14 Storms

Learning Goals

After studying this chapter, students should be able to:

1. analyze mid-latitude cyclones and anticyclones to describe their structure, outline their formation, and account for the weather they produce (pp. 340–353);
2. describe and account for the conditions necessary for the development of hurricanes (pp. 357–358);
3. outline the conditions that determine both the occurrence and the severity of thunderstorms (pp. 358–364); and
4. compare and contrast mid-latitude cyclones, hurricanes, and thunderstorms (pp. 336–371).

Summary

1. **Mid-latitude cyclones** are deep, cold-cored, baroclinic systems that tilt with height. **Tropical cyclones** are shallow, warm-cored, barotropic systems that are vertically stacked. Both produce clouds and precipitation due to rising air.
2. The **polar front theory** describes the stages in the life cycle of a mid-latitude cyclone. The storm is born when a disturbance forms along a **stationary front**. This disturbance leads to the development of cyclonic circulation, and separate warm and cold fronts. In the mature stage, the fronts form an open wave pattern, and there is a sector of warm air between the fronts. In the final stages, the warm-sector air is separated from the low-pressure centre by an **occluded front**. The storm dies once temperature contrasts are eliminated.
3. **Cyclogenesis** usually occurs due to large temperature gradients, or baroclinic instability; such conditions are concentrated along fronts in the mid-latitudes. Mid-latitude cyclones are characterized by decreasing pressure, rising air, temperature advection, and cyclonic spin. Pressure decreases, and air rises, as a result of divergence in the jet stream. Mid-latitude cyclones form below the downstream portion of an upper-air trough because this tends to be an area of divergence. As long as this upper-air divergence is greater than surface convergence, mass is removed from the air column and the cyclone will intensify. We can identify areas of divergence and rising air on upper-air charts by finding areas where **vorticity** is decreasing. Temperature advection occurs at fronts and enhances vertical motions. Temperature advection can also strengthen the upper-air wave pattern. This strengthening creates a feedback because the greater waviness of the upper airflow leads to an increase in the upper-air divergence, and the increase in upper-air divergence, in turn, strengthens the cyclone. Cyclonic spin is caused by increasing vorticity as air converges into the low-pressure centre at the surface. Mid-latitude cyclones dissipate when they become separated from the region of upper-level divergence and the temperature contrasts are wiped out. Cyclogenesis can also occur on the leeward side of a mountain range.
4. As mid-latitude cyclones and anticyclones move from west to east, they produce the variable weather typical of the mid-latitudes. The mid-latitude cyclones bring cloudy, wet weather, but the exact weather conditions can vary considerably within the cyclone itself and from one cyclone to another. The anticyclones bring clear weather. The meandering nature of the upper airflow can cause the semi-permanent highs of the tropical or polar regions to invade the mid-latitudes, bringing longer periods of clear weather and unseasonal temperatures.
5. Tropical cyclones, or **hurricanes**, are severe weather systems with extremely low central pressures. They are composed of inward-spiralling bands of thunderstorms that produce very strong winds, torrential rain, and storm surges. A distinctive feature of hurricanes is their central eye, characterized by calm conditions, fair-weather cumulus, and high temperatures. Hurricanes are more spatially restricted than mid-latitude cyclones, forming only between 5° and 20° latitude and over oceans warmer than 26°C. Tropical disturbances can develop into hurricanes only when all of the following conditions are met: there is a source of latent heat, the Coriolis force is large enough that convergence produces rotation, the atmosphere is unstable, there is minimal vertical wind shear, and humidity is high throughout the troposphere.
6. **Thunderstorms** are convective storms that produce thunder and lightning; heavy rain and/or hail, strong, gusty winds; and occasionally, tornadoes. They form when air near the surface is warm and moist, the atmosphere is conditionally unstable, and some mechanism works to lift

the air. The life cycle of **single-cell thunderstorms** begins with the cumulus stage. In this stage, updrafts are dominant. The mature stage begins when downdrafts develop. The combination of updrafts and downdrafts makes the air very turbulent, so the most intense weather occurs during this stage. In the dissipating stage, the storm is dominated by downdrafts that weaken the storm. **Multicell** and **supercell thunderstorms** can become severe because they are able to sustain themselves. Multicell storms sustain themselves as old cell create new ones, while very strong rotating updrafts sustain supercell storms.

