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# CLOUD PATTERNS AND THE UPPER AIR WIND FIELD


Roger Weldon

Applications Division
National Environmental Satellite Service
National Oceanic and Atmospheric Administration
US Department of Commerce


(Satellite Training Course Notes, Part IV, reprinted with permission)



October 1979

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# PREFACE

The Air Weather Service (AWS) wishes to thank the author and the National Environmental Satellite Service (NESS) for their permission to republish this report as an Air Weather Service Technical Report. NESS provided copies of the notes to AWS.

Parts I-III of the Satellite Training Course Notes were never published and have been incorporated in Part IV.

Satellite Training Course Notes

# PART IV CLOUD PATTERNS AND THE UPPER AIR WIND FIELD

March 1979

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National Oceanographic & Atmospheric Administration
UNITED STATES Department of Commerce

These notes were prepared as reference material to supplement training course lectures & discussions on the interpretation of satellite cloud photographs. The training courses are presented by Applications Division to professional meteorologists, most of whom are engaged in weather forecasting, weather research, or in some other category of applied weather service.

During training sessions, information is illustrated by high quality photography including both still images and time lapse sequences using movie loops, films, and television displays. It is the intended nature of the training courses, that much of the information presented has been recently learned or developed. Thus, many of the concepts, observations, and relationships are not yet included in published literature. The notes are intended to serve as a temporary, but up-to-date, reference material. Although they can be more easily understood by persons who have attended the training sessions, they were written in a format that can be read by persons who have not attended.

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The information presented in the notes was derived empirically from the study of SMS-GOES system satellite imagery and atmospheric data, analyses, and progs distributed by the United States National Weather Service. All concepts and relationships presented are based upon, or substantiated by, the author's personal observations of atmospheric data. Any meteorological terminology used - but not defined - in the notes, and any "meteorological" concepts discussed in the notes, are those routinely used and applied by operational weather forecasters and observers.

# CLOUD PATTERNS AND THE UPPER AIR WIND FIELD

## Subject Outline and Page Index

"Boxed" portions of text or discussion:

Certain portions of the text of these notes are enclosed by a solid line border, or are "boxed". The information in the "boxes" is of supplemental nature. It is not essential for understanding the main points & concepts of the notes. The purpose of the information in the "boxes" varies, but it is the kind of information that some readers want to know, and others don't wish to spend the time reading.

SOME COMMENTS BY THE AUTHOR

A "DIFFERENT APPROACH":

The set of concepts and relationships, many of which have been presented in these notes, have been referred to as a "different approach". This description was made by Vince Oliver, who was referring to the fact that I have related the cloud and weather patterns primarily to aspects of the upper air motion field - to the jet stream/baroclinic zones, rather than to highs, lows, troughs, ridges, surface fronts, and other features of surface analyses. I want to emphasize strongly, that my approach changed to this "different" one; and that it did not change by design. The change evolved quite unintentionally as I studied the SMS satellite data and related the clouds to weather analyses & data. I let the satellite film loops and pictures lead me to those aspects of the wind and density fields that seemed pertinent. And, I tried to find "common denominator" concepts by concentrating on cloud patterns and their behavior, which were common occurrences at different scales and latitudes. Most of the concepts that have resulted from this study involve a change of emphasis rather than being "new" or unique.

NEW TERMINOLOGY:

I have introduced some new terminology. I don't consider this a desirable thing to do, but it seemed necessary. In many cases there was no term that I knew of that adequately and specifically described the particular feature or behavior involved. It seemed better to define a new term than to give a new meaning to an existing one.

QUESTIONS BEFORE ANSWERS:

As we observe our daily quota of about 20 film loops from the SMS satellites and relate the cloud patterns and behavior to analyses and prog charts, we are constantly seeing things we do not understand. Some of these occurrences seem to be new or unique, but others occur over and over with apparent systematic behavior. In this way, new questions are routinely posed by the satellite observation process. As we gradually learn what, how, and perhaps why something is happening; and can predict reasonably when and where it will happen again; then we have some answers. By this kind of process, I often obtain answers to a question which I didn't know existed a few months ago. The result often is, that when we present a concept or relationship concerning clouds and weather, it may appear meaningless - or at least insignificant - to a person who hasn't yet considered the question. You may encounter this type of situation when reading some parts of the notes.

## THE FORMAT OF THE NOTES:

In writing the notes, I tried to keep the "information density" relatively high. In other words, I tried to keep number of explicit concepts and relationships presented high with respect to the number of words and pages; and still, present enough variations, exceptions, and illustrations. This is a problem, and the result is always a compromise. One way to do it, is to concentrate on "what" is happening and "how" it happens; and to minimize the discussion of "why" it happens or "how" it has been learned. I have used that approach. There is little discussion of theory of why certain events occur as they do.. That doesn't mean it hasn't been thoroughly considered; but, I believe you can make your own conclusions in these matters as well as I can. My attempt to be explicit is violated in the writing of Section D on "deformation zones". There I used a "longer winded" approach, but only after careful consideration of the need to put things into better perspective.

## NOT "THE ANSWERS" - BUT, A BETTER PLACE TO START:

Many of the relationships presented in the notes are very explicit; they involve simple comparisons between satellite cloud patterns and the wind field. We can be relatively sure of these relationships, although we may not know why they exist. Many of the other concepts presented are generalizations or models of atmospheric systems and their behavior. They were derived from observations to represent common occurrences or typical relationships; but, they are always a compromise between the simplicity we desire and the complexity of reality. The more generalized a relationship is, the easier it is to understand and use; but more exceptions will be encountered when it is applied to real cases.

There is a natural human tendency to want answers to questions, and to propose tentative answers which have not been sufficiently verified for reliability and accuracy. There is also a natural tendency, when writing notes such as these, to want to include all the answers - even those on the lower end of the reliability scale. I have tried to be careful about this. But I know from experience, that some misinterpretations, misplaced emphasis, and outright errors will have "slipped through". Most readers who are experienced in working with the atmosphere, already know that; but I wanted to point out the problem to readers with less experience, and to those who believe that scientific princiles are discovered, not invented.

Although the notes present many relationships, they do not represent "the answer" to the problems of satellite picture interpretation. When I watch a satellite film loop, I have more questions about the clouds & their behavior than answers. I still do not adequately understand many of the things I see occurring on the loop. The notes present some of the answers. I think they will provide for many readers, a better place to begin solving the puzzles posed by the satellite pictures; and for others the notes will fill in a few of the gaps.

Roger Weldon
April 10 1979

COURSE NOTES NWS - NESS SATELLITE PICTURE INTERPRETATION Roger Weldon

PART IV CLOUD PATTERNS AND THE UPPER AIR WIND FIELD 2 January 1979

A. DEFINITIONS:

1. "Deformation Zones"

The term "deformation zone" is being used more and more often among people looking at satellite pictures and time lapse sequences such as movie loops. This is probably due to the fact that a large amount of the significant clouds and precip are associated with deformation zones - on all spatial scales and at all latitudes.

The first drawing (below) shows two hyperbolic regions or cols surrounded by some highs & lows. The short lines (some of which have arrow heads) represent wind vectors, and the long lines represent streamlines or height contours.

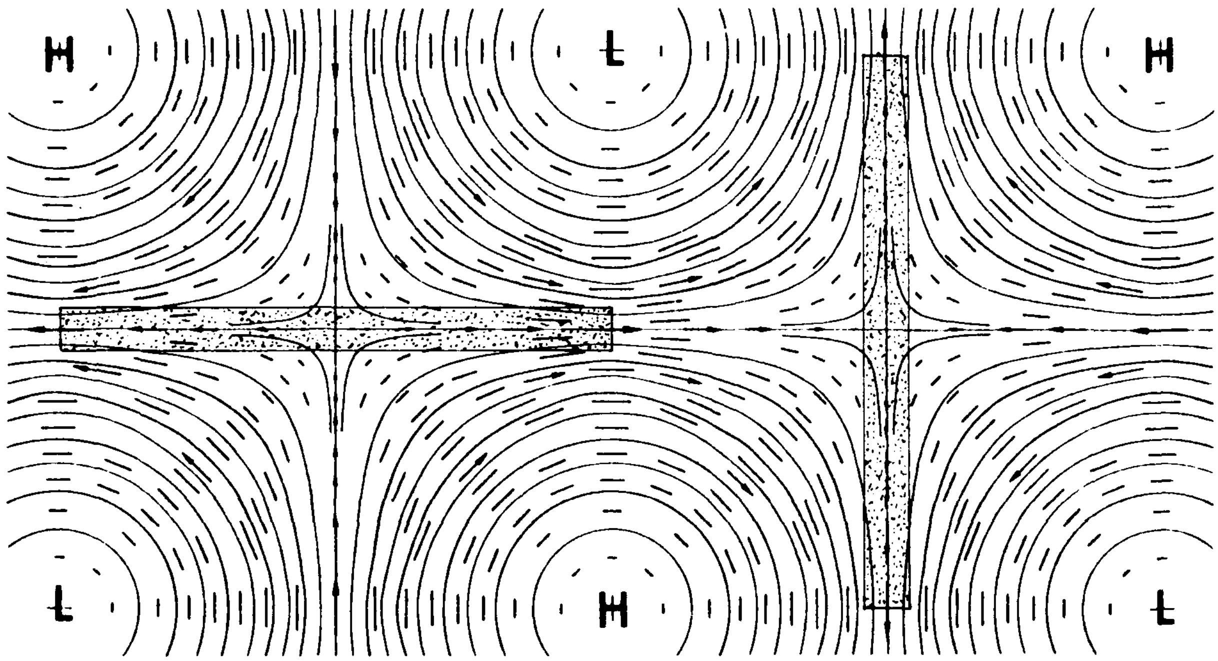



FIGURE 1

In the motion field shown, air parcels would be undergoing deformation over most of the area of the drawing; however, the term "deformation zone" is most often used to describe the regions near the centers of the cols -- where the parcels (and clouds) undergo obvious contraction in one direction and elongation in the orthogonal direction. On satellite pictures, cloud bands and boundaries are frequently observed along the elongation axis (or the confluent asymptote) of the col region. These elongated zones or bands - shown as shaded boxes on the drawing - are called "deformation zones".

If the motion systems involved are not moving, or are moving slowly; the "deformation zones" will correspond to the confluent asymptotes of the cols in the streamlines, or to the elongation axes of the hyperbolic regions. However, most systems are moving, so this relationship between the "deformation zones" and the streamlines is not valid. Consider the next drawing.

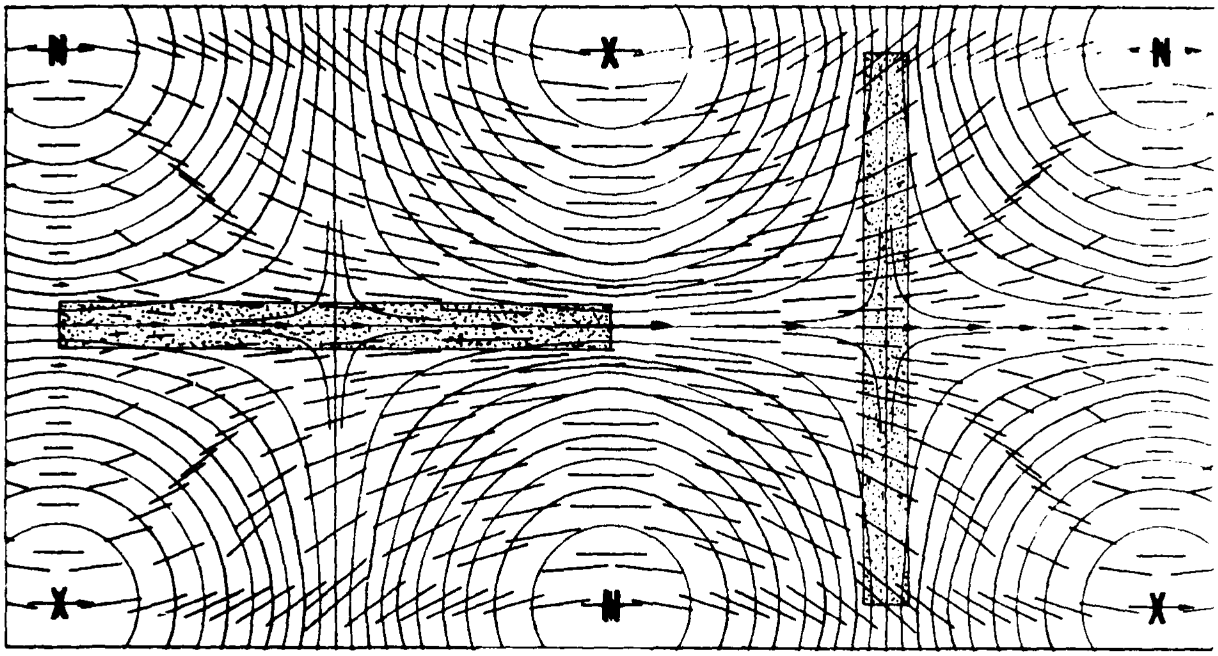



FIGURE 2

Here I have depicted the same set of fluid motions as in drawing one, except that the entire system is undergoing an eastward translation (toward the right). Again, the short lines represent wind vectors; but the long lines do NOT represent streamlines in this case. Streamlines could be drawn tangent to the wind vectors. If they were, no col region or neutral point would be present.

The long lines represent what the streamlines would be IF THE EASTWARD TRANSLATION WERE SUBTRACTED OUT of the wind vector field. In other words, the wind vectors (short lines) represent the motion with respect to the ground; and the long lines represent the motion of the parcels with respect to each other. In this case of translating systems, the "deformation zones" are again shown as shaded elongated boxes. They correspond to the elongation axes of the cols of the "relative motion" streamlines. Note the "deformation zone or band" oriented north south. As the system translates along (eastward), the air to the rear of the band is catching up to the band, and the air in front of the band is falling back toward the band. This air, which is coming together in a relative sense from east & west, is also departing in a relative sense to the north and south. In the relative motion of the air with respect to itself, it is approaching the axis of the deformation band asymptotically.

In the drawing (#2 above) the wind vectors or a set of streamlines drawn to them would not readily reveal the location of the deformation zones. I once thought that the deformation zone axis would be revealed by the inflection points of the wind field streamlines, but that is not correct (in the drawing or in the atmosphere).

The lines that do show the deformation axes are the relative motion streamlines. These would correspond closely to relative vorticity isopleths, and less closely - but decently - to the absolute vorticity isopleths. So, the circulation centers shown in the relative motion correspond closely to vorticity centers. Of the prog and analysis charts routinely available, the "deformation zones" are best related to the cols formed by the vorticity isopleths.

Note that the maximum wind vector on the second drawing is the one in the center of the drawing. The 2 deformation bands shown have a systematic relationship to the wind maximum - one band in advance of and orthogonal to the max wind - and one band to the rear and parallel to the max wind. This is an important relationship.

## 2. Jet Stream Structure: "Channel Jets" & "Advection Jets"

The "jet stream" can be thought of as some continuous belt of strong upper level winds encircling the world, which meanders meridionally in wave motions; or as several such belts with names like: "polar jet", "subtropical jet", or "arctic jet". An alternative approach is to consider these strong middle and upper level wind zones as separate (but interrelated) jet stream segments or "speed maxima", whose change with time (formation & dissipation, intensification & weakening) is of nearly equal importance as their movment. This second approach is much more useful for understanding & interpretating the behavior of cloud systems observed on satellite pictures.

If we use this second approach - thinking of the "jet stream" as an array or group of "jet segments" or "speed maxima" - then, it is also very useful to categorize the jet segments into at least two different types. I call these two types: "channel jets" (or jet channels or merely channels) and "advection jets". By definition, the difference depends on the relation between the height contours and vorticity isopleths on the 500mb surface.

If - along the zone of strongest winds or height gradient - the vorticity isopleths are parallel to the contours, the maximum wind zone there is called a "channel jet" or is "channeled". If - in the strong wind area - the contours are NOT parallel to the vorticity isopleths - but cross at large angles, the max wind zone there is called an "advection jet".

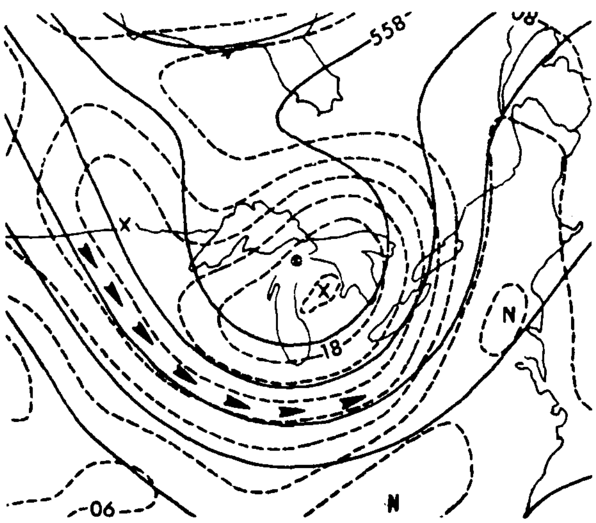



FIGURE 3

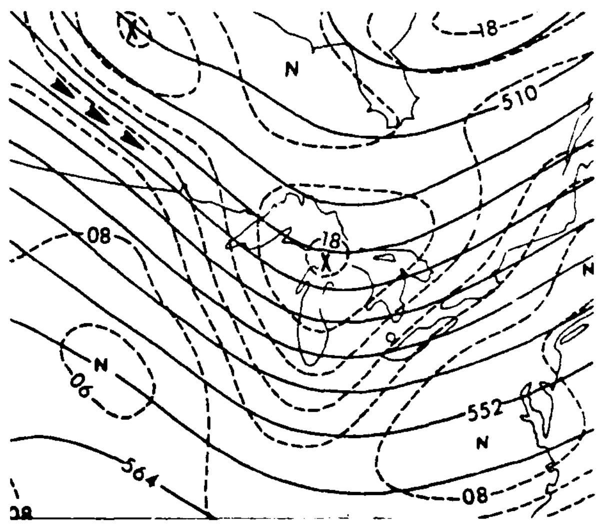



FIGURE 4

**Examples of the two types of jet structure are shown on 500mb analyses in Figures 3 and 4. Solid lines are height contours and dashed lines are vorticity isopleths. Arrowheads have been placed along the strong wind zone where it is "channeled". The vorticity maximum in the center of Fig 3 has a "channeled" zone around its southwestern quadrant. The strong wind zone in Fig 4 is mostly of the "advection" type, except in the northwest corner of the drawing.**

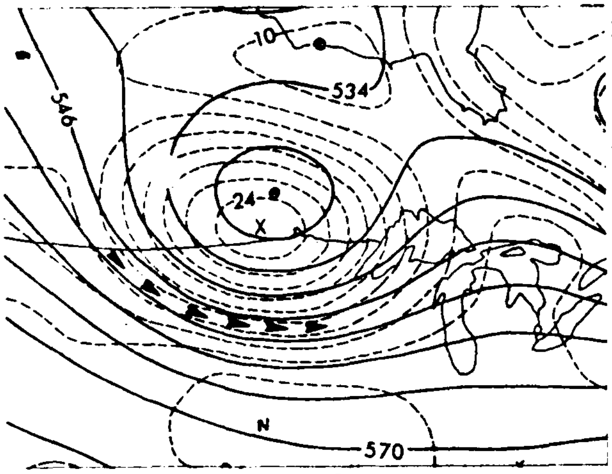



FIGURE 5

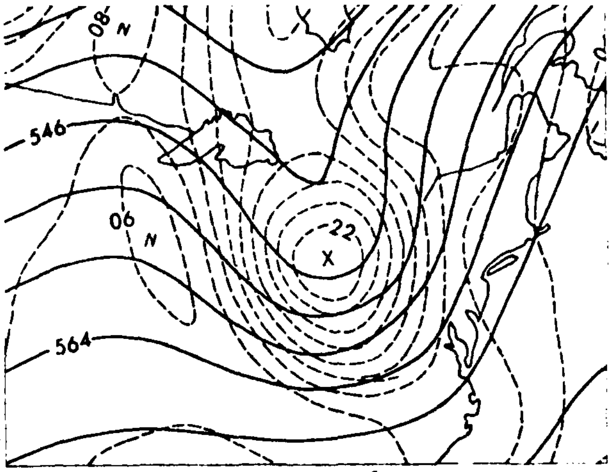



FIGURE 6

In Figure 5, a strong well defined "channeled" jet segment south of the vorticity maximum is identified by arrowheads. The vorticity maximum in Figure 6 has no "channeled" region in its strong wind zone.

Two more examples are shown in Figures 7 and 8 below. There are several vorticity maxima in each figure.

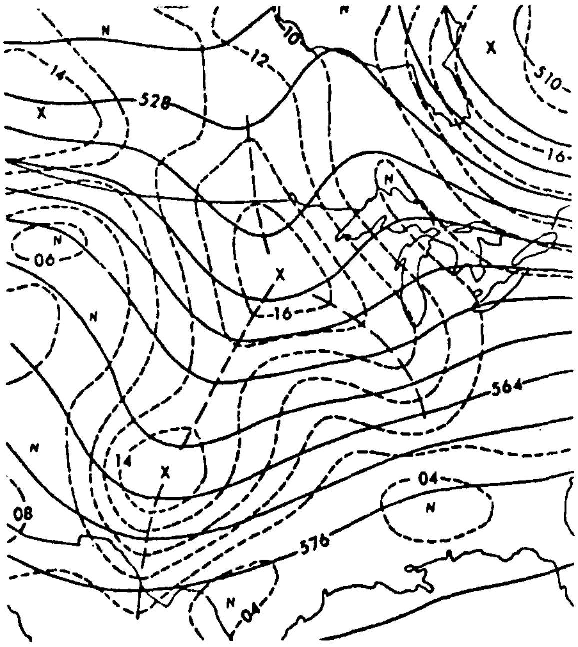



FIGURE 7

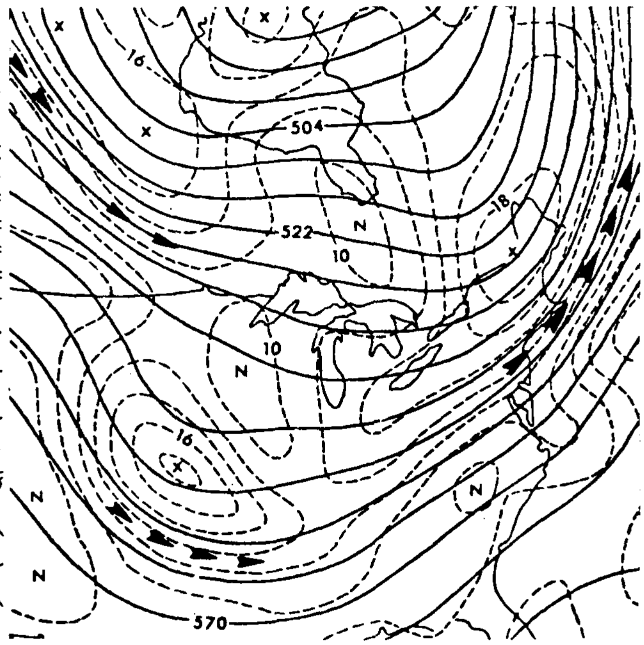



FIGURE 8

In Figure 7, the maximum wind zones are primarily of the "advection" type. In Figure 8, several "channeled" zones are present (identified by arrowheads).

Some characteristics of "channeled" and "advection" type wind maxima are listed on pages 6 & 7.

## 3. Vorticity "Lobes"

A vorticity "lobe" is an elongated ridge or trough in the vorticity field. Use of the terms "vorticity ridge" or "vorticity trough" is confusing (A "vorticity ridge" is usually found with a "trough" in the pressure or height fields). So, I will use the word "lobe", which I first heard used in this purpose by meteorologists at the NESS San Francisco SFSS.

An "advection lobe" is a lobe of vorticity whose axis crosses the height contours or streamlines at large or significant angles. (See lobe "E-F" of Figure 10 and the lobes identified by dashed lines in Figure 7.)

A "shear lobe" is a lobe of vorticity whose axis is parallel or nearly parallel to the height contours or streamlines. In Figure 9, lobes "A-B" and "C-D" are "shear lobes" maximum vorticity; they are on the cyclonic shear side of maximum wind zones. Lobe "1-2" is a "shear lobe" of minimum vorticity on the anticyclonic shear side of a strong wind zone. Note that it is the AXIS of the "shear lobe" which is parallel to the contours - not necessarily the vorticity isopleths. The axis of "shear lobe" "J-K" in Figure 11 is nearly parallel to the contours, but the vorticity isopleths cross at significant angles in a "positive advection" sense. In general, however, "shear lobes" are associated with channeled type maximum wind zones.

A "downstream shear lobe" is that portion of a shear lobe which extends downstream from the largest vorticity value (the vorticity center). In Figure 9, that part of lobe "A-B" downstream from "S" is a "downstream shear lobe", and all of lobe "J-K" (Fig 11) is downstream from the vorticity max. An "upstream shear lobe" extends upstream from the vorticity center.

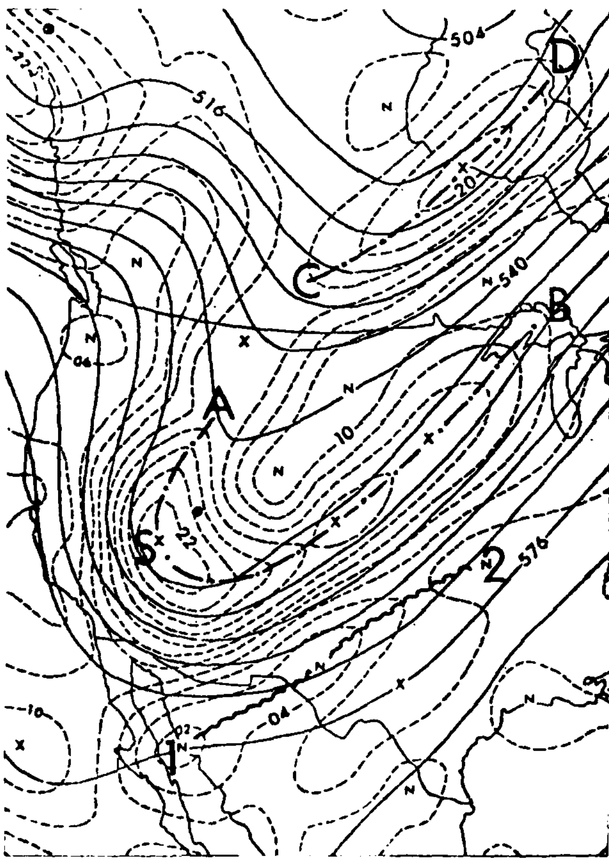



FIGURE 9

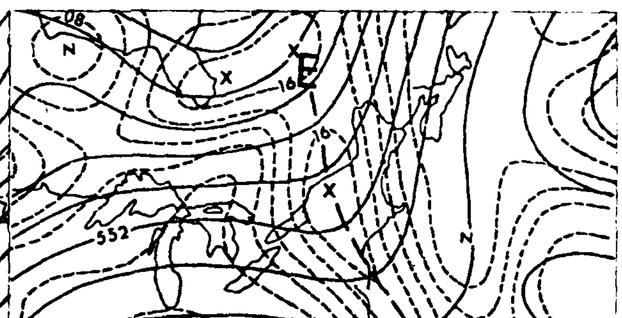



FIGURE 10

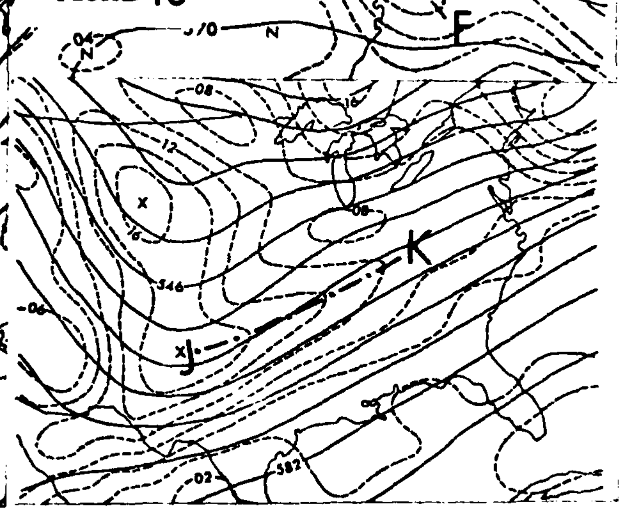



FIGURE 11

The following observations regarding jet stream structure are supplemental to the notes. The information is useful, but not essential, to understanding the remainder of the notes.

## CHARACTERISTICS OF THE "CHANNEL" & "ADVECTION" TYPES OF JET STRUCTURE

1. Where the jet stream is in the "CHANNELED" configuration:

   a. Vorticity lobes are oriented parallel to the streamlines or height contours. (At 500mb)

      Generally, well defined shear lobes are associated with channeled jet structure. Vorticity advection is often present, but not along the associated maximum wind zone.

      All "jet channels" do not have shear lobes present. (This is partly dependent upon the grid interval of the analysis model and upon the density of upper air data.)

   b. The axis of maximum winds at 500mb, and usually the jet stream axis also, is parallel to the streamlines and to the height contours.

      The axis of maximum winds on a given upper air chart - such as 300mb - will usually parallel the same height contour thru the channeled region.

   c. The jet stream axis of maximum winds tends to be better defined over channeled regions (and is even better defined when a vorticity shear lobe is also present).

   d. The overall strongest winds aloft are usually found in the channeled regions as opposed to the advection structured regions.

   e. Within all well defined channeled regions, the 500mb isotherms are parallel to the streamlines, height contours, and the axis of maximum winds. During the winter season in mid latitudes, well defined channeled regions have large vertical depth. In those cases: the 1000-500mb thickness isopleths are also parallel to the axis of maximum winds, and there is little change of wind direction with height within the channeled region.

2. Where the jet stream is of the "ADVECTION" configuration:

   a. Vorticity lobes are not parallel to the winds, but cross the streamlines and height contours at significant angles

   b. The axis of maximum winds is NOT PARALLEL to the wind direction, nor to the contours.

      - Over PVA areas: the axis of maximum winds on a given upper air chart shifts to lower height contours in a downstream direction. (usually a poleward shift)

      - Over NVA areas: the axis of maximum winds on a given upper air chart shifts to higher height contours in the downstream direction. (usually an equatorward shift)

c. The jet stream axis of maximum winds is not as well defined over regions of "advection jet" structure, as it is over "channeled" regions.

3. In general, channeled jet structure is more often associated with higher amplitude systems (troughs & ridges); and advection structure with lower amplitude systems. In other words, a closed low (aloft) is more likely to have channeled jet structure than an open wave is. But this isn't always so - see for example figures 7 & 8. The cloud patterns and their behavior are better related to the jet structure than to the wave amplitude.

4. Since the strongest - best defined - maximum wind zones are found in the regions of "channeled" jet structure, and the weaker - less well defined - segments of the "jet stream" are found in the "advection jet" regions; we could consider the "jet stream" as consisting of a series of "speed maxima" in the channeled regions connected by advection jet segments.

The classical "speed maximum" (such as the one depicted in the center of the drawing of Figure 2 of these notes) is a jet stream segment of the "channeled" type.

## B. GENERAL RELATIONSHIPS BETWEEN CLOUD PATTERNS & JET STREAM AXES

In this section, I will discuss some general relationships between jet stream axes and cloud patterns observed on still pictures (visible or infrared images). More information - and in quantitative format - can be obtained from satellite data by using other techniques, such as measuring cloud element motion in time sequence images, or by measuring density gradients The objective of using the relationships presented here, is to be able to qualitatively locate the axes of the jet streams. If synoptic scale accuracy of 100% is defined as the kind that can be obtained over the U.S. upper air network using operational real time analysis techniques; then, I would say that we can locate the "jet stream" axes from still pictures with about 75% to 85% accuracy.

The task of doing this can be complex - the difficulty depends upon the amount of detail required, and upon the type of atmospheric environment involved. There are many variations that can fool even the most experienced observer. I will discuss many of these variations in following sections of the notes; but, first, it is useful to present some generalized relationships.

If I were asked to provide a simple technique of locating the jet stream axes from still satellite pictures, I would suggest using the following 4 "rules".

---

1. When a well defined poleward side border exists along a large cirrus deck, the axis of a jet stream is likely to be located along the border and just to the clear side of the edge. (The relationship of such cirrus borders to the jet stream was reported by Oliver, Anderson, and Ferguson (1964), and has been discussed in various literature since that report.)
2. Cloud pattern borders or edges of cloud decks formed ACROSS the jet stream, move faster at the jet axis - the wind maximum produces a bend or apex in the cloud border at the jet axis.
3. Low and/or middle clouds are often distinctly different on opposite sides of the jet stream axis. (This type of relationship was pointed out by Oliver (1968)) And the nature of cloudiness along a low level frontal zone is related to the location and character of the upstream jet stream.
4. The location of the jet axis can be interpolated between locations found by rules 1, 2, & 3.

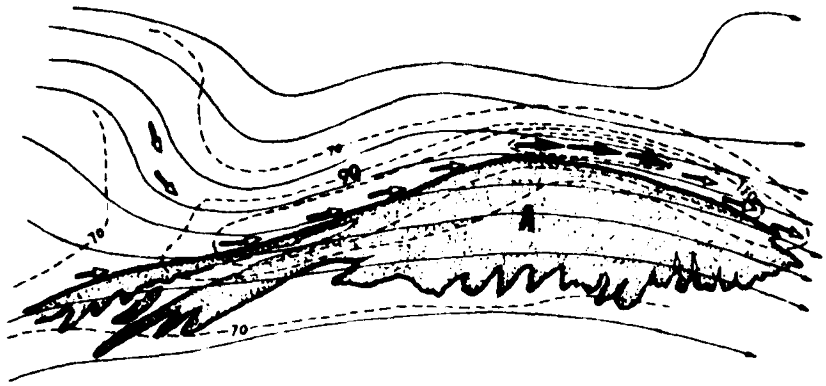
---

Each of the 4 "rules" or relationships listed above is discussed and illustrated in the remainder of this section. The rules are based upon generalized relationships. There are many exceptions and other variations. Many of these variations are systematic and repetitious; they involve specific cloud patterns and related jet stream characteristics, and will be illustrated and discussed in later sections of the notes. An expanded discussion of the above 4 rules follows:

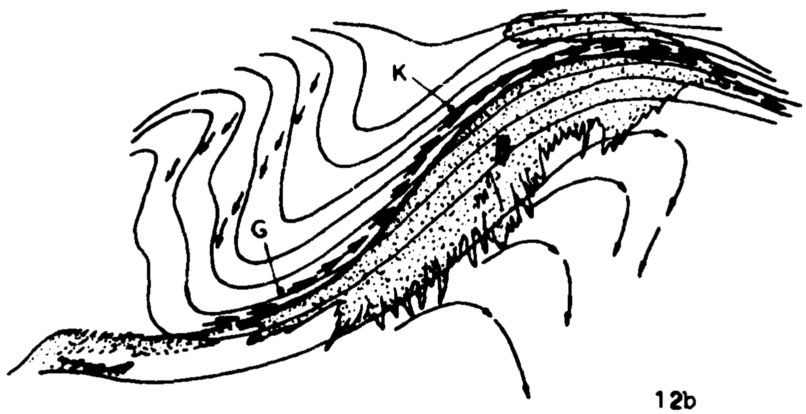
1. **Cirrus cloud decks tend to form or persist on the anticyclonic shear side of the jet stream axes - with a well defined cloud border along the axis.**

Axes of maximum winds <u>aloft</u> act as a border between dry air on their cyclonic shear sides and moist air on the anticyclonic shear sides. This high level moist to dry boundary is often very distinct & well defined - even when high clouds are not present. Thus, if we observe a cloud pattern with high cold cirrus tops and a well defined poleward side border; it is probable that the axis of a jet stream is located parallel to the border - just on the clear side.

Two examples of such cirrus decks are shown in the drawings of Figure 12 below.



12a




12b

Figure 12:

In both drawings, thin solid lines represent 300mb streamlines; short arrows depict the location of maximum 300mb wind speeds; shaded areas are cloud patterns with high cold IR tops.

The thin dashed lines on Fig 12a (top) are isotachs at 20 knot intervals.

On Fig 12a - along the jet axis, the greastest wind speeds (over 150 kts) are shown by solid arrows. In that region, the jet is channeled, the axis of max winds and the cloud border are parallel to the wind direction.

These are common types of very large "baroclinic zone" cloud systems where the relation between the cirrus border and the jet stream axis is a good rule. Cloud system "A" of Fig 12a is primarily located over a low amplitude upper level ridge with the jet structure channeled or nearly channeled along most of the cloud border. This synoptic location - an anticyclonically curved & channeled jet stream - is the most common. The second most common synoptic location for cirrus borders along the jet axis is on the front side (east side) of a high amplitude trough, such as depicted on Fig 12b as cloud system "B". Note that along the cloud border between points "G" and "K" the axis of maximum wind is not parallel to the wind direction and that the streamlines cross the border and the axis. The jet structure there is of the "advection (PVA)" type. Dowstream from "K" over the ridge, the jet is channeled. At times cirrus borders are found along the jet axis at the base of troughs and on the west (back) side of troughs - even with high amplitude ones. These cases (not depicted) are much less frequent than on the front side of troughs and over ridges; and when it happens the jet is in the channeled or nearly channeled configuration.

Rule number 1 can be used to identify or locate the jet stream axes about 25% of the time. Or - to put it another way - of the identifiable well defined jet stream axes about 25% will have cirrus on the anticyclonic shear side with a well defined border along the jet axis. When satellite moisture channel data data becomes routinely available in a useful format, the above percentage will significantly increase. (My guess is that it will double)

Not all cirrus decks with well defined borders or cirrus bands are located along the jet axis. There are two types of cloud patterns that occur frequently, and are exceptions to Rule 1. One type is called (by me) a"baroclinic leaf", and the other is a "deformation zone" band or boundary. These will be discussed later in the notes.

The cirrus decks found to the right side (northern hemisphere) of jet axes are called (by me) baroclinic zone cirrus. This type of cloud pattern and Rule 1 will be discussed in more detail in Section C of the notes. (This is Sec B)

2. | Where "baroclinic zone cirrus" is not present, but other high or middle level clouds are, cloud bands and boundaries will be most advanced downstream where the jet stream axis crosses them. |

An illustration of this concept is shown in Figure 13 below.

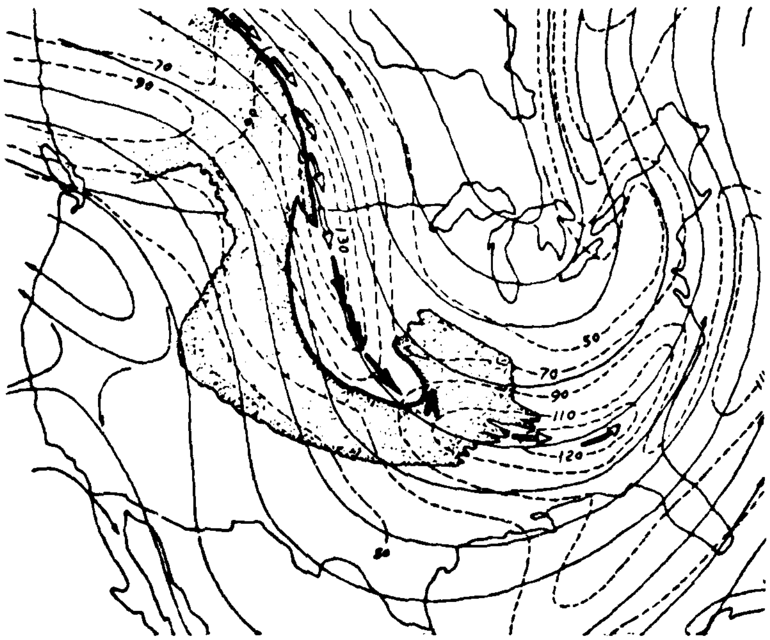



Figure 13

The drawing shows 300mb streamlines (thin solid lines) and isotachs (dashed lines) with the cold cloud area shaded and the axis of maximum winds marked by arrows.

