Convectional Wisdom

Mesoscale convective systems must be understood to mitigate their threat to aviation.

BY ED BROTAK

In October 2006, following a series of fatal crashes, the U.S. National Transportation Safety Board (NTSB) issued a safety alert describing procedures pilots should follow when dealing with "thunderstorm encounters." Despite these instructions, incidents continued to occur. One concern is that terminology often used by meteorologists is unfamiliar to some in the aviation community. For example, the fatal crash of the Hawker 800A at Owatonna, Minnesota, U.S., in June 2008 (*ASW*, 4/11, p. 16) involved a "mesoscale convective complex." The crash of Air France Flight 447 in June 2009, involving an Airbus A330 with a loss of 228 lives, was believed to involve a mesoscale convective system near the equator. More recently, the fatal crash of a medical helicopter in March 2010 in Brownsville, Tennessee, U.S., was related to a "mesoscale convective system with a bow shape."[1]

To improve the warning capabilities of the various weather services, convection has been studied extensively in recent years, leading to many new discoveries. Although breakthroughs in the science have increased our understanding and improved convection forecasts, the problem of conveying the information to those who need it remains, complicated by the flood of new terminology which often accompanies scientific advances.

The study of convection deals with vertical motions in the atmosphere caused by temperature or, more precisely, density differences. The adage "warm air rises" is well known. In meteorological parlance, a parcel of air will rise if it is less dense than air in the surrounding environment. Warmer air is less dense and will rise. Conversely, colder air, being denser, will sink. As pilots, especially glider pilots, know, you don't need moisture — that is, clouds — to have rising and sinking currents of air. However, when air rises it expands and cools. If the air cools to its dew point, condensation occurs and a cloud forms if sufficient moisture is present.

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The bowing section of a squall line (left) can be accompanied by strong winds.

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Cumulus clouds are the typical convective clouds. Convection, in operational meteorology vernacular, refers to convective precipitation — showers and thunderstorms that are the end products of convective activity.

Convective precipitation can be divided into two broad types — unorganized and organized. Unorganized convection would be the typical "air mass showers and thunderstorms" that develop in the warm season. They are the result of daytime heating of humid air masses. The resulting convection is usually haphazard, with no recognizable pattern. Although all convection represents a problem for aviation, these storms tend to be weak by most standards. Occasionally, a pulse storm (*ASW*, 10/09, p. 12) will produce strong surface winds, but that's about it. Individual convective cells, the storms themselves, are fairly small — several miles across at most — and are rather short-lived, lasting an hour or less. For aviation purposes, they usually can be avoided or waited out.

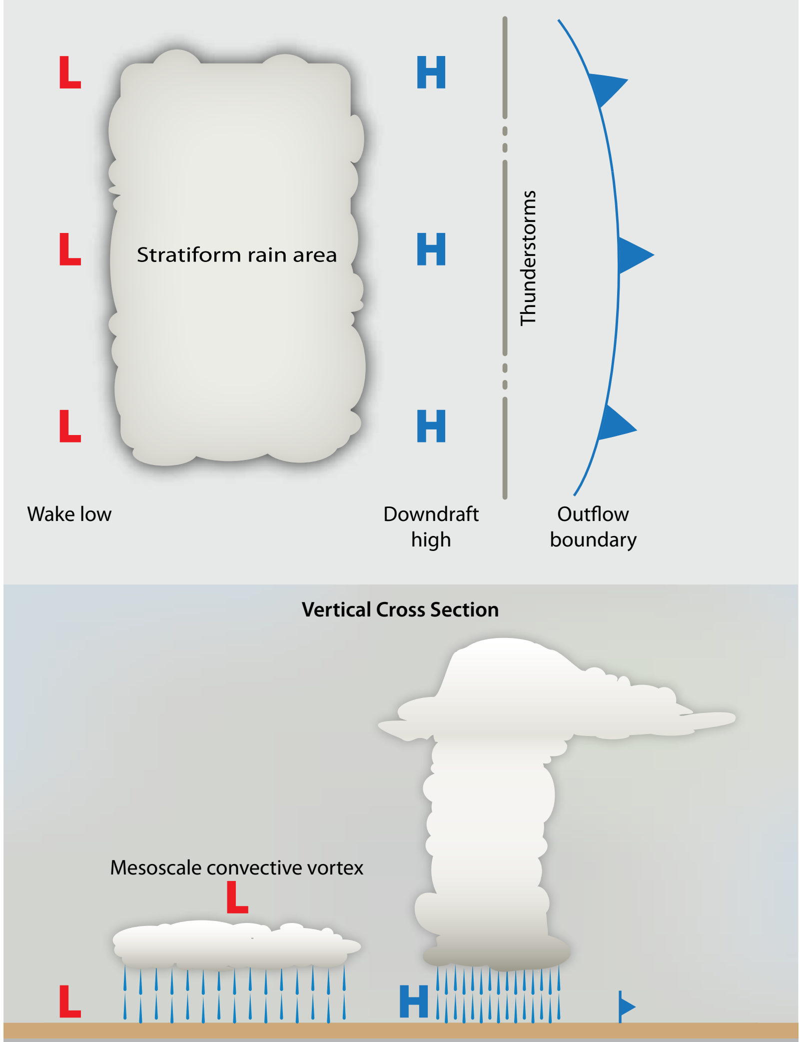
At other times, convection becomes organized. This is either the result of larger-scale atmospheric forces at work or the interaction of various convective elements independent of outside forces. Organized convection takes the form of a mesoscale convective system (MCS), the generic name for a wide variety of systems. MCSs can be as large as several hundred miles across and can persist for hours. An MCS must, by definition, contain some convection but also may contain stratiform precipitation — areas of rain — and areas of cloud with no precipitation. Their size and duration make them more of a hazard for aviation.

