MODULE 4.1A

SHORT RANGE PROGNOSIS

Kinematics

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1. INTRODUCTION

Given the initial (t_0) position s_0, speed v_0, and acceleration, a (presumed constant) of a particle in one direction, kinematic techniques allow one to predict the future position using the formula:

$$s = s_0 + v_0(t - t_0) + \frac{a}{2}(t - t_0)^2$$

without considering the forces involved (these forces are implicit in a). If s_0, v_0, and a are known with relatively constant values and $t-t_0$ is relatively short, the approach is very effective.

Kinematic techniques in meteorology are no different, except that extrapolation is applied to pressure or height values, as well as to the positions (2-dimensional) of specific features: lows/highs, fronts, etc. One problem is that positions and values are no more precise than the resolution of our analyses, but this can be somewhat alleviated through the spatial and temporal continuity of the fields involved. Another problem is that forecasts, and the underlying prognoses, are sometimes required for periods much longer than these techniques can provide.

A third problem is that a hypothetical particle under constant horizontal acceleration can only briefly simulate a particular feature (say a surface low centre) in a complex 3-dimensional system with non-linear interactions, heat sources, terrain effects, etc. in a compressible fluid over a rotating sphere.

Despite such problems, and the tremendous developments of numerical prediction, kinematic techniques can provide the best estimate up to 12 hours or so, and remain useful even to 24 hours. In combination with qualitative dynamics, pattern recognition and climatology, these techniques also contribute to the assessment and improvement of NWP outputs.

The following pages illustrate the use of history and initial trends, winds, and upper flow patterns, to arrive at a surface prognosis chart.

2. UPPER AIR PATTERNS

For the upper air prognosis, the human generally has neither the advantage of more recent data, alternate sources, or greater resolution, except in using satellite pictures and pattern recognition to the fullest extent. Furthermore, 500 mb numerical prognoses are sufficiently good that a 12 or 24 hour old prog will still be competitive, with what the human could do unaided from more recent data.

The exception arises over data sparse areas (mainly the oceans) and in the occasional cases where a model really mishandles the situation (for example, ejecting a closed low into the stream too early, or rejecting critical good data in a poor analysis). Because of such instances, it is a worthwhile practice to sketch the history and expected motion of control lines and short-wave troughs and ridges. This is also a good way to observe and extrapolate the interactions of short and long wave patterns.

The proposed technique is straight forward. For more detailed upper air techniques, consult references (8), (13) and their own sources, as well as most older General Meteorology text books (pre-1960).

1. Analyse (or check the analysis of) control lines and short-wave troughs and ridges that can affect the area of interest. Do this at t_0, t_{0-12}, t_{0-24}, and possibly further back if it helps define the situation. Be sure to make appropriate inferences from satellite pictures, upper wind speeds and directions, misanalysed data, etc.

