North Pacific Climate Overview

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Summary. *The state of the North Pacific atmosphere-ocean system during 2016-2017 featured the moderation of warm sea surface temperature (SST) anomalies associated with the extreme marine heat wave of 2014-16. The sea level pressure (SLP) anomaly patterns varied from season to season, with the most prominent perturbation occurring in winter 2016-17 when the Aleutian Low was much weaker than normal. This kind of anomaly has often been associated with the remote forcing by La Niña; the magnitude of the response was large relative to that of the tropical Pacific signal. The Pacific Decadal Oscillation (PDO) was positive during the past year, with an overall decline in amplitude. The climate models used for seasonal weather predictions are indicating that near-neutral ENSO conditions or a weak La Niña are most likely for the winter of 2017-18, while maintaining North Pacific SST anomalies in a weakly PDO-positive sense.*

1. SST and SLP Anomalies

The state of the North Pacific climate from autumn 2016 through summer 2017 is summarized in terms of seasonal mean sea surface temperature (SST) and sea level pressure (SLP) anomaly maps. The SST and SLP anomalies are relative to mean conditions over the period of 1981-2010. The SST data are from NOAA's Optimum Interpolation Sea Surface Temperature (OISST) analysis; the SLP data are from the NCEP/NCAR Reanalysis project. Both data sets are made available by NOAA's Earth System Research Laboratory (ESRL) at http://www.esrl.noaa.gov/psd/cgi-bin/data/composites/printpage.pl.

The eastern portion of the North Pacific ocean experienced during 2014-16 one of the most extreme marine heat waves in the observational record (Scannell et al. 2016); the interval summarized here can be considered a transition period between that event and a more climatologically normal SST distribution on the basin-scale. More detail on the evolution of the SST and SLP from a seasonal perspective is provided directly below.

The SST in the North Pacific during the autumn (Sep-Nov) of 2016 (Fig. 1a) was warmer than normal in the Gulf of Alaska (GOA) and much warmer than normal (> 2°C) in the northern and eastern Bering Sea. Most of the remainder of the North Pacific Ocean had SSTs that were near to slightly above normal, with the exception of a cold patch at the dateline between 40° and 50° N. The SST anomalies in the tropical Pacific were positive in the west, and negative in the east, with the latter implying weak La Niña conditions. The pattern of anomalous SLP during autumn 2016 featured a pole of strongly negative anomalies over the western Bering Sea, and lower than normal SLP extending eastward to a secondary negative pole off the coast of the Pacific Northwest. This SLP pattern implies wind anomalies from the west across the North Pacific between roughly 40° and 50° N, causing enhanced cooling.

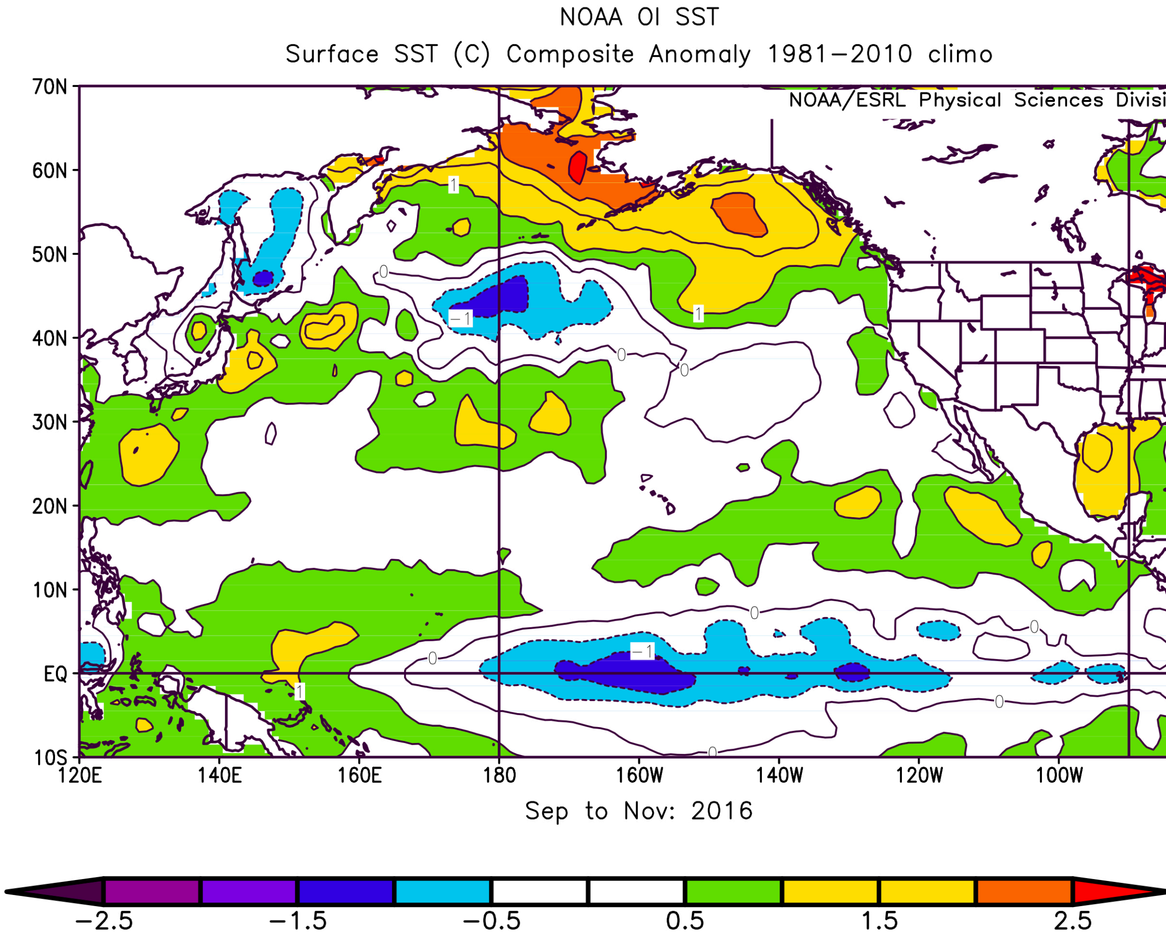

Figure 1a. SST anomalies (°C) for September-November 2016.

