North Pacific Climate Overview

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Summary. *The state of the North Pacific atmosphere-ocean system during 2015-2016 featured the continuance of warm sea surface temperature (SST) anomalies that became prominent late in 2013, with some changes in the pattern. The evolution of the SST distribution can be attributed to the seasonal mean sea level pressure (SLP) and wind anomalies, particularly cyclonic wind anomalies in the central Gulf of Alaska in winter 2015-16 and spring 2016, with a reversal to anticyclonic flow in the following summer of 2016. The Bering Sea experienced the third consecutive winter of reduced sea ice, in what may turn out to be the early stage of an extended warm spell. The Pacific Decadal Oscillation (PDO) was positive during the past year, especially during spring 2016. The climate models used for seasonal weather predictions are indicating borderline to weak La Niña conditions for the winter of 2016-17, while maintaining North Pacific SST anomalies in a PDO-positive sense.*

1. SST and SLP Anomalies

The state of the North Pacific climate from autumn 2015 through summer 2016 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. Previous versions of this overview included SST anomaly distributions based on NOAA's Extended Reconstructed Sea Surface Temperature (ERSST) V4; here the OISST analysis is used because of its finer-scale resolution, and incorporation of satellite data, which is valuable in regions where direct observations of SST by ships and buoys are sparse.

The anomalies that occurred during the past year in the North Pacific beginning in autumn of 2015 reflect, to a large extent, the maintenance of conditions that developed during the previous 1-2 years. In particular, a leading large-scale climate index for the North Pacific, the Pacific Decadal Oscillation (PDO), remained positive following a transition in sign early in 2014. 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 2015 (Fig. 1a) was warmer than normal east of the dateline. The positive anomalies were especially prominent off southern and Baja California and in the eastern tropical Pacific, the latter in association with a strong El Niño. The pattern of anomalous SLP during autumn 2015 featured strongly negative anomalies extending from Bering Strait into northwestern Canada with higher than normal pressure from the Kamchatka Peninsula into the central Gulf of Alaska (GOA). This SLP pattern implies wind anomalies from the west across the Bering Sea and anomalous upwelling in the coastal waters of the GOA.

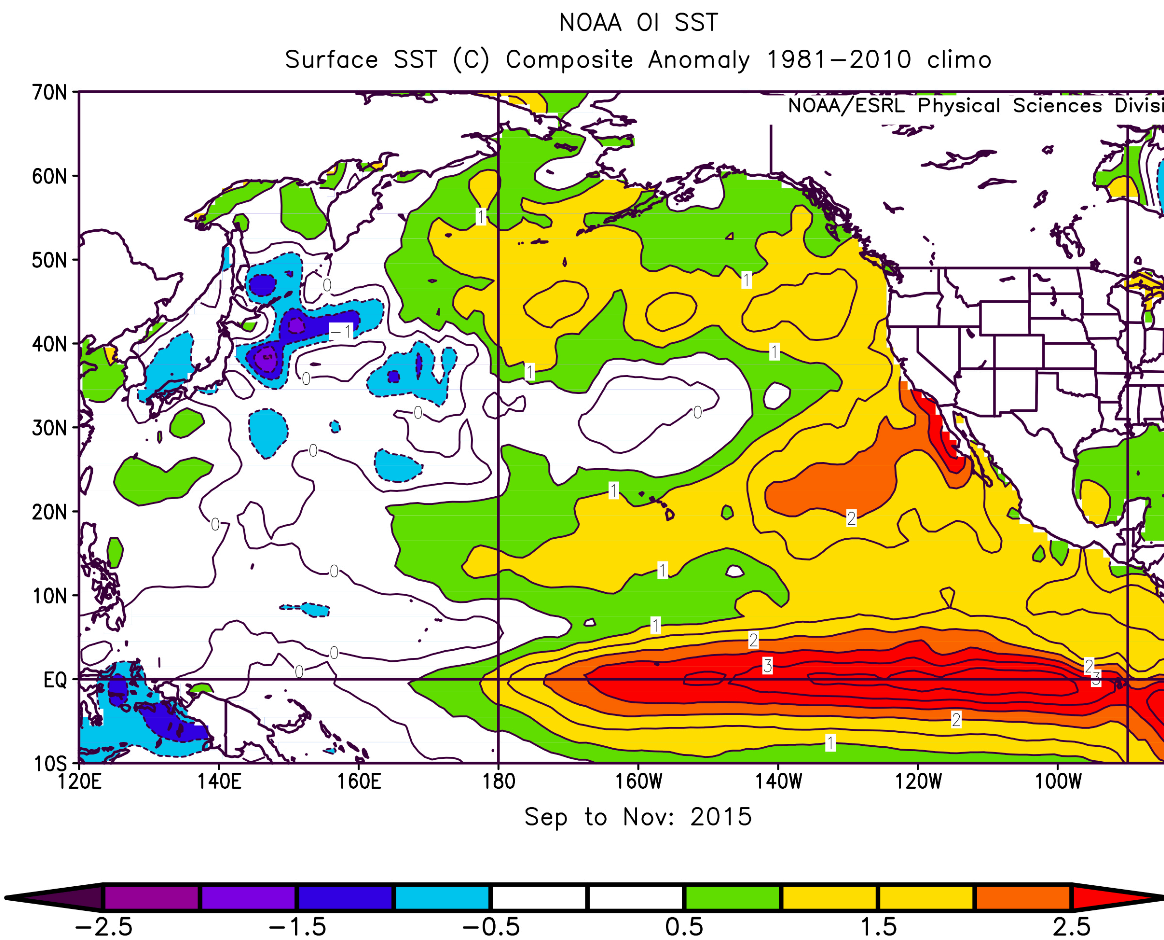

Figure 1a. SST anomalies (°C) for September-November 2015.

