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# An Investigation on the Prediction of Strong Winds Associated With Cold Fronts in the Yupeh Region (Northern Honan) in Spring

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# AN INVESTIGATION ON THE PREDICTION OF STRONG WINDS ASSOCIATED WITH COLD FRONTS IN THE YUPEH REGION (NORTHERN HONAN) IN SPRING

# 豫北地区春季冷鋒大风預报研究

by

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# AN INVESTIGATION ON THE PREDICTION OF STRONG WINDS ASSOCIATED WITH COLD FRONTS IN THE YUPEH REGION (NORTHERN HONAN) IN SPRING*

by

Zhu Zhong-ji Hu Xue-mei Chen Zeng-fu,

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## ABSTRACT

This paper presents an analysis of the occurrence of strong winds over the region of Kaifeng, Chengchow** and Hsinhsiang in Honan Province with respect to orographic conditions. The effect of pressure gradient, the characteristics of the low-level frontal zone and the turbulent exchange on wind speed and the relationship between the flow pattern ahead of the front and the wind speed behind it were also discussed. The synoptic situations associated with the occurrence of strong winds accompanying a cold front over the Yupeh region were classified into three main types, W, N and E, and other subsidiary categories on the basis of synoptic climatology and the trajectories of the cold air. The characteristics of each type of strong winds and the evolution of the associated synoptic process were studied in detail for the formulation of an empirical method to forecast the occurrence of strong winds. The method evolved was then tested for the region under operational conditions during March - May 1964, and the accuracies were found to be 87.5% for Type W, 91.7% for Type N and 40% for Type E.

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## I. INTRODUCTION

Strong winds usually occur over the region of Kaifeng, Chengchow and Hsinhsiang (hereafter called the Yupeh region) during the winter half-year and are particularly prevalent in spring. The evolutionary

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* Manuscript received 29 December 1964.

** Also known as Chenghsien.

processes associated with the development of strong winds behind cold fronts are investigated in the present study and a method for preparing 12-hour strong wind forecasts is described. The method is developed from the results of analysis of surface and upper-air charts for the period 1959 - 1962 and the verification tests made are based on the records for the spring of 1964.

## II. THE INFLUENCE OF TOPOGRAPHY ON THE OCCURRENCE OF STRONG WINDS

The Yupeh (or North Honan) region is bounded by Taihang Shan, Luliang Shan and Chungtiao Shan in the northwest and the eastward extension of the Chinling Range in the west and southwest. Both the River Wei and the Yellow River flow through the region between these ranges, giving rise to narrow and long river valleys with an east-west orientation. To the east and southeast lies the extensive plain of the Yellow River and Hwai Ho (River). Kaifeng and Chengchow are both situated on the southern bank at the eastern extremity of the river valleys adjoining the great plain while Hsinhsiang is located at the eastern slope of Taihang Shan. When cold air spreads eastward along the river valleys after passing over the great bend of the Yellow River (hereafter called the River-bend), winds freshen from northwest at Kaifeng and Chengchow. In Hsinhsiang which is sheltered from the west, the wind speed is generally 4 - 6 m/sec less than that in the former two cities for winds from west or west-northwest. When cold air invades the Yupeh region from the North China plain, the flow tends to become northerly because of the presence of the Shansi Plateau in the west and Tai Shan in the north. The funnelling effect thus results in strong northeast winds in all the three cities with the average speed at Kaifeng and Chengchow greater than that at Hsinhsiang by about 2 - 4 m/sec.

## III. PHYSICAL PARAMETERS GOVERNING THE SPEED OF WIND

### (a) Sea-level Pressure Gradient

As wind speed is related to pressure gradient, strong winds will occur if the pressure gradient reaches a certain value. However, the increase in wind speed and the deformation in the wind field will give rise to a corresponding change in the pressure field. Thus, pressure gradient and wind flow are mutually dependent. On some occasions, the variations are slow and gradual in character but in cold outbreaks, the adjustment processes are generally more abrupt. The importance of the magnitude of pressure gradient and its variation on wind speed has been carefully examined in the present study with particular emphasis on the variation of $\Delta P_3$. It is found that $\Delta P_3$ serves as a useful indicator in predicting the trend of the pressure gradient for short-period changes.

### (b) Low-level Frontal Zone

The activity of southward moving fronts is closely related to the intensity of the frontal zone at low levels (850 mb). Strong winds may develop if the "intensity" of this zone reaches a "critical value". On the other hand, frontolysis may occur if the zone is weak or $\Delta T$ is positive behind a front even though a tight pressure gradient may be present initially. Since the layer of cold air is shallow in the latter case, the front will continue to weaken during its southward movement and strong winds therefore become very unlikely.

### (c) Eddy Exchange

Downward transport of momentum from turbulent exchange tends to increase the surface wind speed. This process is particularly effective when the atmosphere is unstable. The results of a statistical analysis indicate that under similar conditions, the wind speed during the day is, on average, greater than that at night by 2 - 3 m/sec. The actual wind speeds associated with day-time frontal passage are consequently greater than the corresponding computed values.

## IV. RELATIONSHIP BETWEEN THE FLOW FIELD AHEAD OF FRONTS AND THE WIND STRENGTH BEHIND THEM

The strength and duration of strong winds associated with cold outbreaks over the various regions are governed by the distribution of pressure systems ahead of the fronts. The influence of these systems is discussed below:

### (a) Retroverted Southwest Trough (or Northwest Trough)

If marked development is observed in the retroverted southwest trough over the Yangtze - Hwai Ho region or if a broad and deep trough forms over Szechwan, Shensi and the middle Yangtze basin by the amalgamation of the southwest trough and northwest trough before the passage of a cold front, then the invasion of cold air into the Yupeh region from the northwest or east with the rapid fall in pressure ahead of the front will result in a tightening of the pressure gradient, which in turn will lead to the development of strong winds behind the front. However, if the Yangtze - Hwai Ho valley is covered by a ridge instead, the chance of strong winds will be diminished.

