

Pacific Decadal Oscillation modulating marine heatwaves in the Northeast Pacific during recent decades

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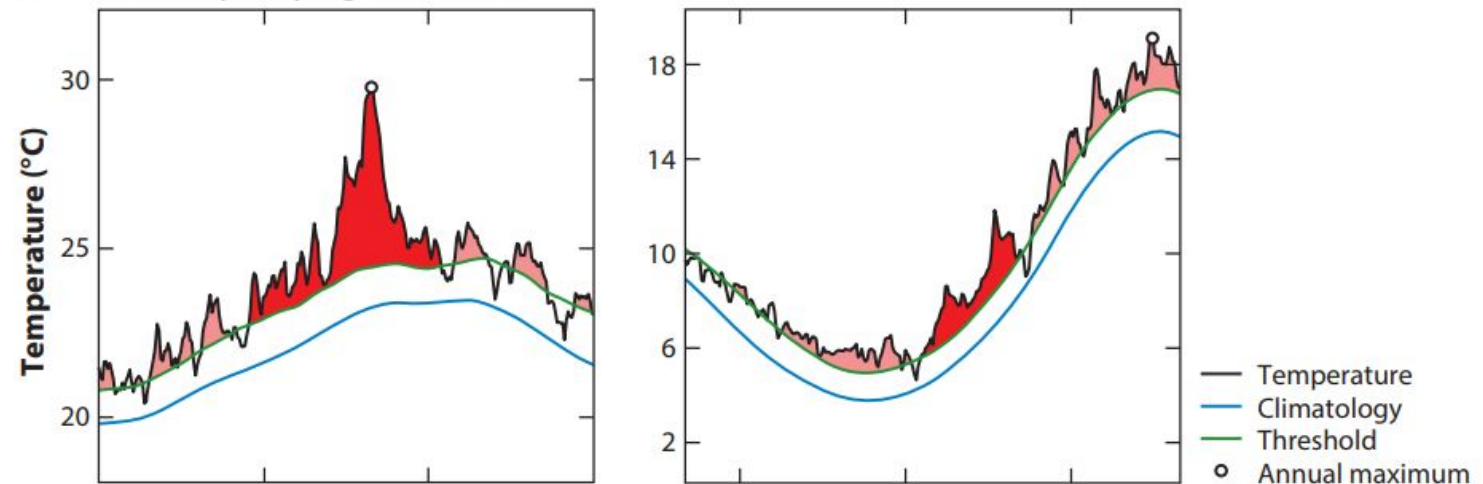
What are Marine Heatwaves (MHWs)?

A discrete prolonged anomalously warm water event in a particular location.

- Temperature is higher than the threshold (the 90th percentile of daily SST climatology)
- Persist for at least five days
- No less than 3 days interval

- Duration(days) = $T_{\text{start}} - T_{\text{end}}$.
- Frequency: Average number of MHWs per year.
- Intensity: Maximum intensity of MHWs.

b Seasonally varying threshold

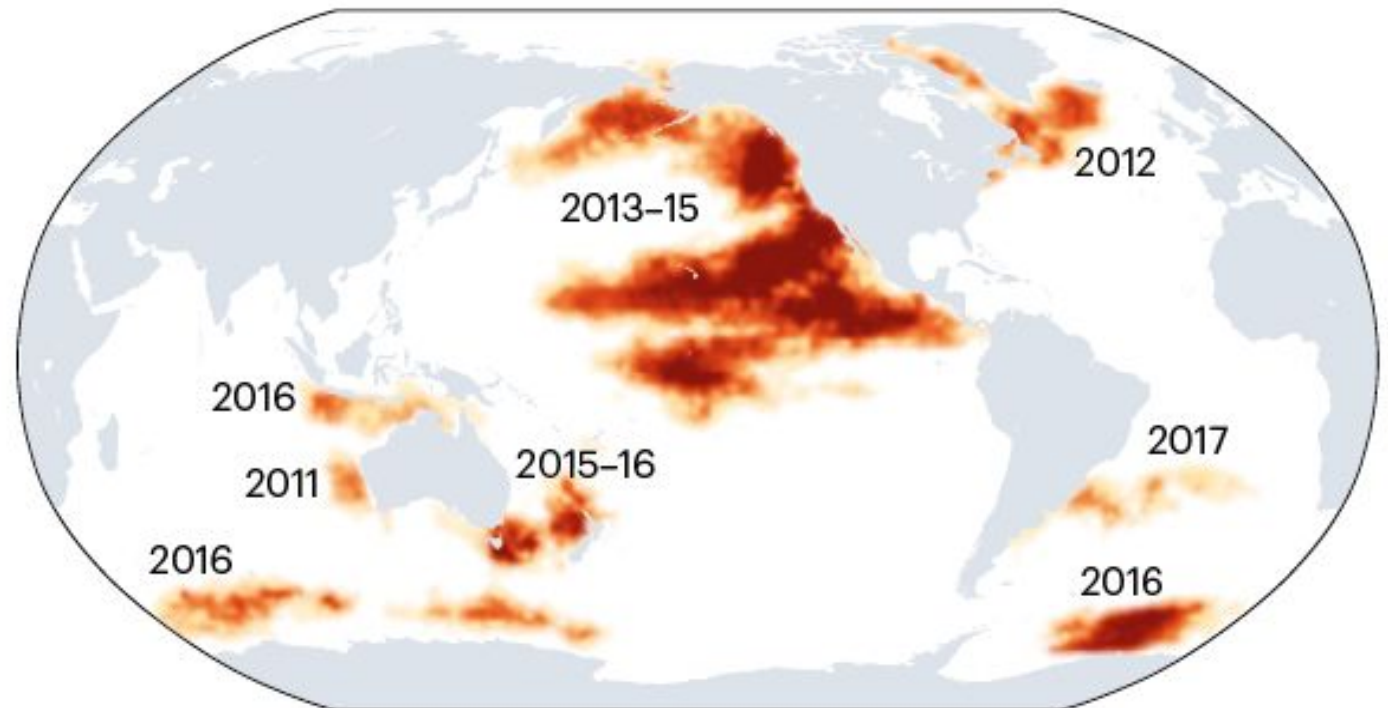
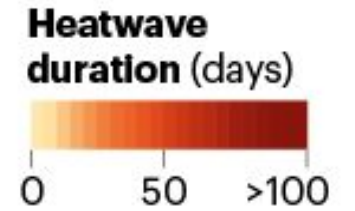


