VARIATIONS

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A Tale of Two Blobs

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From 2013 to 2015, the scientific community and the media were enthralled with two anomalous sea surface temperature events, both getting the moniker the "Blob," although one was warm and one was cold. These events occurred during a period of record-setting global mean surface temperatures. This edition focuses on the timing and extent, possible mechanisms, and impacts of these unusual ocean heat anomalies, and what we might expect in the future as climate changes.

The "Warm Blob" feature appeared in the North Pacific during winter 2013 and was first identified by Nick Bond, University of Washington. This record-breaking event remained through 2015, morphing in shape and causing widespread impacts on the marine ecosystem. Scientists are still answering questions such as whether the warm blob could have played a role in the strong 2015-16 El Niño event and whether these multi-year climate extremes (e.g., marine heatwaves) will become more frequent in a warming climate.

The North Atlantic experienced a record-breaking cold ocean

The evolution and known atmospheric forcing mechanisms behind the 2013-2015 North Pacific warm anomalies

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Year-to-year variations in the El Niño Southern Oscillation (ENSO) indices generate significant interest throughout the general public and the scientific community due to the sometimes destructive nature of this climate mode. For example, so-called "Godzilla" ENSOs can generate billions of dollars in damages from the US agricultural industry alone due to unanticipated flooding or drought (Adams et al. 1999). However, in the winter of 2013/2014, North Pacific sea surface temperature (SST) anomalies exceeded three standard deviations above the mean over a large region, shifting focus away from the tropics and onto the extratropics as the associated atmospheric circulation patterns helped exacerbate the most significant California drought in the instrumental record (Swain et al. 2014; Griffin and Anchukaitis 2014). This extratropical warming has since become known in the media and the literature simply as "the Blob" or "the Warm Blob" and represents a climate state unlike anything seen in the last 30 years (Figure 1; Bond et al. 2015).

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surface temperature, dubbed the "Cold Blob," during 2015 in a region southeast of Greenland. This surface layer cooling has been mostly attributed to air-sea heat loss and ocean heat content anomalies. However, how it formed and if it will stay is still up for debate. The Atlantic Meridional Overturning Circulation may play a role, as well as the decadal variability of the North Atlantic Oscillation. Scientists are also looking into whether meltwater from the Greenland ice sheet could influence and cold blob, with modeling results presented herein suggesting that it doesn't.

The series of articles in this edition highlight research of the North Pacific warm blob—featuring contributions by Amaya et al., Siedelecki et al., and Di Lorenzo et al.—and the North Atlantic cold blob—featuring contributions by Duchez et al., Yeager et al., and Schmittner et al. This collection aims to highlight recent work, theories, and advancements in understanding these phenomena with an aim to stimulate discussion within the community. To facilitate this, a series of webinars will be hosted with the authors in June, with more information found on page 38.

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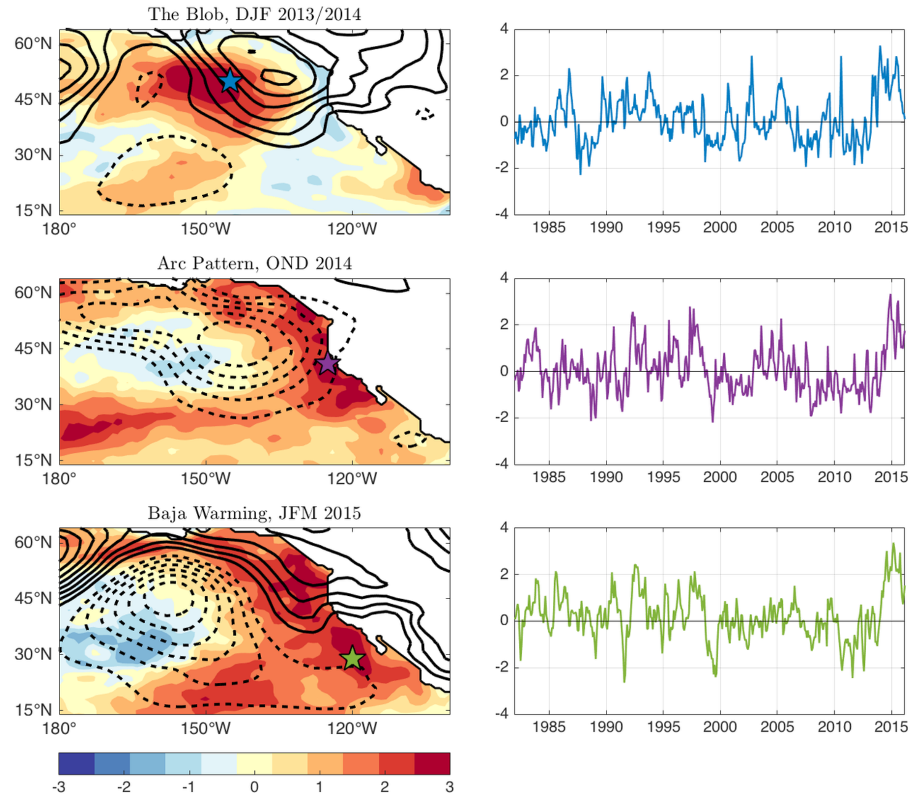

