Spectrum Analysis of Wave Disturbances over Northern Taiwan in Winter

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Abstract

Spectrum analysis is made for the zonal- and meridional-component of upper winds from 700-mb to 150-mb levels at Taoyuan (N 25°03′, E 121°13′) during the period December 1965 through February 1966. Two different high-pass filters are used respectively prior to the spectrum analysis.

Power spectra of the wind components reveal two distinct types of disturbances. One is the wave with period of 8-10 days throughout the troposphere, the other 3-4 days in the lower and upper troposphere.

The horizonal and vertical structures of the disturbances are studied by computing the cross spectrum, the coherence and the phase difference for the zonal and meridional wind disturbances. In the troposphere, the phase of the disturbances at upper level lags behind that at lower level. The axis of disturbance at each level is directed generally from southwest to northeast.

1. Introduction

The -atmosphere is a very complicated thermal and dynamic system. Owing to the diurnal, seasonal and regional variations in the governing mechanism of the atmosphere and the conditions under which phenomena occur naturally are rarely stationary, it is difficult for one to interprete why the observed features at any instant appear as they are. Fortunately, some statistical techniques are available to investigate nonstationary behavior. A statistical technique known as spectrum analysis has been recognized as important and useful tool in meteorological time or space series. This technique is particularly applicable in studies of a series of wave that are normally concealed by a conglomeration of random variation, and its systematic application to tropical time series has provided some compensation of poor spatial distribution of stations. Therefore many authors, such as Maruyama (1967, 1968a, 1968b), Yanai et al. (1968, 1970), Wallace and Chang(1969), Nitta(1970), Madden et al.(1971), Julian(1971), and Chiu(1960, 1973) etc., have made quantitative similar spectral estimates on the data over different regions in the tropics. However, little is known, so far, about the dynamic structure of the wave disturbances and not all the existing studies are aimed at the same goal and gain the same result.

Recently, Nitta et al. (1973) studied the wave disturbances over China continent and the Eastern China Sea in February 1968 and obtained two types of disturbances. One is the wave with 4- to 5-day period existing in the regions to the south of 32°N, the other with 1.5- to 2-day period existing in the lower troposphere in the southern part of the Eastern China Sea.

In winter the anticyclone from Siberia lingers over China continent. Taoyuan(N 25°03′, E 121°13′) is located to the southeast of China continent and in the northern part of Taiwan. The invasion of the severe Siberian cold front is responsible for the capricious cloudy, rainy and cold days in the northern area of the island in winter. The latitude of Taoyuan

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is nearly the same as those of some stations in the study of Nitta et al.(1973). However, they only paid attention to the wave disturbances with 4- to 5-day and 1.5- to 2-day periods. A previous study by Ko et al. (1973) showed that a period longer than 10 days exists in the zonal and meridional wind components at Taoyuan. It seems necessary to examine the disturbances by covering a wider spectral range. The aim of this study is to make a survey of the characteristic features of the wave disturbances by covering a wider period range up to 25 days and to gain information concerning the structures of the prevailing disturbances throughout the troposphere over Taoyuan in winter. The power spectra of the zonal as well as the meridional wind component are examined. A cross spectrum analysis is also involved.

2. Data and method

Data of observations at Taoyuan(N 25°03′, E 121°13) used in this study are obtained from IGY Observation Data (1966, 1967) published by Chinse National Committee. The winter season we define starts from early Deecmber and ends in late February. The

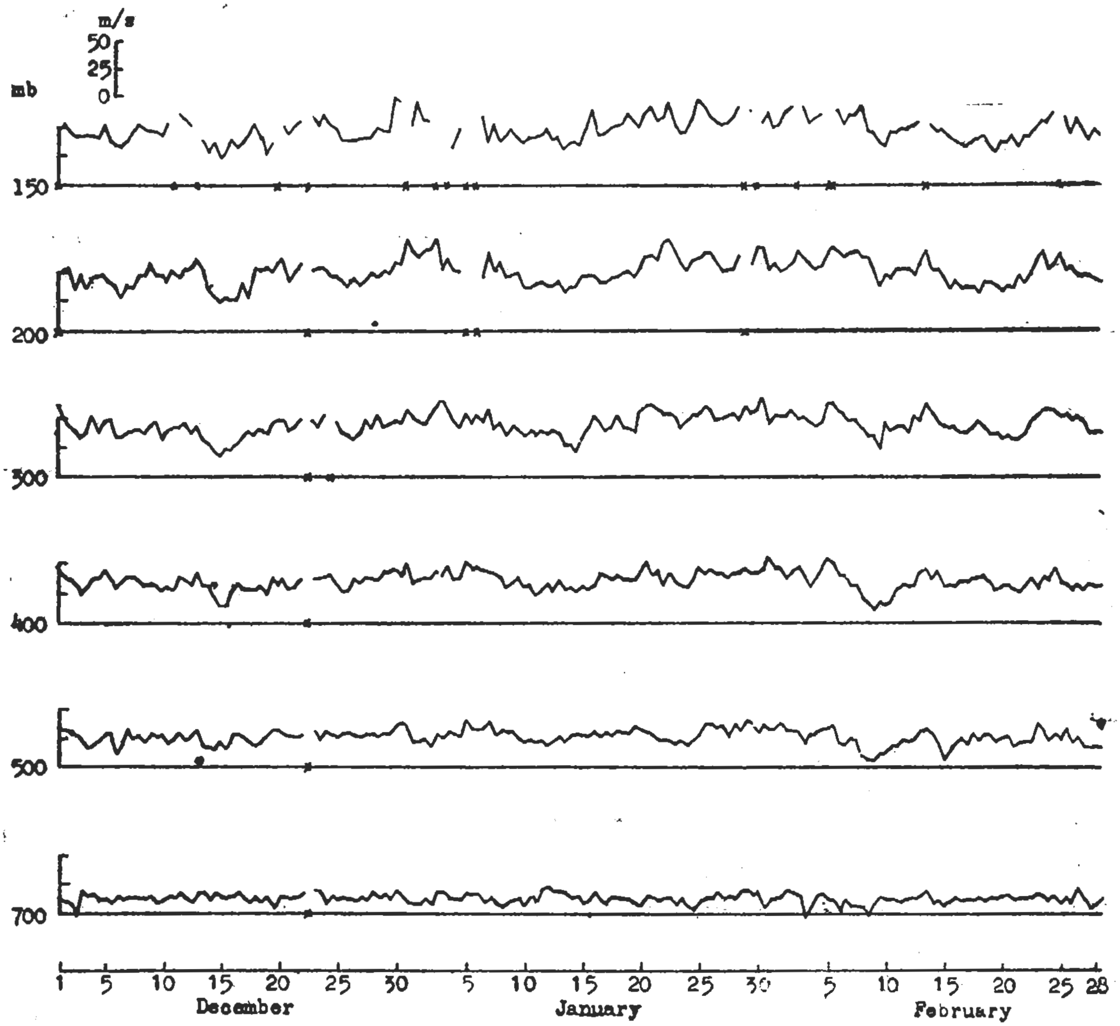


Fig.1 Zonal wind component u for various levels at Taoyuan from 1 December 1965 through 28 February 1966.

