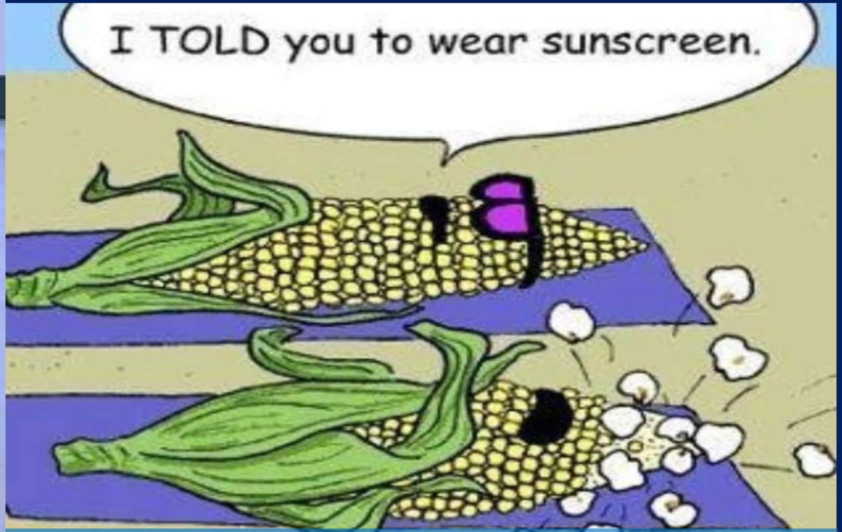
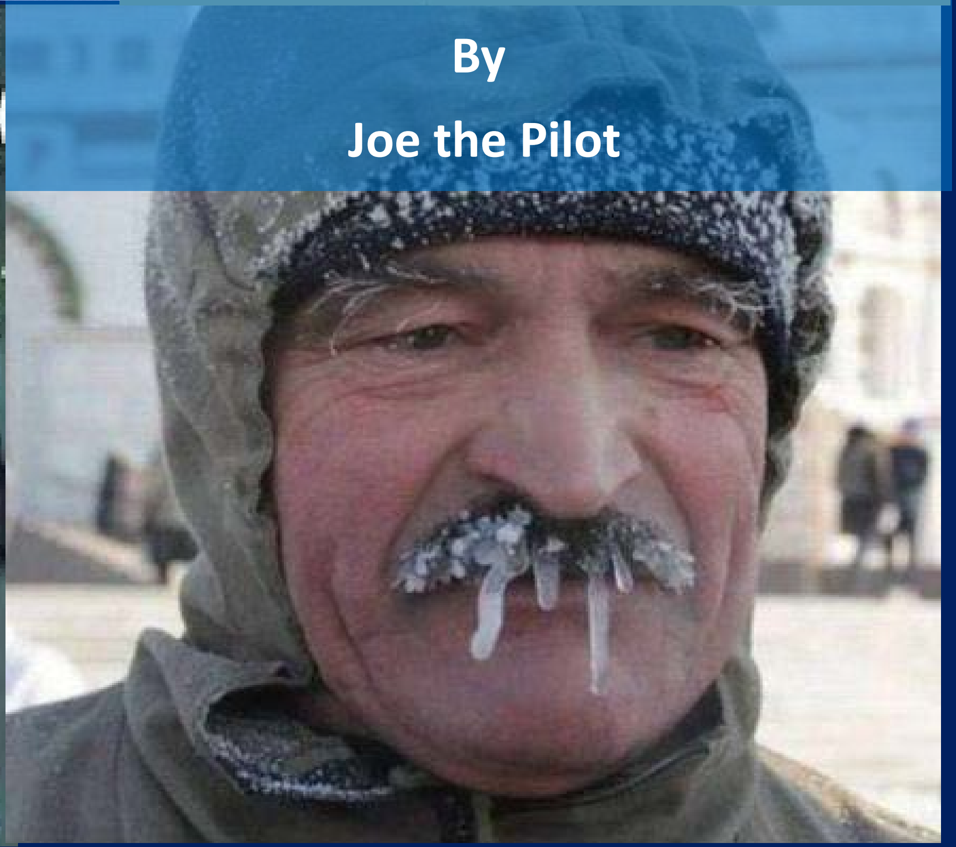


Meteorology Class 101

By

Joe the Pilot



Naval Meteorology and Oceanography Center Preps for Hurricane Season

Story Number: NNS060415-03 Release Date: 4/17/2006 12:01:00 PM

A A A

By Lithographer 2nd Class Pamela Coxe, Fleet Public Affairs Center Atlantic

NORFOLK, Va. (NNS) -- Naval Station Norfolk's Naval Meteorology and Oceanography Center (NMOC) provided a briefing April 13 to illustrate lessons learned and how they are preparing for hurricanes this upcoming season utilizing current technology.

Hurricanes Katrina and Rita brought several changes for NMOC, including discussions on a newly developed storm much earlier than in the past.

"We have extended our discussion of impacts sooner -- as far as 120 plus hours out," said Lt. Cmdr. Erica Kraft, NMOC's assistant operations officer.

"We are stepping through that process literally in the beginning of the storm," said Lt. Jeff M. Palmer, NMOC's tropical support officer.

According to Palmer, the technology used in the process of storm preparation remains the same.

"The technology has been pretty good all along," Palmer said. It has "not changed. We work with the National Hurricane Center to reissue warnings." Warnings are disseminated through e-mail and the Internet.

Palmer added "there's (also) a series of warning conditions, conditions of readiness and sortie conditions that" will be enforced by base installations and sea base units to get ships and personnel prepared earlier and moved away from the storm's path before it hits.

"Make sure you prepare early and get all the things you need set up such as supplies," advised Palmer. "We are looking to have a (hurricane) season forecast almost as severe as last year."

Last year's hurricane season was the worst on record with more than 26 storms. Hurricanes such as Katrina, Rita and Wilma wreaked total havoc upon areas in their path, wiping out extensive areas along the coasts.

"We are particularly concerned about the Caribbean and the Gulf of Mexico, because there is only one way in and out of there," said Aerographer's Mate 2nd Class Joseph L. Lawrence, NMOC's forecast duty officer and hurricane duty officer.

According to Lawrence, NMOC is the leading edge for hurricane preparation. They are constantly watching, planning and providing the best possible routes to keep Navy ships and all its assets out of harm's way during these potentially destructive storms.

Lawrence said NMOC's work last year saved the Navy a lot of money.

"We saved the Navy about $35 million" by giving the best routes for ships and keeping them out of the paths of the storms, said Lawrence.

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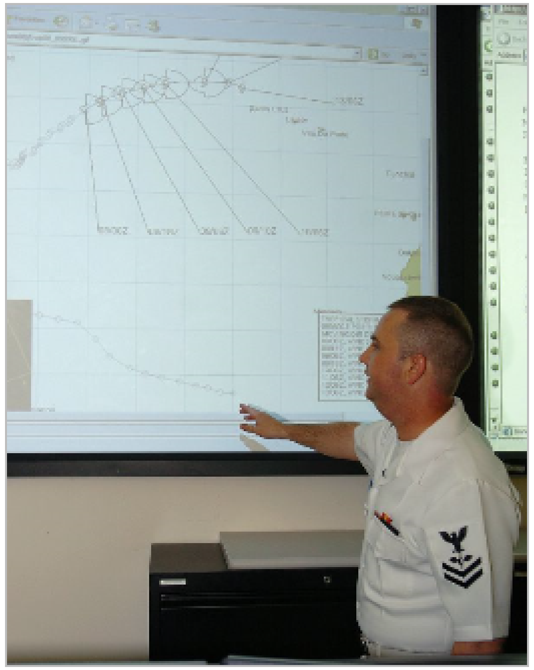

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060413-N-1924T-113 Norfolk, Va. (April 13, 2006) - Aerographer's Mate 2nd Class Joseph Lawrence uses an example of a storm tracking from last year for training in predicting a hurricanes potential path. The Naval Meteorological Center at Naval Station Norfolk is currently preparing for the upcoming hurricane season predicted to be as or more severe than last year. U.S. Navy photo by Photographer's Mate 2nd Class Leslie Tomaino (RELEASED)

April 17, 2006

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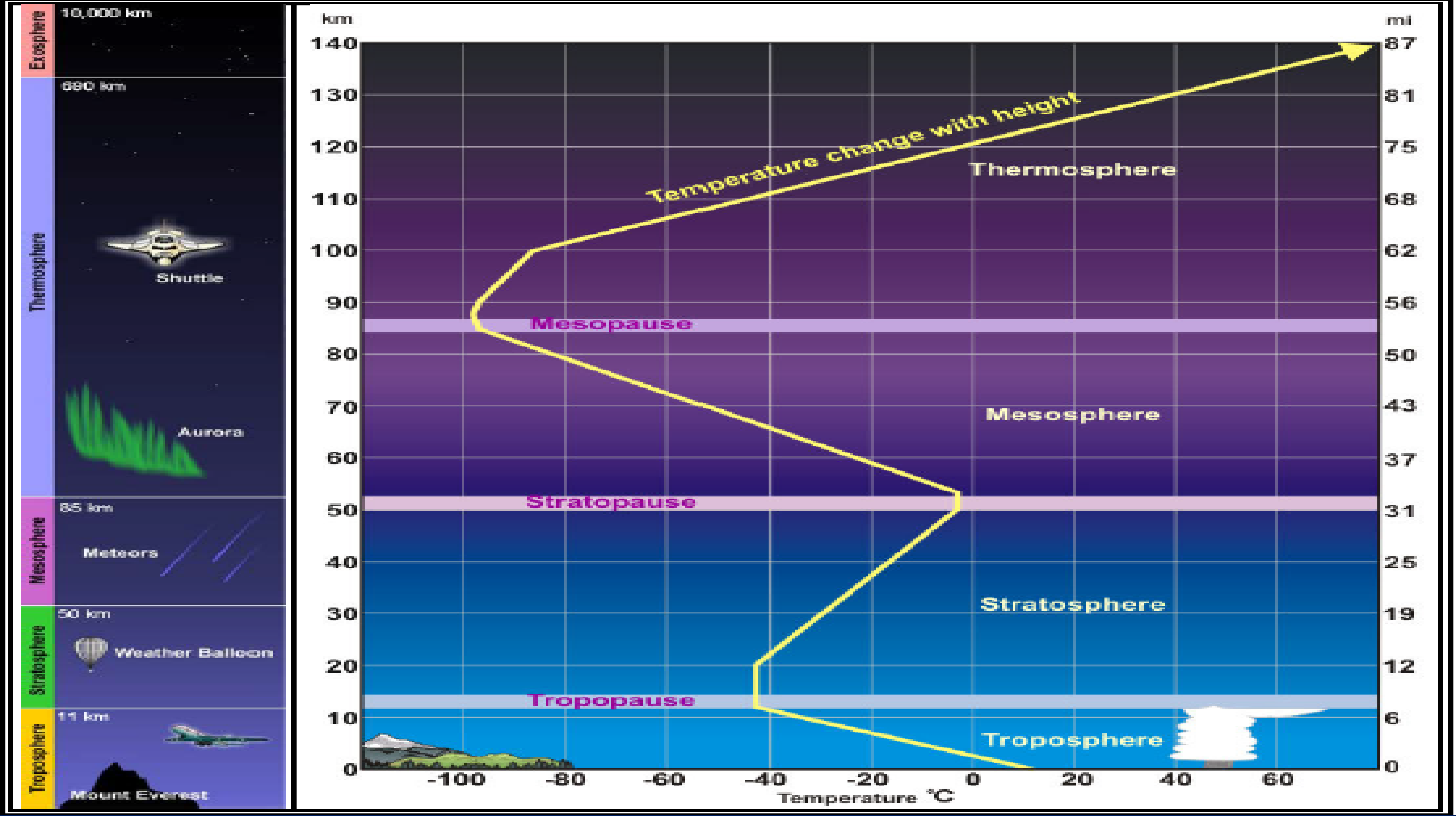