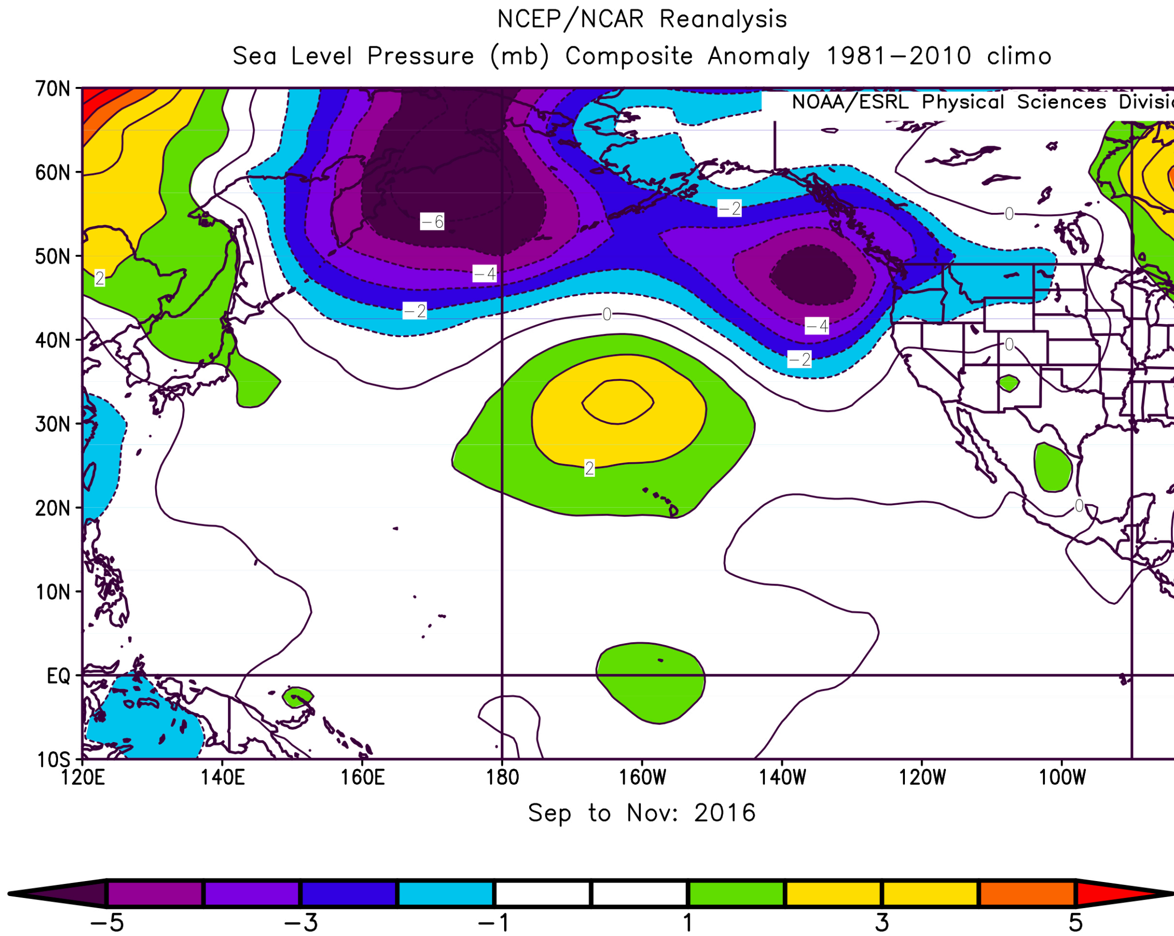

Figure 1b. SLP anomalies (hPa) for September-November 2016.

The pattern of North Pacific SST anomalies during winter (Dec-Feb) of 2016-17 (Fig. 2a) reflected cooling north of about 40°N relative to the previous fall season. This cooling was associated with anomalous winds out of the west across the middle latitudes of the North Pacific in fall, followed by anomalous during winter out of the west across the Bering Sea and out of the northwest in the GOA. The latter wind anomalies were due to a distribution of anomalous SLP during winter 2016-17 that featured much higher pressures than normal over a large portion of the eastern North Pacific (Fig. 2b), with a peak magnitude greater than 12 mb located south of the Alaska Peninsula (Fig. 2b). This is the signature of a particularly weak Aleutian Low, and implies suppressed storminess for the southeastern Bering Sea and GOA. A weak Aleutian Low commonly occurs during La Niña, but as shown in Figure 2a, the SST anomalies in the central and eastern tropical Pacific were not much cooler than normal. It is not known why there appears to have been such a disproportionate response in the atmospheric circulation over the North Pacific. The anomalous northerly flow on the east side of the positive SLP anomaly south of Alaska resulted in the coldest winter for the Pacific Northwest since 1992-93; the region of lower than normal pressure along the west coast of the US was also accompanied by higher than normal precipitation.

