NOTES AND CORRESPONDENCE

Quasi-Weekly Cycle of the Upper Tropospheric Wind Observed near the Southern Japan in Mid-Summer: Quick Looks

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1. Climatological background

The northern summer upper-tropospheric circulation is characterized by the Tibetan and Mexican anticyclones (see, *e.g.*, Newell *et al.*, 1972). There are not a few studies on the intra-seasonal variabilities of this circulation. On one hand, since Madden and Julian (1971, 1972a), we have known the existence of so-called "30–60 day oscillations" mainly in the tropical area. This type of variation is considered to be closely connected to strong activities of cumulus convections over the equatorial Indian and Pacific oceans, based on both satellite imageries (*e.g.*, Yasunari, 1980) and numerical simulations (*e.g.*, Hayashi and Sumi, 1986).

Similar variations are detected also in the extratropical area (*e.g.*, Takeda and Ikeyama, 1984). Recent studies find that such an extratropical quasi-monthly mode is barotropic whereas the equatorial one is baroclinic (see Krishnamurti and Gadgil, 1985). Thus, the extratropical variations may be indirectly, rather than directly, connected to the tropical ones. We remember that so-called teleconnection patterns have been analyzed and interpreted as rays of the tropically-forced Rossby wavepackets (Hoskins and Karoly, 1981; Hayashi and Matsuno, 1984). Anyway such forced waves have quasi-steady structures, so that they induce wind variations of a period at least longer than one month.

On the other hand, we have also known that there are free traveling Rossby waves with typical periods of 5, 10 and 16 days. The existence of

the 5-day wave and its global structure in the summer troposphere were originally found out by Madden and Julian (1972b), using very careful techniques such as analyses of pressure data during longer than several years. Madden (1978) showed that the 16-day wave is strong in winter high-latitude upper troposphere. Recently, by Hirooka and Hirota (1985), the 10-day wave is analyzed out in the upper stratosphere. These are also theoretically expected by Salby (1981). However, these foregoing studies have never described that the wind variations induced by those waves are dominant in the subtropical upper troposphere.

This brief report concerns a striking feature of quasi-periodical wind azimuth revolutions in a cycle of roughly one week, which is discovered in the mid-summer upper troposphere over the

Fig. 1 Time-altitude section of zonal wind over Kagoshima based on 25-year, monthly mean data (JMA, 1984a). Contours are drawn every 10 m/s (easterlies are dashed).

Fig. 2 Time-altitude section of zonal wind over Kagoshima based on 6-hourly (12-hourly for levels upper than 150 hPa) routine radiosonde data (JMA, 1985b). Contours are drawn every 10 m/s (easterlies are dashed).

southern Japan. In a monthly average the observed area is located in the east of the Tibetan anticyclone and there is a very weak zonal wind as shown in Fig. 1. However, the results of this report indicate that such a windless situation is apparent and that there are remarkable oscillating winds. Implication of this fact to the synoptic meteorology and weather prediction in Japan may not be small. For example, the end of Baiu would be defined by the onset of the wind revolutions, and typhoon arrivals might be in concert with this cyclic wind revolutions.

2. Observed quasi-weekly cycle

Figure 2 is the time-altitude diagram of zonal winds over Kagoshima, Japan (31.6°N , 130.6°E), during the mid-summer in 1985 (JMA, 1985a, b). Clearly we find out zonal-wind reversals with a 5–10 day cycle in the altitude range of 300–150 hPa (9–14 km). Taking the standard deviations of zonal winds for each standard pressure levels, we can find that the wind variation amplitude takes a maximum ($\gtrsim 10$ m/s) at 200-hPa (~ 12 -km) altitude (*cf.* Yamanaka, 1987).

Figure 3 shows the wind-azimuth temporal changes at the beginnings of zonal-wind cyclic changes for 1984–86 over Kagoshima and Shanghai, China (31.2°N , 121.4°E). We find clearly that the wind variations over Kagoshima are cyclic, clockwise. We also find that similar features appear throughout mid-summer season which can be defined as a period from the end of Bai-u (late July) to the onset of Shurin (early September). In particular the beginning of

Fig. 3 Temporal variations of wind azimuths at the beginnings of the “quasi-weekly revolutions”. (a)–(c) 150-, 200- and 300-hPa levels (nearly 14-, 12- and 10-km altitudes) over Kagoshima (thick lines; 6-hourly; JMA, 1985b) and Shanghai (thin lines; 12-hourly; JMA, 1985a) in 1985. (d) 200-hPa level in 1984 (12-hourly; JMA, 1984b). (e) 200-hPa level in 1986 (12-hourly; JMA, 1986).

