Temporal and Spatial Scales of the Arctic Circulation

JOHN E. WALSH

Laboratory for Atmospheric Research, University of Illinois, Urbana 61801

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ABSTRACT

Daily data for the years 1952–75 are used in a study of the fluctuations in the arctic circulation over time scales of several days to several months. An updated set of normal sea level pressures is constructed, and a semiannual cycle is found in the high-latitude gradient of zonally averaged pressure. July is the only month in which a mean convergence of the low-level flow into the central arctic is indicated.

The high-latitude fields of sea level pressure, surface temperature and 700 mb height and temperature are represented in terms of empirical orthogonal functions in order to isolate the dominant modes of variability. The amplitudes of the functions are used to evaluate the daily persistence of arctic pressure anomalies as a function of season and to compare the persistence of arctic and midlatitude pressure anomalies. The month-to-month persistence of arctic pressure anomalies is found to be small, although the monthly persistence does exceed that expected from the lagged autocorrelations of the daily data.

Cross correlations between the anomaly fields of pressure (height) and temperature at the surface and 700 mb are evaluated at lags ranging from −8 to +8 months. The cross correlations differ substantially from zero only at 0 lag. Fluctuations in the first eigenvector of 700 mb temperature are in surprisingly good agreement with the surface temperature fluctuations reported in an earlier paper.

1. Introduction

A conclusion that follows a search of the literature is that there has been little attempt to incorporate recent (1961–75) data into a study of the circulation statistics of the arctic atmosphere. Indeed, it can be argued that there is still some validity in the statement made 20 years ago by Hare and Orvig (1958, p. 2) that “the atmospheric circulation over the Arctic occupies few pages in the research publications of meteorology.” The lack of attention paid to the arctic atmosphere prior to the 1950’s was partially attributable to the scarcity of data from the ice-covered oceans of the central arctic. Since the early 1950’s, however, a fairly steady stream of data has been received from drifting arctic ice stations. Approximately 750 station-months of data are now available for the period from 1952 to the present, which might be termed the “modern drift station era.” [A listing of these stations and their dates of operation is given by Walsh (1977).] The present work is a first step toward an update of the synoptic climatology of the arctic circulation based on the more recent data. The emphasis here is on the statistics of the high-latitude sea level pressure fields and on the quantitative relationships between the pressure fields and the corresponding fields of surface temperature and 700 mb height and temperature. The work is concerned primarily with the spatial and temporal scales of the departures from the mean fields; such departure statistics have received little attention in the past because previous estimates of the mean fields were based on relatively short periods and/or were based on years in which there was little or no data input from the central arctic (see Section 2). A by-product of the present work is a relatively current set of arctic normals based on the period 1952–75.

A motivating factor in this study is the dependence of the motion and thickness of sea ice on the forcing by the lower atmosphere. Since the surface air stress is the primary motive force for sea ice (Coon et al., 1974), the geostrophic wind (surface pressure) field is generally the major contributor to the field of sea ice motion. Ice drifts in the general direction of the surface geostrophic wind at a speed on the order of 1% of the geostrophic wind speed. Ice thickness, on the other hand, is strongly dependent on the surface air temperature. The modeling results of Parkinson (1978) indicate that a positive air temperature anomaly of 5 K could melt the arctic ice pack in a period of several years. It follows that long-term (months to years) sea ice simulations, which have generally been forced by mean fields of the low-level meteorological variables, can be placed in better perspective if the spatial and
temporal scales of the departures from the meteorological means are evaluated quantitatively. In addition, shorter term forecasts of sea ice fluctuations are highly dependent on the corresponding forecasts of the meteorological fields. The time scales of the atmospheric circulation anomalies therefore have a direct bearing on attempts to forecast sea ice fluctuations over time scales of several days to several months. The results in Sections 2, 3 and 4 of this study will be examined with an eye toward their implications for arctic sea ice forecasting.

