ROYAL OBSERVATORY, HONG KONG

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COLD SURGES OVER SOUTH CHINA

BY

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1. INTRODUCTION

The advance of cold air over south China is sometimes marked by a cold front but on many occasions cold outbreaks are observed without any well-organized frontal systems. The modified polar air current may travel over the coastal waters and reach the coastal regions of south China. Since there is less frictional drag over the sea, the modified air stream may reach the coastal regions earlier than the drier current, from the same latitude, along an inland track. As the southward advance of cold air continues, the formation of secondary cold fronts may occur over south China from time to time, especially during a sudden intensification of the winter monsoon. Thus it is customary to use the term "cold surge" to designate the weather which is associated with the displacement of modified cold air by the colder air following an inland track from the north. In order that the arrival of cold air and its accompanying weather changes may be forecast accurately, it is necessary to study the properties and structure of cold surges and the behaviour of frontal systems over this region. This paper gives a summary of lectures delivered at the Seminar on Cold Fronts held at the Royal Observatory Hong Kong, on 24 November 1967 and represents a general survey of the current research work in this field carried out by meteorological services in Hong Kong, Taiwan and the Peoples Republic of China.

2. TRACKS OF COLD AIR

The origin of the cold surges which invade China has been extensively studied by Haude (1930) and Lu (1938) and typical tracks are shown in Figure 1. It should be noted that whatever the origin of the cold air, its southward march over land is greatly influenced by the underlying topography. Over rough terrain, the tracks of the invading cold air may be deflected and the speed of movement is likely to decrease. Over the great plains in the eastern part of central China down to the Yangtze Valley, frontal systems can readily be tracked. However, the Nanling Range and the highlands of southeast China usually give rise to considerable modification in the structure of cold surges, which renders synoptic analysis extremely difficult. Cold surges over south China are most common in the period from mid-October to late March but occasionally extend from September to May. It is a well-known experience amongst Chinese farmers that in extreme cases, following a severe winter, the last surge of the season may arrive at the time of the " Dragon-boat Festival " which sometimes occurs in June. (The festival is celebrated on the fifth day of the fifth month according to the Lunar Calendar).

3. TYPES OF COLD SURGES

Cold surges over south China may be either of the Northerly Type or Easterly Type and are generally initiated by depressions which form over east China north of the Shangtung Peninsula or the East China Sea during the early part of the season.

Occasionally cold air may also spread equatorwards across south China as a result of the recurving of a late-season tropical cyclone over the Ryukyu Islands. Cold fronts associated with these depressions conform to the classical model as long as they are north of 25°N but they tend to become more diffuse as they travel southwards. Difficulties in the synoptic analysis of these systems have been described by Gherzi (1951). Thus the arrival of cold air is often associated with only a gradual fall in dew point and temperature, and sharply defined frontal systems are comparatively rare over south China. Because of the wide extent and the gentle slope (generally about 1 in 500) of frontal zones in this region, the northern and southern boundaries of the same frontal zone are often taken as separate fronts. Chyou (1957 b) has shown how two cold fronts may be taken as five systems (Figure 2) in synoptic analysis.

4. STRUCTURE OF COLD FRONTS

The structure of cold fronts is usually examined by analysing the distribution of potential temperature (θ) depicted in space cross-sections and the findings of Bjerknes & Palmen (1937) and Nyberg (1944) indicate that, in Europe and U.S.A., the gradient of this parameter is generally very small along a frontal surface.

In China, the pseudo-equivalent potential temperature (θ_{se}) has been used in cross-section analysis instead of the potential temperature, because θ_{se} is conservative with respect to dry and moist adiabatic processes as well as to precipitation. The parameter also characterizes the stability of the atmosphere and thus provides a broad picture of the distribution of subsiding and ascending motions. Experience of Chinese meteorologists (Koo et al 1958 and Chyou 1956) shows that the θ-field sometimes fails to portray features which are important for operational forecasting while θ_{se} charts are usually found to be more suitable for application, particularly over tropical regions.

An important difference in the structure of cold fronts over China and Europe is given by Koo et al (1958). He found that while the gradient of θ_{se} along a frontal surface is generally less than 5°/ 1000 km in Europe, it often exceeds 10°/1000 km in East Asia. He therefore concluded that the front is not a simple surface always consisting of the same set of air particles but represents a certain metabolism and is constantly subjected to frontogenetic processes. His findings account for the difficulties in tracking frontal systems over south China and suggest that, for forecasting purposes, development associated with frontogenesis and frontolysis should be the prime factor.

Cold fronts usually undergo a marked transformation in their structure and properties when they pass south of the Yellow River. Chyou (1957) found that these systems become less well-defined on surface charts because of mixing and surface heating and often exhibit a double frontal boundary. The meridional cross-sections of a cold front which moved from north to south China on 14 - 15 November 1955 and the associated synoptic situations are given in Figures 3 and 4. It can be seen that the slope in the frictional layer becomes steeper in the south. It should be noted from Figure 4(b) that northerlies caused by the katabatic sinking of the air above the cold dome and the upslope motion of airstream from the south converge in the upper levels.

The formation of the above configuration is probably accentuated by the blocking effect of the Nanling Ranges as pointed out by Shau (1957). He showed that the weather conditions accompanying the passage of cold fronts south of Nanling are dependent on the distribution of vertical velocity and humidity behind these systems. Chyou (1957a) has also examined the relative importance of the various terms in the equation of frontogenesis and pointed out that frontogenesis below 700 mb is mainly due to advection. The layer 700-500 mb is a region of frontolysis in which vertical motion plays a more important part. From a study of the influence of temperature advection, he concluded that this is an important factor in determining the horizontal change within a time interval of 24 hours during the final stage of a cold outbreak. Chyou also indicated that frontogenesis usually takes place ahead of a trough and frontolysis in the southwest extremity of the system.

5. CLIMATOLOGY OF COLD SURGES AND FRONTS

Surges follow one another rather irregularly during the cold season but they occur most frequently at intervals of 5 - 8 days. Heywood (1957) showed that the average number of surges passing through Hong Kong per month rises from 1.2 in September to more than 3 throughout the period November to March and falls to 1.7 in May, while the average annual total amounts to 25.6. This is similar to the figure of 28 for Nanking for the months October to May obtained by Lu (1954) and 27.4 for Shanghai given by Cheng (1955). However, it should be pointed out that cold air which passes the Yangtze Basin over central China does not necessarily move southwards into south China and Chin (1954) found that of the 13 well-marked cold fronts which crossed the south China coast during the period December 1957 - January 1958, 10 originated or regenerated south of 30°N and only 3 were intense polar outbreaks. It is therefore clear that the structure of cold fronts over south China must be significantly different from those originating in temperate latitudes to the north.

On the other hand, Chu (1963) presented some evidence that cold fronts over the mainland of China and the adjacent seas tend to linger or intensify over some regions and degenerate or pass through others rapidly. He determined the monthly frequency of occurrence of cold fronts in each 2½ degree square over East Asia for the period 1955 - 1959 and his mean charts for January, April, October and July are reproduced in this paper as Figures 5 - 8. From these figures, the following main frontal systems can be identified:

(a) Polar Front: A band marking the southern limit of cold waves.

(b) Northeast Front: A shallow system associated with depressions over Lake Baikal, rarely penetrating into southern latitudes.

(c) Mongolian Front: Essentially a spring feature with similar properties as the Northeast Front.

(d) Tienshan Front: A quasi-stationary system mainly caused by the blocking effect of Tienshan.

(e) Front over Pohai and Sea of Japan: Predominantly a winter system associated with depressions over Pohai and the Yellow Sea.

(f) Nanling Front: Part of the polar front in Spring and Autumn, persisting over high grounds of the mountains as a weak system in winter.

The above findings are in good agreement with those obtained earlier by Chu (1945).

(a) Large-scale Synoptic Pattern

Dao (1957) has examined the large-scale development associated with intense cold outbreaks and noted that the outburst takes place when

(i) the general circulation over the northern hemisphere changes from a low to a high index one after the breakdown of the Ural High;

(ii) long waves begin to move eastwards and the major westerly wind belt also shifts polewards with a reduction of wave number from 4 to 3 in middle-latitudes;

(iii) the development of two jet streams, the polar jet and the subtropical jet occurs.

He found that cold air associated with intense outbreaks originates from Greenland near 75°N and moves souteastwards at about 15 degrees longitude per day. The breakdown of the low-index pattern is first shown by a sudden change in the Atlantic Subtropical Ridge or development over the area to the east of Greenland. Hsu et al (1958) showed that a long wave usually remains stationary along the east China coast after the outbreak of cold air with short wave troughs moving away from the parent system. This phenomenon is often regarded as the retrogression of long waves in synoptic analysis.