Fig. 4 Wind and geopotential-height variations at 200 hPa (≈ 12 km) level, based on JMA (1985a). Winds are plotted conventionally and geopotential heights are contoured every 50 gpm. (a) Latitude-time section along 130°E : Minamidaitojima (index number: 47945), Naze (47909), Kagoshima (47827), Fukuoka (47807), Pohang (47138), Pyongyang (47058) and Vladivostok (31960). (b) Longitude-time section along 32°N : Wuhan (57494), Shanghai (58367), Kagoshima, Shionomisaki (47778) and Hachijojima (47678).

the wind cyclic change corresponds quite well to the end of the Baiu season. We cannot concretely decide whether the phase propagates upward or downward, which suggests that the variations are barotropic. Furthermore, we should note the following two points: first, the variations are most typical near the southern Japan. Second, the cycle is not fixed and some short reverse (anticlockwise) periods are included, which suggest a superposition of plural periodical modes. These two points are confirmed below.

Figures 4(a) and (b) show the latitude- and longitude-time cross-sections transcribed from the routine 200-hPa charts (JMA, 1985a). Geopotential variations with time scales similar to that of the wind revolution found in Figs. 2 and 3 can be found over almost all the analyzed area, but the revolutions themselves are most striking near the southern Japan. The northern boundary of the phenomena may exist at around 40°N , because it seems that the phases cannot be continued to the region north of 40°N . The meri-

dional phase propagation seems northward but the zonal propagation is unclear.

As a preliminary band-pass analysis, we calculated each differences between the 4-, 7- and 14-day running means of the data over Kagoshima during the 1985 mid-summer (Fig. 5). We can detect three modes: (i) ≥ 1 month, (ii) ~ 10 days, and (iii) ~ 5 days. For each mode the zonal and meridional winds are in clockwise quadrature, and the geopotential and temperature variations in particular of (i) and (ii) are almost in-phase, that is, barotropic (*cf.* Krishnamurti and Gadgil, 1985). It is quite interesting that the quasi-weekly modes (ii) and (iii) seem to be AM-modulated by the quasi-monthly mode (i); the former amplifies in the easterly phases of the latter. The maximum amplitudes of geopotential, temperature and wind variations with (ii) and (iii) are more than ± 20 gpm, $\pm 1^\circ\text{C}$ and ± 7 m/s, respectively, which are nearly equal to or stronger than those with (i). Although these analyses are only within the quick-look stage, we shall try

Fig. 5 Preliminary band-pass analyses of geopotential (ϕ), temperature (T), zonal wind (u) and meridional wind (v) at 200 hPa (≈ 12 km) level, using 6-hourly observations in Kagoshima (JMA, 1985b). (a) 14-day running mean; (b) difference between 7- and 14-day running means; and (c) difference between 4- and 7-day running means.

to give a brief discussion on them in the next section.

A 4–5 day cycle can be found also in the longitude-time cross-section of the surface weather charts, which is omitted here, but it is not always correlated with the upper-tropospheric cycle (*cf.* Yamanaka, 1987). This discreteness can be found out also in Fig. 2; the wind standard deviation takes a minimum at the middle

troposphere (500-hPa or 5-km altitude). A typhoon, which may have tall structures throughout the whole troposphere, arrived near Shanghai in 31 July–1 August and another one near Kagoshima in 30 August–2 September in 1985 are analyzed here. The former appears weakly in Fig. 4(b) and the latter is shown clearly in Fig. 2. They do not seem to disturb the quasi-weekly cycle so much, and rather they seem in concert with the cycle.

