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Small-Scale Analysis and Prediction

P. WILLIAMS, JR.

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U.S. DEPARTMENT OF COMMERCE / ENVIRONMENTAL SCIENCE SERVICES ADMINISTRATION

WESTERN REGION TECHNICAL MEMORANDA

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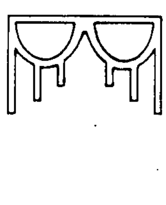

A western Indian symbol for rain. It also symbolizes man's dependence on weather and environment in the West.

U. S. DEPARTMENT OF COMMERCE
ENVIRONMENTAL SCIENCE SERVICES ADMINISTRATION
WEATHER BUREAU

Weather Bureau Technical Memorandum WR-29

SMALL-SCALE ANALYSIS AND PREDICTION

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WESTERN REGION
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I. INTRODUCTION

In March 1965 the Weather Bureau's Small-Scale Analysis and Prediction Program formally got under way with the issuance by Weather Bureau Headquarters of a memo requesting local offices to shift their emphasis from broad-scale features of the synoptic situation to small-scale details. Headquarters stressed the fact that the National Meteorological Center (NMC) should handle problems of large-scale analysis and prediction, and also longer time periods, while field offices should concentrate on improving forecast quality for the first 12 hours. In order to stimulate interest and spur activities along these lines, both in the field and at Regional Headquarters, awards were offered for outstanding accomplishments in the area of small-scale analysis and prediction.

In response to this directive, the Scientific Services Division (SSD) of Western Region Headquarters launched the Small-Scale Program with a Regional Memorandum entitled "Emphasis on Small-Scale Analysis and Prediction" dated May 11, 1965. This memo stated the purposes of the program and gave a general outline for stations to follow in the implementation of their small-scale program. The memorandum also established a continuing program in the Western Region designed to maintain a high quality of interest and performance in small-scale analysis and prediction. Several Regional Memoranda, Technical Attachments to the weekly Staff Minutes, a Technical Memorandum [1], and a tape/slide lecture have been prepared as aids to increase the effectiveness of the program. SSD personnel, in making their regular consultant visits to field stations, have stressed the importance of the program, discussed it at station seminars, and presented clinical demonstrations on the use of small-scale techniques for real-time forecast problems.

The purpose of this Technical Memorandum is to bring under one cover most of the small-scale guidance material issued by SSD, plus newer developments in this area, and finally to present some outstanding small-scale programs that have been developed by various Western Region Meteorologists in Charge (MICs) and their staffs.

II. PROGRAM OBJECTIVES

The Western Region's Small-Scale Analysis and Prediction Program is designed to improve the accuracy of and add detail to short-range weather predictions. This should be accomplished by complementing in a meaningful way, not duplicating, guidance material provided by NMC. The program is also designed to improve the capability of field offices to accommodate and adapt NMC large-scale analyses and prognoses to local conditions by adding such detail as is necessary to account for time and spacial variations that characterize weather situations. All on-station small-scale analyses should, insofar as possible, be reconciled with facsimile analyses provided by NMC. The techniques described apply especially to forecasts of up to 12 hours, and are of particular interest to meteorologists engaged in zone, local and aviation forecasts, as well as to the specialized services of agriculture and fire weather.

The most important information to be gained from analysis and prognosis on the small scale concerns the organization and distribution of weather elements, such as clouds, precipitation areas, squall lines, thunderstorm and fog areas. Many meteorologists in the past have emphasized larger-scale motions to the neglect of smaller-scale detail, considering the latter as insignificant "noise". However, with regard to prediction of weather events in the near future, it is just this so-called "noise" that can be most useful. Much effort by local forecasters has at times been channeled in the wrong direction, with the product suffering as a consequence.

Examples can be given wherein local forecasters devoted most of their time and energy to the problem of the "day after tomorrow" while neglecting the immediate future. Specifically, a case can be cited along these lines wherein the evening forecaster, working under a synoptic situation of a large high pressure system over the area, concerned himself primarily with the rainfall probability on the second day, while completely missing the formation of a dense local fog that same night which badly tied up land, sea, and air traffic.

Other cases may be cited wherein the early morning local forecaster in the Pacific Northwest issued a forecast of straight "rain" for today, tonight and tomorrow. The synoptic situation indicated the passage of a series of rapidly moving short-wave troughs spaced about 18 hours apart. A much more realistic forecast for the first 12 hours or so might indicate rain this morning, with periods of partial clearing and a few hours of sunshine this afternoon, followed by increasing cloudiness in the evening and rain again by night. No detail like this would, of course, be possible for "tomorrow", but it does not require much imagination to visualize the greatly increased usefulness to the user of the more detailed forecast for "today". Times of beginning and ending of precipitation are especially important to local users.

III. "SMALL-SCALE" DEFINED

In order to set the stage for small-scale analysis, various scales of weather systems are illustrated in Figure 1, taken from [2]. NMC analyses, particularly upper-air charts, are mostly on the macroscale; although in areas where data are relatively plentiful, as in eastern United States, surface charts might be considered to be on the subsynoptic scale. Characteristic space-time dimensions of weather systems on this scale are greater than 250 miles and several days, and include long (Rossby) waves, extratropical cyclones, and major frontal systems. A 1:10 million weather plotting chart is suitable for analysis on this scale.

The subsynoptic or small-scale comprises one of the main areas of interest in Figure 1. Unsmoothed isobars, frontal patterns with stable waves, lee troughs, "bubble highs", thermal troughs, etc., are examples of synoptic features of prime interest, with dimensions of 50 to 300 miles and several hours. An observational network spacing of 50 to 150 miles is required. A 1:3 million weather plotting chart is appropriate for analysis on the subsynoptic scale, with sea-level isobars drawn at 1- or 2-mb intervals.

Most field stations have been able to develop and make use of observations on the mesoscale, the other scale of primary interest in Figure 1. Radar is one of the principal analysis and forecast tools in this category. Surface charts on this scale would be drawn to 1-mb isobaric intervals.

The local scale is, of course, very important for very short-range prognostications, including mainly "out-the-window" observations of visible impending weather.

IV. OBSERVATIONAL NETWORKS

Most areas in the Western Region have available surface observations spaced on the order of a macroscale, or at best, a subsynoptic network. For purposes of the small-scale program, it is highly desirable to augment this coarse grid by additional observations. However, the program must, of necessity, be accomplished within present resources. MICs should, therefore, explore all possible sources of data that may be acquired at little or no expense to supplement basic network reports. Some subsynoptic data sources are listed below:

a) Sheriff's office, Highway Patrol.

b) Coast Guard.

c) Fire Weather stations.

d) Agricultural Experiment stations

e) School Science departments.

f) Power plants, pumping stations.

g) Weather Bureau and FAA employee homes.

V. LOCALLY PRODUCED ANALYSES

One of the first steps taken to implement the program in the Western Region was to provide stations with suitable map bases for local charting. A scale of 1:3 million was found to be most useful for this purpose, and maps of this scale were supplied to field stations. It was not intended, however, that these small-scale charts be locally plotted and analyzed on a routine basis. Only when weather elements of especial interest are present or expected should separate local-chart analysis be undertaken.

Generally speaking, small-scale analysis should cover an area 300 miles in radius around the local area, or 600 miles from the center of zones for which forecasts are issued. When weather systems come from preferred directions, these values may apply to upstream areas, with little or no coverage on the downstream side. During different seasons, different directions may be upstream, so coverage could vary from season to season.

VI. EVALUATION OF NMC ANALYSIS

It must be emphasized that for very short-period forecasts, up to 12 hours, the correct analysis of existing conditions is of utmost importance, more so, in fact, than forecasting the development of new features. Thus, the preparation of high-quality short-period forecasts involves more diagnostic than prognostic thought. However, once a thorough detailed analysis has been made, preparation of the forecast must also take into account development of weather systems as well as their movement, since the state of the science is now capable of producing forecasts superior to those based on simple extrapolation.

One of the biggest problems at most field stations is that when small-scale techniques are most needed, i.e., during bad weather periods, time available for charting and analysis is at a minimum. The most efficient way of using this available time is to process NMC charts and prepare activity charts in the manner described below, rather than plotting and analyzing complete surface maps.

The first step in small-scale analysis procedure then, should be evaluation of NMC analyses. This procedure should take the form of adding detail to fax charts, especially to frontal and isobaric analyses, and to vorticity and vertical-motion charts. Missing reports in the area of interest should be added to the fax charts.

Since 1:10 million fax surface maps frequently have only a few ship reports plotted in the Pacific Ocean, MICs at some coastal stations have adopted the practice of plotting and analyzing an off-shore section, to be attached to the fax map. This frequently improves the analysis immediately upstream from the coast.

Since NMC analysis is on the macroscale, some fronts significant to small-scale prediction may be omitted from fax charts, while others are entered too late or dropped too soon for local forecast purposes. Western Region Technical Attachment for April 19, 1966 (Appendix I) provides details on NMC criteria for surface fronts. The Weather Bureau Forecasters Handbook [3] gives NMC's philosophy of surface analysis.

The following procedure for processing NMC charts is suggested:

1. On the 3- and 6-hourly surface fax charts, shade in purple areas of middle and/or high broken to overcast cloudiness. Shade areas of precipitation in green. In the area of interest add late and locally available data.

2. Add intermediate 2-mb isobars in areas of flat gradients. This will help reveal the location of troughs and fronts.

3. Critically evaluate frontal positions in and upstream from the local area.

4. Areas of positive vorticity advection (PVA) on the initial and prognostic panels of the 500-mb vorticity/contour charts should be shaded in yellow. Critical contours should be colored in blue. Fronts are usually found under the leading edge of PVA and the active portion of the front will often lie between the 10 and 12 vorticity isopleths. This is not to say that all PVA areas are associated with fronts, but many are.

5. If it is decided that there is a front in the area, its location can be determined by checking previous maps to establish continuity. The usefulness of fronts in forecasting is largely dependent on the reliability of their continuity from chart to chart.

6. When pinpointing the location of fronts on weather maps, consideration must be given to the possibility of local effects masking synoptic effects. In the Western Region, with its rugged topography, diurnal and terrain effects on standard synoptic surface observations are frequently equal to or greater than those associated with migratory synoptic systems. It is recommended that all forecasters become familiar with Western Region Technical Memorandum No. 5 [1] containing station descriptions of local effects on synoptic weather patterns.

The Technical Attachments reproduced as Appendix I give examples of the use of the procedures outlined above to introduce a front that was not carried on the NMC analysis, and to make a significant adjustment in the position of a front.

VII. SMALL-SCALE TECHNIQUES

When the processing of NMC facsimile charts has been completed, the next step is to apply small-scale techniques appropriate to the synoptic situation. A number of these techniques will be described below. Station personnel, however, should use their ingenuity to devise other techniques appropriate to their own area.

1. Isochrone Analysis.

Hourly positions of fronts, squall lines, leading or trailing edges of broken-to-overcast cloudiness, onset of precipitation, or other appropriate weather elements should be charted on a map of convenient scale. Figure 2 shows isochrones of precipitation onset. The 1:3 million scale maps supplied to stations, or the 1:10 million facsimile maps may be used. Isochrone analysis will bring out clearly accelerations in the movement of weather systems across areas of interest. Rapid accelerations of frontal systems occur frequently during spring months, especially over the plateau region, where marked deepening is common at this season. The FD short-period low-level wind forecasts should be checked for indications of accelerating winds.

Figure 3 illustrates an isochrone analysis of frontal positions. This analysis is best made directly on the surface facsimile maps. NMC 3-hourly past positions of a rapidly moving cold front are shown, along with the current position at 1200Z. Local analysis produced the 1400Z position, with extrapolation used for the 1600Z local prog position. The NMC 12-hour prog position is also shown. Since the latter indicates considerable deceleration of the front, the local 2-hour progs are adjusted to fit the NMC prog. It is a good practice to make "check" forecasts for the time of frontal passage at stations upstream from the area of interest. Adjustments should be made in the locally progged frontal position, as indicated by verification of upstream frontal passages.

2. Trend Charts.

Trend charts (Figure 4 taken from Air Weather Service Manual 105-51/1) can also be useful at times. This is especially true when considering an element not directly reported in hourly aviation sequence reports, such as temperature-dewpoint spread.

3. Time Sections.

Another technique for small-scale analysis and prediction is the time cross-section (Figure 5). This tool is particularly useful in the Western Region where reporting stations are widely spaced and terrain effects on observations frequently large. Time-cross sections enable a forecaster to relate surface and upper-air observations over a period of a few hours up to several days. For example, diurnal temperature and wind regimes are easy to recognize on time sections. Also, they make it possible to locate subsynoptic details which may not be identified on facsimile analyses. With the numerous facsimile charts available, field forecasters at times miss significant details of the synoptic situation by failing to integrate available data.

In the section shown, time increases along the horizontal axis from right to left, while log of pressure is shown along the vertical axis. Upper-air wind and pressure-level data are plotted along a vertical line at observation time, and three-hourly surface observations are plotted at the base of the graph.

In this example, upper-air and surface data at Salt Lake City for a two-day period are plotted. The data indicate passage of a shallow cold front at 1100 MST May 14. Note that little change took place at 500 mb during the two days except for a warming trend toward the end of the period. Also note that the southeast diurnal wind shows up very well during the late night and early morning hours.

Further details on the preparation of time sections are given in Appendix II.

4. Space-Time Charts.

A variation of the time section is the space-time chart (Figure 6, also taken from Air Weather Service Manual 105-51). Station data are plotted along a vertical line with time increasing upwards. The horizontal space axis runs east-west. The frontal position and areas of precipitation are indicated. One-millibar spaced isobars could also be drawn on the chart, and they would clearly indicate filling of the frontal trough from an initial value of 1000 mbs (lower left) to a final value of 1500 mbs (upper right). Analyses of weather reports in this manner frequently provide a better understanding of the detailed synoptic picture than either separate hourly surface charts or the mere scanning of sequence reports.

5. Activity Charts.

The plotting of current weather and remarks transmitted at the end of hourly and special aviation sequence reports, as well as rareps and pireps, is useful in locating and tracking weather elements, especially thunderstorm activity. This is best done on the 1:3 million charts. Figure 7 shows both an area and a line of thunderstorm activity located by triangulation from station remarks and pireps.

6. Radar.

Weather radar, with its capability of detecting spacial distribution of precipitation, has in recent years become very effective as a short-range forecast tool. The capabilities of radar to detect fronts, squall lines, thunderstorms, and tornadoes have also been well documented. Radar has been especially useful for short-range hydrologic forecasting, whereby observations of persistent strong, nearly stationary, echoes have led to successful flash-flood warnings.

With the establishment of weather surveillance capability at the FAA Air Route Traffic Control Center (ARTCC) in Salt Lake City and Palmdale, California, a major portion of the Western Region is now covered by radar; and the area of surveillance is expected to increase in the next few years. It is appropriate, therefore, that all forecasters become thoroughly familiar with the uses of radar in weather detection.

Stations not having their own radar or receiving radar overlays by facsimile should make use of the hourly SD-1 messages. Although this intelligence is in the form of composite radar information, rather than actual echo pattern, important features such as strong cells, boundaries of echo areas, lines, echo tops and speeds of movement are included and should prove useful in short-range forecasting. Short-range is emphasized, because radar information is highly perishable. Extrapolation techniques are usually not satisfactory for more than 3 hours in advance. Also, terrain effects cause the forecasting of radar echoes to be a complex problem.

Boucher and Wexler [4] have discussed the motion and predictability of precipitation lines. They found that line motion (measured normal to line orientation) lies in a direction within 90 degrees to the right of the concurrent 700-mb wind and has the approximate speed of the 700-mb wind component normal to the line. Lines generally move at fairly steady speeds in a direction which undergoes relatively small changes during their brief life span.

Studies of the motion of sharp-edged precipitation echoes have shown a high degree of persistence with regard to speed and direction--more so than lines in most instances. These echoes are, therefore, readily suited to the extrapolation method of forecasting. However, when preparing isochrones of edges of radar echoes, care should be taken to use an average speed--and not the latest hourly displacement only--in making the extrapolation. Unlike line motions, however, there is apparently no useful relationship between edge motion and upper-level winds.

Appendix III contains Western Region Technical Attachments giving examples of how radar can be best used to detect showers, squall lines, and cold fronts in the varied and frequently rugged terrain with which our forecasters must contend.

7. Satellites.

Another forecast tool of comparatively recent vintage is the weather satellite. Many meteorologists tend to think of satellite cloud pictures as purely macroscale forecast aids, particularly useful over vast oceanic regions with little or no data. Many forecasters have tended to overlook the application of satellite pictures to small-scale forecasting. The location of surface fronts, frontal waves, and ridges is one of the most helpful uses of satellite data. Western Region Technical Attachment 67-8 (Appendix IV) describes in detail the positioning of fronts with respect to cloud pictures of a typical wave cyclone. The "comma" cloud associated with positive vorticity advection in a cold upper-trough can usually be detected from satellite pictures, and this very "comma" cloud can bring quite pronounced small-scale weather patterns to the northern coastal areas. Appendix IV also contains discussions of this type of synoptic situation in detail.

Wave clouds formed in the lee of major mountain ranges are another small-scale phenomenon frequently shown by satellite pictures. In this respect, the pictures should be of special help to aviation forecasters for determining areas of moderate to severe turbulence. It is quite likely that satellite pictures at times provide the first indication of the presence of lee waves because of the sparsity of the observing network in western United States, and also because wave clouds may be obscured by precipitation or low clouds and thus not be reported by observers. Examples of lee-wave clouds shown by satellite pictures are given in Appendix IV.

The staff at Flagstaff has made good use of satellite data in local forecasting by noting the distribution of convective clouds on mosaics and relating this to the wind flow. If the wind flow is predicted to be the same on the following day, the distribution of showers should be the same. An atlas could be compiled relating different convective cloud patterns shown on satellite mosaics to wind flow from various directions.

"Cloud Free" atlases are also available [5] to enable forecasters to become familiar with highly reflective terrain features such as salt flats, deserts, and areas of ice and snow. This familiarity can greatly reduce the possibility of confusing terrain features with clouds.

8. Local Soundings.

The twice-daily plotting of a sounding or two in or upstream from the local area is strongly recommended. A careful analysis of the vertical structure of the lower atmosphere is of great value for short-period forecasting of weather elements dependent on moisture and/or stability, including showers, thunderstorm, maximum temperature, time of breaking of stratus, and also strength of low-level inversions and mixing depths for air pollution purposes. Here again, the ingenuity of the local forecaster can be put to good use in order to obtain maximum benefit from the local raob. Even though no local raob is available, one can be constructed by using the local surface-temperature, indications of local inversions, plus interpolated temperatures from 850-, 700-, and 500-mb charts. Space does not permit the detailed description of the standard methods of raob analysis; however, Appendix V describes various convective indices that are available from NMC machine computations twice daily. Many of these indices are available on facsimile charts and are especially helpful during the warm season.

The "K" Chart, as developed by J. J. George [6] has been especially helpful in thunderstorm forecasting for many Western Region fire-weather forecasters. Adaptations to the local forecast area are important, as shown by the Technical Attachment in Appendix VI.

VIII. OBJECTIVE AIDS

The development of objective aids is encouraged as a means of adding detail and accuracy to short-range forecasts. Objective aids help bridge the gap between NMC macroscale circulation forecasts and the prediction of small-scale weather systems, as local effects such as terrain influences are automatically "built" into the aid. A Western Region Technical Memorandum discussing objective forecasting methods will be issued in the near future.

IX. FORECAST CHECK LIST

On many occasions, local short-range forecasts fail because an infrequently occurring phenomenon catches the forecaster by surprise, or a pertinent technique is omitted because of a lack of orderly procedures in preparing the forecast. Scientific Services Division has devised a tentative check list (Appendix VII) to be used in preparing local forecasts. Station personnel can use their ingenuity and experience to improve this list by adding steps that are applicable in their local areas. In general, the procedure is to start by examining large-scale features first, as background information, then working down to consideration of smaller-scale details.

Most consistent results will be obtained if the check list is "quantified" as much as possible, that is, objective aids should be developed on-station for the various items in the check list, i.e., precipitation occurrences from NMC vorticity and vertical-motion progs, etc. (see Appendix VII). Probability values from these aids should then be entered on a form prepared for each forecast. It may be necessary at first to weight these values subjectively in arriving at a forecast until such time as this final step can also be made objective. Use of the check list in this form should tend to keep the local forecast in the correct "ball park", and help avoid major failures.

X. STATION EXAMPLES

Meteorologists in Charge at a number of stations in the Western Region have implemented outstanding Small-Scale Analysis and Prediction Programs. As mentioned earlier, awards were made by Weather Bureau Headquarters for excellent performance in this area; Helena, Montana; and Salem, Oregon, were the first- and second-place recipients in the Western Region. Portions of their programs and those from several other stations will be presented, with emphasis on techniques that give promise of general application in most portions of the Region; and also to illustrate how ingenuity at the local level is being used to solve specific small-scale problems.

1. Forecasters at Helena, Montana, developed a successful aid (Figure 8) for forecasting the current day's maximum temperature. This technique successfully predicted record-breaking maximum temperatures on several occasions, including the June 28, 1966 computation, illustrated in the figure. Subjective modifications to the aid take into account cloudiness and precipitation. Another technique (Figure 9) was developed to determine the depth of Arctic air over the Helena valley. After a winter snowfall, the decrease in depth of cold air is almost always accompanied by warm westerly winds flowing over the top of the cold dome. This warm wind usually shakes or melts the snow off evergreen trees on the surrounding mountains, and the presence of the "Chinook" aloft will produce a darkening of tree color. Sometimes the edge of this darkening hue is the first indication of the decrease in cold air depth.

Another method for determining the height of the local inversion is obtained by observation of smoke plumes from the east Helena smelter or cement plant. The elevation angle at which the plume flattens is measured and, knowing the length of the base line to the stack, it is easy to compute the approximate height of the inversion base.

For measuring very shallow inversions, temperature reports are received from residences of several staff members who live on slopes up to 400 feet higher than the airport. This technique can be quite useful if good quality thermometers, properly exposed, are used. A local sounding is frequently prepared, as described in Section VII-8 above.

2. The MIC at Salem, Oregon, has made excellent use of small-scale surface maps to determine changes in circulation that are critical to fire-weather forecasts. The standard synoptic observations are supplemented by adding reports from fire-weather lookouts. Charts are analyzed at 1-mb isobaric intervals. This detailed type of analysis can assist in locating and following small-scale troughs. Figures 10 and 11 illustrate how the off-shore circulation over the coastal range of Oregon at 0600 PDT September 7, 1965, shifted to strong onshore by 1900 PDT. Changes in humidity, wind, and temperature accompanying this shift have obvious importance to the fire-weather program.

3. The staff at Missoula has the problem of forecasting the infrequent occurrence of strong winds that blow through Hellgate Canyon, directly east of the city (Figure 12). These winter winds are usually accompanied by blowing snow and rapidly dropping temperatures. The so-called "Hellgate" winds occur as Arctic air mass spills westward across the Rockies through Rogers Pass thence down along the Blackfoot River Valley and through Hellgate Canyon into the Missoula area. The MIC has arranged for the Ranger at the Lincoln station to call him whenever a marked shift of the wind to east, accompanied by a rapid temperature drop, is noted. This call gives the Missoula staff a lead time of several hours to issue a warning of Hellgate winds and accompanying severe weather.

4. The Kalispell MIC has made arrangements whereby the low-level temperature structure over the Flathead Valley area can be determined by temperature reports from the Big Mountain ski lift. The valley floor is at an elevation of 3000 feet; ski-lift temperatures are obtained daily at the 4700-foot and 6800-foot elevations. Low-level inversions are especially important in this area due to local pollution problems.

Observations of this type can most likely be obtained from many areas in the Western Region, and should prove of value in local forecasting.

A number of other Western Region stations have active small-scale programs, but space will not permit a documentation of each. Other fire-weather stations, in addition to Salem, prepare detailed small-scale maps, based on supplementary lookout reports plus the regular synoptic network data. Many MICs have developed local networks which provide either regular reports or on-call reports under certain threatening or severe weather conditions.

Station staffs are showing increasing interest in and use of radar and satellite data in their small-scale programs. As radar coverage increases over the Western Region, this will become one of our prime small-scale tools.

Agriculture forecasters have, of course, for many years developed and used hygrometric formulas and other objective aids for minimum temperature forecasting. Agriculture forecasters, along with fire-weather and aviation forecasters, have, over the years, probably worked more in the small-scale area and paid more attention to detail than any other group of forecasters.

XI. CONCLUSION

A summary has been made of various small-scale analysis and forecasting techniques, along with the presentation of various station small-scale programs. It is hoped that station personnel will make use of the techniques and examples presented here, and thereby develop methods for introducing more accuracy and detail into their short-range forecasts. Continued effort along these lines will be necessary in order that Western Region short-range forecasts will have an accuracy equal to the best possible under the present state of the science.

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FIGURE 1

SCALES OF ATMOSPHERIC SYSTEMS

Synoptic Scale	Characteristic Dimensions	Meteorological Examples	Necessary Spacing of Observational Network
MACRO	250 Miles Several Days	Long Waves Cyclones Frontal Systems Widespread Precip. Area	150 to 300 Miles
SMALL SYNOPTIC OR SUBSYNOPTIC	50 to 300 Miles Several Hours	Bubble-Highs Unsmoothed Isobaric and Frontal Patterns Hourly Changes (P, T, Precip.)	50 to 150 Miles
MESO	10 to 100 Miles Hours	Mesosystems (P, T. Precip.) Radar-Echo Patterns	5 to 50 Miles
LOCAL	1 to 20 Miles Several Minutes to an Hour	Visible Weather Cloud Patterns Local Storms Tornado Systems	1000's of Feet to 5 Miles (Visible from a Single Station)
MICRO	Inches to 1000's of Feet Seconds to Minutes	Wind, P, T, or Precip. Variations (turbulence) up to a few Thousand Feet	Inches to 100's of Feet

FIGURE 2

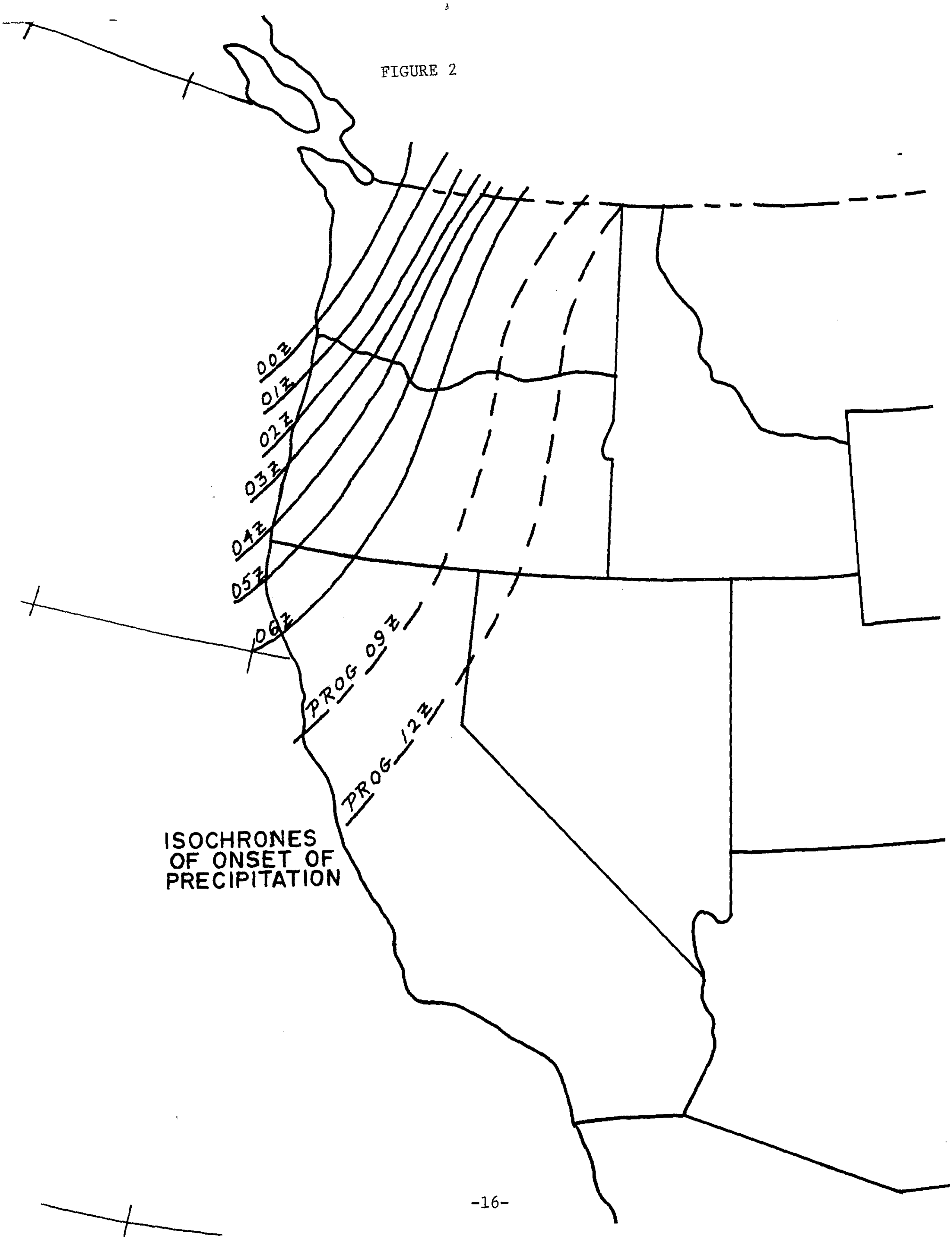

00Z
01Z
02Z
03Z
04Z
05Z
06Z
PROG 09Z
PROG 12Z
ISOCHRONES
OF ONSET OF
PRECIPITATION

FIGURE 3

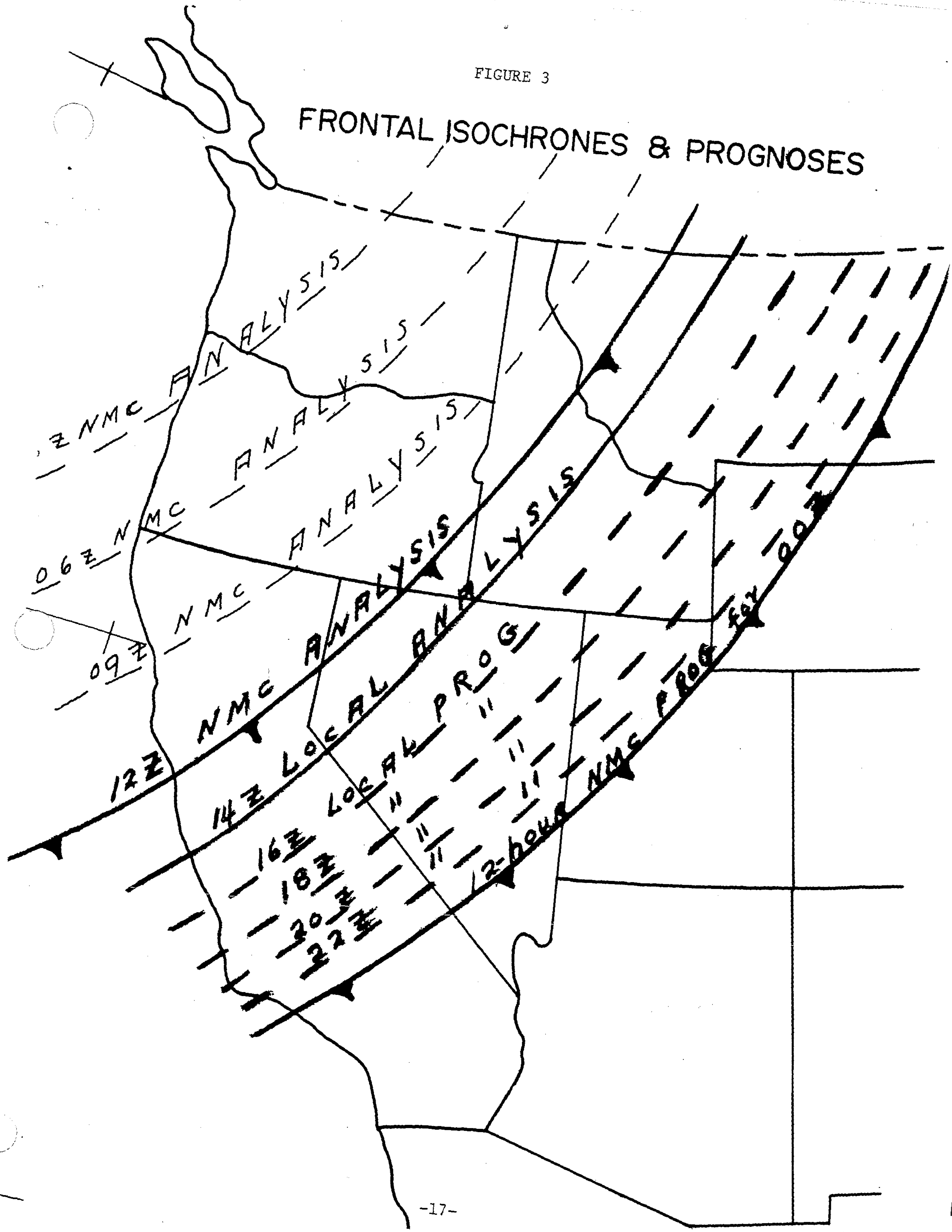

FRONTAL ISOCHRONES & PROGNOSES
Z NMC ANALYSIS
06Z NMC ANALYSIS
09Z NMC ANALYSIS
12Z NMC ANALYSIS
14Z LOCAL ANALYSIS
16Z LOCAL PROG
18Z
20Z
22Z
12-hour NMC PROG for 00Z

