Marine Heat Waves in the Eastern North Pacific: Characteristics and Causes

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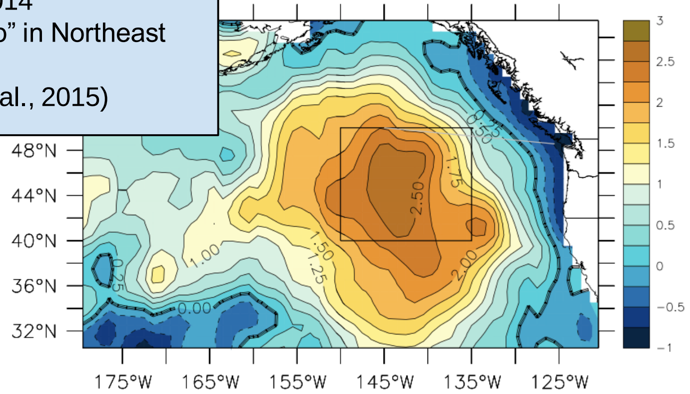
Introduction to the Problem

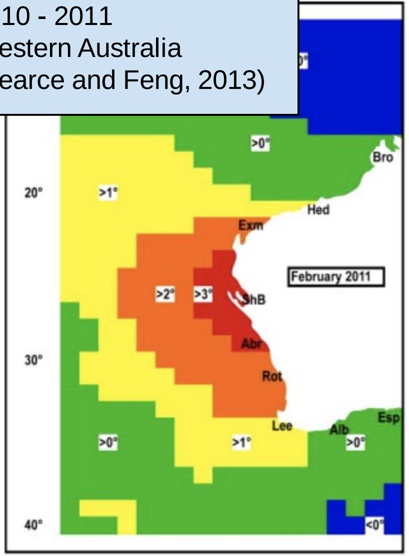
1. MHWs are prolonged above normal SSTAs
2. MHWs have become stronger and more common around the world
3. Mechanisms leading to MHWs are still being investigated, mainly on a case by case basis

Impacts on Society

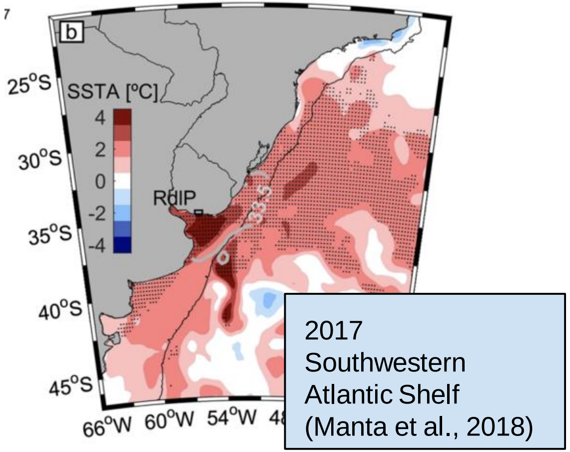
1. Fishery productivity
2. Marine ecosystems
3. Tropical cyclone risks
4. Wildfires in California
5. Upwelling/downwelling



2013 - 2014
“The Blob” in Northeast Pacific
(Bond et al., 2015)

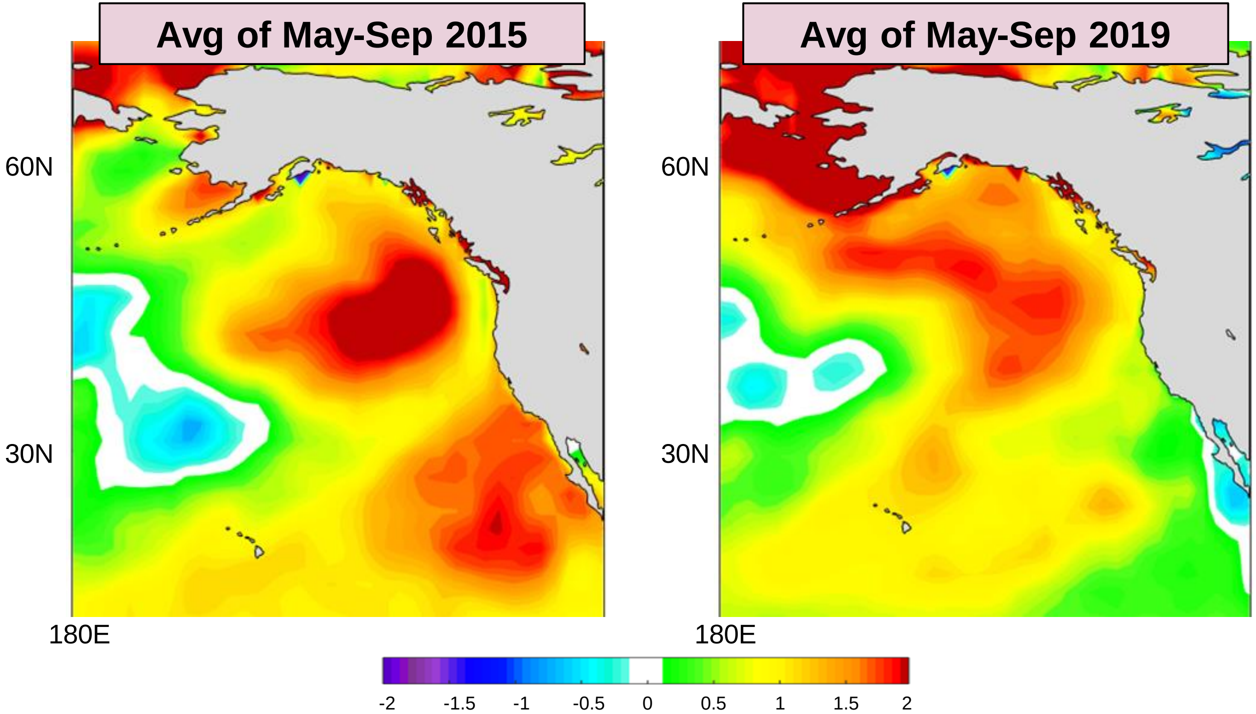


2010 - 2011
Western Australia
(Pearce and Feng, 2013)



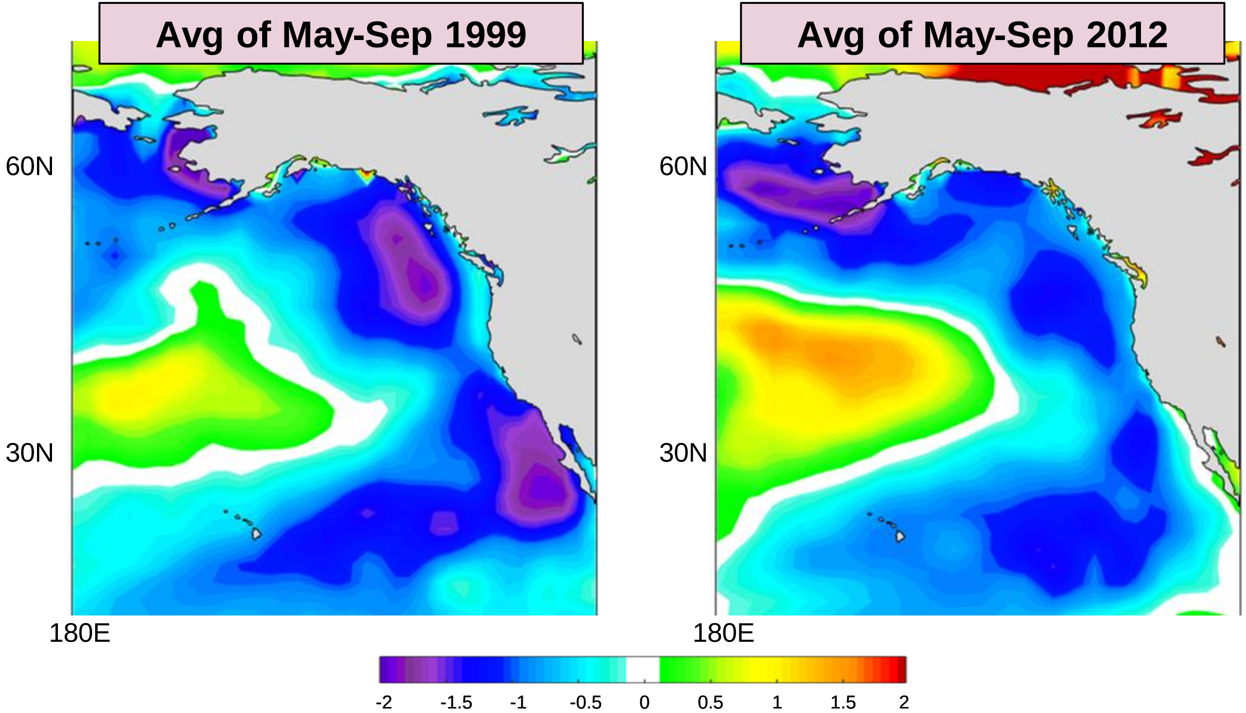
2017
Southwestern Atlantic Shelf
(Manta et al., 2018)

Sea Surface Temperature Anomalies (SSTAs) During Two Warm Events



1. Anomalies vary year to year, but are centered in the ENP.
2. Anomalies associated with anomalies well beyond the ENP, but are strongest in the ENP.
3. Warm anomalies present in recent times, but also were present well into the past.

