CHAPTER 3

FORECASTING SURFACE SYSTEMS

With the upper air prognosis completed, the next step is to construct the surface prognostic chart Since more data is available for the surface chart, and this chart is chiefly the one on which you, the Aerographer's Mate, will base your forecast, you should carefully construct the prognosis of this chart to give the most accurate picture possible for the ensuing period. The surface prognosis may be constructed for periods up to 72 hours, but normally the period is 36 hours or less. In local terminal forecasting, the period may range from 1 to 6 hours.

Construction of the surface prognosis consists of the following three main tasks.

1. Progging the formation, dissipation, movement, and intensity of pressure systems.

2. Progging the formation, dissipation, movement, and intensity of fronts.

3. Progging the pressure pattern; that is, the isobaric configuration and gradient.

From an accurate forecast of the foregoing features, you should be able to forecast the weather phenomena to be expected over the area of interest for the forecast period.

FORECASTING THE FORMATION OF NEW PRESSURE SYSTEMS

LEARNING OBJECTIVES Recognize features on satellite imagery and upper air charts conducive to the formation of new pressure systems.

The central problem of surface prognosis is to predict the formation of new low-pressure centers. This problem is so interrelated to the deepening of lows, that both problems are considered simultaneously when and where applicable. This problem mainly evolves into two categories. One is the distribution of fronts and air masses in the low troposphere, and the other is the velocity distribution in the middle and high troposphere. The rules applicable to these two conditions are discussed when and where appropriate.

For the principal indications of cyclogenesis, frontogenesis, and windflow at upper levels, refer to the *AG2* TRAMAN, volume 1.

The use of hand drawn analyses and prognostic charts in forecasting the development of new pressure systems is in many cases too time-consuming. In most instances, the forecaster will generally rely on satellite imagery or computer drawn prognostic charts.

SATELLITE IMAGERY — THE FORMATION OF NEW PRESSURE SYSTEMS

To most effectively use satellite imagery, the forecaster must be thoroughly familiar with imagery interpretation. Also, the forecaster must be able to associate these images with the corresponding surface phenomena.

The texts, *Satellite Imagery Interpretation in Synoptic and Mesoscale Meteorology,* NAVEDTRA 40950, and *A Workbook on Tropical Cloud Systems Observed in Satellite Imagery,* volume 1, NAVEDTRA 40970, contain useful information for the forecaster on the subject of satellite interpretation. The Naval Technical Training Unit at Keesler AFB, Mississippi, also offers the supplemental 2-week course, Weather Satellite Systems and Photo Interpretation (SAT INTERP).

The widespread cloud patterns produced by cyclonic disturbances represent the combined effect of active condensation from upward vertical motion and horizontal advection of clouds. Storm dynamics restrict the production of clouds to those areas within a storm where extensive upward vertical motion or active convection is taking place. For disturbances in their early stages, upward vertical motion is the predominant factor that controls cloud distribution. The comma-shaped cloud formation that precedes an upper tropospheric vorticity maximum is an example. Here, the clouds are closely related to the upward motion produced by positive vorticity advection (PVA). In

many cases this cloud may be referred to as the PVA Max. See figure 3-1.

Wave or low development along an already existing front may be detected from satellite imagery. In figure 3-2, a secondary vorticity center is shown approaching a frontal zone.

The cloud mass at A (fig. 3-2) is associated with a secondary vorticity center that has moved near the front. Interaction between this vorticity center and the front will result in the development of another wave near B.

By recognizing the vorticity center and determining its movement from successive satellite passes, the forecaster should be able to accurately predict the formation of a second low-pressure system.

UPPER AIR CHARTS — THE FORMATION OF NEW PRESSURE SYSTEMS

Computer drawn charts also provide the forecaster with another tool for forecasting the development of new pressure systems. These prognostic charts maybe used to directly prepare a forecast, or the forecaster may use a sequence of them to construct other charts.

A very beneficial chart used in determining changes in surface pressure, frontogenesis, frontolysis, and development of new pressure systems is the advection chart. The normal methods of

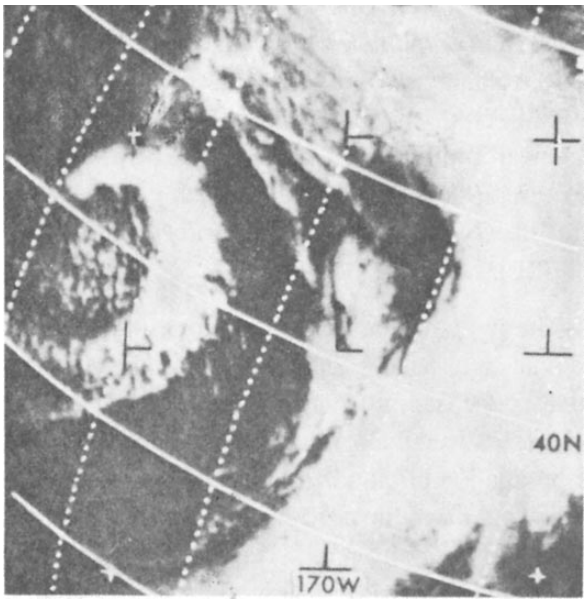

Figure 3-1.-A well developed, comma-shaped cloud is the result of a moving vorticity center to the rear of the polar front. The comma cloud is composed of middle and high clouds over the lower-level cumulus and is preceded by a clear slot.

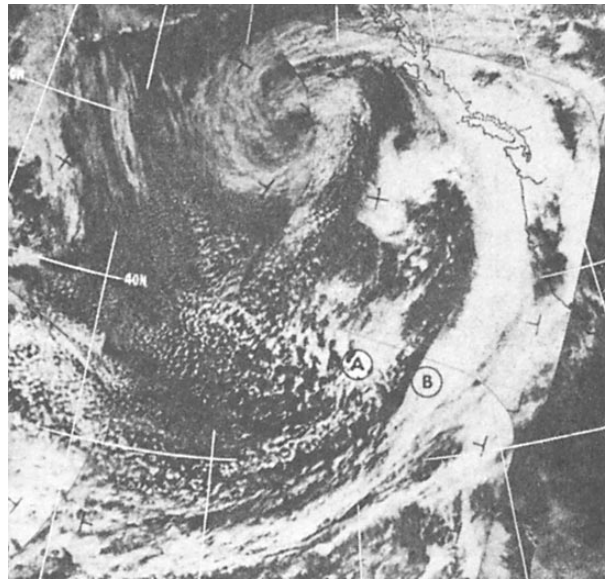

Figure 3-2.-Frontal wave development.

construction are time-consuming; however, by using computer charts, the chart may be more readily constructed.

The 700-hPa, 1000-hPa, and 500-hPa thickness charts should be used in construction of the advection chart. The 700-hPa contours approximate the mean wind vector between the 1000- and 500-hPa levels. On a 1000- to 500-hPa thickness chart, the contours depict thermal wind, which blows parallel to the thickness lines. Meteorologically speaking, we know that lines of greater thickness represent relatively warmer air than lines of less thickness. If the established advection pattern is replacing higher thickness values with lower thickness values, then it must be advecting cooler air (convergence and divergence not considered). The opposite of this is also true. The changing of thickness values can be determined by the mean wind vector within the layer of air. The 700-hPa contours will be used as the mean wind vectors.

The advection chart should be constructed in the following manner:

1. Place the thickness chart over the 700-mb chart and line it up properly.

2. Remember that the 700-hPa contours represent the mean wind vector. Place a red dot indicating warm air at all intersections where the mean wind vector is blowing from higher to lower thickness values.

3. Use the same procedure to place a blue dot at all intersections where the mean wind vector is blowing from lower to higher thickness values.

You need not place red and blue dots for the entire chart-only for the area of interest.

Now, to use this advection chart, it should be compared against the chart from the preceding 12 hours. From comparison of the red and blue dots, you can determine if there has been an increase or decrease in the amount of warm or cold air advection in a particular area, as well as any change in the intensity of advection.

Then, the advection type and amount, as well as change, can be applied to determine the possibility of new pressure system development.

FORECASTING THE MOVEMENT OF SURFACE PRESSURE SYSTEMS

LEARNING OBJECTIVES Forecast the movement of surface low- and high-pressure systems by extrapolation, isallobaric indications, relation to warm sector isobars, relation to frontal movement, thickness lines, relation to the jetstream, and statistical techniques.

Whether you move the high- or low-pressure areas first is a matter of choice for the forecaster, Most forecasters prefer to move the low-pressure areas first, and then the high-pressure areas.

MOVEMENT OF LOW-PRESSURE SYSTEMS

Lows determine, to a large extent, the frontal positions. The y also determine a portion of the isobaric configuration in highs because gradients readjust between the two. As a result of knowing the interplay of energy between the systems, meteorologists have evolved rules and methods for progging the movement, formation, intensification, and dissipation of lows.

Extrapolation

First and foremost in forecasting the movement of lows should be their past history. This is a record of the pressure centers, attendant fronts, their direction and speed of movement, and their intensification/weakening. From this past history, you can draw many valid conclusions as to the future behavior of the systems and their future motion. This technique is valid for both highs and lows for short periods of time.

The general procedure for the extrapolation of low-pressure areas is outlined below. Although only movement is covered, the central pressures with anticipated trends could be added to obtain an intensity forecast.

1. Trace in at least four consecutive past positions of the centers.

2. Place an encircled X over each one of these positions, and connect them with a dashed line, (See fig. 3-3.) If you know the speed and direction of movement, as obtained from past charts, the forecasted position can be calculated. One word of *caution,* straight linear extrapolation is seldom valid beyond 12 hours. Beyond this 12-hour extrapolated position, deepening/filling, acceleration/deceleration, and changes in the path must be taken into consideration. It is *extremely important* that valid history be followed from chart to chart, *Systems do not normally appear out of nowhere, nor do they just disappear*

3. An adjustment based on a comparison between the present chart and the preceding chart must be made, For example, the prolonged path of a cyclone center must not run into a stationary or quasi-stationary anticyclone, notably the stationary anticyclones, over continents in winter. When the projected path points toward such anticyclones, it will usually be found that the speed of the cyclone center decreases and the path curves northward. This path will continue northward until it becomes parallel to the isobars around the quasi-stationary high. The speed of the center will be least where the curvature of the path is greatest. When the center resumes a more or less straight path, the speed again increases.

