



Fig. 10-1. Cirrus uncinus fill the sky. SDG.



Fig. 10-2. Cirrus streamers over Boynton Beach 30 Dec 2016. The streamers fell from a jet's condensation trail. SDG.



Fig. 10-3. Tic-tac-toe contrails with cirrus near the horizon at 10.5 km near horizon over San Mateo, CA 03 Nov 2016. SDG.

Wonders of the Atmosphere

Chapter 10: Cirrus and the Layer Clouds

Started 27 Nov 2024

10.1 Contrails: The Usurpers

Throughout Earth history, cirrus clouds invaded pure azure skies as the first forerunners of approaching storms (Fig. 5-30, Fig. 10-1, Fig. 10-2). Now, their role has been usurped by anthropogenic clouds left in the wake of jet planes – *cirrus homogenitus*, more commonly called condensation trails, or *contrails* (Fig. 10-3).



Fig. 10-4. Contrail behind aileron with stratus over NJ 04 Nov 2015 . SDG.

Contrails form in air that is almost but not quite humid enough to produce natural clouds, as in Fig 10-3, where contrails and cirrus shared the sky around 10.5 km. Contrails form by two distinct processes. 1: Air pressure is lowered as it flows over the wing (Fig.

10-4), which produces adiabatic cooling. This process tends to lead to very short-lived contrails of extremely tiny droplets or ice particles



Fig. 10-5. A contrail is born, 06 Dec 2020 over Cheyenne, WY. Jan Curtis.

over or behind the wing that may be iridescent (see Fig. 14-28). 2: The exhausted fuel of jet engines adds both heat and water vapor. The mixing of the vapor-enriched exhaust with the colder and drier surroundings produces condensation in the manner of steam fog (recall §4.5). This process tends to leads to longer-lasting contrails in air supersaturated with respect to ice (recall §4.3) that form some distance directly behind the jet engines, as in Fig. 10-5.

The cloud canal or altocumulus *cavum* (cavity) over Boynton Beach, FL on 17 Jan 2014 (Fig. 10-6) is an example of a contrail. Temperature at cloud level was -30°C . Circular hole-punch clouds (recall Fig. 4-13) or long cloud canals are contrails that form after jets puncture or fly along patterned cloud sheets that consist of supercooled water droplets. This typically occurs at ambient temperatures between about -15°C and -35°C . The air and droplets above the wings are cooled enough to produce ice particles. The clear gap starts as the ice particles grow at the expense of the nearby droplets, which evaporate. The gap spreads as sinking motion in the jet's wake vortex warms the air and evaporates droplets further away.



Fig. 10-6. Contrail of ice particles making a clear lane in an altocumulus cavum of supercooled droplets over Boynton Beach, FL on 17 Jan 2014. SDG.

Airflow in the wake of jets not only affects the formation of contrails, it largely determines their shapes. A pronounced vortex develops in the wake of each wingtip (Fig. 10-6) as pressurized air beneath the wing swirls outward, up, and back inward atop the wing where air is depressurized. Tracers, such as the red smoke in Fig. 10-7 or droplets at cloud edges render their normally invisible flow fields visible.

A view facing the jet from behind reveals a counterclockwise vortex behind the right wing. If the photo had extended beyond the left wing and if another smoke release occurred on the left side of the plane, it would have revealed a clockwise vortex behind the left wing. Each of the twin vortices is embedded in the sinking flow of the other, so that the pair sinks with time. As the air sinks between the center lines of the vortices it warms, evaporating the droplets or ice crystals.



Fig. 10-7. A wingtip vortex revealed by smoke. NASA EL-1996-00130



Fig. 10-8. Contrails twisted by wingtip vortices. Left over Upper Saddle River, NJ (SDG). Right over Cheyenne, WY 07 Feb 2018 (Jan Curtis).



Fig. 10-9. Wide contrail reflecting double vortex wake flow and snaking due to vertical shear crossing the contrail. The new contrail is still straight. SDG.

Contrails are also twisted in the wingtip vortices, as in the two cases shown in Fig. 10-8. When, in addition, the ambient wind with vertical shear crosses the twisted contrails at near right angles it gives them a serpentine shape, as in Fig. 10-9. If, for example, wind speed across the contrail increases with height from left to right, the contrail's twisted crests will be forced to the right while its troughs will be forced to the left.

The intense flow of the wingtip vortices is often unstable, so that tiny irregularities grow into a variety of pulses and waves. It also causes the distance between the vortices to form snake-like waves. This is called “Crow” instability. The combination of all these motions with various profiles of ambient temperature, humidity, and wind speed and direction, contrails contain a range of fine scale features.

Almost all contrails consist of series of closely spaced beads, somewhat like strings of pearls. Periodic irregularities in the vortex flow may enlarge some of the beads, as in the top frame of Fig. 10-10. Wavy flow in the ambient air may bend the beaded contrails into a wavy shape as in the bottom frame of Fig. 10-10.



Fig. 10-10. Beaded contrails. The bottom contrail reveals waves in the air. SDG.

When a jet flies in a layer of air that has strong vertical wind shear and is stably stratified, possibly with a distinct inversion, its contrail may reveal Kelvin-Helmholtz waves, as in Fig. 10-11 and expose clear air turbulence.



Fig. 10-11. Contrail and possible natural cirrus revealing Kelvin-Helmholtz waves in a stable layer of strong vertical wind shear. SDG.



Fig. 10-12. Buoyant beaded contrails growing into species castellanus. SDG.



Fig. 10-13. Contrails with sinking mamma over San Mateo, CA 09 Nov 2014. SDG.

When a jet flies in unstably stratified air, the contrail beads may be

buoyant and rise to form cirrus castellanus homogenitus, as in Fig. 10-12.

Contrails that form in the descending and converging flow just above the center of the double vortex often assume the shape a V-shaped valley or trough. This shape is quite common with canal clouds, as in Fig. 10-5. The vortex flow enhances the sinking of the ice particles, with cirrus streamers and/or distinct mamma-like pouches, as in Fig 10-13. When there is little vertical wind shear beneath hole punch clouds, the falling streamers converge and take a funnel shape, as in Fig. 10-14.



Fig. 10-14. Hole punch cloud with little shear form goblet-shaped cirrus streamers over San Mateo, CA 14 Sep 2018. SDG.

For better or worse, contrails are here to stay, so we might as well appreciate their artistry (Fig. 10-15). Certainly, contrails are not mere curios. Many mutate so that after a few hours they often cannot be distinguished from natural cirrus (Fig. 10-16). They also persist and spread out to cover the sky from horizon to horizon, adding to the natural cloud cover as in Fig. 10-17 and Fig. 10-18. For three days after 9/11, when all commercial flights were halted, high cloud cover decreased (as did nighttime low temperatures).



