Further Studies on Single Station Climatology: (iii) Time Spectral Analysis of Halley Bay (Antarctic) Rawinsonde Data

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(Manuscript received 26.07.1982, in revised form 03.01.1983)

Abstract:

This single station climatology describes seasonal means, variances, covariances, and the spectral transformations of time series of rawinsonde observations at selected sites. Analyses of stations in the western and eastern part of the Eurasian continent and in the north polar region (Part I and II, see MÜLLER, BUCHWALD and FRAEDRICH, 1979) are extended to Halley Bay in the Antarctic.

(Part III) Three time scales of fluctuation intensities appear in Halley Bay rawinsonde data, but only the long (5–10 days) and short (5 days) period disturbances are significant. Short period disturbances in the vicinity of Halley Bay, their amplitudes and phase relationships are discussed in some detail; they can penetrate to the surface, lift the inversion, lead to cloud- and, in summer, to fog formation; furthermore, weaker (stronger) low level winds occur before (after) the passage of the surface trough.

Zusammenfassung: Studien zur Klimatologie einzelner Stationen: (iii) zeitliche Spektralanalyse der Radiosondendaten von Halley Bay (Antarktis)

Die Klimatologie ausgewählter Stationen wird mit den Zeitreihen von Radiosondendaten beschrieben, ihren jahreszeitlichen Mittelwerten, Varianzen und Kovarianzen, sowie ihrer spektralen Transformation. Die Untersuchungen im westlichen und östlichen Teil des eurasischen Kontinents und in der nördlichen Polarregion (Teil I und II, siehe MÜLLER, BUCHWALD und FRAEDRICH, 1979) werden erweitert um die Station Halley Bay in der Antarktis.

(Teil III) Drei Zeitskalen können in den Daten beobachtet werden, aber nur Störungen mit langen (5–10 Tage) und kurzen (5 Tage) Perioden sind signifikant. Die langen Wellen beeinflussen in der Grenzschicht im wesentlichen nur das Windfeld. Amplituden und Phasen der kürzeren Wellen in der Nähe der Station Halley Bay werden ausführlicher diskutiert; sie können sich bis zum Boden durchsetzen, die Inversion anheben, führen zur Wolken- und (ggf. im Sommer) Nebelbildung und schwächen (verstärken) die Winde der bodennahen Grenzschicht vor (nach) dem Durchzug des Bodentiefs.

Résumé: Etudes sur la climatologie à une seule station: (iii) Analyse spectrale temporelle des données de radiosondages à Halley Bay (Antarctique).

Cette climatologie des stations sélectionnées décrit les moyennes, variances, covariances saisonnières et les transformations spectrales de séries chronologiques de données de radiosondages. Des analyses de stations dans les parties occidentale et orientale du continent eurasien et dans la région polaire boréale (parties I et II, voir MÜLLER, BUCHWALD et FRAEDRICH, 1979) sont étendues à la station de Halley Bay dans l'Antarctique.

(Partie III). Trois échelles de temps se manifestent dans les données de Halley Bay, mais seules les perturbations de longe période (5–10 jours) et de courte période (5 jours) sont significatives. Les ondes longues n'influencent, dans la couche limite, que le champ du vent par des forces de pression à grande échelles. On examine en détail les perturbations de courte période, leurs amplitudes et leurs phases au voisinage de la station de Halley Bay; elle peuvent pénétrer jusqu' à la surface, élever l'inversion, conduire à la formation de nuages et, en été, de brouillard et, de plus, affaiblir (renforcer) le vent de la couche superficielle avant (après) le passage du creux de surface.

