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SATELLITE INTERPRETATION.(U)

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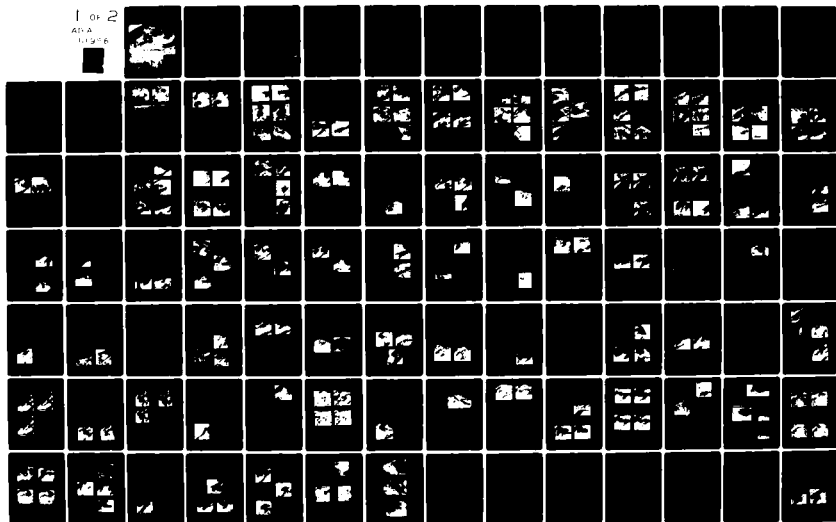
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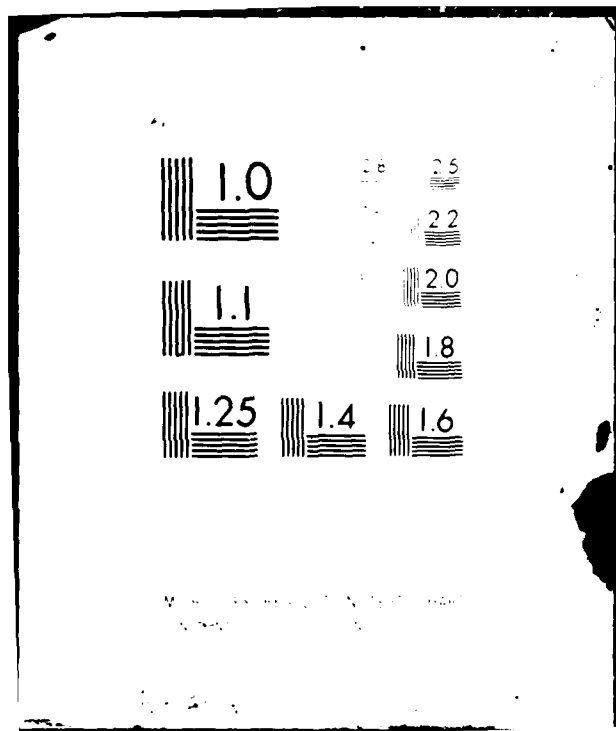
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THIRD WEATHER WING

3WW/TN-81/001

TECHNICAL NOTE

28 DEC 1981

EUGENE M. WEBER

STEVEN WILDEROTTER

THIRD WEATHER WING OFFUTT AFB NE 68113

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SATELLITE INTERPRETATION

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FOR THE COMMANDER

Michael T. Schwitters
MICHAEL T. SCHWITTERS, Lt Col, USAF
Chief, Aerospace Sciences Division

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ACKNOWLEDGEMENTS

This Technical Note is dedicated to all of the men and women of the Third Weather Wing whose efforts obtained satellite equipment and trained our forecasters to use the data.

Special thanks and credit to Mr. Roger Weldon of the National Environmental Satellite Service for use of his Satellite Course Notes and consultation, to Mr. Stephen P. Weaver of the 3350th Technical Training Group, Chanute AFB, to Major Frank Wells of Air Force Global Weather Central and to the co-author, 1Lt Steven Wilderotter, Det 17, 9WS. To Lt Col Mike Schwitters and Major Al King for their consultation and editing assistance; to Mrs. Judy Money, Mrs. Carol Odom and AlC Kelly Dean for assistance in typing and layout and to AlC Joe Covert for his assistance with the illustrations. Also, I wish to acknowledge the specialized photographic assistance provided by the 3902/OTCP and 544TMS at Offutt AFB. Finally, I acknowledge, with my deepest appreciation, the perseverance of my wife, Doris, for the many hours that I spent at home in producing this TN. Her understanding nature and encouragement are largely responsible for this success.

Eugene M. Weber

EUGENE M. WEBER, CMSGT, USAF

Cover Photograph: Omaha Tornado: May 6, 1975

Shortly after this photograph was taken, Omaha, Nebraska was devastated by a tornado and 3 to 4 inch hail. Numerous tornadoes struck other locations spread along this system 1,500 miles length. Photo courtesy of NESS Applications Laboratory.

PREFACE

Having spent nearly a year actively working to obtain satellite data and training our forecasters to use this data, we determined that a need existed for a publication to be used as a standard reference. It was our desire that the most recent findings in the field of satellite interpretation be included along with the meteorological reasoning leading to those findings.

Inspired by a unit training reference constructed by Lt Wilderooter of Det 17, 9WS, Ellsworth AFB, we set out to accomplish a publication for use throughout the Wing. Publications from NESS, AWS, and other meteorologists were researched, thousands of satellite photographs were reviewed, and case studies selected. As each section evolved, NESS and AWS experts in satellite interpretation were consulted to ensure that the meteorological logic was correctly applied.

While this Tech Note is not a training program, we feel it is the most comprehensive and up-to-date reference in the field and should be used as the basis for forecasters training in meteorological satellite interpretation training.



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INTRODUCTION

This Technical Note contains an orderly discussion of meteorological logic applied to the latest techniques in satellite interpretation. Nearly 300 photographs were selected to illustrate the concepts covering the entire range of forecasting and analysis.

Our goal in the publication is to make one reference available which teaches forecasters about the things they see on the photographs and explains their meteorological causes.

We hope to update the Technical Note as new developments occur in this rapidly expanding field.

SECTION 1: General Considerations When Viewing Satellite Data

There are several considerations to make before you attempt to interpret satellite photographs. Some of these are:

- The resolution of the picture
- The frequency range of the light sensor (Visible or Infrared (IR))
- The time of day
- The sector in which picture was taken
- The location and terrain
- The season of the year

Remember that the satellite looks down at clouds. Because of this, higher clouds may obscure the existence of lower clouds. Surface observations should always be used in conjunction with satellite data.

Two primary considerations when interpreting a satellite photo are resolution and frequency range. Were either the visible or infrared (IR) light regions scanned by the satellite? The GOES resolution within the visible range is 1, 2, 4 or 8 kilometers before it is treated by the computer for release to the users. The infrared sensor only has a resolution of 8 km. The visible sensors scan the radiation transmitted from the earth between 0.4 and 0.7 microns. This is the same range in which the human eye is sensitive. Infrared sensors scan the radiation emitted from the earth in the IR region is entirely dependent upon the temperature of the emitting body. A normal GOES infrared picture would show the coldest, highest tops white, and the warmest, lowest returns black; this is shown in the upper half of Figure 1. However, the computer can invert the gray scale, i.e., cold returns become black while warm returns become white; this reversal of gray scale is shown in the lower half of Figure 1. Next, the computer enhances the data. It divides the temperature scale into sections, then assigns a different black gray white shade to each temperature range. Normally, these shades are not in a linear progression from black to white, but jumps shades as noted by the arrows in the IR picture, Figure 2.

The gray scale used with the specific enhancement curve in the IR photo is always shown immediately below the legend data at the top of the picture (Figure 2). The scale varies with different enhancement curves. Another gray scale is located above the legend data and depicts the linear black/gray/white scale. This scale appears on both visible and infrared color pictures.

Returning to the gray scale below the legend (enhancement curve; Figure 3) each step on the scale represents a 10°C temperature range. On the far left hand side of the scale, the temperature is +50°C with the temperature at the far right always being -100°C. In Figure 3, 0°C can be found by the tick mark immediately to the right of the resolution-enhancement curve designator - in this example - 2MB. Incidentally, the most common infrared enhancement curve used is MB.

Two problems which affect the picture within the frequency range of infrared data are: **attenuation** and **contamination**. Attenuation is the loss of energy due to scattering and absorption of energy (Figure 4). Attenuation causes the IR image to appear brighter (colder) than it really is. The satellite viewing angle greatly affects attenuation, with the points farthest from the satellite having the most attenuation (See Figure 4).

Contamination subpoint occurs when the satellite, which is able to see through a thin cloud deck, allows some of the radiation to come from a warmer, denser layer of clouds below. An example of contamination is thin cirrus over a low-stratus deck which gives the appearance of middle clouds. This is illustrated in Figure 5 at point A. One major problem with IR is misinterpretation of a dense cirrus cloud to be a major storm system. Figures 6 and 7, visible

0-25 22 FEB 81 00341 19121 UC2

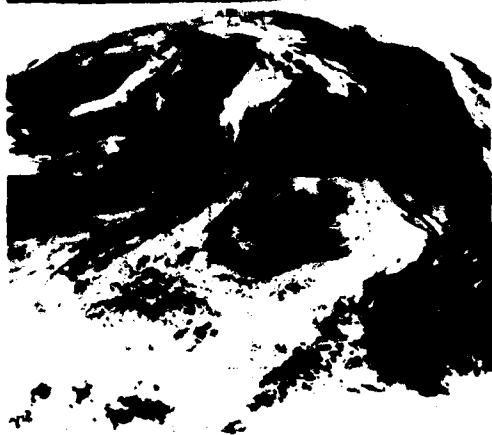


Figure 1: 0545Z 22 February 1981
Inverted Photo

0-25 19 JUL 81 01554 12842 KB8

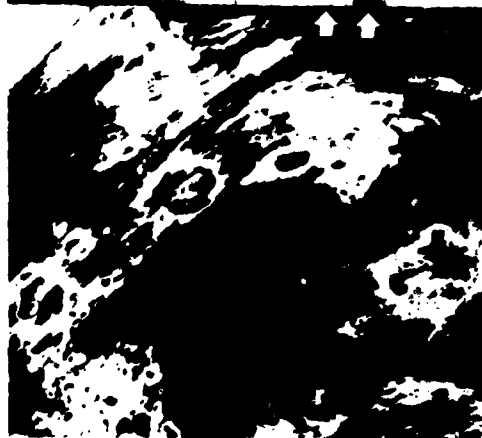


Figure 2: 0130Z 19 July 1981

1900 20FE81 12E-2MB 01301 13071 KB8

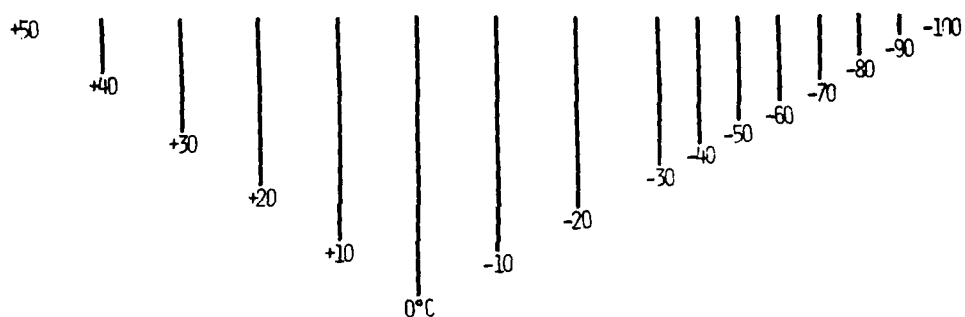


Figure 3: Infrared Satellite Photo Legend

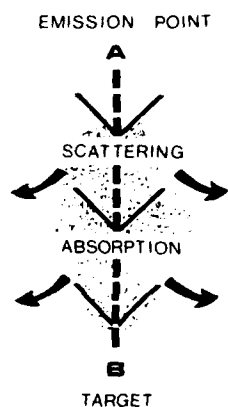


Figure 4: Attenuation

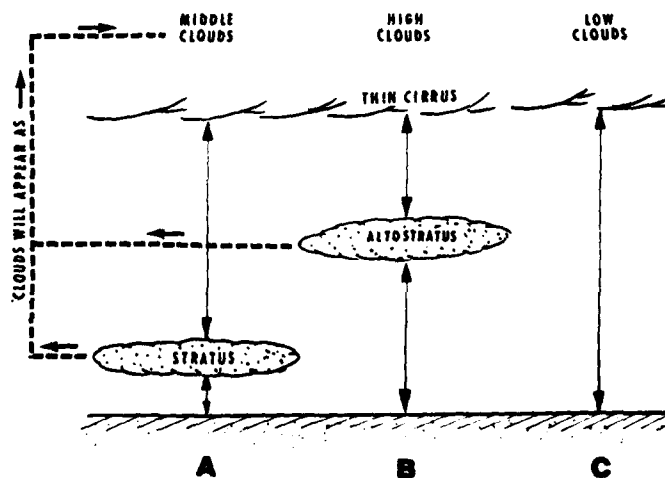
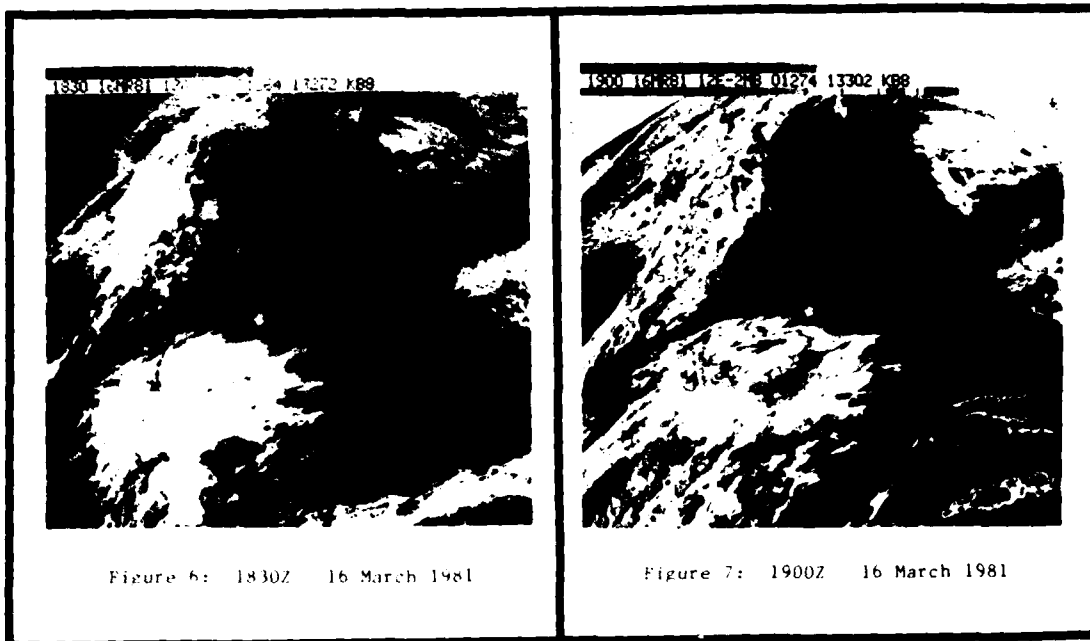


Figure 5: Contamination

and IR photos respectively, depict this misinterpretation. In Figure 6, dense filaments of cirroform clouds appear over Texas and Mexico. The enhanced IR, Figure 7, depicts several gray shades within the cirrus layer; novice satellite interpreters may believe this area to be a significant storm system.



The third consideration to take into account while viewing a visible photo is the time of day. If the sun is low in the sky, the picture will be darker with shadows plainly visible. These shadows help distinguish cloud layers (Figures 8 and 9). In Figure 8, a morning visible picture, note that the shadows within the storm system over the southeastern U.S. enhance the cloud tops. If the sun is directly overhead, the picture will be brighter, and possibly even have a faded appearance due to over exposure. Shadows will be hard to find when the sun is high in the sky. Figure 9, two hours later from Figure 8, illustrates the absence of shadows as the sun approaches overhead. A second example, Figures 10 and 11, shows an early morning and early afternoon photo respectively. Look especially close at the convective cloud system defined near point A in the two figures. Notice in the early morning picture (Figure 10) that the cloud tops appear higher than the afternoon picture (Figure 11) though the reverse is generally true.

A good rule of thumb to use while looking at a visible picture is the obvious: The higher and thicker the cloud, the brighter it will appear. The two major exceptions are that an early morning cloud will not be very bright, and the height of thunderstorm tops cannot be easily correlated with cloud brightness.

The fourth consideration is the sector in which the photo was taken. Data received on GOES pictures become increasingly distorted proportional to the angle that the picture was taken. Figures 12 and 13, enhanced IR photos, illustrate this problem. In Figure 12, (less distortion) the comma cloud pattern over the southern plains appears close to its true configuration. Figure 13, 45 minutes later, depicts a different sector scan which is angled towards the east and has increased longitudinal distortion. Notice the distortion of the comma cloud system; it is more difficult to visualize in Figure 13 due to foreshortening.

Other considerations are: Identification of location and terrain features with respect to the season of the year. Use your basic weather knowledge to determine which clouds are likely or unlikely at a location. Do not expect mountain wave activity over ocean areas or snow in the tropics during the summer.



Figure 8: 1430Z 22 March 1981

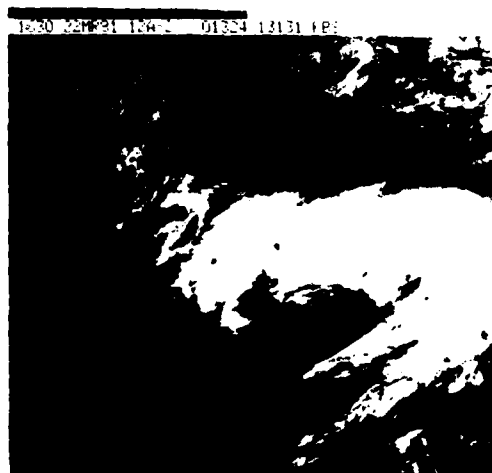


Figure 9: 1830Z 22 March 1981



Figure 10: 1400Z 7 May 1981



Figure 11: 1830Z 7 May 1981

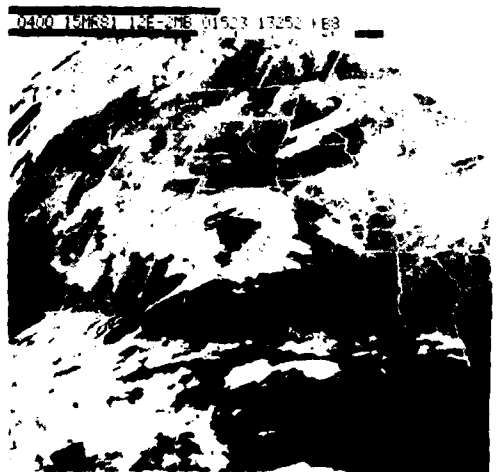


Figure 12: 0400Z 15 March 1981

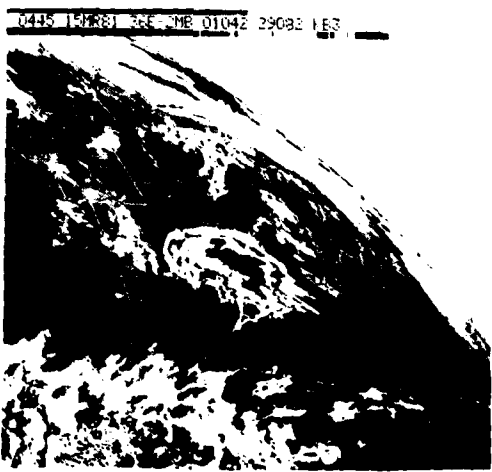


Figure 13: 0445Z 15 March 1981

SECTION 2: Identification of Cloud Types in Satellite Data

In this section a brief review of the characteristics of cloud patterns and types as shown in visible and IR photos will be discussed.

Cloud Patterns:

Synoptic events form cloud systems with various patterns. Some of the most common patterns are illustrated in Figures 14 to 17.

- Cloud Shield - A cloud shield is a broad cloud pattern which is not more than four times as long in one direction as it is wide in the other direction. A cloud shield (A) is shown across the Great Lakes and Ohio Valley.

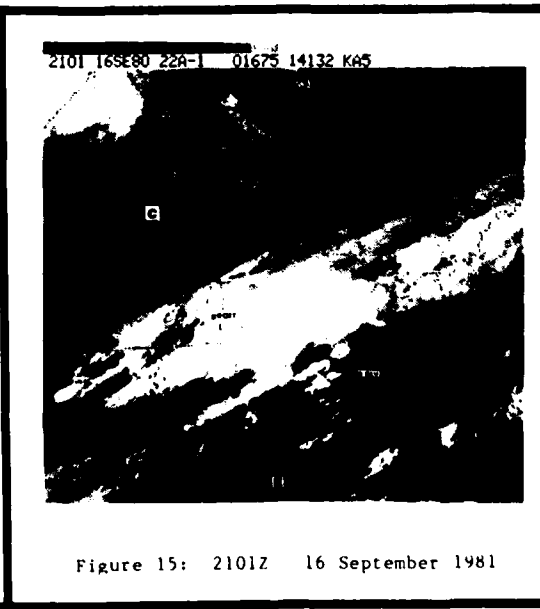
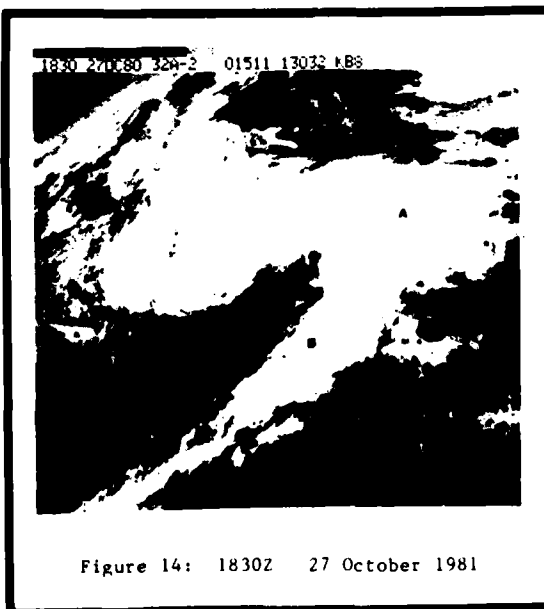
- Cloud Band - A cloud band is a nearly continuous cloud formation with a distinct long axis where the ratio of length to width is at least 4 to 1 and the width is greater than 1 degree of latitude. A cloud band is shown at B in Figure 14.

- Cloud Line - A cloud line is a narrow cloud band in which the individual cells are connected and the lines are less than 1 degree latitude in width. Cloud lines are shown at C in Figure 15 and near D in Figure 15.

- Cloud Street - A cloud street is a narrow cloud band in which the individual cells are not connected. Several streets generally line up parallel to each other with each street not being more than 1 degree in latitude in width. Cloud streets are shown at E in Figure 15. See further cloud street discussion related to Figures 28 and 29.

- Cloud Finger - Cloud fingers develop on the forward edge of the frontal band and are often tied in a nearly-continuous fashion to the frontal clouds. These fingers generally extend in a more southerly direction than the frontal band. Figure 17 illustrates several cloud fingers, noted by the arrows, converging into a storm system located over the southeastern U.S. Cloud fingers generally end at the ridgeline.

- Cloud Element - A cloud element is the smallest cloud form which can be resolved in a satellite picture. Cloud elements are recognizable in Figure 15 within the areas noted by C and E.



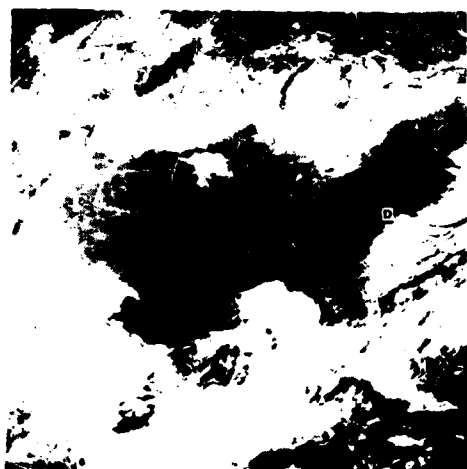


Figure 16: 1740Z 3 February 1981

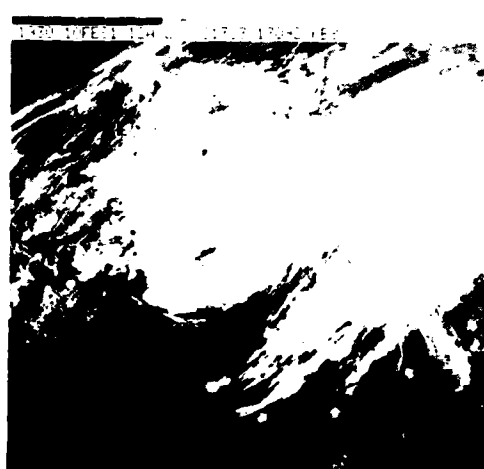


Figure 17: 1930Z 10 February 1981



Figure 18: 2015Z 2 July 1981

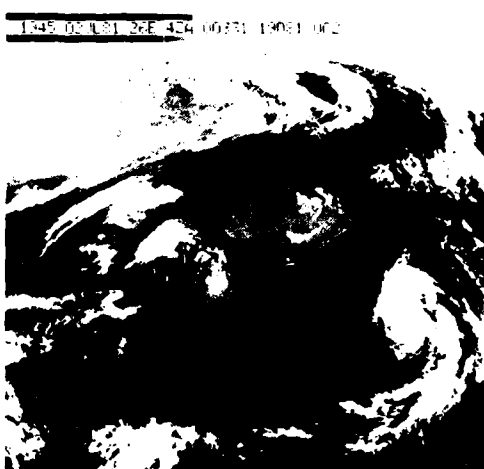


Figure 19: 1945Z 2 July 1981

Cloud Types:

Low Clouds

• Stratocumulus - Stratocumulus cloud fields appear as white, lumpy globular clouds in the visible (A and B in Figure 18) and as a consistent dull gray in infrared photos (if they can be seen at all; Figure 19). They are generally seen in closed cellular patterns with large numbers of relatively bright globular centers often connected to each other with darker, less dense clouds. As these cells continue to decrease in size, they take on a stratiform appearance and it becomes difficult to distinguish stratocumulus from stratus as shown off the California coast in Figure 20.



Figure 20: 1745Z 15 July 1981

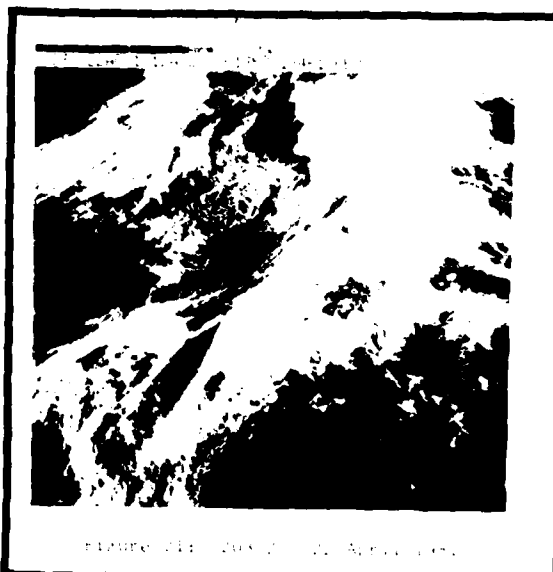


Figure 21: 2007-12 April 1981

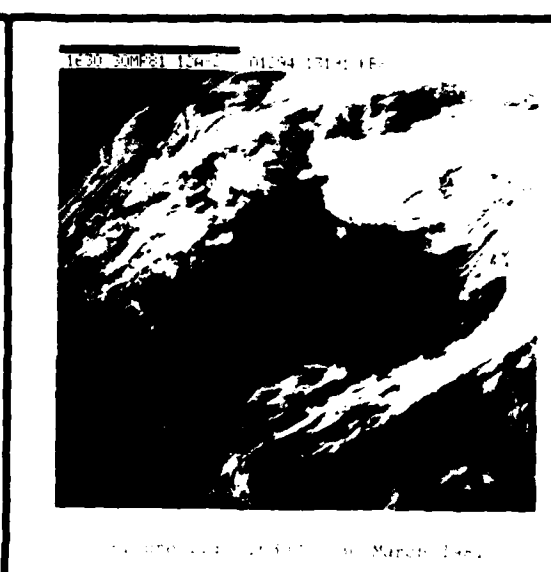


Figure 22: 2007-12 March 1981

Stratus clouds are often found in the northern hemisphere. The first is a cloud with a lot of texture, and it is often found in the northern hemisphere. The second is a cloud with a lot of texture, and it is often found in the northern hemisphere. The third is a cloud with a lot of texture, and it is often found in the northern hemisphere. The fourth is a cloud with a lot of texture, and it is often found in the northern hemisphere. The fifth is a cloud with a lot of texture, and it is often found in the northern hemisphere. The sixth is a cloud with a lot of texture, and it is often found in the northern hemisphere. The seventh is a cloud with a lot of texture, and it is often found in the northern hemisphere. The eighth is a cloud with a lot of texture, and it is often found in the northern hemisphere. The ninth is a cloud with a lot of texture, and it is often found in the northern hemisphere. The tenth is a cloud with a lot of texture, and it is often found in the northern hemisphere.

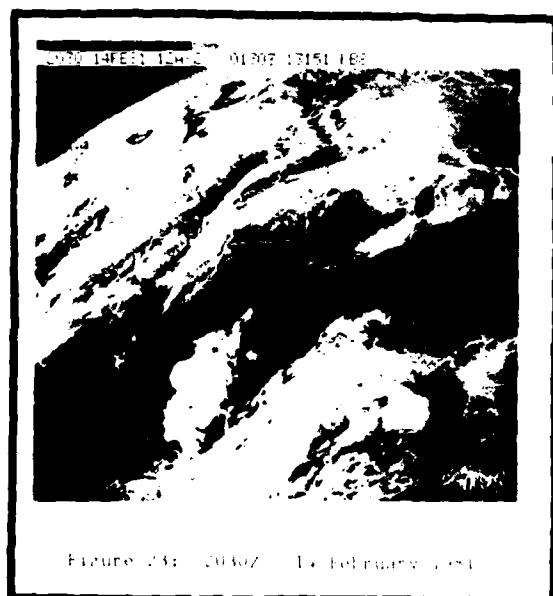


Figure 23: 2007-12 February 1981

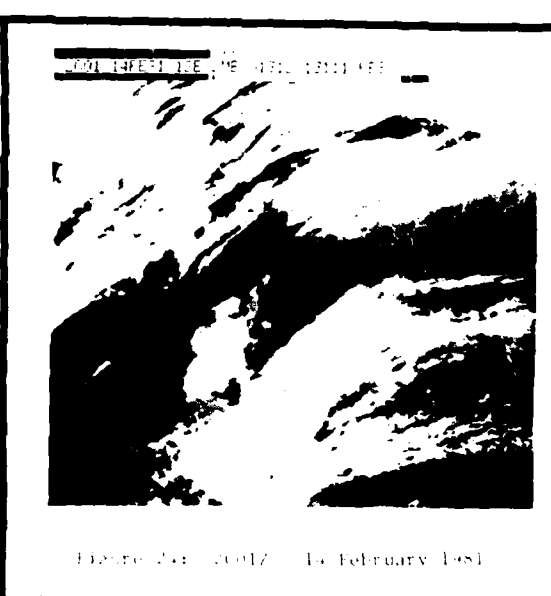


Figure 24: 2007-12 February 1981

• Stratus - Stratus and the northern hemisphere. Stratus clouds are often found in the northern hemisphere. The first is a cloud with a lot of texture, and it is often found in the northern hemisphere. The second is a cloud with a lot of texture, and it is often found in the northern hemisphere. The third is a cloud with a lot of texture, and it is often found in the northern hemisphere. The fourth is a cloud with a lot of texture, and it is often found in the northern hemisphere. The fifth is a cloud with a lot of texture, and it is often found in the northern hemisphere. The sixth is a cloud with a lot of texture, and it is often found in the northern hemisphere. The seventh is a cloud with a lot of texture, and it is often found in the northern hemisphere. The eighth is a cloud with a lot of texture, and it is often found in the northern hemisphere. The ninth is a cloud with a lot of texture, and it is often found in the northern hemisphere. The tenth is a cloud with a lot of texture, and it is often found in the northern hemisphere.

Figure 25a: 1400Z 10 January 1981. The image shows a dark, textured surface, possibly a rock or ice, with a bright, irregular shape in the upper left corner. The text "1400Z 10 JAN 1981" is visible at the top.

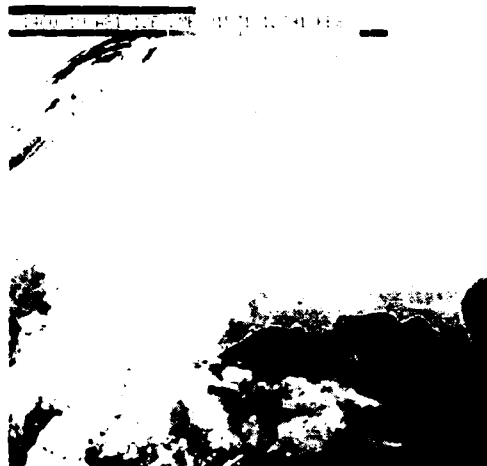


Figure 25a: 1400Z 10 January 1981

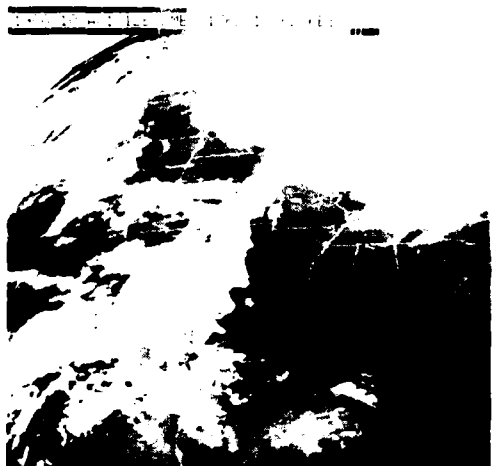


Figure 26a: 1400Z 10 January 1981

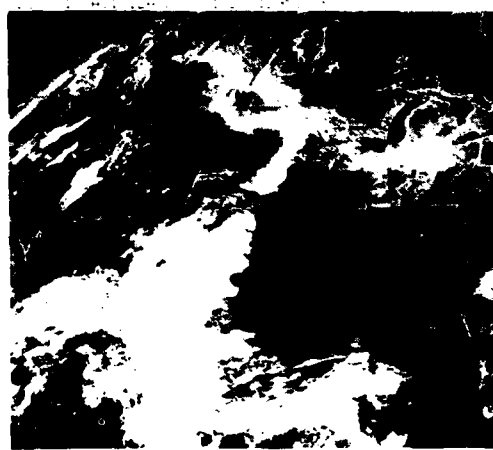


Figure 26a: 1400Z 10 January 1981

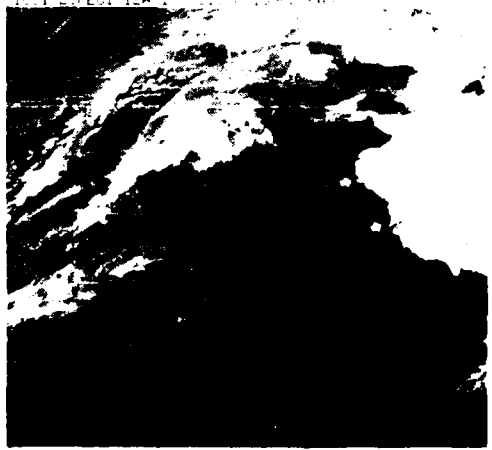


Figure 26a: 1400Z 10 January 1981

Figure 26a: 1400Z 10 January 1981. The image shows a dark, textured surface, possibly a rock or ice, with a bright, irregular shape in the upper left corner. The text "1400Z 10 JAN 1981" is visible at the top.

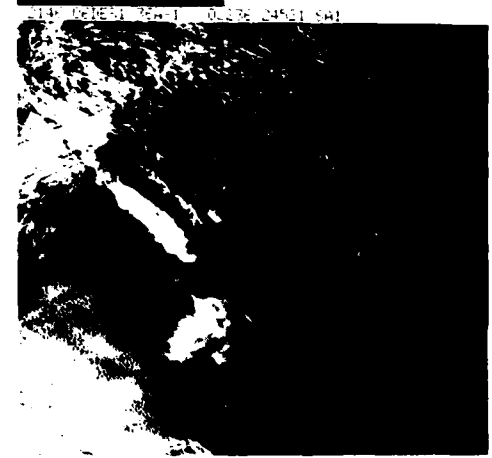


Figure 27: 1400Z 10 December 1981

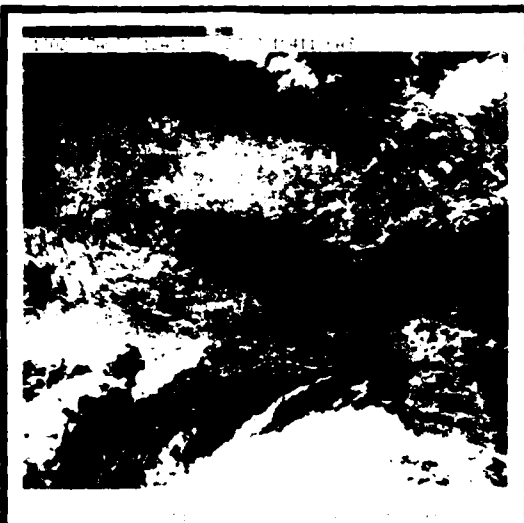


Figure 30: 1907 - 28 March 1981

Figure 31: 1907 - 28 March 1981

Figure 32: 1907 - 28 March 1981

Figure 33: 1907 - 28 March 1981



Figure 3a: 1457 11 October 1951



Figure 3b: 1470 11 October 1951

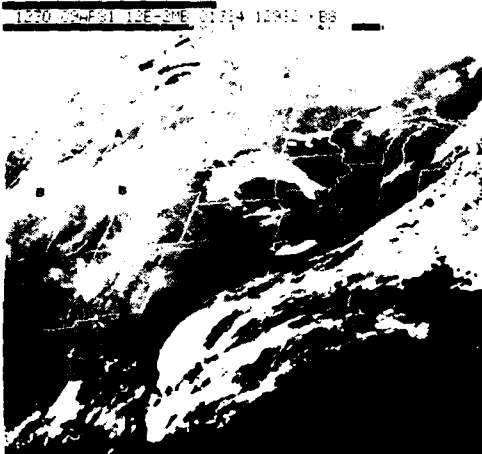


Figure 3c: 12307 9 April 1951

In the 1950s, the surface of the rocks was covered with a thin layer of snow. The snow was not very deep, but it was enough to cover the surface of the rocks. The snow was not very deep, but it was enough to cover the surface of the rocks. The snow was not very deep, but it was enough to cover the surface of the rocks.

DISCUSSION

The results of the study show that the surface of the rocks is covered with a thin layer of snow. The snow is not very deep, but it is enough to cover the surface of the rocks. The snow is not very deep, but it is enough to cover the surface of the rocks. The snow is not very deep, but it is enough to cover the surface of the rocks.

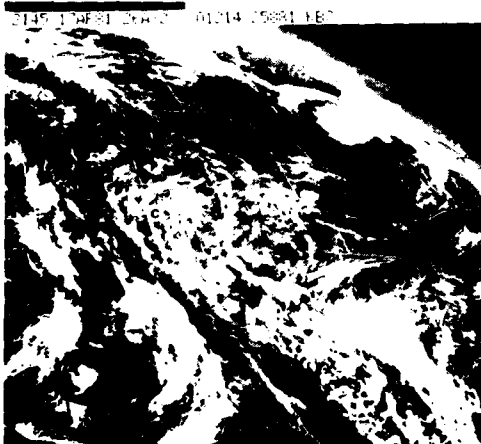


Figure 3d: 21457 1 April 1951

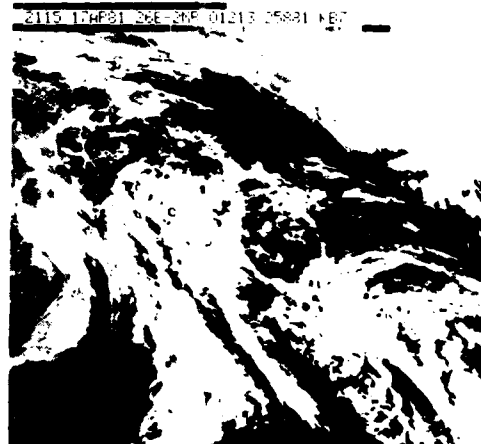


Figure 3e: 21196 1 April 1951

• **Altostratus** - Altostratus clouds are thicker than wispy alto clouds, but they are not extensive sheets. In the visible, the alto clouds are perceived as soft white streaks. In the shades of gray and black reveal the cloud tops. In Figure 37, the alto clouds are seen to the left of the cirrostratus layer associated with the storm system extending from the Gulf of Mexico and Texas. In both pictures, the alto clouds are seen to the left of the cirrostratus layer. In the visible, the alto clouds are perceived as soft white streaks. In the shades of gray and black reveal the cloud tops. In Figure 37, the alto clouds are seen to the left of the cirrostratus layer. In the visible, the alto clouds are perceived as soft white streaks. In the shades of gray and black reveal the cloud tops. In Figure 37, the alto clouds are seen to the left of the cirrostratus layer.



Figure 37: 1930Z 25 January 1981

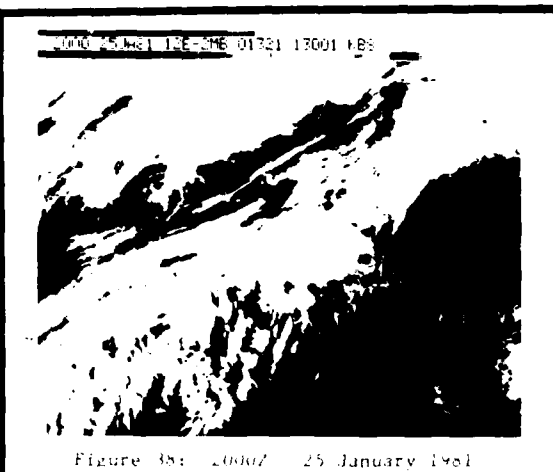


Figure 38: 2000Z 25 January 1981

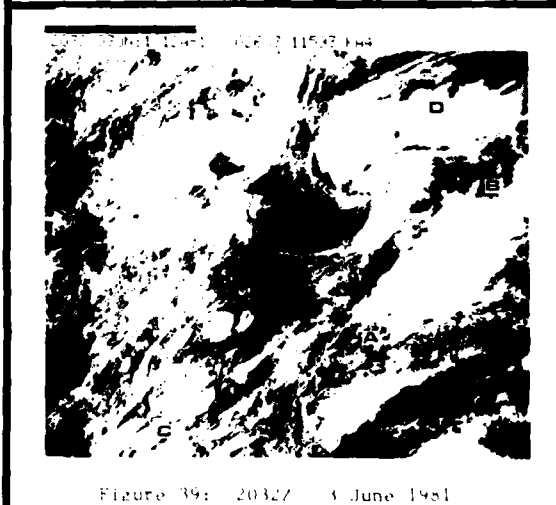


Figure 39: 2032Z 3 June 1981

• **Anvil Cirrus** - Anvil cirrus is blowoff from thunderstorms. Figure 39 depicts several groups of thunderstorms across the southern plains, southern Rockies, and Mexico. Anvil cirrus has a very sharp wind edge (A), and a fuzzy downwind edge (B). The anvil cirrus points out either the direction of the upper winds or the direction of the vertical shear. In Figure 39 it is apparent over Mexico (C) that the upper winds over this area are from a southwest direction. Often the blowoff from numerous thunderstorms combine to form an extensive cirrostratus shield as seen at D in Figure 39.

A second example is shown in Figure 40 where anvil tops can be used to determine the direction of the upper winds. This is shown by the long arrows in Figure 40.

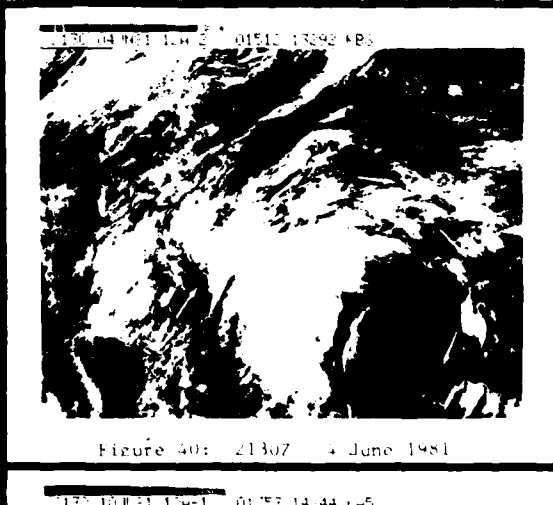


Figure 40: 2130Z 4 June 1981



Figure 41: 2137Z 10 July 1981

• **Cumulonimbus** - Cumulonimbus cells may form into patterns similar to the smaller convection clouds. Each cell is circular in shape as noted across the Gulf coastal states in Figure 42. They appear white in the visible and may cast shadows on lower cloud decks. To the east of an advanced squall line, a cirrostratus shield may develop due to excessive anvil blowoff. Not all cumulonimbus cells have anvils, and their life span is dependent upon the height of the cell.

Figure 42

Satellite photograph of Mount St. Helens, March 29, 1981. The image shows the mountain's profile and the surrounding landscape, including the river valley and the forested area.

• The image shows the mountain's profile and the surrounding landscape, including the river valley and the forested area. The image is a black and white photograph with a high contrast, showing the mountain's silhouette against the sky.

• The image shows the mountain's profile and the surrounding landscape, including the river valley and the forested area. The image is a black and white photograph with a high contrast, showing the mountain's silhouette against the sky.

• Mount St. Helens' eruption is shown in the lower-left corner of the image. The image shows the mountain's profile and the surrounding landscape, including the river valley and the forested area.

