Further Studies on Single Station Climatology:
(i) the summer confluence of subtropic and polar front jet,
(ii) the two northern cold poles.

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Abstract

This single station climatology describes the first and second moments (seasonal averages, variances and covariances) and the spectral decomposition of time series of rawinsonde observations at selected sites. It extends the analysis of the Berlin rawinsonde, representative for the western part of the Eurasian continent in mid-latitudes, to other climatic regions: the eastern part of the Asian continent (Wakkanai in Japan) and the north-polar region (Churchill in Canada, Ojmjakon in Siberia).

(i) Wakkanai is situated at the entrance region of the Pacific jet stream system. The tropospheric disturbances revealed by the power spectra are associated with the three period ranges (short, long, and ultra-long) with short period waves in their developing phase. The variance densities for the zonal wind component are centered at 300 mb. Fluctuations of the subtropic jet at 200 mb are observed only during summer and for the ultra-long periods. At the same period range in summer the relatively high upper-tropospheric temperature variance may be associated with the Tibetan Highland as a large scale elevated heating source.

(ii) At the polar stations the northward eddy flux of sensible heat and the equatorward momentum flux reveal a similar partitioning of the synoptic scale processes in the polar circulation if the seasonal power spectra are considered. The associated temperature fluctuations (and transports) are strongest in the lower troposphere during winter and in the mid-troposphere during summer, with the ultra-long period disturbances being predominant during winter.

Zusammenfassung: Studien zur Klimatologie einzelner Stationen im Bereich (i) des Subtropen- und Polarfront-Strahlstroms und (ii) der beiden nördlichen Kältepole.

Die Klimatologie ausgewählter Stationen wird mit den Zeitreihen von Radiosondendaten beschrieben, ihren ersten und zweiten Momenten (jahreszeitliche Mittel, Varianzen und Kovarianzen), sowie ihrer spektralen Transformation. Die Untersuchung der Berliner Radiosonde, die repräsentativ für den westlichen Teil Eurasiens in mittleren Breiten ist, wird erweitert um Wakkanai in Japan (östlicher Teil Asiens) und um Churchill in Kanada und Ojmjakon in Sibirien (nördliche Polarregion).

(i) Wakkanai liegt im Einzugsgebiet des Strahlstroms über dem Pazifik. Die turbulenten Transporte in der Troposphäre sind für sensible Wärme polwärts gerichtet, aber stark variierend für Impuls und geopotentielle Energie. Die troposphärischen Fluktuationen sind nach den Powerspektren mit den drei Periodenbereichen (kurz, lang und ultralang) assoziiert, wobei sich die kurzperiodischen Störungen in der Entwicklungsphase befinden. Die Varianzdichten des Zonalwindes haben bei 300 mb ihr Maximum. Nur im Sommer und für die ultralangen Perioden werden Fluktuationen des Subtropen-Strahlstroms im 200-mb-Niveau beobachtet. Im gleichen Periodenbereich treten relativ hohe Intensitäten sommerlicher Temperaturschwankungen in der oberen Troposphäre auf, die durch das Tibetanische Hochland als Heizfläche verursacht sein können.

(ii) Die Polstationen zeigen, daß die turbulenten Transporte von sensibler Wärme nach Norden, von Impuls nach Süden gerichtet sind. Diese Flüsse werden nach den Powerspektren durch Störungen in ähnlichen Periodenbereichen hervorgerufen wie in mittleren Breiten. Die Temperaturfluktuationen (und Transporte) sind im Winter in der unteren Troposphäre am stärksten, im Sommer in der oberen Troposphäre, wobei die Störungen mit ultralangen Perioden im Winter vorherrschen.

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Résumé: Etudes climatologiques dans la région (i) des courants-jets subtropical et du front polaire, (ii) des deux pôles du froid de l'hémisphère nord.

Cette climatologie d'une station décrit les premier et second moments (moyennes saisonnières, variances et covariances) et la décomposition spectrale de sèries chronologiques des observations de radiosandages et de vent en des sites sélectionnés. Elle prolonge l'analyse des observations de Berlin représentatives de la partie occidentale du continent eurasien aux latitudes moyennes, à d'autres régions climatologiques; la partie orientale du continent asiatique (Wakkanai au Japan) et la région polaire boréale (Churchill au Canada, Ojmjakon en Sibérie).

(i) Wakkanai est situé dans la région d'entrée du courant-jet du Pacifique. Les transports turbulents troposphériques sont en direction du pôle pour la chaleur sensible, mais très variables pour la quantité de mouvement et l'énergie géopotentielle. Les fluctuations troposphériques révélées par les spectres de puissance sont associées aux trois gammes de périodes (courtes, longues et très longues), avec des perturbations de courte période dans la phase de développement. Les densités du variance pour la composante zonale du vent ont leur maximum à 300 mb. Les fluctuations du courant-jet subtropical à 200 mb sont observées uniquement en été et pour des périodes très longues. Dans cette même gamme de périodes, il y a, en été, des intensités relativement élévées des fluctuations de température, peut-être dues au plateau tibétain agissant comme source de chaleur.