FIGURE 4

TREND CHARTS

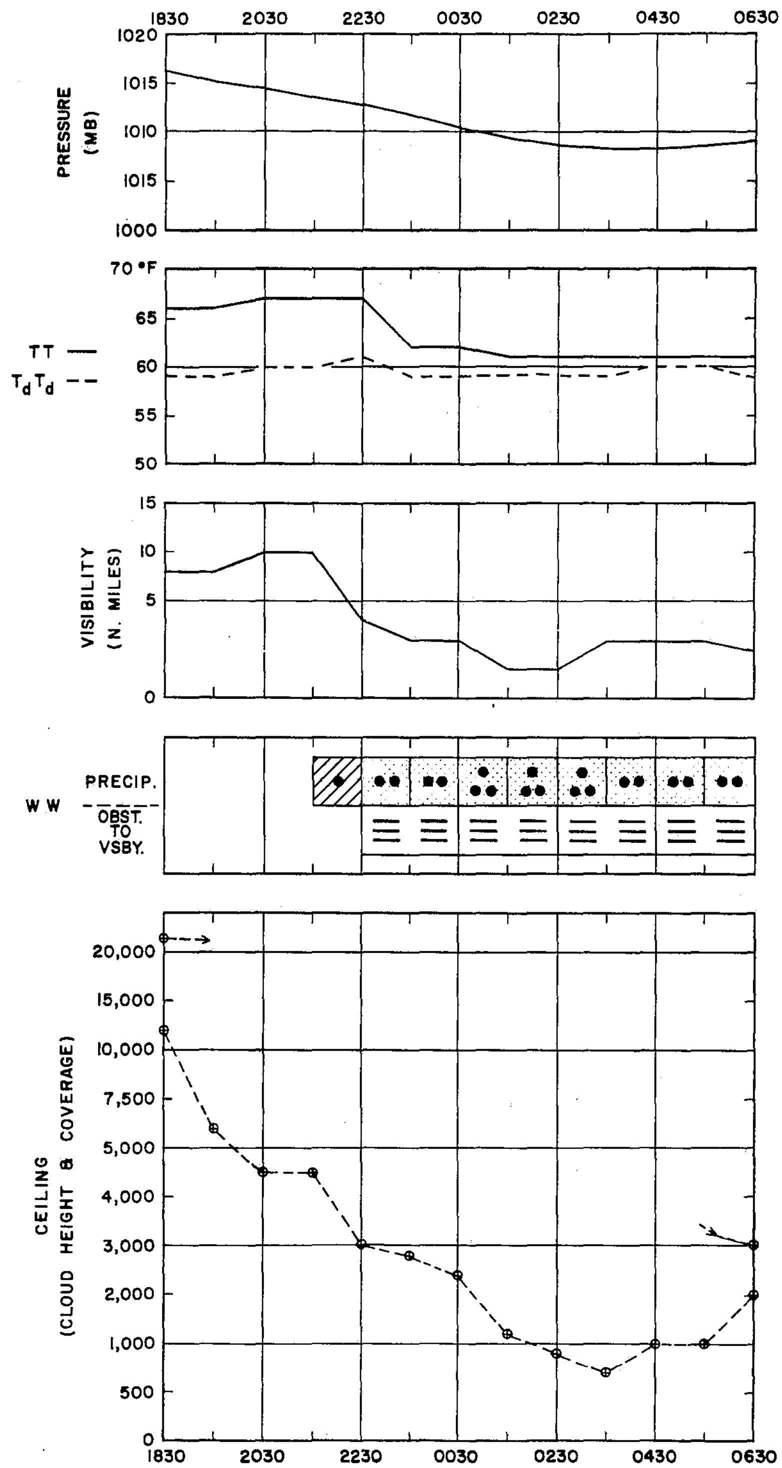
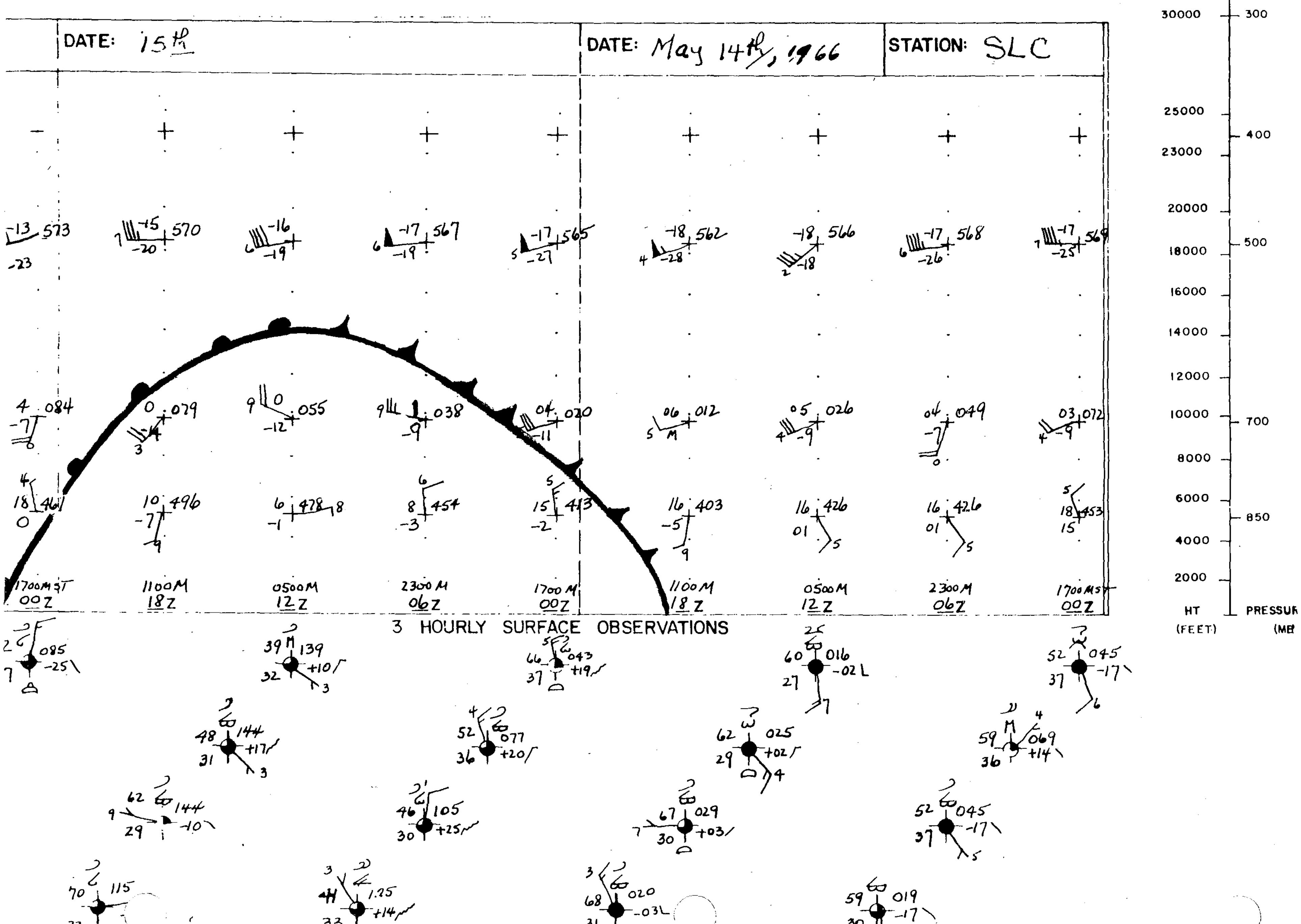


FIGURE 5

—TIME CROSS-SECTION CHART—



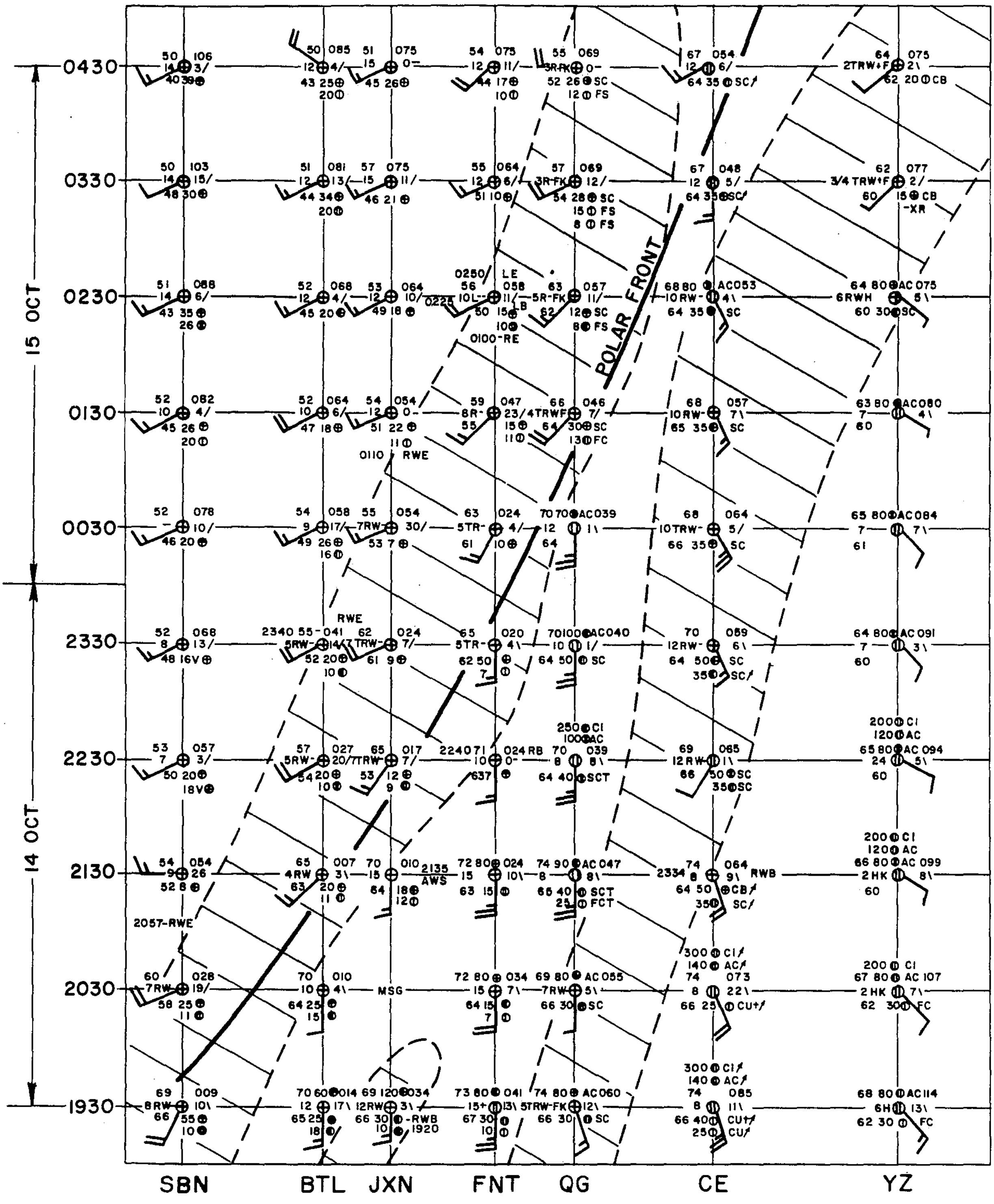


Figure 6 An Example of an x-t Diagram, 1930Z, 14 October – 0430Z, 15 October 1954. The positions of the front relative to the stations are indicated by the heavy continuous line. Showery areas are enclosed by broken lines and hatched.

FIGURE 7

THUNDERSTORM ACTIVITY CHART 1:3 M

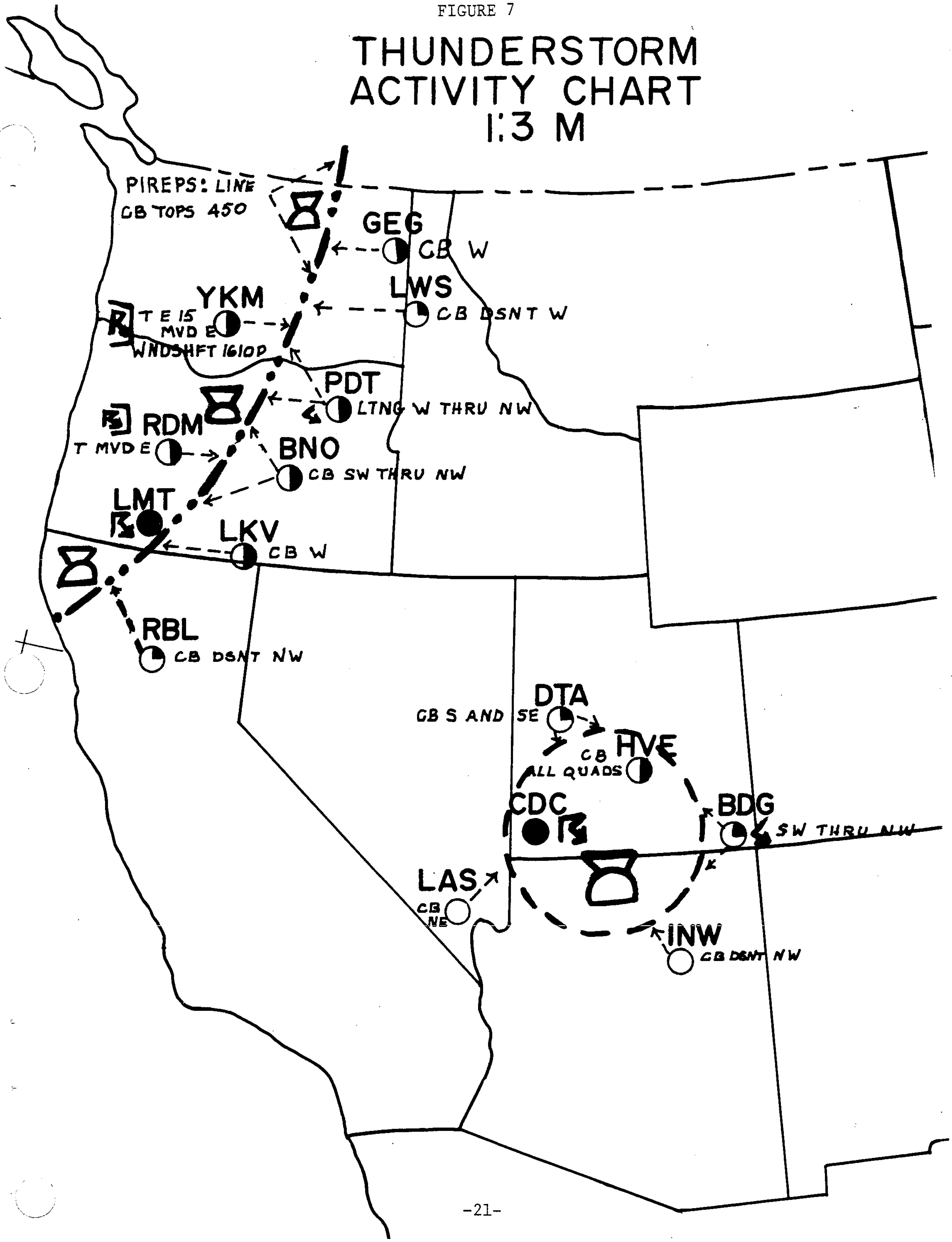


FIGURE 8

HELENA, MONT.

OBJECTIVE FORECAST CHART - MAXIMUM TEMPERATURE FOR THE DAY

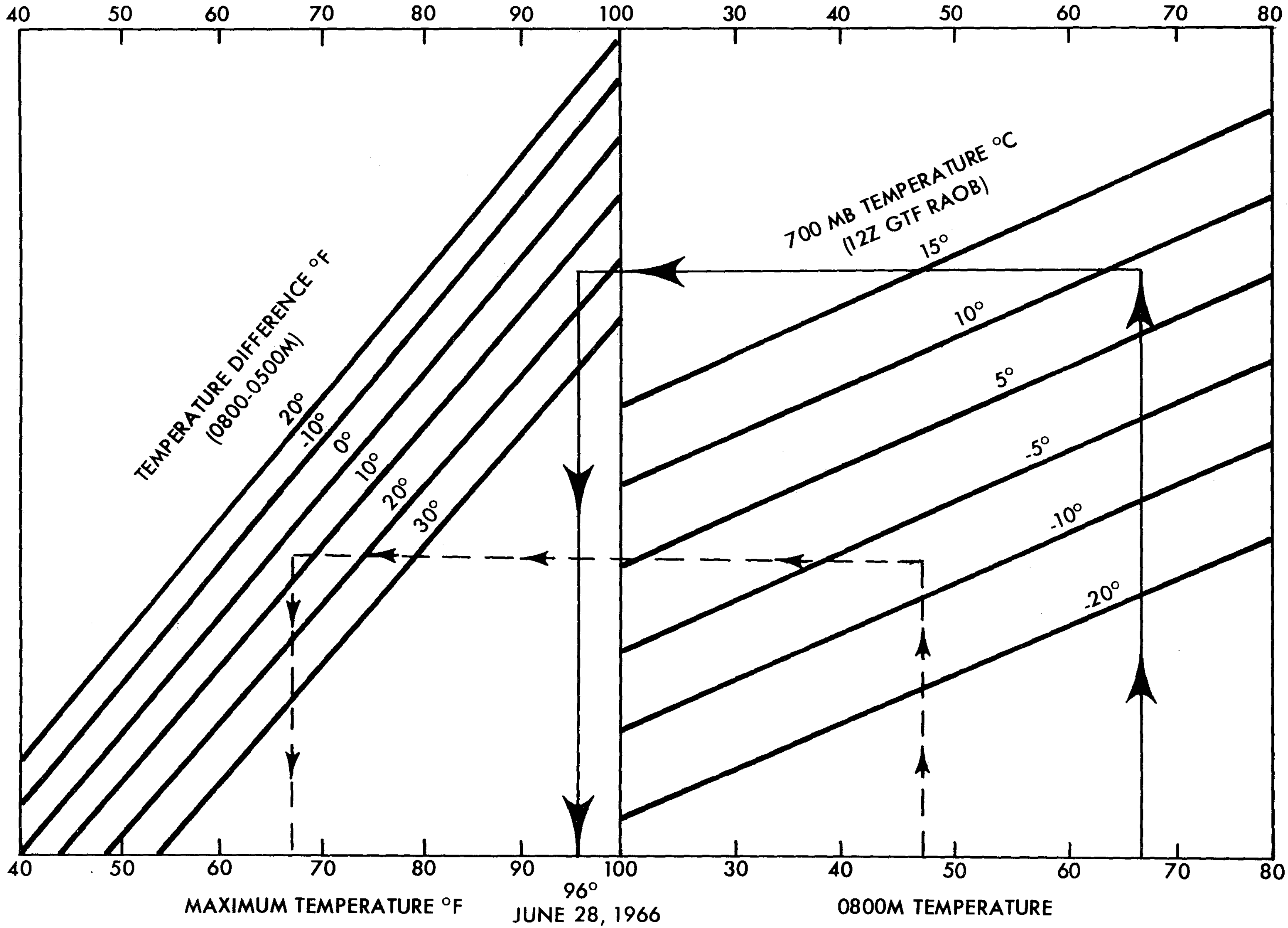


FIGURE 9
ILLUSTRATING THE METHOD OF DETERMINING THE DEPTH OF ARCTIC AIR OVER HELENA, MONTANA

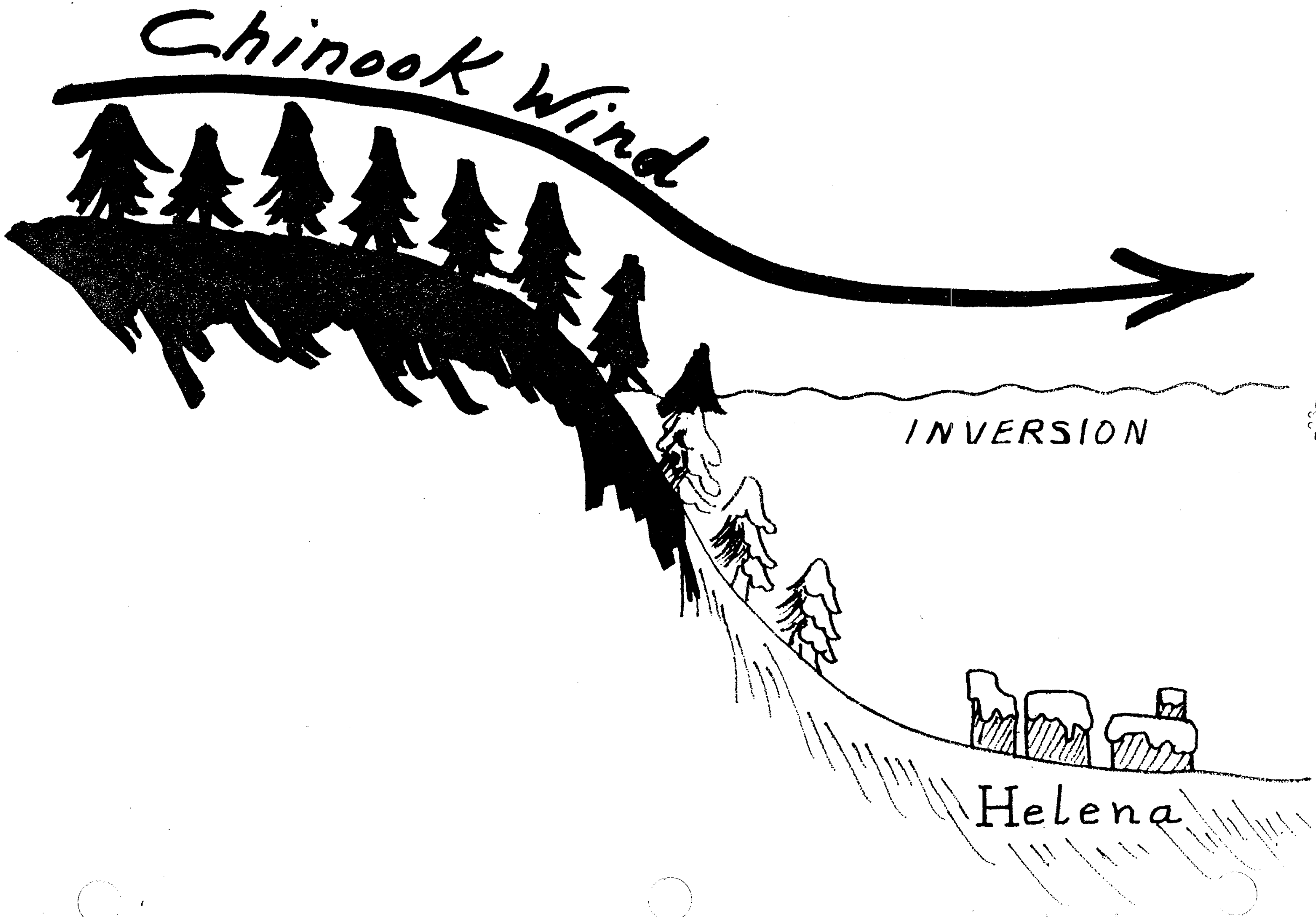


FIGURE 10

SURFACE MAP

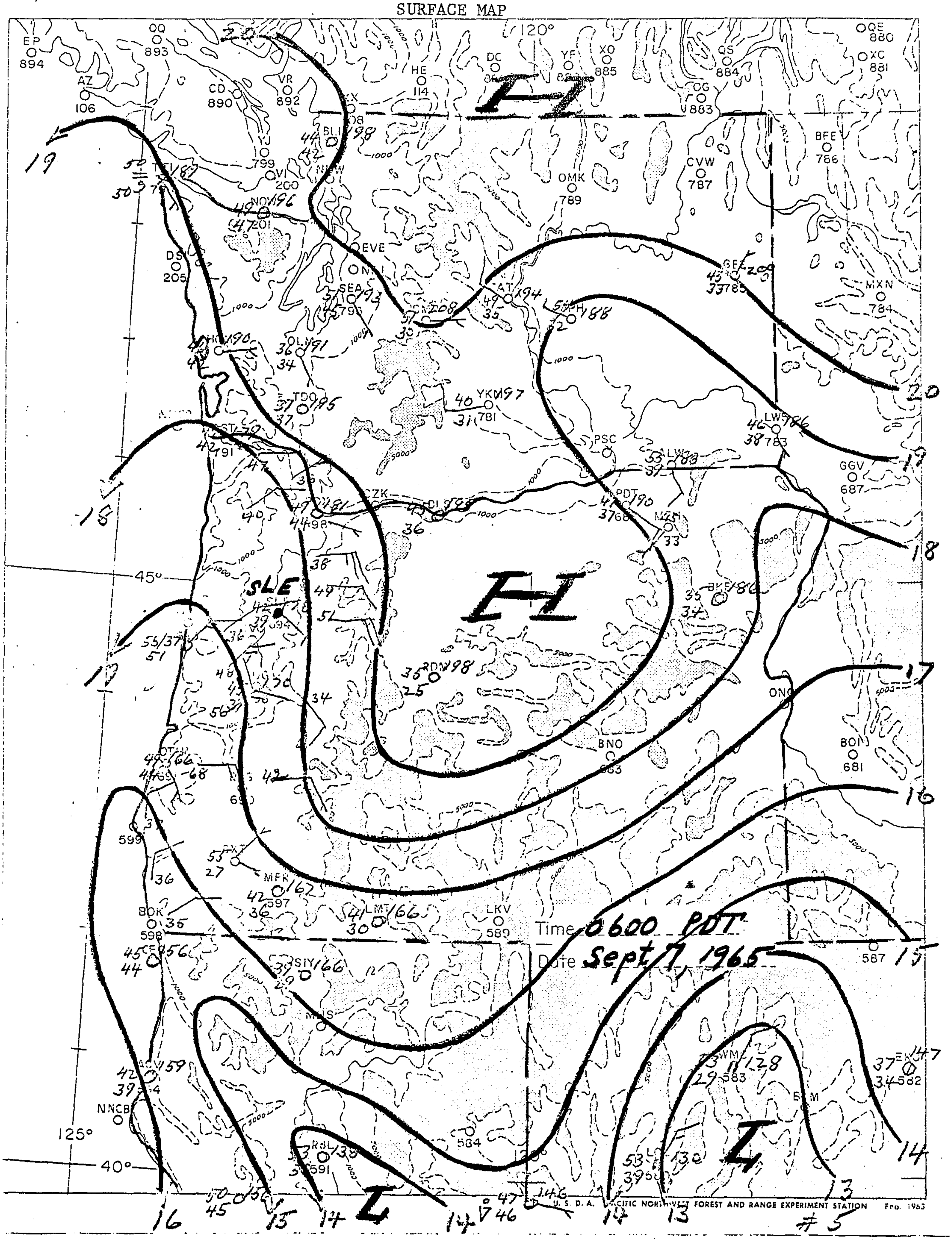


FIGURE 11
SURFACE MAP

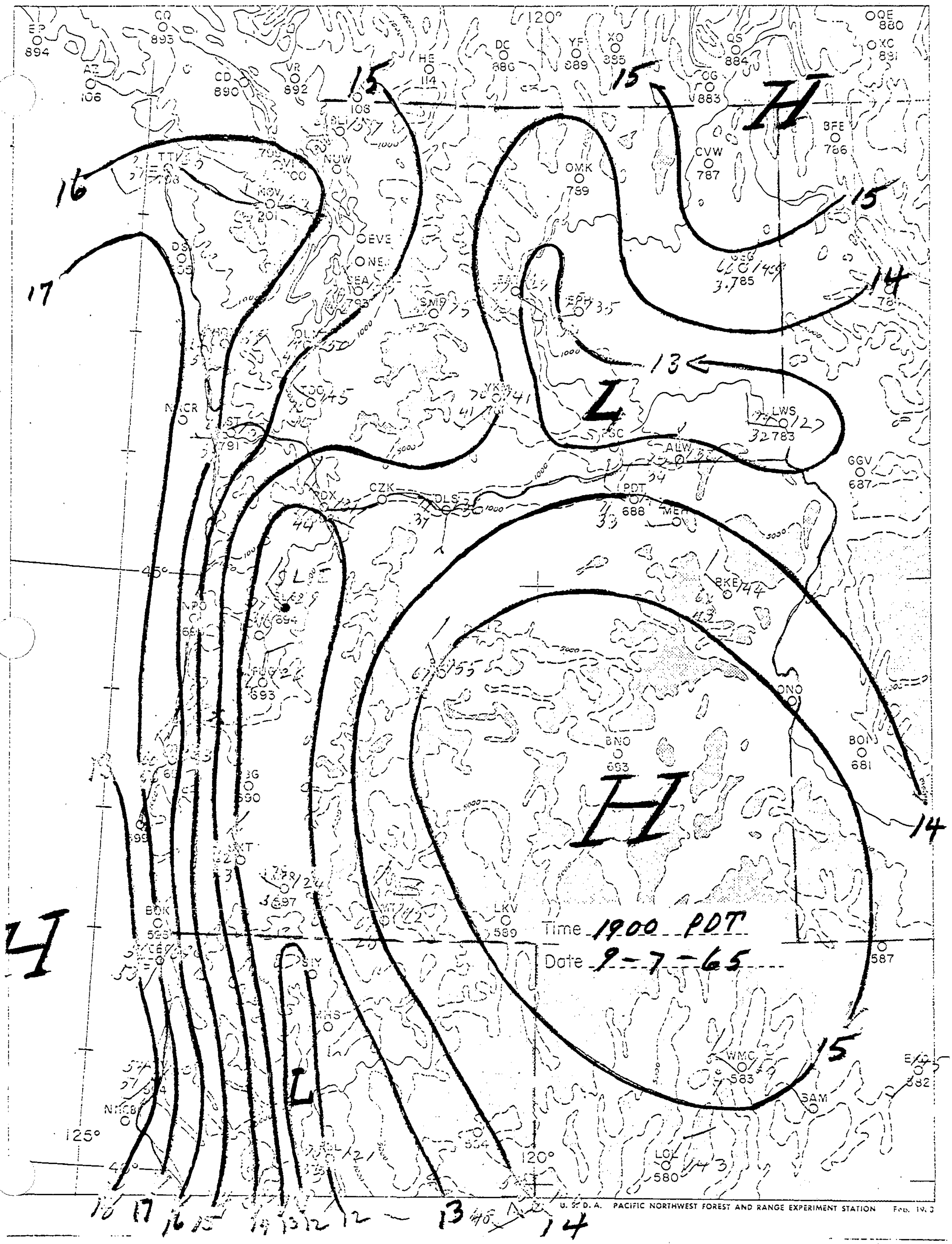
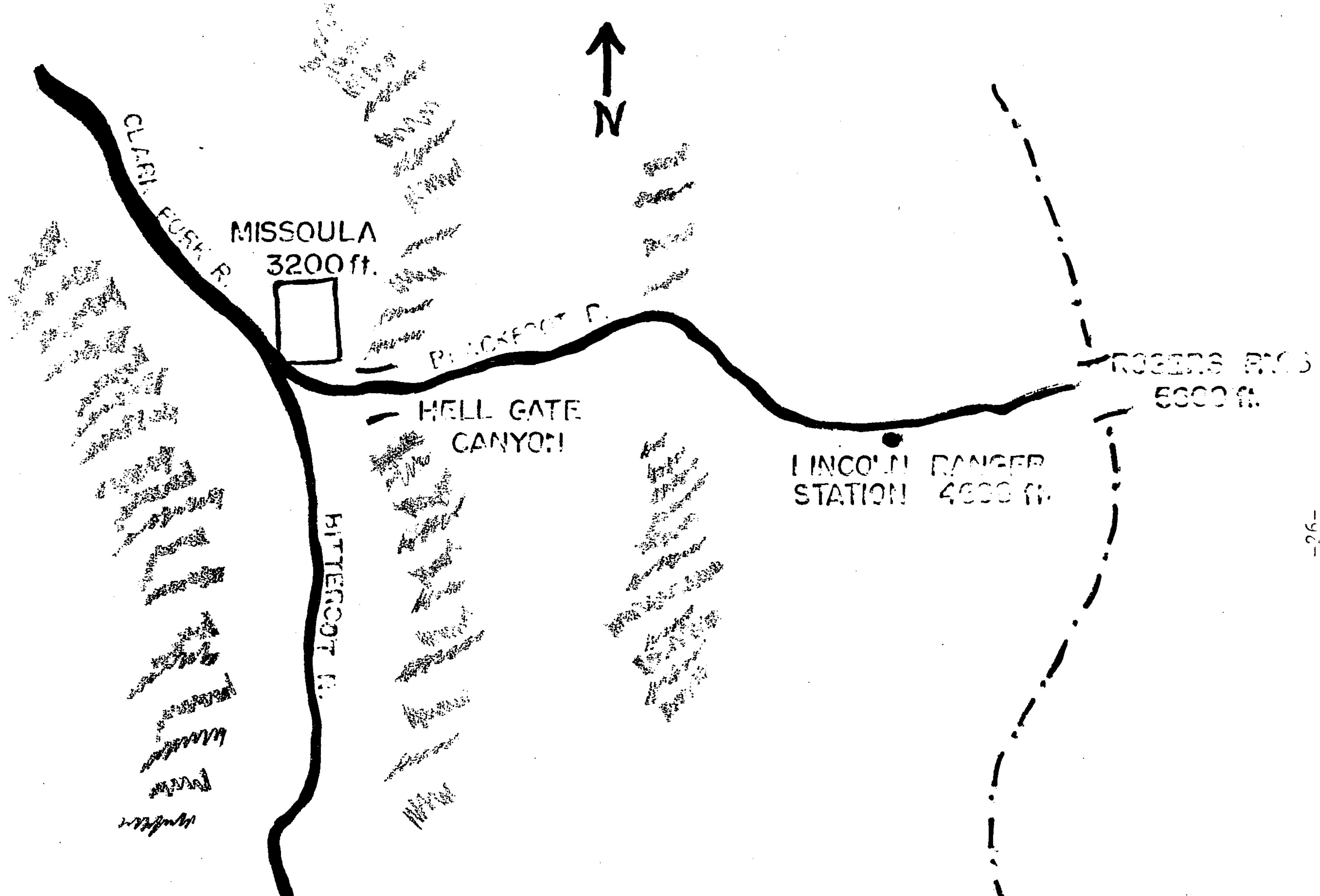


FIGURE 12



MISSOULA AREA

APPENDIX I

WESTERN REGION TECHNICAL ATTACHMENT
April 19, 1966

SPRING FRONTAL ANALYSES

We are entering the time of year when most of the important surface fronts that pass through our Region are weak. This attachment reviews what to expect of NMC surface analyses and suggests a procedure to follow in making detailed small-scale analyses.

