Modeling of California Current Ecosystem's Response to Climate Change

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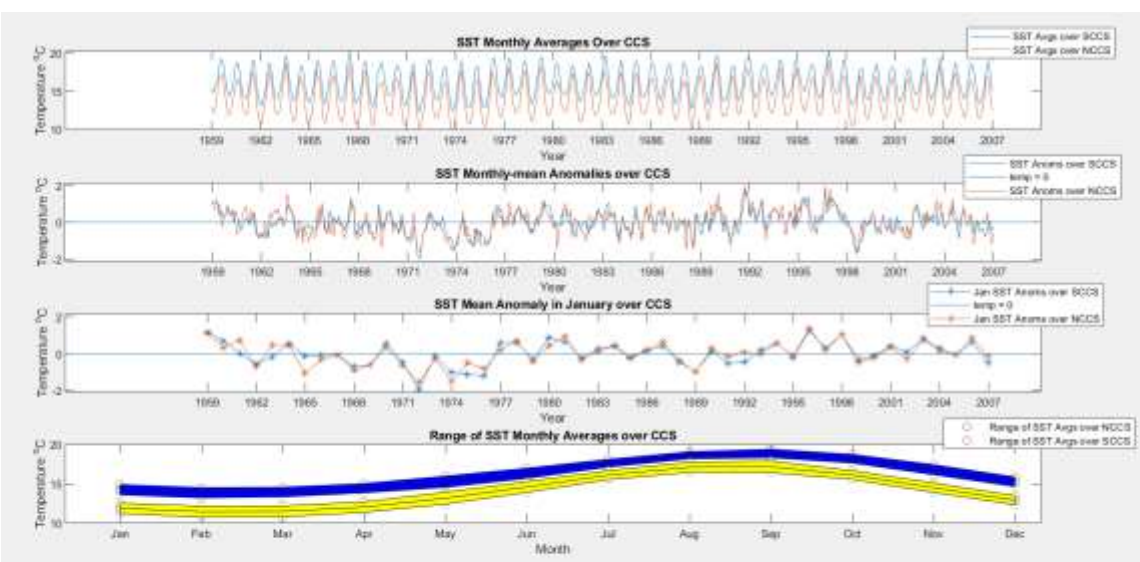
The California Current System (CCS) is a highly biologically productive oceanic region along the west coast of U.S, spanning from Baja California, Mexico, to Oregon and Washington (ref?). The CCS is under the influence of climate events such as El Niño-Southern Oscillation (ENSO) that imprints changes in the sea surface temperature (SST) and the wind pattern along the U.S west coast through atmospheric and oceanic teleconnections (e.g., Schwing *et al.*,2005). This physical variability also drives local changes in the biology of the California Current Ecosystem, and the interplay between them results in a response to ENSO that can be characterized and potentially predicted (Di Lorenzo and Miller, 2017).

My project focuses on studying how these physical and biological variables of the CCS interact and respond to the effects of ENSO. The analysis of 50-years (1958-2007) of data from a simulation using the Regional Ocean Modeling System (ROMS) coupled to the ecosystem model North Pacific Ecosystem Model for Understanding Regional Oceanography (NEMURO) is conducted. ROMS-NEMURO model consists of different physical variables such as temperature, ocean velocities and density in a 3-D grid with latitude, longitude at a 7 km resolution, and 50 vertical levels. The ecosystem component (NEMURO) represents 2 classes of nutrient concentration, 2 groups of phytoplankton, 3 groups of zooplankton, and two detrital pools.

