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General circulation of the atmosphere over the North Pacific and its relationship to the Aleutian Low

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Abstract

The atmospheric processes over the North Pacific are categorized for 1900-1997 into zonal (Z), meridional (M1) and easterly (M2). The zonal (Z) circulation process has dominated since 1972 with above average annual anomalies while the annual frequencies of easterly (M2) and meridional (M1) processes have been below average. The easterly (M2) circulation process was below average to average from 1900-1935, above average 1935-1947, below average 1948-1962 and above average again from 1963-1971. Zonal (Z) processes were generally below average from 1900-1971 with notable prolonged above average periods from 1902-1908 and from 1953-1961 while the meridional (M1) circulation process was generally above average. An index of the general Pacific atmospheric circulation in the winter (December-March) was in agreement with an index of the Aleutian Low Pressure System from 1898 to 1998 with changes in trends occurring around the regime shifts of 1925, 1947, 1977 and 1989. Generally, regimes with weak Aleutian Lows experienced average or above average meridional (M1) processes in winter (e.g. 1900-1925 and 1947-1976). Conversely, regimes with intense Aleutian Lows experienced below average meridional (M1) processes (e.g. 1926-1946 and 1977-1988). The regime of 1989-1998 experienced Aleutian Lows with average intensity and average meridional (M1) processes. Since the winter PCI does reflect the regime shifts denoted by ALPI and it represents an energy transfer mechanism from the atmosphere to the ocean, we suggest that it is a useful indicator of regimes and that it can be developed as an index associated to ocean productivity.

Introduction

Long-term meteorological forecasting using macro-meteorology was first developed by G. Ya Vangengeim (1952) for the Atlantic-Eurasia region. Surface level baric maps were used to classify the daily general atmospheric circulation into one of the three types: westerly (W), easterly (E) and meridional (C). In a similar manner, A. A. Girs (1971) developed a classification scheme for the Pacific-North American region. Under the Girs scheme, a zonal atmospheric circulation process (Z) is characterized by west to east cyclone transfer; the easterly process (M2) is characterized by southerly air mass transfer that is associated with cyclone fields in the northeastern region of the North Pacific; and the meridional atmospheric process (M1) is characterized by north air mass transfer associated with anticyclones above the North Pacific.

The Arctic and Antarctic Research Institute (AARI), St. Petersburg, Russia has produced a catalogue of the daily forms of the Atlantic-Eurasia atmospheric circulation processes since 1891 and has been successful in providing long-term forecasts for the W, E and C processes. This catalogue has been used to study decadal-scale fluctuations in atmospheric circulation which have been linked to changes in temperature and precipitation (Girs, 1971) as well as changes in climate and in the rotation of the solid earth (Sidorendkov and Svirenko 1991). Decadal-scale fluctuations in the Atlantic-Eurasia atmospheric circulation are represented by the atmospheric circulation index (ACI). ACI is calculated as the integral curve of the negative meridional (C) anomalies (Beamish et al. 1998). ACI reflects dominant changes in the Northern Hemisphere's atmospheric circulation and has been used as an indicator of shifts in climate (Beamish et al. 1998). Recently, AARI has produced a catalogue of circulation processes for the Pacific-North American region that extends from 1900 to 1998. In this study, we report the periods which experience above average annual frequencies for a specific circulation process. We also produce a Pacific atmospheric circulation index (PCI) in a similar manner to the ACI.

The Aleutian Low pressure system is the dominant influence in the variation of flow of the westerlies and it is most intense in winter. Beamish and Bouillon (1993) developed an Aleutian Low Pressure Index (ALPI) and related trends in this index to trends in the production of Pacific salmon. Beamish et al. (1998) modified the ALPI and have illustrated that changes in the ALPI also correspond well to the documented climate and ocean regime shifts of 1976 and 1989. In this study we also produce a winter PCI and relate it to ALPI.