Sea Surface Temperature Anomalies (SSTAs) During Two Cold Events



1. Anomalies vary year to year, but are centered in the ENP.
2. Anomalies associated with anomalies well beyond the ENP, but are strongest in the ENP.
3. Cool anomalies present in recent times, but also were present well into the past.

Data

Datasets:

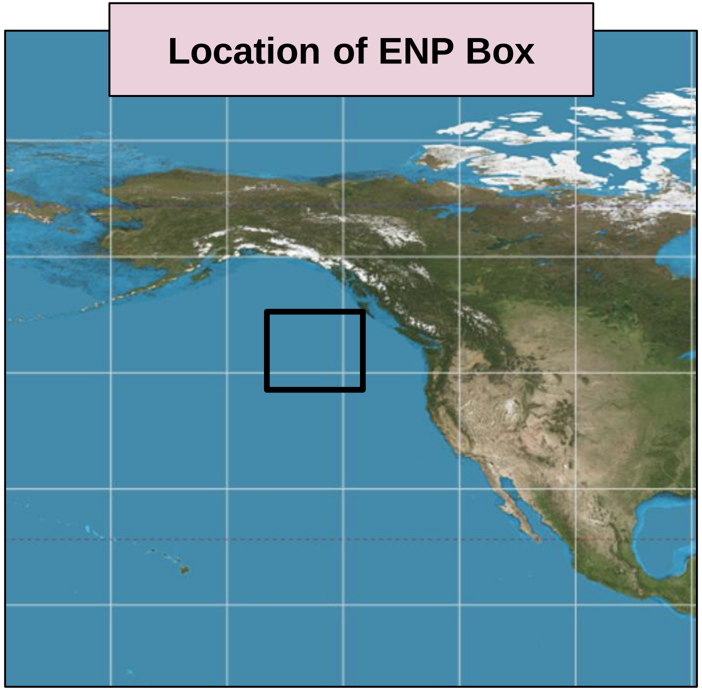
1. Data from NCEP/NCAR Reanalysis 1
2. NOAA Multivariate ENSO Index (MEI; original and version 2)

Focus Study Period:

1. May - Sep 1970 - 2019 (extended summer)
2. Anomalies strongest May - Sep

Focus Study Region

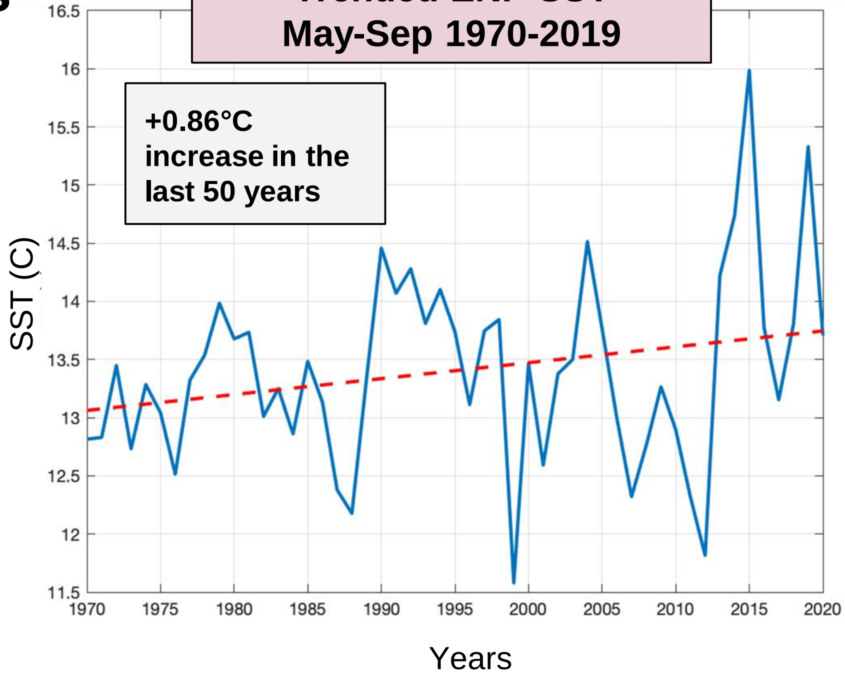
1. Eastern North Pacific (ENP)
2. Focus ENP Box: 43-53N, 215-228E
3. Box chosen to represent most common location for positive and negative extremes in SSTAs



Methods

1. Standardized to facilitate comparison of variables
2. Detrended to separate interannual variations from multi-decadal trends
3. Conditional compositing
    a. Separated into terciles: AN/NN/BN
    b. Averaged together:
        i. **15 AN years/warm events**
        ii. **15 BN years/cool events**
4. Correlation analyses to identify:
    a. regional / global relationships / teleconnections
    b. precursor events and potential predictors
    c. other contributing variables
5. Analyses of dynamical processes and wave trains

Trended ENP SST May-Sep 1970-2019



1. Large interannual variability
2. Large upward trend
3. Despite warming trend, cool events are still occuring
4. Warming trend seems to be amplifying (deamplifying) the warm (cool) events

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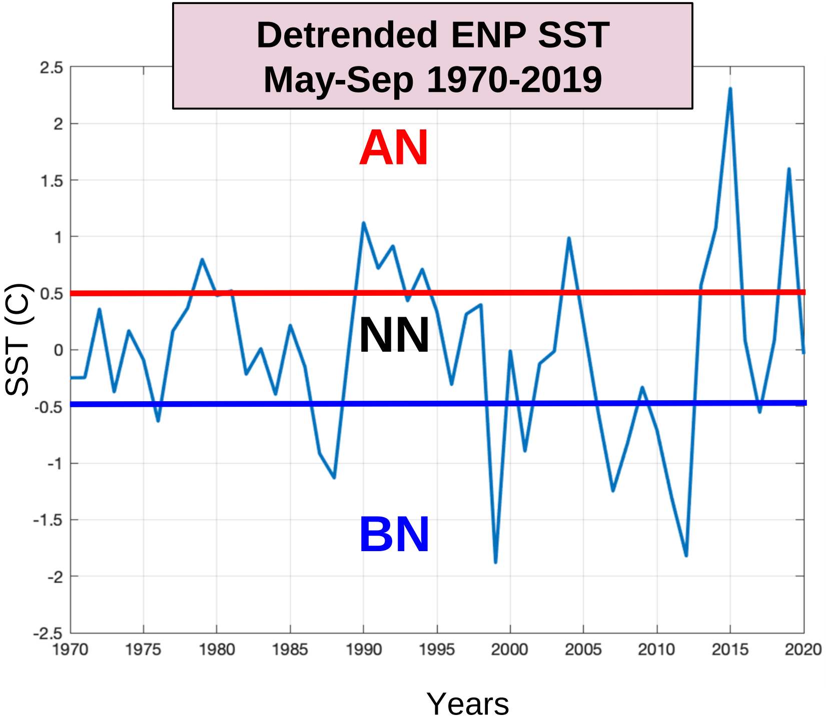
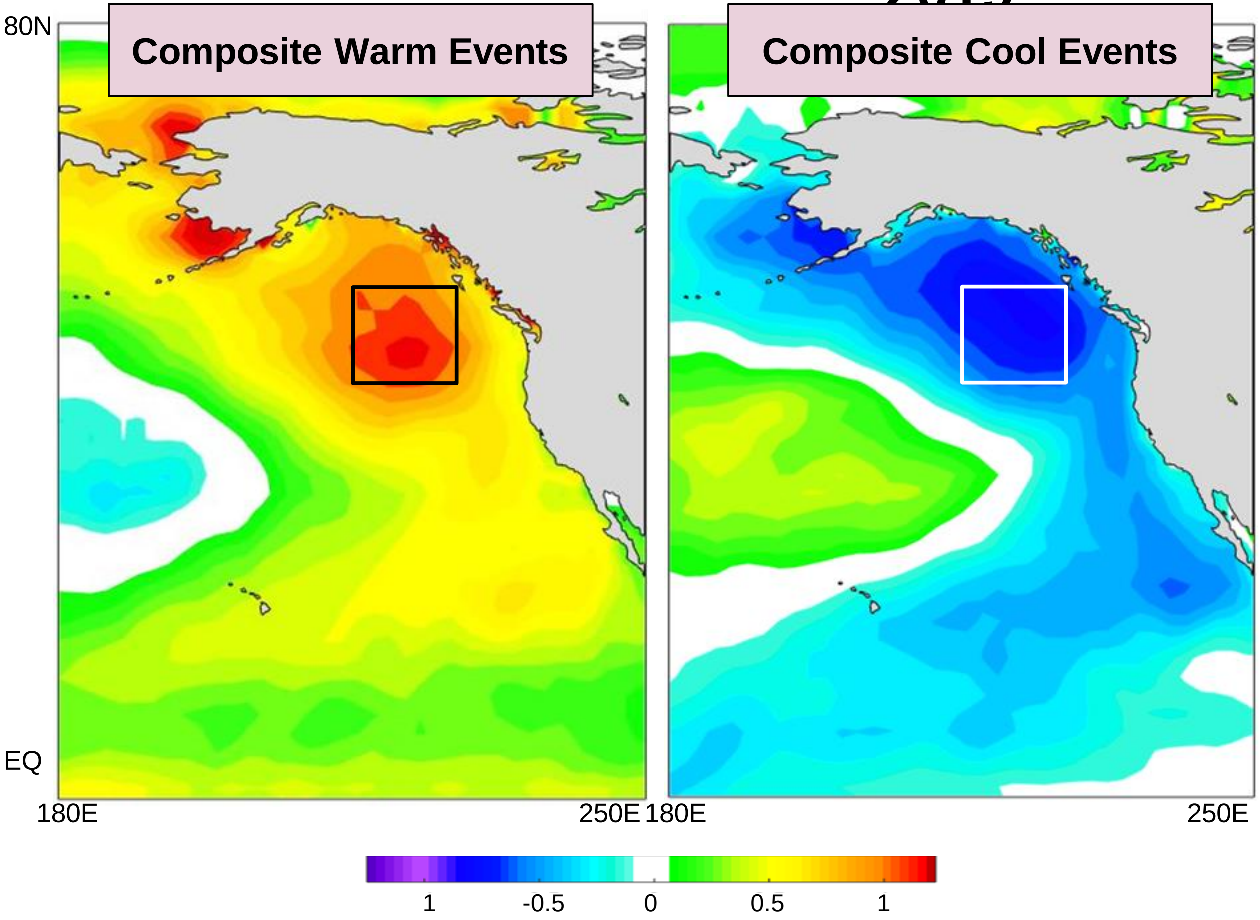


