Pacific Climate Overview – 2006

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***Summary**. Atmospheric circulation over the North Pacific during 2006 was characterized by a high degree of variability. A strong Aleutian low, which dominated in December 2005, substantially weakened and split into two centers in January 2006. The anomalous high pressure center that formed over the central North Pacific is consistent with the weak La Niña that was present in the tropical Pacific. The anomalous atmospheric circulation was accompanied by a southward expansion of negative sea surface temperature anomalies in the Gulf of Alaska and a relatively warm water pool in the North Pacific near the dateline that persisted through spring and summer of 2006. There are conflicting signals regarding the evolution of North Pacific SST anomalies into 2007. Coupled GCM forecasts from the Climate Prediction Center suggest persistence of the current SST anomaly pattern into early 2007. On the other hand, a weak to moderate El Nino is forming in the fall of 2006, which often is associated with a stronger than normal Aleutian low, which itself usually acts to cool the central North Pacific and bring about a narrow strip of warmer than normal waters along the North American coast. A great deal of ambiguity still exists regarding a possible climate regime shift in the late 1990s. Some indices, such as the winter PDO index from N. Mantua and Pacific/North American (PNA) index, lack substantial and systematic changes in their states. An alternative version of the winter PDO index from National Climate Data Center and summer PDO indices, however, feature statistically significant shifts to negative values in 1998/99. That time also corresponds to a statistically significant shift in the El Niño/ Southern Oscillation.*

1. El Niño – Southern Oscillation (ENSO)

During September 2005- January 2006, below-average SSTs developed throughout most of the central and eastern equatorial Pacific. In February 2006 positive SST anomalies developed in the extreme eastern equatorial Pacific, similar to what occurred in 1999, 2000 and 2001 (La Niña years). Based on the Oceanic Niño Index (ONI), which has become the de-facto standard used by NOAA to identify ENSO events, these conditions in the equatorial Pacific qualified as a weak La Niña episode (Fig. 1).

Recently, SST anomalies have increased in the west-central and extreme eastern equatorial Pacific. Statistical and coupled model forecasts produced by the Climate Prediction Center suggest that either ENSO-neutral or weak El Niño conditions are most likely through early 2007. However, the spread of these forecasts indicates considerable uncertainty in the outlook for late 2006 and early 2007.

2. Arctic Sea-Ice

The warming trend in the Arctic is illustrated in Fig. 2, which shows the Northern Hemisphere sea ice extent in March, as measured from passive microwave instruments onboard NOAA satellites. March is the month when Arctic sea ice reaches its maximum extent. The overall downward trend in the sea ice extent has accelerated in the past four years. In 2006 it was 14.5 million square kilometers, the lowest value for any March on record (Fig. 2). This is 1.2 million square kilometers below the long-term (1979-2000) mean. The implications of this trend for the

North Pacific is liable to include a tendency for a shorter season during which intense cold-air outbreaks of arctic origin can occur.

