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Wave disturbances over east China Sea (AMTEX area) during AMTEX 75

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ABSTRACT. In order to understand different aspects of AMTEX 75, heat and moisture budgets over AMTEX area for AMTEX 75 were estimated earlier (Krishna Murty 1976). In continuation of that study, in the present paper the characteristics of the wave disturbances that appeared in AMTEX 75 are studied. Though the AMTEX 75 period is only the latter half of February 1975, for better understanding, analysis of the data is done for the complete months of February and March 1975 separately.

The wave disturbances of both the months are studied for 2 different regions : zone-I and zone-II along latitudes 30° to 32°N and 24° to 26°N respectively. In February, the wave disturbances are of 2-3 day period in both the regions. But, in March there exists a wave disturbance of 3-day period in the north (zone-I) while in the south (zone-II) there exists a disturbance with 5-day period.

The disturbances have the characteristics of propagating eastwards and their wavelength is about 4000 to 5000 km. The vertical structure of these disturbances is same as those of baroclinic waves with warm and moist air to the east of the trough and the trough tilting westwards with height. The change of these characteristics takes place after a certain height, above which the trough tilts eastwards with height and the air to the east of the trough becomes cold and dry. Though the change in the tilting of the trough takes place at a greater height, the change in the characteristics of the air to the east of the trough takes place at a much lower level. Interestingly, the changing level is lower over continent than over sea. It may be due to the difference in the low lying boundary in both the cases.

The vertical velocities are computed for a square area and a triangle area; and their power spectral distribution is also studied. It is noticed that the power density increases as the waves move eastwards.

1. Introduction

Many authors have studied the wave disturbances and their vertical structure over East China Sea, in winter and spring, for different years. Ninomiya (1972) pointed out the development of extratropical cyclones over East China Sea with a period of about 4 days in winter and spring. Many early studies (*e.g.*, Takahashi 1955) also revealed that the cyclone wave with a period of 3-4 day is predominant over East China Sea during winter and spring seasons.

Recently, Nitta *et al.* (1973), as a part of pre-AMTEX study, studied the wave disturbances for the period February 1968 and found that there are 2 types of disturbances, one with 4-5 day period and the other with 1.5 to 2 day period. Yoshizaki (1974) studied for the months of January and March of the same year and pointed out that there are 7-6 day wave disturbances in

January and the periodicity of wave disturbances is weak in March.

In order to understand the wave disturbances during AMTEX 75 period, in the present study, the data are analysed for the months of February and March 1975. The period of the wave disturbances is obtained by the power spectral analysis. Then the vertical structure of the waves with that periodicity is studied. The analysis is made for 2 belts I and II (Fig. 1) in order to facilitate the study of latitudinal variation of those disturbances, if any. Area-averaged vertical P velocity (ω) is computed for the areas of a square (III) and a triangle (IV).

2. Data and method of analysis

For the study of wave disturbances and their structure over East China Sea for the AMTEX 75 period, the upper air data of 7 stations
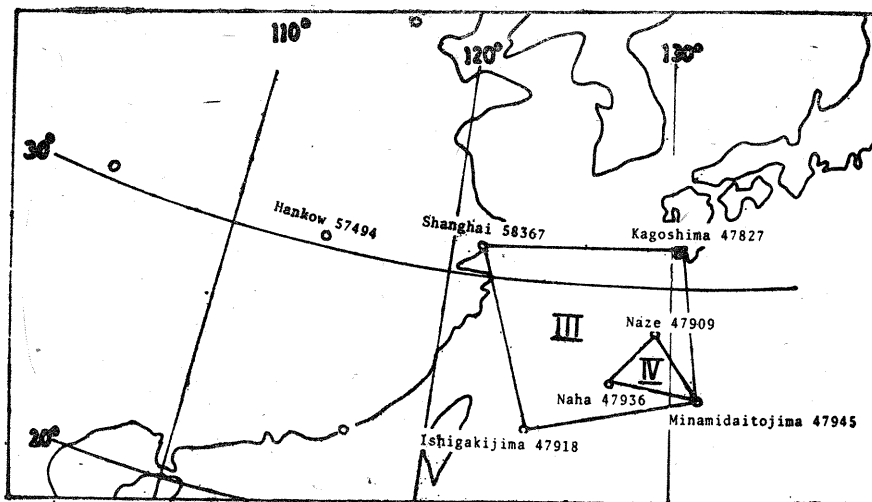
(a) Zones I & II are along 30°-32°N and 24°-26°N respectively
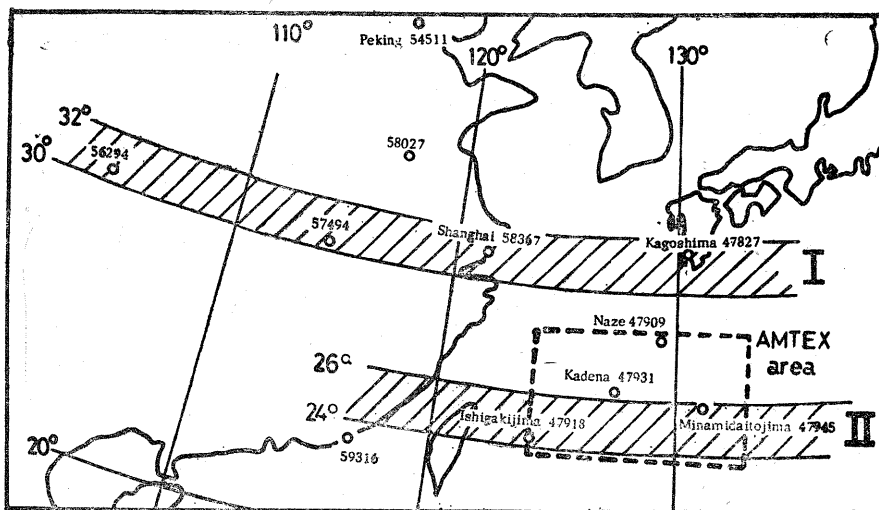
(b) Area III is enclosed by stations Shanghai, Ishigakijima, Minamidaitojima and Kgoshima.
Area IV—is enclosed by stations Naha, Minamidaito and Naze.

