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THE ARCTIC OSCILLATION AS THE DRIVER OF SPRING WARMINGS

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1. INTRODUCTION

Changes are occurring in the Arctic which appear to have begun in the late 1960s and have accelerated in the 1990s. These include tropospheric temperature warming, reductions in sea ice extent, and increased variability in snow cover. Ecological impacts from these changes are already noted. Much scientific interest has focused on the Arctic's leading mode of variability, the Arctic Oscillation (AO). Although mostly annular in character (Monahan *et al.*, 2000), the AO does include regionally enhanced variability in the North Atlantic and East Siberia/Bering Sea (Overland and Adams, 2000).

The AO has received attention because roughly a decade ago it exhibited a rather sudden shift toward a state that includes anomalously low sea level pressure in the Arctic and an increase in zonal winds aloft. It is an interesting contrast that most work on the AO has focused on winter, while many changes in the Arctic, such as those mentioned above, are observed in spring. It is an open question whether the influence of the AO at the end of winter persists through spring and summer, and, in particular, whether these effects are reinforced through feedback processes. In this paper we conduct exploratory data analyses on changes which have occurred in the springtime western Arctic.

2. DECADAL CHANGES AT BARROW, ALASKA

The decadal-scale changes in Arctic climate are illustrated using data from the NCEP reanalysis at gridpoints near Barrow, Alaska (Fig. 1, left) and Eureka, Canada (Fig. 1, right). Our base decade is 1989–1998 because of a prominent shift in the AO in 1989. The top panels of Fig. 1 show the decadal temperature anomalies for the 1950s through the 1990s by month for the 200 hpa level (lower stratosphere). The bottom panels show their counterparts at the 925 hpa levels. Values at 200 hpa are qualitatively similar to other stratospheric levels. Values at 925 mb are similar, but stronger than anomalies at higher tropospheric levels.

Spring temperatures at Barrow in the 1990s at 925 hpa, especially during April, stand out as anomalously warm compared to other months and other decades. Lower tropospheric warming is accompanied by stratospheric cooling, where spring temperatures at 200 hpa are colder than all previous decades, especially in March, at the end of the winter season. The zonal wind

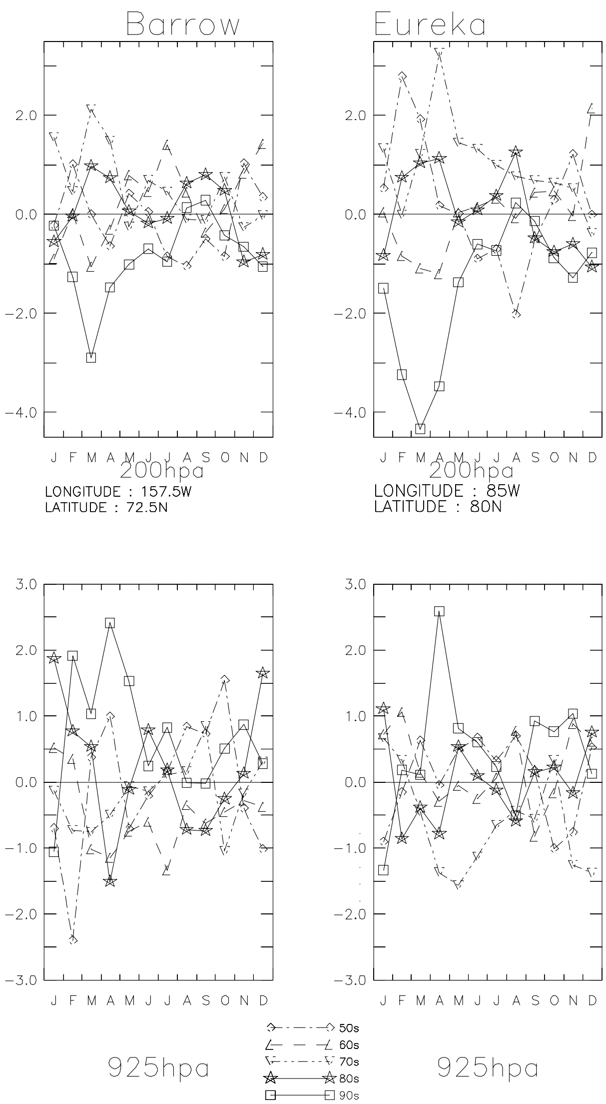

Fig. 1. The decadal mean temperature anomalies at Barrow, Alaska (left panels) and Eureka, Canada (right panels). The top panels are at 200 hpa, and the bottom ones are at 925 hpa based on NCEP/NCAR reanalysis. The five decades are defined as 1949–58,1959–68, 1969–78,1979–88, and 1980–98.

