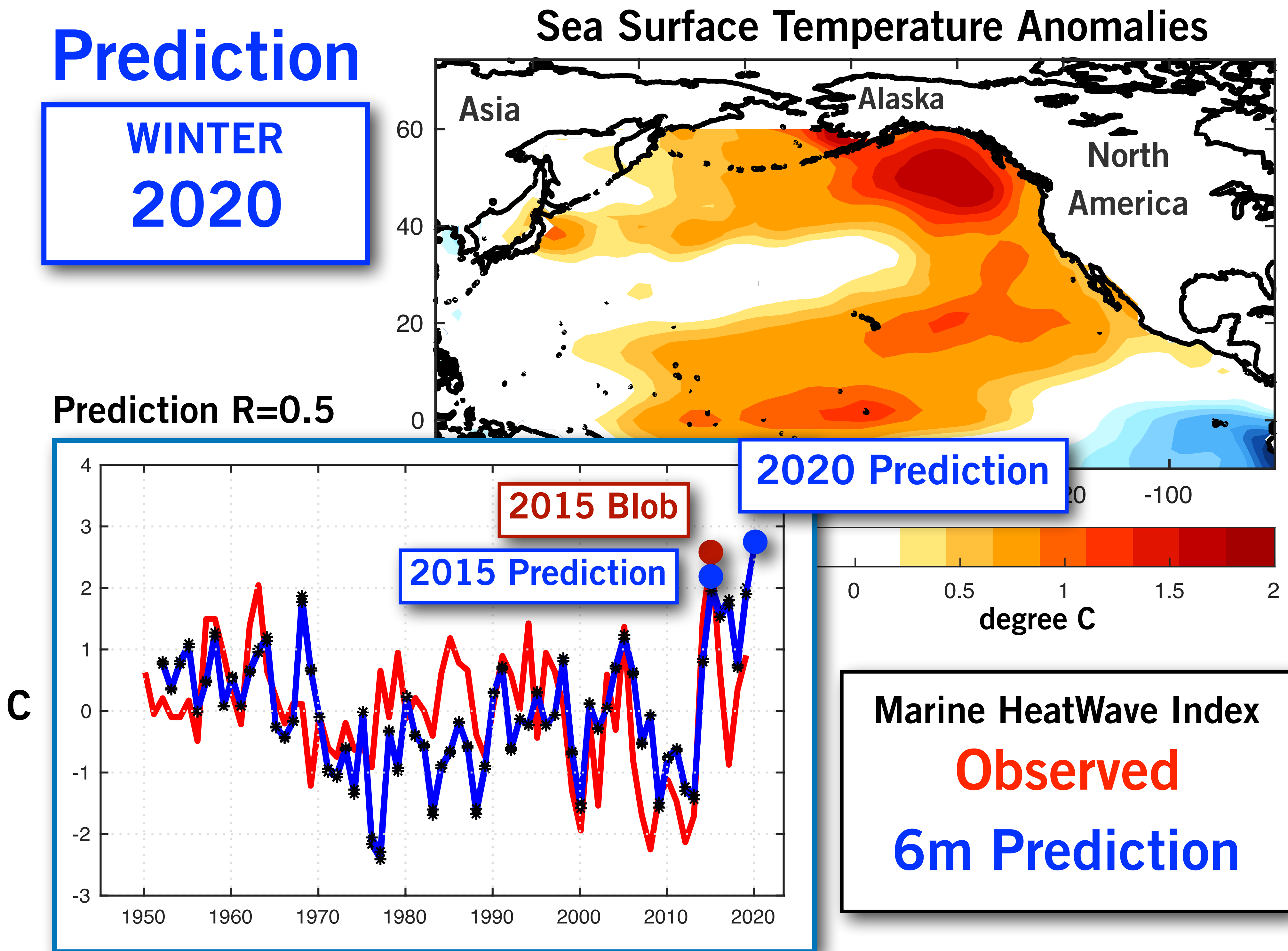
Winter Average
Jan-Feb-March

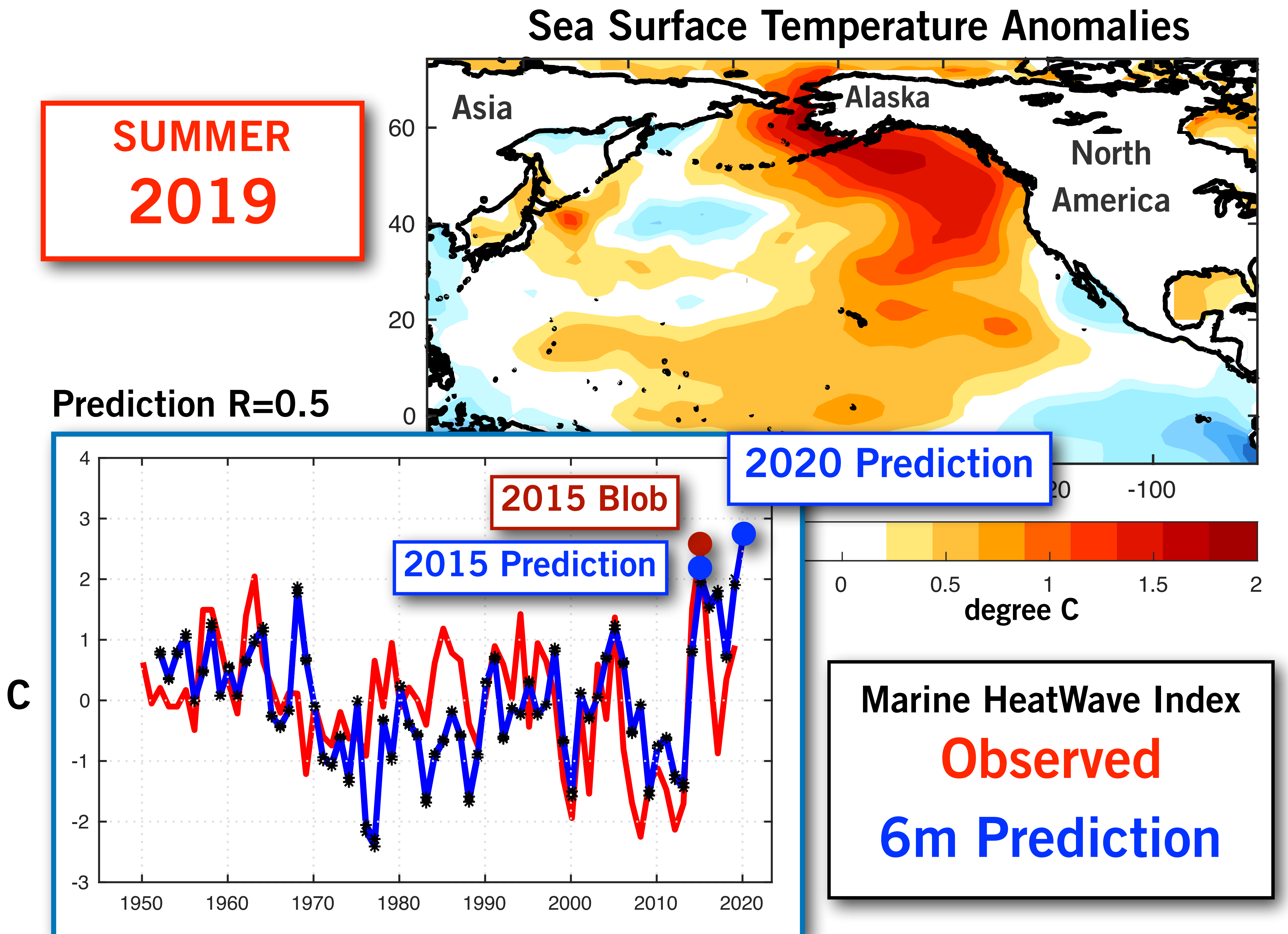
Marine HeatWave Index
MHW Index


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

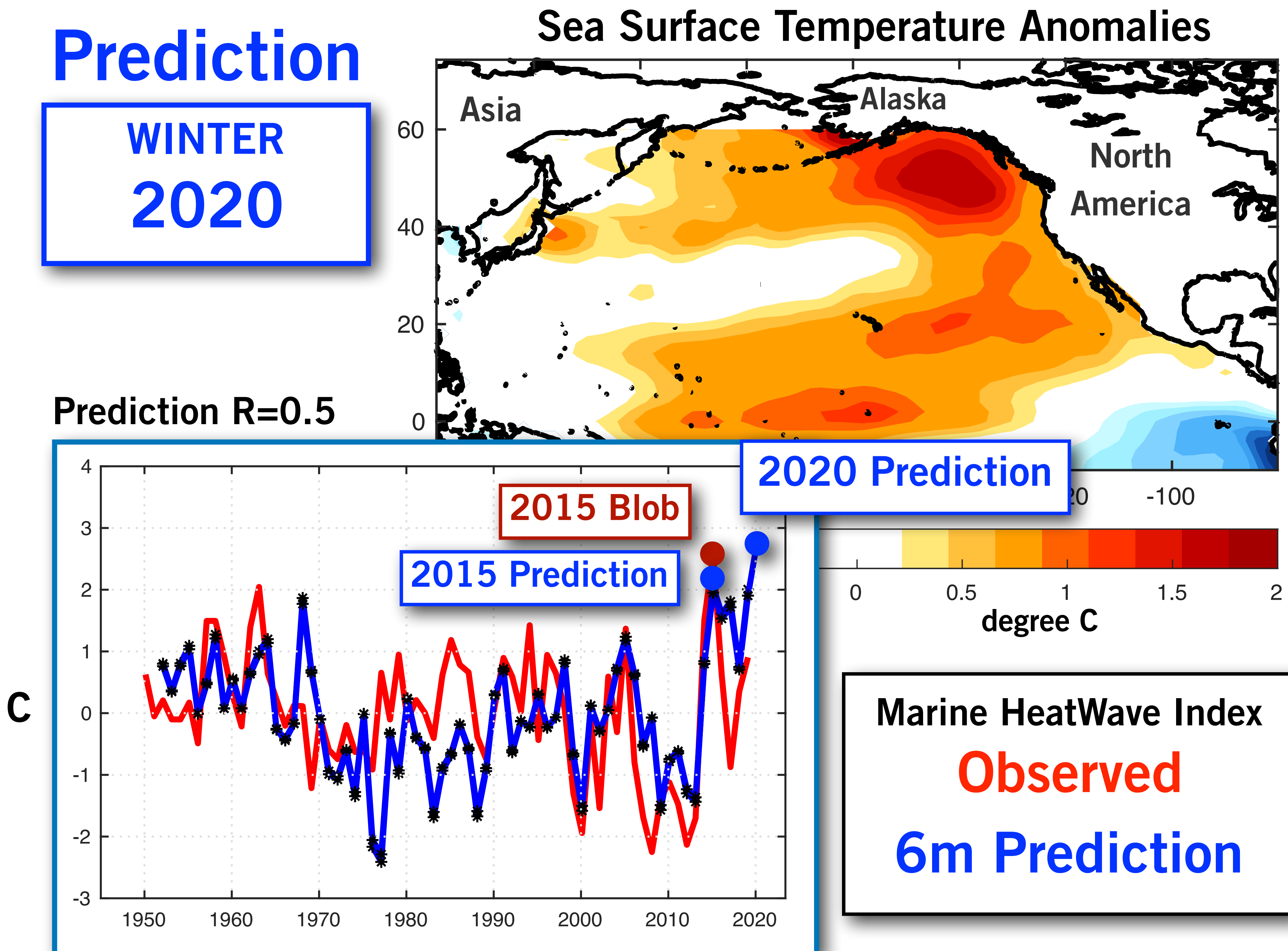

Sea Surface Temperature Anomalies
Empirical Dynamical Model Prediction
Forecast
March
Jan-Feb-March
6 Months Prediction
Initialize
September
0
-160
-140
-120
-100
Winter Average
Jan-Feb-March
Marine HeatWave Index
MHW Index
Skill R=0.5
2015 Blob
2015 Prediction
?
4
3
2
1
0
-1
-2
-3
1950
1960
1970
1980
1990
2000
2010
2020


