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Contributor Abstracts

Analysis of anomalous oceanic conditions along the US West Coast in 2014 using a high resolution regional ocean model

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ABSTRACT
The West Coast Operational (Ocean) Forecast System (WCOFS) is being developed at NOAA, in partnership with Oregon State University. The model has 2-km horizontal resolution and is based on the Regional Ocean Modeling System (ROMS). The model domain extends from 24 to 55N in the alongshore direction and about 700-1000 km in the offshore direction. Boundary conditions are obtained from the Navy global HYCOM model, which assimilates altimetry, SST, and ARGO temperature and salinity profiles. Surface forcing fields are provided by the 12-km resolution NOAA North American Model (NAM). As part of initial model skill assessment, the long simulation has been run without data assimilation, for the period of October 2008-December 2014. The model result is verified against available high-frequency (HF) radar surface velocity, satellite SST, glider temperature and salinity transects, mooring temperature time series, and tide gauge sea level data, and show effects associated with anomalous conditions in 2014 (including weaker winter downwelling and warmer summer). Events of the anomalous 2014 are contrasted with the earlier years. In particular, due to the weaker winter 2013-14 winds, surface Lagrangian particles released across the path of the North Pacific Current (separating the subtropical and subarctic gyres) avoid the area adjacent to the Oregon and Washington shelf. Volume-averaged heat balance analyses over the Oregon shelf volume (41-46N, inshore of 200 m isobath) suggest that relatively warm conditions found in summer-fall 2014 are due to both increased atmospheric heat flux and weaker oceanic advective cooling through the sides of the control volume. Similar analyses for Central California and Southern California coastal volumes suggest that the warm anomaly is predominantly due to the oceanic advection (anomalously weak cooling across the side boundaries of the control volume). Properties of the undercurrent and coastal trapped waves are studied by sampling fields on the 26.5 kg/m3 isopycnal surface. The global HYCOM model, constrained by data assimilation, shows variability in near-coast SSH and isopycnal surface placement associated with the seasonal cycle and El Nino. Improvements in the formulation of boundary conditions are needed to properly translate this variability into the WCOFS domain.

Nesting of two seabird species on Mexican Pacific islands and its relationship with environmental anomalies

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ABSTRACT
The Mexican islands in the Pacific Ocean, off the Baja California Peninsula, are priority-nesting sites for 21 seabird species, including six endemic species. As part of an ongoing seabird restoration project, we carried out nest censuses of Brown Pelican (*Pelecanus occidentalis*) and Brandt's Cormorant (*Phalacrocorax penicillatus)* on seven island groups from 2013 to 2015. We detected massive nest abandonments by Brandt's Cormorants during the last two years and an overall decrease in the total number of active nests for both species. Monthly and yearly anomalies of sea surface temperature, air temperature, and chlorophyll were calculated for a region that includes all islands. A possible relationship between these atypical biological events and changes in environmental variables was investigated using field and satellite data.

Preliminary observations of the impact of anomalous ocean temperatures on the summer distribution of marine fish in the Gulf of Alaska and California Current

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ABSTRACT
In the fall of 2014, researchers projected a continuation of anomalously warm ocean conditions in the northeast Pacific Ocean using a new seasonal forecasting capability. Based on the results of these forecasts, the North Pacific Research Board funded a coordinated research project to examine the impacts of the unusual warming event in the northeast Pacific. This project will evaluate a unique dataset of acoustic and bottom trawl survey data that spans from the southern California Bight to the western Gulf of Alaska. An interdisciplinary multi-national research team has been assembled to conduct this research. The NPRB provided funds to supplement existing surveys with additional oceanographic measurements to enhance our ability to describe the mechanisms underlying observed shifts in spatial distributions. This paper will present the initial observations from the 2015 acoustic and bottom trawl surveys in the Gulf of Alaska and contrast them with previous years when NMFS conducted comprehensive surveys simultaneously in both the GOA and CCS (2003, 2005, 2011 and 2013). Preliminary results suggest that the sea surface temperatures in late July along the northeast Pacific were among the warmest on record and similar to 2005. The heat content was significantly warmer. Distributional responses of Pacific hake, walleye pollock, selected flatfish and rockfish to the observed warming will be presented by length category. Young gadids (smaller size) were observed in a wide range of temperatures. As they aged, they moved to deeper depths and thus a narrower temperature range, with deeper depths on average in warm years. These findings are compared to similar data from the California current.

Biological Response to the Warm Blob of 2013-2015 on phytoplankton, harmful algal blooms, zooplankton, Pacific Salmon and other pelagic fish in the northern California Current

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ABSTRACT
The Gulf of Alaska (GOA) became anomalously warm in autumn/winter 2013-14 due to a lack of cyclonic storms that usually mix (and subsequently cool) the water column. By spring/summer 2014 SST anomalies of +4.5°C were seen in the GOA, Bering Sea and the North Pacific, warmer by 1.5°C than historical data. The Blob began to shift eastward in June 2014 but over the northern California Current (NCC), northerly winds and offshore Ekman transport kept this warm water mass offshore of the coastal upwelling zone. However, on 14 September 2014, northerly winds weakened and the Blob moved shoreward raising SST by 6°C within a five hour period to 19.4°C, flooding the continental shelf off Newport Oregon with water 4°C above climatology to a depth of 30 m; by November the Blob occupied the upper 80 m of the water column. Analysis of our 20+ year time series of biweekly measurements of hydrography and abundance of planktonic species in shelf and slope waters of the NCC revealed that the Blob brought to the NCC 15-20 species of copepods that were either new records for the NCC shelf/slope or known to occur only in waters far offshore of Oregon or during big El Niño events (1983, 1998). Many of these copepod species had North Pacific Gyre and/or North Pacific Transition Zone affinities indicating that the warm "Blob" was not just an expression of local heating rather the source was from far offshore and from the south. "Warm water" phytoplankton and fish species were noted as well. Effects on fish and fisheries became clear immediately – sardines shifted northward > 1000 km and spawned off Oregon in March 2015 and were fished commercially, six months earlier than 'normal'. Fishermen and oceanographers noted the presence of warm-water reptiles and vertebrates 1000s of km north of their normal range, including sea snakes green turtles, moonfish (opah), ocean sunfish, pomfret, pompano, mackerels, tunas and sharks as well as tropical seabirds. Locally, sockeye and summer-run Chinook salmon migrating back to the Columbia River in summer of 2015 experienced high mortality because river waters were anomalously warm water as a result of a drought and subsequent low flows. Given the prognosis for another warm year in 2016 due to an El Niño event, we hypothesize that a major environmental disaster is looming. The Blob and El Niño's provide natural experiment and a metaphorical window through which one can observe the impacts of a future warmer ocean on the pelagic ecosystem and associated fisheries of the California Current, due to with global warming and climate change. Given that global climate models are unable to anticipate "warm events" such as the Blob or major El Nino events, it behooves us maintain existing marine observation programs and begin others so that ecosystem impacts can be more closely tracked.

Waiting for the blob: marine growth of juvenile coho salmon in the Northern California Current, 2000 – 2014

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ABSTRACT
Marine growth of juvenile coho salmon has been measured in the NWFSC, NMFS June juvenile salmon survey (US – Canada border, 48ºN to Newport, OR, 44.5ºN) from 2000 – 2014. Growth has been assessed by measuring levels of the hormone insulin-like growth factor 1 (IGF1), from plasma samples obtained during these surveys. Plasma IGF1 levels measured in June of 2014 were among the highest measured in the time series (2000 – 2014), suggesting that prey for juvenile coho salmon were abundant during the early summer in 2014 in the Northern California Current. Similar measures of coho salmon growth have been obtained in the SWFSC, NMFS survey of the Central California Current (Newport, OR, 44.5ºN to San Francisco, CA, 37.6ºN), 2010 – 2014, and from the AFSC, NMFS survey of the SE Gulf of Alaska (Cross Sound, 58.25ºN to Sitka, AK, 57ºN), 2010, 2012 and 2014. In each case, growth of juvenile coho salmon in 2014 was among the highest measured in each time series, suggesting high abundance of juvenile salmon food in the early summer (June – July) in coastal ecosystems of the Northeast Pacific. Data from physical oceanographic observations suggest that the blob did not impinge on coastal waters until later in 2014 (autumn), helping us to understand the temporal scale of interactions between the blob and coastal marine ecosystems. Returns of Columbia River coho salmon in 2015 were 30% of the 10 year average and the lowest since 1997, suggesting that the blob may have impacted overall survival of salmon populations at sea 2014 – 2015. Samples from 2015 surveys are now being processed and may be available by the time this poster is printed (January 2016).

Did the east-pacific temperature anomaly change recent water quality trends in the urban fjord, Puget Sound

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ABSTRACT
Long-term monitoring data collected by the Washington Department of Ecology show that nutrient concentrations have significantly increased and that nutrient ratios and phytoplankton biomass have steadily changed in Puget Sound. Some biochemical markers that could be interpreted as a result of human impacts, have approached critical turning points with implications for the cycling of energy and material. At the end of 2014, a large temperature anomaly originating in the Pacific Ocean brought very warm water into Puget Sound, which extended throughout the water column and surpasses marine water temperature records. Coinciding with the warm water condition, 2015 is also remarkable for expected drought conditions in summer. Typically, Puget Sound has been considered a diatom-dominated cold-water ecosystem system. Since phytoplankton species will likely respond to warmer water, differences in the physical structure of the water column, and a different nutrient balance, recent conditions are potential future scenarios for changing climatic conditions. High ammonium concentration and high jellyfish abundances coincided with the appearance of warmer water during the mild winter of 2014-2015 setting the stage for the unprecedented conditions in 2015. Evolving conditions will be presented and discussed in context of existing long-term trends in water quality, nutrient balances and phytoplankton biomass.

Persistent record-high temperatures in the North Pacific in 2014/2015: a climate hypothesis

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ABSTRACT
The 2014-15 warm “blob” in the northeast Pacific Ocean has featured record-high sea surface temperature anomalies (> 3°C). It developed during the winter of 2013/2014 in the Gulf of Alaska and later spread along the North American coast in the following fall, winter and spring of 2014/15. Northeast Pacific SST anomalies resembled the patterns of the North Pacific Gyre Oscillation (NPGO) in 2014 and of the Pacific Decadal Oscillation (PDO) early in 2015. We suggest that the generation, persistence, and spatial evolution of the warm anomalies over the winters of 2013/14 and 2014/15 was driven by large-scale climate teleconnections between the tropics and extra-tropics that are typical of El Niño precursor dynamics. More specifically, we show that the strong atmospheric ridge that forced the warm “blob” is linked to the activity of the North Pacific Oscillation (NPO), a well know pattern of atmospheric variability that acts as a stochastic driver for ENSO. Following a strong extra-tropical NPO forcing during winter/spring, tropical El Niño conditions typically develop in the summer. Continued El Niño conditions in the subsequent fall and winter typically excite atmospheric teleconnections to the Aleutian Low (AL) that that carry the signal back to the North Pacific Ocean in ways that favor the positive phase of the Pacific Decadal Oscillation (PDO). This teleconnection dynamic from extra-tropics to tropics (winter year 0) to extra-tropics (winter year +1) is a source of significant interannual persistence of North Pacific SST anomalies as they evolve from an NPO-like (e.g. NPGO) to an AL-like pattern (e.g. PDO). Even though a strong tropical El Niño did not develop during the fall/winter of 2014/2015, we show that this tropical/extra-tropical coupling played an important role in the generation, persistence and evolution of the 2014/2015 warm “blob”. Given that previous studies suggest that greenhouse forcing will energize the NPO precursor dynamics, it is important to establish if the 2014/2015 temperature extreme, and its widespread marine ecosystem impacts, will become more frequent under increasing anthropogenic climate change.

Responses of copepod and euphausiid communities off northern California to warm anomalies of 2014-2015

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ABSTRACT
Several metrics of the zooplankton community off northern California showed strong, persistent shifts in conjunction with relatively warm conditions during the summer of 2014 that culminated in the arrival of 'warm blob' waters in late 2014. The copepod community exhibited an unusually early departure from the normal seasonal pattern of summer dominance by northern taxa, as upwelling weakened and mid-shelf bottom waters began to warm and freshen during the summer, leading up to a dramatic shift to a community dominated by southern and oceanic species in Fall 2014 with the arrival of 'blob' waters. This pattern has persisted through Spring and Summer 2015, and is reflected in negative biomass anomalies of northern species (especially northern neritic species), and positive anomalies in the biomass of southern species. Species richness also increased substantially in response to warming, enhanced in part by several species of southern or offshore copepods that have been observed for the first time in the Trinidad Head Line record. Responses of the euphausiid community to the 2014 warming event also included shifts in species composition and community structure. Adult and larval stages of the sub-tropical krill *Euphausia recurva* (previously unobserved in our samples) were observed at low densities from January until March 2015. Concurrently, biomass of *T. spinifera* declined and remained low through summer 2015. This shift in the euphausiid community was partly countered by high densities of *E. pacifica* and increased abundance of immature *E. pacifica* and *N. difficilis*. Concurrent with increased abundance of these species, however, individuals' size showed marked and persistent declines relative to past years, suggesting poorer growth conditions for euphauisiids off northern California during this period. These observations suggest a variety of responses to the warming event, ranging from patterns dominated by transport and changes in water masses off northern California (*E. recurva*) to those that may also reflect different responses to changes in local productivity or other ecological conditions (e.g., the contrasting patterns observed for *T. spinifera* and *E. pacifica* and changes in individual size).

Nearshore bottom water high temperature anomalies in the Strait of Juan de Fuca in 2013 and 2014

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ABSTRACT
An array of HOBO temperature loggers deployed in the central Strait of Juan de Fuca, around the Elwha River delta, at depths between 6 and 10 m captured a long-period (~1 week) temperature "spike" in July 2013 that was >2C higher than any previously measured temperature in a record dating back to January 2009 (Figure 1). Surface water temperature are not collected at these sites, but surface water temperature collected at the tidal water level measurement station in Port Angeles harbor (~10 km away) were also elevated, nearly exceeding the previously measured range of variability (dating back to late 1997).

Two additional "spikes" with similar or greater magnitude temperature anomalies were subsequently recorded in October 2013 and another longer period (>2 weeks) event was recorded in October/November of 2014. These elevated water temperatures at depth near the Elwha River delta were again mirrored in the surface water temperature records from Port Angeles harbor, where they exceeded, by >2C, the previous range of variability for the fall season (Figure 2).

Data from a nearby CTD logger (<1000 m distant) suggests that this event was associated with lower than average salinity (on the order of 1-2 psu; Figure 3), suggesting the possibility that it may have been associated with a warm water pulse from the Elwha River. However, an analogous surface water temperature spike measured at the tide measurement stations in Neah Bay and Port Townsend (west and east on the Strait of Juan de Fuca) suggest that these warm water pulses propagated into the Strait of Juan de Fuca from off-shore.

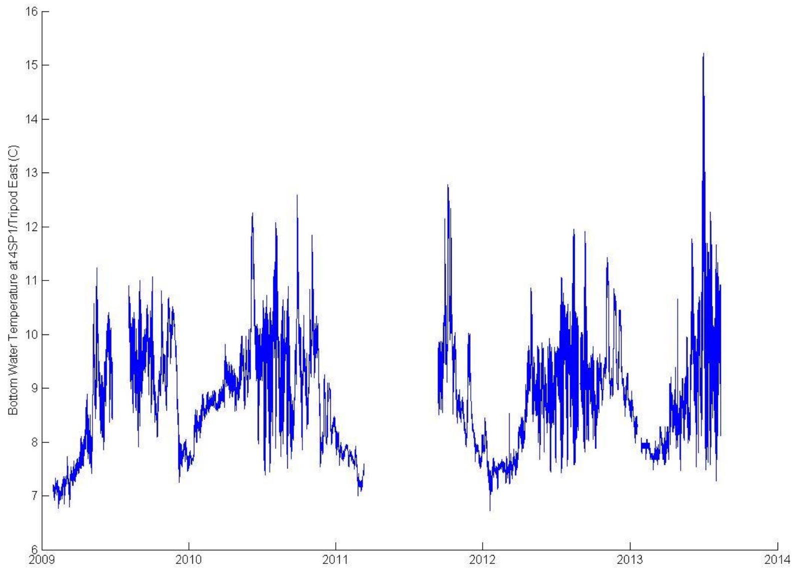

Figure 1. Water temperature record from temperature sensors at depths between 6 and 10 m and located off-shore and ~500 m east of the Elwha River mouth

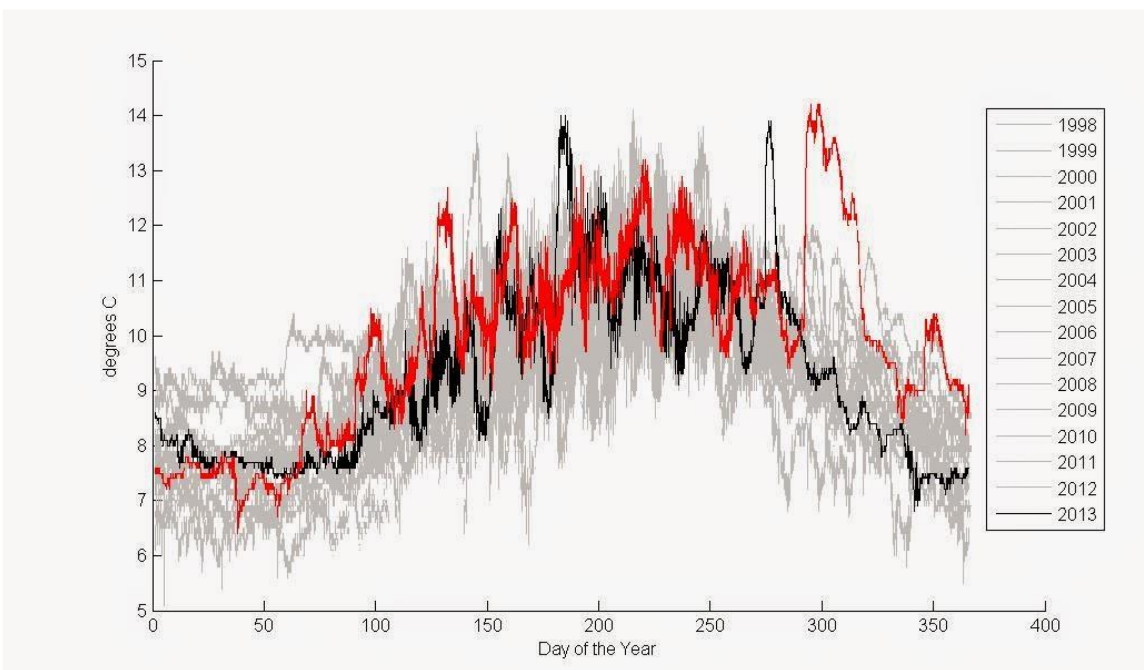

Figure 2. Daily average temperature from the NOAA tide gauge in Port Angeles harbor, for all years on record (starting in 1998). 2013 is shown in black, and 2014 in red.