Hsu and Wang (1958) advocated that cold surges will be initiated by the intense continental anticyclone when its central pressure reaches 1054 mb or above. This is, however, not always the case. Wang (1958) pointed out that a vortex may form over north China and the continental anticyclone may persist for days without any appreciable meridional displacement of the cold air. In a case study of a severe cold outbreak, it was noted that the southward spreading of the cold air was caused by a breakdown of the " equilibrium flow field " at the 850 mb level.

(b) Local Features associated with Cold Outbreaks

(i) Occurrence of double inversions

The passages of cold surges are found to be associated with the development of double inversions for stations over south China and Taiwan. The lower inversion is due to the polar front and occurs between 1500 and 2500 m with a wind discontinuity. The upper one, lying between 4000 and 6000 m, is more marked and stable than the lower one and is considered to be caused by the southward invasion of the polar westerlies (Wang 1958). Its occurrence is a good indication of (1) rain over south China and Taiwan, (2) the onset of severe cold weather and (3) the intensification of the upper westerlies.

(ii) Changes on contrail chart

Hsu and Wang (1958) found that charts showing changes in the contrail level over China provide a useful tool for forecasting cold surges since their outbreaks are associated with large negative falls in this element as shown in Figure 9. The chart may also be used to evaluate temperature advection.

(c) Boundary of Fine Weather

When an anticyclone over China moves into the adjacent seas, fine weather usually prevails north of the axis of wind change from northwest to northeast due to subsidence and dryness of the cold air. South of the axis, cloud and rain develop as a result of air-mass modification at lower levels over the sea and upslope motion of warm air from the southwest as shown in Figure 10. The appearance of a separate high cell over central China is also a sign of fine weather over the Yangtze basin while the passage of an upper-air trough at 850 mb provides a reliable indication of improved conditions over the south China coast.

(d) Weather Conditions

The weather during the passage of cold surges is largely dependent on the position of the subtropical jet stream and the surface and upper-air flow patterns. Synoptic experience indicates that little rain can be expected over the south China coastal region whenever it lies in the subsidence zone south of the jet stream and short waves troughs are absent near 105°E. A typical cross-section of the weather conditions associated with a cold outbreak is shown in Figure 11.

(e) Effect of Temperature Advection on Frontogenesis

Doo and Li (1961) have examined the effect of temperature advection on frontogenesis over East Asia and considered that the local variation in temperature, $\partial T/\partial t$, is mainly determined by advection. This assumption was made on the basis of statistical analysis. The distribution of the temperature advection term, A_T, was determined by evaluating the Jacobian determinant of the isohypse and temperature fields at 850 mb. From an analysis of 30 cases, they concluded that frontogenesis or cyclogenesis normally occurs when there is a sharp spatial change in this parameter along a chosen section (usually across the current surface front). Figure 12 is an example to show how frontogenesis can be forecast by an inspection of the profile of A_T along the line OO' in the weather map shown in Figure 13. The current cold front is located between points 6 and 7 but in 12 hours time a new front develops further north between points 5 and 6 and the original system dissipates. The use of continuity in synoptic analysis in a case like this is therefore likely to produce erroneous conclusions.

(f) Passage of Cold Surges over Hong Kong and the south China coast

(i) Cold surges which affect Hong Kong and the south China coast are usually associated with depressions which form near the East China coast or over the East China Sea south of the Shangtung Peninsula and move east or northeastwards towards Japan. Figure 14 shows the positions of depression centres at the time when cold air reached Hong Kong during the winter months December to February 1959-1968.

(ii) The southward movement of cold air is frequently accompanied by the intensification and southward displacement of the subtropical jet stream.

(iii) There is often a lull in surface winds over Hong Kong ahead of the surge and anemograph records always show a veering of wind from east through south to west in the frontal zone but the westerlies are usually very light and short-lived.

(iv) The location of the maximum 3-hourly isallobaric centres often determines the type of surge. An easterly type is normally preceded by the appearance of a maximum centre over east China while the approach of a northerly surge is heralded by the development of a centre to the northwest of Hong Kong.

(v) The magnitude of temperature fall in Hong Kong is generally dependent on the temperature variation at 850 mb over Kanchow and the mean wind flow between this station and Hong Kong. It has been found that cold surges which exert no effect on the 850 mb temperature field near Kanchow are not likely to produce any appreciable fall in temperature over Hong Kong.

(vi) For 24-36 hour prediction of intense surges through Hong Kong, the following criteria have been found useful:

(1) occurrence of northwest winds over Lake Baikal at 500 mb

(2) presence of a ridge at 90°E and another one in the eastern Pacific

(3) the -30°C isotherm located south of 40°N at the longitude of Hong Kong (i.e. approximately 115°E)

(g) Shape of Cold Front

Because of the presence of a land-sea boundary over the Taiwan Straits and the rugged topography over southeast China, cold fronts which move southwards across 25°N often change rapidly in shape and do not conform to the classical model. The boundary of the cold air does not appear as a smooth line but exhibits an 'undulating structure' depending on the nature of the underlying surface. The probable evolution of such a configuration is depicted in Figure 15. The cold front is first distorted by the difference in speed of movement over land and sea upon entering the Taiwan Straits and further deformation is produced by the Nanling Ranges. Except for a narrow coastal strip, the main cold air mass is held up north of the ranges. Due to the funnelling effect, the front over the Straits advances steadily southwards as a northeasterly airstream and an apparent breaking of the front is often noted. However, marked modifications in the properties of the cold air over the Straits may occur as the sea surface temperature is usually high and relatively warm air from the Pacific may also be dragged around the northern side of the mountain ranges in Taiwan into the Straits to give rise to vigorous mixing, especially over the southwestern side. Thus, accurate location of the front from chart to chart is sometimes extremely difficult. Two typical examples of distorted fronts which occurred on 9 - 10 February 1965 and 3 - 5 February 1966 are shown in Figure 16.

It may be pointed out that although the main frontal system sometimes remains stationary near the Nanling Ranges for a relatively long period, localized shallow pools of cold air may, from time to time, spread southwards to affect the coastal area. This phenomenon accounts for the existence of a broad frontal zone south of the ranges and also for the changes in temperature and winds at certain stations, which cannot otherwise be explained.

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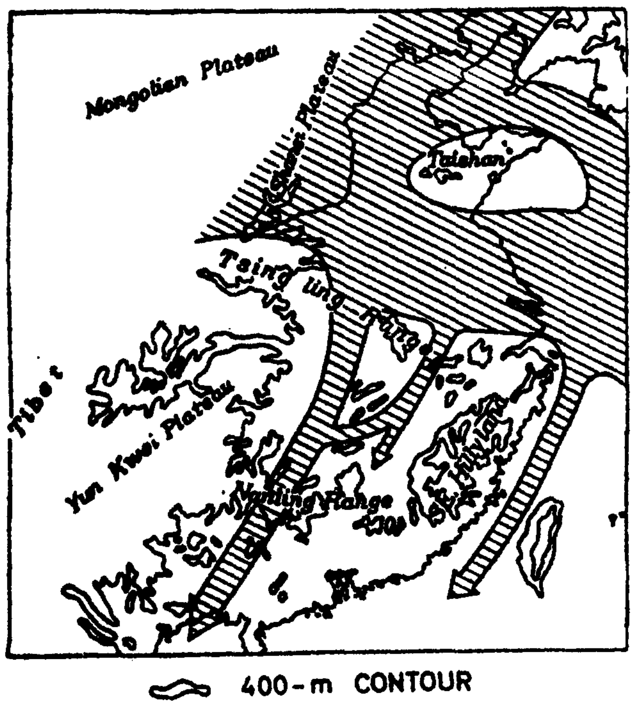

FIGURE 1. TRACKS OF INVADING COLD WAVES (AFTER LU)

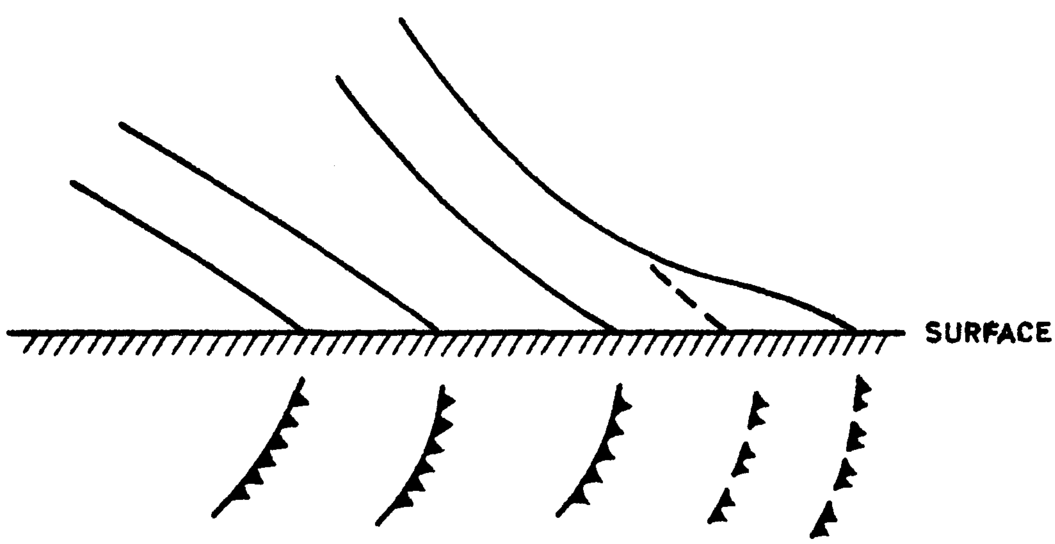

FIGURE 2. A SCHEMATIC DIAGRAM SHOWING HOW TWO COLD FRONTS MAY BE TAKEN AS FIVE SYSTEMS.

