# WAVE BOUNDARY BETWEEN MIDDLE-AND-LOW AND MIDDLE-AND-HIGH LATITUDE CIRCULATIONS, AND SEASONAL TRANSFORMATION OF NORTHERN-HEMISPHERE MEAN CIRCULATION

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## ABSTRACT

The definition for stability $D$ of standing waves given in this paper is used to denote the relative magnitude of annual variation of the waves. Analysis of the temporal (seasonal) and spatial (meridional) changes of the monthly mean circulation at 500 and 100 hPa shows its temporal and spatial demarcation and the bourdary between the middle-and-low latitude circulation and the middle-and-high latitude circulation in the wave field. Based on the annual march of $D$ and the position of the boundary, a discussion is made of the seasonal transformation of the Northern-Hemisphere mean circulation and the pattern of its development.

## I. INTRODUCTION

As far as time and space are concerned, wave action in the mean circulation is one made up mainly of standing waves and ultralong waves, which displays the spatial structure of long-spell weather events (Wang Shaowu, 1981). Its temporal and spatial variation has drawn considerable attention in the field of the atmospheric circulation study. As early as in the 1950s, Tao Shiyan et al. (1957) and Yeh Tucheng et al. (1958a, 1958b) discovered remarkable seasonal transformation in the wave action of the secular mid-latitude mean circulation and noticed its abrupt changes in the transitional seasons of June and October. In recent years Huang Zhongshu (1979) and Yang Hefa (1982), based on the spectrum analysis of the mean circulation at 500 and 100 hPa, revealed the spectrum discontinuity in the meridional distribution of the ultralong wave spectrum of the secular mean circulation. Obviously, standing waves (ultralong waves) do show discontinuity of certain sense in temporal (seasonal) and spatial (meridional) variations.

In this paper instability parameter $D$ in the annual changes of standing waves is defined. Analysis made of the absolute magnitude of $D$ in the monthly mean circulation at 500 and 100 hPa shows the temporal and spatial demarcation in the mean circulation. And the stable and unstable belts of the standing waves in the mean circulation are determined from the analysis of the relative magnitude of $D$. By comparison of the unstable belt and the discontinuous

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belt of the ultralong waves, a large circulation system, the wave boundary, is located. It is found that this system separates the middle-and-low latitude and middle-and-high latitude circulation systems in the wave field. From the discussion of the seasonal transformation in the Northern-Hemisphere mean circulation using the position of the wave boundary and the yearly instability march of the semispheric standing waves, abrupt changes, or rapid changes, are found at the heights of 500 and 100 hPa, but they do not occur at the same time and in the same manner.

## II. TEMPORAL AND SPATIAL DEMARCATION FOR THE INSTABILITY OF STANDING WAVES AND THE MEAN CIRCULATION

Let $H(s,t)$ denote the monthly mean height field in a certain month of the year $t$ at a given latitude, and $s$ the serial number of the grid points distributed along the latitude ($s=1, \cdots, N$). The wave action in $H(s,t)$ is assumed to be made of the filtered standing waves.

From $H(s,t)$ the corresponding zonal deviation field

$$H^*(s,t)=H(s,t)-[H(s,t)] \qquad (1)$$

is detrmined, where $H(s,t)$ being of good statistical nature, is a centralized field and, being of good dynamic nature, can be taken as a vector in the $N$-dimensional space, called zonal deviation vector. Its model $|H^*(t)|$ can directly give the absolute intensity of the standing waves along a given latitude in the year $t$.

For yearly mean circulation, Eq. (1) becomes

$$\overline{H^*(s)}=\overline{H(s)}-[\overline{H(s)}]. \qquad (2)$$

*Its modulus* $\overline{|H^*|}$ *gives the absolute intensity of the standing waves on the yearly mean diagram.*

However, $\overline{|H^*|}$ is a rapidly-changing quantity dependent on season and latitude. Direct use of the yearly absolute variation of $|H^*|$ fails to show the difference in season and latitude of the yearly change of standing waves. It is necessary to introduce a measure of the yearly change of the standing waves free of the seasonal and latitudinal influence. Thus, the instability $D$ of the yearly change of the standing waves is defined as

$$D=\sqrt{\overline{|H^{*\prime}(t)|^2}}\Big/\overline{|H^*|}\ , \qquad (3)$$

where the calculation signs are all in a general sense.