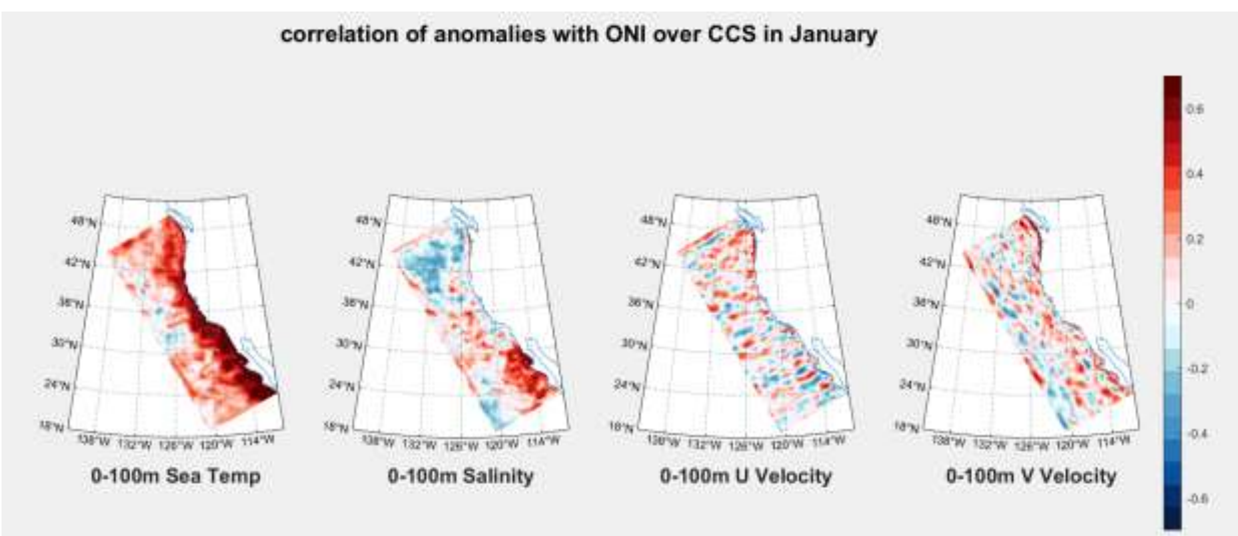
I use MATLAB, a programming tool, to vertically average physical and biological variables over the top 100 meters of the water column for the entire time series. Since there are lower amounts of nitrate and silicate in the top 25 meters of the water column due to the high density of marine organisms consuming them, they are averaged between the top 25 meters and 100 meters. MATLAB is also used to calculate monthly-mean anomalies by subtracting 12-month climatology from entire time series. Moreover, I apply Lanczos high-pass filter that filter out time scales of 10 years to eliminate decadal variability from the model fields and the observations.

After computing monthly averages and monthly-mean anomalies of variables, I create time series plots of these statistics of all variables to present their trend over two onshore regions, one spanning from southern Oregon to Marin County and the other one spanning from Monterey to Northern San Diego. These plots help me compare statistics in North CCS with those in South CCS and detect variability of data in any certain year. In the time-series plots of Sea Surface Temperature (SST) of CCS shown below, monthly averages of SST in Southern CCS are always larger than those in Northern CCS, which matches the expectation that sea surface temperature in the northern region is always lower than that in the southern region due to the southern region's lower latitude. Since SST's anomalies in the two regions vary without pattern, I take a closer look at the anomaly specifically in January for the entire time series. I find that their values deviate most from the monthly mean in January 1972.

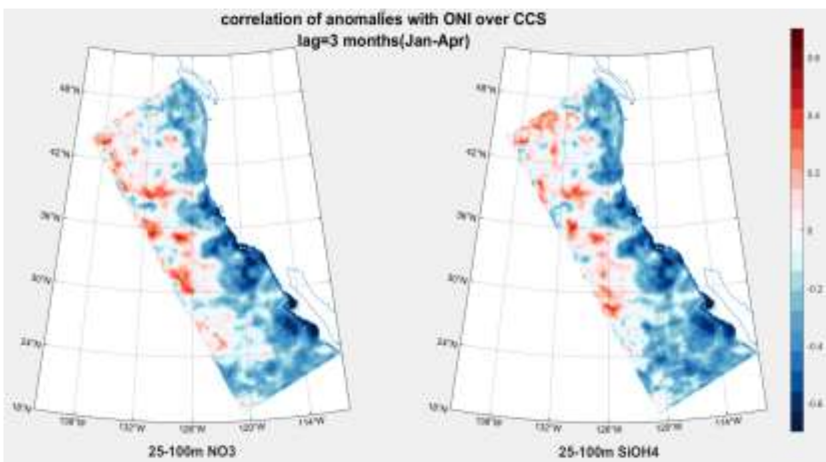


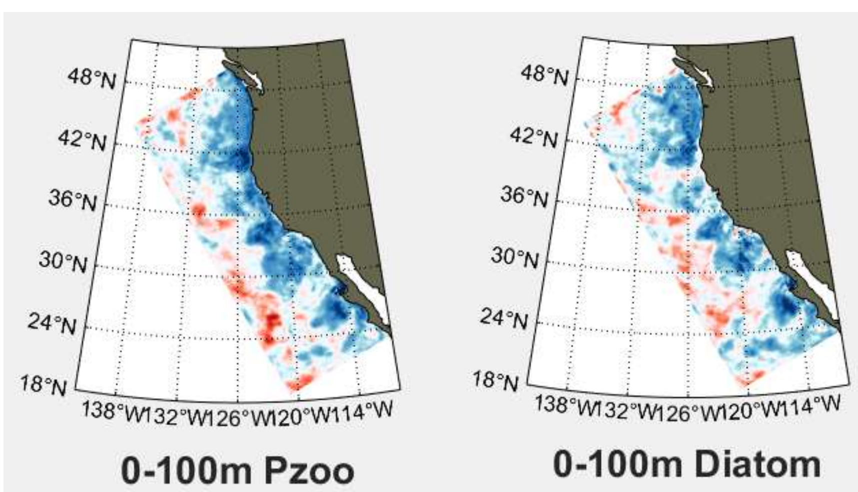
To establish relationships between the CCS and ENSO, I correlate monthly anomalies of physical and biogeochemical fields from ROMS-NEMURO at different time lags with the Oceanic Niño Index (ONI), a leading indicator of anomalous warming or cooling conditions over the El Niño 3.4 region in the Tropical Pacific (5^{o}N-5^{o}S, 120^{o}-170^{o}W). These correlations shed light on the timing in which different physical and biological variables of the CCS respond to ENSO events, and help to identify relationships physics and biogeochemistry.