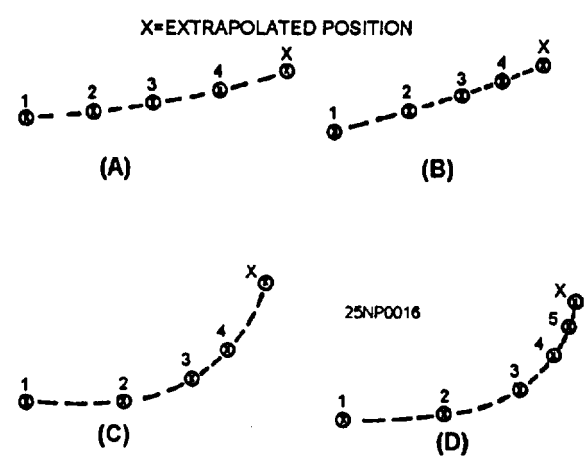

Figure 3-3.-Example of extrapolation procedure. X is the extrapolated position.

Isallobaric Indications

Lows tend to move toward the center of the largest 3-hour pressure falls. This is normally the point where the maximum warm air advection is occurring.

Figure 3-4 shows the movement of an occluding wave cyclone through its stages of development in relation to the surface pressure tendencies. This one factor cannot be used alone, but, compared with other indications, you may arrive at the final forecasted position of the lows. Too, you should remember that the process depicted in this illustration takes place over several days, and many other factors enter into the subsequent movement.

Circular, or nearly circular, cyclonic centers generally move in the direction of the greatest pressure falls. Anticyclone centers move in the direction of the greatest pressure rises.

Troughs move in the direction of the greatest pressure falls, and ridges move in the direction of the greatest pressure rises. See figure 3-5.

Relative to Warm Sector Isobars

Warm, unoccluded lows move in the direction of the warm sector isobars, if those isobars are straight. These lows usually have straight paths (fig. 3-6, view A), whereas old occluded cyclones usually have paths that are curved northward (fig. 3-6, view B). The speed of the cyclones approximates the speed of the warm air.

Whenever either of these rules is in conflict with upper air rules, it is better to use the upper air rules.

Relative to Frontal Movement

The movement of the pressure systems must be reconciled with the movement of the associated fronts if the fronts are progged independently of the pressure systems. Two general rules are in use regarding the relationship of the movement of lows to the movement of the associated fronts: First, warm core lows are steered along the front if the front is stationary or nearly so; and second, lows tend to move with approximately the warm front speed and somewhat slower than the cold front speed.

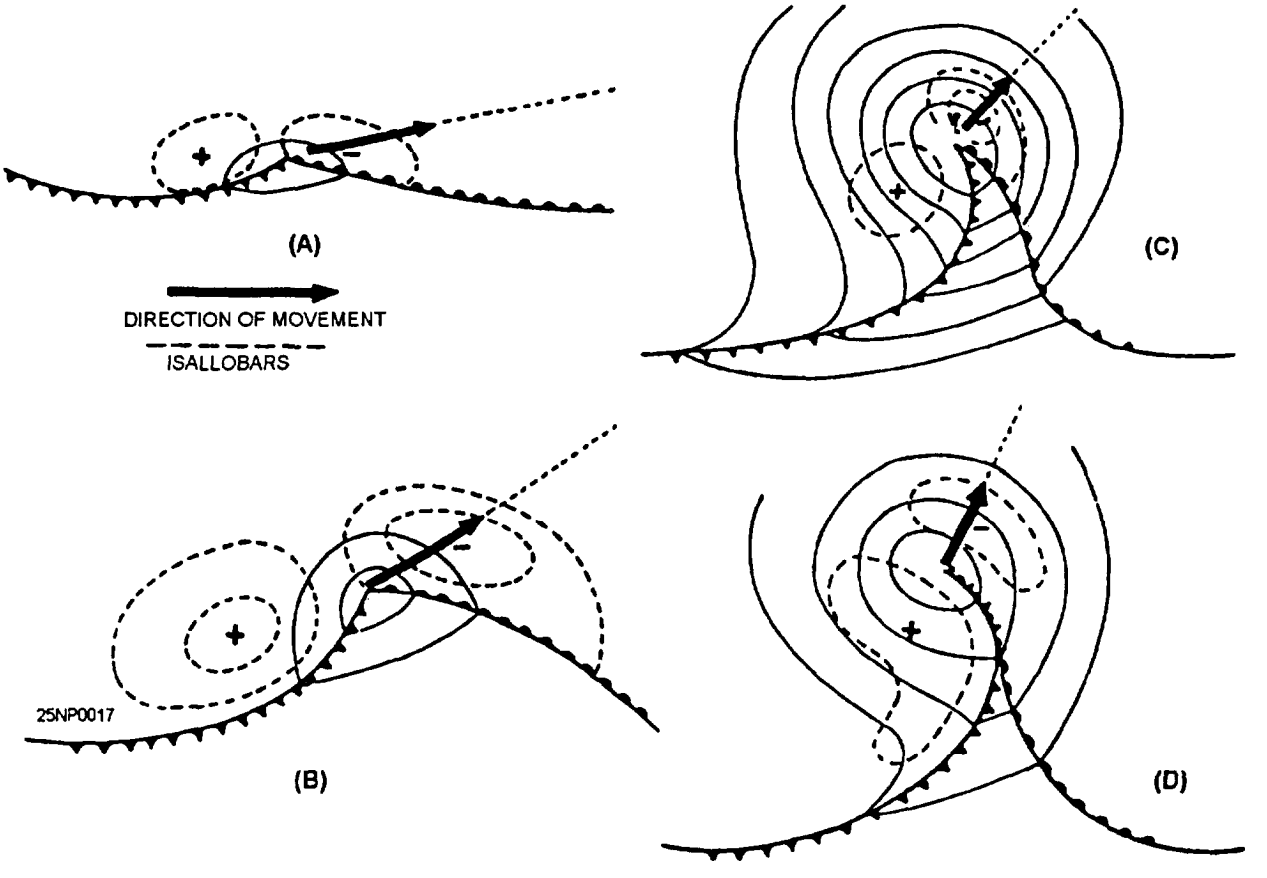

Figure 3-4.-Movement of occluding wave cyclone in relation to isallobaric centers.

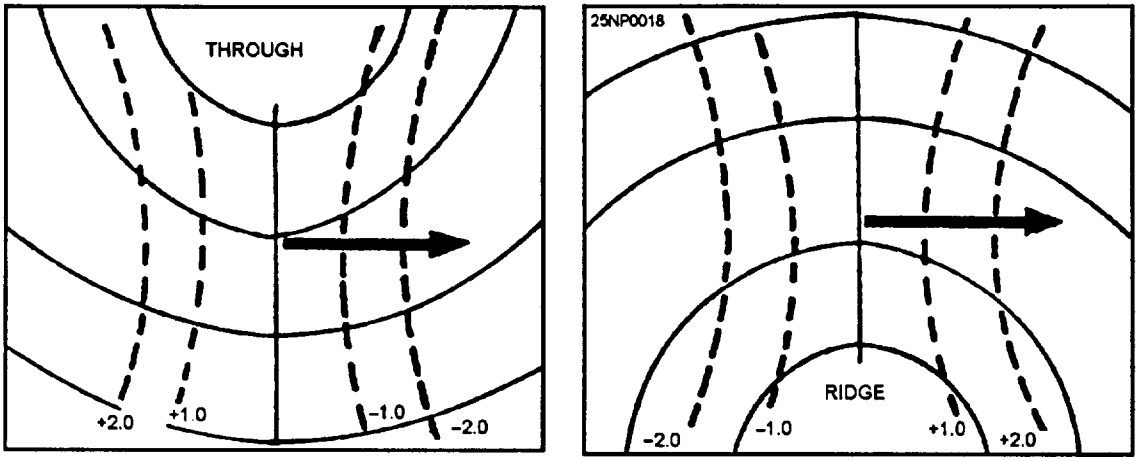

Figure 3-5.-Movement of troughs and ridges in relation to the isallobaric gradient.

Steering

Surface pressure systems move with the upper-level steering current. his principle is based on the concept that pressure systems are moved by the external forces operating on them. Thus, a surface pressure system tends to be steered by the isotherms, contour lines, or streamlines aloft, by the warm sector isobars, or by the orientation of a warm front. This principle is nearly always applied to the relationship between the velocity of a cyclone and the velocity of the basic flow in which it is embedded.

The method works best when the flow pattern changes very slowly, or not at all. If the upper flow pattern is expected to change greatly during the forecast period, you must first forecast the change in this pattern prior to forecasting the movement of the surface pressure systems. *Do not attempt to steer a surface system by the flow of an upper level that has closed contours above the surface system.* When using the steering method, you must first consider the systems that are expected to have little or no movement; namely, warm highs and cold lows. Then, consider movement of migratory highs and lows; and finally, consider the changes in the intensity of the systems.

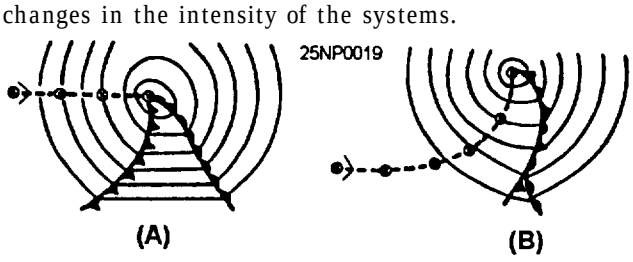

Figure 3-6.-Movement of lows in relation to warm sector isobars. (A) Movement of warm sector lows; (B) movement of old occluded cyclones.

Studies that used the steering technique have found, inmost cases, that there was a displacement of the lows poleward and the highs equatorward of the steering current. Therefore, expect low-pressure centers, especially those of large dimension, to be deflected to the left and high-pressure areas deflected to the right of a westerly steering current. Over North America the angle of deflection averages about 15°, although deviations range from 0° to 25° or even 30°.

CAUTION

The steering technique should not be attempted unless the closed isallobaric minimum is followed by a closed isallobaric maximum some distance to the rear of the low.

THE STEERING CURRENT.— The steering flow or current is the basic flow that exerts a strong influence upon the direction and speed of movement of disturbances embedded in it. The steering current or layer is a level, or a combination of levels, in the atmosphere that has a definite relationship to the velocity of movement of the embedded lower level circulations. The movement of surface systems by this flow is the most direct application of the steering technique. Normally, the level above the last closed isobar is selected. This could be the 700-, 500-, or 300-hPa level. However, in practice, it is better to integrate the steering principle over more than one level. The levels most often used are the 700- and 500-hPa levels.

