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STUDY OF NORTHERN WINTER ATMOSPHERIC ACTIVE CENTERS (AAC) CLIMATE BASE-STATE WITH ITS CLIMATE VARIABILITY AND EFFECTS

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ABSTRACT: The study of low-frequency oscillations is an important part of climate variability research. In view of insufficient efforts spent on multidecadal and ENSO-scale changes of the climate, the present paper undertakes study of > 30 year slowly-varying means, called climate base state (CBS), of northern winter AAC's in the past 100 years and more, with the CBS variability and its temporal evolution investigated, indicating that Aleutian low and Icelandic low (North Pacific high and North American high) experience maximum (minimum) variation in the CBS. The CBS exhibits two modes for its variation. The positive (negative) phase of mode I presents a weak (strong) NAO (North Atlantic Oscillation), a weaker (stronger) NPO (North Pacific Oscillation), a robust (feeble) Siberian high and a quite weak (vigorous) Aleutian low whilst the positive (negative) phase of mode II reveals a feeble (strong) Aleutian low and a weak (robust) Siberian high. Also, the research shows that the recent CBS of northern circulations is in a remarkably negative phase of mode I and a noticeably positive phase of mode II, viz., in the background of slowly-varying circulations of an exceptionally weak Siberian high, an extremely vigorous Aleutian low and an intense NAO. The background field is likely to persist for a matter of 30 years such that northern winter temperature is expected to be in such a warm situation for a long period to follow.

Key words: atmospheric active centers; climate base-state; climate variability

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1 INTRODUCTION

Low-frequency climate change at timescales of decades to centuries has been investigated by Paltridge and Woodruff (1981), Folland et al. (1984), Oort et al. (1987), and Trenberth (1990), and the others. However, in many of the previous studies the time series contained all scales of variability, that is, from ENSO-scale, or short-term (less than a decade), to multidecadal scales. Following the conceptual framework proposed by Rasmusson et al. (1994), hereafter RWR (1994), we put multidecadal secular changes and ENSO-scale variations into two modes for climate variability.

Meteorological fields and the climate system are marked by a slowly varying climate means averaged over > 30 years, called "climate base-state" in RWR (1994). It is necessary to investigate the features of the slowly varying climate mean of a circulation system and an element field and their interrelation. Wang X. L.et al. (1995), Wang B(1995) and Parthasarathy (1991) explored slowly-varying mean as the background effects on the high frequency (HF) variability.

It should be pointed out that atmospheric circulation anomaly characteristics could be represented, to great extent, by the abnormality of AAC's intensity. In recent years there have been many studies on the SO and NAO, including, for example, Alexnder et al. (1992), Hurrell et al. (1995),

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Enfield (1992), Elliot et al. (1988), Meehl and van Loon (1979), Rogers and van Loon (1979) and Jones et al. (1997), but very few efforts were made at all of the northern winter AACs. The present paper aims at the CBS and time evolution of the northern AACs (see Section 3 and 4)

Secular changes can occur both in climate means and measures of variability on a multi-decadal basis. Changes in the mean are those in the 'base-state climate', while changes in variability are more closely related to those in the frequency and/or intensity of drought, heat wave, frost occurrence, and other features on a year-to-year basis. RWR(1994) indicated that ENSO-scale variance has changed by a factor of 2 or more over the past century. This work is devoted to research of the HF variability characteristics of the AACs (Section 5) and Section 6 is concerned with the AAC CBS in relation to winter temperature variation in the northern hemisphere and China, with a summary given in the last section.

2 DATA AND METHODS

2.1 *Data*

The 1873-1995 monthly northern sea-level pressures (SLP), compiled by Dr. M. Hulme at the Climatic Research Unit, University of East Anglia, Norwich, U.K., are used in this study, covering 10°N-85°N at 5° lat. /10° long. resolution. We employed the SLP averaged over December-February, which is defined as the year with the given month of December included.

