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USE OF COASTAL RADIOSONDE DATA IN CALLING THE APPROACH OF STORMS ALONG THE WEST COAST

Thesis by

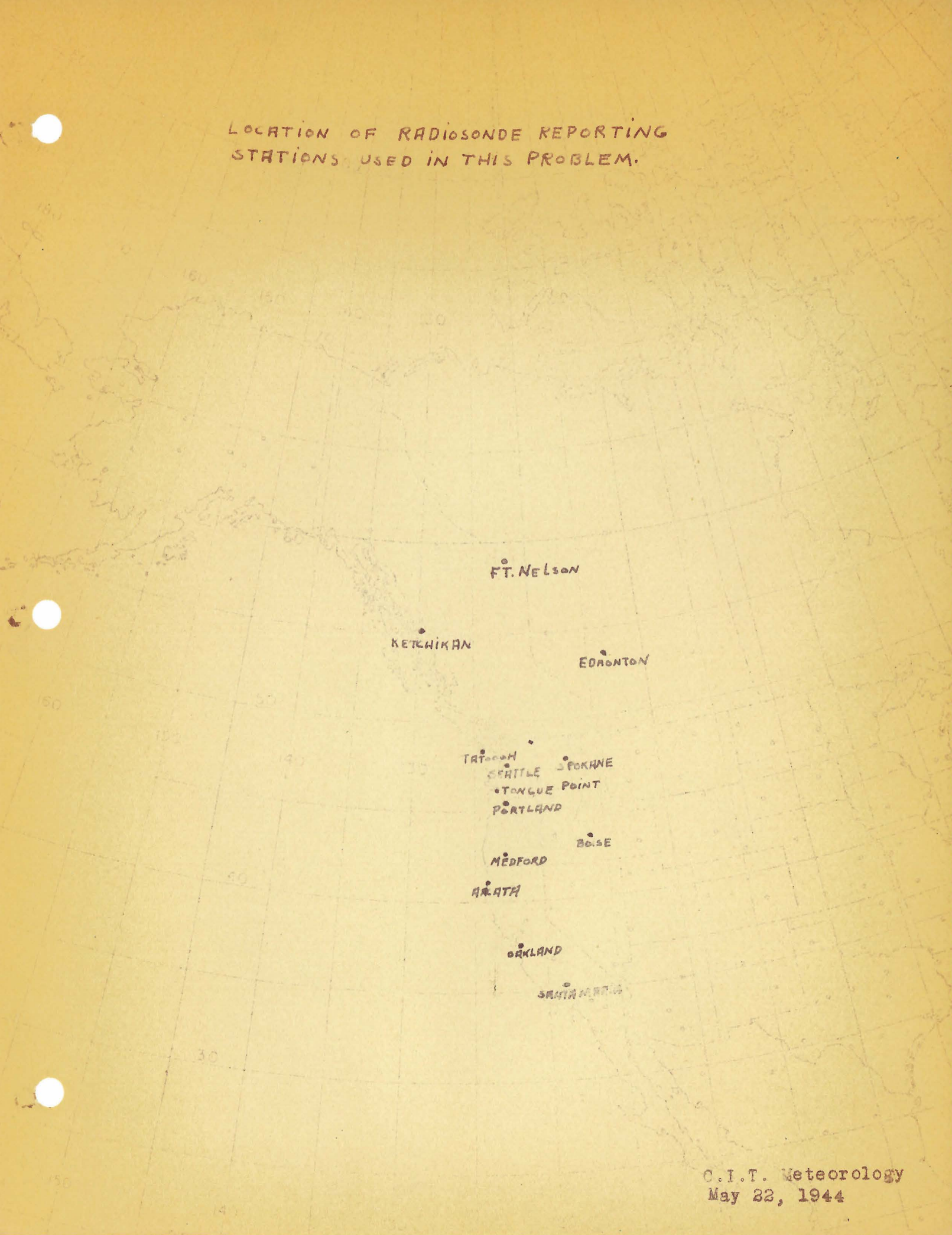
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LOCATION OF RADIOSONDE REPORTING STATIONS USED IN THIS PROBLEM.



C.I.T. Meteorology
May 22, 1944

INTRODUCTION

The purpose of this research project is to determine what use can be made of radiosonde data in forecasting the time of passage of fronts approaching the northwest coast of the United States. After finding the height of the frontal surface above certain coastal stations, the slope was determined and the surface position of the front calculated; and if in some manner an idea of the speed of the front could be attained, the time it should reach a given station could be predicted with some degree of accuracy.

The primary source of information was radiosonde data, and the three most important elements in the order of their significance were: an increase in N value, temperature inversions or nearly isothermal layers, and an increase in relative humidity. Due to frequent cloud cover with a consequent increase in relative humidity when the radiosonde passed through such a cover, this element was of doubtful value in most cases.

The synoptic situations used were those that contained fronts of sufficient strength to enable their movement inland to be traced by means of airway sequences.

The terminology used varies slightly because the cases were worked out by different members of the project, e.g., "height of the inversion", "frontal surface", and "discontinuity surface" are used synonomously in this thesis.

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Case I
February 10-14, 1944

Base of Warm Layer-

The height of this layer was calculated as follows:- on an adiabatic chart, points were plotted using the known pressure of the boundary, i. e. 1,000 and 17,000 feet, levels. By straight line extrapolation between these points the height corresponding to the pressure of the warm layer was determined. The altitude of the warm layer above all stations used in this problem were found in a similar manner. The results were:

Station	Height of warm layer
Tatoosh Island	7500 feet
Tongue Point	10000 "
Medford (3)	17300 "
Medford (15)	10000 "

FROM KHOL WHITH OF 13 FEB 1944

From the map of 14 February 1944, the front was seen to be oriented in an ENE - WSW direction, therefore stations were chosen as far as possible that lie on a line at 90 degrees to the orientation of the front.

The air line distances between the stations chosen are:

(1)	Tatoosh - Tongue Point	150 miles
(2)	Tatoosh - Medford	420 "
(3)	Tongue Point - Medford	270 "

Calculation of Slopes-

$$\frac{\text{Height above Tongue Pt.} - \text{Height above Tatoosh}}{\text{Distance between Tongue Pt. and Tatoosh}}$$

$$= \frac{\frac{10{,}000 - 7{,}500}{5{,}280}}{150} = \frac{1}{325}$$

The slope between Tatoosh and Medford and between Tongue Point and Medford were found to be $\frac{1}{325}$ and $\frac{1}{195}$ respectively. The average slope was approximately $\frac{1}{250}$.

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Using the average slope and the altitude of the warm layer above Medford on the 0330 and 1500 soundings; the speed of the front was determined.

$$\frac{17{,}000 - 10{,}000}{828} \Big/ 1 = \frac{x}{850}$$

x = 345 miles/12 hours

or 29 miles per hour.

By inspection of the 1830 GMT, 14 Feb. 1944, map the front was located 225 miles south of Medford. Assuming it traveled at the constant rate of 29 miles per hour, the front should have passed Medford at 1830 - 0730, or 0500 GMT. By the use of airway sequence the front was found to have passed Medford between 0430 and 0530 GMT. *

Synoptic:-

This particular front was a fair example of Type A, phase I. On 13 Feb 1944, a high cell was centered over the northwest coast and basin area. A southward moving low was centered over Ketchikan.

By 1830 GMT, 14 Feb., the front was centered in the northeastern corner of Nevada, extending in a WSW direction across Nevada and Northern California. An extensive precipitation area accompanied the front.

Conclusion:-

In our opinion, the forecast of the movement of this front was accurate because

(a) the front was moving in a north-south direction and therefore was not impeded or dissipated by longitudinal contact with the coastal mountains, and

(b) the speed of the front could be accurately determined, which is not always possible with fronts approaching the coast from the west.

* V130 FST MF Spl M40 ⊕ ◑ 5 RW-K- 190/45/32 48 /004/ E60 ⊕/810 5306

V130 FST MF Spl M31 ⊕ vv ◑ KW- 196/40/34 → 18/007/ BINOVC

C.I.T. Meteorology
May 28, 1944

PLATE I

MELFORD, OKE. (597)
03 GMT 13 FEB 1944

ELEV FEET	PRESS MBS	TEMP °C	RH %	W GR/KG
	980	4	6	3.1
	961	7	5	3.1
	902	5	5	3.1
5000	855	1	4	2.4
	809	3	3	2.2
	770	-2	3	1.6
10000	707	-3	3	1.6
	626	-10	3	1.1
	530	-18	5	0.9
20,000	473	-23	5	0.7
	400	-32	5	0.4
	302	-48	1	
10 Km	268	-55	1	
	210	-70	1	

MEDFORD, OKE. (597)
15 GMT 13 FEB 1944

ELEV FEET	PRESS MBS	TEMP °C	RH %	W GR/KG
	987	-1	8	3.2
	938	1	5	2.3
	900	1	5	2.2
5000	852	3	3	1.8
	789	-1	2	1.2
10000	702	-8	8	2.5
	686	-7	8	2.7
	614	-13	9	2.1
	573	-13	8	1.4
	548	-16	5	1.1
	537	-15	4	1.0
20000	470	-23	3	0.4
	400	-34	3	0.2
	369	-37		

PATTERSON ISLAND (748)
03 GMT 13 FEB 1944

ELEV FEET	PRESS MBS	TEMP °C	RH %	W GR/KG
	1026	6	8	5.2
	977	3	9	4.4
	896	-3	0	3.4
	865	-2	1	0.5
5000	852	-2	2	0.8
	782	-6	5	1.6
	760	-4	9	3.3
	733	-4	8	3.2
10000	702	-5	2	1.1
	606	-16	5	1.1
	554	-19	0	1.5
20000	468	-28	9	0.8
	400	-35	8	0.4
	333	-46	1	

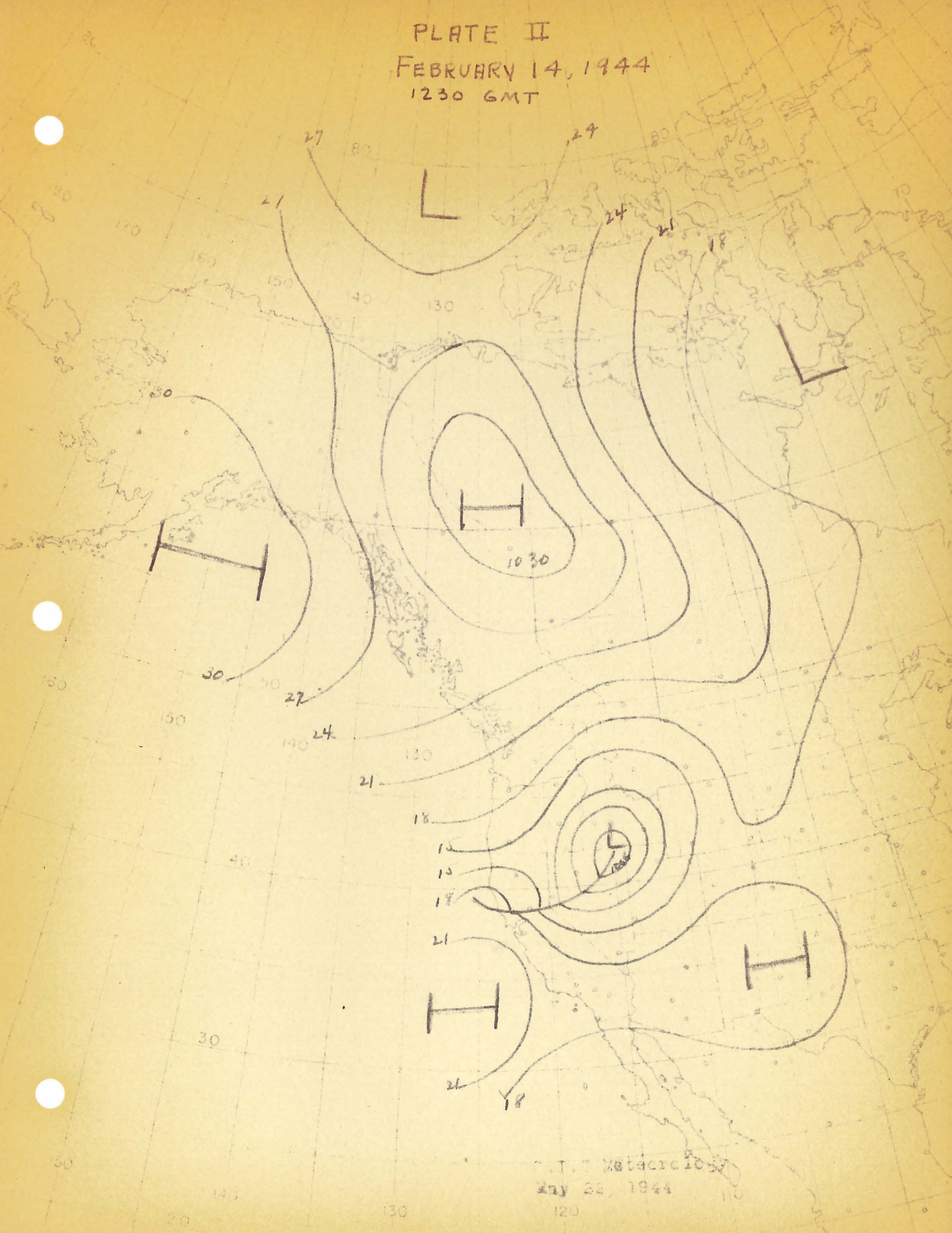
TONGUE POINT (619)
03 GMT 13 FEB 1944

ELEV FEET	PRESS MBS	TEMP °C	RH %	W GR/KG
	1031	7	7	4.8
	915	2	6	3.3
	890	-1	2	0.9
5000	856	2	2	1.1
	845	2	2	1.2
	750	-4	2	1.1
10000	706	-6	5	1.9
	650	-10	9	2.0
	550	-18	0	1.8
20000	471	-27	0	0.9
	400	-34	0	0.5

PLATE II

FEBRUARY 14, 1944

1230 GMT



M.I.T. Meteorology

May 22, 1944

Height of inversion above:

Seattle	17,700 feet
Tatoosh	17,500 "
Tongue Pt.	17,000 "
Ketchikan	13,750 "

Ketchikan is 270 miles west of Tongue Point, therefore the actual slope of this front can be calculated by:-

$$\frac{\frac{17{,}000 - 13{,}750}{5{,}280}}{270} = \frac{1}{x} \qquad x = 170$$

therefore the slope is $\frac{1}{170}$ miles. Using this slope and the known height of the frontal surface above Seattle and Ketchikan, the position of the surface front at 1230 GMT 18 March 1944 was calculated to be:-

550 miles west of Seattle
440 miles west of Ketchikan.

In order to estimate the speed of this front, it was assumed to be moving at the rate of 15° of longitude in 24 hours. At the latitude of Seattle, 15° of longitude is equal approximately to 700 miles, which indicates an hourly speed for the front of 27 miles. On this basis the front should reach Seattle in 20.4 hours, or at 0900 GMT 19 March, which corresponds to 0100 PST 19 March. By inspection of the airways sequences, the front was found to have passed Seattle at 0200 19 March 1944.

Synoptic:-

A fairly strong high cell was centered over the state of Washington with a weak trough extending north-south about 500 miles east of the Canadian Rockies. A moderately intense Low was located in the western Gulf of Alaska extending inland 300 miles into northwest British Columbia. Falling tendencies in this area indicated the approach of a front.

