

Recent Observed Interdecadal Climate Changes in the Northern Hemisphere

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Abstract

The largest increases in surface temperatures over the Northern Hemisphere in the decade prior to 1988 were in Alaska, while substantial decreases occurred in the North Pacific Ocean. This illustrates the considerable geographic spatial structure to interdecadal temperature variations associated with changes in the atmospheric circulation. In particular, from 1977 to 1988, there was a deeper and eastward-shifted Aleutian low-pressure system in the winter half year, which advected warmer and moister air into Alaska and colder air over the North Pacific. Associated changes in surface-wind stress and wind-stress curl altered the North Pacific Ocean currents, as revealed by the Sverdrup transport. The North Pacific changes appear to be linked through teleconnections to tropical atmosphere-ocean interactions and the frequency of El Niño versus La Niña events. Consequently, the question of why it was so warm in Alaska becomes changed to one of why there were three tropical Pacific Warm Events, but no Cold Events, from 1977 to 1988, and whether changes in El Niño frequency will be altered during climate change. At the very least, these linkages and the resulting strongly regional structure of surface-temperature variations complicate any search for a greenhouse effect and global warming.

1. Northern Hemisphere large-scale observed trends

Surface-temperature trends in the Northern Hemisphere (NH) reveal a rise from about 1890 to 1940 of a few tenths of a degree Celsius, a slight downward trend until the early 1970s, and a further increase into the 1980s (Jones 1988). At any one place in the NH, there are major departures from this time sequence (e.g., figure 1), so that "global warming," even if present in the global average, is far from uniform. The temperature anomalies are strongly regional and of both positive and negative signs. The decade 1977–86 features very large North Pacific-basin temperature anomalies, with warming of $>1.5^{\circ}\text{C}$ in Alaska and cooling of $>0.75^{\circ}\text{C}$ in the central and western North Pacific. At present it is possible to define regional temperature anomalies over most of the

hemisphere only after 1945 because of diminished coverage and the need for corrections to sea-surface temperatures (SSTs) and surface-marine temperatures prior to then. Folland and Parker (1988) have presented decadal mean hemispheric surface-temperature anomaly maps beginning in 1947. The mean temperature anomalies for 1977–86 (figure 1) are larger in magnitude and more coherent than for the other decades, but happen to be part of a single regime of "weather," which is explored here from the standpoint of causes of the climate variations.

Most presentations of climate change focus on the surface variables of importance to man, in particular temperature and precipitation. But in order to understand why the changes occur the way they do, it is essential to consider the atmospheric dynamics, as well as the local physical processes operating to induce change. The atmospheric circulation forms the main link between regional changes in wind, temperature, precipitation, and other climatic variables, and there is likely to be a reasonably strong relationship between these even on monthly or longer time scales. Physical and dynamical consistency between changes of several climate variables can add confidence to results for a single variable which might otherwise be compromised by measurement, data coverage, or analysis uncertainties. Because it is well known that temperature variations are closely tied to the quasi-stationary planetary waves in the NH in winter (van Loon and Williams 1976, 1977), the recent anomalies in the North Pacific are examined from this perspective.

Of interest are how the changes in surface temperatures relate to what would be expected from changes in temperature advection, and perhaps vertical mixing over the oceans, by the anomalous winds. In other words, anomalous northerly winds often result in colder-than-normal conditions (in the NH), while anomalous southerlies are typically warmer than normal. Alternatively, in the NH in winter, winds from the ocean are usually milder while winds from the interior of the high-latitude continents may be considerably colder than normal.

Although hemispheric analyses of the atmospheric circulation above the surface are confined to after 1947, a long series of charts of sea-level-pressure

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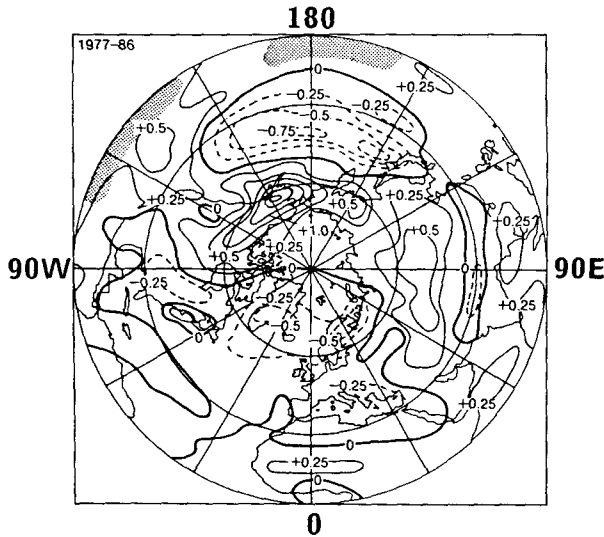


FIG. 1. Decadal average surface-temperature or sea-surface-temperature anomalies as departures from the 1951–80 mean, for 1977–86. Contours every 0.25°C (from Folland and Parker 1989).

variations, beginning in 1899, are available. An evaluation (Trenberth and Paolino 1980) shows them to be most reliable after 1924, and we therefore use monthly mean sea-level pressures to examine the changes in circulation.

