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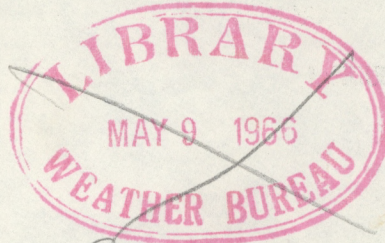
Eastern region technical memorandum no.2.
Application of the barotropic vorticity prognostic field to the surface forecast problem,
by S.G. Simplicio.

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U. S. DEPARTMENT OF COMMERCE
ENVIRONMENTAL SCIENCE SERVICES ADMINISTRATION

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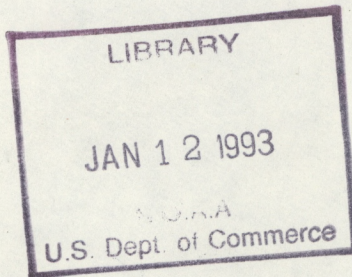
NEW YORK REGIONAL OFFICE



Eastern Region

TECHNICAL MEMORANDUM NO. 2

Application of the Barotropic Vorticity Prognostic Field
to the Surface Forecast Problem



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Scientific Services Division

July 1965

Application of the Barotropic Vorticity Prognostic Field to the Surface Forecast Problem

A. Introduction

Availability of vorticity advection prognostics has made possible a systematic approach to the three dimensional forecast problems. In addition they provide the means for a technique which yields a fairly accurate surface prognostic in a minimum of time. It also appears that they are quite useful in the treatment of non-frontal weather developments.

Aside from the barotropic 500 mb. prognostic, this vorticity field is the best single forecast tool available to the meteorologist today. The discussion that follows is aimed at providing a working knowledge and understanding of the vorticity field in forecasting.

B. Definitions

1. Absolute Vorticity is the sum of the relative vorticity and the Coriolis parameter. Stated mathematically: $\eta = \zeta + f$

$$\zeta = \frac{dv}{dx} - \frac{du}{dy}, \quad f = 2\omega \sin \phi$$

The relative vorticity is generally positive with cyclonic curvature and negative with anti-cyclonic curvature. By definition, if the wind speed decreased to the left (back to the wind), the relative vorticity is positive (cyclonic). If the wind increases towards the left, the relative vorticity is negative (anti-cyclonic). The sign of the Absolute Vorticity is almost always positive since the Coriolis parameter is almost always large enough to negate a negative relative vorticity. An exception to this may be found near the equator where the Coriolis parameter approaches zero and consequently negative values of Absolute Vorticity may be found under certain conditions of anti-cyclonic curvature.

Appendix A, is an excerpt from AWSM 105-50/1, forecasting upper level winds, Part 1, Forecasting by Vorticity Techniques, and offers a neat and simple dissertation on the nature of vorticity.

2. An Absolute Vorticity Maximum (minimum) is defined as the center of the largest (lowest) valued closed vorticity contour.
3. Vorticity Advection may be either positive or negative. If the upstream values of vorticity are increasing then the advection is positive. Lower upstream values indicate negative vorticity advection.

4. Vorticity Gradient is defined as the rate of change of the vorticity in the horizontal plane at a fixed time. When this gradient exceeds the Coriolis parameter gradient (which increases northward) then we have vorticity gradient which is associated with wind field vorticity.

When the wind flow is straight (non-curved) and no horizontal wind shear is present, the vorticity gradient is equal to the Coriolis parameter gradient and is parallel to the latitude circles.

For future reference some values of the Coriolis parameter are presented.

<u>Lat.</u>	<u>f</u>
30°	07x10 ⁻⁵ Sec ⁻¹
45°	10x10 ⁻⁵ Sec ⁻¹
60°	12x10 ⁻⁵ Sec ⁻¹
90°	14x10 ⁻⁵ Sec ⁻¹

(TABLE I)

C. Theoretical Considerations

Differentiation of the second equation of motion with respect to the X-axis from which is subtracted the differentiated (with respect to the Y-axis) first equation of motion yields the vorticity equation. This may be expressed in terms of the divergence of the wind.

$$\nabla \cdot \mathbf{V} = -\frac{1}{h} \left(\frac{\partial \psi}{\partial t} + \mathbf{V} \cdot \nabla \eta + \omega \frac{\partial \psi}{\partial p} \right) \quad (1)$$

The vorticity advection term, $-\mathbf{V} \cdot \nabla \eta$ is usually by far the dominating term above 5 - 600 mb. in the equation. A good assumption therefore is that this term determines the sign of the divergence.

