Recent Abnormal Weather in the Arctic

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1. INTRODUCTION

A detection of an evidence of global warming is an urgent issue in the study of global change. The Arctic is expected as one of the most sensitive regions on the earth against the global warming, according to a series of climate model predictions (IPCC, 1990). Therefore, the climate change, if it happens in the real world, would be detected in the Arctic as a frequent occurrence of abnormal weather. The extreme events may be more detectable in a sequence of the global change than a moderate change in the mean temperature. There is an argument such that the variability of weather may increase when the mean temperature increases by the radiative forcing due to the anthropogenic greenhouse gases. If this is the case, we would observe more abnormal weather, especially in the Arctic. Even if the variability remains constant, the number of days with temperature above a given value at the high end of the distribution would increase substantially by the warming in the mean.

In this study we have carried out a quantitative analysis of recent abnormal weather in the Arctic in order to seek for any evidence of global change. According to a study of short-term climate variability of the Arctic by Walsh and Chapman (1990), an extremely abnormal weather is analyzed in the monthly mean temperature at Barter Island, Alaska for January (very cold) and February (very warm) 1989. The mean temperature in January was about 10°C lower than normal, which corresponds to 2 σ of the monthly mean time series. The cold extreme event in January was followed by even more extreme event of warm weather in the subsequent February. The mean temperature in February was about 20°C higher than normal, which corresponds to 4 σ of the monthly mean time series. Statistically speeking, the probability of an event which exceeds 4 σ is just one in every 17000 events. Hence, the question is "Is this the beginning of increased abnormal weather due to the recent warming?" The analysis of recent abnormal weather in the first 5 years of 1990s in the Arctic attracts increasingly more attention to find the answer to the detection of the evidence of global warming.

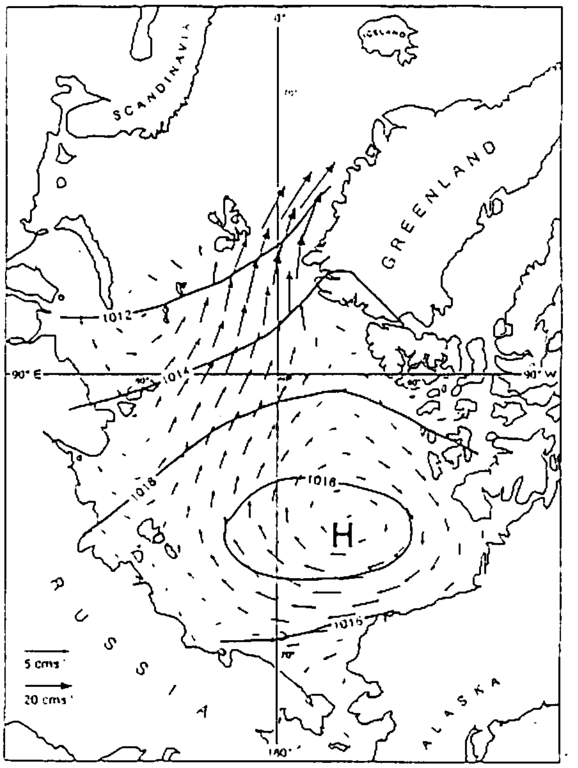

Fig. 1 Mean annual ice drift and mean annual surface pressure (courtesy R. Colony).

Another interesting and important circulation change is documented by Walsh (1994) in association with the intensity of the mean Beaufort High over the Arctic Ocean. The mean annual surface pressure over the Arctic Ocean depicts a characteristic high pressure centered at Beaufort Sea. An anticyclonic gyre is driven by the low level circulation of the Beaufort High. This is referred to as Beaufort gyre. One branch of the clockwise ice drift pushes the sea ice out to the North Atlantic Ocean through Fram Strait (see Fig. 1). Walsh (1994) showed that the vorticity associated with the Beaufort High has changed the sign from negative to positive after the winter 1988/89. Namely, the annual mean Beaufort High has now disappeared and is replaced by "Beaufort Low" (see Fig. 2). If this is the case, the surface Beaufort gyre must change the direction of the circulation to counter clockwise. If this really takes place, the sea ice supply through Fram Strait to the North Atlantic will change completely, probably causing a drastic influence on the maintenance of present climate. Walsh (1994) computed the vorticity over the 80°N polar cap as the numerator of the Laplacian of sea level pressure: i.e., the pressure at 90°N minus the mean pressures at four points along 80°N. Since the computation is based on a rather rough approximation of the vorticity, further analysis with a direct computation of the vorticity is desired.