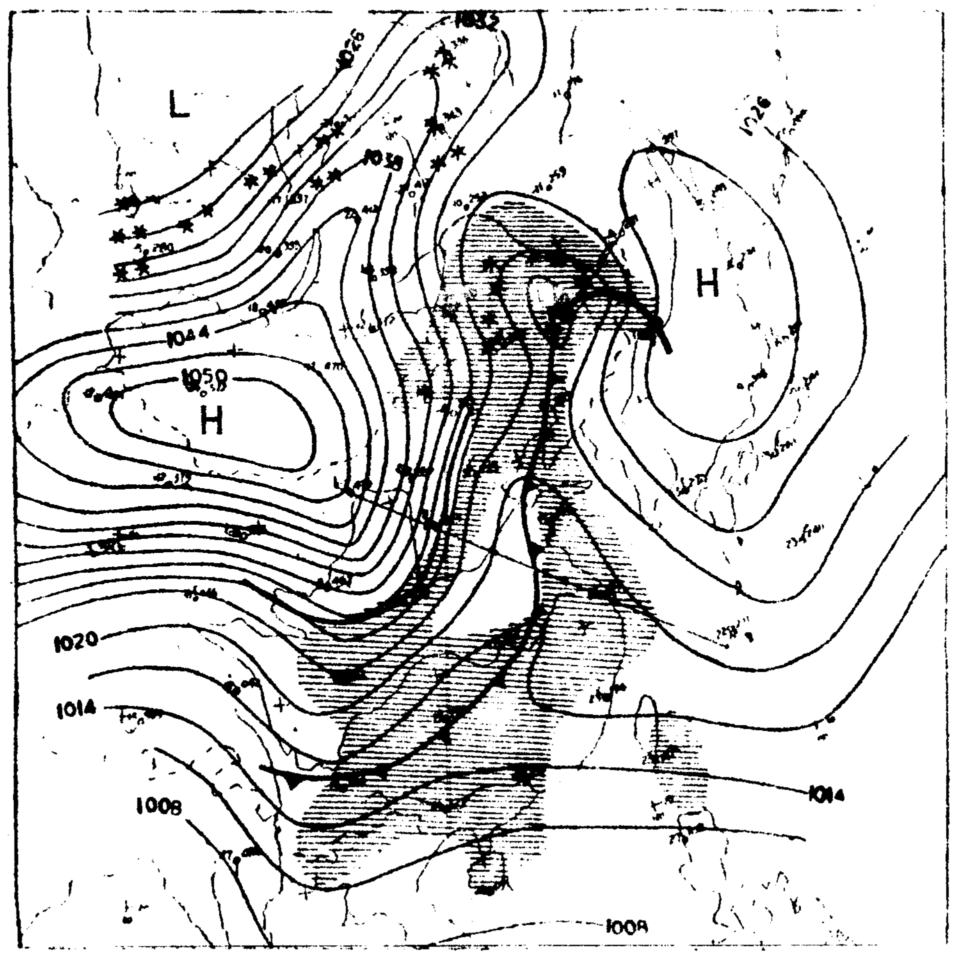

FIGURE 3 (a) SURFACE MAP FOR 1500 Z ON 14 NOVEMBER 1955. (ISOBARS AT 3 mb INTERVALS). (AFTER CHYOU)

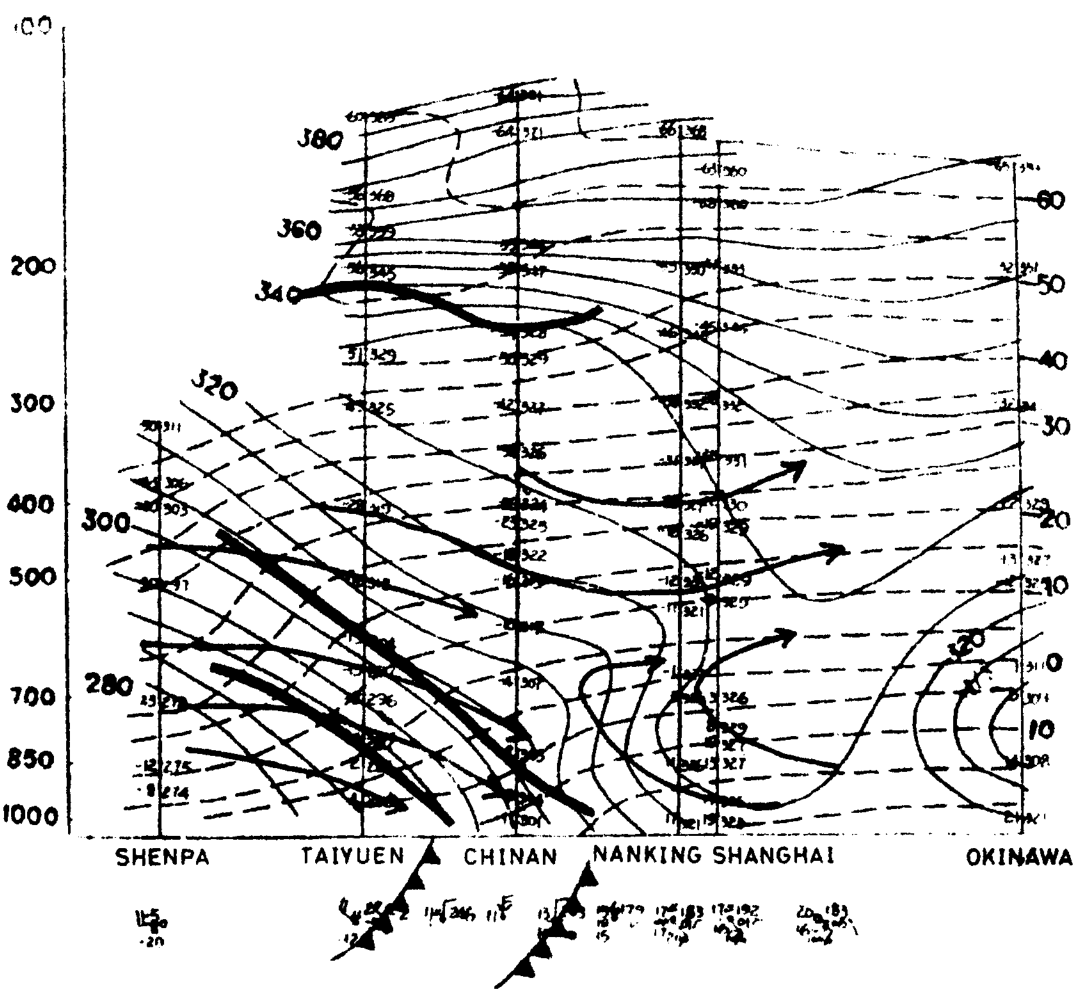

FIGURE 3 (b) SHENPA - OKINAWA CROSS-SECTION FOR 1500Z ON 14 NOVEMBER 1955. THICK LINES DEPICT THE TROPOPAUSE AND FRONTAL BOUNDARIES. THIN FULL LINES DENOTE ISOPLETHS OF θ_{se} AND THIN BROKEN LINES ISOTHERMS AT INTERVALS OF 5°C. ARROWS INDICATE THE AIR MOVEMENT IN THE VERTICAL PLANE. SURFACE OBSERVATIONS AT THE VARIOUS STATIONS ARE PLOTTED BELOW THE ABSCISSA. (AFTER CHYOU)

