Evidence of Short, Long and Ultra-Long Period Fluctuations and Their Related Transports in BERLIN Rawinsonde Data

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Abstract:

Time spectral analysis is applied to the Berlin rawinsonde data. Seasonal averages of the calculated power spectra and cospectra reveal the scales of meteorological processes, at a fixed location, which govern the variations and transports in the general circulation of the mid-latitude atmosphere. Though smoothed by twelve-year averaging, three spectral peaks at short (< 5 days), long (5 to lo days) and ultra-long (> 10 days) periods appear. Considering power- and cospectra, these fluctuations can be related to cyclones (short periods), an ensemble of which is attached to the trough of a slowly travelling major wave (long periods). Both types of synoptic scale disturbances arrange themselves in an index-cycle (ultra-long periods) of enhanced and reduced synoptic activity: An ensemble of long waves with their attached short period disturbances represents the phase of enhanced baroclinity followed by a more inactive period. Thus, short period disturbances are responsible for the locally observed eddy transports in the general circulation. Their internal strucure (phase relations, amplitudes, etc.) is also presented showing their mature stage of development. This produces the observed meridional eddy transport representative for the mid-latitude indirect circulation over the western parts of the continents: equatorward eddy transport of geopotential energy throughout the troposphere, poleward (equatorward) sensible heat flux in the lower (upper) troposphere and seasonally varying momentum flux.

Zusammenfassung: Kurz-, lang- und ultralang periodische Fluktuationen und ihre Transporte in den Berliner Radiosondenbeobachtungen

Die Zeitreihen der Berliner Radiosonden-Daten werden spektral analysiert. Aus den jahreszeitlichen Mitteln der berechneten Power- und Kospektren sind die Störungen und Transporte der Zirkulation in den mittleren Breiten auf meteorologische "scales" zurückzuführen. Trotz der zwölfjährigen Mittelung lassen sich drei Maxima spektraler Varianzdichte bestimmen, die im kurzperiodischen (< 5 Tage), langperiodischen (5 bis 10 Tage) und ultralangen (> 10 Tage) Bereich liegen. Die kurzperiodischen Störungen werden Zyklonen zugeordnet, die zu mehreren an den Trogvorderseiten langer, langsam wandernder Wellen (langperiodisch) auftreten. Diese beiden Typen synoptischer Störungen erscheinen in einem Index-Zyklus (ultralange Perioden), der durch verstärkte und verminderte Aktivität gekennzeichnet ist: Ein Ensemble von Langwellen-Trögen mit ihren entsprechenden kurzperiodischen Zyklonen stellt die Phase verstärkter Aktivität dar, der eine ruhigere folgt. Somit sind für die beobachteten Transporte in allen "scales" vor allem die synoptischen Störungen kürzerer Perioden verantwortlich, deren innere Struktur (Phasen, Amplituden etc.) das Reifestadium darstellt. Dadurch können die beobachteten turbulenten Meridionaltransporte als indirekte thermische Zirkulation beschrieben werden, wie sie nur für den westlichen Teil der Kontinente repräsentativ sind: Transport von geopotentieller Energie nach Süden, zum Pol (zum Äquator) gerichtete Transporte sensibler Wärme in der unteren (oberen) Troposphäre und jahreszeitlich schwankende Impulstransporte.

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Résumé: Fluctuations de périodes courtes, longues et très longues et les transports y associés dans les radiosondages de Berlin.

On effectue une analyse spectrale des séries chronologiques des données de radiosondage de Berlin. Des moyennes saisonnières des spectres de puissance et des cospectres révèlent les échelles des processus météorologiques qui gouvernent les perturbations et les transports dans la circulation des latitudes moyennes. Malgré une moyenne sur douze années, trois maximums spectraux apparaissent, pour des périodes courtes (moins de 5 jours), longues (5 à 10 jours) et très longues (plus de 10 jours). Les perturbations de courte période sont liées aux cyclones, un ensemble de plusieurs cyclones étant associé au creux d'une onde longue, à déplacement lent (longue période). Ces deux types de perturbations synptiques s'insèrent dans un cycle d'index (très longue période), caractérisé par une activité successivement renforcée et réduite: un ensemble d'ondes longues, avec les perturbations de courte période y attachées, représente la phase de forte baroclinie, suivie par une phase plus inactive. Les perturbations de courte période sont responsables des transports turbulents observés localement; leur structure interne (phase, amplitudes, etc.) est présentée dans leur stade de maturité. Les transports turbulents méridiens observés peuvent être décrits comme une circulation thermique indirecte, représentative de la partie occidentale des continents: transport d'énergie géopotentielle vers l'équateur dans toute la troposphère, transport de chaleur sensible vers le pôle dans la troposphère inférieure et vers l'équateur dans la troposphère supṙieure, flux de quantité de mouvement à variation saisonniére.

1 Introduction

A single-station climatology is attempted by a description of the atmospheric processes generating a local climate state. This is achieved by a time series analysis of meteorological variables taken from the Berlin rawinsonde. The first moments define a local climate by e.g. seasonally averaged vertical distributions of meteorological elements. They couple the station with the related hemispheric mean circulation patterns. The second moments, i.e. variances and covariances and their spectral decomposition render a deeper insight into the meteorological phenomena, their time scales and internal structure. They characterize the variability about the seasonal average due to weather processes which perform the transports locally required by the general circulation.

Local time series analyses existing for rawinsonde stations in the tropics (e.g. WALLACE, 1971) and for weather ships in the mid-latitudes (HARTMANN, 1974) are extended by this study. The first moments are known from climatology. Here the main emphasis lies on the second moments to obtain evidence on those weather processes which generate the observed atmospheric variability. Power spectra (Section 3) and cospectra (Section 4) for summer and winter seasons provide the information needed for the meteorological interpretation. The basic weather process with its internal structure is discussed in Section 5.