By using the monthly mean height data at 500 hPa during the 1951—1980 period (CMO, 1982) and at 100 hPa during the 1956—1982 period (Research Group on LTD; WBHP and MOGP) and the grid point data at 100 hPa in September-December of 1982[1], the temporal and spatial distribution of $D$ is determined, as shown in Tables la-b.

The figures given in Tables la-b show that the values of $D$ at 500 hPa are much the same as those at 100 hPa of high latitudes during the winter half year, and a little higher than those at 100 hPa of low latitudes all the year round and of middle latitudes in summer, and remarkably higher at the poles throughout the year.

By taking 1.00 and 0.75 as the criteria for the determination of the magnitude of $D$ at 500 hPa and 100 hPa respectively, the monthly mean circulation at the two levels can be divided into three circulation belts (zones) and two circulation seasons, all having marked difference

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[1] The grid point data are based on the work by the medium-and long-range weather prediction teaching group, the Nanjing Institute of Meteorology.

in instability of the standing waves. Their demarcation lines and instability features are shown in Tables 2a—b.

**Table la.** Instability *D* of the Standing Waves at 500 hPa in the Northern Hemisphere

| latitude °N | Jan. | Feb. | Mar. | Apr. | May | Jun. | Jul. | Aug. | Sept. | Oct. | Nov | Dec. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 85 | 3.18 | 3.00 | 2.83 | 3.03 | 2.99 | 5.32 | 2.89 | 4.58 | 3.26 | 3.38 | 2.93 | 4.31 |
| 80 | 1.82 | 2.10 | 2.06 | 2.15 | 1.71 | 2.90 | 2.33 | 2.92 | 2.15 | 2.35 | 2.11 | 2.57 |
| 75 | 1.24 | 1.58 | 1.55 | 1.54 | 1.17 | 1.95 | 1.50 | 1.93 | 1.70 | 1.59 | 1.49 | 1.89 |
| 70 | 1.04 | 1.27 | 1.32 | 1.21 | 1.04 | 1.42 | 1.13 | 1.49 | 1.45 | 1.28 | 1.19 | 1.60 |
| 65 | 0.93 | 1.06 | 1.15 | 1.04 | 1.01 | 1.11 | 0.94 | 1.12 | 1.23 | 1.05 | 0.98 | 1.25 |
| 60 | 0.83 | 0.88 | 0.96 | 0.86 | 0.88 | 0.92 | 1.04 | 1.03 | 1.09 | 0.87 | 0.83 | 0.94 |
| 55 | 0.70 | 0.72 | 0.74 | 0.70 | 0.70 | 0.81 | 1.33 | 1.13 | 0.97 | 0.72 | 0.68 | 0.69 |
| 50 | 0.59 | 0.62 | 0.60 | 0.65 | 0.65 | 0.79 | 1.39 | 1.35 | 0.96 | 0.73 | 0.64 | 0.67 |
| 45 | 0.52 | 0.56 | 0.55 | 0.69 | 0.68 | 0.75 | 1.08 | 1.50 | 1.01 | 0.82 | 0.64 | 0.53 |
| 40 | 0.52 | 0.60 | 0.61 | 0.86 | 0.90 | 0.78 | 0.92 | 1.28 | 1.15 | 1.02 | 0.76 | 0.56 |
| 35 | 0.61 | 0.80 | 0.84 | 1.14 | 1.17 | 0.83 | 0.79 | 0.92 | 1.22 | 1.04 | 1.03 | 0.68 |
| 30 | 0.85 | 1.18 | 1.43 | 1.42 | 1.28 | 0.83 | 0.61 | 0.60 | 1.05 | 1.07 | 1.11 | 0.94 |
| 25 | 1.15 | 1.44 | 1.70 | 1.42 | 1.08 | 0.68 | 0.50 | 0.46 | 0.83 | 1.29 | 1.02 | 1.08 |
| 20 | 1.13 | 1.30 | 1.10 | 1.17 | 0.91 | 0.62 | 0.44 | 0.45 | 0.73 | 0.65 | 1.03 | 1.02 |
| 15 | 1.17 | 1.29 | 1.02 | 1.04 | 0.86 | 0.64 | 0.50 | 0.50 | 0.68 | 1.55 | 1.45 | 1.12 |
| 10 | 1.52 | 1.52 | 1.20 | 1.25 | 1.01 | 0.76 | 0.72 | 0.67 | 0.86 | 1.32 | 2.02 | 1.65 |