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1 Introduction

Local time series analyses of rawinsonde data from stations in the tropics (e.g. WALLACE, 1971) and in the mid- and polar latitudes of the Northern Hemisphere (HARTMANN, 1974 and SPETH, 1978 over the Atlantic; FRAEDRICH et al., 1979 over the European continent; MÜLLER et al., 1979 over Eastern Asia, the Canadian and Siberian cold poles) are extended to the Antarctic. A statistical analysis is presented for the rawinsonde data of the British Antarctic station Halley Bay at the eastern coast of the Weddell-Sea. The first moments or means reveal the local or regional climatic situation within a larger scale environment. The second moments (variance and covariance, or local eddy transports) give a measure of the transient nature of the atmospheric circulation leading to the observed regional climate. Their time spectral decomposition allows some insight into the dynamic processes generating the atmospheric variability.

The data set and method of analysis are briefly described in section 2, the climatological averages are discussed in section 3, variance, covariance and their spectral decompositions are presented next. Finally, the phase and amplitude structure of short period disturbances is evaluated to yield a "sinusoidal" and averaged short period disturbance for Halley Bay.

2 Data and data analysis

The data analyzed consist of daily rawinsonde observations at Halley Bay (75 °S, 26 °W) running from 1957 to 1968. Seasonal sets of time series of 120 days are extracted for the analysis; the long antarctic winter season starts on May 1, the summer on November 1. Each set of time series contains the following meteorological variables on 13 pressure levels: eastward and northward wind components (u, v in ms^{-1}), geopotential height (Z in gpm), temperature (T in K) and specific humidity (Q in gkg^{-1}). Before being transformed the data set is subject to several modifications: (i) missing data are linearly interpolated; however, the year 1960 is completely eliminated from the analysis because the gaps of missing wind data are too long. (ii) A ten seasons ensemble average is substracted from each time series to exclude the low frequency contribution of annual or semi-annual cycles. (iii) The linear long term trend is removed. The time series are transformed to obtain power-, co-, and quadrature-spectra using the traditional lag correlation method (maximum lag: 32 days) to which application of a lag window is implicit; the Tukey window is used with an equivalent band width of 0.042 cycles per day. For each season the power-, co-, and quadrature-spectra are evaluated and then averaged.

3 Climatological setting: wind and temperature profiles

An easterly or inversion wind flow, which is closely related to direction and steepness of the slope of the terrain, dominates the lower tropospheric wind field at Halley Bay (Figure 1) and leads to a low level wind maximum. In upper levels the easterlies are replaced by westerlies due to the influence of the mid- and higher latitude circulation. Two maxima of eddy kinetic energy of disturbances ($\overline{u'^2}$, or zonal wind variance; see Figure 2) should be noted: The upper tropospheric maximum associated with the jet is large compared with other climates. The secondary low level maximum of eddy kinetic energy is observed at 900 mbar where the easterlies are most intense. Above 300 mbar the stratospheric summer circulation reduces the westerly flow, whereas westwinds continue to increase with height in winter. The meridional wind component and its variance ($\overline{v'^2}$) show similar features. Disturbances at Halley Bay are influenced by the Antarctic Peninsula and the Weddell-Sea (SCHWERDTFEGER, 1975), which leads to a synoptic situation where disturbances in their dissipative stage are observed to predominate. Additionally, the inversion or gravity wind flow in lower layers modifies the surface wind field of the synoptic weather systems considerably (see Section 5).

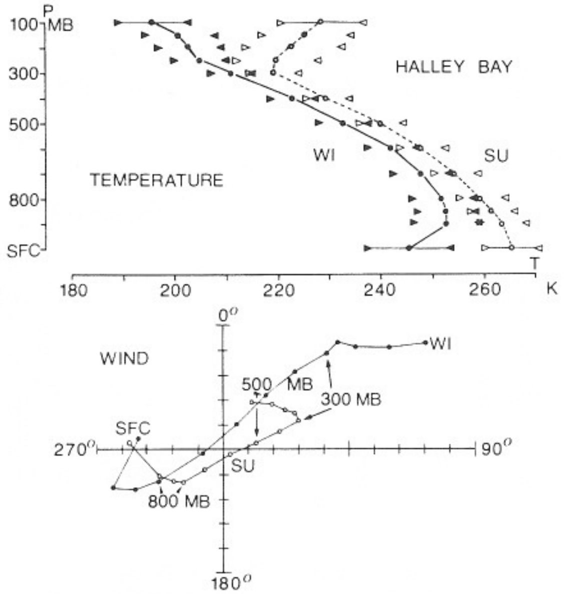


Figure 1
Mean vertical variation of temperature with standard deviation (top) and wind speed and direction (hodograph, bottom) at Halley Bay (Antarctic).