Exosphere
10,000 km
Thermosphere
690 km
Shuttle
Aurora
Mesosphere
85 km
Meteors
Stratosphere
50 km
Weather Balloon
Troposphere
11 km
Mount Everest
km
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140
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10
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87
81
75
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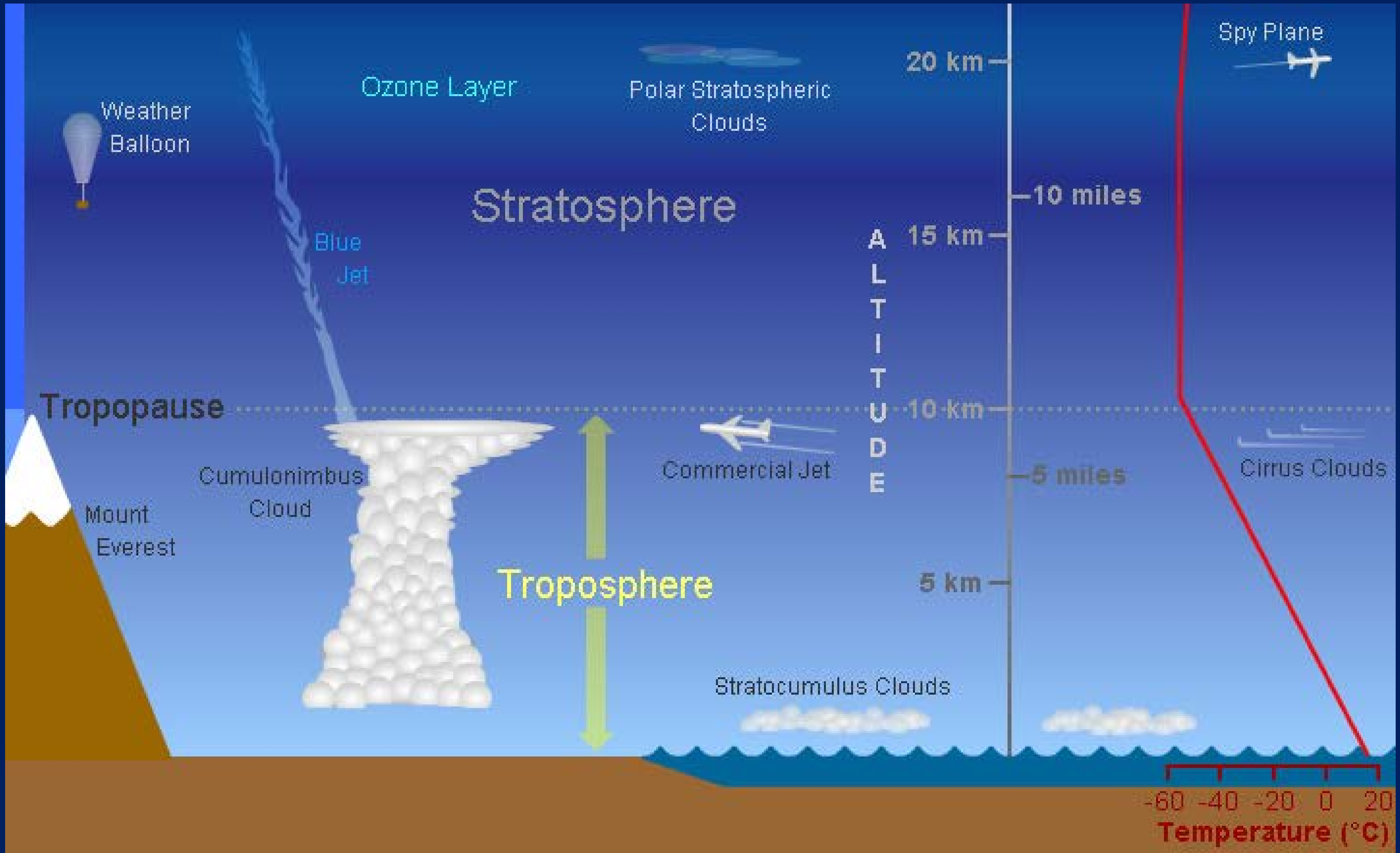
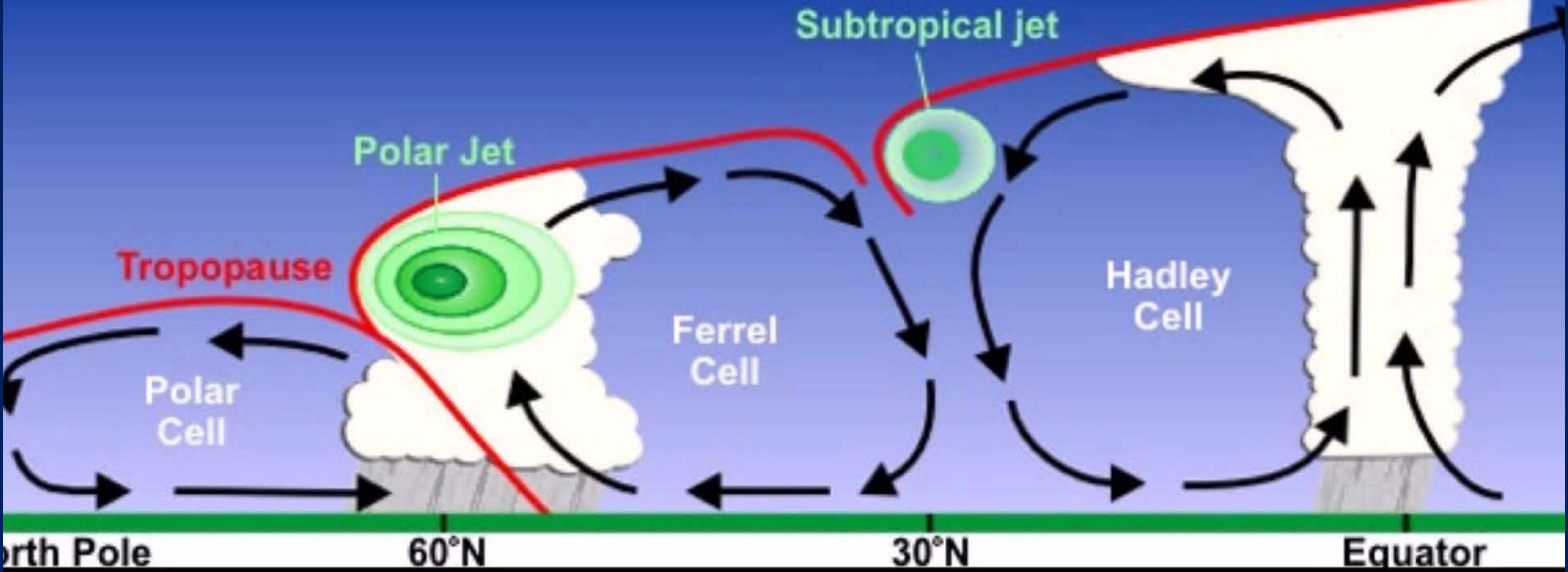
62
56
50
43
37
31
25
19
12
6
0
Temperature change with height
Thermosphere
Mesopause
Mesosphere
Stratopause
Stratosphere
Tropopause
Troposphere
-100
-80
-60
-40
-20
0
20
40
60
Temperature °C

Troposphere. The troposphere begins at the Earth's surface and extends up to about 11 kilometers (36,000 feet) high. This is where we live. As the gases in this layer decrease with height, the air becomes thinner. Therefore, the temperature in the troposphere also decreases with height. As you climb higher, the temperature drops from about 15 °C (59 °F) to -56.5 °C (-70 °F). Almost all weather occurs in this region.



The vertical depth of the troposphere varies due to temperature variations which are closely associated with latitude and season. It decreases from the Equator to the poles, and is higher during summer than in winter. At the Equator, it is around 18-20 kilometers (11-12 miles) high, at 50° N and 50° S latitude, 9 kilometers (5.6 miles), and at the poles, 6 kilometers (3.7 miles) high.

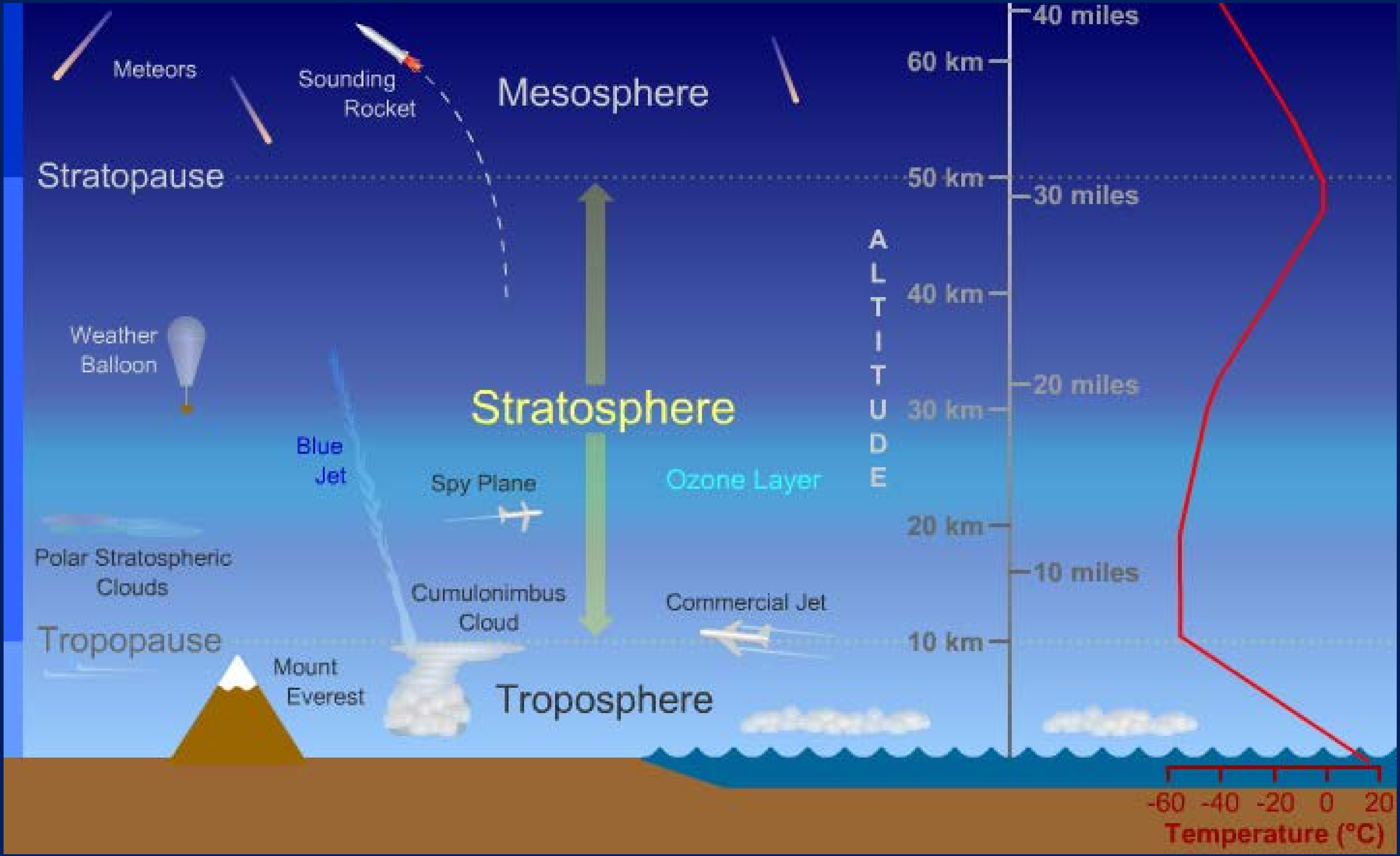
The transition boundary between the troposphere and the layer above is called the tropopause. Both the tropopause and the troposphere are known as the lower atmosphere.