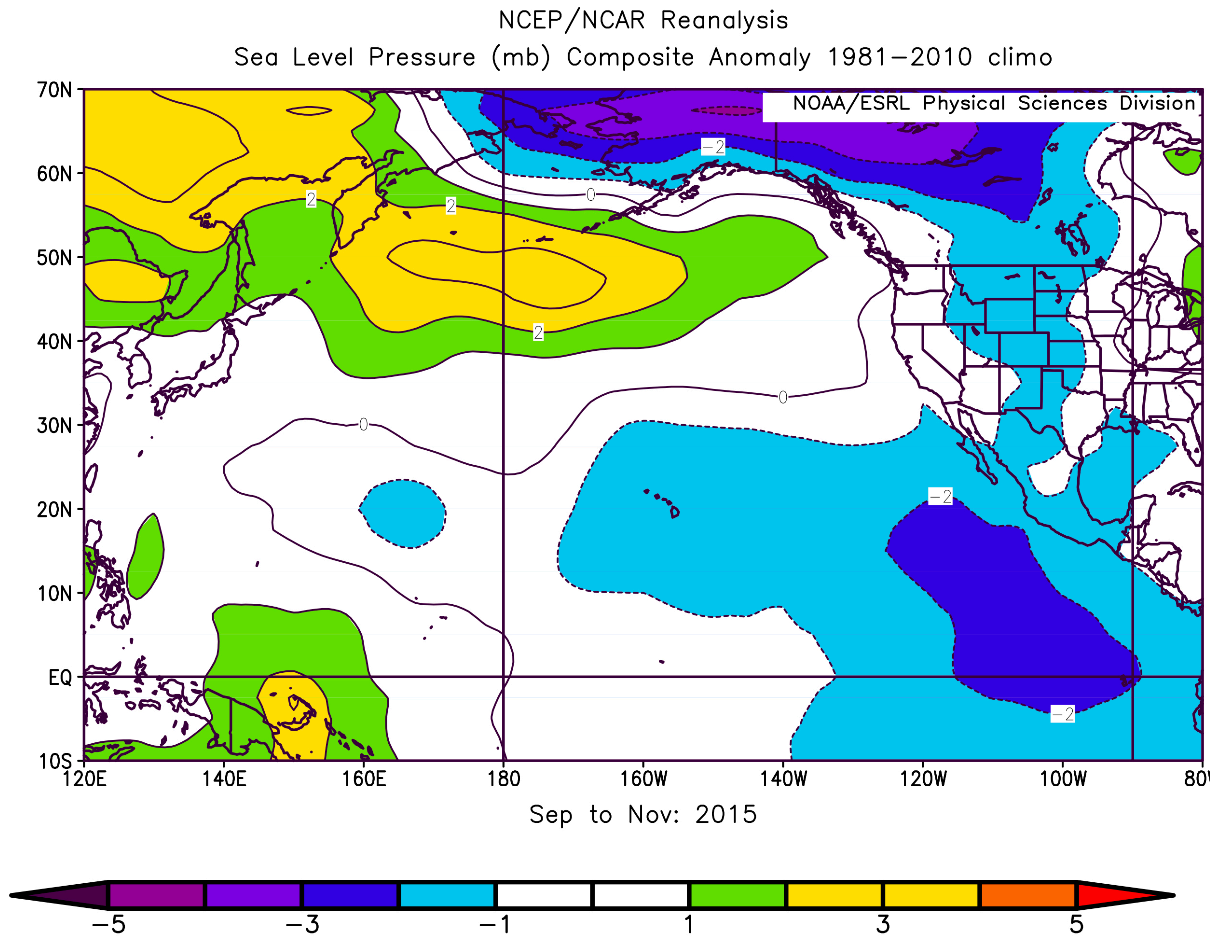

Figure 1b. SLP anomalies (hPa) for September-November 2015.

The pattern of North Pacific SST during winter (Dec-Feb) of 2015-16 relative to the seasonal mean (Fig. 2a) resembled that of the preceding autumn with the exception of the western Bering Sea and Aleutian Islands, which cooled to near normal. The latter cooling was associated with anomalous winds out of the northwest in association with extremely low SLP (negative anomalies exceeding 12 mb) over the eastern Bering Sea and western GOA (Fig. 2b). For the area of 50°N to 60°N, 170°W to 150°W, the SLP was more than 3 mb lower than that during any other December through February in the record back to 1949. This meant relatively frequent gale force winds and high wave heights for the region. A deeper than normal Aleutian Low commonly occurs during El Niño (whose signature is prominent in Fig. 2a) but the center of the anomalous SLP was displaced to the northwest from its usual position during winters with strong El Niños. The anomalous southerly flow to the east of the SLP anomaly minimum brought relatively warm air to the northern Gulf of Alaska, especially from late January into February during which surface air temperatures were about 6°C above normal. The coastal region of the GOA therefore received a greater proportion of rain versus snow than usual at lower elevations, but it is uncertain whether the GOA experienced significantly more freshwater runoff than typical for the season.

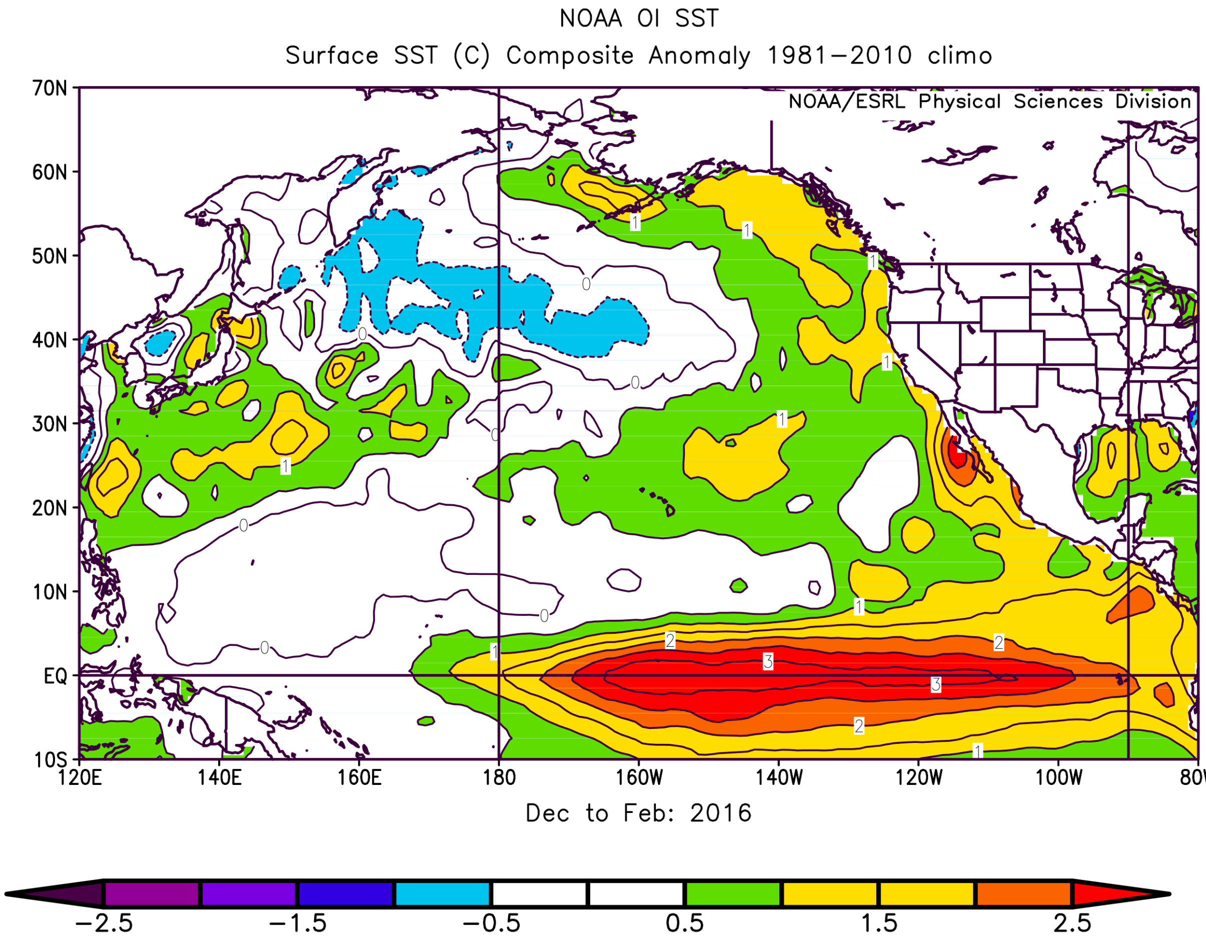

Figure 2a. SST anomalies for December 2015 - February 2016.