For practical usage, the present 700- or 500-mb chart should be used in conjunction with the 24- or

36-hour prognostic charts for these levels. In this way, changes both in space and time can be considered. For a direct application for a short period of time, transfer the position of the low center to the concurrent 700-mb chart. For direction, move the center in the direction of the contours downstream and slightly inclined to the left for low-pressure areas. Experience with moving systems of this type will soon tell you how much deviation should be made. For speed of the surface cyclone, average the basic current downstream over which the cyclone will pass (take into consideration changes indirection and speed of flow over the forecast period). Take 70 percent of this value for the mean speed for 24 hours. Move the low center along the contours, as described above, for this speed for 24 hours. This should be your position at that time.

For the 500-mb chart, follow the same procedure, except use 50 percent of the wind speed for movement. If these two are not in agreement, take a mean of the two. There may be cases where the 500-mb chart is the only one used. In this case, you will not be able to check the movement against the 700-mb chart.

FORECASTING PRINCIPLES.— The following empirical relationships and rules should be taken into account when you use the steering technique:

- Warm, unoccluded lows are steered by the current at the level to which the closed low does not extend. When so steered, lows tend to move slightly to the left of the steering current.

- Warm lows (unoccluded) are steered with the upper flow if a well-defined jet is over the surface center or if there is no appreciable fanning of the contours aloft. Low-pressure systems, especially when large, tend to move slightly to the left of the steering current.

- Rises and falls follow downstream along the 500-hPa contours; the speed is roughly half of the 500-hPa gradient. The 3-hour pressure rises and pressure falls seem to move in the direction of the 700-hPa flow; while 24-hour pressure rises and pressure falls move with the 500-hPa flow.

- Cold lows, with newly vertical axes, are steered with the upper low (in the direction of upper height falls), parallel to the strongest winds in the upper low, and toward the weakest contour gradient.

- Occluded lows, the axes of which are not vertical, are steered partly in the direction of the warm air advection area.

- A surface low that is becoming associated with a cyclone aloft will slow down, become more regular, and follow a strongly cyclonic trajectory.

- Surface lows are steered by jet maximums above them, and deviate to the left as they are so steered. They move at a slower rate than the jet maximum, and are soon left behind as the jet progresses.

- During periods of northwesterly flow at 700 hPa from Western Canada to the Eastern United States, surface lows move rapidly from the northwest to the southeast, bringing cold air outbreaks east of the Continental Divide.

- If the upper height fall center (24 hour) is found in the direction in which the surface cyclone will move, the cyclone will move into the region or just west of it in 24 hours.

Direction of Mean Isotherms (Thickness Lines)

A number of rules have been compiled regarding the movement of low-pressure systems in relation to the mean isotherms or thickness lines. These rules are outlined as follows:

- Unoccluded lows tend to move along the edge of the cold air mass associated with the frontal system that precedes the low; that is, it tends to move along the path of the concentrated thickness lines. When using this method, you should remember that the thickness lines will change position during the forecast period. If there is no concentration of thickness lines, this method cannot be used.

- When the thickness gradient (thermal wind) and the mean windflow are equal, the low moves in a direction midway between the two. This rule is more reliable when both the thermal wind and the mean windflow are strong.

- When the menu windflow gradient is stronger than the thickness gradient, the low will move more in the direction of the mean windflow.

- When the thickness gradient is stronger than the mean windflow gradient, the low will move more in the direction of the thickness lines.

- With warm lows, the mean isotherms show the highest temperature directly over the surface low, which is about halfway between the 700-hPa trough and ridge line. This indicates the mean isotherm and 700-hPa isoheights are 90 degrees out of phase. Since warm

lows move with the mean speed of the warm air above them, they will be rapidly moving systems.

- If the highest mean temperatures occur under the 700-hPa ridge (isotherms and contours in phase), the ridge itself is warm while the low is cold; therefore, the low will move slowly.

- Lows move with a speed of approximately 50 percent of the thermal wind for the 1,000- to 500-hPa stratum, and approximately 75 percent of the thermal wind of the 1,000- to 700-hPa stratum.

Movement of Lows in Relation to the Jetstream

Some of the rules for moving lows in relation to the jetstream position were mentioned previously. One basic rule however, states that "highs and lows situated under or very near the jetstream behave regularly and follow the steering indications." Minimum deviations occur when the upper flow does not change with time.

Forecasting the Movement of Lows by Statistical Techniques

Since it requires many years of experience and a photographic memory to develop a mental catalog of weather patterns, a weather type or normal path classification is a boon to the inexperienced forecaster in identifying situations from the past for application to the present. There are many normal and average conditions to regulate behavior patterns of future movement and development. However, there are also many deviations from the norm. The season of the year and topographical influences are factors to be considered. If we could catalog weather types or average types, and the systems would obey these rules, it would greatly simplify the art of forecasting. However, as a rule, this does not occur. Use these statistical techniques, but do not rely too heavily on them.

Normal Tracks

In 1914, Bowie and Weightman published climatological tables of the average, by month, of the 24-hour speed and direction of cyclonic centers in the United States. The storms were classified with respect to the point of origin and the current location of the centers. Although these tables appear to be antiquated, some of them resemble relatively recent classifications; therefore, they are of some value to the present-day forecaster.

The *Marine Climatic Atlas also* contains average storm tracks for each month of the year for areas over the oceans of the world. Other publications are available that give average or normal tracks for other areas of the world.

Prediction of Maritime Cyclones

This method is an empirically derived method for objectively predicting the 24-hour movement and change in intensity of maritime cyclones. The technique requires only measurement of the 500-hPa height and temperature gradients above the current surface center, and determination of the type of 500-hPa flow within which the surface system is embedded. Full details of this method are described in The *Prediction of Maritime Cyclones,* NAVAIR 50-1P-545.

The deepening prediction should be made first, as this will often give a good indication of movement.

The explosive intensification of maritime cyclones is a fairly common phenomenon, but is presently among the most difficult problems to forecast. Conversely, there are many situations in which it is important to predict the rapid filling of cyclones. This technique gives an objective method for predicting the 24-hour central change in pressure of those maritime cyclones whose initial positions lie north of 30 degrees north latitude. Further, the technique applies to the winter months only (November through March), although it may be used with some degree of confidence in other months.

The following factors are considered the most important:

- The location of the surface cyclone center with respect to the 500-hPa pattern.

- The strength of the 500-hPa flow above the cyclone center.

- The 500-hPa temperature gradient to the northwest of the surface center.

Of the lows that deepened, the deepening was in general greater, the stronger the 500-hPa contour and isotherm gradient. The study also indicated that the preferred location for filling cyclones is inside the closed 500-hPa contours, and that deepening cyclones favor the region under open contours in advance of the 500-hPa trough. The remaining portions of the pattern indicate areas of relatively little change, except lows located under a 500-hPa ridge line fill.

MOVEMENT OF HGH-PRESSURE SYSTEMS

In general, the methods for extrapolation of low-pressure areas are applicable to the movement of high-pressure areas.

The following are general considerations in forecasting the movement of high-pressure systems:

- A surface high, or that portion situated under a blocking high aloft, remains very nearly stationary.
- A high situated under or very near a jetstream is steered by the current aloft.
- Cold, shallow highs are steered more easily than the larger ones. The Canadian and Siberian highs move little when there is no jet max in their vicinity or above them, and they move rapidly when the jet max is present.
- Progressive warm highs move with a speed consistent with that of the major ridges aloft.
- With straight westerly currents aloft, surface highs are displaced equatorward.
- Highs tend to move in the direction of, and with the speed of, the isallobaric centers; however, this rule is not very reliable because the isallobaric rises often follow the low rather than lead the high.

Steering is not used for high-pressure systems as widely as for lows because high-pressure cells do not have as great a vertical extent as low-pressure systems. However, steering seems to work about 75 percent of the time for cold highs.

FORECASTING THE INTENSITY OF SURFACE PRESSURE SYSTEMS

LEARNING OBJECTIVES: Forecast the intensity of surface low- and high-pressure centers by using extrapolation, isallobaric indications, relation to frontal movement, aloft indications, weather type, and in relation to normal storm tracks.

The changes in intensity of pressure systems at the surface are determined, to a large extent, by events occurring above the system.

EXTRAPOLATION

The 3-hour pressure tendencies reported in a synoptic plot indicate the sum of the pressure change due to movement of the system, plus that due to deepening and filling. If the exact amount of pressure change due to movement could be determined, it could be assumed that the system would continue to deepen or fill at that rate. However, it is not normally prudent to assume that the current rate of change will continue, nor just how much of the pressure change is due to movement.

ISALLOBARIC INDICATIONS

Isallobaric analyses at the surface show the following relationships between the isallobars and the change in intensity of pressure systems:

- When the 3-hour pressure falls extend to the rear of the low, the low is deepening.
- When the 3-hour pressure rises extend ahead of the low, the low tends to fill.
- When the 3-hour pressure rises extend to the rear of the high or ridge, the high or ridge tends to fill.
- Since low-pressure systems usually move in a direction parallel to the isobars in the warm sector, and since the air mass in the warm sector is homogeneous, it is possible to assume that the pressure tendencies in the warm sector are an indication of the deepening or filling of the system. The effects of frontal passages must be removed. Therefore, if a low moves parallel to warm sector isobars, the 3-hour pressure tendency in the warm sector is equal to the deepening or falling of the system.

Remember that when you use the present 3-hour pressure tendency values for any of the above rules, they arc merely an indication of what has been happening, and not necessarily what will be taking place in the future. Consequently, if you use the tendencies for indication of deepening or filling, you will need to study the past trend of the tendencies.

RELATIVE TO FRONTAL MOVEMENT

Wave cyclones form most readily on stationary or slow moving fronts. A preferred position is along a decelerating cold front in the region of greatest deceleration. Normally, the 700-hPa winds are parallel to the front along this area.