(ii) Les station polaires montrent que les flux turbulents sont dirigés vers le nord pour la chaleur sensible et vers le sud pour la quantité de mouvement. D'après les spectres de puissance, ces flux sont liés à des perturbations dans les mêmes gammes de périodes qu'aux latitudes moyennes. Les fluctuations et les transports thermiques sont les plus forts dans la troposphère inférieure en hiver et dans la troposphère supérieure en été; les perturbations de très longues périodes prédominent en hiver.

1 Introduction

A climatology based on the statistics of the atmospheric circulation usually contains the first and second moments (averages and variances) of rawinsonde data series. Adding spectral or eigenvector decomposition, even a single station climatology leads to a deeper and quantitative description of the scales and intensities of atmospheric phenomena as climate generating processes. Further insight can be gained from spectra of those individual stations which characterize different climates. Three climatic regions are selected from documentations of spectral analyses of rawinsonde data (BUCHWALD et al., 1979; FRAEDRICH et al., 1979) for further discussion: the climates of the western and eastern part of the Eurasian continent in the mid-latitudes, and the north polar climate.

The western part of the Eurasian land mass in the mid-latitudes lies downstream of the major jet core over the Atlantic, and seems to be reasonably well represented by the Berlin rawinsonde (SPETH, 1974; BLACKMON et al., 1977) with its dynamical features being discussed in detail by FRAEDRICH et al. (1979). As these results provide the background for this note, some should be mentioned: The zonal flow and its shear is weaker than in the corresponding eastern part of the continent. The variance maxima of geopotential height and wind occur in the level of the polar front jet at about 300 mb and the related temperature variance is strongest in the mid-troposphere and at about 200 mb separated by a minimum in between. The upper troposphere is characterized by a southward eddy flux of sensible heat, whereas the heat transport in the lower troposphere and stratosphere is poleward; but the flux of geopotential energy is equatorward throughout the troposphere. Although highly variable, the flux of westerly momentum is poleward and most intense at the jet stream level. The dynamic processes leading to these variations and eddy transports are represented in the frequency domain by three sprectral peaks at short ($<$ 5 days), long (5 to 10 days) and ultra-long ($>$ 10 days) periods. They are interpreted to arrange themselves in an index-cycle (ultra-long period) of an active and inactive phase; the period of synoptic activity is locally realized by the slowly progressing long period waves steering ensembles of short period disturbances, which are more mature in the western part of the continents than over the oceans where they originate. Thus, the observed energy flux patterns of an indirect eddy circulation over the western parts of the continents are produced by the occluded cyclones;

i. e., short period disturbances which, like clouds, undergo a life cycle, are the basic elements performing the locally observed eddy transports. Within this ultra-long cycle the periods of activity are followed by a dynamically more quiet phase. These basic dynamic and climatological considerations are extended to other climatic regions, illustrating that transient eddies exhibit variations often smoothed by a zonally averaged description of the general circulation: (i) Wakkanai (1956–60) in Japan lies upstream from the major jet stream core over the Pacific and in the same latitude belt as Berlin which, however, is situated downstream of the Atlantic jet stream core. Wakkanai is chosen because it seems to be representative for the eastern part of the Asian continent in the mid-latitudes, where polar front and subtropical jet are interacting in summer and, further south, in winter. (ii) Two polar stations are situated in the two cold poles of the Northern Hemisphere: Churchill (1956–60) in Canada and Ojmjakon (1957–60) in Siberia.

The daily rawinsonde ascents from these three stations are analyzed using seasonal time series of 128 days in length. The summer seasons start on 1 May, the winter seasons on 1 November. Each series contains the following meteorological variables on standard pressure levels (see Table 1); eastward (U in ms^{-1}) and northward (V in ms^{-1}) wind components and temperature (T in Kelvin). Throughout the following, some averages and power spectra are shown, but cospectra are also discussed. Before the spectra are deduced, the data are subjected to several modifications in the following sequence:

(a) Missing data and values falling more than four standard deviations away from the mean are replaced by using third order polynomial fit (see Table 1). Series with more than 30 % data missing are rejected.

(b) At all stations and for all variables and pressure levels, the five year ensemble average is subtracted from each time series to exclude the low-frequency variance contributions of annual and semi-annual cycles, (WMO, 1966).

(c) High frequency variance contributions are removed by a first order binomial filter (i. e., moving average over two adjacent data points) with a cut-off frequency equivalent to a 3.2 day period. Additionally, this low-pass filter reduces aliasing.

(d) Although hardly perceptible, the linear long term trend ist removed.

■ **Table 1** Percentage of data interpolated for the spectral analysis.

■ **Tabelle 1** Prozentualer Anteil der für die Spektralanalyse interpolierten Daten.

