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Bidecadal and Pentadecadal Climatic Oscillations over the North Pacific and North America

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Abstract

Climatic variations on bidecadal (about 20 years) and pentadecadal (50-70 years) timescales are analyzed in terms of their seasonal and regional dependencies in the North Pacific and North American sector. The both bidecadal and pentadecadal variations are evident in SLP fields associated with the strength changes of the Aleutian low. The bidecadal variability is evident only in winter, but the pentadecadal signal exists in winter and spring. Bidecadal air-temperature variability over North America is evident in winter in Alaska and western and eastern North America. The Alaska temperature and Aleutian low strength exhibit a prominent out-of-phase relationship throughout the present century. On the other hand, an out-of-phase relationship between the Aleutian low strength and air-temperature in western North America on bidecadal timescale is detectable only after the 1930s, suggesting that the linkage between the atmospheric circulation in the North Pacific and temperature change over North America be modulated on a century timescale. In contrast to the wide spread distribution of the bidecadal signal over North America, significant pentadecadal signals are confined in the western North America, and are found only in spring. Enoshima SST, which is a proxy of Oyashio southward penetration along the Japanese coast, exhibits both the bidecadal and pentadecadal signals. The bidecadal variation is consistent with the variability of the Aleutian low strength throughout the records beginning in 1920's. The difference in the seasonal and regional distribution between the bidecadal and pentadecadal variability is evident, and must be take into account for the assessments of the socio-economic influence of these interdecadal climatic variability.

1. Introduction

Recent investigations have revealed that the variability in the North Pacific is strongly related to the strengthening/weakening of the Aleutian low, which dominantly influences the climate over the North Pacific and western coast of North America from interannual to interdecadal timescales. On the latter timescale, two oscillatory variations have been identified from the analyses of instrumentally observed data ; one is bidecadal (~20 years) (Royer 1989, 1993 ; White et al., 1997 ; Mann and Park 1994, 1996) and the other is a pentadecadal (50-70 years) variability (Minobe, 1997). The evidence of the latter timescale is also found in the tree-rings of the eighteenth and nineteenth centuries (Minobe, 1997). The 50-70 year variability is closely associated with three climatic regime shifts in mid 1920's, late 1940's and mid 1970's (Kondo, 1988 ; Mantua et al., 1997 ; Minobe, 1997). The last regime shift has attracted large attentions of climate researchers (e.g., Nitta and Yamada, 1989 ; Trenberth, 1990). The similarity between the shifts in the 1940's and 1970's were documented by several papers (e.g., Yamamoto et al., 1986 ; Francis and Hare, 1994 ; Dettinger and Cayan, 1995 ; Zhang et al., 1997).

For both timescales, it has been reported that the climatic changes significantly influence the marine eco-systems. Evidence of the effect of the bidecadal variability on fishery resources is summarized by Royer (1989), and significant influences of the 50-70 year variability have been documented by Francis and Hare (1994) and Mantua et al. (1997) for salmon resources in Alaska and Pacific Northwest, and Kodama et al. (1995) for Japanese fish catches. A summary of the influence of the interdecadal regime shift in the 1970's is contained in UNESCO (1992), Trenberth and Hurrel (1994) and Mantua et al. (1997). Therefore, the bidecadal and 50-70 year variability are responsible for important socio-economic effects through the change of fishery resources in the North Pacific.

The important socio-economic effects of the interdecadal changes urged us to understand the nature of the interdecadal variability. Although the existence of the two major timescales has been reported in the North Pacific/North American sector, the features of these timescales has not been fully investigated. The purpose of this paper is, therefore, to clarify the characteristic of the variations of these two timescales. In particular, we focus our attention on similarities and differences of these two interdecadal timescales concerning with their regional and seasonal distributions based on instrumental records obtained in the present century. Hereafter, for a simplicity, the 50-70 year variability is referred to as pentadecadal variability. The rest of present paper is organized as follows ; in section 2, data and method of data analysis are described : the results are shown in section 3, and summary and discussion are given in section 4.

2. Data and processing

We examine two gridded datasets: sea-level pressure (SLP) and air temperatures. The monthly SLP data are the updated version from January 1899 to June 1996 of Trenberth and Paolino (1980). A few gaps whose length is shorter than one year in SLP are removed by an interpolation averaging the two values after and before one year of the same month. The seasonal air-temperature data were compiled by Baker et al. (1994) based on monthly temperature data collected as the Global Historical Climate Network (Vose et. al., 1992), which is the climate dataset created from 15 data sources including, World Weather Records at National Climatic Data Center, Climate Anomaly Monitoring System at Climate Analysis Center, World Monthly Surface Station Climatology at National Center of Atmospheric Research, and Jones' Temperature database for the world.