Winds will also freshen and become persistent if a northwesterly flow is observed over the Hwai Ho basin during the formation of a depression over the Yangtze - Hwai Ho region.

(b) North China Trough

The development of the North China trough ahead of a cold front is often accompanied by the existence of a small high cell or ridge over the River-bend region. An east-west pressure gradient is thereby set up over North Honan. Cold air reaching the region from the west or northwest will accentuate the gradient and cause the northwesterly winds behind the front to increase. The opposite effect would result if the cold air invades the region from the east or northeast and the post-frontal northwesterlies will weaken. Thus the activities of cold surges from both the northwest and the east greatly depend on the behavior of the North China trough.

(c) High Cell over the Yellow Sea

An analysis of the synoptic processes associated with t development of strong winds reveals that the region extending from the Yellow Sea to the middle and lower Yangtze basins is often covered by a northeast-southwest oriented ridge. On occasions, a center of high pressure can be located over the Yellow Sea and Po Hai drifting slowly eastward. If the occurrence of this high cell coincides with the formation of a retroverted trough south of the Yangtze, then the arrival of cold air over the great plain of Honan from the North China plain will readily produce strong winds. However, winds are not likely to increase if the Yellow Sea is dominated by a low pressure system.

### (d) Typhoons

Typhoons over the East and South China Seas exert a pronounced influence on winds behind cold fronts. When the circulation of a typhoon extends to the Hwai Ho basin, conditions become favorable for the increase of wind speed. However, if a ridge covers the Yangtze - Hwai Ho basin with a typhoon well to the south, then cold fronts will move only very slowly over the northern part of the Yupeh region and may even dissipate gradually.

## V. CLASSIFICATION OF STRONG-WIND SITUATIONS

### (a) Guiding Principles for the Classification

A classification of strong-wind situations has been carried out by examining the configuration of the flow field and the distribution of important elements which depict the synoptic situation ahead of cold fronts in relation to the evolutionary processes associated with cold outbreaks (e. g., tracks of cold air and location of high pressure centers ahead of fronts, etc.). From a study of the position of high pressure centers 12 hours prior to the passage of cold fronts and the track of cold air, three main types of strong-wind situations are established, namely, Type W, Type N and Type E. These are further classified into several sub-types in accordance with the flow configuration ahead of fronts and the orientation of these systems (Figure 1).

Type W: The center of the high cell 12 hours prior to the frontal passage is located within 36° - 42°N and 95° - 105°E, and cold air invades the region from the west.

Type N: The corresponding high center is located within 42° - 53°N and 90° - 110°E and cold air spreads in from the northwest.

Type E: Cold air reaches the region from the east and is associated with a high cell within 42° - 53°N and 110° - 125°E 12 hours prior to the frontal passage.

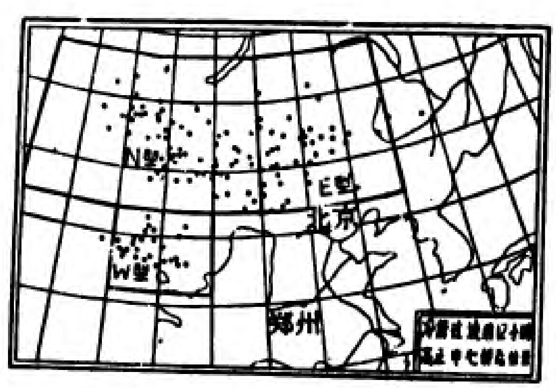


**Figure 1**

**Classification of Types W, N and E.**
**( W型: Type W, N型: Type N, E型: Type E,**
**北京:Peking 郑州: Chengchow**
**Location of high pressure center 12 hours prior to passage of cold front. )**

## (b) General Characteristics of the Various Types and Classification of Sub-types

Type W:

(1) Process of Evolution.

(i) When cold air reaches the western part of the Mongolian People's Republic from Siberia, the region often becomes the seat of a stationary or slowly eastward moving parent anticyclone provided a "horizontal" trough is present at the upper levels. A small but well-marked high cell may form to the south of the upper trough over the Hohsi Corridor*. (This is a Type $W_A$ situation.) If the upper trough is north-south oriented, a small high cell may also break away from the parent anticyclone and move to the Hohsi Corridor. (This is a Type $W_B$ situation.) Both types of situations are normally preceded by a north-east-southwest cold front which lies between Hsining and Lanchow 24 hours before its passage and moves to somewhere between Huachialing and Tienshui in 12 hours.

(ii) A northeast-southwest oriented ridge of high pressure covers Korea, the Yellow Sea and the Yangtze - Hwai Ho region and is occasionally associated with a weak anticyclone over the Yellow Sea or the middle Yangtze basin.

(2) Classification of Sub-types.

Type W is further classified into Type $W_A$ (Figure 2) and Type $W_B$ (Figure 3) according to whether or not an east-west frontal system (or

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* Hohsi Corridor is also known as Kansu Corridor and represents the "corridor" region west of the Yellow River.

upper-air frontal zone) is present over the boundary region between China and Mongolia. The differences in identification criteria between these two types are summarized in Table 1.

