The third Arctic climate pattern: 1930s and early 2000s

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[1] Persistent near-surface warm temperature anomalies have occurred in two localized areas, eastern Siberia/East Siberian Sea and northeastern Canada/Baffin Bay, during winter and spring in recent years (2000–2005) in contrast to previous decades. The proximate cause in winter was a northward displacement and strengthening of the Aleutian Low and a weakening of the Icelandic Low. Spring showed a dipole pattern with higher sea-level pressure (SLP) on the North American side of the Arctic and lower pressures over Eurasia. Phase space trajectories of arctic climate for 1951–2005 based on the first two EOFs of SLP, the Arctic Oscillation and a Pacific North American-like (PNA*) pattern, show multi-annual variability leading to lower SLP and warmer temperatures in the last decades of the 20th century. Recent winters have some projection onto PNA*, but the SLP dipole in recent springs does not strongly project onto either of the two basic climate patterns. The period from 1928–1935 also had a dipole structure in SLP, which contributed to the interdecadal arctic-wide warm temperature anomalies in the first half of the 20th century. Recognition of the recent persistent and somewhat unique Arctic climate pattern is important as it contributes to the ongoing reorganization of arctic ecosystems. **Citation:** Overland, J. E., and M. Wang (2005), The third Arctic climate pattern: 1930s and early 2000s, *Geophys. Res. Lett.*, *32*, L23808, doi:10.1029/2005GL024254.

1. Introduction

[2] There are ongoing physical, ecological, and social changes occurring in the Arctic and sub-Arctic [*Arctic Climate Impact Assessment*, 2004]. Key features over the previous three decades are loss of sea ice and tundra, and reorganizations of ecosystems. Based on arctic-wide averages, there is a multi-decadal trend toward warmer surface temperatures; however, this trend is manifested through substantial regional and temporal variability on a multi-annual basis [*Overland and Wang*, 2005].

[3] Over the previous 6 years (2000–2005), the winter (December–February) and spring (March–May) near-surface (1000 hPa) air temperature anomalies (Figures 1a and 1b) show major warm centers over eastern Siberia/East Siberian Sea and northeastern Canada and Baffin Bay. These anomaly patterns are based on the NCEP reanalysis data using a base period of 1961–1990, but regional/monthly anomalies of 3–4°C are confirmed by local weather station observations. The East Siberian Sea is also the region of recent minimum sea ice extents in the Arctic [*Stroeve et al.*, 2005]. Large temperature anomalies in this region are observed in winter and spring rather than summer, implying that warm temperatures are occurring over regions of thin ice and perhaps different land conditions. The warm northeastern Canadian center is of interest as this area was not a region of warm anomalies in the 1980s and 1990s.

[4] Although the winter and spring temperature anomaly patterns are similar in the early 2000s, the proximate causes for these temperatures are quite different, based on sea level pressure (SLP) fields. In winter (Figure 1c), there was a strong (deep) Aleutian Low which was displaced northward of its typical position, and a weak Icelandic Low with reduced southward advection over northern Baffin Bay. The warm anomaly center over the northeastern Barents Sea relates to the low SLP over northern Europe. In spring (Figure 1d), there was a dipole in the SLP anomaly pattern with higher pressures over the North American side of the Arctic and lower pressures over Eurasia. The temperature and SLP anomaly fields for individual years are roughly similar to the 6-year composites. Fields for 1996 and 1997 were also similar to the 2000–2005 composites.

[5] We address this recent (2000–2005) pattern of arctic temperature anomalies through consideration of large-scale atmospheric circulation patterns over the previous 80 years.