OJMJAKON (63° 16′ N; 143° 09′ E)

pressure level	(mb)	850	700	500	400	300	200	150	100
temperature T	(in %)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
wind U, V	(in %)	14.2	10.5	0.5	23.6	15.0	23.0	49.9	27.7

CHURCHILL (58° 45′ N; 94° 04′ W)

pressure level	(mb)	850	700	500	400	300	200	150	100
temperature T	(in %)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
wind U, V	(in %)	5.2	5.3	0.5	10.5	16.0	21.1	24.4	28.7

WAKKANAI (45° 25′ N; 141° 41′ E)

pressure level	(mb)	850	700	500	400	300	200	150	100
temperature T	(in %)	0.0	0.0	0.0	0.0	0.0	0.2	0.1	0.0
wind U, V	(in %)	0.4	0.7	0.3	8.3	13.4	19.9	23.1	23.7

The method of analysis, presentation of results, and the basic patterns have been described before (FRAEDRICH et al., 1979). The main emphasis, however, lies on those features characterizing the different climatic situations.

2 Summer-confluence of subtropic and polar front jet (Wakkanai)

a. Climatological setting

The troposphere over the eastern part of the Asian continent is governed by the entry region of the major jet stream system, i. e. up-stream of the jet maximum over the Pacific. This situation is different from Europe, which lies downstream the Atlantic jet maximum (LAU, 1978) and experiences mainly mature cyclonic disturbances. But it is similar to NE-America. The zonal flow has its maximum at about 200 mb and is much stronger here than over the western parts of the continents. This is a condition favourable for the generation of baroclinic disturbances. The meridional eddy flux of sensible heat is poleward throughout the troposphere. Thus short period disturbances are in their developing phase (MÜLLER, 1978); i. e., cyclones begin their life cycle over the eastern (or western) parts of the continents (or oceans) and preferably decay over the western area of the land masses. Additionally, the fluxes of geopotential energy and momentum are highly variable, indicating that Wakkanai is influenced by both the mid-latitude westerlies and the subtropics.

b. Power spectra

During summer the power spectrum of the zonal wind component (Figure 2) shows the ultra-long period variance maximum in the 200 mb level, i. e., in the height of maximum mean wind speed. The long and short period fluctuations, however, have their spectral peaks well pronounced some 100 mb further down, i. e., at the 300 mb level. This picture is very similar to the zonal wind variance spectrum at Belgrad (44° 47′ N, 20° 32′ E; BUCHWALD et al., 1979) which, similar to Wakkanai, is also situated at the northern boundary of the subtropic high pressure belt in summer. It should noted that it is not possible to deduce these two effects from the average summer profile of the zonal wind (Figure 1). The height and period