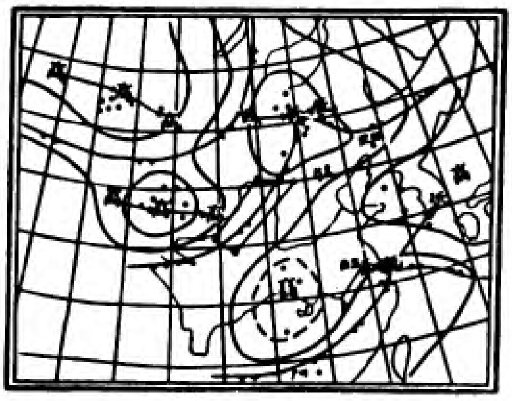

Figure 2

Situation associated with Type $W_A$.
(高: High 低: Low
瀋: Shenyang 北: Peking 南: Nanking 广: Canton)

When a cold front passes over Paotou and Huachialing and arrives at the west of Tatung and Tienshui, the situation should be examined to determine if it belongs to Type $W_A$ or Type $W_B$.

(3) Criteria for Differentiating Type N from Type W.

Type W is easily confused with Type N because of the difficulty in analyzing the properties of the small high cell over the Hohsi Corridor. By plotting $\Delta P_1 = (P_{Chiuchuan} - P_{Chilantai})$ against $\Delta P_2 = [P_{Chasako} - \frac{1}{3} P_{(Erhlien + Wentuerhmiao + Hsilinhaote)}]$, Figure 4 has been prepared to show how the two types may be identified. A situation with large positive values of $\Delta P_1$ and $\Delta P_2$ (pressure higher in the west than the east) indicates that the cold air first moves eastward along the Hohsi Corridor and the situation therefore belongs to Type W. The opposite is true for Type N.

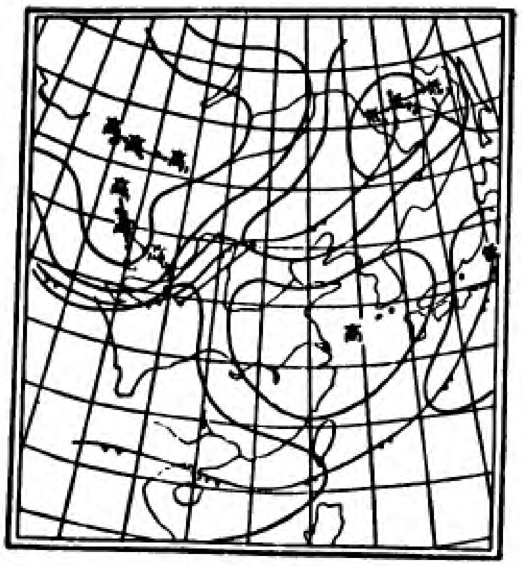

Figure 3

Situation associated with Type $W_B$.

($H_1$ and $L_1$ are centers of high and low pressure respectively 24 hours before passage of cold front, $H_2$ and $L_2$ are the corresponding centers 12 hours before passage while $H_3$ and $L_3$ are current positions. • indicates low center and o high center.)

(高: High 低: Low)

TABLE 1

Criteria for the identification of Type $W_A$ and Type $W_B$

| Type $W_A$ | Type $W_B$ |
|---|---|
| (1) Presence of east-west frontal systems over the border region between China and Mongolia. | Absence of east-west frontal systems over the border region between China and Mongolia. |
| (2) Cyclogenesis over East Mongolia causing cold air to spread from west. | A low pressure area developing ahead of the high cell lying east of the Mongolian cyclone in the vicinity of Heilungkiang or further east. |
| (3) Presence of east-west frontal zone or horizontal trough at 700 mb over Mongolia. | Presence of north-south trough or northeast-southwest frontal zone over Mongolia at 700 mb. |

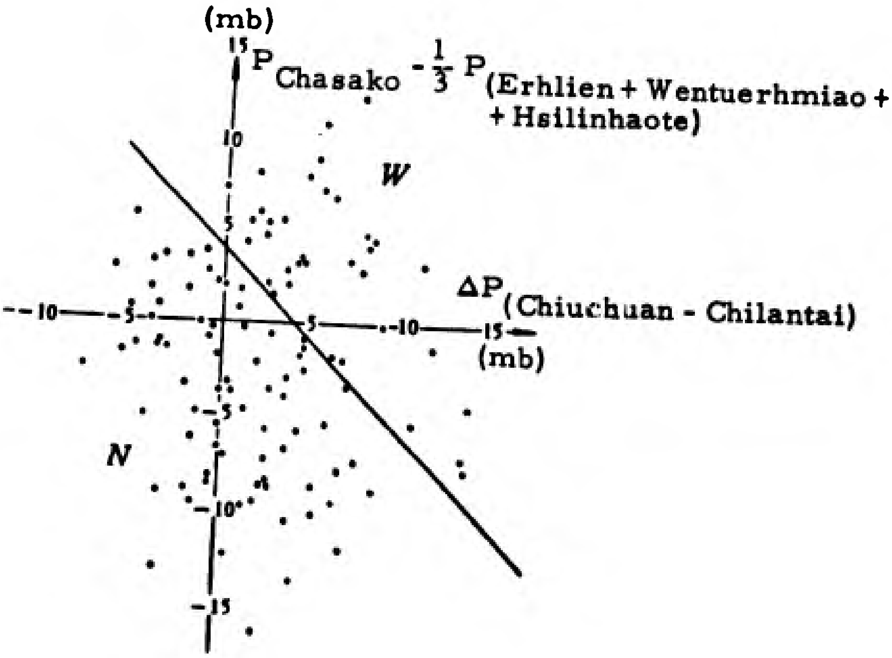


Figure 4

Scatter diagram for Type N and Type W.