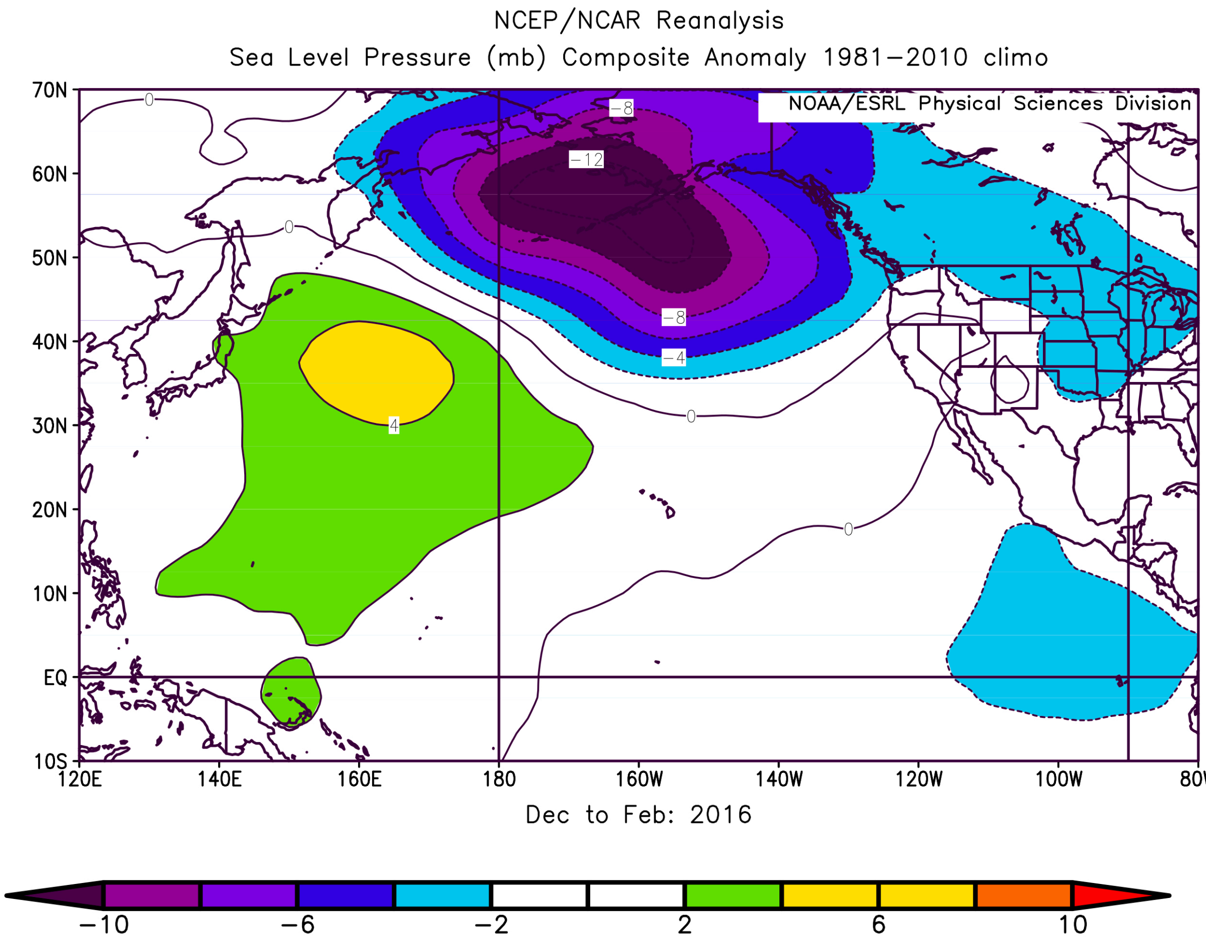

Figure 2b. SLP anomalies for December 2015 - February 2016.

The distribution of anomalous SST in the North Pacific during spring (Mar-May) of 2016 (Fig. 3a) bore some resemblance to that of the season before, with an increase in the magnitude of the positive anomalies in the eastern Bering Sea and GOA. Moderate cooling occurred in the central North Pacific in the vicinity of 40°N, 170°W. The overall pattern projected strongly on the positive phase of the Pacific Decadal Oscillation (PDO) as will be discussed further below. The SST anomalies in the central and eastern tropical Pacific decreased as El Niño wound down. The SLP anomaly pattern (Fig. 3b) for spring 2016 was similar to that of the previous winter season, with a weaker negative anomaly shifted southeast of its previous location. Lower than normal SLP over a broad region extending from the southeastern Bering Sea towards the west coast of the lower 48 states often occurs in the springs following El Niño winters.

