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Weather Journeyman

Volume 3. Meteorological Satellite

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WELCOME TO THE third and final volume of the 1W051B CDC. Upon successful completion of this CDC and your OJT requirement you will have obtained your 5 level. Airmen in the 1W0X2 career field will enroll in an additional CDC before being awarded their 5 level.

This volume has two units. Unit 1 summarizes satellite imagery features and the different METSAT systems. Unit 2 covers interpretation of satellite imagery features and meteorological events.

A glossary of terms, abbreviations, and acronyms is included for your use.

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This volume is valued at 18 hours and 6 points.

NOTE:

In this volume, the subject matter is divided into self-contained units. A unit menu begins each unit, identifying the lesson headings and numbers. After reading the unit menu page and unit introduction, study the section, answer the self-test questions, and compare your answers with those given at the end of the unit. Then do the unit review exercises.

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Unit 1. Satellite Imagery Features

REMOTE SENSING is one of the most important sources of meteorological data available. Since the launch of the first meteorological satellite in 1960, over 50 METSATs have been launched. Satellite data not only encompasses imagery, but also provides input to the preparation of numerical forecasts and research projects. Satellite data provides real-time data that covers all areas of the globe. Obtaining maximum value from this data requires correct interpretation of METSAT imagery. This unit covers the transfer of energy from the earth to the satellite and METSAT systems.

1–1. Remote Sensing

With an understanding of the transfer of energy from the earth to the satellite, you have the basis for how the sensors are designed to function on the spacecraft.

401. Radiative transfer

Energy is exchanged in three ways: radiation, conduction, and convection. Energy transfer by radiation is distinguished from energy transfer by the other two forms because it doesn't occur by means of the medium through which energy passes. Convection is the movement through space of the medium. Conduction is transfer through contact between two mediums. Energy transfer by radiation is the dominant mechanism through which energy is transmitted between the earth and the rest of the universe.

Electromagnetic radiation is a collection of an infinite number of waves (at all wavelengths) known as the electromagnetic spectrum. Passive remote sensing devices on satellites measure the reflected or emitted electromagnetic radiation in the visible, near infrared, infrared, and microwave wavelengths. To understand radiative transfer, we need to know some important terms.

Black body

A black body is a theoretically perfect absorber and emitter of radiation. The theory states a black body will absorb all the radiation it meets and emits all the radiation it absorbs when it is in thermodynamic equilibrium. There are *no* perfect black bodies.

Emissivity

This is the ratio of emitted radiation from an object to the emitted radiation from a black body at the same frequency (or wavelength) and temperature. Since all emitters are not perfect black bodies, the amount of radiation emitted is part of the black body's emittance at the same wavelength and temperature. For example, if iron emits at 50 percent the ability of a black body (100 percent or 1.0) at the same wavelength and temperature, its emissivity at that wavelength is represented as 0.5.

Absorptivity

Absorptivity is the opposite of emissivity. It's the ratio of absorbed radiation by an object to the absorbed radiation by a black body at the same wavelength and temperature. For objects in thermodynamic equilibrium, absorptivity equals emissivity.

Reflectivity

An object's reflectivity is the ratio of the total amount of radiation reflected from the object to the total amount of incident radiation. For example, we see the moon because light from the sun is reflected by the moon to the earth. Two factors affecting the moon's brightness are the absorption of energy by the moon's surface and the scattering of energy by the earth's atmosphere.

In METSAT imagery, the albedo of an object is a measure of its reflectivity. The albedo is the percentage of incident energy actually reflected. An object with a high albedo, such as clouds, reflects much of the light from the sun. An object with a low albedo, such as a forest, reflects little of the sun's light.

Scattering

Scattering occurs when energy at a specific wavelength contacts an object about the same size as the wavelength of the incident radiation. The energy is scattered by objects in all directions.

Transmissivity

This is the ratio of energy that passes through an object to the total amount of energy received. Radiation that is not absorbed, reflected, or scattered by the object is transmitted through the object unhindered.

402. Three laws of radiative transfer

Understanding the laws governing radiative transfer is essential as improvements in depiction of satellite data increase. The use of multispectral color composite imagery (two or three channels of satellite data displayed as one image) or composite imagery (the process of deleting part of an infrared (IR) image and replacing it with visible data) is increasing. Without an understanding of these laws, interpretation of new forms of METSAT imagery becomes more difficult.

Planck's law

This law says the amount of radiation emitted by a black body at a given wavelength is proportional to its temperature. Figure 1–1 shows examples for black bodies having temperatures of 7000°Kelvin (K), 6000°K, and 5000°K (typical temperature values for stars). Here, E is the irradiance (the rate of energy transfer) and the Greek letter Lambda (λ) is the wavelength. These curves show the higher the temperature of an object; the greater is the amount of radiation emitted by the object.

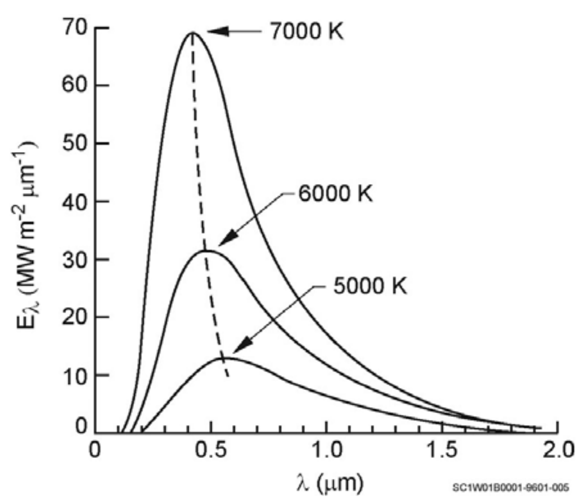

Figure 1–1. Irradiance for black bodies with indicated temperatures.

Wien's displacement law

This law, which is a derivation of Planck's law, says the wavelength of the maximum irradiance of a black body depends on its temperature. A very hot object emits its maximum amount of radiant energy at shorter wavelengths than a cooler object. Figure 1–2 illustrates Wien's displacement law. The figure shows the wavelength of maximum irradiance for the hot solar surface is in the visible light portion of the electromagnetic spectrum and the wavelength of maximum irradiance for the cooler earth's surface is in the IR portion.

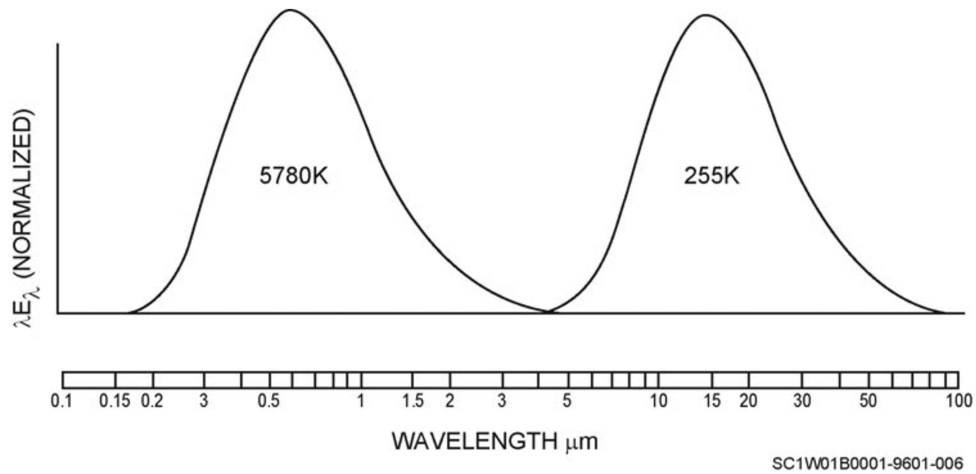

Figure 1–2. Normalized black body irradiances for the sun (5780°K) and the earth (255°K).

Kirchoff's law

Kirchoff's law says for objects in thermodynamic equilibrium (a steady temperature), absorption of radiant energy must be equal to the emission of radiant energy. If an object receives more energy than it emits, the object warms; if the object emits more energy than it absorbs, it cools. Objects that are good emitters are also good absorbers and vice versa.

These three laws directly relate to METSAT imagery. METSAT sensors measure the emitted energy of all objects in their line of sight. The one exception is the microwave sensor. It measures the absence of energy at a specific wavelength to detect specific data. All substances have different emissive characteristics though some differences may be very slight. In the wavelengths used by the IR sensors of all the satellites, the emissive characteristics of land, water, and clouds are nearly the same. Given this, if the temperatures of all three were the same, they would all appear to be nearly the same gray shade on an IR image.

Since the emissive characteristics are nearly the same, this allows the temperature differences between land, water, and clouds to be significant in how they appear on IR imagery. Since high clouds are cooler than low clouds, they appear whiter than the low clouds. Another example of the importance of temperature differences is the "black fog" phenomenon. Generally, the temperature differences between fog and land are not sufficient to distinguish them on IR imagery. But, if an area of fog were to move over an area of land that was sufficiently cooler than the fog, the fog would appear darker than the adjacent land.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

401. Radiative transfer

1. Match the energy transfer terms in column B with the descriptions in column A. Items in column B may be used once.

Column A	*Column B*
____ (1) Occurs when energy at a specific wavelength contacts an object about the same size as the wavelength of the incident radiation.	a. Emissivity.
____ (2) The ratio of emitted radiation from an object to the emitted radiation from a black body at the same wavelength and temperature.	b. Black body.
____ (3) The ratio of absorbed radiation by an object to the absorbed radiation by a black body at the same wavelength and temperature.	c. Scattering.
____ (4) The ratio of the total amount of radiation reflected from the object to the total amount of incident radiation.	d. Absorptivity.
____ (5) The ratio of energy that passes through an object to the total amount of energy received.	e. Reflectivity.
____ (6) A theoretically perfect absorber and emitter of radiation.	f. Transmissivity

2. Under Wien's Law, on what is the wavelength of the maximum irradiance of a black body dependent?

402. Three laws of radiative transfer

1. Explain Planck's law.

2. Explain Wien's displacement law.

3. Explain Kirchoff's law.

1–2. METSAT Systems

The first weather satellite was launched on February 17, 1959; however, due to technical problems it was unable to obtain a significant amount of useful data. The first successful weather satellite was TIROS–1, launched by NASA 1 April 1960. Since then monumental improvements have been made in regards to the quality of satellite systems and the products they provide the weather forecaster. The following sections will discuss meteorological satellite types, coverage, and the different ways we view satellite imagery.

403. METSAT advantages

There are advantages and drawbacks to METSAT imagery and its interpretation. We discuss the drawbacks later. The following lists the advantages of METSAT imagery and its use as an analysis tool.

1. METSAT imagery is an observation that is more frequent than synoptic reports.
2. It provides data in areas lacking conventional data, such as over ocean and desert regions.

3. It also enhances resolution in areas that have an organized, dense synoptic network. Examples of these would be the US and European observation networks.
4. Animated looping allows systems to be put in motion. This allows you to see system motion and the interaction between different pressure systems. You also see interaction between weather systems of different scales.
5. A single METSAT image gives you a more complete idea of the vertical structure of the atmosphere than one or two products. You can see the low-, mid-, and upper-level features simultaneously. You can also determine how they relate to each other.

404. Satellite types and coverage

Let's now discuss the characteristics of different satellite types and the coverages they provide. Understanding these different characteristics will help you in interpreting METSAT imagery.

Polar orbiting

Polar orbiting satellites orbit the globe from pole to pole at a slight angle to the poles providing imagery of the earth's surface. Figure 1–3 illustrates an example of the polar orbiting satellite's inclination angle. In an ascending orbit, the satellite has a south-to-north orbit. In a descending orbit, it has a north-to-south orbit.

The inclination angle (98.7°) and the altitude of the satellite, approximately 472 nautical miles (nm), allow for global coverage every 12 hours. Polar orbiter imagery covers 1600nm across an 8-inch-wide picture. This is about 26.7° latitude width at the equator. Figure 1–4 shows a polar orbiting scan line. Within 30°N/S of the equator, you'll receive two satellite passes every 12 hours at a given location. The closer a station is to the N/S poles, the more satellite passes it will receive in a 12-hour period.

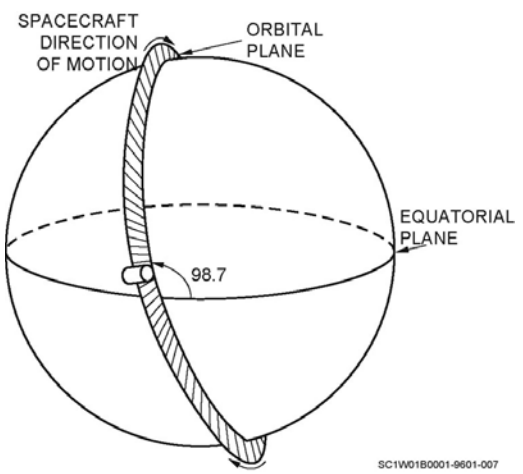

Figure 1–3. Orbital inclination.

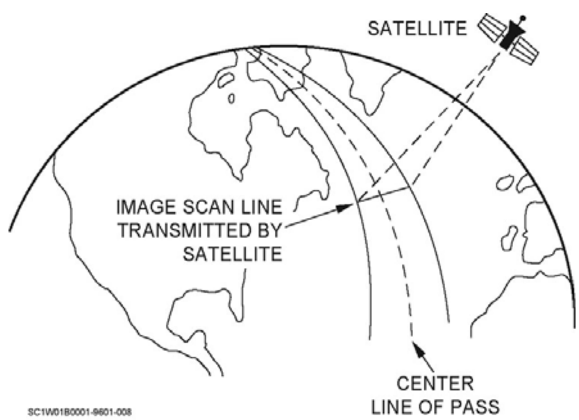

Figure 1–4. Satellite scan line.

You'll only receive this imagery for real-time analysis at direct readout sites (DRO). A DRO can receive a direct transmission of the imagery from a satellite as it passes over the globe.

Geosynchronous

This satellite is stationed over the equator at 19,312nm/35,800 kilometer (km). The satellite stays in position because of a balance between centrifugal force (CeF) and gravity (g); (g = CeF). The satellite orbits the earth at the same angular velocity as the rotating earth. Each satellite covers 140° of longitude and latitude, giving you 120° of useful cloud data (fig. 1–5).

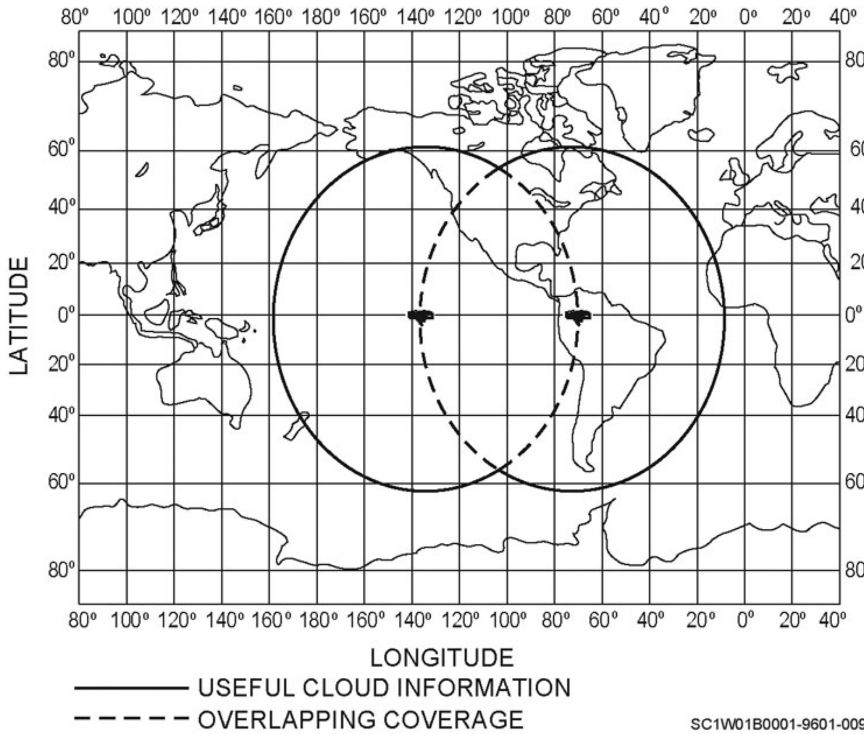

Figure 1–5. GOES coverage.

There are numerous satellites positioned around the earth that provide worldwide coverage (fig. 1–6). They provide continuous coverage of the same location on the earth 24 hours a day.

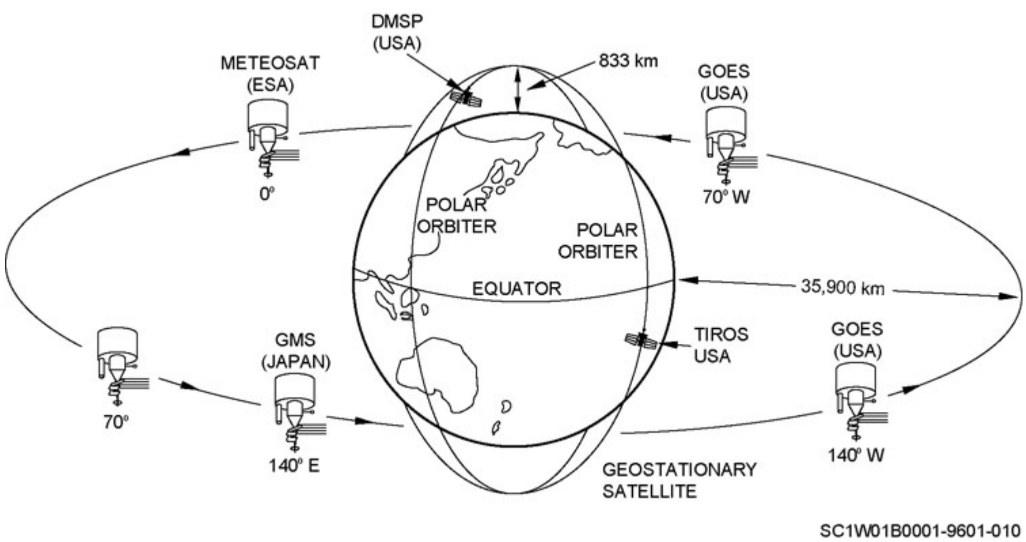

Figure 1–6. Satellites.

Differences

Polar orbiting satellites give you global coverage in a 12-hour period. This works well with our global military mission. You can also see different cloud and terrain features more clearly because of the better resolution of METSAT imagery.

The geostationary satellites give you continuous coverage of the same area over a 24-hour period. This allows you to loop the imagery to follow fronts, lows, severe weather, and many other cloud and non-cloud features.

Operational satellites

There are two types of operational satellites—polar orbiting and geosynchronous. The polar orbiting satellites consist of the Defense Meteorological Satellite Program (DMSP) and National Oceanic and Atmospheric Administration (NOAA) satellites. Geosynchronous satellites consist of geosynchronous operational environmental satellites (GOES)—USA, geostationary meteorological satellite (GMS)—Japan, meteorological satellite (METEOSAT)—European, and Indian satellite (INSAT)–India.

405. Types of weather METSAT imagery

The wavelengths used by METSAT sensors to produce METSAT imagery are part of the electromagnetic spectrum. Figure 1–7 shows the electromagnetic spectrum.

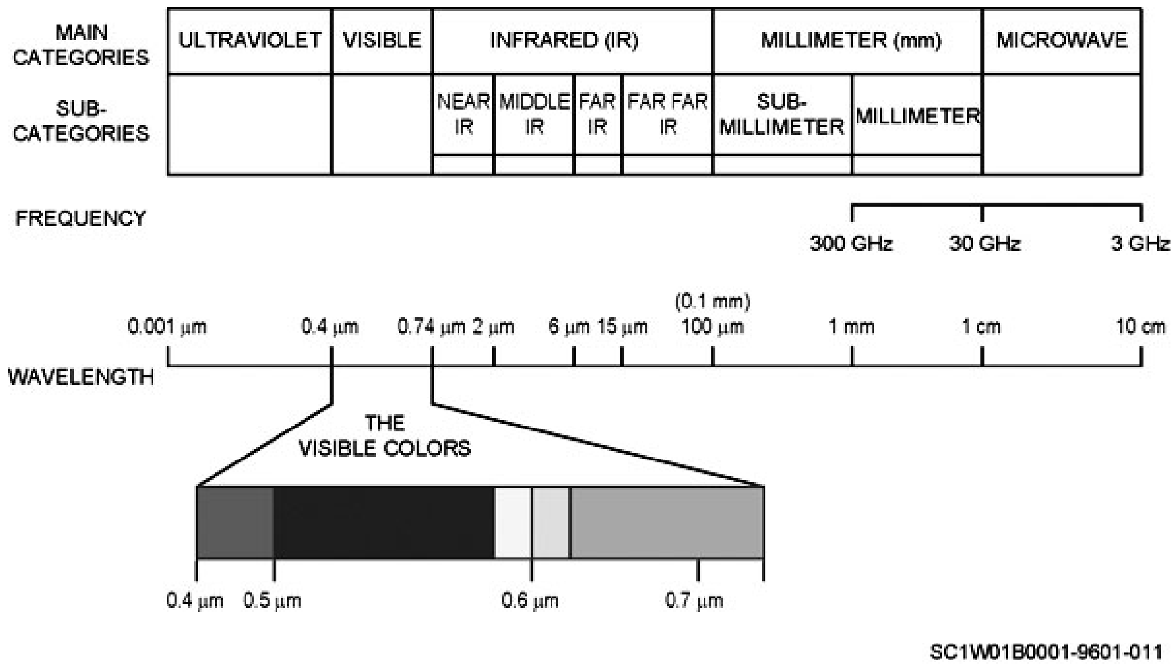

Figure 1–7. Electromagnetic spectrum.

Gray shade description

Gray shades are how we see cloud and non-cloud phenomena on the imagery. A computer assigns 256 gray shades to features on the imagery, ranging from a very dark gray to a very light gray. The eye can only see 15 to 20 gray shades.

A gray shade is assigned a specific brightness or temperature value, depending on the type of imagery you are working with. Figure 1–8 shows the specific gray shade assigned to a particular feature.

On visual imagery, you are seeing the reflectivity of features that are converted to brightness values. With infrared imagery, you’re seeing the temperature of features that are converted to brightness values. On water vapor imagery, you’re seeing the amount of moisture sensed in a vertical layer that is then converted to a brightness value.

We use the contrast in gray shades to help us interpret cloud and non-cloud phenomena on METSAT imagery.

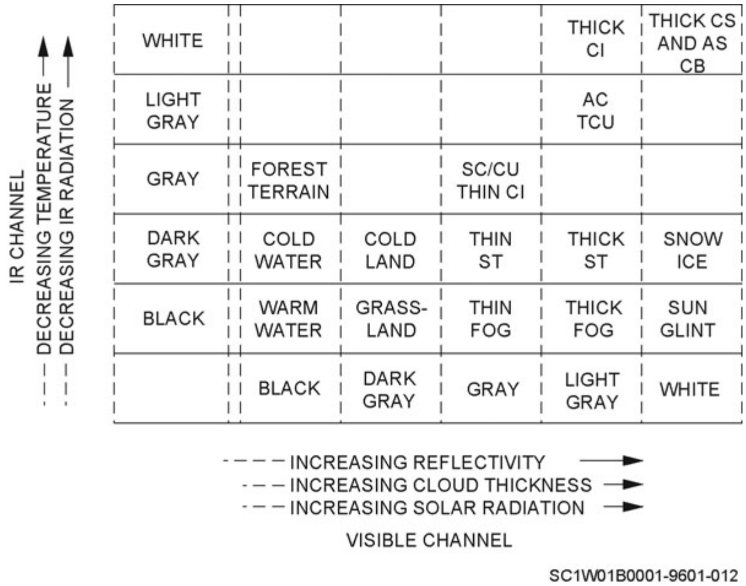

Figure 1–8. Gray shades.

Visible (VIS)

Visible METSAT imagery measures the reflected visible radiation or the brightness of the reflected sunlight with a wavelength of 0.4–0.74 microns (µm) (fig. 1–9). Next, we list some factors that affect the brightness measured.

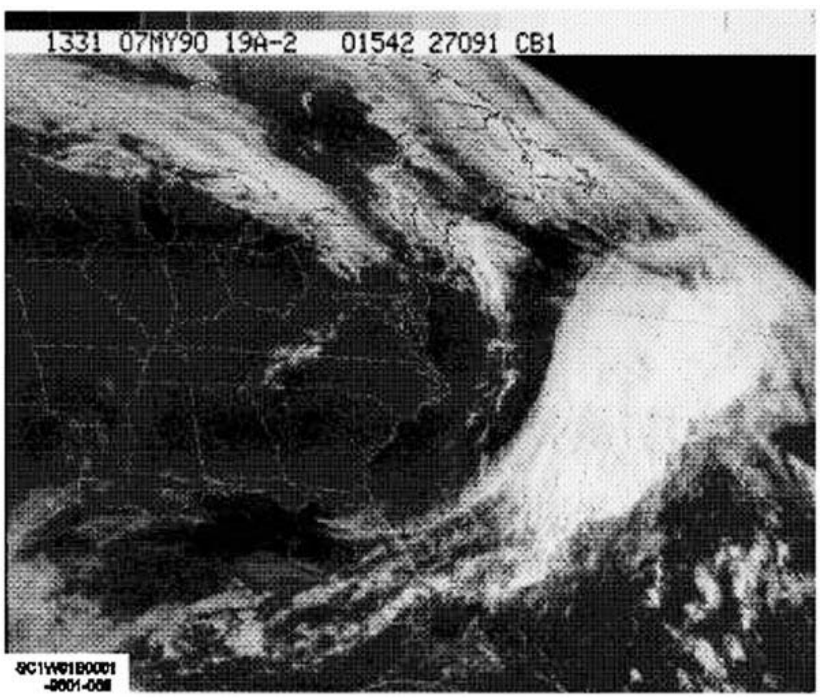

Figure 1–9. Visual imagery.

Illumination

Sun angle considerations are important because they affect your interpretation of clouds, cloud patterns, terrain features, and other atmospheric phenomena. With experience, taking these considerations into account becomes second nature.

Time of year/day

These determine how much sunlight you have at a certain location depending on the season (for example, winter versus summer, noon versus dusk).

Latitude

The equator receives approximately the same amount of sunlight day to day throughout the year. The farther north or south you look the less light you have, depending on the time of the year or the time of day.

Cloud height

Higher clouds cast shadows on the lower-level clouds; the lower-level clouds are harder to see due to less illumination. Figure 1–10 shows an example of how cloud shadows may obscure lower clouds.

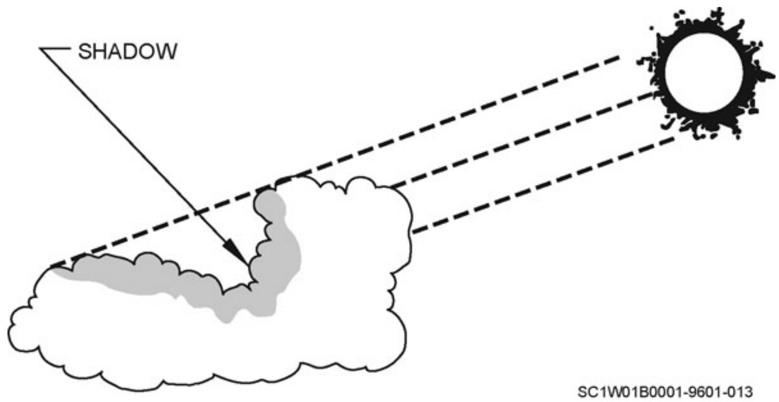

Figure 1–10. Cloud shadows.

Cloud characteristics

Water droplets are five times more reflective than ice crystals when we view them from a satellite. Ice crystals scatter more sunlight away from the sensor than does a water droplet. A thicker or denser layer of ice crystals has the same reflectivity as a lesser amount of water droplets. The brightness increases with increasing density (concentration) of cloud particles (crystals/droplets for example, fog and stratus versus cirrostratus). Brightness increases with increasing cloud thickness (depth for example, cumulonimbus). Brightness also depends on the ability of a surface to reflect sunlight (albedo). The table below shows some different phenomena and their reflectivities.

Cloud Characteristics			
1. Large thunderstorm	92%	7. Thin stratus	42%
2. Fresh new snow	88%	8. Thin cirrostratus	32%
3. Thick cirrostratus	74%	9. Sand, no foliage	27%
4. Thick stratocumulus	68%	10. Sand and brushwood	17%
5. White Sands, NM USA	60%	11. Coniferous forest	12%
6. Snow, 3–7 days old	59%	12. Water surfaces	9%

Near infrared

Near infrared (NIR) measures the amount of reflected sunlight and emitted energy. The factors affecting the brightness in visual imagery have the same effects in the near IR. The NIR wavelength is 0.75 to 2.0 micrometers (µm). Because vegetation reflects best in these wavelengths, you can detect vegetation, terrain features, and lithometeors such as haze, and dust, better than at the visual wavelengths alone.

Most METSAT sensors are designed so the visual imagery is a combination of VIS and NIR wavelengths. This allows for good land and water contrast and provides easier identification of features on the imagery. This wavelength is also very sensitive to lunar radiation. The sensitivity allows us to get nighttime visual imagery from DMSP spacecraft when there is a quarter moon or more. NIR imagery identifies:

- Clouds ≥ 3 km (l.5 nm) in size.
- Emitted light from forest fires, gas fires, city lights, the aurora borealis, and the aurora australis.

Water vapor

Water vapor (WV) imagery measures the earth's radiation at 6.7µm on GOES imagery and 5.7 to 7.1µm on METEOSAT imagery. This is the band of maximum water vapor absorption in the electromagnetic spectrum. The WV channel is also called the moisture channel.

WV imagery is based on the amount of energy at a specific wavelength that does not reach the sensor. The more energy that is blocked from the sensor at a specific wavelength, the lighter is the gray shade.

GOES WV imagery shows the amount of moisture in the atmosphere that is absorbing energy at 6.7 µm (fig. 1–11). The brightness of the radiation observed depends on both the atmosphere's water vapor content and its temperature. By measuring this radiation, the WV imagery shows the moist and dry areas. However, since absorption is highest between 610 to 240 millibars (mb), middle and high-level moisture affects the sensor much more than low-level moisture. Very moist areas in the middle and upper levels that contain cirrus clouds appear white. Areas that are moist in the middle and upper levels with no cirrus clouds appear as a light gray. Dry areas in the mid- and upper-levels with no clouds appear as dark gray or nearly black, provided the low-level temperatures are warm. Even dry areas in the upper levels appear light gray if the surface temperatures are cold.

Moisture pattern

The moisture pattern is the result of vertical motion and moisture advection in the atmosphere. A moisture region is normally associated with upward vertical motion that appears as a light gray shade. A drier region is normally associated with downward vertical motion that appears as a dark gray shade. You can see moisture on the WV imagery although no clouds are evident on other METSAT imagery.

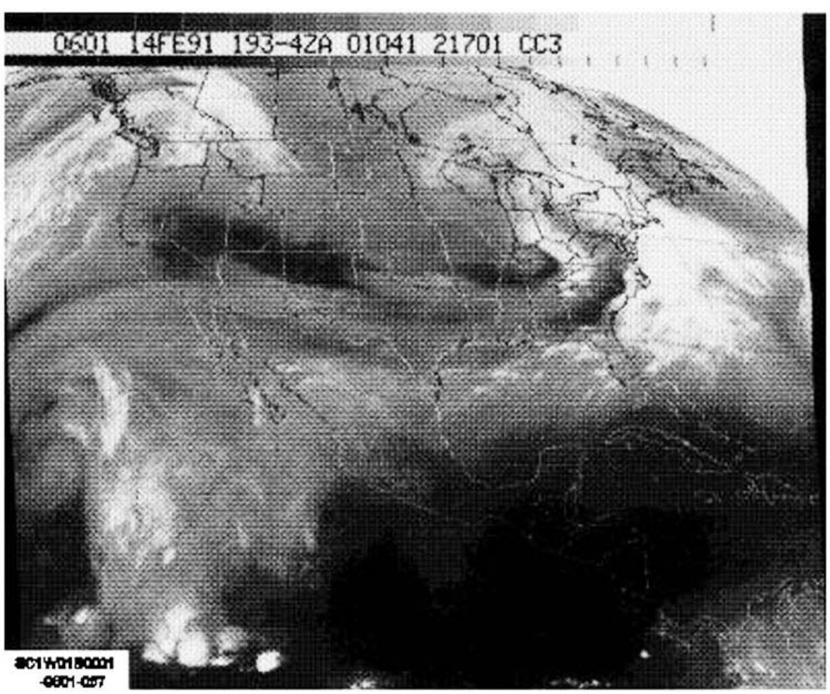

Figure 1–11. Water vapor imagery.

Advantages

WV imagery provides information where no mid- and upper-level clouds are present. You can more accurately locate circulation centers, jet streams, wind maximums, troughs, and ridges. The moisture pattern and the changes to it appear more fluid than the cloud features on other METSAT imagery.

Uses

Since it senses mid- and upper-levels better, features at these levels are more easily distinguished than lower-level features. Some uses of WV imagery are:

- Forecasting cyclogenesis.
- Determining polar front jets (PFJ) and subtropical jets (STJ).
- Locating fronts with little or no associated cloudiness.
- Identifying circulation centers, troughs, ridges, and wind maximums.
- Identifying vorticity maximums.
- Identifying potential thunderstorm areas.

Studies show that 80 percent of the time, well defined "plumes" in the water vapor imagery accompany extreme rainfall (5 inches or more within a 24-hour period). On the global scale to synoptic scale, the 6.7μm water vapor imagery reveals northward movements or surges of mid- to upper-level moisture from the tropics into the mid-latitudes. These surges, called water vapor plumes, are usually associated with large-scale circulations. As the plumes progress from the tropics northward into the US, they often interact with low-level moist, unstable air (represented by ridge axes of equivalent potential temperature) and mechanisms that produce upward vertical motion such as jet streaks. These interactions often result in flash floods. This was the case during the upper Midwest floods of the summer of 1993. Water vapor plumes persisted on the backside of the subtropical ridge (located over the eastern US). Jet streaks, associated with near continuous series of short-wave systems from the west, repeatedly interacted with the western and northern boundary of the persistent moisture plume.

Far infrared

Far infrared (FIR) measures the long-wave radiation of objects (clouds and ground) using a wavelength of 10.2 to 12.8μm. The amount and frequency of long-wave radiation depends on the temperature and emissivity of the object. Different temperatures emit at different IR wavelengths. The computer converts the wavelengths received by the METSAT sensors to brightness values that represent temperatures. Shades of gray ranging from black to white are assigned to temperature values. In normal IR, hot temperatures are white and cold temperatures are black. Gray shades are easier to interpret than on the inverted IR.

FIR METSAT imagery is normally inverted so colder clouds appear white and hot surfaces appear black. The advantage of FIR imagery is that it allows 24-hour a day viewing. It does *not* depend on reflected sunlight for an image. This allows looping of the data 24 hours a day, enabling you to follow systems easily with continuity.

Factors affecting the measured temperature

Knowing the factors affecting the accuracy of the temperature being measured determines your confidence in the data. This next area covers the factors you need to consider.

Time of year/date

Account for diurnal and seasonal temperature fluctuations. These are most apparent in low-level features.

Cloud characteristics

Certain cloud characteristics affect what the sensor detects and, finally, what you interpret. One characteristic is the cloud particle type. Ice crystals are semitransparent to radiation, causing thin cirrus to appear as a medium gray shade.

Another characteristic is the cloud thickness (depth) and density of the cloud. They determine how much radiation from below is allowed through to the sensor. The thicker the cloud and denser the cloud droplet/ice crystals, the more accurate is the cloud top temperature reading (for example, cirrus to cirrostratus). Increasing cloud droplet/ice crystal density reduces radiation from below.

Upper-level clouds are most apparent on unenhanced infrared imagery. Low-level clouds do not stand out as easily because there is little temperature contrast between the cloud and the earth's surface. Enhanced IR (EIR) imagery can give you a temperature contrast for any level in the atmosphere, depending on the enhancement you use.

Enhancement

Enhancement is a series of gray shades corresponding to thermal values that provide a thermal contrast to features on the imagery. Enhancing an image is done on the ground by computers. Unenhanced imagery shows a transition from warm to cold by a uniform increase in brightness. This is a linear-scale relationship where you have one gray shade to one temperature value. Figure 1–12 shows the relationship between the different gray scales and the temperature.

Thresholding

Thresholding is assigning a gray shade to a temperature range. A series of threshold values (alternating dark and light gray shades) on METSAT imagery is known as step contouring. This allows you to see deep, vertically developed clouds, such as a cumulonimbus, easier.

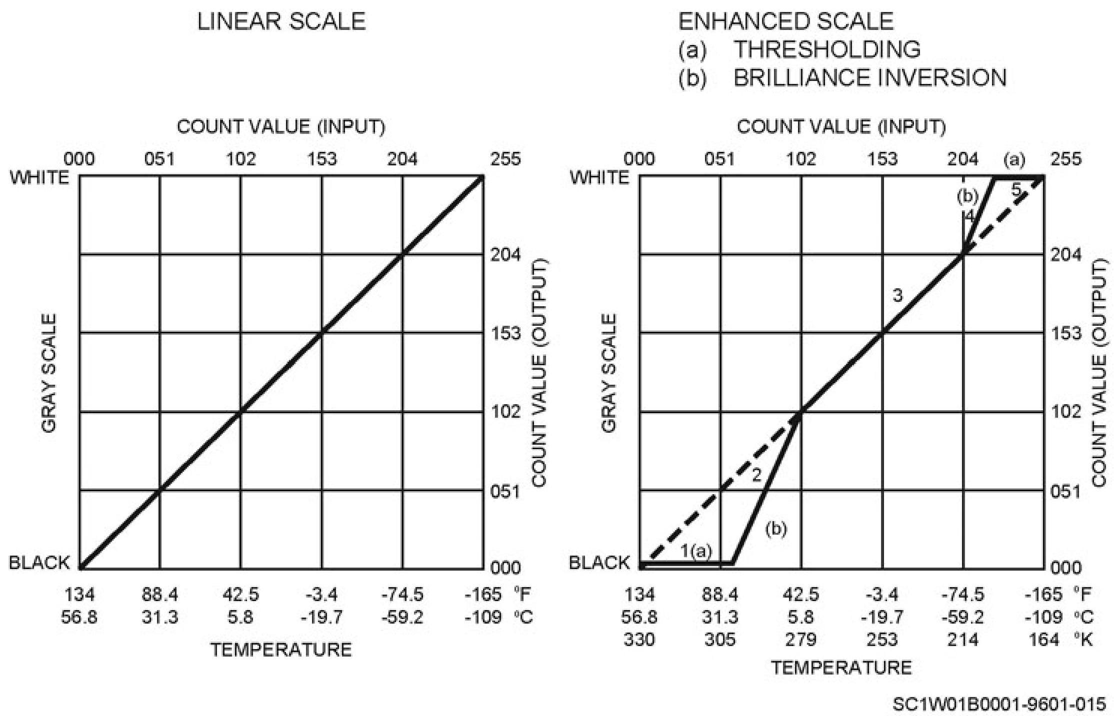

Figure 1–12. Gray scales.

Brilliance inversion

A brilliance inversion occurs by assigning a range of temperatures to a range of gray shades. This process allows you to see more detail in the data. An example would be the change from altostratus to cirrostratus clouds.

Common GOES enhancement curves

There are several types of GOES enhancement curves available for forecasters to use. Many enhancement curves have been applied to polar orbiting imagery. Each curve has a specific purpose or use.

ZA

The ZA curve is closest to a straight linear curve (fig. 1–13). It has a slight low/high linear enhancement, making it one of the most commonly used curves. WV imagery is also enhanced using the ZA curve identifier. Color enhancements should only be accomplished on this curve, if you have this capability.

EC

This is a cool season, general-purpose curve (fig. 1–14). Segment five enhances temperatures ranging from –13°C to –50°C that are normally associated with precipitation during the cool season. Segments six and seven depict convective cloud tops. Figure 1–15 compares the ZA and EC enhancement curves.

MB

This good, all-purpose curve is most commonly used for convective activity (fig. 1–16). Cirrus and cirrostratus are also easily detected on this curve. Segment three gives a good definition to mid-level clouds. Segments four through seven contour convective activities; segment eight allows a more gradual gray shade change to better define convective tops imagery.

JG

This wintertime curve is used to define water currents, low stratus, and coastal fog (fig. 1–17). It can help identify the surface freezing line, where the temperature changes from –0.2°C to –0.7°C between segments two and three. This is useful for temperature forecasting and identifying the freezing level. The portion colder than freezing is identical to the MB curve. Figure 1–18 compares the MB and JG enhancement curves.

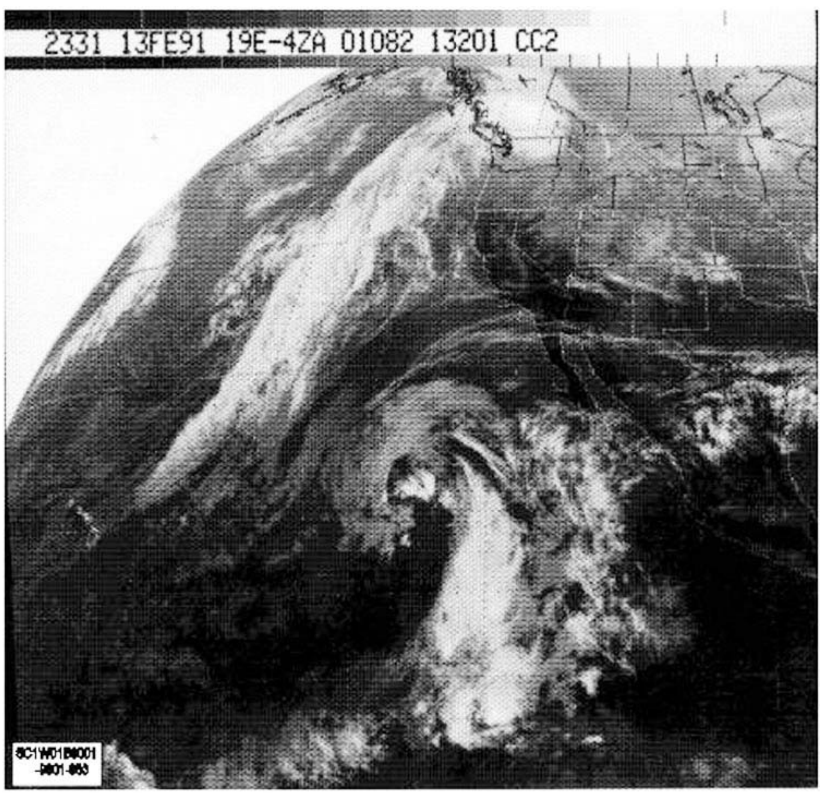

Figure 1–13. ZA.

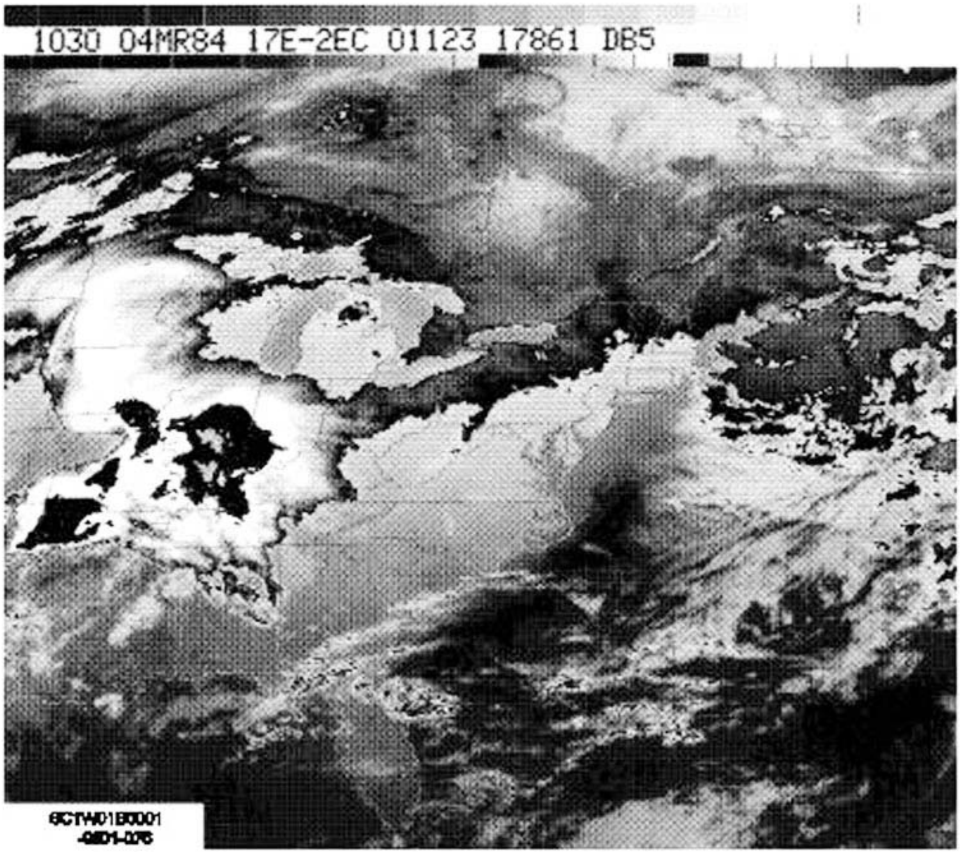

Figure 1–14. EC imagery.

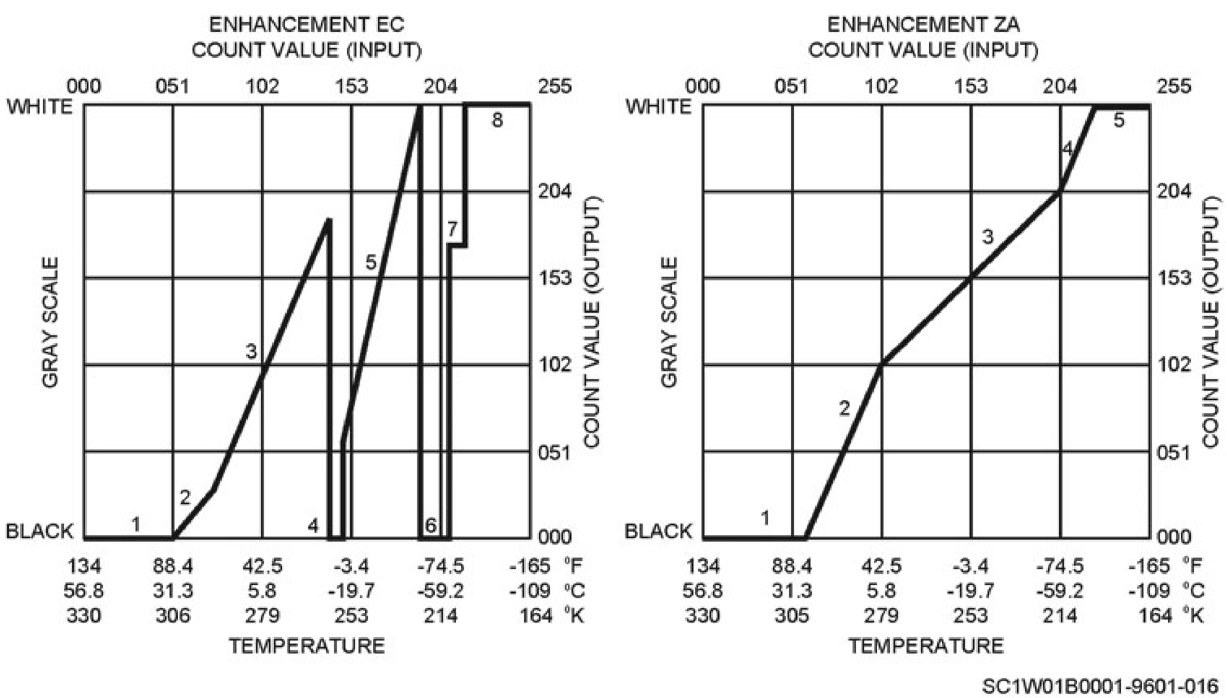

Figure 1–15. ZA/EC enhancement curves.

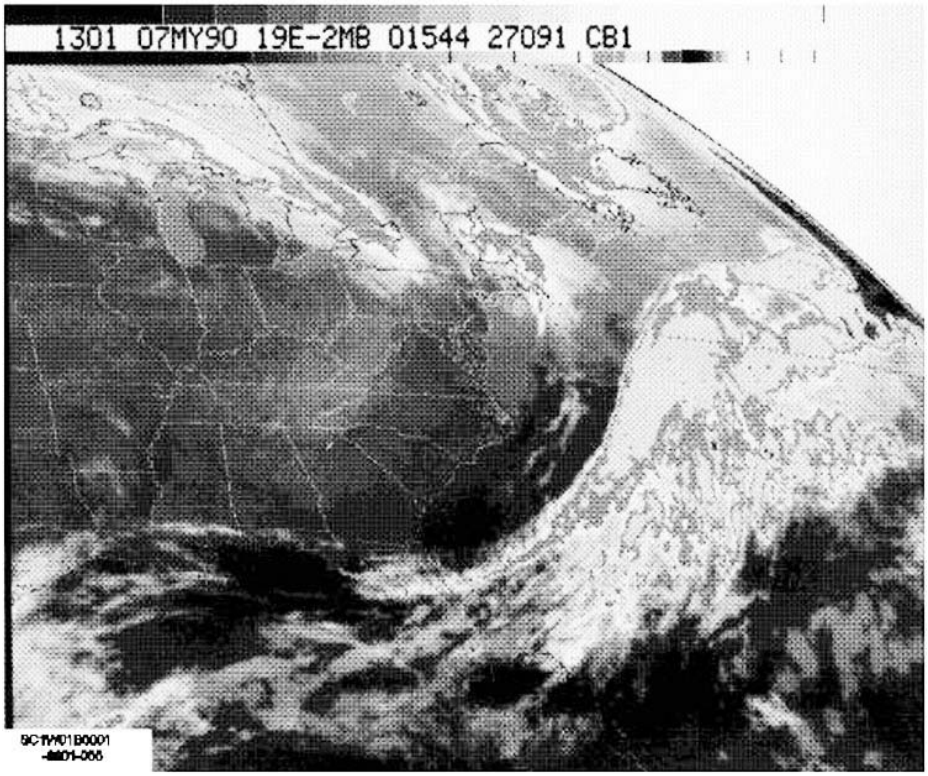

Figure 1–16. MB imagery.