Conclusion:-

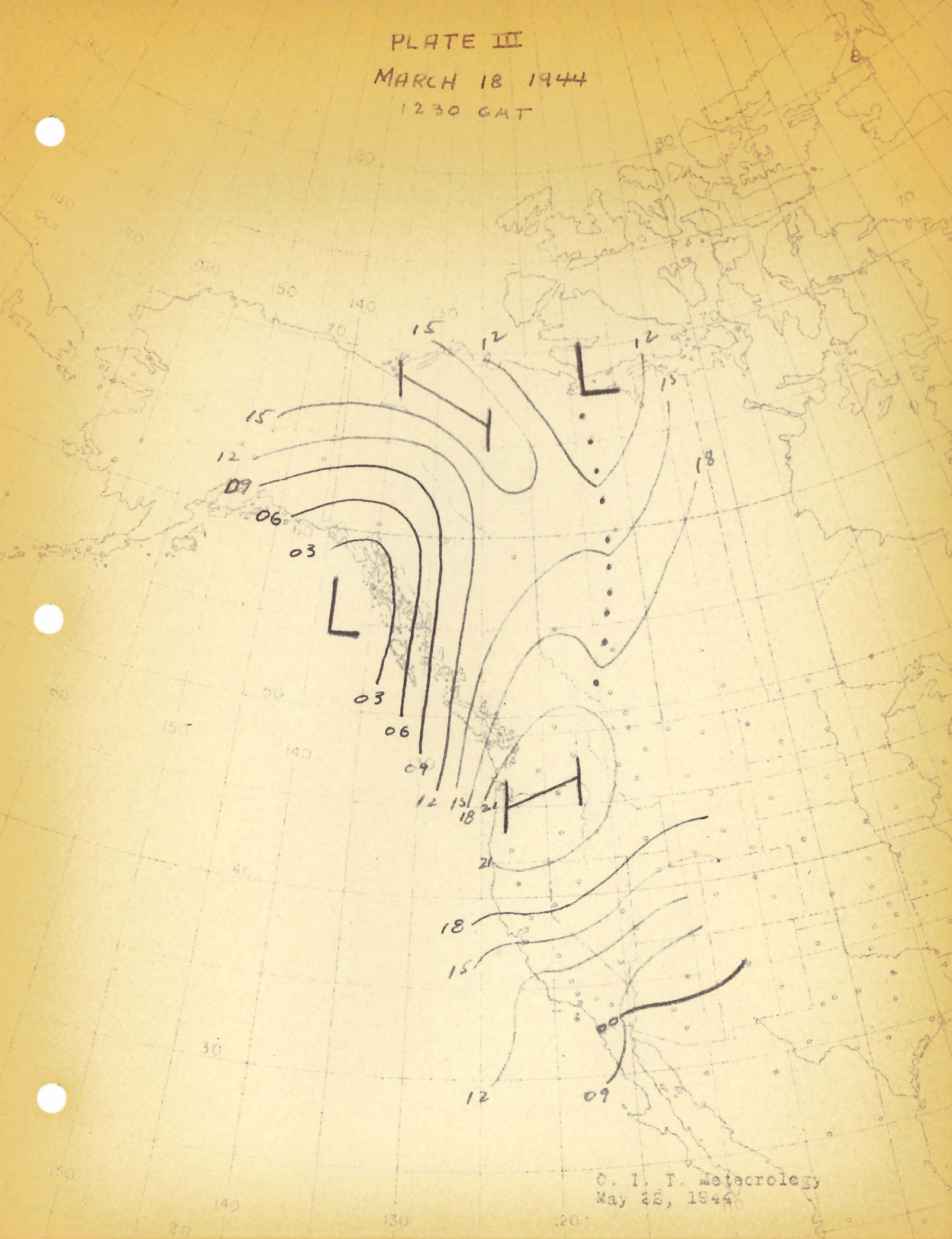
The accuracy of this forecast seems to indicate that a speed of 15° of longitude per 24 hours is reasonably correct; since this was the only assumption made in this particular case. The station chosen, Seattle, is near the coast so it can be assumed that

the surface front in this example maintained its over-water speed at least until it had passed the station.

PLATE III

MARCH 18 1944

1230 GMT

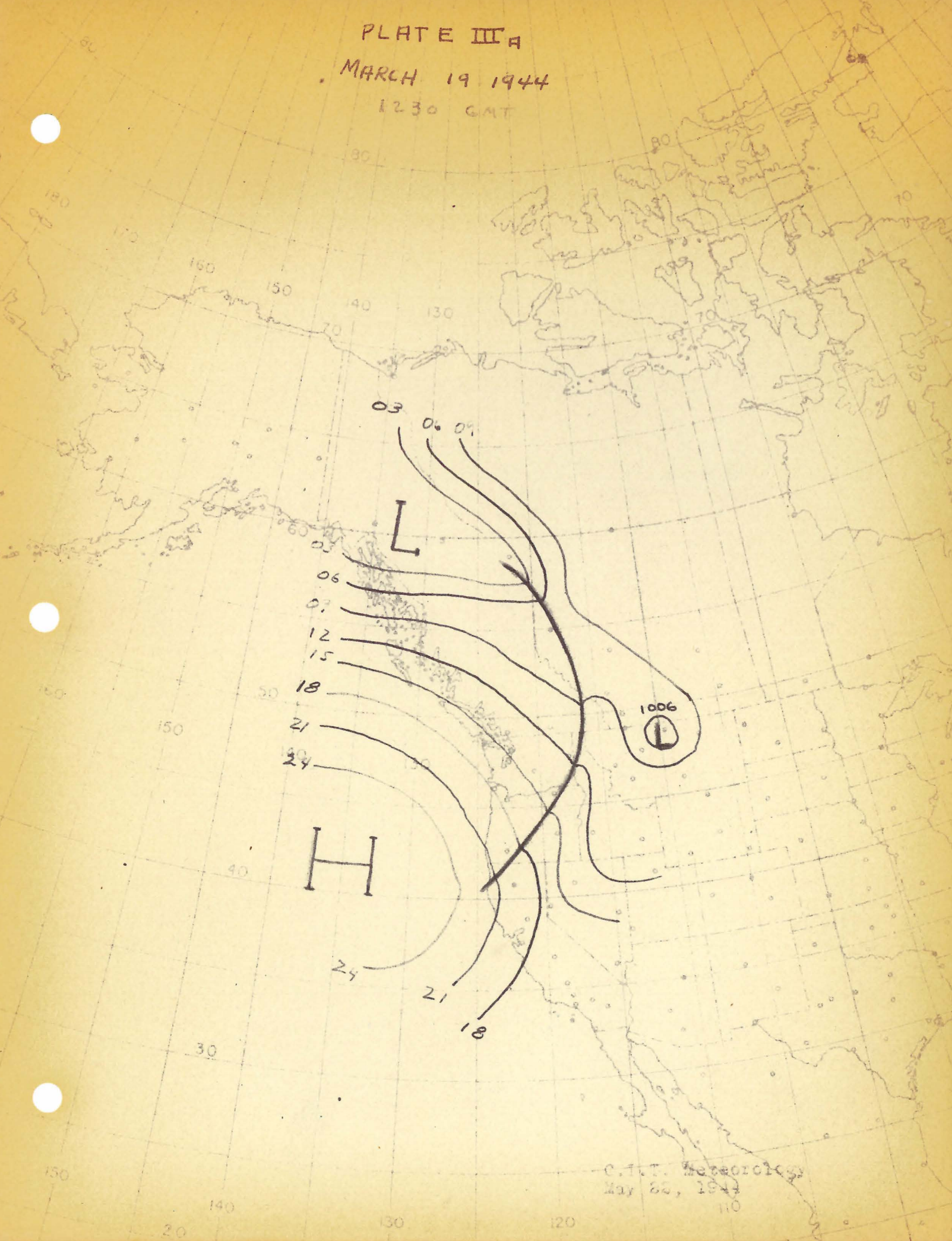


C. I. T. Meteorology
May 28, 1944

PLATE III A

MARCH 19 1944

1230 GMT



C.I.T. Meteorology
May 22, 1944

Case III
January 1[illegible], 1943

The only radiosonde data available indicated the warm surface to be 9,500 feet or 1.8 miles above Tongue Point, Oregon. Since there was insufficient data available for the slope to be calculated, it was assumed to be $\frac{1}{200}$. Using this figure for the slope the distance of the surface front from Tongue Point was found to be:-

$$\frac{1}{200} = \frac{1.8}{x}$$

$$x = 360 \text{ miles west.}$$

If the front was moving at the uniform rate of 15° of longitude per twenty-four hours it should have reached Tongue Point in

$$\frac{360}{27} = 13.3 \text{ hours or at}$$

1730 GCT = 0930 PST.

According to the airway sequence the front actually reached Tongue Point at 1600 PST.

Synoptic:-

This front was an excellent example of an L-O type, phase one, centered in extreme Southwest British Columbia and extending N-S down the coast of the Northwest United States. The second wave was oriented in a similar manner and centered about 500 miles due west of the primary front. A high cell centered over eastern Alaska extended southeastward down to the U.S. border. A small high was located over Northern California.

Conclusions:-

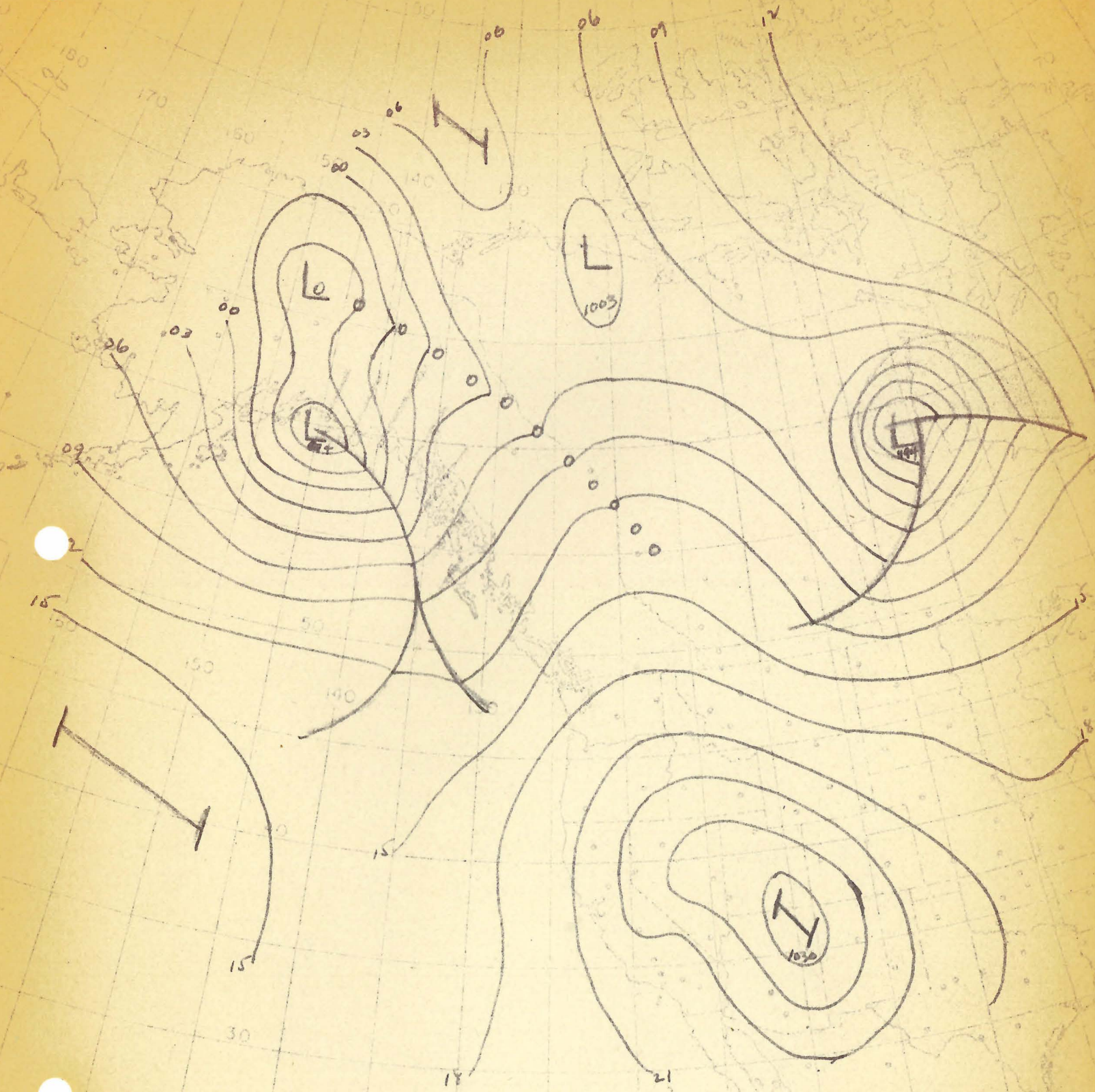
Apparently too many assumptions were made in this case. Either the slope was less steep than calculated, or the speed was less than figured, or both.

C.I.T. Meteorology
May 22, 1944

PLATE II

FEBRUARY 19 1943

1230 GMT



C.I.T. Meteorology
May 22, 1944

Case IV
March 2-4, 1944

The slopes of this front as secured from the radiosonde data were as follows:

Stations	Slope	Airline Distance
Tatoosh to Seattle	$\frac{1}{69}$	125 miles
Seattle to Spokane	$\frac{1}{72}$	225 "
Seattle to Edmonton	$\frac{1}{114}$	550 "
Tatoosh to Edmonton	$\frac{1}{91}$	600 "

These slopes averaged $\frac{1}{87}$.

Using the data for Tatoosh Island for March 2 and March 3 the distance the front moved was calculated by using the average slope of $\frac{1}{87}$. This showed a movement of 870 miles in 24 hours, or an hourly rate of movement of 11 miles.

Using March 3 data for Seattle and using the same slope:

$$\frac{1}{87} = \frac{\frac{5000}{5280}}{x}$$

x = 84 miles away.

$\frac{84}{11}$ = 8 hours, approximately. This added to 0300 GMT equals 1100 GMT or 0400 PWT for the time of passage of the front.

C.I.T. Meteorology
May 22, 1944

Synoptic:-

This case was picked because of what appeared to be an intense low center moving down the coast opposite Ketchikan on March 5, 1944. This occlusion came in on March 4, 1944; after some regeneration east of the mountains it moved across the country about 800 miles per day, which was much faster than its movement off the coast as it was occluding. This more rapid movement can partially be explained by the fact that the system was filling as it moved eastward. Also occlusions slow down as they approach land and mountainous areas, practically stalling in some instances and throwing off upper fronts at irregular intervals.

Conclusion:-

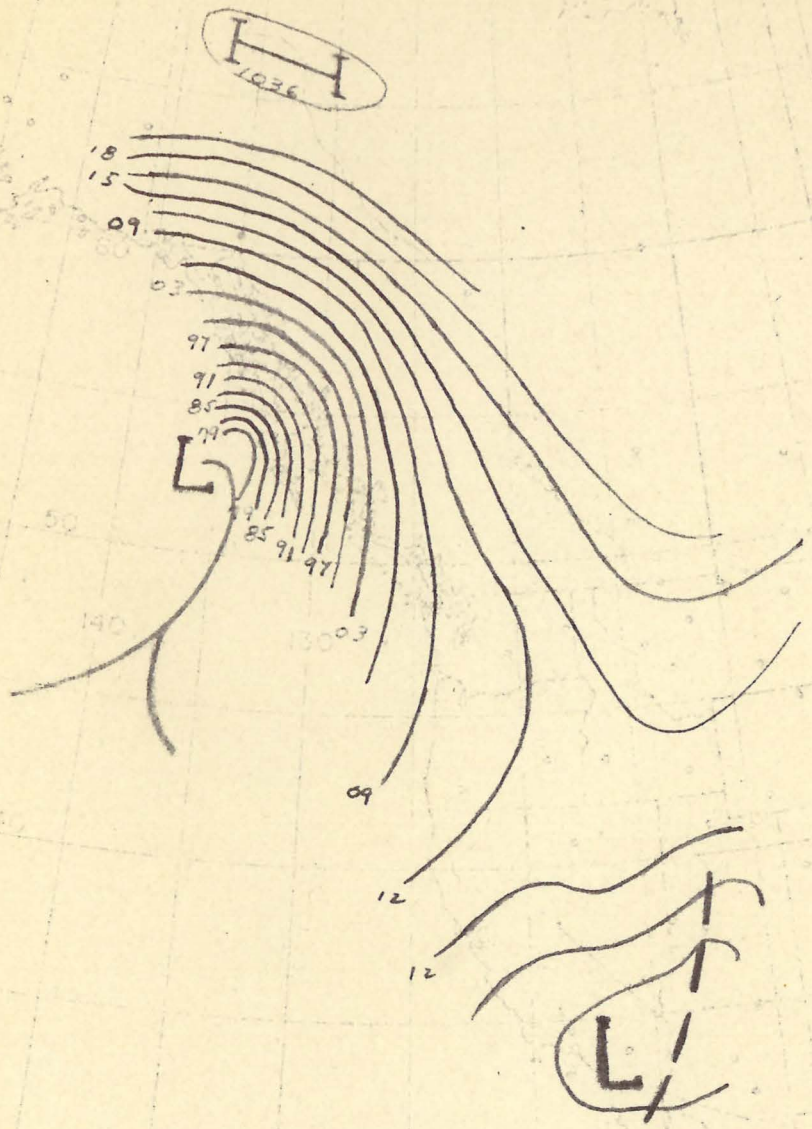
It is rather difficult to time this frontal passage accurately because the occlusion came down just off the coast and did not come in until the center was opposite the California-Oregon coast, at which time it was very well wrapped up but dissipating. While the center stalled off shore the remainder of the occlusion lay up against the Cascade Mountains in the form of a semi-circle. Inspection of the airway sequence was inconclusive since it did not show a clear cut frontal passage. According to calculations the front should have passed at 0400 PWT, March 4, but the sequence showed that the center had passed down the coast and that the pressure had started to rise more than the diurnal at 0830 March 4 This is a variation of no more than five and one half hours, probably less, depending on the interpretation to be placed on the time taken for the frontal passage- which did not, strictly speaking, take place.