2. Arctic Climate Patterns

[6] Two major patterns of variance for the northern hemisphere near surface atmospheric circulation north of 20°N are the Arctic Oscillation (AO) and a Pacific North American (PNA)-like pattern, based on an EOF analysis of SLP (Figures 2a and 2b) [after *Quadrelli and Wallace*, 2004, hereinafter referred to as QW; *Wu and Strauss*, 2004, hereinafter referred to as WS; also see *Trenberth and Shin*, 1984, Figure 4]. These patterns account for roughly half of the variance of SLP at interannual and longer time scales (QW). The third EOF pattern is also shown (Figure 2c). These EOFs are based on a 3-month winter (DJF) for 1950–1999 in comparison to QW's 4 month winter (DJFM), as we want to separate winter and spring influences; the patterns for EOF1 and EOF2 correlate at 0.99 for these two winter definitions. EOF2 (Figure 2b) has a center over the northern Pacific but also a dipole over the northeastern Atlantic; thus following QW we label this PNA-like pattern as PNA* to distinguish it from the more regional, grid point definition of the PNA [*Wallace and Gutzler*, 1981]. We also follow QW in referring to the fields as "patterns" of variability rather than "modes," which often imply a dynamic structure. Of interest is that an EOF analysis based on spring months (not shown) gives patterns similar to those of winter.

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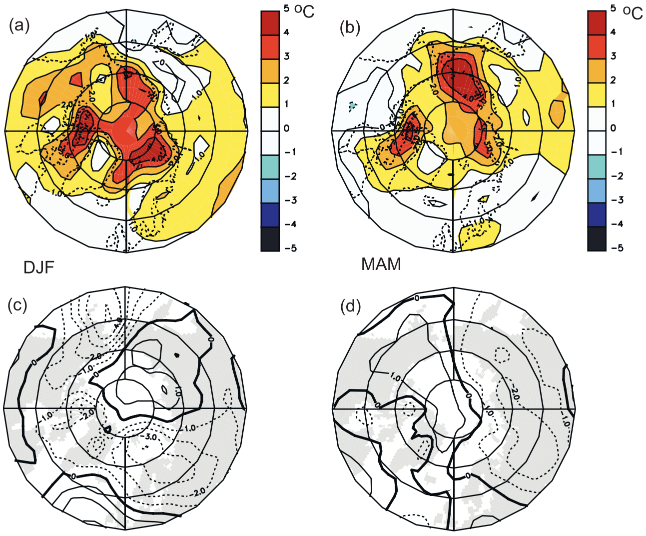

Figure 1. Composite 1000 hPa temperature anomaly fields for 2000–2005 in (a) winter (DJF) and (b) spring (MAM). Corresponding sea-level pressure anomaly fields for (c) winter and (d) spring; negative SLP contours are dashed. All data are from the NCAR/NCEP reanalysis.

[7] Based on 500 hPa geopotential heights, a more classic PNA pattern emerges for EOF2 over North America (Figure 2d), which suggests an upper tropospheric structure for PNA*. Mathematically, a two-dimensional basis function set can be established almost interchangeably using either the 500 hPa height or SLP fields (QW, WS).

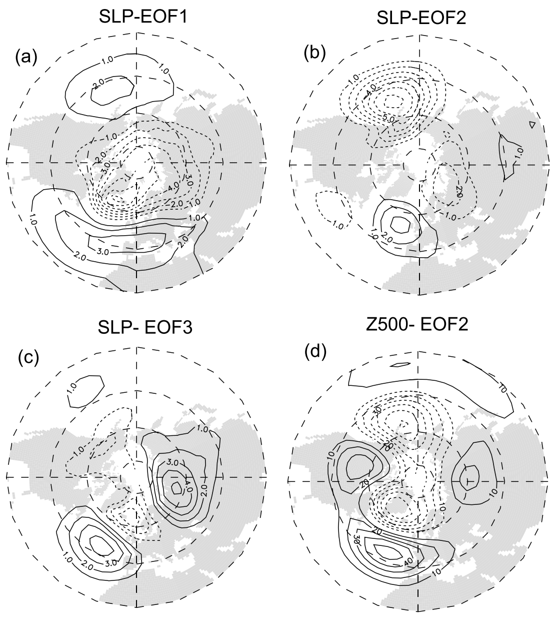

Figure 2. Spatial patterns of winter (DJF) Northern Hemisphere sea-level pressure regressed onto the standardized principal components corresponding to the Empirical Orthogonal Functions (EOF) of SLP north of 20°N for 1950–1999: (a)–(c) the patterns for the AO, PNA*, and EOF3. (d) Winter 500 hPa geopotential height regressed onto the second EOF of the 500 hPa height field. Contour intervals are 1.0 hPa for Figures 2a–2c and 10 m for Figure 2d.