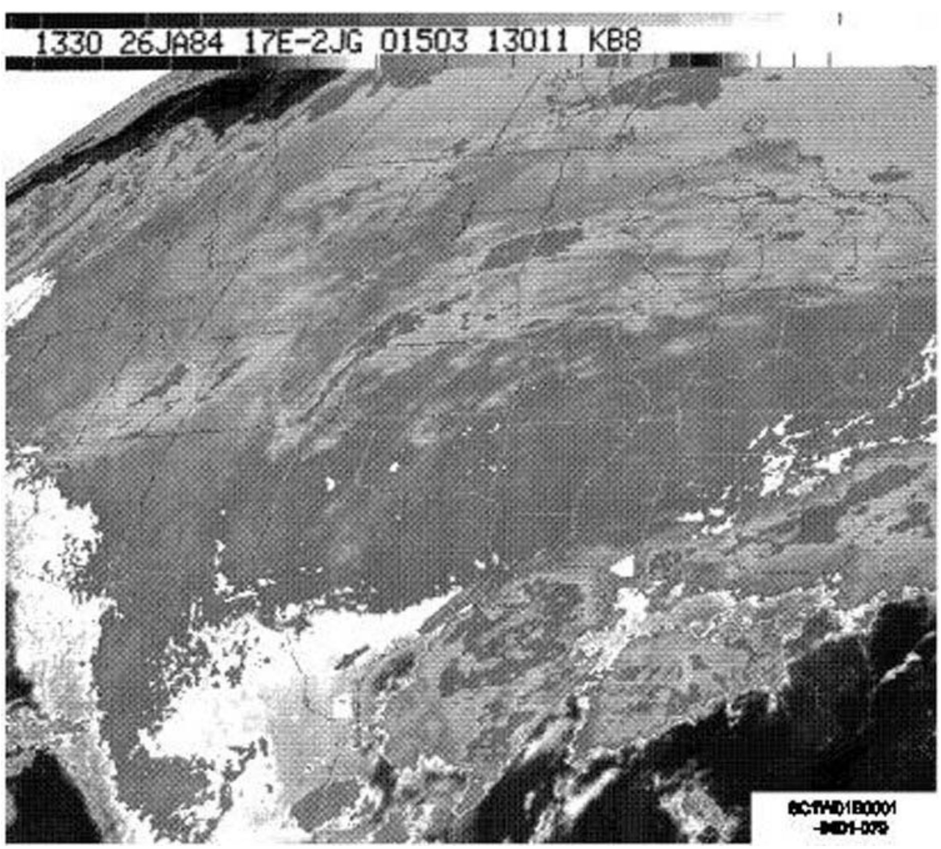

Figure 1–17. JG imagery.

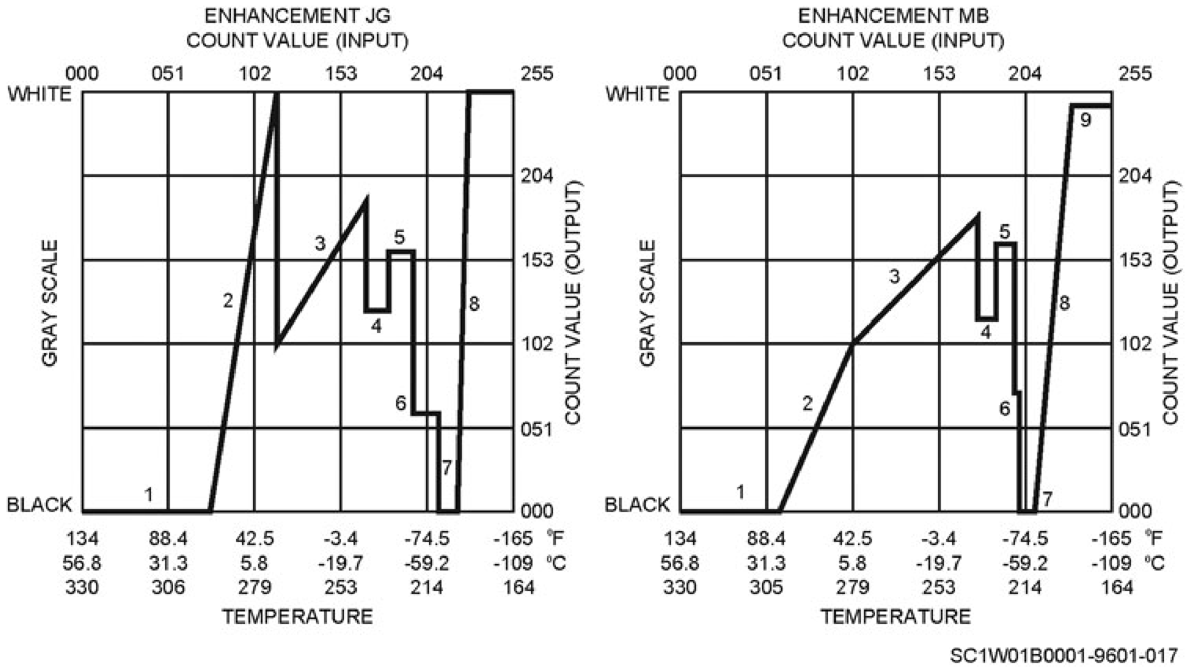

Figure 1–18. MB and JG enhancement curves.

CC

This curve is designed for cloud interpretation in colder northern latitudes in the winter (fig. 1–19). The CC curve makes it easier to identify low and mid clouds associated with colder air in the winter.

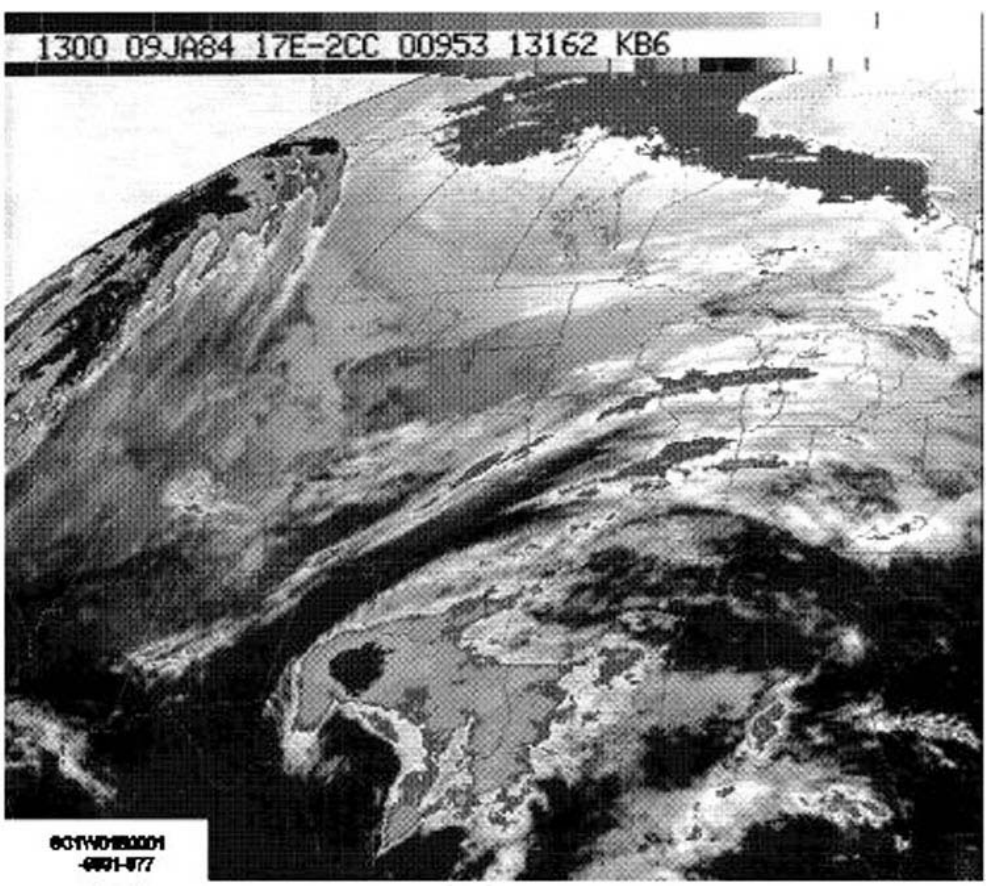

Figure 1–19. CC imagery.

HF

This enhancement curve is designed for west coast forecasters to enhance system cloud tops over the Pacific Ocean. Figure 1–20 compares the CC and HF enhancement curves.

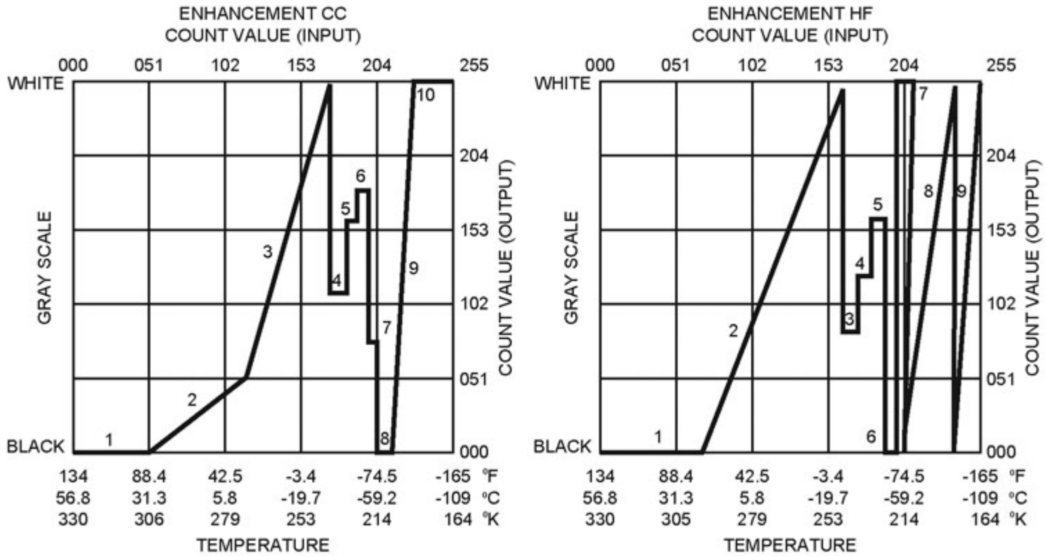

Figure 1–20. CC/HF enhancement curves.

Viewing considerations

The viewing considerations you'll learn about are very important to remember when you interpret METSAT imagery. Satellite imagery doesn't lie to you but it can be misinterpreted if you forget the following considerations during the interpretation process.

Resolution

Resolution is the smallest individual element a sensor can detect. This is designated on the imagery as a small square, known as a pixel. Figure 1–21 shows what pixels look like in a digital image.

Resolution is greatest at the sub point and decreases in all directions away from this point. The sub point is located directly beneath the satellite; on polar orbiting satellites, the series of sub points is known as the "subtract". This designates the track of the satellite (fig. 1–22).

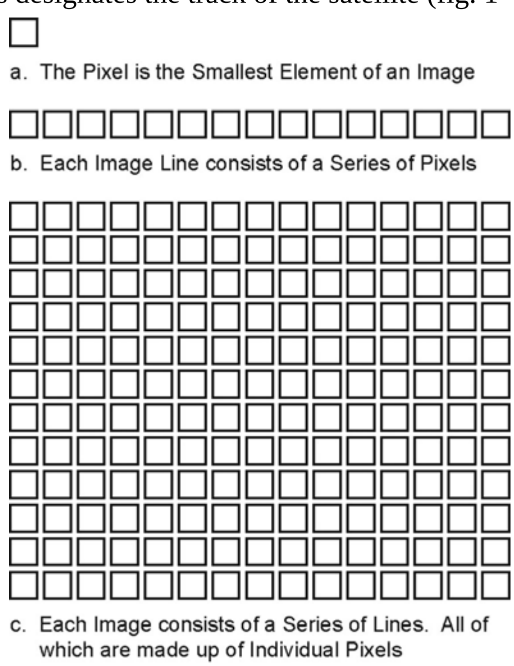

Figure 1–21. Digital image.

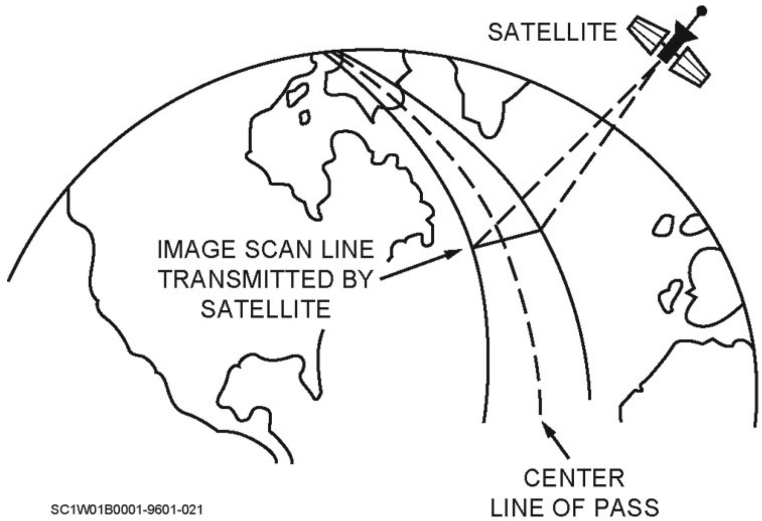

Figure 1–22. Satellite track.

If the object/cloud is below the resolution of the METSAT sensor, the sensor averages the brightness/temperature of the object with the background. Individual elements are not seen and a compromise gray shade results. This causes the clouds to appear warmer and lower in height than they actually are.

> With evolving technology and weather satellites continuing to be launched, sensor resolution is always improving. In the past GOES WV imagery was limited to a 14 KM resolution; as of the publication date of this career development course (CDC), GOES WV imagery could be viewed with a resolution as high as 1 KM.

Attenuation

Attenuation is any loss of energy due to absorption and scattering of IR radiation by atmospheric elements. IR wavelengths are absorbed by water vapor and carbon dioxide. This occurs only in the IR wavelengths. Figure 1–23 illustrates an example of attenuation in a clear atmosphere.

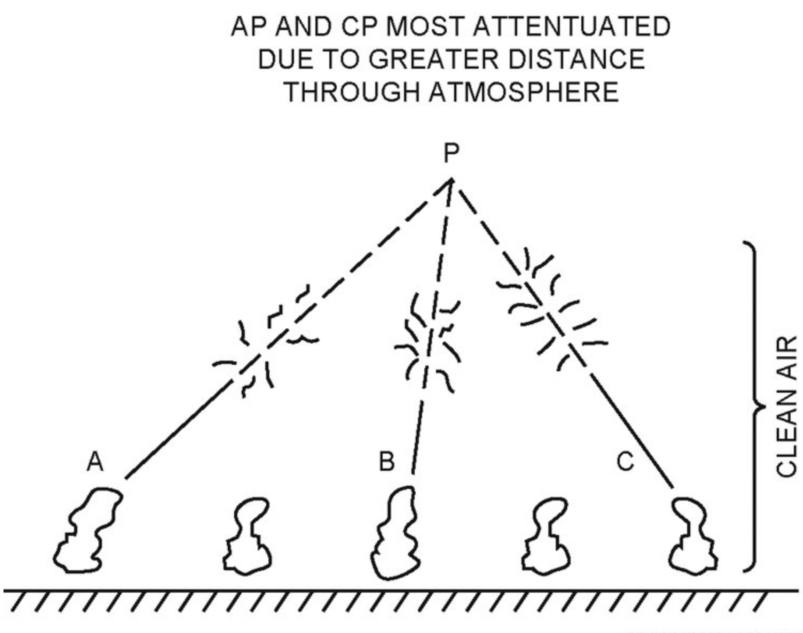

Figure 1–23. Attenuation in a clear atmosphere.

This process reduces the amount of energy reaching the METSAT sensor so cloud tops appear higher and colder than they really are. How much attenuation occurs depends on:

- The viewing angle of the satellite and how much of the atmosphere it must travel through (fig. 1–24).
- The height of the cloud tops. The lower the cloud tops are, the greater the attenuation will be (fig. 1–25).
- The amount of water vapor in the troposphere. The more water vapor there is, the greater the attenuation will be.

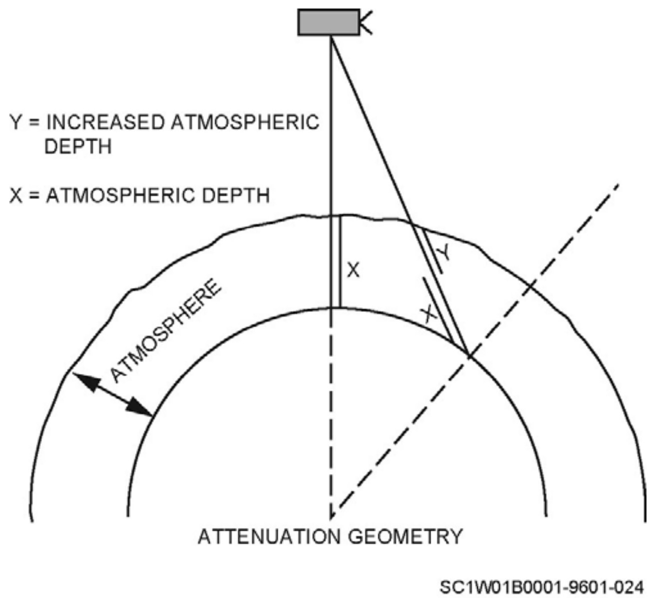

Figure 1–24. Attenuation geometry.

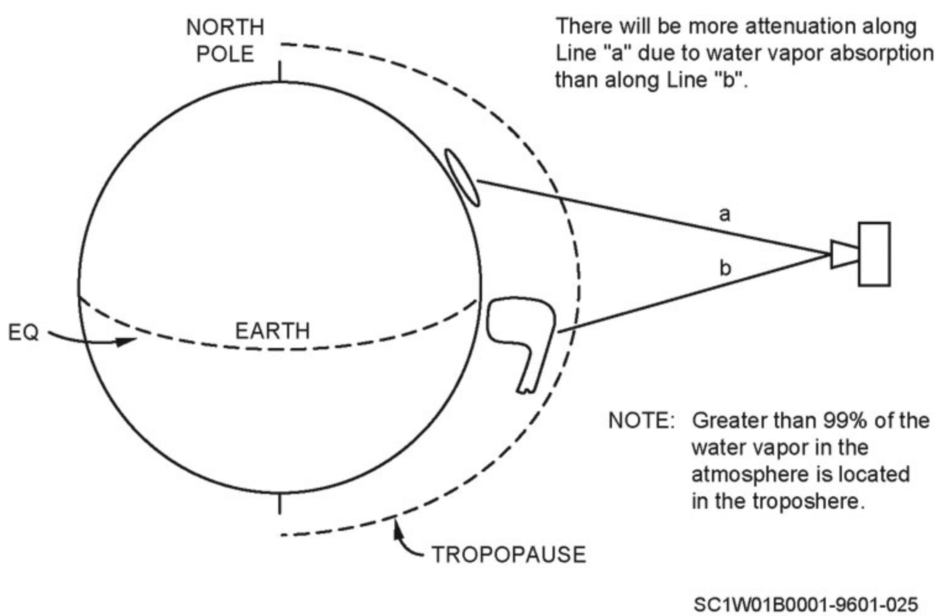

Figure 1–25. Attenuation—cloud levels.

Attenuation is greatest in the tropics, due to a deep layer of moisture, and at the edges of the earth disk (on geosynchronous), due to the oblique (shallow) viewing angle, which increases the amount of moisture through which the energy must propagate.

Contamination

Contamination is energy sensed by the satellite from two or more sources along the same line of sight. The sensor averages the brightness/temperature, thus giving you an inaccurate cloud-top temperature reading. Figure 1–26 shows how contamination can occur through thin cirrus clouds. Contamination can occur on VIS and IR imagery. The amount of contamination depends on the viewing angle, the cloud element spacing, the cloud layer thickness, and the vertical temperature profile through thin cirrus clouds.

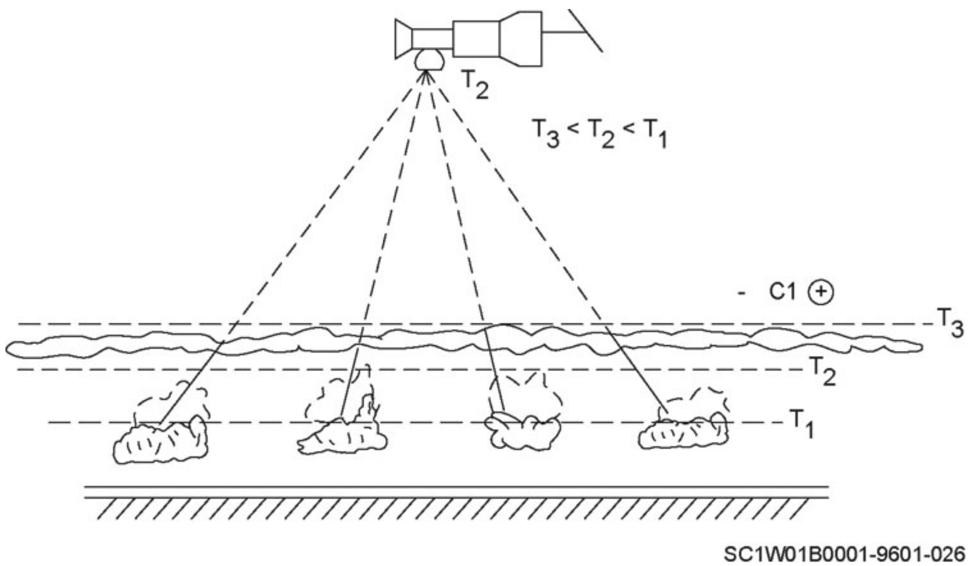

Figure 1–26. Contamination through thin cirrus clouds.

Viewing angle

The viewing angle of the METSAT sensor determines the amount of contamination affecting the sensor. If the sensor is directly over thin cirrus, there is more contamination than if the sensor must look through it at an oblique angle. Remember, the more oblique the viewing angle, the more attenuation is a factor.

Spacing

The land or ocean surface is evident between cloud elements (for example, stratocumulus field). This causes the sensor to interpret two types of gray shades within the same region. This also causes a general darker gray shade in the region, which indicates clouds are lower than they really are.

Thickness

The thickness of the cloud layer or layers interacting with the IR energy from the warm earth or a low-level cloud deck makes a thin upper-level cloud layer appear warmer and lower than it actually is (for example, thin cirrus over water). With VIS imagery, the higher clouds are thin enough so that you can see the earth’s surface or lower clouds.

Vertical temperature profile

This can mislead your interpretation in certain situations. If there is a strong inversion and moisture is trapped below it, there is a difference in temperatures in the vertical over a region. Black stratus is a cloud feature where the stratus traps radiation from the earth. This warms the cloud up significantly while the surrounding clear regions continue to cool as expected. This makes the region where the black stratus is located appear as a clear region with clouds surrounding it. Looking at observations you’ll find the reverse is true.

Foreshortening

Foreshortening is a loss of resolution caused by an oblique (shallow) viewing angle that results in a distortion near the edge of the picture on any type of METSAT imagery. The METSAT sensor is looking into the sides of the clouds, *not* the tops of the clouds, and is overestimating the cloud coverage. The clouds are compressed onto the METSAT image at the disk edge (for example, scattered to broken cloud layers appear overcast). This is most noticeable on geosynchronous METSAT imagery along the edges of the disk.

Cloud location errors can occur due to the oblique (shallow) viewing angle. Figure 1–27 shows a diagram of an actual cloud versus its apparent location. This varies with cloud height. The error isn't significant with synoptic-scale systems. Remember to always adjust the clouds toward the satellite sub point.

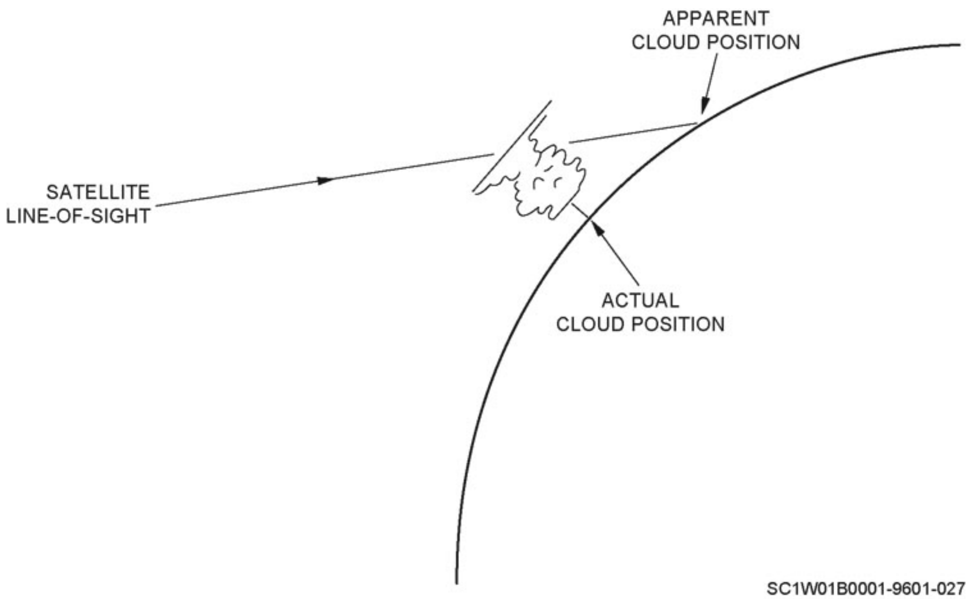

Figure 1–27. Diagram illustrating actual versus apparent cloud location.

Time response

This is the time it takes for the sensor to heat up and cool off plus react to large temperature changes. This can result in the displacement of cloud edges to the east on a GOES METSAT image and the underestimation of cloud-top heights. The GOES IR sensor can only change its reading a maximum of 26°C per pixel. For example, the surface temperature just west of a violent thunderstorm is 32°C and a significant part of the cloud top near the west edge of the storm is –80°C. One pixel would show the correct 32°C. The next pixel would show a temperature no lower than 6°C. The following pixel would show –20°C, while the fourth pixel would be –46°C. The time lag can cause the true cloud-top temperature to be occasionally inaccurate.

Gridding errors

Occasionally the geographic grid, whether it is manually or computer-produced, is mispositioned. There are two ways to compensate for this. One is to develop a master set of clear overlays to overlay the picture so that you'll have the correct depiction. The other is to identify geographic features, such as lakes, rivers, coastlines, or mountains, on any METSAT image.

Sun angle

A low sun angle enhances the cloud-top texture due to shadows. This is seen only on the VIS imagery. Visual image pictures early or late in the day are best for defining clouds, cloud patterns, and cloud layers. Considering the sun angle is your most important viewing consideration with visual METSAT imagery interpretation.

Latitude

Typically, temperatures decrease for clouds and features of the same level, as they get closer to the poles. For example, fog in South Carolina and Georgia has a cloud-top temperature of 15°C. Fog west of Lake Winnipeg has a cloud-top temperature of 3°C. The gray shade for the fog west of Lake Winnipeg is lighter than the fog in South Carolina and Georgia.

Other considerations

Other considerations are the working condition of the satellite equipment, spacecraft problems, and communication line problems between the satellite center and your station. These problems may cause dropouts on the imagery or streaking on the imagery.

Special sensor microwave/imagery

Special sensor microwave/imagery (SSM/I) is a joint Navy/Air Force operational sensor that measures critical atmospheric, oceanographic, and land parameters on a global scale by passive sensing of microwave radiation. The first operational sensor was launched in June 1987 on the DMSP satellite F8. The second sensor was launched on another DMSP satellite in December 1990. These were the first two of seven instruments scheduled to be launched over a 20-year period. The SSM/I have monitored the development and course of 75 percent of the tropical storms and cyclones that have occurred since it was launched. Its global, day-night, all-weather surveillance provides valuable, cost effective data for precisely locating storms and for determining their physical characteristics. Because the microwave radiation from storms can penetrate the dense overlying cirrus clouds with very little attenuation, it reveals physical details not always depicted by visible and infrared images, including the eye of the vortex and the structure of deeply convective regions.

Terms

To understand SSM/I, you must become familiar with some common terminology.

Polarization

Polarization is a term we use to describe the orientation of the electric and magnetic components of electromagnetic radiation waves. When the components are oriented more, or completely, in a particular direction than any other, we term the radiation “polarized.”

Algorithm

Algorithm is a procedure for solving a mathematical problem. Basically, it is a formula.

Brightness temperature

Brightness temperature is the temperature an object/surface appears to have when we measure the intensity of its emitted radiation at a particular frequency/wavelength. It differs from the actual physical temperature according to the emissivity of the object (scale 0–1). Objects with low emissivity (calm water) appear colder than they really are, while objects with high emissivity show the same temperature. For a theoretical black body (perfect emitter/absorber), the brightness temperature would equal the actual temperature of the object at all wavelengths.

Polarization difference

Polarization difference is the arithmetic difference in temperature between the horizontal and vertical channels at any one frequency.

Sensor description

SSM/I is a satellite-borne sensor. It passively detects emitted and reflected microwave radiation at four frequencies/wavelengths, 19.3, 22.2, 37.0, and 85.5 gigahertz (GHz). The 19.3, 37, and 85.5GHz frequencies each have two channels (one horizontal, one vertical). The 22.2GHz frequency is measured by only one channel since it is primarily used to measure water vapor, whose signal is unpolarized. A total of seven channels are sensed.

Using radiation laws, the sensed microwave energy, initially recorded as an electric voltage in each channel, is converted by algorithm to a “brightness temperature.” By combining the brightness temperatures of different channels, we can derive other weather and land parameters by using statistically based algorithms.

Advantages of SSM/I

Microwaves penetrate the clouds with little or no attenuation. The sensing is independent of solar illumination, as it is with IR. SSM/I provides information complementary to that available in the visible and IR spectral regions. One good example is dense ice clouds that completely obscure the ground, both visually and at IR frequencies, and are almost completely transparent to microwaves. Operationally this means we can sense certain surface weather parameters day and night and in cloudy or clear weather.

Orbital characteristics

The satellite orbits at a distance of 833km above the earth in a circular, sun-synchronous, near-polar orbiting path and is inclined at 98.8°. Figure 1–28 shows the SSM/I scan geometry. The orbital period is 102 minutes, giving 14.1 revolutions per day. The satellite track moves at 6.58km/sec along the earth’s surface. These orbital parameters were chosen in a compromise between providing the best global coverage (high orbit is better) at the highest resolution (low orbit is better).

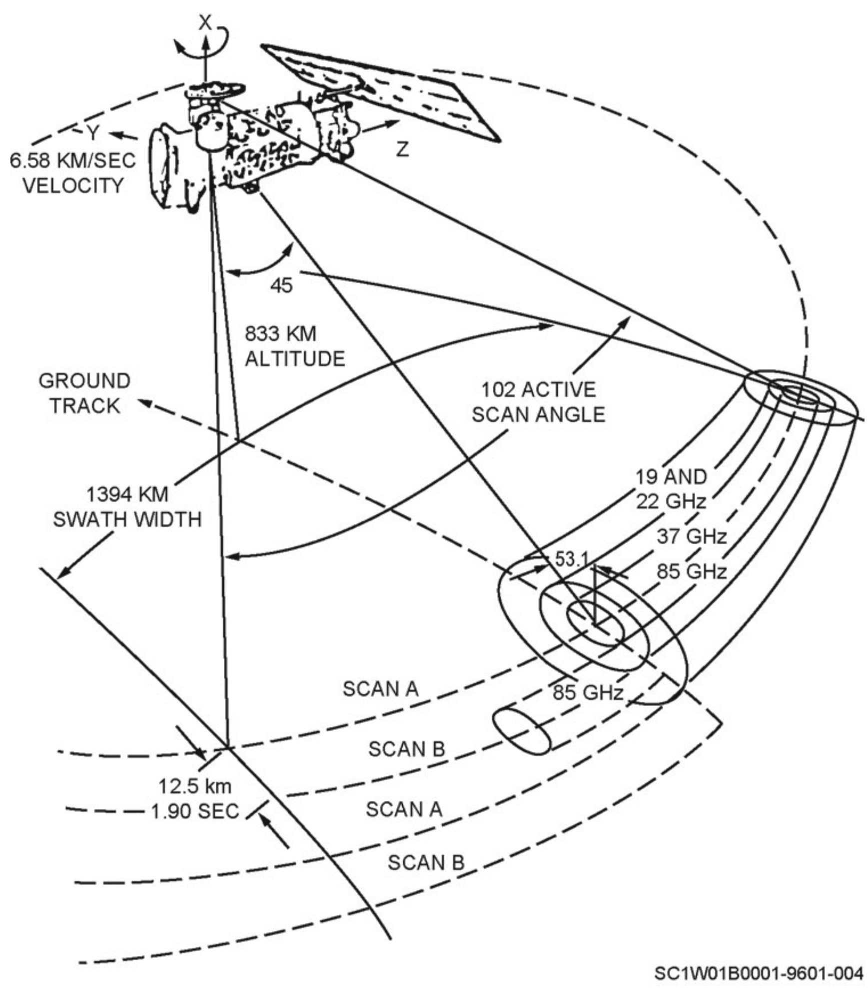

Figure 1–28. SSM/I scan geometry.

Sensor scanning geometry/resolution

The reflector of the SSM/I is positioned at an angle of 45° to the SSM/I spin axis. This angle is called the cone angle because the beam of the antenna sweeps out a 45° cone around the spacecraft. SSM/I's conical scan "sees" the ground at the same angle of incidence throughout the scan. This is beneficial, since the amount of polarization in a sensed pixel depends strongly on the incidence angle. Also, the field of view/resolution remains the same throughout the scan. The scan width at the earth's surface is 1400km. Gaps in the coverage occur between 30°N and S latitude (fig. 1–29). Now, with three SSM/I sensors in orbit, there is a 99 percent probability of viewing a storm in the tropics at least once a day. The resolution for SSM/I is 25 KM with the exception of the rain rate product which has a highest resolution of 15 KM and a lowest resolution of 50 KM.

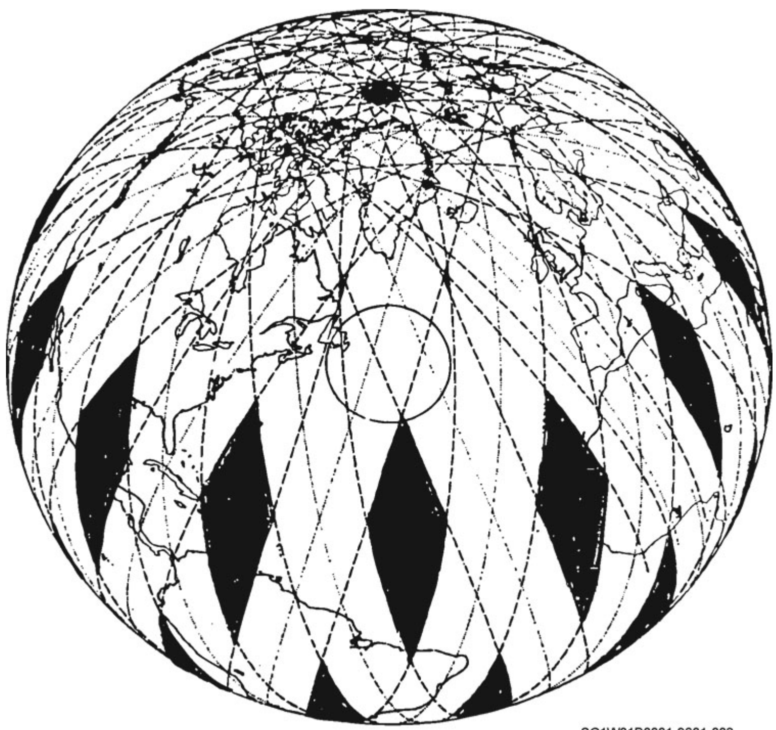

Figure 1–29. The SSM/I swath/coverage in 24 hours.

406. Special sensor microwave/imagery products

The radiation emitted by the earth is predominately in the infrared and microwave portions of the spectrum. The intensity of the radiation is a function of frequency, polarization, the incidence angle of observation, the emissivity of the scene, and the transmission through, and radiation by, the atmosphere. Since the atmosphere is more absorptive at infrared than at microwave frequencies, a microwave sensor receives a greater amount of the radiation from the surface and lower atmosphere. The SSM/I, operating at the frequencies listed above, can sense, by means of emitted and reflected radiation, not only the low-level clouds and water content, but also the wind-roughened sea surface and the type of land below the clouds. The emissivity of the surface is related to its physical properties; therefore, we can make conclusions about those properties.

The SSM/I retrieves information on cloud concentration, precipitation, cloud liquid water, humidity, and marine wind for meteorologists and naval operations. The SSM/I detects not only storms, but also sea ice, and outlines their boundaries for the safe routing of ships, and measures land parameters for geological, agricultural, and military purposes. In just one 13-minute overpass of the tropical zone, for example, it can sense the surface for any of these potential purposes in over 26,000 locations, day or night, in any kind of weather. Within 1–4 hours, receiving terminals around the world, on land or sea, can access the information.

SSM/I products are available in two forms, Sensor Data Records (SDR) and Environmental Data Records (EDR). SDRs are corrected brightness temperatures that comprise the basic raw data the SSM/I is sensing. EDRs are derived from SDRs and contain environmental parameters directly usable by meteorologists or oceanographers. Parameters that can be interpreted from SSM/I include: precipitation intensity of storms over land and water (whether tropical, extra tropical, or polar), cloud concentration, cloud water content, and water vapor over the ocean. Also, parameters such as ocean surface wind speed, sea-ice concentration, ice/water boundaries, differentiation between new, first-year, and multi-year ice, land-surface temperatures, snow-water content, and soil moisture can be determined.

EDR generation

Processing of SDRs into EDRs depends upon the surface type. There are three processing paths possible for detection: land, ocean, and ice parameters. The table below shows which parameters are calculated for each surface type. Scenes tagged as coasts are not processed since mixed land/water footprints are difficult to interpret. The value of a particular EDR is usually calculated as a combination of the brightness temperatures SDRs of specific channels.

Surface type	EDRs to calculate
Ocean	Rain rate Cloud water content Surface wind Water vapor Rain flag
Ice	Ice concentration Ice age Edge flag
Rain over soil	Rain rate
Rain over vegetation	Rain rate
Water/land mix	None
Glacier	None
Vegetation	Surface temperature
Moist soils	Surface temperature Soil moisture
Agricultural and range	Surface temperature
Dry soil, desert	Surface temperature
Coast	None

Data accuracy

Accuracy varies based on the type of data. Brightness temperatures are accurate within 1° Kelvin (K) for SDRs. EDR accuracy depends on the parameter used. For geographic locations, the pixels are within 12km resolution.

SDR interpretation

The most primitive form of SSM/I data likely to be encountered by operational personnel are SDRs. The 19 and 37GHz channels are most useful for viewing surface phenomena. The 22.2GHz channel is for viewing atmospheric water vapor while the 85GHz channel is for viewing rain and clouds.

Land parameters

During the day, the land surfaces of earth, because of their relatively low albedo, receive a great deal of energy from solar radiation. This energy is turned into heat and is reradiated at lower frequencies (infrared and microwave).

When it is dry, bare soil has a high emissivity (0.9–0.95) at microwave frequencies and it is nearly constant with frequency, so that all SSM/I channels record a similar brightness temperature. Emission from dry soil is generally highly polarized (the amount of vertically polarized energy is more than the amount of horizontally polarized).

Wet soil has a dramatically different radiative characteristic and its appearance is different in the imagery. Thoroughly wet soil has an emissivity of about 0.6 and significantly lower brightness temperatures than the same soil in a dry condition.

NOTE: The lower the emissivity is, the lower the brightness temperature will be.

Vegetation

In SSM/I, vegetation appears as a combination of modified radiation from underlying soil and emissions from the vegetation canopy itself. Generally, plants have a higher emissivity (brightness temperatures) than soil. Therefore, vegetation appears warmer than the surrounding ground.

Snow

Snow appears much colder (lower brightness temperatures) than bare soil and, up to a limit, gets even colder as more snow is added. It also reduces the polarization difference of the soil. As with dry soil, the situation changes dramatically when the snow becomes wet. Wet snow appears warmer than dry snow, as well as having a higher polarization difference. As a snow pack melts and refreezes repeatedly, it appears increasingly colder.

Ocean parameters

The emissivity of open calm seawater is relatively low, ranging from about 0.4 to 0.6GHz. Due to the lower emissivity of water relative to land, land/water boundaries stand out dramatically. Salinity of the water has little effect on emissivity so fresh and salt-water bodies at the same temperature appear about the same. The result of these properties is that calm open ocean appears as a cool, uniform background. The presence of clouds, rain, water vapor, or wind changes the signal substantially; this allows us to make accurate measurements of these phenomena.

Using radiometric data, sea ice is classified into three categories: new ice (≤ 30cm); first-year (FY) ice (30cm–1 meter), which has yet to undergo the annual process in which upper layers melt and refreeze; and multi-year (MY) ice (>1 meter), which has undergone at least one melt cycle. Both new and FY ice have high emissivities (0.9–0.95). Since open water has an emissivity of about 0.5, the ice appears much warmer than the surrounding ocean. The emissivity of MY ice is slightly lower (0.8–0.9) than FY ice. Thus, MY ice appears cooler than the FY ice. Snow covered ice appears warmer than ice with no snow.

Atmospheric parameters

SSM/I looks at the following atmospheric phenomena: water vapor, clouds, rain, and wind.

Water vapor

We measure water vapor using the 22.2GHz channel. At this frequency, WV appears warmer than the ocean background. The ocean, because of its uniformity, provides a superior background to land for identifying WV concentrations. Rain or a large amount of liquid cloud water alters the signal, making measurement of WV impossible.

Clouds

Clouds appear in SSM/I imagery as the result of a complex combination of emission, absorption, and scattering. The SSM/I responds to the amount of liquid water in the cloud, not to its thickness.

High-altitude clouds composed of small ice crystals (that is, cirrus) are virtually invisible at microwave frequencies. This is a valuable characteristic when we observe mature tropical storms having a cirrus overcast. Low and mid-altitude clouds appear significantly warmer than the background. Over the ocean, emissivities range from 0.4 to 0.6.

Detection of clouds over land is very difficult, particularly low-altitude clouds. Clouds with extensive vertical development or layers of high liquid water content appear much cooler than the underlying land.

Rain

If rainfall is light and the storm is only mildly convective (that is, nimbostratus), brightness temperatures increase with increasing rainfall rate. In convective storms where a lot of ice is found in the upper regions, scattering plays a major role (especially at 85GHz). In these storms the higher the rain rate, the lower are the brightness temperatures. In non-convective storms, it is sometimes difficult to distinguish rain from clouds. We can overcome this by using several frequencies. As with clouds, rain over land is much more difficult to measure.

Wind

Wind speeds above 15 knots roughen the surface and produce sea foam. Both effects increase the emissivity of the sea surface. Small waves on the surface, known as capillary waves, cause the greatest change in emissivity since they have about the same wavelength as microwaves. The effect from capillary waves saturates at 25–30 knots. Above these speeds the effect of foam is dominant, which under the right conditions can have an emissivity near 1.0. The horizontally polarized channels are more sensitive to the wind speed signal. Wind speed values are not accurate in areas of heavy rain. Even light rain degrades the signal. Degradation of the signal is determined on the 37GHz channels.

EDR interpretation

This section discusses each of the SSM/I-derived environmental products.

Integrated water vapor content

This EDR, also called oceanic total precipitable water, is a measurement of the amount of water vapor in a column extending from the top of the atmosphere to the surface along the sensor-to-ground path. WV is calculated in kg/m^2 and ranges from 0 to 80 kg/m^2, in levels of 0.5 kg/m^2. WV is calculated only over points classed as water. Furthermore, if the rain rate or cloud water content values exceed preset limits, WV is not calculated. Generally, WV values are reliable except in areas of precipitation. Precipitation increases WV error dramatically since the square of the 22V channel temperature is used in the algorithm.

Sea-ice concentration and ice age

Sea-ice concentration (IC) is a fraction of ocean area covered by ice. Operational experience has indicated that when real IC values are low, calculated IC values are biased too high. As a result, one can readily identify the ice edge, but specific concentrations near the edge are unreliable. The distinction between FY and MY ice types has been generally reliable.

Surface types

EDRs require a determination of the surface characteristics before calculation of the parameter. The current algorithm recognizes 13 surface types. The process of determining which surface type belongs involves applying a series of “if-then-else” type tests using combinations of brightness temperatures.

The algorithms discriminate quite well between ocean, land, and sea-ice. Over land, identification of desert areas is reasonably accurate, but sometimes snow appears where none exists. High terrain can be misclassified as wet soil or rain over vegetation.

Soil moisture

The soil moisture (SM) is a measure of the approximate amount of recently deposited precipitation in the soil. Army ground units are interested in this data for determining trafficability estimates. The soil moisture EDR values range from 0 mm to 150 mm. Soil moisture estimation is made difficult by several factors:

1. Vegetation or roughness of the soil.
2. Clouds with high water content.
3. Less than 1 millimeter (mm) of soil penetration depth.

Rain rate

Rain rate (RR) EDR is measured in mm/hr. Small nonconvective rainstorms can be detected only over the ocean, while large convective storms with sufficient vertical development (for ice particles to form) can be detected anywhere. Generally, the EDR rain rates are underestimated, especially in tropical storms.

Rain flag

The rain flag (RF) is a dimensionless quantity ranging from 0 to 3 and provides a quality check on the accuracy of wind speed EDR estimates. The rain flag denotes the accuracy of the wind speed measurement as follows:

Rain Flag	Wind Accuracy
0	< 2m/s
1	2–5m/s
2	5–10m/s
3	> 10m/s

The rain flag is calculated based on a series of tests of SSM/I channels and polarization differences against fixed values.

Ocean surface wind speed

Wind speed (WS) is calculated only over the ocean and values are in units of meters per second (1 m/s = 2 knots), up to 29 m/s. WS is not calculated in areas of heavy rain. It is significantly degraded by other atmospheric phenomena. The presence of rain or cloud water results in WS values higher than they actually are. Thus, a WS value sensed in a dry atmosphere is much more reliable than one sensed in a rainy atmosphere.

Cloud water content

The cloud water content (CW) EDR measures the integrated total cloud water in a footprint in units of kilograms per meter squared ($kg/m^{2)}$.Values range from 0 to 12.6kg/m^2 and are quantified in levels of 0.05kg/m^2. In practice, values more than 10.6kg/m^2 have not been seen.

Land surface temperature

The land surface temperature (ST) EDR is an estimate of the actual ground temperature. Surface temperature values are expressed in Kelvin with a range from 240 to 340° K. Indications are ST values of desert areas are biased high—by about 12° K in Saudi Arabia.

SSM/I observations of tropical storms

You can use the SSM/I imagery of tropical storms in precisely locating the eye and in outlining near gale and gale-force winds. Along with all the validated SSM/I retrievals, this imagery can be obtained day or night, under any kind of cloud cover.

Detection

The microwave radiation penetrates the dense overlying cirrus clouds, revealing physical details not usually detectable with visible and IR images. The eye of the vortex and the structure of deeply convective regions are two features that are better detected using SSM/I.

Accuracy of storm fixes is about the same as with aircraft reconnaissance. Accuracy of storm fixes at sea is better than with IR and visual images. Near gale and gale-force winds (30 knots) are outlined.

Tropical storm tracking

Traditionally, storm tracking has been done using both WC–130s and satellite imagery (visual and IR). Satellite views were limited to top and middle levels of a storm. Fieldwork by Joint Typhoon Warning Center (JTWC) indicates SSM/I products increase the precision of tracking to a level approaching that of all previous techniques combined. A primary factor in the precision of tracking is the ability to locate the center of the eye at the surface. The 85 GHz channels reveal both the eye and windstreaming in the planetary boundary layer (PBL).

SSM/I provides information previously unavailable from meteorological satellites. Atmospheric, land, and oceanic data, available in EDR and SDR formats, provides valuable information. In the tropics the data is useful in determining winds at the ocean surface and with tracking tropical storms.

407. Animated satellite imagery

The easiest way to understand satellite imagery is to infer how weather systems on satellite imagery would look on weather products. The problem is that cloud patterns on satellite imagery develop due to the movement of air parcels with respect to one another. Let's look at how a rectangular cloud mass at 500mb changes shape in various wind fields in figure 1–30.

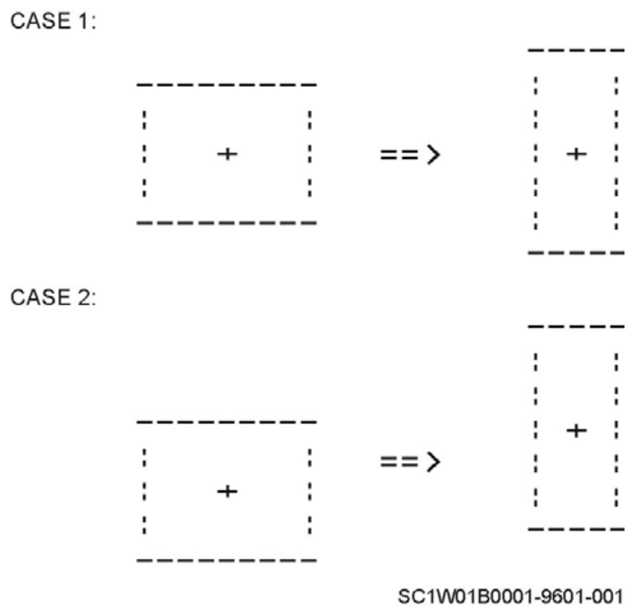

Figure 1–30. Rectangular cloud mass at 500 mb.

Although the center of the cloud mass moves differently in each case, the cloud pattern maintains the same shape. Since the shape of the cloud depends on the motion of air parcels with respect to one another, the cloud would "look" the same in both cases. The geographical center, however, depends on the motion of the cloud parcels with respect to the earth and is different in both cases.

Principal reference frames

In viewing satellite imagery, we need to understand the changing cloud shapes and how they relate to the development of weather systems.

Earth-based reference frame

This reference frame's origin (center) remains fixed at a geographical location of the surface of the earth. Observed winds and motion are viewed in the *earth perspective*. Wind and cloud movement is called *earth* relative. The winds reported on weather products are *earth relative*. They are plotted with respect to a fixed geographical location.

System-based reference frame

This reference frame's origin (center) moves with the center of a weather system. Observed winds and motion are viewed in the *system perspective*. Wind and cloud movement is called *system relative*. This reference frame explains the evolution of cloud patterns over time. To fully understand the evolution of cloud systems on satellite imagery, we must understand the relationship between earth-based and system-based reference frames.

The relationship between the two reference frames

Consider the following situation:

The surface wind is from the northeast at 20 knots. Obviously, observers standing outside looking northeast would feel 20 knots of wind on their face.

What if those observers were in a convertible driving toward the northeast at 20 knots? The observers feel 40 knots of wind on their face. In other words, the measured wind depends on where the anemometer is placed. Here the system perspective equals the moving car and the earth perspective equals the earth. The two observations are related.

$$\text{Wind}_{car} = \text{Wind}_{earth} - \text{Speed of car}$$

NOTE: Remember this equation is a vector. System perspective winds are stronger than earth perspective winds. In more general terms:

$$\text{System perspective winds} = \text{Earth perspective winds} - \text{Movement of System}$$

Kinematics

This is the study of air movement by simply observing the motion of fluid parcels without regard for the forces driving that motion.

Four types of pure motion

Mathematically, we can break the wind field over a region into four types of pure motion (fig. 1–31). Each type is *independent* of all other types. The presence of one type does not relate to the presence of another. This is related to vector components. The u-component (north-south) tells us nothing about the v-component (east-west).

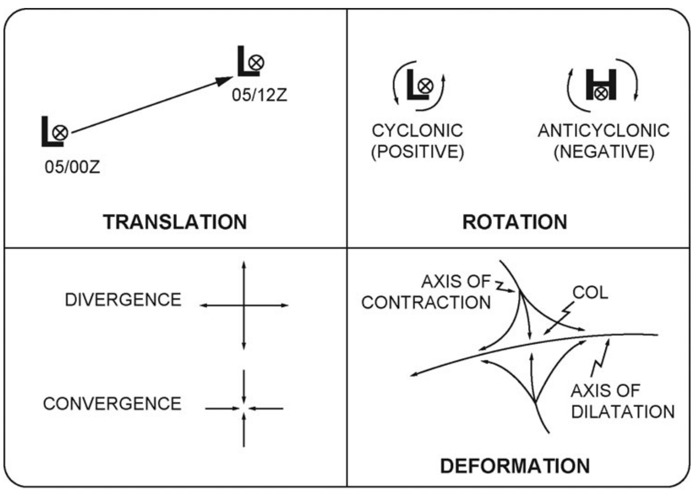

Figure 1–31. Composition of the wind field.