7. Atmospheric soundings can be used to assess thunderstorm potential. Warm, moist air at the surface provides the fuel for the storm. An inversion creates a cap, allowing the warmth and moisture to accumulate. Warm, moist surface air combined with cold air aloft produces unstable conditions. If a trigger allows the warm, moist air to move past the inversion, a thunderstorm will form. **Convective inhibition (CIN)** is a measure of the strength of the cap, while **convective available potential energy (CAPE)** is a measure of thunderstorm potential.
8. The vigorous convection in thunderstorms leads to the separation of electrical charges that results in lightning. In turn, the rapid expansion of air caused by the intense heat of a lightning stroke produces the rumble we know as thunder.

Key Terms

Convective available potential energy (CAPE) A measure of the potential intensity of thunderstorms. (p. 368)

Convective inhibition (CIN) A measure of the strength of the cap preventing surface air from rising to produce a thunderstorm. (p. 368)

Cutoff high A warm upper-air high that has been cut off from the general westerly flow, so that it lies poleward of this flow. (p. 339)

Cutoff low A cold upper-air low that has been cut off from the general westerly flow, so that it lies equatorward of this flow. (p. 339)

Cyclogenesis The development or strengthening of a mid-latitude cyclone. (p. 343)

Deepening A decrease in the central pressure of a low-pressure system. (p. 344)

Downburst A strong, gusty wind that forms due to downdrafts in thunderstorms. (p. 358)

Easterly wave A disturbance, in the shape of a wave, in the general easterly flow of the tropics. (p. 354)

Entrainment A process by which air surrounding a cloud is drawn into the cloud. (p. 358)

Filling An increase in the central pressure of a low-pressure system. (p. 344)

Funnel cloud A narrow cone-shaped rotating cloud that extends from the base of a cumulonimbus cloud. (p. 364)

Gust front The boundary at which the cold air in a thunderstorm downdraft meets warm, moist air at the surface. (p. 361)

Hurricane A tropical cyclone in which sustained winds are higher than 120 km/h. (p. 336)

Lee cyclogenesis The formation of a mid-latitude cyclone on the leeward side of a mountain range. (p. 350)

Lightening An electrical discharge within a cloud, between a cloud and the ground, or between a cloud and the surrounding air. (p. 336)

Limit of convection The height at which rising air stops rising. (p. 367)

Mesocyclone Cyclonically spinning air in a convective system. (p. 364)

Mesoscale convective complex A group of thunderstorms that operate together as a system. (p. 362)

Mesoscale convective system A system driven by vertical circulations (i.e., convection) that is at least 100 km in one direction. (p. 358)

Multicell thunderstorm A thunderstorm containing more than one cell, each at a different stage of development. (p. 359)

Omega high A ridge of high pressure that forms in the shape of the Greek letter omega (Ω) in the upper airflow. (p. 352)

Polar front theory A theory that states that mid-latitude cyclones form along the polar front and have a recognized life cycle. (p. 340)

Radar A system that transmits radio waves and receives their reflection. (p. 365)

Short waves Waves in the upper airflow with a wavelength of about 1000 km. (p. 347)

Single-cell thunderstorm A thunderstorm that contains one cell. (p. 359)

Squall line A line of thunderstorms that forms at or just ahead of a cold front. (p. 363)

Storm surge A rise in water level that can cause flooding along coasts. (p. 354)

Supercell thunderstorm A thunderstorm with one cell consisting of a strong rotating updraft. (p. 359)

Synoptic scale A scale of a few hundred kilometres to a few thousand kilometres. (p. 337)

Thunder The sound produced as the heat from lightning causes a sudden and rapid expansion of the surrounding air. (p. 336)

Thunderstorm A convective storm that produces thunder and lightning and, usually, heavy precipitation and strong winds. (p. 337)

Tornado A violently rotating column of air that can develop in association with severe thunderstorms. (p. 354)