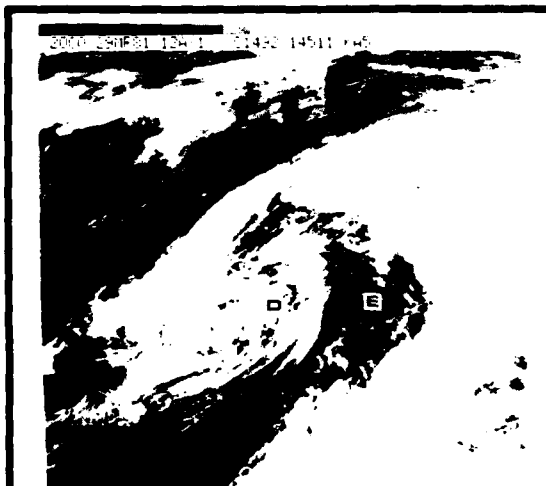


Figure 42: 20007 29 March 1981



Figure 43: 00452 9 June 1981



Figure 44: 22312 24 June 1981

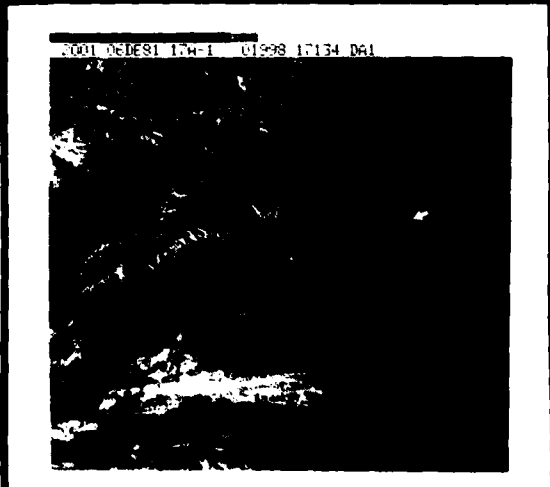


Figure 45: 20012 6 December 1981



Figure 48: 15077 - 4 March 1981

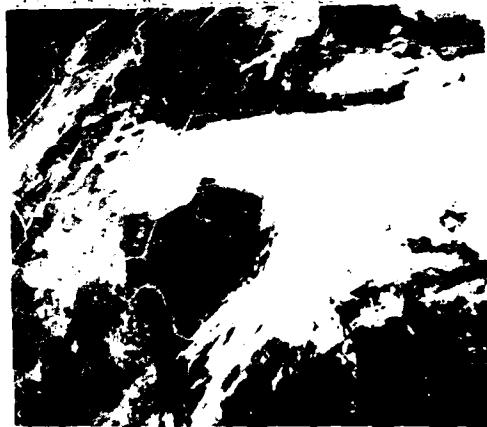


Figure 49: 15078 - 4 March 1981

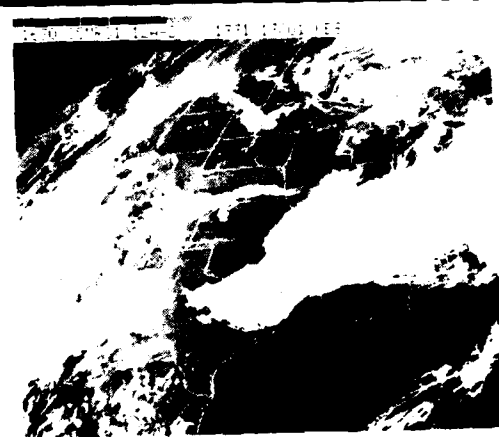
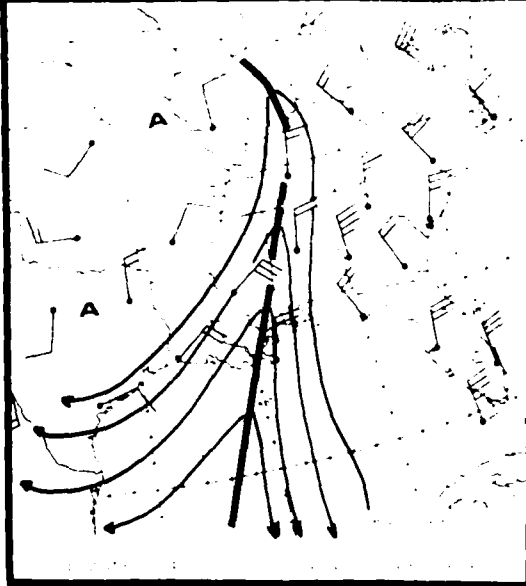
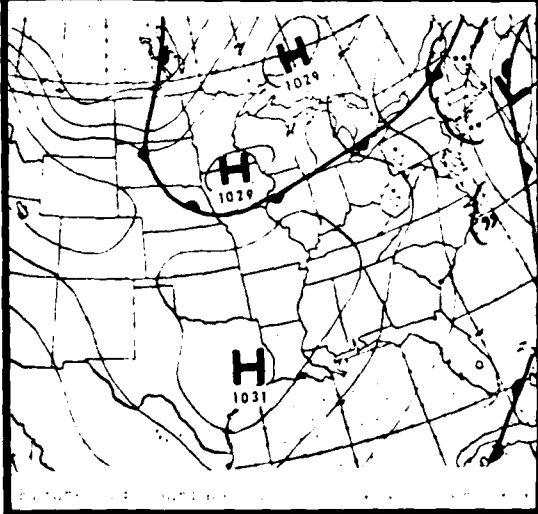


Figure 48: 15302 - 5 March 1981



Figure 49: 15315 - 5 February 1981



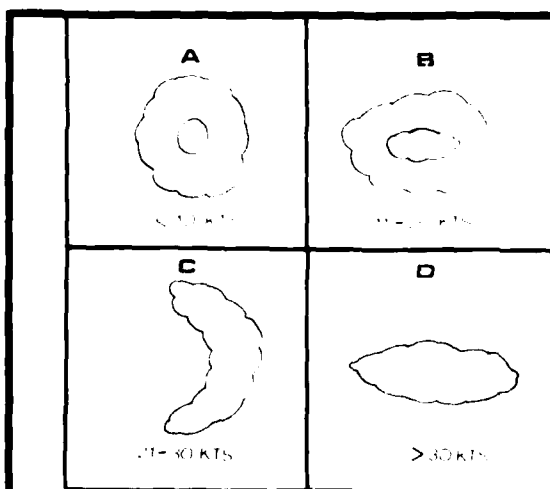


Figure 54: open-cell cumulus shapes



Figure 55: 2200Z 22 February 1981

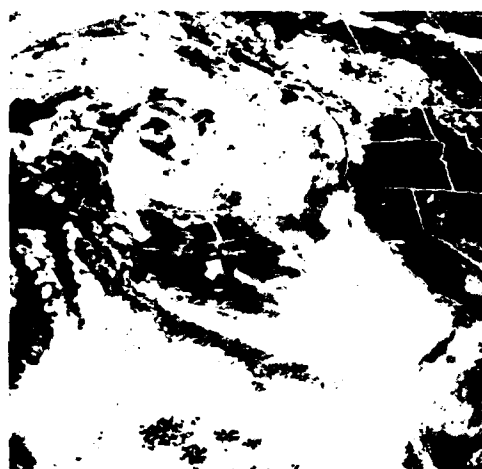


Figure 56: 1815Z 19 July 1981



Figure 57: 2240Z 1 March 1981



Figure 58: 2200Z 1 March 1981

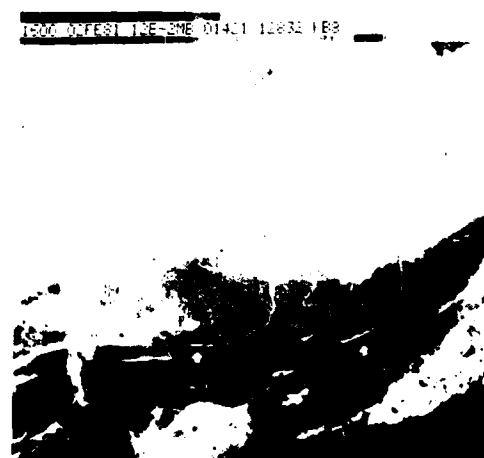


Figure 59: 1600Z 2 February 1981

Striations (Shadows)

Striations are narrow, straight or curved streaks in cloud which are cast from an elevated area. Striations frequently give indication of the orientation of the cloud mass; the low sun angle causes highlights and shadows which produce the striated pattern. Figures 50 and 51 depict morning visible photos with prominent striations. In Figure 50, note the cyclonic striations over the Great Lakes area as noted by the arrows.

A recent example is shown in Figure 52. Again with striated shadows the air circulation which gives the Great Plains storm system an effect of rotation is clearly visible. Areas of separate shadows, as indicated by arrows, are cast by the Great Lakes area, the upper cyclonic front structure, a lower cloud layer, and the cloud mass situated over the Great Lakes, and the lowest layer (low clouds) appears at a distance of about 100 miles from the Great Lakes. Nebraska and Iowa are to the north of the low clouds; note the striated pattern over the Great Lakes within the occluded segment of the frontal system.

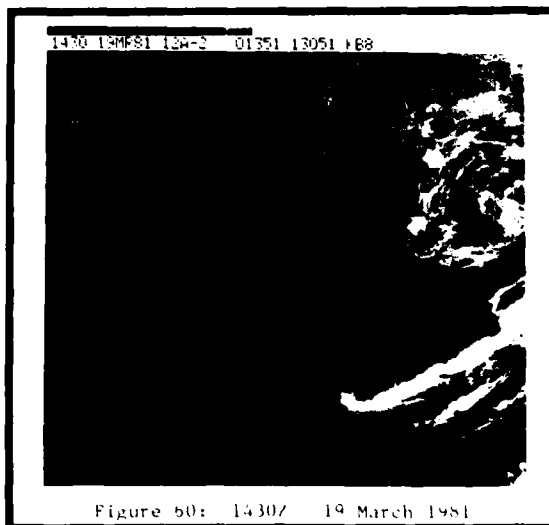


Figure 50: 1430Z 19 March 1981

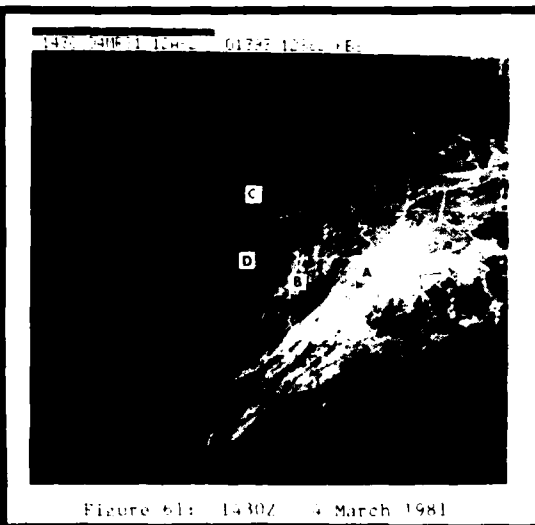


Figure 51: 1430Z 19 March 1981

Lithometeors:

Wind-driven particles such as dust, sand, snow and volcanic ash may in some cases appear as surface features. They are characterized by a dull, gray, fuzzy appearance similar to thin cirrostratus in visible photos; if photo ray or ray not reveal these lithometeors.

A duststorm event associated with a Great Plains storm system is shown over northwestern Texas in Figure 52. Surface wind directions were from a westerly component; wind speeds were reported between 45 and 50 knots. In the 1st, Figure 53, the dust area is apparent and is within the same gray shade scale as low clouds located over the northern Texas panhandle and in the Gulf of Mexico.

A large area of smoke from Canadian forest fires is shown from southern Canada across the upper Midwest to the Great Lakes - Ohio Valley area as indicated by the arrows in Figure 54. Notice how the smoke layer across the central Midwest flows into the Rocky Mountain disturbance; the smoke layer has the same inflow pattern that a cloud layer would have it present.

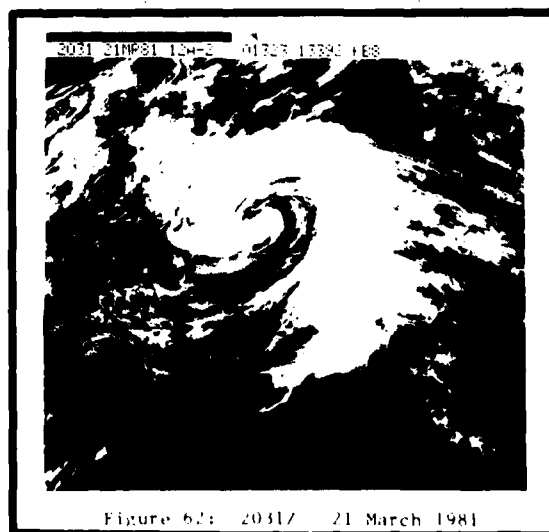


Figure 52: 2031Z 21 March 1981

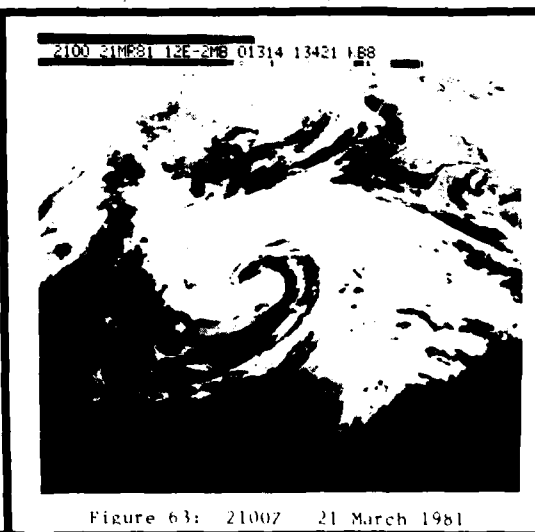


Figure 53: 2100Z 21 March 1981

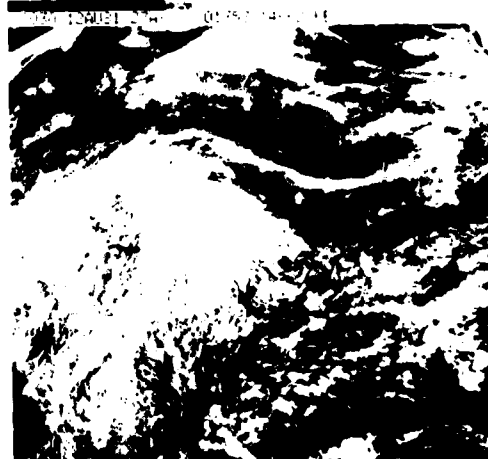


Figure 64: 2030Z 12 August 1981



Figure 65a: 0600Z 25 February 1981

Low-Level Moisture Areas:

Enhanced IR satellite pictures can provide forecasters with an additional tool for forecasting the extent of warm air advection stratus and fog at night. Frequently, areas where fog and stratus are more likely to form over or advect into will appear as relatively dark areas on enhanced satellite pictures (after Gurka, 1976) (1). These dark areas are normally found downwind from a moisture source, such as the Gulf of Mexico and appear to outline the boundary of relatively moist air in the lower levels. This boundary can be monitored and used as an estimate of the extent of nocturnal fog and stratus development and advection. During the night, moist air absorbs the earth's radiation, becomes warmer, and reradiates this energy in all directions - part of it back towards earth. In areas not covered with moist air, the earth's radiation is lost to space. The net effect is a warmer earth in areas covered by air with high moisture content which appears darker on infrared photographs.

Figure sequence 65 shows this event. In Figure 65a, an IR, a dark area can be seen across the southern and central plains; the western boundary of the moisture area is noted by the arrows. This dark area represents a tongue of moisture advection although stratus is not evident. Stratus is occurring across eastern Texas and offshore, but nearly all of the stratus is hidden by a cirrus layer. The northern limits of the dark area extends well to the north reaching into southern Nebraska. From this IR photo, the potential for stratus formation or advection would be forecast as far north as Nebraska provided no air mass changes would occur.

The visible imagery, ten hours later, Figure 65b, depicts subsequent stratus advection. In Figure 65c, 24-hours later from Figure 64b and 34 hours later from Figure 65a) stratus has indeed, advected as far north as Nebraska and has reached into the Dakotas.

Of course, the extent of the moist air at the surface can be located with surface dew points. The satellite, however, has much higher resolution than the surface observation network.



Figure 65b: 1631Z 25 February 1981



Figure 65c: 1630Z 26 February 1981

Terrain Features:

Forecasters should not be confused in interpreting terrain as low clouds on IR photos. In Figure 66, a large grey area is shown over the Rocky Mountains (location G; a small patch of cirrus is shown over the Front Range); the gray shade approximates a layer of low clouds. The related visible photo, Figure 67, reveals that nearly all of the Rocky Mountain areas are cloudless.

A second gray shade area, which could be misleading to novice satellite interpreters as low clouds, is faintly shown across the area noted by H in Figure 66 (arrows mark the western boundary). This grey cloud-free area is cold air; it closely follows the cyclonic configuration of the cold air stratus pattern, location J, associated with the Great Lakes storm system.

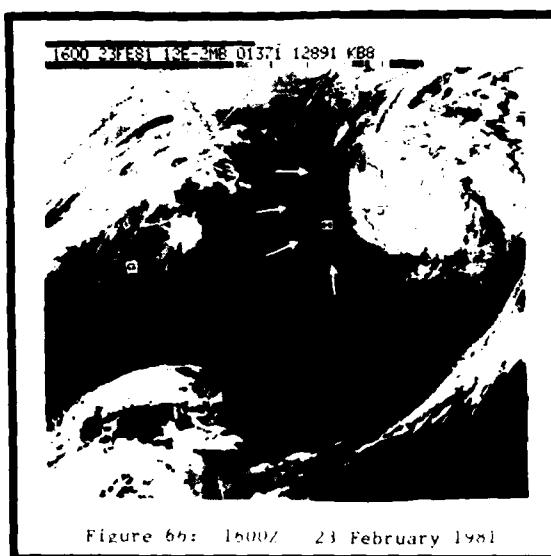


Figure 66: 1600Z 23 February 1981

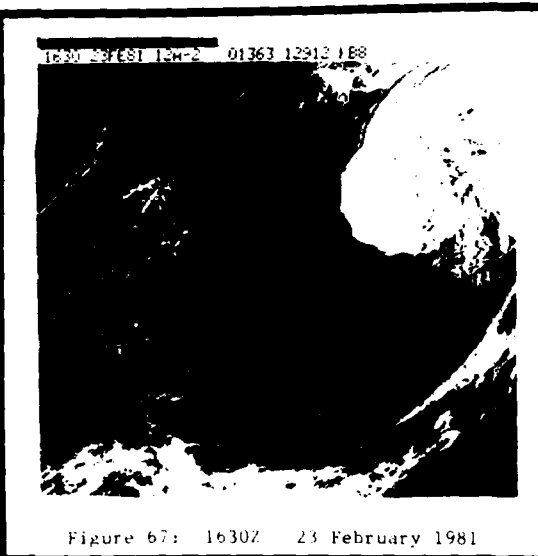


Figure 67: 1630Z 23 February 1981

Source: Photo Courtesy of:

AF RC
SAC RSC
DET 1, RSC

*Figures 274, 275, 276 and 277 courtesy of
National Environmental Satellite Service
(NESS).*

*All conventional analyses shown throughout this Technical Note are
duplicates of either NWS's Daily Weather Maps Weekly Series or
facsimile charts.*

SYNOPTIC CLOUD PATTERNS

In Part II cloud patterns and systems related to large-scale weather systems are discussed. Included are relationships between cloud systems and jet streams, ridges and troughs, fronts, low-levels, and comma systems. In the severe convective weather section that follows, the general squall lines, outflow boundaries and intersecting boundaries will be shown. This section ends with discussion on cutoff lows and tropical storm systems as seen in satellite photography.

SECTION 1: Locating Jet Streams

The location, configuration and velocity of jet streams and their associated wind shear in the mid and upper troposphere are vital keys in the development of storm systems and severe convective storms. Jet streams meander meridionally in westerly directions, such as the "polar jet" and "subtropical jet" have been given to these strong middle and upper level wind zones. These zones are constantly forming, dissipating, intensifying, weakening, retreating and shifting meridionally and longitudinally. Several jet streams often appear simultaneously on upper air analyses such as shown in Figure 68. Jet streams often split into branches which make it more difficult to identify these systems on satellite photos. An example of this is shown in Figure 69; an extensive area of jet-related cirrus and cirrostratus is evident over the central and western U.S. (see related discussion, Figures 6 and 60). This section should help forecasters locate most jet streams on satellite pictures.

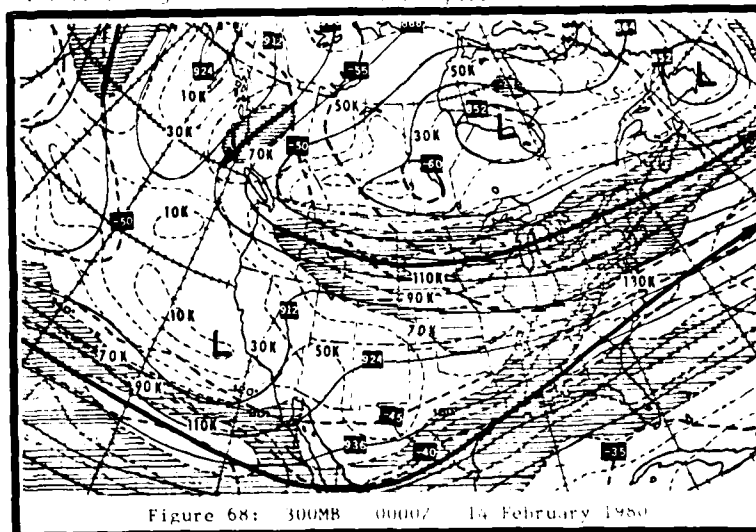


Figure 68: 300MB 0000Z 14 February 1980



Figure 69: 2330Z 2 April 1981

Relationships between Jet Streams and Cloud Patterns

There are several important relationships between jet streams and cloud patterns in satellite pictures. At the outset, it can be stated that *no jet stream can be identified on the cloud picture* without prior analyses. Then with the use of satellite data and other jet stream information identified at the time of the time, according to which, there are four rules to be followed to determine jet stream positions on satellite photos. They are:

Rule 1 - Cirrus cloud shield is tend to form or persist on the anticyclonic shear side of the jet stream axis, with a well defined cloud band along the axis (Figure 71). This cirrus shield is called baroclinic zone cirrus. Figure 71 depicts a baroclinic zone cirrus pattern across the central U.S. Axes of maximum winds (dotted line) border between dry air on their cyclonic shear side (dashed line) boundaries: location A in Figure 71, not located on the anticyclonic shear side (not a distinct cloud band); location B, the jet position, will be about one degree of latitude north (on the cold air side) of the cirrus shield as shown in Figure 71.



Figure 71: Rule 1

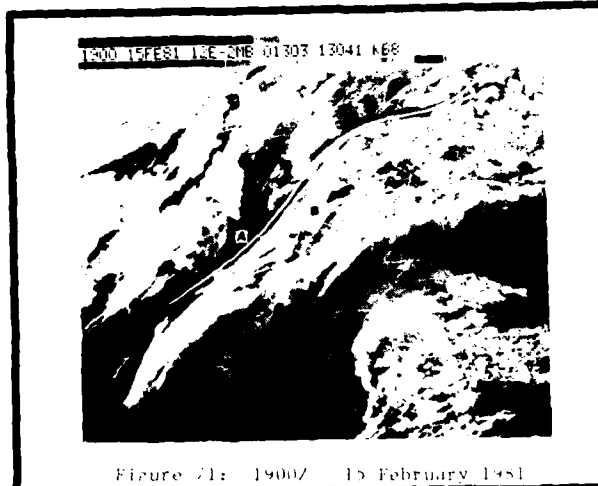


Figure 72: 1300Z 15 February 1981

In visible pictures especially, the jet may be found where the baroclinic cirrus shield crosses a vorticity comma cloud system. The cloud texture goes from lumpy (lower convective clouds) to smooth (higher stratiform clouds). Figures 72 and 73 illustrate this method within a mature storm system. In Figure 72, an IR photo, a vorticity comma cloud system, noted by B, can be seen across Iowa and western Missouri behind the larger baroclinic cirrus shield (A). Focusing in on the comma cloud area in the visible photo, Figure 73, the comma head is noted at C and the tail at B. The polar jet stream can be located where cloud characteristics change from smooth to lumpy; these changes are noted by the arrows and the black line denotes the jet axis. The 500mb analysis, Figure 74, is included to show the flow pattern.

This rule locates the jet stream about 25° of the time.

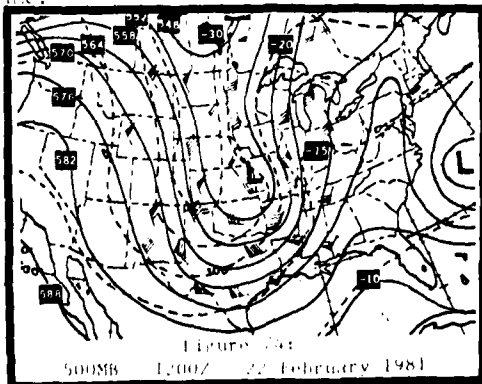


Figure 74:

500MB 1200Z 22 February 1981

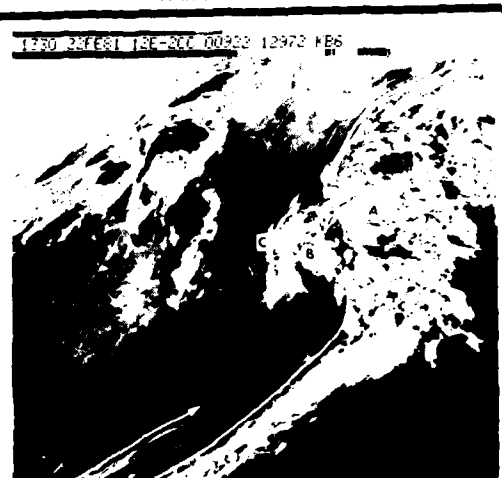


Figure 73: 1430Z 22 February 1981

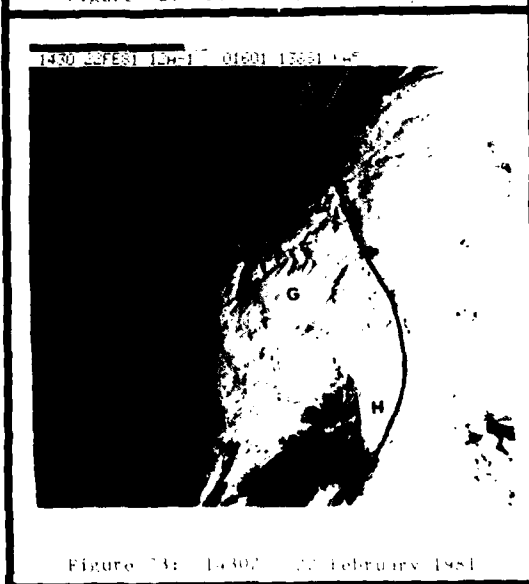


Figure 75: 1430Z 22 February 1981

Rule 2 - The second rule states that where baroclinic zone (irrus) is not present (rule 1), but other high or middle clouds are, cloud bands will be most advanced downstream where the jet axis crosses the point A in figure 76. The downstream borders, point B in figure 76, are usually well defined and form a U or V shape with the axis of maximum winds in or over the slot. This pattern is generally true of young short wave systems - especially when short waves are moving through a long wave zonal pattern or on the front side of a long wave ridge (figure 79).

This method locates the jet about 1/3 of the time.



Figure 76: 0545Z 29 January 1981

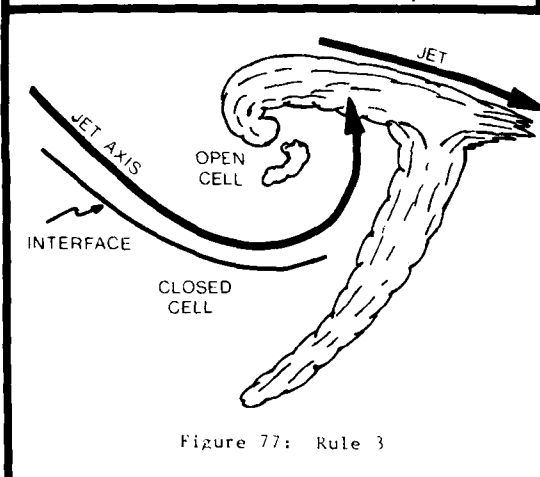


Figure 77: Rule 3

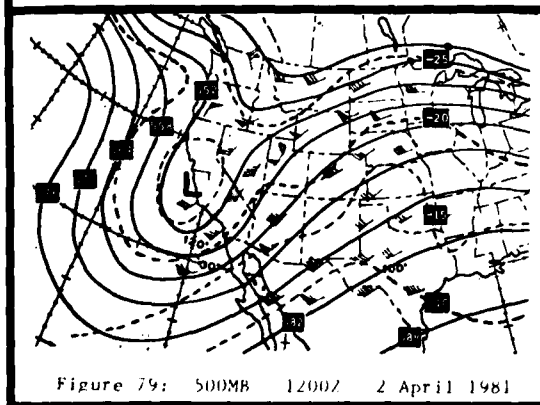


Figure 79: 500MB 1200Z 2 April 1981

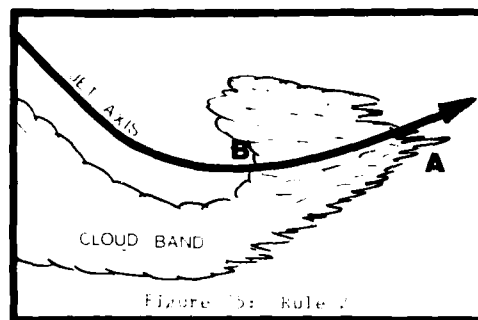


Figure 75: Rule 1

Rule 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 (Figure 77). These lower level boundaries are most commonly found over oceans where abundant low-level moisture exist (Figure 78). In the IR photo, Figure 78, a short wave comma cloud system appears over the southwestern U.S.; the 500mb analysis, Figure 79, reflects this short wave system. To the west of the comma cloud and to the north of the jet stream, a cluster of open cell cumulus is noted near point C. Further to the west, the open cell cumulus lines gradually change characteristics to closed cell stratocumulus lines as noted at H. The interface is marked by the dashed white line; the southern portion of the interface goes off the bottom of the photo. Normally, the jet stream can be located about one to three degrees north of the interface when the jet is aligned west to east as shown in Figure 77. In this particular example, however, the jet stream (aligned north to south) would be located one to three degrees to the left of the interface (looking downstream) as shown in Figure 78. (Note: In Figure 78, "P" marks the northern polar branch; "T" - the southern polar branch and "S" - the subtropical jet.)

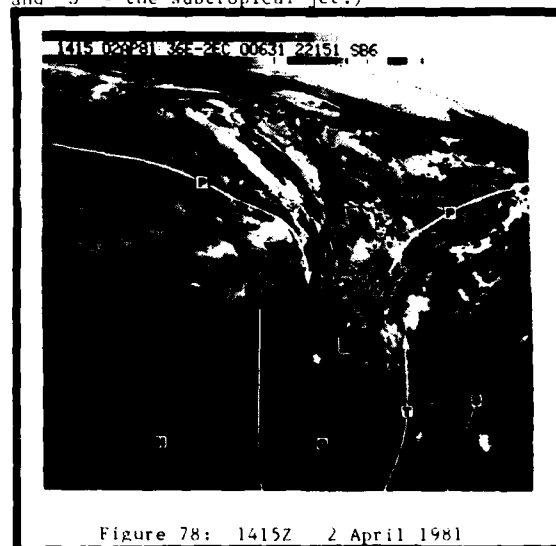


Figure 78: 1415Z 2 April 1981

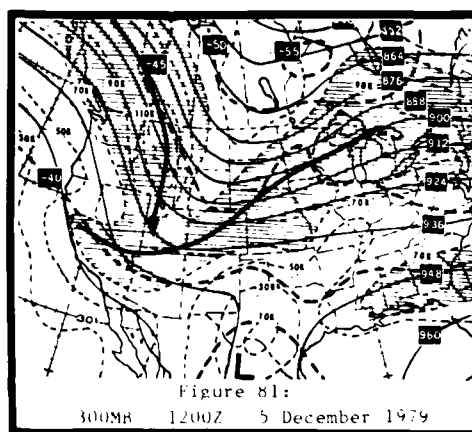
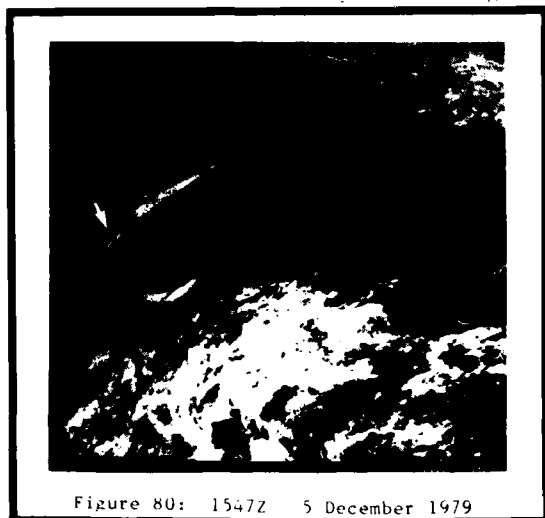
The jet stream/lower cloud interface just presented are most likely to occur when the jet stream is well defined, is channeled (vorticity isopleth parallel to the contours) and is vertically deep in the atmosphere. Over land during the day, stratocumulus clouds are likely to be south of the jet with clear conditions to the north.

This rule will help find the jet stream about 2/3 of the time.

Rule 4 - A combination of the three previous rules will add ten percent to the accuracy rate.

The four rules just presented should help forecasters locate jet streams about 75% to 85% of the time. The remaining 15% to 20% when the jet stream cannot be located on satellite photos may be attributed to a breakdown of the relationships and rules described earlier. Several other reasons why jet stream may be difficult to identify on satellite photos are:

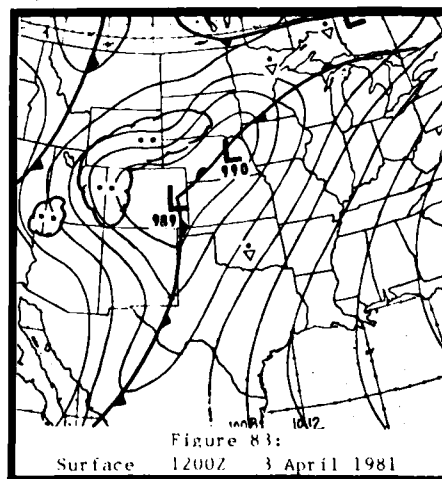
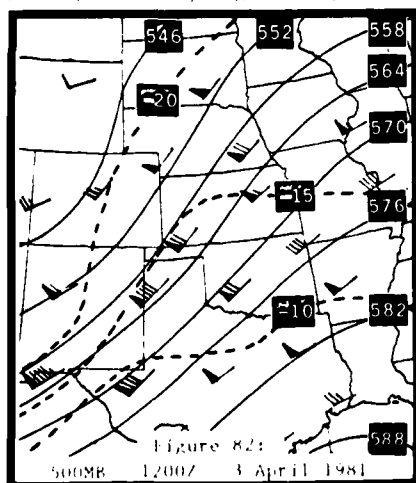
- There is a wide zone of strong winds, but the maximum winds are not concentrated in a narrow enough zone to be identified as a jet axis.
- The jet stream and its associated baroclinic zone isn't continuous between two segments. Often over a ridge, the air spreads and slows into a region with no well defined baroclinicity (and no strong winds).
- There is not enough middle and high level moisture present to produce clouds, even though the jet stream is strong and well defined.
- High level moisture is present with a well defined border along a channeled jet axis (winds parallel to contours flow), but clouds have not formed. In such cases, cirrus will often form sufficiently to the right side of the jet axis as it progresses downstream over a mountain range. A "lee-of-the-mountain" cirrus deck will form downstream from the mountain range and to the right of the jet axis as shown in Figure 80. In Figure 80, a cirrus band stretches southwest - northeast across the southern Rockies to the Great Lakes. The cirrus formation area begins over and to the east of the southern Rockies as noted by the arrow in Figure 80. The related 300mb analysis, Figure 81 (three hours earlier than Figure 80), shows the jet stream location; the cirrostratus layer lies along and to the right of the jet stream.



Other Jet Stream Identifiers:

Some other cloud characteristics which help in the identification and location of jet streams are cirrus streaks, transverse bands, the size and organization of cirrus anvils, and shadows. Cirrus streaks and transverse bands were introduced in Section 3, Part I (see Figures 57 through 59).

• **Transverse Bands** - Transverse bands are an excellent indicator of the jet speed maximum (and turbulence) within the jet axis. Transverse bands do not appear that often in satellite photos, but when they do, forecasters should be aware of their presence. Transverse banding within a southwest-northeast aligned jet stream system should be watched closely for possible cyclogenesis (near the jet maximum).



Figures 82 to 90 depict an example of transverse banding related to cyclogenesis and thunderstorm development. Figures 82 and 83 respectively show the 500-mb (model, not data not available) and surface analyses prior to development of this event. In Figure 82, a strong mid-level jet stream is evident across the Great Plains; 90 to 95 knots are shown over the Texas panhandle and eastern New Mexico. At the surface, Figure 83, a disorganized storm system is shown.

The first visible satellite picture of this series of photos, Figure 84, shows a zone of baroclinic cirrus across the central Great Plains and is noted by A. Transverse bands can be identified from central Kansas extending southwestward into the Texas panhandle. The polar jet (not shown) would be placed to the left of the baroclinic cirrus area (in the clear area) as exemplified in the model shown earlier in Figure 10. Area B, an area of conditionally unstable air reflected by developing cumulus, lies nearly under the jet maximum and to the northwest of the transverse banding. A stationary MP frontal system is shown across the northern plains.

One hour later, Figure 85, the transverse band's northern portion has moved northeastward into eastern Nebraska as noted by the arrows. Area B begins to develop rapidly and an anvil plume is noted within the cumulus cluster. Speed divergence aloft is primarily responsible for the explosive development shown at area B.

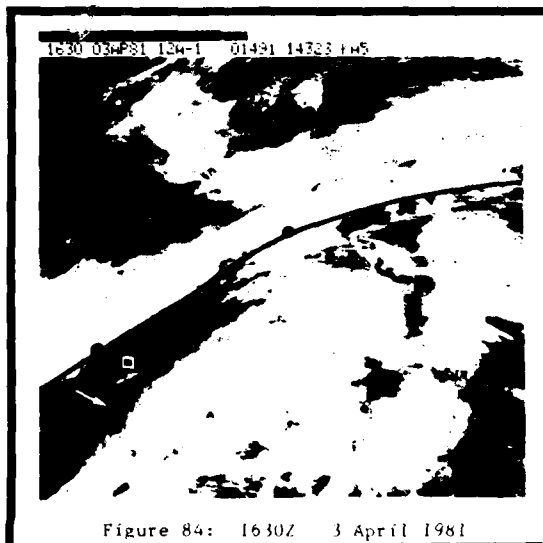


Figure 84: 1630Z 3 April 1981

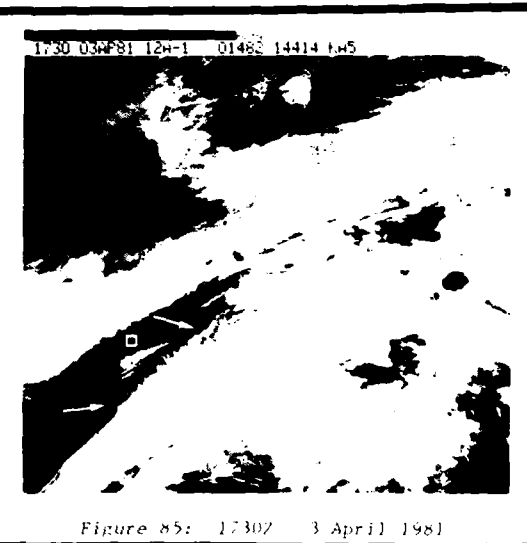


Figure 85: 1730Z 3 April 1981

Let's briefly review the association of transverse banding with thunderstorm development. Since transverse bands are associated with wind maxima, the area upwind from that maxima will undergo speed divergence as indicated in Figure 86. When the area of transverse band moves, the area of speed divergence moves with it. When this area passes over an area of instability, explosive convection can result (Figures 84 and 85, point B). During the winter, this same sequence can explosively develop a weak low level cyclone and result in heavy snowfall.

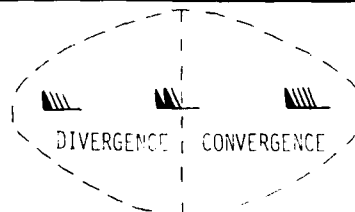


Figure 86:
Example - Speed Divergence/Convergence

About the only way to isolate this area of divergence and track its movement, is with GOES data. After identifying the jet max and determining the speed and direction of movement, forecast a trajectory, and determine if and when the divergent area will pass over any existing low-level disturbances.

Now, let's return to the satellite series. In Figure 87, one hour later, the transverse band area, noted by the arrows, is difficult to see because it has moved into the cirrus shield; it is still moving northeastward and is faintly visible in central Iowa. Area B continues to develop.



Figure 87: 1830Z 3 April 1981

transverse banding is now more noticeable in Figure 88 (two hours later than Figure 87). The jet stream has now moved into Iowa, where it has expanded considerably, and appears to have taken on a comma shape (appearing as a hole). The upper-level jet stream analyses were not available for this event (perhaps a small-scale vorticity center existed).

Finally, in Figure 89, transverse banding is still quite clear (eastern Iowa). The deep convection area and its associated anvil plumes has spread northwestward into central Minnesota. Cyclonic rotation within the stratiform cloud system over the upper Midwest is just becoming noticeable.



Figure 88: 2030Z 3 April 1981



Figure 89: 2100Z 3 April 1981

Figure 90 depicts the surface pattern at 1200Z the following day. An organized storm system, centered in Wisconsin, has evolved. The system's track and its previous 6 and 12 hour centers are respectively shown by the arrows and Xs. The storm moved across eastern Nebraska and Iowa and deepened; undoubtedly triggered by the wind maximum discussed in Figures 87 through 89.

• Anvil Tops - The absence of jet stream cirrus on morning photos may change quickly when afternoon convection, which forms east of the jet stream, develops a series of spreading anvil tops. In Figure 91, young anvil plumes are organizing along a frontal boundary (and east of the upper level jet) of an upper Midwest cyclone. The baroclinic zone, east of the developing thunderstorm line, is cirrus-free; normally this would be the area covered with baroclinic zone cirrus. Perhaps the anvil plumes are quickly spread and fill in the void.

• Shadows - Shadows help define jet stream axes as shown over the eastern U.S. in Figure 92 and across the Gulf of Mexico in Figure 93.

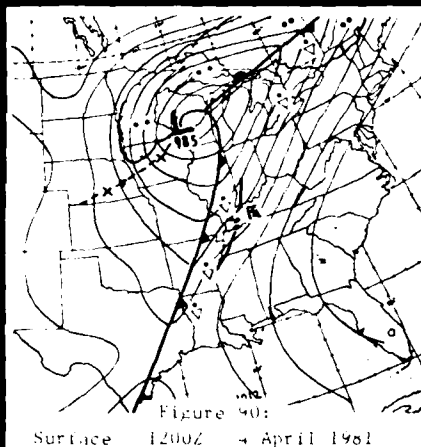


Figure 90:
Surface 1200Z 4 April 1981

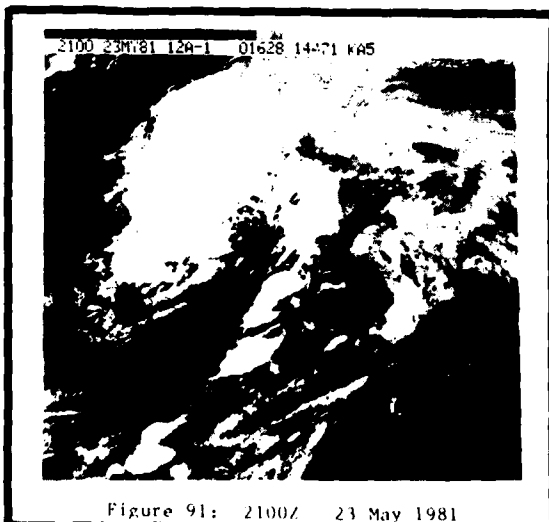


Figure 91: 2100Z 23 May 1981

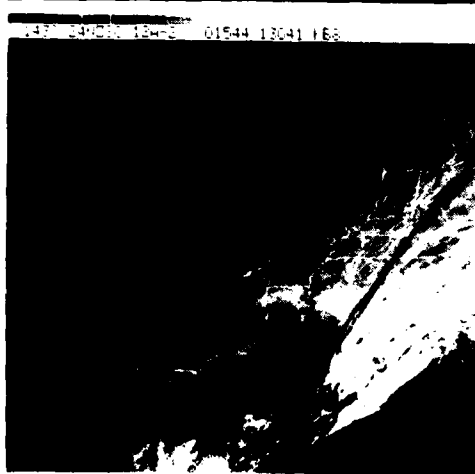


Figure 92: 1430Z 24 November 1980

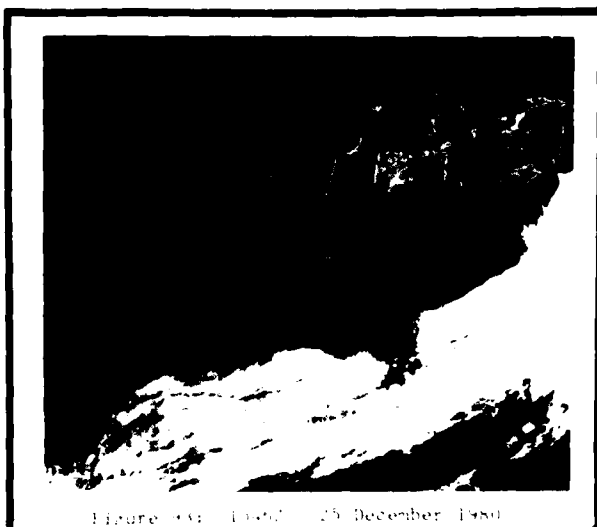


Figure 8a: 1200Z 25 December 1980

Jet Stream Systems:

• **Polar Jet** - The driving force within the westerlies in the development of cyclogenesis is the polar jet stream. During autumn the polar jet shifts southward, and by mid-winter, lies across the southern U.S., as shown in Figure 9a. As mentioned earlier in this section, several polar jet stream systems or branches may appear simultaneously on upper analyses (see Figure 7a). The southern jet stream generally has more extensive baroclinic zones and barostates and barometers than the northern jet stream system.