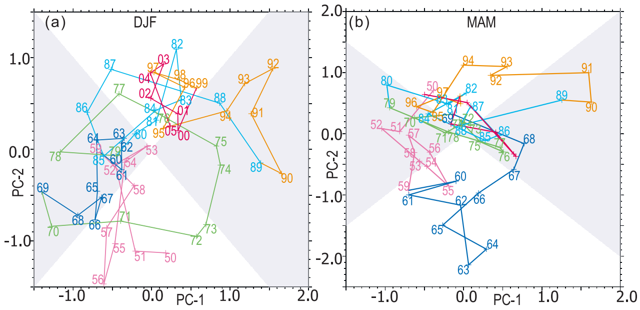

Figure 3. Phase space trajectory of the state of arctic climate for (a) winter and (b) spring. The axes correspond to the values of the AO and PNA* from projections of the SLP fields onto the winter EOF1 and EOF2. Numbers refer to years. A 3-year running mean has been applied to the data.

[8] One can track the state of arctic climate based on the trajectory of the winter and spring values of AO and PNA* plotted in a phase space formed by projections of SLP fields onto the first two winter EOF components. A 3-year running mean has been applied to the data. In winter (Figure 3a) the state lies in the positive AO quadrant in the early 1990s and the negative AO quadrant in the 1960s. The state is in the positive PNA* domain in the early 1980s and in the negative region in the 1950s. In spring (Figure 3b) the state lies near the positive AO axis around 1990 and the negative PNA* quadrant in the 1960s. Because the positive AO and PNA* are both associated with lower SLP in the Arctic and sub-Arctic, most of the northern hemisphere trend in SLP for 1958–1999 is accounted for by these two patterns (QW). Warm air temperature anomalies in Eurasia map onto the positive AO and those of North America onto PNA*; thus about half of the trend in northern hemispheric surface temperature over land for 1948–2002 is accounted for by these two patterns (WS), with PNA* having a larger contribution. The spatial pattern of residual trends after the impact of the AO and PNA* have been removed (QW, WS), shows positive values from eastern Siberia eastward to northeastern Canada.

[9] The title of our paper is not to suggest a new dynamic mode for the Arctic, but simply to show that arctic climate can occupy states other than those determined by the first two EOF patterns. Two examples are the recent period (2000–2005) in spring and the early 1930s in winter. Both periods had major impacts on arctic ecosystems.

3. The Early 2000s

[10] Composite winter air temperature and SLP fields (Figures 1a and 1c) show the impact of a positive PNA* pattern, although the location of the Aleutian Low is shifted further north. The warm anomalies west of Greenland are associated with the positive anomaly of SLP as part of the western Atlantic projection from PNA*, rather than a negative amplitude for the AO. J. M. Wallace (personal communication) notes that the Atlantic projection in EOF2 is a robust feature even under EOF rotation.

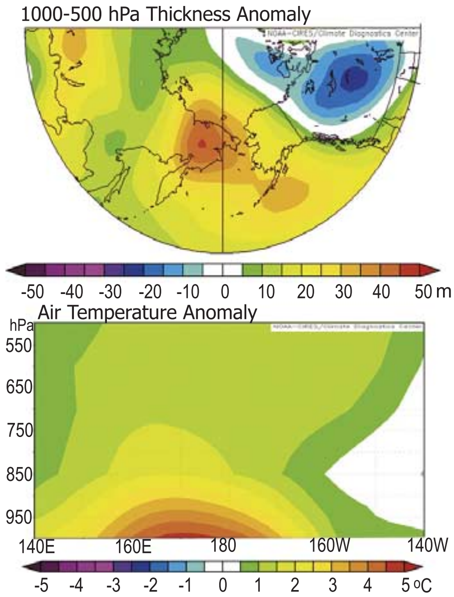

Figure 4. (top) Composite 1000–500 hPa thickness anomaly field for 2000–2005 in spring (MAM). (bottom) Corresponding temperature anomaly cross-section averaged over 65–75°N.