Fig. 10-15. A photographically 'stacked' contrail at sunrise 8 Dec 2020 over Cheyenne, WY. Jan Curtis.



Fig. 10-16. Cirrus uncinus homomutatus descending as streamers from stratocumulus over Cheyenne, WY 31 Oct 2017. Jan Curtis.



Fig. 10-17. Spreading contrails filling the sky over Cheyenne, WY, 10 Oct 2017. Jan Curtis



Fig. 10-18. Spreading contrails cirrus homogenitus curving from top left to center bottom and cirrocumulus homomutatus arching over Cheyenne, WY on 30 Mar 2022. Jan Curtis.

10.2 Cirrus: Angel Hair Clouds

Cirrus, described by Joni Mitchell as Angel Hair, is the most delicate of the cloud genera, certainly in appearance. As stated in Chapter 4,

Cirrus are trails of falling ice crystals twisted by the wind.

In Fig. 10-2 the streamers fell almost straight down because the wind direction (west) and speed (32 m/s) were almost constant between 6.6 and 12.2 km, where they were located. That is the exception. Far more often, wind speed increases with height so that the bottom or tail of each cirrus cloud lags behind the head, which may appear as a distinct generating cell (somewhat like a tiny cumulus) for the ice crystals, as in the cirrus *uncinus* (i. e., hook) in Fig. 10-19.



Fig. 10-19. Cirrus uncinus invading the sky over Boynton Beach, FL 10 Jan 2023.

The comma is the most common shape for cirrus streamers, as illustrated in Fig. 10-20. The top or head of the comma is wider because of the generating cell. The back or bottom of the tail lags further behind and is often nearly horizontal because as the crystals fall they sublimate and shrink. And as they shrink they fall more slowly, lagging ever further behind until they vanish.

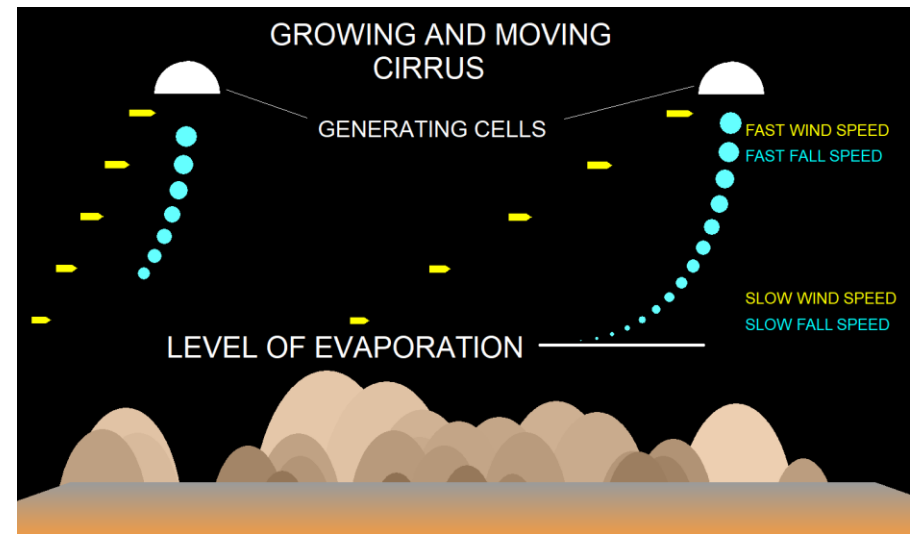


Fig. 10-20. Growing and moving cirrus. Ice crystals form in the generating cells, fall, sublimate, and fall slower as they shrink. When wind speed increases linearly with height trails take a comma shape as slower-falling crystals lag.



Fig. 10-21. Cirrus complex over Sapphire, NC 23 Oct 2022 resembles the head and neck of some animal.



Fig. 10-22. Cirrus uncinus possibly from contrail over Ridgewood, NJ.

Be forewarned, though. Cirrus clouds seldom have such distinct streamers and heads and such simple shapes as in Fig. 10-2 and Fig. 10-19. Far more often, variations of ambient wind direction, speed, ascent rate, and humidity are complex. Then the streamers can twist, get entangled and blurred, and take on fantastic shapes. On occasion, even the least imaginative person will see animal forms in the clouds, as in Fig. 10-21, but it would take the most imaginative person to disentangle the complexities of this particular cirrus formation.

The zig-zag cirrus streamers in Fig. 10-22 reveal a simpler situation to disentangle. This line of cirrus streamers, possibly falling from an old contrail, reveals a nonlinear vertical profile of wind speed. The wind, blowing from right to left decreases in speed below the generating cells to a minimum but then increases in the thin layer where the streamers bend downward to the left. Wind speed again decreases down toward the bottom of the streamers, where the downward slope to the right resumes.



Fig. 10-23. Two cases of paintbrush cirrus fibratus over Upper Saddle River, NJ.



Fig. 10-24. Cirrus fibratus over Vail, AZ 20 Feb 2020. Jan Curtis

Many cirrus clouds lack visible generating cells. Some of these look as if a paint brush were gently slid across a long section of sky

leaving a swath of parallel tracks of separate, individual fibers (Fig. 10-23). A likely cause for such *cirrus fibratus* is a gentle, laminar wave motion produced by wind shear in the ambient air. The tops of the fibers would form at the wave crests, where upward motion would have cooled a moist layer of air to the point of saturation. The shear would then align the fibers to cross the crests at angles up to 90° . A wondrous feature of cirrus fibratus is the vast number of largely distinct fibers (Fig. 10-24) almost as if mounted on a loom – a warp waiting for a woof of crossing threads.



Fig. 10-25. Cirrus floccus in a complete ring around a central tuft over Limerick, Ireland, at sunset 22 Jul 2008.

The tufts in cirrus floccus seldom form lines. The ring of cirrus tufts with one more tuft in the center taken shortly before sunset on 22 Jul 2008 at Limerick, Ireland in Fig. 10-25, looks as if a stone were dropped into the atmosphere causing a circular wave to spread out with a central crest occupied by a tuft and circular crest occupied by

a garland of other tufts. This extraordinary formation may be the remnant of a hole-punch cloud.

Cirrus clouds may be translucent or opaque (i. e., optically thin or thick). Opaque cirrus spissatus (i. e., thickened) may have a large enough ice particle density to cause blobs of cloud air to sink. The sinking will be enhanced by evaporative cooling if the air below the cloud is dry. This is the optimal condition for mamma to develop beneath cirrus.