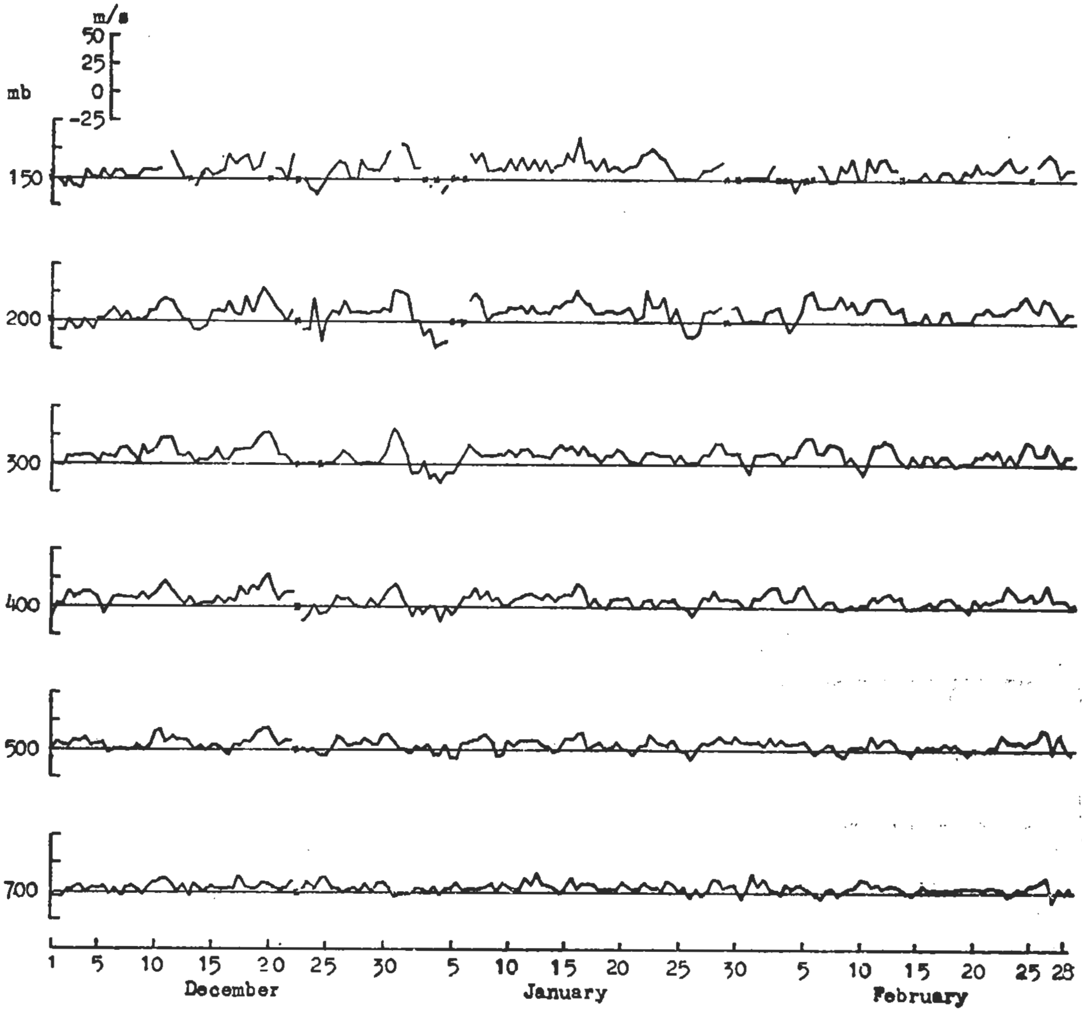


Fig.2 Meridional wind component v for various levels at Taoyuan from 1 December 1965 through 28 February 1966.

upper wind observations were available twice a day, i.e., 0000 GMT and 1200 GMT, during the pering the period from 1 December 1965 through 28 February 1966. Thus there are 90 days or 180 observations available but the use of a high-pass filter and a revised high-pass filter reduce them to 136 observations and 45 observations respectively. Analysis is made for the wind speed and wind direction at the constant pressure levels of 700, 500, 400, 300, 200 and 150 mbs. Tabulated values of wind speed and wind direction are given in units of knots and 10° respectively. The missing data at each level are designated by the sign 'x' in Figs. 1-2. Computations are made by excluding the missing data. The wind data contain a few of doubtful ones, but neither correction nor rejection is made in this study.

The zonal wind component u and meridional wind component v are computed by

$$u = -\mathrm{ff}\sin\theta \qquad (1)$$

$$v = -\mathrm{ff}\cos\theta \qquad (2)$$

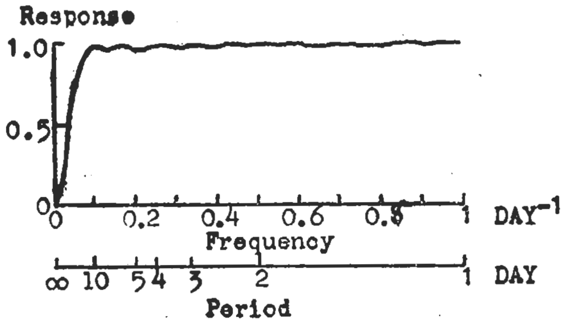


Fig. 3 Response of the high-pass filter.

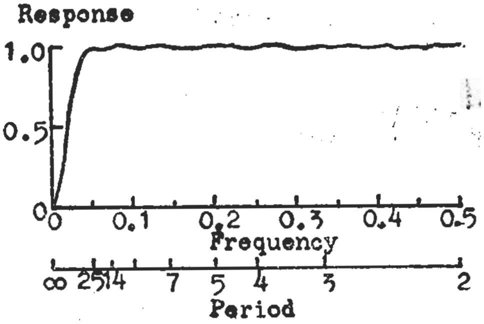


Fig. 4 Response of the revised high-pass filter.

respectively, where ff is the wind speed, and θ is the wind direction in degree referred to the true north. The results are shown in Figs. 1–2.

Prior to the spectrum analysis, we apply a high-pass filter, designed according to Holloway (1958) and Maruyama (1968a), to the original data to remove longer periods and linear trends. The frequency response function of the high-pass filteris illustrated in Fig. 3. The frequency interval is 0.04 cycles per day. The variations with periods shorter than about 10 days are almost perfectly reserved. We shall call the filtered data 'disturbances'.

Let u_l be time series data. For every successive 45 data points, the smoothed data point value $\tilde{u}_l$ is computed by the following linear equation:

$$\tilde{u}_l = \sum_{k=-22}^{22} w_k \, u_{l+k} / \sum_{k=-22}^{22} w_k, \tag{3}$$

where w_k is a particular weight in the smoothing funotion. The smoothing function used for this study is Gaussion distribution function; namely,

$$w_k = (2\pi\sigma^2)^{-1/2}\cdot\exp(-t^2/2\sigma^2)\cdot\Delta t \tag{4}$$

for $\sigma=5$ days and $t=k\Delta t$ ($k=0, \pm1, \cdots\cdots, \pm22$, $\Delta t = 0.5$ day). Then only low frequencies of the original data u_l will appear in the time series of $\tilde{u}$ values. The time series of the filtered data u_l' are given by the deviations from the smoothed data; namely,

$$u_l' = u_l - \tilde{u}_l. \tag{5}$$

If missing data are contained in successive 45 data points, the smoothed data point value $\tilde{u}_l$ is computed by the remaining data. The filtered data u_l' cannot not be defined if u_l is missing.