Figure 1. Normalized SST anomalies (shading) and SLP anomalies in millibars (contours) averaged over December-February (DJF) 2013/2014 (top row), October-December (OND) 2014, and January-March (JFM) 2015. Positive SLP values are solid contours, negative values are dashed, and the contour interval is 1 mb. Colored stars indicate the point location for the respective SST anomaly time series found to the right of each map. SST data for this figure are from NOAA Optimally Interpolated Sea Surface Temperature Version 2 (OISSTv2), and SLP data are from NCEP/NCAR Reanalysis.

The Warm Blob is both unprecedented in magnitude and remarkably persistent as it has hung around in various shapes and sizes since that first winter of 2013/2014 to the present. Godzilla El Niño will at least decay within a year, but the Warm Blob's lingering effects have raised concerns for our understanding of the region, our ability to predict future such events, and the role of anthropogenic climate change in maintaining North Pacific warming. Here, we present a synthesis of what is currently known about the Warm Blob with respect to its historical magnitude and persistence.

"Doctor, nothing will stop it!"-The Blob (1958)

The conundrum that the Warm Blob presents is due, in part, to the fact that the center of action during the winter of 2013/2014 is only one part of a larger story. In reality, the North Pacific Blob has evolved in space over the course of the last three years, growing and decaying between three different centers of action each with three distinct forcing mechanisms. Normalized SST anomalies in the North Pacific for select seasons from 2013-2015 are shown in Figure 1. The canonical Blob first described by Bond et al. (2015) can be seen in the first row. The blue star marks the location of the Warm Blob time series on the right. Based on this curve and the work of several studies (e.g., Bond et al. 2015; Di Lorenzo and Mantua 2016) the Warm Blob is the largest Northeast Pacific SST anomaly seen in at least the last 30 years.

Sea level pressure (SLP) anomalies (black contours) outline a ridge of high-pressure on the eastern flank of the Warm Blob that exhibited strong persistence throughout much of 2013 and 2014, earning it the moniker, "Ridiculously Resilient Ridge" (hereafter called the Ridge). This Ridge caused persistent deflections of wintertime storms north of California, enhancing and sustaining drought conditions in the region (e.g., Swain et al. 2014). Additionally, downstream perturbations to the jet stream associated with the persistence of the Ridge helped generate the historically cold winter season across North America in 2013/2014 (Hartmann 2015). Various hypothesis have been proposed to explain the Ridge's resiliency, including remote teleconnections driven by warmer than normal conditions in the western tropical Pacific, which may have led to significant extratropical ocean-atmosphere feedbacks (Wang et al. 2014; Hartmann 2015; Lee et al. 2015; Seager et al. 2015). Another possibility is the influence of Arctic sea ice loss on North Pacific geopotential height fields through various thermal effects (Lee et al. 2015; Sewall and Sloan 2005; Kug et al. 2015). Atmospheric internal variability could have also played a role (Seager et al. 2015).

Regardless of the specific factors determining its genesis, the Ridge is the driving force behind our first center of action—the Blob (Figure 1, top row). The results of a mixed layer heat budget conducted by Bond et al. (2015) over the Warm Blob region are depicted in Figure 2. They show that the anticyclonic flow around the Ridge significantly reduced the strength of the background westerlies, which limited the amount of energy imparted by the atmosphere into the ocean for mixing processes. As a result, Bond et al. (2015) observed enhanced mixed layer stratification, decreased advection of cold water from the Bering Sea, reduced vertical entrainment of cold waters from below, and limited seasonal cooling of the upper ocean (Figure 2). These results highlight the fact that the Warm Blob owes its existence not to processes that actively warmed the mixed layer, but simply due to a lack of wintertime cooling in 2013/2014.