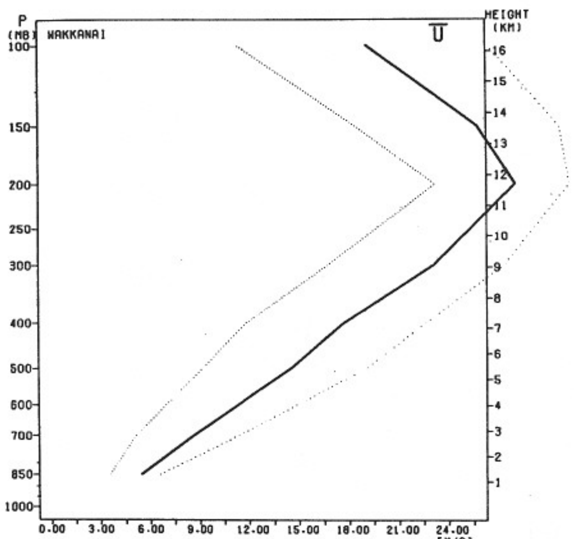
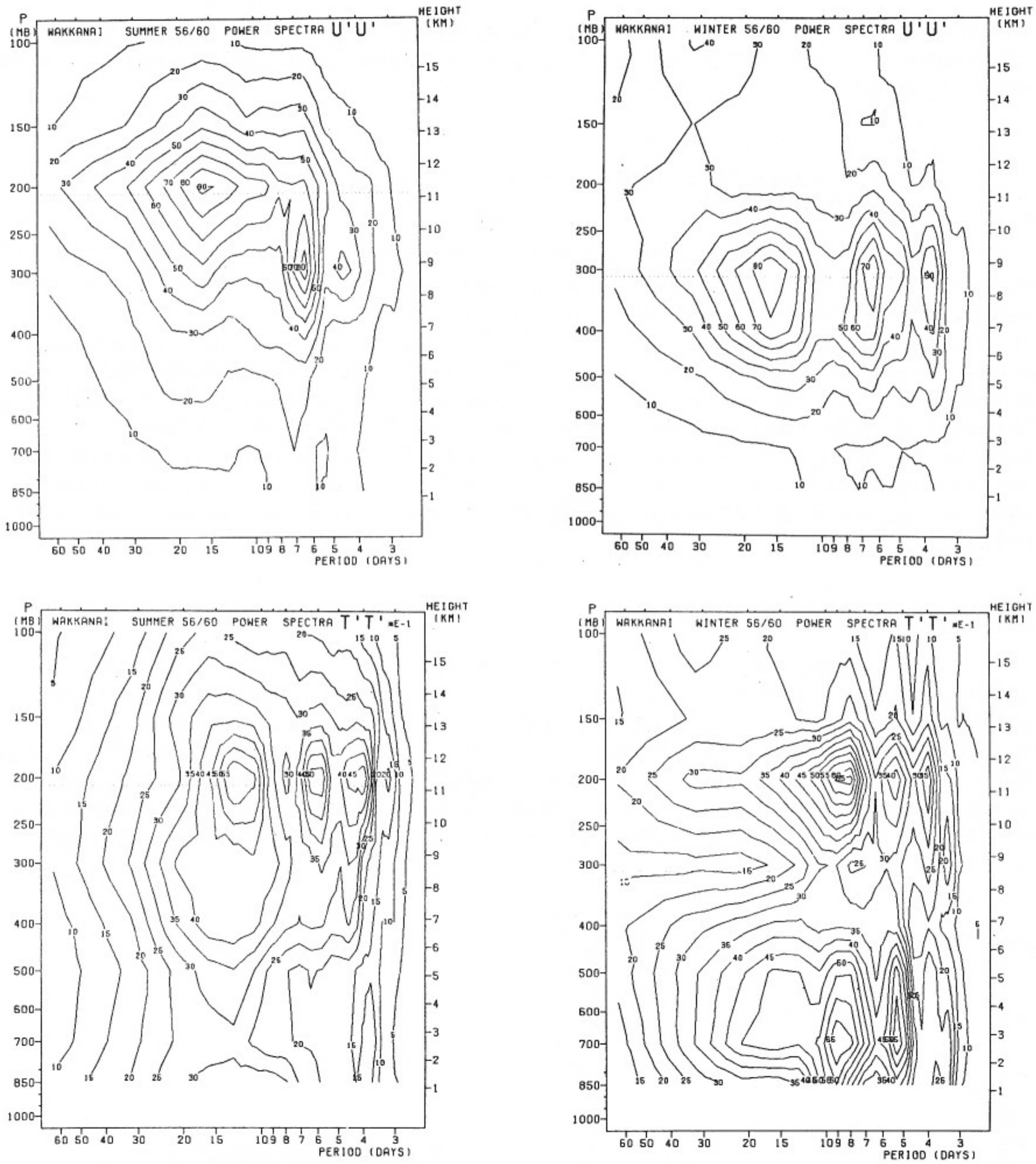


Figure 1 Mean vertical profile of zonal wind ($\overline{U}$) at Wakkanai; average year (——), average summer (……), average winter (. . .).

Bild 1 Mittleres Vertikalprofil der zonalen Windkomponente ($\overline{U}$) von Wakkanai, mittleres Jahr (——), mittlerer Sommer (……), mittlerer Winter (. . .).



● **Figure 2** Power spectra of zonal wind and temperature at Wakkanai averaged over five summer/four winter seasons. The contours (in units of variance) show the frequency-multiplied power spectra. They are scaled by decimal powers indicated in the upper right. The ordinate is the height (in km or mb), the abscissa is the logarithm of frequency labelled according to the period (in days). The average tropopause is given by dotted line.

● **Bild 2** Powerspektren der zonalen Windkomponente und der Temperatur von Wakkanai für Sommer und Winter. Die Isolinien haben die Einheiten der Varianz, da sie mit der Frequenz gewichtete Varianzdichten darstellen. Die Skalierung in Zehnerpotenzen ist oben rechts angegeben. Die Ordinate ist die Höhe in km oder mb, die Abszisse ist proportional dem Logarithmus der Frequenz als Periode (in Tagen) angegeben. Die mittlere Tropopausenhöhe kennzeichnete eine punktierte Linie.

separation of the peaks of the zonal wind variance densities allows the following interpretation: The oscillation with the period of about 15 days in the 200 mb level is due to fluctuations of the meridional position of the subtropical jet. The changes of the subtropical high in the lower troposphere as indicated by the temperature variance spectrum show peaks at the same frequency. The short and long-period peaks of the zonal wind variance density are caused by fluctuations of the polar front jet in 300 mb, about 100 mb below the wind maximum of the subtropic jet; i. e., during summer Wakkanai and Belgrad are also influenced by troughs of the mid-latitude disturbances (long and slowly progressive waves) and the associated minor cyclones (fast moving waves).

During the winter season Wakkanai is situated at the eastern part of the well developed upper trough over Asia, where disturbances of all three period ranges exist. Although a maximum mean zonal wind speed is observed in the 200 mb level, the related variance maximum is found in the 300 mb level of the polar front jet with its oscillations (Figure 2). Thus, the zonal wind at the level of the mean wind maximum is a relatively steady phenomena. During winter the Wakkanai power spectrum of the zonal wind shows features similar to other mid-latitude stations: All three peaks are coupled with the variations of the polar front, including short, long and ultra-long periodic variations.