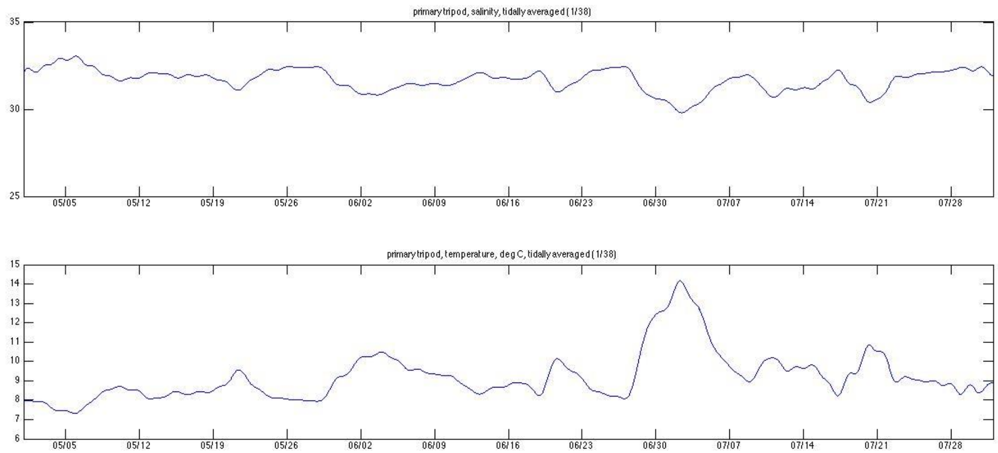

Figure 3. Salinity (top) and temperature(bottom) recorded by a CTD mounted on a seafloor tripod located at a depth of ~15 m, and near the temperature measurement sites referenced in Figure 1

North Central California ecosystem status update for 2014-2015

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ABSTRACT

The Applied California Current Ecosystem Studies (ACCESS) program is a collaborative partnership of Point Blue Conservation Science, Cordell Bank and Greater Farallones National Marine Sanctuaries, and it provides ecosystem information for management. ACCESS has been investigating the spatial and temporal relationships between oceanographic processes, phytoplankton, zooplankton, and marine birds and mammals in the north central California region since 2004 (Figure 1).

Alongshore winds responsible for upwelling in the region were strong in early 2014, then relaxed mid-year and remained weak for the remainder of the year and most of 2015.
The spring transition that marks the beginning of the upwelling season in each year occurred at the long-term average in 2014 and 2015. Spring transition dates have varied, with early dates observed in most years (2006-09, 2012-13), while some of the warmer years had late transition dates (e.g. 2005 and 2010).

On a local scale, Sea surface temperature measured by the NOAA buoy (46013) near Bodega Bay showed warm temperatures for most months in 2014 and 2015.

Pacific-scale climate indices have shown great variability in ocean conditions since the start of our research in 2004. Overall, results from 2014-2015 showed a warm ocean state. From 2005 to 2009, the Pacific Decadal Oscillation (PDO) and North Pacific Gyre Oscillation (NPGO) were following opposite trends, with positive PDO and negative NPGO values during poor ocean condition years (e.g., 2005-06), while negative PDO and positive NPGO values during productive ocean conditions (e.g., 2007-08). Beginning in mid-2009, both PDO and NPGO have been following relatively parallel trends, then showed signs of diverging in mid-2012. From mid-2013 to 2015, the indices had converged, indicating warm conditions.

Zooplankton community composition results are not yet available for 2014-2015, but results to date illustrate the effects of improved ocean conditions on overall zooplankton abundance, with low abundances in poor ocean condition years (2004-06, late 2009, early 2010) and increased zooplankton abundance (particularly for copepods and euphausiids [also known as krill]) in colder ocean periods (2007-08, late 2010, 2011-12). In 2014-2015, large volumes of doliolid salps dominated samples collected in the upper 50 m of the water column from July 2014 and largely decreased in abundance by September 2015.

Adult krill dominated Tucker trawl samples in June 2014, but the remaining cruises of the 2014 and most of 2015 caught mostly smaller, younger stages of krill. Relatively high abundances of adult krill were caught in periods of cold water conditions and strong upwelling (e.g. 2007-08, late 2010, early cruises of most years). We captured a pelagic red crab *(Pleuroncodes planipes)* during a Tucker trawl over Cordell Bank in September 2015, the previous documented sighting of this species in the region occurred during the El Niño 1982-83.

Copepod community composition results are not yet available for 2014-2015. Results to date indicate an increase in the abundance of boreal (northern) and transition zone (mid-latitude) copepods in cold, productive ocean conditions in our region (i.e., 2007-08, early 2009, late 2010, and 2011). Central copepods (i.e., copepods from southern latitudes) increased in abundance in the September cruises of 2007 and 2008, likely when the equatorward California Current flow relaxed.

The Cassin's auklet, a zooplanktivorous seabird, mainly ate euphausiids (krill) in most years, including 2014 and 2015. Mysids were the dominant prey in 2005-06 (poor ocean condition years), and the Cassin's auklet experienced unprecedented breeding failure. Increased amounts of krill in the diet since those years has coincided with improved productivity on the Farallon Islands (Figure 2).

While results for 2015 are not yet available, acoustic measurements of krill in the upper 30 m of the water column and down to 200 m have shown an increase in krill biomass through 2011, followed by a decline observed in 2012-14 (Figures 2 and 3). Krill biomass had low abundances overall from 2004 to 2007, with a misleadingly high abundance in spring 2006 due to high abundance of highly reflective gelatinous zooplankton in the water. High krill biomass was observed in 2009-2011, followed by low densities observed in 2012-14.

The blue whale, a main krill predator, follows very similar patterns to the krill abundance (Figure 2). Years of lower krill abundance (2004-08) have corresponded to low abundance of blue whales in the region. Signs of increasing blue whales abundance began in late 2009, and almost five times as many whales were sighted in the summer and fall of 2010 compared to the first four years of the study. This rise in whale abundance coincided with the great krill biomass observed in 2010; since then, blue whale abundances have been declining along with their prey in the region.

Unusual wildlife observations from 2014-2015 included high numbers of Guadalupe fur seals in July and September 2015, several pods of both short- and long-beaked common dolphins, and overall absence of Pacific white-sided dolphins. Dead common murres were also frequently observed during our September 2015 survey, corresponding to a high mortality event recorded on beaches in the region.

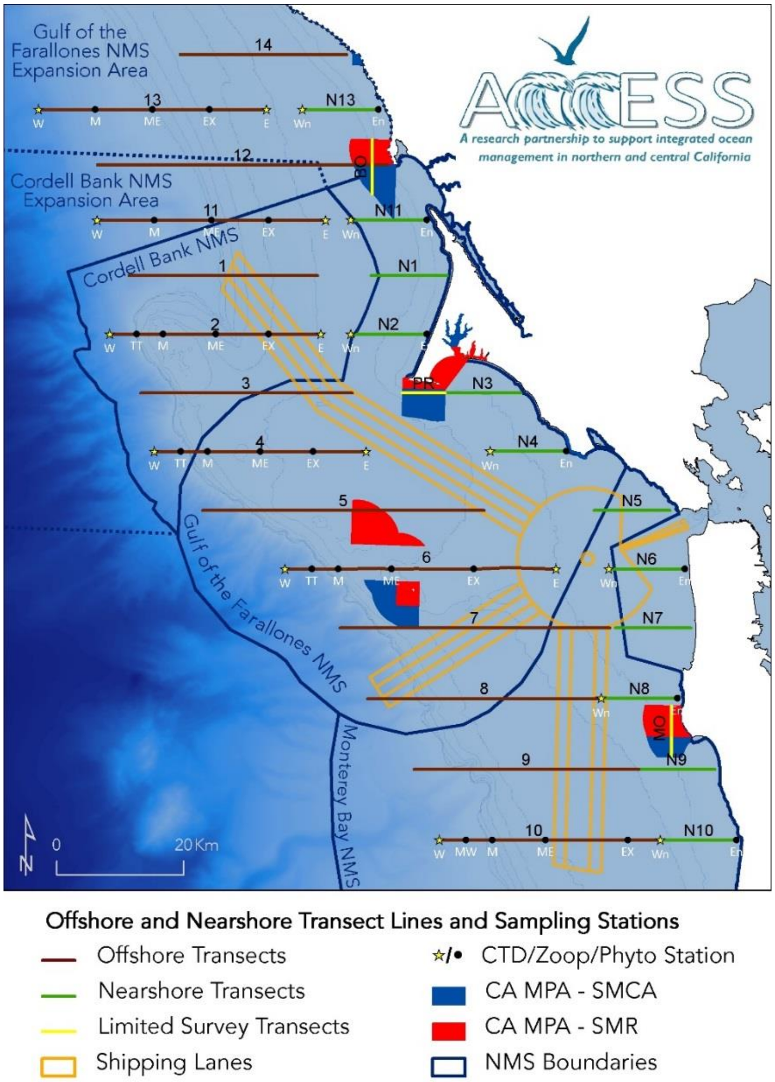

Figure 1. Map showing transect lines within Cordell Bank and Greater Farallones NMS. Lines 1-7 are long term core lines; lines 11-14 have been sampled less frequently.

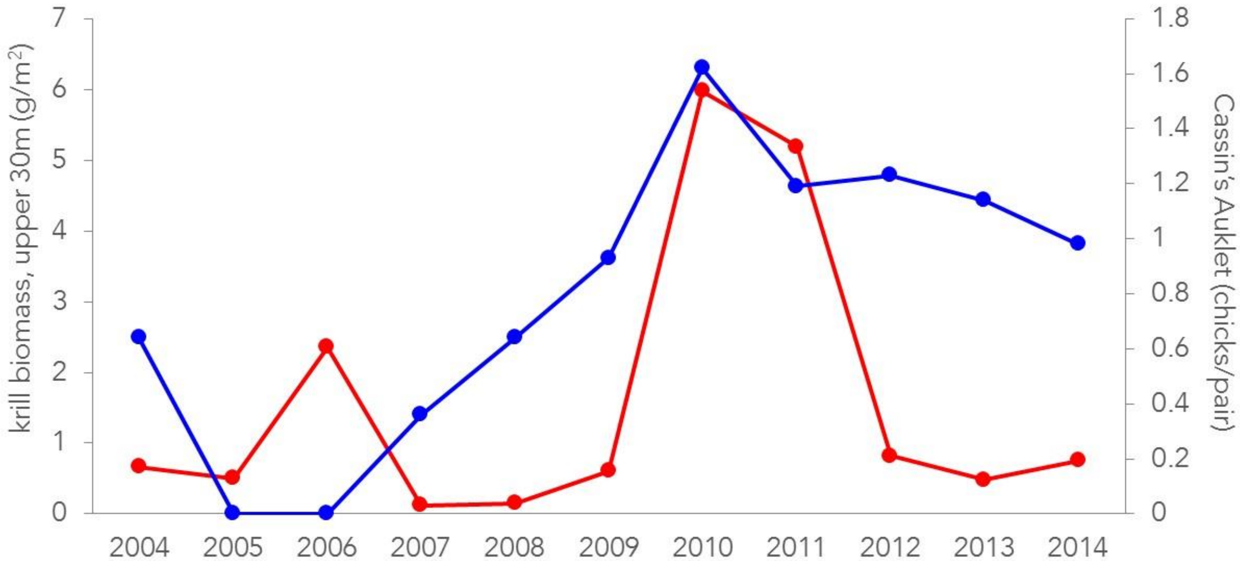

Figure 2. Breeding success of Cassins' Auklet (blue) on Southeast Farallon Island is correlated with abundance of adult krill (red) at 30 m in Cordell Bank and Greater Farallones National Marine Sanctuary.

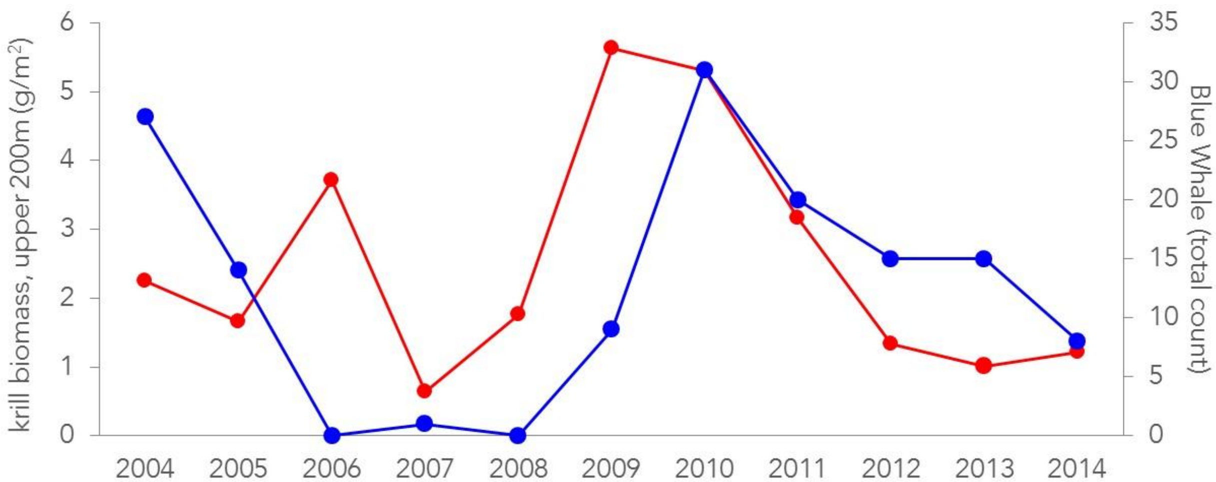

Figure 3. Blue whale counts (blue) are correlated with abundance of adult krill (red) at 200 m in Cordell Bank and Greater Farallones National Marine Sanctuary.

Farallon Island wildlife status update for 2014-2015

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ABSTRACT

Beginning during the summer of 2014, the central California Current region was affected by the unusual combination of a persistent warm water mass known as "the blob" and El Niño conditions. This led to record high sea surface temperatures (SST) throughout much of the region during 2014 and 2015. We summarize the impact this event has had on seabirds and marine mammals breeding at the Farallon National Wildlife Refuge.

2014 and 2015 were two of the top four warmest years on record, joining 1992 and 1998 as the only years in which the seasonal average exceeded 13°C and setting record highs for the months of February, July, August, September and October of 2015. Warm water conditions, such as those observed during the past year, typically lead to unproductive conditions, very low breeding success and even breeding failure. However, biological responses to this warming event have been varied and often not as dramatic as those observed during previous warm water events such as the 1983 or 1992 El Niños.

During the latter part of 2014, we observed reductions in the abundance of krill and juvenile rockfishes in the diet coupled with late season breeding failure for many seabirds and complete abandonment of second clutches for Cassin's auklets (*Ptychoramphus aleuticus*). During 2015, the number of birds attempting to breed and their breeding success were both reduced. Chicks generally took longer to grow and fledged at lower weights than in past seasons. Cassin's auklets failed to attempt any second broods for the first time since 2008 and common murres (*Uria aalga*) fledged chicks at a rate well below average. Seabird diet composition was also significantly different during 2015 than the previous year with juvenile rockfish (*Sebastes* spp.) comprising a much smaller proportion of the diet and northern anchovies (*Engraulis mordax*) becoming a significant portion of the diet for the first time since 2008. Although breeding success was reduced overall, most species were able to fledge chicks at a rate on par with or slightly above the long-term average productivity for this population.

Marine mammals exhibited a similar mixed response. Very high numbers of California sea lions have been hauling out at the island this season and have spread into areas where they are impacting seabird nesting habitat and human infrastructure. There were also record numbers of aborted sea lion fetuses observed during the past two winters as well as record numbers of pups born at the Farallones during the summers of 2014 and 2015. Unseasonably warm weather during the winter of 2014-2015 also led to increased pup mortality for Northern Elephant Seals as pups were prematurely pushed into the water or crushed by adults seeking to get to the water for relief from the heat.

Finally, unusual numbers of warm water associated species were observed at the Farallones during the last two years. These have included first island records for wedge-rumped storm-

petrel (*Oceanodroma tethys*) and kelp gull (*Larus dominicanus*), first records of adult blue-footed boobies (*Sula nebouxii*) present during the summer breeding season, record high numbers of brown boobies year-round (*Sula leucogaster*), and the presence common dolphins (*Delphinus delphis*) near the island.