2 Data, data analysis and presentation of results

The data analyzed consist of daily rawinsonde observations at Berlin-Tempelhof (52°29'N latitude, 13°25'E longitude and 46 m elevation) running from 1966 through 1977. Seasonal sets of time series of 128 days in length are extracted for the analysis; the summer seasons start on 1 May, the winter seasons on 1 November. Each set of time series contains the following meteorological variables on 19 pressure levels (p in mb): eastward (U in m s^{-1}) and northward (V in m s^{-1}) wind components, temperature (T in Kelvin), height of constant pressure surfaces (Z in m), and specific humidity (Q in g kg^{-1}). Before being transformed, the data are subjected to two modifications: (a) For all variables and pressure levels the twelve-year ensemble average is subtracted from each time series to exclude the low-frequency variance contributions of annual and semi-annual cycles. (b) Although it is small, the linear long-term trend is removed.

The time series are transformed to obtain power-, co- and quadrature spectra. Computing the spectra, the lag-correlation method is used (maximum lag: 32 days) to which application of a lag window is implicit (JENKINS and WATTS, 1969). The TUKEY window is used with an equivalent band width of 0.04167 cycles per day.

An area-conserving transformation is applied by which the meteorologically relevant phenomena are emphasized at the higher frequency end of the spectrum: the spectral densities are multiplied by frequency and displayed on a logarithmic frequency scale labelled according to the period in days. This leads to isolines which, plotted in height-period sections, represent the contributions of a frequency band to the total variance or covariance of the time series. The final plots are obtained by linear interpolation. In all sections the contours refer to frequency-weighted spectral densities. Their scaling in decimal powers and the units are obvious from the variables indicated in the upper right corner, where the letters have symbolic meaning; e.g. U'U' * E + 1 stands for the frequency-multiplied spectral variance density (power spectrum) of the zonal wind U with the contour lines being scaled by the decimal power 10^1 in units of $m^2 s^{-2}$; or, V'T' stands for the frequency-multiplied cospectrum of meridional wind V and temperature T (proportional to the turbulent meridional heat transport) with the contour lines being scaled in units of $m\ s^{-1}$ K.

3 Intensities of fluctuations (power spectra) and time scales

The power spectra (and cospectra) of almost all variables reveal time scales and intensities of fluctuations which contribute to the variance and covariance of the meteorological time series. For all individual seasons analyzed, dominating time scales occur with well separated and significant variance density maxima (spectral peaks). The averaging processes over twelve consecutive seasons smooth these peaks, because the predominating periods and their intensities vary from year to year. However, the basic time scales which govern the atmospheric large scale processes can still be quantitatively defined from both the seasonally averaged power spectra of some of the meteorological variables and the cospectra. For comparison with these averages, individual summer and winter seasons are documented (FRAEDRICH et al., 1979).

The following three spectral peaks characterize disturbances in the troposphere, which can be traced into the stratosphere. They contribute to the total variance (or covariance) with stronger intensity in winter than in summer. The variance minima on either side of the spectral peak define the scale-related time intervals:

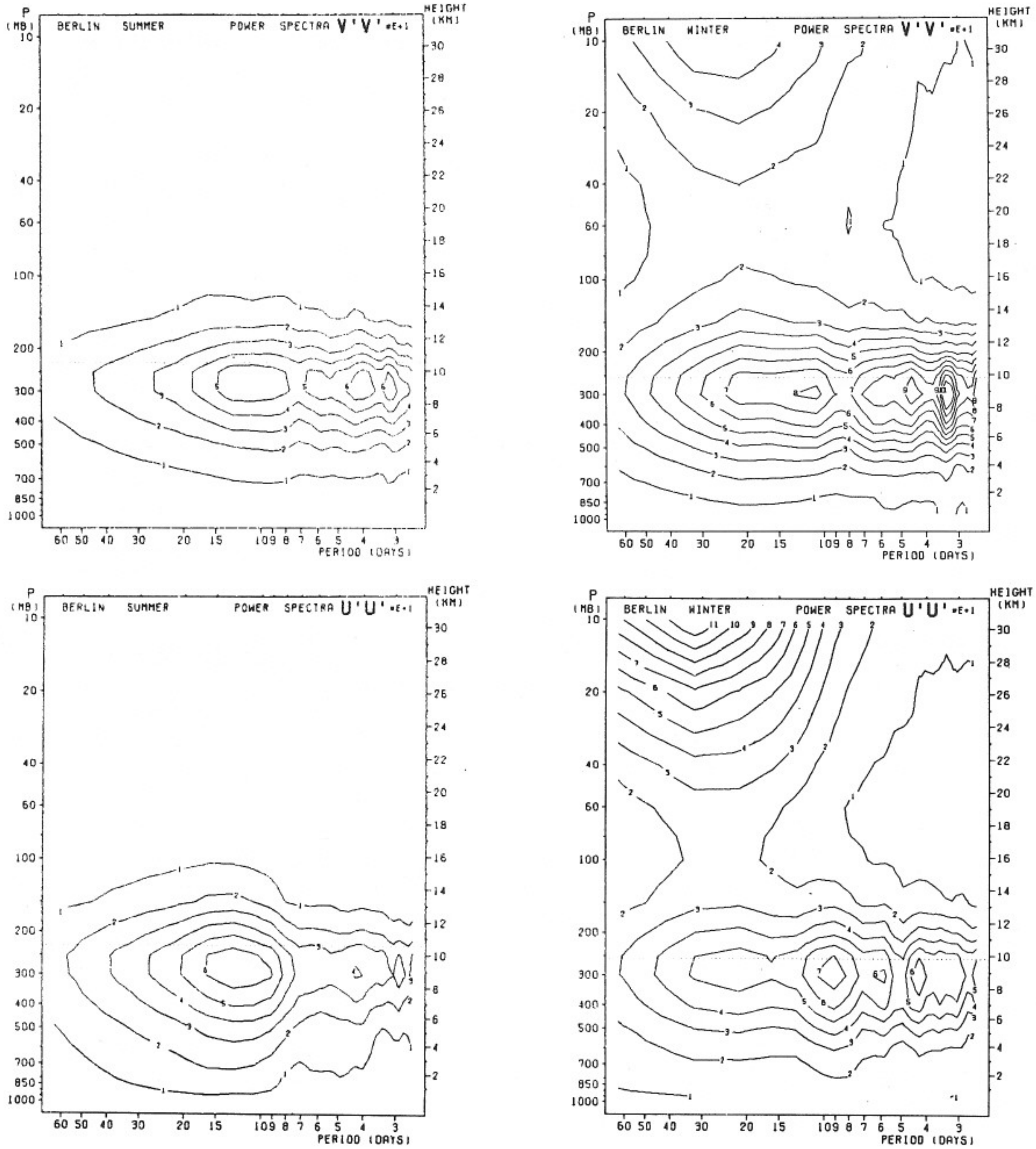
(i) "Short" period fluctuations ($<$ 5 days) contribute to the variability of the time series, caused by minor fast travelling disturbances.