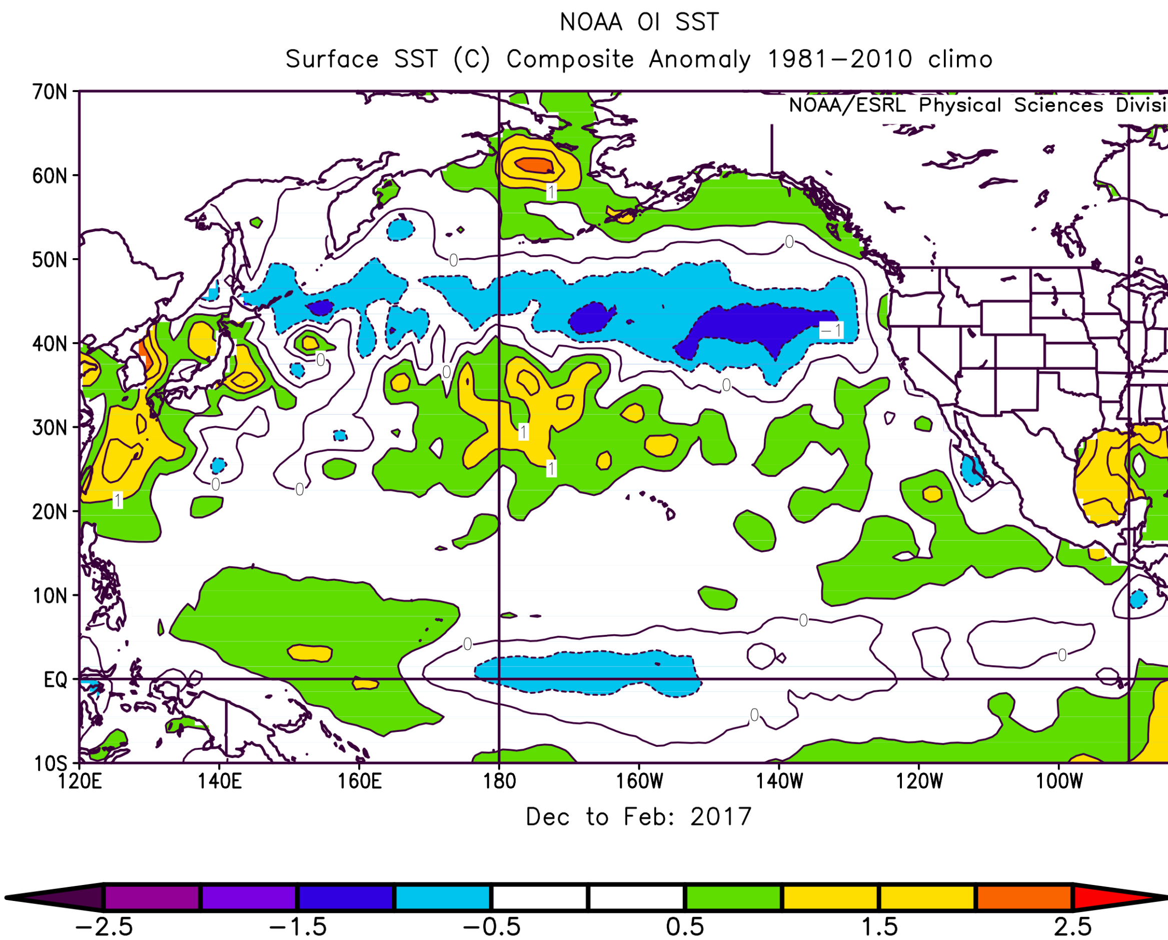

Figure 2a. SST anomalies for December 2016 - February 2017.

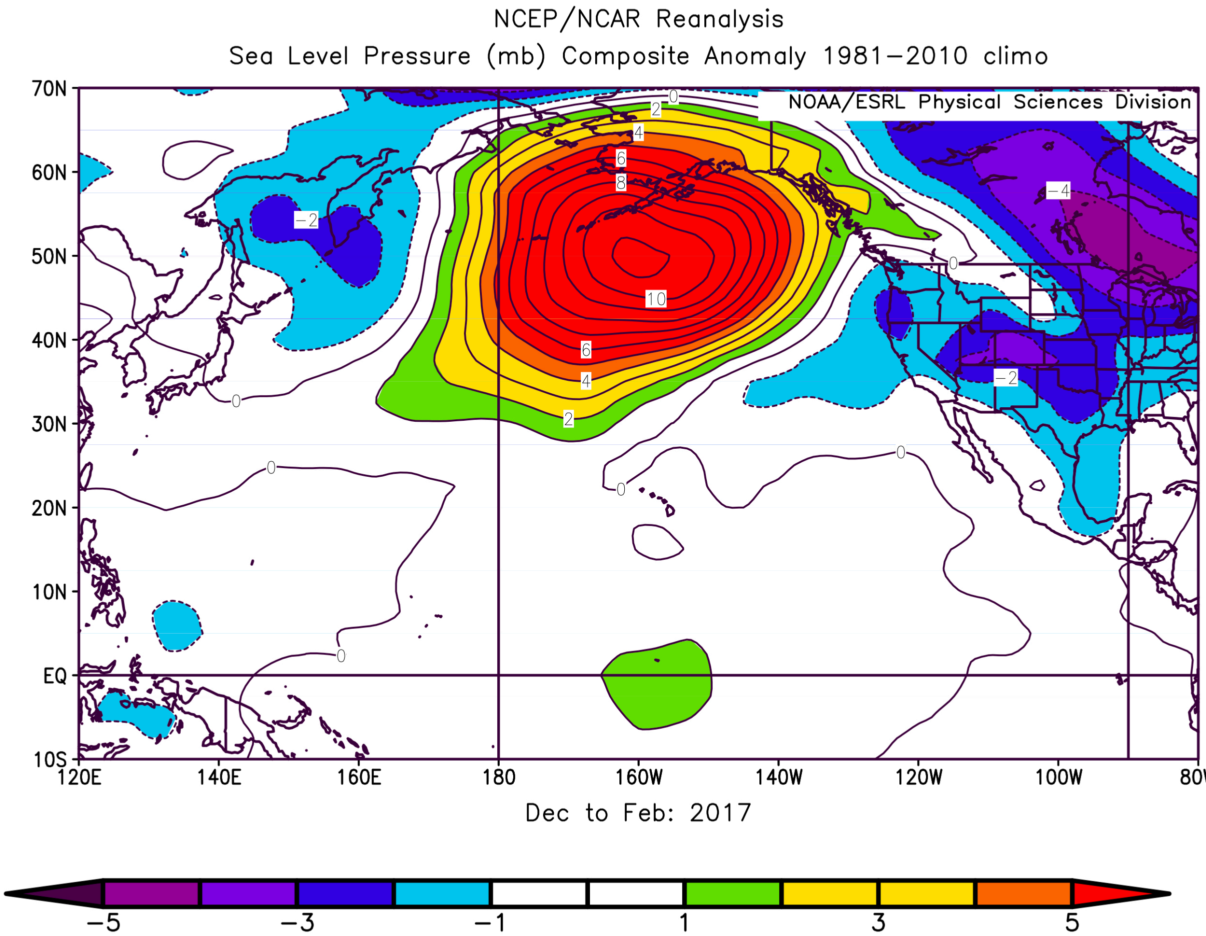

Figure 2b. SLP anomalies for December 2016 - February 2017.

The distribution of anomalous SST in the North Pacific during spring (Mar-May) of 2017 (Fig. 3a) was similar to that during the previous winter season, with moderation in the magnitude of the anomalies north of 30°N and modest warming in the sub-tropical North Pacific. Moderate cooling occurred in the central North Pacific in the vicinity of 40°N, 170°W. The overall pattern projected on the positive phase of the Pacific Decadal Oscillation (PDO), but not as strongly as during the past two years. The SST anomalies in the tropical Pacific were of minor amplitude. The SLP anomaly pattern (Fig. 3b) for spring 2017 featured a band of lower than normal pressure from eastern Siberia to a negative center south of the Aleutian Islands, with an eastward extension to British Columbia. Above-normal SLP resulted in suppressed storminess for the eastern Bering Sea. The atmospheric circulation in the northeast Pacific promoted relatively downwelling-favorable winds in the coastal GOA and wet weather in the Pacific Northwest.

