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DECADAL POLAR MOTION CONNECTED WITH ATMOSPHERIC PRESSURE AND SEA LEVEL PATTERNS OVER THE NORTH ATLANTIC OCEAN

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Abstract
This paper intends to discuss sources of the decadal polar motion, focusing on a decadal fluctuation of the NAO (North Atlantic Oscillation) known as atmospheric pressure oscillation between middle and high latitudes over the North Atlantic Ocean.

Some correlation and similar patterns are found between decadal variations of the polar motion and the NAO index. A model computation shows that the decadal polar motion could be explained by a zonally asymmetric atmospheric pressure distribution of about 1 hPa over the northern hemisphere which may be connected with the NAO. Results of calculation with sea level atmospheric pressure data, however, reveal that the atmosphere cannot be the source of the decadal polar motion.

Sea level changes corresponding to the decadal polar motion are also found in the North Atlantic Ocean, in particular along the east coasts of the North America. A model computation suggests that the decadal polar motion is also explained by sea level changes of a few centimeters in the northern hemisphere. However, if these sea level changes are due to atmospheric pressure variations, they cannot be the source of the decadal polar motion under assumption of inverted barometer rule.

These results suggest that the sources of the decadal polar motion are to be found among land water and glaciers. A water mass redistribution over the northern hemisphere connected with land water variation is the most plausible source for the decadal polar motion.

1. Introduction
The variation of the Earth's rotational axis in the geographical coordinate system is known as the polar motion. It is mainly excited by redistribution of mass and relative angular

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momentum change of the atmosphere and hydrosphere [e.g. Munk and MacDonald 1960; Lambeck 1980; Barnes et al. 1983].

Introduction of space geodesy in the 1970s has markedly improved the accuracy and resolution in the Earth's rotation data. At the same time, new information on intra-and inter-annual polar motions has been accumulated and analyzed in addition to those on the Chandler wobble and the annual wobble [e.g. Chao and Au 1991; Eubanks 1993].

Zhou and Chao (1995), for example, reported the strong correlation between the NAO index and polar motion at the inter-annual timescale. Kikuchi and Naito (1995) also found the decadal polar motion in the IPMS (International Polar Motion Service) data and the SPACE94 data (see Fig. 1). However, its excitation dynamic remains to be an open question.

Variations on decadal timescale are hot topics in the study of the atmosphere-ocean system. One of such variations is the NAO (North Atlantic Oscillation) atmospheric teleconnection pattern having north-south dipole in the North Atlantic [Walker and Bliss 1932; Deser and Blackmon 1993]. Hurell (1995) revealed that decadal variability in the NAO has been remarkable since 1950 using its winter (December through March) index derived from the difference of normalized pressures between Lisbon in Portugal and Stykkisholmur in Iceland.

Decadal scale variations are also seen in the ocean. Groger and Plag(1993) showed east-west motion of the oceanic heights on decadal to interdecadal time scales with Permanent Service for Mean Sea Level (PSMSL) data set. Lately, Unal and Ghil (1995) also reported that decadal sea level variation can be seen globally.

In this paper, we first point out similarity between the decadal polar motion and the NAO index variations, secondly we consider whether or not the NAO teleconnection and the atmospheric pressure variations are physically responsible for the decadal polar motion, thirdly we show the relationship between the decadal polar motion and the global sea level changes, and lastly we discuss their inter-relationship.

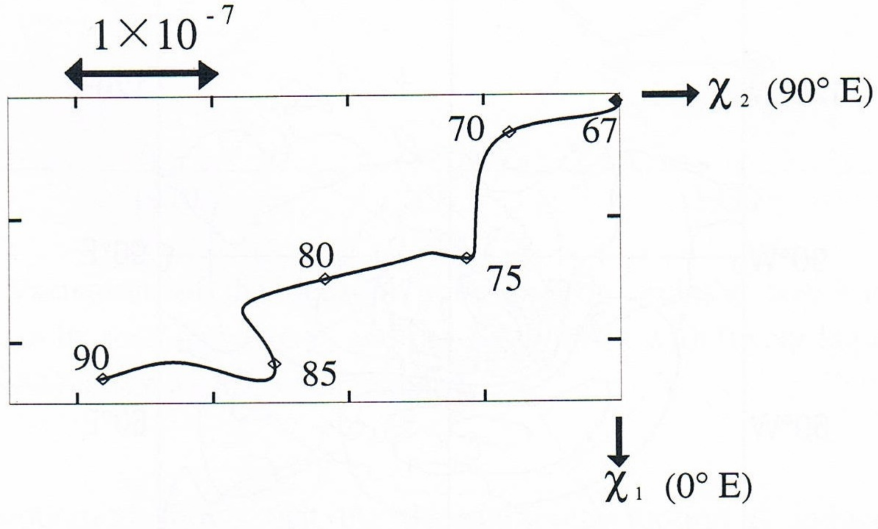

Figure 1 Variation of the excitation pole computed from the observed polar motion for the period 1962-1994 based on IPMS and SPACE94 data sets. Five-year low-pass-filter is used. Unit 1×10^{-7} of the non-dimensional excitation function in the figure corresponds to 64 cm on the Earth's surface. After Kikuchi and Naito (1995).

