Analysis of Surface Heat Flux Anomalies to Understand Recent Northeast Pacific Marine Heatwave Events

Yi-Wei Chen*, Larry W. O'Neill, and Emily E. Hayden

*College of Earth, Ocean, and Atmospheric Sciences, Oregon State University (*chenyiwe@oregonstate.edu)*

Oregon State University

Introduction

Over the last ten years, several large-scale marine heatwave (MHW) events occurred in the Northeast Pacific Ocean (NEP). MHW events were manifested as a sea surface temperature (SST) anomaly of about 3°C warmer during winter (Bond et al., 2015; Phillips and O'Neill, 2020), roughly the size of Alaska (Figure 1). Many of these events are associated with highly anomalies atmospheric conditions, including persistent high-pressure ridging episodes in the Northeast Pacific Ocean. Meanwhile, increased heat flux into the ocean occurred during MHW events. The conditions leading to the formation of these large-scale warm ocean anomalies are not well understood. **This project tests the hypothesis that these ridging episodes contribute to MHW events formation by changing the air-sea heat fluxes.** The relationship between atmospheric circulation, surface heat fluxes, and the warm SST anomalies are assessed through case studies of two recent prominent MHW events during winters of 2013 and 2019. This project focuses on the role of surface heat flux anomalies input in the ocean from the atmosphere, which are approximately 100 W/m^2 higher than the climatological average during the MHW events considered.

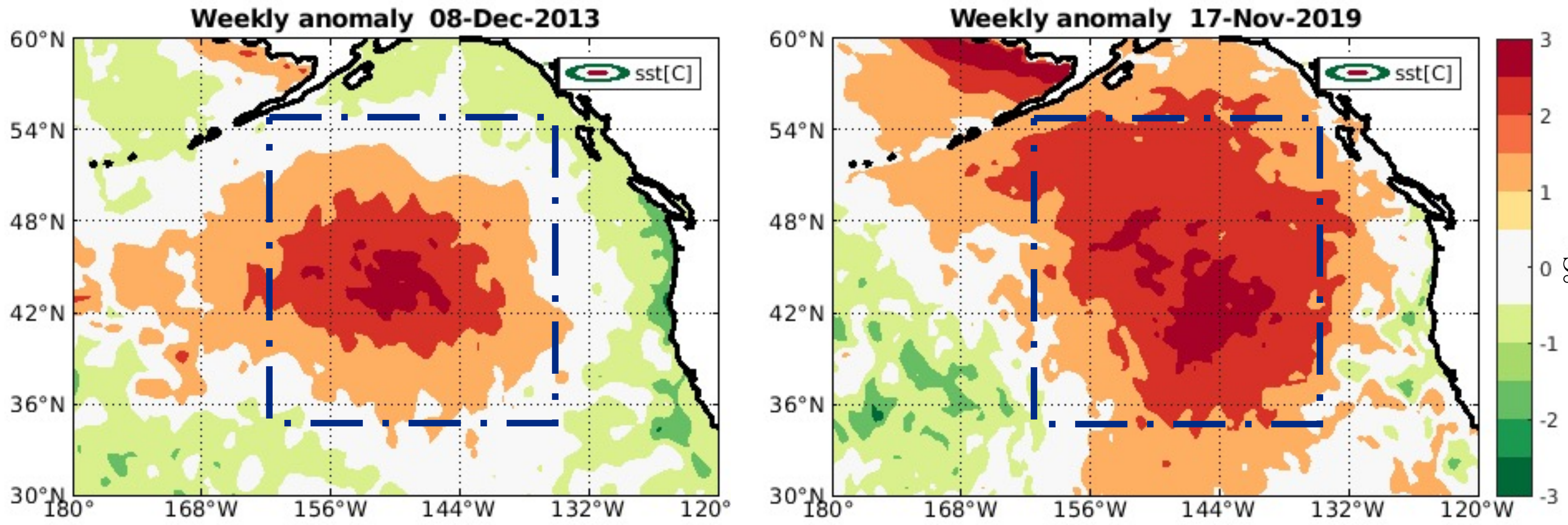

Figure 1. SST anomaly with the study area outlined by the blue square. The peak SST anomaly exceeded 3°C during both events. The blue box is the steady area (35-55°N, 135-160°W).

Extreme Event Case Studies

What happened:

SST anomalies in the Northeast Pacific Ocean were observed to be significantly warmer than average during winter 2013/14 and 2019/20. In February 2014, peak temperature anomalies of the near surface (upper ~100 m) waters exceeded 3˚C (Bond et al., 2015).