Stratosphere. The stratosphere extends from the tropopause up to 50 kilometers (31 miles) above the Earth’s surface. This layer holds 19 percent of the atmosphere’s gases, but very little water vapor.

Temperature increases with height as radiation is increasingly absorbed by oxygen molecules, leading to the formation of ozone. The temperature rises from an average -56.6 °C (-70 °F) at the tropopause to a maximum of about -3 °C (27 °F) at the stratopause due to this absorption of ultraviolet radiation. The increasing temperature also makes it a calm layer, with movements of the gases being slow.

Commercial aircraft often cruise in the lower stratosphere to avoid atmospheric turbulence and convection in the troposphere. Severe turbulence during the cruise phase of flight can be caused by the convective overshoot of thunderstorms from the troposphere below. The disadvantages of flying in the stratosphere can include increased fuel consumption due to warmer temperatures, increased levels of radiation, and increased concentration of ozone.



Meteors
Sounding Rocket
Mesosphere
Stratopause
Weather Balloon
Stratosphere
Blue Jet
Spy Plane
Ozone Layer
Polar Stratospheric Clouds
Cumulonimbus Cloud
Commercial Jet
Tropopause
Mount Everest
Troposphere
ALTITUDE
60 km
50 km
40 km
30 km
20 km
10 km
40 miles
30 miles
20 miles
10 miles
-60 -40 -20 0 20
Temperature (°C)

HEAT AND TEMPERATURE

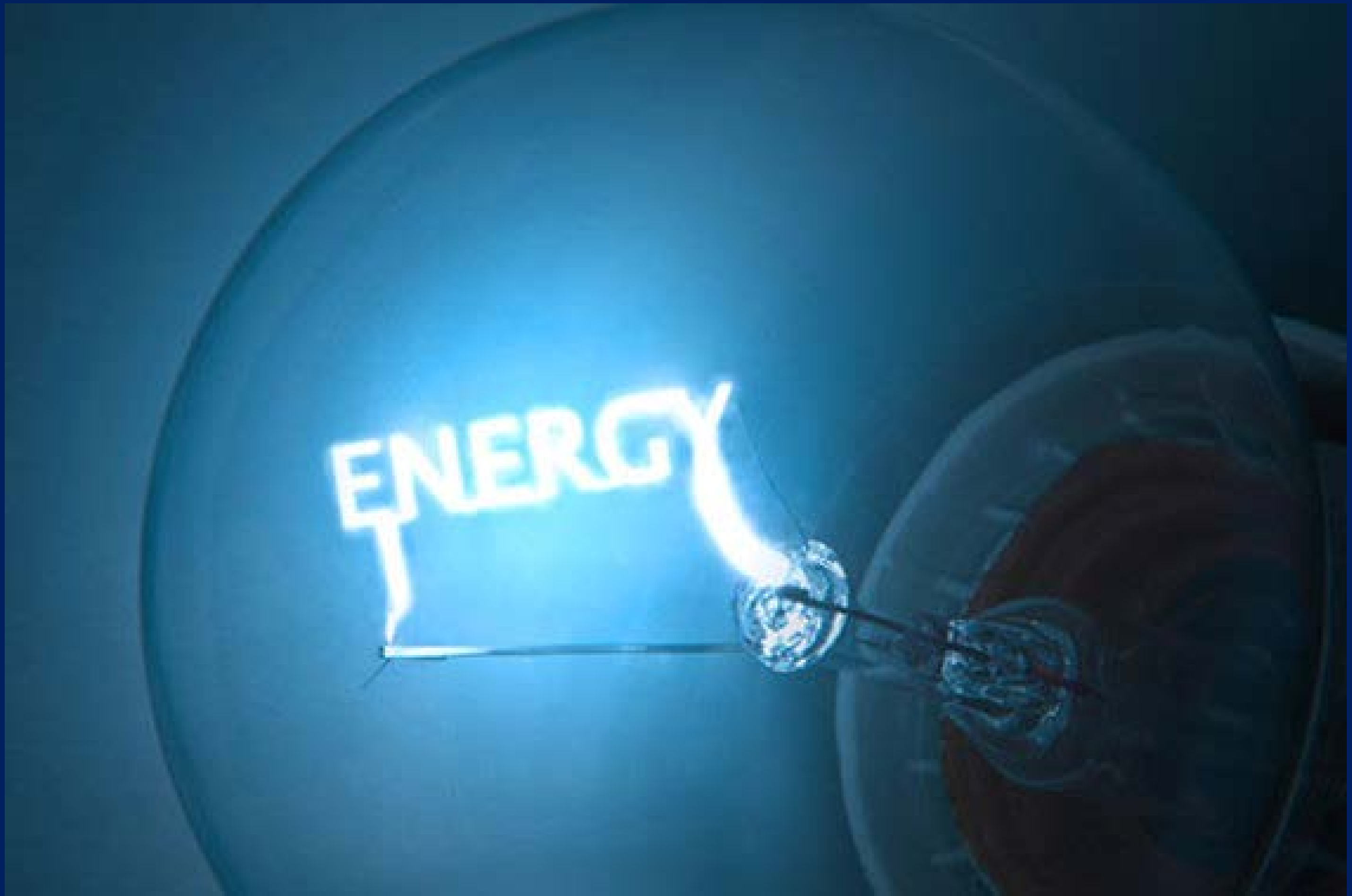
Temperature is one of the most basic variables used to describe the state of the atmosphere. We know that air temperature varies with time from one season to the next, between day and night, and even from one hour to the next. Air temperature also varies from one location to another, from high altitudes and latitudes to low altitudes and latitudes. Temperature can be critical to some flight operations. As a foundation for the study of temperature effects on aviation and weather, this chapter describes temperature, temperature measurement, and heat transfer and imbalances.

The Standard Atmosphere. Continuous fluctuations of atmospheric properties create problems for engineers and meteorologists who require a fixed standard for reference. To solve this problem, they defined a standard atmosphere, which represents an average of conditions throughout the atmosphere for all latitudes, seasons, and altitudes.

Standard atmosphere is a hypothetical vertical distribution of atmospheric temperature, pressure, and density that, by international agreement, is taken to be representative of the atmosphere for purposes of pressure altimeter calibrations, aircraft performance calculations, aircraft and missile design, ballistic tables, etc

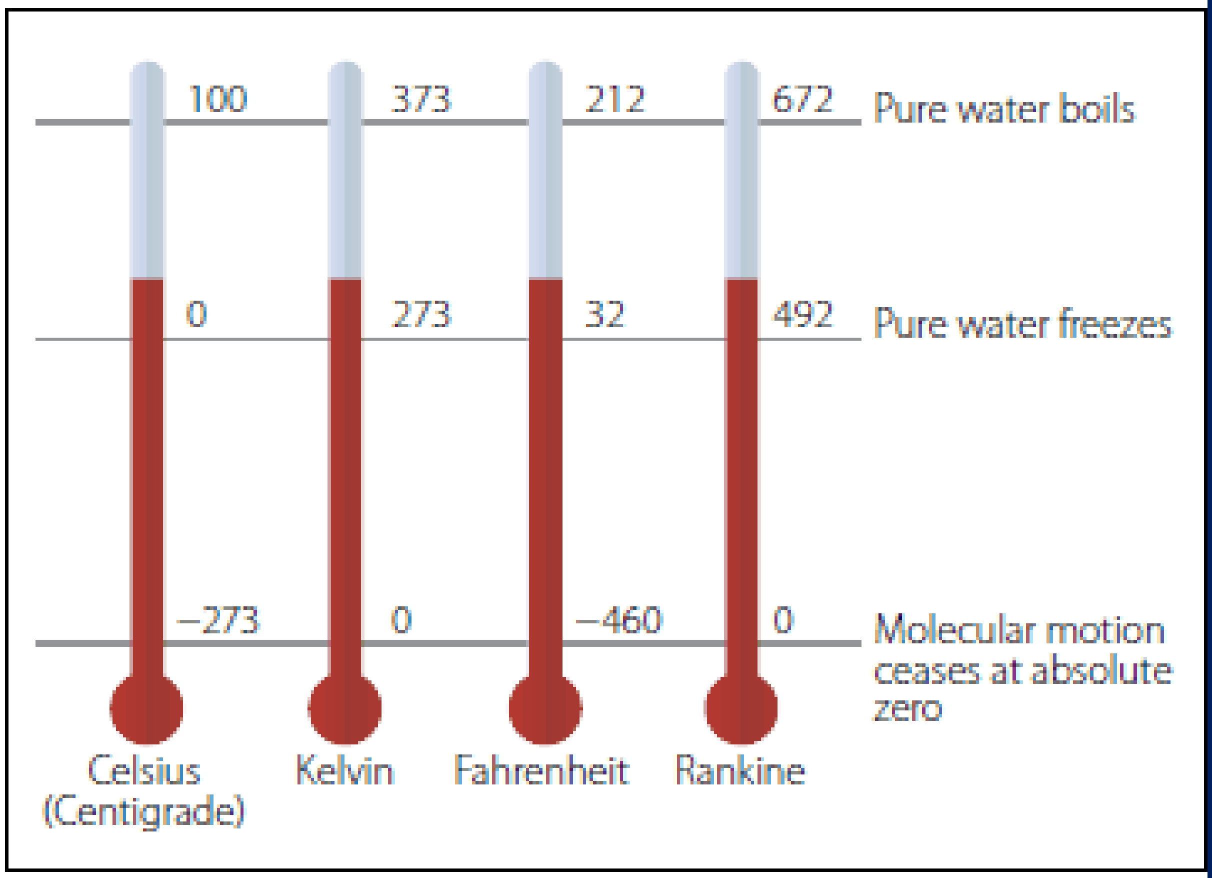
Property	Metric Units	English Units
Sea level pressure	1013.25 hectopascals	29.92 inches of mercury
Sea level temperature	15 °C	59 °F
Lapse rate of temperature in the troposphere	6.5 °C/1,000 meters	3.57 °F/1,000 feet
Pressure altitude of the tropopause	11,000 meters	36,089 feet
Temperature at the tropopause	-56.5 °C	-69.7 °F
Note: 1 hectopascal = 1 millibar.		