In order to extend the spectrum analysis to the period range longer than ten days, a revised high-pass filter is also used. The frequency response function of the revised high-pass filter is shown in Fig. 4. The response is almost kept constant up to about 25 days. To retain enough frequency resolution in the lower frequency range, the frequency interval in the spectrum analysis is changed from 0.04 to 0.02 cycles per day. And we reduce the original time series of twice-daily data to that of once-daily data by taking a weighted average of the successive three original data. We limit the shortest period to 2 days and obtain 26 spectral estimates between and 0.5 cpd (cycles per day) for the maximum lag number of 25.

The spectrum analysis we use is that originally designed by Munk et al. (1959). Its principle is discussed by Blackman and Tukey (1958). The covariance between two time series u_i and v_i is given by

$$C_L(u,\ v) = (1/N\text{-}L\text{-}m) \sum_{i=L+1}^{N} u_i\ v_{i-L} \qquad (6)$$

for L = 0, 1, ……, M, where L is the lag number, M is the maximum lag number, N is the length of the time series and m is the number of the undefined products due to missing data. In general, the covariance between u_i and v_i can be decomposed into a sum of an even part $EC_L(u,v)$ and an odd part $OC_L(u,v)$; that is,

$$C_L(u,v)=EC_L(u,v)+OC_L(u,v) \qquad (7)$$

where

$$EC_L(u,v)= \tfrac{1}{2}\,[C_L(u,v)+C_L(v,u)] \qquad (8)$$

and

$$OC_L(u,v)= \tfrac{1}{2}\,[C_L(u,v)-C_L(v,u)] \qquad (9)$$

Thus, the autocovariance of u_i and of v_i are equal to the even parts of the covariances with themself; namely,

$$C_L(u,u)=EC_L(u,u) \qquad (10)$$

and

$$C_L(v,v)=EC_L(v,v) \qquad (11)$$

respectively.

In order to convert the abrupt ends of covariance into smooth die-aways at the edge of lagging L=M, a lag window D_L, i.e.,

$$D_L = 1+\cos(\pi L/M) = 2\cos^2(\pi L/2M), \qquad (12)$$

is applied beforehand. The power spectra of u_i and v_i with frequency $k/2M\triangle t$ are given by, respectively,

$$P_k(u) = \sum_{L=0}^{M} C_L(u,u)\cdot\cos(kL\pi/M)\cdot D_L\cdot\delta_L \qquad (13)$$

and

$$P_k(v) = \sum_{L=0}^{M} C_L(v,v)\cdot\cos(kK\pi/M)\cdot D_L\cdot\delta_L, \qquad (14)$$

where k has the values 0, 1, ……, M, and δ_L =1/2 for L = 0 or M, and δ_L = 1 otherwise.

The cospectrum S, the quadrature-spectrum Q, the coherence R and the phase difference θ between u_i and v_i are, respectively,

$$S_k(u,v) = \sum_{L=0}^{M} EC_L(u,v)\cdot\cos(kL\pi/M)\cdot D_L\cdot\delta_L \qquad (15)$$

$$Q_k(u,v) = \sum_{L=0}^{M} OC_L(u,v)\cdot\sin(kL\pi/M)\cdot D_L\cdot\delta_L \qquad (16)$$

$$R_k(u,v) = \{[S_k^2(u,v)+Q_k^2(u,v)]/[P_k(u)\cdot P_k(v)]\}^{1/2} \qquad (17)$$

and

$$\theta_k(u,v) = \tan^{-1}[Q_k(u,v)/S_k(u,v)] \qquad (18)$$

for k = 0, 1, ……, M, where θ is taken between 0° and 180° if Q is positive, and between 0° and −180° if Q is negative. With this convention, θ is the phase lead of v-record relative to u-record. If the two time series data are identical and simultaneous, $S_k(u,v) = [P_k(u)\cdot P_k(v)]^{1/2}$ and $Q_k(u,v) = 0$. If they are series identical but there is time lag in one series corresponding a phase difference $\theta_k(u,v)$, then the coherence is +1. If the two time series data are unrelated, $S_k(u,v)$, $Q_k(u,v)$ and $R_k(u,v)$ tend to zero for long records, but with finite time series they have random values.

3. General trend of the power spectra

The power spectra of the filtered zonal and merional wind disturbances at 700-, 500-, 400-, 300-, 200- and 150-mb levels during the period 1 December 1965 through 28 Februry 1966 are shown in the upper parts of Figs. 5-6. The amplitude of the wave disturbances may be reflected in the shapes of the power spectra at various levels. Since the zonal and meridional wind components may contain a longer period range than 10 days, we illustrate in Fig. 5 a wider spectral range up to the 25-day period. In this section we shall investigate the period ranges at which the pronounced peaks of the u-spectra and v-spectra appear, and from which we may get a general idea about the wind disturbances.

In the u-spectra, we find the amplitude of the power spectra is larger at higher level than that at lower level. At 700-mb level, we find no evident peak but two relative maxima. One exists at about 8-day period the other in 3- to 4-day period. At 500-, 200- and 150-mb levels, there are pronounced peaks at the period of 8-10 days. At the four levels of 400-, 300-, 200- and 150-mb we find large spectra at the period longer than 14 days and vague peaks in 1- to 1.5-day period. In addition, at 300-mb level a prevailing peak is found near the period of 5 days; at 200- and 150-mb levels a minor peak exists in the3- to 4-day period range.

In the v-spectra, remarkable peaks are noted around the 8-day period for all levels except 700 mb at which relative maximum appears in the period range of 3- to 4-day. We find minor peaks at the period of 4-5 days for 400- and 300-mb levels, and in the period range of 3- to 4-day for 200- and 150-mb levels. Besides, there are also small peaks in 1- to 1.5-day period at 300, 200 and 150 mbs.

