Figure SPM.8 | Maps of CMIP5 multi-model mean results for the scenarios RCP2.6 and RCP8.5 in 2081–2100 of (a) annual mean surface temperature change, (b) average percent change in annual mean precipitation, (c) Northern Hemisphere September sea ice extent, and (d) change in ocean surface pH. Changes in panels (a), (b) and (d) are shown relative to 1986–2005. The number of CMIP5 models used to calculate the multi-model mean is indicated in the upper right corner of each panel. For panels (a) and (b), hatching indicates regions where the multi-model mean is small compared to natural internal variability (i.e., less than one standard deviation of natural internal variability in 20-year means). Stippling indicates regions where the multi-model mean is large compared to natural internal variability (i.e., greater than two standard deviations of natural internal variability in 20-year means) and where at least 90% of models agree on the sign of change (see Box 12.1). In panel (c), the lines are the modelled means for 1986 − 2005; the filled areas are for the end of the century. The CMIP5 multi-model mean is given in white colour, the projected mean sea ice extent of a subset of models (number of models given in brackets) that most closely reproduce the climatological mean state and 1979 to 2012 trend of the Arctic sea ice extent is given in light blue colour. For further technical details see the Technical Summary Supplementary Material. {Figures 6.28, 12.11, 12.22, and 12.29; Figures TS.15, TS.16, TS.17, and TS.20}
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Sea Surface Temperature Anomalies

Marine HeatWave Index

MHW Index

July-Aug-Sept 2019

Marine HeatWave Index

C

C

Marine HeatWave Index
MHW Index
Average of Extremes

Sea Surface Temperature Anomalies

Marine HeatWave Index

MHW Index
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?

Sea Surface Temperature Anomalies

Correlation of MHW Index with SSTa

Marine HeatWave Index

MHW Index
Regression of MHW Index on SLPa

Sea Surface Pressure Anomalies

Marine HeatWave Index

MHW Index
Regression of MHW Index on SLPa
Regression of MHW Index on SLPa

Sea Surface Pressure Anomalies

High Pressure GOA System

SLPI Index

AR-1 Model

\[ \frac{dSST_a(t)}{dt} = a \cdot SLPI(t) - \frac{SST_a(t)}{t_{dissipation}} \]
Regression of MHW Index on SLPa


gOAO System

SLPI Index

AR-1 Model

\[
\frac{dSSTa(t)}{dt} = a \cdot SLPI(t) - \frac{SSTa(t)}{t_{\text{dissipation}}}
\]
Marine HeatWave Index
MHW Index
SSTa Anomalies 2013-2019

Marine HeatWave Index
MHW Index
SSTa Anomalies 2013-2019

Marine HeatWave Index
MHW Index

C

1957 2014/15 2019

Marine HeatWave Index
NPGO-like
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.

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

Emanuele Di Lorenzo* and Nathan Mantua

Between the winters of 2013/14 and 2014/15 during the strong North American drought, the strongest multiyear 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 weak 2014/2015 El Niño linked the atmospheric forcing to the tropics during patterns of this event. These teleconnection dynamics from the extratropics to the tropics during winter 2014/15, are a key source of multiyear persistence of the extratropical anomalies back to the tropics.

The corresponding ocean anomalies map onto known patterns of North Pacific decadal variability, specifically the North Pacific Gyre Oscillation (NPGO). The patterns of the peak SSTa in JFM 2014 and 2015 show important spatial differences that spanned the winters of 2013/2014 and 2014/2015 (Di Lorenzo & Mantua, 2016), culminating in one of the largest ocean temperature anomalies in the Northeast Pacific during 2014/15, it reached a record-breaking amplitude with sea surface temperature anomalies exceeding three standard deviations (Fig. 1). By the summer and fall of 2014, the warm water mass anomaly reached the Pacific coastal boundary of North America, resembling the expression of the Pacific Decadal Oscillation (PDO) in 2014 and 2015. The PDO is a known precursor of whether tropical/extratropical teleconnections were also important in driving the expression of the 2015 SSTa has not been examined. The patterns of the peak SSTa in JFM 2014 and 2015 show important spatial differences that spanned the winters of 2013/2014 and 2014/2015 (Di Lorenzo & Mantua, 2016), culminating in one of the largest ocean temperature anomalies in the Northeast Pacific during 2014/15, it reached a record-breaking amplitude with sea surface temperature anomalies exceeding three standard deviations (Fig. 1). By the summer and fall of 2014, the warm water mass anomaly reached the Pacific coastal boundary of North America, resembling the expression of the Pacific Decadal Oscillation (PDO) in 2014 and 2015. The PDO is a known precursor of whether tropical/extratropical teleconnections were also important in driving the expression of the 2015 SSTa has not been examined.