2.2 *Methods*

2.2.1 ACC INTENSITY INDICES

The northern wintertime AACs consist of Aleutian low, Icelandic low, North Pacific high, Siberian high and North American high. The winter SLP averaged over the region is utilized as the indicator of the strength, shown as follows:

Aleutian low	40°N-50°N, 160°E-160°W;	Icelandic low	55°N-65°N, 50°W-20°W;
Siberian high	40°N-55°N, 90°-110°E;	North Atlantic high	30°N-45°N, 20°W-10°E;
North Pacific high	20°N-30°N,120°-170°E	North American high	40°N-60°N,90°W-120°W.

2.2.2 DISSOCIATION OF HIGH- AND LOW-FREQUENCY BANDS

To separate the high frequency from multidecadal climate changes, a multistage filter (Zheng and Dong, 1986; Shi et al., 2000) is applied to divide the time series of the intensity of the AAC into low-frequency and high-frequency components as follows:

$$X = X_L + X_H \tag{1}$$

where X_L (X_H) represents low- (high-) frequency component of the intensity of the AAC at periods longer (shorter) than 30 years. The filter is also employed in this study, with the computational scheme of Wang X. L. (personal communication) adopted.

To explore the anomalous climate variability, we computed 30-yr running mean squared deviation of X_H, following RWR(1994), as

$$X_{HV}(t)=\left[\sum_{k=-15}^{k=15} X_H{}^2(t+k)31\right]^{1/2} \quad (2)$$

where time series $X_{HV}(t)$ is the estimate of the 30-yr running mean squared deviation and will be used to approximate the secular changes in climate variability of the AAC intensity.

2.2.3 CLIMATIC TREND COEFFICIENT r_{xt}

To make approach to the secular trend change in a meteorological element X_t we adopted the expression of linear regression in the form

$$X_t = a_0 + a_1 t \qquad t = 1,2,3\cdots n \text{ (year)} \quad (3)$$

where a_0 denotes the constant, *t* the time (year) and a_1 the regression coefficient. We utilized the so-called unitless climatic trend coefficient r_{xt} which is defined as the correlation coefficient between the element's series and sequence of natural numbers of 1, 2, 3,...*n*. and verified in terms of the commonly used Student' s T scheme for correlatively. In view of the fact that r_{xt} is unitless, its magnitudes can be compared to each other.

2.2.4 ZONAL / MERIDIONAL CIRCULATION INDICES IN EASTERN ASIA

To investigate the anomalous features of atmospheric circulations, we have calculated zonal/meridional circulation indices in eastern Asia with the aid of

$$I_Z = \frac{\sum_{i=1}^{L} Z_{1i} - \sum_{i=1}^{L} Z_{2i}}{L(x_2 - x_1)} \qquad I_M = \frac{1}{nm\Delta l}\sum_{j=1}^{n}\left|\left[\sum_{i=1}^{m}\left(\frac{\Delta Z_j}{\cos x_i}\right)\right]_j\right| \quad (5)$$

where I_z (I_M) signifies the zonal (meridional) index; x_1 and x_2 the latitude for computing zonal circulation (40°N ~ 60°N, 160°E ~ 150°E); Z_{1i} and Z_{2i} the SLP readings along x_1 and x_2, respectively; *L* the number of gridpoints on x_1 and x_2, separately. In calculating the meridional circulation index, the study belt was divided into *n* subregions to get ΔZ_j (the SLP difference between neighboring points at longitude spacing from *m* latitude circles for subsequent uses.

3 NORTHERN WINTER AAC CBS CHARACTERISTICS

Fig.1 is a plot of the CBS of northern winter AACs and east-Asian zonal/meridional indices, with their trend and regression coefficients to the AACs summarized in Tab.1.

It is seen therefrom that the AAC CBSs exhibit the features as follows.

i) The Aleutian low and Icelandic (North Pacific high and North American high) experience maximum (minimum) variation in the CBS ,with the North, Atlantic a bit higher variation than the North American high.

ii) The Aleutian low shows a robust negative trend, following which are, in order, the North

American high and in contrast, the Siberian high, North, Atlantic high, Icelandic low as well as zonal circulation index show no secular trend variation.

iii) The AAC CBS displays oscillations at periods of 60-80 years, which are superimposed on the secular trend, the maximum (minimum) amplitude occurring to the Icelandic low (North American high and North Pacific high), with the Aleutian low intervening.

iv) The Icelandic low is negatively correlated, to a great degree, with the North Atlantic high in the CBS, exhibiting the same North Atlantic Oscillation (NAO).