Methods

Daily sea surface level pressure fields were used to construct daily synoptical maps from January 1900 - March 1998 for the Pacific-North American region of the Northern Hemisphere. The AARI used these maps to classify the daily atmospheric circulation processes visually according to the classification developed by Girs (1971). This classification scheme characterizes the atmospheric circulation process into three types: Z-type for westerly zonal flow; M2-type for southwesterly meridional flow; M1-type for northwesterly meridional flow. The annual number of days for each type of process was expressed as anomalies from a long-term mean. The time series of these anomalies were used to identify periods when one of the three processes generally remained above average while the other two processes were generally below average. We use the term ‘circulation epoch’ to describe these periods.

The anomalies from the long-term means of each process will sum to zero, so that

M1=-(Z+M2). The integral curve of the negative annual anomalies of M1 was used as a PCI and was compared to the ACI. We also determined the PCI for the winter season of December through March and compared its long-term fluctuations to an index of the Aleutian Low Pressure System (ALPI). The ALPI is a measure of the intensity of the Aleutian Low and is the average monthly area (km^2) of low pressure in the North Pacific ocean, less than or equal to 100.5 kPa, averaged for December through March and expressed as an anomaly from a 47 year mean (1950-1997). For comparison to the PCI, we also expressed ALPI as an integrative form.

Results

The most distinct features of the time series of the frequencies of Z, M1 and M2 processes are (*i*)-the prolonged period of above average annual frequency of Z type from 1972-1997 (Figure 1A) and (*ii*)-the corresponding prolonged periods of below average annual frequencies for both the M1 and M2 types (Figures 1B and 1C). This 26 year circulation epoch of Z processes is the longest observed from 1900-1997. The remainder of the time series can be described as: a Z-epoch from 1900-1909; a M1-epoch from 1910-1919; a Z-epoch from 1920-1932; a M2-epoch from 1933-1952; a Z-epoch from 1953-1961; and a M2-epoch from 1962-1971 (Figure 1). Generally, the annual frequency of Z process is opposite in trend to the annual frequency of M2 process (Figure 1), such that periods of above (or below) average frequency Z process experienced below (or above) average frequency of the M2 process. Any trend in the annual frequency of the M1 process was not opposite to either the Z process or the M2 process. Aside from 1910-1919 the only period of a prolonged trend in the frequency of the M1 process was the prolonged below average frequencies from 1969-1998.

The annual PCI (Figure 2A) exhibited a general decline from 1900-1924, remained relatively unchanged from 1925-1948, declined again from 1949-1973, increased from 1974-1991 and has remained relatively unchanged from 1992-1997 escept for a slight increase from 1996-97. The winter PCI (Figure 2B) was relatively unchanged from 1900-1923, it then increased until 1948, decreased from 1949-1976, increased from 1977-1988 and remained relatively unchanged from 1989-1998 except for a slight increase from 1997-98. The annual ACI increased from 1900-1939, decreased from 1940-1971, increased from 1972-1990, remained relatively unchanged from 1991-1996 and has started to decline in 1997 and 1998 (Figure 3A). The only shifts that were similar in the PCI and ACI occurred in the early 1970s and in the early 1990s. The winter ACI increased from 1900-1925, remained relatively unchanged from 1926-1961, decreased from 1962-1976, increased from 1977-1995 and has been decreasing since 1996 (Figure 3B). The only shifts that were similar in the winter PCI and the winter ACI were the mid-1920s shift and the 1976/77 shift.