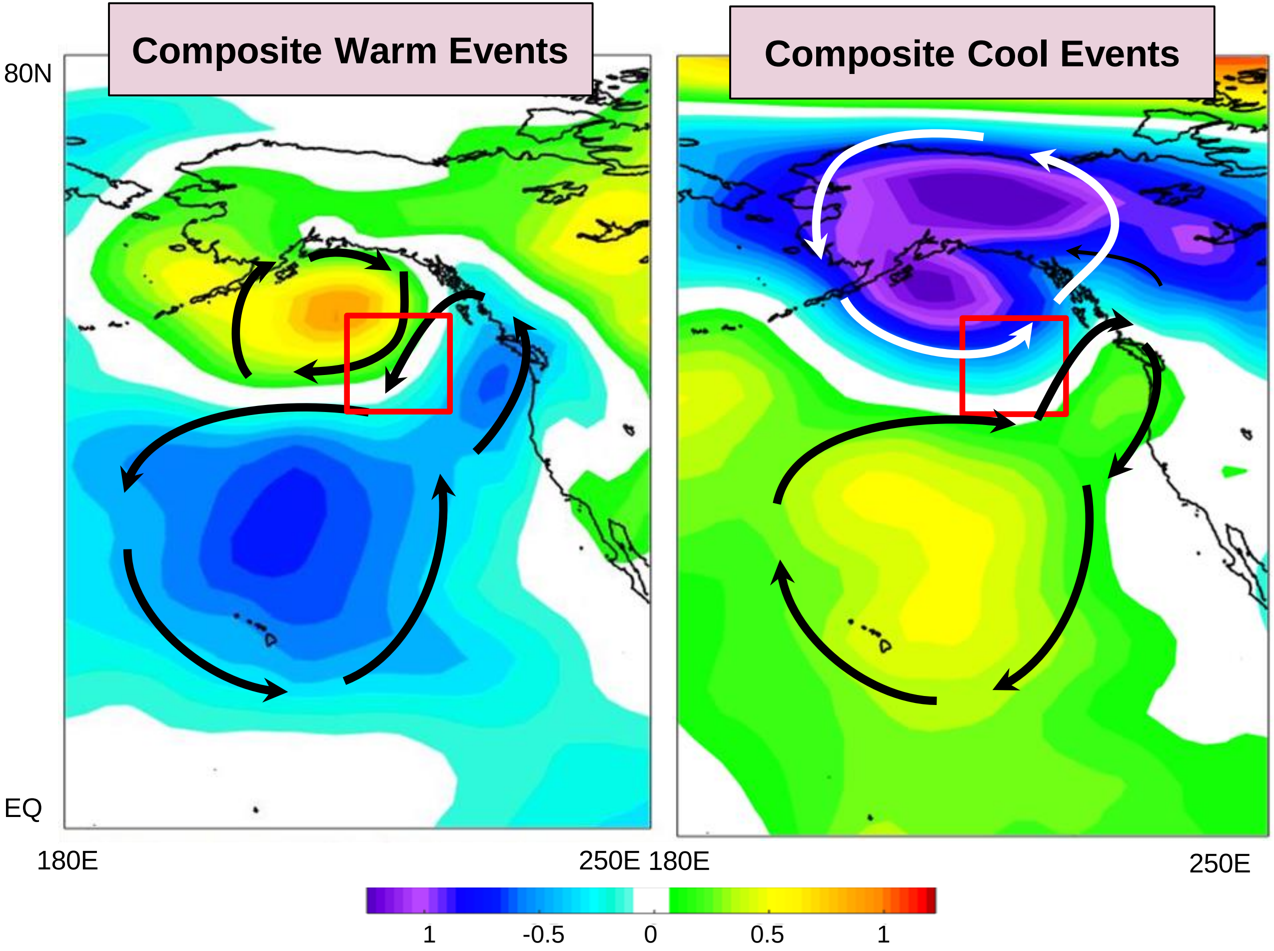
ENP SSTAs for Warm and Cool Events, May-Sep 1970-2019