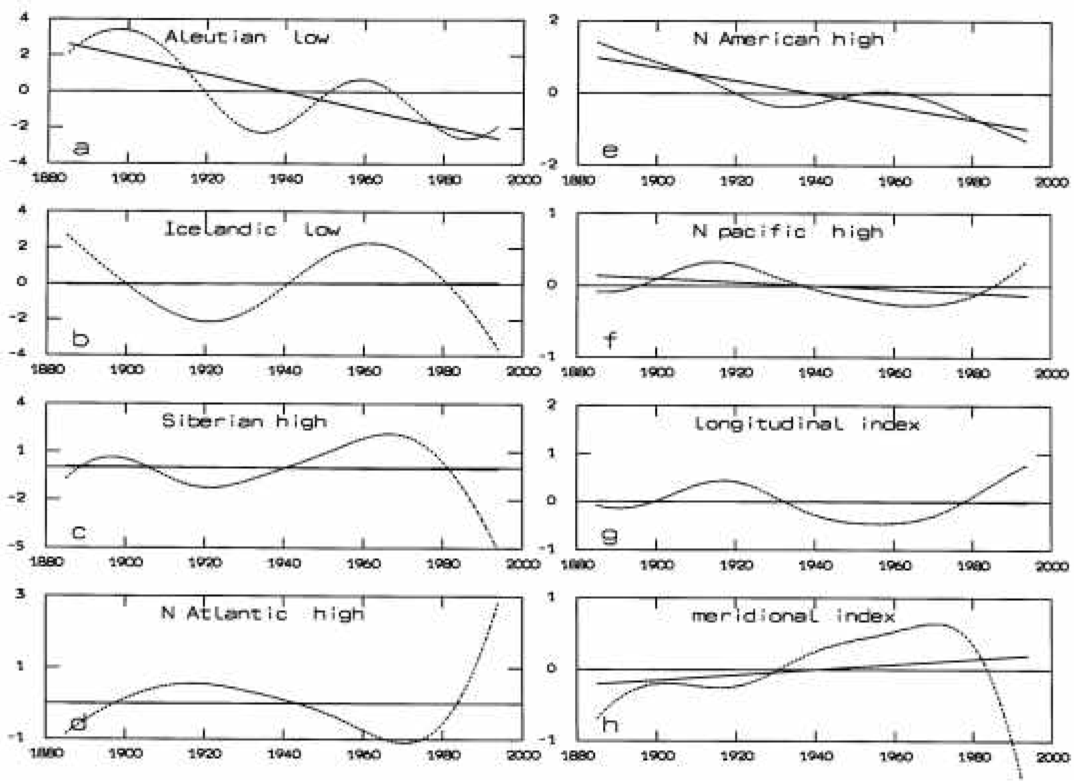

Fig.1. The northern winter AAC CBS and east-Asian zonal/meridional indices (in anomaly form). Units: 0.1 hPa a) Aleutian low; b) Icelandic low; c) Siberian high; d) North Atlantic high; e) North American high f) North Pacific high; g) zonal circulation index; h) meridional circulation index

Tab.1. The trend and regression coefficients of AAC CBS and east-Asian zonal/meridional circulation indices

	Trend coefficient	Regional coefficient
Aleutian low	–0.41	–0.47
Icelandic low	0.01	0.01
Siberian high	–0.03	–0.03
North Atlantic high	–0.04	0.00
North American high	–0.41	–0.18
North Pacific high	–0.09	–0.02
Zonal circulation index	0.02	0.02
Meridional circulation index	0.20	0.05

v) The circulation features in the late 1990s are marked by the Siberian high, Aleutian low, Icelandic low and North American high in a considerably low CBS as opposed to the North Atlantic high and North Pacific high, a situation that reminiscent of the picture in the 1920's- 1930's. On the other hand, an especially feeble Siberian high, exceptionally vigorous Aleutian low, robust NAO have been prominent in the last century, as shown in Fig.1, leading to a most robust zonal and a most feeble meridional circulation in this century, a fact that is in agreement with the occurrence of northern winter warming. One can see from the slowly varying variability that the current circulation background is likely to sustain for 30 years or so.