As a proxy of the variation of the Oyashio current, we also employ the coastal SST data of Kodama et al. (1995) at Enoshima (141.5°E, 38.4°N), Japan. When the Oyashio anomalously intrudes toward the south along the Japanese coast, the SST is colder (Kodama et al., 1995). The SST exhibits changes consistent with the three regime shifts in the present century, with further southward penetration of the Oyashio in a regime of a stronger Aleutian low (Minobe, 1997). Interannual variability of Oyashio intrusions was documented by Sekine (1988).

Through the present paper, the yearly time series are examined for each month or each season. The yearly time series of a variable for each season is obtained from averaging the variable for each season. The year for winter (December, January and February) time series is denoted as the year of the January.

In order to identify the variability associated with the bidecadal and pentadecadal variability, we employ the Multi-Taper-Method (MTM) (Thomson, 1982, Dettinger et al., 1995). The MTM estimates a spectrum using a set of tapers, which provide independent spectrum estimate, so that the significance of the spectrum can be examined through a F-test. 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.

Some results shown later are based on filtered time series. The filtering method is a fifth order Chebyshev type I filter. This filter is applied twice to original time series: after filtering in the forward direction, the filtered sequence is then reversed and run back through the filter. The resulting sequence has precisely zero-phase distortion and double the filter order. To avoid loss of at the ends of each time sequence due to filtering, maximum-entropy spectral analysis was applied using spectral coefficients to extend both ends of each sequence by 20% of the length of time series.

3. Results

In order to examine the seasonality of the interdecadal variations of the Aleutian low, we examine the existence of significant spectrum peaks in the North Pacific (NP) index for each month using the MTM. The NP index represents the strength of the Aleutian low, and is defined as the SLP averaged over 160°E-140°W, 30°N-65°N (Trenberth, 1990). The MTM spectra exhibit significant peaks around the period of 20 years from December to January, with most of the spectrum power concentrating in January (Fig. 1). The other cluster of significant spectrum peaks found from 50 to 70 years from December

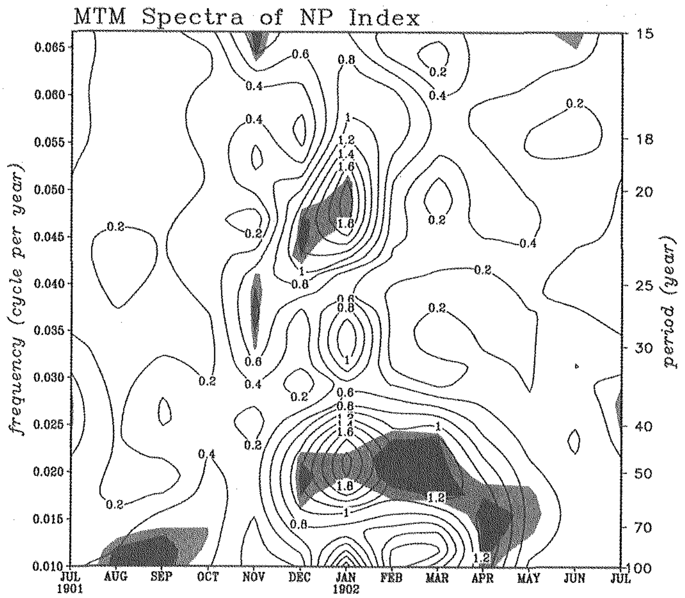

Fig. 1. MTM spectra of NP index for each month. The contour indicates the spectrum amplitude and the color denotes the significance of the spectrum. Heavy and light shade indicates where the spectrum peak is significant at 90 and 95 % confidence limits, respectively.

