On the General Circulation over Eastern Asia (I)

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Abstract

A summary of synoptic and aerological studies of the circulation over the Far East is given. The mean field of motion in the lower troposphere is considered. Mean cross sections for winter and summer and for different latitudes are discussed. The last section contains a discussion of the seasonal variation of the circulation over the Far East.

During the last few years the aerological network in new China has had a very rapid development. The sounding stations increased from a few stations to more than 60, the pibal stations increased to more than 150 and the number of these stations is still increasing. This rapid development enabled us to make comparatively detailed studies on the general

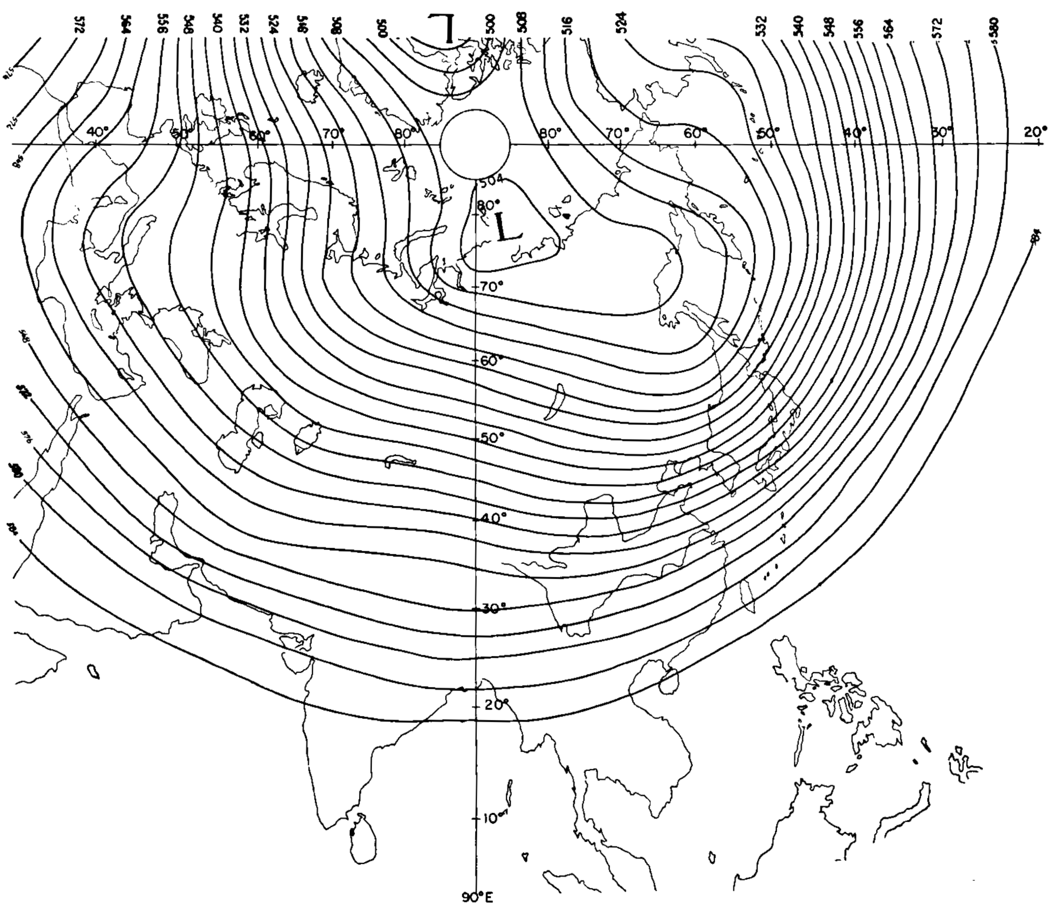

Fig. 1. Mean January 500-mb chart, in geopotential decameters.

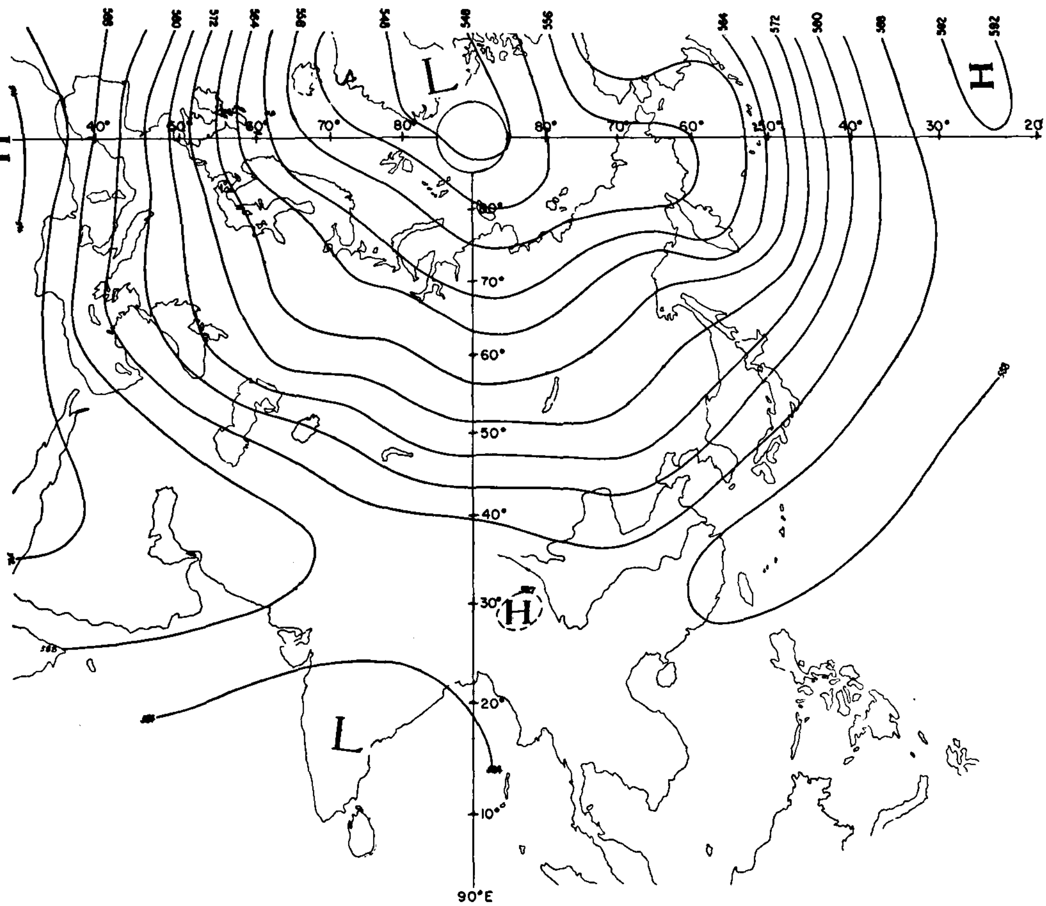

Fig. 2 a. Mean July 500-mb chart, in geopotential decameters.

circulation over Eastern Asia. Owing to the large increase in aerological observations we discovered many interesting phenomena. Since most of the papers concerning these studies were published in Chinese which is unfamiliar to our foreign colleagues we would like now to summarize our past investigations in English.

The following are the main participants in this study: Chang[1] Cheng-yü; Chao Jih-ping; Chen Lung-shun; Chu Pao-chen; Dao[2] Shih-yen; Kuei Pei-lan; Jü Chang; Kao[1] Yu-hsi; Koo[2] Chen-chao; Liu Kwang-nan; Lo Szu-wei; Pan Jün-fang; Wu Hung-shun; Yang Chien-chu; Yeh[2] Tu-cheng.

Besides our group other Chinese meteorologists also have done important researches on the general circulation over the Far East. Some of them will be mentioned in the proper place in this report.