Energy is the ability to do work. It can exist in many forms and can be converted from one form to another. For example, if a ball is located at the edge of a slide, it contains some amount of potential energy (energy of position). This potential energy is converted to kinetic energy (energy of motion) when the ball rolls down the slide. Atoms and molecules produce kinetic energy because they are in constant motion. Higher speeds of motion indicate higher levels of kinetic energy.

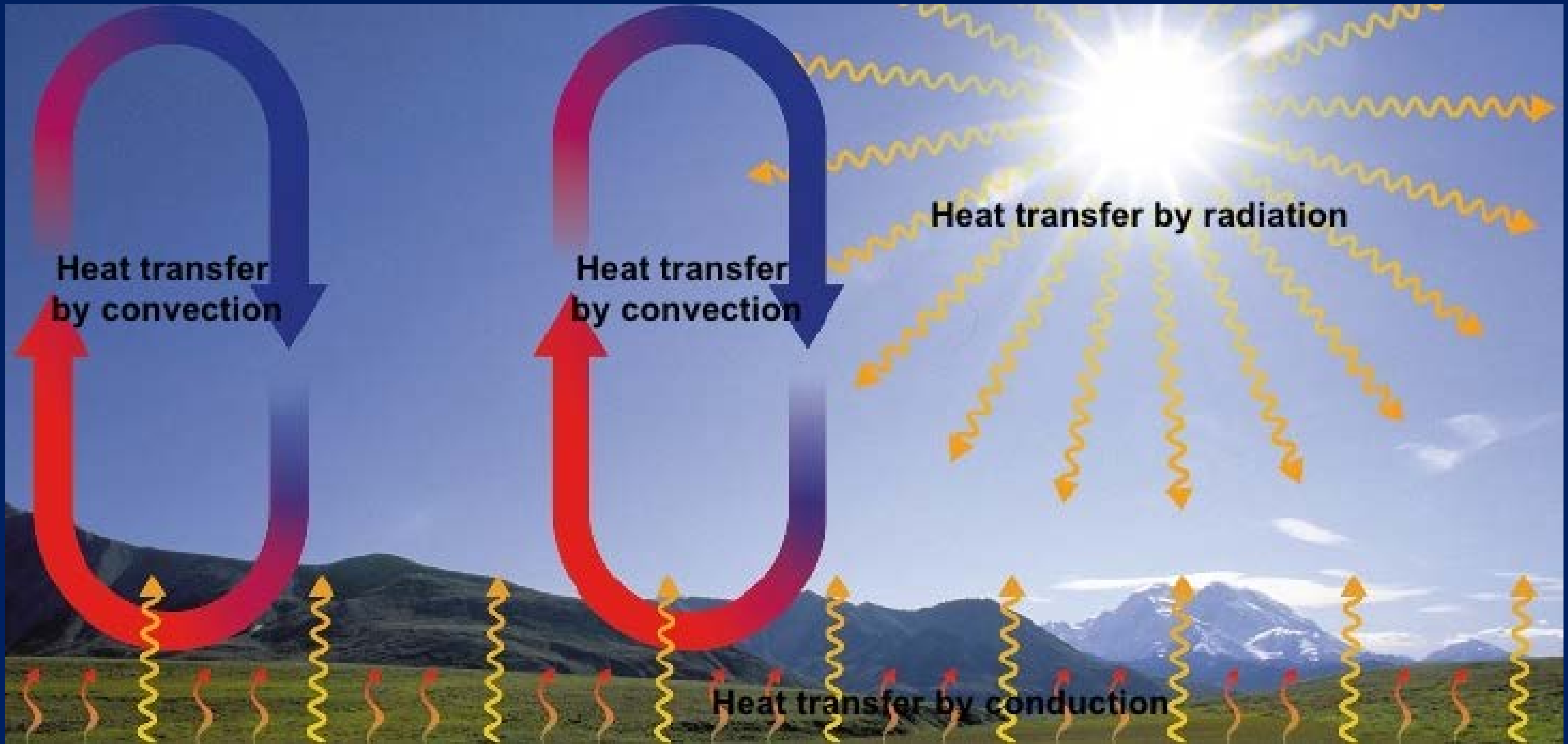


The Celsius (°C) scale is the most commonly used temperature scale worldwide and in meteorology. The scale is approximately based on the freezing point (0 °C) and boiling point of water (100 °C) under a pressure of one standard atmosphere (approximately sea level).

The United States uses Fahrenheit (°F) scale for everyday temperature measurements. In this scale, the freezing point of water is 32 degrees Fahrenheit (32 °F) and the boiling point is 212 degrees Fahrenheit (212 °F).



Heat transfer is energy transfer as a consequence of temperature difference. When a physical body (e.g., an object or fluid) is at a different temperature than its surroundings or another body, transfer of thermal energy, also known as heat transfer (or heat exchange) occurs in such a way that the body and the surroundings reach thermal equilibrium (balance). Heat transfer always occurs from a hot body to a cold body. Where there is a temperature difference between objects in proximity, heat transfer between them can never be stopped; it can only be slowed down.

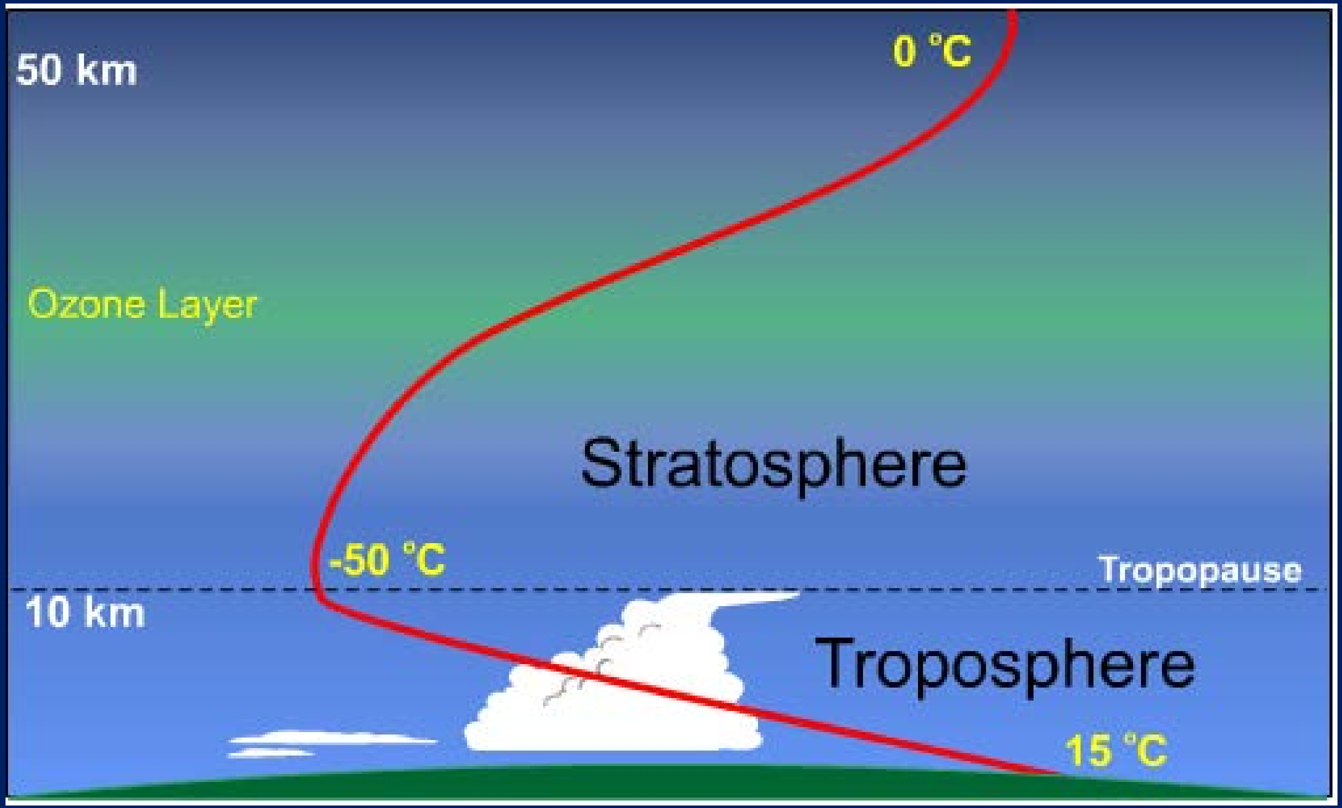


Temperature Inversion. A temperature inversion, or simply inversion, is a layer in which the temperature increases with altitude. If the base of the inversion is at the surface, it is termed a surface-based inversion. If the base of the inversion is not at the surface, it is termed an inversion aloft.

A surface-based inversion typically develops over land on clear nights when wind is light. The ground radiates and cools much faster than the overlying air. Air in contact with the ground becomes cool, while the temperature a few hundred feet above changes very little. Thus, temperature increases with height.

An inversion may also occur at any altitude when conditions are favorable. For example, a current of warm air aloft overrunning cold air near the surface produces an inversion aloft. Inversions are common in the stratosphere.
The principal characteristic of an inversion layer is its marked stability, so that very little turbulence can occur within it.

