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DEPARTMENT OF TRANSPORT
METEOROLOGICAL BRANCH

A CASE STUDY OF A CALIFORNIA COLD LOW MOVING INTO SOUTHERN B.C.

BY
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ABSTRACT

A synoptic study is carried out for the period May 3-7, 1966. A split flow over the Eastern Pacific characterizes the 500-mb pattern with a cold low off the California coast which is gradually forced northeastward into southwestern British Columbia in response to upstream changes. The surface developments accompanying this evolution are studied and it is found that the motion of the surface thermal trough is identifiable with the initial motion of the 500-mb short wave ridge in the southern stream. The 500-mb cold low is accompanied by a cold front that overtakes the thermal trough and both then continue eastward in phase with the upper low. The main weather features are related to the synoptic development.

ÉTUDE SUR UNE DÉPRESSION FROIDE DE CALIFORNIE SE DIRIGEANT VERS LE SUD DE LA COLOMBIE-BRITANNIQUE

par

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RÉSUMÉ

L'auteur fait une étude synoptique pour la période allant du 3 au 7 mai 1966. Un courant divisé au-dessus de l'est du Pacifique caractérise le niveau de 500 mb et comporte au large de la côte de Californie une dépression froide qui est refoulée graduellement, en direction nord-est, dans le sud-ouest de la Colombie-Britannique par suite des variations en amont. L'auteur étudie les phénomènes à la surface qui accompagnent cette évolution et constate que le mouvement du creux thermique en surface s'identifie au mouvement initial de la crête d'onde courte à 500 mb du courant sud. La dépression froide à 500 mb s'accompagne d'un front froid qui rattrape le creux thermique et tous deux continuent vers l'est en phase avec la dépression en altitude. Les principales caractéristiques du temps sont en relation avec le développement synoptique.