Translation

Translation is *movement* in a straight line. Straight-line winds of a constant wind speed would characterize a wind field where only translation is occurring. All air parcels in this flow would move at the same speed and in the same direction. Speed of movement of a meteorological phenomenon is the most commonly used measure of translation (a vorticity maximum, 500-mb low, jet maximum, etc.).

Rotation

This is *turning* about a point. Winds turning in a circular pattern about one point characterize a wind field where only rotation is occurring. Cyclonic rotation is positive. Anticyclonic rotation is negative. Air parcels within this flow are moving in curved paths. Vorticity is the most commonly used measure of rotation.

Divergence

This is the *spreading* or *contracting* of the wind field. Winds spreading out from/contracting toward a central point characterize a wind field of pure divergence. Positive divergence (or divergence) is movement away from the central point. Negative divergence (or convergence) is contraction toward the central point. Air parcels in a field of pure divergence are either moving directly toward the central point or moving directly away from the central point. Since numerical values are difficult to calculate accurately, meteorologists normally refer to divergence qualitatively (that is, it's either occurring or not).

Deformation

This is the *stretching* or *shearing* of the wind field. An oval-shaped streamline pattern characterizes wind flow in a pure deformation zone.

Col (neutral point)

A col is the center of the deformation zone where winds are calm.

Axis of dilatation

The axis of most rapid stretching. Air parcels are traveling away from the col.

Axis of contraction

The axis of most rapid shrinking. Air parcels are moving toward the col.

Air parcels in a field of deformation are moving toward the col along the axis of contraction as rapidly as they are moving away from the col along the axis of dilatation. No divergence exists in a region of pure deformation. Since numerical values are difficult to calculate accurately, meteorologists normally refer to deformation qualitatively (that is, either it occurs or doesn't). In using weather products, we normally identify the parts of the deformation zone. Satellite meteorologists normally refer to the axis of dilatation as a "deformation zone."

Combinations of the four primary types of motion

Because the observed wind field is composed of all four types of motion, locating just one of the pure types of motion on a weather product is rare. It is important to remember that we can consider each type of motion separately. The overall wind field may be represented by the following equation:

Total wind field = Translation + Rotation + Divergence + Deformation

Recall that the total wind shown on weather products is the earth perspective wind field, so we rewrite the equation as:

Earth perspective = Translation + Rotation + Divergence + Deformation

Also, recall from before the

System perspective winds = Earth perspective winds – Movement of System

So,

System perspective winds = Translation + Rotation + Divergence + Deformation - Movement of system

But translation is really the movement of the system, so we simplify the equation to:

System perspective winds = Rotation + Divergence + Deformation

Divergence is typically smaller than rotation and deformation. Consequently, rotation and deformation are the two main types of motion responsible for system perspective winds.

The system perspective winds are responsible for determining the shape of the cloud mass on satellite imagery. Rotation and deformation are the main components of the system perspective winds. Therefore, satellite meteorologists spend more time analyzing signatures of rotation and deformation on satellite imagery. The signature of rotation is the vorticity comma cloud. The signature of deformation is the deformation zone cloud system.

Initialization

This is the process of using still and looper imagery to help place surface and upper-air features. Looper imagery, valid at the same time as an upper-air product, can help with initial placement of short waves, jets, or surface features. We can also determine moisture coverage with synoptic-scale systems. We can also analyze amplitude changes to the jet, long-wave and short wave troughs and ridges to help trends in intensity changes. If the placement is incorrect, make adjustments to the products.

Satellite loops

Geostationary satellite data is more conducive to looping than polar orbiting data.

Animated visible satellite imagery

Animating visual imagery has definite advantages and limitations.

Advantages

Visible imagery offers the best spatial resolution imagery. High resolution GOES images are ideal for studying mesoscale phenomena. Visible imagery offers the best temporal resolution as well. GOES sector images are available every half hour.

Limitations

Imagery is only available during the daylight hours. The changing sun angle throughout the day is distracting. Imagery from early and late in the day is difficult to evaluate. While GOES-sector images provide detailed mesoscale data, entire synoptic-scale systems do not generally fit on the image. Keep in mind; time intervals with the satellite imagery may not be close enough to observe all events.

Animated infrared satellite imagery

As with animating visual imagery, animated IR imagery has advantages and limitations.

Advantages

Infrared imagery is available 24 hours a day. Clouds on infrared imagery appear the same despite the time of day. Many different sectors are available to view various phenomena. It’s easier to determine cloud tops and their location on infrared.

Limitations

Non-cloud features, such as land, may change significantly from day to night. This can be distracting. The user is limited to preselected enhancement curves. Low-level phenomena are sometimes difficult to detect.

Animated water vapor satellite imagery

Animated WV imagery also has its own advantages and limitations.

Advantages

It is an excellent tool for analyzing the jet stream and the synoptic situation. This imagery reveals the interactions between middle latitude and tropical systems. Often apparent is high-level moisture feeding from subtropical regions into mid-latitude storms. Also, we can see colder air aloft moving southward in strong low zonal situations. The imagery also shows areas of strong upward or downward vertical motion by evaluating the changes in the moisture gradient.

Limitations

The imagery is sent with a ZA curve. This makes assessing subtle changes in gray shades difficult. Interpretation is not as straightforward as interpreting visible or infrared imagery. The user must become comfortable with assigning meaning to various satellite signatures or to similar satellite signatures that are caused for different reasons. For example, a dark band may suggest either a jet stream or the pole ward side of an upper-level deformation zone.

Enhancement curves

Most operational satellite loopers allow the user to apply locally developed color enhancement curves to the imagery being looped. A few simple considerations make the development of enhancement curves easier. Most loopers enhance pixel brightness rather than temperature. If you are adding an enhancement on an infrared image other than a ZA curve, you cannot “split” repeat colors. For example, when you enhance an MB curve, it is impossible to enhance temperatures near 0° C without making the medium gray (–32° C through –42° C) enhancement the same color. It is easier to enhance a brilliance inversion than a threshold. Brilliance inversions produce better contrast.

Where possible, it is best to obtain unenhanced or ZA enhanced imagery and to apply a custom enhancement over it. This eliminates the repeat color problem. Target a color enhancement for a single type of satellite image. Work with a sample image that has the largest brightness range possible. If you use a ZA curve, for example, use an image with the highest thunderstorm top you can find. This ensures all images in the loop appear with the desired color for the coldest cloud tops.

Both water vapor and far infrared images are available with the ZA curves. Since the land fluctuates greatly on the far IR, but not at all on the water vapor, they require different enhancements. Keep the color schemes simple. Ask yourself this question, “Will another forecaster’s attention be drawn to the significant features on the image?” For example, it may not be obvious blue indicates colder tops than purple.

If you use too many colors on an enhancement, the enhancement detracts rather than adds to interpretation of meteorological phenomena. Generally, it is best to use no more than two colors on an enhancement. Use different shades of each color to add detail to the enhancement scheme. A third color can add to the utility of the enhancement if it meets the following criteria:

- It corresponds to extreme conditions that occur over a very small geographical area.
- It occurs within an area enhanced with another color.

A good example would be using shades of yellow to enhance cold cloud tops. Add just enough red to enhance the highest cloud tops within a convective complex.

Image intervals

You must consider the intervals between images in the loop when you develop satellite loops. Generally, the smaller the size and time scales of the phenomena is, the shorter the interval will be needed between pictures in the loop.

You must also give consideration to missing pictures. Operationally, you need to plan for at least one missing picture in a loop. This doubles the interval around the missing picture.

The following intervals were found useful for the data described.

- Planetary scale: 3 or 6-hour intervals are satisfactory.
- Synoptic scale: 2 hours is satisfactory, 1 hour is ideal.
- Mesoscale: 1 hour intervals are essential for capturing the details of the development of mesoscale systems.

Interpretation techniques

Generally, the techniques learned for still photo interpretation also apply to animated imagery interpretation. However, animated satellite imagery (ASI) interpretation is better for some specific problems. With looped imagery, you're examining changes for cloud systems and flow over time. Do not become locked into your area of interest. Always observe what is occurring around the area of interest before you make your final determination of the feature, system, or flow.

Low-level wind flow

Determine low-level wind flow by following the motion of low clouds with time, their location in relation to systems, and their interaction with terrain. On infrared imagery, low clouds appear murky gray. On visible imagery, use your cloud identification skills to identify low clouds.

Upper-level wind flow

Determine upper-level wind flow by following the motion of high clouds with time. On (unenhanced) infrared imagery, high clouds appear bright white.

Special forecasting situations

In this last section on ASI, we look at some of the special forecasting situations.

Gulf return flow

You can track the return flow of moisture from the Gulf of Mexico into the central United States by following the northward movement of stratus clouds. This is important to monitor when you forecast precipitation in the central and eastern United States.

Closed circulation centers

Recall from our discussion of relative motion that closed circulation centers are difficult to identify and locate on still imagery. On animated imagery, because you tend to follow the system and not its translation, cyclones and anticyclones are easier to locate.

Cyclones

Locate cyclones by identifying the center of a closed cyclonic circulation in the clouds. Infrared loops are best for identifying upper-level cyclones. Visible loops are best for identifying surface cyclones. As long as thicker, higher clouds do not obscure the lower clouds, water vapor loops generally reveal the circulation center along a moisture gradient. The dry slot generally starts southwest of the low and wraps around the east side of the low. As this dry slot darkens, the low intensifies. As the dry slot becomes diffuse, the system begins to weaken. Upper-level cyclones over subtropical and tropical regions tend to be almost circular clear areas.

Anticyclones

Because upper-level highs are normally associated with dry air and subsidence aloft, they are easiest to locate on water vapor loops. Enough water vapor may be present aloft to show anticyclonic spiraling of the moisture. You can usually observe an elongated moisture shield with a smooth inside border SW–N of the upper-level high. Because anticyclones are large, broad features, the exact location of the circulation center is difficult to place.

Split flow

Sometimes the westerly flow aloft splits into two or more significant branches. These branches merge a considerable distance downstream. Weather conditions vary, depending on which branch of the flow affects a region.

Forecasting for locations near the boundary between each flow regime is difficult. Weather varies significantly over small distances. Water vapor loops are invaluable when you deal with this type of forecast problem. Moisture rich air in the southern stream contrasts with dry air in the northern stream. This creates a well-defined boundary on water vapor imagery. The northward progression of moisture is easy to extrapolate using satellite loops. If a short-wave trough in the northern stream moves southward toward the moisture shield advancing from the southern stream, the moisture shield is normally deflected toward the southeast.

Water vapor loops are ideal for recognizing this scenario. Cloudiness associated with the northern stream short-wave trough is scarce or nonexistent. The trough shows up as a dark band on the water vapor imagery.

Upper ridges

Changes in the amplitude and sharpness of ridges are easy to monitor using ASI.

Sharpness

As a ridge sharpens, the amount of high cloudiness streaming over the ridge axis decreases. Satellite loops reveal the rapid movement of clouds over the ridge axis. The clouds rapidly evaporate as the subsidence strengthens downstream while the ridge sharpens. As a ridge flattens, the cloudiness flowing over the ridge axis increases and progresses further downstream before it dissipates.

Amplitude

While a ridge builds, the jet stream axis along the ridge shifts northward. This corresponds to a northward advance of the baroclinic zone cirrus cloud shield. As a ridge collapses, the cirrus shield slips southward.

Vorticity comma clouds wrapping into deformation zone cloud systems

ASI reveals the rapidly changing nature of the synoptic-scale comma-cloud system associated with extra tropical cyclones. When we view still imagery, the natural tendency is to rely too heavily on extrapolation when we forecast the movement of the cloud pattern. While the system may change relatively little on weather products, the satellite cloud pattern may change significantly. The smaller scale structure of the system is often visible on satellite imagery.

Often, major storms develop the comma-cloud pattern when a vorticity comma-cloud system wraps back around the north side of the system and becomes a deformation zone cloud system. The process begins with an old deformation zone cloud system. This system is normally very well defined. A new vorticity comma cloud rapidly forms as convection develops in the dry air aloft behind the baroclinic zone cloud shield. As the new vorticity comma cloud grows, the old deformation zone cloud shield rapidly warms and fragments. As the thunderstorms continue to develop, high-level cloudiness (cold tops) expands rapidly. The expanding vorticity comma cloud then moves northward into the deformation field north of the closed/closing 500-mb low and is stretched into a new deformation zone cloud system. With some storms, this may occur only once. Sometimes it occurs several times. The synoptic-scale vorticity product often does not have sufficient detail to define each vorticity maximum involved in the process.

Often, the first clue in the above process is the movement of a band of high-level moisture into the dry slot of an extra tropical cyclone. The moisture is associated with the divergence ahead of the vorticity maxima. As divergence acts on lower-level moisture close to the baroclinic zone cloud shield, convection associated with the new vorticity comma cloud develops.

Precipitation forecasting

Precipitation generally increases when the cloud tops of infrared imagery cool and/or the area of cold cloud tops expands. Rapidly expanding and cooling cloud tops are an indication precipitation will increase. The heaviest precipitation from synoptic-scale systems tends to fall along the southern edge of the coldest cloud tops. Use satellite loops to extrapolate the movement of heavy precipitation areas associated with these coldest cloud tops.

Long-wave pattern amplification

Amplification of the long-wave pattern normally proceeds around the globe from west to east. In other words, a trough deepens over the dateline. This results in a ridge building into the Gulf of Alaska, which deepens a trough over the West Coast. Loops of full-disk C-sector imagery are excellent tools for following this process because they show the evolution of the long-wave pattern.

Mesoscale boundary interaction

Intersecting boundaries are one of the best indicators of thunderstorm development. Satellite loops of high-resolution visible imagery are useful for tracking boundaries. You can use extrapolation to estimate where and when boundaries are likely to interact. This shows where and when to forecast convection.

Short-wave trough interacting with the front

Usually the cloud pattern is the first indicator a short-wave trough is interacting with a frontal boundary. A slight "S" shape develops on the cold-air side of the cloud pattern. The cloud pattern becomes more defined and organized as the self-development process continues.

Changes in zonal index

Observing and forecasting changes in the overall zonal index, or flow, helps you forecast weather at your station. Apply the dynamics of system interaction to looped satellite interpretation. This allows you to anticipate changes in the zonal index before you receive your 12-hourly run of upper-air and model products.

Development of short-wave trough behind a cold front

Sometimes, short-wave troughs appear at the surface as a developing front in the cold air behind an existing cold front. Usually there is not a large amount of moisture associated with this system until it cuts off the cold air from the leading cold front. This is very common along and off the east coast of continents. It's known as a "Cold-Air Vortex system."

Decay of an upper-level high

Upper-level highs are usually most apparent as they develop and persist. Knowledge of a weakening or dissipating upper-level high is very useful in forecasting weather changes. Upper-level highs in the subtropics can dissipate with the intrusion of cold air at the surface.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

403. METSAT advantages

1. List the advantages of METSAT imagery.

2. What METSAT function allows systems to be put in motion?

404. Satellite types and coverage

1. What is the inclination angle of the polar orbiting satellites?

2. Of what areas do polar orbiting satellites provide coverage?

3. Geosynchronous satellites orbit the earth at the same angular velocity as what?

4. Which satellite allows you to loop imagery to follow fronts, lows, severe weather, and many other cloud and non-cloud features?

5. What satellites are considered geosynchronous satellites?

405. Types of weather METSAT imagery

1. Indicate for each statement below whether it represents visible, far infrared, near infrared, water vapor, or SSM/I imagery.

   a. Operates at a wavelength of 0.4 to 0.74 microns (µm).

   b. Operates at a wavelength of 0.75 to 2.0µm.

   c. Passively detects emitted and reflected microwave radiation at four wavelengths.

   d. Operates at 6.7µ on GOES imagery and 5.7 to 7.1µm on METEOSAT imagery.

   e. Operates at a wavelength of 10.2 to 12.8µm.

   f. The wavelength is very sensitive to lunar radiation.

   g. Measures reflected sunlight.

   h. This imagery is used for identifying vorticity maximums.

   i. Does *not* depend on reflected sunlight for an image.

   j. Gaps occur in the global coverage between 30°N and S latitude.

   k. You are seeing the reflectivity of features that are converted to brightness values.

   l. You are seeing the temperature of features that are converted to brightness values.

   m. You are seeing the amount of moisture sensed in the vertical, which is then converted to a brightness value.

2. Match the GOES enhancement curves in column B with their descriptions in column A. Items in column B may be used once.

Column A	*Column B*
____ (1) Cool season, general purpose curve.	a. CC.
____ (2) WV imagery is also enhanced using this curve identifier.	b. EC.
____ (3) Good all-purpose curve most commonly used for convective activity.	c. HF.
____ (4) A winter time curve used to define water currents, low stratus and coastal fog.	d. JG.
____ (5) Designed for cloud interpretation in colder northern latitudes in the winter.	e. MB.
____ **(6)** Designed for west coast forecasters to enhance system cloud tops over the Pacific Ocean.	**f.** ZA.

3. On a global scale, what critical parameters does SSM/I measure?

4. What frequencies have two channels to include both horizontal and vertical polarizations?

5. What are the three main advantages of the SSM/I?

6. How long does it take the SSM/I sensor to complete one complete revolution of the globe? How many revolutions occur per day?

7. What is the scan width covered by SSM/I at the earth's surface?

406. Special sensor microwave/imagery products

1. What are the parameters that can be interpreted from SSM/I using EDRs?

2. How accurate are brightness temperatures for SDRs?

3. When you interpret SDRs, what are each of the frequencies best for viewing?

4. What clouds are virtually invisible at microwave frequencies and why?

5. Using SSM/I, what two main features of tropical storms can we better detect?

407. Animated satellite imagery

1. How are the winds reported on weather products?

2. What are the four types of pure motion? Describe each.

3. What are the two main types of motion responsible for system perspective winds? How do they appear on satellite imagery?

4. What satellite data is the most conducive for satellite looping?

5. Match the type of animated satellite imagery in column B with their descriptions in column A. Items in column B may be used more than once. Items in column B may be used more than once.

Column A	*Column B*
____ (1) Shows the interaction between the mid-latitude systems and tropical systems.	a. Animated infrared satellite imagery.
____ (2) Clouds appear the same despite the time of day.	b. Animated visible satellite imagery.
____ (3) Offers the best spatial resolution imagery and the best temporal resolution as well.	c. Animated water vapor satellite imagery.
____ (4) Interpretation is not straightforward.	
____ (5) Only available during daylight hours.	
____ (6) Low-level phenomena are sometimes difficult to detect.	

6. Generally, when enhancing satellite imagery, how many colors is it best to use? Can you exceed that number? If so, what are the criteria?

7. What are the satellite imagery time intervals that are useful for looping data on a planetary scale? Synoptic scale? Mesoscale?

8. Cyclones are located by identifying the center of a closed cyclonic circulation in the clouds. Which satellite loops are best for identifying upper-level and surface cyclones?

9. Why is the exact location of the anticyclone’s circulation center difficult to place?

10. What should you look for on infrared imagery to indicate that precipitation is increasing?

11. What type of cloud pattern is the first indicator a short-wave trough is interacting with a frontal boundary?

Answers to Self-Test Questions

401

1. (1) c.
   (2) a.
   (3) d.
   (4) e.
   (5) f.
   (6) b.
2. Temperature.

402

1. Planck's law says that the amount of radiation emitted by a black body at a given wavelength is proportional to its temperature.
2. Wien's displacement law, which comes from Planck's law, says the wavelength of the maximum irradiance of a black body depends on its temperature.
3. Kirchoff's law says for objects in thermodynamic equilibrium, the absorption of radiant energy must be equal to the emission of radiant energy.

403

1. (1) METSAT imagery is an observation that is more frequent than synoptic reports.
   (2) It provides data in areas lacking conventional data, such as over ocean and desert regions.
   (3) It also enhances resolution in areas that have an organized, dense synoptic network.
   (4) Animated looping allows systems to be put in motion. This allows you to see system motion and the interaction between different pressure systems. You also see interaction between weather systems of different scales.
   (5) A single METSAT image gives you a more complete idea of the vertical structure of the atmosphere than one or two products. You can see the low-, mid-, and upper-level features simultaneously. You can also determine how they relate to each other.
2. Animated looping.

404

1. Polar orbiting satellites have an inclination angle of 98.7°.
2. The entire earth's surface.
3. The rotating earth.
4. Geostationary satellites.
5. GOES, GMS, METEOSAT, and INSAT satellites.

405

1. (a) Visible.
   (b) Near infrared.
   (c) SSM/I.
   (d) Water vapor.
   (e) Far infrared.
   (f) Near infrared.
   (g) Visible.
   (h) Water vapor.
   (i) Far infrared.
   (j) SSM/I.
   (k) Visible.
   (l) Applies to both far and near infrared.
   (m) Water vapor.

2. (1) b.
   (2) f.
   (3) e.
   (4) d.
   (5) a.
   (6) c.
3. Atmospheric, oceanographic, and land parameters.
4. The 19.3, 37, and 85.5 gigahertz frequencies.
5. The microwaves penetrate the clouds with little or no attenuation. The sensing is independent of solar illumination. Also, SSM/I provides information complementary to that available with visible and IR imagery.
6. 102 minutes. 14.1 revolutions per day.
7. 1,400 kilometers.

406

1. Parameters that can be interpreted from SSM/I include: precipitation intensity of storms over land and water (whether tropical, extra tropical, or polar), cloud concentration, cloud water content, and water vapor over the ocean. Also, parameters such as ocean surface wind speed, sea-ice concentration, ice/water boundaries, differentiation between new, first-year, and multi-year ice, land-surface temperatures, snow-water content, and soil moisture can be determined.
2. Within 1°Kelvin.
3. The 19 and 37GHz channels are most useful for viewing surface phenomena. The 22.2GHz channel is for viewing atmospheric water vapor while the 85GHz channel is for viewing rain and clouds.
4. Cirrus, because they are composed mostly of small ice crystals.
5. The eye of the vortex and the structure of deeply convective regions.

407

1. Earth relative.
2. They are translation, rotation, divergence and deformation. Translation is straight-line movement. Rotation is the turning about a point. Divergence is the spreading or contraction of the wind field. Deformation is the stretching or shearing of the wind field.
3. Rotation and deformation. The signature of rotation is the vorticity comma cloud. The signature of deformation is the deformation zone cloud system.
4. Geostationary satellite data.
5. (1) c.
   (2) a.
   (3) b.
   (4) c.
   (5) b.
   (6) a.
6. Generally, no more than two colors. A third color can add to the utility of the enhancement if it corresponds to extreme conditions that occur over a very small geographical area or if it occurs within an area enhanced with another color.
7. On the planetary scale: 3 or 6 hour intervals. On the synoptic scale: 2 hours is satisfactory, 1 hour is ideal. On the mesoscale: 1 hour intervals are essential.
8. Infrared loops are best for identifying upper-level cyclones and visible loops are best for identifying surface cyclones.
9. Because anticyclones are large, broad features.
10. Rapidly expanding and cooling cloud tops are an indication precipitation will increase.
11. A slight “S” shape developing on the cold-air side of the cloud pattern.

Do the unit review exercises before going to the next unit.

Unit Review Exercises

Note to Student: Consider all choices carefully, select the *best* answer to each question, and *circle* the corresponding letter. When you have completed all unit review exercises, transfer your answers to the Field-Scoring Answer Sheet.

Do not return your answer sheet to the Air Force Career Development Academy (AFCDA).

1. (401) A theoretically perfect absorber and emitter of radiation is
   a. a gray body.
   b. a black body.
   c. a white body.
   d. an electromagnetic body.

2. (401) The ratio of the total amount of radiation reflected from an object to the total amount of incident radiation is called
   a. emissivity.
   b. scattering.
   c. reflectivity.
   d. absorptivity.

3. (402) Which law says that the amount of radiation emitted by a black body at a given wavelength is proportional to its temperature?
   a. Stefan's law.
   b. Planck's law.
   c. Kirchoff's law.
   d. Wien displacement law.

4. (403) Meteorological satellite (METSAT) imagery is more advantageous than synoptic reports because it
   a. is less contaminated by raw data.
   b. is a forecast that occurs more frequently.
   c. is an observation that occurs more frequently.
   d. shows areas of high temperature and moisture relationships.

5. (403) Why is animated looping of meteorological satellite (METSAT) imagery an advantage?
   a. It also enhances resolution in areas that have an organized, dense synoptic network.
   b. It can help you determine how disorganized and organized systems relate to each other.
   c. It provides data in areas lacking conventional data such as over ocean and desert regions.
   d. This allows you to see system motion and the interaction between different pressure systems.

6. (404) The inclination angle and the altitude of the polar orbiting satellite allow for global coverage every
   a. 6 hours.
   b. 12 hours.
   c. 18 hours.
   d. 24 hours.

7. (404) The geosynchronous satellite stays in position because of a combination of
   a. centrifugal force and gravity.
   b. centripetal force and gravity.
   c. angular velocity and centrifugal force.
   d. angular velocity and centripetal force.

8. (404) Which is *not* a geosynchronous satellite?
   a. Meteorological Satellite (METEOSAT).
   b. Geostationary Meteorological Satellite (GMS).
   c. Defense Meteorological Satellite Program (DMSP) satellite.
   d. Geosynchronous Operational Environmental Satellite (GOES).

9. (405) Which is a factor that affects the amount of brightness measured by visible meteorological satellite (METSAT) imagery?
   a. Angle of the sun.
   b. Types of radiative transfer taking place.
   c. Type of passive remote sensing device on the satellite.
   d. Type of multispectral color-composite imagery involved.

10. (405) Most meteorological satellite (METSAT) sensors are designed so that the visual imagery is a combination of
    a. near and far infrared wave lengths.
    b. visual and far infrared wave lengths.
    c. visual and near infrared wave lengths.
    d. water vapor and far infrared wave lengths.

11. (405) With water vapor (WV) imagery, why do middle and high-level moisture affect the sensor much more than low-level moisture?
    a. Absorption is lowest between 610 to 240 millibars (mb).
    b. Absorption is highest between 610 to 240mb.
    c. Reflectivity is lowest between 610 to 240mb.
    d. Reflectivity is highest between 610 to 240mb.

12. (405) Which is *not* a use for water vapor imagery?
    a. Identifying potential thunderstorm areas.
    b. Determining the thickness of mid and upper-level clouds.
    c. Determining the polar front (PFJ) and subtropical jets (STJ).
    d. Identifying circulation centers, troughs, ridges, and wind maximums.

13. (405) Which far infrared (FIR) enhancement curve is a good all-purpose curve we most commonly use for identifying convective activity?
    a. CC curve.
    b. JG curve.
    c. MB curve.
    d. ZA curve.

14. (405) Which far infrared (FIR) enhancement curve was designed for forecasters along the US west coast to enhance weather system cloud tops over the Pacific Ocean?
    a. EC curve.
    b. HF curve.
    c. MB curve.
    d. ZA curve.

15. (405) The temperature an object appears to have when we measure the intensity of its emitted radiation at a particular wavelength describes the
    a. apparent temperature.
    b. brightness temperature.
    c. wavelength temperature.
    d. molecular-scale temperature.

16. (405) How many channels are sensed by special sensor microwave/imagery (SSM/I)?
    a. 3.
    b. 4.
    c. 7.
    d. 9.

17. (405) What is the scan width of the special sensor microwave/imagery (SSM/I) at the earth's surface?
    a. 1,000 miles.
    b. 1,400 miles.
    c. 1,000 kilometers.
    d. 1,400 kilometers.

18. (406) In what two forms are special sensor microwave/imagery (SSM/I) products available?
    a. Sensor data records (SDRs) and emissivity data records (EDRs).
    b. Satellite data records (SDRs) and emissivity data records (EDRs).
    c. Sensor data records (SDRs) and environmental data records (EDRs).
    d. Satellite data records (SDRs) and environmental data records (EDRs).

19. (406) What special sensor microwave/imagery (SSM/I) product form is derived from SDRs and contains environmental parameters directly usable by oceanographers?
    a. Sensor Data Records (SDRs).
    b. Satellite Data Records (SDRs).
    c. Emissivity Data Records (EDRs).
    d. Environmental Data Records (EDRs).

20. (406) The processing of sensor data records (SDR) into emissivity data records (EDR) depends on the
    a. surface type.
    b. type of data received.
    c. brightness temperature.
    d. microwave channel used.

21. (406) Integrated water vapor (WV) content is calculated only over points classed as water. However, if the rain rate or cloud water content values exceed preset limits, what happens to WV values?
    a. WV is not calculated.
    b. Calculated WV values are biased too low.
    c. Calculated WV values are biased too high.
    d. Precipitation rate errors increase dramatically.

22. (406) For determining trafficability estimates, Army ground units are interested in
    a. surface type.
    b. rain rate (RR).
    c. soil moisture (SM).
    d. land surface temperature (ST).

23. (406) What tropical cyclone phenomena is best detected using special sensor microwave/imagery (SSM/I)?
    a. Near-gale and gale force winds.
    b. The direction of movement and cloud pattern weakening.
    c. Low-level wind stream and upper-level cloud pattern shearing.
    d. The eye of the vortex and the structure of deeply convective regions.

24. (407) Straight-line winds of a constant wind speed would characterize a wind field where the only type of pure motion occurring is
    a. rotation.
    b. translation.
    c. divergence.
    d. deformation.

25. (407) What is the axis of *most* rapid stretching where the air parcels are traveling away from the col called?
    a. Axis of dilatation.
    b. Axis of contraction.
    c. Axis of deformation.
    d. Axis of geopotentiality.

26. (407) What are the two main types of motion responsible for system perspective winds?
    a. Rotation and divergence.
    b. Rotation and deformation.
    c. Translation and divergence.
    d. Translation and deformation.

27. (407) What types of winds are responsible for determining the shape of cloud masses on satellite imagery?
    a. Earth relative winds.
    b. System relative winds.
    c. Earth perspective winds.
    d. System perspective winds.

28. (407) In relation to the coldest cloud tops, where does the heaviest precipitation from synoptic-scale systems tend to fall?
    a. Along the northern edge.
    b. Along the eastern edge.
    c. Along the southern edge.
    d. Along the western edge.

Please read the unit menu for unit 2 and continue ➔

Student Notes

Unit 2. Interpretation of Satellite Imagery Features and Meteorological Events

IN THIS UNIT we primarily use the visible and various infrared data in cloud identification. We begin by looking at cloud and non-cloud features. We then look at the different satellite signatures related to the atmospheric circulation by looking at the upper-level, the lower-level, atmospheric flow, and local circulation patterns and their cloud features. In the process, we use the many data forms available, including the visible and the infrared.

Remember: In identifying clouds, we are *not* seeing what an observer sees from the ground! Hence, we learn the *cloud signature* terminology, as we see them from satellite.

2–1. Cloud and Non-Cloud Features

In this section we look at both cloud and non-cloud features and how to identify them.

408. Cloud features

When you interpret cloud features, remember the considerations we discussed previously. These considerations need to be an integral part of the imagery interpretation concepts you're going to read about next. Cloud features are important clues about the atmospheric stability and synoptic features.

Imagery interpretation concepts

When you interpret specific features, first ensure you look at the whole satellite picture to decide what the feature is and how it fits into the synoptic situation. Don't get tunnel vision and look at one specific feature. Use the different imagery together whenever possible to take advantage of each one's unique properties. Look at water vapor (WV) imagery first. It allows you to determine the large-scale atmospheric patterns and flow. The visual (VIS) defines small-scale features, terrain, cloud shadows, texture, and low clouds. Infrared (IR) imagery allows you to find relative cloud heights and, from there, specific cloud types. Continuity is another excellent way to follow cloud features; always use it. At night when no VIS is available, look at the last VIS and far infrared (FIR) of the day. Then follow the features on the FIR through the night, keeping in mind what they would look like on the VIS. Always use your atlas or local terrain map when you interpret the imagery. This ensures you don't mistake terrain features for clouds (for example, the difference between fog/stratus and snow).

Terminology

We use certain terms extensively in METSAT imagery interpretation. They are valuable because they actually give you a label for certain atmospheric processes. For example, cloud lines typically indicate parallel wind flow.

Cloud type

This is a form of cloud seen in the sky (cumulus, altocumulus, etc.).

Cloud element

This is the smallest cloud that you can see on an image as determined by the resolution of the METSAT sensor. Careful examination of the cloud lines forming over Wisconsin (fig. 2–1) reveals individual cloud elements. These elements are small bright cells, separate from each other, which make up the cloud line over Wisconsin.

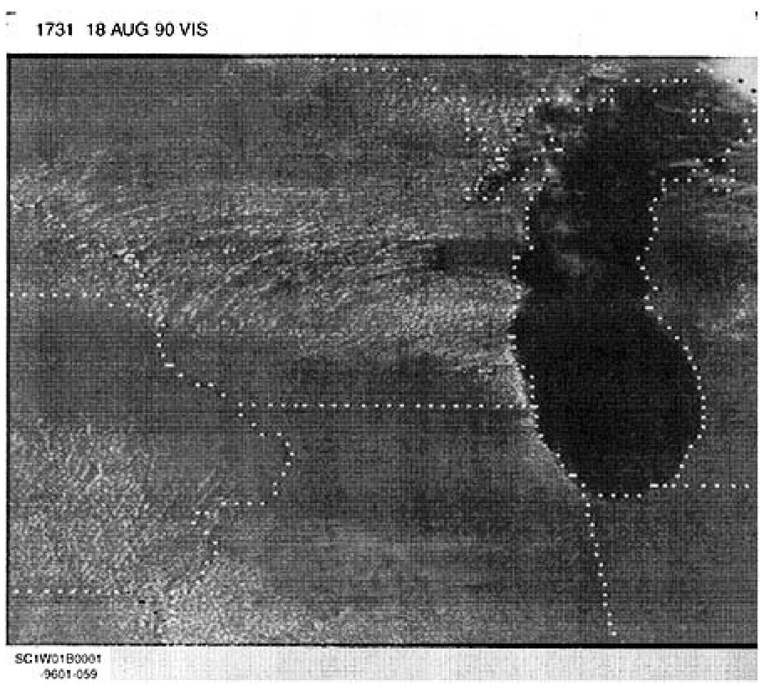

Figure 2–1. Cloud elements.

Cloud fingers

These are low-level clouds that develop because of low-level convergence.

Cloud lines

These are nearly continuous cloud formations where elements *are* connected and the line is less than 1° in width. Cloud lines parallel the vector difference between the wind velocity at the base and top of the cloud. Cloud lines tend to parallel each other. Figure 2–2 shows several nearly parallel cloud lines in the Gulf of Mexico off the Texas and Louisiana coast.

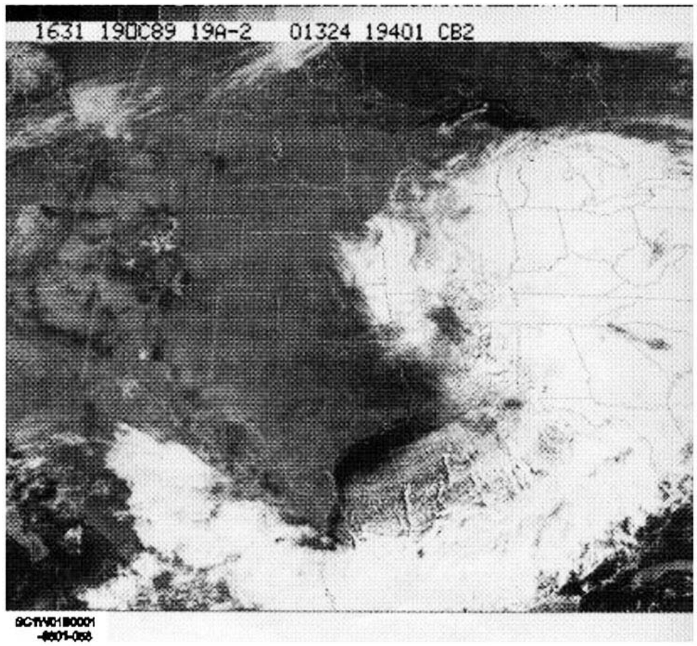

Figure 2–2. Cloud lines.

Cloud streets

These are very similar to cloud lines; however, the elements are *not* connected. Cloud streets also parallel the vector difference between the wind velocity at the base and top of the cloud. These are common in the tropic and subtropical regions. Figure 2–3 shows cloud streets over South Carolina and Georgia as seen from Gemini IV. The cumulus elements form into nearly parallel rows.

Cloud types

Being able to identify different cloud types is useful for atmospheric stability. To do this, first determine the level where the cloud is. Then, determine the type of cloud.

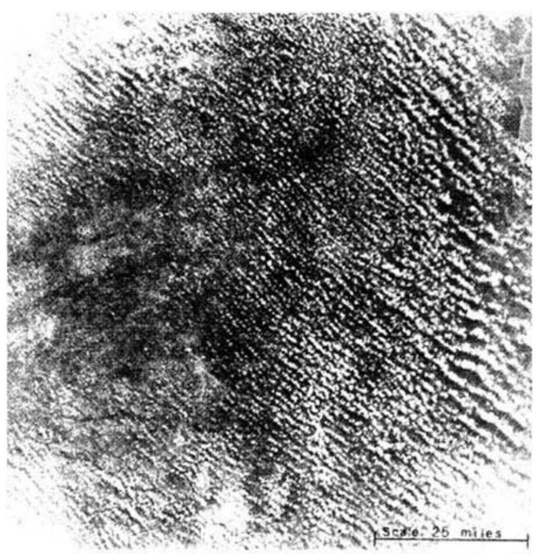

Figure 2–3. Cloud streets.

Low clouds

Low clouds show a variety of shapes and dimensions due to the effects of diurnal temperature changes, thermal advection, low-level convergence or divergence, terrain effects, land/water and air/sea interface.

Fog and stratus

Determining fog and stratus on METSAT imagery is difficult to begin with. It is further complicated because these weather elements have a variety of gray shades on IR imagery during different seasons. However, with continuity and knowledge of the synoptic pattern, you can find it easily.

Stratus

These are low clouds caused by the advection of warm moist air over a cooler area (for example, lifting of fog during stable conditions, or evaporation of precipitation into cool air). This is a common phenomenon during the night and early to mid-morning hours.

Fog

This is a stratiform cloud with its base on the ground. It is composed of water droplets (except ice fog). Radiation fog and sea fog are the two types we can discern best on imagery. On the imagery, radiation fog dissipates from the outside edges into the middle due to differential heating. Advection fog (sea fog) is very similar to stratus in its characteristics.

Appearance

Fog and stratus (ST) are easier to see on VIS imagery because of the good contrast between the fog/stratus and the terrain. You can differentiate between the two by noting the motion of the cloud mass. Fog typically remains stationary, while ST moves.

On visual imagery, fog and ST appear as a white to light gray shade in a uniform sheet with no texture. Any sharp boundaries are normally caused by higher terrain features that may penetrate the cloud top. Cloud edges define terrain features and elevation changes (for example, in eastern Colorado and New Mexico where the plains rapidly lead into a mountainous region). In mountainous or hilly areas, fog and ST in small valleys may have a branching or vein-like appearance. Fog and ST are at their brightest over deep terrain. Fog/stratus may sometimes look like snow on mountain ridges. If the visibility at the surface is greater than the vertical depth of the fog and the sky is discernible, the fog may not be visible on the image.

Fog and ST appear on FIR imagery as a dark gray shade (warm temperature) due to the small thermal contrast between the fog/stratus and the surface. Fog and stratus are very hard to detect. Occasionally, ST forming underneath a radiation inversion appears as a darker gray shade and warmer than the surrounding surface area that is cloud free. This is known as black stratus. If available, use the Defense Meteorological Satellite Program (DMSP) nighttime VIS imagery to detect black stratus.

Stratocumulus

Stratocumulus (SC) is formed by the spreading out of cumulus or the lifting of stratus. This occurs with a stable layer aloft and limited vertical mixing in the lower level and is usually a subsidence or frontal inversion. Areas of SC typically develop in stable regions dominated by high-pressure systems (for example, in association with high pressure behind a cold front moving off the East Coast). It can also form due to weak cold-air advection over a warm surface (for example, in polar air masses over land with strong surface heating).

SC appears on VIS imagery as a light gray to white shaded, continuous cloud sheet composed of parallel rolls or cellular elements with a textured appearance. In the tropics, SC is usually widely scattered except in upslope regions or where the clouds pack against terrain features.

On FIR imagery, SC clouds appear as a dark gray shade, suggesting warm temperatures. The cellular or textured appearance may not be observable due to the sensor resolution.

Cumulus

Cumulus (CU) are small, vertically developed clouds that form due to surface heating, low-level convergence, or both. These clouds are very common over land during the warm season and in the tropics. CU dissipates over and downwind of lakes or coastlines. This is due to differences in land and water temperatures (for example, Great Lakes, Gulf Coast). As cumulus develops over land and moves over relatively cooler lakes, it dissipates. Where the cooler lake temperature advects downstream, there'll be a clear area for a distance before it begins to heat up again and form more CU.

Cumulus appears on VIS imagery as a small, white cloud that is usually seen as a field of unorganized "popcorn" CU. Many individual elements are below the sensor resolution of most satellites. Often a field of CU appears as a uniform lighter gray shade because the sensor averages the smaller cloud element's gray shade with the background's gray shade.

On FIR imagery, only the large concentrated areas of CU show up. They appear as a very dark gray shade, which represents warm temperatures. The field of CU appears as a slightly lighter gray shade than the earth's surface because the cloud elements are below the sensor's resolution.

Towering cumulus

Due to a more unstable atmosphere, towering cumulus (TCU) is more vertically developed than CU, which makes it easier to see on the imagery. TCUs may be embedded within or at the downstream edge of a field of CU.

Towering cumulus are circular clouds that appear light gray to bright white on VIS imagery. On FIR imagery, the light gray shade makes them easier to detect than CU. Due to the sensor's resolution, the tops may be contaminated. Depending on the enhancement curve we use, the tops may be contoured. This helps to define the cloud height.

Cumulonimbus

Cumulonimbus (CB) clouds are cumulus clouds of strong vertical development, with or without an anvil cirrus plume. CB clouds vary in size and shape, depending on the storm intensity and the storm environment in which they develop. The size and shape of the anvil cirrus are determined by the strength of the upper-level winds. The cirrus is circular with light winds and elongated downstream with stronger winds. CB clouds can develop singularly, in clusters or in lines. In large clusters or lines, individual cells may not be identifiable due to the combined effects of the anvil cirrus making one large cirrus canopy and covering the cells.

CB clouds appear very bright white with a round or elongated anvil plume on VIS imagery. Because of the upper-level winds, a CB may have a sharp upstream cloud edge and thin, diffuse anvil cirrus downstream. We can detect individual cells, known as "overshooting tops," above the cirrus canopy when the sun angle is low, due to shadows we see on the cirrus canopy. CB clouds also cast shadows on lower cloud decks with a low sun angle. Often, decaying CB clouds leave behind a cirrus plume cloud and low- and mid-level clouds.

CB clouds appear bright white and usually cellular on FIR imagery. On enhanced IR imagery, step contouring helps define the CB. Smaller CB clouds are difficult to discern if they are embedded in a cirrostratus shield. A light gray shade gradient is present on the upstream edge of the anvil cirrus where the CB is. The gray shade gradient loosens rapidly downstream.

On WV imagery, CB clouds appear a very bright white shade; however, individual cells are usually not identifiable.

Special low cloud types

The special low cloud types we discuss are large cloud patterns associated with certain synoptic situations. Because of their unique formation characteristics, they are classified differently for our purpose.

Cumulus lines/streets

These clouds are mainly formed due to surface heating and strong vertical wind shear. Strong vertical wind shear results in the formation of the clouds into lines or streets. These long narrow lines of unconnected cumuli are not more than 60 nautical miles (nm) apart and are parallel to the low-level wind direction. CU lines/streets appear the same as CU on VIS and FIR imagery except that they are in lines and streets.

Stratocumulus lines

These are SC elements formed by low-level instability that is caused by a large air/sea temperature difference (for example, continental polar air speedily advected offshore over warmer water). The lines are created by the strong vertical speed shear or strong low-level winds (≥15 knots) and an inversion that caps the vertical development of the cloud. The elements form a line of connected stratocumulus clouds that is aligned with the wind direction normally with a well-defined clear area along the upstream shore.

Figure 2–4 shows SC lines in weak and strong vertical speed shears. Under similar conditions as closed-cell stratocumulus, clouds often merge into such a field.

On VIS imagery, SC lines appear light gray to white, depending on the contamination factor. Small cells on the upstream side conform to the coastline and get larger downstream. The individual cloud elements may not be identifiable as they often merge into SC fields downstream. The smaller elements mean more closely packed lines and stronger winds. The elements eventually enlarge as the winds decrease. The winds must decrease to less than 20 knots to see a visible separation of cloud elements.

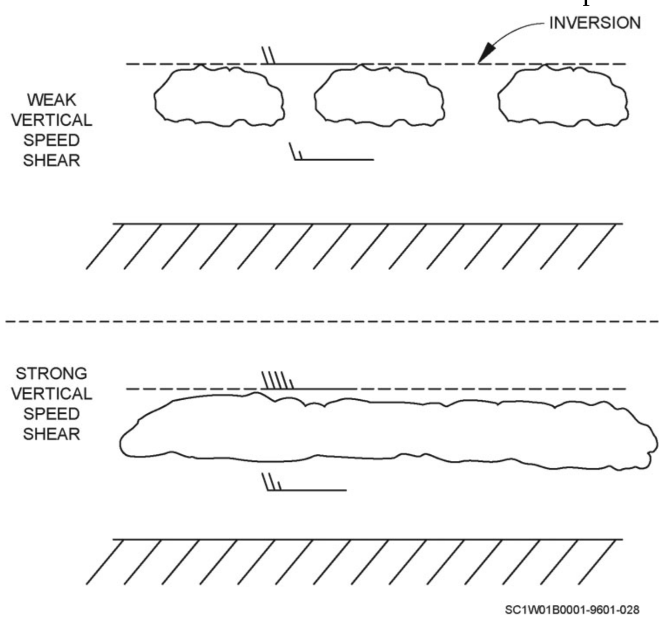

Figure 2–4. Stratocumulus lines.

FIR imagery shows SC lines as a medium to dark gray shade, which indicates warm temperatures. Thermally warm and uniform, difficult to distinguish due to contamination or vertical temp profile when lines are small, the lines may or may not be identifiable, depending on the sensor resolution. You can see stratocumulus lines on the CC, EC, or JG curves.

Closed-cell stratocumulus

Closed-cell SC is cellular, closely packed SC that forms mostly over ocean areas. They have rising air in the center of closely packed cloud cells with descending air at the edges. The individual elements vary in size from 5 to 50 kilometers (km). They’re typically found in large sheets and are associated with the anticyclonic flow of the subtropical high or with high-pressure systems behind cold fronts. Wind speeds are generally less than 20 knots and the wind direction is perpendicular to the strands. Clouds typically are located in the southern half of the high.

Closed-cell SC is formed due to low-level instability or to convective mixing with a strong subsidence inversion capping the mixing. The instability or mixing is due to surface heating, radiative cloud top cooling, or weak cold-air advection over a warmer water surface.

Closed-cell SC appears on VIS imagery as gray shades that range from white in the center to medium gray to white on the edges. They have a large quilt-like pattern with a slight separation between elements.

On FIR imagery, closed-cell SC usually appears similar to ST; that is, it is thermally warm, with a very uniform, medium to dark gray shade due to resolution problems.

Open-cell cumulus

These are CU clouds that usually form over water behind mid-latitude cyclones and are caused by strong cold-air advection over warmer water. They are associated with cyclonic or straight-line flow. There is a sharp transition between cellular clouds, which shows a separation between stable (closed-cell SC) and unstable (open-cell CU) air. Their vertical development is typically capped by a weak inversion above the cloud layer. The elements vary in size from 5 to 50km.

Open-cell CU appears on VIS imagery as open and closed ringlets of CU with clear centers like chicken wire. In strong low-level winds, these ringlets become distorted and line up. Individual elements may be difficult to detect due to the sensor's resolution.

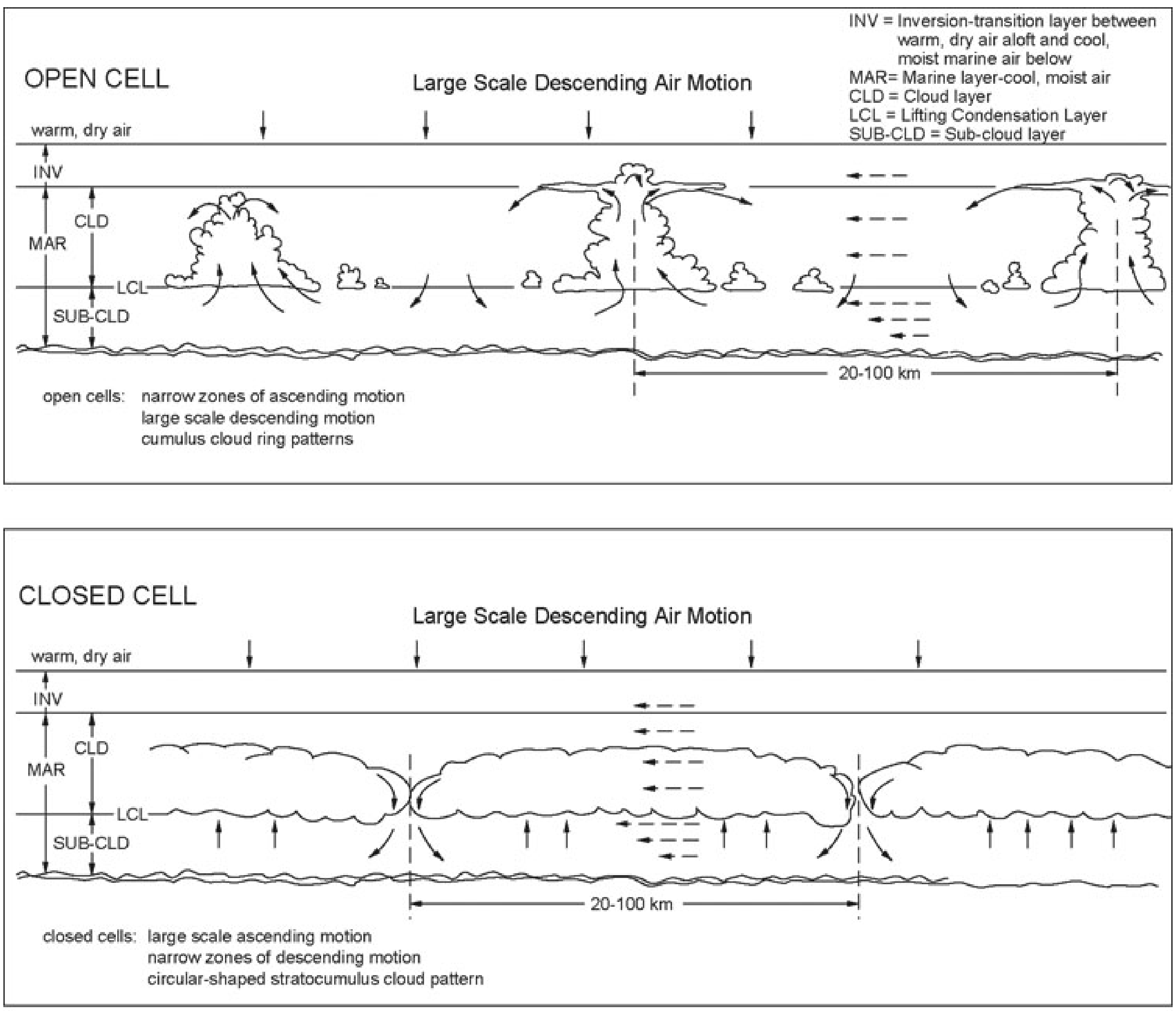

Figure 2–5. Typical cellular cloud patterns.

