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

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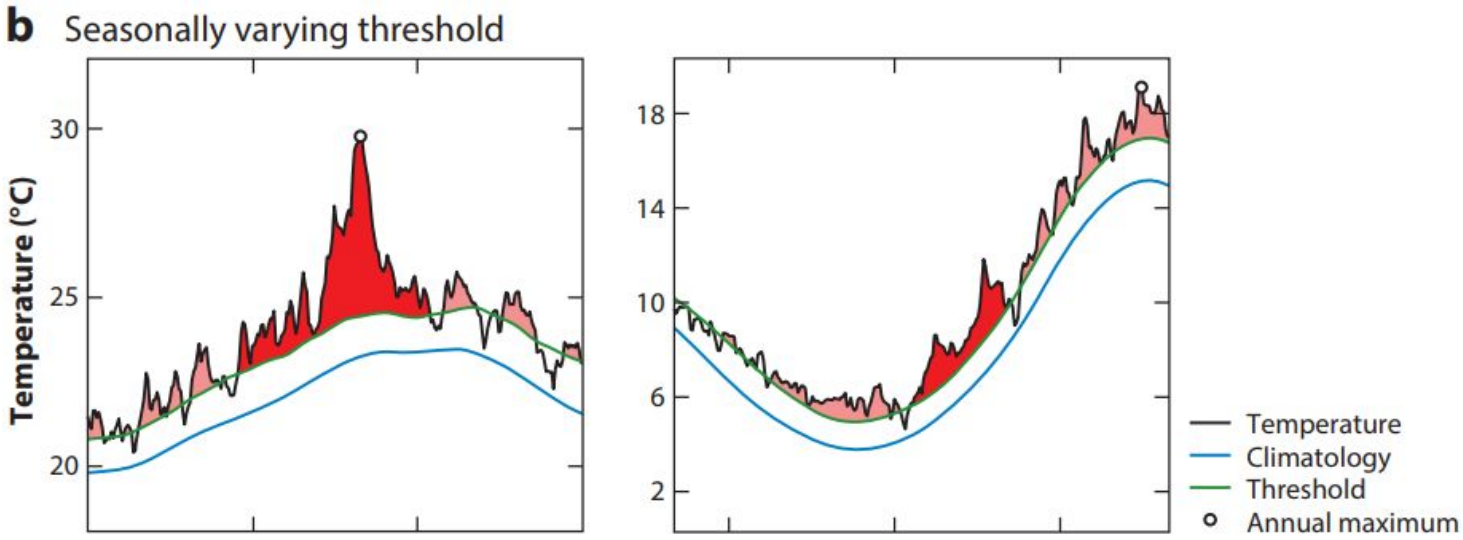
What are Marine Heatwaves (MHWs)?

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

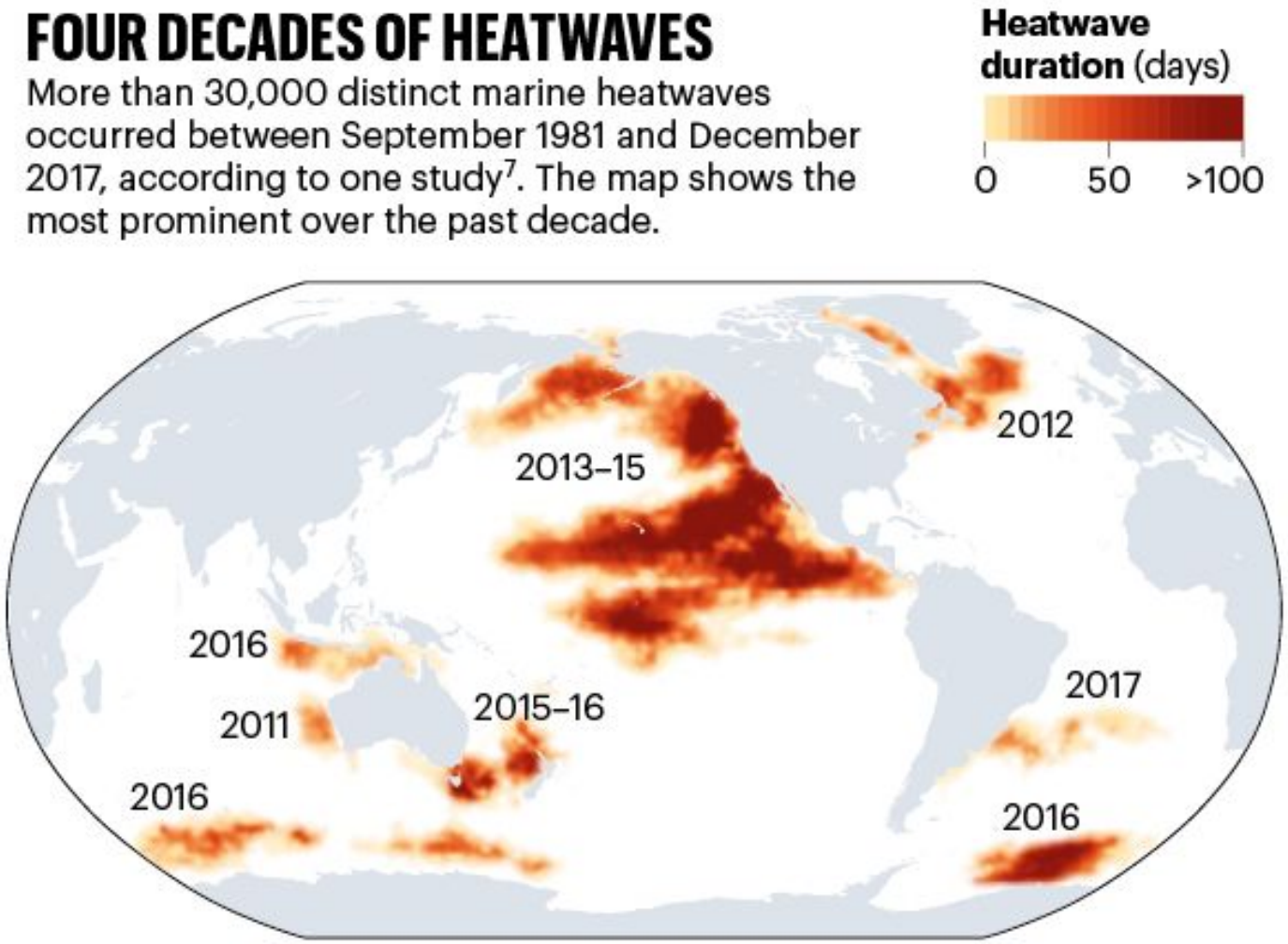
- Duration(days) = T_{start} - $T_{end.}$
- Frequency: Average number of MHWs per year.
- Intensity: Maximum intensity of MHWs.