C.I.P. Meteorology
May 22, 1944

PLATE V

2 MARCH 1944

1230 GMT

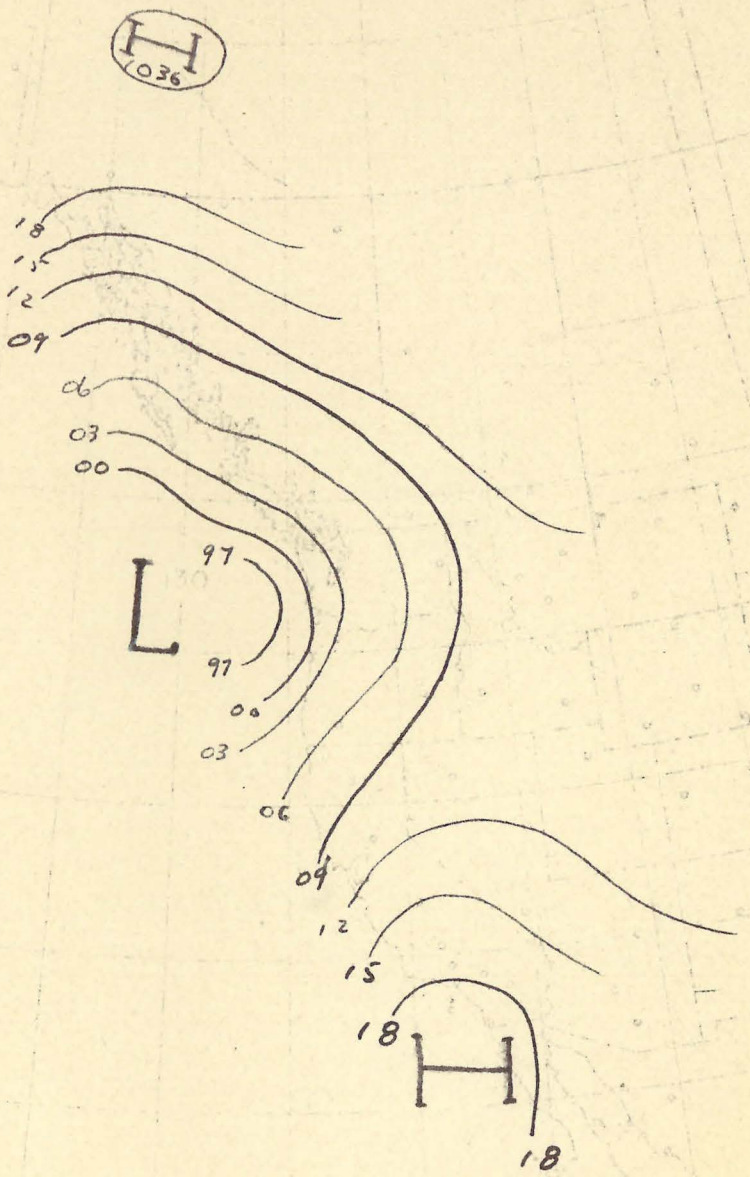


C.I.T. Meteorology
May 22, 1944

PLATE VI

3 MARCH 1944

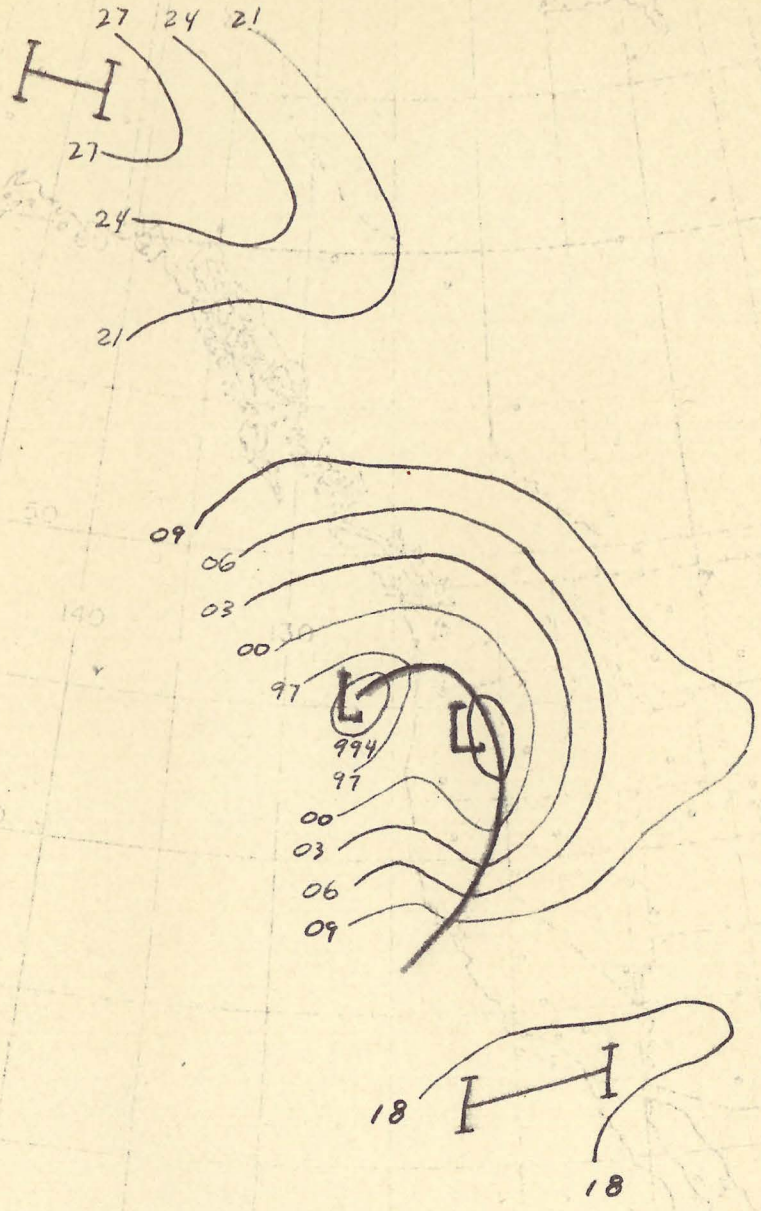
1230 GMT



C.I.T. Meteorology
May 22, 1944

PLATE VI A

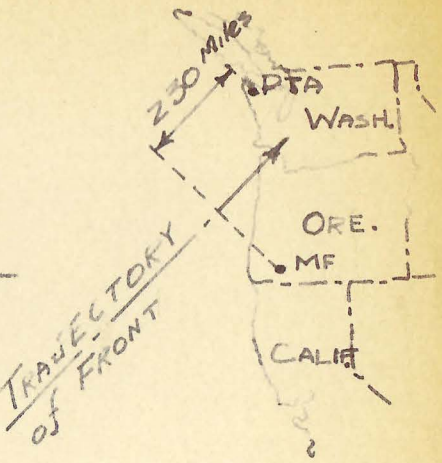
4 MARCH 1944
1230 GMT



Case V
October 23, 1943

Height of inversion above:
Medford 10,000 feet
Tatoosh Island 12,200 "

The distance from Medford to Tatoosh perpendicular to the front was calculated to be 230 miles as illustrated in the diagram to the right.



$$\frac{\frac{12{,}200}{5{,}280} - \frac{10{,}000}{5{,}280}}{230} = \frac{1}{x}$$

$x = 550$ or the slope is $\frac{1}{550}$

To calculate the distance of the surface front from Medford:

$$\frac{1}{550} = \frac{\frac{10{,}000}{5{,}280}}{x}$$

$x = 1040$ miles southwest of Medford.
Similarly the front is calculated to be 1275 miles southwest of Tatoosh Island.

The speed of the front using the 15° per day at latitude 40° north was assumed to be 32.5 miles per hour. Therefore the front should have reached
Medford in 32 hours,
Tatoosh in 39.2 " .
From the synoptic map of 1230 GMT 24 Oct 194. the front was found to have passed both stations at 1230 GMT 24 October.

Synoptic:-

This situation is an example of Phase ___ of a [illegible]. A deep occlusion is moving toward the north coast of the United States from the southwest. Such occlusions moved on the coast for several days from

C.I.T. Meteorology
May 22, 1944

the same direction and caused much weather from San Francisco to southern British Columbia.

Conclusion:-

1) Forecast was only $\frac{1}{2}$ hour early at Medford,

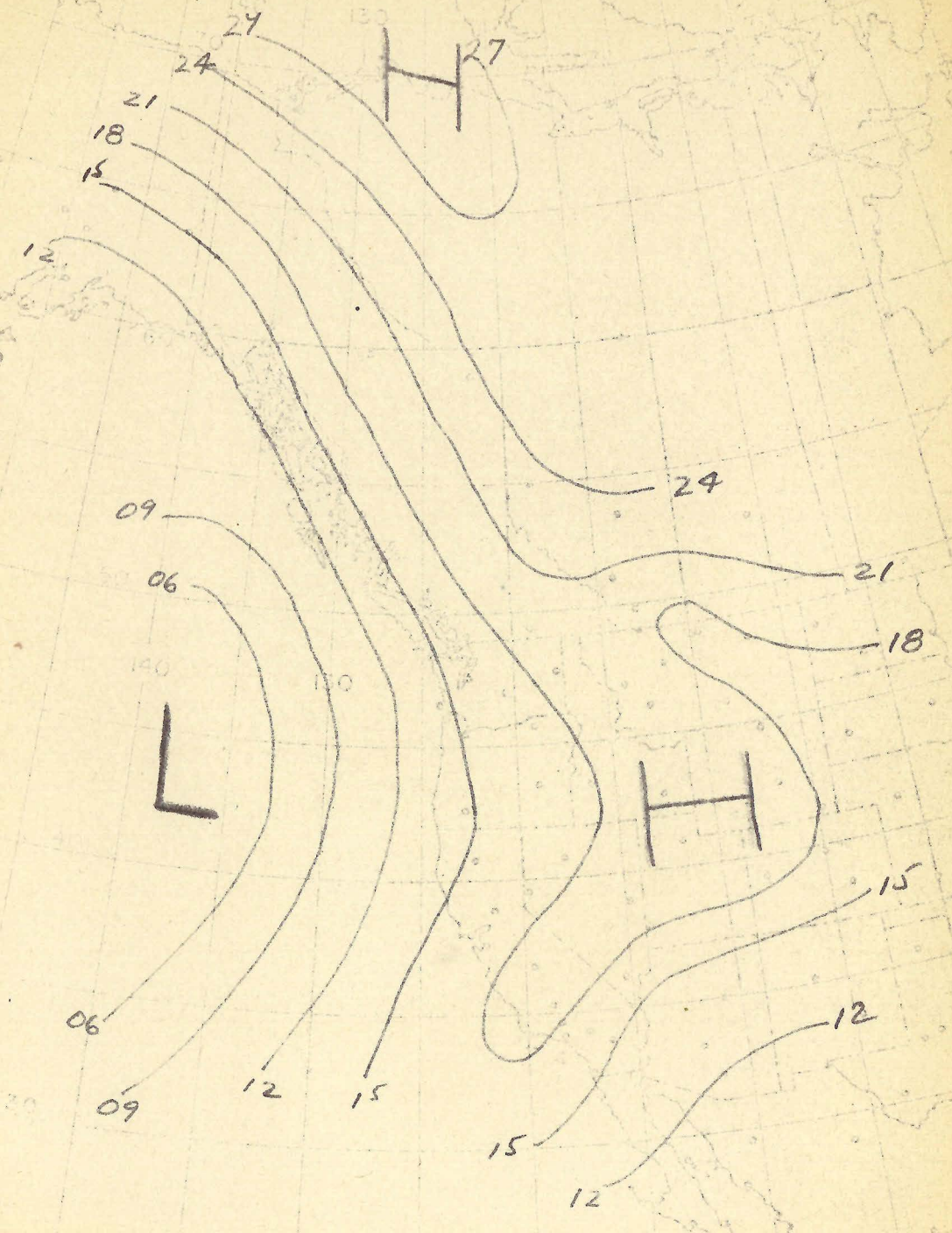
2) Forecast was 7 hours late at Tatoosh.

The latter forecast was probably not as close as the first because of the reorientation of the occlusion as it came onto the coast, with the part that passed Tatoosh becoming more north-south. A number of rather bold assumptions were made, and with the lack of radiosonde data for the 24th they seem to have some justification, judging from the forecast time calculation.

This case serves to show the difficulty with Ea and Em waves (waves moving up from the lower latitudes and onto the northwest coast with a south-east-northeast trajectory). Due to a lack of ship reports the orientation of the waves and the exact direction which they are approaching the coast is a matter of conjecture.

C.I.T. Meteorology
May [illegible], 1944

PLATE VII
October 23 1943.
1230 GMT

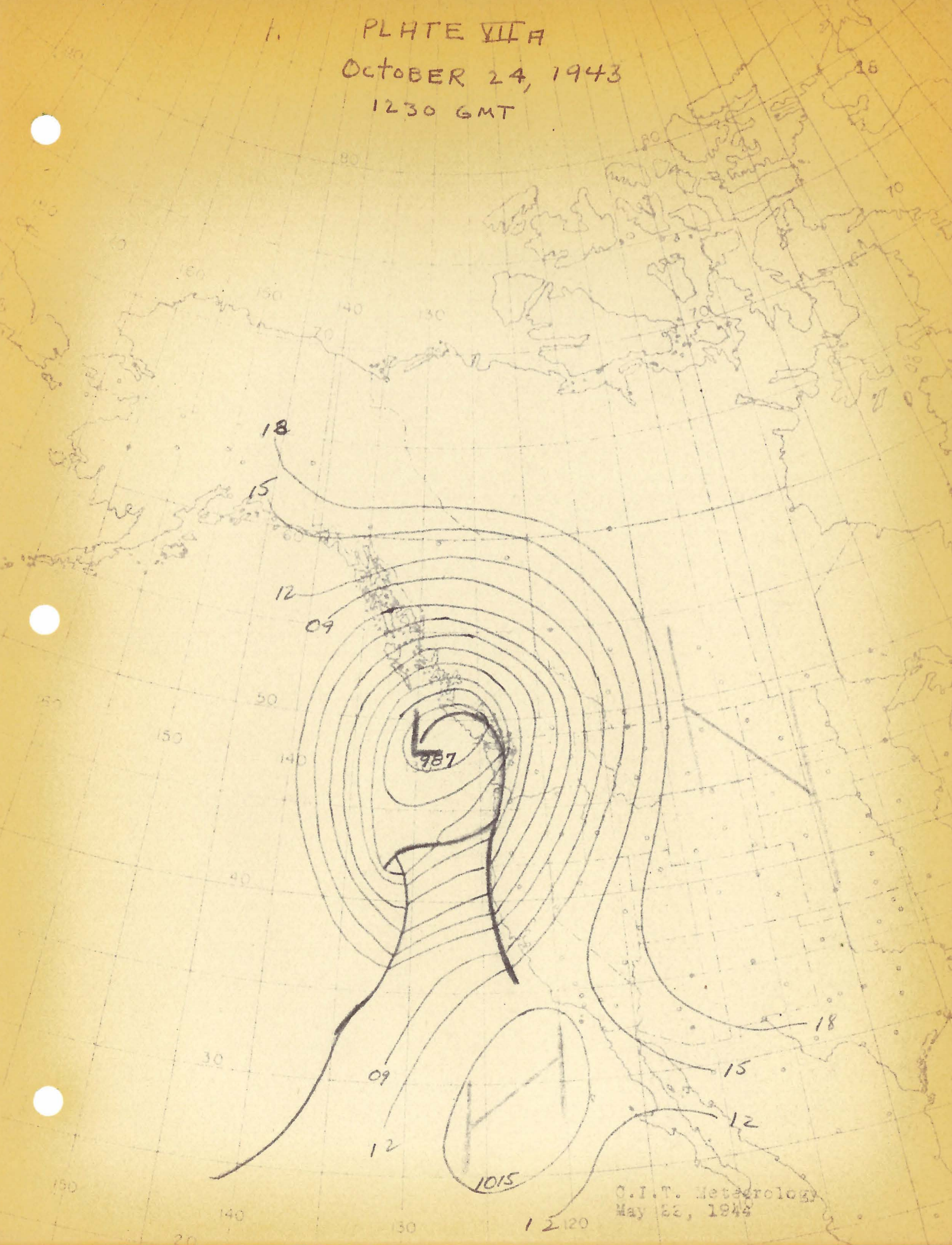


C.I.T. Meteorology
May 28, 1944

1. PLATE VII A

October 24, 1943

1230 GMT



O.I.T. Meteorology
May 22, 1944

Case VI
March 22, 1944

The radiosonde data for 0400 GMT March 22, 1944, gave indications of frontal surfaces at Seattle, Spokane, Medford, and Oakland. The slope from Seattle to Spokane, a distance of approximately 350 miles, was $\frac{1}{400}$. This was out of line with respect to the other slopes due to the fact that a line running between these stations was at about a 45° angle with the surface front. Best results have been secured when the line between stations used to calculate the slope is at an angle of 90° with the surface front. This 90° angle was to be found in each of the other three calculations. The frontal discontinuity was calculated to be:

.7 of a mile above Seattle at 0400 GMT,
1.8 miles " Medford " " " ,
2.6 " " Oakland " " " .

Using the above data the following was calculated:

Stations	Slope	Distance
Seattle to Medford	$\frac{1}{335}$	375 miles
Seattle to Oakland	$\frac{1}{330}$	675 "
Medford to Oakland	$\frac{1}{300}$	300 "

Data for the preceding day was not conclusive enough to calculate the speed of the front so the speed was determined in the following manner:

At 0400 GMT 22 March, from the radiosonde data and using an average slope of $\frac{1}{320}$ the front was calculated to be 250 miles away from Seattle, thus,

$$\frac{1}{320} = \frac{.7}{x}$$

$$x = 250$$

By inspection of the 1330 GMT surface map, the distance was estimated to be 180 miles.