Sea Surface Temperature Anomalies
Empirical Dynamical Model Prediction
Forecast
March
Jan-Feb-March
6 Months Prediction
Initialize
September
0
-100
2020 Prediction
Skill R=0.5
2015 Blob
2015 Prediction
4
3
2
1
0
-1
-2
-3
1950
1960
1970
1980
1990
2000
2010
2020
Winter Average
Jan-Feb-March
Marine HeatWave Index
MHW Index


Prediction
WINTER
2020
Sea Surface Temperature Anomalies
Asia
Alaska
North America
60
40
20
0
-100
0
0.5
1
1.5
2
degree C
Prediction R=0.5
C
2015 Blob
2015 Prediction
2020 Prediction
4
3
2
1
0
-1
-2
-3
1950
1960
1970
1980
1990
2000
2010
2020
Marine HeatWave Index
Observed
6m Prediction



Sea Surface Temperature Anomalies
SUMMER
2019
Asia
Alaska
North
America
60
40
20
0
-100
0
0.5
1
1.5
2
degree C
Prediction R=0.5
2020 Prediction
2015 Blob
2015 Prediction
C
4
3
2
1
0
-1
-2
-3
1950
1960
1970
1980
1990
2000
2010
2020
Marine HeatWave Index
Observed
6m Prediction


Prediction
WINTER
2020
Sea Surface Temperature Anomalies
Asia
Alaska
North
America
60
40
20
0
-100
0
0.5
1
1.5
2
degree C
Prediction R=0.5
C
4
3
2
1
0
-1
-2
-3
1950
1960
1970
1980
1990
2000
2010
2020
2015 Blob
2015 Prediction
2020 Prediction
Marine HeatWave Index
Observed
6m Prediction