Impacts:

The long duration and the location of MHW had significant impacts on downstream weather and precipitation patterns (e.g., Swain et al., 2014; Seager et al., 2015) and regional ocean ecological dynamics (e.g., McCabe et al., 2016, Jones et al., 2018).

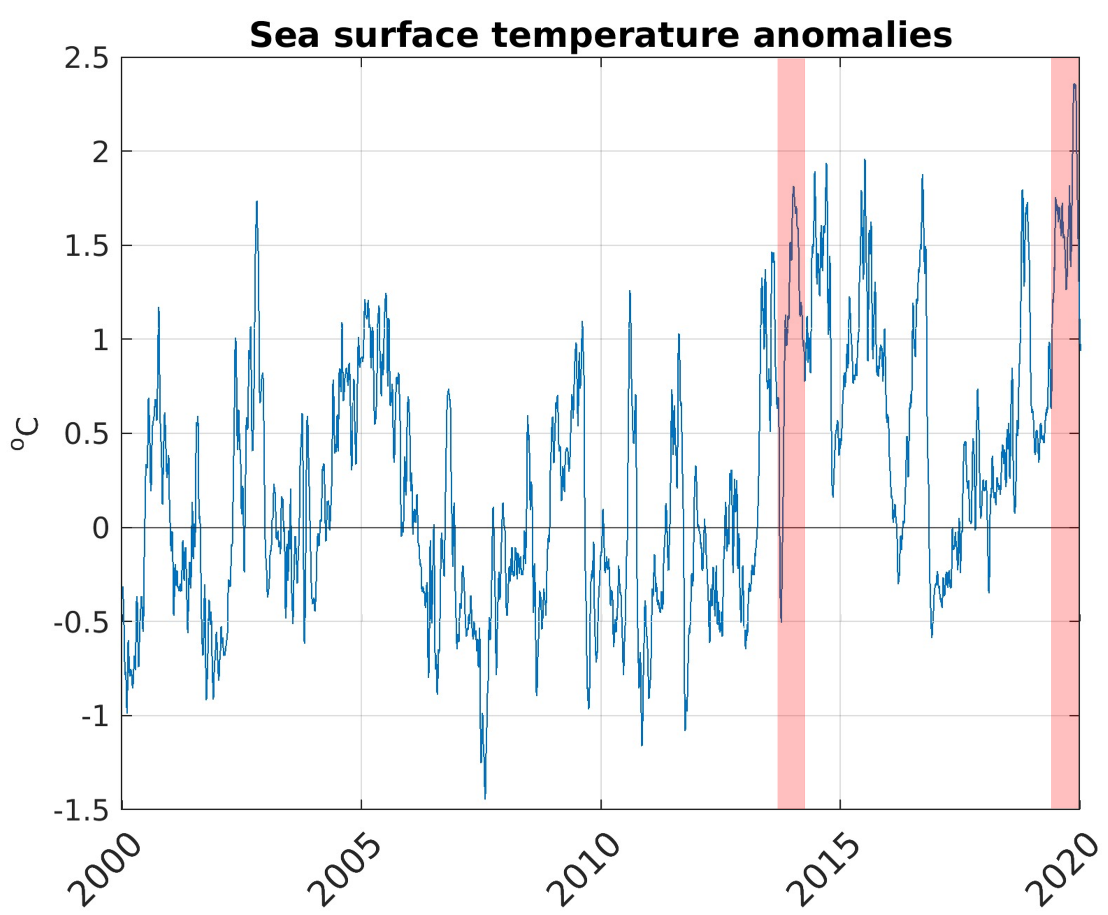

Figure 2. Time series of daily area-averaged SST anomalies since 2001, the region shown in Figure 1. These were smoothed using a 7-day running average. We chose two MHW episodes for analysis during the winter of 2013/14 and 2019/20.

Objectives / Methodology

We used hourly ERA5 reanalysis fields of the surface turbulent and radiative heat fluxes, SST, and 10-meter winds. Daily anomalies were computed relative to the 1979-2010 base period. The blue square in Figure 1 shows the study area (35-55°N, 135-160°W). This area was chosen since it captures the most intense warm SST associated with the recent MHW episodes in 2013/14 and 2019/20. For the analysis presented here, the fluxes and SST anomalies were spatially averaged over the target region in Figure 1.

