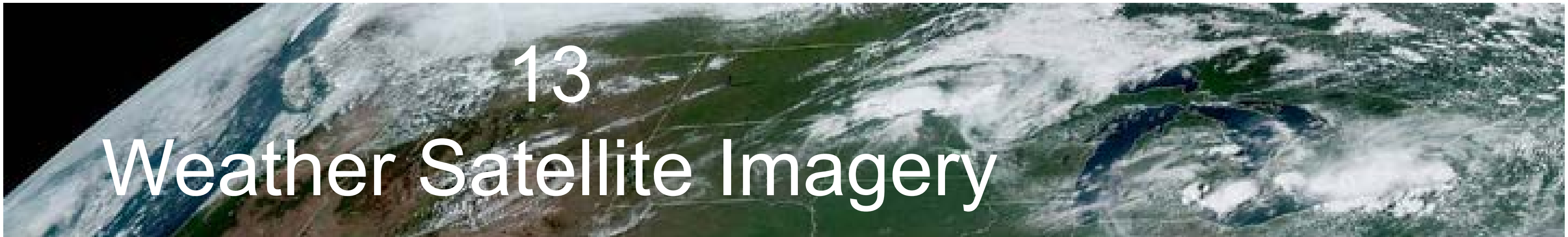


13
Weather Satellite Imagery

Weather satellites have been in orbit since the 1960s. Geostationary Operational Environmental Satellites (GOES) orbit the Equator at approximately 19,000 nautical miles (nm). They circle the Earth every 24 hours. From the satellite's perspective it's always over the same point—thus *geostationary*. Pilots have access to satellite images through Leidos Flight Service and the Aviation Weather Center websites, and other Internet sources, television broadcasts, and Date Link.

Two primary satellites provide images for the United States and adjacent oceanic areas—GOES west at approximately 135º west longitude and GOES east at approximately 75º west longitude. GOES west provides coverage for Hawaii, Alaska, the eastern Pacific, and the western third of the contiguous U.S. GOES east covers the eastern two-thirds of the contiguous U.S., the Caribbean, and western Atlantic.

Satellite interpretation is a science. Therefore, we will limit our discussion to two basics images: visible and infrared (IR). Visible—as the name implies—is a "snapshot" of conditions over the Earth. A visible image is the result of reflected sunlight. IR is a temperature picture; that is, the satellite senses the temperature of an area. Resolution varies, but is typically less than one nm over the continental U.S.

Resolution deteriorates with distance from the satellite, both north and south of the equator, and west and east of satellite's position. As a result of parallax, some clouds may be displaced several miles from their actual location and some objects will not show accurate brightness. Cloud elements smaller than the satellite's resolution will not be detected.

Comparing visible with infrared image (same time frame) allows optimum image

cloud element—The smallest cloud form that can be resolved on satellite imagery from a given satellite system.

interpretation. Often what may be misinterpreted or ambiguous on one image is resolved by comparing it with the other. Unfortunately, this doesn't work at night, with only the IR image available.

Case study

> I was briefing a pilot early one morning at the Oakland, California FSS. The pilot asked for a description of the "visible satellite image." In an attempt at "a little humor" I explained that the "flash bulb" on the satellite had failed. The pilot responded: "Yes, you've been having a lot of trouble with that satellite lately." Oh, well!

If we have the capability to view several images in succession—a satellite *loop*—we can often differentiate between surface and cloud features and get a sense of weather development, movement, and dissipation.

Note

> Computer enhanced imagery provides an approximation of daylight true color. At night an IR-based multispectral product differentiates between low liquid water clouds and higher ice clouds and provides a nighttime background for geo-referencing.

Most satellite images have a grid depicting geographical areas—large lakes and coastlines, and cultural boundaries—county, state, and international borders. A knowledge of terrain features helps in determining the location of specific terrain and weather features. Since Visual Flight Rules (VFR) aeronautical charts provide topographical features, these charts are often useful in locating various cultural and geographical locations, and thus weather features. When using satellite imagery, it's important to establish correct grid locations. This can often be accomplished by comparing the grid with geographical features.

Case Study

> Prior to the current generation of weather satellites, the grid was applied at

the satellite. Well, you know what happened; Murphy's law came into play. An error developed in the placement of the grid and it's a little tough to service these things 19,000 miles above the Earth. We were still able to use the images, but a lot of mental gymnastics was required for proper interpretation. Today's imagery processing places the grid at the receiver site; thus, eliminating any such problems.

Visible Imagery

Various types of clouds and terrain reflect different amounts of sunlight—clouds white, land masses gray, and water dark (almost black). At night without sunlight, there can be no direct visible imagery. Since neither the Earth's atmosphere nor empty space reflect sunlight, any background area on visible imagery will be black.

<<insert white sands callout>>

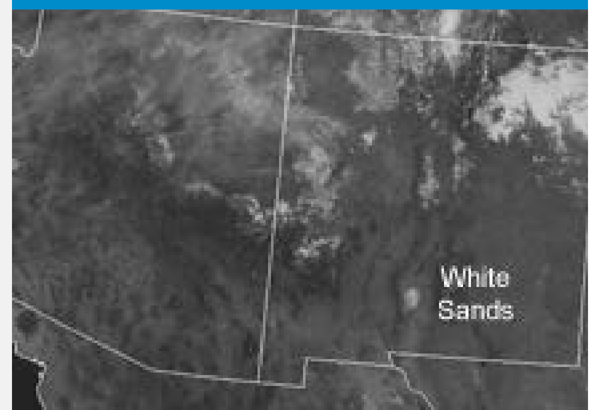
The amount of visible light reflected by objects is generally referred to as albedo. Table 13-1 lists various surface reflectivity.

Table 13-1. *Visible Satellite Surface Reflectivity*

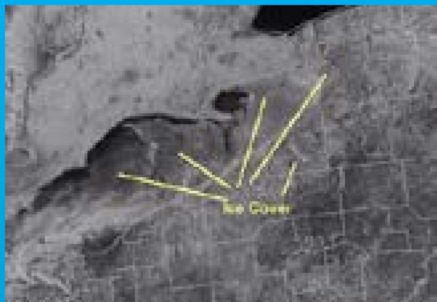
Surface	%	Surface	%	Surface	%
Large TS	92	White Sands, NM	60	Sand	27
Fresh SN	88	Old Snow	59	Sand & Brush	17
Thick Cs[1]	74	Thin St[3]	42	Forest	12
Thick Sc[2]	68	Thin Cs[1]	32	Water	9

[1]Cirrostratus
[2]Stratocumulus
[3]Stratus

Typically, a distinct boundary exists between land and oceans on visible imagery. Various types of terrain have intermediate or low reflectivity. Land surfaces appear as shades of gray; water surfaces—the poorest reflector—almost black. Water will always be dark—unless it's very shallow, muddy, or frozen. Therefore, land-water contrast is usually good on visible imagery. Large lakes, bays, and rivers can normally be identified. Major mountain ranges and valleys can also be seen; these features usually have different reflectivity. Deserts are also distinguishable because of the low reflectivity of sand compared to adjacent wooded and mountain areas.



White Sands, NM is clearly identifiable on visible imagery. We'll expand on terrain features throughout the chapter.



Why does Lake Erie freeze?

Lake Erie often freezes while the other Great Lakes remain ice free. In the autumn surface lake temperatures decrease. Just like in the atmosphere, the denser surface water sinks as warm water rises. Mixing continues through mid-winter until the lake reaches about 4°C. With further cooling, surface water becomes less dense which sets the stage for freezing. The other, deeper, Great Lakes almost never reach 4°C throughout their depths. Upwelling of warmer water prevents freezing.

Clouds are excellent reflectors of sun light and appear white—with large cumulonimbus clouds the best reflector. Differences in shading do not provide any information about cloud height, only thickness. On visible imagery, all thick clouds will be essentially the same shade—almost white. Thin clouds or areas of small clouds appear darker because less sunlight is reflected. Normally, small or thin clouds, in themselves, do not present an aviation hazard. However, a problem could arise should a pilot make an incorrect interpretation. It's important to be able to accurately interpret shading on an image.

Figure 13-1 illustrates the problem with small or thin clouds. Part of the reflected sunlight sensed by the satellite comes from the tops of the clouds, part from the land or water surface below. The resultant gray shade depicts an average. It is darker than a thick cloud and lighter than the surface. Small or thin clouds may not be detected at all. A comparison of visible and IR imagery often resolves these issues.

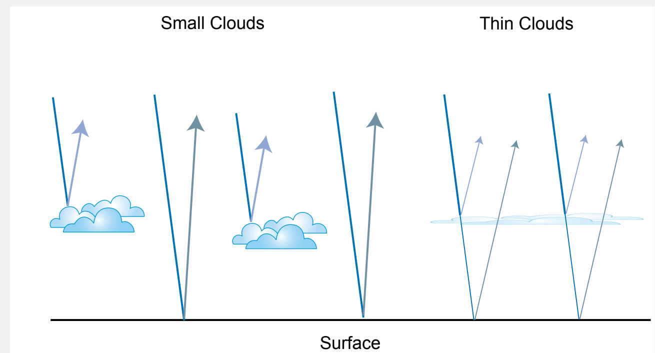


Fig. 13-1. *Small or thin clouds distort reflected brightness on visible imagery.*

Difficult to differentiate, both low clouds and snow reflect about the same amount of sunlight (Table 13-1). This is especially true over relatively flat terrain. The brightness of a snowy area depends, among other things, on whether there is vegetation within the area, the type of vegetation, and how much snow covered.

