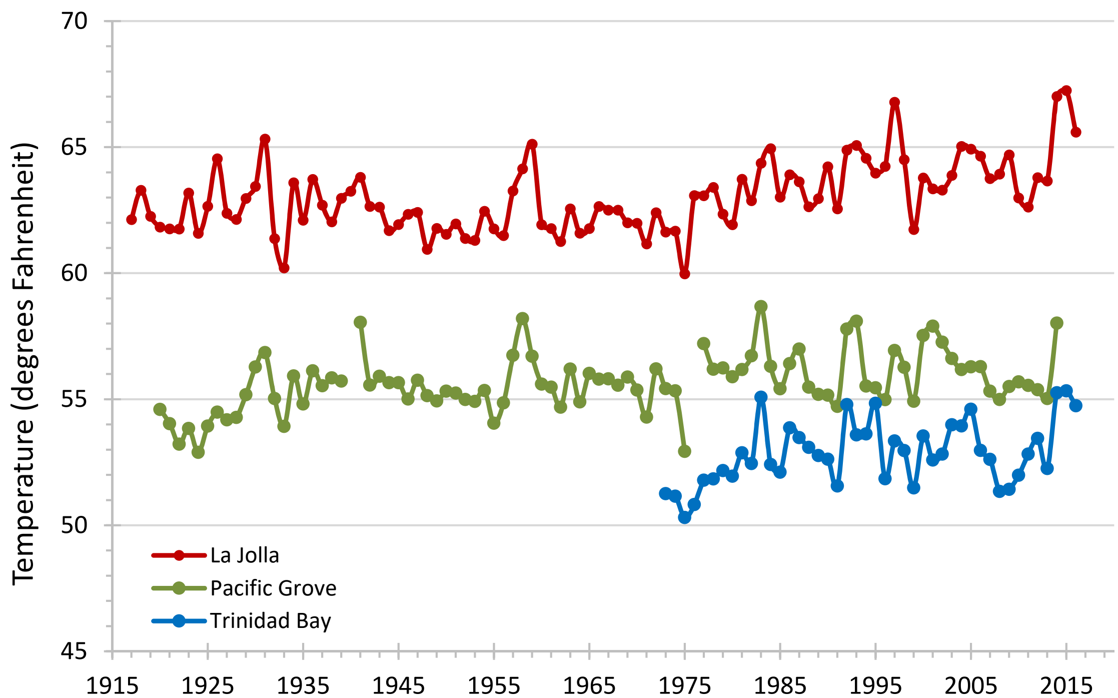
COASTAL OCEAN TEMPERATURE

Like global ocean temperatures, California coastal temperatures have warmed over the past century.

Figure 1. Annual average sea surface temperatures at selected coastal locations

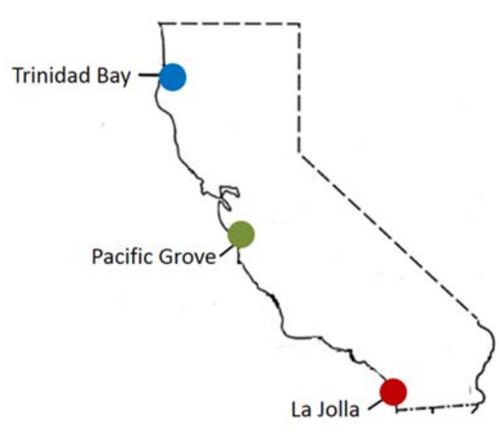


Source: SIO, 2017

What does the indicator show?

California coastal ocean temperatures have warmed over the past century. Although sea surface temperature (SST) fluctuates naturally each year, trends of sea surface warming are clearly detected. Specifically, as shown in Figure 1, SST has increased at the rate of 0.2 Fahrenheit (°F) per decade at Pacific Grove between 1920 and 2014. SSTs at La Jolla increased at about the same rate between 1917-2016, but at a faster rate of 0.6°F per decade since 1973. At Trinidad Bay, SSTs increased at the rate of 0.4°F per decade over the same shorter time period (1973-2016). (See Figure 2 for coastal measurement locations.)

Figure 2. Location of coastal sites



Source: Modified from SIO, 2017

These observations are consistent with those observed globally. Global scale changes in sea and land surface temperature are unequivocal (IPCC, 2013). From 1950 to 2016, globally averaged sea surface temperatures warmed at a rate of about 1.8°F per century, while the rate of warming for 2000 to 2016 is 2.9°F per century, reflecting sharper increases in sea surface temperatures over the recent 16-year period (NOAA, 2017).

Why is this indicator important?