Before starting the main part of this report we should acknowledge the assistance to us of the Chinese Central Weather Bureau with which we have been in close cooperation.

I. Synoptic and aerological study

1. Mean field of motion

Eastern Asia is a region of pronounced monsoon climate. Thus there is a pronounced difference in structure of the basic current in winter and summer. In winter there prevails the winter monsoon in low levels, but in upper levels the whole continent is dominated by the westerlies. In summer the northward retreat of the planetary wind belt is more pronounced over Asia than over any other

[1] Not in our section at present.
[2] Major Contributors to this study.

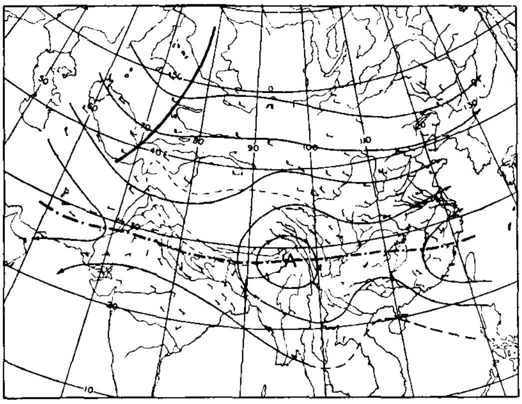

Fig. 2 b. Mean July circulation at 6 km over Far East. The wind vectors in China are means of the period 1950—55, and for India and Indochina, 1953—55. Thin dashed line represents the contour of 4,000 meters of the plateau, heavy dashed-dotted line represents diffluent axis. In this and following drawings *A* stands for anticyclonic circulation, and *C* for cyclonic circulation, heavy lines for trough lines in the westerlies.

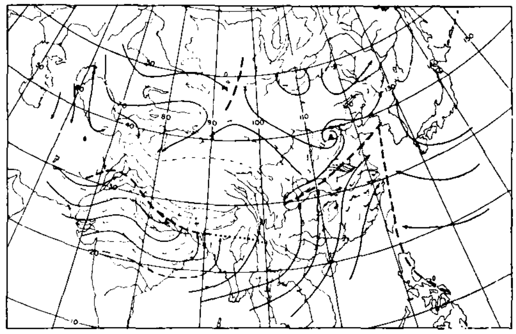

Fig. 4. Mean July circulation at 1.5 km over Far East. Thick dashed lines represent convergence zones, dotted line convergence zone not clear.

region of the world. In this season the basic current appears more complicated than in winter.

a) Flow pattern in lower troposphere

Fig. 1 and fig. 2a are respectively the 5-year (1951—1956) mean 500 mb charts for January and July. These charts are drawn with all the available new material over China. The main features of these charts are similar to those previously published (Pogosian, 1947, Scherhag, 1948, U.S. Weather Bureau, 1952). But in details there are many differences between ours and others. The major trough off the Asiatic east coast is more to the west in fig. 1 than U.S. Weather Bureau mean January chart. The ridge over Central Siberia and North China in our chart is stronger than Scherhag's and U.S. Weather Bureau's, but weaker than Pogosian's. In our July mean (fig. 2a) there is between 25° N and 30° N a pronounced subtropical ridge belt which is not clear in all other July means. The minor trough along 110° E and that from the White Sea to the Black Sea are also clearer in our chart than in others'. Over the Tibetan Plateau there exists a huge closed anticyclone. However, owing to the scarcity of soundings over the Plateau this anticyclone is not clearly indicated. But according to the mean summer stream line chart (fig. 2b) of 1954—56 the existence of this huge anticyclone is beyond any doubt. Its center on 500 mb is situated over the SE corner of the Plateau and its axis slopes westward.

To give the detailed situation of the basic current in the lower troposphere over the Far East in winter we have prepared fig. 3, the mean 3 km stream line pattern of 1950—55.

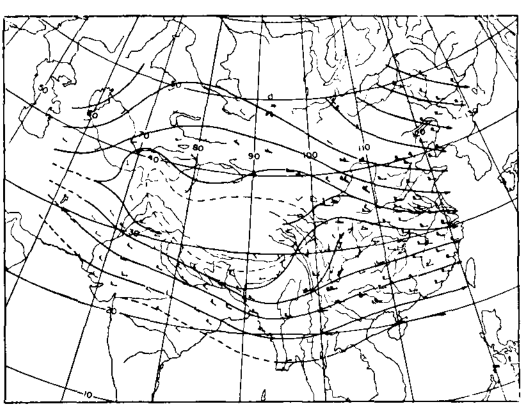

Fig. 3. Mean January circulation at 3 km over Far East.

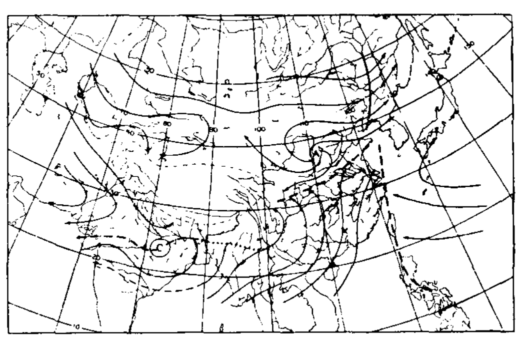

Fig. 5. Mean July circulation at 3 km over Far East.

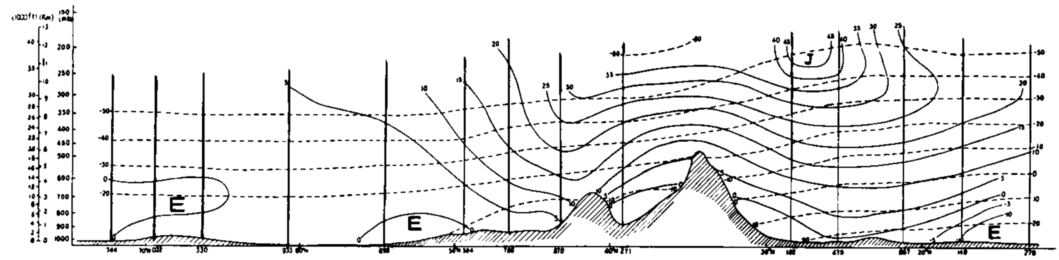

Fig. 6 a. Mean zonal geostrophic wind (full lines) and temperature (dashed lines) along 76° E, for January—March, 1956. The figures along the base line are the station numbers, wind speed in mps.

We shall mention only one feature of this figure, i.e., the shear line to the east of the Tibetan Plateau. This shear line is most pronounced on 2.5 km level and decreases very rapidly upward. On 500 mb (fig. 1) only a confluent zone is left. Because of this confluent zone which extends as far as Japan the cyclones to the south of 40°N over China seldom develop.