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

Youngji Joh and Emanuele Di Lorenzo

Using historical reanalysis products and a climate model ensemble, this study provides a diagnostic of ocean-forcing and impacts. 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 be linked to each other. Here we evaluate the role of the extratropical NPGO anomalies and the following winter PDO, a strong NPGO-Like and PDO-like pattern in the following winter. The coupling between winter NPGO and the following winter PDO is a known precursor of the PDO-like pattern in the following winter. A stronger NPGO-PDO coupling is predicted under anthropogenic climate warming. The pattern of the peak SSTa in JFM 2014 and 2015 show important spatial differences that spanned the winters of 2013/2014 and 2014/2015 (Di Lorenzo & Mantua, 2016), culminating in one of the largest ocean temperature anomalies in the Northeast Pacific during 2014/15, it reached a record-breaking amplitude with sea surface temperature anomalies exceeding three standard deviations (Fig. 1). By the summer and fall of 2014, the warm water mass anomaly reached the Pacific coastal boundary of North America, resembling the expression of the Pacific Decadal Oscillation (PDO) in 2014 and 2015. The PDO is a known precursor of whether tropical/extratropical teleconnections were also important in driving the expression of the 2015 SSTa has not been examined.

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Correlation of MHW Index with SSTa

Marine HeatWave Index

NPGO Index \( R = 0.49 \)

PDO Index \( R = 0.36 \)

- Amplitude of SST Trend
  - MHW Index PDF
    - NPGO > 1 STD
  - MHW Index PDF
    - NPGO < -1 STD
Observational Record

Problem: small size statistics

Correlation of MHW Index with SSTa

Marine HeatWave Index

NPGO Index $R=0.49$

PDO Index $R=0.36$

Amplitude of SST Trend

Occurrences

SST Anomaly

Problem: small size statistics
Problem: small size statistics

MPI-Grand Ensemble: 100 ensemble members

1850-2005 with historical radiative forcing

2006-2100 with RCP8.5
Probability Distribution Function

Pre-Industrial 1850-1879

MPI Model
100 Member Ensemble

SST Anomaly (MHW Index)
Probability Distribution Function

Present Day 1980-2019

Pre-Industrial 1850-1879

MPI Model
100 Member Ensemble

SST Anomaly (MHW Index)
Probability Distribution Function

SST Anomaly (MHW Index)

- NPGO < -1 STD
- NPGO > 1 STD

MPI Model
100 Member Ensemble

Average Shift
**Blob Index**

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<thead>
<tr>
<th>Blob Index</th>
<th>Annual</th>
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<tr>
<td>Δ95&lt;sup&gt;th&lt;/sup&gt;</td>
<td>0.13 0.26 0.42</td>
</tr>
<tr>
<td>Δ99&lt;sup&gt;th&lt;/sup&gt;</td>
<td>0.05 0.13 0.21</td>
</tr>
</tbody>
</table>

**SST Anomaly (MHW Index)**

- **+NPGO Present Day**
- **-NPGO**
<table>
<thead>
<tr>
<th>Blob Index</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>+NPGO</td>
<td>Present Day</td>
<td>-NPGO</td>
</tr>
<tr>
<td>Δ95th</td>
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<td>0.21</td>
</tr>
</tbody>
</table>

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

\[
\frac{dx}{dt} = Lx + \xi \quad \text{Linear Inverse Model}
\]

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Empirical Dynamical Model Prediction

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By solving the LIM system, we obtain

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

\[
\begin{bmatrix}
\hat{s}(t + \tau) \\
\hat{p}(t + \tau)
\end{bmatrix} = G(\tau = 6\text{months})
\begin{bmatrix}
s(t) \\
p(t)
\end{bmatrix} \quad \leftarrow \text{SSTA, SLPA}
\]
Empirical Dynamical Model Prediction

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s(t) \\
p(t)
\end{bmatrix} \quad \text{SSTA}\quad \text{SLPA}
\]

Forecast March

Jan-Feb-March

Initialize September

6 Months Prediction
Empirical Dynamical Model Prediction

Forecast
March
Jan-Feb-March

Initialize
September

6 Months Prediction
Empirical Dynamical Model Prediction

- Initialize September
- Forecast March

Jan-Feb-March

6 Months Prediction

Marine HeatWave Index

MHW Index
Empirical Dynamical Model Prediction

Forecast March
Jan-Feb-March

Initialize September

6 Months Prediction

2015 Blob

Winter Average
Jan-Feb-March

Marine HeatWave Index
MHW Index
Empirical Dynamical Model Prediction

- Forecast March
- Jan-Feb-March

Initialize September

6 Months Prediction

Cross-Validation

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

6 Months Prediction
Initialize September

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

- Initialize September
- Forecast March
- Jan-Feb-March

Skill R=0.5

- 2015 Blob
- 2015 Prediction

Winter Average Jan-Feb-March

2020 Prediction

Marine HeatWave Index

MHW Index
Sea Surface Temperature Anomalies

Prediction WINTER 2020

Prediction R=0.5

2015 Blob

2015 Prediction

2020 Prediction

Marine HeatWave Index
Observed
6m Prediction
SUMMER 2019

Sea Surface Temperature Anomalies

Marine HeatWave Index

Prediction R=0.5

2015 Blob

2015 Prediction

2020 Prediction

Observed

6m Prediction

North America

Asia

Alaska
WINTER 2020

Sea Surface Temperature Anomalies

Marine HeatWave Index
Observed
6m Prediction