On FIR imagery, open-cell CU appears medium to dark gray due to contamination and resolution problems. Parts of the open-cell CU field may appear uniformly darker gray than the rest of the field. Although open-cell CU is higher than closed-cell SC, open-cell CU looks lower due to contamination and sensor resolution.

Closed-cell SC has larger cloud elements with very little of the surface showing through to the METSAT sensor. This allows for a more accurate cloud-top temperature measurement. With open-cell CU, more of the surface is showing through to the METSAT sensor. The clouds are smaller and narrower than closed-cell SC. The sensor averages the open-cell CU and the surface of the earth, which results in a higher temperature than the actual cloud-top temperature. Figure 2–5 illustrates the typical open-cell and closed-cell patterns. Figure 2–6 shows both open-cell and closed-cell patterns in the Pacific Ocean.

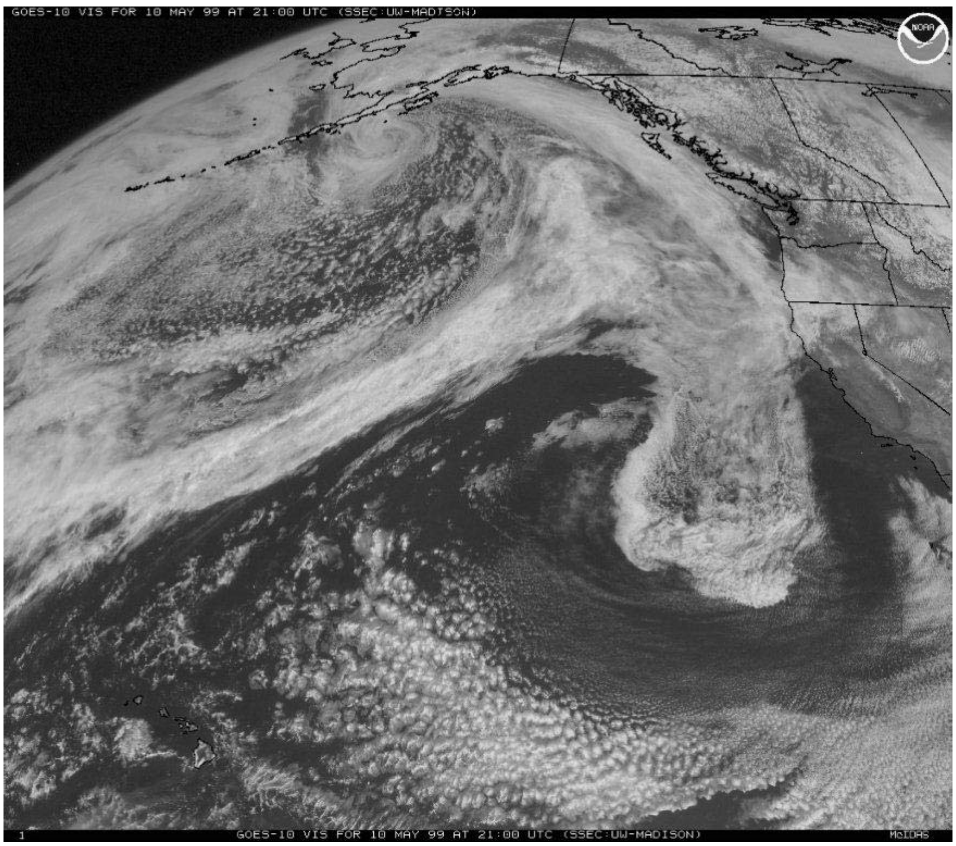

Figure 2–6. Open-cell and closed-cell clouds.

Enhanced cumulus

Enhanced CU is an area of TCUs and small CB clouds found in an area of open-cell CU due to a secondary vorticity maxima or positive vorticity advection. Winds are generally 10 to 20 knots higher than those in the surrounding area. Enhanced CU looks the same as small CB clouds or TCUs on VIS imagery. The convective cluster may even have a comma-shaped appearance. Visually they are bright white “blobs.” On FIR imagery, enhanced CU appears to be in the same gray shade as CB clouds/TCUs. On enhanced IR imagery, the clouds are contoured, which helps define higher cloud tops. The tops are cold due to vertical development; therefore, we refer to them as “enhanced.” In WV imagery, enhanced CU is bright white with the same cloud shape as the VIS and FIR.

Actiniform clouds

These are the skeletal remains of closed-cell SC, which are easily confused with open-cell CU. Actiniform clouds are found in or along the western side of the closed-cell SC.

On VIS imagery, actiniform clouds are light gray due to contamination, with a fish bone or chicken wire appearance.

Actiniform clouds are medium gray to dark gray, showing up slightly warmer than open-cell CU on FIR imagery. Individual elements are not identifiable. If too much contamination is present, the area shows up as a dark spot or hole in the clouds.

Arc clouds

This curved line of CU clouds is formed due to a thunderstorm downdraft of cold dry air. It looks the same as CU/TCU/CB clouds on the VIS and FIR imagery.

Rope clouds

This is a very narrow line of CU/TCU usually found over water and occasionally over very moist coastal land areas. Rope clouds can range from several hundred miles in length to several thousand. They are very representative of the surface cold front over water. The rope cloud has the same appearance as CU/TCU in the VIS and FIR imagery.

Middle clouds

Middle clouds are composed of super cooled water droplets and ice crystals. Often these clouds are hidden by higher-level clouds or, if fragmented, mistaken for other cloud types.

Altostratus/Nimbostratus

These are extensive sheets of stratiform clouds found in the mid levels. Altostratus (AS) and nimbostratus (NS) are found in the eastern portion of surface cyclones and the leading edge of frontal systems. These clouds are often masked by higher-level clouds in active regions of comma-cloud systems.

AS and NS appear on VIS imagery as a bright white, extensive sheet, which is fairly uniform. Shadows either cast on, or by, AS/NS can help you distinguish them from cirrostratus and ST.

On FIR imagery, they appear as a uniform gray shade that ranges from medium gray to light gray. AS/NS is a lighter gray shade than low clouds and a darker gray shade than higher clouds. On enhanced IR imagery, you may see a gray shade contouring, depending on the enhancement curve used. The EC enhancement curve can help you to identify the mid-level clouds.

On WV imagery, the range of gray shades varies quite a bit depending on the amount of moisture above the AS and how thick the cloud layer is.

Altocumulus

Altocumulus (AC) suggests vertical motions and moisture at the middle levels of the troposphere. They’re hard to distinguish from AS because the individual convective elements may not be resolved.

Terrain-induced wave clouds, altocumulus standing lenticular (ACSL), are the most common type of AC cloud detected on METSAT imagery. They’re also known as mountain-wave clouds (fig. 2–7). They’re regularly spaced cloud bands in a herringbone pattern. They are formed when strong mid-level flow crosses a hilly or mountainous ridgeline at a perpendicular or nearly perpendicular angle. The clouds form and dissipate due to the vertical up and down motions. They alternately condense and evaporate moisture on the leeside of the mountains. Winds do not advect clouds; the cloud bands remain along the mountain. Generally the wavelengths are proportional to the wind speed.

AC appears on VIS imagery as a bright white cloud sheet with a textured or lumpy appearance cloud bands or ACSL parallel mountain ranges.

The appearance of AC on FIR/enhanced IR is the same gray shades and enhancement capabilities as AS/NS, except the wave clouds frequently appear warmer (lower) due to contamination. This is especially true with higher elevation terrain located below the clouds.

On WV imagery, AC clouds have the same imagery interpretation considerations as AS/NS.

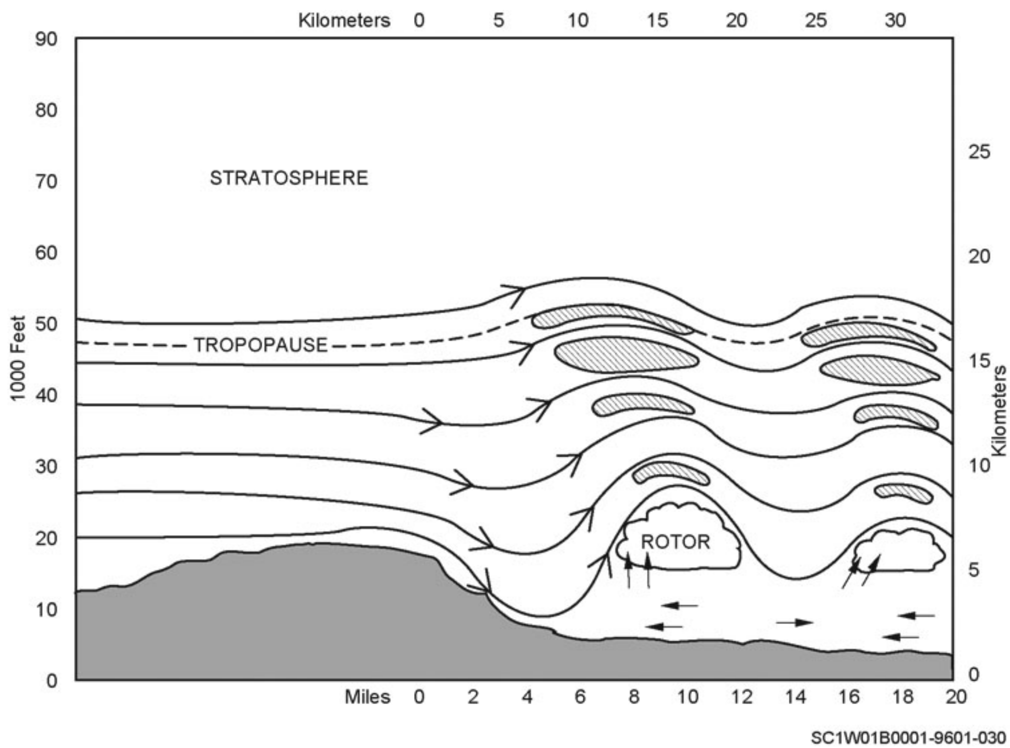

Figure 2–7. Mountain-wave structure.

High clouds

High clouds are composed of ice crystals. You'll learn about the different types of cirrus and cirrostratus clouds and how to interpret for them. One high cloud type we do not discuss is cirrocumulus. Since the elements are so small and below the sensor resolution, this type is not typically identifiable on METSAT imagery.

Cirrus

Thin cirrus (CI) appears as fibrous, wispy strands and filaments on VIS imagery. Thin CI is translucent; often obscuring the definitions of lower features, and appears less brilliant than lower or thicker clouds. CI is difficult to detect due to visual contamination. Dense CI often looks like patches, streaks, or bands, and casts shadows on lower clouds or terrain. Fibrous bands are often perpendicular to the winds while streaks are parallel.

On FIR, imagery dense patches of CI are bright and thin CI is very contaminated and appears warmer than the actual temperature. The gray shades have a large range due to the problems with contamination. Enhanced IR imagery shows gray shade contouring on most enhancements, even with thin CI.

On WV imagery, CI ranges from a light gray to a bright white shade, depending on how thick the cloud is and the amount of water vapor below it.

Special types of cirrus

These cloud patterns give you clues as to how the atmosphere is behaving. This can be useful for updating upper-air products, filling data void regions, or for determining hazards for pilots and missions.

Cirrus streaks

These are small isolated patches of CI generally occurring away from other clouds and aligned with the upper-level winds. They develop in areas where there is insufficient moisture for an entire CI shield to form. Cirrus forms on the backside of the trough along a channel jet.

Thin wisps of CI are very susceptible to contamination. On VIS imagery, the gray shades range from medium gray to white.

CI streaks appear on FIR imagery as a medium gray to white shade. Again, the imagery is very susceptible to contamination. On enhanced IR imagery, gray shade contouring is limited due to contamination problems.

CI streaks appear on WV imagery as a light gray to white shade, depending on the amount of moisture in the atmosphere.

Transverse bands

Transverse bands are irregularly spaced, parallel bands of thin CI filaments and strands oriented perpendicular to the wind flow. The speeds in transverse bands are usually greater than or equal to 80 knots. Cirrostratus typically obscures transverse bands in the middle latitudes, making it difficult to detect them. Transverse bands appear similar to CI streaks on VIS, FIR, and WV imagery. Light to moderate turbulence is commonly associated with this cloud type.

Billow clouds

These clouds are regularly spaced parallel CI cloud bands that advect with the wind. They're caused by vertical shear, due to the stronger winds aloft, although they can occur at low levels in the atmosphere. Billow clouds are oriented perpendicular to the winds. The distance between the billow cloud elements is less than with mountain-wave clouds. Varying degrees of turbulence are associated with billow clouds. Winds advect the cloud bands. The wavelengths are proportional to the wind speed. Remember, billow clouds are not associated with terrain features; they are caused by vertical shear aloft.

Billow clouds appear on VIS imagery as light gray to white with a washboard appearance. The clouds are usually thick versus filaments or strands. Contamination is a problem, depending on the spacing between elements.

Due to contamination on FIR imagery, the gray shades range from medium gray to white. The individual elements may not be identifiable.

Billow clouds may appear disorganized and chaotic on EIR imagery. The appearance varies, depending on the cloud element spacing, cloud organization, and satellite resolution.

Billow clouds may or may not be detectable on WV imagery, depending on whether there are other clouds over the billow clouds and how much moisture is available along with the other factors listed above.

Contrails

Contrails (condensation trails) are CI cloud lines formed from jet exhaust that appear as unnatural anomalous cloud lines. They don't last as long as ship trails because the upper-level winds are stronger and more mixing is occurring. You may see these on the FIR as a small thin CI cloud. Another factor is the sensor resolution versus the size of the cloud element.

Cirrostratus

These clouds are high, continuous, variably dense veils that cover an extensive area. They appear on VIS imagery as a bright white gray shade. Cirrostratus (CS) is thick and fairly uniform except along the edges where it is thin and wispy. Because of its thickness, it's not as subject to contamination. CS casts shadows on lower clouds and surfaces.

On FIR and WV imagery, CS clouds appear as a uniform white shade, except at the edges where contamination is a problem. Enhanced IR imagery contours the cloud tops, allowing you to define cloud heights. Except for CB clouds, these are normally the coldest cloud tops.

Anvil cirrus

Anvil cirrus or thunderstorm blow off has a sharp upwind edge with a strong thermal gradient. The fuzzy, diffuse downstream edge is more translucent and appears warmer, but not actually lower. The blow off from numerous thunderstorms combines to form an extensive CS canopy, which is aligned with the upper-level winds.

Anvil cirrus appears on VIS imagery as bright white on the upstream edge. They gradually darken on the downstream side as they thin and become translucent. Unless overshooting tops are present, anvil cirrus is very smooth.

On FIR and WV imagery, anvil cirrus appears as bright white patches. On enhanced IR imagery, there is a contouring of the cloud tops to help you define the height.

Lee-of-the-mountain cirrus

Lee-of-the-mountain cirrus or leeside cirrus is a multilayered CI cloud shield on the lee of a mountain chain. A sharp, stationary, upwind cloud edge along the ridgeline shows the presence of standing mountain waves. Towards the downstream edge, they are more translucent and appear warmer, but not actually lower. They tend to form late at night and dissipate in the afternoon. There is an inversion or isothermal layer above the mountaintops. The cloud tops range from 25,000–35,000 ft with bases from 10,000–15,000 ft. Their occurrence appears highly dependent on the presence of a high-level moisture source in a strong wind zone. It's typically located with, and just south of, the polar front jet (PFJ), but does not have to be near the jet stream. WV imagery helps identify areas of moist air where leeside cirrus may occur while other imagery shows the area as cloud free. Leeside cirrus affects temperatures by blocking out incoming solar radiation. Mountains as low as 1,000 feet can cause leeside cirrus.

On VIS imagery, leeside cirrus appears bright white with a sharp edge along the ridgeline. It can appear as thick as CS, but becomes more diffuse downstream. Contamination is a problem on the downstream edge.

On FIR and WV imagery, lee-of-the-mountain cirrus is a bright white gray shade. Lee-of-the-mountain cirrus is the coldest non-thunderstorm cloud in the mid-latitudes. Enhanced IR imagery shows contouring of the cloud tops.

409. Non-cloud features

Snow, ice, and lithometeors are the types of non-cloud phenomena we discuss. We can easily mistake some of these features for clouds if we do not use viewing considerations and continuity. In recent history, some of these phenomena have played a major role in favorable mission accomplishments.

Snow

VIS imagery picks up snow and ice much better than IR because of the brightness contrast on the imagery. (Reflectivity: New snow—88 percent; three- to seven-day-old snow—59 percent.) Following are some considerations when you interpret for snow.

The brightness increases with a snow depth up to four inches. Above four inches, the brightness doesn't change. Snow has a dendritic (vein-like) pattern in mountain areas; rivers and lakes are sometimes snow free; and snowfields in the plain's region tend to be long, narrow, and smooth with sharp edges.

Snow has a mottled (blotchy) appearance in forested areas. It is bright white in the plains and decreases in brightness with increasing vegetation density and height.

The sun angle is an important factor because brightness decreases rapidly when the sun angle is below 45°. It is easier to discern snow from cloud cover with a low sun angle because of the shadows from the clouds. On FIR imagery, the detection of snow, ice, low clouds, and the ground is difficult without a simultaneous visual imagery. You may be able to see certain prominent terrain features.

Ice

Ice is seen on METSAT imagery in large lakes, bays, and seas (for example, the Great Lakes, Hudson Bay, Bering Sea). Ice forms along the shorelines first. Offshore winds move and break up the ice next to the shore. Water and new, thin, transparent ice appears as a dark band along the shore.

Ice has the same gray shades as snow and is difficult to distinguish from snow cover on VIS and FIR imagery. There may be dark fractures or cracks in the ice that we call leads.

Lithometeors

Remember that lithometeors are dry, solid particles either suspended in the air or lifted from the ground by the wind. Therefore, lithometeors can and do show up on METSAT imagery.

Dust and sand

These suspended surface particles are carried aloft by strong synoptic-scale surface winds for long distances. The upstream edge usually is not well defined. These appear most often in desert regions and in very dry, cropland areas (e.g., Arizona, Texas, Kansas, Sahara and Gobi deserts).

Dust has a filmy, diffuse appearance with a medium to light gray shade on VIS and FIR imagery. If it shows up on FIR, it is a dark to medium gray shade.

Smoke and ash

The sources for smoke and ash are fires, industrial areas, and volcanoes. These phenomena usually have a sharp boundary at the source of the plume. Smoke and ash from volcanoes are discernible depending on the level of volcanic activity. Volcanic ash reaches ambient air temperature very rapidly. If a volcanic plume reaches high altitudes, the ash cloud appears cold on the FIR and enhanced IR imagery. Ash clouds in the upper levels can be advected long distances by the upper-level flow. The upstream edge can be thick while downstream, the ash cloud becomes diffuse and thin. It appears the same as thick CI on the VIS, FIR, and enhanced IR imagery.

Haze, pollution, and aerosols

On METSAT imagery, these items appear in stable conditions with light winds. Haze is very common during the warm season in the subtropics (for example, southern and southeast US and California). Haze forms from suspended particles that absorb water vapor in a high moisture atmosphere. Pollution consists of the by-products of industry, agriculture, and the burning of fossil fuels. Aerosols are small, suspended liquid or solid particles that absorb and scatter light.

On VIS imagery, haze, pollution, and aerosols appear to be dull, filmy, and diffuse with a light to medium gray shade, depending on the density. They are easier to see over dark terrain and become more diffuse due to atmospheric mixing.

On FIR imagery haze, pollution and aerosols appear only if they are at high altitudes or in large concentrations. Contamination is a major consideration with these features.

410. Topographic influences

Your awareness of different topographic influences allows you to interpret all the features on the imagery correctly. We discuss land, water, and solar effects on the METSAT imagery.

Variations in the earth’s surface

Over land you get varying gray shades on VIS and FIR imagery, depending on vegetation coverage, rough versus smooth terrain, wet versus dry, and soil type. Over water you see varying differences in gray shades due to wind speed, wave action, plant life, “muddy” water versus “clean” water, and the water depth, along with the topographical makeup of the ocean bottom.

Solar effects on imagery

Solar effects provide valuable information on a variety of synoptic features. Such effects are also useful for determining general wind flow patterns.

Sun glint

A Sun glint is caused by the reflection of the sun's rays off the water surface directly into the METSAT sensor (seen only on visual imagery). A Sun glint typically occurs under stable conditions, with light or calm winds, such as with high-pressure systems, especially the subtropical ridge. Figure 2–8 is an example of a diffuse sun glint. Figure 2–9 shows an intense sun glint. Figure 2–10 shows a sun glint on the water surrounding Florida, which outlines the coastline in great detail. Tampa Bay is seen at A and Cape Kennedy at B. The very bright spots at C are from a sun glint on the many lakes of central Florida, while a sun glint on Lake Okeechobee is seen at D.

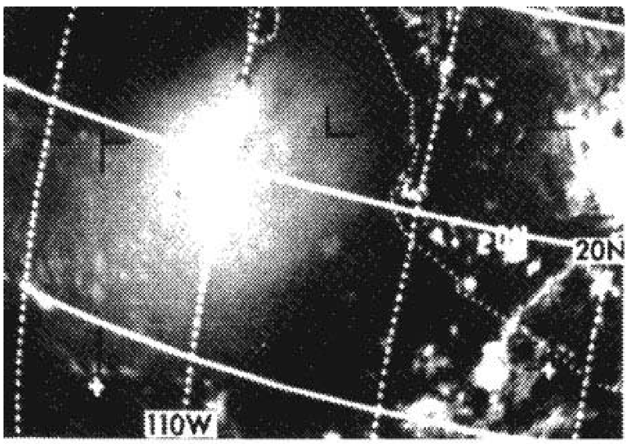

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Figure 2–8. Diffuse sun glint.

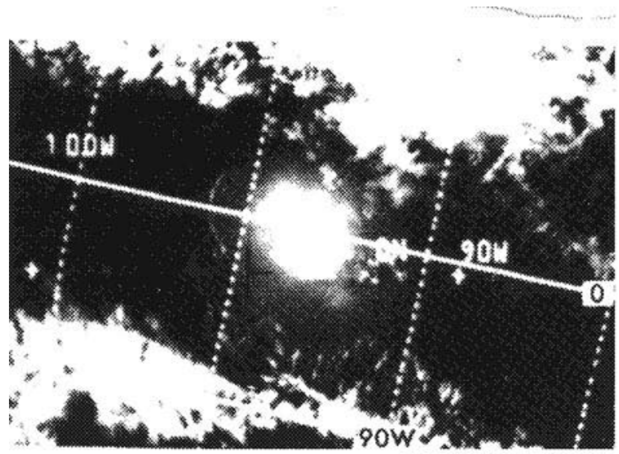

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Figure 2–9. Intense sun glint.

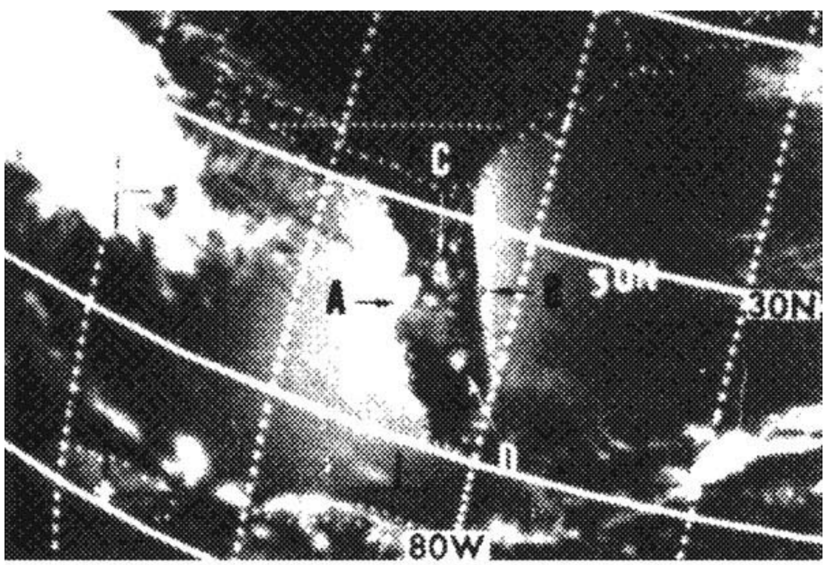

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Figure 2–10. Sun glint near Florida.

Geostationary imagery

The sun glint pattern has a circular shape to it when we view it with a geostationary METSAT image. The higher the wind speeds, the larger and more diffuse the sun glint pattern will be. The lower the wind speeds, the smaller, brighter, and better defined the sun glint pattern will be.

Polar orbiting imagery

These show a line pattern from the top to the bottom of the picture if the satellite sub point and the solar sub point are sufficiently close. The sun glint is produced by the reflection of sunlight off many small waves when the satellite is at a latitude other than the solar sub point. The higher the wind speed, the larger and more diffuse the glint zone will be. The lower the wind speeds, the smaller and more intense the sun glint will be.

Land sun glint

A land sun glint occurs over very wet, flat terrain, such as that found over China's rice patties, flooded lowlands, rivers, and lakes.

Sun glint utility

We use sun glint to estimate the surface wind speeds, direction (occurs in areas of anticyclonic flow), and sea state. We also use sun glint to locate flooded lowlands that can be used for the Army trafficability support (to determine whether Army vehicles can travel over a specific surface).

The terminator

This phenomenon is only seen on visual imagery. It's the transition line from day to night. It deceives by "hiding" major systems behind the line, thus making the systems seem less ominous. It's very distinctive on geostationary imagery.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

408. Cloud features

1. Match each cloud formation/appearance in column B with its description in column A. Cloud formations are used only once.

Column A	*Column B*
____ (1) Common in the tropic and subtropic regions.	a. Cloud type.
____ (2) A cloud form such as cumulus, stratus, altostratus, etc.	b. Cloud lines.
____ (3) Low-level clouds that develop because of low-level convergence.	c. Cloud element.
____ (4) The smallest cloud seen on an image as determined by the resolution of the satellite sensor.	d. Cloud streets.
____ (5) A nearly continuous cloud formation where elements are connected and the line is less than 1° in width.	e. Cloud fingers.

2. Match the cloud type in column B with its description in column A. Cloud types are used only once.

Column A

____ (1) These clouds look the same as a small CB cloud or TCUs on VIS imagery.
____ (2) These appear on VIS imagery as light gray to white with a washboard appearance.
____ (3) These appear bright white with a sharp edge along the ridgeline on VIS imagery.
____ (4) These are medium gray to dark gray showing up slightly warmer than open-cell CU on FIR imagery.
____ (5) On VIS imagery, these clouds appear light gray to white depending on the contamination factor.
____ (6) On visual imagery, these appear as a white to light gray shade in a uniform sheet with no texture.
____ (7) On VIS imagery, these clouds appear as a bright white cloud sheet with a textured or lumpy appearance.
____ (8) On VIS imagery, these clouds appear as gray shades, ranging from white in the center to medium gray to white on the edges.
____ (9) On WV imagery, these range from a light gray to a bright white shade, depending on how thick the cloud is and the amount of water vapor below them.
____ (10) On FIR imagery, only the large concentrated areas of these clouds show up; they appear as a very dark gray shade, which represents warm temperatures.
____ (11) On FIR imagery, these clouds appear as a dark gray shade, which suggests warm temperatures. Their cellular or textured appearance may not be observable due to the sensor resolution.

Column B

a. Cirrus.
b. Cumulus.
c. Altocumulus.
d. Billow clouds.
e. Stratocumulus.
f. Fog and stratus.
g. Enhanced cumulus.
h. Actiniform clouds.
i. Stratocumulus lines.
j. Closed-ellstratocumulus.
k. Lee-of-the-mountain cirrus.

409. Non-cloud features

1. Why does VIS imagery pick up snow and ice better than IR imagery?

2. Why is sun angle an important consideration when we look at snow?

3. How does dust appear on METSAT imagery?

4. How do haze, pollution, and aerosols appear on VIS imagery?

5. How do haze, pollution and aerosols appear on FIR imagery?

410. Topographic influences

1. What causes sun glint?

2. How does sun glint appear on geostationary satellites? On polar orbiting satellites?

3. What is sun glint used for?

4. On what METSAT imagery does the terminator phenomena appear?

2–2. Upper-Level Flow and Features

In this section you'll learn the fundamentals of interpreting upper-level flow and synoptic-scale features on METSAT imagery. Using METSAT imagery with the various products allows you a more objective look at the atmosphere. In this section, we consider only the METSAT imagery and how to analyze the features and flow on the METSAT imagery. Understanding how to determine the wind flow and upper-level features on METSAT imagery allows you to continue to forecast weather even if you do not receive any products during certain periods or situations. METSAT imagery also fills in data sparse areas between synoptic stations.

411. Composition of the wind field

Before we can look at interpreting the upper troposphere on METSAT imagery, we need to define the composition of the wind field in the atmosphere.

Translation

Translation is the movement of an air parcel in a straight line. Theoretically, all air parcels move at the same speed in the same direction. We commonly use translation to measure the speed of lows, the jet maximum, and so forth.

Rotation

Rotation is a circular wind pattern turning around a specific point. Cyclonic rotation is positive rotation and anticyclonic rotation is negative rotation.

Divergence (convergence)

This is a spreading (contraction) of the wind field away from (divergence) or toward (convergence) a central point.

Deformation

Deformation is the stretching or shearing of the wind field. The wind flow in a field of pure deformation shows a specific streamline pattern. There are three parts to a deformation zone we need to identify.

Col (neutral point)

A col is the center of the deformation zone where the winds are calm.

Axis of dilatation

The horizontal axis where air parcels are moving away from the col is called the axis of dilatation.

Axis of contraction

The axis of contraction is the horizontal axis where air parcels are moving toward the col.

Although we defined four types of motion separately, normally a combination of these motions occurs; they may look quite different from the pure form.

For example, surface winds around a low-pressure area primarily are composed of rotation and convergence (fig. 2–11). Deformation combined with translation appears as difluence in the wind flow (fig. 2–12).

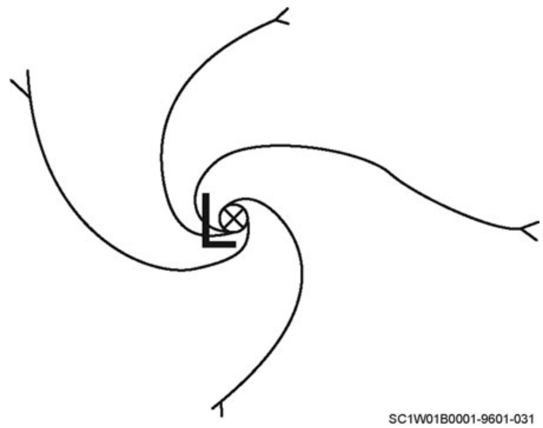

Figure 2–11. Flow with the low.

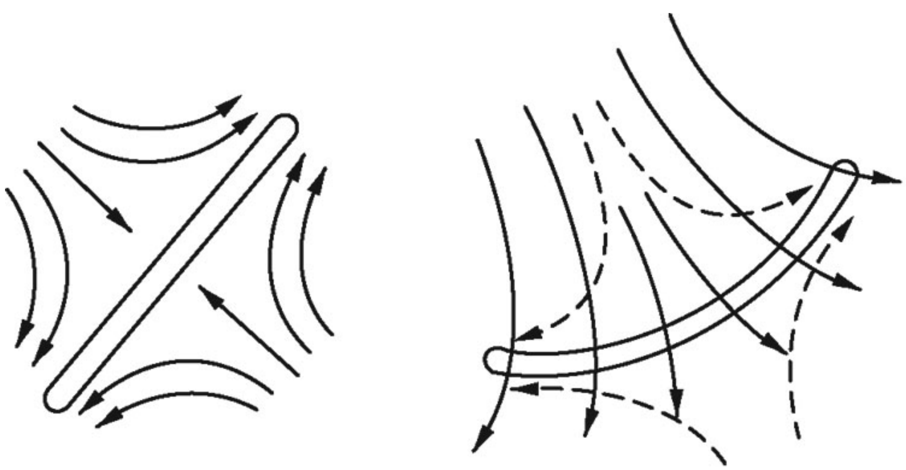

Figure 2–12. Deformation.

When we view cloud systems on METSAT imagery, we need to consider the four basic types of motion as well as the combinations of it.

412. Upper tropospheric interpretation

Meteorologists rely on constant-pressure products to view the atmosphere. This is how they identify low height centers, fronts, and so forth. In METSAT imagery interpretation, we have a different way of looking at weather features. METSAT imagery allows us to see the cloudiness a feature produces.

In interpreting METSAT imagery, we first identify cloud patterns. This is called cloud pattern recognition. Second, we use cloud pattern recognition and cloud and non-cloud phenomena to help us determine wind flow. Third, we use the cloud patterns and wind flow to determine specific synoptic features and relate them to the map features.

You must view the cloud patterns several different ways when you interpret METSAT imagery. First, you may not see the moisture on the different upper-air products. The detectable moisture can begin and/or end at levels in the atmosphere between the upper-air levels analyzed. Second, use the cloud patterns to draw in moisture patterns when you analyze upper-air products. The METSAT imagery may be showing areas of moisture that fall between upper-air stations on the product.

413. Cloud pattern recognition

With experience, you'll begin to recognize cloud patterns quickly and understand their meteorological significance. Over the next lessons you'll learn about basic cloud patterns and their meaning to you.

Baroclinic leaf

This thick mid- and upper-level cloud pattern is recognized as the first sign of comma-cloud development. It normally has a shallow "S" shape on the sharp, upstream edge of the cloud system. A unique characteristic is the "V" notch in the tail of the leaf. This cloud feature is seen in straight-line to cyclonic flow. Baroclinic leaves are smaller than the more developed synoptic systems, such as baroclinic zone cirrus. Baroclinic leaves vary in shape, as seen in figure 2–13. Figures 2–14 to 2–16 show the evolution of a baroclinic leaf in the central US.

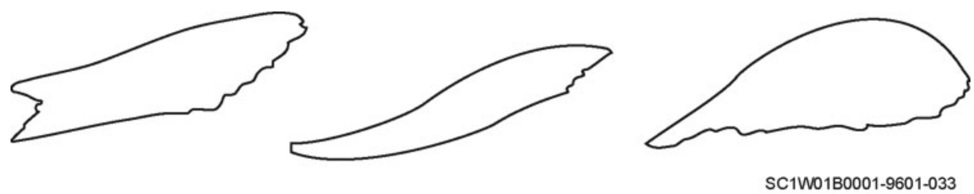

Figure 2–13. Baroclinic leaves.

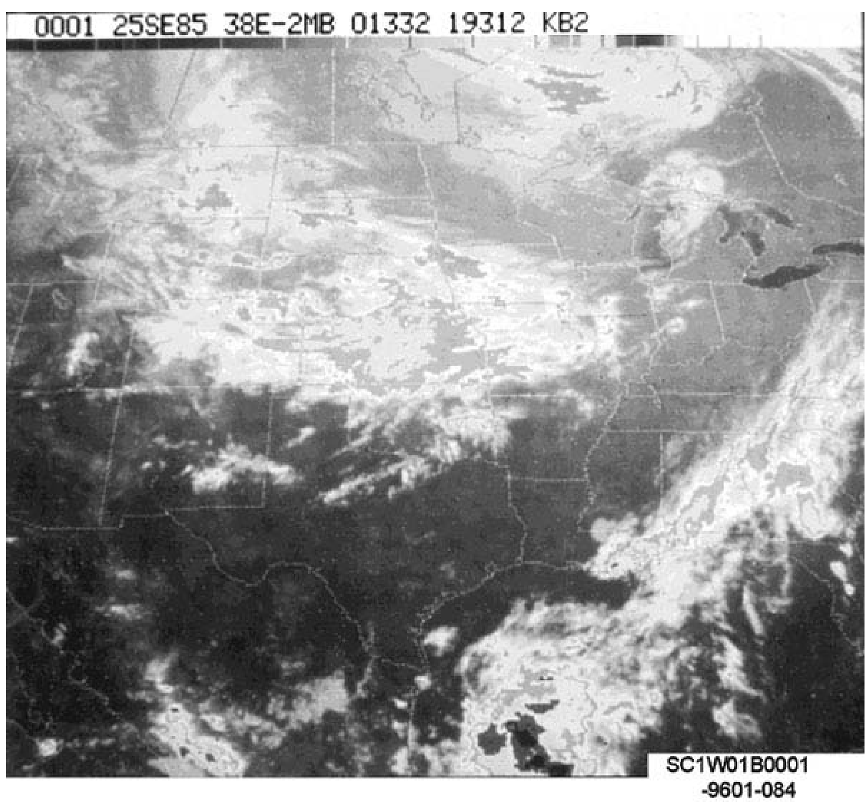

Figure 2–14. Baroclinic leaf, 25 Sep 85, 0001Z.

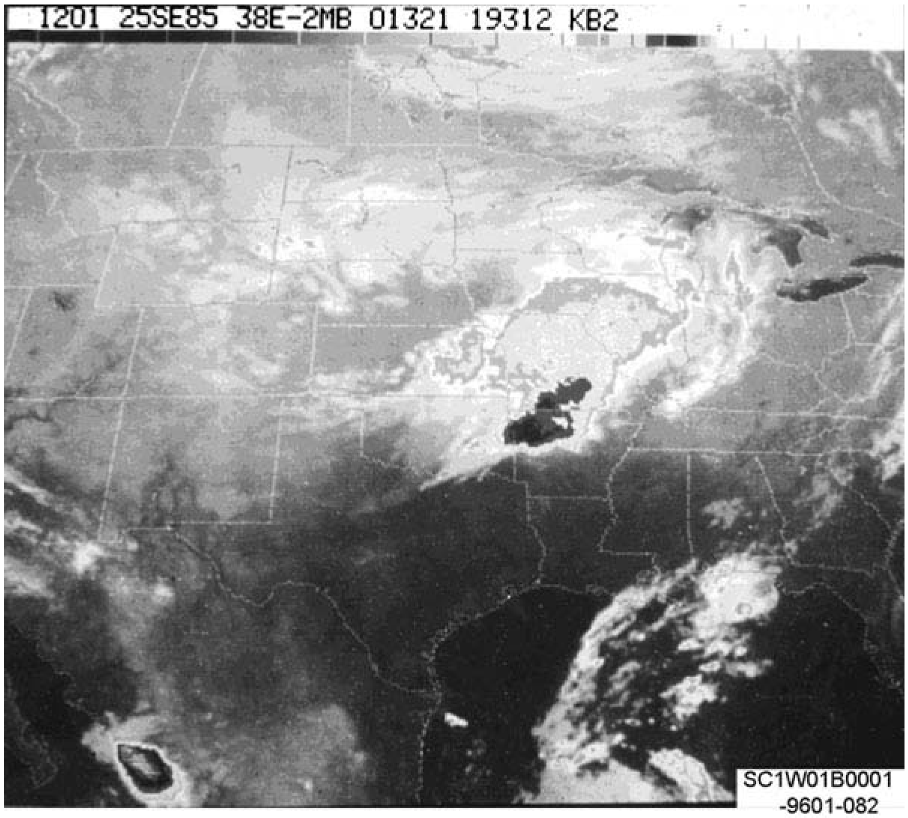

Figure 2–15. Baroclinic leaf, 25 Sep 85, 1201Z.

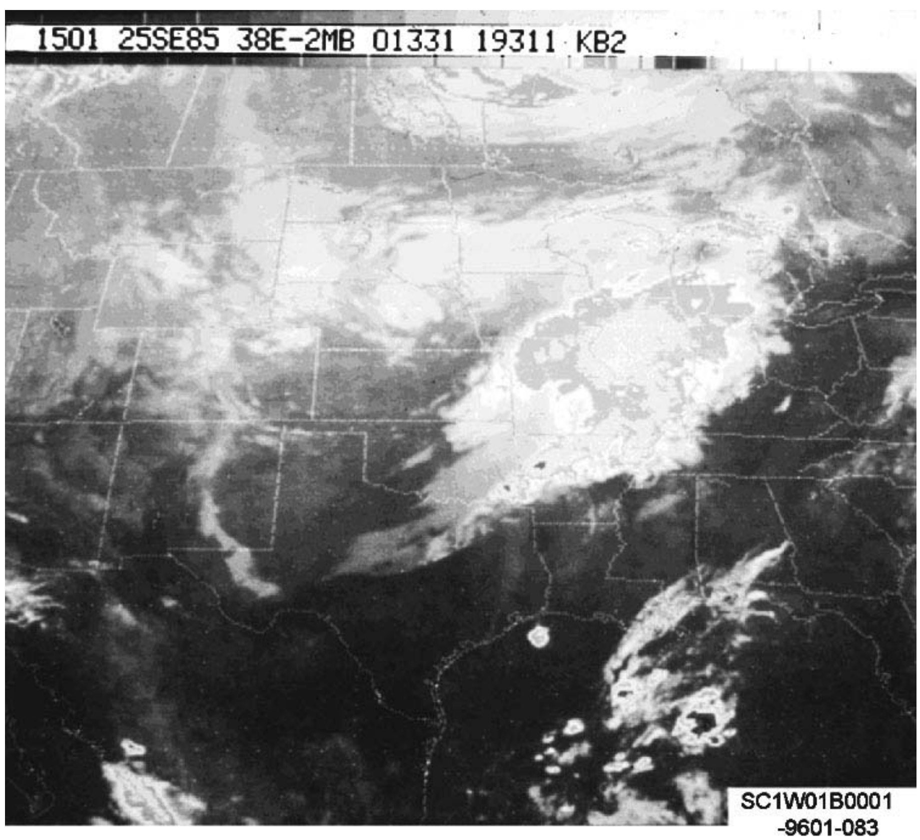

Figure 2–16. Baroclinic leaf, 25 Sep 85, 1501Z.

Comma cloud structure

Comma clouds are associated with low-pressure systems within the mid-latitude westerlies. There are three cloud features that make up a synoptic-scale comma cloud; baroclinic zone, vorticity comma, and deformation zone clouds. Figure 2–17 shows the makeup of a comma cloud.

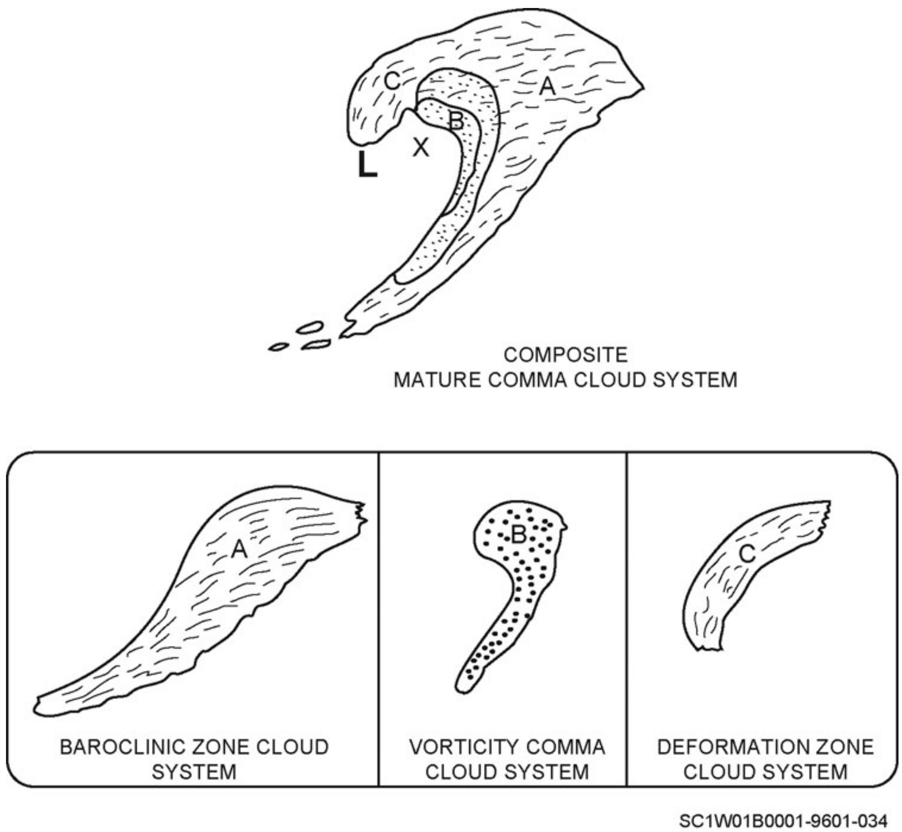

Figure 2–17. Comma-cloud structure.

Baroclinic zone cloud system

Multilayered clouds are associated with the cold and warm fronts. Multilayered clouds are usually topped by a large CS shield and precipitation is continuous with possible thunderstorms embedded. The PFJ is located on the poleward side of the baroclinic zone clouds. The baroclinic zone cloud system is associated with the thickness ribbon on the thickness product.

Clouds are due to deformation of the thermal gradient and, therefore, vertical motions. These cloud systems are layered with mostly cirrus tops.

Vorticity comma-cloud system

This low to mid-level cloudiness in a comma shape is associated with a vorticity maximum. The vorticity comma cloud is often hidden around the higher baroclinic and deformation cirrus cloud cover. Precipitation is convective in nature within this cloud pattern.

Rotation results in convergence and, then, strong vertical motions. When a vorticity cloud system is not overshadowed by baroclinic zone cirrus, it is overshadowed by convective clouds.

Deformation zone cloud system

Cirrus clouds west to north of an upper-level low range from very thin to very thick. The cirrus clouds are usually lower than the baroclinic zone cirrus. The baroclinic and deformation zone cirrus may or may not merge. An upper-level deformation zone is associated with this cloud system.

Clouds warmer than baroclinic zone cirrus stretch along the axis of dilatation. A dark region in water vapor runs along the axis of dilatation and is easily mistaken for jet location. Figures 2–18 and 2–19 show a deformation zone cloud system in the central US on the MB curve and a visual imagery an hour-and-a-half later.

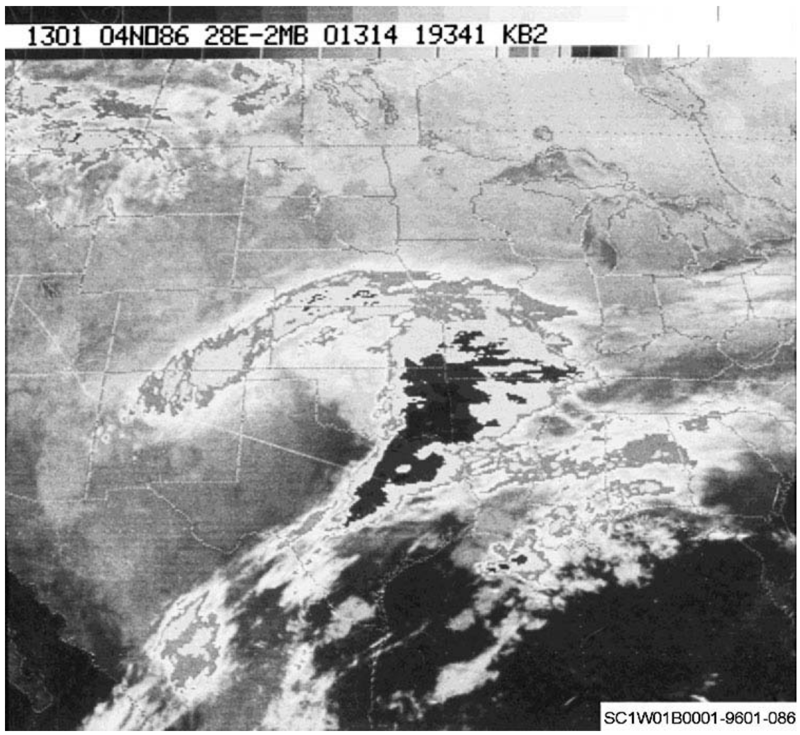

Figure 2–18. Deformation zone cloud system on MB imagery.

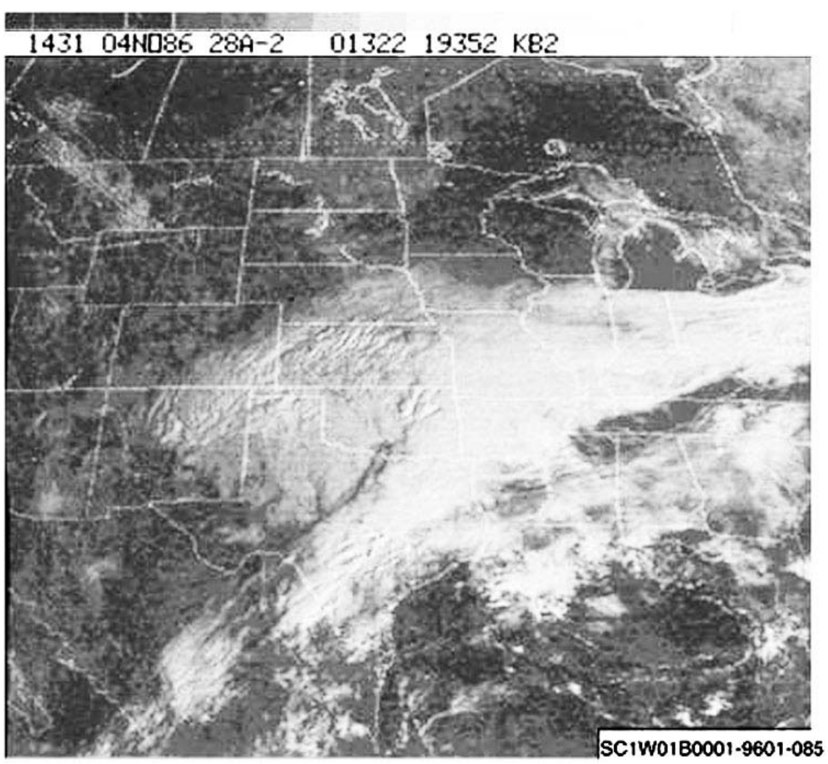

Figure 2–19. Deformation zone cloud system on visual imagery.

Surge region (dry slot)

The surge region (fig. 2–20) is the dry intrusion of air into the comma. It's located near the region of highest winds, near the cloud-top level (excluding convective activity). The surge region is commonly called the dry slot.

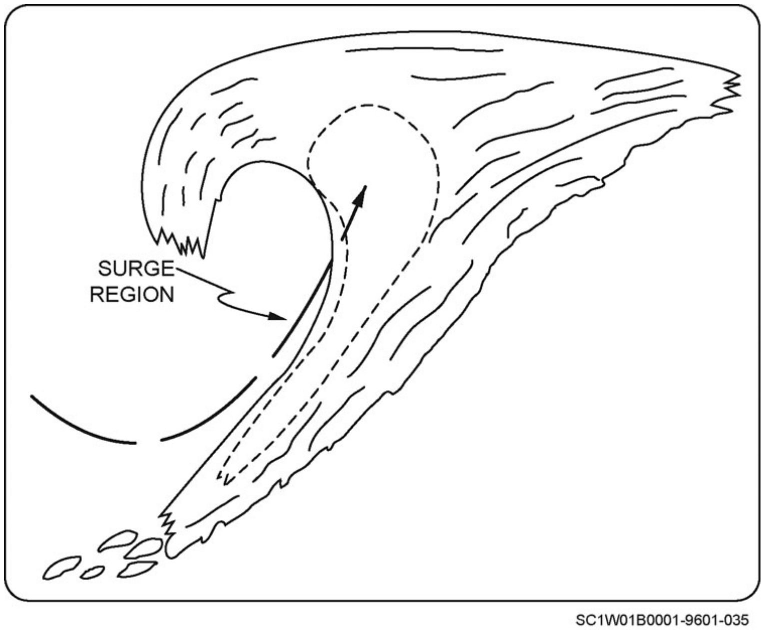

Figure 2–20. Surge region.