Temperature is one of the best-measured signals of climate change. The ocean's large mass and high heat capacity allow it to store large amounts of heat. As atmospheric concentrations of greenhouse gases increase, excess heat is absorbed and stored by the oceans and atmosphere. It is estimated that over 90 percent of the observed heat energy increase on the Earth over the past 50 years has occurred in the ocean (Rhein et al., 2013; NOAA, 2015).

Changes in temperature can affect the physical and chemical properties of the ocean. Since warmer water is less dense than colder water, changes in SST can alter currents and transport patterns. Warming SSTs can cause more stable layers of seawater to form near the surface, thus increasing "stratification"; when this happens, vertical mixing that transports nutrients, oxygen, carbon, plankton and other material across ocean layers is reduced (Roemmich and McGowan, 1995). Temperature also impact affects air-sea gas exchange. Surface water temperature affects weather, specifically the occurrence of coastal fog and the strength of winds, as well as the thickness of the marine atmospheric boundary layer. The latter is a primary factor controlling the inland intrusion of cool coastal air and therefore inland weather patterns. Warmer waters play a role in extreme weather events by increasing the energy and moisture of the atmosphere. Warmer ocean temperatures also contribute to global sea level rise because warming water not only expands but also accelerates the melting of land-based ice sheets.

Changes in SST along the coast of California can alter the distribution and abundance of many marine organisms, including commercially important species. Fluctuations in the distribution and abundance of many California coastal marine populations have been related to temperature variability (e.g., Sagarin et al., 1999; Goericke et al., 2007). The direct effects of temperature on the physiological performance of marine organisms and the timing of their key developmental stages (such as from egg to larva) are the likely mechanisms underlying these patterns. Water temperature can also influence species indirectly, by altering interactions between species and their competitors, predators, parasites, facilitators, and prey.

The period of unusually high SSTs in 2014-2015 (discussed further in the next section) was accompanied by northward shifts in the geographic distributions of a variety of marine animals including fish, sea turtles, pelagic red crabs, southern copepods and many other marine invertebrates (Leising et al., 2015; Cavole et al., 2016). The 2014-2015 warm-water anomaly was also associated with mass strandings of some marine mammals and sea birds (Cavole et al., 2016). High temperatures initiated toxic algal blooms that affected the commercial and recreational crab fishing season (Gentemann et al., 2017). Temporary shifts in species distributions have also occurred during past warm-water anomalies, including major El Niño-Southern Oscillation (ENSO) events (Pearcy and Schoener, 1987). While these impacts of coastal temperature change are beginning to be documented, offshore temperature variability is complex and may influence a suite of other biological processes, including migration patterns.

What factors influence this indicator?

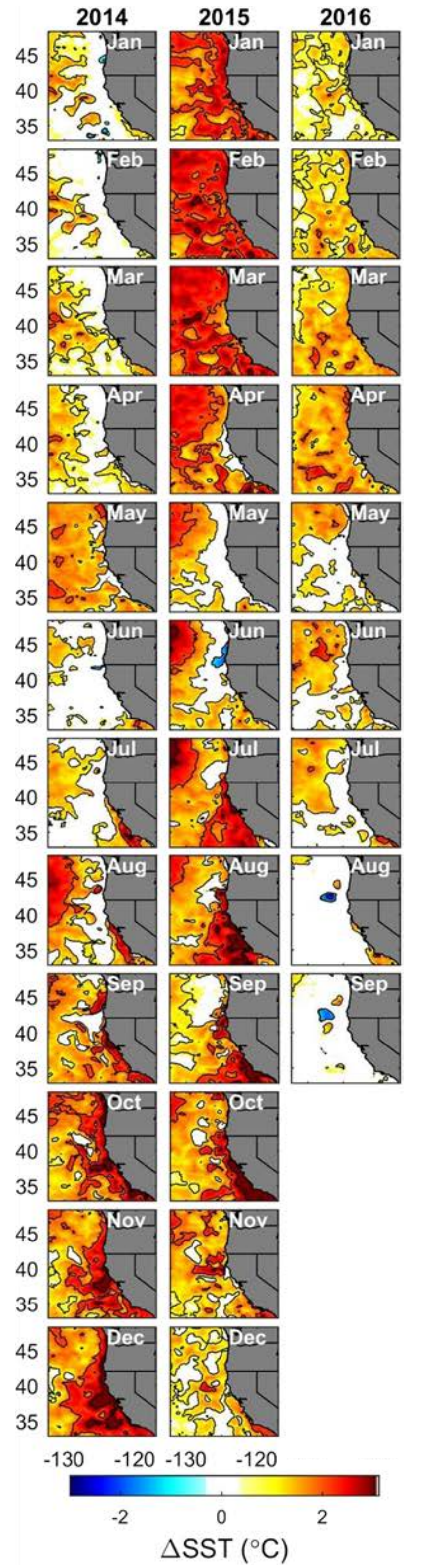
As noted above, global SSTs have increased due to a net heat flux from the atmosphere stemming from the greenhouse effect. Deeper regions of the oceans have also warmed, to depths of 3000 meters during the past several decades (Levitus et al., 2001).