Figure 8b depicts another common event where several polar jet streams appear on analyses, with a deepening upper trough (increasing amplitude) initial cyclogenesis and extensive baroclinic zone cloudiness are associated with the southern jet. The northern jet becomes aligned north-south within the colder northwesterly flow on the trough's backside and advects in the necessary cold air, and perhaps secondary short waves, to enhance cyclogenesis as shown in Figure 9c.

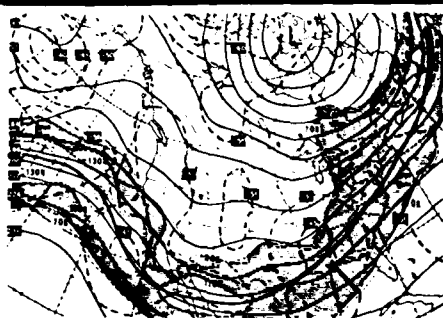


Figure 9a: 200MB 1200Z 17 January 1975

Note: These jet stream systems may split into smaller branches especially with split flow short wave systems.

• **Subtropical Jet** - The subtropical jet is the dominant jet stream system across the southern and central U.S. during summer. During the cold season it migrates southward into Mexico as the polar jet becomes the prevailing jet stream system. During winter the subtropical jet may briefly drift northward across the southern plains and Gulf coastal states ahead of low latitude short wave systems moving across Arizona and New Mexico (see Figures 9b and 9c).

During the transitional period of spring, the location of the subtropical jet becomes important in severe weather forecasting. The subtropical jet axis delineates the farthest southern extent of organized severe thunderstorms (large hail and thunderstorms) in a given severe weather outbreak (2).

• Jet Stream Identification - An Example

Figure 9b illustrates the jet stream pattern ahead of an intensifying short wave off lower California (not shown). The polar jet's southern branch is shown at A; the northern branch is noted at B. A split in the northern branch is identified at C. (Note: smaller splits within branches of the polar jet are important to severe weather forecasting. See discussion in Section 8, Part II). The jet stream shown over Florida is the tail end of a short wave offshore. The subtropical jet (D) is not as noticeable because of its close proximity to the southern branch polar jet. On Day 2, Figure 9c, the southern branch (A) has shifted northward and merged with the split jet of the northern branch (C in Figure 9b). The subtropical jet is now noticeable over southern Texas (D).

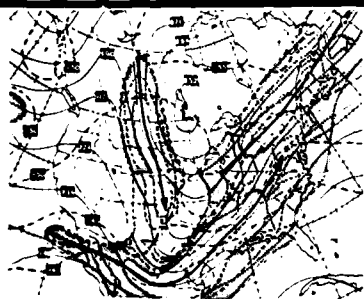


Figure 9b: 300MB 1200Z 25 January 1975

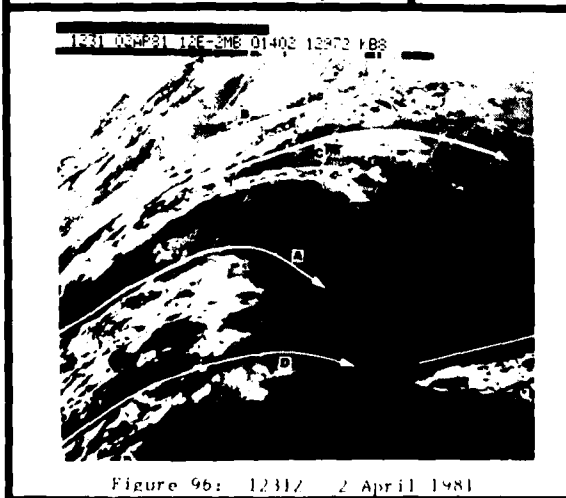


Figure 9b: 1231Z 2 April 1981

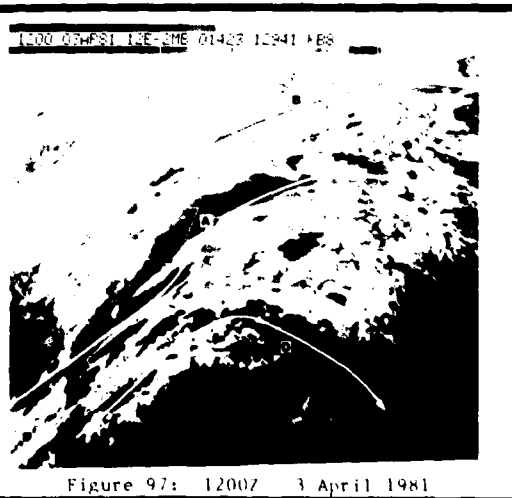


Figure 9c: 1200Z 3 April 1981

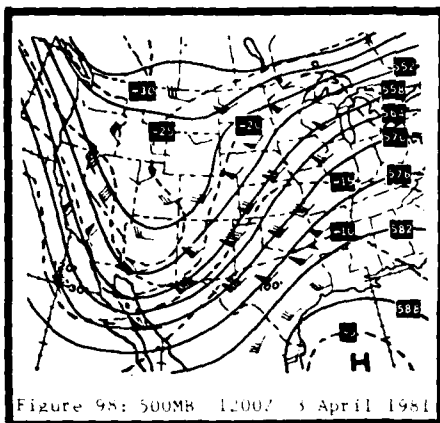


Figure 98 depicts the related 500mb analysis; a subtropical anticyclone appears in the Gulf of Mexico.

Non-Jet Stream Cloud Systems:

There are many cloud patterns which look as though they are associated with jet streams but actually have no association with each other. Some of these cloud patterns include deformation zone cirrus. Deformation zone cirrus shields usually form on the northern and west side of an occluded comma system (Figure 99). Deformation zone cirrus is associated with light winds within an upper air col; this col area is shown within the area marked by the location D in Figure 99.

Figure 100, an IR, illustrates a band of deformation zone cirrus (F) across eastern Iowa and northern Missouri, associated with an upper Midwest storm system. The cloud system at G is related to the upper tropospheric baroclinic zone and associated jet stream (PVA area). Note in the figure how the two higher level cloud systems narrow over southern Wisconsin (indicated by the arrow); this is the col area of the storm system.

Further discussion of deformation zone cirrus will be presented in Section 7, Part II.

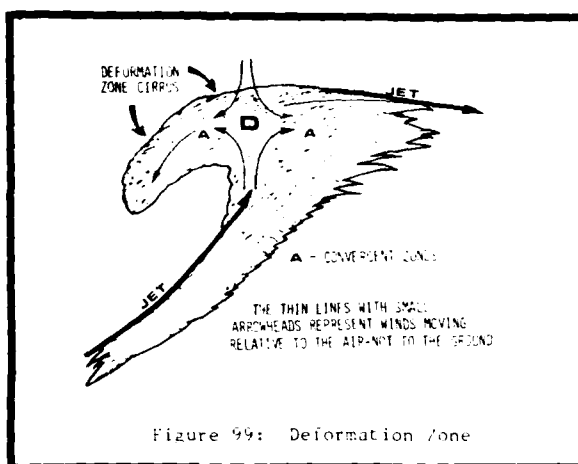


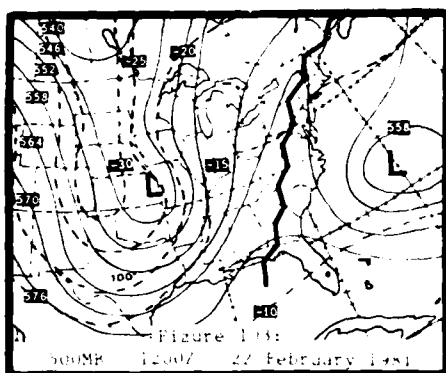
Figure 99: Deformation Zone

SECTION 1: Locating Upper Level Ridges and Troughs

Ridges:

Upper ridges in mid-latitudes can best be located by analyzing the cloud pattern. The width of the cloud pattern, its orientation and the character of the leading edge can be used to determine the amplitude or sharpness of the ridge. Cloud ridges can be categorized into three main groups consisting of sharp, blocking and

• **Sharp Ridges** - A sharp ridge has a narrow cloud band, a north to south orientation and the cloud system has a sharp leading edge (little, if any, spillover of clouds over the ridgeline; Figure 103). Sharp ridges will be relatively narrow due to the close spacing of the trough and ridge which results in a narrow area of upward vertical motion. Consequently, the leading edge of the cloud band will end abruptly at the ridgeline due to the rapid change from upward to downward motion. A sharp ridgeline pattern is shown in Figure 103; the related IR photo, Figure 104, shows the forward edge of the cloud system ending at the ridgeline.



Another sharp ridgeline pattern is shown in Figure 105; this pattern is associated with blocking systems. This pattern occurs more often over the eastern Pacific during the winter months when a major ridge builds and persists along or off the west coast of North America and northward into Alaska. Figures 106 and 107 illustrate this event. Trough systems approaching from the west decelerate as they approach the blocking ridgeline. The cloud system becomes stationary and may linger for several days or longer until the blocking ridge flattens or shifts to another area. In these patterns, short waves either move northward west of the ridge towards Alaska or move southeastward towards California (eventually eroding the southern portion of the blocking ridge.) Sharp ridgelines are generally associated with slow-moving meridional trough/ridge systems.

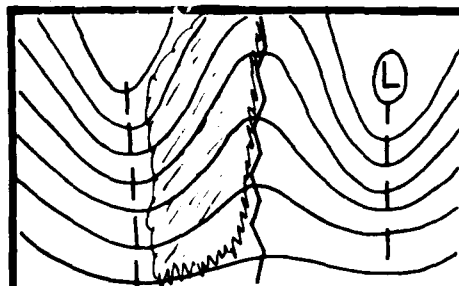
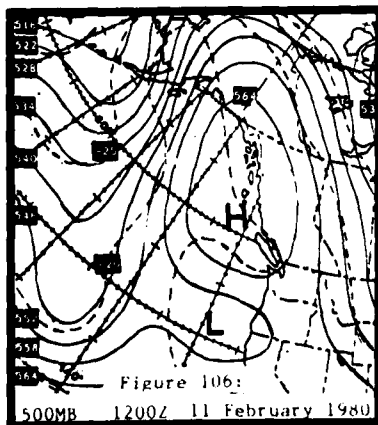


Figure 104: Sharp Ridgeline Pattern

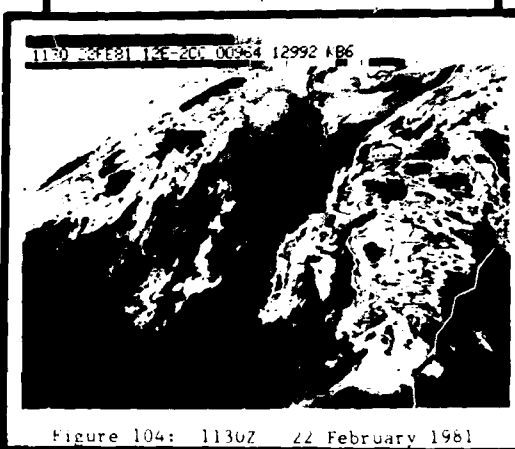


Figure 105: 1130Z 22 February 1981

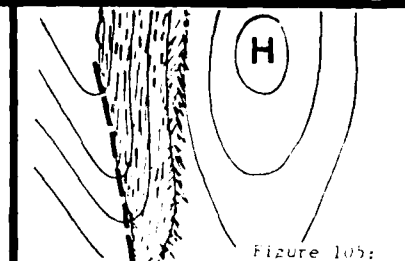


Figure 106: Sharp Ridgeline - Blocking Pattern

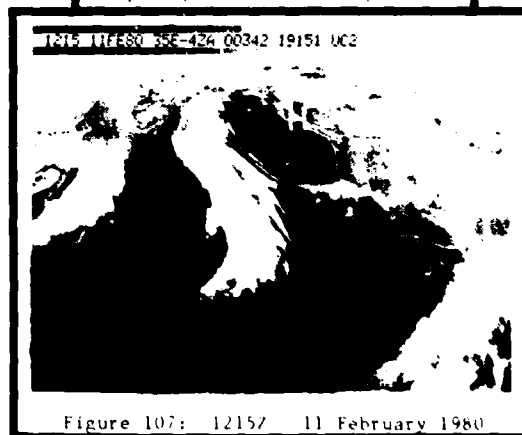


Figure 107: 1215Z 11 February 1980

• The first of the two main types of the above mentioned is the "normal" type, which is characterized by a relatively small number of small, isolated, and often irregularly shaped islands. The second type is the "atoll" type, which is characterized by a large number of small, isolated, and often irregularly shaped islands. The "normal" type is more common in the Pacific Ocean, while the "atoll" type is more common in the Indian Ocean. The "normal" type is characterized by a relatively small number of small, isolated, and often irregularly shaped islands. The "atoll" type is characterized by a large number of small, isolated, and often irregularly shaped islands. The "normal" type is more common in the Pacific Ocean, while the "atoll" type is more common in the Indian Ocean.

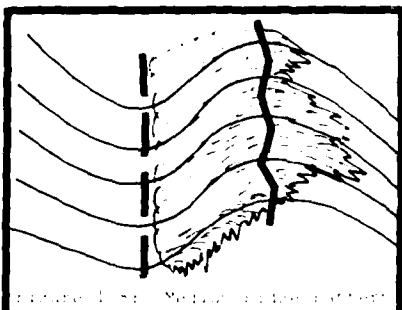
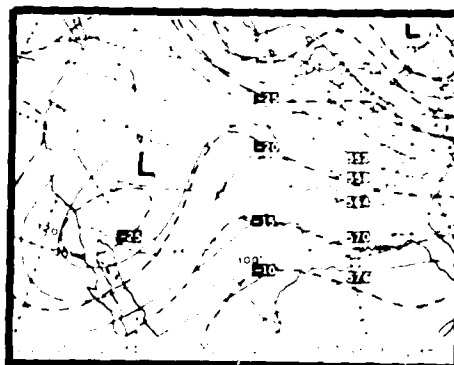


Figure 110: Schematic diagram of a geological structure.



• The second of the two main types of the above mentioned is the "atoll" type, which is characterized by a large number of small, isolated, and often irregularly shaped islands. The "atoll" type is more common in the Indian Ocean. The "atoll" type is characterized by a large number of small, isolated, and often irregularly shaped islands. The "atoll" type is more common in the Indian Ocean. The "atoll" type is characterized by a large number of small, isolated, and often irregularly shaped islands. The "atoll" type is more common in the Indian Ocean.

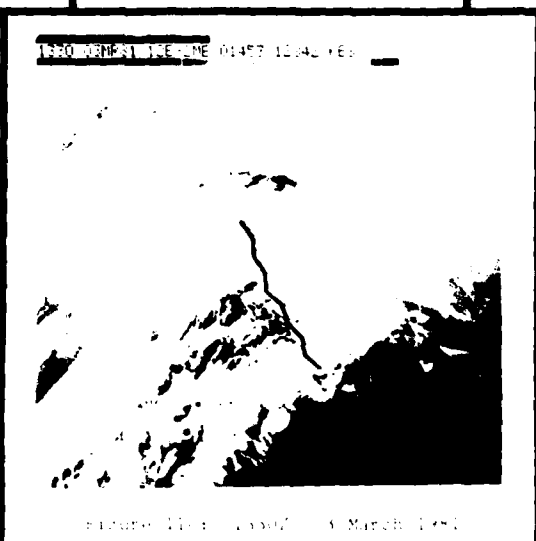


Figure 112: Photograph of a dark, irregularly shaped object.

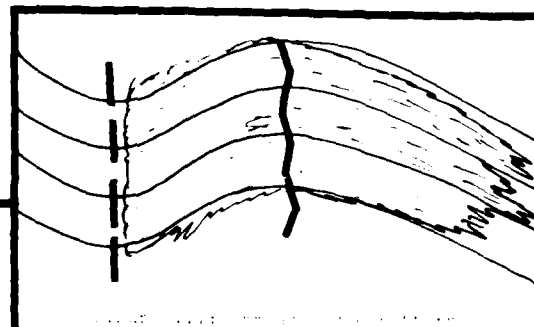


Figure 113: Schematic diagram of a geological structure.

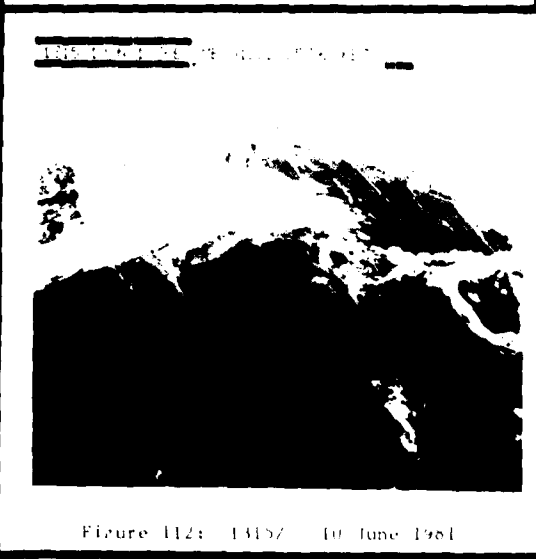


Figure 114: Photograph of a dark, irregularly shaped object.

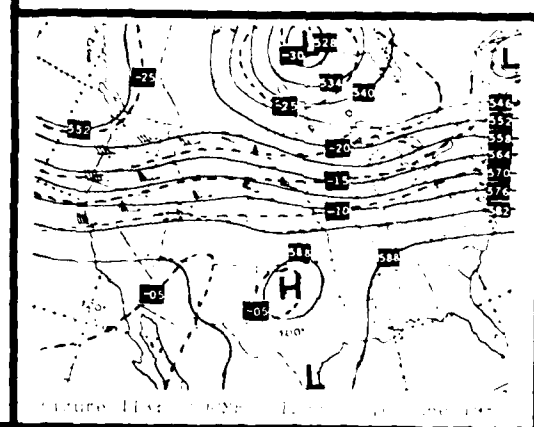
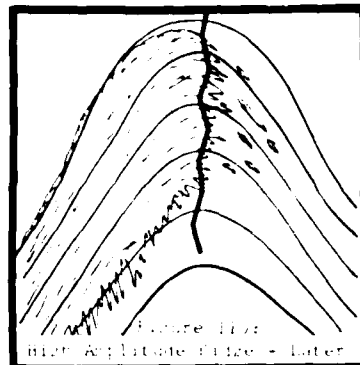
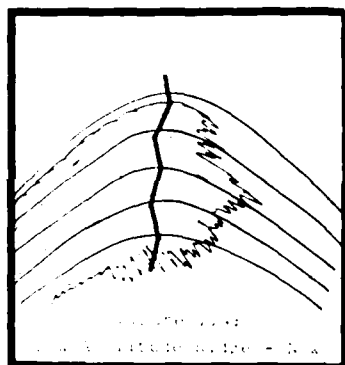


Figure 115: Map showing a network of dashed lines representing a geological or hydrological structure.

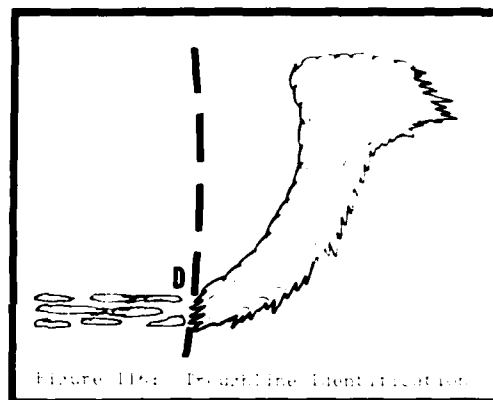
Figure 110 shows the most common cloud pattern that can be observed in a low-level cloud system. The pattern is a series of alternating ridges and troughs in the cloudiness. The ridges are composed of upper level clouds, and the troughs are composed of lower level clouds. Figure 111 illustrates a model for a low-level cloud system with clouds spilling over the ridge line. Figure 112 illustrates a model for a high-level cloud system with clouds spilling over the ridge line. Forecasters can follow continuity of the ridge and troughs to determine if a low is intensifying or if it is beginning to break down a frontal wave pattern. If continuity of the ridge and trough sequence is such that it indicates a frontal wave pattern (see Figure 113), the trend is as depicted and the ridge and trough sequence will be true if the trend is continuing.



Troughs:

The change in the sign of the vertical motion and wind directions at the troughline is reflected on satellite pictures by differing cloud patterns. Three of the most common cloud patterns used to identify the location of mid and upper troughs are: breaks in frontal bands, enhanced cumulus clouds, and comma-shaped clouds. These three patterns and combinations thereof should aid forecasters in locating most trough systems.

• **Frontal Cloud Bands** - The mid tropospheric troughline can frequently be located where a frontal band and trough intersect as shown at point D in Figure 114. At this point of intersection, the frontal clouds will lessen, become fragmented or disappear where the mid level vertical motion changes from upward to downward at the troughline. Figures 115 and 116 illustrate cloud pattern changes (points D) where troughlines intersect frontal bands. East of the troughlines and along the active bands, cloud tops reach into the mid and upper levels reflecting upper vertical motion (and precipitation). West of these troughlines, frontal bands become inactive, change cloud character and decrease in coverage; the clouds are primarily low clouds reflecting mid and upper level downward vertical motion (little, if any, precipitation).



• Enhanced Cumulus - Areas of positive vorticity advection are reflected in the appearance of cellular clouds to the rear of cold fronts. The upward motion produces areas of enhanced cumulus. These areas are observed frequently over oceanic areas (and less over land) where there is an abundance of lower level moisture. In Figure 119, an area of enhanced cumulus is noted by the arrow along and to the east of the troughline. The 500mb analysis, Figure 120, (five hours earlier from Figure 119) shows the troughline west of California.



Figure 119: 1115Z 2 April 1981

Continued vertical development of enhanced cumulus areas (associated with PVA) eventually will form small comma-shaped cloud systems. The anvil plumes reach into the mid and upper levels and form comma-shaped cloud systems. This is more likely to occur over land areas during the warm season; Figures 121 through 123 depict such an event over land. In Figure 121, an area of enhanced cumulus appears over most of Mississippi and is noted as area G. The troughline associated with this short wave system is also shown and is placed to the left of the enhanced cumulus area. Further to the east over Alabama, a comma-shaped cloud system (area H) has developed from enhanced cumulus. The related IR photo, Figure 122, shows the vorticity comma cloud system very well (see arrow). The related 500mb analysis (Figure 123; seven hours earlier) shows the short wave trough system.

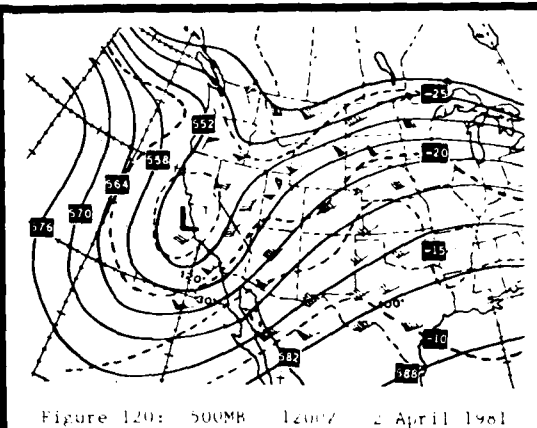


Figure 120: 500MB 1200Z 2 April 1981

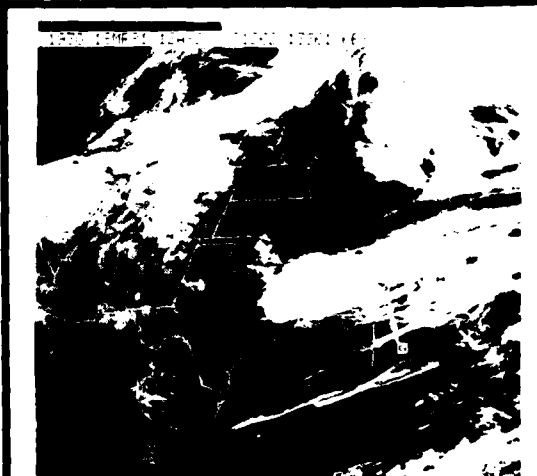


Figure 121: 1930Z 18 March 1981

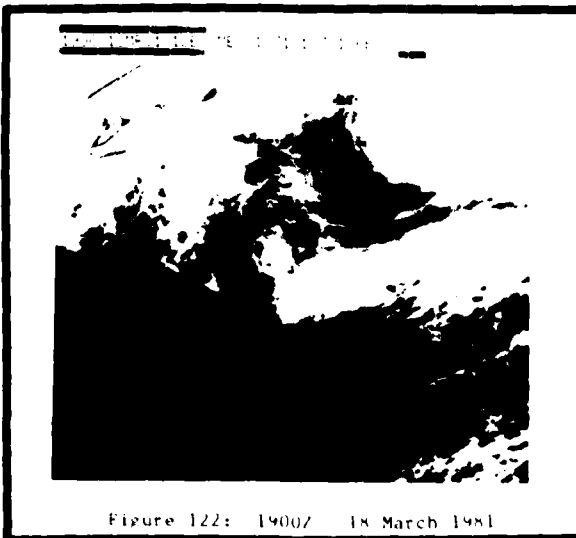


Figure 122: 1900Z 18 March 1981

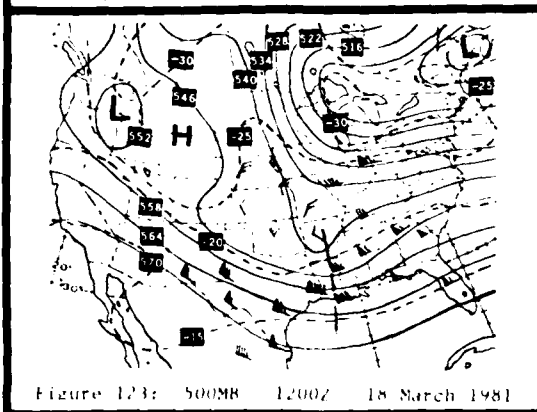


Figure 123: 500MB 1200Z 18 March 1981

Enhanced cumulus areas located well to the rear of a short wave comma cloud system often reflects either the major trough's position or the presence of a new vorticity center within the cold air of the trough system. An example is shown in Figures 124 and 125. In Figure 124, a short wave comma cloud system is shown over the eastern U.S. The trough and frontal band stretches southwestward across southern Georgia and into the Gulf of Mexico. The band becomes fragmented at point F reflecting a change from upward to downward vertical motion in the middle to high levels. The short wave's troughline can be placed at point F, however, when looking at the 500mb analysis shown in Figure 125, forecasters would be hard pressed to locate the troughline. The main troughline and cold air is located farther to the west across the central and southern plains as revealed in Figure 125. In Figure 124, the enhanced cumulus area noted at location G over the central Great Plains has developed within the cold air pocket of the major troughline. Forecasters should be alerted, especially during spring (winter), for possible cold air thunderstorms (snow showers) developing in these enhanced cumulus areas.

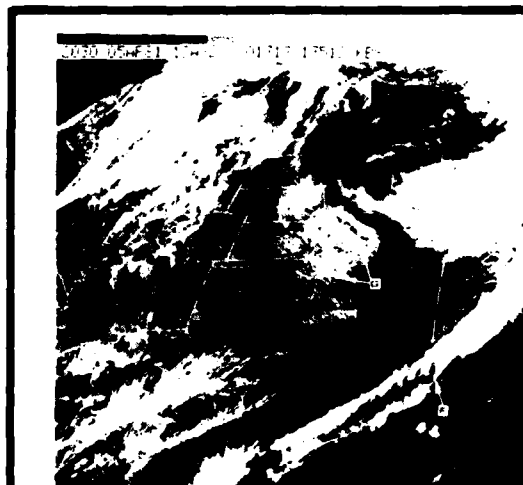


Figure 124: 2030Z 5 April 1981

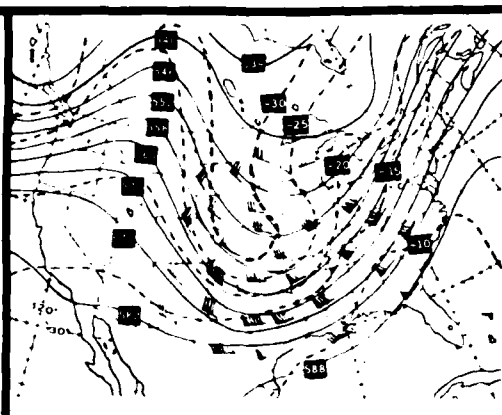


Figure 125: 500mb

April 1981

• Other Comma-Shaped Cloud Systems - In the preceding discussion it was shown that vorticity comma cloud systems often develop within enhanced cumulus areas. Mid tropospheric level troughlines can also be located using other vorticity comma shape cloud patterns. Over land areas during the cold season, many vorticity comma cloud patterns to the rear of major cyclones are mid-level features and appear to be stratiform in satellite pictures. These systems, however, are often highly convective, but they generally do not produce anvil plumes. Figures 126 and 127 depict two such events.

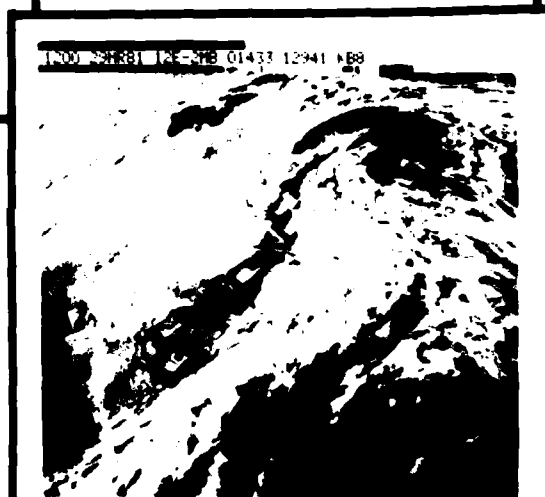


Figure 126: 1200Z 29 March 1981

In Figure 126 (500mb; 1200Z wind data has been added), a vorticity comma cloud system is noted at location B, and it is located to the rear of the larger comma system. The troughline can be placed to the rear of the comma cloud at location B and also to the rear of the small mid-level cloud system over southern New Mexico. The IR temperature scale indicates that the vorticity comma is primarily composed of mid-level clouds.

A second example is shown in Figure 127. The vorticity comma head is noted at B; the comma tail extends southeastward across southeastern Missouri. A negative-tilt (oriented northwest-southeast) short wave trough can be placed to the rear of the comma cloud. The related bomb analysis, Figure 128, shows the minor short wave within the flow of the long wave trough system. Negative-tilted short wave systems such as shown in Figure 128 are often dynamic systems and produce strong cyclones.

The tail end of the short wave troughline in Figure 127 is placed at the bend in the frontal cloud band noted at point E. This bend reflects the area of maximum cyclonic curvature around the inflection point shown at point E. Returning to Figure 126, a jet maximum axis of 8 knots across northeastern Texas into central Arkansas can be seen; this jet maximum is pushing northward and is reflected by the bend in the cloud frontal band.

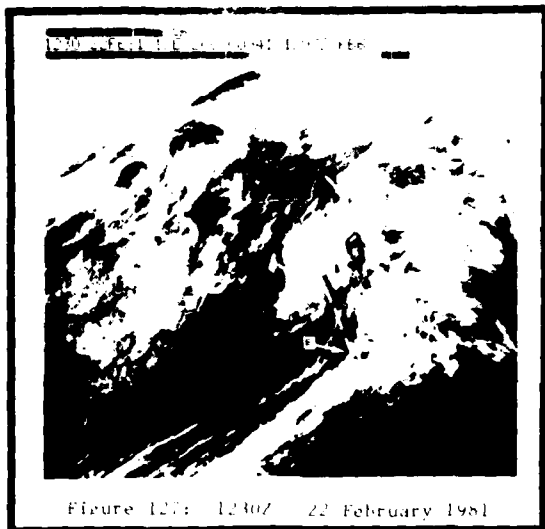


Figure 127: 1200Z 22 February 1981

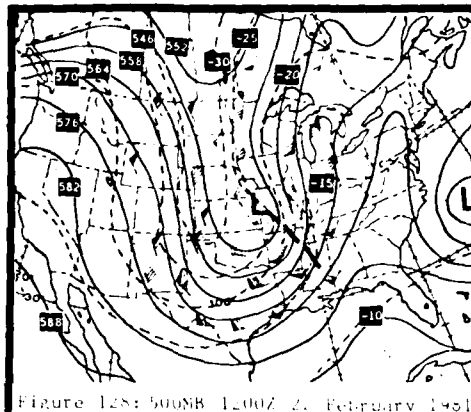


Figure 128: 500MB 1200Z 22 February 1981

* Cirrus Streaks - Forecasters should evaluate all cloud systems for hints in determining troughline positioning. Cirrus streaks may be helpful; this is shown in Figure 129. In Figure 129, a west to east cirrus streak is noted across the Gulf of Mexico. A bend in the streak is shown at point T; this bend reflects maximum cyclonic curvature. Three features in Figure 129 (two have been presented earlier) can identify the general location of the troughline. First, the troughline lies west of the vorticity comma cloud noted at S (hard to see). Secondly, the troughline can be placed in the cyclonic curvature of the cirrus streak. Finally, the cloud frontal band terminates at point U reflecting a change in mid and upper level vertical motion.

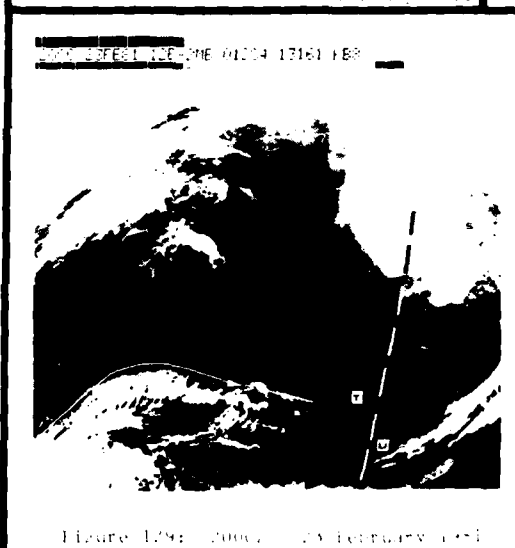


Figure 129: 2000Z 23 February 1981

Northeast-Southwest Aligned Troughs:

The situations described earlier in troughline identification primarily exist with troughs oriented north to south. There are those occasions, however, when troughs become oriented northeast to southwest (positive tilt) as do the cloud patterns accompanying them. In these cases, the upper level trough does not actually intersect the frontal cloud band so the strong change in cloud character is not evident. Figure 130 is an example of such a system. In these cases, clouds to the northwest are suppressed due to downward vertical motion, but convection, overrunning and low-level convergence team up to produce clouds on the right side of the troughline. In Figure 130, the chance for frontal wave development increases in area D where the cloud frontal band lies parallel to the trough axis. Examples of this type of trough orientation are illustrated in Figures 131 through 134.

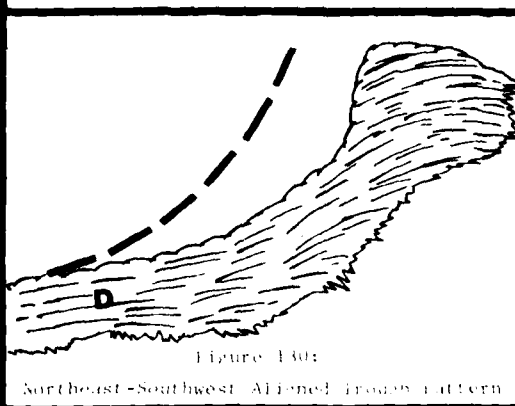


Figure 130:

Northeast-Southwest Aligned Trough Pattern

• Example 1 - In Figure 131, the 500mb analysis shows a short wave system moving across the central and upper Midwest. A closed low appears over Mexico. The short wave trough's southern location across Texas is becoming oriented northeast to southwest. In the related visible satellite photo, Figure 132, a cirroform layer is evident across the southern plains (point G) and is spreading northeastward up the frontal cloud band. The cirrus layer is a result of convection which developed a cross central Texas ahead of the closed low.

• Example 2 - During the warm season, thunder storm activity often breaks out (especially at night) along and to the right of upper troughlines oriented northeast to southwest. The 500mb analysis, Figure 133, reveals a trough system oriented northeast to southwest across the southern plains. In Figure 134, widespread cloudiness with some thunderstorm activity is clearly evident across Texas and Mexico.

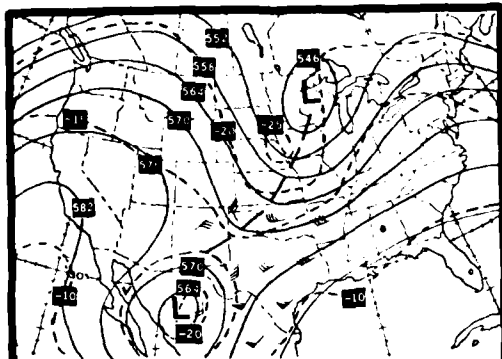


Figure 131: 500MB 1200Z 23 April 1981



Figure 132: 1400Z 23 April 1981

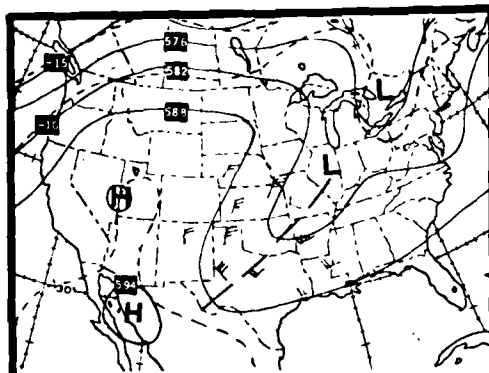


Figure 133: 500MB 1200Z 5 July 1981

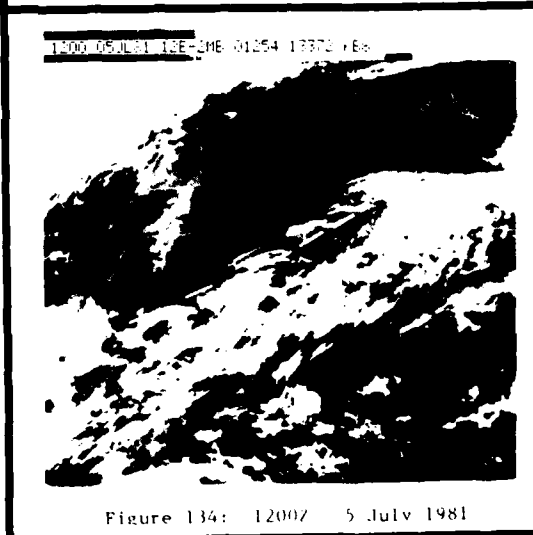


Figure 134: 1200Z 5 July 1981

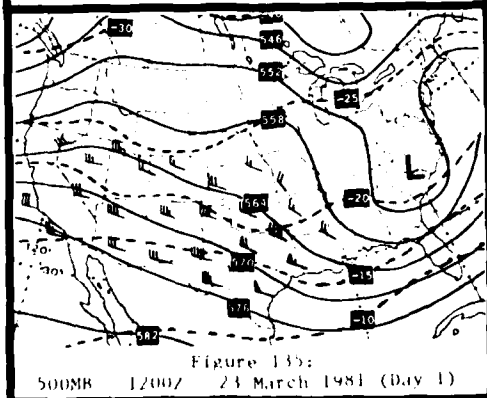
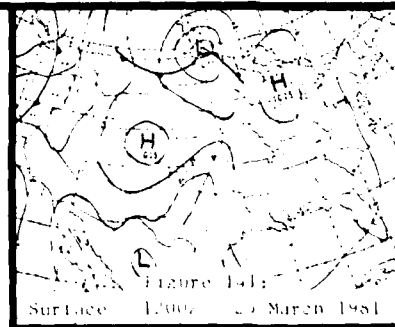
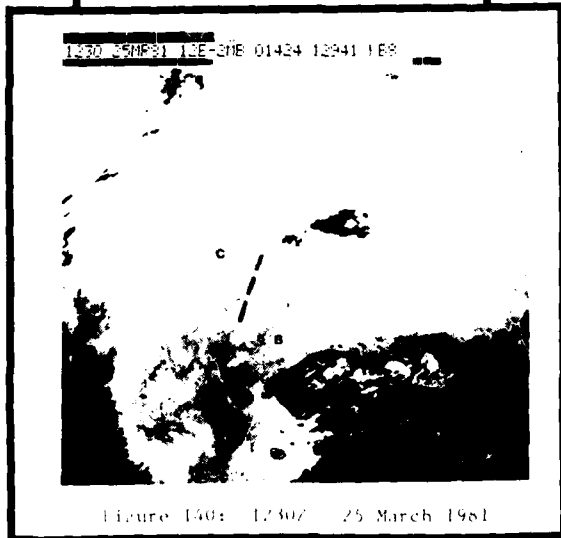
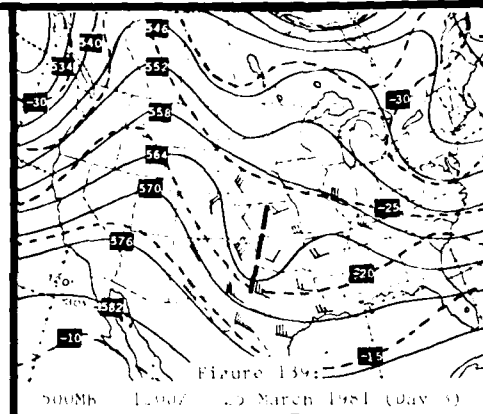
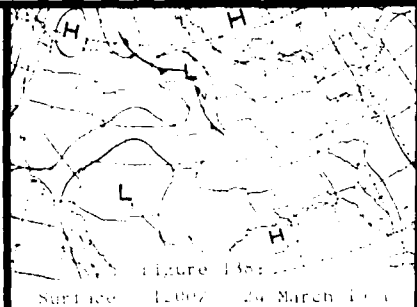
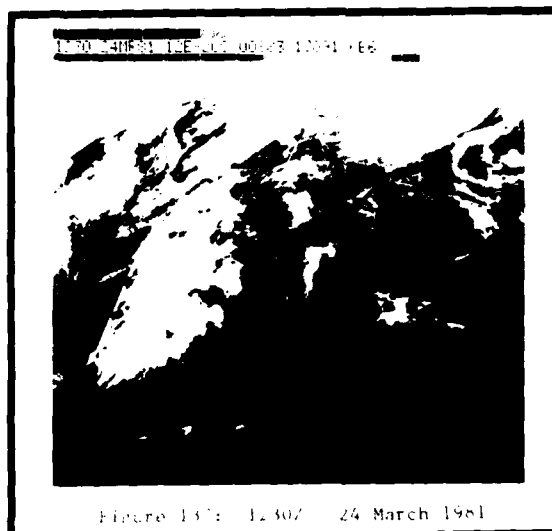
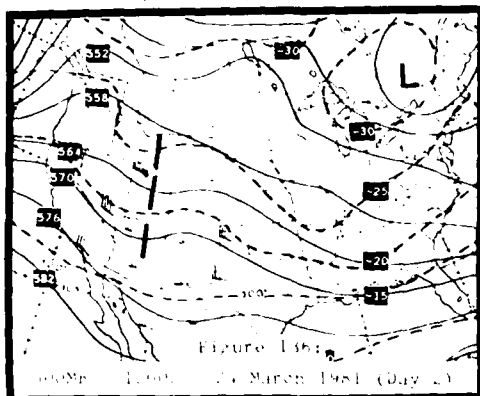


Figure 135:
500MB 1200Z 23 March 1981 (Day 1)

Trough Deepening:

The following example depicts trough deepening within an east to west upper level west of the Rocky Mountains. On Day 1, Figure 135, a west to east 500mb flow prevails over the western U.S. No significant trough system is approaching the West Coast. Some slight thermal troughing is noted over the Rockies.

On Day 2, Figure 136, a trough is evident across Utah and Arizona. The related satellite photo, Figure 137, identifies the trough system very well. During this early stage of development, the troughline can be placed immediately behind the cloud system as indicated in Figure 137. The surface pattern is shown in Figure 138; no surface frontal system appears in the area of the deepening upper trough.



By Day 3, Figure 139, the trough has continued to deepen and has moved out of the Rocky Mountains. A jet maximum (60 knots) appears at the base of the trough. In the satellite photo, Figure 140, some cyclonic organization is beginning to take shape. The vorticity cloud system is noted at location B, but it has not yet assumed a comma-shape appearance. The troughline lies just west of the vorticity cloud system as shown in Figure 140. A narrow band of deformation zone clouds is noted at location C which may give a hint that a low could subsequently develop within the base of the trough over Oklahoma.

The surface analysis, Figure 141, depicts an inverted trough pattern across the central and southern plains - a reflection of the deepening upper trough. This example typifies those situations when cold fronts suddenly develop east of the Rocky Mountains. In addition, explosive cyclogenesis can occur in the northern portion of the inverted trough below the upper level trough system.

SECTION 3: Significant Mid and Upper Level Cloud Systems

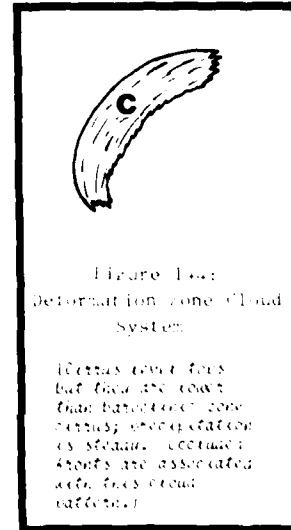
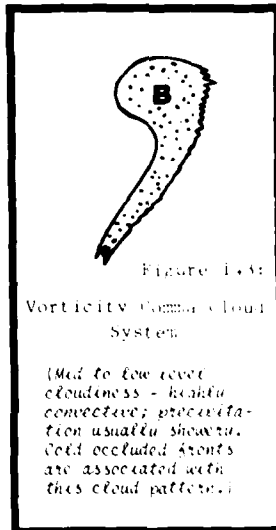
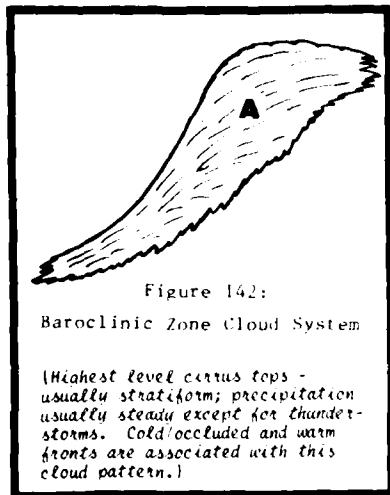
The purpose of this section is to give the reader an overview of certain mid and upper level cloud systems which appear on satellite pictures and are significant to storm development. The next four sections of this part of the Technical Note (TN) and Part III, Patterns of Cyclogenesis, will discuss these cloud systems in detail. Additionally, terminology such as advection and channel jets and vorticity lobes, which are being used in satellite interpretation messages and satellite literature, will be presented. Forecasters should have an understanding of what these terms represent.