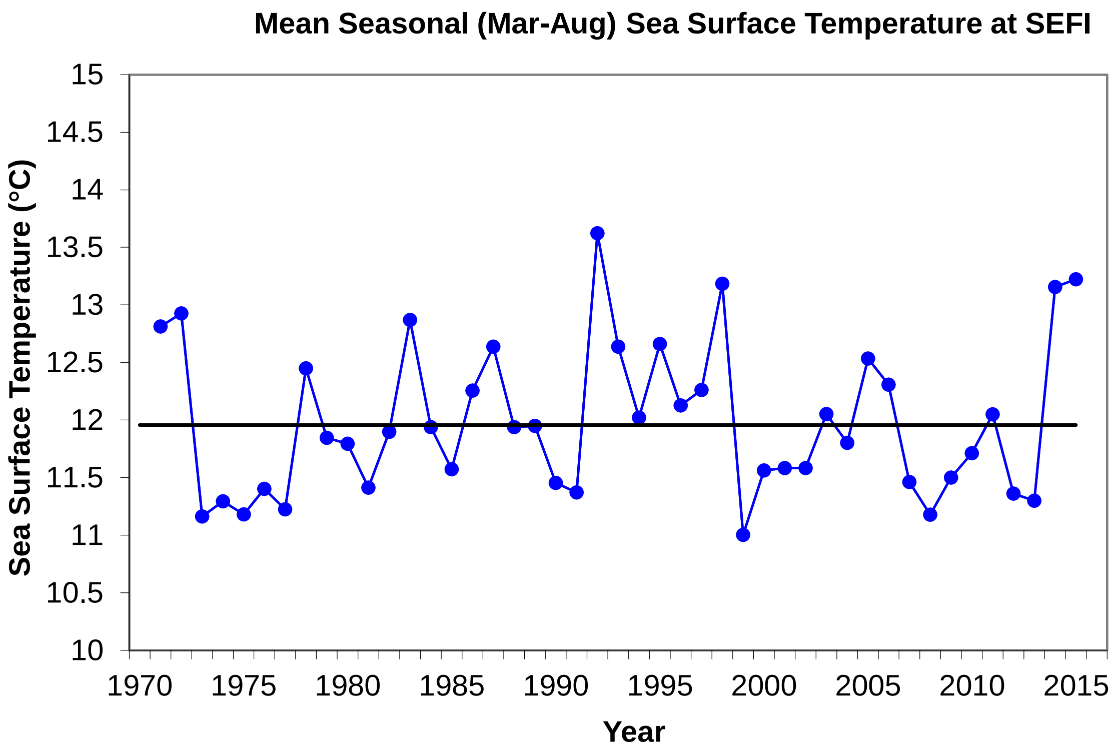


Figure 1. Mean seasonal (March through August) sea surface temperature recorded locally at Southeast Farallon Island from 1971 to 2015.

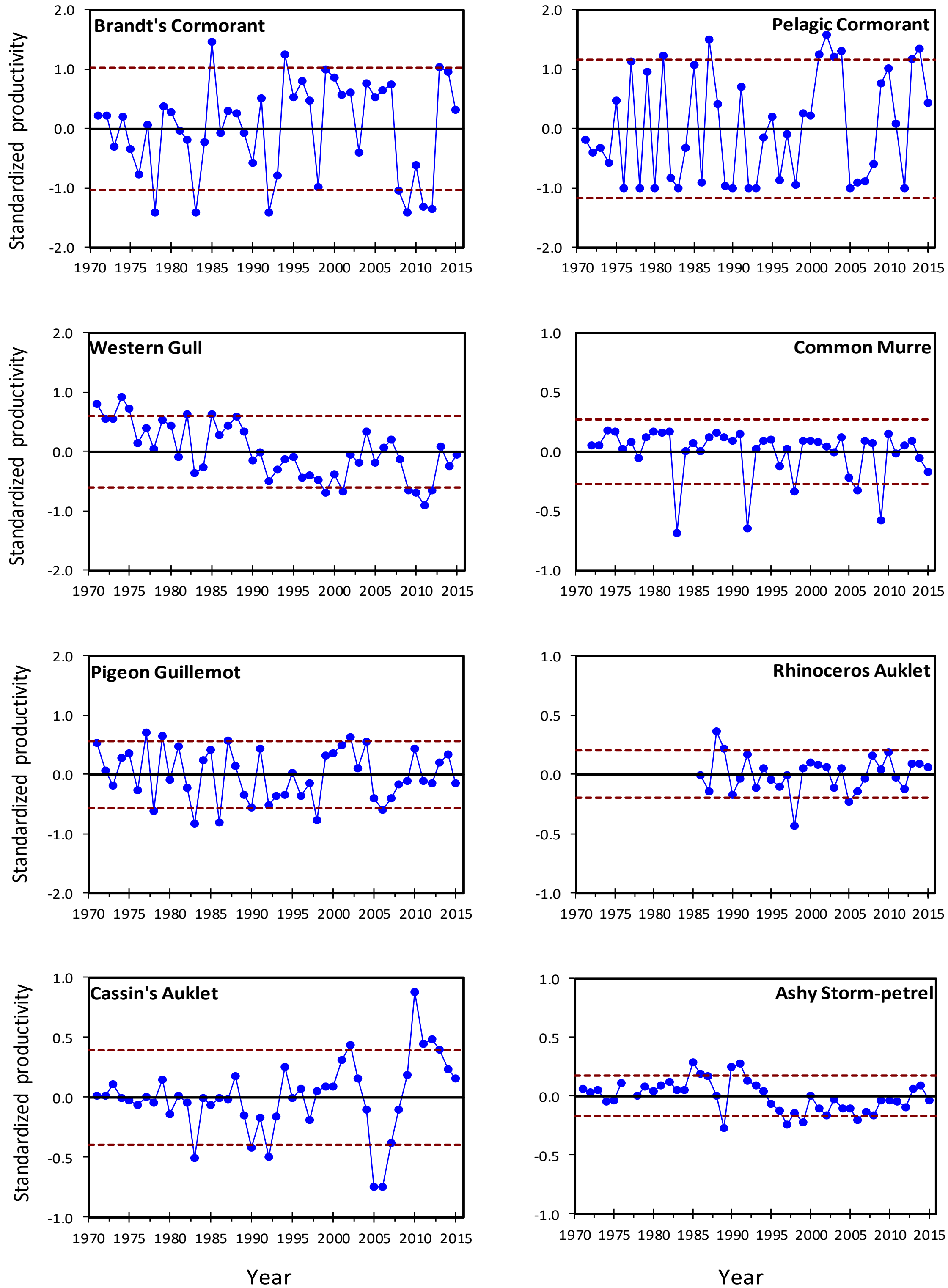
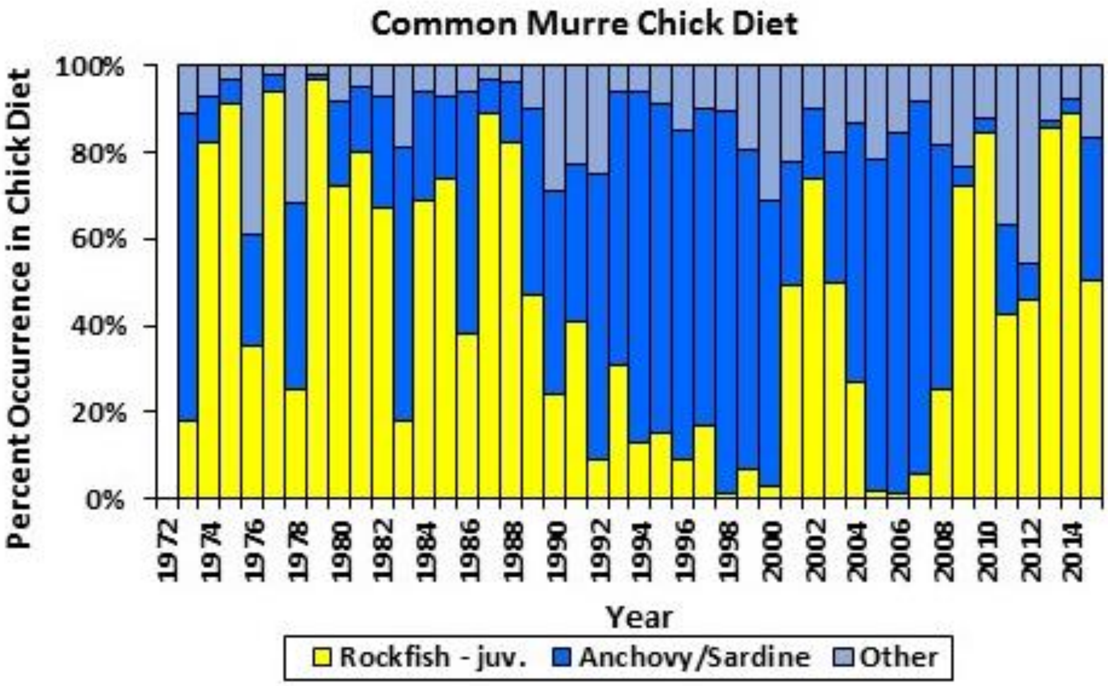


Figure 2. Mean annual reproductive success anomaly for Cassin's auklets breeding at Southeast Farallon Island from 1971 to 2015. The dashed lines represent the 80% prediction interval around the long-term mean. Points outside this range are considered anomalous years.



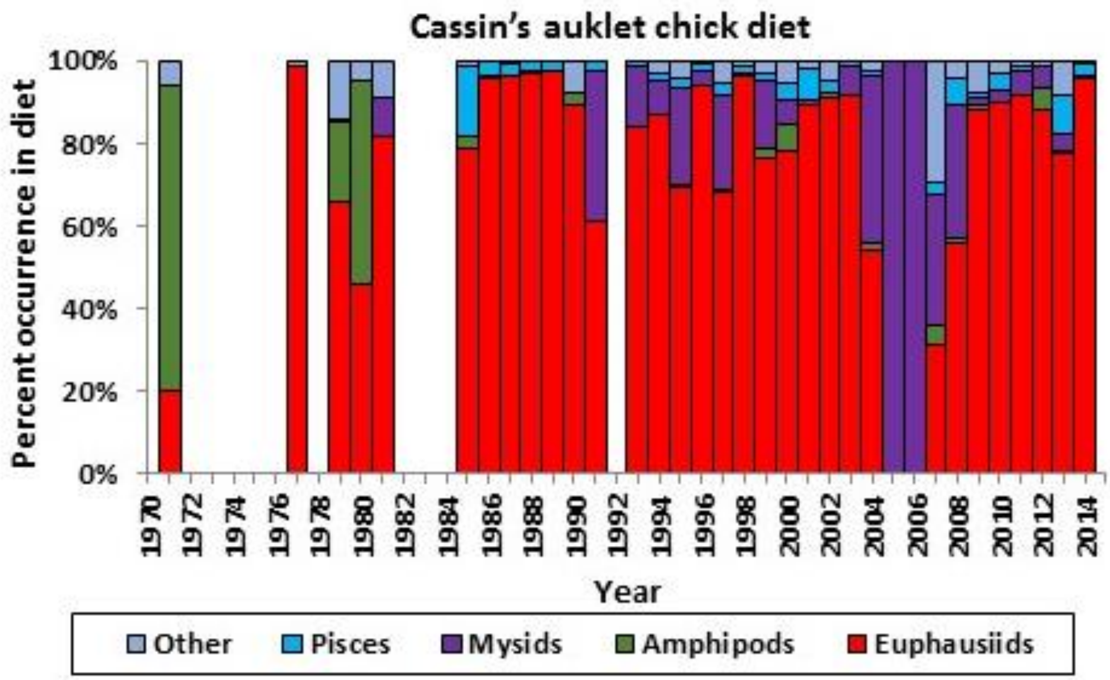


Figure 3. Annual diet composition for common murres and Cassin's auklets breeding at Southeast Farallon Island 1971-2015.

Physcial, biological, and chemical observations of 'the Blob' on the British Columbia central coast

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ABSTRACT
The Hakai Institute is a privately-funded research institute that conducts year-round, long-term monitoring at remote locations on the British Columbia coastal margin. Since 2012,the Hakai Institute have collected physical (CTD), chemical (nutrients, carbon system and oxygen) and biological (viruses, bacteria, phytoplankton and zooplankton) data at stations surrounding Calvert Island on British Columbia's central coast. These stations are sampled using small boats (less than 12 m) at daily to monthly time intervals.

The Blob was first observed in the waters around Calvert Island in November 2014. From CTD data, the Blob appeared as water that was about 2°C warmer than the previous winters. The Blob was observed to depths of at least 100 m and the anomalously high temperature persisted throughout the winter. Chemical and biological data showed that, during the spring and summer of 2015, waters around Calvert Island had reduced nutrients and lower phytoplankton and zooplankton biomass. Impacts of the Blob on the coastal ecosystem will be discussed.

The role of the atmosphere in northeast Pacific warming: Century-long trends and recent anomalies

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ABSTRACT
Sea surface temperatures (SSTs) in the northeast Pacific (NEP) vary in coherent fashion, largely in response to regional wind forcing of surface turbulent heat fluxes. Century-long records of regional sea-level pressure (SLP) suggest that weakening winds and net increases in turbulent fluxes can account for the entirety of NEP surface warming from 1900 to 2012. Here we focus on the historically warm period from 2013 to 2015, placing recent atmosphere-ocean anomalies in the context of longer trends.

We also show that recent warm conditions in the Gulf of Alaska (GoA, i.e. 'the blob') reflect forcing by atmospheric patterns that operate on two different spatial scales. At the basin scale, GoA warming occurs in conjunction with the broader NEP 'Arc' region that extends from the coastline to ~1000 km offshore. Arc SST changes are sensitive to strength of the mean anticyclonic winds, centered around the subtropical high northeast of Hawaii. Warming ensues when *negative* SLP anomalies in this area lead to large-scale reductions in wind speeds and lower evaporative cooling rates over much of the Arc.

At the smaller regional scale of the GoA, however, SST increases with locally *positive* SLP anomalies, which generate local wind speed reductions and net positive turbulent fluxes. We show that atmospheric forcing of GoA SSTs includes wo opposite scale-dependent responses to SLP, and that understanding of recent and long-term changes can be improved by separately accounting for basin-scale and regional forcing patterns.

Observations of biogeochemical conditions in the Columbia River estuary associated with the 2014-2015 North Pacific temperature anomaly

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ABSTRACT

During 2014 and 2015 the Columbia River estuary was strongly influenced by warm ocean temperatures that resulted from the nearshore presence of the NE Pacific temperature anomaly - a phenomenon of warm surface waters that that persisted in the North Pacific. Biogeochemical observations from observatory platforms within the estuary demonstrated that warm, low nutrient seawater was transported into the estuary in September 2014 and persisted intermittently through April 2015. Upwelling favorable winds resulted in the replacement of these warm waters with colder, nutrient replete waters in spring and summer 2015. Concurrently, record-high river temperatures persisted through the summer of 2015 as a result of low winter snowpack and subsequent low freshwater inputs to the estuary. Here we present time series biogeochemical observations from the sensor platforms in the Columbia River Estuary that illustrate the phytoplankton response to both river and ocean forcing and we discuss the implications of the temperature anomalies for estuarine ecosystem productivity.

The anomalous 2014 warming of the California coastal ocean and San Francisco Bay: Observations and model simulations

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ABSTRACT

During 2014 exceptionally warm ocean temperatures developed across a wide area off the California coast. Observations show positive anomalies exceeding 2.5^{o}C in the upper 100 meters of the ocean at a number of locations along the coast for much of the latter half of the year and into 2015 (Figure 1). In the vertical, gridded Argo data reveal that the maximum depth covered by strong positive anomalies expands from around 80 meters to 140 meters as the anomalies moved eastward from the open waters of the NE Pacific toward the California coast. The magnitude and evolution of these positive anomalies is accurately reproduced in a ROMS-based data-assimilative model configured for the California coastal ocean. Concurrently, anomalously warm water temperatures also developed in the San Francisco Bay. Observations from two water quality stations and monthly USGS ship surveys are used to document this warming inside the bay (Figure 2). An unstructured-grid numerical model (SCHISM) configured for the San Francisco Bay is found to realistically simulate the warming. Both the California coastal model and the San Francisco Bay model are used to study the origin of these warming signals. The warming in San Francisco Bay occurs in several pulses, with the first early in 2014 being followed by three more reinforcing pulses during the second half of the year. An analysis of the spatial evolution of the temperature anomalies during one of these warming pulses in the second half of 2014 suggests that the bay warming originates in the adjacent California coastal ocean and propagates through the Golden Gate Bridge into San Francisco Bay. An examination of the SCHISM model heat budget for the Central San Francisco Bay lends support to this conjecture. The ROMS model simulations with and without the warming included in the lateral boundary conditions suggest that the California coastal warming originates further offshore as a result of oceanic processes causing the movement of the anomalously warm surface waters from the northeast Pacific Ocean to California.