Note location "A". The clearing zone just to the rear of "A" is most advanced downstream under the axis of maximum winds.

Frequently cloud bands and borders (especially on the upstream side where the borders are usually most well defined) form a "U" or "V" shape with the axis of maximum winds in or over the slot.

This situation usually occurs where the jet stream is NOT channeled, and is common with the cloud patterns of short-wave scale systems - especially when the system is in a long wave zonal pattern or on the front side of a long wave ridge.

Details will be discussed in Section E of the notes. Rule 2 allows us to locate the axis of maximum winds another 25% of the time.

3. When no high clouds (with tops at jet stream levels) are present, the axis of the jet stream will often be revealed as a boundary or interface between different types of low level cloud cover.

An example of this is depicted by Figure 14 below.

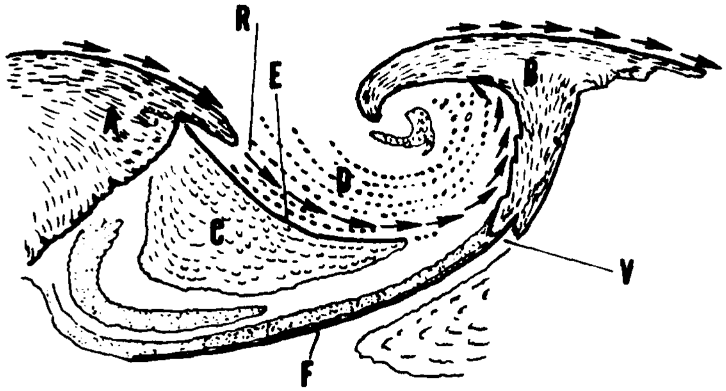



Figure 14

Cloud patterns "A" and "B" are high cloud systems. Cirrus level tops are present. Arrows represent the jet stream axis

On the drawing, line "E", which is parallel to the axis of maximum winds aloft, is an interface between two different types of lower level clouds. Such interfaces are most commonly found over oceans or when abundant low level moisture is present elsewhere; and in the synoptic location shown (on the downstream side of a ridge aloft and extending to the next trough).

Over oceans, the clouds (at "D") on the north side of the interface are convective cells with little or no persistence of debris at their tops. The clouds at "C" are similar convective cells with "outflow layer" debris spreading and persisting in a stable layer near the cloud top level. At middle levels in the jet stream baroclinic zone along "E" there is a strong temperature gradient with cooler air over the "D" type clouds, and warmer air over the "C" type clouds. Thus, there is a stable layer over the "C" area clouds - perhaps even an inversion.

I have found that the cloud interfaces - such as "E" - are usually parallel to the associated jet stream axes, but are usually farther south than the jet axis (typically from 1 to 3 degrees of latitude). The position of the interfaces that I studied carefully, corresponded best with the axis of maximum winds at 700mb.

My observations are that the jet stream related lower cloud interfaces are most likely to be present when the associated jet stream is: (1) well defined, (2) in a channeled or nearly channeled configuration, (3) vertically deep in the atmosphere, and (4) over the ocean or some other source of abundant moisture.

Over land, similar boundaries - as that located at "E" - sometimes occur; but the cloud patterns are often more complicated and depend upon variations in available moisture. There are differences in cloud type and large diurnal variations superimposed upon the synoptic pattern changes. Many times - without sufficient moisture - there are no low or middle clouds present, although the jet stream conditions are adequate. When low level moisture is sufficient, the most prevalent cloud condition is to have an overcast deck of stratocumulus under the cyclonic side of the jet axis (in position of the "D" clouds in Fig14). When even more moisture is present, there will be a deck of altostratus (or low level convective clouds with a layer of altostratus near the tops) on the anticyclonic side of the jet axis, in addition to the overcast stratocumulus. When this occurs, the altostratus will have a well defined boundary near the axis of maximum winds at its level, and a clear band separating it from the stratocumulus.

At times - when the jet stream upstream was initially channeled with a low cloud interface present - but is changing to advection type (NVA), there will be a period of time when the interface is still identifiable and the jet is not channeled, In such cases the interface will roughly identify the jet axis position, but will not be parallel to the axis. The jet axis orientation will be rotated somewhat clockwise from that of the interface.

Such a change from channel to advection structure often occurs when the upstream ridge is building northward, (at "A" on Fig 14) or when the next short wave perturbation or speed max coming over the ridge does so at a higher latitude than the preceding one. The latter process is usually the way it happens - although the larger scale result is still that the upstream ridge has "built" northward.

Another indication of jet location and structure in the area of the "E" interface of Fig 14 is the type clouds along the frontal zone (F) that extends back from cloud system "B". Along that zone, cirrus topped clouds - likely convective in nature - extend down the frontal zone as far as "V". Note that north of "V" the jet axis is of the advection type - PVA (the arrows shift to the left as they progress downstream toward "B".) Upstream from "V" (to the west) the jet is channeled as far as point "R". Even without the occurrence of the low cloud interface at "E", we could guess that the jet was well defined and channeled upstream from the frontal zone at "V". If the jet were weaker and less well defined along "E", and strong and channeled on the front side of the trough (from "V" to "B"), convection or persistent high clouds would not likely extend down the frontal zone to "V". This relationship between the frontal zone weather and the upstream jet is a good one, EXCEPT over land during the spring and summer seasons during the afternoon and evening hours.

Rule 3 accounts for about 25% more cases of jet stream location.

4. Rule 4 is to interpolate the jet axis position between places it could be located using rules 1 thru 3.

This doesn't mean draw a straight line. We must take into account likely curvature of the axis based upon the long wave synoptic environment. We must remember to shift the axis polward where PVA is indicated, and equatorward where NVA is indicated.

Using rule 4 can enable us to locate the jet axis another 10% of the time.

**Applying rules 1 thru 4 will allow us to locate the axes of the jet streams with typical synoptic scale accuracy from 75% to 85% of the time.**

Of the remaining 15% to 25% of the time, when the jet stream axis cannot be located with synoptic scale accuracy; part of the cases will be missed because the relationships and rules presented here are not good enough. One of the following situations is likely:

a. There is no "jet axis" over the region concerned. This can occur two ways:

   (1) There is a wide zone of strong winds, but the maximum wind speeds are not concentrated in a narrow enough zone to be identified as a "jet axis".

   (2) The jet stream and its associated baroclinic zone isn't continuous between two well defined segments. Often, over an upper air ridge, the air spreads with difluence and slows into a region with no well defined baroclinity (and no strong winds).

b. There is not sufficient moisture present to produce clouds, even though the jet stream is strong and well defined.

c. High level moisture is present, with a well defined moist-to-dry border along a channeled jet axis, but clouds have not formed.

   In such cases, cirrus will often form suddenly on the right side of the jet axis, as the region of strong winds and moist/dry boundary progresses downstream over a mountain range. A high - cold - deck of cirrus, which we refer to as "lee-of-the-mountain-cirrus" will form downstream from the mountain range, and to the right of the jet axis. Such cirrus decks are not always on the right side of the jet axis; the occurrence seems highly dependent upon where the high level moisture is located within the strong wind zone. Lower level "lenticular" mountain wave clouds may form under such a cirrus deck. When the high level cirrus is confined to the right side of the jet axis, the lower level lenticular wave clouds will often extend out from under the cirrus well to the left side of the axis.

   Cirrus formations similar in appearance & behavior to the "lee-of-the-mountain-cirrus" decks, will also form suddenly as such a jet stream moisture deck passes over a lower level trough or frontal zone.

## C. "BAROCLINIC ZONE CIRRUS" PATTERNS and the JET STREAM

The drawing in Figure 15 below depicts a typical "baroclinic zone cirrus" cloud system with 300mb streamlines and isotachs superimposed. Such cirrus patterns were introduced as Rule 1 of the preceding section.

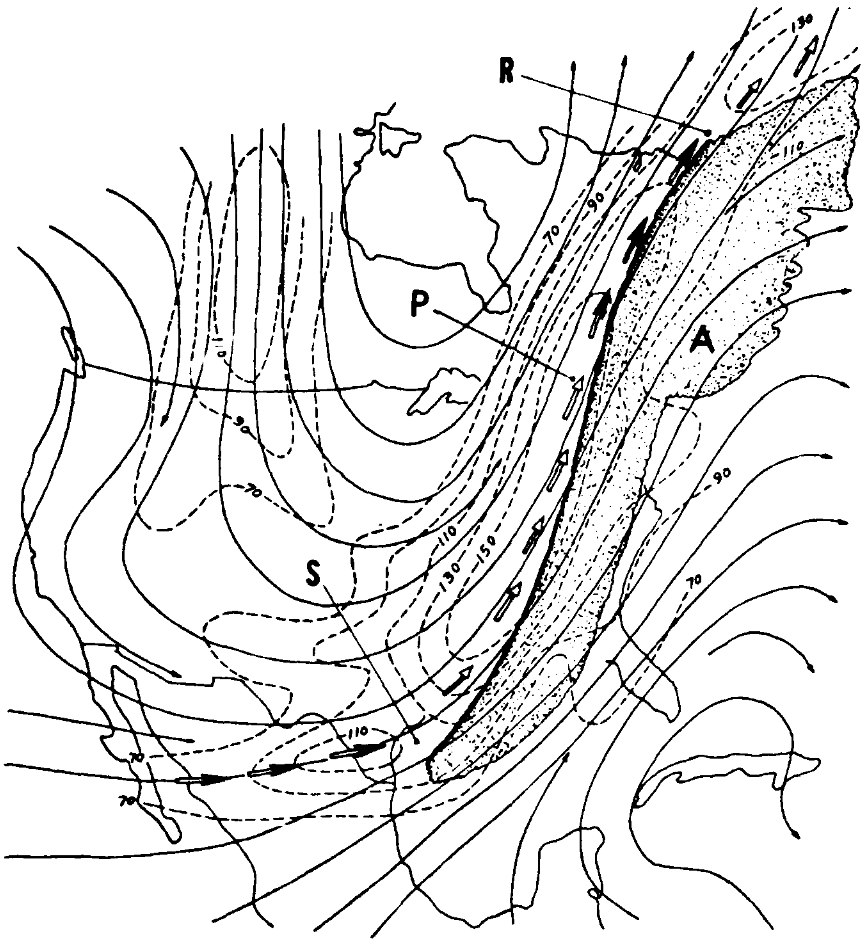



FIGURE 15

The cloud system - labeled "A" has a distinct well defined border in a shallow "S" shaped curve on its western and northwestern side. Arrows are drawn along the axis of maximum winds, and the arrow heads are solid where the jet stream is channeled. The jet stream is in the advection mode where the arrow heads are open (PVA type from "S" to "P", and NVA type downstream from "R"). Note that along the clear side of the edge from S to R wind speeds are generally over 130 kts without large or complicated variations. There are speed minima (along the jet) at S and R.

Using Rule 1 to locate the axis of maximum winds just on the clear side of the distinct cirrus edge of cloud system "A" would work well. When such a large well defined cirrus edge is located on the front side of a large high amplitude trough - as in Fig 15 - the cirrus is most likely of the "baroclinic zone cirrus" category, and Rule 1 can be applied with high reliability.

As noted, such cirrus decks with their distinct edges parallel and just to the right (northern hemisphere) side of jet stream axes are most frequently observed on the front side of troughs and over ridges (where the jet axis curves anti-cyclonically with a ridge or vorticity minimum on its equatorward side.) Often the same cirrus deck on the front of a trough - where the moisture is being accumulated aloft - extends over the downstream ridge.

I call such cloud decks "baroclinic zone cirrus" because they are associated with the jet stream baroclinic zone aloft. In a case as in Fig 15, where the trough is high amplitude, large, in the main belt of the polar westerlies; the cirrus deck would represent the top of a deep cloud system and deep baroclinic zone with a well defined surface frontal zone (probably along the east side of the cloud pattern from S to P -- and in the middle from P to R). A decent question follows: why not just call the cloud pattern "frontal zone clouds" or "Frontal zone cirrus" or something? The reason is that not all jet stream related high level baroclinic zones have lower level related fronts; and in many situations, when they do, the lower level frontal zone varies considerably in location and character from the high level one. Yet, the high level cloud patterns have the same relationships to the hgih level wind field. Therefore, it was necessary to differentiate the high level baroclinic zone cloud system from low level fronts.

The following "boxed" information is not essential to notes

After considerable study of the jet stream related edges using satellite pictures, film loops, soundings, cross sections, time-lapse movies looking upward, etc, --- I still do not really understand why they are there.

But here are some observations:

The clouds are on the warm side of the jet - based upon the temperature field below the level of maximum winds (say at 500 mb typically). But above the level of maximum winds this is the cold side (say at 200mb on a typical case). Cloud top temperatures indicate that the clouds are at or extend up into the cold air above the level of maximum winds. Thus, I believe that the distinct edge we see on the satellite pictures represents a boundary between warmer drier air to the left of the jet axis, and cooler moist air to the right in the anticyclonic shear zone.

In most cases, evidence indicates that the distinct border is associated with a zone of sinking air and high level convergence along the edge. I now believe this is so even along the PVA structured segments - such as from S to P of Fig 15 where the streamlines cross the edge from the clear toward the cloudy side. It appears that - in a relative motion sense - the moist air (although moving toward the cloudy side with respect to the ground) is losing ground with respect to the moving border and sinking; while the dry air is catching up to the border and sinking. This correlated with the observations that the greatest wind speeds are not exactly at the edge, but on the clear air side.

Along the NVA type segments of the edges it is much more obvious that the clouds are dissipating rather than forming at the edge. The streamlines cross from the cloudy toward the clear side. NVA correlates with upper level convergence and sinking, etc.

Along the channeled regions - where the correlation between the cirrus edge and the jet stream axis is highest - the streamlines are parallel to the edge on a synoptic scale. However, observations indicate that strong local circulation along the edge often occurs along these segments as well, and that the air sinks along the edge.

Below, Figures 16 & 17 show two more examples of baroclinic zone cirrus decks on the front side of troughs and extending over a downstream ridge.

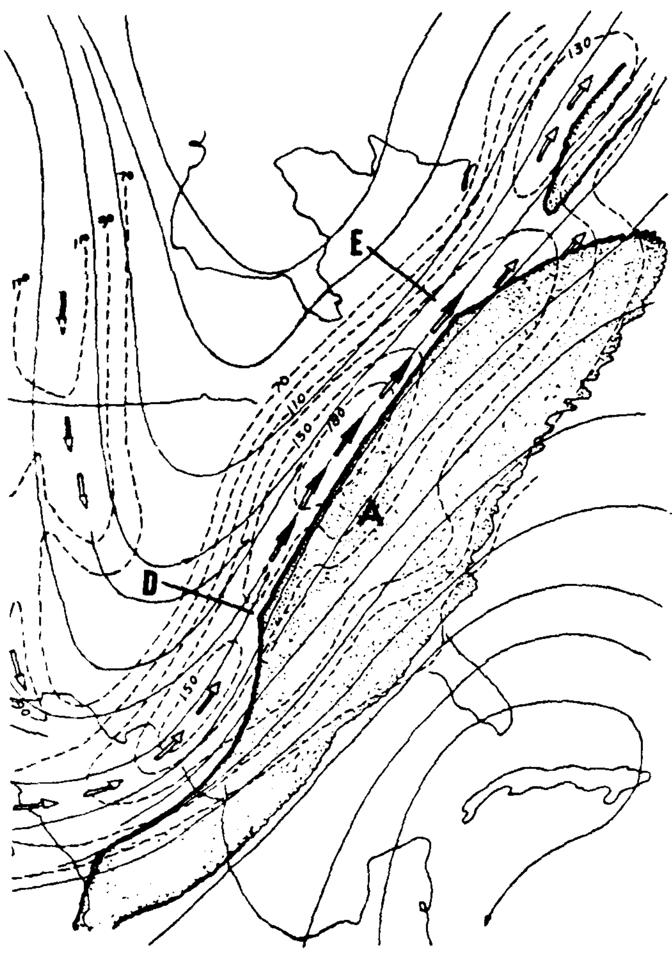



FIGURE 16

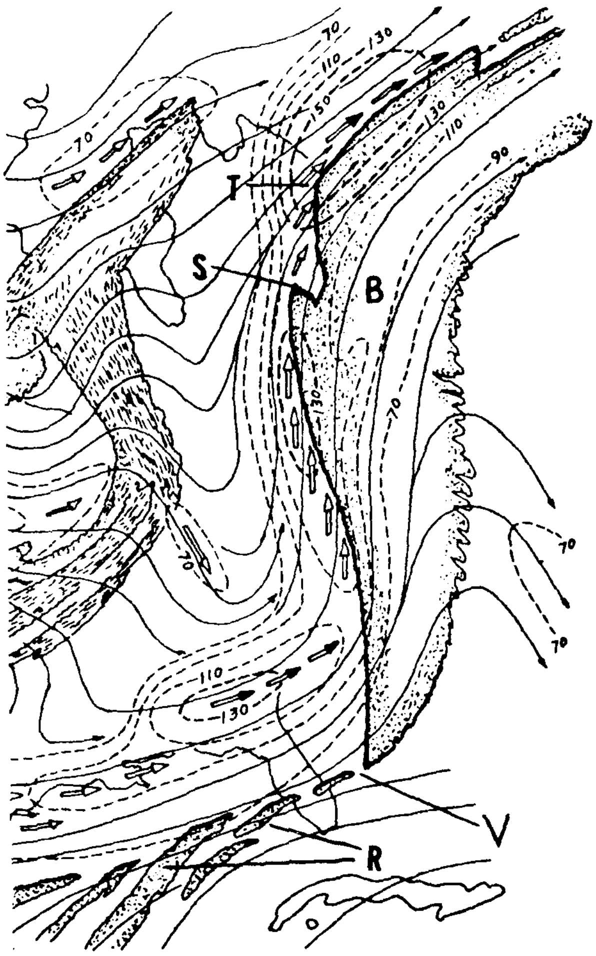



FIGURE 17

Recall that the cirrus edge in Fig 15 had a relatively straight edge along the jet axis. Its edge had a low amplitude "S" shape upstream from "R". At point "R" the edge did "bend" in an "anticyclonic" curved sense. At that point, there was a relative speed minimum along the edge, and the jet structure changed from channeled to NVA type.

Cloud systems "A" & "B" on the figures above are not as straight and uncomplicated as the one in Fig 15. Also, their associated jet streams are more complicated. In general, where the cloud edge is "bent" or broken, there is an area of lower wind speeds (relative to elsewhere along the jet). The speed maxima are along the segments between the bends or breaks. On Fig 16, the maximum winds (over 180 kts) are along a channeled segment between the bends on the cloud edge at "D" & "E". On Fig 17, the maximum winds are along the channeled segment downstream from "T". The break between "S" & "T" is associated with a relative speed minimum. In other systems, at the apex of a ridge, 3 variations are observed: a break may occur as it does at "S-T", the edge may be filled in with a sharply curved angle or bend, or a thin cirrus band may connect the points at "S" & "T" with a hole or thinner cirrus where the break is on Fig 17. All three types of cloud structure are observed with wind fields similar to the one in the "S-T" region of Fig 17.

On Fig 17, the cirrus "fingers" at "R" can be thought of as an extension of cloud system "B" upstream. If so, the break at point "V" would represent a "bend" in the opposite sense as the "S-T" region ----- a bend in the cyclonic sense associated with a trough - or a lobe of higher vorticity. As such cyclonic bends begin to occur and amplify along a "baroclinic zone cirrus" deck, the clouds to the upstream side of the bend begin to thin out or dissipate entirely. This is true even though there is still a significant speed maximum along the upstream portion of the jet - to the rear of the vorticity lobe or trough.

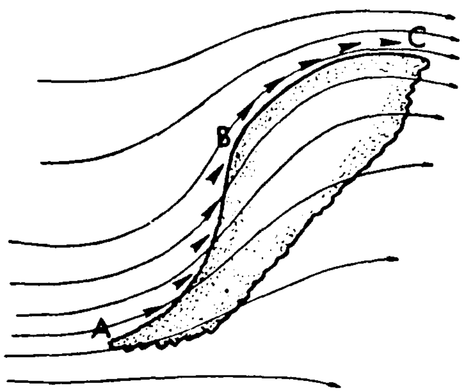



FIGURE 18a

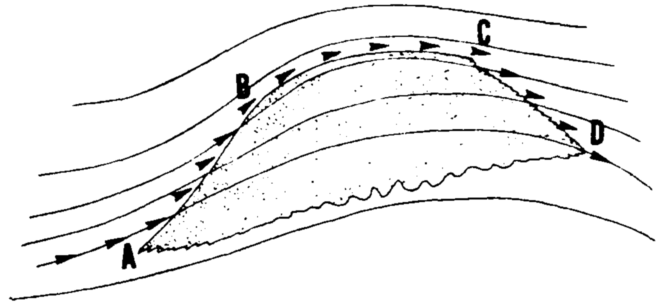



FIGURE 18b

General Relationships Between Cirrus Deck Edges and the Jet Configuration

If a "baroclinic zone cirrus" pattern has a gentle "S" shape along its west and/or poleward side edge - as in Figure 18a above - the jet structure will most likely be of "PVA/advection" type along the concave segment (or the cyclonically curved portion) and "channeled" along the convex segment (or anticyclonically curved portion). I hesitate to use the terms "cyclonic" and "anticyclonic" when describing the shape of the edge, because it implies that the wind direction or streamlines are parallel to the edge. This is true if the jet is channeled; and is a good description along the convex or "anticyclonic" segments, where the jet is very frequently channeled. Along the concave portions (segments A-B in Fig 18) the jet is most frequently of the PVA advection type, and even though the streamlines are not parallel to the edge (they cross from the clear to cloudy side) they are generally cyclonically curved at the edge. With both patterns of Fig 18, the jet is likely to be PVA type along "A-B", and channeled along "B-C". At times, such as at "C" in Fig 18b, there will be either a slight bend along the edge or a change to more ragged or saw-toothed type of border - or both. There, the jet structure will likely change from channeled to NVA type (segment "C-D" Fig 18b).

"BENDS" on the EDGES OF BAROCLINIC ZONE CIRRUS DECKS

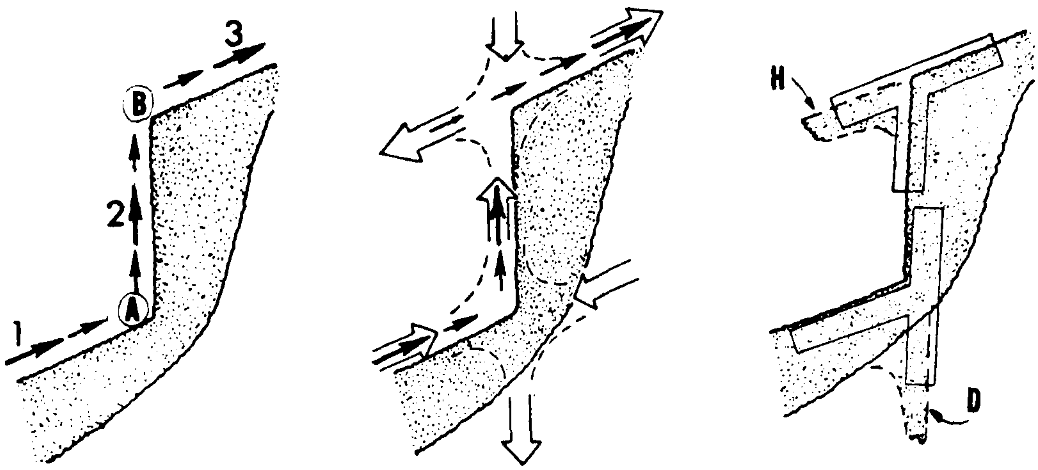



FIGURE 19a FIGURE 19b FIGURE 19c

Figure 19 above illustrates general relationships between "bends" along cirrus deck edges and the associated wind field conditions. Within the maximum wind zone along the clear side of the edge, there will be relative speed minima at the bends (at "A" & "B" Fig 19a) and maxima in between bends (at 1,2,& 3 Fig 19a). At each bend deformation will be occurring in the relative motion of the air with stretching and compacting indicated by the large open arrows on Fig 19b. The deformation regions may be associated with hyperbolic zones in the vorticity isopleths (dashed lines in Fig 19b). One of the basic cloud patterns we see on satellite pictures has a "T" shape, where the stem of the "T" is parallel to a wind speed maximum, and the cross-bar lies along the stretching axis of the deformation zone in advance of the speed max. Figure 19c indicates that the bends along the cirrus edge are related to the basic "T" pattern, except that in this case, the clouds along one of the cross-bars is missing (at "H" & "D" Fig 19c). Examples of this are shown in Figure 23.

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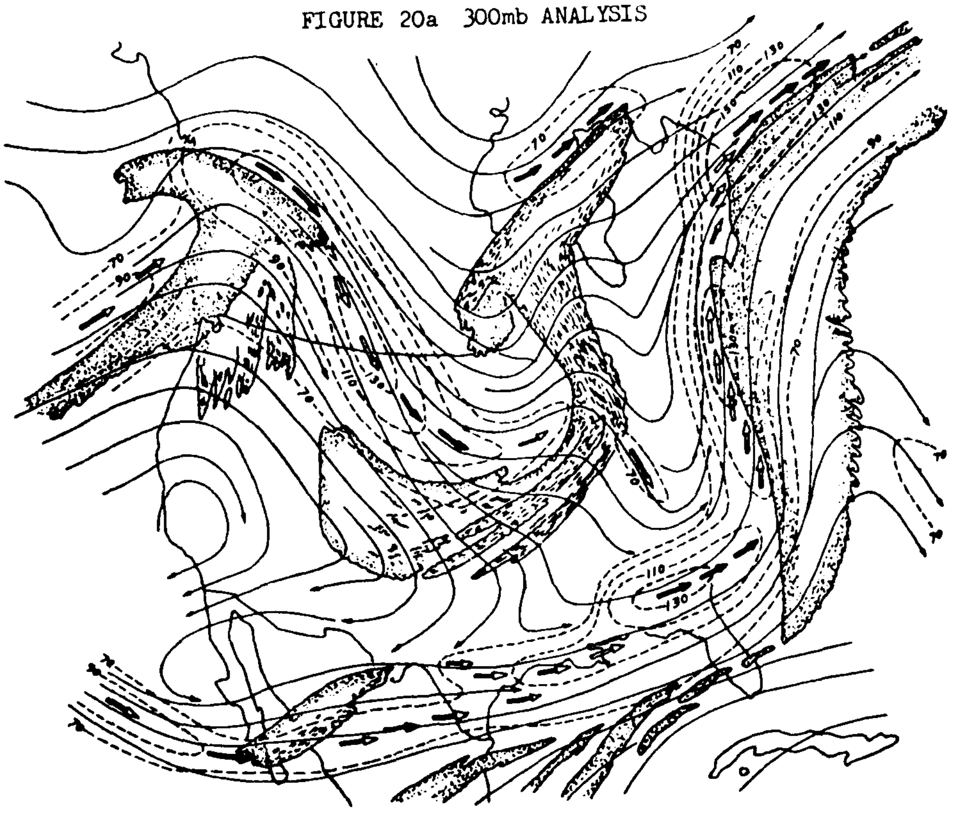
Figure 20a on the facing page shows a set of cold high cloud systems with 300mb streamlines and isotachs. The wide arrows identify axes of maximum wind speed - open arrows = advection jet structure and solid arrows = channel structure. Figure 20b depicts the same cloud systems with 500mb height contours & vorticity isopleths (dashed). Hyperbolic regions formed by vorticity isopleths are marked by letters, and bold arrowheads indicating axes of stretching in the relative motion. There is a good empiracal relationship between the vorticity col stretching axes and relative motion deformation zones discussed on page 2 of the notes.

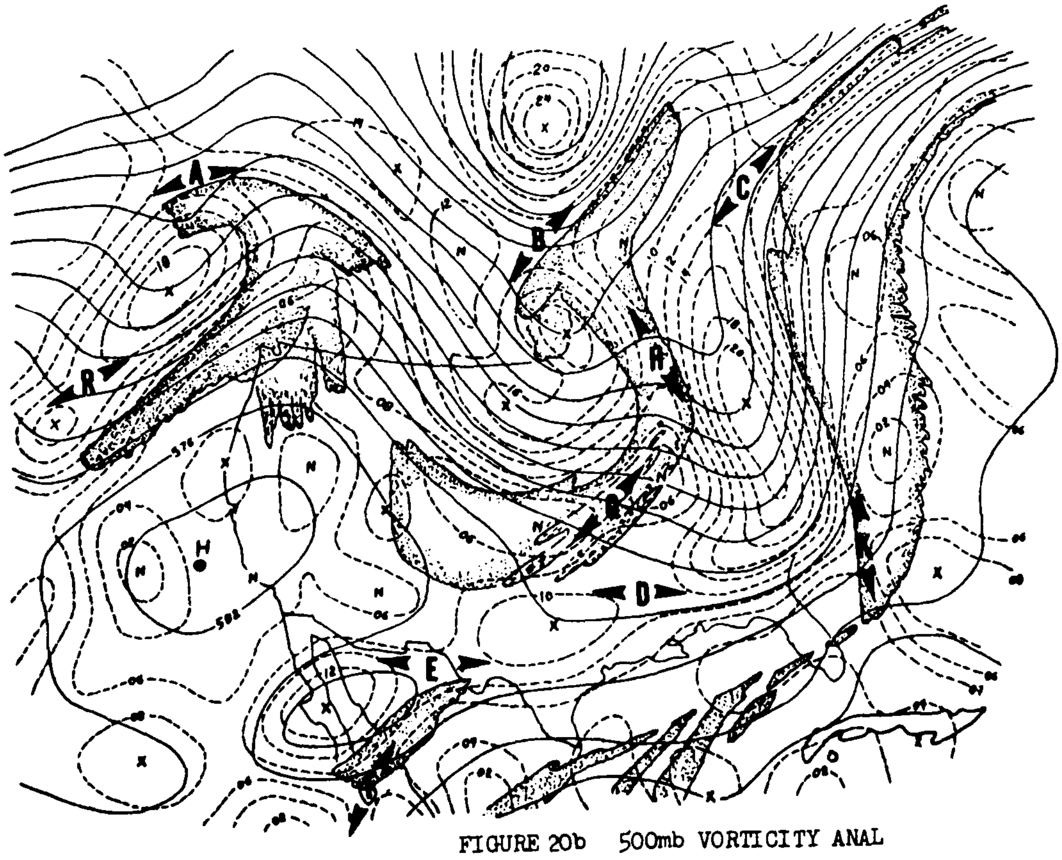
Note on figures 20a & 20b that many of the cloud edges and bands are aligned with either deformation zones, or maximum wind axes, or both. Compare the channeled regions on both the 300mb & 500mb analyses with cloud edges.

Deformation zones "A", "B", & "C" are all parallel to - and upstream from - channeled jet segments. Zones "A" & "B" are near the "head" portion of "comma patterns" and "C" is near an "anticyclonic" shape bend of a baroclinic zone cirrus deck. Deformation zones "G" & "K" are orthogonal to - and downstream from - jet channels. Note that the cloud edge north of "K" is along the PVA type max wind axis, but extends along "K" rather than back to the southwest along the next upstream jet axis.

FIGURE 20a 300mb ANALYSIS



20a



20b

FIGURE 20b 500mb VORTICITY ANAL

In cases where a cloud edge extends partly along the axis of maximum wind and partly along the associated "upstream" deformation zone - such as at "A", "B", and "K" on Figure 20 - it is very difficult to determine on still pictures which part is along the strong wind and along the weak wind deformation zone.

Figure 21 below shows another example where a cloud edge is along the weak wind deformation zone (from "A" to "B"). In this example, PVA is present along the max wind axis from "B" to "C", and the jet structure is channeled downstream from "C". A slight "anticyclonic" type bend is evident at "C". The bend has just begun to form at the time of the analysis, and amplifies rapidly afterward.

At the time of the analysis and drawing, there was no separate wind maximum identifiable in the data between "B" & "C". But, at the next sounding time, when bend "C" was large, a separate max was distinct along the "B-C" segment with a relative minimum at "C".

While bend "C" became more distinct - the angle increased; bend "B" became less distinct. The entire "A" to "C" edge became concave or "cyclonically curved", yet part was still along a max wind axis and part along the deformation zone.

From a single still picture of a pattern such as in Fig 21, I can not determine that edge "A-B" is along the deformation zone.

Some clues are given in the next section.

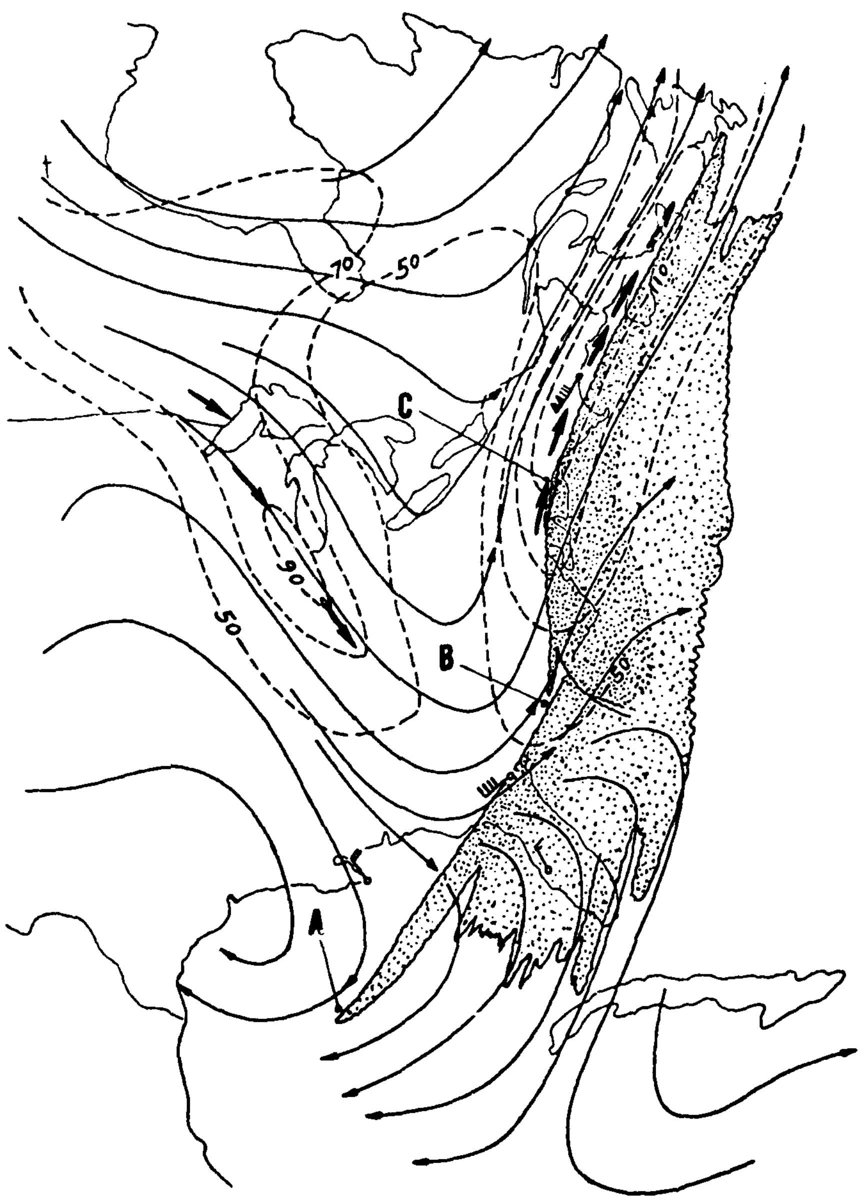



FIGURE 21 200mb Streamlines & Isotachs

VARIATIONS IN HIGH CLOUD PATTERNS RELATED TO A COMMON SET OF WIND FIELD FEATURES

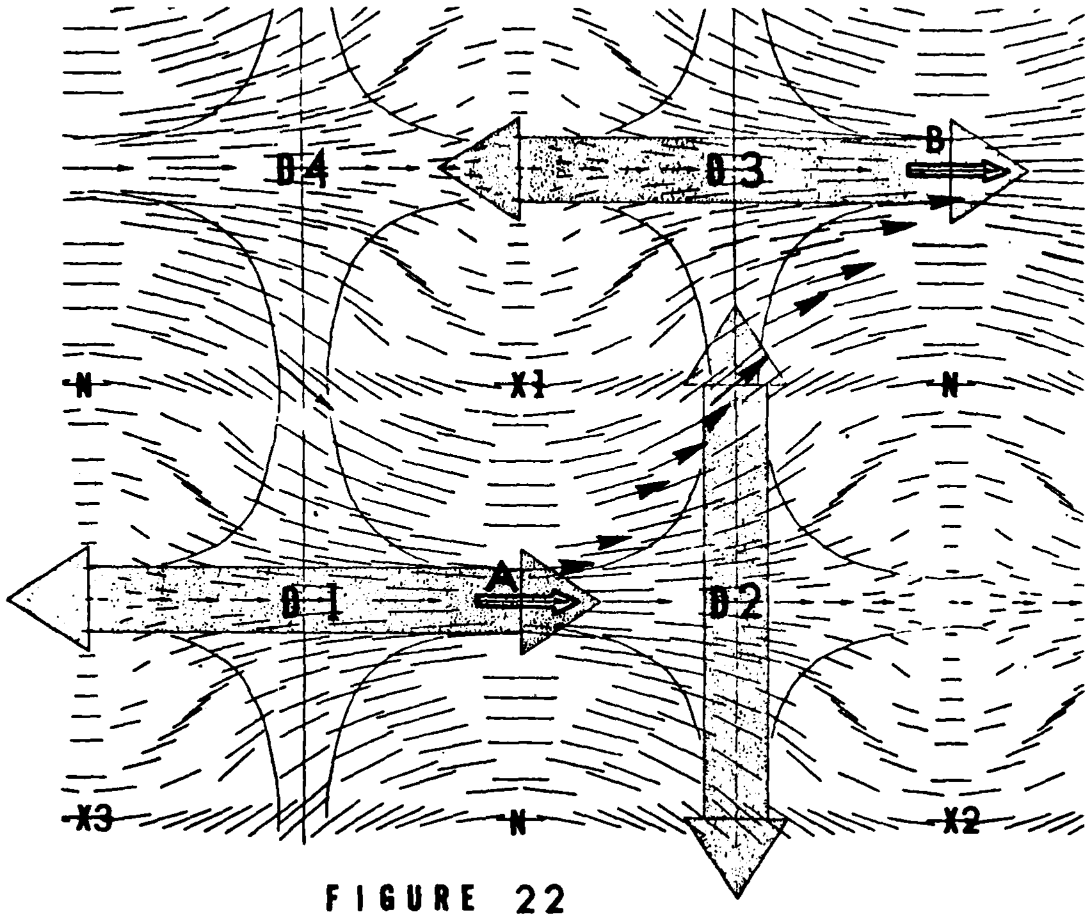



FIGURE 22

Figure 22 above shows the same set of fluid motions as in Figure 2, except that the field of view has been extended northward, and most of the "relative motion streamlines" (thin solid lines) have been removed. Recall that Figure 2 showed a field of motion consisting of two hyperbolic regions to which an equal west to east translation vector had been added. The short thin lines are resultant vectors which correspond to the wind field. On Figure 22, the remaining "relative motion streamlines" show four deformation zones, labeled D1, D2, D3, & D4. Note that only the deformation zones that correspond to D1 & D2 were shown on Figure 2. I stated that the relationship of the two deformation zones to each other, and to the maximum wind vector between them (labeled "A" on Fig 22) was systematic & important. The wind maximum at "A" is of the "channeled" configuration.