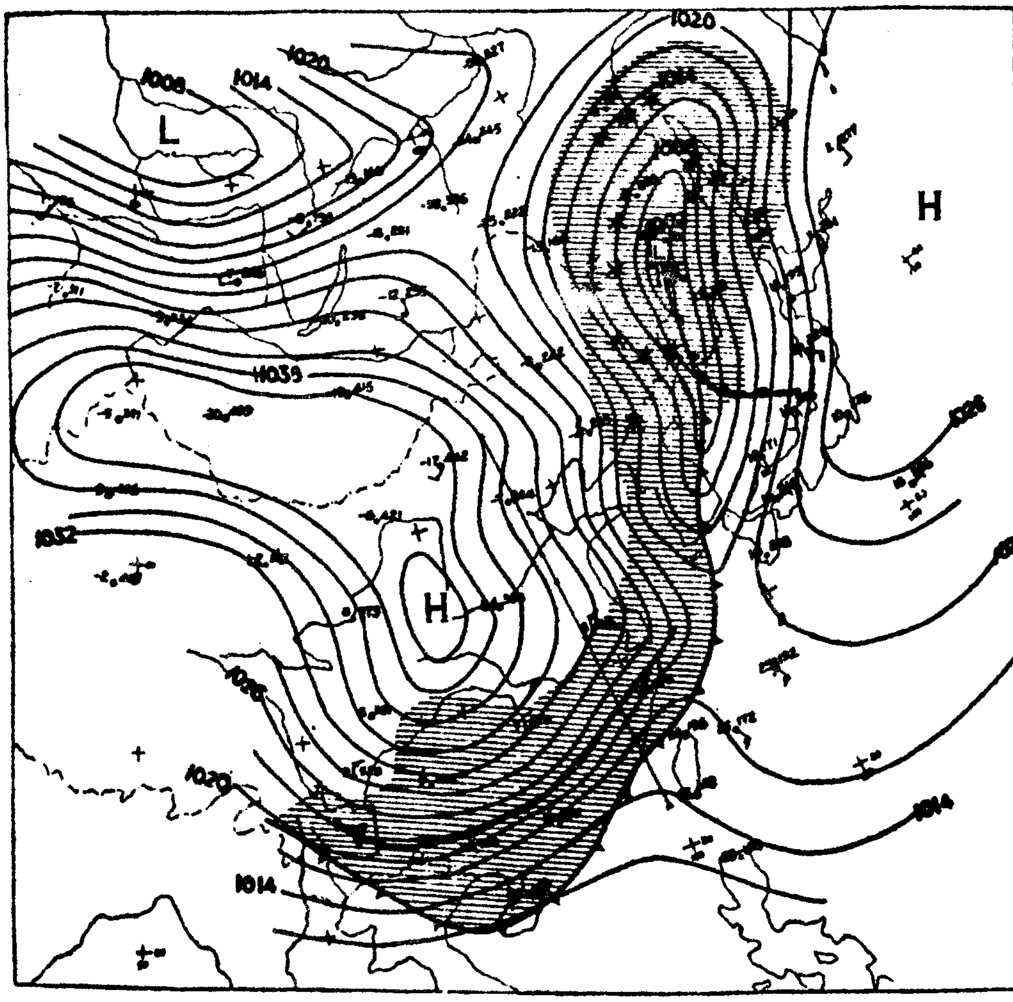

FIGURE 4(a) SURFACE MAP FOR 1200Z ON 15 NOVEMBER 1955. (ISOBARS AT 3 mb INTERVALS). (AFTER CHYOU)

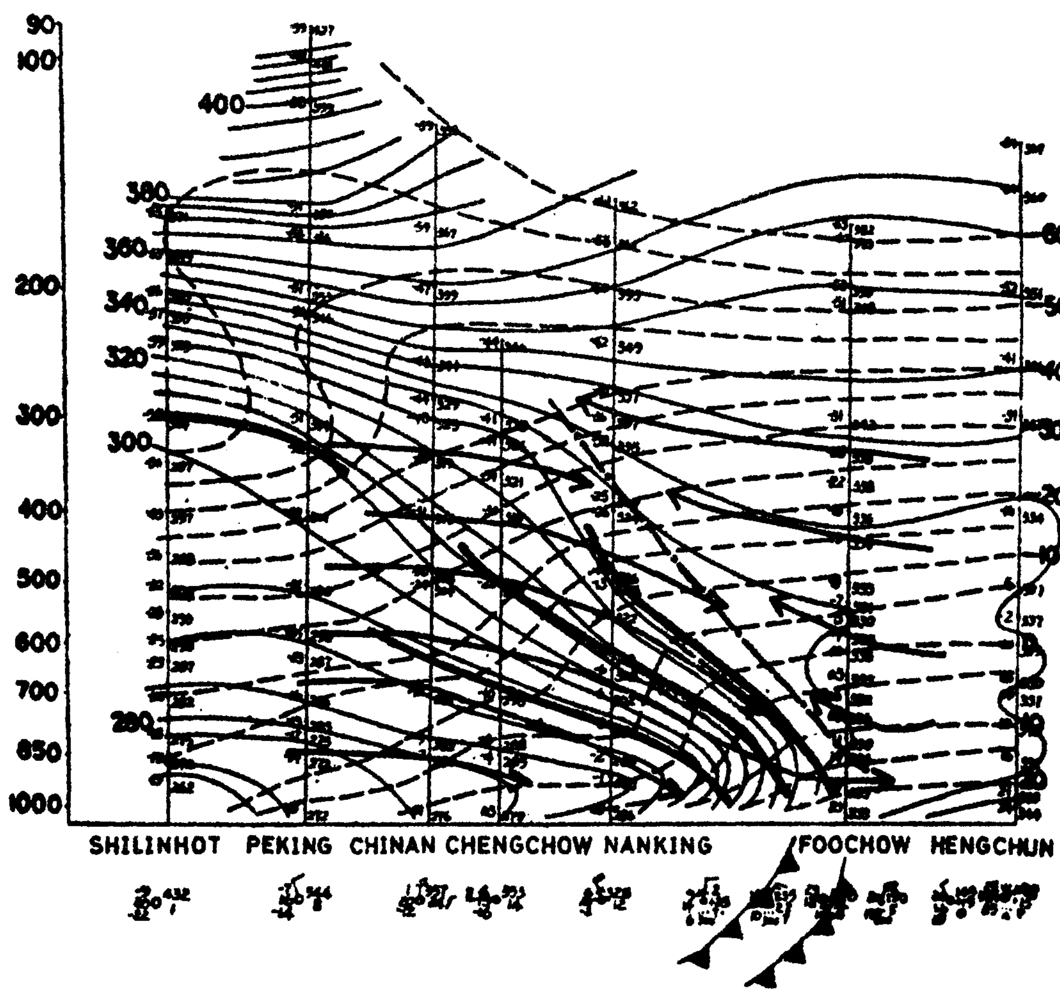

FIGURE 4(b) SHILINHOT-HENGCHUN CROSS-SECTION FOR 1500Z ON 15 NOVEMBER 1955. (THE THICK DASH-DOT LINE MARKS THE BOUNDARY BETWEEN WARM AIR CURRENTS FROM TWO DIFFERENT SOURCES. MEANING OF OTHER SYMBOLS SAME AS IN FIGURE 3(b)). (AFTER CHYOU)

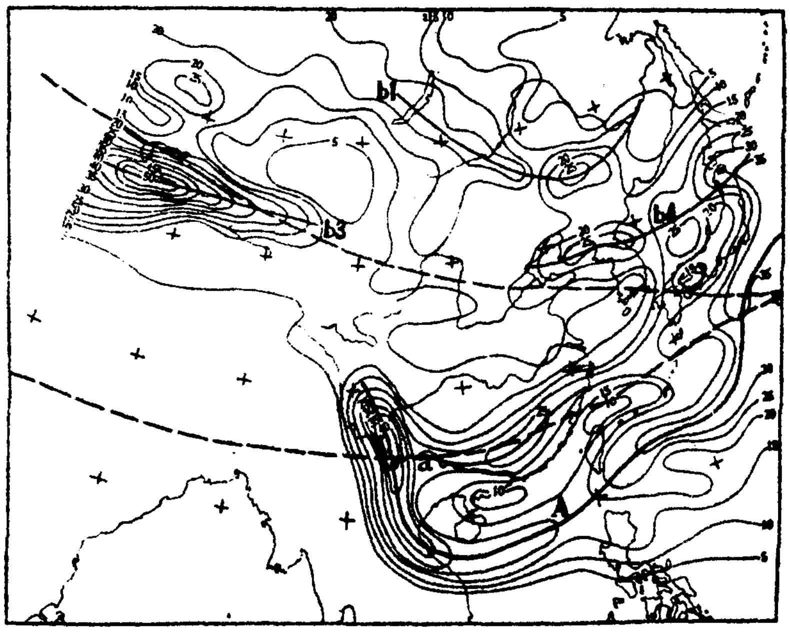

FIGURE 5. MONTHLY FREQUENCY OF OCCURRENCE OF COLD FRONTS IN EACH $2\frac{1}{2}$ DEGREE SQUARE FOR THE PERIOD 1955 - 1959 AND THE "CLIMATIC FRONTAL ZONES OVER EAST ASIA"—JANUARY. (FULL THICK LINES DEPICT THE CLIMATIC FRONTAL ZONES AND BROKEN LINES THE AXES OF MAXIMUM WEST-WIND COMPONENT AT 500 mb).