SOURCE: Oliver et al., Annu. Rev. Mar. Sci. 2021. 13:313–42

Background information

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



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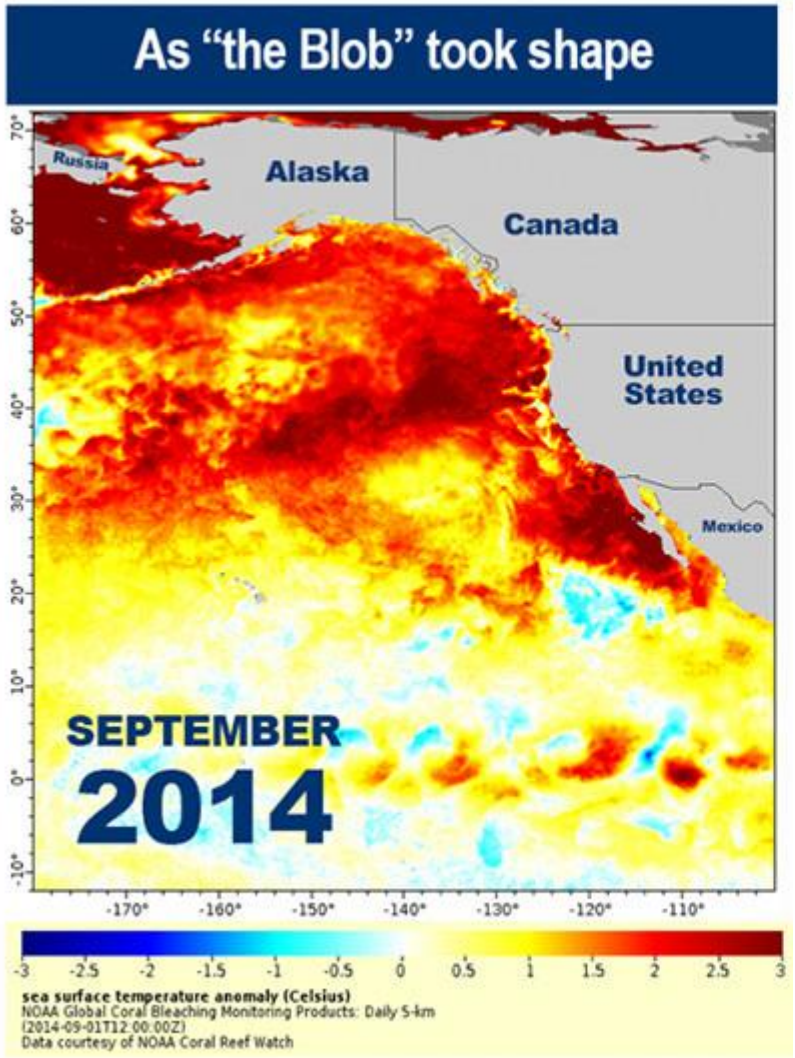
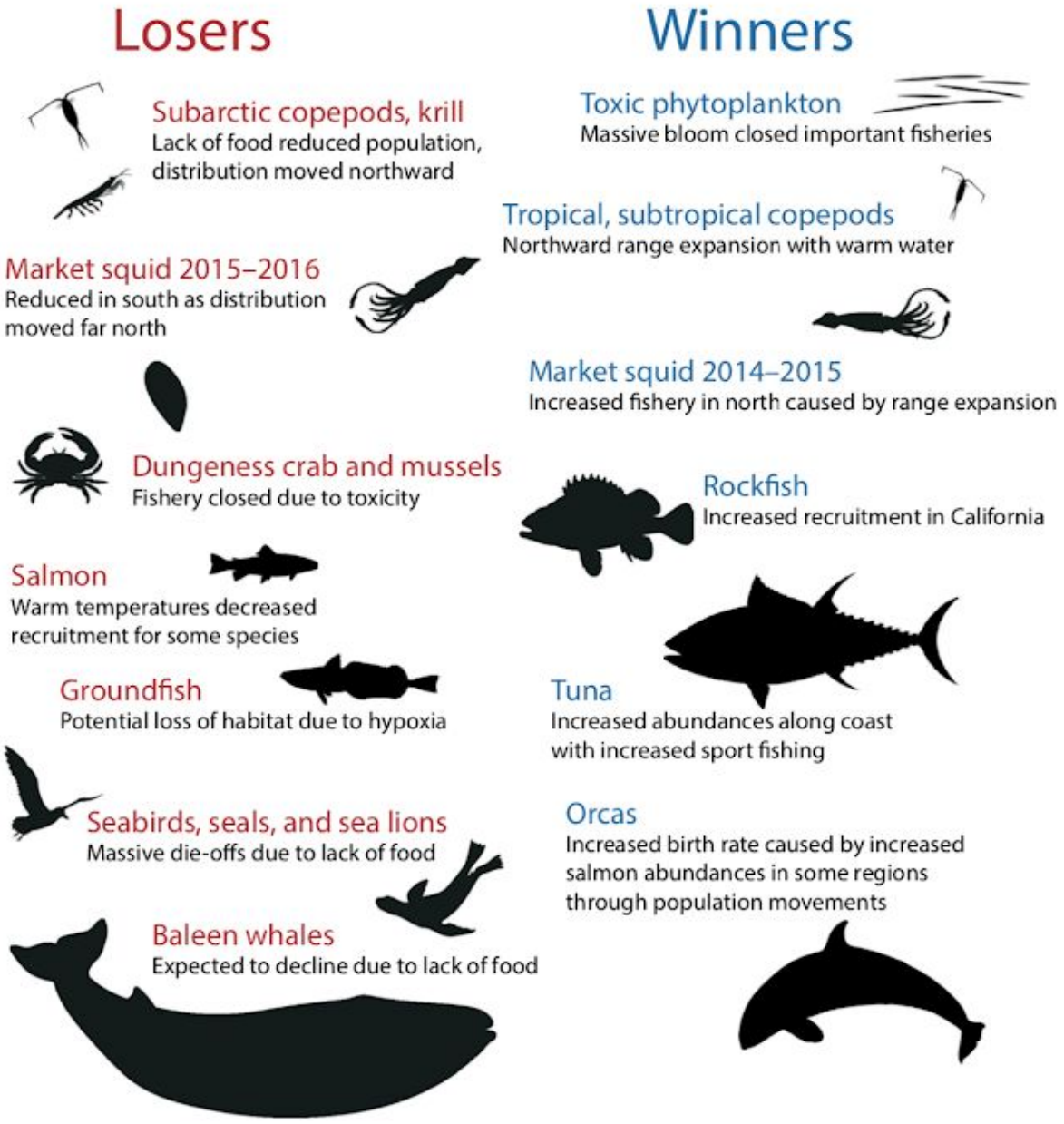
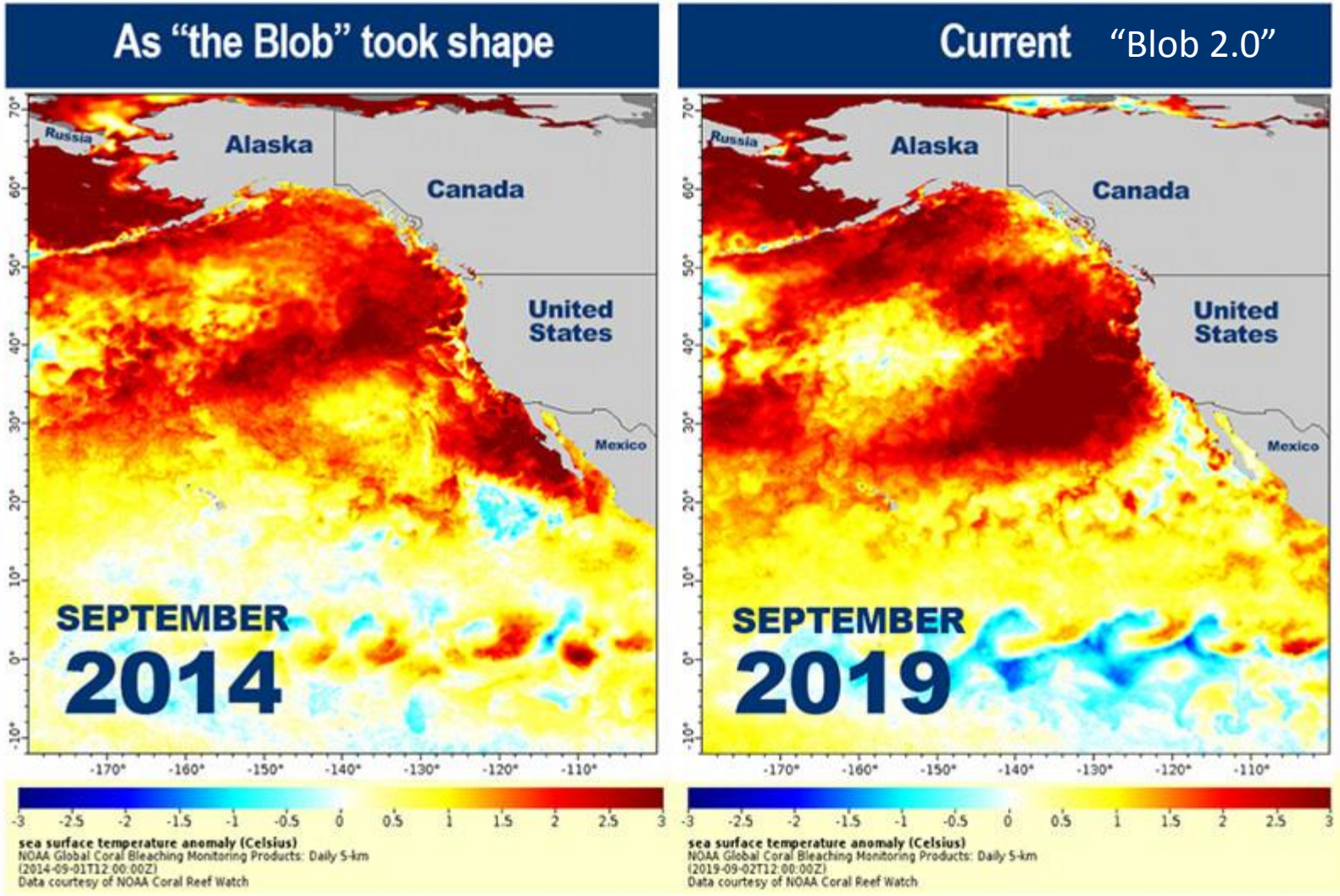