3. Trapped Rossby waves?

We notice that the periods of quasi-weekly modes, (ii) and (iii), are close to those of free Rossby waves. Indeed, the dominant existence of (iii) seems consistent with the foregoing studies (*e.g.*, Madden and Julian, 1972b), while the dominance of (ii) in the subtropical upper troposphere is not always found in them. If (ii) and (iii) can be expressed as Rossby waves, their zonal phase velocity (relative to the ground), c_x , should be less than the easterly, $\bar{u}$ (<0), induced by (i). The meridional flow, $\bar{v}$, can be neglected by the quadrature character of (i). Thus we may write, based on Fig. 5(a).

$$c_x < \bar{u} \approx -5 \text{ m/s} \approx -20 \text{ km/h} \approx -400 \text{ km/day}.$$

(1)

which implies that the zonal wavelengths of (ii) and (iii) are longer than 4000 and 2000 km, respectively. However, in the present stage, the zonal phase velocity of the quasi-weekly modes is unclear as shown in Fig. 4(b), so that we cannot decide observationally whether the quasi-weekly variations are Rossby waves or not.

By the way, the foregoing studies mentioned before considered a pure sinusoidal wave structure in the zonal direction (as a result of the Fourier analysis) superposed in a DC zonal-mean flow. However, we have found in Fig. 5 that the amplitudes of (ii) and (iii) are modulated by (i). Thus, at least concerning the present results, we had better consider that *the quasi-weekly-mode wavepackets are trapped in the easterly phase of the quasi-monthly mode*. Note that the Fourier analysis is not always consistent with the wavepacket kinematics, because in the former the wave parameters are constant whereas in the latter they are modulated in space and time (*cf.*

Fig. 6 Trapped-Rossby-wave hypothesis: (a) the Longuet-Higgins' 'locus' for a shallow-water (barotropic, non-divergent) Rossby wave in a rest media (x and y : eastward and northward coordinates; $\mathbf{c}$ and $\mathbf{c}_g$: phase and group velocity vectors; c_x and c_y : zonal and meridional phase velocities; α : wave-number vector direction); (b) 'locus' with a basic zonal flow $\bar{u}$ (assumed here to be negative); and (c) schematic illustration of a wavepacket trapped in the easterly phase of a larger-scale variation.

Hayashi and Matsuno, 1984).

We follow the simplest treatment of a Rossby wavepacket, that is, the barotropic non-divergent (or shallow-water) theory. In case of no basic flow, $\bar{u} = (\bar{u}, \bar{v}) = 0$, there is a relationship, so-called Longuet-Higgins' (1964) locus, between the group velocity, $\mathbf{c}_g$, and the phase velocity, $\mathbf{c}$, as shown in Fig. 6(a). Note that the zonal component of $\mathbf{c}$ is smaller in magnitude than the zonal phase velocity, c_x [$= -\beta/k^2$, where $k \equiv (k, l) \equiv |k|(\cos\alpha, \sin\alpha)$ is the horizontal wave-number vector and β is the Rossby parameter]. A useful expression is

$$\mathbf{c}_g = -c_x(\cos 2\alpha, \sin 2\alpha) \quad \text{for } \bar{u} = 0. \quad (2)$$

The wave vector direction α defines whether the zonal group velocity is parallel with or opposite to the zonal phase velocity. The meridional group velocity is in general opposite to the meridional phase velocity, which holds as long as $\bar{v} = 0$.

In the present case, $\bar{u} \neq 0$ and $\bar{v} \approx 0$. Then c_x and $\mathbf{c}_g$ in (2) should be replaced by $(c_x - \bar{u})$ and $(\mathbf{c}_g - \bar{u})$, respectively [see Fig. 6(b)]. The zonal group velocity, c_{gx} , is given by

$$c_{gx} = \bar{u} + (\bar{u} - c_x) \cdot \cos 2\alpha. \quad (3)$$

If the quasi-weekly mode, (ii) or (iii), is a Rossby wavepacket trapped in the quasi-monthly mode (i), as schematically shown in Fig. 6(c), then the group velocity of the former should be equal to the phase velocity of the latter:

$$c_{gx} = \bar{c}, \quad (4)$$

where $\bar{c}$, the zonal phase velocity of (i), is not Doppler-shifted with $\bar{u}$ produced by (i) itself. Using (1), (3) and (4), the condition of the wave vector for the quasi-weekly-mode packet trapped by the quasi-monthly mode is given by

$$\cos 2\alpha \geq 0 \quad \text{for } \bar{c} \geq \bar{u} \approx -5 \text{ m/s}. \quad (5)$$

Therefore, if we know $\bar{c}$ and $\bar{u}$ of (i), an unique relation between c_x and α for the trapped waves (ii) can be derived. Of course, in order to explain the discrete dominance of the quasi-weekly modes, we must specify the boundary conditions.