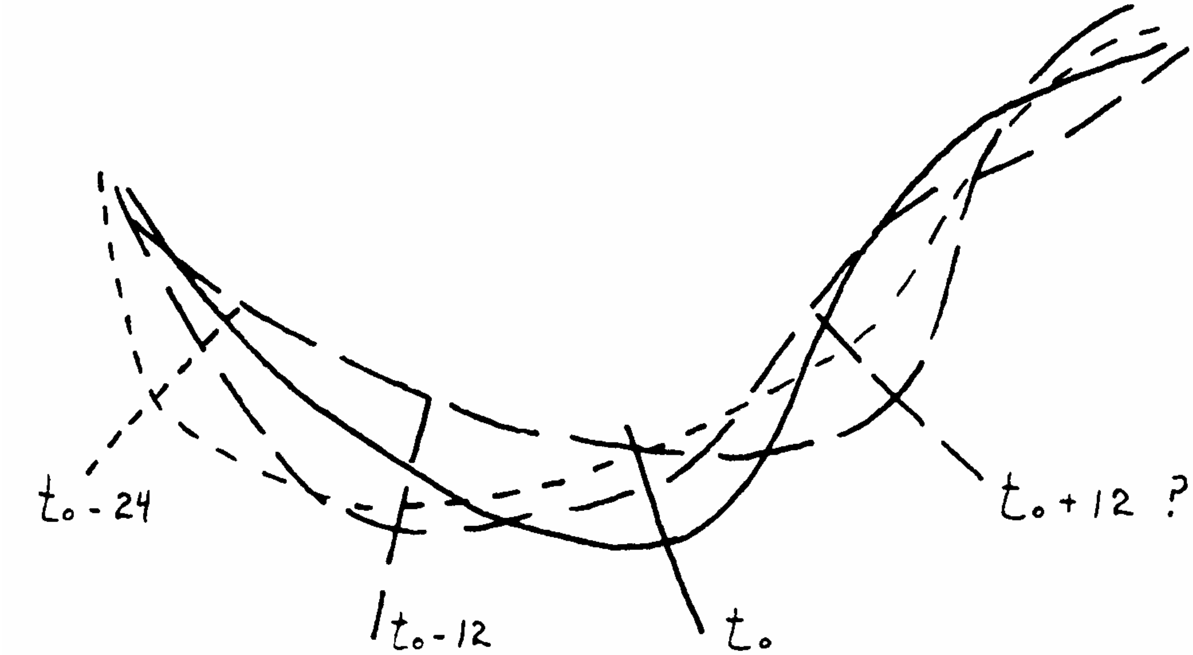


Figure 1. Motion of 500 mb control lines.

2. Combine the previous three analyses in one of two ways:

a) the safest: doing a separate control line chart including the history of control lines, short waves and vorticity centres, with the speeds noted (^{o}lat/12hr)

b) the quickest: note only the history of short waves and vorticity centres, not that of control lines, and do this right on the t_0 chart. This is unsafe however, if marked short-waves are significantly modifying the basic long-wave pattern.

3. Sketch the extrapolated position of these features over the period of interest.

4. You can also estimate the future direction and speed of a short-wave as fifty percent (50%) of the 500 mb winds in the main stream (speed in ^{o}lat/12hr = speed in kt ÷ 5). This is most useful for a weak wave in a strong, nearly straight flow, where the analysed positions become doubtful.

5. Refine your extrapolation by using the past 12-hour height change analysis (if available) semi-quantitatively:

a) to project where heights should be falling/rising in the next 12-hours and by approximately how much.

b) to estimate the speed of the short-wave trough/ridge from Petterssen's formula:

$$C = -\left(\frac{\dfrac{\partial^2 Z}{\partial x \partial t}}{\dfrac{\partial^2 Z}{\partial x^2}} \right)$$

$$C = -L \frac{\left(\dfrac{\Delta Z}{12hr}\right)_{\frac{L}{2}} - \left(\dfrac{\Delta Z}{12hr}\right)_{-\frac{L}{2}}}{\left(Z_L + Z_{-L} - 2Z_0\right)_{t_0 - 6}}$$

in degrees latitude per 12hr. Where L is in degrees latitude.

6. Estimate qualitatively whether the vorticity and thickness advection will modify the height tendencies during the prog period (refer to the geopotential tendency equation). Adjust your previous extrapolation (steps 3 to 5) to account for this.

3. POSITION OF SURFACE FEATURES

With surface features, the importance of kinematic techniques is much greater. The forecaster has data up to 12 hours or so beyond the latest model input, with a much greater resolution than the model can use. This is also a level where numerical prediction is clearly lagging behind the forecaster's pressing need for precise prognoses of the motion of structures (lows, fronts, etc.) upon which to hang the predicted weather and resulting forecasts. For example, the most critical task in an aviation forecaster's day could be the accurate prediction of a front's position for the next 6-12 hours.

As with the upper air, one can view the following techniques as a set of successive approximations:

1. Analyse (or check the analysis of) the current and previous surface maps for features that can affect the area of interest. Be sure to consider historical continuity, data-sparse area problems, pressure tendencies, winds, clouds and weather, etc. as indicators.

2. Trace the (revised) history of pressure centres onto your analysis. Also, note the speed and direction of ridges and troughs, fronts and waves, etc. Special charts can be used for this purpose, such as isochrone charts, or x-t cross sections (figures 2 and 3).