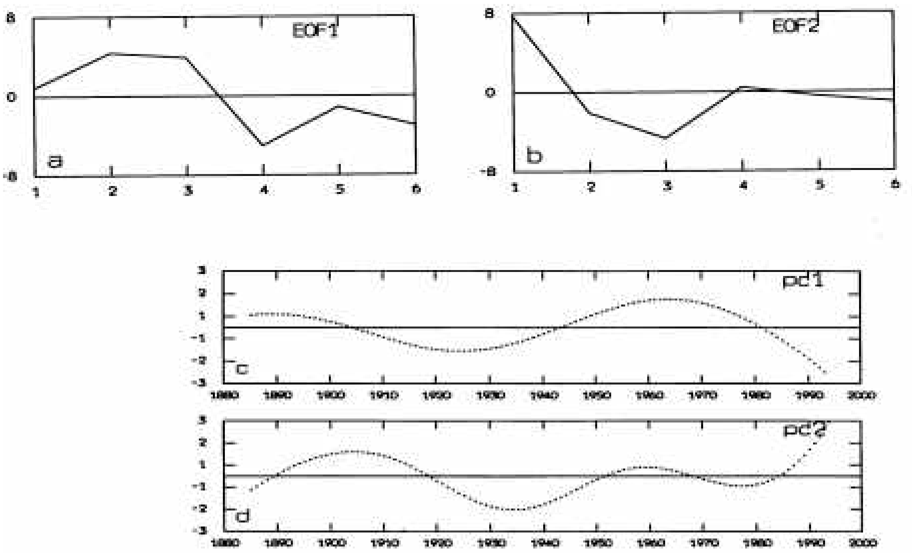

Fig.2. EOF1 (a) and EOF2 (b) with the related temporal coefficients (c, d) for the CBS of each of the AACs; Both the abscissas in Panels c and d are from 1880 to 2000 at intervals of 10 years.

4 ANALYSIS OF PRINCIPAL COMPONENTS OF NORTHERN WINTER AAC CBS

Fig.1 suggests that the relationships among the CBSs of the six AACs. Can we use one or two characteristic modes to describe the CBS? For this reason, Empirical Orthogonal Function (EOF) analysis based on the variance matrix of X_L is used to identify, as far as possible, the spatial/temporal structures of the CBS with the result that eigenmodes 1 and 2 explain 75.5% and 18.5% of the total variance, respectively, both having passed the North (1982) statistical test. Fig.2 depicts EOF1 and EOF2 with the corresponding time coefficients given, where the serial number of each AAC is the same as in Tab.1.

One can see therefrom that:

1) For the AAC CBSs, EOF1 has high positive (negative) load on the Icelandic low and Siberian high (North Atlantic high), indicating a weak Icelandic low, robust Siberian high and weak North Atlantic high, with the feeble North Atlantic high and weak Icelandic low constituting a negative NAO phase, suggesting a weak NAO. On the other hand, small positive (negative) load is on the Aleutian low (North American high and North Pacific high), the North Pacific high and Aleutian low making up a negative NPO phase. If we define the situation (Fig.1) as the positive phase of mode I of the AAC CBS, then the related circulations of positive time coefficients in a given year should be indicative of greatly reduced NAO, weaker NPO, a vigorous Siberian high and

feeble Aleutian low. Referring to the time coefficient curve (Fig.2c) we inferred that such circulation features in the main were available in the 1960's-1970's and 1880's-1890's. However, these coefficients were considerably negative in the 1920's-1930's and after the 1980's in striking contrast to the slowly varying feature of atmospheric circulations. As stated earlier, EOF1 accounts for 75.5% of the total variance for the CBS and is thus the principal mode. Subsequent to the 1990's, the temporal coefficients are minimum (greatly negative) over the nearly 100 year interval, implying that the northern circulation pattern is related to greatly intensified NAO, stronger NPO, weak Siberian high and stronger Aleutian low, a situation that is likely to stay 30 years or so.