Bild 1
Mittleres vertikales Profil von Temperatur (oben) und Wind (unten) in Halley Bay (Antarktis).

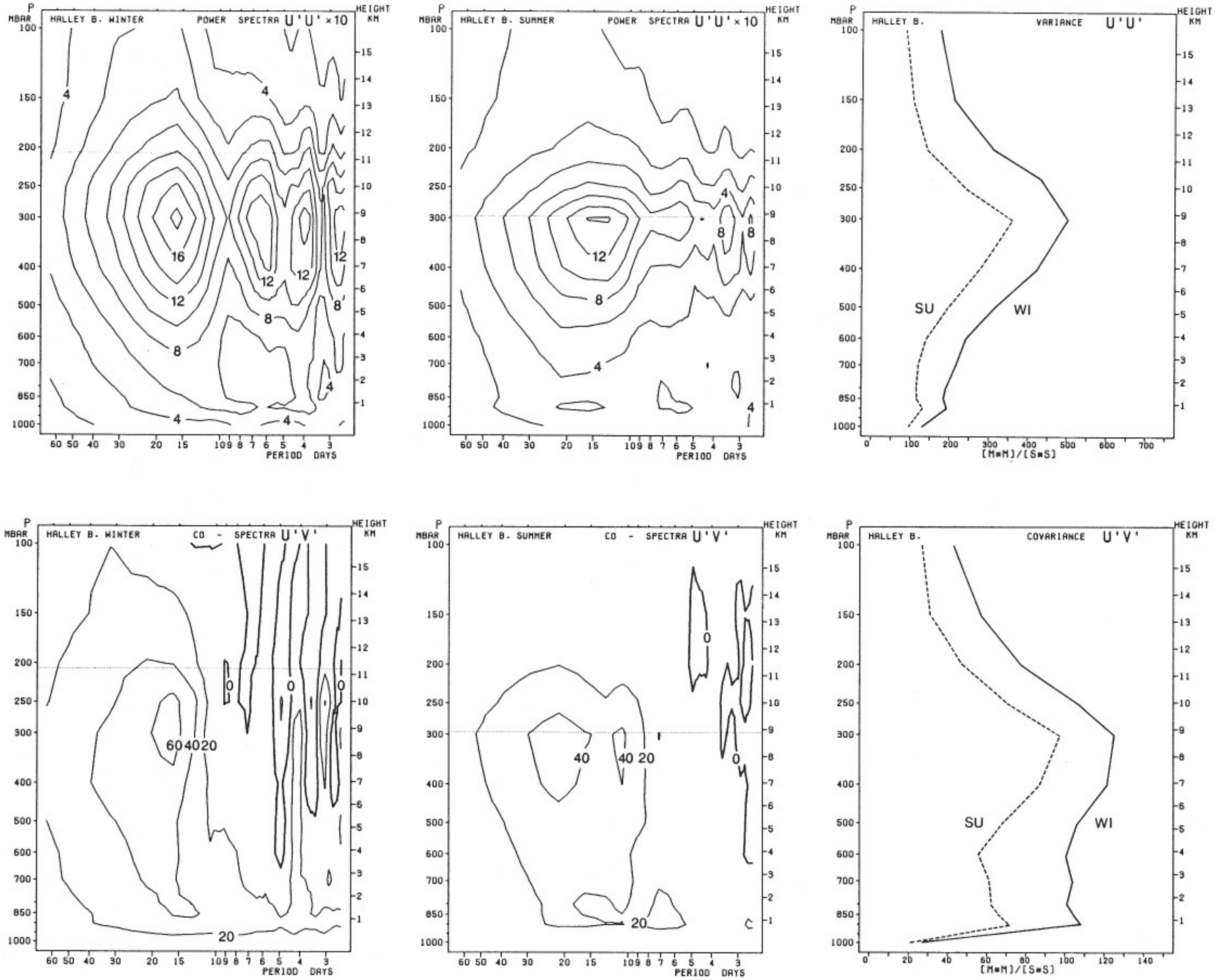
Mean temperature profiles (Figure 1) show the well-known surface inversion in winter and a well-defined tropopause in summer. Temperature fluctuations ($\overline{T'^2}$) have a maximum above the tropopause and at the surface, which is due to passing disturbances, which change heights and can erode boundary layer inversions.