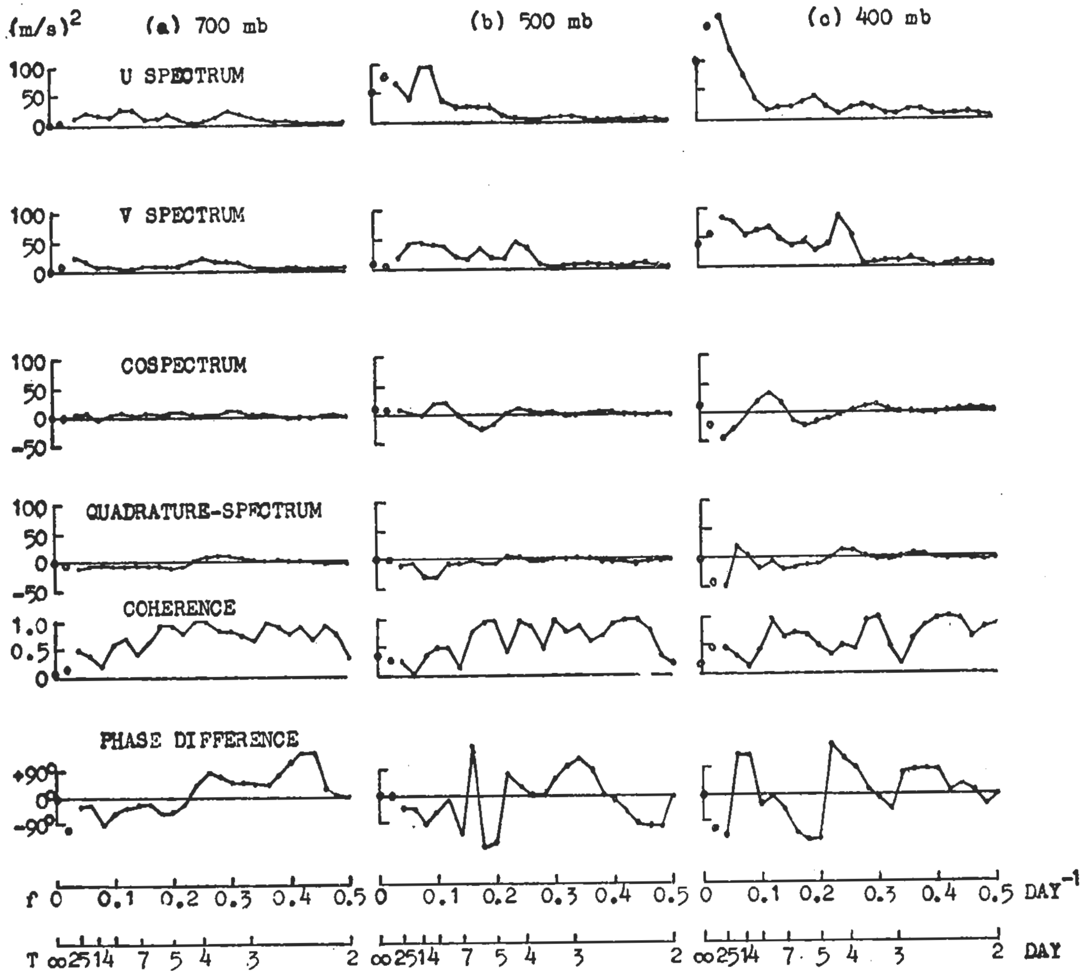


Fig.5 Power spectra of u and v with cospectra, quadrature-spectra, coherences and phase differences between both components for various levels at Taoyuan.

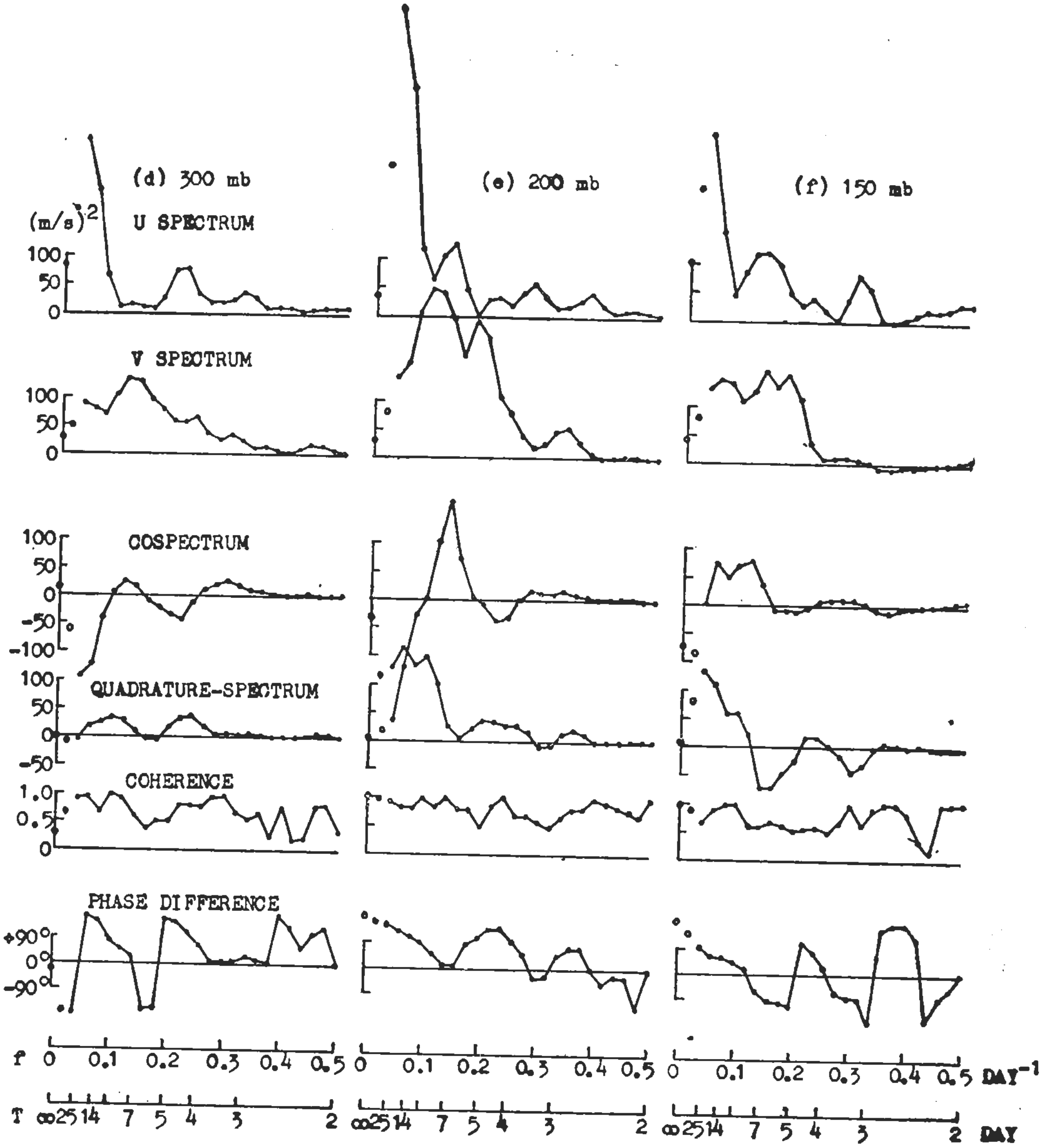


Fig.5 (continued)

As mentioned above, in the upper troposphere the zonal wind disturbance has periods of 8–10 days and longer than 14 days, but about 8 days and 3–4 days in the lower troposphere. For the meridional wind component, it reveals about 8-day periodicity for all levels except 700 mb at which 3- to 4-day periodicity prevails. It may be worth mentioning that both the zonal and meridional wave disturbances appear to have 3- to 4-day period in the lower and upper troposphere, 1- to 1.5-day period in the upper troposphere and about 5-day period near the middle tropospheric level. Nitta et al.(1973) indicated that a remarkable peak, for the v-spectra, exists at 4-to 5-day period in the lower and upper tropopsphere, that large power densities in the u-spectra exist in the middle troposphere centered about 400 mb in the 4- to 5-day period range at Ishigakijima(N 24°, E 124°), and that a rather

