Recent warming in the Eastern Pacific

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INTRODUCTION/OBJECTIVES

A large warm anomaly in SST, located in the Northeast Pacific, appeared Nov 2013 (Bond et al, 2014). The warm anomaly was associated with a high pressure ridge, nicknamed the 'Ridiculously Resilient Ridge' (RRR), in the atmosphere that prevented normal winter storms from reaching the west coast which resulted in drought conditions across the entire west coast. The warm anomaly was attributed to the effects of this atmospheric ridge on the ocean, namely a decrease in surface fluxes (a lack of cooling) and a decrease in Ekman transport (normally bringing cooler water from the North to the South) by Bond et al., 2014.

In 2014-2015, the RRR shifted southward and towards the West Coast and the warm SST anomaly moved from the Gulf of Alaska to along the West Coast {Leising, 2016}. {Zaba, 2016} reported SST anomalies of 5 K off Santa Barbara, confined to the upper 50 m. Analysis of the Bakun upwelling index {Leising, 2016} indicated that in 2014, the upwelling-favorable winds were mostly normal, but with stronger winds 36-42N in June and higher spring Chlorophyll-a from 38-42N. In 2015, the upwelling-favorable winds were stronger than average in 2015 north of 33N and weaker than average south of 35N. There was an early spring transition to upwelling favorable winds, with high Spring Chlorophyll-a north of 35N and low Chlorophyll-a in July. This is the first report of anomalies in oceanic upwelling in 2014 and 2015 based on changes in SST, from a high temporal and spatial multi-satellite analysis and relates these changes to anomalies in wind induced upwelling.

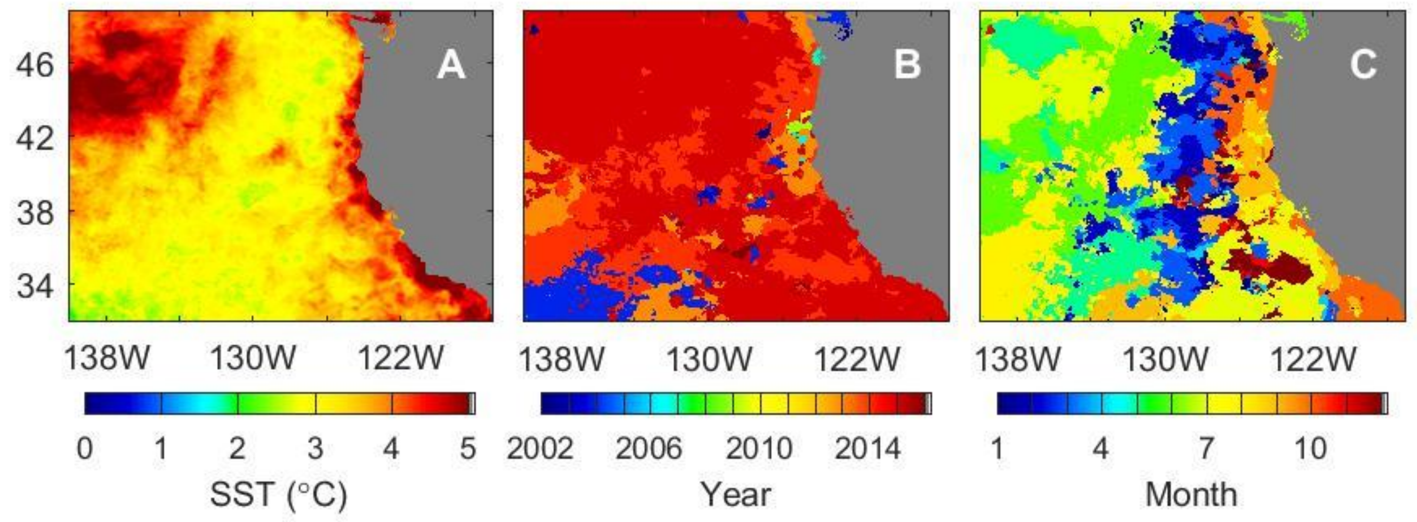
Objectives:
Examine how the warm anomaly impacted upwelling, coastal temperatures, and sea life.