Fig. 1. Investigational area : China, East China Sea and AMTEX area

(Hankow, Shanghai, Kagoshima, Naha, Naze, Ishigakijima and Minamidaitojima) were collected for the months of February and March 1975 from the daily weather reports of the Japan Meteorological Agency. The observations are 2 times a day. Though the data are completely available for Japanese stations, there are many missing data for Chinese stations. However, the missing data are covered by the linear interpolation of the other data.

Fig. 1 illustrates the area of investigation. Zone I is taken along latitudes 30° to 32° N and Zone II along 24° to 26° N. The square area (III) is made up of the stations Shanghai, Kagoshima, Minamidaitojima and Ishigakijima. The stations Naze, Minamidaitojima and Naha form the triangle area (IV). The data of the stations in zones I and II are used for the analysis of v, T and q, while the areas III and IV are used for the calculation and analysis of vertical p-velocity.

In the preparation of longtitudinal cross-section for 24°-26°N (zone II) and 30°-32°N (zone I), 850 mb wind data are used. In zone I, in the range of 110° to 130° E, the data are available for only 3 stations. In the same longitudinal range in zone II, five stations are there where the data are available. Using line integral of the normal components of wind along border line of the areas III and IV, horizontal divergence is calculated for both the areas. Equation of continuity is used for evaluating the averaged vertical p-velocity ($\bar{\omega}$) of the above areas.
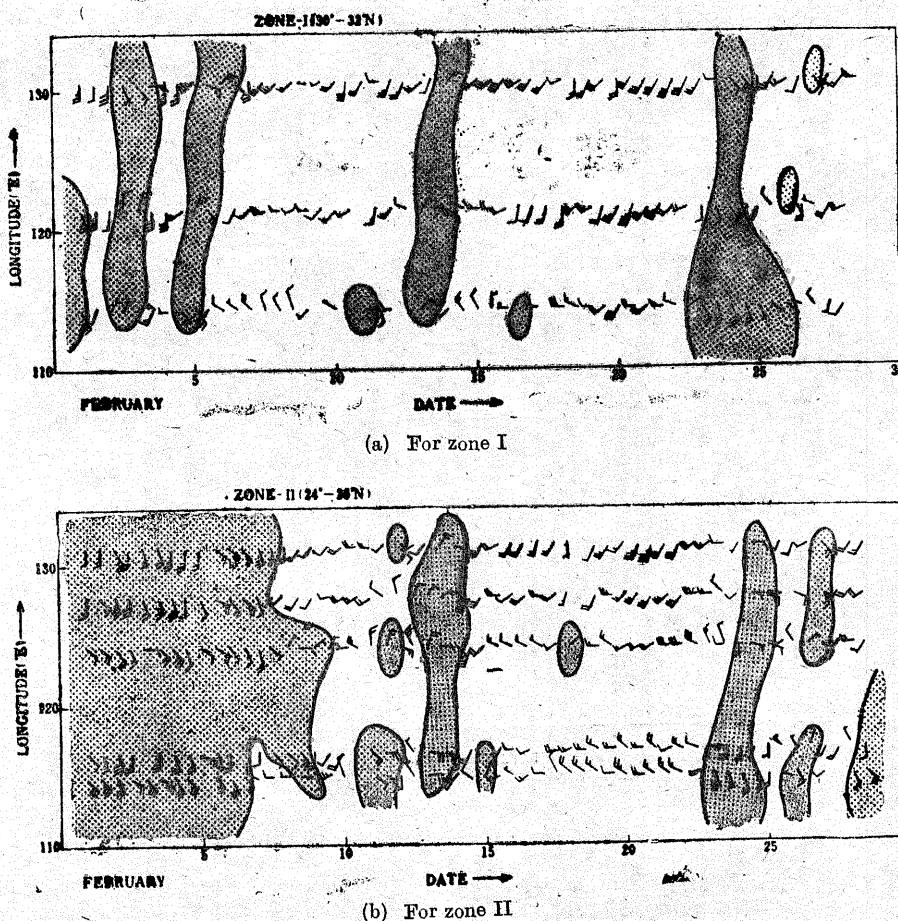
(a) For zone I

(b) For zone II

Fig. 2. Longitude-time cross-section of wind at 850 mb level in the month of February 1975

The triangle area (IV) is used in order to get a fine resolution. As the lateral extent of the square is about 1000 km, any wave disturbances with less than that wave length cannot be detected by analysis of $\bar{\omega}$ of that area. Analysis of $\bar{\omega}$ of the triangle area may bring out the features of such wave disturbances (if present). Further, the analysis of $\bar{\omega}$ in these 2 areas separately, may help to understand the north-south extent (amplitude) of the wave disturbances present over AMTEX area.

The method of power spectral analysis is the same as that used earlier by Ninomiya (1972), Nitta et al. (1973) and Yoshizaki (1974). The details are available in Maruyama (1968).

As discussed by Blackman and Tukey (1958), in power spectral analysis, the lag maximum should preferably be less than or equal to 1/3 of the total observations. Nitta et al. (1973) used 10 days as lag maximum for the month of February 1968. They also used two band-pass filters to study the wave disturbances with 1.5 to 2 day and 4 to 5 day periods. But Yoshizaki

(1974) used a lag maximum of 12 days for the months of January and March 1968 and he did not use any band-pass filters. In the present study a lag maximum of 10 days is taken for both the months of Fabruary and March 1975 and no band pass filter is used.