Time series of Pacific mean sea-level pressure for the winter period November–March (figure 2), averaged from 27.5°N to 72.5°N, 147.5°E to 122.5°W, or virtually the entire North Pacific, reveals the different regime after 1976. This time series depicts changes in the intensity of the Aleutian low, and is also an index of the Pacific–North American (PNA) teleconnection pattern. The PNA appears to be a preferred mode of the atmosphere in the NH in winter and consists of four centers of action in the midtropospheric height field, of one sign near Hawaii and along the West Coast of North America, and of opposite signs over the North Pacific and southeast United States (Wallace and Gutzler 1981). The latter show that the surface signature of the PNA is confined mostly to the Pacific in the area selected for figure 2; the correlation of this index with a PNA index based on all four PNA teleconnected centers at 700 and 500 mb is -0.92 for 1947–87.

In the Aleutian low, from 1977 to 1988, for November through March, pressures averaged over the vast area of the North Pacific were lower by 2 mb. Lower pressures were present individually in all five winter months, and are highly statistically significant (figure 3). No such change is present in any of the other months of the year. The wintertime changes correspond to the center of the low farther east and deeper, on average by 4.3 mb for the five winter months, and deeper by 7 to 9 mb in January (Trenberth 1989).

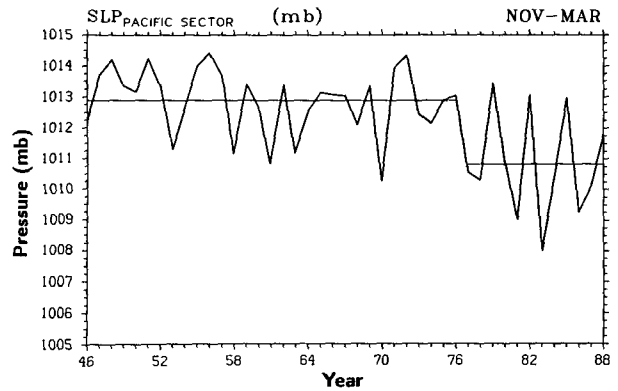


FIG. 2. Time series of mean North Pacific sea-level pressures averaged over 27.5° to 72.5°N, 147.5°E to 122.5°W for the months November–March. Means for 1946–76 and 1977–87 are indicated.

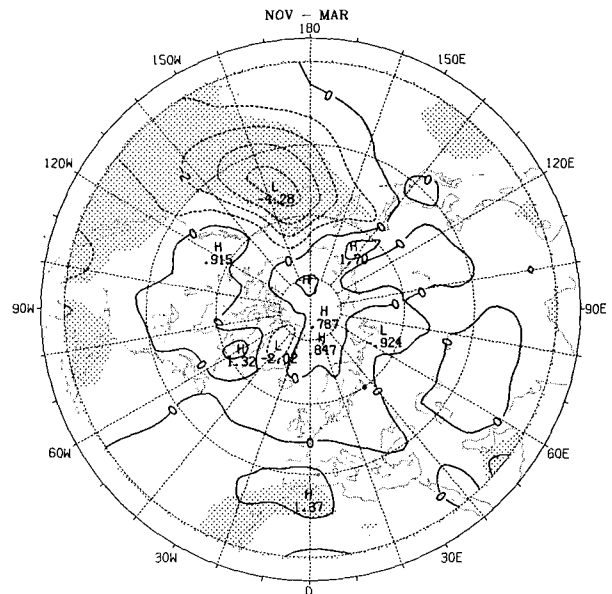


FIG. 3. The difference in mean sea-level pressures from 1977–88 for November–March versus 1924–76 (mb). Stippling indicates statistical significance at 5%.

A climatology for surface-wind stress, based on 1980–86 data (Trenberth et al. 1989), revealed changes in the North Pacific compared with the Helder and Rosenstein (1983) climatology, based on ship data prior to 1977, that help confirm the reality of the sea-level pressure changes (Trenberth 1989), and so do analyses with independent datasets (Nitta and Yamada 1989). Moreover, the associated changes in the curl of the wind stress and the corresponding Sverdrup transport in the ocean (Trenberth et al. 1989) over such a long period imply significant changes in the North Pacific Ocean currents.