2. Data

We use the two polar motion data sets; one is the IPMS data for 1962-1975 and the other the SPACE94 data for 1976 - 1995. The sampling interval of both data set are 5 days. Older polar motion data based on ILS (International Latitude Service) are not used here because of their low precision [e.g. Eubanks 1993].

To study the relation between the polar motion and the NAO index, we use time series data of the NAO index for 1962-1995 [Hurell 1995] during which a typical NAO pressure pattern is found (see Fig. 2). In addition, the monthly mean atmospheric sea level pressure data in the northern hemisphere for the period 1951-1990 provided from the Japan Meteorological Agency (JMA) are used to calculate excitation of the decadal polar motion; for excitation dynamics of polar motion, see chapter 3 of Eubanks (1993).

Monthly mean sea level data of PSMSL [Woodworth 1991] for 1951-1990 are used to search decadal sea level variations, but the data including steps or gaps are not used here.

3. Results of Analysis

Excitation function given by a deconvolution of the polar motion is expressed conventionally with χ_1 (along the Greenwich meridian) and χ_2 (90° E) components [Barnes et al. 1983; Eubanks 1993]. Fig. 3 shows the decadal variation of the excitation pole in Fig. 1 smoothed with 5-year low-pass filter and detrended by a least-square fitting. Here we call this the decadal polar motion. Note that it rotates counterclockwise.

Fig. 4 shows the polar motion and variation of the NAO index. Noteworthy is that χ_1 and the NAO index have similar behavior; the NAO index also has correlation with χ_2 of 2.5 years lag.

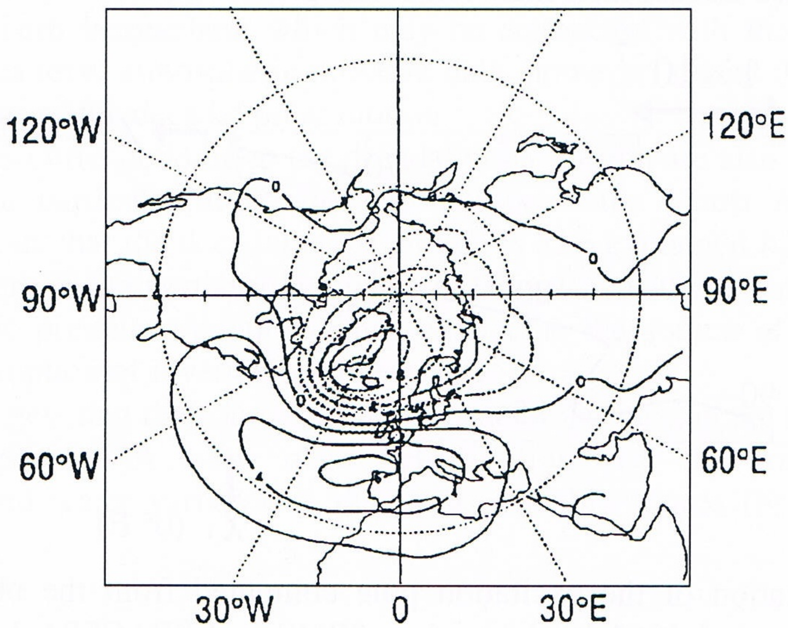

Figure 2 Difference in sea level atmospheric pressure (hPa) between high index minus low index of the NAO (after Hurell 1995), which shows the typical NAO teleconnection pattern. Dashed contour lines show negative values.