The power spectra of temperature also show the three spectral peaks (Figure 2). In summer they are well pronounced around 200 mb and caused by height variations of the tropopause during the passage of cyclones and anticyclones (see FRAEDRICH et al., 1979). During winter there are large variance contributions mainly from short and long periods in the lower troposphere (below 400 mb). These can be related to air mass changes accompanying the mid-latitude wave disturbances, being most severe during continental cold air outbreaks. During summer, however, the low tropospheric variance constribution is dominated by the shallow phenomena of ultra-long periods, which we have interpreted as expansions of the subtropic high pressure belt.

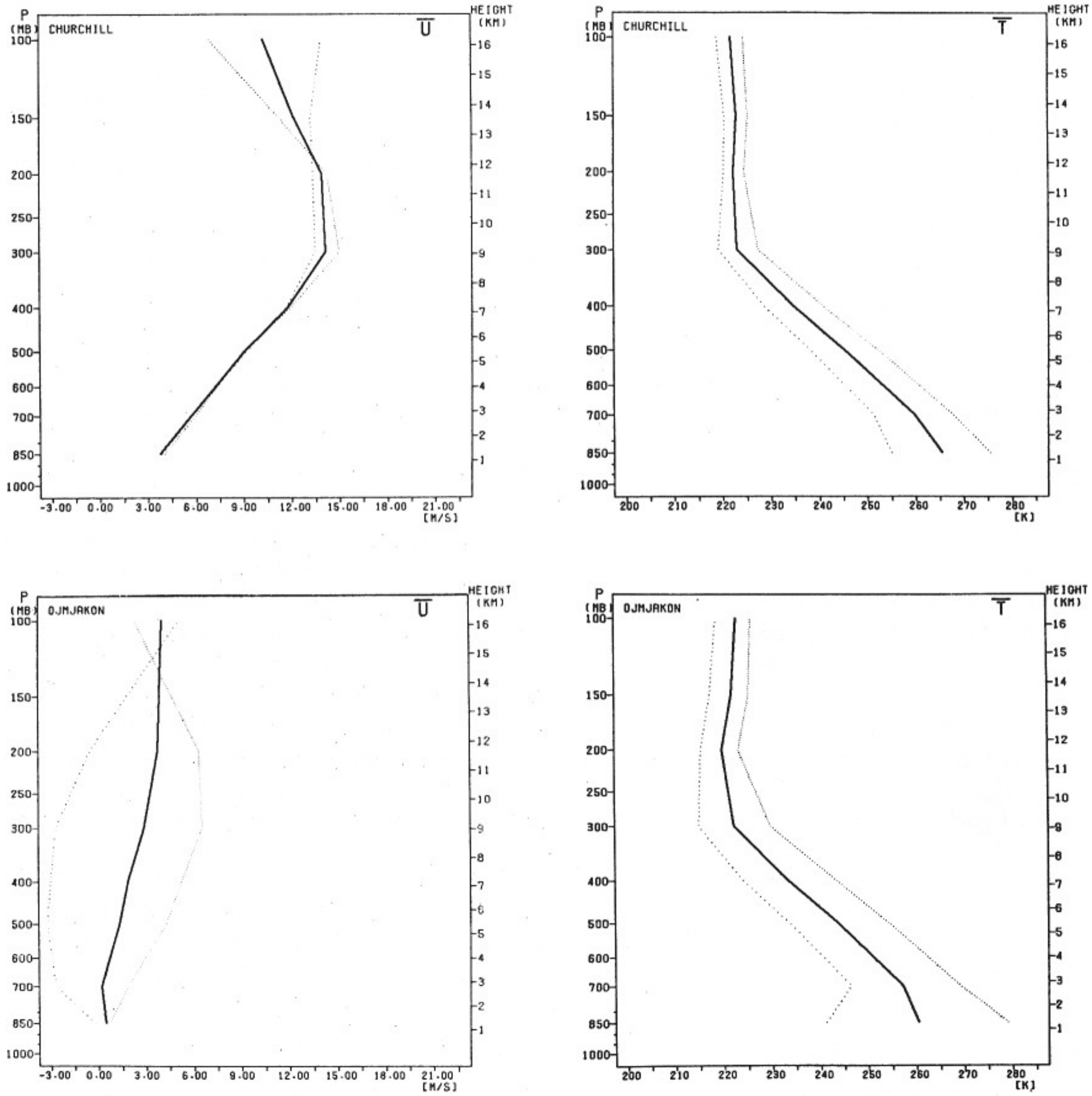
The temperature variance minimum in the upper troposphere is typical for mid-latitude stations and also for Wakkanai during the winter seasons. It defines the upper bound which temperature disturbances from the lower troposphere reach, whereas the separate maximum at 200 mb is due to temperature variations associated with changes in tropopause levels. During summer, however, no mid-tropospheric minimum of temperature variance is observed; particularly in the ultra-long periods the temperature variance maximum at 200 mb extends downward to 500 mb and lower. It may be possible to relate this effect to the Tibetan Highland and air masses heated by such a large plateau in about 3 km altitude (FLOHN, 1968). Disturbances related to the ultra-long periods of the subtropical westerlies north of the Tibetan Highlands could transport the heated air toward the east leading to considerable temperature variances in the upper troposphere.