Under conditions characteristic of the eastern Pacific, a secondary wave cyclone may rapidly develop (fig. 3-7, step 1). As the secondary wave forms on the

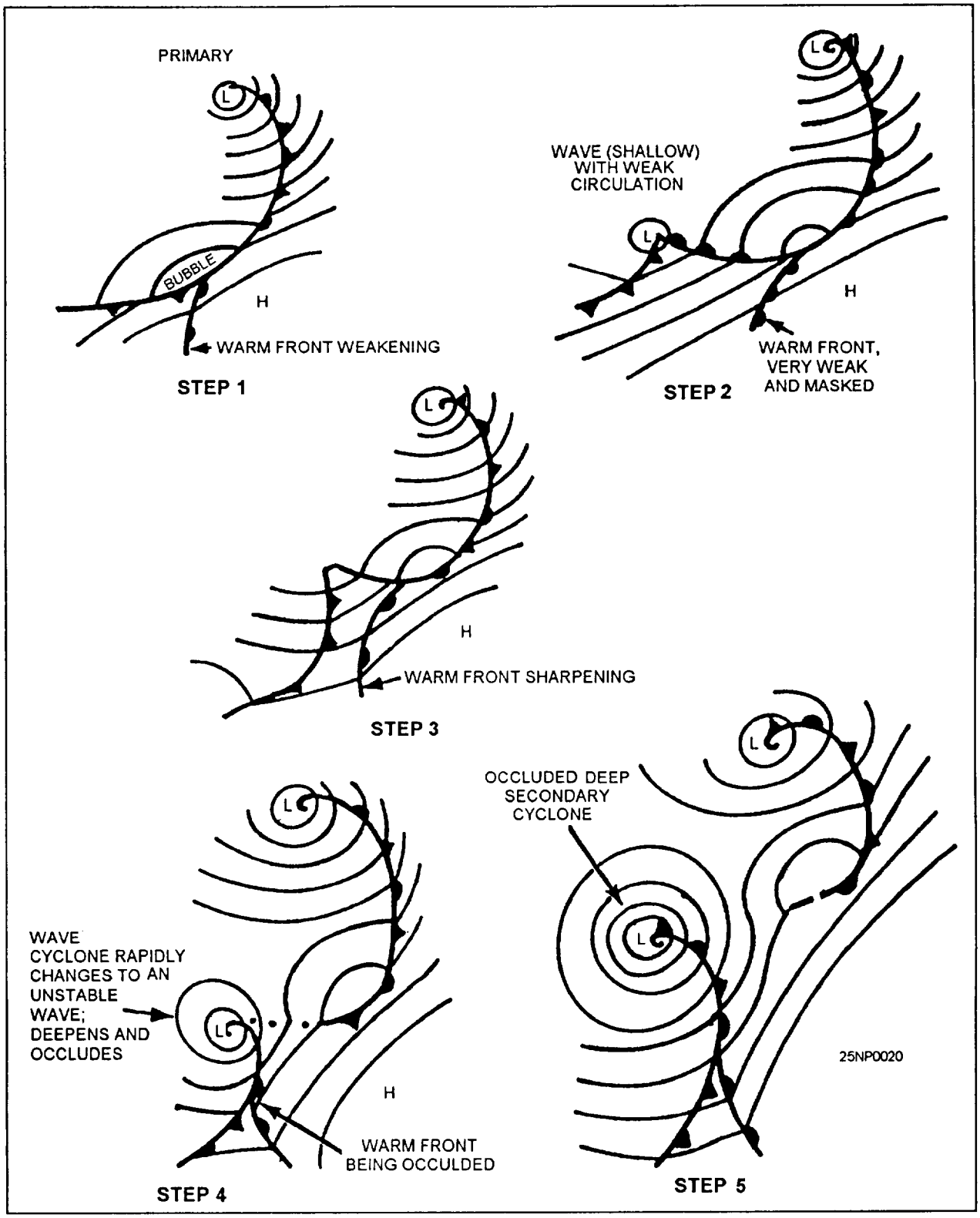

Figure 3-7.-Illustration of secondary cyclone development over the eastern Pacific.

retarded portion of the cold front, the original warm front associated with the primary cyclone tends to wash out, or become masked in the more or less parallel flow between the returning cold air from the high to the east and the original warm feeding current. In this stage of development, the new secondary wave cyclone is rapidly moving, but with no appreciable deepening as it moves along the front and few, if any, indications of occluding (fig. 3-7, step 2). As this new low moves eastward along the front, the pressure gradients

surrounding it will tighten and tend to intensify the old masked warm front (fig. 3-7, step 3). Later, as the wave moves rapidly eastward, it will pickup this intensified warm front and begin to occlude (fig. 3-7, step 4).

This occlusion deepens as much as 10 to 15 hPa in 12 hours. The resultant rapid deepening and increase in cyclonic circulation results in a portion of the original polar front discontinuity between the new and the old cyclone being washed out (fig. 3-7, step 5).

INDICATIONS ALOFT FOR DEEPENING AND FILLING OF SURFACE LOWS

There are numerous atmospheric factors aloft that affect the central pressure of surface lows. The following text discusses a few of these factors.

Temperature Advection Changes

The role of temperature advection in contributing to the pressure or height changes can be misleading. On the one hand, low-level (usually the 1,000- to 500-hPa stratum) warm air advection is frequently cited as responsible for the surface pressure falls ahead of moving surface lows (the converse for cold air advection); on the other hand, warm air advection is frequently associated with rising heights in the upper levels.

The pressure change at the SURFACE is equal to the pressure change at some UPPER LEVEL, plus the change in mass of the column of air between the two. That is, if the pressure at some upper level remains UNCHANGED and the intervening column is replaced with warmer air, the mass of the whole atmospheric column (and consequently the surface pressure) decreases, and so does the height of the 1,000-hPa surface.

As an example, assume that warm air advection is indicated below the 500-hPa surface (5,460 meters) above a certain station. If no change in mass is expected above this level, the height of the 500-hPa level (5,460 meters) will remain unchanged. Suppose the 1,000- to 500-hPa advection chart indicates that the 5,400-meter thickness line is now over the station in question and will be replaced by the 5,490-meter thickness line in a given time interval; that is, warm air advection of 90 meters. The consequence is that the 1,000-hPa surface, which is now 60 meters above sea level, will lower 90 meters to 30 meters below sea level, and the surface pressure will decrease a corresponding amount, about 11 hPa (7.5 hPa approximately equals 60 meters). Whenever the surface pressure is less than 1,000 hPa, the 1,000-hPa surface is below the ground and is entirely fictitious. In view of the above description of advective temperature changes, the following rules may apply:

- Warm air advection between 1,000 and 500 hPa induces falling surface pressures.

- Cold air advection between 1,000 and 500 hPa induces rising surface pressures.

Indications of Deepening From Vorticity

Cyclogenesis and deepening are closely related to cyclonic flow or cyclonic vorticity aloft If you recall from the discussion of vorticity in chapter 1, vorticity is the measure of the path of motion of a parcel plus the wind shear along the path of motion. Thus, we have the following rules for the relationship of vorticity aloft to the deepening or falling of surface lows:

- Increasing cyclonic (positive) relative vorticity induces downstream surface pressure falls.

- Increasing antic cyclonic (negative) relative vorticity induces downstream surface pressure rises.

- A wave will be unstable and deepen if the 700-hPa wind field over it possesses cyclonic relative vorticity.

- A wave will be stable if the 700-hPa wind over it possesses anticyclonic vorticity.

- If there are several waves along a front, the one with the most intense cyclonic vorticity aloft will develop at the expense of the others. This is usually the one nearest the axis of the trough.

Deepening of Lows Relative to Upper Contours

The amount of deepening of eastern United States lows moving northeastward into the Maritime Provinces of Canada frequently can be predicted by estimating the number of contours at the 200- or 300-hPa level that would be traversed by the surface low during the forecast period. For a close approximation, multiply the 200-hPa current height difference in *tens of meters* by 3/4 to obtain the surface pressure change in hectopascals. For example: a 240-meter height difference at 200 hPa results in a pressure change of 18 hPa at the surface.

$$24 \times 3/4 = 18 \text{ hPa pressure change}$$

If FALLING heights are indicated aloft, the AMOUNT of fall need not be estimated. The deepening of the surface low and greater advective cooling, associated with the occlusion process, appear to compensate for the upper height falls.

If FUSING heights are indicated aloft over the expected low position, the AMOUNT MUST BE ESTIMATED to determine the ACTUAL height difference to which the rule will apply. In some cases the height rises aloft over the expected position of the low may be quite large, indicating the development of a high-latitude ridge aloft, which tends to block the eastward progress of the low. This may result in rapid deceleration of the low, with falling and/or recurvature to the north. In such a case, the forecast position of the low is revised in light of the changing circulation aloft.

The above technique works *only* when lows are expected to move northeastward out of a heat source, such as the Southern Plains. When a low moves into the Southern Plains from the west or northwest, there is frequently no accompanying cooling in the low troposphere, since the low is moving toward the heat source.

Some rules for the falling and deepening of surface lows in relation to upper contours areas follows:

- Filling is indicated when a surface low moves into or ahead of the major ridge position of the 500-hPa level.

- Surface lows tend to fill when the associated upper-level trough weakens.

- Surface lows tend to fill when they move toward values of higher thickness lines.

- When the associated upper trough deepens, the surface low also deepens.

- Surface lows deepen when they move toward lower thickness values.

- Waves develop along fronts when the 700-hPa windflow is parallel to the front, or nearly so.

- During periods of southerly flow at 700 hPa along the east coast of the United States, secondary storms frequently develop in the vicinity of Cape Hatteras.

High Tropospheric Divergence in Developing Lows

In the case of developing (dynamic) cyclones, horizontal divergence is at a maximum in the 400- to 200-hPa stratum, and the air above must sink and warm adiabatically to maintain equilibrium. See figure 3-8.

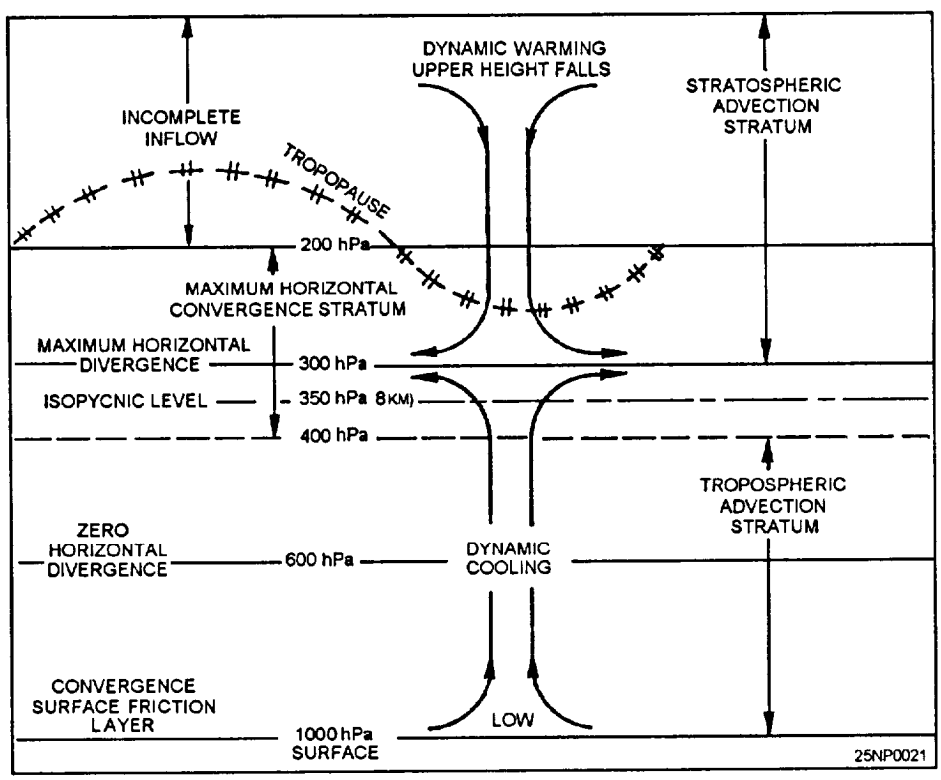

Figure 3-8.-Vertical circulation over developing low.

