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TECHNICAL REPORT 105-79

NON-FRONTAL AND OTHER TYPES OF THUNDERSTORMS IN THE LEE OF THE ROCKY MOUNTAINS

DECEMBER 1945

HEADQUARTERS
AIR WEATHER SERVICE
WASHINGTON, D.C.

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August 1951

Air Weather Service Technical Report No. 105-79, "Non-frontal and Other Tpyes of Thunderstorms in the Lee of the Rocky Mountains," is published for the information and guidance of all concerned.

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U.S. AIR FORCES, AIR WEATHER SERVICES, WASH., D.C.
(AIR WEATHER SERVICE TECHNICAL REPORT NO. 105-79)

NON-FRONTAL AND OTHER TYPES OF THUNDERSTORMS IN THE LEE OF THE ROCKY MOUNTAINS

DEC'45 35PP GRAPHS, CHARTS

THUNDERSTORMS - CHARACTERISTICS

METEOROLOGY (30)
ATMOSPHERIC STRUCTURE (2)

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P R E F A C E

This study presents an analysis of the various types of thunderstorms found in the Great Plains states which the forecaster will find very useful in practical operations. The study was initially prepared in December 1945 by Captain John B. Young, AC, while assigned to the 23rd Weather Squadron, and has not previously received wide distribution.

Recent research on squall lines indicates that the discussion of non-frontal thunderstorms in this paper presents an important original contribution to the theory of squall-line formation.

Hq, AWS
August 1951

NON-FRONTAL AND OTHER TYPES OF THUNDERSTORMS AS THEY OCCUR IN THE LEE OF THE ROCKY MOUNTAINS

I. PURPOSE

The purpose of this study is to acquaint forecasters with the basic types of thunderstorms which occur in the states to the east of the Rocky Mountains, namely Kansas, Nebraska, Colorado, New Mexico, and the Panhandle regions, and as a result increase the forecasting accuracy associated with these storms.

II. GENERAL

Thunderstorms in this region occur mainly during the summer season beginning in April and continuing through October, with a few during March and November. Those of maximum intensity will be found in the hotter months, July and August. On the average, the majority of these thunderstorms are non-frontal and therefore a great deal of this paper will be devoted to a discussion of the non-frontal type. This type of thunderstorm is unique in that it is often unannounced to the inexperienced forecaster. The other types of thunderstorms to be dealt with here are: 1) prefrontal, 2) those associated with intense low pressures, and 3) convergence. These three kinds of storms are of no less importance, but are less frequent and follow a more widely recognized pattern of development. An attempt has been made in this paper to correlate the latest techniques, including the analysis of the 3 kilometer theta E chart, the standard altitude pressure charts, the upper air soundings, advective pressure and temperature changes from winds aloft, and the surface synoptic charts with the forecasting of thunderstorms.

III. NON-FRONTAL

A. The non-frontal thunderstorm is one which occurs without benefit of frontal activity. It often happens that the conditions which are responsible for these thunderstorms remain static over a period of several days and cause the recurrence of the storms until the pressure pattern has changed sufficiently both at the surface and aloft to alter the situation so that the thunderstorms cease. The following are the conditions which have been found to be conducive to the occurrence of non-frontal thunderstorms.

1. The surface pressure pattern shows a relatively high index over the United States with one high pressure cell centered over the eastern portion of the U.S. associated with but not necessarily connected with the Azores Bermuda high pressure, and another over the western portion ofthe U.S. associated with the Pacific high pressure cell. Just to the east of the Continental Divide will be found a low pressure trough between these two cells, which exists due to the action of the coriolis force upon westerlies producing cyclonic curvature of the streamlines as the air flows down the eastern slopes of the Rocky Mountains. The pressure values found in this trough may

vary diurnally as a result of the daytime insolation effect which is associated with convective activity and valley breezes. Therefore the lowest pressures most often will be found on the 1930 C T synoptic chart. On this chart there will sometimes be found over western Kansas or eastern Colorado an intense low pressure which is the result of a combination of the coriolis effect, daytime insolation, and convergence within a column of air as it moves northward across latitude lines. This low pressure will tend to disappear on succeeding synoptic charts when daytime insolation is lacking. The predominant circulation over the area under consideration is southerly and generally quite strong, associated with a steep pressure gradient directed to the west. The surface temperature is always average or above for the period under consideration and the relative humidity at the surface is greater than 75%: these facts result in the stifling heat that prompts laymen to expect the development of thunderstorms. The high moisture content of the air is the result of a long trajectory of this air over the Gulf of Mexico. Forecasters often place fronts erroneously in this low pressure trough and become confused when the fronts fail to move but remain stationary from day to day. This accounts for forecasts of frontal passages in connection with thunderstorms, when actually there will be little change in the synoptic chart on the following morning. Sometimes, however, upper frontal systems migrate from the Pacific and become active at the surface in this area, in which case the placement of the front on the synoptic chart is justified and the thunderstorms which occur are associated with the front. To establish a correct analysis requires careful consideration of the movements of frontal systems aloft, over the Rockies. As an example of surface conditions associated with non-frontal thunderstorms, the 0130 CWT synoptic chart of 17 July 1944 has been chosen, as illustrated in Fig. I. This chart varies from the mean in that there is a weak low pressure trough over the eastern portion of the U.S. with a weak high pressure centered over the Great Lakes region. It is typical as regards the rest of the pertinent pressure pattern. At the time of observation it should be noted that there are several thunderstorms reported over Kansas, Nebraska, and the Panhandle region, and no frontal systems are associated with them.

2. The upper air soundings in connection with non-frontal thunderstorms indicate a stable structure of the atmosphere from the surface up to 3 to 4 kilometers, a slight inversion of 200 to 500 meters and above that a conditionally unstable lapse rate. Such a sounding will be found in Fig. 2 which is the 2330C sounding at Dodge City for 17 July 1944. The limited number of RAOBs taken at this station makes necessary an intermediate comparison with other stations. Therefore the dashed curve which is a portion of the Oklahoma City sounding is presented. The OL sounding clearly shows the typical high level inversion which would have been over Dodge City at 1130C on 18 July 1944. It should be pointed out that normal daytime heating will not alter this lapse rate enough to cause a thunderstorm to occur. Also, a hodograph analysis of the Dodge City pibal at 0015CWT, Fig. 3, shows no shear from the surface

to 6000 ft and cold air advection from 6000 ft to 16000 ft. A minor deviation from the accepted theory of hodograph analysis here becomes evident. Analysis of temperature fields from the surface up to 20000 ft shows that a southerly or southwesterly current of air will raise the temperature at a given point within this air flow in a specified period. On the other hand, a flow of air from the west or northwest at any of these levels will lower the temperature of that point over a specified period. Figs. 2A, 2B and 2C are presented in an effort to prove that a hodograph analysis such as in Fig. 3 near the Rocky Mountains will not verify with respect to advective temperature changes. In the case under consideration, absolute instability will be reached in a short period while the hodograph analysis will predict increased instability at levels up to 16000 ft. Fig. 4 shows a hodograph of the Dodge City pibal taken six hours later than Fig. 3. It can be seen that there has been no great change in the winds during this period although thunderstorms have formed and passed through the area. The moisture distribution aloft, Fig. 2D, shows a maximum in the lower levels and directly above the inversion with dry air through the rest of the sounding. The moisture in the lower levels will be carried upward by convective activity and the moisture already present above the inversion will form the clouds which precede the thunderstorm as the air at that level is cooled.

3. The Theta E Chart for 3 kilometers, Fig. 2E, has proved very helpful in forecasting this type of thunderstorm. Usually there will be a ridge of high Theta E values located over New

Mexico on the midnight sounding which will tend to be moved eastward to the Central Plains region by the flow pattern at 3 km. A positive check must be made to determine the movement of this ridge. Critical values have been established by months during the thunderstorm season by correlating the occurrence of thunderstorms at Dodge City with the actual value of Theta E closest to the time of the thunderstorm occurrence. These critical values are as follows:

March, 316°
April, 316°
May, 318°
June, 326°
July, 332°
August, 334°
Sept., 327°

4. By using conventional analysis methods, the forecaster examining the situation on 17 July 1944 would find nothing to indicate to him the probability of thunderstorms, and in his forecast he will not predict the occurrence of thunderstorms. However, they will happen and he will usually be unable to reconstruct a plausible explanation. The deciding factor is, therefore, the actual density of air being advected above and below the inversion located above 3 kilometers. In the case under consideration, much colder air is being transported over the Great Plains region above the inversion while at the same time the air below this inversion is becoming increasingly warmer and more moist. Eventually, absolute instability near the inversion level must be realized and thunderstorms of the non-frontal type will develop.

5. The cloud sequence associated with non-frontal thunderstorms is pictured in Fig. 5 and shows an early morning prevalence of

altocumulus type clouds which develop into the castellatus type by midmorning, tend to dissipate near noon, become stratus type and then increase, becoming altocumulus near sundown, with the subsequent formation of cumulonimbus clouds with bases near 3 km. These cumulonimbus clouds build downward as well as upward in the atmosphere, lowering their bases to 4000 to 5000 ft as the thunderstorms increase in intensity. It is thought that a small convective cell develops in the vicinity of the inversion as the altocumulus type clouds appear and that this cell extends upward and downward as absolute instability is realized. The thunderstorm which develops realizes added energy from the latent heat of condensation of the moisture supplied to the low pressure on itssouthern and eastern edges.

B. As a general rule, the behavior of these thunderstorms is as follows:

1. They begin active precipitation and lightning near 2000 CST, joining into an active line squall or pseudo cold front which runs from northeast to southwest and moves with a speed of 25 to 30 miles per hour from west to east reaching an eastern boundary extending from Lincoln, Neb., to Clinton, Okla. Pilots' reports during the occurrence of this type of thunderstorm indicate that their height is well over 25000 ft with excessive turbulence in and around the clouds and icing in the clouds above the freezing level which generally lies at 14000 ft.

2. Precipitation is showery and intense for very short periods of time with frequent heavy hail.

3. The surface winds associated with these storms are most often quite strong with velocities ranging from 40 to 50 miles

per hour for one to two hours with occasional gusts as high as 90 mph. If no advance warning of high winds is issued, a considerable amount of damage will be done to property and aircraft, and even loss of life may result. However, there are cases on record which show a wind speed of 15 mph or less occurring with this type of thunderstorm. No explanation of this has yet been found.

4. The temperature at the surface will be found to rise to its maximum as the thunderstorm approaches the station and immediately upon the passage of the pseudo cold front and the beginning of precipitation, the temperature will drop as much as 20° in an hour and then begin to rise slowly to the average nocturnal minimum.

5. Tornadoes quite often occur in connection with non-frontal type thunderstorms and seem to move from southwest to northeast, causing a considerable amount of damage in their wake regardless of precautions taken. Tornadoes are most likely to occur with extremely high values of the equivalent potential temperature at 3 km., that is, greater than 335°.

C. As an aid to forecasting these storms, the following situations should be carefully watched for:

1. Altocumulus castellatus clouds over the station near sunrise.

2. A relatively high index situation on the surface synoptic chart.

3. A strong pressure gradient over the midwest.

4. Winds southerly at the surface and southerly through 3 km., veering to westerly and on to northwesterly above that level.

5. An inversion in the lapse rate at 3 to 4 km., with an adiabatic lapse rate above and a convectively stable one in the lower levels.

6. Concentration of moisture in the lower levels and directly above the inversion.

7. Theta E values at 10,000 ft equal to or greater than those listed above which are critical values for each month during the thunderstorm season.