In this study we have carried out a direct computation of vorticity based on the wind field of the upper air analysis data. The change in the intensity of the vorticity over the polar chap is compared with the simplified results by Walsh (1994). Moreover, the vertical distribution of the change in vorticity is investigated in order to infer the cause of the vorticity change.

2. DATA AND METHODOLOGY

We obtained the grid-point global analysis data from National Meteorological Center (NMC) and edited for monthly mean during January 1981 through December 1994. The dataset contains meteorological variables of horizontal wind $\mathbf{v} = (u, v)$, temperature T, and geopotential height Z on the $2.5° \times 2.5°$ grids at the standard pressure levels from 1000 to 50hPa.

The mean vorticity $\bar{\zeta}$ integrated over a polar cap is computed from the wind vector based on Stokes' theorem.

$$\bar{\zeta} = \frac{C}{A} = \frac{1}{A}\oint \vec{v} \cdot d\vec{l} = \frac{l}{An}\sum_{i=1}^{n} u_i \quad (1)$$

where C is circulation, A is the area of the polar cap, l is the length of the periphery.

3. RESULTS

Figure 3 illustrates time series of the monthly mean vorticity over the polar cap 80°N -90°N during 1981 through 1993 for pressure levels at 1000, 850, 500, and 200hPa. The result for 1000hPa indicates a large variation of vorticity within a range of ± 5 $(10^{-6}s^{-1})$ before the year 1988. Strong anticyclonic circulations occur occasionally in winter, which result in a negative annual mean vorticity. In general, Beaufort High over the Arctic Ocean is intensified in both spring and fall and the high disappears in winter and summer (e.g., Walsh and Chapman, 1990). Present result show, however, that the vorticity indicates large negative values (anticyclonic) in winter. The variability is reduced after 1988 indicating less occur-

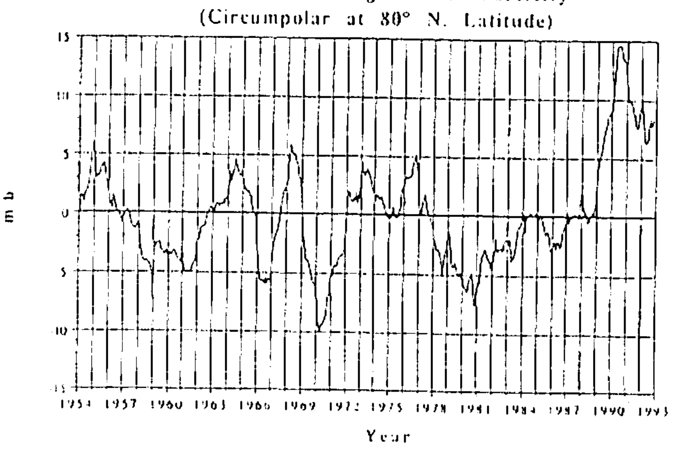

Fig. 2 Time series of 24 month running mean of the surface vorticity averaged over the polar cap, 80°-90°N (after Walsh, 1994).

rence of negative vorticity. Evidently, the average of the vorticity is positive (i.e., cyclonic) after the year 1988. Similar tendency as in 1000hPa level is seen for 850hPa level. The strong anticyclonic circulation is absent after 1988. The upper air vorticity is, in general, positive (cyclonic) due to the effect of the dominant polar vortex. The intensity of the cyclonic circulation tends to increase as the altitude increases.