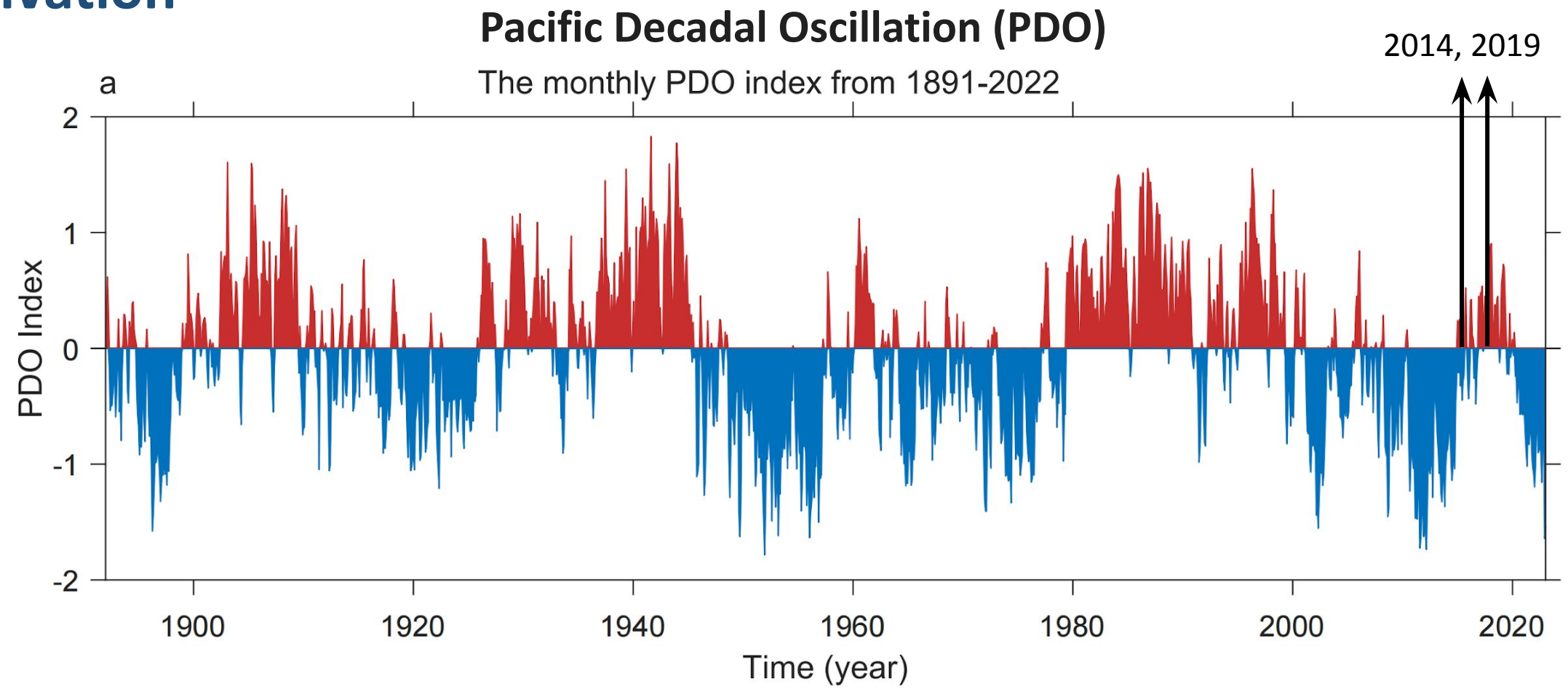
https://scripps.ucsd.edu/research/climate-change-resources/californias-marine-heatwaves