Regionally, near-surface ocean water temperatures along the California coast are influenced by seasonal upwelling. Upwelling is a wind-driven process in the spring and summer months that brings deep, colder, nutrient-rich waters to the surface. Trends in coastal temperatures are complex owing to the simultaneous interaction of surface warming and the cooling effect of upwelling. In general, it is expected that surface temperatures will increase offshore and in sheltered coastal waters, where upwelling does not occur. In contrast, cooler SSTs are observed during the upwelling season in open shelf waters, especially off central and northern California (Largier et al., 2010; Garcia-Reyes and Largier, 2010; Sydeman et al., 2014). In certain upwelling regions, including the California Current, studies suggest that upwelling favorable winds may intensify with climate change (Bakun, 1990; Garcia-Reyes and Largier, 2010; Sydeman et al., 2014). In parts of coastal California, summer SSTs decreased between the 1980s and 2000s, at rates of 0.2-0.4°C per decade with stronger upwelling favorable winds (Garcia-Reyes and Largier, 2010).

Natural fluctuations in temperature, wind, and circulation patterns that occur in coastal waters can introduce variability observed in long-term trends. Although the long-term increase in SST in California waters is clearly evident, significant interannual and interdecadal fluctuations are also observed. A recent notable event occurred when anomalously warm waters were observed across the northeast Pacific in 2014 and 2015 (Figure 3). A large area of exceptionally high SSTs first appeared in the Gulf of Alaska in November 2013. Known as the “warm blob” or a “marine heat wave”, this phenomenon resulted in unprecedented sea surface temperatures off central/northern California (Di Lorenzo and Mantua, 2016). While marine heat waves have occurred in the past, the magnitude and duration of the warming during this event was unprecedented for the west coast of North America. Further, it was followed by El Niño-Southern Oscillation (ENSO) conditions during the 2015-2016 winter. ENSO is responsible for anomalously warm (or cool) ocean temperatures during El Niño (or La Niña) events, with major El Niño events occurring every 5-10 years (UCAR, 1994). Additionally, the West Coast is affected by multi-decadal variability in temperature, characterized by patterns such as the Pacific Decadal Oscillation, or PDO

(Mantua et al., 1997), and the North Pacific Gyre Oscillation, or NPGO (Di Lorenzo et al., 2008). While these natural fluctuations make it more difficult to isolate the magnitude of anthropogenic climate change, they also provide an indication of the ecosystem's sensitivity to extremes in temperature and other factors. Recent work projects that future SSTs (by year 2070) will always be warmer than the warmest year in the historical record, despite all of the natural variability inherent to this system (Alexander et al., 2018).

Figure 3. Monthly SST anomalies* during the marine heatwave



**relative to 2002-2012*

Source: Gentemann et al., 2017

Technical Considerations

Data Characteristics

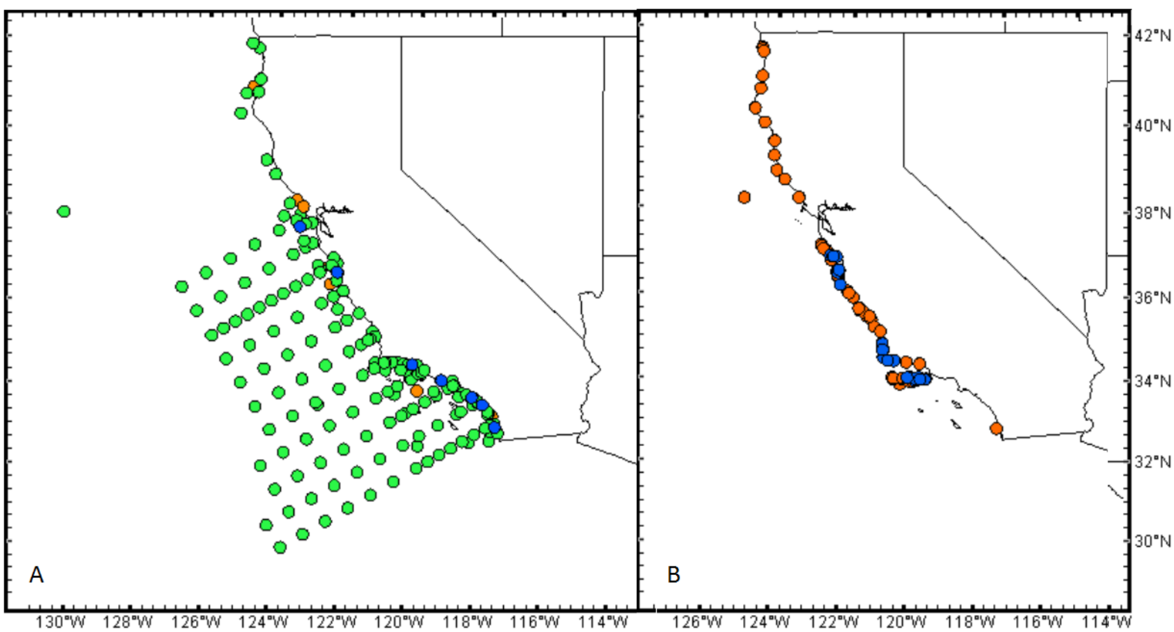
Coastal California is home to the longest continuous record of SST on the US West Coast and the Pacific Rim. In total, there are over 300 sites with SST time series along the shore and in the nearshore region of California (see Figure 4).