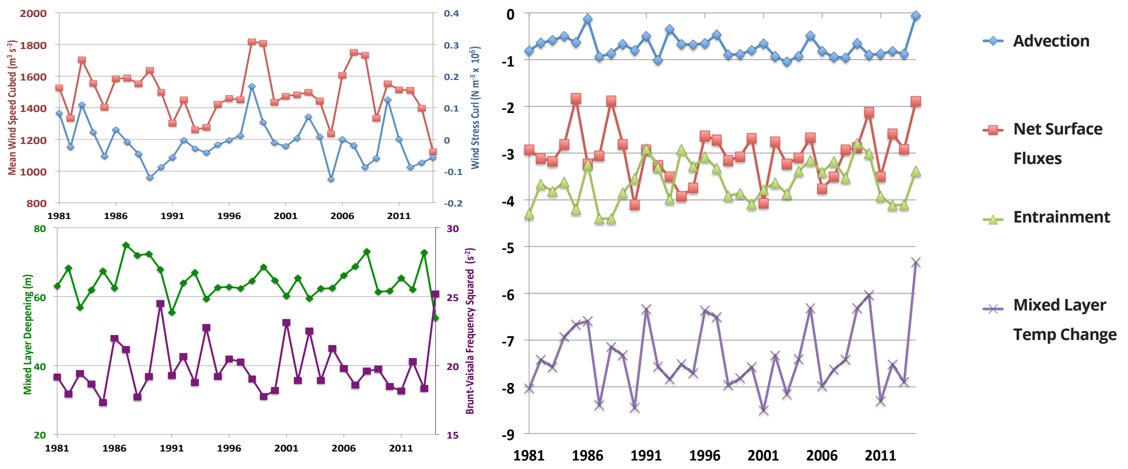

Figure 2. (top, left) Time series of seasonal mean (October–January) wind speed cubed (red) and wind stress curl (blue) for the area of 50–40°N, 150–135°W. (bottom, left) Time series of mean seasonal mixed layer deepening (September-February; green) and stratification at the base of the mixed layer (February; purple) for the area of 50–40°N, 150–135°W. The years refer to averaged January–February values. (right) Seasonal values of the mixed layer temperature change from September to February for the area of 50–40°N, 150–135°W (°C; purple) and budget terms contributing to this temperature change. Budget terms include horizontal advection (blue), net surface heat fluxes (red), and entrainment (light green). Values represent temperature change (°C) associated with the individual terms. Adapted from Bond et al. (2015).

A shift in forcing mechanisms

In early 2014 nearly every forecasting model predicted the arrival of a significant El Niño in the following winter. However, by the fall it became evident that the weak warming along the equatorial strip was not going to amplify into a major warm event. Even though the 2014/2015 El Niño fizzled out early, a recent study by Di Lorenzo and Mantua (2016) indicates that this equatorial warming may have been enough to produce a positive state of the Pacific North American (PNA) pattern, and in particular a relatively deep and southeast displaced Aleutian Low (Figure 1, second row). By breaking down the Ridge, the "El Niño that wasn't" altered the atmospheric forcing driving North Pacific warming the previous winter, and allowed the Warm Blob to evolve into something else entirely—the Arc Pattern.

In contrast to the more offshore Blob, the Arc Pattern is characterized by broad coastal warming, reminiscent of a Pacific Decadal Oscillation (PDO)-like structure (Figure 1, second row). The "arrival" of the Warm Blob onshore had substantial consequences for regional ecosystems in Gulf of Alaska all the way to the Baja California Peninsula (see Siedlecki et al., this issue) and also represented a 30-year record warming along the coast (Figure 1, second row). However, the preliminary research outlined above indicates that the Arc Pattern is not the result of the Warm Blob "moving" or advecting onshore, but rather a consequence of an entirely different forcing mechanism. Di Lorenzo and Mantua (2016) advance this theory by showing that a simple one-dimensional auto-regressive model based on a short-term memory of the SST and the altered SLP anomaly pattern in fall 2014 (deepened Aleutian low) can accurately reproduce the Arc Pattern warming.

In addition, Zaba and Rudnick (2016) used underwater glider data to suggest that the anomalous cyclonic circulation during this time period weakened the climatological upwelling favorable winds along the California coastline, which then suppressed upper ocean mixing and seasonal upwelling. Their observations indicated that once positive SST anomalies were established, a reduction in low-level cloud cover may have enhanced downward shortwave radiation at the surface, resulting in more SST warming and a positive feedback (Zaba and Rudnick 2016; Schwartz et al. 2014). While these results are primarily associated with the Southern California Current System, they illustrate the importance of different atmospheric forcing mechanisms in facilitating the transition from the Warm Blob to the Arc Pattern.