Using the Current 500-hPa Chart

In the deepening of lows there must be removal of air at high levels due to divergence in the 400- to 200-hPa stratum, resulting in stratospheric warming. Insufficient inflow at very high levels to compensate the subsidence results in 500-hPa contour falls.

This is roughly the mechanism thought to be responsible for the development of low-pressure systems. The high-level decrease in mass overcompensates the low tropospheric increase in density; the high-level effect thus determines the reduction of pressure at the surface when lows are intensifying.

Stratospheric and Upper Tropospheric Decrease in Mass

The chief cause of deepening lows is the decrease in mass in the upper troposphere and the lower stratosphere. With rapidly deepening lows, it is known that the change in mass in the stratosphere contributes as much to the local surface pressure change as do the tropospheric changes in density, if not more. Warming is frequently observed in the stratosphere over deepening surface lows, pointing to subsidence in the lower stratosphere. This warming is accompanied by lowering heights of constant pressure surfaces in the lower stratosphere, indicating a decrease in mass at high levels. See figure 3-8.

Deepening, to a large extent is controlled by mass changes in the upper atmosphere. For example, it has been shown that the lower two-thirds (below about 300-hPa level) of the central column become colder and denser as the areas of low pressure deepen, while the upper one-third of the column becomes warmer. The upper mass decreases by an amount sufficient to counteract the cooling in the lower layers, plus an additional amount to deepen the low. The preferred region for deepening of lows is in the top third of the atmospheric column or, roughly, the stratosphere. See figure 3-8.

Using Facsimile and NODDS Products

Facsimile and NODDS products currently contain prognostic 500 mb, 1000- to 500-mb thickness, and 500-mb vorticity charts. These charts can be used in making predictions of advective changes, thickness patterns, and subsequent changes to the surface pattern.

DEEPENING OF LOWS RELATIVE TO WEATHER TYPES

Weather types were discussed previously under the section Movement of Low-Pressure Systems. This method can also be used to forecast changes in intensity of pressure systems, as each system or type has its own average movement plus average deepening or filling.

DEEPENING OF LOWS IN RELATION TO NORMAL STORM TRACK

Lows whose tracks deviate to the left of the normal track frequently deepen. In general, the normal track of a low is parallel to the upper flow. If a low deviates to the left of normal, it crosses upper contours (assuming an undisturbed upper current) and becomes superimposed by less mass aloft, resulting in deepening of the low. As long as this crossing of upper contours is unaccompanied by sufficient compensatory cooling at the surface low center, the system will deepen.

RELATION BETWEEN DEEPENING LOWS AND MOVEMENT

There is little basis for the rule that deepening storms move slowly and tilling storms move rapidly. The speed of movement of a low, whatever its intensity, is dependent upon the isallobaric gradient and other factors. The magnitude of the surface isallobaric gradients depends upon the low-level advection, the magnitude of the upper-level height changes, and the phase relation between the two levels.

FORECASTING THE INTENSITY OF SURFACE HIGHS

The following section will deal with atmospheric factors aloft and how they affect surface anticyclogenesis. This section will also discuss rules for forecasting the intensity of surface highs.

Anticyclogenesis Indicators

In the case of developing dynamic anticyclones, cooling takes place at about 200 hPa and above. This cooling is due to the ascent of air, resulting from convergence in the 400- to 200-hPa stratum. Incomplete outflow at very high levels causes piling up of air above fixed upper levels, resulting in high-level pressure rises. At the same time, warming occurs in the lower troposphere. This warming sometimes occurs very rapidly in the lower troposphere above the surface

levels, which may remain quite cold. A warming of 10°C per day at the 500-hPa level is not unusual. Such a rate of warming is not entirely due to subsidence but probably has a considerable contribution from warm advection. However, continuity considerations suggest that the convergence in the 400- to 200-hPa stratum produces some sinking and adiabatic warming in the lower troposphere. See figure 3-9.

Thus, in the building of anticyclones, there must be a piling up of air at high levels due to horizontal velocity convergence in the 400- to 200-hPa stratum, which results in the stratospheric cooling observed with developing anticyclones. Insufficient outflow at very high levels results in an accumulation of mass. This is roughly the mechanism thought to be responsible for the development of high-pressure systems. The high-level increase of mass overcompensates the low tropospheric decrease of density, and the high-level effect thus determines the sign of increase of pressure at the surface when highs are intensifying. See figure 3-9.

The development of anticyclones appears to be just the reverse of the deepening of cyclones. Outside of cold source regions, and frequently in cold source regions, high-level anticyclogenesis appears to be associated with an accumulation of mass in the lower stratosphere accompanied by ceding. In many cases this stratospheric cooling maybe advective, but more frequently the cooling appears to be clearly dynamic; that is, due to the ascent of air resulting from horizontal convergence in the upper troposphere.

Studies of successive soundings accompanying anticyclogenesis outside cold source regions show progressive warming throughout the troposphere. This constitutes a negative contribution to anticyclogenesis. In other words, outside of cold source regions, during anticyclone development, the decrease in DENSITY in the troposphere is overcompensated by an increase in

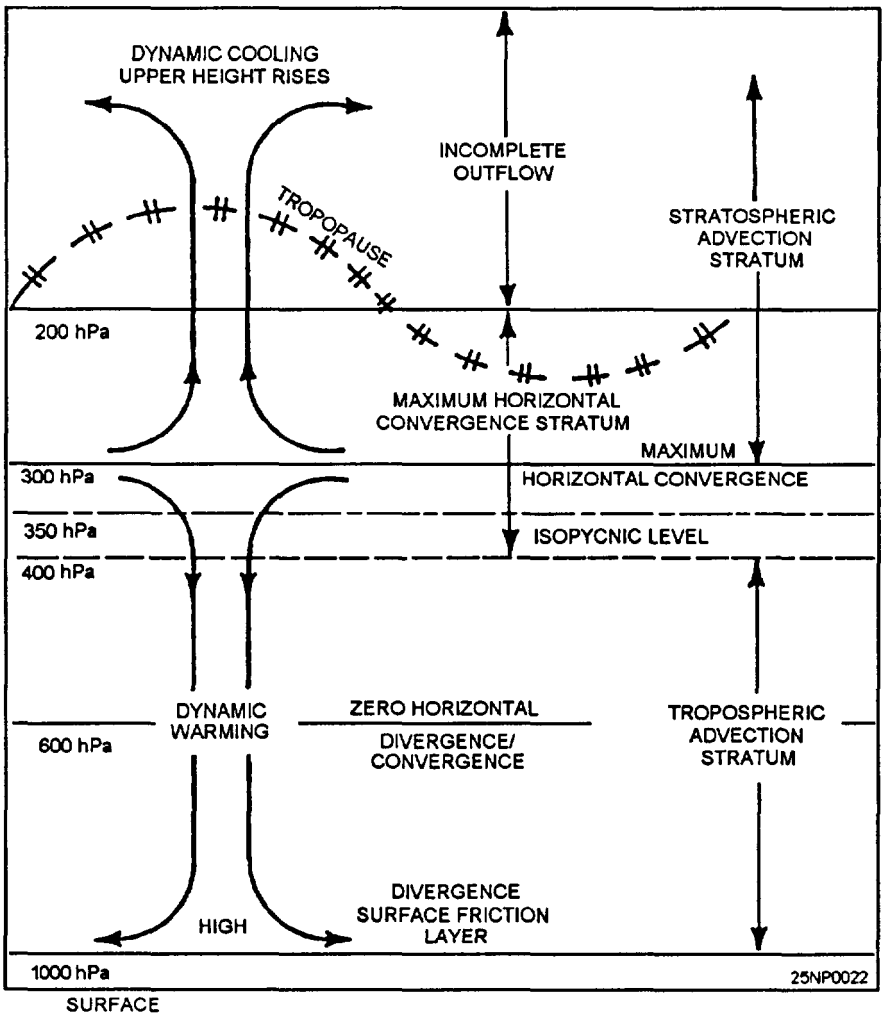

Figure 3-9.-Vertical circulation over developing high.

mass, and generally accompanied by cooling in the stratosphere. This is analogous to the deepening of lows where the decrease in mass, generally accompanied by warming at high levels, overcompensates the cooling in the troposphere.

The evidence, therefore, indicates that high-level changes, undoubtedly due to dynamic mechanisms in the upper troposphere, are largely responsible for deepening and filling of surface pressure systems. This fact is of considerable prognostic value if the dynamic processes that induce these mass and density changes can be detected on the working charts.

Rules for Forecasting the Intensity of Highs

The following rules are for forecasting the intensity of surface highs:

- Intensification of surface highs is indicated, and should be forecasted, when cold air advection is occurring in the stratum between 1,000 hPa and 500 hPa when either no height change is occurring or forecasted at 500 hPa, when convergence is indicated at and above 500 hPa or both, and when the cold advection is increasing rapidly. A high also intensifies when the 3-hour pressure tendency rises are occurring near the center, and in the rear quadrants of the high. When a moving surface high that is not subjected to heating from below is associated with a well-defined upper ridge, the change in intensity is largely governed by changes in intensity of the upper-level ridge.

- Weakening of surface highs is indicated and should be forecasted when the cold air advection is decreasing, or is replaced by warm air advection in the lower tropospheric stratum, with either no height change at 500 hPa or when divergence is occurring or forecasted at and above 500 hPa, or when both are occurring at the same time.