Now
$$\mathbf{V} \cdot \nabla \eta = \mathbf{V} \cdot \left(\frac{\partial \eta}{\partial x} + \frac{\partial \eta}{\partial y} \right)$$

If η is increasing downstream then $\mathbf{V} \cdot \nabla \eta > 0$ in which case, from equation (1), $\nabla \cdot \mathbf{V}$ the divergence, is therefore negative which means that convergence is taking place.

From similar reasoning it follows that if η is decreasing downstream, then divergence is taking place.

Two important ideas are necessary to complete the phase of the discussion,

1. Empirically it has been found that the vertical tilts of troughs and ridges in the middle Troposphere, above 600 mb., are negligible. This implies that the vorticity fields above this level are also quasi-vertical.
2. An important theoretical concept is that enunciated by Dines and known as the Dines Compensation concept. This concept states that the divergence changes sign at least once in the vertical. It has been found that for the major synoptic development areas it changes only once and that this change occurs fairly close to the 500 mb. surface.

By virtue of 1. above, the sign of the divergence computed by vorticity advection at 500 mb. is valid for the levels above 500 mbs. Now if the 500 mb. level is the level of zero divergence, Dines' concept tells us that the sign of the divergence below 500 mb. is opposite to that of the divergence above.

D. Correlations to Synoptic Features.

1. Surface Centers

The "center" of the negative vorticity advection area is usually associated with a center of surface divergence (high, ridge) and rising pressures. (Figure 1, A). Conversely, centers of positive vorticity advection areas are associated with surface convergence (lows, cyclonically curved isobar) and surface pressure falls. (Figure 1, B).

A rule of thumb that is often quite useful is that developing surface lows are generally located from 5-7° of latitude downstream from a 500 mb. trough. However, for the more exact placement of the surface low, the vorticity advection area should be referred to.

2. Surface Fronts

- a. Open frontal system (non-occluded) are generally located along the line where the vorticity gradient begins. The vorticity contour with which the front is usually identified is that contour which approximates the Coriolis parameter. Table I above, notes these values.

There are occasions (frequently observed over the SE portion of the country) when strong vorticity gradients exist with values much less than the Coriolis parameter. Under these circumstances the foregoing rule does not apply since the relative vorticity reflects a strong anti-cyclonic curvature of the 500 mb. field rather than a frontal gradient.

An example of an open system and its associated vorticity field is shown in figure 2. Also indicated on this figure are the 500 mb. baroclinic zone (front) and the 500 mb. Jet axis. It can be seen that the surface front is located at the "beginning" of the vorticity gradient and the 500 mb. front near the "end" of the gradient with the Jet axis between the two but favoring the 500 mb. front.

b. Occluded systems may be classified into two types -- Deepening and Fully Occluded.

i. Deepening Systems -- refer to figure 3.

A deepening system shows the occlusion cutting across the vorticity gradient and forming a vorticity ridge (similar to a thermal ridge on thickness charts). The "open" portion of the front lies along the vorticity gradient as discussed in section D-2 above. This configuration will continue until the deepening process is through. This leads us to the second type.

ii. Fully occluded system -- Figure 4 depicts this situation. The occluded system lies in the vorticity max or at the "end" of the vorticity gradient as indicated. Surface pressure fields will indicate cyclonic curvature and pressure falls in advance of the occlusion under the area of vorticity advection.

3. Non-Frontal Vorticity Fields

At times a vorticity max (min) will be associated with a 500 mb. trough (ridge) with no associated frontal fields. This type of vorticity field is quite important in the development on non-frontal weather which will be discussed under F, below.

E. Analysis Utilizing Vorticity Fields

The correlations discussed in Section D, quite obviously, may be applied to the surface and upper air analysis. The type of front, its location, its strength (the stronger the vorticity gradient -- the more active the front) etc., may be determined by the association of observed vorticity fields.

At times a short wave will not be obvious from the 500 mb. contours but the observed vorticity field shows it quite clearly. Figure 5.