(ii) "Long" period variability (5–10 days) is produced by major slowly progressive waves in the westerlies, the cold trough-lines of which are steering the smaller scale cyclones (i).

(iii) "Ultra-long" processes ($>$ 10 days) contribute to the total variance within a wide range of several weeks, which can be ascribed to the index or vacillation cycle.

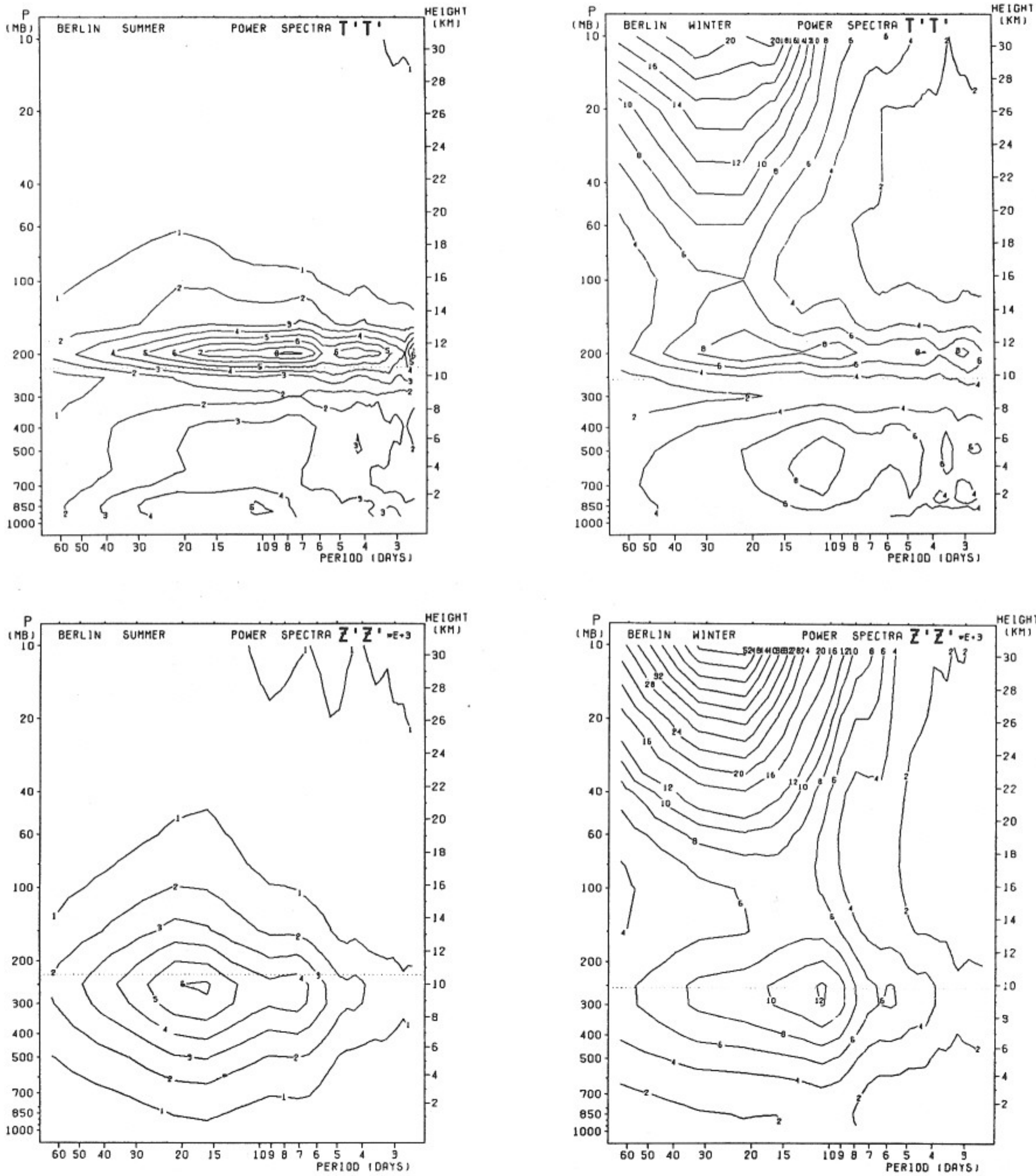
This classification, based on time series of local aerological soundings, is well known from the more qualitative description of mid-latitude synoptic meteorology (e.g. PALMEN and NEWTON, 1969) and recent wavenumber-frequency analyses (e.g. BÖTTGER and FRAEDRICH, 1980). Different climatic regions contribute additional aspects to this broad picture (e.g. HARTMANN, 1974; SPETH, 1978; or WALLACE, 1971).