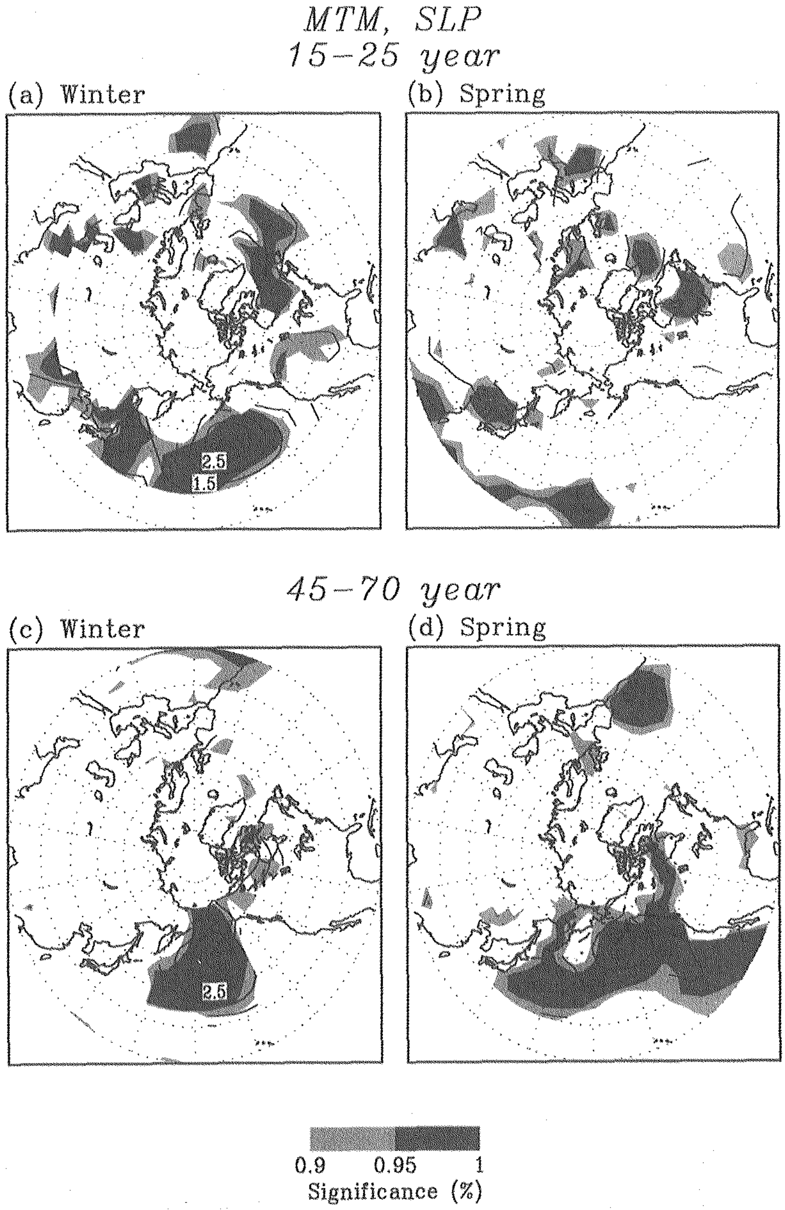

Fig. 2. MTM spectra for winter (a and c), and spring (d and e) in bands of 15–25 year period (a and b), and 45–70 year period (c and d). The contour indicates the spectrum amplitude at the most significant spectrum peak, and the color denotes the significance of the peak. The contour is drawn for the region where the significance is larger than 0.8.

to May. In short, bidecadal variability was observed only in wintertime, whereas pentadecadal variability was found both in winter and spring.

The spatial distribution of the bidecadal and pentadecadal signals are identified by examining MTM spectra at each grid point in winter (Dec.-Feb.) and spring (Mar.-May) separately. The results are summarized into spectrum amplitudes and their significance in two bands of 15-25 and 45-70 year periods (Fig. 2). These band ranges are chosen so that the bidecadal and pentadecadal variability is separated. The spectrum amplitudes and their significance are shown for the most significant peak in each band. Spectra were not obtained for a wide region of Eurasian continent (40°-130°E, north of 35°N) due to many of unavailable grid points in the period of the World War I and successive few

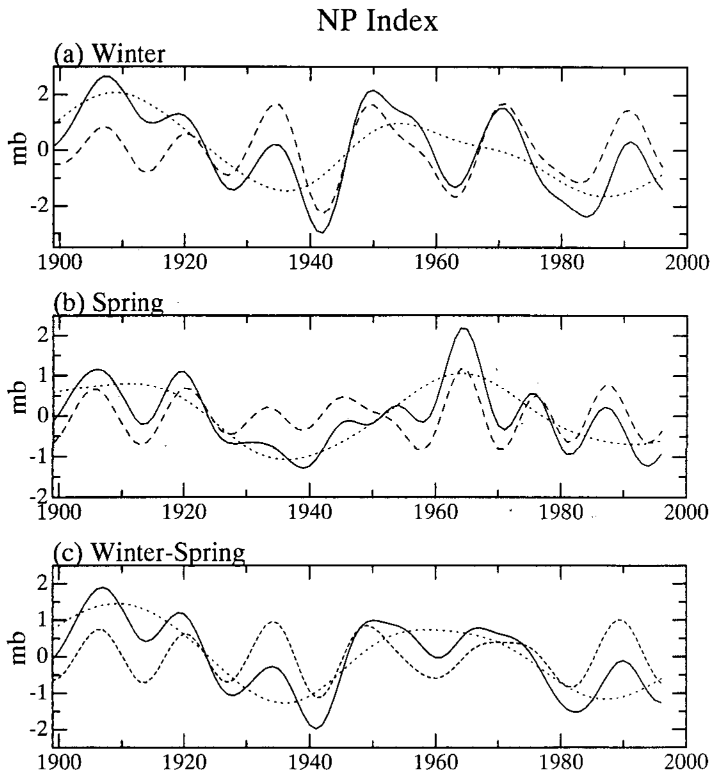

Fig. 3. NP index averaged over (a) winter, (b) spring and (c) winter to spring. Solid curves indicate the low-pass filtered NP index (<10 yr), dashed curves indicate the band-pass filtered NP index (10 yr~25 yr), and dotted curves indicate the low-pass filtered NP index (>25 yr).

years. The distributions of the MTM spectra indicate that the significant spectrum peak occurs in Aleutian region in winter for the 15-25 year band, and both in winter and spring for the 45-70 year band, as expected from the analysis of the NP index in Fig. 1. In both timescales, these two peaks are the most well organized in the central North Pacific. In particular, there is no other substantial signal on the pentadecadal timescale.