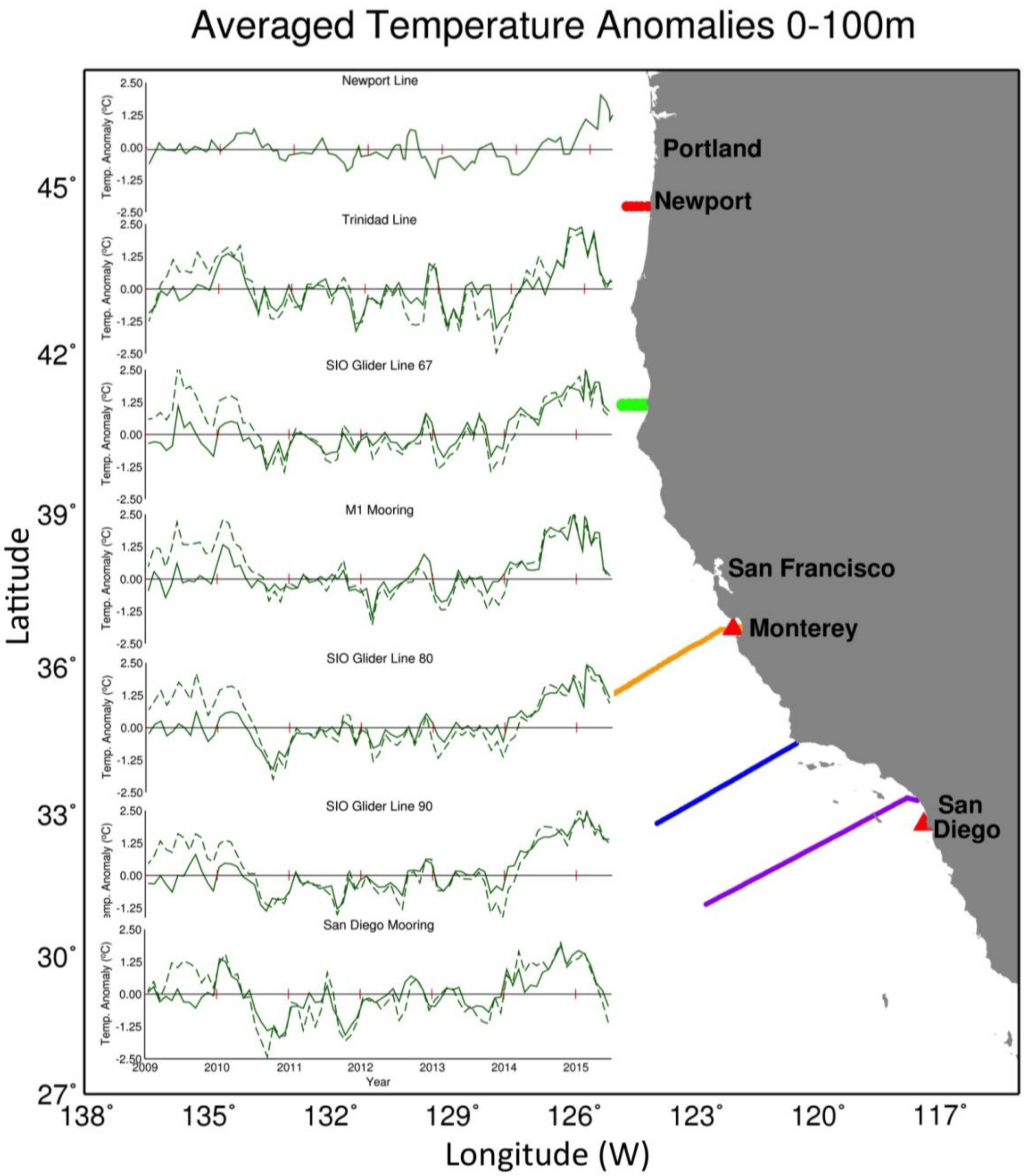

Figure 1. Time series of heat content anomalies (Joules; anomalies from the 2009 – 2014 means) for the period Jan 2009 – Apr 2015 from south to north: San Diego mooring (cyan triangle), Scripps glider transecting CalCOFI line 90 (purple line), Scripps glider transecting CalCOFI line 80 (blue line), M1 mooring (green triangle), Scripps glider transecting CalCOFI line 67 (orange line) and ship CTD observations near Trinidad, CA (green line) and near Newport, OR (red line). The dashed lines represent the anomalies from the CA ROMS hindcast run that includes data assimilation.

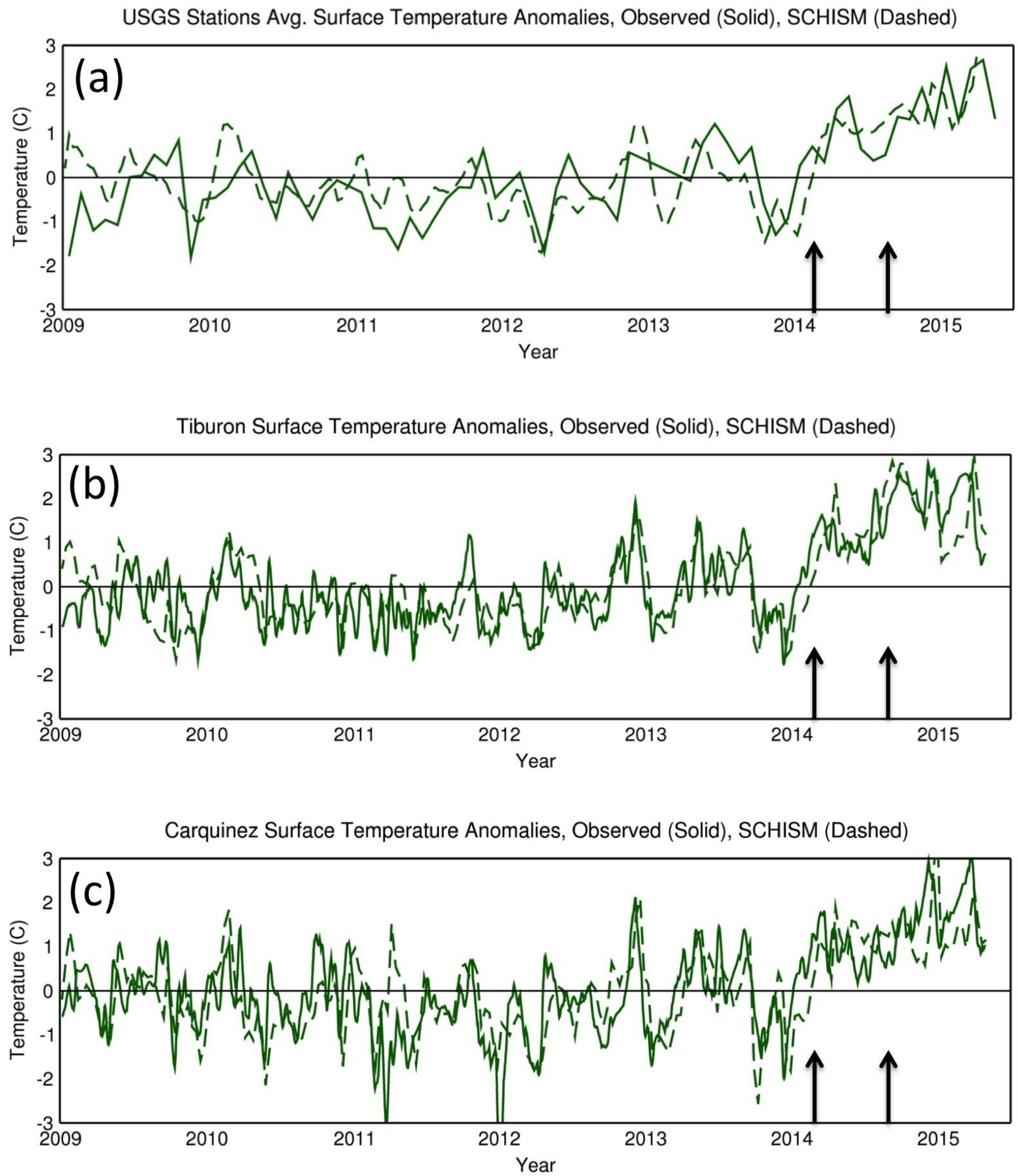

Figure 2. Time series of surface water temperature anomalies (^{o}C; anomalies from the 2009 – 2014 means) for the period Jan 2009 – Apr 2015 for the following: (a) average of the 36 USGS water quality monitoring stations within San Francisco Bay, (b) the Romberg Tiburon Center pier station, (c) California Maritime Pier in Carquinez. The black arrows show the times during which the two warming pulses discussed in the text develop.

The response of Puget Sound to the 2014–2015 North Pacific warm anomaly

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ABSTRACT
The flow of the unprecedentedly-warm upper-ocean North Pacific "Blob" water into Puget Sound, Washington, caused local extreme water property anomalies that extended from the arrival of the water inshore in the fall of 2014 through 2015. Here we report on moored observations from Puget Sound, where temperature was more than 2 standard deviations above the 10-year climatology for much of the year with maximum temperature anomalies at depth and at the surface +2.5 °C and +7 °C respectively. In Hood Canal, a branch of Puget Sound, the low density of the oceanic warm "Blob" water resulted in weak deep water flushing in the fall of 2014, which combined with a lack of wintertime flushing to result in anomalously-low dissolved oxygen (DO) concentrations at depth. Late-summer 2015 DO values were the lowest in a decade of mooring observations and more than 2 standard deviations below climatology. The anomalously low density of the deep basin water allowed a very early onset of the annually-occurring, late-summer intrusion, which first entered Hood Canal at the end of July compared to the usual arrival in early to mid-September. In late August this intrusion conspired with an early fall storm to lift the very low DO deep water to surface at the south end of Hood Canal, causing a significant fish kill event.

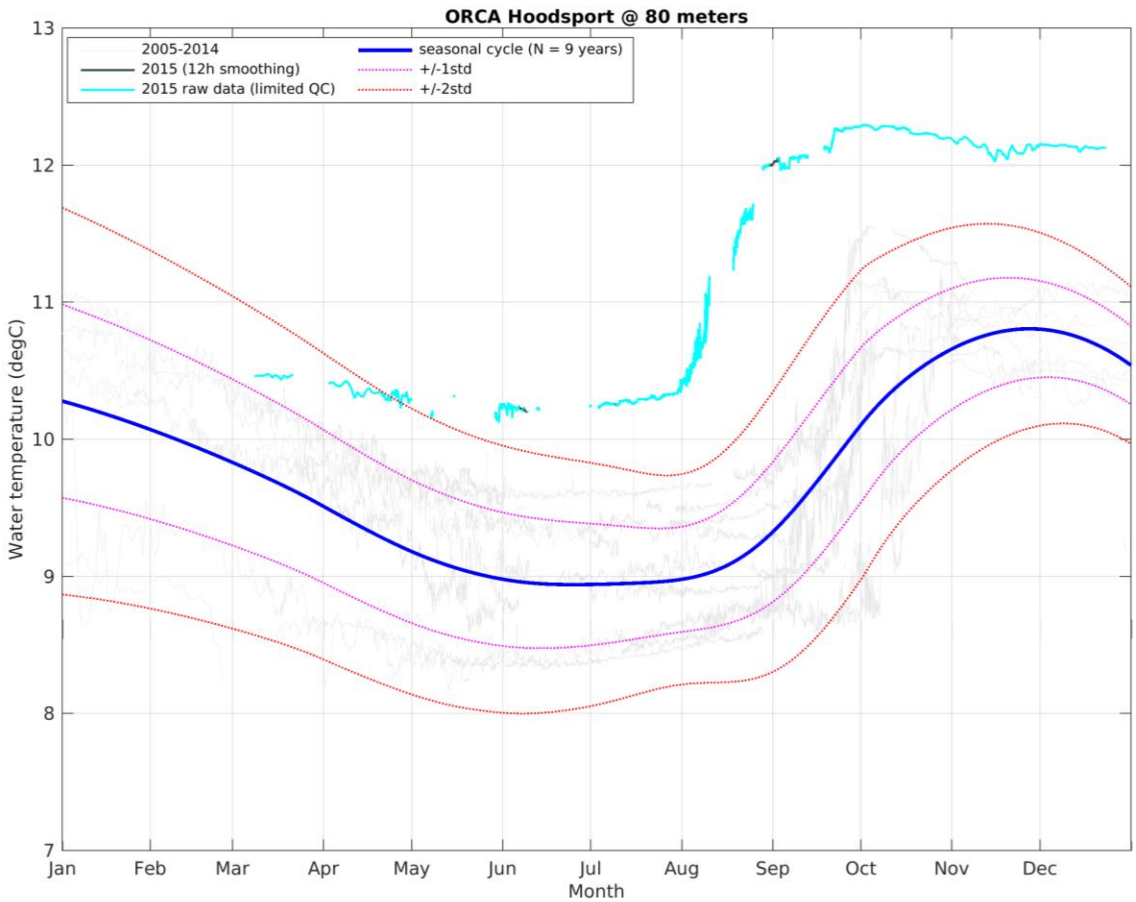

Figure 1: Temperature at 80 m depth at Hoodsport. Cyan (2015) is compared to mean 10-year climatology (blue) with one and two standard deviations shown (magenta and red). Other years are plotted in gray.

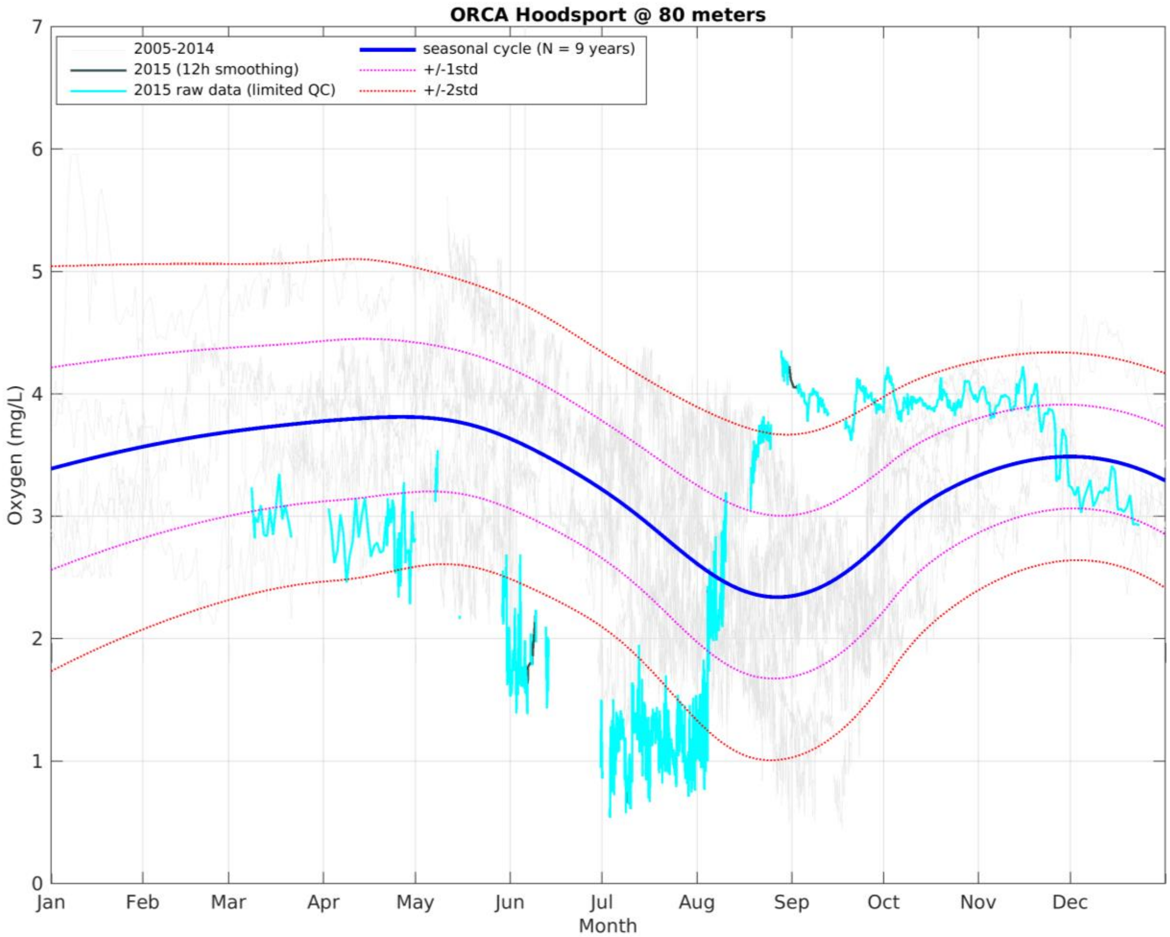

Figure 2: Dissolved oxygen at 80 m depth at Hoodsport. Cyan (2015) is compared to mean 10-year climatology (blue) with one and two standard deviations shown (magenta and red). Other years are plotted in gray.

Glider Observations of the 2014–2015 Warming Anomaly in the Southern California Current System

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ABSTRACT

During 2014-2015, basin-wide patterns of oceanic and atmospheric anomalies affected surface waters throughout the North Pacific Ocean. We present coastal physical and biological effects of the warming, as measured by our autonomous underwater gliders in the southern California Current System (SCCS).

Established in 2006, the California Glider Network provides sustained subsurface observations for monitoring the regional effects of large-scale climate variability. Along repeat sections that extend to 350-500 km in offshore distance and 500 m in depth, Spray gliders have continuously occupied CalCOFI lines 66.7, 80 and 90 for nearly nine years. Following a sawtooth trajectory, the gliders complete each dive in approximately 3 hours and over 3 kilometers. Measured variables include pressure, temperature, salinity, chlorophyll fluorescence, and velocity. For each of the three lines, a comprehensive climatology has been constructed from the multiyear timeseries.

The ongoing surface-intensified warming anomaly, which began locally in early 2014 and persists through present, is unprecedented in the glider climatology (Fig. 1). Reaching up to 5°C, positive temperature anomalies have been generally confined to the upper 50 m and persistent for nearly 2 years. The timing of the warming was in phase along each glider line (Fig. 2a) but out of phase with equatorial SST anomalies (Fig. 2f), suggesting a decoupling of tropical and mid-latitude dynamics. Concurrent physical oceanographic anomalies included high stratification (Fig. 2b), a depressed thermocline (Fig. 2c), and subsurface freshening (Fig. 2d). Induced biological consequences included a deepening of the subsurface chl-a fluorescence maximum (Fig. 2e). Ancillary atmospheric data from the NCEP North American Mesoscale (NAM) model indicate that a combination of surface forcing anomalies, namely high downward heat flux and weak wind stress magnitude, caused the unusual warm, downwelling conditions. With a strong El Niño event underway, our sustained glider network continues to measure the evolution of the shallow warm pool in the SCCS and its potential interaction with ENSO-related anomalies.