1. ENP box represents both warm and cool events

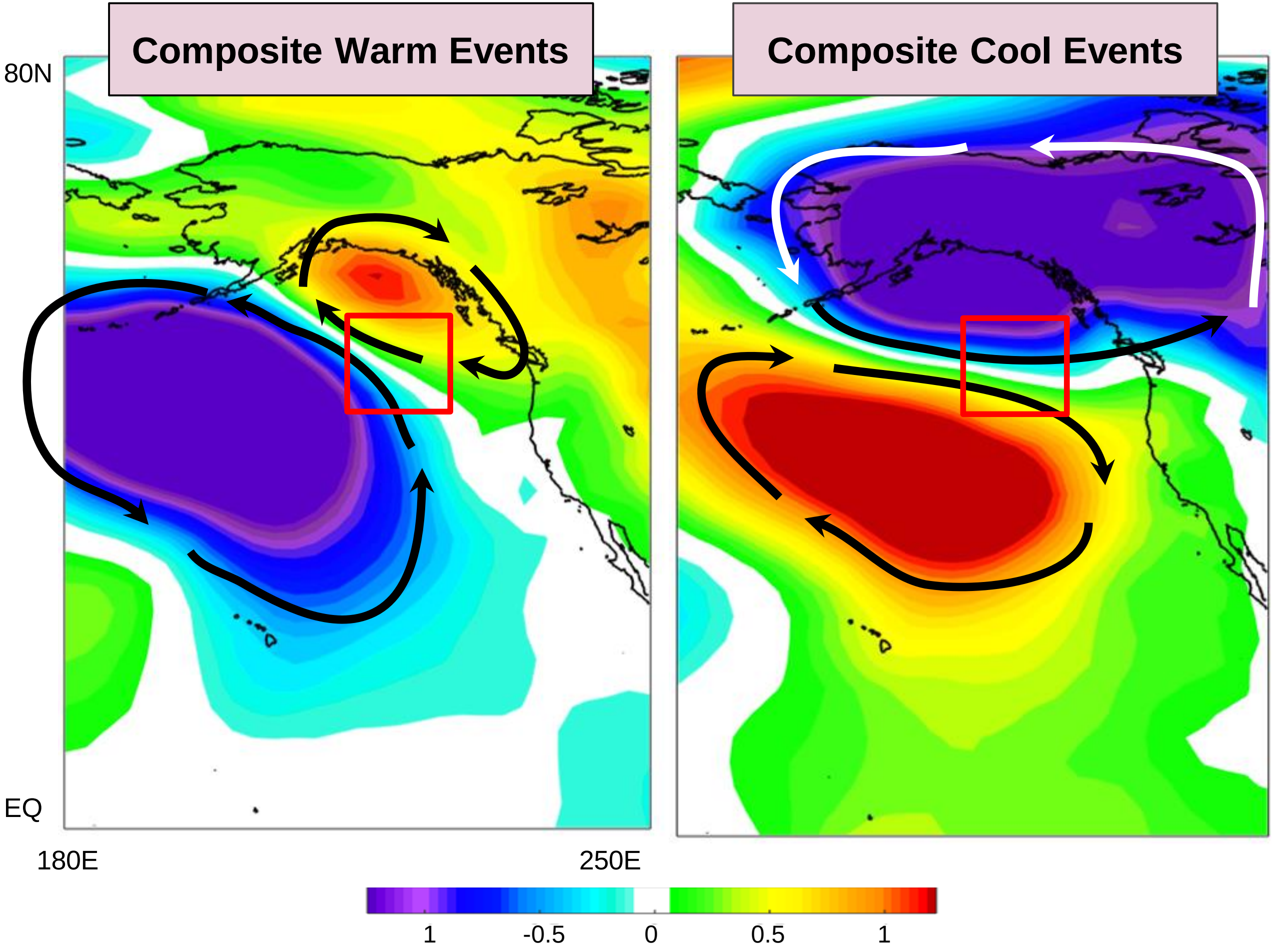
1. Note the opposite SSTA patterns throughout the ENP

SLP & Surface Wind Anomalies, Warm / Cool Events, May-Sep 1970-2019



1. Warm and cool events are characterized by opposite SLPA dipoles in the ENP.
2. The dipoles are similar to but not the same as the North Pacific Oscillation (NPO).
3. For warm (cool) events, the corresponding surface wind speed anomalies are negative (positive) in and near the ENP box.
4. These wind speed anomalies are consistent with atmosphere-ocean heat and momentum flux anomalies that lead to positive (negative) SSTAs and the development of warm (cool) events.
5. Dipoles are even more pronounced in prior Mar-May, suggesting that ENP SSTAs are caused by many months of wind speed anomalies.

SLP & Surface Wind Anomalies, Warm / Cool Events, Mar-May 1970-2019



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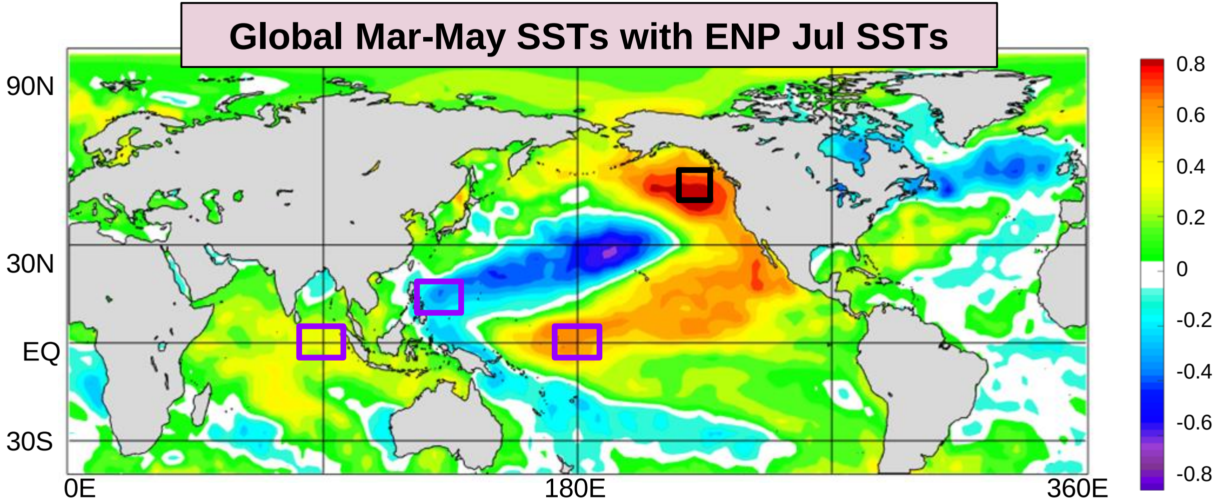
4. These wind speed anomalies are consistent with atmosphere-ocean heat and momentum flux anomalies that lead to positive (negative) SSTAs and the development of warm (cool) events.
5. Dipoles are most pronounced in Mar-May, but also occur in May-Sep, suggesting that ENP SSTAs are caused by many months of wind speed anomalies.

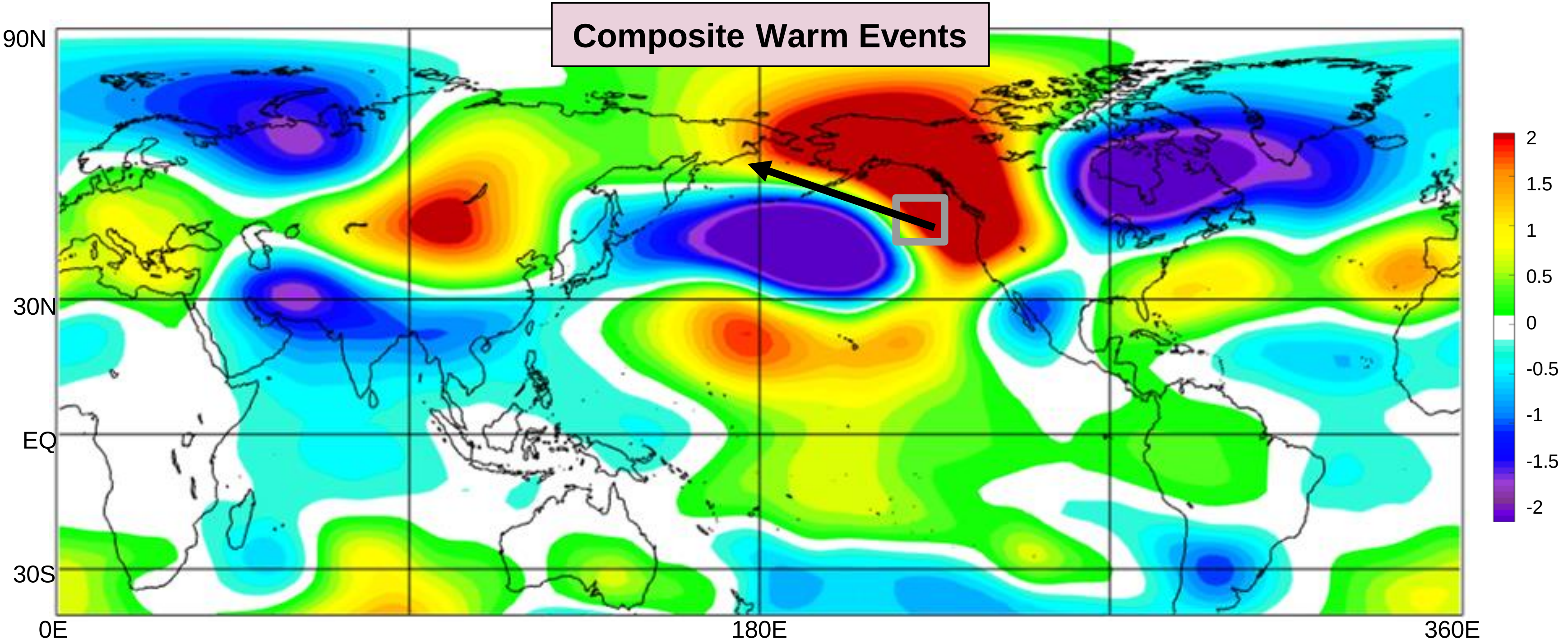
Correlation of SST in ENP box in July with Global SST in Prior Mar-May



1. Summer SSTs in the ENP box are significantly correlated with Mar - May SSTs in the tropical eastern IO (EIO)-maritime continent (MC)-central tropical Pacific (CTP). Example:
   - Mar-May CTP with Apr-Jul ENP: R = 0.57-0.68
1. This suggests SST in the EIO, MC, and CTP may be useful predictors of warm and cool events in the ENP.