The difference between low clouds and snow can often be resolved by identifying terrain features, such as unfrozen rivers and large lakes. Clouds normally obscure terrain features, snow cover does not. Snow in mountainous areas is usually identifiable because it often forms a dendritic pattern. Mountain ridges above the tree line are essentially barren and snow is visible. In the tree filled valleys, most of the snow is hidden beneath the trees. This branchy, saw tooth, dendritic pattern identifies areas of snow cover. A satellite "loop" is also useful clouds tend to move, snow does not.

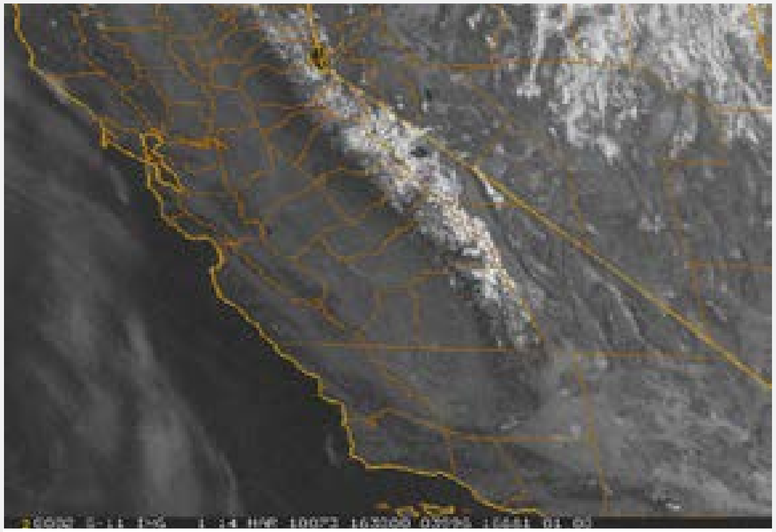
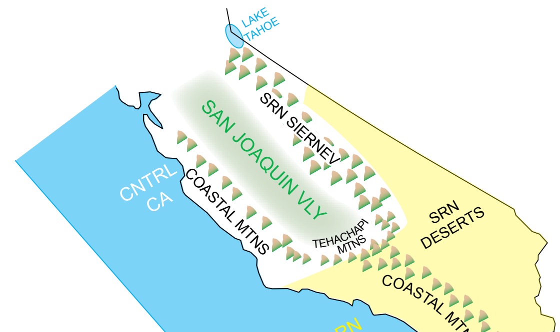
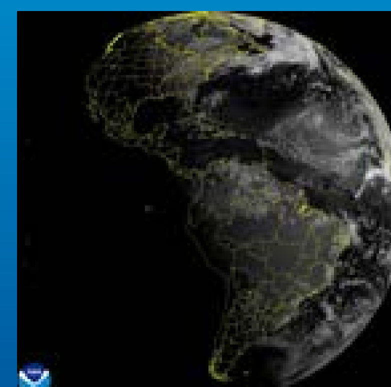


Fig. 13-2. *Many terrain features are identifiable on visible satellite imagery.*

Figure 13-2 (along with the callout) illustrates terrain and cloud features on visual imagery. The boundary between land (gray) and ocean (dark) is clearly visible. Mountains are typically darker than valleys and the southern deserts are distinct in the image. Snow cover dendritic patterns are apparent over the southern Sierra Nevada (SIERNEV) mountains. Large lakes, such as Lake Tahoe, are typically clearly visible. (Note the thin cloud pattern well off the coast in Fig. 13-2.)



The "Full Disk" GOES east visible image (callout) illustrates the "black" empty space surrounding the Earth. The terminator, the sunrise/sunset line, appears on visible satellite imagery when part of the surface is in darkness—as clearly seen in the callout. Thick clouds are bright white, thin or small clouds are shades of gray.



Infrared Imagery

Everything with a temperature above absolute zero radiates electromagnetic energy; wavelength varies with temperature. As energy radiates from the surface of the Earth and the tops of clouds, the satellite's infrared sensor measures the reflected energy.

absolute zero—The complete absence of heat (-273°C).

Infrared images begin by portraying different temperatures as black, shades of gray, and white. Typically, black represents a temperature of about 33ºC and white -65ºC, with gray shades representing decreasing temperature toward white. In fact, there are 256 distinct shades from black to white. Warm temperatures are dark, cool temperatures gray, and cold temperatures white.

Figure 13-3 illustrates shading on a basic infrared image, a simple straight line relationship between temperature and gray shade. Temperature ranges from 56.8ºC (the Sahara Desert in summer) to -109ºC (tops of high clouds—about 60,000 ft). Computer programs produce and recognize 256 distinct shades from black to white. However, the human eye can only distinguish between about 15 and 20 shades, depending on conditions. Therefore, a basic IR image is of limited operational value.

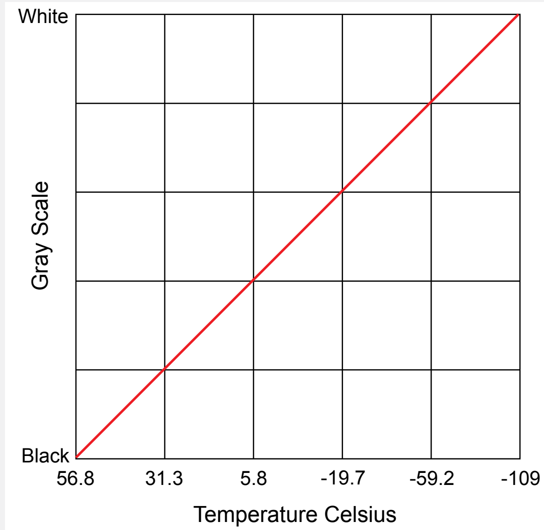


Fig. 13-3. *An unenhanced IR image is simply a straight line relationship between temperature and gray shades.*

Land-water contrast depends on temperature. During daylight hours, as the land warms, it takes on a dark gray shade as its temperature increases. Water areas, on the other hand, remain nearly the same temperature and appear as a shade of gray. At night the land cools rapidly and may become cooler than the water. Then the land appears as a lighter shade than water. When the temperatures are the same there is no discernable land-water contrast.

Surface temperatures can vary greatly from day to night, so the shading on infrared images will also vary considerably in a 24-hour period. The most dramatic changes are produced by the day-nighttime variation of land surface temperature, especially in desert regions. Major mountain ranges and valleys can usually be seen. These features typically have different temperature ranges. Deserts are distinguishable because of temperature contrasts, especially during maximum daytime heating.

Snow covered terrain usually appears brighter in the IR imagery than its surroundings; although, snow cover may be difficult to detect on a basic image. Normally, there may not be enough temperature contrast between snow cover and adjacent surfaces to appear as contrasting shades of gray. On days when the sky is clear, barren terrain not covered by snow, can become significantly warmer than nearby snow covered areas, at least for a few hours in the afternoon. Under these conditions, the boundaries of snow cover can be identified.

Light snow on the tops of high mountains is less detectable on IR than on a visible image because of the small temperature difference between land and snow. It may be difficult to distinguish snow from clouds. On IR images the clouds can be warmer than snow covered terrain and appear as a darker area; or they may be the same temperature or colder than the terrain and appear as bright or brighter than the snow covered areas. With few exceptions, clouds seldom persist in one location for more than a few hours. Snow fields can usually be identified by comparing successive images.

Low cloud tops are warm—dark gray, middle clouds cool—medium to light gray, and high clouds cold—light gray to white. Small or thin clouds introduce errors on IR imagery. Satellite sensors average cloud top temperature with ground temperature as illustrated in Fig. 13-4. The result portrays the cloud layer at a lower than actual altitude. For example, assume an area half covered with small clouds. The tops of the clouds are at 10,000 ft and the temperature at clouds tops is 0°C. The temperature of the surface is 20°C. Half of the radiation coming from the area would be from cloud tops and half from the surface. The satellite senses an average temperature and the resultant gray shade on the image would correspond to 10°C.

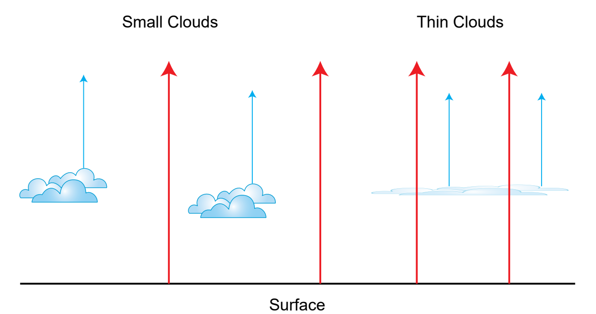
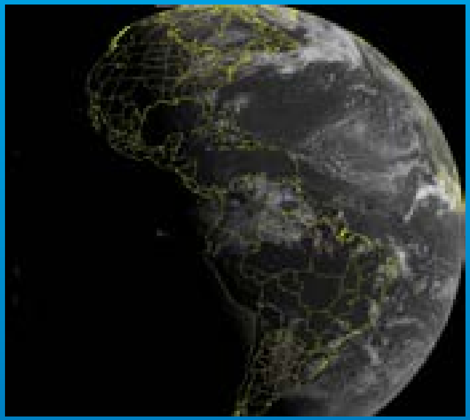


Fig. 13-4. *The infrared sensor averages the temperature of cloud tops with surface temperature.*

Figure 13-5 illustrates terrain and cloud feature differences between day and night infrared imagery. On the left, a mid-afternoon image shows considerable contrast



between cool ocean and the warm land areas. Mountains are typically darker than valleys due to their cooler temperatures. Contrast increases during the afternoon as the valleys warm. The Sierra Nevada snow cover is indistinguishable from terrain—due to similar temperature and lower resolution on IR images. A distinct contrast exists between valleys, plateaus, and mountains. On the right, an early morning nighttime image shows similar sea and land temperature, resulting in the same shade of gray.