At the start it is best that we recognize that frontal analysis is subjective and that classical frontal theory has important dynamic and kinematic shortcomings; therefore, let us consider the problem from a field forecaster's point of view, recognizing that differences of opinion exist and making allowance for them.

NMC has stated very clearly that " . . . the primary purpose of [their] surface analysis is to describe the pressure pattern and the important three-dimensional frontal boundaries; the two most important properties that [NMC] ascribes to the frontal boundaries are a pressure gradient discontinuity and a three-dimensional mean temperature gradient discontinuity . . . Fronts are introduced only to explain the large-scale three-dimensional baroclinic zones which are defined directly in terms of thickness gradients and indirectly in terms of convergence as implied by existing weather phenomena." (1)

The NMC Thermal Shear Criteria for fronts are:

$\leq$ 25 kts	No front or frontolysis
> 25 and $\leq$ 50 kts	Weak front or frontogenesis
> 50 and $\leq$ 75 kts	Moderate
> 75 kts	Strong

You can get a little better idea of these criteria by referring to the graphical illustration of thermal shears in Figure 3. Note that even a weak front requires a rather strong thermal gradient for our Region during the warm part of the year. The NMC analyst may modify the above criteria according to his interpretation of the existing weather. In general, though, it can be said that these criteria result in NMC omitting some fronts which to us are important from an operational standpoint. Similarly, some fronts are entered too late and taken off the charts too soon.

The short-period (up to 18 hours) forecasting problem is as much or more of a diagnostic than a prognostic problem. This fact has resulted in the Central Office and the Western Region Headquarters vigorously promoting the practice of field stations routinely preparing small-scale detailed surface analyses as an important step to improving short-period public forecasting. This small-scale analysis program for most of our stations should take the form of adding detail to the surface facsimile charts. Adding details to both the frontal and isobaric analyses for your limited area of concern will improve the utility of the surface fax chart and is within the workload limits of all of our stations. Applying the type of knowledge contained in Technical Memo No.5(2) when making this detailed analysis over a limited area is also feasible and beneficial.

A sectional chart should, of course, be plotted and analyzed by those stations where considerably more data is available than can be or is plotted on the fax charts, and where the necessary manpower is available. However, for most of our stations, the best procedure is to "massage" the surface fax analyses.

A suggested analysis procedure of facsimile or sectional charts is as follows (Note these steps refer to your own limited area of concern, not the whole chart):

A. To locate frontal zones:

1. Shade in the areas of middle and/or high broken-to-overcast cloudiness on the surface fax charts. Purple shading is suggested.

2. Note areas of positive vorticity advection (PVA) indicated on the initial panel of the 500-mb Vorticity/Contour chart. Yellow shading is suggested.

3. Study the plotted surface data beneath and at the downstream edge of the PVA areas for the possible location of a frontal zone. This is not to say that fronts exist under all PVA areas, but many do.

4. If a front is considered to exist, determine its specific location by checking previous maps to establish a continuity. The usefulness of fronts in forecasting is largely dependent on the quality of their continuity from chart to chart.

B. To improve the isobaric analysis, add intermediate isobars, especially in flat gradient areas.

The synoptic regime of April 11 - 12, 1966, illustrates rather well the principles and problems discussed above. Unfortunately, the 00Z April 12 chart was not readily available to us, so we have substituted the 0300Z surface analysis, Figure 1.

The NMC analysis for 0300Z, April 12, 1966, did not include any front in Washington or Oregon. (The thickness gradient indicated by dashed lines apparently was considered to be below that needed to justify a front.) Reference to the initial vorticity chart, Figure 2, shows a substantial region of PVA just off the West Coast. A study and interpretation of the plotted surface data and thermal field indicate a front should be entered on a detailed analysis. The frontal position chosen is as shown in Figure 1. Precipitation, wind-shifts, and changes in the character of the cloudiness were associated with the front as it moved eastward; and these, of course, were significant features to consider when preparing local forecasts.

NMC first entered this front on their 1200Z April 12 analysis, locating it along the northeast Idaho border, southward through central Idaho to the Nevada border, then southwestward through Reno and San Francisco. This position fits in well with the frontal continuity that was followed through the 0600 and 0900Z analyses prior to receipt of the 1200Z chart. Thus, by following the procedures recommended above and by studying the surface facsimile chart, one was able to add significant detail to this analysis and use it in preparing the widely disseminated early morning forecasts.

Use of satellite nephs was also involved in our analysis, but this is the topic of a subsequent Technical Attachment.

In summary, NMC will locate the large-scale three-dimensional baroclinic zones by their frontal analysis. Field station forecasters must add small-scale detail to this NMC analysis, especially during the spring and summer when weak fronts (often associated with significant weather phenomena) are not found on the fax charts.

(1) The NAWAC Manual, March 1963, Pages 5, 6, and 7.

(2) Western Region Technical Memorandum No. 5, "Station Descriptions of Local Effects on Synoptic Weather Patterns", by Williams, April 1966.

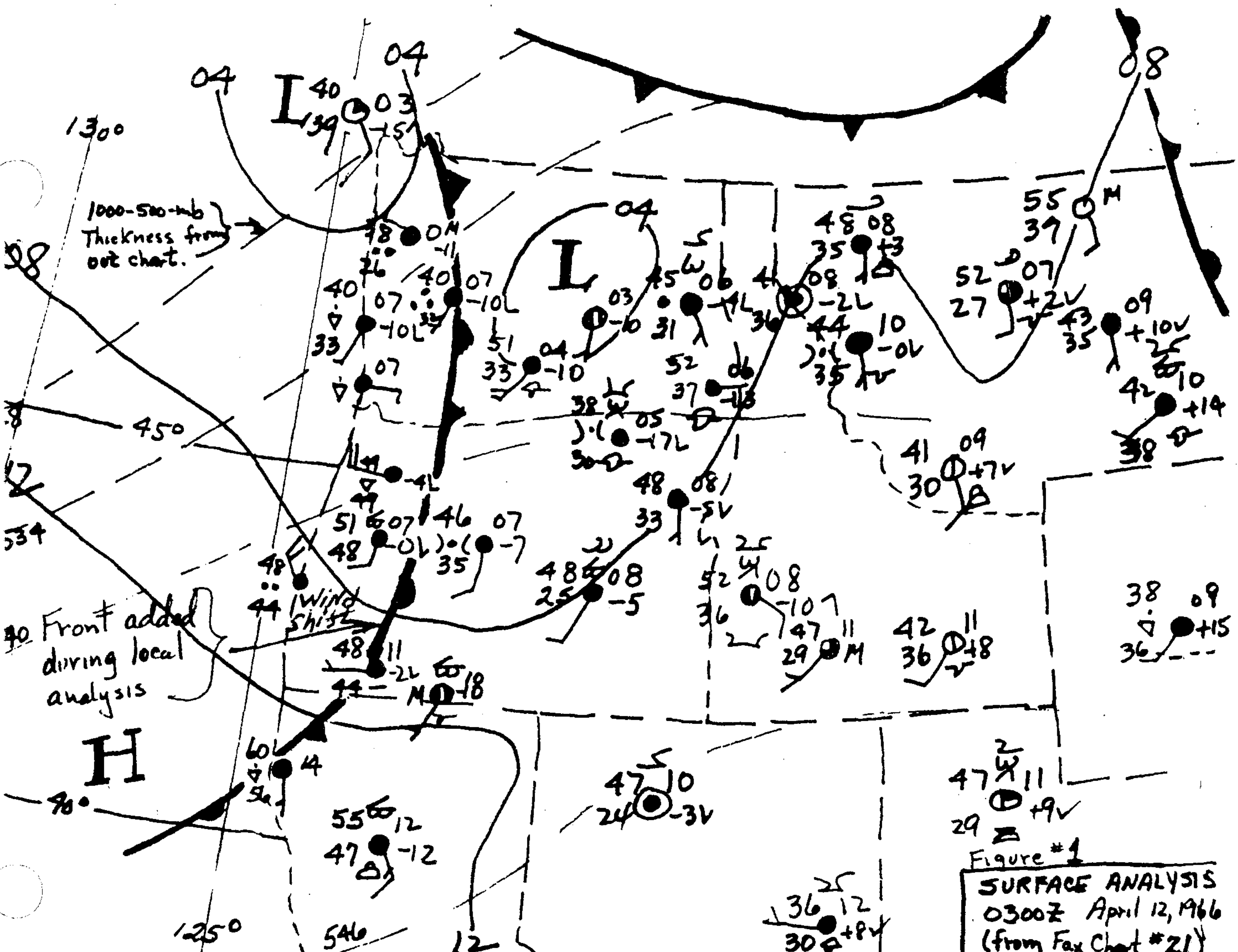
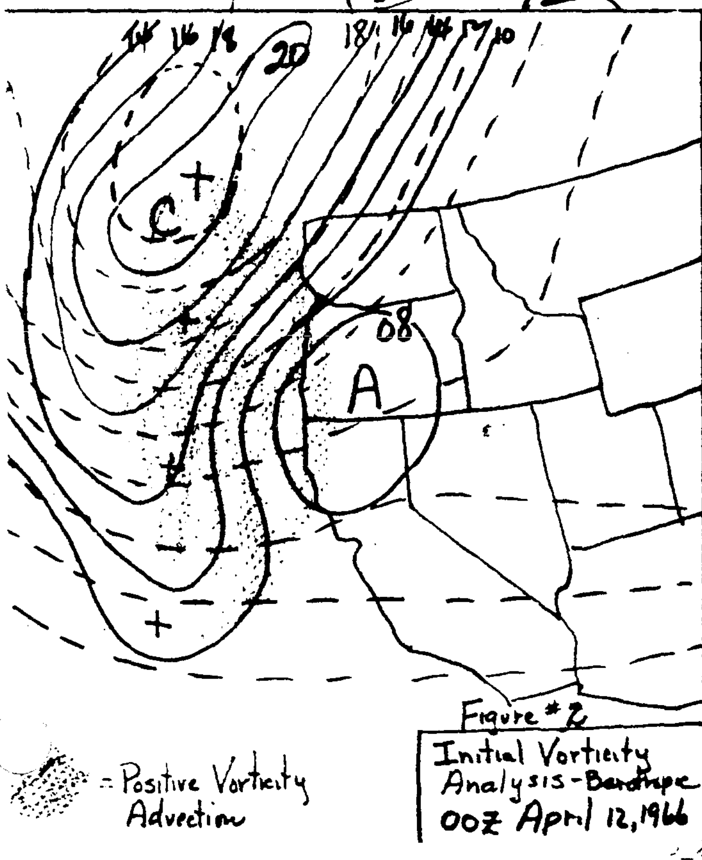


Figure #1
SURFACE ANALYSIS
0300Z April 12, 1966
(from Fax Chart #21)



= Positive Vorticity Advection

Figure #2
Initial Vorticity Analysis - Barotrope
00Z April 12, 1966

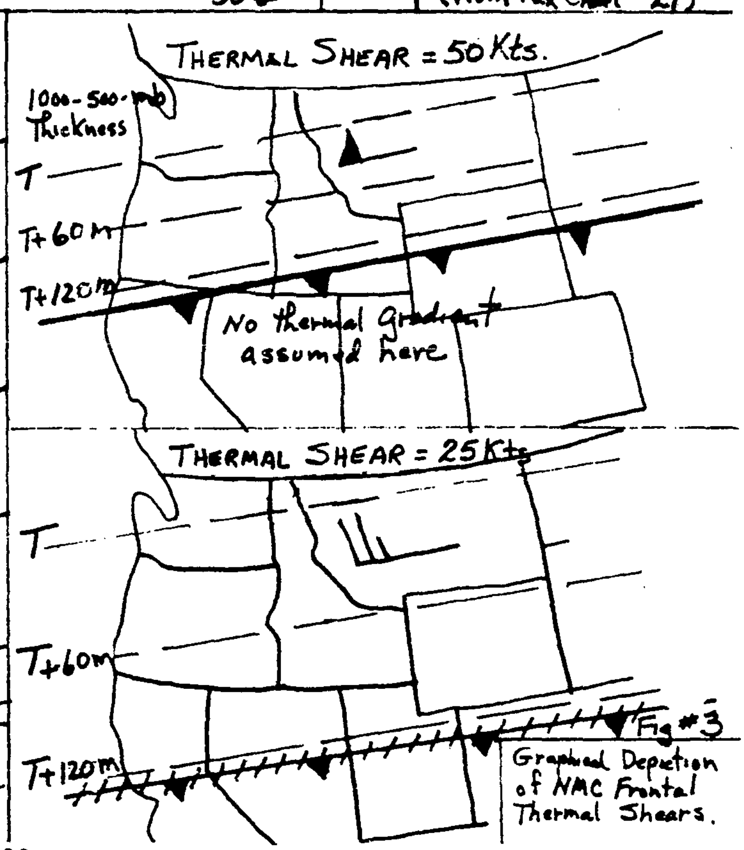


Fig #3
Graphical Depiction of NMC Frontal Thermal Shears.

WESTERN REGION TECHNICAL ATTACHMENT
November 22, 1966
No. 37-66

SHORT-PERIOD FORECASTING

This Technical Attachment illustrates how NMC 12- and 24-hour surface and upper-air prognoses can be used in short-period forecasting.

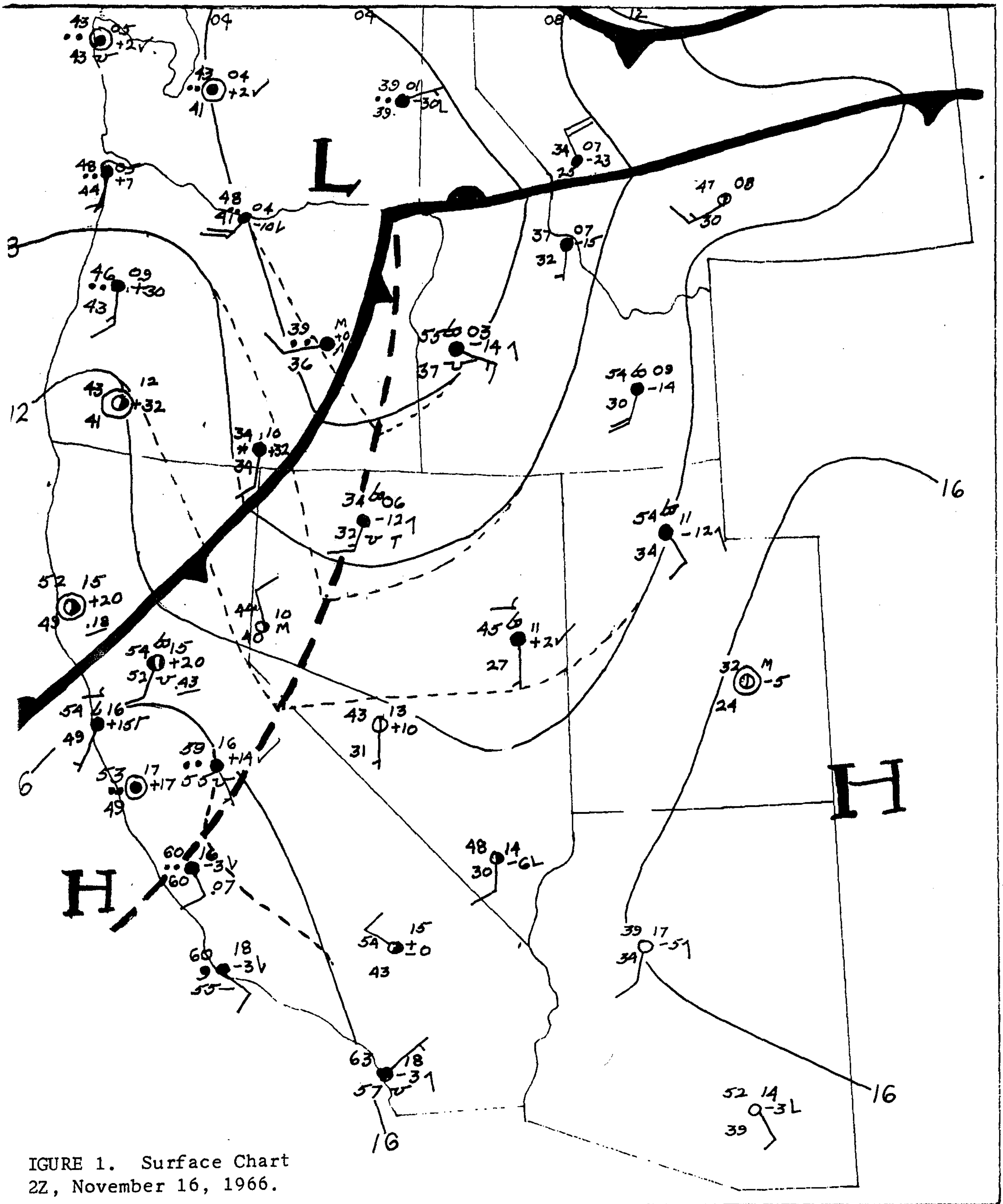
The advent of radar observations in the Intermountain Region has been a great boon to many Western Region forecasters. These radar reports plus APT satellite pictures and, to some extent, satellite nephanalyses, now give us the opportunity to prepare analyses in greater detail than was ever before possible. With our regular surface observational network so widely spaced over the Pacific and much of the Region, we must make optimum use of these new sources of data in determining the actual distribution and intensity of weather elements during the preparation of our small-scale analyses. The basis of a good short-range forecast is a good analysis. Another way of saying this is, the preparation of high-quality short-period forecasts involves more diagnostic than prognostic thought. However, once a careful and detailed analysis has been made, preparation of the forecast must take into account the development of weather systems as well as their movement. The development part is easily overlooked since extrapolation of past positions is such a useful short-period forecast tool.

The state of the science has become capable of producing forecasts superior to those based on simple extrapolation, now that forecast tools such as high-quality NWP upper-air forecasts and NMC surface prognoses are available to most forecasters. The highly successful 6-layer Primitive Equation forecasts and the timely barotropic vorticity charts are especially helpful in showing when extrapolation is useful and when its indications must be modified. The fact that these NWP forecasts and some NMC surface prognostic charts are available in 12-hour time steps makes them especially valuable and easy to use in preparing short-period forecasts of less than 24 hours. An excellent example of how these forecasts can be used to modify extrapolation occurred a few days ago:

On Wednesday, November 16, 1966, a frontal system was moving across the Region. At 1200Z the facsimile analysis located the front as shown in Figure 1. Shortly after this facsimile analysis was transmitted, the Salt Lake City ARTC rarep for 1445Z became available (Figure 2a). This additional data showed the NMC frontal position to be too far west in Nevada and California, even allowing for the 3-hour time difference between the charts. A small-scale analysis of the facsimile data, taking into account the rarep, resulted in the more detailed analysis indicated by the dashed lines in Figure 1.

With the detailed analysis prepared, the preparation of the forecast for Utah was well begun. Extrapolation of the precipitation shield associated with the front suggested that rain was likely for most of the state. The NWP 500-mb prognoses kept the long-wave trough off the West Coast, and forecast a good northward component and some weakening of the short-wave trough associated with the front. (See Figure 3a and 3b for this trough forecast.) Taking these forecasts into account suggested that the front and the weather associated with it would weaken as it moved into Utah. In light of these indications, the probabilities of precipitation should be lower than those that would be based on extrapolation only. Precipitation associated with the front did, in fact, decrease as the system moved eastward. This is shown by the 1645 and 1845 rareps (Figures 2b and 2c). Also, the 24-hour precipitation chart, Figure 3c, shows very clearly just how well the precipitation areas followed the NWP short-wave prognosis.

In summary, a detailed analysis is essential to a successful short-range forecast, but this analysis must not be used to the exclusion of developments indicated by the NWP and NMC prognoses. Optimum use of observational data includes a realization that this is a picture of what has recently occurred, not what will occur downstream in the next 6 - 24 hours.



IGURE 1. Surface Chart
2Z, November 16, 1966.

Figure 1. Surface analysis, 1200Z, November 16, 1966, copied from facsimile transmission No. 69. The dashed lines indicate revisions based on a more detailed analysis.

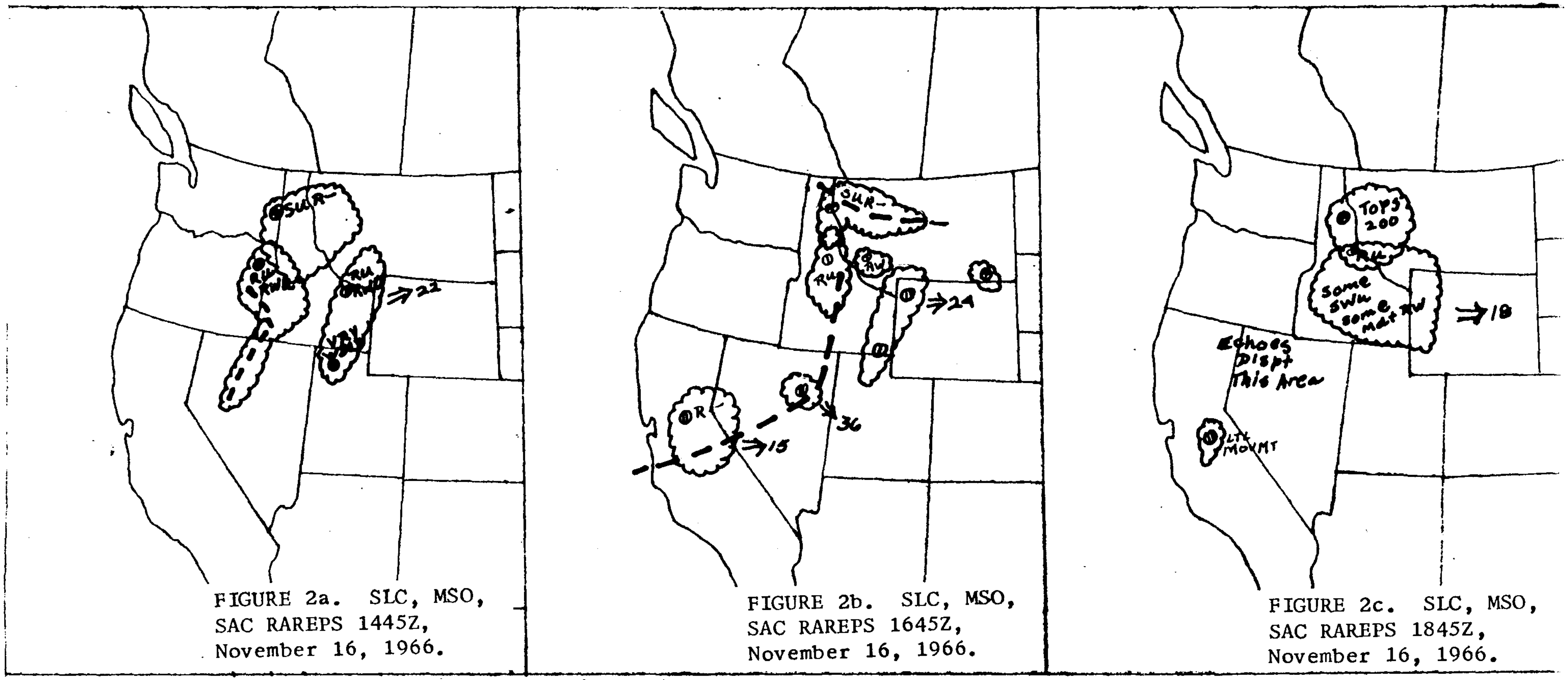


FIGURE 2a. SLC, MSO, SAC RAREPS 1445Z, November 16, 1966.

FIGURE 2b. SLC, MSO, SAC RAREPS 1645Z, November 16, 1966.

FIGURE 2c. SLC, MSO, SAC RAREPS 1845Z, November 16, 1966.

Figure 2. Plot of SLC, MSO, and SAC RAREPS for November 16, 1966, at times indicated on charts.

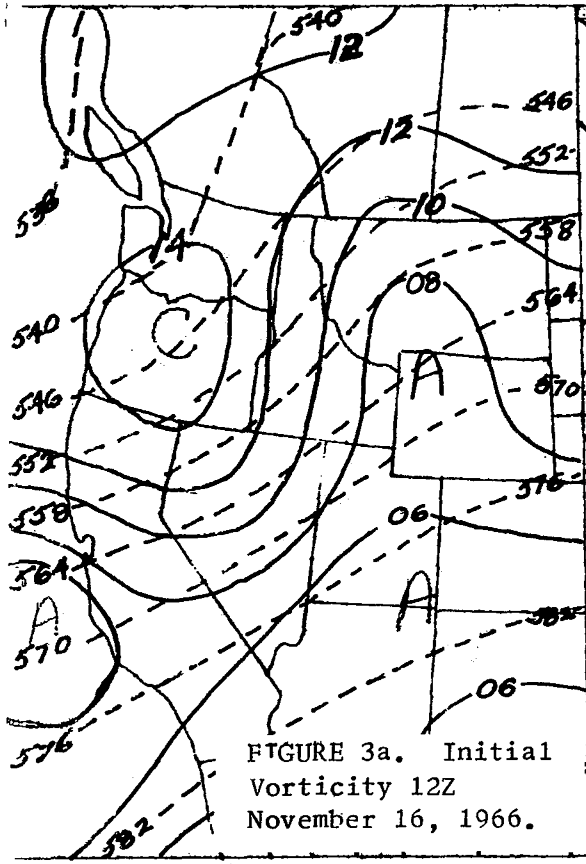


FIGURE 3a. Initial Vorticity 12Z November 16, 1966.

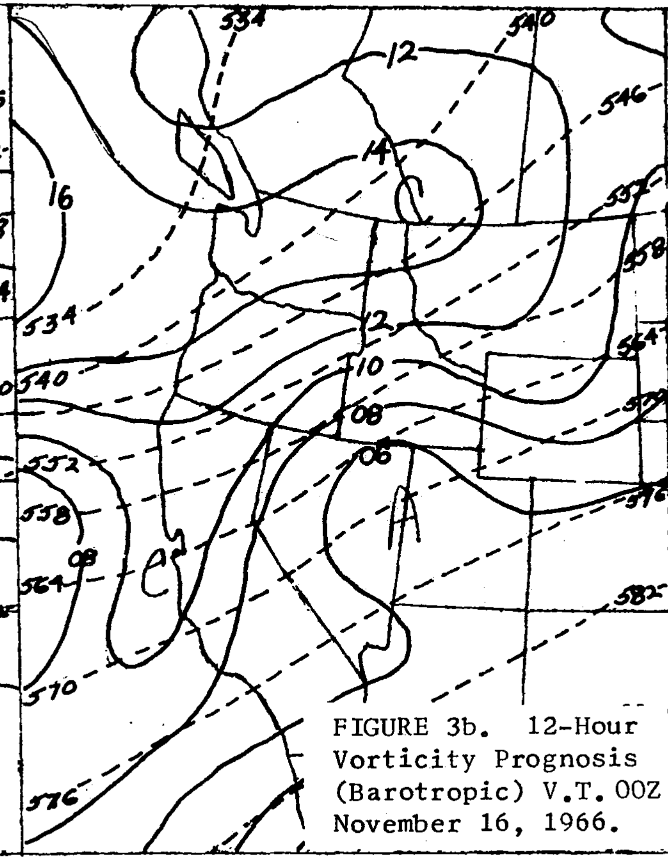


FIGURE 3b. 12-Hour Vorticity Prognosis (Barotropic) V.T. 00Z November 16, 1966.

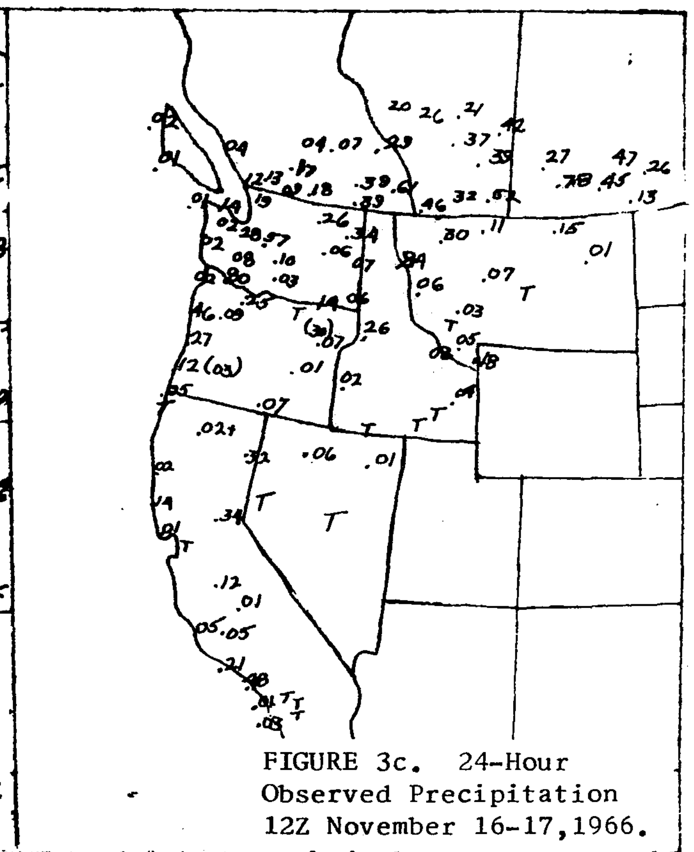


FIGURE 3c. 24-Hour Observed Precipitation 12Z November 16-17, 1966.

Figure 3a. Initial 500-mb contour and vorticity analyses for 1200Z November 16, 1966. Dashed lines are contours labeled in decameters. Solid lines are absolute vorticity isopleths 10^{-5} per second.

Figure 3b. 12-hour barotropic 500-mb contour and vorticity prognoses, valid time 0000Z November 17, 1966.

Figure 3c. 24-hour observed precipitation for period ending 1200Z November 17, 1966.

APPENDIX II

WESTERN REGION TECHNICAL ATTACHMENT
November 15, 1966
No. 36-66

SURFACE TIME SECTIONS

Finding time to do small-scale analysis during bad weather situations--when such analysis is most needed--is a common problem throughout our Region. To help solve this problem, Regional Headquarters has promoted at most stations the use of the 1:10M surface facsimile chart as the basic small-scale analysis work chart rather than a locally plotted and analyzed 1:3M chart. For most of our inland stations, there are only a few reports available that are not plotted on the facsimile chart. These reports plus additional data such as radar reports can be plotted on the facsimile chart itself or on an acetate overlay. This added information plus knowledge of the representativeness of the originally plotted data (see Western Region Technical Memorandum No. 5) frequently permits the local forecaster to add significant detail to the facsimile analysis. When this is done, the 1:3M chart is used as an "activity" chart, i.e., a chart where important phenomena are plotted and followed. Such a small-scale analysis program frequently makes time available to produce and use to advantage other small-scale analysis and forecast techniques.

Time sections of various kinds are examples of these helpful techniques. A time vertical cross-section using raob data was discussed in the Technical Attachment to the minutes of May 17, 1966. The surface time section is another of these very useful tools which takes very little time to construct and use.

The importance of this analysis tool was ably demonstrated by the Great Falls forecasters last week. Critical weather was imminent in Montana with the approach of both a Pacific front and an Arctic front. Twelve hours or more before the bad weather was expected to hit the area, a surface time section was started using several upstream stations (see Figure 2). The forecasters entered the hourly reports of these stations on the form and tracked the deteriorating weather into and through their district. The short-term 6- to 18-hour forecasts of the expected start of the snow and frontal passages verified well. As is to be expected, the Great Falls forecasters were very busy during this weather situation; yet, the little time needed to keep up the time section and its usefulness in following and forecasting the weather made it an important part of the duty forecaster's work routine.