The northern portion of the comma cloud is known as the comma head. The comma tail typically extends from the comma head to the south or southwest (figs. 2–21, 2–22 and 2–23).

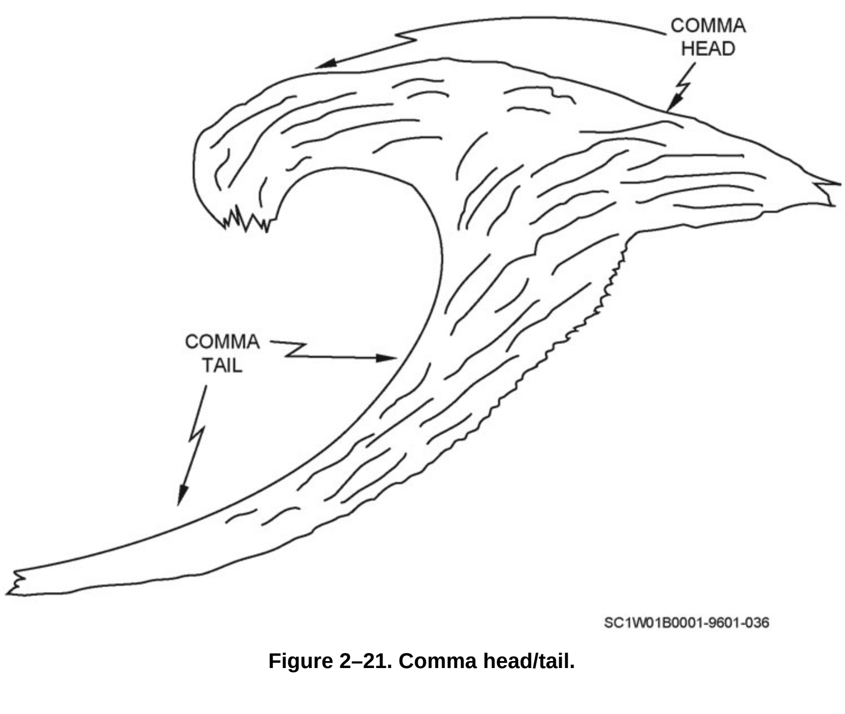

Figure 2–21. Comma head/tail.

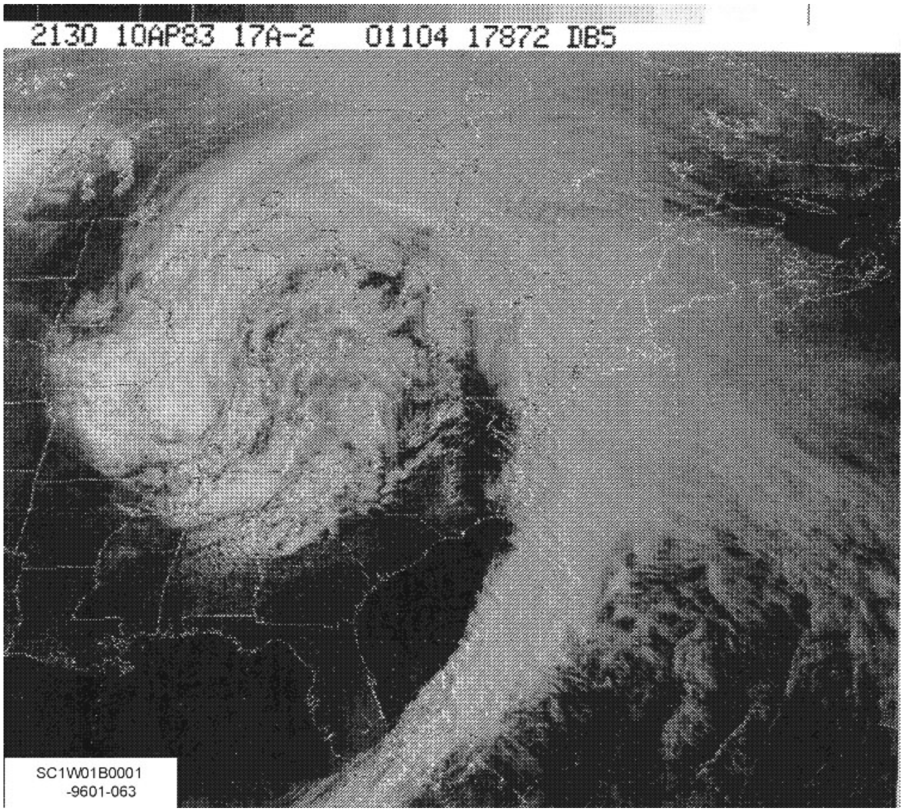

Figure 2–22. Comma cloud on visual imagery.

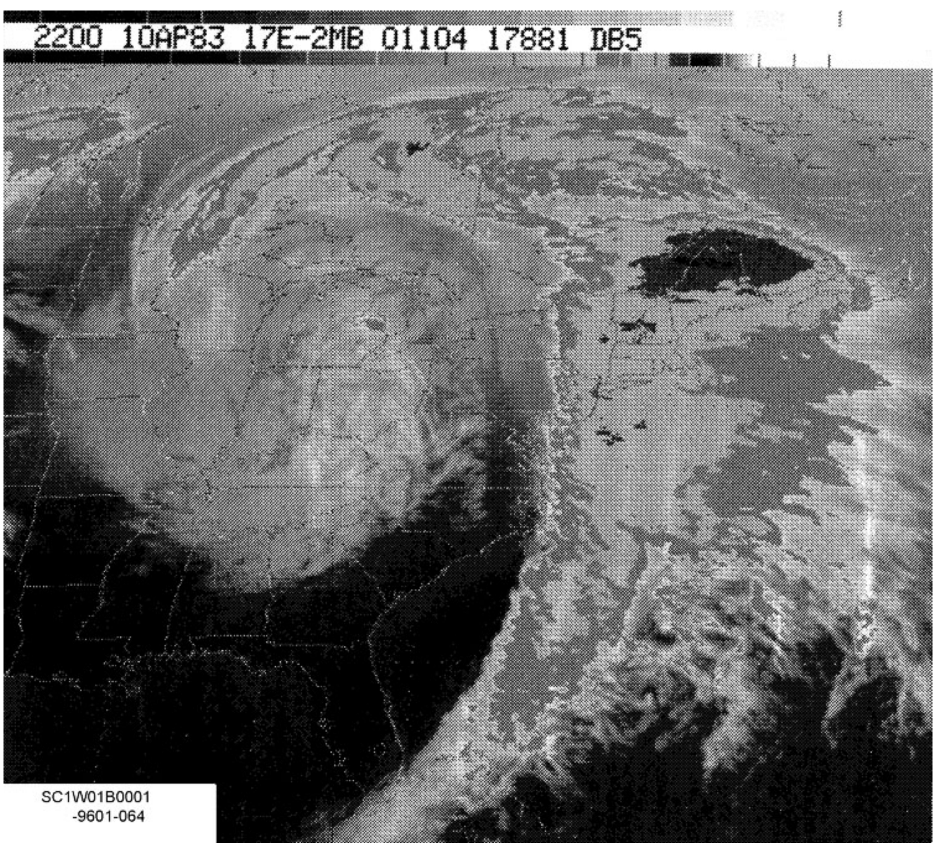

Figure 2–23. Comma cloud on IR imagery.

The flow in the western portion of the comma cloud is cyclonic. The flow behind the comma cloud is also cyclonic. Anticyclonic flow is located in the extreme eastern portion and ahead of the comma cloud. Figure 2–24 illustrates the upper-level circulation associated with a comma cloud.

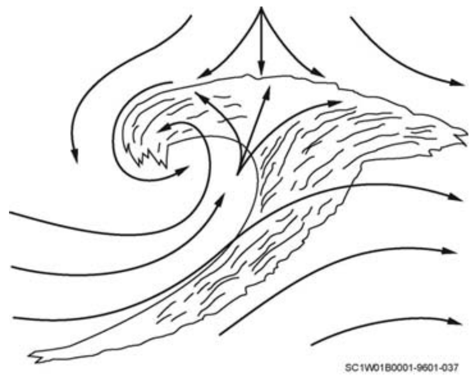

Figure 2–24. High level circulation.

Ridge pattern

This ridge pattern is indicated on imagery as an anticyclonically curved multilayered cloud pattern (baroclinic zone cirrus). Clouds show ridge amplitudes ranging from sharp to broad and are prevalent on the upstream side of the ridge axis. Such a pattern usually has a well-defined cloud edge on the poleward side where the jet stream is typically located (fig. 2–25).

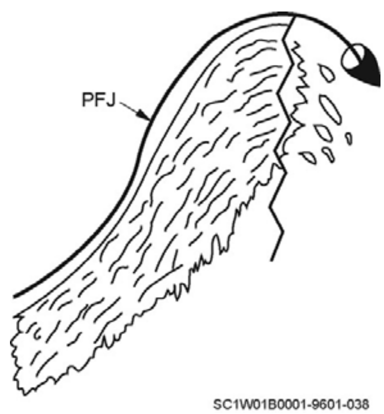

Figure 2–25. Trough.

Trough pattern

The trough is located slightly upstream from the comma-shape cloudiness it produces and/or influences (fig. 2–26). The comma-shape clouds may be in the form of enhanced CU, baroclinic leaves, an “S” shape or bulge in frontal cloud bands, and comma-cloud systems. Cyclonic flow is associated with troughs. Figures 2–27 and 2–28 show a trough and ridge pattern on visual and IR imagery.

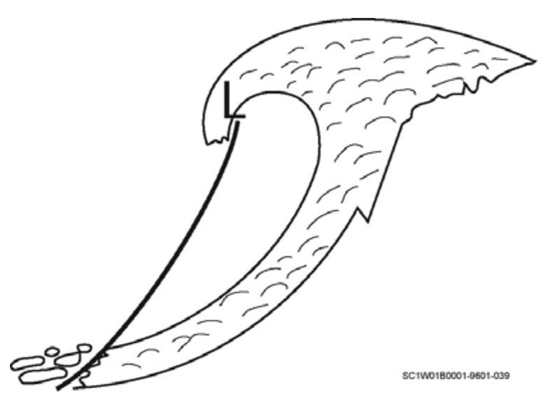

Figure 2–26. Trough.

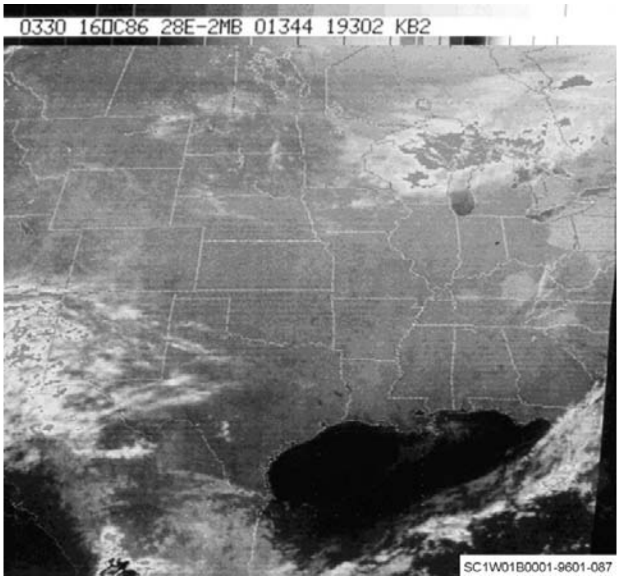

Figure 2–27. Trough and ridge pattern on visible METSAT imagery.

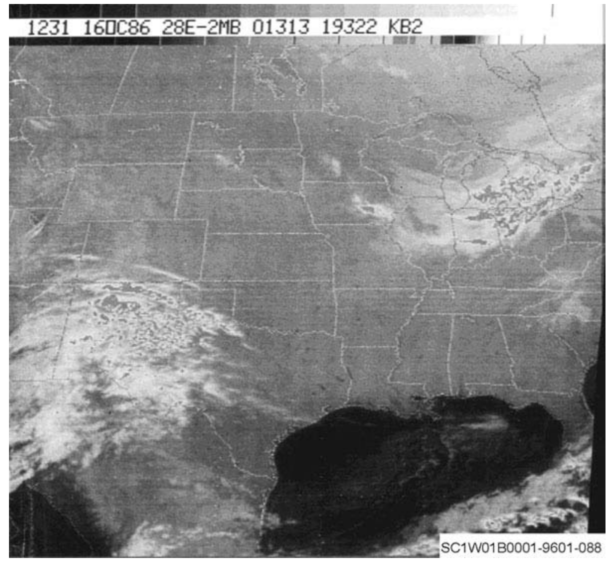

Figure 2–28. Trough and ridge pattern on IR METSAT imagery.

Low center

These are identified by the cyclonic swirl in the clouds. The amount and type of associated cloudiness depends on the intensity of the system and moisture availability. Figure 2–29 shows two examples of low centers.

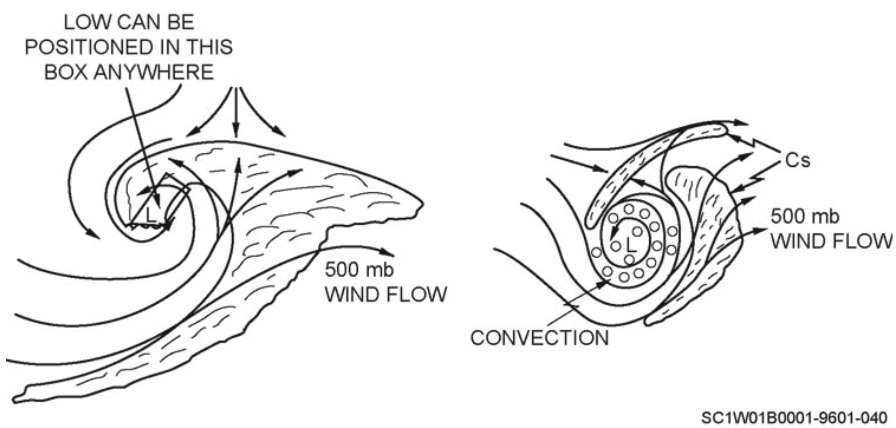

Figure 2–29. Low centers.

414. Upper-level wind flow determination

We can determine upper-level wind flow with two different techniques. One is by following specific cloud elements on animated METSAT imagery to determine the flow. This technique is used at research centers, weather centrals, and stations with looping capabilities. The second technique is to interpret specific cloud and non-cloud phenomena to determine wind flow.

Empirically, wind observations have been noted with certain cloud and non-cloud phenomena. The technique we discuss is interpreting specific cloud and non-cloud phenomena. We use different types of METSAT imagery to determine wind flow and synoptic features.

When we view certain cloud and non-cloud phenomena on VIS imagery, the upstream cloud edge is very sharp and well defined. The cloud becomes very thin and diffuse with the flow downstream. The wind flow is coming from the sharp upstream edge. If the weather system producing the clouds is stationary or nearly stationary (for example, cut-off lows), the cloud pattern provides a fairly accurate idea of the upper-level wind flow. The clouds are aligned parallel to the upper-level wind flow.

When the parent weather system is moving, the upper-level clouds can still be a fair approximation of the upper-level wind flow. This is a fair assumption because the wind at the upper-level usually blows much faster than the system moves. A good example is anvil cirrus. A CB is moving toward 100° at 25 knots (fig. 2–30). The 300-mb winds are toward 60° at 30 knots. The resultant is 20° at 20 knots. This is the direction toward which the anvil cirrus is moving.

On enhanced IR imagery, the tightest gray shade gradient is on the upstream side. The gradient spreads out downstream as the cloud thins and shows increased warming (contamination). This is normally true for synoptic-scale systems but not always for mesoscale features like thunderstorm complexes.

On FIR and WV imagery, the lightest gray shades are usually on the upstream side and they gradually become darker as you go downstream.

We discuss other cloud types we use to empirically determine wind direction below.

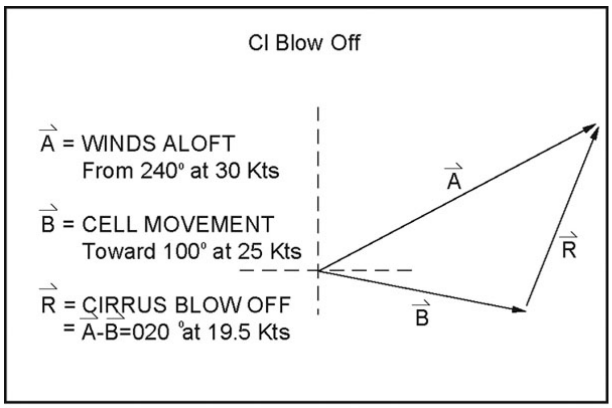

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Figure 2–30. Upper-level wind determination from anvil cirrus.

Cirrostratus/baroclinic zone cirrus

Cirrostratus forms on the equatorward side of the jet stream. Because of translation and divergence, winds are not always oriented in the same direction as the PFJ axis. Winds near the PFJ axis are parallel, or nearly parallel, to it. Further to the equatorward side of the PFJ, winds are at a slight angle to the right (fig. 2–31).

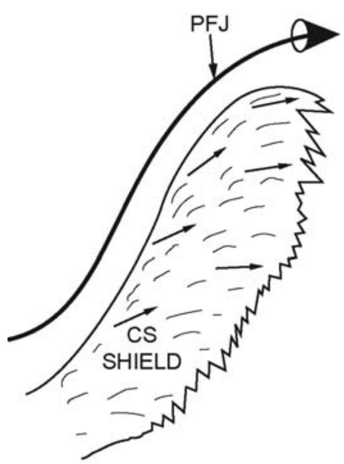

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Figure 2–31. Winds related to the PFJ.

Cirrus streaks

Cirrus streaks usually form parallel to, and on the equatorward side of, the jet stream flow and need at least 60 knots for formation. These are normally observed in the base of the trough and between the trough and the upstream ridge axis.

Contamination is a problem with VIS, FIR, and enhanced IR imagery. On WV imagery, there usually is a contrast between moist (light), on the equatorward side of the jet, and dry (dark), on the poleward side.

Lee-of-the-mountain cirrus

These clouds form on the leeside of the mountain and on the equatorward side of the jet stream axis. The jet stream may or may not be close to the cirrus clouds. The winds are parallel to the cloud strands with the upstream cloud edge typically conforming to the mountain ridge line (fig. 2–32).

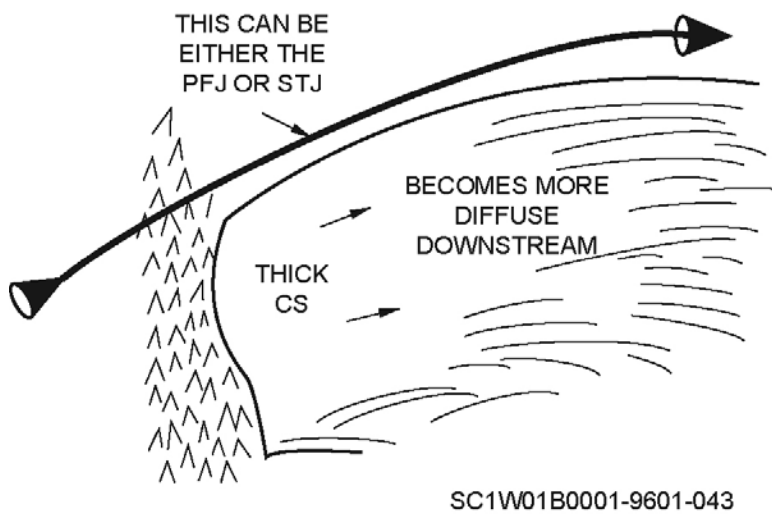

Figure 2–32. Lee-of-the-mountain cirrus.

Transverse bands/billow clouds/mountain-wave clouds

Remember these clouds have a washboard or banded appearance with the wind flow perpendicular or nearly perpendicular to the clouds. We’ll assume the winds are perpendicular to the clouds. To determine the level of the winds, determine the cloud-top temperature and then compare it to an appropriate sounding. You can also use observations from the area.

415. Synoptic feature identification and placement

The ability to identify systems on METSAT imagery depends on the type of weather and the amount of cloudiness associated with the system. Lows and troughs that produce significant cloudiness and weather are the easiest to identify. If a system does not produce a large cloud signature, METSAT imagery can still be a useful tool in identifying the feature. A careful analysis of the surrounding area may reveal conditions that do or do not support the feature in question, although it is not possible to “see” the feature itself on the METSAT imagery. An example of this is determining upper-level high centers located in the long-wave ridge.

Techniques for locating the jet stream

These techniques help you determine the jet stream axis and the speed maximum through empirically observed cloud features associated with the jet stream. The first three rules we discuss are empirically observed cloud features that have worked well in locating the jet stream on METSAT imagery.

Baroclinic zone cirrus (cirrus shields)

The jet causes a sharp poleward edge on the large cirrus shield (fig. 2–33). The jet axis position is about 1° latitude on the poleward side of the cloud edge. While the baroclinic zone cirrus is usually smooth in appearance, the middle clouds on the poleward side of the jet stream have a textured or lumpy appearance.

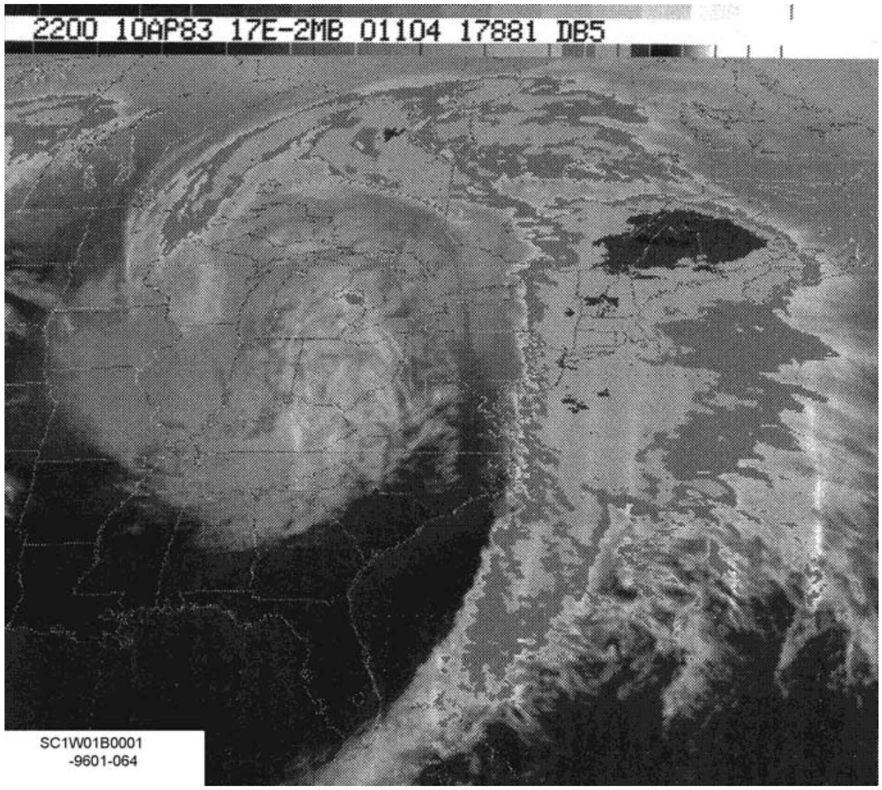

Figure 2–33. PFJ with cirrus.

High or middle clouds in absence of the cirrus shield

Where baroclinic zone cirrus is not present, but other high- or mid-level clouds are, the cloud bands are most advanced downstream from the jet axis and the cloud band intersection (fig. 2–34). Upstream cloud borders are usually well defined and form a U or V shape with the axis of maximum winds in or over the dry slot in the clouds.

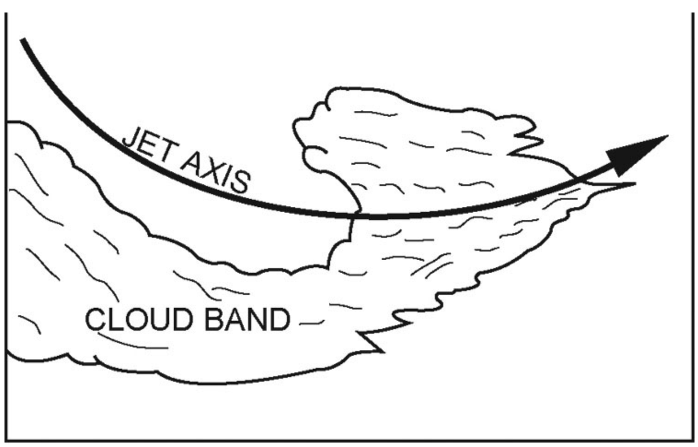

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Figure 2–34. PFJ with cloud differences

Low cloud boundaries

When no high clouds (tops at jet stream level) are present, the axis of the jet stream is normally 1° to 3° on the poleward side of the boundary between the open-cell CU and the closed-cell SC (fig. 2–35). This boundary is most commonly observed over oceans where abundant low-level moisture is present. Over land, we find SC on the equatorward side. Clear skies are prevalent beneath and on the poleward side of the PFJ. This cloud pattern typically defines the jet stream in the long-wave trough positions. Figure 2–36 illustrates a composite of the three rules listed above.

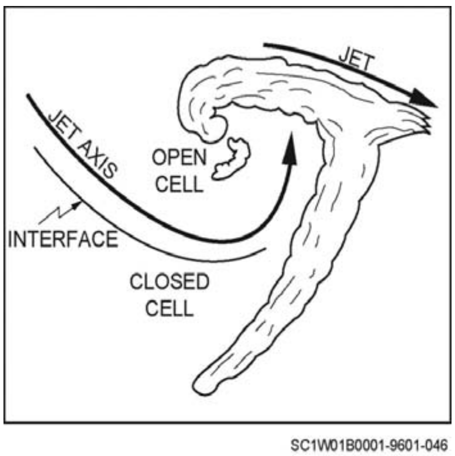

Figure 2–35. PFJ with low cloud.

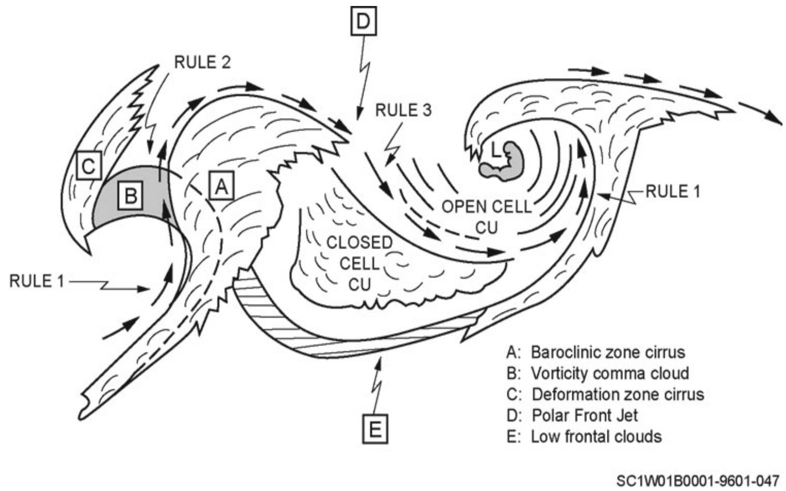

Figure 2–36. Composite of the jet stream location rules.

Other cloud phenomena

These phenomena can also help you locate the jet stream.

Cirrus streaks

Cirrus streaks form parallel to the flow, on the equatorward side of the jet axis, and at the leading edge of a jet maximum.

Transverse bands

The jet axis flows perpendicular to the cloud band orientation and is located on the poleward side of the cloud bands. When associated with the PFJ, it typically indicates the speed maximum. It also indicates the subtropical jet (STJ) axis and is most commonly seen with this jet.

Billow clouds

These cloud bands are oriented perpendicular to the jet stream flow and located on the equatorward side of the jet stream axis.

Lee-of-the-mountain cirrus

If the jet stream axis is located with this cloud feature, it's about 1° of latitude on the poleward side of the cirrus cloud.

Cloud shadows

Baroclinic zone cirrus casts cloud shadows onto low- and mid-level clouds. The jet axis is typically 1° latitude poleward of the cirrus cloud deck that is casting the shadow.

Areas where the jet stream is difficult to locate

There isn't enough mid- and upper-level moisture present to produce clouds, although the jet stream is strong and well defined. 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 are not continuous between two systems. Often air flowing through a ridge must slow to remain in gradient wind balance.

How the jet stream is seen on the imagery

On VIS, FIR and enhanced IR imagery look for the basic cloud and non-cloud signatures discussed previously. On WV imagery, look for areas of dark (dry) and light (moist) gray shade contrast parallel to the jet stream axis. With straight-line flow, the jet stream axis is generally placed in the center of the dark gray shade (dark band). A cyclonically curved jet stream axis is placed on the poleward side of the dark band. You'll see a lighter gray shade on the poleward side of the dark band (jet stream). Place an anticyclonically curved jet stream axis on the equatorward side of the dark band. A lighter gray shade is located on the equatorward side of the dark band (jet stream).

The WV imagery shows a jet stream is strengthening when the dark band becomes better defined. Well-defined means the dark band is becoming darker and wider. Wind speeds at 300 millibars (mb) and 500mb typically are increasing. This is usually an indicator of a speed maximum.

Not all areas of gray shade contrast are jet streams. They could be:

- Flow around circulation centers.
- Deformation zone locations.
- The result of dry-air advection.
- Areas of subsidence or downward vertical motion.

Use a combination of WV imagery and other METSAT imagery to locate the jet stream and determine the general wind flow. Use the same rules and techniques you learned earlier in combination with the WV imagery to place the jet stream more accurately. Follow continuity to determine if a feature is a jet stream or not. Two-hour intervals of animated (time looped) METSAT imagery help to distinguish the causes of the dark bands.

Jet stream pattern utilization

Remember, the PFJ outlines the long-wave pattern in the atmosphere. This helps us identify long-wave ridges and troughs. By identifying the jet stream, we can also determine possible cyclogenesis and anticyclogenesis areas in the atmosphere. Typically, baroclinic lows and highs develop/intensify near or below the PFJ.

Long waves

Determining long-wave patterns and positions is important because of their effect on the movement of major and minor short-wave troughs and ridges.

Ridges

Position the long-wave ridge axis through the point where the jet stream is farthest poleward. VIS and FIR imagery help locate the jet that we use to locate the ridge. WV imagery shows the broad anticyclonic turning of the jet stream axis as it flows around the crest of the ridge.

Troughs

Position the long-wave trough axis through the point where the jet stream is farthest equatorward. VIS and FIR imagery helps locate the jet that you use to locate the trough. WV imagery shows the broad cyclonic turning of the jet stream axis as it flows around the base of the trough.

You can use cirrus streaks to locate the long-wave trough. Look for the base of the long-wave trough in the curvature of the streaks. Cirrus streaks are prevalent with long-wave troughs, but occasionally you may see them with major short-wave troughs.

Major/minor short waves

Within the long-wave pattern, being able to locate and determine the movement and intensity of short waves directly affects your local weather. The rules you are about to learn have been tested through time and are very accurate and useful.

Ridges

Position the ridge axis in the area of maximum anticyclonic cloud curvature. On VIS and FIR imagery, the clouds are prevalent on the upstream side of the ridge axis. How far past the ridge axis the clouds extend depends on the amplitude of the ridge and the amount of moisture present.

Normally on WV imagery, you see a very moist area upstream of the ridge axis and a dry area downstream from the axis. This boundary also depends on the ridge amplitude (sharpness) and the amount of moisture present.

The amplitude of the ridge axis is very important. The more clouds that spill over the ridge axis, the lower is the amplitude of the ridge axis. Generally, the lower the amplitude ridge, the wider the cloud band will be. A sharp ridge axis has clouds ending at the ridge axis. The upstream cloud band tends to be very narrow.

Continuity can help in determining changes in the ridge amplitude between upper-air analysis periods. For example, a low amplitude ridge has clouds spilling over it and extending halfway to the inflection point. Twelve hours later, the clouds have dissipated on the downstream side of the ridge axis and are ending at the ridge axis. The clouds show the ridge has increased its amplitude during the twelve-hour period (fig. 2–37).

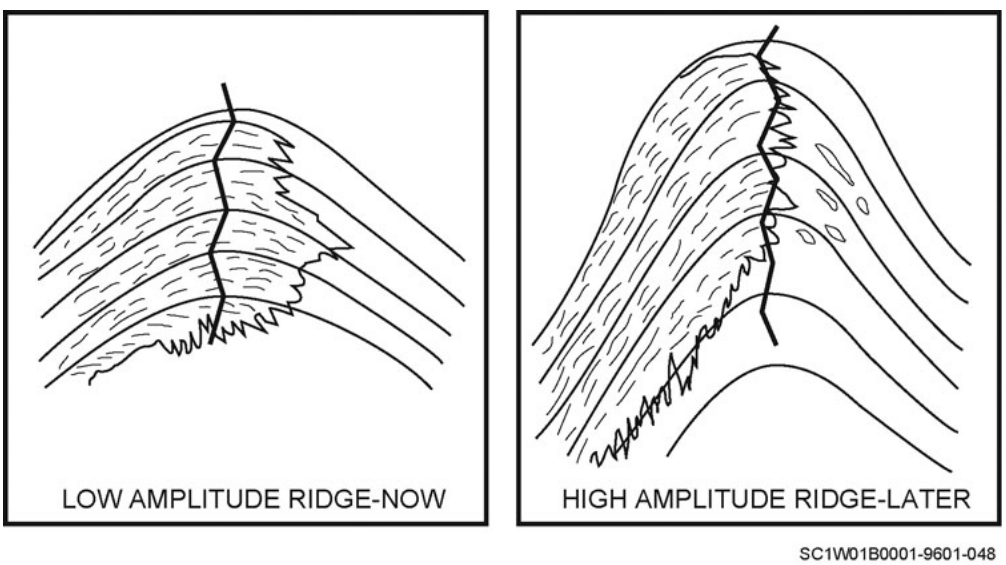

Figure 2–37. Ridge amplitude change.

Analysts can follow the continuity of the ridge axis to determine how systems are developing upstream. Figure 2–37 indicates the upstream trough or low is deepening. The opposite would be true if the trend were reversed.

Troughs

Position the trough in the area of maximum cyclonic cloud curvature. Typically, clouds of significant vertical development exist downstream from the trough axis. On VIS and FIR imagery, clouds are easily identifiable because of their strong vertical development. On WV imagery, the areas of moisture vary due to the intensity of the downward vertical motion behind the trough. You normally see moisture ahead of the trough axis and a dry area behind it.

Trough intersecting frontal cloud bands

Generally, when you see a 500-mb trough intersect a frontal cloud band, the trough is in a north-to-south orientation (fig. 2–38). You can also see troughs in a northwest-to-southeast or west-to-east orientation.

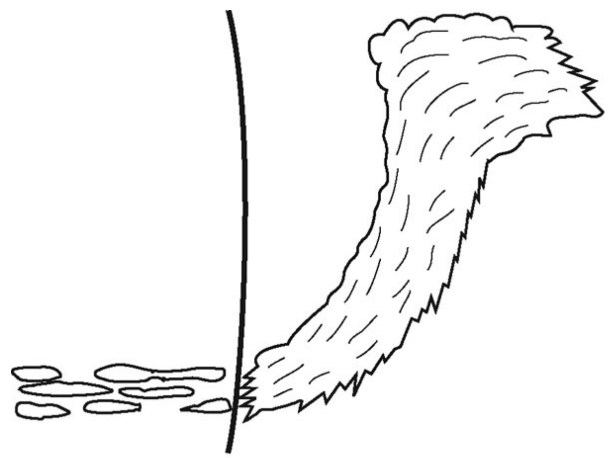

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Figure 2–38. Trough intersecting frontal.

Where the trough intersects a frontal cloud band, there is an abrupt change in cloud type and coverage. Downstream from the intersection, baroclinic zone clouds are present. Upstream from the point of intersection, high- and mid-level clouds are not present. Low frontal clouds lessen, become fragmented, and may even disappear due to downward vertical motion. Figures 2–22 and 2–23 show a 500-mb trough which intersects a frontal cloud band off the coast of Florida.

Occasionally, with a slow-moving, major short-wave trough, or a long-wave trough, minor short-wave troughs move through the larger scale pattern. You may see a bulge or slight "S" shape develop and move along the back side of the frontal cloud band (fig. 2–39), or you may see a separate cloud cluster or small comma cloud develop in the cold air behind the frontal cloud band. In both cases, a wave on the front (frontal wave) is associated with the wider frontal cloud band.

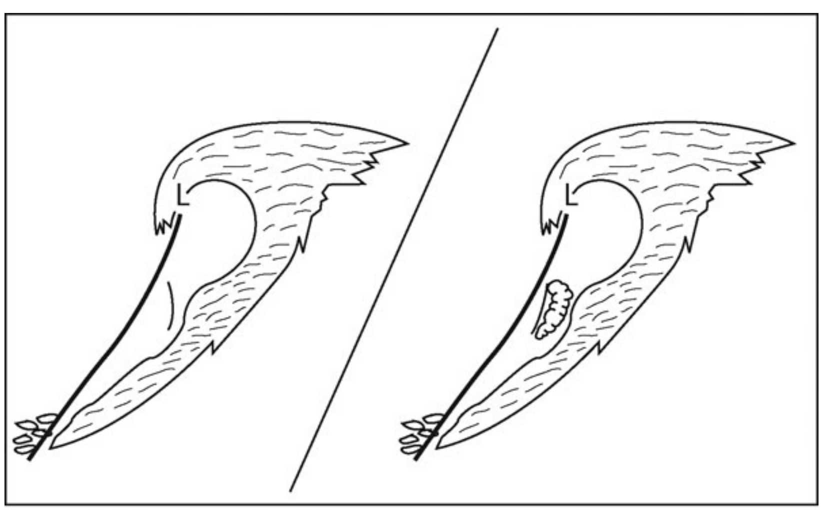

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Figure 2–39. Cloud signatures with troughs.

Trough NOT intersecting frontal cloud bands

When a northeast-to-southwest oriented trough is associated with a cloud band in the same orientation, the trough axis does not typically intersect the frontal cloud band. Where the tail end of the trough lies very close to the cloud band, it may cause a cloud bulge or an “S” shape along the backside of the frontal cloud band (fig. 2–40). The bulge or wider frontal cloud is an indicator of a frontal wave.

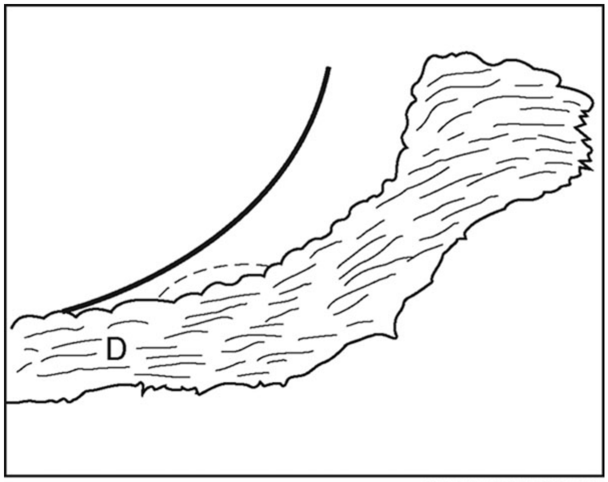

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Figure 2–40. Northeast-to-southwest aligned trough.

Enhanced cumulus

Enhanced CU forms in the cold air mass, in the base, or downstream from either a long-wave or major short-wave trough axis. Enhanced CU is easier to see over water than land due to moisture. A minor short-wave trough axis is located slightly upstream from the enhanced CU (fig. 2–41).

You can see a series of enhanced CU moving through either the long-wave trough pattern or a slow-moving major short-wave trough pattern (fig. 2–42). They may develop into comma clouds downstream from the trough axis.

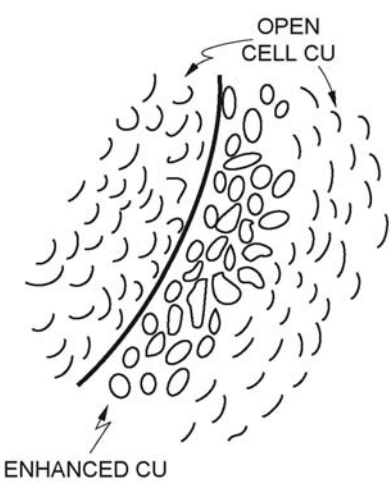

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Figure 2–41. Enhanced CU.

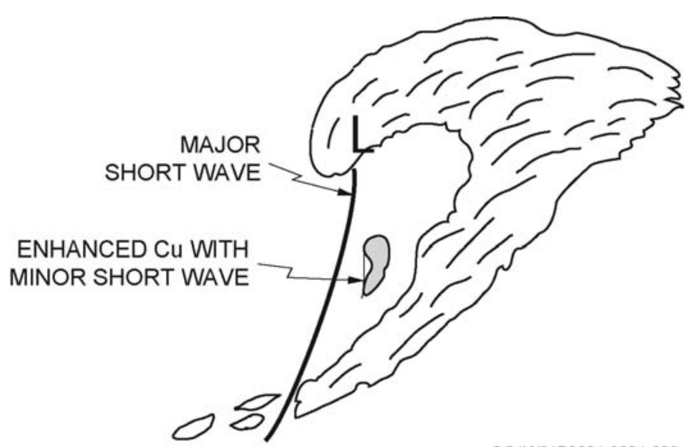

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Figure 2–42. Enhanced CU moving through trough pattern.

While the enhanced CU appears as a cloud cluster, you can associate a minor short-wave trough with it. When the enhanced CU begins to take on a comma-cloud shape, it indicates the minor short-wave trough is developing into a major short-wave trough. Figure 2–43 shows an enhanced CU cloud cluster at approximately 25–30°N latitude and 170°W longitude.

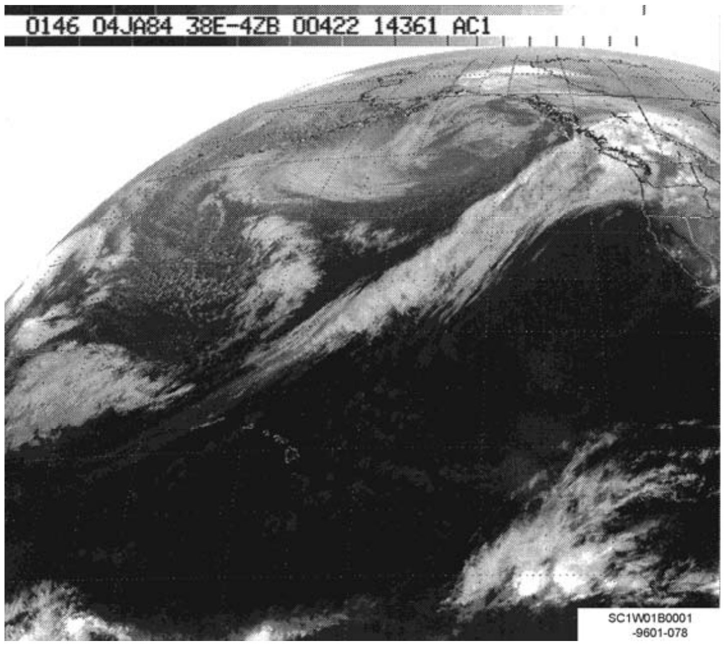

Figure 2–43. Enhanced CU.

Cloud cluster moving over the ridge

A minor short-wave trough moving over the long-wave ridge appears as a small, unorganized cloud cluster projecting from beneath the northern border of the cirrus clouds. As it moves into the base of the long-wave trough, it may take on a comma-cloud shape.

Since the atmosphere is characterized by short waves moving through the long-wave pattern, you can identify both types of waves on the imagery. If a short-wave trough is located near a long-wave trough position, determining the exact position of each is difficult. The same holds true for long-wave and short wave ridges.

Combination of upper lows and any of the previous systems

To place an upper trough, you can anchor the northern part of the trough to the upper low (fig. 2–44) and place the southern part of the trough with any of the methods we previously described. This method allows more accurate placement of the upper trough. This is usually associated with a major short-wave trough.

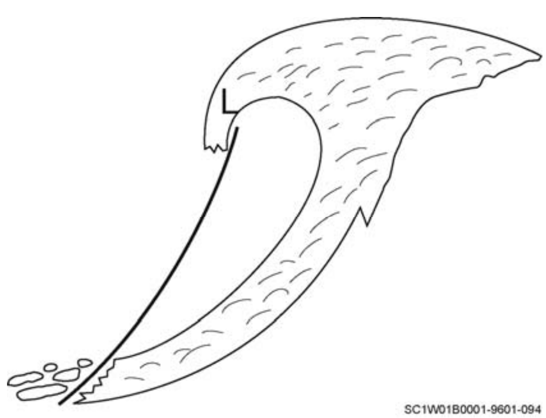

Figure 2–44. Trough positioning with low.

Upper-level deformation zones

Upper-level deformation zones are significant for the identification of upper-level lows. They reveal important information about the flow pattern aloft. Usually, deformation zones with mid-latitude cyclones develop when the upper low circulation closes off. They occur west to north of upper-level lows. This forms a col, or neutral point, where easterly or southerly flow opposes westerly flow. Figure 2–45 illustrates some deformation zones associated with comma clouds. Some regions of upper-level difluence are characterized by a spreading band of clouds we call the "fountain" (fig. 2–46).

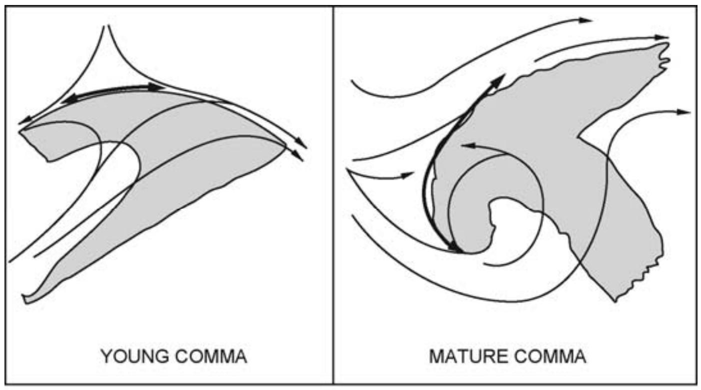

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Figure 2–45. Deformation zone with comma cloud.

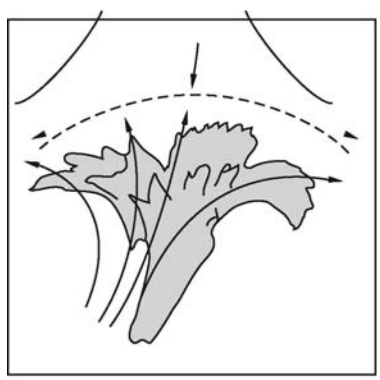

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Figure 2–46. Fountain deformation zone.

Regions of confluence are often associated with the merging of moist and dry-air streams that form the deformation zone. A smooth cloud border normally develops along the boundary between the two air streams as clouds form in the moist air and spread out along the border. The position of this border is useful for identifying the deformation zone.

WV imagery is useful in detecting upper deformation zones (fig. 2–47). The deformation zone location is marked by a sharp gray shade contrast between dark (dry) and light (moist) regions.

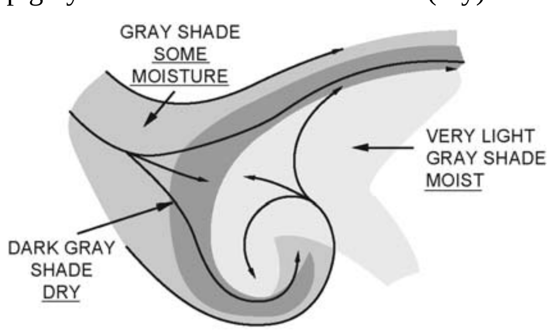

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Figure 2–47. WV schematic of upper-level deformation zone.

Upper lows

These are identified by the cyclonic swirl in the cloud pattern and are usually found with the upper-level deformation zone. Around the low is a large amount of vertical cloud development that indicates an unstable atmosphere. Extra tropical lows are lows that develop outside the Tropics. Lows associated with the comma-cloud structure are positioned slightly west of the center of the swirl of upper-level cloudiness within the deformation zone cirrus (fig. 2–48).

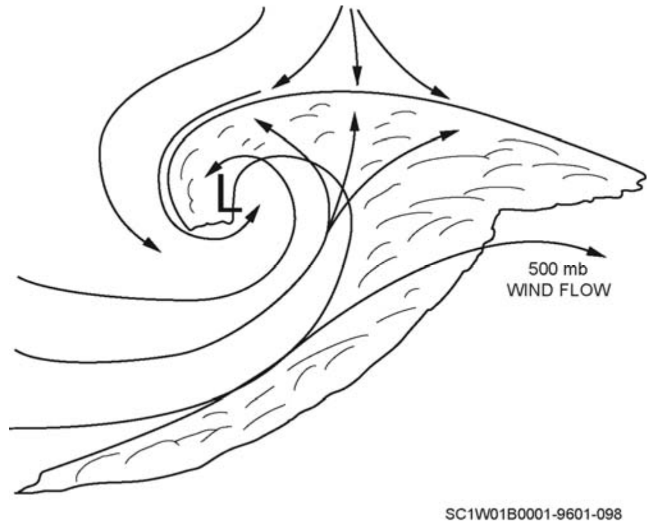

Figure 2–48. Low positioning.

Cut-off lows

Cut-off lows are small, deep pools of cold air located equatorward of the PFJ. Three types of clouds are normally associated with cut-off lows. Refer to figure 2–49 as you read the descriptions of each cloud type.

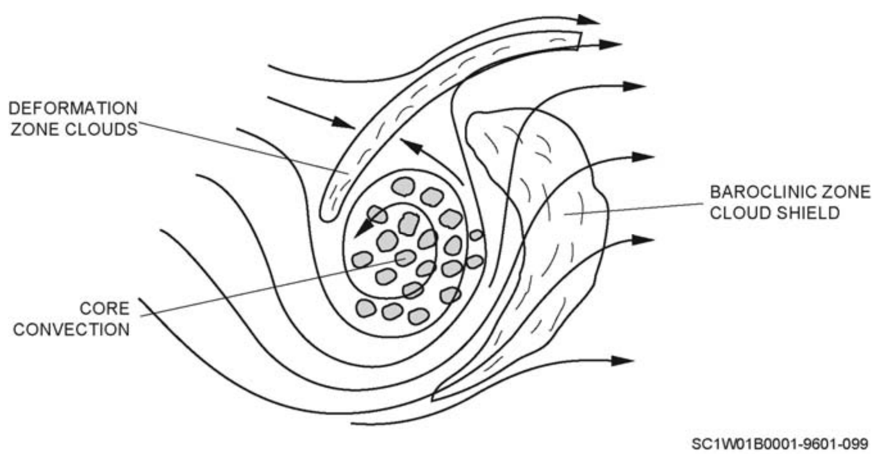

Figure 2–49. Cloud signatures with cut-off lows.

Baroclinic zone cirrus

Cut-off lows initially have the jet stream oriented with a strong south-north component east of the low center. Baroclinic zone cirrus forms on the equatorward side of the jet stream. This cloud band is similar to the upper-level cloud band you see with lows associated with fronts.

Deformation zone cirrus

This is a band of cirrus that develops due to the flow from the north opposing the southerly flow from the remnants of the upper-level trough. The cirrus is normally stretched in a northeast-to-southwest direction.

Core convection

Core convection is normally observed over water. Air over the ocean is most unstable where the upper-air temperatures are the coldest. With cut-off lows, the coldest air is at the center, so convection is most likely to form there.

WV imagery for both types typically shows a dark slot spiraling around the low. The dark slot indicates drier air and subsidence.