Baja warming and Godzilla El Niño

With 2014 drawing to a close, all signs once again pointed to the possibility of a strong El Niño in the following winter. The Aleutian Low maintained negative anomalies into early 2015, possibly as a result of these continued El Niño-like conditions. However, during the first few months of 2015, anomalously low pressures dipped further south and east into the tropics. This would tend to produce surface wind anomalies that opposed the climatological trade winds below 30˚N. Consequently, reduced evaporative cooling at the surface would drive a heat flux into the ocean and shift the center of action for North Pacific warming southward, off the coast of the Baja California Peninsula (Figure 1, last row). The transition to the Baja Warming Pattern is further highlighted by the three time series depicted in Figure 1. When the Baja Warming time series reaches a 30-year peak in January-March (JFM) 2015, the Arc Pattern time series sharply decreases to less positive values. To date, there is little published research on the transition from the Arc Pattern to Baja warming. Therefore, the mechanisms outlined above and to follow are merely the conjectures of the authors, and we encourage future study on the topic.

The Baja Warming Pattern has similar spatial characteristics to the Pacific Merdional Mode (Chiang and Vimont 2004). Thus, it is likely that air-sea interactions like the wind-evaporation-SST feedback and/or the low-level cloud/SST feedback play significant roles in maintaining the broad nature of the Baja Warming Pattern (e.g., Chiang and Vimont 2004; Di Lorenzo and Mantua 2016). Similarly, there are indications from preliminary results presented at the Pacific Anomalies Workshop II, held this January at the University of Washington, that coastally trapped Kelvin waves generated during the formation of the 2015/2016 El Niño may have contributed to the warming along the coastline of Mexico by suppressing upwelling. This signal could then propagate westward as Rossby waves and potentially enhance the broader-scale warming seen in Figure 1.

A final separate but related question would be, what was the role of the Baja Warming in generating the Godzilla El Niño of 2015/2016 in the first place? Feng et al. (2014) and others argue that SST anomalies off the coast of Baja California can act as a possible precursor of ENSO through the dynamics associated with the Pacific Merdional Mode. It is therefore possible that the Baja Warming Pattern, which had its origins in the Arc Pattern, helped drive the formation of a significant El Niño in 2015 that then could have potentially reinforced the Baja Warming further via the coastally trapped Kelvin waves.

The end of the Blob?

As predicted by nearly every model, the late 2015-early 2016 El Niño was one of the strongest tropical Pacific SST warming events ever captured by the instrumental record. This increased warming and associated strengthening in deep convection teleconnected to the North Pacific and helped deepen the Aleutian Low and drive the steady decline of the North Pacific warming features described previously. The JFM 2016 average SST and SLP anomalies in the North Pacific are shown in Figure 3. Here, we see the anomalous low-pressure center driving a PDO-like pattern of SST anomalies, with cold anomalies in the central North Pacific and warming along the southern, eastern, and northern edges of the Aleutian Low. These anomalies are most likely due to anomalous wind driven heat fluxes at each of these locations (e.g., Alexander and Scott 1997). As a result of this forcing, the Gulf of Alaska warming associated with the Blob has decayed to neutral values while the Arc Pattern and Baja Warming have weakened substantially (Figure 1, timeseries).

Is the Warm Blob gone for good? Based on current observations, this seems to be the case, at least for now. The anomalous warming in the Gulf of Alaska has weakened and then experienced a significant resurgence once before, from late 2014 to early 2015 (Figure 1), so it is difficult to make a prediction with high certainty. In particular, anomalously warm water below the mixed layer, as indicated by ARGO (not shown) suggests that the thermal "inertia" of this region may be especially high. Additionally, mid-April model projections suggest there is a 60% chance of La Niña conditions in the equatorial Pacific by the winter of 2016/2017 (CPC/IRI Probabilistic ENSO Forecast). La Niña tends to produce opposite signed anomalies in the Aleutian Low, and if the Ridge was the driving force of the Warm Blob in 2013/2014, then it is possible a La Niña-driven high-pressure anomaly over the Gulf of Alaska may give the Blob new life.