Type N:

(1) Process of Evolution.

(i) During the first stage, cold air moves along a southeasterly course and spreads into the Yupeh region from the central and western parts of Mongolia via two paths. The first passes over the North China plain (a Type $N_A$ situation) while the other moves directly over the River-bend region (a Type $N_B$ situation). A cold front lies over the border of China and Mongolia 24 hours before its passage into the Yupeh region but reaches a line joining Peking and Hochu in 12 hours.

(ii) A well-marked depression appears ahead of the Mongolian high and is located north of 40°N and east of 120°E 12 hours prior to the frontal passage over North Honan. When this depression intensifies, a continuous supply of cold air is brought into the region by the northwesterlies behind the system.

(iii) A ridge of high pressure extends from the Sea of Japan southwestward across the Yellow Sea to the south of the Yangtze. The system may occasionally recede to the east but is generally stable and persistent.

(2) Classification of Sub-types.

The classification of sub-types is based on the difference in the tracks of the cold air. Type $N_A$ is associated with the southward spreading of cold air over North China east of 110°E (i.e., near Paotou). A situation with cold air travelling southward to the west of 110°E and passing over the northern part of the River-bend region is taken as Type $N_B$ (Figure 5). Figure 6 is prepared for the classification of these two sub-types by plotting $\frac{1}{2}\Delta P_{(\text{Pailingmiao + Wentuerhmiao}) - (\text{Minchin + Chilantai})}$ against $\Delta P_{3\,(\text{Pailingmiao + Wentuerhmiao}) - (\text{Minchin + Chilantai})}$. Type $N_A$ may further be subdivided into Type $N_{A_1}$ and Type $N_{A_2}$ in accordance with the flow configuration ahead of cold fronts.

(i) Type $N_{A_1}$: The flow field is characterized by high pressure in the north and low in the south and satisfies the condition that $\Delta P_{(\text{Kaifeng - Shihchiachuang})} \leq 0.5$ mb. The trough over the River-bend region (or the southwest trough) ahead of the cold front is particularly marked. When the central and western parts of Mongolia are covered by two separate high centers, activities of cold air from the west are often noted during the later stage of the evolutionary process. However, if the region is dominated by only one extensive high cell, then the activities of cold surges are usually most marked during the initial stage. Cold outbreaks associated with this type of situation are generally more intense and likely to produce strong winds (Figure 7).

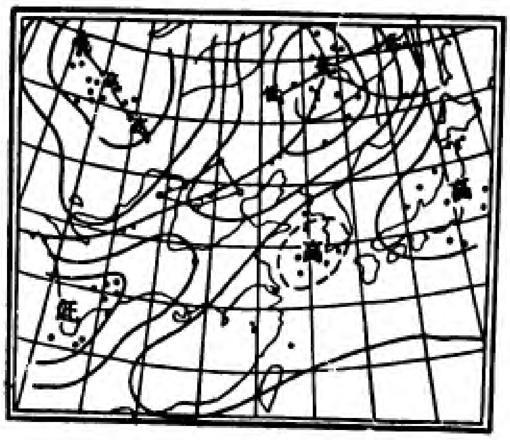

Figure 5

Situation associated with Type $N_B$.

(高: High 低: Low)

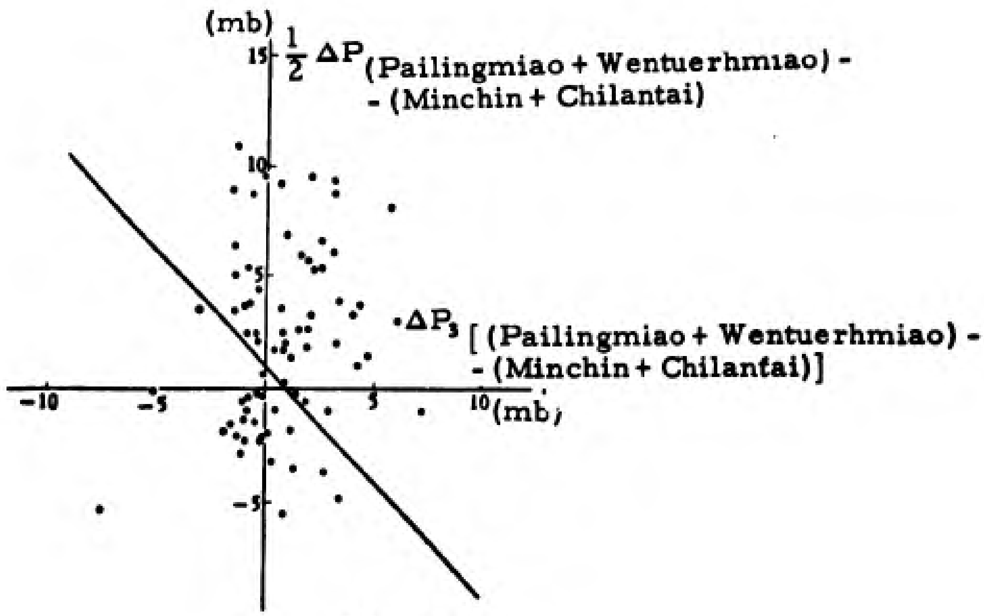


Figure 6

Scatter diagram for Type $N_A$ and Type $N_B$.

