Atmospheric Forcing of Marine Heat Waves in the Eastern North Pacific

PennState College of Earth and Mineral Sciences

Katie Kohlman[1] (*kmk6399@psu.edu*), Seth Madden[2] (*semadden13@gmail.com*), and Tom Murphree[3] (*murphree@nps.edu*)

[1]Pennsylvania State University Department of Meteorology, [2]York School, [3]Naval Postgraduate School

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A. Introduction & Motivation

Marine heat waves (MHWs) are anomalous events in which extreme positive sea surface temperature anomalies (SSTAs) occur. MHWs have major impacts on weather, climate, marine ecosystems, and fisheries[1,2]. Many prior studies have focused on individual events in specific seasons (especially in winter). Relatively few studies had attempted to characterize multiple events in specific regions.

In our study, we analyzed the regional and global oceanic and atmospheric anomalies associated with warm and cool events in the eastern North Pacific (ENP). We focused on the generation of summer events, which tend to have the largest anomalies. Our region of focus was an ENP box in which both positive and negative SSTAs tended to have the greatest magnitudes (Fig. 1).

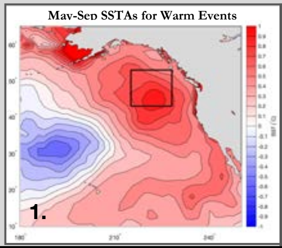

Fig. 1. Composite SSTAs (°C) for the 15 warmest events during May-Sep 1970-2019.

Black box shows our focus region within the ENP (43-53N, 215-228E). This box encompasses the strongest SSTAs for both ENP warm events (shown in this figure) *and* cool events (not shown).

B. Data & Methods

Our main data was monthly mean values from the NCEP/NCAR Reanalysis (R1) for 1970-2019. We chose R1 to allow us to work with a larger number of years than more recent reanalyses. We defined warm (cool) events as the fifteen May-Sep periods in which the detrended SSTAs in the ENP box were warmest (coolest) (Fig. 2). We conducted a range of statistical and dynamical analyses of oceanic and atmospheric variables to identify spatial and temporal anomaly patterns, and dynamical processes associated with the development and decay of warm and cool events in the ENP. For brevity, we only discuss warm events in this poster.

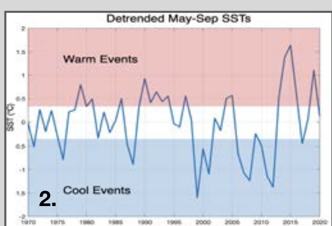

Fig. 2. Detrended SSTs (°C) for May-Sep 1970-2019 for ENP box. Warm (cool) events are identified by the red (blue) coloring.

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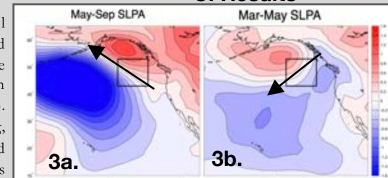
Research Questions

1. What regional and global scale atmospheric-oceanic processes generate extreme sea surface temperature anomalies (SSTAs) in the eastern North Pacific?
2. How are these extreme SSTAs related to known tropical climate variations, such as El Niño-La Niña?
3. How are these extreme SSTAs related to multidecadal climate change?

C. Results

1. Regional and Global Processes

May-Sep SSTs in the ENP have varied between warm and cool events during 1970-2019 (Fig. 2). Warm events are associated with a summer sea level pressure anomaly (SLPA) dipole in the ENP[3], with corresponding surface wind, heat, and momentum flux anomalies that are consistent with increasing SSTs (Fig. 3). A similar but stronger dipole occurs in the prior spring, suggesting that summer ENP SSTAs are initiated by spring wind speed anomalies. The spring is also when warm event SSTAs increase the most (not shown). Fig. 4 shows that the spring ENP SLPA dipole is part of a tropospheric-deep circulation anomaly pattern and anomalous arching and zonal wave trains. These wave trains indicate that the ENP dipole is triggered by anomalously weak (strong) convection in the tropical eastern Indian Ocean (central Pacific) (Fig. 4,5).



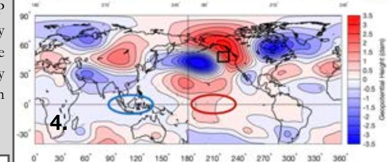


Fig. 3. SLP (mb) and implied surface wind anomalies for warm events in: **(a)** Mar-May; **(b)** prior May-Sep.

Fig. 4. 200 mb eddy geopotential height anomalies (dam) in Mar-May prior to warm events. Red (blue) ovals show strong (weak) convective anomaly areas.