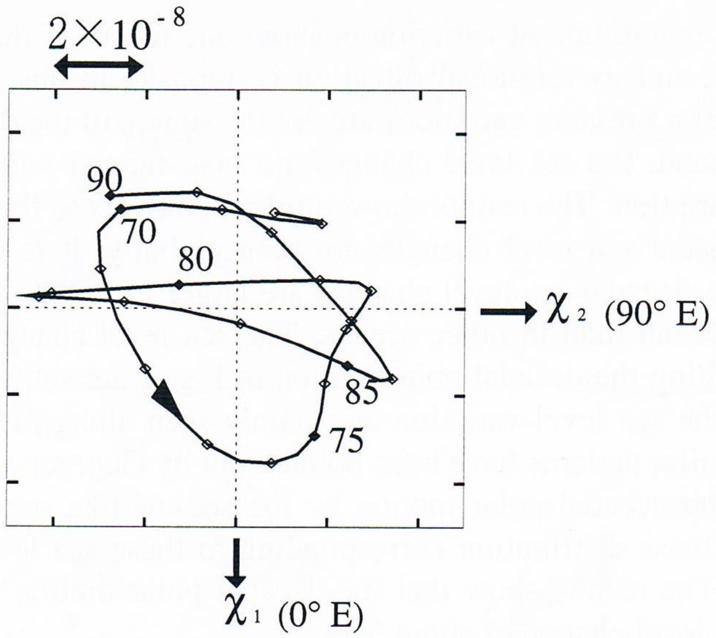

Figure 3 The Decadal polar motion after removing the secular variation and bias (see Fig. 1). Note that the pole rotates counterclockwise. Unit 2×10^{-8} in the figure corresponds to 13 cm on the Earth's surface.

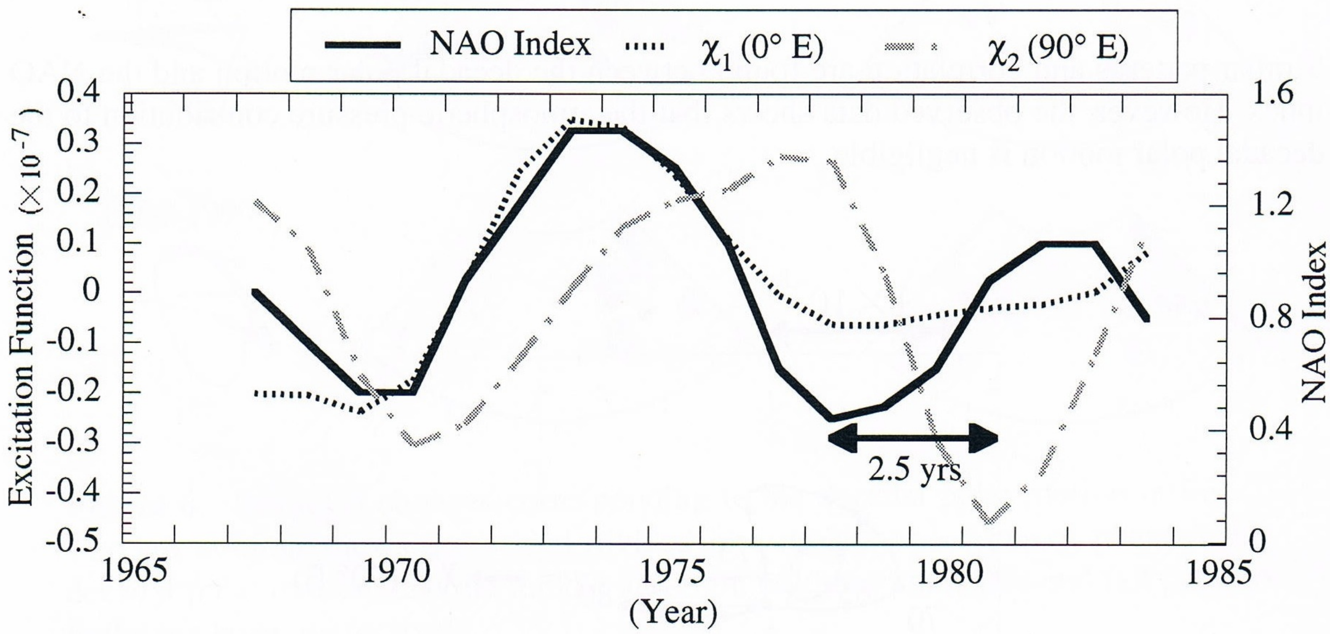

Figure 4 Variations of the decadal polar motion and the NAO index. Some correlation can be seen between χ_1 and the NAO index with 0 year lag and between χ_2 and the NAO index with 2.5 years lags.

A model computation shows that the decadal polar motion is induced by a global atmospheric pressure distribution of 1 hPa of spherical harmonic function of degree 2 and order 1. Therefore, we try to calculate the excitation function for the decadal polar motion by the observed atmospheric sea level pressure data over the northern hemisphere. The calculations are done assuming IB(Inverted Barometer) response of the ocean is assumed [e.g. Munk and MacDonald 1960; Ponte et al. 1991]. Fig. 5 shows the calculated decadal polar motion. Its magnitude of variation is about one fourth of the observed decadal polar motion in Fig. 2, and its rotational direction is opposite to observed one. These suggest that the atmospheric pressure variations are not the source of the decadal polar motion.