Forms for time sections are easily constructed. A few vertical lines on a ruled sheet of paper are all that is needed. Distance is the vertical axis with the upstream stations entered along this axis and spaced roughly in accord with the distance between stations on a weather map. The particular stations to be used can be entered on the time section just before putting it into use. The line of stations used is determined by the direction from which the weather is expected to come. The spacing can be obtained by overlaying the vertical edge of the form on a blank weather chart and marking off the distance between stations to be used. Time is the horizontal axis and is labeled so that the hours increase from right to left (see Figure 2). The time axis is directed from right to left in order to have the time section resemble a space plot (i.e., a regular weather chart). For example, if a trough passes a station and the time axis is directed from right to left, the trough looks the same on the time section as it does on a weather chart (see Figure 1a). If time is directed from left to right, it looks like a ridge (see Figure 1b).

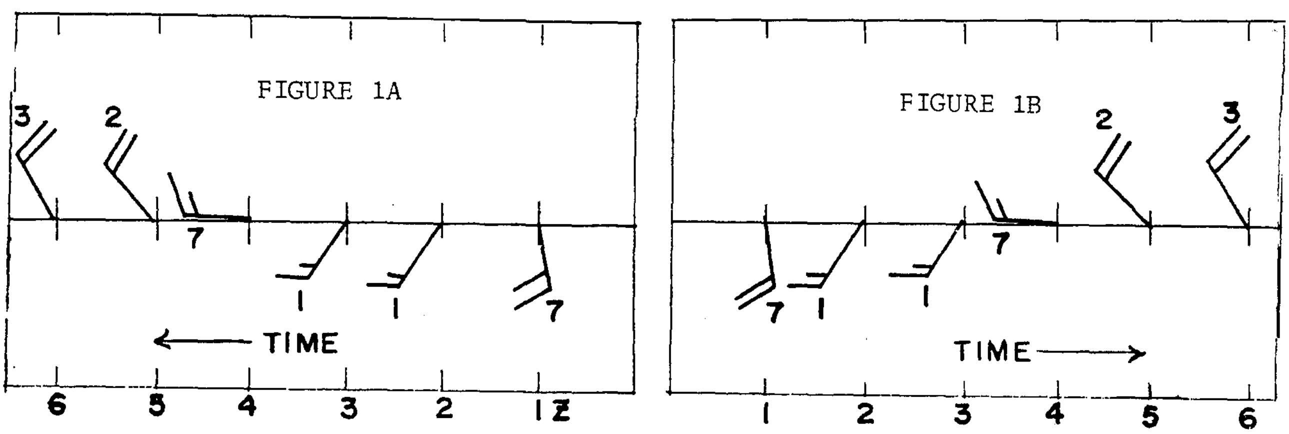


Figure 1. Schematic surface-wind time sections illustrating the differences in presentation when the time axis is directed from right to left (1A) and from left to right (1B).

Figure 2 is a portion of the time section prepared by Great Falls forecasters last week as an aid in timing the arrival of the Pacific front and the onset of snow at stations in their district. Note that it is easy to extend the frontal passage lines into the future.

A time section is not an aid that is prepared daily, or that is even useful every day. This forecaster's tool is only useful in tracking significant weather changes associated with migratory systems. As such, it is frequently most useful during the cold season of the year and can be used in place of "activity" charts.

In summary, a small-scale analysis program does not consist of plotting and analyzing a 1:3M weather map--although this is very important at some stations--but, rather, it consists of discriminant employment of facsimile products, time sections, conditional climatological studies, etc., to get the best short-range forecast possible.

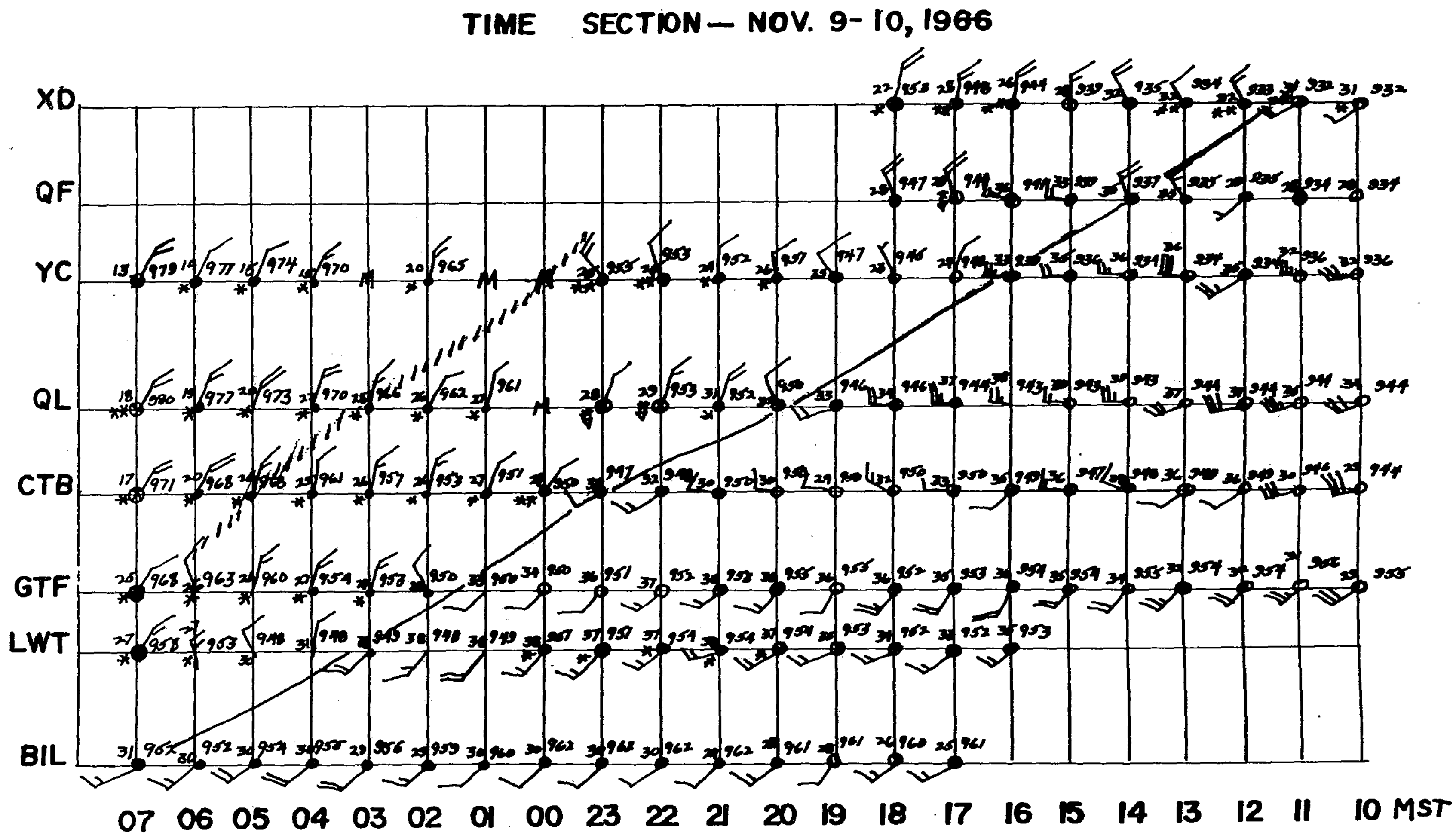


Figure 2, Surface Time Section, November 9 - 10, 1966, prepared at Great Falls. The solid diagonal line indicates Pacific frontal motion. The wind shifts at QF are difficult to interpret; however the wind shifts at stations south of QF are quite consistent and were extrapolated downstream as one indication of the onset of snow and northerly winds. The dashed line indicates the strong temperature drop which is associated with the influx of the Arctic air. Note the reports indicate the Arctic front is diffuse. The station descriptions in Western Region Technical Memorandum No. 5 were used to interpret some of plotted reports. Unfortunately, descriptions for the Canadian stations are not yet available. (This figure was made available through the courtesy of Mr. A. Jacobson, Great Falls.)

APPENDIX III

WESTERN REGION TECHNICAL ATTACHMENT
June 6, 1967
No. 67-21a

RADAR HELPS THE SMALL-SCALE FORECAST

The problem of detecting or isolating small-scale weather phenomena, using data from synoptic-scale networks, can often be difficult due to our inability to recognize areal weather patterns from widely scattered observations. It is in this problem area that weather radar has frequently come to the rescue. Weather radar, coupled with other small-scale analysis techniques, is becoming more and more effective as a short-range forecast tool. This fact was vividly demonstrated at Salt Lake City on Memorial Day, 1967.

Through the alertness of the Radar Meteorologist and the Aviation Forecaster, the Salt Lake City WBAS was able to issue excellent aviation forecasts of significant weather by adding mesoscale information provided by the radar. Without radar, a squall line which developed over the Great Salt Lake Desert would probably have gone unnoticed until encountered by some unsuspecting pilot.

Figure 1 shows the radar scope overlay composite prepared by the FAA FSS Radar Unit at Salt Lake City at 1635Z (0935 MST) May 30, 1967. The weather indicated by the radars at this hour was as expected, i.e., widely scattered showers in their early stages of development with heavier activity over the mountainous areas. However, two hours later (Figure 2) convective shower activity and thunderstorms had increased at a surprising rate. Hourly aviation sequence reports indicated the presence of showers and thunderstorms, and even hail at Wendover, but gave no clue as to the presence of the squall line forming east of Wendover, plainly evident on the radar overlay.

The Radar Meteorologist, alerted by the development of the squall line and the proliferation of shower activity over the general area, called the forecast center to bring these developments to the special attention of the Aviation Forecaster. For the next 30 minutes he studied the radar developments carefully in the light of his discussion with the Aviation Forecaster. At 1915Z the Radar Meteorologist again called the forecast center to report that the radar picture had developed to the point where warnings should be considered for hail and heavy shower activity in association with the squall line just east of Wendover, Utah. He advised that the squall line was extrapolated to be over the Salt Lake City area in 3-1/2 hours, based on current movement. Pilot reports had indicated tops 36 - 37 thousand feet.

Based on this information, the aviation forecaster quickly issued the following AIRMET: "COR AIRMET DELTA 1. FAA-ESSA RADAR REPORTS LN OF TSTMS EXTDG N-S FROM APPROX 30 MIS NE OF ENV TO 10 MIS NW OF MLF WITH LEADING EDGE OF LN APPROX 56 MIS W OF SLC AT 1920Z. LN APPARENTLY MOVG EWD AT APPROX 16 KTS. TOPS OF TSTMS RCHG TO NR 400 AND ARE BLDG AND SPRDG RPDLY. EXTRM CTN ADZD AND REFERENCE IS MADE TO OUR SIGMET CHARLIE 1."

TECHNICAL ATTACHMENT

While this advisory is a bit long, it did provide a timely warning to pilots of significant weather associated with the squall line. The Salt Lake City weather observation at 1555 MST was: -X20⦶M33⦷50⊕6RW-/3012 G25/ 2233 FROPA LTGCG.

As the day progressed, the radar data concerning the squall line were passed directly to the forecasters. These data provided timely and direct input to the afternoon FT's issued by Salt Lake City. In the words of the forecasters, "The radar really helped us on this one!" The radar prediction was 15 minutes fast, but this severe weather could well have gone undetected until encountered by aircraft in flight.

The SLC ARTCC radar reports now give forecasters the best opportunity that they have ever had to keep track of shower activity over the data-sparse Intermountain Region.

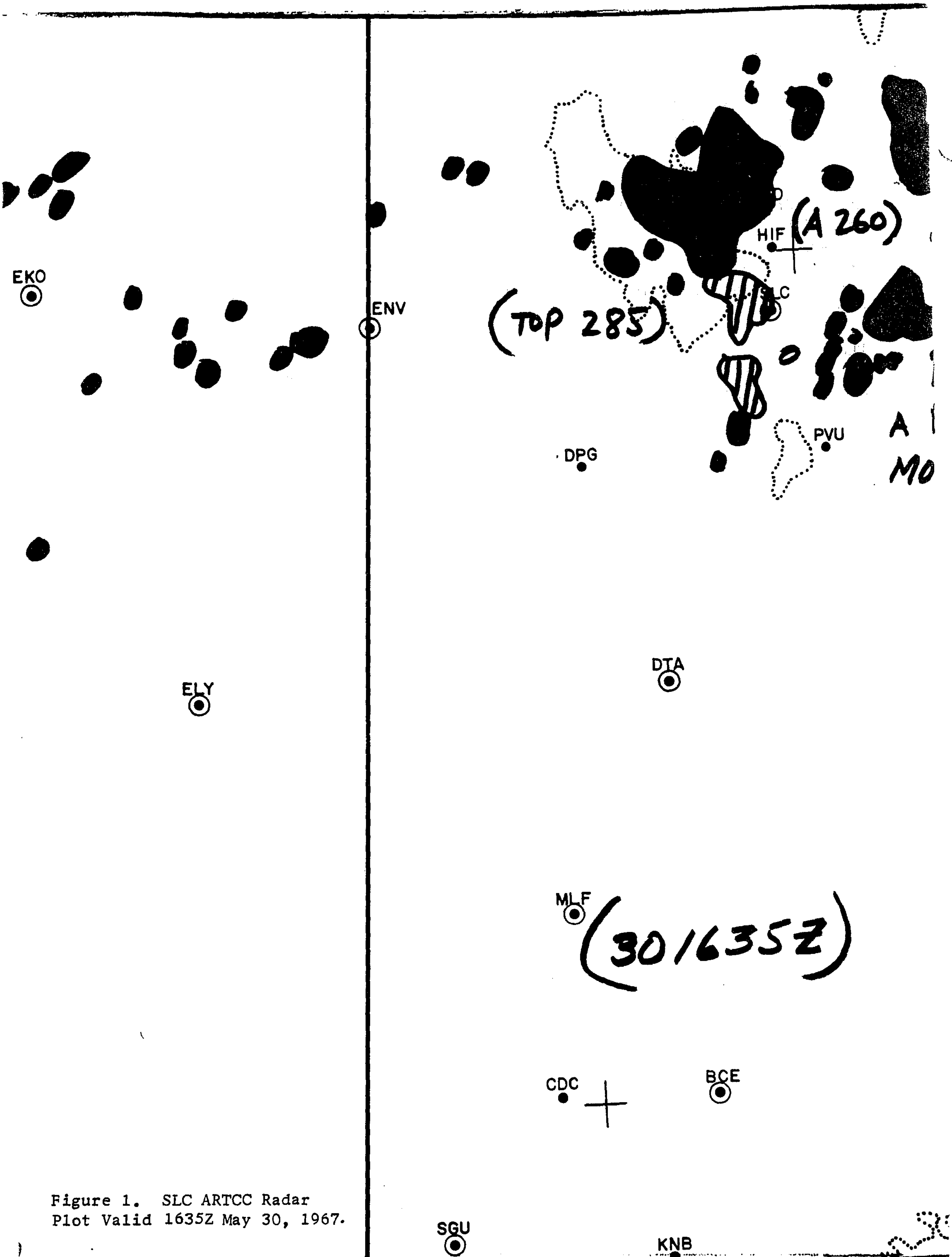


Figure 1. SLC ARTCC Radar Plot Valid 1635Z May 30, 1967.

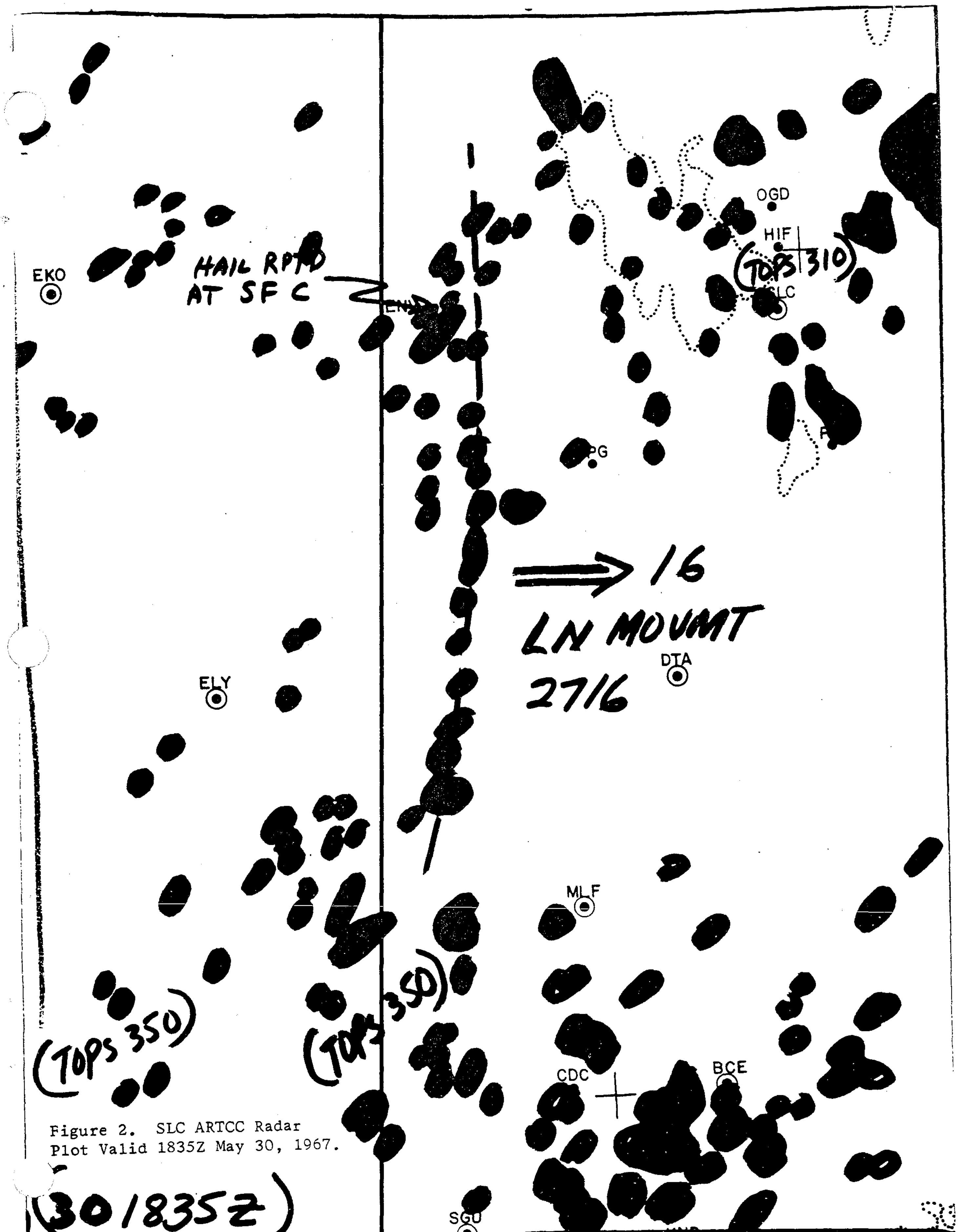
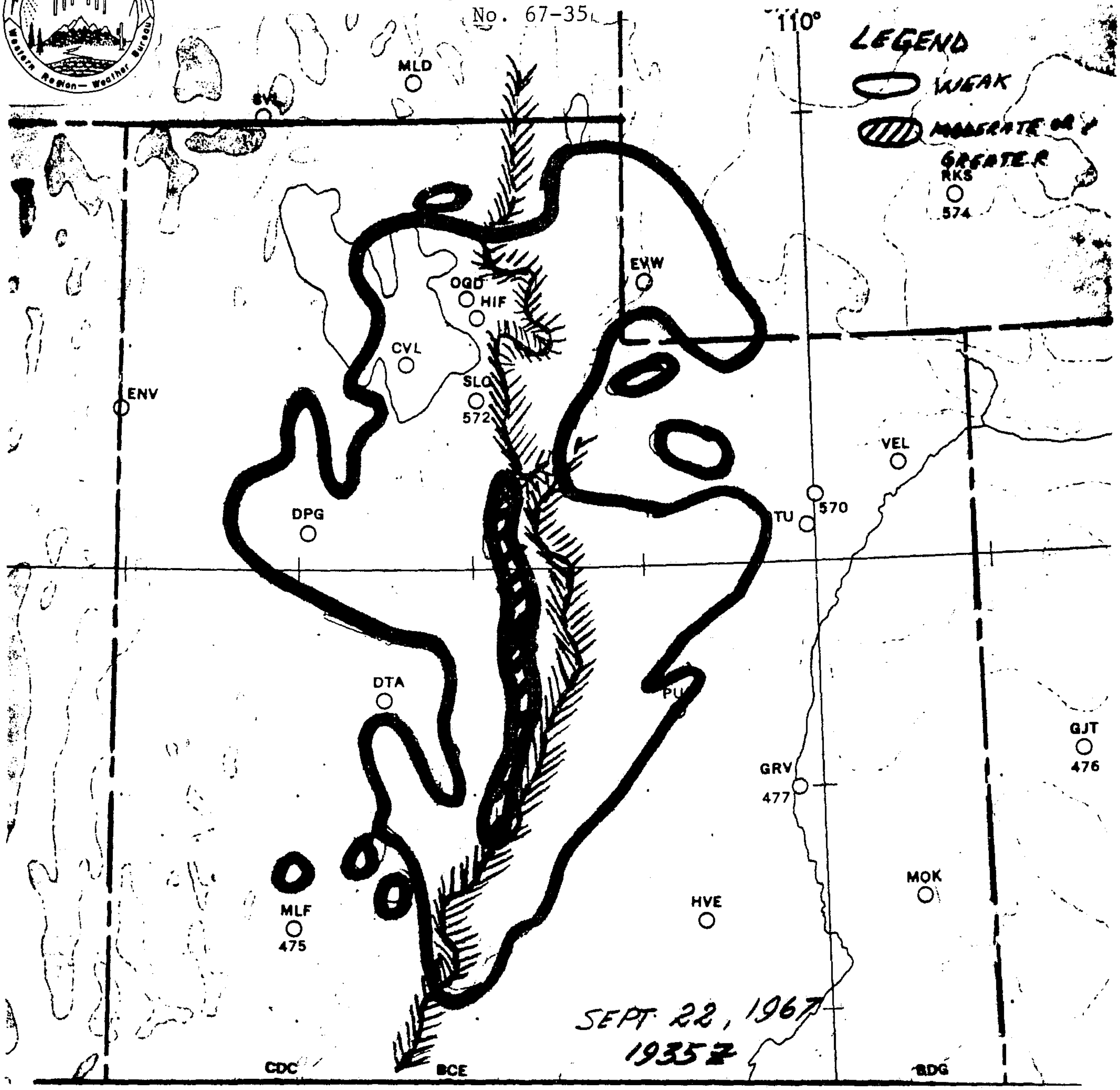


Figure 2. SLC ARTCC Radar Plot Valid 1835Z May 30, 1967.

WESTERN REGION TECHNICAL ATTACHMENT
September 26, 1967
No. 67-35



MOUNTAINS AND RADAR

The above radarscope overlay prepared by the Salt Lake City ARTCC, ESSA-FAA Weather Radar unit shows the kind of detailed information that can be obtained from the FAA radar systems. Shown above is a moderate-to-strong solid line embedded in the wide-spread precipitation area extending the entire length of Utah. The narrow band of more intense precipitation appears to be the result of orographic lifting along the Wasatch Mountains shown by the feathered line. Echoes of this nature persisted over the Wasatch throughout the day. Orographic intensification of precipitation along the Wasatch Front often produces downpours which cause local flooding in residential areas lying along the foothills. The FAA radars cannot provide quantitative precipitation data directly since they lack the necessary circuitry. However, through careful comparison of echo displays at various operating modes, the radar meteorologist is able to provide two contours of relative precipitation intensity.

WESTERN REGION TECHNICAL ATTACHMENT
December 19, 1967
No. 67-47

LOCAL-USE RADAR AT ITS BEST

Based on the forecast for December 6, 1967, MIC Ivan Anderson of the Eureka Weather Bureau Office had a hunch he would be able to detect echoes on his WSR-3 that afternoon. His hunch was right, and what he saw was quite interesting.

At approximately 1600 PST his radar detected thin wisps of precipitation echoes about 70 miles west-northwest of Eureka. Mr. Anderson then called the Sacramento Weather Bureau Office, which is collocated with the River Forecast Center, and advised of his radar detection of the storm. Arrangements were made to transmit hourly radar reports over Service A. The subsequent reports proved to be very useful.

Figure 1 is a radarscope photo taken at 1905 PST, several hours after the initial detection. This photo shows the cold front about 14 miles west of Eureka. The radar display is typical of cold fronts in that region, and also shows the semblance of a "Line Echo Wave Pattern" (LEWP). LEWPs are often associated with severe weather. Figure 2 shows the surface analysis at 1600 PST, December 6. The cold front reached Eureka 42 minutes after the picture was taken, accompanied by thunderstorms and hail. The thunderstorms were not severe, nor was the hail large; but for Eureka this was a significant storm. Rainfall amount recorded during the four-hour storm was .80 of an inch at the Eureka WBO, with .38 inch falling in one hour as the front passed over.

Based partly on his radar returns, Mr. Anderson included "moderate to heavy rain" in his local forecast for that afternoon.

Certainly the actions and events described here are not spectacular, but they do demonstrate how an alert MIC improved his service in the local area, and at the same time provided vital data input to the RFC.

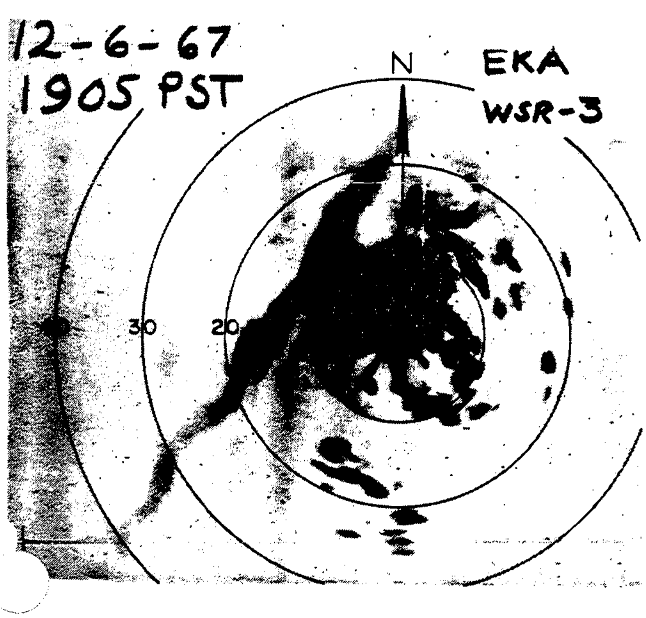


FIG 1

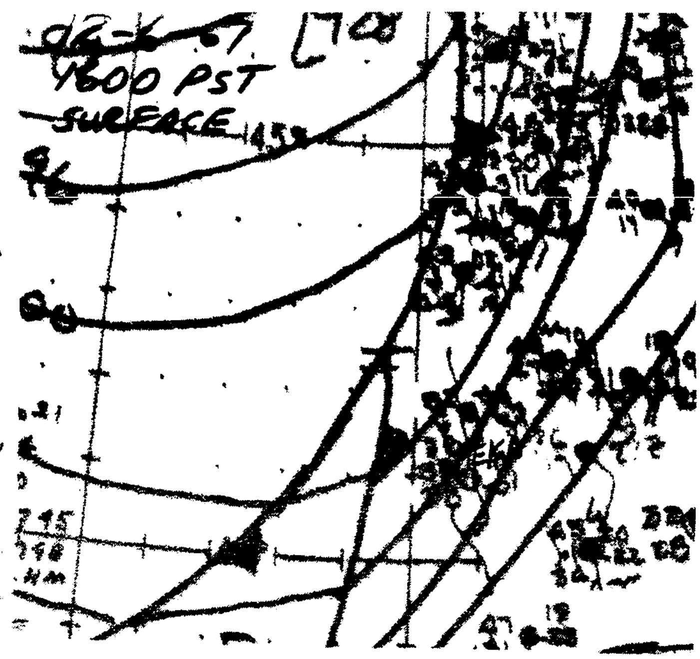


FIG 2.

WESTERN REGION TECHNICAL ATTACHMENT
October 24, 1967
No. 67-39

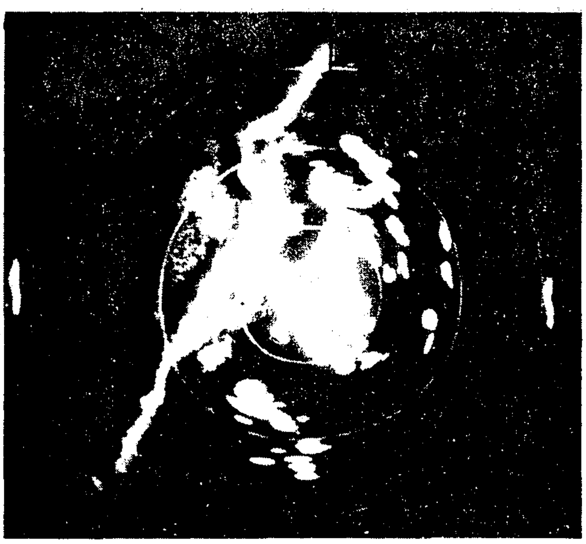
RADAR LINES

Have you wondered what a radar operator sees when he reports a line?

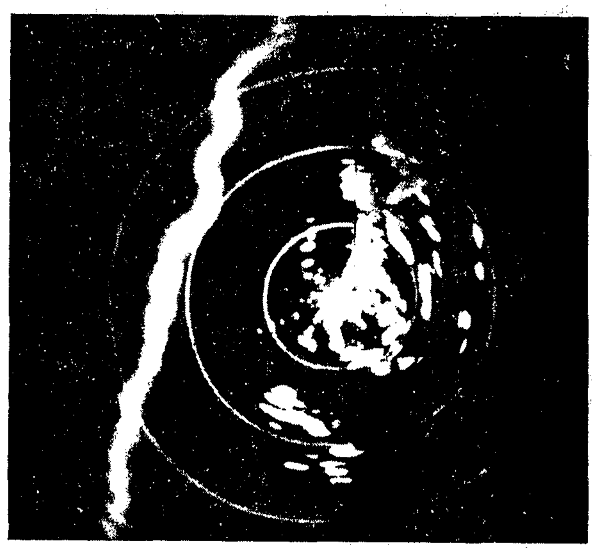
The accompanying two pictures show the PPI scope presentation of a WSR-3 radar at Eureka, California. Picture A was taken on January 2, 1965, and Picture B on December 13, 1966. Range markers were set at 10 nautical mile intervals. Radar return from coastal hills (ground clutter) can be seen in the north-northwest, east, and south-southwest quadrants. The ground clutter echoes are apparent due to their "hard" appearance. Also, one can distinguish them by comparing the two pictures. The line of weather echoes to the west in each photograph exhibits sharp and wavy characteristics which are indicative of very active fronts and/or squall lines over water along the West Coast.

Picture A, taken at 1925 PST, shows a line associated with an approaching cold front about 12 miles west of the radar. The line is moving toward Eureka at about 25 mph. At 2000 PST (35 minutes later) Eureka reported a wind shift from southwest to northwest, with speeds of 18 to 20 mph. Thunder and lightning occurred from 1957 - 2012 PST. During the passage of the cold front, a half-inch of rain was recorded in a two-hour period.

Picture B, taken at 0710 PST on December 13, 1966, shows a cold front 23 miles west of Eureka moving eastward approximately 25 mph. Passage of the cold front at Eureka 50 minutes later was accompanied by thunder, lightning, and heavy rain.



Picture A. Eureka, Calif.
WSR-3, January 2, 1965,
1925 PST.



Picture B. Eureka, Calif.
WSR-3, December 13, 1966,
0710 PST.

WESTERN REGION TECHNICAL ATTACHMENT
August 22, 1967
No. 67-31a

RADAR - A MOISTURE DETECTOR

One of the difficulties that forecasters in the Intermountain Region face during summer is the assessment of moisture available for the development of afternoon showers. The air is usually unstable enough so that the normally high afternoon temperatures develop sufficient convection to cause showers and thunderstorms if there is adequate moisture present. The wide spacing of radiosonde stations seldom permits a good delineation of moisture distribution, but the newly available Salt Lake City ARTC-Center radar reports appear to be a partial solution to this problem.

Following the daily pattern of afternoon showers via radar reports and comparing day-to-day changes of this pattern give forecasters a useful guide in evaluating the likelihood of afternoon shower development. An excellent recent example illustrating the use of radar reports in this way is presented, covering the period Monday, Tuesday and Wednesday, August 14, 15 and 16.

Before discussing this example, a word needs to be said about the problem of presenting forecasters a picture of radar echo distribution by means of a word description, e.g., the SD-1 teletype bulletin. Figures 1, 2, 3 and 4 present plots of SD-1 messages superimposed on copies of the actual radar echo patterns from which they were prepared. Obviously much of the detail of the patterns is unavoidably lost in the SD-1 messages. Furthermore, deciding on the best description of an echo pattern is highly subjective. For example, in Figure 4 there is considerable room for differences of opinion as to how best to describe the echo patterns in southern Nevada and in Wyoming. The same problems exist with regard to preparation of national radar summary facsimile charts (see Figure 5). Consequently, SD-1 and national facsimile radar summary charts should be used as a tool in evaluating the overall synoptic situation, rather than meso-scale* details. The important role of radar in evaluating these details for short-period forecasts is realized only when the radar readout, or an actual copy of the pattern is immediately available to the forecaster.