(ii) Type $N_{A_2}$: The flow pattern is represented by high pressure in the south and low in the north and satisfies the condition that $\Delta P_{(Kaifeng - Shihchiachuang)} > 0.5$ mb. The type is generally associated with a deep trough over North China, a high pressure belt lying from west to east across the Yangtze basin and a high cell or ridge over Szechwan. Frontolysis is common when the surges are weak (Figure 8).

When a cold front reaches Changchiakou and Hochu (and also Yulin* for a Type $N_B$ situation), but remains north of the line joining Tientsin and Taiyuan, a classification of the sub-types becomes necessary for synoptic analysis.

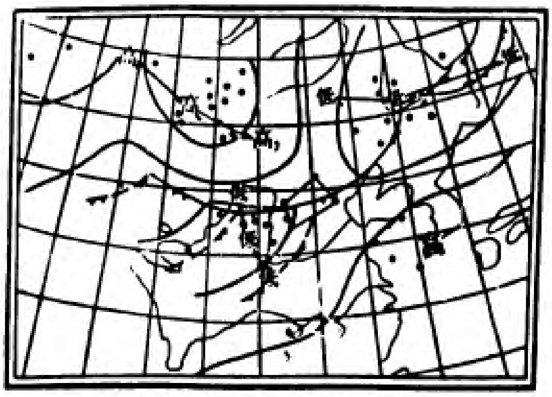

Figure 7

Situation associated with Type $N_{A_1}$.

(高: High 低: Low)

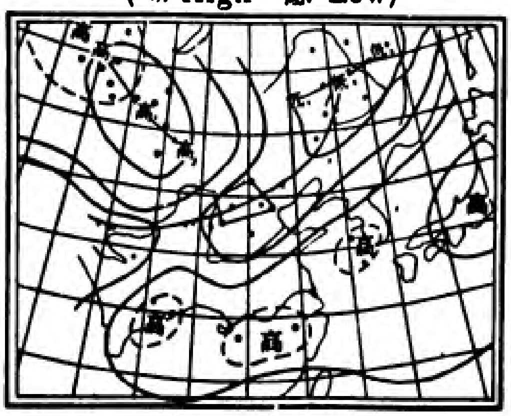

Figure 8

Situation associated with Type $N_{A_2}$.

(高: High 低: Low)

* Yulin quoted here is in Shensi.

Type E:

(1) Process of evolution.

(i) During the initial stage, cold air spreads into eastern Mongolia from the central part of the country and also from Lake Baikal. Over West Mongolia, a weak but persistent ridge is generally present. The Yupeh region is affected by the cold air which sets in over North China after passing over Po Hai.

(ii) An active "northeast depression" covers the region ahead of a ridge. The system first develops over the northern part of Northeast China but slowly moves to the east and conditions become favorable for the cold air to travel southeastward after it has intensified sufficiently and reached a more southern position.

(iii) The axis of the Pacific ridge is in a northeast - southwest orientation and extends from Japan to the Yangtze basin.

(2) Classification of Sub-types.

(i) Type $E_A$ (Figure 9): The flow field ahead of a cold front is shown by high pressure in the east and low in the west ($P_{Hsuchow} > P_{Sian}$). The northwest trough is well-marked and merges with the southwest trough over the River-bend region.

(ii) Type $E_B$: This type is associated with high pressure in the west and low in the east ($P_{Hsuchow} < P_{Sian}$) indicating the absence of high pressure over the River-bend region and the establishment of China trough. A further sub-division of the type may be made by orientation of the fronts and the position of the high pressure c

Type $E_{B_1}$: The eastern portion of the cold front passes simultaneously over Peking, Chinchow as well as over Chining (and generally over Hochu).

The center of the high cell 12 hours prior to the passage of the front is located west of 117°E (Figure 10).

Type $E_{B_2}$: The cold front does not pass over Chining when its eastern portion reaches Peking and Chinchow. The center of the high cell is located east of 117°E (Figure 11).

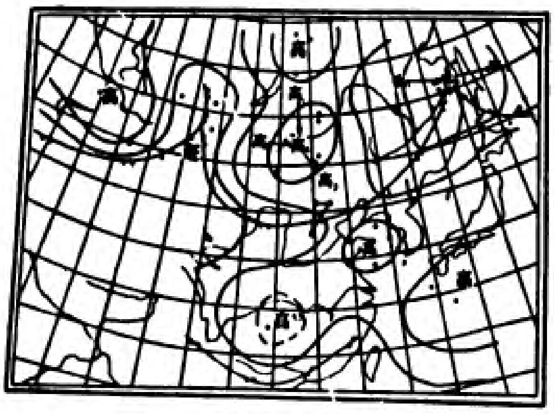

Figure 9

Situation associated with Type $E_A$.
(高: High 低: Low)

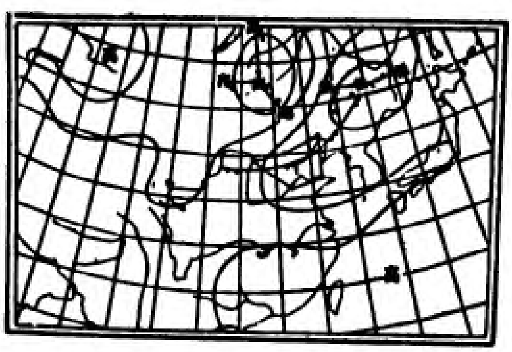

Figure 10

Situation associated with Type $E_{B_1}$.
(高: High 低: Low)