8. DECIDING FACTOR: Marked advection of colder air above and warmer air below the high level inversion.

IV. PRE-FRONTAL

A. The pre-frontal thunderstorm is one which occurs from 50 to 100 miles in advance of a surface cold front moving eastward over the Great Plains states. The cold front is one which has migrated from the Pacific in the form of an occlusion, becoming active at the surface as a cold front east of the Continental Divide. An average of two of this type of front will pass over the Great Plains states per week during the thunderstorm season. For the most part these thunderstorms are similar to non-frontal in that conducive conditions for non-frontal type apply to a large extent to the pre-frontal type. The following are conditions which have been found to be associated with the occurrence of pre-frontal thunderstorms.

1. The surface synoptic indicates a low pressure which may be either of the North Pacific or Colorado type, having a cold front extending to the south and curving slightly to the west, located to the east of the Continental Divide. To the east

will be found a high pressure cell of 1023 mm or greater, with its center in the vicinity of Cape Hatteras. To the west will be a moderate to strong Pacific high pressure moving eastward behind the cold front. As a rule, tl low pressure becomes very intense (993 to 999 mb) as it moves down the Continental Divide. This fall in pressure is associated with: 1) coriolis effect upon westerlies producing cyclonic circulation, 2) lighter and more moist air being drawn into the eastern portion of the low from over the great plains, which has the effect of intensifying convective activity, 3) convergence within a column of air as it moves northward across latitude lines is experienced in the strong southerly flow over the Great Plains toward the center of the low.

2. The surface temperature contrast through the cold front is on the average 20°F. The relative humidity east of the front will be well above 75% while on the western side it will be low (except in precipitation areas) averaging 30%. An example of pre-frontal thunderstorm conditions is shown in Fig. 6, which is the synoptic chart of 0130 C T, 15 July 1944. This situation indicates a low pressure centered in the vicinity of the Hudson Bay and a very strong Pacific high pressure moving eastward behind the front with a tight pressure gradient. Stations reporting showers or thunderstorms are indicated by the appropriate symbols.

3. The upper air soundings taken closest to the time of the occurrence of pre-frontal thunderstorms are very similar to those associated with the non-frontal type and indicate a stable structure of the atmosphere from the surface up to 3

to 4 km., a slight inversion through 200 to 500 meters, and above that a conditionally unstable lapse rate. The average moisture value in the lower levels is 12 grams which is characteristic of maritime tropical air lying east of the cold front. The moisture content decreases rapidly near the inversion. The upper air sounding for Dodge City in Fig. 8, as associated with the synoptic situation in Fig. 6, indicates a moisture value of 12.3 grams at the surface falling off to 2.9 grams at 550 mb and .06 at 400 mb. Again it is necessary to incorporate a portion of the OL sounding twelve hours later to indicate the marked inversion aloft which would have been expected over Dodge City simultaneously. It is important to note that the critical temperature of this sounding would be very near 40°C, which is extremely high and undoubtedly would not be conducive to the development of a thunderstorm, barring of course marked warm air advection below 550 mb and marked cold air advection above that level. Therefore the lift realized from the slope of a cold front would be sufficient to cause convection up to the 650 mb level which should form a thunderstorm along the cold front at the surface. However, the strong westerly and northerly winds at the 8000 ft level and above, blowing down-slope over the frontal surface, as indicated by the hodograph in Fig. 7, will neutralize the lifting effect and the typical non-frontal thunderstorm will develop 50 to 100 miles in advance of the front at the surface. Therefore, the conditions aloft conducive to the formation of non-frontal thunderstorms as outlined above must necessarily apply to this type. The value of Theta E at 3 km over Dodge City at the time of the chart in

Fig. 6 was 320°A and 12 hours later had risen to 334°A, associated with a tongue of high values of Theta E moving eastward with the surface cold front. Fig. 7 shows the hodograph analysis of the pibal over Dodge City for 2330 CWT on 15 July 1944. In this case too, it becomes necessary to deviate from the accepted method of hodograph analysis, since a conventional analysis would give warm air advection up through 20000 ft. However, the temperature field is similar in structure to that in Figs. 2A, 2B and 2C so that the stable picture present in Fig. 8 would eventually become unstable as long as the wind flow above and below the inversion remains fairly constant.

B. The cloud sequence associated with pre-frontal thunderstorms is pictured in Fig. 9, which is idealized from a general knowledge of actual observations. This picture illustrates behavior of pressure, temperature and winds on a time cross section basis and is self-explanatory. The pre-frontal thunderstorms are generally touched off by late afternoon and begin to move rapidly eastward as a squall line or pseudo cold front extending eastward as far as a line running from Tulsa, Okla., to Omaha, Neb. The velocity of movement of the squall line varies from 20 to 30 miles an hour.

C. As an aid to forecasting these storms the checklist outlined under non-frontal thunderstorms applies here with the added condition of a dry cold front at the surface east of the Continental Divide.

V. CONVERGENCE

A. This type of thunderstorm is considered air mass and its main difference lies in itsscattered occurrence instead of being linked up in a line squall. The synoptic situation is pictured in Fig. 10, which shows a weak high pressure centered over southern Manitoba extending southward to 38°N, a weak low pressure trough running from over Quebec southwestward to Missouri, on to the Panhandle region, joining with a thermal low over the southwestern states, and a weak high pressure over the southeastern portion of the U.S. The stationary front carried on this chart is in itself inactive and separates polar from tropical air. The arrows on the chart indicate air flow with the exception of the one over western Kansas pointed eastward which represents the effect of the Rocky Mountain range over Colorado. The air converging on Kansas and the Panhandle region gives rise to the following features: 1) upslope motion in the easterly current, 2) upslope plus dynamic convergence in the southerly flow, 3) isentropic lifting of the tropical air over the shallow dome of continental air.

B. As an example of the above circulation pattern, a column of air moving from the vicinity of Omaha westward to western Kansas will experience in the neighborhood of 2000 ft of lift in the lower levels. The RAOB for Dodge City which accompanied this situation was convectively unstable with a critical temperature of 31.5°. The sounding for Omaha at the same time was also convectively unstable. Therefore, with an easterly circulation, the lower p ortion of the Omaha sounding would be lifted orographically and the resulting lapse rate over western

Kansas and the Panhandle region would be more unstable than originally.

This type of thunderstorm is generally considered to be a high level type and causes very little damage upon occurrence. The movement of the weak high pressure cell to the north must be forecast properly to obtain an indication of the number of days on which the storm will successively recur. The pibal accompanying this situation is analyzed in Fig. 11, where gentle warm air advection is shown up through 14000 ft. Here we find a slight resemblance to non-frontal type thunderstorm situations with actual cold air advection evident above 14000 ft. Due to the usual heavy cloud coverage over the area in question associated with this type of synoptic situation, no evidence of easterly winds can be presented. However, the pressure pattern at 5000 ft does indicate easterly circulation over Kansas. Isentropic uplift is indicated on the pibal in Fig. 11 by southerly flow aloft over the shallow dome of continental polar air which is centered over southern Canada.

VI. INTENSE LOW PRESSURE

A. Thunderstorms very often occur associated with a deep Colorado type low pressure as it moves across the Continental Divide and intensifies over the Plains states. This type of low pressure will most generally be found conducive to thunderstorm activity in April and May and later during September. As a rule there will be a cold front running southward from the center of the low as indicated in Fig. 12, and a warm front running eastward with the system occluding as it moves to the east. A very steep pressure gradient around the center of the low gives rise to excessive wind speeds at the surface and aloft. The high pressures over the west and east coasts of the U.S. will be found above normal in value and the Pacific high pressure pushes eastward behind the Colorado low. The important features aloft and at the surface are as follows: 1) marked convergence to very high levels, 2) lifting associated with frontal surfaces, 3) active upslope conditions in the northern sector of the low pressure in the lower levels, 4) moisture is injected into the southeastern portion of this low pressure by southerly winds covering a long trajectory over the Gulf of Mexico.

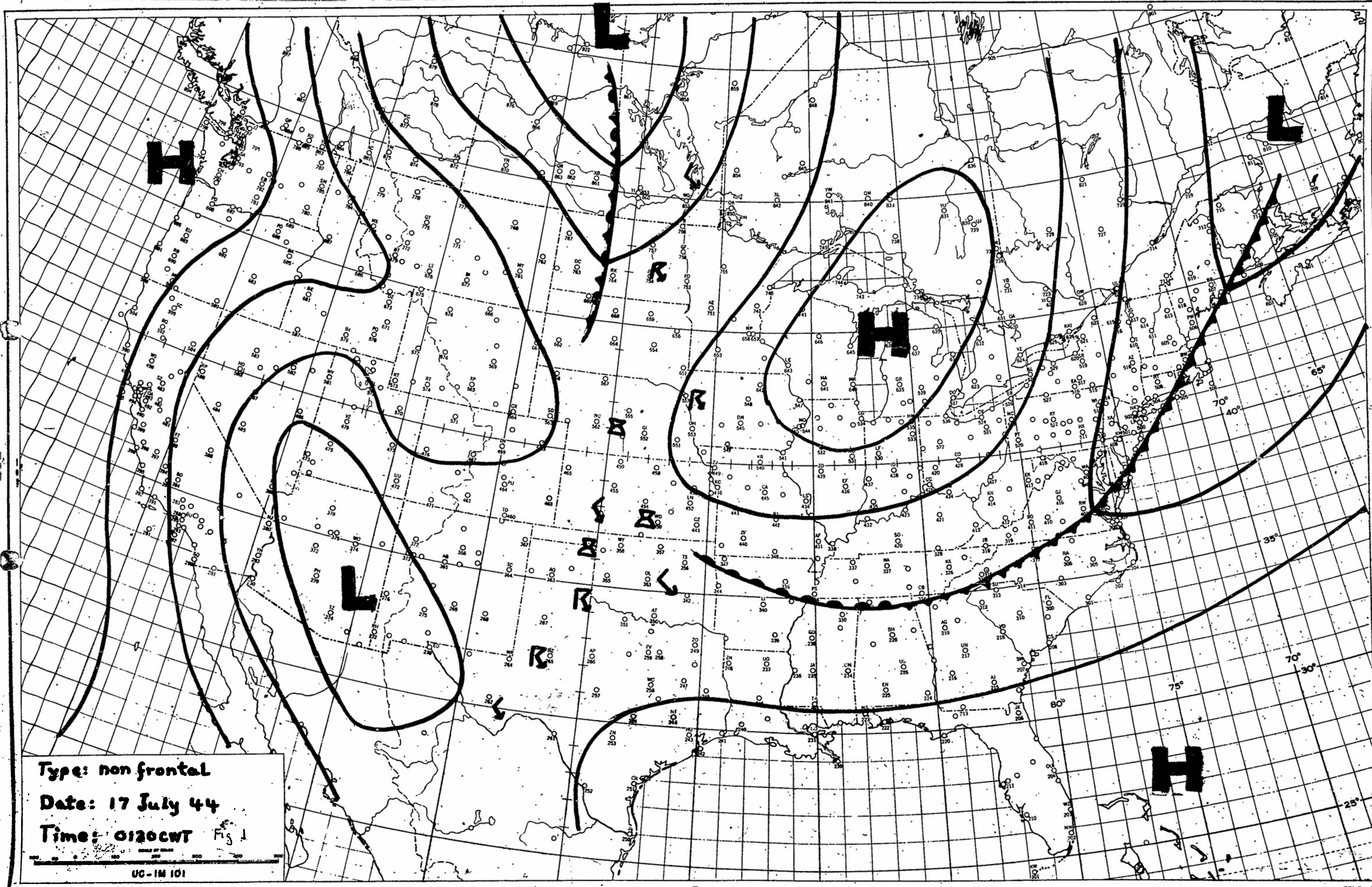
The upper air pressure charts associated with the above synoptic situation are characterized by closed low pressure centers in juxtaposition from surface to 20,000 ft. Due to this arrangement there is no marked shear zone aloft and a hodograph analysis will give little indication of advection. Fig. 13 represents this situation and shows warm air advection through the entire run.