Figure 4 illustrate the same time series as Fig. 3, but the 24 month running mean is applied for the original time series. The result is interesting in that the mean vorticity has increased discontinuously after the year 1988. At the 1000hPa level, the vorticity is approximately zero before 1988, whereas it is about 2 ($10^{-6}s^{-1}$) after 1988. The result implies that the Beaufort High is disappearing in the annual mean surface pressure, as documented, first, by Walsh (1994). We anticipate that the wind driven sea ice movement of the anticyclonic Beaufort gyre can be distorted by this change in the low-level wind. If this is a real case, annual mean Beaufort High would be replaced by Beaufort Low, and the the amount of sea ice drifting toward North Atlantic would change enormously. The impact upon the climate change would be considerably large. The discontinuous increase in the vorticity is detectable throughout the troposphere. The result of the similar analysis for upper air levels suggests that the intensity of the cyclonic polar vortex has increased throughout the troposphere, thus the anticyclonic Beaufort High near the surface has been destroyed. However, the detail of the circulation change is unclear by present study.

4. CONCLUDING REMARKS

The Arctic is the key region for the recent global change issue in that the evidence of the global warming, if it is real, would appear first in the Arctic. The occurrence of the abnormal weather and extreme events may be regarded as one of the evidences of the global warming. This study is devoted to investigate recent abnormal weather in the Arctic.

As the first example, we noted that the winter of 1988/89 was indeed unusual in Alaska with respect to the drastic variation of temperature. The surface minimum temperature at the interior Alaska was lower than -40°C during two weeks, which was followed by extremely warm weather with 4 times the standard deviation in time variation (see Walsh and Chapman, 1990; Tanaka and Milkovich, 1990).

During the summer of 1993, abnormal weather broke out over the world, including the heavy flood along the Mississippi river, long rainy season and record breaking cool summer in Japan, and the heavy rain and flood in China which killed a number of people. According to the analysis of the abnormal weather, many observational facts suggest that an abnormally developed vortex

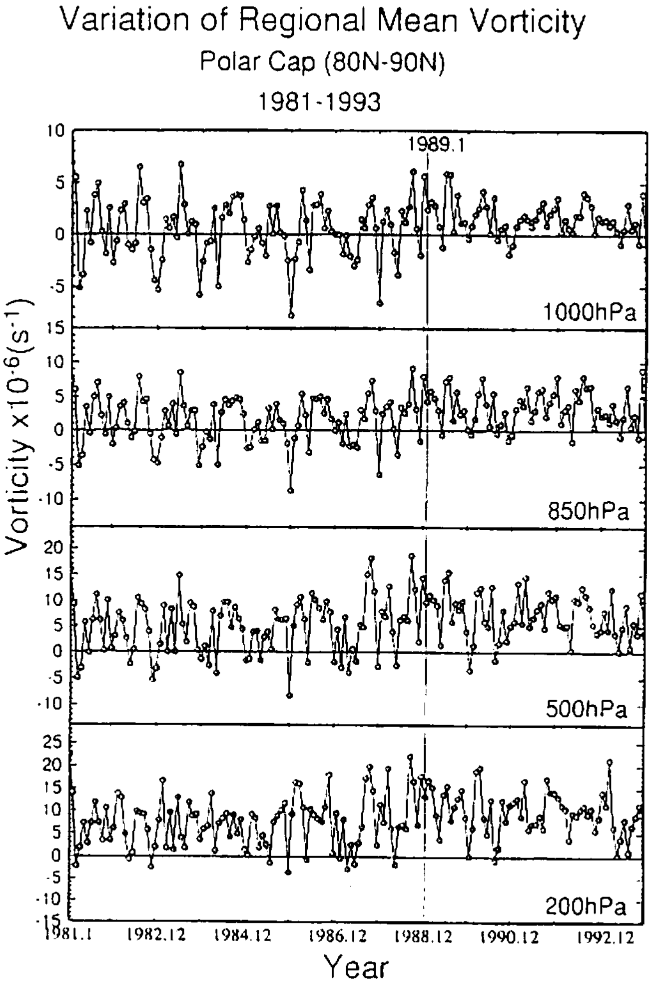

Fig. 3 Time series of the monthly mean vorticity over the polar cap, 80°N -90°N, during 1981 through 1993.