The most compelling argument that these changes in sea-level pressure are real is the physical consistency in the large regional Pacific temperature anomalies for 1977–86 in figure 1. The warming over

Alaska and cooling in the central and western North Pacific would be expected with a stronger Aleutian low from considerations of thermal advection and increased ocean mixing. The increased southward gradient flow in the eastern North Pacific, revealed by the pressure pattern in figure 3, would bring warmer and moister air into Alaska and along the West Coast of North America, while anomalous northerly winds gives rise to colder-than-normal conditions in the central and western North Pacific. Cayan and Peterson (1989) found that increased streamflow in the Alaskan coastal region of the northern Gulf of Alaska occurs from increased coastal rainfall associated with a deepened Aleutian low and changes in the PNA. In addition, increased mixing in the ocean, stronger heat fluxes into the atmosphere, and the changes in ocean currents help account for the recent persistently cold SSTs in the North Pacific.

Confirmation of the link between temperatures and the atmospheric circulation comes from correlations between the SLP-index time series in figure 2 and 700-mb temperatures (figure 4). The pattern of correlations reveals the four centers of the PNA. Over the Pacific and North America this pattern (with an opposite sign) bears a striking resemblance to the actual surface temperature anomalies for 1977–86 (figure 1), including the cooling over the eastern part of North America. The latter is thus revealed as part of the overall teleconnection pattern.

To provide a longer-term perspective and an alternative smoothing to that given in figure 2, the time series of North Pacific sea-level pressures is extended back to 1925 in figure 5. Note that the difference

map presented in figure 3 is relative to the longer 1924–76 interval. The low pass curve shows how unusual the 1977–88 period is; the only previous time that comparable values occurred was from 1940–41.

Large-scale changes in both atmospheric and oceanic fields over the North Pacific had been noted earlier by Douglas et al. (1982) who contrasted the 1969–80 period with 1947–66 and found a correspondence between the pattern of lower SSTs to strengthened northerly wind and/or lower 700-mb heights. Our time series (figure 2), however, indicates that a more coherent picture emerges if the different regime is considered to have begun in 1977. The recent SST anomalies, with negative values in the central North Pacific and positive values along the West Coast, are typified by the pattern in 1987. This configuration exhibits the strongest persistence during the past four decades because of the link with long-lasting atmospheric circulation anomalies (Naminas et al. 1988).

The changes stated previously may also provide a partial explanation for the upper-ocean temperature changes in the Gulf of Alaska found by Royer (1989). Because of the persistence of ocean-temperature anomalies into summer, the changes also have profound effects on the central Pacific epipelagic ecosystem because of the associated significant increase in total chlorophyll in the water column (and thus in phytoplankton) observed in the central North Pacific Ocean during the summer (Venrick et al. 1988).