F. Forecast Implications

1. Highs and lows will tend to move under the area of (negative and positive respectively) vorticity advection. A deepening low will continue to lie under the area of vorticity advection

in the initial stages of the deepening. As the deepening progresses the center will tend to move towards the center of vorticity maximum unless continued vorticity advection is indicated in the prognostic field. In this event the center will continue to move into the area of positive vorticity advection as indicated in the prognostic field. In this event the center will continue to move into the area of positive vorticity advection.

In the same manner, highs (ridges) will be associated with negative vorticity advection. If the absolute values of vorticity tend to increase in a given area and the negative vorticity advection is also decreasing -- this implies the breakdown of the ridge (high) in question.

2. Positive Vorticity Advection associated with strong thermal vorticity advection is a large scale deepener (perhaps 24 mbs. in 24 hours). The thermal vorticity is merely the vorticity of the thermal wind. The 1,000 - 500 mb. thickness field is a direct delineation of the geostrophic thermal wind for the layer, but an approximation to this field is further reflected in the 500 mb. isotherm field.
3. Positive Vorticity Advection associated with low level cold advection is indicative of stable conditions and weak sea level convergence. Figure 6.
4. If vorticity fields are in phase with the 500 mb. contour fields this is indicative of little movement and no deepening. Figure 7.
5. Short wave and small amplitude vorticity features are indicative of rapidly moving, non-deepening systems. An example is shown in Figure 5.
6. Quite often the first indication of the filling of an old low or trough is indicated by stronger negative vorticity advection to the rear of the trough than there is positive vorticity advection in advance of it. In this case the lower values of vorticity tend to overtake the higher values and consequent filling takes place. An example is Figure 8.
7. Squall Line Formation - There is some evidence that squall development may be anticipated by the action of vorticity gradients. It appears that if a certain vorticity pattern is associated with a surface frontal system as in Figure 9(a) and this finally deteriorates into a field as shown on 9(b), a squall line would develop at the leading edge of the vorticity gradient. This situation may be referred to as a "breakout" of the vorticity field ahead of the front.

8. Positive Vorticity Advection without surface baroclinicity implies movement of the 500 mb. features only with little change in the associated surface pressure field. However, areas of maximum vorticity (and associated positive vorticity advection) not associated with surface frontal features are of considerable importance in the development of non-frontal weather. If the air associated with this phenomena is moist then one can expect that the advection of this area will be associated with both middle and instability type cloudiness. This type of advection is conducive to precipitation over large areas. If the air is relatively dry then little or no weather will be associated with the advection.

On the other hand, if negative vorticity advection is moving into an area which has moist air, it will tend to reduce the amount of instability and perhaps limit it to scattered phenomena.

G. Operational Procedure in Using Vorticity Field

In utilizing the vorticity patterns in forecasting, the following steps are suggested.

1. Establish the existing relationship between the initial (observed) 500 mb. vorticity advection pattern and the surface system and isobaric curvature. This is done simply by tracing the salient features of the surface field on the observed vorticity fields for the same time.
2. These relations are then used with little or no modification as estimates of the future positions of surface systems, troughs, ridges, etc., placing them by means of the prognostic vorticity charts.
3. Some subjective adjustment should be made in the event of large baroclinic development on the basis of later surface information than that available at the time the barotropic prognostic was prepared. A good procedure to use here is that of determining whether or not the implication of the current observed vorticity advection is actually being felt at the surface (on the latest surface chart). If it is, then the vorticity may be used with little or no adjustment. If the implications are not being felt, then modification might be necessary.

S. G. Simplicio

APPENDIX A

Excerpt from AWSM 105-50/1, Forecasting Upper-Level Winds, Part One, Forecasting by Vorticity Techniques, June 1954., pps. 1 and 2.

"1.2. Vorticity:

Vorticity is the term used in fluid mechanics to describe the rotational motion of infinitesimal fluid elements. The synoptic meteorologist, however, is concerned with flow patterns of a scale found on a weather map, rather than the motion of individual fluid elements. Therefore, we will be dealing here with mean vorticity averaged over an area whose linear dimensions are some hundreds of miles.

Relative Vorticity. The vorticity in a horizontal current can be broken down into two components, one due to the curvature of the streamlines, and the other due to the shear in the current. An example will illustrate this. Consider a flowing river. Place on the water two sticks, one perpendicular to the current (A) and one parallel to the streamlines of the flow (B) (see figure 1a).