As there are many missing data for Chinese stations above 200 mb, the spectral analysis of temperature (T), northward component of wind (v), and mixing ratio of water vapour (q) is limited up to 200 mb level only. As the surface pressure of Naha and Naze is always less than 1000 mb, the wind data at 1000 mb level for these stations are not available. In the earlier studies (Nitta 1976, Krishna Murty 1976) the wind at 1000 mb was obtained by extrapolating the winds at higher levels (without using surface data). In the present study, as the winds are available at standard pressure levels only, the wind at 1000 mb is assumed to be the same as that of the 850 mb level. Because of frictional effects, the surface wind is not considered in estimating the wind at 1000 mb. The spectral analysis of $\bar{\omega}$ is made from 850 mb level to 300 mb level.
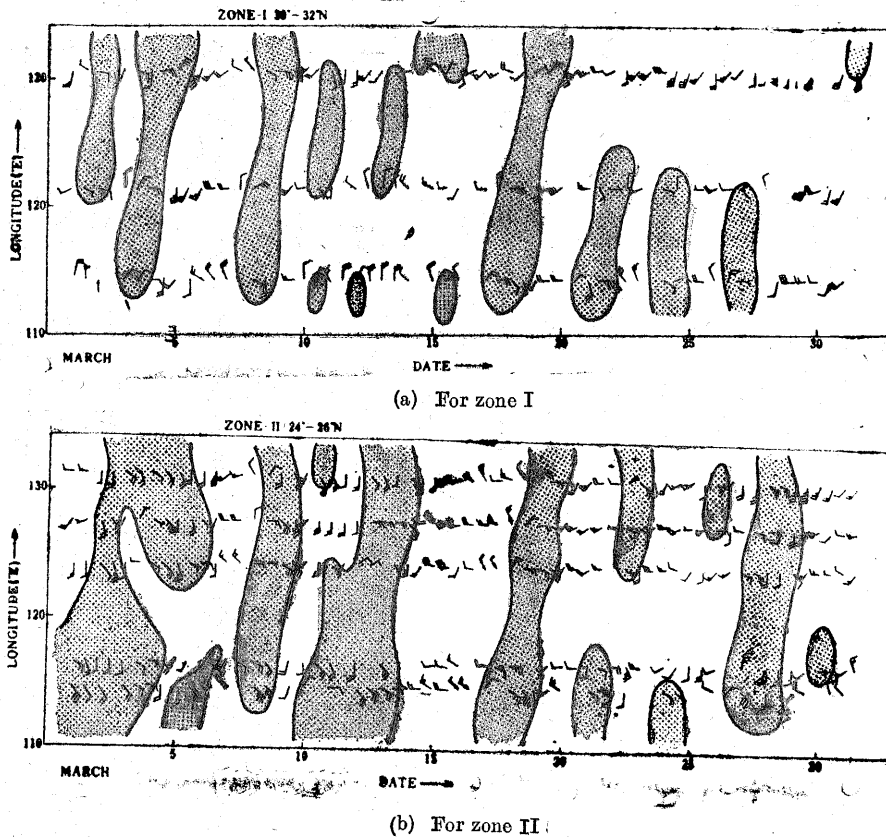
(a) For zone I

(b) For zone II

Fig. 3. Same as Fig. 2 except for the month of March 1975

3. General features

The Figs. 2 and 3 illustrate the longitudinal-time section of the wind at 850 mb level for the months of February and March 1975 respectively. The areas of wind with southerly component are shaded.

In the zone I (30°-32 ° N), though there are disturbances with 2 day periodicity in the first week of February, there are only 8-9 day period waves in the remaining part of the month (Fig. 2a). In the zone II (24°—26°N), as shown in Fig. 2(b), there is no regular periodicity. For the first 10 days the winds are southerlies. For the next one week, there are wave disturbances with a 2 day periodicity. Similar situation is observed in the last week of the month also.

As pointed out by Nitta et al. (1973) and Yoshizaki (1974) for the case of February 1968, the propagating disturbances could not be found clearly. But, short period disturbances are found more clearly compared to 1968 case (Ninomiya 1972, Nitta et al. 1973). Thus there are no passing wave disturbances over AMTEX area except in the beginning and latter part of the AMTEX 75 period (14 to 28 February 1975).

Unlike in the month of February, the wave disturbances are more regular in the month of March. In the northern latitudes (zone I) ; the

disturbances have a periodicity of about 3 days and they are propagating from west to east (Fig. 3a). In the latter part of the month, though the disturbances are present over the continent, they are absent over the sea. This is not the case with zone II, where the disturbances have a periodicity of 2-3 days throughout the month both over land and sea, as illustrated in Fig. 3(b).

4. Discussion of the results

Now let us discuss the wave disturbances in detail for both the months and both the regions.

(a) Wave disturbances in February

Figs. 4 (a, b, c) indicate the power spectra of temperature (T), v-component of the wind (v), and mixing ratio of the water vapour (q) corresponding to the stations of Hankow, Shanghai, and Kagoshima of zone I for the month of February 1975. There exist wave disturbances of 2-day period with maximum amplitude near 850 mb level. The spectral density maximum though small is prominent over the continent (Hankow) than near the coast (Shanghai) or over the island (Kagoshima). The long wave disturbances of 4-5 day period noticed by Nitta et al. (1973) for February 1968, are apparently neither present nor prominent in this case. However, they are present in the upper levels around 300 mb.
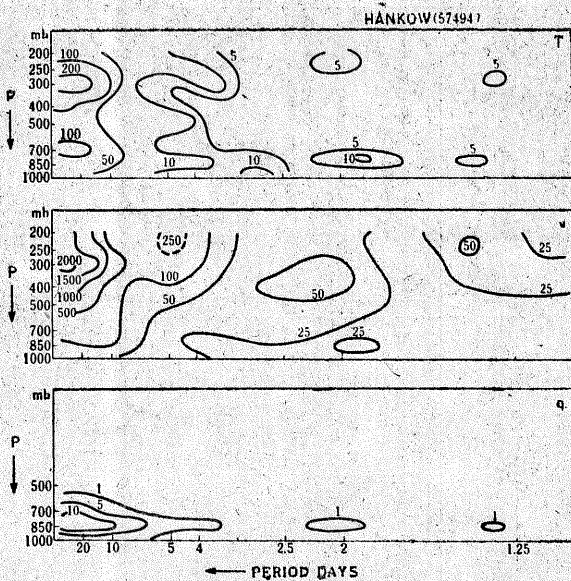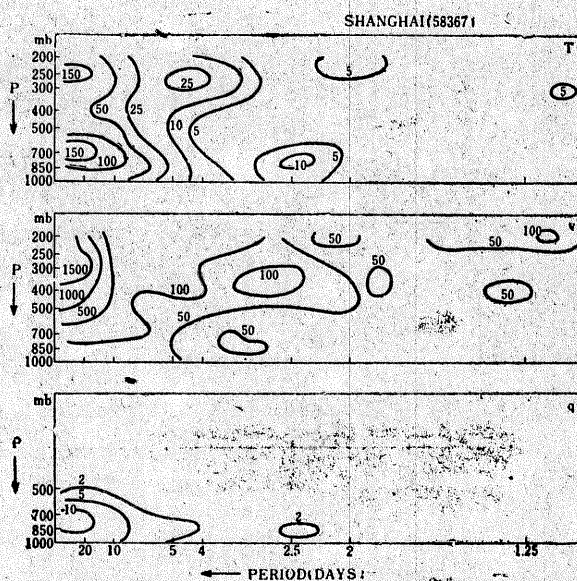
Fig. 4 (a). Hankow (57494)
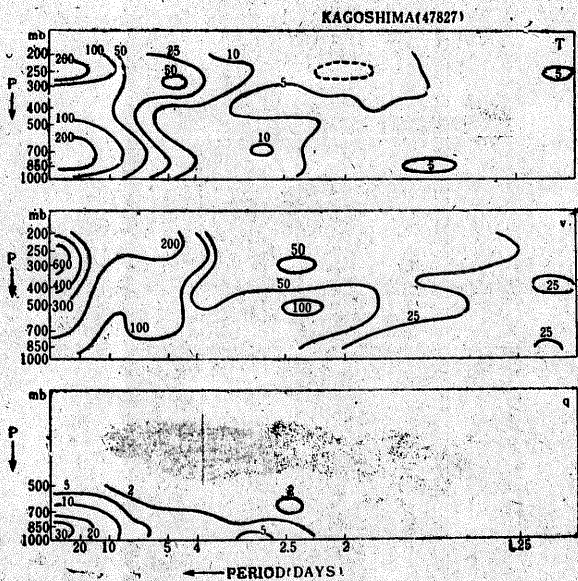