Fig. 10-26. Cirrus spissatus mamma over San Mateo, CA 31 May 2015. Sublimation has made the mamma translucent. A thin layer of gray fog from the Pacific Ocean tops the crest of the Coast Range.

The cirrus spissatus of Fig. 10-26 formed in a humid layer at 7.4 km. With $T = -24^{\circ}\text{C}$, it was likely for supercooled droplets and altocumulus. Indeed, one hour later a sheet of cellular altocumulus did form just above the cirrus. The mamma fell into a dry layer of air where RH fell as low as 15%. A closeup view



Fig. 10-27. Closeup of Fig. 10-18 with evaporating mamma.



Fig. 10-28. Cirrus radiatus vertebratus over Cheyenne, WY 15 Feb 2017. Jan Curtis



Fig. 10-29. Cirrus vertebratus over Pacific Palisades, CA, possibly a remnant of a contrail.

shows that sublimation exacted a ‘heavy’ toll on the blob that sank the most (Fig. 10-27) making it translucent. Much lower, over the ridge of the Coast Range in Fig. 10-26, ragged tendrils of gray fog

from the Pacific Ocean also evaporated after cascading down the lee slope.



Fig. 10-30. Cirrus homogenitus vertebratus over Upper Saddle River, NJ 22 Feb 2010 early in its evolution from contrails.

Sometimes cirrus takes the form of a central spine with vertebra on both sides, as in the cirrus vertebratus (i. e., jointed) of Fig. 10-28. Some cirrus vertebratus may be caused by the double wingtip vortex flow in the wake of jets, as possibly in Fig. 10-29 and certainly in Fig. 10-30. In those cases of cirrus homogenitus vertebratus, the vertebra form near the crest of each vortex and then sink, converge, and join to form the central spinal cord.

Parallel bands of cirrus radiatus will sometimes line the sky like the stripes of a flag (Fig. 10-31). The bands may be so long that they cross the sky (Fig. 10-32). When they do satellites provide an overview that may differ from the surface-based classification.

An extraordinary case of cirrus that would be identified as *radiatus* by a ground-based observer but more likely as *vertebratus* from Space occurred over the ocean south of Adelaide, Australia on 17 Oct 2017 (Fig. 10-33). The streamers, from 100 km long in the north to 200 km long in the south, were evenly spaced about 40 km apart

and were oriented at almost right angles to the NW wind. The even



Fig. 10-31. Cirrus radiatus over Shepard Hall, CCNY.



Fig. 10-32. Cirrus radiatus crossing the sky over the Weisshorn, Switzerland, Jun 2004.

spacing suggests waves and the sounding did contain relatively small vertical wind shear centered at 12 km, the height of the tropopause and cloud top.

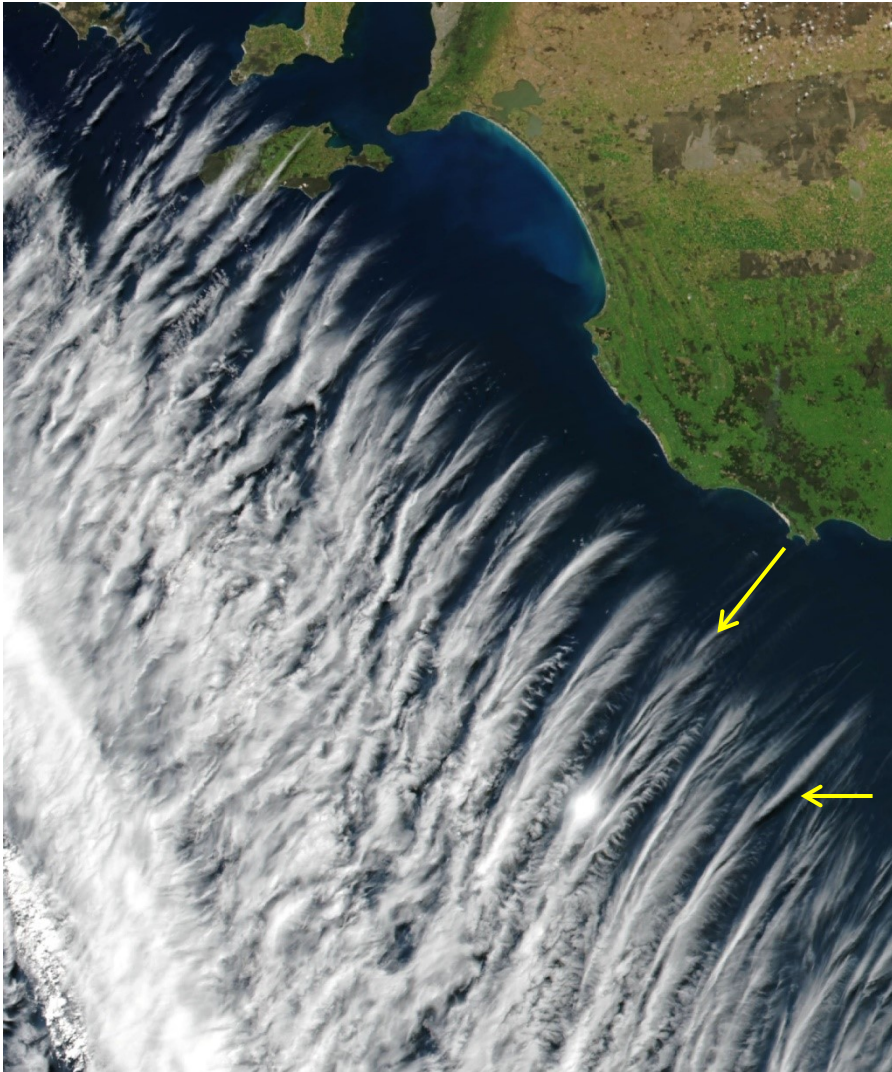


Fig. 10-33. Evenly spaced, parallel bands of cirrus south of Adelaide, Australia 17 Oct, 2017. A subsun appears where arrows converge. NASA Suomi NPP VIIRS.

A subsun can be seen toward the lower right of the image in the streamer pointing to the small cape at Portland. Subsuns occur when ice crystals (which formed at $T \approx -60^{\circ}\text{C}$ in this case) fall with the top surface almost horizontal and act like tiny mirrors.