NASA ECCO ocean state estimate mixed layer heat budget analysis during 2013/14 MHW episodes

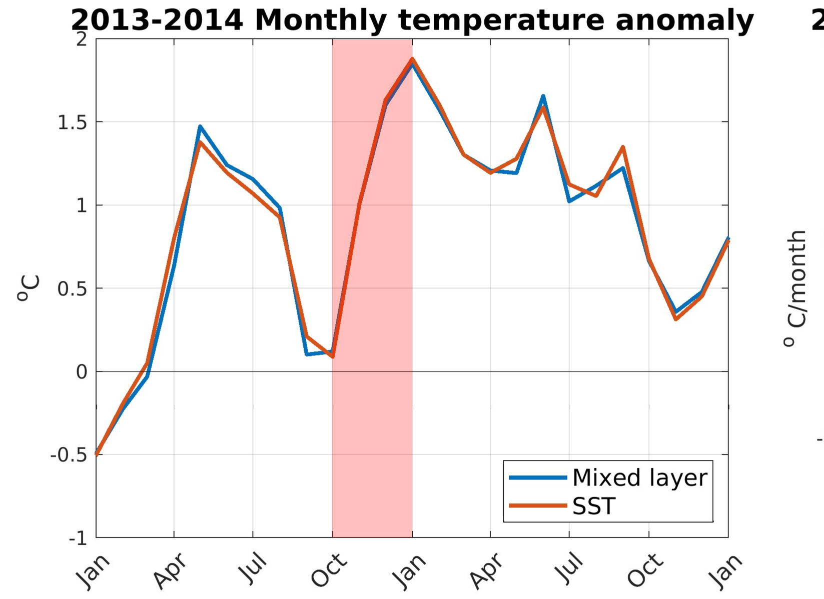

Figure 3. Monthly-area-averaged ECCO mixed layer temperature anomalies and SST anomalies during the 2013/14 MHW event.

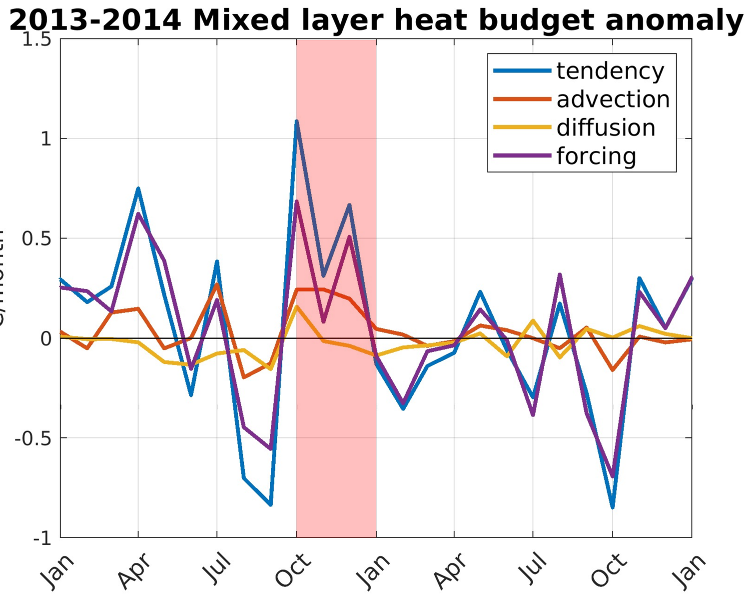

Figure 4. Monthly-area-averaged ECCO mixed layer heat budget anomalies during the 2013-14 event.

- Figure 3 shows that the mixed layer temperature anomalies agree very closely with the SST anomalies. This means that the SST anomalies associated with the 2013/14 MHW can be used as a surrogate for the mixed layer temperature anomalies.
- The blue curve in Figure 4 shows that the mixed layer temperature tendency anomaly was positive, indicating that the study area has been warming up between 0.5 and 0.7°C per month due to surface flux anomalies during the 2013/14 MHW events. The total diffusion and advection terms contributed relatively little to the mixed layer temperature tendency.
- **The 2013/14 MHW was due to atmospheric forcing rather than internal ocean variability.**