Background information

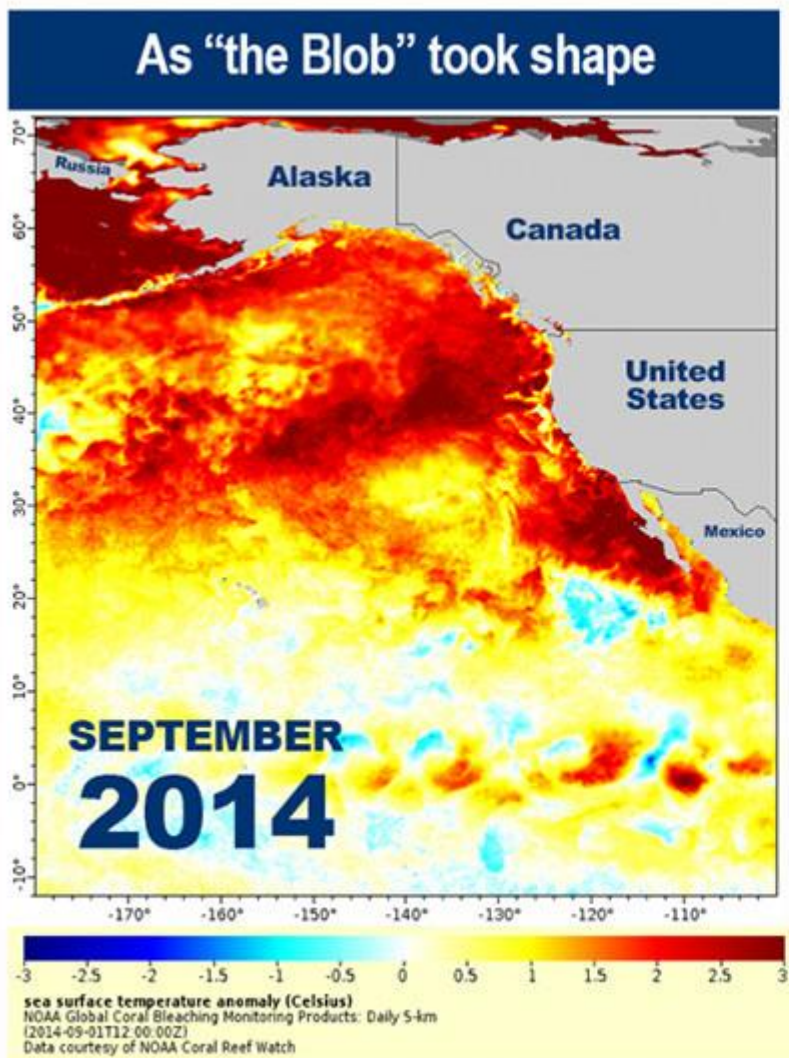
In a warming climate, strong marine heatwaves (MHWs) have occurred in various ocean basins around the world.

FOUR DECADES OF HEATWAVES

More than 30,000 distinct marine heatwaves occurred between September 1981 and December 2017, according to one study⁷. The map shows the most prominent over the past decade.



Background information



Losers

Subarctic copepods, krill
Lack of food reduced population, distribution moved northward