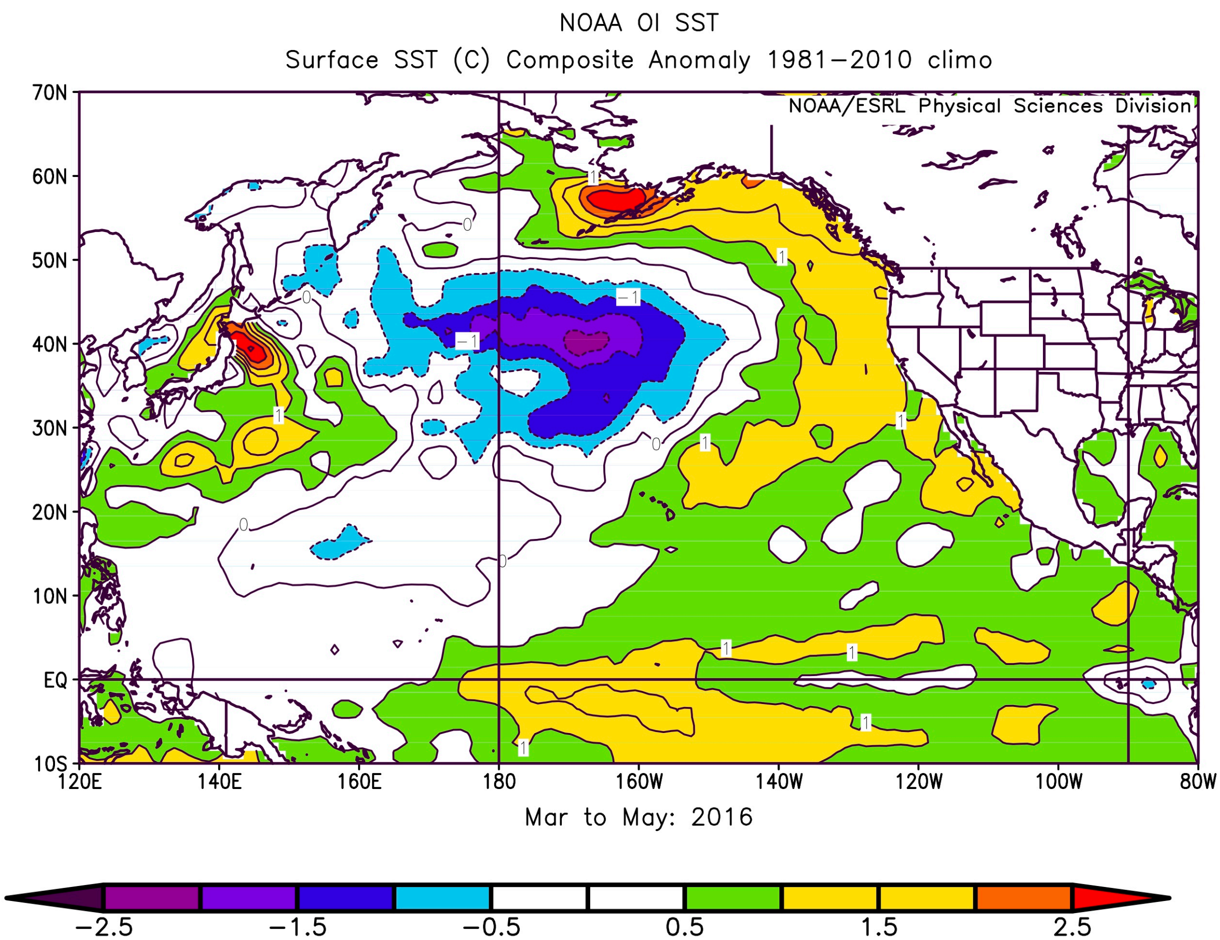

Figure 3a. SST anomalies for March – May 2016.

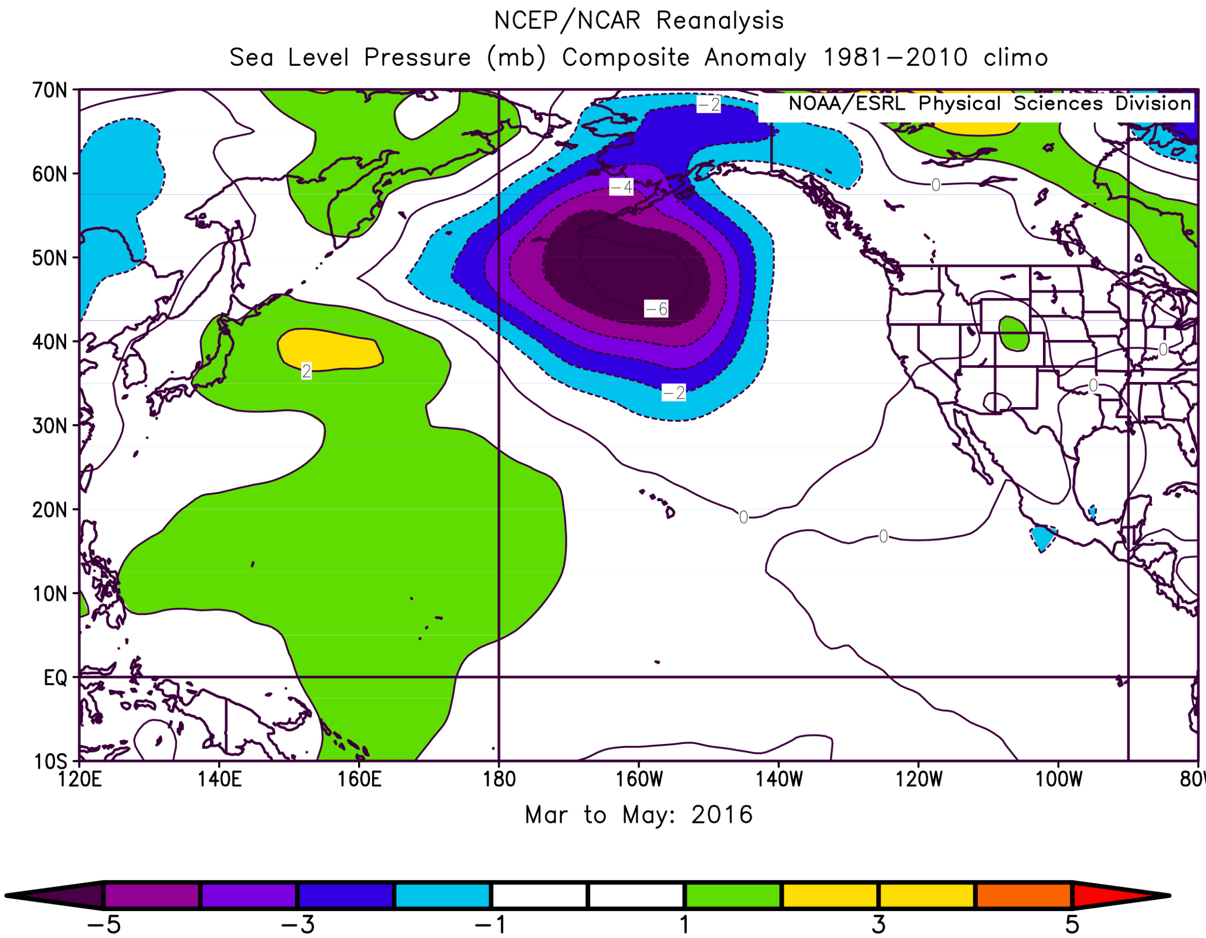

Figure 3b. SLP anomalies for March – May 2016.

The SST anomaly pattern in the North Pacific during summer (Jun-Aug) 2016 is shown in Figure 4a. It was warmer than normal in the north, with especially positive anomalies region exceeding 3°C in the southeastern Bering Sea. Relatively cool water was present in a broad band between roughly 25°N and 40°N from the east coast of Asia to the central North Pacific, with the most negative anomalies located north of the Hawaiian Islands. Warm water persisted in the subtropical North Pacific. Finally, cold anomalies developed in a narrow strip along the equator in the east-central Pacific, signifying the demise of El Niño and the potential for the development of La Niña. The distribution of anomalous SLP (Fig. 4b) during summer 2016 featured higher than normal pressure between the Alaska Peninsula and the Hawaiian Islands that was almost opposite to that of the previous season. The relatively high SLP extended into the Bering Sea and was associated with seasonally suppressed storminess and hence scant vertical mixing of the upper ocean, resulting in the very warm surface temperatures shown in Fig. 4a. The higher than normal SLP off the coast of the Pacific Northwest and California brought about strong coastal upwelling, and a moderation of SST in the immediate vicinity of the coast.