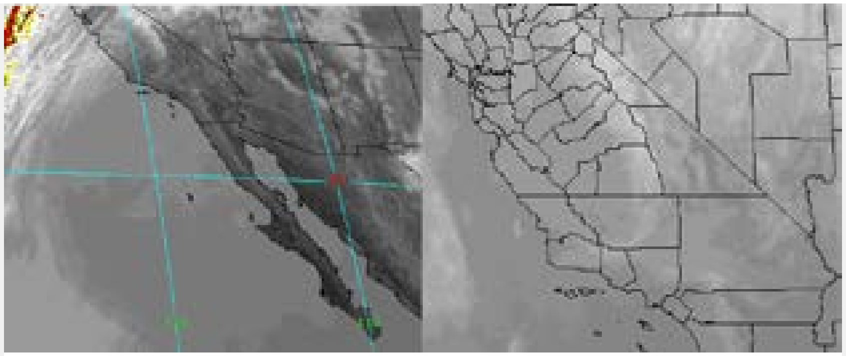


Fig. 13-5. *During the afternoon land/ocean contrast is greatest (left); at night land/ocean temperatures may be the same, resulting in no discernable boundary (right); .*

The callout shows a"Full Disk" GOES east IR image. High clouds are white; middle clouds light gray; and low or thin clouds gray.

Enhancement

Computer technology allows the enhancement of infrared images permitting the satellite provider to highlight areas of interest. In the enhancement process, any of the 256 shades of gray may be assigned any shade of gray or hue. This results in the variety of black and white and color images seen on television and available through various providers. Enhancement curves allow for greater detail of certain phenomena, such as snow and ice, fog, haze, dust, volcanic ash, and thunderstorms. However, without knowing the exact enhancement curve specific interpretation may be difficult. The breakdown of the enhancement curve may not be available.

For an enhancement curve to be effective two basic criteria are considered. First, a limited number of features are enhanced. Second, the enhancement should contain as much detail as possible without making the display overly cluttered. This technique has the advantage of making deep vertically structured clouds stand out. However, some details may be lost when assigning a specific hue to a range of temperatures.

Multiple enhancements provide increased contrast over the total temperature range, but also introduce multiple boundaries in cloud systems, which may mask significant cloud edges. There is always a tradeoff between simple enhancement curves—which sacrifice detail, but can be quickly interpreted for operational use, and complex curves—which maximize information content, but require more time to decipher.

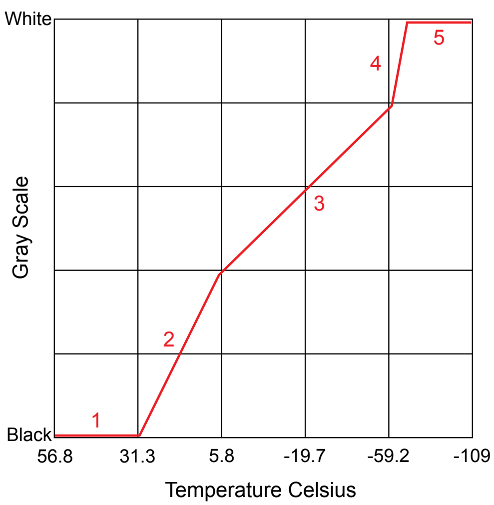


Fig. 13-6. *Enhancement curves emphasize details of interest to the end user.*

The red line in Fig. 13-6 illustrates a slight modification to the unenhanced IR curve described in Fig. 13-3. The very warm temperatures in segment 1 (56.8 to 31.3) are depicted as black. Since there are no clouds in this temperature range, no need exists for different shading.

Segment 2 (31.3 to 5.8) contains the temperatures of most low clouds and water surfaces. In this way, the darker shades of gray are used over a smaller temperature range; smaller differences in temperature can be more easily seen.

A similar process is used at the other end of the temperature scale, except that it affects a much smaller temperature range. Temperatures of –75.2ºC or colder are shown as white—segment 5. Here, too, since there are few clouds in this temperature range, there is no need for differential shading. The very light gray shades out to white are used in the temperature range of cirrus clouds—segment 4 (-59.2 to -72.2).

Between the extremes—segment 3 (5.8 to -59.2)—no enhancement is assigned. Clouds in this temperature range will be shaded as if they are an unenhanced image. This curve is a somewhat improved version of the unenhanced image. These infrared products are generally used in place of unenhanced images. There are literally hundreds of enhancement curves. Unfortunately, we rarely have access to enhanced data. Nonetheless, a comparison of visible and IR images, as we'll see, have many operational applications.

Figure 13-7 illustrates the use of enhancement curves. Strong convection has developed in the middle Atlantic states. Note the bright (thick) clouds in the visible image. It also shows a well-defined gust front.

The bottom image in Fig. 13-7 illustrates an enhancement curve. This curve highlights severe weather. Enhancement begins at about -15°C (purple), about 15,000 ft. Green at -45°C or about 30,000 ft indicates the clouds have a steep vertical gradient, indicating strong convection. Maximum cloud tops have temperatures in the -65°C range, tops to above 50,000 ft! This system produced severe thunderstorms. However, note the loss of detail in the IR image.

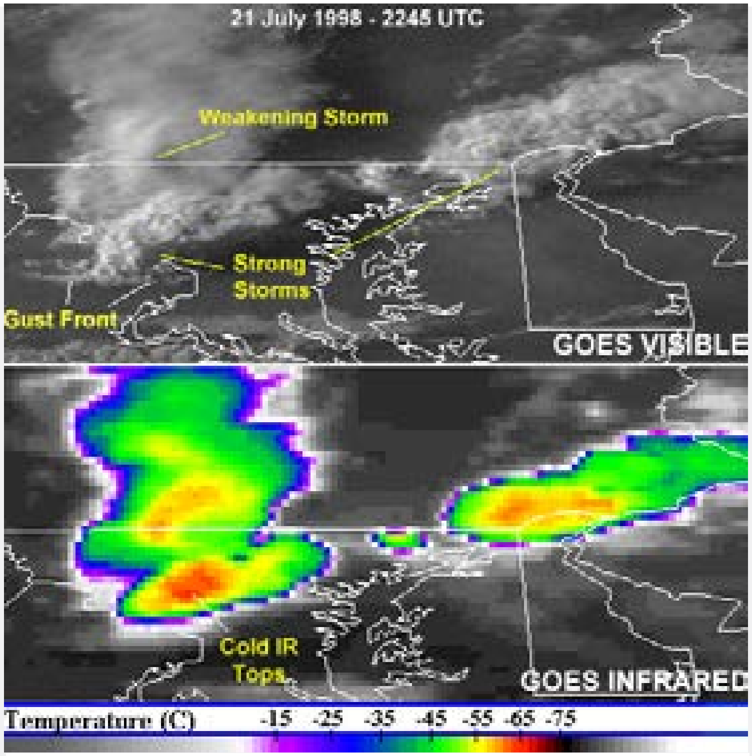


Fig. 13-7. *This enhancement curve emphasizes severe weather by detailing very cold temperature regions.*

GeoColor Product

GeoColor products provide an approximation to daytime color imagery. At night, an IR-based multispectral product differentiates between low liquid water clouds and higher ice clouds. A static “city lights” database provides nighttime background for geo-referencing major population centers.

Note

At present GeoColor images are not available from Leidos Flight Service or the Aviation Weather Center. Products are available from the National Weather Service:

www.star.nesdis.noaa.gov/GOES/

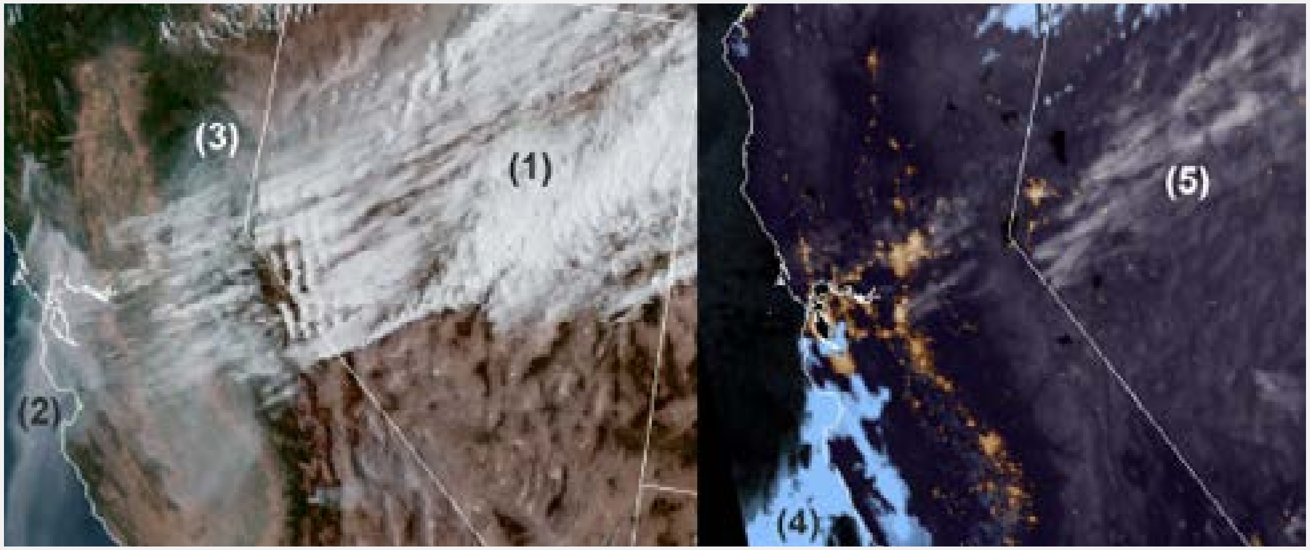


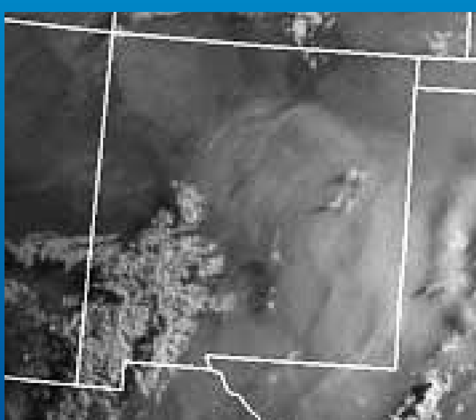
Fig. 13-8. *The GeoColor product uses five IR channels to create a color approximation.*