ERA5 surface heat flux anomalies associated with MHW events

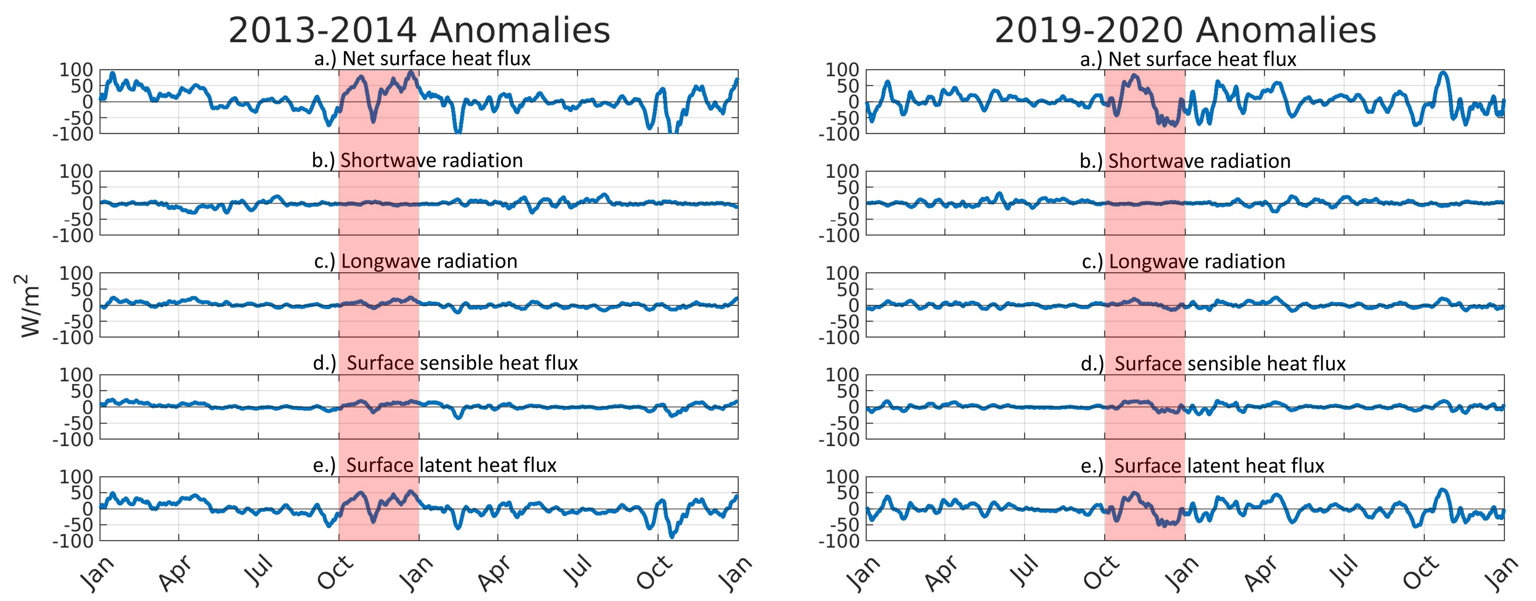

Figure 5. Time series of the area-averaged net surface heat flux anomalies during the MHW episodes of 2013/14 and 2019/20. Those were smoothed using a 7-day running average. Red box indicates the MHW episodes.