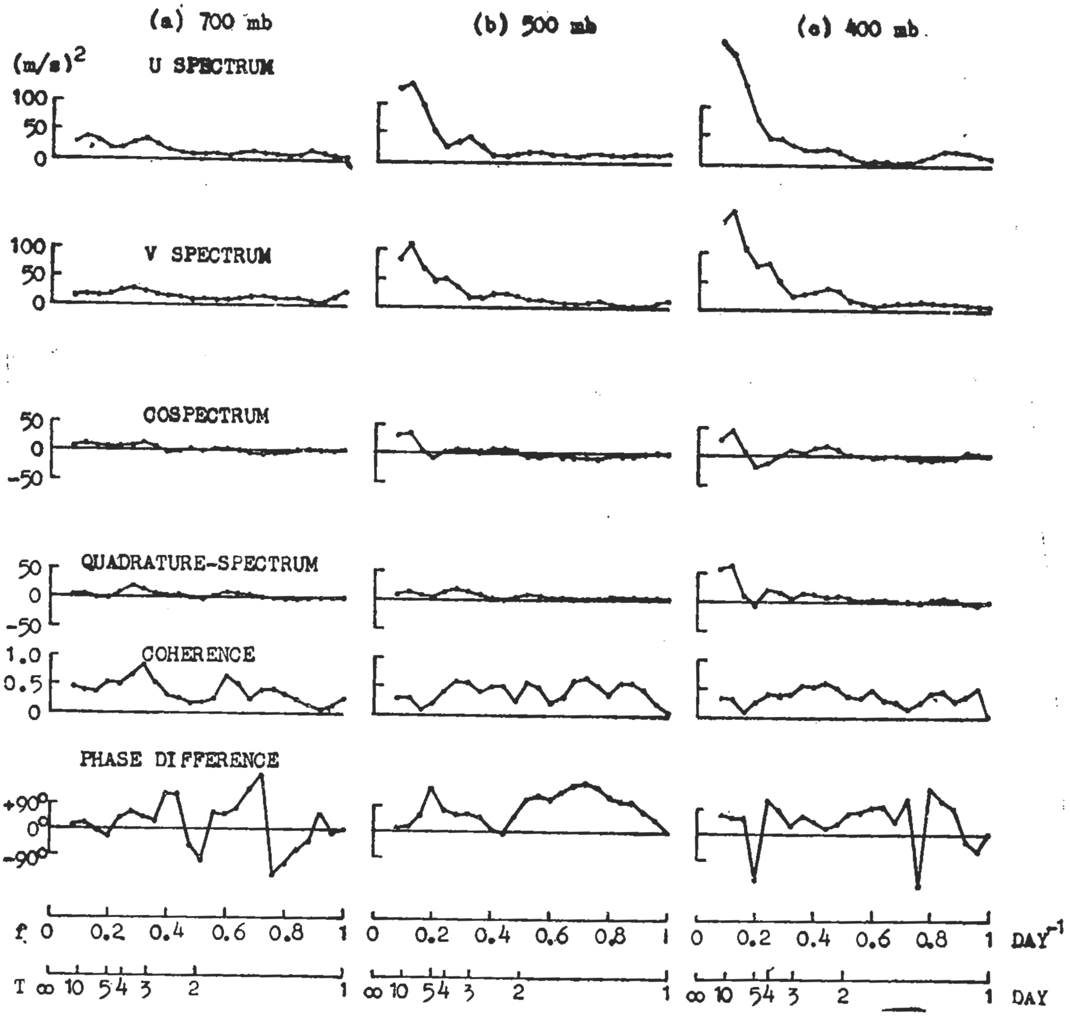


Fig.6 The same as Fig.5.

larg power density for v-spectra exists in the period range from 1.5 days to 2 days in the lower troposphere centered about 900 mb at Ishigakijima, Kadena(N26°, E 128°) and Minamidaitojima(N26°, E 121°). These stations are situated nearly at the same latitude as Taoyuan(N 25°, E 121°). However, the results we obtain for Taoyuan do not agree well with those obtained by Nitta at al.

4. Horizontal structure of the disturbances

In this section we shall examine the horizontal structure of the disturbances from the cross spectrum, coherence and phase difference between u- and v-component at each level. They are illustrated in the lower parts of Figs. 5-6. For periods shorter than 10 days, we refer to Fig. 6.

At 700-mb level, we find vague peaks of cospectrum and quadratue-spectrum in the 3- to 4-day period range with positive phase difference and coherence greater than 0.8. For the 500-mb level, the cospectrum has a relative maximum at about 8-day period with small quadrature-spectrum and phase difference about zero. This indicates that both the u- and v-component have the same period of about 8 days and are nearly in the same phase. For the 400-mb level, both the cospectrm and

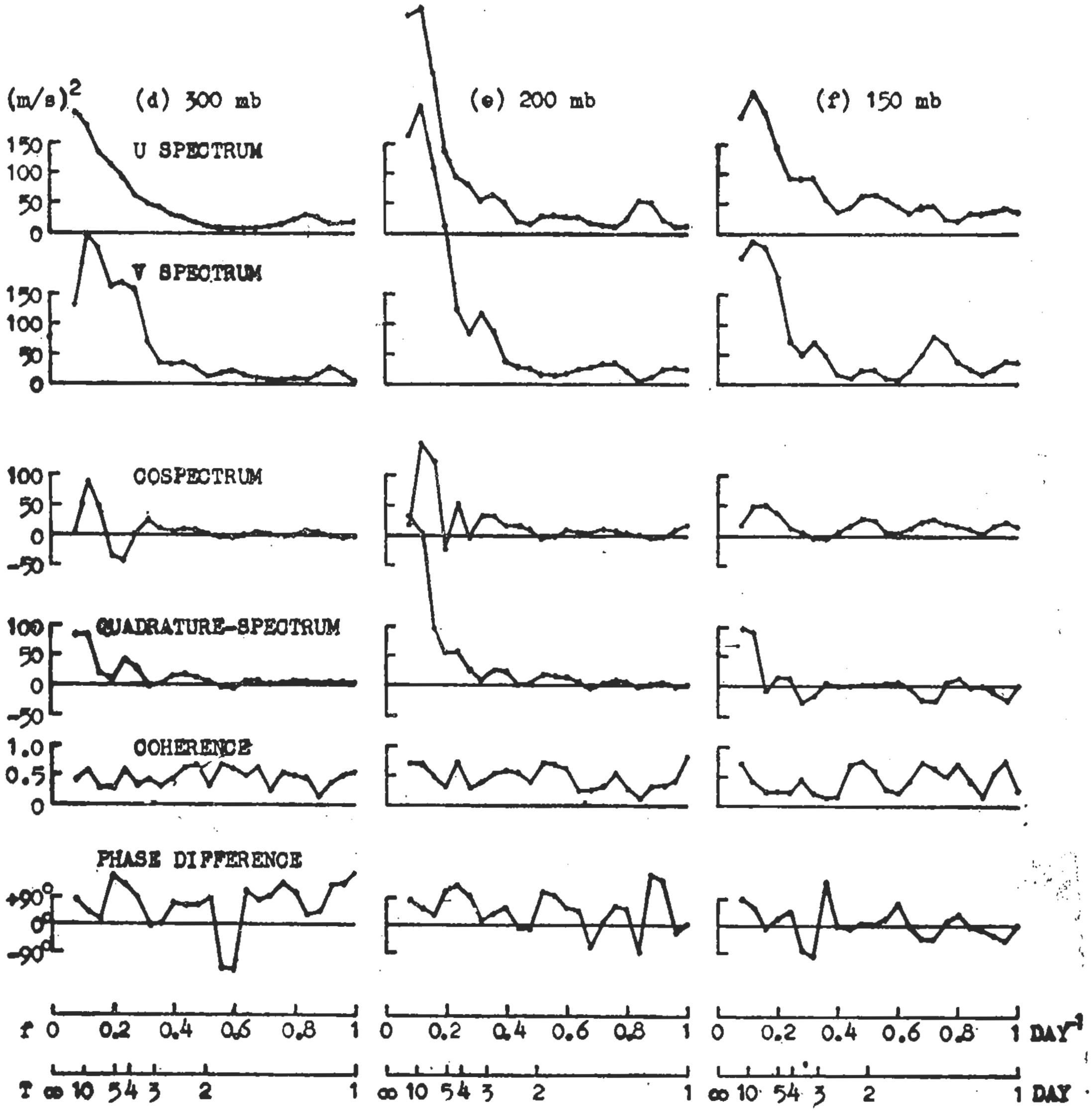


Fig.6 (continued)