Cloud Systems of a Developing Storm:

The three primary cloud systems which comprise a synoptic comma cloud system within the westerlies are as shown in Figures 142 through 144. They are:

- Baroclinic Zone (A; Figure 142)
- Vorticity Comma Cloud (B; Figure 143)
- Deformation Zone (C; Figure 144)

The letter shown in parenthesis behind each cloud system above will be used throughout this TN to identify these particular cloud systems (after Weldon, 1975).



These three cloud systems have been placed in their respective positions in the model of a mature comma cloud system shown in Figure 145. It will be shown later in Part III that cyclogenesis occurs in different ways, and that the primary consideration for identification of different types of cyclogenesis is the order in which these cloud systems develop. In Figure 145, the primary vorticity comma cloud (B) is often hidden below the higher level cirrus layers and cannot be observed on satellite photos. In the visible photo, Figure 146, however, the higher level baroclinic cloud shield (A) has moved faster than the mid-level vorticity comma cloud (B), consequently, the vorticity comma can be seen. Area C identifies the related deformation zone cloud band.

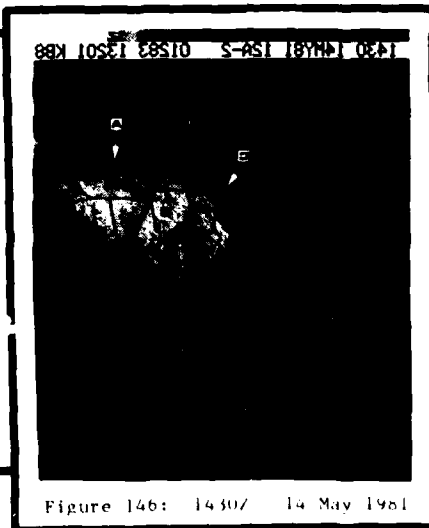
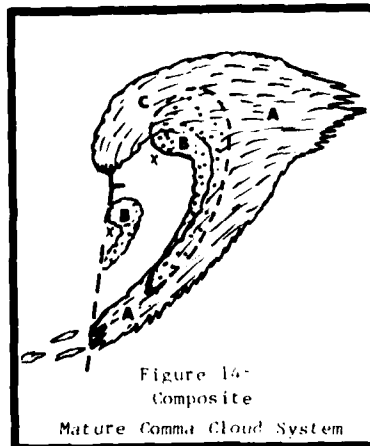


Figure 13 illustrates these three cloud systems within a disorganized storm system over the western Pacific. Area A identifies a large, south to north baroclinic zone cloud system. A well developed vorticity comma cloud (with cirrus plumes from deep convection) is noted in area B. The comma cloud most likely developed from the enhanced cumulus area located south of area B. Area C indicates a band of deformation zone cloudiness.

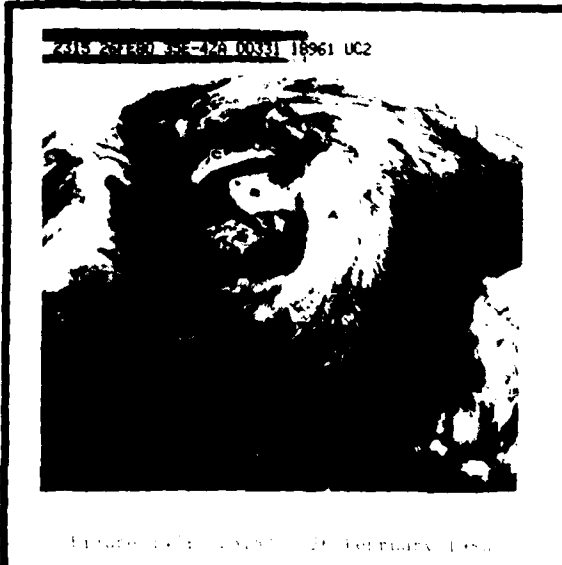


Figure 13a: 18961 UC2 20 February 1964

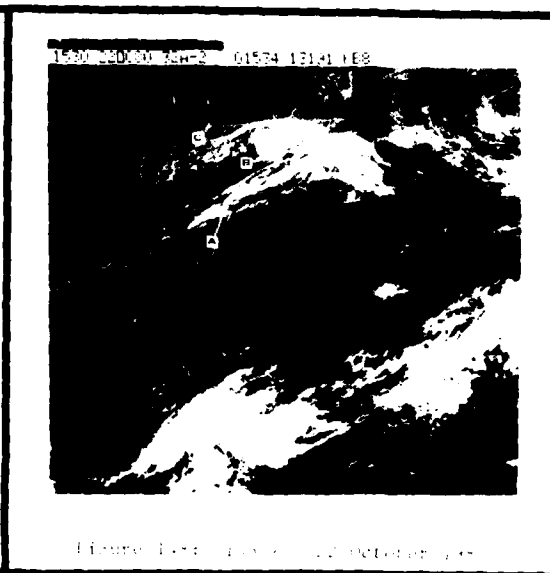


Figure 13b: 01574 HE8 22 October 1964

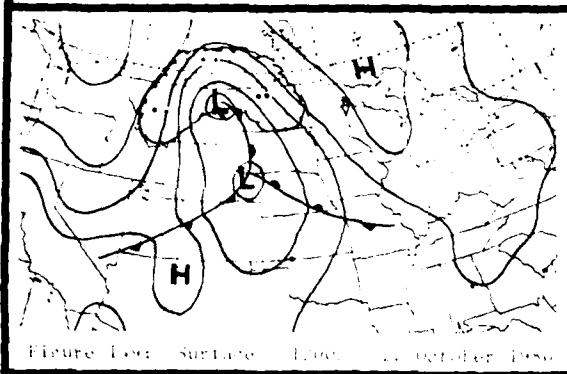


Figure 14a: Surface Map 22 October 1964

A third example is shown in Figure 14b across the northern Rockies and Northern Great Plains. In the visible photo, the baroclinic cloud shield and band (A) is well defined from the Colorado Rockies to Minnesota. Part of the vorticity comma cloud (lower cloud layer and convective) is noted at B; the rest of the comma cloud is hidden under the baroclinic zone cirrus layer. Deformation zone clouds can be seen in area C. The related surface analysis, Figure 14a, shows the storm system over the northern Rockies. (Note: the jet stream can be located to the left of the baroclinic cloud system; also, note jet stream formation along and east of the Colorado Rockies; see Figure 50.)

Baroclinic Leafs:

It has been observed in satellite photography that many comma cloud systems evolve from deep cloud systems which often resemble a leaf pattern. They usually form on the east side of high amplitude trough systems. In Figure 150, a leaf-type cloud system is shown during the initial stage. Later, Figure 151, the leaf has evolved into a comma cloud system. These leaf systems will be presented in the next section.

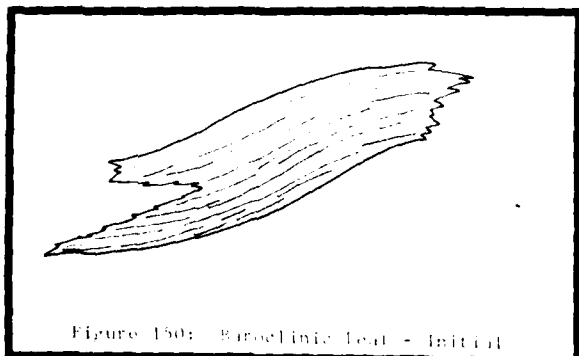


Figure 150: Baroclinic Leaf - Initial

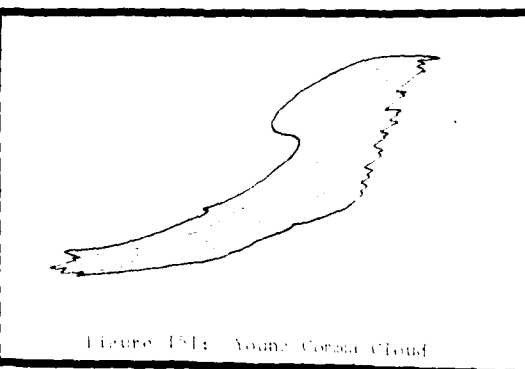
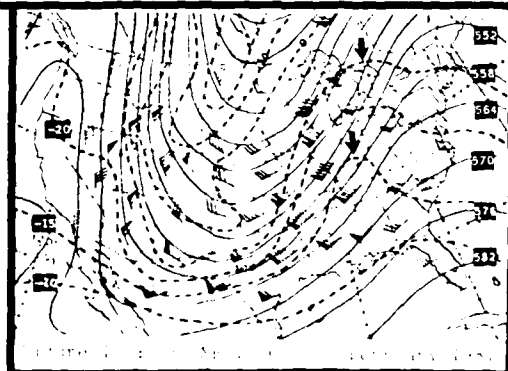
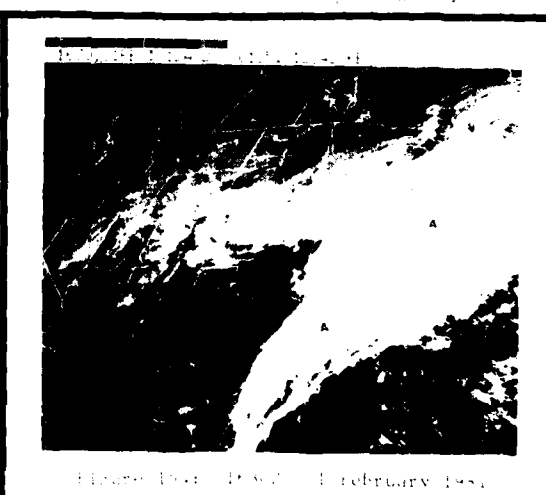
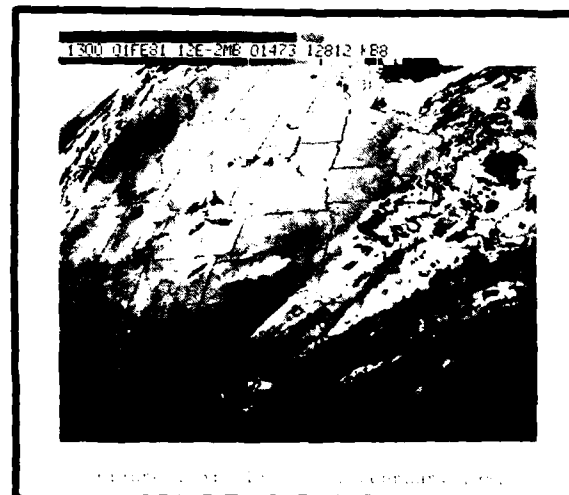
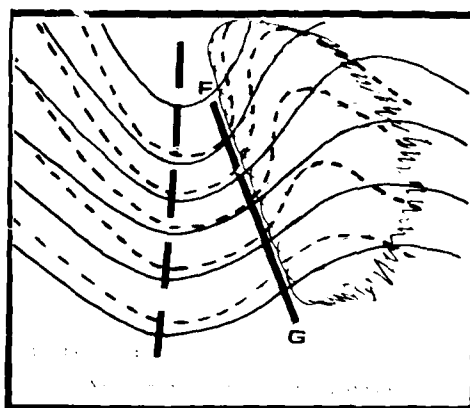


Figure 151: Young Comma Cloud

the trough axis. The trough axis is the line of greatest curvature of the trough axis. The trough axis is the line of greatest curvature of the trough axis.

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The deepest baroclinic zone cloud systems are associated with large, high-amplitude trough systems located within the mid-latitude westerlies. These deep cloud systems are observed more often east of the Rocky Mountains where there is an abundance of moisture from the Gulf of Mexico and the Atlantic Ocean. Conversely, baroclinic zones may have little or no cloudiness associated with them. This is likely to occur over the western Great Plains and westward. The first visible signs of the baroclinic zone are cirrus layers appearing east of the troughline. The cloud system increases as it moves eastward into an area favorable for lower-level moisture across the central Midwest and eastward.

Forecasters may say that these cloud systems are simply cloud frontal bands. In most cases, yes, they are. However, not all jet stream-related mid and high-level baroclinic zones have lower-level related frontal systems.

Relationships between 500mb height contours and Vorticity Isopleths:

The following information describes terminology which may appear in satellite interpretation messages and forecast bulletins.

Jet Stream:

In section 4, Part II, jet streams were shown as continuous belts of strong upper level winds extending across large areas. Another approach is to consider these strong middle and upper level wind zones as separate, but interrelated, jet stream segments or speed maxima. This approach is more useful for understanding and interpreting cloud systems observed on satellite pictures. Note: In the following 500mb illustrations, the solid lines are height contours; dashed lines are vorticity isopleths.

- Channel Jet - A "channel jet" is a jet stream segment in which height contours and vorticity isopleths intersect at small angles or are parallel. (A channel jet is usually associated with a shear lobe; to be shown later.) In Figure 157, the heavy arrowheads mark a channel jet pattern; the vorticity maximum (not a PVA maximum) shown in Figure 157 over Michigan has a channeled zone around its southwestern quadrant. Other characteristics of channel type pattern are:

- Within well defined channeled zones, the 500mb isotherms are parallel to the wind direction, height contours and the axis of maximum winds. Additionally, during the winter season, well defined channeled regions have large vertical depth.

- The strongest winds aloft are usually found in the channeled regions.

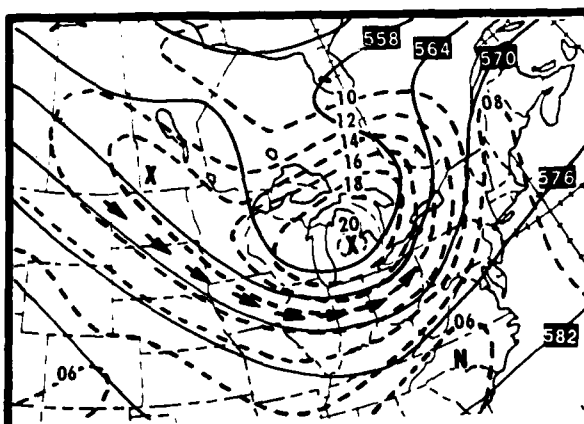


Figure 157: 500MB Height/Vorticity Analysis Channeled Jet Stream

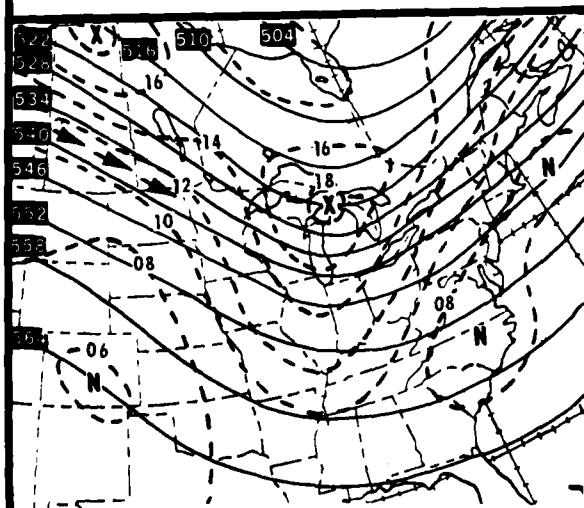


Figure 158: 500MB Height/Vorticity Analysis Advection Jet

- Advection Jet - An "advection jet" is a jet stream segment in which the height contours intersect vorticity isopleths at large angles in the area of maximum winds (an advection jet is usually associated with advection lobes). In Figure 158, the strong wind zones within the large vorticity field are mostly of the advection type, except as noted in the channeled region by the arrowheads. Other characteristics of the advection type pattern are:

- The axis of maximum winds is not parallel to the wind direction or the contours; this is shown in Figure 159. In Figure 159, the 500mb maximum winds of > 100 knots (shaded area) cross the contour flow along a south to north axis. The wind direction, however, follows the contour flow. (This pattern indicates strong PVA; the temperature and moisture fields would also cross the contours at large angles as discussed earlier in Figure 152.)

- Over PVA areas, the axis of maximum winds aloft shifts to lower height contours (looking downstream). Over NVA areas, the axis of maximum winds shifts to higher contours (looking downstream).

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

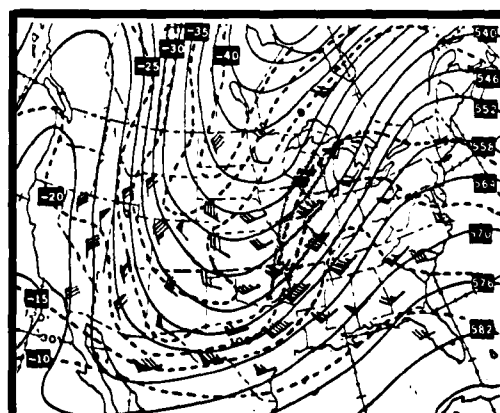


Figure 159: 500MB 1 February 1980

Vorticity Lobes:

A vorticity lobe is an elongated ridge or tract of the vorticity field which is associated with vorticity maxima or vorticity minima. In a broad sense, a vorticity lobe is a vorticity lobe to separate areas of positive vorticity and negative vorticity, or vorticity advection. This is especially true in the case of a strong wind zone, such as a jet, and at the vorticity lobe. This can further be used to help identify vorticity maxima. If clouds exist where PVA is indicated, then the probability of a cyclone is high.

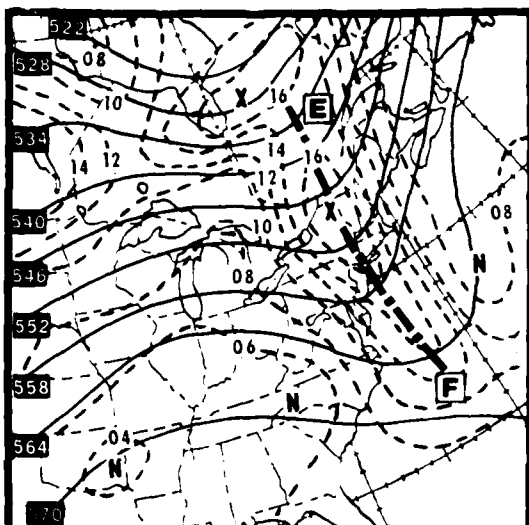


Figure 160: 500MB Height Vorticity Analysis
Advection Lobes

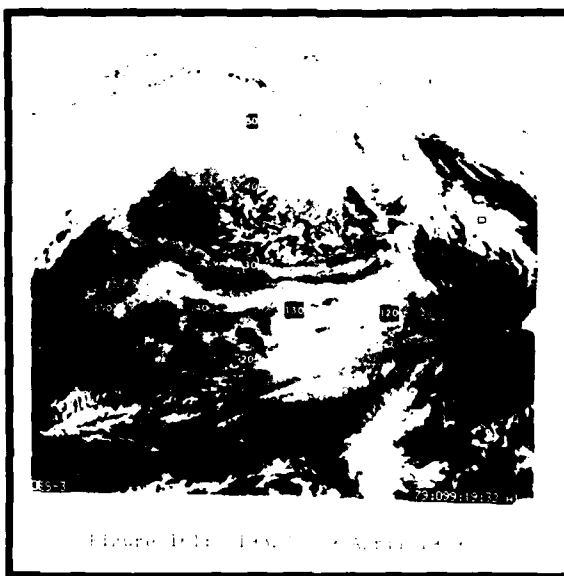


Figure 161: 1600Z 10 April 1964

• **Advection Lobe** - An advection lobe is a vorticity lobe whose axis crosses the height contours at large angles (related to advection jets). In Figure 160, the lobe's axis is located between E and F. A negative tilt pattern - east of axis E-F strong PVA, considerable cloudiness and precipitation and the likelihood of frontal cyclogenesis would occur. An example is shown in Figures 161 and 162. In the satellite photo, Figure 161, two lobes of vorticity with PVA and clouds are noted at locations 2 and 3 east of the lobe axis. These correspond closely to the related 500mb vorticity pattern shown in Figure 160 (vorticity nodes later from Figure 161).

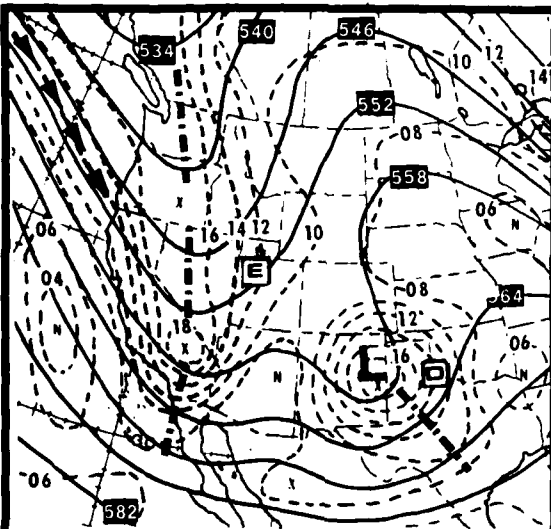


Figure 162: 500MB Height Vorticity Analysis
0000Z 10 April 1964

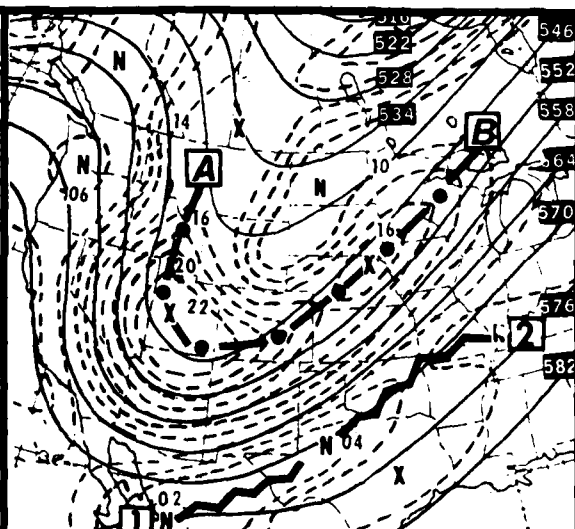


Figure 163: 500MB Height Vorticity Analysis
Shear Lobes

• **Shear Lobe** - a "shear lobe" is a vorticity lobe whose axis crosses the height contours at very small angles or is parallel to it (related to channeled jets). In Figure 163, lobe "A-B" is a shear lobe of maximum vorticity (even though the very small segment near A is not quite parallel to the contours). The lobe is on the cyclonic shear side of the maximum wind zone. In Figure 163, 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. Few clouds are associated with these systems.

SECTION 4: The Baroclinic Leaf

There is a certain cloud system observed in satellite pictures which appears as an elongated cloud pattern on Day 1 only to evolve into a full scale comma cloud system by Day 2. This cloud system is appropriately nicknamed the baroclinic leaf - because of its overall leaflike appearance. In this section, leaf characteristics, patterns and evolution from leaf to comma will be presented. Also, relationships between leaf systems and synoptic features will be shown.

Characteristics:

A baroclinic leaf is a cloud system associated with frontogenesis aloft within a westerly wind flow. Usually, the system is vertically deep and surface frontogenesis and possibly cyclogenesis are also occurring. Because it is a thin cloud system, it is easily seen on both visual and IR scans.

The baroclinic leaf usually has an elongated pattern with well defined borders on both sides as illustrated in Figure 164. (Note: Baroclinic leaves are best defined in high amplitude trough patterns.) The poleward side frequently has a shallow "S" shape as shown in Figure 164. The upstream end has cyclonic curvature (location S in Figure 164) while the downstream end has an anticyclonic curvature appearance (location T). The anticyclonic end eventually becomes the comma head. Often, a telltale sign (and the first sign of comma development) is a "V" notch forming on the western edge of the leaf as noted at point W in Figure 164. The "V" notch is caused from the jet stream (and wind maximum) digging into the western end of the cloud system as noted in Figure 164.

Figure 165 depicts a model baroclinic leaf and its relationship with several upper level and surface features. Figures 166 through 168 are included to reinforce the discussion which will be shown in Figure 165. Note: In Figures 166 through 168 (valid at the same hour), the same leaf system is shown with each analysis. The features are:

- **Jet Stream** - The jet stream axis is indicated by solid arrowheads in Figure 166. The jet stream upstream from the leaf (location D) is likely to be channeled with a maximum wind speed zone along it. Downstream, the jet axis is likely to be south of the leaf (and lesser wind speeds), but it may occur further northward. Figure 166 illustrates the 300mb jet stream relationship to the baroclinic leaf. A wind maximum of 130 knots is digging southeastward into the leaf system. A "V" notch appears - a reflection of the jet stream affecting the western end of the leaf.

- **Vorticity** - The vorticity center, noted as "X" in Figure 165, is located on the clear side of the upstream border near the inflection point (location P in Figure 165). Generally, two vorticity lobes intersect at the vorticity center (X) and form a rough L-shaped pattern as shown by the dash-dot and dashed lines in Figure 165. The dashed line (base of the "L" pattern) is usually an advection lobe (location E) and is parallel to the leaf. A region of packed vorticity isopleths (with PVA) is over the leaf pattern; this is shown in Figure 167 (isopleths are thin dashed lines).

Returning to Figure 165, the other lobe - a shear lobe; location F - forms the stem of the "L" pattern. This area is in a channeled configuration and is parallel to the upstream jet stream (location D in Figure 165).

The interrelation between these vorticity lobes and the baroclinic leaf can be seen in Figure 167. (Note: The solid lines are the 500mb contour flow.)

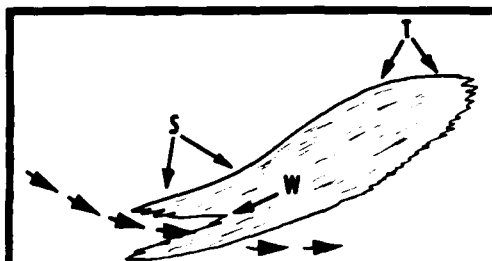


Figure 164: Baroclinic leaf
"S" Shape and "V" Notch

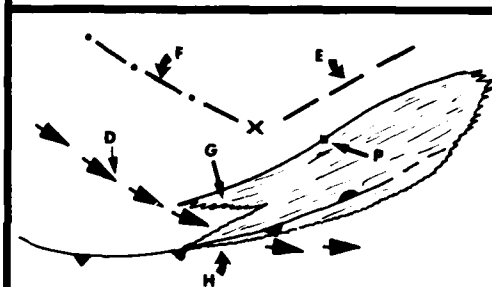


Figure 165: Baroclinic leaf
Jet stream and Vorticity Lobes

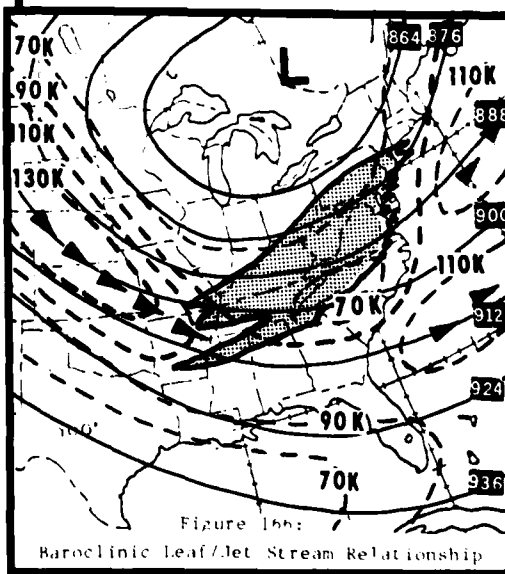


Figure 166:
Baroclinic Leaf/Jet Stream Relationship

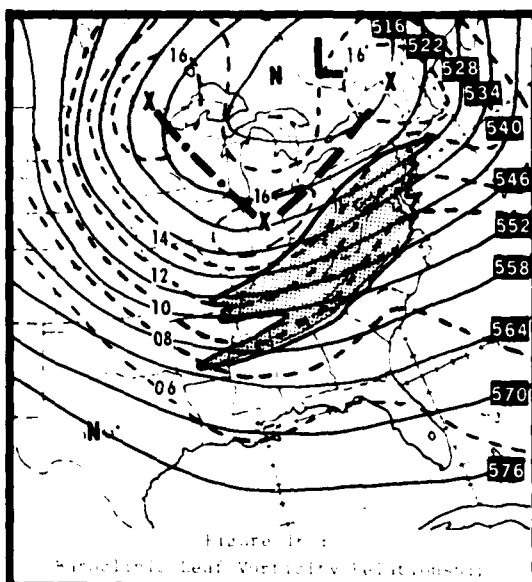


Figure 16a:
Baroclinic Leaf Vorticity Relationship

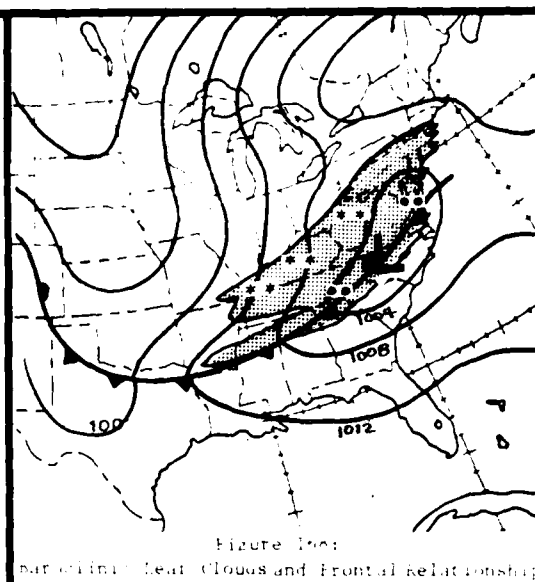


Figure 16b:
Baroclinic Leaf Clouds and Frontal Relationship

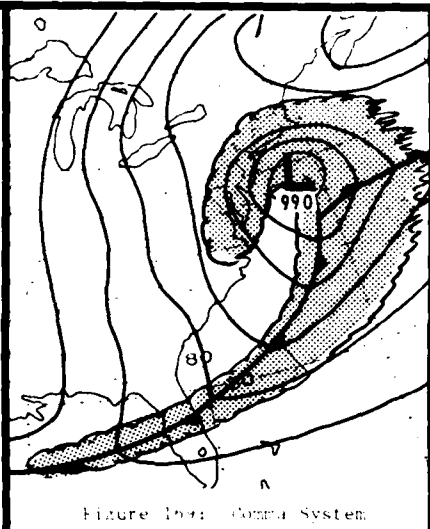


Figure 16c: Comma System



Figure 170: 1946Z, 27 November 1979

• Clouds and Fronts - Generally, the highest cloud tops are located over the eastern portion of the leaf. (Note: The eastern end will become the comma head.) The cloud tops decrease westward with middle level tops appearing over the western end of the "V" notch's northern border (location G in Figure 16b). The southern border of the notch is composed of low clouds (excluding CB's; location H, in Figure 16b) and lie along the cold front segment.

In Figure 16b, the newly forming cold front would be located along the southern border of the leaf as shown in the illustration. The eastern end of the frontal segment (located under the deeper part of the cloud system) is likely to be stationary with a disorganized surface pressure pattern. A surface trough may exist instead of an identifiable frontal system. Figure 16b typifies the cloud frontal/precipitation relationships with this particular leaf system.

Twelve hours later, Figure 16c, the baroclinic leaf has evolved into a comma pattern.

• Example - Let's examine a case event of a baroclinic leaf system; satellite photos and conventional data are included in Figures 170 through 177. This example does not exactly follow the models shown earlier, however, forecasters should be able to recognize some of the more important features. NOTE: The baroclinic system shown in the satellite picture, Figure 170, has been superimposed on the four analyses (Figures 171 through 174) which will follow. Keep in mind that there is a seven hour difference between the baroclinic leaf system and the analyses.

At the beginning of this event, Figure 170, a pronounced leaf system appears over the central Midwest. The system is elongated and has well defined borders. A "V" notch appears over the western end which reflects the jet stream axis aloft (long white arrow). Low-level Gulf moisture has advected into the system across eastern Texas and Louisiana.

Figure 173: A cross-section of the atmosphere from Figure 172 reveals the vertical structure of the atmosphere. The cloud tops are shown as a series of peaks and valleys. The cloud tops are generally higher over the western part of the storm and lower over the eastern part of the storm.

Figure 174: A cross-section of the atmosphere from Figure 173 reveals the vertical structure of the atmosphere. The cloud tops are shown as a series of peaks and valleys. The cloud tops are generally higher over the western part of the storm and lower over the eastern part of the storm.

Figure 175: A cross-section of the atmosphere from Figure 174 reveals the vertical structure of the atmosphere. The cloud tops are shown as a series of peaks and valleys. The cloud tops are generally higher over the western part of the storm and lower over the eastern part of the storm.

Figure 176: A cross-section of the atmosphere from Figure 175 reveals the vertical structure of the atmosphere. The cloud tops are shown as a series of peaks and valleys. The cloud tops are generally higher over the western part of the storm and lower over the eastern part of the storm.

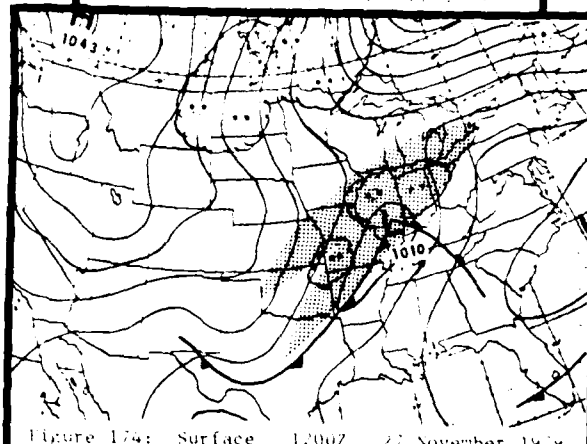
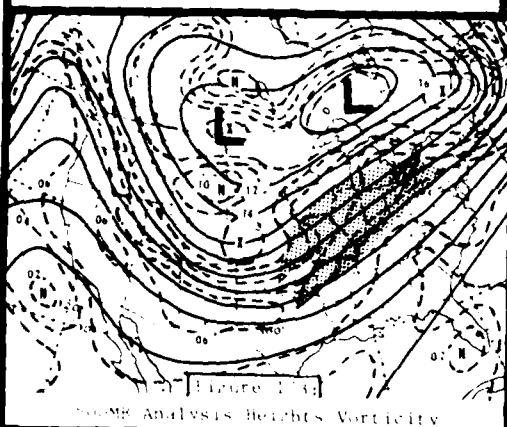
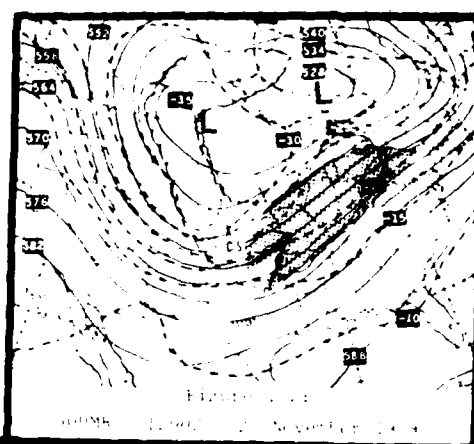
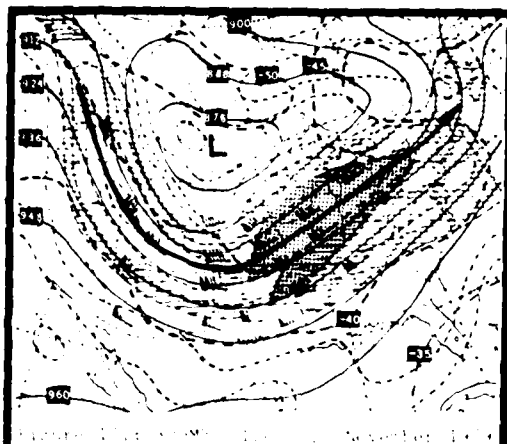


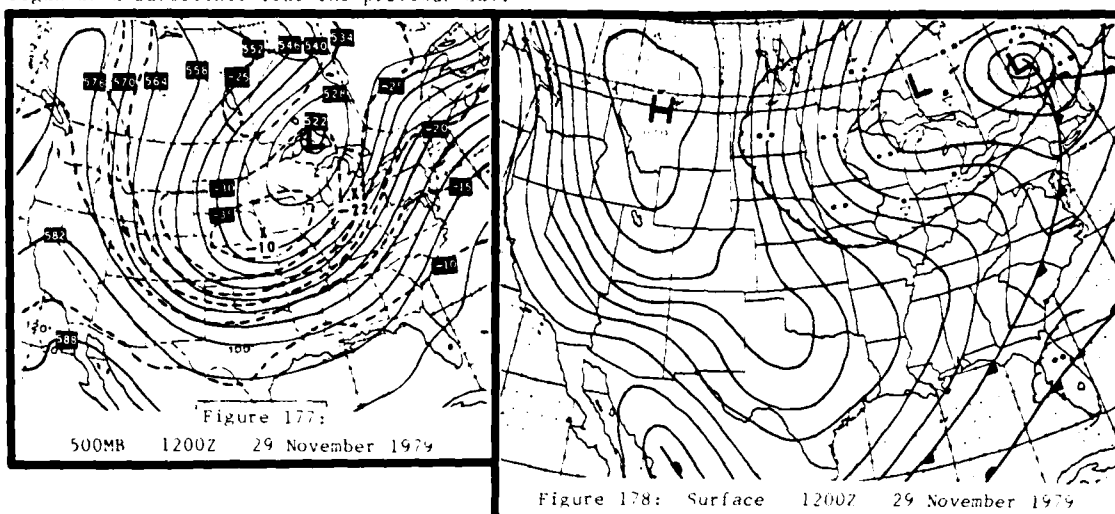
Figure 175: 0017Z 28 November 1979



Figure 176: 1616Z 28 November 1979

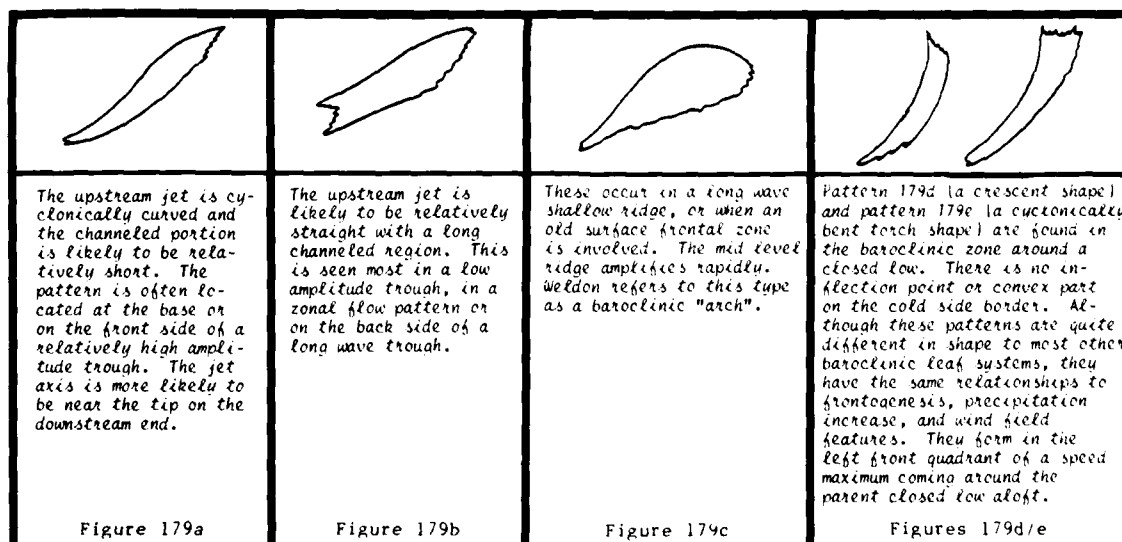
Figures 176 through 178 depict subsequent comma cloud development the following morning. In Figure 176, the comma head is located over the northeastern U.S. and is not shown in the photo. The cold frontal cloud band is evident across the southeastern U.S. and into the western Gulf of Mexico. The 500mb analysis, Figure 177, shows the deepening trough system. Two height fall centers are noted by X's; the centers closely approximate the location of two vorticity centers. The 500mb height fall center, previously located over western Kansas 12 hours earlier, has moved into southern Michigan and appears as a -22 center.

Finally, in Figure 178, an organized storm system appears over the east U.S. - its birth began as a baroclinic leaf the previous day.



Patterns:

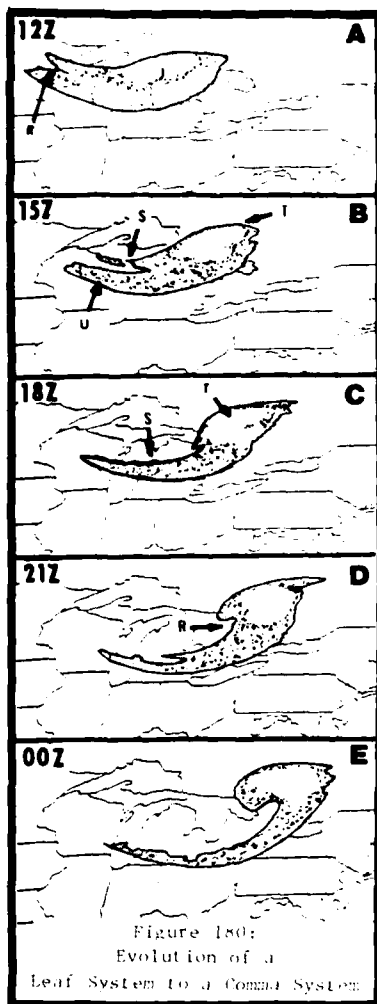
There are many variations, large and small, in the shape of leaf systems. Some are long and narrow, some have a much longer cyclonic and anticyclonic curvature along the poleward side (a longer "S" shape) and some are fat with the anticyclonic portion appearing as an arch shape. Figure sequence 179 depicts some examples of leaf configurations and have been empirically related to specific features of the wind flow. A brief description of the upper level pattern and related wind flow is shown below each figure (after Weldon, 1979).



Evolution:

A baroclinic leaf evolving into a comma cloud system may take some time to change. Or, it may be fast. Forecasters, using half-hour GOES scans, may not immediately notice the change that is occurring within the leaf system. They must review previous pictures over several hours to detect these important changes.

Figure sequence 180 shows a well defined baroclinic leaf pattern at 1200Z which changed into a comma pattern by 0000Z. The sequence was taken from actual IR photos; the highest IR tops are indicated as the unshaded areas (white areas) in each illustration.



In Figure 180A, 1200Z, the first sign of cloud development is a "V" notch forming on the western side of the cloud (location 1); note the "S" shape organization of the cloud system. By 1300Z, Figure 180B, the "V" notch portion of the cloud system boundary (location 1) has begun to dissipate, while the other cyclonic portion remains well defined (location 1). The frontalogenesis is occurring along the western part of the southern border (location 1).

By 1500Z, Figure 180C, part of the cloud system at the northern border (location 1) has dissipated leaving a more ragged edge to the tail part of the cloud system. As the tail narrows and the slot forms, during the transition from a leaf to a comma cloud system, the surface low begins to deepen. The slot (location 1) is beginning to free on the appearance of a comma cloud.

Three hours later, Figure 180D, a comma cloud system is formed and the "V" notch slot (location 1) has been totally freed, as it invades the side edge of the system. At this time, a comma cloud system has taken shape. The surface frontal system (not shown) has become well organized as it continues to develop.

• Example - The following satellite photos, Figures 181 through 183 depict a comma cloud development from a horizontal leaf over a 12-hour period. In Figure 181, the "V" notch is seen in the IR scan at location 1 over Minnesota. Part of the northern boundary has begun to dissipate (location 1, Figure 180B) and is shown at location 1. Note: In suspected tropical leaf events, forecasters should look for these "V" notches within the mid and upper tropospheric regions - frontalogenesis slits are occurring at these levels.

Ten hours later, Figure 182, the visible cloud system reveals a frontal wave over the Lake Superior area. Finally, in Figure 183, (approximately 18 hours later from Figure 181), a well defined comma cloud can be located between the Great Lakes and Hudson Bay; the comma head (1) is well defined away from the tail (2) is faintly visible due to its lower cloud structure.

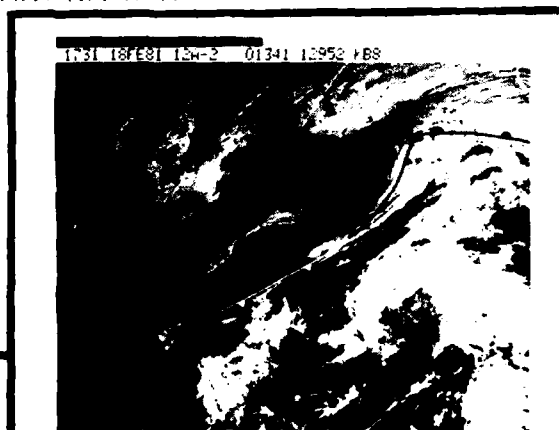


Figure 182: 1731Z 18 February 1981

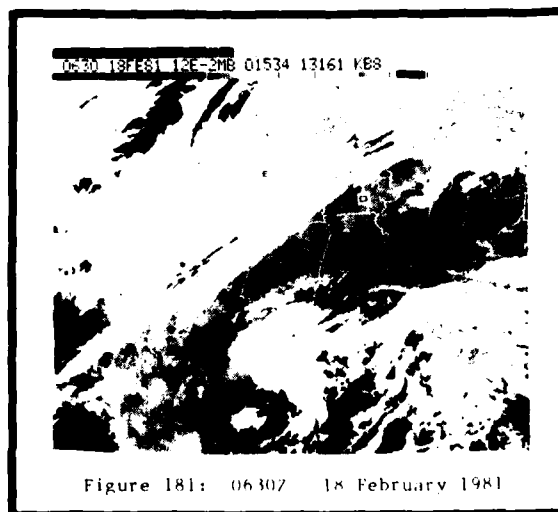


Figure 181: 0630Z 18 February 1981



Figure 183: 2300Z 18 February 1981

• Other Signatures - The preceding figures depicted classic examples of leaf to comma evolution over a short period of time. The "V" notch was apparent indicating the presence of the upper level jet. Not all leaf systems will have the "V" notch signature; several of these non-"V" notch systems were shown earlier in leaf patterns (figure sequence 189). An example now follows:

Figures 184 and 185 depict a leaf pattern which evolved into a comma cloud system off the west coast of North America. In figure 184, the cloud system appears as a lat cloud shield (A), and it closely resembles the model shown in figure 186c. Ten hours later, figure 185, a comma cloud system has evolved. This particular system did not have the familiar "V" notch at the western end, however, the strong cyclonic curvature noted by the arrow in figure 184, indicates that the jet stream is punching into the system. The 900mb analysis, figure 186, shows the jet stream pattern associated with the leaf system. The analysis did indicate that a jet maximum was occurring (over the data-sparse area) near the western end of the leaf system.