Here we cannot obtain $\bar{c}$ directly from the observational evidence without global analyses. However, for further studies in the future, it may be worth our while to estimate the wave parameters under the trapped-Rossby-wave hypothesis by using an expected typical value of $\bar{c}$. It is not unreasonable to consider that the quasi-monthly mode (i) might be identical to the 30–60 day oscillations mentioned in Section 1. Thus, assuming $\bar{c} \approx +10$ m/s as a typical value, the formulae (3)–(5) lead to

$$c_x = -(5 + 15/\cos 2\alpha) \text{ m/s}, \quad \cos 2\alpha > 0. \quad (6)$$

The phase and group velocities are expressed from (6) by functions of the wave vector direction, which are plotted by solid curves in Fig. 7.

Fig. 7 Parameters for Rossby waves trapped in a typical 30–60 day oscillation ($\bar{c} = +10$ m/s). Solid and dashed curves are the cases of its typical easterly ($\bar{u} = -5$ m/s) and westerly ($\bar{u} = +5$ m/s) phases, respectively. Angles are measured anti-clockwise from the eastward direction. (a) Relations between the phase and group velocity directions (dotted line: $\bar{u} = 0$ case); and (b) phase and group velocities, (c_x , c_y) and (c_{gx} , c_{gy}), as functions of the wavenumber vector direction (α in Fig. 6).

We can easily find that c directs almost westward ($3\pi/4 < \alpha < 5\pi/4$), whereas the direction of c_g varies clockwise from south to north [cf. Fig. 6(b)]. An interesting case is $\alpha = \pi$, at which c_g and c are purely eastward and westward, respectively, and c_x takes the slowest value (≈ -20 m/s ≈ -2000 km/day). Then the wavepacket might keep its enforced latitude and, if we are there, it could be observed as a cycle given by the easterly phase width (≈ 20000 km) of (i) divided by c_x , which is close to (ii) observed here. It is also interesting that the meridional phase velocity c_y (faster than c_{gy} , in general) has positive (northward) and negative (southward) minima ($\approx \pm 60$ m/s $\approx \pm 5000$ km/day) at $\alpha \approx 5\pi/6$ and $7\pi/6$, respectively. Then $c_x \approx -30$ m/s ≈ -2500 km/day, which could be observed as a cycle shorter than the case mentioned above; if the zonal wavelength is shorter than the full span of the easterly phase width, the period to be observed may be close to (iii).

We can consider the case of westerly phase ($\bar{u} \approx +5$ m/s) of (i) in a similar way, which is also plotted by dashed curves in Fig. 7. Again we find $c_{gy} = 0$ at $\alpha = \pi$, but in this case c vanishes, i.e., the period becomes infinity. Furthermore, the nonzero minima of the $|c_x|$ do not exist in the westerly-phase case. If (ii) and (iii) are amplified in the easterly phase of (i) with satisfying some meridional boundary conditions, they could not amplify in the westerly phase. They might be radiated and dissipated, or else they are buried into other modes including (i) and the DC component.

Therefore the trapped-wave hypothesis seems to explain some characteristic features of the quasi-weekly cycle observed here. Again we note that the boundary conditions should be specified, and further we must be careful to use such a local-Cartesian description (cf. Hayashi and Matsuno, 1984). We would like to state again that we need an extension of the foregoing

Rossby-wave calculations (Salby, 1981) treating only a zonally-uniform basic flow field. Perhaps quasi-weekly modes such as the 5-, 10- and 16-day waves can be selected, modulated and trapped locally in quasi-monthly modes such as the 30–60 day oscillation dominant in the tropical troposphere.