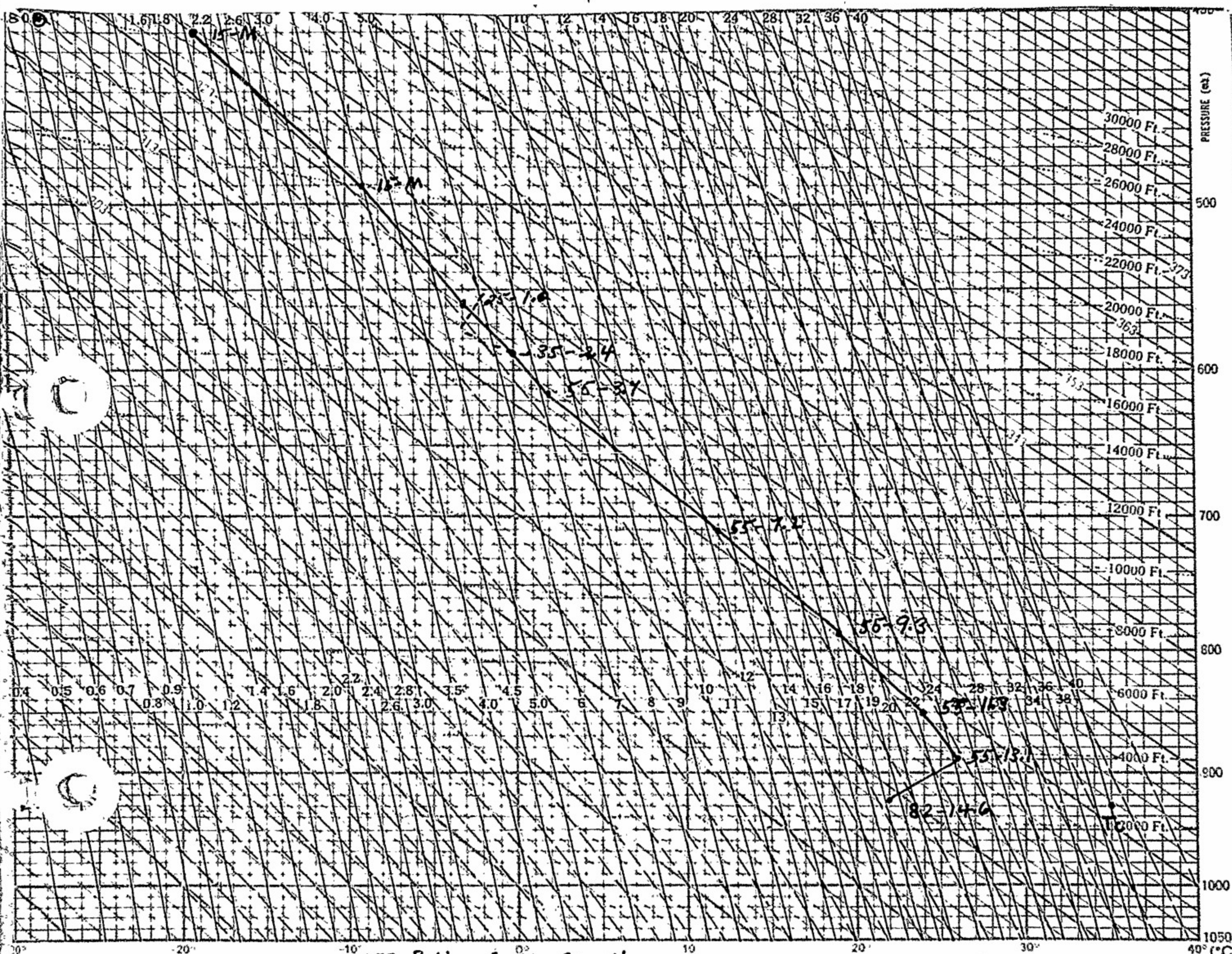
B. Forecasting this type of thunderstorm is considered comparatively simple once the movement of the surface system is decided upon. However, there must be an indication of high moisture valuesaloft which will be sh wn on the 3 km. Theta E chart as values of four grams of greater. A point of interest here is that the 10,000 ft circulation will tend to draw moisture from over Texas and Oklahoma around the northern side of the low pressure, and forecasters must take into consideration this flow of moisture which, if cut off, will lessen the chances of thunderstorm occurrence. Theta E values at 3 km will not be abnormally high but a definite tongue of high values will be associated with the low pressure at 10,000 ft.

Damage caused by thunderstorms of this type will be mainly due to hailstones and not winds since the winds maintain high velocities for periods of from twelve to eighteen hours and are not extremely gusty.

VII. CONCLUSION.

Forecasters should now have a basic knowledge of the thunderstorms which they will encounter over the Great Plains states and after having decided upon pertinent synoptic situations they will be able to follow the check list as outlined insofar as possible, arriving at definite conclusions concerning time of occurrence, extent and intensity of all types of thunderstorms.


Type: non frontal
Date: 17 July 44
Time: 0120CWT
Fig 1
UC-IM 101
H
L
H
L
L
H
65°
70°
40°
35°
70°
30°
75°
80°
25°



--- Portion of OL Sounding

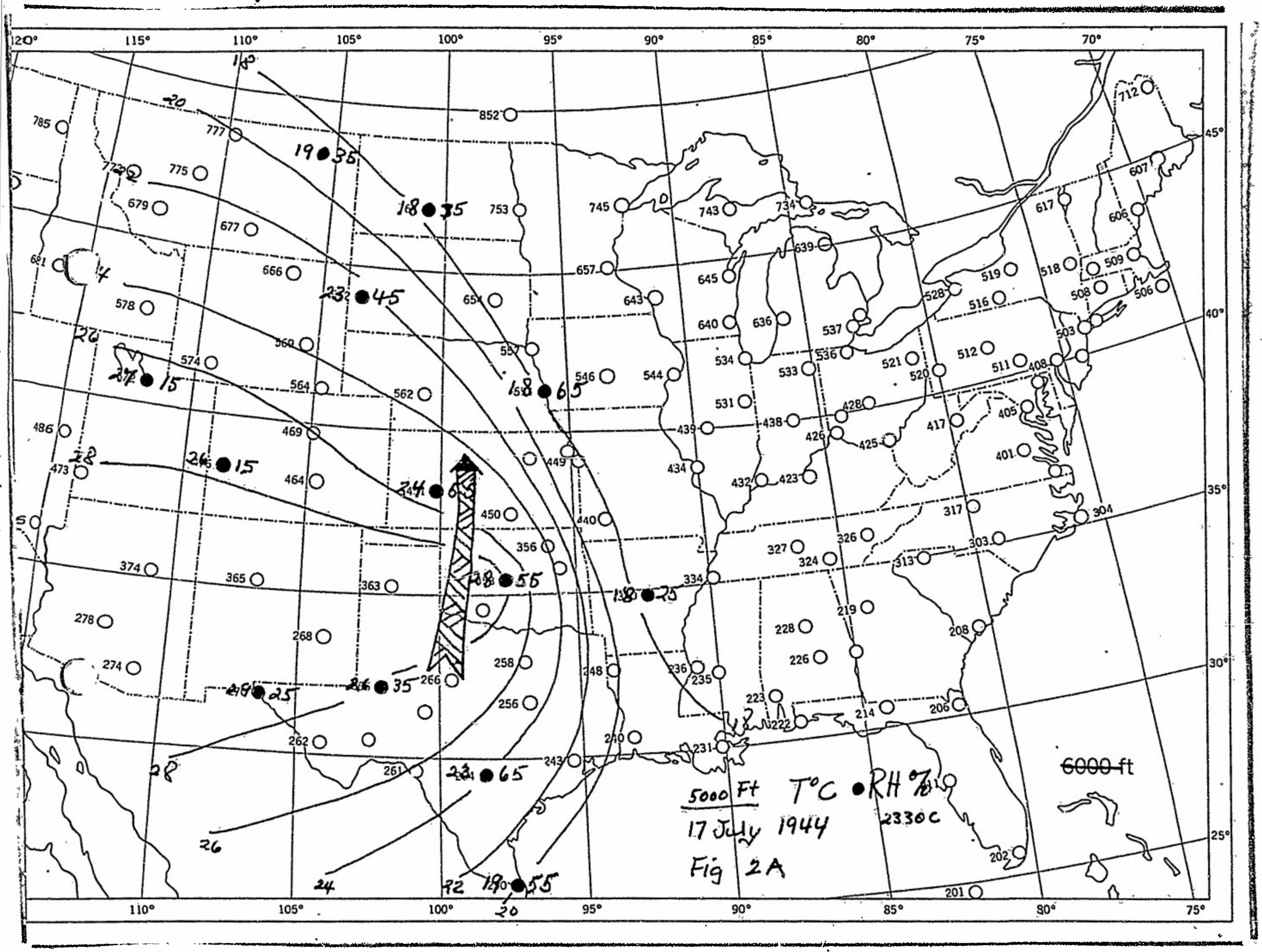
Fig 2

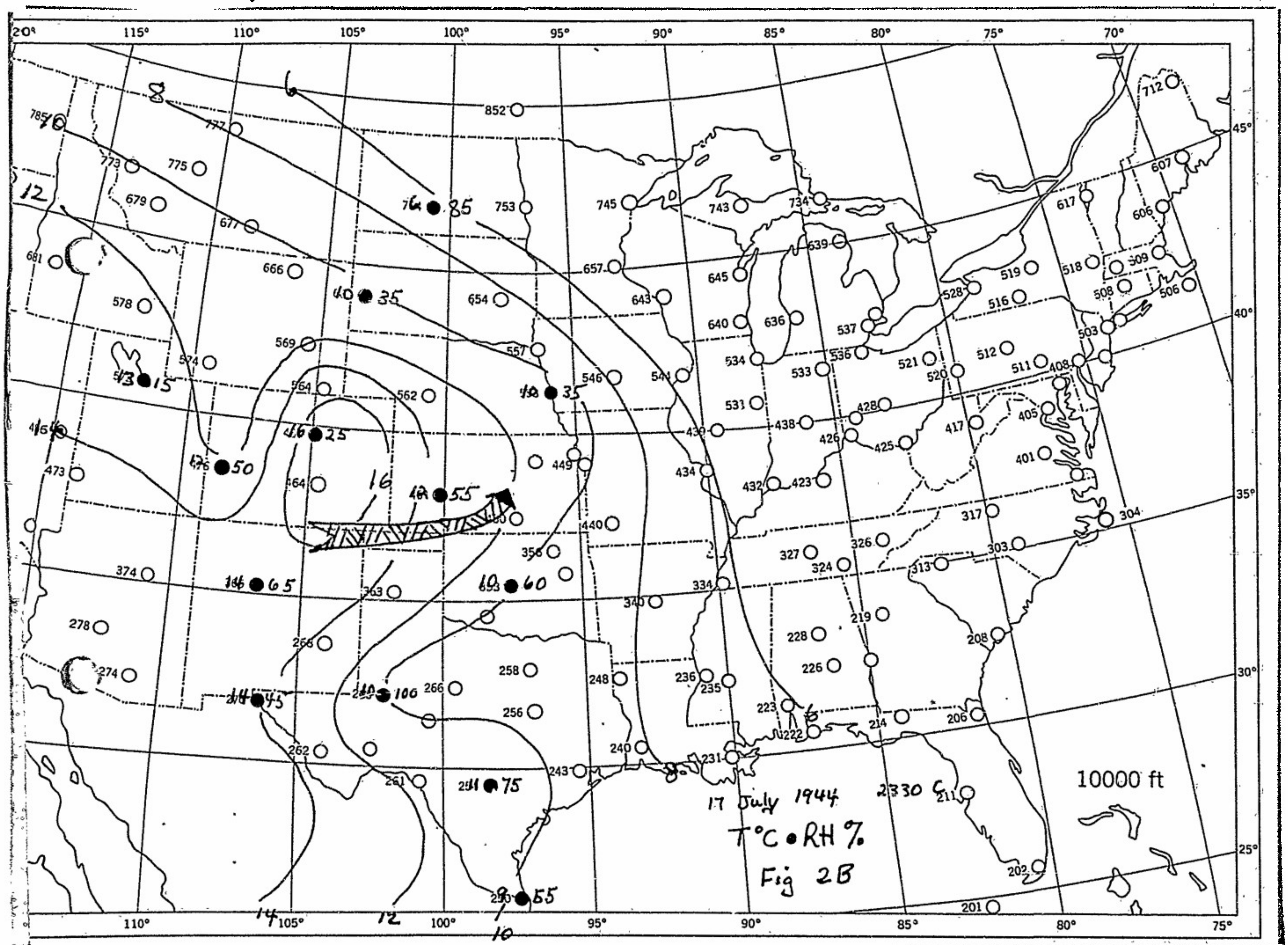
DATE 17 July 1944

STATION O.D.