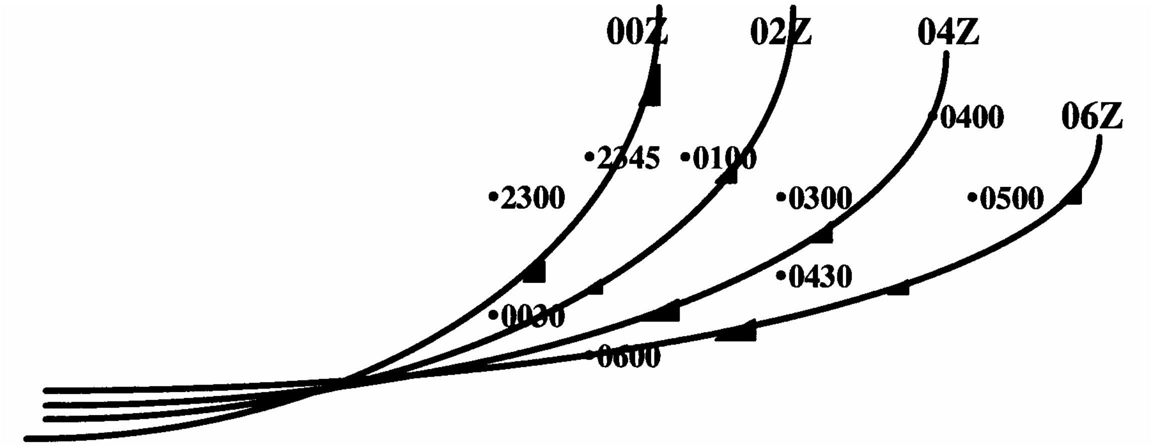


Figure 2. Isochrones of cold frontal positions. Times of frontal passage inferred from hourly weather reports are plotted.

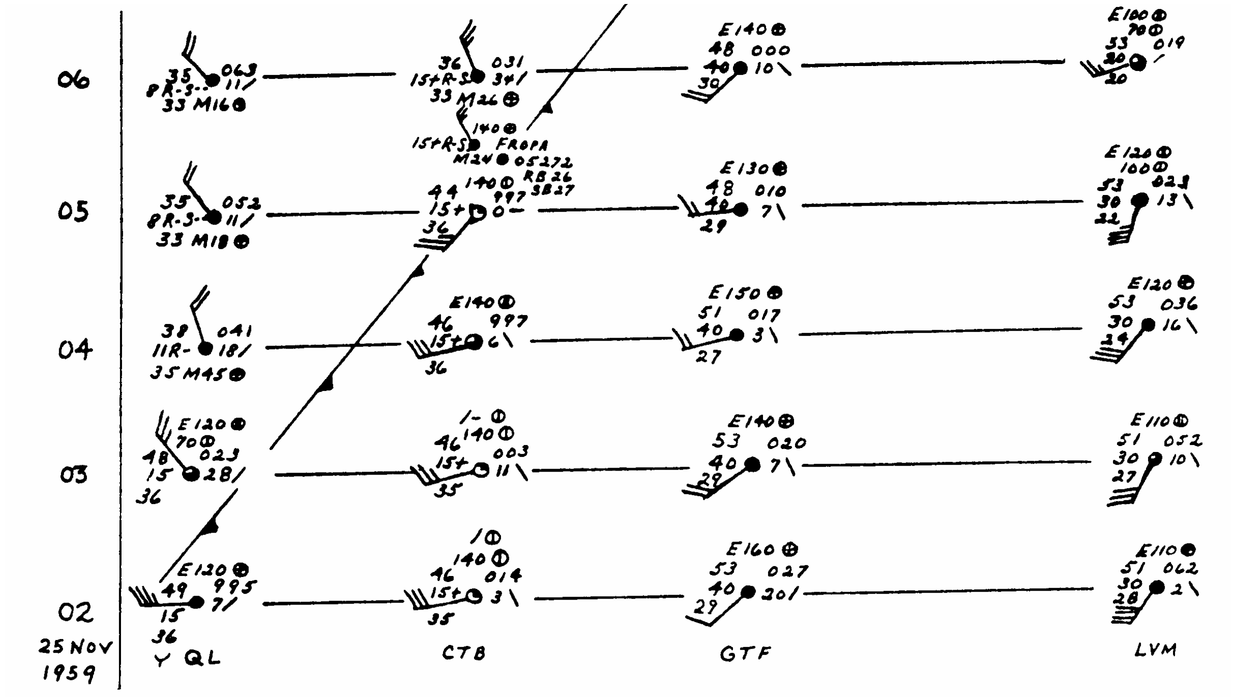
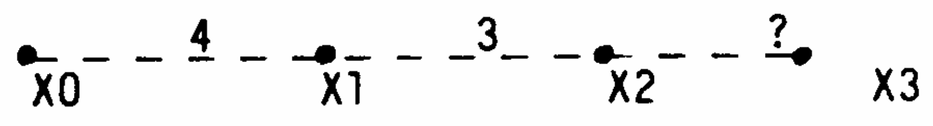