Section 2 contains a discussion of the seasonal cycle of the high-latitude sea level pressure fields based on data for the period 1952–75. The seasonal cycle and frequency spectrum of the gradient of zonally averaged pressure are presented, as are the secular trends in sea level pressure for the entire polar cap north of 60°N. The spatial and temporal scales of the arctic circulation are then described in terms of empirical orthogonal functions. The amplitudes of the orthogonal functions are used to examine the persistence of arctic circulation anomalies on several time scales. First, 15 years of daily data are used in a comparison of the day-to-day persistence of high-latitude and middle-latitude circulation regimes. The seasonal dependence of the high-latitude persistence is also examined. Monthly data are then used in an assessment of the longer-term departures from the monthly means. In Section 3, the temporal and spatial scales of the anomalies in surface temperature and upper air (700 mb) height and temperature are evaluated. Finally, in Section 4, the various time series of eigen-vector amplitudes are used to quantify the relationships between the pressure and temperature anomalies and between the surface and upper-air anomalies.

2. The sea level pressure fields

a. The normal seasonal cycle

An update of the arctic normals was undertaken because previous compilations were based either on relatively short periods (≤10 years) or on periods that included the pre-1950 years during which analysts tended, in the absence of data from the arctic, to bias the analyses toward high-pressure and anticyclonic flow in the central arctic (Reed and Kunkel, 1960). Examples of the short-period compilations are the July means of Reed and Kunkel for the period 1952–56, and the January/April/July/October means of Namias (1958) and O’Connor (1961) based on the years 1948–55 and 1947–58, respectively. Compilations based largely on the pre-1950 years include those of Crutcher and Meserve (1970) for the years 1931–60 and Prik (1959), whose charts are based on an unspecified number of years of Soviet data ending in the mid-1950’s. Some substantial differences can be seen in these earlier mean pressure fields. Reed and Kunkel, for example, indicate a 1005 mb low pressure center between the Bering Strait and the North Pole in July, while Prik’s analysis shows a 1013 mb high pressure center north of Alaska. Crutcher and Meserve also show a closed anticyclone in July between the Alaskan coast and the Pole. Prik’s analyses show considerably higher pressure in the Greenland area when compared with the other sources, although sea-level pressures derived for the elevated Greenland ice cap must be considered rather dubious.

The present analyses are restricted to the 24-year period 1952–75 because of the scarcity of data from the central arctic in earlier years. The data source for the pressure computations is the set of daily sea-level pressure analyses archived at the National Center for Atmospheric Research (NCAR). The NCAR analyses, which are in the form of 5° latitude-longitude grids from 20°–90°N, were in turn obtained from several sources (Jenne, 1975). It should be mentioned here that tabulations of arctic drift station data (e.g., ESSA, 1969) were used to check the accuracy of the NCAR analyses in the central Arctic. Since the discrepancies between the observed station pressures and the analyzed values at the nearest grid points were generally less than 1–2 mb (Karpovich, 1977, personal communication) it is apparent that the ice station data were included in the NCAR analyses.

The pressures are shown in Fig. 1 as seasonal means, where the seasons are defined as December–February (winter), March–May (spring), June–August (summer) and September–November (autumn). The equinoctial seasons are characterized by mean high-pressure centers in the Alaskan arctic; the winter pattern is dominated by a ridge extending from eastern Asia across the Arctic Ocean to northwestern Canada. Low pressure is found in the Barents Sea in all seasons except the summer. The summer pressure gradients are extremely weak over the entire arctic (Fig. 1c). While these general features have been noted in earlier studies (e.g., Namias, 1958; Vowinckel and Orvig, 1970), several additional points will be made here. First, the high-latitude gradient of zonally averaged pressure, which might be taken as a measure of the intensity of the mean polar anticyclone, shows a pronounced semiannual oscillation (Fig. 2). The maximum values of \( p_{90} - p_{70} \) are typically found in April and November, while the minima are found in July and December. The statistical significance of this semi-annual variation is evident in Fig. 3, which is the frequency spectrum of \( p_{90} - p_{70} \) for the 288-month sample. Fig. 3 also shows the corresponding red noise continuum computed from the serial correlation coefficient (=0.30) at lag 1, to-
Fig. 1. 1952–75 sea-level pressure means for winter (a), spring (b), summer (c) and autumn (d). Contour interval is 1 mb.

tgether with the associated 95 and 99% confidence limits (Mitchell et al., 1966, p. 36). The spectral peak at approximately six months is significant at the 99% confidence level.