When the significance of the three power spectral peaks is tested against a first order MARKOV process as "null"-hypothesis having the same total variance (WMO, 1966), they prove to be significant on a 95 % a priori confidence level for nearly every individual season. Thus, significance seems to be well establis-



- **Figure 1** Power spectra of zonal and meridional wind for summer and winter seasons. The contours in units of variance show the frequency-multiplied power spectra. They are scaled by decimal powers as 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 1** Power-Spektrum der zonalen und meridionalen Windkomponenten 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 Abzisse ist proportional dem Logarithmus der Frequenz als Periode (in Tagen) angegeben. Die mittlere Tropopausenhöhe kennzeichnet eine gestrichelte Linie.



- **Figure 2** Power spectra of temperature and geopotential height for summer and winter seasons.

- **Bild 2** Power-Spektrum der Temperatur und der geopotentiellen Höhe für Sommer und Winter.

hed for the averages. However, the ultra-long and long period fluctuations can hardly be separated if only the power spectra are considered (see Section 5). Cospectra have to be interpreted simultaneously to achieve a scale separation. In the two-dimensional space-time domain these three spectral peaks are much better resolved and remain clearly separated even after seasonal averaging (FRAEDRICH and BÖTTGER, 1978).

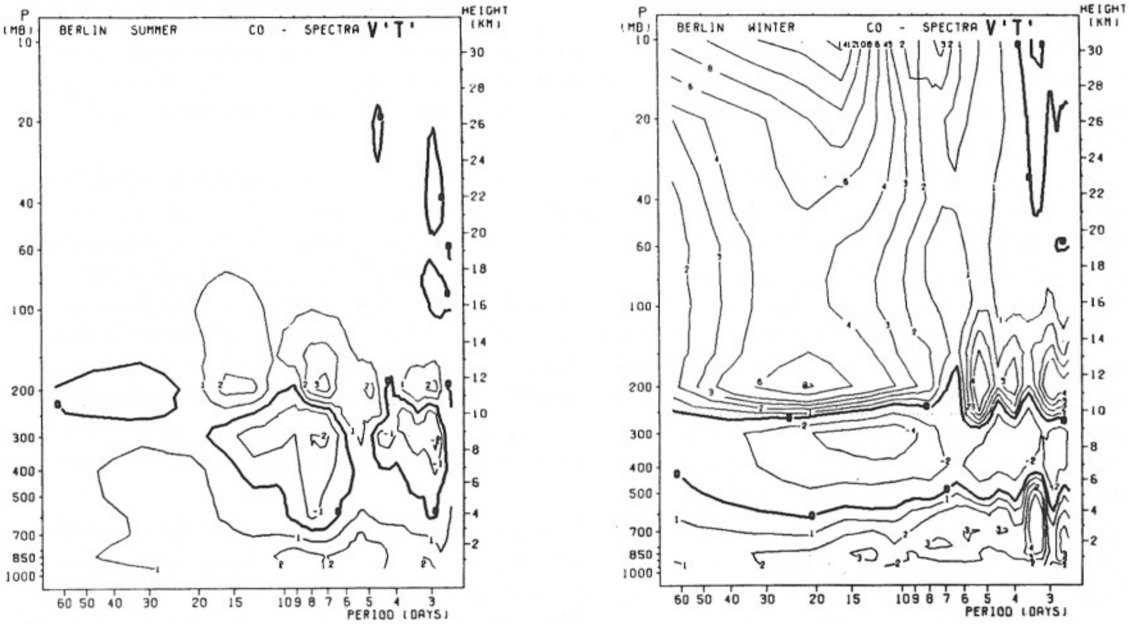
The spectral peaks of the zonal and meridional wind components (Figure 1) appear just below the seasonal mean tropopause (dotted line). They occur in the level of the polar front jet at about 300 mb, the fluctuations of which are related to processes of short, long and ultra-long time scales. For long and ultra-long periods zonal and meridional wind variations are of comparable magnitude, whereas the meridional wind variance exceeds the zonal in the short period range. During winter the stratospheric dynamics are well developed producing variance contributions in the ultra-long period range (20–40 days) above a lower stratospheric minimum at 100 mb. During summer there is almost no variance in the stratosphere. This stratospheric feature is also observed in the spectra of the variables temperature and geopotential height. The power spectra of geopotential height (Figure 2) show similar patterns where the maximum variance contributions are realized near the seasonal mean tropopause level due to lower- and mid-tropospheric temperature fluctuations.

The temperature variance shows broad maxima in the lower (summer) and middle (winter) troposphere (Figure 2). Separated by a minimum at about 300 mb, there is a second layer of strong temperature fluctuations at 200 mb, i.e. just above the seasonal mean tropopause where all three time scales are individually represented. These maxima are caused by height variations of the tropopause during the passage of synoptic disturbances: The uppermost tropopause position (at about 200 mb) coincides with the level of maximum variance, whereas low tropopause positions (within a trough) contribute little to the upper troposphere temperature variance, which explains the minimum at 300 mb. But tropospheric temperature values continue to decrease with height when the tropopause (within a ridge) is lifted into a previously existing isothermal stratosphere. Thus, the tropopause height variations lead to the three temperature variance maxima at 200 mb effecting all three scales by the same physical mechanism.

4 Eddy transports (cospectra) and reinterpretation of the time scales

The local cospectra reveal the more complex structure of the atmospheric disturbances in the time domain where correlations with a wind component can be interpreted as an eddy transport process, and the related cospectrum by frequency or period dependent contributions to this eddy flux. It must be realized that the local cospectra depend in sign and magnitude on the year-to-year changes, and that they are relevant only locally and in the time domain.