4 Variance and covariance, power- and co-spectra

For all individual seasons the meteorological time series are spectrally transformed into the frequency space and then seasonally averaged to reveal the time scales and fluctuation intensities contributing to the observed average variance and covariance. From the zonal wind component (Figure 2) three time scales may be identified, which are most intense in the upper troposphere: Short (< 5 days) and long (5–10 days) period disturbances, and ultra-long period fluctuations (> 10 days). As the dominating periods and intensities vary from year to year, the seasonal averaging process tends to smooth the spectra. Therefore, the ultra-long periods (> 10 days) observed in the upper troposphere do not appear to be significant on a 95 % confidence level, if tested against red noise. However, the westward propagating external Rossby wave (wavenumber 2) matches with the observed relatively high intensity of the 16 day period (MADDEN, 1979; pers. com. P. SPETH).

The spectra of the (zonal) wind fluctuations $\overline{u'^2}$ reveal secondary intensity maxima in the lower troposphere for periods > 5 days which, if contributing to the mean low level easterlies (Figure 1), indicate a tendency towards the development of a low level jet. This is supported by the vertical profiles of the meridional eddy transports of zonal momentum (covariance $\overline{u'\,v'}$). The short period disturbances (< 5 days) or local weather systems do not contribute most of the variance to the low level katabatic or gravity winds, whereas larger waves passing Halley Bay at a longer distance seem to be important; i.e. the low level wind field seems to react sensitively on large scale pressure gradient forces over the Antarctic topography.

The meridional eddy transport of sensible heat $\overline{v'\,T'}$ is positive (e.g. positive anomaly southward or negative anomaly northward) in the middle and upper troposphere and negative below 850 mbar.


HALLEY B. WINTER
POWER SPECTRA U'U' × 10
HALLEY B. SUMMER
POWER SPECTRA U'U' × 10
HALLEY B.
VARIANCE U'U'
HALLEY B. WINTER
CO - SPECTRA U'V'
HALLEY B. SUMMER
CO - SPECTRA U'V'
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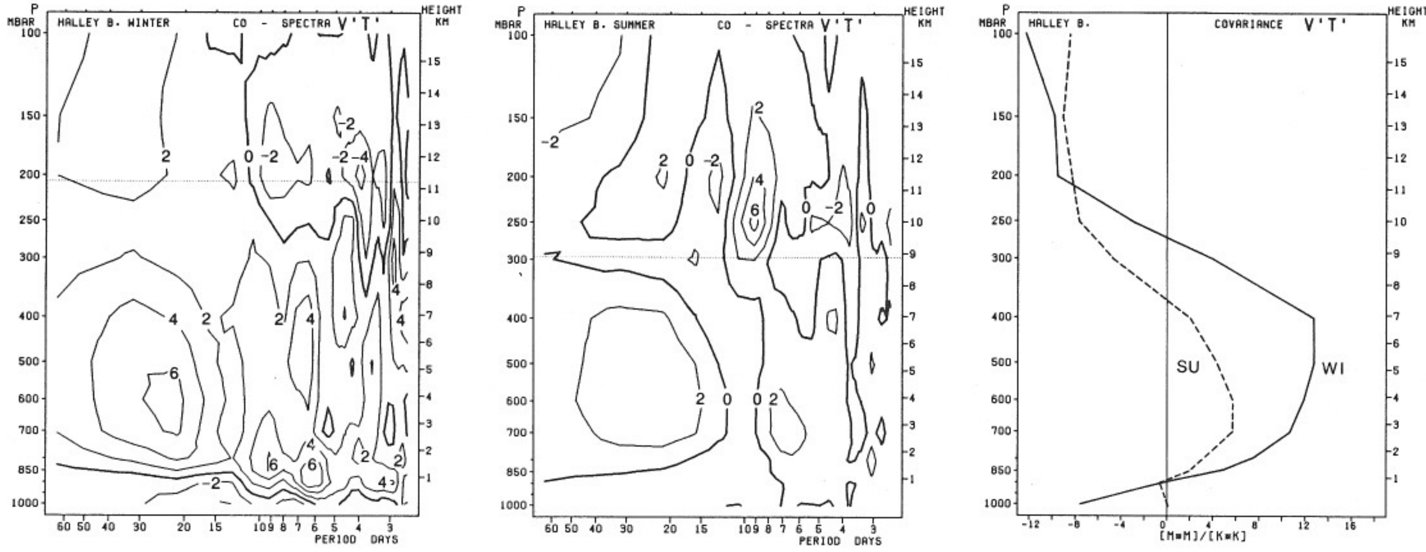