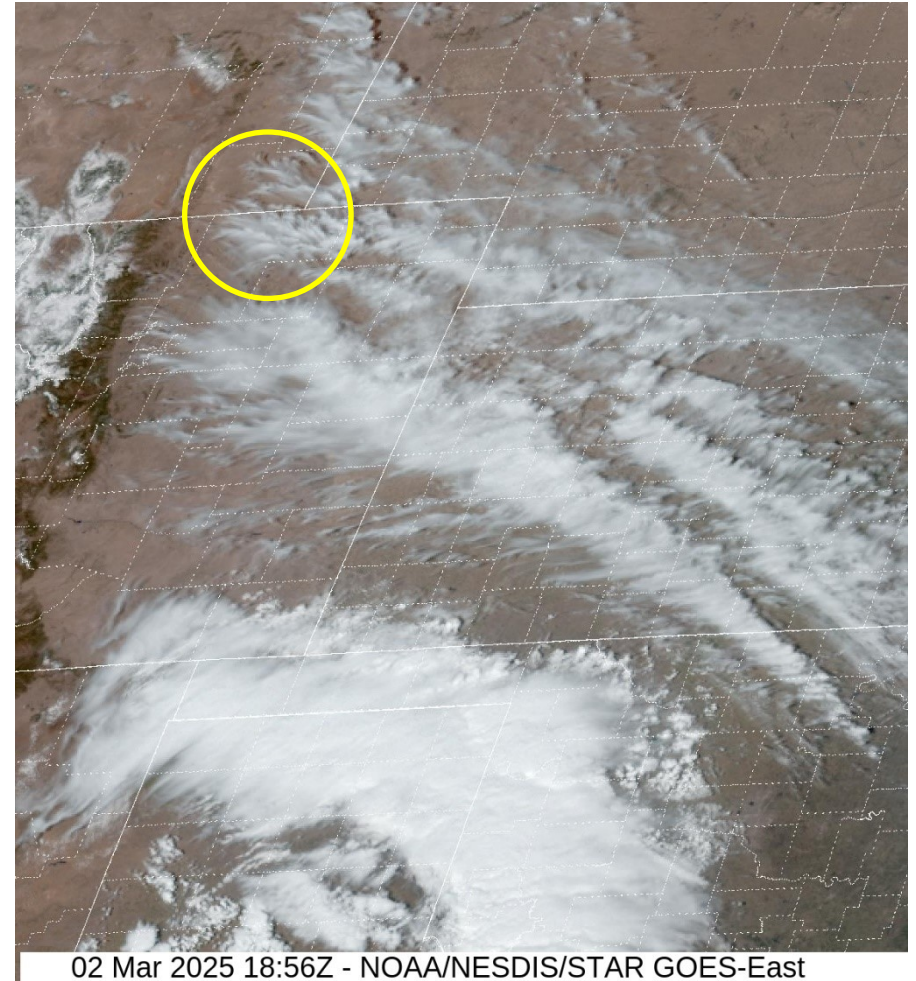


Fig. 10-34. Cirrus bands propagating ahead of a cyclone on 02 Mar 2025. Cirrus radiatus photographed from the ground appear in the yellow circle.

The drama of a similar outbreak of cirrus radiatus, though on a smaller scale, was imaged from both above (Fig. 10-34) and below (Fig. 10-35) on 02 Mar 2025. Its dynamism was captured by

simultaneous time lapse GOES images and by a ground-based time lapse video (facing east) in,

https://www.flickr.com/photos/cloud_spirit/54361753915/in/photostream/lightbox/

The cirrus radiatus formed at the western edge of long bands of cirrus that stretched from Colorado and Wyoming eastward through Kansas and Oklahoma. While the satellite imagery shows the long bands



Fig. 10-35. Cirrus vertebratus east of Cheyenne, WY 02 Mar 2025. Jan Curtis ground-based video propagating northward out in advance of an extratropical cyclone centered over the Texas Panhandle, the ground-based video shows band after band of the feathery cirrus radiatus racing across the sky.

The reason that cirrus clouds are often forerunners of approaching tropical and extratropical cyclones as well as thunderstorms, is that all these storms expel cirrus in their outflows high in the troposphere. Hurricanes in particular generate parallel curved bands of cirrus radiatus in the anticyclonic outflow (Fig. 10-36). Blobby, asymmetric convection in the eye wall generates gravity waves that spiral outward, and instability at the periphery of the outflow produces the parallel bands of cirrus radiatus.

Gravity waves also produce cirrus bands in the outflow ahead of deepening extratropical cyclones. These bands seldom approach the symmetric beauty of hurricane outflow cirrus. An exception was developing Winter Storm Anya on 08 Nov 2024 (Fig. 10-37), which ejected two 1000-km long parallel bands that propagated so far ahead of the main cloud mass that skies cleared for hours after each passed. But the storm was on its way.

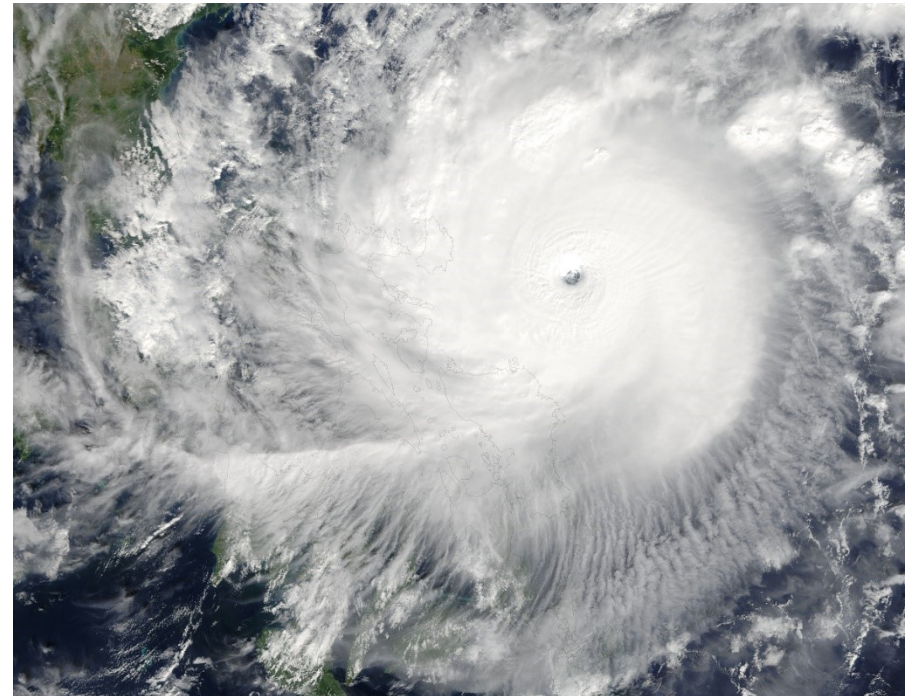


Fig. 10-36. Spiral cirrus and parallel bands of curved cirrus radiatus in the outflow of Typhoon Chaba, 03 Oct 2016.