3 The two northern cold poles

a. Climatological setting

The arctic winter is dominated by the two main troughs over Canada and Siberia and a third but minor one over NW-Europe. They are coupled over the pole but zonally separated by two more or less well-pronounced ridges over Alaska and NE-Europe (SCHERHAG ,1969). There is a low level anticyclone with a deep and strong surface inversion (Figure 3) underlying the Siberian trough as documented by the observed E to SE vertical wind shear. The Canadian trough, however, extends through the troposphere from the Canadian archipelago to the Hudson Bay with a much weaker indication of a surface anticyclone and subsequently less deep and strong surface inversions (see tropospheric temperature profile at Churchill, Figure 3).

The arctic summer circulation pattern appears to be more complex due to the enhanced synoptic activity in the polar latitudes. This can be inferred from the existence of more than two stationary hemisperic waves and by the occurrence of an arctic front (see, e.g., MCINTYRE, 1959; SEREBRENY et al., 1962),



● **Figure 3** Mean vertical profiles of zonal ($\overline{U}$) wind and temperature ($\overline{T}$) at Churchill and Ojmjakon (see Fig. 1).

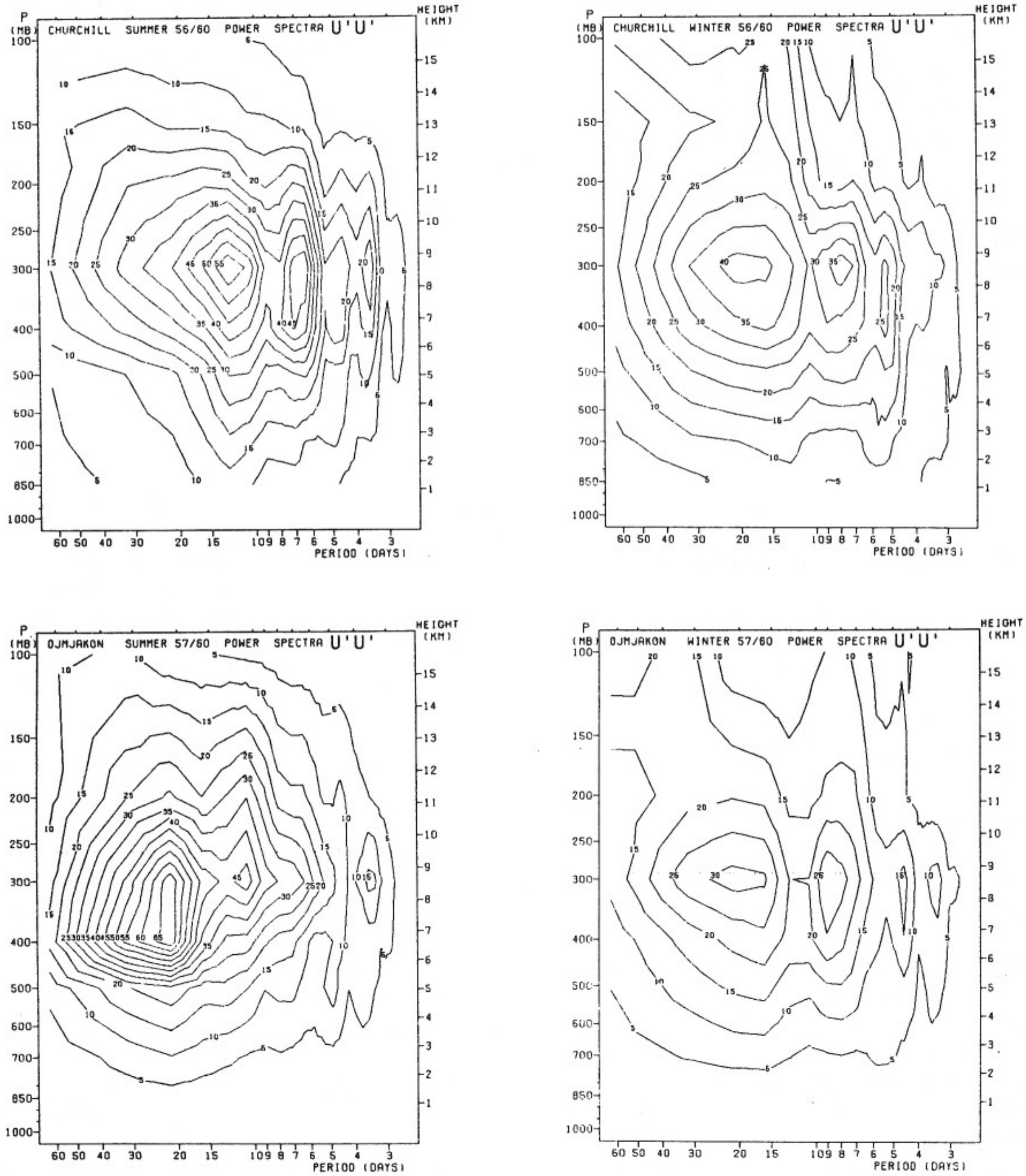
● **Bild 3** Mittlere Vertikalprofile der zonalen Windkomponente ($\overline{U}$) und der Temperatur ($\overline{T}$) von Churchill und Ojmjakon (s. Fig. 1).