C.I.T. Meteorology
May 22, 1944

$$\frac{250 - 160}{1830GMT - 0400GMT} = \frac{90}{8.5} = 10.5 \text{ miles per hour.}$$

$$\frac{160}{10.5} = 15 \text{ hours after 0430 PST, time of sur-}$$

face synoptic map, which is 2030 PWT 22 March 1944. Inspection of the airways sequence for Seattle showed that an upper front, which the radiosonde data gave no indication for, passed at 1130 to 1230 PWT. The surface front came through at 2330 to 2330 PWT 22 March, which was 2 hours later than the calculated time.

Synoptic:-

On March 22 there was a 1003 millibar Low situated east of the mountains in Canada and oriented north-south to about 100 miles north of the border, curving sharply there to an east-west position with an open wave developing over the mountains just north of the border. The front again curved to a southwest-northeast direction crossing the western border of the United States and Canada. A secondary was oriented east-west from this same center along latitude 50° North. A 1030 mb. high was centered over Nevada with a 1027 high over the Yukon.

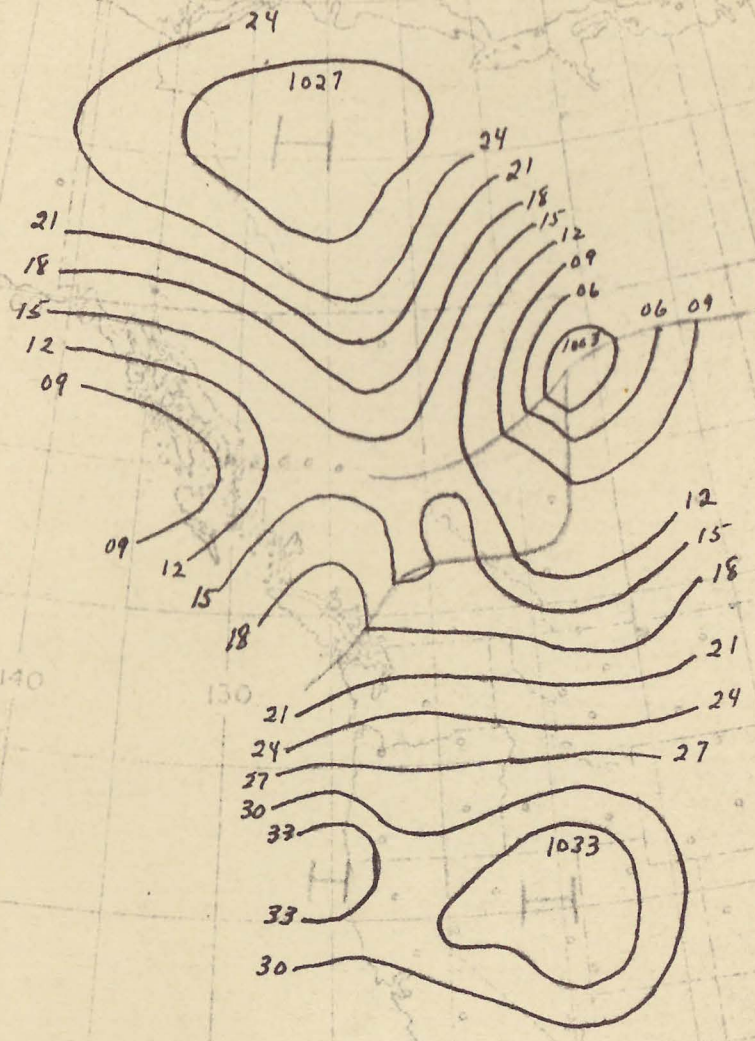
Conclusion:-

The actual 15 hour forecast made correct to within 2 hours in this case must be discounted somewhat because by the time the surface map was plotted and analyzed part of the 15 hours would have elapsed. However, by closely following airway sequences for frontal passage time and by having experience in the particular region, an observer would undoubtedly be aided in further refining his forecast, and for a longer period of time.

Radiosonde data for 23 March 1944 was not available. Copies were not available for this project, thus making it impossible to calculate the slope of this front for a greater distance from Seattle. March 20 data gave no information that would indicate the position of an upper frontal surface.

C.I.T. Meteorology
May 12, 1944

22 March 1944
1230 G.M.T.
PLATE VIII



C.I.T. Meteorology
May 22, 1944

Case VII
March 23, 1944

Using radiosonde data for March 23 to calculate slopes the following results were secured:

Stations	Slope	Distance
Tongue Point to Arcata	1/470	375 miles
Tongue Point to Medford	1/300	260 "
Tongue Point to Boise	1/130	425 "

Average slope was 1/275, which, due to the various angles which the three lines (connecting the three pairs of stations) made with the front, resulted in slopes which disagreed greatly. There was the further complication that upper fronts kept coming through and it was impossible to spot some of them on the radiosonde data. Furthermore there is a great chance that in computing the slopes between the stations separate frontal surfaces were mistaken to be the same one.

$$\frac{1}{275} = \frac{1.8}{x}$$

x = 503 miles from Medford at 0400 GMT.

Surface synoptic map of 1830 G.C.T revealed the front to be 300 miles north of Medford.

$$\frac{503 - 300}{1830 \text{ GMT} - 0400 \text{ GMT}} = \frac{203}{8.5} = 26 \text{ miles}$$

per hour as compared with 10.3 miles per hour computed for March 22. This could result in surface front passage at 1830 PWT 23 March at Medford.

$$\frac{370 \text{ (distance between Seattle and Medford)}}{26} = 14$$

hours after 2330 22 March (the passage time at Seattle) or 1830 PWT 23 March.

C. I. T. Meteorology
May 22, 1944

Inspection of the airways sequence for Medford revealed that there was a frontal passage at 1730 P.S.T, which apparently was another upper front not carried on the synoptic map. The front in question came through 5 hours later than the time calculated for the surface front. This error in timing is probably due to the fact that the speed used was that of the surface front whereas this was undoubtedly an upper, which by synoptic map time on March 14 had disappeared to an extent that it was omitted from the map. From the indistinct data on the 8"x8" synoptic map print, there seems to be some indication that the upper front might have been carried another day. The fact that the weather associated with it had almost entirely disappeared probably accounts for its being dropped.

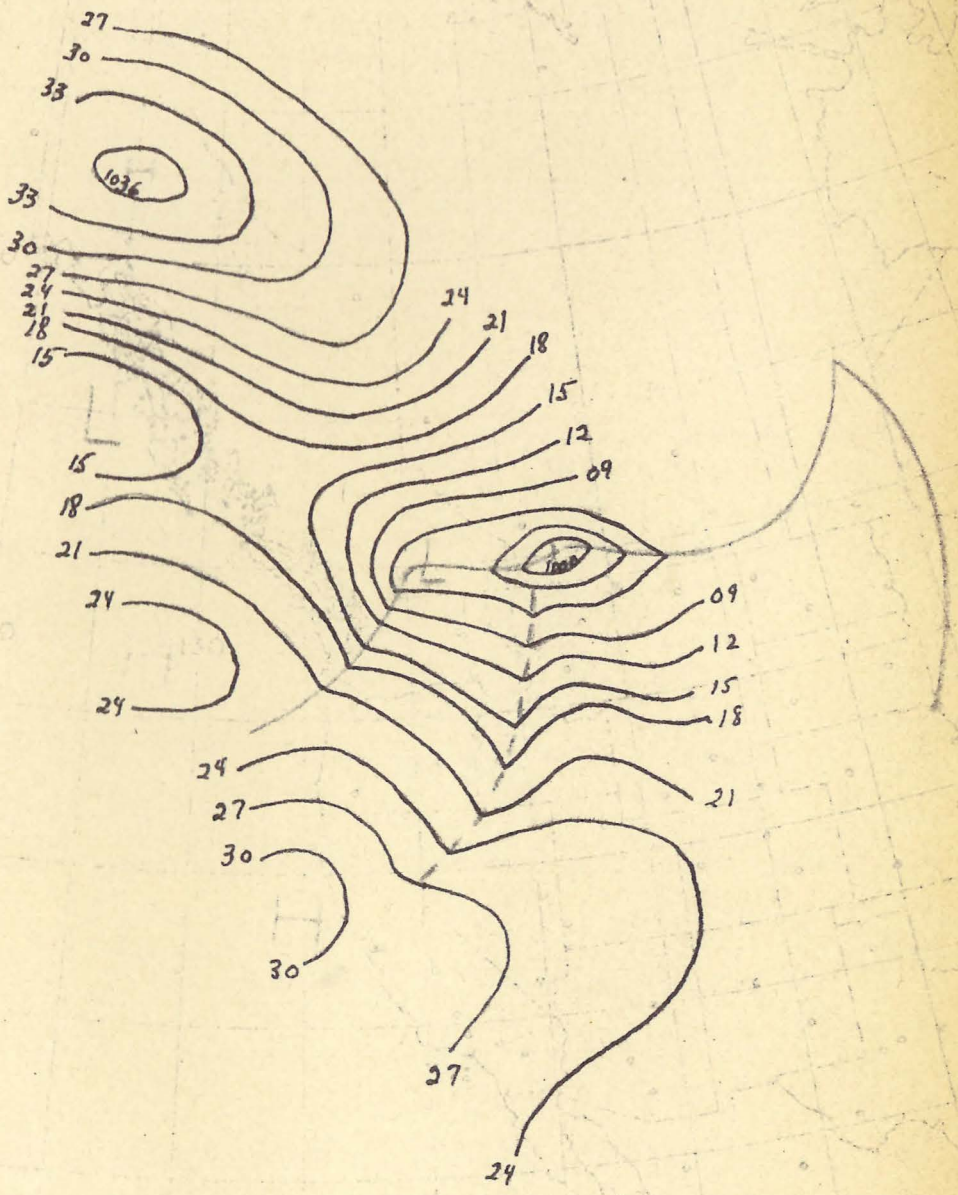
Synoptic:-

On March 13 the low center had moved east and centered 300 miles north of the Canadian border and even with the Minnesota-North Dakota border. The cold front ordered back to a 1000 millibar center of an open wave in the southeast corner of Alberta. From there it intensified its east-west orientation to another open wave at 120° longitude where a cold front oriented northeast-southwest cut the coast at 46° north latitude. A north-south upper front was oriented through central Nevada. The high over the Yukon had intensified 6 millibars and moved slightly south.

Conclusion:-

See case VIII. (The conclusion for this situation is incorporated in that of the next case.)

23 March 1944
1230 G.M.T.
PLATE IX



O.I.T. Meteorology
May 28, 1944

Case VIII
March 24, 1944

Calculation of the time for the surface front passage from the rate of movement originally, and the passage time at Seattle gives:

$$\frac{375}{10.5} = 35.7 \text{ hours later or } 1030 \text{ P"T}$$

24 March. Inspection of the sequence showed the passage to be from 0230 to 0630 P"T 24 March. The definite time was impossible to determine because reports for the time in between were missing from the files. This indicates passage 4 to 7 hours ahead of schedule. Inspection of the synoptic map for March 24 revealed that the trail end of the surface front seemed to whip across the southwestern part of the United States in a hurry. At the time it passed through Medford it had spent most of its energy and showed promise of becoming very weak- hence the acceleration, which indicates that later on in the day the part of the front we were concerned with entirely dissipated.

Synoptic:-

This system was centered over the western end of Lake Superior with the cold front taking an east-west position through the Rocky Mountains, passing off the coast at the Oregon-California border. Another occlusion was centered in northwest Canada coming off the coast at Juneau. A 1024 high separated the two systems, the high being centered over east central Alberta.

This particular case was picked because of its east-west orientation as it moved in a north-south direction over the Pacific Coastal Region. In addition it was desired to determine what effect upper fronts would have on this method of determining frontal locations.

Conclusion:-

Using the speed of 26 miles per hour as calculated from March 23 data gives a frontal passage time 14 hours later at Medford rather than 35.7 hours later as calculated from the 10.5 miles per hour rate of movement derived from the data of March 24.

These calculations were respectively

C.I.T. Meteorology
May 28, 1944

5 hours late and 4 to 7 hours ahead of actual frontal passages. There are several reasons for these errors among which the lack of consistent frontal slope calculations was probably the most important. This inconsistency was due in a great measure to the fact that the straight line joining each pair of stations which showed frontal surfaces, was not at a 90° angle with the front. The larger the angle of deviation the larger the error in calculating the distance between the station and the front.

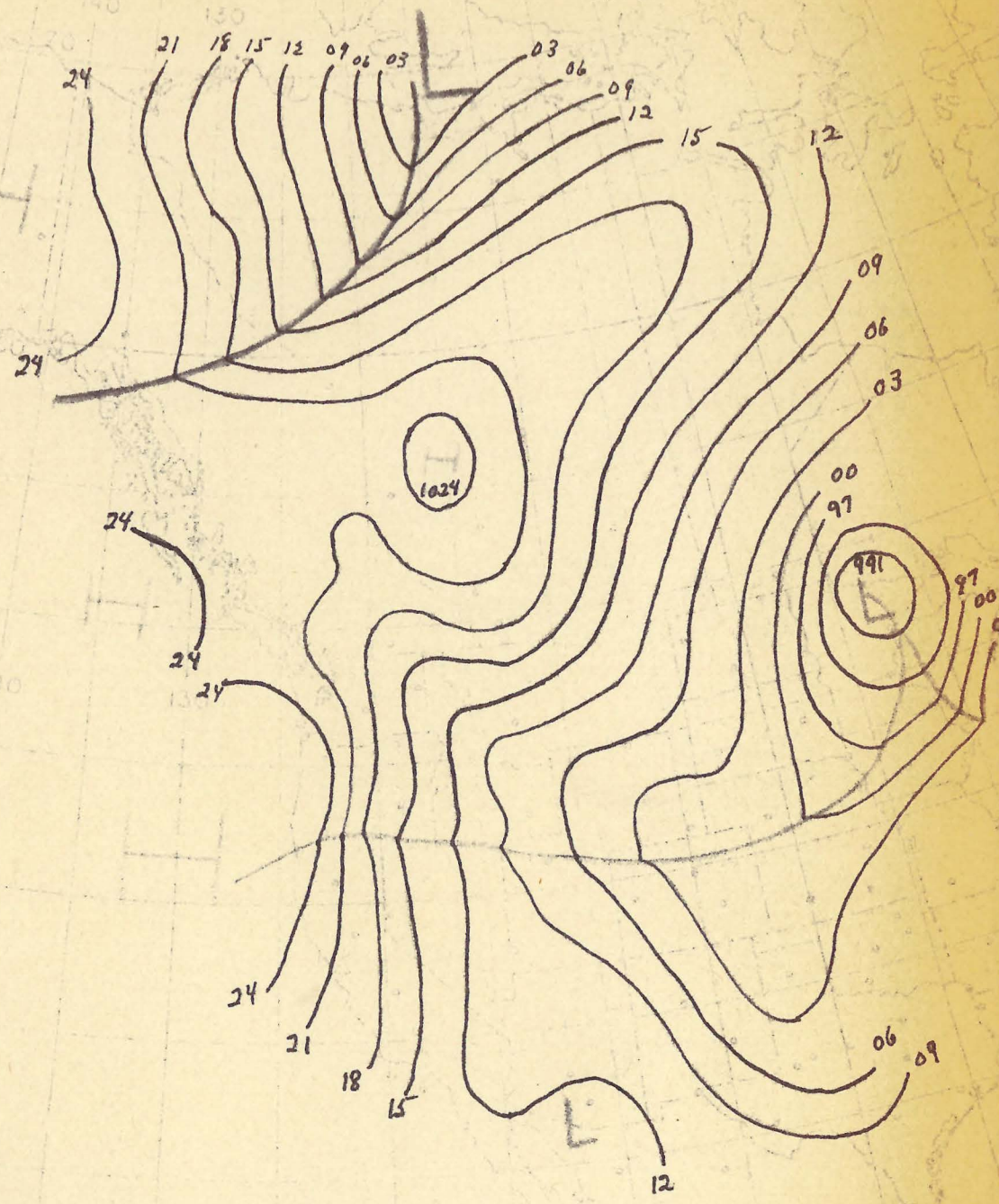
Furthermore, due to lack of data for 12 and 24 hour periods at the same station for the same frontal discontinuities, it became necessary to use very rough approximations of distances over an 8 hour period. This magnified the error 3 times as compared with a 24 hour period, which for an 80 mile error in approximating the position of the surface front would amount to a 10 mile per hour error in speed. Such an error on east-west oriented fronts moving down the coast is not out of the ordinary, especially when reporting stations in Western Canada are rather great distances apart and the exact location of the frontal surface is debatable.

The error in misplacing upper air frontal surfaces, especially with numerous upper frontal passages, undoubtedly could be largely eliminated by experience with radiosonde reports in a particular region. These two cases, i. e., March 23 and March 24, seem to be close enough to being correct to show promise that with further refinement of this method, a much more accurate prediction could be obtained. No promise is seen in longer range (2-3 days) forecasting frontal passage time because of frequent and indistinct upper and surface frontal systems.