DATA

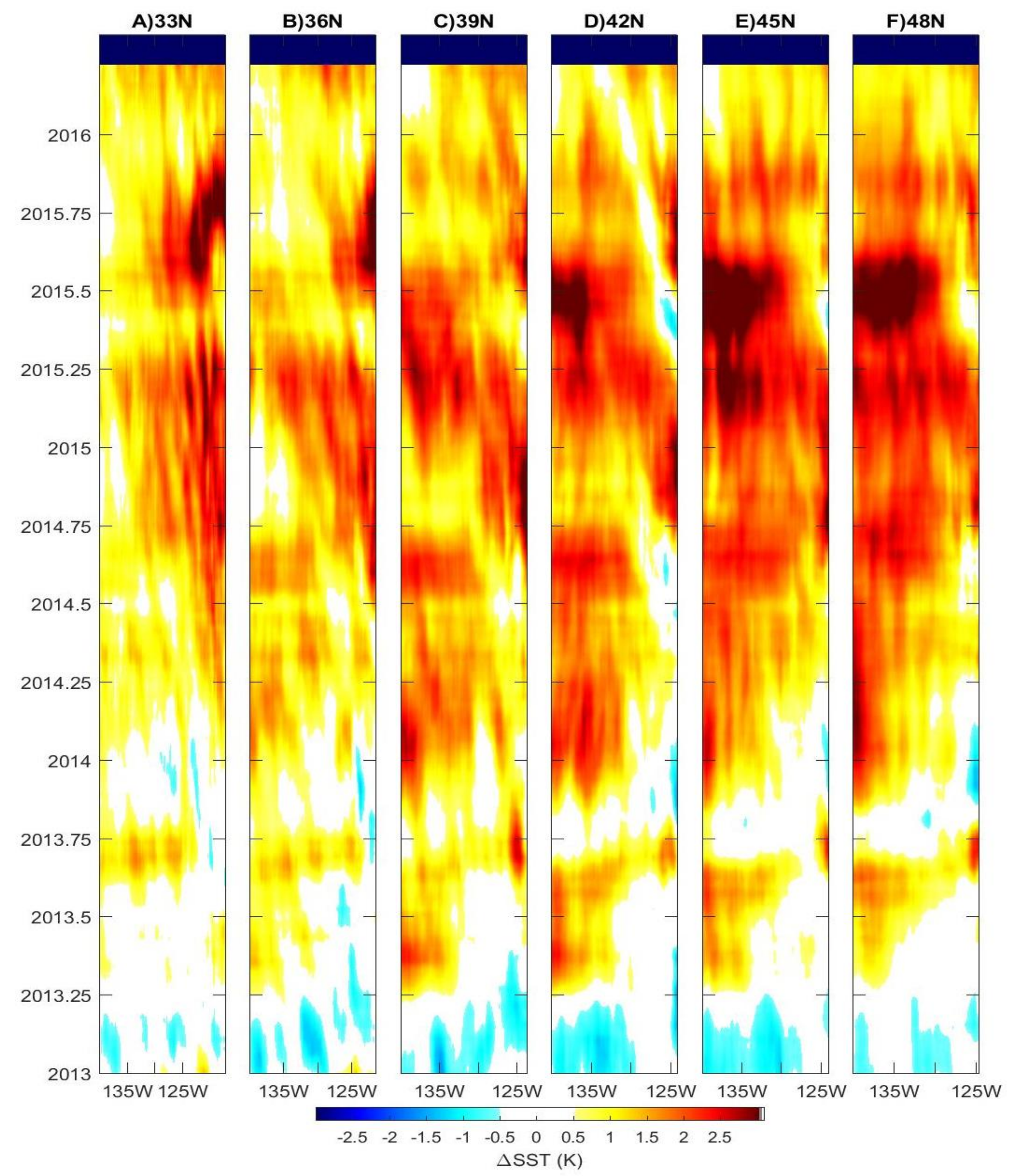
MUR SST
NASA's JPL produces the global, daily, 1km, Multi-scale, motion-compensated analysis of SST (MUR SST) version 4.0 (Chin et al, 2010). This high temporal and spatial resolution analysis of satellite SSTs has proven useful for research into coastal upwelling (Vazquez et al., 2013). 5-day averages were used to create a climatology using data from 2002 - 2012. 5-day, monthly, and 3 monthly SST anomalies were then calculated by subtracting the climatology at each point from the SSTs.

CCMP-Winds
The RSS Cross-Calibrated Multi-Platform wind speeds are global 25km winds produced using multiple passive and active microwave retrievals of wind speed and direction.