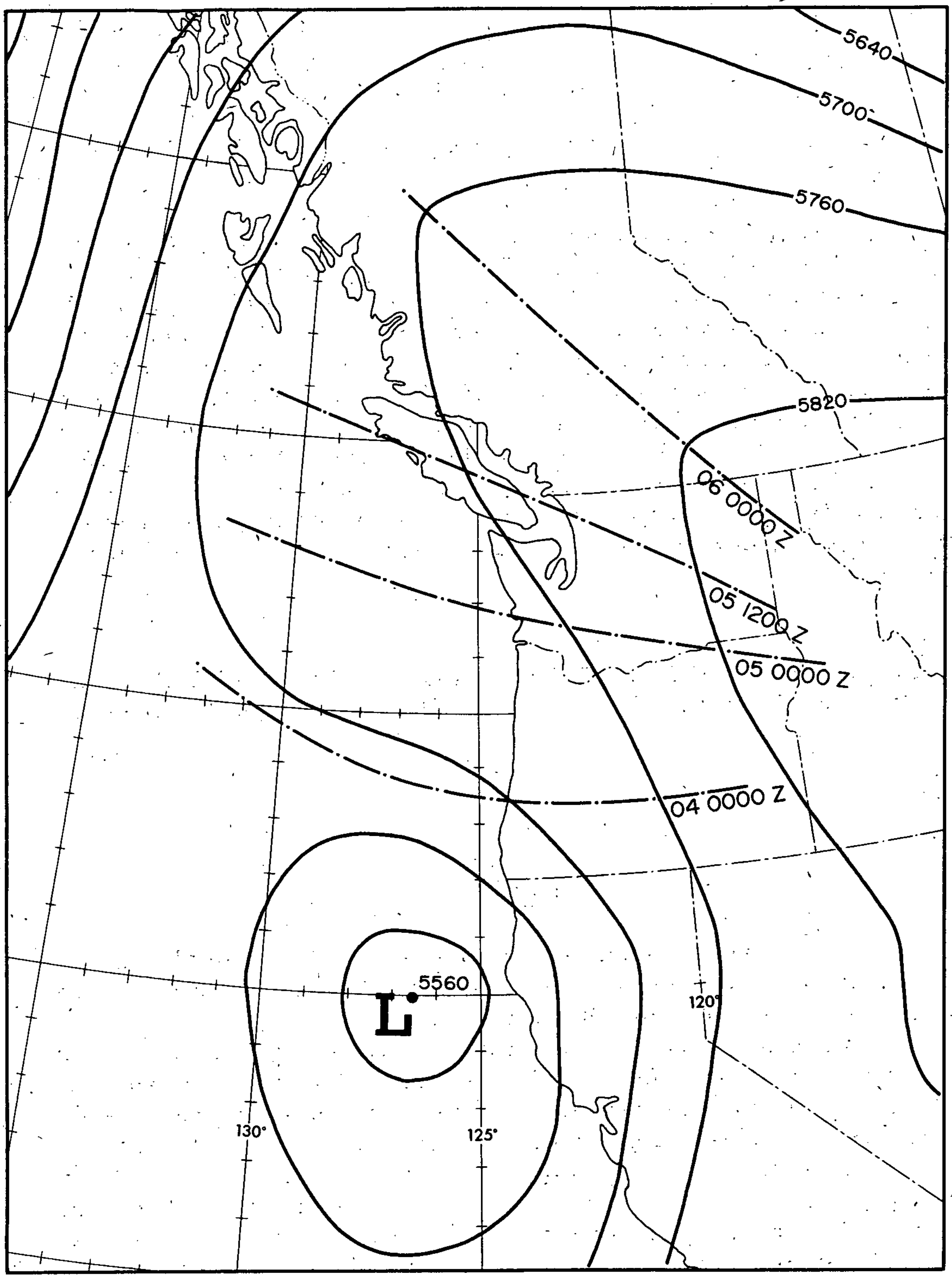

Figure 1   500 mb. Analysis - May 6, 0000 z, 1966

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1. Introduction

The 500-mb flow during the period May 3 - 7, 1966, portrays a common pattern that is easily recognized and usually follows a well defined evolution. Nevertheless, two major forecast errors were committed in this period. Maximum temperatures for May 4 were forecast much too low and the precipitation that occurred May 6 was not forecast. The purpose of this study is to endeavour to establish the relationships between the 500-mb changes and corresponding surface developments, and to associate the observed weather characteristics with these developments.

2. 500-mb Upper Air Analysis

The 500-mb chart for May 2, 0000Z, indicated a full latitudinal trough over the Eastern Pacific. Very cold air in the southern portion of the trough gave a good indication of the development that was to follow, namely, a shearing of the trough with resulting cutting off of a cold pool west of the California coast while the northern portion of the trough weakened and moved inland over British Columbia. The ensuing pattern (Figure 1), shows a strong Maritime stream extending from Ship Papa to British Columbia, and a weaker Polar stream flowing northward from the cold low west of California to eventually turn eastward near the southern British Columbia border. This configuration of the main air streams in the Eastern Pacific is quite common in the summer months and its further evolution is typical. A major trough approaches the Eastern Pacific from the west and when the upstream wave length becomes too short to maintain a major trough position off the California coast, the trough is forced northeastward into southern British California (Figure 1). The features of interest are the short wave trough and ridge embedded in the southern stream. At 040000Z, a short wave ridge is situated along an east-west line through southern Oregon, and it subsequently progresses steadily northeastward to Vancouver Island in 36 hours (Figure 1). During this time, there is only a slight northward drift of the cold low and associated trough on the California coast. However, following this period, the trough and low accelerate northeastward into Washington in response to the changes taking place in the upstream circulation controls.

3. Surface Analysis

Figures 4 - 10 show the three main developments observed at the surface during this period.

(a) The weak surface low off the California coast remains quasistationary in phase with the 500-mb centre. When the latter accelerates to the northeast, the surface low loses its upper air support and fills rapidly. It disappears completely by 061200Z and is replaced by a ridge with its axis along the coast.

(b) The principal surface feature during the period 040000Z - 051200Z (Figures 4 - 6), is a trough which gradually moves northward from California to a line extending from eastern Oregon to just west of Vancouver Island. In the terminology of West Coast forecasters this is called the "thermal trough" and will be designated as such henceforth. The trough is marked as a dashed line on the surface charts.

(c) During the period 060000Z - 071200Z, (Figures 7 - 10), a cold front moves northeastward from the ocean across northwestern U. S. A. and southern British Columbia. Simultaneously, the low pressure centre in northern Oregon moves northward into the Cariboo and finally into Alberta. The cold front gradually overtakes the low near Prince George and they then continue eastward together.

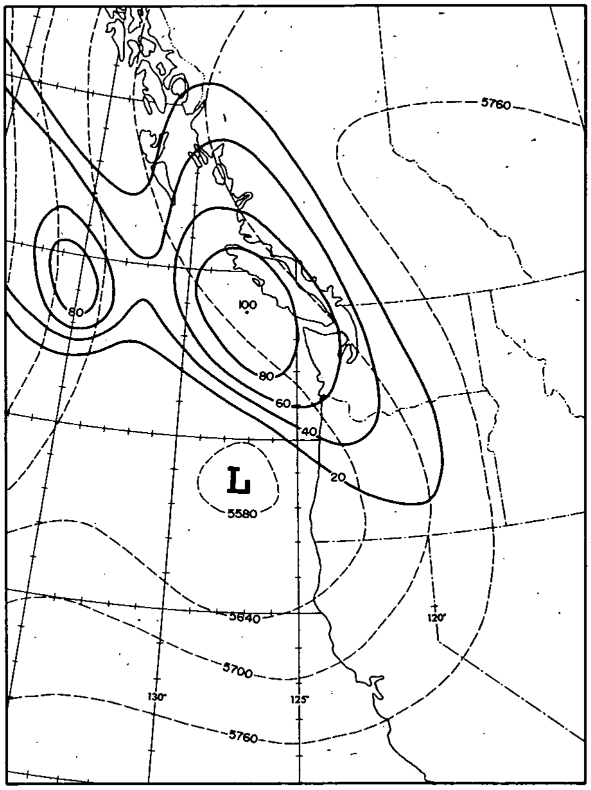

Figure 2 C.A.O. 500 mb. Analysis - May 6, 1200 z, 1966. and Computed Vorticity Advection