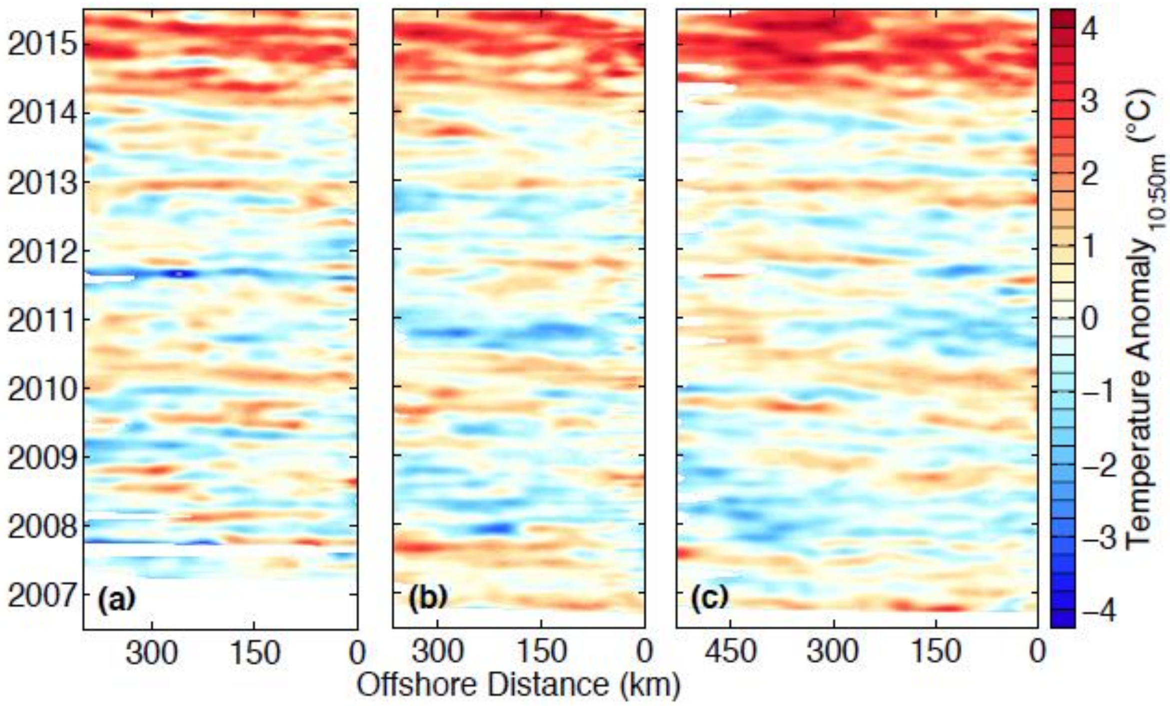

Figure 1: Hovmöller plots of: temperature anomalies depth-averaged over 10-50 m along (a) Line 66.7, (b) Line 80, and (c) Line 90.

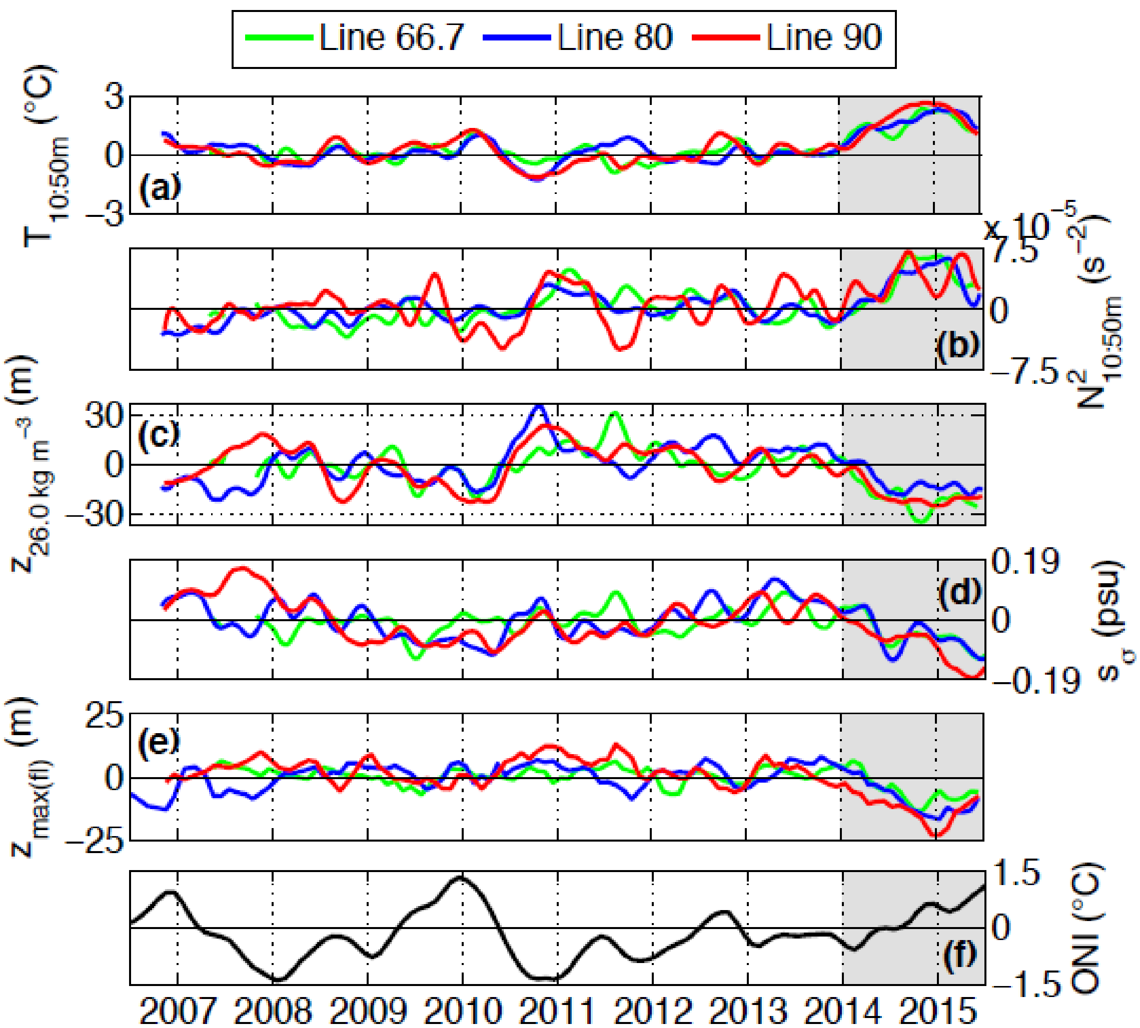

Figure 2: Timeseries of oceanic and atmospheric property anomalies. Glider-measured (a) temperature in the upper 50 m, (b) buoyancy frequency in the upper 50 m, (c) depth of the 26.0 kg/m3 isopycnal (negative indicates deep), (d) salinity along isopycnals (the 25.75, 25.50, 25.25 kg/m3 isopycnals for lines 66.7, 80, 90, respectively), (e) depth of the subsurface chl-a fluorescence maximum (negative indicates deep). The glider-measured anomalies (a-e) are averaged along the inshore 200 km of lines 66.7 (green), 80 (blue), and 90 (red). (f) Oceanic Niño Index, ONI, shows equatorial SST anomalies averaged over the Niño 3.4 region. All anomalies are filtered with a 3-month running mean. The anomalous period is highlighted in grey.

Biological mortality anomalies in the northern and central California ecosystem, 2014-2015

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ABSTRACT
Beach Watch ecosystem monitoring project is a partnership of Greater Farallones National Marine Sanctuary and Farallones Marine Sanctuary Association. Established in 1993, Beach Watch (BW) engages citizen scientists in bi-monthly surveys for live and beach cast birds and mammals on sanctuary beaches from Año Nuevo State Reserve, San Mateo County to Bodega Bay, Sonoma County. In November 2014 additional surveys were added to the project, extending north to Manchester Beach, Mendocino County. Currently, over 1300 surveys are performed annually, spanning 280 km of coastline. The Beach Watch project provides over 22 years of status and trend data for over 300 species of coastal wildlife. The most abundant beach cast species are Common Murres (*Uria aalge*), Northern Fulmar *(Fulmarus glacialis)*, Western Gull *(Larus occidentalis)*, Brandts Cormorants *(Phalacrocorax penicillatus)* and California Sea Lions (*Zalophus californianus*). All beach cast birds and mammals are documented with measurements and photographs. Species identification, age, and sex are reviewed and confirmed by seabird and marine mammal experts on staff.

In 2014 and 2015 BW surveys documented unusual mortality events in two seabird species, Cassin's Auklets *(Ptychoramphus aleuticus)* and Common Murres and one pinniped species, the threatened Guadalupe Fur Seal (*Arctocephalus townsendi*). Cassin's Auklets are zooplanktivores feeding nearly exclusively on krill. Murres and Fur Seals are piscavores. BW collected specimens of each species for necropsy to determine cause of death.

Cassin's Auklets, a pelagic species, are historically rare on beached bird surveys in north central CA typically found at a rate of 0.017 birds/km surveyed. In July 2014 through February 2015 emaciated Cassin's washed ashore in above average numbers. During November and December Cassin's were observed at a rate of 2.82 birds/km an increase of over 166 times baseline rates. Guadalupe Fur Seals are uncommon in the north central coast of CA and rarely found on beach surveys typically found at a rate of 0.0002 mammals/km. In March through July 2015 Guadalupe Fur Seals were documented at a rate of 0.025 mammals/km, an increase 124 times baseline. Common Murres are the most common species of beach cast bird documented on BW surveys typically at a rate of 0.28 birds/km. In September through November of 2015 Common Murres were documented at a rate of 5.95 birds/km, an increase of over 20 times baseline.

BW data clearly show three anomalous mortality events in 2014-2015 including multiple trophic levels. Necropsies, performed by multiple agencies, suggest emaciation as the cause of death for all three species. During these mortality events, a prolonged period of unusually high sea surface temperature occurred, including the “Warm Water Blob” (WWB) and El Niño. These environmental conditions appear to have affected prey availability. We continue to investigate the warm water impacts on seabirds and marine mammals in central and northern CA.

Oceanographic and ecosystem response to the 2013-2015 Pacific warm anomaly in Kachemak Bay Alaska

Kris Holderied*[1] and Dominic Hondolero[1]

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ABSTRACT

Subarctic estuarine waters in Kachemak Bay Alaska responded to the 2013-2015 Pacific Warm Anomaly starting in late 2013, with a transition from cooler or near-average conditions to warmer than average temperatures observed in October 2013. The warming was preceded by an eight year period of below average or near-average surface water temperatures in Kachemak Bay and the region starting in October 2005, with a brief warm period in the winter of 2010. Since October 2013, Kachemak Bay water temperatures have remained consistently above average, with the largest warm anomalies recorded during the winter of 2014-2015. Kachemak Bay is a subarctic fjord estuary in the northern Gulf of Alaska, located within and near the southeast entrance of Cook Inlet. Marine conditions in the bay are affected by atmospheric temperature and wind forcing, large tides with 8.7 meter maximum range, and freshwater input from precipitation and snowpack and glacier meltwaters. Kachemak Bay is also influenced by exchange with waters from the inlet and by exchange with and upwelling of waters from the adjacent shelf, including from the Alaska Coastal Current which flows westward along the Gulf of Alaska coast in this region. Since 2001, oceanographic observations have been made in Kachemak Bay at water quality stations operated by the Kachemak Bay National Estuarine Research Reserve at the Homer and Seldovia harbors. We use temperature observations from the Seldovia station to compare the recent warming to average conditions from continuous measurements made in the same location from 2004-2015. On average, warmest water temperatures are observed in August and September and coldest water temperatures are observed in March each year. Average monthly water temperatures were above the 2004-2015 means for most months in 2014 and 2015 and were warmer than at any time since 2005, with summer temperatures near 12 degrees C in both 2014 and 2005 and close to 11 C in 2015. The monthly temperature anomalies ranged from 0.5 to 2.5 C above the 2004-2015 means, with the highest warm anomaly of any month observed in January 2015. Winter temperatures in February and March of 2015 were near 5 C, which is a degree warmer than the same months in 2014 and 2 C higher than the long-term mean for March. By contrast, water temperatures near 2 C (with cold temperature anomalies of 1-2 C) were observed at Seldovia during the winter months of 2012. In 2014, the biological responses in Kachemak Bay to the warmer atmospheric and marine conditions were less than originally expected, but dramatic changes were observed in 2015. The 2015 observations included early and more intense phytoplankton blooms (including of Pseudo-nitzschia species which can cause domoic acid toxicity), unusual numbers and seasonal duration of humpback whales feeding in the bay, significant mortality events for both seabirds and sea otters, and temporary closures of some commercial oyster farms due the first paralytic shellfish poisoning event in over a decade. Unusually large numbers of herring were also reported by fisherman and water taxi operators in Kachemak Bay in the summer and fall of 2015, though there is no routine forage fish sampling to confirm these observations. Also, in both 2014 and 2015, sport fishing for foraging (not spawning) king salmon was reported to be consistently

better than normal in Kachemak Bay. We compared Seldovia water temperatures to conditions on the shelf, using continuous, near-surface water temperature measurements made at the Gulf of Alaska 1 (GAK1) mooring, which is located near the entrance to Resurrection Bay and upstream (along the Alaska Coastal Current) from Kachemak Bay. Near-surface water temperatures at GAK 1 are usually warmer than at Seldovia with a greater difference in summer (1.5 to 2 C) than winter (0.5 to 1 C) months. The relative cooling and warming patterns are very similar between the estuarine and shelf observations, though there are differences between the two locations on time scales of less than three months. During 2013-2015, GAK1 water temperatures remained warmer than at Seldovia in summer, but winter warming was stronger at Seldovia, which resulted in relatively small winter water temperature differences between the near-surface waters of the estuary and the shelf. In addition to the direct temperature effects examined here, shifts in large-scale weather patterns associated with the Pacific Warm Anomaly can change the amount and timing of freshwater input, as well as wind-driven exchange and upwelling from the adjacent Gulf of Alaska shelf. In the future, we plan to more closely examine if and how the local biological changes observed in forage species and apex predators are being driven by bottom-up food web changes associated with persistently warm conditions in estuarine and shelf waters, along with changes in ocean transport and freshwater input.

Tracking 2014-15 sea surface temperature anomalies using Coastal Data Information Program (CDIP) nearshore buoys

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ABSTRACT
Anomalous water temperatures developed across the California Current System (CCS) during 2014, and persisted through fall 2015. The presence of a warm-water "Blob" in the Gulf of Alaska in winter 2013-14 led to speculation that the 2014 warming in the CCS was due to direct southward propagation of warm waters from the Blob. However, timeseries of sea surface temperature (SST) records from nearshore Coastal Data Information Program (CDIP) wave buoys suggest that the onset of warm waters in the coastal CCS occurred at different times depending on location. Waters off Southern California showed preliminary warm anomalies in January 2014, and clear anomalies beginning in May 2014 (Fig. 1, turquoise line). Waters off Central California south of Cape Mendocino showed clear anomalies beginning in July 2014. In contrast, waters north of Cape Mendocino and off Oregon and Washington did not show definite anomalies until October 2014, at which point SST values rose above all previous records (Fig. 1). Record high SSTs (1-5oC above all past years) persisted at all locations through March 2015, at which point waters throughout the CCS cooled uniformly, suggesting the onset of spring upwelling. Warm SSTs returned in summer 2015, and have remained high through fall 2015, although below levels for fall 2014.

Consistent with other SST time-series and analysis of 2014-15 water movements, our data suggest that the warm "Blob" from the Gulf of Alaska eventually propagated south to Washington and Oregon. The delay in onset of anomalous SST until fall 2014 suggests that warm waters were held offshore during spring-summer 2014 by upwelling-favorable winds (and thus not detected by CDIP buoys, which are 5 nautical miles (Grays Harbor, WA) and 15 nautical miles (Umpqua, OR) offshore). In contrast, the spring-summer 2014 onset of anomalously warm SSTs in the Southern-Central CCS suggests that these warm anomalies moved north from a different warm source off Baja California.

Since CDIP started monitoring SST in the early 1990s, climatological comparisons reveal that SSTs for summer 2014-winter 2015 are the highest temperatures recorded at each station. However, Mission Bay, CA and Point Reyes, CA, had similarly high SSTs during the 1997-1998 El Nino (October '97-March '98).

Monitoring long-term SST variations provides valuable information about physical oceanographic parameters, which can influence the biology and climate of the region, and larger-scale processes. Accurate observation and analysis of temperature trends can help inform recreational ocean users and the general public about present ocean conditions and related

physical and biological changes (e.g. unusual species sightings, fishing stock status, coastal ocean health, atmospheric changes).

Data Source
Coastal Data Information Program (CDIP) buoys measure nearshore wave parameters and SST. Buoy temperature sensors are located at the buoy hull mooring eye, approximately 45 cm below the water surface. Buoys collect SST data every 30 minutes. Data are transmitted in near-real-time to NDBC servers, disseminated to the National Weather Service, and also available through the CDIP website. Primary CDIP sponsors are the U.S. Army Corps of Engineers and the California Department of Parks and Recreation.

