A 50–70 year climatic oscillation over the North Pacific and North America

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Abstract. The chronology of interdecadal climatic regime shifts is examined, using instrumental data over the North Pacific, North America and the tropical oceans, and reconstructed climate records for North America. In the North Pacific and North America, climatic regime shifts around 1890 and in the 1920s with alternating polarities are detected, whose spatial structure is similar to that of the previously-known climatic shifts observed in the 1940s and 1970s. Sea-surface temperatures in the tropical Indian Ocean-maritime continent region exhibit changes corresponding to these four shifts. Spectra obtained by the Multi-Taper-Method suggest that these regime shifts are associated with 50–70 year climate variability over the North Pacific and North America.

The leading mode of the empirical orthogonal functions of the air-temperature reconstructed from tree-rings in North America exhibits a spatial distribution that is reminiscent of instrumentally observed air-temperature differences associated with the regime shifts. The temporal evolution of this mode is characterized by a 50–70 year oscillation in the eighteenth and nineteenth centuries. This result, combined with the results of the analyses of the instrumental data, indicates that the 50–70 year oscillation is prevalent from the eighteenth century to the present in North America.

Introduction

Recent studies have revealed a significant interdecadal climatic regime shift occurred in 1976/77 in association with a deepening of the Aleutian low (Nitta and Yamada 1989, Trenberth 1990), and changes in the physical and biological environments over the North Pacific and North America (for a summary, see UNESCO 1992, Trenberth and Hurrel 1994, Mantua et al. 1997). A climatic regime shift is defined as a transition from one climatic state to another within a period substantially shorter than the lengths of the individual epochs of each climate states. Several analyses indicated that a similar regime shift occurred in the 1940s, but in the opposite tendencies (Yamamoto et al. 1986, Francis and Hare 1994, Dettinger and Cayan 1995, Zhang et al. 1996). Since temperature and pressure data used in most of the previous studies are for the post-war period, we are not sure whether the same kind of climatic shifts as observed in the 1940s and 1970s occurred in the first half of this century and even in the former centuries, and if so, how periodic their occurrences were. In the present study, therefore, we examine the chronology of the interdecadal regime shifts over the North Pacific and North America, based on instrumental data from the late eighteenth century to 1990 and climate reconstruction records in the last few centuries.

Interdecadal variability observed in instrumental data

We examine following instrumental datasets: air-temperatures at long-term weather stations collected in *World Monthly Surface Station Climatology* produced by the National Climate Data Center, sea-level pressure (SLP) of Trenberth and Paolino (1980), sea-surface temperature (SST) of Bottomley et al. (1990), and coastal SST data of Kodama et al. (1995) at Enoshima (141.5°E, 38.4°N), Japan. Air-temperature data affected by non-climatic changes, i.e., station move or urbanization, were detected through visual inspection, and are not included in the analysis. For some of the above datasets, the quality of the data in the early period of the records might be lower than those observed more recently. For example, SLP data should be less reliable for the first few decades of this century than for the recent decades (Trenberth and Paolino, 1980). Therefore, an occurrence of a regime shift must be detected as a coherent signal among several independent datasets.

In association with the regime shifts in the 1940s and 1970s, significant cooling and warming were observed, respectively, in surface air-temperature over western North America in spring (Figs. 1a, and 2a,b), and over Alaska and western Canada in winter (not shown, see Parker et al. 1994 and Zhang et al. 1996). In addition to these known changes, two interdecadal changes are evident in the springtime data in the 1920s and around 1890 with alternating polarities in the former region (Figs. 1a, and 2c,d). Also, spring SST in the eastern North Pacific exhibits a similar temporal evolution (Fig. 1b), supporting the occurrence of these two earlier shifts. Wintertime temperature changes in the 1920s are detectable in the western Alaska, but there are no stations available for detecting the change around 1890 in this region. SST changes in the central North Pacific had opposite polarities to the SST changes in the eastern North Pacific for the shifts in the 1940s and 1970s (Zhang et al. 1996), though SST changes associated with the climatic shifts in the 1920s and before cannot be identified convincingly, even if they existed, because of low quality of the data.