Figure 13-8 illustrates GeoColor imagery, day on the left and night on the right. On daytime images ocean surface are shown in shades of blue, vegetation/forest green, and dry/deserts brown. High/thick clouds (1) appear bright white. Thick smoke (2) shows up as dark gray/tan; thinner smoke (3) as a bluish gray. Nighttime images display clear sky land areas as dark purple, city lights gold. Low-Level (liquid water) clouds (4) light blue, and mid-level and cirrus (ice) clouds (5) a grayish white. ("Loop" and limited "Zoom" capabilities are available.)

Case Study

> I planned an early morning departure from Petaluma to Livermore, California. Petaluma (Class G airspace, surface to 700 AGL) is in a coastal valley just north of San Francisco. Coastal stratus was over Petaluma forecast to dissipate during the morning; Livermore was clear. The GeoColor image showed low-level clouds along the coast and into the coastal valleys, clear inland. AWOS reported visibility 10SM, ceiling overcast 500ft. I could see the edge of the stratus just north of the field.

The decision to conduct this flight was based on my training and experience, personal minimums, knowledge of the regulations, and a complete weather briefing. (It should make some interesting hanger discussions!)



As well as texture, low sun angles highlight areas of smoke—the light gray over eastern New Mexico.

I monitored CTAF for VFR or IFR traffic and departed north bound, remaining clear of clouds climbing over an uncongested area. Within minutes I was in the clear and proceeded to Livermore. (I contacted Flight Service with a PIREP and was told that "VFR was not recommended." Hum?)

Cloud Features

The most useful application of satellite imagery is the identification of cloud features. This often requires a comparison of visible and infrared images, the use of a satellite *loop*, and other products such as METARs, PIREPs, and radar.

We'll discuss the various cloud categories in ch3, Clouds and Fronts. Additionally, we'll talk about specific cloud features, such as texture, frontal bands, and the jet stream. And, as they present themselves, we'll look at additional cloud and terrain features as seen on visible and IR imagery.

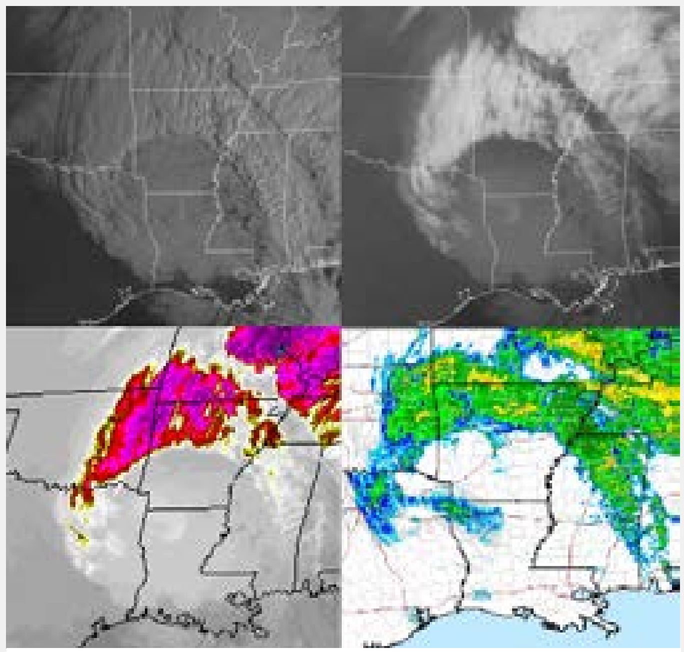


Fig. 13-9. *This illustration shows same time frame visible, infrared, enhanced infrared, and radar images.*

Texture

Texture often identifies cloud types and may indicate atmosphere stability. Texture appears lumpy. On visible imagery, especially during early morning and late afternoon with a low sun angle, shadows appear on lower clouds or the surface. A texture pattern, from an early morning, visible image appears in the top left frame of Fig. 13-9.

With unstable air, the tops of some cumulus clouds are higher than others. At midday with the sun directly overhead shadows are missing. Even without shadows, cumuliform clouds may be identified by their lumpy appearance. At times, however, cumuliform clouds may appear similar to stratiform on visible images. In such cases cloud types require other means of identification.

Infrared images lack texture; shadows do not directly appear. The top right frame in Fig. 13-9 contains an unenhanced IR image. The area of texture—as seen on the visible image—appears as bright (high), cold cloud tops. From the IR image alone, stability cannot be directly inferred. On this image a distinct boundary appears between low (warm) and high (cold) cloud tops.

On enhanced IR images, as seen in the bottom left frame of Fig. 13-9, color contours correspond to texturing on the visible image. These contours clearly identify the boundary between low (warm) clouds—which are almost indistinguishable from terrain, the bright (cool) mid-level clouds, and the color contouring of the high (cold) clouds.

A "same time" radar image appears in the lower, right frame of Fig. 13-9. The radar mosaic confirms instability. A comparison of satellite imagery and radar can often confirm or refute convective activity.

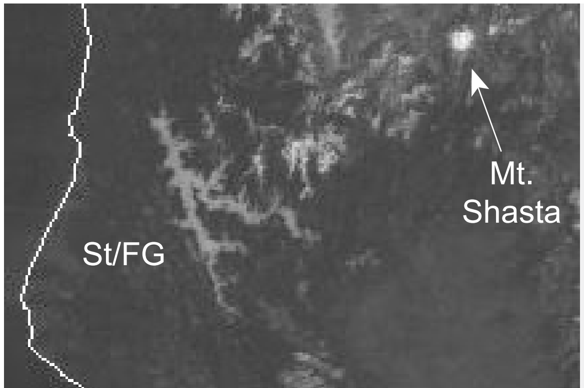
Table 13-2 provides a summary of basic satellite weather interpretation criteria.

Table 13-2. *Satellite Cloud Characteristics*

Visible		Unenhanced IR	
Thick	White	Low	Dk Gray-Gray
Thin	Gray	Middle	Gray-Lt Gray
Cumulus	Textured	High	Lt Gray-White
No Height		No Texture	

Stratiform Clouds

Stratiform clouds form in stable air, indicating a stable air mass at cloud tops. They are characterized by a flat, smooth, white appearance, and a lack of an organized pattern or texture. The boundary is often sharp and defined by topography. Figure 13-9 shows stratiform clouds over extreme eastern Texas, southern Arkansas, Louisiana, and the southwestern portion of Mississippi. On the visible image there is a sharp boundary between the stratus and the surface; on the IR images enough of a temperature contrast exists to show the boundary. This is confirmed by the lack of precipitation, as seen on the radar image.



Stratus (St) and fog (FG) may exhibit dendritic patterns, as illustrated in the callout. These dendritic patterns are the result of passes and canyons adjacent to areas of valley fog or stratus. It may be difficult to distinguish fog from low stratus or snow. On visible imagery fog or stratus appears bright when thick; on IR images stratus appears dark to medium gray and may be difficult to differentiate from the surface since there is little temperature contrast between the surface and cloud tops. Most types of fog show up well on visible satellite imagery—if higher clouds are not present. Often, the satellite is better at determining the extent of fog and stratus than surface observations. The bright, circular spot in the upper, right corner of the callout is snow covered Mt. Shasta, California—Elev. 14,180 ft.

Stratocumulus (Sc) represent a moist layer with some convection. Figure 13-10 depicts stratocumulus over the Pacific Ocean west of the frontal system. Stratocumulus appear bright on a visible image with some texturing; on an IR image they are typically medium to dark gray. Stratocumulus clouds often appear as sheets or lines of clouds. Sometimes individual cloud elements are seen. These clouds sometimes form in narrow bands in which individual cloud cells are connected, and are known as *cloud lines*, or not connected and called *cloud streets* as seen in the callout.

Stratocumulus sometimes exhibits a more-or-less cellular pattern. They may form as *closed cells* or *open cells*. Closed cells refer to a solid cloud cover, with individual convective elements rising through the layer (Fig. 13-10). Closed cell stratocumulus are characterized by approximately polygonal clouds. Closed cells form where weaker air-sea temperature contrast exists—usually over warmer water. The vertical motion from this process is capped by a subsidence inversion away from the more active cyclonic circulation. The result is an atmospheric balance of upward and downward vertical motion in the lower levels, producing a cellular pattern. Open cells consist of clear air surrounding each individual cell (Fig. 13-10). These areas will be characterized by relatively low tops, turbulence below the clouds and generally smooth above. Open cells form where there is a large air-sea temperature difference. As the cold air to the rear of a front moves over warmer water the air mass warms from below. The open cells are composed of cloudless, or less cloudy, centers surrounded by clouds.

