2.10 SPATIAL AND TEMPORAL VARIABILITY OF ARCTIC BASIN PRECIPITATION

David H. Bromwich[1,2*], Sheng-Hung Wang[1,2], and Elizabeth N. Cassano[1]
[1] Polar Meteorology Group, Byrd Polar Research Center, The Ohio State University, Columbus, Ohio
[2] Atmospheric Sciences Program, Department of Geography, The Ohio State University, Columbus, Ohio

1. Introduction

Precipitation plays a primary role in the hydrologic budget of the Arctic basin. Variations in Arctic precipitation directly and indirectly affect ocean salinity and ice conditions, which potentially have a significant impact on the climate system (Broecker 1997). The dominant atmospheric variability pattern in the North Atlantic region is the North Atlantic Oscillation (NAO) (van Loon and Rogers 1978), which is very similar to but less comprehensive than the Arctic Oscillation (AO) (Thompson and Wallace 1998). This mass oscillation between the subpolar low near Iceland and the subtropical high near the Azores enhances the westerlies during a positive NAO phase. Serreze et al. (1997) found that a more positive NAO index in recent years has been associated with a significant increase in cyclones north of 60° N. This trend was very noticeable over the central Arctic Ocean, where it was associated with a decrease in high latitude sea level pressure and also with changes in sea ice conditions and surface temperatures. Overpeck et al. (1997) showed that the variability seen in a 400-year compilation of Arctic surface temperature proxies may be connected to decadal-scale variability in phenomena such as the NAO and the themohaline circulation. This arises because atmospheric temperature is closely related to moisture transport via cyclonic activity (Maslanik et al. 1996) and regional sea ice variations (Chapman and Walsh 1993).

In Cullather et al. (2000), computed and forecast precipitation from atmospheric reanalyses were compared with available observations and previous studies to assess the potential for using moisture budget equation in high northern latitude precipitation studies. It was found that the result from the moisture budget equation (P-E) is more representative of the observations than are the forecast precipitation and evaporation variables available from the Reanalysis data set, which result from a short-term model forecast. In this study, the relationship between large-scale atmospheric patterns and Arctic Basin moisture budget (P-E) will be examined. The spatial and temporal variability of Arctic Basin moisture flux will also be discussed.

[*]Corresponding author address: David H. Bromwich, Polar Meteorology Group, Byrd Polar Research Center, The Ohio State University, 1090 Carmack Road, Columbus, OH 43210.
Email: bromwich@polarmet1.mps.ohio-state.edu

2. Data and Methods

Reanalysis products have great potential for climate studies due to the consistent assimilation procedures and maximum observation usage employed during their creation. The NCEP/NCAR Reanalysis data set consists of analyses that are available four times daily, with T62 horizontal resolution (approximate horizontal resolution of 210 km) and 28 sigma-levels in the vertical. The data used in this study were obtained from NCAR at 2.5° x 2.5° horizontal resolution. The time period covers 1949 through 1999.

The moisture budget (P-E) of the Arctic Basin can be calculated for each month from advection of water vapor and local storage changes. Monthly mean vertically integrated moisture fluxes are obtained directly from the archived NCEP/NCAR Reanalysis data set. The vertically integrated moisture fluxes are calculated directly from sigma coordinates and so do not suffer from mass balance errors that can arise during the conversion to archived pressure level data.

From the equation of state, the hydrostatic equation, and the continuity equation (Trenberth and Guillemot 1995), the moisture budget equation can be written in pressure coordinates as

$$P - E = -\frac{\partial W}{\partial t} - \nabla \cdot Q,$$

where W is precipitable water and Q is the atmospheric moisture transport, defined as

$$Q = \frac{1}{g}\int_{P_{top}}^{P_{sfc}} qV dp,$$

where g is the gravity constant, P_{sfc} is surface pressure, q is specific humidity, and V is the horizontal wind vector. The variable P_{top} is the highest level of the atmosphere considered, which is 300 hPa.

More extensive discussions of moisture budget calculations can be found in earlier studies (Cullather et al. 1998, 2000; Bromwich et al. 2000).

3. NAO/AO and NPO Modulations of Arctic Basin Moisture Budget (P-E)

Precipitation minus evaporation (P-E) calculated from moisture flux convergence is compared with three large scale circulation patterns that strongly impact the interannual variability of P-E over the Arctic and its environs: the North Atlantic Oscillation (NAO), the Arctic Oscillation (AO), and the North Pacific Oscillation (NPO). Figure 1 shows an average annual spatial depiction of NCEP/NCAR Reanalysis P-E truncated to T21 resolution from 1949 to 1998.