quadrature-spectrum have a pronounced peak at about 8-day period with positive phase difference. For 300-mb level, a remarkable peak around the 8-day period exists in both the cospectrum and the quadrature-spectrum. The coherence is large and the phase difference is positive. At 4- to 5-day period, there are a minimum in the cospectrum and a maximum in the quadrature-spectrum with high probability level and positive phase difference about 140°. As for the 200-mb level, the cospectrum and quadrature-spectrum have rather large peaks in the period range of 8-10 days. The phase difference is positive and the coherence is at high level. In addition, at around 20-day period there are remarkable minimum in the cospectrum and maximum in the quadrature-spectrum with large coherence and positive phase difference. At 150-mb level, we find pronounced peaks in 8- to 10-day period for both cospectrum and quadrature-spectum. The phase differences are positive too. At the period around 25 days, large maximum is also found in the quadrature-spectrum, and cospectrum is small with zonal wind disturbance lagging behind the meridional one.

It is noted from above that both the cospectrum and quadrature-spectrum between the zonal and meridional wind components at each level, except 700mb, show positive pronounced peaks at 8- to 10-day period. The phase differences are all positive. These imply that in this period range the zonal wind disturbances at each level lags behind the meridional one and that the axis of disturbance is directed generally from southwest to northeast throughout the middle and upper troposphere.

5. Vertical structure of the disturbances

To investigate the vertical structure of the disturbances we calculate the cross spectrum, the coherence and the phase difference for the u-and v-component on the basis of 700-mb level. Figs. 7-8 show the cospectrum, quadrature-spectrum, coherence and phase difference

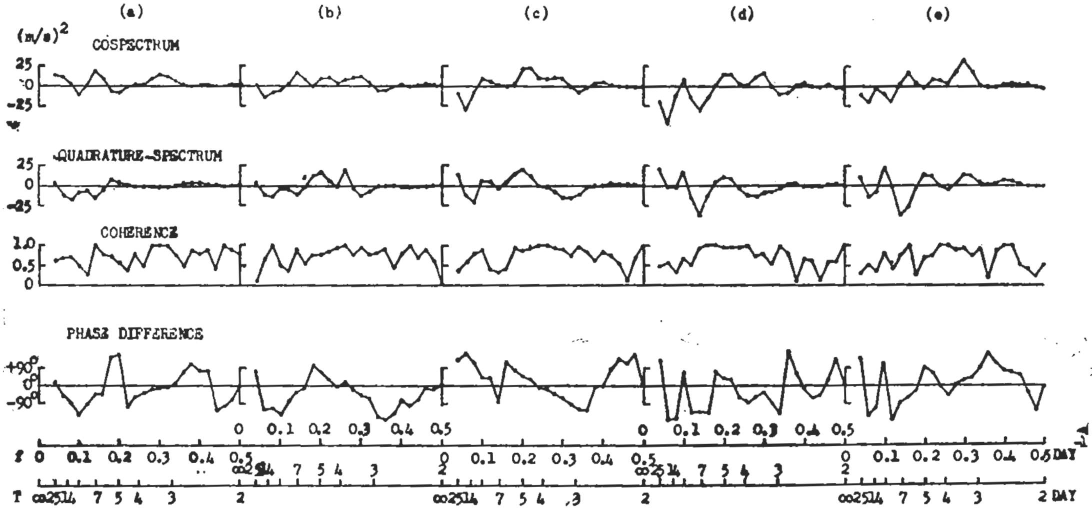


Fig.7 Cospectra, quadrature-spectra, coherences and phase differences between u at 700-mb level and that at (a) 500-mb, (b) 400-mb, (c) 300-mb, (d) 200-mb and (e) 150-mb levels at Taoyuan.

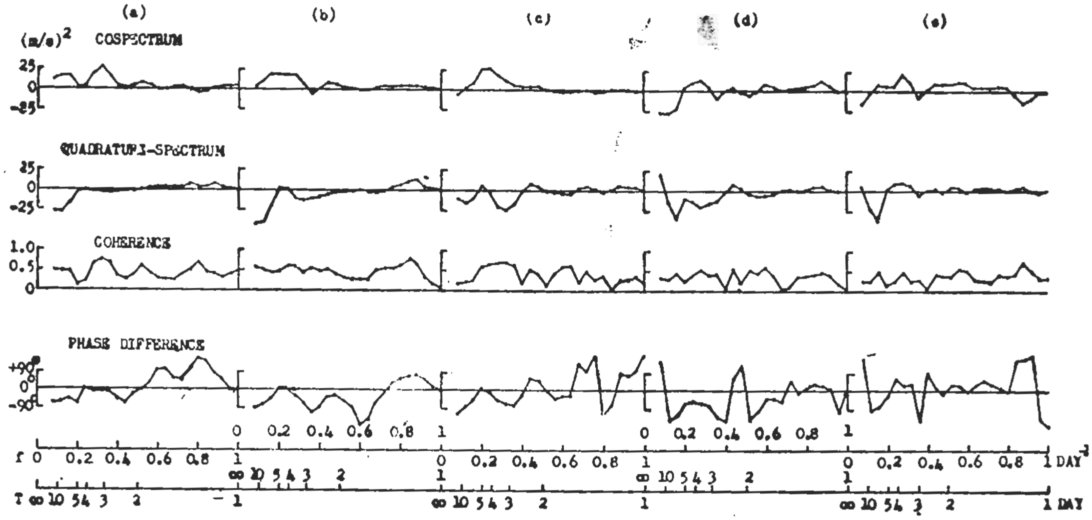


Fig.8 The same as Fig.7.