The detailed situation of basic current in the lower troposphere in summer may be shown by the mean 1.5 km stream line (fig. 4) and mean 3,0 km stream line chart (fig. 5). From these figures we may see a convergence zone extending from the Arabic Sea to North India. This is a part of the intertropical convergence zone. It separates the SW monsoon to the south and the easterlies to the north. This convergence zone becomes indistinct over Burma and Indochina. Over the Yellow River valley there is another confluent zone which is near to the mean polar front position over the continent in summer. Besides, extending from Taiwan through the Philippines to the SW Pacific there is a third convergence line which separates SW monsoon and SE monsoon from the Pacific. Over the above mentioned SW monsoon on the continent are the general easterlies which may be seen from the 500 mb chart (fig. 2 a).

b) Mean winter cross sections

Fig. 6a—6d are the mean cross sections of January to March, 1956, along 76° E, 90° E, 105° E and 120° E respectively. Fig. 6a represents the condition at the west border of the Tibetan Plateau. The main features of this cross section is the existence of two maximum westerlies, one to the south and the other to the north of the Plateau. The southern branch is situated near 27.5° N and above 200 mb with an intensity of about 50 m/s. The position and intensity of this jet obtained here are in good agreement with those obtained by KOTESWA-

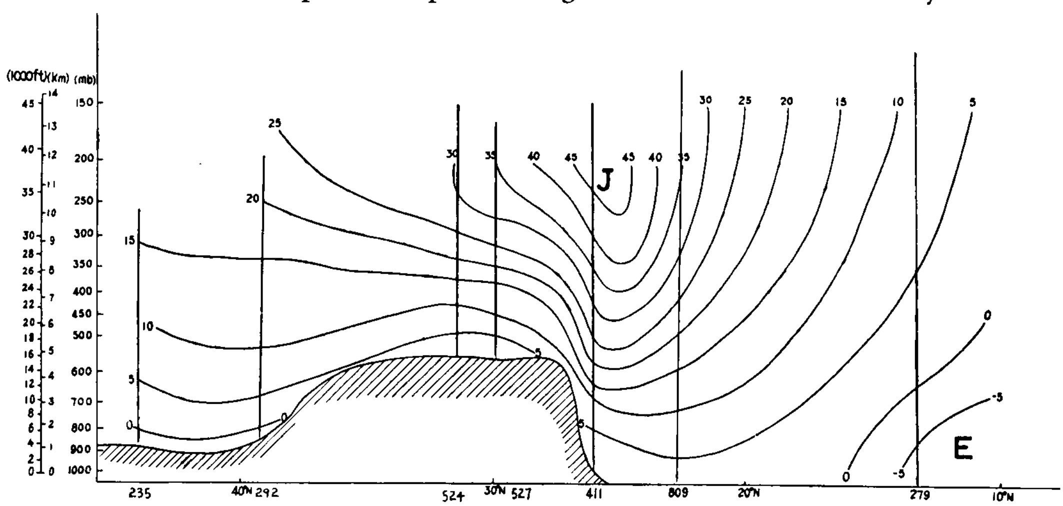

Fig. 6 b. Mean zonal actual wind along 90° E, for January—March, 1956.

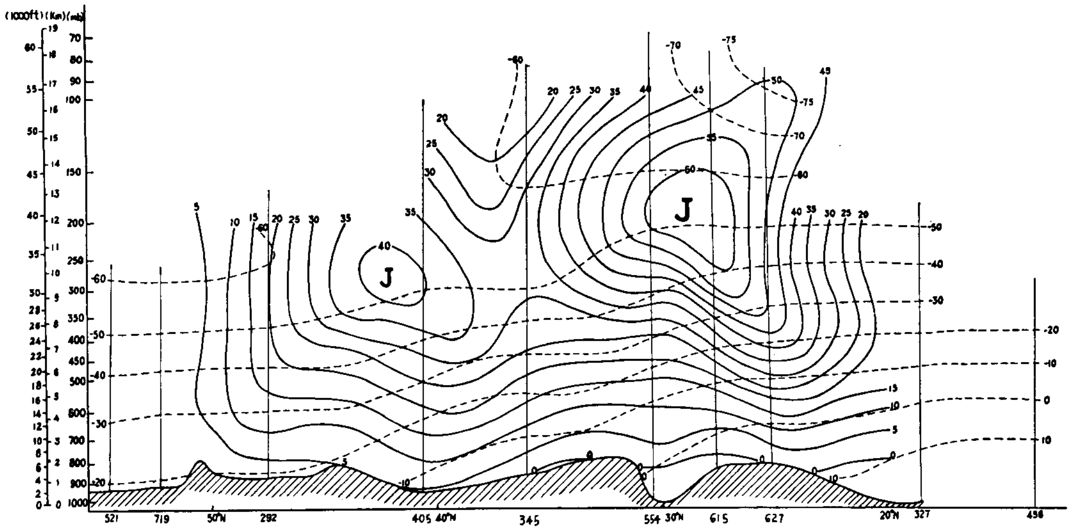

Fig. 6 c. Mean zonal geostrophic wind and temperature along 105° E, for January—March, 1956.

RAM, etc. (1953). The equatorial jet found by CHAUDHURY (1950) does not exist in our cross section. As the data above 300 mb to the north of Pamir is not available the position of the northern jet is not clearly defined in this cross section. However, from the available material its existence is of little doubt and its latitude may be located near 43° N. Compared to the northern one the southern jet is stronger. Corresponding to these two jets there are two belts of large baroclinity, between which the temperature gradient is quite small.

The cross section right across the Tibetan Plateau (along 90° E, fig. 6 b) was constructed from the actual winds. From this figure we see that close to the southern boundary of the Plateau there is a jet near 200 mb. Due to the fact that the number of wind observations decreases upward, the intensity of the jet should not be taken too literally. It is also seen in this figure that the axis of this jet is almost vertical from 800 mb upward. Near the axis the vertical wind shear is large. At Gauhati (26°11′ N, 91°45′ E) the shear reaches 7.2 mps/km between 700 and 500 mb, corresponding to a temperature gradient of 1.3° C/100 km. At Lhasa (29° 43′ N, 91°02′ E) the shear between 400 and 300 mb is 7.5 mps/km, corresponding to a temperature gradient of 1.4° C/100 km; which is a fairly large value in

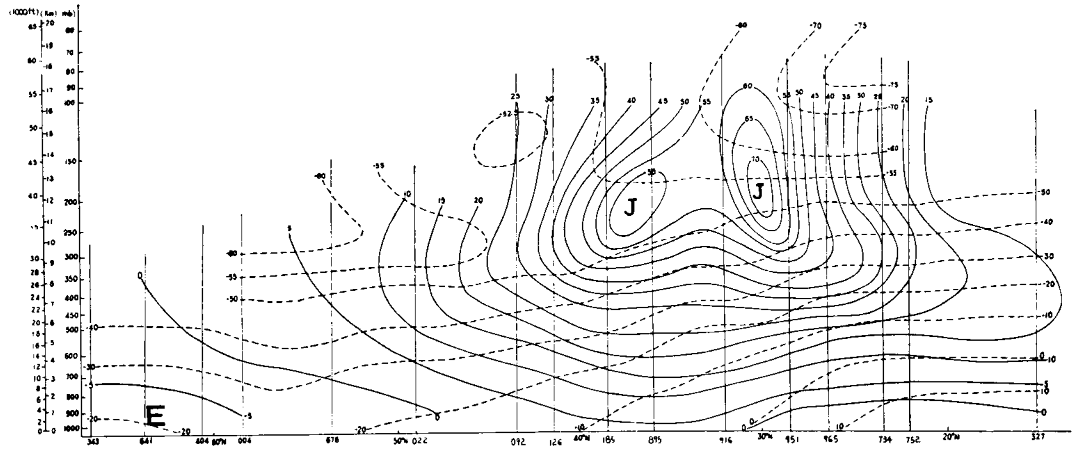

Fig. 6 d. Mean zonal geostrophic wind and temperature along 120° E for January—March, 1956.