Cirrus clouds are not always forerunners of storms. Quite often, they stand alone on their own, filling the skies for a precious few hours with beauty and grace before disappearing with nary a trace or passing over the horizon, leaving cloudless cobalt blue skies behind. While moving quietly in the background they adorn and embellish the foreground scenery. They go especially well with fall foliage (Fig. 10-38) and roses (Fig. 10-39).

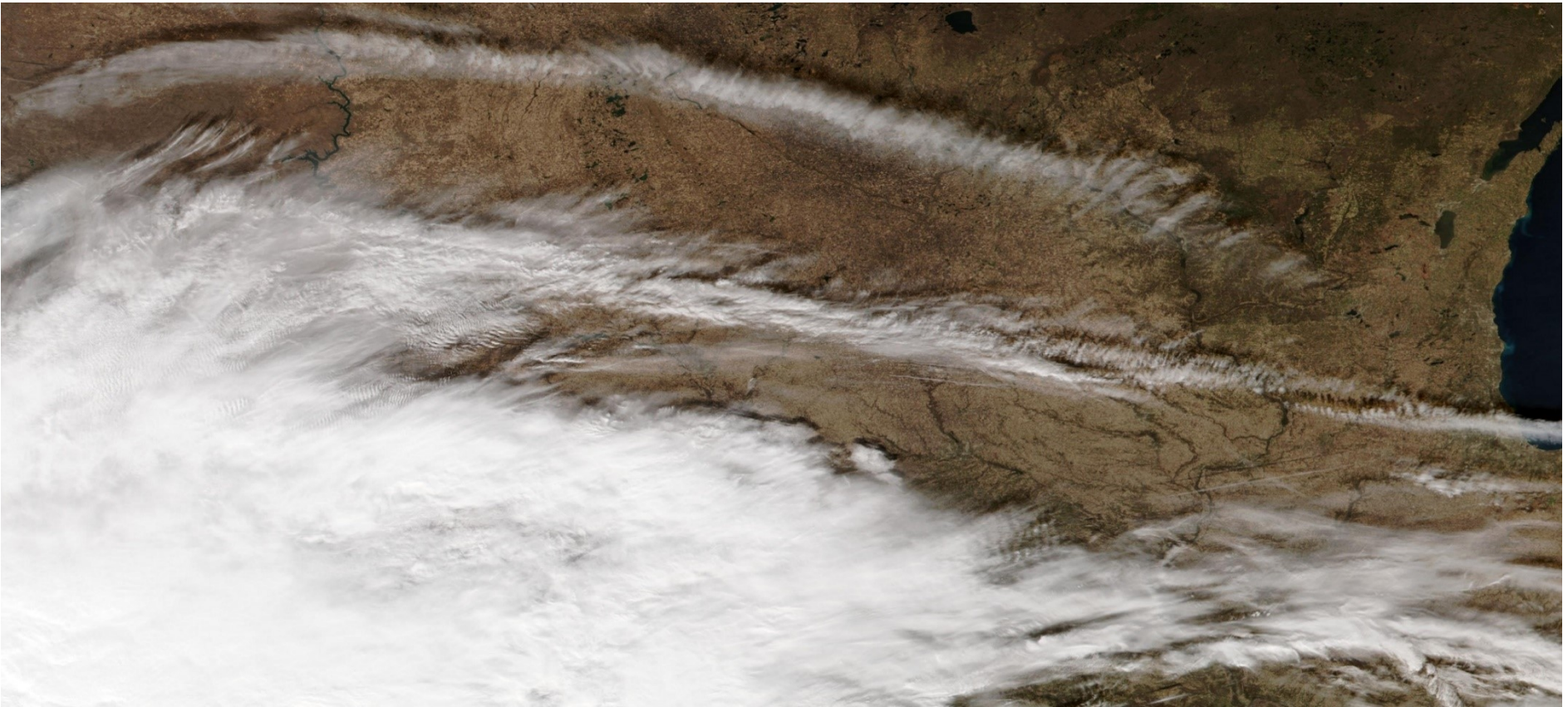


Fig. 10-37. Parallel bands of Cirrus radiatus moving ahead of the cloud shield from deepening Winter Storm Anya, 08 Nov 2024 NOAA 21 VIIRS satellite image.

Around sunrise and sunset, and sometimes almost an hour into twilight, cirrus clouds can take on colors. Because cirrus are high clouds, they bask in direct sunlight when all lower clouds are submerged in Earth's shadow. At such times, if they are optically thick, they can take on a deep red color because to reach them the Sun must pass through up to almost 80 equivalent atmospheric masses. Because of their great height, cirrus differ in color from lower clouds. Cirrus (and cumulonimbus tops) are the first clouds to turn white after sunrise and the last to remain white as the Sun sets.

Despite their great height, cirrus are seldom the best sunrise and sunset clouds. This is because cirrus tend to be scattered and optically thin. As a result, their color palette tends to be less fiery,

even gentle – more pastel than spectral, as in Fig. 10-39. As we will see in Chapter 12, the honor of best sunrise and sunset clouds usually goes to patterned sheets of altocumulus because of their great optical thickness to the horizontal rays of the rising and setting sun.

10.3 Overcast Layer Clouds

Layer clouds are the opposite of penetrative clouds. Penetrative clouds are short-lived, buoyant plumes. Even though they tend to form where moisture and upward motion are enhanced by the large-scale setting, they appear to act with dramatic flair as rogues. They



Fig. 10-38. Cirrus radiatus over Saddle River, NJ. SDG.



Fig. 10-40. (also Fig. 4-2). Cirrus sunset at Vail, AZ 15 Nov 2022. Jan Curtis.



Fig. 10-39. Cirrus fibratus and uncinus over the San Mateo, CA rose garden, 30 May 2012. SDG.



Fig. 10-41. The advancing edge of a cirrostratus veil. SDG.

are narrow enough to be viewed in their entirety from the ground and so, convey a false impression that the atmosphere is deep.