Altostratus (As) indicate a stable atmosphere at mid-levels. Some altostratus are thin, semitransparent, while others are thick enough to hide the sun or moon. Altostratus

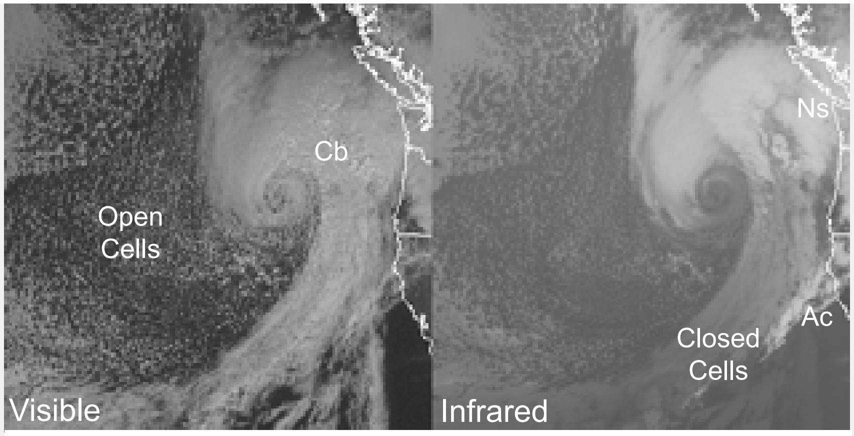


Fig. 13-10. *Cloud thickness and height can be determine by a comparison of visible and IR satellite imagery.*

appear as bright, sheet like clouds on a visible image with no texturing. Altostratus are shown associated with the southern portion of the frontal band in Fig. 13-10.

Nimbostratus (Ns) have low cloud bases, usually uniform, and appear dark gray in appearance—with relatively high tops. On a visible image nimbostratus appear very bright with little or no texturing; on an IR image they are typically light gray to white due to their relatively high, cold tops. in Fig. 13-10 nimbostratus are associated with of the warm frontal boundary.

Cumuliform Clouds

Cumulus (Cu) and cumulonimbus (Cb) are classified as clouds with vertical development. They tend to be thick and infer unstable air. The instability layer begins at some point below the top of the clouds—not necessarily the surface. On visible imagery cumuliform clouds appear rounded, billowy, and puffy—textured. Large thunderstorms appear bright, topping the list of reflectivity. On IR imagery they appear light gray to white. The closer to white, the colder, and therefore the higher the tops. Overshooting cirriform is an indicator of potentially severe weather. Clouds with extensive vertical development tend to cast shadows, especially during morning and afternoon on visible imagery and contouring on some enhanced IR images.

Refer to the visible image in Fig. 13-11 for southeastern Oregon and eastern Nevada. The clouds show a rounded, billowy, puffy appearance indicating cumulus clouds. In the infrared image in Fig. 13-11 cumulus clouds appear a gray shade indicating relative low tops—lower in southeastern Oregon (gray) and higher in eastern Nevada (light gray to white).

Figure 13-11 shows a distinct resolution difference between the visible and IR images. The higher resolution on the visible image reveals distinct cloud elements, not depicted on the IR image. The sheet-like band of clouds in central Nevada (light gray on the visible image and white on the IR image) indicates high, cold, thin cirrus clouds.

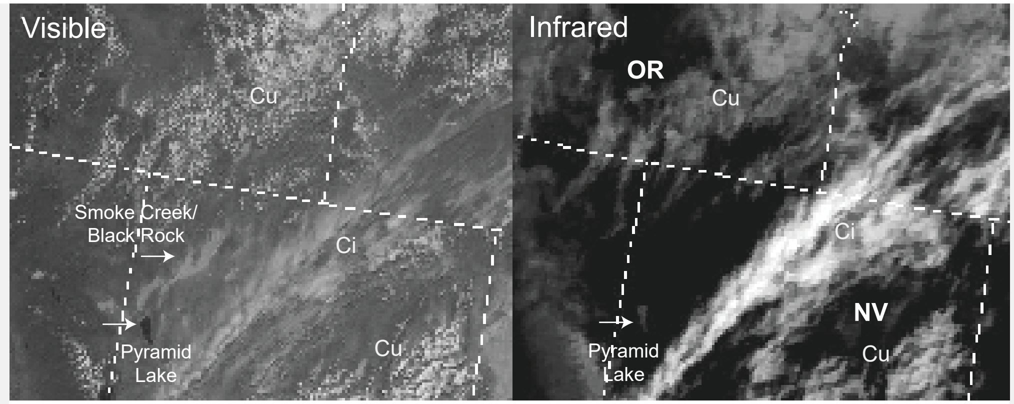


Fig. 13-11. *The cumulus clouds are thick—bright on the visible image, tops are relatively low—gray on the IR image.*

Pyramid Lake can be clearly seen in the visible image. The lake is less distinguishable on infrared because the lake is only slightly warmer than the surrounding terrain. The Smoke Creek and Black Rock deserts are the “light gray” area to the north and northeast of Pyramid Lake on the visible image. Since the desert temperature and its surrounding terrain are similar, it does not appear as distinct on IR.

arc line (arc cloud)—An arc-shaped line of convective clouds often observed on satellite imagery moving away from an area of dissipating thunderstorms.

Cumulonimbus clouds (convection) appear very bright on both visible and unenhanced IR imagery—due to cloud thickness and high, cold tops. Often individual cells can be identified with air mass thunderstorms. Organized convection, produced by fronts and squall lines, can also be seen. Once the cells or lines have developed, the exact location of individual thunderstorm cells may be obscured by overrunning cirrus. However, overshooting tops may be identified on visible imagery, especially with a low sun angle. *Arc lines* form as air flows rapidly out of the storm at the surface. They indicate severe or greater turbulence. Often, new thunderstorms develop along outflow boundaries, The strongest convection occurs where two or more arc lines converge, which may result in severe weather.

Figure 13-12 shows early afternoon visible images of a squall line nearing the

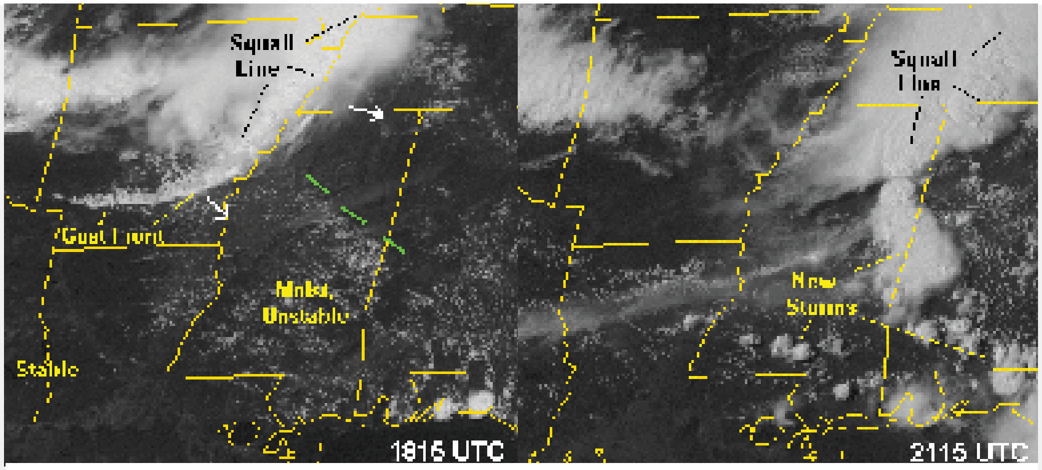


Fig. 13-12. *Atmospheric stability and system movement can often be determine by viewing a time sequence (loop) of images.*

Mississippi River from western Kentucky to south of Memphis, Tennessee. Storm movement is from the northwest. A *gust front* has developed and extends from the southern end of the squall line into southern Arkansas. Ahead of the system, an area of extensive cumulus is developing in the moist unstable air. A more stable air mass exists over southwest Louisiana. By 2115Z satellite imagery shows that new convection has developed over southern Mississippi and Alabama. These storms are relatively isolated, easily identifiable, and should be visually circumnavigable. The squall line to the north has strengthened, due to afternoon heating and a moist, unstable air mass. These storms most likely will not be circumnavigable, even with storm avoidance equipment.

Figure 13-13 shows a large severe storm in western Kansas. An overshooting cloud turret—within the circle lower left—identifies the most intense part of the storm. Small scale

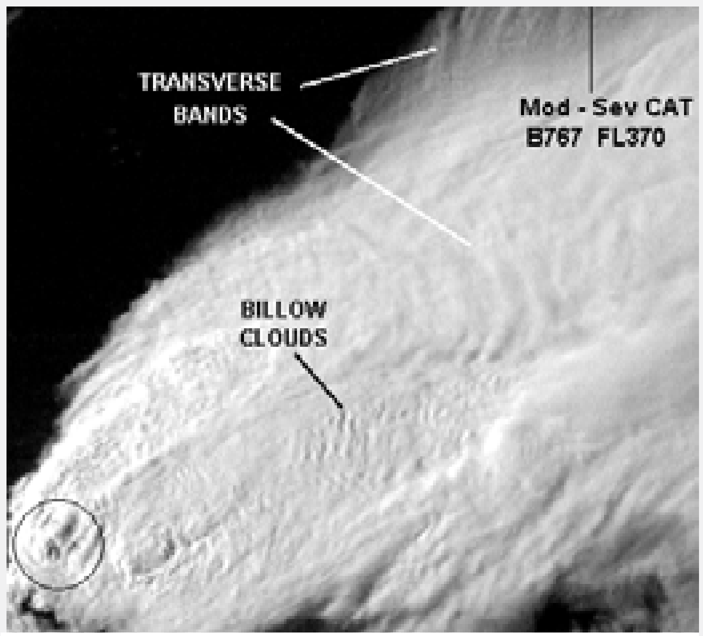


Fig. 13-13. *Often severe weather can be inferred from texture and cloud patterns.*

transverse bands—Irregularly spaced bandlike cirrus clouds that form nearly perpendicular to a jet stream axis. They indicate turbulence associated with the jet.