(AFTER CHU)

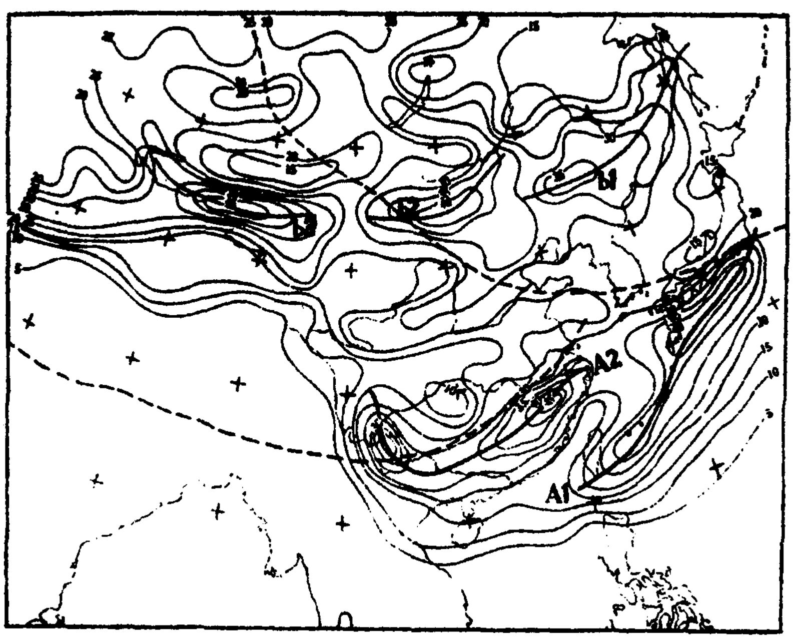

FIGURE 6. MONTHLY FREQUENCY OF OCCURRENCE OF COLD FRONTS IN EACH $2\frac{1}{2}$ DEGREE SQUARE FOR THE PERIOD 1955-1959 AND THE " CLIMATIC FRONTAL ZONES OVER EAST ASIA" — APRIL . (LEGEND SAME AS FIGURE 5).

(AFTER CHU)

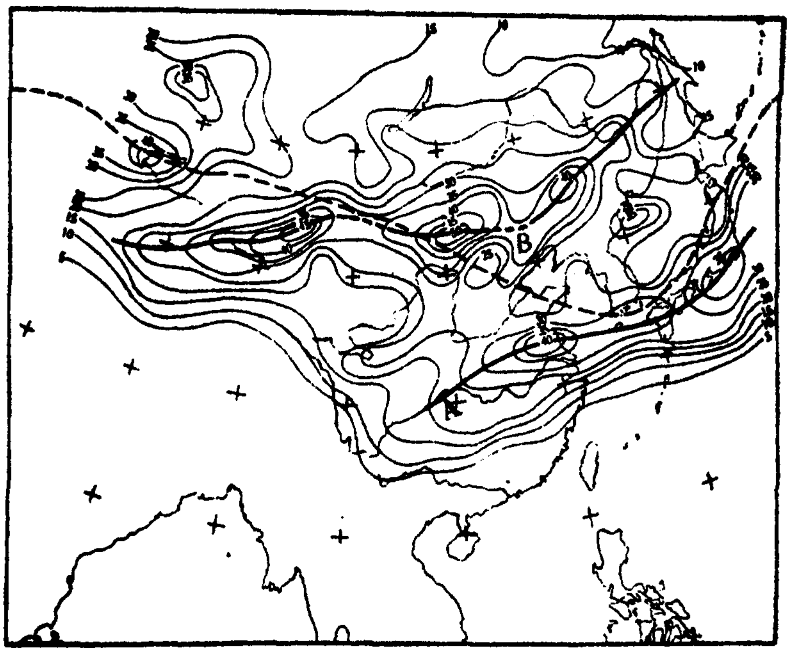

FIGURE 7. MONTHLY FREQUENCY OF OCCURRENCE OF COLD FRONTS IN EACH $2\frac{1}{2}$ DEGREE SQUARE FOR THE PERIOD 1955 - 1959 AND THE "CLIMATIC FRONTAL ZONES OVER EAST ASIA" — JULY. (LEGEND SAME AS FIGURE 5).

(AFTER CHU)

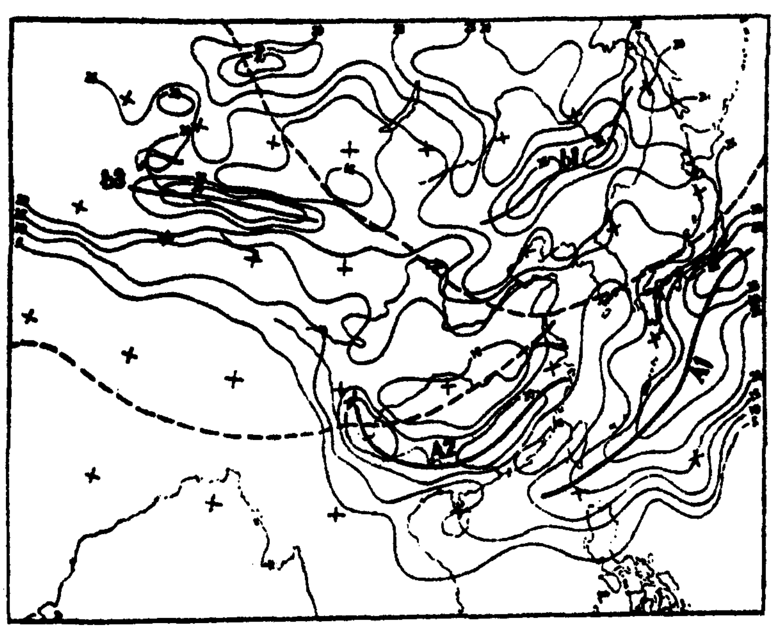

FIGURE 8. MONTHLY FREQUENCY OF OCCURRENCE OF COLD FRONTS IN EACH $2\frac{1}{2}$ DEGREE SQUARE FOR THE PERIOD 1955 - 1959 AND THE "CLIMATIC FRONTAL ZONES OVER EAST ASIA" OCTOBER. (LEGEND SAME AS FIGURE 5).

(AFTER CHU)

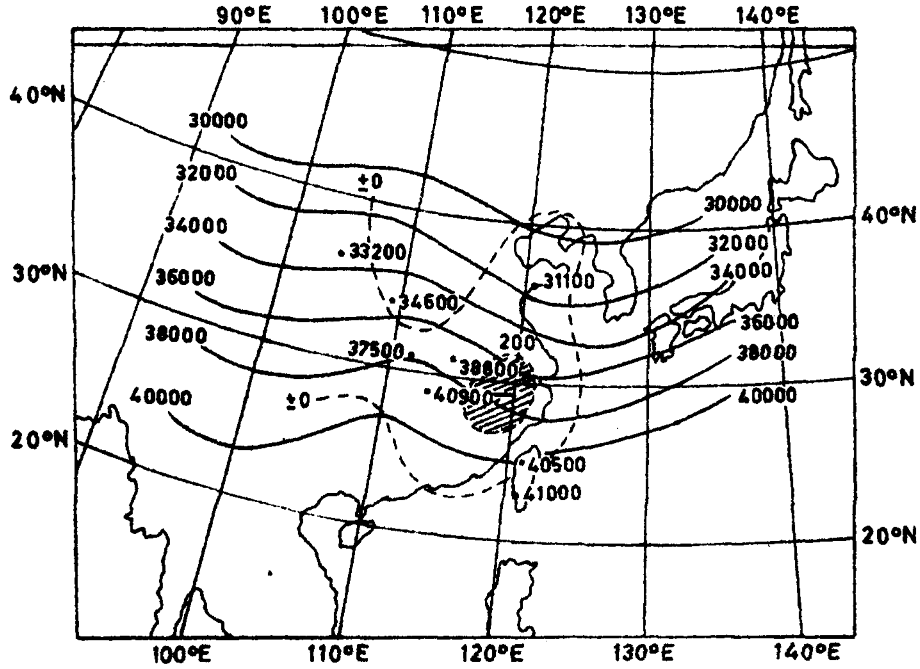

FIGURE 9(a) CONTRAIL CHART FOR 1200Z ON 24 MARCH 1958. (HEIGHTS OF CONTRAIL FORMATION OVER THE VARIOUS STATIONS ARE PLOTTED IN ft. FULL LINES DEPICT ISOPLETHS OF CONTRAIL LEVEL AND BROKEN LINES 12-hr CHANGES IN CONTRAIL LEVEL. AREA WITH A FALL OF MORE THAN 200 ft IN CONTRAIL LEVEL IS SHADED.)