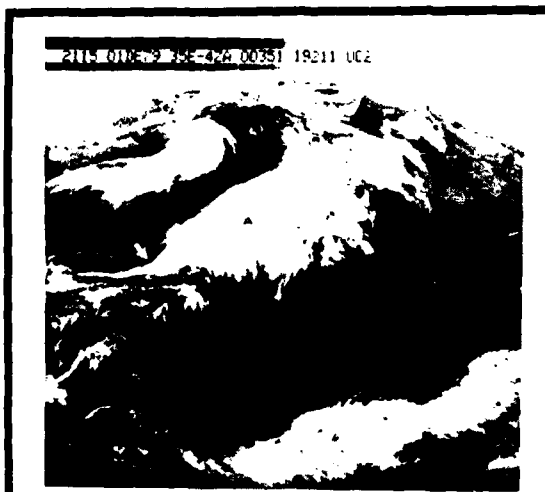


Figure 184: 2115Z 1 December 1979



Figure 185: 0715Z 2 December 1979

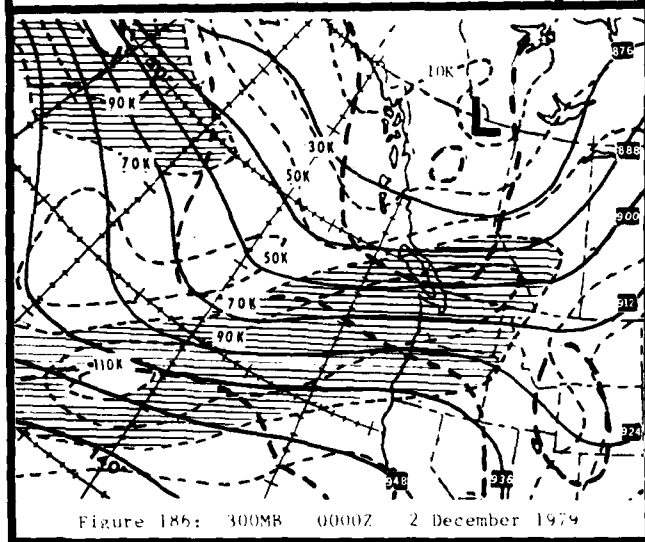


Figure 186: 300MB 0000Z 2 December 1979

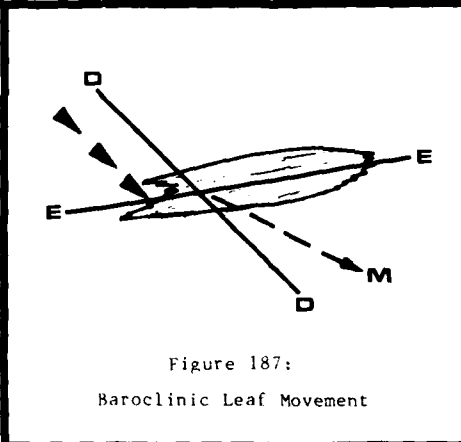


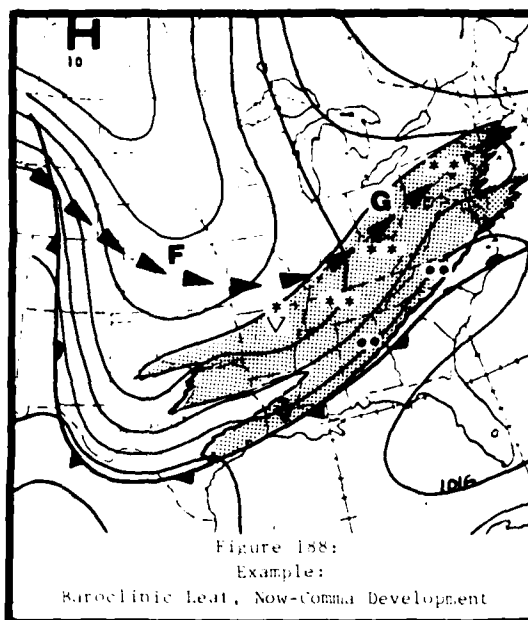
Figure 187:
Baroclinic Leaf Movement

Miscellaneous:

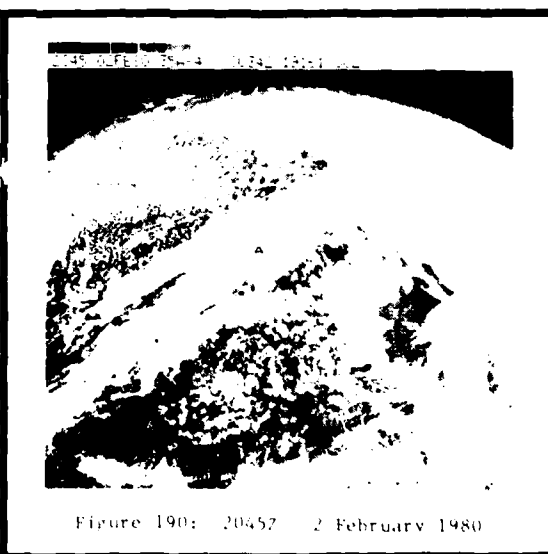
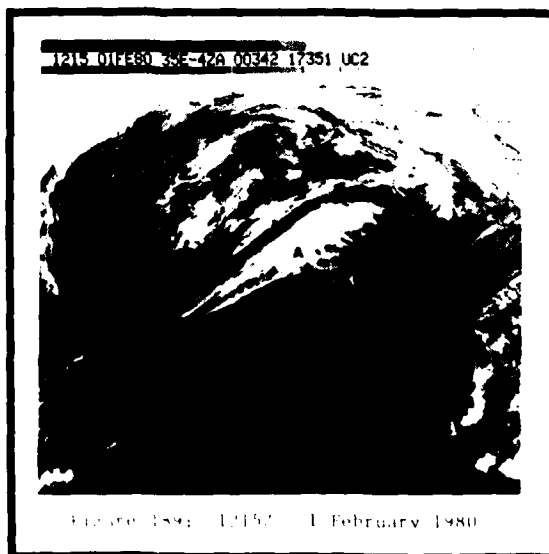
• Leaf Movement - A feature that helps in the recognition of a leaf cloud system is its direction of movement. Generally, it does not move in the direction of its orientation as shown along points E-E in Figure 187. Line D-D in Figure 187 parallels the axis of the channelled jet upstream. This stronger jet serves to push the leaf system southward (digging). The most likely direction of movement that the system will take is shown along the dashed line (M); it lies between lines D-D and E-E but closer to the line D-D (channel jet axis).

• **Jet stream location.** It has been shown throughout this section that the interrelationship between the jet stream and the developing leaf system. There will be those infrequent events where a leaf-like cloud system is apparent in satellite pictures, however, it will not evolve into a comma cloud. Figure 188 illustrates this event; the wind pattern has been included in the satellite picture.

In this example, the wind speed maximum is located further north of the "V" notch. Additionally, the jet stream speeds were significantly greater on the downstream side of the system cloud. If wind velocities should be less than the threshold value, in this example a wide stream of cloudiness might develop and surface frontogenesis might occur, but the system did not evolve into a comma cloud pattern.



Another event is shown in Figures 189 and 190 (IR and visible respectively). In Figure 189, a leaf-like cloud system appears off the west coast of North America. The jet stream lies poleward and parallel to the cloud system; therefore, it should not evolve into a comma cloud system. Thirty-two hours later, Figure 190, the leaf system is not apparent, however, an extensive baroclinic zone cloud band remains in the same general area as shown in Figure 189.



In summary, look for the telltale sign of the "V" notch or a cyclonic "S" shape at the western end of the leaf system. Associate the satellite cloud system with the initial LRM vortex analysis to see if vorticity (and, if center) really exist (both height fall centers and/or fronts). On the surface chart, there should be signs of frontal waving and cyclogenesis.

In this section we will consider the development of the β function for the $U(1)$ gauge coupling constant. The β function is defined as $\beta(g) = \mu \frac{dg}{d\mu}$, where μ is the renormalization scale. The β function is determined by the anomalous dimension of the gauge coupling, which is given by $\gamma_A = -\frac{1}{2} \text{Tr}(\gamma_A)$, where γ_A is the anomalous dimension of the gauge field. The β function is then given by $\beta(g) = -\frac{1}{2} \text{Tr}(\gamma_A) g$. The β function is negative for the $U(1)$ gauge coupling, which implies that the coupling constant decreases as the renormalization scale increases.

- differentiating inflation into its components
- causes of inflation
- differentiating the different levels of inflation
- the effects of inflation
- the effects of inflation on the economy
- the effects of inflation on the environment

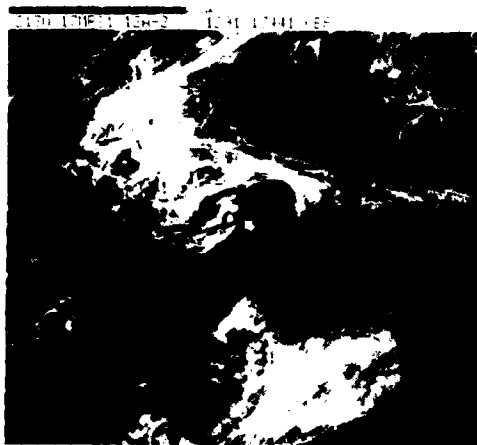


Figure 191: 2130Z 17 March 1981

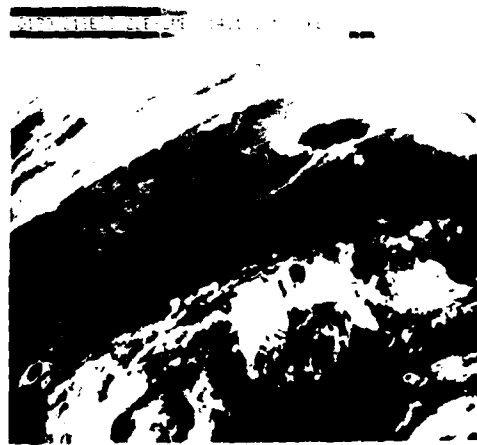


Figure 19.1: 01307 21 September 1950

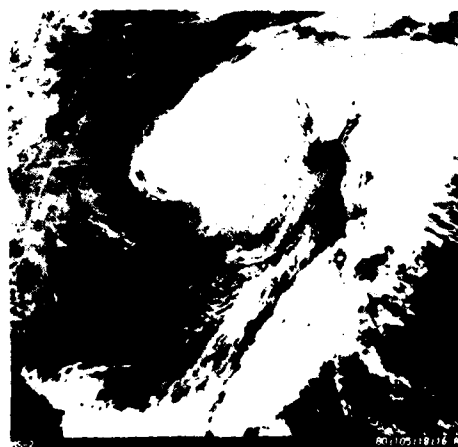
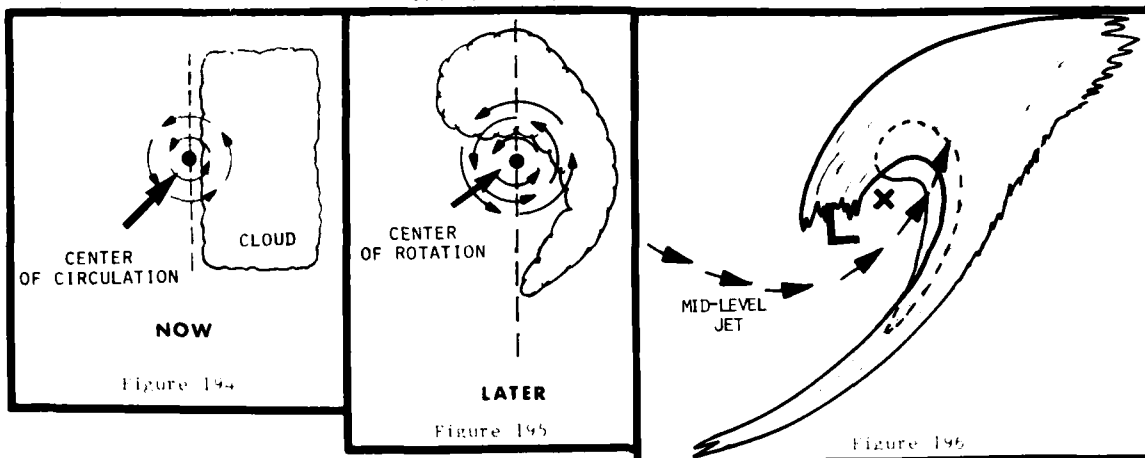


Figure 193: 18167 14 April 1980

Comma Cloud Development:

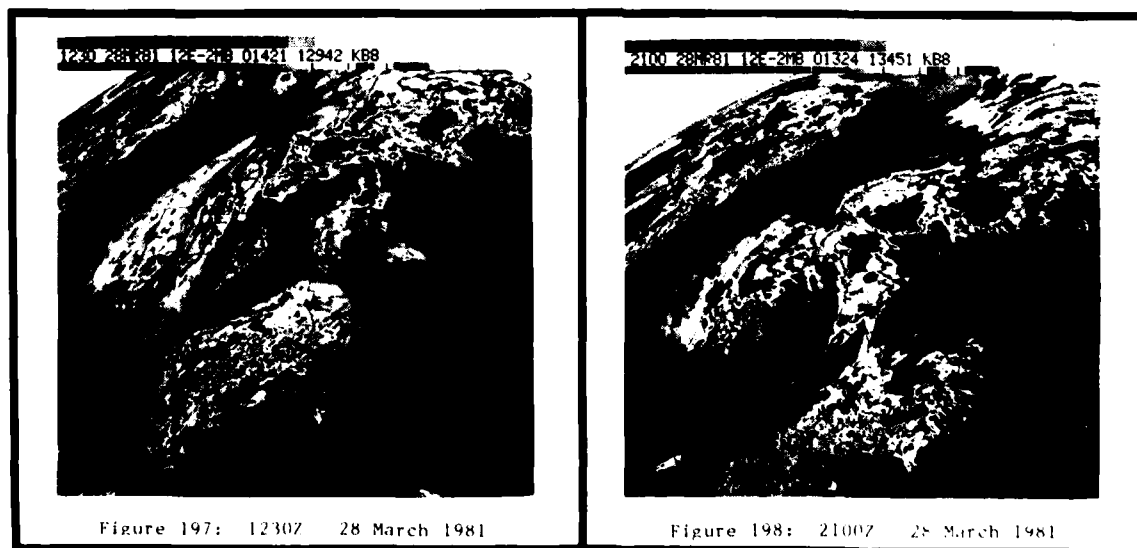
Regardless of the comma size, whether it is a small vorticity comma or a large-scale comma, the concepts of comma system development are similar.

• **Differential Rotation** - The comma shape of the cloud system is caused by distortion of the cloud mass due to rotation of the air around a center. If the system is not moving, the clouds will move with the rotating wind field as shown in Figure 194 and gradually develop a comma shape as illustrated in Figure 195. In this case, the low pressure center and the center of maximum vorticity will be the same. If the system moves eastward, the cloud system undergoes further distortion (see Figure 196). The area of maximum vorticity, denoted by the X, moves away from the lowest pressure denoted by the L.



• **Large-Scale Comma Cloud development - An Example** - The evolution of many large-scale comma cloud systems is much more complex than the theoretical model shown in Figures 194 and 195. (Note: one type of comma cloud evolution is the baroclinic leaf system which was presented in Section 3, Part II.) In this example, several disorganized cloud sub-systems may exist prior to the approach of the vorticity system. An example is shown in Figures 197 and 198. In Figure 197, several large cloud systems are noted. Baroclinic zone cirrus lies across Texas and the lower Mississippi Valley area. A closed upper low is noted by the L over the Four Corners; a deformation zone cloud band stretches north-south across Utah and Wyoming. Higher cirrus tops are shown across the upper Midwest and are occurring along an old frontal zone.

Approximately eight hours later, Figure 198, a large developing comma system appears over the Rockies and Great Plains. Rotation within the approaching vorticity center is noted across the central Rockies. The system intensified rapidly when it began to recurve toward the north-east and when Gulf moisture reached the system and began to release latent heat into the atmosphere.



Comma Cloud Structure (General):

The following relationships apply to comma clouds in general - whether it be a small-scale vorticity comma cloud (mid-level system; Figure 199) or a large-scale comma cloud system as shown in Figure 200 (mid and high level system).

- "S" Shape - The most distinguishing feature in most comma patterns is the characteristic back edge of the comma. This edge - with its usual "S" shape, or inflection point and reversal of curvature (locations F in Figures 199 and 200) - is generally the best defined part of most comma patterns. The comma cloud will have a very distinct back edge (upwind), but the front edge (downwind) will be ragged as indicated at locations G in Figures 199 and 200.

- Comma Head - The comma head will be to the left of the axis of maximum winds in an area of large PVA (locations H in Figures 199 and 200). The comma head tends to lag and shows the most tendency for rotation.

- Surge Region - The surge region (locations E) is the dry intrusion of air into the comma. The surge region is located near the region of highest winds at a level near the cloud tops (dashed lines in Figures 199 and 200; excluding convective activity). The surge region in both examples shown in Figures 199 and 200 would be moving northeastward more rapidly while the part to the left (comma head) would be lagging and tending towards rotation.

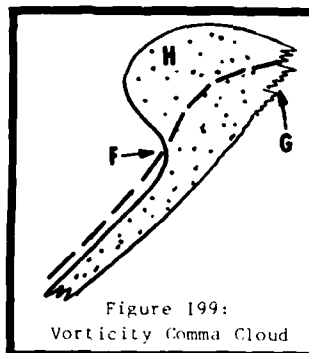


Figure 199:
Vorticity Comma Cloud

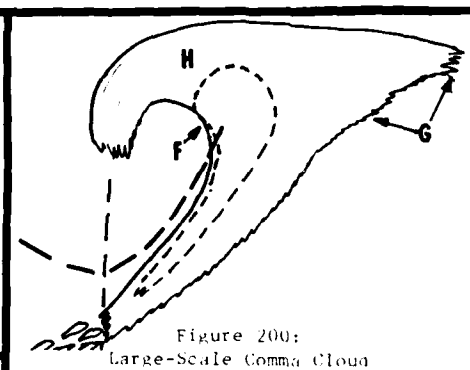


Figure 200:
Large-Scale Comma Cloud

- Comma Tail - The comma tail extends back from the surge region (locations E) to the south and becomes parallel to the axis of maximum winds at cloud top level (channeled jet) with the edge just to the right of the axis. Generally, a cold or occluded frontal system lies along the cyclonically curved portion of the comma (locations F) and down the comma tail. If the surface frontal system has not organized, weather (clouds, precipitation and convection) will be associated with the comma tail and not related to the location of the surface front.

Comma Cloud Structure - Deformation Zones (Synoptic Scale):

The streamline flow is respectively shown in Figures 201a (high levels) and 201b (low levels below 700mb) within a mature comma cloud system. According to Weldon two deformation zones develop within these flow patterns. They are:

- High Level Deformation Zone - In Figure 201a, clouds form and expand in the upward motion area (D) in advance of the vorticity maximum (X) and the jet maximum (heavy arrow). The air slows and undergoes diffluence, some turning cyclonically around the upper low and others turning anticyclonically over the upper level ridge. At the top of the comma head along the converging streamlines, a distinct high cloud boundary develops. The clouds spread out in either direction (appears to stretch) and produces the comma configuration shown in Figure 201a.

In Figure 201b, the low level circulation center approximates the location of the mid-level vorticity comma cloud system. A cloud band, which forms the comma tail, lies along the converging flow as shown in Figure 201b. In the low level deformation zone (S), subsiding air decreases cloudiness, and the air generally becomes stable. The lowest cloud tops (excluding convection) within a comma system are generally located in the comma tail. Tops decrease significantly in the comma tail where the upper troughline intersects the tail (see discussion on page 30).

The IR satellite photo, Figure 202, illustrates these points. In Figure 202, the high-level deformation zone is indicated across the area noted at D. The low level deformation zone is shown at S along the comma tail. Note that the higher level cloud tops end at the troughline, however, a lower level cloud band extends southwestward down the comma tail as marked by the arrows in Figure 202.

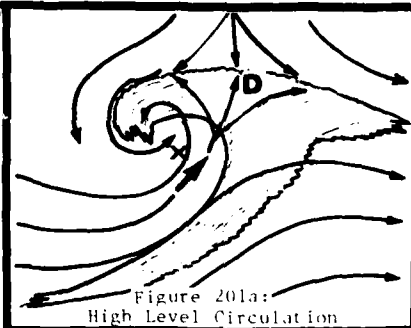


Figure 201a:
High Level Circulation

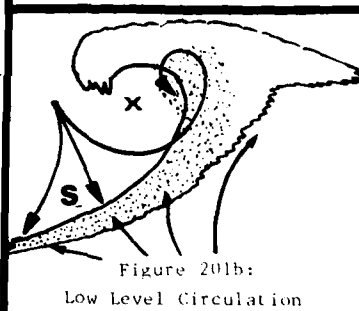


Figure 201b:
Low Level Circulation

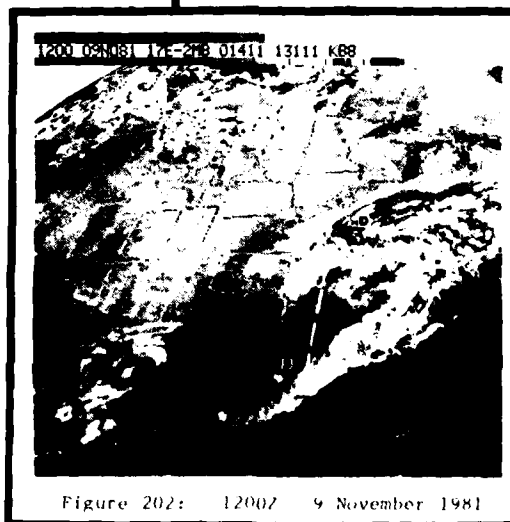


Figure 202: 1200Z 9 November 1981

• Mid and High Level Jet Streams - The mid and high level jet stream enters the comma system in the surge region as noted in Figures 203a and 203b. The speed maximum lies upstream from the surge region as indicated by the closed dashed lines in Figures 203a and b. The high level jet may still be identifiable within a young comma system as shown in Figure 203a, but, as the comma system matures, Figure 203b, the jet becomes increasingly weaker (dashed line; increased wave air advection and ridging within the cloud system). Meanwhile, an intensifying jet stream either forms or strengthens along and parallel to the strengthening baroclinic zone (stronger temperature gradient) either layer at the top of the comma head (east of the deformation zone (DD) as illustrated in Figure 203b).

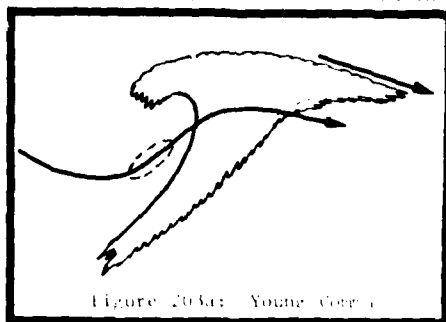


Figure 203a: Young Comma

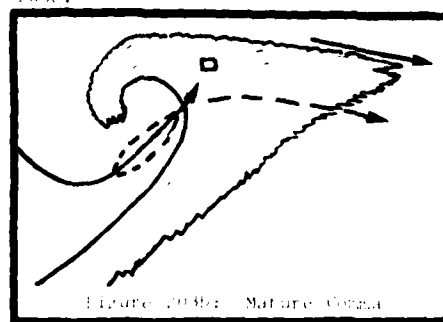


Figure 203b: Mature Comma

Empirical Relationship between Vorticity Advection and a Comma Cloud System - An Example:

Forecasters should be knowledgeable in placing comma cloud systems on local AVE vorticity analyses and pros. Figure 204 depicts a typical comma cloud vorticity pattern empirical relationship. Each vorticity pattern is different; some will be small scale while others are very large. Some will be elongated across a large area and others will be either negatively or positively tilted.

In Figure 204, the cloud system should be located where the vorticity isolines (isopleths) cross the contour lines with the wind flow blowing from higher to lower values. This is the area of PVA (and the baroclinic zone). The strongest PVA area is where the isopleths cross the contours at the greatest angles; this area is noted at B in Figure 204. A good rule to use to locate maximum PVA is to find the smallest squares formed by the height contours and vorticity isopleths as shown in the region of B in Figure 204. If squares cannot be formed, locate the smallest parallelograms which are closest to the square. Note: The closer the contours are together, the stronger the winds will be; the closer the vorticity isopleths are together, the greater the vorticity gradient will be.

The vorticity comma cloud head (noted in region B in Figure 204), associated with a synoptic-scale comma system, lies within the area of maximum PVA. This area is the deepest part of the comma system, and where the lowest ceilings and heaviest precipitation would likely be occurring. The vorticity center noted at X in Figure 204, lies upstream from the comma head generally in a cloud-free area. Anywhere the clouds usually form further downstream where the vorticity gradient is stronger. Over ocean areas or at other places where cumulus clouds form behind the vorticity comma, rotation will be seen at the vorticity center.

The thick dashed line shown across the vorticity comma's surge region in Figure 204 denotes one of the axes of maximum vorticity and is the end of the area of maximum PVA. In this example, vorticity isopleths/height contour angles become increasingly smaller south of the axis and down the comma tail. The back edge of the cloud system should be located where there is no further crossing of the vorticity isopleths across the contours. The flow pattern behind the cloud system becomes channelled and eventually changes to negative vorticity advection (NVA; area C) in Figure 204 west of the troughline.

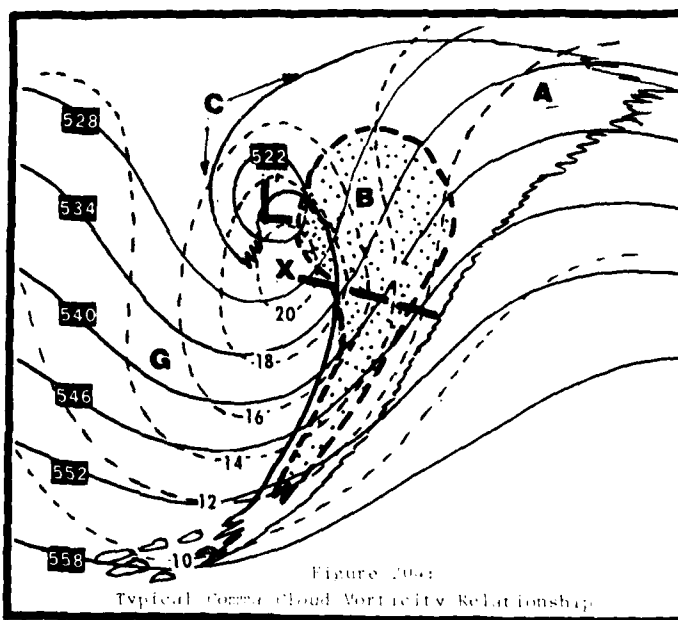
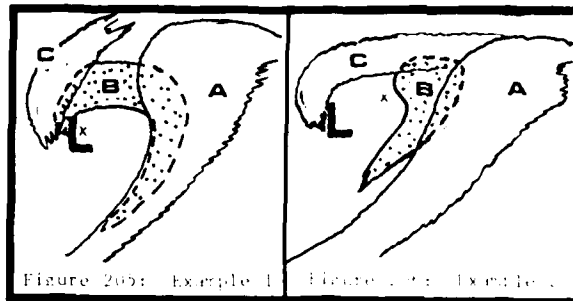


Figure 204:

Typical Comma Cloud Vorticity Relationship

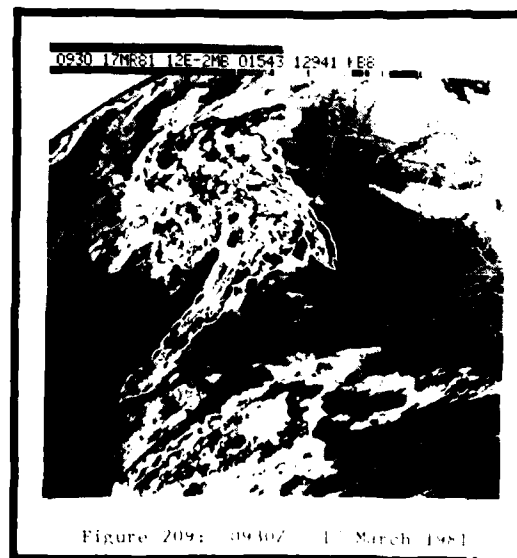
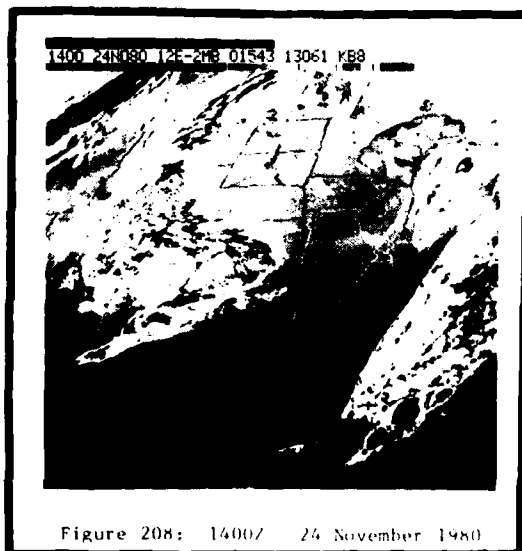
Each mature comma system's cloud structure is different, and it will not always resemble the model shown in Figure 204. Figures 205 and 206 illustrate two examples. The overall appearance of the system depends upon the configuration of the associated vorticity system - e.g., the strongest PVA area's orientation may become different than the PVA area (B) shown in Figure 204. Sometimes in mature comma systems, the rotation center pulls away from the circulation center to develop a new low further to the east; this is shown in Figure 206. The old, vertically-deep low will die and a new low will form along the baroclinic zone ahead of the approaching short wave vorticity comma (a common occurrence over the northeastern U.S.). (Note: The three cloud sub-systems (A; B and C) shown in Figures 204 through 206 were presented on page 36.)



Factors to Consider when Studying Comma Clouds:

A comma cloud system's overall pattern may change significantly within a short period of time, especially with rapidly moving short wave systems. Organized comma systems moving over the western U.S. from the Pacific Ocean (Figure 207) may become poorly defined in satellite pictures in just a few hours because moisture is depleted while moving across the mountains.

Infrared photos should be used to identify comma cloud patterns as shown in Figures 208 and 209. The temperatures at cloud top level should enable forecasters to determine how deep the system is. In Figures 208 and 209 (short wave systems), the highest tops shown in the comma systems over the central and western U.S. are in the -30 to -35°C range which would indicate cirrus tops to the 400mb level. (Use the Skew T to determine height.)



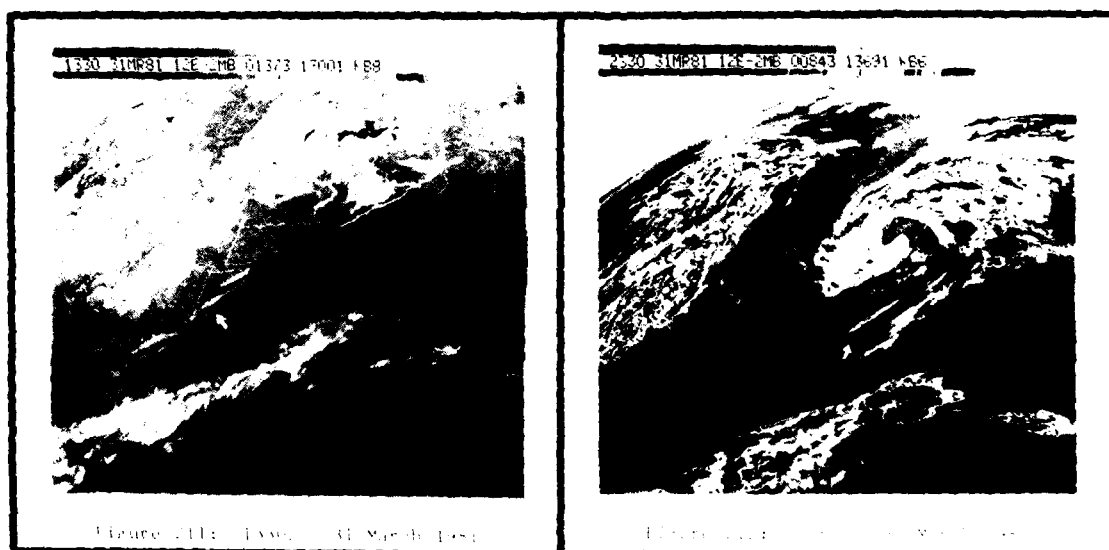


Figure 211: 1990, 31 March 1990.

1. *Intergovernmental Commission on the Danube* (1948-1954)

The share of total national labour force employed in :

- the relative position of the picture to the scene;
- which, following the golden rule, contains information about the picture, continuity of the movement, the necessity to follow the picture, the relative visibility, which, in a way, determines the direction of the movement;
- where the subject of the picture is located, where the picture is oriented;
- the relation of the picture to the other pictures in the scene, which is a kind of attention, the subject of the picture, the picture.

SECTION 6: Other Vorticity Comma Systems

In the previous section most of the information that was presented dealt with the development and structure of synoptic-scale comma cloud systems. In this section we will look at smaller scale, short-wave vorticity systems which are not part of a large comma system. They often appear within the colder air behind a larger, mature comma cloud. Or, a short wave vorticity comma may move into a stationary baroclinic zone to enhance frontal waving and cyclogenesis. These small comma systems may develop rapidly, and their interactions with large comma systems, with baroclinic zones and with moist, unstable zones, require close examination. Perhaps the selected examples included in this section will help forecasters to recognize some of the more common occurrences. Keep in mind while reading this section, that we will be discussing vorticity comma clouds which are not part of the main vorticity system located within the synoptic comma system.

Vorticity Comma Cloud Patterns (Figures 213,214,215):

The development and structure of vorticity comma systems were discussed in the previous section. The appearance of a secondary short wave vorticity comma cloud may take on many forms, especially during the developmental stage when it is moving southeastward towards the base of the main trough system. Initially, the comma may appear as a thin line, a blob, cluster or an elongated cloud band. When the vorticity center emerges from the base of the trough and begins to move northeastward (increased PVA), it will generally assume the shape of a comma cloud. The following three examples illustrate the most observed patterns of formation and development according to Miller (2). These patterns will be referenced, where appropriate, in the various synoptic examples that will follow later.

Pattern 1 - Figure 213 depicts the classic comma; it becomes increasingly well defined in the mid troposphere when it moves into an area of upward vertical motion and PVA (and in a zone ahead of which low-level frontogenesis is taking place).

Pattern 2 - Occasionally, a comma cloud will not attain the distinctive comma shape but will still initiate convective activity (and perhaps cyclogenesis) as it approaches and moves over favorable lower level features. This is illustrated in Figure 214.

Pattern 3 - When the mid and upper troposphere levels are too dry to support cloud formation, the comma will not become apparent until or unless thunderstorms develop (invisible comma; Figure 215). In these instances, conventional data must be used and close watch maintained for the first signs of line of cloud development on the satellite imagery. The activity is triggered by the approach of the PVA area over lower level moisture and stability fields. As thunderstorms develop, low-level moisture is transported upward, and in time, the comma shape becomes evident.

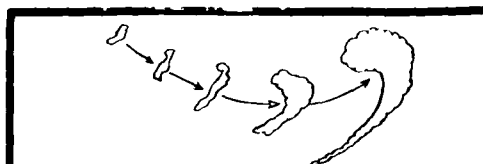


Figure 213: Classic Comma

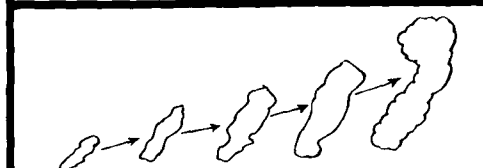


Figure 214: Blob or Band Comma

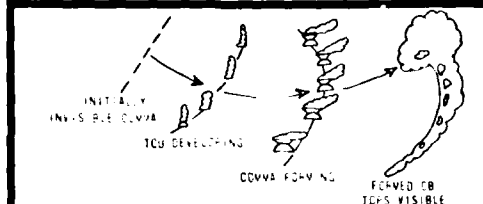


Figure 215: Invisible Comma

Synoptic Examples:

• Example 1 (Figures 216 and 217) - In satellite photos, smaller short wave troughs interacting with a large storm system often develop along the main troughline as noted by the arrow in Figure 216a. Several of these small commas may form and move eastward to produce increased cloudiness and precipitation for several hours behind the main system. On the surface analysis, Figure 216b, these secondary commas are reflected by showery precipitation (thunderstorms may occur if conditions are favorable) along and ahead of a wind shift trough. Each successive comma brings with it a new surge of precipitation, colder air and accompanying gusty winds. Figure 217 reveals a springtime event; a small vorticity comma system (arrow) is rotating through an old mature system. The small comma is composed of thunderstorms.

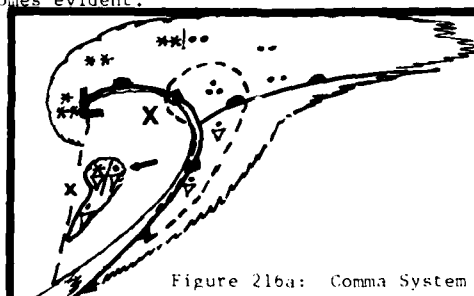


Figure 216a: Comma System

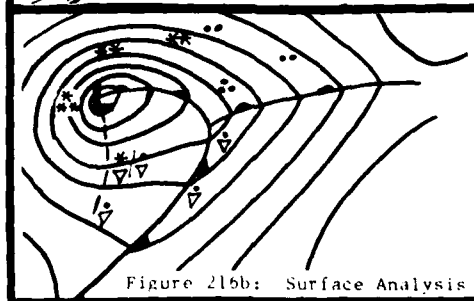


Figure 216b: Surface Analysis



Figure 217: 1500Z 29 March 1971



Case Study (Figures 217 through 222) - The 500mb analysis (Figure 217; height falls and the height fall center (X) are included) and the surface pattern (Figure 221) depict the synoptic conditions several hours prior to comma cloud development. In Figure 219, a short wave system is approaching the southern plains. At the surface, Figure 221, a large area of precipitation (PVA) within a disorganized pressure pattern is shown across the Great Plains.

In the first satellite picture of this series, Figure 217, two hours later than Figures 217 and 219, a disorganized mid-level cloud formation, indicated by the area A, appears behind the ill-defined, synoptic-scale comma system (and higher tops) over Texas.

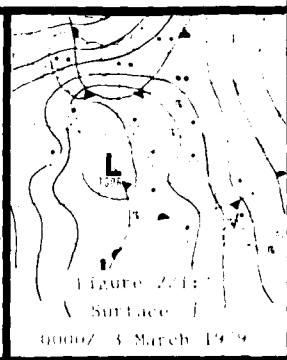
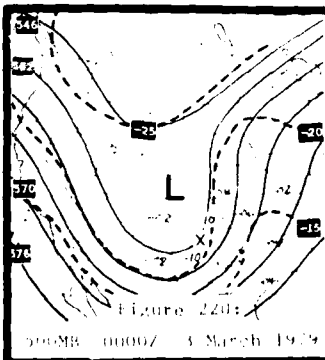


Figure 218, Figures 217 and 219 - The pattern of mid-level clouds (height falls) is centered with upper level height falls, mostly across the southern plains and Great Plains. In Figure 218, a large PVA area is located over the Great Plains and large amounts of cloud moisture have built up well ahead of the approaching trough system. In fact, a vorticity comma cloud level is ahead of the vorticity maximum (X) over New Mexico or west Texas. An increased moisture is encountered by the vorticity center. Generally, at the surface, in its organized low pressure pattern with stationary frontal systems lie within the PVA area. Figure 218 shows an example of the defined large comma cloud located over the Great Plains, and a well-defined vorticity comma system (X) over New Mexico is part of the storm system. Organization and intensification of the storm system can be expected (and often recedes toward the northeast) as the vorticity comma moves into the stationary PVA area. Let's look at a case study.

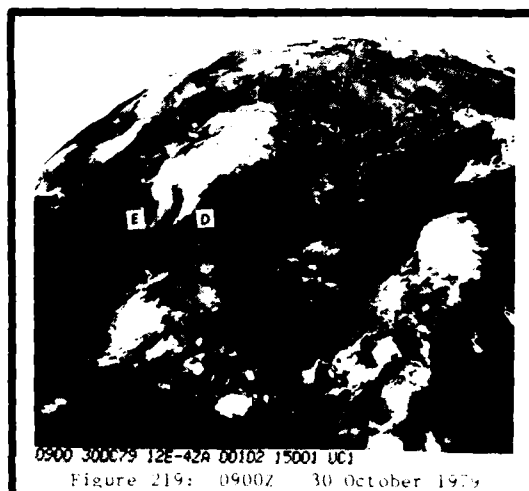


Figure 219: 0900Z 30 October 1979

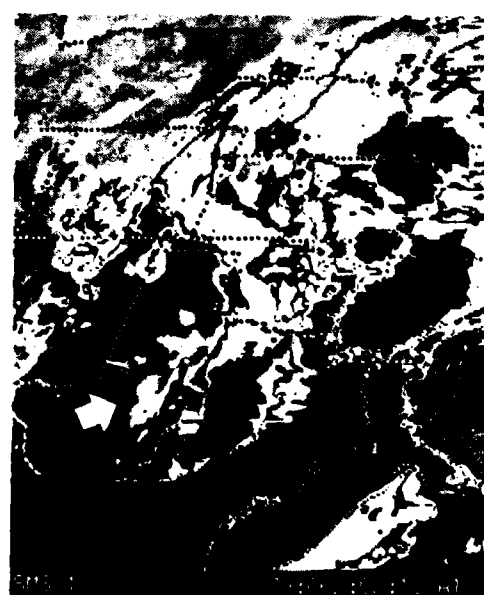


Figure 222: 0210Z 3 March 1979

SM5 1 79:062:02:55 A1

SMC 1 79.062.07.55.01

• Example 5 (Figure 223) - This example, Figure 223, shows a vorticity maximum (X) moving across a comma tail to enhance cyclogenesis within a PVA area. Look for a "S" shape configuration developing along the west side (cold air side) of the comma tail as the vorticity maximum and jet stream maximum approaches the tail. A vorticity comma will develop beneath the higher level baroclinic zone cirrus layers unless the comma is formed by thunderstorm cirrus plumes; the following case study depicts such an event.

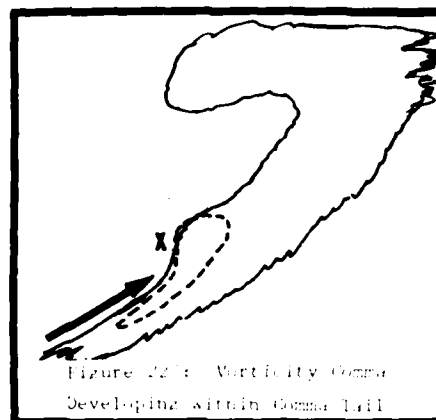
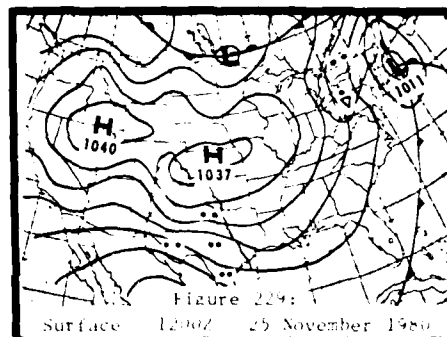
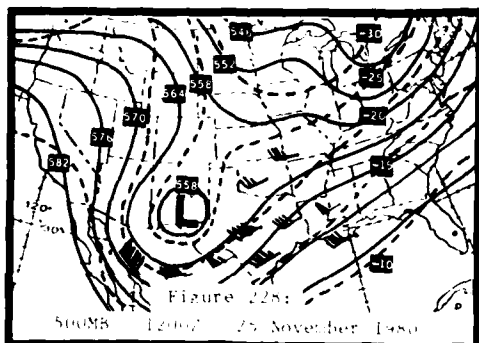


Figure 223: Vorticity Comma
Developing within Comma Tail

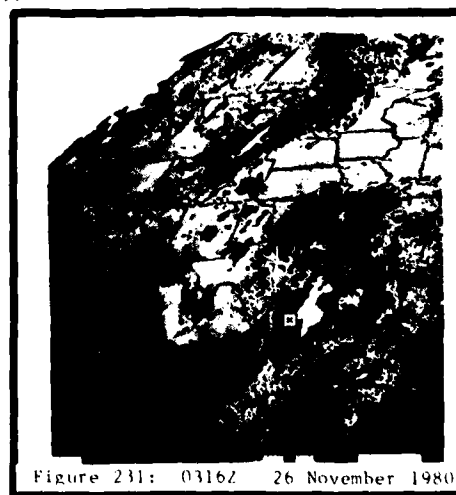
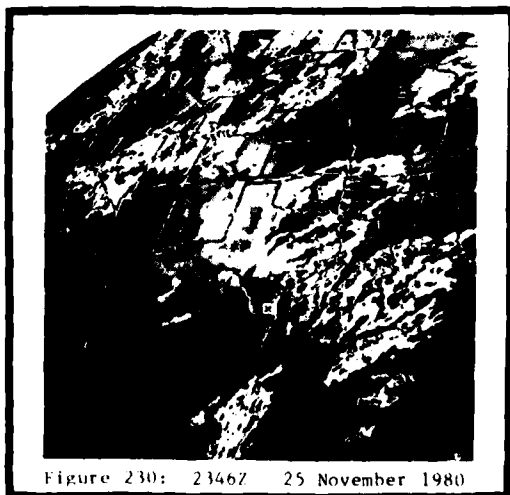
• Case Study (Figures 227 through 231) - This particular example resembles the case study shown in Example 2 in several ways: an upper trough system is approaching Texas and the Gulf Coast and a large PVA area (becoming a synoptic-scale comma system) is evident across the south-central U.S.