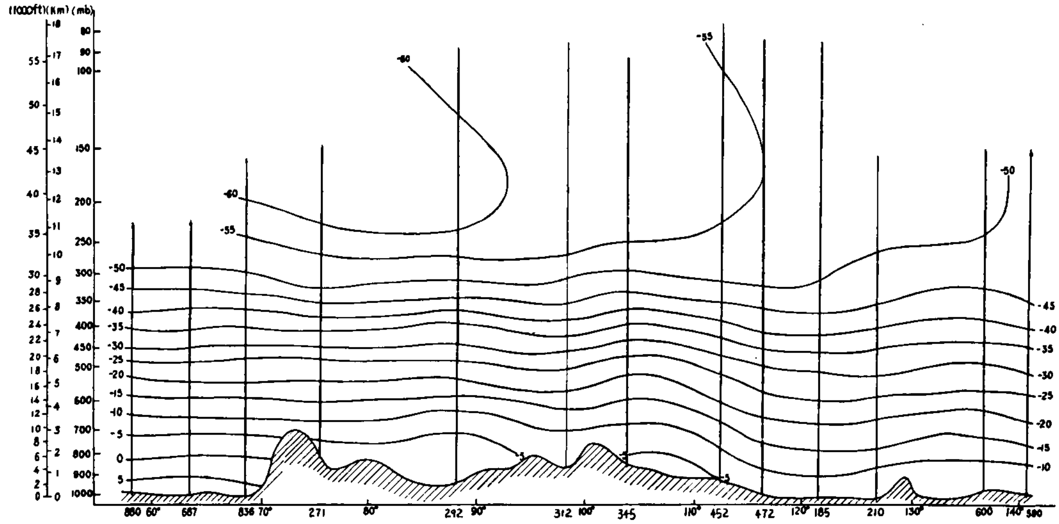

Fig. 7. Mean vertical cross section of temperature along latitude 39° N, January—March, 1956.

low latitudes. The vertical wind shear to the north of the Plateau is rather small, so must also be the temperature gradient.

The cross section along 105° E (fig. 6c) may represent the structure of wind and temperature field of the east border of the Plateau. There are also two belts of large baroclinity, corresponding to two jet streams. The southern one, situated near 28° N and 200 mb, has an intensity of about 62 mps which is more than 10 mps stronger than that upstream at 76° E. The northern jet near 42° N and 250 mb has an intensity of about 43 mps. Between these two jets the westerlies are weak and broad; over Szechwan basin even east wind appears.

Fig. 6d (along 120° E) shows the structure of the wind and temperature field along the east coast of Asia. Between 25° N and 45° N is a belt of very strong baroclinity. Take 400 mb as an illustrating example, the temperature contrast in the latitude belts between 25° and 35° N reaches 17° C. This temperature contrast is evidently larger than the corresponding one along 76° E and 105° E. This strong meridional temperature contrast is the result of the gradual confluence of the two jets, one to the south and the other to the north of Tibet.

Along 120° E the existence of two maximum westerlies is still evident. The southern one which is situated near 30° N and 180 mb has a central velocity 71 mps, about 10 mps higher than that along 105° E. The position of this jet in 1956 is very near to that found in 1946 by Yeh (1950). The northern one which situates near 37° N and 200 mb has a central velocity about 60 mps, almost 15 mps higher than the corresponding upstream one along 105° E.

It is interesting to compare the cross section along 120° E with that along 80° W by Hess (1948). Firstly along the Asiatic coast two jets are evident while along the American east coast there is only one. The latitude of the southern jet at 120° E is about 5° latitude more to the south than that of the American one. Further the central velocity of our southern jet is about 20 mps higher, thus in our cross section there is a much stronger baroclinity. On 400 mb the maximum temperature contrast between 15° and 35° N along 120° E is about 17° C which is about 5° C larger than the corresponding contrast along 80° W. The central axis of the jet along 80° W is nearly vertical, while that of ours slopes northward. However, our northern jet is more to the north and has a weaker intensity than that off the American east coast.

The cross sections further to the east of 120° E will not be presented here (because it is more or less familiar to our foreign colleagues). They have been studied by Chinese meteorologists, notably by Hsieh and Chen (1951) and Chyou (1956) and by Japanese meteorologists, Mohri (1955) and others.

Fig. 7 is a west to east cross section along 39° N. From this figure we see that below 300 mb the temperature is higher to the west

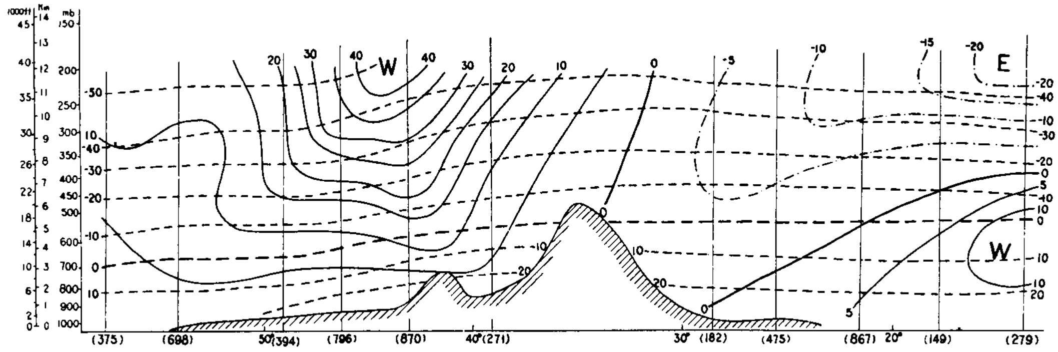

Fig. 8 a. Mean zonal geostrophic wind and temperature along 76° E, for July—August, 1956.

than to the east of the Plateau. On 850 mb the temperature at 60° E is about 12° C higher than at 120° E. The temperature difference between these two longitudes at 500 mb is about 3° C. Above 300 mb the temperature becomes almost uniform. It is also interesting to observe from this figure that the region of maximum west to east temperature gradient is not near the coast but just to the east of the Plateau. We may also find in this figure the existence of a temperature trough between 110° and 115° E in the lower half of the troposphere. This temperature trough is related to the presence of the Plateau.

To summarize the structure of the upper circulation over Eastern Asia in winter we may give the following points.

(i) There exist two jets, one to the north and the other to the south of the Plateau. Both of them are accelerated downstream. And they join into one off the coast.

(ii) Over Eastern Asia the main baroclinity is concentrated near the Plateau.

(iii) There is a thermal trough between 110° and 115° E.

(c) Mean summer cross sections

The summer situation is very different from that of the winter. Figs. 8 a—e are the cross sections respectively along 76° E, 90° E, 105° E, 120° E and 140° E. The cross section along 90° E (fig. 8 b) and south of 20° N along 120° E was constructed from actual wind data. The rest were made from geostrophic computations which were, however, checked by rawin data. The cross section along 76° E (fig. 8 a) is representative for the condition when the Indian summer monsoon is at its highly developed stage. The thickness of the SW monsoon reaches 400 mb at 15° N and reaches the ground near 27° N which may be defined as its northernmost boundary. The SW monsoon is overlaid by easterlies. At the southern margin of Himalayas upper easterlies extend downward to the surface. The intensity of the easterlies increases southward so that there would be an easterly jet aloft near 10° N.

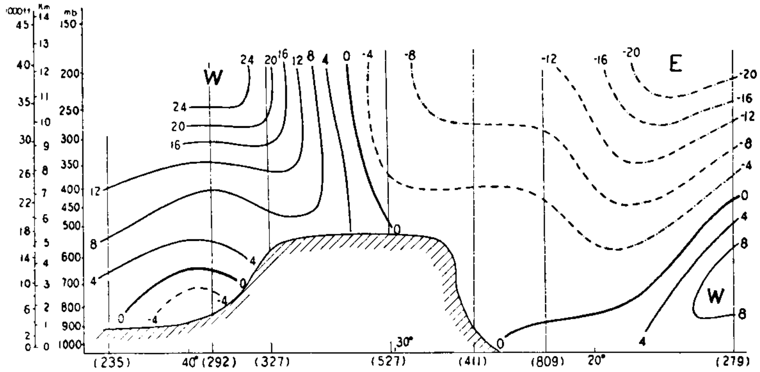

Fig. 8 b. Mean zonal actual wind along 90° E for July—August, 1956.