Buoy	**Offshore (nm)**	**Depth (m)**
Grays Harbor, WA	4.5	42.4
Umpqua, OR	15.5	183
Cape Mendocino, CA	17.5	334
Point Reyes, CA	21.5	575
Harvest, CA	15.5	549
San Nicolas Island, CA	15.5*	307
Mission Bay, CA	5.5	192

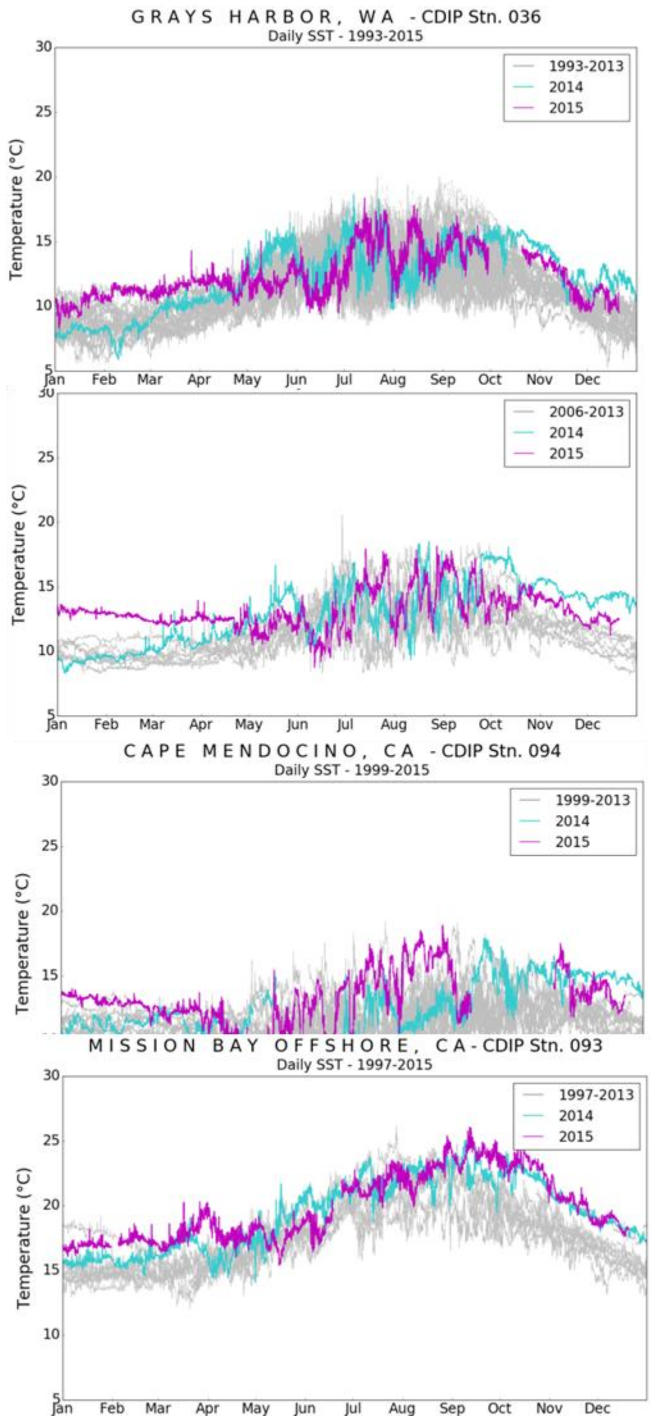

Figure 1. Climatological comparisons of SST at four CDIP buoys. Past years (through 2013) are shown in gray, 2014 in turquoise, and 2015 in magenta. Mission Bay shows anomalously high SST values starting in May 2014; the other stations show high SST from fall 2014-fall 2015.

Figure 2. *(top)* U.S. West Coast CDIP buoy stations. SST climatology stations are labeled and marked in orange. *(right)* Table of highlighted buoy distances offshore (nautical miles) and depth (meters). *West of San Nicolas Island, Channel Islands.

North Pacific Research Board investment in understanding the mechanisms driving the persistence of North Pacific anomalous warming and consequences for ecological interactions in the Gulf of Alaska

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ABSTRACT
Scientists have documented persistent anomalous warming in the waters of the North Pacific Basin. The North Pacific Research Board (NPRB) is supporting research to characterize this phenomenon, determine the physical dynamics perpetuating these conditions, and explore consequences for biological communities and ecological interactions in the Gulf of Alaska. This phenomena provides a unique opportunity to explore the impact of warming conditions on fish and invertebrate stocks, potential shifts in distribution and life history, and predator-prey interactions under climate change. NPRB is currently funding an international team of researchers from agencies throughout the northeast Pacific coast to analyze and predict patterns in groundfish species movement and spatial distribution in response to the anomalously warm ocean conditions (see Hollowed et al. in this session). The research explores potential mechanisms driving fish movement, estimating spatial indicators of fish movement for suites of species with diverse life history characteristics (e.g., gadids, rockfish, and flatfish), Analyses also explore movement probabilities relative to climate velocity. Oceanographic observations will quantitatively assess the accuracy of the NOAA Climate Forecast System. Further research is needed to leverage existing time series data from oceanographic moorings in the Gulf of Alaska and Bering Sea, the Argo array of free-drifting profiling oceanographic floats, fisheries and oceanographic surveys, remote sensing, and relevant ecosystem monitoring programs to explore the connection of ocean responses to climate processes (e.g., El Niño Southern Oscillation and the Pacific Decadal Oscillation) and impacts on fisheries and marine ecology.

Major decline in coastal phytoplankton population and species diversity in the Southern California Bight during anomalous warm conditions of 2014-2015

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ABSTRACT
Coastal measurements of temperature, salinity, chlorophyll, nutrients and abundance of harmful algal species have been measured at five pier-based stations along 500 kilometers of the California coast. These stations are part of the Harmful Algal Bloom (HAB) Monitoring Program, conducted by the Southern California Coastal Ocean Observing System (SCCOOS), which has collected weekly samples since June 2008.

Long-term observations of temperature and salinity at Scripps Pier, La Jolla began in 1916 and expanded in 1930 to include phytoplankton species abundance. Over 40 years of phytoplankton observations have been collected at Scripps Pier by researchers, E. W. Allen (1930-1939), J. McGowan et al. (1983-2000), L. Busse et al. (2003-2005), including SCCOOS current efforts (2008-2015), which can be used to determine if phytoplankton species have changed over time and in relation to climate variability.

The recent and most rapid temperature increase event since the generalized warming of the late 70's has been observed in southern California and the biological responses of primary producers include a major decline in chlorophyll concentration and species diversity observed at Scripps Pier. Warm temperatures and low chlorophyll have also been observed at the three Southern California Bight (SCB) stations, however the most northern station, just outside of the SCB shows varied results. Preliminary results of plankton response during two other major warming events (1930-31) and (1997-98) are compared to (2013-2015) at Scripps Pier, La Jolla.

Further information on these programs can be found on the Manual Shore Stations Program website, http://shorestations.ucsd.edu/, and the Southern California Coastal Ocean Observing System website, http://sccoos.org/data/habs/

Warm events in the California Current: El Niño or not

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ABSTRACT

The El Niño – Southern Oscillation (ENSO) is a dominant mode of interannual climate variability throughout the Pacific. However, warm events occur in the extra-tropical California Current System (CCS) that are neither contemporaneous with an El Niño nor mechanistically linked to ENSO. Likewise, not every tropical El Niño is reflected by a CCS warming. The paradigm that changes in the surface layer of the eastern equatorial Pacific propagate poleward along the coasts of North and South America does not completely account for CCS warmings. Atmospheric variations affecting winds that drive surface heat and momentum fluxes must be considered. These wind fluctuations result from local/regional pressure anomalies, which are only sometimes clearly related to remote forcing by atmospheric teleconnections. We document the history of El Niño and CCS warm events since 1950 and show how relationships between the ocean-atmosphere interactions forcing these events vary between events. The North Pacific warming known as “the Blob” is a notable example of a CCS warming that was not a result of El Niño generated teleconnections. The recent warming in the NE Pacific has persisted as the 2015-2016 El Niño develops. The coincidence of these two events in 2015 is now causing major changes in the California Current Ecosystem.

Hot times in the NE Pacific: How much precedence in the historical record?

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ABSTRACT

Strongly positive temperature anomalies developed in the NE Pacific Ocean during the boreal winter of 2013-14. Relatively warm temperatures have persisted up to the present time, with significant evolution on seasonal time scales, as illustrated in Figure 1. The winter of 2015-16 is featuring a very strong El Nino, which should have substantial impacts on air-sea interactions in the NE Pacific, and ultimately upper-ocean conditions, presuming that the basin-scale atmospheric response in the North Pacific to El Nino resembles that which has occurred with past events. The objective of this paper is to compare the current NE Pacific event with past warm episodes in the historical record. This comparison will involve both the evolution of upper ocean properties in the NE Pacific, and their linkages to remote influences such as ENSO.

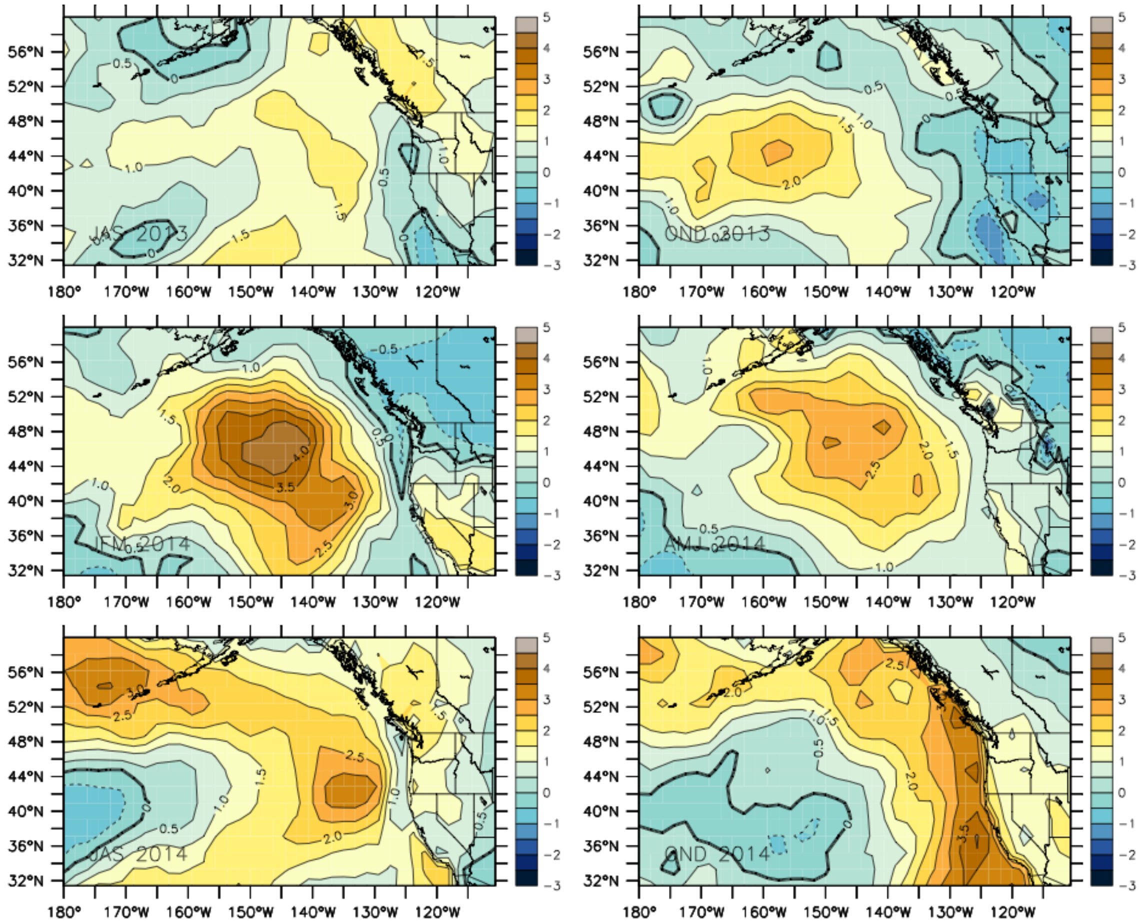

Figure 1. Skin temperature anomalies in units of standard deviations from the 1981-2010 climatological mean for JAS 2013 (upper left); OND 2013 (upper right); JFM

2014 (middle left); AMJ 2014 (middle right); JAS 2014 (lower left); and OND 2014 (lower right).

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Bond, N.A., M.F. Cronin, H. Freeland and N. Mantua, 2015: Causes and impacts of the 2014 warm anomaly in the NE Pacific. Geophysical Research Letters, doi: 10.1002/2015GL063306.

Effect of the "Blob" on shelf water properties in the NE Pacific

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ABSTRACT

The anomalously warm water mass in the NE Pacific, "the Blob," has strongly perturbed NE Pacific waters since 2013. Here we explore the effect of this anomaly on shelf and slope water properties, using a high-resolution (1.5 km) realistic hindcast model. The model, LiveOcean (http://faculty.washington.edu/pmacc/LO/LiveOcean.html) is run as a daily forecast, and has been run continuously since January 2013. The model is forced with realistic WRF winds, tides, 16 rivers, and open ocean boundary conditions supplied by the global data-assimilative HYCOM model (10 km resolution). The perturbations due to the Blob are compared with other sources of variability over the model domain 43-50 N.

The warm NEP conditions – A Canadian assessment of the dynamics and status

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ABSTRACT

The anomalously warm ocean surface conditions in the northeast Pacific developed in late 2013 and early 2014 as a result of a weak Aleutian Low and minimal related storm activity. Ekman pumping and mixed layer turbulence were significantly reduced, resulting in a reduction of cooling from below, rather than any significant increase in heating. By early 2014 analysis of various surface temperature sources revealed a statistically remarkable event was developing. The "Blob" has subsequently been tracked and monitored for nearly two years, and although present (November 2015) satellite imagery might suggest it is waning or breaking-up, subsurface data from ARGO floats near station Papa indicate it still remains quite intact and extends to over 200m in depth. Looking back, there is evidence that the regional atmospheric conditions in all of 2013 were anomalous, and that at least one smoking gun may point to major processes in the Arctic in 2012-13 and the coupling between the Arctic Vortex and the northern Jet Stream, among other possible causes. Looking further back, some similar conditions existed in 1977 and 2005, but the 2013-15 collection of events and records have exceeded all past extremes or comparable "regimes".

Effects of changing coastal conditions in 2014 on nutrients and productivity in the northern California upwelling ecosystem

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ABSTRACT

In May 2013 and 2014 vertical profiles of concentrations of nutrients and chlorophyll, along with rates of primary productivity and nutrient uptake measured with 13C and 15N were collected along transects made at Davenport, Pescadero, Point Reyes and Fort Ross (northern California) during Rockfish Recruitment Assessment cruises led by NOAA-NMFS South West Fisheries Center. These data will be compared between years and used to evaluate if the warming in 2014 influenced the productivity, so linking the climatological event with the food web changes described by others. Having rate data in addition to nutrient and chlorophyll standing stock may contribute to understanding the mechanisms of the ecological response. In addition, these data may help fill in the northern California geographical data gap of the first workshop.

Anomalously high surface water fCO_2 values in the 2014-15 NE Pacific warm water "Blob"

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ABSTRACT
Since 2014 SSTs in the Northeast Pacific Ocean (NEP) reached historically high levels exceeding more than 2°C warmer than normal (Figure 1). This mass of anomalously warm water has been centered in the eastern and central North Pacific and, more recently, along the Pacific coast from Canada to Mexico (Bond et al., 2015). Concomitant with the large SST anomalies from January 2014 through May 2015 are higher than normal surface water fCO2 values (400-450 µatm; Figure 2), which exceed atmosphere values in this region by as much as 60 µatm (Figure 3). These preliminary results indicate the surface water fCO2 values have changed along the cruise track, causing the region to transition from a carbon dioxide sink to a source during the warm season from March to November. If this mass of anomalously warm water continues to expand these changes to the oceanic carbon sink in the region could have significant implications for the oceanic carbon budget.