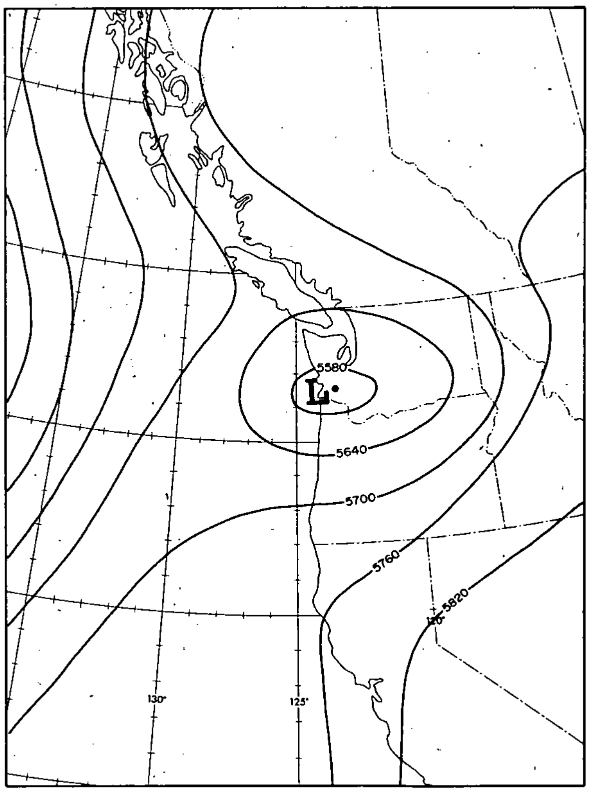

Figure 3 500 mb. Analysis - May 7, 0000 z, 1966

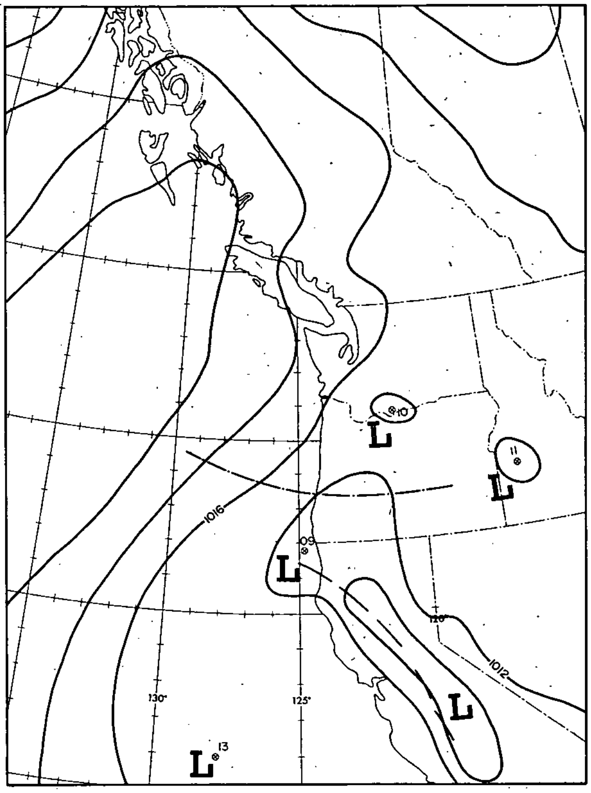

Figure 4 Surface Analysis - May 4, 0000z, 1966

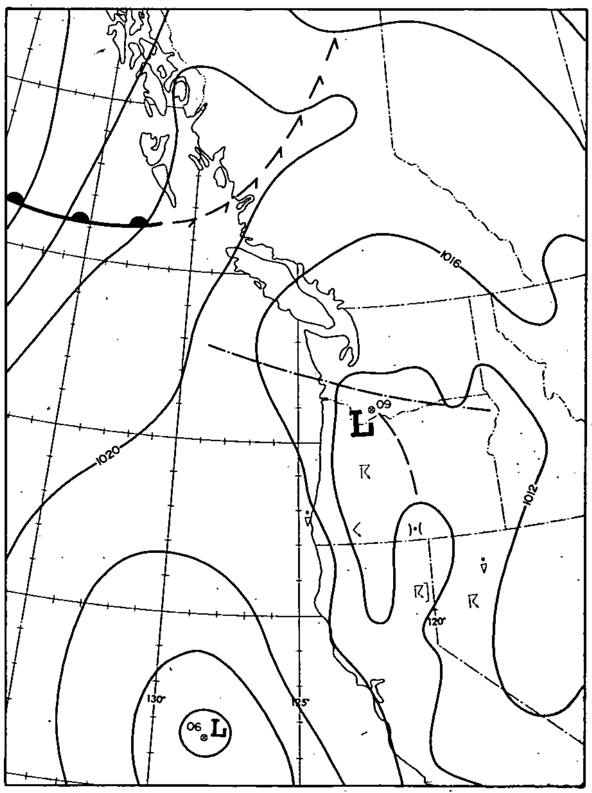

Figure 5 Surface Analysis - May 5, 0000z, 1966

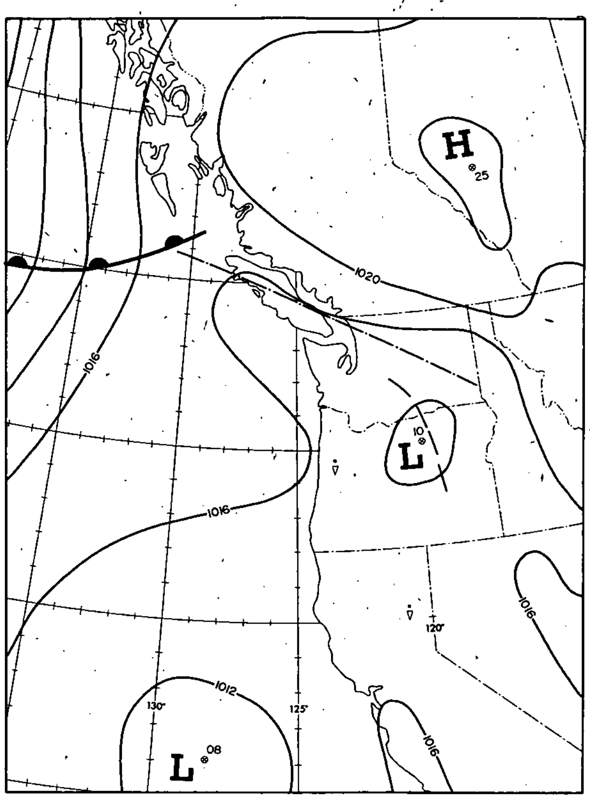

Figure 6 Surface Analysis - May 5, 1200z, 1966

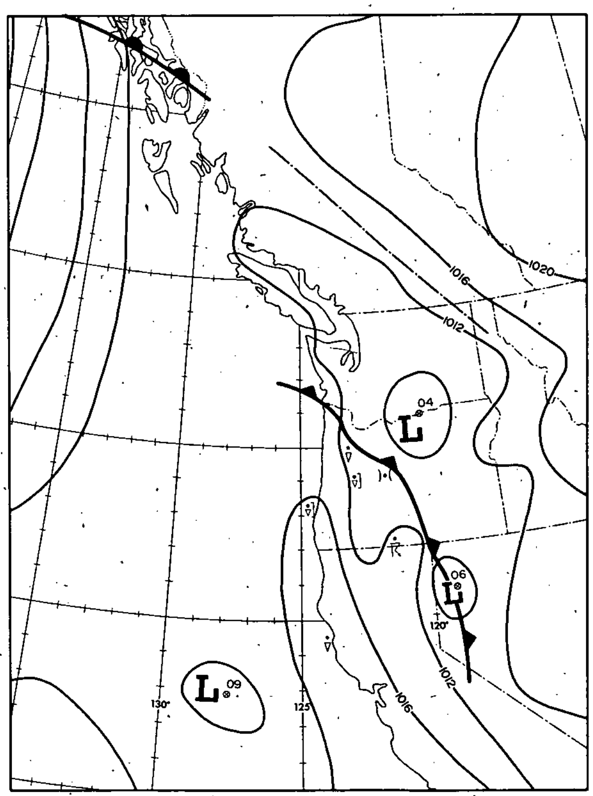

Figure 7 Surface Analysis - May 6, 0000z, 1966

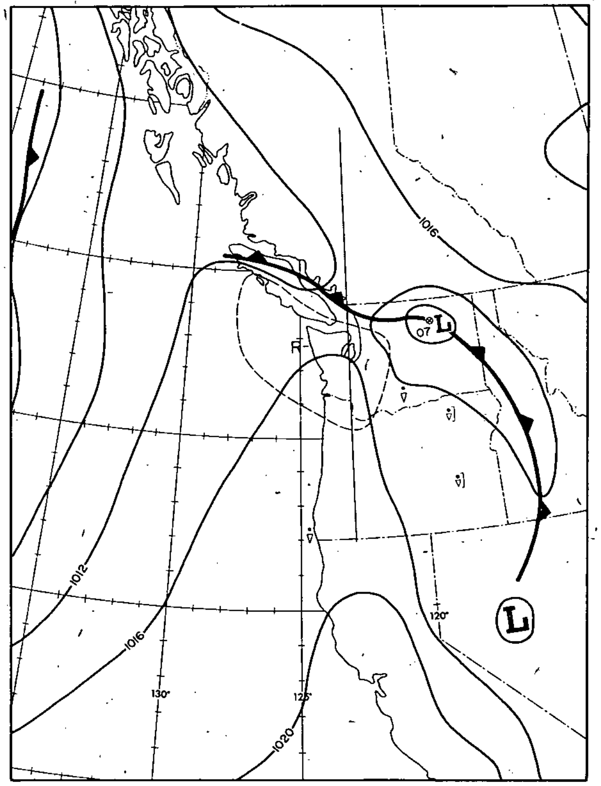

Figure 8 Surface Analysis - May 6, 1200z, 1966

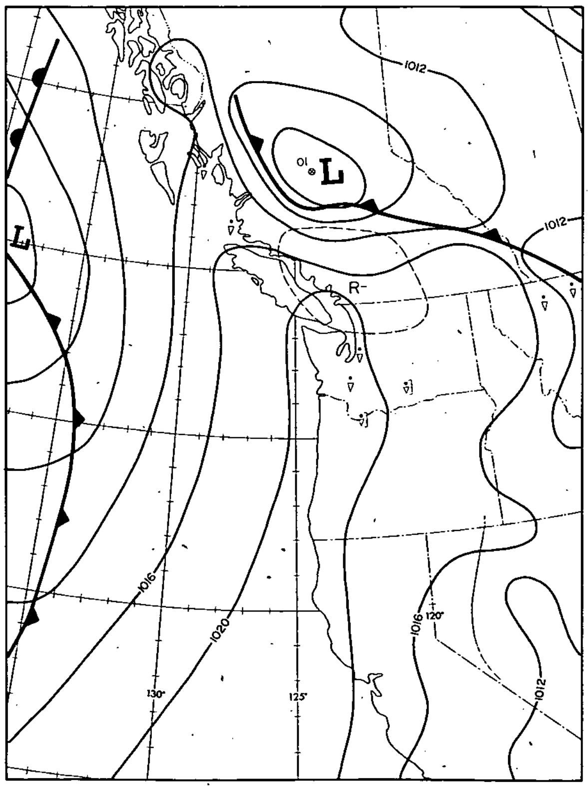

Figure 9 Surface Analysis - May 7, 0000z, 1966

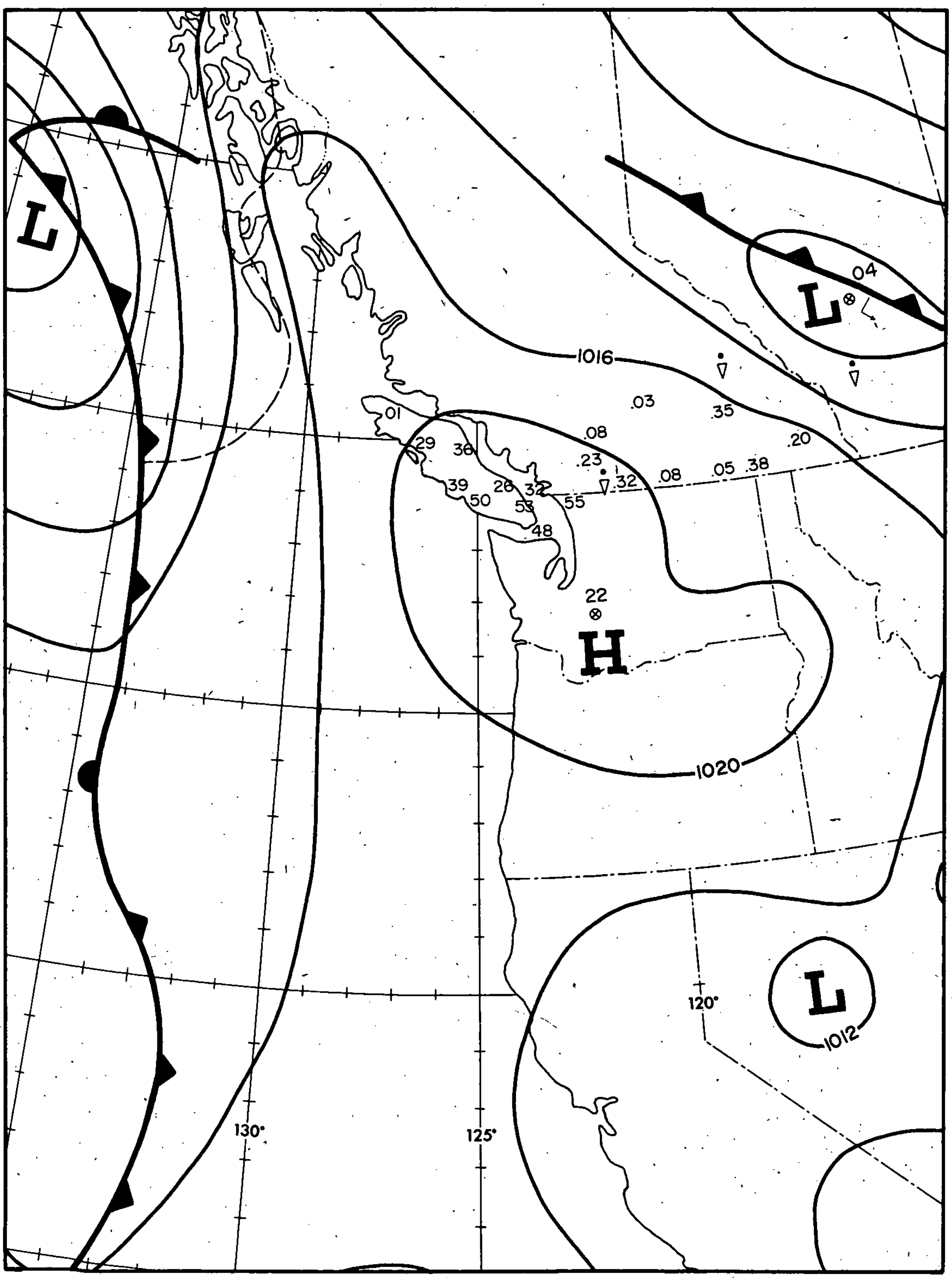

Figure 10 Surface Analysis - May 7, 1200 z, 1966
Maximum 6 hourly Precipitation Amounts

> The events described are of particular interest because they generally bring an end to a spell of exceptionally fine weather. Possibly because of this there is a reluctance to predict drastic changes and the timing of the event is often imprecise. Frontal analysis is difficult because of the presence of a marine stratum and the occurrence of pre-frontal cooling. However, radiosondes available at six hourly intervals from Medford, Tatoosh Island, and Spokane greatly clarify the analysis.

The filling of the low centre off the California coast noted in (a) is an obvious outcome of the movement of the cold low aloft. The events noted in (b) and (c) are closely related to the forecast errors and they will now be examined in more detail to see how these changes evolve from those at the 500-mb level and the type of weather that results.