Upper highs

These are associated with anticyclonic cloud curvature. They're more difficult to position because cloudiness is scarce in the downward vertical motion east of the ridge axis.

Water vapor imagery is particularly useful for identifying closed upper-level highs. With the ridge, we learned the WV imagery shows a boundary between the moist and dry air. Where this is indicated depends on the ridge amplitude. As the closed high circulation develops, the inside boundary of moist versus dry air smoothes out, which indicates strong easterly flow. This is located in the southern-western-northern quadrants (fig. 2–50).

VIS, FIR, and enhanced IR imagery show this smoothness. However, it generally is seen on WV imagery first.

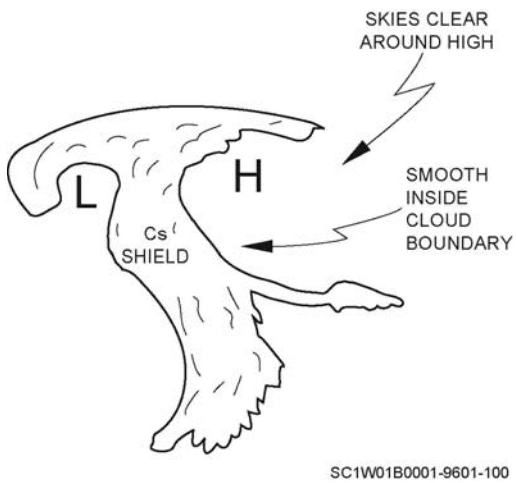

Figure 2–50. High positioning.

Vorticity maximums

Vorticity maximums are associated with a cloud pattern known as the vorticity comma cloud. The cloud pattern is located downstream from the vorticity maximum. The precipitation associated with the cloud pattern is convective in nature. Cyclonic wind flow is also associated with the vorticity cloud pattern. Figure 2–51 shows a vorticity cloud pattern. Figure 2–52 shows a vorticity maximum off the coast of Baja, Mexico.

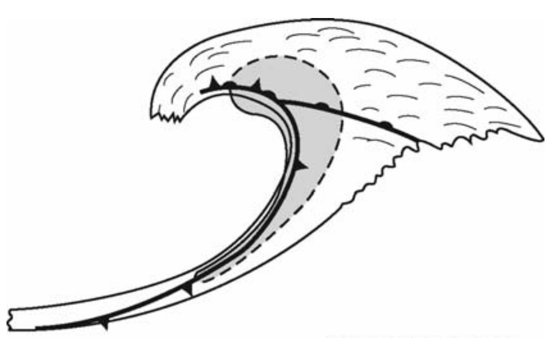

Figure 2–51. Vorticity comma cloud.

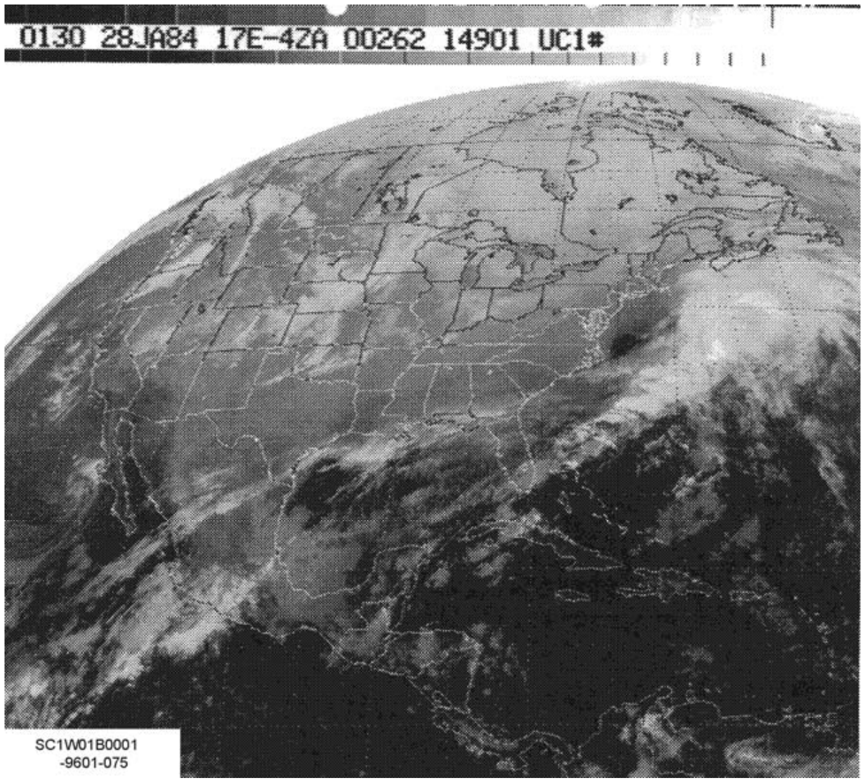

Figure 2–52. Vorticity maximum.

The vorticity cloud pattern varies in size, shape, and organization. Vorticity maximums are associated with cloud structures such as baroclinic leaves, enhanced CU, and the vorticity comma cloud associated with the synoptic-scale comma cloud. When the vorticity comma cloud is identified with a synoptic-scale comma cloud, it is also associated with the cold and occluded fronts and, to some extent, with the warm front.

The vorticity maximum is located approximately 1° of latitude in the clear air away from the inflection point of the “S shape” upstream cloud edge of the vorticity comma cloud (fig. 2–53).

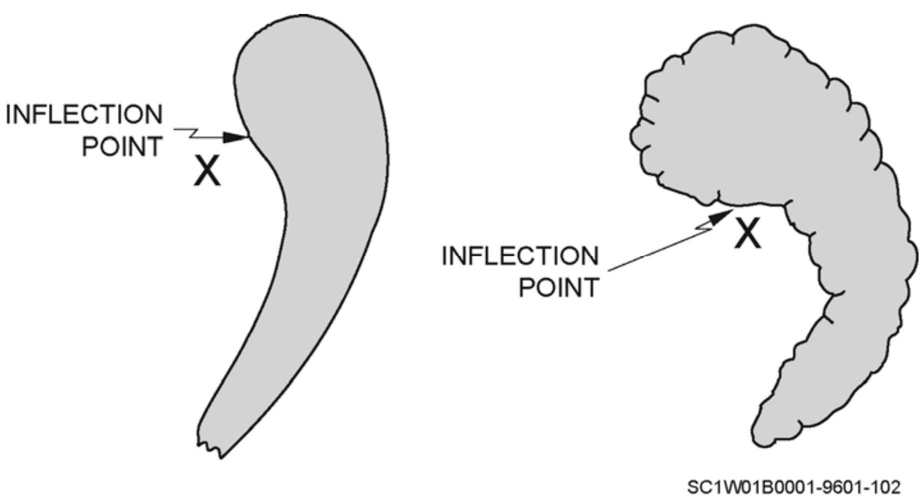

Figure 2–53. Vorticity maximum placement.

The vorticity comma cloud is often hidden beneath the baroclinic and deformation zone cirrus clouds. You must look at the synoptic-scale comma-cloud pattern to place the vorticity center. Place the vorticity center approximately 1° in the clear air to the right of the cusp in the cirrus clouds (fig. 2–54). The cusp is the equatorward point on the downstream side (inside) of the deformation zone cirrus.

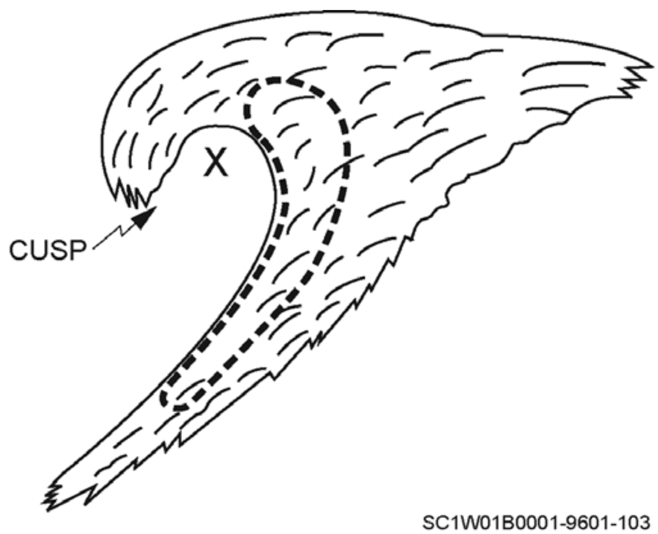

Figure 2–54. Vorticity maximum placement with the cusp.

A rapidly translating comma-cloud pattern has an elongated appearance. The vorticity maximum position remains the same. However, it is located further back in the clear air, as shown in figure 2–55.

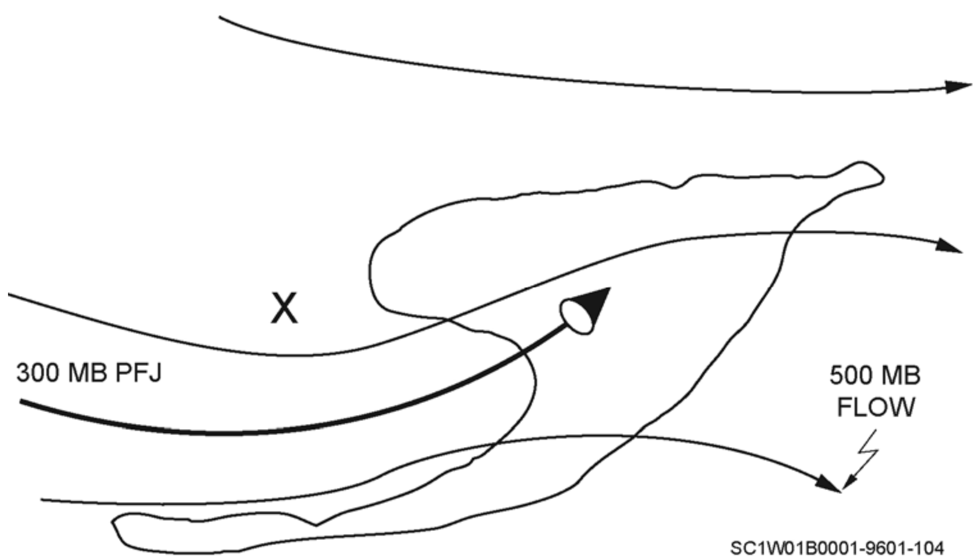

Figure 2–55. Vorticity maximum placement with a rapidly translating comma-cloud system.

Over land, beware of the apparent cloud rotation, which indicates the vorticity maximum center. The cloud pattern can be very misleading when you try to place the vorticity maximum. The vorticity center is usually located further back into the clear air than the apparent rotation center. Since there is less moisture available, you can't usually determine the true vorticity center with 100 percent accuracy. It's much easier to pick out the vorticity maximum over water due to the abundance of convective clouds over the moisture source.

Baroclinic leaf cloud patterns

These are vorticity clouds in the westerly wind flow. They're usually best defined on the downstream side of a high amplitude trough pattern. A baroclinic leaf is caused by mid-level deformation ahead of the jet maximum, upstream from the leaf. The jet stream cuts across the western end or tail of the baroclinic leaf (fig. 2–56). This may cause a "V" notch signature in the tail of the cloud. If the "V" notch is there, it may be well defined or very ragged in appearance. The baroclinic leaf is typically located in the left-front quadrant of the speed maximum where divergence is strong. It can also be located in the right-rear quadrant of the speed maximum.

Baroclinic leaves generally have a shallow "S" shape on their upstream cloud border. The upstream end of the cloud pattern has cyclonic curvature while the downstream end has anticyclonic curvature. Usually, the vorticity maximum is located approximately 1° into the clear air from the inflection point on the upstream side. The leaf does not move in the direction it's oriented. It moves with the upper-level winds. Figure 2–57 shows an example of baroclinic leaf movement.

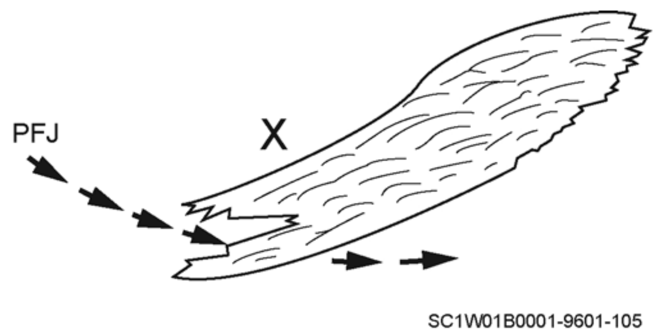

Figure 2–56. Baroclinic leaf cloud signature.

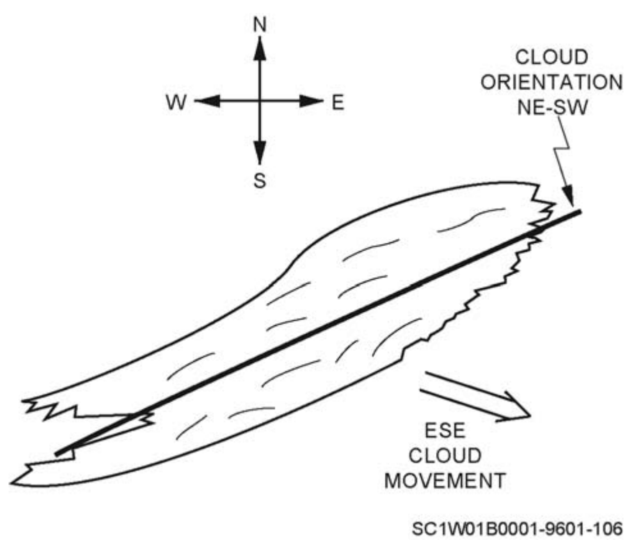

Figure 2–57. Baroclinic leaf movement.

On VIS imagery, cirrostratus cloud tops are predominant in the downstream end while we see mid-level cloud tops on the upstream end. Depending on the time of day, cloud shadows can help you define the cloud types and the changes in coverage.

On FIR, enhanced infrared (EIR), and WV imagery, the colder and smoother cloud tops occur in the wider, forward portion of the leaf. EIR imagery shows gray shade contouring similar to CS clouds. The cloud mass becomes fragmented and warmer toward the narrow tail, indicating mid-level and possible low-level clouds.

416. Mesoscale convective complex and severe thunderstorms

Mesoscale convective complex are organized, persistent areas of deep convection noted in METSAT imagery during the warm season, especially over the US. These systems are mesoscale convective complexes (MCC). The MCC usually begins as a group of cells forming within a moist unstable zone in the afternoon hours. The cells continue to grow and merge. Through this process, large amounts of moisture are transported into the upper atmosphere. As the moisture spreads and the cells continue to merge and grow, the area begins to appear like one large cell or area on METSAT imagery. These systems continue to grow throughout the night, producing numerous thunderstorms and areas of heavy precipitation. The MCC may contain cells severe enough to produce phenomena associated with severe thunderstorms, but this type of weather diminishes once the nocturnal MCC develops. MCC systems usually have an egg-like appearance with a strong thermal gradient evident in the IR on the right-rear edge with respect to movement. It is in the area of this thermal gradient that most severe weather associated with these systems occurs.

In figure 2–58, an area of afternoon thunderstorms has developed in northeastern New Mexico and southeastern Colorado. An upper-level ridge is located from Louisiana to the Great Lakes. The thunderstorm activity is located in the diffluent flow on the upstream side of the ridge. This is the region where most MCC development occurs. By 0300Z (fig. 2–59), the area of thunderstorms has developed into an MCC and moved eastward. The MCC continues to be located in the diffluent zone of the upper-level ridge. If any severe weather were associated with this MCC, it would be located near the greatest thermal gradient in northern Texas.

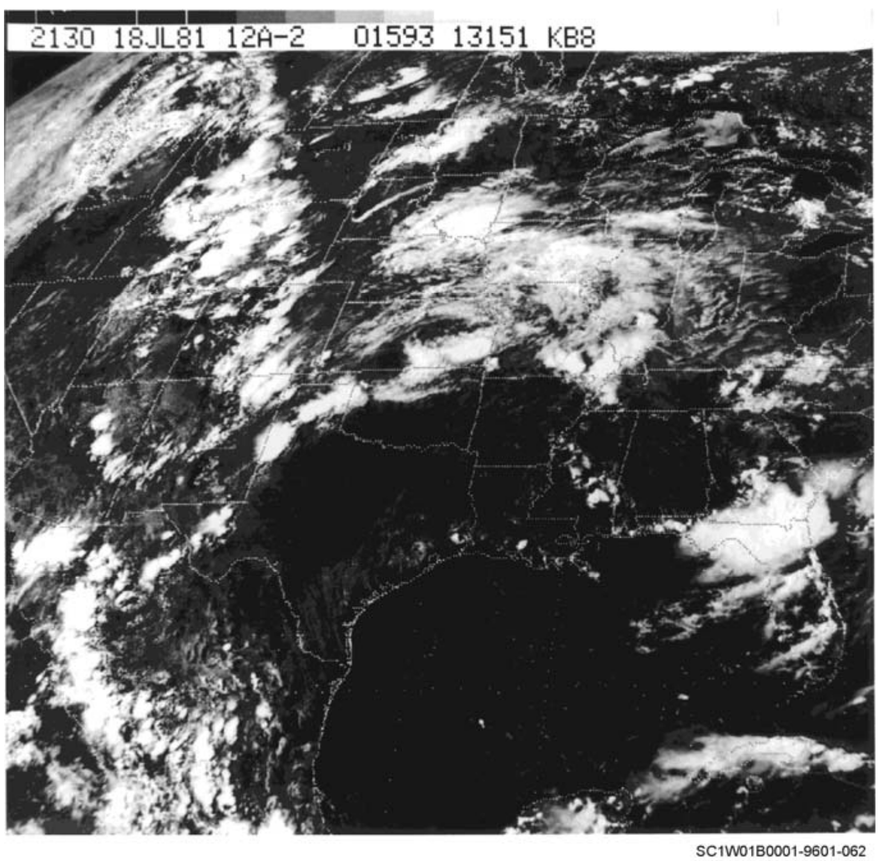

Figure 2–58. Thunderstorms. GOES E visible image, 18 Jul 81, 2130Z.

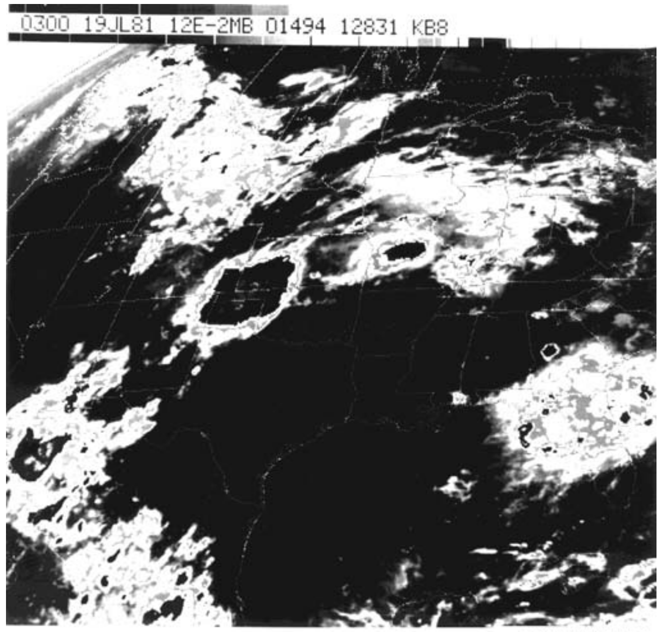

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Figure 2–59. Mesoscale convective complex. GOES E visible image, 19 Jul 81, 0300Z.

A trigger that maintains the MCC is the convergence of the outflow boundaries associated with the individual cells. These outflow boundaries (arc clouds) appear as a curved line of cumulus clouds. They act as miniature cold fronts. Often, like the MCC, these cloud lines merge to form one large arc cloud that extends over hundreds of miles. When these arc clouds converge, they tend to initiate the development of new thunderstorms that are stronger than the arc cloud’s parent storms. This is due to the combination of the energy fields of the two parent storms into one.

In figure 2–60, numerous outflow boundaries are scattered throughout east Texas, Arkansas, Louisiana, and Oklahoma. After the parent storm dissipates, the residual outflow boundary appears as a clear area encircled by cumulus. Often thunderstorms develop along the edges of these outflow boundaries, as seen in Oklahoma.

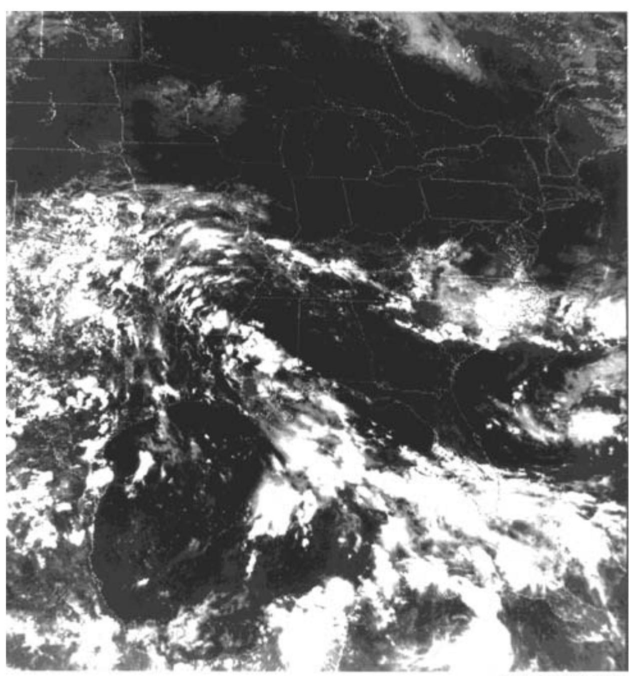
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Figure 2–60. Outflow boundaries. GOES visible image, 01 Sep 91, 2028Z.

417. Tropical cyclone analysis

We use the Dvorak method of tropical cyclone analysis to determine tropical cyclone intensity from METSAT imagery. The analysis techniques of the past used cloud feature measurements and rules based on a model of tropical cyclone development to arrive at the current and future intensity of a tropical cyclone. The Dvorak method describes tropical cyclone development in terms of day-by-day changes in the cloud pattern of the storm and its environment.

An important observation made during the early years of tropical cyclone analysis using satellite data was of the cloud patterns evolving through recognizable stages as the intensity changed. Generally, the patterns showed the dense (cold) clouds of the disturbance formed around the storm center in the shape of a curved band in the early stages of development. The band was observed to curve halfway around the center in the weak tropical storm stage and completely around the center to form an “eye” at the weak hurricane stage. Further intensification was indicated by increasing dense (cold) clouds around the eye or by the eye becoming better defined (warmer). However, the difficulty inherent in following this pattern of evolution lies in the variance of the form and clarity of the pattern with time. Periods of cloud pattern distortion, dissipation, or development of an obscuring central overcast makes it difficult to follow the evolution of the curved bands.

Loops of the METSAT images show the storm development does not evolve continuously from stage to stage but appears to form in surges. During the surges, the storm center generally appears well defined. Following surges, the cloud features become poorly defined. Some reasons for this variability are short-period convective scale activity, diurnal influences, and adjacent circulation impinging on the storm. To cover all the possible changes occurring during storm development, the Dvorak method uses many rules to govern intensity determination. These rules are too numerous to detail and remain within the scope of this text, but a description of the different intensity ratings follows.

The first and most important rule of tropical storm analysis states the pattern formed by the clouds of a tropical cyclone is related to the cyclone’s intensity rather than to the amount of clouds in the pattern. The cyclone’s intensity at any given time is related to the distance the curved band is wrapped (coiled) around the storm center. Figure 2–61 is an example of the model we use to determine the T (tropical) number of the tropical cyclone. We use the T number to describe the rate of development or dissipation of a tropical cyclone. The straight line of the graph shows the typical rate of storm development. When the curved band coils around the center at the day-by-day rate, as shown in figure 2–61, the storm is developing at a typical rate. When the curved band coils faster or slower, rapid or slow growth is indicated.

We express the rate of storm development as one “T” number per day. The T number is defined by the cloud features of a cyclone related to its intensity. The relationship between the T numbers, wind speed, and central pressure is shown on the left side of the graph. This is a very simplified explanation of T number determination. As we stated earlier, there are many variables.

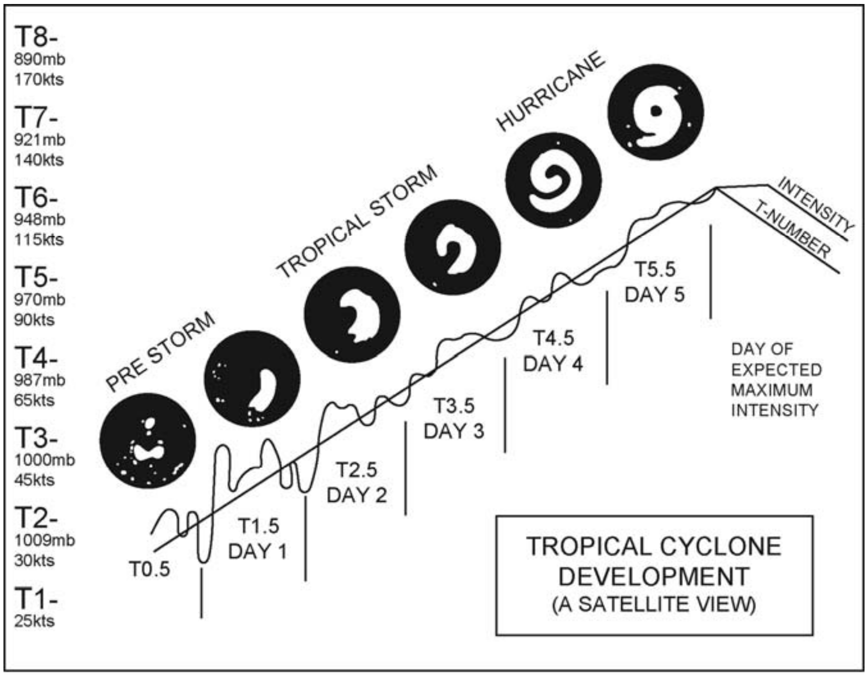

Figure 2–61. T number model.

Another indicator of tropical cyclone development is the current intensity (CI) number. In operational practice, it is the CI number and not the T number that describes the true intensity of the storm. The CI number is essentially the same as the T number. The two numbers are not only expressed in the same manner (T number 1.5 and CI number 1.5 are the same); they are equal as the tropical cyclone develops. During the dissipation stage, however, the T and CI numbers are different, though the difference is generally small. The CI number tends to remain higher than the T number as the storm dissipates. This is because the clouds associated with the storm dissipate faster than the central pressure rises or the wind speeds decrease.

The table below shows the relationship between the CI number and the storm's wind speed and central pressure for the Atlantic and the NW Pacific.

CI Number	MWS (Knots)	MSLP (Atlantic)	MSLP (NW Pacific)
1	25		
1.5	25		
2	30	1009 mb	1000 mb
2.5	35	1005 mb	997 mb
3	45	1000 mb	991 mb
3.5	55	994 mb	984 mb
4	65	987 mb	976 mb
4.5	77	979 mb	966 mb
5	90	970 mb	954 mb
5.5	102	960 mb	941 mb
6	115	948 mb	927 mb
6.5	127	935 mb	914 mb
7	140	921 mb	898 mb
7.5	155	906 mb	879 mb
8	170	890 mb	858 mb

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

411. Composition of the wind field

1. Match the wind field composition terms in column B with their descriptions in column A. Items in column B may be used once.

Column A	*Column B*
____ (1) Shearing or stretching of the wind field.	a. Rotation.
____ (2) Movement of an air parcel in a straight line.	b. Divergence.
____ (3) Contraction of the wind field toward a central point.	c. Translation.
____ (4) Circular wind pattern turning around a specific point.	d. Convergence.
____ (5) Spreading of the wind field away from a central point.	e. Deformation.
____ (6) The center of the deformation zone where the winds are calm.	f. Neutral point.
____ (7) The horizontal axis where air parcels are moving toward the col.	g. Axis of dilatation.
____ (8) The horizontal axis where air parcels are moving away from the col.	h. Axis of contraction.

2. What primarily compose surface winds around a low-pressure area?

412. Upper tropospheric interpretation

1. List the steps involved in using METSAT imagery for upper tropospheric interpretation.

2. What is used to draw in moisture patterns when analyzing upper-air products?

413. Cloud pattern recognition

1. What are the cloud features that make up a synoptic-scale comma cloud?

2. Which comma-cloud feature is associated with the thickness ribbon on the thickness product?

3. What is another name for the surge region?

414. Upper-level wind flow determination

1. What are the two techniques we use to determine the upper-level wind flow?

2. Which clouds form parallel to, and on the equatorward side of the jet stream flow and needs at least 60 knots for formation?

415. Synoptic feature identification and placement

1. Where is the jet stream axis located in relation to baroclinic zone cirrus?

2. When no high clouds are present at the jet stream level, where would the axis be located?

3. Where would the jet axis be located with lee-of-the-mountain cirrus?

4. On WV imagery, what would you look for when you try to locate the jet stream?

5. When a 500-mb short-wave trough intersects a frontal cloud band, what happens to the cloud types and coverages?

6. What METSAT imagery is the most useful in detecting upper-level deformation zones and why?

7. With what cloud structures are vorticity maximums associated?

416. Mesoscale convective complex and severe thunderstorms

1. What type of appearance do MCC systems usually have?

2. What trigger maintains the MCC?

417. Tropical cyclone analysis

1. What is the first and most important rule of tropical storm analysis?

2. What are the different intensity ratings that the Dvorak method uses?

2–3. Low-Level Flow and Features

In this section, you learn how to determine low-level wind flow and synoptic features. The methods and ideas we used in the previous sections continue to hold true in this section.

418. Lower tropospheric interpretation

Follow the same steps for lower tropospheric interpretation as you did with upper tropospheric interpretation. First, there is cloud pattern recognition, then you determine wind flow from specific cloud and non-cloud phenomena, and finally, you analyze for specific synoptic systems.

When you interpret the lower troposphere, you can also use the terrain's effects on clouds to determine low-level wind flow and identify synoptic systems. Mountains, islands, and lakes change the cloud patterns, providing many valuable clues for your analysis.

419. Cloud pattern recognition

The same reason you recognize cloud patterns for upper-level features and use them in analysis applies to cloud pattern recognition for low-level features.

Fronts

Cold, warm, occluded, and stationary fronts are the surface features associated with the comma cloud structure. Cloudiness ranges from an organized area of thick, multilayered clouds at the comma head to the central portion of the comma cloud structure to fragmented, low-level clouds at the tail end of the comma tail. Cyclonic wind flow is associated with the cold, warm, and occluded fronts. The wind flow is light and variable with stationary fronts.

Lows

Look at the cyclonic swirl of low-level clouds within the mature comma cloud to place an extra tropical low. Initially, with extra tropical lows, the surface low cannot be positioned because it's embedded in multilayered cloudiness (baroclinic zone clouds).

Highs/ridges

Due to the general stable atmosphere associated with highs and ridges, you normally see stratiform cloudiness around the high. Occasionally, you see cumulus clouds to the west and north of the high center. The clouds surround the high center, which is typically clear. The combination of these clouds and how they're affected by the terrain (blocking, cloud shape changes, etc.) helps you determine the wind flow. This information allows you to position the high center and ridge axis.

Low-level deformation zones

These are the easiest to see over the water. They are commonly found at the tail end of the comma cloud. Open and closed-cellular clouds are the best indicators of a low-level deformation zone behind the cold front. Figure 2–62 shows the wind flow around a low-level deformation zone.

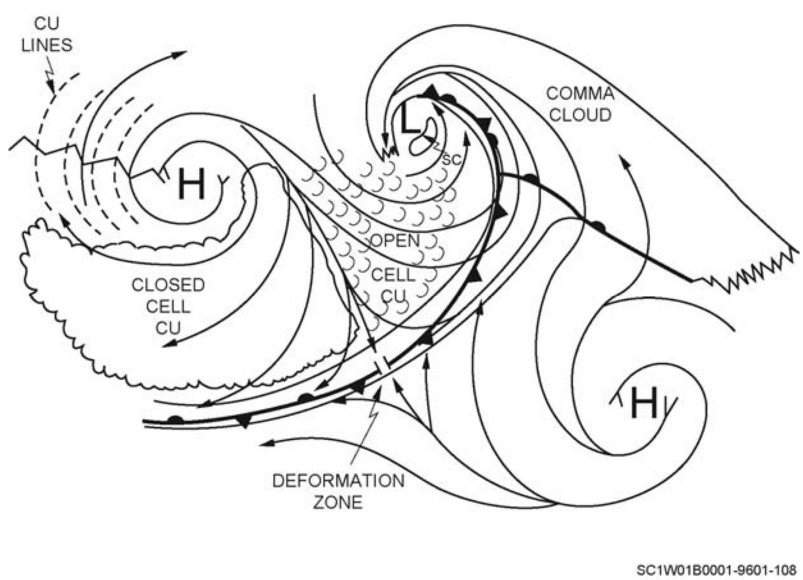

Figure 2–62. Low-level wind flow.

420. Low-level wind flow determination

The atlas is an essential tool for evaluating low-level wind flow. Knowing the terrain in a region helps tremendously when you analyze the wind flow in the lower troposphere. For example, clouds can be blocked by hilly or mountainous terrain. When you analyze METSAT imagery, open your atlas to the area in question.

When we determine lower tropospheric wind flow, we interpret specific cloud and non-cloud phenomena and the empirical wind observations indicated by these features. First, look at the cloud organization and alignment within the general synoptic pattern. Second, determine the interaction of the clouds with the changing terrain. Keep in mind the flow being analyzed is at the cloud base level and isn't necessarily the same as the surface wind. Thus, you must consider the strength of cold-air and warm-air advection, when applicable.

Empirical wind observations indicated by cloud organization and alignment

Since METSAT data has been used, we have learned clouds around the world provide us useful wind direction and speed information. In this lesson, you'll learn how to use these empirical techniques to make wind flow determinations.

Open-cell cumulus

Straight-line or cyclonic flow is associated with these clouds. Straight-line flow is along the border of the open-cell CU and closed-cell SC. Cyclonic flow is seen in the rest of the open-cell CU field.

You can determine wind speeds using the following criteria:

- Doughnut shape with a hole: <10 knots.
- Elongated doughnut shape: 11–20 knots.
- Arc shape: 21–30 knots.
- Solid, elongated cloud: >30 knots.

Figure 2–63 shows the different shapes that open-cell CU may have.

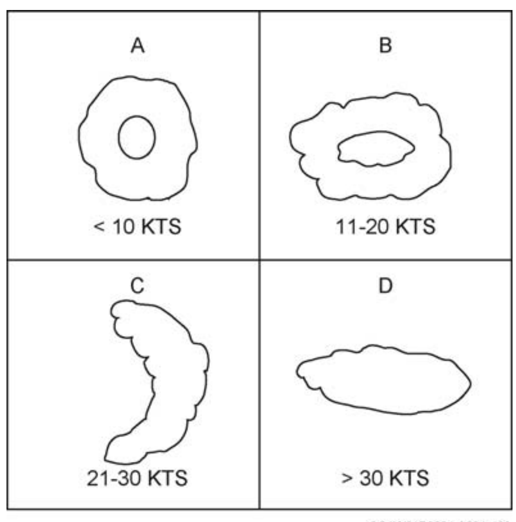

Figure 2–63. Open-cell CU shapes.

Closed-cell SC

The wind flow is anticyclonic with this cloud pattern. You cannot determine the general wind direction until you define all the other synoptic features around the closed-cell SC. Generally; the wind speeds are less than 20 knots.

Stratocumulus lines

SC lines are seen off the eastern and southern coastlines of continents and large lakes. The wind flow is parallel or nearly parallel to the cloud lines. The winds can be cyclonic, anticyclonic, or straight-line.

You can also determine the wind speeds from SC lines. The smaller the cloud elements, the stronger the wind will be. As the winds decrease, the cloud elements get larger. If a separation is visible between the SC lines, the wind speeds are greater than 20 knots. If no separation is visible, then the winds are less than 20 knots.

CU lines/streets

The wind flow is parallel or nearly parallel with CU lines/streets. These are mainly seen in the tropical and subtropical regions.

Smoke/ash/dust

These can be seen at different levels in the atmosphere. You'll need observations from the area to determine the height of the phenomena. To determine the wind direction, find the sharp cloud boundary; this is your upstream side. Downstream, the phenomena become more diffuse.

NOTE: Behind a strong cold front, blowing dust can spread out cyclonically and anticyclonically in the low-level deformation zone. There is a sharp definition on the upstream side of the dust cloud. Here, the upstream boundary of the dust cloud is not a good indicator of the wind direction.

Ship trails

You'll see these under very stable, high-pressure conditions, which causes the flow to be light and anticyclonic. Continuity of the ship trails' movement allows you to determine the general wind direction.

Empirical wind observations associated with terrain features

The interaction of clouds or lack of clouds with terrain can give you information on the wind direction and speed.

Upslope/orographic lift

The wind flow forces moisture up higher terrain. The moisture condenses and, depending on the stability of the air mass, forms specific cloud types. You can determine general wind flow using this feature with other information.

Unstable

A front moving through the Rockies may be associated with convective cloudiness. This is due to air being forced up the mountains and the instability associated with the front.

Stable

A high-pressure system over the central and southern US bring moisture in the form of fog/stratus and SC against the eastern slopes of the Rockies and the western slopes of the Appalachians (fig. 2–64).

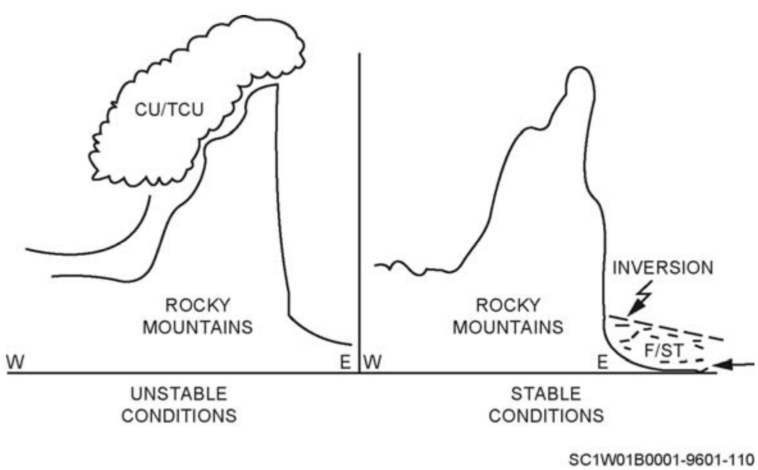

Figure 2–64. Orographic lift/upslope.

Leeside clearing

Leeside clearing is very common along the eastern slopes of the Rocky and Appalachian Mountains. It indicates winds are crossing the mountain ridgeline at an angle greater than 45°. On the leeside of the mountains, the winds are cyclonic.

Lake effect

The effect the moisture from lakes has on cloud patterns is significant. Wind flow is parallel to the axis of the patterns that we will be discussing. Keep in mind the strength of the air masses moving across the lake and the season in which it’s happening.

Summer

Cumulus clouds developing upwind over warmer land dissipate as they move over the relatively cooler lake. This forms a cloud-free area downstream over land for a distance before more clouds begin to develop with surface heating.

Winter

Colder, drier air moving over a relatively warmer, mostly unfrozen lake forms stratocumulus (SC) lines over the lake and downstream over the land. There is a cloud-free region on the upstream side of the lake.

Ice packs on large lakes and seas

Regions of ice are pushed away from the upstream shore by low-level winds, which persist over the area for long periods. A narrow black line showing the location of open water or newly formed ice results as the old ice pack is pushed away from the shoreline. Ice is then packed against the downstream shore. It’s more useful to look at the downstream shore of a lake or sea to determine low-level winds when the ice is newly formed. The reason is the ice is blown into the shore by the prevailing winds.

Bow waves/plume clouds/Karman vortices

These phenomena are caused by wind flow interacting with an island or peninsula in the ocean. By locating the island and phenomena, then looking downstream, you can determine the general low-level synoptic wind flow.

421. Synoptic feature identification and placement

Use the information from the previous techniques to help analyze for pressure systems and low-level deformation zones. Also, remember to follow continuity to help you track the systems.

Fronts

Fronts are normally located within the comma cloud structure or an organized multilayered cloud band. Usually with METSAT imagery, you can only place the general position of the front so the techniques you’ll learn are a general guide and not a foolproof positioning technique. To get an accurate frontal position, use conventional synoptic data. Fronts are usually easier to identify over water than land because more moisture is available for cloud formation along the frontal boundary.

Cold fronts

Typically, a cold front is located under the multilayered, baroclinic zone cirrus of the comma cloud structure. If you do not have synoptic reports, the following technique will help you maintain continuity of a cold front until conventional reports become available. Place the cold front near the back edge of the comma head. Draw the front toward the comma tail, gradually transitioning from near the back edge of the comma head to the leading edge on the end of the comma tail (fig. 2–65). Along the tail end and over water, there is usually a rope cloud that shows the exact frontal position. The rope cloud is just a line of low-level convergence with little weather associated with it.

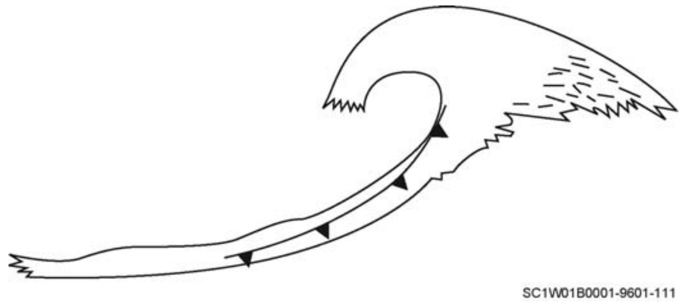

Figure 2–65. Cold front placement.

Along a cold front, you see stratiform clouds with convective clouds embedded. Ahead of the front, there is usually a mix of scattered stratocumulus and cumuliform clouds. Behind the cold front over water, you see an open- and closed-cellular cloud pattern. Over land, it normally is clear or you have scattered low clouds.

Warm fronts

Warm fronts are more difficult to position because the cloudiness ranges from scattered clouds to multilayered clouds (baroclinic zone cirrus cloud shield). The amount and type of cloudiness depends on the amount of available moisture and the stability of the warm air. The PFJ turns anticyclonically on the cold side of the warm front.

The surface front is typically located within the notch or wedge on the warm side of the baroclinic zone cloud shield, as shown in figure 2–66. Sometimes, there may be convection on the warm airside of the warm front. This appears a little more fragmented with thicker baroclinic zone cloudiness on the cold airside of the warm front.

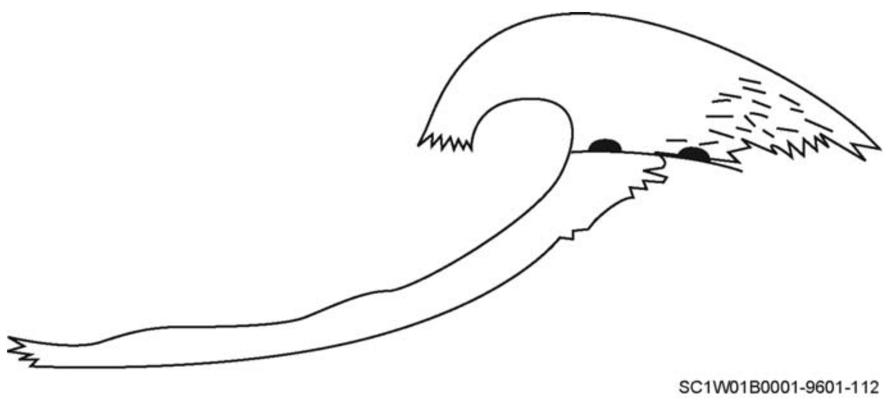

Figure 2–66. Warm front placement.

Occluded fronts

Position the occluded front along the back edge of the comma cloud head (fig. 2–67). Draw the front back to the northern half of the low, but not into a low with well-developed comma clouds.

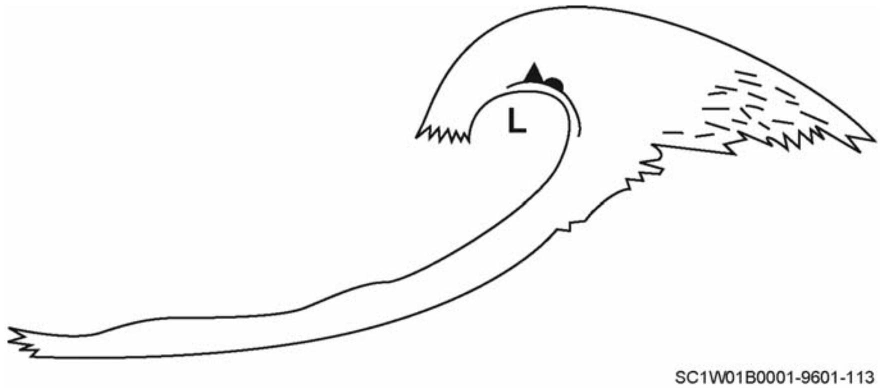

Figure 2–67. Occluded front placement.

You can locate the triple point two different ways. If the PFJ cuts eastward across the comma cloud, there is a sharp cloud boundary between the baroclinic zone cirrus on the equatorward side of the PFJ and the AS/AC (vorticity-induced cloud) below and on the poleward side of the PFJ. The triple point has been empirically located on the equatorward side of this boundary near the back of the upstream cloud edge of the baroclinic zone cirrus. On WV imagery, there is a slight gray shade difference between the two cloud layers.

If the PFJ does not cut across the comma cloud, you can extrapolate the warm and cold fronts until they meet. Do this only if you do not have any, or very little, conventional data with which to place the triple point. Figure 2–68 shows an example of how to place the triple point.

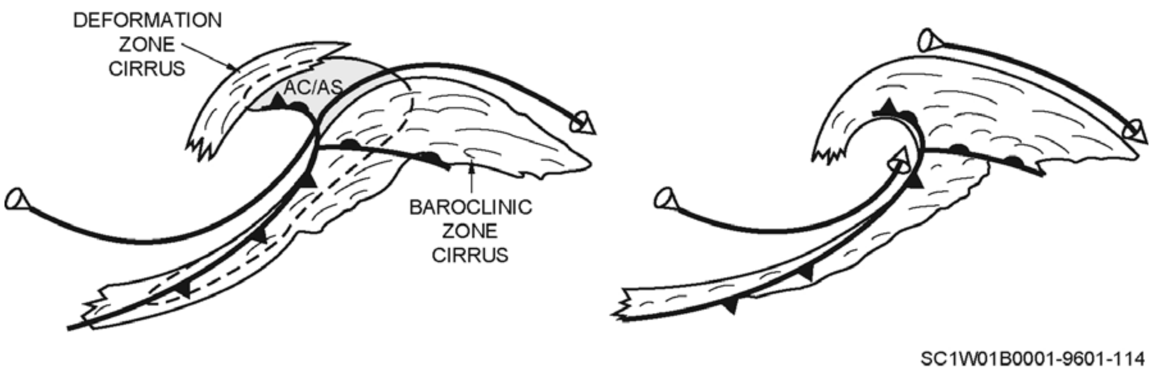

Figure 2–68. Triple point placement.

Stationary fronts

The cloudiness with stationary fronts ranges from thick, multilayered clouds to fragmented, scattered clouds. Place the front along the leading edge of the cloud band. Over water, you’ll usually have a rope cloud, which is a good indicator of the front. Clouds are normally cumuliform on the warm side of the front, while more stratiform type cloudiness is on the cold air side (fig. 2–69). The type of cloudiness depends on the stability of the warm air.

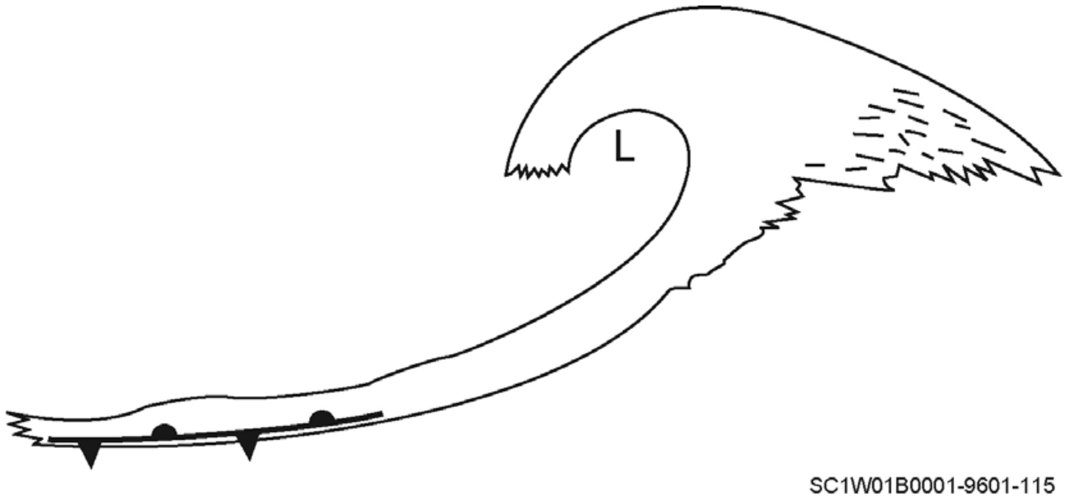

Figure 2–69. Stationary front placement.

Extratropical lows

We concentrate on lows associated with the comma cloud pattern and the low's placement in different stages of development

Initial stage

On a slow-moving cold front or stationary front, the frontal clouds begin to widen and have a slight "S" shape on the poleward side of the cloud band. On FIR and EIR imagery, clouds begin to show cooler tops, which indicate increased upward vertical motion. With WV imagery, gray shade contrast becomes more distinct as the short-wave trough begins to interact with the front, increasing the divergence aloft. You can locate the surface low approximately halfway into the cloud pattern from the inflection point in the frontal cloud band (fig. 2–70).

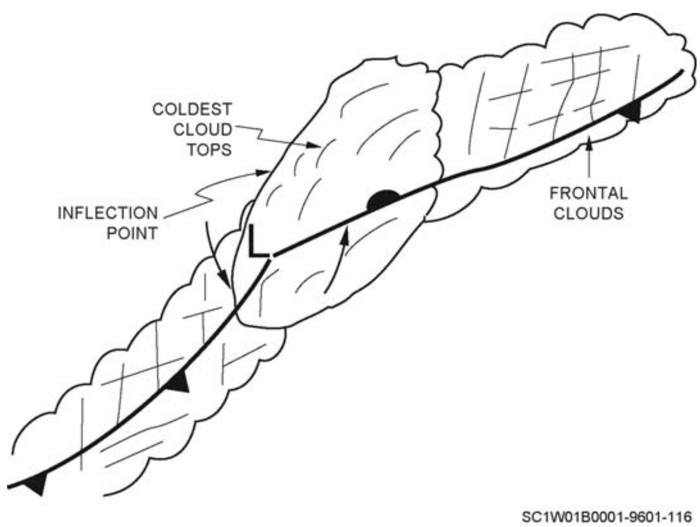

Figure 2–70. Initial low stage.

Intensification stage

As the low intensifies, the synoptic-scale comma cloud becomes larger and better defined with a developing dry slot (cloud minima zone or surge region). The dry slot begins to wrap around the upper low. The surface low translates along the back edge of the comma head (fig. 2–71). The comma head is composed mainly of the vorticity comma cloud.