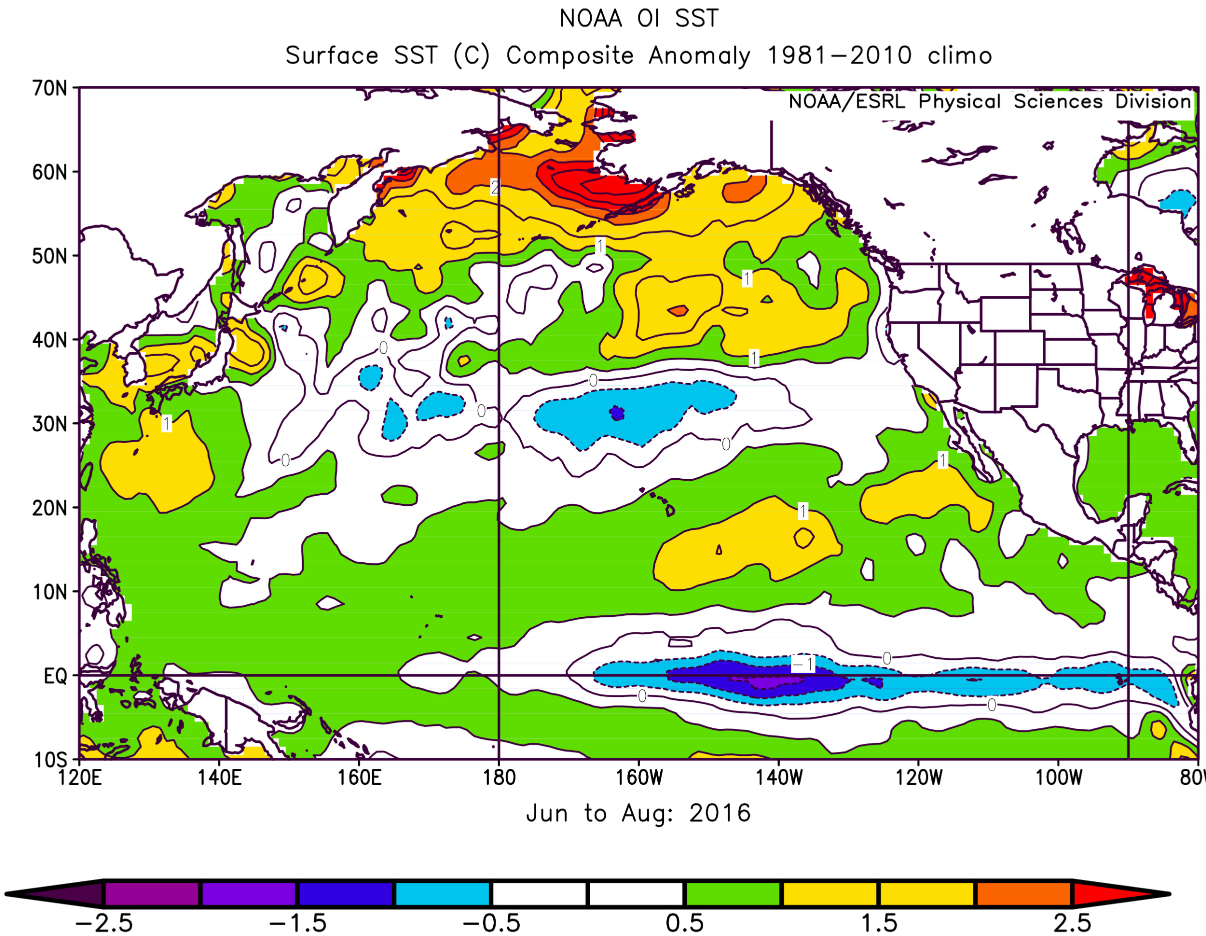

Figure 4a. SST anomalies for June – August 2016.

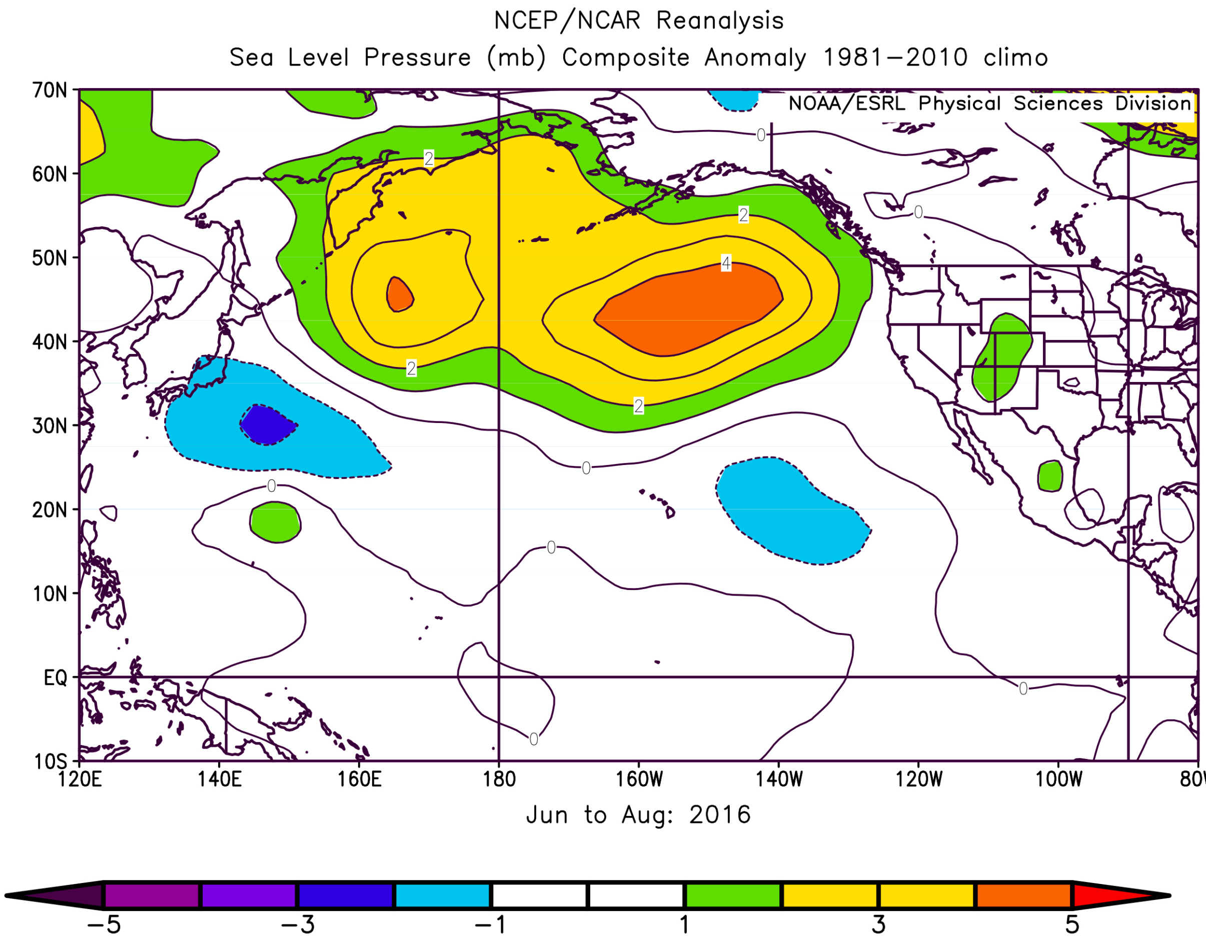

Figure 4b. SLP anomalies for June – August 2016.

2. Climate Indices

Climate indices provide a complementary perspective on the North Pacific atmosphere-ocean climate system to the SST and SLP anomaly maps presented above. The focus here is on five commonly used indices: the NINO3.4 index to characterize 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 2006 into summer 2016 are plotted in Figure 5.