Market squid 2015–2016
Reduced in south as distribution moved far north

Dungeness crab and mussels
Fishery closed due to toxicity

Salmon
Warm temperatures decreased recruitment for some species

Groundfish
Potential loss of habitat due to hypoxia

Seabirds, seals, and sea lions
Massive die-offs due to lack of food

Baleen whales
Expected to decline due to lack of food

Winners

Toxic phytoplankton
Massive bloom closed important fisheries

Tropical, subtropical copepods
Northward range expansion with warm water

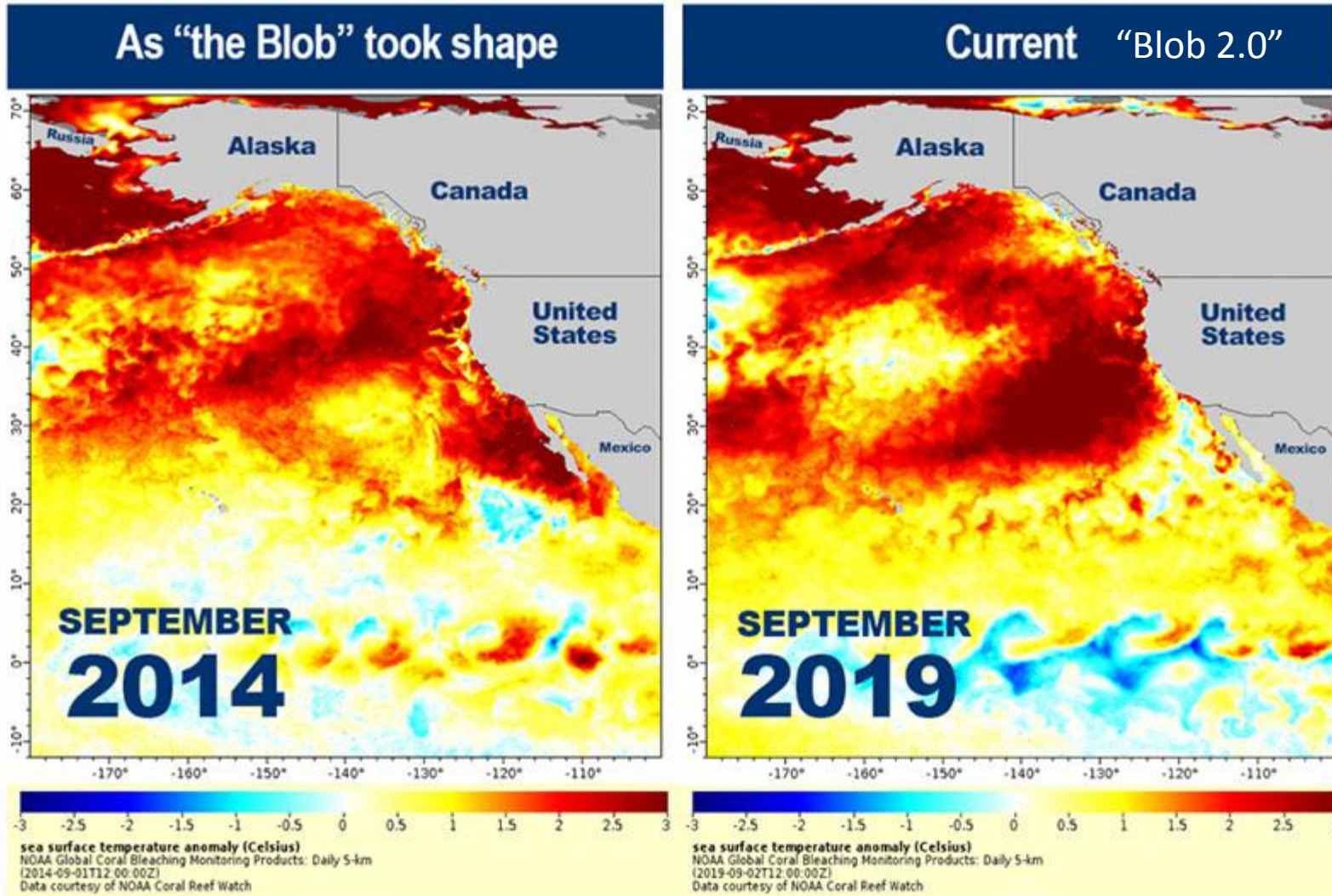
Market squid 2014–2015
Increased fishery in north caused by range expansion

Rockfish
Increased recruitment in California

Tuna
Increased abundances along coast with increased sport fishing

Orcas
Increased birth rate caused by increased salmon abundances in some regions through population movements

Background information

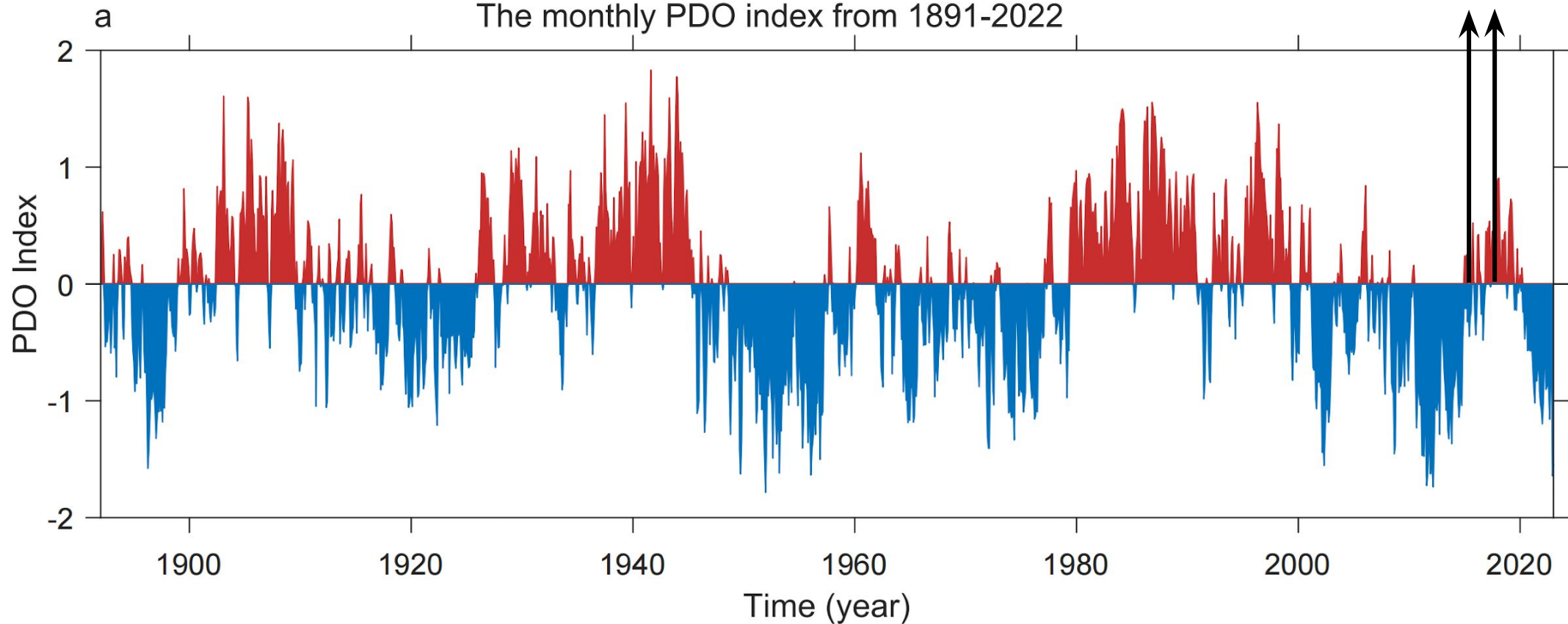


- Several extreme ocean temperature events have occurred off the California coast in the past decade.