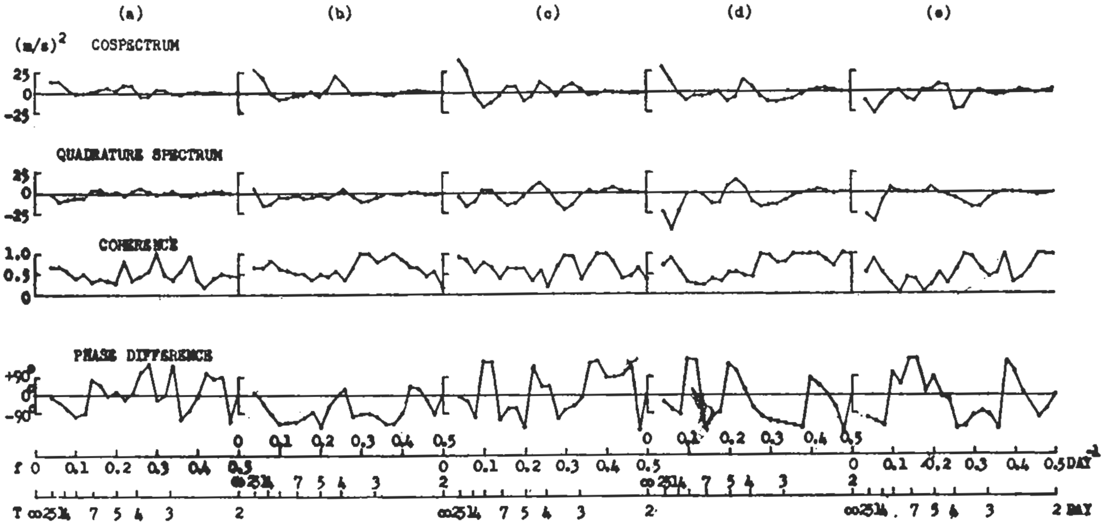


Fig.9 The same as Fig.7 except for v.

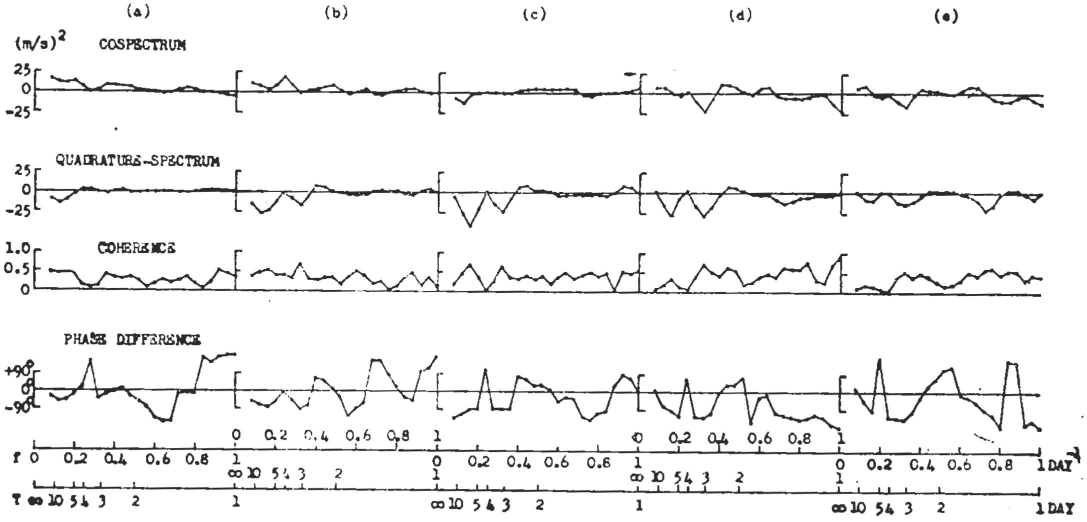
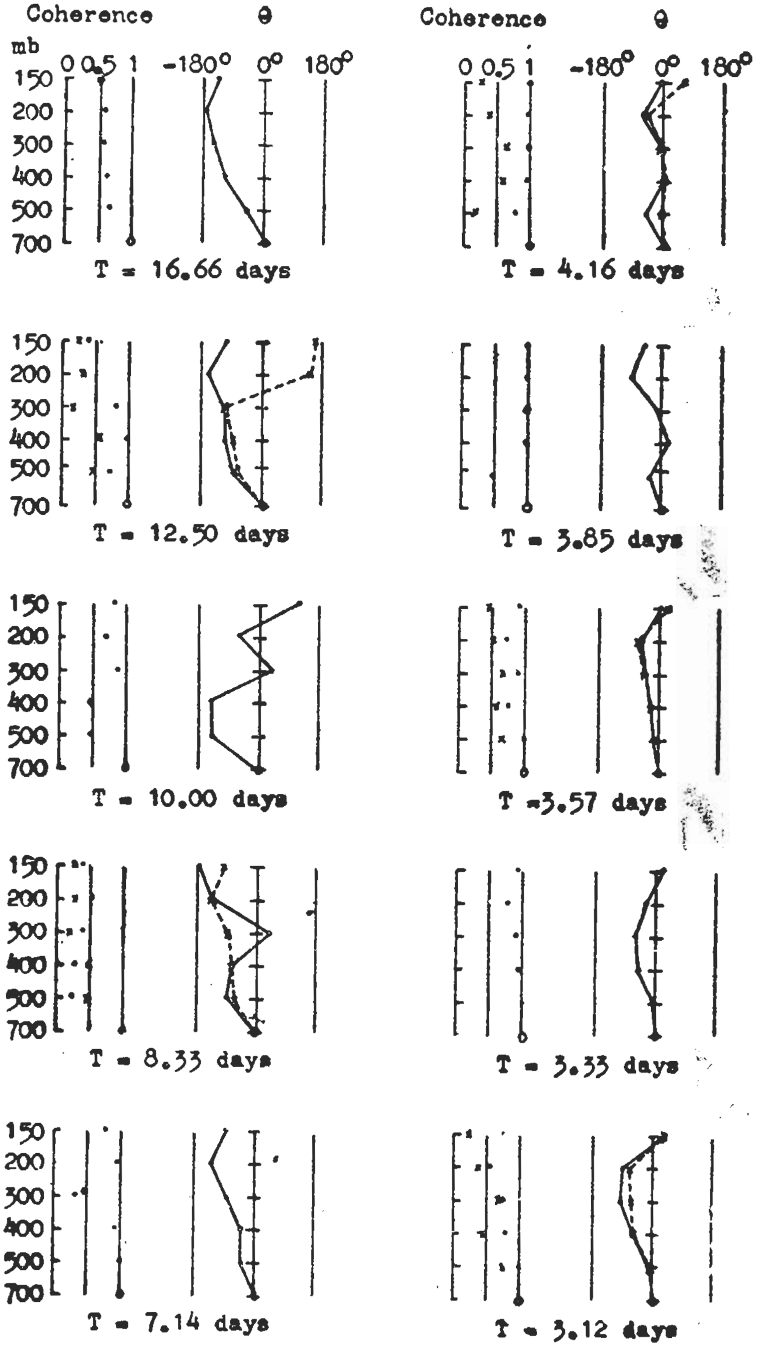


Fig.10 The same as Fig.9.

between the u-component at 700 mb and that at otherlevel. Figs. 9–10 show the same items except for the v-component.

In Figs. 7–8, we find the cospectrum for 500 mb has two distinct peaks. One exists at around 8-day period and at which a large minimum of quadrature-spectrum appears too. The phase difference is about -50°. The other exists in the 3- to 4-day period range and in which the quadrature-spectrum is very small, the phase differnnce tends to zero. This implies that the disturbance of the u-component at 700-mb level is nearly identical and simultaneously with that at 500-mb level in the 3- to 4-day period range. As for the 400-mb level, the cospectrum shows a minimum at about 17-day period and two peaks at around 7-day and 3- to 4-day periods. The quadrature-spectrum shows relative minima, the coherences are at high level, and the phase difference are negative at these two peaks. Besides, we notice distinct minimum exists in the quadrat-



• —— By revised high-pass filter

ˣ ---- By high-pass filter

Fig.11 Vertical coherence and phase difference of u on the basis of 700-mb level for some selected period ranges at Taoyuan.