● **Figure 2** Power- and cospetra (left and middle), variance and covariance (right) for summer (SU) and winter (WI) seasons. The spectral contours in units of variance or covariance show frequency-multiplied spectra. The ordinate is the height in km or mbar, the abscissa is the logarithm of frequency labelled according to the period in days.

From top to bottom: zonal wind, meridional eddy transport of zonal momentum and sensible heat.

● **Bild 2** Power- und Ko-Spektren (links und Mitte), Varianzen und Kovarianzen (rechts) für Sommer (SU) und Winter (WI). – Die Isolinien haben die Einheiten der Varianz oder Kovarianz, da sie mit der Frequenz gewichtete Dichten darstellen. Die Ordinate ist die Höhe in km oder mbar, die Abszisse ist proportional dem Logarithmus der Frequenz als Periode (in Tagen) angegeben.

Von oben nach unten: Zonalwind, turbulenter Meridionaltransport von zonalem Impuls und von fühlbarer Wärme.

Such a two layer troposphere exists only for the longer period disturbances (> 5 days), which, particularly in winter, seem to be unable to erode the surface inversion; low level jet intensities are associated with these longer periods and preferable occur at about the top of a well developed boundary (inversion) layer. Short period disturbances, however, can penetrate to the surface, modify the boundary layer dynamics (with thermal inversion and the low level wind maximum), and produce the same meridional heat transports throughout the whole troposphere. The zonal heat transports $\overline{u'T'}$ show similar behavior. Therefore, the short period weather disturbances passing the station Halley Bay and penetrating to the surface will be discussed next.

5 Amplitude and phase structure of the short period disturbances at Halley Bay

The internal structure of short period fluctuations is evaluated by a method described earlier (FRAEDRICH et al., 1979); amplitudes and phases, coherence and phase error are deduced to obtain an average short period (< 5 days) wave disturbance at Halley Bay. The "horizontal" phases between two meteorological variables are derived in reference to the position of the geopotential height axis of the same level; the vertical tilt of this axis is determined by the "vertical" phase differences (of geopotential height) between two adjacent levels. Amplitudes are proportional to frequency integrated power spectra; coherence, phase errors and their significance are calculated by standard methods. It appears that physically meaningful results can be obtained even if coherence between time series is below the 95% significance level (with correspondingly high phase errors). Such points are marked in the figures (Figure 3), which show the structure of the short period disturbances by amplitude and phase of temperature, humidity and meridional wind related to the geopotential or trough/ridge axis.