For physical variables, I create unlagged correlation plots by correlating physical fields in the model in January with ONI data in January. Vertically averaged water temperature over the top 100 meters shows stronger correlation with ONI near Baja California and California coast and shows weaker correlation near Oregon and offshore areas. Salinity reveals stronger correlation with ONI near South CCS than North CCS. Since I average zonal and meridional velocities of currents over the top 100 meters, but currents do not have such large vertical distances, correlation maps of current velocities exhibit a lot of noise. However, zonal velocity still exhibits slightly stronger correlation with ONI in the North CCS.



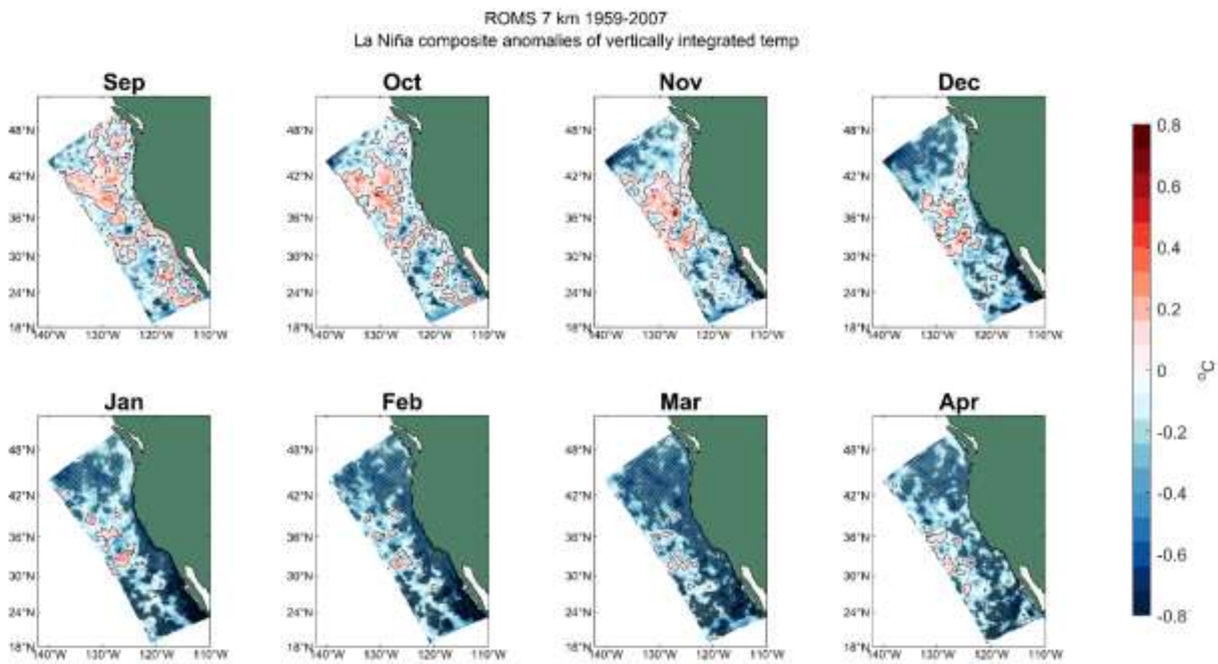
Since biological and nutrient variables are still developing in early spring, I use the 3-month lag and correlate them with ONI from the peak of El Niño in January to April, before plankton bloom. Correlation maps of nitrate and silicate show similar results in that they exhibit a stronger negative correlation with ONI, indicating lower concentrations of them along California Coast and Baja California. This is the same case for predator zooplankton and diatoms. This might be due to nitrate and silicate being important food sources for diatoms and zooplankton. They are consumed by microorganisms near the coast, resulting in a low concentration of nutrients along the shore and their abundance offshore.