95% significance: >0.25

Eddy ZA200 for Warm Events, Mar-May 1970-2019



1. Anomalous dipole in ENP also occurs in upper troposphere.
2. Anomalous zonal and arcing wave trains are especially evident in Mar - May.
3. Patterns are similar to but not the same as El Nino patterns.
4. Evidence of anomalously reduced (enhanced) convection in the eastern IO (central Pacfic).

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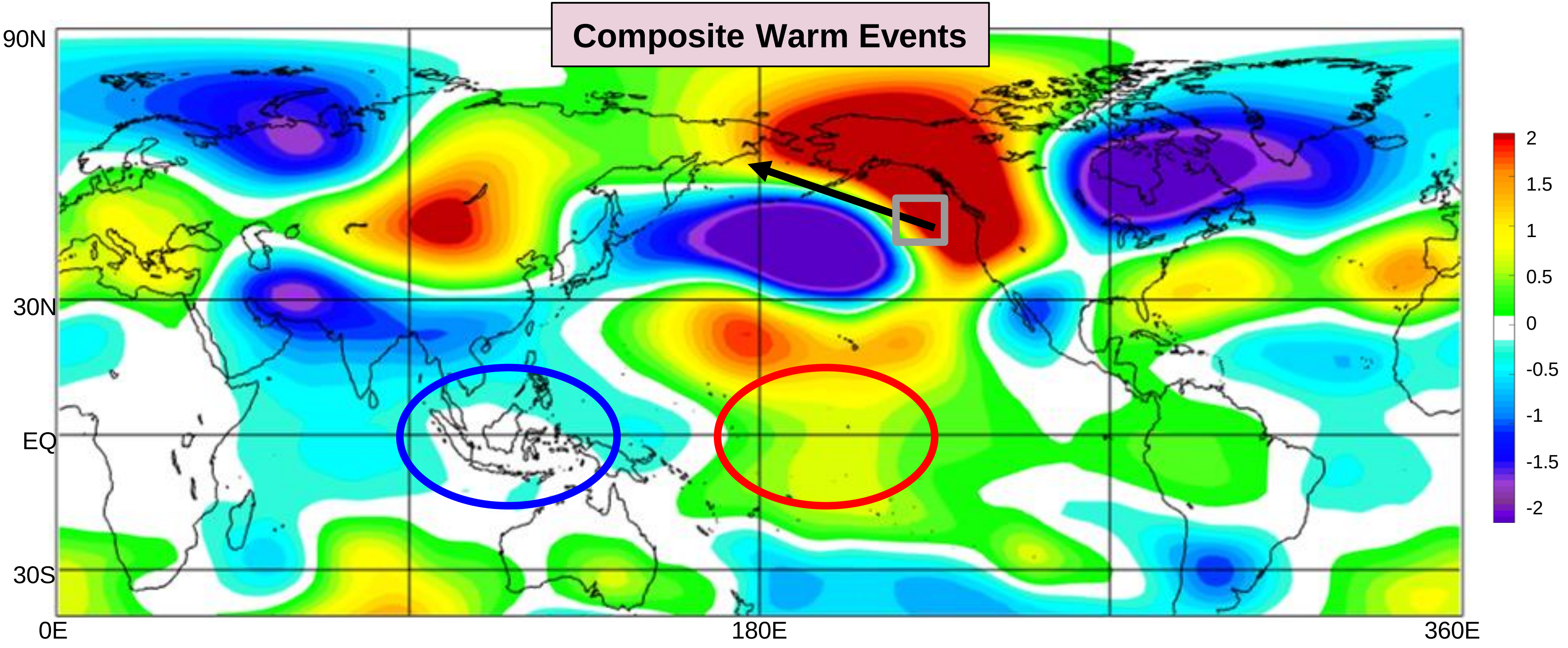

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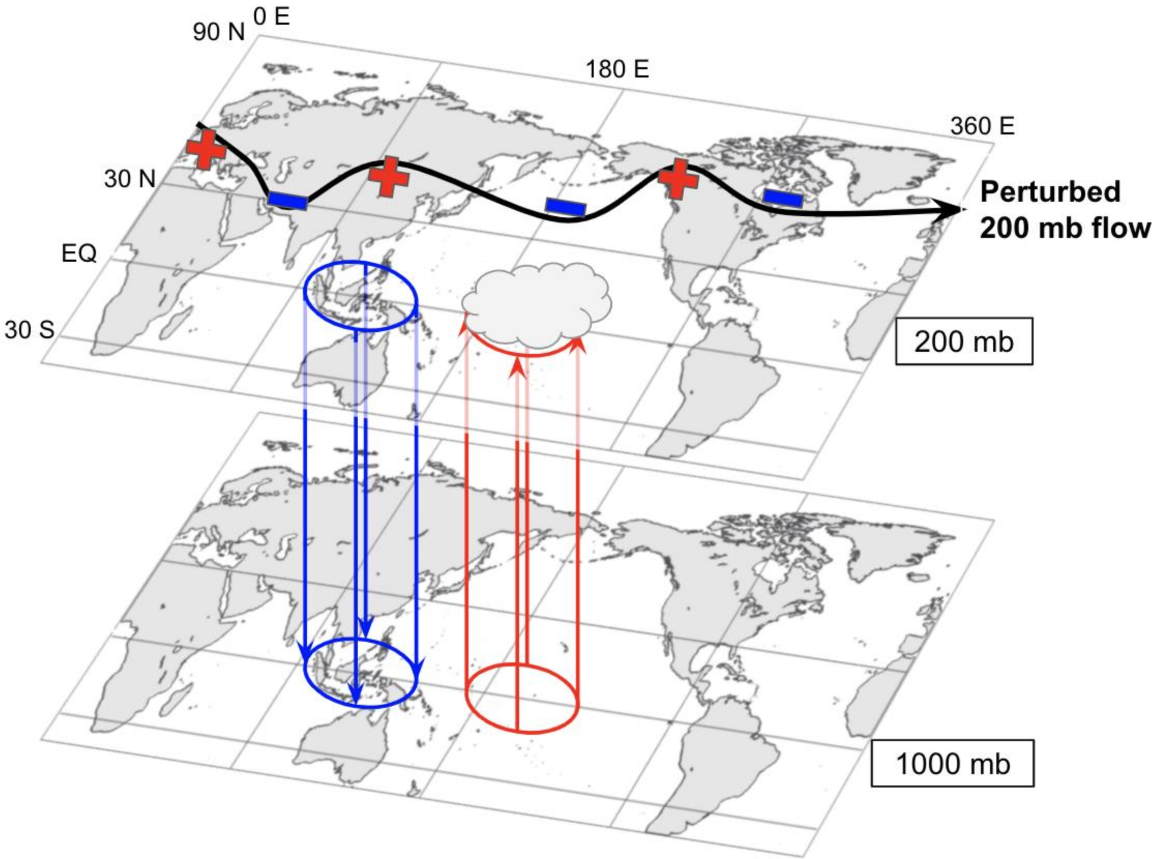
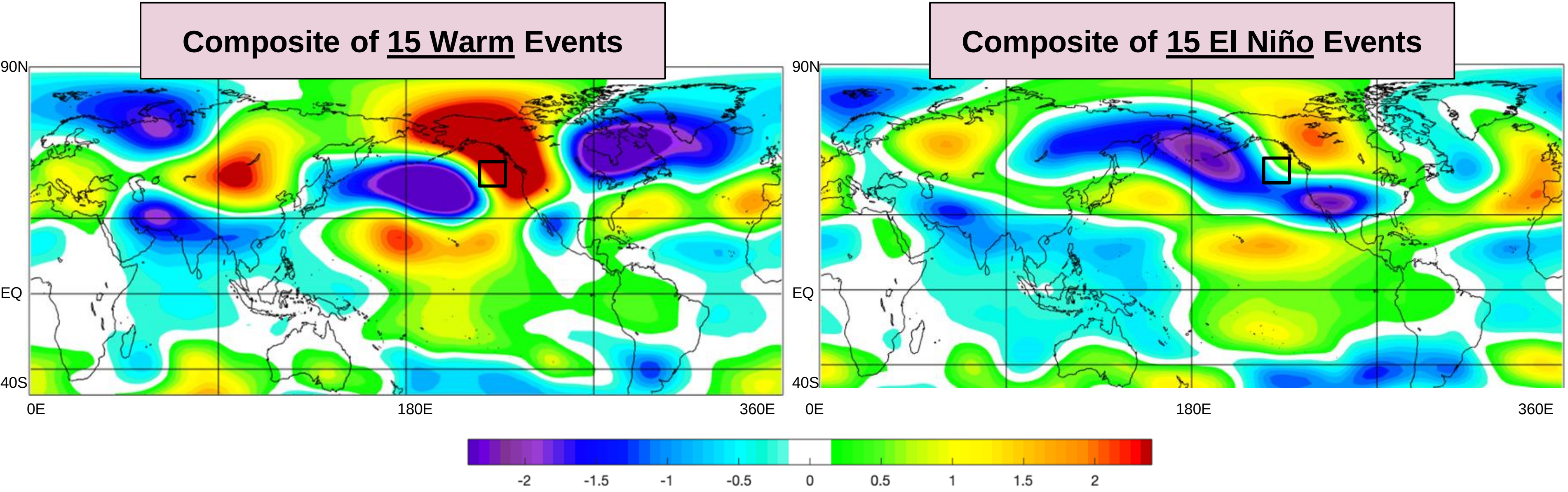
Tropical Convective Anomalies and Wave Trains Leading to ENP