Background information



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

Motivation



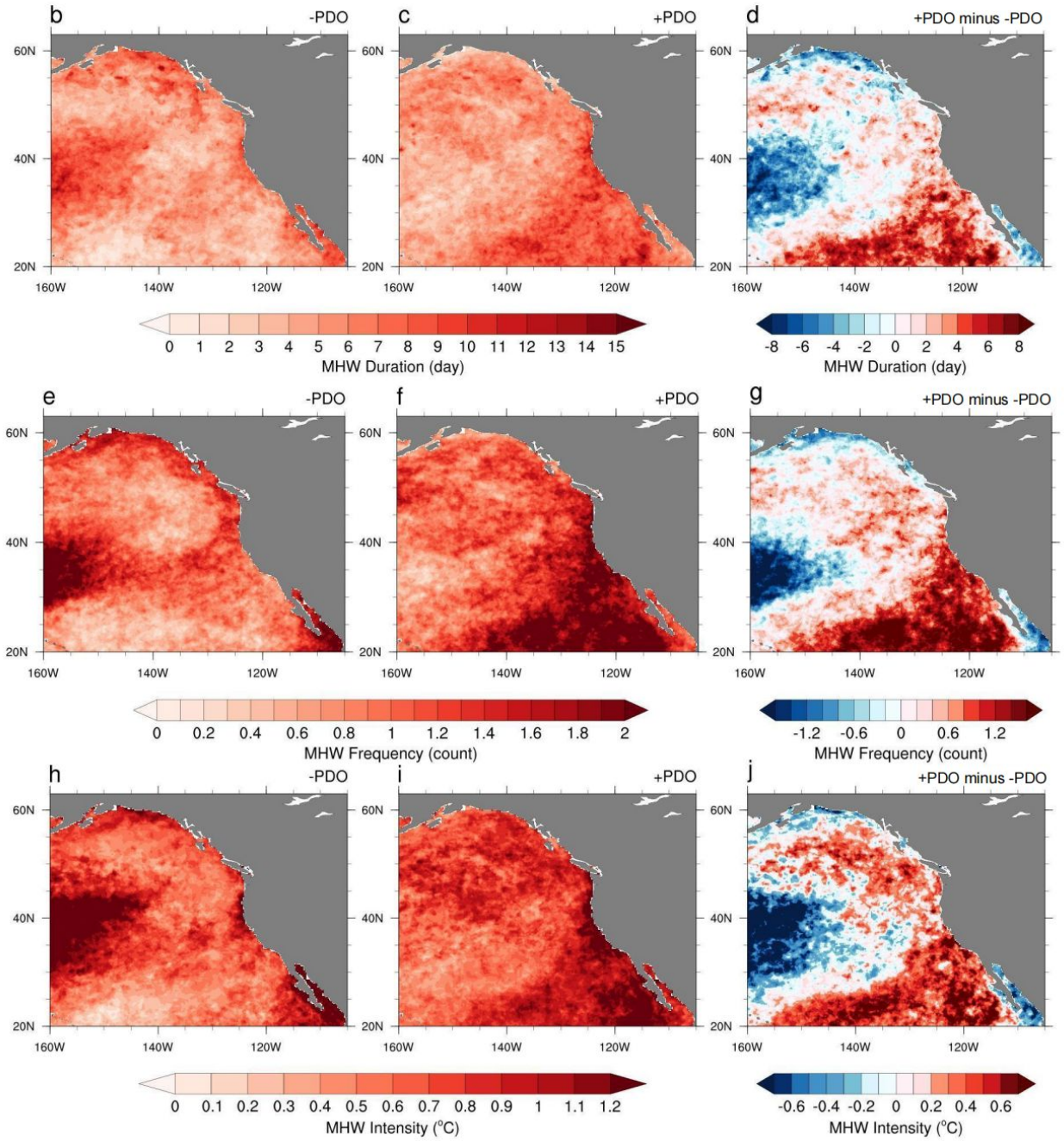
Scientific Question:

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

Observed marine heatwaves

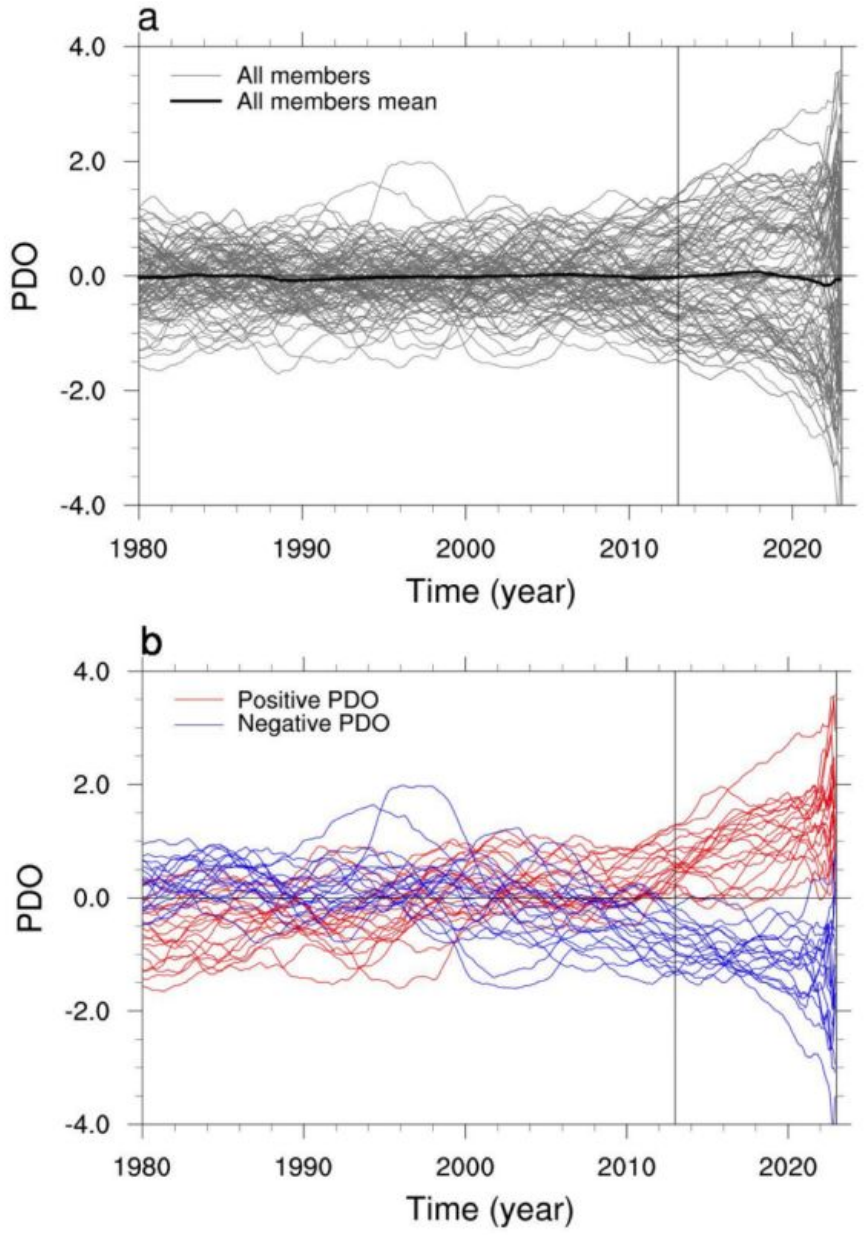
- Data: OISST v2.1
  +PDO (1982-1998 & 2013-2022)
  -PDO (1998-2013)