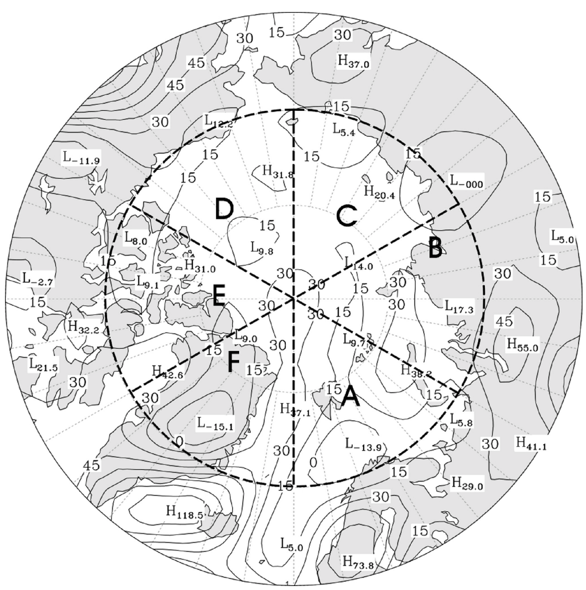


Fig. 1. Average annual spatial depiction of P-E at T21 resolution using the NCEP/NCAR Reanalysis data spanning 1949 to 1998. The contour interval is 15 cm / yr. The dashed lines enclose sectors used to evaluate the regional variability of P-E. Sectors are bounded on the south by the 70° N parallel and span 60° longitude starting eastward from the Greenwich meridian.

Table 1 shows the correlation analysis between annual and seasonal P-E and three large-scale atmospheric circulation modes for entire Arctic Basin and each sector. On an annual basis, Arctic Basin P-E is much more closely correlated with the NAO (0.69) than with the AO (0.49), consistent with the Atlantic Ocean domination of the northward poleward moisture flux across 70° N. The impact of these large scale oscillations is found to be more significant during the winter, with a correlation of 0.49 for NAO and 0.56 for the AO. Regional analysis confirms that the NAO impact on P-E is concentrated around the periphery of the North Atlantic Ocean and extends north into the Arctic Ocean during winter. The NAO and AO differ in their P-E modulation over the northern Eurasia sector (sector C) with the AO being much more important for all seasons except summer (winter AO/P-E correlation is 0.53, NAO/P-E correlation is 0.16), consistent with its much stronger impact on the atmospheric circulation in that area. In contrast, the NPO was associated with a much more modest modulation of Arctic Basin P-E (winter correlation of 0.33 and annual value of 0.10), with its regional signal being strongest over Alaska, northwestern Canada, and areas to the north (sector D). About 40% of the inter-winter variance of P-E over the sector that includes northeastern Canada (sector E) is linked with the combined influence of the NAO/AO and NPO.

Table 1. Correlation analysis between annual and seasonal P-E vs. the NAO, AO, and NPO indices. Correlations greater than 0.40 are statistically significant at greater than 99% confidence level, and are bolded.

NAO	ALL	A	B	C	D	E	F
Annual	**.69**	**.40**	-.04	.19	.38	.13	**.59**
Fall	**.49**	.34	.20	.10	-.11	-.21	**.59**
Winter	**.49**	**.46**	**.40**	.16	.16	**-.53**	.31
Spring	**.42**	.39	-.03	.12	.21	-.05	.35
Summer	.29	.02	-.20	-.22	.31	.36	**.54**

AO	ALL	A	B	C	D	E	F
Annual	**.49**	.37	.16	**.42**	.28	.08	.11
Fall	.36	.31	.29	**.41**	.16	-.09	-.04
Winter	**.56**	**.63**	.30	**.53**	.28	-.31	.04
Spring	**.57**	.34	.33	**.47**	.35	.10	-.08
Summer	**.56**	.36	.08	-.17	.29	**.57**	.06

NPO	ALL	A	B	C	D	E	F
Annual	.10	.16	-.18	-.11	**.44**	.30	-.19
Fall	-.11	.02	-.09	-.03	.30	.14	-.31
Winter	.33	.14	.12	.16	**.59**	-.30	.15
Spring	.15	-.10	.14	-.02	.39	.22	-.19
Summer	-.13	-.14	-.08	.23	-.34	.12	.22

A region of large poleward moisture transport variability during summer was identified over western Siberia, east of the Urals, associated with the development of the Urals trough. This is due to an opposing circulation pattern, with high (low) poleward moisture transport over the west Siberian plain during low (high) poleward moisture transport over Scandinavia. A pronounced trough/ridge pattern accompanies this circulation regime which is primarily confined to July. Because the summer moisture transport dominates the annual total for this region, this variability determines this area's large interannual poleward moisture transport variability.

4. Spatial and Temporal Analysis

Rotated principal component analysis (PCA) has been applied to the annual P-E data from 50° N to 90° N. The result shows that there is a large variability over the Arctic Basin. On the PCA1 figure (not shown), high variability can be observed over central Siberia, the North Atlantic, the North Pacific, central Canada, southwest of Greenland, and around Alaska. A spectral analysis performed on the score of the first PCA shows a periodicity of 6.7 years, significant at greater than the 95 % confidence level (Fig.2).