On the other hand, the sea level changes are investigated with a spectrum analysis to detect decadal variation. The results show similar behaviors to those obtained by Unal and Ghil (1995); decadal sea level changes are seen globally. It is found, in particular, that amplitudes of the decadal sea level changes are larger in the North Pacific Ocean and the North Atlantic Ocean than in other oceans. The sea level changes in the North Atlantic Ocean corresponding the decadal polar motion in Fig. 2 are shown in Fig. 6. The seesaw-like patterns of the sea level variation are mainly seen along the east coast of the North America. The similar patterns have been pointed out by Georger and Plag (1992).

We calculate the decadal polar motion by the seesaw-like sea level changes assuming that there exists mass distribution corresponding to these sea level changes in the North Atlantic Ocean. The results show that the decadal polar motion can be explained by the hypothesized sea level change of about 5cm.

4. Discussion and Concluding Remarks

Similar patterns and correlation are found between the decadal polar motion and the NAO index. However, the observed data shows that the atmospheric pressure contribution to the decadal polar motion is negligible.

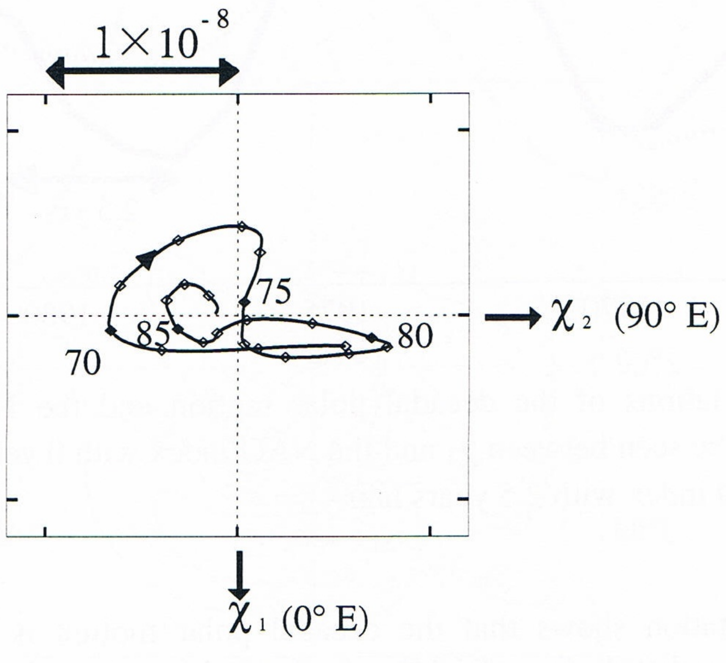

Figure 5 Calculated Decadal polar motion from the atmospheric pressure data in the northern hemisphere. Magnitude of variation is about one fourth of that of the observed decadal polar motion in Fig. 3. Note that the pole rotates clockwise. Unit 1×10^{-8} in the figure corresponds to 6.5 cm on the Earth's surface.