- 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

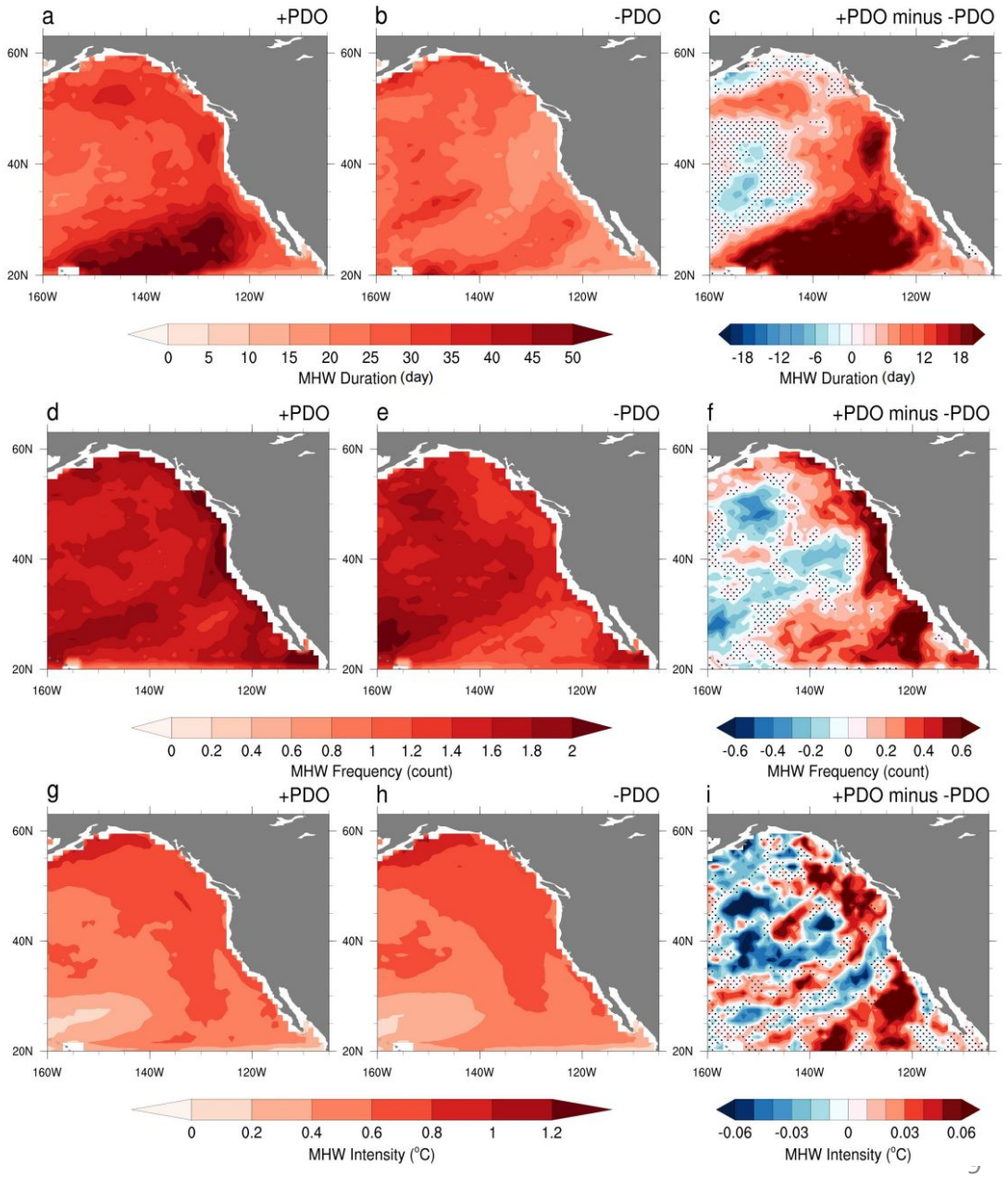
Model	Number of members	Forcing scenarios	+ PDO and –PDO members
ACCESS-ESM1.5	30	Historical + SSP245	+PDO: (r2, r23, r25, r26)i1p1f1 –PDO: (r15, r18, r24, r28)i1p1f1
CanESM5	20	Historical + SSP245	+PDO: (r2, r3, r6)i1p2f1, r10i1p1f1 –PDO: (r1,r5, r7)i1p1f1, r1i1p2f1
CESM1	40	Historical + RCP8.5	+PDO: 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**



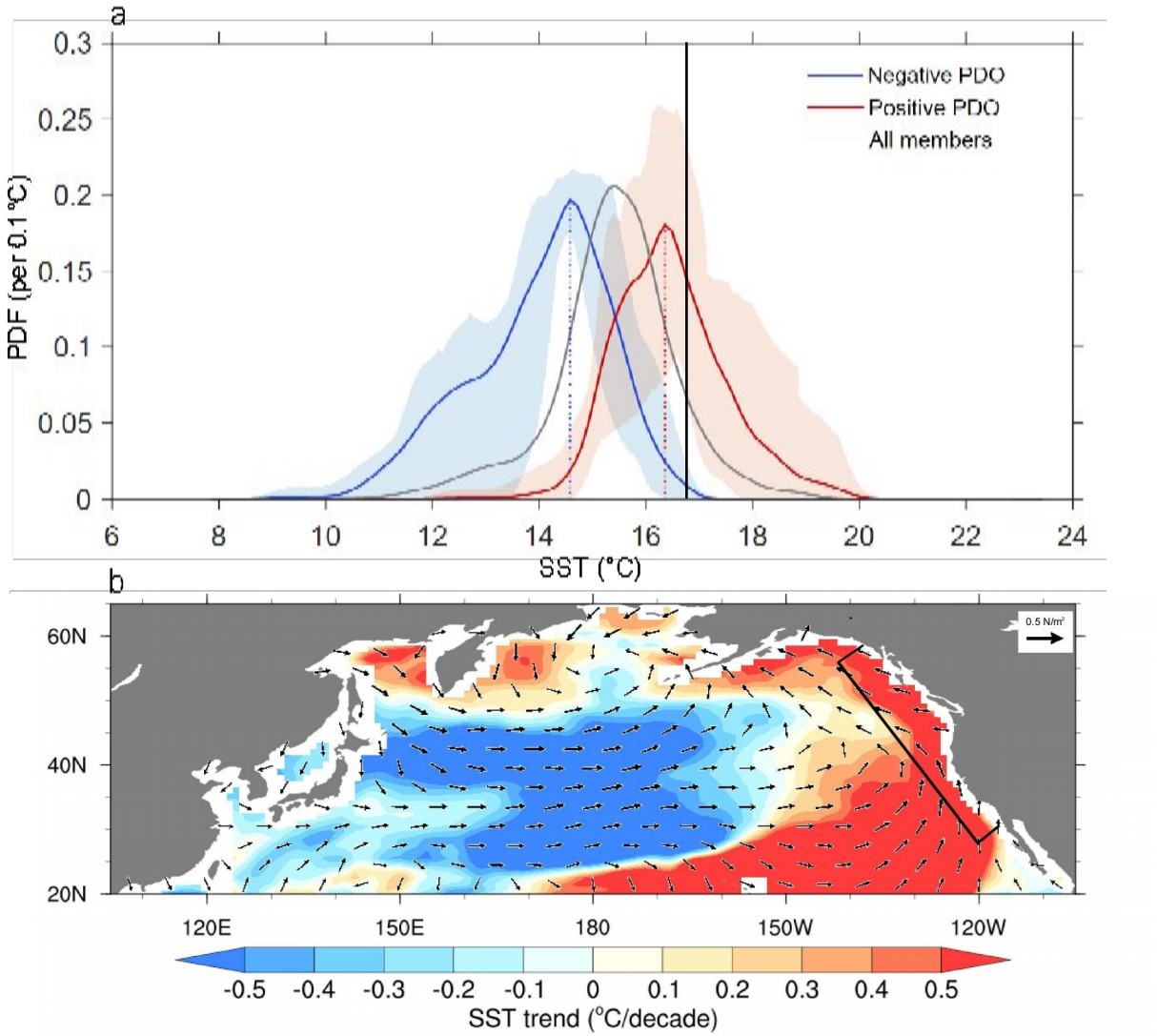
Positive and negative PDOs modulating North Pacific MHWs