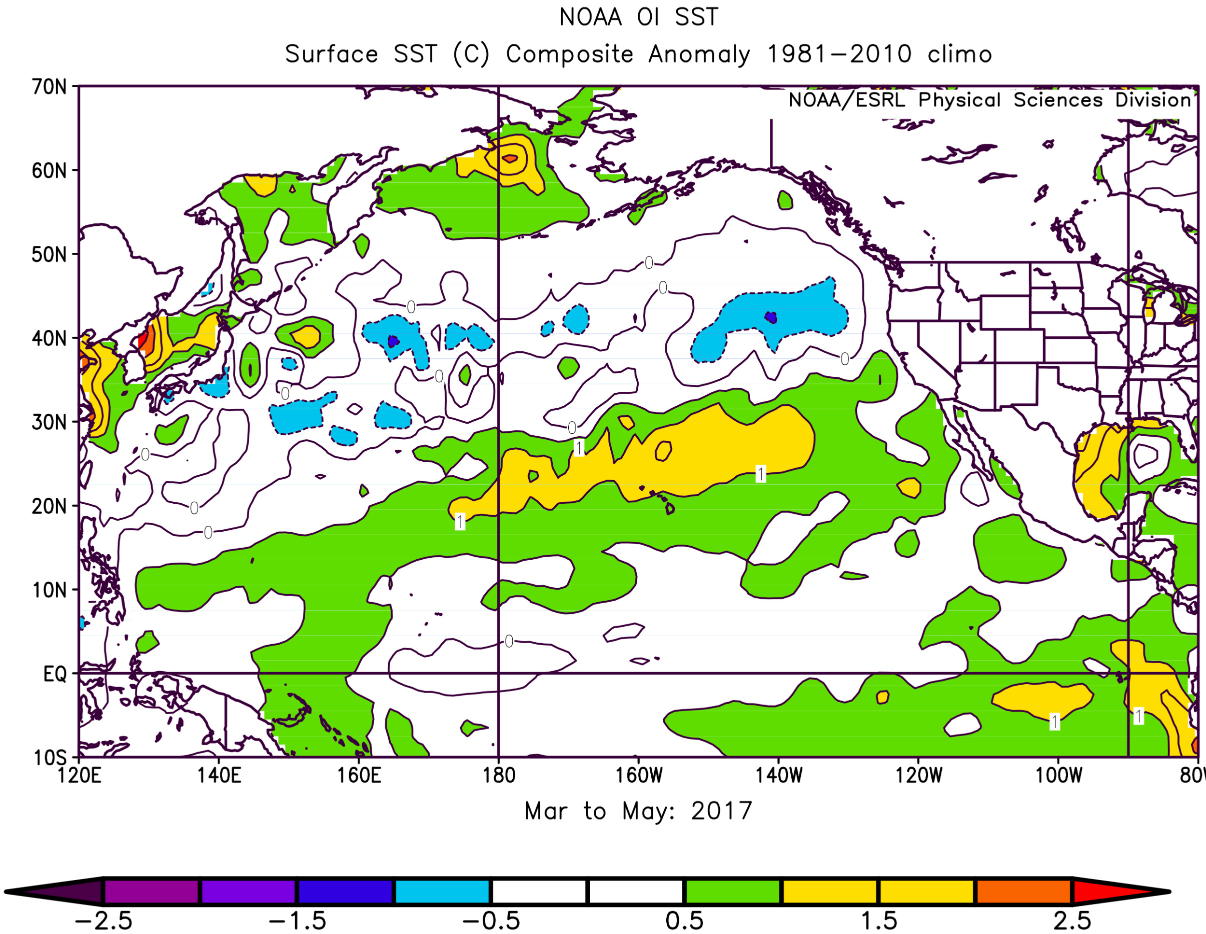

Figure 3a. SST anomalies for March – May 2017.

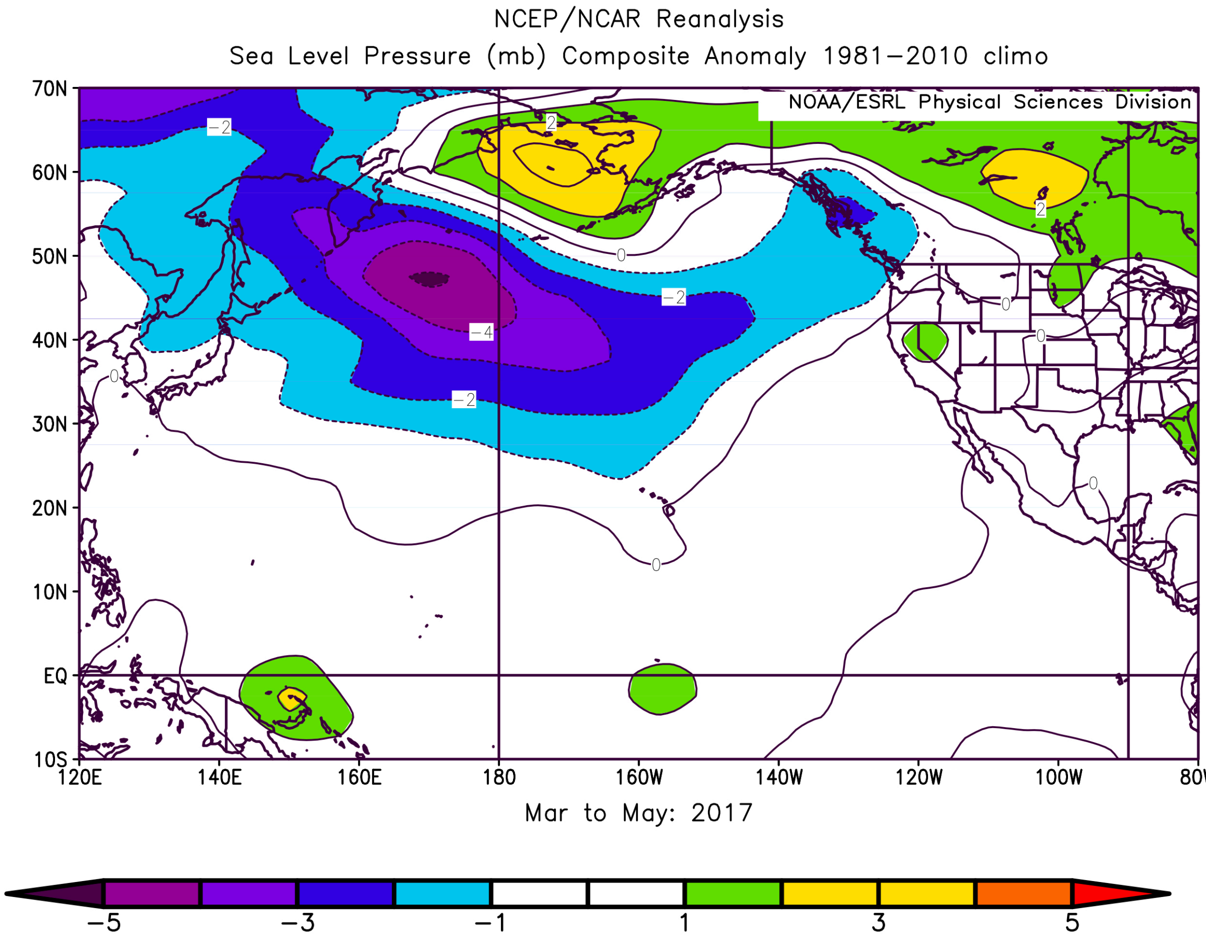

Figure 3b. SLP anomalies for March – May 2017.