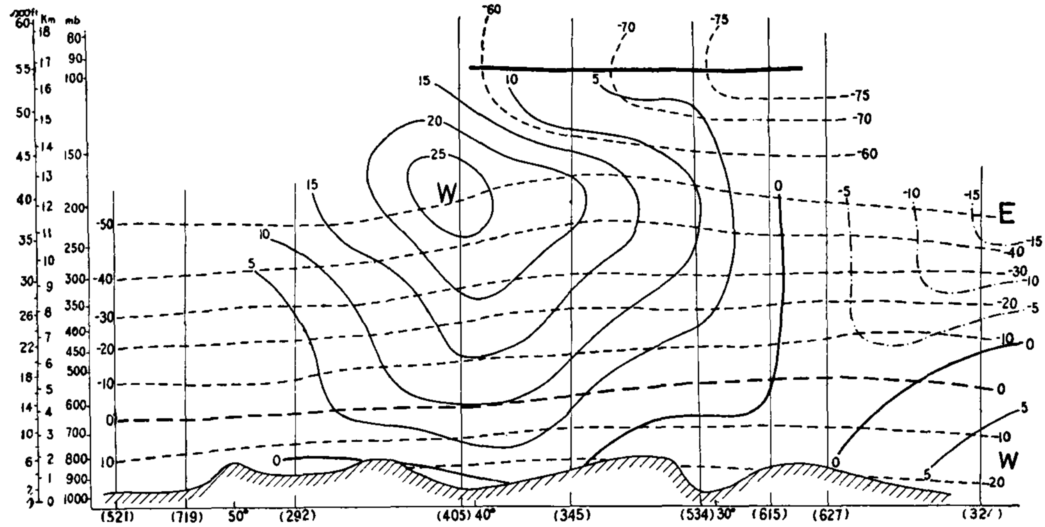

Fig. 8 c. Mean zonal geostrophic wind and temperature along 105° E for July—August, 1956.

Between the easterlies and the SW monsoon to the south there is a line of convergence. Corresponding to this kind of vertical wind structure the temperature decreases southward. This reversed temperature gradient is still very marked at 200 mb which is the top of our cross section.

Over Tibet there appears a dividing line separating the easterlies from the westerlies further to the north; this line corresponds to the difluent axis in fig. 4 and fig. 5. In the westerlies there is a jet with a central velocity near to 42 mps.

The wind field along 90° E (fig. 8 b) is similar to that along 76° E (fig. 8 a). But in the Tarim Basin of Sinkiang there is a shallow easterly current below the general westerlies.

The wind field along 105° E (fig. 8 c) still possesses some of the characteristics of those along 76° E and 90° E. South of 27° N above

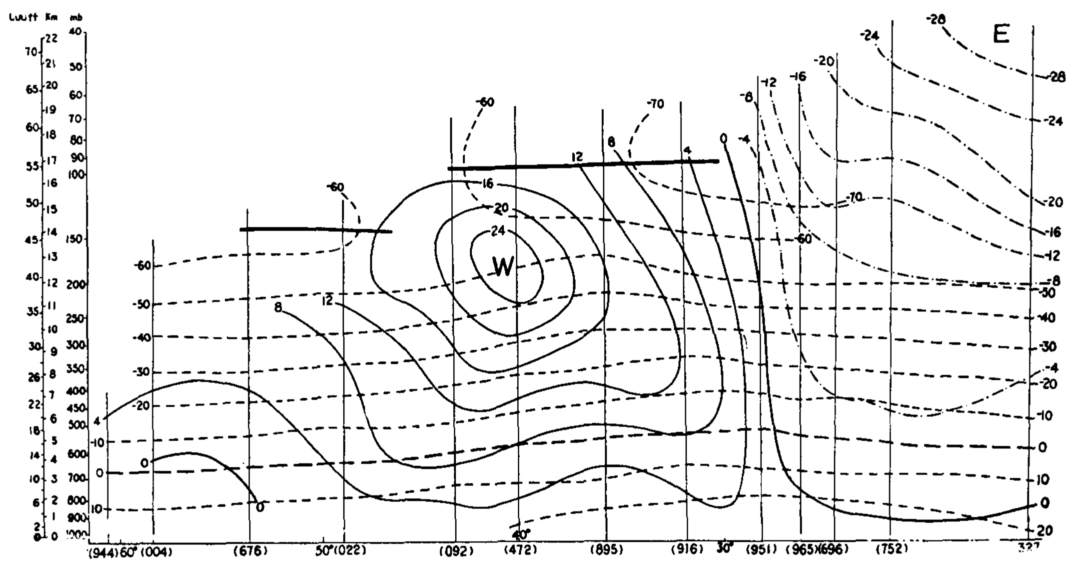

Fig. 8 d. Mean zonal wind (north of latitude 30° N geostrophic, south of 30° N actual) and temperature along 120° E for July—August, 1956.

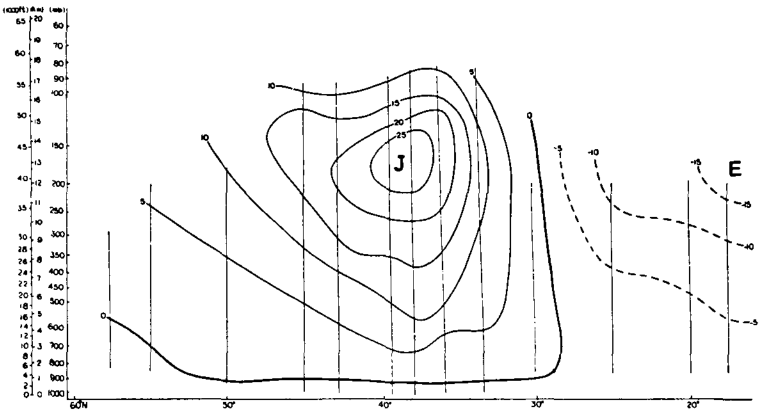

Fig. 8 e. Mean zonal actual wind along 140° E for July—August, 1956.

the SW monsoon are still the upper easterlies in which there may be an easterly jet near 15° N. Near 40° N there is a westerly jet with a central velocity of about 27 mps which is much weaker than the upstream one. This phenomenon is opposite to the winter case mentioned above.

Along 120° E (fig. 8 d) the cross section has a considerable difference from the three upstream cross sections. Here the SW monsoon is very indistinct. Over 28° N there is a vertical line separating the easterlies and westerlies. In the westerlies there is a jet, the position and velocity of which is almost the same as that along 105° E. In the easterlies there is an easterly jet over the Philippines. Comparing this cross section with HESS' (1948) summer case we find that the northward extension of the easterlies as well as the strength of the westerlies along the two coasts are similar, only the jet position along the Asiatic coast is a little to the south.

Fig. 8 e shows the cross section along 140° E. In this cross section the main features are the same as in the cross section along 120° E.

The temperature field is closely related to the wind field. Baroclinity is concentrated in the region of large vertical wind shear, i.e. below the jet stream. In the belt 28—30° N there is a thermal ridge in the troposphere. This thermal ridge separates the easterlies and westerlies.

From the above discussion we may conclude that the three-dimensional wind field over Eastern Asia in summer consists of three basic currents: (1) the westerlies with a jet between 40° and 45° N, (2) the low latitude easterlies with an easterly jet between 10° and 15° N and (3) the SW monsoon below the upper easterlies.