- 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

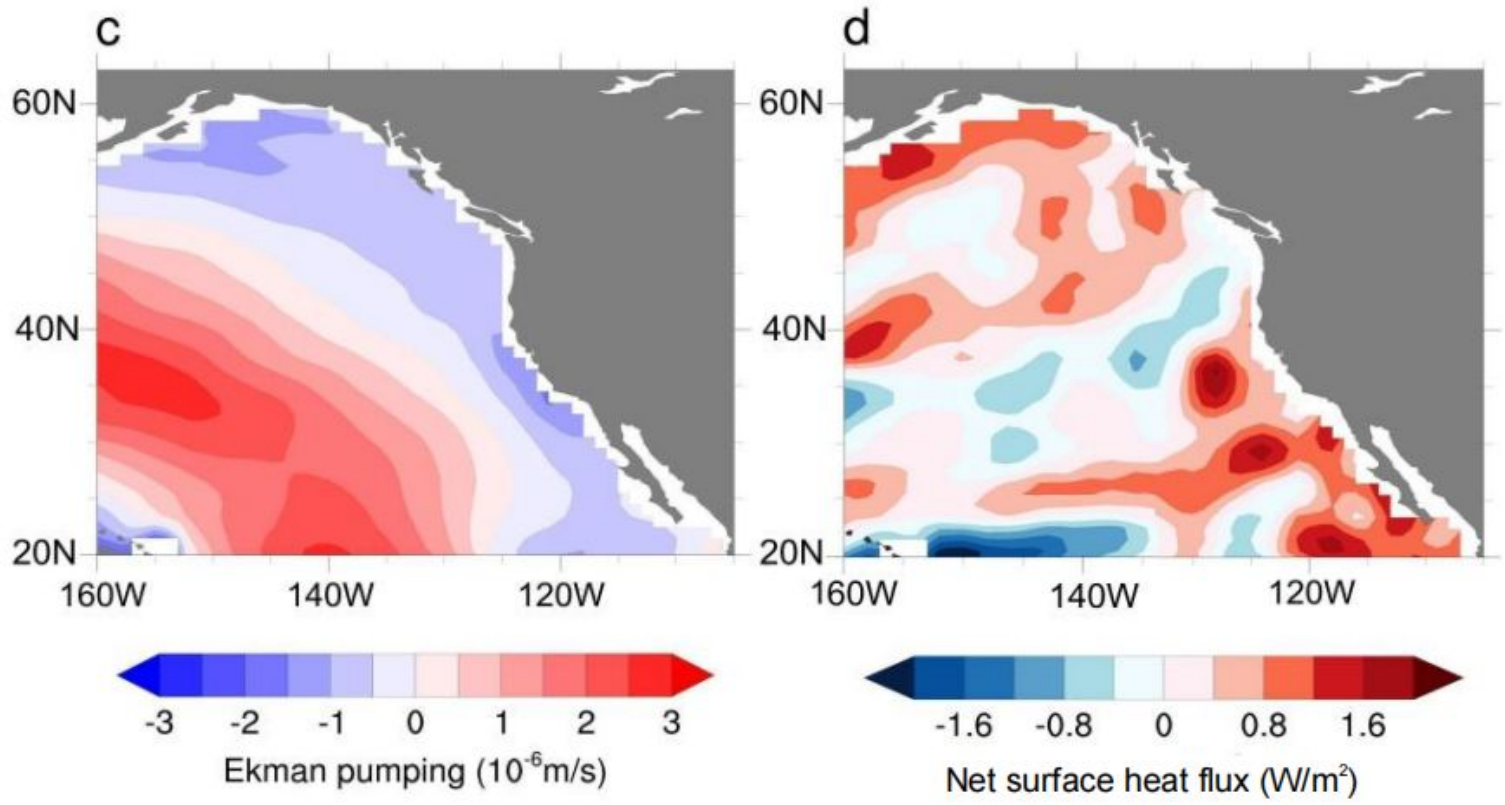
Abnormal southeast wind

↓

Abnormal downward Ekman pumping

↓

SST warming



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

Quantifications of the PDO effect on North Pacific MHWs

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

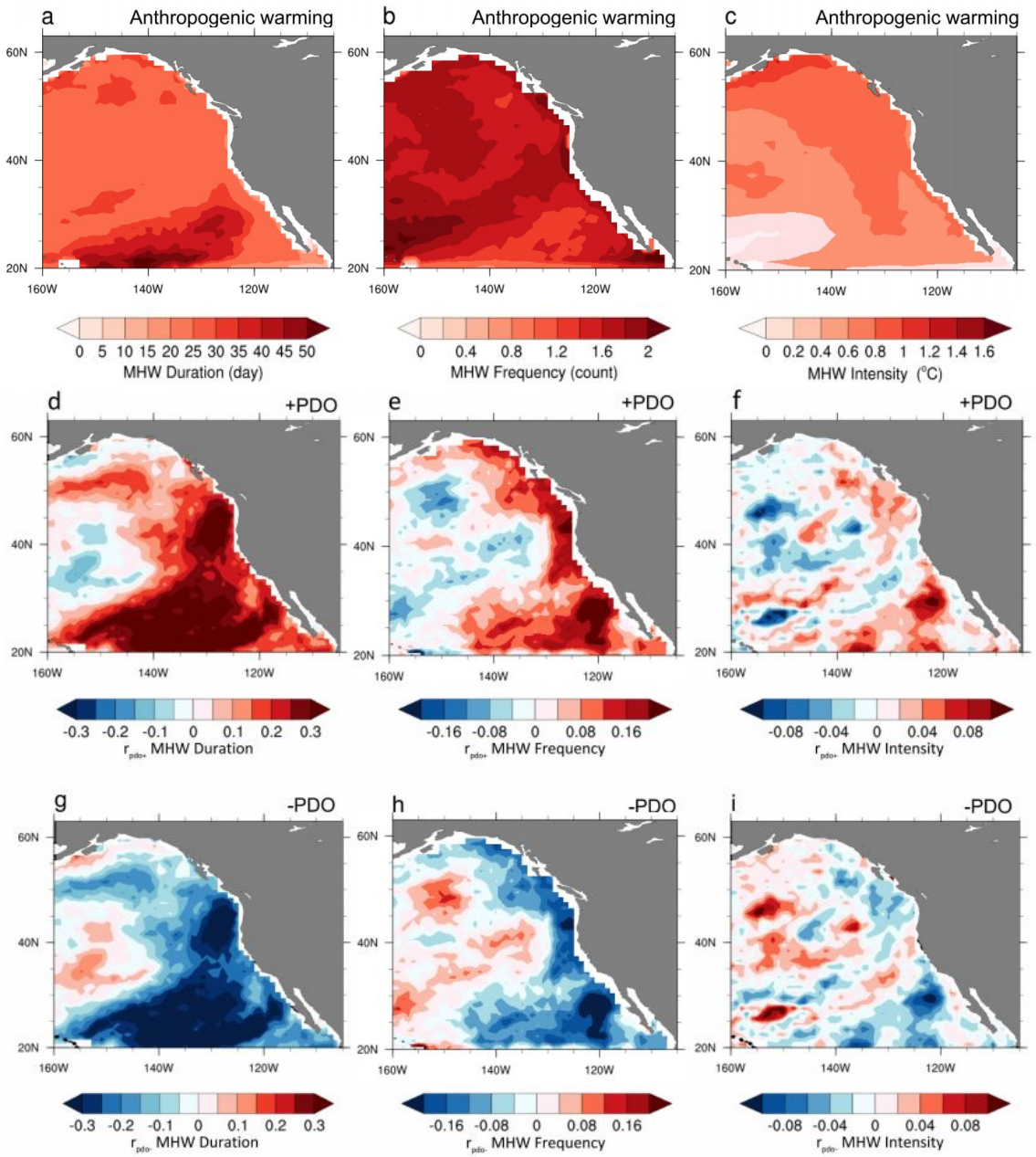
$$r_{pdo-} = (\overline{MHW}_{pdo-} - \overline{MHW}_{agw}) / \overline{MHW}_{agw} \quad (2)$$