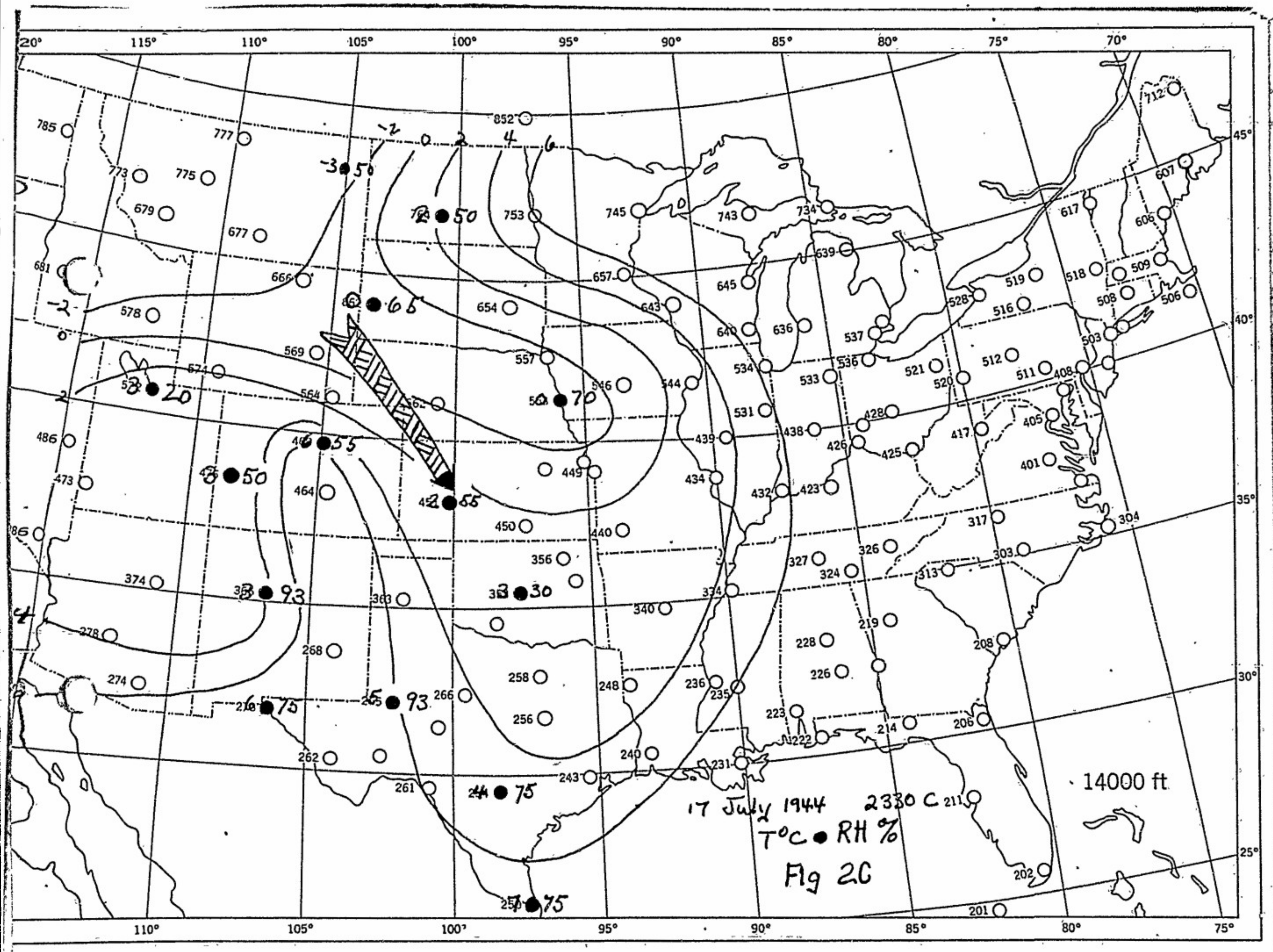
HOUR 2330 (90 TH MERIDIAN TIME)

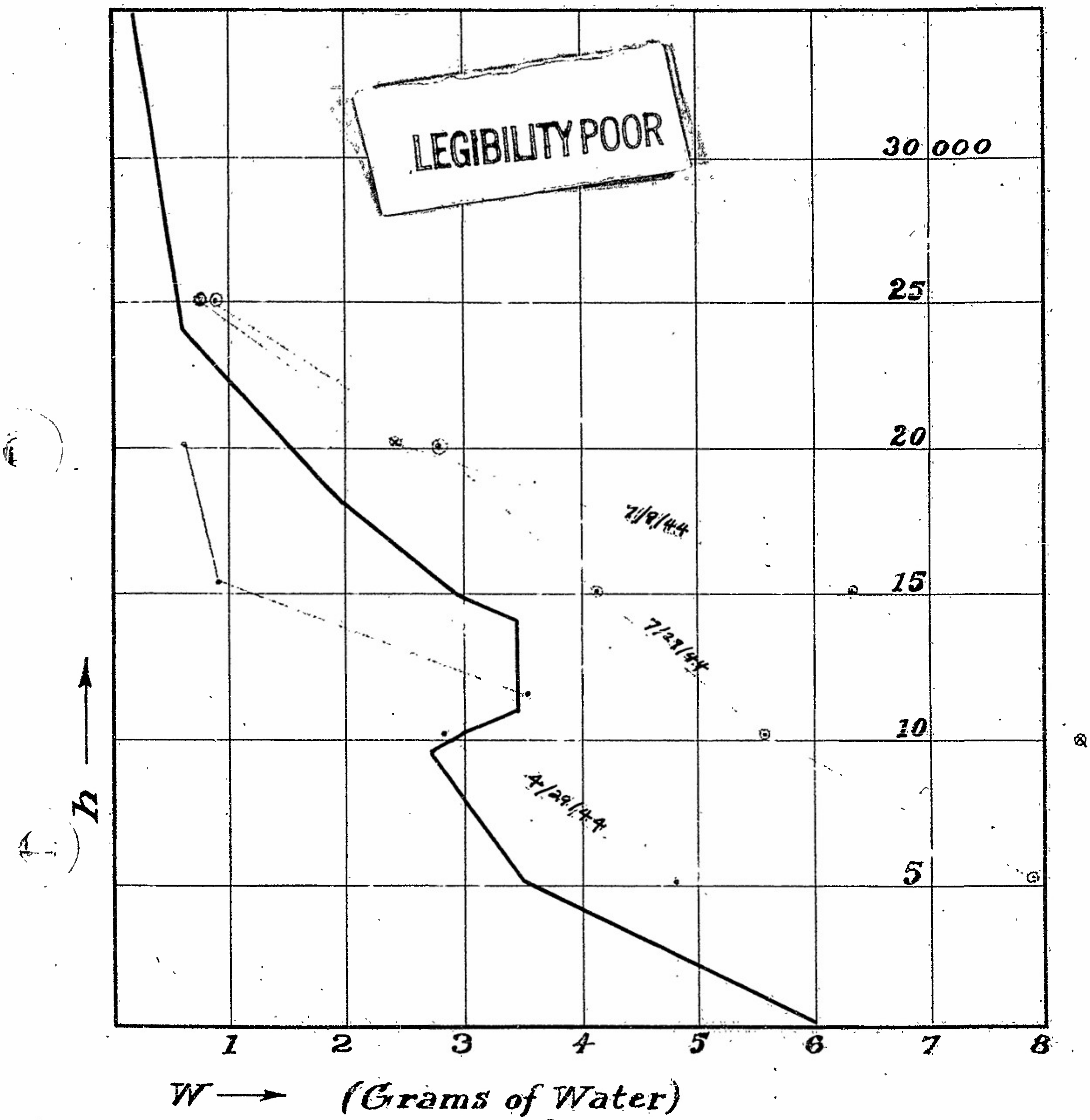
201054


6000 ft
5000 Ft
T°C ●RH %
2330C
17 July 1944
Fig 2A



115° 110° 105° 100° 95° 90° 85° 80° 75° 70°
45° 40° 35° 30° 25°
10000 ft
17 July 1944 2330 C
T°C • RH %
Fig 2B