The SST anomaly pattern in the North Pacific during summer (Jun-Aug) 2017 is shown in Figure 4a. It was warmer than normal north of 50°N, with the greatest positive anomalies of +2°C near Bering Strait into the southern Chukchi Sea. Warm SSTs were also present in a band between about 30° and 15°N across the entire North Pacific Ocean with the greatest anomalies located northeast of the Hawaiian Islands. Upper ocean temperatures in the tropical Pacific were quite close to their climatological norms. The distribution of anomalous SLP (Fig. 4b) during summer 2017 included negative centers in the northwestern portion of the North Pacific basin and south of mainland Alaska straddling a region of slightly higher than normal SLP centered near 40°N and the dateline.

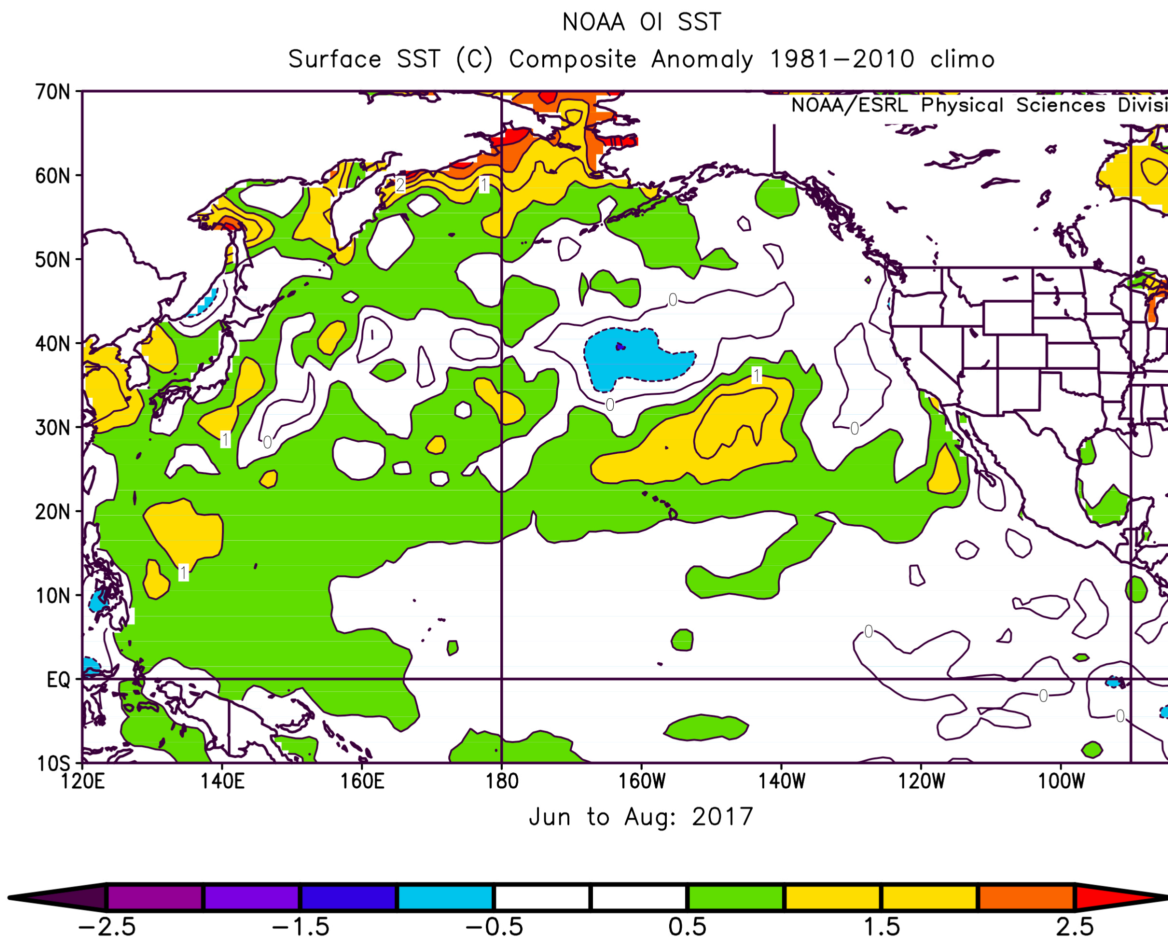

Figure 4a. SST anomalies for June – August 2017.

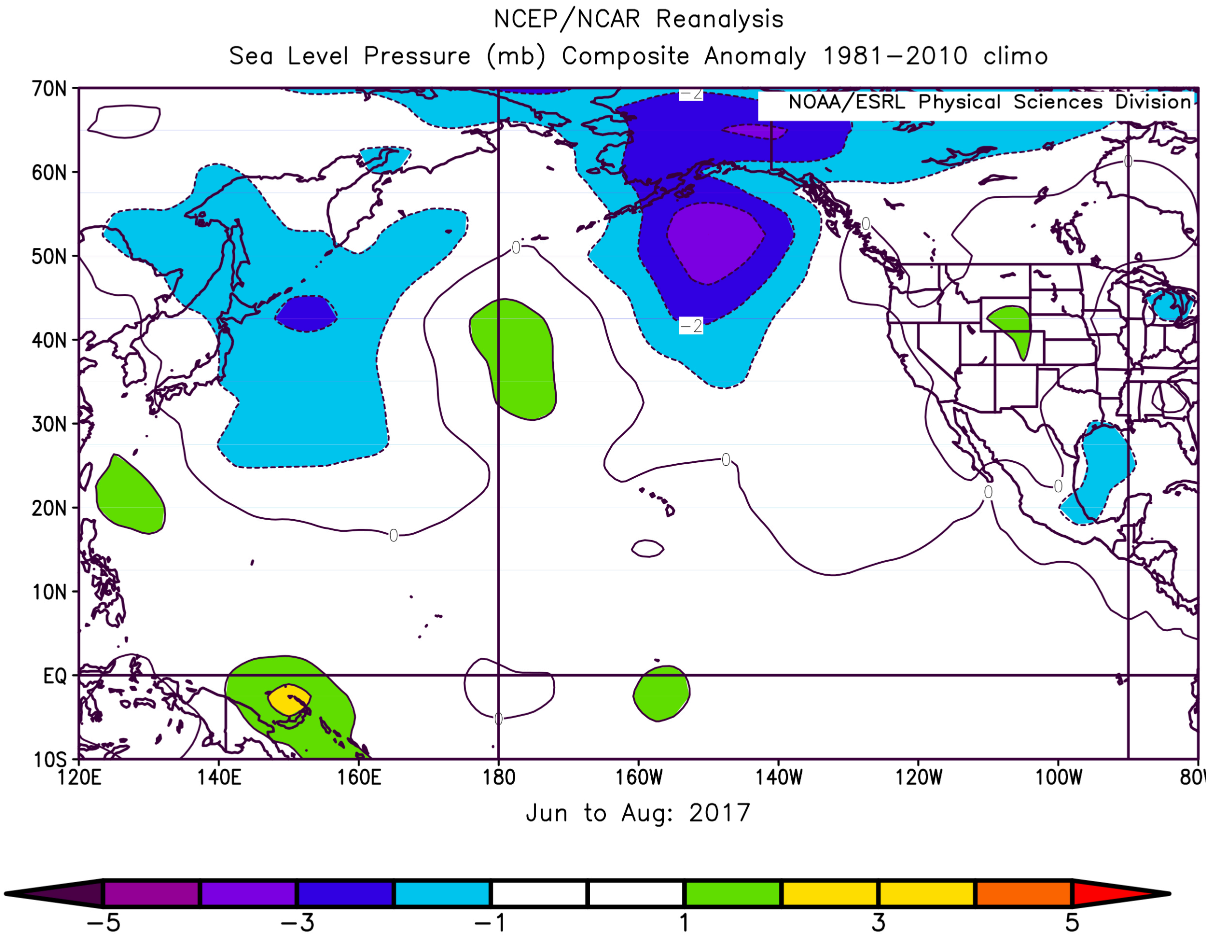

Figure 4b. SLP anomalies for June – August 2017.