- When warm air and low tropospheric advection is coupled with convergence aloft, or when cold air and low tropospheric advection is coupled with divergence aloft, the contribution of either maybe canceled by the

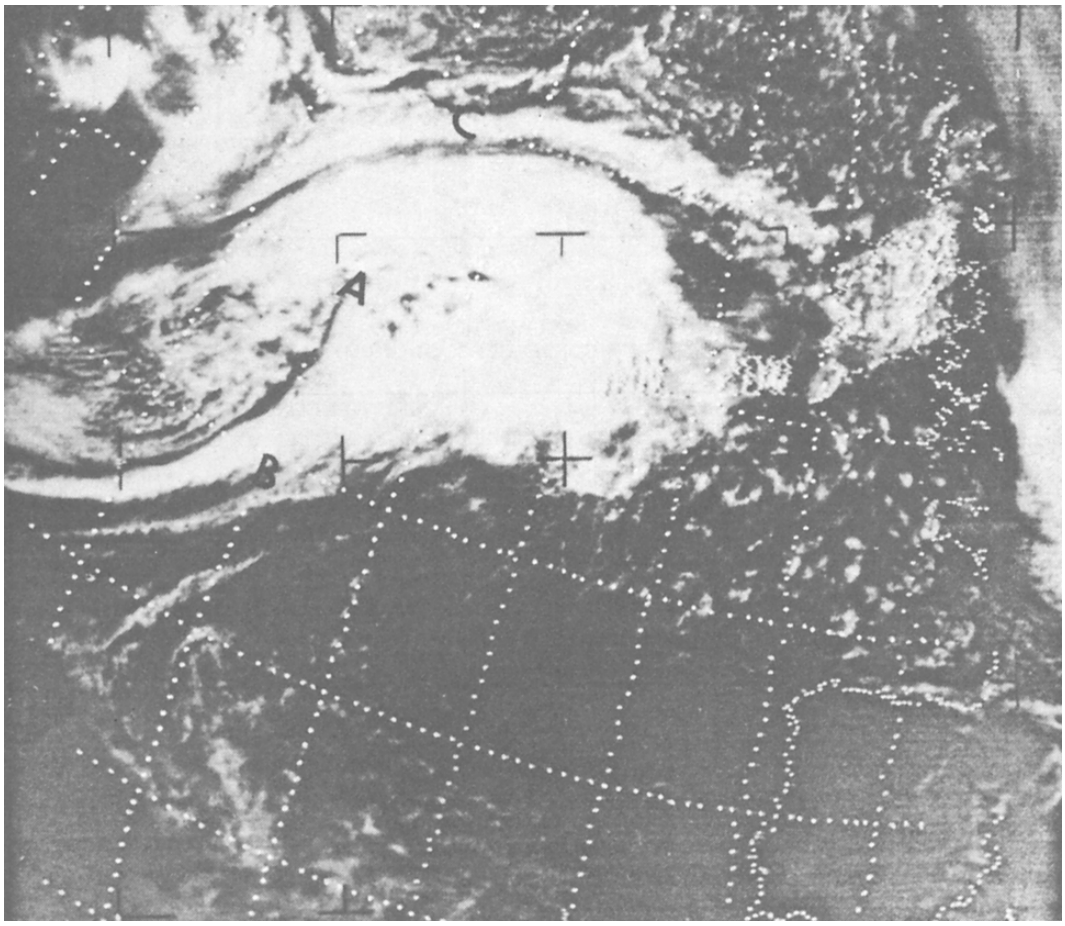

Figure 3-10.—Visual, local noon, first day.

other. An estimate of the effects of each must be made before a decision is reached.

- When surface pressure falls occur near the center and in the forward quadrants of the high, the high will weaken.

- When a cold high that is moving southward is being heated from below, it will weaken, unless the heating is compensated by intensification of the ridge aloft. The amount of intensification can be determined by correlating the contributions of height change at the 500-hPa level as progged and the change in thickness as advected.

SATELLITE IMAGERY

The *AG2* TRAMAN, volume 1, provides a detailed discussion of satellite imagery analysis. It may be beneficial to review Unit 10 before you read this chapter.

Satellite imagery provides the forecaster with an aid in forecasting the deepening of surface low-pressure systems. In the following series of illustrations, both visual and infrared imagery depicts the cloud features over a 60-hour period during the deepening of a low-pressure system. See figures 3-10 through 3-15.

In figure 3-10, the visual pass at noon local time shows a large cloud mass with a low level vortex centered near A. A frontal band, B, extends to the southwest from the large cloud mass. The beginning of a dry tongue is evident. An interesting cloud band, C, which appears just north of the cloud mass, is of about the same brightness as the major cloud mass.

The infrared scan for midnight, figure 3-11, shows the further development of the vortex with penetration of the dry tongue. Low-level circulation is not visible, but the brightness (temperature) distribution differs from the visual picture. The detail within the frontal band is apparent, with a bright cold line, DE, along the upstream edge of the band. In all probability, this is the cirrus generated by the convection near the polar jetstream. The cloud band, C, from the previous (daylight) picture is seen in the IR, and is composed of lower clouds than would be anticipated from the video.

By the second noon (fig. 3-12), the vortex is clearly defined, but again the spiral arm of the frontal band is nearly saturated, with a few shadows to provide detail on cloud layering. The National Meteorological Center (NMC) operational surface analysis during this period shows that the cyclone has deepened.

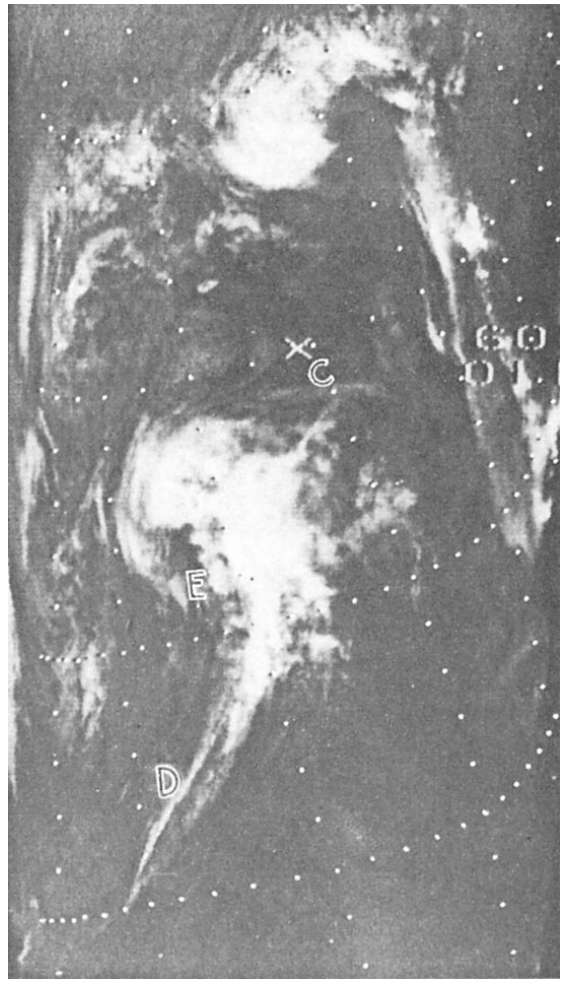

Figure 3-11.-Infrared, local midnight, first night.

In figure 3-13, the pass for the second midnight shows the coldest temperatures form a hooked-shaped pattern with the highest cloudiness still equatorward of the vortex center at F. The granular gray-to-light-gray temperature within the dry tongue area, G, suggests cells that consist of cumulus formed from stratocumulus, and small white blobs indicating cumulus congestus.

The visual pass for the third noon (fig. 3-14) shows the vortex to be tightly spiraled, indicating a mature system. The frontal band is narrower than it was 24 hours earlier, with some cloud shadows present to aid in determining the cloud structure. Surface analysis indicates that the lowest central pressure of the cyclone was reached approximately 6 hours prior to this picture.

The final pass in this series (fig. 3-15) shows the coldest temperatures completely surround the vortex. The frontal band also shows the segmented nature of the active weather areas within the band. A typical vorticity

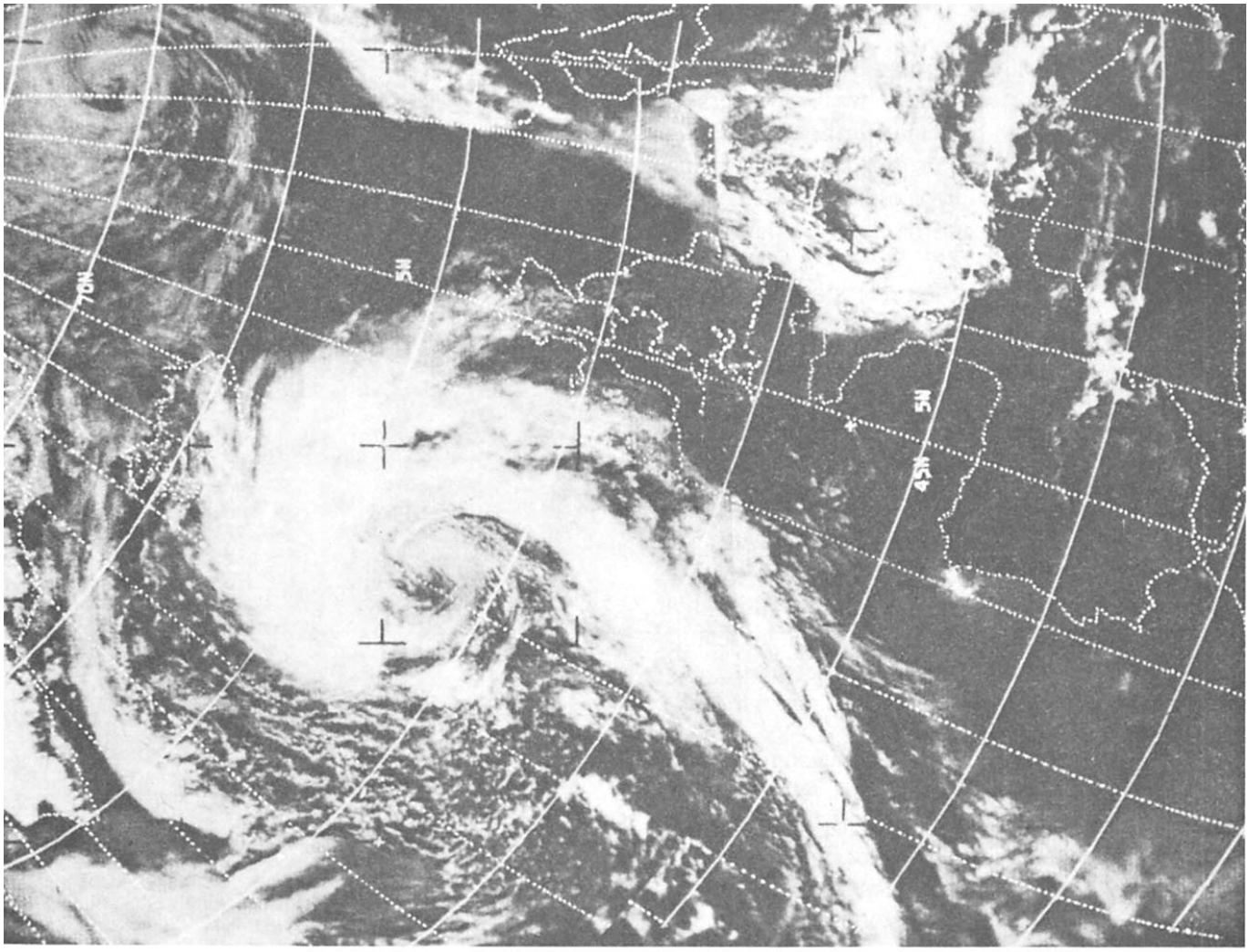

Figure 3-12.-Visual, loud noon, second day.

center at H shows the cold temperatures of cumulus congestus and cumulonimbus cloud tops. The same vorticity center is apparent in the previous (daylight) picture (fig. 3-14) west of the frontal blind.