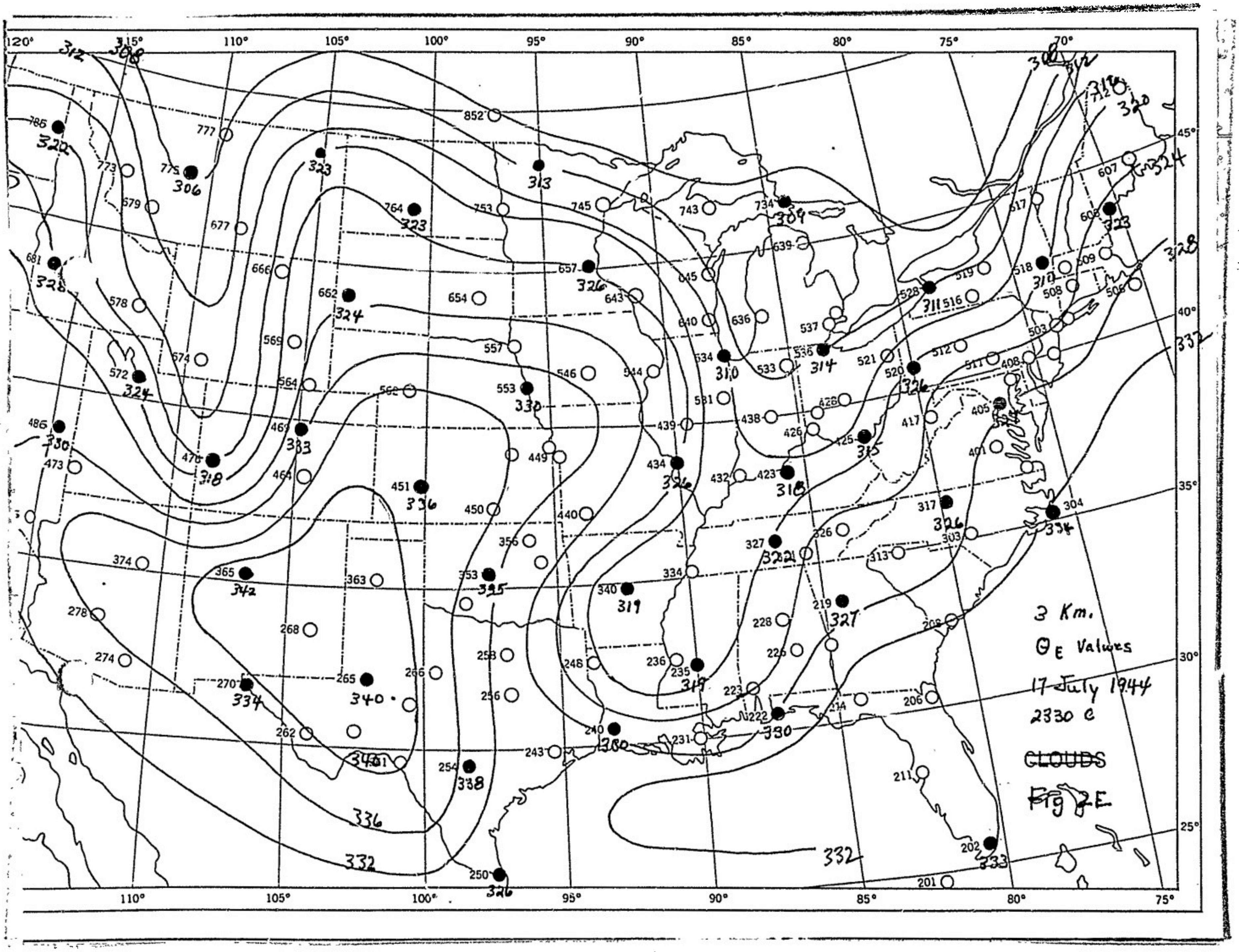

14000 ft
17 July 1944 2330 C
T°C ● RH %
Fig 2C

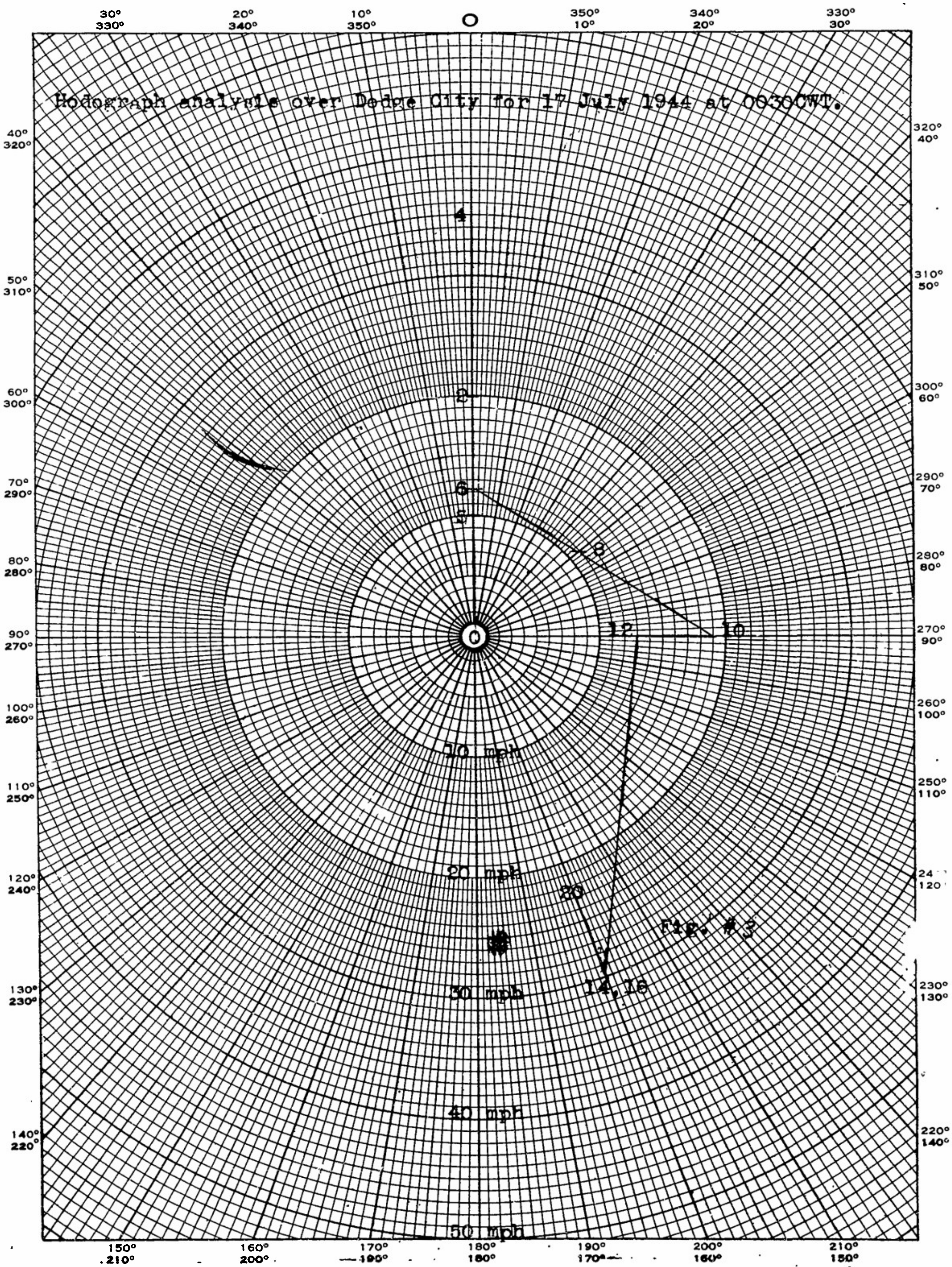


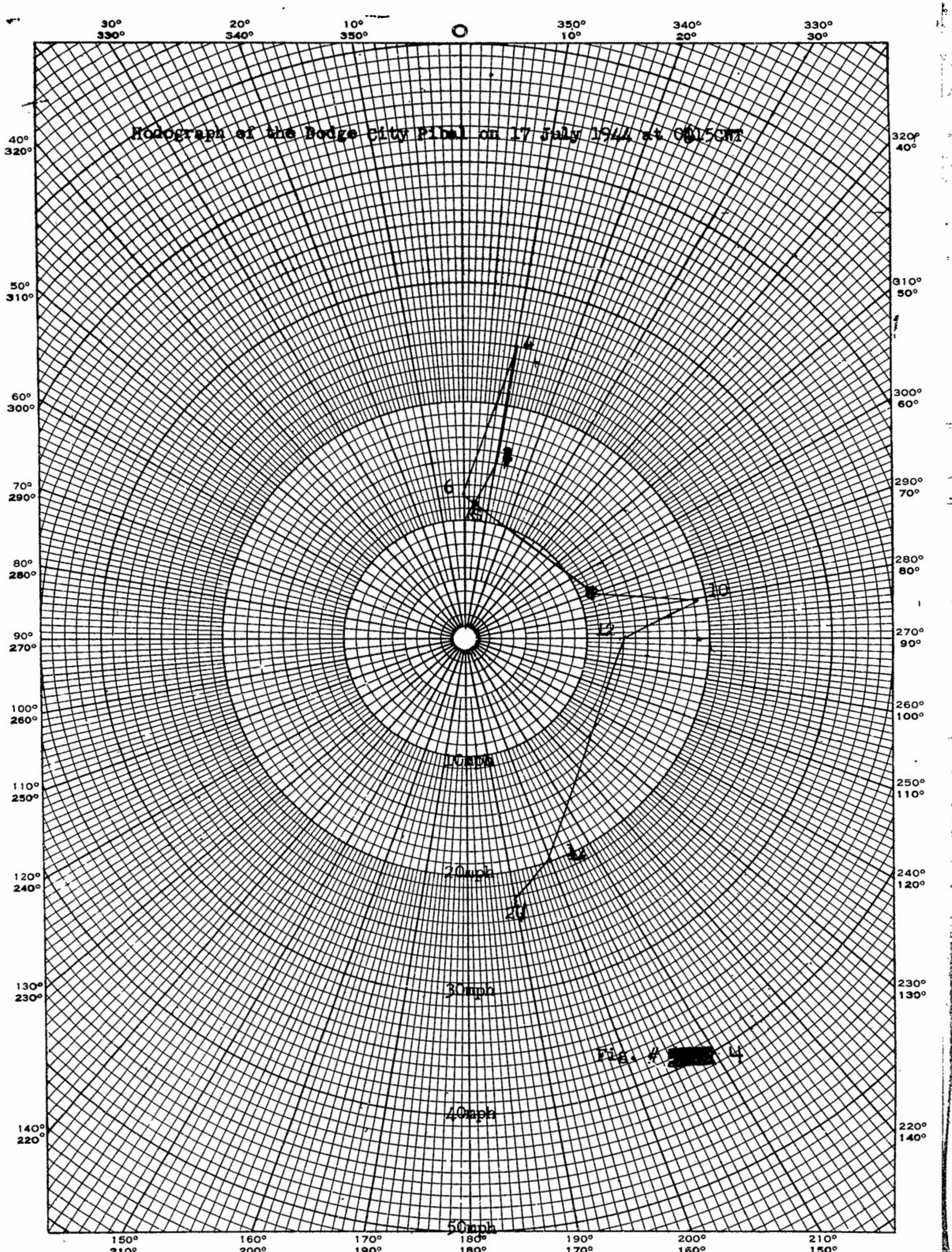
Ideal Moisture Distribution for Non-Frontal Type.