The broad picture of the spectral decomposition of the meridional eddy transport of sensible heat shows a remarkable vertical structure which is similar for the three time scales contributing to this transport (Figure 3): The troposphere is divided into two layers, where the positive (northward) heat transport in the lower troposphere is almost, but not totally, balanced by a negative (southward) transport above it. In the stratosphere the heat transport changes its sign again, with the three spectral maxima at near 200 mb (just above the mean seasonal tropopause) related to the tropospheric processes described in Section 3. These patterns are not essentially different for the average winter and summer seasons except, again, for a stratospheric winter maximum, which occurs only in higher altitudes in the ultra-long period range and contrasts with the calm summer seasons. Integrated over all periods, the total eddy heat flux and its vertical distribution can be distinguished from other stations of the same latitude belt (SPETH, 1974), and the zonally averaged conditions at 50 °N (OORT and RASMUSSON, 1971). The latter shows no vertical sign change in the direction of the meridional eddy heat transport in the upper layers; i.e. the zonally averaged flux is northward in all levels. The structure of the spectral decomposition



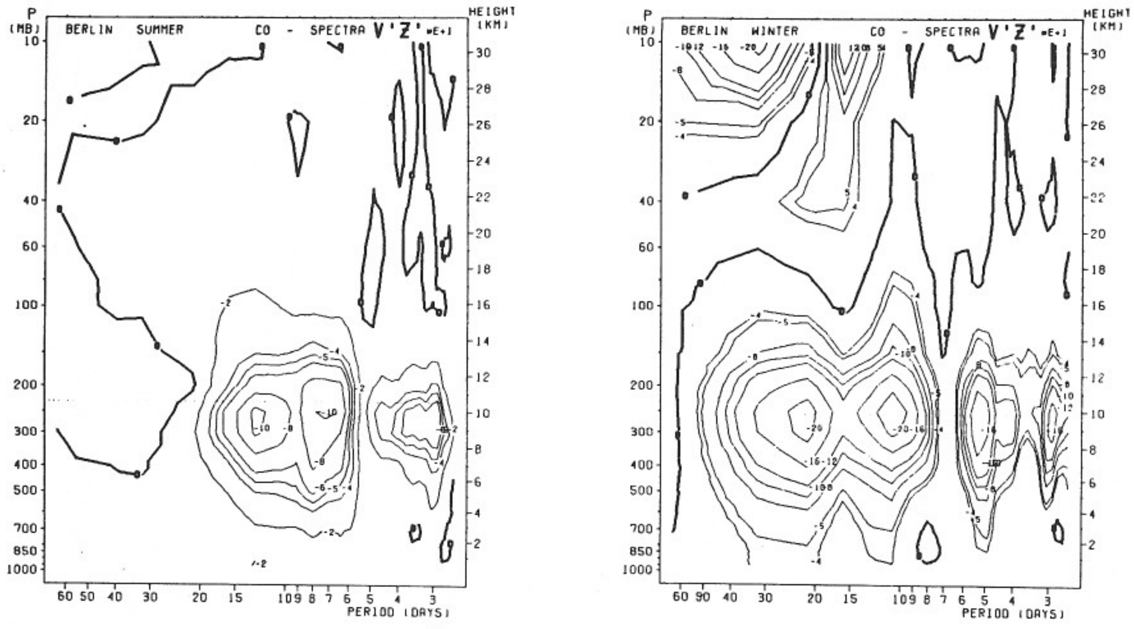
● **Figure 3** Cospectra of meridional wind and temperature for summer and winter seasons. The contours in units of covariance show the frequency-multiplied cospectra in terms of a northward (positive) heat transport (see Figure 1).

● **Bild 3** Kospektren zwischen meridionalem Wind und Temperatur für Sommer und Winter. – Die Isolinien haben die Einheiten der Kovarianz, da sie frequenzgewichtete Kovarianzdichten sind und stellen nordwärts (positiv) gerichtete Wärmetransporte dar.

shows, for all periods contributing to the cospectrum, that there is a phase shift between the meridional wind and the temperature wave with more (less) than 90° time lag for $V'T' < 0$ above ($V'T' > 0$ below) the 500 mb level. Such a pattern is adopted by disturbances no longer in their developing phase and thus occurs at stations frequented by mature or occluded cyclones at the western parts of the continents (see also LAU, 1978). A more detailed discussion follows in Section 5.

The spectral contributions to the eddy flux of potential energy are negative during winter and summer in the whole troposphere and stratosphere (Figure 4). They exhibit the three distinct but similarly structured maxima which are related to the three scales of tropospheric disturbances and are largest at or just below the mean tropopause.

The eddy transport of relative angular momentum has its maxima just below the seasonal mean tropopause (Figure 5). The spectral decomposition shows that during winter the disturbances with shorter periods provide the northward eddy transport of westerly momentum which, in summer, is performed by those with longer periods. The smaller scale disturbances in summer and the longer scale ones in winter have weak or irregular features which, after averaging, result in a southward transport. It should be noted, however, that the year-to-year variability of all the seasonal cospectra is largest for the momentum transport and, in addition, the coherence between zonal and meridional wind is hardly significant even for an individual season. Some causes may be: (a) The direction of eddy westerly momentum flux is southward north of the polar front jet, and northward south of it. Thus, the momentum transport at Berlin reflects, at least in part, the variability of the polar front over Europe; the statistics of "Großwetteranlagen" (HESS and BREZOWSKY, 1977) shows the occurence of zonal, meridional and



- **Figure 4** Cospectra of meridional wind and geopotential height for summer and winter seasons (northward transport of potential energy).