**Table 1b.** Instability *D* of the Standing Waves at 100 hPa in the Northern Hemisphere

| latitude °N | Jan. | Feb. | Mar. | Apr. | May | Jun. | Jul. | Aug. | Sept. | Oct. | Nov. | Dec. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 80 | 1.11 | 1.09 | 1.24 | 1.14 | 1.36 | 2.52 | 0.98 | 1.36 | 1.82 | 1.07 | 1.39 | 1.35 |
| 70 | 0.77 | 0.80 | 0.96 | 0.85 | 1.05 | 1.56 | 0.76 | 1.11 | 1.58 | 0.74 | 0.83 | 0.85 |
| 60 | 0.67 | 0.68 | 0.73 | 0.69 | 0.94 | 1.08 | 0.84 | 1.24 | 1.32 | 0.61 | 0.62 | 0.57 |
| 50 | 0.59 | 0.60 | 0.65 | 0.75 | 0.92 | 0.75 | 0.77 | 1.14 | 1.76 | 0.74 | 0.60 | 0.50 |
| 40 | 0.62 | 0.71 | 0.83 | 1.23 | 0.82 | 0.54 | 0.53 | 0.60 | 1.24 | 1.44 | 0.95 | 0.60 |
| 30 | 1.03 | 1.59 | 1.48 | 0.91 | 0.52 | 0.40 | 0.30 | 0.39 | 0.51 | 0.84 | 0.89 | 1.15 |
| 20 | 0.81 | 1.06 | 0.79 | 0.86 | 0.59 | 0.50 | 0.49 | 0.58 | 0.67 | 0.87 | 0.73 | 0.85 |
| 10 | 1.04 | 1.46 | 1.10 | 1.08 | 1.19 | 1.26 | 0.86 | 0.91 | 1.28 | 1.57 | 1.12 | 1.10 |

**Table 2a.** Three Circulation Belts (Zones) of the Northern-Hemisphere Mean Circulation at 500 and 100 hPa

| Name | Item | Height | |
|---|---|---|---|
| | | 500 hPa | 100 hPa |
| Low-Latitude Circulation Belt (Zone) | Location | south of 35°N | 30°N & to the south |
| | Feature | Stable from June to Sept. | Stable from May to Sept. |
| | | Unstable from Oct. until next May | Unstable from Oct. until next Apr. |
| Mid-Latitude Circulation Belt (Zone) | Location | North of 35°—60°N | 40°—60°N |
| | Feature | Stable from Oct. until next June | Stable from Oct. until next Apr. |
| | | Unstable from June to Sept. | Unstable from May to Sept. |
| Polar Circulation Belt (Zone) | Location | North of 65°N | 70°N & to the north |
| | Feature | Unstable all the year | unstable all the year |

**Table 2b.** Two Circulation Seasons of the Northern-Hemisphere Mean Circulation at 500 and 100 hPa

| Name | Item | Height | |
|---|---|---|---|
| | | 500 hPa | 100 hPa |
| Winter Circulation | Month | Oct-next May | Oct.-next Apr. |
| | Feature | Stable circulation belt in middle lat., unstable in low lat. and polar regions | ditto |
| Summer Circulation | Month | July—Sept. | May—Sept. |
| | Feature | Stable circulation belt in low lat., unstable in middle lat. and polar regions | ditto |

There may be several reasons for the reversed annual march in the change of instability of the standing waves between the low-and-middle latitudes and middle-and-high latitudes (Yeh et al., 1958b). However, it is noteworthy that the seasonal variation in the zonal difference of the atmospheric heat source may be the decisive factor. The stable equilibrium of ultralong-wave scale in the middle troposphere and the lower stratosphere at middle-and-high and middle-and-low latitudes given in literatures (Zhu et al., 1982 and Zhu, 1986) was obtained when there existed marked zonal difference of the planetary-scale heat source.