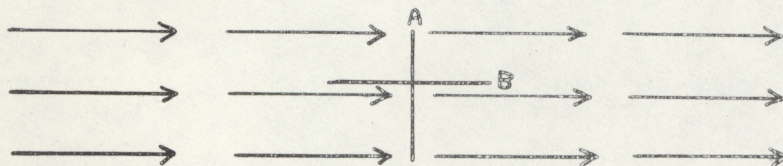


Figure 1a. Schematic diagram illustrating zero relative vorticity.

If there is neither curvature nor shear in the current, neither of the sticks will alter its orientation relative to a fixed coordinate system as they are translated (transported) downstream. Such a current can be said to have no vorticity relative to the coordinate system. Now let us assume a horizontal shear exists in the current; as illustrated in figure 1b the shear results in stick (A) being rotated.

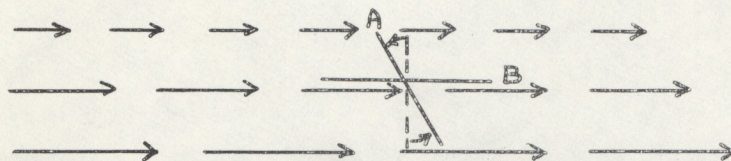


Figure 1b. Schematic diagram illustrating positive (cyclonic) vorticity due to shear.

The vorticity in general is the sum of the rotations of the two sticks in relation to a fixed coordinate system. The vorticity is then said to be relative to this coordinate system. (Rotation is the change in angle per time unit.) In the case above only the stick normal to the streamlines will rotate and it is seen that the vorticity is equal to the shear of the current. Next assume that there is no shear but that the streamlines of the flow are curved. This results in a rotation of stick (B) as illustrated in figure 1c. Note that stick (A) does not rotate, since the shear is zero.

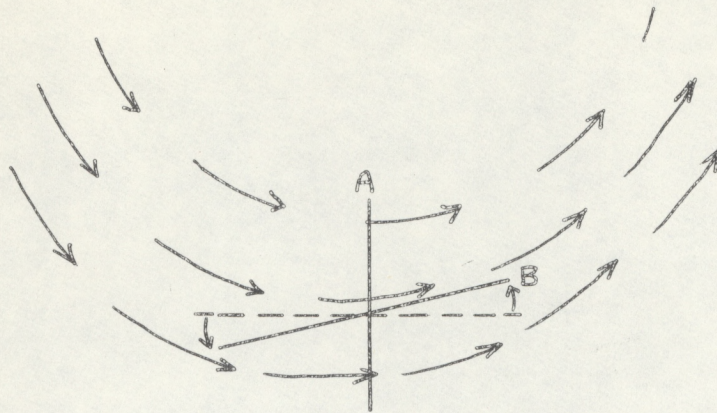


Figure 1c. Schematic diagram illustrating positive (cyclonic) vorticity due to curvature.

For daily operational use in weather analysis and forecasting, the relative vorticity field of atmospheric flow patterns (i.e. relative to the earth's surface) may be evaluated from the curvature and spacing of contours on constant-pressure surfaces.

Absolute Vorticity. However, the quantity which appears in the vorticity equation is the absolute vorticity. The vorticity equation, being derived from Newton's Second Law, of motion, must contain terms describing motion with reference to celestial coordinates, i.e., with respect to the earth's orientation in space rather than with respect to the earth's surface. Since the earth is a rotating spheroid, all points on its surface except those on the equator, have a component of rotation around the local vertical. The magnitude of this component of rotation is a function of latitude and is equal to the Coriolis parameter ($2\Omega \sin \phi$). The absolute vorticity is thus defined as the sum of the Coriolis parameter and the relative vorticity."