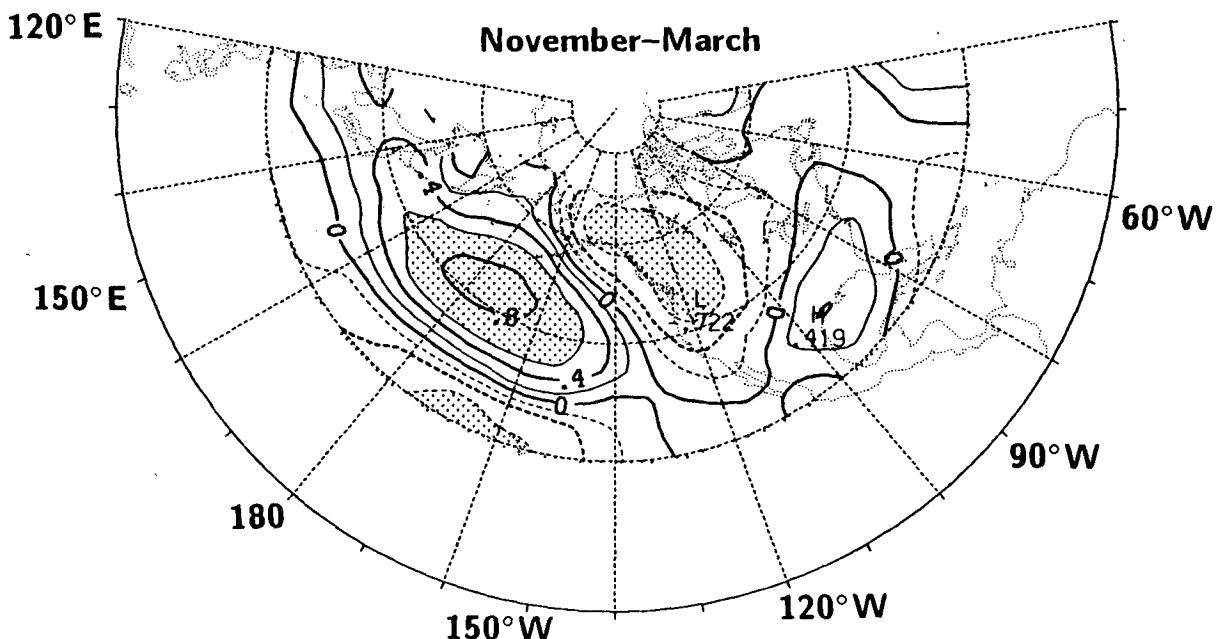


FIG. 4. Correlations between the North Pacific SLP index in figure 2 and 700-mb temperatures. Negative values are dashed, and magnitudes exceeding $r = \pm 0.6$ are stippled; the 1% significance level is 0.40.

2. Causes of change

Examination of the possible causes of the changes focuses attention on the association between the large-scale coherent climate variations and changes in atmospheric waves. The stationary planetary waves in the atmosphere are forced by orography and patterns of diabatic heating arising from the distribution of land and sea, both in the extratropics and in the tropics (e.g., Nigam et al. 1988). Therefore in the NH, changes in diabatic heating, for instance, can change the planetary waves and associated poleward heat flux (e.g., Chen and Trenberth 1988). This mechanism does not operate in summer, nor does it work at any time of year in the Southern Hemisphere (SH), where heat transports are dominated by the transient component (van Loon 1979). Consequently, not only are the changes in NH winter temperature (figure 1) greatly affected locally by changes in the planetary waves, but the zonal means and, by extension, the NH mean are also greatly influenced by changes in planetary waves. In addition, by altering temperature gradients that the transients feed on through baroclinic instability, there are changes in the transient storm tracks (van Loon 1979). Transient disturbances influence the amount of stirring of the atmosphere, so that the strength of winter-surface temperature inversions is changed, and cloudiness and radiative losses to space are also apt to be affected.

When possible causes of change and teleconnection are considered for the North Pacific, one prospect is in situ forcing through the influence of extratropical SST anomalies in the North Pacific on the circulation (Namias 1959, 1963). It has been difficult to substantiate such influences either statistically or with models, probably because results depend greatly on the changing synoptic situation. Also, insofar as the effects on planetary waves are concerned, enhanced land-sea contrasts would be needed to give a deeper Aleutian low, whereas the observations show the latter was accompanied by below-normal SSTs. In addition, changes in snow-cover over Siberia appear to be capable of altering the Siberian high and Aleutian low (Yamazaki 1989).

Because of the tendency for atmospheric motions to conserve absolute vorticity, they occur as Rossby waves. A consequence of this is that local forcing of such waves sets up a wave train of disturbances and "teleconnections" downstream. Teleconnections are important because they induce anomalies in the circulation and associated anomalies in temperature and precipitation in remote regions. The best-known examples of global impacts of local forcing are with changes in tropical SSTs, such as the El Niño/Southern Oscillation (ENSO) phenomenon, whereby cou-

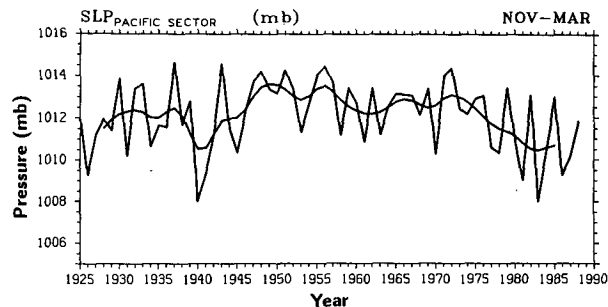


FIG. 5. Time series of mean North Pacific sea-level pressures for November–March, as in figure 2, but beginning in 1925 and smoothed with a low-pass filter involving the seven weights (1, 4, 8, 10, 8, 4, 1)/36.