Similar to the winter PCI, the ALPI integrative form exhibited shifts in 1925/26, 1946/47, 1976/77 and 1988/89 (Figure 4). When the ALPI integrative form increased or decreased, the PCI also increased or decreased. This indicates that a period of intense Aleutian Low pressure systems is associated with a period of above average zonal (Z) and easterly (M2) winter processes and below average meridional (M1) processes. From 1900-1925, the ALPI integrative form decreased and the winter PCI remained relatively unchanged, indicating a period of weak Aleutian Lows along with average zonal (Z), easterly (M2) and meridional (M1) processes. For 1926-1946, the APLI integrative form increased as did the winter PCI. This was a period of strong Aleutian Lows and below average meridional (M1) processes but above average zonal (Z) and easterly (M2) processes. From 1947-1976 the integrative for of ALPI and the winter PCI decreased indicating a period of weak Aleutian Lows and above average meridional (M1) processes. For the period of 1977-1988, the ALPI integrative form and the winter PCI increased indicating intense Aleutian Lows, below average meridional (M1) processes, and above average zonal (Z) and easterly (M2) processes. Finally, in the period from 1989-1998 the ALPI integrative form and the winter PCI appear to remain stable except for a distinct increase in ALPI in 1998. The winter PCI has a slight increase in 1998 but it is not as dramatic, so it is difficult to associate a change in trend to the winter PCI. The 1989-1998 period experienced average Aleutian Lows and average occurrence of zonal, easterly and meridional processes.

Discussion

Ebbesmeyer et al. (1990) were the first to identify a major shift in 1976/77 of the trends of several environmental and biological data series from the Pacific region. Since then other major shifts in climate and ocean conditions have been identified around 1925, 1947 and 1989 (Yamamoto et al. 1986, Francis and Hare, 1994, Zhang et al. 1996, Minobe 1997, Watanabe et al. 1998). However studies on the direct relationship between climate regimes and trends in fish production are not common. A recent study linked a principal components analysis of Pacific ocean surface temperatures from November through March with the production of Pacific salmon along the west coast of North America (Mantua et al. 1997). Their Pacific Decadal Oscillation Index reflected the 1925, 1947, 1977 and 1989 climate regime shifts and they illustrated synchronous shifts in fish production. Here, the annual PCI reflected similar regime shifts but the timing was slightly different. However, the winter PCI reflected the published climate regime shifts with more accuracy. This suggests that in the North Pacific, the winter season is a dynamic period and is the most important time of year for quantifying changes in circulation processes.

In North America there have been some studies linking general atmospheric circulation patterns to trends in environmental parameters such as precipitation and river flows (Moore and McKendry 1996). However, few attempts have been made to link atmospheric circulation patterns to fish production. The influence of atmospheric processes on ocean processes are commonly studied using both wind direction and intensity to calculate indices of wind-induced ocean currents or coastal upwelling

(Bakun 1973; Thompson and Ware 1996). The direction of winds is a major determinant of the transition from winter coastal downwelling to upwelling conditions along the west coast of British Columbia, Canada (Thomson, 1981). The duration and intensity of the winter downwelling season have been linked to zooplankton productivity (Brodeur and Ware, 1992; Hollowed and Wooster 1992; McFarlane *et al.* 1996), to the survival of early life stages of offshore fish species such as rockfish and sablefish (McFarlane et al. 1996) and to the yearclass strength of other groundfish (Hollowed and Wooster 1992). Although wind-intensity is important, the variation in upwelling and downwelling seasonal cycles (and hence the variation in ocean or fish productivity), can also be captured by wind direction data.

Beamish and Bouillon (1993) provided a link between the intensity of the Aleutian Low and marine production off the northwest coast of North America. Recently, changes in the Aleutian Low have been shown to correspond to changes in the index of general atmospheric circulation in the Atlantic-Eurasia region or ACI (Beamish et al. 1998). Our winter index of the general circulation in the Pacific-North American region (winter PCI) also corresponded well with the index for the Aleutian Low (ALPI). Both indices illustrated shifts similar to the published 1925, 1947, 1977 and 1989 regime shifts.