Fig. 4 (b). Shanghai (58367)
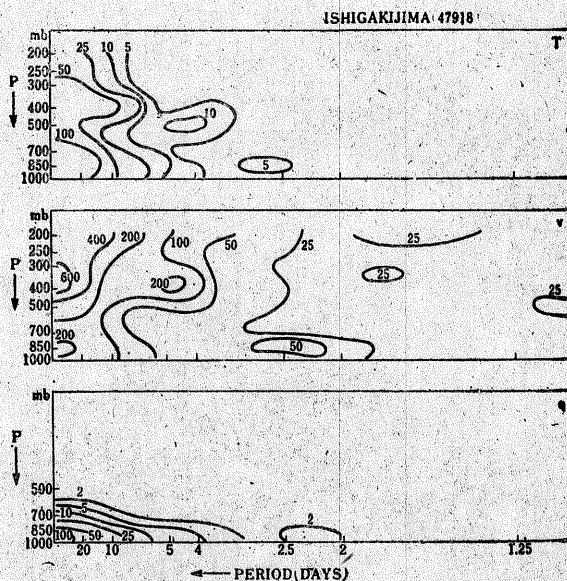

Fig. 4 (c). Kagoshima (47827)

Fig. 5 (a). Ishigakijima (47918)

Figs. 4 & 5. Power spectra of temperature (T), v-component of wind (v) and mixing ratio (q) [Fig. 4: All in zone I and Fig. 5: Except for zone II]. The units of isopleths are $(°C)^2$ day for T, $(m/sec)^2$ day for v and $(gm/kg)^2$ day for q.

Figs. 5 (a, b) is same as Fig. 4 except for stations Ishigakijima and Naha corresponding to the zone II. Here also, though feeble, the spectral density maximum near 850 mb corresponds to 2 to 2.5 day wave disturbances. Even in this zone the long waves with 4-5 day period couldn't be noticed. Similar to zone I, these long waves with 5-day period are present in the upper levels around 400 mb.

With the help of horizontal phase difference between stations for zones I and II separately,

the wave length, direction of propagation and phase velocity of the disturbances are deduced. Figs. 6 (a, b) indicate the horizontal phase difference *versus* the longitudinal difference between stations for zones I and II respectively. The horizontal phase differences at levels 1000 mb, 850 mb, and 700 mb, are plotted in the 2-3 day period range. The cases with coherence less than 90 per cent and the cases with coherence larger than 90 per cent are both considered. In zone I (30° to 32° N) the disturbances are propagating eastward with a wavelength of about
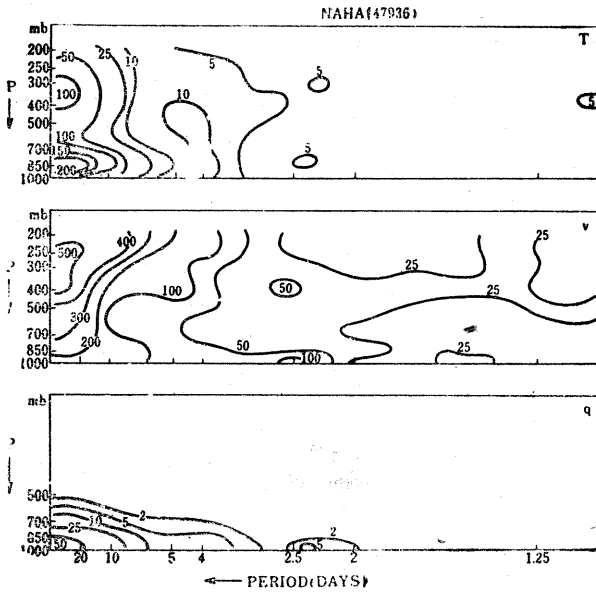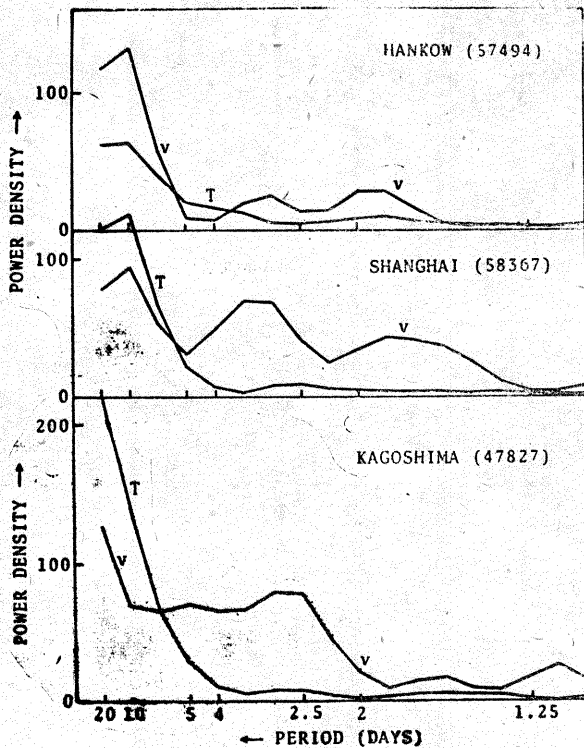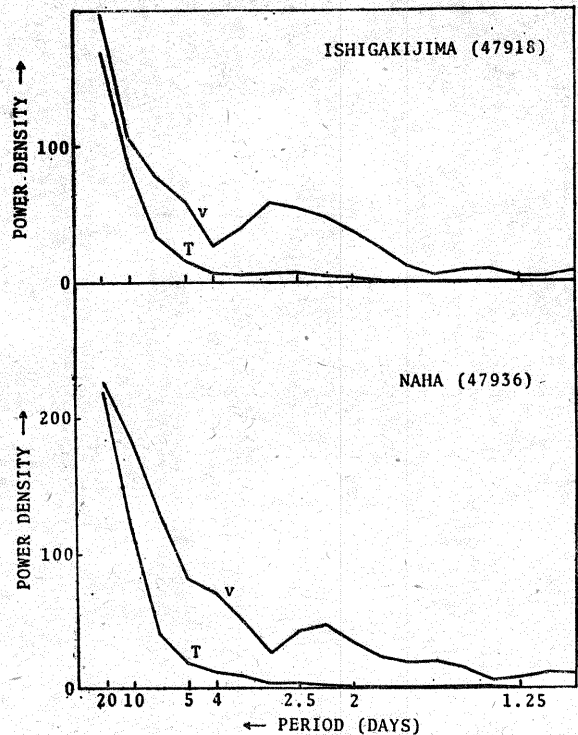
Fig. 8 (a). For stations of zone II