Figure 3.x-t cross section showing positions of a cold front moving southward across a line of stations.

3. A first draft extrapolation may be done at this point, although for any but a short period, and/or straight line motion, the future direction will be ill-determined. Note that the following rule is recommended to take acceleration into account:

$$X_3 - X_0 = 3(X_2 - X_1)$$



4. The isallobaric analysis (pressure tendencies over the past 3 hours) can be used semi-quantitatively.

a) to predict the direction of motion of lows, highs, troughs, ridges:

- lows and troughs move away from pressure rises towards pressure falls (the reverse for highs and ridges)
- circular pressure patterns move parallel to the isallobaric gradient
- elongated pressure patterns move in a direction between the longest axis and the isallobaric gradient.

b) to estimate the speed of motion from Petterssen's formula:

$$C = -\left(\frac{\frac{\partial^2 p}{\partial x \partial t}}{\frac{\partial^2 p}{\partial x^2}} \right)$$

$$C = -L \frac{\left(\frac{\Delta p}{3hr}\right)_{\frac{L}{2}} - \left(\frac{\Delta p}{3hr}\right)_{-\frac{L}{2}}}{\left(P_L + P_{-L} - 2P_0\right)}$$

in degrees latitude per 3 hours (^{o}lat/3hr) with L in ^{o}lat, extending roughly to the maximum rise/falls areas. Note that the denominator really applies at the point (t-1.5), but the discrepancy should be negligible.