Calculation (Kubota, 1970) shows that this heat source occurs at mid-latitudes during winter and at low latitudes during summer. It is obvious that the planetary-scale strong zonal-deviation heat source is of great importance to the yearly stability of the standing waves.

## III. STABLE AND UNSTABLE BELTS OF THE STANDING WAVES

Fig. 1 is drawn from *D* in Tables 1a–b. It is seen that there are two circulation belts which have relatively small values of *D* throughout the year (discontinuous at 100 hPa in June), one in the middle-and-low latitudes and the other in the middle-and-high latitudes, called (relatively) stable belts of the middle-and-low and middle-and-high latitude standing waves, respectively. The heavy broken line indicates the annual march of central position. Between the two stable belts there is a circulation belt having relatively great values of *D* throughout the year (discontinuous at 100 hPa in June), called the (relatively) unstable belt of the standing waves. The heavy solid line denotes the annual march of their central position. In midwinter the low-andmiddle latitude stable belt of the standing waves is located between 15°N and 20°N, whichmay not in keeping with the actual situation. For the stability of the standing waves at low latitudes it is better to make calculations from the mean flow field, but at present such calculation is difficult to obtain.

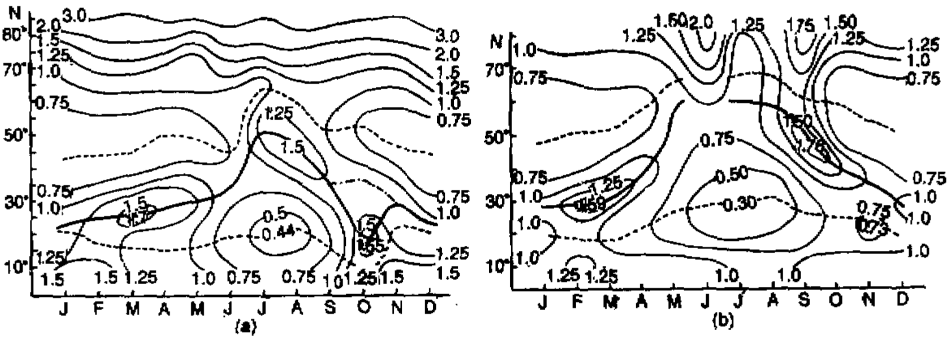

Fig. 1. Instability of the standing waves in the Northern-Hemisphere monthly mean circulation at 500 hPa (a) and at 100 hPa (b).

In view of its exceptional importance in the following discussion, the annual march of the position of the unstable belt of the standing waves is shown in Table 3.

Table 3. Annual March of the Position (°N) of the Unstable Belt of the Northern-Hemisphere Monthly Mean Circulation Standing Waves at 500 and 100 hPa

| Month | Jan. | Feb. | Mar. | Apr. | May | Jun. | Jul. | Aug. | Sept. | Oct. | Nov. | Dec. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 500 hPa | 23 | 24 | 26 | 28 | 31 | 33 | 52 | 46 | 36 | 19 | 30 | 21 |
| 100 hPa | 29 | 29 | 30 | 39 | 58 | — | 60 | 59 | 50 | 40 | 37 | 29 |

Note: In October the unstable belt of the weak standing waves at 500 hPa is located along 37°N, and in June the unstable belt of the standing waves at 100 hPa breaks off.

It should be noted that Table 1a shows no maximum for value $D$ between 30° and 40°N at 500 hPa in October (remarkable maximum occurs along 19°N), and the weak unstable belt of the standing waves at 37°N, indicated by broken dots in Fig. 1a, is determined by means of quadratic interpolation. As a result, branches occur in the annual march curve of the position of the unstable belt of the standing waves at 500 hPa in October.