Motivation

Pacific Decadal Oscillation (PDO)

The monthly PDO index from 1891-2022

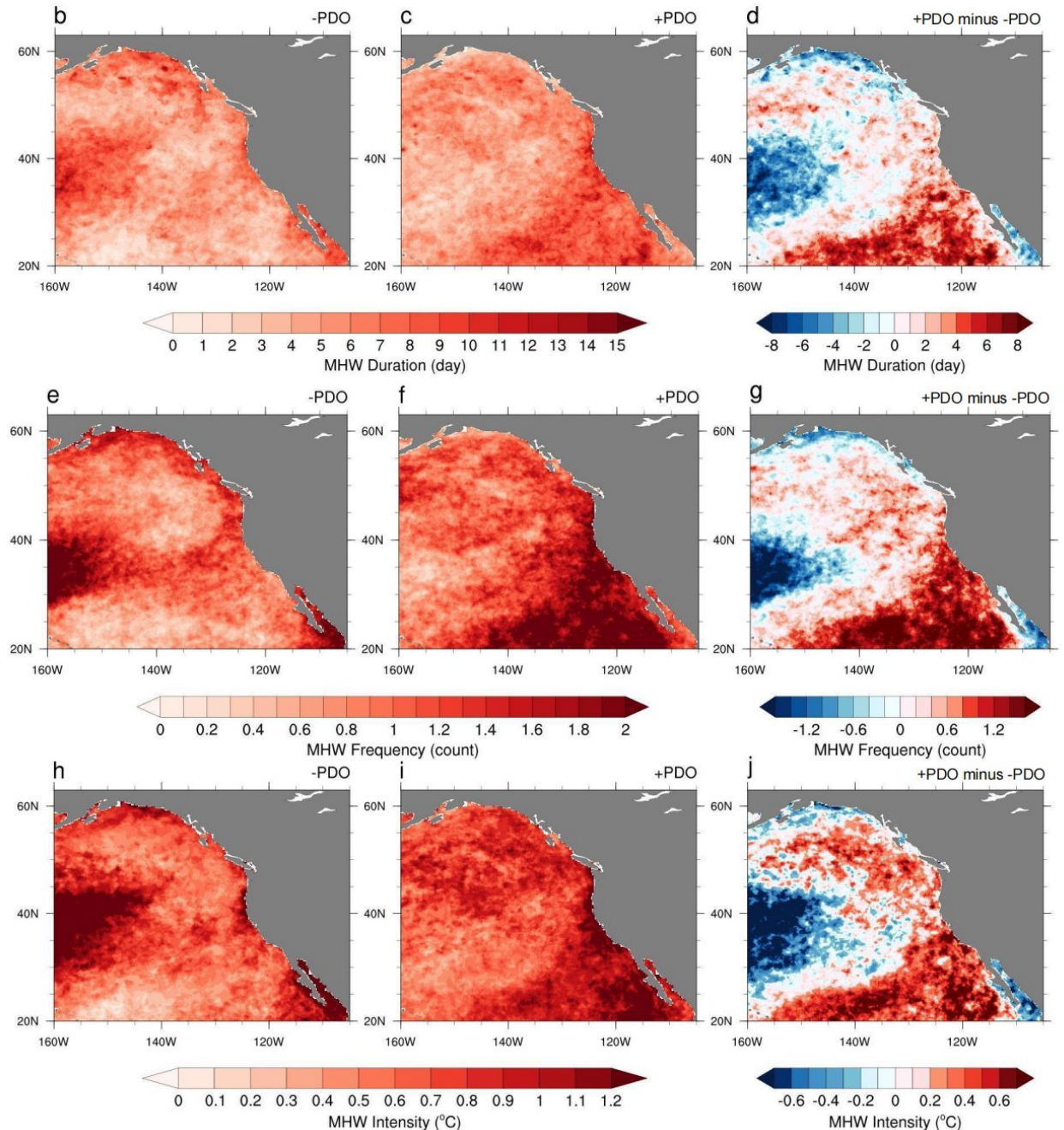


Scientific Question:

How does the PDO regulate the MHWs in the Northeast Pacific?