SATELLITE IMAGERY PRINCIPLES

The forecaster may use the following general conclusions in adapting satellite imagery to forecasting the change in intensity of surface cyclones:

- The use of nighttime IR data together with daytime data yields 12-hour continuity with respect to cyclone development or decay.

- A hook-shaped cloud mass composed of cold temperatures, (high cloud tops) indicates an area of strong upward vertical motion with attendant surface pressure falls.

- As the dry tongue widens, the cyclone continues to deepen.

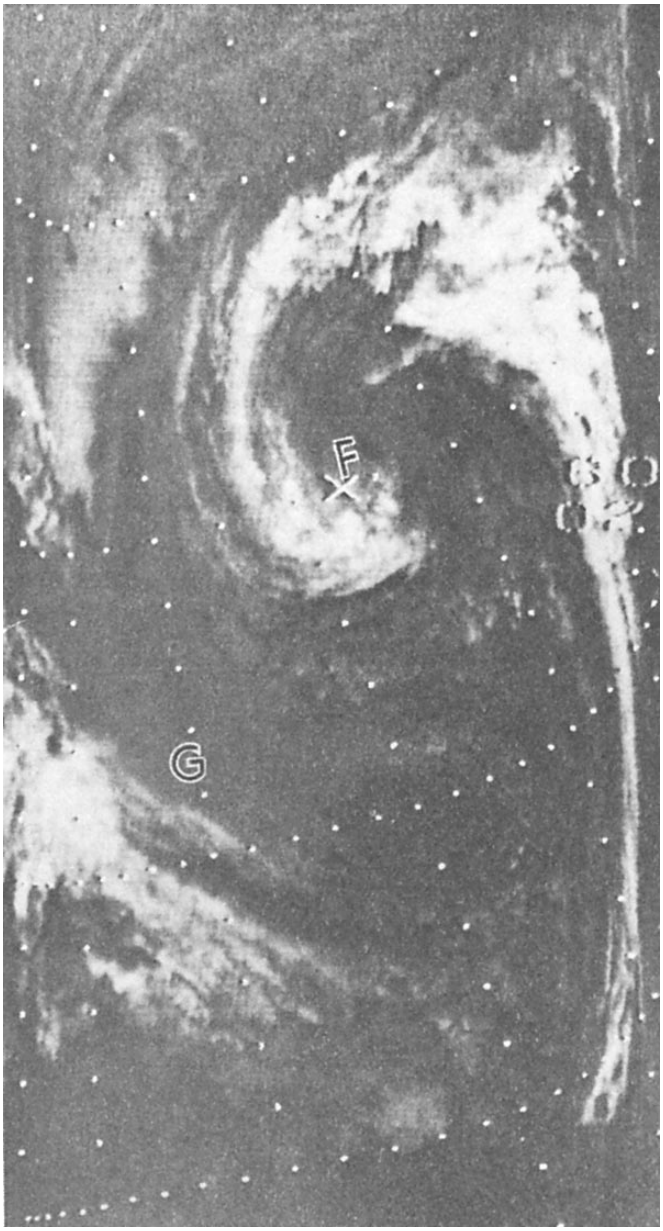

Figure 3-13.-Infrared, local midnight, second day.

- When high or middle clouds completely surround the vortex center, the cyclone has reached maturity and can be expected to fill. This generally indicates the advection of cold, dry air into the cyclone has ceased.

FORECASTING THE MOVEMENTS AND INTENSITY OF FRONTS

LEARNING OBJECTIVES Forecast the movement and intensity of fronts by using extrapolation and the geostrophic wind method.

The following text discusses various rules for the movement of fronts, as well as the effects upper air features have on fronts.

MOVEMENT OF FRONTS

Fronts are ordinarily forecasted after the pressure systems have been forecasted. However, there may be cases for short-range forecasting where movement of all of the systems is unnecessary. Extrapolation is perhaps the simplest and most widely used method of moving fronts for short periods. When moving fronts for longer periods, other considerations must be taken into account.

The following text discusses a simple extrapolation method, as well as the geostrophic wind method, and considerations based on upper air influences.

Extrapolation

When fronts are moved by extrapolation, they are merely moved based on past motion. Of course such factors as occluding, frontogensis, frontolysis, change in position, intensity of air masses and cyclones, and orographic influences must be taken into account. Adjustments to the extrapolation frontal positions are made on the basis of the above considerations.

You should keep in mind that the adjacent air masses and associated cyclones are the mechanisms that drive the fronts.

You should also keep in mind the upper air influences on fronts; for example, the role the 700-hPa winds play in the movement and modification of fronts. Finally, you should remember that past motion is not a guarantee of future movement, and the emphasis should be on considering the changes indicated, and incorporating these changes into an extrapolated movement.

Geostrophic Wind Method

Frontal movement is forecasted by the geostrophic wind at the surface, and at the 700-hPa level at several points along the front. The basic idea is to determine the component of the wind at the surface and aloft, which is normal (perpendicular) to the front and, therefore, drives the front. Determination of the component normal to the front is made by triangulation.

THE PROCEDURE.— The steps are as follows:

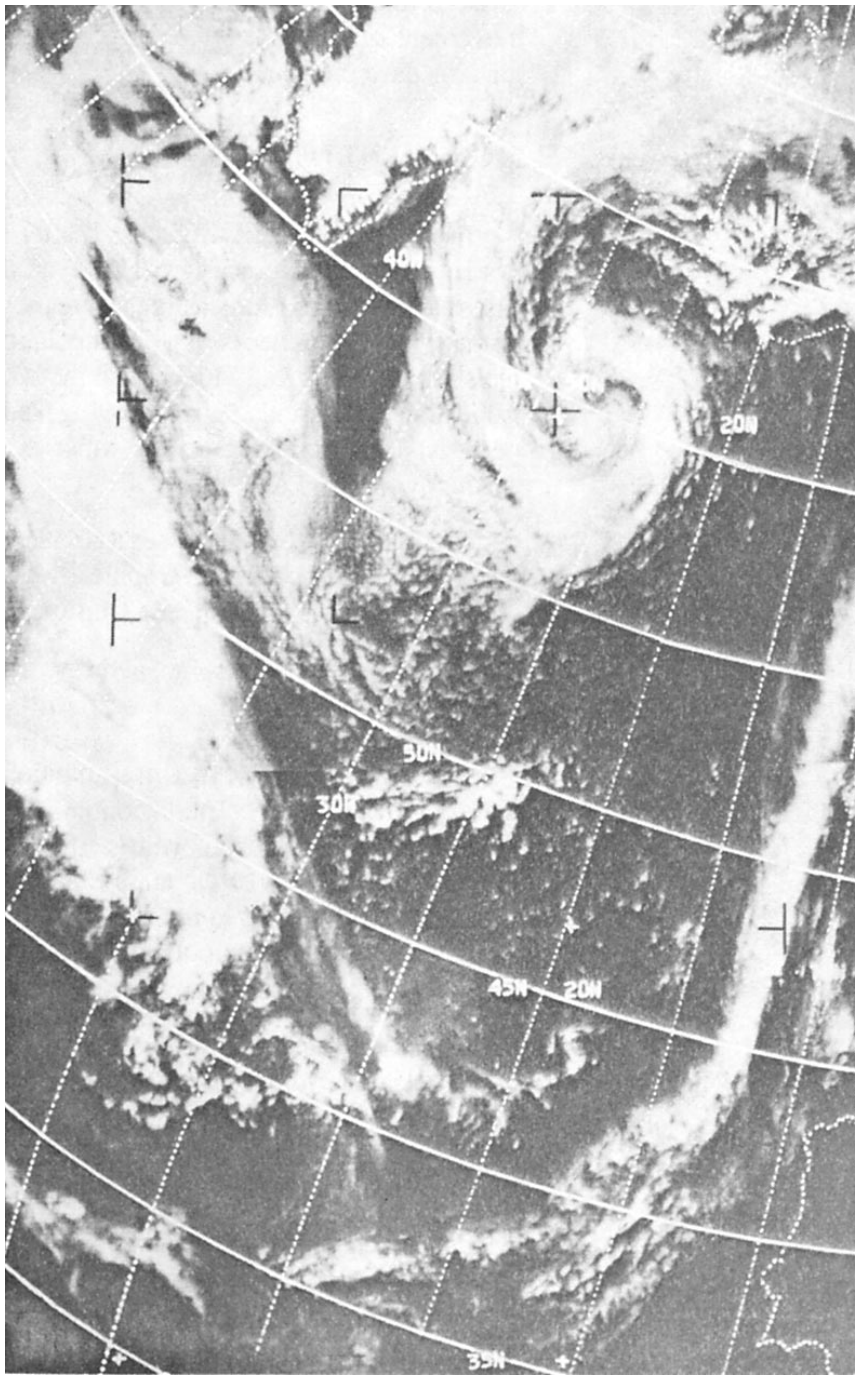

Figure 3-14.-Visual, local noon, third day.

1. Select two to four points along the front where a regular and reliable pressure gradient exists, and determine the geostrophic wind by use of the geostrophic wind scale. (**NOTE**: Do not use the observed wind.) The wind speed should be determined a short distance behind a cold front and a short distance ahead of the warm front where a representative gradient can be found. The points on the isobars in figure 3-16 serve as a guide to the proper selection of the geostrophic wind measurements.

2. Draw a vector toward the front, parallel to the isobars from where the geostrophic wind was determined. The vectors labeled "y" in figure 3-16 illustrate this step.

3. Draw a vector perpendicular to the front originating at the point where the "y" vector intersects the front, and label this vector "x," as illustrated in figure 3-16.