Although not as frequent, it is also common in the westerlies, to have a 3rd deformation zone and a 2nd channeled speed maximum involved, as shown in Figure 22 with deformation zones D1, D2, D3, and channeled speed maxima "A" & "B". The two speed maxima are connected by an axis of maximum winds shown by solid arrowheads.

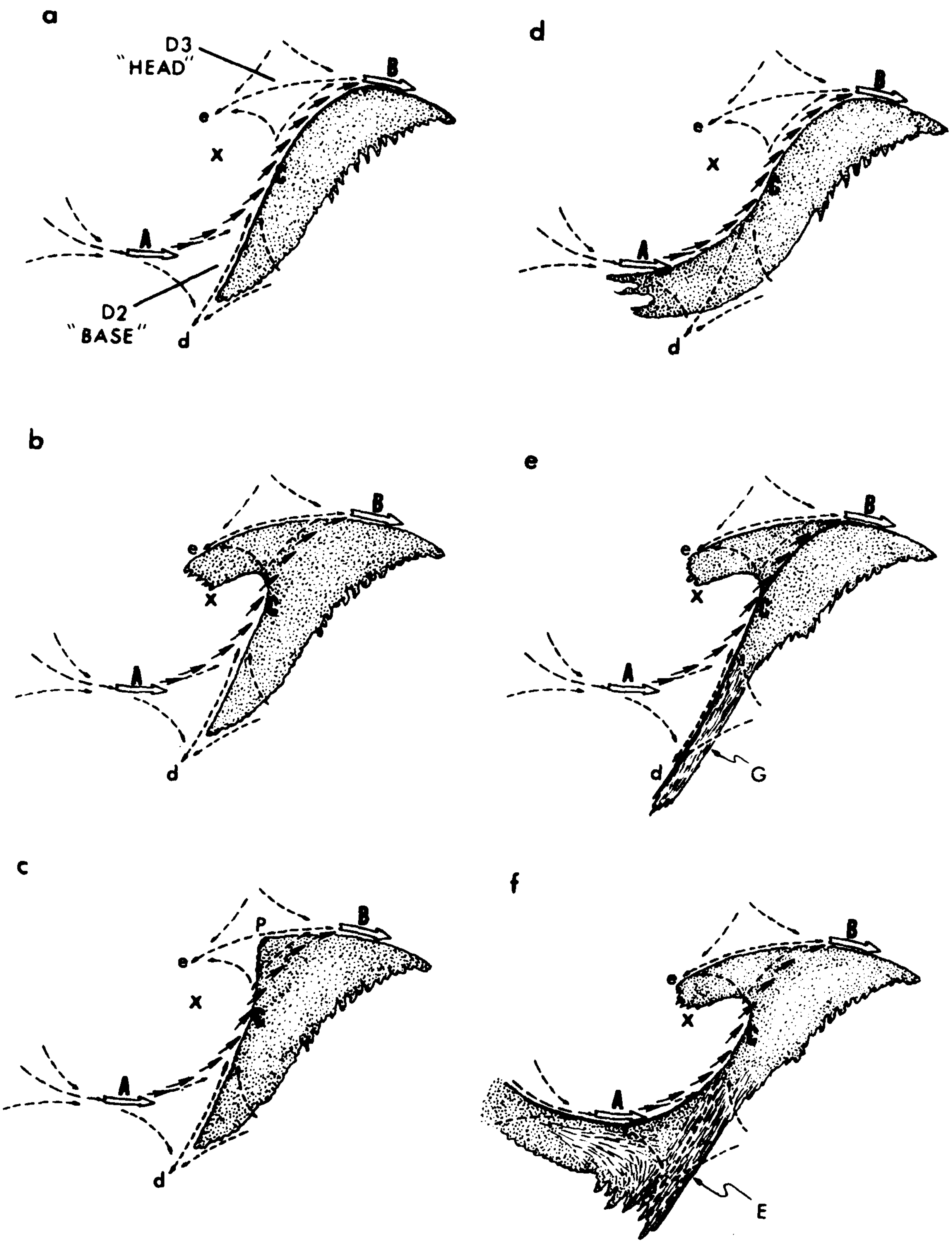



FIGURE 23

Although the motion field in Figure 22 is idealized, the basic configuration of 3 deformation zones and two channeled speed maxima occurs frequently. In Figure 23, I have repeated this basic set of features six times. The dashed lines are "relative motion streamlines" to indicate the deformation zones. More realistic curvature is shown, and only a part of the deformation zone corresponding to D1 is included. The 2 channeled speed maxima, "A" & "B" are shown by open arrows, and the axis of maximum winds connecting them is shown by solid arrows. In this configuration, I refer to deformation zone D3 as the "head" deformation zone, and D2 as the "base" deformation zone. (These are indicated on Figure 23a)

The shaded areas on Figure 23 represent variations of high cloud patterns that I have frequently observed in relation to the basic set of wind field features. There are 4 variations at the "head" region, and 4 variations at the "base" region. These are observed in different combinations. I have depicted six combinations that I commonly observe on satellite pictures.

23a: This is probably the most prevalent combination. At the "head" area, the baroclinic zone cirrus edge is along the axis of maximum winds from "C" to "B", and on downstream along the channeled speed maximum at "B". In the "base" region, the axis of maximum winds extends upstream from "C" to channeled wind maximum "A", but the cloud edge extends roughly parallel to deformation zone D2 toward "d". So, in this case, a part of the well defined edge is along the axis of maximum winds, and a part is along the deformation zone.

23b: Here the "base" configuration of clouds is the same as in Fig 23a. At the "head" region, the clouds have filled in to the northwest along the D3 deformation zone (from "B" to "e") forming a "comma" pattern of high clouds. I use the term "comma HEAD" to refer to that part of the comma pattern to the left of the axis of maximum winds "C" - "B". Sometimes, especially in this configuration, the axis of maximum winds from "C" to "B" is not well defined. Then, I refer to the comma "HEAD" as that part of the comma to the left-front quadrant of the upstream channeled speed maximum. Cloud comma systems will be discussed in detail in Section E of these notes.

23c: Again, the same "base" cloud pattern is shown; but, at the "head" region, cirrus fills in a quarter of the deformation region "D3", forming a sharp -nearly right - angle. This often happens when a cloud system in the 23a configuration is amplifying rapidly. In those cases, there is frequently a lower cloud comma head present to the left of max wind axis "C-B", before the cirrus fills in to "P". Sometimes, the clouds inside the triangle "C-P-B" will become thin - or even dissipate - with only a cloud bend along the edge. Note that the edge of this pattern is along relatively weaker wind zones except at "C" (where it is NOT parallel to the max wind axis) and along channeled jet "B".

23d: The "head" configuration is that of Figure 23a. Along the "base" area, the cloud edge extends upstream along the axis of maximum winds to speed max "A". Thus, in this case, the entire poleward edge of the cirrus is along the axis of maximum winds. When this occurs, sufficient moisture has been placed into the high atmosphere to the right-rear quadrant of "A". Also, vorticity max "X3" (Figure 22) is usually of greater magnitude than "X2".

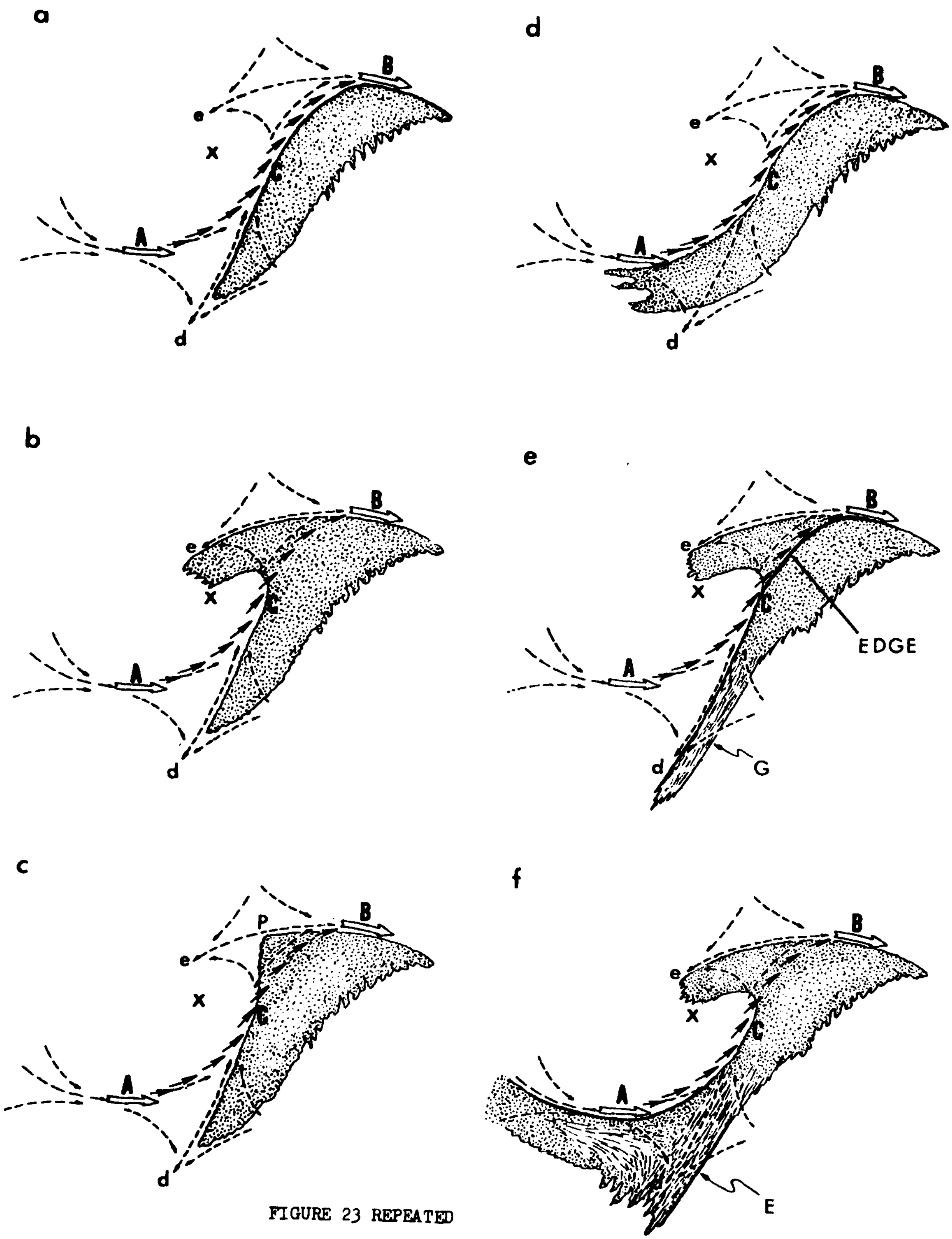



FIGURE 23 REPEATED

23e: Here the "head" region clouds form the general comma configuration, but the clouds on the east side of maximum wind axis "C-B", are higher - or have higher tops - than those on the west side over the comma "head". I refer to this pattern, which has a distinct cloud edge of higher cirrus at "EDGE", as a "cross-over" storm comma. The primary difference between this "cross-over" pattern and the one in Figure 23b is that, in this case, the axis of maximum winds "C-B" remains well defined. In a case of no edge as with Fig 23b, the primary middle & upper tropospheric baroclinic zone downstream from "C", is along "e-B". In the Figure 23e - "cross-over" type - with the edge present, the primary middle & upper tropospheric baroclincic zone downstream from "C" is along "C-B". This concept will be illustrated and discussed in more detail in Section E. The presence or absence of the cirrus "cross-over" edge is related directly to, and correlated highly with, the middle and upper tropospheric conditions.

At the "base" area of Figure 23e, the cloud configuration is also different from the other cases shown. Here, the cloud edge extends farther to the SSW through the deformation zone (from "C" to "d"); and, there is a straight well defined eastern edge along the cirrus in the deformation zone. (at "G") Farther to the north along that eastern edge, the border is ragged and poorly defined. In such cases that part of the high clouds with well defined edges on both sides usually has striations on the cloud tops oriented nearly parallel to the edges. Those conditions (the striations & well defined edges) are a good indication that the clouds lie through the relatively weak wind deformation zone, and NOT along the jet axis upstream from "C". The striations on the cloud tops are usaully related to gravity waves moving generally in a direction from speed max "A" toward "G" through the deformation zone. The proper interpretation of this pattern is important. Improper interpretation would cause the observer to place a jet stream axis at "d" with the upper air trough extending much too far to the south. The pattern will be discussed more in the next section.

23f: Here the "head" region is in the comma configuration as in 23b, but the "base" area cloud pattern forms what I refer to as a "DELTA" pattern. The "delta" pattern is a cloud system that forms a roughly triangular shape with two well defined sides and one ragged side. One of the well defined sides is along the jet axis, and the other is along the stretching axis of the deformation zone. The third border of the triangle - the southern border in this case - is usually poorly defined. Although the cloud top region of the "delta" is cold on IR images, and often relatively bright on visible pictures; the clouds are usually confined to high levels. The low and middle levels under the delta are generally warm and dry; precipitation is not normally present. When a delta is present, as in the case in Figure 23e, high level moisture is produced to the right-rear quadrant of "A"; but in this case, vorticity center "X2" (Figure 22) is usually stronger than "X3" - or it is sufficiently strong to cause the isotherms at middle levels over the ridge south of "A" to curve anticyclonically toward the southeast thru the deformation zone D2 rather than merely fan out. At mid tropospheric levels under the delta, warm advection is generally present.

## WELL DEFINED EDGES ON THE EQUATORWARD SIDE OF "BAROCLINIC ZONE CIRRUS" PATTERNS

Most "baroclinic zone cirrus" cloud systems have a well defined border on the poleward side. The relation of the well defined edge to axes of maximum winds and deformation zones has been discussed. Usually the equatorward side edges of these cloud systems are ragged or not well defined - as depicted at "R" on Figure 24 below.

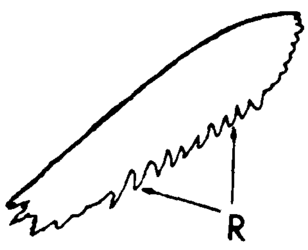



FIGURE 24

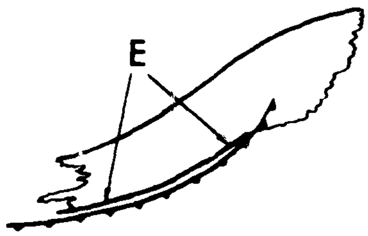



FIGURE 25

Often, however, the equatorward side of the cloud system is also well defined; and in some cases, the equatorward side is well defined and the poleward side is not.

I have categorized cases of well defined equatorward edges into four categories. (really three and a half categories)

1. SURFACE FRONT This is illustrated in Fig 25. The well defined edge at "E" has a surface frontal zone associated. When this occurs, a well defined low cloud edge or band is usually identifiable on visible pictures, and high clouds fill in the region between the front and the jet stream axis. Such low cloud - or low based cloud - bands often have a "stranded rope" or "scalloped" appearance.

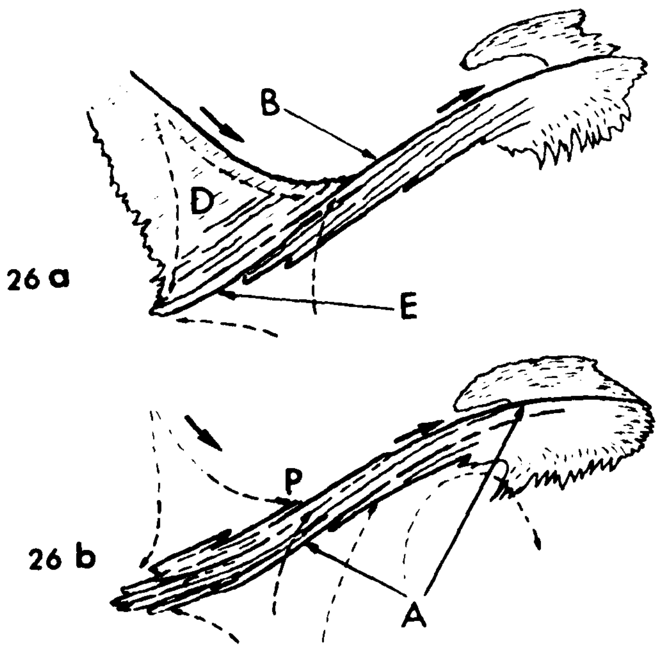



FIGURE 26

2. DEFORMATION ZONE Such edges were illustrated in Fig 23e and 23f. Two more illustrations are shown in Fig 26. In this case the well defined edge is formed by high level clouds, and is related to a deformation zone in the middle and upper level wind field.

The well defined edge or border may be associated with a "delta" pattern "D" - as in Fig 26a; or without a "delta" - as in Fig 26b.

The edge may be very continuous for a distance of a thousand miles. The cloud system north of the well defined edge may be striated or composed of many long bands. The striations or bands may be parallel to the edges and to the cloud system itself. Frequently, however, a close look will reveal a band configuration as depicted in Fig 26.

On Fig 26a, note that the same cloud band that forms the southern border at "E" forms the northern border at "B". Cloud band "A" does a similar thing in Fig 26b. Although the bands or striations are parallel to the edges, they are not quite parallel to the cirrus zone itself. This kind of deviation in orientation between the striations and the cloud system is common, although the identification of a single band forming part of both the north and south edges isn't always observed.

On Fig 26b, note the detailed configuration of the edges of the cloud system. The edges have a zig zag or "lightening bolt" type shape formed by the ends of the major bands. Such configurations in the detailed edge structure is common, even when bands or striations are not identifiable on top of the cloud deck.

Note on Fig 26b, that the cirrus formation southwest of "P" is thru the deformation zone, and northeast of "P" is along the jet stream on the front side of the upper level trough. At times the southern border of the cirrus will change from well defined to ragged at point "P", but in other cases - as depicted here - the well defined edge extends well to the northeast in front of the trough. The change from well defined to ragged is my "first guess" rule for determining which part of the cirrus is along the jet or along the deformation zone, but it isn't good enough. Another thing to check is the position of the upstream jet axis (northwest of "P"). If a delta is present, this will be revealed by a high cloud edge. If no high clouds are present, the jet axis may be revealed in the low clouds (as discussed on page 11). Since convection or other significant precipitation is likely to be occurring along the low level frontal zone northeast of "P", there may be a change in the cloud top configuration, the cloud thickness (brightness on vis - coldness on IR), or in the heights in the tops at "P".

3. DOUBLE JET STRUCTURE Well defined equatorward edges often occur on baroclinic zone cirrus systems when two jet maxima are present, as shown in Fig 27. Note the well defined edge at "E". There may be more cirrus on the anticyclonic shear side of the axis of the southern jet maxima, or there may not be.

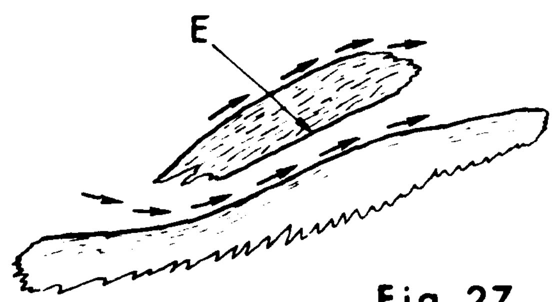



Fig 27

I have not been able to determine from the sounding network the wind or temperature field feature that is associated with the well defined southern border in these cases.

As near as I can determine at this time, the edge is related to the cyclonic shear zone of the southern speed maximum. This shear zone is usually reflected in the 500mb vorticity field as a "shear lobe" - an elongated lobe or "ridge" of maximum vorticity. I have noticed that when two jet maxima are associated with a well defined southern edge of baroclinic zone cirrus, the edge is frequently near and parallel to a "shear lobe" of maximum vorticity on the related 500mb analysis. This introduces the next category.

4. DOWNSTREAM SHEAR LOBES Figure 28a on the next page shows a baroclinic zone cirrus cloud system (shaded area), two jet stream axes, and two vorticity centers (points of maximum vorticity value identified by "X"s). Shear lobes of maximum vorticity are identified by dash-dot lines along their axes.

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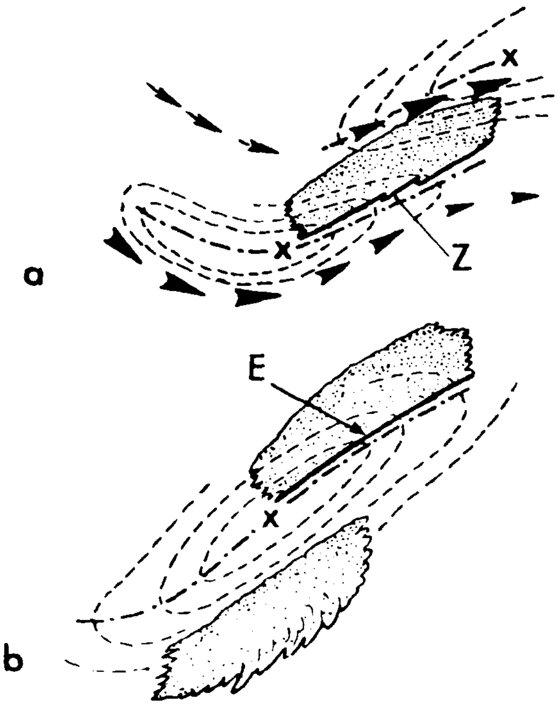


FIGURE 28

Both edges of the cloud system are well defined, and the system is between two jet maxima. Note that the wind speeds (relative speeds are related to the arrow head size) of the northern jet are weaker to the west, and those of the southern jet are weaker to the east.

Edge "Z" is near and parallel to the downstream shear lobe from the southern vorticity maximum. Although the sharp southern border fits category 3 - there is another jet to its south; it is more specifically identified by the "downstream shear lobe" rule.

In addition to the southern border relationship, there is another significant point illustrated in Fig 28a. The cloud system shown occupies what I consider to bethe overall most common location for high level or high top cloud systems with respect to the upper level winds: BETWEEN THE LEFT FRONT QUADRANT OF ONE SPEED MAX AND THE RIGHT REAR QUADRANT OF THE NEXT DOWNSTREAM SPEED MAX.

Figure 28b illustrates another general rule: With an elongated vorticity maximum along the "jet stream", high cloud systems are most likely to be found on the left side of the downstream shear lobe, and on the right side of the upstream shear lobe.

---

Another location where a well defined southern edge is often near and parallel to a downstream shear lobe is shown on Figure 29.

Edge "E" is along the downstream shear lobe and is the southern border of the "head" portion of a comma cloud pattern. Such a border forms the poleward side of the "dry slot" and is frequently observed - especially along a strong jet stream when the comma head becomes elongated parallel to the wind direction. Note on Fig 29 that the comma tail which is associated with the lower level frontal boundary is covered over by the baroclinic zone cirrus "S" (The "tail" is "T"). Often in such cases, the channeled part of the jet will advance across the tail in advance of the slot (south of "B") & the clouds along the tail at "B" dissipate., causing a "break" in the frontal zone weather & 2 separate cirrus patterns.

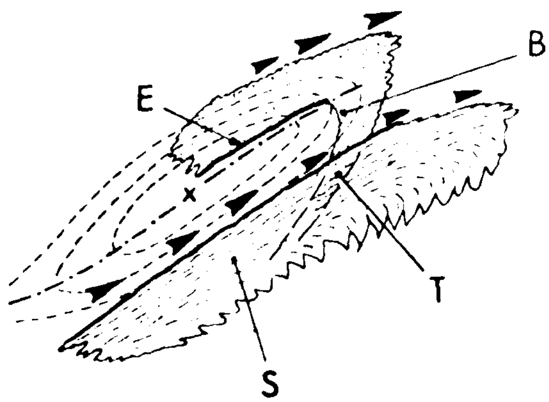


FIGURE 29

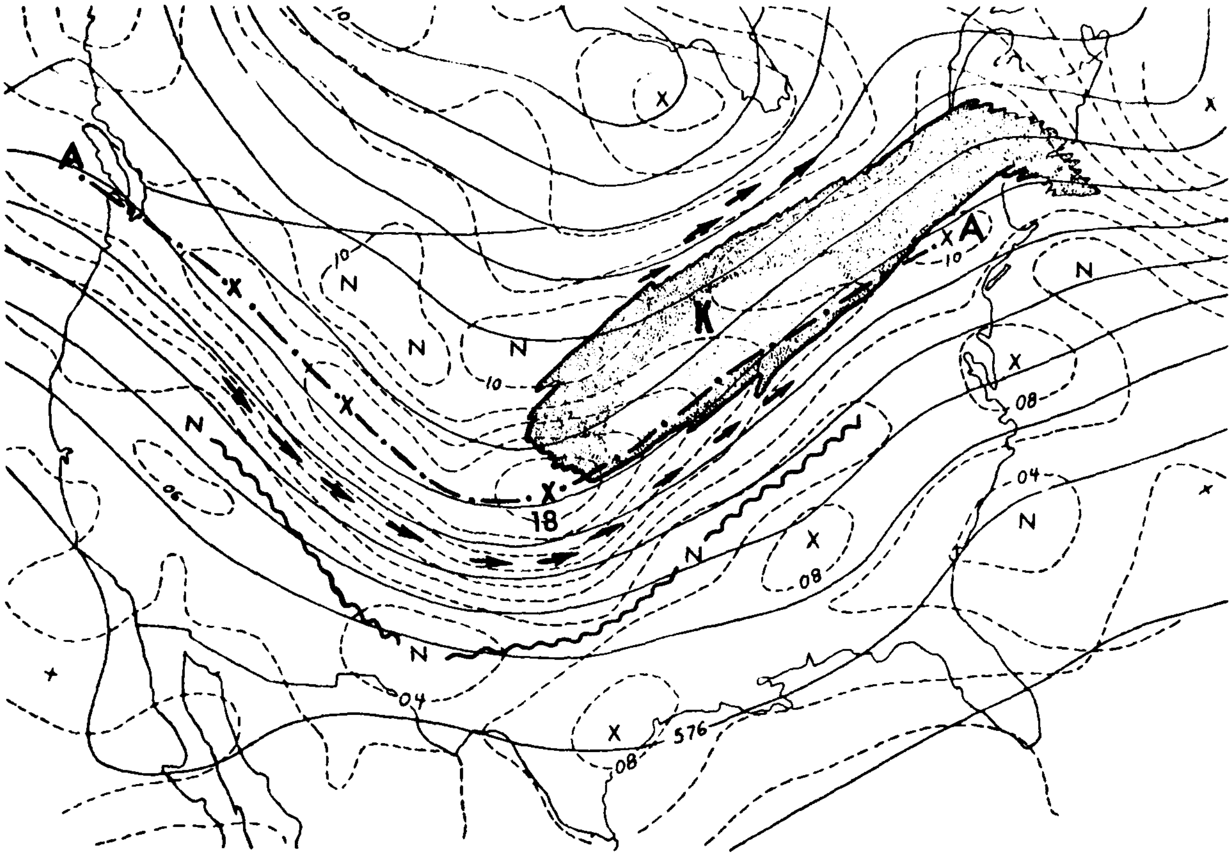


FIGURE 30

The figure above shows a cirrus cloud system "K" with the 500mb height (thin solid line contours) and vorticity (short dashed line isopleths) superimposed. Arrows depict the axes of maximum 500mb winds where speeds were greater than 70 kts. The dash-dot line is the axis of a shear lobe of maximum vorticity, and the largest vorticity value along that lobe is at the "X" in the center of the drawing with the "18" isopleth around it.

That part of the shear lobe downstream from the maximum value is closely related to the well defined southeastern edge of cloud system "K".

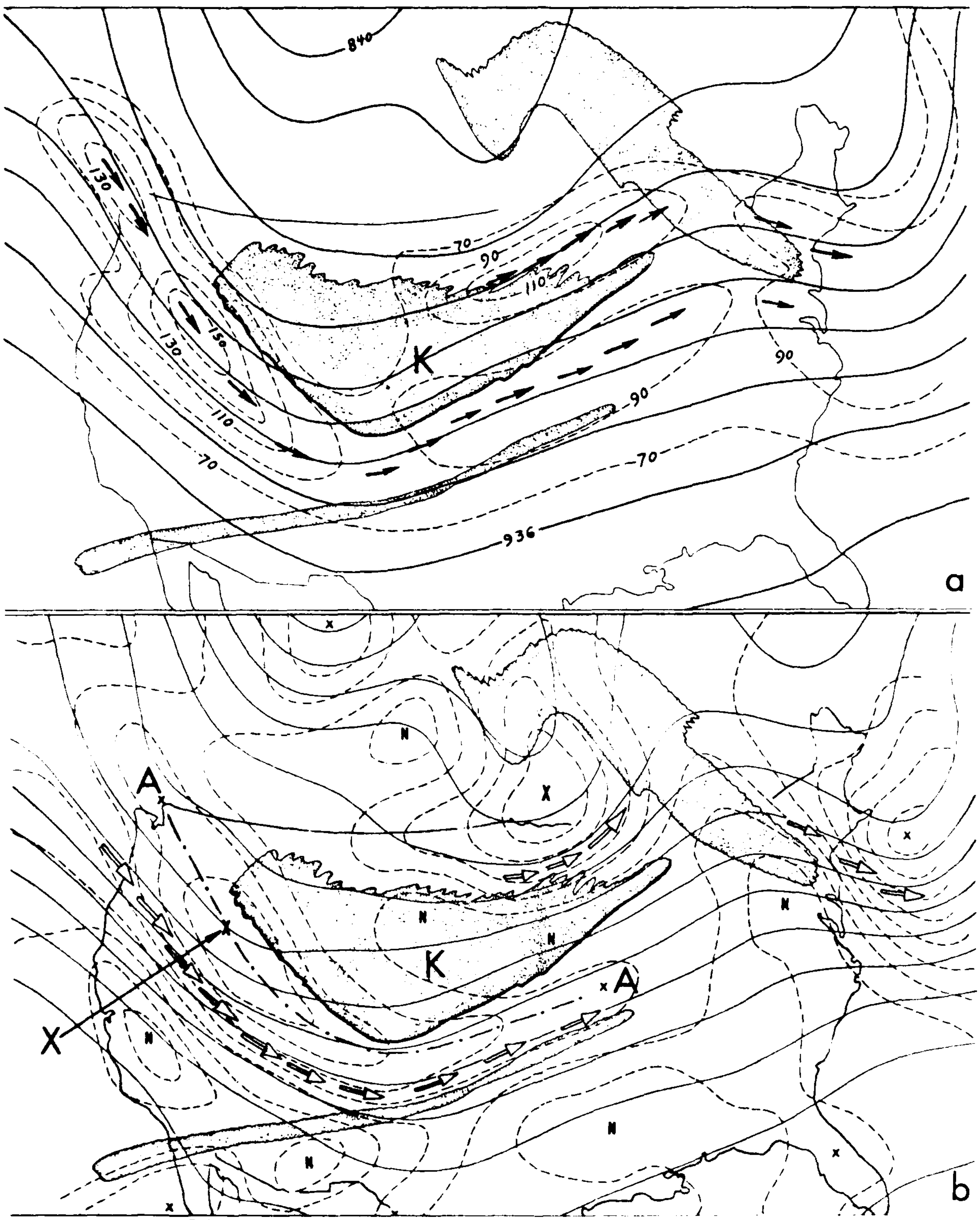


FIGURE 31 Figure 31a: 300mb height contours and isotachs (dashed).
Figure 31b: 500mb height contours and vorticity (dashed) with 500mb axis of maximum winds (open arrows)

Figure 31b on the facing page depicts a set of high cloud systems with the 500mb height and vorticity analysis as in Fig 30. Here the 500mb axes of maximum winds are shown as open arrows.

The same cloud systems are shown on Fig 31a with 300mb contours and isotachs (dashed lines).

Whereas the maximum vorticity along the shear lobe in Fig 30 was near the base of the 500mb trough, in Fig 31b it is on the back side of the trough (shown by the large "X"). Note that a wind speed maximum along the jet stream at 300mb is almost over the vorticity center. Along the southern wind maximum (associated with shear lobe "A-A") the axis of maximum wind at 300mb is poleward of the axis at 500mb.

In this case, cloud system "K" has a well defined equatorward border, and a ragged poorly defined poleward border. The well defined southern border is nearly parallel to the "downstream" shear lobe, and to the axis of maximum 300mb winds downstream from the speed maximum.

On the eastern part of cloud system "K" there are two associated speed maxima with the strongest winds in the northern one.

The coldest infrared return cloud top temperatures are the lightly shaded portion of cloud system "K".

Such cloud systems as "K" with a ragged poleward side and well defined equatorward side seem to be inverted north to south from the general type of baroclinic zone cirrus systems. Everyone I've been able to study with good upper air data has been associated with a downstream shear lobe.

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Side topic: The long cirrus band south of system "K" is half along the jet stream and half along a deformation zone. At the time of the analysis, the band is stretching and dissipating. Such bands occur frequently as speed maximum digs and turns onto the front side of an upper level trough. They are sometimes mistaken for low level frontal features.

---

Concluding Remarks: I have identified four conditions that are associated with well defined equatorward side borders of "baroclinic zone cirrus" cloud systems. Obviously, the 3rd & 4th categories (double jet structure & downstream shear lobes) are similar situations. The downstream shear lobe case is a specific type of double jet structure. A cloud pattern with a well defined southern border may fit into more than one of the 4 categories. I have observed several cases where all 4 conditions were involved with the same cloud system.

One very specific and important type of cloud system that normally has well defined borders on both sides is called a "baroclinic leaf". This cloud pattern is discussed in Section F. Of the 4 conditions just discussed, surface frontal zones and deformation zones are associated with the well defined equatorward edges of "baroclinic leaf" cloud systems.

## D. DEFORMATION ZONES - RELATIONSHIPS TO JET STRUCTURE & WEATHER PATTERNS

"Deformation zones" were defined on pages 1 & 2 as the elongated zones along the stretching axes of hyperbloic regions. Some of their relationships to "baroclinic zone cirrus" cloud systems were discussed and illustrated in Section C. Deformation zones are observed in the cloud motions and in the wind fields at all levels, and many seem to affect a very deep layer of the atmosphere. The very same type of cloud motions and behavior that has been related to deformation zone wind fields on the large scales, is observed also at very small scales, and from high latitudes to the equatorial regions.

The discussion of deformation zones in this section is presented in 4 parts:

(1) a general discussion of deformation zones - a different perspective of the cloud motion fields.

(2) changes with time following systems - the role of changing deformation fields.

(3) two types of deformation zones and their characteristics.

(4) precipitation regimes related to deformation zones and jet stream structure.

### PART ONE - A GENERAL DISCUSSION OF DEFORMATION ZONES

At this point, you might ask - and with good reason, "why so much sudden emphasis on deformation zones?" I think I can best answer that question by explaining how my own perspective evolved.

On the satellite pictures, we observe cloud patterns, their movement, and change with time. Although this tells us something about the temperature and moisture fields, it is basically related to the motion field. Several aspects of the motion field can be considered. I first concentrated on the rotational aspects of the motion field: such as the sign & amount of curvature of the flow, troughs, ridges, and wave type perturbations. I soon learned that the rotation of cloud borders and the evolution of patterns was best related to wind shear rather than the curvature of the streamlines. It was the relative motions of the air parcels with respect to each other that contributed most of the rotation of the cloud elements and pattern borders observed on the satellite pictures and time lapse depiction. These relationships of curvature, vorticity, and pattern rotation were discussed in detail in Part III of the Course Notes.

Becasue of the importance of relative motion and wind shear in the production of cloud patterns, I began to pay considerable attention to the wind speed field. It became apparent that the speed maxima and minima within the strong wind zones, and their production, movement, and decay; were highly correlated with the cloud patterns and their evolution. These speed maxima & minima are fundamentally related to the vorticity & rotaional aspects of the motion field. But, I found from experience of observing the cloud patterns and their evolution, that I obtained a better understanding and more practical results by considering the speed field as primary and the rotaional field as secondary and dependent upon the changes in the speed field.

It was within this changing perspective that I became aware of the importance of a third aspect of the motion field - the deformation field. It is basically related to the speed maxima and minima, and to the rotational field; but it provided an additional perspective and more understanding of the cloud patterns. I had been watching satellite film loops daily for almost a year before I explicitly identified deformation zone cloud bands & boundaries. I first noticed the effect on SMS IR film loops at cirrus levels. The cloud elements on opposite ends of a cirrus band were apparently moving in opposite directions. The associated winds from sounding data showed that the cloud band was along the stretching axis of a hyperbolic or col type streamline pattern. Once this initial identification had been made, I then observed numerous examples of deformation zone cloud bands and boundaries. They were present on almost every film loop - some at cirrus levels, and others in cloud systems at lower levels.

I found, however; that many of the well defined stretching bands & boundaries were NOT associated with a hyperbolic or col pattern in the wind field. Using film loops with high space and time resolution, I noticed that cloud elements on both ends of such bands were moving in the same direction, but at a much larger speed on one of the ends; or, that the cloud elements were not moving parallel to the band orientation. I then realized that - as in the case of rotation - it was probably the relative motion of the air with respect to itself that was important, rather than the motion with respect to the ground. I made some time lapse sequences of deformation zone cloud systems, in which the cloud boundary was held stationary instead of the geographical features. In these sequences, the cloud elements moved in a hyperbolic type motion field with the boundary along the stretching axis. This suggested that whether or not a deformation zone cloud system was associated with a hyperbolic region in the wind field was dependent upon whether or not the cloud system was moving and how rapidly.

This was true in the case of rotation; but, for that aspect of the motion, fields of vorticity were routinely available to identify and quantify the relative rotation. In order to better understand the moving deformation zone cloud systems, I set down a simple hyperbolic type of motion field and added different amounts of translation in various orientations with respect to the axes. I compared the resultant motion fields to streamline patterns associated with deformation zone cloud systems and to the movement of cloud elements associated with the systems. By this process, I became convinced that the numerous well defined stretching bands and boundaries observed on the satellite images were located along the stretching axes of deformation zones in the relative motion of the air with respect to the adjacent air.

This allowed us to better understand why the well defined bands and boundaries were there. Since the relative deformation zones are fundamentally related to the speed and rotational fields, it also allowed us to relate the deformation zone cloud patterns to circulation centers and speed maxima. Thus, the satellite images could be more accurately interpretated in regard to their associated wind fields; or, given a computer prog of the speed and vorticity fields, the location of the deformation zone boundaries could be forecast. For the first time, I bagan to understand why the clouds, weather, and density gradients associated with a rapidly moving frontal zone were behind the wind shift zone - and whether thay would be or not.

Many of the cloud systems that are identified with deformation zone motion fields are also identifiable as other features, such as: frontal zones, fronts aloft, dry lines, shear lines, arc lines, feeder bands, etc. --- or as parts of other cloud patterns such as "inverted V's" or "screaming eagles" (!). The additional identification of such features as deformation zones provides a common denominator that can be applied to weather systems from winter storm size to "bubble high" scale; and from polar to equatorial latitudes. As far as I can determine by careful observation of time lapse motions, the basic wind fields or relative motion fields associated

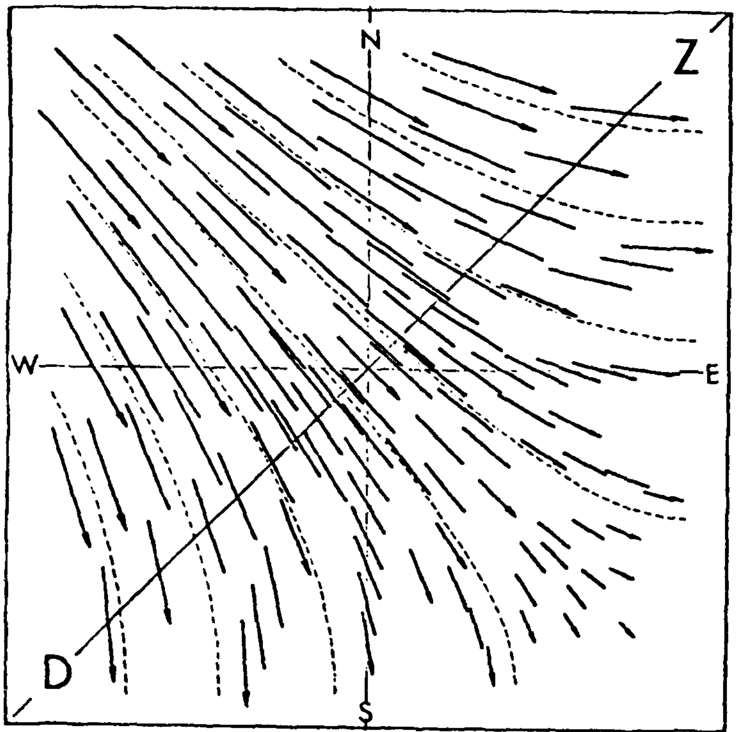


Fig 32a

Vector "R" is the mean resultant wind vector of the motion field to the left.