The North Pacific atmosphere-ocean climate system has been in a highly perturbed state recently. Specifically, NINO3.4 reached a peak value of 2.3 in December 2015 in association with the strong El Nino of 2015-16. This measure of ENSO has declined over the first 8 months of 2016 and is now slightly negative. 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) during the last 2 years. The magnitude of the PDO actually decreased in 2015 during the ramp-up of El Niño, which is unusual. It generally tracks ENSO, with a lag of a few months, as illustrated here for the period of 2008-13 in Figure 5. The PDO did increase in early 2016 to a value exceeding +2, followed by a decrease in late spring/early summer 2015. The NPI was strongly negative during the past winter and spring, which implies a deeper than normal and often displaced Aleutian Low, as indicated in Figs. 2b and 3b. This represents a typical atmospheric response to El Niño. The deep Aleutian Low was accompanied by anomalous winds from the south and relatively warm air along the west of North America, i.e., atmospheric forcing favoring a positive trend in the PDO.

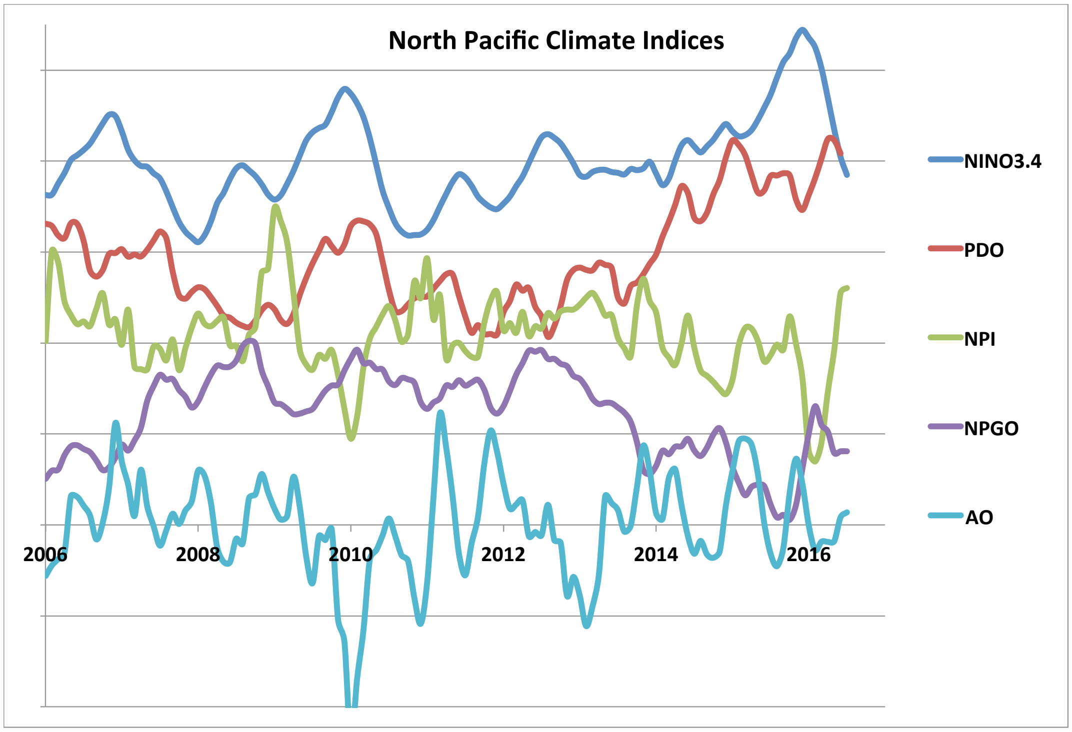

Figure 5. Time series of the NINO3.4 (blue), PDO (red), NPI (green), NPGO (purple), and AO (turquoise) indices. Each time series represents monthly values that are normalized using a climatology based on the years of 1981-2010, and then smoothed with the application of three-month running means. The 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 underwent a transition from negative in 2015 to a near-neutral state in 2016. A negative sense of this index, which is formally related to the 2nd mode of variability in sea surface height in the North Pacific, implies a reduced west wind drift and projects on weaker than normal flows in both the Alaska Current portion of the Subarctic Gyre and the California Current. 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 latter portion of 2015, and then mostly negative during early 2016. Most winters since 2009-10 have included relatively strong and persistent (multi-month) signals in the AO, in either the positive and negative sense, but that was not the case for the winter of 2015-16.

3. Regional Highlights

a. **West Coast of Lower 48** – This region continues to be impacted by warm ocean temperatures. These anomalies were not restricted to just the very upper part of the water column but rather extended to as much as 200-300 meters depth based on data from ARGO profilers. The winter of 2015-16 featured above-normal precipitation in the Pacific Northwest and below normal precipitation in southern California, with ~1 standard deviation warmer than normal temperatures along the entire coast. The end of winter snowpack was above normal in the Pacific Northwest and near normal in northern California; relatively warm weather in spring 2016 resulted in an early melt. Many streams ran low and warm in the summer of 2016 but not as severe an extent as was observed in 2015. The spring and summer of 2016 from ~Vancouver Island to Point Conception included relatively robust upwelling in the northern portion and a thin strip of water of moderate temperatures in the immediate vicinity of the coast. Further south, downwelling wind anomalies prevailed.

b. **Gulf of Alaska** –The upper ocean in this region was relatively salty in fall 2015, presumably at least in part due to the lack of lower elevation snow that was melted during the fall rains. On the other hand, there was an early freshening in 2016 due to the anomalously warm winter and hence more rain than snow than usual in coastal watersheds. The sub-arctic front was farther north than usual, which is consistent with the poleward surface currents shown in the Ocean Surface Currents – Papa Trajectory Index section (Stockhausen and Ingraham). The coastal wind anomalies were generally downwelling favorable during winter and spring but switched to more upwelling favorable during the summer of 2016. A prominent eddy was located on the outer shelf south of the Kenai Peninsula during the summer of 2016 and probably contributed to enhanced cross-shelf exchanges in its immediate vicinity.

c. **Alaska Peninsula and Aleutian Islands** – The waters of this region were relatively warm, especially in the fall of 2015 and summer of 2016. In part this can be attributed to the overall warmth of the North Pacific and in part to the weather, which featured persistently above normal air temperatures during the past year with only short and minor exceptions. Based on synthetic data from NOAA's Global Ocean Data Assimilation System (GODAS), the Alaskan Stream appears to have had a relatively strong westward flow from late 2015 into 2016. 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 Bering Sea shelf experienced a much warmer than normal winter and spring, for the 3rd year in a row. The warm weather can be attributed mostly to the deeper than usual Aleutian low and a preponderance of air masses of maritime rather than of Arctic or continental origins. There was little sea ice south of 59° N and consequently a lack of a cold pool in the middle domain of the southern Bering Sea shelf. The early summer of 2016 was also less stormy than typical. During August 2016, total heat contents on the shelf were at or near record levels.

e. Arctic – Remarkably warm air temperatures occurred in the central Arctic during the winter of 2015-16, mostly due to an anomalous atmospheric circulation leading to intrusions of mild air from the mid-latitudes. One implication is that there was probably less growth than usual in the thickness of first-year ice over much of the Arctic. A modest cold snap in late September in the Chukchi and Beaufort Seas marked the end of the 2015 melt season, but it was not until November 2015 before the shelf regions of these seas were covered by ice. A coastal polynya developed early in the season (the first week of May) in the eastern Chukchi Sea from approximately Cape Lisburne to Point Barrow. In the Beaufort Sea, rapid melting during August of a large area near the coast resulted in a broad band of open water from near Point Barrow to beyond the Mackenzie River delta. During summer 2016, the sea ice extent in the Beaufort Sea was considerably less than any of the previous 4 summers; for the Chukchi Sea the ice extent during the summer of 2016 has been comparable to that of recent summers. For the Arctic as a whole, the area of sea ice cover during the middle of August 2016 was slightly less than 2 standard deviations below normal, which represents the 3^{rd} lowest value in the observational record.