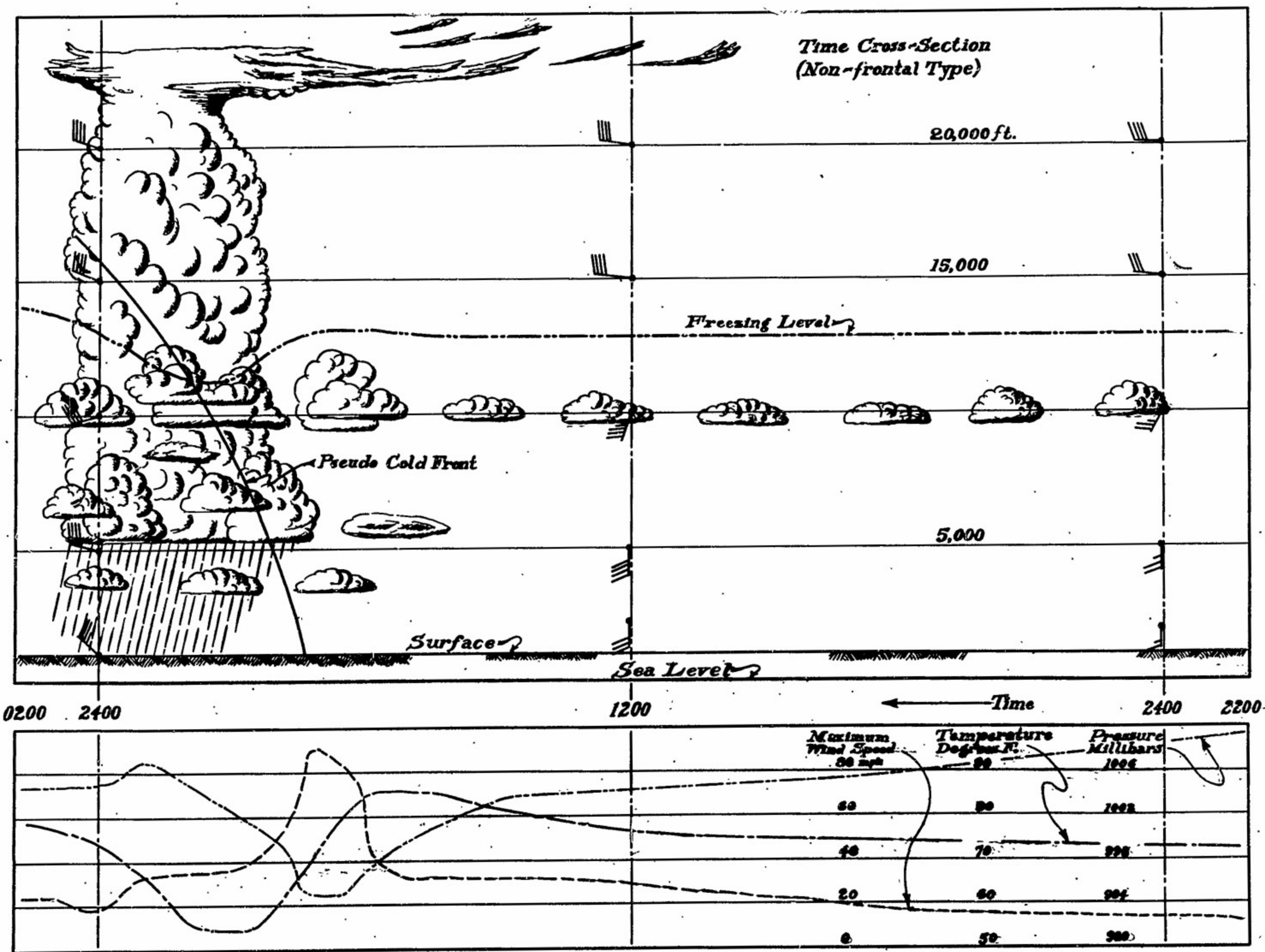
Figure 3 2D

actual values taken from soundings on dates indicated on the curve.. OD 2330 G


3 Km.
Θ_E Values
17 July 1944
2330 C
CLOUDS
Fig 2E

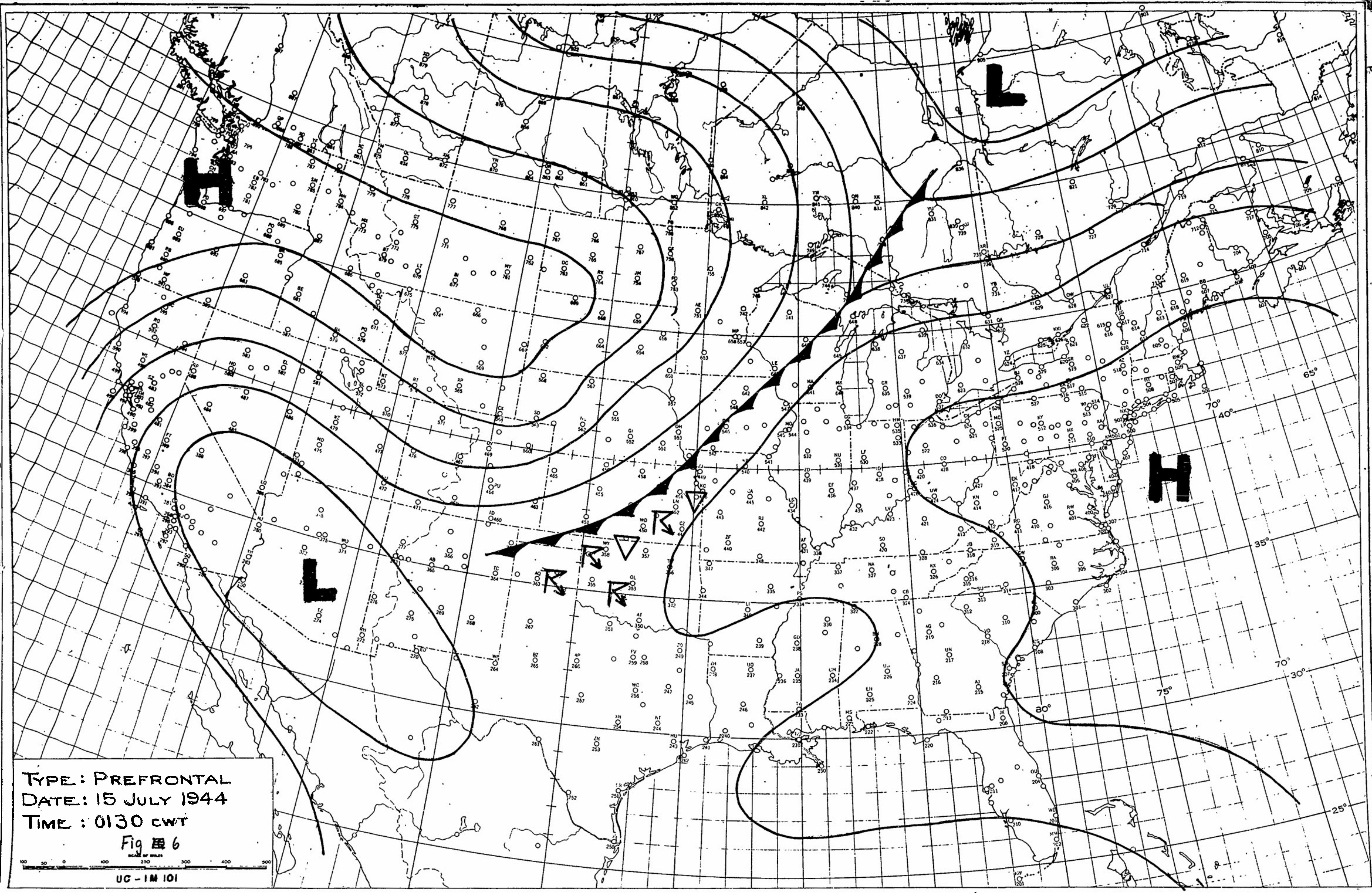

Hodograph analysis over Dodge City for 17 July 1944 at 0030CWT.
0
4
8
6
5
8
12
10
10 mph
20 mph
20
Fig. #3
14, 16
30 mph
40 mph
50 mph


Hodograph of the Dodge City Pibal on 17 July 1944 at 0015CWT
6
10
12
20
10mph
20mph
30mph
40mph
50mph
Fig. # [redacted] 4
NO. 340-P DIETZGEN CO.
POLAR CO- PAPER

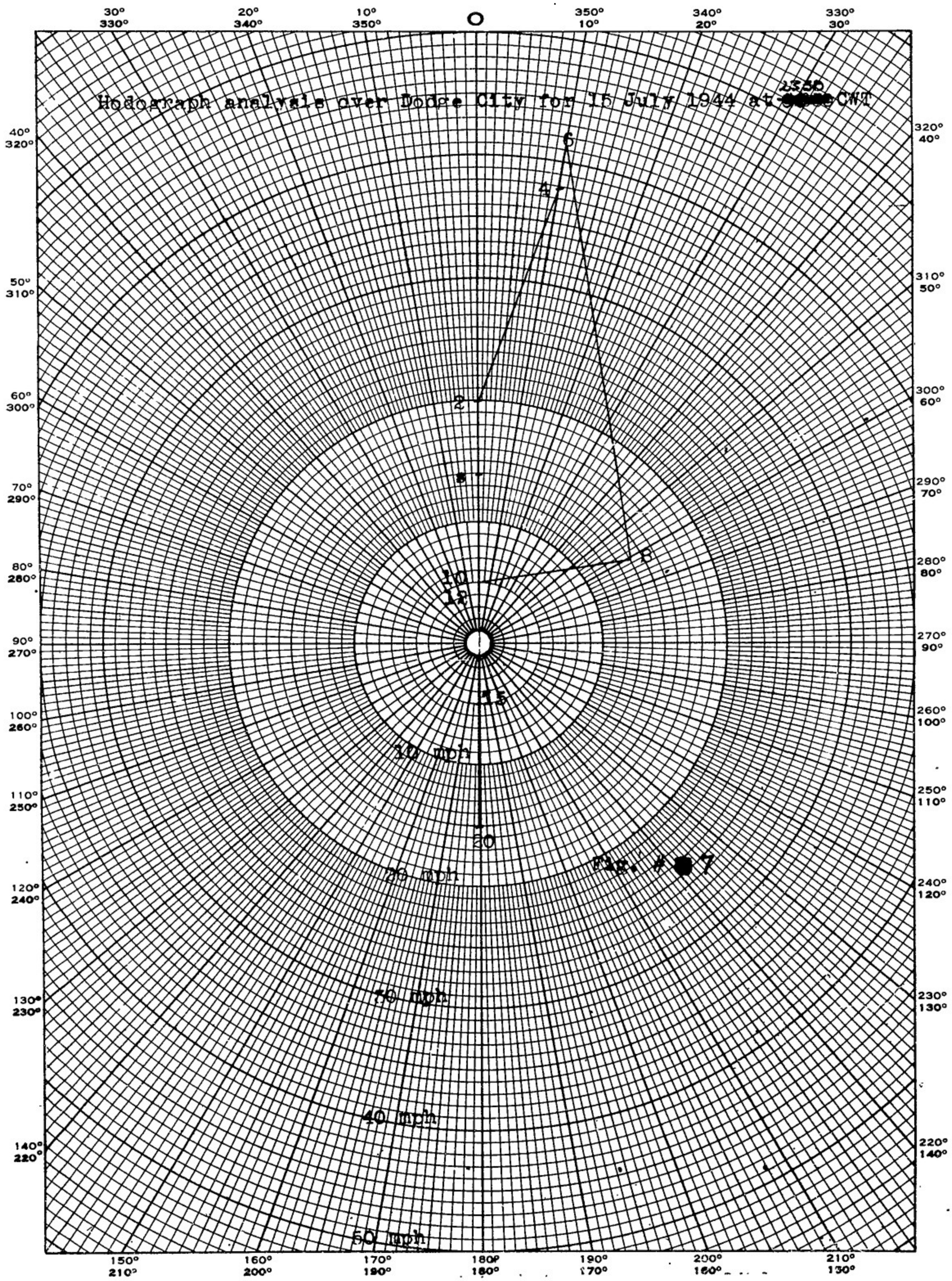


Time Cross-Section
(Non-frontal Type)
20,000 ft.
15,000
Freezing Level
Pseudo Cold Front
5,000
Surface
Sea Level
0200
2400
1200
2400
2200
Time
Maximum Wind Speed
80 mph
60
40
20
0
Temperature Degrees F.
90
80
70
60
50
Pressure Millibars
1006
1002
998
994
990