From the above analysis, the hemispheric circulation system can be regarded as a unity made of a middle-and-low and a middle-and-high latitude circulation systems. As far as the stability of the standing waves is concerned, both the area controlled by the two systems and the variation in stability vary considerably with season increase or decrease. During the period from winter to summer the area controlled by the low-and-middle circulation system extends to the middle latitudes and during the period from summer to winter the area controlled by the middle-and-high latitude circulation extends to the subtropical latitudes; in both cases the stability of the standing waves increases greatly. Thus, there exists a good correlation between the time (season) of the hemispheric mean circulation and the stable belt of the prevailing standing waves, that is, the temporal and spatial charateristics of the mean circulation correspond to each other quite well.

## IV. UNSTABLE BELT OF THE STANDING WAVES, DISCONTINUOUS BELT OF THE ULTRALONG WAVES AND WAVE BOUNDARY

The discontinuous belt of the ultralong waves at 500 hPa given by Huang (1979) is the latitudinal line along which secular changes in the ultralong wave spectrum (phase and amplitude spectrum) take place in the mean circulation. In view of the fact that the ultralong waves account for a very large proportion in the secular mean circulation, the discontinuous belt should be the boundary separating the two circulation systems with rather uniform wave spectrum in the secular mean circulation.

Having introduced the ratio of the total long-wave variance $V_s$ in the secular mean circulation to the total ultralong wave variance $V_l$, we have

$$r = V_s / V_l \tag{4}$$

and temporal and spatial distribution of $r$ as shown in Fig. 2. In the calculation the ultralong and long waves are selected as in Table 4.

Table 4. Selection of the Ultralong and Long Wave Band

| Height / Item | 500 hPa | | 100 hPa | |
|---|---|---|---|---|
| Month | Nov.-Mar. | Apr.-Oct. | Oct.-Apr. | May-Sept. |
| Ultralong waves | 1—3 | 1—4 | 1—3 | 1—2 |
| Long waves | 4—6 | 5—8 | 4—6 | 3—4 |

Analysis suggests that remarkable maximum belts of $r$ exist at both levels (as indicated by the broken line), called the maximum energy ratio belt.

Contrast analysis has been made of the energy ratio maximum in two ways. (1) By comparison with the zonal variability of the harmonic wave phase (wavenumbers 1, 2, and 3) in the

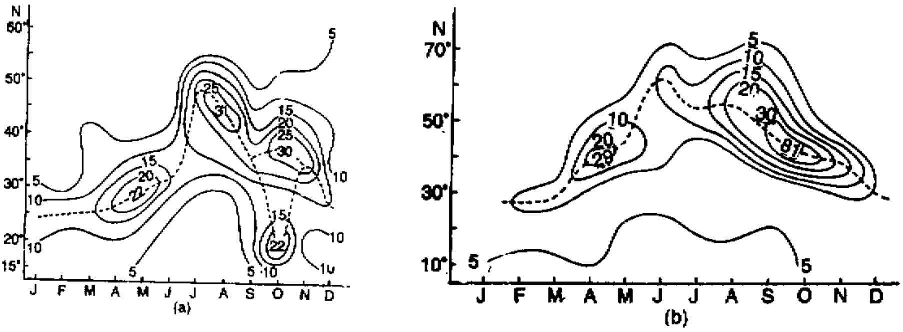

Fig. 2. Maximum belt of the secular mean circulation energy ratio of $r$(%) at 500 hPa (a) and 100 hPa (b) in the Northern Hemisphere.

secular mean circulation (unit: degrees/latitude interval), the maximum belt and the annual march in the zonal distribution of the amplitude spectrum, it is found that the maximum energy ratio belt is in good agreement with the position of the strongest zonal variation in the ultralong wave phase and amplitude spectrum. By the definition in literature as Huang (1979) it can be used to represent the discontinuous belt of the ultralong waves in the secular mean circulation. (2) By comparison of the maximum energy ratio belt with the annual march of the unstable belt of the standing waves, as shown in Fig. 3, their positions are in surprising agreement.