It is also apparent from Fig. 2 that July is somewhat unique in the sense that it is the only month in which the pressure at the Pole is lower than the zonally averaged pressures in the 60–80°N latitude belt. A mean (albeit weak) low-level convergence into the central arctic can therefore be inferred only in July. While the previously referenced studies of Reed and Kunkel, Namias, O’Connor and Prik use July means to illustrate the summer flow patterns in the arctic, it can be argued from Fig. 2 that the July mean is not representative of the summer mean. Alternatively, the uniqueness of the July pressure distribution may simply indicate the brevity of “summer” in the northern high latitudes.

The seasonal plots of Fig. 1 also have some implications for the drift of arctic sea ice. The long-term drift of arctic ice is generally discussed in terms of two large-scale features: the Pacific gyre in the North American sector and the transpolar drift stream extending from the northern Siberian Coast across the Pole to the East Greenland Sea (Campbell, 1965; Parkinson, 1978). Since the
Pacific gyre is essentially a manifestation of an anticyclonic flow pattern in the lower atmosphere, the gyre should be a normal feature of only the spring and autumn ice velocity fields. Most discussions of the large-scale patterns of arctic ice drift are based on annual pressure means (e.g., Gordienko, 1958). As a result, the seasonal dependence of the Pacific gyre is often ignored.

b. Recent secular trends

Trends of the seasonal and annual pressures were computed for all grid points north of 60°N. The trends are the slopes (mb year\(^{-1}\)) of the linear regression lines fitted by least squares to the data for the 24 years. The changes (mb year\(^{-1}\) \(\times\) 24 years) in the annual means are shown in Fig. 4. The area of pressure increases forms a tongue that extends into the central arctic along the 180° meridian. The largest changes are found in the East Siberian Sea and in northeastern Canada. An examination of the seasonal trends (not shown) indicates that the pattern in Fig. 4 is due primarily to changes in spring and summer. The summer changes include pressure increases of 3–4 mb in the East Siberian Sea and pressure decreases of 1–2 mb in the Canadian Archipelago, implying stronger onshore airflow (and ice drift) in the coastal waters north of Alaska. These results are in general agreement with the summer trends obtained by van Loon and Williams (1976) for the 1942–72 period.

c. Spatial patterns of the departures from normal

Because the emphasis of this work is on the spatial and temporal scales of the departures from normal, the departure fields are represented in terms of empirical orthogonal functions. Empirical orthogonal functions have the advantage that they are the most efficient possible data representations in the sense that the dominant orthogonal functions account for more of the variance of a set of data fields than any other combination of the same number of parameters or functions. Kutzback (1967) outlines the construction of empirical orthogonal functions which are also referred to as eigenvectors or principal components.

The data used in constructing the orthogonal functions were expressed as normalized departures.

Fig. 2. Monthly means (24 years) of the difference between the polar pressure \((p_{po})\) and the zonally averaged pressure at 70°N \((\bar{p}_{70})\).

Fig. 3. Normalized frequency spectrum of the difference between the polar pressure \((p_{po})\) and the zonally averaged pressure at 70°N \((\bar{p}_{70})\). Also shown are the red noise continuum (dashed line) and the associated 95% (dashed-dotted line) and 99% (dotted line) confidence limits.

Fig. 4. Pressure changes (mb) computed from the slopes (mb year\(^{-1}\)) of the pressure trend lines for the period 1952–75. Shaded areas are those in which the trends are positive. Symbols H and L denote maxima and minima in the computed trends. Contour interval is 1 mb.