2. *The seasonal variation*

The seasonal variation of the general circulation over Asia is very distinct and fairly abrupt. We shall start the discussion with the monthly change of the total mass of the atmosphere over Asia and then discuss the process of the seasonal variation of the general circulation.

a) The inter-monthly variation of the total mass of the atmosphere over Asia

From January to July air is transported from the northern to the southern hemisphere. On the average the total transport in this half year is 10.3×10^{18} gm. From July to January the same amount of air comes back to northern hemisphere. This inter-hemispherical trans-

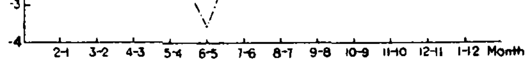

Fig. 9. Mean intermonthly variation of total mass of air over different regions of northern hemisphere, unit 10^{18} gms, ——— Asia; - - - - - Europe; . . . . . Pacific; — — — America; — . — . — . Northern hemisphere; — . . — . . — . . Atlantic.

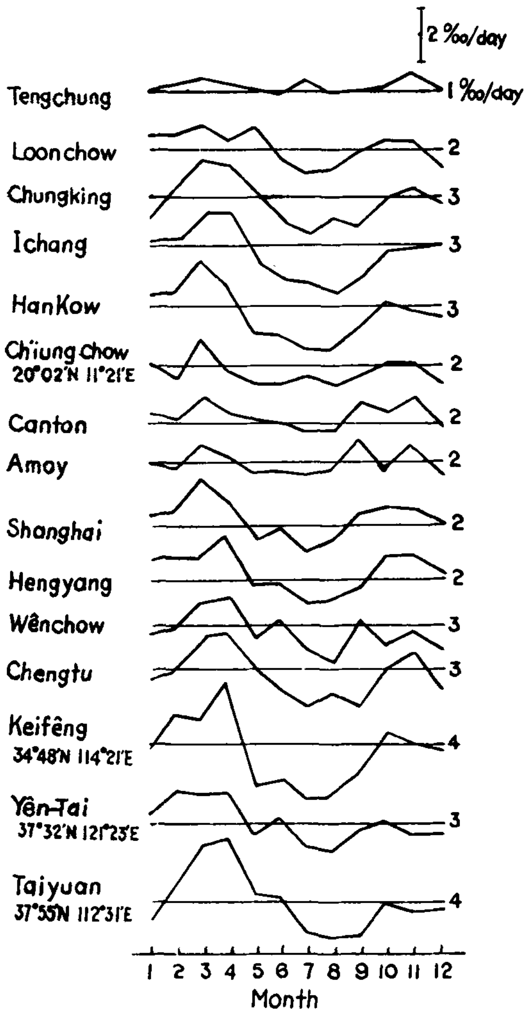

Fig. 10 a. Mean monthly interdiurnal variability of pressure at selected stations in China (1934).

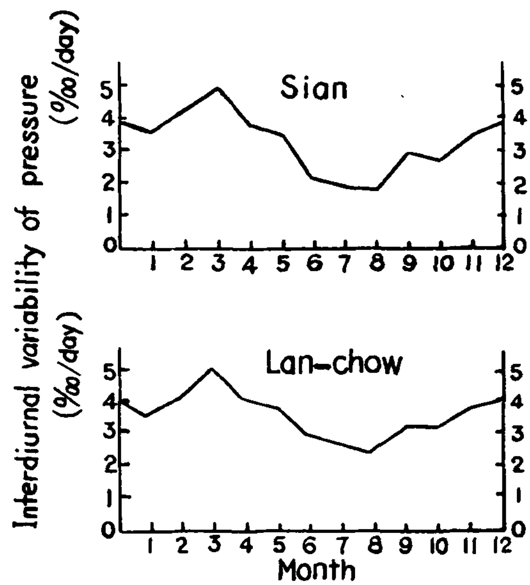

Fig. 10 b. Mean monthly interdiurnal variability of pressure at Sian and Lanchow in the period 1944—48.

port is in the main determined by the variation of the total amount of air over Asia. Fig. 9 shows the 10-year (1930—39) average monthly change of the mass of air over different parts of northern hemisphere. From this figure we see that the monthly change of total air over northern hemisphere has the same sign and order of magnitude as that over Asia. Of the regions shown in the figure Asia has the largest monthly variation, almost triple the variation over other parts. The sum of the variations over Asia and Europe almost equals the total change of the whole hemisphere. Thus we see the important role of Asia in the mass balance of the northern hemisphere.

b) Seasonal change of circulation

According to a recent study based on the material of five years (1951—55) we find that the seasonal variation of the circulation over East Asia is closely related to the advance and retreat of the westerly jet stream. The average position and intensity of the westerly jet may be used as a good index in determining the natural synoptic season over East Asia. However, it should be noted that the jet over Japan and that to the south of Tibetan Plateau do not form or retreat at the same time. Therefore, from this point of view the division and variation of natural seasons over Eastern Asia is not so simple as the four seasons of the calendar.

(i) From winter to spring.

It is known that the circulation index over the northern hemisphere is lowest in February (NAMIAS, 1950). In this month blocking process is frequent. At the end of the blocking process the circulation index rises. At this time the westerlies over Eastern Asia starts to retreat northward and the intensity of the jet of the south of the Tibetan Plateau weakens suddenly while the northern branch of westerlies (north of the Plateau) strengthens. With this change the number of disturbances in the northern branch increases considerably. This reflects that in China (except over the Plateau) the

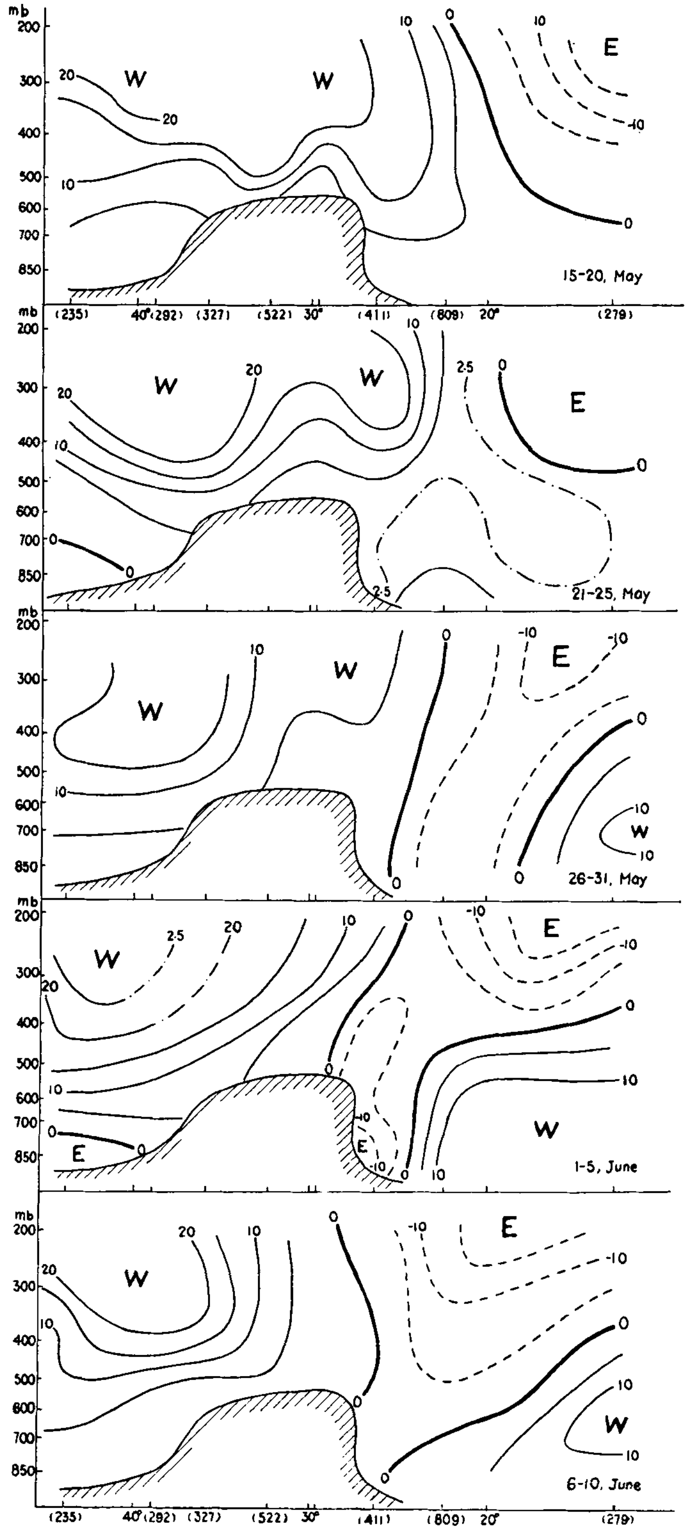

Fig. 11. 5-day mean zonal wind along 90° E for the period from May 15 to June 10, 1956. Note the sudden northward shift of the planetary wind systems in the beginning of June.