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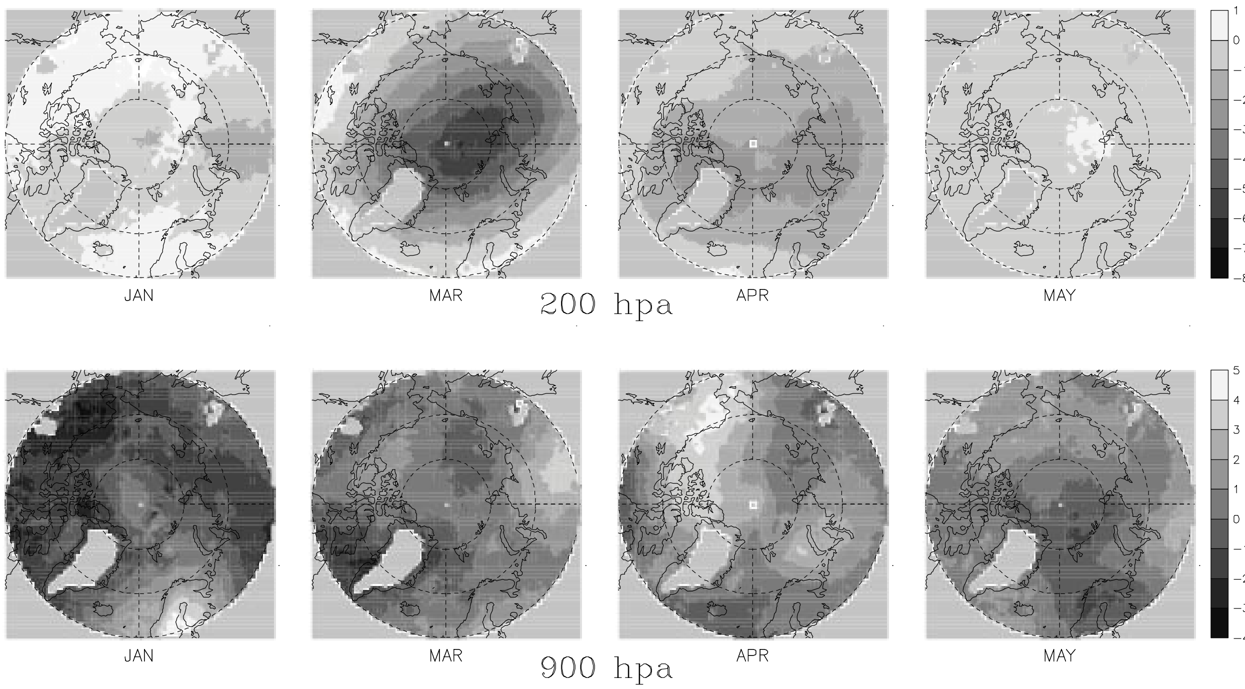

Fig. 2. The decadal monthly mean temperature change over the polar region between 1989–1998 and 1980–1988 based on TOVS Path-P data set. The top panels are interpolated to 200 hpa, while the bottom panels are at 900 hpa. From left to right it corresponds to January, March, April, and May, respectively. The light gray area over Greenland is a data void.