The most recognizable and best-known MCS configuration is the squall line. A squall line is a more or less continuous line of thunderstorms, at least initially. If conditions are favorable, the squall line can persist for hours and evolve into a much larger and complex system (Figure 1, p. 14). There may be several lines of convection, with the strongest on the leading edge of the system, usually the east or south side in the northern hemisphere mid-latitudes, and progressively weaker behind it.

A larger region of mainly stratiform rain with possibly some embedded convection can develop behind the line or lines of stronger convective cells, usually to the west or north. And trailing this, you can have a mesoscale low pressure area called the "wake low." Squall lines may be symmetrical, with the stratiform rain area just behind, to the west of the convective line, or asymmetrical, with the convective cells more to the south and the stratiform precipitation more northward.

In terms of aircraft operation, there are several areas to watch. Ahead of the main line of thunderstorms, to the east or south, is the

Squall Line System



Source: Ed Brotak

Figure 1

low-level outflow boundary also known as the gust front. A rapid change in wind direction and increase in wind speed often follow its passage. Obviously, the main line of storms should be avoided due to the strong downdrafts and winds at the surface and turbulence aloft. The trailing stratiform rain area is not as turbulent but still may produce problems. The final wake low could be accompanied by strong, gusty winds.

Another feature which may affect aircraft is the mid-level "mesoscale convective vortex" (MCV). This cyclonic circulation can develop above the stratiform precipitation area. It can be 30 to 60 mi (50 to 100 km) across and 1 to 3 mi (2 to 5 km) deep. MCVs occasionally have a life of their own, existing as long as 12 hours after the parent squall line has died out. Importantly, they can generate new convection or intensify existing convection as they move. On May 8, 2009, a particularly intense MCV ravaged parts of Kansas, Missouri and Illinois in the United States, with straight line winds over 100 mph (161 kph), large hail and dozens of tornadoes, some of them violent.

To show what airport conditions are like during the passage of a mature MCS, consider the observations taken at Columbia, South Carolina, U.S., on the evening of June 3, 2011: At 19:56 local standard time (LST), winds were from the east-northeast at 7 kt, the visibility was 6.0 mi (9.7 km) in haze, the temperature was 91degrees F (33 degrees C), and thunder could be heard with cumulonimbus clouds to the north. A wind shift was noted at 19:57 LST. This was with the passage of the outflow boundary or gust front. By 20:17 LST, the winds had picked up from the northeast at 12 kt, the temperature had dropped to 88 degrees F (31 degrees C), and barometric pressure was rising rapidly. At 20:31 LST, the airport was under the leading convective cells. Winds were blowing from the north at 27 kt with gusts to 43 kt. The visibility had dropped to 1.5 mi (2.4 km) in a heavy thunderstorm with rain and constant lightning. The temperature had dropped to 75 degrees F (24 degrees C). The heavy thunderstorms continued for 25 minutes. At 21:08 LST, only a weak thunderstorm was reported and barometric pressure was falling rapidly. However, moderate to heavy rain continued for another 50 minutes. At 21:56 LST, a gust of 26 kt accompanied the passage of the wake low. The rain ended at 22:01 LST and the temperature was 70 degrees F (21 degrees C).