Winter-spring SLP in the central North Pacific exhibits long-term changes corresponding to the three shifts of the spring air-temperature in western North America in the present century (Fig. 1a, c). Correspondence between warmer (colder) temperature and a stronger (weaker) Aleutian low is apparent. The correlation coefficients between them are high with the values of -0.73 with a five-year running mean, and -0.60 without the smoothing. The relation between the SLP and air-temperature is a consequence of the strengthened (weakened) Aleutian low enhancing (reducing) the advection of warmer air onto the west cost of North America (van Loon and Williams 1976). Between two successive periods of a regime, the spatial distributions of SLP differences exhibit approximately the same patterns, with strongest anomalies over the central northern North Pacific and a weaker anomalies with the opposite sign over western North America (not shown). These patterns are related to the Pacific/North American teleconnection pattern in the atmospheric circulation aloft (Wallace and Gutzler 1981).

On the western side of the Pacific basin, the Japanese coastal SST at Enoshima provides further evidence for the occurrences of the regime shifts associated with the Aleutian low. The SST averaged from spring to summer tends to be lower than its climatological mean in the regimes with the deepened Aleutian low and vice versa (Fig. 1d). The spring-summer SST is a good indicator of the southward penetration of the Oyashio along the Japanese coast, with colder SST indicating its farther penetration (Kodama et al. 1995). One may speculate that on interdecadal time scales,

the stronger wind forcing associated with the deepened Aleutian low causes farther southward penetration of the Oyashio and lower SST at Enoshima, the same scenario as suggested previously by Sekine (1988) for interannual variability. Consequently, evidence of regime shifts associated with the Aleutian low is detectable across the Pacific basin in a physically consistent manner. The occurrence of the three regime shifts in the present century was confirmed by a very recent analysis by Zhang et al. (1996), who detected the shifts by examining empirical orthogonal functions (EOFs) of SST and SLP over the North Pacific.

The climate changes in the 1970s and 1940s in midlatitudes are accompanied by sea-surface temperature changes in the tropical Indian and Pacific Oceans (Nitta and Yamada 1989, Trenberth 1990, Zhang et al. 1996). Also, in association with the climate changes around 1890 and in the 1920s, annual mean SST exhibits significant cooling and warming, respectively, in the tropical Indian Ocean-maritime continent region (Fig. 1e). Thus, as in the regime shifts in the 1940s and 1970s, the earlier two interdecadal climate changes associated with the Aleutian low appear to be related to the variability in the tropics, in particular in the Indian Ocean-maritime continent region. In the tropical eastern Pacific, SST changes corresponding to the earlier two shifts are not evident, but this might be due to poorer sampling rates in this region than those in the Indian Ocean-maritime continent region.

We have shown that the last four incidences of climatic regime shifts over the North Pacific/North American sector have occurred at fairly regular time intervals. In order to get some idea of the dominant time scale of the climate variability in this sector, we employ the Multi-Taper-Method (MTM) (Thomson 1982, Dettinger et al. 1995). The MTM enables us to examine the statistical significance of a spectral peak using shorter data-length than those required for conventional spectral estimates, i.e., the Blackman-Tukey autocorrelation method. For each of the time series shown in Fig. 1, the MTM spectrum has a significant peak at the 95% confidence level between periods of 50 and 70 years, as exemplified by the spectra of the spring air-temperature in western North America and the winter-spring SLP in the central North Pacific (Fig. 3). This result agrees well with our observation that the individual epochs are of 23~35 years in length, since the period of each regime consists of two epochs with opposite sings. The existence of the 50–70 year variability is consistent with a regional analysis of Ware (1995), who found variability on this time scale in coastal air- and sea-surface temperatures and wind stresses along the west coast of North America. The present results indicate that variability with these periods characterizes the interdecadal climate changes over the North Pacific and North America from the late nineteenth century onward.