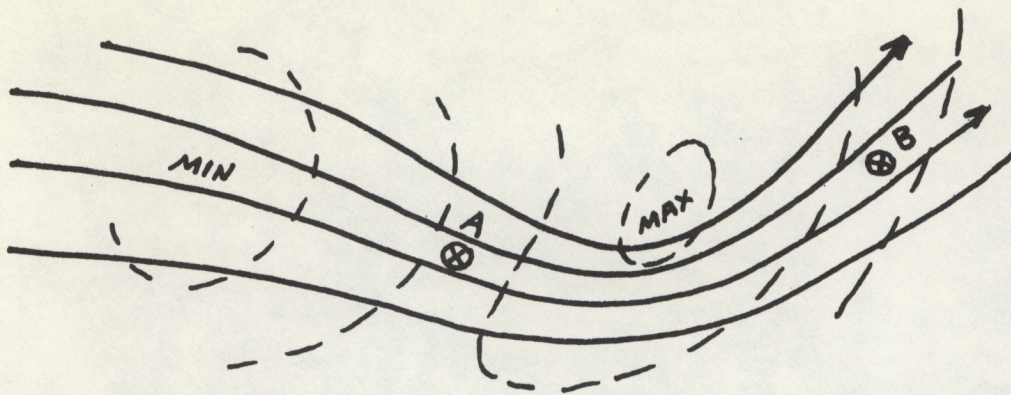


Figure 1

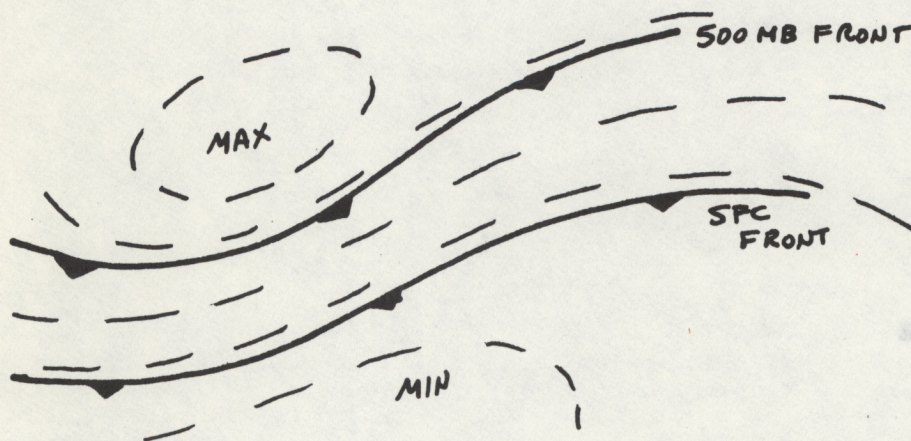


Figure 2

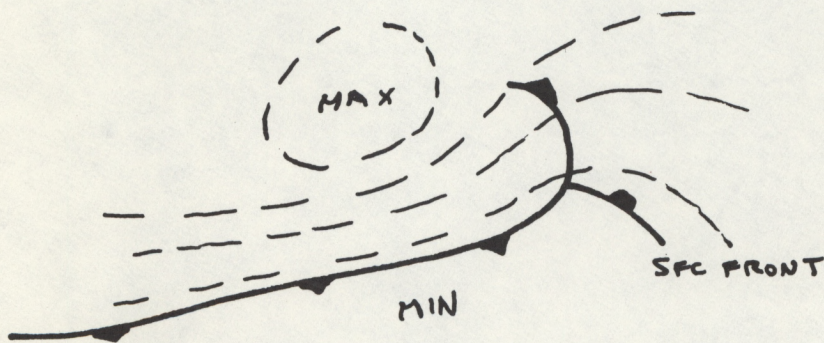


Figure 3

Vorticity
500 mb. contours

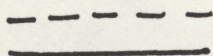




Figure 4