If a squall line or part of a squall line begins to curve or bow outward, it is referred to as a "bow echo." Echo refers to a radar return, as these systems were first discovered and are usually still identified on weather radar. The bowing segment of the line can move very quickly, occasionally in excess of 50 kt. Bow echoes are often associated with strong straight-line winds and occasionally weak tornadoes. On March 25, 2010, the pilot of the medical helicopter stationed in Brownsville referred to earlier decided he could beat a convective line and make it safely back to Brownsville from Jackson. The line developed a bow, which shot ahead of the main system with an estimated forward speed of 60 kt. Radar indicated that the helicopter was overtaken by strong convection before reaching its destination and this may have resulted in the crash, which killed the three people aboard.

Another variation of the squall line is the quasi-linear convective system (QLCS). The QLCS has some linear parts but also other discrete elements. This means that some storms are in a squall line but other nearby storms are separate. QLCSs are often associated with strong straight-line winds and tornadoes.

Another term which comes up in discussions about convection is "derecho." Not really a different type of MCS, a derecho adds a time element to the description. It is a long-lived, often large convective system which produces strong and often damaging winds for hours.

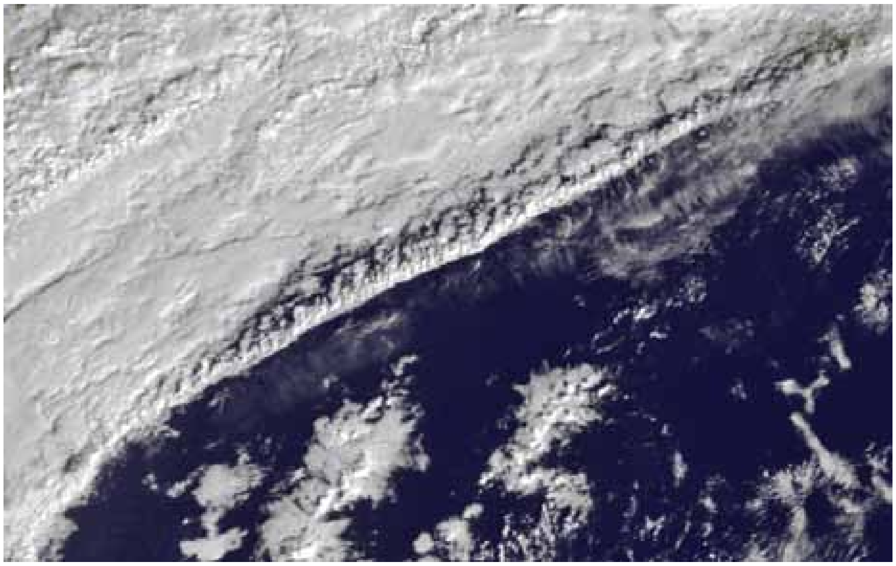
Squall lines usually develop where there is moderate to strong synoptic forcing — in other words, the line is the result of not just instability but other atmospheric effects. Usually, squall lines occur in the warm sector of an extratropical cyclone or low, ahead of the associated cold front. There is often an upper-level trough just to the west with the jet stream. Other MCSs can develop on their own without much help.

Before meteorologists came up with the generic MCS classification, they had already identified a very specific type of MCS which they named a mesoscale convective complex (MCC). An MCC differs from other MCSs in shape; it is rounded or at least elliptical. MCCs are also large, covering thousands of square miles and can last six hours or more. Primarily a summer phenomenon, MCCs develop in what appears to be a fairly benign environment, often on the east side of an upper-level ridge, away from any low pressure areas or fronts. MCCs often start as unorganized, air mass convection in the late afternoon or early evening. The initially independent storms start to interact and form a cohesive, self-maintaining complex that often lasts into or through the night. The strongest convection, similar to a squall line, is on the outside perimeter of the system, with stratiform but often heavy rain in the middle.