Our index of winter circulation provides a measure of the mechanism of energy transfer from the atmosphere to the oceans and eventually to ocean productivity. A positive trend in PCI indicates a period of below average meridional processes and above average zonal or easterly processes. The meridional process translates into winds from the northwest near the coast of North America, while the zonal process translates into westerly winds and the easterly process translates into winds from the southwest. We feel that the winter PCI is another index of ecosystem change that can be used along with other indices to determine regime shifts. It will be an important tool for relating climate changes to fish production off the west coast of Canada. The AARI has been able to develop a method of forecasting the circulation processes for the Atlantic-Eurasia region, and will be able to produce similar forecasts for the Pacific-North American region. We believe that since the winter PCI reflects regime shifts in the North Pacific, being able to produce a winter forecast may lead to an ability to detect possible regime shifts. More importantly, a forecasted winter PCI will have implications for predicting oceanic conditions and fish production which will be of interest to fisheries managers.

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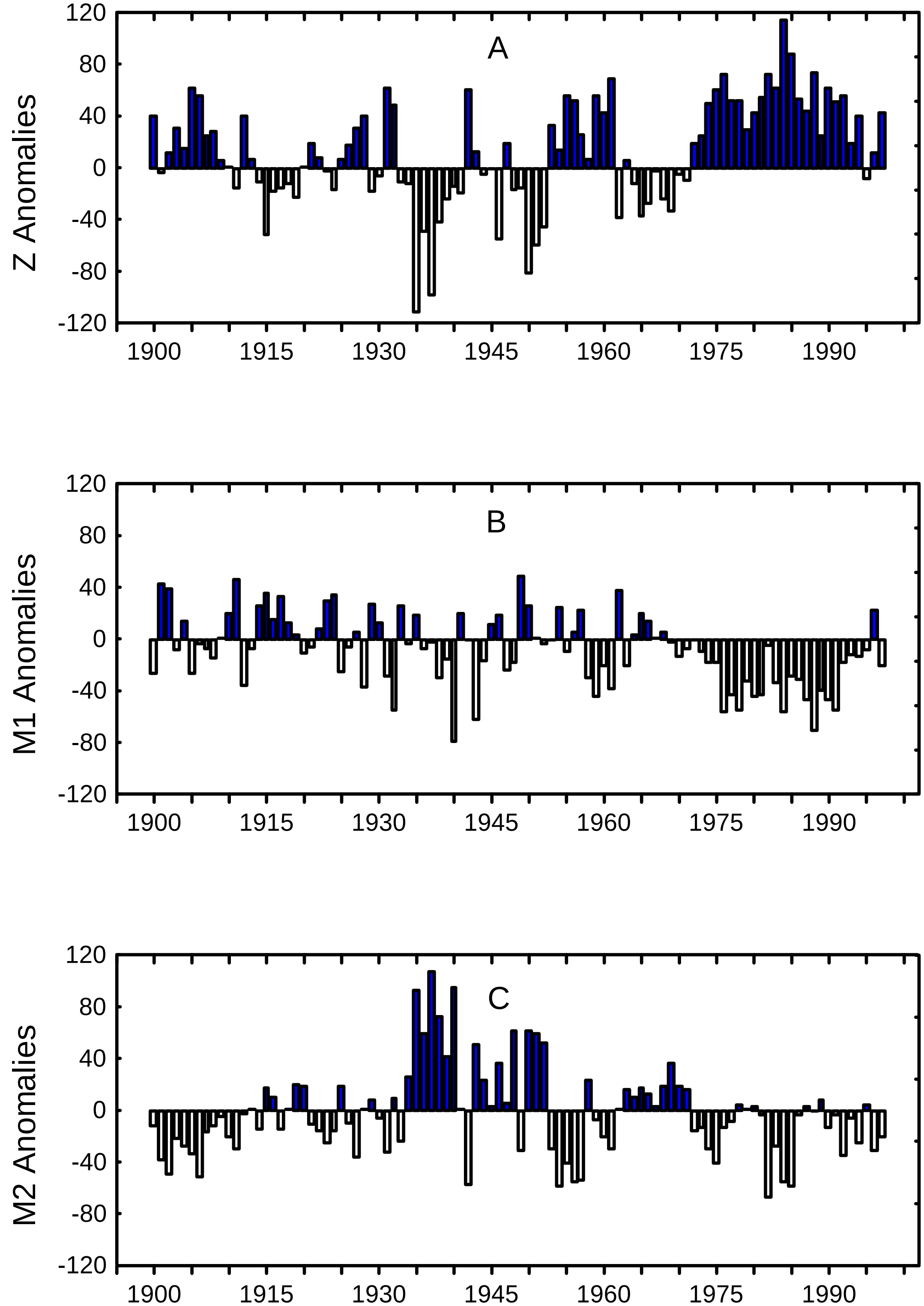
A
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1975
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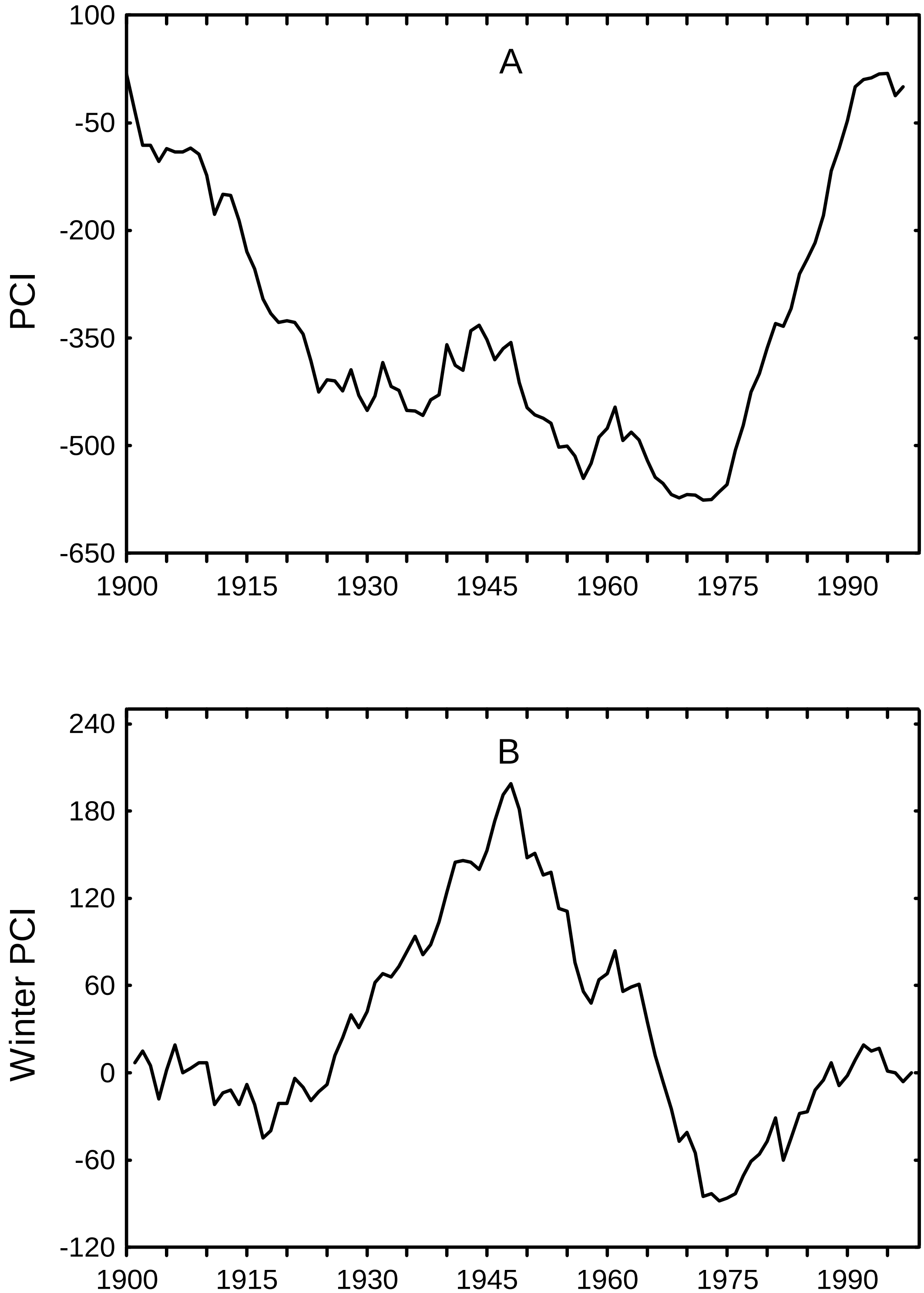