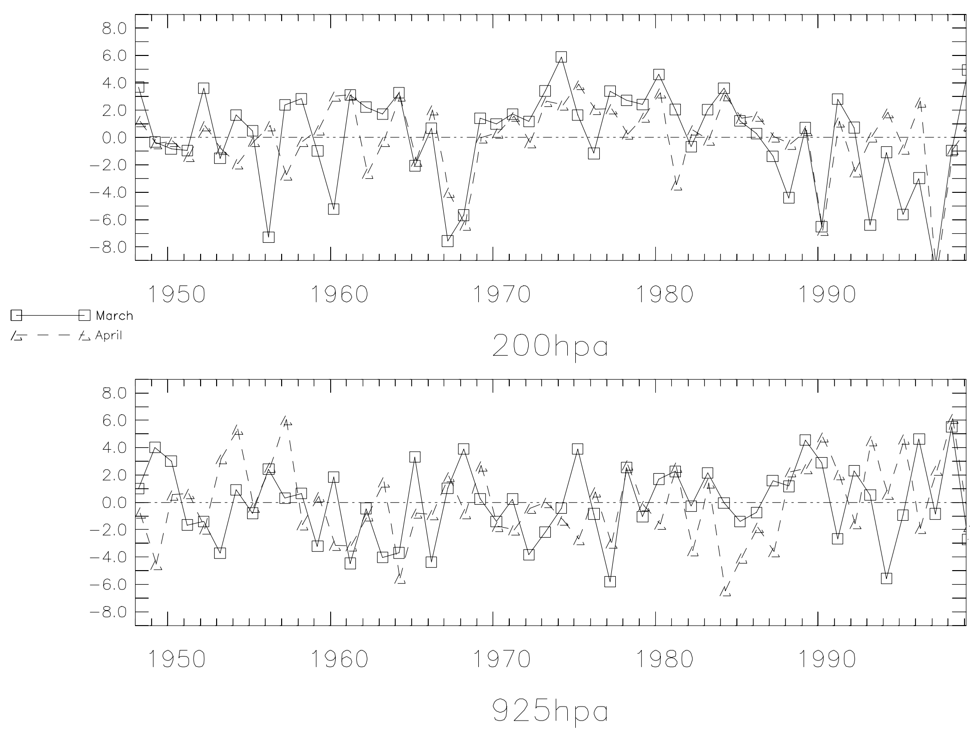

Fig. 3. The monthly temperature anomalies from its 52-year mean (1948–1999) based on NCEP/NCAR reanalysis at Barrow Alaska. The top panel shows 200 hpa, and the bottom panel shows the 925 hpa anomaly. Solid line with square is for March, while the dashed line with triangle is for April.

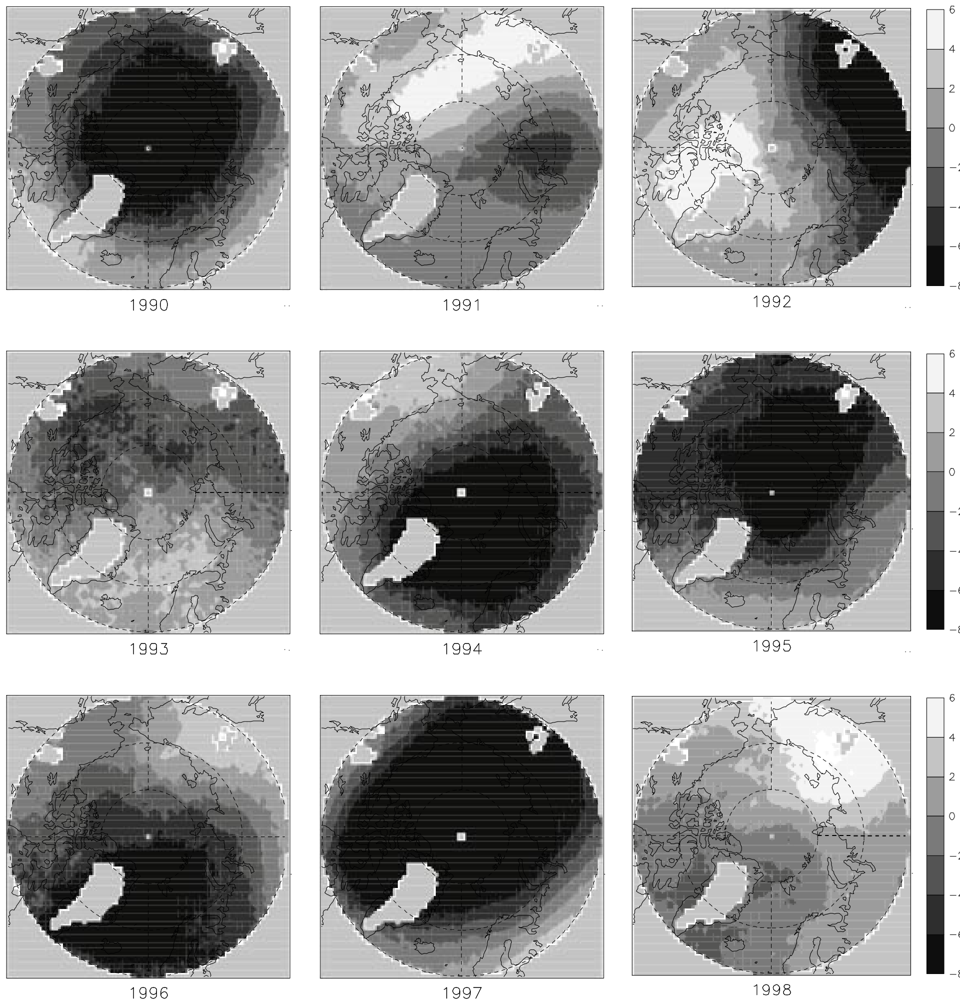

Fig. 4. The satellite-derived 200 hpa temperature anomalies from its 19-year mean in March for the 1990s. There is no data over Greenland.