being well separated from the polar front. Anticyclones (e.g., blocking highs) over Scandinavia and/or eastern Europe lead to a splitting of the cyclonic activity (or jet streams) over Eurasia, which is indicated by a regional frequency analysis of polar cyclones (REED and KUNKEL ,1960). North of such a continental anticyclone the arctic front is created as a new baroclinic zone adjacent to the polar sea and/or by a northward deviation of cyclones which rejuvenate in this area (e.g., LYDOLPH, 1977; ORVIG, Ed. 1970). The southern branch of the split jet (or cyclonic activity) remains the polar front. Both the arctic and polar front seem to influence Siberia in summer, with westerly winds predominating (Figure 3); whereas in winter the southward shift of the planetary westerly wind maximum does not permit the double frontal structure (KEEGAN, 1958). The summer circulation pattern over Siberia continues eastward toward North America: The double jet structure, with the arctic front over the polar sea and the polar front about 20–25° latitude to the south, is maintained across the Pacific and over Alaska (where, in the climatological average, an anticyclone is situated, e.g., due to strong and/or frequent blocking actions). Further eastward, however, the arctic front deviates toward the south along the quasi-permanent cold trough over the Canadian Archipelago and Hudson Bay, thus affecting the station Churchill. This meridional circulation pattern, which prevents the arctic baroclinity from remaining merely zonal, may be related to the geography of the North American continent. At both polar stations and at North (81° 36′ N, 16° 40′ W; see BUCHWALD et al., 1979), these dynamic processes lead to a southward eddy flux of westerly momentum with maxima between 500 mb and the seasonal mean tropopause. The disturbances also produce a positive sensible heat transfer which, during winter, is particularly strong in lower layers and associated with cold air outbreaks from the poles. But during the summer season the eddy flux becomes more intense in the mid-troposphere due to the synoptic scale disturbances related to the arctic front. By transporting heat northward, these disturbances arrange themselves in a hierarchy of dynamic processes which can be observed in some of the cospectra (see BUCHWALD et al., 1979), but they are more obvious in the power spectra.