2. Climate Indices

Climate indices provide an alternative means of characterizing the state of the North Pacific atmosphere-ocean system. The focus here is on five commonly used indices: the NINO3.4 index for the state of the El Niño/Southern Oscillation (ENSO) phenomenon, Pacific Decadal Oscillation (PDO) index (the leading mode of North Pacific SST variability), North Pacific Index (NPI), North Pacific Gyre Oscillation (NPGO) and Arctic Oscillation (AO). The time series of these indices from 2007 into summer 2017 are plotted in Figure 5.

The North Pacific atmosphere-ocean climate system, in an overall sense, was in a more moderate state during 2016-17 than during the previous two years. The NINO3.4 index ranged from slightly negative during late 2016 to slightly positive during spring of 2017, with little trend over the course of summer 2017. This rather quiet state for the tropical Pacific is in contrast with the large swings that occurred in 2015-16. The PDO has been positive (indicating warmer than normal SST along the west coast of North America and cooler than normal in the central and western North Pacific) since early 2014. The magnitude of the PDO has generally decreased since early 2016. Much of this decline can probably be attributed to ENSO, and in particular the transition from a strong El Niño to a weak La Niña in 2016. The NPI was negative during the past fall and spring, implying a deeper than normal Aleutian Low, as indicated in Figs. 1b and 3b. In contrast, the winter of 2016-17 included a large positive value for the

NPI. While this sign of the NPI represents a typical atmospheric response to La Niña, its magnitude is disproportionately large considering the weak amplitude of La Niña in late 2016.

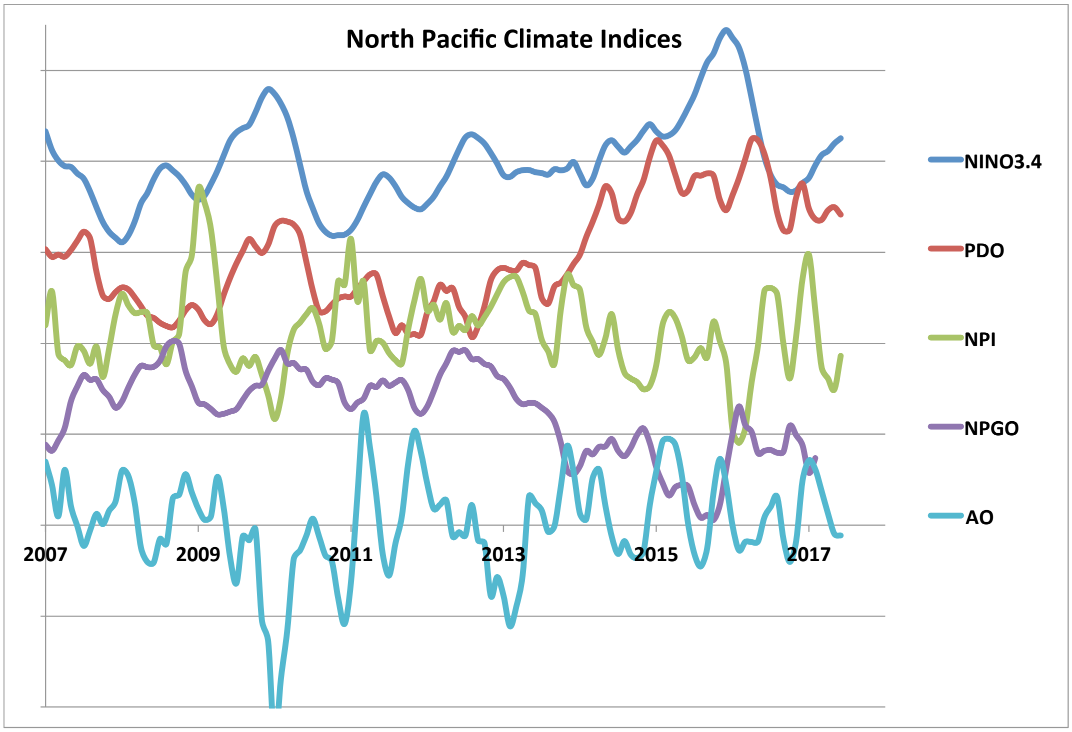

Figure 5. Time series of the NINO3.4 (blue), PDO (red), NPI (green), NPGO (purple), and AO (turquoise) indices. Each time series represents monthly values that are normalized using a climatology based on the years of 1981-2010, and then smoothed with the application of three-month running means. The distance between the horizontal grid lines represents 2 standard deviations. More information on these indices is available from NOAA's Earth Systems Laboratory at http://www.esrl.noaa.gov/psd/data/climateindices/.

The NPGO mostly declined from a small positive value in early 2016 to a small negative value in early 2017. This index has been shown to be positively correlated with nitrate concentrations on Line P extending from Vancouver Island to Station P at 50°N, 145°W. The AO represents a measure of the strength of the polar vortex, with positive values signifying anomalously low pressure over the Arctic and high pressure over the Pacific and Atlantic Ocean at a latitude of roughly 45°N. It has a weakly positive correlation with sea ice extent in the Bering Sea. The AO was positive during the winter of 2016-17, perhaps contributing to the anomalously weak Aleutian Low (Fig. 2b), and otherwise in a mostly neutral state on seasonal time scales since early 2016.