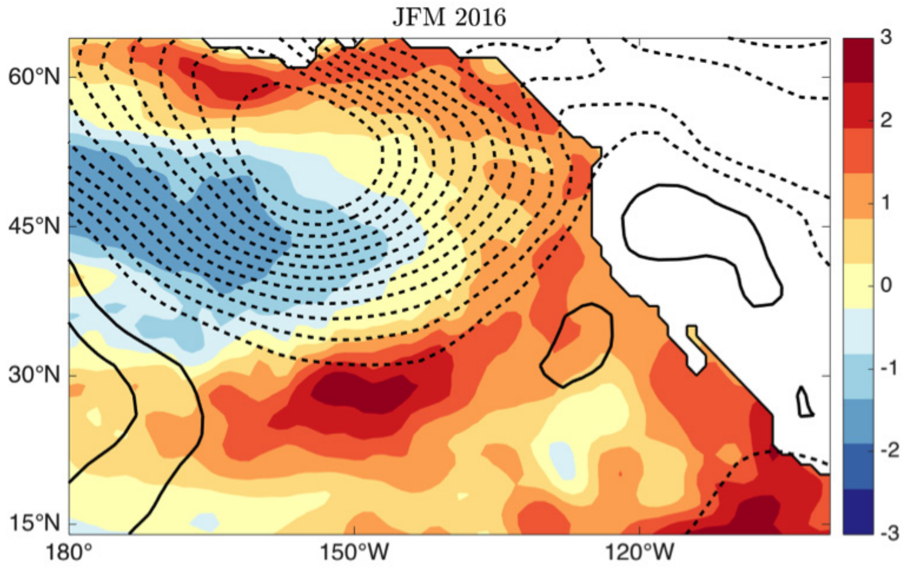

Figure 3: As in Figure 1, but SST and SLP anomalies are averaged from January-March (JFM) 2016. Data sources same as in Figure 1.

The warm anomalies throughout the Pacific from 2013 to present have been truly historic and have provided us with a significant opportunity to explore extratropical oceanic heat waves like never before due to the high spatiotemporal density of modern-day observational networks. We encourage future investigation into each of the centers of action described in this article, as well as a stronger focus on the role of the ocean-atmosphere interactions that may have led to transitions between them. As discussed in a later article these types of events may become more frequent in a changing climate. Therefore, it is of high socioeconomic concern to understand these phenomena moving forward.

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Impact of the Blob on the Northeast Pacific Ocean biogeochemistry and ecosystems

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During winter 2013-14, a region of unusually warm water now commonly referred to as the Blob (Bond et al. 2015) emerged in the North Pacific, due to a persistent high-pressure ridge that inhibited winter mixing, thus preventing typical cooling of surface waters. This physical disturbance persisted for more than a year and was associated with the strongest North Pacific Ocean warming of a non-El Niño pattern. The Blob was first apparent in the Gulf of Alaska (GOA), and then was evident off the US West Coast, where it intersected with the coastal California Current System (CCS).

While the physical disturbance into 2016 was compounded by another anomalously warm set of conditions driven by El Niño, the biogeochemical and ecosystem ramifications are still being sorted out and will likely remain impacted for years to come. This is a result of the important role temperature plays in biogeochemical cycles and ecosystem dynamics.

Temperature largely determines what biogeochemists call the solubility pump for carbon in the ocean. The solubility pump transports carbon from the ocean's surface to the deep interior as dissolved inorganic carbon. The same solubility pump affects all gases in the ocean to various degrees. For oxygen and carbon, the solubility is a strong inverse function of temperature, such that cold water has the greater capacity to hold more gas. This mostly impacts the gas concentrations and fluxes at the surface, but the signal is propagated through mixing downwards throughout the water column. Oxygen equilibrates quickly with the atmosphere, but carbon takes longer (~1 year). All of these processes combined result in outgassing for carbon and oxygen from the warming.

NOAA's Pacific Marine Environmental Laboratory (PMEL) has been monitoring sea surface CO_2 concentrations in the Pacific since 1982, including underway pCO_2 systems on six different container ships, which document changes in surface pCO_2 across the Pacific basin. One transect line traveled through the Blob region (15°N to 35°N). In that region, the decadal increase in pCO_2 values reached up to 49 µatm, which constitutes a 47% enrichment in pCO_2 due to the anomalously warm waters relative to the decadal change. This enhanced carbon source may have strong implications for the oceanic carbon budget during the Blob's existence, and has the potential to transition this region of the Northeast Pacific from a CO_2 sink to a CO_2 source (Cosca et al. 2016). Because CO_2 has a long