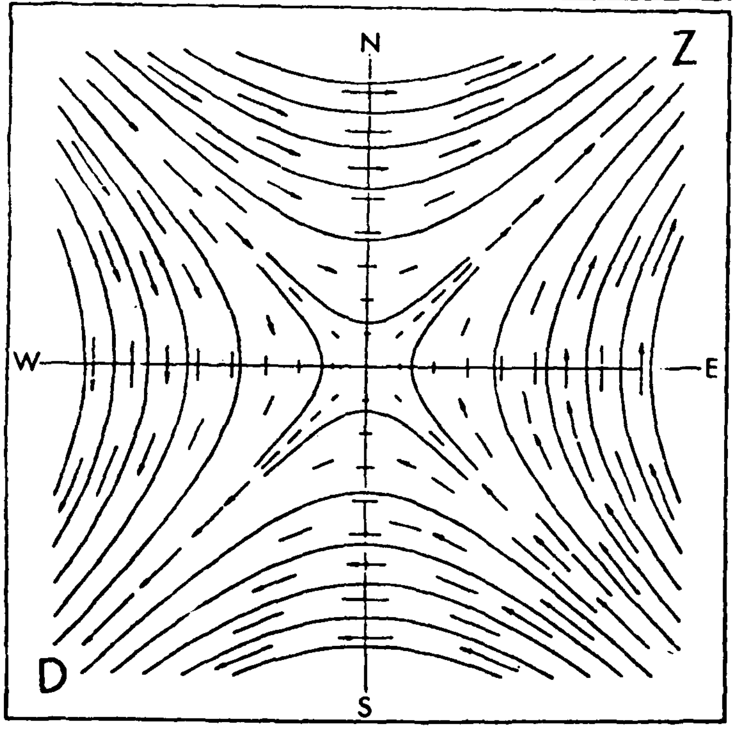


Fig 32b

This motion field is the remaining motion field with vector "R" subtracted.

with these different cloud systems is fundamentally the same.

Consider the following examples and illustrations of the deformation zone motion field and associated cloud systems.

Shown in Figure 32a is a set of motion vectors which can be considered to represent a wind field on a weather chart. The basic flow pattern is one of generally northwesterly winds. The maximum speed is in the northwest corner. Downstream from there, the streamlines are difluent and speeds decrease. If the vectors of Fig 32a are added and the mean resultant wind is determined, it is the northwest vector "R", shown to the right of the diagram.

If vector "R" is subtracted from the flow pattern in Figure 32a, the resultant flow pattern is that shown in Figure 32b.

The flow pattern in Figure 32b can be considered to be the air motion with respect to a plane moving with the motion of vector "R". That flow field is a hyperbolic or col motion pattern with the stretching axis "D-Z". The motion pattern of Fig 32b can also be considered as the relative motion of the air with respect to the mean flow; or, it can be considered as a motion "system" translating toward the southeast at the speed of "R". If so, the air can be said to "flow through" the system in the manner shown in Figure 32b. Regardless of which way we prefer to consider the relative motions involved, the following conditions apply.

The air to the northwest of "DZ" is moving faster than "DZ" in its progression toward the southeast, but it can never reach the "DZ" axis. As that air approaches the "DZ" axis its speed is decreasing and approaching the speed of the air along the axis. The air to the northwest of the axis decreases in speed, moves to the sides, and approaches the axis asymptotically. Likewise (or unlikewise),the air on the southeast side of the "DZ" axis falls back toward the axis - or is being "caught uo to" by the axis. In the relative sense, the slower moving air southeast of "DZ" is approaching the axis asymptotically from the southeast as shown in Figure 32b.

The "line" of air parcels along the "DZ" axis are those which have the unique property of moving only orthogonally with respect to the mean flow. All of the other parcels in the system are either catching up to or being caught up to by the line of air along "DZ". In a practical sense, this means that air approaching from the northwest does not proceed beyond "DZ" with respect to the other air. Or, if moisture, dust, or smoke is introduced into the flow upstrean from "DZ", then "DZ" acts as a southeastern boundary to the southeastward progression of that material - not with respect to the ground - but with respect to the moving system or to the other air. Axis "DZ" is the stretching axis or "deformation zone" of the flow pattern of Figure 32a.

The flow pattern shown is unrealistically simple. It represents pure deformation. Parcels within the pattern would be compacted in the NW-SE direction at the same rate to which they are stretched in the SW-NE direction. If there is a net compaction occurring - or horizontal velocity convergence occurring, then compensation is provided by vertical stretching. Air moves out of the plane in the vertical as well as toward the NE and SW. This vertical stretching in combination with the boundary effect at "DZ" results in matter such as dust, smoke, or moisture in the system to be vertically thickest in a band along the DZ axis. It may become thicker by part of the material moving upward, or by moving downward, or by both. I will discuss this subject from an empirical perspective later in this section.

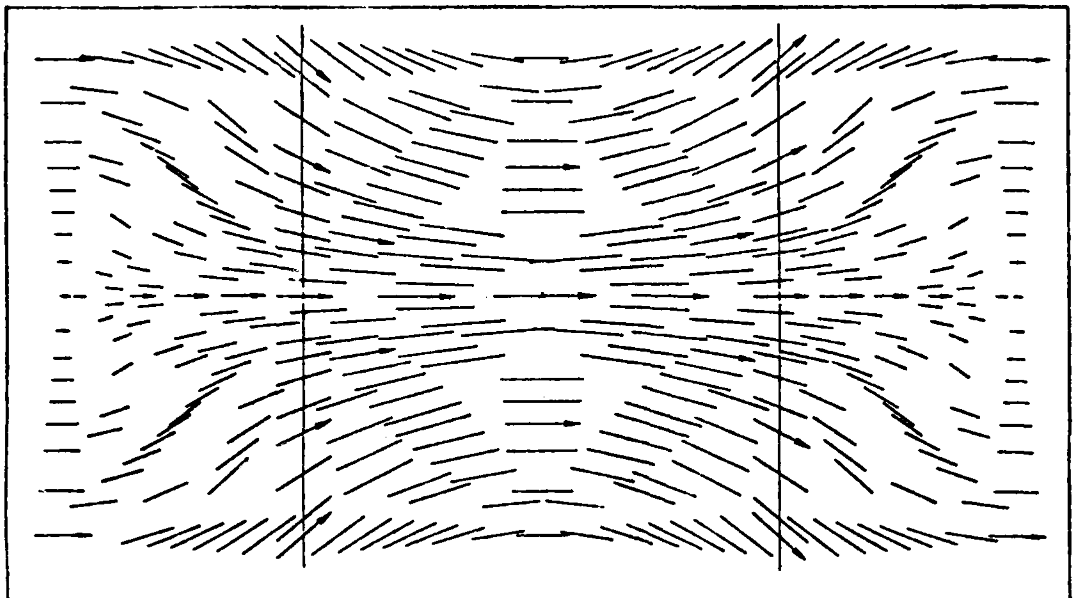

Fig 32c MEAN RESULTANT VECTOR R

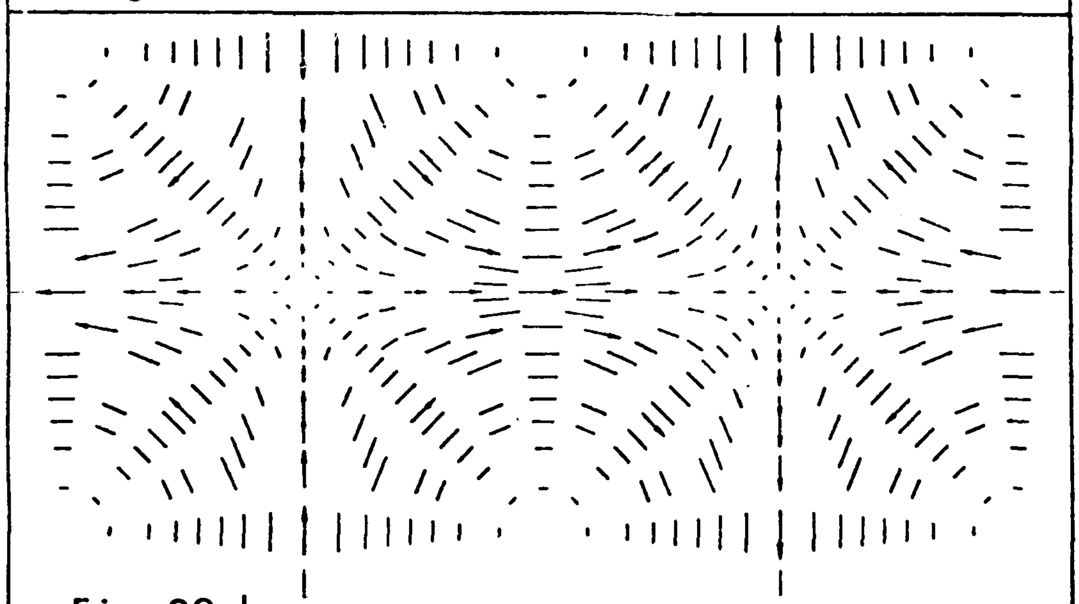

Fig 32d THIS IS THE TOP MOTION FIELD MINUS VECTOR "R"

Consider next the motion field in Figure 32c above. We can consider it from at least three aspects: (1) rotation, (2) speed & shear, or (3) deformation. Observing the flow pattern, you might think of the pattern primarily as a region of basically cyclonically curved flow north of a region of basically anticyclonically curved flow. When I look at that pattern, now, I think of it primarily as a "speed maximum" in the center with the flow upstream undergoing confluence and increasing in speed, and the flow downstream difluent and decreasing in speed.

Secondarily, I see the pattern as a "speed maximum" with two basically related "deformation zones", one parallel to the basic flow and upstream from the speed max, and one transverse to the flow and downstream from the speed max. This is more obvious when the mean resultant wind vector (vector "R") is subtracted out of the flow. The resulting pattern is shown in Figure 32d. There in the remaining "relative motion" flow field, two deformation zones and six circulation centers are explicitly depicted.

After considering the motion fields from all three perspectives and interrelating them, we can choose that aspect which best applies to the practical problem under consideration. In the task of satellite picture interpretation, we may often find it useful to consider first the deformation aspect of the motion field. The following is an example.

---

At times - where there is very little upper level moisture present - the only high clouds present consist of cirrus bands along the deformation zone axes. This location seems to be one of the first places that clouds form, and one of the last places that they dissipate. This is a common problem encountered during the summer season over the east Pacific south of 40 degrees north latitude. Significant upper level circulation systems are present, but middle and upper level moisture is sparce. Frequently we will observe a single band of cirrus, which is usually along a deformation zone. If satellite pictures are available in time lapse motion, the elements can be observed for direction of motion; but, if time lapse motion is not available, a considerable amount of information can still be derived.

Consider the cloud band depicted in Figure 33a. As a "first guess", I will assume that the band is nearly stationary, and that the cloud elements on opposite ends of the band are moving in opposite directions as implied by the arrows. It is a band of cirrus along the deformation zone or stretching axis of a col region in the wind field. To determine the probable rotational and speed field characteristics associated, draw an orthogonal line bisecting the cloud band (line "A-B" in Figure 33b). Using the hyperbolic type of flow pattern model, I can then infer the

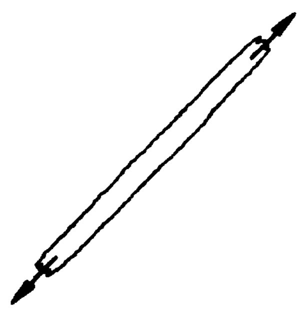

Fig 33a

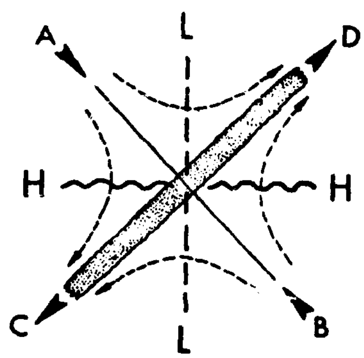


Fig 33b

location of two highs and two lows with 4 speed maxima at arrows "A,B,C, & D". This oversimplified model can then be combined with other available data, such as aircraft reports and soundings to produce a better upper air analysis.

If the observed cloud band is moving - rather than stationary - the model can be refined. Consider the band of Figure 33c.

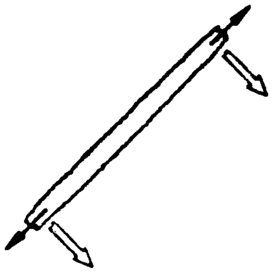

Fig 33 c

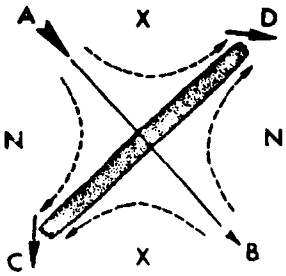


Fig 33 d

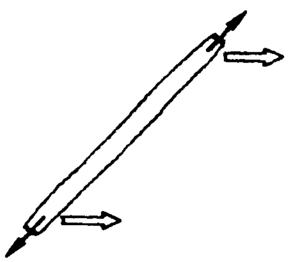

Fig 33 e

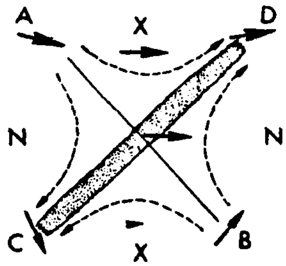


Fig 33 f

In this case the band is moving toward the southeast. If the translation is rapid, there may be no closed streamline centers associated; but we can assume the general location of vorticity maxima and minima - located by the "X's" and "N's" in Figure 33d. The most significant speed maximum will be near "A" with secondary maxima likely at "C" & "D". A northwest wind of minimum speed is likely near "B".

If the band is moving toward the east as shown in Figure 33e, a band of strong wind is likely across the northern part of the pattern with maxima at "A" & "D". The speeds will be less between "A" & "D", but the speeds will still be relatively high there compared to areas farther south in the pattern.

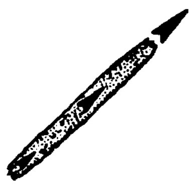

Fig 33g

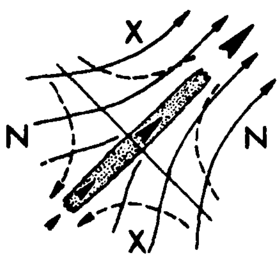


Fig 33h

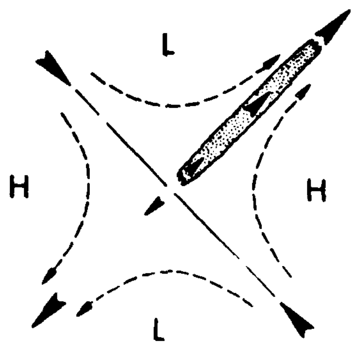


Fig 33i

There are other complications that may occur. If, as in Figure 33g, the elements on the southwest end of the band are not moving toward the SW, but are moving at a slow rate toward the NE; there are at least two common variations observed. The associated motion field may be similar to that in Figure 33h. In that case the band will most likely be moving toward the northeast. But, the band may be nearly stationary and extending only half way through the col region as shown in Fig 33i. Often - when deformation cirrus bands are oriented NE-SW - clouds will be absent on the southwestern half of the col region. This is true less than 50% of the time, but the possibility must be considered.


Fig 33 j

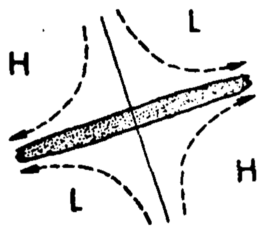

Fig 33k

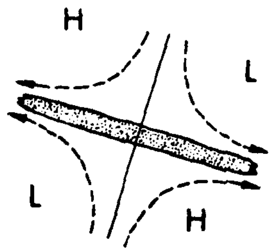

Fig 33 l

If the deformation band is rotating, as depicted in Figure 33j, it is usually associated with an area south of the main belt of westerlies, and the northern pair of systems (high & low) are moving faster than the southern pair. This is shown in the change from Figure 33k to Figure 33l. In such cases, the systems are generally changing with time as well as moving. The northern high tends to "roll over" as it moves east, and the northern low tends to "dig" somewhat equatorward as it moves east of the center of the southern high.

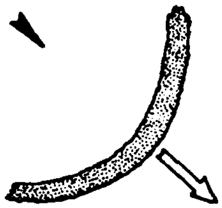
Fig 33 m

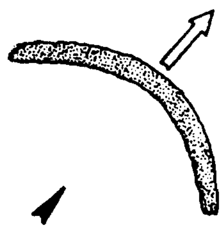
Fig 33 n

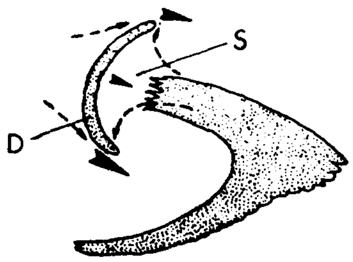

Fig 33 o

When deformation bands are curved as in Figures 33 m & n, they are generally moving in the direction of the convex edge, but there are exceptions to this rule. Some of these exceptions are systematic and prevalent. An example is shown in Figure 33o. A curved deformation zone band is located to the rear of the "head" of "comma pattern" which is moving rapidly toward the east-southeast. At the ragged rear portion of the comma, air is sinking; middle and high clouds are dissipating there. The deformation band "D" is along a boundary between air sinking at "S" and air which is not sinking. Such deformation zones in this synoptic location may appear as a cloud line, a cloud band, or as an interface between two kinds of low clouds. Typically the boundary is moving toward its concave side in the same direction as the comma system. If the comma system is slower moving with a "closed" wind field at middle levels, the deformation boundary will then move westward. In either case, the southern end of the boundary may curl around in a cyclonic sense and swing toward the south as a "secondary frontal zone".

The foregoing discussion illustrates how the presence and behavior of a single deformation zone cloud band may be used to infer information about the speed and rotational motion fields in the vicinity. It provides only a qualitative model with limitations; but when combined with other data available plus time continuity, a much better analysis can be made.

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There are many kinds of cloud systems associated with the deformation zone flow fields. The following examples illustrate some of the variations:

a. The deformation zone may appear as a deformation "band" as in the examples of Figure 34a.

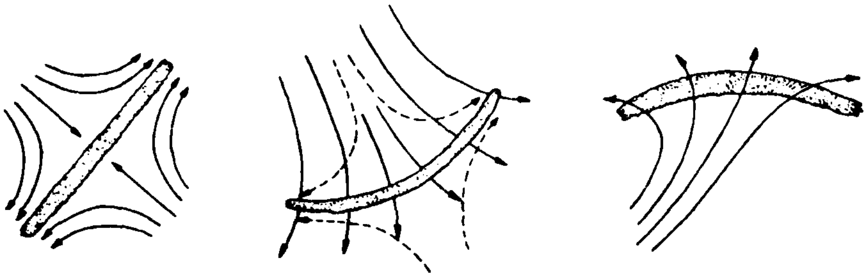

Fig 34 a

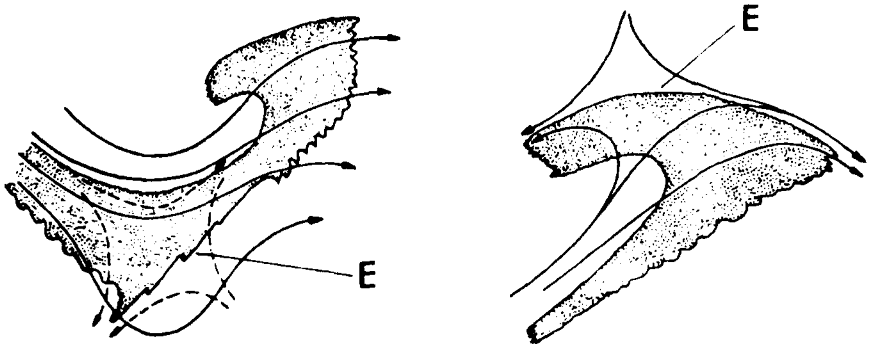


Fig 34 b

b. The cloud feature may consist of a border or edge of a cloud system, as in the examples of Figure 34b. The deformation borders are labeled "E" on both cloud systems. In both Figures 34 a & b, solid lines are streamlines and dashed lines represent the relative motion.

c. Deformation zone cloud systems often occur in combinations. A typical one is a "high-low" combination as illustrated in Figure 34c. Here the thin dashed lines with arrowheads are upper level ("high") streamlines, and cloud feature "A" is a band of cirrus along an upper level deformation zone. The thin solid lines are low level streamlines, and cloud system "B" is a pattern of overcast stratocumulus with a deformation boundary on its southern border. Such combinations are prevalent over the oceans on the northerly flow side of persistent subtropical high pressure cells, where middle and upper level moisture is sparce and low level stratocumulus is common. The two deformation zones are actually parts of the same system that is revealed only by a "skeleton" of cloud features. The two heavy dashed lines on Figure 34c represent the borders of a cloud comma pattern and its frontal tail feature. This area would be filled in with clouds, if deeper level moisture was present. Often, the region labeled "C" is nearly cloud-free in such systems.

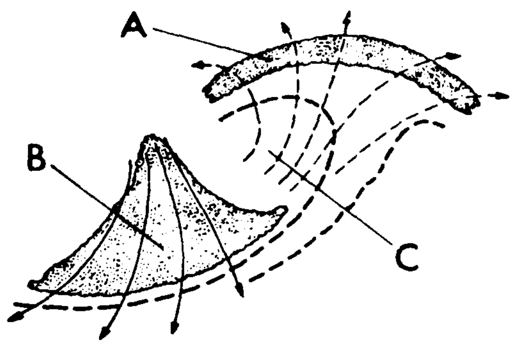


Fig 34c

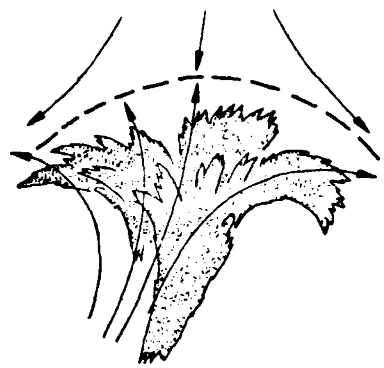

Fig 34d

d. The cloud pattern shown in Figure 34d is another type often associated with middle and upper level deformation zones. The clouds form a ragged "fountain" like pattern, with some of the clouds curving cyclonically around a low, and others anticyclonically around an adjacent ridge. The clouds dissipate before reaching the deformation zone shown by the dashed line. Sometimes with such systems, the clouds will suddenly "fill in" to the deformation zone and form a well defined edge there. At other times, there will be - in addition to the "fountain" pattern - a narrow band of cirrus along the deformation zone.

e. The pattern in Figure 34e is one often seen with cirrus and at times with middle clouds. The cloud labeled "B" could be the same cloud which is labeled "A" at a later time. It is common to see a cloud pattern change shape in that manner as it moves into a deformation region. Or, the shapes shown could represent a series of different clouds in the system at one time.

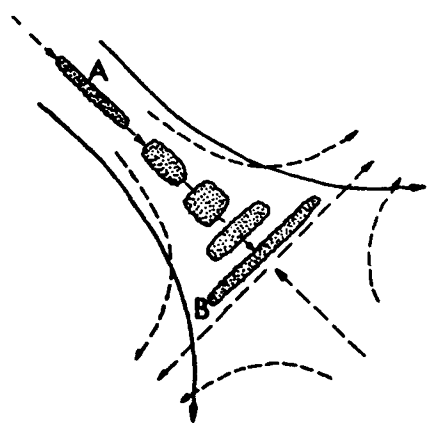


Fig 34e

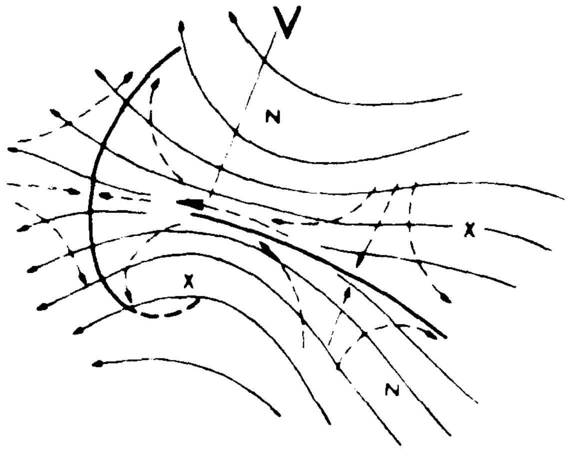


Fig 34f

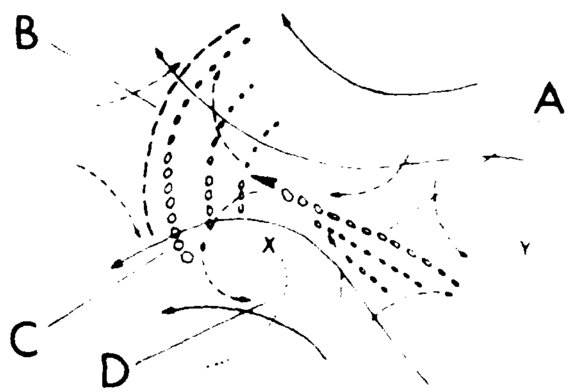


Fig 34g

f. Two deformation zones in a prevalent form of combination are shown in Figure 34f. This represents a pattern in the low and middle level easterlies. A speed maximum is shown by the arrow at "V". Thin solid lines are streamlines; thin dashed lines with arrowheads represent the relative motion and the deformation zone flow fields. Two deformation zones are shown by heavy solid lines. Thev form the rough "T" shape with respect to each other, which is common in relation to the speed max. One deformation zone is downstream (to the west) from the speed max and transverse to the basic flow; the other is upstream from the speed max and parallel to the basic flow. In this type of case, the type of cloud conditions associated with the deformation zones varies considerably depending upon environmental conditions. Often the deformation zones appear as interfaces between two different types of cloud conditions, and - at other times - cloud bands or lines of enhanced convection occur along the deformation zones. But, it seems significant that the cloud features are usually aligned with the deformation zones rather than along trough or ridge axes.

g. In Figure 34g, a system similar to that of Fig 34f is shown, but it represents a smaller scale system. This is included to illustrate a typical low cloud pattern associated with a speed maximum and two related deformation zones. Lines of clouds are aligned with the two deformation zones. In advance of the speed maximum (to the west) cloud lines will be transverse to the flow. The leading band will often be the most well defined, and frequently will have a clear band on its west side. The western border of the clear band is shown as the heavy dashed line "B". The band of clearing will often be more persistent and maintain better continuity than the cloud line. It will usually be seen as a distinct warm band on IR images. Although my observations have been casual in regard to these systems, there are several behavioral aspects of the deformation zone boundaries that appear to correlate with the amplification of the vorticity center at "X".

These are:

(1) When the southern end of deformation zone "B" remains well defined and curls southward, the streamline perturbation associated with "X" amplifies.

(2) When the boundary with deformation zone "B" remains relatively well defined, but accelerates westward (or west-northwestward in the case of Fig 34g) and deforms into a "U" shape; the vorticity maximum elongates and appears to weaken. Any convection occurring remained on the eastern end of the elongating vorticity lobe.

(3) When the cloud features of Deformation zone "B" lost definition, and those of deformation zone "A" became better defined, the vorticity center at "X" appeared to weaken. A newer vorticity center in the vicinity of "Y" seemed to strengthen at the expense of the one at "X". It seems reasonable that a new surge of northeasterly flow around the anticyclone to the north would concurrently strengthen the cyclonic vorticity at "Y" and the boundary at "A", but I don't know why it would weaken the vorticity center at "X".

Sometimes cloud lines will be present south of the vorticity center oriented similarly to the dotted line (south of "X"). It's shape is related to the relative flow. There is a minimum speed in the easterlies at "D" in most cases. I should point out that the streamline patterns shown are based primarily upon the movements of low clouds observed in time lapse motion.

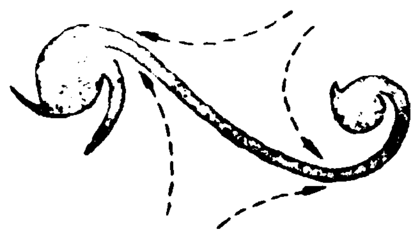

Fig 34h

h. Another common form of cloud pattern related to deformation zones is often called a "connecting band". Examples of these are shown in Figures 34h and 34i. Dashed lines represent relative motion.

The connecting band in Fig 34h is between two tropical cloud systems. That of Fig 34i is between two comma patterns in the westerlies.

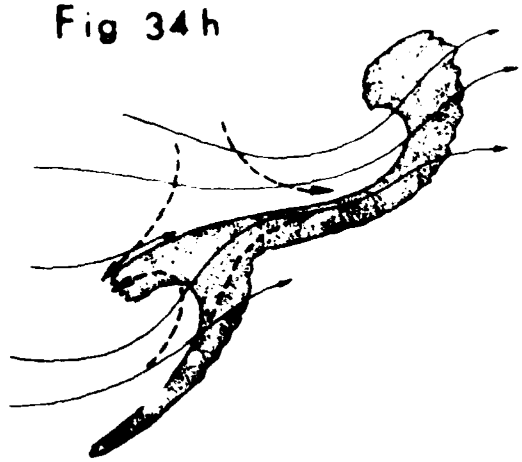

Fig 34 i

PART TWO - CHANGE WITH TIME FOLLOWING THE SYSTEM

Some time ago, I noticed that many persons, when observing satellite images in time lapse motion - such as movie loops, frequently used terms such as: SURGE, IMPULSE, SPURT, FLARE-UP, TWISTING, and BURST. Generally, these terms were used by young meteorologists, or those with less experience, or by non meteorologists. The more experienced, more knowledgeable, meteorologists used instead terms such as: jet stream, speed maximum, rotating, and out-break. When I found myself beginning to use the terms SURGE, IMPULSE, and TWIST; I thought about it, and realized that that the thing that these "unorthodox" terms had in common was the implication of "TEMPORARINESS" or of "CHANGE WITH TIME". When I look at the film loops with this in mind, I note that - in the baroclinic zones where a large proportion of the significant weather is occurring - the cloud motions (and probably the air) are routinely undergoing accelerr .ons (or decelerations). It is rare that I observe a system that is not signif; antly changing with time as it propagates. Frequently, as I observe speed maxima moving within the jet stream baroclinic zone, I observe speeds increase as the speed maximum "forms", then immediately decrease. The word, "surge", seems to apply well to this type of behavior.

The fact that atmospheric systems change with time is not new to us. We have known that systems form, intensify, weaken, and dissipate; and we have known that the change with time is important. It is the relative significance of the change with time of systems with respect to their translation that I have found to be much larger than I previously thought. As the systems change with time, associated patterns of clouds and precipitation form and dissipate. I am now convinced that the formation and dissipation of precipitation and cloud systems is of equal importance as their movement in the contribution to local weather changes. When we try to use satellite data for short range forecasting, our efforts are often defeated by the unexpected formation or dissipation of weather patterns. We must improve our ability to extrapolate changes as well as movement.

---

This subject is a complex 4 dimensional problem. It is difficult to treat quantitatively; the forces acting on the air are not in balance; the systems are not steady-state. The problem involves vertical differences in atmospheric behavior. Vertical exchange processes (from significant convective type rising and sinking zones) feed-back onto the wind & density fields of various levels. To me, it is very complex. The increased time and space resolution of satellite data, when integrated with the 12 hourly sounding information, has answered some of the questions involved, but it has introduced many more. There are certain cloud pattern changes which are systematic and repetitious. Although I do not fully understand the processes involved, I know which aspects of the motion field are important; and the search for answers is narrowed. One of these types of repetitious pattern changes involves the role of deformation zones in redirecting or transferring the energy of jet stream speed maxima.

Consider a case where the jet stream maximum wind zone is "channeled" and strong on the back side of an upper air trough; and - at a later time - the strong "channeled" speed maximum shifts to the front side of the trough. There are different ways that this change can occur. One of the ways is illustrated in Figure 35a.

In Figure 35a, the open arrow represents a "channeled" speed maximum; the solid arrowheads depict the position of the axis of maximum winds upstream from the speed maximum. The axis of a deformation zone is shown by double solid lines, and the dashed streamlines represent relative motion associated with the deformation zone.

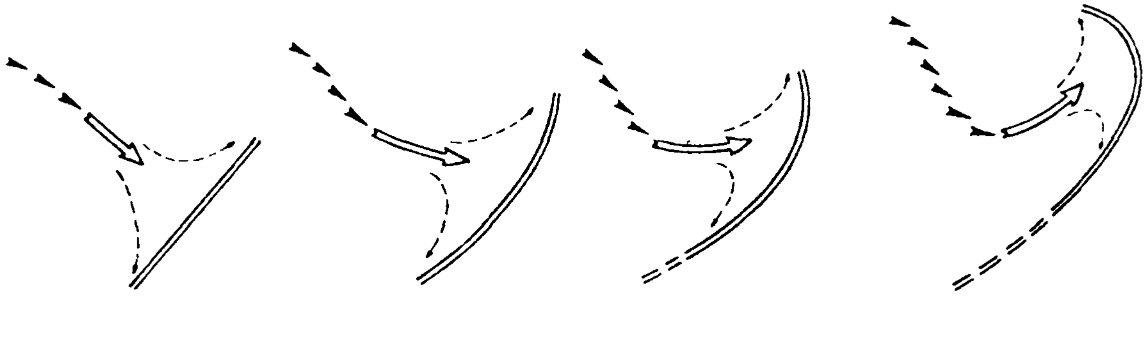


Fig 35a

The figure illustrates a time sequence, in which the channeled speed maximum moves from the northwesterly flow on the back side of the trough to the southwesterly flow on the front side.. It does so by rotating around the base of the amplifying trough. This kind of process usually occurs when the trough or streamline perturbation involved is of relatively high amplitude, especially when the upstream ridge remains at high amplitude or increases its amplitude during the process.

Note that the deformation zone is initially (at time 1) in the "base-of-the-trough" location. With time, it moves in advance of the rotating speed maximum and becomes curved into a spiral-like shape. By "time 4", the northern part of the deformation zone has moved well up the front side of the "deepened" trough. It trails back with the shape and orientation of a surface cold front, but it is primarily a boundary feature of the middle and upper troposphere. I should point out here, that such boundaries - although they move and behave according to the upper air flow field - often have a relatively deep vertical influence. Low clouds and low based convective activity can be affected as the boundary passes.

The type of change illustrated above can easily be described as a "wave" type behavior; a wave type perturbation propagated eastward and amplified.

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There is another - quite different - way in which speed maxima shift from the back to the front side of a trough. I describe this other process as a "hydraulic effect", or as the "transfer of energy through a deformation zone". In this case, the the speed maximum or its related vorticity maximum does not actually move from the back to the front side of the trough; the initial speed maximum dissipates and a new one forms on the front side.

As we observe satellite images in time lapse motion, we frequently see regions undergoing "stretching" and "compacting" in the horizontal. For example, a region may be stretching in a north-south axis while compacting in the east-west axis. Generally, the two effects are not occurring equally. There is a net stretching or a net compacting, and this will often change from one type to the other during the period of observation. In other words, horizontal deformation is occurring, and is changing with time. The changes with time are not long lasting with respect to the 12-hour time intervals of upper air observations. A typical example can be described in simple terms as follows. A sudden increase in the motions will be observed along jet stream baroclinic zone. The air accelerates as a speed maximum forms or intensifies. The cloud elements in the strong wind zone appear to "surge" ahead. In advance of this "surge" or "push" in the motion, cloud elements are suddenly undergoing a compacting or squeezing effect in the direction of the surge, while beginning to stretch to the sides. The process reminds me of having an array of water filled balloons; then suddenly pushing on one, and observing the energy of the push being transferred through the adjacent ones. The motion is redirected to the sides in addition to being transferred directly ahead of the push. This is a "hydraulic" effect. The behavior observed on the satellite images is, however, a bit more complex. Usually, we observe, that immediately after the initiation of the surge, the sidewards stretching in the downstream region is lagging in its response with respect to the compacting. In other words, during that phase, there is a net compacting occurring. In the single horizontal plane of the satellite image there is a net compression. This can be partly compensated for by a total density change, but it is primarily compensated by vertical stretching. As the surge begins, and air is compacted in the line of direction of the speed maximum, the stretching occurs in the vertical plane orthogonal to the speed max vector. It occurs vertically as well as horizontally in that plane. In the typical sequence of events of such a surge in the satellite images, the sidewards stretching appears to catch-up to the compacting, so that the two effects are temporarily equal; then the stretching becomes greater than the compacting.

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This kind of process observed in satellite time lapse motion; if real within the air motion, should be detectable in the wind field. It is. There are certain basic changes - accelerations & decelerations - that must accompany the horizontal deformation and its changes with time. This is very difficult to observe using sounding data and upper air analyses alone, because of the 12 hour time gaps; but, by using satellite data at half hourly intervals, enough continuity is provided to understand the wind changes.

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Consider the drawing in Figure 35b. The arrow labeled "V1" represents a strong channeled speed maximum on the back side of an upper air trough. The motions discussed in this illustration involve a layer of the atmosphere rather than merely a single level; however, they can be considered to be near jet axis level with the temperature field as mid tropospheric. Speed maximum "V1" has just formed or begun to intensify and is still intensifying at time 1 (Fig 35b). There are two deformation zones or hyperbolic regions shown (#1 to the rear of the "V1" speed max, and #2 in front of the speed max). The air parcels in the region of deformation zone 2 in advance of the "surge" or speed max "V1" is stretching in the northeast-southwest direction, and compacting in the northwest-southeast direction. At this time, the compacting is greater than the stretching. To accommodate the NE-SW stretching, which is increasing with time, a new or newly intensifying speed maximum is located at "V2". At this phase, there is likely also to be vertical stretching occurring in the vertical plane of deformation zone #2. (actually in a vertical layer oriented NE-SW in advance of speed max "V1").

Try to imagine this process 3-dimensionally. There is a sudden "push" or "surge" at "V1". The volume of air in advance of the "push" responds to it by stretching vertically and sideways, and by pushing ahead toward the southeast. But the push southeastward is dampened because of the ability of the air to also stretch orthogonally (NE-SW & vertically). The response of the air in the #2 deformation zone area begins to occur before any of the air at "V1" can move there, but it isn't instantaneous either. A finite amount of time is required for the response to be transmitted. This kind of reasoning would fit the array of balloons or a bowl of jello well; but, perhaps more "meteorological" kind of reasoning should be used. Consider the temperature field.

At TIME 1, a strong baroclinic zone is concentrated along speed max "V1" in the middle troposphere. The isotherms are packed and generally parallel to the wind direction, the temperature gradient "vector" is oriented NE-SW.

As the deformation process (shown by the relative hyperbolic motion pattern of the large arrows) occurs in advance of "V1", a new - or newly intensifying - baroclinic zone is forming along deformation zone #2. This new baroclinic zone is oriented orthogonally to the initial one at "V1".