Tropical cyclone A low-pressure area that forms in the tropics. (p. 336)

Tropical depression A tropical disturbance that has begun to develop cyclonic rotation. (p. 353)

Tropical disturbance A small cluster of thunderstorms that forms in association with easterly waves over tropical oceans and in which wind speeds do not exceed 60 km/h. (p. 353)

Tropical storm A tropical depression in which sustained winds are greater than 60 km/h but less than 120 km/h. (p. 353)

Warm-sector air The warm air lying between the cold front and the warm front in a mid-latitude cyclone. (p. 340)

Answers to Selected Review Questions (p. 373)

1. **What are the stages in the life cycle of a mid-latitude cyclone?**

   In the first stage, a disturbance forms along a stationary front. In the mature stage, there is a clearly defined warm front and a clearly defined cold front with a warm sector of air between the fronts. In the final stage, the warm-sector air is separated from the low-pressure centre by an occluded front. Once the temperature contrasts are eliminated, the storm dies.

3. **Consider a mid-latitude cyclone. What causes the pressure to drop? What causes the air to rise? Why does temperature advection occur? What causes the air to spin?**

   An area of upper divergence in the upper airflow above the surface low-pressure centre causes the pressure to drop in the mid-latitude cyclone. The air begins to rise from the surface to replace the diverging air aloft. Temperature advection occurs because the rising air leads to convergence at the surface which pulls warm and cold air together, forming warm and cold fronts. Behind the warm front, warm air is being advected. Behind the cold front, cold air is being advected. Convergence causes vorticity to increase, thus creating a cyclonic spin.

5. **What is the relationship between vertical motions and vorticity? How do meteorologists make use of this relationship to find areas of vertical motion?**

   Where air is rising, vorticity is decreasing. Where air is sinking, vorticity is increasing. Meteorologists use vorticity to find areas of divergence and, therefore, rising air.

7. **Why can cyclogenesis occur on the lee side of mountain ranges?**

   As an air layer is lifted over mountains, it will shrink in height. When the air layer descends the leeward side of the mountains, it will stretch. This results in horizontal convergence and an increase in relative vorticity. To increase relative vorticity, the air must take on cyclonic rotation.

9. **How is the weather associated with a mid-latitude cyclone different than that associated with an anticyclone? How can the meanders of the jet stream influence mid-latitude weather?**

   Cyclones are associated with clouds, precipitation, and winds. Anticyclonic weather is characterized by clear skies caused by sinking air and light winds. Clear skies associated with anticyclones can result in very high temperatures in the summer and very low temperatures in the winter.

   When the jet stream meanders equatorward of a location, the polar high brings unseasonably cold, dry weather. When the jet stream meanders poleward of a location, the subtropical high moves poleward, resulting in unseasonably warm temperatures. These warm highs extend through the troposphere and are referred to as blocking highs (or an Omega high) because they block the paths of cyclones which forces them to travel around the blocking high, resulting in weather that is warmer and drier than normal within the high; warmer and wetter slightly west of the high; and cooler and wetter to the east of the high.

11. **What is the importance of each of the five requirements necessary for a hurricane to form?**

The necessity of a *heat source* explains why hurricanes form over tropical oceans and why they form in the late summer and early fall. The *Coriolis force* requirement explains why hurricanes do not form within 5° of the equator. The *unstable atmosphere* requirement is more likely to occur over the western regions of tropical oceans than it is over the eastern regions of these oceans. The *minimal vertical wind shear* requirement may explain why hurricanes rarely form off the east coast of South America. The requirement of *high humidity* throughout the troposphere explains why hurricanes form in moist environments.

13. **How and why are the paths generally followed by mid-latitude cyclones different from the paths followed by hurricanes?**

Mid-latitude cyclones travel in an eastward direction and are steered by the jet stream. Hurricanes travel in a westward direction over tropical oceans. Hurricane paths are more erratic than mid-latitude cyclones since they are not steered by the jet stream and can be veered by fronts once they move into the mid-latitudes as well as by high-pressure systems.