The seasonality between these two timescales in NP index is confirmed by a visual inspection of the time series NP index in winter and spring (Fig. 3a,b). The averaging the NP index over winter and spring yields abrupt changes in the 1920's, 1940's and 1970's as shown Minobe (1997) (Fig. 3c).

In parallel to the above MTM assessment for the SLP, MTM spectra were calculated for the surface air-temperature at each grid and in each season over North America (Fig. 4). Again, significant signals on two interdecadal timescales are found with a distinction between winter and spring over North America. For the 15-25 year band, the significant peak is found in the both sides of the continent. The significant temperature variability of 45-70 year period is seen almost in midlatitude western North America in spring with a further penetration toward the inside of the land than for the 10-25 year band. It is noteworthy, in contrast to the existence of the pentadecadal SLP signal in both winter and spring, the temperature signal on pentadecadal timescale is evident only in spring and absent in winter. The absence of the winter pentadecadal signal over North America might be resulted from the fact that the SLP signal in winter is more confined to the west than that in spring. The significant pentadecadal signal (Fig. 2c,d) distributed longitudinally in winter between 170°E and 150°W, but in spring between 180-125°W. The springtime similarity between the 1930s and 1980s were documented also by Parker et al. (1994).

The seasonality of the pentadecadal signal reflects in the difference of means between two periods. The difference is widely used for the detection of a regime shift. The sign reversals of the pentadecadal variability corresponds to the regime shifts in 1920's, 1940's and 1970's (Minobe, 1997 ; Mantua et al., 1997). Figure 5 shows the winter and spring SLP difference between successive two periods, which are separated at 1924/25, 1947/48, 1976/77. As shown in Fig. 5, the regime shifts are detectable in both in winter and spring. 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 anomaly with the opposite sign over western North America. These patterns are related to the Pacific/North

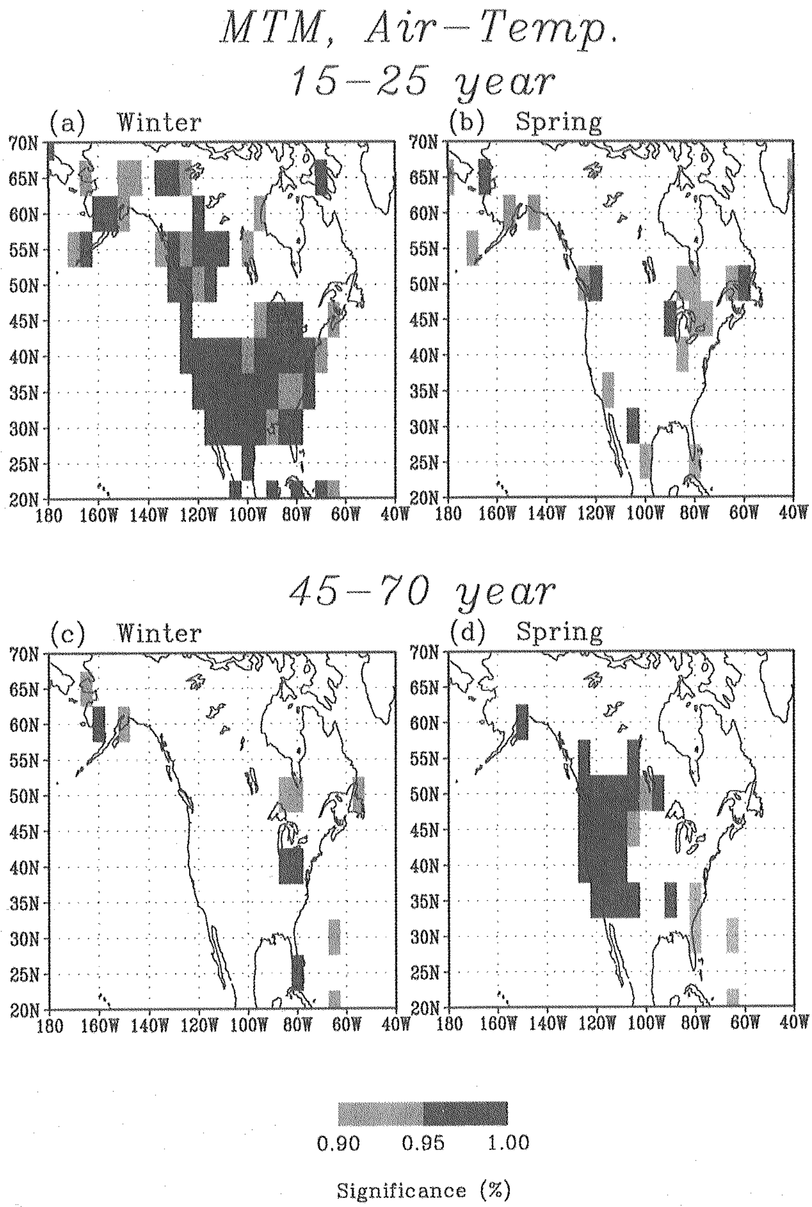

Fig. 4. Same as Fig. 2, but for the significance of the MTM spectra of the surface air-temperature at each grid point over North America.