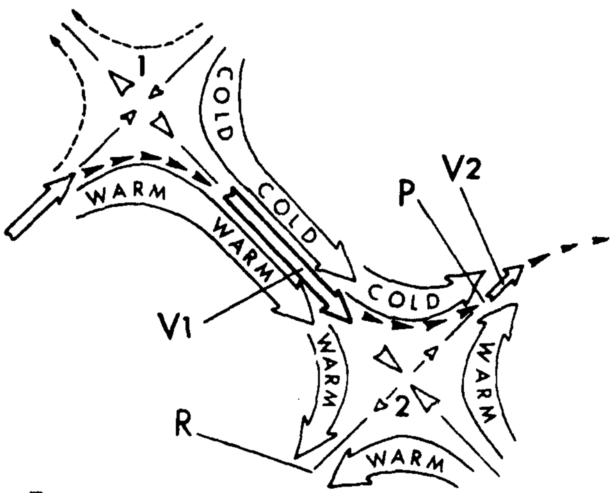


Fig 35b TIME 1

In the example used, the systems are translating within the westerlies in addition to changing with time. The deformation zones shown are in the relative motion of the air. The temperature and wind fields are not symmetrical. This was chosen to represent a more typical case in the westerlies. Therefore, the stretching of the #2 deformation zone is not a symmetrical process. Equal and oppositely directed speed maxima are not occurring on the ends of the deformation zone. This is also shown in the temperature field. The air which is turning - or spreading - to the right side in advance of "V1" is of nearly the same temperature as that falling back from the southeast (both branches are labeled "warm"). So, the new temperature gradient at "R" is weak. At "P" a strong new temperature gradient is growing. There the baroclinity is increasing with time, and the air is accelerating to form new speed maximum "V2". That region is "frontogenetic" in the middle troposphere. I must emphasize that I am talking of changes FOLLOWING THE SYSTEM, not with respect to the ground, or with respect to the air parcels. So, the "frontogenesis" and the "acceleration" is with respect to the moving system at point "P" (Point "P" is moving and retaining the same relationship to the deformation zone.)

The same system is shown at a later time in Figure 35c - labeled TIME 2.

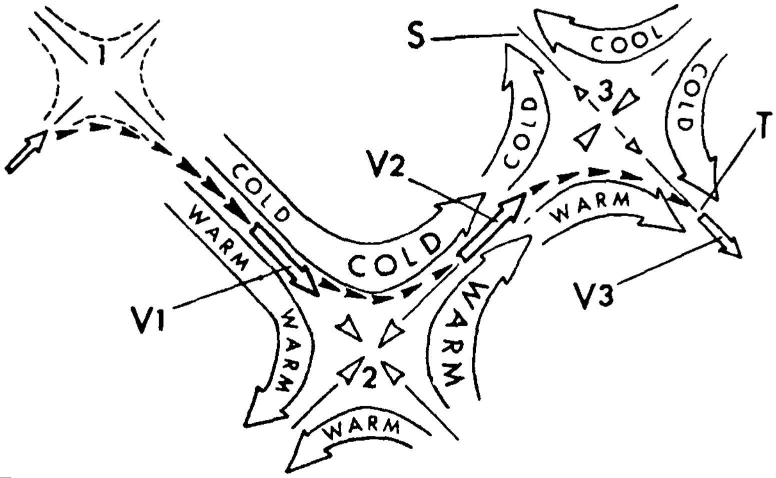


Fig 35c TIME 2

At TIME 2, speed maximum "V1" is no longer intensifying. Speed maximum "V2" has reached a magnitude similar to that of "V1" and is still intensifying. The stretching and compacting processes of deformation zone #2 are now balanced. In advance of newly intensifying speed max "V2", a new deformation zone #3 is present. It is compacting in the NE-SW direction more than it is stretching in the NW-SE direction. A new baroclinic zone is intensifying at point "T", and a new speed maximum "V3" is forming. At point "S" the winds are becoming less westerly with height (or more easterly) as the deformation process modifies the temperature gradient there.

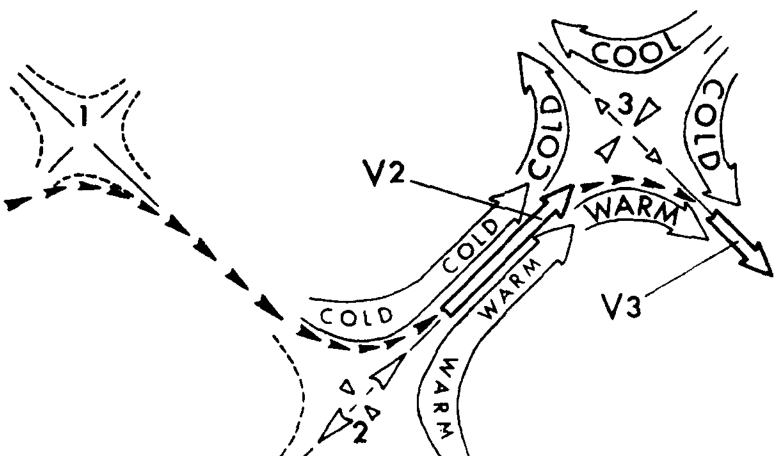


Fig 35d TIME 3

By time 3, speed maximum "V1" has decreased significantly to the point that it is no longer well defined. Deformation zone 2 is stretching more than it is compacting. The primary channeled wind maximum in the system is "V2", which is still increasing some, but nearly at its peak. Speed maximum "V3" has become strong and channeled, and is increasing rapidly.

---

At time 1, the primary speed maximum was in the northwest flow on the back side of the trough as speed maximum "V1". By time 3, the primary speed maximum had become "V2" - now strong and channeled on the front side of the trough. During the process, the trough had amplified. The resulting change in the trough structure from time 1 to time 3 was similar to the change shown in Fig 35a. But, in that first case, the speed maximum had maintained its identity as it "rotated" under the base of the deepening trough onto the front side. In this second case, the result was achieved by the speed maximum dissipating on the back side of the trough, while a new one formed on the front side. This kind of process is what I meant by "transferring the energy through the deformation zone". It is also an example of the "hydraulic effect", when thinking of the process as a "push", compacting, and stretching effect. I think it's important to note that the role of the deformation zone involved "changing" deformation. The motion field - during the period illustrated - was under constant change with time following the system as it translated. As the wind speed at one point (following the system) was accelerating, the speed at another point was decelerating. In such a situation, the cloud patterns (and associated weather) are also changing with time.

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I have shown two processes - or models of processes - in which the wind field configuration of a trough changed with time. When this type of configuration change occurs in real atmospheric systems, the change usually involves a combination of both processes. At times, the contributions of the two processes appear to be nearly equal. At other times, the change appears to be almost entirely contributed by one process or by the other. In those cases, the examples presented represent the real atmosphere reasonably well in regard to how the changes are occurring. A good question is: why - in some cases - does the speed maximum rotate onto the front side of a trough, whereas in other cases it reforms there by the "changing deformation zone" process? Although I have been able to correlate these differences with some differences in the environmental wind field, the relationships have not yet been tested enough for me to consider them reliable.

I should point out that the same kind of different processes are involved in the shift of a speed maximum from the back to the front side of a ridge, as well as from back to front of a trough. And, during the summer season, when the strong wind zone of the westerlies is narrow and shifted poleward; a speed maximum such as "V1" of Figure 35b can shift to position "R" as a northeasterly speed maximum, or it can rotate around the ridge into that position. The energy may be "split" at the deformation zone with oppositely directed new speed maxima on both ends. Such variations occur during other seasons also, but are more prevalent during the summer.

In each example of Figure 36, the large open arrow represents a well defined channeled speed maximum which is undergoing intensification (following the system with time). A deformation zone - or stretching axis of a hyperbolic region in the relative motion of the air - is depicted by a double dashed lines with arrows on opposite ends. The dashed lines represent mid tropospheric isotherms, such as 500mb isotherms, or thickness isopleths for some mid tropospheric layer, such as 700-500mb. Solid streamlines show the relative motion of the deformation zones.

The objective of showing Figure 36 is to discuss briefly the changes that occur in the region in front of - or downstream from - and intensifying speed maximum or "surge".

From observations, I could list several dozens of different changes to cloud patterns and analysis features - all of which I have seen with enough repetition to know that they are not merely coincidental. But, I do not understand enough about the variations to make the information very useful.

The following observations are resonably reliable and worthwhile:

A surprisingly (to me) large area in front of the speed max is affected.

Exactly what changes occur depends upon what is already there.

A general change that occurs is that baroclinic zones are produced or intensified in an orientation which is transverse to the baroclinic zone of the speed maximum or "surge".

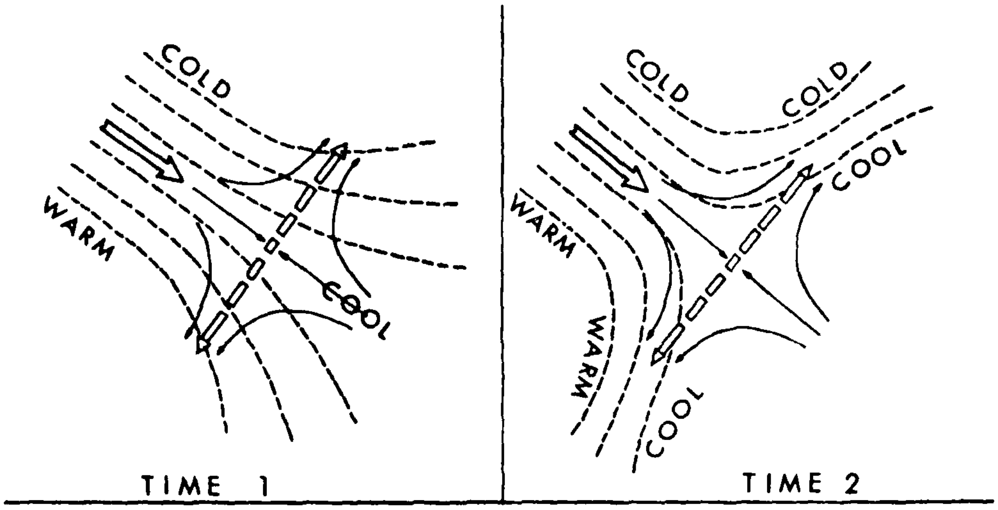
Cloud systems in the region tend to elongate into an orientation parallel to the stretching axis of the deformation. Weak troughs, ridges, highs, and lows pre-existing in the region tend to become elongated or "shear out" in an orientation parallel to that axis.

In Figure 36a, TIME 1, the isotherms simply "fan out" through the deformation zone, and the primary baroclinic zone is that associated with the intensifying speed maximum. By TIME 2 the deformation process has modified the temperature field. Regions of packed isotherms nearly orthogonal to the original baroclinic zone have been produced. The new baroclinic zone to the left front quadrant of the speed max is moving as a mid tropospheric cold front, and that to the right front quadrant as a warm frontal zone.

A similar change is shown in Figure 36b, except in that case, a better defined system or perturbation pre-existed on the southeast side of the deformation zone. The general change that occurs is to enhance or intensify temperature gradients oriented transverse to that of the upstream speed max, and to weaken those parallel to it.

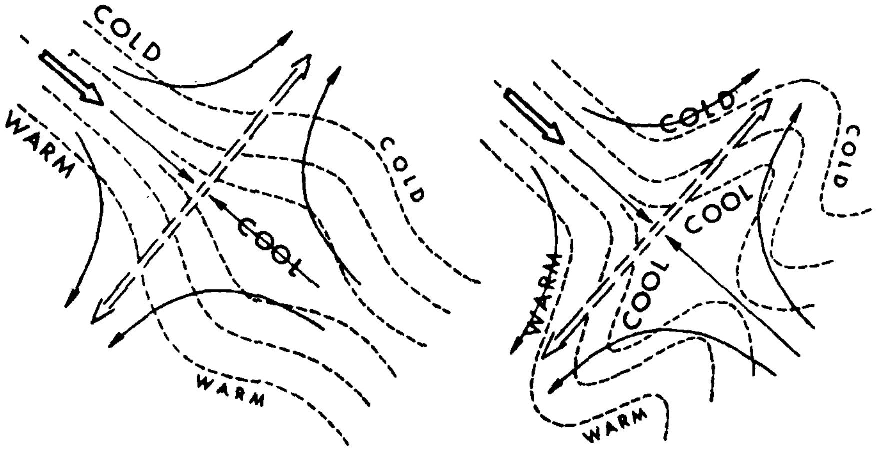
Such unrealistic symmetry as shown in Figures 36a & 36b are not likely in atmospheric systems. Figure 36c shows a more realistic pattern. The speed max has undergone some rotation and the systems to the north have moved at a faster rate than the southern ones.

The type of cloud systems that would form at locations "A" & "B" in Fig 36c are discussed in Section F of the notes. See page 62.




TIME 1 TIME 2

Fig 36a




TIME 1 TIME 2

Fig 36b

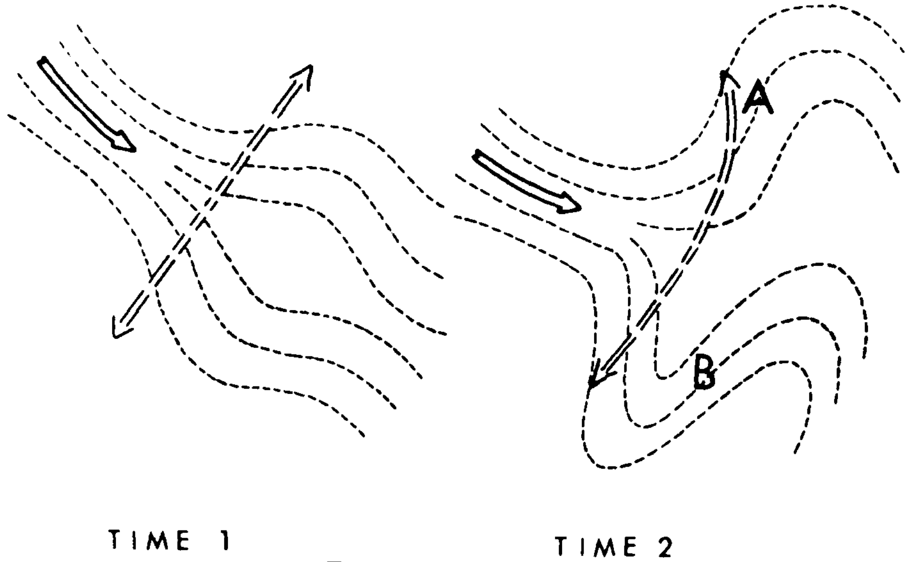



Fig 36c

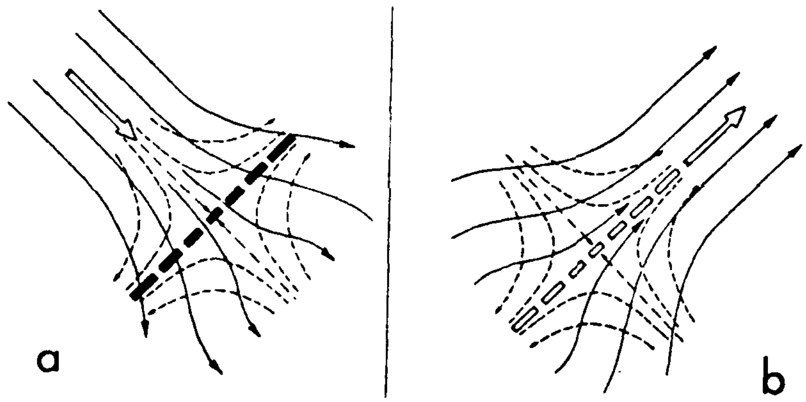



Fig 37a & b

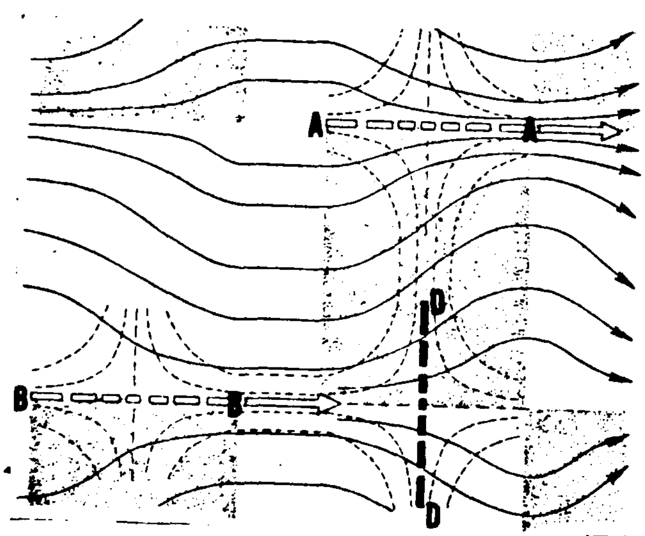



Fig 37c

## PART THREE - TWO TYPES OF DEFORMATION ZONES AND THEIR CHARACTERISTICS

Shown in Figures 37a & b are two deformation zones. Both are oriented NE-SW. In each case, air within the deformation region would be undergoing NE-SW stretching and NW-SE compacting. This is indicated by the relative motion streamlines shown as thin dashed lines. In both drawings, the thin solid lines are wind field streamlines, and the large open arrows represent channeled speed maxima. The differences between the deformation zones and their associated wind field patterns can be used to illustrate two types of deformation zones.

### "TRANSVERSE TYPE" Deformation Zone: Figure 37a

A deformation zone (stretching axis) which is oriented nearly orthogonal or transverse to the basic flow, and is downstream from a channeled speed maximum in the wind field. For practical use, I will stretch the definition to mean "nearly channeled". (I originally refered to this kind of deformation zone as "Type G")

### "LONGITUDINAL TYPE" Deformation Zone: Figure 37b

A deformation zone (stretching axis) which is oriented nearly parallel to the basic flow, and is upstream from a channeled speed maximum in the wind field. Again, I mean "nearly channeled". (I originally referred to this kind of deformation zone as "Type L")

In Figure 37, "transverse type" deformation zones are shown as wide solid dashed lines, and "longitudinal types" are shown as wide open dashed lines.

Many deformation zones that are associated with mid & upper tropospheric wind fields in the atmosphere do not fit into either of the two types defined; but many do, and those have certain specific relationships to cloud and weather patterns.

The idealized drawing in Figure 37c shows 2 "longitudinal type" deformation zones ("A-A" and "B-B") and one "transverse type" ("D-D"). In the drawing, thin solid lines are streamlines, dashed lines are isopleths of relative vorticity, and "PVA" areas are shaded. Large open arrows are channeled speed maxima. Note that the two "longitudinal type" deformation zones act as a border or interface between "PVA" & "NVA" areas. The "transverse type" is not such a border. The associated "PVA" area is across the axis on that part which is to the left front quadrant of the upstream channeled speed max. That part which is to the right front quadrant of the speed max has "NVA" associated.

From empirical observation, I have found that a "transverse type" deformation zone is very likely to be associated with mid tropospheric frontogenesis, and that a "longitudinal type" deformation zone is more likely to be associated with mid tropospheric frontolysis. There are exceptions to this relationship, and I now believe it may be dependent upon whether or not the associated channeled speed maximum is increasing with time (following the system). But, even with the exceptions, the relationship between frontogenesis and "transverse type" deformation zones is a useful one. I emphasize that I refer to frontogenesis & frontolysis following the system.

There are also some useful relationships between the types of deformation zones and the occurrence of precipitation. These are presented next.

## PART FOUR - PRECIPITATION REGIMES RELATED TO JET CHANNELS & DEFORMATION ZONES

The following relationships between precipitation regimes and characteristics of the upper air wind field were empirically observed. The "regimes" of precipitation discussed typically involve moderate or greater continuous precip, or moderate to heavy showers or thundershowers. In fact, the precip within the areas discussed, tends to be mostly convective in nature, although it is often reported as rain or snow rather than rainshowers or snowshowers.

In the drawings, the large open arrows labeled "A" are channeled speed maxima. Wide dashed lines represent deformation zones. Longitudinal type deformation zones are open dashed, and transverse type are solid dashed.

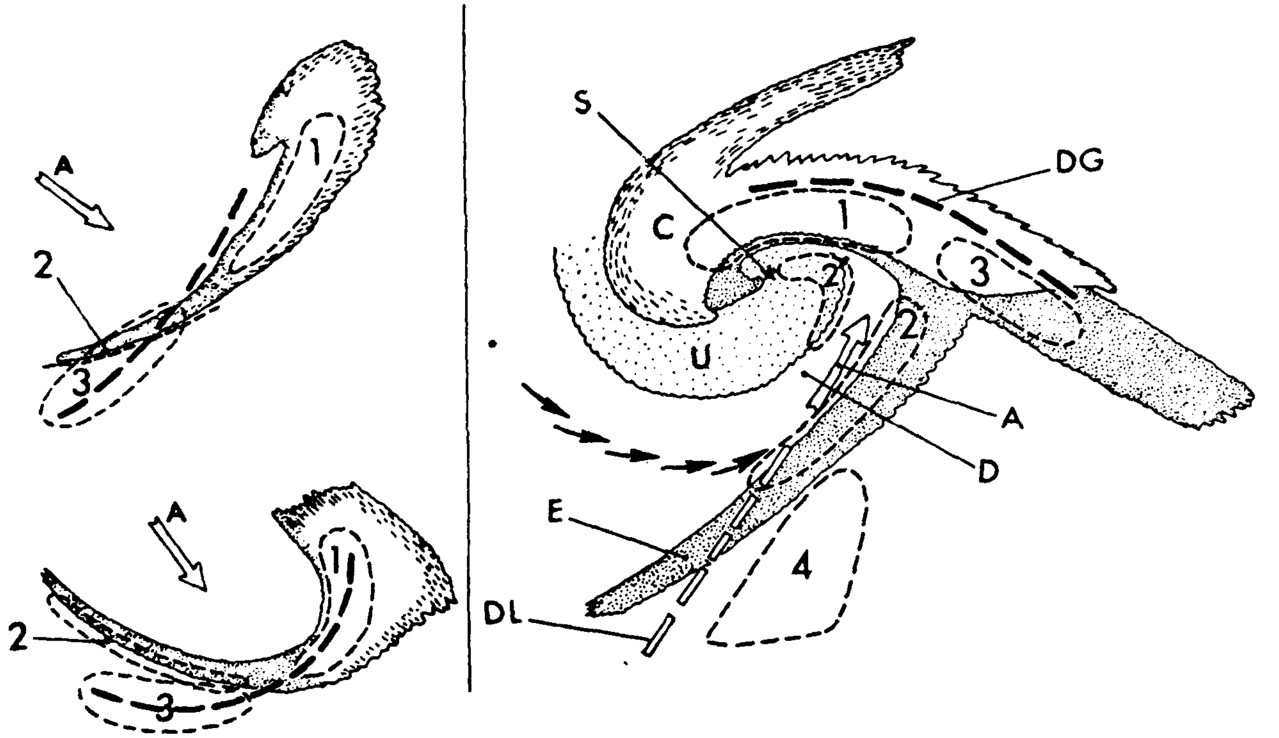



Fig 38a Fig 38b

### Figure 38a: Channeled speed maxima on the back side of a trough

Figure 38a shows two cloud comma patterns with channeled speed maxima upstream from "transverse type" deformation zones. Areas of significant precipitation are marked and numbered. The difference between cases in Fig 38a is that the top drawing represents a relatively new comma pattern which is likely associated with a relatively short - and probably curved - channeled region. It is, thus, more likely to be moving in a curved path. The bottom drawing represents an older comma pattern which is likely associated with a longer straighter channeled region. It is likely to be moving in a straighter (more "digging") path than the system in the top drawing.

PRECIPITATION REGIMES

□ 1 Significant precip in this region is the most common location. It is diurnally persistent and more continuous. The only difference between the top & bottom cases is that more precip may accumulate at a given location with an older system where the precip regime is more curved back - more parallel to the middle level wind field; thus the precip can last longer at the location.

□ 2 This precip regime is along the leading edge of the comma tail band to the right side of the upstream channel (looking downstream). Over land this regime produces convective precip beginning in the afternoon hours and lasting into the evening. Over the oceans, I don't believe much deep convection occurs in that location, but I can only guess looking at satellite pictures.

□ 3 This regime is along the middle tropospheric deformation zone to the right front quadrant of the upstream channeled jet. It is likely to occur within a 500mb NVA area. It is usually convective and begins after midnight and lasts until a few hours past sunrise. Sometimes during summer or late spring when the low level enviroment is very moist, the outflow boundaries from the convection will continue to produce new convection; thus, allowing the regime to last all day (although it moves out of the initial synoptic location - usually to the south or southeast).

Figure 38b: Channeled speed maximum on the front side of a trough

This drawing depicts a somewhat older and more complicated "storm comma" system. The large open arrow ("A") is a channeled max wind zone with a "transverse type" deformation zone ("DG") in advance and a "longitudinal type" deformation zone ("DL") to the rear. Together they form a "T-shaped" pattern. A typical position of the surface low pressure center is at "S". That part of the cloud pattern, which is labeled "C" has high cold cirrus tops. The cloud region of dark shading is most often low based with middle level persistent tops. The height of these tops generally decreases southwestward along the "tail band" toward "E". That part of the "tail band" which is southwest of its intersection with the upstream jet axis (shown by solid arrows) is commonly best related to the low level frontal boundary (typically near 850mb), and has a decent relationship to the surface cold front. The lightly shaded area "U" represents low based convective clouds (Cu or StCu).

PRECIPITATION REGIMES

● 1 This is the most frequently observed location for significant precip. It is diurnally persistent. It is similar for systems over the oceans. It is - as with area 1 of Fig 38a - to the left front quadrant of the jet channel within the primary PVA area. (at 500mb)

● 2 This regime has an afternoon & evening diurnal maximum. The primary location is along the front border of the dry slot and north or northeast of the point over which the upstream jet axis intersects the frontal zone. The convection may also begin within the frontal "tail" cloud pattern Convective bands often are oriented at an angle deviated somewhat clockwise to that of the tail band itself.

● 2' This regime is on the rear border of the dry slot and curves around to a position just in advance of the surface low center. This also has an afternoon and evening diurnal maximum over land. (I have no evidence that this regime or #2 occurs over the oceans) Sometimes convection in regime 2' is diurnally persistent as is regime 1, but this usually happens when a new secondary vorticity maximum or speed maximum swings around under the south side of the upper level low. So, it's really the same as adding a small Figure 38a cloud system within the bigger storm pattern.

● 3 This regime is along the middle level deformation zone (which is now in this case probably referred to as a "warm frontal zone") to the right front quadrant of the jet channel. This regime has a diurnal maximum between local midnight and a few hours after sunrise. Peak time is just before sunrise. The precipitation is usually convective, but is often embedded in layered cloudiness.

● 4 This area is located to the right rear quadrant of the jet channel, on the east side of the axis of the middle level "L" type deformation zone. This is usually ahead of the low level frontal zone. When low level thermodynamic conditions support the convection, it will occur with diurnal persistence. This regime should not be confused with the type of cloud system in position "B" of Figure 36c. That type of weather system becomes a separate entity on many occasions after the system to its north weakens or moves off. Convection regime 4 seems to be dependent on the related storm system to the north for survival. It can - however - provide a significant deep level moisture source for a Fig 36c type system, if a new channeled speed maximum comes down the back side of the trough - where the NVA type jet axis is shown on Figure 38b.

The precipitation regimes discribed have meaning ONLY when related to the specific type of jet stream structure and deformation zones indicated. For those situations, the rules (although generalizations) are pretty good ones. Much of the late night and early morning convection that occurs over the U.S. east of the Rockies during summer months is in the #3 Precip Regime location with respect to the 24 hour 500mb LFM prog issued by NMC.

Occurrence of convection in the locations indicated also depends on the geographical area, the time of year, and the local low level moisture fields. Regime 1 is the least affected by these environmental conditions.

And, I emphasize, that lighter precipitation and less persistent heavy precipitation was not considered as part of the relationships. There are many rather systematic variations which cannot be mentioned here without a great deal of further "ground work", and many other variations that are obviously important, but which I do not understand.

38a REPEATED 38b

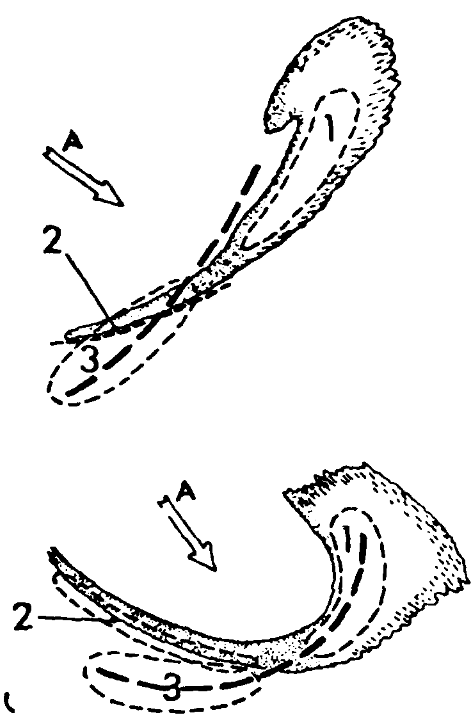



FIGURE 38a REPEATED

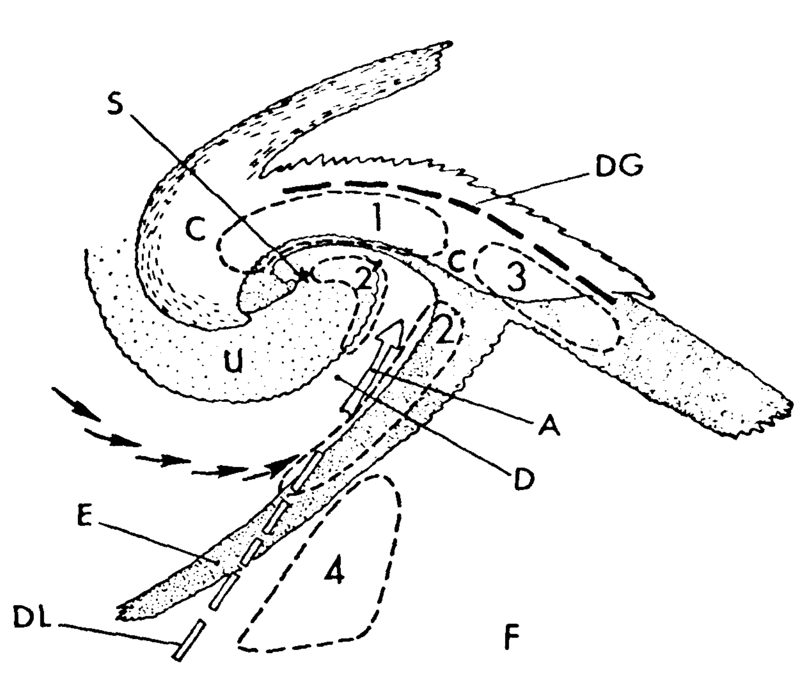



FIGURE 38b REPEATED

Note that in the drawings of Figure 38, I have depicted the cloud systems as they might appear when only the #1 precipitation regimes are active. The systems are depicted as they would typically appear over the eastern parts of the oceans - except that more low clouds would then be present. If - for example - convection were occurring in location #2 of Fig 38b, cirrus outflow would cover most of the middle top band in that area, and would likely connect with high cloud system "C" to the northeast of "2". No clouds at all are shown in area #4. If convection were occurring there, the cirrus outflow often forms a kind of "fan" shape, with some moving to the northeast and others to the east.

In the case of Figure 38b, the boundary or frontal zone associated with deformation zone "DG" would most likely be intensifying at the time of the drawing. That portion to the southeast of the figure "3" would be warm frontal in nature, and would likely have a surface warm front associated. If the channeled jet segment at "A" arrived onto the front side of the trough by rotating around as illustrated in Figure 34; then the frontal configuration shown would most likely have evolved in a manner similar to the classical "occlusion" process. However, if the jet channel formed on the front side of the trough in the manner illustrated by Figure 35; then the frontal zone associated with "DG" formed and intensified in that position with respect to the storm, and an old - now shallow - cold frontal zone might be located east or southeast of "4" — at "F".

## E. CLOUD COMMA PATTERNS and the UPPER AIR WIND FIELD

A large variety of cloud system shapes are given the "comma pattern" nomenclature. You probably wouldn't believe some of the cloud system shapes that are called "commas", especially when observed on time lapse motion. The term "comma" originated because of the similarity between the shape of the punctuation mark and the shape of the cloud pattern; but, as more was learned about such cloud systems, the "comma" term began to be also associated with particular kinds of cloud system behavior in addition to shape alone.

The primary characteristic of cloud "comma" patterns is the "S" shaped relatively well defined back border. Many processes of the wind and density fields contribute to the specific shapes of cloud comma patterns. I am convinced that the most basic of these is the role played by "differential rotation". This concept is illustrated in Figure 39 below.

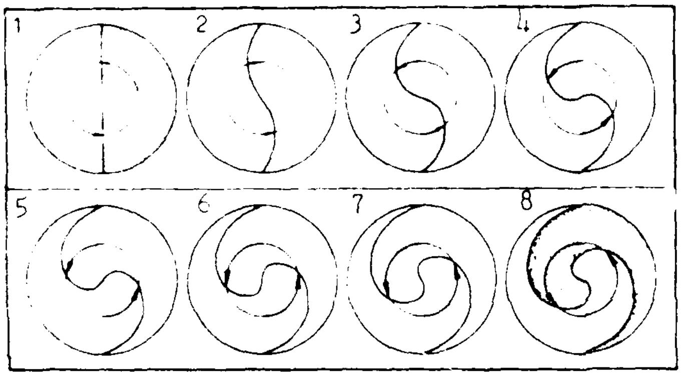



FIGURE 39a

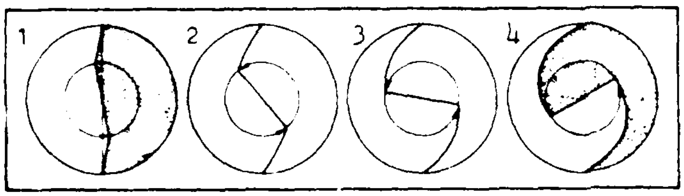



FIGURE 39b

In Figure 39a an initially straight border dividing the circle (time #1) is allowed to rotate differentially.

The largest tangential speed is at the inner circle or arrow. Radially inward & outward from there, the tangentail speeds decrease.

With time the border forms a modified "S" shape, and the two halves of the circle form comma patterns. Part of the border rotates cyclonically, and parts rotate anticyclonically to form the "S", The vorticity varies with a cyclonic maximum at the inflection point.

In Figure 39b a similar differential rotation is shown with the shear of the tangential speed constant. Even in this latter case, a "comma" pattern similar to many cloud patterns results.

In the patterns of Figure 39a, the border is through the point of maximum vorticity. Most cloud patterns of comma shape do not have borders that lie through the center of maximum vorticity (at 500mb).

Some cloud comma patterns have an "S" shaped rear border with an inflection point as at "S" in Figure 40a (next page). Many, however, have instead a point such as at "P" of Figure 40b, with a "slot" or "surge region" behind the sharply concave part of the border. And even more have a somewhat rectangular or double pointed region such as at "A" & "B" in Figure 40c.

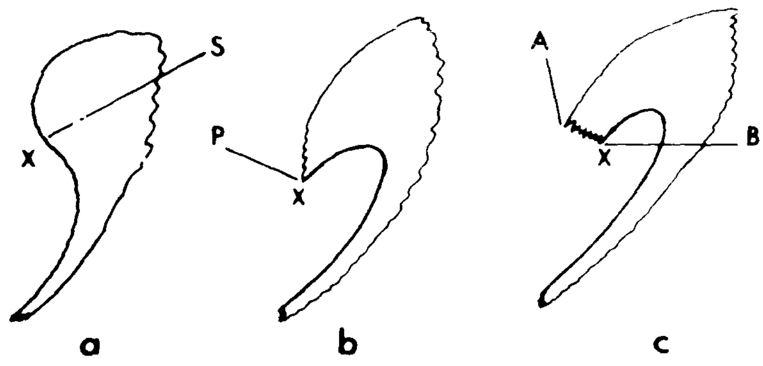



FIGURE 40

In the drawings of Fig 40, the "X's" show the location of the center of maximum 500mb vorticity as related the specific cloud comma shape. The relationship is empirical.

In cloud comma systems, as in the drawings of Fig 39, it is a boundary that deforms into an "S" shape by differential rotation. It is rarely a case of the clouds merely moving along within the motion field. It is the case of a boundary propagating within the differentially rotating motion field. The boundary doesn't move at the same speed as the winds, but its movement rate and direction is closely correlated with the wind speeds.

I said that differential rotation was the most basic process which contributes to the comma shape. Obviously, the production and maintenance of the cloud boundary is also a fundamental contribution. In many cases during the formation of a cloud comma pattern, the cloud border is produced very early while the interface or boundary which produces the cloud edge is nearly straight. I call this early stage cloud pattern a "baroclinic leaf" (it will be discussed in the next section.) With other cases of comma formation, the interface or boundary is present and undergoes differential rotation before the clouds form. When the clouds do form, the pattern is already in a "comma" shape.

Sometimes the boundaries that form cloud comma patterns are basically within the same vertical layer. The boundaries with a particular comma may be all within a low layer, or all within a high layer; but this is not the typical case. Most single cloud comma systems have boundaries at different levels forming the cloud pattern. Below, I use this concept to categorize cloud comma patterns.

## FOUR BASIC TYPES OF CLOUD COMMA SYSTEMS IN THE WESTERLIES:

Drawings which illustrate the 4 types are placed together on the next page for easier comparison.

Briefly, the first two types are primarily associated with low and lower middle tropospheric boundaries and motion field perturbations. The third type has high level baroclinic zone cirrus associated, and the 4th type directly involves a perturbation of the upper tropospheric layers.

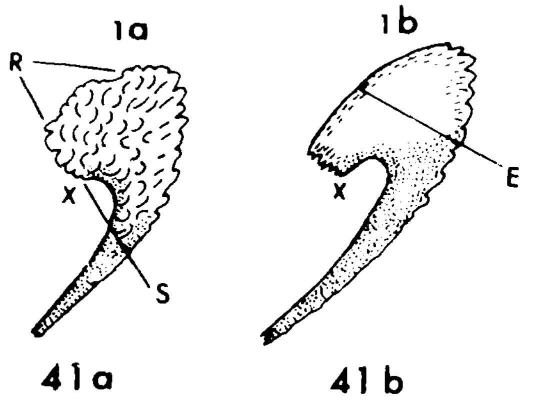



FIGURE 41

"Naked" Comma Patterns

41a - Type 1a Boundaries are mid & low level

41b - Type 1b New high level boundary formed at "head"

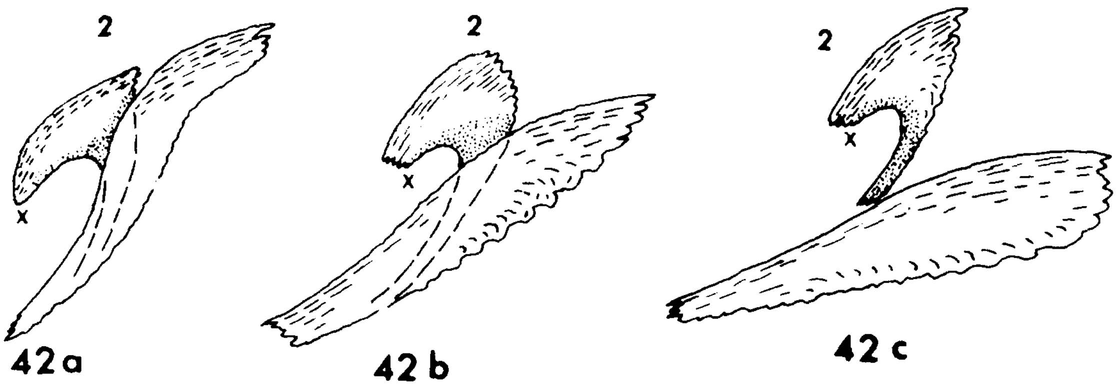



FIGURE 42
"Baroclinic zone cirrus" decks are present along the axis of the related jet stream.

