Thundersnow

Difficult to forecast and rare, but a real threat to landing or low-altitude aircraft.

BY ED BROTAK

DainisDerics/istockphoto

It was a cold April morning in the mountains of western North Carolina in the United States. It was raining lightly, with temperatures above 40 degrees F (4 degrees C). The rain started to pick up. The temperature dropped dramatically in minutes, down to 32 degrees F (0 degrees C). The rain changed to snow. Then a flash lit the sky — lightning! This was a thunder snowstorm.

Blinding snow filled the sky, dropping the visibility at the Asheville Airport to 1/4 mile (400 m) at times. It snowed heavily for an hour, with numerous lightning flashes. Four inches (10.2 cm) of snow accumulated. Even though the ground was warm, snow covered everything. Just as quickly as it had started, the storm ended. Temperatures warmed back up above freezing, and the snow melted nearly as fast as it had fallen.

Thundersnow is defined as a snowstorm accompanied by lightning and thunder — a type of convective precipitation with below-freezing temperatures. We normally think of convective showers and thunderstorms occurring in the warmer months, but convection is not a direct function of high temperature. It is controlled by the change of temperature with altitude — the lapse rate. Convection is a type of lifting in the atmosphere that occurs when a parcel of air becomes warmer than the environment. The parcel is buoyant and begins to rise. The difference in temperature between the parcel and the surrounding atmosphere — not any particular range of temperatures — is the key in the development of convective activity.

A parcel of air can be below freezing and still rise if it is warmer than a very cold surrounding environment. The lapse rate determines this environmental temperature at different elevations. A steep lapse rate, defined by a rapid temperature drop with altitude, favors convection. Within clouds, saturated parcels rise and cool at the moist adiabatic lapse rate — approximately 3 degrees F (2 degrees C) per 1,000 ft. If the environmental lapse rate is greater than that, convection can occur. Steep lapse rates are more common in the warmer months when strong solar radiation heats the surface, which then warms the air directly over it. However, steep lapse rates can occur at any time, even with below-freezing temperatures.

Convection brings with it hazards to aviation, even without electrical activity. The occurrence of lightning adds yet another problem, but often this is not as serious as the issues accompanying the precipitation itself. In these cases, lightning and thunder also act as warning signs of convective activity.

For aviation interests, convective snow or thundersnow can produce problematic, if not outright dangerous, conditions. The reductions in visibility are an obvious concern. Occasionally, visibility drops in a matter of minutes to near zero in whiteout conditions. Although the storms themselves usually aren't particularly strong as thunderstorms go, there still is some turbulence. Hail occasionally accompanies these storms, but most commonly it is the small, graupel[1] type. High winds can also occur, but these are not the "downburst" type winds associated with severe thunderstorms. Rather, they are strong straight-line winds aloft brought down to the surface in the

© Mike Tigas/Flickr

Kyle House/Flickr

thunderstorm downdraft. They produce high gusts, adding to the existing wind pattern. If there is lightning, this is another threat. There are numerous reports of aircraft in flight being hit by lightning during thundersnow events, including two documented incidents in Alaska. On Feb. 22, 1997, near Kodiak, a Lockheed C-130 was hit twice, and on Feb. 1, 2009, near Sitka, an Alaska Airlines Boeing 737 was hit. In both events, minor damage was reported.

Runway conditions can also deteriorate in a hurry. Snowfall rates are often excessive. Four in (10 cm) per hour is not unusual, and rates as high as 6 to 9 in (15 to 23 cm) per hour have been recorded. With such extreme snowfall rates, runways become snow-covered within minutes, and snow removal efforts are unable to keep up with the accumulation. Even if ground temperatures are above freezing, the snow sticks and piles up, the accumulation rate exceeding the melting rate. This also applies to snow accumulating on the exposed surfaces of aircraft on the ground. If the situation favoring convective snows continues for a number of hours, total snowfall amounts can be prodigious. Several feet of snow are possible in a day. The sheer bulk of the snow can make removal difficult or even impossible.

The crux of the problem for aviation is the "magnification effect" of snow versus rain.

Convective lifting is usually intense. Therefore, precipitation rates are excessive. The combination of adiabatic cooling due to lifting and evaporative cooling from the precipitation drives down temperatures. In some cases, the induced temperature fall can drop temperatures below freezing. Rain can change to snow, and a fairly benign rain situation can become a critical snow event.

For aircraft in flight, these storms look fairly innocuous and pilots may not try to avoid them, but the only major concern is attempting an approach and landing in such conditions, or if a thundersnow develops during an approach. There would be some turbulence, but it would not be nearly as bad as during warm-season storms.

The actual surface temperature may not indicate what could happen in the near future. Keep in mind that snowflakes are formed within the clouds thousands of feet above the surface. If the layer of air near the surface has temperatures above freezing and is sufficiently deep, the snow melts and falls to the ground as rain. If the near-ground layer of air is shallow, then snow can reach the ground even with surface temperatures above 32 degrees F. Snow has been reported with surface temperatures, at least at the start, above 40 degrees F and sometimes, rarely, above 50 degrees F (10 degrees C), but temperatures plunge once the snow begins to fall. Convective snow situations often feature steep lapse rates which favor such switch-overs.