Figures 228 and 229 respectively depict the 500mb and surface analyses 12 hours prior to vorticity comma formation. In Figure 228, an upper low system is approaching Texas. The surface pattern (Figure 230) reveals the presence of an extensive high pressure zone across the U.S. Precipitation is occurring from central and west Texas westward to the Rocky Mountains - a reflection of increased PVA ahead of the approaching short wave system and upslope flow.



The first IR satellite picture of the series, Figure 230 (approximately four hours prior to comma cloud development and 12 hours later than Figures 228 and 229), a vorticity center noted at X over southern Texas is approaching the tail of a developing comma system located across the southern plains and lower Mississippi Valley.

Approximately four hours later, Figure 231 (note: different enhancement curve), the large area of PVA has become organized and has taken on a comma shape appearance. The apparent circulation center appears to be located over north-central Texas indicated by the L; the rotation center noted at X is shown off the Texas coast. The highest cloud tops observed (white in this particular enhancement) are apparently a result of thunderstorm plumes. A "S" shape along the cloud edge is apparent to the right of the X in Figure 231.



The subsequent series of satellite photos shown in Figures 231 through 234 reveal the development of a vorticity center within the core of Figure 230. In Figure 231, note cirrus fingers over the eastern end of the comma head. (See pattern of Figure 230.)

Figures 231 and 232 respectively depict the initial stages of the development of a vorticity center after tall vertically oriented cloud levels are shown in Figure 230. In Figure 232, a feature with a developing center in the vorticity center system shown in Figure 230 is well defined. About 12 hours later, Figure 233, the organized storm system has moved to the eastward of the comma head area.



Figure 232: 0346Z 26 November 1980



Figure 233: 0416Z 26 November 1980

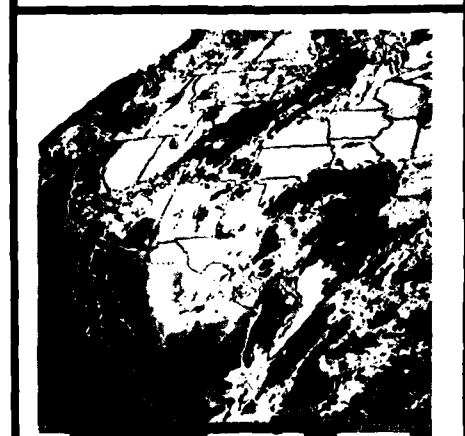


Figure 234: 0516Z 26 November 1980

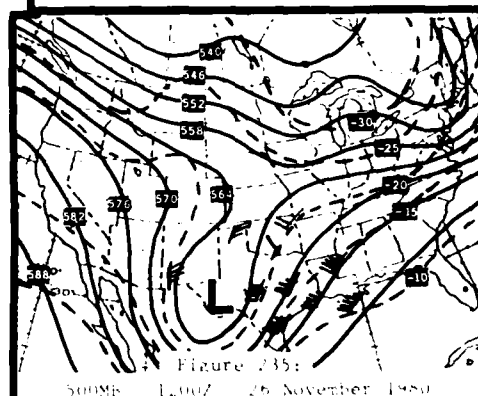


Figure 235:
500mb 1200Z 26 November 1980

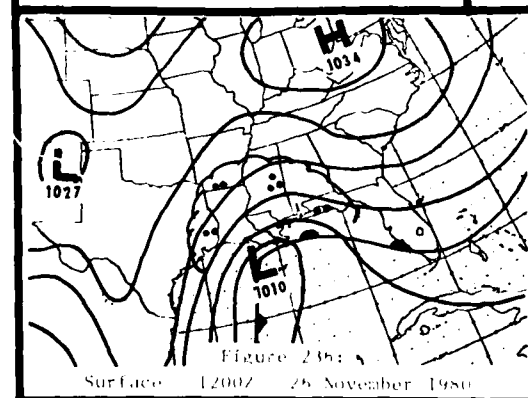


Figure 236:
Surface 1200Z 26 November 1980

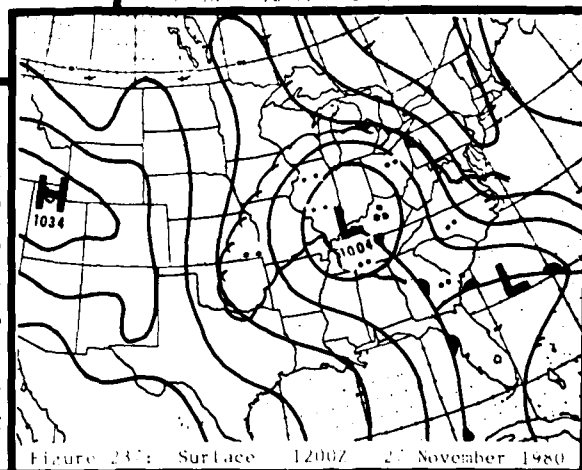


Figure 237: Surface 1200Z 27 November 1980

In this particular example, the vorticity center moved into the comma tail rather than the comma head and triggered thunderstorms. In previous discussions it was mentioned that, typically, the southern end of a comma tail has lower cloud tops excluding convection. The lesson learned in this example is that each system is different and the relationships between large comma and small vorticity comma systems will have many variations.

• Example - (Figure 238) - This pattern is common during the cold season across the eastern one-third of the U.S. when long wave trough systems prevail. Short wave systems, moving rapidly south-eastward from central Canada across the Great Lakes area, induce waving and cyclogenesis along the older baroclinic frontal zone. (Note: This pattern and several other similar patterns will be shown in Part III, Patterns of Cyclogenesis.)

In Figure 238a, the approaching short wave's vorticity comma system (B) generally is not well defined as it moves southeastward towards the base of the major trough system. It may appear as a band, blob (or enhanced cumulus cluster) as shown earlier in Figure 214. The satellite picture, Figure 241, illustrates a band configuration of the short wave comma system (B).

Later, Figure 238b, as the vorticity center moves into the long wave trough, the comma becomes well defined, and induces a "S" shape (developing surge region noted by the arrow in Figure 238b) which produces frontal waving and cyclogenesis along the old frontal zone.

• Case Study 1 (Figures 239 through 241) - Figures 239 and 240 respectively depict the 500mb and surface analyses several hours prior to the satellite picture shown in Figure 241. In Figure 239, a long wave trough system is noted; short wave troughs would be difficult to locate within this particular pressure pattern. At the surface, Figure 240, frontal cyclogenesis has begun; the primary low for continued development is likely to be the Pennsylvania low. The satellite picture, Figure 241, shows a short wave comma cloud (b; see Figure 214) located over eastern Pennsylvania approaching the large baroclinic zone. This short wave system has induced frontal cyclogenesis; the short wave is reflected at the surface (Figure 240) by the secondary east-west trough system located across the Great Lakes.

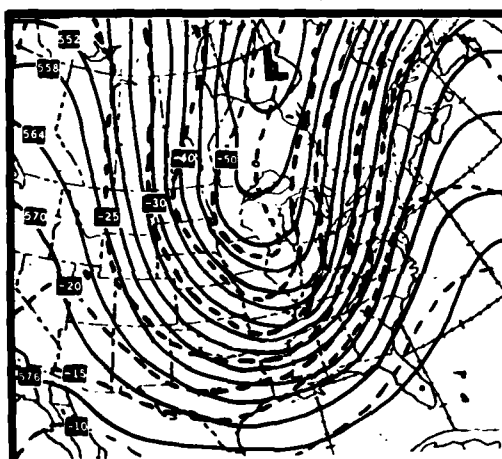
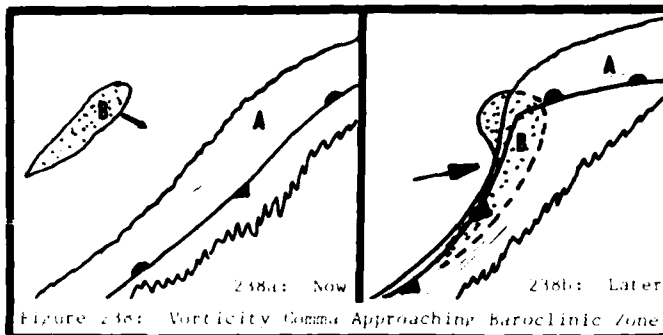


Figure 239: 500MB 1200Z 2 February 1981

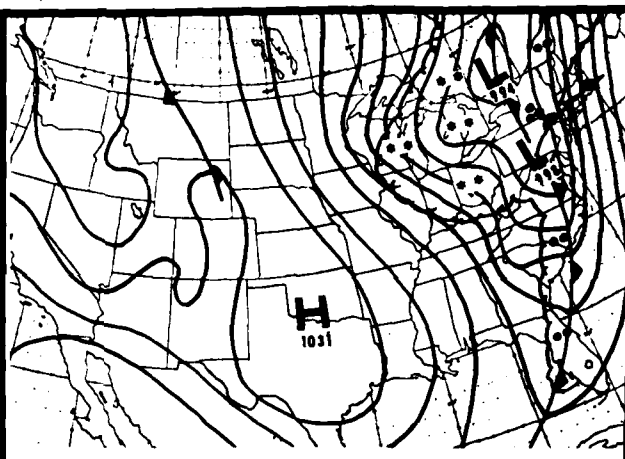


Figure 240: Surface 1200Z 2 February 1981

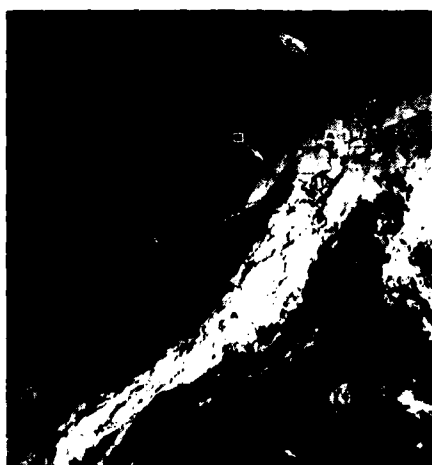
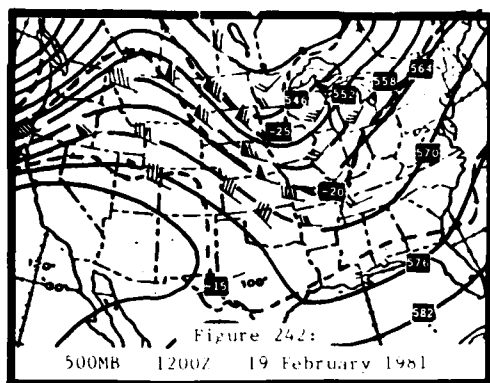
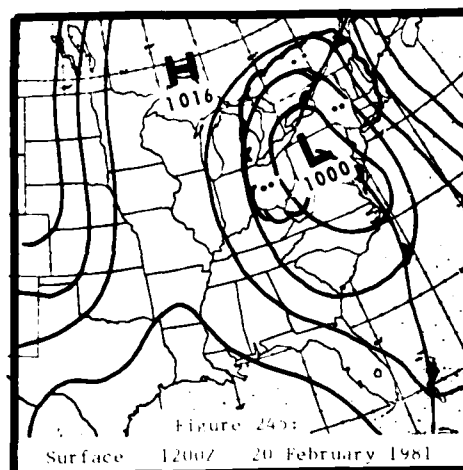
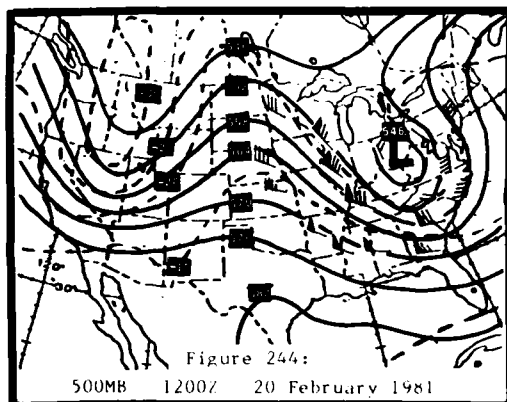


Figure 241: 1430Z 2 February 1981

• Case Study 2 (Figures 242 through 245) - In this example, the upper trough system is not as pronounced as the trough system shown in the previous example. The 500mb analysis, Figure 242, approximately seven hours earlier than the satellite picture shown in Figure 243, reveals a strong 500mb jet stream (75-80 knots) over the upper plains states moving southeastward towards the Mississippi Valley area. This jet maximum undoubtedly reflects a short wave within the flow, but it is difficult to find in Figure 242. The satellite photo, Figure 243, however, gives a clue of the short wave's presence - a developing comma cloud located over Illinois as noted by the arrow. At the time of the photo, the vorticity comma is composed mostly of a cluster of enhanced cumulus. Soon, it will move into the stationary baroclinic zone noted over Indiana and Michigan and eastward. Frontal waving has already begun as shown in Figure 243.



Figures 244 and 245 respectively show the 500mb and surface analyses the next morning. A 500mb closed low is shown over Ohio in Figure 244. In Figure 245, the upper low is reflected at the surface in central Pennsylvania.



• Example 5 (Figures 246 through 251) - During the warm season, weak trough systems (and weak vorticity centers) may have little, if any, mid and high level baroclinic cloudiness accompanying them. When the vorticity center moves into and over a moist, unstable area, convection develops. The anvil plumes may reveal rotation; this is shown in the following sequence of pictures.

Figures 246 and 247 respectively depict the 500mb and surface patterns during the morning prior to increased convection. In Figure 246, a weak low system is shown over the central Great Plains, however, it is not reflected at the surface in Figure 247.

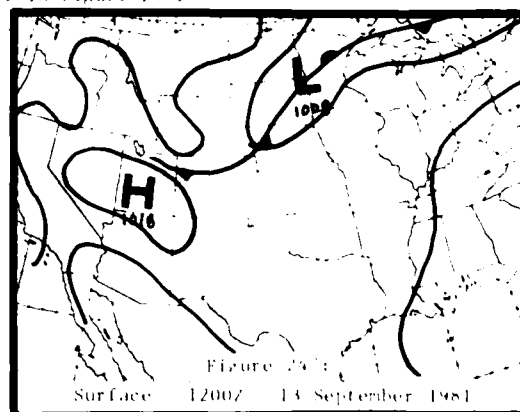
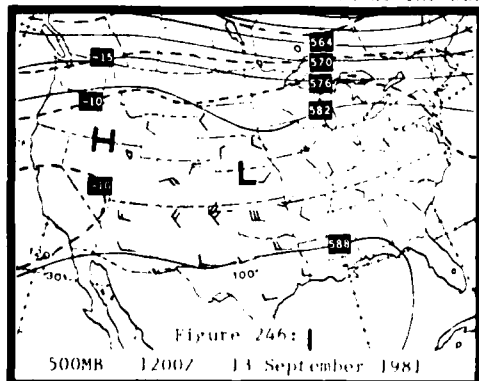


Figure 248: 1530Z 13 September 1981. This image shows a satellite view of a cloud system over the North Atlantic. The cloud system is characterized by a dense, bright white area in the center, surrounded by a darker, more diffuse cloud mass. The image is labeled with the time 1530Z and the date 13 September 1981.

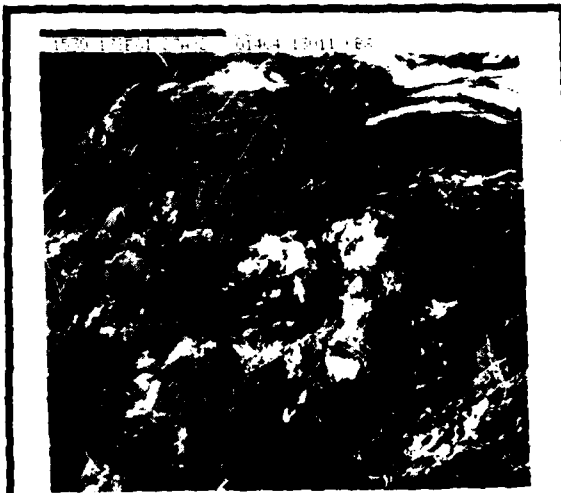


Figure 248: 1530Z 13 September 1981

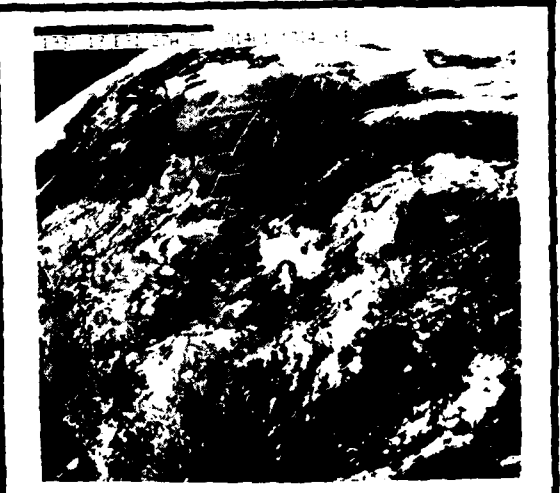


Figure 249: 1630Z 13 September 1981

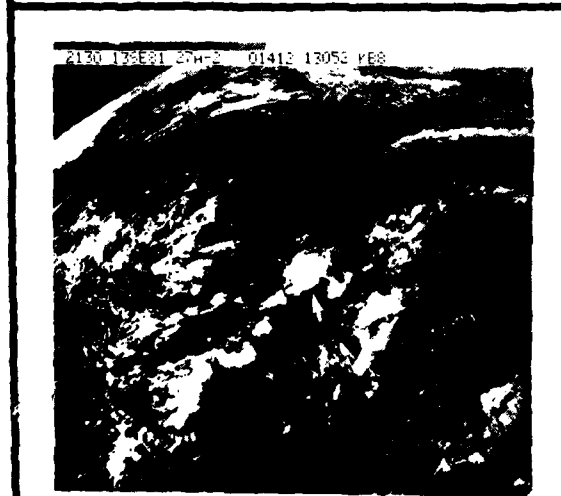


Figure 250: 2130Z 13 September 1981



Figure 251: 2230Z 13 September 1981

SECTION 1: Deformation Zones

Deformation zone cloud patterns associated with comma cloud systems were presented in some of the preceding sections. In this section additional deformation patterns and their usefulness in forecasting will be shown.

Deformation zones are neutral points in the atmosphere's motion relative to itself. 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; significant clouds and precipitation are associated with these zones.

In the upper atmosphere, these deformation zones may be found by subtracting the earth's rotation from the wind vector. In Figure 252, the shaded areas mark confluent zones where clouds form. The shape of these clouds depends upon the synoptic pattern, the amount of convergence and the availability of moisture. Figure sequence 253 illustrates some of the more common deformation cloud forms observed in satellite photos (of course, many variations and combinations of these patterns are likely).

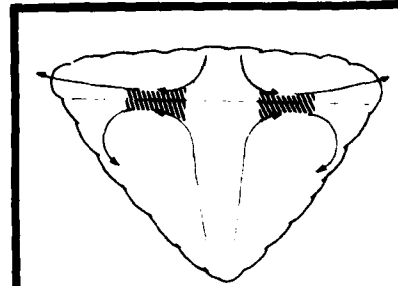
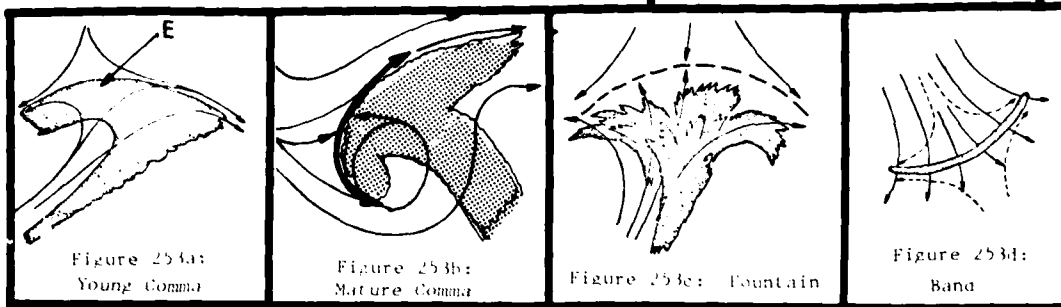


Figure 252: Confluent Zones



Case examples (IR Photos):

The following IR case examples show several deformation shapes related to the patterns shown in Figure 253. Some conventional data is also included.

• Example 1 (Figures 254 and 255) - In Figure 254, the mid level cloud pattern shown over Kansas, Nebraska and the Dakotas resembles the fountain-like deformation zone pattern shown in Figure 253c. Some of the clouds curve cyclonically around a low in western Oklahoma (R; see white large arrow) while the other clouds curve anticyclonically around an adjacent ridge (S; see arrow). The 500mb analysis, Figure 255 shows the high/low pressure combination to produce this deformation pattern. In Figure 254, the deformation cloud band stretches eastward across Iowa to the Ohio Valley area - a reflection of the converging wind flow shown across Nebraska and Iowa in Figure 255.



Figure 254: 0001Z 18 March 1981

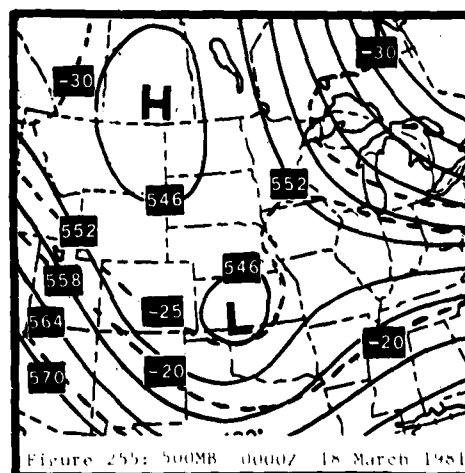
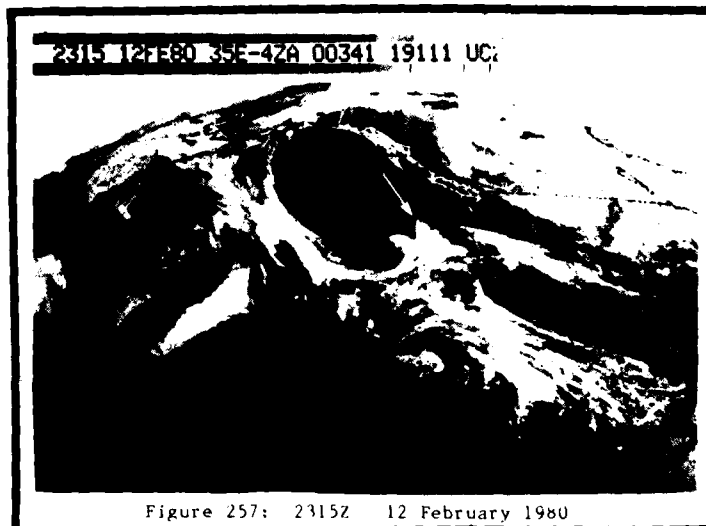
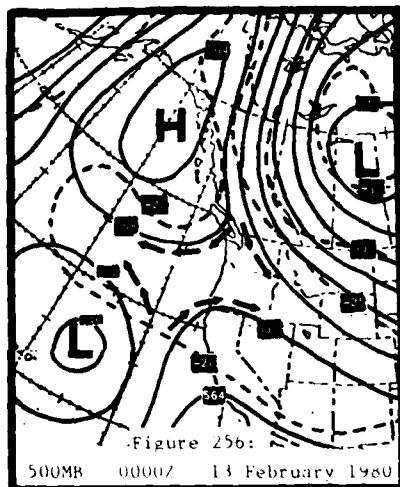


Figure 255: 500MB 0000Z 18 March 1981

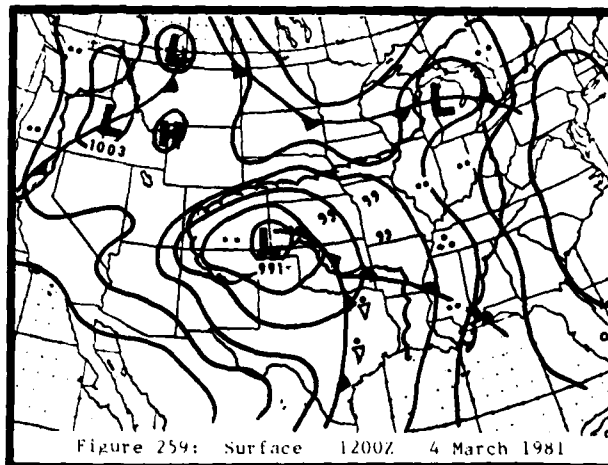
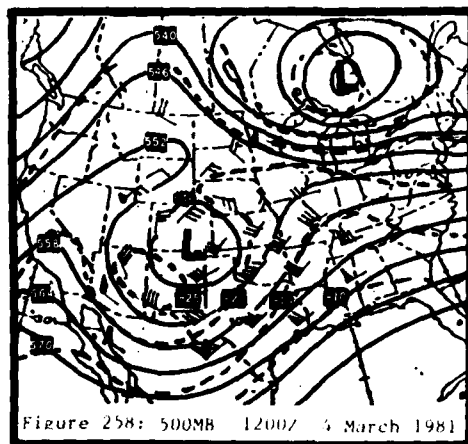
• Example 2 (Figures 256 and 257) - The following example typifies a deformation zone cloud pattern associated with blocking patterns. The high system is poleward of the low. This pattern is observed off the West Coast during the winter season when blocking highs become established across Alaska and western Canada and adjacent ocean areas. Figures 256 and 257 illustrate this pattern. The 500mb analysis (Figure 256) depicts a blocking high in the Gulf of Alaska which has produced a fetch of cold Canadian air into the central U.S. plains. In Figure 257, a deformation zone cloud system, noted by the arrow, is located west of Oregon; it compares favorably with the deformation zone C pattern in Figure 253. Forecasters may use this cloud system feature as a tool in determining either the persistence or the breakdown of the blocking pattern. For instance, if the deformation cloud pattern shown in Figure 257 continues in subsequent photos, then there is no apparent change in the blocking high pattern. Conversely, if the deformation cloud system shown in Figure 257 begins to dissipate or shift to another area, too, upper level changes are occurring.

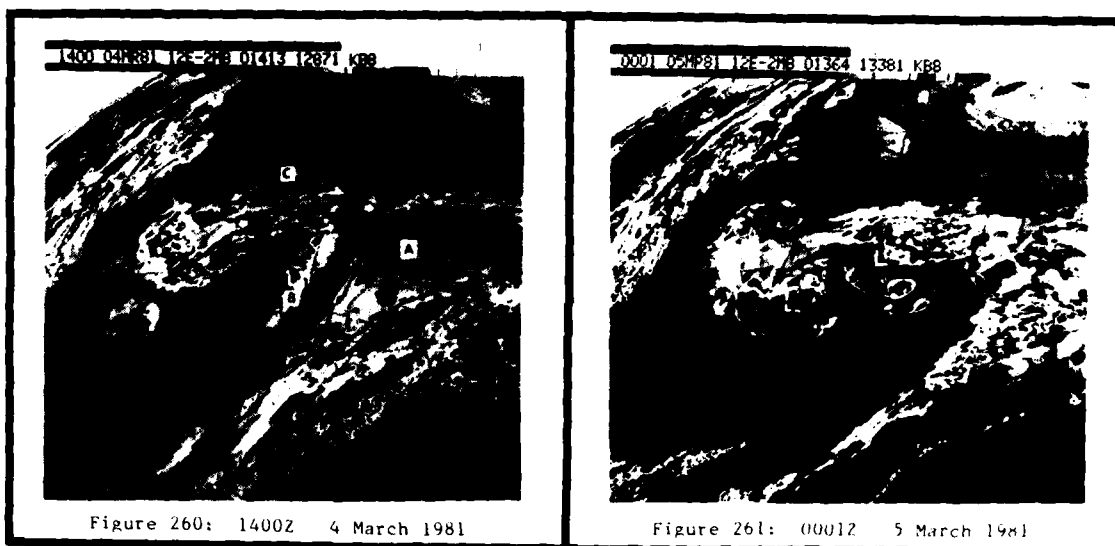


Elongated Mature Comma Deformation Zone Cloud Bands (Figures 258 through 260):

Forecasters should pay particular attention to deformation zone cloud bands which stretch some distance upstream from the main comma system (see points C in Figure 260). In these cases, the associated vorticity comma and baroclinic zone cloud system continue to move eastward while the vertically-deep upper low lags behind. Eventually the old low dies and a new low develops further to the east. An example follows:

The 500mb and surface analyses (respectively Figures 258 and 259) portray the synoptic events during the morning hours. An upper closed low and its related surface storm are shown emerging from the southern Rockies. Two hours later, the satellite photo, Figure 260, reveals the cyclonic circulation of the storm system over Kansas and Colorado. This system's comma shape is somewhat ill-defined; the baroclinic zone (A) appears to have separated from the deformation zone cloud band (C) within the col area of the comma head over eastern Iowa. The vorticity comma system, noted at B, appears as a cloud band.





The separation of these cloud systems and the long, stretched deformation zone cloud system noted between points C is an indicator that upper level changes are likely to happen. Ten hours later, Figure 261, two circulation centers are noted. The old center, marked by the dashed white L, is decaying while a new center is forming over southern Missouri (solid white L).

The above sequence occurs more often over the eastern U.S. Old, vertically-deep occluded lows over the Great Lakes slow down and fill while a new frontal storm system develops either along the East Coast or offshore (or a combination thereof).

Deformation Clouds Forecast Movement of Low:

Trying to forecast the short range motion of closed upper-air lows using upper air charts may be difficult; objective analyses often miss important details by being too smooth. However, satellite pictures can be of great help especially if a good band of deformation cloudiness exist upstream from the closed low.

The reasoning is: if a closed low exists, there is a splitting of the flow (deformation) upstream from the low. When the low center is essentially stationary, the deformation field will remain strong and the associated deformation cloudiness will persist. However, if the low center is on the move the deformation cloudiness will decrease with time (3).

(NOTE: Currently, investigations regarding significant turbulence within areas of upper level deformation zones are being done by NESS.)

SECTION 8: Convective Weather

GOES satellite data is one of the most powerful tools available to help forecasters isolate areas in which convective and severe convective weather is occurring and, in addition, can be a very powerful short range forecasting tool to the astute forecaster.

There really is no magic involved. As you have learned in school, convective activity requires moisture, instability, and a trigger. This section will concentrate on helping the forecaster to search out the clues that will lead to correctly forecasting thunderstorm outbreaks.

Upper Level Divergence

Severe convective weather is frequently associated with a high level divergence zone between the subtropical jet and the southern branch of the polar jet (Figure 262). Since these two jet streams are at different levels, it is often hard to locate them both on the same constant pressure charts. The cirrus shields and bands shown in infrared photos are an excellent way to locate jet streams (see pages 20-27). Figure 263 illustrates this principle. A diffluent area between these jets encompasses an area from the central plains eastward to the East Coast. Thunderstorms are visible from Oklahoma to the Great Lakes as noted by the arrows. The diffluent/threat area shown in Figure 263 covers a large area; forecasters must still locate the most likely area where convection will fire (low-level moisture, instability, convergence, etc.) within these large diffluent areas.

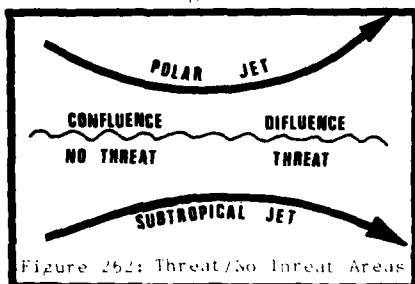


Figure 262: Threat/No Threat Areas



Figure 263: 2200Z 28 April 1981

Low-Level Convergence (Figures 264 through 269):

Many of the most severe outbreaks of convective activity occur along squall or instability lines which develop in the convergence zones in advance of cold frontal systems; an example is shown and noted by the arrow in Figure 264. The first activity usually develops on the western side of the low-level convergence zone and travels eastward. The reason for this is that the vertical motions are stronger here, the moisture content is highest here, and the solar insolation reaching the ground is greater in the clear air just to the west of this region. The convergent zone is usually visible, though it sometimes is quite far in advance of the cold front (see Figure 264). If the low-level clouds are visible, you will frequently see a wedge shaped zone of small cumulus clouds streaming south to north and perhaps spiraling towards the center of the advancing low pressure system. If a cirrus shield exists, forecasters may have to rely on the conventional wind data and stream line analyses to determine the areas of greatest low-level convergence and on dew point analysis to locate areas of greatest humidity to determine the most active regions. The degree of instability must be obtained from Skew-T charts.

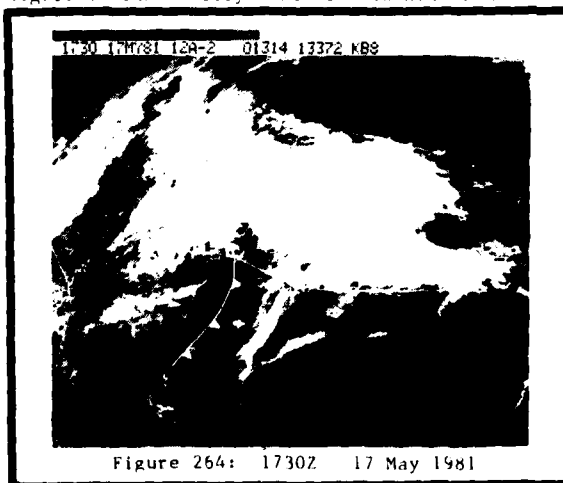


Figure 264: 1730Z 17 May 1981

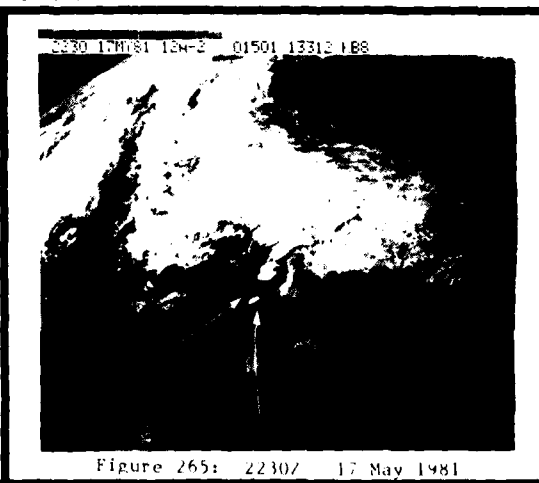


Figure 265: 2230Z 17 May 1981

Figure sequence 19 through 26 illustrates the evolution of the storm system through convergence. In this sequence, a squall line is established in the PVA region (Figure 24) with extensive overrunning of the east-west wind front. A squall line is also seen as it is being riveted by moisture from the Gulf of Mexico. This is the first squall line in the sequence. First thunderstorms occurred in the PVA region (Figure 25) and the squall line (Figure 26) are fully developed. The squall line is located in the central Oklahoma into northwestern Missouri. The front area is characterized by a line of clouds with arrows pointing to the area of maximum development. This line is oriented eastward throughout the night and was evident in Arkansas on the day of 18 May (Figure 27) and Figure 28).



Figure 264: 1800Z 18 May 1981



Figure 267: 1830Z 18 May 1981

Further development occurs along the outflow boundaries (see outflow boundaries in next page) south of the bearing squall line (A, Figure 26) and are also evident in the PVA stratus north of the wind front (B, Figure 26). The new squall line which developed along the outflow boundary moved eastward into northern Mississippi the following day, and triggered new activity in western Tennessee (C, Figure 26) and (D, Figure 269). As the squall line moves eastward away from the front, new convection develops back to the west along the dry line close to the front (C, Figure 27) and (D, Figure 269). Thunderstorms in the midstratus region continue to persist (E, Figure 27) and (F, Figure 269). With time, they tend to organize into a comma-shaped system apparently associated with the PVA margin of the storm (G, Figure 269).

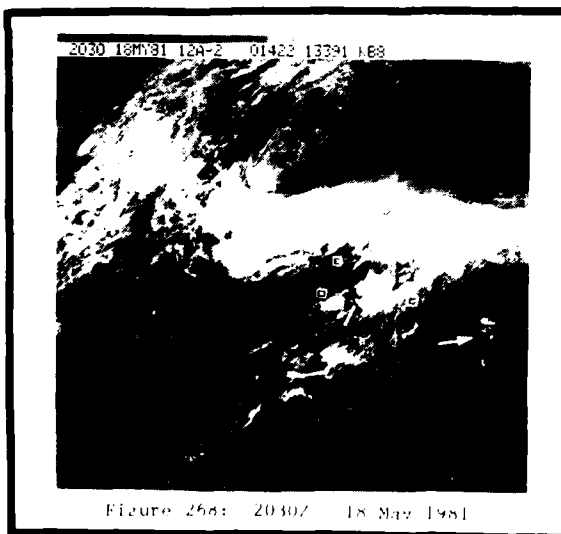


Figure 268: 2030Z 18 May 1981

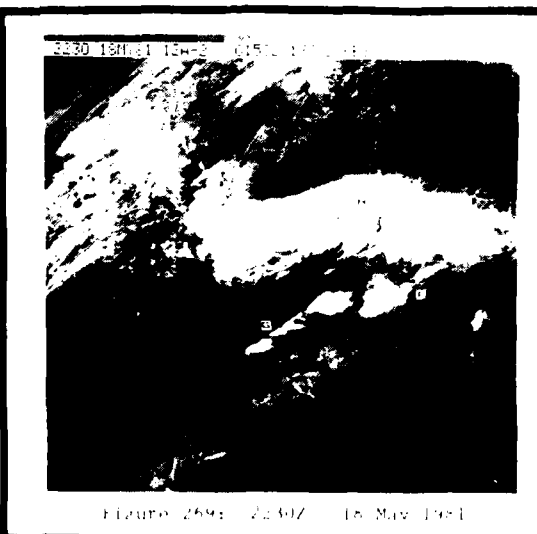
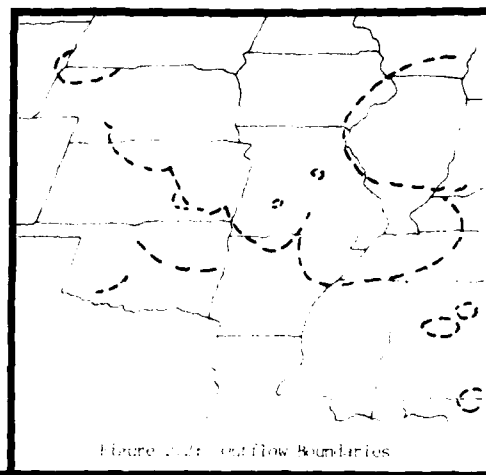
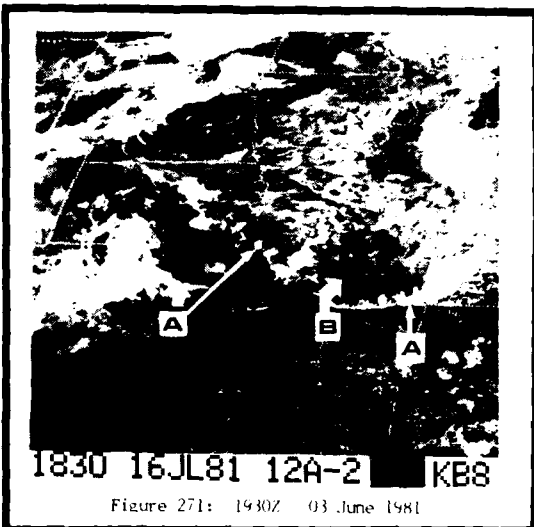
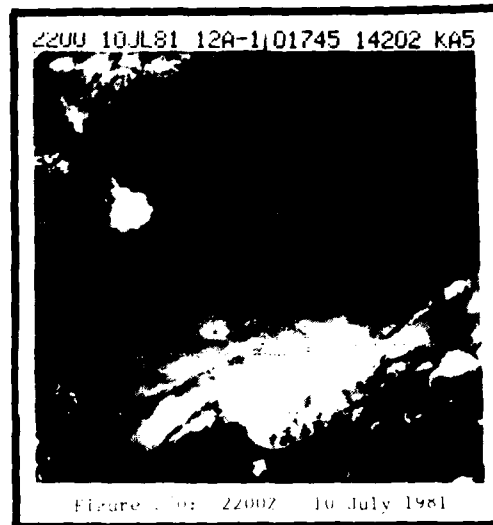


Figure 269: 2230Z 18 May 1981

Outflow Boundaries (Arc Clouds):

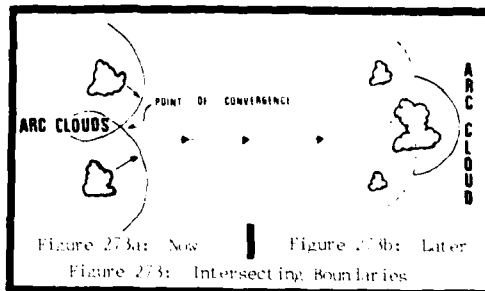
Satellite pictures have proven that thunderstorms usually develop in areas which receive maximum solar insolation (cloud-free areas). As these storms dissipate, they produce an outflow boundary similar to a "mini" cold front (often called a gust front or arc clouds) as they dissipate. Figure 2-2 illustrates an outflow boundary across northern Mississippi and Alabama (see arrow). During the warm season, outflow boundaries can be seen on most visible satellite pictures such as shown at A, Figure 2-1. The irregular dark areas within the arc-like streaks are areas of drier, cooler air (downrush) located behind these outflow boundaries (B, Figure 2-1); the parent thunderstorm has dissipated and is no longer visible. In Figure 2-1, new convection is forming along the outflow boundary. In Figure 2-2, the dashed line indicates the leading edges of outflow boundaries noted in Figure 2-1. (Note: Many outflow boundaries appear much smaller than the boundary at A in Figure 2-1. Several small boundaries are noticeable in Alabama and Missouri in Figure 2-1.)



Intersecting Boundaries and Convergence:

The outflow boundaries move away from the base of the parent cloud and interact with outflow boundaries from other such storms (Figure 2-3 a and b) or with existing boundaries such as fronts, sea breeze fronts, moisture ridges, etc., to cause new thunderstorm development (after Purdom, 1979)(1). The new storms are likely to be more severe than their parents due to the added energy of low-level convergence.

Some of these outflow boundaries have long lives (some have been recognizable out to 8 to 10 hours) while others can be monitored for only two to three hours. The greater the intensity of the parent thunderstorm, the more obvious and long-lived the outflow boundary. Forecasters must be aware that cirrus will obscure their view of outflow boundaries on many occasions, but they must not forget that these boundaries still exist and should be considered in the short range forecast for the area. They must also remember that convective cloud development is especially dependent on the time of day so they must maintain continuity on features that are located in their area of interest using conventional data. Let's look at a case study.



• **Case Study (Figures 2-4 through 2-7)** - Figure 2-4 shows the location of the things discussed above. Starting at 1401Z, Figure 2-4, the photograph shows an area of intense convection over eastern Texas and Louisiana; there is a noticeable lack of weather outside of this convective zone. From the previous day's photos and current maps, we know that an old frontal boundary exists westward from this convective zone across north-central Texas. Also, the sea breeze front was well established on the satellite pictures on the previous day. In both cases, clouds are not evident because of the time of day.

1401 28JUL80 134-1 03601 14274 64059

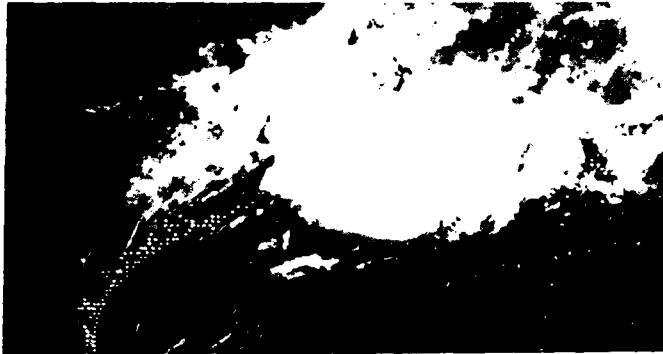


Figure 2-41. 1401 28 JUL 80

Figure 2: The effect of the number of nodes on the performance of the proposed algorithm.

1601 28JUL80 12A-1 03654 1427

A

D

E

G

Figure 2(b): 1601Z 28 July 1980.

Figure 10: 1947 - 18 July 1950.

1901 38JUL80 12A-1 037

A

B

C

D

E

Figure 1. (A) Large mass. (B) Small mass. (C) Line. (D) Point. (E) Point.

11. *Phragmites australis* (Cav.) Trin. ex Steud.

1. *Chlorophyll a* (Chl *a*)

Again, there is no such, to severe weather analysis and forecasting as long as you know that it takes instability, moisture and a trigger. This case study clearly illustrates that meteorological logic can be applied to the clues obtained from the photographs to provide top quality weather warning and MIA&D service for convective activity.

Organized Convection

Most of the information we have discussed considers possible "triggers" (usually, thunderstorms will develop in lines associated with "trigger" atmospheric features - see photograph). These thunderstorms are most likely to be the real severe weather weathering factors - perhaps even tornadoes. The trigger is not always evident in conventional data, maybe not even on satellite data. Forecasters must observe the clouds and look for evidence of any organized convection.

An example is shown in Figure 275 (see arrow). In Figure 275, numerous fair weather cumulus clouds exist throughout the central U.S., but appear to be enhanced more actively in eastern Missouri. Two hours later, a squall line has developed in western Missouri (see arrow, Figure 279). The point is: Forecasters should be wary of thunderstorms in squall lines which develop along lines - the forecast may make many save lives.