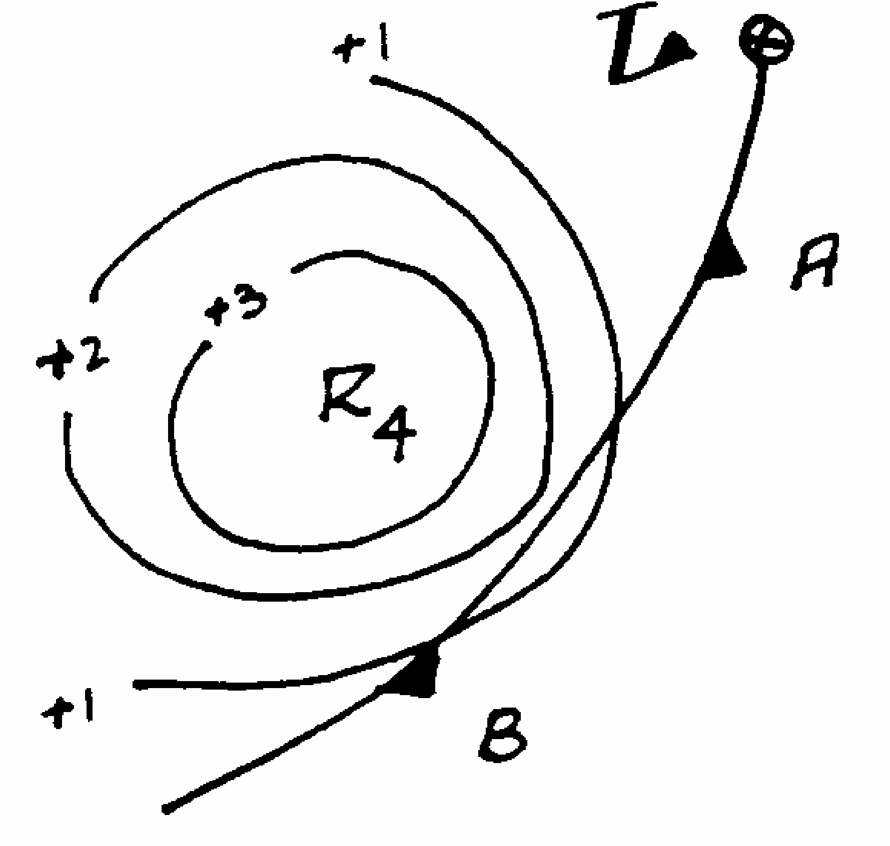


Figure 4. Isallobars across a cold front.

c) to determine the acceleration/deceleration of a front, based on changes in pressure, gradient:

- the front accelerates where the pressure tendencies increase as one moves away from the low (at A)
- the front decelerates where pressure tendencies decrease as one moves away from the low (at B)

- the acceleration in knots/hour can be, estimated as:

$$\frac{1}{12}\left[\frac{1}{\rho f}\frac{\partial}{\partial s}\left(\frac{\partial p}{\partial t}\right)\right]$$

where $\frac{\partial p}{\partial t}$ is in mb/3hr

and the expression in brackets can be evaluated from the geostrophic wind scale applied to isallobars drawn at 1 mb/3hr intervals.

5. Initial wind information can also be applied:

a) for cold fronts:

- They move at approximately the 850 mb or surface geostrophic wind component perpendicular to the front.
- The wind shear hodograph may also be used to estimate the instantaneous speed and direction of motion of any frontal surface found above the station. For example, consider the schematic hodograph shown in Figure 5.

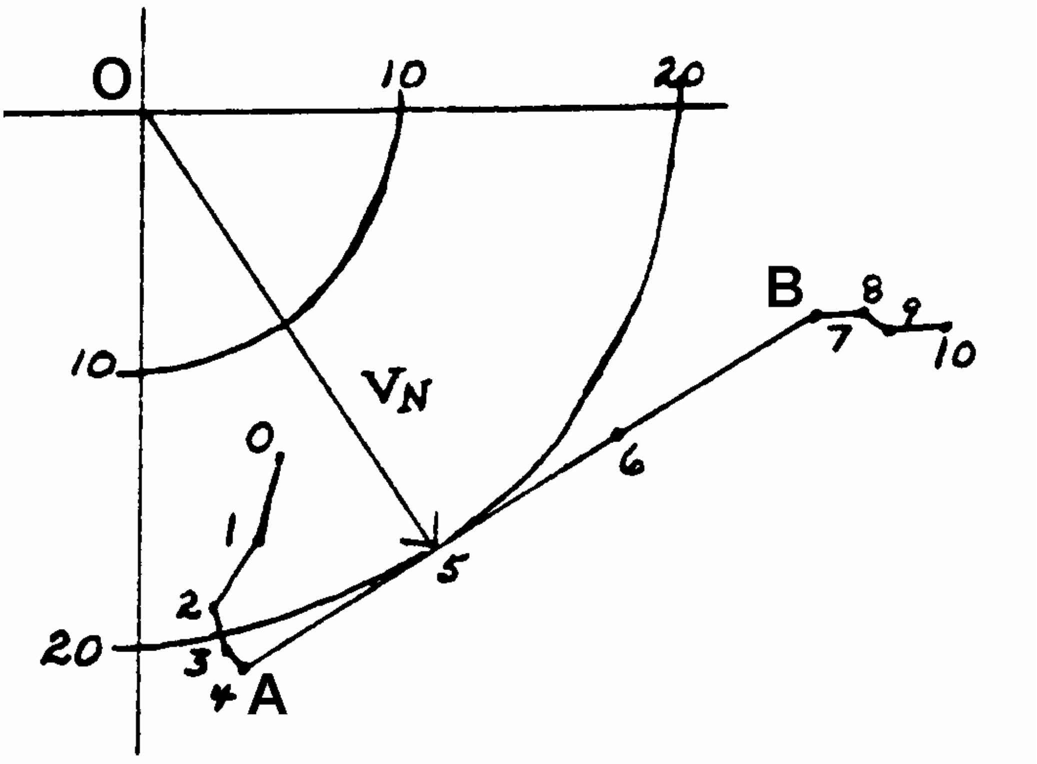


Figure 5. The Hodograph.