4. Movement of Thermal Trough

Although the formation of this surface trough is probably due to direct thermal effects it will be shown that the subsequent deformation and movement are the result of dynamical effects which are linked to well defined changes in the upper air pattern. The term thermal trough, however, will still be used to identify it during its eastward motion. At 031200Z, the thermal low is centred in its normal position in the California Great Interior Valley. In the next 12 hours the trough extends northward and a centre develops near Medford (Figure 4). The centre continues northeastward into northern Oregon by 051200Z with a fairly well developed trough extending northwestward to a position off the west coast of Vancouver Island (Figure 10). The easterly low level circulation in advance of the trough produces clear skies over southwestern British Columbia and extremely high temperatures are recorded in the area. Maxima observed on May 4th are 84 at Abbotsford where the mean maximum for May is 65, 81 at Nanaimo, 76 at Victoria and 70 at Vancouver Airport. The forecast issued at 9 a.m. the previous day forecast temperatures an average of 12 degrees too low for all stations of the South Coast region and the forecast issued the same morning averaged over 9 degrees too low although the sky condition was forecast correctly in both cases. Unusually high temperatures can be expected when the thermal trough extends off the Washington coast and the error in the temperature forecast is mainly a result of the failure to forecast the motion of the surface trough accurately.

The United States Weather Bureau Forecast Manual (1) lists 3 rules based on synoptic experience for forecasting the northward extension of the thermal trough.

1. The surface trough will develop along the West Coast in connection with the building of a 500-mb ridge. The trough will develop under the portion of the 500-mb ridge south of the latitude of the 500-mb jet crossing the ridge and usually where the 500-mb wind is less than about 25 knots.

2. The trough will reach maximum strength when vertical with the 500-mb ridge.

3. The trough will move eastward with the speed of the next upstream trough when the ridge reaches a position about 3 degrees of latitude east of the trough.

The 500-mb charts indicate that the rules give a good indication of the development that takes place. In particular, the development of the trough northward coincides with the building of the 500-mb ridge. An examination of the short waves, however, reveals an even better correspondence. The building of the 500-mb ridge is due to a 500-mb short wave ridge progressing into the long wave ridge position and the motion of the short wave ridge is closely connected with the elongation of the thermal surface trough. The 500-mb ridge positions have been marked on the surface charts (DOT - Dash Line) and the relationship between the upper ridge and surface trough is most striking. Although at first glance it appears strange to identify the surface trough with an upper ridge it can be shown that this relationship does not violate dynamic considerations.

We can make a qualitative assessment of the vorticity pattern by noting that although there is little horizontal shear to contribute to the vorticity over northwestern U. S. A., there is a sharp curvature of the contours at the ridge line which is followed by a relatively straight flow until the trough line is reached, (Figure 1). On the basis of curvature, therefore, a vorticity minimum will exist along the ridge axis and the vorticity gradient will be concentrated near the ridge line. This results in a positive vorticity advection area immediately following the ridge.

The close relationship observed between the surface trough and rear of the upper ridge suggests that the motion of the positive vorticity advection area is the main mechanism instrumental in moving the thermal trough northeast. Conversely, subsidence preceding the ridge contributes to warming temperatures and this combined with the low level offshore flow, results in the much above normal values reported in advance of the trough. The motion of the short wave ridge is, therefore, a good indicator of the motion of the thermal trough along the coast and it also provides a physical explanation for the much above normal temperatures reported in this type of situation.

