CLASSIFICATION OF UPPER LEVEL CIRCULATION PATTERNS IN THE POLAR REGION AND THEIR RELATIONSHIP TO SURFACE AIR TEMPERATURE

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ABSTRACT: It has been recognized that variations in surface air temperature are closely related to upper level circulation patterns. In order to achieve a better understanding of circulation diversity in the circumpolar region, both principal component analysis (PCA) and clustering analysis are employed to study the major modes of variation at the 500 mb level. An analysis of the yearly variations of mean January daily surface temperatures, obtained from seven Russian meteorological stations, indicates that polar modes of mid-tropospheric variation are important to surface temperature in that region.

INTRODUCTION

Many studies have documented the interannual and intraannual variations of upper level circulation. Of these studies, some have used the 700 mb level (Barnston and Livezey 1987; Esbensen 1984; Klein and Walsh 1983; Walsh 1979) while others have focused on 500 mb level data (Wallace et al, 1981; Shabbar et al. 1990). These studies were conducted in diverse regions across the Northern Hemisphere (Shabbar et al. 1990; Wallace et al. 1981; Barnston and Livezey 1987; Esbensen 1984) and investigated teleconnections in geopotential height fields which might be indicative of standing oscillations in the planetary waves. One of the following three methodologies were employed in the studies cited above. These methods include contemporaneous correlations between geopotential heights on a given pressure surface, principal component analysis (PCA), and orthogonally rotated PCA (RPCA). Teleconnections derived using RPCA have been verified as being physically meaningful and statistically stable (Barnston and Livezey 1987).

Many studies have shown that surface temperature and precipitation variations can be explained by upper level circulation changes (Kunkel et al. 1993; Palecki and Leathers 1993; Klein and Walsh 1983; and Leathers et al. 1991). In a previous study, Paul (1990) showed that in high latitude areas, surface air mass frequency and character changes cannot be explained by the patterns that normally characterize the entire Northern Hemisphere.

In this paper, the authors will to focus on areas from 60°N to 90°N, in order to classify January circulation patterns at 500 mb. The modes of atmospheric variation that are identified will be used to investigate the relationships between Russian surface air temperature and the circumpolar circulation.

DATA AND PROCEDURE

January is chosen as representative of typical winter conditions for each year. Mean January height data from 1946 through 1989 from the National Meteorology Center (NMC) octagonal grids is utilized (Jenne 1975). The subset selected is comprised of 221 grid points that cover the polar region north of 60°N latitude. January height departures from the 44-year mean are calculated for each year during the period by subtracting the 44-year mean value from the corresponding grid point value.

Principal component analysis is applied to the data to reduce the interrelated 221 grid point values to 6 orthogonal components. The resulting temporal indices explain 85.3% of the variance of the original data set. Correlation analysis and stepwise regression are subsequently employed to investigate a possible relationship between the polar indices and commonly recognized teleconnection patterns of the Northern Hemisphere. An average linkage clustering procedure is applied to the component scores to group the years with similar component scores into separate categories. This clustering procedure uses hierarchical and agglomerative techniques. The technique starts with each individual object as a one-member cluster. Close objects are then merged on a step by step basis until all are united into one cluster containing all of the objects. The distances are determined based upon the mean of all distances between the objects in two clusters, weighted by the number of members (Sokal and Michener 1958; Hawkins et al. 1982). This clustering technique tends to produce groups with small within-cluster variance and large between-cluster separation. Therefore, average linkage has been successfully used in various studies (Davis and Kalkstein 1990).

The January mean daily surface temperature is determined by averaging the daily mean temperatures for each of the seven Russian meteorological stations that are located north of 60°N. The location of these Russian stations are mapped in fig 1. The temperature departure for each category is obtained by subtracting the January mean daily temperature averaged for the whole 44-year period from that averaged for the years within that category. To verify the statistical significance of these temperature departures, the students t-test is applied.

Results

Fig 2 shows the six 500 mb configurations identified by the PCA. Component one, which explains 30.17% of total variance, describes circumpolar vortex activity. It is found that the larger the component one value is for a particular year, the weaker the circumpolar vortex is for that year. Component 2, which explains 17.67% of the total variance, shows two strong centers with opposite signs. A large component 2 value indicates a deeper trough in Canada and a weaker trough in the Scandinavian region compared to normal conditions. Component 3, which explains 11.57% of the total variance, shows two discernible centers with a positive center over the north Atlantic and a negative center over Russia. Component 4, which explains 9.14% of the total original variance, describes a strong Aleutian low feature, a large negative center that is located over the Aleutian islands. Component 5, which explains 7.2% of the original total variance, evidences three uniform but weak positive and negative centers. The three centers are: positive in the north Atlantic; negative on the European continent; and positive in eastern Russia. Component 6, which explains only 4.6% of the total variance, is characterized by a positive center in the north American continent.

The results of a correlation analysis between these six polar indices and eight well known modes of variation for the Northern Hemisphere (Barnston and Livizy 1987; Palecki and Leathers 1993) indicate that component one is highly correlated with the North Asian pattern (the correlation coefficient is -0.78) while component three is highly correlated with the north Atlantic Oscillation (the correlation coefficient was -0.86). By applying stepwise regression, more than 77% of the variance of the first three polar indices can be explained by a combination of these eight patterns (see table 1).

As a result of cluster analysis, eleven January circulation categories are defined for the 500 mb level during the 44-year period. Of the eleven, eight categories are considered as robust patterns which occurred more than once during the period. In January, the mean 500 mb circulation is a three wave pattern, which consists of three troughs around the circumpolar regions. These include a deep trough in eastern Northern America, a large trough which extends from eastern Russia to Japan, and a weak trough in Eurasia.