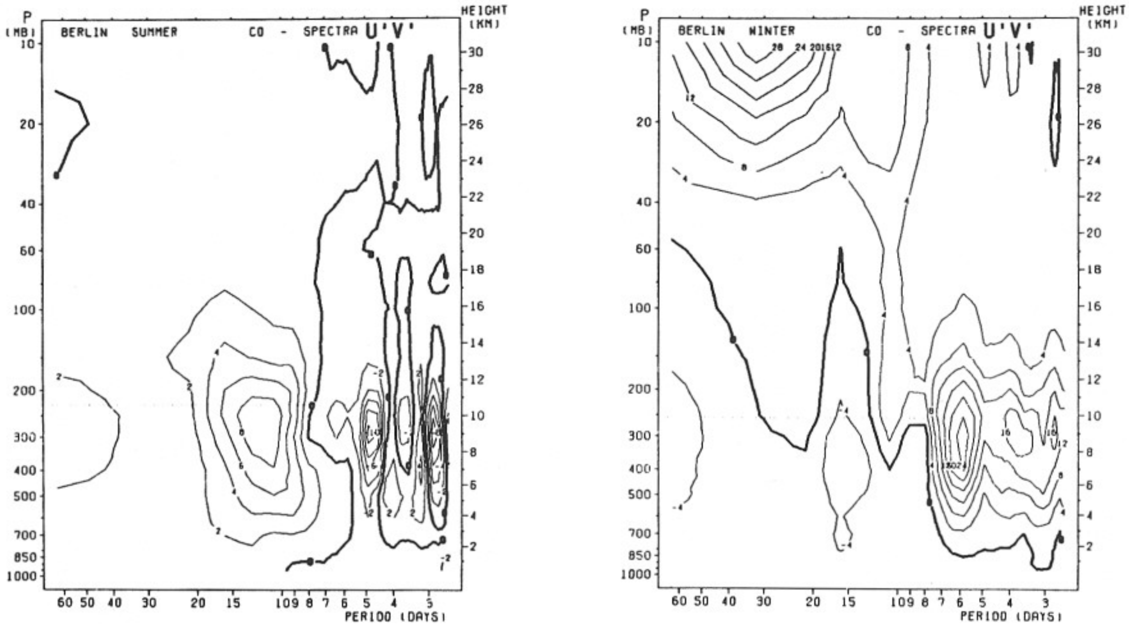
- **Bild 4** Kospektren zwischen meridionalem Wind und geopotentieller Höhe für Sommer und Winter (nordwärts gerichteter Transport potentieller Energie).

mixed types and their variability from season to season. (b) A disturbance travelling over a mid-latitude station has generally one minimum and maximum in the waves of geopotential height, temperature and meridional wind, but often two maxima and minima for the zonal wind component. Both arguments lead to the basic difficulties in interpreting the spectral decomposition of the U' V'-covariance at selected frequency bands.

All local cospectra give additional information and confirm the three time scales which have been deduced from the local power spectra. Most striking is the fact that each seasonal cospectrum shows a similarity among the three different scales such that the related transports are performed by the same mechanism: The scales are mainly distinguished from one another by their flux intensities, in particular if the meridonal eddy fluxes of sensible and potential energy (and latent heat, see FRAEDRICH et al., 1979) are considered; the vertical structures are alike. Thus, an additional interpretation can be attributed to the three time scales defined by the local spectra (Section 3).

(i) The "short" period fluctuations (or synoptic disturbances) represent the basic elements of the general circulation. They appear as baroclinic wave disturbances with troughs and ridges passing over a fixed observer. At some locations disturbances in their developing stage, at other sites mature or occluded cyclones are more frequently observed.

(ii) The "long" period fluctuations are locally represented by phases of enhanced and reduced baroclinity: An ensemble of the basic short period disturbances (i) occurs in a sequence ahead of the trough line of the major slowly progressive waves. It is followed by a calm stage of reduced baroclinity after the passage of this line. Thus, an ensemble of short period disturbances is responsible for the locally observed eddy flux with its maximum in the long period range.



● **Figure 5** Cospectra of meridional and zonal wind for winter and summer seasons (northward momentum transport).

● **Bild 5** Kospektren zwischen meridionalem und zonalem Wind für Sommer und Winter (nordwärts gerichteter Transport von Impuls).

(iii) The "ultra-long" period fluctuations define an index or vacillation cycle consisting of an active and inactive phase. Synoptic activity is locally realized by a series of long period fluctuations; i.e. an ensemble of the slowly progressive long waves (ii) travels over the station steering the related ensembles of shorter period disturbances (i) attached to them. This active part of the index cycle is followed by a dynamically more quiet phase.

From the general circulation point of view the overall process which simultaneously explains the power- and cospectra can be visualized as follows: The outbreak of baroclinic activity during one part of the index cycle (or the ultra-long period fluctuation) reduces the meridional temperature gradient by an enhanced poleward sensible heat flux due to frequent passages of synoptic scale disturbances. Thus, the level or baroclinity reduces itself simultaneously. This leads to the more quiet phase of the index cycle with the poleward heat flux being diminished by less frequent synoptic scale disturbances. During this phase radiative heating starts to built up the reduced meridional remperature gradient until the cycle rejuvenates and repeats itself. But, each cycle may be different from the preceding one, due to the non-linearities of the system. In this sense the ultra-long period is locally interpreted as a cycle in the time domain, within which two distinct synoptic scales arrange themselves such that they transport the sensible heat poleward, which has been made available during the dynamically more inactive (i.e. less baroclinic) phase of the cycle.

Now, it seems reasonable that an individual index or vacillation cycle can be finished after a sufficiently strong long period wave with an active ensemble of short period disturbances. This justifies the lower limit given for the ultra-long processes. (Section 3). It also makes plausible the large variations which are observed in the ultra-long period range of power- and cospectra. Thus, the peaks of long and ultra-long periods appear jointly in some of the power spectra after the seasonal averaging, i.e. without the separating minimum. But the short period fluctuations remain separable.

5 Amplitude and phase structure of the local, short period disturbances at Berlin

In this section the average internal structure of the short period disturbances is discussed, bebause they have been determined as basic elements performing the locally observed eddy transport in the general circulation (Section 4). As seen by an observer fixed in space, these disturbances are affected by numerous influences. It is therefore not surprising that the spectral maximum does not occur every year in the same narrow frequency band, but the peaks are always somewhere within the 2 to 6 day period. Although the preferred periods vary within this range, the short period disturbances are expected to have similar structures, when phases and amplitudes of these waves are to be determined. By averaging over a wide period interval (from 2 days to 5.56 days with 21 data points) to represent the short period disturbances, the major peaks are hopefully included, but simultaneously so are periods of weak variance and less significance.