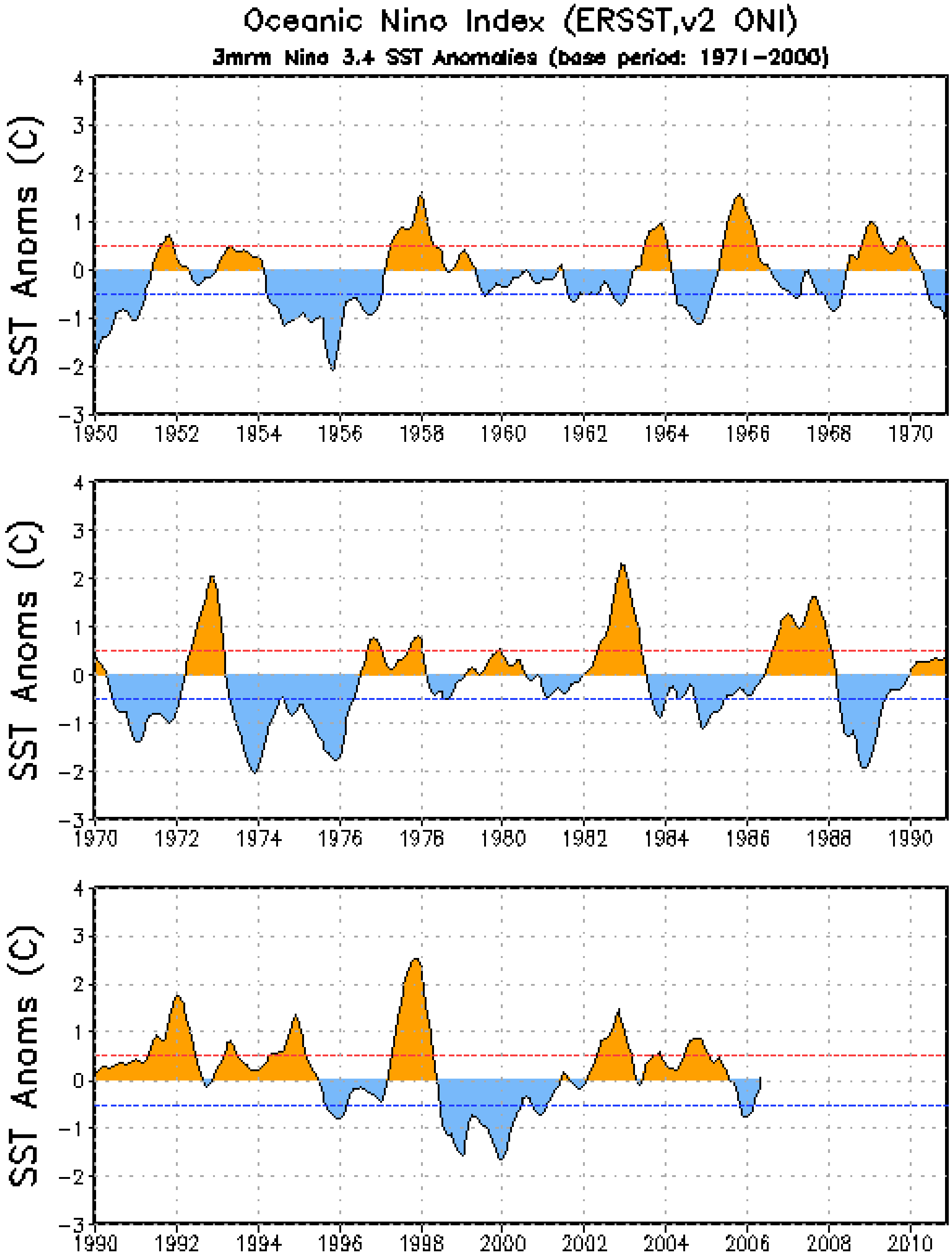


Fig. 1. The Oceanic Niño Index (ONI) is the running 3-month mean SST anomaly for the equatorial Pacific and is the standard used by NOAA to identify El Niño (warm) and La Niña (cool) events in the tropical Pacific.

3. North Pacific

3.1 Atmospheric Circulation

In the winter of 2005/06, the atmospheric circulation was characterized by a high degree of variability. Specifically, December 2005 featured an anomalously strong Aleutian low, with sea-level pressure (SLP) in its center being 12 hPa below long-term average. The North Pacific index (NPI), which is the area-weighted SLP over the region 30N-65N, 160E-140W (Trenberth and Hurrell, 1994), was 999.5, the record lowest value for December since 1899. It is particularly unusual that this abnormally low pressure occurred in the absence of an El Niño event, which is considered as one of the major factors leading to a stronger-than-normal Aleutian low (Lau, 1996). Overall, the atmospheric circulation in December 2005 can be classified as W1, which is the most typical pattern associated with positive surface air temperature anomalies (SAT) in the eastern Bering Sea (Rodionov et al., 2005).

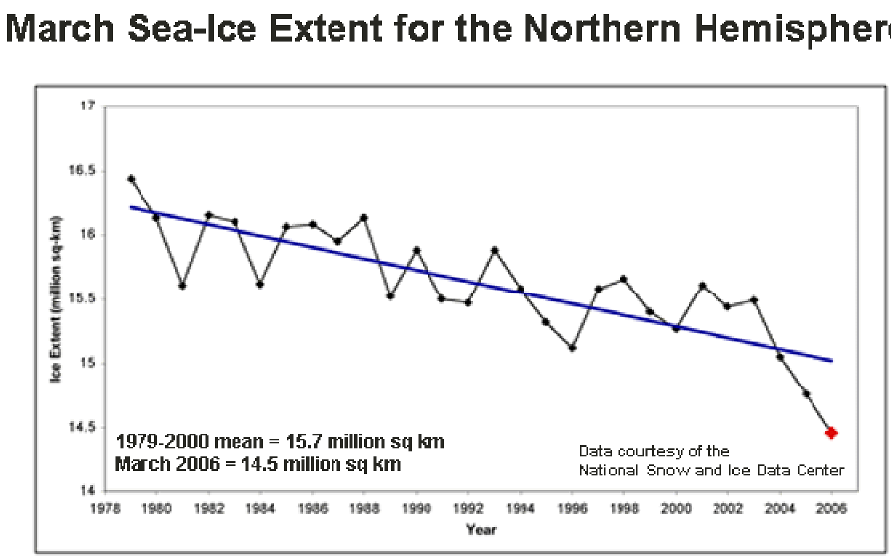


Fig. 2. March sea-ice extent (in millions of square kilometers) across the Northern Hemisphere.

In January 2006, the Aleutian low was weak and split into two centers, one in the northwestern Pacific and the other one in the Gulf of Alaska. This pattern is classified as C1, which is the major circulation pattern for anomalously cold temperatures in the Bering Sea (Rodionov et al., 2005). Indeed, January SATs in the Bering Sea and Alaska were much below normal (see the report for the Bering Sea). The atmospheric circulation also featured anomalous middle to upper tropspheric troughing from the Gulf of Alaska into western Canada. This resulted in a near zonal flow over much of the Pacific-North American sector and advection of warm Pacific air masses deep into the continent, where monthly temperatures in much of the U.S. and Canada were above the 90th percentile of occurrences.