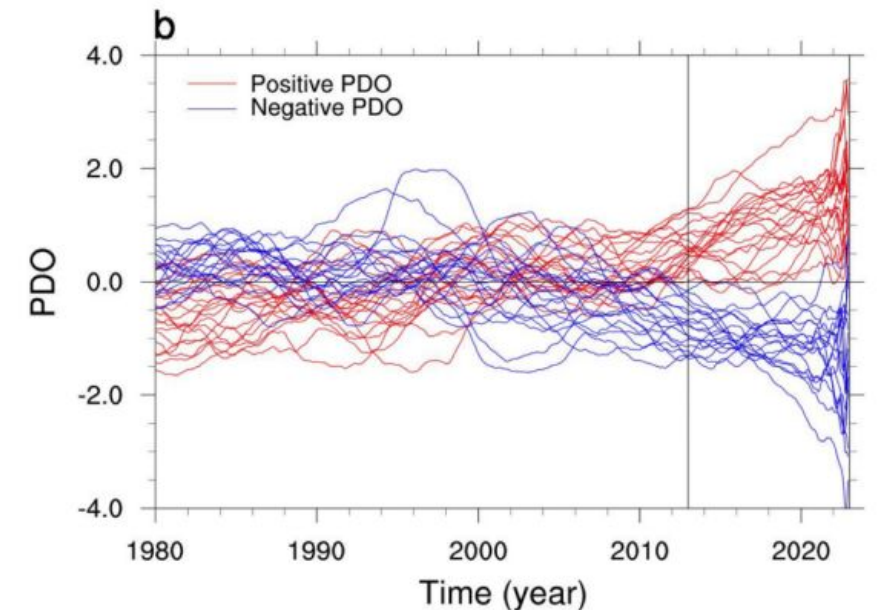
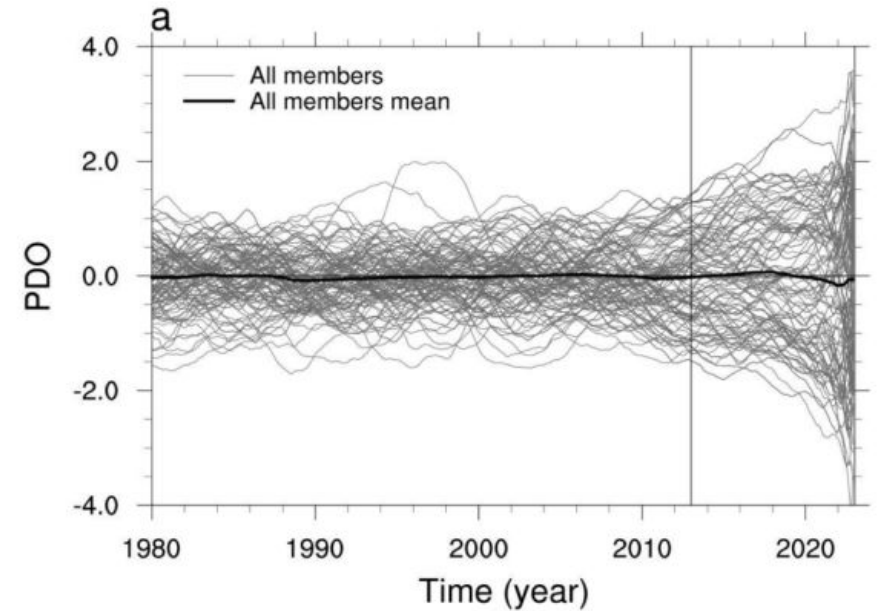
Observed marine heatwaves

- Data: OISST v2.1
+PDO (1982-1998 & 2013-2022)
-PDO (1998-2013)
- MHWs along the Northeast Pacific coast show **longer durations and greater annual frequencies** during positive PDO phase compared to the negative one.



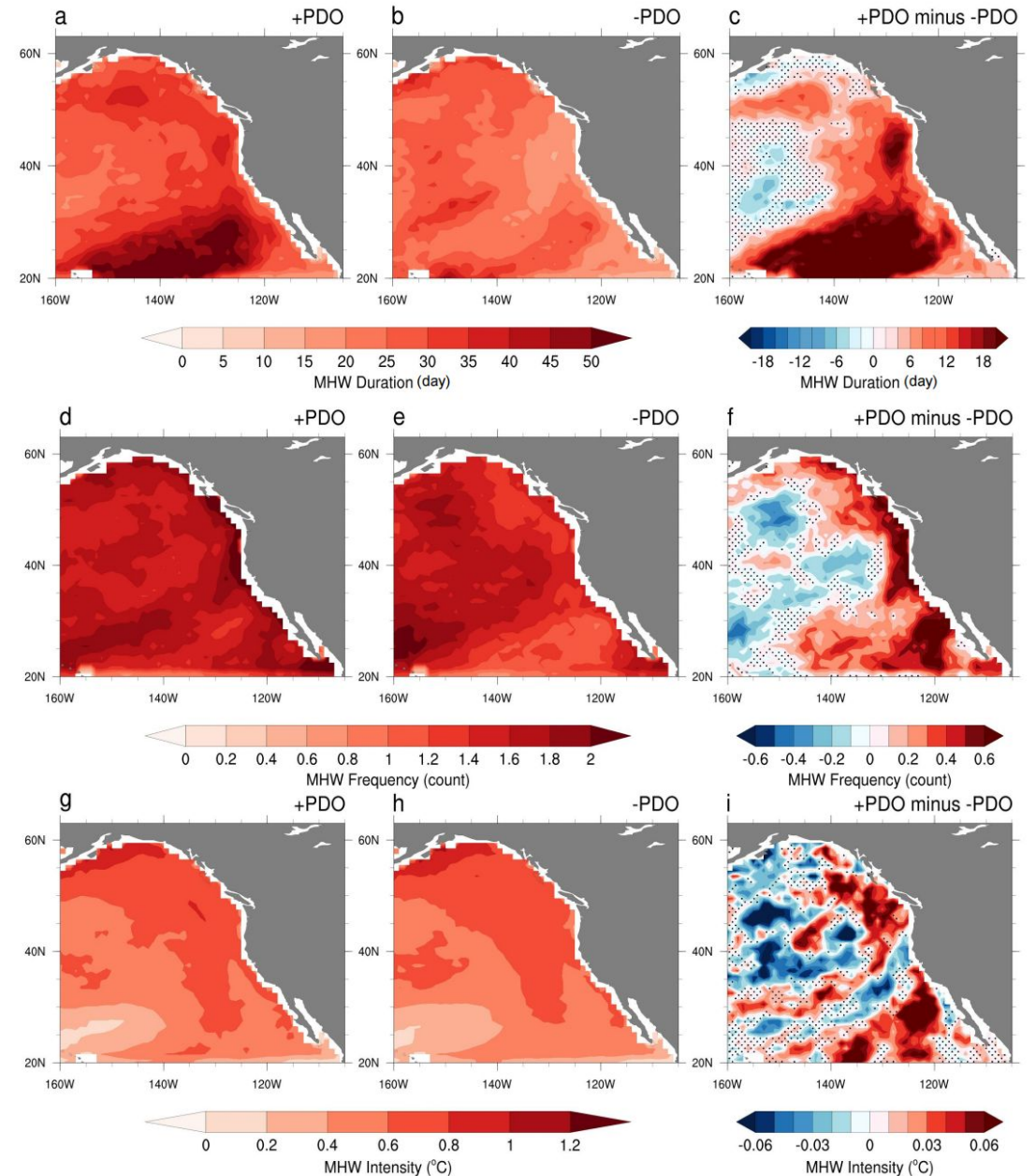
Climate models & large ensemble simulations