Fig. 8 (b). For stations of zone II

Fig. 8.   Power density of T and v at 850 mb level.   Units same as in Fig. 4.

shima) than over inland station (800 mb at Hankow). This may be due to the difference between the warm moist sea surface and the cold dry land surface.

Compared to the case of February 1968 (Nitta *et al.* 1973), reversal of the tilt of the trough takes place at a lower level indicating that the wave disturbance in 1975 are shallow in their vertical extent. Fig. 8 indicates the power densities of v and T spectra of 850 mb level for all the 5 stations. Though the temperature (T) spectra has power density peaks at periods 10 days or more, in the shorter periods the peaks are either nil or less prominent. The response of v-spectra is more than T-spectra for the waves with shorter periods. The v-spectral density peak is more pronounced over ocean than over land. This is just similar to that found by Ninomiya (1972) and Nitta *et al.* (1973). Comparing the spectral peaks Shanghai with Ishigakijima, and Kagoshima with Naha it can be noticed that there is an increase in the spectral density with latitude.

Fig. 9 shows the power spectra of vertical p-velocity (ω) for the areas III and IV covered by a triangle and a square. As also pointed out by Murakami (1972), the smaller the area becomes, the more intense the spectral density becomes. Thus the power spectral density of $\overline{\omega}$

is more for the triangle area than for the square area. During the investigation of 'Intermediate scale disturbances over Marshall Islands', Murakami (1972) commented that the vertical motion calculated from the large dimensional area fails to detect the variations associated with the disturbances of 3 days period. He emphasized this statement through the analysis of $\overline{\omega}$ over 4 different areas, domain I to domain IV (for details please refer Murakami 1972). The differences pointed out by him might be due to the selection of stations consisting the domain rather than the area covered by the domain. Except the domain IV (Figs. not shown), all the remaining 3 domains are having one or two stations near the equator at which the effect of the wave disturbances is very little. This might have resulted in the failure of the detection of variations associated with the disturbances. The domain IV, which does not contain any station near the equator could very well depict the variations. It is the latitudinal variation and not the area variation that made the difference. Thus in the present study, though the square area ($5 \cdot 71 \times 10^5$ km^2) is about 10 time larger than the triangle area ($0 \cdot 46 \times 10^5$ km^2), the variations depicted by the vertical motion calculated from the triangle area are also brought out by that of the square area (Figs. 9 and 14).
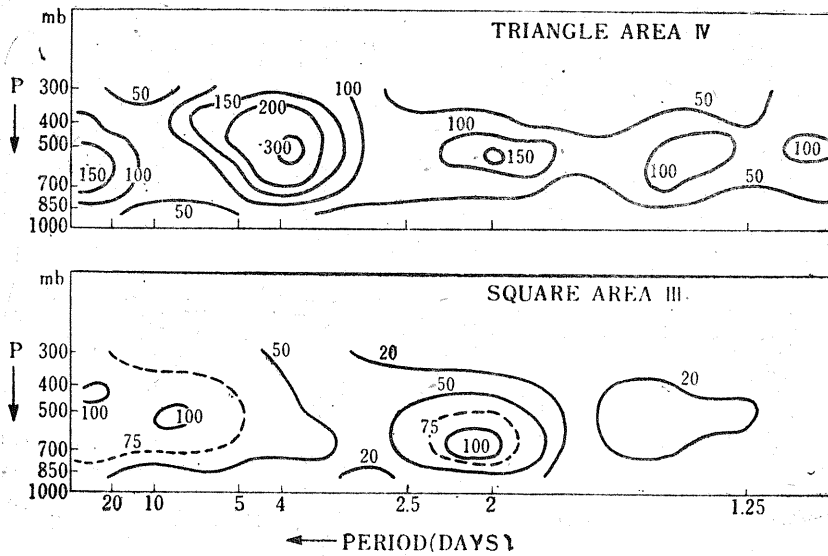
Fig. 9. Power spectra of $\bar{\omega}$ for the areas III and IV. The units are (mb/hr)² day.
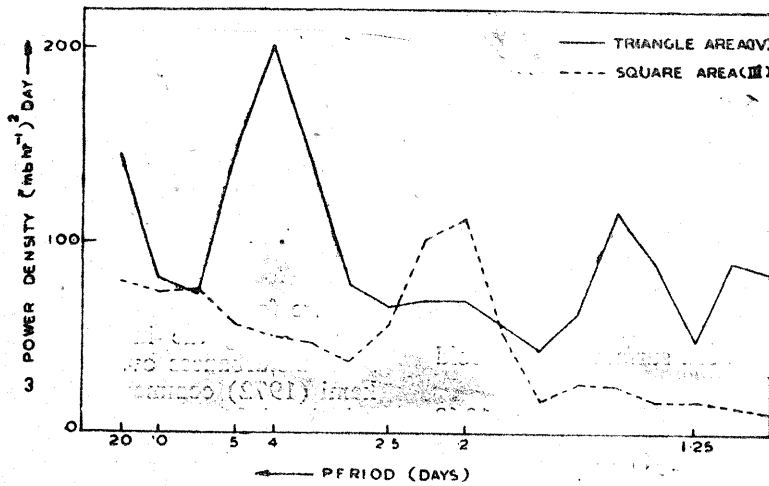