Returning to the synoptic situation of August 14 to 16, the forecast problem in the Intermountain Region was primarily a determination of where afternoon showers would develop. The surface and upper-air patterns were essentially stationary over the Region--see Figures 6 and 7. The Salt Lake City raobs for 1200Z on the 14th and 15th (Figure 8) indicated little change in moisture and stability conditions from the 14th to the 15th, except for an increase in moisture above 500mb. Further, they showed that the usual deep unstable air mass would exist on both days once diurnal heating wiped out low-level stability.

*Characteristic dimensions 10-100 miles. Not to be confused with "small synoptic scale"--characteristic dimensions 50-300 miles.

In other words, little difference between the shower activity on the 15th from that on the 14th was indicated, yet there was a significant change in the weather in northern Utah, southeast Idaho, and western Wyoming--compare radar echo patterns of Figures 2 and 4 in these areas. This radar comparison clearly shows that drier air had moved southeastward into northern Utah and Wyoming by the afternoon of the 15th, thus cutting off the development of shower activity.

These radar charts or plotted SD-1 reports used in conjunction with other facsimile charts, clearly indicated a forecast of decreased shower activity developing southeastward over the Intermountain area. Figure 9 gives the radar echo pattern for Wednesday afternoon, August 16.

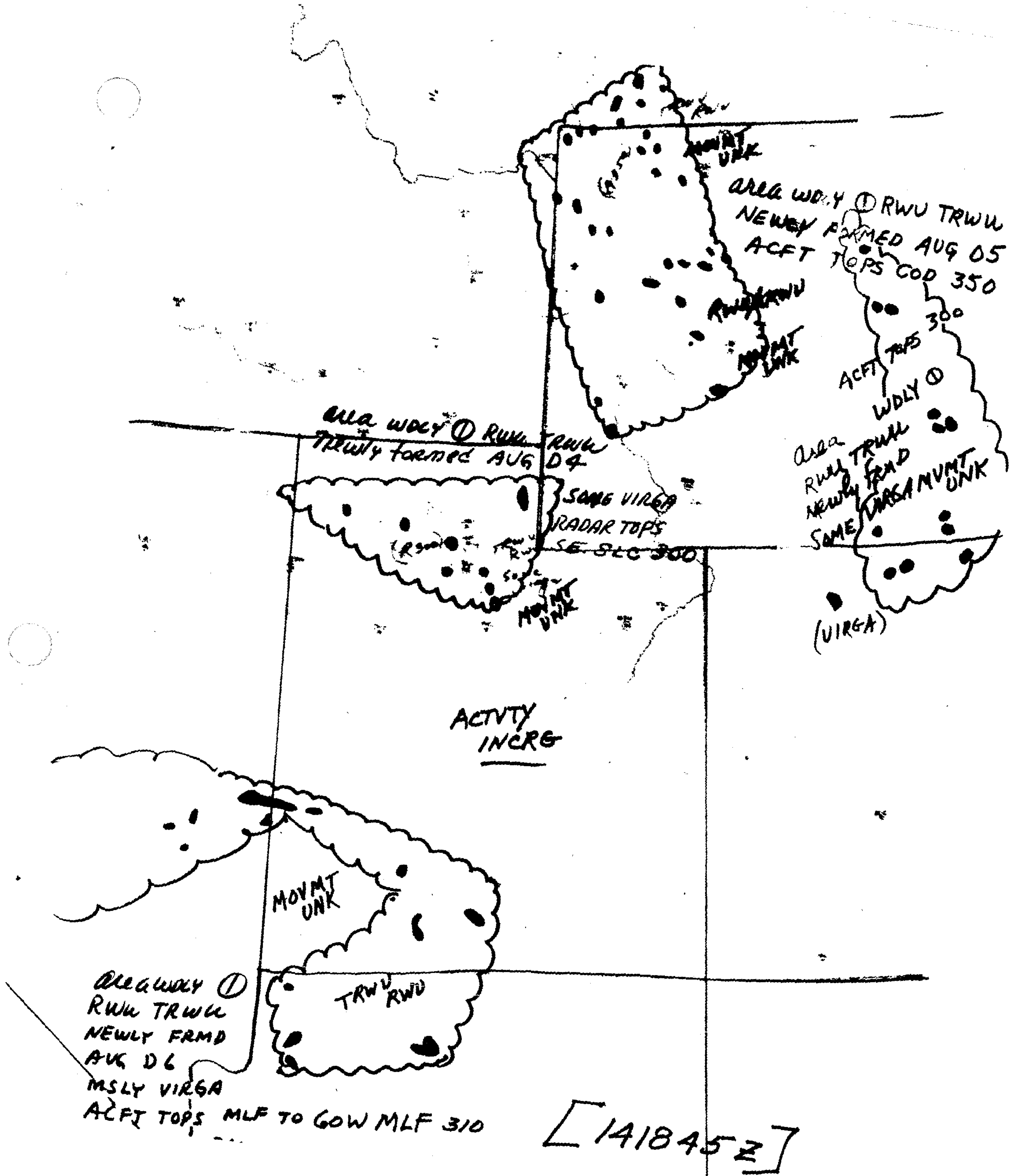


Figure 1: SLC ARTCC Radar Echo Chart for 1845Z (1245 MDT) August 14, 1967. The scalloped lines indicate the echo areas as given by the SD-1 teletype bulletin.

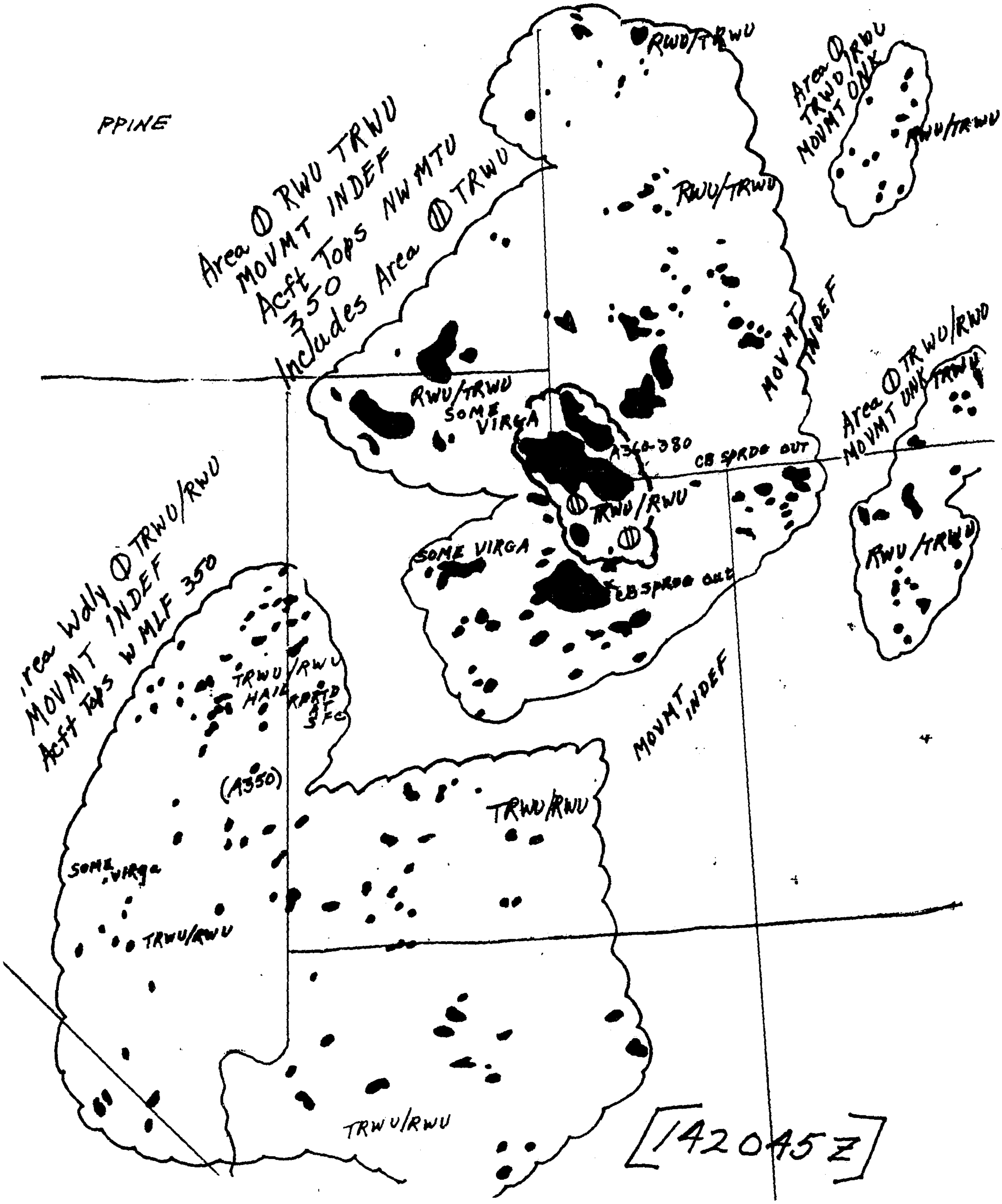


Figure 2: Same as Figure 1 except for 2045Z (1445 MDT) August 14, 1967.

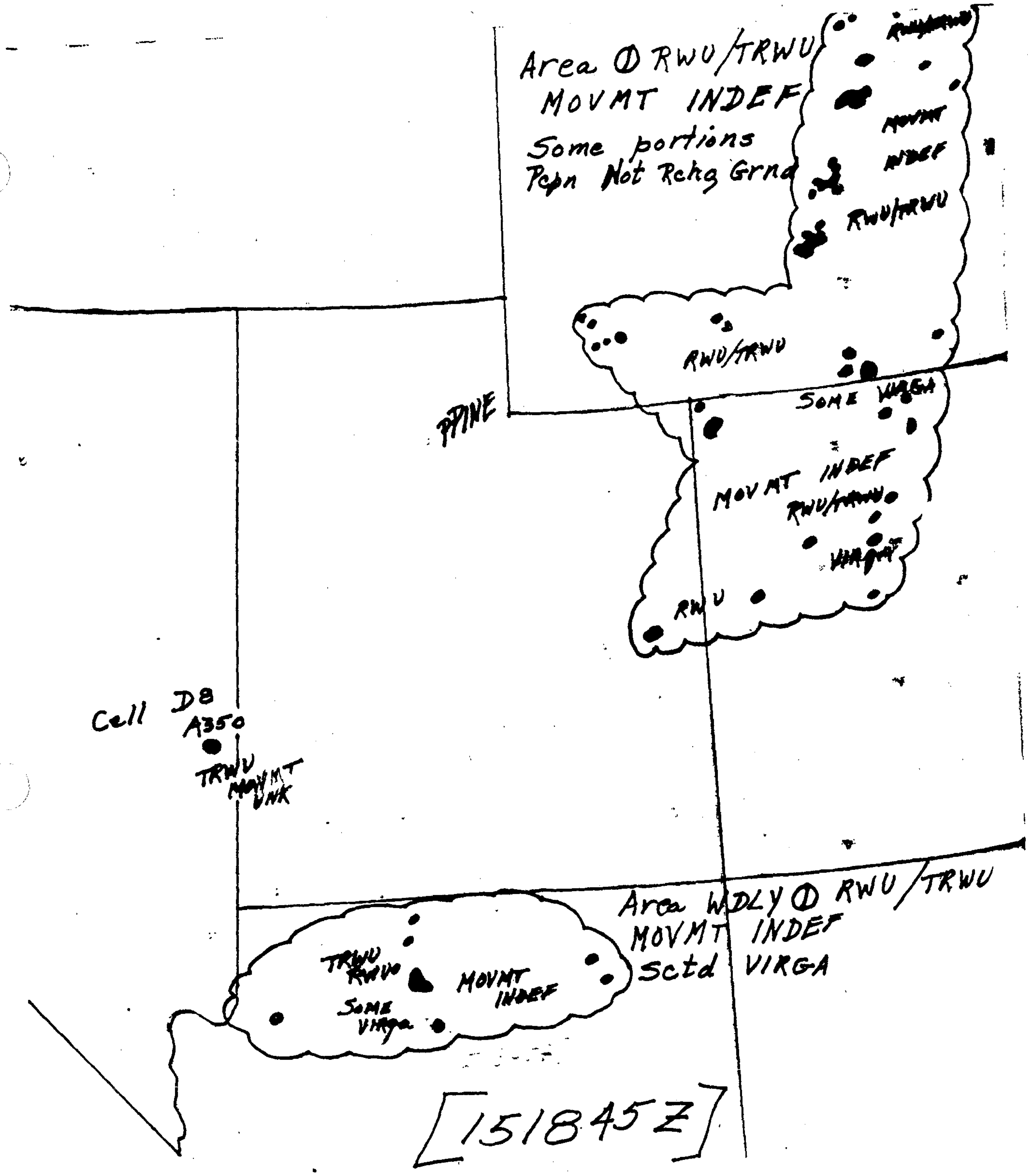


Figure 3: Same as Figure 1 except for 1845Z (1245 MDT) August 15, 1967.

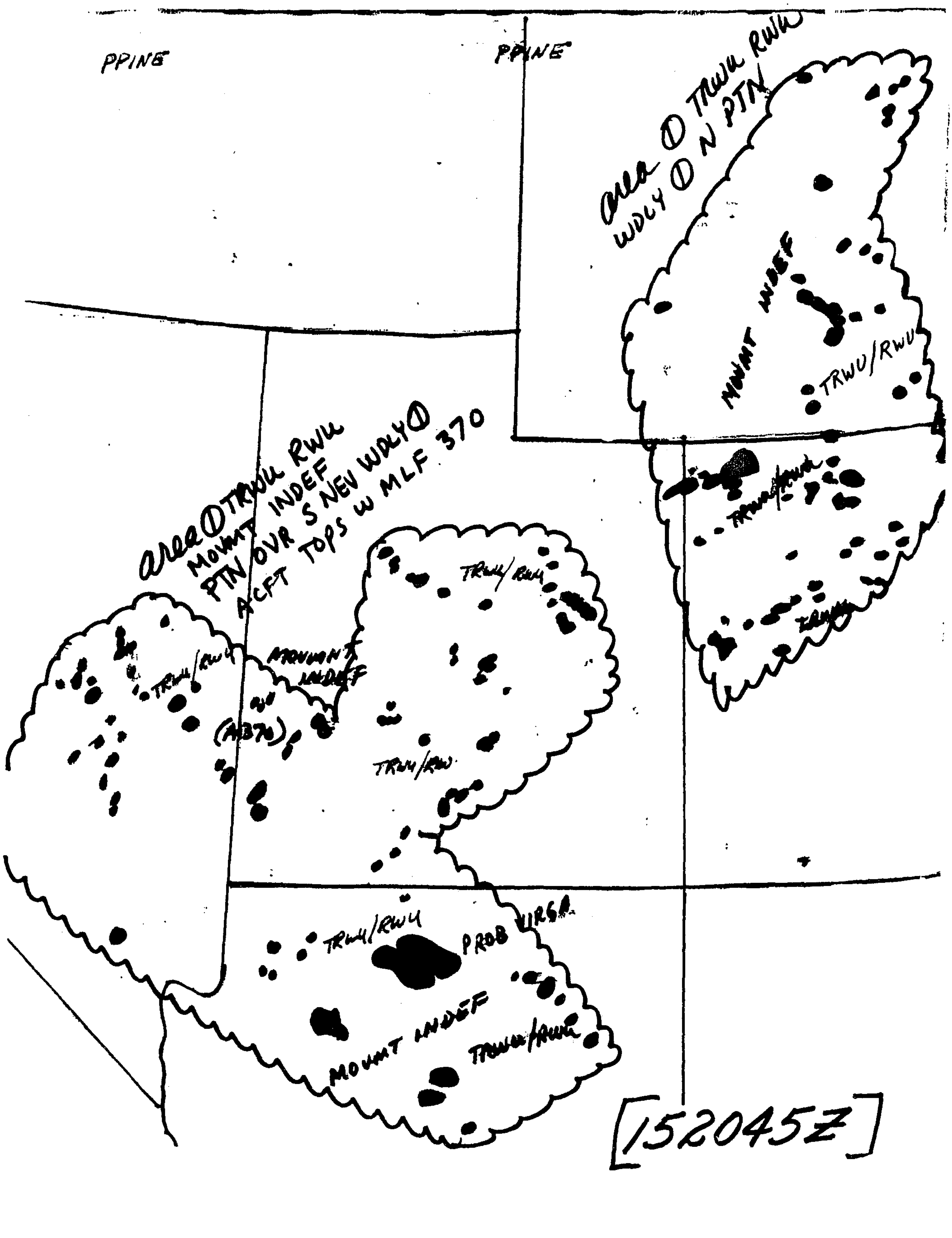


Figure 4: Same as Figure 1 except for 2045Z (1445 MDT) August 15, 1967.

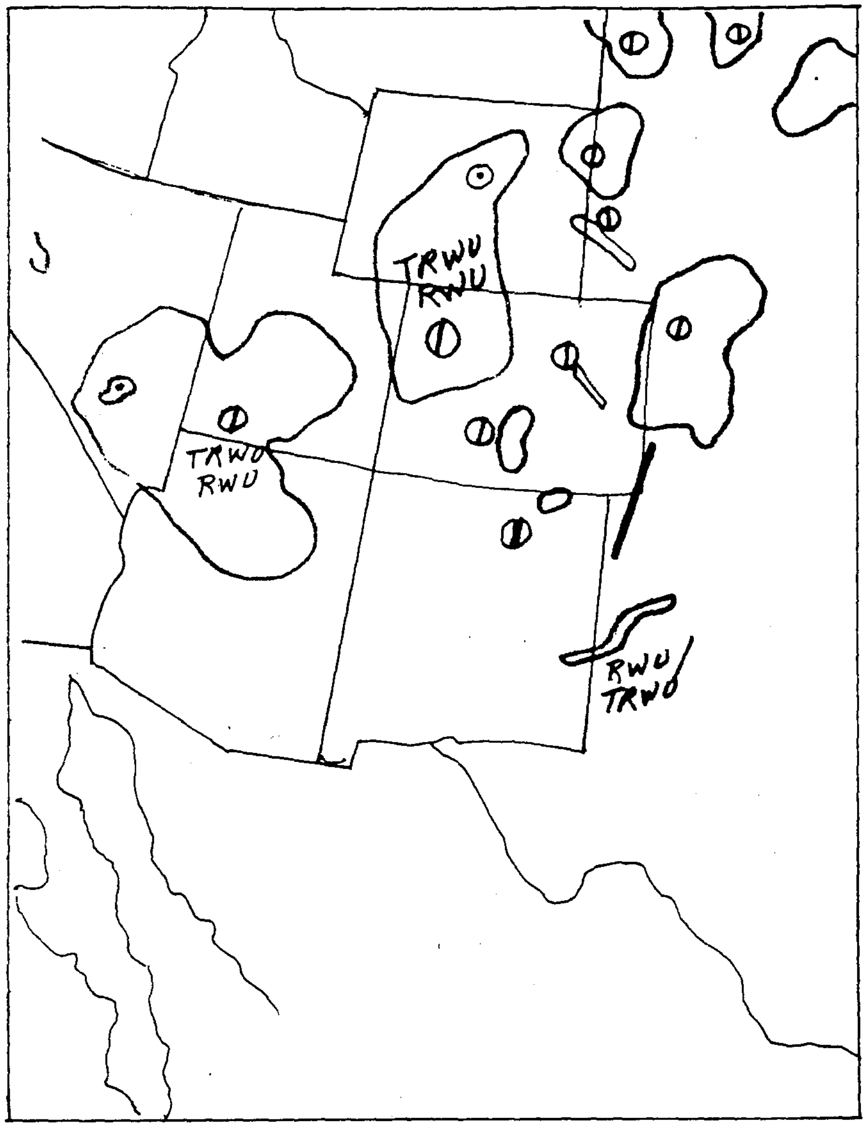


Figure 5: National Facsimile Radar Summary Chart for 2045Z August 15, 1967. (Western half of facsimile transmission #107.)

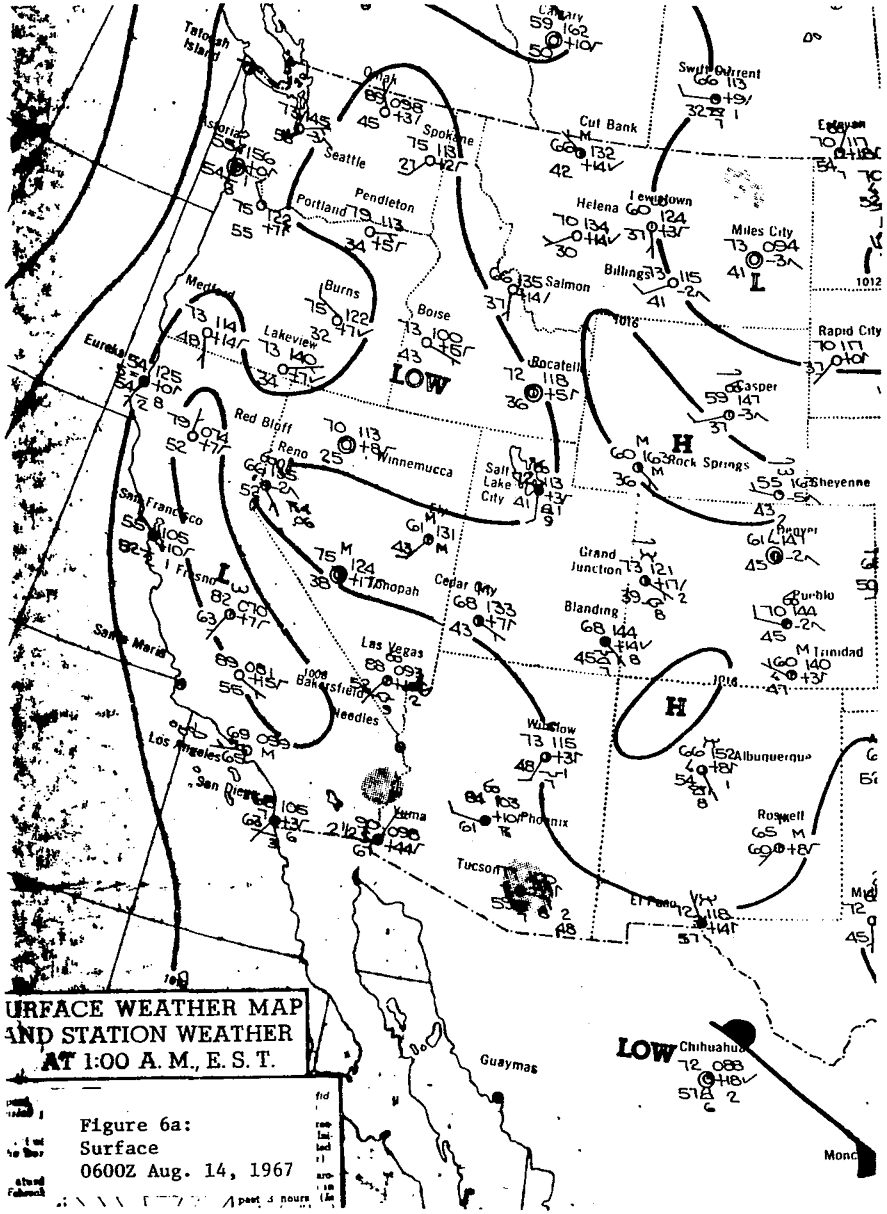


Figure 6a:
Surface
0600Z Aug. 14, 1967

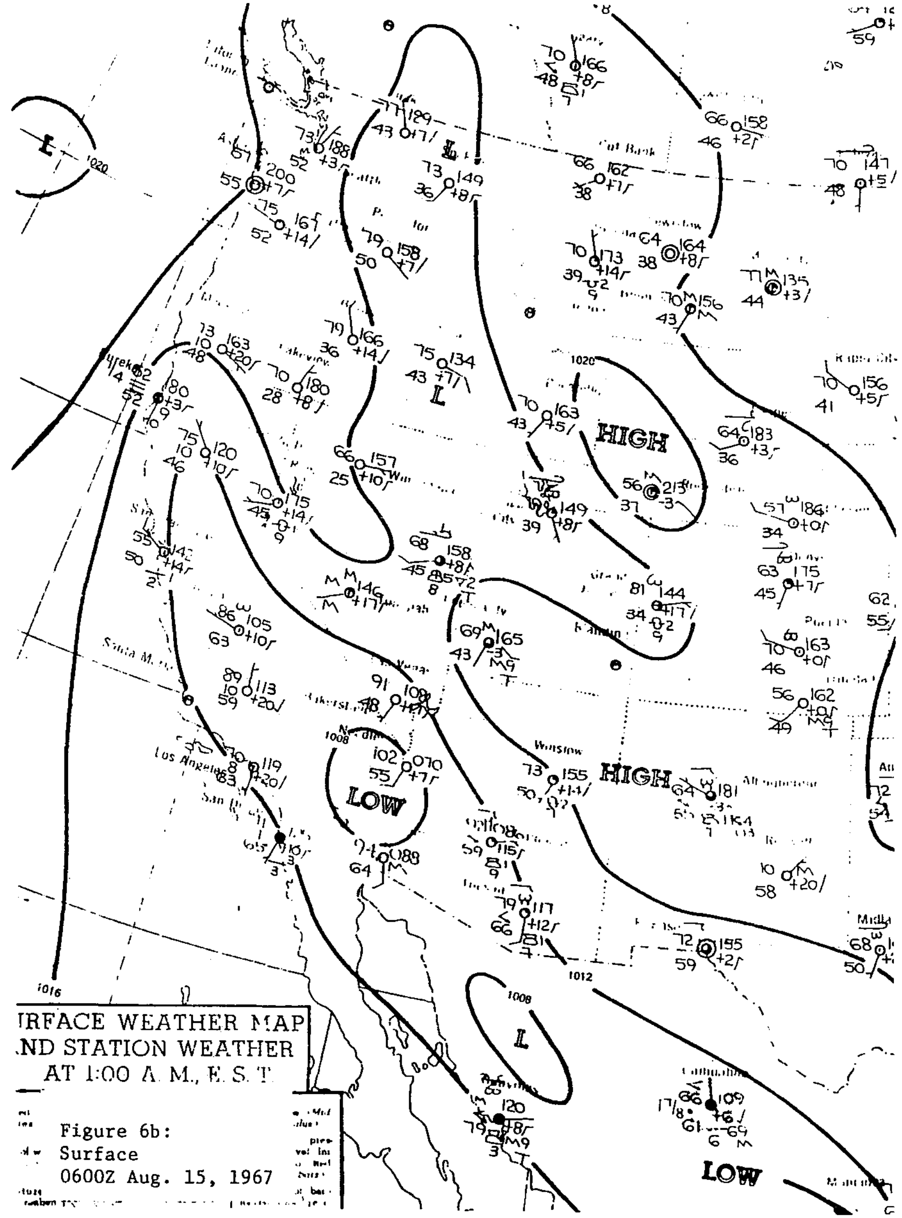


Figure 6b:
Surface
0600Z Aug. 15, 1967

Figure 6: Surface Weather Maps for 0600Z August 14 and 15, 1967.

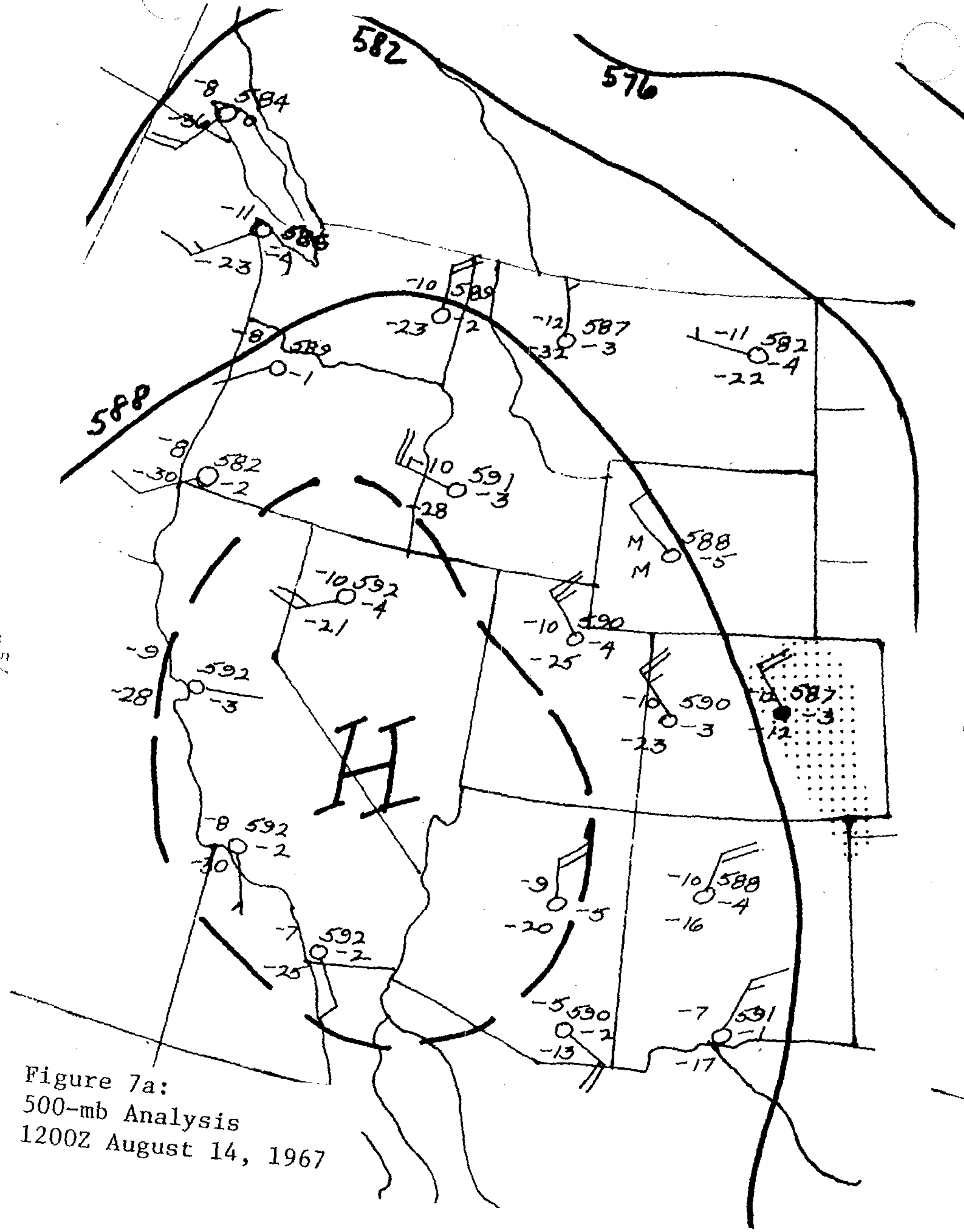


Figure 7a:
500-mb Analysis
1200Z August 14, 1967

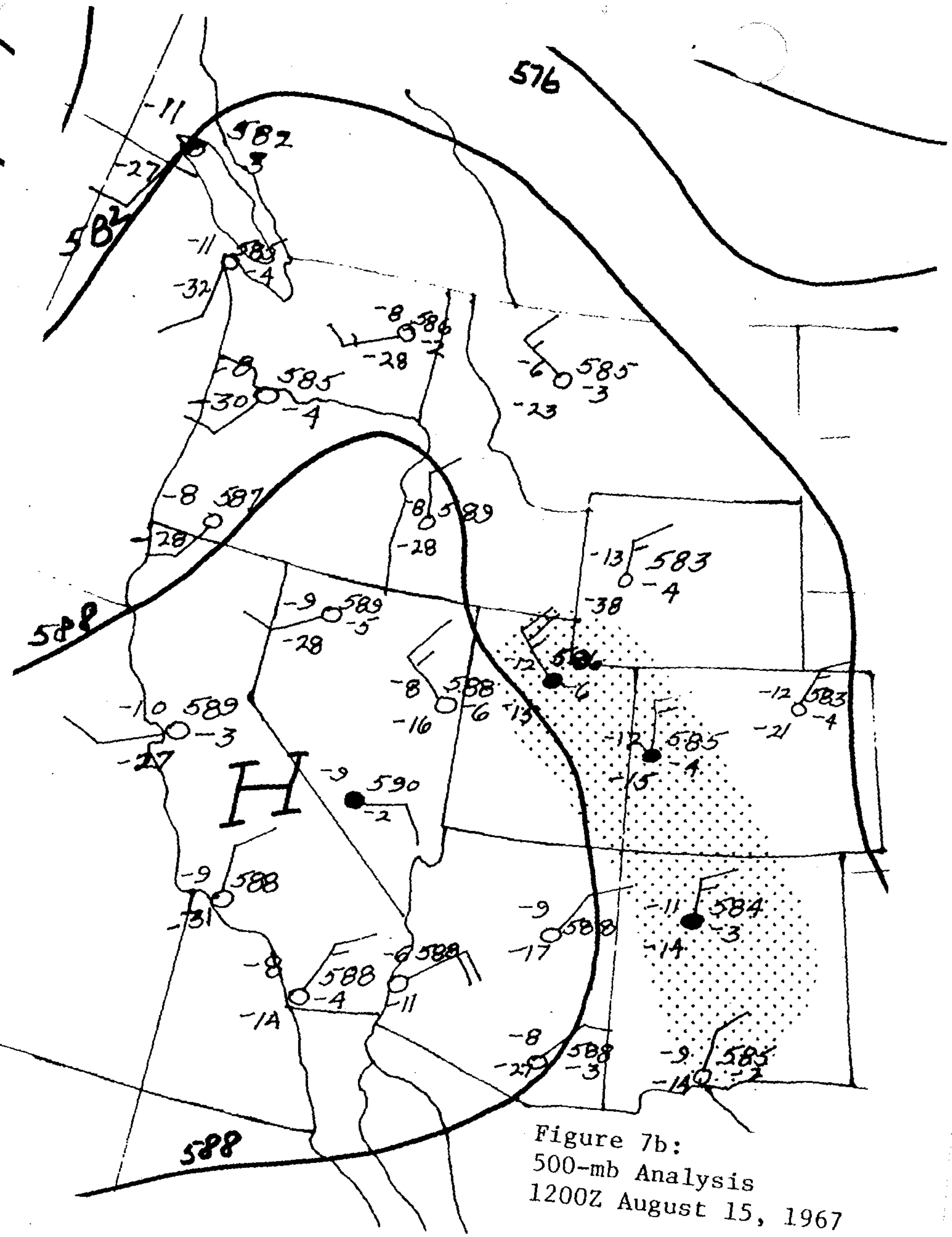
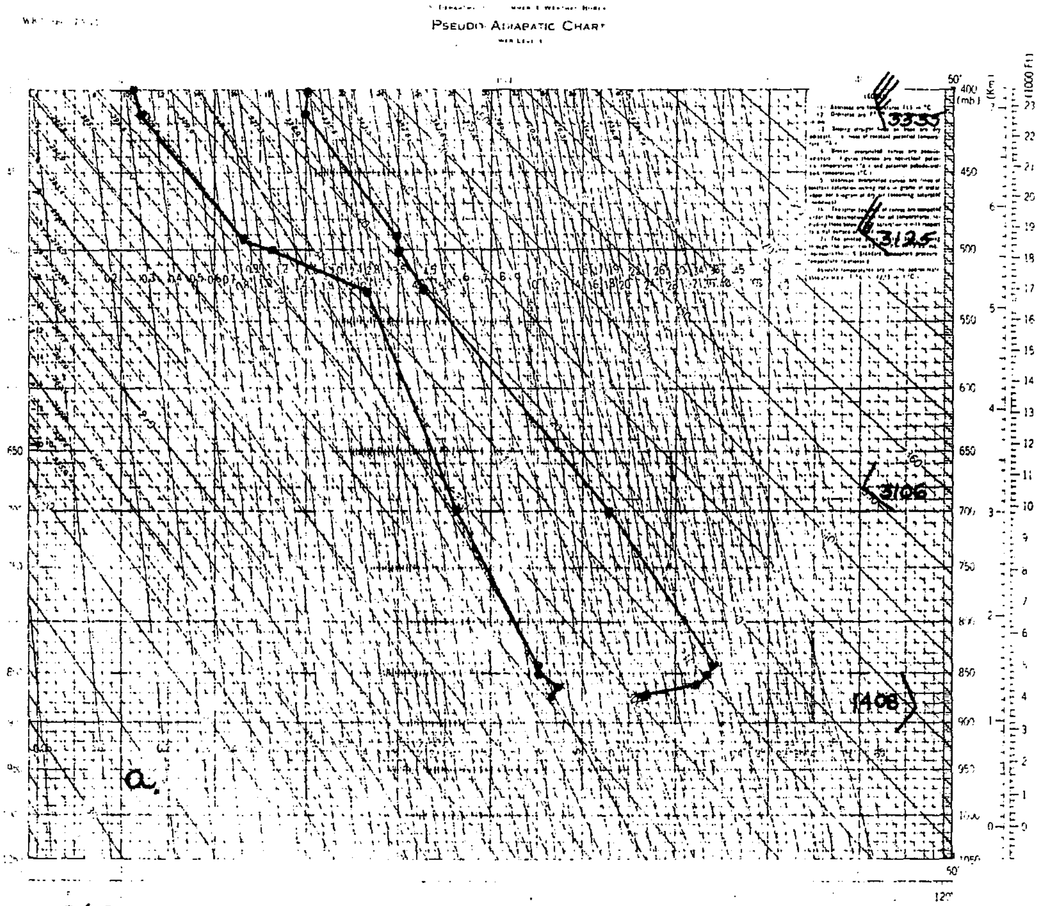