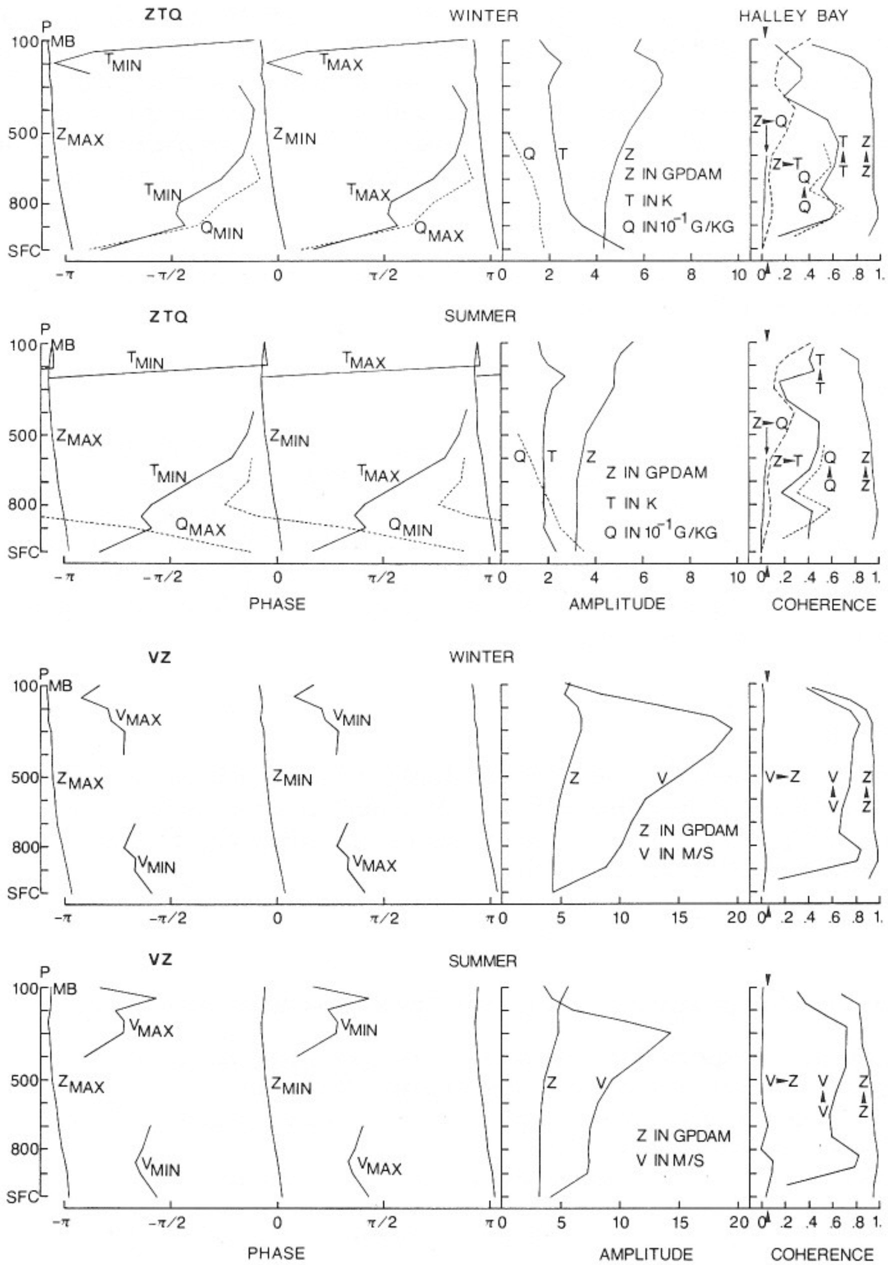
As some of the results are dynamically evident, only a few features are mentioned with reference to the vertical trough axis:

(i) The vertical trough axis tends weakly backwards, whereas the temperature minimum has a strong foreward tilt approaching the trough line in the mid-troposphere. Only mature cyclones show this pattern, when warming occurs aloft on the "backside" of the low.