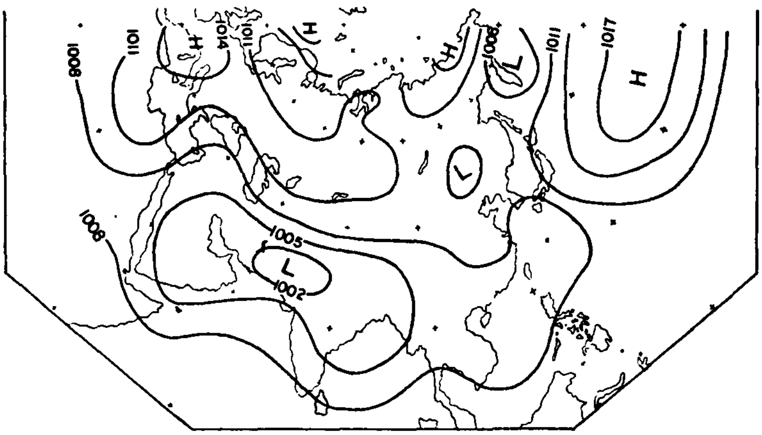

Fig. 12 a. Mean surface chart of the 15 days from August 27 to September 10, 1955.

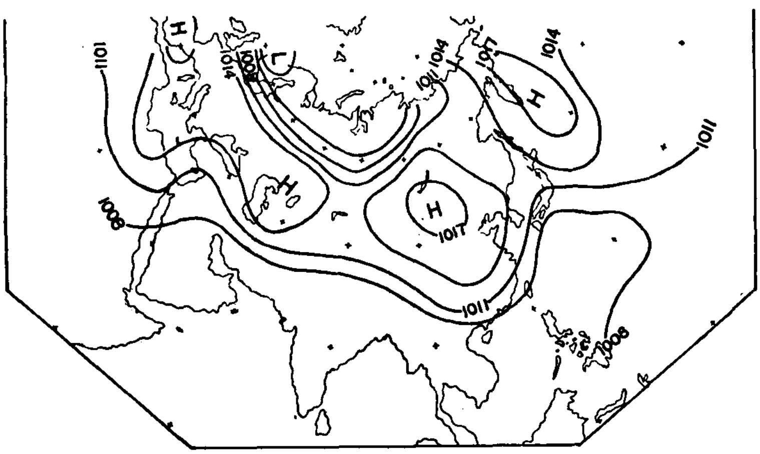

Fig. 12 b. Mean surface chart of the 15 days, September 11—25, 1935.

interdiurnal pressure variability reaches maximum in the period following this change. Fig. 10 is an illustration. We can see from this figure that the variability reaches maximum in March. This is quite different from the other regions of middle latitude over northern hemisphere.

(ii) From spring to Mai-yü[1] period.

At the end of May or in the beginning of June the jet to the south of Tibet suddenly

[1] Mai-yü is an important type of rainfall in China and Japan. It prolongs in the mean from the beginning of June to 10th July. During the Mai-yü period there is usually a typical upper circulation pattern (fig. 14). In high latitudes aloft there are two quasi-stationary ridges situated respectively over Okhotzk Sea and Urals. In between is a quasi-stationary trough. The ridge over Okhotzk is usually of the blocking type. To the south of this warm anticyclone appears cut-off lows. There are two jet streams in this period. One appears to the north of 65° N and the other extends from the north of the Tibetan Plateau through Yangtze River and Hwai-ho (a river, north of Yangtze River) to Japan. Along this branch of westerlies series of upper waves moves over Yangtze River and Hwai-ho from the west. The warm and moist air from the south form with the air to the north the Mai-yü front. The cold air of the front is NPc from NW China, but not SNPc or Pm from Okhotzk (Chen, 1951, Kao, 1953). Thus, the large amount of rainfall (with shower character) in the Mai-yü period is of frontal origin. The longer the flow pattern of fig. 14 prolongs, the longer Mai-yü lasts in China. The year 1954 is a good example of long duration of Mai-yü. In this year the circulation pattern of fig. 14 lasted for two months (June and July), as a result the largest flood of the recent hundred years occurred over Yangtze River and Hwai-ho.

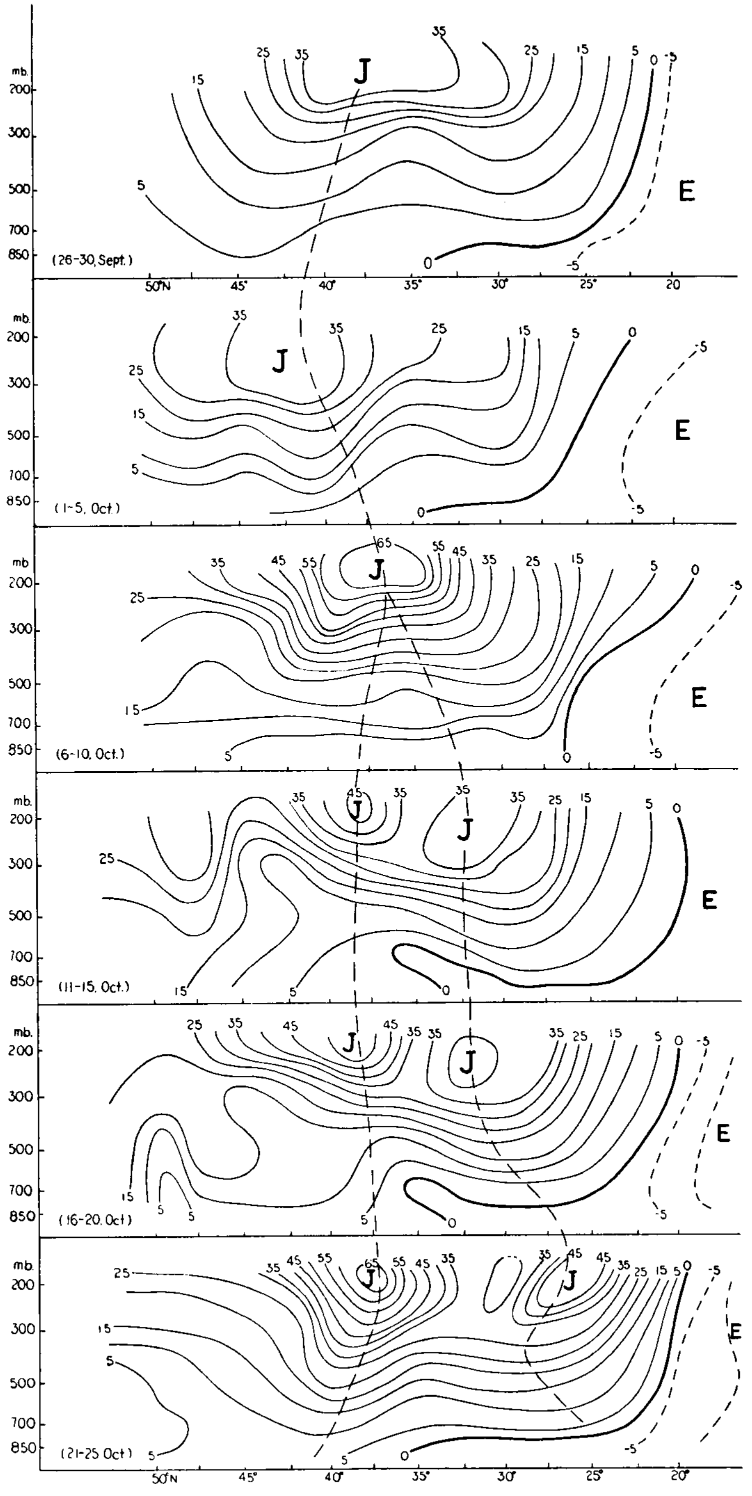

Fig. 13. 5-day mean zonal wind along 125° E for the period from September 26 to October 25, 1956. Note the sudden formation of the southern jet at the period October 11—25.