In February 2006, an anomalously high pressure cell in the central North Pacific strengthened even further, with SLP anomalies exceeding 12 hPa, and pushing the storm activity far north into the Bering Sea. The monthly NPI was the 6th largest for all Februaries since 1899. This extreme variability in atmospheric circulation over the North pacific is illustrated in Fig. 3, which shows a time-latitude plot of SLP anomalies averaged for the meridional section 150W-170W. Although the high pressure cell weakened in the subsequent months, the NPI remained positive through June 2006.

3.2 Sea Surface Temperature Evolution

A sequence of by-monthly sea surface temperature (SST) anomaly maps from January-February 2006 to July-August 2006 is presented in Fig. 4. These maps demonstrate two important features of SST evolution during the winter and spring of 2006: 1) Disappearance of negative SST anomalies in the central and eastern equatorial Pacific in association with the final stages of the weak La Niña episode, and 2) Developing of a SST anomaly pattern in the North Pacific, with some elements of a negative Pacific Decadal Oscillation (PDO) phase. One of those elements is the strengthening and southward expansion of negative SST anomalies in the northeastern Pacific from January-February through, at least, May-June. This process was associated with the prevalent northwesterly anomalous wind over the eastern North Pacific in the first eight month of this year (Fig. 5).

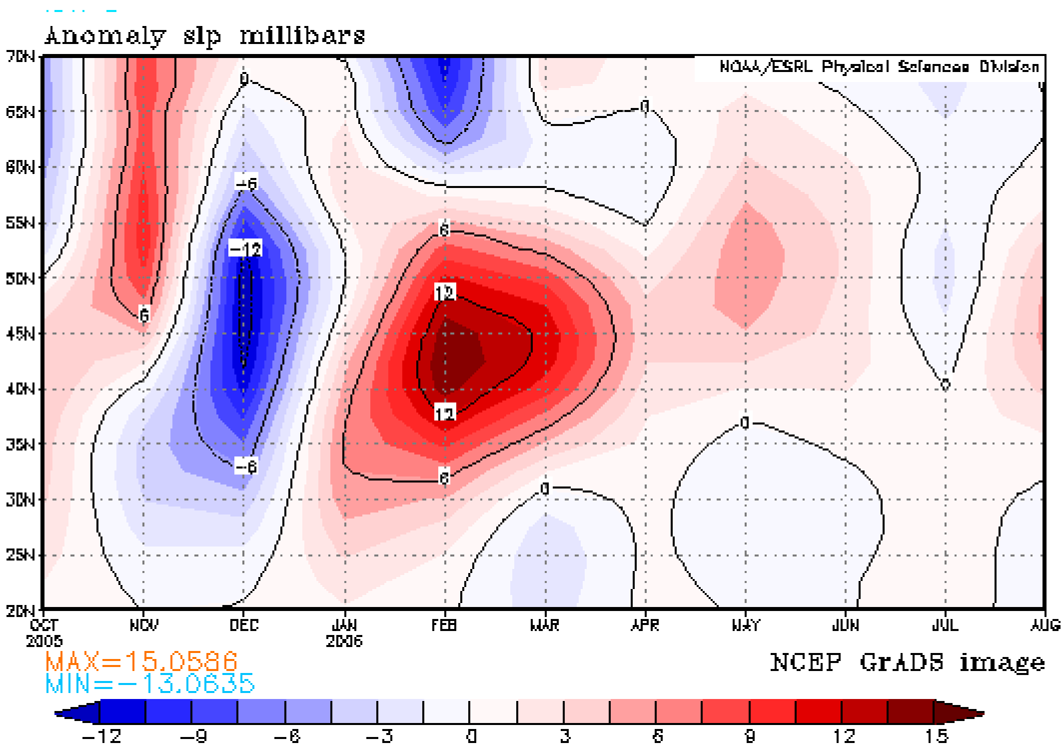
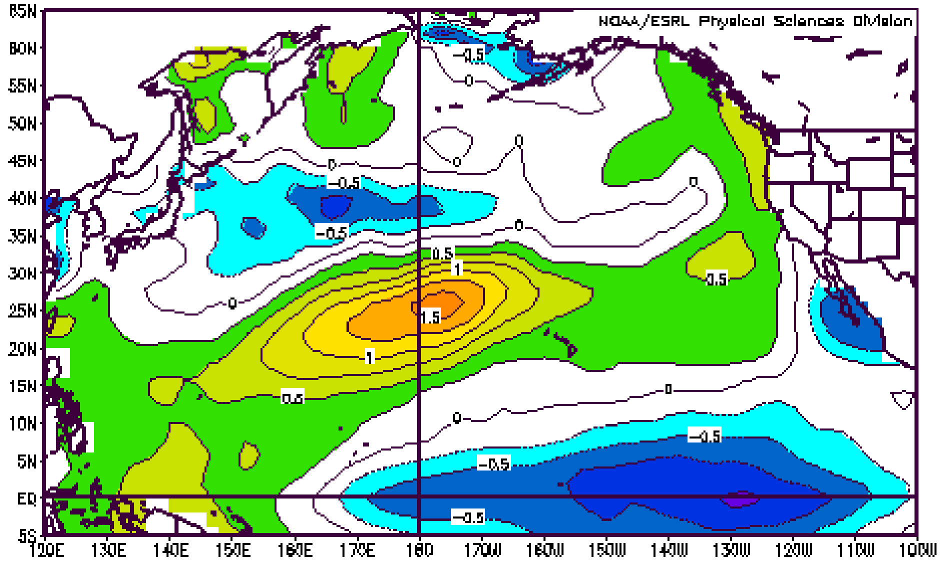
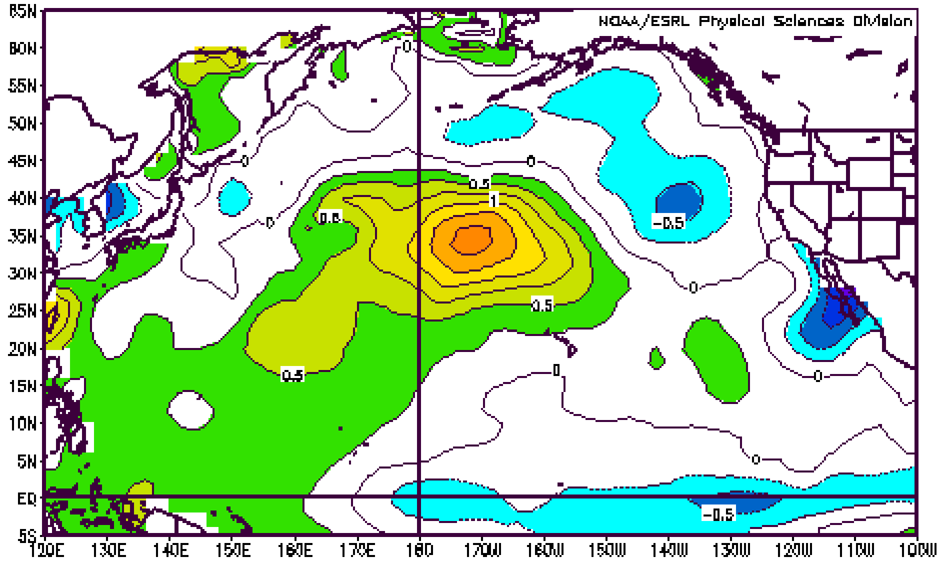