Model	Number of members	Forcing scenarios	+ PDO and -PDO members
ACCESS-ES M1.5	30	Historical + SSP245	+PDO: (r2, r23, r25, r26)i1p1f1 -PDO: (r15, r18, r24, r28)i1p1f1
CanESM5	20	Historical + SSP245	+PDO: (r2, r3, r6)i1p2f1, r10i1p1f1 -PDO: (r1,r5, r7)i1p1f1, r1i1p2f1
CESM1	40	Historical + RCP8.5	+PDO: Member (02, 23, 26, 30) -PDO: Member (06, 14, 26, 35)
CESM2	50	Historical + SSP370	+PDO: Member (05, 08, 14, 17) -PDO: Member (13, 15, 21, 29)
EC-Earth3	32	Historical + SSP245	+PDO: (r12, r17, r21, r22)i1p1f1 -PDO: (r2, r7, r10, r20)i1p1f1
Sum	172		+PDO: 20 -PDO: 20

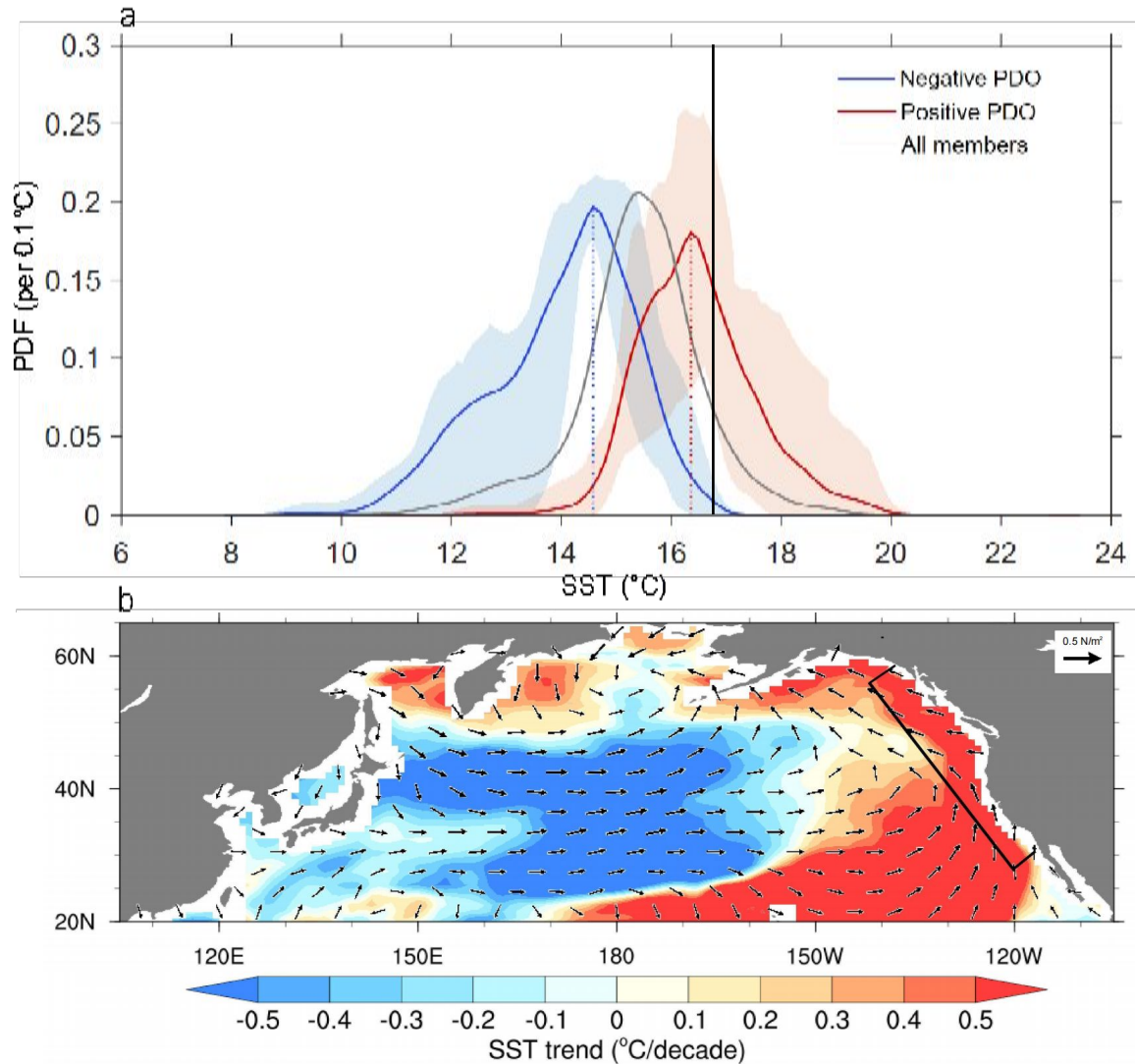


Positive and negative PDOs modulating North Pacific MHWs

- The duration and annual frequency of MHWs along the Northeast Pacific coast were significantly higher in the positive PDO group compared to the negative PDO group.
- The PDO has a moderating effect on Northeast Pacific MHWs during the last decade.