C.I.T. Meteorology
May 25, 1944

24 March 1944
1230 G.M.T.

PLATE X



C.I.T. Meteorology
May 22, 1944

Case IX
September 25-26, 1943

Surface and upper air data was used for Medford, Oregon, and Seattle and Spokane, Washington.

Height of inversions above sea level

Medford	9,800 feet
Seattle	10,000 "
Spokane	11,800 "

Using the above data the average slope was calculated to be $\frac{1}{135}$.

The distance of the system from Medford was determined by the following equation:

$$\frac{1}{135} = \frac{9,800}{5,280 \over x}$$

$$x = 323 \text{ miles.}$$

Using the basis of a 15° of longitude movement in 24 hours the movement of the system was calculated to be 27 miles per hour, or to reach Medford in $9\frac{1}{2}$ hours. The original data was calculated from the 1330 GMT 25 September 1943 synoptic chart; therefore, the system should arrive at 2300 GMT or 1500 PST on 25 September 1943. According to the airways sequence reports a warm front passed through Medford at 0200 PST 26 September 1943.

Synoptic:-

This system has the features of a B-E Fall Type, Phase 3. The reference cell has a west-east orientation terminating in a weak wedge of high pressure extending into the west coast of the United States. In this third phase there is evidence of the approach of a migratory wedge in the rising isallobaric field over Alaska and northwestern Canada. Surface

C.I.T. Meteorology
May 22, 1944

data indicated that a trough of low pressure was approaching.

Conclusion:-

1-) Forecast time of passage- 1500 PST 25 September 1943,

2-) Actual " " " - 0800 PST 26 September 1943.

Throughout these situations the front invariably arrives later than the calculated time. In Lt. R. L. Hillyard's notes concerning this area the following statement is made:

"It is not uncommon to find a system moving slowly eastward and then veer suddenly, in a retrograde action, back towards the northwest through central or western Alaska . . . . ."

In this case it is believed that the system started a northerly trajectory before reaching the coast, therefore this method of calculation which assumes frontal systems continue their original trajectory, needs some refinement to account for retrograding and digressing movements.

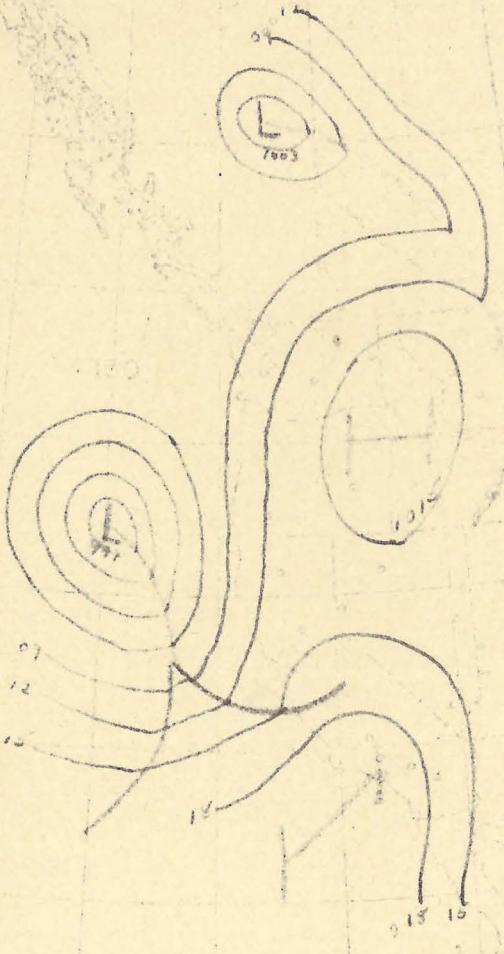
C.I.T. Meteorology
May 22, 1944

PLATE XI

SYNOPTIC CHART

25 SEPTEMBER 1943

1230 GMT



B/E FIELD PHASE (3)

C.I.T. Meteorology
May 28, 1944.

Case X
September 11-12, 1943

From available radiosonde data the heights of the frontal slope at Tatoosh and Ketchikan were calculated.

Height of inversion above sea level

Tatoosh	13,000 feet
Ketchikan	10,300 "

Using the above data the following equation was set up:

$$\frac{\frac{13,000}{5,280} - \frac{10,300}{5,280}}{300} = \frac{1}{x}$$

$x = 150$, therefore the slope of the front is $\frac{1}{150}$.

The front was calculated to be 300 miles north and west of Ketchikan. It was assumed that the system would move at a rate of 15° of longitude in 24 hours. At this latitude 15° of longitude is equal to approximately 660 miles. On this basis the system would move at a rate of 28 miles per hour. At this speed the system should have passed through Ketchikan by 0430 GCT on September 12, or 2030 PST on September 11. Airways sequence data revealed that an occlusion passed through Ketchikan near midnight on the 11th of September, 1943.

Synoptic:-

This system had the characteristics of Type D Summer, Phase I, centered northwest of Seattle somewhere in the Gulf of Alaska. The synoptic situation showed a high cell centered over upper western Canada with indications of a high with an elongated north-south extension off the west coast of the United States. A tightening of the pressure gradient and falling barometric tendencies indicated the approach of a frontal system.

C.I.T. Meteorology
May 24, 1944

Conclusion:-

1) Forecasted time of frontal passage was 2030 PST 11 September 1943,

2) Actual " " " " was 2330 PST 11 September 1943, approximately.

In this case the method worked comparatively well. While the system actually arrived some 3 hours later than calculated, there was evidence from surface reports that a diffused upper front probably passed near the calculated time. By investigation it has been found that systems approaching this area are indistinct and usually are not accompanied by the regular wind shifts and air mass discontinuities, making it difficult to determine the exact time of the arrival of the frontal system.

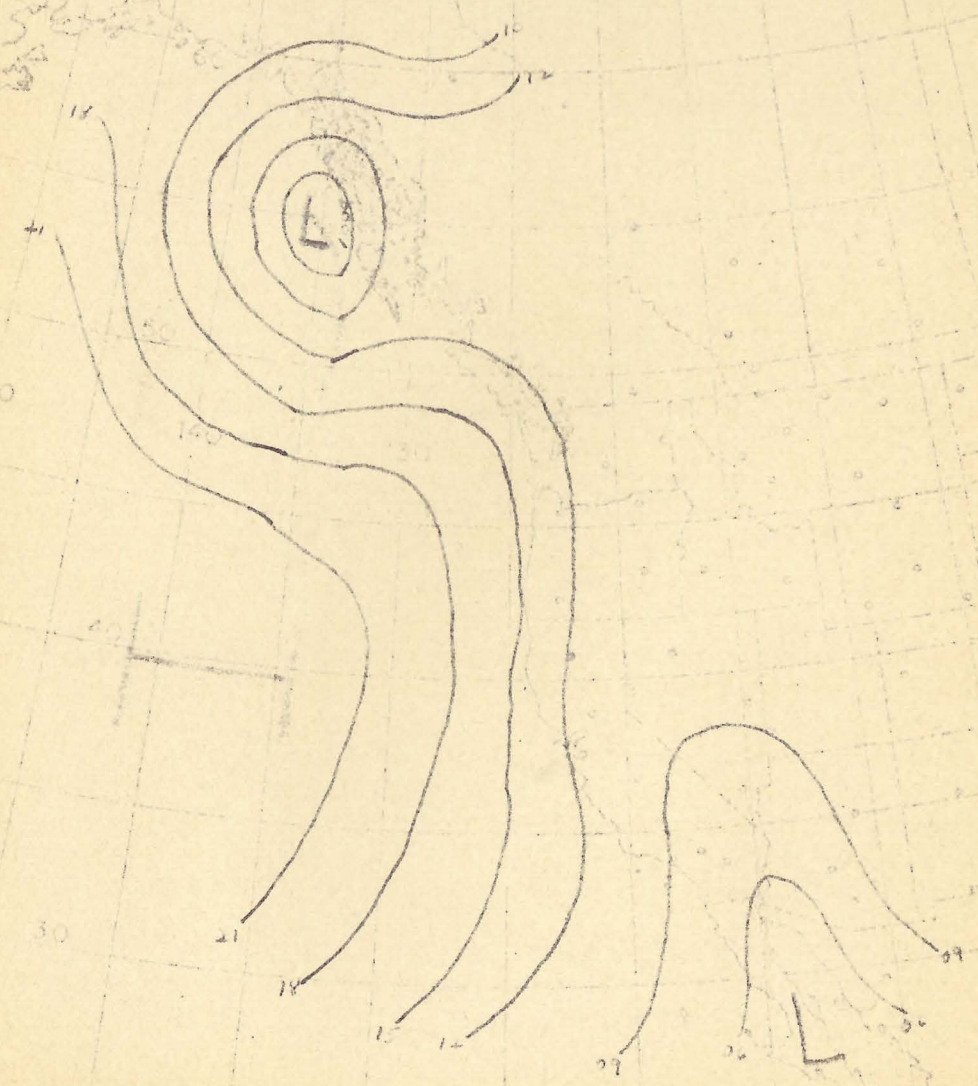
C.I.T. Meteorology
May 22, 1944

PLATE XI

SYNOPTIC CHART

11 SEPTEMBER 1943

1230 GMT



TYPE D PHASE (1)

C.I.T. Meteorology
May 25, 1944

Case XI
October 29, 1943

Using 0400 E radiosonde data the heights of the inversion were found to be:

Station	Height of inversion
Medford	12,160 feet
Tongue Point	6,210 "

Since the distance between the two stations is 270 miles the following equation may be set up:

$$\frac{\frac{12{,}160}{5{,}280} - \frac{6{,}210}{5{,}280}}{270} = \frac{1}{240}$$ the slope

of the front. Since the height of the frontal discontinuity is 6,810 feet above Tongue Point, the position of the surface front should be:

$$\frac{x}{6{,}210 \text{ (in feet)}} = \frac{240}{1} \cdot \frac{1}{5{,}280}$$

$= 281$ miles from Tongue Point. If our assumption of a constant frontal slope of $\frac{1}{240}$ is correct, this calculation locates a point on the surface front lying 281 miles from Tongue Point on the extension of a straight line through Medford and Tongue Point. Assuming a normal movement of 15° per day which in this latitude is approximately 27 miles per hour, the surface front should pass Tongue Point $\frac{281}{27} = 10.4$ hours after the rad., or at approximately 1430 Z = 0630 PST 29 October 1943.

Synoptic:-

The 1630 G.T. 28 October 1943 map indicated an occlusion with a center of 988 millibars over southwest Yukon Province. Filling pressures along the Washington-Oregon coast indicated that the occlusion extended that far south.

C.I.T. Meteorology
May 22, 1944

Conclusion:-

1) Predicted time of frontal passage was 0830 PST 28 October 1943,

2) Actual " " " " "
1030 PST 28 October 1943, as nearly as could be determined from 6 hourly synoptic reports.

The fact that this front passed 4 hours later than predicted is likely due to two principal reasons:

1) the assumed rate of approach of 15° of longitude per 24 hours may have been in error, since this rate is merely an average of all situations, and

2) the front may not have moved directly toward Tongue Point. Since the front was assumed to move straight towards Tongue Point any variation from this path would cause it to arrive later than calculated.

C.J.T. Meteorology
May 28, 1944


PLATE XII
October 29 1943
1230 GMT
06
03
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000
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21
18
09
12
15
C.I.T. Meteorology
May 22, 1944

Case XII
November 29, 1943

From investigation of the radiosonde data for 29 November the following was calculated:

Station	Height of inversion
Tongue Point	10,000 feet
Boise	14,300 "

Since the distance between the two stations is 350 miles the following equation may be set up:

$$\frac{14{,}600 - 10{,}000}{5{,}280 - 5{,}280} = \frac{1}{x}$$

$$\frac{4{,}600}{350} = \frac{1}{x}$$

$x = 390$, therefore the slope is $\frac{1}{390}$.

Calculating this front's surface location by means of its slope and its height above Medford we have:

$$\frac{390}{1} = \frac{x}{\frac{10{,}000}{5{,}280}}$$

$x = 740$ miles west of Medford.

Assuming a speed of 30 miles per hour for Medford the front should pass in $\frac{740}{30} = 24.7$ hours or at 0330 GMT on the 30th of November which is 2040 PWT on the 29th of November. The front actually passed in the vicinity of 0630 G.T. of the 30th.

Synoptic:-

This is an example of Type Bs, Phase S, on the 1230 GMT 29 November 1943 Synoptic Map. A low was centered off the southern Washington Coast with a Basin High and a low over Southern Alaska on the 29th. On the 30th it moved in with an easterly direction, moving

C.I.T. Meteorology
May 28, 1944

slightly to the north and centered off Seattle on the 30th. The discontinuity was between Polar Pacific and Polar Basin air.

Conclusion:-

1) Predicted time of frontal passage was 0340 G.C.T. 30 November 1943,

2) Actual " " " " "
0630 G.C.T. 30 November 1943, approximately.

This front moved slower than the assumed rate of 30 miles per hour. A lack of significant rawin. data may also lead to an erroneous impression of the slope

The upper front, parallel to and about 350 miles ahead of the surface trace, may have caused a diffusion of the surface front. We have encountered considerable difficulty with occlusions and upper fronts which moved in in rapid succession as they so often do along the coast.

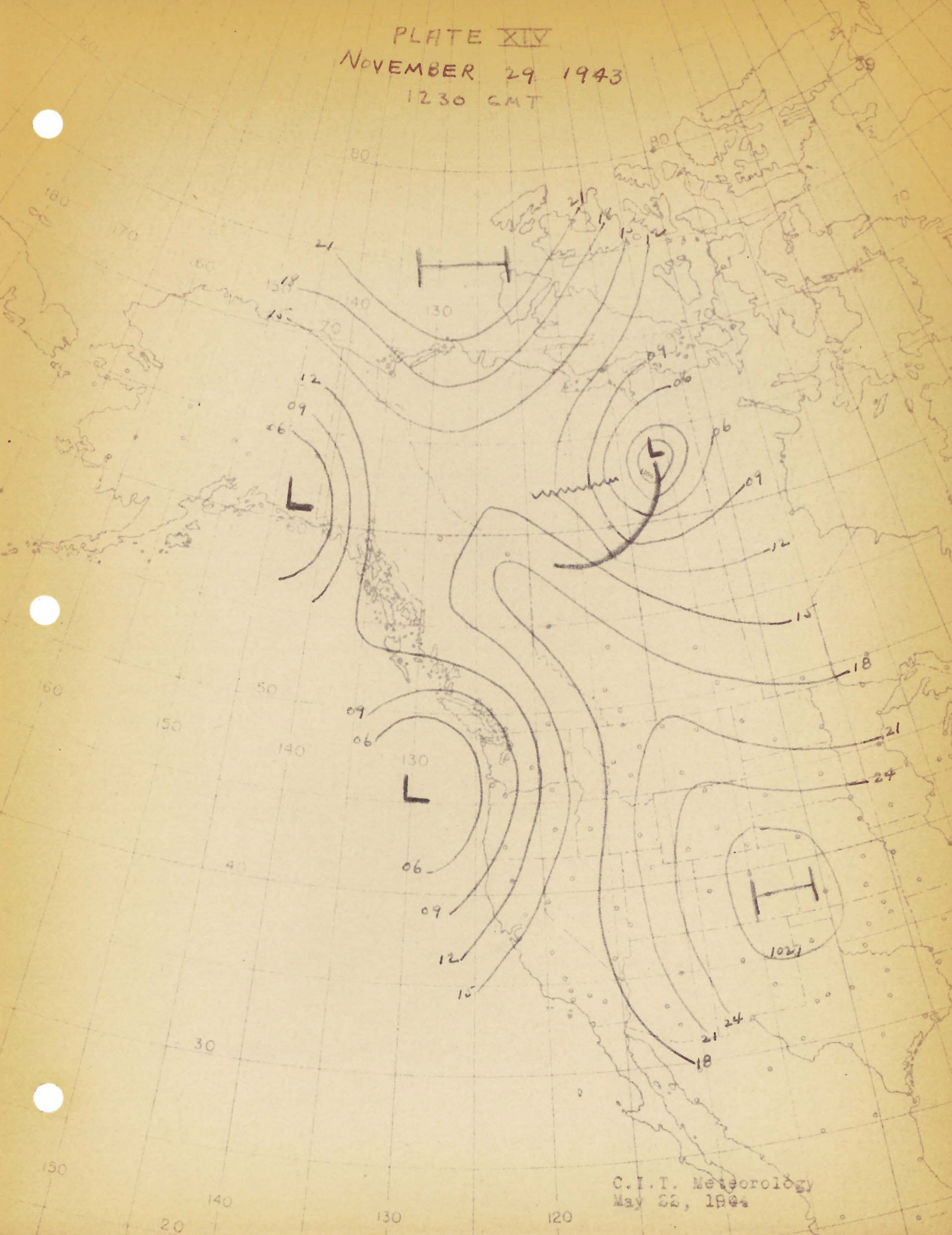
In order to draw any valid conclusion considerable detailed study would have to be made at some of the stations by the personnel therein. They would know the exact time of passage of the occlusions and fronts, and would also be able to recognize the type and intensity of these trough passages. The conclusion may be drawn that, under the foregoing conditions, the frontal passages could be forecasted with considerable accuracy; however the realization of these conditions is beyond the immediate scope of this project.