Fig. 10. Power density of $\bar{\omega}$ at 700 mb level. Units same as in Fig. 9.
(Note : Figs. 4 to 10 correspond to the month of Feb 75,
Figs. 11 to 15 correspond to the month of Mar 75)

Though the $\bar{\omega}$ spectra of the triangle area shows 3 distinct wave disturbances with 1.5, 2 and 4 day periods, the spectra of the square area shows the power concentration for the disturbances with 2 day period only. This indicates that, though there are wave disturbances, with 1.5, 2 and 4 day periods in southern latitudes, the amplitude of the 2 day period wave only is large. This is supported by Fig. 10, which is the power density of $\bar{\omega}$ at 700 mb level. Though there are 3 peaks for the triangle area, the only peak supported by the square area is 2-day period. The sharp peak of the triangle area around 4-day period indicates that 4-5 day period disturbances are present in the lower latitudes only. This is in confirmation with Fig. 5(b) where these disturbances are noticed above 500 mb level.

(b) *Wave disturbances in March*

Now let us see in detail the characteristics of the wave disturbances in the month of March 1975.

Unlike in February, in March the wave disturbances with 3-day period and 5-day period are dominant. While zone I is dominated by the 3-day period disturbances, 5-day period disturbances are more distinct in zone II where the 3-day period disturbances are also noticed, but at higher levels around 400 mb. Figs. 11 (a) & 11(b) are shown as example, one for each zone. Though the 3 day wave disturbance at Shanghai (zone I) could be traced in the power spectra of all the three elements, the spectral peak corresponding to the disturbances with

(a) Shanghai (58367), zone I
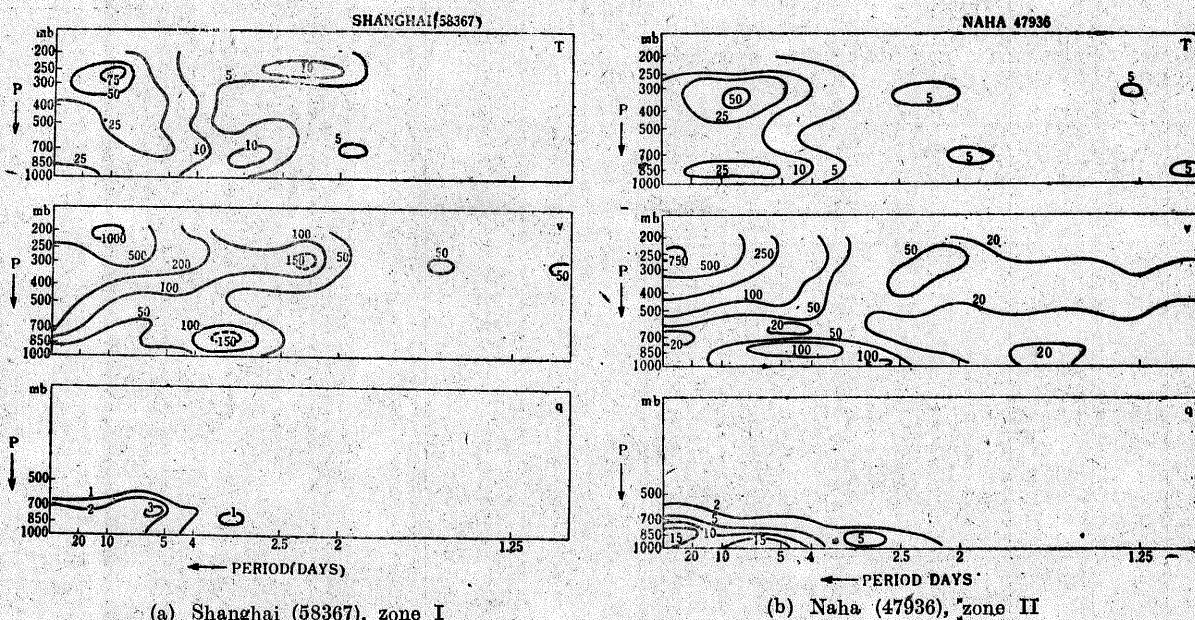
(b) Naha (47936), zone II

Fig. 11. Same as Fig. 4 except for the month of March

5 day period at Naha (zone II) is rather diffused, extending from 4 to 10-day period range. It is distinct in the power spectra of v, compared to T and q. When we examine the power densities at 850 mb level (Fig. 12a) it is larger over sea (Kagoshima) than over land (Hankow), similar to that noticed in February. Further, even over sea, the power density becomes more as the wave disturbances travel eastwards, with Ishigakijima having less density than Naha (Fig. 12b).

The examination of the horizontal phase differences (figures not shown), indicated that the wave disturbances are propagating eastwards. While the wave disturbances with 3-day period of zone I are having a wave lengthy of about 4000 km, the disturbances with 5-day period of zone II are having more than 6000 km, similar to that noticed by Yoshizaki (1974) for January 1968.