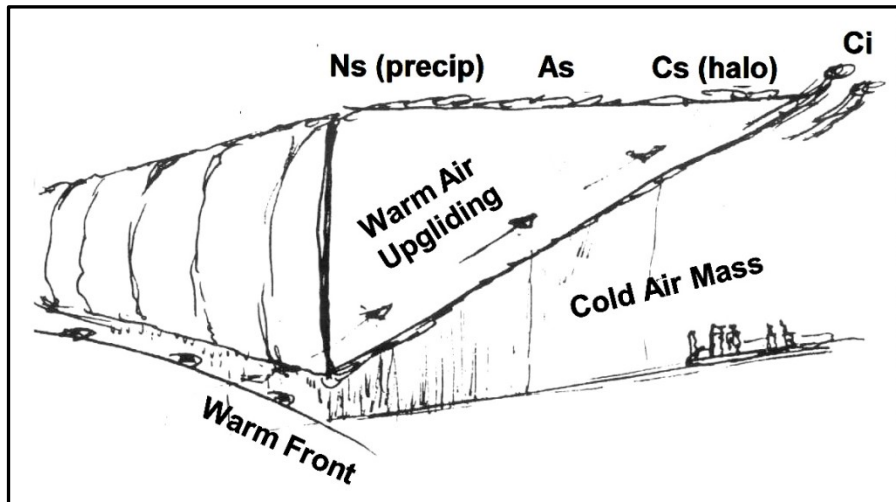


Fig. 10-42. The cloud wedge above the warm frontal surface. The actual slope is much smaller – of order $1/100$. SDG.

Layer or stratiform clouds form from air that ascends at a gentle slope of about $1/100$ and at little more than a snail's pace (typically 1 to 50 cm/s). The air may surmount broad highlands or huge domes of cold air masses as part of extratropical cyclones (Fig. 10-42, see also Fig. 4-24). Stratiform cloud decks act as extended units hundreds of kilometers across that operate with little fanfare but great endurance for hours or days on end. Stratiform clouds are so extensive they can only be seen in their entirety from space. In this way, they restore a proper perspective that the atmosphere is a thin veneer.

Stratiform clouds can be complex. They often contain several layers with enclosed clearings and embedded convective clouds, just as a layer cake is interspersed with layers of frosting and often laced with chocolate bits.

Stratiform clouds produce most of the rain and snow outside the tropics during the cold part of the year. Even in the tropics, where thunderstorms command much of the attention, stratiform clouds

often knit the anvils together, outlast the thunderstorms that created them, and produce about 40% of the rain.

In extratropical cyclones, stratiform clouds form a wide wedge as tropical air slides over a dome of polar air. This is the warm conveyor belt (recall §5.7). Nimbostratus, which provides the bulk of the extratropical cyclone's rain and snow, forms as tropical air begins its ascent over the dome of polar air. Frontal fog may form when rain falls through the shallow cold air dome just poleward of the surface front. Further east and poleward the cloud thins and its base rises as the altostratus, through which the Sun or Moon may peer dimly and from which rain or snow may fall. As the air continues ascending the dome the cloud sheet thins to cirrostratus, sometimes marked by halos. With further rising, almost all the water vapor has been removed and the highest, furthest east cloud remnants are the cirrus

The entire stratiform cloud pattern becomes a sequence in time for an observer at a fixed location as it moves from west to east to provide early warning signs of the approaching storm. The highest clouds arrive first and lead to the classical lowering cloud sequence,

cirrus → cirrostratus → altostratus → nimbostratus

Precipitation begins about 12 to 24 hours after cirrus appears. It typically lasts another 12 to 24 hours. Fog or a fracturing, ragged complex of clouds marks the end and then the temperature rises.

Cirrus clouds, the first in the storm sequence, and which we have just seen in §10.2 are so beautiful and delicate they rouse little suspicion of a possible storm. But high aloft they may be weaving their web silently. If you have not been watching the change, you may suddenly notice that the landscape does not seem to sparkle as it did a short time before. Looking up, you may catch the edge of the veil of cirrostratus advancing across remnants of azure sky, as in Fig. 10-41. More likely, you are a bit too late and the azure sky now appears milky blue. The cirrus clouds have thickened and congealed into a complete but translucent fabric of cirrostratus. The Sun still shines through cirrostratus, but it casts less pronounced shadows.



Fig. 10-43. Cirrostratus with 22° halo over Cheyenne, WY on 18 Feb 2017. Jan Curtis.

Quite often, cirrostratus provides compensation in the sky for the loss of brilliance to the landscape below. Stretch your arm out and use your outstretched palm to shield your eyes from the still blinding Sun. Look all around your hand and if you are lucky, you will see a large circular ice crystal halo, the classic insignia of cirrostratus and oncoming storms. Recall the fateful lines in Henry Wadsworth's poem, *The Wreck of the Hesperus*,

Then up and spake an old Sailòr,
Had sailed to the Spanish Main,
"I pray thee, put into yonder port,
For I fear a hurricane.

"Last night, the moon had a *golden ring*,



Fig. 10-44. Leading edge of cirrostratus with 22° halo at its best over Cheyenne, WY at noon on 24 Jan 2022. Snow arrived 12 hours later. Jan Curtis.

And to-night no moon we see!"
The skipper, he blew a whiff from his pipe,
And a scornful laugh laughed he.

Of course, the old Sailòr was spot on and the skipper was dead wrong, for the 'golden' ring is the circular 22° halo, so named because its bright inside (which is reddish and not golden) appears at an angle of 22° away from the Sun or Moon in all directions. The first example of an ice crystal halo we present (Fig. 10-43) is typical but is neither brilliant nor highly colorful, so that most people would not notice it. Its subdued appearance results from two factors that so often impair the potential beauty of halos and even presence of halos in cirrus and cirrostratus, namely, 1: many crystals are 'imperfectly' shaped and, 2: the cloud is optically thick.

A more alluring but still modest appearing halo (Fig. 10-44) graced the leading edge of an optically thinner layer of cirrostratus on 24 Jan 2022 over Cheyenne, WY. The time lapse video of that halo,

https://www.flickr.com/photos/cloud_spirit/51842056189/in/album-72157632749850748

shows that it faded whenever and wherever the cirrostratus got too thick.

Ice crystal halos that form from perfectly shaped and oriented crystals in clouds of optimal optical thickness with the proper Sun angle can be so stunning they can take your breath away, especially if you are immersed in them. We present views of such extraordinary halos and explain how they form in Chapter 11.

When a halo appears in cirrostratus (halos also appear in cirrus and, near ground level on frigid days, when ‘diamond dust’ crystals form



Fig. 10-45. Altostratus with a watery Sun and lower scud clouds over Cliffside Park, NJ. SDG

and sparkle in clear air) there is a 50% chance of rain or snow within 24 hours. That probability rises to over 80% if the cloud cover thickens and lowers and the cirrostratus transitions to altostratus.