The relative maximum vertical wind shear **AB** between 4,000 and 7,000 feet may be interpreted as defining the mixing zone of a frontal surface above the station, with the frontal surface at **B**.

Its orientation would be WSW-ENE with colder air to the northwest of the station. The wind at the top of the front (or the top of the frontal mixing zone) is given by the vector **OB**, while its component normal to the front, $\mathbf{V_N}$ gives the instantaneous frontal speed, in this case, 20 knots.

Thus, the rule for determining the speed of a front from a hodograph may be formulated as follows. The length of the perpendicular from the origin of the hodograph to the vertical wind shear vector identified with the frontal mixing zone, measured with the wind speed scale, gives the instantaneous speed.

b) For most surface features, an estimate of the direction and speed can be obtained by taking 50% of the 500 mb winds.

6. The previous guideline is simply a corollary to a method for estimating the 500 mb short wave motion. The surface feature tends to keep its position with respect to the 500-mb short-wave pattern and can be inferred from the 500-mb prog.

However:

- falling/rising surface pressures will shift the surface feature to lower/higher 500mb contours, by about 6 dam per 8 mb change.
- a weak, fast moving short-wave may outstrip its surface reflection.
- multiple, ill-defined surface and/or upper air features may take time to evolve into organised and somewhat predictable features.
- the surface pattern may be mainly thermal and shallow
- etc.

7. Estimate qualitatively whether the temperature and vorticity advection (or divergence) patterns will modify the pressure tendencies and subsequent motion (refer to the pressure tendency equation in the appendix). This step is best covered along with section 4-4 and 5-3.

8. Consider any changes related to terrain and/or local heat sources and sinks.

9. Apply climatological knowledge of preferred tracks and locations of lows and highs, and seasonal frontal areas.

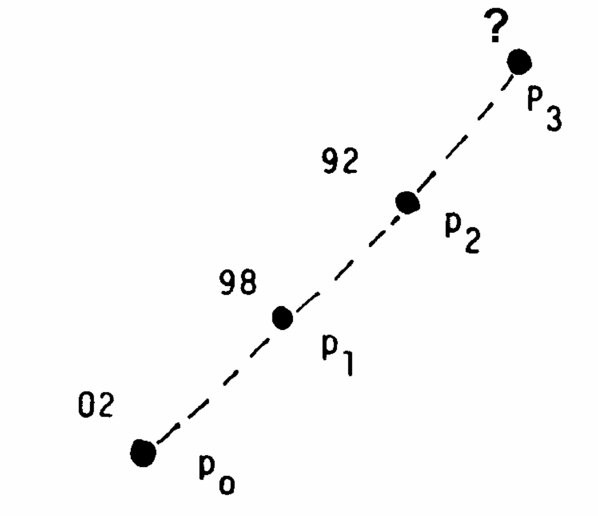
4. CENTRAL PRESSURE OF SURFACE HIGHS/LOWS

Here, as with the location of these features, having later data and greater resolution gives the prognostician an advantage over straight numerical progs.

The basic tools and techniques remain the same:

1. Obtain the necessary analyses and history as in 3-1, 3-2.

2. Extrapolate the value, using the same rule as in 3-3:



$p_3 - p_0 = 3\ (p_2 - p_1)$

$p_3 = 1002 + 3\ (992 - 998) = 984$ mb

Figure 6. Extrapolation.

3. Use the value of the isallobar through the low or high centre, corrected for the diurnal pressure tendency (2), as the instantaneous rate of filling/deepening of the moving systems (Appendix), and extrapolate into the future. (Note that the low position at t_0-1.5 hours should really be used, but the difference generally falls within the uncertainty of the isallobaric analysis.)