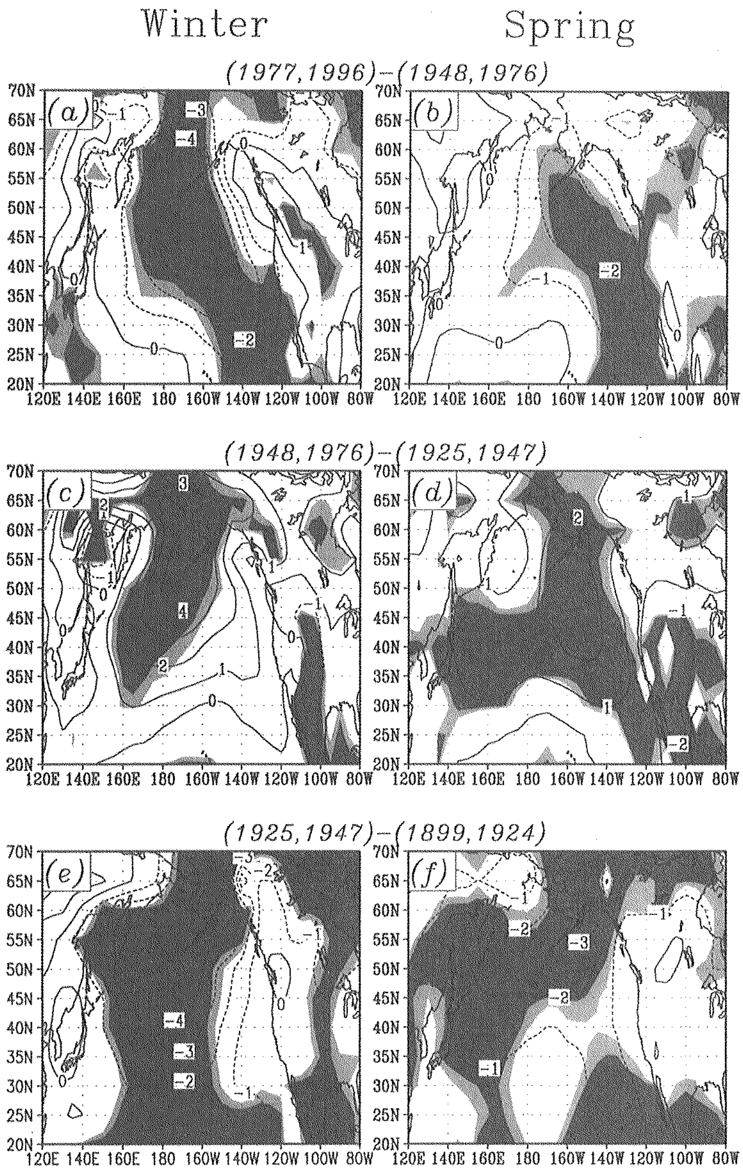

Fig. 5. SLP difference between two successive periods in winter (left panels) and spring (right panels). The periods are defined as 1977-1996, 1948-1976, 1925-1947 and 1899-1924. The contour indicates the amplitude of the difference and the shaded region indicates where the difference is significant at the 95 % confidence limit, assuming each year is independent.

American teleconnection pattern in the atmospheric circulation aloft (Wallace and Gutzler, 1981).