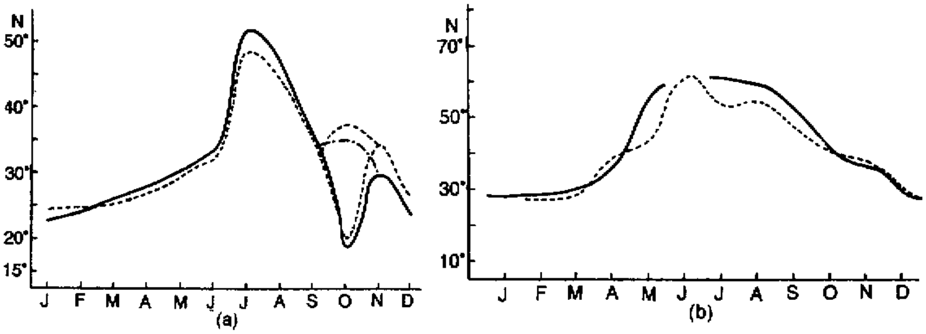

Fig. 3. Unstable belt of the standing waves and discontinuous belt of the ultralong waves (the maximum energy ratio belt) at 500 hPa (a) and 100 hPa (b) in the Northern Hemisphere.

The unstable belt of the standing waves and the discontinuous belt of the ultralong waves are obtained from the study of the yearly variation in the mean circulation and the zonal variation in the secular mean circulation respectively. Statistically, the former is derived from the study of assembling the diverging quantities of $\{H^*(t),\ t=1,\cdots,M\}$ and the latter from the study of assembling the converging quantities. The agreement of their positions suggest that there exists an inner relation between the temporal and spatial characteristics of the mean circulation and the unstable belts of the standing and ultralong waves should be a reflection in time (yearly) and space (latitudinal) of the same circulation entity in the mean circulation. From the analysis above, this circulation entity is in fact the boundary between the middle-and-low wave system and the middle-and-high wave system in the mean circulation, called the wave boundary for short.

From the study of the properties of the unstable belt of the standing waves and the discontinuous belt of the ultralong waves, the standing waves (ultralong waves) in the two circulation systems divided by the wave boundary exhibit the following different characteristics: (1) they both have their own uniform ultralong wave spectrum (phase and amplitude spectrum) and remarkably different ultralong wave spectrum; (2) the standing waves in the middle-and-low latitude circulation system are more stable in summer than in winter and those in the middle-and-high latitude circulation system are more stable in winter than in summer; and (3) the middle-and-low circulation system extends to a larger area in summer than in winter and the middle-and-high latitude circulation system extends to a larger area in winter than in summer.

Obviously, the wave boundary plays different roles in separating the two circulation systems and dividing the planetary front and the Northern-Hemisphere mean circulation. This can be seen from the annual march of their positions, as shown in Fig. 4. Thus, the wave boundary is another large circulation system different from the planetary frontal zone. In fact, the wave boundary exhibits the difference in the dynamic properties of the two circulation systems and the planetary frontal zone exhibits the difference in the thermal properties.

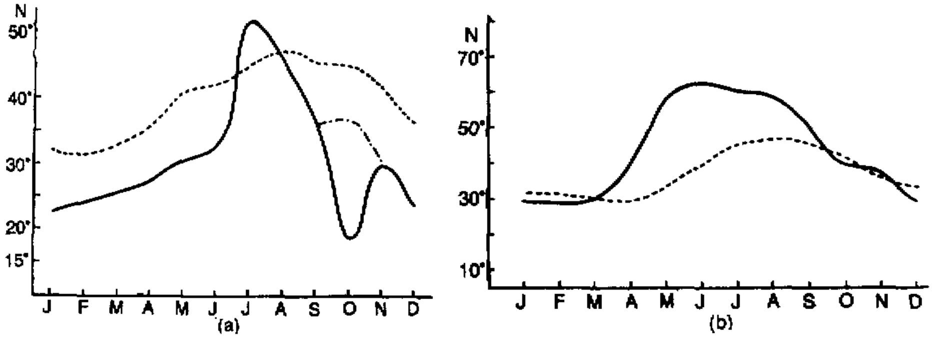

Fig. 4. Annual march of the position of the wave boundary and west jet stream axis at 500 hPa (a) and 100 hpa (b) in the Northern Hemisphere.

## V. TIME AND PATTERN OF THE SEASONAL TRANSFORMATION OF THE MEAN CIRCULATION IN THE NORTHERN HEMISPHERE

This paper deals mainly with the mean circulation in the polar and extra-tropical regions, based on the growth and decline of the two stable circulation belts in the wave field with stress on the time and pattern of the seasonal transformation.