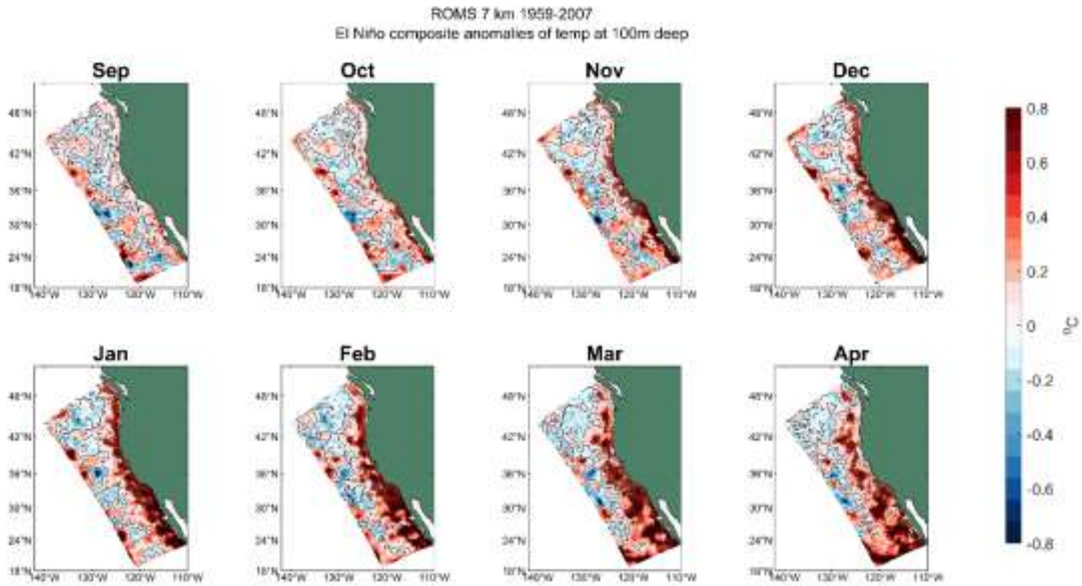




In order to understand the response of the CCS to ENSO, I construct composites of the physical and biogeochemical variables from the ROMS-NEMURO by averaging anomalies in El Niño and La Niña events identified in the period of the simulation. I identify El Niño and La Niña events as follows: “model composites focus on 3 months before the wintertime peak of the event (Sep-Nov) and 8 months after the peak of the event (Jan-Aug). The years identified as El Niño and La Niña follow the ONI of the NOAA protocol (https://origin.cpc.ncep.noaa.gov/products/analysis_monitoring/ensostuff/ONI_v5.php) but only include the moderate-to-strong events and exclude the weak events. In brief, we identify El Niño years as those when Niño-3.4 3-month averaged SSTa $\geqslant$1.0 °C and La Niña years as those when SSTa $\leqslant$-1.0 °C, where the anomalies persist during both the fall (SON) and winter (DJF) seasons” (Cordero-Quirós *et al.*, 2019). The identified El Niño years are 1963–1964, 1965–1966, 1968–1969, 1972–1973, 1982–1983, 1986– 1987, 1987–1988, 1991–1992, 1994–1995, 1997–1998, and 2002–2003. The identified La Niña years are 1970–1971, 1971–1972, 1973–1974, 1975– 1976, 1983–1984, 1984–1985, 1988–1989, 1995–1996, 1998–1999, and 1999–2000. To highlight significant anomalies, I randomly pick 100 years and compute their composites. After comparing those randomly computed composites to composites of El Niño and La Niña identified, I mark anomalies that are greater than 2 standard deviations of randomly computed ones as statistically significant.

The composites development of vertically averaged water temperature over the top 100 meters during La Niña is shown below. Negative anomalies show that the cold phase along Baja California begins in November of the pre-peak year, but anomalies, which are not statistically significant until the water temperature reaches the lower value in January of the post-peak year, become more intense until March and subside in April. In contrast, during El Niño, water temperature starts to rise along Baja California from September of the pre-peak year. During the peak of the event and when the water temperature reaches maximum between November of the pre-peak year and February of the post-peak year, positive anomalies become statistically significant. Then, starting from March of the post-peak year, less negative anomalies signal cooler water temperature and the El Niño event fading away. By comparing El Niño composites with La Niña composites, I find that both events develop over broad regions in November of the pre-peak year, indicating symmetric response of the CCS (Fiedler and Mantua, 2017).





The results of the research described above help me to better analyze model data to characterize relationships between the model and observational data, to understand how physical and biological aspects of CCS interact and respond to ENSO, and to quantify the predictable nature of the ecosystem. This knowledge will be beneficial for long-term current ecosystem research.

Acknowledgement

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References

Nathalí Cordero-Quirós, Arthur J. Miller, Aneesh C. Subramanian, Jessica Y. Luo, and Antonietta Capotondi. 2019. Composite physical-biological El Niño and La Niña conditions in the California Current System in CESM1-POP2-BEC. Ocean Modelling 142.

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