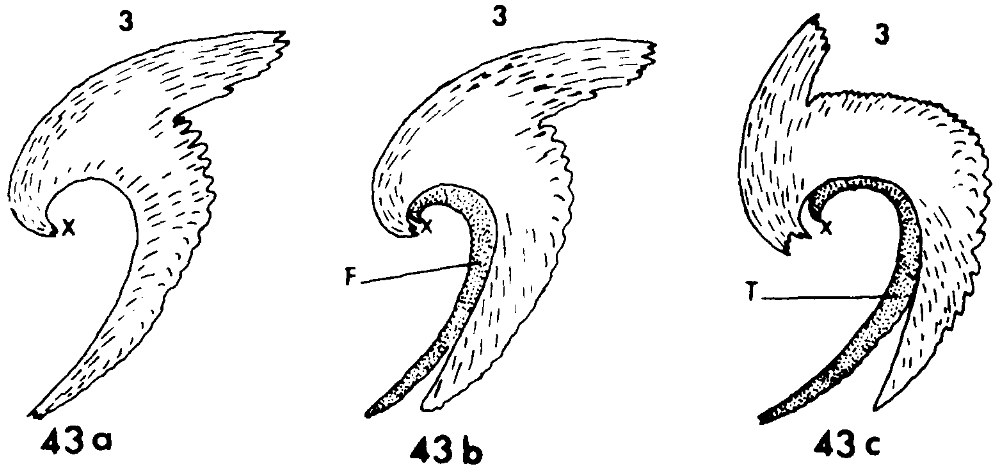



FIGURE 43
A complete comma shaped cloud pattern is formed by high level boundaries.

I often refer to both of the first two types of comma patterns as "naked" commas, because jet stream related cirrus is not present to cover the features.

Type 1a:

This is shown in Figure 41a. The primary perturbation producing the cloud system is in the middle troposphere. The cloud system border at the back side (western side) is well defined at mid and low tropospheric levels. That part of the border along the "head" of the comma - indicated by "R" is primarily a mid level interface, and secondarily low level. This is generally true around the rear of the head to the apex of the "slot" - at point "S". **From the slot SW-ward** along the comma tail, the associated boundary is primarily low level. The clouds or convective cells within the "head" area of the comma may reach to high levels. If they do, they obviously affect the upper atmosphere there, but generally the outflow debris does not persist; and the temperature/moisture changes at high levels are disorganized.

Such comma systems as Type 1a, often form under an upper tropospheric long wave trough.

Type 1b:

This type is very similar to type 1a, except that the outflow layer debris over the comma "head" is persisting and formed into a solid overcast cirrus deck with a well defined boundary at middle and high levels at "E". Often, as a type 1a comma continues to develop, the cirrus outflow begins to persist and fill in between cells forming a sold deck. Coincident with this change is the formation of a warm mid tropospheric ridge or amplified anticyclonic vorticity minimum over the "head" region, and the formation of a new middle tropospheric baroclinic zone along "E". A new high level speed maximum also forms along the east or northeastern end of "E". More about this process is given later. **(See Figures 44 and 54)**

Type 2:

Three examples of type 2 comma systems are shown in Figure 42. This type consists basically of a type 1b comma pattern with a cirrus deck present along the jet stream. Baroclinic zone cirrus decks were discussed extensively in Section C. The major high level baroclinic zone of these systems is not perturbed as much as the middle and low levels. It may become so, and the two ways that it happens will be discussed later.

Type 3:

Three examples are shown in Figure 43. In this type of comma pattern, the primary boundaries at the rear of the cloud system are at high levels. Often a type 2 cloud system will evolve to type 3 by intensifying vertically upward in the atmosphere. In effect, the high level ridge extends north and northwestward around the head of the comma. The processes involved will be discussed. Some systems evolve directly into a type 3 system; the upper level development in those cases is often ahead of (in time) the low level development. Or, the system may be developed at high levels only. This often happens within the equatorward branch of a split in the westerlies around a high/low couple. If the type 3 system extends downward into the mid and low troposphere, the low level comma "tail" may be in phase & under the upper level "tail" (Fig 43a), or it may be to the rear as at "F" & "T" in Figures 43b & 43c.

VERTICAL DIFFERENCES IN THE FEATURES OF A TYPICAL CLOUD COMMA SYSTEM

As soon as a new baroclinic zone is formed - or newly intensified - vertical motion regimes immediately begin or increase. The resulting "vertical exchange" of air "feeds back" upon the wind fields, by enhancing or reducing baroclinity at different levels and locations. A typical cloud comma pattern as observed on satellite images is an amalgamation of clouds & cloud boundaries of primarily different levels. This is illustrated by Figure 44 below.

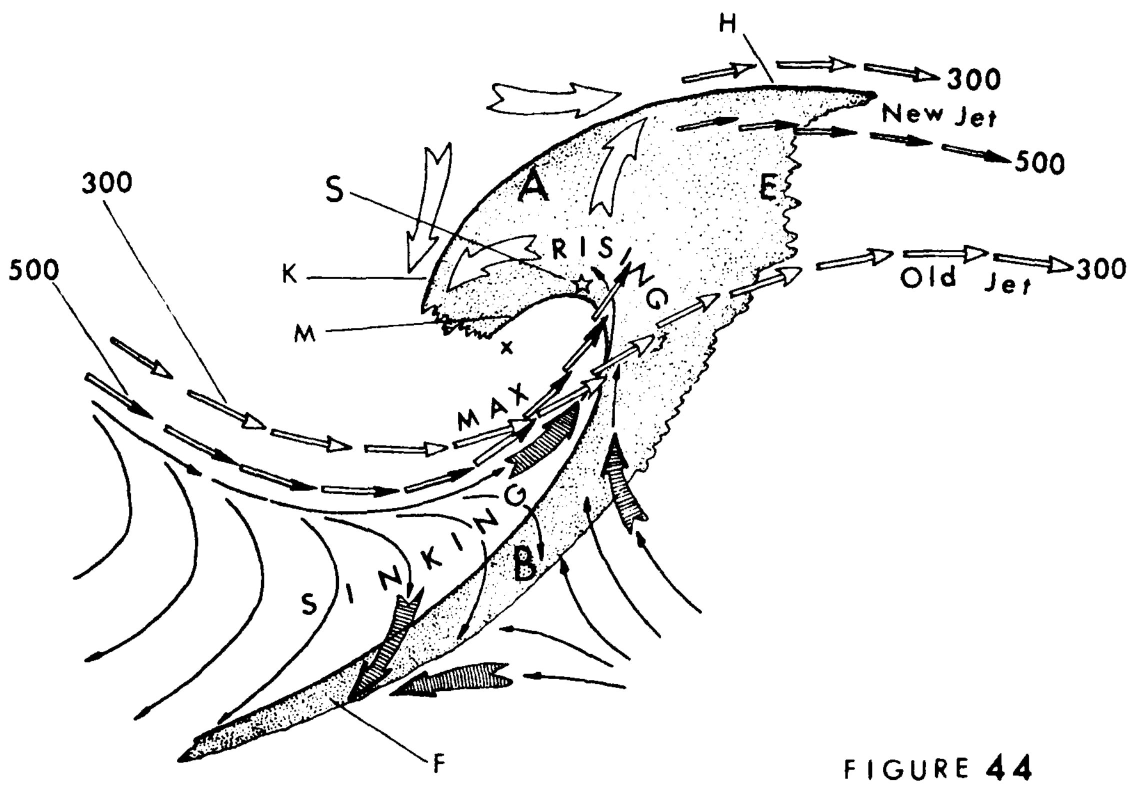



FIGURE 44

The cloud pattern in Fig 44 represents a typical cloud comma system moving within the westerlies. The streamline and height contour fields would likely be closed only at and below 850mb. There would be no easterly winds involved at 700mb or at higher levels (up to 150mb). The vorticity center (point of maximum value of 500mb vorticity) and surface low center are moving toward the east-northeast at the time of the drawing . Almost any of the features or relationships shown could vary from one system to another, but I tried to put together a set of the most typical ones.

On the drawing, the axes of maximum winds at 300mb are depicted by open arrows with open arrowheads, and the axes of max winds at 500mb are open arrows with solid arrowheads. Thin lines with arrowheads are surface streamlines. Large open arrows indicate the relative motion field associated with deformation zones. Those that are cross-hatched indicate deformation in the low level flow. The surface low pressure center is marked by a star at "S". A small "X" is located at the 500mb vorticity center.

THE MAXIMUM WIND ZONES:

The maximum wind speeds along the associated jet stream are just upstream from the comma near "MAX". At that location, maximum speed would be near 400mb. At 500mb the maximum speed would also be near "MAX", and the speed would decrease considerably within the cloud comma area. In fact, it would probably be difficult to identify an axis of maximum 500mb winds in the ridge area where no axis is shown on the drawing. If the system is developing rapidly at the time of the drawing, then the 300mb wind maximum would also be near "MAX". From there downstream along the axis shown, the speeds would decrease over the cloud system, then increase again further downstream - but not to as high of values as near "MAX". On the downstream side of the comma pattern, there are two jet stream zones. The branch at "old jet" is located along the previously existing high level baroclinic zone in that area. The jet core in that zone would be relatively high - max speeds near 250mb. There would likely be a 500mb axis of maximum winds associated with that southern branch (no axis is shown on the drawing), but the 500mb wind speeds would be stronger with the northern branch where an axis is shown. Along the northern branch (labeled "new jet")maximum speeds would likely be near 300mb and the jet core would extend farther downward in the atmosphere than along the southern branch. (Note that there is no "sub-tropical" jet stream shown on the drawing)

In the middle troposphere - typically at 500mb -, in the area bounded by edge "K-H" and the word "RISING", and downstream to the ragged edge at "E"; warming occurs with time as the system develops (and cooling with time often occurs over that area a high levels). This process tends to decrease the mid tropospheric baroclinity along the "old jet" zone, and increase the baroclinity along boundary "K-H" and the "new jet" zone. On the downstream side of the cloud system, the southern jet stream weakens, and the northern jet strengthens with time. If the development of the system continues, the southern max wind zone loses identiy, and the northern one becomes stronger, better defined, and takes over as the primary "jet stream" downstream from the system.

THE CLOUD SYSTEM BOUNDARIES:

The well defined border at the "top of the comma head" is associated with deformation zone "A". It is at this stage of the system primarily a middle and upper level feature. At 500mb the edge is associated with a zone of isotherm packing - cold to the poleward side and warm to the cloudy side. At some higher level, the temperature gradient is reversed. This could be so at 300mb, but more likely is at 250mb and 200mb. At the first level at which the gradient is reversed across "K-H", it is likely to be cooler between the two downstream wind maxima, with warmer air north of the northern speed max, and south of the southern speed max. The comma head border is likely to be better defined at lower middle levels a "K" and at higher middle levels at "H". This baroclinic zone is formed as the cloud system develops; it develops or intensifies first at mid & high levels, then increases downward as the system develops. There is not likely to be a well defined surface frontal zone associated at the time - or stage of evolution - of the drawing. If the previous system downstream and its associated middle and low level trailing baroclinic zone were at higher latitudes, then a surface extension of boundary "K-H" would probably be present even at this stage of development.

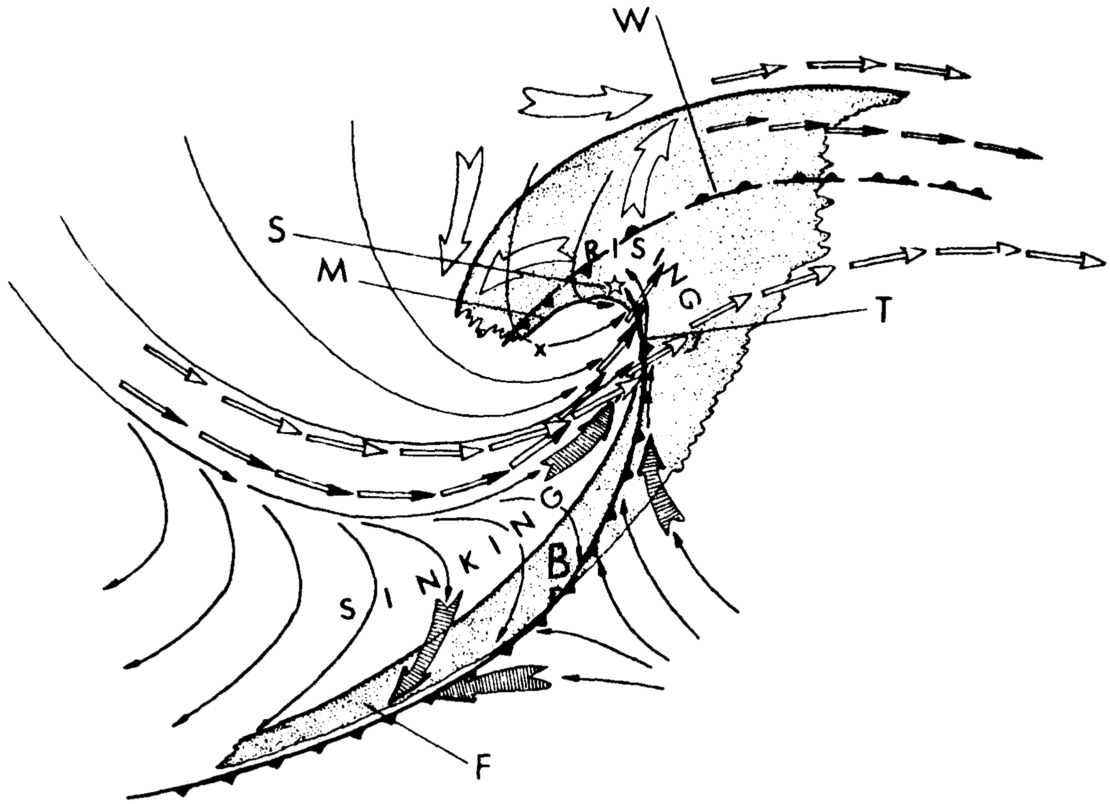



FIGURE 45 The drawing is the same as in Figure 44, except that surface streamlines have been added upstream from the cloud system, and surface frontal boundaries are shown.

If a surface frontal zone were present with the northern boundary, a typical location would be as shown at "W". The boundary would behave as a new warm front for most of its extent, and as a cold front along its westward extension beyond the surface low pressure center at "S".

The vertically deep baroclinic zone upstream from the cloud system would be located parallel to and on the south side of the channeled jet stream. As the system developed and sinking began or increased, a new low level frontal boundary was established along the comma "tail" south of "T". This boundary is associated with the low level deformation zone "B" with large hatched arrows showing the relative motion. The tail feature of a typical (type 1) "naked" cloud comma system is primarily a low level feature. In Figure 45, the location of the surface cold front is shown. That part of the rear edge of the comma pattern at "M" and extending around to about "T", is primarily a mid tropospheric boundary and secondarily a low level feature. West of the cloud system: north of "T" the cold air is very deep (vertically), and south of "T" it is relatively shallow and low - and becomes more so farther southwestward toward "F". North of "T" and downstream from the cloud edge; a region of relatively warm air extends to high levels, with a shallow layer of relatively cool air between level of maximum winds and the tropopause.

The cloud comma system shown in Figures 44 & 45 is of the type 1b(Fig 41b) of those categorized on page48. If there were baroclinic zone cirrus along the jet axis on the anticyclonic side, it would cross over the comma along the southern 300mb axis of maximum winds - the northern edge of the cirrus would be near the 300mb axis. Then the cloud system would be of type 2 and similar to the pattern in Figure 42b.

---

COMMA PATTERN CHARACTERISTICS

The SHAPE of a cloud comma pattern can be related to:

(1) the relative age or stage of evolution of the system

(2) which direction the related 500mb vorticity center is moving (at the instantaneous time of the picture)

(3) where the 500mb vorticity center is located

(4) where the jet stream speed maximum is located, and generally which direction it is oriented (these factors are closely related to item 2 above)

(5) the relative amplitude of the cloud level wind field (whether the streamlines are forming a "closed" pattern)

(6) the location & type of jet stream structure in the vicinity of the cloud system

The intensity of the system relates to:

(1) the distinctiveness of the cloud pattern and its borders

(2) how rapidly the system is evolving - or changing with time

Until this point, I haven't said much about the size or scale of the cloud patterns and their related perturbations of the motion & density fields. In general, the younger a system is - the smaller the cloud pattern, and the older it is the larger the cloud pattern. This relationships is a good one for any given system, but doesn't work as well from one system to another. One of the reasons that size hasn't been emphasized, is that most of the relationships are independent of size or scale.

In the following pages some examples of comma patterns and their related wind fields are shown. Many of the relationships listed above are discussed.

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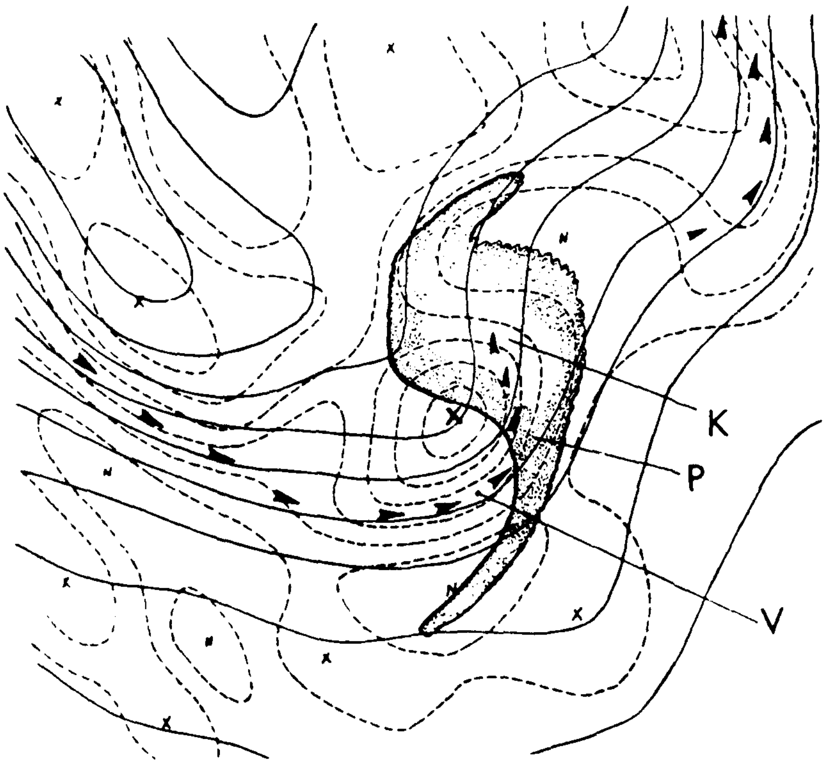


FIGURE 46

The cloud pattern is on a 500mb analysis with height contours (solid lines) and vorticity isopleths (dashed lines). Arrows locate the axis of maximum 500mb wind speeds.

The vorticity center is moving toward the east-northeast at the time of the drawing. The coldest IR cloud top temperatures are within the unshaded area at "K". Cloud tops south of "P" along the tail are at middle & low levels. North of "P" the system is cirrus topped. The max wind zone is channeled at "V". The system is in an early stage.

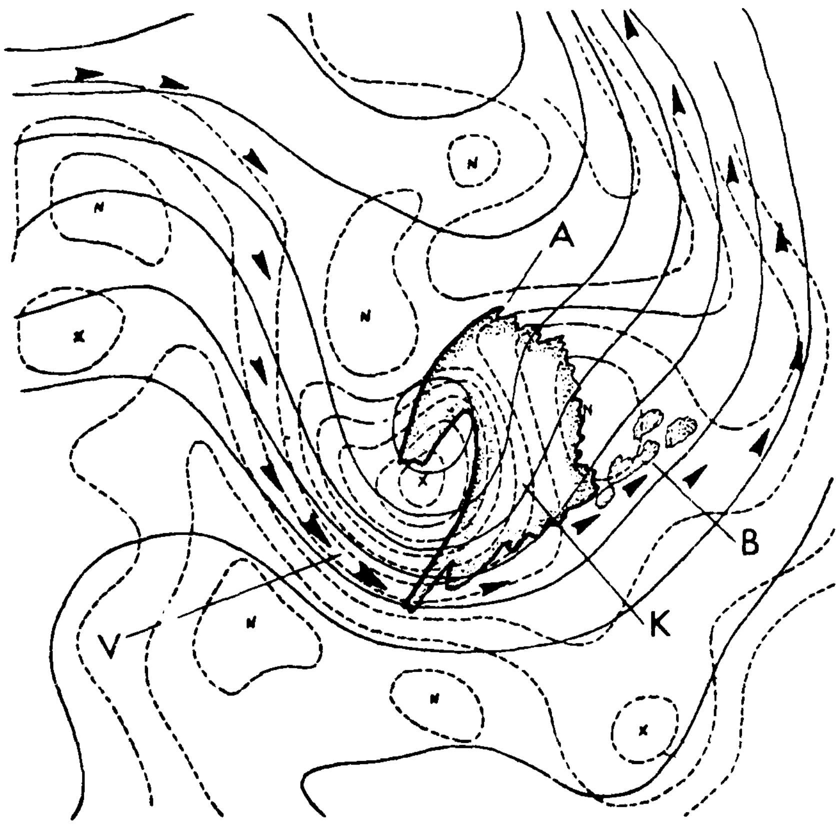


FIGURE 47

The comma pattern is on the same type of analysis, except that the arrowheads are along the jet stream axis.

At the time of the drawing, the vorticity center is moving toward the south-east. The channeled zone is on the SW quadrant of the vorticity center & the coldest IR tops extend around the east side of the system (unshaded area labeled "K"). The tail area is wide and cirrus topped. This is also a relatively young cloud system.

The system in Figure 46 is curving slightly to the left with time, but the path is straighter than that of Figure 47. The system in Fig 47 has a closed 500mb wind field, and a much higher amplitude upstream wind field. The path of the system is curving relatively quickly to the left with time. In Figure 47 the axis of maximum winds is easily identified downstream from the cloud comma and runs along the SE border of the cloud system. Wind speeds are weak at "A". With this type of pattern and with the jet stream configuration on the downstream side, patches of cirrus - such as at "B" - are frequently present.

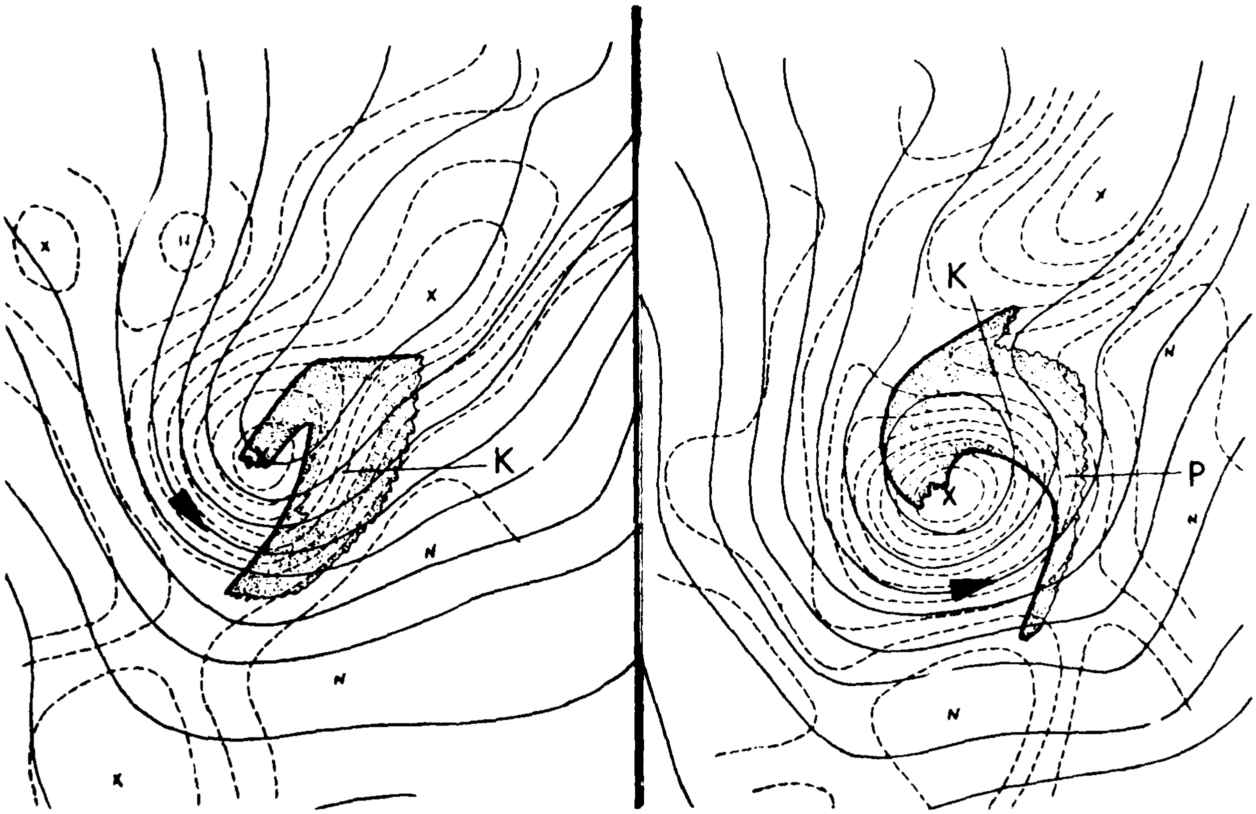


FIGURE 48 a FIGURE 48 b

Figure 48a shows a cloud comma pattern similar to the one of Figure 47. The same cloud system is shown 12 hours later in time in Figure 48b. In Fig 48, solid lines are 500mb height contours, dashed lines are 500mb vorticity isopleths, arrowheads are located at the location of maximum 500mb wind speeds, and the coldest IR cloud top areas are unshaded and identified by "K".

The system is at the base of a sharp trough and swinging in a sharply cyclonically curved path (the path of the vorticity center "X"). At the initial time (Fig 48a), the vorticity center is moving to the SE, the speed max is on the SW quadrant & channeled, and coldest cloud top area is around the ESE quadrant. The comma tail region is wide and cirrus topped. In Figure 48b, 12 hours later, the system is moving toward the ENE and curving to the left with time - the path is cyclonically curved. The speed max is SSE of the vorticity center; the coldest cloud top area is in the NE quadrant. The system is cirrus topped except along the tail south of "P".

The cloud comma systems illustrated in Figures 46, 47, & 48 fit into the type 1 group. They are all relatively small short wave systems. In each case, the coldest topped & vertically thickest parts of the cloud pattern are to the left front quadrant of the channeled speed maximum. The vorticity center moves approximately in the same direction as the orientation of the strongest winds within the channeled region. A young system moving from the northwest tends to have a wide tail region with little or no extension on the anticyclonic side of the jet stream axis.

The cloud pattern in Figure 49 below is a relatively old "storm comma" system. Such older systems are usually bigger and more complex than a young system.

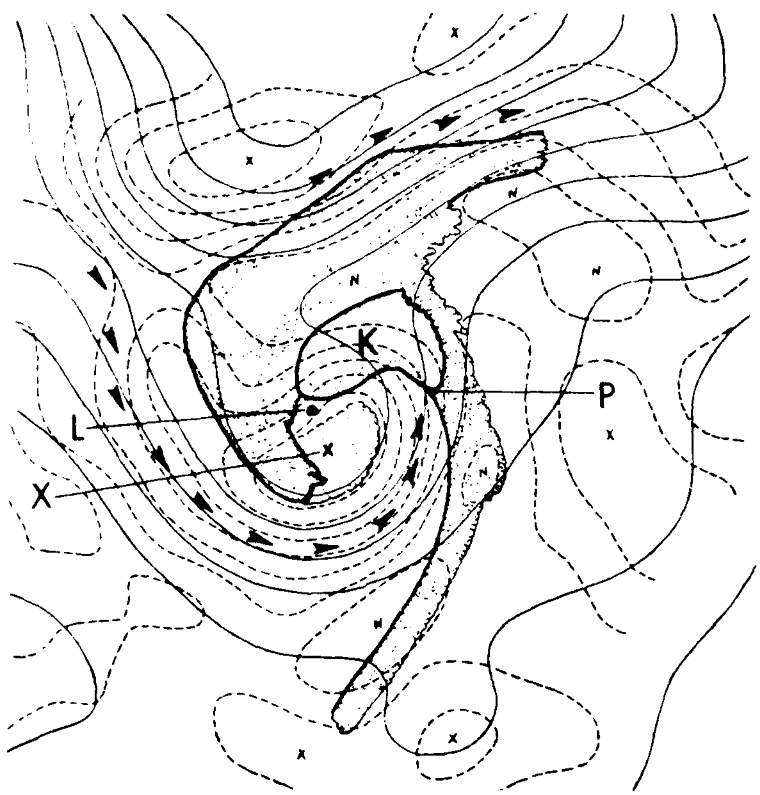

FIGURE 49

The system is generally cirrus topped except for the tail feature south of point "P". The coldest top areas are unshaded, but the deepest coldest tops are within the bordered region labeled "K".

The analysis is again 500mb height contours with dashed line vorticity isopleths. A 500mb low center is at "L" with a vorticity center at "X". The lightly shaded cloud pattern around the vorticity center are low based low topped convective cells.

The system has a long curved channeled zone which extends from west of the vorticity center around to a point SSE of the center.

The arrowheads are located along the axis of the jet stream. The strong wind zone extends into the slot just behind "P", and weaken considerably from there over the ridge. A jet axis is again identifiable along the northern edge of the comma pattern on the downstream end. This type of storm comma system is a type 3 comma pattern. The upper level wind field is high amplitude and the jet stream does not cross over the cloud system.

The coldest - thickest - clouds are again to the left front quadrant of the leading part of the channeled zone. With a high amplitude upper level wind field as this, and with a channeled maximum wind zone more than a quarter of the way around the system; the thick - cold topped - cloud region (at "K"), which is probably associated with the #1 precip regime, will rotate rapidly around the system as it translates. It will maintain its intensity as it rotates. Without the long upstream channel weakening could be expected.

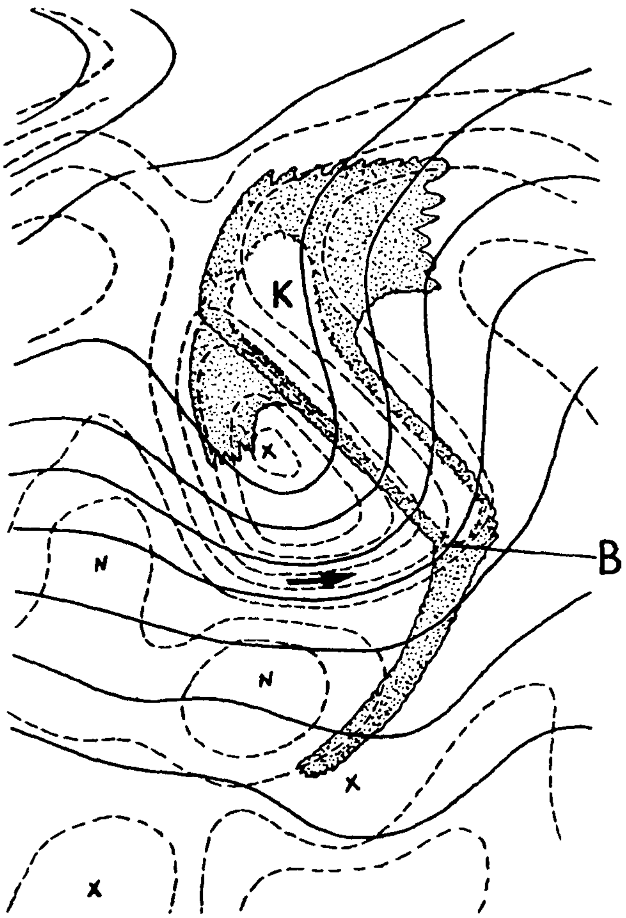


FIGURE 50

The cloud pattern shown in Figure 50 is again a large storm comma pattern with some complexity.

This is shown to illustrate the features related to the "bend" in the comma tail at "B".

Note that the wind field is channeled upstream from "B" with the speed maximum in the channeled zone pointing toward the bend.

The tail southwest of the bend is of low & middle cloud tops. To the northwest of "B" the system is cirrus topped with the thickest coldest topped clouds within the unshaded region "K". The maximum vorticity area is triangular in shape with "PVA" on the front side, "NVA" on the back side, and channeled on the base. In this type of situation, there is often a distinct vorticity "advection lobe" extending from the vorticity center ("X") toward the bend.
If that is the case, and the jet stream is channeled as in Fig 50, there will be another vorticity lobe (shear lobe) extending back along the wind maximum.

With the configuration shown - the wind max channeled upstream from "B", the frontal zone from "B" northwestward toward "K" will remain a[illegible] with convection and significant precip. If the channel is relatively sh[illegible]t [illegible]shown, point "B" will swing toward the northeast moving faster than the [illegible] [illegible]enter. The vorticity advection lobe will stretch and weaken on it[illegible] [illegible]rthwest end.

If the upstream channel is long and nearly straight (as the short segment shown is), point "B" will not rotate to the NE, but will "dig" eastward into the ridge. A new vorticity center will form on the southeast end of the extending vorticity lobe, and the old vorticity center at "X" will weaken with time.

If there is no channeled region upstream from "B" - the "NVA" area extends thru the max wind zone where the channeled region is on Fig 50; then, the entire baroclinic zone from "B" to "K" will stretch out and weaken with time as it swings northeastward.

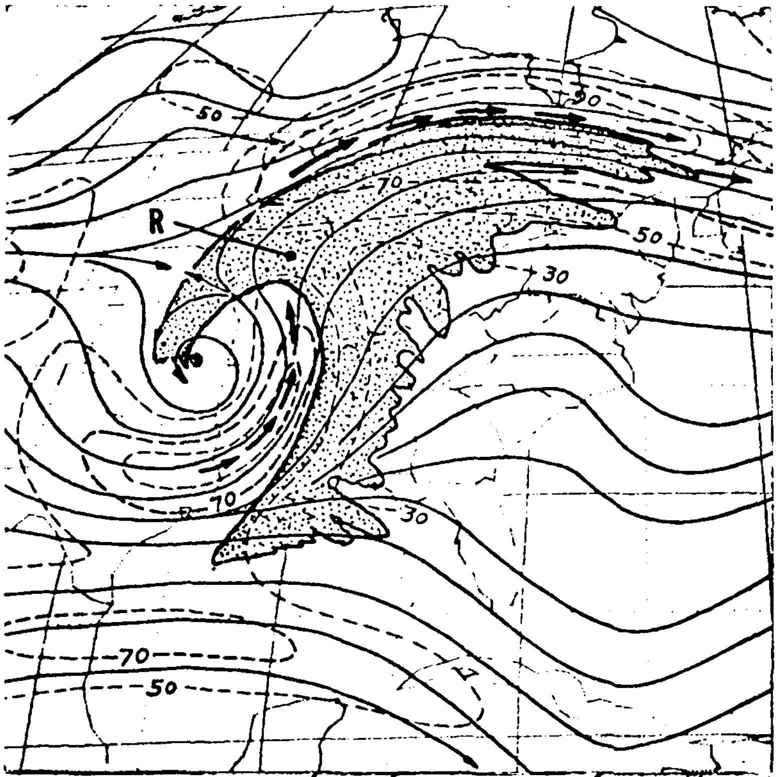


FIGURE 51

The storm comma system shown in Fig 51 is a type 3 comma pattern. The analysis consists of 300mb streamlines, isotachs, and arrows along the 300mb axes of max winds.

There is a "closed" wind field at 300mb. The ridge is "wrapped" around the comma slot, and the jet stream is weak and difficult to define over the ridge at "R".

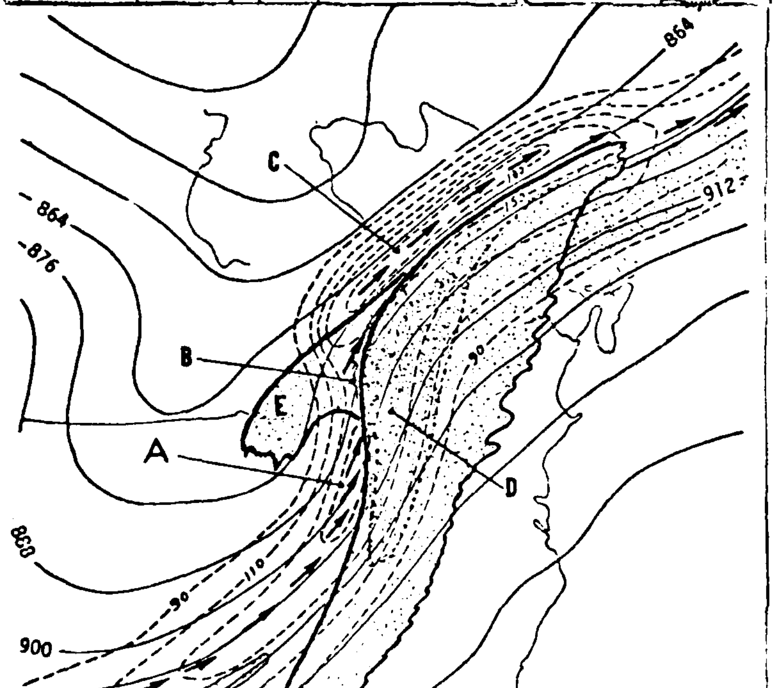


FIGURE 52

The analysis consists of 300mb height contours & isotachs.

The cloud system is a type 2 comma pattern.

Upstream in the slot region, 300mb wind speeds are over 150 knots. Over the ridge at "C" speeds are over 180 knots. The speeds are less between these two maxima at "B" over the comma head region, but are still between 130 and 150 knots - and the axis is well defined. This "JET CIRRUS CROSS-OVER" is associated with a sharp edgejust east of point "B". The clouds to the anticyclonic shear side of the edge are higher and colder at the top than those over the comma "head" at "E". The comma "head" area is also cirrus topped. The coldest IR tops are within the darker shaded area at "D".

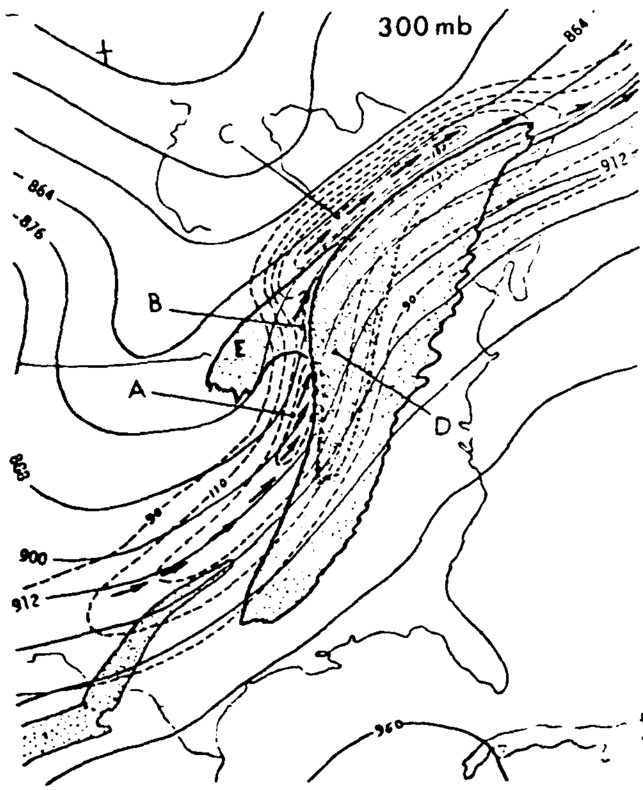


FIGURE 53 a

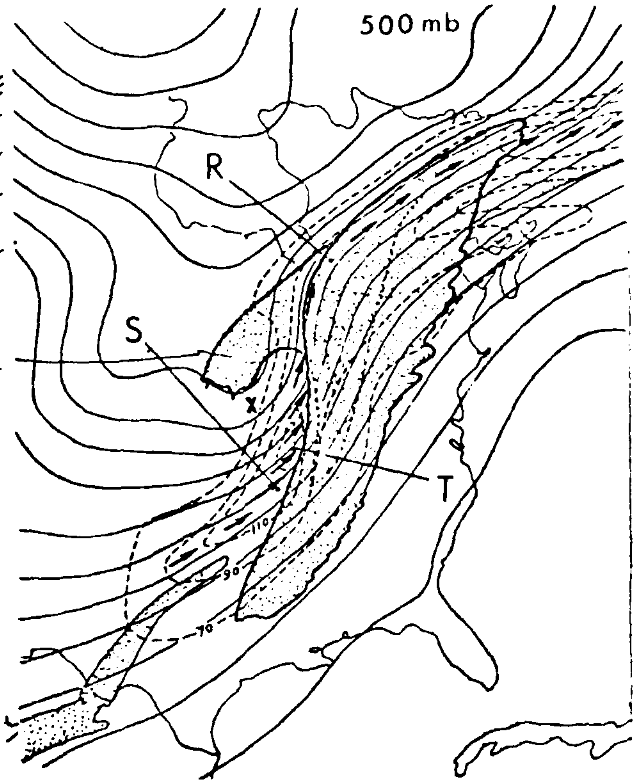


FIGURE 53 b

The drawing on the left above is the same as Fig 52. The drawing on the right is the same cloud pattern with the 500mb height contours, 500mb isotachs, and 500mb axes of maximum wind speeds.