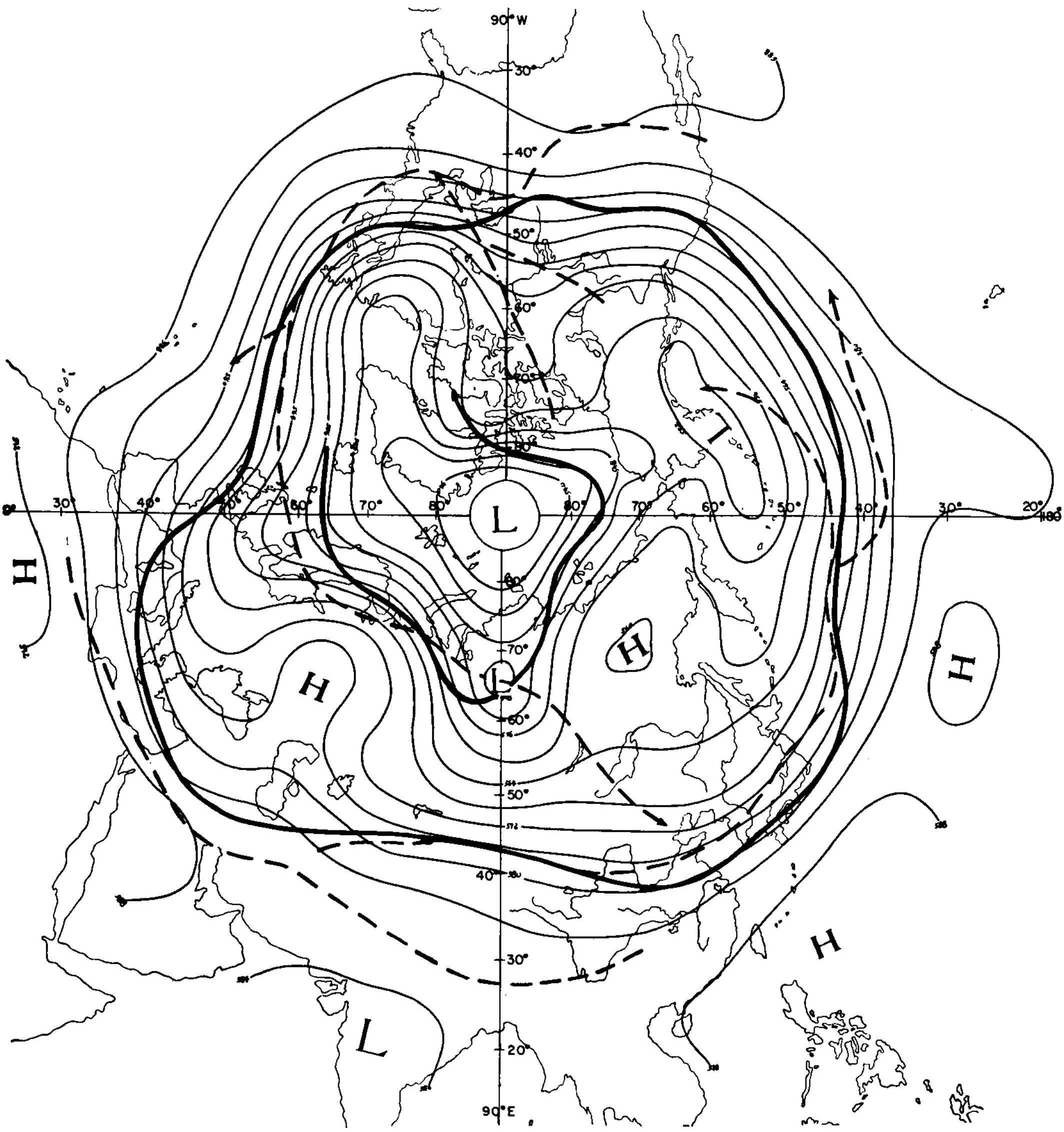

Fig. 14. Mean 500-mb chart for the period of Mai-yü, June 5—30, 1956. Heavy lines represent the axis of maximum geostrophic wind at 500-mb (full lines for June 5—30, 1956, dashed lines for May 1—30, 1956). Note the structure of double jets during the pre-Mai-yü period, while during the Mai-yü period there is only a single jet which passes south of Yellow River toward Japan.

disappears (YIN, 1950; YEH, KAO and LIU, 1951). To illustrate this we give fig. 11 which describes the variation of the structure of westerlies along 90° E in May and June, 1956. In this figure we observe the sudden dissolution of the southern jet in the beginning of June. But it should be mentioned that at this time of the year the jet over southern Japan usually still persists, only the intensity weakens. The sudden disappearance of the jet to the south of Tibet is in accordance with the northward shift of the rainfall belt over China. This brings the well-known rainfall of Mai-yü season to Yangtze River. The sudden change of circulation[1] here in this period is not only coincident with the onset of SW monsoon over India, but also coincident with the sudden northward retreat of the westerlies over Middle East (SUTCLIFFE and BANNON, 1956). The time interval from this sudden change to the summer mentioned below may be termed as easily summer or Mai-yü period.

(iii) From Mai-yü period to summer

With the sudden disappearance of the jet near 35° N over Japan Mai-yü ends over the continent, the major trough over Japan disappears, and the subtropical ridge invades the Far East. Then the true summer season starts. This happens around 10th July. In the changing period typhoons usually invade China; July of 1953 may serve as an example. The subtropical ridge usually follows typhoon to extend to China.

(iv) From summer to autumn

The transition from summer to autumn over East Asia is indicated by the reappearence of the westerly jet over Japan and the reestablishment of the major trough off the Asiatic coast. At this time the surface Asiatic cold high reaches 35° N. The circulation is now anticyclonic in both upper and lower levels. Thus, the clear high autumn weather starts in East China. From this time on typhoons either move straight westward or recurve northward to the east of 125° E. This period which starts in the beginning of September is the first stage from summer to winter. Figs. 12 a—b will illustrate the abruptness of this change. Fig. 12 a is the mean surface chart of the period from 27th August to 10th September, 1935 (15 days) while fig. 12b is the mean surface chart of the following 15 days. From these two figures we see two different types of weather pattern.

(v) From autumn to winter

This starts from middle October, characterized by the sudden formation of the jet to the south of the Tibetan Plateau and a general deepening of the major trough off the coast to the winter intensity. Then the character of winter circulation over East Asia will now be fully developed. Fig. 13 will illustrate the sudden onset of this jet.[1]

[1] According to our recent study (to be published) the sudden northward shift of westerlies in June is not limited to Asia but it is a world-wide phenomenon, being earliest over Asia and latest over N. America. In the period from middle September to middle October there is a world-wide sudden onset of westerlies southward.

[1] To be continued in the next issue of this journal.