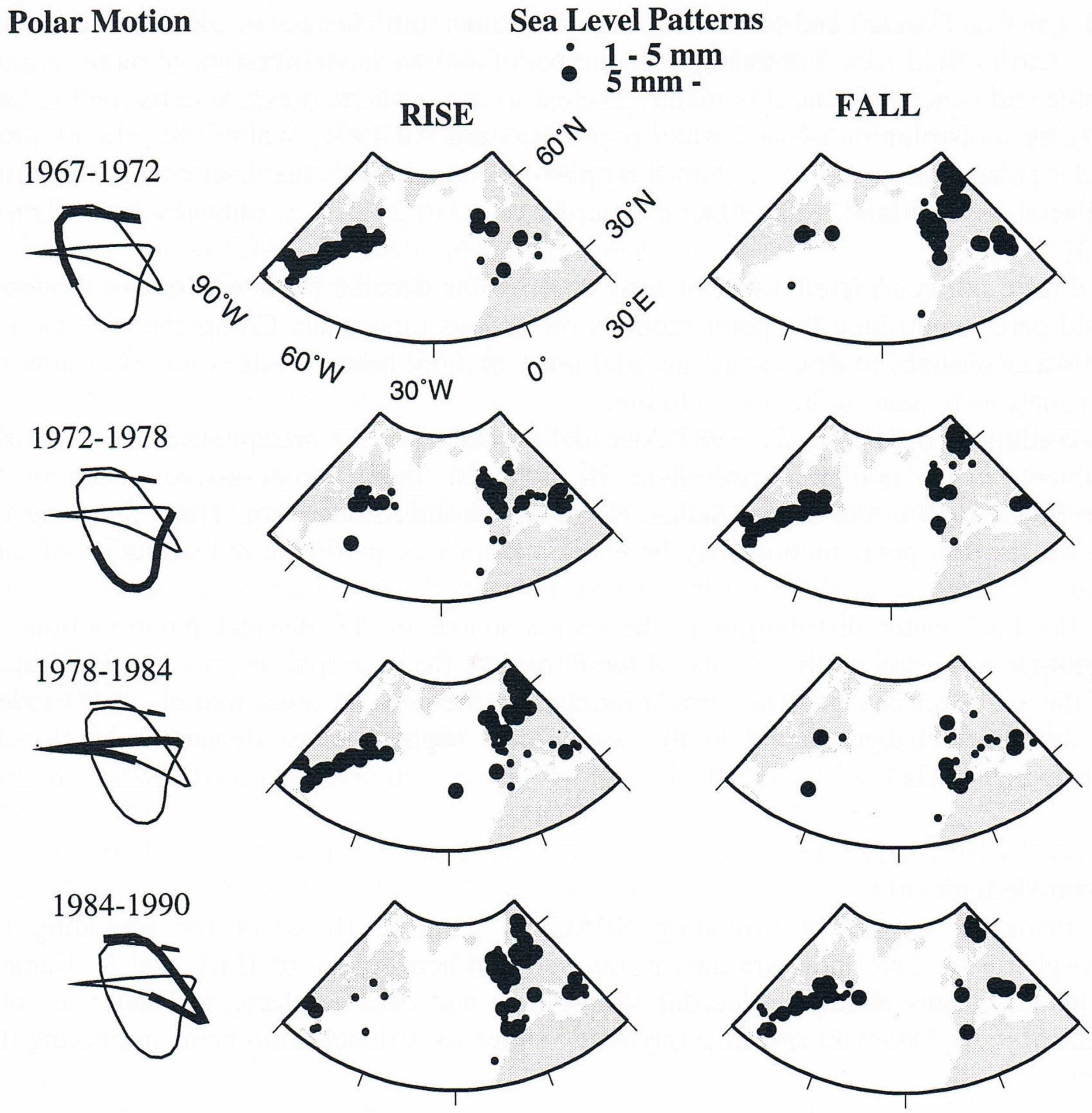

Figure 6 Sea level changes corresponding to the decadal polar motion in Fig. 2. The left column shows the period divided into typical two types of phase in the decadal polar motion, and the middle and right columns show rise and fall patterns in the sea level, respectively.

On the other hand, decadal sea level changes are found to exist globally. In particular, seesaw-like sea level changes corresponding to the decadal polar motion are found in the North Atlantic Ocean. The decadal polar motion can be excited by these sea level changes if they reflect real mass distribution. The possibility depends upon whether or not these sea level changes are net changes in oceanic mass. This is a problem to be explained in physical oceanography.

Now, the polar motion is generally ascribed to mass redistribution of the atmosphere, land water and ocean, and to relative angular momentum changes of atmosphere, ocean, and Earth's fluid core. For example, a number of authors have investigated on the annual wobble and concluded that it is mainly excited by atmospheric pressure redistribution and partly by redistribution of land water [e.g. Chao and Au 1991; Wahr 1983]. In addition, secular polar motion can be explained by post-glacial rebound, sea level changes, melting of glacial ice and land water storage on order of 10 to 20% [e.g. Eubanks 1993; Trupin 1993].

We have not considered effect of land water to the decadal polar motion yet though it would partly contribute the polar motions on various time-scale. Comprehensive data of land water changes to discuss the decadal polar motion, however, does not exist now, so such analysis remains to be solved future.

According to Bradley et al. (1987), decadal variations of the precipitation exist over the continents in the northern hemisphere. In particular, these variations have been strong since about 1950 in the United States, North Africa and Middle East. These facts suggest that the decadal polar motion may be excited mainly or partly by redistribution of land water.

If the land water distribution is the major source of the decadal polar motion, its magnitude is $1 g/cm^2$ on the surface of the Earth like the atmospheric pressure distribution and the sea level change. The correlation among the decadal polar motion, NAO index, and sea level changes found in this study may suggest an existence of the decadal hydrological cycle.

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