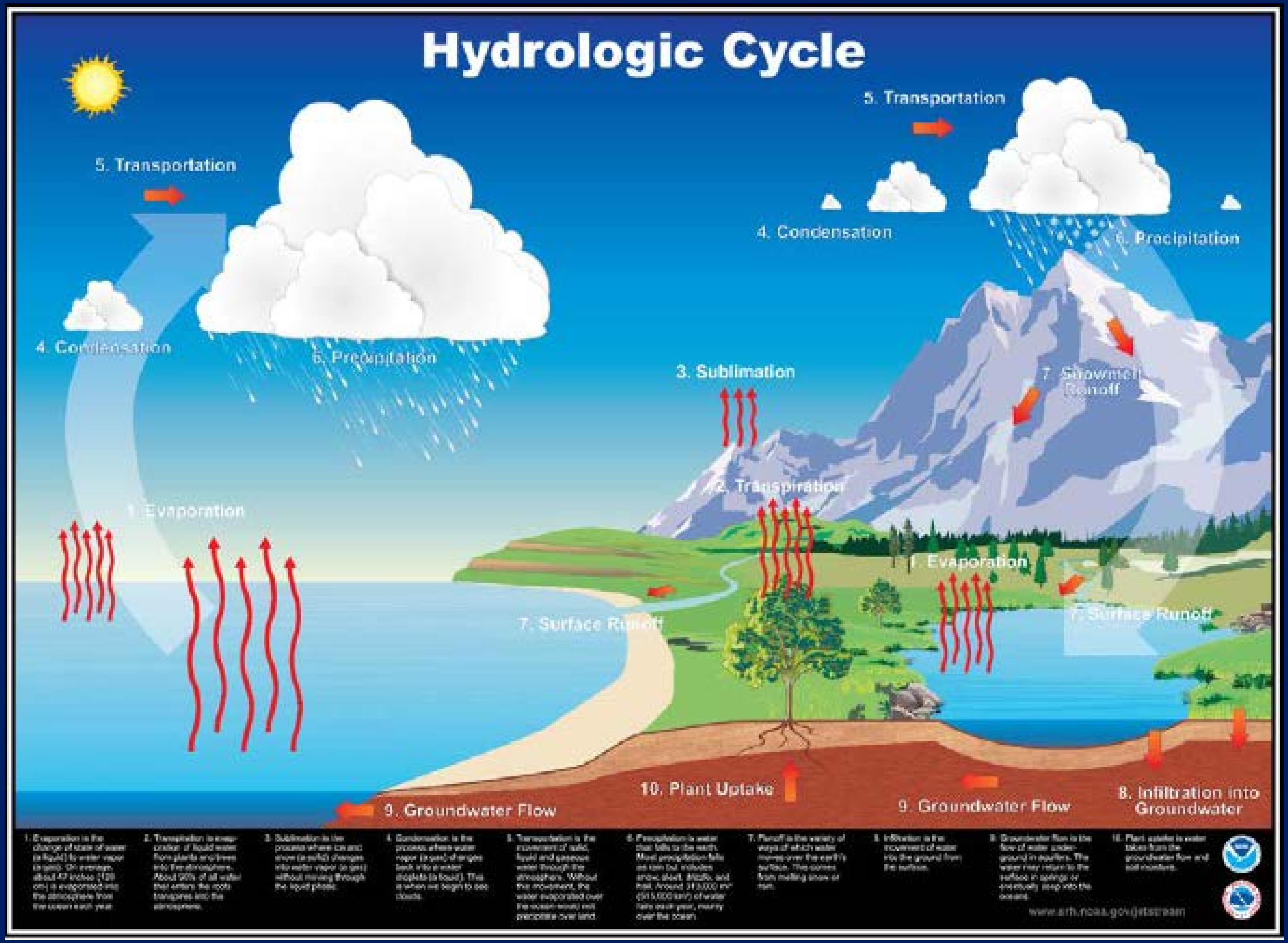
Atmospheric Sounding. An atmospheric sounding, or simply sounding, is a plot of the vertical profile of one or more atmospheric parameters, such as temperature, dewpoint, or wind above a fixed location. Soundings are used extensively by meteorologists to determine the state of the atmosphere.



WATER VAPOR

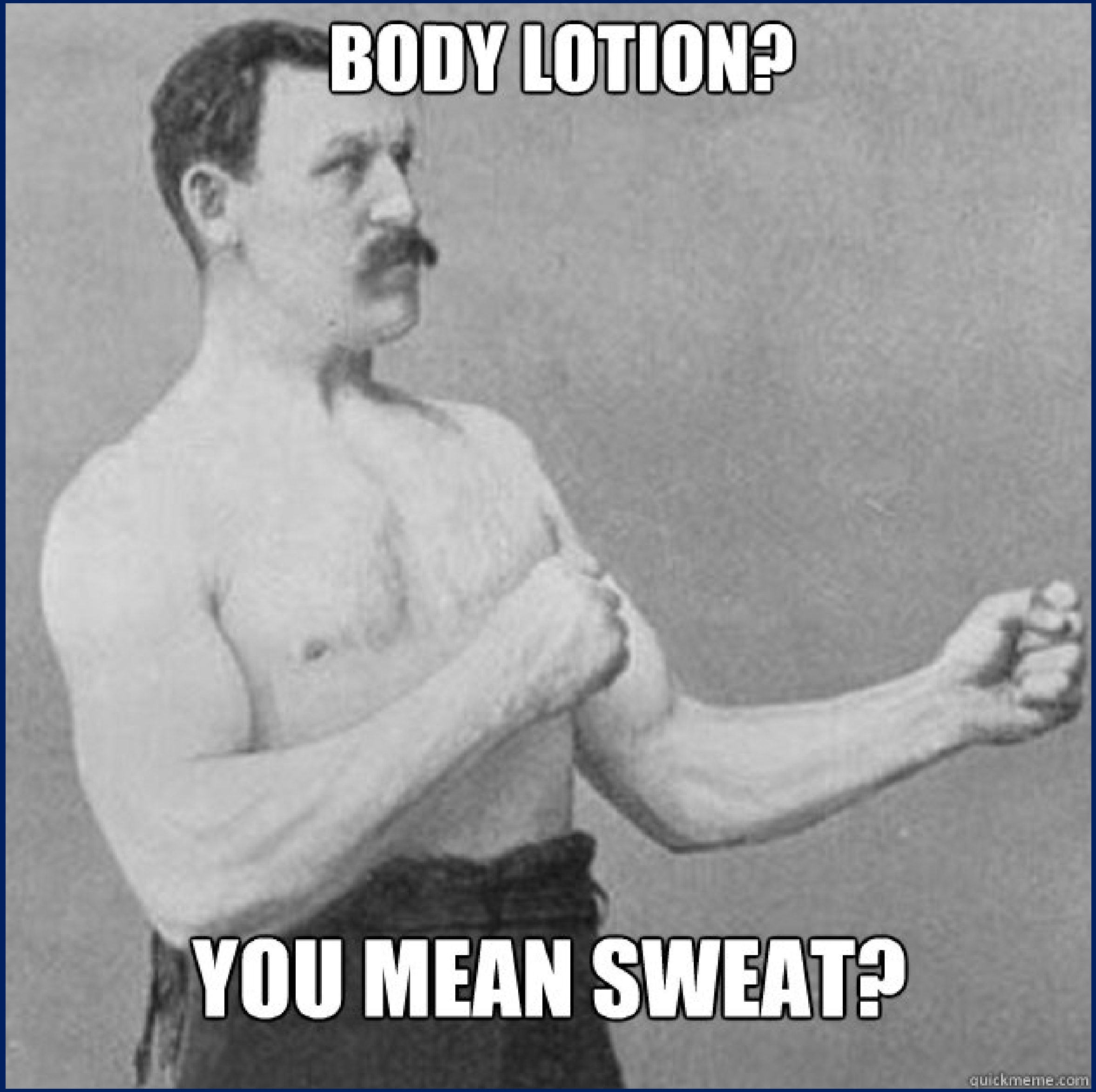
Water vapor is the gaseous form of water and one of the most important of all constituents of the atmosphere. It constitutes only a small percentage of the Earth's atmosphere, varying from only trace amounts to 4 percent by volume, and its amount varies widely in space and time. Approximately half of all of the atmospheric water vapor is found below 2 kilometers (6,500 feet) altitude, and only a minute fraction of the total occurs above the tropopause. Water vapor is important, not only as the raw material for clouds and precipitation (e.g., rain and snow), but also as a vehicle for the transfer of heat energy and as a regulator of the Earth's temperatures through absorption and emission of radiation, most significantly in the thermal infrared (i.e., the greenhouse effect). The amount of water vapor present in a given air sample may be measured in a number of different ways, involving such concepts as relative humidity and dewpoint. Before we talk about these subjects, we will first discuss how water cycles through the Earth-atmosphere system.

The Hydrologic Cycle. The hydrologic cycle involves the continuous circulation of water in the Earth-atmosphere system. Water vapor plays a critical role in the cycle.

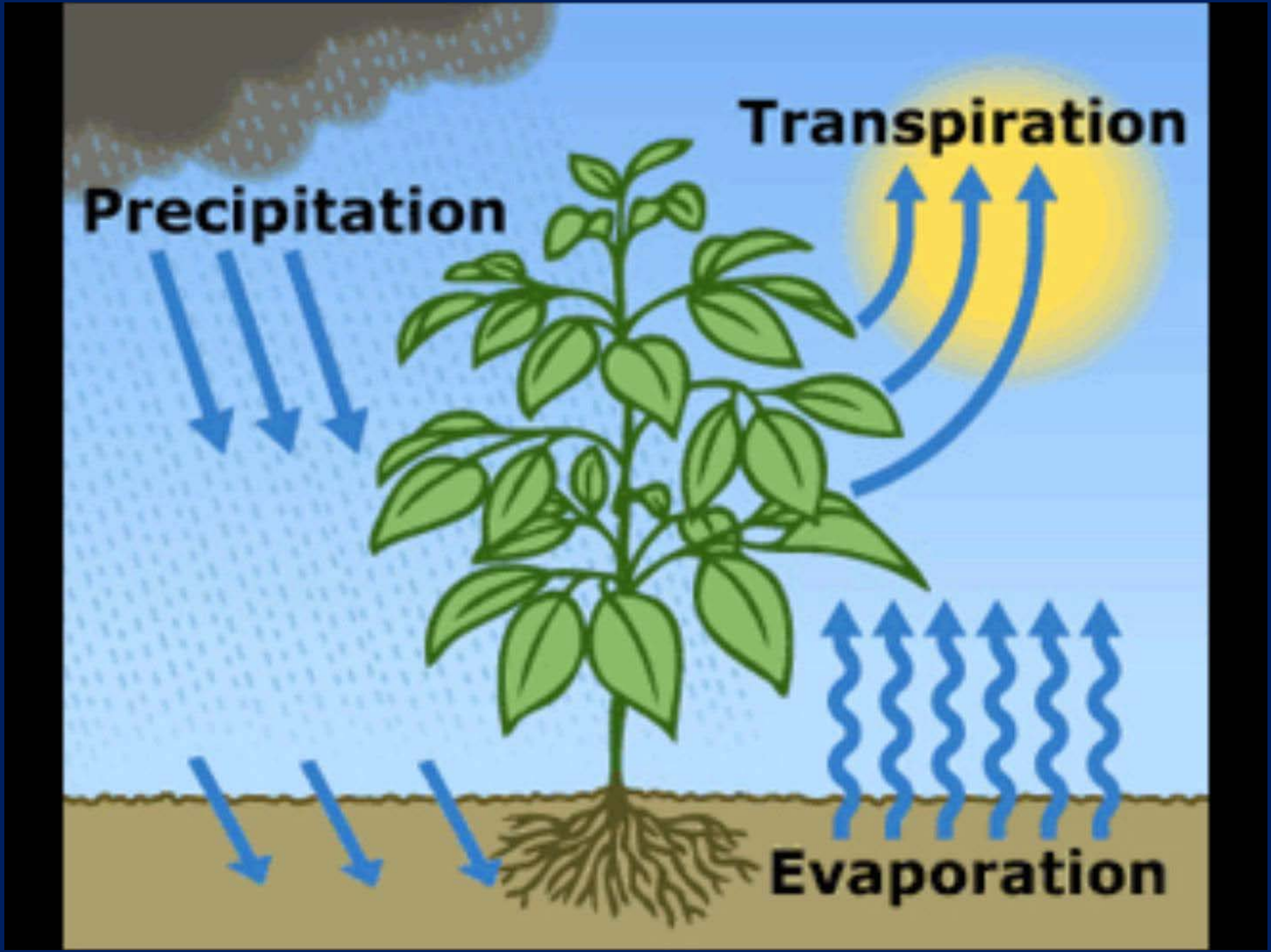


Evaporation is the phase transition by which a liquid is changed to a vapor (gas). In meteorology, the substance we are concerned about the most is water, and the primary source is the ocean. On average, about 120 centimeters (47 inches) is evaporated into the atmosphere from the ocean each year. For evaporation to take place, energy is required. The energy can come from any source: the sun, the atmosphere, the Earth, or objects on the Earth, such as humans.