+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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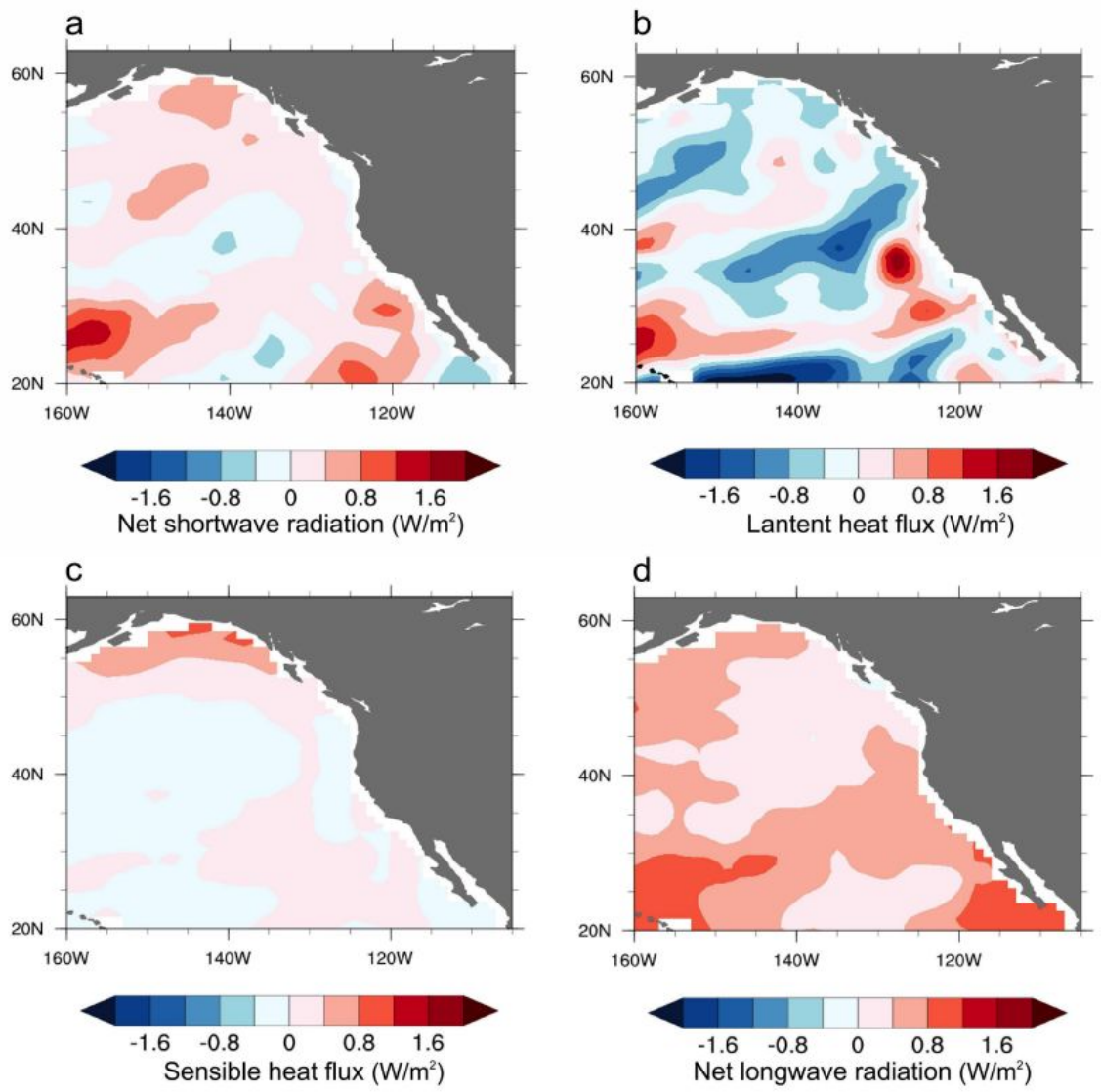

Figure 5. Differences of surface heat flux components between positive and negative PDOs. The ensemble-mean differences of surface (**a**) shortwave and (**b**) longwave radiation and (**c**) sensible and (**d**) latent heat fluxes during 2013-2022 between the positive and negative PDO groups (positive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