Figures 13-7, 13-12, 13-13 and 13-14 are courtesy of Mr. Gary Ellrod National Oceanic and Atmospheric Administration, National Environmental Satellite, Data, and Information Service (NESDIS)—retired.

waves, known as *billow clouds*, appear near the cloud top. This is most likely an area of significant turbulence. On the north side of the system cirrus bands oriented perpendicular to the upper flow—*transverse bands*—indicate another area of significant turbulence. A Boeing 767 reported moderate to severe turbulence in southern Nebraska in the thin cirrus just north of the main anvil cloud. Since intense storms act as a barrier to air flow, stronger than forecast winds and wind shear may be found on either side of the visible cloud system.

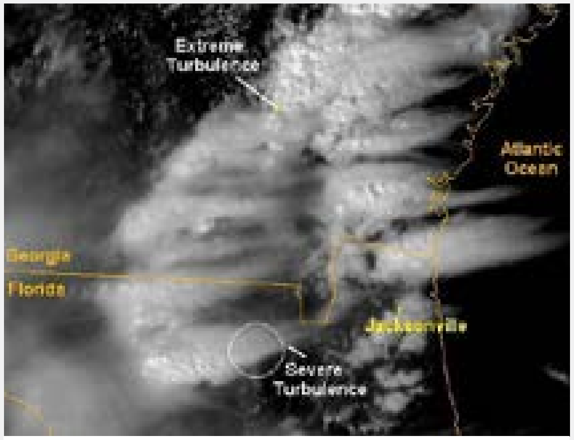


Fig. 13-14. Significant turbulence can be encountered well outside, below, and above cloud tops.

Figure 13-14 depicts a visible satellite image where a Boeing 727 encountered extreme turbulence near Alma, Georgia. The incident resulted in several severe injuries. It occurred in an area of thunderstorms with tops to approximately 35,000 ft. Winds near this altitude were about 115 knots. (If we apply the rule-of-thumb: 1000 ft above the thunderstorm cloud tops for each 10 knots of wind. A safe altitude would be 46,500 ft!) The image shows several scattered to broken lines of convective storms, with the cirrus anvils extending well downstream. An additional report of severe turbulence at 33,000 ft was reported in northern Florida near one of the cirrus plumes. The circle identifies billow wave clouds, indicating strong wind shear. Farther north, in the vicinity of Alma, Georgia, there was considerable cirrus from upstream convective clouds, and beneath the cirrus a new line of convection was rapidly forming. Overshooting tops, visible in Fig. 13-14, indicate supercell thunderstorms.

Figure 13-15 shows two GeoColor mid-Spring images. On the left a midday image shows developing air mass thunderstorms over the Great Basin and the California Sierra Nevada mountains. On the right thunderstorms continue to develop east to west with increased surface heating. There are no overshooting tops—indicating storms are not severe. Typically winds at mid and upper levels are light; this is indicated by the absence of significant cirrus blow off, with little or no thunderstorm movement. Usually, these storms are circumnavigable for both VFR and IFR operations. Cirrus tops cover the storms. Without access to real time weather radar or visual contact with the storms—the ability to maintain separation—no pilot should attempt to navigate these areas.

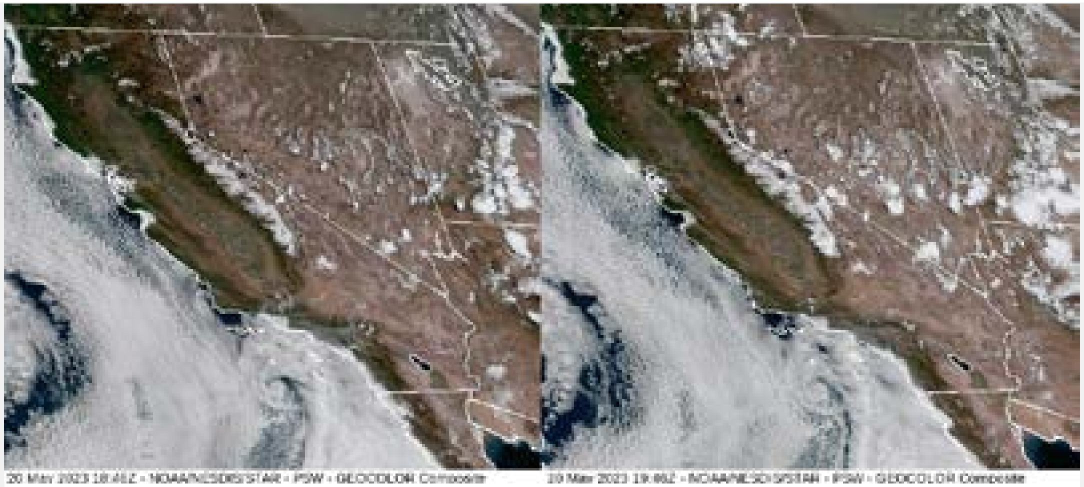


Fig. 13-15. *Air mass thunderstorms are usually not severe and usually circumnavigated.*

These rules apply to any area of air mass thunderstorms. The lack of strong winds aloft prevents clouds from developing the “classical” anvil shape—an indicator of severe storms. Notice the rapid development of convictive activity in northwestern Nevada, northeast California, and southern Oregon. In addition to air mass thunderstorms, Fig. 13-15 shows advection stratus along the California coast

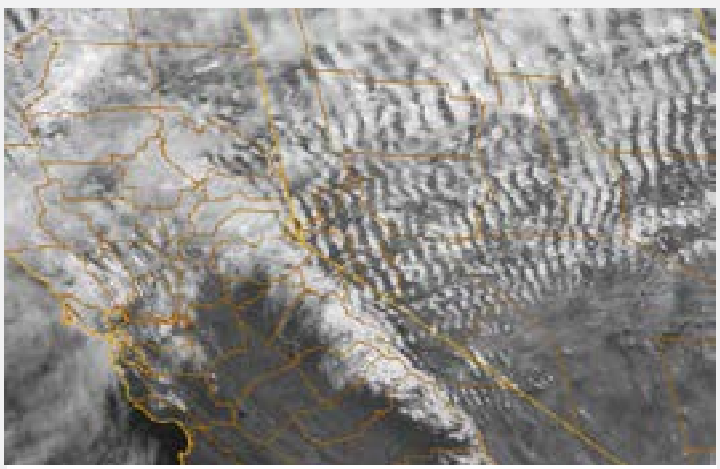
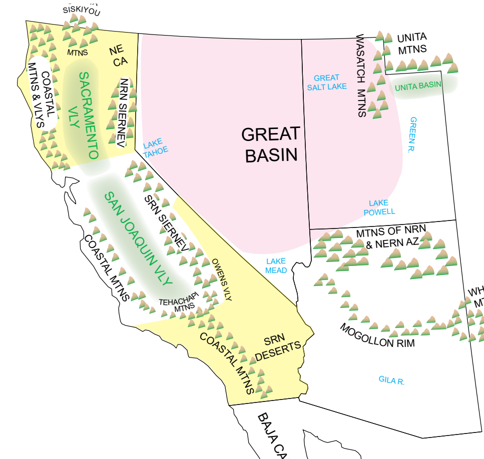


Fig. 13-16. *“Mountain waves” may appear on satellite imagery.*

Altocumulus indicate vertical motion and possible instability at mid-levels. Altocumulus may be thin, mostly semitransparent. Some altocumulus are thick, developed, and may be associated with other cloud forms. Thick, developed altocumulus appear bright on a visible image with a cellular appearance and texturing; on an IR image they are typically light gray to white because of their high, cold tops. Figure 13-16 shows Standing Lenticular Altocumulus (ACSL) clouds. ACSL indicates



possible significant turbulence, but form in a stable air mass. (We'll get into the details of mountain waves, and techniques and strategies to avoid hazardous turbulence in ch 21, Turbulence.)

Other altocumulus (Altocumulus Castellanus) form in an unstable air mass at mid-levels and may foretell the development of thunderstorms. The photo in the callout illustrates these clouds. They are high based and typically develop in a relatively dry environment. On visible imagery they appear bright and may be textured; on IR imagery they appear light gray to white, depending on the height of their tops.

Cirriform Clouds

Cirriform clouds often have a fibrous texture and frequently consist of filaments, commonly known as "mares' tails." Others are associated with cumulonimbus clouds. Cirrostratus appear as sheets or layers of cirrus. Cirrocumulus indicate vertical motion at high levels.

Figure 13-17 shows the appearance of thin cirrus and illustrates the application of visible and IR imagery to determine cloud character and type. Over northern Mexico and western Texas the visible image shows light gray "thin clouds." From the visible image alone, there is no way to determine cloud height. The infrared image, however, reveals these clouds have high, cold tops. A combined analysis confirms these are high, thin cirrus clouds. Thick cirrus appears bright on a visible image with no texturing; on an unenhanced IR image they are typically white.