b. Power spectra

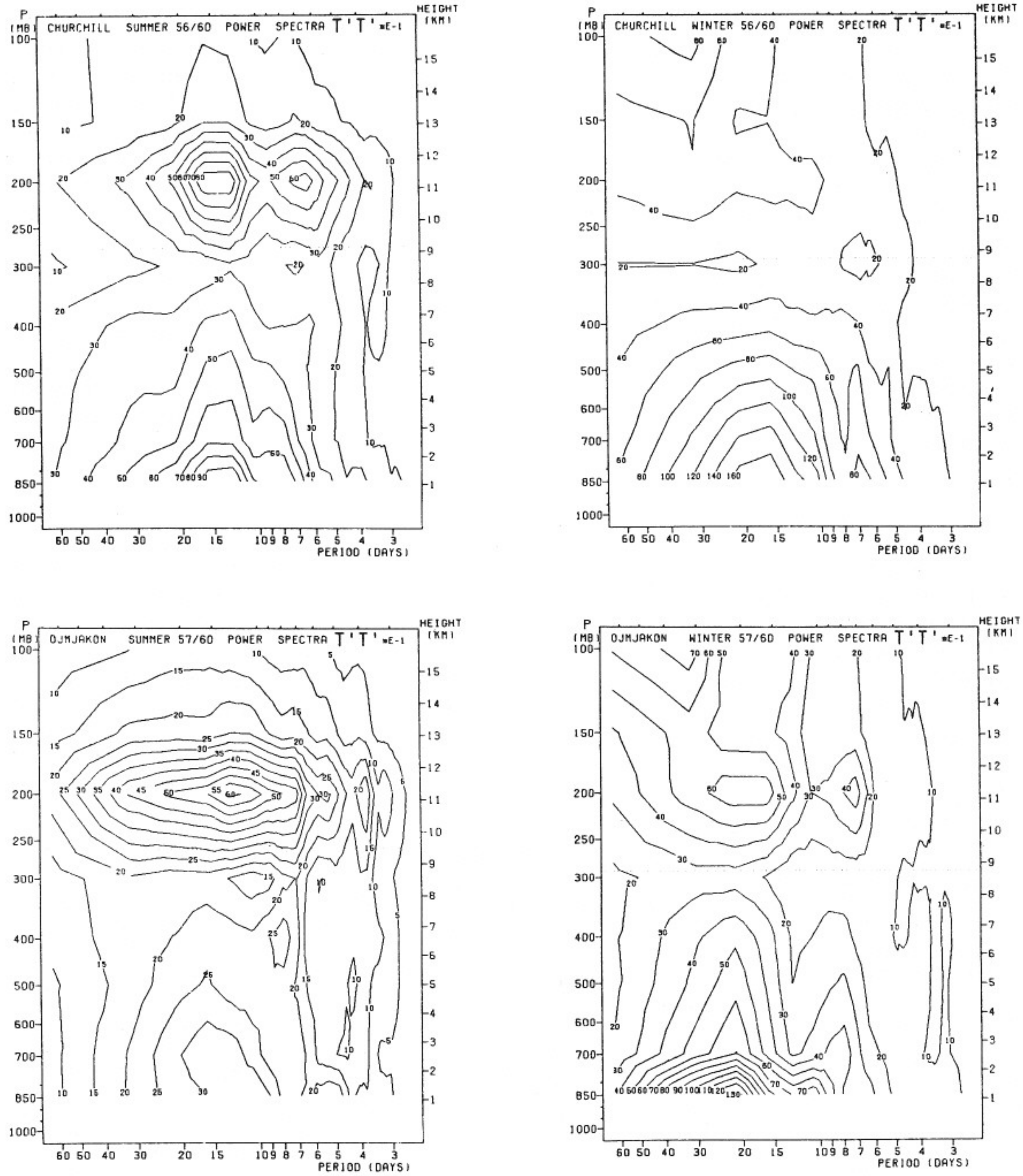
For almost all variables the seasonally averaged power spectra reveal the three spectral variance maxima. For the zonal (and meridional) wind components (Figure 4) these peaks appear just below the seasonal mean tropopause (dotted line). As in mid-latitudes, they are concentrated about the 300 mb level. However, during the polar summer season there is a deeper layer (500–250 mb) affected by the wind variability, which is caused by disturbances along the arctic front. These disturbances are much more variable in depth and structure than mid-latitude weather systems (SEREBRENY et al., 1962; MCINTYRE, 1959); and determine the climate of the stations Churchill and Ojmjakon. The occasional deeper polar front cyclones also have this effect. During the winter seasons the synoptic activity is reduced. There is no indication of an arctic front, which is probably further south. The peaks are centered at about 300 mb but weaker than in summer and than in the mid-latitudes, where they are caused by the tropospheric variations closer to the mean position of the core of the polar front jet.

The temperature variance shows fluctuations with strong seasonal changes which are also related to the synoptic processes of short, long, and ultra-long periods. The spectral peaks during winter (Figure 5) are paricularly strong in the lower troposphere, where the predominating ultra-long period range appears to be associated with the cold air outbreaks (see, e.g., SCHWERDTFEGER, 1931, loc. cit.). This is remarkably different from mid-latitude stations (HARTMANN, 1974; BUCHWALD et al., 1979), where all three temperature variance maxima are reasonably well defined at about 200 mb and in the lower or mid-troposphere: over the oceans they are confined to the mid-troposphere, i.e., variance is reduced in the surface layers due to the larger heat capacity of the sea; over the continents these peaks extend downward to the surface. The lower troposphere of the winter cold poles is hardly influenced by the short and long period weather disturbances. This characterizes their high persistence with maximum variance contributions in the 15–20



● **Figure 4** Power spectra of zonal wind at Churchill and Ojmjakon (for details see Fig. 2).

● **Bild 4** Powerspektren des zonalen Windes von Churchill und Ojmjakon (s. Fig. 2).



● **Figure 5** Power spectra of temperature at Churchill and Ojmjakon (for details see Fig. 2).

● **Bild 5** Powerspektren der Temperatur von Churchill und Ojmjakon (s. Fig. 2).

days period (Figure 5). Thus, the cold poles are of great climatological relevance in winter. Separated from the middle and lower troposphere, maxima of temperature variations can be observed around 200 mb (just above the mean seasonal tropopause). These maxima are caused by height variations of the tropopause during the passage of synoptic disturbances, where the uppermost tropopause position (at about 200 mb) coincides with the level of maximum variance: Low tropopause positions contribute little to the temperature variance, which explains the minimum at 300 mb (FRAEDRICH et al., 1979). These dynamically induced peaks about 200 mb seem to be stronger in summer than in winter, when they are almost absent at Churchill. At all stations the variance gradually increases towards altitudes which are influenced by the stratospheric winter circulation (Figure 5).

In summary, it appears that the polar atmospheric circulation can hardly be separated from the mid-latitude circulation with which it is closely connected. This is indicated by the general patterns of the local variance spectra and the climatological averages, because these show features which are also common in the belt of the planetary westerlies. During winter, mainly hemispheric circulation patterns in the ultra-long period range have a major influence on the polar vortex (and vice versa) and, in particular, on its temperature field near the surface. In summer, also short and long period fluctuations connected with the arctic front determine the weather at the two stations.

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