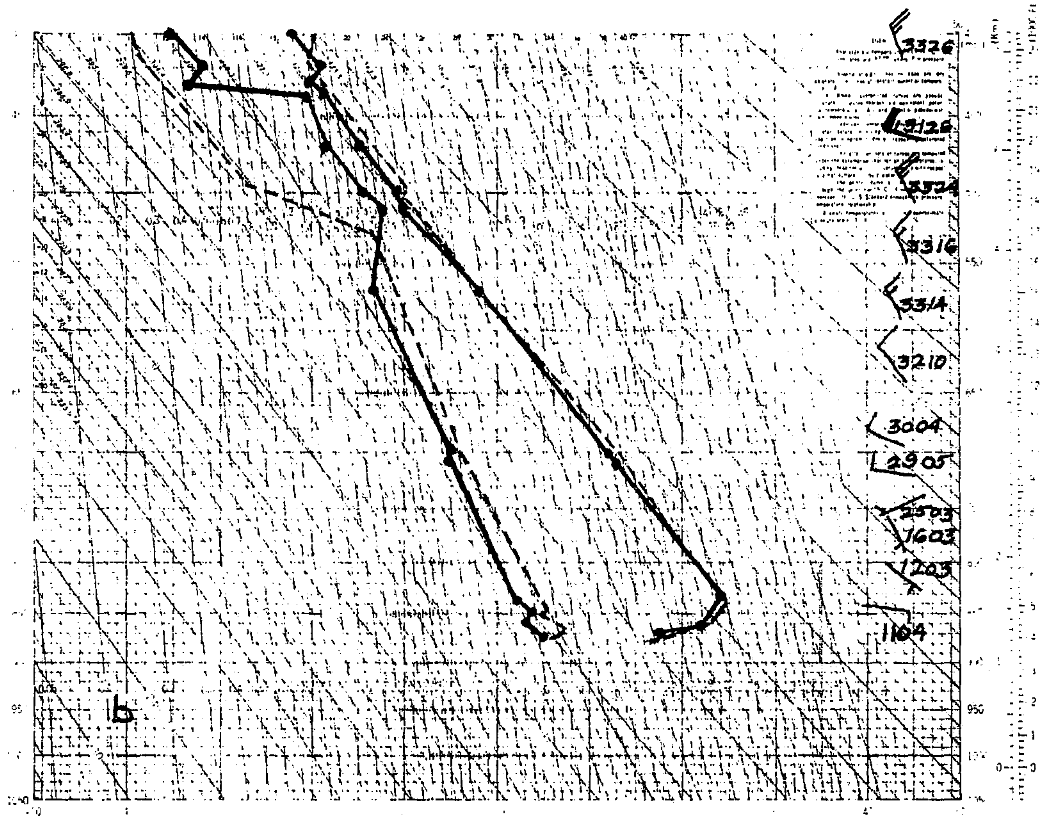
Figure 7b:
500-mb Analysis
1200Z August 15, 1967

Figure 7: 500-mb Analyses for 1200Z August 14 and 15, 1967. Stipling indicates dew-point depression ≤ 5°C.



Station SLC 8/14/67 12 Z

USCOMM WB-DC



Station SLC 8/15/67 12Z

USCOMM-WB DC

Figure 8: Salt Lake City Raobs 1200Z August 14 [illegible] 1[illegible], [illegible]6[illegible] [illegible] line in Figure 8b is sounding for 1200Z August [illegible]

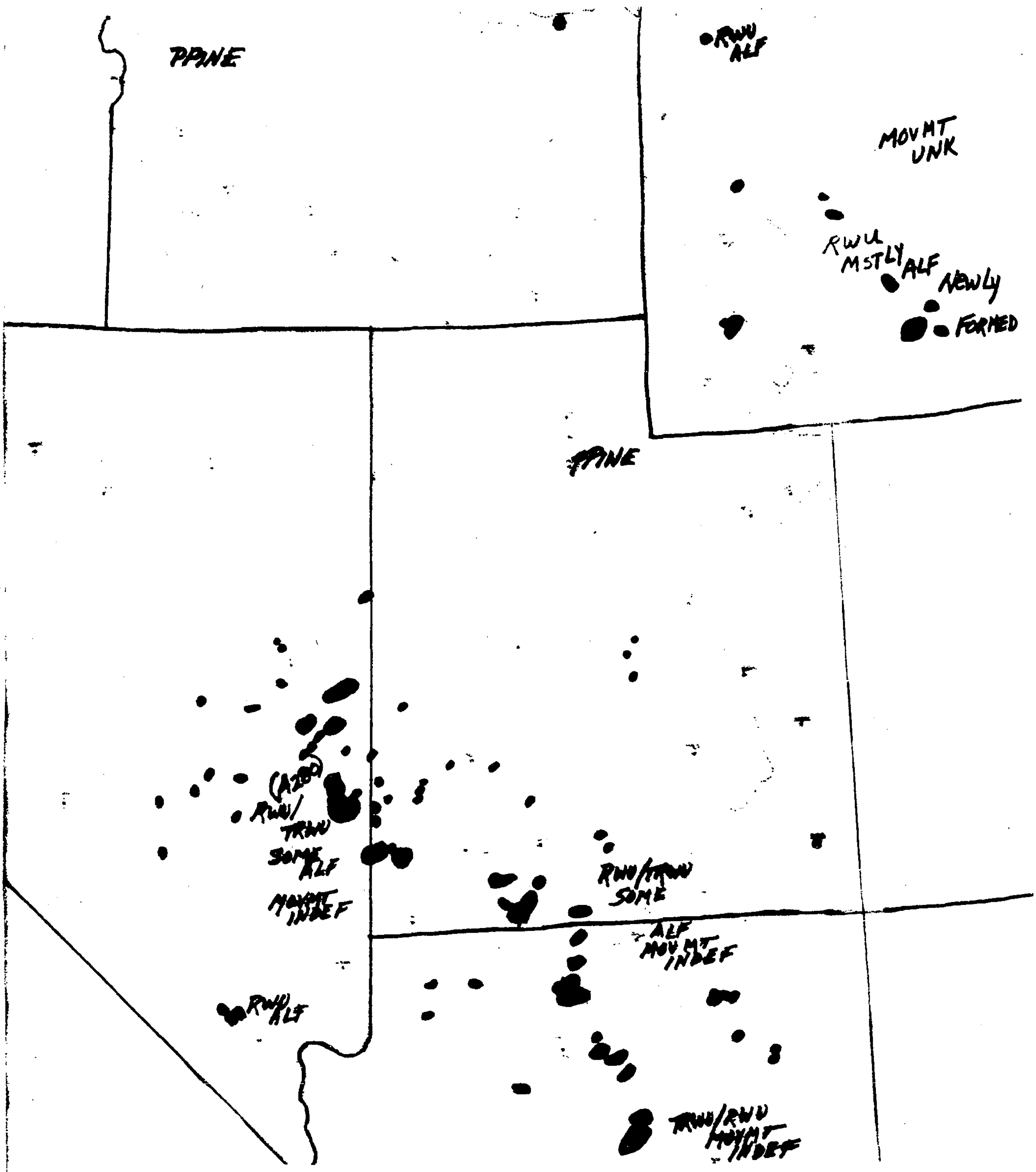


Figure 9: SLC ARTCC Radar Echo Chart for 2045Z August 16, 1967.

APPENDIX IV
WESTERN REGION TECHNICAL ATTACHMENT
February 28, 1967
No. 67-8

INTERPRETATION OF SATELLITE PICTURES

The study of the growing number of good satellite pictures is bringing about significant changes in the classical occluded wave cyclone models of Bergeron and Schereschewsky. This Technical Attachment discusses a new occluded cyclone cloud model based on satellite pictures. Such a discussion is timely since the routine transmission of satellite mosaics over the National Facsimile Network began last week. These mosaics are giving Western Region forecasters the opportunity to see on a daily basis the total cloud systems associated with synoptic patterns.

The classical cloud and weather distributions associated with extratropical cyclones are given in Figures 1 and 2. Figure 1 gives the essentials of Bergeron's classical model. Figure 2 is Schereschewsky's schematic diagram of the cloud types associated with a typical occluded cyclone. Figure 3 is the new schematic proposal based on the study of satellite pictures relating surface flow, 500-mb trough, upper-level jet stream, and surface frontal positions to cloud formations. A comparison of these three figures indicates that there is general agreement on most of the main cloud features, but that the important details are quite different. Rather than point out these differences, this discussion will concentrate on the operationally useful relationships represented in Figure 3.

The location of surface fronts is one of the most helpful uses of satellite pictures (mosaics). The surface front is usually placed near the trailing edge of the frontal cloud band. If there is a wave on the front, it will be associated with a widening of the frontal cloud band. Also, there will be a definite change of curvature to the trailing edge of the cloud shield. Note the relationship of the front to the cloud band in Figure 3, and note that the crest of the wave is located near the extreme southwestern edge of the wider cloud area. Farther southwest along the front, cloudiness continues to be represented as a more or less solid shield until the front intersects the 500-mb trough. At this intersection the frontal cloudiness branches and breaks up. Thus, the intensity of the frontal weather also decreases west of the 500-mb trough. This may not be obvious from satellite pictures, but has been established from the study of other data in association with both satellite and astronaut pictures.

Moving westward from the frontal zone, there are several important and frequently recurring patterns indicated by the schematic model. Immediately to the west of the frontal wave, a comma-shaped cloud is shown. This is the characteristic shape of the cloudiness associated with positive vorticity advection (PVA). The comma cloud can be used to check on the correctness of the PVA areas indicated in the initial analysis by comparing the location of the comma cloud with significant PVA areas. (Note that both Bergeron and Schereschewsky have the suggestion of a similar type of cloud area. Bergeron called it low-level convergence (CL). The motion of this comma cloud can be used to determine the degree of frontal wave development that will take place. If the comma cloud moves eastward, the wave will develop rapidly; if it moves north, the wave will not amount to much. The vorticity forecasts modified by the evaluation of the initial analysis plus continuity of the comma cloud movement must be used in determining future comma cloud movement.

The upper-level jet stream can frequently be located by noting changes in the character of the low cloudiness to the west of the 500-mb trough. The jet axis is located where the open cellular pattern changes to the so-called closed cellular cloud pattern /_1_/. The open cellular pattern is related to active cumulus and shower-type weather while the closed cellular is related to stratocumulus-type cloudiness. This latter cloudiness shows up whiter in satellite pictures, because the individual cloud elements are much larger horizontally than the cumulus clouds to the north. The jet stream can also be located in the frontal cloud band if the resolution of the mosaic transmission is good enough. The frontal clouds appear lumpy to the north of the jet and smooth to the south. (This is illustrated in Figure 3.) The smooth appearance is believed to be due to the extensive cirrus shield usually found to the south of the jet axis. Jet-stream cirrus has a sharp edge. When the satellite picture is taken in the morning or afternoon, the cirrus will cast a shadow on the lower cloudiness. This shadow will appear as a dark line on the picture and is a good indicator of the position of the jet axis. Current facsimile mosaics are prepared from pictures taken by ESSA III, which is sun-synchronous about 3 p.m. The low sun angle at this time of day gives good shadows.

Warm fronts are difficult to locate on satellite pictures except during the early stages of a developing wave cyclone. Therefore, the relationship of the warm front to the cloudiness suggested in Figure 3 is probably the weakest of the relationships presented. Considerable study needs to be directed toward better interpretation of pictures in the vicinity of indicated warm fronts. Studies that have been made on this subject suggest that some indicated warm fronts never existed.

Figure 3 gives the schematic relationship of clouds to flow patterns and fronts as they have been observed over the ocean. Cloud patterns are modified strongly by topographic effects once they move over land. The study of such effects is under way.

Determination of the modifications that will take place is difficult as it involves the interaction of factors like the stability of the airmass, magnitude of the vorticity, angle with which the flow is impinging on the mountain or coastline, etc. Nevertheless, having a clear idea of what cloud and weather patterns exist over the ocean and data-sparse land areas will help forecasters make better forecasts by improving their local analyses and increasing their understanding of their FP and FP-3 guidance material. It has been found useful to sketch directly on the mosaic those synoptic features indicated by the cloud patterns, and we recommend this practice. Use of an acetate overlay works well, also.

In summary, use the satellite mosaic transmissions and the relationships of cloud patterns and synoptic features given in Figure 3 to help you prepare better surface analyses and make better use of NWP forecasts and FP guidance.

REFERENCE:

[1] Western Region Technical Memorandum No. 4, "Use of Meteorological Satellite Data"

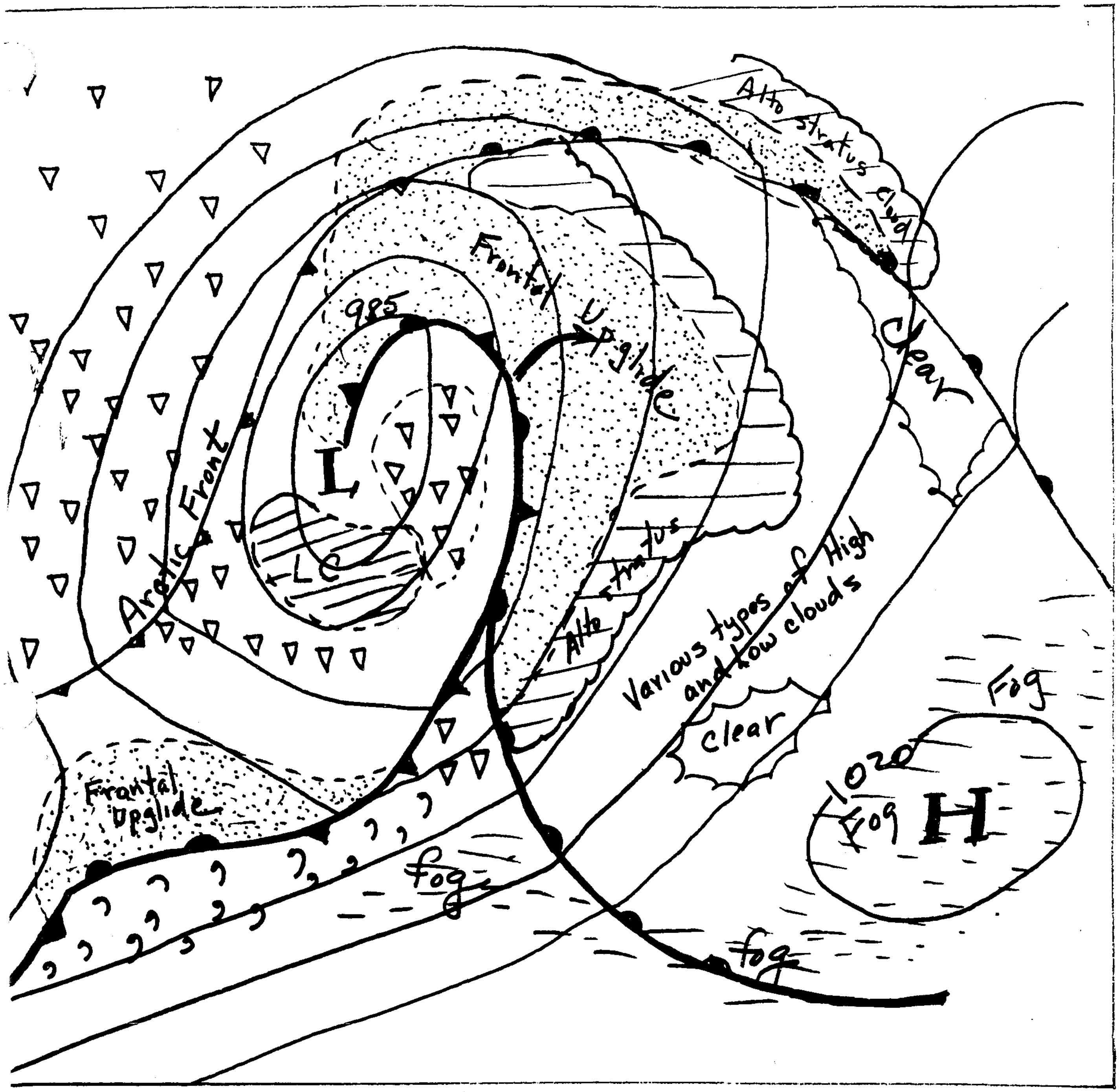


Figure 1. Bergeron's schematic model of fronts, cloud, precipitation and surface flow associated with occluded systems. "LC" near the center of the diagram stands for "low-level convergence". (Adapted from a slide presented by Mr. Oliver at our recent workshop.)

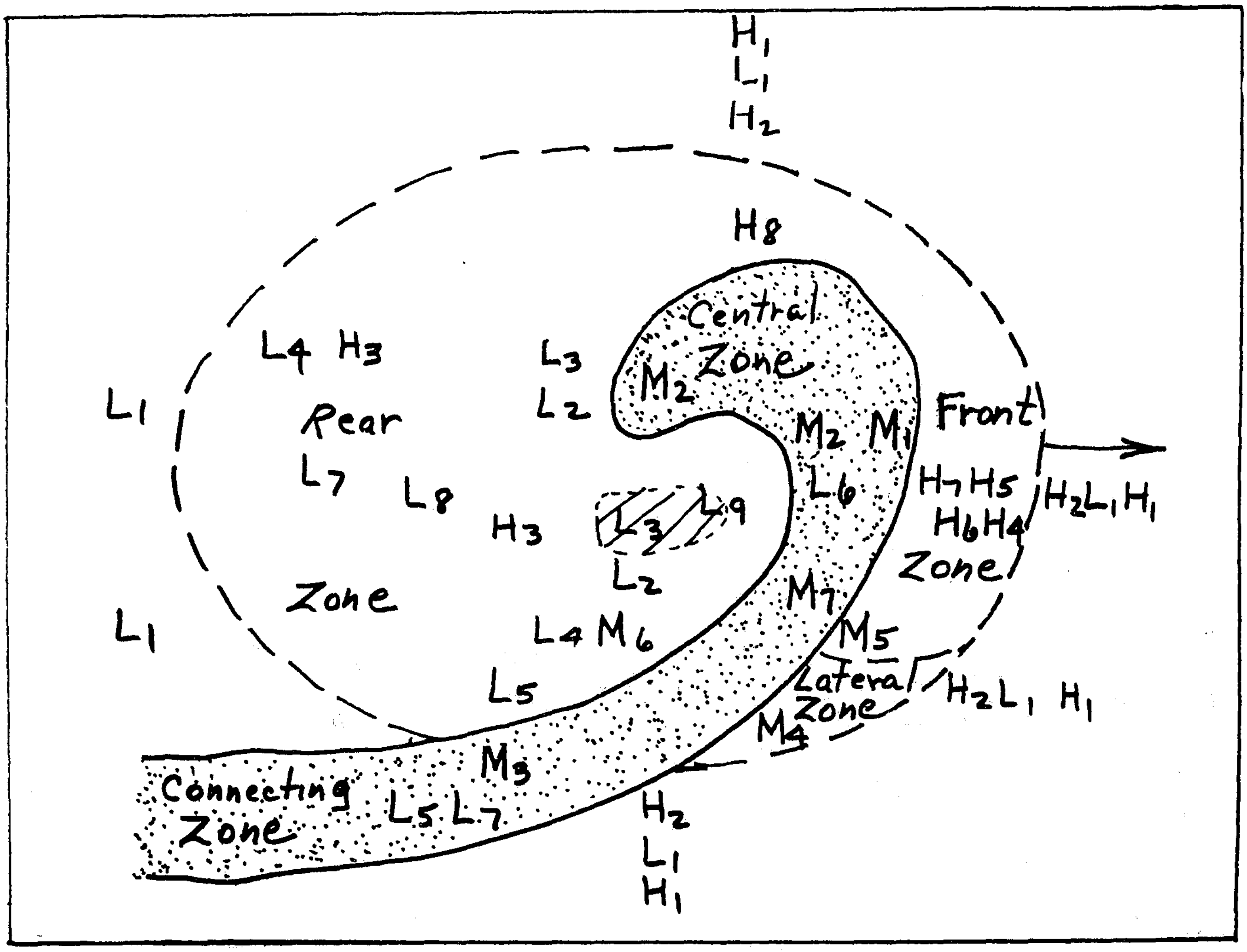


Figure 2. Schereschewsky's schematic model of the cloud types associated with occluded systems. Cross-hatching added to identify shower area similar in location to "comma" area in Figure 3. (Copied from slide by Mr. Oliver. Original is in Handbook of Meteorology by Berry, Bollay, and Beers.)

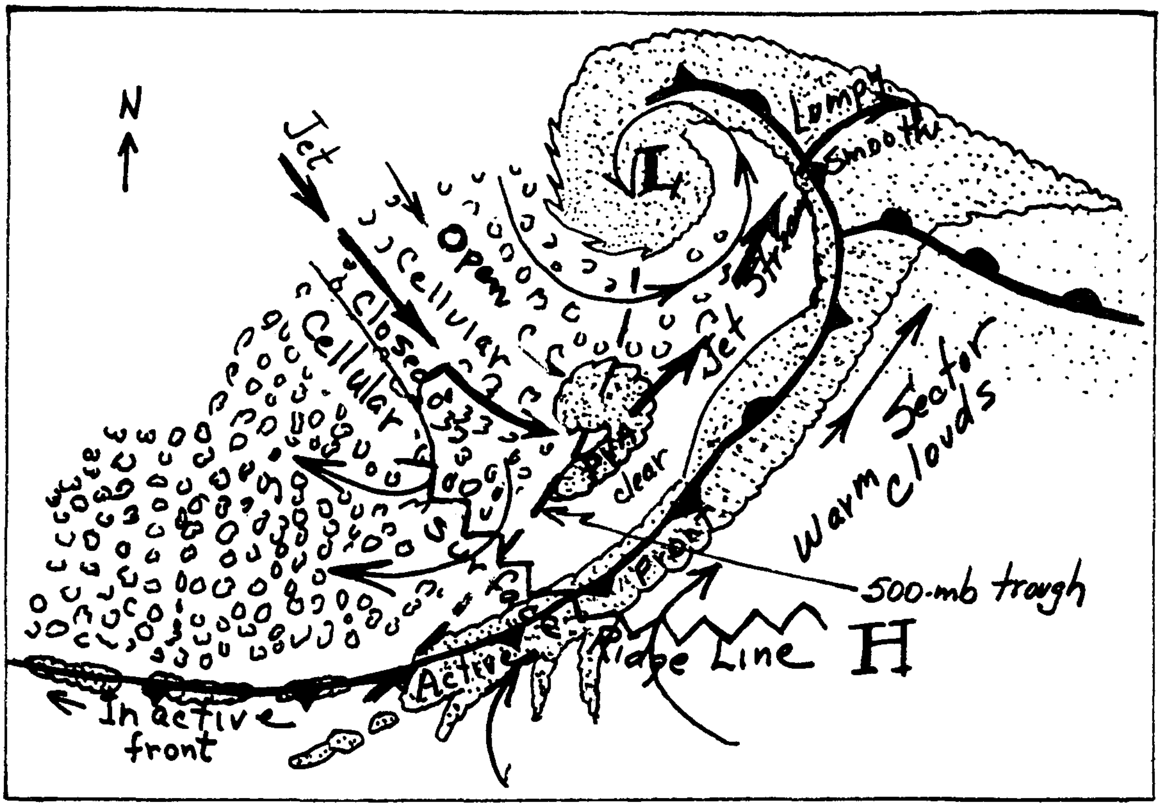


Figure 3. Schematic illustration relating surface flow, 500-mb trough, upper-level jet stream, and surface frontal positions to cloud formations observed in satellite pictures. (Copied from slide by Mr. Oliver.)

WESTERN REGION TECHNICAL ATTACHMENT
May 2, 1967
No. 67-17

THE CONFUSING COMMA

The cloud distribution indicated off the California coast in the satellite mosaic for Monday afternoon, about 0000Z May 2, 1967 (Figure 1), was--and still is--difficult to interpret. This is the first time that we have seen a comma cloud move out ahead of the frontal cloudiness. At the time of the mosaic shown in Figure 1, the comma was ahead of the front and immediately above a strong surface ridge (Figure 3). A detailed study of the satellite pictures for this anomalous situation may well lead to significant improvement in our understanding of the relationship of high- and low-level migratory systems. Although there are no ready answers to the problem of proper interpretation and use of this satellite mosaic at this time, a discussion of its possible interpretation is appropriate as we build our experience in using these new observations.

The comma cloud was well developed in Figure 1, and it suggested the existence of positive vorticity advection (PVA) in about the area of PVA actually shown off the California coast on the 0000Z May 2, 1967 initial "barotropic" vorticity chart (Figure 2). The comma cloudiness also suggested that the PVA on the vorticity chart should be stronger than shown. Looking at this cloudiness in more detail, the sharp western edge of the cloud shield, together with streamers on the eastern edge, suggested some cumulonimbus and showers in addition to middle and high cloudiness associated with the comma. If this was the case, the base of the showers must have been very high since the comma cloud was located over a strong surface ridge (i.e., low-level divergent flow pattern). If the base of the showers was 15,000 feet or higher, the precipitation would probably never reach the earth; yet the cloudiness viewed from a satellite would look the same as though the cloud bases were low and showers were observed at the ground. In discussing this mosaic with Mr. Oliver, he stated that he had observed such high-level showers over the Pacific on his recent trip to Alaska.

Use of the above interpretation of the mosaic and the barotropic vorticity chart in preparing a short-period forecast suggests that considerable middle and high cloudiness with high-level virga should have been expected, but no precipitation would be expected to reach the ground. This, of course, is "hindcasting". Our original interpretation was to increase significantly the probabilities of precipitation for California, Nevada, and Utah with the arrival of the comma cloud.

This "confusing comma" brings back memories of the 1940's, when occasionally observed high-speed winds at 30,000 feet were disconcerting to analysts, because they knew little of the existence of the jet stream. High-speed wind observations are no longer "anomalies", and it is highly probable that in the near future "confusing commas" will be well understood also.

TECHNICAL ATTACHMENT

To sum: Study of the satellite mosaic for 0000Z May 2, 1967, suggests the following inferences: 1) a mid-tropospheric short-wave trough was moving independently of low-tropospheric systems, and 2) high-level showers were associated with the short wave.

* * * * *

P. S. The satellite mosaic for Tuesday afternoon (24 hours after Figure 1) illustrates the importance of using continuity and known landmarks in evaluating the mosaic. This mosaic indicated no snow on the Sierras or the Wasatch Mountains. Obviously, something was wrong. Actually, the Pacific cloud pattern was repeated over the land as the result of a computer or program malfunction. Since the mosaic is never seen until it is transmitted over the facsimile circuit, such errors may go undetected, as this one did.


A 3 R/O 2558 05/01/67 CENTER AT 38N 118W
50°
40°
FRONTAL

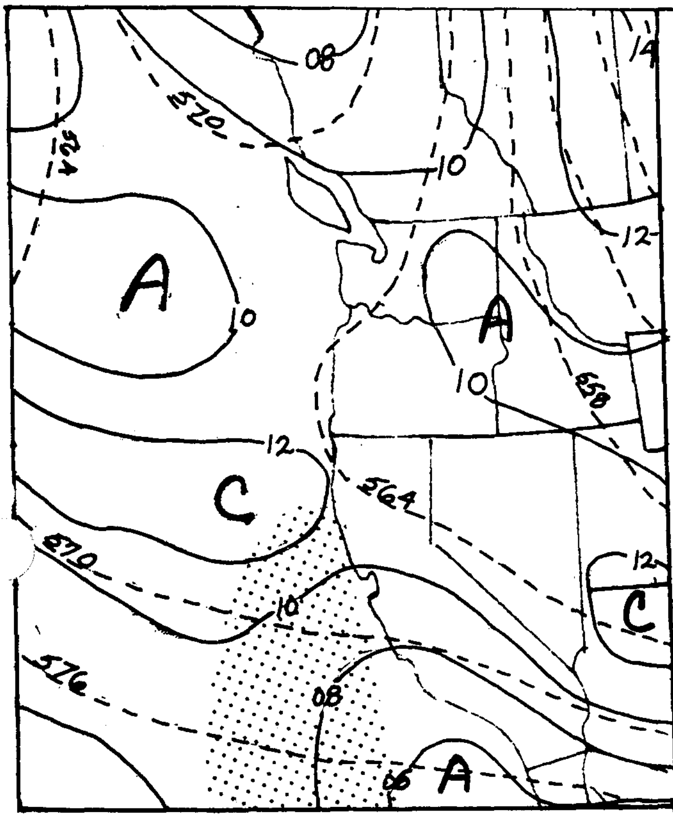


Figure 2. Initial barotropic vorticity chart for 0000Z May 2, 1967. Solid lines are vorticity isopleths; dashed lines, 500-mb contours; the stippling indicates significant PVA.