Interdecadal variability observed in tree-ring data

In addition to the climate parameters examined above, the air-temperature was reconstructed based on chronologies of tree-ring width in North America (Fritts 1991). The air-temperatures were estimated based on regression relationships in principal components between instrumentally observed air-temperatures over the United States and a part of Canada and tree-ring widths obtained from a tree-ring network consisting of 65 sites in the western part of the reconstructed area. Reflecting the distribution difference between the air-temperature stations and tree-ring sites, the temperature reconstruction in the western region is more reliable than in the eastern region. Therefore, the reconstructed temperatures are expected to be capable of detecting air-temperature changes associated with the regime shifts, since the changes are evident over western North America as revealed by the above analysis of the instrumental data.

The pattern of the leading EOF for the reconstructed springtime air-temperature (Fig. 4a) is reminiscent of the pattern of air-temperature differences based on instrumental measurements (Fig. 2), suggesting that this mode is associated with the variability of the Aleutian low. The regime shifts in the 1920s and 1940s are evident in the time coefficient of this mode, though another shift around 1890 is not reproduced (Fig. 4b). In the early period for which instrumental data are not available, several interdecadal shifts of the temperature are seen in the time coefficient since the end of the eighteenth century. The MTM spectra of the time coefficient of EOF 1 have statistically significant peaks between 50–70 year periods in the eighteenth and nineteenth centuries (Fig. 4c). Therefore, the results from the reconstructed temperature combined with the results of the analyses of the instrumental data indicate that the 50–70 year interdecadal variability has been prevalent from the eighteenth century to the present in North America.

Discussion

There are two possible causes of the 50–70 year variability. One is external oscillatory forcing, such as variations in the solar constant, and the other is an internal oscillation of the atmosphere-ocean system. In the present century, the periods of the deepened Aleutian low and warmer tropical SST roughly correspond to the periods of a stronger solar radiation as estimated from the length of the sunspot cycle (e.g., Friis-Christensen and Lassen 1991). However, comparison between the tree-ring reconstructed air-temperature and the record of the length of the sunspot cycle reveals no significant relation in the eighteenth and nineteenth centuries. Therefore, the 50–70 year variability is likely to be essentially an internal oscillation in the coupled atmosphere-ocean system, although it could be modulated by the external solar radiation heating in the present century.

Several recent studies reported that fish populations over the North Pacific were significantly influenced by the interdecadal regime shifts in the 1920s and 1940s, and the shift in the 1970s as well. Francis and Hare (1994) and Mantua et al. (1997) showed that the stock of the Alaska salmon decreased in the 1940s and increased in the 1970s. The catch of the Japanese sardine was affected by all of three regime shifts in the present century, with larger catch amounts in the regimes with the deepened Aleutian low (I. Yasuda, personal communication). Kodama et al. (1995) reported that local catches of ten fish species near Enoshima have been influenced by the long term changes in the Oyashio penetration, which may be interpreted as an influence on the marine ecosystem of climatic regime shifts as presented in the present study. Interestingly, a recent paleoclimate analysis by Baumgartner et al. (1992) provided information of interdecadal fluctuation in fish populations over a number of centuries. They found about 60 year variability, which has nearly the same time scale as found in the present study, in the populations of sardine and northern anchovy in the eastern North Pacific from sediments in the Santa Barbara basin off California dating

back to AD 270. These results indicate that the 50–70 year climatic variability exerts a strong influence on long-term changes of fish populations, and hence has important socio-economic effects.

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References

Baumgartner, T. R., A. Soutar and V. Ferreira-Bartrina, Reconstruction of the history of Pacific sardine and northern anchovy populations over the past two millennia from sediments of the Santa Barbara basin, California. *CalCOFI Reports 33*, 24–40, 1992.

Bottomley, M., C. K. Folland, J. Hsiung, R. E. Newell, and D. E. Parker, *Global Ocean Surface Temperature Atlas (GOSTA)*. 20+iv pp and 313 plates, UK Met. Office, Bracknell, 1990.

Dettinger, M. D., M. Ghil, C. M. Strong, W. Weibel, and P. Yiou, Software expedites singular-spectrum analysis of noisy time series. *Eos, Trans. American Geophysical Union, 76,* 12–21, 1995.

Dettinger, M. D., and D. R. Cayan, Large-scale atmospheric forcing of recent trends toward early snowmelt runoff in California, *J. Climate, 8*, 606–623, 1995.