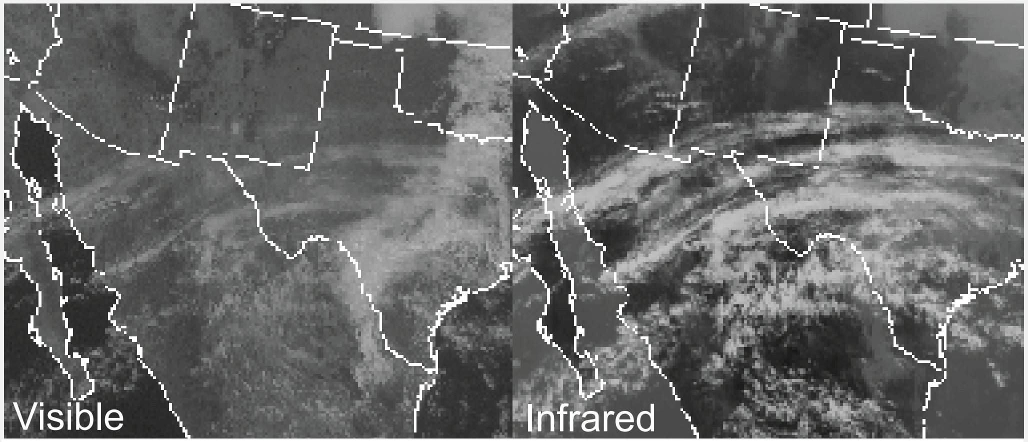


Fig. 13-17. *High, thin clouds can be recognized by a comparison of visible and IR images.*

Thick cirrus may be indistinguishable from other thick clouds on visible imagery. In Fig. 13-18 the visible image shows bright, thick clouds over central California and California's coastal waters. From the visible image alone cloud heights are difficult to determine. Now compare the visible image with the enhanced IR image in Fig. 13-18. Cloud tops over central California are cold, and over the coastal waters warm. From the two images we can conclude clouds over central California are high, thick cirrus; over the coastal waters low, thick stratus. (The IR image shows that the temperature of the stratus tops is similar to ocean surface temperatures. From the visible image the extent of the stratus and open areas are evident.)

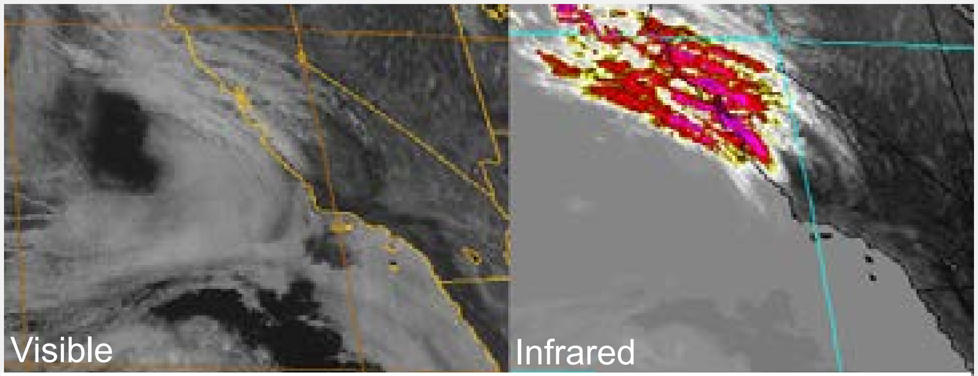


Fig. 13-18. *Cloud character and type is most easily determined by a comparison of visual and infrared imagery.*

Often associated with strong fronts, thick cirrus (cirrostratus), especially with stable systems, extend well in advance of surface fronts.

Frontal Clouds

On satellite imagery fronts are identified by their distinctive cloud bands. Recall from ch 4, that as a rule, well defined cloud bands occur with active cold, warm, and occluded fronts in strong *baroclinic* zones. Active fronts have upper air winds parallel, or nearly parallel, to the frontal zone. This results in a broad band of continuous multilayered low, middle, and high clouds.

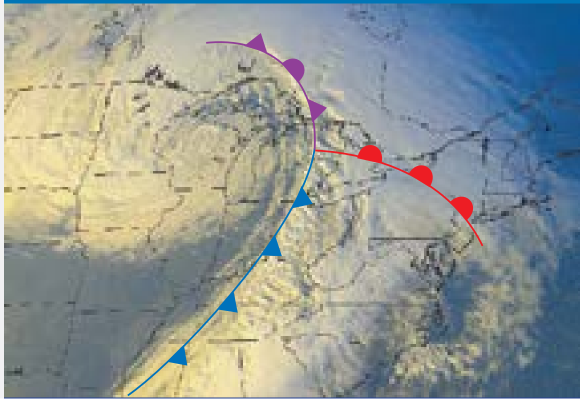


Fig. 13-19 shows a satellite view of an "active" frontal system off the west coast of the U.S. Frontal clouds spiral out of the low pressure center. The callout shows a "typical" active frontal system in the eastern U.S. Active systems take on a *comma cloud* appearance. The comma cloud consists of the *comma head*—the rounded portion of the comma cloud system. This region often produces the most widespread, steady precipitation. The *comma tail* lies to the right of, and often nearly parallel to, the axis of

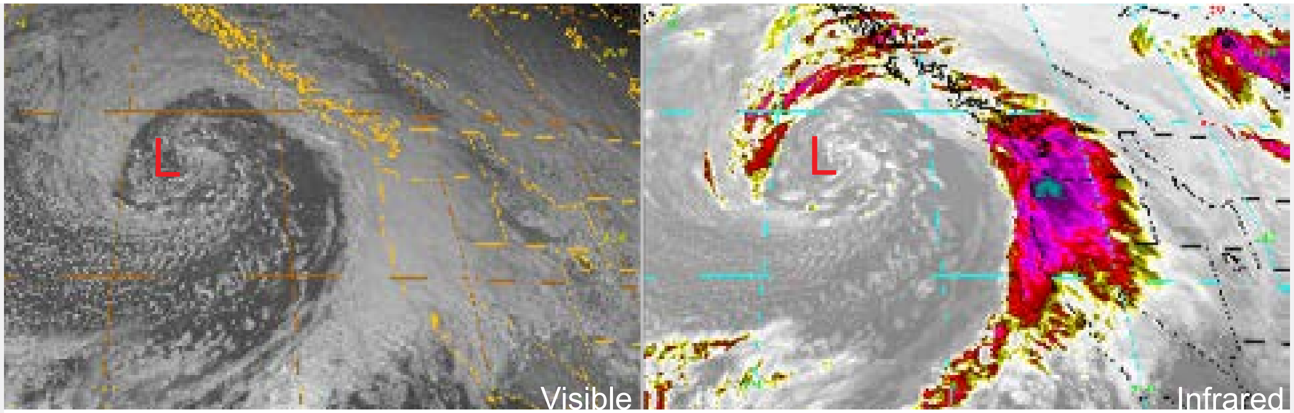


Fig. 13-19. *Active frontal systems take on a "typical" comma cloud appearance.*

maximum winds—the jet stream. The visible image reveals thick clouds; the IR imagery cold, high tops associated with the comma cloud.

Distinct texturing occurs in the region of the occluded and warm fronts. However, the exact location of the warm front is hidden by a *cirrus shield* (thick cirrus). The cold front is typically distinctly visible, along with its surface boundary. Ahead of the cold front are cloud formations associated with this phenomenon. There are considerable, relatively thick clouds along the front. As the frontal boundary extends south it tends to weaken. A large area of the eastern Pacific (Fig. 13-19), behind the front, is covered by *open cell* stratocumulus. Thick cirrus are present over Washington, Oregon, and California—ahead of the cold frontal boundary. They appear bright, lacking texture, on the visible image; with high, cold tops on the enhanced IR image.

After an over-water trajectory, frontal cloud bands usually change character as they move inland. A well-developed continuous cloud band over water changes to a discontinuous, fragmented collection of clouds as the front moves from the Pacific Ocean into the intermountain region. This change in cloud character results from a decrease in the amount of moisture available over the land. Frontal bands east of the Rockies tend to regenerate from an influx of moist air. Active fronts take on their more "classical" appearance (callout). After a sufficiently long over land trajectory, frontal cloud moving offshore changes in appearance. As a rule, frontal bands tend to have more continuous clouds over water than over land, although continuous cloud bands, with strong systems, also appear over land.

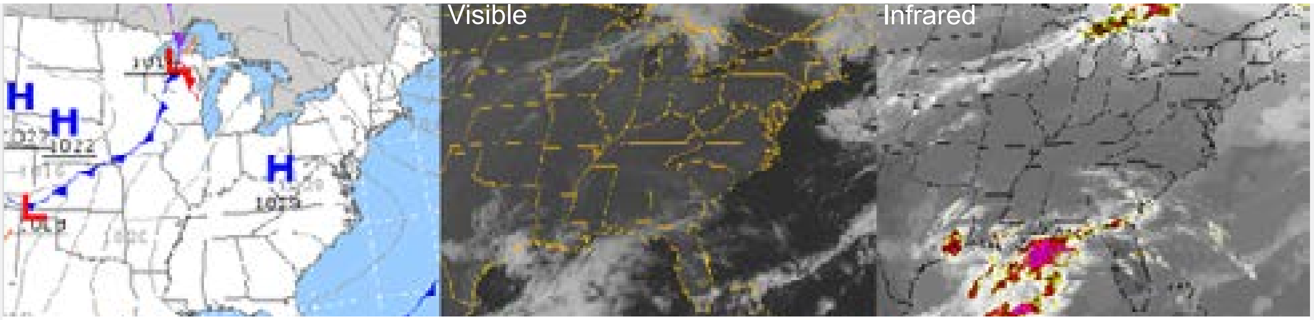


Fig. 13-20. *Weak or inactive fronts are often seen as narrow, fragmented, discontinuous cold bands.*

Inactive fronts typically have upper level winds perpendicular to the frontal zone—*barotropic*. This results in considerable subsidence over the frontal zone, reducing the amount of clouds associated with the front. Weak or inactive fronts are characterized by limited, poorly defined, or even the complete absence of clouds. Inactive fronts are often seen as narrow, fragmented, discontinuous cloud bands. This is illustrated in Fig. 13-20. Near the low over the Great Lakes clouds are relatively thick with high, cold tops. Along the front to the southwest clouds become thin, with high, cold tops—mostly cirriform. There is almost a complete absence of clouds associated with the low in the Texas/Oklahoma panhandle.