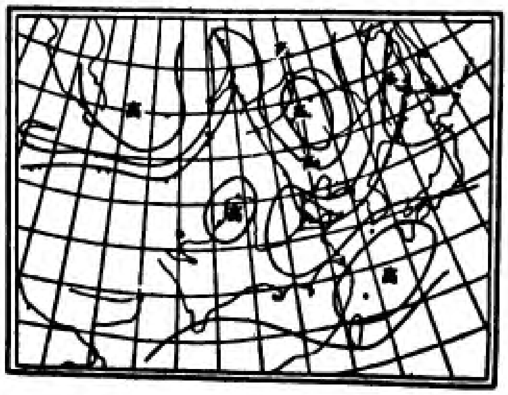

Figure 11

Situation associated with Type $E_{B_2}$.
(高: High 低: Low)

For verification purposes, the following criteria have been taken as typical features associated with the various types:

Type $E_A$: Cold front passing over Changchiakou (or Chengte) and reaching the area of Shihchiachuang.

Type $E_{B_1}$: Cold front passing over Chinchow, Peking and Hochu and reaching the area of Yentai and Techow.

Type $E_{B_2}$: Cold front passing over Tangshan, Yentai and reaching the area of Tsingtao and Chinan.

## VI. PREDICTORS FOR THE VARIOUS TYPES OF SITUATION

### (a) Predictors for Type W

(1) Identification of Frontolysis.

The term "frontolysis" used in the present text refers to the dissipation of cold fronts over the Yupeh region. Type W is characterized by the presence of a north-south thermal trough over the western side of the River-bend region. Hence $\Delta T_{850}$ (Chiuchuan - Taiyuan) has been chosen to indicate the intensity of the low-level frontal zone and $\frac{1}{2}\Delta(P + \Delta P_3)$(Chungning* + + Chilantai) - (Shihchiachuang + Chengchow) to represent the magnitude of the pressure gradient ahead of the front. These parameters are then used to prepare Figure 12, which shows the frontolysis does not usually occur when $\Delta(P + \Delta P_3)$ and $\Delta T$ are large and vice versa.

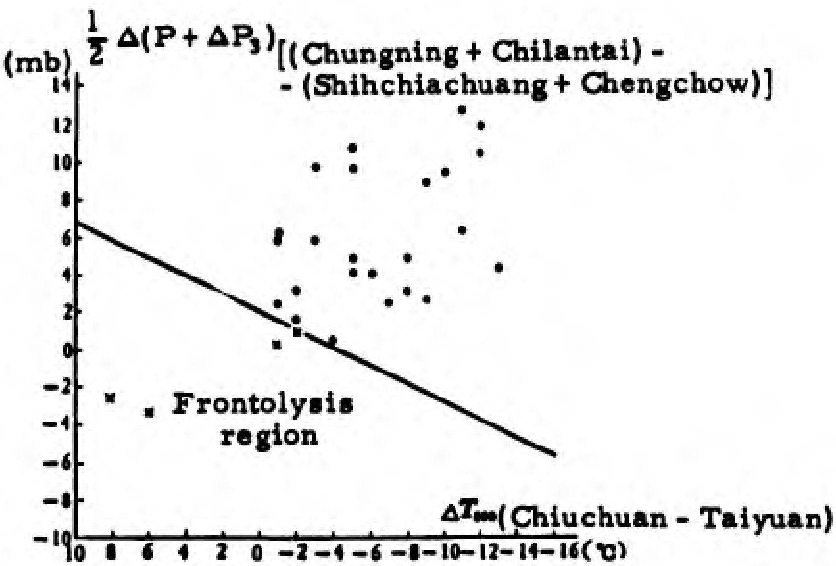


Figure 12

Frontolysis associated with Type W situation.

(2) Movement of Front (based on computation of displacement from Chengchow).

(i) Type $W_B$: The movement is slow when the retroverted south-west trough extends northward or a closed high cell forms over North China ahead of the front. The average speed is 20 - 25 km/hr.

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* A correction of 2.5 mb should be made for the pressure reported at Chungning.

(ii) Type $W_A$: The average speed is 30 - 40 km/hr when a retroverted southwest trough or a wave disturbance develops over the middle and lower Yangtze basins but the front may accelerate to 40 - 45 km/hr after the wave disturbance has moved northeastward and entered the adjacent sea.

(iii) Difference in time of frontal passage over Chengchow, Kaifeng and Hsinhsiang: Statistical analyses of the time of passage of both Type $W_B$ and Type $W_A$ cold surges over the above three stations show that the fronts take generally less than 2 hours to reach Hsinhsiang from Chengchow (12/16) with a maximum lapse of 3 hours and about 2 - 4 hours to arrive at Kaifeng after passing over Chengchow (19/27) with a maximum interval of 5 - 6 hours.

(3) Forecasting of Maximum Mean Wind.

(i) The empirical equations for Type $W_A$ are:

$$V = \frac{1}{2}\,\Delta(P + \Delta P_3)_{(\text{Chang-I + Chiuchuan}) - (\text{Shihchiachuang + Chasako*})} \qquad (1)$$

$$V = \Delta(P + \Delta P_3)_{(\text{Chang-I - minimum pressure ahead of front**})} \qquad (2)$$

(ii) The empirical equations for Type $W_B$ are:

<u>Main equation</u>

$$V = \frac{1}{2}\,P_{(\text{Chilantai + Chungning})} - P_{\text{Shihchiachuang}} + 5. \qquad (3)$$

---

* Observations from Hochu may be used if reports from Chasako are not available.