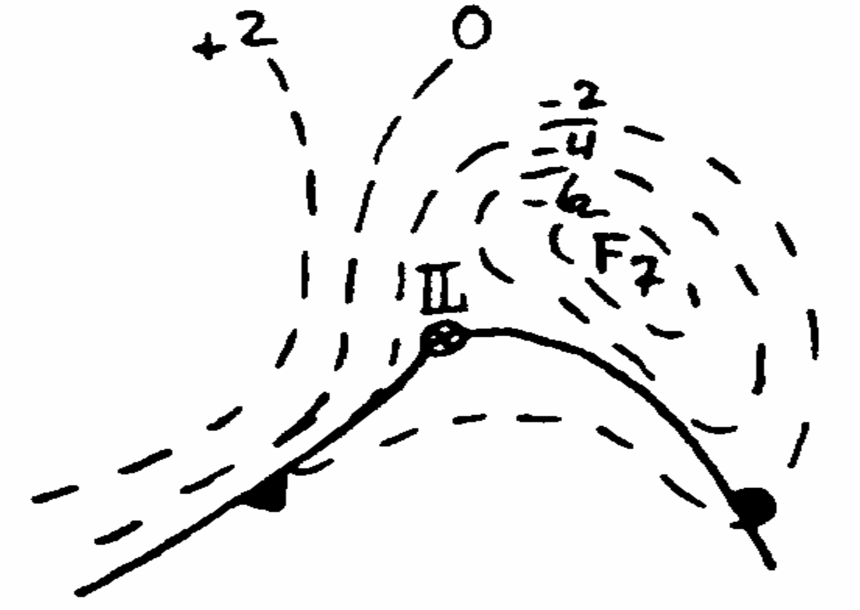


Figure 7. **Isallobars across a wave.**

In figure 7, $\partial p/\partial t$ at the low centre is about -3 mb/3 hours. Suppose the diurnal trend at this time of year, time of day and location is -0.5 mb/3 hours. One is left to extrapolate a trend of -

2.5 mb/3 hours, suggesting a fall of 10 mb in the central pressure of this low over the next 12 hours.

4. Infer changes in the current rate of filling/deepening, related to the vorticity and temperature fields (pressure tendency equation in Appendix).

5. Consider changes related to terrain and/or local heat sources and sinks.

5. INTENSITY/CIRCULATION OF SURFACE PRESSURE FEATURES

This part of the prognosis may be done to fill in the pattern once all the main features have been forecast (see step 1 below). It may also be used to help in forecasting where these features should be and how intense, as well as filling them in.

1. The basic "filling in" technique consists in superposing the first draft prog over the initial analysis, shifted so that each progged feature coincides with its initial self. Seldom if ever will there be a good match in both position and pressure for all features. But fitting them one at a time, and increasing/decreasing the number of isobars over specific areas as required, you can come to a reasonable prog: one that looks as if it could be the analysis 12-24 hours later (an important criterion).

2. The isallobaric analysis can also be used, and is particularly advantageous if the prog is for the short range and concentrates on a single feature (say you haven't given much thought to the motion and strength of the highs preceding and following "your" low and cannot assess their contribution to the pressure gradient).

a) Tightening/weakening and veering/backing can be expected depending on the mutual positions of the isobars and isallobars (Appendix).

b) The intensification of a pressure system $\left(\partial I/\partial t\right)$ can be measured by the Laplacian of the pressure tendencies around the system $\nabla^2\left(\partial p/\partial t\right)$, or in finite-difference form:

$$\frac{\left(b_1+b_2+b_3+b_4-4b_0\right)}{d^2}$$

where $b=\Delta p/3hr$, and the sign (the asymmetry) is the main concern.

See the example in figure 8 (assuming the diurnal tendency negligible or already removed).