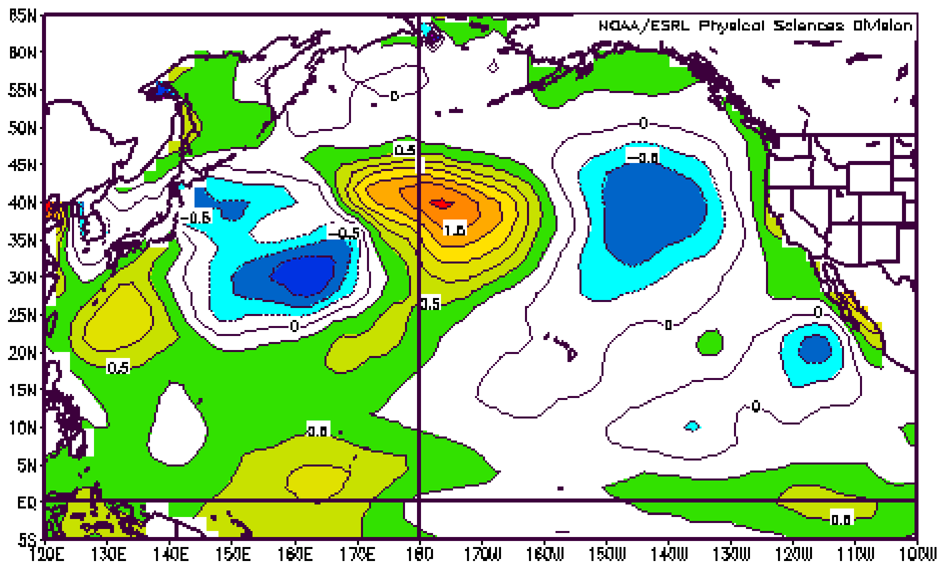
Fig. 3. Time-latitude plot of SLP anomalies averaged over the meridional sector 150W-170W.