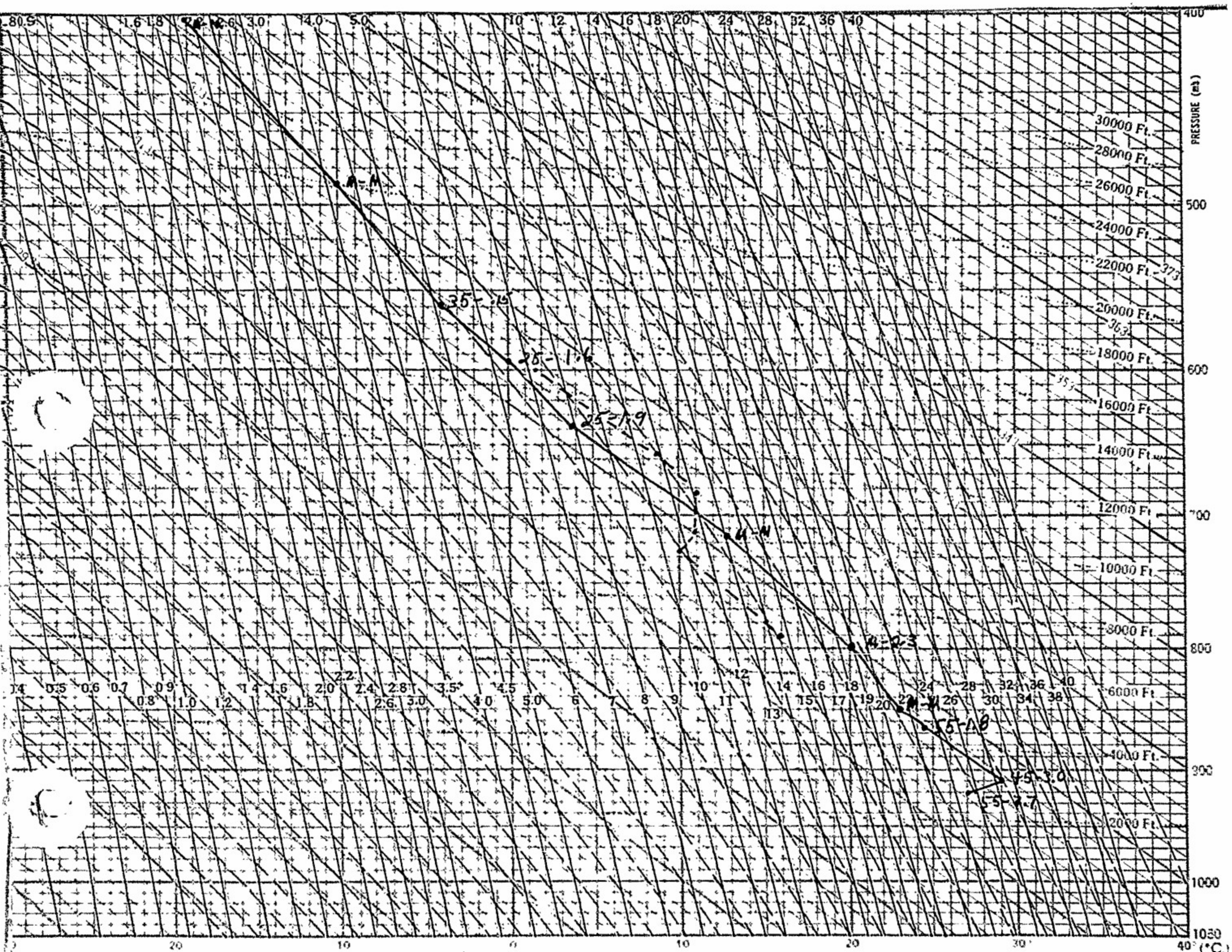
Figure 13 5



H
L
L
H
TYPE: PREFRONTAL
DATE: 15 JULY 1944
TIME: 0130 CWT
Fig 6
UC - IM 101



Hodograph analysis over Dodge City for 15 July 1944 at 2330 CWT
2
4
6
8
10
12
15
20
10 mph
20 mph
30 mph
40 mph
50 mph
Fig. # 7



--- Portion of OL Sounding 24 hours Later

Fig 8

DATE 15 July 1944

STATION O.D.

HOUR 2330 (90 TH MERIDIAN TIME)

201054

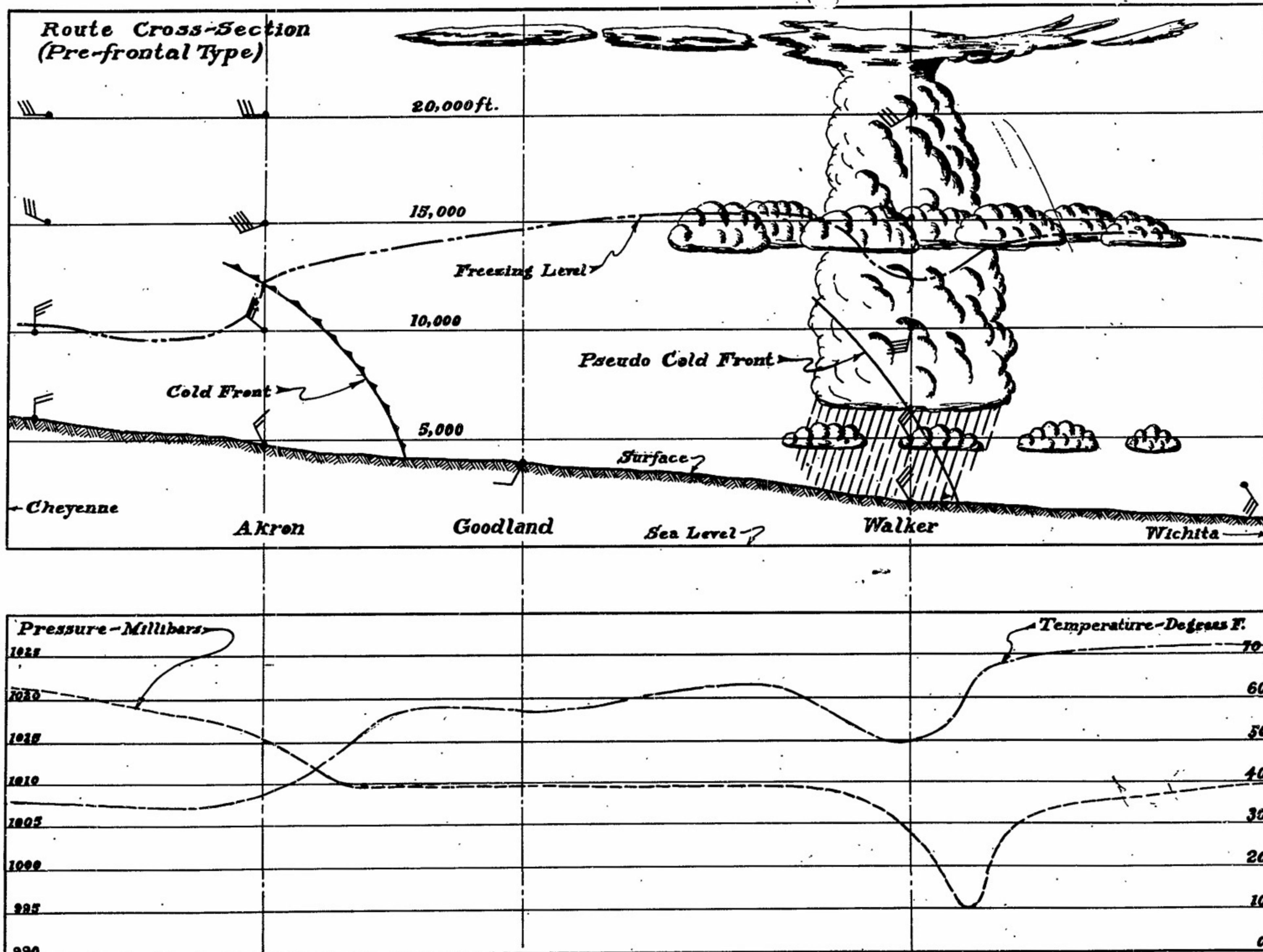
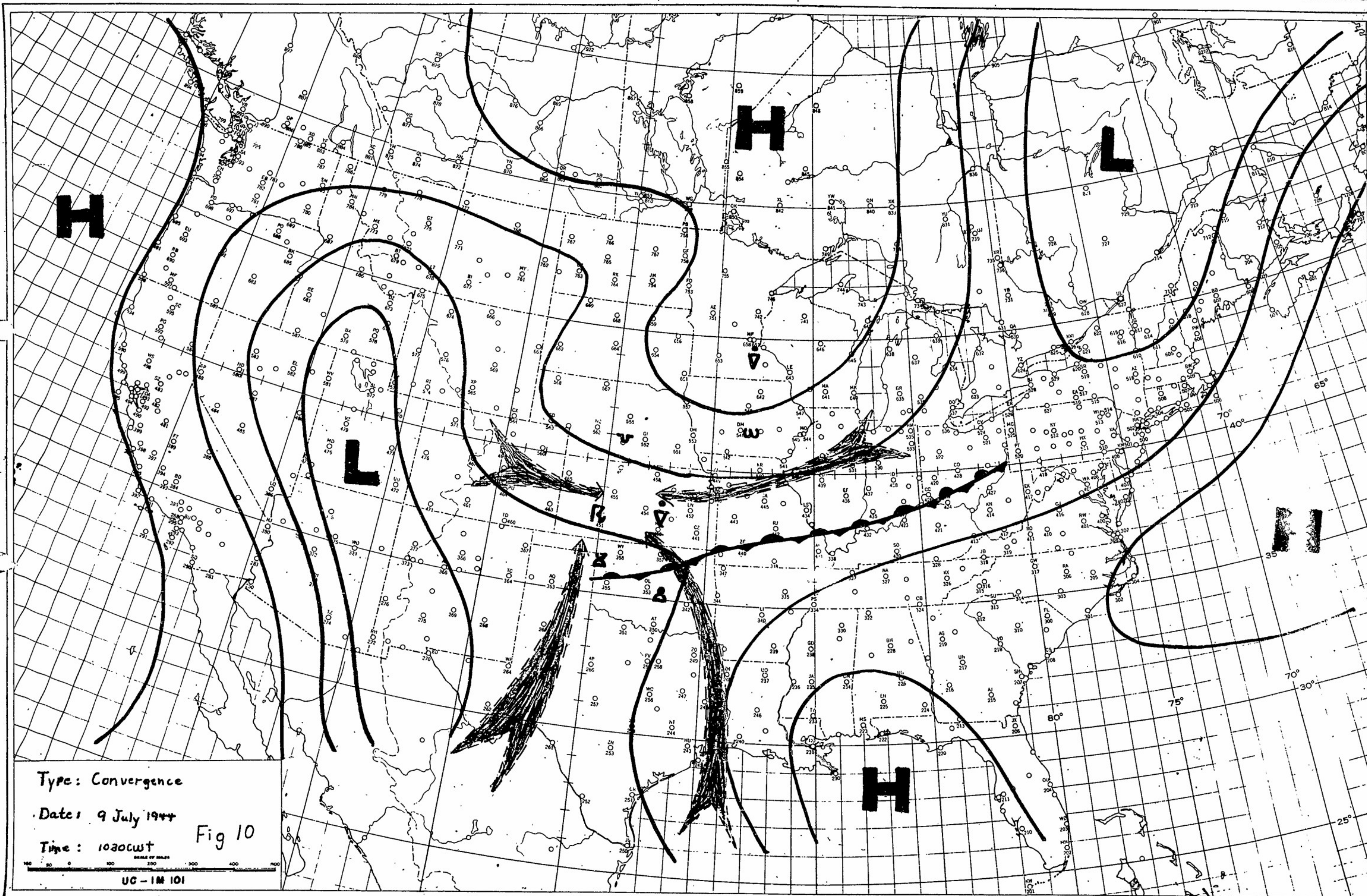
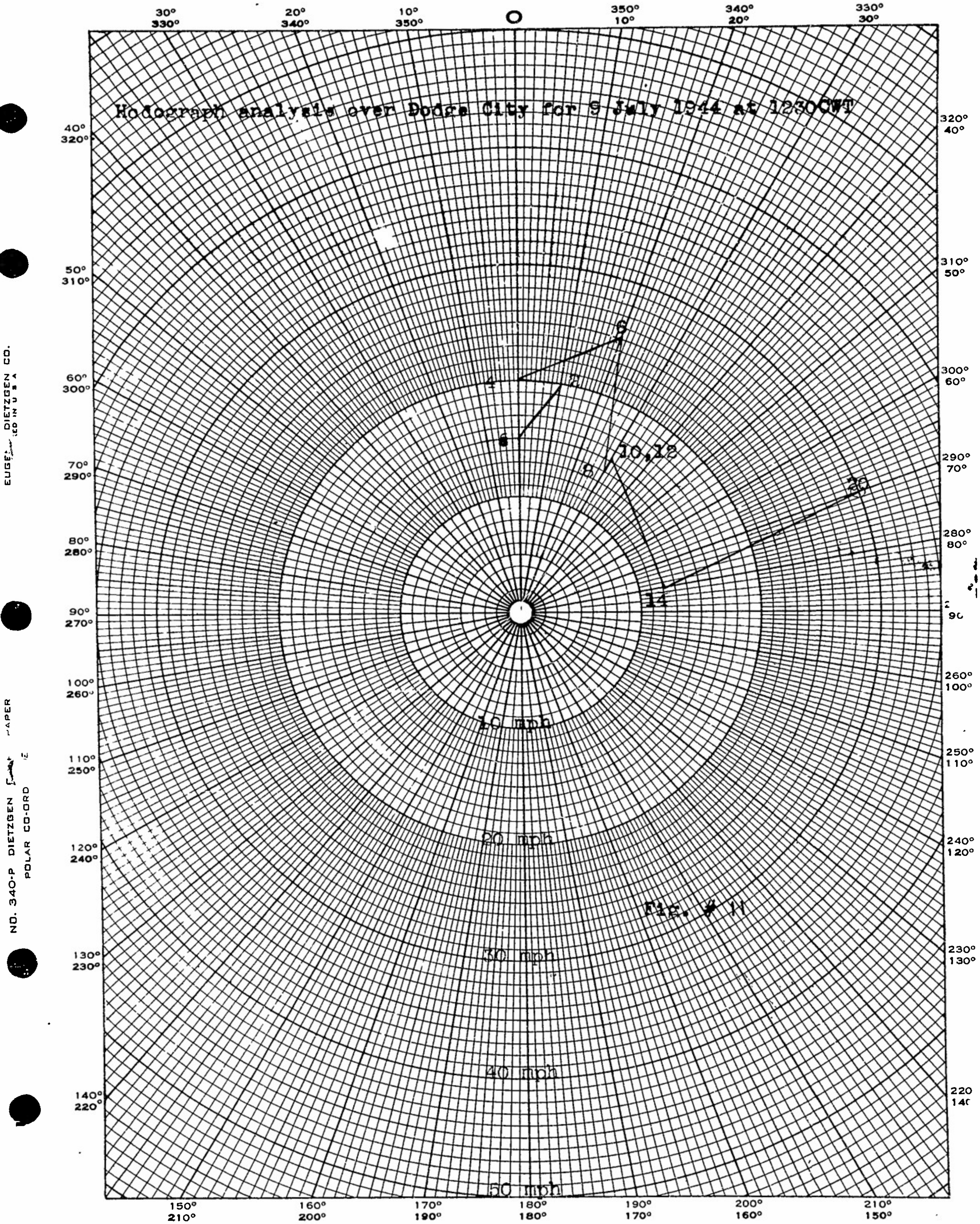
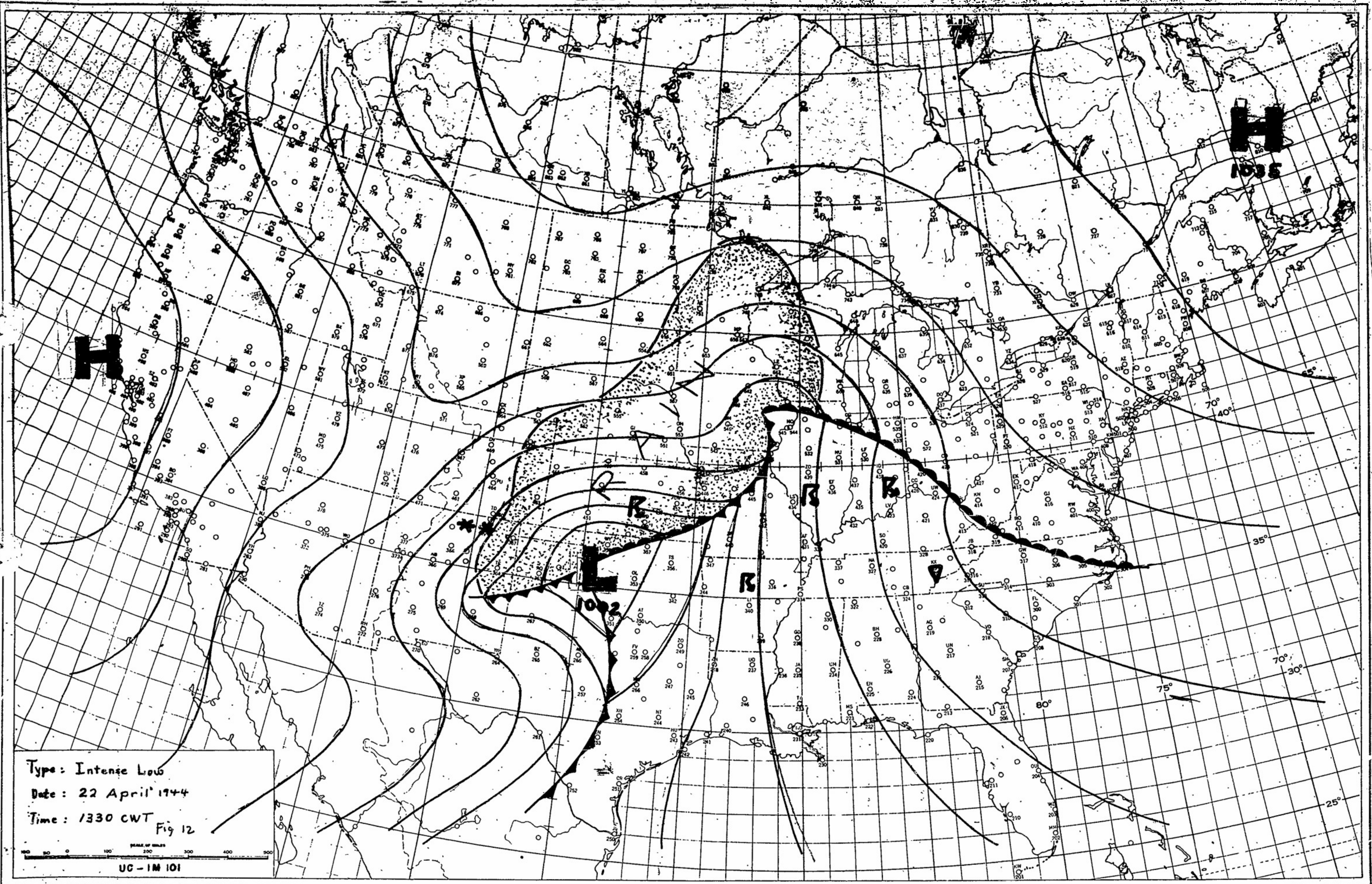