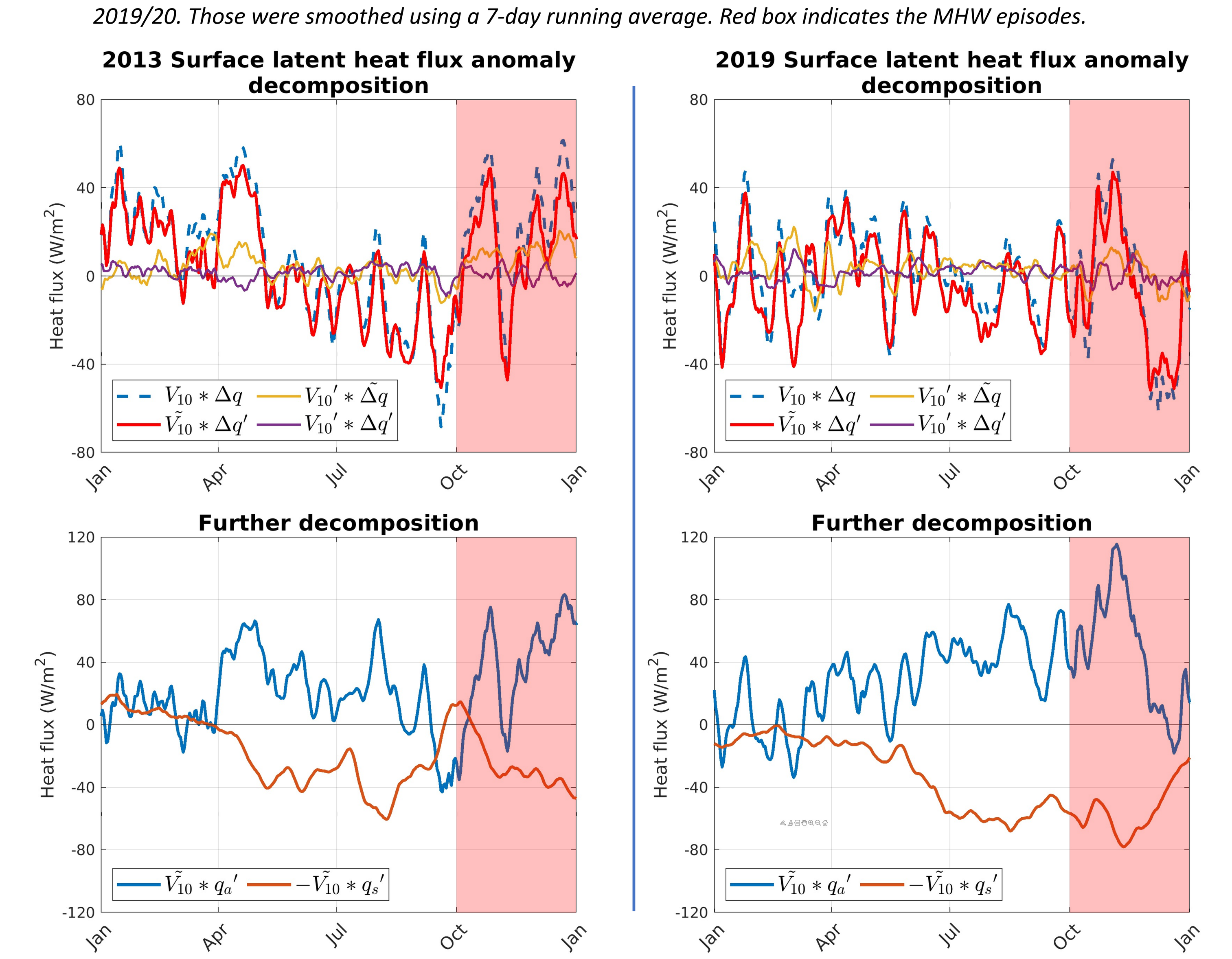

Figure 6. Time series of the area-averaged latent heat flux anomalies and the terms in the decomposition in 2013 and 2019. Those were smoothed using a 7-day running average. Red box indicates the MHW episodes.

Latent heat flux is the most dominant term in the net sea surface heat flux anomalies during the MHW events (Figure 5).

- To isolate the oceanic and meteorological conditions which contribute to the latent heat flux anomaly, the latent heat flux anomalies were decomposed into terms related to climatological and anomalous wind speed and air-sea humidity differences.

Latent heat flux anomaly (LH'):

$$\boldsymbol{LH' \rightarrow \rho * C_E * L_v * (\tilde{V} * \Delta q' + V' * \widetilde{\Delta q} + V' * \Delta q')}$$

q_a= specific humidity[g/kg]; q_s= surface saturated specific humidity[g/kg]

ρ = 1.2 [kg/m^3]; C_E =1*10^{-3} ; L_v = 2.5*10^6 [J/kg]

$\tilde{V}, \widetilde{\Delta q}$ = daily climatology; $V', \Delta q'$ = daily anomaly

$\widetilde{\Delta q} = \tilde{q}_a - \tilde{q}_s$; $\Delta q' = q_a' - q_s'$

- The climatological 10-meter wind speed ($\widetilde{V_{10}}$) multiplied by the air-sea specific humidity difference anomaly ($q_a' - q_s'$) accounts for most of the latent heat flux anomaly (Figure 6 top).
- The specific humidity anomaly (q_a') is the largest amplitude term, while the $\widetilde{V_{10}} * (-q_s')$ term has a relatively minor effect on the latent heat flux anomaly (Figure 6 bottom).
- Figure 7 shows q_a' average as a function of anomaly wind direction. Anomalous southerly winds bring moist warm air from the tropical region to the south of the study area and vice versa. These humidity anomalies modulate evaporative heat loss from the ocean surface.
- **Wind speed anomalies are not driving turbulent heat flux anomalies.**
- **This analysis shows that atmospheric circulation anomalies were the dominant factor in generating these MHW events by decreasing evaporative cooling of the sea surface.**