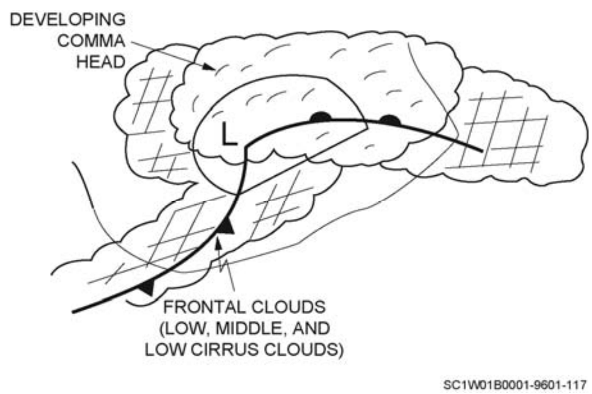

Figure 2–71. Low intensification stage.

Mature stage

The surface low is starting to become vertically stacked with the upper-level low. The surface low is located in the eastern portion of the deformation zone cloud (fig. 2–72). Often, the deformation zone cirrus and the dry slot wrap around the low.

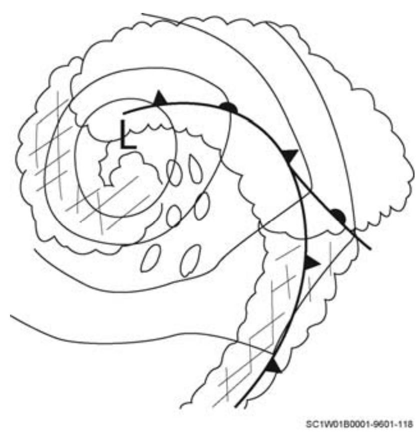

Figure 2–72. Mature low stage.

Dissipation stage

During this stage, the surface low fills and is usually not identifiable on METSAT imagery.

Highs and ridges

These two features are normally discussed together when we talk about interpreting METSAT imagery. Their positions are based mainly on low-level cloud indicators and terrain influences on the clouds surrounding the high center and ridge axis.

Baroclinic highs and ridges over land

Positioning these over land is very difficult because there is usually not one indicator that gives you the exact location. You must rely on a combination of indicators to give you a general location of these features.

Some features you can use to position baroclinic highs and ridges during the different seasons follow. Remember; look at these features in a big picture perspective.

Late fall to early spring

To find the position of the high or ridge, determine the low-level wind flow around them first. Use SC lines off lakes and coastlines east of the high, ice movement, and mountain waves. You can also use fog/stratus and SC that is pushed up against higher terrain south and west of the high to determine the anticyclonic wind flow. These clouds typically suggest stable conditions.

Mid spring to mid fall

Use the clearing of clouds on the leeside of lakes, fog/stratus, SC and convective clouds that are pushed up against higher terrain and mountain waves to determine low-level anticyclonic flow. Another indicator is the clearing of clouds in the eastern half of the high with convective clouds occurring in the western half and showing anticyclonic flow. Place the surface ridge axis in the strongest anticyclonic turning within the CU line/street field. This cloud signature is common in the midwestern and southern US.

In the middle latitudes, the surface high has an upper-level short-wave ridge axis located on its upstream side. Upper-level cloudiness associated with the next upstream system normally extends over the upper-level ridge axis to the approximate surface high position (fig. 2–73). In extra tropical regions, when you see a well developed low and front, there is a surface high or ridge located upstream.

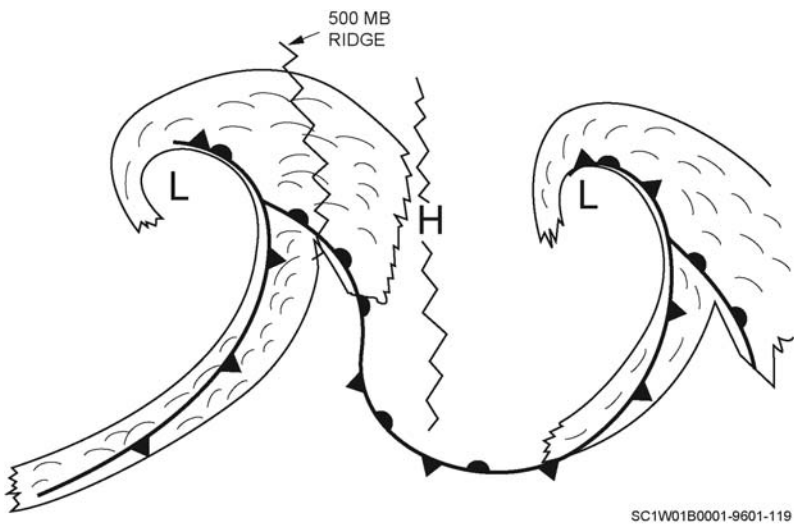

Figure 2–73. Surface high with upper-level clouds.

High centers and ridge axis over water

It’s easier to position these features over water than over land because of the large amount of moisture available for cloud formation.

Extratropical systems

A high center and ridge axis can be positioned behind a cold front with a combination of cloud patterns, terrain influences, and the low-pressure center location. In the southern half of a high, you normally see closed-cell SC with a clear zone to the west. West of the clear zone is usually another frontal system with low-level clouds converging into it. The high center is normally located in the eastern portion of the clear zone (fig. 2–74). Place the ridge axis where the clouds show the strongest anticyclonic turning.

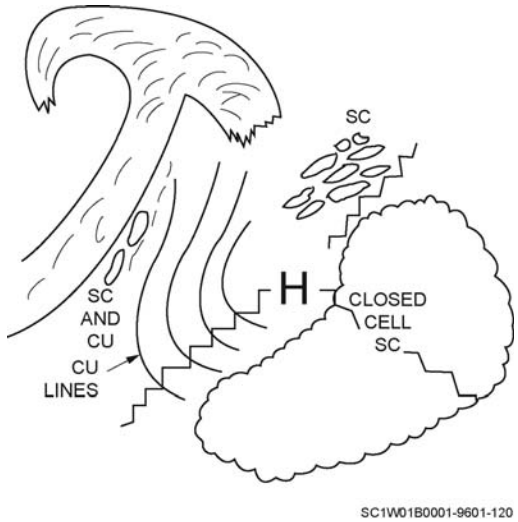

Figure 2–74. Surface high in clear zone.

Determining the low-level wind flow from SC lines, the packing of clouds against islands and terrain, bow waves, plume clouds, Karman vortices, CU lines/streets, and the movement of anomalous cloud lines helps you position the high center and ridge axis.

When two frontal systems come in close proximity, a sharp surface ridge is found between them (fig. 2–75). On the northern side of the surface high, winds shift from southwesterly or westerly to northwesterly or northerly. The surface ridge axis is positioned along a line where the CU clouds first develop in the low-level cold air that has a northerly component over warmer water. This line is usually coincident with the forward edge of the overcast clouds from the upstream storm system moving over the upper-level ridge.

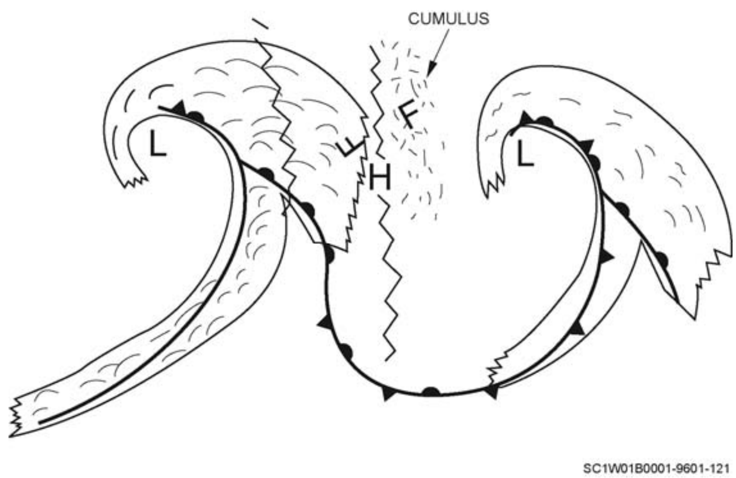

Figure 2–75. High placement with cumulus clouds.

Subtropical high

This high is centered over the water and extends over the continents. The high center ranges from approximately 28°N to 35°N. The mean ridge axis is typically in an east-to-west orientation. In the middle latitudes, you'll also see a ridge axis oriented in a northerly direction.

You can identify the subtropical high on METSAT imagery by considering the flow pattern in the surrounding region. Systems within the PFJ flow generally move from west to east. Tropical systems to the south move east to west. East to southwest of the high center, closed-cell SC is usually present, which is commonly seen off the west coasts of continents. To the west of the high, you see anticyclonically curved CU lines/streets. Place the ridge axis in the center of the strongest anticyclonic turning.

The cumulus cloud elements on the poleward side of the ridge axis are typically smaller than the cumulus cloud elements on the tropical side. Cloud elements on the poleward side may even be SC.

Cloud fingers are SC clouds that protrude from the equatorward side of the cold front. At the *extreme* end of the cloud finger is where the surface ridge axis has been empirically observed. Figure 2–76 shows the placement of the ridge axis with cloud fingers.

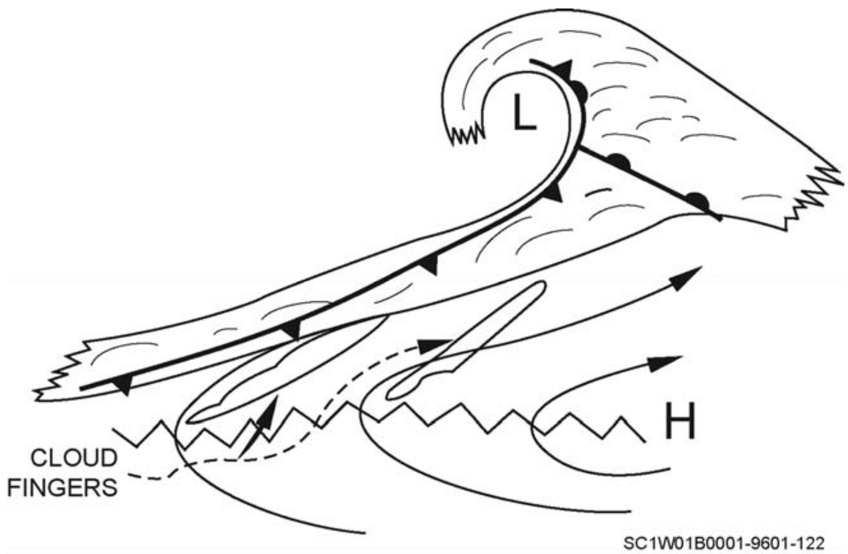

Figure 2–76. Ridge axis placement with cloud fingers.

The ridge axis has been empirically observed within the “V” notch in the sun glint pattern. You’ll have either one or two “V” notches. Where the cloud fingers end and the sun glint begins is where the ridge axis is. The movement of anomalous cloud lines, terrain blocking, bow waves, plume clouds, and Karman vortices helps you determine the position of the high center and ridge axis.

Low-level deformation zones

Low-level deformation zones are formed for the same reasons as upper-level deformation zones. Opposing wind flow diverges between two high-pressure systems and converge leading into one of two low-pressure systems.

On METSAT imagery, a low-level deformation zone is most evident over water behind cold fronts with open and closed-cellular cloud patterns. Visual imagery is normally the best imagery to use for deformation zone analysis. Open-cell CU indicates straight-line and cyclonic flow, while closed-cell SC indicates anticyclonic flow. Between the cold front and the cellular clouds, you may also see a band of low clouds that are perpendicular to the flow (fig. 2–77). Ahead of the front, analyze for any indicators that would help you determine the low-level wind flow. Along the front, normally a rope cloud indicates where the low-level wind flow converges.

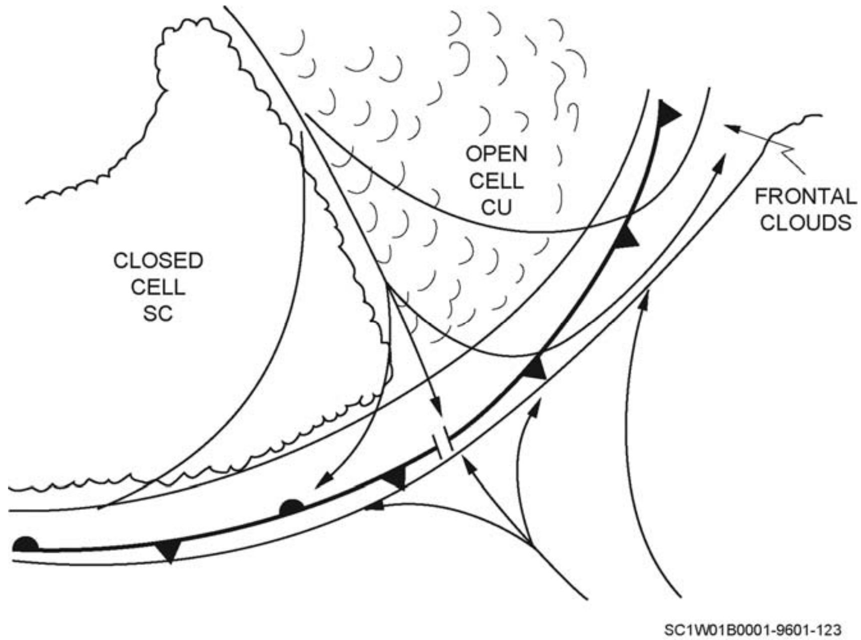

Figure 2–77. Low-level deformation zone.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

418. Lower tropospheric interpretation

1. What effect do you consider when you interpret lower-level wind flow that you do *not* consider in upper-level wind flow analysis?

2. What type of terrain offers clues in analyzing the lower troposphere?

419. Cloud pattern recognition

1. Why is the extra tropical surface low hard to position initially?

2. Where are low-level deformation zones commonly found?

420. Low-level wind flow determination

1. Why is an atlas an essential tool for evaluating low-level wind flow?

2. Match the cloud type in column B with its empirical wind observation in column A. Cloud types are used only once.

Column A

____ (1) Straight-line or cyclonic flow associated with these clouds.
____ (2) You see these under very stable, high-pressure conditions with light, anticyclonic flow.
____ (3) Behind a strong cold front, this can spread out cyclonically and anticyclonically in the low-level deformation zone.
____ (4) The wind flow is parallel or nearly parallel, but these clouds are mainly seen in the tropical and subtropical regions.
____ (5) These are seen off the eastern and southern coastlines of continents and large lakes with a parallel or nearly parallel wind flow.

Column B

a. Ship trails.
b. Blowing dust.
c. Open-cell cumulus.
d. Stratocumulus lines.
e. Cumulus lines/streets.

3. What phenomena are caused by the wind flow interacting with an ocean island?

421. Synoptic feature identification and placement

1. Match the frontal type in column B with its frontal placement in column A. Frontal types are used only once.

Column A

____ (1) Place the front along the leading edge of the cloud band.
____ (2) The PFJ turns anticyclonically on the cold side of this front.
____ (3) This front is positioned along the back edge of the comma cloud head.
____ (4) Over water, along the tail end there is usually a rope cloud that shows the exact frontal position.

Column B

a. Cold front.
b. Warm front.
c. Occluded front.
d. Stationary front.

2. Match the extra tropical low stage in column B with its description in column A. Low stages are used only once.

Column A

____ (1) The surface low is located in the eastern portion of the deformation zone cloud.
____ (2) During this stage, the surface low is usually ***NOT*** identifiable on METSAT imagery.
____ (3) On infrared imagery the clouds begin to show cooler tops indicating increased upward vertical motion.
____ (4) The surge region begins to wrap around the upper low with the surface low translating along the back edge of the comma head.

Column B

a. Mature stage.
b. Initial stage.
c. Dissipation stage.
d. Intensification stage.

3. Why is it easier to position high centers and ridge axes over water than land?

4. What is the best METSAT imagery to use for low-level deformation zone analysis?

2–4. Atmospheric Flow

The atmosphere always has flow occurring in the vertical and horizontal. In this section you'll look at the vertical and horizontal motions and what is causing these motions. You'll learn the relationship of vertical and horizontal motions to low-pressure systems.

422. Baroclinic lows

These may develop into a synoptic comma cloud. The following diagrams are composites of a typical comma cloud (figs. 2–78 and 2–79). There are often variations to this pattern from system to system.

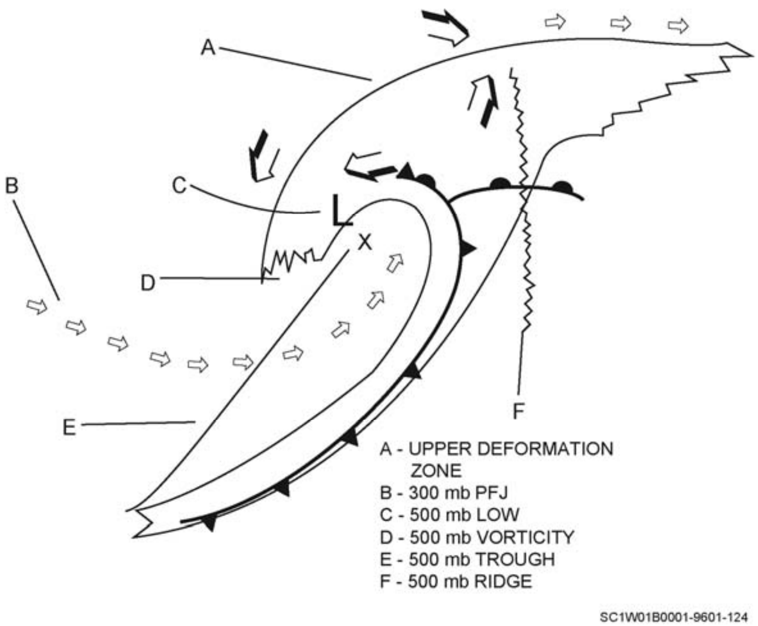

Figure 2–78. Upper-level features and flow with the comma cloud.

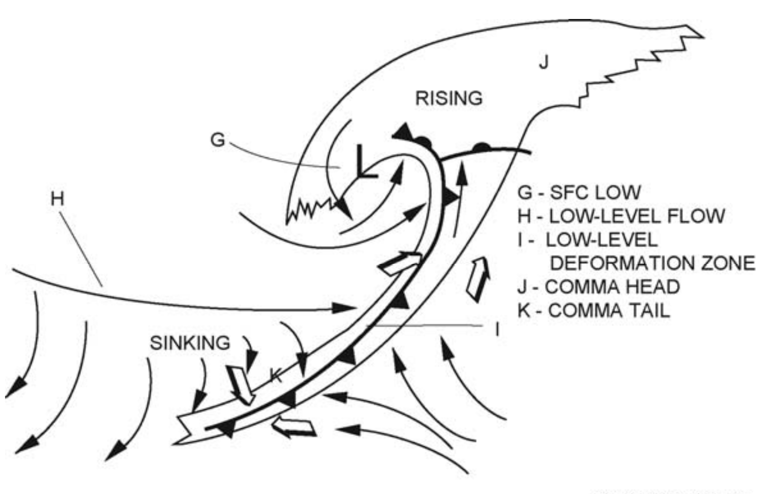

Figure 2–79. Low-level features and flow with the comma cloud.

Conveyor belts

We use conveyor belts to explain the horizontal and vertical movements of an air parcel simultaneously with a comma cloud. Your understanding of the airflow with the comma cloud and the cloud types associated will improve your analysis and forecasting skills.

Warm conveyor belt

Baroclinic zone cirrus is associated with the northern portion of the warm conveyor belt (WCB). Baroclinic zone cirrus composes the eastern and, frequently, the central portion of the comma head. Except for possible convection along the cold front, the coldest (highest) cloud tops are associated with the WCB.

Cold conveyor belt

Low clouds may be associated with the cold conveyor belt (CCB) ahead of the warm front. Near the low center, mid- and upper-level clouds form when the CCB sharply ascends. The CCB forms the comma head.

Dry-air conveyor belt

The dry-air conveyor belt (DACB) does not cause any cloudiness. However, it does affect the cloudiness associated with the WCB and CCB. As the DACB nears the low, it splits into two branches. One branch turns cyclonically and flows just northwest of the WCB. You can see the boundary between the two conveyor belts on VIS and IR imagery as a smooth high cloud border north of the low. On WV imagery, you see a gray shade contrast between the moist air (light gray) and the dry air (dark gray). The other branch turns anticyclonically and descends behind the low. Figure 2–80 shows the relationship between the comma cloud and the conveyor belts.

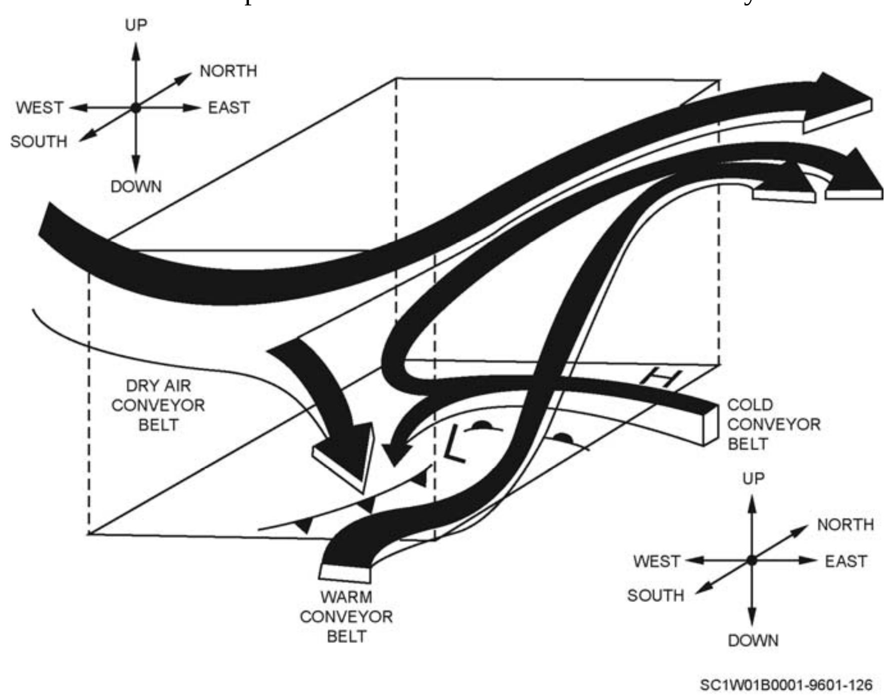

Figure 2–80. Conveyor belt relationship to the comma cloud.

Polar front jet relationship to the comma cloud

The jet stream axis is associated with the comma cloud system. Two patterns are possible.

Type A

The polar front jet (PFJ) is continuous and crosses the comma cloud system at, or north of, the triple point. The PFJ separates baroclinic zone cirrus from deformation zone cirrus. Deformation zone cirrus is typically lower and thinner than the baroclinic zone cirrus. The vorticity comma cloud is visible on the poleward side of the PFJ axis.

Type B

The PFJ is not continuous through the comma cloud system. The PFJ wraps around the upper-level low and weakens. It reforms north of the warm front at the top of the comma cloud and extends eastward. The baroclinic and deformation zone cirrus merge. The deformation zone cirrus is approximately the same height as baroclinic zone cirrus and is much thicker.

PFJ speed maximums

The PFJ lies in the dry slot (surge region) associated with the comma cloud system. There is a speed maximum located within the dry slot on the equatorward side of the 500-mb low (fig. 2–81).

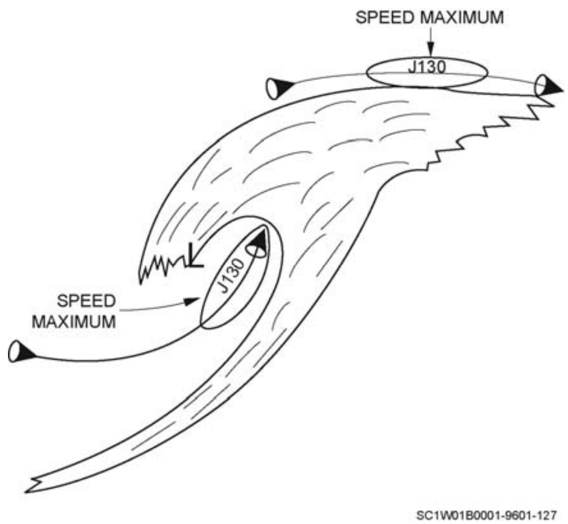

Figure 2–81. Speed maximum relationship to the comma cloud.

On VIS and IR imagery, the dry slot is cloud free in the upper levels. The PFJ lies in this region. There may be low SC or CU clouds located in this area. The dry slot appears as a dark band on the WV imagery. The dry slot wraps around the upper low. Typically, a speed maximum is located in the darkest portion of the dark band. Using figures 2–82 and 2–83, you should be able to place a speed maximum in the Kentucky/Indiana border area.

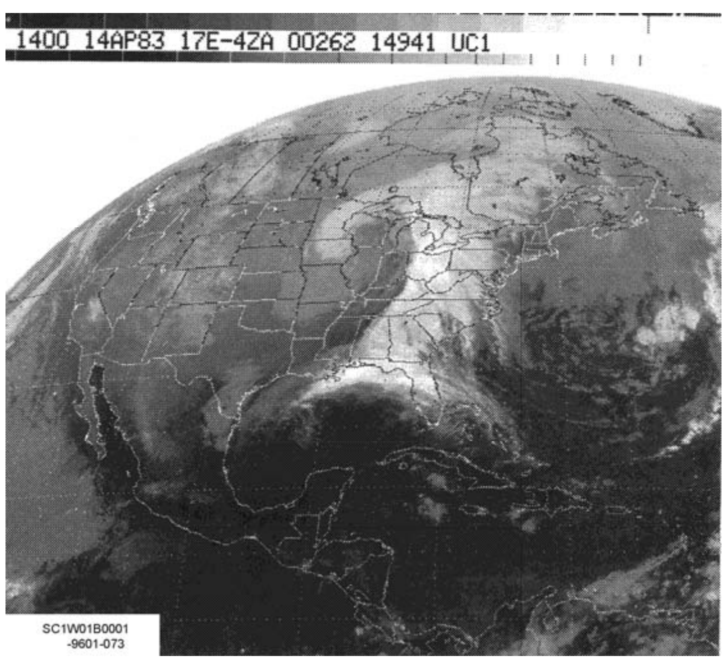

Figure 2–82. Speed maximum on water vapor imagery, 1400Z, 14 April 1983.

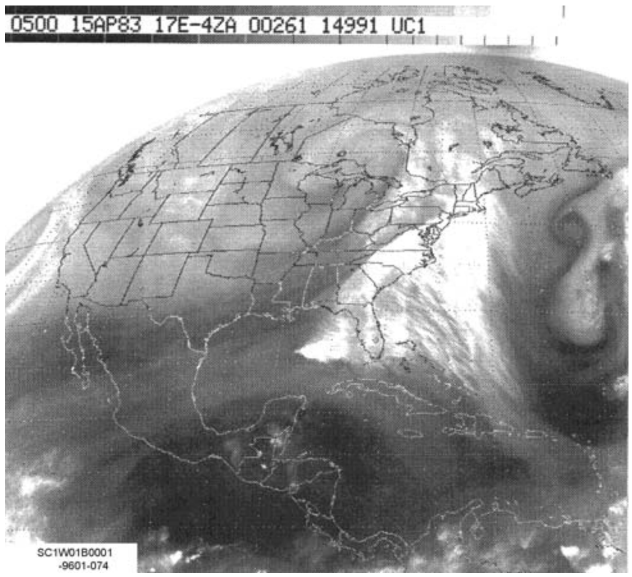

Figure 2–83. Speed maximum on water vapor imagery, 0500Z, 15 April 1983.

On the poleward side of the comma cloud, downstream from the upper-level ridge axis, there is normally another speed maximum. METSAT imagery has the same gray shade appearance as with the dry slot (fig. 2–81).

Vorticity relationship to the comma cloud

Understanding the vorticity relationship to the comma cloud is useful for two reasons. The first is to determine accurately what the weather pattern is in comparison to the products. The second is to conduct the initialization and verification process with the models.

Shear lobes

These are normally seen with speed maximums. There is a vorticity maximum located on the poleward side of the speed maximum. The 500-mb low is located on the poleward side of the vorticity maximum, with respect to the vorticity maximum's direction of movement. Figure 2–84 illustrates this relationship.

Divergence, indicated by positive voricity advection (PVA), is located downstream from the vorticity maximum, in the left-front quadrant of the speed maximum. If enough moisture is available, upward vertical motion can lead to the vorticity comma cloud development. On METSAT imagery, the coldest cloud tops are typically located in the area of maximum upward vertical motion.

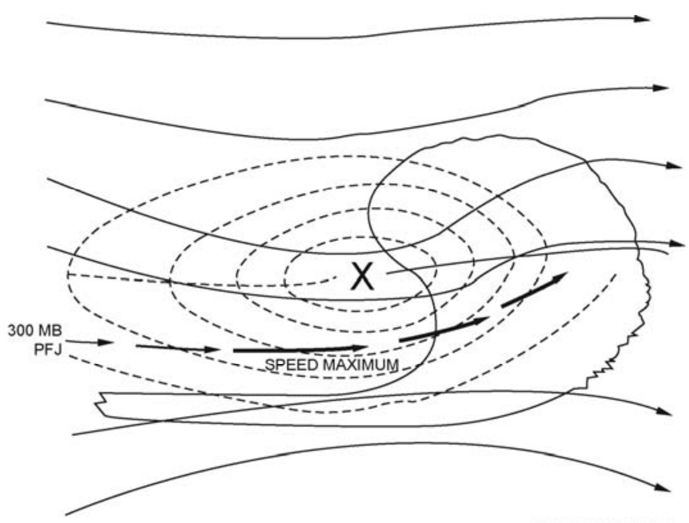

Figure 2–84. Shear lobe relationship to the vorticity comma cloud.

Convergence, which is indicated by negative vorticity advection (NVA), is located upstream from the vorticity maximum, in the left-rear quadrant of the maximum. Downward vertical motion leads to clearing of the clouds behind the comma cloud. This clearing is also associated with the dry slot.

Advection lobes

A major short-wave trough and ridge couplet are associated with a synoptic comma cloud system. Typically, there are vorticity advection lobes associated with the trough and ridge. When you view METSAT imagery, you can determine what vertical motions are occurring around and within a synoptic comma cloud.

Downward vertical motion is occurring upstream from the advection lobe associated with the trough (fig. 2–85, area 1) and downstream from the advection lobe associated with the ridge (fig. 2–85, area 2). Cloudiness has either dissipated or is dissipating in these areas. These areas are associated with convergence aloft and/or cold-air advection (CAA).

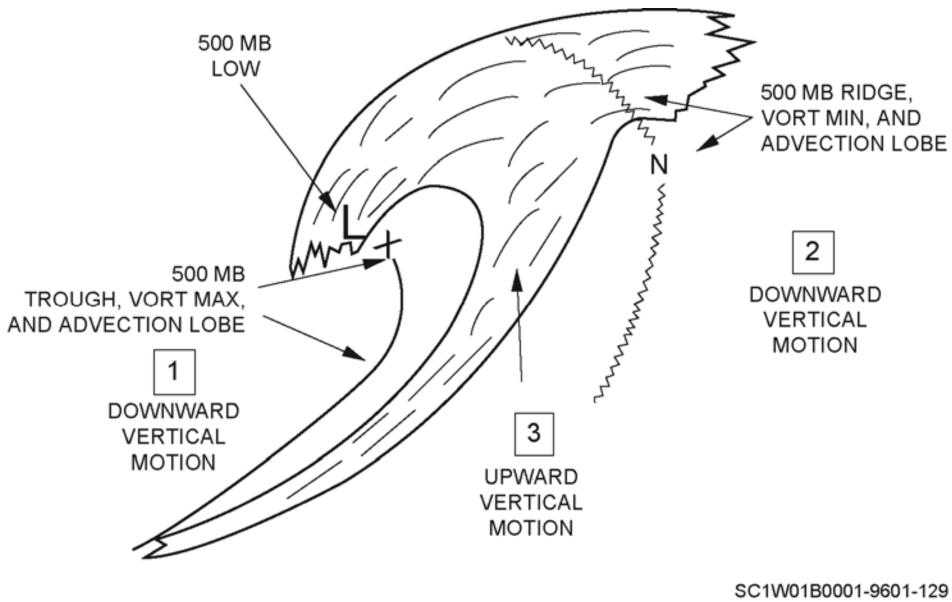

Figure 2–85. Advection lobe relationship with the comma cloud (vertical motions).

Upward vertical motion is occurring between the trough and ridge (fig. 2–85, area 3). Cloudiness is typically multilayered and covers an extensive area. This area is caused by divergence aloft, warm-air advection (WAA), and air being lifted in association with the front.

Thickness relationship to the comma cloud system

The surface low becomes removed from the warm air mass at low levels (occluded) as it continues to develop back into the cold air.

Strong CAA is occurring behind the surface low. CAA helps create downward vertical motion besides convergence aloft. This helps lead to the formation of the dry slot. The orientation of the PFJ determines where the clouds are located in relation to the surface front.

WAA is occurring ahead of the surface low. Typically, a thickness ridge is located just downstream from the surface low. WAA causes the strong lift of the WCB north of the warm front. The type of cloudiness seen on the METSAT imagery depends on the stability of the warm air.

423. Life cycle of a baroclinic low (frontal wave stage)

In this lesson, you learn how the cloud patterns relate to the life cycle of a baroclinic low. Often synoptic data may be missing or you're not able to receive it. Knowing how to analyze METSAT imagery allows you to continue to forecast with confidence. Use figures 2–86 through 2–93 as reference imagery while you study this lesson.

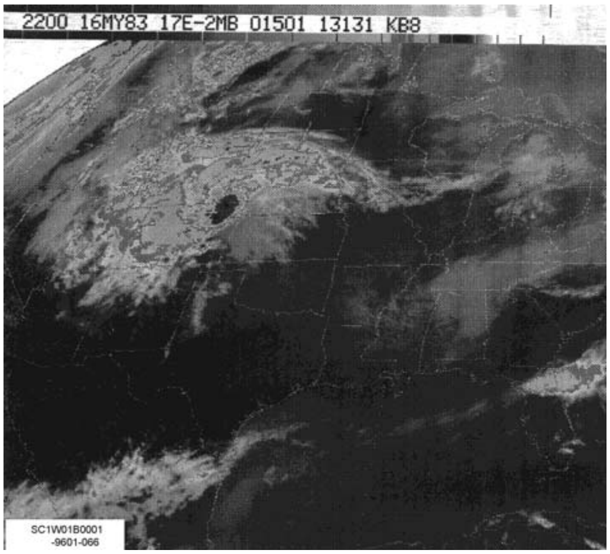

Figure 2–86. Upper low in CO developing, 2200Z, 16 May 1983.

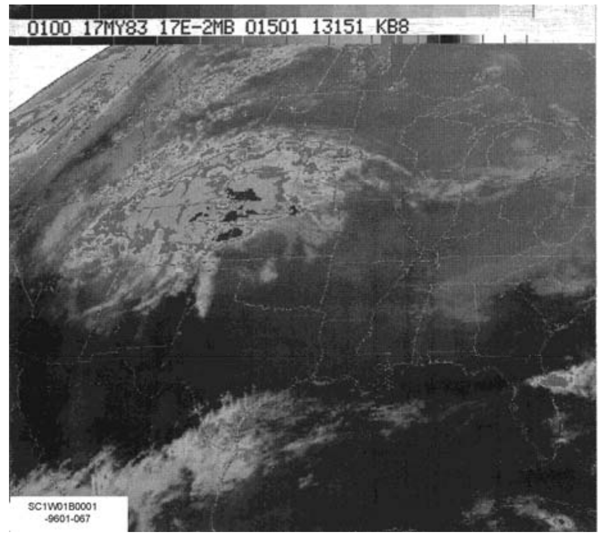

Figure 2–87. Upper low in CO developing, 0100Z, 17 May 1983.

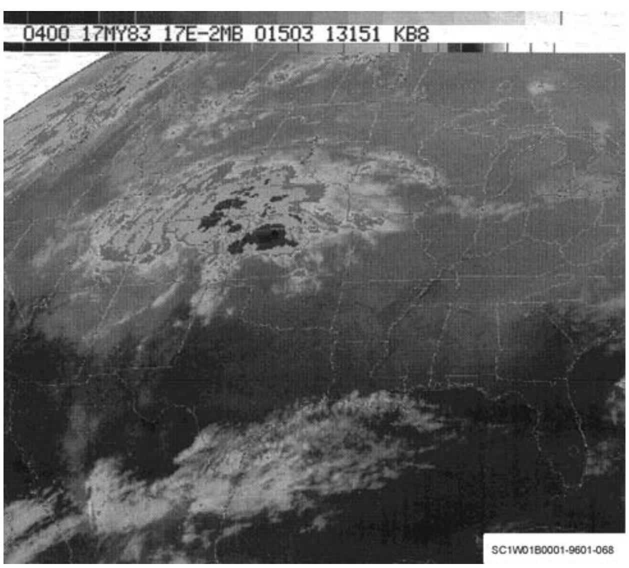

Figure 2–88. Upper low in CO developing, 0400Z, 17 May 1983.

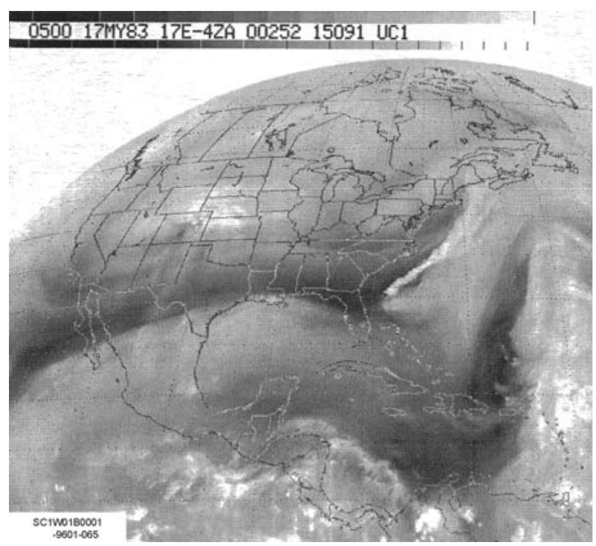

Figure 2–89. Upper low in CO developing, 0500Z, 17 May 1983.

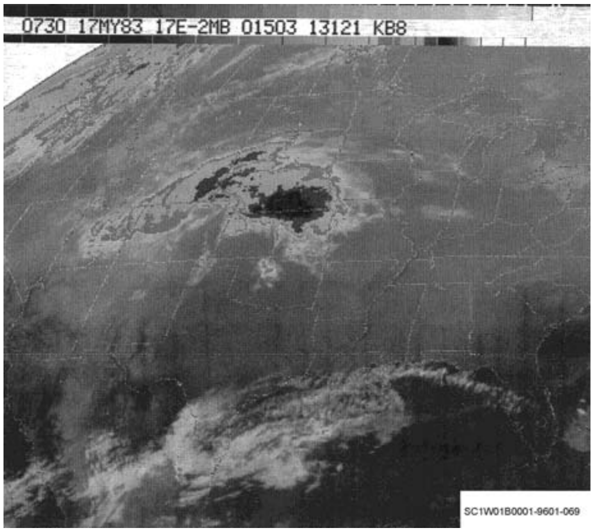

Figure 2–90. Upper low in CO developing, 0730Z, 17 May 1983.

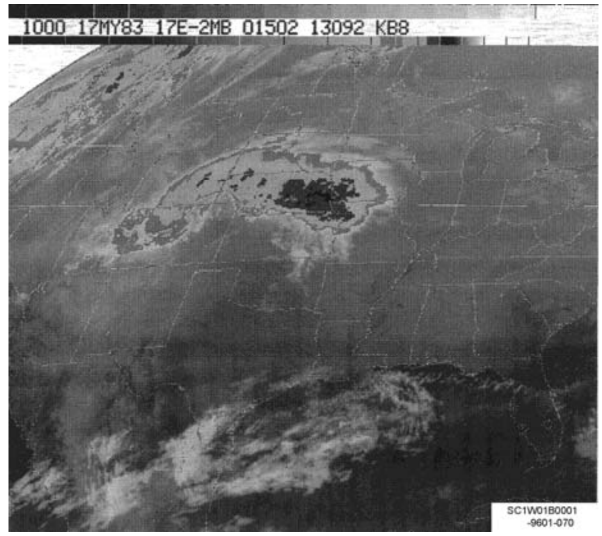

Figure 2–91. Upper low in CO developing, 1000Z, 17 May 1983.

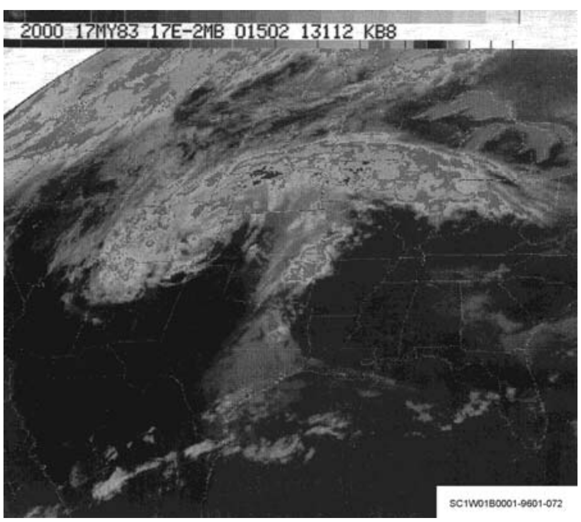

Figure 2–92. Upper low in CO developing, 1600Z, 17 May 1983.

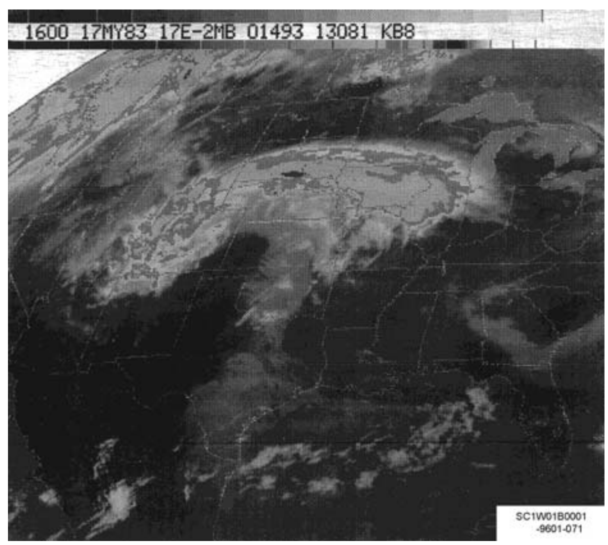

Figure 2–93. Upper low in CO developing, 2000Z, 17 May 1983.

Classic case

We discuss the cloud pattern and the associated synoptic features as they relate to the classic self-development situation. Remember, there are many variations in appearance but the basic pattern is generally the same.

Initial stage

When a baroclinic low initially develops along a front, the baroclinic zone cloud system (frontal cloud band) begins to widen on the METSAT imagery. On the cold airside of the widening baroclinic zone, there is a slight “S” shape to the cloud pattern. The PFJ is located on the cold airside of the baroclinic zone clouds. Convective activity is often more widespread and organized near the surface low.

The thickness product shows weak thermal advection ahead and behind the surface low. However, a strong thermal gradient exists. The vorticity product may indicate weak divergence above the cloud band. Over water, open-cell CU clouds may begin to show the low-level circulation developing. Cumulus clouds begin to flow into the developing low.

Intensification stage

The comma cloud pattern indicates increased horizontal and vertical motions as the self-development process occurs. Multilayered clouds increase in area, thickness, and organization.

Baroclinic zone clouds (frontal cloud bands)

As the self-development process begins, the “S” shape of the widening cloud band becomes better defined. The PFJ speed maximum and vorticity maximum are located upstream. As development continues, the cloud band takes on a wave appearance. This is the comma head developing. The wave appearance in a cloud pattern is similar to how an ocean wave looks as it develops. As the ocean wave becomes larger, the top of the wave begins to curl cyclonically and wrap in. As the baroclinic zone cloud system becomes larger and wraps, it exhibits this same wave appearance. It begins to curl cyclonically and to wrap around and toward the vorticity maximum. Cloud-top temperatures decrease as the cloud heights increase. They indicate upward vertical motion is increasing as the system develops. Baroclinic zone clouds may or may not merge with the deformation zone clouds.

Vorticity comma clouds

The vorticity comma cloud is associated with a vorticity maximum and either a shear lobe or an advection lobe. The vorticity comma cloud can be located in one of two areas in relation to the baroclinic zone clouds. It can develop within the baroclinic zone cloud system. It can also be just upstream of the baroclinic cloud system. As the vorticity comma cloud develops, it moves under and merges with the baroclinic zone clouds.

If the vorticity comma cloud develops within the baroclinic zone clouds, it also has a well-defined “S” shape on its cold airside. As it develops, it waves back into the cold air and wraps around the upper low and 500-mb vorticity maximum. The vorticity comma cloud’s development indicates increased divergence and upward vertical motion.

If the vorticity comma cloud develops just upstream from the baroclinic zone clouds, the vorticity comma cloud initially has a well-defined “S” shape on the cold airside of the cloud pattern. As the vorticity comma cloud begins to wrap around the vorticity maximum, the baroclinic zone clouds are waving back and the two cloud systems merge, forming the synoptic comma cloud. The vorticity comma cloud may be a baroclinic leaf, enhanced CU, or just mid-level cloudiness.

Trough/ridge pattern

Increasing amplitude between the trough and downstream ridge can be related to the changing size and organization of the baroclinic zone clouds and the vorticity comma cloud pattern. Also the ridge increases its amplitude due to WAA ahead of the surface low and into the upper-level ridge. The increasing sharpness of the ridge is evident in the baroclinic zone clouds.

Deformation zone cirrus

Deformation zone cirrus typically forms toward the end of the intensification stage or in the mature stage. Deformation zone cirrus develops in the northern portion of the trough as it amplifies and begins closing off into a low. On VIS and IR imagery, the deformation zone cirrus initially appears thin and ragged. As the low intensifies, horizontal and vertical motions increase around the low. As the vorticity comma cloud enlarges, the associated upper-level clouds wrap around the vorticity maximum, developing more deformation zone cirrus.

Deformation zone cirrus initially appears as a slight gray shade contrast north and east of the low on the WV imagery. The dark band is parallel to where the axis of dilatation is. Usually the WV imagery displays the deformation zone pattern before the cloud shows up on VIS and IR imagery.

Dry slot

The dry slot is evident on the upstream side of the “S” shape of the vorticity comma cloud. The dry slot becomes more evident as the surface low develops and the synoptic comma cloud system organizes. On WV imagery, the dark band becomes longer, wider, and darker. Before the baroclinic low reaches the mature stage, the dark band curves cyclonically within the comma head. This depends on whether the comma cloud is developing into a type A or type B system.

Low-level deformation zone

Over water, as the surface low and upstream surface high develop and intensify, the low deformation zone may become more evident in the cloud field. The open-cell CU and closed-cell SC increase in organization and area.

Mature stage

The mature baroclinic low is identifiable in the upper levels by the dry slot that wraps around the low. The farther the dry slot wraps around the low, the deeper and older the system will be. WV imagery shows the dark band wrapped around the upper low. WV imagery also shows the dark band with the upper deformation zone has become more defined. The surface low begins to move under the upper low. Over water, you can see the surface low with the cyclonic turning in the open-cell CU field. The comma cloud is at its largest size and most organized.

Dissipation stage

The upper low and surface low become vertically stacked. Over land, the surface low may not be identifiable in the SC cloud field. Over water, you see the surface low in the low-level cumulus and stratocumulus cloud field. Since the surface low fills before the upper low, it gradually becomes less evident in the cloud field. Cloudiness is more circular since the low is more circular. The clouds gradually thin and dissipate as the entire system fills and upward vertical motion decreases. Sometimes a new low may begin developing along the trailing cold front and the process begins again.

Variations of cyclogenesis

There are a variety of scenarios where cyclogenesis can occur. Different cloud patterns and abrupt changes in zonal flow increase your chances for recognizing these situations before they occur or are apparent on upper-air products.

Baroclinic leaf cloud pattern

This cloud pattern has proven very reliable since it was discovered on METSAT imagery. It takes on a variety of shapes and can either be poorly organized or very well defined.

Characteristics

The significance of the baroclinic leaf pattern is that 75 percent of them develop into comma clouds. More than 60 percent of all comma clouds develop from the baroclinic leaf pattern.

There are three ways a baroclinic leaf can develop into a comma cloud:

1. It can develop along the cold airside of the baroclinic clouds.
2. It can develop upstream from the baroclinic zone clouds and merge with the baroclinic zone clouds.
3. It can develop into a comma cloud well upstream from a baroclinic zone cloud pattern.

The baroclinic leaf is a cloud pattern associated with the frontogenetic phase of system development. Surface cyclogenesis typically begins as the baroclinic leaf transitions into the comma cloud. The baroclinic leaf has an advection lobe associated with it on the poleward side of the cloud edge. A shear lobe is associated with the upstream speed maximum (fig. 2–94).

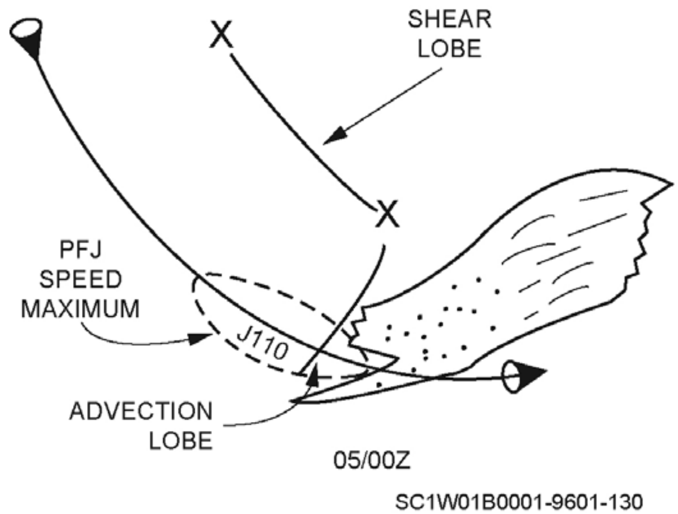

Figure 2–94. Vorticity and PFJ relationship with the baroclinic leaf.

Previously, you located the baroclinic leaf in the left-front quadrant of the PFJ speed maximum. As the baroclinic leaf begins its transition to a comma cloud, the vorticity and PFJ pattern also changes (fig. 2–95). The PFJ reorients and flows through the cloud pattern. The older branch of the PFJ is still located equatorward of the baroclinic leaf. A downstream shear lobe may be apparent on the vorticity product.

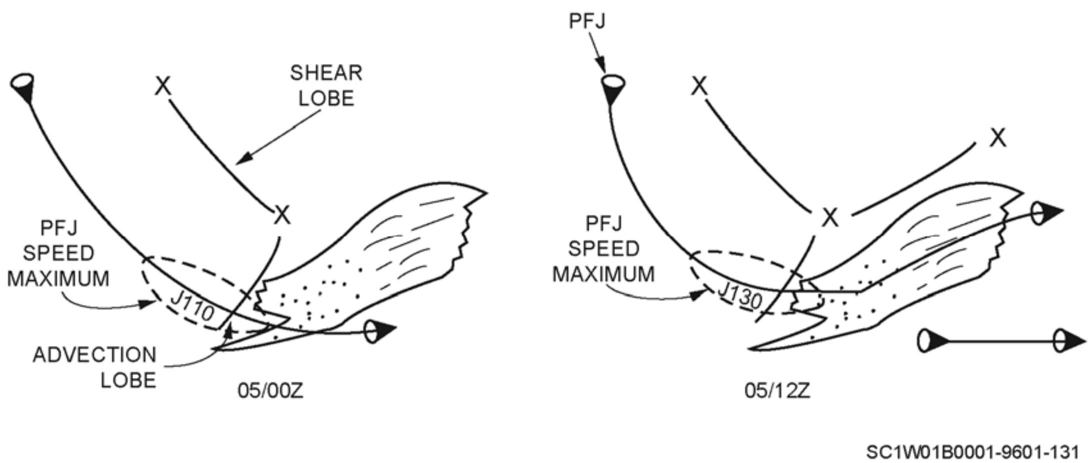

Figure 2–95. Vorticity/PFJ change with the baroclinic leaf.