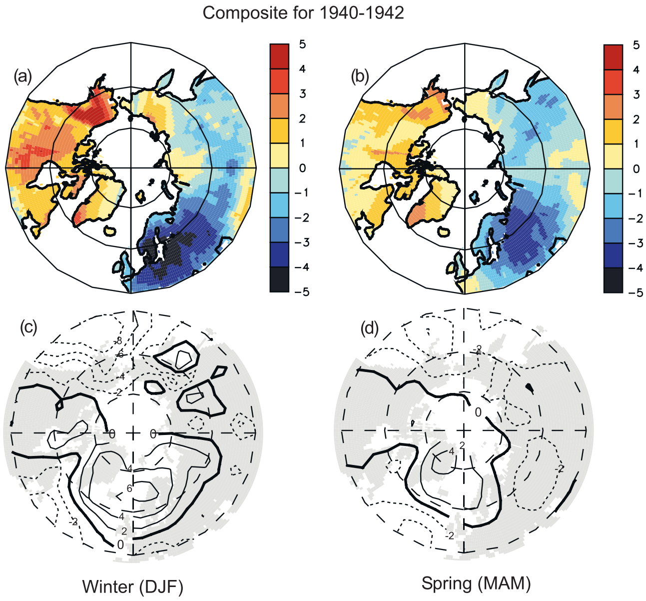

Figure 6. Similar to Figure 5, but for 1940–1942. Surface temperature and SLP anomaly fields are shown for both (a) and (c) winter and (b) and (d) spring (MAM). Note the similarity of the spatial variation in the temperature fields to the recent (2000–2005) period.

[11] As stated in the introduction, spring has a similar pattern of temperature anomalies as winter, but a different pattern of SLP. In the Pacific sector there is a persistent dipole of low SLP over Siberia and higher pressures over Alaska (Figure 1d), giving an anomalous southerly wind over the Bering Sea and extending into the central Arctic. The temperature anomalies seen at the surface are manifest as high as 500 hPa (Figure 4). This dome of warm air is reflected in the 1000–500 hPa thickness anomaly field. The warm anomalies near the surface suggest boundary forcing, while the weaker warm anomalies in the lower to mid-troposphere suggest horizontal advection associated with the general circulation.

[12] The hemispheric dipole of pressure difference between the North American and Eurasian sides of the Arctic in spring (Figure 1d) is similar to the third EOF of SLP (Figure 2c); for 2000–2005 the influence of EOF3 is greater than the combined influence of EOF1 and 2. *Skeie* [2000] and *Wu et al.* [2005] note that a SLP dipole structure is important in the Atlantic sector of the Arctic, influencing ocean-air heat flux and the exit of ice through Fram Strait. Even though the third hemispheric EOF is not necessarily a unique and separate mode (QW), it carries much of the SLP pattern in spring for 2000–2005.

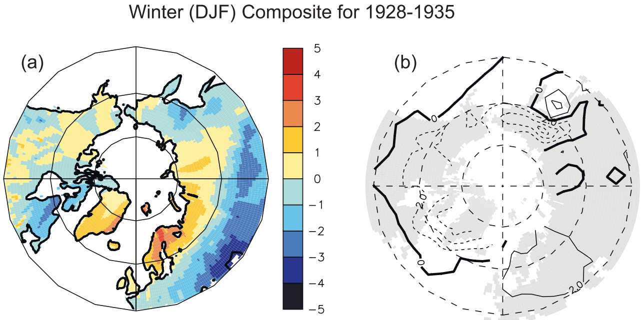

Figure 5. Composite of winter (DJF) (a) surface air temperature and (b) sea-level pressure anomaly fields for 1928–1935. Temperature data are from CRU TS2.0 [*New et al.*, 2000] and SLP are from *Trenberth and Paolino* [1980], updated. Note the large trough of low pressure beginning near Iceland and extending westward across North America.

4. The Decades of the 1920s, 1930s, and 1940s

[13] It is well known that arctic-wide average temperature anomalies were positive for most of the 1930s and extending into adjacent decades [*Polyakov et al.*, 2003; *Johannessen et al.*, 2004]. However, these average anomalies are composed of considerable regional and interannual variability [*Bengtsson et al.*, 2004; *Overland et al.*, 2004].