Francis, R. and S. R. Hare, Decadal-scale regime shifts in the large marine ecosystems of the North-east Pacific: a case for historical science, *Fish. Oceanogr., 3,* 279–291, 1994.

Friis-Christensen, E., and K. Lassen, Length of the solar cycle: An indicator of solar activity closely associated with climate, *Science, 254,* 698–700, 1991.

Fritts, H. C., *Reconstructing Large-scale Climatic Patterns from Tree-Ring Data.* The University of Arizona Press, Tucson & London, pp. 286, 1991.

Kodama, J., H. Nagashima, and Y. Izumi, Long-term variations in the "mongoku herring", clupea pallasi valenciennes resources in relation to the ocean environments in the waters off sanrikua and Joban. *Bull. Miyagi Pref. Fish. Res. Dev. Center, 14,* 17–36, 1995. (In Japanese)

Mantua, N. J., S. R. Hare, Y. Zhang, J. M. Wallace and R. C. Francis, A Pacific interdecadal climate oscillation with impacts on salmon production. *Bull. Am. met. Soc*., in press, 1997.

Nitta, T., and S. Yamada, Recent warming of tropical sea surface temperature and is relationship to the Northern Hemisphere circulation. *J. Meteor. Soc. Japan, 67,* 375–383,1989.

Parker, D. E., P. D. Jones, C. K. Folland, and A. Bevan, Interdecadal changes of surface temperature since the late nineteenth century. *J. Geophys. Res., 99 (D7),* 14373–14399, 1994.

Sekine, Y., Anomalous southward intrusion of the Oyashio east of Japan 1. Influence of the seasonal and interannual variations in the wind stress over the North Pacific. *J. Geophys. Res., 93 (C3),* 2247–2255, 1988.

Thomson, D. J., Spectrum estimation and harmonic analysis. *Proc. IEEE, 70,* 1055–1096, 1982.

Trenberth, K. E., and D. A. Paolino, The Northern Hemisphere sea-level pressure data set: Trends, errors, and discontinuities. *Mon. Wea. Rev., 108,* 855–872, 1980.

Trenberth, K. E., Recent observed interdecadal climate changes in the Northern Hemisphere. *Bull. Am. met. Soc., 71,* 988–993, 1990.

Trenberth, K. E., and J. W. Hurrel, Decadal atmosphere-ocean variations in the Pacific. *Clim. Dyn., 9,* 303–319, 1994.

UNESCO, Oceanic interdecadal climate variability. *Intergovernmental Oceanographic Commission Tech. Ser., No. 40,* 1992.

van Loon, H., and J. Williams, The connection between trends of mean temperature and circulation at the surface: Part I. Winter. *Mon. Wea. Rev., 104,* 365–380, 1976.

Wallace, J. M., and D. S. Gutzler, Teleconnections in the geopotential height field during the Northern Hemisphere winter. *Mon. Wea. Rev., 109,* 784–812, 1981.

Ware, D. M., A century and a half of change in the climate of the NE Pacific. *Fisheries Oceanography, 4,* 267–277, 1995.

Yamamoto R., T. Iwashima, N. K. Sanga, and M. Hoshiai, Climatic jump. *Annuals, Disas. Prev. Res. Inst., Kyoto Univ., 29 B-1,* 297–313, 1986. (in Japanese)

Zhang, Y., J. M. Wallace, and D. S. Battisti, ENSO-like interdecadal variability: 1900–1993. in press, *J. Climate*, 1996.