(AFTER HSU AND WANG)

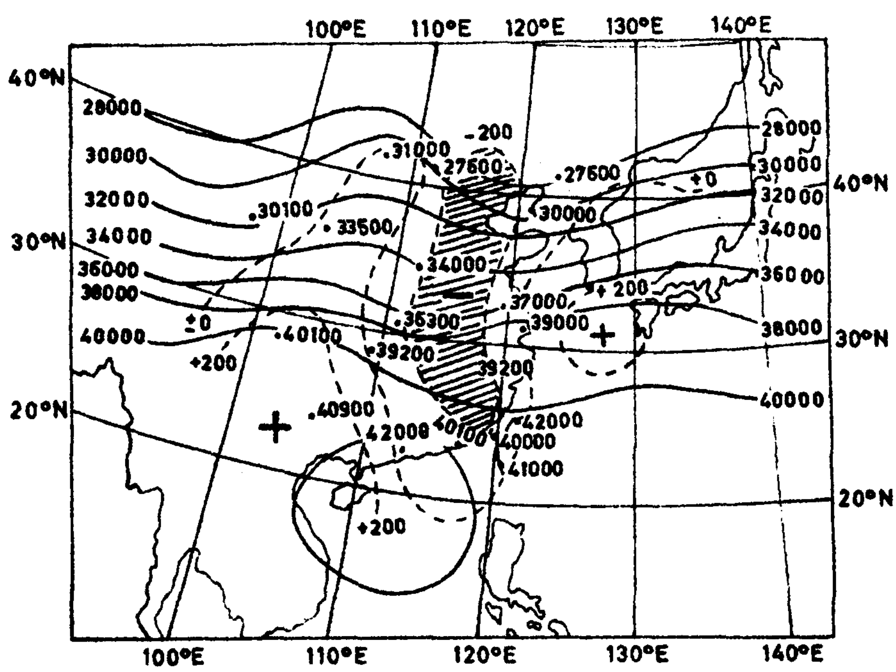

FIGURE 9(b) CONTRAIL CHART FOR 1200Z ON 25 MARCH 1958.

(LEGEND SAME AS FIGURE 9(a).)

(AFTER HSU AND WANG)

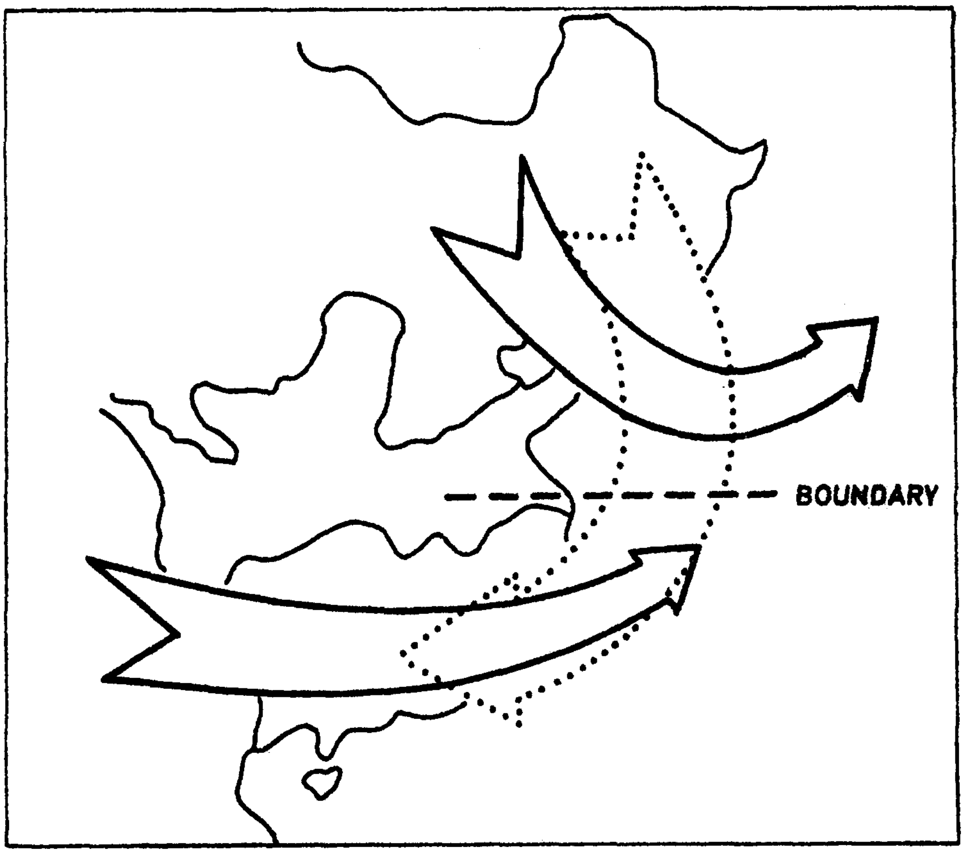

FIGURE 10. SCHEMATIC DIAGRAM SHOWING THE POSITION OF THE BOUNDARY BETWEEN ZONES OF GOOD AND BAD WEATHER IN RELATION TO THE FLOW PATTERN DURING THE STABLE PERIOD AFTER A COLD WAVE.

(AFTER HSU AND WANG)

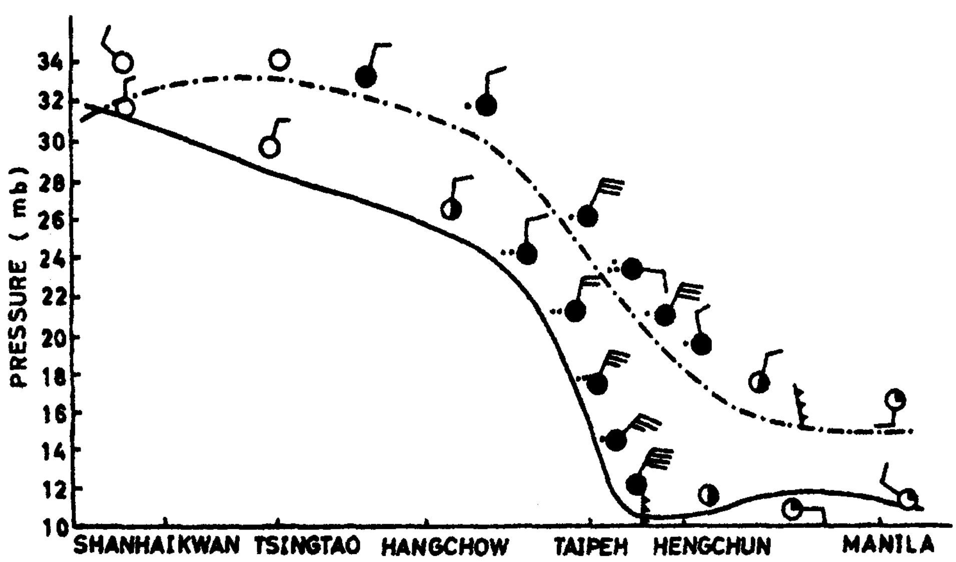

FIGURE 11. WIND AND WEATHER CHANGES IN RELATION TO PRESSURE CHANGE ALONG 120°E DURING 26-27 MARCH 1958. (SOLID LINE DEPICTS PRESSURE PROFILE AT 0000 Z ON 26 MARCH 1958 AND DASH-DOT LINE AT 0000Z ON 27 MARCH 1958.

(AFTER HSU AND WANG)

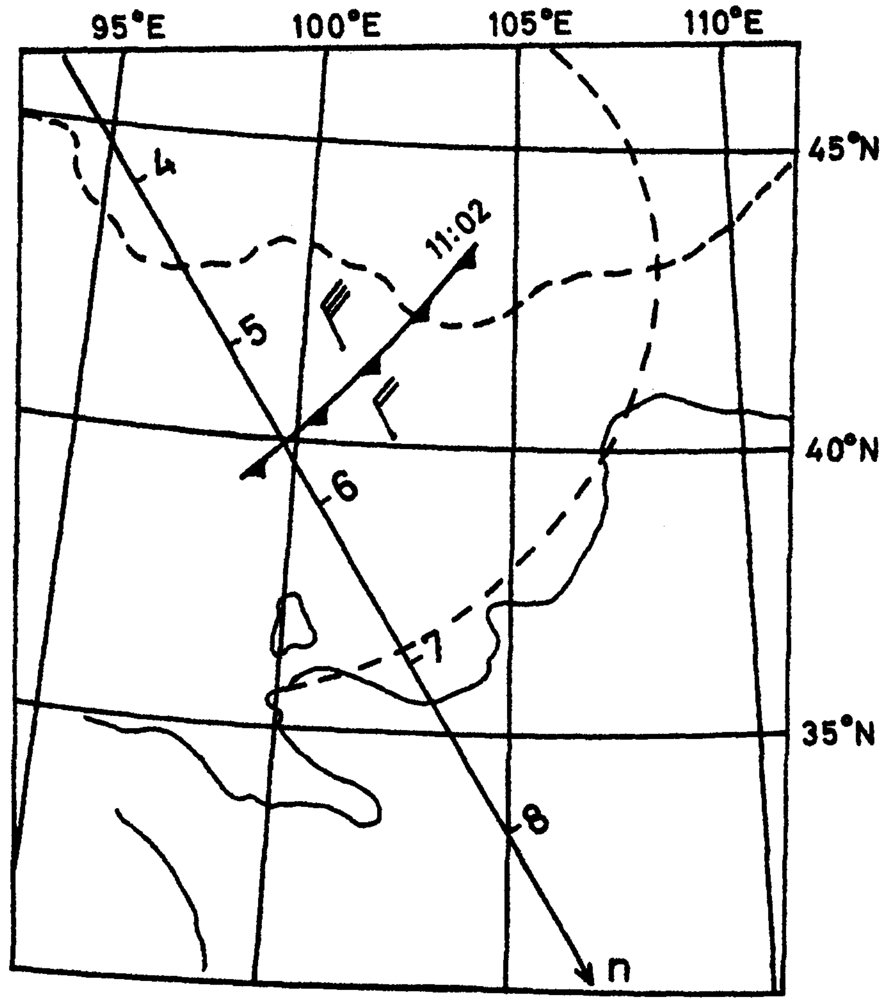

FIGURE 12. SELECTED CROSS-SECTION FOR THE STUDY OF TEMPERATURE ADVECTION (A_T)
(AFTER DOO AND LI)