4. At a convenient distance from the intersection, along the "x" vector, construct a perpendicular to the "x"

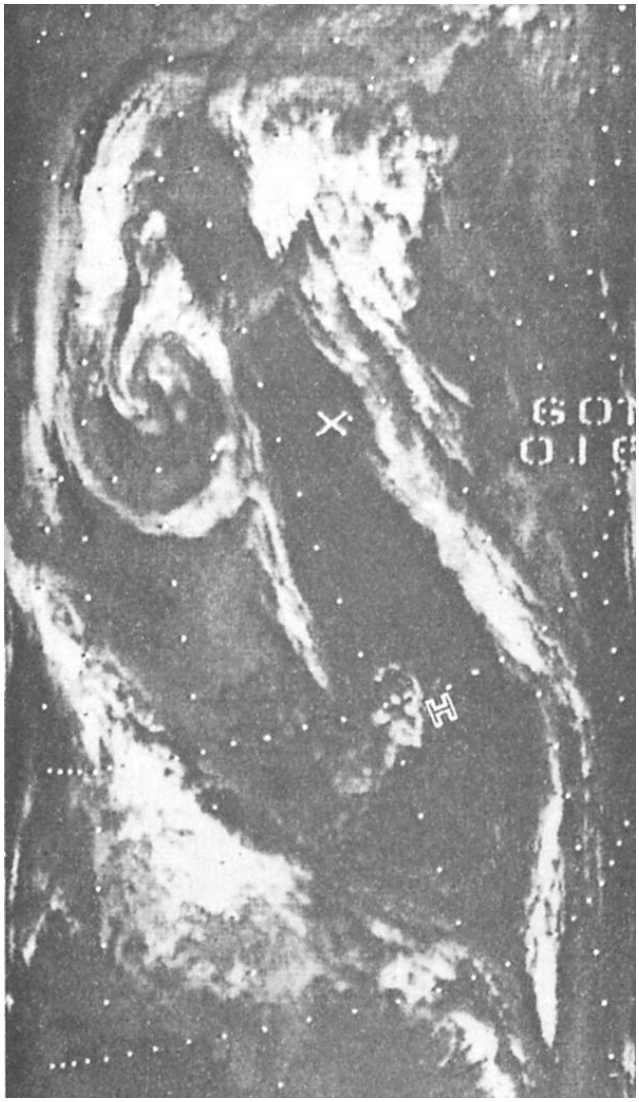

Figure 3-15.-Infrared, local midnight, third night.

vector, letting it intersect the “y” vector. This is line c in figure 3-16.

5. The angle formed at the intersection of the “y” vector and the perpendicular originating from the “x” vector is labeled θ (theta). Measure angle θ to the nearest degree with a protractor, and determine the value of its sine by using trigonometric tables or a slide rule.

6. Let side a of the right triangle formed in step 4 represent the value of the geostrophic wind obtained in step 1, and call it “Cgs.” Solve the triangle for side b by multiplying the sine of θ by the value of Cgs. The resulting value of b is the component of the wind normal to the front, giving it its forward motion. The formula is

$$b = Cgs \times \sin \theta$$

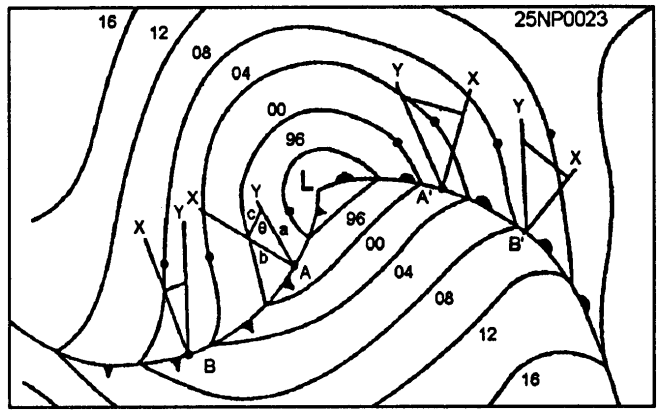

Figure 3-16.-Geostrophic wind method.

In the sample problem, if the Cgs was determined to be 25 knots and angle θ to be 40°, b is 19.1 knots, since the sine of angle θ is 0.643.

As you can see, the components normal to the front should be equal on both sides of the front, and that in reality, it would matter very little where the component is computed in advance of or to the rear of the front. In cold fronts the reason that the component to the rear is chosen is that this flow, as well as this air mass, is the flow supplying the push for the forward motion. In the case of a warm front, the receding cold air mass under the warm front determines the forward motion, because the warm air mass is merely replacing the retreating cold air, not displacing it.

OTHER CONSIDERATIONS.— The foregoing discussion neglected to discuss the effects of cyclonic and anticyclonic curvature on the isobars, and the effect of vertical motion along the frontal surfaces. The upslope motion along the frontal surfaces reduces the effective component normal to the front. Furthermore, the cyclonic curvature in the isobars indicates convergence in the horizontal and divergence in the vertical, further reducing the effective component normal to the front. For these reasons, the component normal to the front is reduced at the surface only by the following amounts for the different types of fronts and isobaric curvature:

Slow moving cold front,
anticyclonic curvature 0%

Fast moving cold front,
cyclonic curvature 10-20%

Warm front 20-40%

Warm occluded fronts 20-40%

Cold occluded fronts 10-30%

- If the pressure gradient is forecast to increase, decrease the component by the least percentage.

- If the pressure gradient is forecast to decrease, decrease the component normal to the front by the highest percentage value.

- If the pressure gradient is forecast to remain static, decrease the component normal to the front by the middle percentage value as listed above.

Upper Air Influences on the Movement of Surface Fronts

A number of the rules relating the upper air contours to the movement of fronts were discussed in the AG2 TRAMAN, volume 1. You saw that a slow moving cold front has parallel contours behind the front, and in a fast moving cold front, the contours were at an angle to the front, and at times normal to the front.

Some additional rules are stated below:

- During periods of strong, continued westerly flow aloft (high index) over North America, surface fronts move rapidly eastward. A rule of thumb, the front will move eastward at a speed that is 50 percent of the 500-hPa flow and 70 percent of the 700-hPa flow.

- Cold fronts associated with cP outbreaks are closely dependant on the vertical extent of the northerly winds. The following relationships are evident: For cP air to push southward into the Great Basin from British Columbia, strong northerlies must exist to at least 500 hPa over the area; for cP air to push southward into the Gulf of Mexico, northerly and/or northwesterly winds must extend, or be expected to extend, to at least 500 hPa as far south as Texas; for cP air to push southward over Florida to Cuba, northerlies must extend to at least 500 hPa as far south as the Gulf States.

FORECASTING THE INTENSITY OF FRONTS

The following text deals with the forecasting of the intensity of fronts, as well as indicators of frontogenesis and frontolysis.

Frontogenesis

Surface fronts generally intensify when one of the following three conditions and/or combination occurs:

1. The mean isotherms (thickness lines) become packed along the front.

2. The fronts approach deep upper troughs.

3. Either or both air masses move over a surface that strengthens their original properties.

Frontogenesis occurs when two adjacent air masses exhibit different temperatures and density, and prevailing winds bring them together. This condition, however, is the normal permanent condition along the polar front zone; therefore, the polar front is semipermanent.

Generation of a new front, or the intensifying of an existing front, occurs during the winter months along the eastern coasts of the American and Asian Continents. During this time the underlying surface (ocean) is much warmer than the overlying air mass.

Frontolysis

Weakening or dissipation of fronts occurs when:

- The mean isotherms become more perpendicular to the front or more widely spaced.
- The surface front moves out ahead of the associated pressure trough.
- Either or both air masses modify.
- The front(s) meet with orographic barriers.

FORECASTING ISOBARIC CONFIGURATION

LEARNING OBJECTIVES: Evaluate isobaric configuration in preparation of surface charts.

Isobars may be constructed on the surface prognosis either by computing the central pressures for the high and low centers and numerous other points on the surface prognosis chart and drawing the isobars, or by moving the isobars in accordance with the surface pressure 3-hour tendencies and indications.

A thickness prognosis is used in constructing the isobaric configuration on your forecast. The steps for constructing forecasted isobaric configuration by using the thickness chart are as follows:

1. At a selected point, determine the difference between the present 500-hPa height and the forecasted 500-hPa height. A forecasted rise at the 500-hPa level is positive; a forecasted fall is negative.

2. At the same selected point, determine the difference between the current and the forecasted thickness value.

3. Algebraically subtract the difference of the forecasted thickness value from the forecast difference of the 500-hPa level.

4. Convert this difference in meters to hectopascals by using the expression 60 meters equal 7 1/2 hPa. Be sure to assign the proper sign.

5. Add (or subtract if the value is negative) this value to the current sea level pressure. This is the progged sea-level pressure.

6. Repeat steps 1 through 5 for all the points selected, and sketch the isobars.

EXTENDED WEATHER FORECASTS

LEARNING OBJECTIVES: Recognize the need for extended weather forecasts.

While most routine forecasting does cover a short period of time, generally 12 to 36 hours, the forecaster will, upon occasion, be required to provide outlooks for extended periods of up to 7 days or longer.

Fleet Numerical Meteorology and Oceanography Center (FNMOC) and the National Weather Service prepare facsimile products to aid the forecaster in providing extended forecasts.

Of major importance to the forecaster in preparing an extended outlook without the benefit of facsimile prognostic charts is the determination of the type of flow (zonal or meridional) that can be expected to persist during the outlook period. With a zonal flow, a steady progression of pressure systems moving regularly can be anticipated. With the change to a meridional flow, the introduction of cold polar or arctic air into the lower latitudes and mixing with the warmer air will create a number of problems to be considered. Among these will be the development of new pressure systems, deepening or filling of present systems, and movement of the systems.

The forecaster should also become familiar with the particular areas that tend to trigger cyclogenesis and/or frontogenesis, and use this information when preparing his/her outlook. Many of the climatological publications that are readily available make note of these areas.

Many local area forecaster's handbooks contain detailed information on how various weather situations approaching the station affect the station weather well in advance. These should be used when available.

SUMMARY

In this chapter we first discussed the formation of new pressure systems, and available tools used for their interpretation. The next topic discussed was that of the forecasting of the movement of surface pressure systems; lows followed by high-pressure centers. We also discussed forecasting the intensity of surface pressure systems. Topics discussed were extrapolation, isallobaric indications, relation to frontal movements, and lastly, aloft indications of deepening and filling. We then discussed forecasting the movement and intensity of fronts by using extrapolation and the geostrophic wind methods. We also discussed the importance of and the procedures used in the construction of the isobaric configuration on forecasts. Lastly, we discussed extended weather forecasts.