Fig. 13(a) represents the vertical structure of 3-day period wave disturbances at Shanghai (zone I). It is similar to the baroclinic wave with warm moist air to the east of the trough. The westerly tilt of the trough reverses above 500 mb level. Up to that level, warm air remains to the east of the trough. Fig. 13(b) corresponds to 5-day period disturbance at Naha (zone II). The westerly tilt of the trough continues beyond 500 mb. But the warm moist air to the east of the trough changes to cold dry air above 700 mb level.

In $\bar{\omega}$ power spectra (Fig. 14), 3 disturbances with periods 1.5 day, 3 and 5-6 day are noticed for the square area. But in the triangle area only 2 wave disturbances are noticed with 1.5-day and 3-day periods. This indicates that the wave disturbances of shorter periods have larger amplitudes. The power densities of $\bar{\omega}$ at 700 mb level are shown in Fig. 15. They are larger for the triangle area than the square area. The 3-day period wave disturbances corresponding to zone I are very well depicted by the $\bar{\omega}$ power density of both the triangle and square areas. However, the 5 day period disturbances of zone II are not reflected in $\bar{\omega}$ of the triangle area. Even in square area, it is feeble. This may be due to that the 5-day period wave disturbances appearing in zone II might be less intense so that the $\bar{\omega}$ associated with them may not be strong enough to get reflected in the areal average. As mentioned earlier, the 5-day period disturbances appearing in zone II are rather diffused, as such the $\bar{\omega}$ corresponding to them could not appear prominently in the $\bar{\omega}$ spectral analysis.

In the month of February, the disturbances appearing in zone I and zone II are same with 2-3 day period in the lower levels, and 4-5 day period at upper levels. In March while they are of 3-day period with shorter latitudinal extent (than in February) in zone I, they are shallow in zone II with 5-day period in lower levels and 3-day period in the upper levels. This indicates that the influence of the weather systems of the northern latitudes on those of southern latitudes is more in February than in March. This is consistent with the fact that the weather systems in the northern hemisphere shift northwards and become weaker as the summer approaches.

TABLE 1

Characteristics of the wave disturbances over East China Sea

	February 1975		March 1975	
	Zone I	Zone II	Zone I	Zone II
Period of wave disturbances (day)	2 (5)	3 (5)	3	5 (3)
Wavelength (km)	4000	6000	4000	8000
Phase velocity (mps) (by spectral analysis)	23	23	15	18
Phase velocity (mps) (by synoptic analysis)	20	12	13	10

Note—Numbers in brackets correspond to higher levels (above 500 mb).
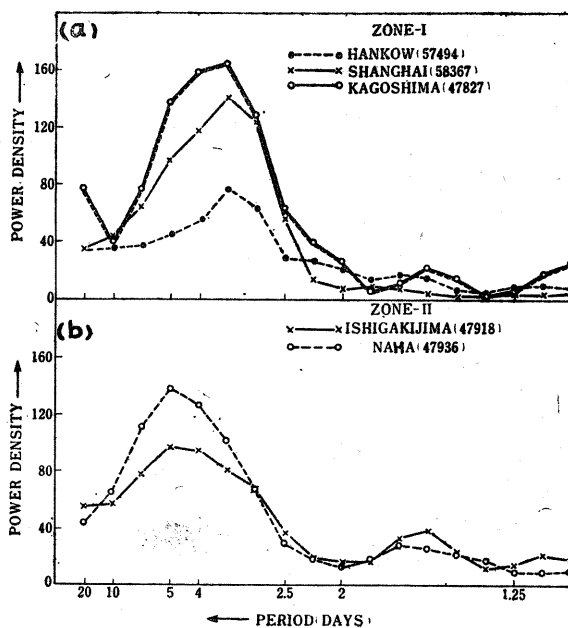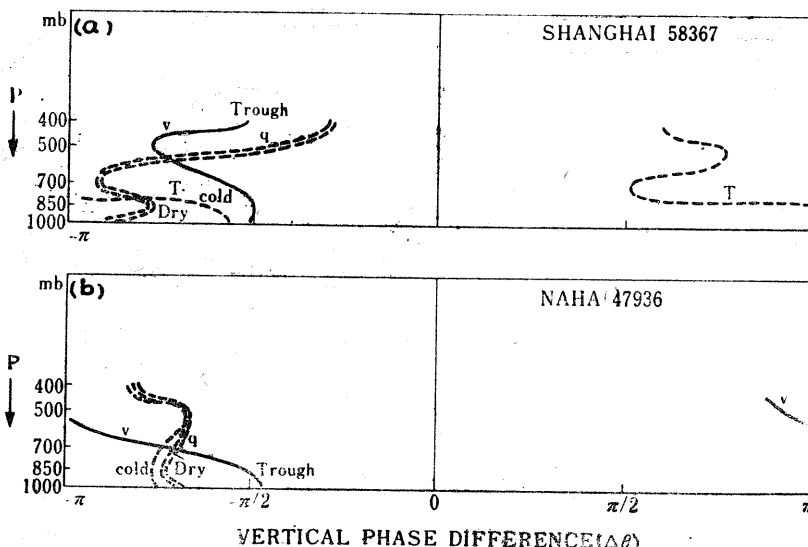

Fig. 12. Power density of v at 850 mb level for the month of March. Units same as in Fig. 4.

(a) Shanghai (zone I) corresponding to a 3-day, (b) Naha (zone II) corresponding to a 5-day period disturbance.

Fig. 13. Same as Fig. 7 except for the month of March

Now let us discuss about phase velocities. Phase velocities can be determined in 2 ways. One method is to determine directly from the propagation of disturbances (through longitudinal-time cross section). Another method is from the horizontal phase difference of the wave disturbance of a particular period obtained through spectral analysis of the time series data. While the earlier one gives the phase velocity of that particular situation, the latter one gives the average phase velocity for that time series data.