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 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/.

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 2016) with a smaller region of near normal temperatures northwest of the Hawaiian Islands (Fig. 6a). The magnitude of the positive anomalies is projected to be greatest (exceeding 1°C) in the GOA and eastern Bering Sea. Negative SST anomalies are projected in the central equatorial Pacific. The latter are associated with the potential for a weak La Niña. As of September 2016, 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 a 55 to 60% chance of neutral conditions and about a 40% probability of La Niña during the upcoming fall and early winter. The overall pattern of SST anomalies across the North Pacific is maintained through the 3-month periods of December 2016 – February 2017 (Fig. 6b) and February – April 2017 (Fig. 6c) with a moderation of the strength of the anomalies in most regions. It is unclear whether the equatorial Pacific will be perturbed enough, particularly with respect to the intensity and distribution of deep atmospheric convection, to cause the usual response to La Niña. Past La Niña events have included a weaker than normal Aleutian low and a relatively cold winter for Alaska, western Canada and the Pacific Northwest. On the other hand, the models comprising the NMME are indicating at most borderline La Niña conditions, and remote responses to the equatorial Pacific that are relatively weak. The model consensus includes slightly warmer than normal temperatures for western North America. The weak and competing signals suggest that the North Pacific climate may be in a state of rather low predictability. That being said, it is unlikely that the upcoming winter in Alaska and western Canada will be as mild as those of the last three years.

The SST anomaly maps shown in Figs. 6a-c share an unusual feature and that is the co-existence of a relatively cold equatorial Pacific with a horseshoe-shaped pattern of warm water along the west coast of North America, a signature of the positive phase of the PDO. The closest analog to that situation in recent decades was from late 1980 into spring 1981. In that case, the PDO was not as strongly positive as predicted for the upcoming winter and spring, and the NINO3.4 anomalies were of modest amplitude (about -0.4 in early 1981). The maintenance of positive PDO conditions in the North Pacific during the upcoming year, despite an ENSO state that generally brings about an SST anomaly pattern associated with the negative phase of the PDO, could be a reflection of the enormous amount of extra heat in the upper ocean now present along most of the west coast of North America, and the model projections of a muted atmospheric response in the mid-latitudes to the equatorial Pacific during the next 2 seasons.

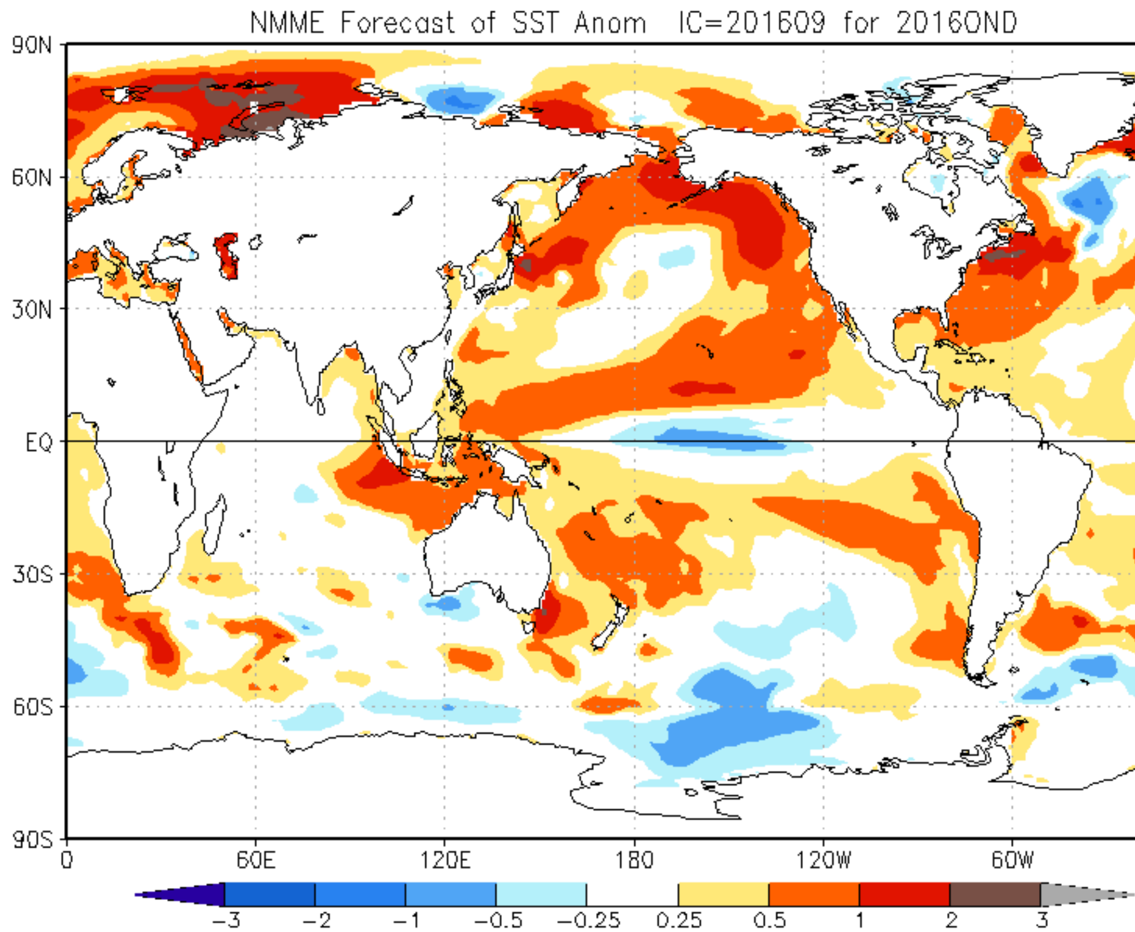

Figure 6a Predicted SST anomalies for October-December 2016 (1 month lead) from the National Multi-Model Ensemble (NMME) of coupled atmosphere-ocean climate models. See text for details.