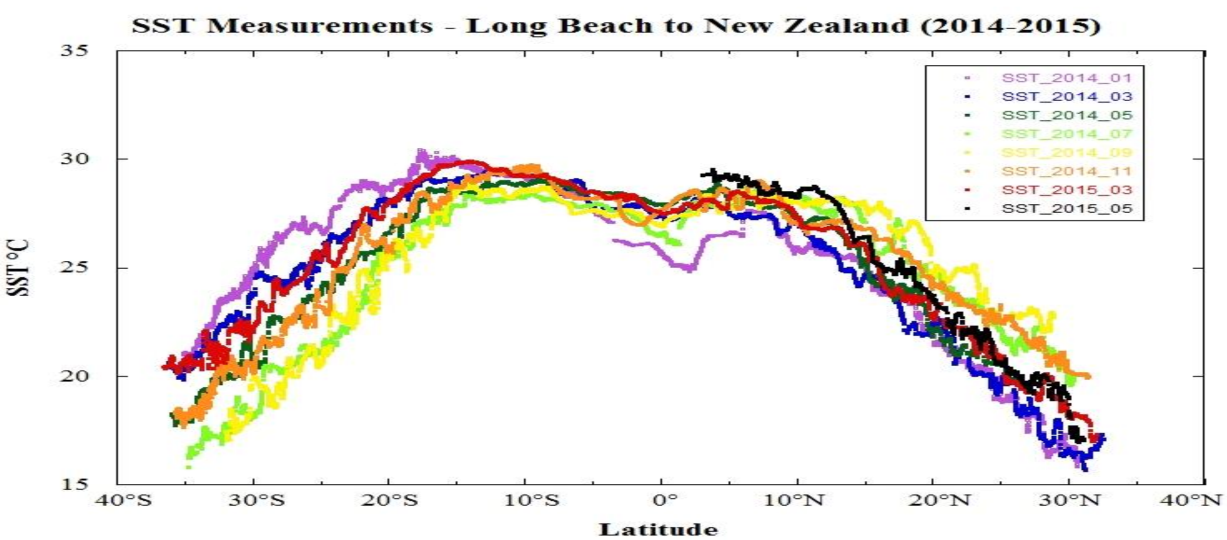

Figure 1. Sea Surface Temperature (SST) from Long Beach to New Zealand

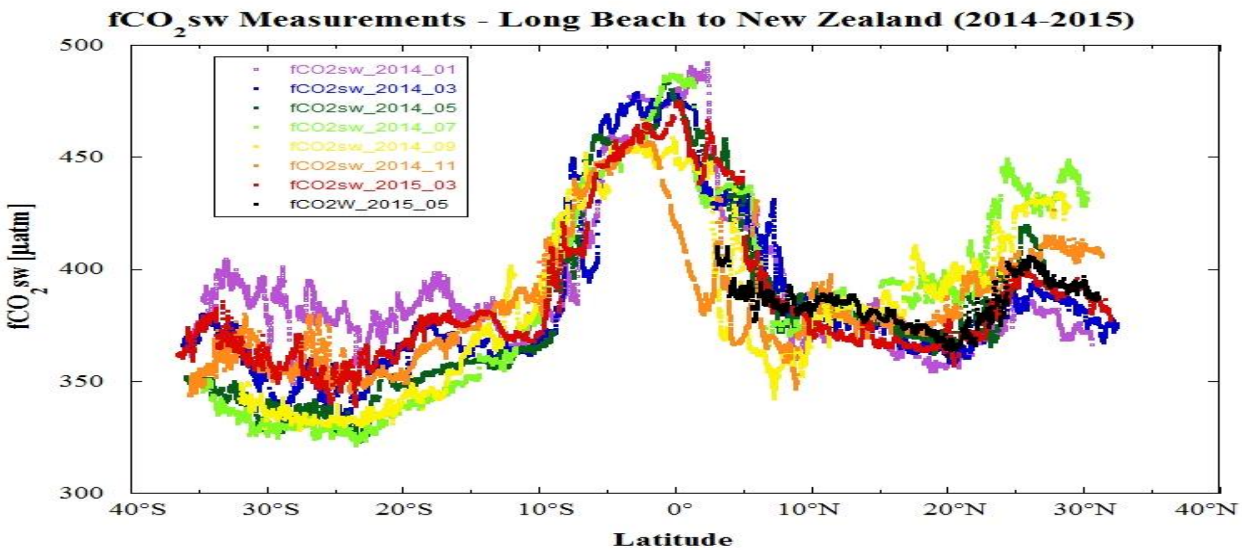

Figure 2. Surface ocean fCO_2 (in µatm) from Long Beach to New Zealand

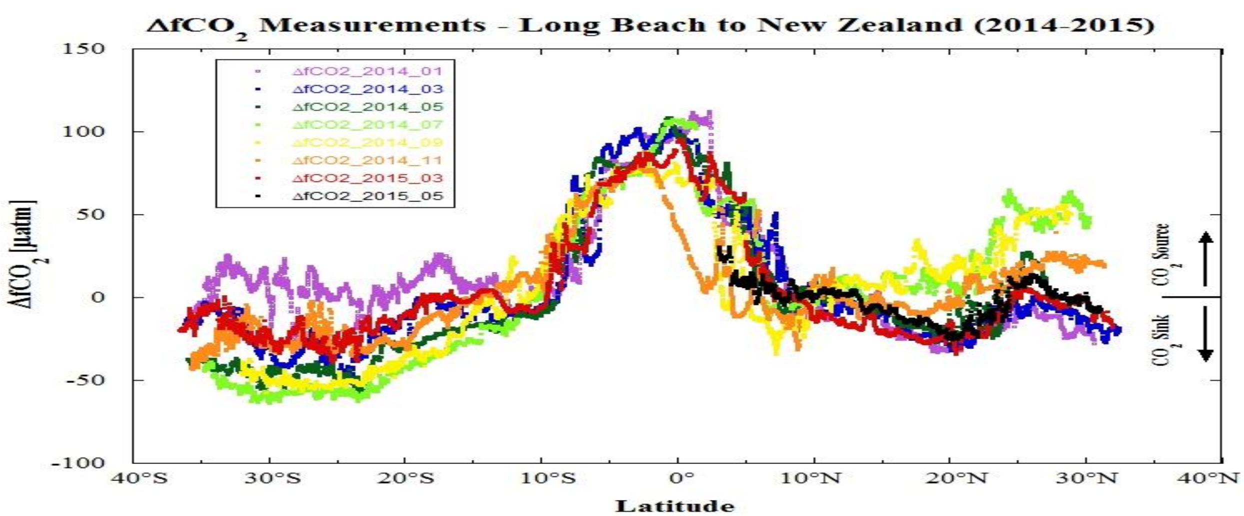

Figure 3. Surface ocean ΔfCO_2 (in µatm) from Long Beach to New Zealand

Effects of the 2013-2015 warm anomaly in Prince William Sound

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ABSTRACT

The surface waters in Prince William Sound switched from a generally negative temperature anomaly to a positive one in the last quarter of 2013, approximately the same time as the formation of the large warm anomaly in the Gulf of Alaska. Temperatures were ~1.5-2°C above average over most of the water column for 2014 and into 2015 (fig. 1). The effect was great enough to overwhelm a cooling and fresehening trend (presumably caused by precipitation onto ice sheets and loss of ice mass) observed in surface waters of the Northwest portion of the Sound in recent years. The spring bloom in central PWS was remarkably different between 2014 and 2015: 2014 was possibly the earliest on record with nitrate concentrations approaching zero several weeks ahead of schedule. The 2015 bloom was approximately on time, but was quite small and episodic, and often did not result in a full drawdown of nitrate. The zooplankton species assemblage in the Sound also appeared to change somewhat, although there was not the influx of traditionally "southern" species observed on the shelf; some inshore locations may function as refugia for those species. There was also some suggestion of a shift in phenology in the timing of the appearance of different species.

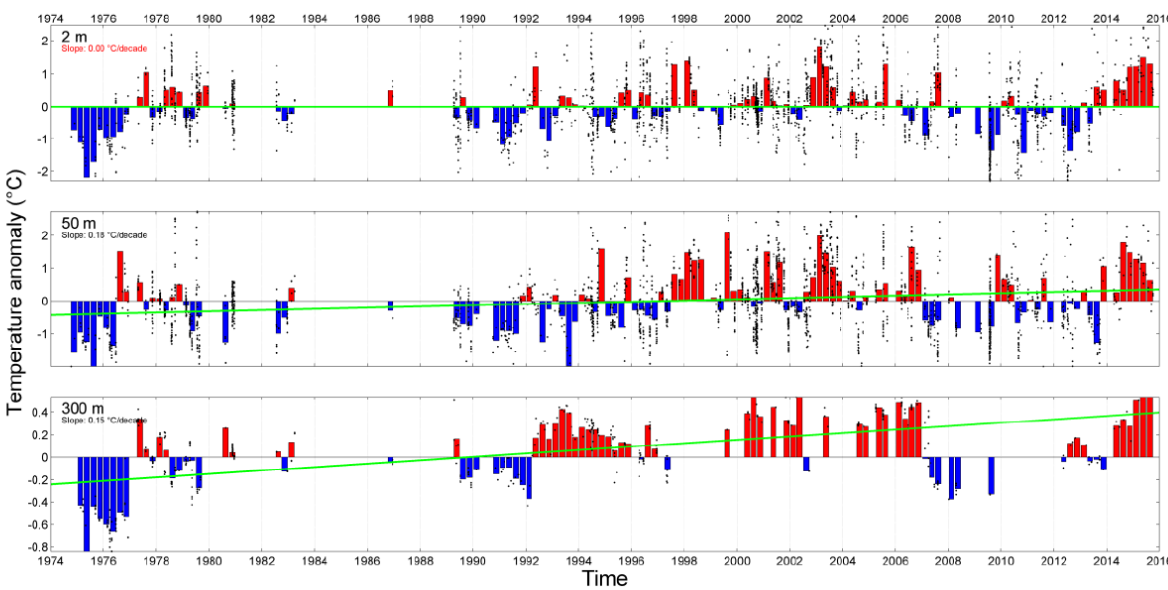

Figure 1: Temperature anomalies at three depths in central PWS, 1974-2015.

Thermohaline anomalies in the northern Gulf of Alaska, 1970 to 2015

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ABSTRACT

Temperature and salinity anomalies are examined from three long-term conductivity-temperature-depth (CTD) time series datasets in the northern Gulf of Alaska (GOA). Near-coast oceanographic monitoring station GAK1 is located at the mouth of Resurrection Bay near Seward, with nominally monthly vertical profiles that extend from the present back to 1970 and hourly moored time series from six depth levels since 2000. The Seward Line transect of hydrographic stations extends from station GAK1 more than 200 km across the shelf to the continental slope and has been occupied 67 times since 1997 and 84 times since 1974. In southeast Alaska, CTD profiles were taken approximately quarterly in Glacier Bay over 1992-2008 and eight times per year since 2009. We summarize the data from these three time series in order to examine the temporal and spatial (depth; along-shelf; across-shelf) extents of the recent thermohaline anomalies. 2015 Seward Line temperature anomalies at depth are the largest observed here shelf since the blob's onset, with temperatures 1.5-2.5 standard deviations (~ 0.5-1.5 □C) above normal in May between 50 and 200 m depth. These temperatures were associated with a negative salinity anomaly of ~ 0.25. Shelf temperatures in September 2015 were mostly 0.5-1.0 □C above normal, with suggestions of a stronger and shallower seasonal pycnocline.

The effects of the anomalous warming on lower trophic levels in the NE Pacific, from Continuous Plankton Recorder sampling

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ABSTRACT

Continuous Plankton Recorders (CPRs) were first deployed in the NE Pacific in 2000 so that there is now a 15-year time series of taxonomically resolved, lower trophic level abundance data. During this time the ocean has experienced periods of warmer and colder conditions, as indexed by the Pacific Decadal Oscillation, with noticeable responses in the plankton such as a higher abundance of warm water species and a more northerly distribution in warm years, or a later spring zooplankton increase in colder years. This presentation will compare 2014 data and provisional 2015 data, collected during the anomalous warming, with the preceding time series for two contrasting regions that had good CPR sampling coverage; the oceanic NE Pacific and the central Alaskan Shelf. Preliminary findings suggest that some of the planktonic responses to the anomalous warming were in-line with previous warm conditions in the mid-2000s, but some were not. For example: The larger diatoms that the CPR samples were unusually low in both region and comprised a higher proportion of long, narrow cells than normal. Zooplankton biomass was very high through 2014 on the Alaskan shelf and the previously strong positive relationship between diatoms and zooplankton biomass did not hold true in 2014. Warm water copepods were more numerous in both regions than in recent cold years, but not as numerous as expected in the oceanic region. Some speculative conclusions will be drawn and it is hoped that these data can contribute to a larger understanding of the impact of the unusual conditions on the marine ecosystem.

Using ecosystem indicators to track effects of recent warm conditions in Alaska's Large Marine Ecosystems

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ABSTRACT
A comprehensive suite of ecosystem indicators, defined simply here as time-series of data that measure some component of an ecosystem, can provide a holistic and long-term view of ecosystem status and response to change. In Alaska, marine ecosystem indicators are tracked in the Gulf of Alaska, Aleutian Islands and eastern Bering Sea to inform annual ecosystem assessments for managers and scientists, and in particular, to inform ecosystem-based fisheries management. We will present the most recent indicator-based assessments of these three large marine ecosystems (LMEs) that integrate data from climate and oceanographic indicators through lower and upper-trophic biological indicators and highlight regional and species-specific apparent responses to the recent warm anomalies in the North Pacific. We will use comparisons among the three LMEs to illustrate how the effects of the anomalies may propagate through ecosystems and food webs. In general, we expect to see more changes in indicators' status that may be attributed to the Warm Blob in the Gulf of Alaska relative to the other LMEs, as a result of the proximity of the Gulf of Alaska to the areas where the temperature anomalies originated. In the eastern Bering Sea, which is separated from the North Pacific by the Aleutian Island chain, we expect to see more modulated responses. We will discuss the types of biological indicators that are expected to show direct responses to temperatures, such as changes in species distribution, compared to those that may show lagged effects.

AXBT observation of upper-ocean temperature during CalWater2

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ABSTRACT
The CalWater2 is a multi-agency supported field campaign conducted during the January-March 2015 period over the Northern California coast to study the Atmospheric River (AR). To assess the AR upstream moisture evolution over the ocean prior to landfall, we deployed 148 Airborne eXpendable Bathy Thermographs (AXBTs) from NOAA P-3 in order to investigate the upper-ocean temperature changes that arise before, during, and after the AR events. These AXBT deployments are released in tandem with co-located atmosphere dropsondes. Together, the AXBT and dropsondes provided a four dimensional depiction of the atmosphere and ocean boundary layer, which can be used to validate and study the impact the coupled air-ocean model forecast of the AR. Comparisons of the AXBT profiles before and after the AR passage showed the ocean surface cools about 0.5 °C after the passage of AR, but the subsurface temperature in average over the AXBT sample area warms about 0.35 °C. It is also noticed that the position of the California current system warm/cold core eddies shifted within the two week sample period. During the AR, a strong upwelling led to a layer mean temperature of approximately 12 °C over the upper 100 m of the ocean. The AXBT cross section analysis indicates the upwelling does not reach the ocean surface. The maximum horizontal ocean temperature gradient across this upwelling region is on the order of 5-6 °C per 50 km. In contrast, the temperatures collected in the pre- and post-AR periods on the 27 Jan and 9 Feb near these two cross sections show the temperature variability is only about 1-2 °C. Interestingly,very warm SST anomalies persist from mid-2014 to 2015 along the US West Coast. The observed AXBT profile is consistent with the trend of warming and is well outside the 2 standard deviation climate variability envelope in the upper 80 m. We will discuss in detail the analysis of these AXBTs and the derived fluxes from a combination of the axbt-dropsonde data as well as coupled and uncoupled adjoint modeling effort to further investigate the sensitivity of the air-sea energy transfer during the AR.

Tropical Connections to the Eastern Pacific Warm Anomalies

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ABSTRACT

We use altimeter data to investigate whether there have been connections between the warm anomalies along the northeast margin of the Pacific Ocean during 2014-15 and the eastern boundary of the ocean in the tropics. In particular, are there connections to the abbreviated 2014 El Niño and the developing 2015 El Niño? Alongtrack altimeter data in the 100 km next to the coast during 1997-98 provide a record of the temporal development of that event along the ocean margin between 50°S and 50°N (Figure 1, top). Similar data during 2014-15 demonstrate the degree to which the equatorial connections in sea level were similar (Figure 1, bottom). During 2014, higher sea levels appeared at the Equator during April and progressed rapidly down the coast of South America and along the coast of Central America to approximately 15°N, then more slowly to the tip of Baja California, reaching 23°-30°N by July 2014. This signal diminished in August, reappearing with no tropical connections in September-October. Thus there may have been an initial contribution from the tropics to the anomaly off Baja California in July, but not to the later anomalies. At the lower latitudes, this is similar to the development of the first pulse of high sea level that developed in May 1997 and moved rapidly down the South American coast but stalled off Baja California in the Northern Hemisphere. During 2015, the sea level signals at the equator have resembled those of 1997, with pulses divided into May-June and August-November (to date). Each of these spread into the Northern and Southern Hemispheres. Off North America, the tropical signals added to higher sea levels that were already in place. Further analysis of the altimeter data are needed to better define the signals that moved from the lower latitudes and the extent to which it enhanced the existing anomaly. Comparisons of the two hemispheres helps to identify signals that are propagating away from the equator as opposed to those that appear due to local processes, which have no reason to be symmetrical, especially considering the opposite seasonal influences in the two hemispheres.