On the other hand, in consistent with the MTM assessment of the air-

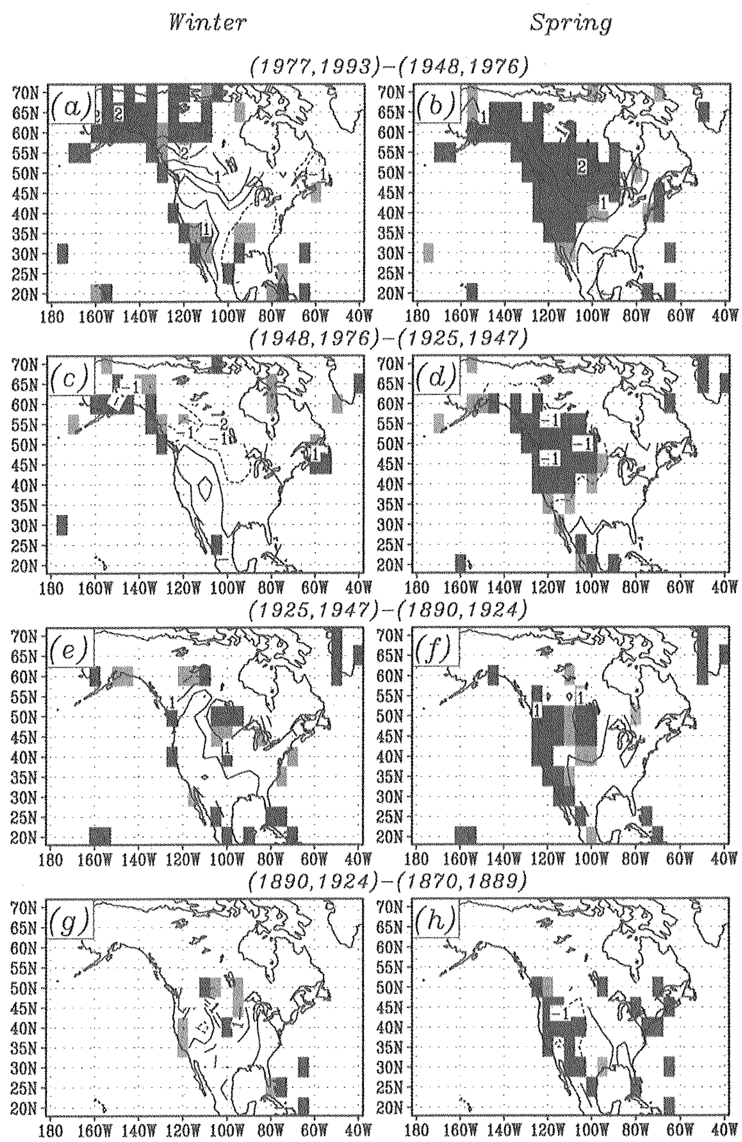

Fig. 6. Same as Fig. 5, but for the surface air-temperature. The periods are defined as 1977-1993, 1948-1976, 1926-1947, 1890-1925 and 1870-1889.

temperature, the air-temperature difference between two periods in midlatitude North America is significant mainly in spring, but not in winter (Fig. 6). 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). The warming after the mid 1970s, which occurred over a wider area than the earlier three changes, might be due in part to the anomalous atmospheric circulation associated with the North Atlantic Oscillation (Hurrel, 1995).

The linkage between the wintertime Aleutian low strength and air-temperatures on the bidecadal timescale is further examined by comparing low-pass and band-pass filtered time series. The NP Index is used as a proxy of the Aleutian low strength again. Averaging air-temperatures over Alaska 170-145°W, 50-50°N), western North America (125-110°W, 35-50°N) and eastern North America (95-75°W, 30-40°N), respectively, it yields the air-temperature time series in each region. The regional averaged low-pass filtered and band-pass filtered time series are shown in Figs. 7, 8 and 9 for these three regions, with filtered NP Index in each figure. The tightest linkage is found between the NP Index and

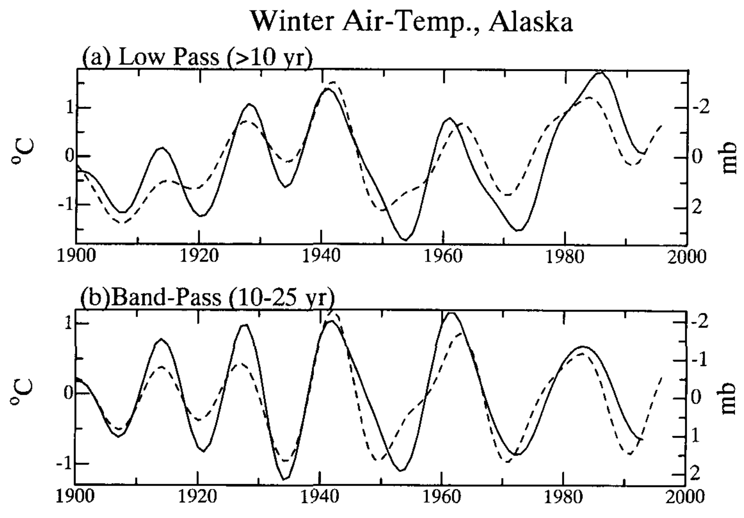

Fig. 7. (a) Low-pass filtered and (b) band-pass filtered winter air-temperature over Alaska (solid curve with left axis) and NP index (dashed curve with right axis). The cut-off period of the low-pass filter is 10 years, and cut-off periods of the band-pass filter are 10 and 25 years. For the easier comparison between the air-temperature and NP index, the axis for the NP index is reversed (negative direction is toward the top of the page).