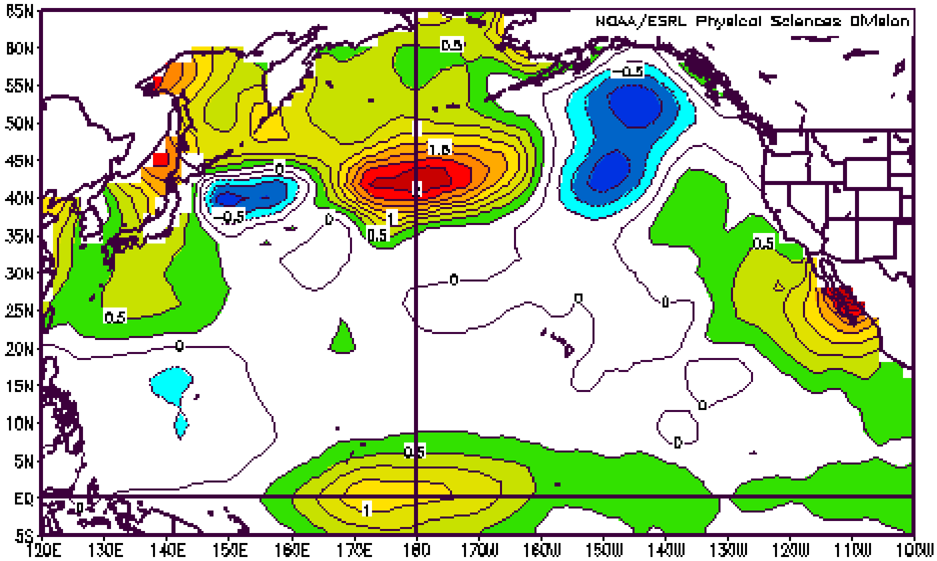
a) Jan-Feb 2006



b) Mar-Apr 2006



c) May-Jun 2006



d) Jul-Aug 2006

Fig. 4. Monthly SST anomalies (relative to 1971-2000 climatology) from December 2005 through May 2006.

Another important aspect of the SST evolution in 2006 is strengthening of the positive SST anomaly in the central North Pacific. The atmospheric circulation pattern, with its anomalous anticyclonic circulation over the basin (Fig. 5), was conducive to this process. Several mechanisms contribute to the formation of a warm water pool under a high pressure cell over the central North Pacific. Anomalously high pressure implies less cyclonic activity in the area and hence less cloudiness, which means enhanced solar heating of the upper ocean. Strong easterly anomalous winds in the subtropical latitudes imply an enhanced transport of warm waters in the Ekman layer to the north and stronger than normal downwelling in center of the subtropical ocean gyre.

It is somewhat surprising, therefore, that in spite of atmospheric pressure and wind patterns that were characteristic of the negative PDO phase, that the monthly PDO index remained positive through the first half of 2006. A contributing factor here is that the west Pacific was colder than normal, which projects on a positive phase of the PDO.

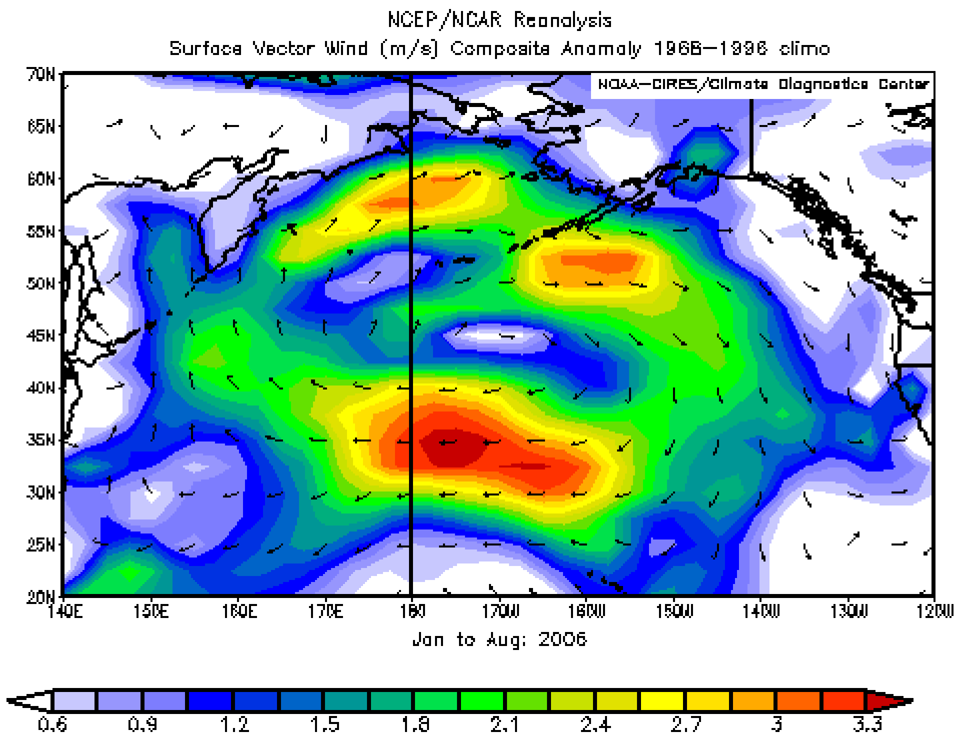


Fig. 5. Surface vector wind anomalies averaged for the period from January 2006 through August 2006.

3.3 Sea Surface Temperature Forecast from NCEP

The latest seasonal forecast produced by the NCEP coupled forecast system model (CFS03) suggests that the atmospheric processes described above will continue to operate throughout the rest of the year and in winter and spring of 2007. The model suggest anomalously frequent troughing in the lower to middle troposphere along the North American west coast, which tends to promote negative SST anomalies in the Northeast Pacific. Anomalously cold waters east of Japan are forecast to warm up, and the entire pattern will resemble the negative phase of the PDO (Fig. 6). Due to a probable El Niño event, a narrow strip of warmer than normal waters off the west coast of North America is likely to develop.