Fig. 10-46. Altostratus undulatus asperitas over the City College of New York and the George Washington Bridge. SDG.

Altostratus, the central cloud genus in the warm, moist conveyor belt, imparts a somber look to every scene, without a hint of blue in the gray sky. Altostratus can be translucent (Fig. 10-45), with its trademark ‘watery’ Sun only dimly visible through the thickened veil as through ground glass so that at best it casts faint shadows. Scud or *pannus* (shred) often forms nearer the ground. Altostratus may also be opaque, and if so, can be quite dramatic when the polar below the frontal surface is dry. Then the strong vertical wind shear across the frontal surface produces a series of ripples and waves that can give the cloud base the almost cosmic look of asperitas, as in Fig. 10-46.

The first light rain or snow from a winter storm sometimes falls from altostratus. An indication that rain or snow may soon reach the ground is that the once distinct corrugations of the base of the altostratus have become blurred and indistinct. Then, provided the polar air below the frontal surface is not too dry rain can begin in about 15 minutes, or snow in about 30 minutes if it is cold enough. This is the time it takes raindrops or snowflakes to reach the ground

from the blurred cloud base of the altostratus, typically around 2 km above the surface.



Fig. 10-47. Nimbostratus at beginning of the snowstorm of 03-04 Oct 1987 in Chittenden, VT. SDG.



Fig. 10-48. Nimbostratus cutting off tops of skyscrapers over Manhattan, NY 08 Sep 2011. SDG.



Fig. 10-49. Snow from nimbostratus filling the air at City College. SDG.

Steady rain or snow or freezing precipitation begins in earnest once the altostratus lowers and thickens to nimbostratus. Nimbostratus is generally almost featureless, though cloud fragments called scud sometimes appear below. The base of the amorphous cloud is almost indecipherable unless it is marked by some towering landscape feature such as a mountain (Fig. 10-47) or skyscraper (Fig. 10-48).

Light rain had just begun to fall around Vermont on 03 Oct 1987 at the moment shown in Fig. 10-47, but aloft it was cold and snowing. Over the next few hours the falling snow cooled the air as it melted, just as ice cubes cool a glass of water and the rain turned to snow at the surface. For the next 12 hours snow totals up to 50 cm fell, weighing down the trees, which were in fall foliage mode, breaking their limbs or felling them en masse and making the forest sound like a pitched battle.

Moderate or heavy snow can be a beautiful sight, even if everything is gray, as in the pre-Halloween storm of 2011 in northern New Jersey and southern New York (Fig. 10-49). In very cold air, flakes



Fig. 10-50. Huge, clumping wet snowflakes at start of storm on 30 Oct 2011 in Upper Saddle River, NJ. SDG.



Fig. 10-51. Snow-burdened foliage adds color to a gray scene under nimbostratus clouds, Rockaway NJ, 30 Oct 2011. SDG.

tend to be small and fine and the snow on the ground is so fluffy that 30 cm of snow on the ground will melt to as little as 1 cm of water. When either $T \approx 15^{\circ}\text{C}$ where the flakes are shaped like branched dendrites and interlock, or especially as $T \rightarrow 0^{\circ}\text{C}$ so that the flakes begin to melt and stick, they can form huge flakes several cm across, as in Fig. 10-50. It is the heavy, wet flakes that pile on tree branches, especially those still in full leaf, make them bow down or topple them completely. This occurred in both the 04 Oct 1987 snowstorm from the northern border of New York and Vermont south to the gates of New York City, and the pre-Halloween 30 Oct 2011 snowstorm (Fig. 10-51) with up to 40 cm.



Fig. 10-52. Altostratus reflected by Cloud Gate Chicago 15 Jul 2009. SDG.

What about aesthetics, always a matter of individual taste? Stratus and nimbostratus are the classic gray, often featureless clouds that either render scenes gloomy or obscure them. All other cloud genera can be photographed without any other foreground and look attractive or at least distinctive. Even altostratus exhibits some variation, as in Fig. 10-45, Fig. 10-46, and reflected by Cloud Gate



slates, and then they remove all sparkle from the landmarks they cover, as with the United States Capitol (Fig. 10-53) and Yosemite Valley (Fig. 10-54).

Fig. 10-53. Stratus covering the United States Capitol 13 Apr 2013. SDG.



Fig. 10-54. Stratus covering Yosemite Valley, CA 16 May 2017. SDG.

in Chicago (Fig. 10-52). Featureless stratus and nimbostratus require foregrounds in order to appear as anything other than blank, gray



Fig. 10-55. Same scene during Blizzard whiteout conditions Cheyenne, WY 14 May 2021 (top) and clear sky the next day (bottom) .. Jan Curtis.

Blizzards can cause whiteout conditions that make cloud and snow-covered ground look the same and obscure everything not immediately in front of the viewer as during the height of the

blizzard of 14 Mar 2021 in Cheyenne, WY (Fig. 10-55 top). The same scene under clear skies a day later (Fig. 10-55 bottom) looks worlds different.

The forms of precipitation in the great warm conveyor belt cloud shields of extratropical cyclones include snow, ice pellets (sleet), freezing rain, and rain. And, just as there is a pattern of cloud genera in the warm conveyor belt, so too, there is a pattern of precipitation forms, with snow furthest poleward, grading in order to ice pellets, freezing rain, and rain. However, freezing rain and ice pellets require special conditions.

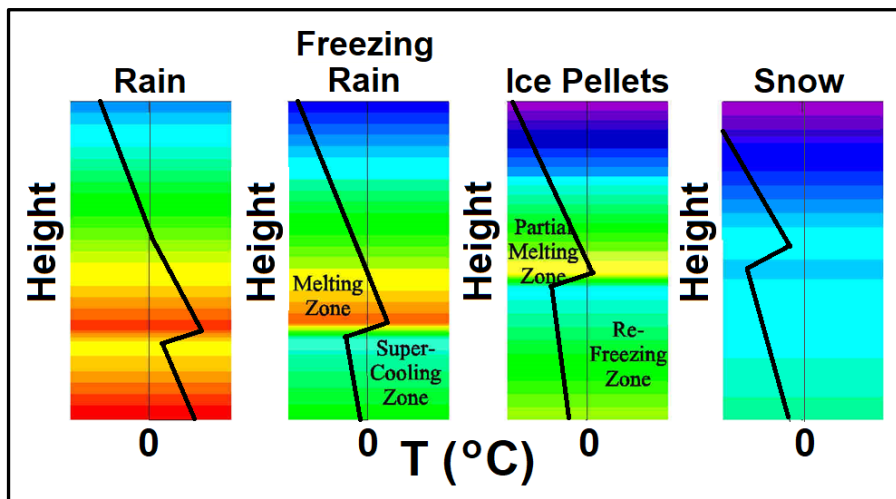


Fig. 10-56. Precipitation forms and their soundings. The sequence from left to right mimics the sequence moving poleward from the warm front. SDG.