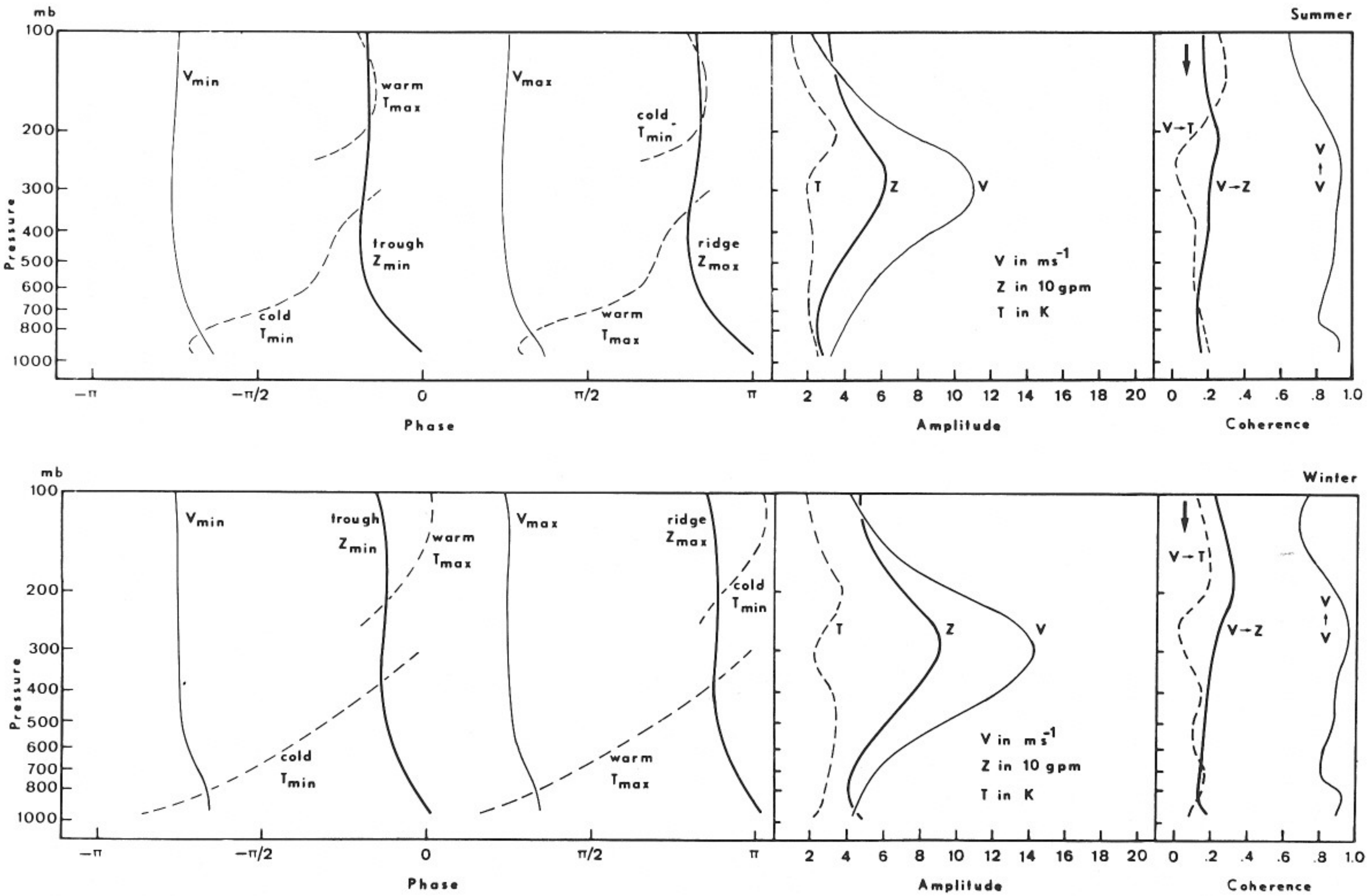
The phase relationships for the meteorological variables, geopotential height, temperature and meridional wind, are calculated in the following way: The "horizontal" phase between two different variables at the same pressure level is deduced from the seasonally averaged cospectrum and quadrature spectrum of the two time series. The "vertical" phase difference for the same variable is derived analogously, but between two adjacent levels; thus, a two-variable, one-level correlation and single-variable, two-level correlation is used (HARTMANN, 1974).

The phase diagram of the short period disturbance is centered with respect to the meridional wind and its vertical tilt; however, other choices lead to essentially similar results. Then the horizontal phase differences are calculated from the "horizontal" wind-temperature and wind-geopotential height correlations for all levels (Figure 6). The amplitudes are determined by the power spectra after integration over the frequency band occupied by the short period fluctuations. Thus, all values represent measures integrated over this short period interval, which are averaged over the twelve individual seasons. The reliability of these final results is tested in several ways:

(a) It turns out that the seasonally averaged results are similar to those obtained for an individual season; additionally, the short period disturbances of winter and summer can also hadly be distinguished.

(b) A lower confidence limit can be placed on the estimated squared coherence $coh^2 = (C^2 + Q^2)/P_1P_2$; (cospectrum C, quadrature spectrum Q and P_1, P_2 power spectra of two series). It is given by the limit of true coherence which depends on the number of degrees of freedom and the prescribed probability level. The low value of coherence ($coh^2 = 0.034$; vertical arrow in Figure 6) determined at the 95 % significance level is due to the large number of degrees of freedom. For a frequency band each spectral estimate has $(2N\text{-}m/2)/m$ degrees of freedom with $N = 128$ observations and the maximum lag $m = 32$. The degrees of freedom were weighted by 4/3 due to the application of the TUKEY window (JENKINS and WATTS, 1968). Thus, the 21 estimates in the short period spectral band (from 2 to 5.56 days) and the average over twelve seasons gives more than 2500 degrees of freedom. This allows a reliable judgement on the statistics.