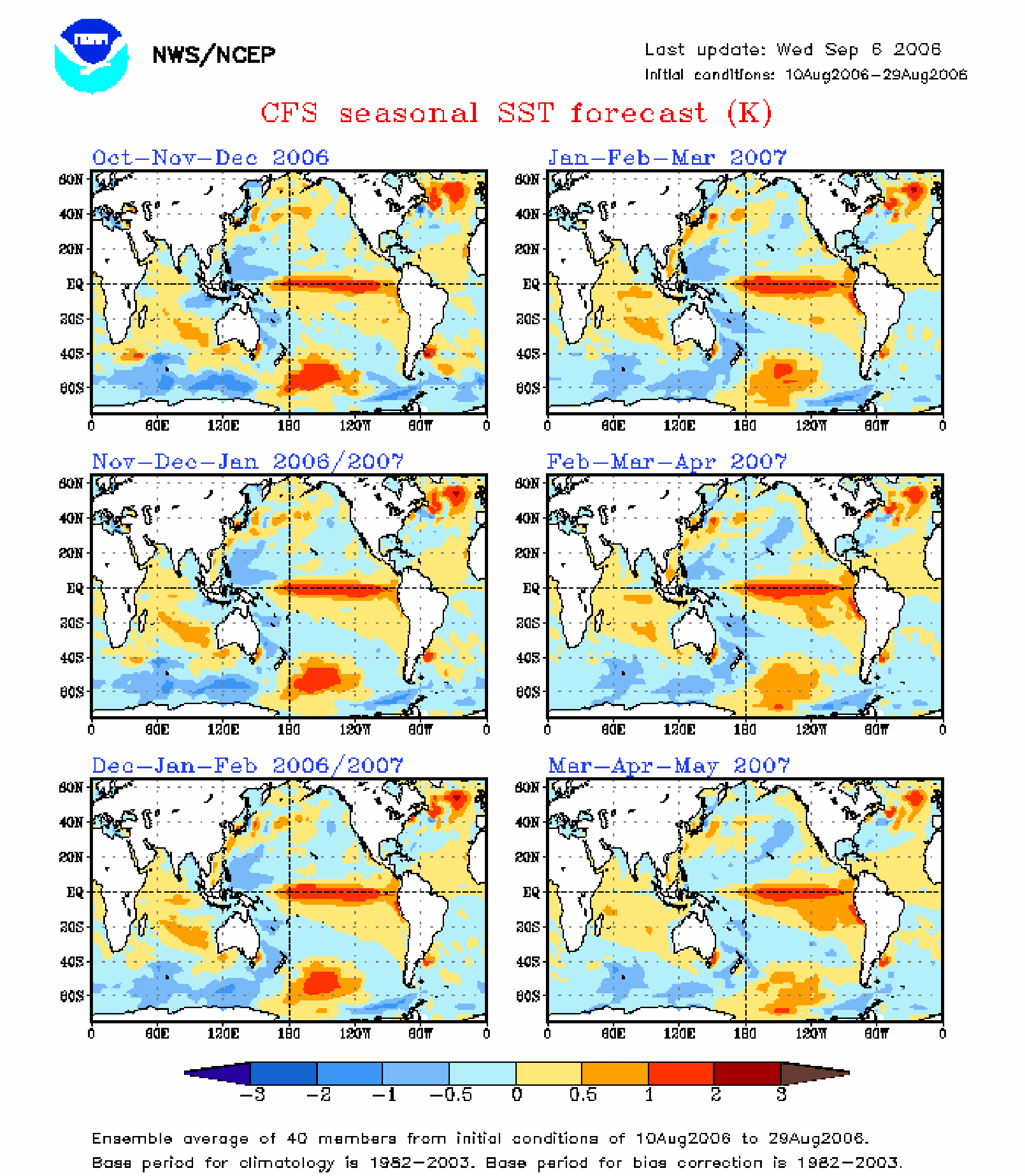


Fig. 6. Seasonal forecast of SST anomalies from the NCEP coupled forecast system model.

4. Regime Shift Analysis

The NP index jumped to a positive value in the winter of 2005-06, which is characteristic of the weak Aleutian low regime of 1947-1976 (Fig. 7a). Since this shift just occurred, it is uncertain whether it represents just a temporary change or actually heralds the beginning of a new regime. At the same time, the PDO index remained slightly positive (Fig. 7b), which is more consistent with the current regime established since the late 1970s than for the previous regime of a PDO phase.