1. Summarizes previous findings from two pressure surfaces
2. Convective anomalies forcing teleconnections to ENP
3. Black arrow represents perspective wave train from Mar-May ZA200 with “plus” (“minus”) signs representing the positive (negative) anomalies

Eddy ZA200s for Warm and El Niño Events, Mar-May 1970-2019



1. Anomaly patterns are roughly similar for ENP warm events and El Niño (EN) events.
2. However, for warm events:
   a. ENP dipole strength and orientation are more favorable for ENP warming.
   b. Tropical convective anomalies are stronger and located further to the west.
   c. Zonal wave train at 30-40N is more pronounced.

ENP Warm Events and El Niños

Do El Niños cause warm events?

Probably no, but occasionally maybe.

1. Only 20% of warm events are preceded by EN
2. Only 40% are simultaneous with EN

Need to investigate further the role of El Niño/La Niña Modoki

Do warm events cause El Niño?

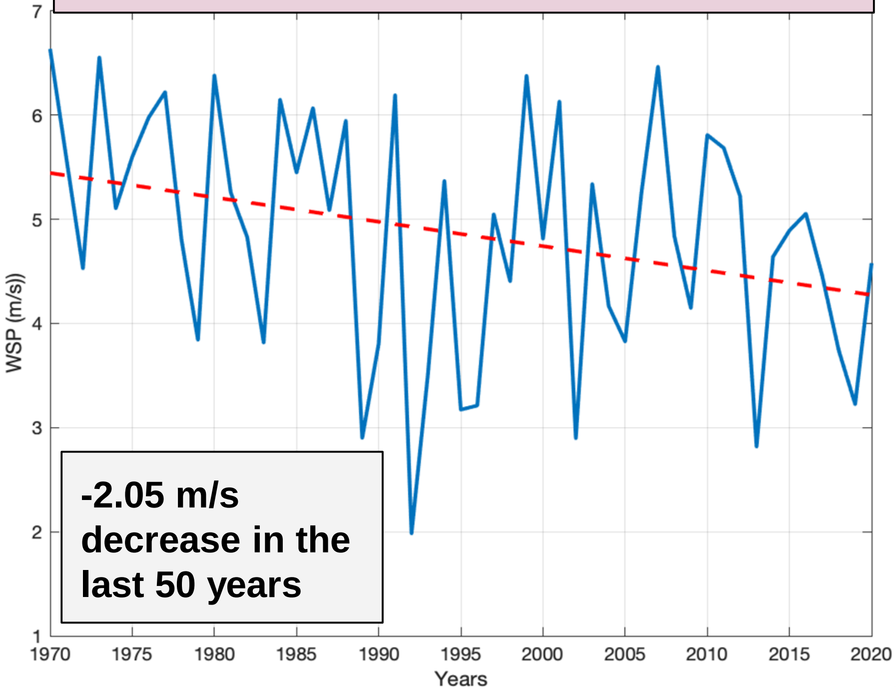
Warm events may contribute to EN development.

1. 27% of warm events are during the beginning of an EN period
2. 40% of warm events are followed by an EN

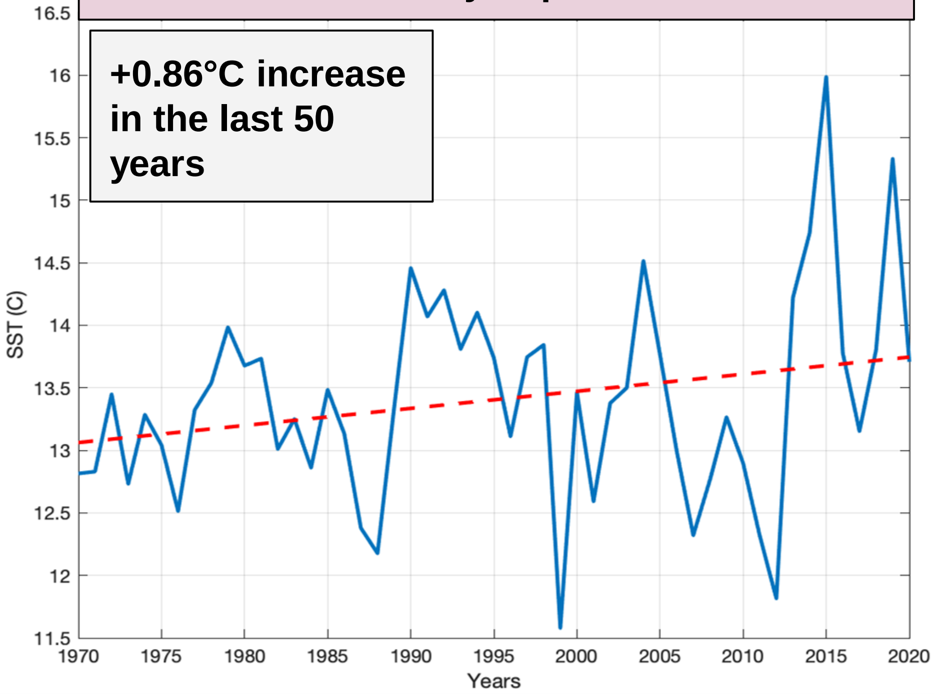
Warm events are associated with NPO-like conditions, and other studies have shown that NPO may contribute to EN development (e.g., Pegion and Selman, 2017).

ENP Warm Events and Climate

ENP 1000mb Wind Speed Mar-May 1970-2019

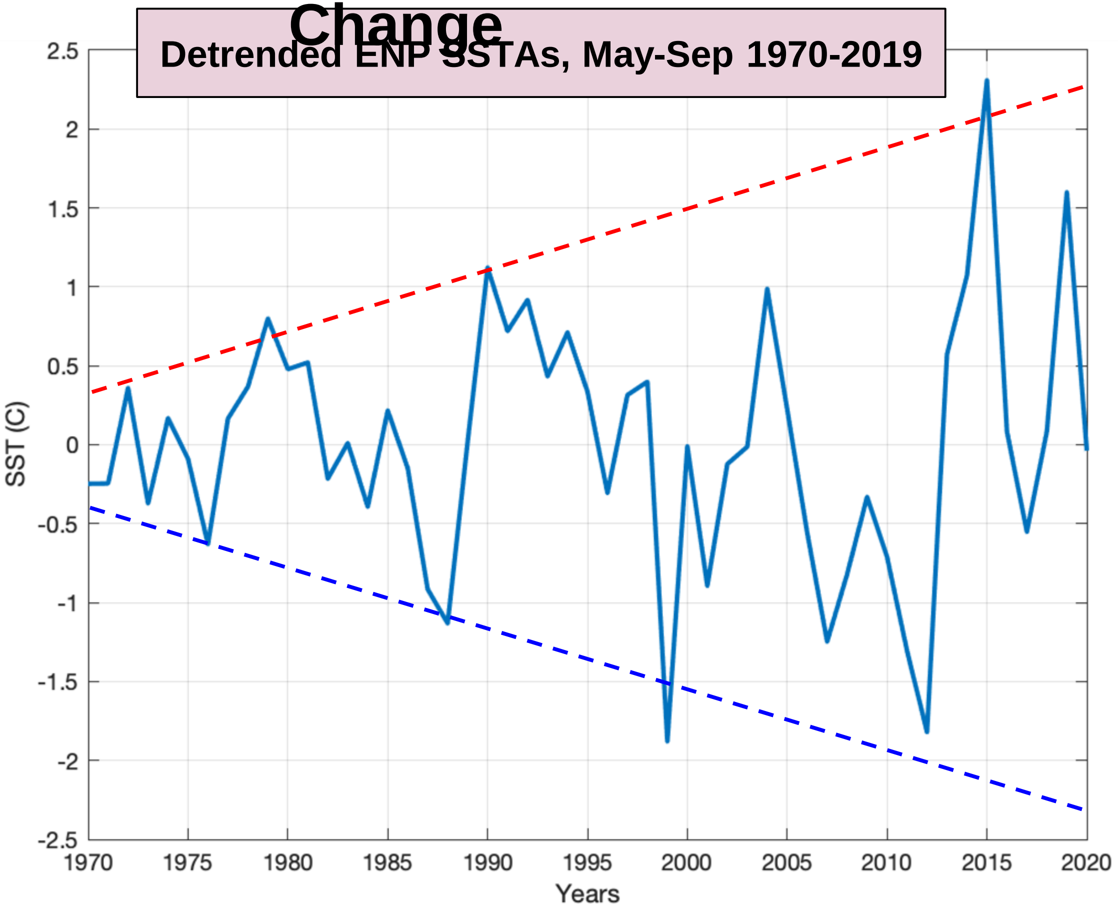


ENP SST May-Sep 1970-2019



1. Multidecadal decrease in ENP wind speeds consistent with corresponding increase in ENP SSTs
2. Reduced heat fluxes from ocean and reduced upper ocean mixing are favorable for SST increases