3. Regional Highlights

a. **West Coast of Lower 48** – This region experienced moderate upper ocean temperatures with the exception of Baja California, where relatively warm water prevailed. The winter of 2016-17 was wetter than normal along the entire west coast, with portions of Northern California receiving record amounts. It was also quite chilly in the Pacific Northwest, where it was the coldest winter since 1992-93, and a full 5°C colder than the record warm winter of 2014-15. The end of winter snowpack was above normal for all of the Pacific coast states. The coastal wind anomalies were downwelling-favorable during the fall of 2016. Enhanced upwelling occurred along the northern and central California coast during late spring into summer 2017. Upwelling was also prominent at times along the coast of the Pacific Northwest, which during August 2017 included relatively high near-surface chlorophyll concentrations; moored buoys indicated relatively cool water with low oxygen content below about 80 meters depth. Based on anecdotal accounts, there do not appear to have been as many unusual species sighted. An exception was during late spring into summer along the coast of the Pacific Northwest, where there were multiple sightings of large assemblages of pyrosomes, a gelatinous tunicate that are rarely found in such large numbers.
b. **Gulf of Alaska** –The weather of the coastal GOA was generally warmer than normal during the past year with the exception of winter 2016-17, during which air temperatures were near normal. The freshwater runoff into the GOA appears to have been greater than normal during the fall of 2016 and somewhat less than normal in summer 2017, with implications for the baroclinic component of the Alaska Coastal Current. The coastal wind anomalies were upwelling favorable during the winter. The sub-arctic front was farther south than last year, which is consistent with the surface currents shown in the Ocean Surface Currents – Papa Trajectory Index section (Stockhausen and Ingraham).
c. **Alaska Peninsula and Aleutian Islands** – The weather of this region featured enhanced storminess in the fall of 2016, especially in the west, and suppressed storminess during the following winter. Easterly wind anomalies and mild temperatures occurred during spring 2017. Based on synthetic data from NOAA's Global Ocean Data Assimilation System (GODAS), the westward flow associated with the Alaskan Stream decreased from relatively high values late in 2016 to lower than normal values in the summer of 2017. The GODAS product suggests there were pulses in the strength of the eastward flow associated with the Aleutian North Slope Current.
d. **Bering Sea** –The weather on the Bering Sea shelf was generally warmer than normal, for the 4th year in a row. An exception was early 2017, which included the usual intermittent outbreaks of Arctic air. The fall of 2016 was stormier than normal; winter and spring were relatively calm. During the winter of 2016-17, sea ice was present mostly between the coast and the 70-meter isobath. While ice reached the M2 mooring site on the southeast Bering Sea shelf, the water column did not fully mix. The result was moderate bottom temperatures (~0°C) for the summer cold pool in the middle domain of the southern Bering Sea shelf. In this region the thermal

stratification was greater than usual in summer 2017, but the vertically integrated heat content was more typical, at least as compared with 2015 and 2016.

e. **Arctic** – The fall of 2016 featured particularly low sea ice extents in the Chukchi and Beaufort Seas. For the Arctic as a whole, the maximum sea ice extent at the end of winter was the lowest on record. In addition, Barrow, Alaska experienced a record warm winter. The sea ice melted rapidly in Chukchi Sea beginning in May 2017, presumably due to a combination of the weather and relatively thin ice associated with the unusually short period of ice cover. The ice edge was farther north than usual during summer 2017 for the Chukchi Sea and much of the Beaufort Sea. For the Arctic as a whole, the area of sea ice cover during the middle of August 2017 was the 5th lowest value in the observational record, despite a weather pattern unfavorable to ice melt.

4. Seasonal Projections from the National Multi-Model Ensemble (NMME)

Seasonal projections of SST from the National Multi-Model Ensemble (NMME) are shown in Figures 6a-c. An ensemble approach incorporating different models is particularly appropriate for seasonal and longer-term simulations; the NMME represents the average of eight climate models. The uncertainties and errors in the predictions from any single climate model can be substantial. More detail on the NMME, and projections of other variables, are available at the following website: http://www.cpc.ncep.noaa.gov/products/NMME/.

First, the projections from a year ago are reviewed qualitatively. The one-month lead forecast for Oct-Dec 2016 was quite accurate, which is not surprising in that the upper ocean has a great deal of thermal inertia, i.e., persistence, with the initial state being a primary determinant of near-term future conditions. This influence lessens with time and indeed for the period considered here, the longer-range (3-month and 5-month) forecasts were not as skillful. The models as a group, as reflected in the ensemble averages, correctly predicted the signs and the magnitudes of the SST anomalies in the sub-tropical and tropical Pacific, with only minor discrepancies. The NMME forecasts at the 3-month and 5-month forecast horizons did not validate as well north of about 30°N, where the modeled SSTs were generally warmer than observed. The models simulated too-little moderation of the pre-existing warm anomalies in the GOA and Bering Sea, and also under-predicted the amount of cooling in the waters offshore of the Pacific Northwest. Nevertheless, the models did reproduce the overall patterns in anomalous SST that were observed, even in the longer-range projections; the positive skill in these forecasts discussed here (and found in other studies) suggest that the NMME SST output merits consideration.

These NMME forecasts of three-month average SST anomalies indicate a continuation of warm conditions across most of the North Pacific through the end of the year (Oct-Dec 2017) with a reduction in the longitudinal extent of cooler than normal temperatures offshore of the Pacific Northwest (Fig. 6a). The magnitude of the positive anomalies is projected to be greatest (exceeding 1°C) in the western Bering Sea. Negative SST anomalies are projected in the central and eastern equatorial Pacific. It is uncertain whether they will remain weak enough to constitute neutral conditions or become strong enough to constitute La Niña. As of early September 2017, the probabilistic forecast provided by NOAA's Climate Prediction Center (CPC) in collaboration with the International Research Institute for Climate and Society (IRI) for the upcoming fall through winter indicates about a 40% chance of neutral conditions and a 55% chance of a weak La Niña. The overall pattern of SST anomalies across the North Pacific is maintained through the 3-month periods of December 2017 – February 2018 (Fig. 6b) and February – April 2018 (Fig. 6c) with some slight cooling in the eastern Bering Sea, GOA and nearshore waters of the Pacific Northwest. The distribution of forecast SST anomalies projects on the positive phase of the PDO, but also exhibits some substantial differences with the characteristic pattern of the PDO. In particular, the positive phase of the PDO generally includes significantly warmer than normal water in the GOA, and only modest anomalies in the western Bering Sea, while just the reverse is shown in the forecasts. This discrepancy appears to be related to some of the individual NMME models forecasts of a relatively weak Aleutian low (not shown).