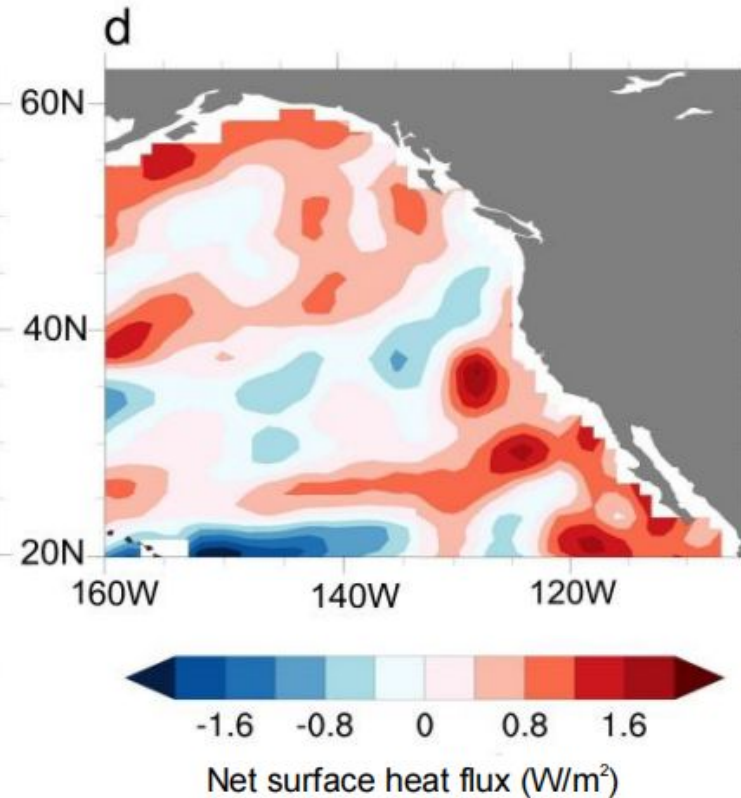
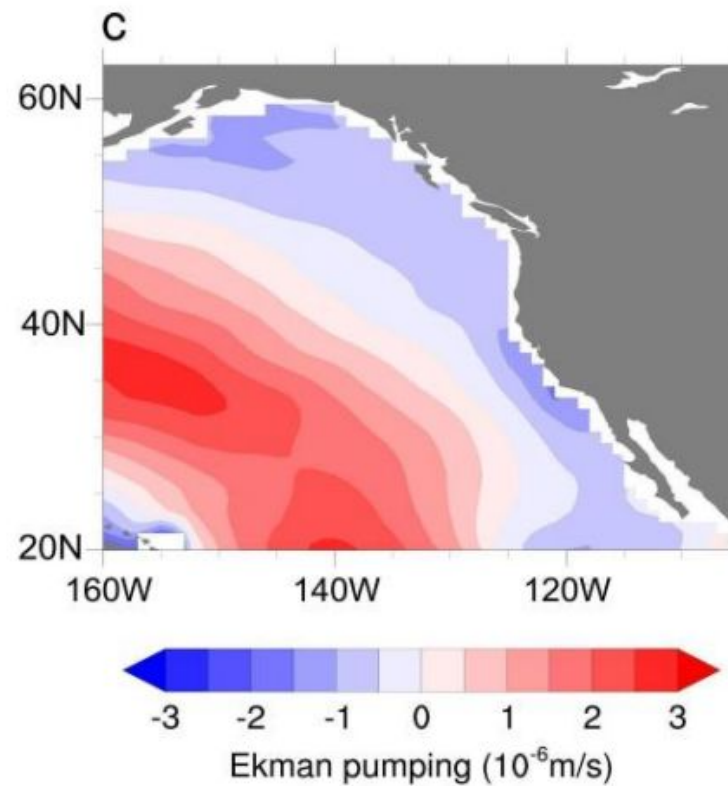
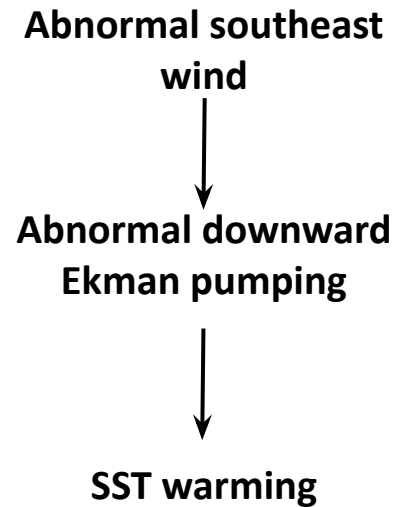


The physical mechanisms



- The difference in the probability density functions (PDFs) of sea surface temperature (SST) between the two PDO groups reflects the PDO effects on altering the mean-state SST and shifting the SST PDF in this region.
- Compared with the negative PDO phase, the coastal SST shows an anomalous warming trend of **0.6-2.3°C/year** during the positive PDO phase.