Everyone has experienced evaporation personally. When the body heats up due to the air temperature, or through exercise, the body sweats, secreting water onto the skin. The purpose is to cause the body to use its heat to evaporate the liquid, thereby removing heat and cooling the body. The same effect can be seen when you step out of a shower or swimming pool. The coolness you feel is from the removal of bodily heat used to evaporate the water on your skin.

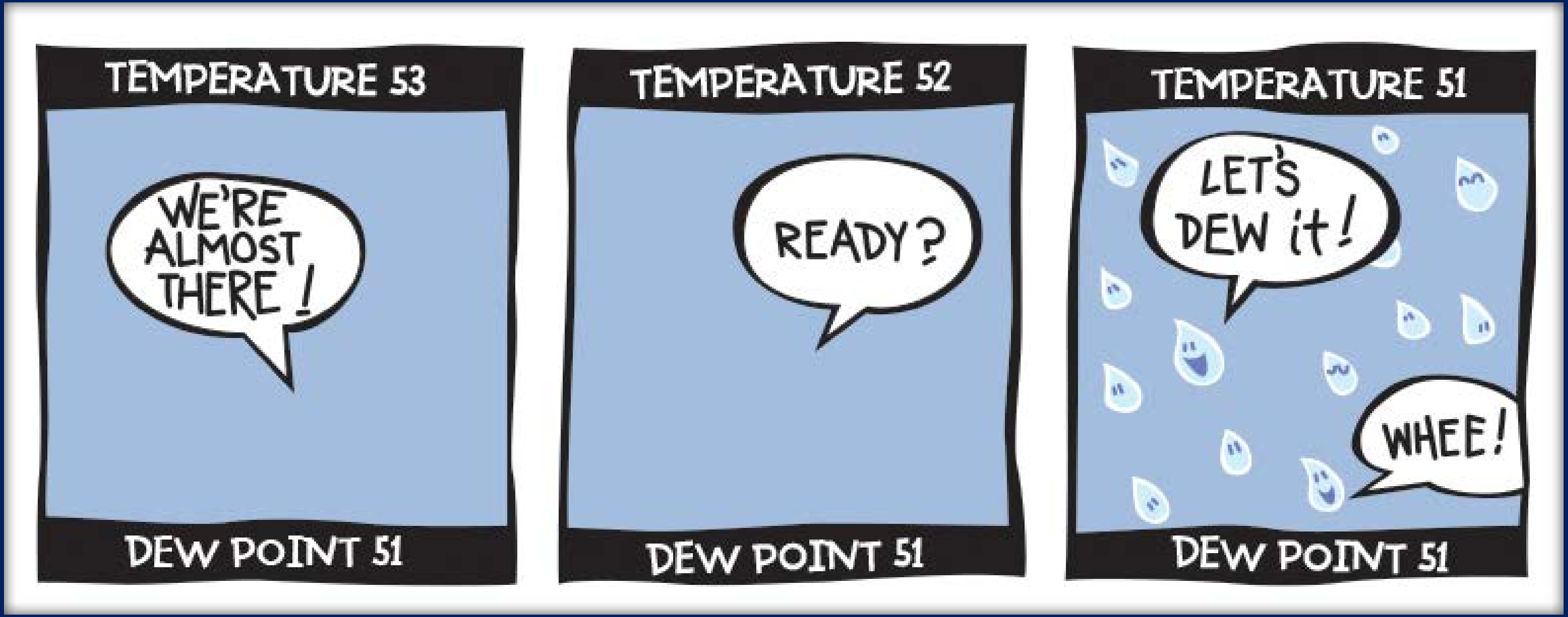


Transpiration is the evaporation of water from plants. In most plants, transpiration is a passive process largely controlled by the humidity of the atmosphere and the moisture content of the soil. Of the transpired water passing through a plant, only 1 percent is used in the growth process of the plant. The remaining 99 percent is passed into the atmosphere



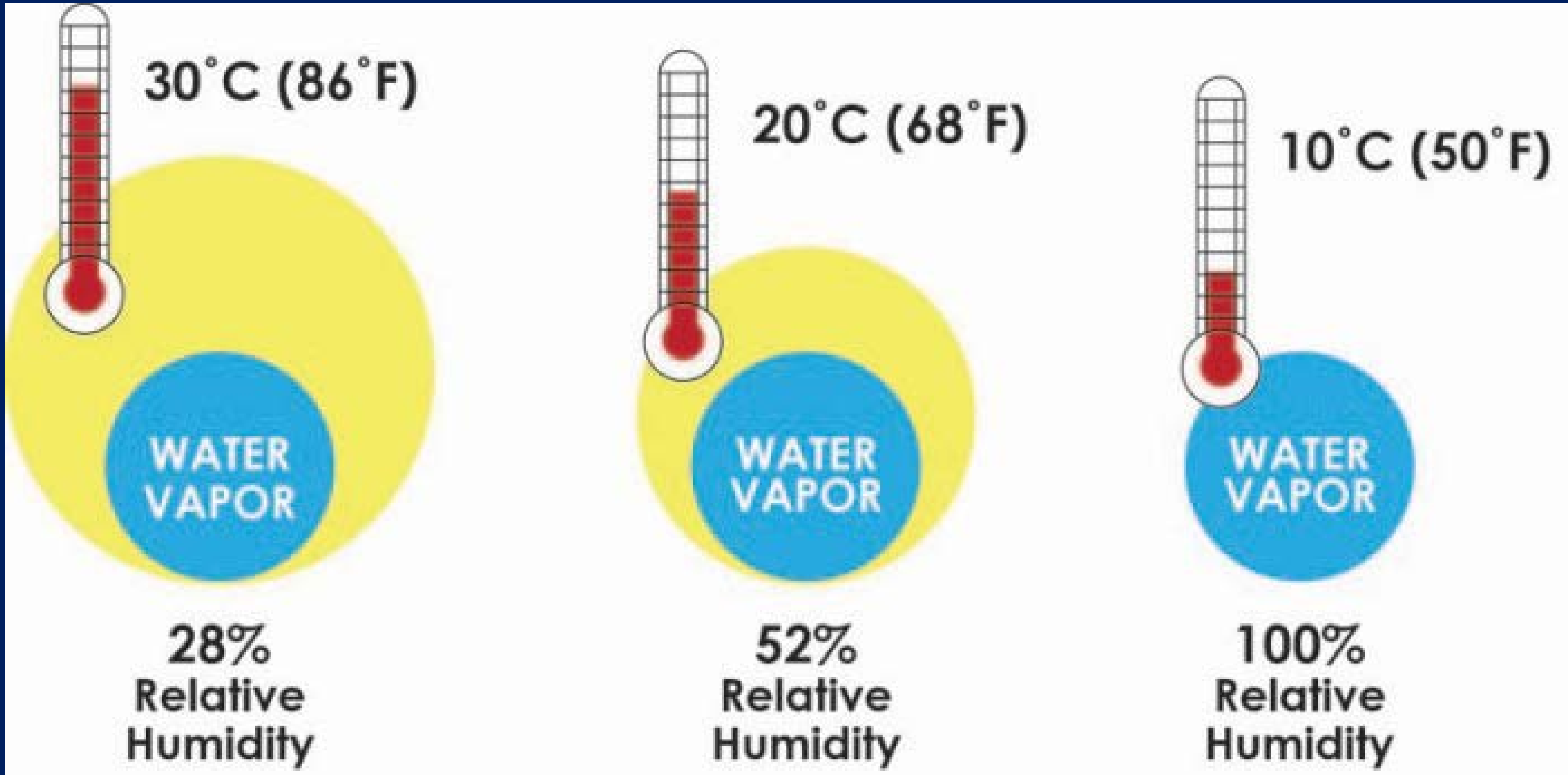
Sublimation is the phase transition by which a solid is changed into vapor (a gas) without passing through the liquid phase. In the atmosphere, sublimation of water occurs when ice and snow (solids) change into water vapor (a gas).

Saturation is the maximum possible quantity of water vapor that an air parcel can hold at any given temperature and pressure. The term saturated air means an air parcel has all the water vapor it can hold, while unsaturated air means an air parcel can hold more water vapor.



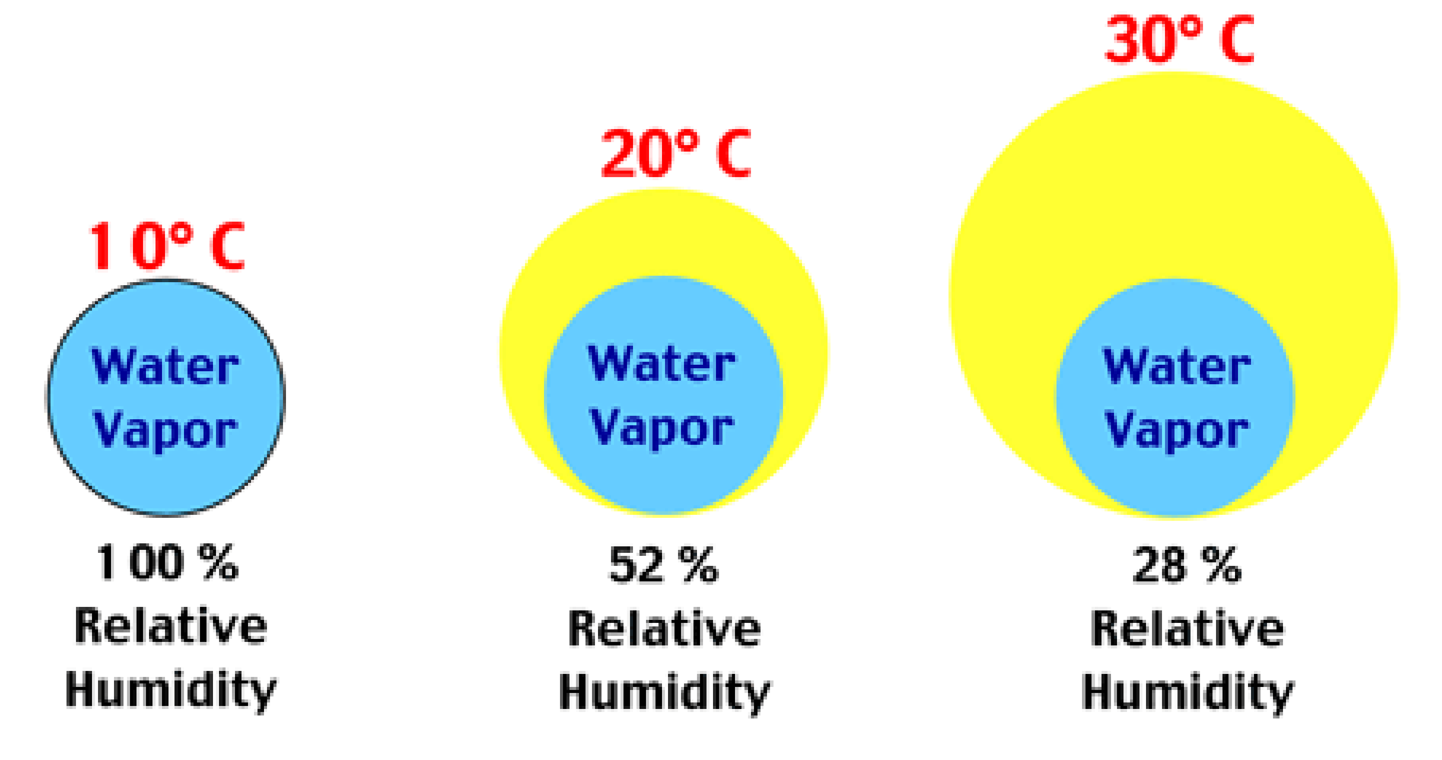
Relative humidity is the ratio, usually expressed as a percentage, of water vapor actually in the air parcel compared to the amount of water vapor the air parcel could hold at a particular temperature and pressure.