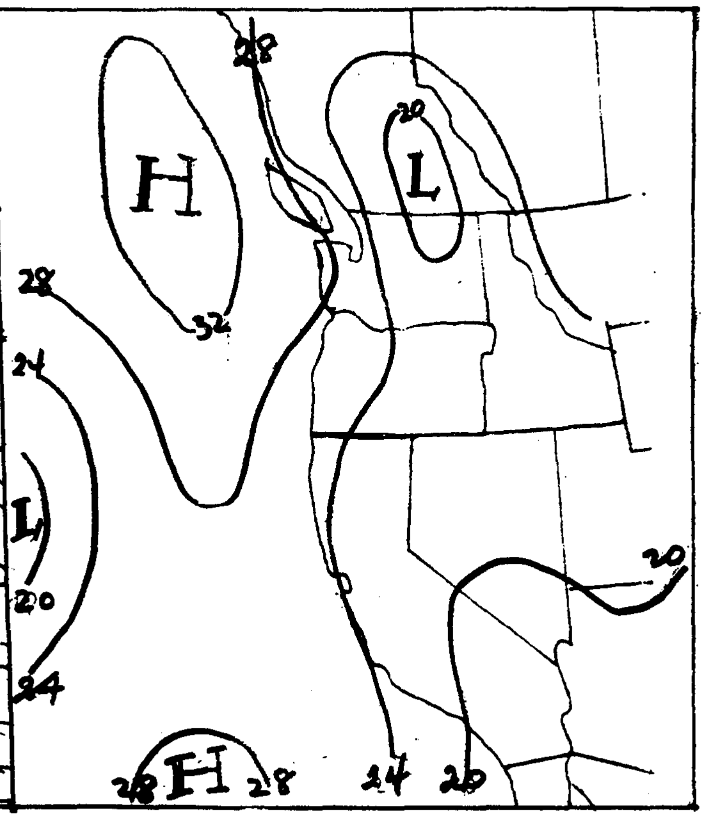


Figure 3. Surface analysis 0000Z May 2, 1967.

SATELLITE PICTURES IMPROVE SHORT-RANGE FORECAST

The satellite pictures taken on April 10 had a very important part in the preparation of short-range forecasts for California, Nevada, and Utah. As we go to press, this is the latest of a series of cases over the past two weeks where the satellite pictures have made a significant contribution to short-period forecasting in our region.

The ESSA IV APT satellite picture of the cloudiness along the West Coast and adjacent ocean areas at approximately 1930Z, April 10, 1967, showed the initial vorticity pattern for 1200Z, April 10, 1967 (Figure 1a) to be in error, with due allowance for the time difference. The cloud band shown in the attached picture, extending from "A" through California to "B", was associated with a southeast-bound positive vorticity advection (PVA) area. The brightness of the cloudiness in the vicinity of 35°N. and 130°W., plus the branching and break-up of the cloudiness to the west of this area, indicated that the 500-mb trough was oriented along the dashed line added to the picture.

Comparison of the PVA area shown in Figure 1a with the cloud picture showed that the solid cloud band in the vicinity of "A" was in a negative vorticity advection area! This disagreement indicated that the PVA in this area on Figure 1a was placed too far to the east. Furthermore, it suggested that the forecast of strong PVA shown on the 12-hour P.E. prognosis (Figure 1b) over southern California and southern Nevada at 0000Z, April 11, was not going to verify.

This interpretation of the satellite picture also agreed with the decreasing cloudiness in southern Nevada Monday afternoon (April 10). Note that the PVA on the 12-hour prog (Figure 1b) suggests <u>thickening</u> cloudiness over southern Nevada, not <u>decreasing</u> middle and high cloud. The verifying vorticity chart for 0000Z, April 11 (Figure 1c), shows only weak PVA over northern Nevada and no PVA over southern Nevada and southern California where the strongest PVA was forecast (Figure 1b). Consequently, the satellite picture was instrumental in correctly delaying the forecast of precipitation into southern California, Nevada, and Utah.

An ESSA IV APT picture was discussed in this Attachment, because it was used in preparing the SLC 2158Z FP-3 on Monday, April 10, The facsimile ESSA III satellite mosaic available about nine hours later over the National Facsimile Circuit showed the same features as discussed above.

We are grateful to Mr. Oliver for his assistance in interpreting this satellite picture. There is some question regarding the precise rectification of the upper part of the picture, but this in no way detracted from the picture's usefulness in detecting the erroneous initial vorticity pattern as discussed above.

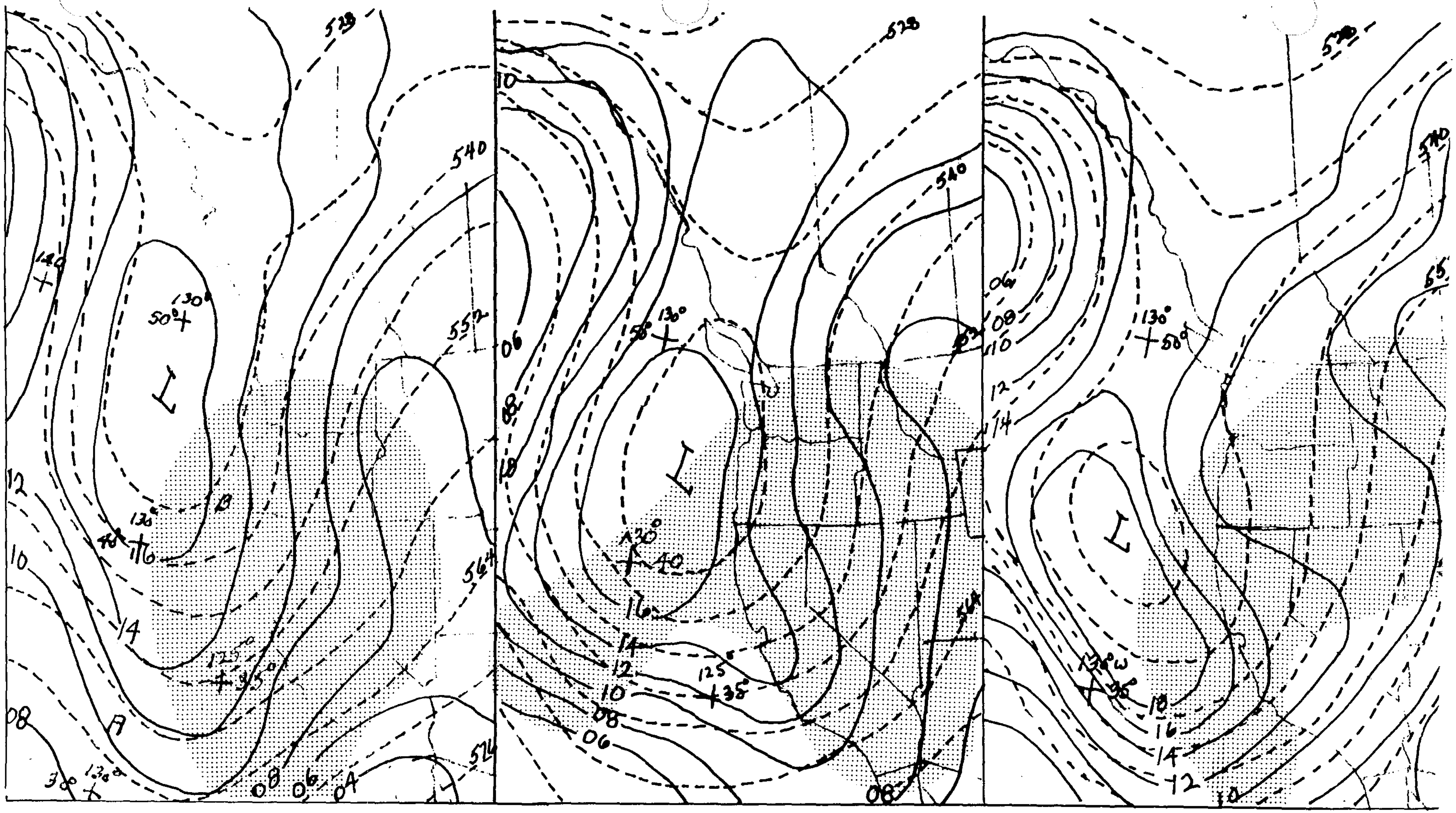
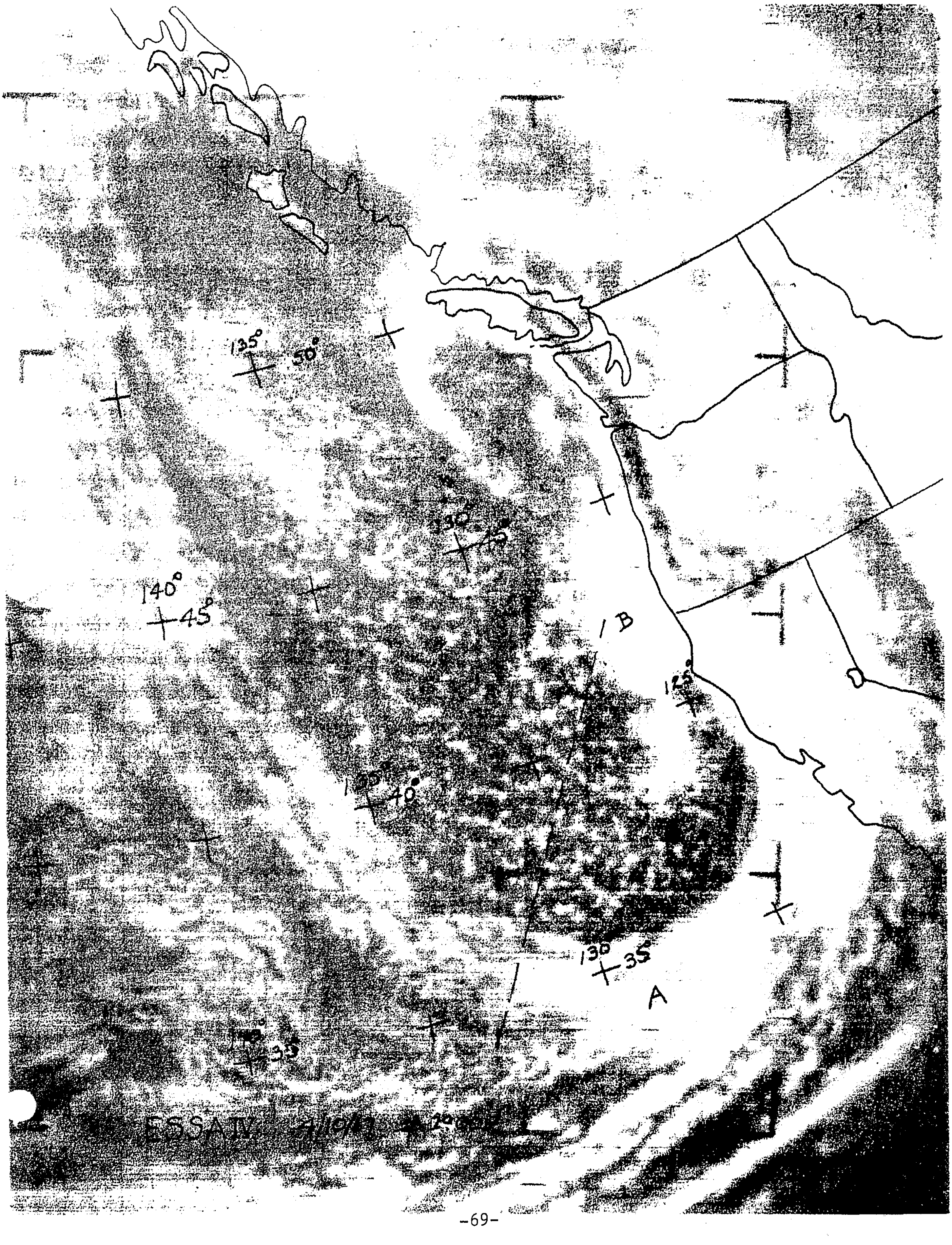


Figure 1a. Initial P.E. vorticity for 1200Z April 10, 1967. Solid lines are vorticity isopleths; dashed lines, 500-mb contours. Stippling indicates significant PVA.

Figure 1b. Same as 1a except 12-hour P.E. prog, valid time 0000Z, April 11, 1967.

Figure 1c. Observed vorticity for 0000Z April 11, 1967.


135°
50°
130°
45°
140°
45°
B
125°
135°
40°
130°
35
A
ESSA IV

WESTERN REGION TECHNICAL ATTACHMENT
March 28, 1967
No. 67-12

WAVE CLOUDS ON SATELLITE PICTURE

A new feature is being introduced into the Technical Attachment of this week--an outstanding APT picture. From time to time, such pictures will be discussed in order to point out features of significance to Western Region forecasters. Stations with APT are invited to submit worthwhile pictures for inclusion in the Technical Attachments. Interpretation and discussion should accompany the picture.

This APT picture was taken at 1743Z on March 9, 1967. The center fiducial is at 44.0°N. and 111.0°W. The dendritic snow pattern of the Sierra Nevada is easily visible in the lower-left portion of the picture, with extensive stratus off the California coast. Of particular interest are the transverse cloud bands over northeastern California, northwestern Nevada, and southeastern Oregon. These are stationary wave clouds formed in the lee of the Northern Sierra and Southern Cascades. Note the complete absence of wave clouds in the lee of the Southern and Central Sierra Nevada. 700-mb winds at 1200Z March 9 (see Figure 1) were WSW about 35 knots over the Southern Cascades and Northern Sierra, diminishing to 15 knots or less over the Central and Southern Sierra. Investigators of the Sierra Wave have indicated that a wind speed of at least 25 knots is necessary for the formation of mountain waves [1]. Wind speed also increased with height, reaching 55 knots at 500 mbs at Medford. The air at 700 mbs over Medford was saturated; thus, there was also sufficient moisture for wave clouds to form. The surface chart at 1800Z showed an ENE-WSW-oriented cold front along a line from north of Boise to Medford, thence offshore. This front was moving slowly southeastward.

REFERENCE: [1] WRH Technical Attachment, March 21, 1967.

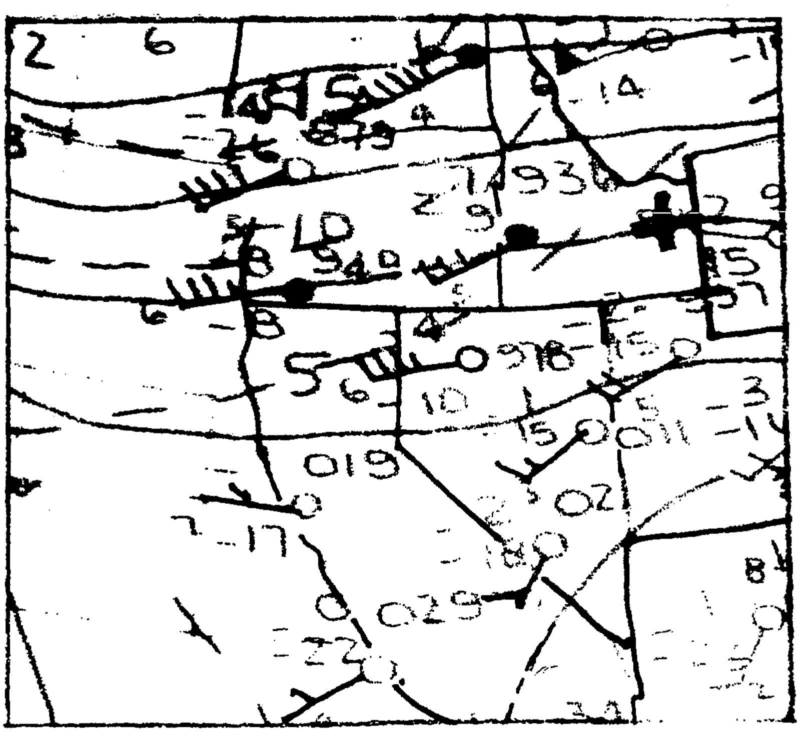


Figure 1. 700-mb. Analysis, 1200Z, March 9, 1967. Heavy cross is location of center fiducial point of attached satellite picture.

WESTERN REGION TECHNICAL ATTACHMENT
April 25, 1967
No. 67-16

SATELLITE PICTURES HELP AGAIN

The synoptic regime that has existed over our Region for the past month has given us several excellent opportunities to appreciate the importance of satellite pictures in short-period forecasting.

One of the important factors to be taken into account when preparing local forecasts is the location and subsequent movement of short-wave troughs. During the past month, for the most part there has been a quasi-stationary large-scale trough along the West Coast with a generally moist, unstable airmass over most of the Region. Each short-wave trough moving through the Region has been associated with a wide variety of weather--some of it severe in character. Our best tools for locating and forecasting the movement of such troughs are usually the "barotropic" and "6-L" NWP vorticity charts [1, 2]. Unfortunately, the vorticity analysis off the West Coast is based upon little or no data except the previous NWP 12-hour prognosis. On several occasions recently the initial vorticity advection indicated by the initial analysis was in error and consequently misleading. Such errors have been especially numerous during the past month because the short-wave troughs have been moving <u>southward</u> over the ocean from the central Gulf of Alaska through no-data areas to latitudes as low as 30 - 35 degrees before moving eastward into our Region. Fortunately, during this period our major forecast stations have had both satellite mosaics and APT pictures of this area, and most field stations have had satellite mosaics once a day to evaluate the accuracy of the 0000Z initial vorticity charts before using them in preparing forecast guidance and/or local forecasts. An example of this evaluation procedure was discussed in a recent Technical Attachment [3].

Today's Technical Attachment discusses three additional examples that occurred late last week (April 19 - 21, 1967). Reference will be made only to "barotropic" initial vorticity analyses; however, the "P.E." analyses could have been used, as there was no significant difference in these analyses as far as this discussion is concerned.

The initial vorticity chart for Wednesday afternoon, 0000Z April 20 (Figure 1a), shows little or no positive vorticity advection (PVA) off the Washington and Oregon coasts. The ESSA IV APT satellite picture of this area, taken at about 1900Z April 19 (Figure 2), and the ESSA III satellite mosaic for about 2300Z April 19 (which was transmitted over National Fax), both showed a strong comma cloud near 45° latitude (marked "A" in Figure 2). Since the comma cloud is well developed and this cloud pattern is known to be associated with PVA areas, the satellite picture suggests that the vorticity analysis off the West Coast is incorrect. The PVA area in Figure 1a is indicated too far south. Furthermore, this bright, solid comma cloud and the substantial area

area of no middle or high cloudiness directly north of it (located by "B" in Figure 2), indicates that the associated upper trough or low center is moving directly south at picture time. The PVA on the vorticity chart indicates eastward movement of the trough. The conclusion from a study of the satellite picture is that the best upper-air support for the development of showers over California and Nevada will be almost 24 hours later than indicated by the barotropic NWP forecast (not included in figures).

Thursday's APT picture, taken at approximately 2000Z April 20 (Figure 3), shows the West Coast comma cloud located just off the northern California coast. In all probability this cloudiness moved southward over the ocean Wednesday and then southeastward Thursday. The broken appearance of the clouds (area marked "A" in Figure 3) indicates that the PVA was weaker on Thursday than Wednesday. (Note the solid cloud coverage of the comma cloudiness in Figure 2.) This weaker PVA (broken cloudiness) resulted from the associated trough or low either weakening or moving slower, or both. The combination of the cloud located by "A's" in Figure 3, and the cloudless area located by "B" suggests that the upper trough was moving slowly southeastward at picture time. Here, again, even when the time difference is taken into account, the PVA areas depicted on the initial vorticity chart for 0000Z April 21 (Figure 1b) and the satellite cloud patterns do not agree very well, but the agreement is better than the day before.

Friday's picture, taken about 1800Z April 21 (Figure 4), shows that the comma cloudiness, although no longer having the characteristic comma shape, was over California, and that no significant high or middle cloudiness existed off the coast. This pattern indicates eastward movement of the associated trough with negative vorticity advection off the coast. This cloud pattern agrees rather well with the initial vorticity chart for 0000Z April 22 (Figure 1c).

In summary, the satellite cloud pictures taken last Wednesday, Thursday, and Friday were useful to field forecasters: 1) in assessing the accuracy of initial vorticity-advection patterns off the West Coast; 2) in indicating the direction of motion of the trough and/or low center at picture time; and 3) in indicating a change of intensity or speed of the short-wave trough.

APT pictures were used in this discussion because mosaics were not transmitted for our Region on the National Facsimile circuit for April 20 and 21. We hope that reliable and more frequent mosaic transmissions will be forthcoming soon. On this hope, we will continue to discuss specific situations when satellite pictures have a significant part in the preparation of short-period forecasts. (Note that the 35^{o} latitude line in Figure 4 is misplaced about 2 degrees latitude too far south.)

We wish to acknowledge Mr. Oliver's assistance in the interpretation of the satellite pictures discussed above, and to thank Salt Lake City WBAS for making their operational APT satellite pictures available for reproduction.

REFERENCES:

[1] "Qualitative Rules Concerning Vorticity", Technical Attachment to Western Region Staff Minutes, January 18, 1966.

[2] "The Physical Relationship Between Vorticity Advection and Vertical Motion", Technical Attachment to Western Region Staff Minutes, July 19, 1966.

[3] "Satellite Pictures Improve Short-Range Forecast", Technical Attachment to Western Region Staff Minutes, April 11, 1967.

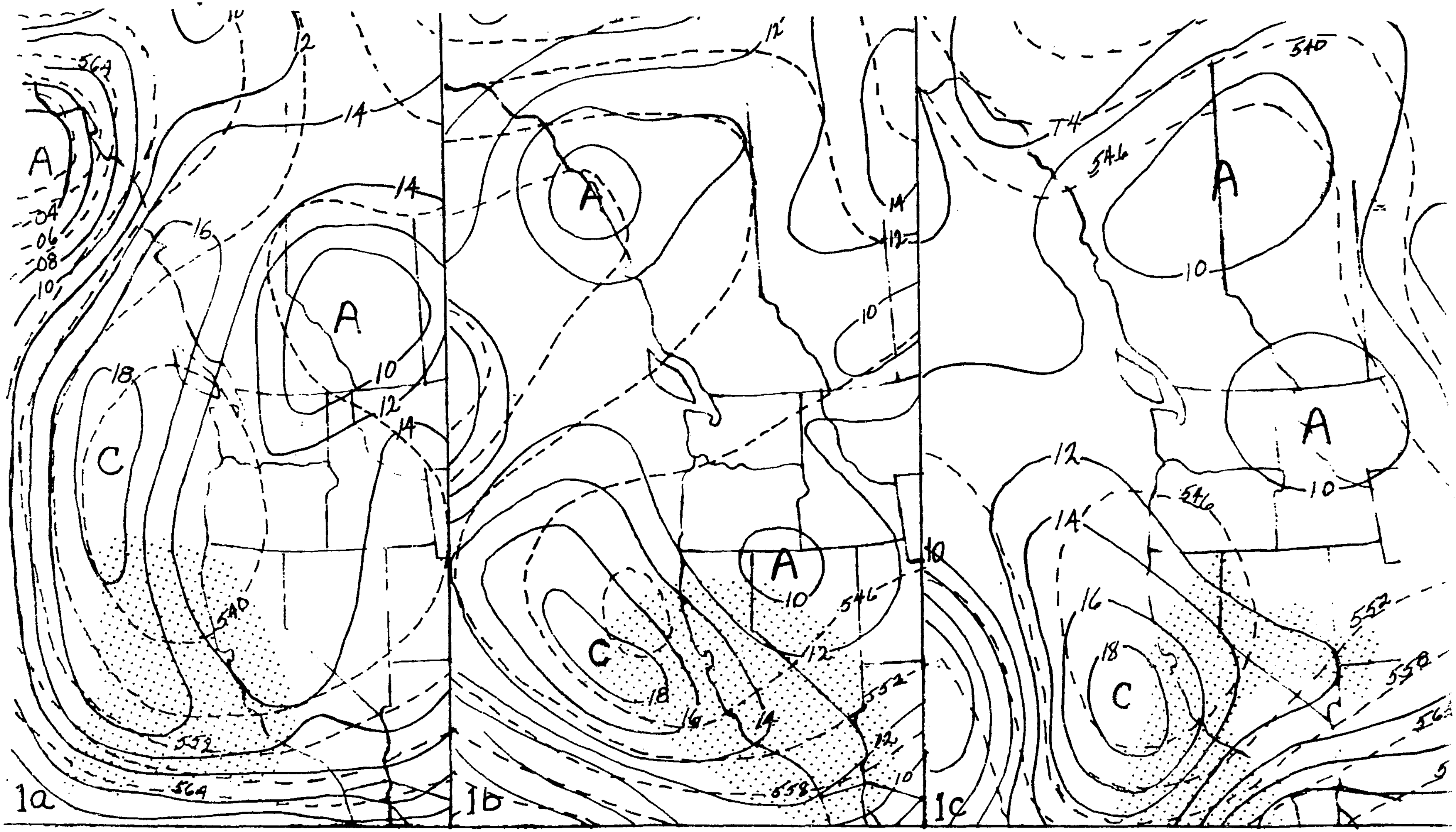


Figure 1a. Initial Barotropic vorticity chart for 0000Z April 20, 1967. Solid lines are vorticity isopleths; dashed lines, 500-mb contours; the stippling indicates significant PVA.

Figure 1b. Initial Barotropic vorticity chart for 0000Z April 21, 1967. Solid lines are vorticity isopleths; dashed lines, 500-mb contours; the stippling indicates significant PVA.

Figure 1c. Initial Barotropic vorticity chart for 0000Z April 22, 1967. Solid lines are vorticity isopleths; dashed lines, 500-mb contours; the stippling indicates significant PVA.

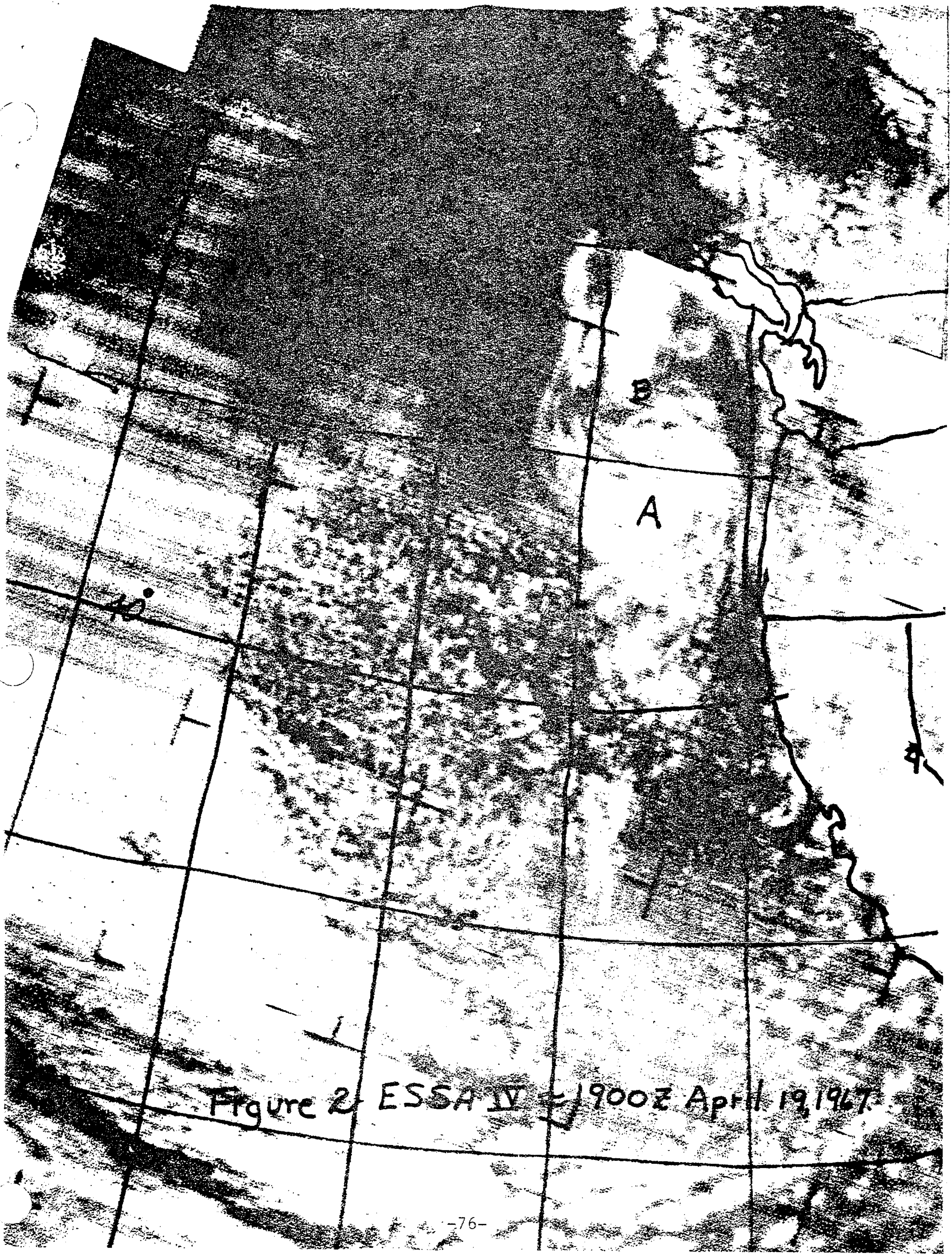


Figure 2 ESSA V ≈ 1900Z April 19, 1967

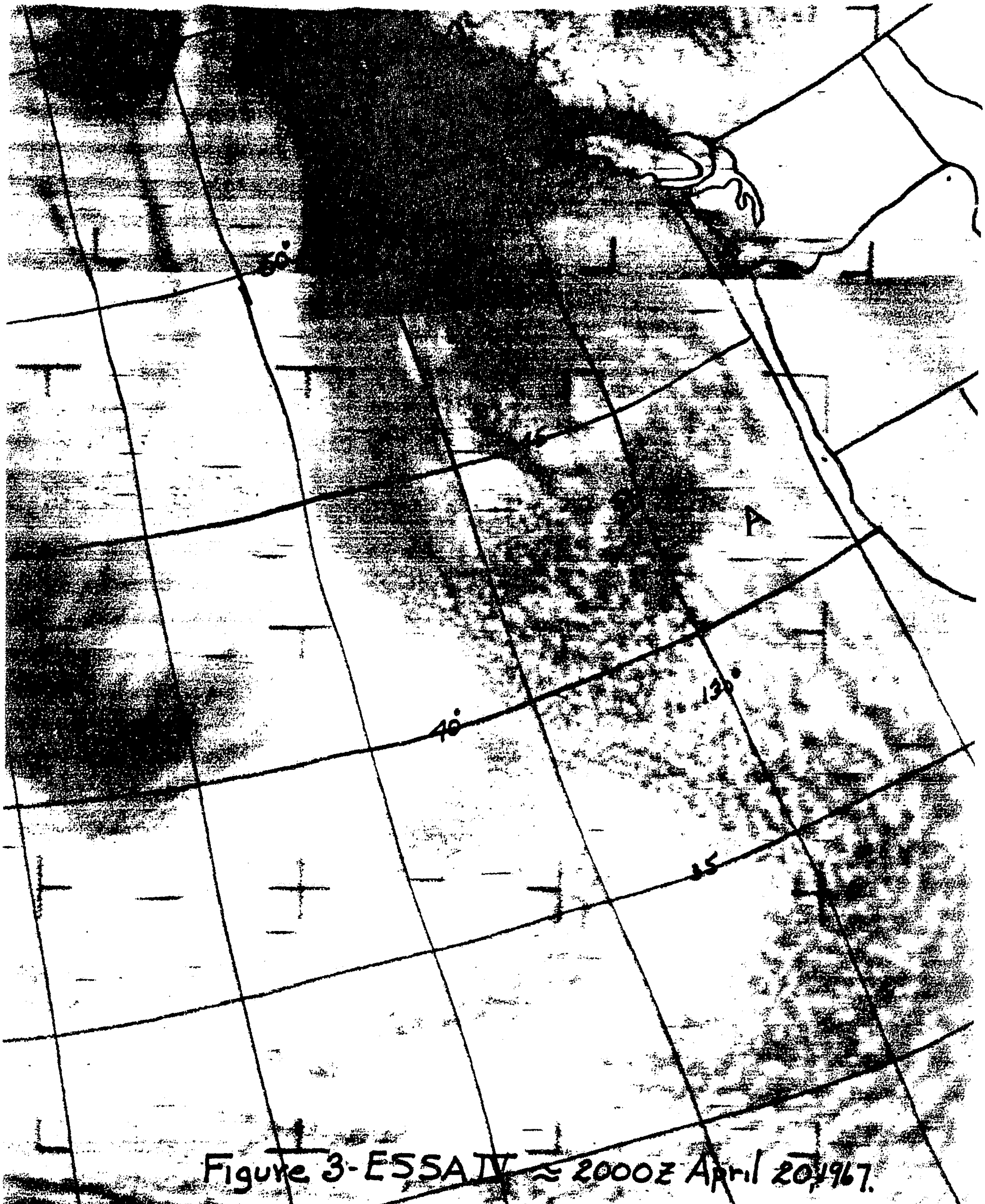
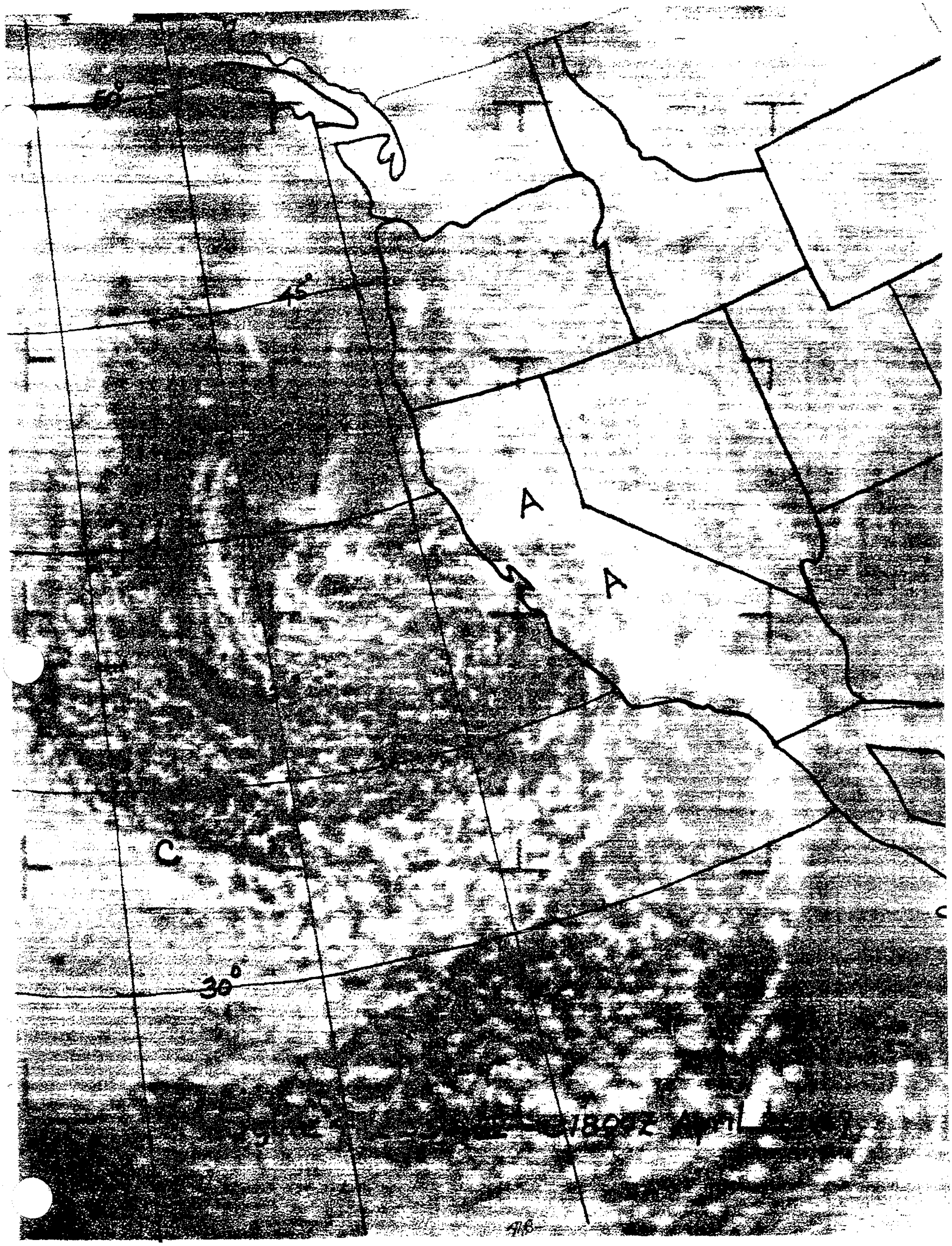


Figure 3 - ESSA IV ≈ 2000z April 20, 1967.