The crux of the problem for aviation is what I'll call the "magnification effect" of snow versus rain. You've probably heard the adage "one inch of rain would equal ten inches of snow." This is a general rule, dependent on the actual temperature, but it makes the point. For example, suppose the precipitation rate is 0.5 in (1.3 cm) of liquid water equivalent an hour. If it all falls as rain, that's 0.5 in of rain in an hour, a good rain but not excessive. Convert that same precipitation rate to snow, and you have 5 in (13 cm) of snow per hour and major problems. Reductions in visibility probably follow a similar ratio since snowflakes have a much larger surface area than raindrops. A visibility of 4 mi (6 km) in rain could easily drop to ¼ mi (400 m) in heavy snow even though the actual precipitation rate does not change.

There are a number of weather situations in which thunder snowstorms can develop. Cold air moving across a warmer body of water can set up a lapse rate sufficiently steep to generate convection, and the added moisture from below can generate more precipitation. Such a setup often occurs around the Great Lakes of the United States and Canada in winter. The famous "lake effect" snows often have a convective

Don Sutherland/Flickr

nature, especially early in the winter when the lake waters are their warmest and cold polar or arctic air masses move in from the northwest. This usually occurs following the passage of a low pressure area and its associated cold front. With the low to the northeast of the region, the cyclonic flow produces a westerly wind across the lakes. As the cold air moves across the warm lake waters, the air near the surface is warmed and moistened.

Convective snows are common on the lee side of lakes. Extreme snowfall rates and incredible snowfall totals can evolve. Fortunately, the more extreme situations tend to be confined to the immediate lee of the lakes. For example, on Oct. 13, 2006, at 0153 local time, the Buffalo, New York, airport was reporting ¼ mi visibility with a thunderstorm and heavy snow, a ceiling of 200 ft and frequent lightning. Twelve in (30 cm) of snow had fallen in the previous six hours, with 4 in (10 cm) falling in the previous hour alone.

Ocean areas with warm currents and their adjacent coastal regions could see similar situations in the winter. Extremely cold arctic air masses can move from their inland source regions out over the open waters. The lower layer of air can warm quickly from below while temperatures aloft remain very low, setting up steep lapse rates and possible convective activity. Thundersnow has occurred along the northwest coast of North America from Alaska southward to Washington, in the British Isles and northwestern Europe, and in Japan. All of these regions feature warm ocean currents and relatively warm waters.

Another area in which convective snows can develop is near the center of major winter storms. Warm, unstable air from the south can be pulled into the cyclonic circulation. As this air is lifted, it cools. If lifted high enough, the layer of air may cool to below freezing but still have an unstable lapse rate. By this point, the unstable layer often has been rotated cyclonically to the northwest side of the low center. Convectively enhanced snow bands can add to the more stratiform precipitation shield of the storm. The major snowstorm that affected the East Coast of the United States on Feb. 6, 2010, featured convective snow bands. For example, at 0326 local time, Georgetown, Delaware reported heavy snow with thunder and a visibility of ¼ mi. The wind was from the east-northeast at 27 kt with gusts to 37 kt.

Sometimes, vigorous upper-level troughs induce snow-producing thunderstorms. The troughs are pools of cold air aloft that induce lifting on their east side. Often convection is produced, and, with cold surface temperatures, snow can form. The situation described in the opening paragraph was an example of this dynamic. In this situation, an actual upper-level closed low was centered just south of the southern Appalachians in the eastern U.S. A trough rotating around the low instigated the thunder snowstorm.

Thundersnow is more common in mountainous terrain. The higher elevations result in colder temperatures, and orographic lifting — winds pushed up by rising terrain — aids in thunderstorm development.

Because of their rarity, thundersnow or convective snow in general is difficult to predict. Meteorologists can look at the situations described above and make generic forecasts that thundersnow might occur, but specific forecasts (times and snowfall amounts) are impossible. As with most convective situations, an examination of local soundings gives the best clues as to the potential for thundersnow. But, as has been mentioned, these are not strong storms. These are low-topped thunderstorms developing in a marginally unstable environment.

Sometimes standard stability indices indicate instability in these cases. This is more likely for the "warm water" events. For example, a convective snow situation developed in the U.S. Pacific Northwest on Jan. 27, 2008. The indices all indicated at least some convective activity. In cases like this, the unstable layer extended from the surface to above 18,000 ft.

However, in cyclonic cases like the U.S. East Coast storms, the unstable layer is not near or at the surface, and typical stability indices are usually worthless for prediction. In the thundersnow event in Georgetown, the indices indicated extreme stability in the atmosphere and no chance of convection. The unstable layer, where the convection was generated, was located well above the surface. In these cases, a close examination of the sounding usually is required to identify regions of instability in the atmosphere that would otherwise go undetected. Even then, it's difficult to predict with certainty that convective snow or thundersnow will occur.

Edward Brotak, Ph.D., retired in 2007 after 25 years as a professor and program director in the Department of Atmospheric Sciences at the University of North Carolina Asheville.

Note

1. Heavily rimed snow particles, often called snow pellets; often indistinguishable from very small soft hail except for the size convention that hail must have a diameter greater than 5 mm. Sometimes distinguished by shape into conical, hexagonal, and lump (irregular) graupel.