5. Motion of the 500-mb Cold Low

Changes at the surface in the period after 051200Z are due to the northeastward motion of the 500-mb cold low. An examination of the charts indicates that the surface thermal trough remains nearly stationary (Figures 6 - 7) until the upper low phases with it and they then continue northeastward together. The first indication that this is occurring is at 051800Z when the southern portion of the thermal trough over California begins to move into Nevada. Simultaneously, a cold front moves into western Oregon as the motion of the cold low brings cooler marine air northward. The cold front gradually overtakes the thermal trough. This occurs by 061200Z over eastern Washington (Figure 8). Further north in the Prince George area, the cold front moves into the thermal trough at 070600Z and both features then continue eastward into Alberta (Figures 9 - 10).

The frontal analysis poses problems as weak surface gradients and lack of data make it difficult to follow the front offshore and it is often dropped in this type of situation only to suddenly reappear inland when the cold low accelerates northeastward. In addition, the previous motion of the thermal trough inland results in a slight surface ridging along the outer coast which contributes to masking the front as it moves inland (Figures 5 - 7). A cross-section showing the distribution of temperature and wet bulb potential temperature across the front is constructed along a line from Port Hardy to Oakland at 061200Z (Figure 11). The wet bulb potential temperatures in each isothermal surface are shown in the vertical. Isopleths of temperatures are given at 5 degree intervals, those of wet bulb potential temperature at 2 degree intervals. During the period when the cold front is lagging behind the surface trough (Figures 7 - 8), the placing of the front from surface data is difficult, but as the cross-section indicates, a well marked discontinuity exists aloft in both temperature and wet bulb potential temperature.

Another factor that contributes to the difficulty of analysis is the marked pre-frontal cooling that occurs in the coastal area below the 700-mb level. This can be seen on the cross-section. Detailed study of consecutive ascents shows that at Tatoosh, this amounts to 8 degrees Centigrade at the 850-mb level and 4 degrees at the 700-mb level between 060600Z and 061200Z. Similar cooling occurs at Salem earlier as the front approaches that station. The reason pre-frontal cooling is so marked in the coastal areas west of the Cascades is the stability of the air mass at low levels, which is, in turn, due to previous subsidence in the offshore flow combined with the presence of a cool marine stratum. In the interior, intense diabatic heating maintains a very steep lapse rate at least to the 700-mb level. Vertical motion, therefore, produces rather large temperature changes in the lower levels in coastal areas, but only small changes in the interior.

The precipitation pattern associated with this system is quite different from that which usually occurs with a cold frontal passage inasmuch as the main precipitation area occurs in post-frontal conditions when pressures are rising and a surface ridge is building along the coast (Figures 8 - 9). The cold low offshore has a trough extending eastward from the centre and as the system moves northeastward, a positive vorticity advection area develops and precedes the low into southwestern British Columbia. In a cold low, the isotherms and contours are closely in phase and values of thickness advection are not large. According to Penner's