Two physical mechanisms that may drive coastal SST warming during the positive PDO



More heat entering the ocean from the surface of the Northeast Pacific coast

Quantifications of the PDO effect on North Pacific MHWs

$$r_{pdo+} = (\overline{MHW}_{pdo+} - \overline{MHW}_{agw}) / \overline{MHW}_{agw} \quad (1)$$

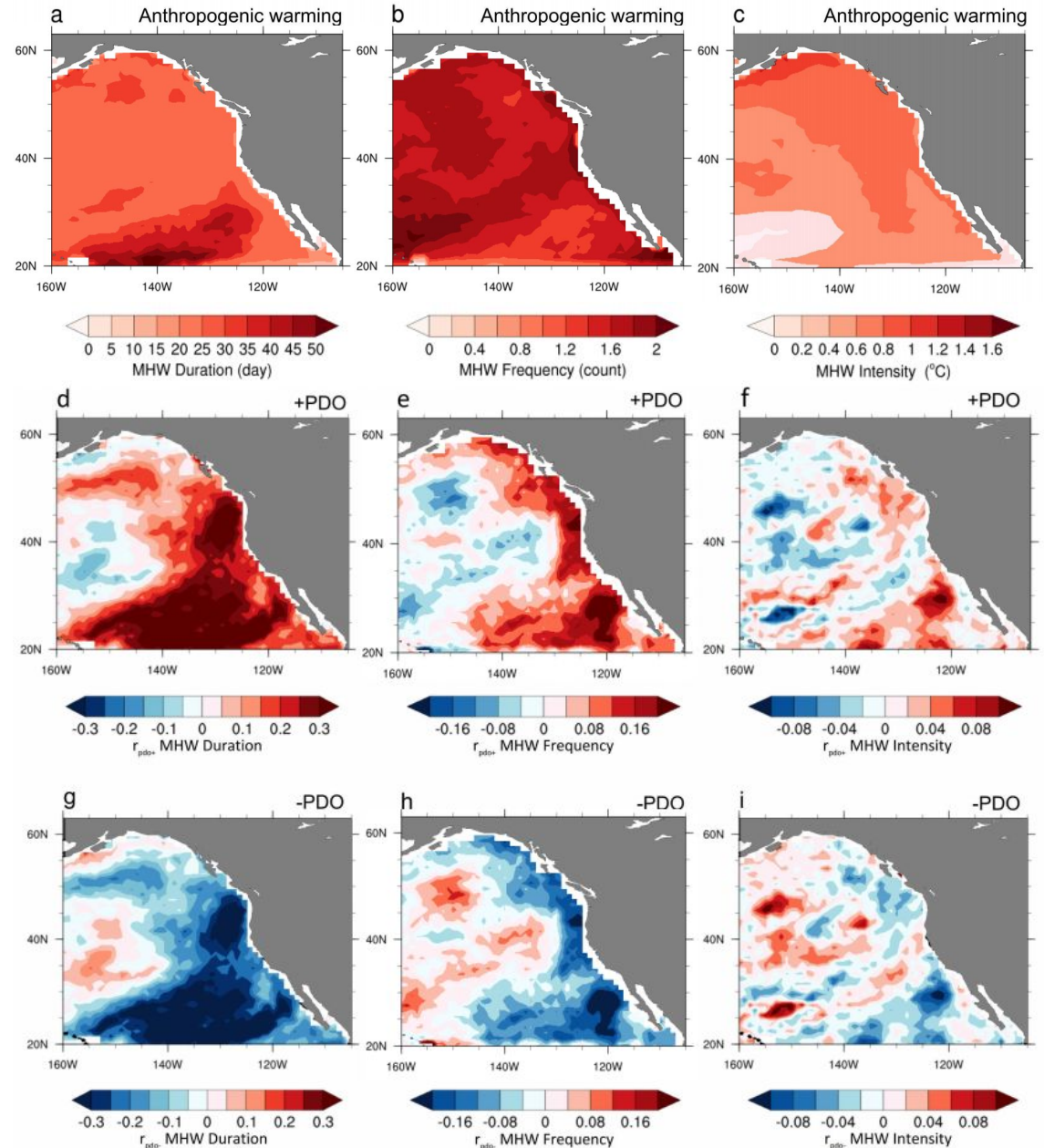
$$r_{pdo-} = (\overline{MHW}_{pdo-} - \overline{MHW}_{agw}) / \overline{MHW}_{agw} \quad (2)$$

+PDO

- Increase MHW duration by 43%;
- Increase MHW annual frequency by 32%;
- Increase MHW intensity by 10%.

-PDO

- Decrease MHW duration by 38%;
- Decrease MHW annual frequency by 29%;
- Decrease MHW intensity by 10%.



Conclusion

- During the past decade, MHW along the NE Pacific coast has become longer, stronger, and more frequent in the positive PDO phase. This is due to the **suppression of cold coastal upwelling** and **enhanced net surface heat flux**.
- Positive PDO can increase MHW duration by **43%** , annual frequency by **32%** and intensity by **10%** along the Northeast Pacific coast relative to background anthropogenic global warming.

Ren X, W Liu, A Capotondi, DJ Amaya, NJ Holbrook (2023) Pacific Decadal Oscillations modulating marine heatwave in the Northeast Pacific. Communications Earth & Environment, Accepted.

Thank You

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Figure 5. Differences of surface heat flux components between positive and negative PDOs. The ensemble-mean differences of surface (a) shortwave and (b) longwave radiation and (c) sensible and (d) latent heat fluxes during 2013-2022 between the positive and negative PDO groups (positive minus negative) for the large ensemble simulations with the five climate models (downward positive).