2) EOF2 (Fig.2b) reveals a heavy positive (negative) load on the Aleutian low (Siberian high), the load on other AACs being secondary. Hence, the positive phase of mode II is defined as a situation of a weak Aleutian and a feeble Siberian high. But considerably positive time coefficients after the 1990's (Fig.2d) indicate that the vigor of the low and high is being reduced. As shown before, mode II explains 18.5% of the total variance.

3) EOF1, EOF2 and their temporal coefficients have revealed the extraordinarily feeble Siberian high after the 1990s.

4) The lower load on the North Pacific high and North American high (Figs.2a & b) suggests very small change in the CBS of the two AACs, a result which is in accordance with Fig.1.

5 ANALYSIS OF THE AAC CBS VARIABILITY

We have dealt with the HF component of the Aleutian low, Icelandic low and Siberian high that show greater variability. As revealed by (2) for the HF running mean square deviation X_{HV} for each of the AACs, with the results shown in Fig.3.

It is seen therefrom that X_{HV} shows bigger variation of the two lows as opposed to the high (figure not shown). In particular, the Aleutian low's X_{HV} exhibits linear increase in the study period with the vigor displaying a significantly negative trend on which superimposed is the strong-weak-strong-weak evolution.

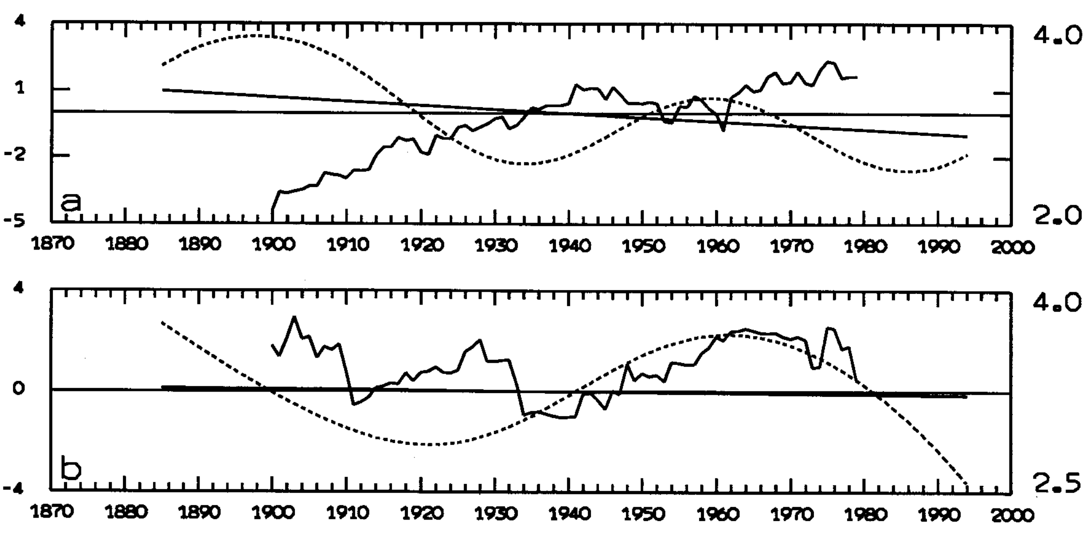

Fig.3 Time series of low-pass filtered base-state variation (dotted curve), 31-year running mean squared deviation (thin curve) and linear trend function (line) for intensity of the winter Aleutian low (a) and Icelandic low (b), with the climate base state (left) and running mean square deviation (right) in units of 0.1 hPa.