Long-term time series from three sites — Trinidad Bay in Humboldt County, Pacific Grove in Monterey County, and La Jolla in San Diego — are presented in this report; these sites were chosen based upon their long operational duration (~40 to 100 years), public data availability, and regional/geographic coverage. Data for the three sites have been collected by the Shore Stations Program (SIO, 2017), which provides access to current and historical data records of SST from 9 coastal California sites. The time series at Scripps Pier, La Jolla Shores, which extends back to 1916, is the longest running SST data set in the state.

Trinidad Bay temperature measurements are taken daily by staff from the Humboldt State University Marine Laboratory, located on the rocky headland between the ocean and Trinidad Bay. Bay temperature is measured from the fishing pier on the southeast side of the headland. Pacific Grove measurements are taken daily by staff from Stanford University's Hopkins Marine Station from a beach on the north side of Point Cabrillo. This location is representative of coastal conditions on the south side of Monterey Bay. La Jolla temperature measurements are taken daily at Scripps Pier by representatives from Scripps Birch Aquarium. The proximity of the pier to the deep waters at the head of La Jolla submarine canyon results in data representative of oceanic conditions.

Publicly available datasets on coastal ocean temperatures in California are presented in Figure 4. While SST is being measured throughout the entire state (N=300 datasets), more data are being collected south of San Francisco Bay; 71 percent of datasets (N=214) are 10 years or longer (green and blue dots); however, only 65 percent of datasets (N=194) are both ongoing and 10 or more years long (green and blue dots, Panel A). Long-term, ongoing datasets present the greatest opportunity to detect a signature of climate change in SST along the California coast. It is also important to sustain more recently established datasets to better understand SST trends.

Figure 4. Publicly available datasets on California coastal ocean temperatures



Panel (A) shows SST datasets that are ongoing, including the CalCOFI program. The colors of the dots refer to dataset length: Blue: >50 years; Green: 11-50 years; Orange: 0-10 years. Panel (B) shows SST datasets that have been terminated or may not be ongoing. The colors of the dots refer to dataset length: Blue: >10 years; Orange: 0-10 years.

The colors of the dots refer to dataset length: Blue: >50 years; Green: 11-50 years; Orange: 0-10 years.

Source: UC Davis Bodega Marine Laboratory, 2016

Strengths and Limitations of the Data

A growing network of ocean monitoring along California is an important resource for separating natural and anthropogenic influences on increasing temperatures. The California Cooperative Oceanic Fisheries Investigations (CalCOFI) and National Oceanic and Atmospheric Administration (NOAA) National Data Buoy programs represent the largest coordinated efforts to collect SST data across broad spatial scales. In addition, the Central and Northern California Ocean Observing System and the Southern California Coastal Observing System provide coordinated long-term monitoring of environmental conditions to support ocean management decisions as part of an eleven-region US Integrated Ocean Observing System (IOOS, 2018).

Many SST datasets for California are short and/or terminated time series (41 percent), providing limited utility in separating anthropogenic and natural processes. Climate-related trends are challenging to distinguish from natural variability for SST datasets covering less than 10 years (Henson et al., 2016). Longer data sets are ideal in light of the natural fluctuations that recur at subdecadal and multi-decadal intervals. Thus, it is critical that data collection continues and is extended to increase the coverage of datasets from which to evaluate climate change-induced SST in California waters.

One collective limitation of the datasets currently available is that there is less information to describe the effects of climate change in Northern California, because fewer time series have been collected in that region. While SST is being measured throughout the entire state, data collections to date have been concentrated south of the San Francisco Bay, in Central and Southern California.

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2009 indicator contributed by Frank Schwing, NOAA.
2017 updates provided by UC Davis team: Hill, Largier, Sanford, Rivest, Myhre, Gaylord

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