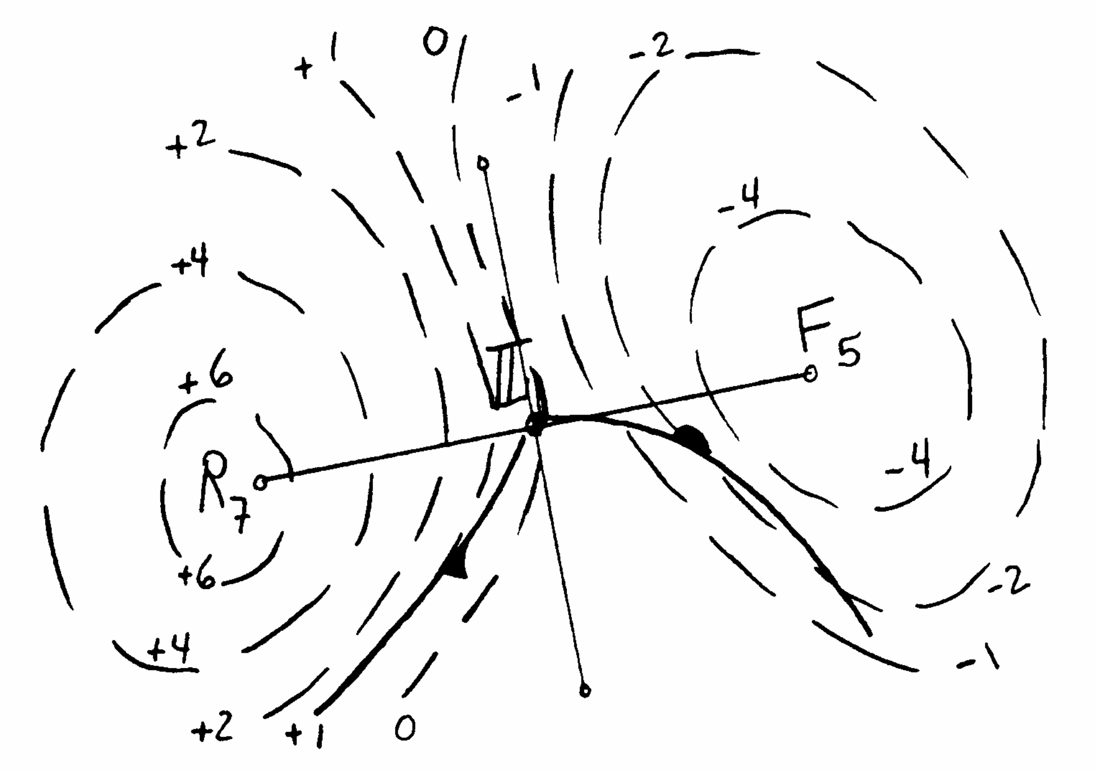


Figure 8.

$$\nabla^2 b = \frac{(-5 - 0.5 + 7 - 4(0.25))}{d^2} = 0$$

no change in intensity.

Note that the size and orientation of the grid becomes more significant and much more ambiguous when:

- the fall and rise centres are at uneven distances
- these centres and the low are not aligned
- there are several low centres.

3. Apply the Petterssen - Sutcliffe equation (Appendix) qualitatively to assess whether vorticity and thickness advections, vertical motion and diabatic effects combine to increase or decrease the surface vorticity.

6. FORMATION OF NEW FEATURES

The main concern here is with the formation of a new low centre (or at least a cyclonic area such as a new frontal wave, even without a closed isobar).

All the factors previously mentioned to forecast the position, central pressure, and intensity of a low can in fact point to an area away from the initial low's track, and suggest a new centre.

The following are among the best indicators:

- new vorticity
- intensification of vorticity and thickness advections
- passage of a short-wave trough over a baroclinic zone
- development of a new pressure fall centre.

This last indicator is the most likely to be observed, and one should make a point of checking pressure tendencies every three (3) hours in suspect areas (if indicators 1, 2, 3, Petterssen-Sutcliffe equation, climatology, etc.)

7. CONCLUSION

More has yet to be said and done about combining these techniques with numerical models outputs, energetics assessment, empirical rules, etc. The better you know the partial techniques described here, their assets and limitations, the more you can appreciate the later part of this module.

8. REFERENCES

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