C.I.T. Meteorology
May 22, 1944

PLATE XIV

NOVEMBER 29 1943

1230 GMT



C.I.T. Meteorology
May 22, 1944

Case XIII
February 1, 1943

From 04 GMT radiosonde data the following was calculated:

Station	Height of inversion
Medford	1660 feet
Spokane	10,650 "
Boise	7,630 "

Distance between Spokane and Medford in an east-west direction is 270 miles.

Difference between heights above Medford and Spokane = 10,650feet - 1860 feet = 8790 feet.

Therefore,

$$\frac{\frac{8790}{5660}}{270} = \frac{1.65}{270} = \frac{1}{x}$$

$x = 160$ therefore the slope is $\frac{1}{160}$.

To calculate the location of the surface front:

$$\frac{1}{160} = \frac{0.35}{x}$$

$x = 56$ miles west of Medford.

At a speed of 27 miles per hour the front should have reached Medford in two hours, or at 0600 GMT 1 February 1944. The front actually reached Medford shortly before 0630 GMT.

Synoptic:-

A partially occluded front was centered at 55° north latitude and 140° west longitude, extending south-southwest to 36° latitude and 148° longitude. A warm front extended from 51° latitude and 135° longitude to 42° latitude and 128° longitude. An extensive precipitation area existed ahead of the front. High

pressure over the western United States was centered in southwestern Wyoming. A small weak high was centered over Yukon northeast of the front.

Conclusion:-

A speed of 37 miles per hour was apparently a valid assumption in this case. However, the front was so close to Bedford at the time of the radiosonde sounding that other factors such as precip. and pressure tendency may have been of more value in forecasting the movement of the front than were the calculations made above.

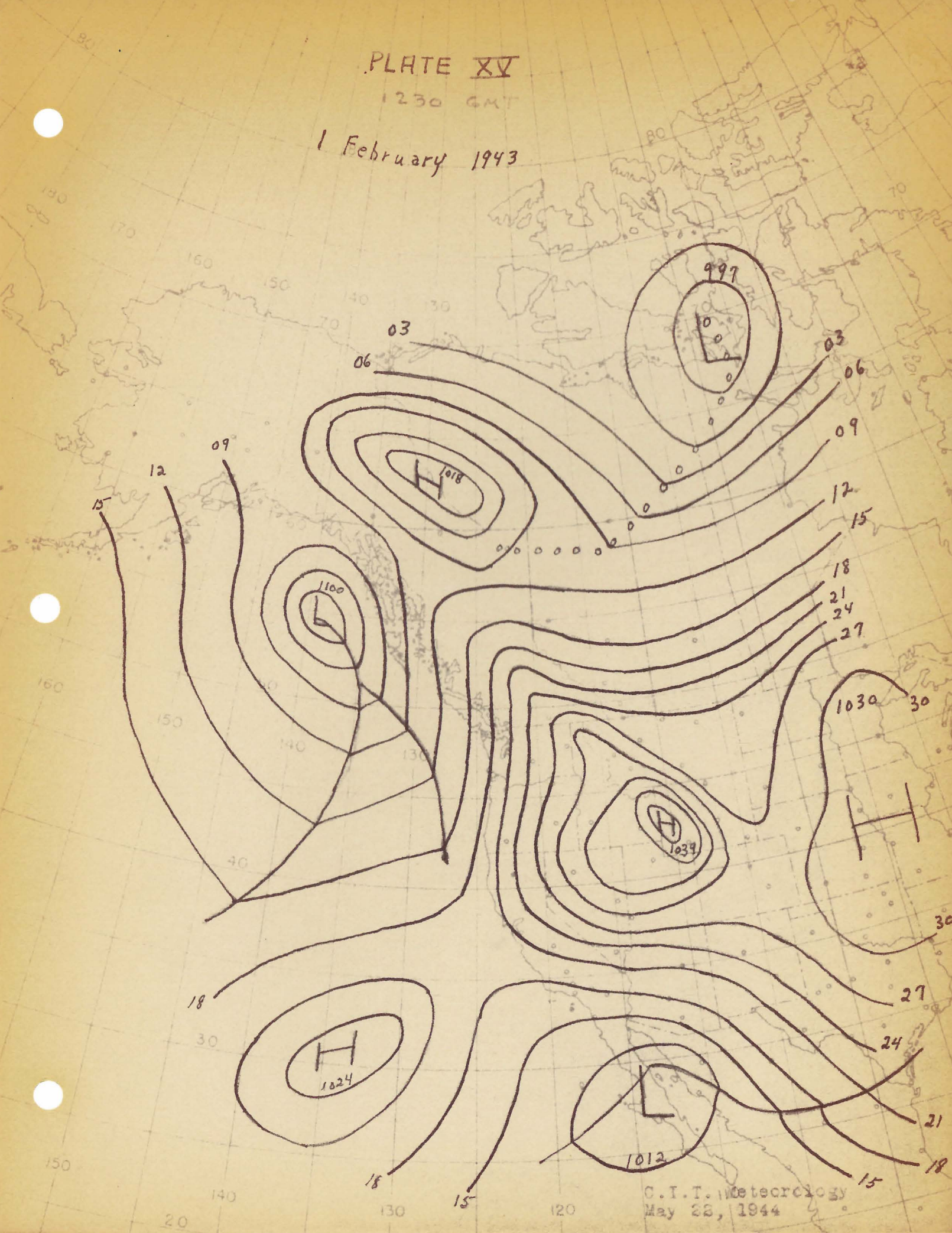
The front in this case actually reached the station at approximately the time forecasted.

C.I.T. Meteorology
May 28, 1944

PLATE XV

1230 GMT

1 February 1943



C.I.T. Meteorology
May 28, 1944

Case XIV
February 10, 1943

From 04 GMT radiosonde data the following was calculated:

Station	Height of inversion
Medford	6,700 feet
Spokane	14,300 "

Using the distance between the two stations as 270 miles and the heights of the inversion from the table above, the slope may be calculated:

$$\frac{\frac{14,300}{5,280} - \frac{6,700}{5,280}}{270} = \frac{1}{x}$$

$$\frac{1.45}{270} = \frac{1}{x}$$

$x = 186$, therefore the slope $= \frac{1}{186}$.

To calculate the location of the surface front:

$$\frac{1}{186} = \frac{\frac{6,700}{5,280}}{x} = \frac{1.27}{x}$$

$x =$ 236 miles west of Medford. At a speed of 27 miles per hour, it should reach Medford in 8.8 hours or at 1240 GMT 10 February 1943. It actually reached Medford shortly before 1230 GMT on the 10th with considerable instability showers succeeding the passage.

Synoptic:-

An occluded front with a low center of 970 millibars was located at 126° west longitude and 53° north latitude, with the cold front extending southwestward, and the warm front extending almost due south. A fairly extensive precip. area extended along the coast.

C.I.T. Meteorology
May 28, 1944

A basin high of 1036 millibars was centered 150 miles west-southwest of Salt Lake City, Utah.

Conclusions:-

1) The predicted time of frontal passage was 1240 GMT 10 February 1943,

2) The actual " " " "

was slightly before 1230 GMT 10 February 1943, as nearly as could be determined from available data.

This surface front was fairly wide and difficult to define sharply. Nevertheless this forecast of its movement was reasonably accurate, indicating once more that a speed of 27 miles per hour is very nearly correct for fronts moving across the North Pacific in the latitude of Medford. Six-hourly airways make it extremely difficult to determine the exact time a front passes a given station.

C.I.I. Meteorology
May 28, 1944

PLATE XVI

SYNOPTIC CHART

10 FEB 1944

1230 GMT



C.I.T. Meteorology
May 25, 1944

Case XV
APRIL 6-7, 1944

Situation:-
Falling barometric tendencies and configuration of isobars on the April 6, 1944 synoptic weather chart indicated a frontal system to the west.

Calculations:
From radiosonde data for Seattle and Tatoosh the height of frontal inversions were found:

Height of inversions above sea level:
Seattle 15,500 feet
Tatoosh 14,800 "
(The two stations are 125 miles apart)

The slope of the front was found by the following equation:

$$\frac{15{,}500 - 14{,}800}{125} = \frac{1}{126} = \text{slope}$$

The position of the front was calculated to be 390 miles west of Seattle at 1230 GMT 6 April 1944, having a north - south configuration. It was assumed that the front moved at a rate of 15° of longitude in 24 hours. At the latitude of Seattle 15° of longitude is approximately equal to 700 miles. On this basis the speed of the front is 27 miles per hour and should reach Seattle at 0230 GMT 7 April 1944, or 1830 PST 6 April 1944.
Actually a front passed through Seattle at 0030 PST 7 April 1944, according to teletype reports.

Conclusion:
Because of the irregular frequency with which a major system off the west coast "throws off" upper fronts, this method can be said to give only a rough estimation of the time that fronts are expected to arrive at a given coastal station. In this situation of April6-7, 1944, the front arrived 6 hours later than the calculated time. This was probably due to the orographic influence of the coastal range on a fast moving system.

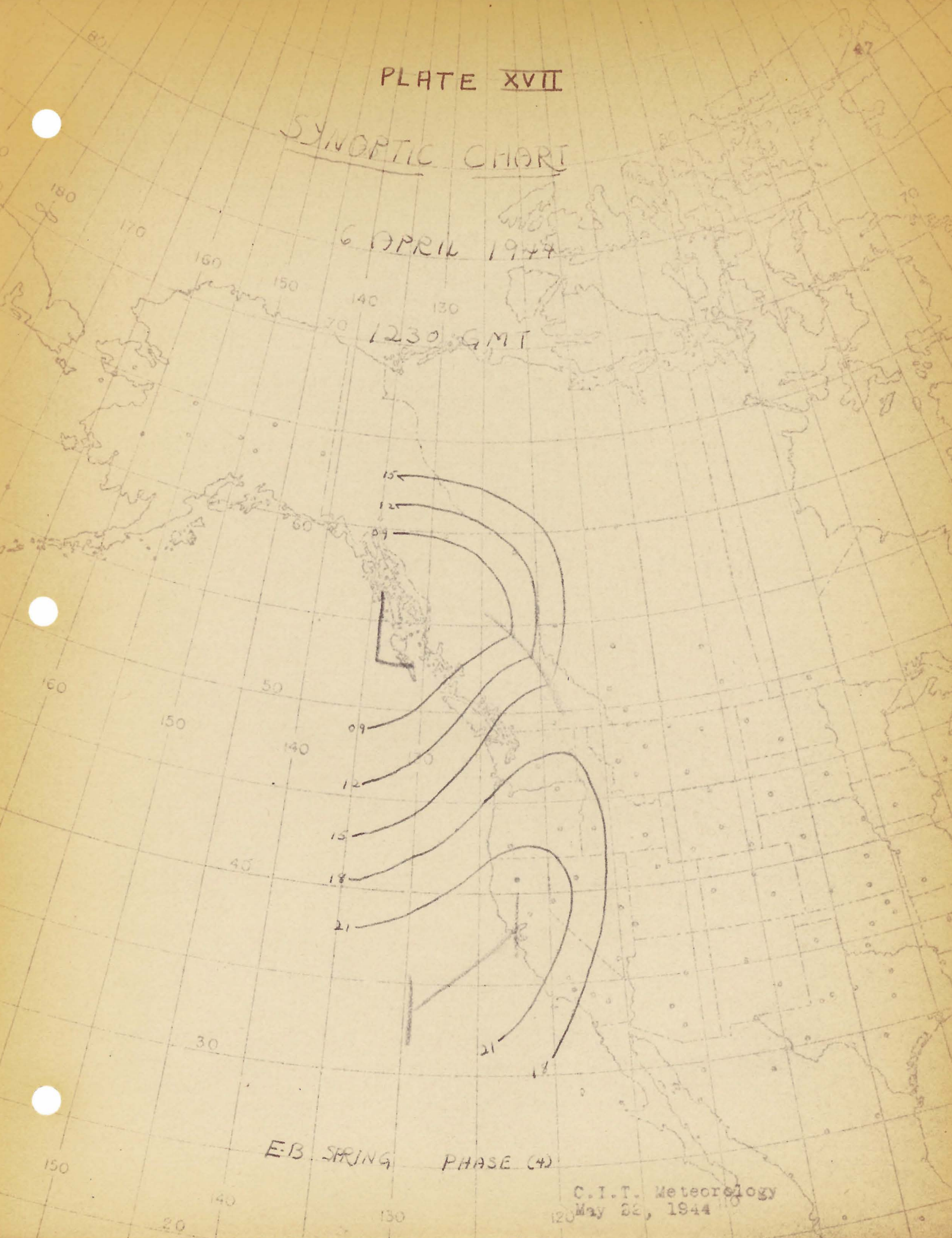
C.I.T. Meteorology
May 22, 1944

PLATE XVII

SYNOPTIC CHART

6 APRIL 1944

1230 GMT



E.B. SPRING PHASE (4)

C.I.T. Meteorology
May 22, 1944

Case XVI
April 25-26, 1944

Situation:

Surface data and configuration of isobars in Seattle, Washington, area indicate the presence of a frontal system somewhere to the west.

Calculations:

Taking radiosonde data for Tongue Point and Ketchikan, 270 miles west of Tongue Point, the height of the frontal inversions were found.

Height of inversions above sea level:

Tongue Point	19,200 feet
Ketchikan	15,600 "

Using this data the following equations were set up:

$$\frac{\frac{19,200}{5,280} - \frac{15,600}{5,280}}{270} = \frac{1}{x}$$

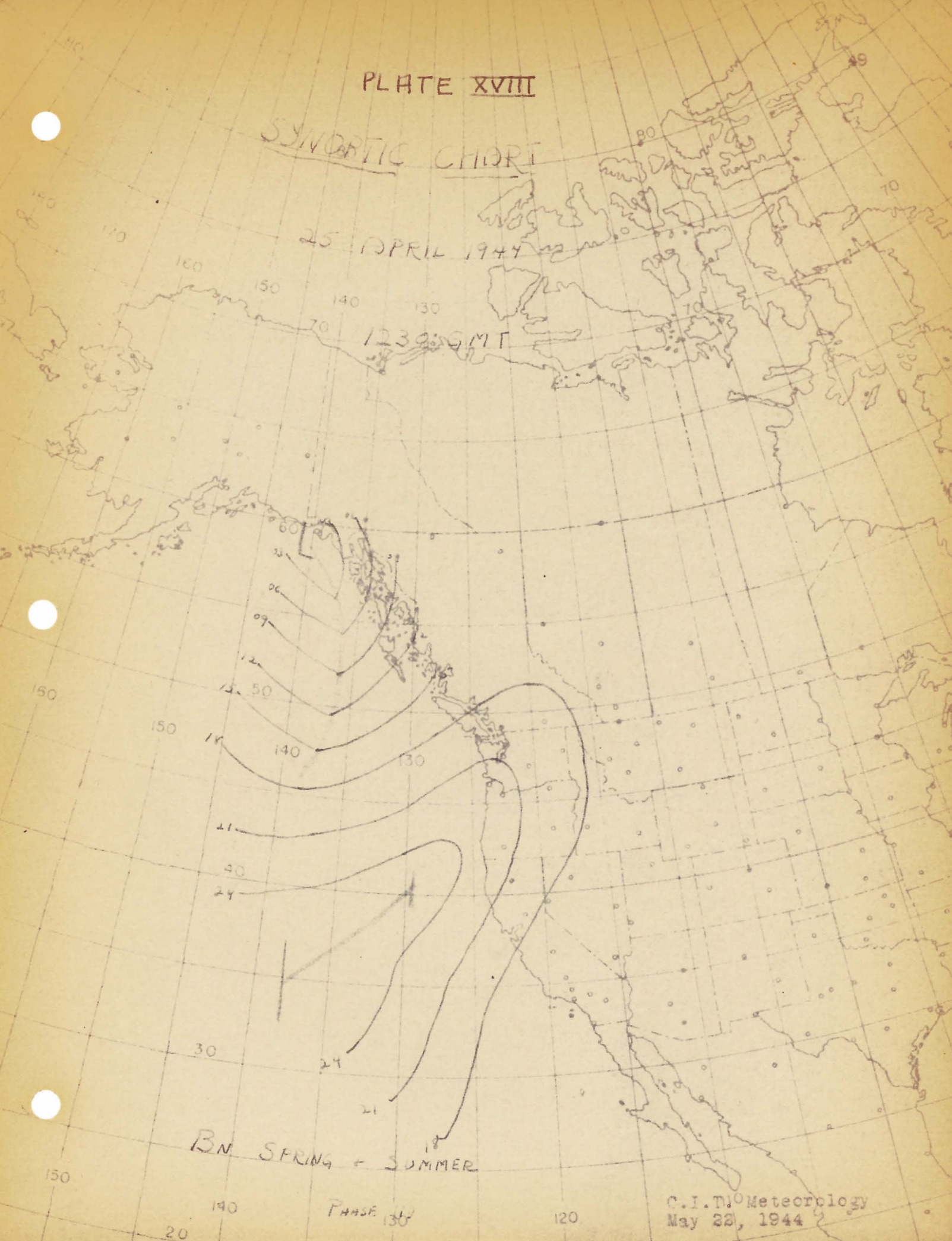
$$= \frac{1}{189}$$ which is the slope of the front.