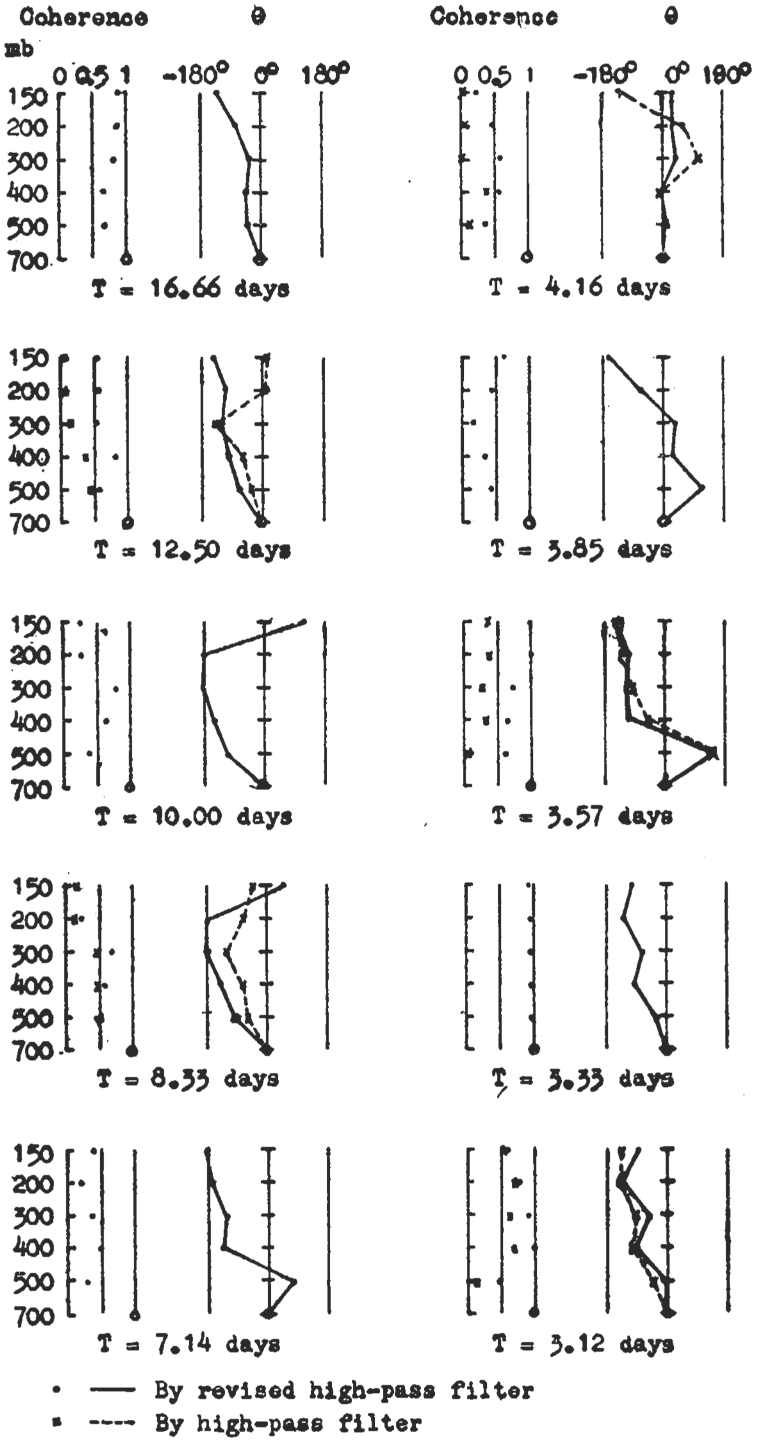


Fig.12 The same as Fig.11 except for v.

ure-spectrum at the period near 12 days with large coherence and negative phase difference. For 300-mb level, at about 5-day period a predominant peak is found in the cospectrum. There is also a prevailing minimum of cospectrum in the vicinity of 17-day period. In the 3- to 4-day period range, there is a remarkable minimum in the quadrature-spectrum. The coherence is about 0.8 and the phase difference is about -60°. In the cospectrum for 200-mb level, somewhat complicated features are found. There are two distinct maxima at about 5-day and 3- to 4-day periods, and two rather large minima around 17-day and 7-day periods. In the 7-day and 3- to 4-day periods, we also find large minimum in the quadrature-spectrum with negative phase difference. For the 150-mb level, thecos pectrum shows large peak in the 3- to 4-day period range and pronounced minima at the periods close to 17 and 7 days. In the quadrature-spectrum, distinct minimum exists at about 17-day and 7-day periods.

The vertical relation of the v-component on the basis of 700-mb level is illustrated in Figs. 9–10. Except for 500-mb level, the quadrature-spectra have distinct minima in the period ranges of about 17, 7 and 3-4 days. As for the cospectrum, prevailing peak exists at about 10-day period for 300 mb, around 17-day period for 150 mb and at 3- to 4-day period for 200 and 150 mbs.

The coherence and phase difference of the disturbances between different levels may give us some information concerning the vertical structure of the disturbances. Fig. 11 and Fig. 12 show the coherence and phase difference of u and v disturbances respectively for some selected period ranges in which the cospectrum and quadrature-spectrum prevail. As shown in Figs. 11–12, the u and v disturbances at lower level generally leads that at upper level forthe altitude below 150 mb in the period ranges of around 17, 7 and 3-4 ays.

6. Conclusions and remarks.

Spectrum analysis is made for the data of upper wind at Taoyuan during the period from 1 December 1965 to 28 February 1966. We conclude by stating some remarkable feature for the zonal and meridional disturbancesas follows:

(1) The zonal wind component shows three types of disturbances. The first is a large distubance with the period longer than 14 days above the middle troposphere, the second is that with the period of 8-10 days throughout the entire troposphere, and the third is the one with the period of 3-4 days in the lower and upper troposphere.

(2) The meridional wind component reveals two types of disturbances. One is that with the period of about 8 days above the middle troposphere. the other with the period of 3-4 days in the lower and upper troposphere.

(3) Above the middle troposphere, the zonal wind disturbance lags behind the meridional one at each level and the axis of disturbance is directed generally from southwest to northeast in the 8- to 10-day period range.

(4) The disturbances at lower level lead those at upper level in the period ranges of around 17, 7 and 3-4 days.

From the above statistical evidences, we may classify the wave disturbances over northern Taiwan in winter into three types. Type 1 is the large-scale disturbance with period longer than 14 days, type 2 is the medium-scale one with period around 8 days and type 3 is the small-scale one with 3- to 4- day period. Type 2 is prevailing at all levels. It is the most significant type in winter and is probably generated by the northeast monsoon prevailing from December through February. The monsoon is originated from Siberia and northern China continent in the form of polar outbreaks or so-called cold wave which is always led by a cold front. Type 3 is prevailing particularly in the upper troposphere and is probably produced by the southern jet stream over China continent. The large-scale type probably results from the repeated existence of blocking anticyclone over Middle East and Far East.

Although it is not clear how the upper-level and low-level disturbances are coupled vertically, the knowledge we obtain may be used as a reference in winter weather forecasting over northern Taiwan. To gain more information concerning the disturbances further analyses are still required.

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