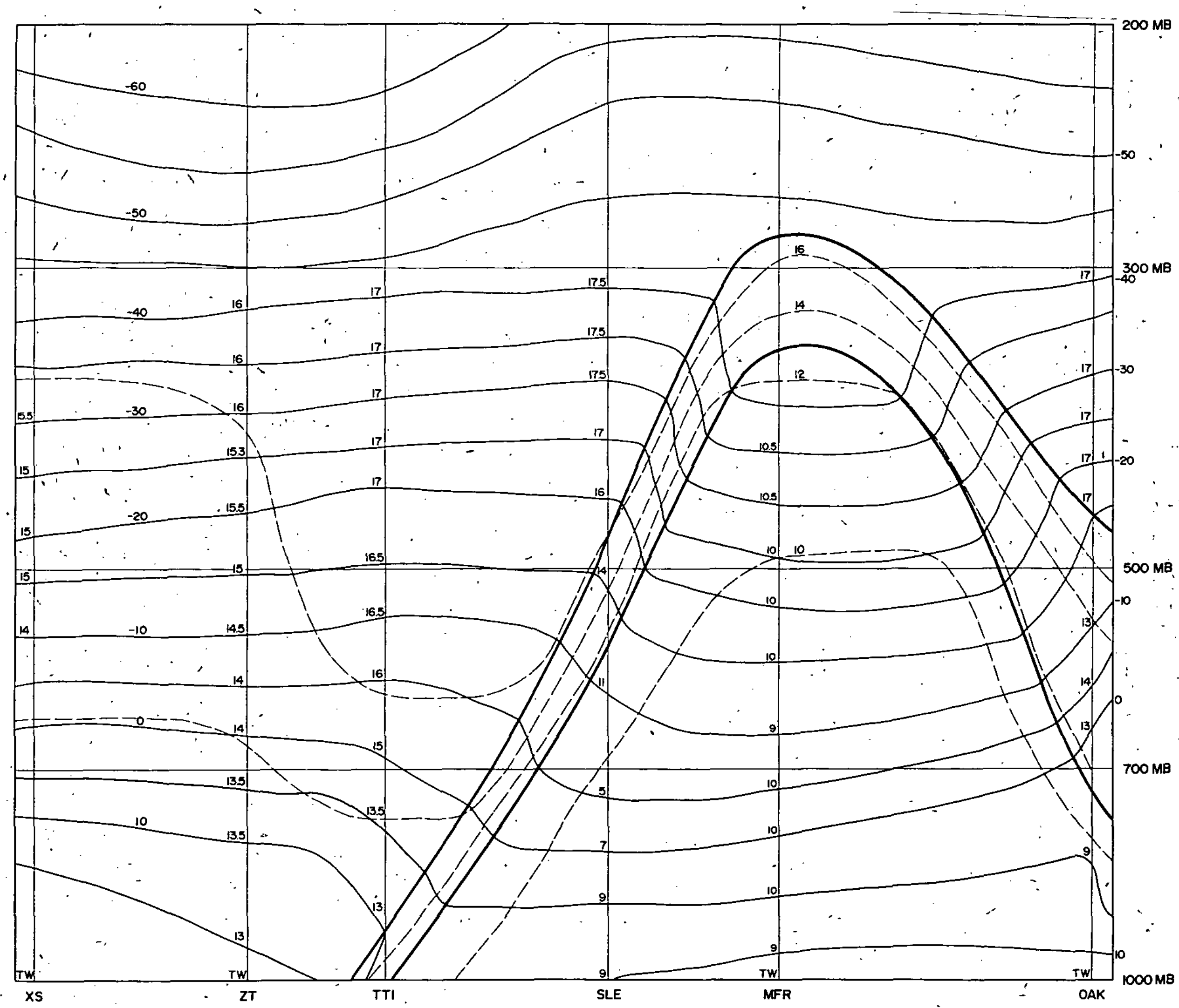

Figure 11 - Cross Section - May 6, 1200z, 1966

vertical velocity equation, therefore, the positive vorticity advection area should provide a good indication of the upward vertical velocity. The vorticity advection computed from the Central Analysis Office 500-mb vorticity analysis confirms the association between the vorticity advection and rainfall (Figures 2 and 8). The increasing vorticity advection west of 132W (Figure 2), is due to a cold front approaching from the Pacific. The displacement of the precipitation area from 061200Z-070000Z coincides with the motion of the cold low (Figures 3 and 9). The time of maximum 6-hourly rainfall occurs at 061800Z over Vancouver Island, at 070000Z at Vancouver and Abbotsford and at 070600Z in the Penticton-Kimberley region which agrees with the motion of the low centre. The precipitation rate at 061200Z for Tatoosh Island is computed by the Penner-Harley QPF Technique and equals .35 for 6 hours when no orographic effect is considered. The highest 6-hourly amounts recorded over southern British Columbia during the passage of this storm are plotted (Figure 10). The variation due to orography is apparent but nevertheless, Harley's technique gives a useful indication of the amounts that occur.

Precipitation amounts are not available over the ocean, but the scanty reports available indicate that precipitation is much more widespread after 060600Z. The increase in precipitation agrees with the vorticity patterns as the previous Central Analysis Office vorticity charts do not show any vorticity advection associated with the low before 061200Z. Figures 1 - 3 indicate that although the upper low accelerates northeast after 051200Z, the downstream short wave ridge continues at about the same speed which results in a gradual decrease in wave length and an accompanying increase in vorticity advection. The intensification of the precipitation pattern as it approaches British Columbia, may be due to this factor.

6. Conclusions

An interesting feature of the analysis is that the initial motion of the thermal surface trough is closely associated with the short wave ridge. Although USWB rules are helpful in predicting this phenomenon the identification of the thermal trough with the rotating ridge in the Polar stream enables a more accurate forecast to be made of the trough motion and permits a satisfactory explanation of the observed temperature distribution. The motion of the thermal trough is particularly important as it not only influences the surface temperature, but is is also an indicator that upstream influences are becoming effective. As the wave length of the short wave entities in the southern stream is quite short, the associated vorticity pattern is smoothed considerably in machine analysis due to the grid employed. In addition, small scale features are quickly smoothed out in numerical prognostics. For this reason, the synoptic identification of the short wave ridge combined with model considerations would appear to be a desirable procedure in forecasting this event. The subsequent motion of the cold low is accompanied with an influx of maritime air onto the coast and although frontal analysis is difficult, the cross-section indicates a well marked air mass discontinuity. The cold front gradually overtakes the thermal trough and both continue eastward in phase with the cold low. The precipitation area is closely associated with the 500-mb centre and PVA area and there are indications that an intensification of this feature may have occurred due to the acceleration of the cold low towards British Columbia. The sequence of events described is typical of a situation that occurs fairly frequently over the western part of the continent during the warmer season and it can be adequately analysed using Weather Central procedures. It is hoped that the results of this investigation will be useful when forecasting similar situations in the future.

APPROVED,

J. R. H. Noble,
Director,
Meteorological Branch.

7. References

(1) Synoptic Meteorology as Practised by the National Meteorological Centre. (The NAWAC Manual) United States Weather Bureau, Washington, 1960.

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