From Tables 2a—b, there exist two typical seasons, winter and summer, in the Northern-Hemisphere mean circulations. In fact, the discussion of the seasonal transformation is one of the seasonal alternation.

Table 5 shows the monthly change of the position of the wave boundary at the two levels. As the position of the unstable belt of the standing waves is more objective than those of the discontinuous belt (the maximum energy ratio belt) of the ultralong waves, the former is used to represent the position of the wave boundary in the circulation. However, the position of the maximum energy ratio belt (62° N) is taken as the position of the wave boundary for June, when the unstable belt of the standing waves breaks off at 100 hPa.

**Table 5.** Monthly Change in the Position of the Wave Boundary at 500 and 100 hPa in the Northern Hemisphere (unit: latitude interval)

| Month | Jan. — Feb. | Feb. — Mar. | Mar. — Apr. | Apr. — May | May — Jun. | Jun. — Jul. | Jul. — Aug. | Aug. — Sept. | Sept. — Oct. | Oct. — Nov. | Nov. — Dec. | Dec — Jan. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 500 hPa | 1 | 2 | 2 | 3 | 2 | 19 | −6 | −10 | −17 | 11 | −6 | −1 |
| 100 hPa | 0 | 1 | 7 | 19 | 4 | −2 | −1 | −9 | −11 | −3 | −8 | 0 |

Note: The figure for October at 500 hPa is based on the position of the unstable belt of the strong standing waves.

From the time when the wave boundary advances farthest north and retreats farthest south we can determine that the transformation from winter to summer at 500 hPa occurs in June–July and at 100 hPa, in April–May, and the transformation from summer to winter occurs in September–October at both levels.

It is seen from Fig.1 that at the time of seasonal transition qualitative changes take place in the stability of the standing waves of the two circulation belts (according to the standard given), and remarkable changes are also found in the area where the standing waves prevail. The time needed for the transformation is much shorter than that needed for the persistence of the winter and summer circulation systems. Thus, it might as well be said that the seasonal transformation, even for the hemispheric mean circulation, is also a process of "abrupt" or "rapid" change.

Detailed analysis shows that the transformation from winter to summer at 500 hPa covers two stages. At the first stage (from May to June) the low-latitude stable circulation belt is formed while the mid-latitude stable circulation belt has not disappeared. Thus, as far as the whole Northern Hemisphere is concerned, the summer circulation has not taken its final form. At the second stage (from June to July) the mid-latitude stable circulation belt disappears, leading to the final establishment of the summer circulation. For this reason, the two simultaneous stable circulation belts in June can be regarded as the pattern of the seasonal transformation from the winter circulation to the summer circulation. This suggests that the transformation from winter to summer is an abrupt south-to-north advance (from the lower to middle latitudes). However, the transformation from summer to winter at 500 hPa is a more abrupt process and no transitional state gets involved.

It seems that the seasonal transformation at 100 hPa is much more complicated. Around the transitional time there is a period of time when the wave boundary is displaced in the same direction rather rapidly. Also found is a remarkable quantitative change in the width of the stable circulation belt. During midwinter (from December to next February) and midsummer (from June to August) both the mid-latitude and low-latitude stable belts are wider than in their early or late stages.

The difference in the time and pattern of the seasonal transformation at the two levels shows that attention should be paid to the decisive thermal forcing effect of the underlying surface. The outside forcing source for the atmospheric circulation in the troposphere comes mainly from the underlying surface, which can delay the transformation from summer to winter (Liu et al., 1983). The outside forcing source for the stratosphere comes not only from part of the direct solar radiation but also from the energy leak from the troposphere to the stratosphere. However, from the viewpoint of the annual march of the wave boundary position, the seasonal transformation even at the bottom of the stratosphere (100 hPa) is different in quality from that in the troposphere, thus showing obviously its feature of being more directly controlled by the annual march of solar radiation.

## VI. SUMMARY

From the above discussion we may come to the following conclusions:

(1) The mean circulation at 500 and 100 hPa in the Northern Hemisphere can be divided into three circulation belts (zones): the low–latitude circulation belt, the midlatitude circulation belt and the polar circulation belt, and two circulation seasons: winter and summer.