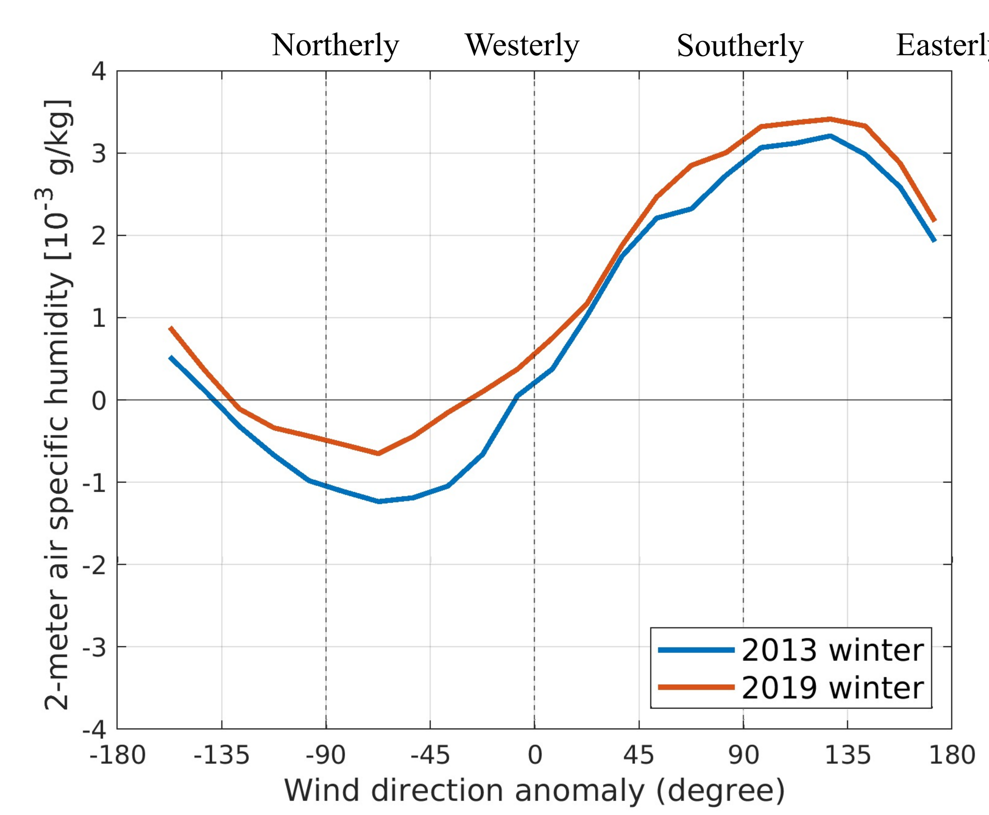

Figure 7. Specific humidity anomaly bin averaged as a function of wind angle during the year of MHW events.

Conclusion

- Atmospheric circulation anomalies are the dominant factor in generating the MHW episodes of 2013/14 and 2019/20 by decreasing turbulent heat loss in the Northeast Pacific subpolar gyre.
- These turbulent heat flux anomalies are generated by warm moist air anomalies, which reduced evaporative cooling of the sea surface.
- SLP anomaly patterns during MHW generation are consistent with northward advection of subtropical air.

References

- Bond, Nicholas A., et al. (2015). "Causes and Impacts of the 2014 Warm Anomaly in the NE Pacific." *Geophysical Research Letters*, vol. 42, no. 9, pp. 3414–3420.
- Jones, Timothy, et al. (2018). "Massive Mortality of a Planktivorous Seabird in Response to a Marine Heatwave." *Geophysical Research Letters*, vol. 45, no. 7 pp. 3193–3202.
- McCabe, Ryan M., et al. (2016). "An Unprecedented Coastwide Toxic Algal Bloom Linked to Anomalous Ocean Conditions." *Geophysical Research Letters*, vol. 43, no. 19.
- Phillips, Briana, and Larry O'Neill. (2020). "Observational Analysis of Extratropical Cyclone Interactions with Northeast Pacific Sea Surface Temperature Anomalies." *Journal of Climate*, vol. 33, no. 15, pp. 6745–6763.
- Seager, Richard, et al. (2015). "Causes of the 2011–14 California Drought." *Journal of Climate*, vol. 28, no. 18, pp. 6997–7024.
- Swain, D.L., et al., (2014). "The extraordinary California drought of 2013–2014: Character, context, and the role of climate change [in "Explaining Extremes of 2013 from a Climate Perspective"]. Bull. Amer. Meteor. Soc., 95 (9), S3–S7.