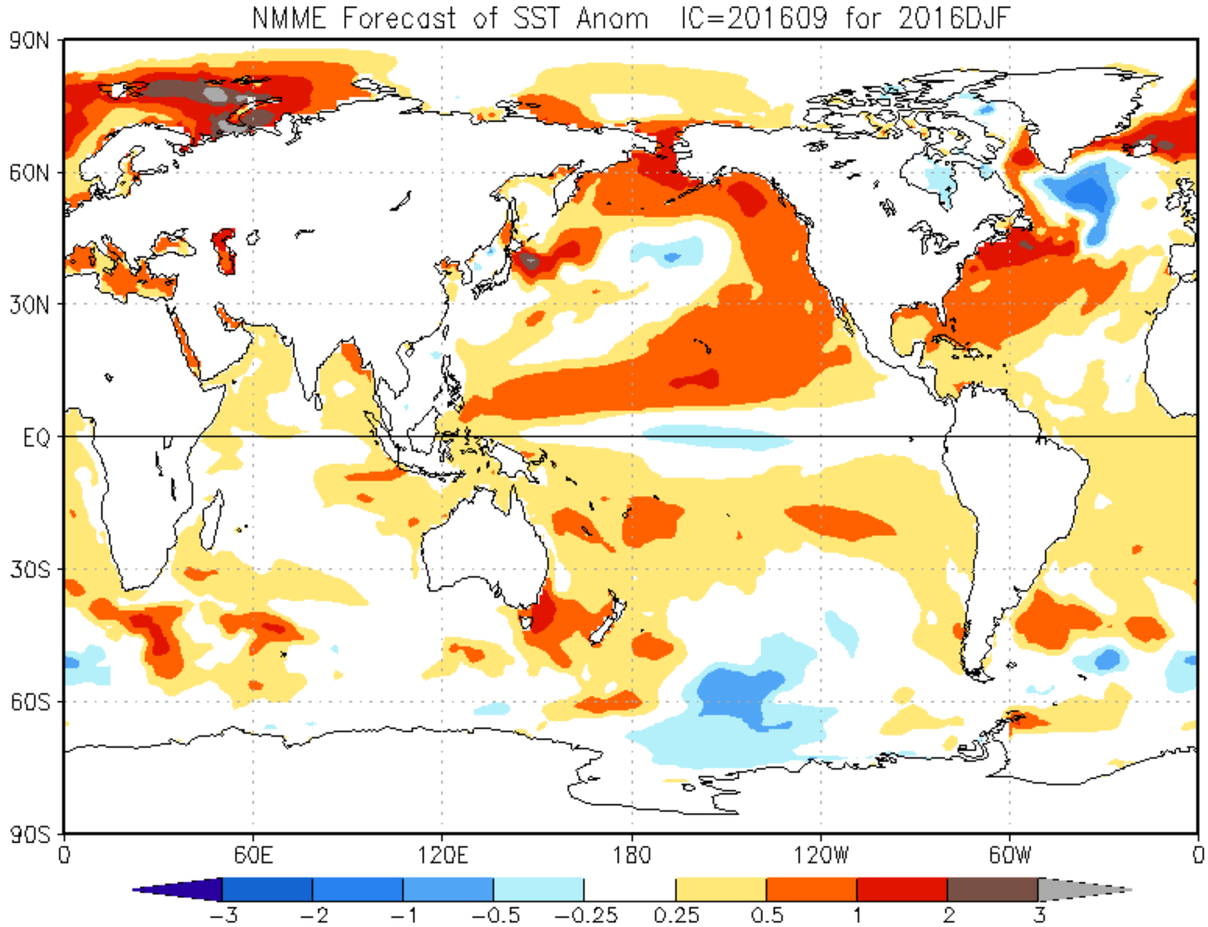

Figure 6b As in Fig. 6a, but for December 2016-February 2017 (3 month lead).

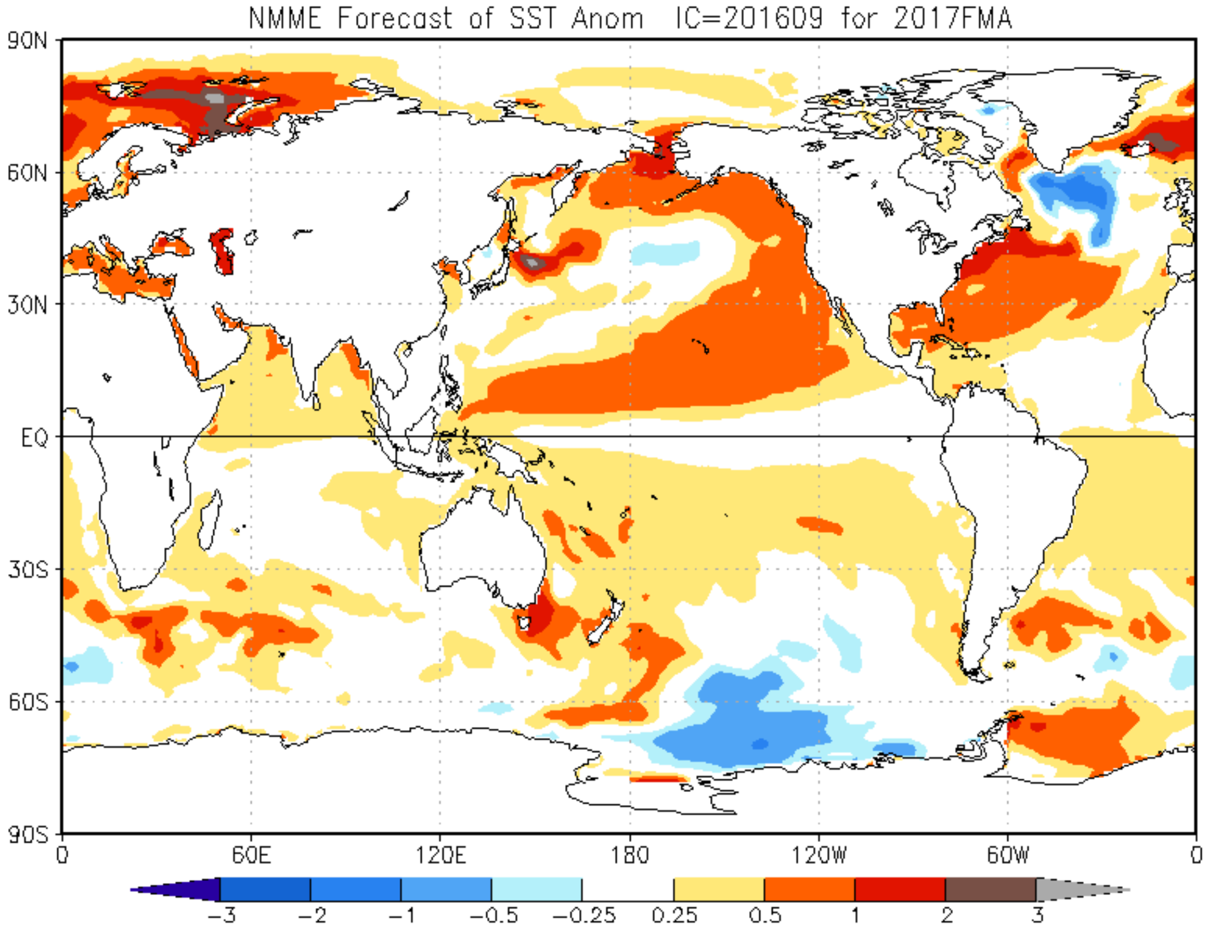

Figure 6c. As in Fig. 6a, but for February-April 2017 (5 month lead).