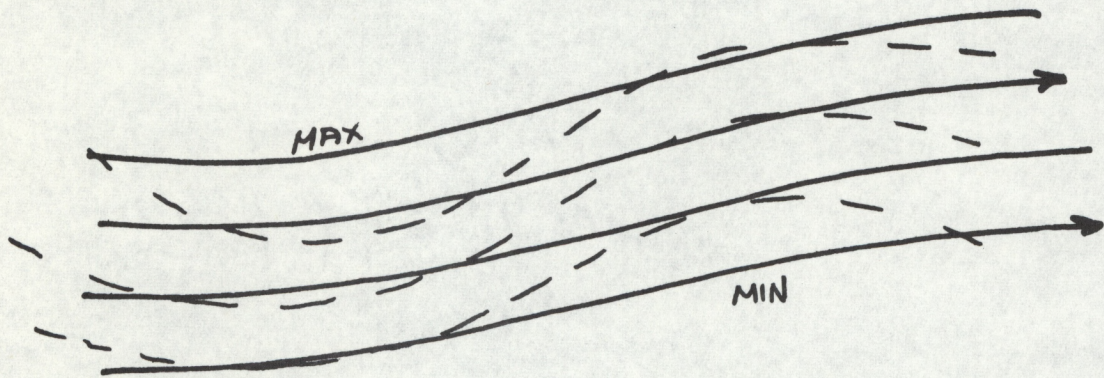


Figure 5

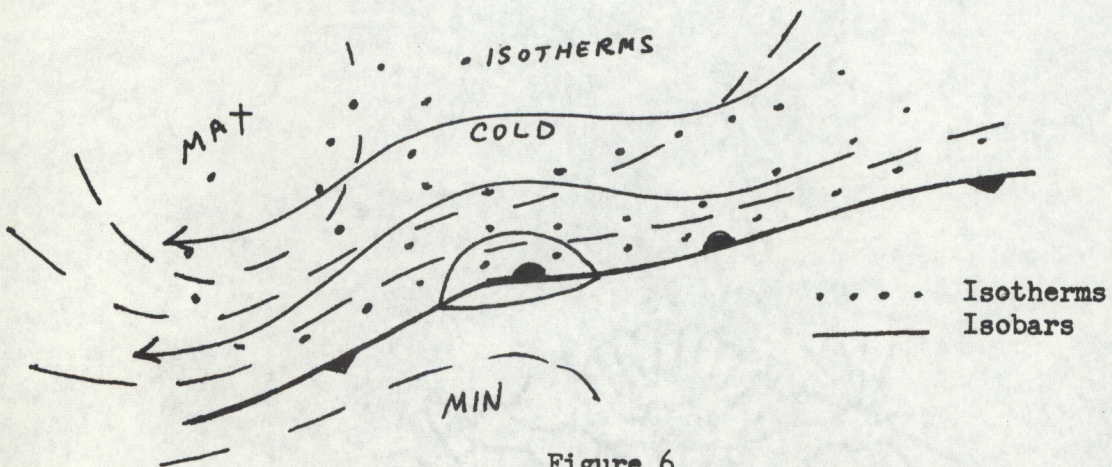


Figure 6



Figure 7

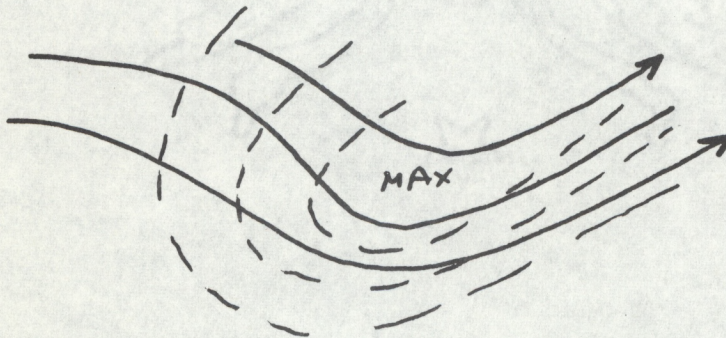
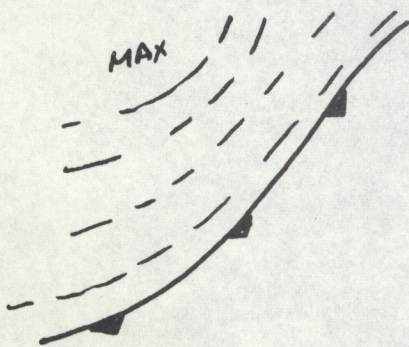
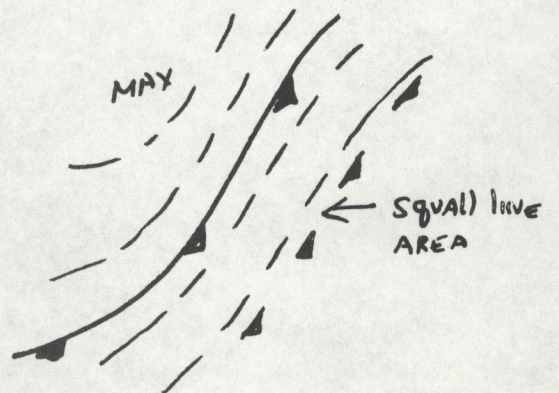


Figure 8



(a)



(b)

Figure 9