[14] In the early period, roughly 1920–1927, the positive phase of the AO, or more locally the North Atlantic Oscillation (NAO), had a contribution to the North Atlantic seesaw with warm temperature anomalies in Europe and cold anomalies in west Greenland [*van Loon and Rogers*, 1978]. This pattern was not particularly unusual as the AO/NAO has a strong decadal signal throughout the 20th century. What contributes to the interdecadal nature of the 1930s is a particular pattern of SLP and temperature anomalies in winter for 1928–1935 (Figure 5), with warm temperatures in both Europe and west Greenland [*Rogers*, 1985]. These temperatures are in response to a trough of low pressure which extends from Iceland westward over Canada (Figure 5b). This SLP pattern has elements of the negative phase of EOF3 (Figure 2c) with a dipole anomaly pattern across the Arctic. The final period of 1940–1942 had warm surface temperatures in eastern Siberia, Alaska, and northeastern Canada for winter and spring (Figures 6a and 6b) not unlike recent winters, but

western Eurasia was quite different. The associated SLP patterns (Figures 6c and 6d) had high pressures east of Greenland, which promotes warm west Greenland temperature anomalies. These SLP patterns have some resemblance to the positive PNA* pattern. The strong Aleutian Low SLP anomalies were centered over the Gulf of Alaska giving the strong warm air advection anomalies over central Alaska (Figure 6a). Eurasian anomalies were not as pronounced as in PNA*.

5. Discussion and Conclusions

[15] The atmospheric circulation over the Arctic/subarctic has multi-annual periods which are associated with certain principal components of SLP. The positive phase of the AO in winter for 1989–1995 is an example, but other examples exist such as the negative PNA* in the 1950s.

[16] Much of the variability of SLP and associated temperature patterns from the 1950s through the 1990s are characterized by the first two climate patterns, the AO and PNA*. The recent period (2000–2005) is somewhat different with persistent warm anomalies in eastern Siberia/Eastern Siberian Sea and northeast Canada/Baffin Bay. These are related to a weak positive PNA* pattern in winter with the Aleutian Low shifted northward, and a contribution from a SLP dipole over the pole in spring, similar to the third EOF pattern of northern hemisphere SLP. The amplitude of the spring trajectory of arctic climate based on (AO, PNA*) is near the origin in recent years. The early 1930s were somewhat similar to an EOF3 pattern and contributed to the interdecadal nature of arctic-wide warm temperature anomalies. The early 1940s had a temperature pattern similar to recent winters for eastern Siberia and North America. Both periods had elements of a positive PNA*.

[17] The multi-annual persistence of atmospheric arctic climate patterns has impacts on regional physical systems and ecosystems. The persistence of anomalous atmospheric circulation patterns in the Pacific sector over the last 6 years has led to loss of sea ice, warmer ocean temperatures, and major ecosystem changes, such as a shift from arctic benthic ecosystems toward subarctic pelagic ecosystems [*Overland and Stabeno*, 2004]. The warm temperatures off west Greenland in the 1930s–early 1940s were associated with the establishment of cod stocks, which lasted into the 1960s [*Hovgaard*, 1993]. West Greenland is now dominated by a shrimp fishery, but with recent warm temperatures future climate/ecosystem developments should be watched closely.

[18] Arctic circulation does not necessarily always project strongly on the two leading patterns of variability, the AO and PNA*. That the recent warming is not strongly associated with the two main arctic climate patterns may be a feature of the current climate system through recent feedbacks within the Arctic such as albedo shifts, i.e., changes in surface fluxes and clouds, and influences from lower latitudes. The absorption of additional solar energy in regions of reduced sea ice may already be providing persistence to a new regime of reduced sea ice [*Lindsay and Zhang*, 2005]. Loss of tundra and permafrost is underway [*Sturm et al.*, 2005]. However, although atmospheric climate patterns in the Arctic show multi-annual persistence, their temporal structure in this and the previous century suggests that the atmospheric general circulation can still be expected to switch between multiple patterns in the future. The existence of a new climate state for the Arctic makes its future trajectory more uncertain.

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