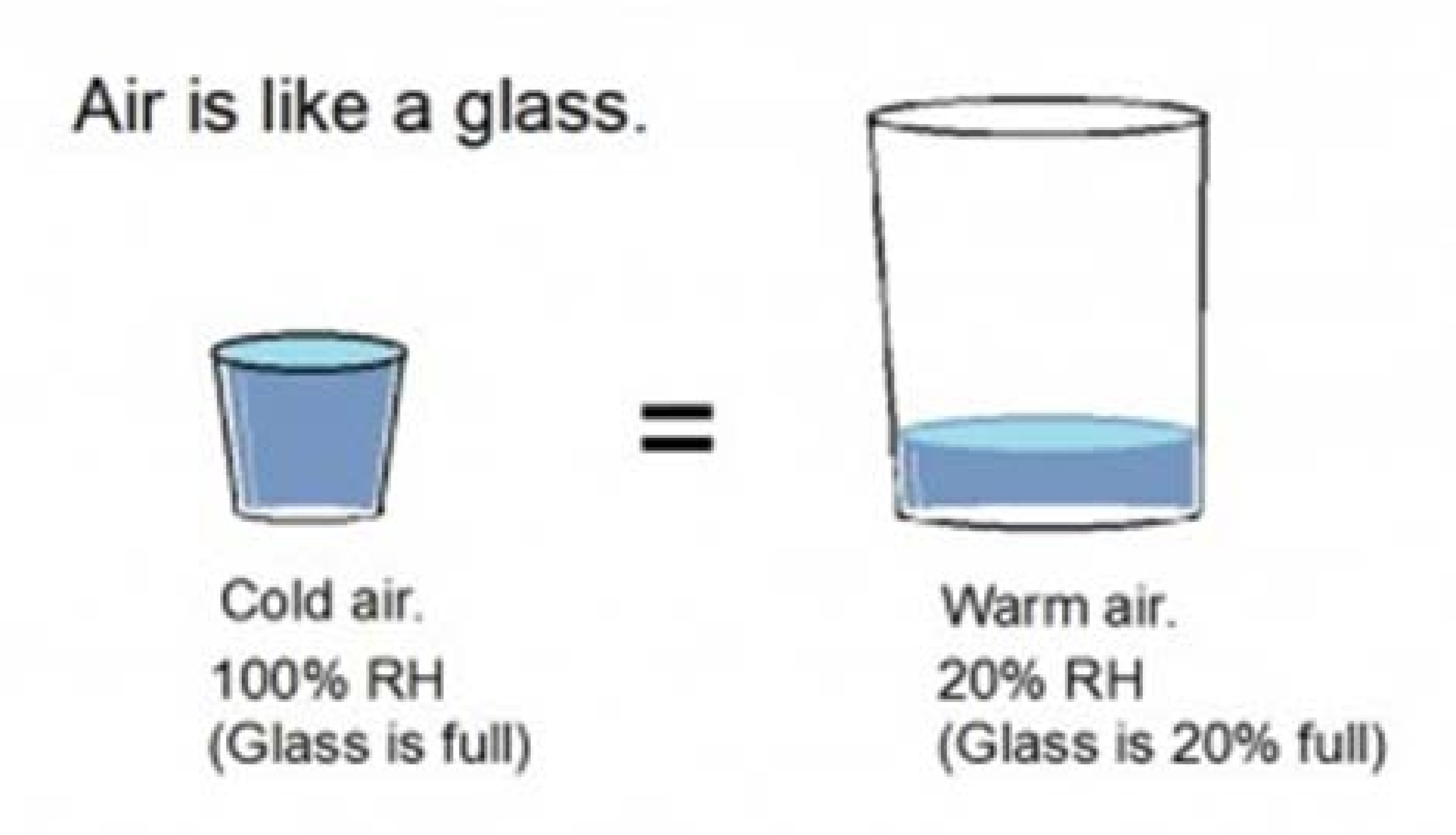
While relative humidity is the most common method of describing atmospheric moisture, it is also the most misunderstood. Relative humidity can be confusing because it does not indicate the actual water vapor content of the air, but rather how close the air is to saturation. An air parcel with 100 percent relative humidity is saturated, while an air parcel with relative humidity less than 100 percent is unsaturated.



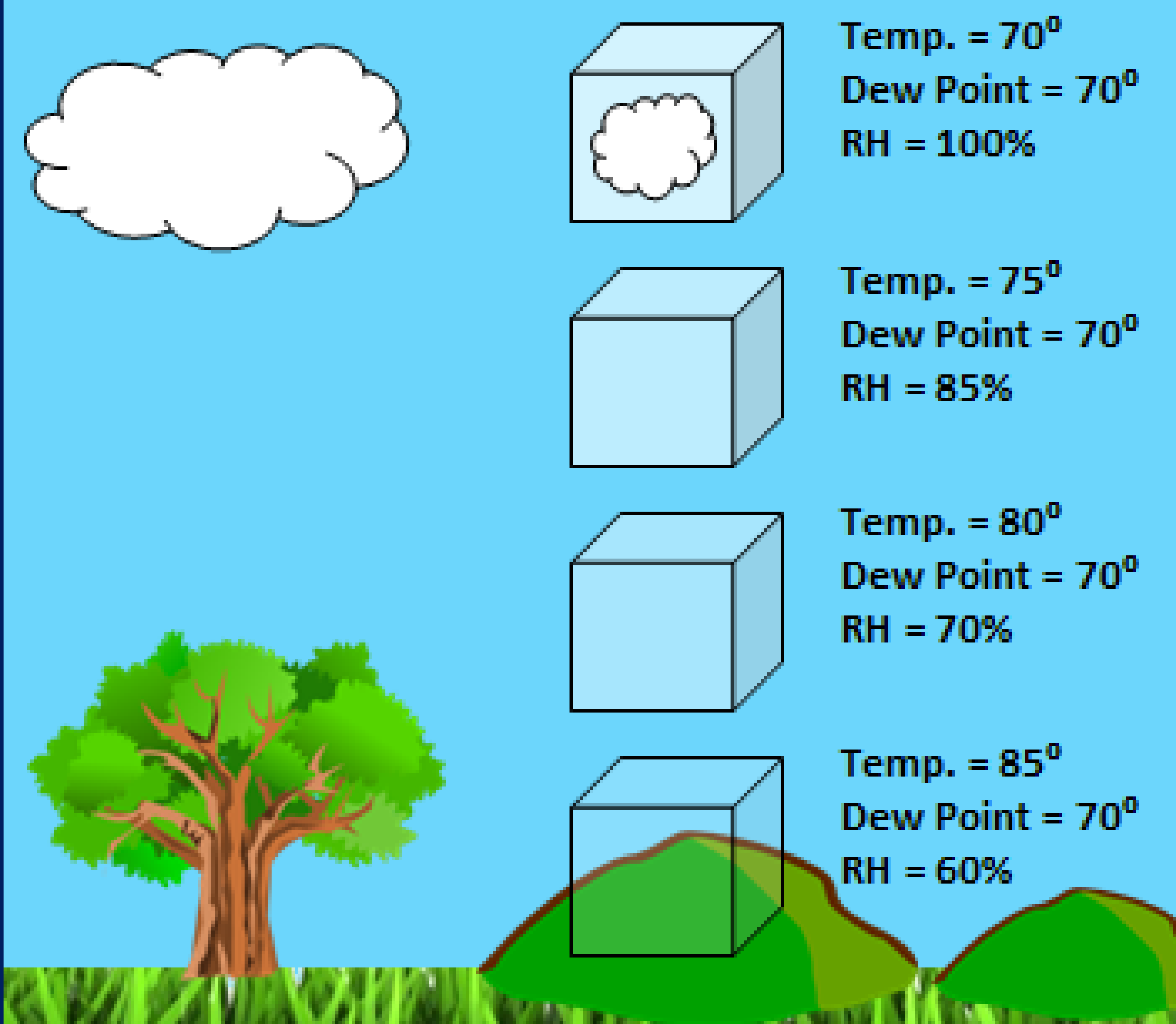
An air parcel's capacity to hold water vapor (at a constant pressure) is directly related to its temperature. It is possible to change an air parcel's relative humidity without changing its water vapor content.

An air parcel at sea level at a temperature of 30 °C has the capacity to hold 27 grams of water vapor. If it actually held 8 grams, its relative humidity would be 30 percent, and it would be unsaturated. However, if the air parcel's temperature decreases to 20 °C, its water vapor storage capacity decreases to 15 grams and its relative humidity rises to 53 percent. At 10 °C, the air parcel's water vapor storage capacity decreases to equal the amount of water vapor it actually holds (8 grams), its relative humidity increases to 100 percent, and it becomes saturated. During this cooling process, the air parcel's actual water vapor content remained constant, but relative humidity increased with decreasing temperature.

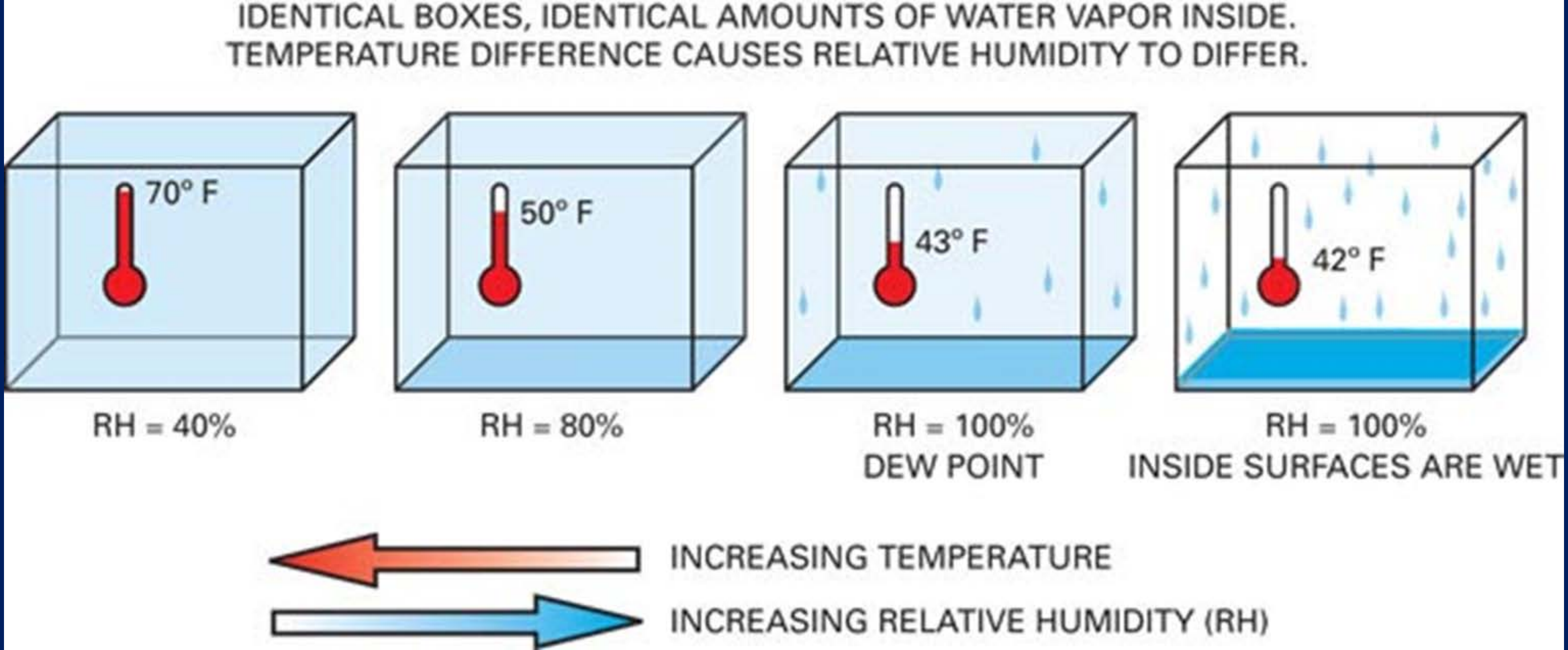



Air is like a glass.
=
Cold air.
100% RH
(Glass is full)
Warm air.
20% RH
(Glass is 20% full)