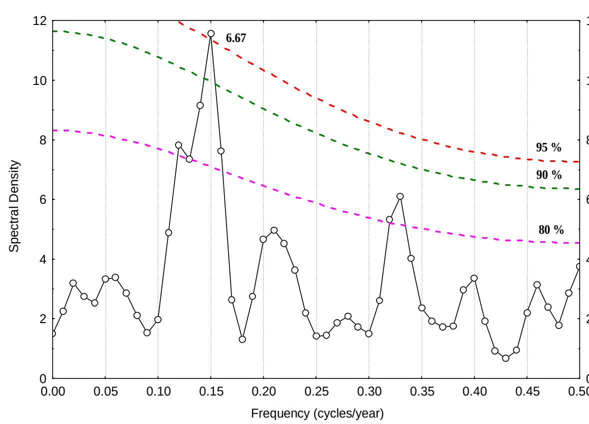
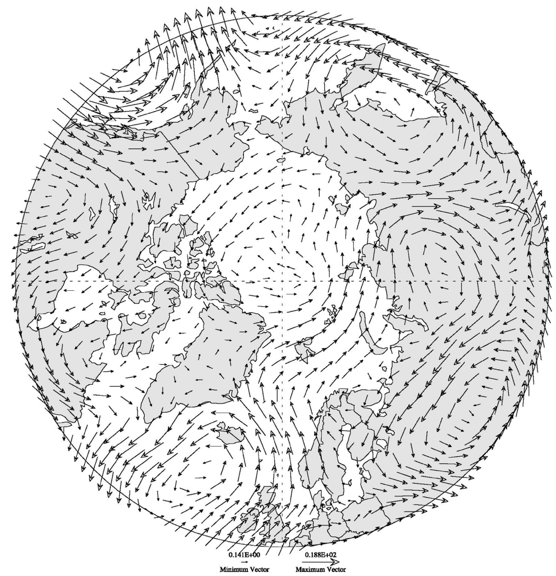


Fig. 2. Spectral analysis of PCA1 score of annual P-E data. The highest peak is 6.67 year at 95% confidence level.

The moisture flux transport patterns (Figs. 3a and 3b) based on the scores of the largest five positive years and the largest five negative years are compared to show the difference between the opposite phases of the first PCA pattern. Anticyclonic moisture circulation is much more prominent over the Beaufort Sea for the negative phases than the positive phases. During positive phase years, zonal winds from the northeast coast of Canada stretch to Great Britain, and meridional winds are much stronger through the North Atlantic region. There is much more poleward moisture transport through the northern North Atlantic Ocean into the Arctic Basin. In contrast, westerlies are weak over North Atlantic and stronger over North Pacific during negative phase year. There is less moisture transport into the Arctic Basin.

(a)



(b)

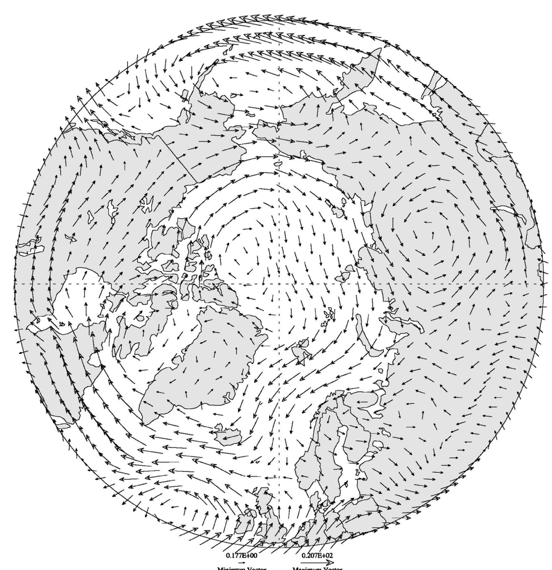


Fig. 3. Moisture flux transport anomaly for 5 largest positive phase years (3a) and negative phase years (3b).

5. Discussions and Conclusions

Results of this study using the 50-year NCEP/NCAR Reanalysis to gauge atmospheric variability associated with the AO, NAO, and NPO are consistent with those found in previous studies. Further, it is found that these oscillations do significantly impact Arctic Basin P-E.

The findings presented in this study also demonstrate that large-scale modes of atmospheric variability have varying regional impacts on Arctic Basin P-E. In general, the Atlantic sector (sector A) dominates the variability, especially during winter. Other sectors usually show much weaker signals.

From the spatial and temporal analysis of Arctic Basin P-E, it shows cyclonic and anticyclonic rotation occur during positive and negative phases. Detailed P-E variability could be caused by the combination of NAO, AO and NPO. This is being investigated at the moment.

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