Alaska air-temperature (Fig. 7). These two time series exhibit a prominent out-of-phase relationship throughout the present century. On the other hand, the out-of-phase linkage between the Aleutian low strength and air-tempera-

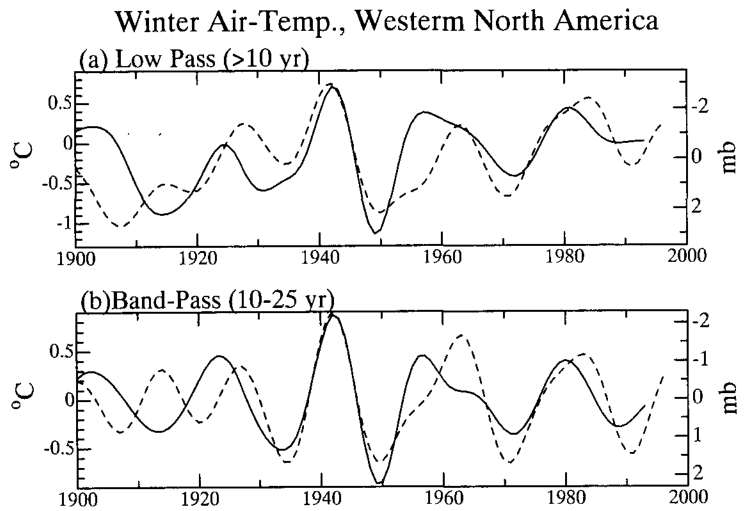

Fig. 8. Same as Fig. 7, but for the winter air-temperature over western North America.

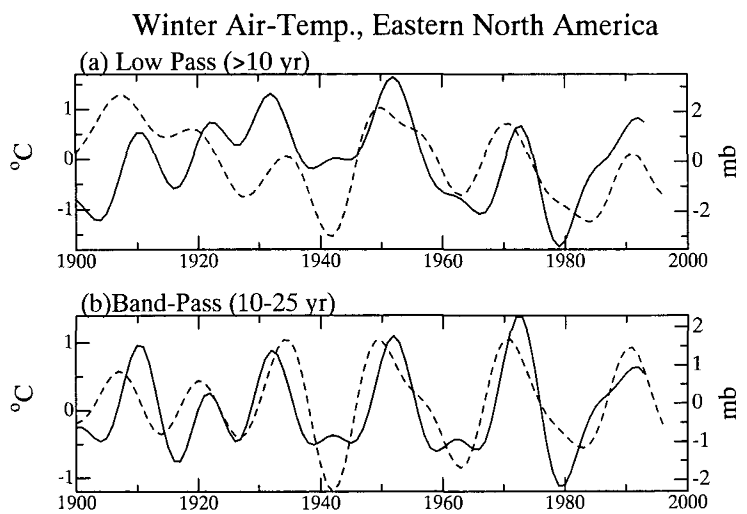

Fig. 9. Same as Fig. 7, but for the winter air-temperature over eastern North America. The axis for the NP index is not reversed (negative direction is toward the bottom of the page).

ture in western North America holds only after 1930's (Fig. 8). This suggests that the linkage is modulated on a century timescale. The air-temperature in eastern North America has in-phase relation with the Aleutian low strength after 1920's (Fig. 7). Although the quality of the SLP data in the first a few decades might be worse than those in the present, the consistent relation between the NP Index and Alaska temperature supports that the NP Index would be a reliable proxy throughout the present century. Thus, the century scale modulation of relationship of western and eastern North America with the Aleutian low is considered to be a real feature and not due to the change of the quality of the data.

The Enoshima SST provides the information of the interdecadal variability in the western side of the basin, while the SLP and air-temperature exhibits the changes over the central North Pacific and North America, respectively. The MTM spectra for each month indicate the Enoshima SST has a prominent 50-70 year signal from spring to summer and an about 18 year signal from April to June (Fig. 10). The filtered time series show that the SST change is consistent with the atmospheric circulation change on the pentadecadal timescale as shown by Minobe (1997) and also on the bidecadal timescale (Fig. 11). This result

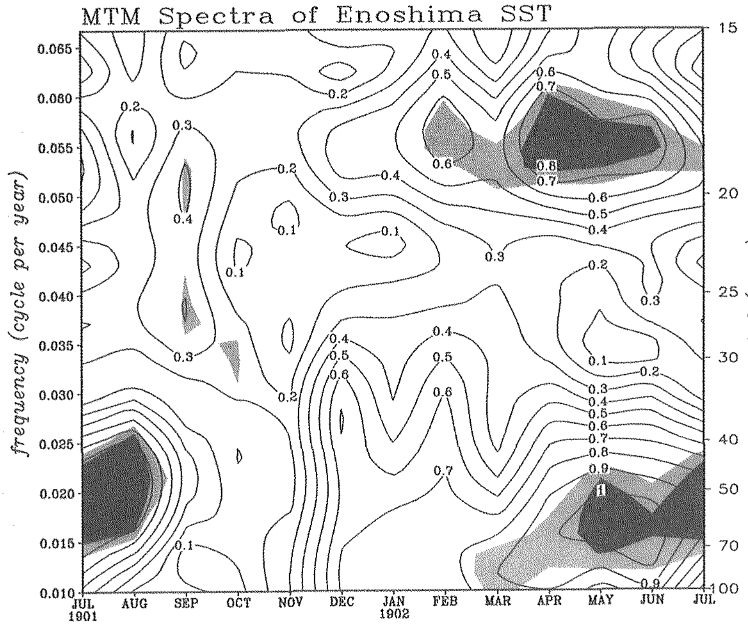

Fig. 10. Same as Fig. 1, but for the Enoshima SST.