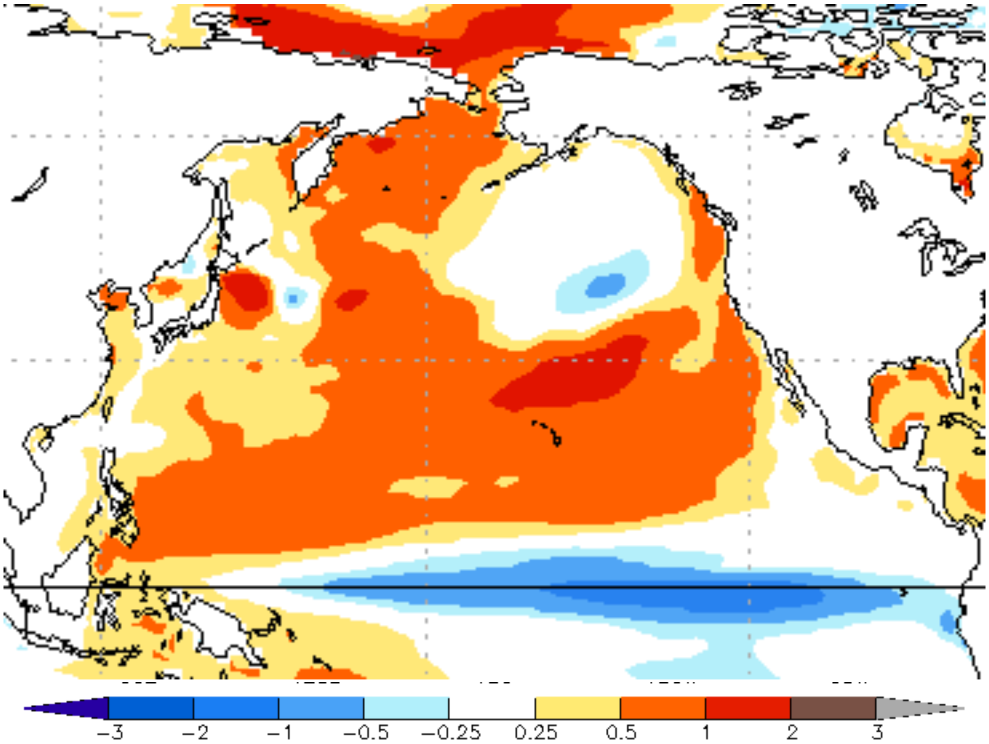

Figure 6a Predicted SST anomalies (°C) for October-December 2017 (1 month lead) from the National Multi-Model Ensemble (NMME) of coupled atmosphere-ocean climate models. See text for details.

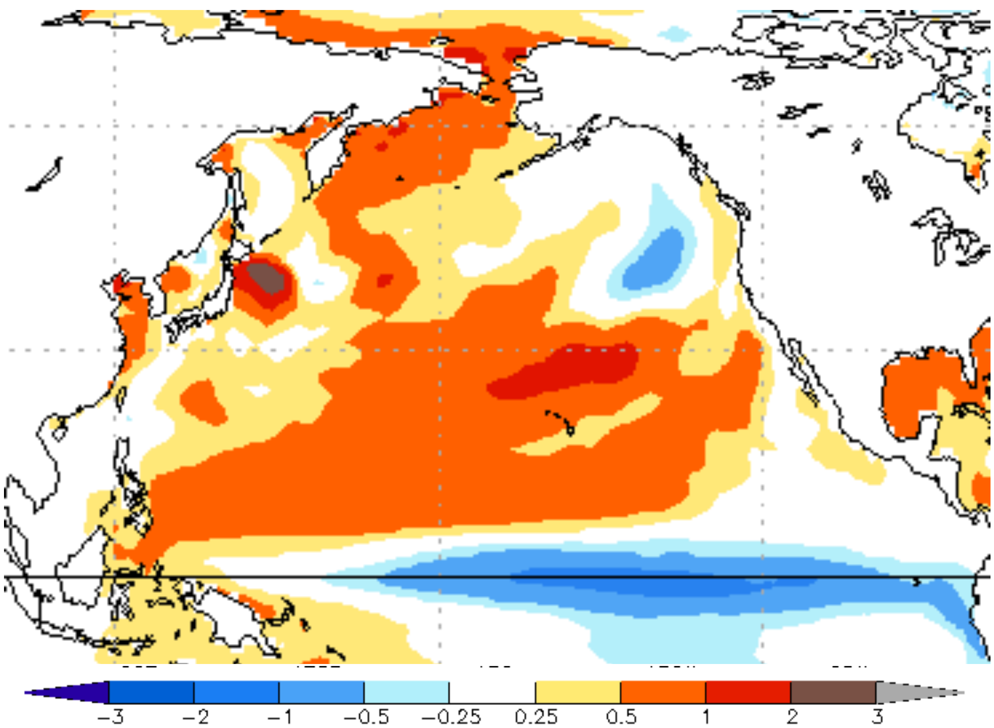

Figure 6b As in Fig. 6a, but for December 2017-February 2018 (3 month lead).

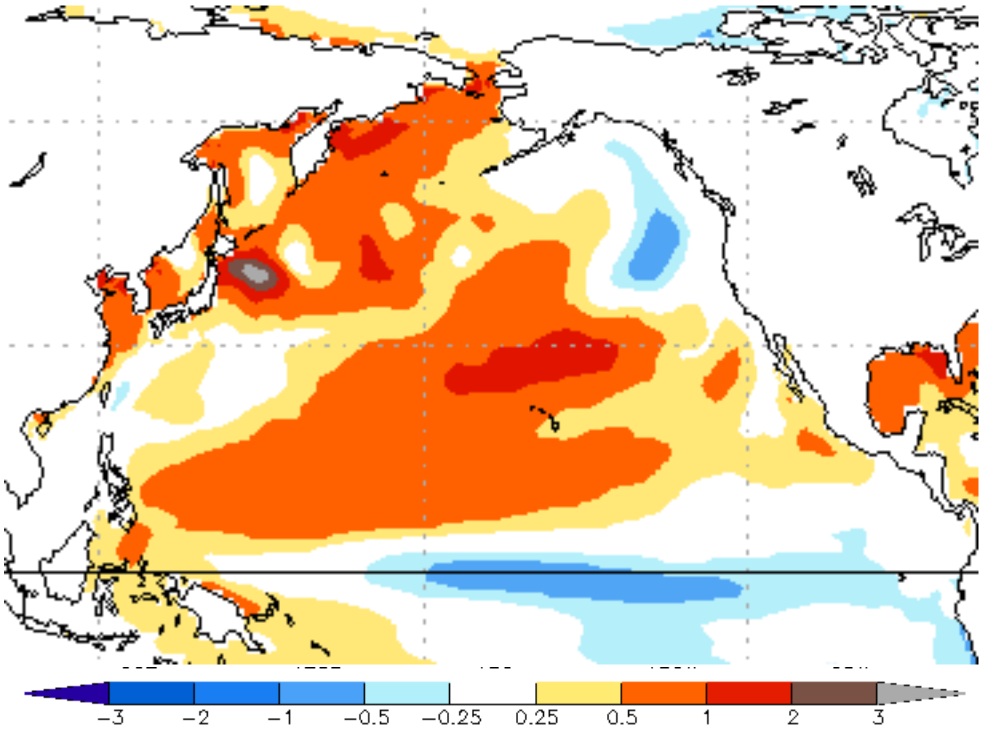

Figure 6c. As in Fig. 6a, but for February-April 2018 (5 month lead).