From the calculated data the position of the frontal system at 1230 GMT 25 April 1944 was found to be 710 miles west of Tongue Point. It was assumed that the frontal system moved at a rate of 15° of longitude in 24 hours. At the latitude of Tongue Point, 15° of longitude is equal to 700 miles. On this basis the speed of the system is 27 miles an hour and should reach Tongue Point at 1800 GMT, or 1000 PST, on 26 April 1944.

Conclusion:

For this situation the assumption of a 15° per 24 hour movement for a frontal system seems quite accurate. That the occlusion reached Tongue Point 3 1/2 hours later than the calculated time could be due to the fact that systems tend to stagnate, temporarily, near the coast, and send off upper fronts across the mountains, the main system finally moving inland.

C.I.T. Meteorology
May 22, 1944


PLATE XVIII
SYNOPTIC CHART
25 APRIL 1944
1239 GMT
BN SPRING + SUMMER
PHASE
C.I.T. Meteorology
May 28, 1944

Case XVII
September 3-4, 1943

Pseudo-adiabatic charts were plotted for Seattle and Spokane, Washington, and a slight inversion in the lapse rate indicated the presence of a front.

Station	Height of inversion above sea level
Seattle	14,600 feet
Spokane	15,300 "

The slope was then calculated to be $\frac{1}{190}$. Using this slope and the known height of the frontal surface above Seattle and Spokane, the system was calculated to be 650 miles from Seattle at 1230 GMT 4 September 1943. It was assumed that the system would move 15° of longitude in 24 hours. At this latitude such a frontal movement would amount to 27 miles per hour. On this basis the front should reach Seattle at 1230 GMT or 0430 PST on 4 September 1943. The 1230 GMT synoptic chart for that date showed the front running east-west through Seattle.

Synoptic:-

The synoptic chart for September 3rd showed characteristics of a type A-B (Summer and Early Fall), Phase 5. A high cell was centered over the Great Basin area with a frontal system located in northwestern Canada. The upper level charts as well as surface charts indicated that this system would have a trajectory through Washington State, thus making it advisable to use radiosonde data from Seattle and Spokane.

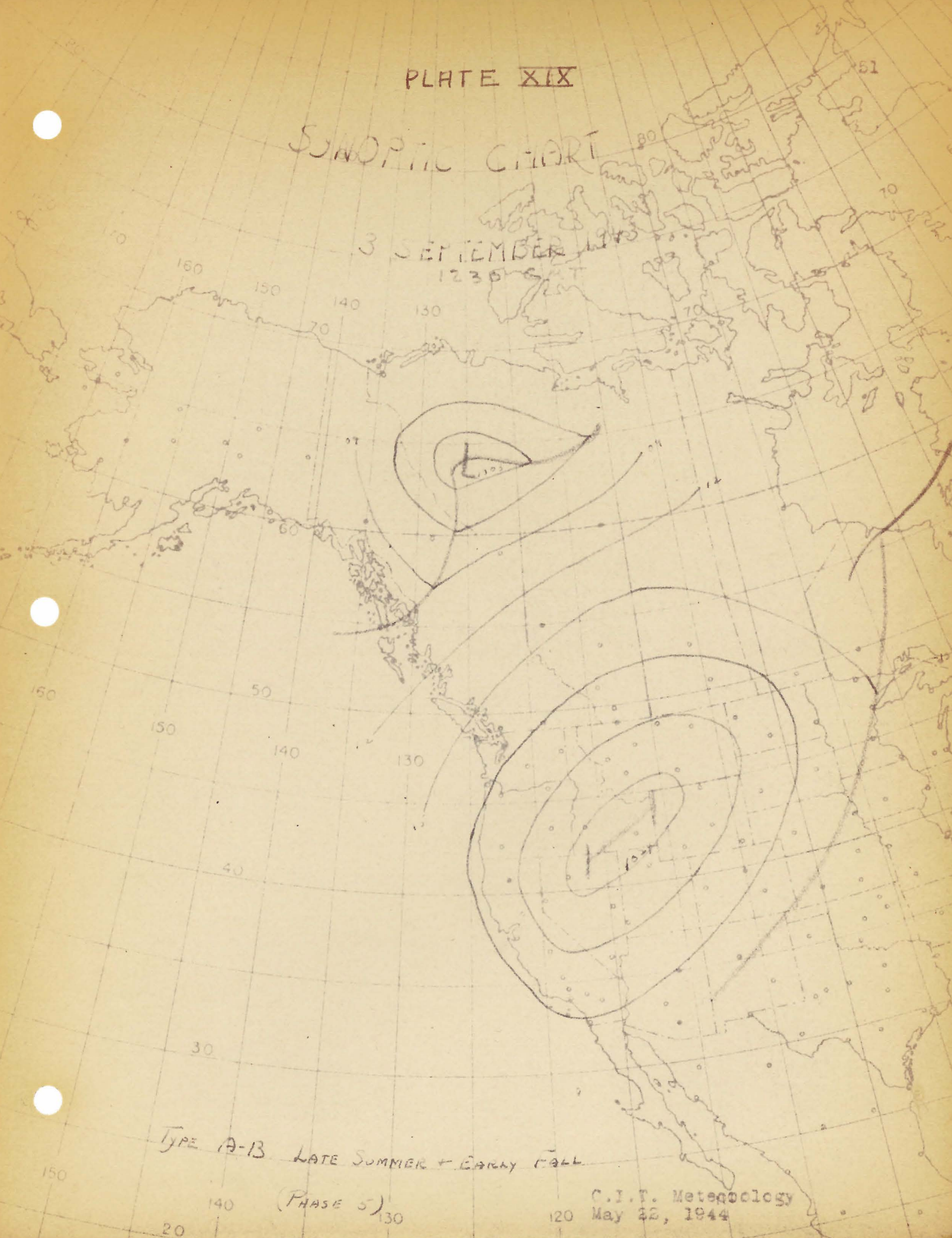
Conclusion:-

1) Predicted time of frontal passage was 1230 GMT 4 September 1943,
2) Actual time " " "
" 1230 GMT 4 September 1943.

In this situation the method was found to be quite accurate. A fair assumption might be then that when a system has a continental trajectory, this method may be expected to attain considerable accuracy.

C.I.T. Meteorology
May 22, 1944

PLATE XIX



TYPE A-13 LATE SUMMER + EARLY FALL

(PHASE 5)

C.I.T. Meteorology
May 22, 1944

SYNOPSIS OF JANUARY 1943

Introduction: The aim of this portion of this project is, rather than selecting specific instances and forecasting the time of arrival of a front at the west coast, to apply that principle to a complete month of synoptic charts. January, 1943, was selected somewhat at random. Some consideration, however, was given to the fact that definite fronts were moving on the coast throughout the entire month.

Procedure: The month will be covered day by day, correlating the radiosonde data and the synoptic situation. The time of passage of a front will be determined by the path method from the C.I.T. 5X8 charts. This method is used because the only available material for that date are six-hourly synoptics. The method used in determining the slopes of the approaching fronts is the same as explained elsewhere in this paper. Whenever possible the slope will be calculated and a forecast made as to time of passage of the surface front. The forecast will be verified in chronological order. The principal stations considered will be the stations of Washington, Oregon, Idaho, British Columbia, and Northern California. The weather types are taken from the C.I.T. Catalogue of Types.

January 1 -- Synoptic situation: Weak front oriented in east-west direction through southern Oregon and weakening off the coast, trailing into a low center indicated at 150 degrees west longitude; Polar Pacific air throughout the region with a weak low center in northern Wyoming; a 1027 Polar Continental High over western Canada. Thunder was heard at the station in Spokane, and alto-stratus and alto-cumulus persisted throughout the area, ranging from 3/10 to 10/10 cloud cover. Weather type is phase 1, BE winter.

The radiosonde data of coastal stations indicated no approach of a frontal system except a double inversion at the level of, or near, the tropopause, at Spokane and Medford.

January 2 -- Synoptic situation: The system located through Oregon and southern Idaho on January 1 is located with the center in southern Idaho, and the orientation is northeast- southwest. There is a general crowding of the isobars throughout the area extending in a north-south direction along the western coast of Canada. The low in the Pacific has moved northward, the center now being at 140 degrees west longitude, 55 degrees north latitude.

Radiosonde data: A temperature discontinuity approaching an isothermal condition appeared on the radiosonde at Medford at 6300 meters. At Tongue Point the relative humidity shows an increase with a constant w value in the

layer at 5000 meters, indicating the system to be with its center north of Medford.

January 3 -- Synoptic situation: A high pressure area is dominating the northwest area, with a low pressure area remaining stagnant at its January 2 position. Weather type is phase 3, BE winter.

Radiosonde data: None available.

January 4 - - Synoptic situation: The high pressure area is now south and centered over Nebraska with 1039 pressure. The low in the Gulf of Alaska has begun to fill, and a B wave is shown off the coast, centered at 50 degrees north latitude and 142 degrees west longitude. Weather type is phase 4, BE winter.

Radiosonde data: Medford indicates a definite temperature inversion at 1100 meters MSL with a second inversion at 4100 meters. Boise, Idaho, has an inversion at 2300 meters. No upper inversion is shown. An isothermal layer is shown at 3800 meters at Spokane. At 2900 meters at Fort Nelson, British Columbia, a very slight inversion is indicated. Calculating the slope of discontinuity by the method described elsewhere in this paper, the slope is 1/123. Also from January 3 to January 4 the frontal slope has lowered from 6300 meters at Medford to 1100 meters. Using these values to determine the velocity of the approaching low center, we find it to be approximately 800 miles in 24 hours. The inversions at higher levels were not used in the calculation because no historical trace could be made of them. From the above data a frontal passage is forecast for 9 hours after the sounding.

January 5 -- Synoptic situation: The synoptic map shows a frontal system lying just east of the Rockies and trailing down through Central Nevada and California westward to the Pacific. The main system is moving northward and remaining off shore with the center at 140 degrees west longitude and 58 degrees north latitude. By the path method the frontal passage is verified within 3 hours. Weather type is phase 5, BE winter.

Radiosonde data: None available.

January 6 -- Synoptic situation: The occlusion centered off the coast has moved in east of the Rockies and a secondary system is off the coast with a frontolysis situation connecting the second system of the Pacific and the old occlusion of the eastern Rockies. This passes through Idaho and southern Oregon. The Seattle area is under the complete influence of Polar Pacific air.

Radiosonde data: A definite inversion is shown at Tongue Point with an increase in temperature and w values. The remaining stations have a number of inversions shown, but nothing definite could be associated (from them) with the approaching frontal system. This is the last day of type B winter.

January 7 -- Synoptic situation: A large Polar Pacific high has moved into the Washington area, with the wave that was off the coast moving northward, centering at 140 degrees west longitude and 52 degrees north latitude. It is shown as an occlusion extending along the coast south to 45 degrees north latitude. Phase1, type BN.

Radiosonde data: Available radiosonde data gives no indication of the approaching system on January 7. Fort Nelson, lying 600 miles inland in northern British Columbia, does not seem to indicate an approaching system by an inversion or air mass discontinuity. The synoptic situation and radiosonde data indicate considerable cloud cover throughout the area at approximately 9000 meters. This inversion is characterized by an intense temperature inversion and a definite decrease in w values. This inversion is due to subsidence. Spokane shows an increase of 30 percent in relative humidity at 5800 meters and Sand Point, Washington, shows an iso-w value between 3800 and 4000 meters with a sharp increase in relativ e humidity from 33 to 52 percent. By selecting these levels, the one of 5800 meters at Spokane and the Sand Point value, the front can be located approximately 500 miles to the west of Spokane, with a slope of 1,160. No forecast can be made from the slope, but assuming a 15° per 24 hour movement, the front should pass Spokane 16 hours after the radio sounding, or at 2400 on January 7.

January 8 -- Synoptic situation: The occlusion along the coast has moved rapidly inland and joined with the old occlusion lying east of the Rockies on January7. The Polar Pacific high is holding in the area of Washington. The front moved well to the north of the state of Washington. The latitudinal location of the centers verfies the calculations of the frontal location made on January 7 and the assumption of normal eastward velocity. A new system is shown well off shore centered at 150 degrees west longitude and 54 degrees north latitude, extending southwestward to 155 degrees west longitude and 40 degrees north latitude. Phase 2, type BN.

Radiosonde data: The subsidence inversion remains and is intensifying, but there is no indication of the approaching system. For a slope of 1/100 the air mass differential line would be well above the sounding, assuming the location of the front to be correct.

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January 9 -- Synoptic situation: The occlusion has moved inland with the center at 140 degrees west longitude and 55 degrees north latitude. It passes through British Columbia but trails well off the coast east of Washington.

Radiosonde data: Fort Nelson shows a sharp inversion at 3600 meters. Assuming approximately the same slope as the preceding system, 1/160, the front should be 400 miles west of Fort Nelson. Actually it is shown on the chart to be 300 miles west, with Polar Pacific air throughout the area. The second system has moved well to the north. No indication is present in the soundings to the south of Fort Nelson. Phase 3, type En.

January 10 -- Synoptic situation: All fronts are out of the area, and a Polar Pacific high cell is starting to move south. A system is shown far off the coast, centering at 150 degrees west longitude and 50 degrees north latitude.

Radiosonde data: Subsidence inversion is distinct. There is no inversion indicative of Pacific system. Phase 4, type En.

January 11 -- Synoptic situation: A frontal system is shown off the coast of British Columbia with a high pressure belt to the east, extending southward to southern Nevada. A second wave is in the Pacific. Phase 3, En winter.

Radiosonde: No indication of front. Subsidence remains.

January 12 -- Synoptic situation: Occlusion off coast of British Columbia has undergone frontolysis and a simple system is centered at 140 degrees west longitude, 60 degrees north latitude, and extending southwestward to 150 degrees west longitude, 40 degrees north latitude. Orientation of main system is approximately north-south from northern British Columbia to northern United States. The system is well occluded. Phase1, type PA.

Radiosonde data: Spokane has low value inversion at 4100 meters. Sand Point shows a more intense w inversion at 3500 meters, i.e. increase in w value. The slope is calculated to be 1/160. Assuming the front to be somewhat north of Sand Point, since the high is persisting in the Washington area, the slope would be more acute. However, using the calculated slope the front would be on the surface 350 miles east of Sand Point. This is within fifty miles of the location on the map. Assuming 15 degrees movement, the front should pass Sand Point 12 hours after the sounding, or at 2000 on January 12. The subsidence inversion is still persisting.

January 13 -- Synoptic situation: The system has developed into two waves; the first wave is in central

Canada, the second in northern British Columbia. Phase 2, type BA.

Radiosonde data: Frontal inversion at Sand Point is at 600 meters and at Spokane at 1600 meters. This inversion is due to the wave off the coast. The system is far to the north of both Spokane and Sand Point. The inversions indicate a slope of 1/350, which is again too shallow due to the location.

January 14 -- Synoptic situation: The wave is stagnant in northern British Columbia, and the general isobaric pattern has weakened. An upper front is indicated with a north-south orientation through British Columbia, with a cold front off shore. The center is at 135 degrees west longitude, 60 degrees north latitude. Phase 3, type BA winter and early spring.

Radiosonde dat : There is a sharp W increase at 6500 meters at Spokane. - 10/10 stratus cover at Tongue Point with a strong surface inversion renders the data at that station unreliable. Western shows an increase in relative humidity at 7500 meters. If the Medford sounding at 6500 meters is associated with the front the slope is 1/240. The surface front should be located 825 miles to the northwest. Assuming a normal 15 degree movement, the surface front should be in the immediate area of Spokane 36 hours after the sounding.

January 15 -- Synoptic situation: The synoptic map shows a front centered at Spokane and lying in a southwesterly direction across northwestern Oregon. This synoptic chart is 36 hours after the sounding of January 14, and the forecast of the progress is verified within two hours. This is phase 4, type BA winter and early spring.

Radiosonde data: The entire area is overcast with stratus. Oakland, California, has no frontal inversions but is showing an increase in W values and temperature.

January 16 -- Synoptic situation: The frontal system has moved south into Utah and California, with a strong Polar Continental outbreak moving from Alaska. Phase 5, BA winter and early spring.

Radiosonde: No data available.

January 17 -- Synoptic situation: The Polar Continental outbreak is influencing the whole area. A frontal system is indicated, centered at 51 degrees north latitude and 146 degrees west longitude. The Polar Continental

outbreak has extended over into the Pacific ahead of the approaching system. Phase 6, BA winter and early spring.