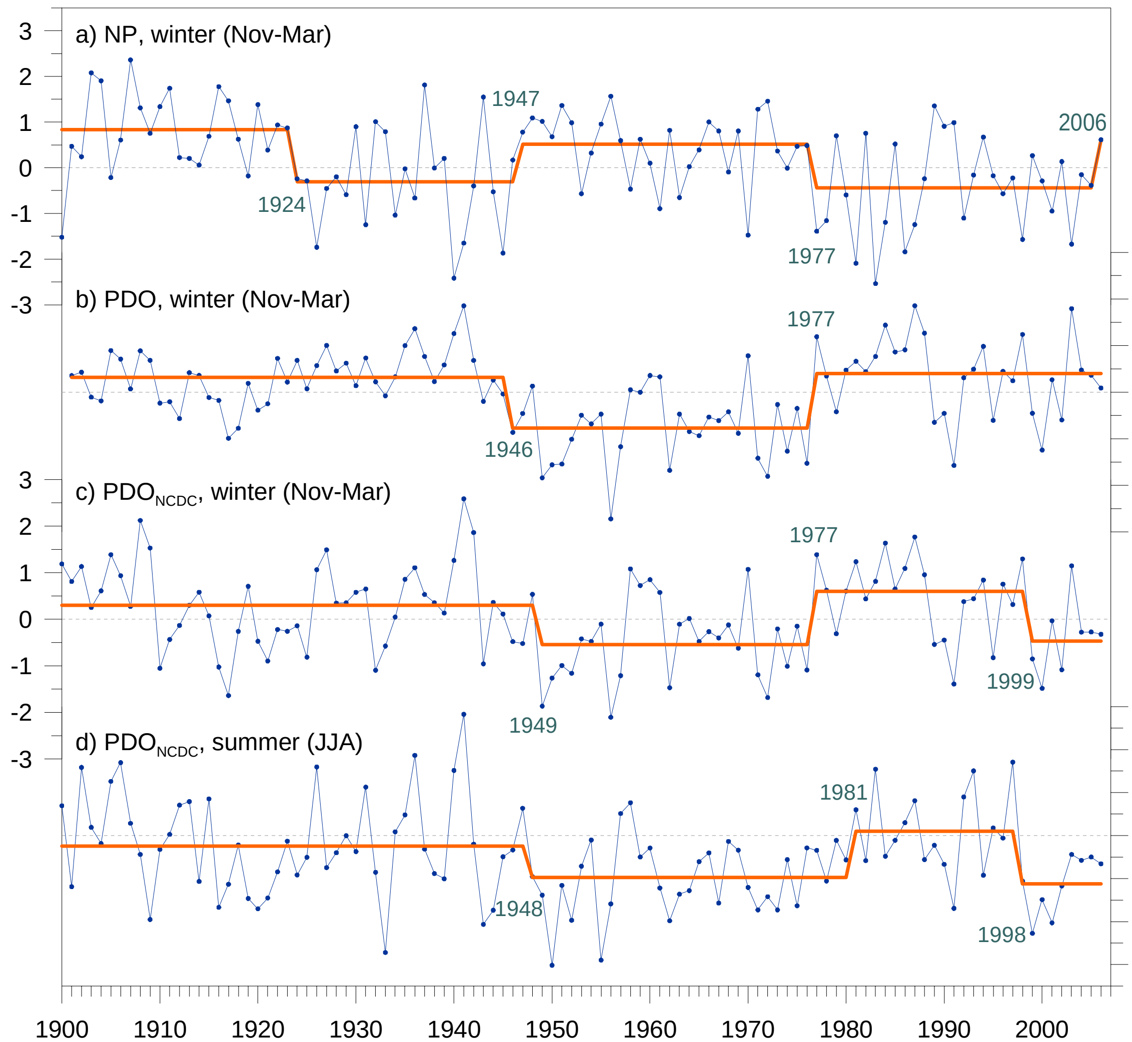


Fig. 7. a) Winter (Nov-Mar) NP index from NCAR, b) Winter (DJF) PDO index from N. Mantua, University of Washington, c) Winter (DJF) PDO index from NCDC, and d) Summer (JJA) PDO index from N. Mantua. The stepwise trends (orange lines) were calculated using the sequential method (Rodionov, 2004) with the cutoff length l = 20 years, probability level p = 0.05, and Huber weight parameter h = 1.

It should be noted that the data source used by N. Mantua to calculate his index (Reynold's Optimally Interpolated SST) changed in 2002 from ver. 1 to ver. 2, and this could affect the values of the index. There is another PDO index calculated at the National Climate Data Center (NCDC) based on a single data source, the Extended Reconstructed SST data set. NCDC uses the same loading pattern as N. Mantua, but somewhat different technique to calculate the index. Although the correlation between the two variants of the PDO index is 0.87 (for the period 1901-2005), the implications for the regime shift analysis are substantial. Unlike the PDO index from N. Mantua, the PDO$_{NCDC}$ index has a statistically significant (at the 0.01) level shift in 1999 (Fig. 7 c). Since this year, there was only one positive value of the index in 2003 (a year of El Niño). The magnitude of this shift is even greater for the summer PDO index (Fig. 7d), being statistically significant at the 0.0007 level).