Cluster one is very close to the mean pattern: the locations of the troughs and ridge

TABLE 1.

N.H. Circulation Indices Entering the Multiple Regression Equation
With Polar Indices at $P<0.05$

Polar Indices	Teleconnetion Patterns Entered	R^2
INDEX 1	North Asian	0.6123
	Western Pacific	0.0864
	North Atlantic	0.0370
	Tropical/Northern Hemisphere	0.0342
INDEX 2	Tropical Northern Hemisphere	0.3165
	Western Eurasia	0.3025
	North Asian	0.0955
	Pacific/North America	0.0563
INDEX 3	North Atlantic	0.7354
	Western Pacific	0.0475
INDEX 4	Western Pacific	0.2402
	Tropical Northern Hemisphere	0.1808
INDEX 5	Western Pacific	0.1749
	East Atlantic	0.3446
	North Asian	0.4986
INDEX 6	Pacific/North American	0.1027
	Eastern Pacific	0.0922

are in the normal positions. With this pattern, the temperature departures are close to zero in most of the stations except in Nar'jar-mar, which was 3.19°C higher than normal (Table 2).

Cluster two is characterized by an expansion of the polar vortex far to the south. Most of the stations in Russia evidence lower than normal temperatures, except for two stations that are located in northeastern Russia, at Coku and at Korf (Table 2). These two stations have higher than normal temperature because of the return flow from the east, which brings in warmer Pacific air.

The center of the polar vortex shifts towards the North Atlantic in Cluster three. The troughs in the eastern part of North America and in Eurasia are stronger than normal, and a very strong pressure gradient is found in the North Atlantic region. No statistically significant temperature departures occur at the Russia stations in this category (Table 2).

The center of the polar vortex shifts towards western Russia in Cluster four. The troughs in the eastern part of Northern America and in Japan are stronger than normal and moved to the lower latitude. The weak trough in Eurasia is moved more toward Europe and is stronger than normal. In this cluster, the western hemisphere is characterized by higher than normal heights, while the eastern hemisphere has lower than normal heights. The temperature departures at the Russian stations are all negative except for Kem'port where the departure is positive but not statistically significant (Table 2).

In Cluster five, the eastern Northern American trough is located even farther southward. The Japan trough is deeper than normal, and the Alaskan ridge is more evident. The circulation in the western hemisphere is generally more meridional. Only Coku has a statistically significant negative temperature departure which corresponds to the deeper trough in this region (Table 2).

Cluster six is the most influential cluster, and it is closely related to temperature departures in Russia. The Eurasia trough is much deeper than normal, and a strong ridge appears along the western coast of Europe. The circulation is very meridional in the eastern hemisphere. Tura and Viljujsk have statistically significant positive temperature departures. Other stations, except at Kem'port, have statistically significant negative temperature departures (Table 2).

Category seven is characterized by a very strong ridge along the west coast of North America, and a strong trough in the eastern portion of this continent. The circulation is very meridional in the Western Hemisphere. The Eurasian trough is shifted slightly eastward. For this cluster, only Tura evidences a statistically significant positive temperature departure (Table 2).

Category eight occurs only twice. The pressure gradient in the eastern part of Northern America is very strong. A strong ridge is present in eastern Europe, but the Alaska ridge is barely discernible. The Eurasian trough is more evident and extended to a lower latitude. Most stations have negative temperature departure, but none are statistically significant.

Stepwise regression is applied for each Russia station. The mean January temperature is used as the dependent variable, and six polar indices are used as independent variables. The results are listed in table 3. The variances determined by these indices increased greatly from northwestern Russia to northeastern Russia, increasing from 14.56% to 66.21%.

CONCLUSIONS

PCA and cluster analysis are used to identify eight major circulation categories at the 500 mb level in January during last 44-year period. The circulation pattern of category six, which is characterized by a much stronger than normal meridional circulation over the eastern hemisphere, is closely related to surface temperature anomalies in Russia. The stepwise regression results show that the temperature variation in the western part of north Russia is not as sensitive to upper level circulation changes as in central and eastern regions of north Russia. Finally, in the eastern part of north Russia, over 50% of surface temperature variation can be explained by the upper level circulation variations.

TABLE 2. The Temperature Departures From the Means(°C) for Eight Categories

Station	Clus1	Clus2	Clus3	Clus4	Clus5	Clus6	Clus7	Clus8
KEMP	0.93	-1.31	-0.47	-3.16[c]	0.72	1.16	2.23	-0.09
NARJ	3.19[a]	-3.00[c]	-0.77	-0.75	0.10	-3.52[c]	2.77	-0.95
OSTR	1.58	-1.25	2.16	-2.89	-1.81	-4.04[c]	-1.35	0.73
TURA	-0.57	-3.93[c]	1.06	-5.43[b]	-1.05	4.34[c]	4.91[c]	-3.67
VILJ	-1.57	-0.77	0.23	-4.20	-2.65	4.70[b]	1.77	-6.17
COKU	-0.20	4.34[a]	1.59	-1.81	-3.46[c]	-6.19[a]	0.43	-4.46
KORF	-0.60	1.42	0.24	1.36	-0.68	-7.50[a]	2.10	0.84

a: The difference is statistically significant at 0.05 level
b: The difference is statistically significant at 0.10 level
c: The difference is statistically significant at 0.15 level

TABLE 3. Polar Circulation Indices Entering the Multiple Regression With Temperature in Several Russian Stations at $P<0.05$

Station	Indices	Total R^2
KEMP	Component 1	0.1456
NARJ	Component 3	0.1820
OSTR	Component 3	0.4459
TURA	Component 1, 2, 5	0.5402
VILJ	Component 5, 6, 1	0.4708
COKU	Component 1, 3	0.6621
KORF	Component 4, 1	0.6087

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