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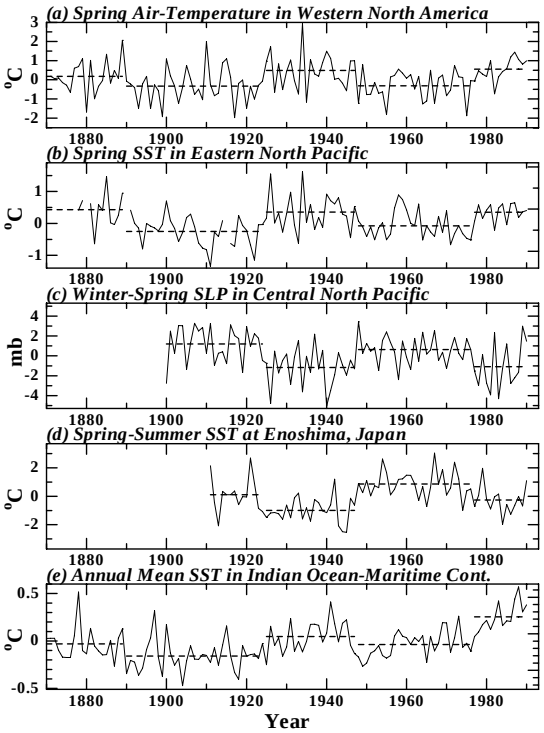

Figure 1. Time series of anomalies exhibiting coherent interdecadal climate changes (thin solid curve), with temporal averages of the anomalies for the periods 1870–1889, 1890–1924, 1925–1947, 1948–1976 and 1977–1990 (thick dashed lines). (a) Spring (Mar.–May) air-temperature anomalies in western North America averaged over 130°W–105°W, 30°N–55°N. The air-temperature anomaly is calculated relative to 1930–50 at each station, and then the anomalies are averaged spatially. (b) Spring SST anomalies in the eastern North Pacific averaged over 140°W–110°W, 30°N–55°N. The average is calculated when available grid points are more than 20% of total grid points in the spring of respective years. (c) Winter-spring (Dec.–May) SLP anomalies in the central North Pacific averaged over 160°E–140°W, 30°N–65°N. (d) Spring-

summer (Mar.–Aug.) SST anomalies at Enoshima, Japan. (e) Annual mean SST anomalies in the Indian Ocean–maritime continent region averaged over 40°E–160°E, 15°S–15°N. All differences in the temporal average between successive periods are significant at the 95% confidence level in each time series.