** This refers to the minimum value reported within the area 35° -40°N and from the front to 115°E.

<u>Supplementary equation</u>

$$V = \frac{1}{2} P_{(Chilantai + Lanchow)} - P_{Shihchiachuang} + 5. \qquad (4)$$

The above equations are for use in Chengchow.

(iii) Difference in wind speed between Chengchow, Kaifeng and Hsinhsiang: The wind speed at Kaifeng is greater than that at Chengchow by 2 m/sec for Type $W_A$ situations (and 4 m/sec for Type $W_B$ situations), while the speed at Chengchow is greater than that at Hsinhsiang by 4 m/sec.

(4) Time of Occurrence of Maximum Mean Wind and Variation in Wind Speed.

Figures 13 and 14 depict the variations of wind with time for Type $W_A$ and Type $W_B$ situations and show that the maximum mean wind generally occurs 5 hours after the passage of a cold front through Kaifeng and Hsinhsiang and about 6 - 7 hours for Chengchow. The rate of change in wind speed per hour is 1.7 m/sec at Chengchow, 2.0 m/sec at Kaifeng and 1.3 m/sec at Hsinhsiang. After the maximum is reached, the wind then decreases at 0.9 m/sec per hour at all the three stations.

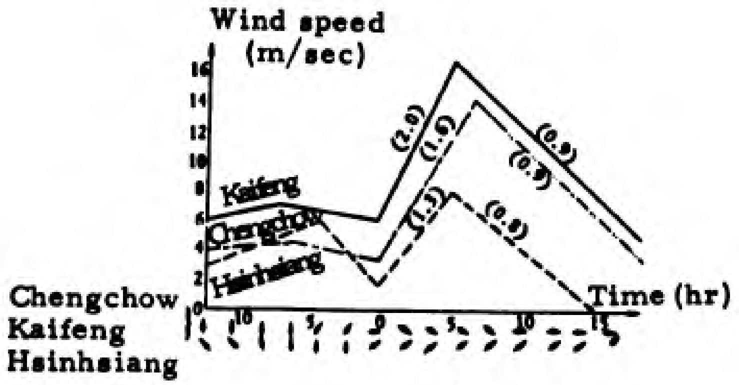


Figure 13

Variation of meteorological elements associated with Type $W_A$ situation.

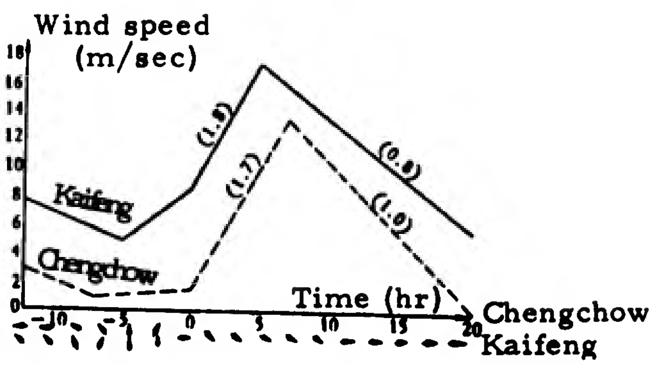


Figure 14

Variation of meteorological elements associated with Type $W_B$ situation.

## (b) Predictors for Type N

Type $N_A$:

(1) Movement of Front.

This factor should be considered as soon as a cold front passes between Hochu - Changchiakou and Tientsin - Taiyuan. Type $N_{A_1}$ fronts pass over Kaifeng and Chengchow simultaneously one hour after passage over Hsinhsiang with an average speed of 43 km/hr. Type $N_{A_2}$ fronts also reach Kaifeng and Chengchow simultaneously 1 - 2 hours after passage over Hsinhsiang and the average speed of movement is 32 km/hr.

(2) Forecasting of Maximum Mean Wind.

(i) Type $N_{A_1}$:

The appropriate equation for use is

$$V = P_{max} - P_{min} + K, \qquad (5)$$

where $P_{max}$ is taken from the highest pressure reported by Pailingmiao, Wentuerhmiao or Hsilinhaote and $P_{min}$ from the lowest pressure reported by Kaifeng, Loyang or Sian. The value of K is 2 when frontal passage takes place during daylight hours and -2 when the passage occurs at night time.

(ii) Type $N_{A_2}$:

Prediction of the maximum mean speed may be made by the use of a scatter diagram (Figure 15) or an empirical equation. The parameters used in the first method are $\Delta(P + \Delta P_3)_{(Pailingmiao - Kaifeng)}$ and $\frac{1}{2}\Delta T_{850}$ (Erhlien + + Hsilinhaote) - (Peking + Huhehot). The empirical equation is

$$V = \Delta(P + \Delta P_3)_{(Pailingmiao\ -\ Kaifeng)} + K, \qquad (6)$$

where K equals to 2 for daytime passages and -1 for night-time passages. Both Figure 15 and Equation 6 are for application in Chengchow.

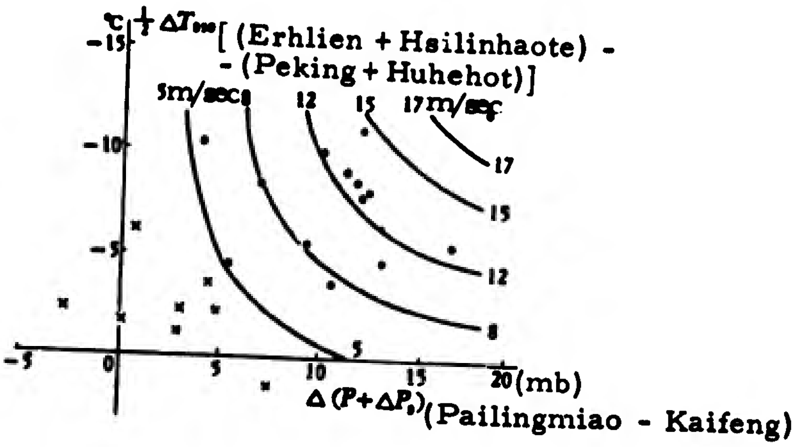


Figure 15

Nomogram for the prediction of wind speed in a Type $N_{A_2}$ situation.