Radiosonde data: Tongue Point shows an isothermal layer at 2800 meters, Spokane a distinct lapse rate discontinuity at 3400 meters. Medford, Oregon radiosonde indicates an inversion in temperature at 4200 meters; also a slight inversion at 6700 meters. By calculation of the slope from the inversions the result is 1/180, which would put the surface front 350 miles off shore. The synoptic map shows the system to be approximately 700 miles west of the Washington coast. Tongue Point radiosounding also shows a relative humidity and T value increase with a lapse rate in temperature approaching an isothermal at 4300 meters. This slope calculated from these particular figures is 1/320. This figure would indicate the surface front to be 640 miles off shore. Forecasting from the slopes, assuming 15 degree longitudinal movement in 24 hours, the first slope will move the front through Tongue Point 15 hours after the sounding. The second, which could seem more reliable because the relative humidity, temperature, and mixing ratio all show increases, placed the front in the vicinity of Tongue Point at 15 30 GMT, January 16.

January 18 -- Synoptic situation: The frontal system forecast for Tongue Point is shown 300 miles west of Tongue Point with the large Polar Continental high centering over Washington. The failure of the Pacific system to reach Tongue Point may be explained to be a result of the retarding effect of the Polar Continental high. Phase 7, BA winter and early spring.

Radiosonde data: Tongue Point sounding does not show a definite inversion. An isothermal layer is indicated from 1400 to 1800 meters. Spokane has an inversion in temperature at 3800 meters. Neither case, however, is sharply enough defined for calculating the slope. By using the two figures given, the front should be approximately 300 miles off shore. Also the frontal slope has steepened from approximately 1/320 to 1/200. Taking an average of the two the slope would be 1/260. This value places the front 240 miles off shore, which, according to the synoptic situation, is a fairly reliable figure. Forecast is for the front to move by Tongue Point in 24 hours. Using the path method for velocity and the slope for the location, it should reach Tongue Point at 2000, January 18.

January 19 -- Synoptic situation: This is the first phase of an EC winter type. The synoptic map shows the Polar Continental high to be east of the Rockies, with a very intense isobaric pattern and frontal system centered just north of the northern boundary of Washington, and

extending an occlusion south along the coast to northern California. A second occlusion is directly following the first system, and is centered 500 miles west of the coast. Evidently the Polar Continental high further retarded the movement of the system, and the forecast was not verified with any accuracy.

Radiosonde data: The sounding at Spokane shows a discontinuity in temperature and mixing ratio at 1600 meters; it is not very pronounced. This value bears out the slope obtained on January 18 of 1/200, and locates the front just off the coast. The remaining stations on the coast are under the influence of the front and cannot be used.

January 20 -- Synoptic situation: The two occlusions have intensified and centered in Washington as separate systems. The second system extends as an occlusion, and warm front off shore southward to lower California. The first occlusion is inland. Phase 2, EC winter.

Radiosonde data: None available.

January 21 -- Synoptic situation: The system is weakening and moving southward along the coast. The center is off the northern California coast. Phase 3, type EC winter.

Radiosonde data: There is a temperature inversion and an increase in mixing ratio at Tongue Point at 3200 meters. Spokane has a similar situation at 4700 meters. The slope is 1/250. A system should be located 500 miles off shore.

January 22 -- Synoptic situation: No system is in the Pacific area to verify the forecast of a front 500 miles west of Tongue Point on January 21. A weak occluded wave is centered 450 miles off the northern coast of California, but apparently has no connection with the data of January 17. Phase 4, EC winter.

Radiosonde data: At Oakland the only available data shows a discontinuity at 4600 meters. Assuming a slope of 1/200, which is the average of all cases thus far considered, the front should be 300 miles off shore. If the front moves 15 degrees west in 24 hours it should be located in central Utah on January 23.

January 23-- Synoptic situation: The wave off the coast has completely occluded and is centered in Utah, thus verifying the forecast of January 22, Phase 5, type EC winter.

Radiosonde data: The area soundings do not indicate any approaching systems. Tongue Point has a slight temperature and mixing ratio increase that has remained constant at approximately 2800 meters for two days. No frontal

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approach is forecast.

January 24 -- Synoptic situation: A Polar Continental outbreak is influencing the Washington region. The wave, centered in Utah on the twenty-third, has moved east of the Rockies. A partially occluded wave is in the Pacific, centered at 48 degrees north latitude and 145 degrees west longitude. Both the Polar Continental outbreak and the system in the Pacific are intense. Phase 6, type EC winter.

Radiosonde data: None available

January 25 -- Synoptic situation: The Polar Continental high has begun to move eastward and into the basin area. The system off the coast has become a well occluded system and has move northwestward, now being centered at 137 degrees west longitude and 50 degrees north latitude. The isobaric pattern is extremely steep along the entire coast from northern California to Alaska. A second wave is shown developing on the cold front of the occluded system. This wave is located at 140 degrees west longitude and 37 degrees north latitude. This is the first phase of an EM winter.

Radiosonde data: The data at Spokane does not give any indication of the approaching system. Medford, Oregon, shows a very high relative humidity value at 2200 meters. However, there is no increase in mixing ratio and no temperature inversion. Therefore the sounding is of little use in forecasting either the location of the front or its position. The high relative humidity content in this case probably indicates an unaccounted for cloud layer. No forecast can be made from the radiosonde information.

January 26-- Synoptic situation: Phase 2 of EM winter type on the synoptic map has a well occluded system centered just off the coast of British Columbia at 54 degrees north latitude, and moving inland down the coast to northern California. It is attached to a second system beginning to occlude, located at 140 degrees west longitude and 48 degrees north latitude. The Polar Continental high is completely out of the area.

Radiosonde data: Medford, Oregon, is the only sounding that offers any possibility of a forecast. Spokane is under the influence of the occlusion which has already passed Medford. Sand Point is very near the center of the occlusion. Medford has an isothermal layer at 4900 meters with an increase in mixing ratio. The relative humidity is 84 percent throughout the level. A forecast will be made

from this, because of the mixing ratio increase. Assuming a slope of 1/200 the next system should lie 615 miles west of Medford. Actually the center, as shown on the synoptic chart is approximately 850 miles west of Medford.

January 27 -- Synoptic situation: An occlusion along the coast of Washington is the same occlusion that was shown 850 miles west of the coast on the chart of January 26. This occlusion, assuming normal movement, may have definitely been associated with the discontinuity at Medford on January 26. The location of the system, assuming a slope of 1/200, was 615 miles west. There is no means of checking whether or not the Medford sounding and the frontal surface were in any manner connected. Phase 3, type EM winter.

Radiosonde data: The radio soundings do not indicate any approach of further frontal systems.

January 28 -- Synoptic situation: The fourth phase of the EM winter has a low center along the coast of northern Washington with an upper front through Utah. The area is occupied by Polar Pacific air.

Radiosonde data: All soundings show stable lapse rates with steady decrease in mixing ratio, with the exception of Oakland, which has a very weak inversion at the top of a cloud layer. There are no frontal approaches.

January 29 -- Synoptic situation: A weak occlusion is shown off the west coast of Oregon. A frontolysis area is shown in southern Oregon and Idaho. Phase 5, type EM winter.

Radiosonde data: Medford has a temperature and mixing ratio increase at 4200 meters. Oakland shows a similar situation at 4000 meters. A slope of 1/200 would place the location of the front 500 miles west of Oakland. The synoptic chart shows it to be approximately 100 miles west. Extensive cloud formations render the soundings impractical for such forecasts as are being studied.

January 30 -- Synoptic situation: Two small waves are lying northeast-southwest across Utah, Nevada, and central California. The front is very weak. There is a line of demarcation between Polar Basin air to the south and Polar Continental air to the north. An upper front is shown in British Columbia but is not influencing the Washington-Oregon area. Phase 6, type EM winter.

Radiosonde data: No indication of approaching fronts.

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January 31 -- Synoptic Situation: This is phase 1 of Bs fall and winter type. The west coast area is occupied by Polar Basin air. Two fronts, partially occluded, are shown far to the north, one centering in Alaska, and the second along the Aleutian chain. Neither system is very intense.

Radiosonde data: Fort Nelson, British Columbia, has a temperature and mixing ratio inversion at 1000 meters, which cannot be associated with the system shown 950 miles west. A discontinuity in temperature and mixing ratio (or increase) at 3800 meters would place the front 1200 miles to the west, assuming a slope of 1/300. This is rather unreliable since the isobaric pattern indicates a Polar Continental flow rather than circulation from the Maritime system of the Pacific.

Conclusion: The aim of this particular problem is to make a study of the correlation of the radio soundings made on the west coast and frontal systems approaching the west coast from the Pacific. A day-by-day- analysis of January, 1943, was made, simulating conditions that a forecaster of a northwest coastal station might face during any particular month. The problem was made difficult and extremely general in its results by a lack of sufficient soundings.

Ten cases were considered in which forecasts were made as to location of the front in the Pacific and the time that it would be expected to pass some station on the coast. Where only one set of soundings were available the slope was calculated, the location forecast, and a normal eastward movement assumed, to forecast the time of passing the station. Seven cases were verified as the correct locations and forecasts. When the only available data was a sounding from a single station the front was assumed to have a slope of 1/300 in making the forecasts. Only one case was found where a sequence of soundings were available to make both a forecast of the location of the slope and the velocity of movement. This was from January 2 to January 4. Radiosonde data for January 3 is missing. The forecast of this particular case was accurate both in regards to location and time of passage on shore. One case in which the forecast of the location was verified, but not the time of passing onto the coast, was influenced by a large Polar Continental high in the Washington area. The front actually was well off shore at the time the forecast called for it to pass inland.

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The inversions used in making the calculation for the slope of the front in most cases were detected first at approximately 6000 to 7000 meters. The inversions that proved to be the most accurate were those including not only a temperature inversion but also an increase in mixing ratio values. Many inversions were shown in the soundings that had no connection with the approaching systems. A number of fronts passed inland without any indication in the available soundings. This was particularly true during the period that the coastal area was under the influence of Bn type weather. These waves passed north of Washington and south of Fort Nelson, British Columbia. Fort Nelson is 800 miles north of the northern boundary of Washington. Any soundings made in this region would no doubt have been significant and useful for forecasting purposes. Cloud layers through which the soundings were made in most cases made the sounding a very inaccurate instrument to be used for forecasting: accurate forecasts should be possible with an increase in soundings in order to more accurately determine the slope of the front and the location of the surface occlusion, and an increase in the frequency of the soundings to 12 hourly reports in order to be able to determine the velocity of the front from a sequence of soundings.

A forecaster in northwestern United States should find radiosonde used as a supplement to synoptic data to be an important tool for forecasting in that area.

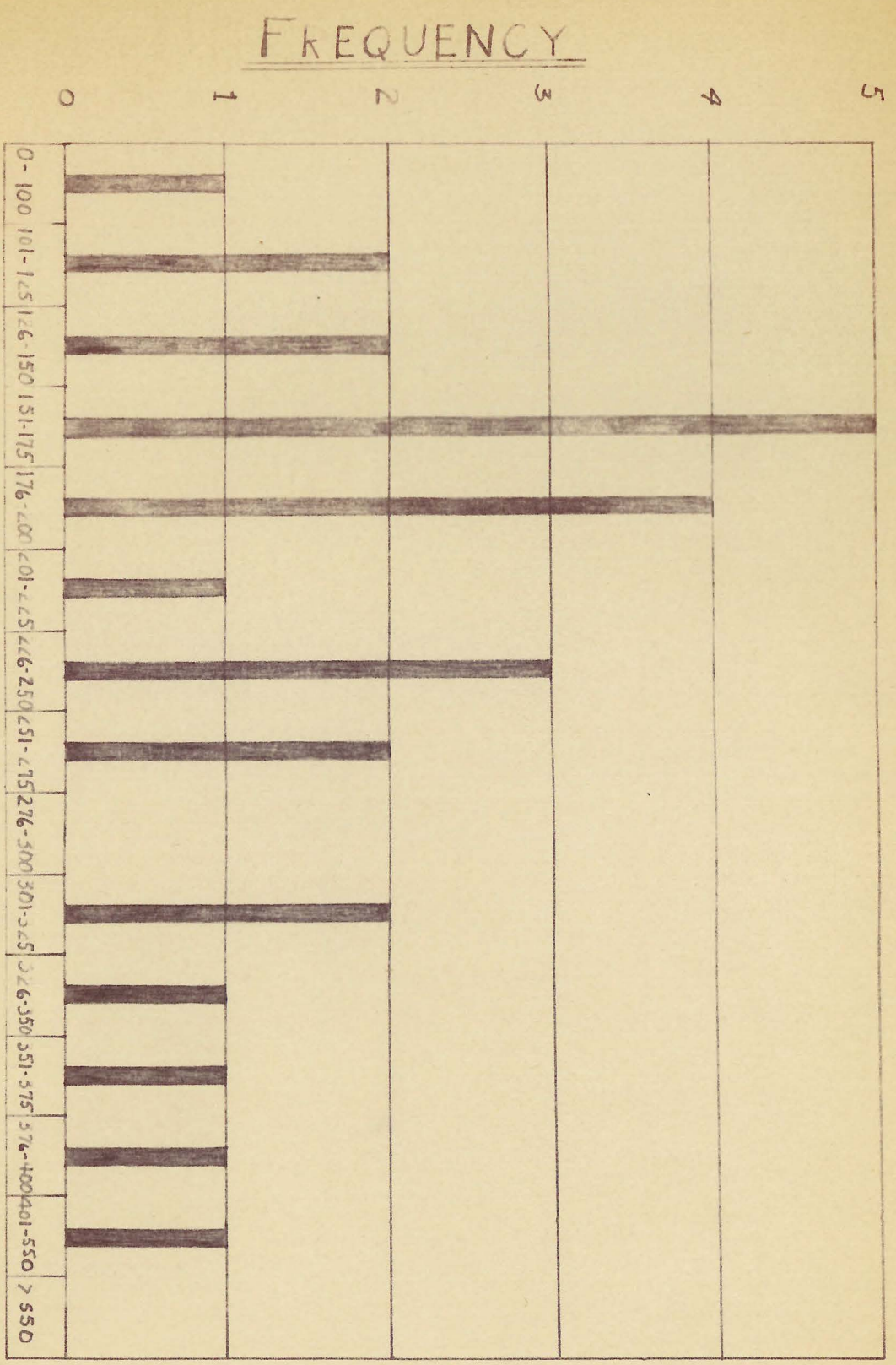
FRONTAL SLOPE FREQUENCY

The graph on Plate XX was included in order to show a correlation between the frequency and and the mean slope of fronts. Although it is risky to draw general conclusions from only a few cases, there seems to be a definite trend in the frequencies as can be seen from the graph.

The highest frequencies lay in the interval $\frac{1}{151}$ to $\frac{1}{175}$, while the average slope was in the interval $\frac{1}{226}$ to $\frac{1}{250}$.

It was interesting to note that 50% of the cases had slopes between $\frac{1}{151}$ and $\frac{1}{250}$.

PLATE XX



26 CASES USED

SUMMARY

Used as a supplement to other available synoptic data there is apparently some merit in this method of determining the surface position of fronts approaching the northwest coast of the United States. Where possible, data from stations located on a line at 90° to the orientation of the front should be chosen in order to simplify the calculation of the frontal slope. To arrive at the speed of the front it is necessary to have twelve hourly radiosonde data because in the great majority of cases, a front will pass a station well within twenty-four hours after the frontal surface is located above the station. When no other data is available it seems to be reasonable to assume a speed of fifteen degrees of longitude per twenty-four hours, converted to miles at the particular latitude of the station.

There was considerable variation in the slopes calculated; the maximum slope found was $\frac{1}{67}$, the minimum $\frac{1}{550}$, with the average $\frac{1}{233}$.

This method is of more value with fronts in the first or second phase of a weather type.

It was found that the single most important element in determining the height of a frontal surface is an increase in T value. An increase in the relative humidity, may or may not be of significance, since if the radiosonde passes through a cloud layer, an abrupt increase in RH will be indicated although there is no air mass surface present.

Of the twenty-seven cases investigated, twelve arrived at the station within thirty minutes of the time forecast; however the average time of arrival was 2.6 hours after the time of forecast. This is probably caused by the tendency of the fronts approaching the west coast to slow down or stall when within 300 miles of the land, due to the effect of coastal mountains.

The passage of upper fronts over a station tend to result in considerable error in calculating the slope of a front because of the difficulty in locating the surface above the station.

It should be emphasized that all cases should be treated individually, since no over-all average is applicable.

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This technique would be of greater value to personnel located at coastal stations, since the approach and passage of fronts could be closely observed.

It has been assumed where necessary that west to east moving fronts in temperate latitudes move at an average rate of 10° per 24 hours. This was figured to be 27 miles per hour. This rate of movement is generally accepted by meteorologists to be reasonably accurate.

RECOMMENDATIONS

We feel that this problem merits further investigation. An increase in the number of radiosonde reporting stations on the Northwest Coast would greatly simplify the use of this technique.

If any subsequent work is done on this method, we recommend that an attempt be made to accurately determine the speeds of fronts when close to the west coast.

The establishment of radiosonde reporting Coast Guard Units at sea off the Northwest Coast would be of considerable value in the solution of this problem.

Note of Appreciation:-

We wish to express our appreciation for the help given us in the preparation of this thesis by Professor P. M. Odell, Ruth Higby, Paul J. Saurenman, and the officers and men of the Army Weather Station.

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