45°
A
A
C
30°
1800Z April

APPENDIX V

WESTERN REGION TECHNICAL ATTACHMENT
August 15, 1967
No. 67-30

CONVECTIVE INDICES

The recently received notes of the Forecaster Reference Course [Staff Minutes, July 25, 1967, SSD Item #4] contains an excellent discussion on Convective Indices which will be of interest to Western Region forecasters. Although a good part of the summer is over, there are still several weeks left when forecasters will need to extract the maximum amount of information from plotted soundings when considering the inclusion of showers in their local forecasts. Even though these machine-computed indices are not all available at field stations, forecasters may compute them by hand and determine which are most useful when applied to soundings in their local areas. The following notes were prepared by the Technical Procedures Branch of CO WXAP:

"The information outlined in these notes covers a brief explanation of the various indices derived from machine computation available at approximately 0400 and 1600Z daily at NMC.

Brief Synopsis - The machine computation of the indices uses the 'Parcel' Theory as a basis for determining the static stability and certain thermodynamic energy relationships. The method differs from the conventional graphical methods in that the values from the moisture profile are first converted to produce a pseudo-wet bulb potential temperature profile before computations are made of the various indices. An additional important difference lies in the flexibility available to NMC in defining the surface moist layer. For the purpose of computing moisture content the surface moist layer is defined in two depths:

a. A 100-mb column containing the greatest average moisture located within a 160-mb column above the surface.

b. A 160-mb column containing the greatest average moisture located within a 240-mb column above the surface.

The computation program proceeds to compute the moisture values for the full column and then divides the values into 20-mb steps. A mean value for each 20-mb column is determined and for a 160-mb column the program selects 5 consecutive 20-mb intervals that give a maximum mean value of pseudo-wet bulb temperature. For a 240-mb column 8 intervals are selected. The pressure is averaged linearly in the column so that the midpoint is the linear midpoint, i.e., 50 mb for a 100-mb column; while the temperatures (pseudo-wet bulb potential and air temperatures) are averaged on a ln p (logarithmic) basis. The computations of all the parameters are made from linear midpoint of the layer.

The machine-computed parameters which use a maximum moist column above the station level have several advantages over those computed from some fixed level. Maximum moisture values from a moist column above the surface represent a relatively large sampling of this layer and are much more likely to be representative than single values from fixed surfaces.

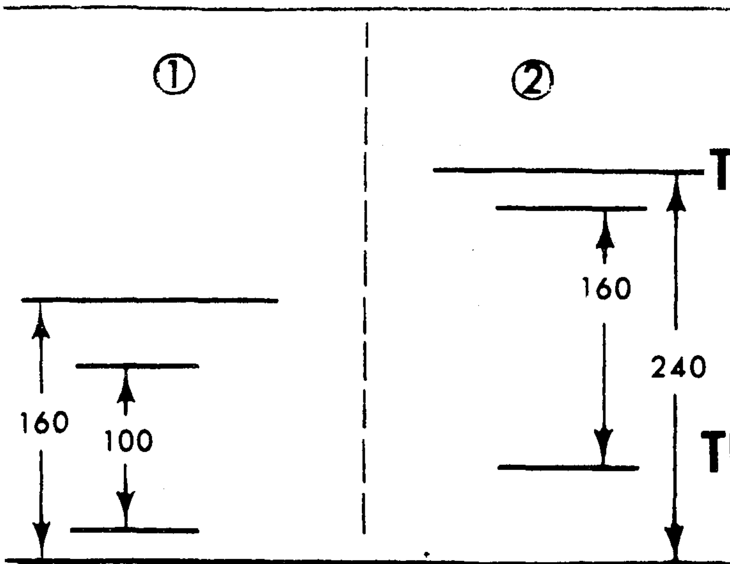
Using a moist column avoids the problem of surface elevation. Parameters derived from values restricted to single, fixed surfaces become largely unrepresentative in mountain areas. For example, the 850-mb level which is used in the Showalter Index comes too close to the surface at many mountain stations and, therefore, will give values of moisture larger than is actually available for significant convective activity.

GLOSSARY

The convective indices computed by machine are listed below:

θ_{sw}	Pseudo-wet bulb potential temperature
$\bar{\theta}_{sw}^{100}$	Mean pseudo-wet bulb potential temperature for a 100-mb column within a 160-mb column
$\bar{\theta}_{sw}^{160}$	Mean pseudo-wet bulb potential temperature for a 160-mb column within a 240-mb column
PSFC	Station pressure (mb)
TH18	Thickness 1000-850 (gpm)
TH75	Thickness 1000-700 (gpm)
SK75	Saturation thickness 700-500 (gpm)
SSPA	Severe storm positive area (gpm)
SSI	Severe storm index (gpm)
PLCL	Pressure at condensation level (mb)
PLFC	Pressure at level of free convection
PBML	Pressure at the base of 100-mb moist layer (mb)
CIPA	Convective index positive area (gpm)
CI	Convective index (gpm)
PCCL	Convective condensation level (mb)
STCCL	Convective temperature (tenths °F)
K-Factor	(850-mb temp - 500-mb temp) + 850-mb dewpoint) - (700-mb temp - 700-mb dewpoint)

The various lifted condensation level parameters are described schematically in the following pages."



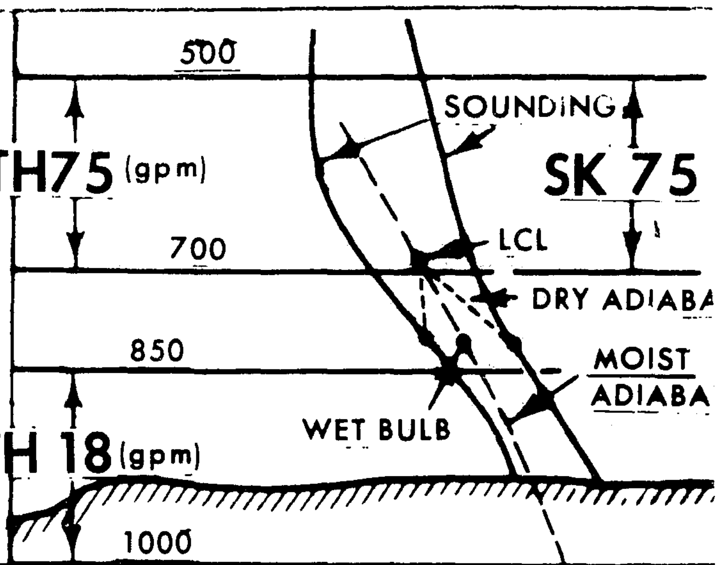
STATION LEVEL — PSFC (MB)

WO SETS ARE COMPUTED

1) 100 MB layer selected within a 160-MB layer above station pressure.

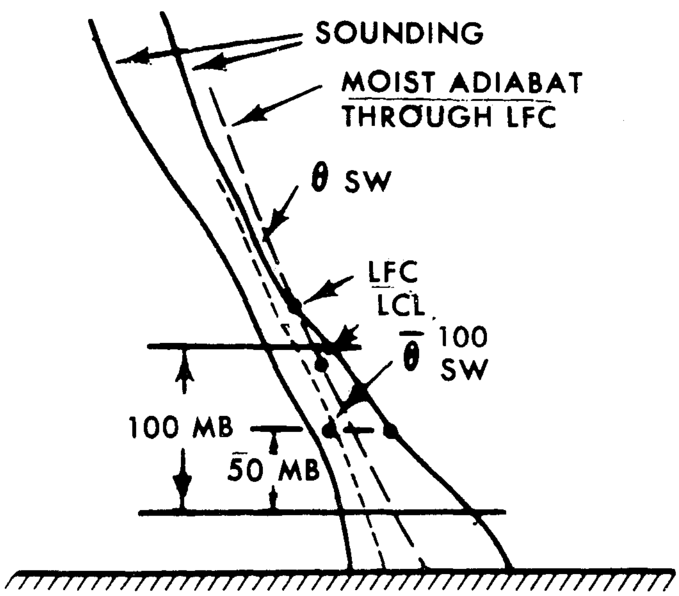
2) 160 MB layer selected within a 240-MB layer above station pressure.

putes a full layer, then steps by 20 MB increments to find the greatest moisture in erms of θ_{sw}. The mean $\bar{\theta}^{100}_{sw}$ is used for comitations from linear midpoint in the layer.



SK 75

θ_{sw} = Pseudo-wet bulb potential temperature. The mean $\bar{\theta}^{160}_{sw}$ of the θ_{sw} values for a <u>160-MB</u> layer within the 240 MB layer starting at station level is converted to a moist adiabat which then is converted to saturation thickness for the layer 7 - 5 (700 - 500 MB)



SSPA

SSPA

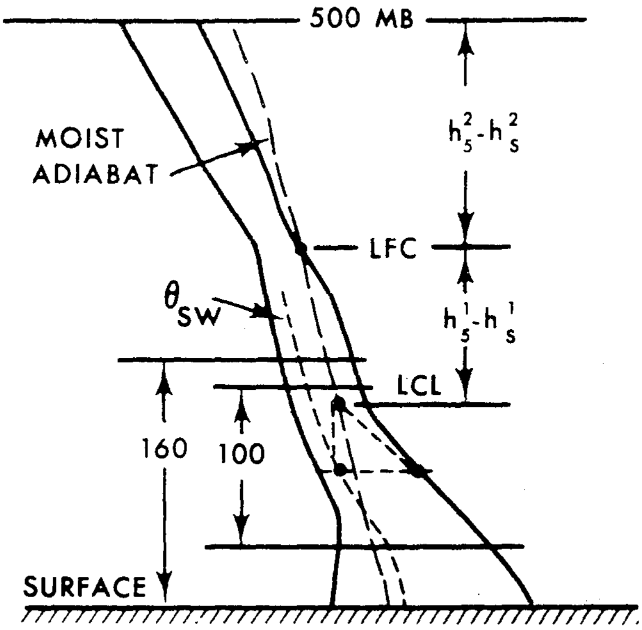
LFC is determined from $\bar{\theta}^{100}_{sw}$ and the temperature at the midpoint of the 100 MB layer. Saturation thickness from LFC to 500 MB is computed from moist adiabat going through LFC. This value is subtracted from the actual thickness of the sounding from LFC to 500 MB.

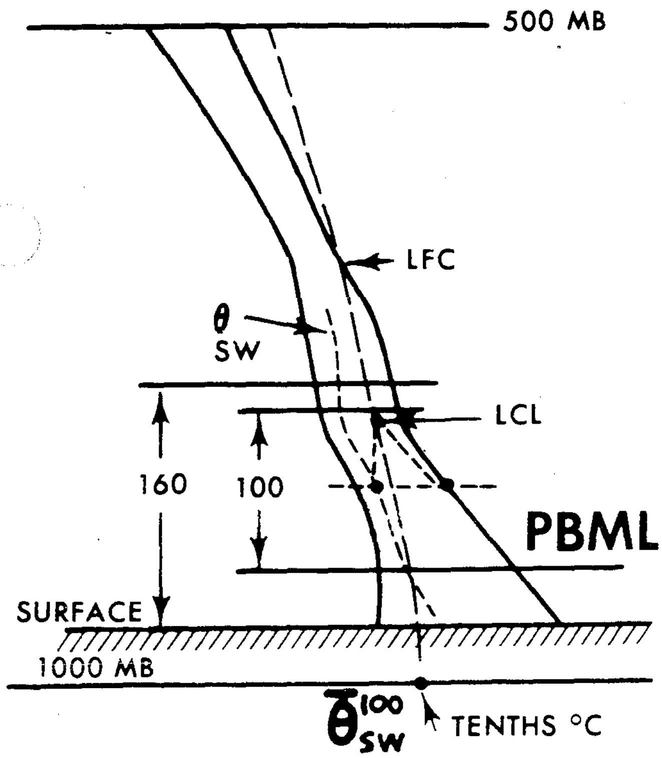
negative values = instability, LFC exist
99999 = No LFC to 500 MB
positive values = LFC exists but stable layer above and net energy values inhibit motion to 500 MB.

DI DOWNDRAFT INDEX **SSPA—CIPA**

:he greater negative values of DI give in- ations of evaporative cooling which devel- ops denser air - sinks, causing downdrafts. The layer values imply that quick drying will occur above the level of wet bulb zero derived from 100 MB thick layer. Also large values of DI show wet bulb zero (intersection of wet bulb with 0°C line) to be low. This is an indirect indication of downdraft evergy avail- able when convective release takes place.

SSI





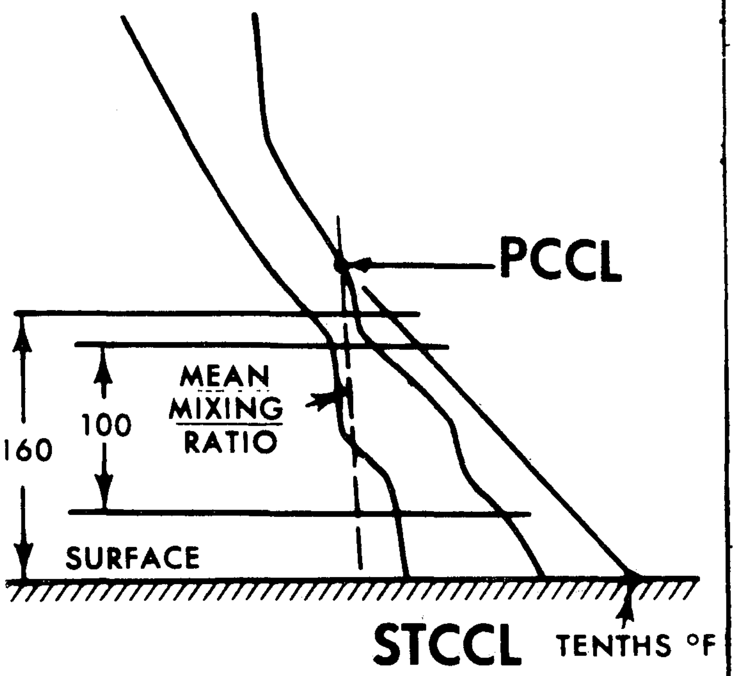
Using $\bar{\theta}^{100}_{sw}$ taken from pressure midpoint of layer and corresponding actual temperatu. the thickness difference (actual--saturation) of the LFC-LCL layer subtracted from the thickness difference of the LFC-500-MB layer $(h_5^2 - h_s^2) - (h_5^i - h_s^i)$ = **SSI** (gpm)

PLCL pressure (MB) at LCL using $\bar{\theta}^{100}_{sw}$ lifted from midpoint of 100-MB layer

PLFC pressure (MB) at LFC using $\bar{\theta}^{100}_{sw}$ lifted from midpoint of 100 MB layer

$\bar{\theta}^{100}_{sw}$ LCL of the mean $\bar{\theta}^{100}_{sw}$ brought down to 1000 MB - value in tenths °

PBML pressure at the base of the 100-MB layer. Compared with station pressure indicates concentration of moisture in the 100-MB layer.



PCCL Pressure of the lowest intersection of the mean mixing ratio of the 100-MB layer and the actual temperature curve.

STCCL PCCL brought down dry adiabatically to station pressure (tenth °F).

FOR THE 160 MB LAYER

SSPA becomes **CIPA**

SSI becomes **CI**

THE REMAINDER ARE ALL THE SAME, COMPUTED FOR THE 160-MB LAYER

SELECTIONS

The following parameters (defined in the attached diagrams) are recommended selections in order of importance:

1. CI or SSI or both (see glossary on p. 4)
2. SSPA
3. STCCL
4. θ_{sw}^{100}
5. 700-500-mb saturation thickness deficit (or TH75 and SK75)
6. DI
7. STCCL (160-mb layer)

The selection was based mainly on subjective experience at A&FD and a few case studies made at Technical Procedures Branch. Thus the conclusions presented are only tentative.

In the limited study made at TPB, the following indices were analyzed separately:

1. TH18
2. TH75
3. 700-500-mb saturation thickness deficit
4. SSPA
5. SSI
6. THSW (θ_{sw}^{100})
7. PLFC
8. PCCL
9. STCCL
10. CI
11. DI
12. K-Factor
13. Showalter Index

The indices were compared graphically with each other and with the distribution of convective activity at the surface. The results are summarized below.

TH18

The association was rather poor. Some of the precipitation was located in gradients, some in cold areas, and some in warm tongues.

TH75

Similar to TH18. In general the convective activity was confined to warm tongues and mid tropospheric precipitation to cold regions in the pattern. Association of patterns to precipitation was fair to poor.

700- 500-mb deficit

Very similar to SSI. Rather good agreement of both pattern and centers with areas of precipitation. Also relatively good agreement with the cloud field.

SSPA

Only an indefinite association occurs. The patterns show fair agreement with cloud patterns but rather poor agreement with precipitation patterns. About all that can be said is that the precipitation occurs near the maximum negative values. However, as in the case of DI, there were frequently large number of stations lacking a value. This causes difficulties in the analyses due to the discontinuities and lack of continuity from chart to chart.

SSI

This one seems to be a very good indicator. The association of patterns with areas of convective precipitation and cloud fields was good to excellent. In addition the long broad gradient seems to identify important zones of thermal discontinuities.

THSW (θ_{sw}^{100})

There was a considerable similarity to SSI. A rather good relationship between centers and pattern with areas of precipitation as well as clouds.

PLFC

The agreement here was only fair. There were many exceptions.

PCCL

Comments made for THSW apply here. Improvements are balanced by some lack of association.

STCCL

The results here were disappointing. The agreement of pattern and gradient with precipitation and radar echoes patterns was rather poor.

CI

A good agreement in general was observed. There were isolated CB reports in positive centers.

DI

The appraisal was inconclusive. A large field of no data, i.e., one or the other of the two parameters (SSPA, CIPA) did not exist. This caused warm discontinuities in the analyses resulting in incomplete and ill-defined patterns. Where patterns existed, the associations were good.

K-Factor

Good agreement in broad terms of pattern and gradient but lacked detail discrimination. Its use would be analogous to that of positive vorticity advection field. [The K-factor has been found especially useful by Fire-Weather forecasters in the Western Region.]

Showalter Index

The agreement was fair. There was general convective activity in some areas which had values greater than +4.

APPENDIX VI

WESTERN REGION TECHNICAL ATTACHMENT
April 13, 1966

THUNDERSTORM FORECASTING AND THE "K" CHART

Spring is here, and with it comes the thunderstorm forecast problem. Several forecasters have brought to our attention the usefulness of J. J. George's "K" chart (1) as a thunderstorm forecast tool. This attachment discusses the construction and use of the "K" chart.

Airmass stability and moisture distribution are well established as important parameters associated with thunderstorm activity. To take these parameters into account easily during the preparation of operational forecasts, George defined an empirically determined moisture-stability index and called it "K". K is defined as:

K = (850-mb temperature - 500-mb temperature) + (850-mb dew point) - (700-mb dew-point depression).
Temperature and dew points are in Celsius degrees.

The "K" chart is a graphic depiction of the geographical distribution of K values; therefore, it resembles and is used in much the same way that we use the stability chart currently transmitted via facsimile. The "K" chart is considered superior to the stability chart, because it includes a stability factor plus moisture parameters.

George has published the following table relating K values to thunderstorm frequency in the eastern states:

TABLE I

K Value	Frequency Category
$K < 20$	None
$20 \leq K < 25$	Isolated thunderstorms
$25 \leq K < 30$	Widely scattered thunderstorms
$30 \leq K < 35$	Scattered thunderstorms
$K \geq 35$	Numerous thunderstorms

Mr. Hambidge, Reno Fire-Weather Forecaster, has assigned the following probabilities of thunderstorms to K values for the Reno fire-weather district (2):

TABLE II

K Value	Probability of Thunderstorms
$K < 20$	< 20%
$20 \leq K < 25$	20 - 40%
$25 \leq K < 30$	40 - 60%
$30 \leq K < 35$	60 - 80%
$K \geq 35$	> 80%

These two tables are in general agreement, even though the geographical areas for which they were developed are quite different. However, due to the varied topography over the Western Region, we believe that forecasters should use the above tables as general guides only. As experience is gained in using K values, forecasters should be able to add more detail to the K-value thunderstorm relationship for their specific forecast area.

The K chart can be prepared easily and quickly by extracting the necessary data, either from the fax 850- 700- and 500-mb charts, or the coded radiosonde teletype bulletins. The use of a worksheet similar to that illustrated below is suggested. Care and judgment must be exercised in the use of 1200Z 850-mb data from stations where these data may be influenced by the diurnal surface inversion. A temperature and dew point representative of the airmass at 850-mb must be used.

Although our experience with the K chart is limited, we have found it convenient to plot and analyze the K values on the 700-mb fax analysis. K values you consider critical can be highlighted by shading. The end result is a composite chart that gives potential thunderstorm areas, and that indicates their apparent advection.

A trigger of some kind is usually needed to release the thunderstorm potential indicated by the K chart. Upward vertical motion (usually indicated by positive vorticity advection and/or upslope flow) and surface heating are important triggers in our region. Fronts certainly trigger thunderstorms; however, a good, detailed small-scale analysis is needed to follow fronts during the thunderstorm season, because many fronts are too weak to meet NMC criteria for inclusion in the surface fax analysis. For this reason, we believe positive vorticity advection may turn out to be a more significant parameter than fronts for some stations.

The K chart can be prepared in a routine manner, and we are exploring the possibility of getting this chart transmitted on the national facsimile network.

(1) George, Joseph J., "Weather Forecasting for Aeronautics", 1960 pp 409 - 415.

(2) Hambidge, Richard E., "K Chart Application to Thunderstorm Forecast in the Reno Fire-Weather District", unpublished manuscript, presented at Western Fire-Weather Conference, Portland, Oregon, March 1966.

APPENDIX VII

WESTERN REGION TECHNICAL ATTACHMENT
April 2, 1968
No. 68-13

CHECKLIST FOR LOCAL FORECASTING

During the past year SSD has been concentrating on developing a systematic approach to preparing local forecasts during field consultant visits. The following checklist has evolved as the result of working with field forecasters thus far. Since each local station has its own unique forecast requirements, deadlines, etc., this checklist should be considered as a general outline from which each station can develop its own format. Comments and suggestions are solicited after stations have had some experience in using it.

Suggested checklist for preparation of local forecasts:

1) Check the 500-mb flow and predicted large-scale changes. Refer to latest analysis, 24-, 48- and 72-hour prognoses.

2) Read FXUS and FP-3 discussion bulletins. (These bulletins will have more meaning if they are read after studying the 500-mb charts.)

3) Process selected fax charts as follows:

   a) Vorticity charts: shade PVA areas and color a given valued contour in all four panels.

   b) Vertical-motion charts: shade positive areas and color same contour as in a).

   c) Surface chart:

      1) Shade middle and high broken to overcast cloudiness. Use weather depiction chart to help determine cloud shields.

      2) Shade precipitation areas. Use radar reports when applicable.

      3) Check frontal positions before coloring them. Adjust when necessary, using vorticity charts.

   d) 850- and 700-mb charts: plot 24-hour temperature changes.

4) Compare cloud and precipitation areas shaded in 3c above and indicated in satellite mosaics with PVA and vertical-motion areas shaded in 3a and 3b above.

5) Compare NMC surface prognoses of clouds and weather with ideas obtained from steps 3 and 4 above.

6) Check temperature trends:

   a) Compare 1000-500-mb thickness analysis with 30-hour prognosis and with 850- 500-mb 24-hour NWP thickness prognosis.

   b) Study radiosonde plots.

   c) Note 24-hour 850- and 700-mb temperature changes.

   d) Examine NMC temperature-forecast chart.

7) Use objective techniques or other local forecast aids.

   a) Temperature

   b) Precipitation (including rain vs. snow)

   c) Wind

   d) Fog

   e) Local Forecast Rules.

8) Consider warnings--snow, frost, wind, severe thunderstorms, hail.

9) Study FP forecast: if this forecast differs significantly from indications given by above procedures, call forecast center.

Additional Comments:

1) Process only the area of each fax chart that is needed.

2) Process the minimum number of charts needed.

(In most cases we have not specified the colors to be used in shading various items. At the request of a number of stations, we are working on standardization of these colors, and Operations plans to issue more specific guidance on this subject soon.)

THE RELATIONSHIP OF PRECIPITATION TO VERTICAL MOTION AND VORTICITY ADVECTION

Last week's Technical Attachment [1] discussed the relationship between vertical motion and the two factors, vorticity and temperature advection. (NOTE: The labels on Figures 1a and 1b should be reversed in that T.A.) It was pointed out that contrary indications with regard to precipitation occurrence are sometimes shown by the barotropic vorticity and the P.E. vertical-motion prognostic charts received on facsimile from NMC. Earlier T.A.'s [2] [3] discussed weather and vertical-motion charts.

In order to determine the relative usefulness of the barotropic vorticity and the P.E. vertical-motion prog charts for precipitation forecasting in the local area, it is recommended that forecasters undertake a simple verification scheme. Several stations in the Western Region are, in fact, already doing this. If the data are gathered on a routine daily basis, time can usually be found for the project; whereas, it is usually true that station personnel cannot find time to gather data if it is allowed to collect for a long period of time.

There are several ways in which the P.E. vertical-motion and barotropic vorticity progs can be related to precipitation occurrence. One way uses current weather at prog verification time, and the other uses observed precipitation amount. This amount can either be for a 12-hour period centered at the time the chart verifies, or for the 12 hours ending at or following verification time. Although the latter fits the periods "today" or "tonight" better and therefore is more useful in public forecasting, the 12-hour period centered on verification time will most likely show better results.

A worksheet can be set up as shown in Table 1. While the table includes only verification based on 12-hour progs, it is suggested that 6-hour vertical motion, observed (initial) barotropic vorticity (for concurrent specifications of weather), and possibly the 24- and 36-hour prog values also be tabulated as time permits. It may be possible to evaluate only one set of progs per day. The longer-range progs should have the lowest priority since most stations will be concentrating on the earlier portion of the forecast period as an aid to their small-scale program.

The form has a column for vertical motion (extracted from the 12-hour P.E. prog), absolute vorticity (from the 12-hour barotropic prog), the sign of the vorticity advection (plus, zero, or minus), the observed station weather at verification time, and 12-hour precipitation, centered at verification time. The 12-hour forecast change in absolute vorticity can also be correlated with 12-hour precipitation amounts for the same time interval.

Verification Studies

NMC has recently completed a study of vertical motion vs. clouds and weather for 55 stations in the United States, based on 18 forecasts issued between November 15 and 25, 1967; 6-, 12-, 24-, 36-, and 48-hour progs were verified. The study showed that 12-hour progs had the best relationship between weather and vertical motion. For Western Region stations, the test was not very definitive as the vertical motion was between +1 and -1 most of the time, and two-thirds of the precipitation cases fell in this range. However, when the progs did indicate large positive values, rain usually occurred.

A three-month study has been completed in WRH relating the 6-hour vertical velocity prog to measurable precipitation in the subsequent 12-hour period at Salt Lake City, with results shown in Table 2. A fair relationship is shown, but the scarcity of cases with vertical velocity prog values greater than +1 is startling. The mountain term in the P.E. model most likely has a strong influence here. An earlier study [4] related precipitation to 500-mb vorticity progs.

Forecasters at Wenatchee WBO have made a study relating vertical motion and vorticity advection, as shown on 12-hour progs, to weather and precipitation at their station for October and November 1967. Some of their conclusions are given below. (It should be noted in trying to rationalize these figures that Wenatchee is located immediately east of a major mountain range; whereas the "terrain" used for the mountain term in both the barotropic and P.E. models is "upslope" from well off the coast to the Continental Divide.)

1. Zero or negative vertical motion: essentially no precip.

2. Positive vertical motion: about 25% probability of a trace or more; about 20% probability of .01 or more.

3. Magnitude of vertical motion not significant for occurrence of precip.

4. Negative vorticity advection: less than 10% probability of any precip.

5. PVA: Probability about 30% for trace or more; 20 to 25% for .01 or more.

6. Absolute vorticity value had only a slight relationship with precip occurrence.

7. Plus 0.5 microbars/sec. or more vertical motion combined with PVA: about 35% probability of a trace, 25% probability .01 or more.

Conclusions

Vertical motion and vorticity advection as shown on NMC prog charts have a definite relationship to clouds and precipitation occurrence. Field station personnel can best determine how useful these progs are in their local areas of interest by conducting simple verification studies as described above. A joint relationship, using both PVA and vertical motion, may prove to be most useful. SSD will be interested in hearing about the results of such studies.

REFERENCES:

[1] T.A. 68-5, "Vorticity and Temperature Advection as Related to Vertical Motion".

[2] T.A. 67-38, "Weather and Vertical-Motion Charts".

[3] T.A. 67-36, "6-Layer Vertical Motion Charts".

[4] "Precipitation Forecasting from Prognostic Charts of 500-mb Vorticity", P. Williams, Jr., U. S. Weather Bureau Manuscript, June 1964.

U. S. DEPARTMENT OF COMMERCE - ESSA WEATHER BUREAU
Computation and Tabulation Sheet

Weather and Precip vs. Vertical Motion and Vorticity

Station ____________________ February 1968

		V.T. 0000Z					V.T. 1200Z			
Date	Vert. Motion	Abs. Vort.	Vort. Adv.	Ob Wx	Precip. 18 - 06Z	Vert. Motion	Abs. Vort.	Vort. Adv.	Ob Wx	Precip. 06 - 18Z
1	-2.5	08	-	Φ/	0	+0.5	08	+	●	T
2	+2.2	14	+	R	.15	+1.5	18	O	RW-	.01

TABLE 1
(Sample)

PRECIPITATION OCCURRENCES AT SALT LAKE CITY
VS PROGNOSTIC VERTICAL MOTION
(12-Hour Period after Prog. Verifying Time)
October - December 1967

P.E. 6-hr Vert. Vel. Prog.

	< -1.0	0 to -1.0	+0.1 to +1.0	> +1.0
No. Cases	19	102	48	3
Precipitation ≥ .01	0	10	12	3
% Precipitation	0%	10%	25%	100%

TABLE 2

Western Region Technical Memoranda: (Continued)

No. 24 Historical and Climatological Study of Grinnell Glacier, Montana. Richard A. Dightman. July 1967.

No. 25 Verification of Operational Probability of Precipitation Forecasts, April 1966 - March 1967. W. W. Dickey. October 1967.

No. 26 A Study of Winds in the Lake Mead Recreation Area. R. P. Augulis. January 1968.

No. 27 Objective Minimum Temperature Forecasting for Helena, Montana. D. E. Olsen. February 1968.

No. 28 Weather Extremes. R. J. Schmidli. April 1968.

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