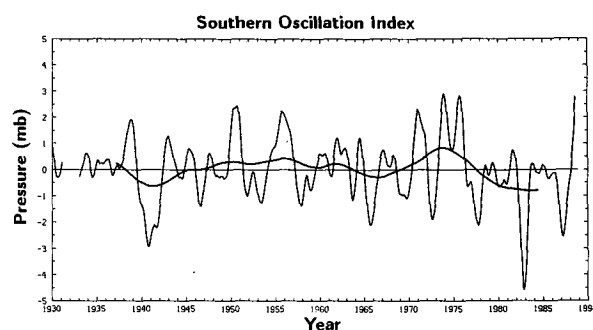


FIG. 6. Monthly time series of a Southern Oscillation index (Tahiti minus Darwin sea-level-pressure anomalies), filtered with two low-pass filters; the first has 11 terms and removes periods less than 12 months, the second with 109 weights removes periods less than 10 years.

pling between changes in the atmosphere and the underlying ocean in the tropical Pacific are linked by teleconnections to higher latitudes (Bjerknes 1969; Horel and Wallace 1981). The 1988 North American drought appears to have been one example of this (Trenberth et al. 1988; Palmer and Branković 1989).

The period of deeper Aleutian low regime extends from 1977 to 1988 when there were three El Niño (Warm) events in the tropical Pacific, but no compensating La Niña (Cold) events, so that the tropical Pacific experienced above normal SSTs and a persistently negative southern-oscillation index for that period (figure 6). Modeling studies (e.g., Blackmon et al. (1983) confirm the causal link between SSTs in the tropics and the North Pacific circulation, with a deeper Aleutian low set up as a teleconnection due to El Niño conditions. But the results obtained here are not simply due to the 1982–83 and 1986–87 El Niños; the Aleutian low was also much deeper than normal in several other years and especially in the winter of 1980/81. Note, however, from figure 5, that the previous time when comparably low values occurred over the North Pacific was during the major 1939–42 El Niño event (figure 6).

Since the late 1970s, increases in SSTs throughout the tropics of the central and eastern Pacific, as well as the Indian Ocean, have been linked to enhanced convective activity in the same region (Nitta and Yamada 1989). There is also some indication of increased tropospheric temperatures and water vapor in the western tropical Pacific in recent years (although unresolved uncertainties remain in the data because of inhomogeneities in the station measurements [Hense et al. 1988]).

3. Links with the greenhouse effect?

Results from wind stress, sea-level pressure, and surface and 700-mb temperature changes, essentially based upon independent data and methods of analysis, provide strong evidence that the Aleutian low was significantly deeper and extended farther east in the period from 1977 to 1988. The general pattern around the North Pacific basin, notably the warming trend along western North America and the strong cooling between Japan and 160°W in midlatitudes, is consistent with the expected anomalous advection patterns associated with the change in circulation.

It is clear that natural variations are capable of producing low-frequency fluctuations in the climate system through the long-term memory of the ocean. In the case of ENSO, a self-contained, low-frequency oscillation can result. A major, but as yet unanswered, question is whether either the intensity or frequency of ENSO events might change as a result of global warming. A longer observational record than that given in figure 6 reveals that the frequency and intensity of ENSO events have changed in the past (Trenberth and Shea 1987), with strong ENSO fluctuations from about 1880 to 1920, which led to the discovery and naming of the southern oscillation by Sir Gilbert Walker. Aside from the major event from 1939 to 1942, stronger and more regular ENSO events only resumed in the 1950s. However, the low-pass curve in figure 6 indicates that the recent imbalance between the occurrence of Warm versus Cold events in the tropical Pacific is unprecedented.

Whether the unusual 1977–88 imbalance can be ascribed to any cause, or is merely a part of natural variability is a difficult question. The major change that occurred in March–April 1988, with a transition from El Niño to a strong La Niña (figure 6, and Trenberth et al. 1989), may have ended the climate regime but still leaves open the question of long-term variability of El Niño events and any relationship with the greenhouse effect. Because the ocean is simultaneously affected by many climate forcings, including increasing greenhouse gases, there is great

difficulty in separating the real cause of any observed change. Indeed, generally there will be multiple forcings contributing to any observed change in differing amounts.

From the perspective of changes in the atmosphere, it may be possible to attribute a particular change in surface temperatures and circulation to SST anomalies, but this does not necessarily rule out other external mechanisms. Instead it changes the focus of the question to the origin of the changes in SSTs. Because it is clear that changes in temperature are not uniform over the globe, but rather contain considerable large-scale coherent structure with regions of opposite sign (figure 1), it is vital to establish the linkages between changes in circulation and temperatures and precipitation to build understanding of the climate changes. Inevitably, consideration of all the different factors involved will complicate any interpretation of surface-temperature changes in terms of global warming.

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