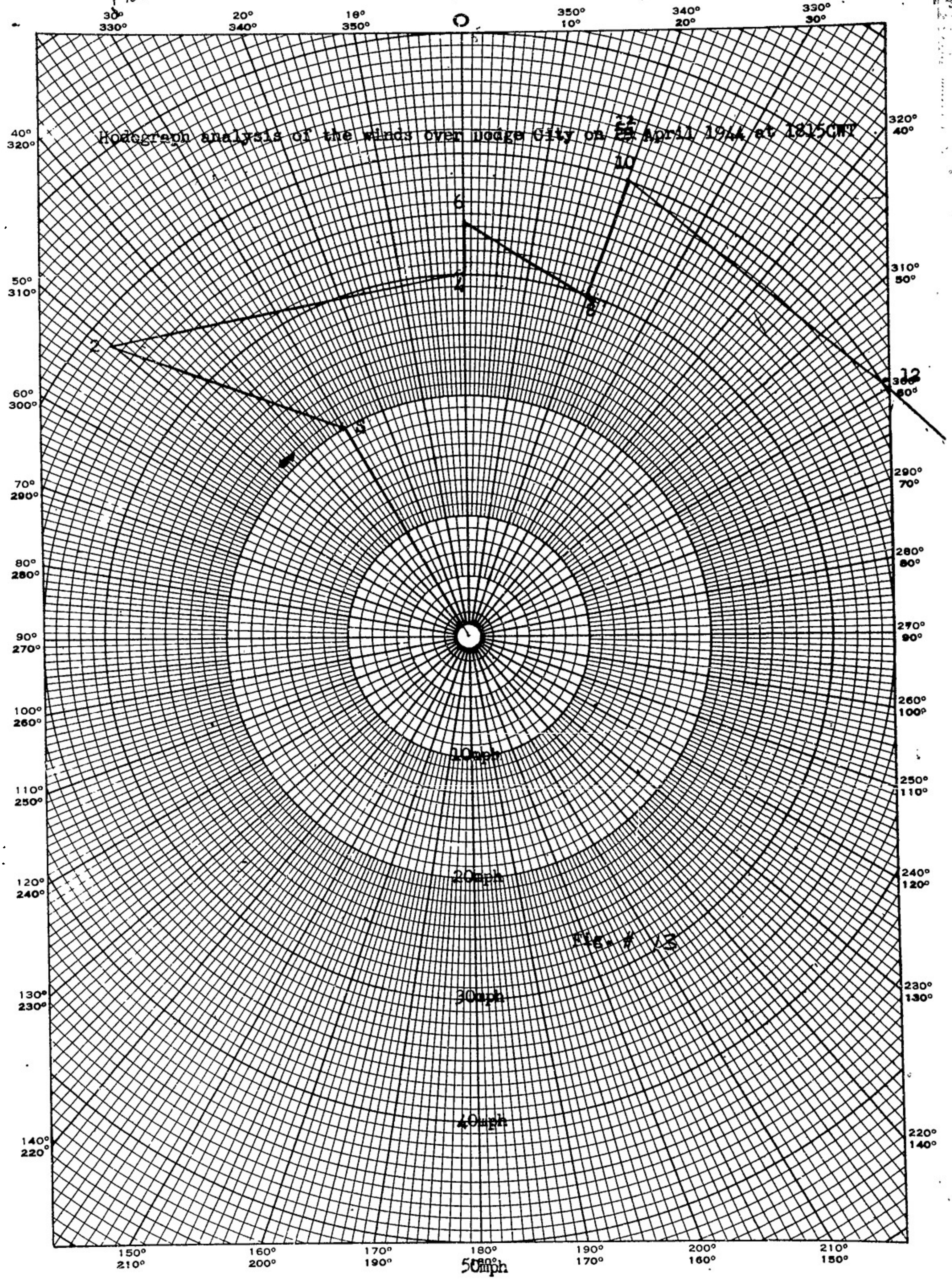
Figure [redacted] 9


H
H
L
L
H
H
Type: Convergence
Date: 9 July 1944
Time: 1030CWT
UC - IM 101
Fig 10


Hodograph analysis over Dodge City for 9 July 1944 at 1230CWT
4
2
6
8
10,12
14
20
10 mph
20 mph
30 mph
40 mph
50 mph
Fig. # 11
NO. 340-P DIETZGEN POLAR CO-ORD PAPER
EUGENE DIETZGEN CO.



Type: Intense Low
Date: 22 April 1944
Time: 1330 CWT
Fig 12
UC-IM 101
H
H
1035
L
1002



Hodograph analysis of the winds over Dodge City on
April 1944 at 1815CWT
2
3
4
6
8
10
12
10mph
20mph
30mph
40mph
50mph
Fig. # 13