in the Arctic is the key event for the middle latitude abnormal weather. There was a wide open sea abnormally created along the East Siberian coast in response to the upper air vortex. Computation of the meridional Rossby wave dispersion indicates that the highly negative pressure anomaly over the Arctic propagates to the middle latitudes to cause the excursion of the polar frontal jet. The unusual behavior of the jet stream has caused the abnormal weather in many places. Therefore, the investigation of the behavior of the polar vortex attracts attentions as an important research subject to explain the recent extreme events which might be associated with the evidence of the recent global change.

In the present study we have analyzed the time series of the polar vortex which controls the arctic sea ice extent and motions. As is originally documented by Walsh (1994), we have confirmed in this study that the vorticity of the polar cap (80 - 90°N) has increased abruptly after 1988 when abovementioned abnormal weather breaks out in Alaska. The increased vorticity remains positive, suggesting that the anticyclonic Beaufort High is disappearing, and is being replaced by a Beaufort Low for the annual mean. We anticipate that the wind driven sea ice movement of the anticyclonic Beaufort gyre can be distorted by this change in the low-level wind.

In the past study, we experienced similar discontinuous change before and after 1976 in the intensity of the Aleutian low or annual mean temperature at interior Alaska (Bowling, personal communication). It is suggested in this study that a similar discontinuous shift in circulation regime has occurred before and after 1988. Further study is necessary to investigate the regime change in the polar vortex.

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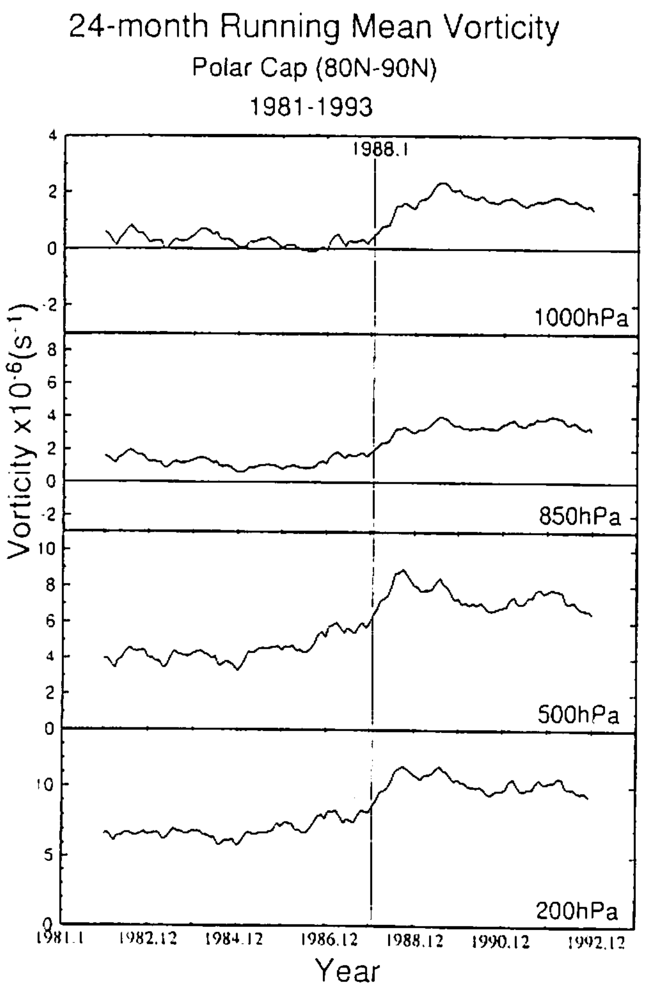

Fig. 4 Time series of 24 month running mean of the vorticity in Fig. 3.