The form of precipitation at any particular location in a storm is determined by the vertical profile of temperature and humidity the hydrometeors form in and fall through, i. e., the sounding and it tends to occur in order from furthest poleward to nearest the surface warm front as shown in Fig. 10-56.

In almost all cases, precipitation forms as snow but melts to rain if there is a thick layer from the surface up where $T > 0^{\circ}\text{C}$. Snow reaches the ground and sticks if $T < 0^{\circ}\text{C}$ all the way to the ground.

Because snowflakes do not melt immediately once $T > 0^{\circ}\text{C}$, snow can also reach the ground if the lowest few hundred meters is just above freezing, particularly if RH is low, because then evaporation will dominate melting and keep the snowflakes frozen. Except in the rapid downbursts in thunderstorms, the highest temperature that snow can reach the ground is $\approx 10^{\circ}\text{C}$. Of course, if $T > 0^{\circ}\text{C}$ the snow will not stick on the ground very long.

Ice pellets (i. e., sleet) and freezing rain only form when there is a wrinkle in the sounding – a melting zone aloft (just above the frontal surface) where $T > 0^{\circ}\text{C}$ sandwiched between layers higher aloft and near the surface where $T < 0^{\circ}\text{C}$. Freezing rain dominates when the melting zone is warm and thick enough to melt snowflakes completely to raindrops, because even if the surface layer of air is extremely cold the raindrops will not easily refreeze. Ice pellets dominate when the melting zone is thin and barely above 0°C so that the snowflakes do not melt completely. The partially melted flakes collapse into tiny slush drops, which easily refreeze if the surface layer they fall into is cold enough. Once hydrometeors have largely melted, they never regain their virginal crystalline form. Instead, they refreeze as ice pellets that sting when they hit your face and often bounce like the much larger hailstones when they hit the ground.

Freezing rain is deceptively dangerous and destructive. It seems like normal rain, but since it is supercooled, it freezes upon contact with the ground, with trees, with power lines, even with eye glasses. Freezing rain turns the ground into a skating rink, much like the scene in the movie, *Home Alone*, where Kevin (the boy) hosed the steps to the house, which quickly freeze so that Harry (the chief burglar) almost broke his back and Marv (the second burglar) slipped down the stairs on his back and failed in several attempts to stand up. In a film this may be hilarious, but it is accurate and not funny in real life when it happens to people who fall or to cars and trucks that slide and crash into each other, brakes being utterly useless.

When freezing rain sticks on trees it can be a beautiful sight if the freezing layer is thin (Fig. 10-57), but if it is thick it can and has

downed power lines, tree limbs and whole trees. In short, nothing moves and power outages are widespread and long-lasting, even if the weather turns warm.



Fig. 10-57. Alder branches coated with a thin layer of ice and Spruce branches with snow at Fairbanks, AK, moonlit winter night 1999. Jan Curtis.

Winter storms may seem to last an eternity, but eventually they move on. If the storm center passes by poleward of the observer the air begins to warm and the cloud base continues to lower, often reaching the ground as frontal fog. After that, warming continues and the sky tends to clear and often hazy.

If, however the storm center passes by equatorward of the observer, the weather remains cold and the cloud layer clears fitfully, lifting, severing and shredding in a sometimes ominous manner (Fig. 10-58) and sometimes in a hopeful manner with a setting Sun finally peeking through the western edge of the overcast (Fig. 10-59). Sometimes smooth, rounded evaporating remnants resembling cumulus but classified as fractostratus are all that remain (Fig. 10-

60). Soon though, they too disappear, leaving behind some of the deepest blue pristine skies, the air having been swept clean of all aerosols by the falling raindrops and snowflakes.



Fig. 10-58. Departing storm over Cliffside Park, NJ with altostratus above fractostratus tilted by strong vertical wind shear. Clearing occurred a few hours later SDG.

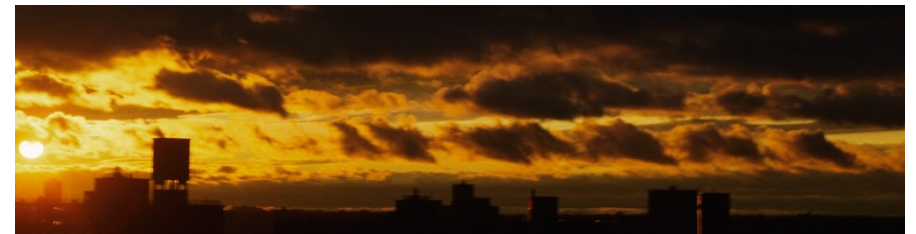


Fig. 10-59. Lifting cloud veil with fractostratus after a storm at sunset. SDG.

Extensive covers of stratus and fog often form far from extratropical cyclones when air passes over cold water. The fog often lifts and breaks up to fractostratus during the day as it drifts over land and gets heated, as on Inch Beach, Ireland on the afternoon of 21 July 2008 (Fig. 10-60). In such places the beauty is striking, especially when it comes after many hours or days of gray, and with the prospect of returning as the air cools when the Sun goes down.



Fig. 10-60. Fragmenting, evaporating fractostratus after 4 days of rain on Unga Island in the Aleutians. ©Margaret Winslow.



Fig. 10-61. Dissipating fractostratus, Inch Beach Ireland, 21 July 2008. SDG.

10.4 Gallery

Cirrus is beautiful enough to make a scene all by itself or can embellish any scene.



Fig. 10-62. Cirrus uncinus Granada, Spain 06 Oct 2007. SDG.



Fig. 10-63. Cirrus fibratus Boynton Beach, FL 15 Jan 2012. SDG.



Fig. 10-64. Clear morning sky vs nimbostratus afternoon with ice pellets Long's Peak CO 01 Aug 1976. What a difference a cloud makes. SDG.
A little sunshine and a little (or big) red highlight do wonders to scenes with skies covered by stratus.



Fig. 10-65. Stratus fractus San Francisco, CA 13 Apr 2013. SDG.



Fig. 10-66. Sunlight breaking through stratus at Killington, VT 28 Feb 2010.. SDG.