(c) A phase error can be placed on the estimated phase $\phi = \arctan Q/C$. It is determined by the degrees of freedom, the prescribed probability level and a coherence (WMO, 1966). The phase error is less than $15°$ or $6°$ at the 95 % significance level assuming the confidence limit of coherence 0.034 or an observed coherence value of 0.2, which is well above this limit.



- **Figure 6** Diagram of phase relationships, amplitudes and coherences of meridional wind, geopotential height and temperature for short period disturbances (see Section 5); top: summer; bottom: winter.

- **Bild 6** Darstellung der Phasenbeziehungen, Amplituden und Kohärenzen zwischen meridionalem Wind, geopotentieller Höhe und Temperatur für kurzperiodische Störungen (siehe Kapitel 5); oben: Sommer; unten: Winter.

It appears that statistically meaningful results are obtained from the local rawinsonde observations bebause the coherence is far beyond the confidence limit (b) and the phase error is sufficiently small (c). As the results are more or less self-evident from the dynamics point of view, they can be discussed briefly.

Figure 6 shows the internal structure of the synoptic scale disturbances producing the local fluctuations in the short period range: the vertical tilt of the axes of meridional wind (V_{max}, V_{min}), temperature (T_{max}, T_{min}) and geopotential height (Z_{max}, Z_{min}), their phase differences, their amplitudes and the squared coherences of the two-variable, one-level (VT; VZ) correlation and the single-variable, two-level correlation (VV).

Some features should be mentioned: (a) The vertical axes of the trough and the meridional wind tilt backward with larger slopes in the lower troposphere. Above 500 mb their phase lines become more vertical. The temperature axis, however, shows a remarkable forward tilt, crossing the trough or ridge in the middle troposphere. This pattern is typical for disturbances in a more mature stage of development, while during the developing stage, generally modelled by quasi-geostrophic baroclinic instability theory, trough and cold air axes cross at higher levels, if they meet at all. But, in occluded cyclones warm air appears aloft (GEB, 1971) on the "back side" of the low, enhanced by subsidence. This explains the southward heat transport in upper levels and reduces the available potential energy. (b) An asymmetry of the short period disturbances becomes evident by the phase lag between meridional wind and trough axes: The strongest northward wind (V_{max}) preceeds the trough (Z_{min}) by less than 90°. Even if the phase error is considered, this asymmetry seems to be meaningful. (c) The temperature phase jump at the tropopause is a well-known feature of synoptic scale disturbances, which, as expected, is accompanied by reduced amplitude and coherence. (d) The amplitudes are a measure for the contribution of the short period fluctuations to the total variance. As such they quantify the discussion of Section 3 in an integrated way. The largest fluctuations of the meridional wind and geopotential height occur just below the mean seasonal tropopause. Due to the occluded stage of this system, the temperature amplitude is nearly constant with height; it is somewhat larger in the lower and middle troposphere than in the tropopause levels but rises again in the lower stratosphere.

The short period disturbances represent a statistical state at a fixed location. Any individual case and, of course, stations in other climatic regions deviate from this average pattern (see BUCHWALD et al., 1979). These synoptic scale disturbances form the basic elements which collectively make up the meridional eddy transport of the observed mid-latitude indirect circulation (described in Section 4) as it is representative for the western parts of the continents (LAU, 1978) but not for the eastern parts or the oceans where the disturbances originate.

6 Final remarks

The hierarchy of scales assumed for the mid-latitude disturbances may be interpreted with respect to their fractional time coverage at Berlin: about 50 % of the total observation time is taken by the disturbed phase of the ultra-long period fluctuations; about 50 % of this time is covered by the disturbed part of long periods of which again 50 % is occupied by the disturbed part of the short period waves (at Berlin represented by occluded cyclones). Altogether about 12.5 % or 1/8 of the total observation time is therefore covered by synoptically disturbed weather conditions, which should be supported by precipitation statistics: At Berlin average fractional rainfall duration is about 14.6 % where the non-registered but observed precipitation is included in the ten-year (1968–77) single-station measurements of hourly rainfall (SCHLAAK, 1978). Distrometer registration at Bonn with much higher resolution in time shows 12.4 % relative duration for winter precipitation but less in summer with higher convective activity (KREUELS, 1976). However, in the tropics about one percent observation time is actually covered by rainfall which is in agreement with the instanteneous fractional area coverage by "hot towers" (RIEHL and

MALKUS, 1958). The analogue relationship between time and area scales may perhaps hold for the mid-latitudes in the western parts of the continents, where the active rain producing disturbances (with slantwise convection in their more occluded phase) form the basic elements of the observed indirect eddy circulation.

In summary, this study gives an examination of the Berlin rawinsonde observations by extending the single-station climatology of the first moments of the time series to the second moments and their spectral decompositions. Such a statistical analysis allows a detailed description of the meteorological phenomena which, as climate generating processes, are not only of local significance. The information also provides appropriate quantities to verify statistics produced by atmospheric circulation models. In particular, a complete and quantitative single-station climatology with high regional resolution leads to results generally smoothed out by the common zonal averaging process. The conclusion drawn from this analysis may also be applicable to a medium range forecasting; the prediction of dry and wet spells of several days' duration (BAUR, 1956; rules 11 to 15) appears to be closely related to the ultra-long period fluctuations as interpreted in Section 4. This method of analysis has also been applied to stations in different climatic regions (documented in BUCHWALD et. al., 1979) and to wavenumber-frequency analysis along the 50 °N latitude circle (BÖTTGER and FRAEDRICH, 1980) in order to substantiate our results and their validity.

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