(ii) The temperature phase jump (of about half a wave length π) at the tropopause is known for synoptic scale disturbances. In addition, there is an inversion capping the boundary layer above 900 mbar, which normally extends down to the surface but has been lifted by the approaching disturbance.

(iii) The specific humidity, although of less (< 95 %) significant coherence with the geopotential, shows strong seasonal dependence: In winter disturbances the specific humidity wave behaves as the temperature wave in the surface boundary layer ($\leq$ 900 mbar), but advances above 900 mbar; this may indicate cloud formation at maximum humidity, which is a quarter wave length ($\pi/2$) ahead of the trough line. In summer disturbances, after having travelled over areas of open water, the humidity wave advances the temperature wave by about half a wave length (π) in the surface boundary layer (below 900 mbar) and less ($\sim\pi/2$) in higher levels; this may again indicate cloud formation $\pi/2$ ahead of the trough and, in addition, a tendency towards fog advection with high humidity and low temperatures in a shallow surface layer near the trough line.

(iv) The trough-ridge related winds reveal interesting phase patterns. It should be noted that the average short period disturbances has to be superimposed on the mean profiles (e.g. hodograph, Figure 1) to obtain meteorologically meaningful wind fields. This helps to explain the phase jump in the midtropospheric wind field which, not unexpectedly, coincides with the mean wind profiles changing their direction. In these levels the phase lags are omitted due to low, insignificant coherence values between adjacent layers. Explicitly superimposing the disturbance (with its zonal and meridional wind amplitude) on the mean wind profile yields southern hemisphere (SH) cyclonic flow around the upper level trough with southwesterly (northeasterly) flow before (after) the passage of the trough line. But the lower



● **Figure 3** Diagrams of phase relationships, amplitudes and coherences of geopotential height Z, temperature T, specific humidity Q, and meridional wind v for short period disturbances at Halley Bay (Antarctic) in winter and summer. 95 % significant coherence is indicated by arrows (▲) at the abscissa.

● **Bild 3** Darstellungen der Phasenbeziehungen, Amplituden und Kohärenzen der geopotentiellen Höhe Z, der Temperatur T, der spezifischen Feuchte Q und des meridionalen Windes v für kurzperiodische Störungen in Halley Bay (Antarktis). Zu 95 % signifikante Kohärenzen sind durch Pfeile (▲) an der Abszisse markiert.

tropospheric flow around the trough shows a different effect after superposition: The low level winds tend to weaken when a surface trough approaches. After its passage the mean wind field (largely determined by the gravity flows) is reinforced and, even more, intensifies due to the superimposed pressure gradient. The lack of strong winds during the pre-storm surface pressure fall and the occurrence of strong winds with rising pressure is an important feature of these storms. Thus, winds in the upper troposphere are easier to predict, because they are closely related to the pressure height fields than the surface flow which is strongly effected by the gravity winds (ASTAPENKO, 1964).

The qualitative description of short period disturbances at Halley Bay is based on one statistically averaged Fourier wave in time where no asymmetries (but phase differences) occur. Individual cases, of course, can strongly deviate from this average description.

6 Conclusions

This note extends the single station climatology of means and variances to the dynamically relevant synoptic scale processes with the aid of spectral analysis. Some of the results suggest further research, before final conclusions can be drawn; this includes (i) the boundary layer and synoptic scale interaction, where low level jet and inversion influence the momentum and heat transports of all scales; (ii) the importance of clouds within a disturbance and, finally, (iii) the ultra-long period fluctuations; as they are hardly evident in SH midlatitudes (FRAEDRICH and KIETZIG, 1983), they may be part of a topographically forced Antarctic circulation pattern.

Acknowledgement

Thanks are due to Dr. D. LIMBERT, British Antarctic Survey (UK), for kindly supplying the rawinsonde data tapes of the British Station Halley Bay and to M. SCHOLZ, H. HAUG and W. MÜLLER for typing, drawing and photographing. Computations and plotting were carried out at the Zentraleinrichtung für Datenverarbeitung (ZEDAT), F. U. Berlin.

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