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from the monthly means, thereby removing the
seasonal cycle. Fig. 5 shows the first four
eigenvectors of a 29-eigenvector representation
of the pressure departures. The eigenvector construc-
tion is based on the 29 points shown in the figures.
These four eigenvectors account for 66% of the total
pressure variance. The first eigenvector corresponds
to a general excess or deficit of mass over the
polar cap; the largest anomaly is found fairly close
to the Pole. The second and third eigenvectors
represent pressure gradients in approximately per-
pendicular directions. The second corresponds to
a gradient between the Siberian and North American
sectors of the arctic, while the third represents a
gradient between Scandinavia and the Bering Sea.
The fourth mode illustrates the tendency toward
the finer structure of the higher modes. It should
be noted that the first three eigenvectors of Fig. 5
contain many of the general features of the high-
latitude portions of Kidson's (1975) first three
Northern Hemisphere eigenvectors for the period
1951–60. We may infer that the dominant modes
of the high-latitude pressure fluctuations have been
similar in the 1951–60 and 1961–75 periods. The

Fig. 5. The first four eigenvectors of the normalized departures from the monthly means of the arctic sea level pressures. H and L
denote maxima and minima in the anomaly fields. Heavy dots are the grid points used in the construction of the eigenvectors. The
percentage of variance described by each eigenvector is shown in the upper right corner.
resemblance between the vectors of Fig. 5 and Kidson's high-latitude patterns is also an indication that the computed eigenvectors are not strongly dependent on the admittedly arbitrary definition (60°–90°N) of the arctic used in this work.

Whereas the dominant pressure mode is one in which the anomaly is of the same sign over essentially the entire arctic, the first two modes of temperature variability (Walsh, 1977) correspond to gradients between above-normal and below-normal regions within the arctic. A quantitative examination of the correspondence between the pressure and temperature departures will be presented after the time scales of the pressure anomalies are described.

d. Persistence of arctic pressure anomalies

1) Daily persistence

In order to evaluate the persistence of arctic pressure anomaly patterns, pressure eigenvectors and their coefficients were recomputed from 15 years (1961–75) of daily data. The 5478 daily grids were seasonally stratified, and the persistence was evaluated at lags 0–10 days as a variance-weighted mean of the autocorrelations of the first six eigenvector amplitudes. Approximately 75% of the variance is contained in the first six eigenvectors, which closely resemble the corresponding eigenvectors computed from the monthly data.

Fig. 6 shows the seasonal dependence of the persistence of the daily pressure anomalies. The quasi-exponential decay curves show that the persistence is somewhat larger in the winter than in the other three seasons. The winter autocorrelation decays to 0.30 by day 5 and to 0.15 by day 10, while the corresponding values for the other seasons are 0.18–0.21 at day 5 and 0.02–0.04 at day 10. Persistence will evidently be of little forecast value in the spring, summer and autumn, which are the seasons when short-term fluctuations in the pressure fields contribute to sea ice fluctuations that can seriously impede navigation efforts along the coasts of the northern land areas (e.g., Barnett, 1978).

The persistence of the arctic pressure anomalies was also compared with the corresponding anomalies in the three midlatitude regions listed in Table 1. The regions ML-1, ML-2 and ML-3 include the midlatitude portions of North America, western Eurasia and the western Pacific, respectively. The area of each midlatitude region is very nearly equal to that of the polar cap north of 65°N. (The arctic “boundary” in this eigenvector construction was moved northward to 65°N in order to reduce the tendency for the Aleutian and Icelandic low pressure centers to overlap the arctic and midlatitude regions.)

The comparison of the arctic and midlatitude persistence values was motivated by Namias' observation that the relatively large monthly and seasonal departures from normal in the arctic are attributable to large serial correlations in the daily, weekly and monthly circulations (Namias, 1958, p. 47). Fig. 7 shows that the persistence values of the arctic anomalies are indeed larger than those of the three midlatitude regions, although the differences between the arctic and western Eurasian (ML-2) curves can be considered negligible. The persistence of the arctic anomalies beyond about three days is approximately twice as large as the corresponding persistence in the midlatitude region (ML-1) containing the continental United States.