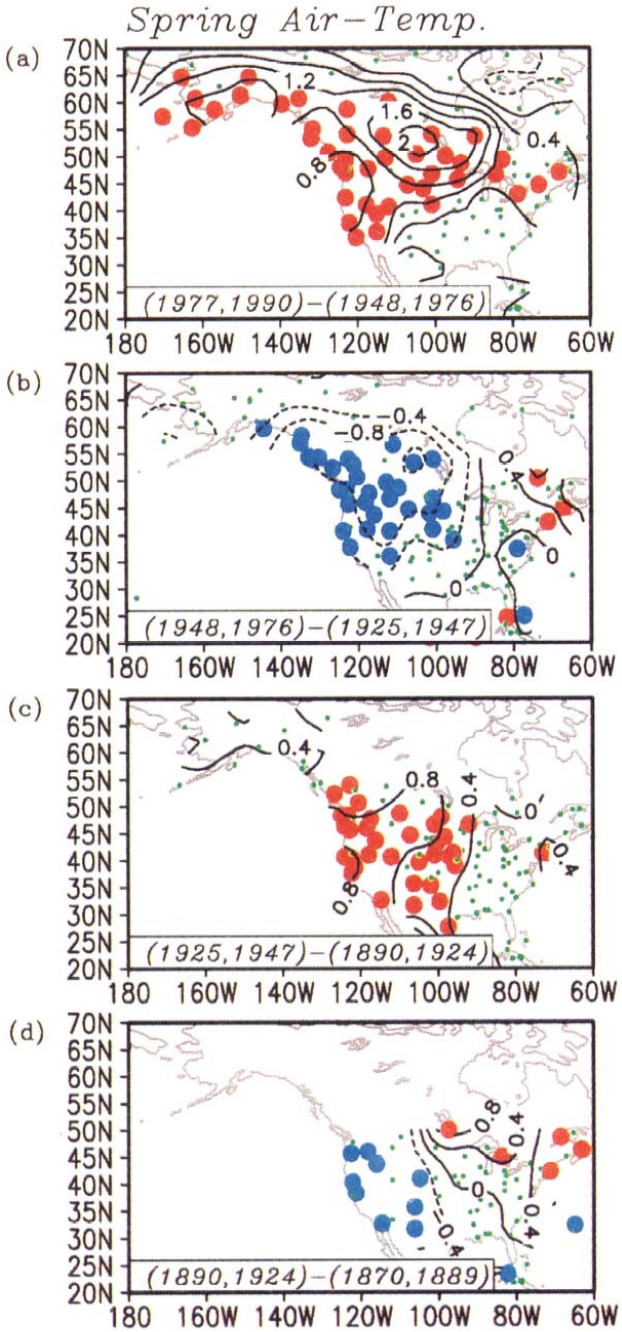

Figure 2. Spring air-temperature differences at the long-term weather stations between two periods: (a) 1977–1990 minus 1948–1976; (b) 1948–1976 minus 1925–1947; (c) 1925–1947 minus 1890–1924; and (d) 1890–1924 minus 1870–1889. A red (blue) closed circle indicates that the temperature increase (decrease) at the station is significant at the 95% confidence level, whereas a green dot indicates an insignificant difference. The contours indicate the amplitude of temperature differences, as calculated for respective stations and smoothed with a Gaussian filter of an *e*-folding length of 400 km. The contour interval is 0.4°C, and dashed contours indicate negative values.

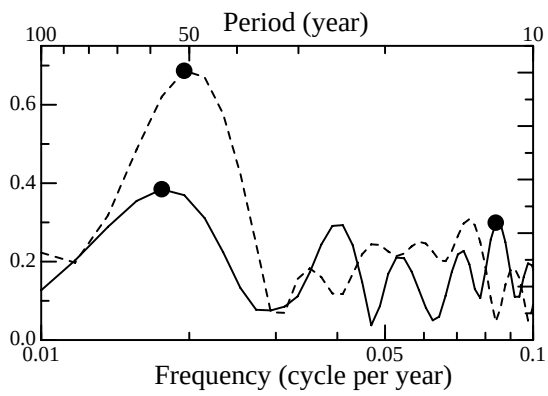

Figure 3. Normalized MTM spectrum of the spring air-temperature in western North America shown in Fig. 1a (solid curve), and spectrum of the winter-spring SLP in the central North Pacific shown in Fig. 1c (dashed curve). A dot indicates a spectrum peak that is significant at the 95% confidence.

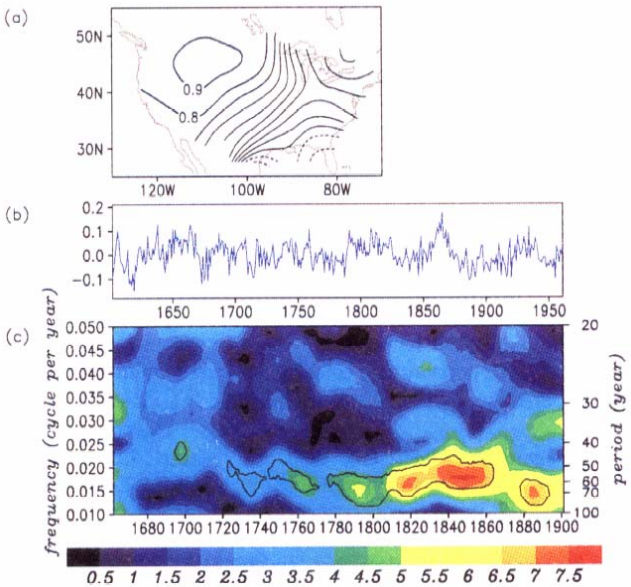

Figure 4. (a) Spatial distribution and (b) time coefficient of EOF 1 of the spring air-temperature reconstructed from tree-rings; and (c) evolutive MTM power spectra of the time coefficient using a 120-year moving window evaluated in 1-year steps. The EOF 1 explains 48.3% of the total variance. The shaded region in (a) indicates that the EOF 1 is larger than 0.7, and therefore accounts for more than the half of the variance. The EOF is calculated using the station data, and is smoothed for (a) in the same manner as in Fig. 2. In (c), the horizontal axis indicates the center year of each 120 year segment, and the contours indicate where the spectrum is significant at the 95% confidence level.