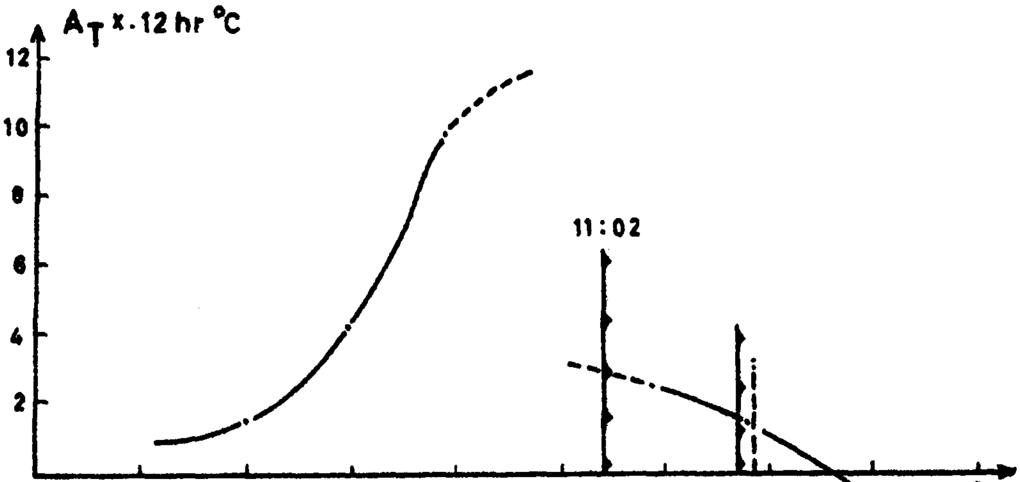

FIGURE 13. PROFILE OF A_T ALONG A SELECTED CROSS-SECTION (THE NUMBERS ALONG THE ABSCISSA REFER TO THE POINTS GIVEN IN FIG. 12).
(AFTER DOO AND LI)

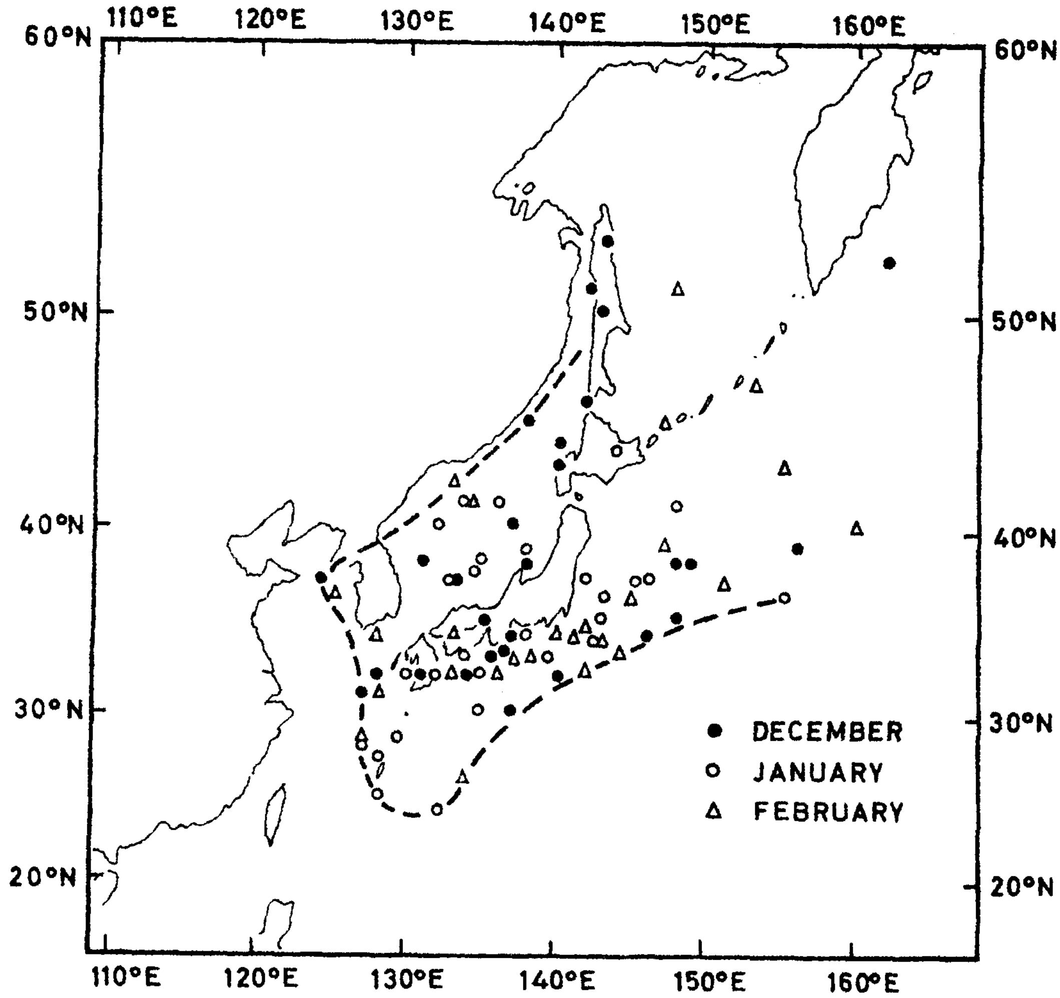

FIGURE 14. POSITIONS OF DEPRESSION CENTRES WHEN COLD FRONTS PASSED THROUGH HONG KONG (DECEMBER - FEBRUARY, 1959 - 1968)