In the case of the Hawker 800A crash, the leading edge of the MCC with the strongest convection had affected the Owatonna airport an hour earlier but had moved on by the time the aircraft arrived. However, the heavy stratiform rain region was still affecting the terminal when the landing was attempted. The wet runway complicated the pilot's efforts to stop the airplane, leading to his belated decision to attempt a go-around that ended in the fatal accident. Linear squall lines and rounded MCCs are just two types of MCSs. If a system doesn't fit into either of those categories, it is simply referred to as an MCS.

The movement of MCSs is affected by two things — simple advection by the wind and propagation of the whole system, which is the result of development and dissipation of individual convective elements — the storms themselves. Advection by the wind is simple enough, with convective cells being driven by the mean wind — the average wind in the layer of air containing them. Individual cells or storms can move rapidly at rates up to 60 kt. Propagation effects are more complicated. Individual convective cells, which have a much shorter lifespan than the MCS, form and dissipate within the MCS. This affects the overall movement of the mesoscale system. Convective cells and convective systems tend to propagate in the direction from which warm, moist air is being "fed" into them. This is usually from the south, in the northern hemisphere. This causes a seeming deflection to the right. Supercell thunderstorms are notorious "right movers,"

The squall line leading this MCS is obvious in this photo from space.



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moving well to the right of the mean wind. For an MCS such as a squall line, new cells tend to develop on the south end of the line while older ones to the north die out. This causes the whole system to move or propagate to the right of the mean wind. For example, it is common for a squall line to move due east while individual storms within it move rapidly northeast.

MCSs are not confined to mid-latitudes. There are tropical versions, too. It is widely believed that a tropical MCS was involved in the Air France Flight 447 crash in the tropical Atlantic not far north of the equator. Information gathered from the recently recovered black boxes indicated that the airplane was cruising at 35,000 ft with no problems. But just ahead was an area of thunderstorms that infrared satellite imagery indicated had tops of 50,000 ft. The pilots were aware of this and warned the cabin crew of potential turbulence. Instruments showed that the turbulence never became more than moderate. However, the pitot tubes for the airspeed sensors iced over when the plane encountered the high clouds, triggering a series of events that ended with the aircraft stalling and falling into the ocean.

The area of thunderstorms Flight 447 encountered was the result of an MCS embedded in the inter-tropical convergence zone (ITCZ). The ITCZ is where the northeast trade winds from the Northern Hemisphere collide with the southeast trade winds from the Southern Hemisphere. The resulting convergence produces lifting and, with the very moist air, showers and thunderstorms. Although the ITCZ is fairly continuous, there are areas of enhanced lifting and convection. This was what Flight 447 flew into. Some of the cloud bands were curved and there seemed to be a circulation center, both indications of a well-developed MCS. If conditions are favorable and the ITCZ is far enough away from the equator for the Coriolis effect[2] to enhance rotation, a tropical MCS produced along the ITCZ can become a full-fledged tropical cyclone. Tropical cyclones up to and including hurricanes and typhoons are just larger versions of tropical MCSs.

Besides the ITCZ, tropical waves — also called easterly waves or African waves — can generate convection in the Atlantic basin. They are common in the warm season, May to November. Tropical waves are inverted troughs of low pressure, with the lowest pressure to the south. Low-level features move westward in tropical easterly winds or trade winds at an average speed of 15–20 mph (25–35 kph). They have wave lengths between 1,000 and 1,500 mi (2,000–2,500 km) and continue for about three days. Low-level convergence is found just to the east of the trough axis and often generates convection. The convection can organize into tropical squall lines. Moving to the west in the tropical easterly winds, these squall lines have the strongest convection on their west side, with the stratiform rain area to their east. In the summer, these waves can impact locations in the subtropics, such as Florida, Texas or Mexico.

Although the name may not be widely known, mesoscale convective systems are common in many parts of the world. They produce much more serious hazards to aviation than individual thunderstorms. Understanding them is essential to treating them with proper respect when they are encountered.

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Notes

1. NTSB Preliminary Report, ERA10MA188.
2. Coriolis effect is the tendency for any moving body on or above the Earth's surface — for instance, winds — to be deflected by the Earth's rotation.