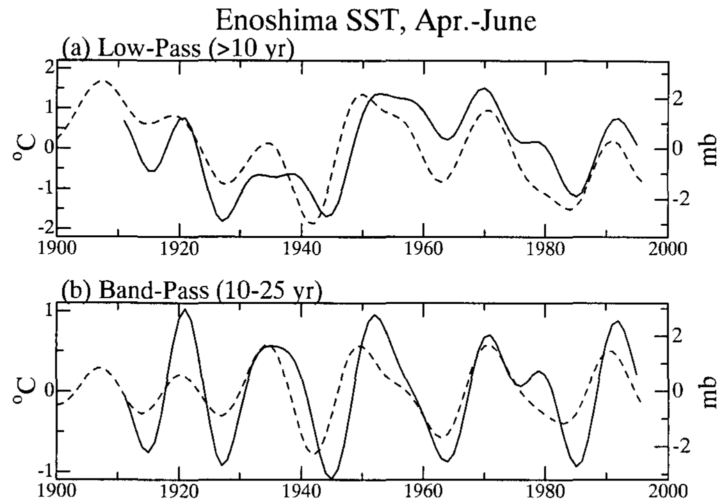

Fig. 11. Same as Fig. 9, but for the Enoshima SST averaged from April to June.

indicates that the interdecadal variability of the Oyashio penetration is sensitive to both the bidecadal and pentadecadal atmospheric variability over the North Pacific. The months when the Oyashio exhibits its bidecadal and pentadecadal variability are generally lags by about four months to the months of the when the NP index exhibits its bidecadal and pentadecadal variability, respectively. The lag of only a few months suggests that the information propagates as a barotropic response from the central North Pacific to the Japanese coast, since baloclinic Rossby wave propagation takes several years, but such large lags are not found.

4. Discussion and conclusions

We have shown that the two dominant interdecadal timescales, about 20 years (bidecadal) and 50-70 years (pentadecadal), exhibit significant regional and seasonal differences in its distributions. The bidecadal variability is found in the wintertime SLP in the central North Pacific and also in the winter air-temperature over North America. The air-temperature in western (eastern) North America is high (low) when the Aleutian low is strong. The out-of-phase relationship between the air-temperature and Aleutian low strength holds throughout the present century in Alaska, but after 1930s in midlatitude western North America. The pentadecadal signal is evident in SLP both in the winter and spring, but the corresponding air-temperature variability is found only in the springtime air-temperature in western North America. The Enoshima SST, a proxy of the Oyashio southward penetration along the Japanese cost, exhibits both the bidecadal and pentadecadal variations, with a further southward penetration is associated with a stronger Aleutian low.

The bidecadal variability in winter has been documented in several papers in a regional or global analyses (Royer 1989, 1993 ; Mann and Park 1994, 1996 : Lau and Wang 1996 ; White et al. 1997). The results of the present analyses are consistent with these studies, but indicate that the bidecadal variability is limited to the winter in the SLP and surface air-temperature over the North Pacific and North American sector.

Although global 65-75 year climate variability was reported by few papers (Schlesinger and Ramankutty, 1994 ; Mann and Park, 1996), this oscillatory variability is likely to be significantly different from the pentadecadal variability documented in the present paper. First, the 50-70 variability has the range of the periodicity from 50 years to 70 years in the eighteenth and nineteenth centuries, but tends to about 50 year variability in the present century. The MTM spectra for NP index averaged from winter to spring has the peak at a period of 51 years, which is somewhat shorter than the global 65-75 year periodicity. The global 65-75 year time series of Shelesinger and Ramankutty (1994) and Mann and Park (1996) exhibit a sign reversal in the mid 1920's as well as the pentadecadal variability in the North Pacific. However, the next sign reversal of the global 65-75 year variability occurred around 1960, and there is no sign reversal after that to the present, whereas the pentadecadal variability exhibits sign reversals in the 1940's and 1970's. Probably, the global analyses mainly picked up the signal over the North Atlantic and northwestern Eurasian continent, and hence the signal mainly occurring in the Pacific might not be captured well as in the major global mode in their analyses.

The difference between the bidecadal and pentadecadal oscillations must be taken into account for the assessments of the socio-economic influences of these interdecadal variations, and for a planning of paleoclimate reconstructions. For example, Minobe (1997) showed that the reconstructed spring air-temperature over western North America exhibits the 50-70 year variability at least last three centuries. The results of the present paper indicates that this region is a most suitable region for capture the pentadecadal variability in North American continent linked with the Aleutian low strength. However, the bidecadal variability in the Aleutian low is likely to reflect more properly to the air-temperature in Alaska than in the western North America. Therefore, for a specific timescale of the variability, one should choose proper paleoclimate proxies in terms of their regional and seasonal dependencies.

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