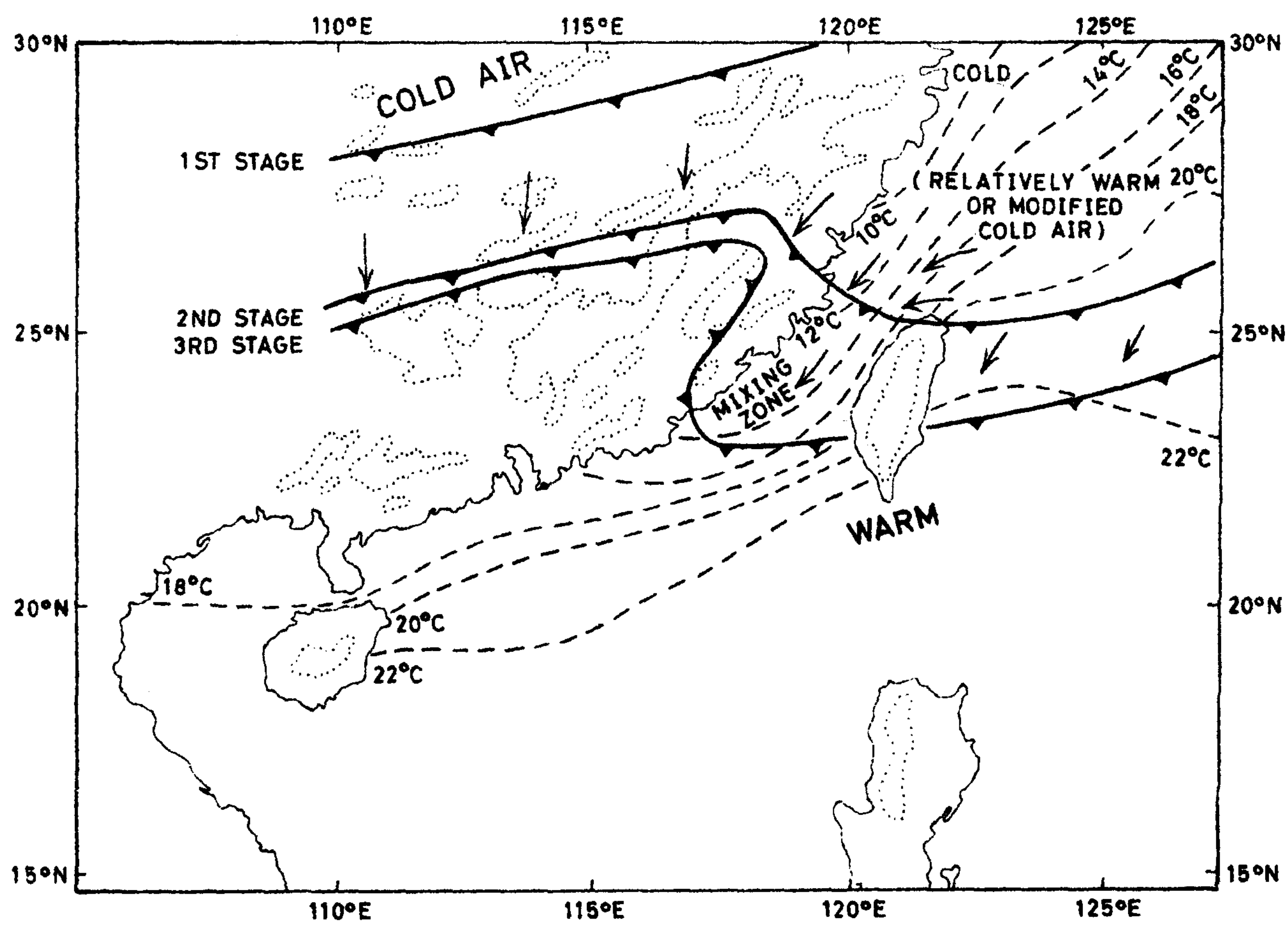

FIGURE 15. SOUTHWARD MOVEMENT OF A COLD FRONT OVER SOUTH CHINA

– – – ISOTHERM OF MEAN SEA SURFACE TEMPERATURE FOR FEBRUARY;

COLD FRONT; 300 - ft CONTOUR.

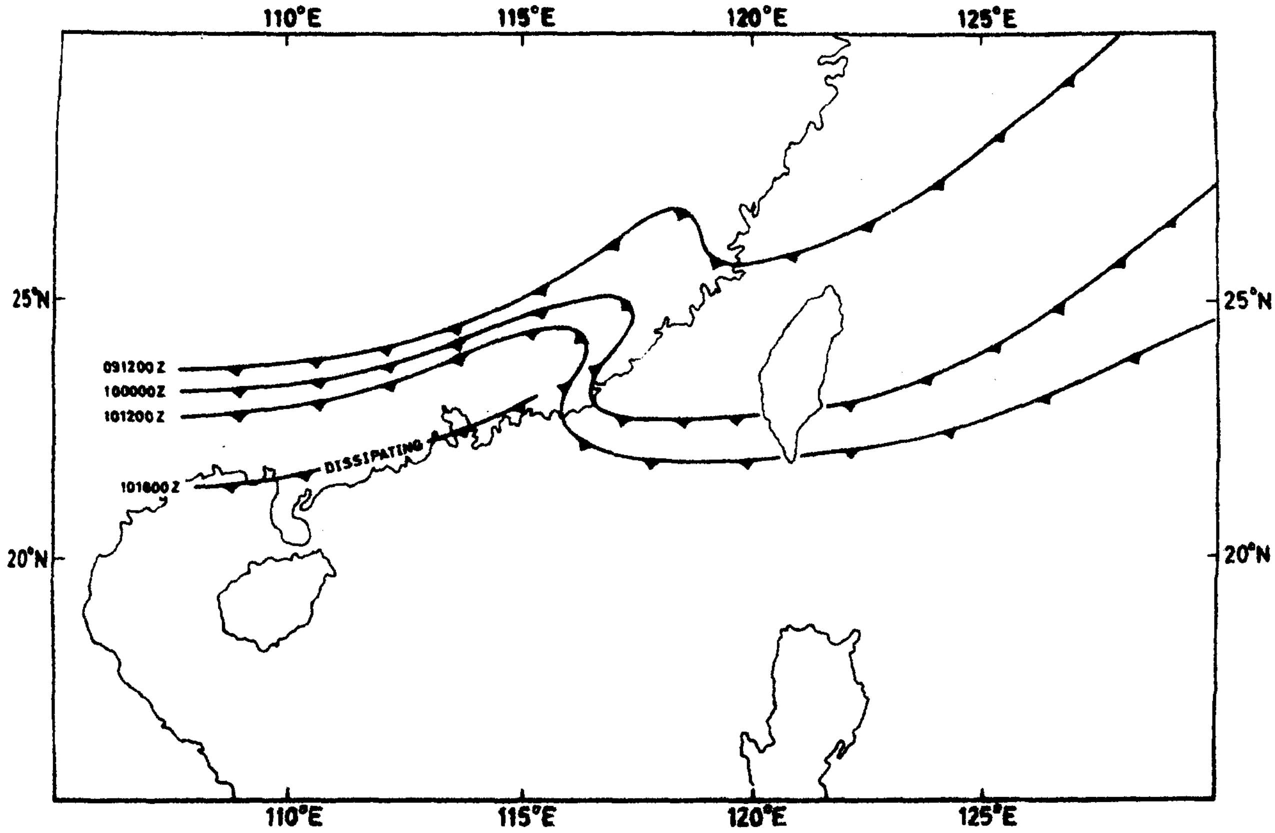

FIGURE 16 (a) SUCCESSIVE POSITIONS OF COLD FRONT DURING THE PERIOD 091200Z-101800Z FEBRUARY 1965.

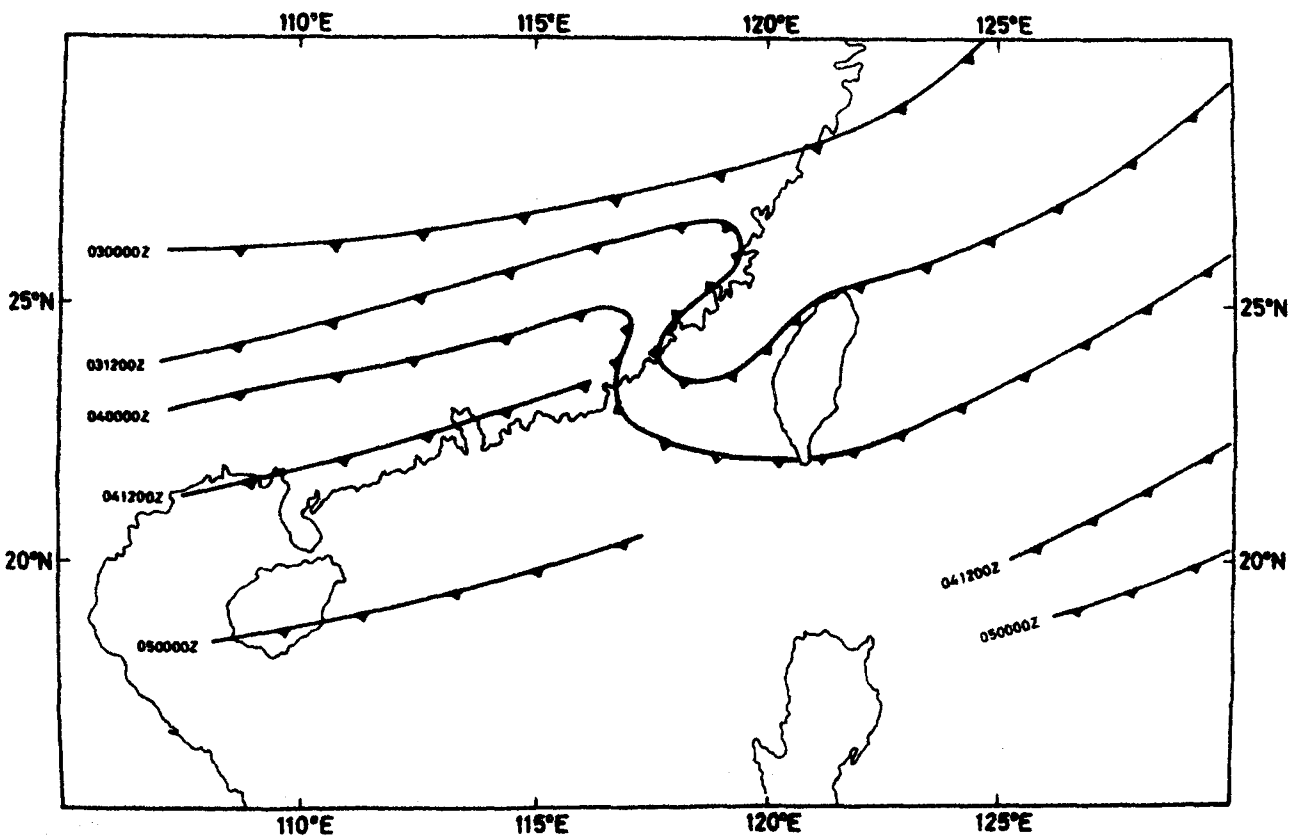

FIGURE 16 (b) SUCCESSIVE POSITIONS OF COLD FRONT DURING THE PERIOD 030000Z-050000Z FEBRUARY 1966.