2) Monthly persistence

In order to examine the persistence of the high-latitude pressure anomalies on longer time scales, autocorrelations of the time series of the monthly eigenvector amplitudes were computed. Each series

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1 The autocorrelation curves of Fig. 7 are based on all days in the 1961–75 period and therefore are not seasonally stratified.
Fig. 7. Autocorrelations at lags 0–10 days of the pressure anomaly field in the arctic (ARC) and in the midlatitude regions ML-1, ML-2 and ML-3 (see Table 1). Plotted values are variance-weighted means of the autocorrelations of the first six eigenvectors for each region.

consisted of 288 monthly values. The autocorrelations at lags 0–8 months are shown in Fig. 8a for the first four pressure eigenvectors. The autocorrelations decay rapidly to values of less than 0.2 at 1-month lag and do not exceed 0.15 in magnitude thereafter. The implication is that persistence will be of little value in forecasting arctic sea-level pressure anomalies on the time scale of months.

The autocorrelations at 1-month lag are influenced by the tendency for short-term (~days) anomalies to overlap adjacent months. In order to estimate this “overlap” component \( R_o \) of the computed 1-month persistence values, we may follow Davis’ (1976) use of Munk’s (1960) relation

\[
R_o = 0.5[\alpha(30 \text{ days}) - 1]^{-1},
\]

where \( \alpha \) defines the decay rate of the daily autocorrelations \( R_d \) as a function of the lag \( \tau \), i.e.,

\[
R_d(\tau) = e^{-\alpha \tau}
\]

(see Leith, 1973). The daily autocorrelations of Fig. 6 give \( \alpha = 0.27 \), which leads to an estimate from (1) of \( R_o \approx 0.07 \). Since the 1 month autocorrelations of Fig. 8a range from 0.08 to 0.18, we may conclude that not all the monthly persistence is attributable to the overlap of the shorter term anomalies into adjacent months.

3. Temporal scales of the upper-air and temperature anomalies

The computed eigenvectors were used to compare the scales of the dominant pressure modes and the dominant modes of surface temperature, 700 mb height and 700 mb temperature. The surface temperature eigenvectors based on the years 1954–75 have been described by Walsh (1977); the recomputed temperature eigenvectors for the years 1952–75 are nearly identical and will not be reproduced here.

The 700 mb eigenvectors are based on two data sources. The data for 1952–67 were in the form of daily analyses on \( 5^\circ \times 10^\circ \) latitude-longitude grids. The grids were provided by the Extended Forecast Division of the National Meteorological Center (NMC) and are stored on tape at the National Center for Atmospheric Research. The data for the years 1968–75 were taken from the set of NMC analyses archived at NCAR. Since the latter set of daily data is analyzed on the NMC octagonal grid, the analyses from the earlier years (1952–67) were converted to the octagonal grid format.

The first three eigenvectors of the normalized monthly anomalies of 700 mb height and temperature are shown in Figs. 9 and 10, respectively. The three eigenvectors account for slightly over 40% of the variance in each case. The figures also show the subset of 25 NMC grid points that were used in the eigenvector construction. (A series of sensitivity tests indicated that the computed eigenvectors were virtually unchanged by an increase in the density of the grid points within the boundary formed by the outermost grid points in Figs. 9 and 10.)

The first eigenvector of 700 mb height corresponds to height departures having the same sign over all
areas except Scandinavia and the Sea of Okhotsk. The largest departures are found over Baffin Bay and northeastern Canada. The second eigenvector represents a height gradient extending across the Pole from the Eurasian arctic to the North American arctic. The third mode corresponds to a trough (ridge) extending from the Bering Sea across the Pole to the Barents Sea, while the heights over North America are above (below) normal.

The first eigenvector of Fig. 10 corresponds to 700 mb temperature anomalies of the same sign at all but the northern European grid points. The second temperature eigenvector represents a pattern in which the North American anomalies are opposite in sign to those over most of the other high-latitude areas, especially Scandinavia. The third eigenvector contains several positive and negative anomalies, and illustrates the tendency toward the finer structure that is found in the higher eigenvectors.