component at Barrow has a major increase in March at both 200 and 925 hpa compared with other months and other decades (not shown). Eureka (Fig. 1, right) suggests similar behavior. The cold temperature anomaly in March at 200 hpa for the 1990s is –4.0° and almost +3° in April at 925 hpa.

3. RELATION TO HEMISPHERIC PATTERNS

Figure 2 shows the spatial pattern of decadal change for the 1990s (1989–1998) minus the 1980s (1980–1988) at two levels, 200 and 900 hpa. These fields are based on the TOVs gridded temperature fields as discussed by Wang *et al.* (2001, this volume). Four months are shown. Although Alaska in winter has a linear warming trend from the 1970s to the 1990s, there was actually some cooling from the 1980s to the 1990s at low levels (900 hpa). The major winter warming is over Scandinavia and the Barents Sea, related to the North Atlantic Oscillation. On the other hand, the principal warming during April at 900 hpa has been over Alaska, the Beaufort Sea, and Northern Canada. There was also some warming in the Kara Sea, downstream of the Atlantic sector over ice-free waters. At 200 hpa there are no strong anomalies in January, but –6°C anomalies in March. The strength of anomalies weakens in April but is still present. In general the magnitude of warm anomalies decrease with height, and change sign above the 300 hpa level. While there is a warm anomalous near-surface signature (900 hpa) in May across the Beaufort, Chukchi, and East Siberian Sea, this anomaly is not present above 850 hpa.

4. REPRESENTATIVENESS OF DECADAL MEANS

It is clear that the 1990s on the whole were colder aloft, and warmer near the surface, than previous decades. It is instructive to examine how individual years contribute to these composites. Figure 3 shows the March and April monthly temperature anomalies at 200 and 925 hpa for Barrow as a function of year beginning in

1948. Cold temperatures are seen in March of 1990, 1993, 1995, and 1997 at 200 hpa. The magnitudes of the anomalies during these cold years in the 1990s are roughly equivalent to their counterparts during earlier cold years (e.g., 1956, 1960, 1967). The 1990s were cold as a whole because of the increased frequency of cold years. In a similar fashion, the warm period of the 1970s through the mid-1980s appears to be more due to a change in the frequency distribution of warm versus cold years rather than systematic changes in the magnitudes of their anomalies. Similar conclusions are given by Pawson and Naujokat (1999) and Angell (2000).

At lower levels, warm anomalies occurred in April of 1990, 1993, 1995, and 1998. There were corresponding cold anomalies at 200 hpa in March during 1990, 1993, and 1995.

Figure 4, and the color cover of this volume, show the March temperature anomalies for 1990 through 1998 for the northern hemisphere at 200 hpa. The years 1990, 1993, 1995, and 1997 include cold anomalies over much of Northern Alaska and Canada. Cold anomalies were present in two other years, only here they are centered on the Atlantic side of the Arctic (1994, 1996). Two additional years had cold anomalies centered over Siberia (1991, 1992).

5. DISCUSSION

We have used five decades of data from the NCEP reanalysis and the two decades of data from TOVs for exploratory analysis of Western Arctic temperature trends. Large temperature anomalies are seen in spring in the 1990s with cold anomalies in the lower stratosphere peaking in March and warm anomalies in the troposphere peaking in April. Prominent cold anomalies occurred aloft in six of the nine years during the 1990s. Because of interannual variations in the location of the anomalies, only four of the nine years were cold at Barrow.

We interpret the presence of the lower stratospheric cold anomalies in March during the 1990s as a signature of the Arctic Oscillation phenomena. Future work involves understanding the relation of lower stratospheric temperatures in March to lower tropospheric temperatures in April. It is possible that the enhanced polar vortex associated with cold anomalies aloft causes anomalous low-level warm advection into the Arctic when the polar vortex breaks down, which typically occurs near the end of March. A second area of speculation is that the warm temperatures in April, combined with early ice and snow melt, cause continued low level warming and increased moisture into the summer months, contributing to albedo feedback processes.

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