Development of a baroclinic leaf

Figure 2–96 and the following discussion show the typical development process of a baroclinic leaf. From system to system, there are variations in cloud patterns, synoptic feature location, and rate of development.

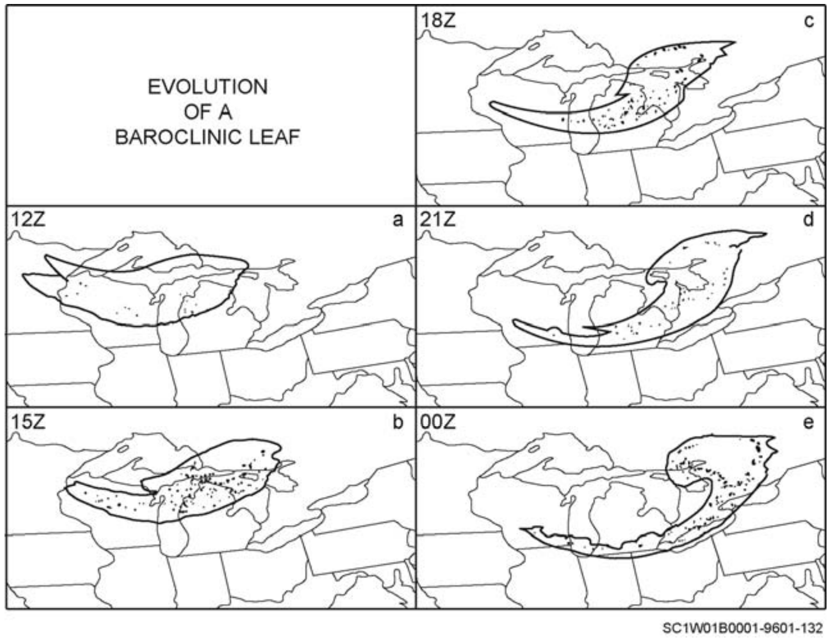

Figure 2–96. Baroclinic leaf pattern.

In 12Z (fig. 2–96, a), we see the classic baroclinic leaf signature we discussed earlier. **NOTE:** The coldest cloud temperatures are unshaded in all diagrams.

In 15Z (fig. 2–96, b), the cyclonic portion (upstream end) of the leaf tail has begun to dissipate as the speed maximum digs into the cloud pattern. The convex (downstream) portion remains well defined while the southern border has sharpened. Surface frontogenesis is occurring along the western half of the southern border.

In 18Z (fig. 2–96, c), most of the concave part of the northern border has dissipated, leaving a ragged; less well defined northern cloud edge to the developing comma tail. The narrowing of the comma tail and the formation of the dry slot during the transition to a comma cloud indicates the PFJ and the speed maximum are flowing into the developing comma cloud. A surface low center consolidates and surface pressures begin to fall.

In 21Z/00Z (fig. 2–96, d and e), the comma cloud is in the cyclogenetic phase and the system continues to develop to maturity and dissipation.

Cold-air vortex

There are four phases to this type of development.

Phase one

Located downstream from a long-wave or major short-wave trough is a baroclinic zone cloud shield and jet stream axis. A new short-wave trough is approaching the old baroclinic zone from the west. The new short-wave trough is typically associated with mid-level and some upper-level clouds. The new trough is apparent on METSAT imagery as a vorticity comma cloud or a baroclinic leaf. A branch of the PFJ is associated with the baroclinic zone cloud shield. A new branch of the PFJ is associated with the short-wave trough. If the newer branch of the PFJ merges with the downstream PFJ, cyclogenesis typically occurs along the baroclinic zone cloud band as we described earlier. If the newer branch of the PFJ curves around the trough and becomes parallel to the downstream (older) PFJ, cyclogenesis follows the cold-air vortex pattern.

Phase two

If the new jet remains parallel to the old jet, development continues as follows. The short-wave trough amplifies as it moves through the long wave. The mid-level clouds associated with the smaller trough begin to form the vorticity comma cloud. Convection increases with the vorticity comma cloud, resulting in higher cirrus clouds. The PFJ is parallel to the downstream branch of the PFJ. Several lows may be evident with a surface trough associated with the cloud pattern.

Phase three

A synoptic comma cloud pattern is becoming evident as baroclinic zone clouds form on the equatorward side of the new PFJ axis over the intensifying vorticity comma cloud. The cloud pattern shows the increased amplitude of the developing short-wave trough. As the trough increases amplitude, the older baroclinic zone clouds parallel the developing cloud pattern. This cloud pattern begins to weaken and thin as the new development occurs to the west. A surface cold and warm front develop with a consolidated surface low.

Phase four

The new synoptic comma cloud has completely formed with the development of deformation zone clouds in the upper levels. An upper low has developed, helping form the deformation zone clouds. The old baroclinic zone continues to weaken, thin, and become fragmented. The downstream branch of the PFJ weakens while the newer branch becomes more dominant. This cyclogenesis often develops into intense type B systems.

Analysis information

Two other pieces of information you can interpret from METSAT imagery are estimating sea-level pressure and determining the strongest wind regions with lows. Empirically, both of the techniques we discuss have proven fairly reliable.

Estimating sea-level pressures of baroclinic lows over the ocean

You can estimate sea-level pressure (SLP) for baroclinic lows with comma clouds from 40°N and poleward. If the system is very strong, you can estimate sea-level pressure further south. This technique assumes environmental pressures at the beginning of development are above 1000mb. If the SLPs are below 1000mb at the beginning of development, adjust the estimates. For example, assume the initial pressures around a low are 980mb and the system calls for lowering each category from this point by 20mb. Therefore, the 980-mb category will be the 1000-mb category.

Categories for estimating SLPs

Following are the categories for determining sea-level pressure with baroclinic lows. Keep in mind this works well over oceans but not over land. Refer to figure 2–97 throughout this material.

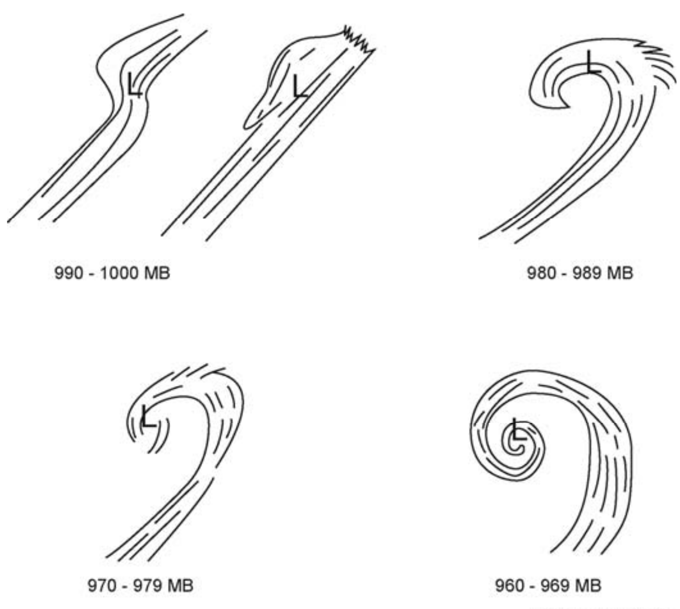

Figure 2–97. Cloud patterns with estimated SLPs.

990mb to 1000mb

A low at this intensity has a well-defined “S” shaped pattern along the back edge of the frontal cloud bands. The dry slot may start to form when a low is at this intensity.

980 to 989mb

A low at this intensity is characterized by a well-defined “hooked” pattern in the cloud band. The dry slot is more apparent.

970 to 979mb

A low at this intensity is characterized by a cloud band wrapping once around the low center.

960 to 969mb

A low at this intensity is characterized by a cloud band that wraps one and one-half times around the low center.

Below 960mb

This cannot be determined by METSAT imagery at this time.

Location and intensity of strongest surface winds

We can estimate the strength of surface winds based on comma cloud organization, which is often coincidental with the SLP categories we previously discussed. Determining the regions of the strongest winds can be invaluable to forecasters on the West Coast or for forecasting in operational areas that are located in data sparse regions. Refer to figure 2–98 throughout this material.

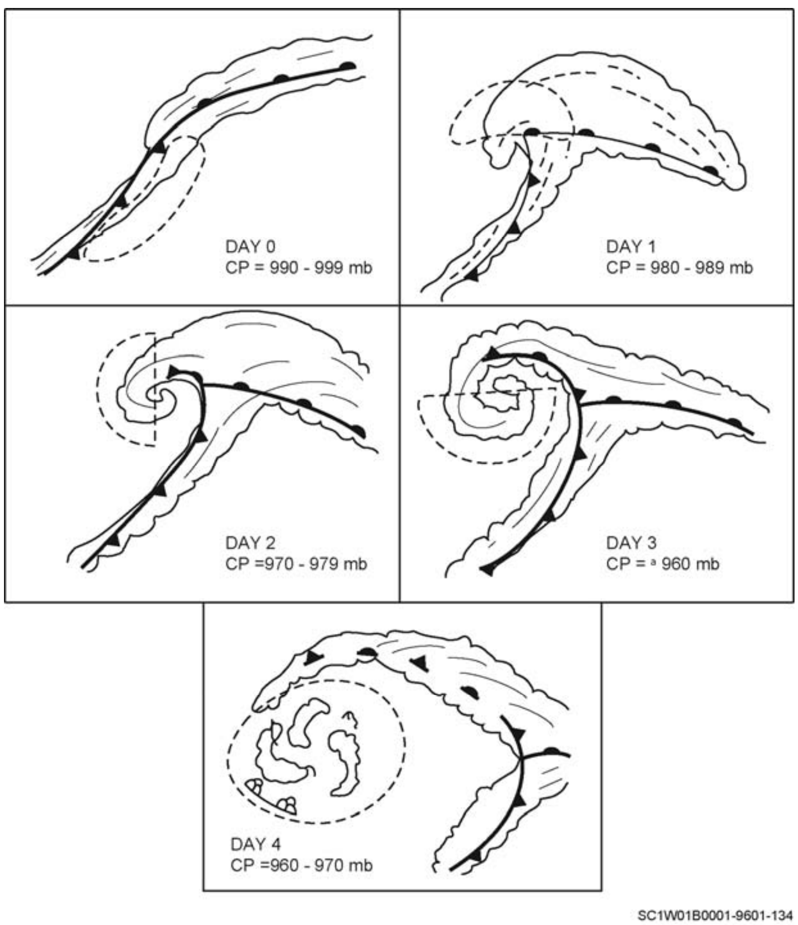

Figure 2–98. Strongest wind regions.

Initial stages of comma development (990mb to 999mb)

On the average, maximum winds occur in the eastern portion along, and ahead of, the baroclinic zone cloud band in the warm air.

Comma cloud development (980mb to 989mb)
The maximum winds are found in the northern semicircle of the storm center.

Continued comma cloud development (970mb to 979mb)
The maximum winds are found in the western semicircle of the storm center.

Mature stage of comma cloud (960mb)
The maximum winds are found in the southern semicircle of the storm center.

As the storm slowly fills (960mb to 970mb), the maximum winds encircle the storm center.

424. Life cycle of a cut-off low

Our discussion on the life cycle of a cut-off low focuses on the cloud patterns and their relation to the flow and features around the low center.

Initial development

A deepening major short-wave trough is evident with baroclinic zone clouds located downstream. Upstream from the trough, a major short-wave ridge is building. Upper-level clouds are ending at the ridge axis or just downstream. The PFJ is evident with the sharp cloud edge on the poleward cloud edge upstream from the ridge. Also, look for the same cloud signature downstream from the trough.

Development

As the major short-wave trough continues to deepen, a closed upper-level low develops. The upper-level clouds indicate increased cyclonic turning. The baroclinic clouds associated with PFJ and the major short-wave ridge continues to extend poleward and to the east. This indicates the ridge is increasing its amplitude. The cloud pattern shows the PFJ is not able to continue its turn into the low. The low is now cut off from the cold air and the main PFJ. During this period, deformation zone cirrus has developed. A branch of the PFJ is still evident with the baroclinic zone clouds east of the cut-off low. Sometimes, an upper-level high center develops north of the cut-off low. The equatorward side of the upper-level clouds associated with the ridge becomes smoother and sharper, indicating the high has developed. The cut-off low has a vorticity maximum that is nearly coincident with it. There may be smaller scale comma-shaped clouds rotating around the low and moving eastward away from it. Minor short-wave troughs and advection lobes are associated with them.

Dissipation/change in character

A cut-off low may slowly fill and dissipate. Cloudiness gradually decreases over time. A cut-off low can eventually rejoin the main westerlies. If a major short-wave trough approaches the cut-off low from the west, the low begins to open up and move. The low then accelerates northeastward, eventually loses its closed circulation, and becomes a moving short-wave trough.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

422. Baroclinic lows

1. Why are conveyor belts used to explain a comma cloud pattern?

2. Name the conveyor belts associated with a comma cloud.

3. In which comma cloud pattern does the PFJ separate baroclinic zone cirrus from deformation zone cirrus?

4. With what are shear lobes normally seen?

5. With what meteorological phenomena are vorticity advection lobes normally associated?

6. What kind of thickness phenomenon is located downstream from a surface low?

423. Life cycle of a baroclinic low (frontal wave stage)

1. Match the frontal wave stages in column B with their description/ characteristic in column A. Column B items may be used more than once.

Column A

____ (1) The surface low begins to move under the upper low.
____ (2) WV imagery shows the dark band wrapped around the upper low.
____ (3) The upper low and the surface low become vertically stacked.
____ (4) There is a slight “S” shape to the cloud pattern on the cold airside of the widening baroclinic zone.
____ (5) The thickness product shows weak thermal advection ahead and behind the surface low although a strong thermal gradient exists.
____ (6) A dark band curves cyclonically within the comma head depending if the comma cloud is developing into a type A or type B system.
____ (7) As the vorticity comma cloud is increasing, the associated upper-level clouds wrap around the vorticity maximum, developing more deformation zone cirrus.

Column B

a. Mature stage.
b. Initial stage.
c. Dissipation stage.
d. Intensification stage.

2. What are the ways that a baroclinic leaf can develop into a comma cloud?

3. Given a baroclinic low over the ocean with an initial pressure of 990mb, what central pressure would the low have with the following characteristics: the low has a well-defined hooked pattern in the cloud band with a surge region that is very apparent?

4. What central pressure would a low have if the maximum winds are found in the northern semicircle of the low center?

424. Life cycle of a cut-off low

1. When does the deformation zone cirrus develop with a cut-off low?

2. If a major short-wave trough approaches the cut-off low from the west, what will the low do?

2–5. Local Circulation

In this section you learn about local circulations in the low-levels and the type of weather that develops due to these circulations. You also learn how wind flow is affected by land, water, and air interaction, including the types of clouds caused by these interactions.

425. Specific local circulations

When synoptic wind flow is less than 10 knots, cloud patterns may develop from local wind circulations. These cloud patterns are evident on METSAT imagery. There are four local circulations we discuss.

Valley breeze

Due to differential heating, winds generally flow up the mountain. Convective cloudiness tends to form along the peaks and ridgelines. Clouds range from CU to CB clouds. Moisture availability and the stability of the air determine the vertical development of the clouds.

Mountain breeze

Due to cooling of the mountaintops, winds generally flow downhill. The cool air accumulates in the valley and, under clear skies; radiational cooling creates favorable conditions for the formation of radiational fog. In deep valleys with rivers, the fog conforms to the meanders of the river.

Land breeze

The contrast between the cool land air moving seaward and the warmer air offshore creates a mesoscale low-level convergence boundary. Convective cloud lines and thunderstorms may develop along this boundary that can last until midmorning. Land breezes are often most intense offshore from mountainous coastal regions. Along the coast and just inland, the skies are generally clear.

Sea/lake breeze

The contrast between the cooler, moister air moving inland over the warmer land forms a mesoscale low-level convergence boundary, which is known as a sea-breeze front. Convective cloud lines and thunderstorms develop along this boundary. There is an absence of clouds along and just offshore.

426. Land/water interface

The interface between land and water can give you clues to what is happening with the low-level wind flow. Terrain in the open water areas, such as islands, and mountains tell you the type of wind flow. The cloud pattern can indicate where the inversion is in relation to the terrain in the region of interest.

Bow waves (leeside effects)

Bow waves occur when the low-level cloud field is disrupted by the low-level wind flow being diverted around an obstacle, such as an island in the ocean. A clear area is found on the leeside of the island in the wake of the obstruction. These clear areas can extend downstream a considerable distance. On the VIS and FIR imagery, this shows up as a dark area.

Karman vortices

Karman vortices are counter-rotating cloud spirals (eddies) of SC clouds found in the wake of an island and associated with winds of 10 to 25 knots. They may or may not be occurring with a bow wave. An inversion is present and the terrain must penetrate the inversion. On the VIS, they appear as a white, swirling cloud in the wake of the island. On the FIR, they appear dark gray. Figure 2–99 shows Karman vortices downwind of the Guadeloupe Islands off the western shore of Baja. There are three vortices shown by cutouts A, B, and C.

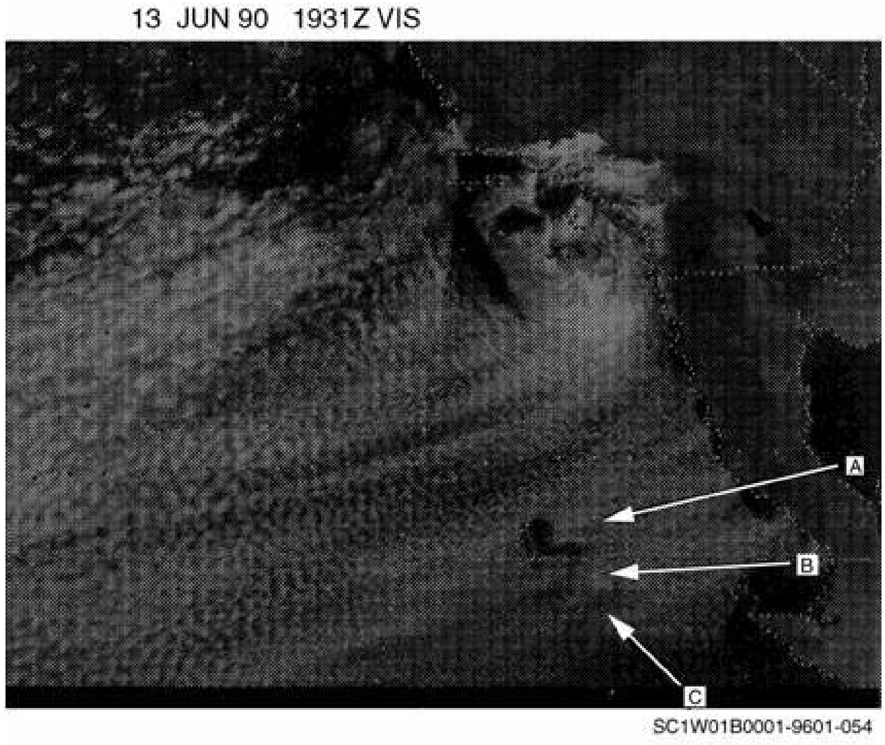

Figure 2–99. Karman vortices.

Cloud plumes

Cloud plumes are long, narrow SC lines produced by the turbulent vertical motion of air forced around an island in a strong low-level wind. An inversion is present; normally, it is located above the terrain. If the inversion is below the terrain, a plume cloud can form if the low-level winds are lighter or stronger than the winds needed to form Karman vortices. The plume originates at the tallest portion of the terrain. On the VIS and FIR, these are straight or wavy cloud lines and have the same gray shades as Karman vortices. Plume clouds can form for other reasons. However, these are the main causes of this cloud phenomenon.

427. Air/water interface

The temperature difference between the air and water can cause certain cloud patterns, depending on the stability of the low levels. Another factor is the presence of manmade pollutants that might contribute to cloud formation. These cloud patterns are identified as ship trails, upwelling fog, and stratocumulus.

Anomalous cloud lines (ship trails)

This is a low-level SC cloud line that is produced by the interaction of ship exhaust with a stable, moist marine air layer. They form in regions of light anticyclonic wind flow. They look the same as SC clouds on the VIS and FIR imagery.

Fog caused by upwelling

This occurs along the west coast of continents in a stable, low-level atmosphere. Such fog is due to air coming in contact with the cold ocean surface and condensing into water droplets. The sheets of fog and stratus typically cover an extensive area over water, along the coast. The fog does not develop inland. However, it may move inland over time. This is mainly a phenomenon that occurs in the summer where wind flow is fairly light.

Stratocumulus lines

These form when cold, dry air moves off the continents in the winter over the relatively, warmer ocean where the dry air can pick up moisture. Low-level instability causes the formation of these clouds. These occur in the winter and are seen off the eastern and southern coasts of the United States (including Alaska), Korea, China, and Japan. They can also occur over large, unfrozen lakes, such as the Great Lakes.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

425. Specific local circulations

1. What causes winds generally to flow up the mountain?

2. During the sea/lake breeze, what type of cloud forms along and just offshore?

426. Land/water interface

1. What cloud type is associated with winds of 10 to 25 knots in the wake of an island?

2. Describe a cloud plume.

427. Air/water interface

1. What cloud patterns can the temperature difference between the air and water cause, depending on the stability of the low-level?

2. Where does upwelling fog occur? Why?

3. State how and when stratocumulus lines occur.

Answers to Self-Test Questions

408

1. (1) d.
   (2) a.
   (3) e.
   (4) c.
   (5) b.
2. (1) g.
   (2) d.
   (3) k.
   (4) h.
   (5) i.

(6) f.
(7) c
(8) j.
(9) a.
(10) b.
(11) e.

409

1. Because of the brightness contrasts on the imagery.
2. The brightness (reflectivity) of the snow decreases rapidly when the angle is below 45 degrees. Also it is easier to distinguish cloud cover from snow because of the shadows with a low sun angle.
3. Dust has a filmy, diffuse appearance with a medium to light gray shade on VIS and FIR imagery. If it shows up on FIR, it is a dark to medium gray shade.
4. They appear dull, filmy, and diffuse with a light to medium gray shade, depending on how dense.
5. They only appear if they are at high altitudes or in large concentrations.

410

1. The sun's rays reflecting off the water surface directly into the METSAT sensor.
2. The sun glint pattern has a circular shape to it when we view it on a geostationary METSAT image. On polar orbiting satellites, it shows a line pattern from the top to the bottom of the picture if the satellite subpoint and the solar subpoint are sufficiently close.
3. To estimate the surface wind speeds, direction, and the state of the sea and to locate flooded lowlands that can be used for Army trafficability support.
4. VIS imagery.

411

1. (1) e.
   (2) c.
   (3) d.
   (4) a.
   (5) b.
   (6) f.
   (7) h.
   (8) g.
2. Rotation and convergence.

412

1. (1) Identify the cloud pattern.
   (2) Use the cloud pattern recognition, and cloud and non-cloud phenomena, to help determine the wind flow.
   (3) Use the cloud patterns and wind flow to determine specific synoptic features and relate them to the map features.
2. Cloud patterns.

413

1. Baroclinic zone clouds, vorticity comma clouds, and deformation zone clouds.
2. Baroclinic zone clouds.
3. Dry slot.

414

1. The first is by following specific cloud elements on an animated satellite imagery. The second is to interpret specific cloud and non-cloud phenomena to find the wind flow.
2. Cirrus streaks.

415

1. About 1° latitude on the poleward side of the sharp cloud edge.
2. Normally 1 to 3° on the poleward side of the boundary between the open-cell CU and the closed-cell SC.
3. About 1° of latitude on the poleward side of the cirrus cloud.
4. Areas of dark (dry) and light (moist) gray shade contrast.
5. Downstream from the intersection, baroclinic zone clouds are present. Upstream from the intersection point, no high- and mid-level clouds are present. The low frontal clouds thin out, become fragmented, and may even disappear due to the downward vertical motion.
6. WV imagery, because the deformation zone location is marked by a sharp gray shade contrast between dry and moist regions.
7. Baroclinic leaves, enhanced CU, and the vorticity comma cloud associated with the synoptic-scale comma cloud.

416

1. An egg-like appearance.
2. The convergence of the outflow boundaries (arc clouds) associated with the individual cells.

417

1. The pattern formed by the tropical cyclone's clouds is related to the cyclone's intensity rather than to the amount of clouds in the pattern. The cyclone's intensity is related to the distance the curved band is curved around the storm center.
2. The first is the T (tropical) number. The T number describes the rate of development or dissipation of a tropical cyclone. The second indicator is the current intensity (CI) number. It describes the true intensity of the storm.

418

1. The terrain's effects on clouds.
2. Mountains, islands, and lakes.

419

1. Because it's embedded in the multilayered cloudiness (baroclinic zone clouds).
2. At the tail end of the comma cloud.

420

1. Knowing the terrain in a region helps tremendously when you analyze the wind flow in the lower troposphere.
2. (1) c.
   (2) a.
   (3) b.
   (4) e.
   (5) d.
3. Bow waves, plume clouds, and Karman vortices.

421

1. (1) d.
   (2) b.
   (3) a and c.
   (4) d.

2 (1) a.
   (2) c.
   (3) b.
   (4) d.

3. Because of the large amount of moisture available for cloud formation.
4. Visual METSAT imagery.

422

1. Because they explain the simultaneous horizontal and vertical movement of an air parcel with a comma cloud.
2. The warm conveyor belt (WCB), cold conveyor belt (CCB), and dry-air conveyor belt (DACB).
3. Type A pattern.
4. Speed maximums.
5. Short-wave troughs and ridges.
6. A thickness ridge.

423

1. (1) a.
   (2) a.
   (3) c.
   (4) b.
   (5) b.
   (6) d.
   (7) d.
2. It can develop upstream from the baroclinic zone clouds and merge with the baroclinic zone clouds; it can develop into a comma cloud well upstream from a baroclinic zone cloud pattern; or it can develop along the cold air side of the baroclinic clouds.
3. 980 to 989 mb.
4. 980 to 989 mb.

424

1. When the low cuts off from the cold air and the main PFJ.
2. The low will begin to open up and move, accelerating northeastward, and eventually losing its closed circulation pattern to become a short-wave trough.

425

1. Differential heating.
2. None.

426

1. Karman vortices.
2. They are long, narrow SC lines produced by the turbulent vertical motion of air forced around an island in a strong low-level wind.

427

1. Ship trails, upwelling fog, and stratocumulus lines.
2. This occurs along the west coast of continents in a stable, low-level atmosphere. It is caused by air coming in contact with the cold ocean surface and condensing into water droplets.
3. These form when cold, dry air moves off the continents in the winter over the relatively, warmer ocean where the dry air picks up moisture.

Unit Review Exercises

Note to Student: Consider all choices carefully, select the *best* answer to each question, and *circle* the corresponding letter. When you have completed all unit review exercises, transfer your answers to the Field-Scoring Answer Sheet.

Do not return your answer sheet to the Air Force Career Development Academy (AFCDA).

29. (408) A series of aligned cloud elements, nearly all of which are connected with a general width of less than 1 degree of latitude, is called a
   a. striation.
   b. cloud line.
   c. cloud band.
   d. cloud street.

30. (408) Cloud streets are very similar to cloud lines except the
   a. pixels are connected.
   b. elements are connected.
   c. pixels are not connected.
   d. elements are not connected.

31. (408) What two fog types can we best discern on meteorological satellite (METSAT) imagery?
   a. Ice and ground fog.
   b. Sea and radiation fog.
   c. Coastal and steam fog.
   d. Advection and upwelling fog.

32. (408) On far infrared (FIR) imagery, the cellular or textured appearance of stratocumulus clouds may not be observable due to the
   a. sun angle.
   b. viewing angle.
   c. sensor resolution.
   d. cloud-top temperatures.

33. (408) The size and shape of a cumulonimbus cloud's anvil cirrus are determined by the
   a. height of the tropopause.
   b. strength of the inversion.
   c. stability of the atmosphere.
   d. strength of the upper-level winds.

34. (408) With what kind of windflow are open-cell cumulus clouds associated?
   a. Cyclonic flow only.
   b. Anticyclonic flow only.
   c. Cyclonic or straight-line flow.
   d. Anticyclonic or straight-line flow.

35. (408) Which far infrared (FIR) enhancement curve helps to identify mid-level clouds?
   a. EC curve.
   b. HF curve.
   c. MB curve.
   d. ZA curve.

36. (408) The wind speeds in transverse bands are usually greater than or equal to
   a. 80 knots.
   b. 70 knots.
   c. 60 knots.
   d. 50 knots.

37. (409) It is easier to distinguish snow from cloud cover with a low sun angle because of the
   a. shadows from the clouds.
   b. lower cloud-top temperatures at higher sun angles.
   c. high reflectivity of the Sun off snow at lower sun angles.
   d. low reflectivity of the Sun off the snow at higher sun angles.

38. (409) When do haze, pollution, and aerosols appear on FIR imagery?
   a. Only over dark terrain.
   b. When viewed with a simultaneous VIS imagery.
   c. Only if they are at high altitudes or in large concentrations.
   d. When the satellite is at a latitude other than the solar subpoint.

39. (410) Sun glint typically occurs under
   a. a stable condition with strong winds.
   b. an unstable condition with strong winds.
   c. a stable condition with light or calm winds.
   d. an unstable condition with light or calm winds.

40. (410) What is the terminator phenomenon in meteorological satellite (METSAT) imagery?
   a. The transition line from day to night.
   b. The thermal contrast of the sun's angle.
   c. When the satellite and the solar subpoints are close.
   d. When the satellite is at a latitude other than the solar subpoint.

41. (411) What do we commonly use translation to measure?
   a. Speed of lows.
   b. Shearing of the wind field.
   c. Expansion of the wind field.
   d. Contraction of the wind field.

42. (411) The horizontal axis where air parcels are moving away from the col is called the axis of
   a. dilatation.
   b. contraction.
   c. deformation.
   d. magnification.

43. (412) When you interpret meteorological satellite (METSAT) imagery, what is the first thing that you must do?
   a. Determine the windflow.
   b. Identify the cloud patterns.
   c. Determine specific synoptic features.
   d. Determine specific mesoscale features.

44. (412) When you interpret meteorological satellite (METSAT) imagery, what is the second thing that you must do?
   a. Determine the wind flow.
   b. Identify the cloud patterns.
   c. Determine specific synoptic features.
   d. Determine specific mesoscale features.

45. (413) A unique characteristic of the baroclinic leaf is the
   a. "V" notch in the tail of the leaf.
   b. cyclonic swirl in the cloud pattern.
   c. mid-level comma-shaped cloudiness.
   d. shallow "S" shape on the sharp upstream edge of the cloud system.

46. (413) What is the comma-shaped low to mid-level cloudiness in a comma cloud called?
  a. Surge region.
  b. Baroclinic zone clouds.
  c. Vorticity comma clouds.
  d. Deformation zone clouds.

47. (414) Where do cirrus streaks form?
  a. Parallel to, and on the poleward side of, the jet stream flow.
  b. Parallel to, and on the equatorward side of, the jet stream flow.
  c. Perpendicular to, and on the poleward side of, the jet stream flow.
  d. Perpendicular to, and on the equatorward side of, the jet stream flow.

48. (415) Where is the jet stream axis located in relation to the baroclinic zone cirrus?
  a. 1 degree latitude on the poleward side of the cloud edge.
  b. 1 degree latitude on the equatorward side of the cloud edge.
  c. Perpendicular to the cloud band orientation and on the poleward side of the cloud bands.
  d. Parallel to the flow, on the equatorward side of the jet axis, and at the leading edge of a jet maximum.

49. (415) How does water vapor (WV) imagery show the strengthening of a jet stream?
  a. An increase in the amount of cirrus streaks visible.
  b. A decrease in the moisture ahead of the trough axis.
  c. Less contrast between the dark and light gray shades.
  d. The dark band (jet stream) becomes darker and wider.

50. (415) What is occurring when you see a bulge or slight “S” shape develop and move along the back side of the frontal cloud band?
  a. The front is strengthening.
  b. The frontal wave is dissipating.
  c. A wave is developing on the front.
  d. The front has out run its upper-level support.

51. (415) What is taking place in the atmosphere when enhanced cumulus starts to take on a comma-cloud shape?
  a. The minor short-wave trough associated with the enhanced cumulus (CU) is moving over a long-wave ridge.
  b. The major short-wave trough associated with the enhanced CU is moving over a long-wave ridge.
  c. The major short-wave trough associated with the enhanced CU is developing into a minor short-wave trough.
  d. The minor short-wave trough associated with the enhanced CU is developing into a major short-wave trough.

52. (415) Where are upper lows associated with the comma cloud structure positioned?
  a. Slightly west of the center of the swirl of upper-level cloudiness within the deformation zone cirrus.
  b. Slightly east of the center of the swirl of upper-level cloudiness within the deformation zone cirrus.
  c. Slightly west of the center of the swirl of upper-level cloudiness within the baroclinic zone cirrus.
  d. Slightly east of the center of the swirl of upper-level cloudiness within the baroclinic zone cirrus.

53. (415) The deformation zone cirrus associated with a cut-off low is normally stretched in
  a. east-to-west direction.
  b. north-to-south direction.
  c. northeast-to-southwest direction.
  d. southeast-to-northwest direction.

54. (415) It is easier to pick out vorticity maximums over water than over land because of the
  a. strong deformation zone predominant over water.
  b. warmer temperatures normally over the water source.
  c. strong cloud rotation that occurs over the water source.
  d. abundance of convective clouds over the moisture source.

55. (415) What causes baroclinic leaf cloud patterns?
a. Mid-level deformation ahead of the jet maximum, upstream from the leaf.
b. Mid-level deformation behind the jet maximum, downstream from the leaf.
c. Upper-level deformation ahead of the jet maximum, upstream from the leaf.
d. Upper-level deformation behind the jet maximum, downstream from the leaf.

56. (416) What are organized, persistent areas of deep convection noted in meteorological satellite (METSAT) imagery during the warm season called?
a. Mesoscale convective systems (MCS).
b. Mesoscale convective complexes (MCC).
c. Synoptic-scale convective systems (SCS).
d. Synoptic-scale convective complexes (SCC).

57. (417) What does the Dvorak method of tropical cyclone analysis describe?
a. Tropical cyclone outflow and the day-to-day changes in the cloud patterns of the storm.
b. Tropical cyclone intensity changes and the hour-by-hour changes in central pressures of the storm.
c. Tropical cyclone development in terms of day-by-day changes in the cloud pattern of the storm and its environment.
d. Tropical cyclone dissipation in terms of day-to-day changes in central pressures of the storm and its cloud patterns.

58. (417) What do we use the T number in the Dvorak method of tropical cyclone analysis to describe?
a. Rate of development or dissipation of a tropical cyclone.
b. Rate of change in the cloud pattern associated with the tropical cyclone.
c. Recognizable cloud pattern stages in the tropical cyclone as the intensity changes.
d. Short-period convective scale activity, diurnal influences, and adjacent circulation obstructing development of the storm.

59. (417) In operational practice, what do we use to describe the intensity of a tropical storm?
a. T number.
b. CI number.
c. KT number.
d. Fujita scale.

60. (418) When interpreting clouds in the lower troposphere, what is the first thing you must do?
a. Determine the windflow.
b. Identify the cloud patterns.
c. Determine specific synoptic features.
d. Determine specific mesoscale features.

61. (418) When interpreting clouds in the lower troposphere, what can you use to help determine the low-level windflow?
a. Terrain effects.
b. Moisture pattern.
c. 700 millibar (mb) product analysis.
d. Type of advection occurring.

62. (419) It is hard to initially position an extratropical surface low because it’s embedded in
a. enhanced cumulus clouds.
b. deformation zone cirrus.
c. core convection clouds.
d. baroclinic zone clouds.

63. (420) An open-cell cumulus field in the shape of elongated doughnuts is associated with windspeeds of
a. <10 knots.
b. 11 to 20 knots.
c. 21 to 30 knots.
d. > 30 knots.

64. (420) Leeside clearing along the eastern slopes of the Rockies and the Appalachian Mountains indicates the winds
 a. on the leeside are anticyclonic.
 b. cross the ridge line in excess of 50 knots.
 c. cross the mountain ridge line at an angle of less than 45 degrees.
 d. cross the mountain ridge line at an angle of greater than 45 degrees.

65. (420) What happens to cumulus clouds that develop upwind of a lake and over warm land in the summer as they move over the comparatively cooler lake?
 a. They dissipate as they become cooled from below.
 b. They form stratocumulus lines downstream over the lake.
 c. They build into towering cumulus or cumulonimbus clouds.
 d. They cool to the dew point producing fog and/or stratus clouds.

66. (421) Fronts are easier to identify over water on meteorological satellite (METSAT) imagery than over land because
 a. cloud-top temperatures are more easily discerned over water than over land.
 b. more moisture is available for cloud formation along the frontal boundary.
 c. less moisture is available for cloud formation along the frontal boundary.
 d. the satellites' resolution over water is better than over land.

67. (421) With a warm front, the amount and type of cloudiness depends on the amount of
 a. convective instability in the cold air.
 b. convective instability in the warm air.
 c. available moisture and the stability of the cold air.
 d. available moisture and the stability of the warm air.

68. (421) The type of cloudiness with a stationary front depends on the
 a. height of the inversion.
 b. stability of the cold air.
 c. type of vertical motions.
 d. stability of the warm air.

69. (421) At what stage of development of an extratropical low does the dry slot begin to wrap around the upper low?
 a. Initial stage.
 b. Intensification stage.
 c. Mature stage.
 d. Dissipation stage.

70. (421) To find the position of a surface baroclinic high over land in the late fall to early spring, what must you first determine?
 a. Position of the low-pressure center.
 b. Upper-level wind flow.
 c. Low-level wind flow.
 d. Terrain influences.

71. (422) Except for possible convection along the cold front, which conveyor has the coldest (highest) cloud tops associated with it?
 a. Cold conveyor belt (CCB).
 b. Warm conveyor belt (WCB).
 c. Dry-air conveyor belt (DACB).
 d. Moist air conveyor belt (MACB).

72. (422) Which conveyor belt forms the comma cloud head?
 a. Cold conveyor belt (CCB).
 b. Warm conveyor belt (WCB).
 c. Dry-air conveyor belt (DACB).
 d. Moist air conveyor belt (MACB).

73. (422) Which statement describes a type A comma cloud pattern?
   a. Polar front jet (PFJ) reforms north of the warm front at the top of the comma cloud and extends eastward.
   b. PFJ is continuous and crosses the comma cloud system at, or north of, the triple point.
   c. PFJ is not continuous through the comma cloud system.
   d. PFJ wraps around the upper-level low and weakens.

74. (422) Which statement describes a type B comma cloud pattern?
   a. Polar front jet (PFJ) separates baroclinic zone cirrus from deformation zone cirrus.
   b. PFJ is continuous and crosses the comma cloud system at or north of the triple point.
   c. Deformation zone cirrus is typically lower and thinner than the baroclinic zone cirrus.
   d. Deformation zone cirrus is approximately the same height as baroclinic zone cirrus and is much thicker.

75. (422) If the polar front jet (PFJ) lies in the surge region of the comma cloud system, the PFJ speed maximum is located in the
   a. dry slot on the equatorward side of the 500 millibar (mb) low.
   b. surge region on the poleward side of the 500-mb low.
   c. vorticity comma cloud system on the poleward side of the 500-mb low.
   d. vorticity comma cloud system on the equatorward side of the 500-mb low.

76. (423) During the initial stage of development of a frontal wave, the baroclinic zone cloud system (frontal cloud band) begins to
   a. widen.
   b. shrink.
   c. dissipate.
   d. flux.

77. (423) During which stage of development of a frontal wave does the low become identifiable in the upper levels by the dry slot wrapping around the low?
   a. Initial stage.
   b. Intensification stage.
   c. Mature stage.
   d. Dissipation stage.

78. (423) What cloud pattern develops into a comma cloud 75 percent of the time?
   a. Baroclinic leaf.
   b. Deformation zone.
   c. Anomalous clouds.
   d. Vorticity comma cloud.

79. (423) During what phase of development of a cold-air vortex do mid-level clouds, which are associated with a short-wave trough, begin to form the vorticity comma cloud?
   a. Phase one.
   b. Phase two.
   c. Phase three.
   d. Phase four.

80. (423) When you estimate sea-level pressures using meteorological satellite (METSAT) imagery, where must you locate the baroclinic lows associated with comma clouds?
   a. From 40°N and poleward.
   b. From 40°S and poleward.
   c. From 40°N and equatorward.
   d. From 40°S and equatorward.

81. (423) At what estimated sea-level pressure would a low be characterized by a cloud band wrapped once around the low center?
   a. 990 millibar (mb) to 1000mb.
   b. 980 to 989mb.
   c. 970 to 979mb.
   d. 960 to 969mb.

82. (424) During the development of a cut-off low, after the low becomes cut off from the cold air and the polar front jet (PFJ), what cloud type develops?
a. Baroclinic zone cirrus.
b. Baroclinic leaf clouds.
c. Vorticity comma clouds.
d. Deformation zone cirrus.

83. (425) What factors determine the vertical development of the clouds associated with the valley breeze?
a. Availability of moisture and the stability of the air.
b. Height of the mountains and the speed of the winds.
c. Temperature and dew point that the air parcels start at.
d. Amount of temperature change and the ability of the air to hold the moisture.

84. (425) The mesoscale low-level convergence boundary created by the cooler, moister air moving inland over the warmer land during the day is known as
a. sea-breeze front.
b. lake-effect front.
c. land-breeze front.
d. land/water interface.

85. (426) What causes bow waves?
a. These are cumulus streets produced by the turbulent horizontal motion of air forced around an island in a strong low-level wind.
b. When low-level counter rotating cloud spirals of stratocumulus (SC) clouds occur in the wake of an island associated with winds of 10 to 25 knots.
c. When a low-level cloud field is disrupted by the low-level wind flow being diverted around an obstacle such as an island in the ocean.
d. These are long, narrow SC lines produced by the turbulent vertical motion of air forced around an island in a strong low-level wind.

86. (426) What cloud created by a barrier appears on visual imagery as a white swirling cloud?
a. Eddies.
b. Bow waves.
c. Cloud plumes.
d. Karman vortices.

87. (427) Anomalous cloud lines form in
a. a stable, moist marine air layer in a light cyclonic wind flow.
b. an unstable, moist marine air layer in a light cyclonic wind flow.
c. a stable, moist marine air layer in a light anticyclonic wind flow.
d. an unstable, moist marine air layer in a light anticyclonic wind flow.

88. (427) What causes the formation of stratocumulus lines?
a. Low-level stability.
b. Low-level instability.
c. Stable, low-level windflow.
d. Stable, low-level inversions.

Glossary

Terms

Absorptivity—The ratio of absorbed radiation by an object to the absorbed radiation by a black body at the same wavelength and temperature.

Actiniform clouds—Skeletal remains of closed-cell stratocumulus, easily confused with open-cell cumulus.

Albedo—The percentage of incident energy actually reflected.

Algorithm—A procedure for solving a mathematical problem. Basically, it is a formula.

Anomalous cloud lines—Low-level stratocumulus cloud line produced by the interaction of ship exhaust with a stable, moist marine air layer forming in regions of light anticyclonic wind flow.

Anvil cirrus—Thunderstorm blowoff.

Arc clouds—A curved line of cumulus clouds formed due to a thunderstorm downdraft of cold dry air.

Attenuation—Any loss of energy due to absorption and scattering of IR radiation by atmospheric elements.

Axis of contraction—The axis of most rapid shrinking where air parcels are moving toward the col.

Axis of dilatation—The axis of most rapid stretching where air parcels are traveling away from the col.

Baroclinic leaf—Thick mid- and upper-level cloud pattern recognized as the first sign of comma-cloud development. It normally has a shallow “S” shape on the sharp upstream edge of the cloud system.

Baroclinic zone cloud system—Multilayered clouds associated with the cold and warm fronts.

Billow clouds—Regularly spaced parallel cirrus cloud bands caused by vertical shear due to the stronger winds aloft, oriented perpendicular to the winds.

Cirrus streaks—Small isolated patches of cirrus generally occurring away from other clouds and aligned with the upper-level winds.

Closed-cell stratocumulus—Cellular, closely packed stratocumulus that forms mostly over ocean areas. Forms with rising air in the center of closely packed cloud cells and with descending air at the edges.

Cloud element—The smallest cloud that can be seen on an image as determined by the resolution of the METSAT sensor.

Cloud fingers—Low-level clouds that develop because of low-level convergence.

Cloud lines—A nearly continuous cloud formation where elements are connected and the line is less than one degree in width.

Cloud plumes—Long, narrow stratocumulus lines produced by the turbulent vertical motion of air forced around an island in a strong low-level wind.

Cloud streets—A nearly continuous cloud formation where elements are not connected.

Cloud type—A form of cloud seen in the sky (cumulus, altocumulus, etc.).

Col—The center of the deformation zone where winds are calm.

Comma head—The northern portion of the comma cloud.

Condensation trails—See contrails.

Contamination—Energy sensed by the satellite from two or more sources along the same line of sight.

Contrails—Cirrus cloud lines formed from jet exhaust that appear as unnatural anomalous cloud lines.

Contrast—The difference in reflectance or albedo between an object and its background.

Cut off lows—Small, deep pools of cold air located equatorward of the PFJ.

Deformation—The stretching or shearing of the wind field.

Dendritic—Vein-like.

Divergence—The spreading or contracting of the wind field.

Dry slot—See surge region.

Emissivity—The ratio of emitted radiation from an object to the emitted radiation from a black body at the same frequency (or wavelength) and temperature.

Enhanced cumulus—An area of towering cumulus and small cumulonimbus clouds found in an area of open-cell cumulus due to a secondary vorticity maxima or positive vorticity advection.

Enhancement—A series of gray shades corresponding to thermal values that provide a thermal contrast to features on the imagery.

Foreshortening—A loss of resolution caused by an oblique (shallow) viewing angle that results in a distortion near the edge of the picture on any type of METSAT imagery.

Geometric scattering—Scattering by cloud or fog droplets and precipitation.

Infrared contrast—A radiometric temperature difference between a target and its background.

Inherent contrast—The actual contrast between two objects based solely on their properties.

Integrated water vapor (WV) content—This EDR is a measurement of the amount of water vapor in a column extending from the top of the atmosphere to the surface along the sensor-to-ground path.

Karman vortices—Counter-rotating cloud spirals (eddies) of stratocumulus clouds found in the wake of an island and associated with winds of 10 to 25 knots.

Kirchoff’s law—This law says for objects in thermodynamic equilibrium (a steady temperature), absorption of radiant energy must be equal to the emission of radiant energy.

Lee-of-the-mountain cirrus—Multilayered cirrus cloud shield on the lee of a mountain chain.

Leeside cirrus—See lee-of-the-mountain cirrus.

Lithometeors—Dry, solid particles either suspended in the air or lifted from the ground by the wind.

Mesoscale convective complex (MCC)—Organized, persistent areas of deep convection noted in METSAT imagery during the warm season, especially over the US

Moisture channel—See water vapor imagery.

Neutral point—See col.

Oceanic total precipitable water—See integrated water vapor (WV) content.

Open-cell cumulus—Cumulus clouds that usually form over water behind mid-latitude cyclones. They are caused by strong cold-air advection over warmer water.

Planck's law—This law says the amount of radiation emitted by a black body at a given wavelength is proportional to its temperature.

Polarization—The orientation of the electric and magnetic components of electromagnetic radiation waves.

Polarization difference—The arithmetic difference in temperature between the horizontal and vertical channels at any one frequency.

Reflectivity—The ratio of the total amount of radiation reflected from the object to the total amount of incident radiation.

Resolution—The smallest individual element a sensor can detect.

Rope clouds—A very narrow line of cumulus/towering cumulus that is usually found over water and, occasionally, over very moist coastal land areas ranging from several hundred miles in length to several thousand.

Rotation—Turning about a point.

Scattering—The redirection of photons by molecules, aerosols, or other particles in the air.

Sea-ice concentration (IC)—A fraction of ocean area covered by ice.

Ship trails—See anomalous cloud lines.

The Stefan-Boltzmann law—This law relates the total amount of energy emitted at all wavelengths of the EM spectrum to the temperature of the black body.

Stratocumulus lines—SC elements formed by low-level instability caused by a large air/sea temperature difference.

Sun glint—The reflection of the sun's rays off the water surface directly into the METSAT sensor (seen only on visual imagery).

Surge region—The dry intrusion of air into the comma located near the region of highest winds near the cloud-top level (excluding convective activity).

Terminator—The transition line from day to night. Only seen on visual imagery.

Translation—Movement in a straight line.

Transmissivity—The ratio of energy that passes through an object to the total amount of energy received.

Transverse bands—Irregularly spaced, parallel bands of thin cirrus filaments and strands oriented perpendicular to the wind flow.

Vorticity comma-cloud system—Low to mid-level cloudiness in a comma shape. Associated with a vorticity maximum.

Water vapor imagery—Imagery measuring the earth's radiation at 6.7µm on GOES imagery and 5.7 to 7.1µm on METEOSAT imagery.

Wien's law—Also called Wien's displacement law. This law says the wavelength of the maximum irradiance of a black body depends on its temperature.

Abbreviations and Acronyms

λ	wavelength
ν	frequency
ε	emissivity
μm	micrometers or microns
λ_{Max}	the wavelength of maximum emitted energy
AC	altocumulus
ACSL	altocumulus standing lenticular
AS	altostratus
ASI	animated satellite imagery
CAA	cold-air advection
CAS	close air support
CB	cumulonimbus
CCB	cold conveyor belt
CeF	centrifugal force
CDC	career development course
CI	cirrus
CIN	current intensity number
Co(th)	threshold contrast
Co(x)	apparent contrast
CS	cirrostratus
CU	cumulus
CW	cloud water content
DACB	dry-air conveyor belt
DMSP	Defense Meteorological Satellite Program
DRO	direct readout sites
EDR	environmental data record
EIR	enhanced infrared
EM	electromagnetic
EMR	electromagnetic radiation
FIR	far infrared

FNMOC	Fleet Numerical Meteorology and Oceanography Center
FY	first-year ice
g	gravity
GHz	gigahertz
GMS	geostationary meteorological satellite
GOES	geosynchronous operational environmental satellite
H_2O	the molecular formula for water
IA	ice age
IC	sea-ice concentration
INSAT	Indian satellite
IR	infrared
IRDS	infrared detection set
IREPS	Integrated Refractive Effects Prediction System
IRSTS	Infrared Search and Track System
JTWC	Joint Typhoon Warning Center
K	Kelvin
kg	kilogram
km	kilometer
mb	millibars
MCC	mesoscale convective complex
METEOSAT	meteorological satellite
METSAT	meteorological satellite
mm/MW	millimeter/microwave
MY	multi-year ice
NASA	National Aeronautics and Space Administration
NIR	near infrared
nm	nautical miles
NOAA	National Oceanic and Atmospheric Administration
NS	nimbostratus
NWS	National Weather Service
PFJ	polar front jet

PBL	planetary boundary layer
RF	rain flag
RR	rain rate
SC	stratocumulus
SDR	sensor data record
SLP	sea-level pressure
SM	soil moisture
SSM/I	special sensor microwave/imagery
ST	land surface temperature; stratus
STJ	subtropical jet
TCU	towering cumulus
VIS	visible
WAA	warm-air advection
WCB	warm conveyor belt
WS	windspeed
WV	water vapor
µm	micrometer
CDC	career development course
T	tropical
PVA	positive voricity advection
NVA	negative vorticity advection

Student Notes

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