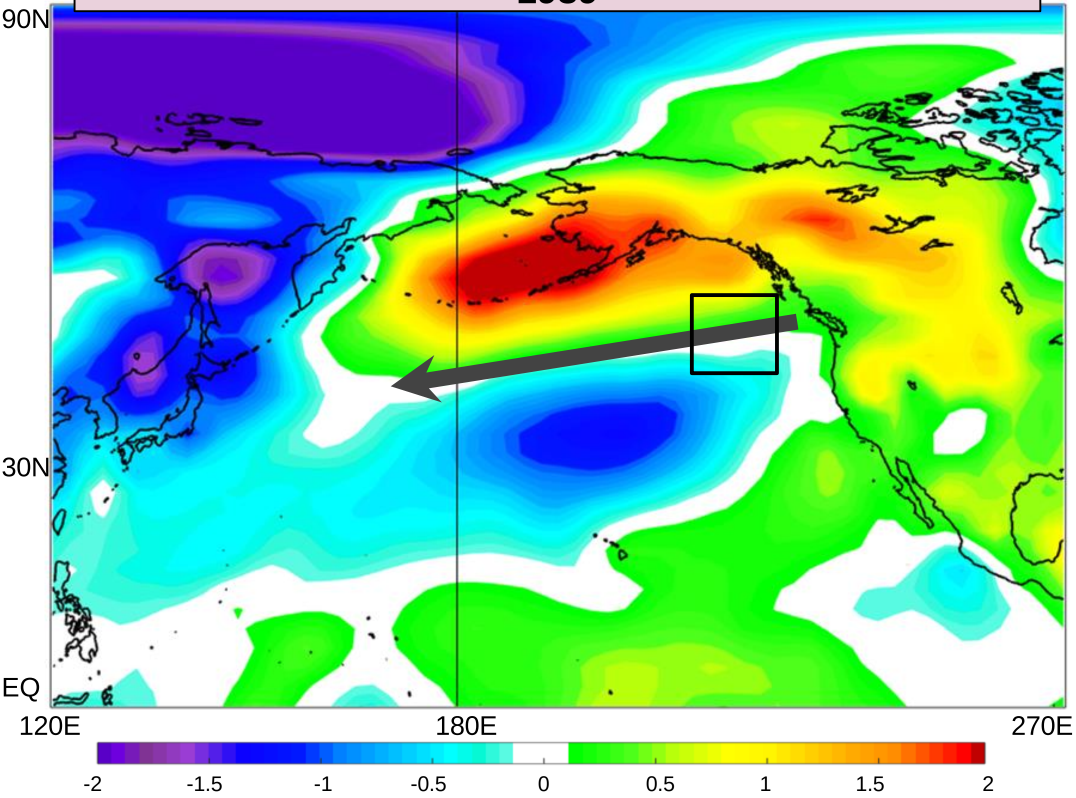
ENP Warm and Cool Events and Climate Change



1. Large interannual variability
2. Magnitude of the extremes has increased over the 50 year study period
3. Extremes are becoming more common (as with many other aspects of climate change)

ENP Warm Events and Climate

SLP Difference, Mar-May 2000-2019 minus 1970-1989



1. Spring-summer SLP in ENP has changed substantially in the last 50 years.
2. These changes have contributed to lower wind speeds in much of the ENP during spring-summer.
3. The SLP difference pattern in the Alaska-Hawaii region suggests that the spring-summer equivalent of the +NPO has become more pronounced.
4. Still to be determined: What caused the shifts in atmospheric mass that led to these SLP changes? Loss of Arctic mass, shift of Hadley-Walker Circulation, … ?

Initial Findings

1. ENP warm/cool events alternate interannually
2. Warm events are driven by an NPO-like SLPA dipole in ENP (part of global-scale anomalous wave trains)
3. ENP anomalies triggered by tropical SSTs and convective anomalies in the IO to CTP
4. Tropical-ENP teleconnections in Mar-May especially important in initiating ENP events
5. Warm events not generated by EN but may help initiate EN
6. Warm and cool events associated with opposite anomalies
7. Cool events have moderate links to LN
8. Warm events have become more extreme over the last 50 years
9. Climate change seems to have made the positive ENP SLPA dipole stronger and more common, leading to an increase in ENP SSTs and warm events over the last 50 years

Future Investigations

1. Development of ENP monitoring system (e.g., wind, SST, mixed layer depth anomalies)
2. ENP atmosphere-ocean dynamics associated with ENP events (e.g., heat/momentum fluxes, changes in upper ocean structure, ocean advection, etc.)
3. Relationships to tropical climate variations (e.g., IOD, ENLN Modoki, ENLN)
4. Predictability of ENP events using tropical SST predictors
5. ENP SLPA dipole connections to NPO and multidecadal change mechanisms
6. Relevance of ENP event mechanisms to neighboring regions (e.g., North America)
7. Applicability of our methods and results to MHWs in other regions

Acknowledgements

We'd like to thank:

1. Access to R1 data and analysis tools provided by the NOAA-ESRL Physical Sciences Laboratory, Boulder Colorado from their web site at https://psl.noaa.gov/
2. Kellen Jones, LCDR, USN, Naval Postgraduate School
3. Fellow interns

Supplemental Slides

ENP Box Top/Bottom Years and SST Values

AN Years (Warm)	SST	BN Years (Cool)	SST
1993	*13.347*	1999	*11.417*
1981	*13.195*	2012	*11.87*
1986	*13.292*	2008	*11.94*
2004	*13.609*	2011	*12.085*
2013	*13.79*	2001	*11.956*
1994	*13.482*	2007	*12.085*
1997	*13.538*	1988	*11.936*
2005	*13.69*	1976	*11.827*
2016	*13.914*	2006	*12.481*
1992	*13.54*	2000	*12.479*
1979	*13.465*	1971	*12.013*
1990	*13.788*	2010	*12.727*
2019	*14.471*	1987	*12.339*
2014	*14.662*	2017	*12.887*
2015	*14.936*	1982	*12.39*

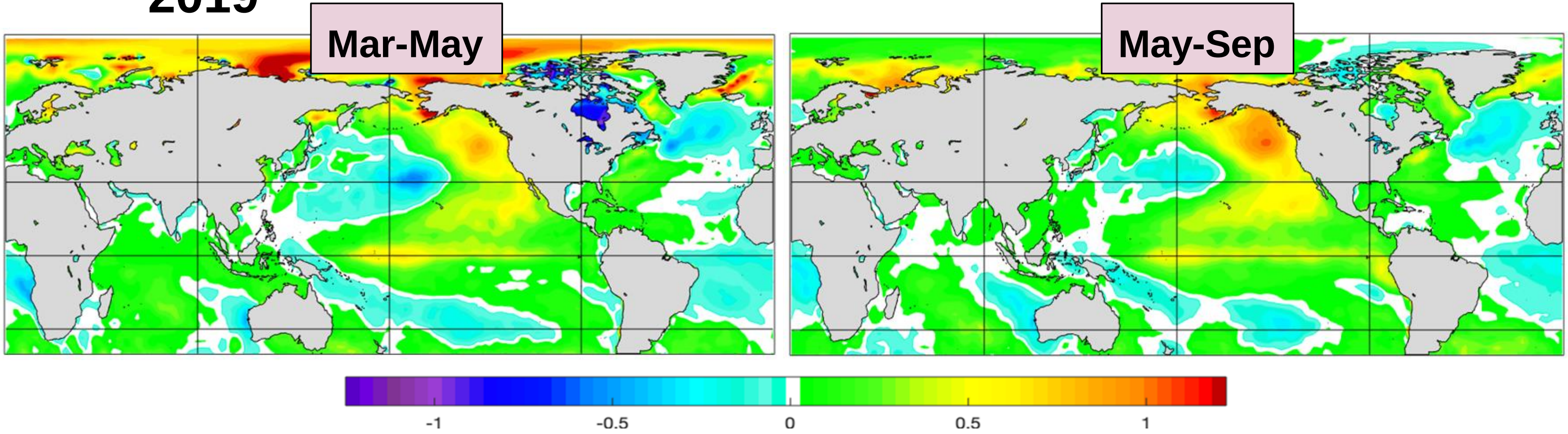
Coldest years to Warmest years

How common are the AN/BN becoming?