Figs. 8b–8d show the autocorrelations of the coefficients of the first three eigenvectors of surface temperature ($T$), 700 mb height ($z$) and 700 mb temperature ($t$). The autocorrelations are shown at lags of 0 to 8 months for comparison with Fig. 8a. While the autocorrelations of the 700 mb height coefficients decay very rapidly, the surface and 700 mb temperature fields show somewhat more persistence. The curve of $T_1$, for example, decays only to 0.41 at one month and to 0.17 at two months; both values are larger than those found for any pressure coefficient at any lag. The autocorrelations of the
first two coefficients ($t_1$ and $t_2$) of 700 mb temperature are positive out to 8 months. The coefficient $t_1$ remains at or above 0.3 at each lag. However, an examination of the various time series shows that a secular trend has contributed to the apparent persistence of $t_1$ and $t_2$. The persistence of the surface temperature coefficients is also partially attributable to a trend effect. Table 2 lists these trends, which are the slopes (month$^{-1}$) of the linear regression lines fitted by least squares to the 288 monthly coefficients. Also listed for each slope is the ratio $S$ of the computed slope to the standard deviation of the slopes to be expected when samples of the same size are drawn from an infinite series of randomly distributed values having the same variance; therefore, $S$ is a measure of the extent to which the trend computed from a finite time series is attributable to one or two large fluctuations near the extremes of the series (van Loon and Williams, 1977). The $S$ values of $T_1$, $T_3$, $z_1$ and $t_1$ are well above 2.0, while the (negative) slopes of $T_3$ and $t_1$ are more than three times the standard deviation to be expected from a random series. Since $T_3$ and $t_1$ are coefficients of corresponding eigenvectors in the sense that they represent positive temperature anomalies over nearly the entire arctic [see Fig. 2c in Walsh (1977) and Fig. 10a in this paper], the implication is that the cooling of the arctic troposphere over the past 24 years is statistically significant. The negative trend is apparent in Fig. 11, which shows the time series of $t_1$ as a running 12-month mean. The sharp decrease in $t_1$ during the early 1960's, followed by a rather abrupt increase several years later, is very similar to the pattern.
shown by the surface mode $T_3$ (Walsh, 1977, Fig. 8). The latter, in turn, behaves approximately as the departure from normal of the area-weighted surface temperature of the polar cap. The correspondence between the time series of $t_1$ and $T_3$ suggests that the surface and 700 mb temperature fields are closely coupled despite the high frequency of low-level inversions in the Arctic (Vowinckel and Orvig, 1967). The two time series indicate that the cooling at both the surface and 700 mb took place primarily in the first half of the 1952–75 period; the northern high latitudes have not experienced a net cooling during the last 10–12 years.

Mention should be made of the possibility that the trend and/or abrupt changes in $t_1$ are attributable to changes in the NMC analysis procedure. Wahl (1972) points to evidence of a changed analysis procedure in the 700 mb height data for the 1959–61 period. While the possibility of such a bias in the 700 mb temperature data cannot be dismissed, Fig. 11 does indicate that the fluctuations in $t_1$ were rather uneventful during the years 1959–61. Perhaps more importantly, the time series of $t_1$ and $T_3$ are very similar despite the fact that $T_3$ is based on surface data that were analyzed independently from NMC and by a procedure different from that used by NMC in analyzing the 700 mb data.

4. Pressure-temperature and surface to 700 mb interrelationships

The relationships between the fields of sea-level pressure, surface temperature, and 700 mb height and temperature were examined quantitatively by performing cross correlations between the coefficients of the dominant eigenvectors at various lags. Fig. 12 shows a sample of the six sets of cross correlations between the four variables. In all cases, the lag between the first and second variable ranges from −8 to +8 months. Among the generalizations that can be made are the following:

1) For all pairings of the four variables, at least several cross correlations depart substantially from 0 at zero-lag. Simultaneous fields of the different variables are clearly not independent.

2) The signs of the zero-lag correlations are consistent with expectations based on fundamental meteorological reasoning. The cross correlations between sea-level pressure and surface temperature, for example, are attributable to advection by the geostrophic wind: positive $\langle P_1 T_1 \rangle$ corresponds to southeasterly flow and warm advection into Baffin Bay and the Canadian Archipelago, and northerly flow with cold advection into northern Asia; negative $\langle P_2 T_2 \rangle$ corresponds to southerly flow with warm advection into the vicinity of Iceland and the Barents Sea, and cold advection into northeast Asia and northwestern North America.