B
M1 Anomalies
C
M2 Anomalies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PCI
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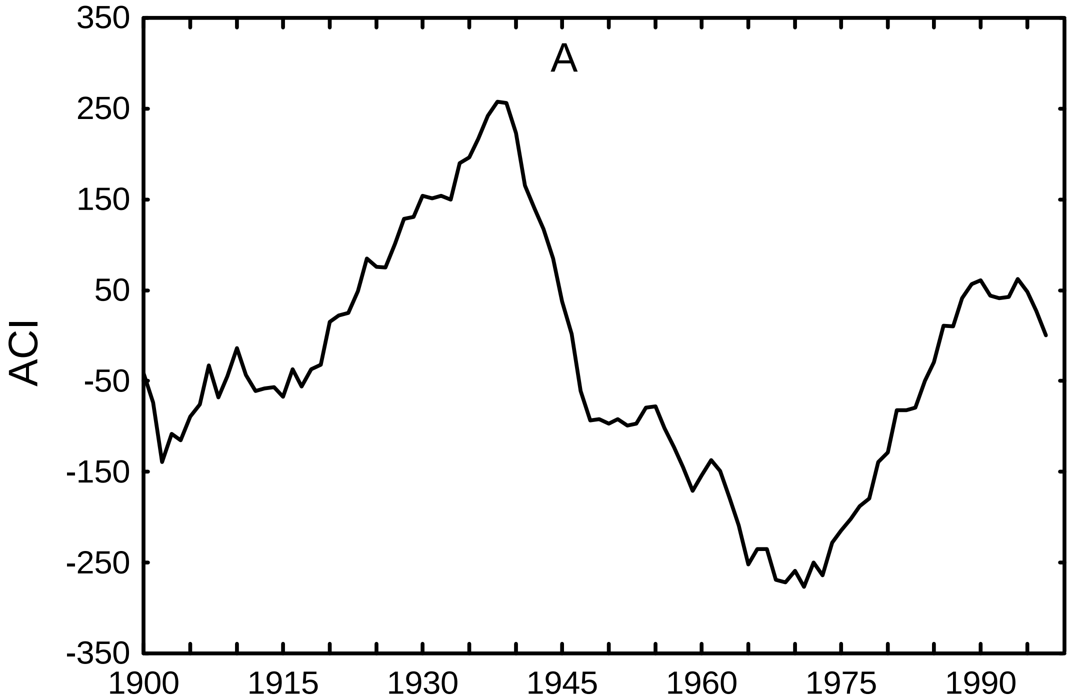
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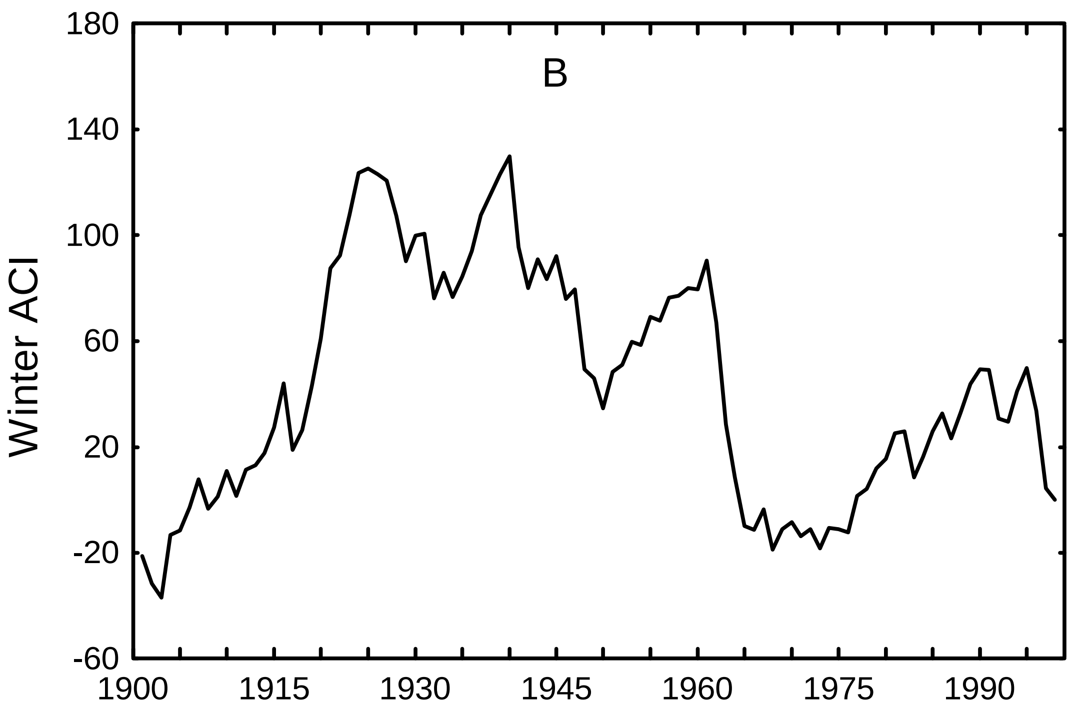
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Winter ACI
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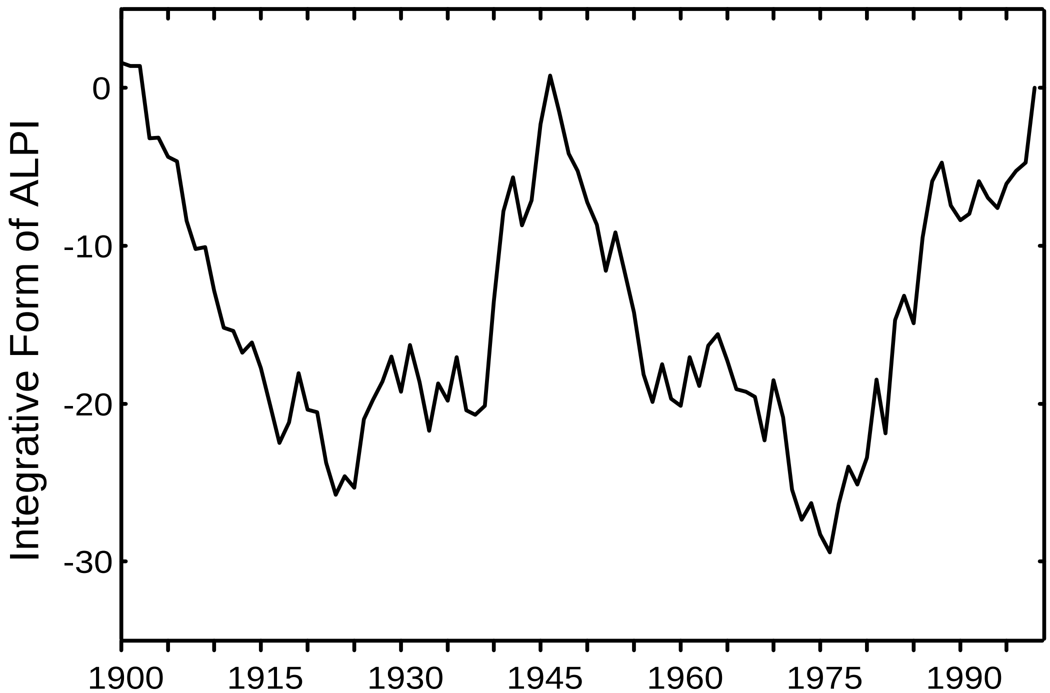
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