Eastern Pacific Coastal (0-100km) Coastal Median Height: Monthly Seasons Removed

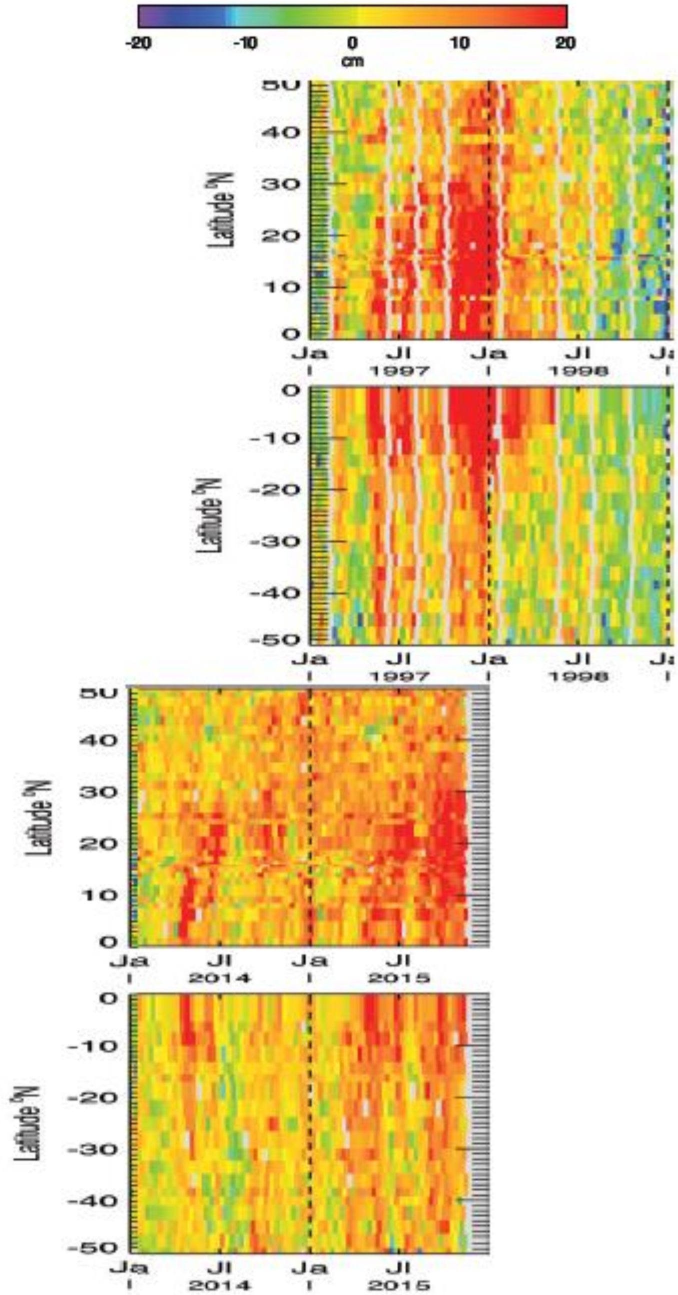

Figure 1. Time-latitude plot of altimeter sea level anomaly, as determined by the median height along the altimeter tracks within 100km of the coast. The 20-year temporal mean for 1993-2012 has been subtracted from each alongtrack location. No long-term trend has been removed.

Mass mortality of Cassin's auklets in 2014-15: Legacy of the Blob?

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[3]NOAA Fisheries, Hatfield Marine Science Center, OR, USA (Email: bill.peterson@noaa.gov)
[4]Wildlife Research Division, Environment Canada, BC, Canada (Email: Mark.Hipfner@ec.gc.ca)
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ABSTRACT

In the late summer and early fall of 2014, untoward numbers of Cassin's Auklets (*Ptychoramphus aleuticus*) washed ashore starting in northern California (Nov) and progressing northward into northern Oregon and the outer coast of Washington (Dec-Feb). Three citizen science programs with hundreds of trained data collectors collectively monitoring over 200 beach sites at least monthly documented monthly encounter rates of new (not previously encountered) carcasses 1-3 orders of magnitude above regional long-term averages. Across the four month event, more than 8,000 carcasses were found. Although the data collection effort was large, it represented less than 2% of kilometer days, indicating that total deposition may have been in the hundreds of thousands.

We used a multivariate approach to begin exploring relationships between annualized auklet encounter rates in the highest deposition area (43-48.5^{o}N) in Oct-Feb and a four nonexclusive forcing factors:

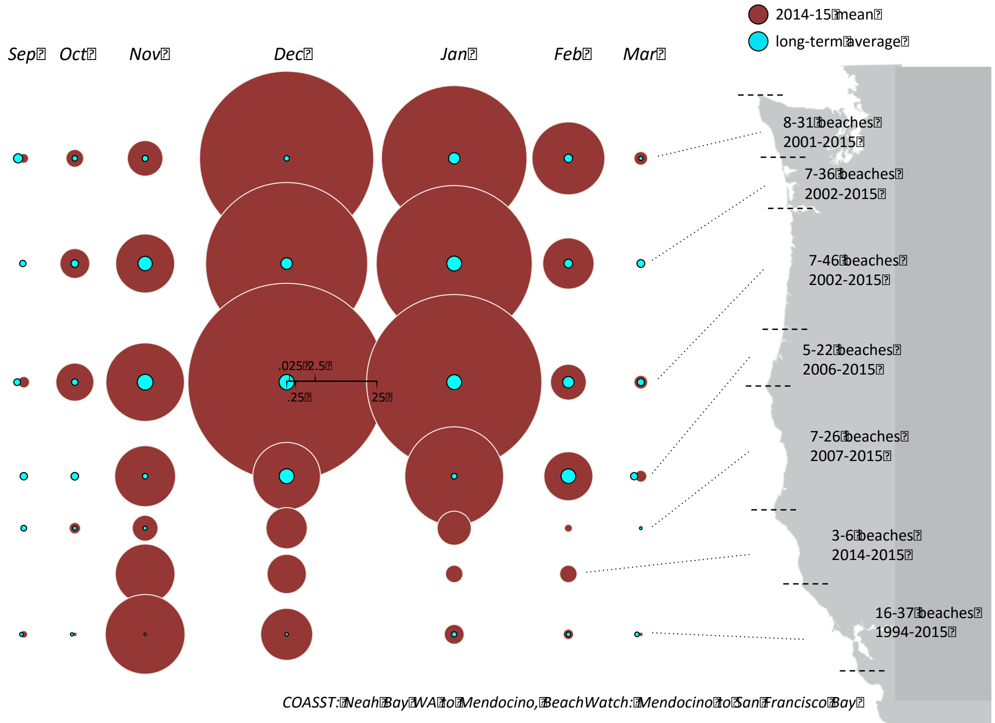
1. ***Colony production***, proxied by 25-day chick mass on Triangle Island, BC, the colony housing ~70% of the world's population of ~3M birds (1996-2015). Hypothesis: more chicks = more carcasses through expected juvenile mortality as Canadian birds disperse south along the Pacific Northwest coastline.
2. ***Food type and availability***, proxied by southern and northern copepod biomass, respectively, along the Newport Line (1969-2015). Hypotheses: higher abundance of northern assemblage = fewer carcasses due to better food supply, and vice versa.
3. **Post-breeding habitat availability**, proxied by the area within contiguous 2^{o} latitude bands out to 200km (38-50^{o}N) exceeding an SST anomaly of >1^{o}C (1981-2015). Hypothesis: narrower strip of available cold water equates to habitat compression = more carcasses as live population moves closer to shore increasing the chance of beaching regardless of mortality rate.
4. ***Winter storminess***, proxied by significant wave height event number and duration recorded at 5 buoys along the PNW coastline (1991-2015). Hypothesis: increased storm exposure = more carcasses via physiological stress, or winterkill.

where all variables were generated as annualized anomalies over the year range specified above. All possible GLM combinations of these five predictors listed above, as well as all two-way interactions, were evaluated and models were ranked based on AICc. The response variable of CAAU annual encounter rate were weighted when fitting the model to account for differences in survey effort among years. Of 15 initial models, including all main effects and interactions, highest ranking (AICc) models included the sole effect of southern copepod biomass, and this factor with the added effect of the proportion of habitat with an SST anomaly >1^{o}C. Both factors were explanatory even excluding the outlier point 2014, which drove the full time window relationships. There were no discernable effects of colony-based variables or storminess.

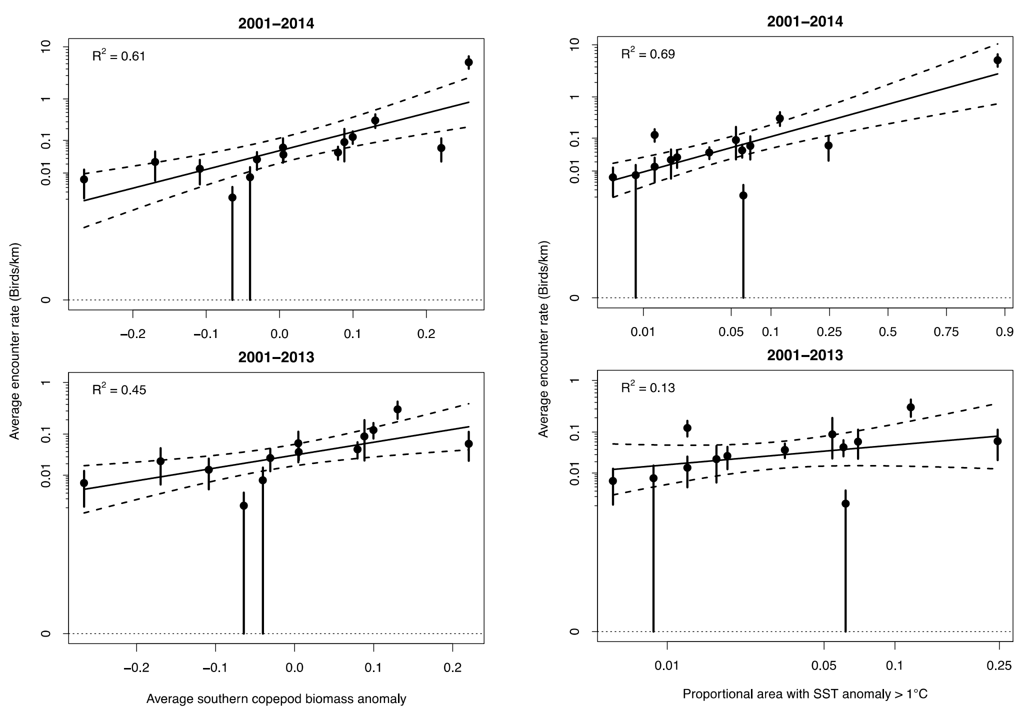
These preliminary analyses suggest that introgression of the “wrong” type of food – smaller, less energetically valuable copepods may have stressed dispersing auklets, and that this stressed population may have simultaneously been compressed into remnant cold water concentrated along the coastline as seasonal upwelling broke down and downwelling pushed offshore anomalously warm water to shore.

Figure 1. Scaled regionalized monthly encounter rate (carcasses/km) of Cassin’s Auklets on beaches throughout the Pacific Northwest showing the average of the 2014-15 season (red) relative to the long-term average (blue), where the latter is calculated over a variable number of years (see region). Copepod data are from COASST and Beach Watch, two citizen science programs.

Figure 2. *left side*: Annualized encounter rate of Cassin’s Auklets as a function of the biomass anomaly of southern copepods collected in surveys of the Newport Line. top: including the 2014-15 point, bottom: excluding the 014-15 point. Data are courtesy of Bill Peterson, NOAA. *right side*: same as at left, excepting the predictor variable is the proportional area between 43^{o} and 48^{o}N and out to 200 km with an SST anomaly greater than 1^{o}C. SST data are courtesy of Nick Bond.



2014-15 mean
long-term average
Sep
Oct
Nov
Dec
Jan
Feb
Mar
.025
2.5
.25
25
8-31 beaches
2001-2015
7-36 beaches
2002-2015
7-46 beaches
2002-2015
5-22 beaches
2006-2015
7-26 beaches
2007-2015
3-6 beaches
2014-2015
16-37 beaches
1994-2015
COASST: Neah Bay WA to Mendocino, BeachWatch: Mendocino to San Francisco Bay



2001–2014
R2 = 0.61
2001–2014
R2 = 0.69
2001–2013
R2 = 0.45
2001–2013
R2 = 0.13
Average encounter rate (Birds/km)
Average southern copepod biomass anomaly
Proportional area with SST anomaly > 1°C

Three years of NE Pacific Ocean variability observed with satellite imagery

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ABSTRACT

The West Coast Regional Node of NOAA CoastWatch has been monitoring ocean surface characteristics over the last three years to capture the evolution of Northeast Pacific SST anomalies and the ongoing El Niño. These data are presented to illustrate the temporal and spatial variability occurring during this anomalously warm period and to provide a large-scale context to the regional data presented at the PAW2 meeting.

Decreases in standing biomass and physiological state of giant kelp canopy during the 2014 – 2015 warming event in the Santa Barbara Channel

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ABSTRACT
Giant kelp (*Macrocystis pyrifera*) is an ecosystem engineer that serves as the foundation species to an incredibly diverse and productive ecosystem on shallow (<30m), sub-tidal rocky reefs across the globe. Reductions in giant kelp populations can have adverse effects on the recruitment of many fish species and the health of invertebrates that feed on drift kelp, negatively affecting fisheries (reviewed in Leet et al. 2001). Kelp canopy dynamics are more closely associated with changes in nutrients than disturbance in areas protected from large northwest swell, such as the Santa Barbara Channel (Bell et al. 2015a). Therefore, we can expect negative effects on this foundation species during the anomalous warming of the California coastal ocean in 2014, which featured persistent low-nutrient conditions.

Here we present data on local giant kelp forests along the northern coast of the Santa Barbara Channel collected by the Santa Barbara Coastal Long Term Ecological Research project (SBC LTER) and well as aerial hyperspectral (AVIRIS) and multispectral satellite imagery (Landsat 7 ETM+; Landsat 8 OLI). During the period from 2014 – early 2015 we observed declines in the amount of canopy biomass of these forests during the anomalous warm event, leading to complete absence in late 2015, most likely associated with the present El Niño event. This initial decrease in biomass was associated with a lightening of canopy blade color (Fig.1), which was associated with a decrease in chlorophyll *a* pigment concentrations in the blades as well as the chlorophyll *a* to carbon ratio (Chl:C; Fig. 2), a proxy for physiological condition (Bell et al. 2015b). Hyperspectral aerial imagery showed the temporal and spatial variability in Chl:C throughout the Santa Barbara Channel during the anomalous period.

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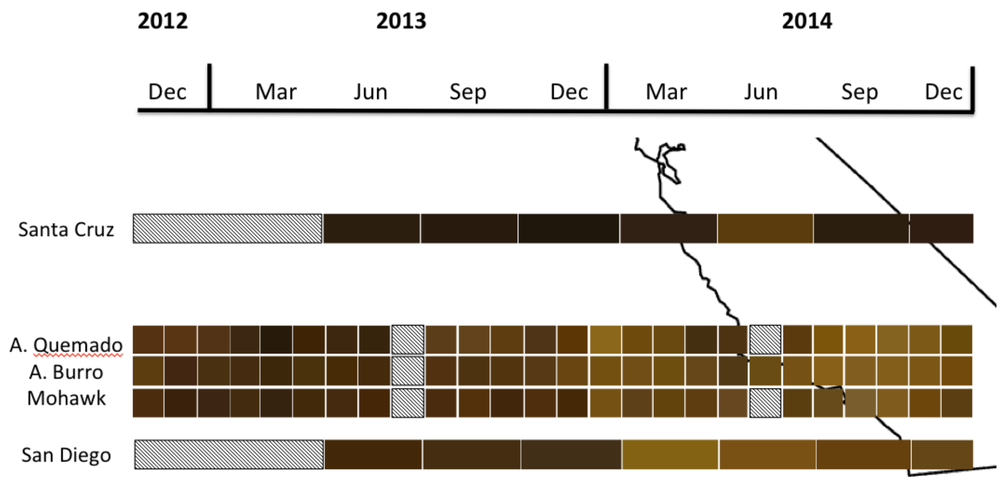

Figure 1. Time series of giant kelp canopy blade color from 3 sites in the Santa Barbara Channel (Arroyo Quemado, Arroyo Burro, & Mohawk reefs) as well as 2 sites at the extreme north and south of this species' range of dominance in California. Dashed boxes represent missing data.

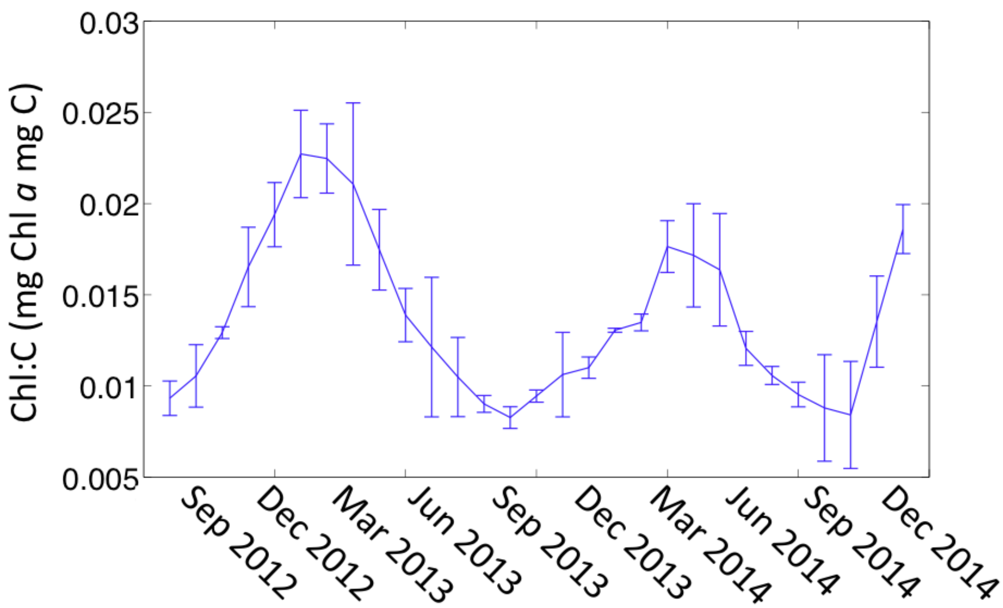

Figure 2. Time series of chlorophyll *a* to carbon ratio (Chl:C) in the canopy blades of 3 giant kelp forests in the Santa Barbara Channel. Error bars represent standard error.

"Blob" Tracking with Robotic Swarms

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ABSTRACT
We present our initial development of a swarm of in-situ ocean trackers. We begin with simulated models and then show these models at work on real hardware operating in the water and managed by high-level tunable parameters. "Sea-trials" were conducted using very simple robotic model-scale boats with limited intervehicle communication. The "swarm" comprising about two-dozen boats was set in a shallow saltwater intertidal basin. Three collective behaviors were demonstrated: a cohesive, dynamic size-varying behavior, migration up a gradient, and piloted motion.

Additional simulations demonstrate adaptive behavior where the swarm location is constantly updated by spontaneous group behavior in direct response to in-situ measurements.