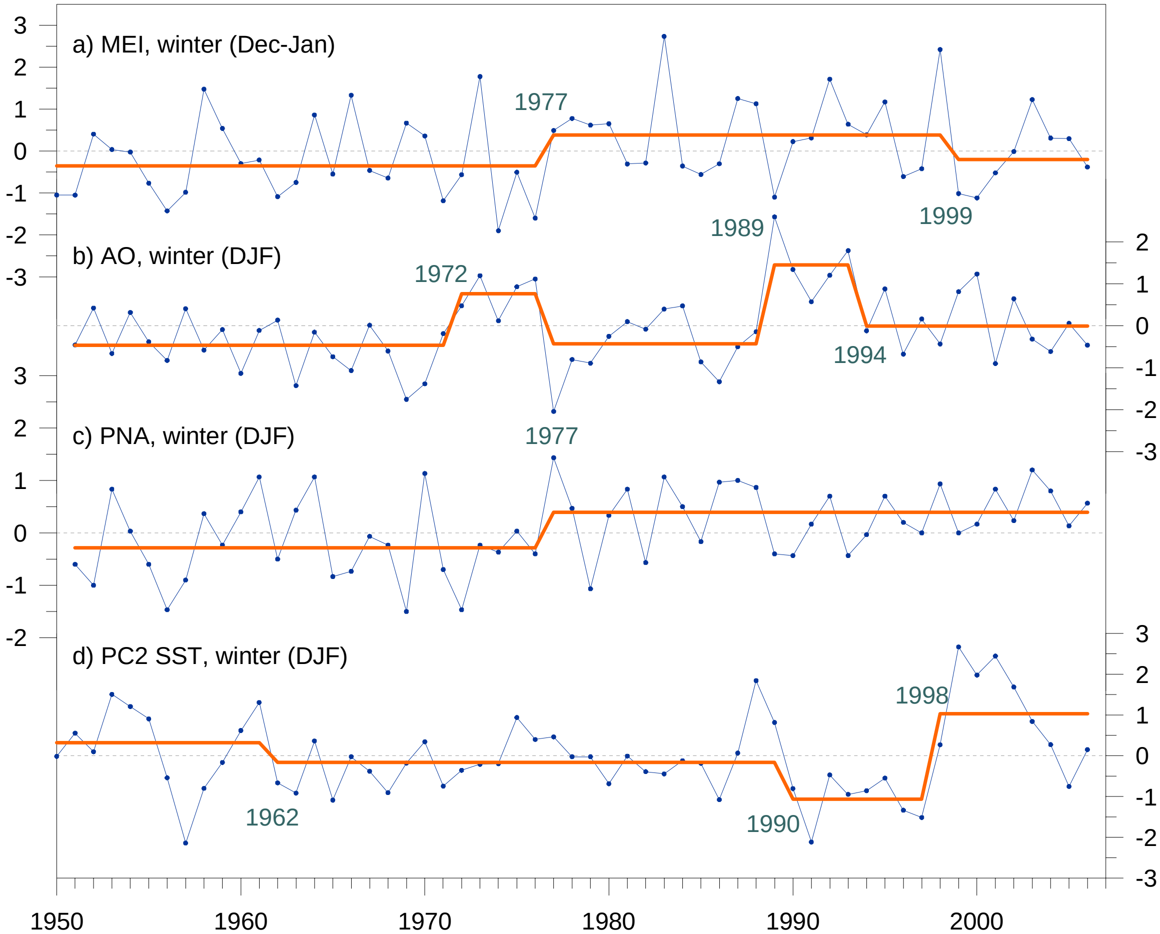


Fig. 8. a) Winter (Dec-Jan) Multivariate ENSO index (*l* = 10, *p* = 0.3, *h* = 1), b) Winter (DJF) Arctic Oscillation index (*l* = 10, *p* = 0.2, *h* = 1), c) Winter (DJF) Pacific/North American index (*l* = 10, *p* = 0.1, *h* = 1), and d) Winter Victoria (PC2 SST) index (*l* = 10, *p* = 0.3, *h* = 1).

The indices presented in Fig. 8 are available since the 1950s, and they were analyzed using less strict *l* and *p* parameters. The Multivariate ENSO index (MEI) shows an upward shift in 1977 and a downward shift in 1999 (Fig. 8a). Despite a relatively small magnitude of the shifts (compared to those in the PDO), they are statistically significant at the 0.01 and 0.1 levels, respectively. The Arctic Oscillation (AO) index (Fig. 8b), which jumped to its record high value in 1989, has substantially declined since then and cannot longer serve as part of the explanation for the continuing Arctic warming (Overland and Wang, 2005). The Pacific/North American (PNA) teleconnection pattern is the leading mode of atmospheric circulation over the North Pacific and North America. The PNA index, obtained from the Climate Prediction Center (CPC), shows no sign of reversal from the high index regime established since 1977 (Fig. 8c). The second empirical orthogonal function (EOF2) of SST in the North Pacific, also known as the Victoria pattern, accounted for much of the climate variability since 1990 (Bond et al., 2003). In the past several years, the principal component of this pattern (Fig. 8d) declined to near zero values, and its role diminished. For more information on these and other climate indices, visit www.BeringClimate.noaa.gov.

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