Difference in wind speed between Chengchow, Kaifeng and Hsinhsiang: The wind speed is the same at Chengchow and Kaifeng for Type $N_{A_1}$ situations and is greater than that at Hsinhsiang by 3 m/sec. For Type $N_{A_2}$ patterns, the wind speed at Chengchow is greater than that at Hsinhsiang by 3 m/sec and smaller than that at Kaifeng by 2 m/sec.

The time of occurrence of the maximum mean wind and the rate of change of wind speed may be estimated as follows:

Type $N_{A_1}$: The maximum wind occurs about 6 hours after the passage of a cold front over Kaifeng and Chengchow and about 8 hours behind the front at Hsinhsiang. The wind speed increases at a rate of 2.2 m/sec per hour at Chengchow and Kaifeng until the maximum value is reached and thereafter decreases at 1.0 m/sec per hour.

Type $N_{A_2}$: The maximum wind occurs 5 - 6 hours after the passage of a front and the variation in speed per hour is 1.6 m/sec at Chengchow, 2.2 m/sec at Kaifeng and 1.3 m/sec at Hsinhsiang before the maximum and 1.2 m/sec at Kaifeng and Chengchow and 0.8 m/sec at Hsinhsiang after t[illegible] maximum.

Type $N_B$:

(1) Movement of Front.

(i) An average speed of 35 - 40 km/hr is observed during the development of the retroverted southwest trough or the northwest trough, but fronts only move at 23 - 28 km/hr when the North China trough is dominant or when the River-bend region is covered by a high cell. However, with the presence of well-marked low centers over North China and the River-bend region, fronts usually accelerate to 35 km/hr when entering the trough region associated with these centers.

(ii) Difference in the time of frontal passage over Chengchow, Kaifeng and Hsinhsiang: Fronts generally pass over Hsinhsiang earlier than over Chengchow by one hour. Similarly, they take about one hour to reach Kaifeng from Chengchow.

(2) Forecasting of Maximum Mean Wind.

(i) The scatter diagram method: By using $\frac{1}{2}\Delta(P + \Delta P_3)_{(Chilantai + Pailingmiao) - (Yuncheng + Kaifeng)}$ to represent pressure gradient and $\frac{1}{2}\Delta T_{850\,(Tengkou + Pailingmiao) - (Sian + Taiyuan)}$ the intensity of the upper frontal zone, a scatter diagram may be constructed for the prediction of the maximum mean wind speed (figure omitted).

(ii) The empirical equation method: The following may be used as an auxiliary indicator:

$$\frac{1}{2}\Delta(P + \Delta P_3)_{(Chilantai + Pailingmiao) - (Yuncheng + Kaifeng)} + K, \quad (7)$$

where K is 2 when the time of frontal passage lies between 0600 and 1700 hr and 0 when the passage is between 1800 and 0500 hr.

$$\frac{1}{2}\Delta(P + \Delta P_3)_{(Chilantai + Pailingmiao) - (Yenan + Shihchiachuang)} + K, \quad (8)$$

where K is 5 for frontal passages between 0600 and 1700 hr and 2 between 1800 and 0500 hr. Both equations can be used for Chengchow.

(iii) Difference in wind speed between Chengchow, Kaifeng and Hsinhsiang: The wind speed at Chengchow is greater than that at Hsinhsiang by 2 m/sec and smaller than that at Kaifeng by 2 m/sec.

(3) Time of Occurrence of Maximum Mean Wind and Variation in Wind Speed.

The time sections of wind speed for Chengchow, Kaifeng and Hsinhsiang (figure omitted) show that the strongest wind is observed at all the 3 stations about 3 hours after the passage of a cold front and persists for 2 hours (winds at Hsinhsiang decrease at 1.0 - 1.4 m/sec per hour shortly after the maximum speed is attained).

### (c) Predictors for Type E

Examples of this type are comparatively too few for any conclusion to be drawn.

## VII. RESULTS OF VERIFICATION TESTS

The predictors discussed in the previous sections have been tested over the Chengchow region during March - May 1964. By considering forecasts of wind speed with errors of $\leq$ 2 m/sec as accurate and those with errors of $\geq$ 3 m/sec as inaccurate and forecasts of time of occurrence of strong winds with errors of less than 4 hours as accurate and those with errors greater than this interval as inaccurate, the results of the verification show that:

Occurrence of Type W situations: 8 cases, number of accurate forecasts: 7, percentage accuracy: 87%;

occurrence of Type N situations: 12 cases, number of accurate forecasts: 11, percentage accuracy: 91.7%;

occurrence of Type E situations: 10 cases, number of accurate forecasts: 4, percentage accuracy: 40%.

## VIII. SOME OUTSTANDING PROBLEMS

(a) The use of statistical analysis of the various types of synoptic situations in computing the average speed of frontal movement may give rise to values which depart considerably from actual observations.

(b) Because of the small size of samples studied, the coefficients determined for the various empirical equations for the prediction of wind speed may not be very accurate. Difficulties may also be experienced in the construction of the scatter diagrams. Further improvement in this direction is needed.

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