(2) There exists a wave boundary with remarkable annual march, which divides the mean circulation into a middle-and-low latitude circulation belt and a middle–and–high latitude circulation belt. And the wave boundary is a large circulation system different from the planetary frontal zone.

(3) The seasonal transformation of the mean circulation from winter to summer in the Northern-Hemisphere occurs at 500 hPa around June and at 100 hPa in April–May, and the transformation from summer to winter at both heights in September. And the transformation at 500 hPa is more severe and abrupt than that at 100 hPa.

As the wave boundary is a planetary–scale circulation system, the anomaly of its seasonal march is in some degree associated with that of the large–scale weather event in the Northern Hemisphere. Studying the difference in its annual march will reveal the anomalous year. By analyzing the years when anomalous weather events occur in the Northern Hemisphere, their relationship can be determined. This will certainly make a great difference to the long–range prediction of the hemispheric–scale circulation and anomalous weather phenomena. The key problem is how to determine the position of the wave boundary at a certain time on a certain isobaric surface. It is suggested in this paper that, by calculating and analyzing the change with latitude in the analogous zonal coefficient of the height field, the problem can be easily solved. Some progress has been achieved and will be presented in another paper of ours.

## REFERENCES

Central Meteorological Observatory (1982), *Atlas of* 1951—1980 *monthly Mean* 500 *hPa Heights and Departures*, Meteorological Press, Beijing (in Chinese).

Huang Zhongshu (1979), A preliminary analysis on the seasonal variation in the general circulation over the Northern Hemisphere at 500 hPa, Ed. Office of Long–Standing of the Changjiang River Basin, *The Collected Works of Medium- and Long-Range Prediction of Hydrometeorology I*, pp. 88--97 (in Chinese).

Isao Kubota (1970), Seasonal variation of energy sources in the earth surface layer and in the atmosphere over the Northern Hemisphere, *J. Meteoro. Soc. Japan*, **48**: 30—46.

Liu Chongjian and Tao Shiyan (1983), Northward moving of subtropical high pressure and CUSP abrupt change, *Scientia Sinica* (*Series B*), **24**:474—480 (in Chinese).

Research Group on Low Temperature Disaster over Northeast China, *The NH* 100 *hPa Height and Departure Data*, 1956—*August* 1976 (in Chinese).

Tao Shiyan and Chen Longxun (1957), The structure of the general circulation over the continent of Asia in summer, *Acta Meteorologica Sinica*, **28**:234—247 (in Chinese with English abstract).

Wang Shaowu (1981), The scale and structure of long-range weather process and its formation, Ed. Office of Long-Standing of the Changjiang River Basin, *The collected Works of Medium- and Long Range Prediction of Hydrometeorology II*, pp. 401—410 (in Chinese).

Weather Bureau of Heilongjiang Province and Meteorological Observatory of Guangdong Province, *Net Grid Data of Height and Departure at* 100 *hPa, Sept.* 1976—*Aug.* 1982 (in Chinese).

Yang Hefa (1982), Climatological features of monthly mean ultra-long waves at 100 hPa in the Northern Hemisphere, *Meteorological Monthly*, No. 10, 8—10 (in Chinese).

Yeh Tucheng, Tao Shiyan and Li Maicun (1958a), The abrupt Change of the circulation over the Northern Hemisphere during June and October, *Acta Meteorologica Sinica*, **29**:249—263 (in Chinese with English abstract).

Yeh Tucheng and Zhu Baozhen (1958b), *Some Fundamental Problems of the General Circulation of the Atmosphere*, Science Press, Beijing (in Chinese with English abstract).

Zhu Zhengxin and Zhu Baozhen (1982), Equilibrium of ultra-long waves driven by adiabatic heating and blocking situation, *Scientia Sinica* (*Series B*), **23**:1201—1212 (in Chinese).

Zhu Zhengxin (1986), On the dynamic mechanism of quasi-steady subtropical vortices in the upper troposphere, *Acta Meteorologica Sinica* (in Chinese with English abstract).