CHANGES IN SST



The maximum 5-day SST for the West Coast, June 2002 - April 2016 are shown in Figure 1. The maximum anomaly of 6.2 K occurred on 14 September 2015, just off of Santa Barbara (Fig. 1A). In this region, 3.% of the anomalies were greater than 5K, 25% were greater than 4 K, and 78% were greater than 3K. There is an offshore maximum SST, at approximately 138W and 44N, in May - July 2015 (Fig., upper left of each panel). The maximum SST anomaly is smallest through a corridor offshore at ~130W, where the maximum anomaly occurred in February and March of 2015 (Fig: yellow in A, dark blue in C). Along the coast, the maximum anomalies occurred in 2013 along Oregon, 2014 along Washington, and 2015 in the Southern California Bight and near San Francisco,. Along the coast, regardless of year, the maximum anomalies occurred in August - October. This figure indicates there are two different mechanisms at work: the offshore maximum, 'the Blob', is separated from the onshore maxima, and the coastal anomalies were not simply caused by the offshore maximum being advected onshore.



SST shows record warming along the coast for different latitudes, but also some strong upwelling events that are able to break through the warm surface water and return the SSTs to near normal or below normal (Figure 2). Winter SSTs affect the type of phytoplankton that are the base of the food chain, for example macrozooplankton have been shown to decrease in warmer waters {McGowan, 1998}. So how have the SSTs and upwelling phenology changed along the West Coast during this event?

ACKNOWLEDGEMENTS

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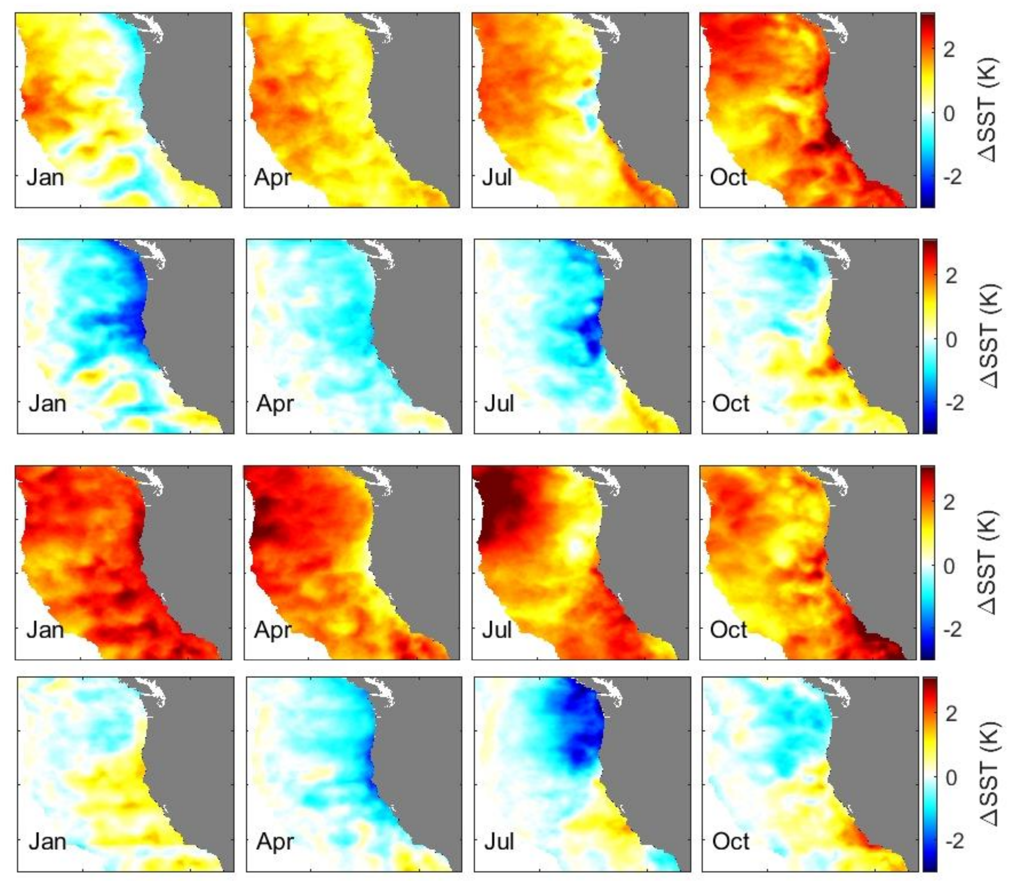
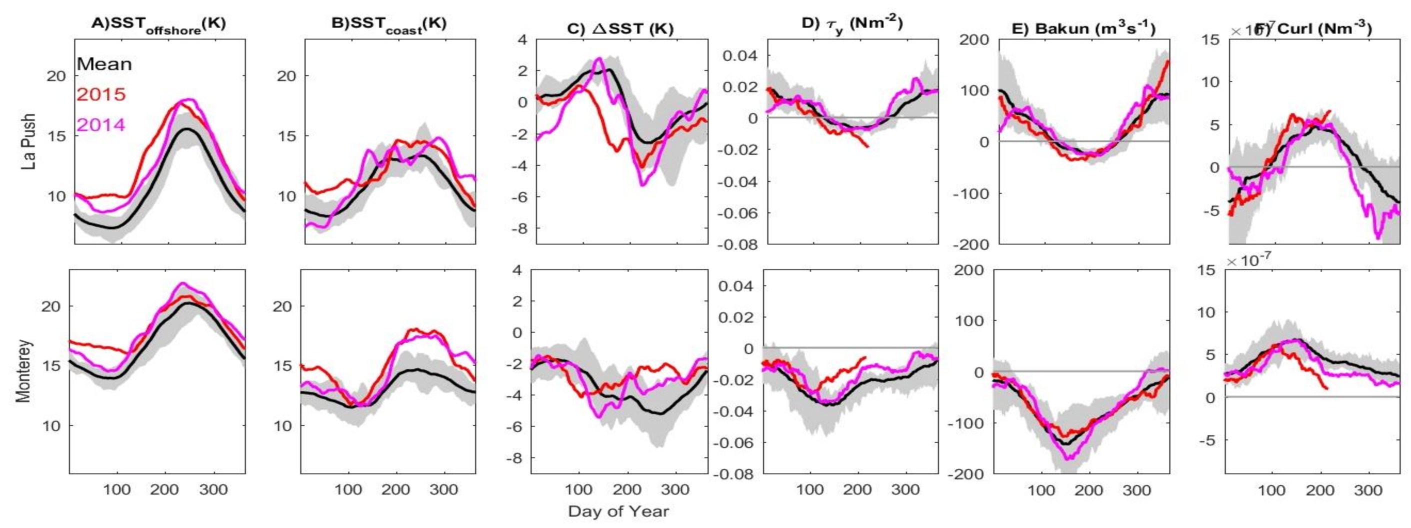
COASTAL WARMING/UPWELLING