6 NORTHERN WINTER TEMPERATURE AND AAC CBS ANOMALY

It deserves efforts to examine the relation between northern winter temperature and AACs as regards >30 year means during this period. Tab.2 presents the categories of the AAC vigor (based on CBS magnitudes) from the 1870's to the 1990's, indicating the same interdecadal variation of the Icelandic low and North Atlantic high as that of NAO (see Hurrell, 1995). Moreover, since the end of the 19th century, northern winter temperature has experienced, on the whole, a period of cold-warm-cold-warm interval (see Tab.2). One can see therefrom that the warm (cold) interval is associated with a very strong (weak) Aleutian and Icelandic low, a considerably weak (robust) Siberian high and a stronger (weaker) North Atlantic high. The small CBS variability of the two highs indicates their feeble relation to the winter temperature.

We calculated the CBS correlatively of time coefficients of the Aleutian low, Icelandic low and Siberian high (Fig.1) to northern winter temperature, arriving at 0.90, -0.12 and -0.11, respectively. This shows that as the Aleutian low is in a low CBS (small magnitude, high vigor), the temperature is in a high CBS (big value, high temperature). By removing the linear trend out of the above factors, we dealt with the correlation, i.e., we considered only the trend-free, quasi-periodic case for >30 years to within 110 years, attaining -0.74, -0.39 and -0.32, respectively. This suggests that as the Aleutian low and Icelandic low have small CBS values (viz., high vigor) and the Siberian high is small valued (low vigor), the temperature exhibits high CBS magnitude (warm winter), in accordance with the results of Tab.2.

We computed the correlation coefficients between the time coefficients of EOF1 and EOF2 of the AAC CBS and the temperature counterpart, reaching -0.48 and -0.63, respectively, suggesting a close correlativity in CBS between the Aleutian low Icelandic low and Siberian high intensity to the temperature. The robust Aleutian low, intense Icelandic low and exceptionally feeble Siberian high in the current period is extremely favorable for the northern winter warming.

Tab.2 CBS data-defined AAC vigor in relation to northern winter temperature

Active center	1880s	1890s	1900s	1910s	1920s	1930s	1940s	1950s	1960s	1970s	1980s	1990s
Aleutian Low	W	W-est	W-est	W		S-est				S	S-est	S
Icelandic low	W-est			S	S-est	S		W	W-est	W		S-est
Siberian High		S		W	W			S	S	S-est	W-est	W-est
N. Atlantic High	W		S	S-est	S			W	W-est	W-est		S-est
N. American High	S-est	S-est	S	S		W				W	W-est	W-est
N. Pacific High			S	S-est	S		W	W	W-est	W-est		S-est
Temperature	C	C		W	W	W-est	W-er		C-er		W	W-est

Note that W, W-er and W-est denote weak, weaker and weakest (vigor) and also warm, warmer and warmest (temperature); S, S-er and S-est stand for strong, stronger and strongest, and C, C-er and C-est stand for cool, cooler and coolest, respectively.

7 CONCLUDING REMARKS

From the foregoing analysis, we come to the following.

a) Based on the study of >30 year slowly-varying means (CBS) of the northern winter AACs for the past 100 years and more, the variability features and time evolution were examined. We discovered that the Aleutian low and Icelandic low, Siberian high (North Pacific high and North American high) experience maximum (minimum) variation in the CBS

b) The AAC CBSs fall into two modes. The positive (negative) phase of mode I indicates a weak (strong) NAO, a weaker (strong) NPO, a robust (feeble) Siberian high and a weaker (intense) Aleutian low while the positive (negative) phase of mode II suggests dominantly a weak (strong) Aleutian low and a feeble (intense) Siberian high. The CBS of recent northern circulations falls into a significantly negative (positive) phase of mode I (II).

c) The HF mean squared deviation of the Aleutian low exhibits linear growth in the study period.

d) The CBS of the Aleutian low, Siberian high and NAO intensity bears a close relation to that of northern winter temperature. The current lower-tropospheric circulations are in a slowly varying background of a weak Siberian high, intense Aleutian low and strong NAO, a situation that is particularly favorable for winter warming maintenance and likely to persist 30 years or so.

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