In the present study, the phase velocities are calculated by both the methods for the respective wave disturbances appearing in the respective months (February and March 1975), in the respective zones (zone I and zone II). As discussed earlier, the wave disturbances appearing in the month of February are having a period of 2 days with a wave length of 4000 km in
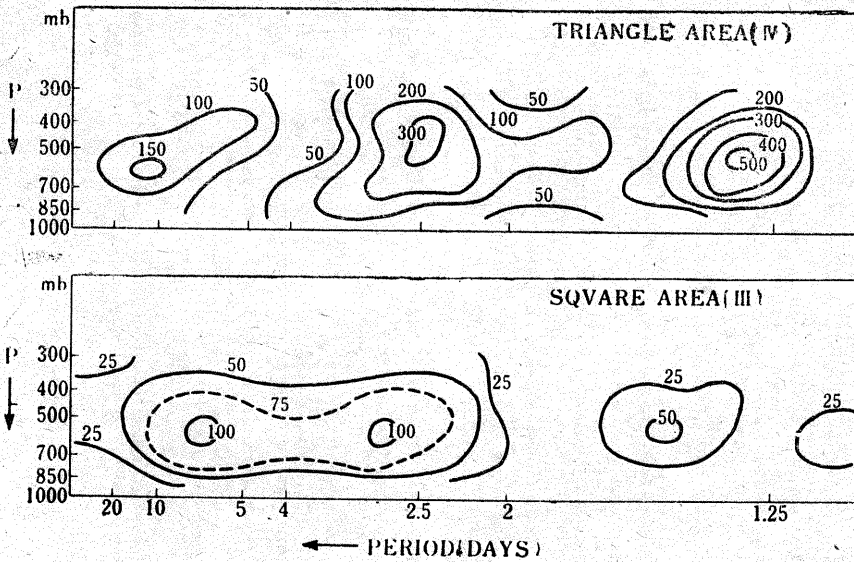
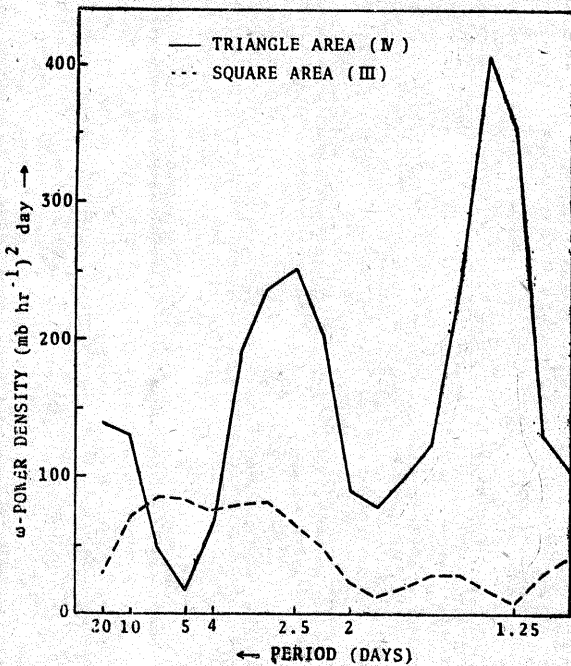Fig. 14. Same as Fig. 9 except for the month of March

Fig. 15. Same as Fig. 10 except for the month of March

velocity corresponding to the wave disturbance appearing on 5 February 1975 (Fig. 2a) is 20 mps, almost same as that calculated by the spectral analysis. But, the phase velocity in zone II (of 23 February 1975, Fig. 2b) is 12 mps, which is only half of that obtained earlier. This may be due to that in the first 10 days of February, the region was under the influence of strong southerlies (due to Taiwan cyclone) and this might have effected the phase velocity calculation by the spectral analysis which is an average one. In the month of March, the phase velocities are 13 and 10 mps for zone I (17 March, Fig. 3a) and zone II (17 March, Fig. 3b) respectively. Similar to the month of February, the phase velocities calculated by these two different methods agree in zone I. These results are summarized in Table 1.

In general, the results by both the methods are tallying in zone I. The phase velocity is higher in February than in March. In zone II also the phase velocity for the month of February is larger than that of March, but the values obtained by the spectral analysis are almost double that of the values obtained by the other method.

5. Conclusions

Though the characteristic features of wave disturbances over East China Sea were studied earlier for the year 1968 by different authors, the present study revealed some differences between the characteristics of the disturbances in the years 1968 and 1975.

(a) Though the medium scale disturbances of 2-3 day period are present in 1975 case also (similar to 1968), the long wave of 4-5 day period noticed in 1968

zone I. In zone II, the period is 3 days and the wave length is 6000 km. The resultant phase velocity for both the zones is the same, about 23 mps. In the month of March, the phase velocity in zone I comes out to be 15 mps (as the period is 3 days and the wave length is 4000 km) and in zone II it is 18 mps (since the period is 5 days and the wave length is 8000 km).

From the individual synoptic situations, the phase velocities are estimated for both the months and both the regions. In zone I the phase

are not present in the lower atmosphere clearly either in zone I or zone II.

(b) The wave disturbances in the month of March are more regular (in the sense of propagating eastwards) in 1975 than in 1968. Further, the period of wave disturbances noticed in March 1975 is 3-day for zone I and 5-day for zone II. Thus, it is different from the situation of March 1968 where the periodicity of the wave disturbances is weak and even the preferred period is 6-8 day (Yoshizaki 1974).

(c) Though the wave lengths of the disturbances are of similar magnitude in both the years, the vertical structure is slightly different. The air is warm and moist to the east of the trough throughout the lower troposphere in 1968. In 1975, while the characteristics are similar to the 1968 case in the lower levels of the lower troposphere, they are opposite to that situation in the levels just above. Thus, in 1975 also, the wave disturbances are more similar to the baroclinic waves.

(d) The phase velocities of the wave disturbances are higher in the month of February than in the month of March 1975. As the phase velocities for the year 1968 were not reported in the earlier studies, a comparative study of 1975 results with those of 1968 could not be made.

(e) The wave disturbances appearing in February in both the zones are with a period of 2-3 days, wave length of 4000-6000 km and a phase velocity of 23 mps. This indicates that in the month of February, the wave disturbances appearing in both the latitudinal belts are the same ones with larger latitudinal extent (amplitude large).

(f) In the month of March, the disturbances appearing in both the latitudinal belts are different with different wave length, period and phase velocity. While they are having shorter period and wave length in the northern latitudes, it is just the opposite in southern latitudes.

Acknowledgements

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