15. **What are the differences between single-cell thunderstorms, multicell thunderstorms, and supercell thunderstorms? Why are multicell and supercell thunderstorms able to become severe?**

Single-cell thunderstorms generally do not last longer than an hour and they form within an air mass. They occur under conditions of little to no vertical wind shear. In a multicell thunderstorm system, old cells will lead to the formation of new cells. Vertical wind shear causes these cells to tilt so that the downdrafts and precipitation do not fall into the updrafts. These storms can form along cold fronts. Supercell storms have only one cell, which is characterized by a very strong rotating updraft. They are much larger than single-cell storms and can last from two to four hours. These storms require wind shear that is strong in both speed and direction and they are the most likely to produce tornadoes. Multicell and supercell thunderstorms are able to become severe because they are able to sustain themselves.

17. **What are CIN and CAPE? What do they indicate about the conditions that favour the formation of thunderstorms?**

CIN (convective inhibition) is a measure of the strength of the cap preventing surface air from rising to produce a thunderstorm. CAPE (convective available potential energy) is a measure of the potential intensity for thunderstorms.

The value of the CIN represents the size of the trigger needed to initiate thunderstorm development. The surface air can warm enough by the afternoon to eliminate CIN or it can be forced upward by a cold front or a mountain. If CIN is too large, a storm may not form.

The greater the value of the CAPE, the greater will be the vertical velocity, instability, and the intensity of the storm.

19. **What causes lightning and thunder?**

During fair-weather conditions, the upper atmosphere is positively charged, while Earth's surface is negatively charged. During a thunderstorm, the top of the cloud typically takes on a positive charge, and the bottom of the cloud takes on a negative charge. The reasons for the charge separation in the cloud are not clearly understood but appear to be associated with vigorous convection that carries positive charges up and negative charges down within the cloud. Since like charges repel each other, the negative charge at the base of the cloud then induces a positive charge on Earth's surface. The charge separation that develops causes the rapid and sudden flow of electricity (lightning), which eliminates the charge separation. The very high temperature of the lightning stroke causes a rapid expansion of the surrounding air, which creates the sound of thunder.

Study Questions

For suggested answers, see below.

1. Where might cyclogenesis occur? Provide several examples.
2. What are the three components of the conveyor belt model? Briefly describe each.
3. What is an omega high and how will weather vary on either side of it?
4. In Canada, what is the definition of a severe thunderstorm?
5. Why do cumulonimbus clouds develop an anvil top?

Answers to Study Questions

1. Most cyclogenesis occurs due to temperature contrasts between air masses. Temperature contrasts are particularly marked in the air over oceans where warm currents flow past colder ones, or along coastlines where, in winter, colder continental air masses meet warmer oceanic air masses. Cyclogenesis also occurs on the leeward side of mountain ranges. (pp. 343, 350)

2. The warm conveyor belt represents the warm air from the warm sector rising up the slope of the warm front. The warm conveyor belt eventually joins the upper airflow and moves northeastward. The cold conveyor belt carries the cold air from ahead of the warm front under the warm conveyor belt and toward the northwest. Once this cold air reaches the low pressure centre, it begins to rise and rotate; it ultimately joins the upper airflow, moving northeastward. The dry conveyor belt carries cold, dry air from upper levels down behind the cold front. (p. 349)

3. An omega high is a ridge of high pressure that forms in the shape of the Greek letter *omega* (Ω) in the upper airflow. They are warm highs that are also referred to as blocking highs because they extend through the troposphere blocking the paths of cyclones. Regions situated within the high, and slightly west of it, will likely experience weather that is warmer than normal, while regions to the east of the high will experience weather that is cooler than normal. (p. 352)

4. In Canada, thunderstorms are considered to be severe when they produce winds greater than 90 km/h, hail larger than 20 mm in diameter, and/or rain with intensity greater than 50 mm in one hour or 75 mm in two hours. (p. 359)

5. As the rising air in the cumulonimbus cloud reaches the tropopause, it encounters the stable air of the stratosphere; at this point, it will stop rising and spread horizontally, creating the anvil. The anvil top is composed of ice crystals and upper-level winds blow the ice crystals thus contributing to the anvil shape. (p. 361)