The Jet Stream

The jet stream can often be located on satellite imagery. Cirrus clouds typically dominate the equatorial side of the jet in an anticyclonic flow. The poleward boundary is often abrupt and lies under or slightly on the equatorial side of the jet axis. These cirrus may cast a shadow on the surface or lower clouds.

Figure 13-21 shows the jet axis over northern Mexico and Texas. Clouds appear relatively dark on the visible image and bright on the IR image, with a distinctive anticyclonic curvature. This indicates high, cold, thin, jet stream cirrus. The jet runs just north of the cloud band from central Baja California through southern New Mexico and the Texas panhandle. The satellite imagery depicts an upper ridge of high pressure over the southwest United States.

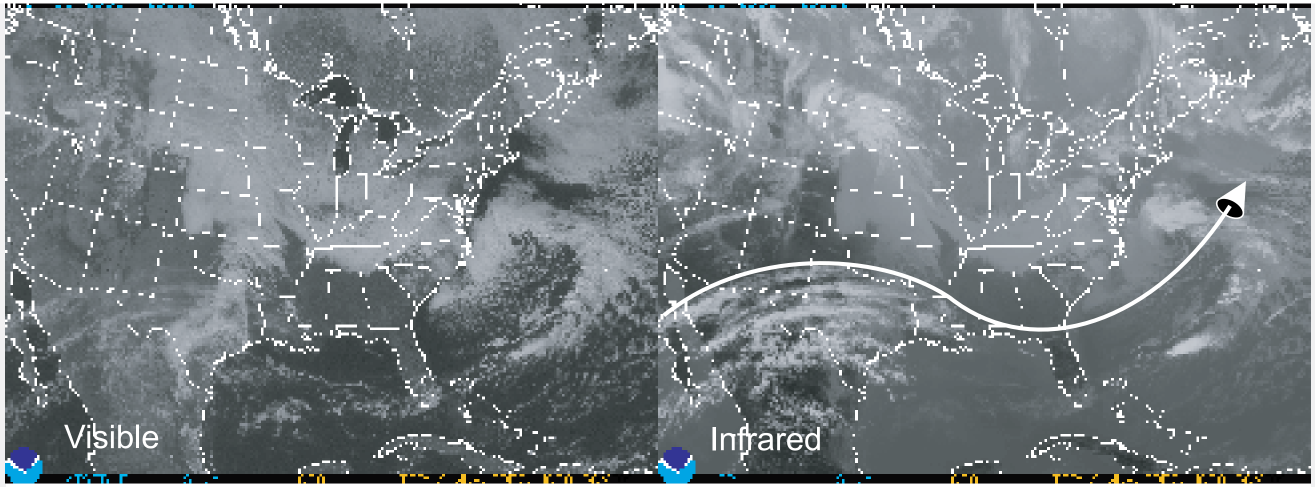


Fig. 13-21. *The jet stream can often be located by a comparison of visible and IR satellite imagery.*

The jet stream continues through southern Oklahoma, weakens over an area of relatively high pressure in the southeastern United States, then curves northeast through the dry slot in the weather system offshore, and exits northeast over the Atlantic Ocean.

Clouds over the Gulf of Mexico are dark on the IR image, indicating low, warm tops. This along with their cellular appearance in the visible image indicates stratocumulus; an area of subsidence in the ridge-to-trough flow.

An upper trough of low pressure dominates the southeast Atlantic coast. The trough-to-ridge flow supports the frontal weather off the Atlantic coast—the comma cloud in the western Atlantic. The jet usually crosses an occluded system just north of the point of occlusion, as depicted in the callout.

Expect turbulence on both sides of the sharp edge of jet stream cirrus, generally within 180 nm of the jet axis. Moderate or greater turbulence is indicated by cirrus that forms as *transverse lines* (bands in Fig. 13-13) or *cloud trails* perpendicular to the jet, and *cirrus streaks* parallel to the jet—long narrow streaks of cirrus frequently seen with jet streams. These clouds often appear as cirrocumulus.

Product Availability

In this chapter we'll address satellite weather product available from Leidos Flight Service and the Aviation Weather Center. Products consist of visible, infrared, and water vapor images. Water vapor displays the quantity of water vapor in the middle and upper troposphere. (Additional information on the interpretation of water vapor products is provided in FAA-H-8083-28A Aviation Weather Handbook 2024,)

Leidos Flight Service (www.1800wxbrief.com)

For Leidos Flight Service Satellite products use the "Home Page" (Fig. 11-1), "Wx Charts" menu (Fig. 11-2) presented in ch 11, Graphical Observational Products. "Click" the Weather Imagery, Satellite option dropdown box in the Layer Controls panel shown in Fig. 13-22. Selections include Visible, IR4, and Water Vapor. "Opacity" and "Loop" controls are provided in the lower left of the image, "Zoom" controls in the upper right—below the Layers icon (inset Fig. 11-3).

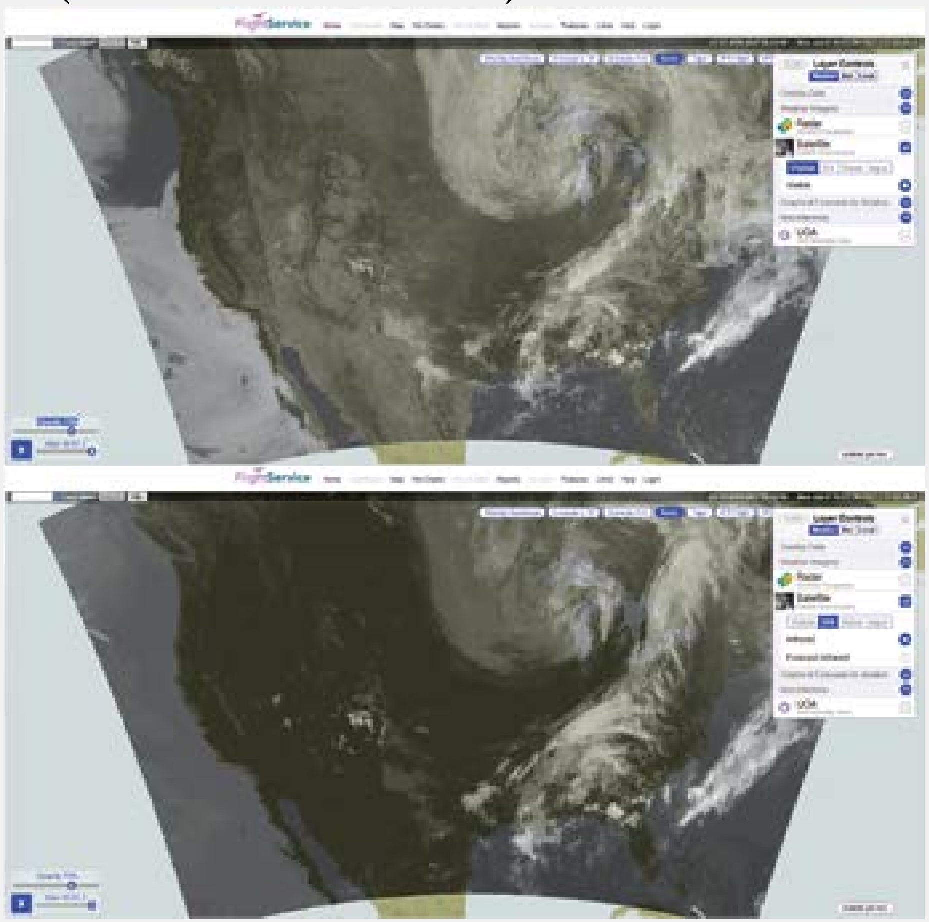
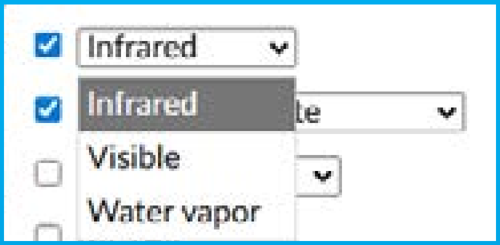


Fig. 13-22. *Leidos Flight Service satellite images are available on the Home Page "Wx Charts" tab.*



Aviation Weather Center (www.aviationweather.gov)

For Aviation Weather Center satellite products use the “Home Page” (Fig. 11-4). From the “Weather” dropdown menu, select Observations. “Click” the top “Layers Selector” icon in the Options Panel (inset Fig. 11-4). Options consist of Infrared, Visible, and Water vapor (callout).

A “Zoom” option is available (Fig. 11-5 Options Panel). Adjust “Opacity” using the “Map Options,” Imager, Satellite menu. (“Loop” function is not currently available on AWC satellite products.)