On the contrary, we may consider that the quasi-weekly-mode packets enforce the quasi-monthly mode, since a Rossby wavepacket accelerates easterly and westerly in its 'precursor' and 'postcursor' regions, respectively. Recent numerical models suggest that the 30–60 day oscillation might be a wave-CISK solution in the fully-moist tropical atmosphere (Hayashi and Sumi, 1986). Could we speculate that Rossby wavepackets generated somewhere enforce the oscillation in a broad area with their propagations? Interestingly, a quasi-weekly cycle without wind-azimuth rotations can be found in the upper troposphere even in seasons other than the mid-summer, as shown in closed contours within westerlies near the left and right sides in Fig. 2 and also in recent analyses by Ohno and Hirooka (personal communication). Furthermore, Zhang (1981) has pointed out an about 10-day cycle descent of the summer stratospheric easterly, suggesting an interaction between the stratospheric polar and upper-tropospheric Tibetan anticyclones. Is this the same phenomenon as the present results? Anyway, we need more detailed analyses, such as the global structure and the correlation to cloud activities, in order to study those problems.

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References

- Hayashi, Y.-Y. and T. Matsuno, 1984: Amplitude of Rossby wave-trains on a sphere. *J. Meteor. Soc. Japan*, **62**, 377–387.
- and A. Sumi, 1986: The 30–40 day oscillation simulated in an "aqua planet" model. *J. Meteor. Soc. Japan*, **64**, 451–467.
- Hirooka, T. and I. Hirota, 1985: Normal mode Rossby waves observed in the upper stratosphere, Part II: Second antisymmetric and symmetric modes of zonal wavenumbers 1 and 2. *J. Atmos. Sci.*, **42**, 536–548.
- Hoskins, B.J. and D.J. Karoly, 1981: The steady linear response of a spherical atmosphere to thermal and orographic forcing. *J. Atmos. Sci.*, **38**, 1179–1196.
- JMA (Japan Meteorological Agency), 1984a: *Aerological Data of Japan, 30-Year Mean (1951–1980)*, Vols. 1 and 2.
- , 1984b: *Daily Weather Maps, July–August, 1984*.
- , 1985a: *Daily Weather Maps, July–September, 1985*.
- , 1985b: *Aerological Data of Japan, July–September, 1985*.
- , 1986: *Daily Weather Maps, July–September, 1986*.
- Krishnamurti, T.N. and S. Gadgil, 1985: On the structure of the 30 to 50 day mode over the globe during FGGE. *Tellus*, **37A**, 336–360.
- Longuet-Higgins, M.S., 1964: On group velocity and energy flux in planetary wave motions. *Deep-Sea Res.*, **11**, 35–42.
- Madden, R.A., 1978: Further evidence of traveling planetary waves. *J. Atmos. Sci.*, **35**, 1605–1618.
- and P.R. Julian, 1971: Detection of a 40–50 day oscillation in the zonal winds in the tropical Pacific. *J. Atmos. Sci.*, **28**, 702–708.
- and ———, 1972a: Description of global-scale circulation cells in the tropics with a 40–50 day period. *J. Atmos. Sci.*, **29**, 1109–1123.
- and ———, 1972b: Further evidence of global-scale, 5-day pressure waves. *J. Atmos. Sci.*, **29**, 1464–1469.
- Newell, R.E., J.W. Kidson, D.G. Vincent and G.J. Boer, 1972: *The General Circulation of the Tropical Atmosphere and Integrations with Extratropical Latitudes*, Vol. 1. The MIT Press, 258 pp.
- Salby, M.L., 1981: Rossby normal modes in nonuniform background configurations, Part II: Equinox and solstice conditions. *J. Atmos. Sci.*, **38**, 1827–1840.
- Takeda, T. and M. Ikeyama, 1984: Time variation of

- cloud amount with about 30-day period in the western north Pacific. *J. Meteor. Soc. Japan*, **62**, 165–171.
- Yamanaka, M.D., 1987: Meteorological aspects of the Japan-China cooperative transoceanic ballooning. *Bull. Inst. Space Astron. Sci., Spec. Issue* **20**, 43–59 (in Japanese).
- Yasunari, T., 1980: A quasi-stationary appearance of 30 to 40 day period in the cloudiness fluctuations during the summer monsoon over India. *J. Meteor. Soc. Japan*, **58**, 225–229.
- Zhang, H.-C., 1981: On the mechanism of the east-west oscillation of the South Asian High. *Geological and Ecological Studies of Qinghai-Xizang Plateau, Vol. 2*, Science Press, Beijing, 1529–1538.

盛夏季南日本付近で観測された
上部対流圏の風の約1週間サイクル：速報

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