The $\langle P_z T_z \rangle$ correlations indicate the tendency for ridges at 700 mb to be found in the general vicinity of surface high pressure systems in the northern high latitudes. The $\langle z T \rangle$ correlations show that above-normal 700 mb heights are associated with above-normal 700 mb temperatures (e.g., $\langle z_0 T_0 \rangle$). The $\langle T_z \rangle$ curves indicate that above-normal 700 mb heights are generally observed in regions of above-normal surface temperatures. Finally, the relatively large magnitudes of the 0-lag $\langle T \rangle$ correlations are further evidence of the tendency for temperature anomalies at the surface and at 700 mb to be of the same sign in a particular area (Section 3).

3) Several cross correlations between the coefficients of surface temperature and 700 mb height ($\langle z T \rangle$), surface pressure and 700 mb temperature ($\langle P T \rangle$) and surface and 700 mb temperatures ($\langle T \rangle$)

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### Table 2. Slopes (month$^{-1}$) of the coefficients of the first three eigenvectors of sea-level pressure $P$, surface temperature $T$, 700 mb height $z$ and 700 mb temperature $t$. Also listed is the significance parameter $S$ (defined in text) for each slope.

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<thead>
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<th>Parameter</th>
<th>Slope</th>
<th>$S$</th>
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<tr>
<td>$P_1$</td>
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<tr>
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<td>2.05</td>
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</tr>
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</tr>
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<tr>
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<td>1.94</td>
</tr>
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<td>1.75</td>
</tr>
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are in the 0.2–0.4 range at lags of 1–2 months. In the cases of \( zT \) and \( Tt \), there is no apparent tendency for one variable to lead the other. While the \( Pr \) correlations are generally larger at positive lags of \( t \), the lagged correlations are most likely too small to be useful for forecasting on the time scale of one to several months.

5. Summary and conclusions

This work has been a quantitative evaluation of the fluctuations in the arctic circulation over time scales of several days to several months. The 1952–75 period was chosen because it is the period in which ice station data from the central arctic
have been available on a routine basis. The findings include the following:

1) The gradient of the zonally averaged pressure has a pronounced semiannual component in high latitudes. Pressures in the 60–80°N latitude belt are lowest relative to pressures near the pole in the spring and autumn.

2) July is the only month in which a (weak) convergence of surface flow into the central Arctic is implied by the zonally averaged pressure field north of 70°N. The use of July mean pressures to represent the summer flow patterns in the Arctic may therefore be somewhat misleading.

3) The day-to-day persistence of normalized departures from the mean monthly high-latitude pressure fields is largest in winter and smallest in summer.

4) The day-to-day persistence of sea-level pressure is slightly greater in the arctic than in mid-latitudes, although such statements must be interpreted with caution because of the longitudinal dependence of the midlatitude persistence values.

5) Even with the seasonal cycle removed, the dominant mode of spatial variability of the arctic sea-level pressure field corresponds to a general excess or deficit of mass over essentially the entire polar cap north of 60°N.

6) While recent trends in sea level pressure and 700 mb height are not highly significant statistically, the trend in the coefficient of the dominant 700 mb temperature eigenvector is statistically significant and similar to the trend of the corresponding surface temperature mode. In each case, cooling is indicated for the first half of the study period.

7) The month-to-month persistence of departures from the normal sea-level pressures and 700 mb heights is very small.

8) Cross correlations between the anomaly patterns of the four variables (P, T, z, t) depart substantially from 0 at zero-lag and are of the expected sign. The lagged cross correlations appear to be too small to be useful in forecasting on the time scale of months.

An implication of the last point is that long-range forecasts of sea ice drift and extent will be severely constrained by forecasts of the high-latitude meteorological fields. The results of Haupt and Kant (1976) suggest that month-to-month departures from normal sea ice extent in the North Atlantic can be hindcasted with some success from prior anomalies in the sea-level pressure fields. Further and more quantitative examination of atmosphere/ice relationships on monthly time scales are needed. Regardless of hindcasting success, however, it is evident that any successful long-range ice forecast-

ing efforts must be based on more than the simple persistence of high-latitude meteorological anomalies.

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