Note that at 300mb the maximum wind speeds are at "C" and downstream along the clear side of the baroclinic zone cirrus border there. At 500mb, the maximum winds are upstream from the cloud system at "T" where speeds are over 130 knots. Along the speed maximum zone at and east of "R", the 500mb wind speeds are between 90 and 110 knots. They do pick up to values above 130 knots in the NVA structure speed max over Newfoundland, but that zone is associated with another trough in the north Atlantic. Note that the jet structure is channeled upstream from "S", and downstream from "R" as far as the cirrus tip; and is of PVA structure between "S" & "R". That type of configuration is common for a well defined developing cloud system.

It is also common to have the maximum wind speeds along the associated jet stream at "the top of the ridge" for a developing cloud system, IF it is in a type 2 pattern such as this one or example 42a on page 48. In such cases, the older pre-existing jet baroclinic zone downstream from the new developing system is located at a higher latitude. During the developmental phase - then - there is only one maximum wind zone on the downstream side of the system. The warming with time occurring in the developing middle tropospheric ridge then enhances the existing baroclinic zone downstream, instead of developing a new one as in the model in Figure 44.

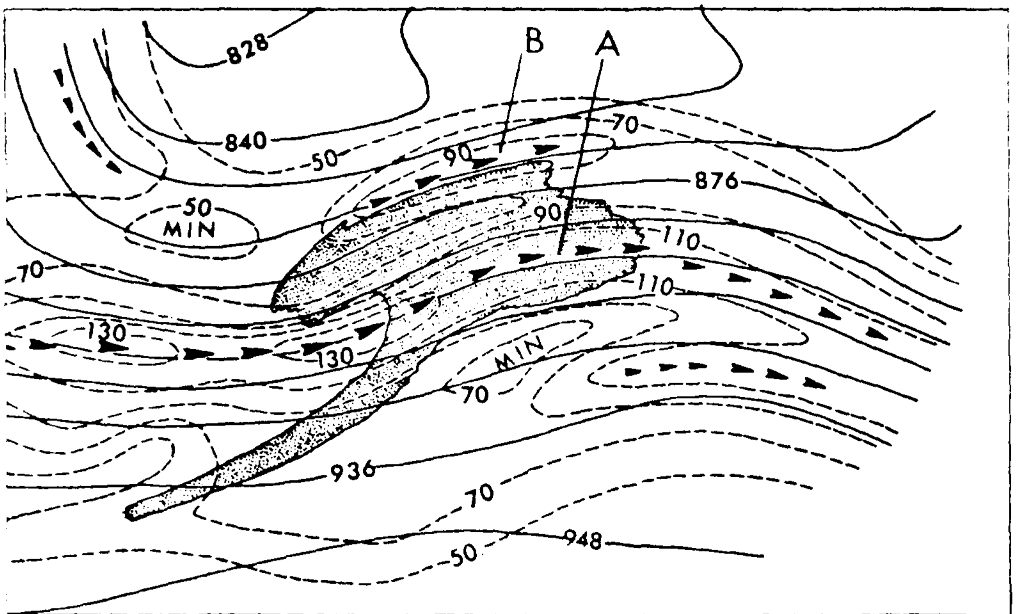


FIGURE 54 a

300mb ANALYSIS

height contours (solid lines)

isotachs - knots (dashed lines)

axes of maximum wind speed at 300mb (arrowheads)

Cloud Comma at INITIAL TIME

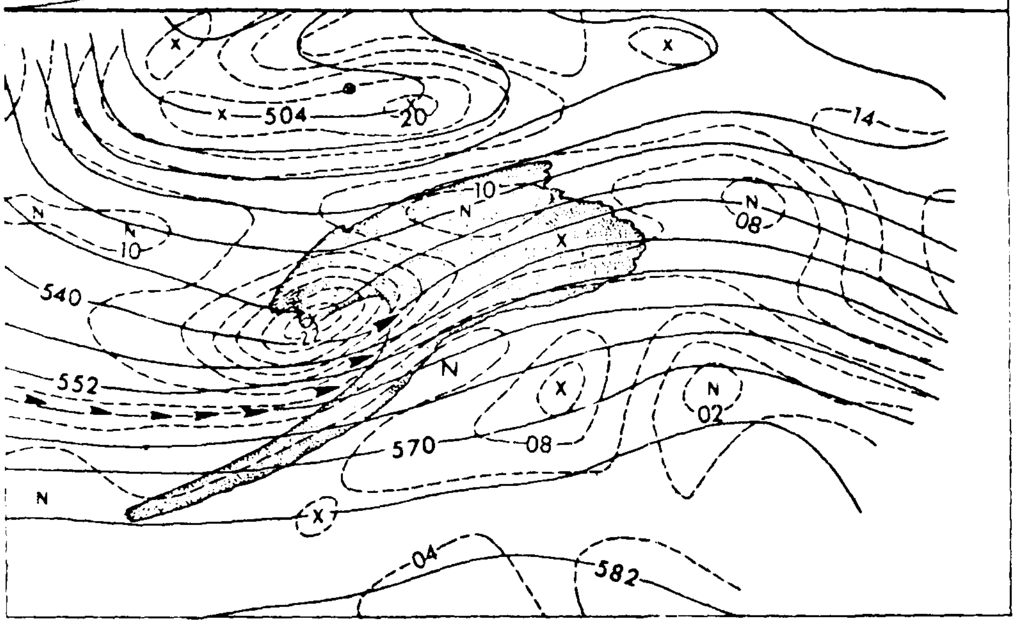


FIGURE 54 b

500mb ANALYSIS

height contours (solid lines)

vorticity isopleths (dashed lines)

axis of maximum wind speeds over 70 knots (arrowheads)

Same Cloud Comma INITIAL TIME

The cloud comma system shown in Figures 54 a & b above is in an early phase of development, is intensifying rapidly, and is moving toward the east-northeast at 50 knots. The maximum wind speeds at both 300mb & 500mb are upstream from the cloud system. On the downstream end of the cloud comma, there are two maximum wind zones. The older southern one at "A" is stronger than the newer northern one at "B". Although the cyclonic vorticity maximum is strong, the amplitude of the perturbation in the height contours & streamlines above 850mb is very small.

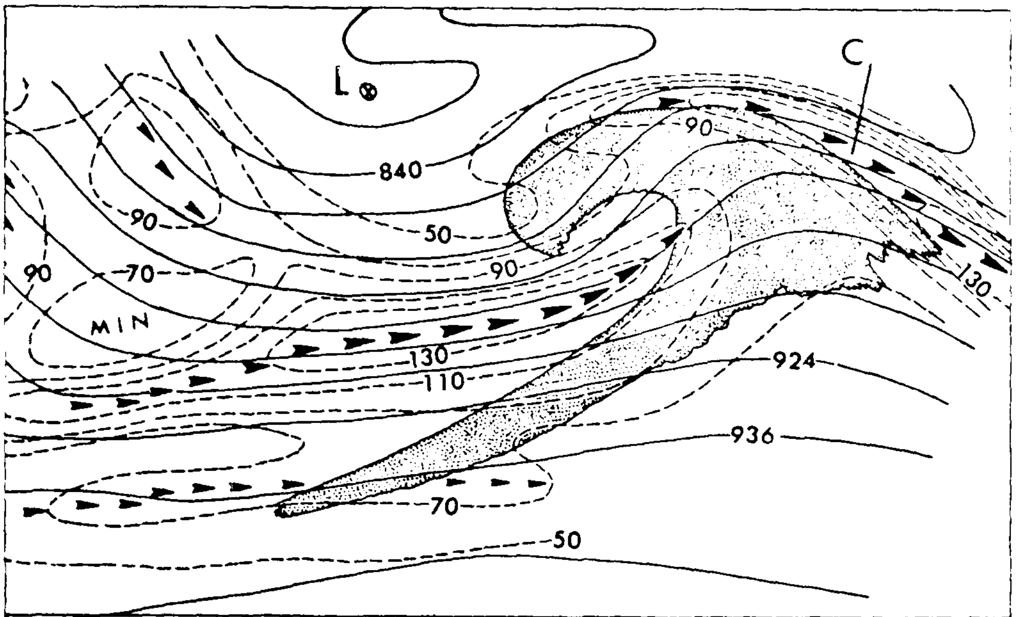


FIGURE 54 c

300mb ANALYSIS

Same analysis features

12 HOURS LATER THAN FIG 54a

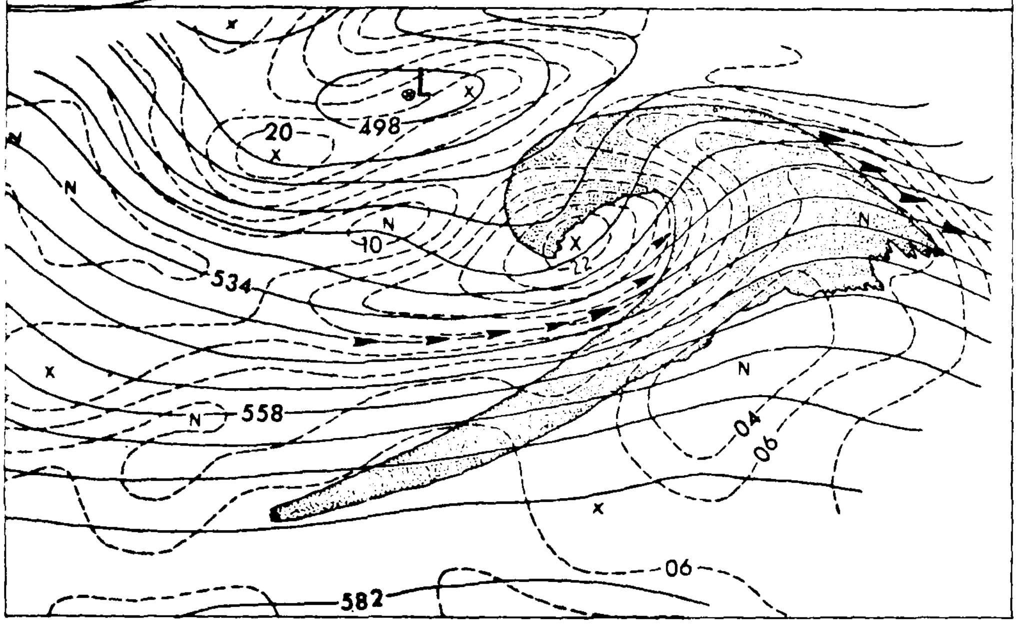


FIGURE 54 d

500mb ANALYSIS

Same Analysis Features

12 HOURS LATER THAN FIG 54b

The same cloud comma system shown in Figures 54 a & b at an initial time, is shown above twelve hours later. All 4 drawings of Figure 54 cover the same geographical area. The cloud system has gotten bigger, moved ENE; and the surface pressure center has lowered 13mb. The amplitude of the 300mb & 500mb contour perturbation has increased, and the curvature of the northern border of the comma has increased. Upstream from the cloud system, the jet stream is still channeled and strong. On the downstream side of the system, the older southern speed maximum has dissipated, and the northern one (now at "C") has strengthened. The 300mb wind speeds at the eastern tip of the comma are now nearly equal to those upstream. The northeastern tip of the comma now extends farther downstream than any other portion of the clouds. This relates to the fact that the primary downstream jet stream is now the one near the tip.

## F. "BAROCLINIC LEAF" CLOUD SYSTEMS

In Section E, page 47, while discussing the role of differential rotation in forming the "S" shape upstream border of comma patterns; I wrote that it is a "boundary" or "interface" which is being deformed, and that in many cases this "boundary" forms very early before the comma shape is produced. The cloud system which is associated with this early stage "pre-comma" boundary is called by me a "BAROCLINIC LEAF". Although I haven't made a statistical survey, I would estimate that more than 60% of the cloud comma systems that form in the westerlies are preceded by "baroclinic leaf" patterns. We could consider the "baroclinic leaf" cloud system as merely the early stage of a cloud comma; however, I have found it practical to differentiate between the two types of patterns. One reason is that all baroclinic leaf systems do NOT evolve into comma systems. Of those I studied, 75% evolved into comma systems.

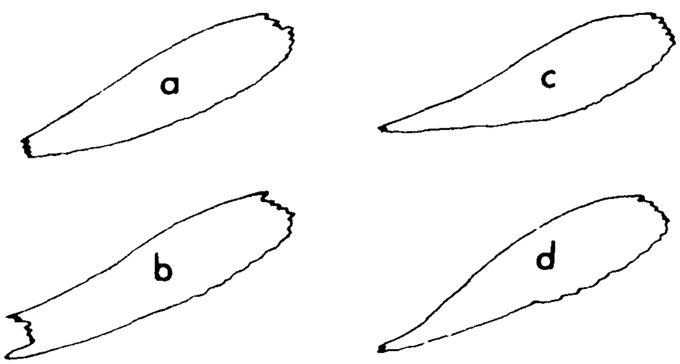


FIGURE 55

The four shapes shown in Figure 55 illustrate typical patterns of "baroclinic leaf" cloud systems.

In Figure 56 a cloud pattern is shown at 3 hourly intervals as it evolves rapidly from a "leaf" pattern to a "comma" pattern. As in all cases, there is the question of "when does the leaf become a comma?". The 1st two patterns fit the "leaf" category, and the last two are "commas". The pattern of Fig 56c is in a transition stage. I don't think it matters which name we give it, but we should know the atmospheric conditions that usually accompany the transition. Those will be discussed.

The "baroclinic leaf" is the cloud pattern associated with the "frontogenetic" phase of system development; whereas, the comma pattern is the "cyclogenetic" phase. Actually these two processes overlap in time and are complex; but I think the above generalization is decent and useful. The "baroclinic leaf" pattern is the type of cloud system that would be associated with deformation zone #2 of Fig 35b, and in locations "A" and "B" of Fig 36c.

A "baroclinic leaf" a cloud system associated with frontogenesis aloft within a westerly wind fi The frontogenesis is related to the deformation process described in Section D, wherein a new baroclinic zone is forming or intensifying downstream from an existing baroclinic zone. Usually the system is vertically deep and surface frontogenesis is also occurring. The cloud system involved is usually an elongated pattern with well defined borders on both sides. The poleward side frequently has a shallow amplitude "S" shape with the upstream end concave & the downstream end convex. (See Fig 55). But the poleward edge can also be ( in order of frequency of occurrence) all convex, nearly straight, and all concave. Details and examples of the above characteristics will be discussed.

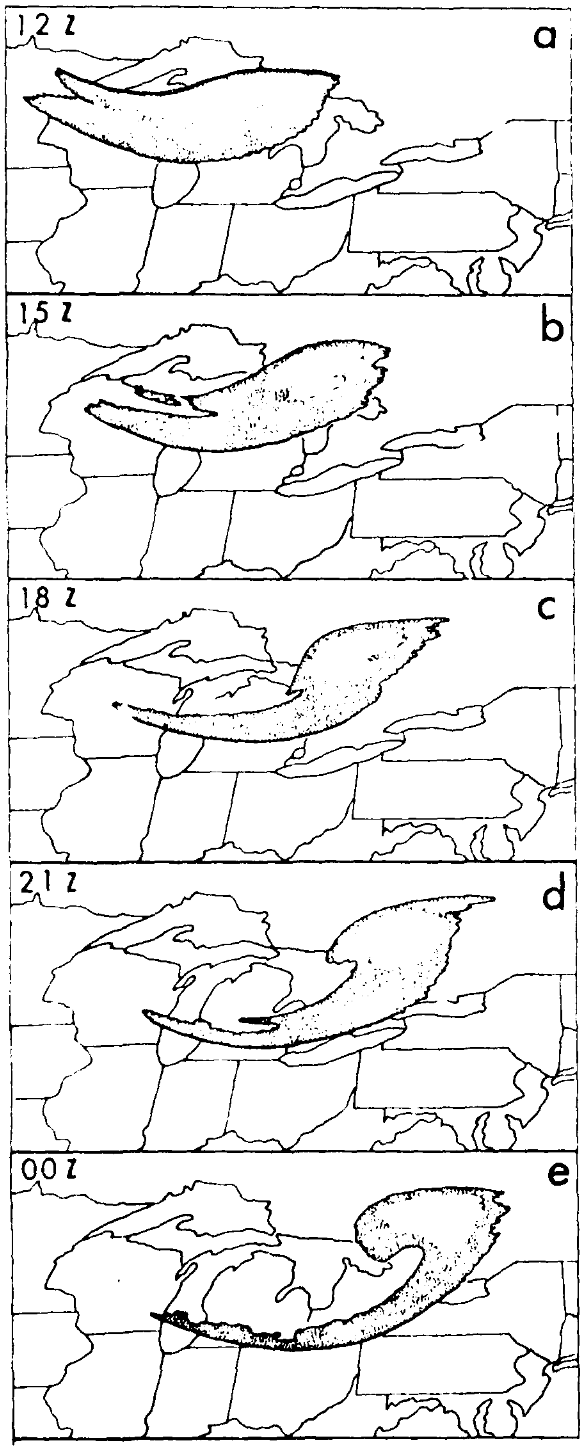


FIGURE 56

Discussion of Figure 56

The drawings (traced from IR pictures) show a well defined "baroclinic leaf" pattern at 12Z evolve to a well defined comma pattern by 00Z. The system is relatively small and evolving relatively fast.

At 12Z (Fig 56a) the northern border is better defined than the southern one and has a shallow "S" shape. (the coldest cloud top temperatures are unshaded on all 5 drawings)

By 15Z, the concave portion of the northern (upstream) boundary of the system has begun to dissipate and become poorly defined, while the convex portion remains well defined. The southern border has sharpened. Surface frontogenesis has been and is occuring along the western half of the southern border.

By 18Z most of the concave part of the northern border has dissipated leaving a more ragged less well defined northern edge to the "tail" part of the forming comma pattern.
During this transition phase from "leaf" to "comma", surface cyclogenesis begins. During the "leaf" phase, there is usually an elongated surface trough oriented parallel to the leaf - but without a definable center. As the "tail" narrows and the "slot" forms during the transition to comma; a surface low center consolidates and pressures begin to drop.

As the pattern evolution continues, (Figures d & e) the convex portion of the northern edge of the leaf, becomes the border of the "head" of the new comma.

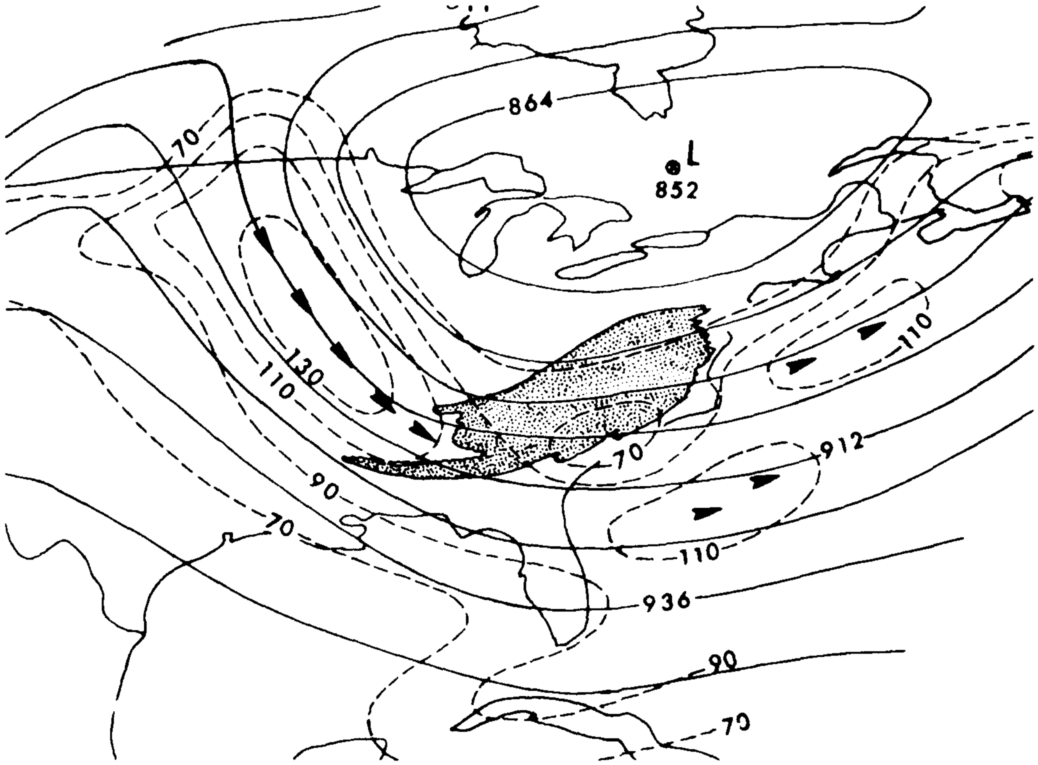


FIGURE 57a 300mb Analysis: Height Contours, Isotachs, Axes of Maximum Winds
Discussed on page 67

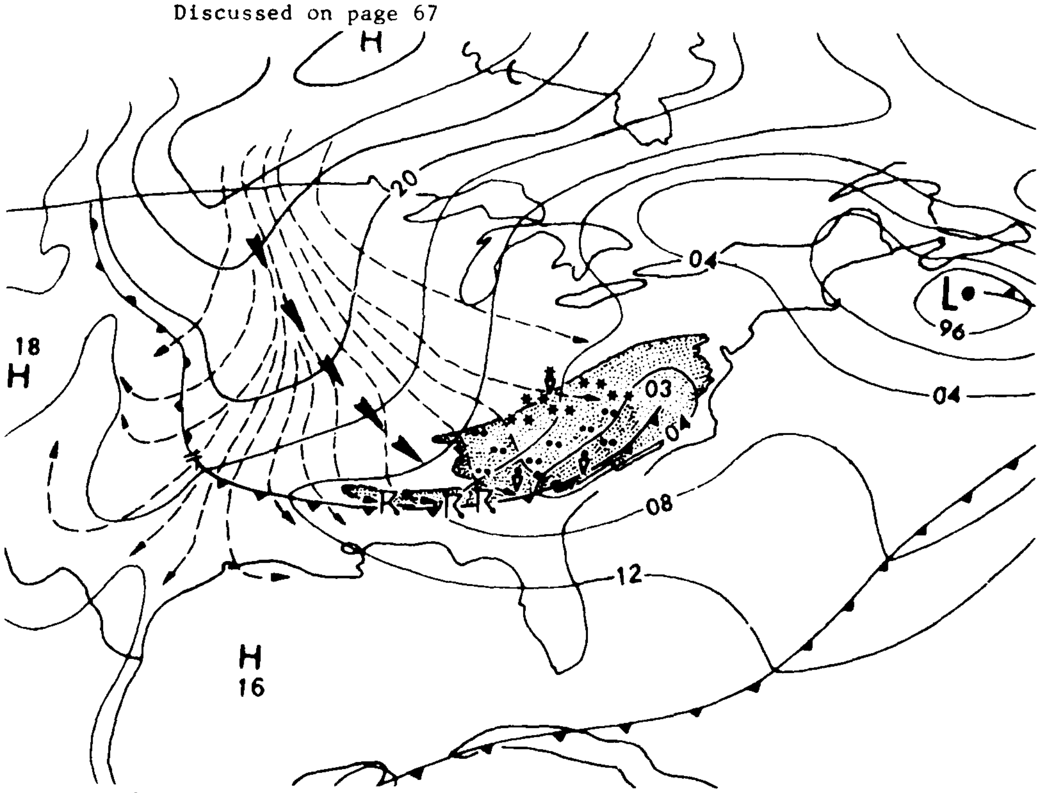


FIGURE 57b Surface Analysis: Isobars, Fronts, Streamlines, Precip, 300mb Max Wind Axis
Discussed on page 67

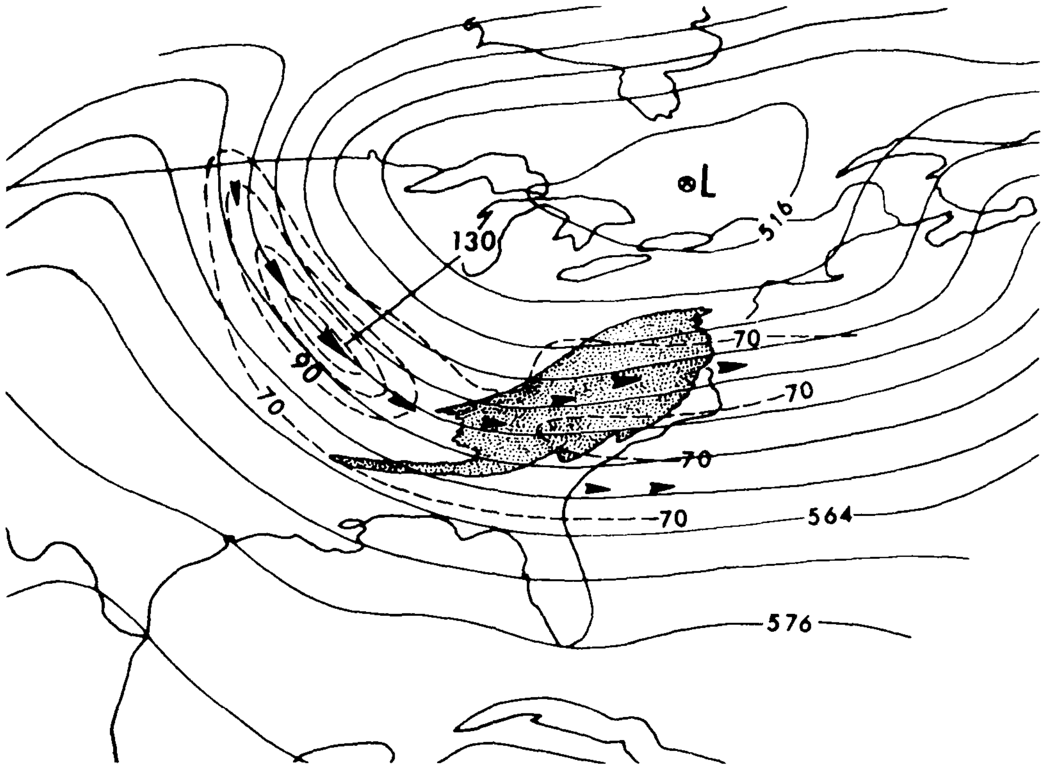


FIGURE 57c 500mb Analysis: Height Contours, Isotachs, Axes of Maximum Winds
Discussed on page 67

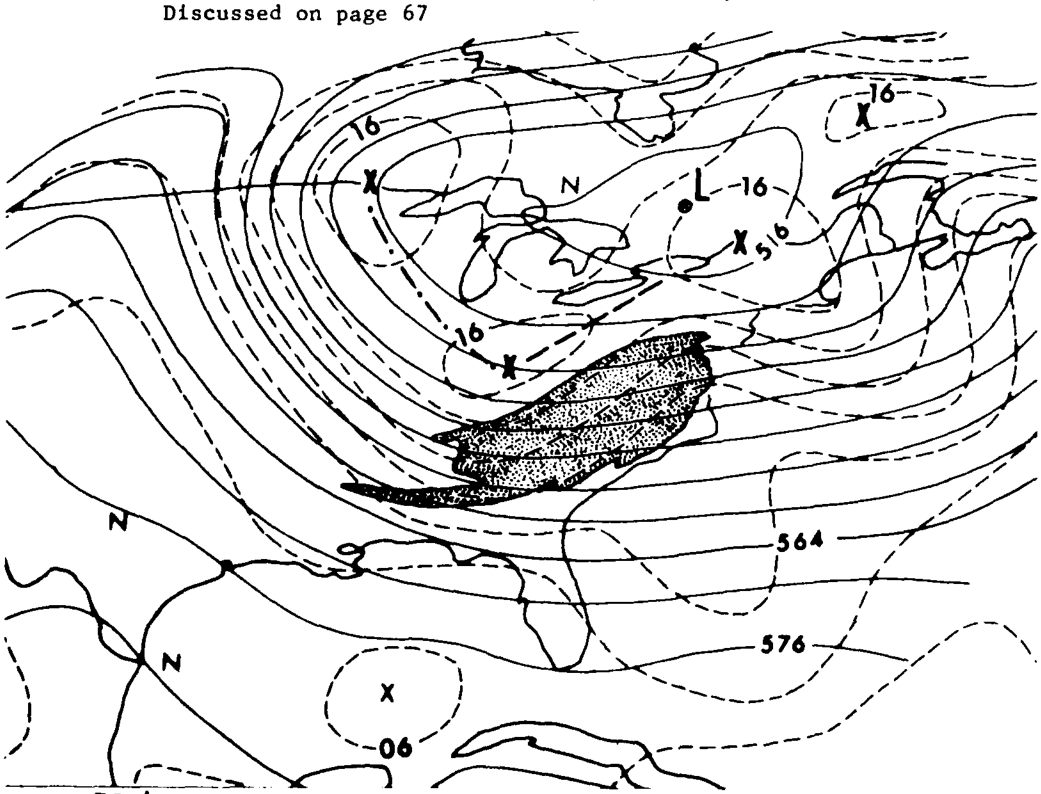


FIGURE 57d 500mb Vorticity & Height Contour Analysis

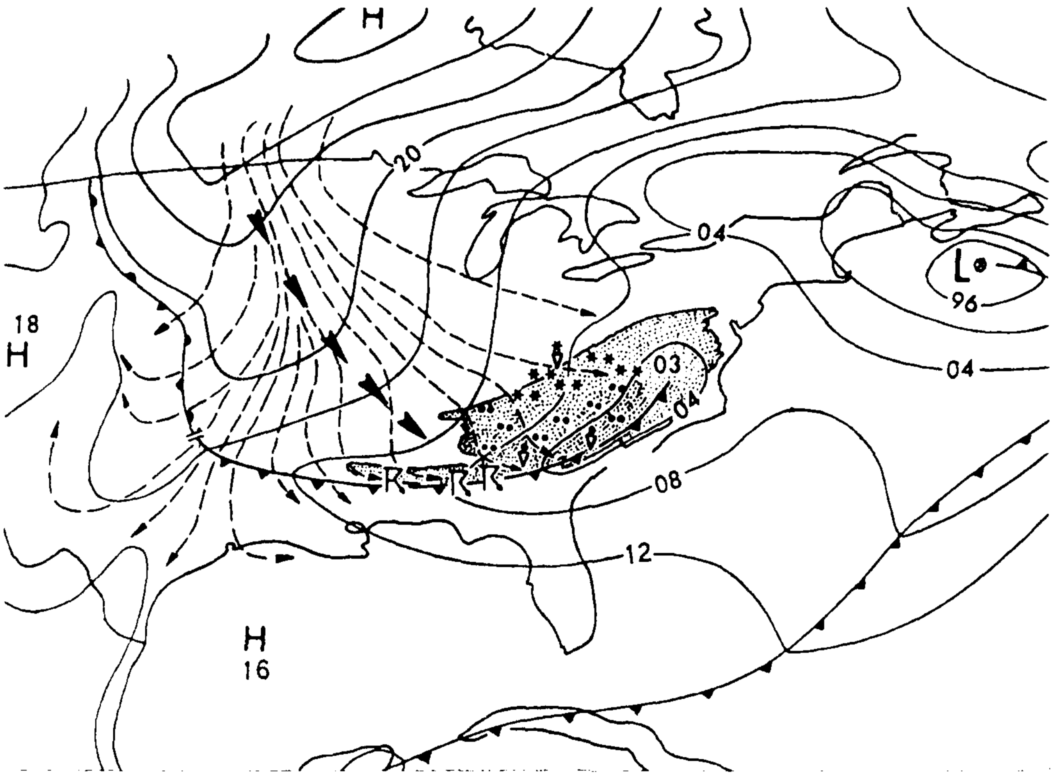


FIGURE 58a Same illustration as Figure 57b. Surface Analysis + 300mb Max Wind Axis

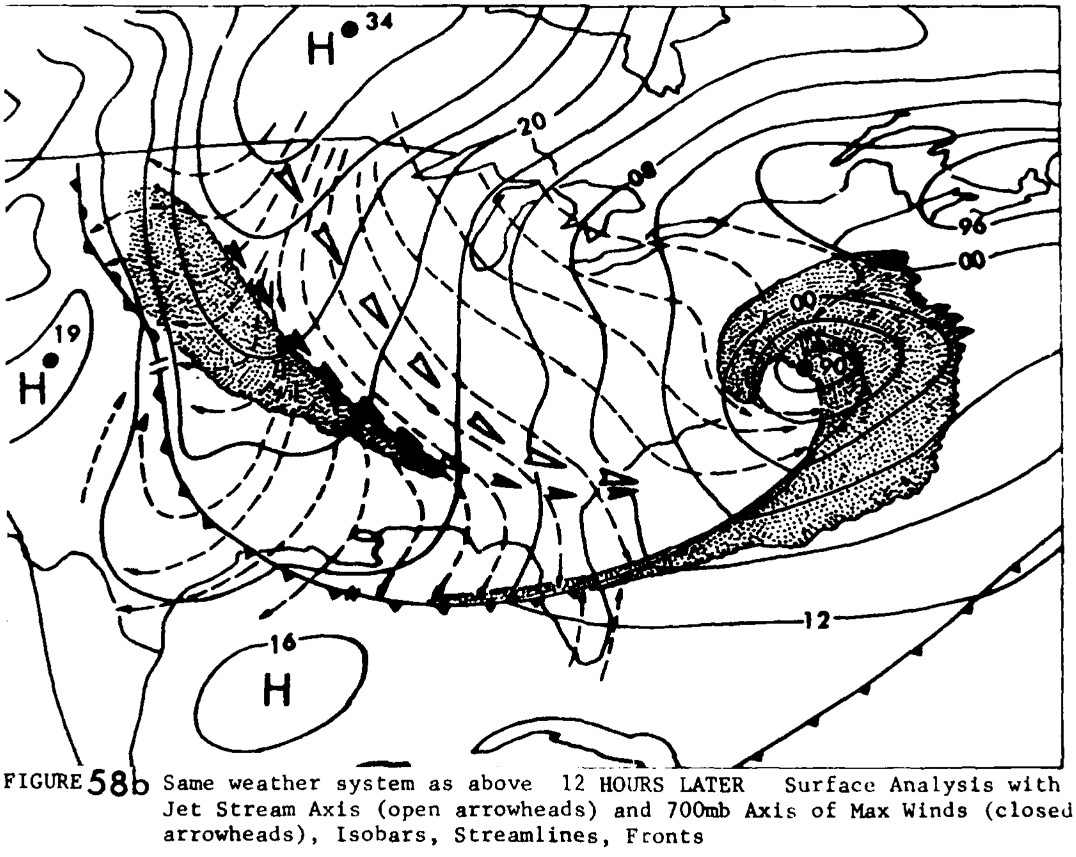


FIGURE 58b Same weather system as above 12 HOURS LATER Surface Analysis with Jet Stream Axis (open arrowheads) and 700mb Axis of Max Winds (closed arrowheads), Isobars, Streamlines, Fronts

## An Example of a Baroclinic Leaf Cloud System with Analyses

In Figures 57 a thru 57 d, the same baroclinic leaf cloud system is shown with analyses at 500mb, 300mb, and the surface. The figures do most of the talking, but note the following.

At both 300mb (Fig 57a) and 500mb (Fig 57c) the maximum wind speeds are upstream from the cloud system, where the max wind zone is nearly channeled. At both levels, the axis of maximum winds intersects the cloud system near where the northern boundary of the leaf reaches its westernmost point. On the downstream side of the leaf, the maximum wind zone is split into two branches, with speeds much lower than upstream, and with both branches south of the distinct northern border of the cloud system. This downstream location of the axes of maximum winds is characteristic of almost all "baroclinic leaf" systems. This is in contrast to many baroclinic zone cirrus patterns where the jet axis is found along the clear side of a well defined poleward cirrus border. The characteristic location I refer to is that the jet axis is NOT near the well defined border or the downstream tip of that border, but is farther south - over the cloud system ragged edge - or south of that ragged area. There are certain synoptic patterns where the jet axis is near the tip; I will illustrate this later. Recall that during the evolution of a leaf into a comma, the convex portion (often referred to as "anticyclonically curved") of the poleward edge becomes the border of the comma head. Frequently - if development continues - a "new" jet speed maximum does form along the eastern end of that border, but this usually happens after the leaf phase. Note that the maximum wind zone on the downstream end of the leaf is not always split into two branches as in this case. (In Fig 57a there is a 3rd branch south of Florida. The maximum wind speeds in this southernmost branch are near 150mb. It has "subtropical jet" characteristics.)

The 500mb vorticity center associated with the leaf (See Fig 57d) on the clear side of the northern border near the inflection point of the border; that is a common location, but the distance between the center and the edge varies significantly from case to case. Two vorticity lobes intersect at the vorticity center (the "X") and form an "L" shape. The stem of the "L" is parallel to the upstream jet stream, and the base of the "L" is oriented similarly to the long axis of the leaf.

At the surface (Figure 57b) an elongated trough runs parallel to the leaf. It has no well defined center - either in the pressure or wind fields. Significant precipitation is occurring under the western two thirds of the leaf. That is typical of a well defined leaf system that extends downward into the low levels. Also typical of such a vertically developed system is the similar location of a newly formed surface frontal zone which lies parallel to and near the southern border of the leaf. In the case shown convection is occurring along the surface frontal zone, causing a thin tail-like western extension to the leaf's southern border.

Shown in Figure 58b is the same weather system 12 hours after the time of Figure 57, after the leaf has evolved into a comma pattern. For comparison purpose, Fig 57b is repeated as Figure 58a. So, the two drawings show surface analyses and accompanying cloud patterns 12 hours apart. Note that on the surface analyses, in the notes, streamlines are drawn only where the surface wind field is well enough defined to do so, and that precipitation symbols are placed directly over the location of occurrence. Precipitation is not shown on Fig 58b because the system is now mostly over the ocean, and only a partial precip pattern could be shown. During the 12 hours previous to Fig 58a, there was no significant drop in the surface pressure associated with the system, although the cloud system formed and became a well defined leaf, and precipitation bagan and spread rapidly. Between the times of Figures 58a and 58b, the leaf evolved to a comma, a surface center became consolidated, and the cnetral pressure dropped 13 mb.

On Fig 58a, the solid arrowheads indicate the position of the 300mb axis of maximum winds upstream from the cloud system. This is very near to the jet stream axis in this case; so, the arrowheads can be considered to be along the jet axis. On Fig 58b, the open arrowheads do indicate the jet stream axis; and the solid arrowheads indicate the position of the 700mb axis of maximum winds.