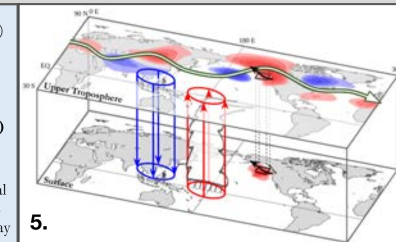


Fig. 5. Schematic of tropospheric anomalies in the spring prior to warm events. Suppressed (enhanced) convection anomalies shown by blue (red) column. Perturbed flow represented as outlined arrow. Inferred wind anomalies represented with black arrows above the ENP.

2. Connections to the Tropics

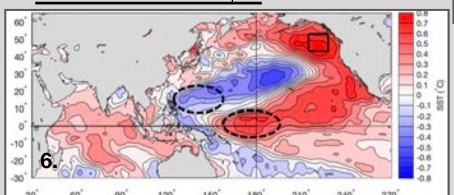


Fig. 6. Correlation map of July SSTs in ENP box (black) with prior Mar-May SSTs. Areas of high correlation outlined with dashed circles.

The anomalies in Figs. 4-5 are similar to those for El Niño (EN) events[4]. However, compared to EN events, warm events have: (a) an ENP dipole that is stronger and more favorably for ENP warming, (b) tropical convective anomalies that are stronger and further to the west, and (c) a zonal wave train at 30-40 °N that is more pronounced. Also, the links between warm events and EN events are weak. Only 20% of warm events are preceded by EN and only 40% are simultaneous with EN. But other tropical climate variations may be important in triggering warm events. Summer SSTs and wind speeds in the ENP box are well correlated with prior spring SSTs in the western-central tropical Pacific (e.g., Fig. 6). For example, correlations between Apr-Jul ENP SSTs and Mar-May central tropical Pacific SSTs give R values of 0.57-0.61.

3. Connections to Climate Change

During Mar-May 1970-2019, windspeeds in the ENP experienced a strong downward trend with a decrease of 2.05 m/s (Fig. 7a). During May-Sep 1970-2019, SSTs in the ENP experienced a strong upward trend with an increase of 0.86°C (Fig. 7b). In this 50-year period, spring-summer SLP in the ENP changed substantially in ways that made SLPA dipole conditions more common and intense, leading to lower wind speeds across much of the Pacific (Fig. 8). These results indicate that multidecadal climate change has contributed to an increase in the frequency, intensity, and duration of warm events over the last 50 years (Figs. 2,7b).

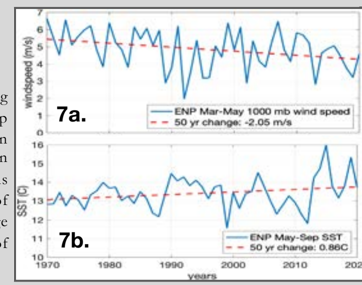


Fig. 7. (a) ENP 1000 mb wind speed (m/s) for Mar-May 1970-2019; **(b)** ENP SST (°C) for May-Sep 1970-2019.

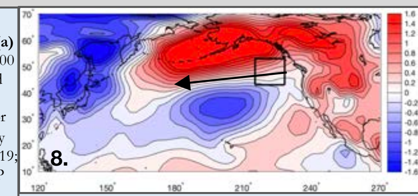


Fig. 8. Difference in SLP (mb), Mar-May 2000-2019 minus Mar-May 1970-1989. Black arrows show corresponding implied surface wind differences.

D. Summary and Discussion

We have found that ENP warm events, including recent MHWs, are a result of complex interactions between: (a) interannual variations and multidecadal climate change in the ENP; (b) SSTs and convective anomalies in the tropics; and (c) anomalous atmospheric forcing in the extratropical ENP. Warm alternate interannually with cool events. The regional and global anomalies for warm events are generally opposite than those for cool events (not shown). Both types of events are have become more extreme over approximately the last 20 years. Warm events and cool events do not appear to be strongly related to El Niño/La Niña. Climate change seems to have contributed to an ENP SLPA dipole, leading to a multidecadal decrease in ENP wind speeds and increase in ENP SSTs.

E. Future Work

- Analysis of ENP atmosphere-ocean fluxes
- Links to other tropical climate variations
- Predictability of ENP warm and cool events
- Impacts of ENP events on North American climate
- Development of ENP monitoring system

F. Practical Applications

- Develop and apply systems for monitoring and predicting ENP events
- Apply results to improve S2S predictions
- Apply results to improve ecosystem management

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