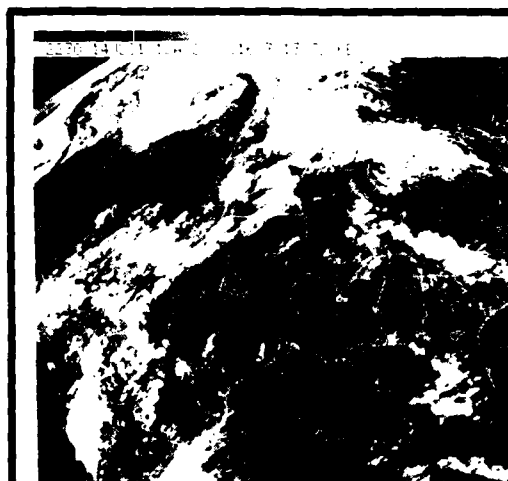


Figure 275: 2030Z 14 July 1981

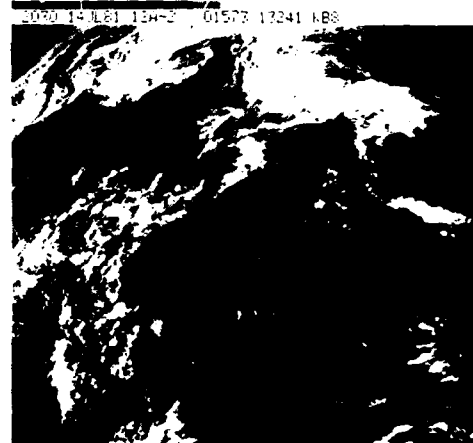


Figure 279: 2200Z 14 July 1981

Mesoscale Convective Complex (MCC):

Organized, persistent areas of deep convection are noted in satellite photos during the warm season, especially over the central areas of the U.S. These thunderstorm areas, referred to by Maddox (6) as mesoscale convective complexes (MCCs), are shown in the following figures.

Mesoscale convective complexes usually begin as a group of cells forming within a moist, unstable zone during the afternoon hours. The triggers, besides surface heating, may be low-level convergence zones, dry lines, fronts and the Rocky Mountains. Figures 276 and 277 depict a Rocky Mountain event. In Figure 280, many developing cells are noted in the arrows across eastern Colorado and Wyoming.

The cells continue to grow and merge (and, still going through their life cycles, large amounts of moisture are transported into the upper levels by these cells, and eventually combine to produce an apparent single monster as noted by the arrow in Figure 281, seven hours later than Figure 280). These systems continue to grow throughout the night (a few hours producing numerous thunderstorms and heavy precipitation over a given area). They eventually fade as the result of severe thunderstorms with tornadoes and hail, but this type of weather rarely persists once the nocturnal MCC has developed.

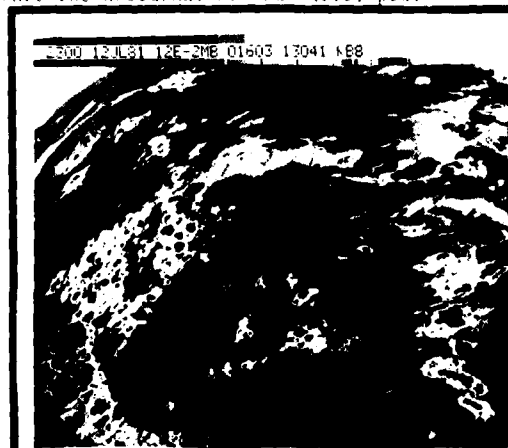


Figure 280: 2300Z 12 July 1981

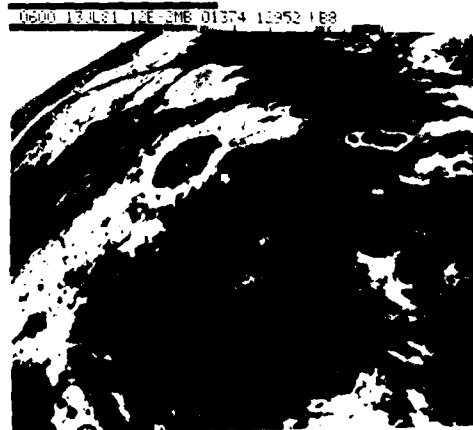


Figure 281: 0600Z 13 July 1981

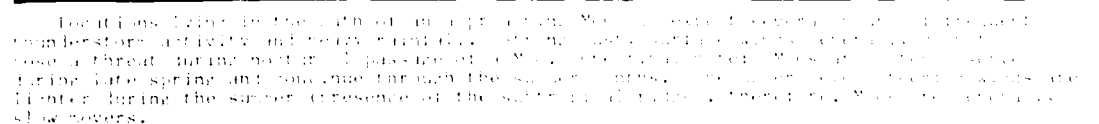




Figure 1881: 1800Z 12 February 1981



Figure 1882: 1800Z 14 May 1981

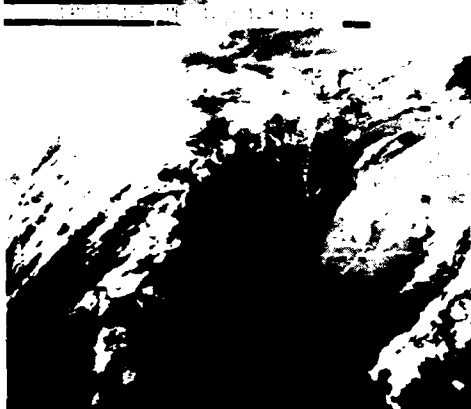


Figure 1883: 2300Z 14 May 1981

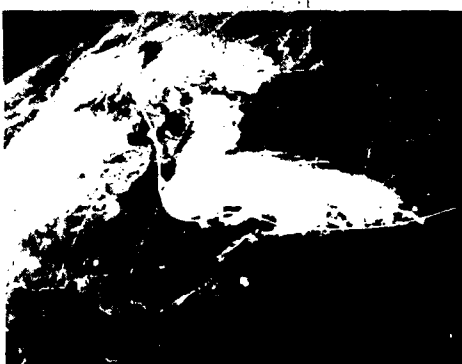


Figure 1893: 1000Z 17 January 1981

In mature comma systems, the occlusion and the fast-moving portion of the cold front are easy to locate; they lie along the western end of the cloud system within the surge region as shown at F in Figure 290. The slower trailing portion of the cold front will be near the frontside of the cloud band as shown at G in Figure 290. Warm fronts are difficult to place across the comma head where a large area of cloudiness exists. Conventional data should be used to locate warm fronts.

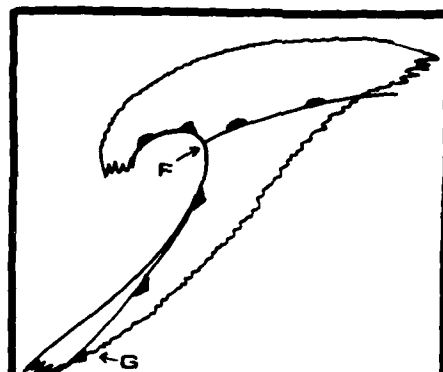


Figure 290:

Example: Frontal Locations

Cutoff Lows:

Cutoff lows appear more often during the transitional periods of autumn and spring because the main belt of westerlies lies across the northern U.S. and Canada. In Figure 291, two cutoff low systems are shown across the southern U.S. occasionally, short-wave trough systems moving through the westerlies extend far enough southward into the central and southern U.S. so that conditions favorable for a closed low circulation are established. Preceding and during the cutoff period, the main jet stream continues to lie to the north although a weaker jet may appear within the closed low circulation. Cutoff lows may occur over any area of the U.S. at any time of the year. They seem to favor the area over the southwestern U.S. and adjacent ocean areas. These systems often move slowly, and it is not uncommon for one to appear continuously on the upper air charts for a week or more. Cutoff lows sometimes appear as a result of blocking patterns and may remain nearly stationary for days until the block has broken down.

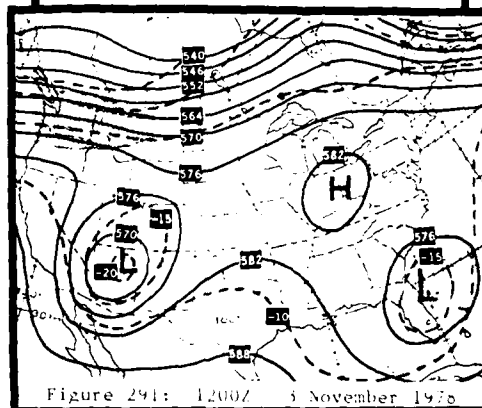


Figure 291: 1200Z 3 November 1978

The surface weather associated with these systems varies and is dependent upon the cutoff low's area of development. Heavy rains and flooding conditions may occur over the central and eastern U.S. for several days when a cutoff low moves into or develops over the south-central U.S. The surface system circulation is generally weak. Widespread fog formation is possible after passage of a cutoff low due to the weak pressure pattern, clearing skies, cooler temperature and a wet surface. Let's look at a case study.

• Case Study - The following cutoff low system affected the central U.S. for at least a week. Satellite and conventional data are included with this autumn event.

Figure 292 depicts the IR satellite photo approximately 12 hours before upper low development. A short wave vorticity system (X), located over the central Rockies, is moving towards a weak, stationary baroclinic zone cloud system (A) lying from Texas to the Great Lakes. The related 500mb Height/Vorticity initial analysis, Figure 293, reveals the Rocky Mountain vorticity system. The baroclinic zone (A) is weak - the vorticity isopleths barely cross the height contours across the central plains.

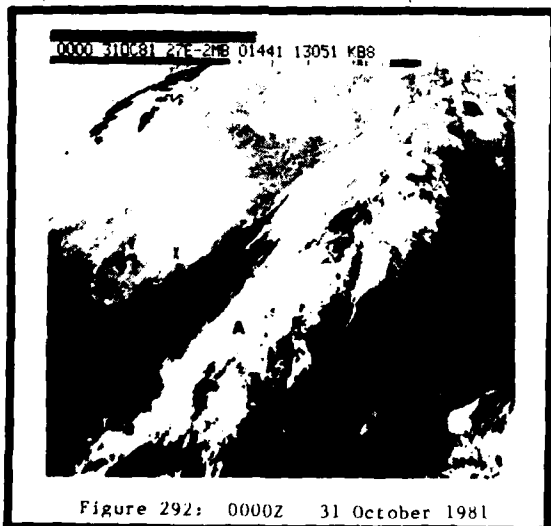


Figure 292: 0000Z 31 October 1981

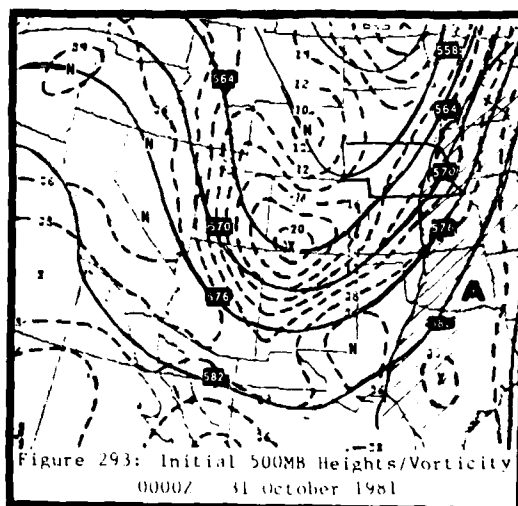
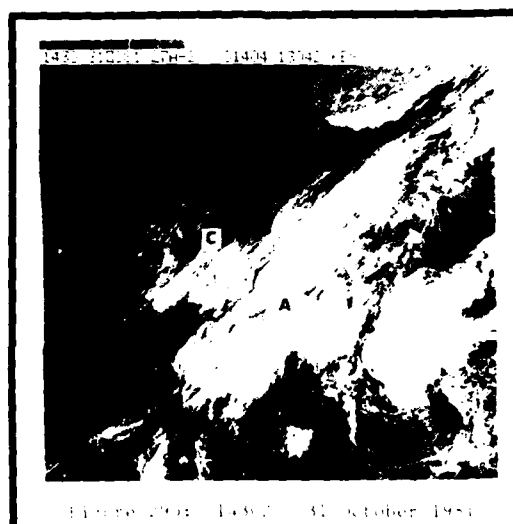


Figure 293: Initial 500MB Heights/Vorticity
0000Z 31 October 1981

stated that it is the "theoretical" information system that defines the "practical" information system. The "practical" information system is the one that is actually used by the organization. The "theoretical" information system is the one that is defined by the organization's management. The "practical" information system is the one that is defined by the organization's users. The "theoretical" information system is the one that is defined by the organization's management. The "practical" information system is the one that is defined by the organization's users.

In the 1:4 photo eight years later, Figure 2b, the northern zone of collapse is expanded, and the great Plains suggesting that sea-level has risen. The tops of the alluvium clays have built up into the gray shales.



File no. 200-14567-31 October 1954

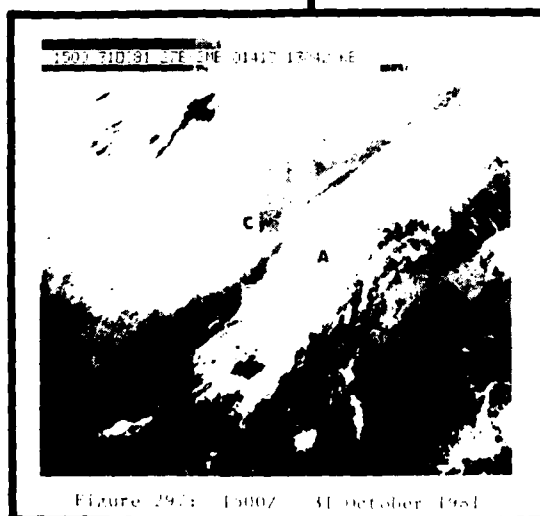
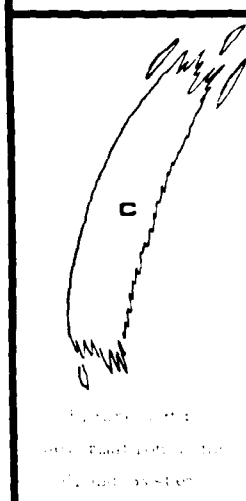


Figure 297: 1500Z 31 October 1951

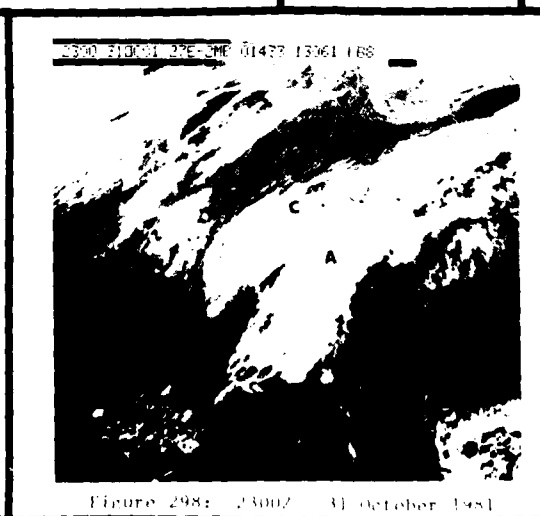
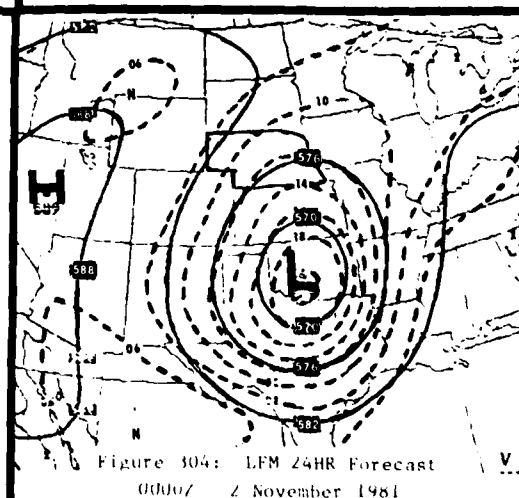
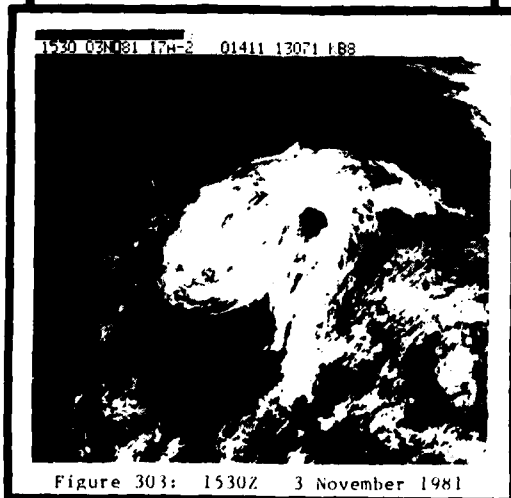
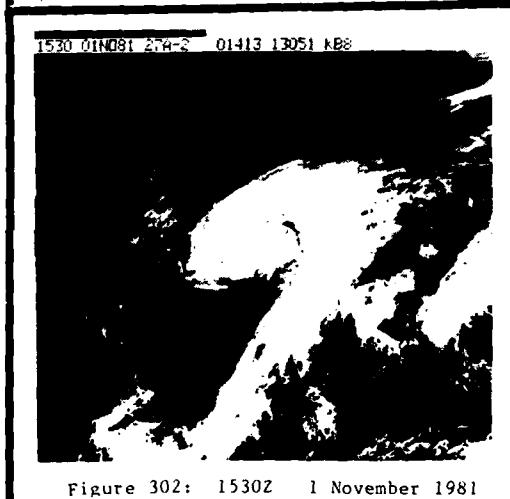
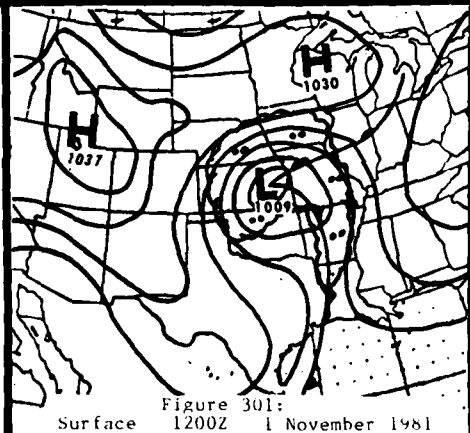
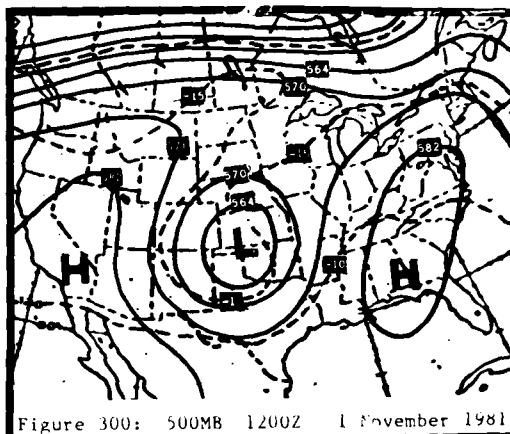
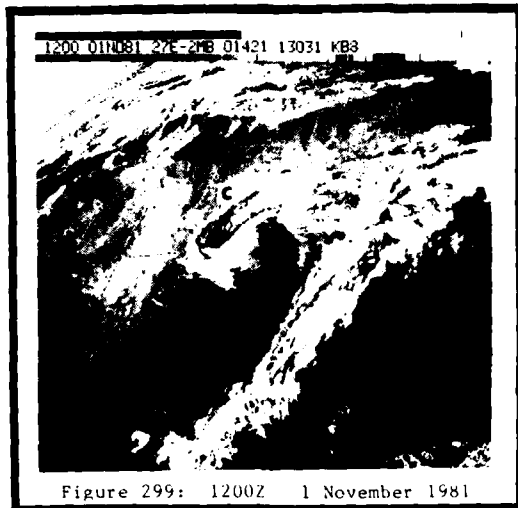


Figure 298: 23007 3) October 1981

The following morning, Figure 299, the deformation zone cloud borders have become better defined and reveal cyclonic circulation. The related 500mb analysis, Figure 300, shows a cutoff low system over the southern Great Plains - a blocking high/cutoff low pattern has evolved - a pattern typical during autumn. Figure 301 depicts the surface pattern - low ceiling and steady rain are noted across the central Great Plains. The visible photo, several hours later, Figure 302, shows a mature cutoff low system. Forty-eight hours later, Figure 303, the system still appears over the same general area but shows signs of dissipation. The low shifted slightly eastward during the next several days and continued to weaken.

Mature cutoff lows often become barotropic (Figure 304) and begin to dissipate. Locations affected by these stagnant systems may experience the same weather conditions for several days in a row. Attempting to forecast the overall movement of cutoff systems is a challenge.



Tropical Storms:

Tropical storms appear on the satellite scene during the warm season usually by late summer. They may, however, appear as early as May. Tropical storm events generally end by late October or early November.

- Western U.S. - Tropical storms are frequently found on satellite photos south of Baja, California such as shown in Figure 305. They form off the west coast of Mexico and Central America. System movement is generally towards the west or northwest dissipating as they move across the vast expanse of the eastern Pacific. Occasionally, however, tropical storms will drift northward or north-westward to affect Baja, California, Mexico and the southwest U.S. (more likely to drift northward during August and September as the subtropical ridge, located over land, weakens and shifts southward). Consequently, increased moisture and instability associated with these systems produces heavy thunderstorms and flash floods over the desert southwest. The effects of these systems may even be felt over the southern Rockies eastward into the Great Plains; the associated cloud systems can be easily tracked on satellite photos.

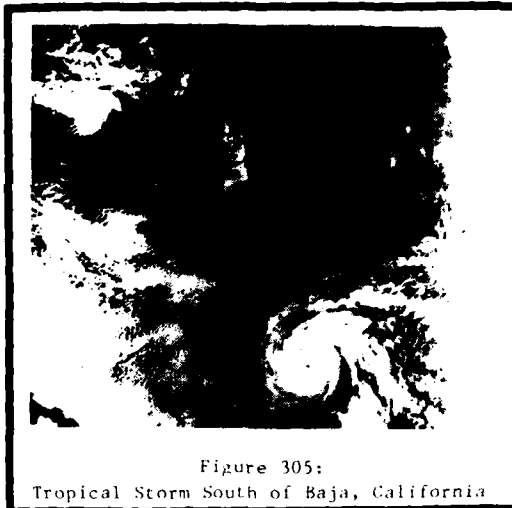


Figure 305:
Tropical Storm South of Baja, California

- Eastern U.S./Gulf Coast - Early warning is generally provided to U.S. interests when tropical storms form within the ITCZ across the central Atlantic eastward to the African coast. On the other hand, coastal forecasters may be surprised by the quick development of a disturbance over the warm waters of the Atlantic Ocean, Caribbean Sea and Gulf of Mexico (Figures 306 and 307, respectively visible and IR photos).



Figure 306: 2000Z 16 August 1981
(T. S. Dennis)

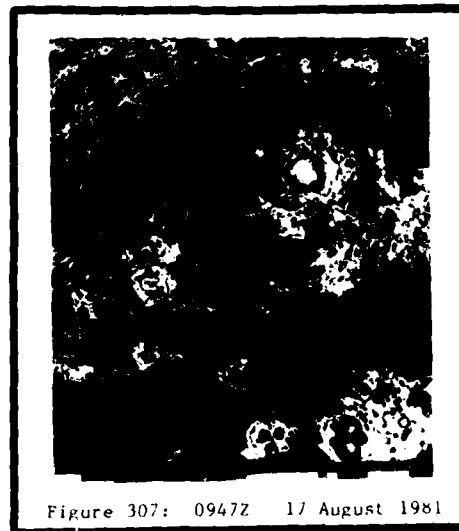


Figure 307: 0947Z 17 August 1981

An example of a Gulf of Mexico event is now shown:

- Example - Forecasters should suspect all disorganized, deep convective cloud systems which appear offshore such as shown across the eastern Gulf of Mexico in Figure 308 (the cloud system shown in Figure 308 is often designated an easterly wave). These systems may be upgraded from a tropical depression to a tropical storm, or perhaps, a hurricane within a short time.

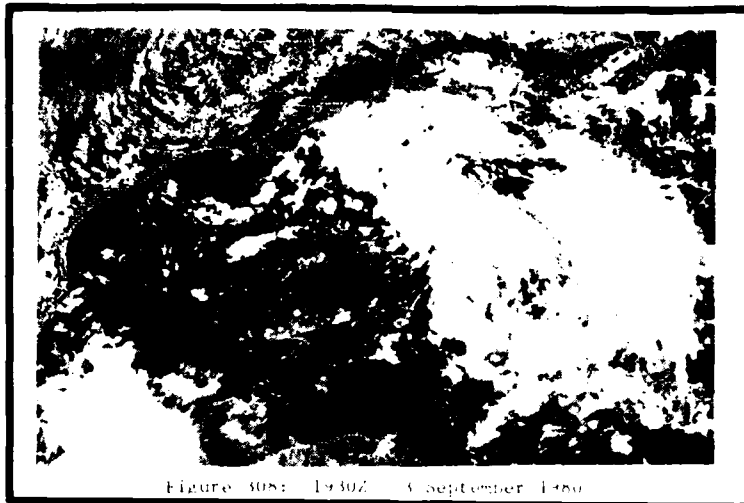


Figure 308: 1930Z - 3 September 1980

In Figure 309, 11 hours later, some organization is noted within the main system, and it appeared on surface charts as a weak low system. Fortunately, this system remains a tropical depression as it moves slowly towards Texas.

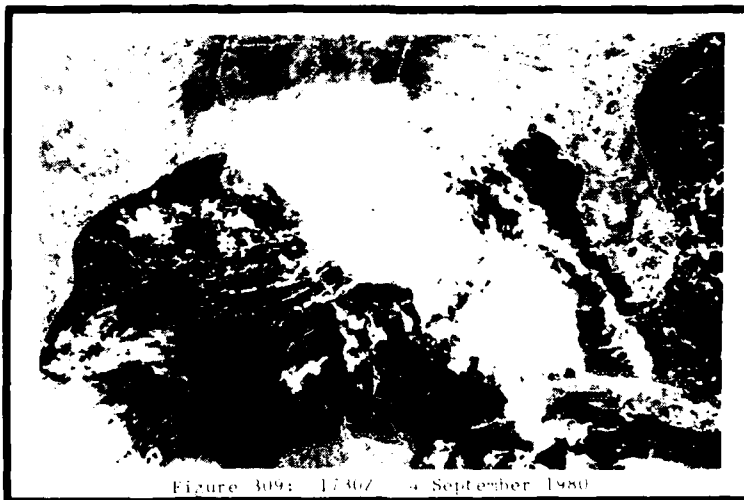


Figure 309: 1730Z - 4 September 1980

Weak tropical storms such as shown in the example in Figures 308 and 309 may still be dangerous to inland locations lying within its path. The associated moisture and instability spread inland (combined with heating and rising terrain), and trigger thunderstorms, tornadoes and heavy rainfall over a large region (Figure 310). The remnants of a hurricane can spread havoc far into the interior over a period of several days.

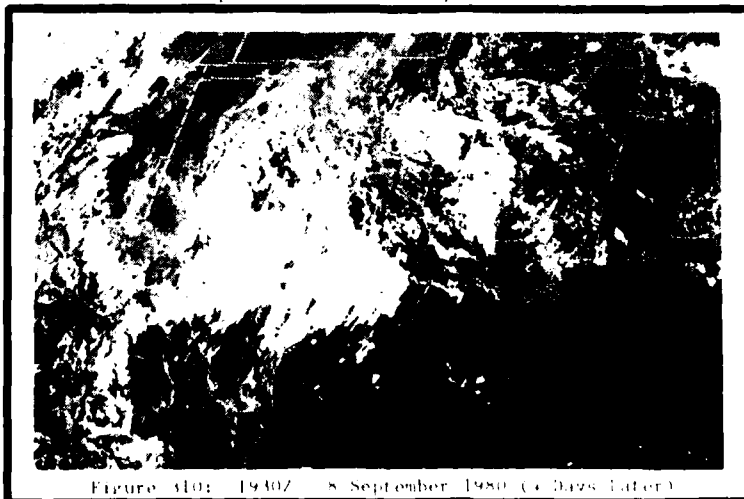


Figure 310: 1930Z - 8 September 1980 (4 Days Later)

PART III
PATTERNS OF CYCLOGENESIS

This part is designed to illustrate basic comma cloud cyclone development patterns as seen in satellite pictures. The information that follows was extracted from the NWS satellite training course notes (1975; unpublished) by Mr. Roger Weldon.

Part III will begin by showing two primary winter cyclone patterns. Then, several models of cyclone development will be discussed.

SECTION 1: Cloud Patterns Associated with
Mature Winter Storms:

Major cyclones, especially the large winter storms of the westerlies, often have complex cloud and weather patterns associated with them. Each cyclone's cloud pattern is different and each storm is made up of the sum of its parts. Some storms begin with one short wave disturbance and develop into a large mature storm pattern before any additional short waves enter the circulation pattern. Most mature winter storms, however, contain one or more short wave disturbances in addition to the primary one which was involved in the initial cyclogenesis. In fact, it is very common to have two or three short wave disturbances at any given time within the circulation system of a large winter storm. It is the presence of these smaller scale systems which contribute largely to the variability in the cloud and weather patterns of the storms. This is the reason for the earlier statement that a storm is made up of the sum of its parts.

Major Cloud Systems:

In the models that will be presented, three major cloud subsystems are observed during various phases of system development. These systems were defined and shown in many illustrations in Part II. Again, the cloud systems are:

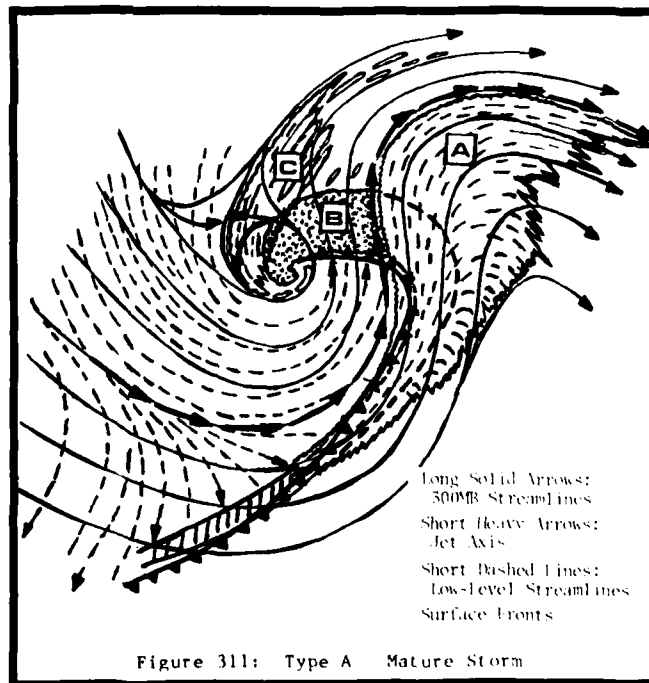
- Baroclinic Zone Cirrus (A)
- Vorticity Comma (B)
- Deformation Zone Cirrus (C)

Cloud Structure of Mature Storms (Figures 311 and 312):

The cloud structures or patterns during the mature stage of cyclones differ less than during their developmental phases. Two typical cloud patterns observed during the mature stages are identified as: Type A and Type B. The cloud patterns in both types are intended to represent storms which have just reached their lowest central pressure.

• Type A (Figure 311) - Type A systems initially develop within the lower levels and subsequently appear within the mid and upper tropospheric level as the cyclone matures. With the Type A systems, there is a large expanse of baroclinic zone cirrus just east of the comma surge region (area A in Figure 311). This cirrus shield often masks part of the comma surge region and comma tail which only reach up to mid-levels (area B). There is only a small amount of deformation cirrus near the comma head (area C). There is a distinct separation between the baroclinic zone cirrostratus and deformation cirrus layers. A Type A system has a well defined jet axis and lies close to the edge of the baroclinic zone cirrus deck as shown in Figure 311 (see Figure 148, page 37).

The cold and occluded fronts are usually easy to locate in Type A systems as illustrated in Figure 311. Warm fronts locations are difficult to find, especially if the cirrus shield is too thick to see through. This is true in both Type A and Type B (Figure 312) systems. If the clouds are too thick to see through, a first guess at the warm frontal location is that it would be below the widest point on the baroclinic cirrus shield.



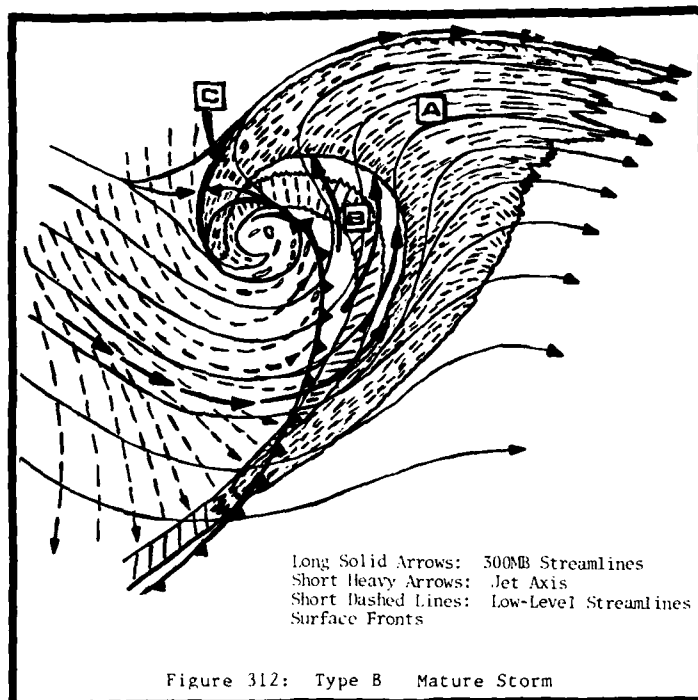


Figure 312: Type B Mature Storm

• Type B (Figure 312) - Type B systems initially develop within the mid levels and builds both upward and downward. The Type B system's baroclinic zone cirrus (area A in Figure 312) merges with the large sheet of thick deformation cirrus (C). The baroclinic cirrus shield tends to move faster than the middle level comma (B); thus the comma emerges from under the rear edge of cirrus with time (see Figure 146, page 36). There will be a four to six hour clearing of mid and upper clouds between the baroclinic zone cirrus shield and the vorticity comma. Units located within this gap or slot in the higher clouds (low clouds may cover the gap) should look for a return of precipitation and embedded convection as the vorticity comma approaches. The jet stream in a Type B system is often ill-defined due to its spreading out under the baroclinic cirrus shield. This spreading of the jet stream is noted by the three larger arrows near B in Figure 312. The baroclinic leaf usually evolves into the stronger Type B systems.

Type B's are usually deep, well-developed systems with all types of severe weather under the comma in its mature stage. During fall and winter, the convection within the comma can cause heavy precipitation; during spring, severe thunderstorms may occur. Even more convective precipitation may break out along the cold front. Both Type A and Type B will produce heavy snows, however, Type B systems produce the heaviest blizzards. Type B systems have the potential to be a stronger, better developed system than the Type A system. A Type A system may evolve into a Type B system once its vertical support reaches mid levels.

Fronts on the Type B system are usually complex, and large areas of cirrus make it more difficult to locate frontal systems. The baroclinic zone cirrus shield and vorticity comma and their associated clouds and precipitation may outrun the surface cold frontal system as depicted in Figure 312.

Models of Cyclogenesis:

The models of cyclogenesis which will be presented in Section Four are systems whose cloud patterns evolve to one of the two mature stages illustrated in Figures 311 and 312. Many more systems begin to develop, but they do not make it to the mature stage. As an example, many short wave systems develop and intensify within a zonal flow pattern. They continue to maintain their short wave structure as they track across the U.S.

Three primary models of cyclogenesis, meridional, split flow and cold air regime, will be presented respectively in Sections Two through Four; Section Four will contain two types of cold air cyclogenesis: cold air vortex and induced wave type.

SECTION 2: Meridional Trough Cyclogenesis

Meridional trough cyclogenesis is most prevalent along the east coast of North America and over the adjacent western Atlantic. This type occurs also over parts of the U.S. and over the oceans as well. The sequence of cloud development in meridional trough cyclogenesis is:

- Baroclinic Zone Cirrus (A)
- Vorticity Comma Cloud (B)
- Deformation Zone Cirrus (C)

Upper Air Flow Patterns (Figure 313):

The upper air support for the initial stage of this type of cyclogenesis is a trough that has a large meridional extent. Two examples are shown in Figures 313a and 313b. In Figure 313a, the trough axis is aligned north-south, whereas in Figure 313b, the axis is oriented northeast-southwest (positive tilt). The jet axis is located around the trough - without any significant jet branches extending either across the trough or outward into the adjacent ridges. Short wave disturbances including the one initiating the cyclogenesis, move around the major trough within or under the jet baroclinic zone. These disturbances or impulses are difficult to locate in the curvature of the contour and thermal fields of the large-scale trough; they usually show best as maxima or perturbations in the 500mb vorticity field, or as speed maxima moving within the jet zone.

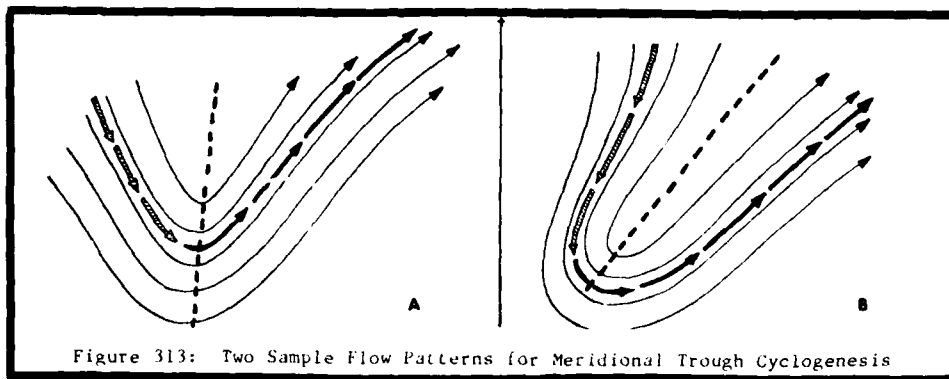


Figure 313: Two Sample Flow Patterns for Meridional Trough Cyclogenesis

Note: In Figures 313a and 313b, and in all subsequent upper flow pattern illustrations, the jet stream directly associated with cyclogenesis is shown as cross-hatched. The main (older) jet is indicated by the solid arrows.

Early Stage - Phase 1 (Figure 314):

The cloud pattern at the beginning of the cyclogenetic process shows a large band of baroclinic zone cirrus to the south of a relatively strong jet stream (area A in Figure 314). Below the baroclinic zone, there is a relatively stationary or very slow moving cold frontal system. All along this front there are small ill-defined low pressure waves as shown in Figure 314. Each wave has its own small comma cloud and precipitation; the small commas are generally hidden below the large area of baroclinic zone cirrus and cirrostratus. When meridional trough cyclogenesis does begin, it will be in response to one of the small or short wave scale vorticity maxima as they come around to the front side of the main trough. The problem is: which one, and can it be seen coming either in the satellite or other conventional data. Usually they move rapidly down the backside of the major trough and are often difficult to pinpoint within the upper air network. Additionally, there are few clouds associated with the minor disturbance when it is moving southward behind the trough. (Sometimes, an area of thin cirrus streaks on the backside of the trough may be seen; this indicates the position of the major short wave.) The clouds form when the disturbance reaches the east side of the major trough (recurvature), and then it is likely under the baroclinic zone cirrostratus layer. The only real key to catching the development is to wait until it begins and catch it immediately. The first real hint of development is a significant waving of the back edge of the cirrus shield - this is Phase 2.

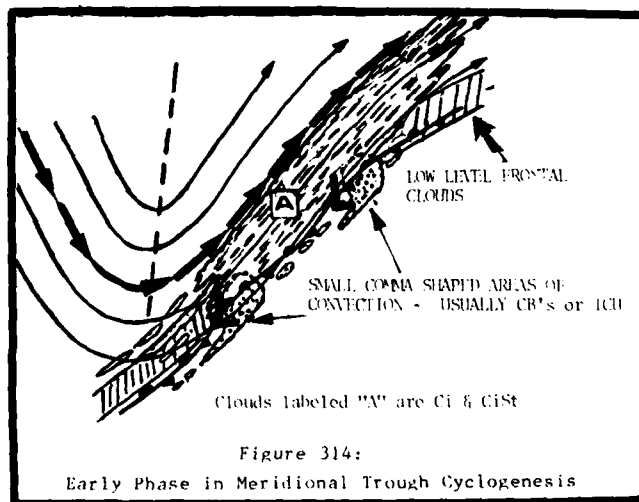


Figure 314:

Early Phase in Meridional Trough Cyclogenesis

Phase 2 (Figure 315):

In the second phase, the cirrus edge has formed a wave pattern which is also matched by the jet axis and streamlines (Figure 315). This waving of clouds and the flow indicates that a short wave trough either has formed or has bottomed out within the major trough. In Figure 315, the dashed line is a comma-shaped area (B), it would not be visible on satellite data, since it is under the baroclinic cirrostratus deck (A). It corresponds to the location of the vorticity comma which has now formed in the process of cyclogenesis. The short wave's influence within the base of the major trough has caused the trough axis to become negatively-tilted. Aside from any thunderstorm development, area B is likely to be the area of heaviest precipitation. At this stage, the frontal system shows strong waving; the associated frontal low begins to deepen.

Phase 3 (Figure 316):

In the third phase of development, the system begins to "wrap up" and form a closed circulation center into the middle troposphere. The lower level comma head begins to emerge from under the cirrus deck (area B in Figure 315). The comma head, although emerging, is not likely moving westward (or rearward) with respect to the ground; rather the cirrus edge is moving faster. The short wave trough has lifted so much and has increased in size; the entire base of the major trough now has a negative tilt. By this time, the system is closed up to 700mb but not up to 500mb. The short wave ridge has increased its amplitude.

The surface cold front is under the cirrus near the back edge of the comma pattern, and the surface low is now nearer to the back edge of the cirrus deck (the low was near the eastern edge at the initial phase). The storm is developing very rapidly at this time.

Significant precipitation will be falling throughout the comma head. Although the cloud tops in the comma head are normally middle level, they do often reach cirrus levels but lower than the cirrus deck to the right of the jet axis.

Phase 4 - Mature Stage (Figure 317):

In the final phase of development, the closed circulation has deepened even more; an area of deformation cirrus (area C) has formed, and the overall pattern fits the Type A cyclone shown earlier in Figure 311. The dry slot has wrapped itself into the comma head. The jet in this type of cyclogenesis is still relatively strong while crossing the comma. The jet and its baroclinic zone cirrus shield will be well to the east and separated from the deformation cirrus. By this time, the low should be closed up to at least 500mb. There is a trend for the surface and upper centers to rotate cyclonically with respect to each other, getting closer together, until the systems are vertically stacked.

The surface low is well west of the cirrostratus deck and north of the mid and upper level low centers. Remember, this is a Type A system, and as such, it will fill as it was built - from the bottom.

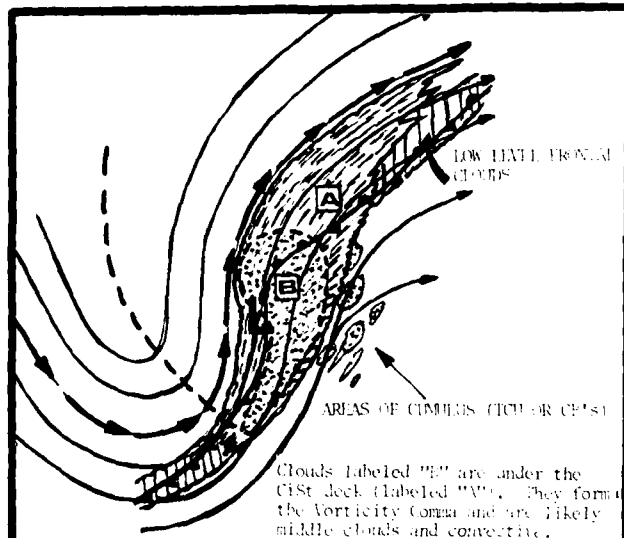
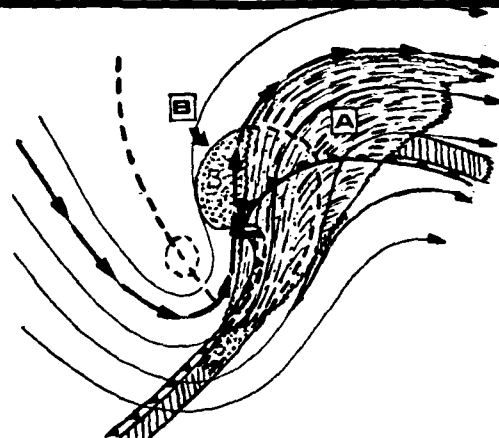


Figure 315:

Second Phase in Meridional Trough Cyclogenesis



SECTION 3: Split Flow Cyclogenesis

Split flow cyclogenesis is the most prevalent form of cyclogenesis over the central U.S. just east of the Rocky Mountains. The split flow pattern is most often induced by a major mountain chain. Split flow patterns occur frequently, such as on the west side of the common blocking patterns, but the development of cyclogenesis also requires a jet moving into the southern branch. Thus, split flow cyclogenesis is much less common than split flow. Split flow cyclogenesis develops in the mid levels, and as such, it develops directly into a Type B cloud system (see Figure 312). The sequence of cloud development in split flow cyclogenesis is:

- Deformation Zone Cirrus (C)
- Vorticity Comma (B)
- Baroclinic Zone Cirrus (A)

Upper Air Flow Patterns (Figure 318):

The upper level flow splits or is diffluent. Often there are two branches of the westerlies forming, with the northern one being the older one. The new branch then forms farther southward and may induce cyclogenesis as shown in Figure 318a. Or, there may be two branches throughout the period, with the main energy transferring to the southern branch during cyclogenesis (Figure 318b). In either case, the development occurs south of and on the warm air side of the older northern jet baroclinic zone.