The cloud pattern shown by the shaded area west of the cloud comma pattern consists of low based clouds with tops ranging from 600mb to 700mb. Note that a well defined northern border of that cloud pattern lies close to the 700mb axis of maximum winds. On the north side of that axis, surface streamlines are nearly parallel to the jet stream. On the south side, the streamlines turn anticyclonically. These relationships are typical with a well defined channeled jet stream on the back side of an upper air trough. If the system were over the ocean, the solid arrowheads (Fig 58b) would most likely correspond to the cloud type interface discussed on page 11 and indicated by "E" on Figure 14.

## SOME GENERAL CHARACTERISTICS OF BAROCLINIC LEAF CLOUD SYSTEMS

There are many interesting variations in the cloud patterns and behavior of baroclinic leaf cloud systems. I will show and discuss some of them; but, first consider a generalized model pattern and its characteristics. I have integrated common features of baroclinic leaf cloud systems into a model pattern shown in Figure 59. The model represents a well defined baroclinic leaf system located within a main branch of the winter season westerlies, which is intensifying and evolving into a comma pattern with time.

How do we recognize the cloud pattern as a "baroclinic leaf"? Unfortunately, the word "LEAF" will not likely be written on top of the clouds on the satellite picture. The system will have an elongated pattern with a ragged downstream end (at "R") and relatively well defined - or distinct - borders on both sides. The equatorward side may be well defined along its entire distance, or it may be much more distinct along its western or upstream end. (I use the terms "upstream" and "downstream" in relation to the mid tropospheric wind field.) The northern border (or upstream border - the mid tropospheric level streamlines cross from the clear to the cloudy side) will most likely have a gentle "S" curvature, as in Fig 59. The clouds forming that border frequently display a gradual lowering of top height toward the western end. With the type of system shown, the tops will likely be relatively uniform in height from "E" to "P", then lower gradually from "P" to "T". This lowering will be indicated as warming on an IR image. The clouds near "T" and near "R" may be thin; but at "R" they will be very high level, and at "T" they will be mid level. Clouds along the southern border near tip "F" will be low based & distinct on a visible image. The tops depend upon the type of convection occurring there. If CB's are there, the tops will be high and distinct on the IR image also. In the region between "T" & "F" low level convective clouds often form in lines oriented roughly parallel to the leaf orientation,

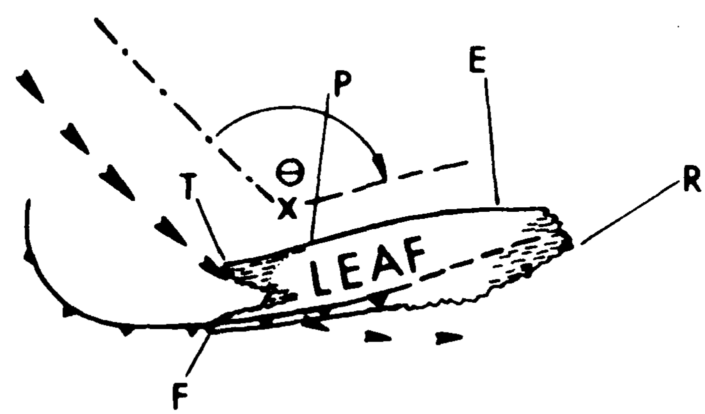


FIGURE 59

and with a peculiar twisted-rope-like appearance which is unique to this particular synoptic location. (Location = under the jet stream to the rear of a developing baroclinic leaf or relatively young comma, and between the mid & low level boundary interfaces or their upstream extensions) Such cumulus lines are present only if the system is over the oceans or an abundant low level moisture source such as the Great Lakes.

Another feature that helps in the recognition of a leaf cloud system involves its direction of movement. It does not move in the direction of its orientation ("B-B" on Figure 60). Generally the cloud system is rotating somewhat counterclockwise and changing shape with time, in addition to moving. The most conservative feature is likely the inflection point on the upwind border which becomes the rear tip of the comma head as the system evolves. This has a good empirical relationship to the 500mb vorticity center - indicated by the "X" on Figures 59 & 60. On Fig 60 line "A-A" depicts the orientation of the upstream jet axis and vorticity shear lobe (dash-dot lines). The inflection point ("P") generally moves in a direction similar to arrow "M" --- a direction in between the orientation of the leaf ("B-B") and the upstream jet ("A-A"), but usually closer to that of the upstream jet axis. The centroid of the cloud pattern area moves in a direction slightly to the left of the movement of the inflection point.

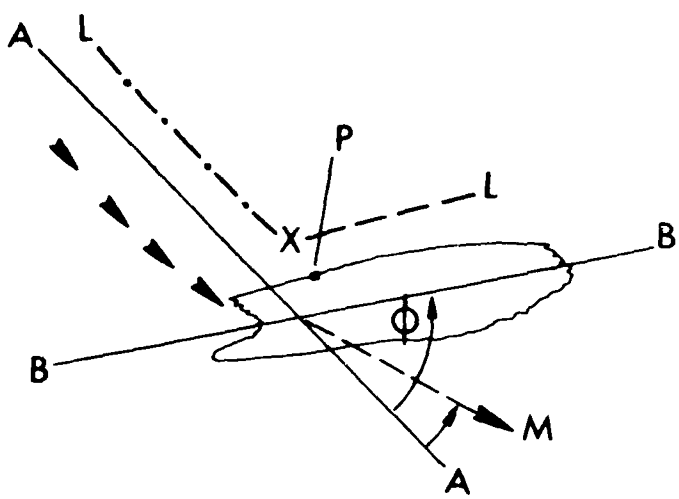


FIGURE 60

In relation to the 500mb vorticity field, the leaf pattern has the following relationships. The vorticity center is on the clear side of the upstream border near the inflection point. Two vorticity lobes intersecting at the center ("X") form a rough "L" shape, with the base of the "L" parallel to the leaf (usually and advection lobe - dashed line on Fig 59), and the stem of the "L" an upstream shear lobe (dash-dot line on Fig 59) parallel to the upstream jet stream. A region of packed vorticity isopleths (parallel to the leaf) with "PVA" present is over the leaf pattern.

The jet stream axis upstream from the leaf is indicated by solid arrowheads on Figures 59 & 60. The jet stream is most likely channeled there with maximum wind speeds along that segment. Downstream the jet axis is likely to be south of the cloud system as shown. or as far north as point "R" (Fig 59). It is not likely to be near point "E".

The newly forming surface cold front is located near the southern border of the leaf near "F". From "F" eastward the surface front will be near the distinct part of the southern border. Where the border becomes ragged or less distinct, the front will be under the cloud system - or may become only a surface trough. No distinct consolidated surface low pressure center is likely at this phase of system evolution.

Whereas the distinct southern border and tip "F" are associated with the surface frontal zone, the northern border and tip "T" are associated with the lower middle tropospheric baroclinic zone. The cloud border at "T" is typically related to the frontal inversion and packed isotherm gradient near 700mb. In different systems, this height ranges between 800mb and 500mb. In cases where the cloud border extends upstream beyond "T"; it is not parallel to the surface frontal zone, but departs in an orientation similar to that of the jet axis.

In the mid troposphere - typically in the 850mb to 500mb range - a zone of packed isotherms forms a rough "L" shape similar to the vorticity lobes. At the time of the well defined leaf existing, the angle of the "L" (indicated by theta on Figure 59) is likely decreasing with time, and the gradient is increasing along the base leg of the "L" with time. Precipitation has formed and is increasing in amount and area coverage under the leaf. Generally the precipitation is present under the upstream half or two thirds of the cloud system (in relation to the long axis). A surface front has formed and is intensifying aided by strong sinking in the region between the upstream jet axis and the surface frontal location.

## VARIATIONS IN THE CLOUD PATTERNS OF BAROCLINIC LEAF SYSTEMS

In departure from the generalized patterns shown in previous pages, there are many variations in the shape of leaf systems. Some are long and narrow, some have a much longer concave or convex portion to the northern edge, some are fat with a convex northern edge forming an arch shape. The first leaf systems that I identified and studied were similar to the general shape of Figures 59 & 60. They were formed within relatively low amplitude upper level wind perturbations in nearly zonal flow. Then I noted that leaf systems that formed on the front side or at the base of higher amplitude upper level troughs tended to be narrow with a longer portion of concave upwind border present behind the inflection point. That relation to the amplitude of the upper air wind field in which the system forms is a good correlation, but it doesn't account for enough of the variability.

One of the ways that the shape of a leaf system can vary systematically is illustrated by Figure 61.

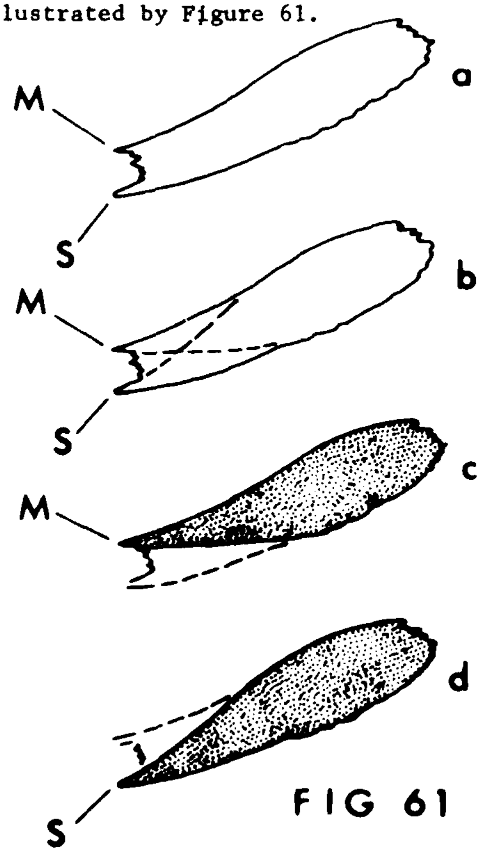


FIG 61

Note that patterns "a" & "b" have the two tips on the western end. The northern tips (labeled "M") are associated with the mid troposphere boundary or baroclinic zone, and the southern tips (labeled "S") are related to the surface or near surface frontal zone.

The dashed lines in drawing "b" indicate two ways the pattern can be modified by changing the borders.

In drawing "c" the southern border is modified with tip "s" eliminated. The leaf has a pointed western end at the middle level baroclinic zone. Drawing "d" shows the opposite case.

Pattern "c" is characteristic of leaf systems where the upper or middle level development is advanced in time with respect to the low level development (such as often occurs east of the Rockies of the U.S.) or there is no accopanying low level development (such as in the southern branch of an omega split in the westerlies).

Pattern "d" (the wing shape) occurs when the low level frontal zone is advanced, (such as happens when the leaf is developing over or near an older pre-existing surface frontal zone), or when the middle level moisture is low. I have observed patterns "a", "c", and "d" frequently. Note that in the "c" configuration, the concave portion of the northern boundary is longer than with "d" where a greater portion of the boundary is convex.

This change of curvature of the northern edge is also related to the synoptic environment in which the system is located. If the system is forming within the flow around a high amplitude trough, the convex portion of the edge is decreased, and the concave portion is enhanced. The opposite is true in a zonal or long wave ridge environment. In those cases, especially when an old pre-existing surface frontal zone is involved, the convex part of the leaf dominates and the ridge builds rapidly even before evolving to the comma stage.

The patterns shown in Figure 62 below have been empirically related to specific features of the wind field.

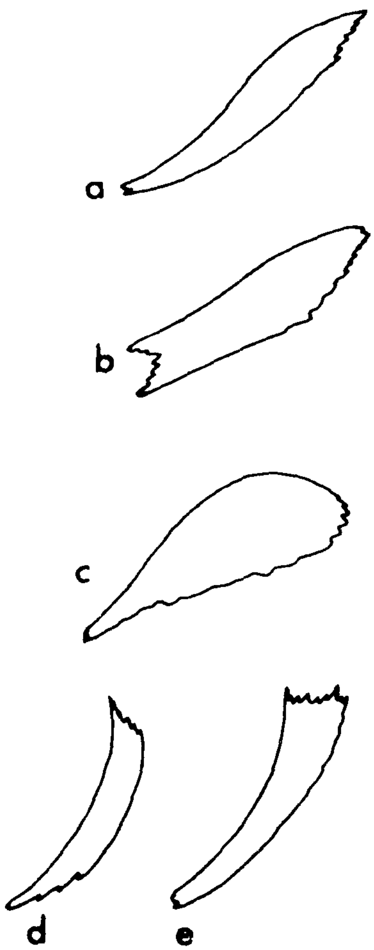


FIGURE 62

Pattern 62a has a relatively long concave segment on its poleward side (cold side) and the southern border has the truncated configuration as in Fig 61c. With such a pattern, the upstream jet is cyclonically curved & the channeled portion is likely to be relatively short. The pattern is often located at the base or on the front side of a relatively high amplitude trough. The jet axis is more likely to be near the tip on the downstream end.

Pattern 62b has been discussed. The upstream jet is likely to be relatively straight with a long channeled region. This is seen most in a zonal flow pattern or on the back side of a long wave trough.

Pattern 62c has the wing configuration of Fig 61d, but the convex portion is great. These occur in a long wave shallow ridge, or when an old surface frontal zone is involved. The mid tropospheric ridge amplifies rapidly. I refer to this type as a baroclinic "arch".

Patterns 62d (a crescent shape) and 62e (a cyclonically bent torch shape) are found in the baroclinc zone around a closed low. There is no inflection point or convex part on the cold side border. Although these patterns are quite different in shape to most other baroclinic leaf systems, they have the same relationships to frontogenesis, precipitation increase, and wind field features. They form in the left front quadrant of a speed maximum coming around the parent closed low aloft.

## VARIATIONS IN THE SHAPE OF THE "WARM SIDE" BORDERS OF LEAF SYSTEMS

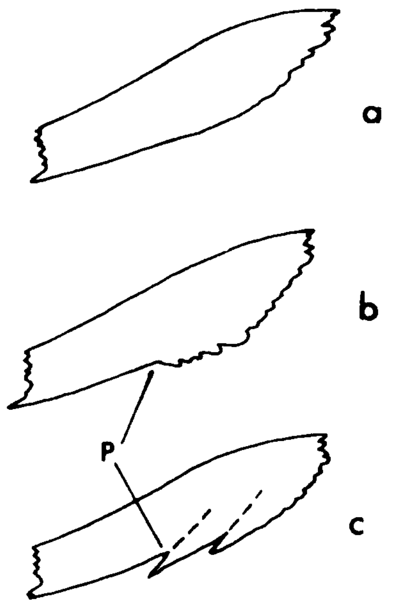


FIGURE 63

Shown in Figure 63 are three types of borders found frequently on the equatorward side of leaf systems.

With types "b" and "c", the surface frontal zone is generally near the border along the portion west of "P". I do not know of any specific relationship between the surface front and the border for the "a" type, other than the fact that the frontal zone will be nearer to the equatorward border, if it exists.

I have also not been able - so far - to correlate these different configurations to specific differences in the synoptic conditions associated with the leaf's environment.

I have observed many other types of equatorward borders on leaf patterns, most of them - in those cases - somewhat ragged and complex. In those cases, the system is usually involved with other nearby weather systems; or, the leaf system is relatively weak in intensity.

## EXAMPLES OF BAROCLINIC LEAF PATTERNS WITH DIFFERENT ENVIRONMENTAL CONDITIONS

The leaf system in Figure 64 is formed on the front side of a high amplitude trough. The arrows indicate the position of the 300mb axis of maximum winds.

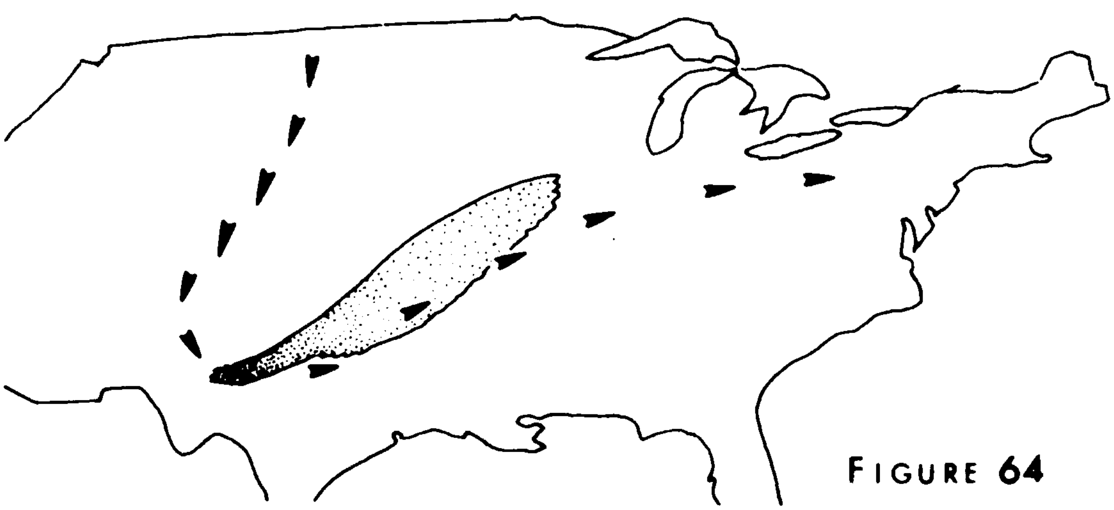

FIGURE 64

The trough is of large amplitude, and the jet stream is channeled only along a short segment at the base of the trough. The leaf is similar to the drawing in Fig 62a. The entire cloud top area of this system was cirrus with the warmest IR temperatures on the southwest end where the shading is greatest on Fig 64. This was a case where the upper level development of the system preceded the low level development. There was no surface front formed yet with the leaf system, and very little precipitation had begun under the leaf pattern.

A similar shaped leaf cloud system is shown in Figure 65 below. Here again the system is on the front side of a high amplitude trough. In this case the arrowheads are along the 500mb maximum wind axis, and the associated vorticity centers ("X's") and vorticity lobes (dash-dot line) are shown. The jet stream axis was located close to the 500mb max wind axis except on the east side of the cloud system, where the jet stream axis was farther south - departing the coast in South Carolina. The coldest cloud tops are shaded darkly. There the tops were at cirrus levels becoming thinner and lower toward the southwestern tip. The lightly shaded cloud band is associated with the surface frontal position. The clouds there were low based with tops below 700mb in a stable layer. No deep convection was occurring along the band. Precipitation was present under the leaf system north and northeast of where the frontal band intersects.

Such a leaf system - when viewed on an IR image - appears very similar to the one in Figure 64 or the type of Figure 62a. But when observed on a visible picture, the frontal band clouds - especially along the northern end - are as bright as the cirrus topped portion; so, the pattern looks more like the type shown in Figure 62b

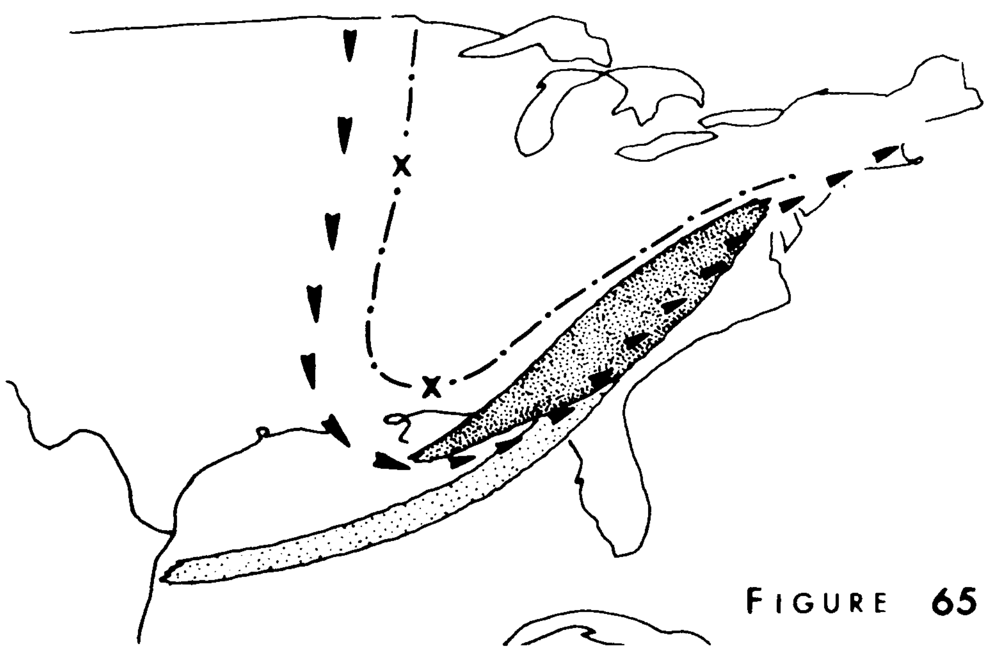


FIGURE 65

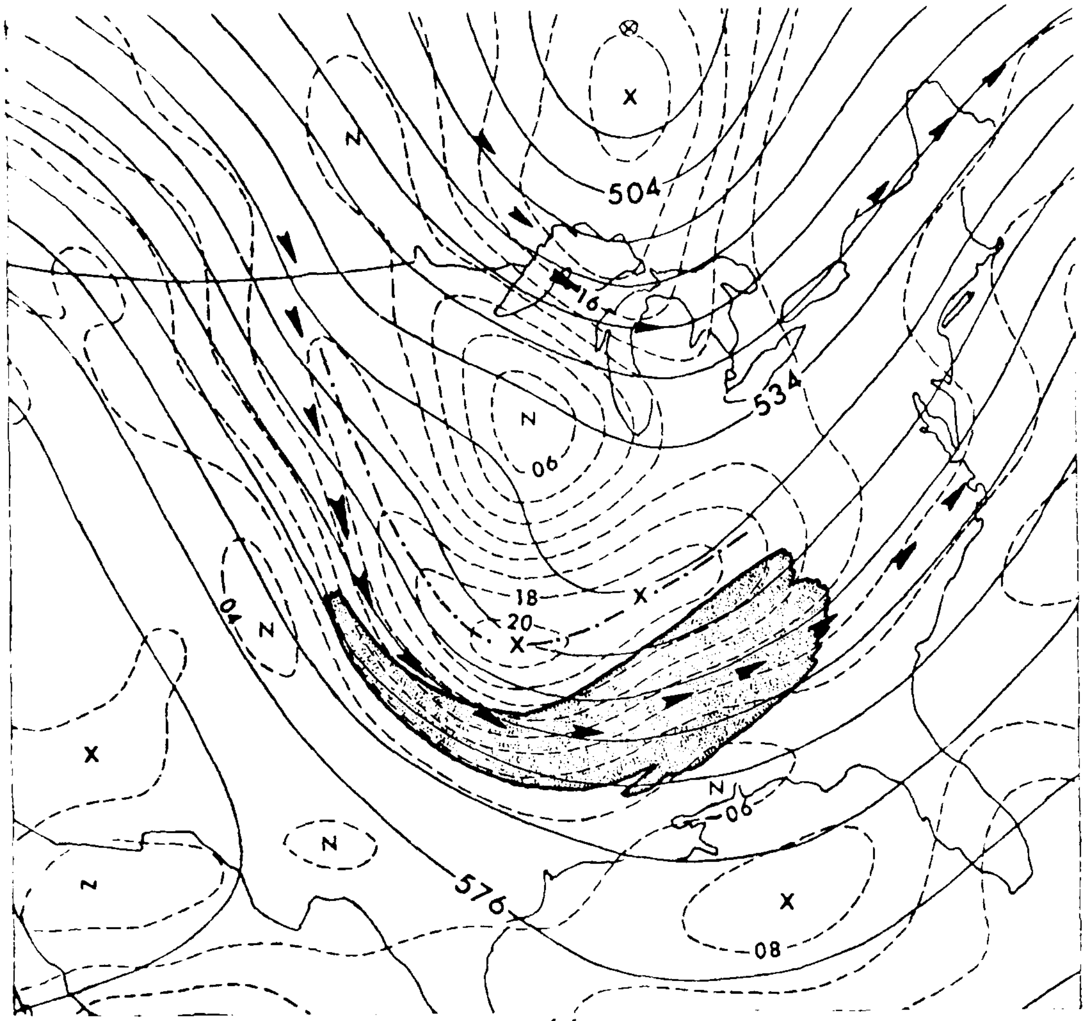


FIGURE 66

The leaf system depicted in Figure 66 is at the base of a relatively high amplitude and deepening trough. Shown with the system are 500mb height contours, 500mb vorticity, and the 300mb axes of maximum winds. The cloud system has just become defined as a leaf during the previous few hours. In Section E, beginning on page 34, I described two different types of "frontogenetic" processes: one in which the channeled speed max rotates around an amplifying trough, and the other in which the "energy is transferred through a deformation zone". I also stated that in most atmospheric systems, I observe a combination of both processes occurring. The system shown above in Figure 66 was one in which the 1st process dominated. In this case the channeled speed maximum was rotating around the base of the trough as the trough deepened (amplified).

Note that the "cold side" (northern) border of the leaf system is mostly concave shaped, and the remainder is almost straight. Also, the "cyclonically" curved tail-like western end of the leaf extends upstream onto the back side of the trough, and on the warm side of the axis of maximum winds. Such conditions of the leaf pattern and location with respect to the wind field are typical when the "rotation of the jet channel" process is dominating.

During the 6 hours after the time of the drawing, the eastern end of the cold side border of the leaf became convex as a short wave ridge began to build there.

Another characteristic difference typically found with this type of system is that the associated vorticity lobe is more like a "C" than an "L". And, even when an inflection point forms along the cold side edge on the front side of the trough, the maximum vorticity value is back at the base of the trough where the curvature contribution is greatest. So, the general empirical relationship of the inflection point to the vorticity center does not apply.

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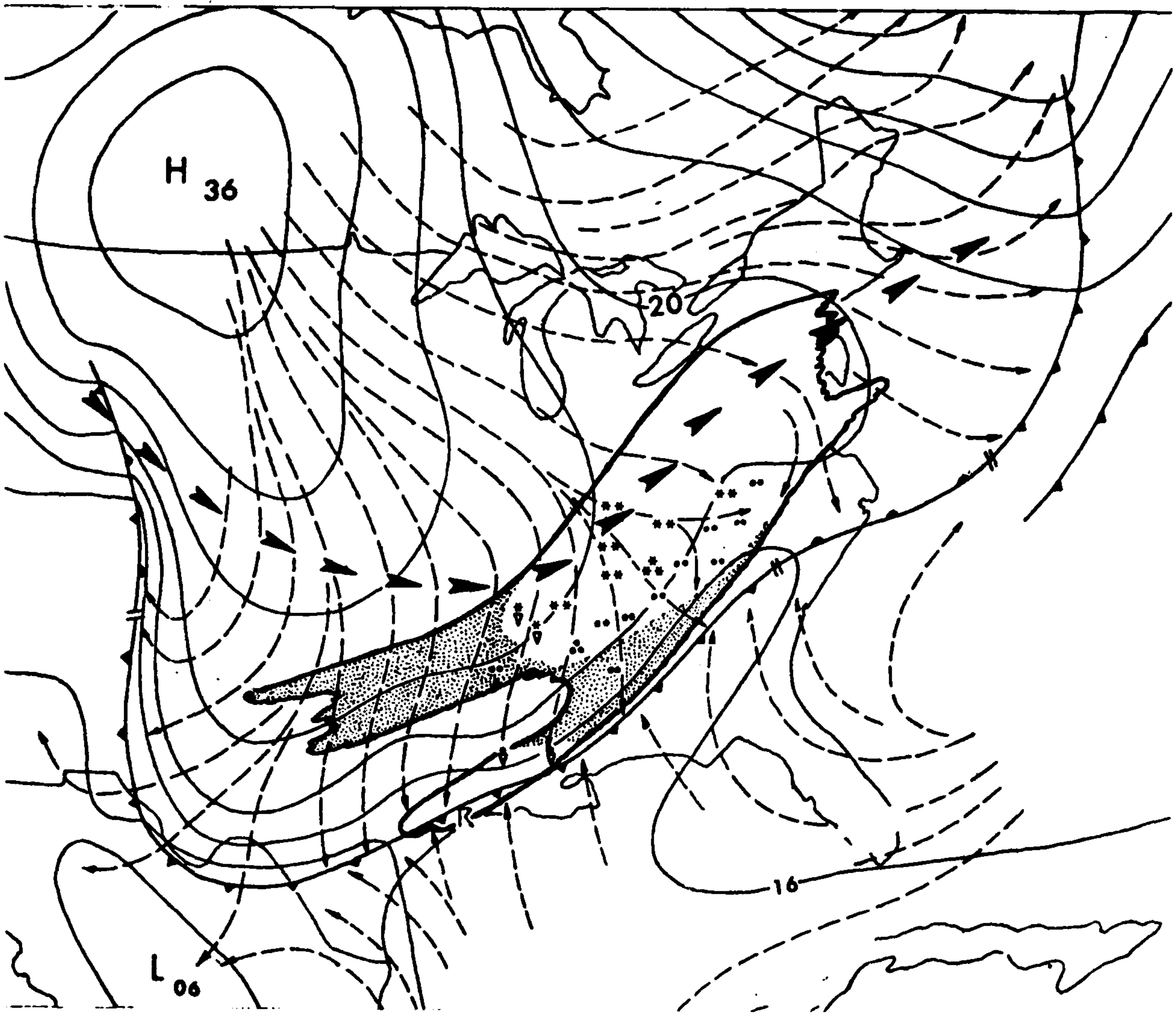


FIGURE 67

The large leaf cloud system shown in Figure 67 is an example of one which did not evolve into a comma system, and cyclogenesis did not occur. Yet, as the leaf formed and became better defined, mid level temperature gradients changed orientation and strengthened, the vorticty gradient strengthened, surface frontogenesis occurred, and precipitation formed and spread under the cloud system.

On the drawing, the cloud system is enclosed by a thick solid line. That part which is shaded indicates areas where the clouds had middle level tops. The clouds in the unshaded portion had cirrus level tops. There are two regions of high cold cloud tops: one over the main part of the leaf, and another along the surface frontal boundary where deep convection is occurring. The dashed lines are surface streamlines. The arrowheads are along the 300mb axis of maximum winds.

In this case, the wind speeds at both 300mb and 500mb were significantly greater on the downstream side of the system. The maximum wind zone upstream from the system was channeled for a short distance, and the speeds were relatively weak. In some cases, especially over the oceans where alot of moisture is available, I can determine from the satellite images that this condition of the wind field is present. Then, I can guess that the leaf system - although already a very significant weather system - will not proceed to evolve to a comma and undergo cyclogenesis. But, I have not been able to determine from the characteristics of the leaf cloud system itself, whether it is going to continue the evolution. There are a few hints and correlations, but I'm not sure how general they are. One is that the cold side boudary will extend upstream well under the warm side of the jet axis - without curving back along the axis. This is present on Fig 67. Several leaf systems that did not evolve to commas had that characteristic. Another condition that I've observed with such systems, is the presence of considerable low based stable topped clouds (tops under 700mb) to the rear of the leaf between the jet axis and the surface frontal zone. Such a condition or trend is observed anywhere, but is most frequent and enhanced when the leaf system is over the U.S. Great Plains. There - as in the case shown in Fig 67 - the surface frontal boundary and the sinking air behind it surges southward between the system and the Rocky Mountains which prevent the low level air from spreading westward. Thus the front bulges southward more than if the system were somewhere else. With leaf systems that are not proceeding to comma systems and cyclogenesis, a large portion of the region between the mountains, the surface front, and the middle level location of the jet stream axis is covered by the low based stratus topped cloud pattern.

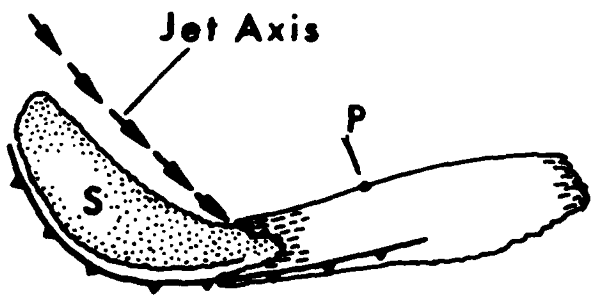


Figure 68

The area of low clouds referred to above is shown with respect to a model leaf pattern in Figure 68. The clouds are labeled "S" This condition should be differentiated from the clouds shown in Figures 14 and 58b. In those cases the clouds did not extend eastward to the leaf or comma tail involved, as they do in Figure 68.

During the normal progression of a leaf system with time, as it evolves into a comma; the typical pattern evolution involves the following trend. During early stages of the leaf, the northern border of the leaf extends farthest west from the inflection point (point "P"), and there may be considerable low level stratified topped clouds extending to the rear of the leaf. These clouds occupy an area where the baroclinic zone below the level of maximum wind speed is sloped greatly from the vertical - forming a nearly horizontal stable layer or inversion in many cases. As the system evolves (normally), sinking increases, the clouds forming the poleward side border of the leaf dissipate west of "P", and the low clouds to the rear of the leaf dissipate. Over land, complete clearing usually occurs, and over ocean cumulus cells remain.

The following three figures show baroclinic leaf systems over the Pacific Ocean and their subsequent comma form at a later time. The arrowheads indicate my estimated location of the jet axes, based upon a few wind reports, film loops, and experience in observing similar system over data dense areas.


FIGURE 69a

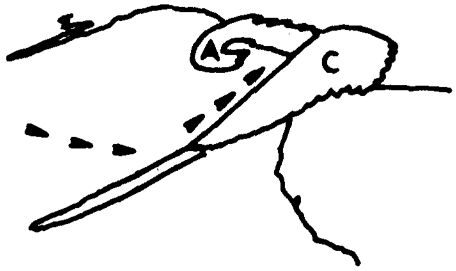


FIGURE 69b

The leaf cloud pattern in Figure 69a is located within a nearly zonal low amplitude flow field. It has the double rear tip pattern of the model leaf system, and an already well defined low cloud tail associated with the new surface frontal boundary. There is also a large convex portion of the northern border. That part of the leaf with the convex border (labeled "A") became the comma head. This is shown 18 hours later in Figure 69b. Cloud pattern "C" in that later figure is a newly formed baroclinic zone cirrus deck which covers over part of the new comma and its slot.

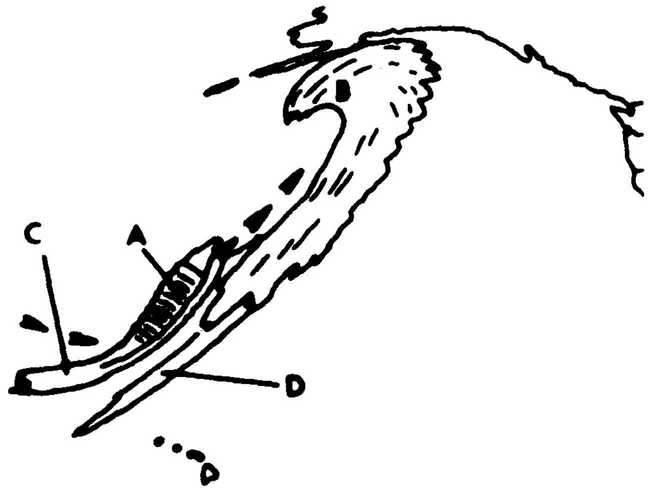


FIGURE 70a

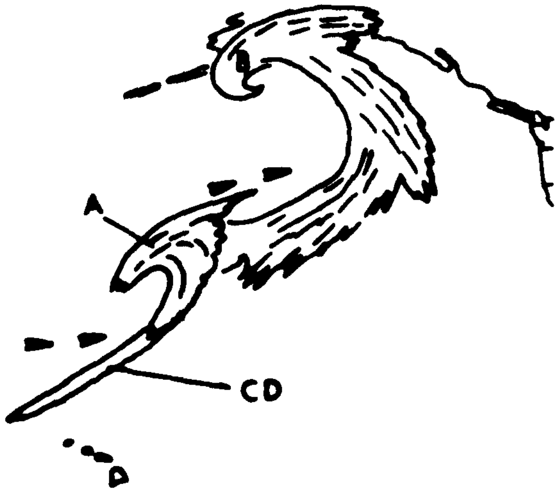


FIGURE 70b

The leaf system (labeled "A") in Figure 70a is located at the base of a relatively high amplitude trough. It has an already developed new surface frontal zone at "C" which is catching up with the old surface frontal cloud band at "D". The cloud top of the leaf has a transverse banded structure which is often seen on leaf patterns in that synoptic location. I believe these bands are related to convection and the mid to high troposphere vertical shear rather than transverse wave phenomena. The vertically deep frontal zone between the new leaf "A" and the older system "B" is covered by a wide zone of cirrus. This is common for two systems of this nature on the front side of a trough. Figure 70b shows the two systems 12 hours later. Leaf "A" has evolved into a comma. The new speed maximum formed on the downstream end of the comma head is causing the frontal zone of system "B" to accelerate eastward and remain convectively active, while the comma head of "B" moved northward. Low level frontal zone "C" has overtaken and merged with "D".

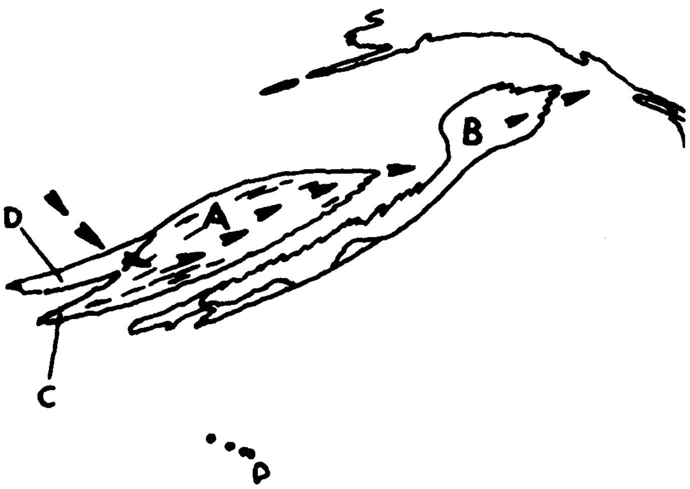


FIGURE 71a

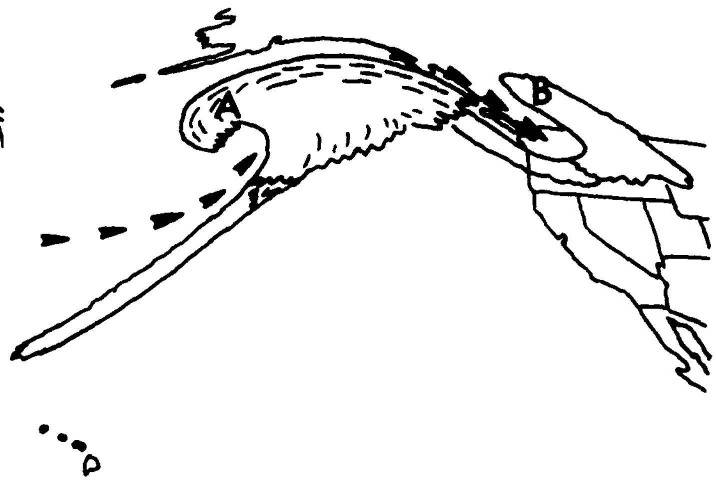


FIGURE 71b

In Figures 71 a & b, systems "A" & "B" are shown initially and 24 hours later. On Figure 71a, the large leaf system "A" has the "wing" type pattern with deep convection and cold cloud tops over the new low level frontal boundary at "C". Cloud tip "D" consisted of relatively thin middle topped clouds.

At the initial time, cloud system "B" is moving toward the east-northeast. Twenty-four hours later (Figure 71b) system "A" has evolved into a large storm comma. The associated ridge has amplified significantly. The newly channeled and strong jet segment over the ridge is driving system "B" southeastward - now in the shape of a "digging" comma pattern.

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