BN in first 20 years
33%
AN in first 20 years
20%

BN in recent 20 years 60%
AN in recent 20 years 47%

Global SSTA Composites for Warm Events 1970-2019

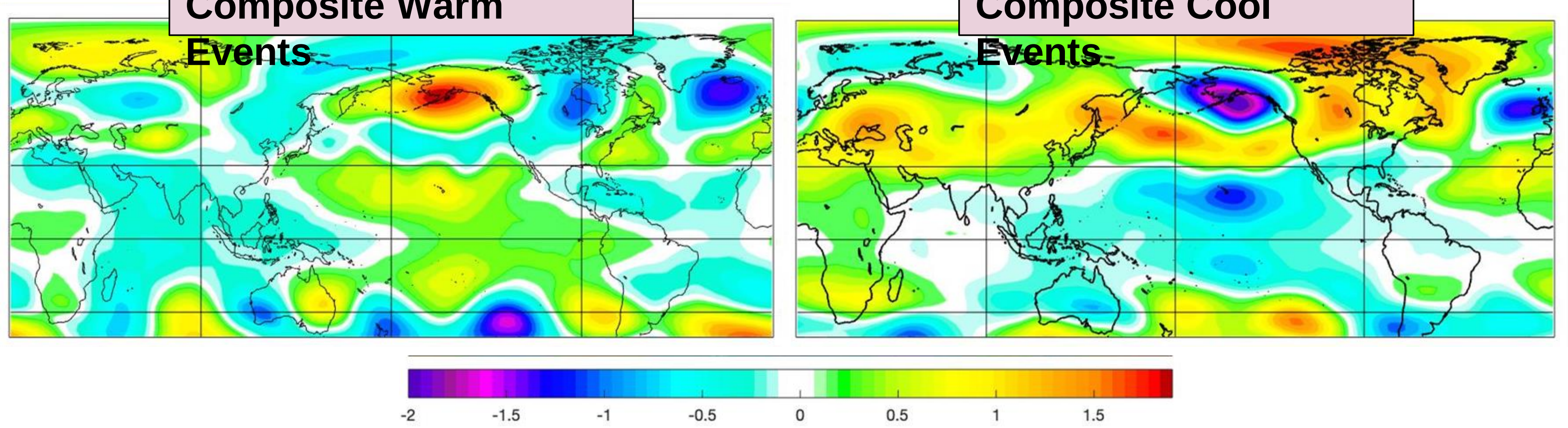


1. ENP is representative of almost all of Eastern North Pacific
2. ENP anomalies part of a larger pattern that extends into the tropics
3. SSTAs resemble EN patterns for warm events.
4. However, ENLN do not appear to be major drivers of ENP warm events

Eddy ZA200 for Warm and Cool Events, May-Sep 1970-2019

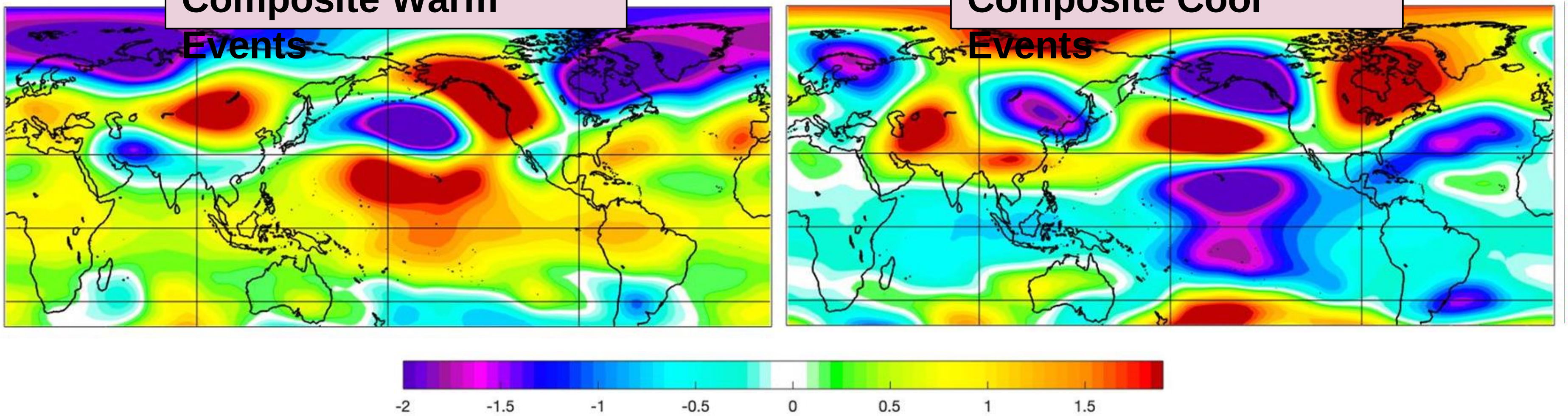
Composite Warm Events

Composite Cool Events



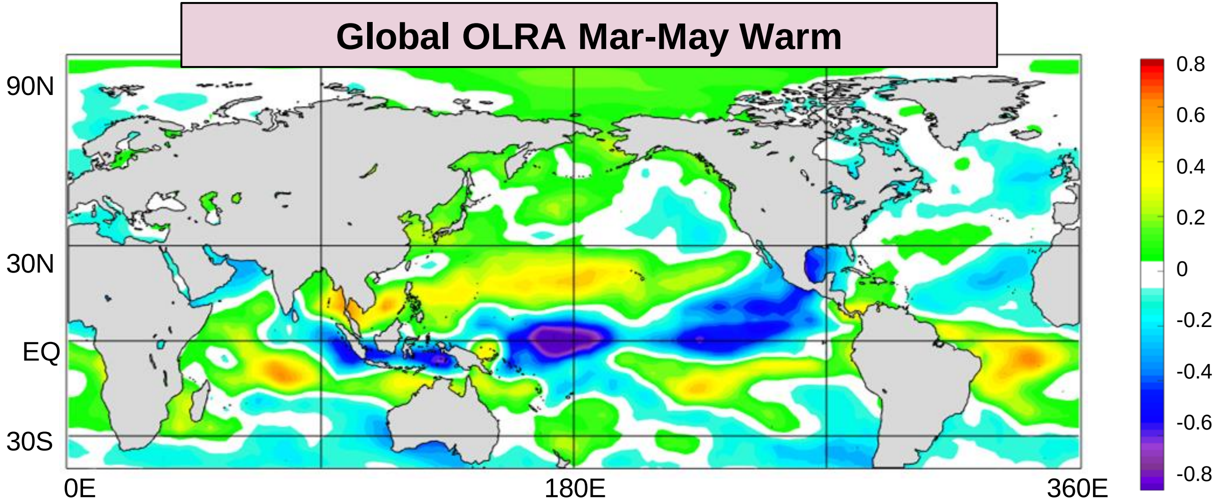
1. Roughly opposite anomaly patterns between warm and cool events. Examples:
   a. Dipole over ENP
   b. Convection anomalies in tropical Pacific
2. Zonal and arching wave trains apparent in both warm and cool events

Eddy ZA200 for Warm and Cool Events, Mar-May 1970-201



1. Stronger anomalies Mar-May
2. Roughly opposite anomaly patterns between warm and cool events. Examples:
   a. Dipole over ENP
   b. Convection anomalies in tropical Pacific
3. Zonal and arching wave trains apparent in both warm and cool events

Global OLRA in Prior Mar-May 1970-2019



1. Anomalous enhanced convection in CTP and EIO in Mar-May
2. Anomalous reduced convection in MC in Mar-May

Global SST Mar-May Correlated with ENP SST Jul

1. MC correlations get stronger at larger lead times
2. EIO/CTP correlations strongest at shorter lead times