Three month average anomalies of MUR SSTs in 2014. a) SST anomaly, b) SST gradient from off to onshore (SST anomaly minus offshore SSTs. There is a clear difference in upwelling North of Cape Mendocino where upwelling was always neutral to stronger than climatological upwelling, and South of Cape Mendocino. North of Cape Mendocino, where there was neutral to weaker upwelling. In 2014, the Northern area was stronger in Jan-April, when there normal is no seasonal upwelling, while in 2015 it was weaker May-Aug, the normal peak in seasonal upwelling. The Southern region has weaker upwelling July-Dec in 2014 and July-October in 2015. Much of this area has year-round upwelling, weakest in strength and smallest in extent in March each year, peaking in magnitude and extent July-October.



This figure shows the A) SST offshore (1000km), B) at the coast, and C) the difference (offshore minus onshore), D) alongshore wind stress, E) the Bakun index and F) wind curl. The alongshore wind stress was calculated from CCMP wind vectors rotated along the coast direction at each location (Dorman and Winant, 1995). Column A, the offshore SST, shows that by 2014, the offshore SSTs were already warmer than normal and remained so through 2015. In 2014, SSTs still experienced some cooling in the Winter, by in 2015, there was no offshore cooling of SSTs in the Winter. At the coast, from Bodega Bay to the North, temperatures exceeded the average after Feb. 2014. South of Bodega Bay, temperatures were already exceeding the average at the start of 2014, but for all locations, the Winter coastal SSTs returned to their average values just for a short period each Winter when the offshore Ekman transport was at it's maximum (alongshore stress negative maximum). As the wind stress (Ekman transport) decreased, the temperatures quickly returned to the anomalously warm values. The warming along the coast was compounded by weak alongshore winds and lower than normal wind curl. The Bakun index is commonly used as a measure of upwelling, but Figure 5E shows that it is clearly different that the alongshore wind stress during crucial periods for monitoring upwelling.

Conclusions

In 2014-2015, SSTs in the region along Oregon, Washington, and California coast were significantly warmer than usual with a maximum anomaly of 6.2 K measured near Santa Barbara, an unprecedented magnitude in the historical record, leading to an unparalleled toxic algae bloom of *Pseudo-nitzschia* which caused a delay of the commercial crab season among other economic and ecological effects. Using wind stress instead of the Bakun index shows clear differences in upwelling characteristics, especially in 2015. Changes in SST and winter upwelling phenology in this region are strongly related to changes in spring health of marine species and seabird populations which have evolved to capitalize on the upwelling driven peak in primary productivity, while changes in summer upwelling phenology have bottom-up effects on harmful algal blooms and fisheries in the California Current Upwelling System (CCUS).