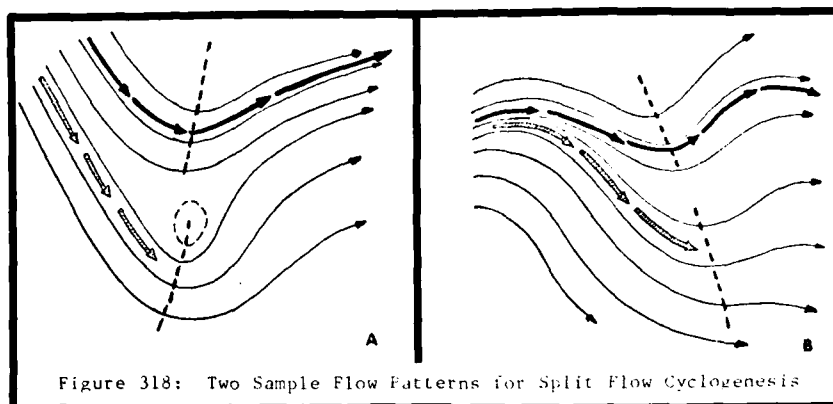


Figure 318: Two Sample Flow Patterns for Split Flow Cyclogenesis

Phase 1 (Figure 319):

In the beginning of split flow cyclogenesis, the jet stream enters the southern trough region on the western side of the troughline (Figure 319). Generally, a closed circulation center in the middle troposphere (500mb) appears early in the development. If the southern short wave is already closed as shown in Figure 319, then it will dig and deepen as the jet approaches the troughline. The early development of this mid-level low is probably the most important single factor that influences the evolution of cloud and weather patterns.

The cloud pattern usually begins with an area of cirrus (and perhaps middle clouds) and is indicated as area C in Figure 319. This is deformation zone cirrus. Deformation zone cirrus exists where there is convergence on the east side of the out-of-phase troughline. The cirrus lies generally north and northwest of where the cyclogenesis is about to take place (if it hasn't already occurred). Deformation cirrus develops within a region of weak upper level winds located south of the northern branch of the polar jet and northwest of the developing mid-level low.

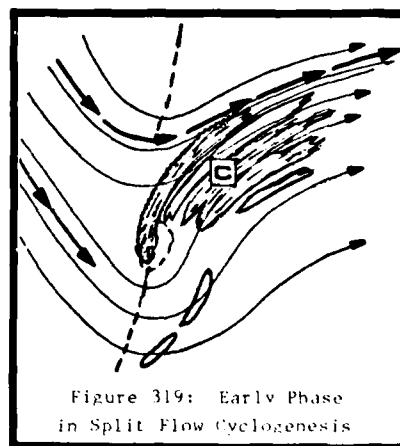


Figure 319: Early Phase in Split Flow Cyclogenesis

Note: In Phase 1 and the subsequent three phases of cloud evolution, the cloud systems identified are at the mid and high tropospheric levels. Great Plains forecasters must consider the advection (often rapid advection) of lower level Gulf moisture into these split flow patterns approaching the Rocky Mountains. With the introduction of Gulf moisture, the cloud evolution of the system may change dramatically within a very short time.

Phase 2 (Figure 320):

In the second phase of cyclogenesis, the most important change in the cloud pattern has been the development of the vorticity comma pattern which has formed very rapidly to the southeast of the closed low (area B in Figure 320). The cloud type in this early comma is highly dependent upon the time of day and the season of the year. In the springtime, this comma is highly convective during the day, but still primarily of middle cloud height tops. Deformation zone cirrus continues to increase as the col area develops.

Phase 3 (Figure 321):

By phase three, the cloud patterns have become bigger and better defined. The comma pattern is topped by cirroform clouds. Over the comma tail portion, the cirrus will appear thicker and striated, as the jet baroclinic zone develops aloft over that area (this is the third cloud system; this area is noted by the large arrow in Figure 321). At this stage of development, Gulf moisture has spread into the system and is being lifted rapidly into the middle levels. As a result of this lifting, a large area of PVA (and precipitation) develops ahead of the disturbance across the Great Plains.

The jet stream has advanced south of the closed center and the jet maxima swings east of the trough-line; these actions causes continued trough deepening, and most important, probable system recurvature towards the northeast (bottomed out).

No surface low or surface fronts have been included in Figures 319 through 321. The reason for this omission is the large variability involved in the relation between these surface features and the cloud patterns for this type of cyclogenesis. There is a good relationship between the cloud patterns and the weather (precipitation), but a much poorer relationship between the cloud patterns and the surface pressure and temperature fields. A generalized rule for placing the surface low center would be the following: the surface low will usually appear at a location somewhere near the rear edge of the comma head shown in Figures 320 and 321, and on the cyclonic side of where the jet is shown crossing the comma's rear edge.

Phase 4 (Figure 322):

In phase four the jet wind maxima spreads out behind the baroclinic cirrus edge which produces light winds in the cloud shield itself. The entire system is evolving into a Type B mature storm pattern (see Figure 312). The short wave trough has become in phase with the northern short wave and may become negative tilted. (Negative-tilted troughs are often very dynamic and produce the most severe weather conditions.)

By this phase, the area of thick cirrus has greatly increased. Cirrus has formed over the vorticity comma and has merged with the northern, older area of cirrus (shown in Figures 319 through 321). By this time, it is often difficult to distinguish between the cirrus deck associated with the jet baroclinic zone (area A in Figure 322) and the deformation zone cirrus (C) to the north and rear of the closed low aloft.

Usually the cirrus deck that develops over the comma pattern is not contiguous with the lower middle layers. Quite often, then, the rear edge of the cirrus deck moves faster than the middle (or lower) deck which emerges at the rear. If the cirrus continues to outrun the comma cloud then a gap (possible clearing) between these two systems evolves and eventually becomes similar to the Type B storm pattern shown in Figure 312.

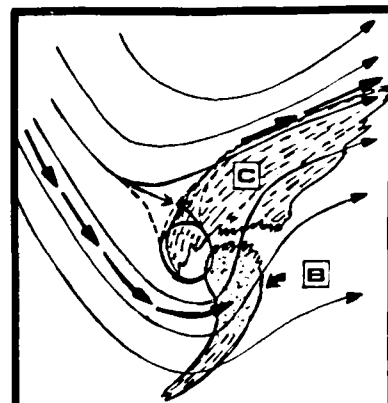


Figure 320:
Second Phase
in Split Flow Cyclogenesis

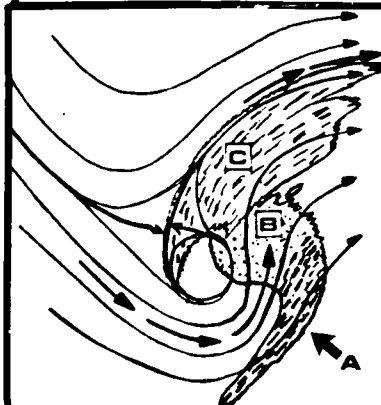


Figure 321:
Third Phase
in Split Flow Cyclogenesis

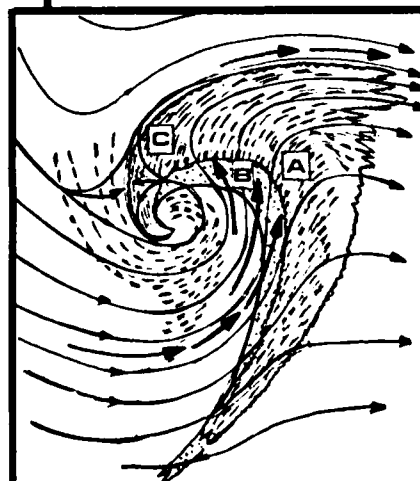


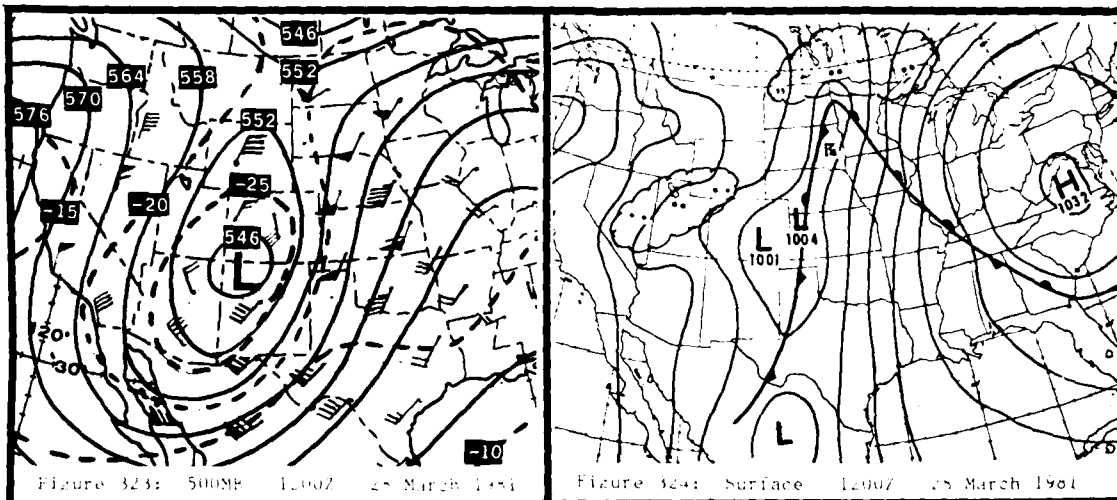
Figure 322:
Fourth Phase
in Split Flow Cyclogenesis

Many major snowstorms and severe weather occurrences across the Rocky Mountains and Great Plains are associated with split flow cyclogenesis events over the southwestern U.S. Forecasters may find it difficult at times to identify deformation zone and vorticity comma cloud systems which are associated with these developing upper lows over the western U.S. Sometimes mountain influences tend to dry out accompanying Pacific moisture which will produce ill-defined deformation zone and vorticity comma cloud systems. The cloud systems become better defined when the cyclone moves out of the Rockies and frequently encounters Gulf moisture advection. Let's look at a case study:

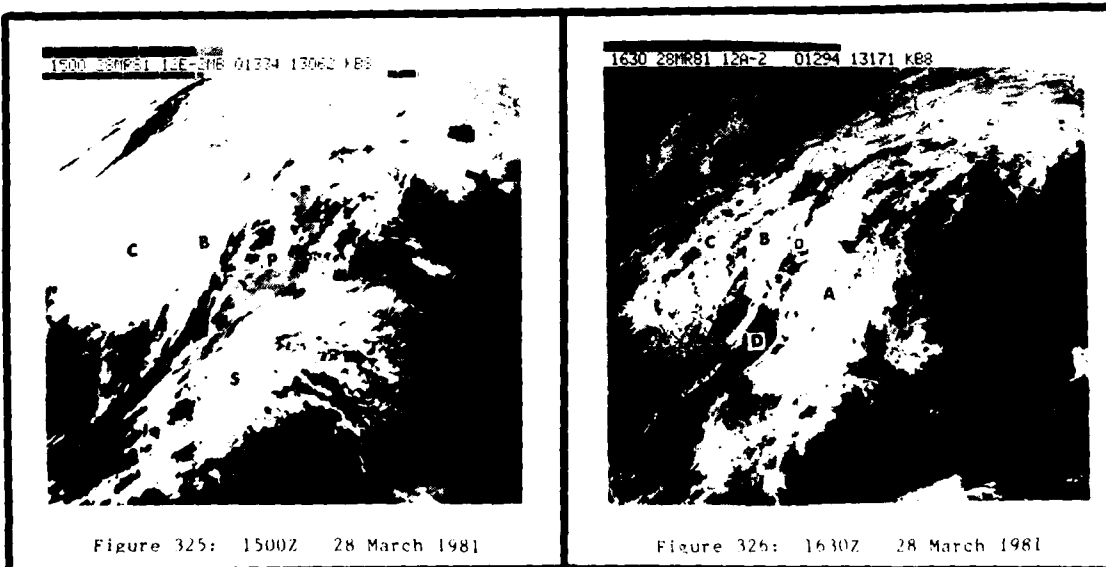
Split Flow Cyclogenesis - A Case Study (Figures 323 through 327):

Figures 323 and 324, respectively depict the 500mb and surface analyses approximately 24 hours prior to Great Plains storm development.

In Figure 323, a low system is shown over northwestern New Mexico. At the surface, a cold frontal system is becoming stationary across the western Great Plains.



The IR photo, Figure 325 (three hours later), depicts a disorganized pattern of cloud systems across the central U.S. Deformation zone clouds are noted at C; an ill-defined vorticity comma system is shown at B. A PVA area (P), reflected by the highest cloud tops, lies to the right of the polar jet (and along the frontal zone) across western Kansas and Nebraska. Cirrus layers (S) associated with the subtropical jet are noted across Texas and the lower Mississippi Valley.



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Minimum Resolvable Number of Lines per Millimeter

One hour and thirty minutes later, the related visible picture, Figure 327, reveals the deformation zone (C) and vorticity comma cloud (A) systems. Another cloud system, noted at (B), appears across the Great Plains in the visible photo. Initially visible in the left third, this cloud system is Gulf moisture advection, and it has produced its own lower level, high-level, cloud system. The moisture tongue will continue, and with increased IFA associated with the approaching upper system, precipitation will break out over the Great Plains.

The area noted at D in Figure 326 marks the western extremity of Gulf moisture; it later becomes the developing cyclone's dry slot as drier, southwest winds move northeastward into the system.

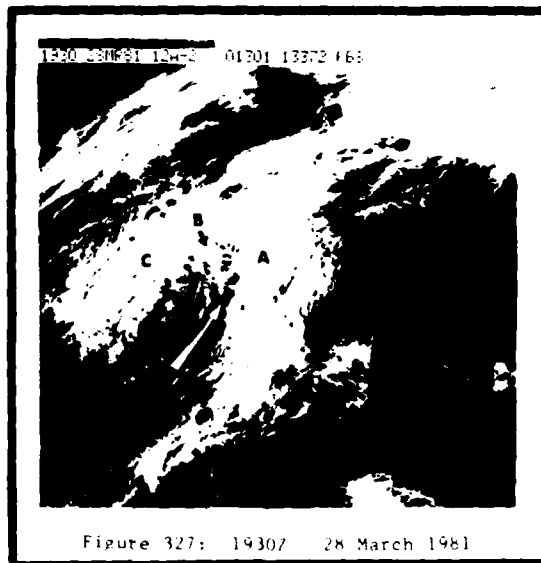


Figure 327: 1930Z 28 March 1981

Three hours later, Figure 327, the visible photo reveals system organization as the upper low moves toward eastern Colorado. The vorticity comma cloud's head lies over central and eastern Colorado (B); the comma tail extends southeastward into western Kansas. The growing dry slot is indicated by the long white arrow.

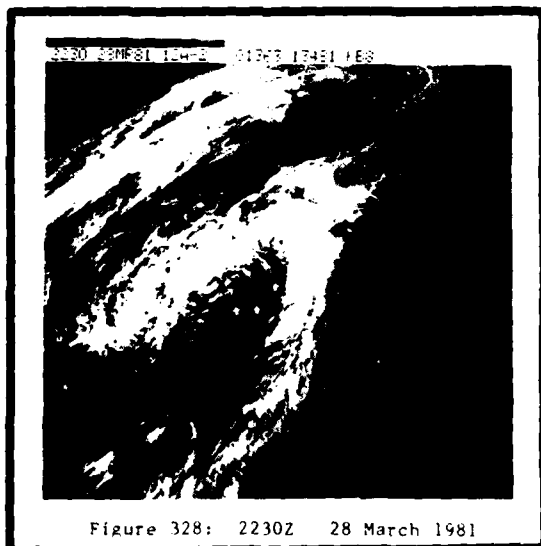


Figure 328: 2230Z 28 March 1981

Several hours later, Figure 325, the visible photo shows strong cloud circulation within the storm as it emerges from the central Rockies. The small arrows denote several small enhanced cumulus comma cloud systems rotating through the large scale system within the dry slot. Dust can be seen as the faint gray swath across west Texas.

SECTION 4: Cold Air Regime Cyclogenesis

In the previous two patterns shown, the influence of the North American continent (coastal and mountains) frequently induce the flow patterns for meridional and split flow developments. According to Helden's studies, the third type of cyclogenesis, cold air regime development, was the most frequent type observed across North America and the north Pacific and Atlantic oceans. The cold air regime forms of cyclogenesis were most prevalent over the oceans, however, the geographical preferences for this type is not as strong as for meridional and split flow cyclogenesis.

The two cold air regime cyclogenesis patterns are: cold air vortex and induced wave. Cold air vortex developments occur frequently just off the West Coast and over the eastern U.S. Induced wave developments are observed more often east of the Rocky Mountains (and eastward).

Upper Air Flow Patterns (Figure 329):

Two sample upper air flow patterns are shown in Figure 329. These patterns occur with both types of cold air regime cyclogenesis. In these patterns, short wave disturbances and their accompanying jet stream systems (noted at S in both figures) move southeastward within the cold air towards the base of the main trough. Cyclogenesis occurs on the cold air side of the older or initially stronger jet baroclinic zone (short solid arrows in both figures), and it occurs within a generally confluent area of the large-scale flow pattern.

Both cold air vortex and induced wave cyclogenesis begin similarly as shown in the two sample illustrations (Figure 329). With cold air vortex types, a complete new cyclone forms behind the older baroclinic zone producing its own separate baroclinic zone and surface fronts. In induced wave cyclogenesis, however, the short wave disturbance which initiates cyclogenesis induces a wave on the original baroclinic zone. The main jet stream and frontal zone are those of the original baroclinic zone which have responded to the approaching short wave.

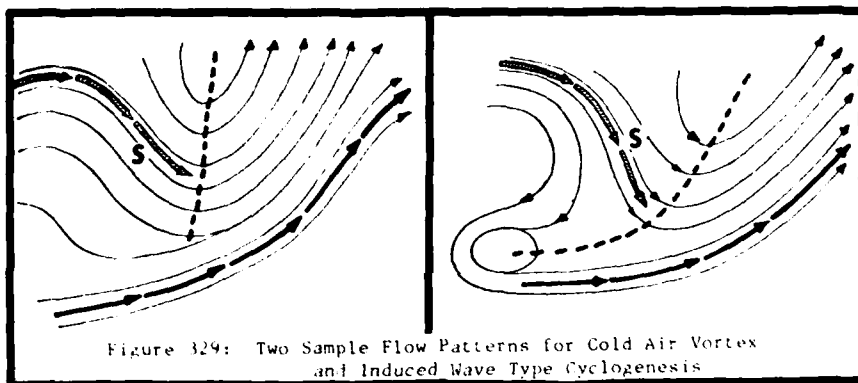


Figure 329: Two Sample Flow Patterns for Cold Air Vortex and Induced Wave Type Cyclogenesis

The rest of this section will discuss various stages of evolution of these two cold air cyclogenesis patterns. We will begin with cold air vortex cyclogenesis:

Cold Air Vortex Cyclogenesis (Figures 330 through 344)

In the beginning of development, the dominant cloud pattern will be the old baroclinic zone cloud system located on the anticyclone side of a major trough. The baroclinic zone could be in the form of a long band of high and middle clouds along the jet-frontal zone of an elongated southwest-northeast oriented trough, or with a west-east oriented zonal flow. The baroclinic zone may still have some resemblance of an old, decaying comma cloud. The sequence of cloud development in cold air vortex cyclogenesis is:

- Vorticity Comma (B)
- Baroclinic Zone Cirrus (A)
- Deformation Zone Cirrus (C)

Phase 1 (Figure 330):

In the beginning of development, a "new" short wave and jet stream has entered the major trough circulation as noted by T in Figure 330. In Figure 330, the new jet axis is beginning to bend around the trough axis instead of joining with the older baroclinic jet system on the front side of the trough. The strongest winds are still upstream and are moving over the ridge. When the new jet begins to curve around and becomes parallel to the old jet (with a zone of weaker winds between the two axes), it is an indicator that cold vortex cyclogenesis is likely to develop. (Note: If the new and old jet streams merge, then induced wave cyclogenesis is likely to develop).

When a short wave disturbance that will initiate cyclogenesis is approaching the major trough axis, it will usually be evident in LR data as a pattern of middle clouds. Often these middle clouds will have a distinct well-defined northern edge which will be just to the right of the axis of maximum winds at cloud top level as shown in Figure 330.

In Figure 330, a single short wave is indicated. This, however, is not always the case - there may be several smaller short waves with less defined cloud systems moving down the back side of the major trough. As these cloud systems arrive on the east side of the trough axis, each seems to add more energy to the development, until finally, a well-defined comma pattern begins to form.

Phase 2 (Figure 331):

In the second phase the short wave middle cloud pattern has just arrived on the east side of the major trough axis (the axis becomes sharper and better defined as increased curvature forms there).

The short wave pattern begins to form the vorticity comma shape (B in Figure 331) with convection increasing over the comma and resulting in higher cloud tops (and heavier precipitation). A single surface low may not have organized yet; several lows may be evident within the surface trough north of the jet stream.

Phase 3 (Figure 332):

The new storm has begun to form the comma pattern. Considerable cirrus and cirrostratus has formed along the newer jet axis on the east side of the major trough (smaller A in Figure 332), however, the older jet axis and its cirrus deck remains further to the east. As the new storm intensifies and sharpens the amplitude of the upper level trough, the edge of the older cirrus deck will tend to become generally parallel to the new cirrus - especially along the cyclonically curved portion. There may still be smaller scale waves along the older cirrus edge, which are out of phase with the new system.

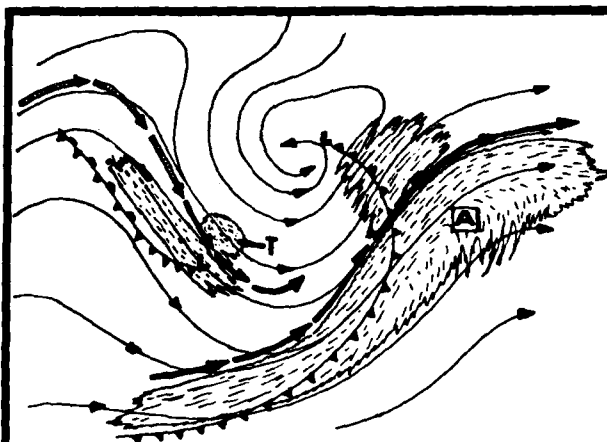


Figure 330:

First Phase in Cold Air Vortex Cyclogenesis

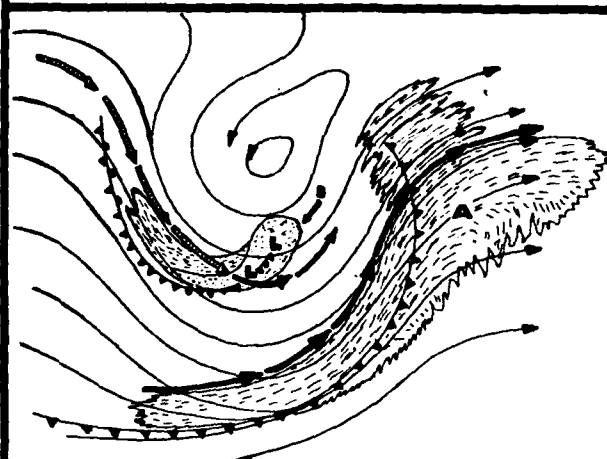


Figure 331:

Second Phase in Cold Air Vortex Cyclogenesis

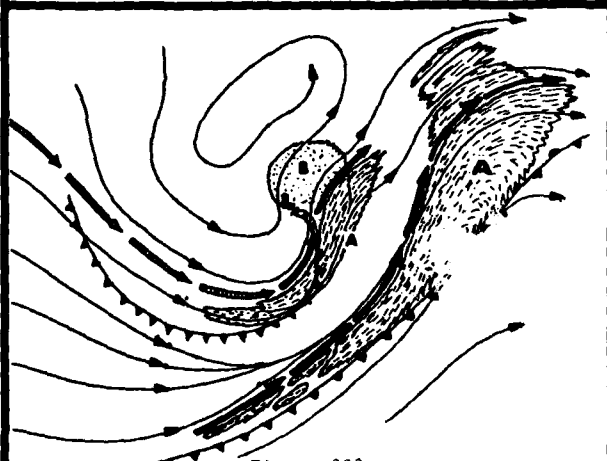


Figure 332:

Third Phase in Cold Air Vortex Cyclogenesis

Phase 4 (Figure 333):

In the final phase a complete new storm cloud pattern has formed behind (or on the cold side) of the old baroclinic zone. Usually, as the new system develops, the older jet baroclinic zone and its cloud system weakens primarily due to its cold air supply being cut off, and the development of warm moist air aloft in advance of the new system.

If the new cyclone continues to develop beyond this stage, it is likely that the new frontal zone will catch up to the old one in the south quadrant of the low. Eventually, the two frontal zones will merge into one.

The old baroclinic zone jet stream (eastern jet) will often weaken while the newer jet zone becomes dominant. These systems often develop into very intense Type B systems as illustrated earlier in Figure 312.

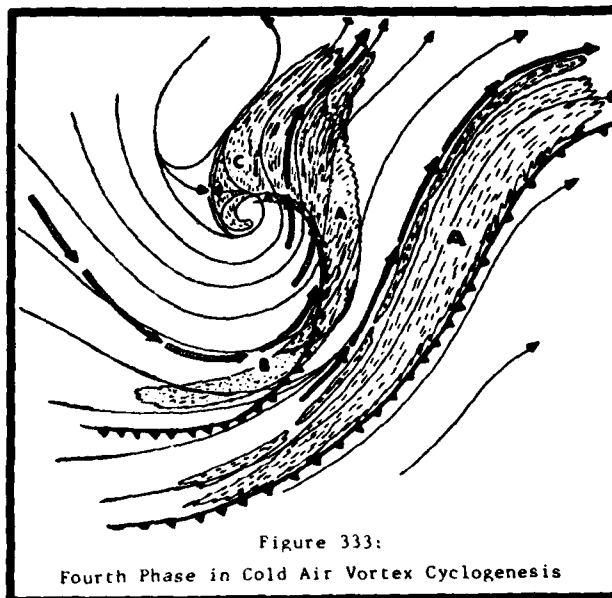


Figure 333:

Fourth Phase in Cold Air Vortex Cyclogenesis

Induced Wave Cyclogenesis (Figures 334 through 337)

Induced wave cyclogenesis occurs when a short wave disturbance moves within the cold air across the major trough and merges with the older baroclinic zone located on the east side of the major trough. As the middle cloud comma cloud pattern forms and approaches the older baroclinic zone, it will appear to induce a wave on it.

Of all the types of cyclogenesis presented, this last type is the most frequent form of development, and it has the least geographical preference. The sequence of development of the major cloud systems in an induced wave pattern are:

- Vorticity Comma (B)
- Wave on Baroclinic Zone (A)
- Deformation Zone Cirrus (C)

Phase 1 (Figure 334):

At this early stage, the pattern will be very similar to that of the cold air vortex development. The older jet zone cirrus (large A in Figure 334) is likely to be closer to the major trough axis - especially at the point where the new speed maximum and short wave is approaching the older zone as noted at R in Figure 334. The leading portion of the jet maximum coming over the ridge may appear to merge with the older jet axis, such that no double jet structure can be seen east of the trough axis.

In some cases, the leading part of the new jet will "turn the corner" and move up the east side of the major trough with two parallel jet axes present. When this kind of jet structure evolves, it is common to have a series of smaller scale disturbances moving along both jet zones. One series showing as middle clouds will move down the newer jet branch, and the other showing as perturbations in the older jet cirrus deck will be moving from the southwest. As the two streams merge closer together, the small scale disturbance of the two streams will usually be out of phase; if they are, development is deterred. When a pair of systems arrives in phase, development begins.

At other times, as in the case depicted in Figure 334, a single larger scale disturbance approaches the older baroclinic zone.

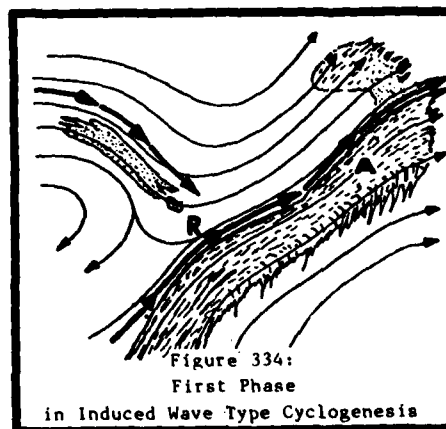


Figure 334:

First Phase

in Induced Wave Type Cyclogenesis

Phase 2 (Figure 335):

As the disturbance and the leading portion of the strong winds arrive at the major trough axis, a comma-shaped middle cloud pattern develops (B in Figure 335), often with convection and precipitation forming rapidly. Some higher cloud tops will likely form over the comma and develop a plume where the axis of maximum winds crosses the comma surge region.

The rear edge of the older baroclinic zone cirrus layer immediately begins to deform to the pattern of the developing comma.



Figure 335:
Second Phase
in Induced Wave Type Cyclogenesis

Phase 3 (Figure 336):

By this time, the comma (B) has become better defined and grown larger, and the jet streams have merged into a single upper level baroclinic zone. The region of strong winds is likely to be wider in this area, but no jet structure can usually be found - either in the upper air network or in evidence of the cirrus.

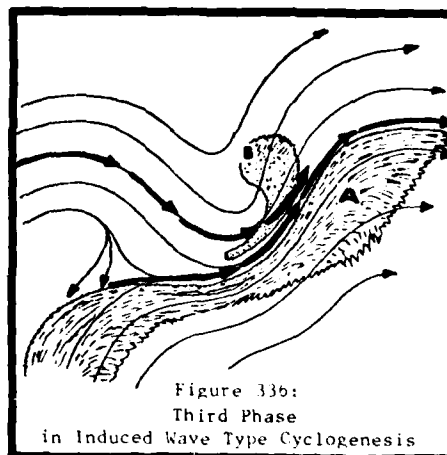


Figure 336:
Third Phase
in Induced Wave Type Cyclogenesis

Phase 4 (Figure 337):

In the previous phase, the comma tail was parallel to the western edge of the cirrus deck, but by the fourth phase, Figure 337, the comma has now rotated and the tail has moved under the cirrus deck. More cirrus has formed over the comma head - especially at the deformation region (C), and now a mature storm pattern has formed.

The clouds over the comma head near where the jet axis and cirrus edge crosses are likely to be lower than on the rest of the comma head.

In Figure 337, the comma tail is shown swinging around under the baroclinic zone cirrus with only the comma head showing. This action would be most likely when the storm system continues to develop to maturity; but, with many developments which do not go full cycle (and most don't), the comma tail may remain nearly parallel to the cirrus edge (out in the open west of the cirrus edge). In many cases, a well-defined comma pattern does not form, however, a region of irregular-shaped middle clouds shows at the position where the comma head appears in Figures 335 through 337.

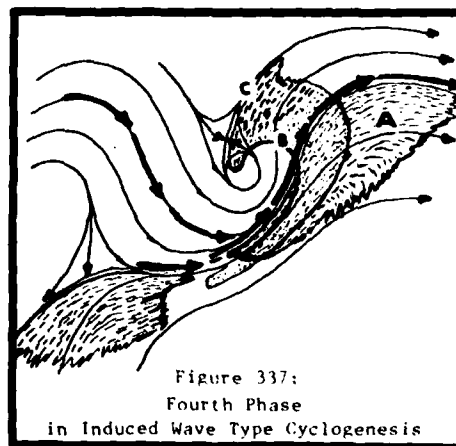


Figure 337:
Fourth Phase
in Induced Wave Type Cyclogenesis

Case Study (Figures 335 through 343)

The following sequence of four satellite photos shows a cold front system and the associated stationary front that developed from the system. The sequence of photos shows the three stages of low wave development from 1600 UTC to 0000 UTC.

The cold and satellite analyses are respectively shown in Figures 337 and 338. In Figure 337, a long wave trough system is shown. The short wave responsible for cold front development, which will be shown in subsequent satellite photos, is difficult to locate within the long wave flow. At the surface, frontal waving over Pennsylvania has begun.

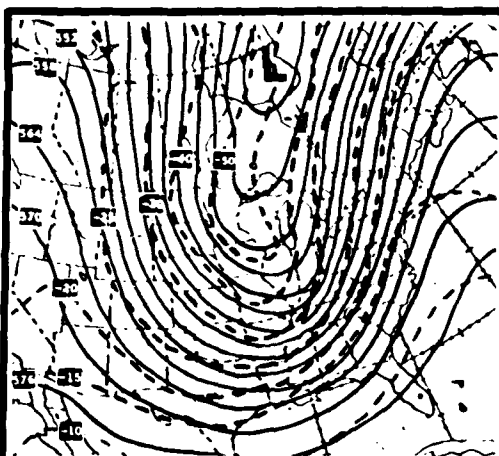


Figure 337: Surface 1600 UTC 2 February 1981

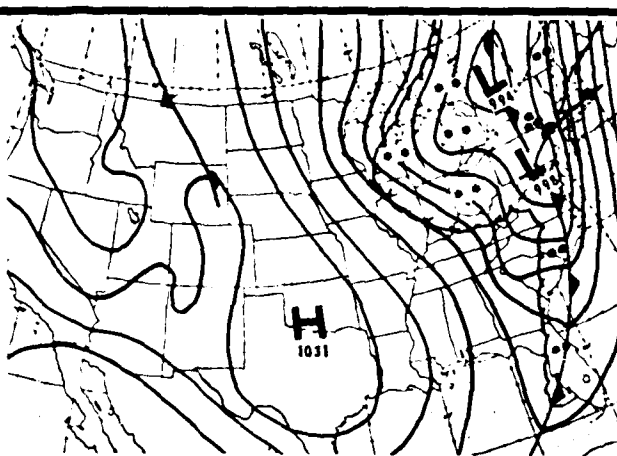


Figure 338: Satellite 1600 UTC 2 February 1981

In Figure 338, the stationary, low-level jet zone and show signs of induced waving as a short wave is located across eastern Pennsylvania and west Virginia. It reaches the zone of the stationary front. Also, the cloud wave reports have been ahead of the cold cloud is forming the short wave. The high-level zone cloud system. Area 2 shows a high-level jet zone in the low-level cloudiness.

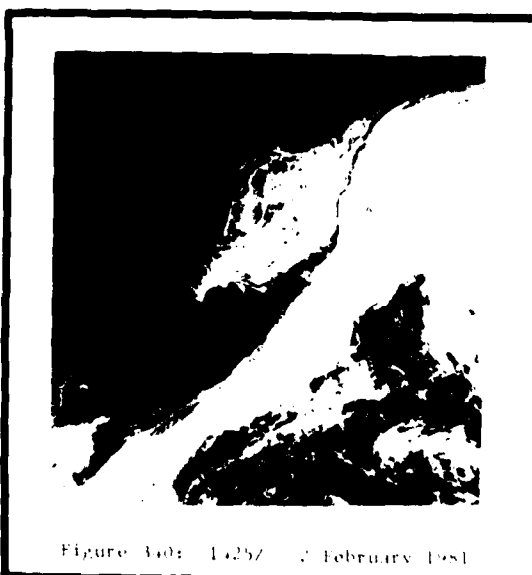


Figure 340: 1425 UTC 2 February 1981

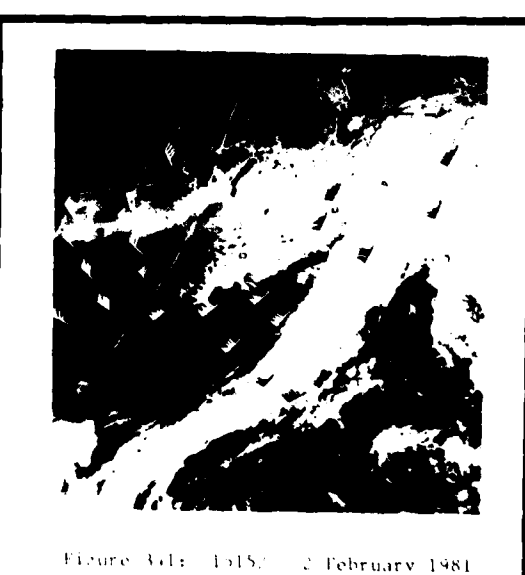


Figure 341: 1515 UTC 2 February 1981

Several hours later, Figure 342, nearly half of the comma system (B) has moved under the cirrus deck. Finally, in Figure 343, only the western end of the comma system (B) is visible in the photo. This system continued to develop, moved northward, and became a mature storm system over eastern Canada within 24 hours.



Figure 342: 1846Z 2 February 1981

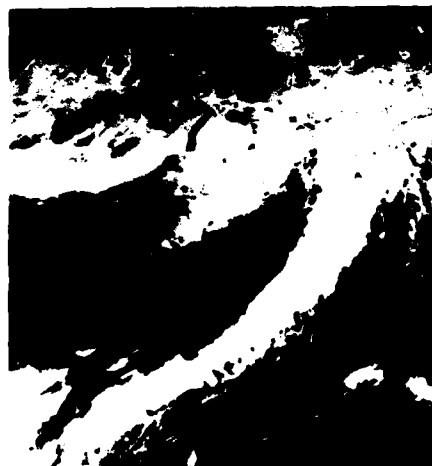


Figure 343: 1916Z 2 February 1981

It has been shown in both types of cold air regime cyclogenesis that the comma cloud associated with the short wave disturbance crossing the cold air, is primarily a middle level cloud system. Often, over the oceans, and especially with induced wave cyclogenesis, the "new" short wave will appear as an area of deeper convection embedded within the general cold advection cumulus field (enhanced cumulus). These enhanced cumulus areas reflect a PVA area and often initiate cyclogenesis along the baroclinic zone. An example was shown earlier in Figure 243, page 60.

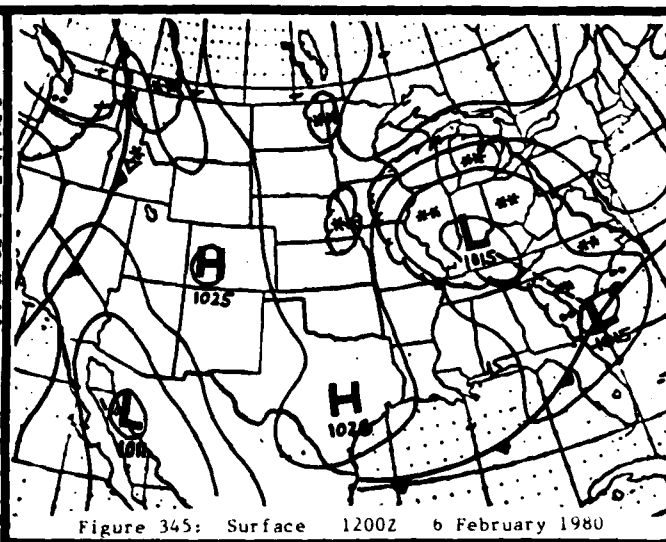
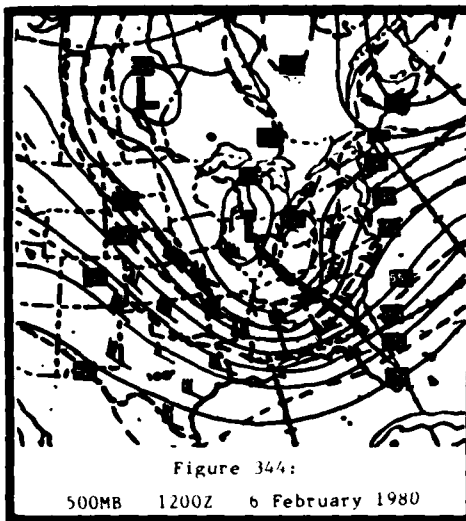
SECTION 5: Miscellaneous

In this section several more cyclogenesis events which occur over the central and eastern U.S. will be shown. The basic cloud systems that were discussed in previous sections will probably be recognizable, however, each system's structure and development is different.

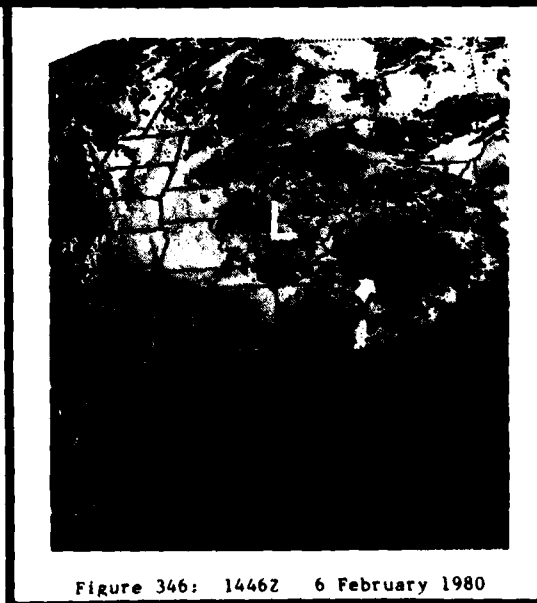
Case Study 1 - Cyclogenesis along the East Coast:

Forecasters located over the eastern U.S. should pay particular attention to the actions of decaying, vertically-deep low systems which "hang up" over the Great Lakes area. Often, new frontal cyclogenesis occurs along the eastern seaboard or offshore (generally triple point development) as the old low system dies. An apparent transfer of energy evolves to the new system where the baroclinic zone strengthens due to stronger temperature, moisture and wind discontinuities. These new disturbances can mature quickly into major cyclones - nor'easter events are not unusual with this pattern.

The 500mb and surface analyses are respectively shown in Figures 344 and 345 several hours prior to the satellite photos. In Figure 344, a closed low appears over the Great Lakes area; the strongest wind field reflecting the polar jet stream lies well to the south of the low system. A negative-tilt trough extends from the low southeastward to Florida - often this type of short wave trough orientation across the southeastern U.S. breeds intense cyclones. The related surface analysis shows a disorganized low pressure pattern across the eastern U.S. The Illinois low stacks with the upper low; a weak frontal low appears offshore. Widespread light snowfall is occurring within the two systems.

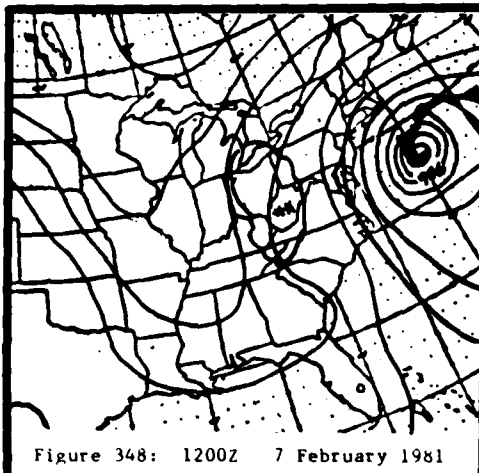


The enhanced IR photo several hours later, Figure 346, reveals that the highest tops cover a large area across Virginia, North Carolina and offshore (see arrow). This area is the strengthening baroclinic zone; the old decaying low system, indicated by the white L, shows lower (warmer) cloud tops.



In the related visible, Figure 347, approximately two hours later, shadows help reveal the baroclinic zone structure (A) and the highest cloud tops. Heavier precipitation would be occurring under cloud system A; precipitation would also be occurring in the lower cloud systems over the Ohio Valley - Great Lakes area, but intensities would be lighter than in cloud system A.

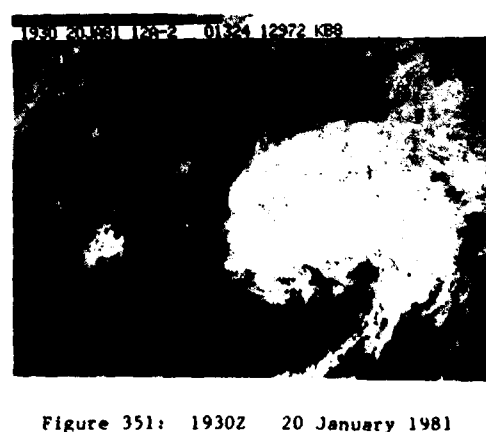
It is emphasized again that when a cloud system such as shown at A in Figures 346 and 347 appears in that general location, an intensified METWATCH must be initiated for locations from Virginia northward into New England. Figure 348 depicts the surface pattern the following morning. Indeed, an intense cyclone did develop; fortunately, for East Coast forecasters, this system intensified far enough offshore to keep severe winter weather away from the mainland.



Case Study 2 - Cyclogenesis along the Gulf Coast:

During the cold season, large areas of cloudiness, located over the central and southern U.S., may persist for several days or more. Generally, an extensive zone of stagnant high pressure (polar air) lies across the central and northern U.S. and Canada. Consequently, storm tracks are shifted southward across the southern U.S., Mexico and the Gulf of Mexico. Forecasters, located along the storm track, should look for telltale signs of system development in satellite photos. Several indications have been discussed in this TN such as "V" notches and "S" shape cloud systems which reflects jet stream maxima. The following three photos illustrate the development of a southern storm system.

In Figure 349, the three primary cloud systems are noted. The vorticity comma cloud (B) is partially hidden under the baroclinic zone cloud system (A). Seven hours later, the IR photo, Figure 350, shows a notch (noted by the arrow) on the western side of the cloud system. The notch reflects a jet stream maximum which probably will initiate cyclogenesis. In the visible picture the following day, Figure 351, a large disturbance has evolved. Significant precipitation occurred over a large area from the Gulf of Mexico to the Ohio Valley.



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Errata - 3WW/TN-81/001, 28 Dec 1981

29 January 1982

The following errors have been noted. Corrections, in the form of page changes, will be forthcoming.

Page 36, Figure 146: Photo in backwards.

Page 69, Figure 278: Photo should be shown in Figure 279's location and vice-versa.

Pen and Ink change: Page 67, Figure 271: Change time and date to read: 1830Z 16 July 1981.

Note: Several pictures are either too bright or too dark; we will attempt to improve these pictures with subsequent page changes.

CORRECTION - PAGE 15

Cumulus - Open-cell cumulus cloud shapes are even better for determining surface and lower-level wind speeds. Figure 54 depicts various stages of open-cell cumulus with respect to wind speeds. If the cells are circular shape, then the winds are less than ten knots (Figure 54a). When they start to become oval shape, the winds are between ten and twenty knots (Figure 54b). When the cells become horseshoe shaped, the surface winds are between twenty and thirty knots (Figure 54c). Finally, when the cells become severely elongated (Figure 54d), the winds are greater than thirty knots. In Figure 55, an enhanced IR, horseshoe-shaped, open-cell cumulus are recognizable within the cold, cyclonic flow of a Great Plains storm system (see related visible photo, Figure 50).

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