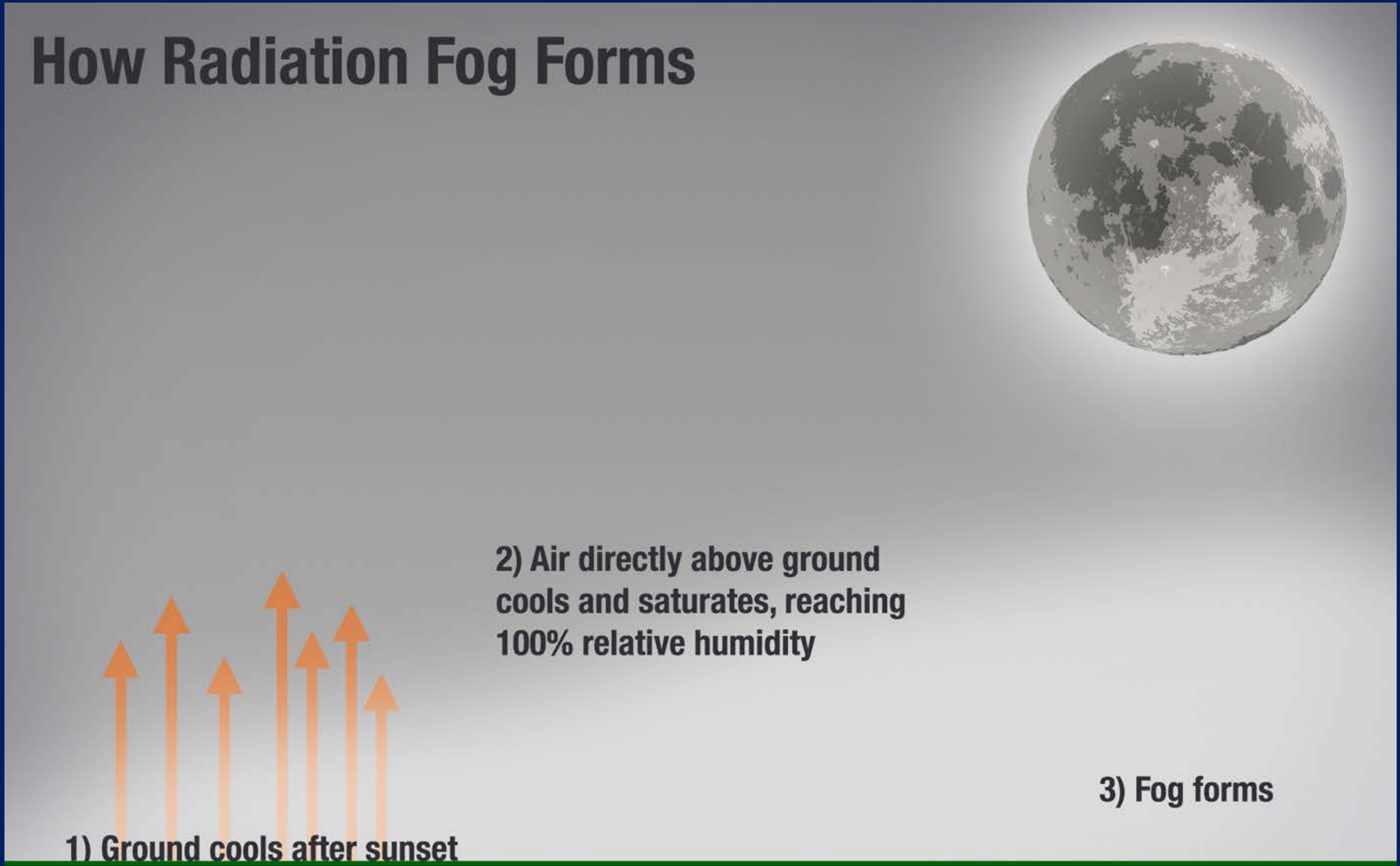
Dewpoint is the temperature an air parcel must be cooled at constant pressure and constant water vapor pressure to allow the water vapor in the parcel to condense into water (dew). When this temperature is below 0 °C (32 °F), it is sometimes called the frost point. Lowering an air parcel's temperature reduces its capacity to hold water vapor



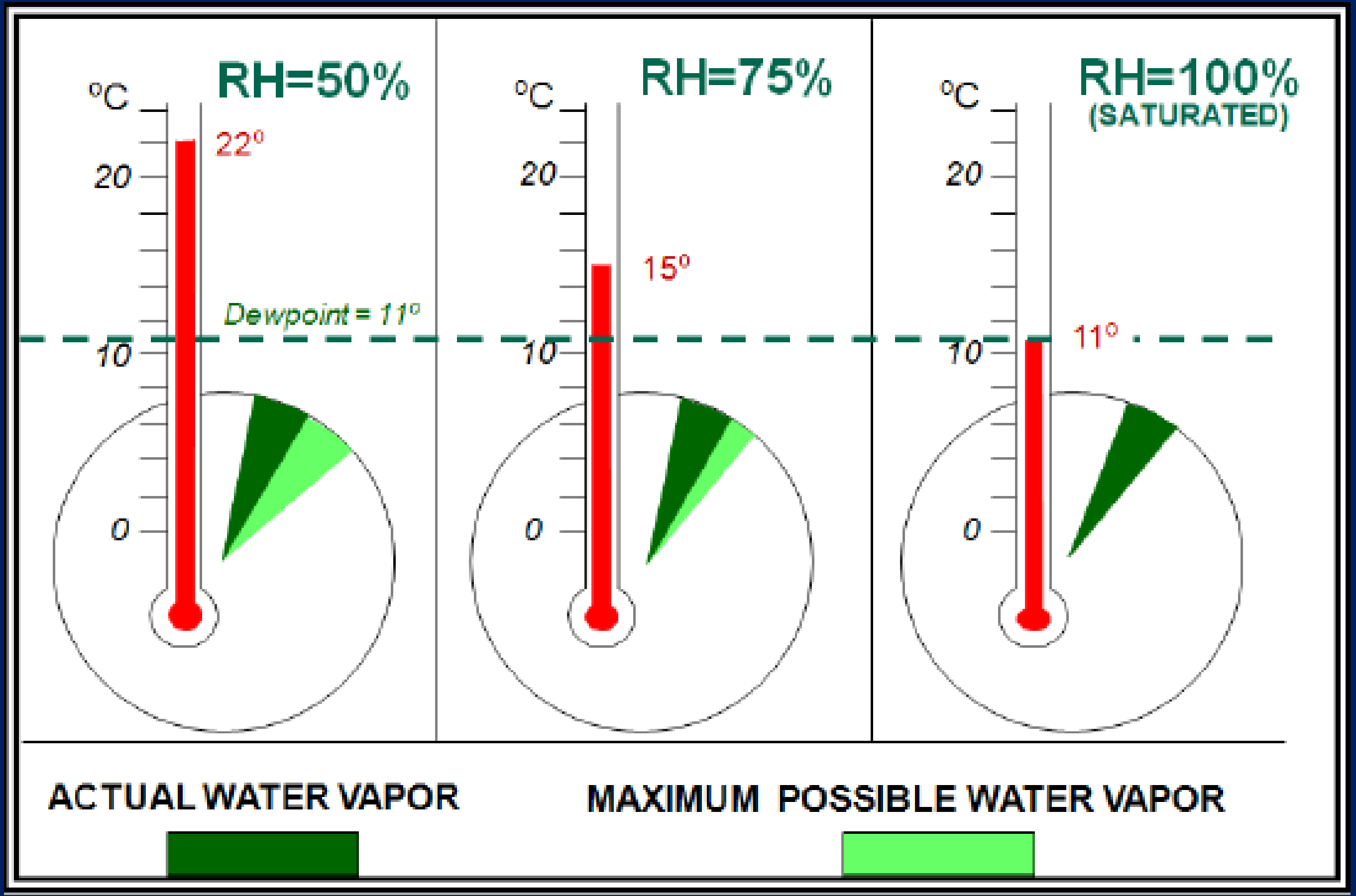
Temperature-Dewpoint Spread (Dewpoint Depression). The difference between an air parcel's temperature and its dewpoint is the dewpoint depression, or commonly referred to as the spread. Surface aviation weather reports (e.g., Aviation Routine Weather Reports (METAR)/Aviation Selected Special Weather Reports (SPECI)) provide observations of both temperature and dewpoint. The temperature greatly affects the air parcel's ability to hold water vapor, while the dewpoint indicates the actual quantity of water vapor in the parcel. As the spread decreases, relative humidity increases. When the spread decreases to zero, relative humidity is 100 percent, and the air parcel is saturated.



Surface temperature-dewpoint spread is important in anticipating fog, but has little bearing on precipitation. To support precipitation, air must be saturated through thick layers aloft.



Dewpoint is constant but temperature decreases from left to right. On the left panel, relative humidity is 50 percent, which indicates the air parcel could hold twice as much water vapor as is actually present. As the air parcel cools, the temperature-dewpoint spread decreases while relative humidity increases. When the air parcel's temperature cools to equal its dewpoint (11 °C), its capacity to hold water vapor is reduced to the amount actually present. The temperature-dewpoint spread is zero, relative humidity is 100 percent, and the air parcel is now saturated.



Change of Phase. Water changes from one state of matter (solid, liquid, or vapor) to another at the temperatures and pressures experienced near the surface of the Earth. Interestingly, water is the only substance on Earth that exists naturally in all three phases: as water droplets and ice crystals (visible as clouds) and as water vapor.

Water has some unique thermal properties which make it a powerful heat transport mechanism. It has the highest specific heat capacity of any naturally occurring substance.

That means water has a much higher capacity for storing heat energy (with little resulting temperature change) than other substances. These properties make water an ideal heat transport mechanism, and have important implications on weather and climate.

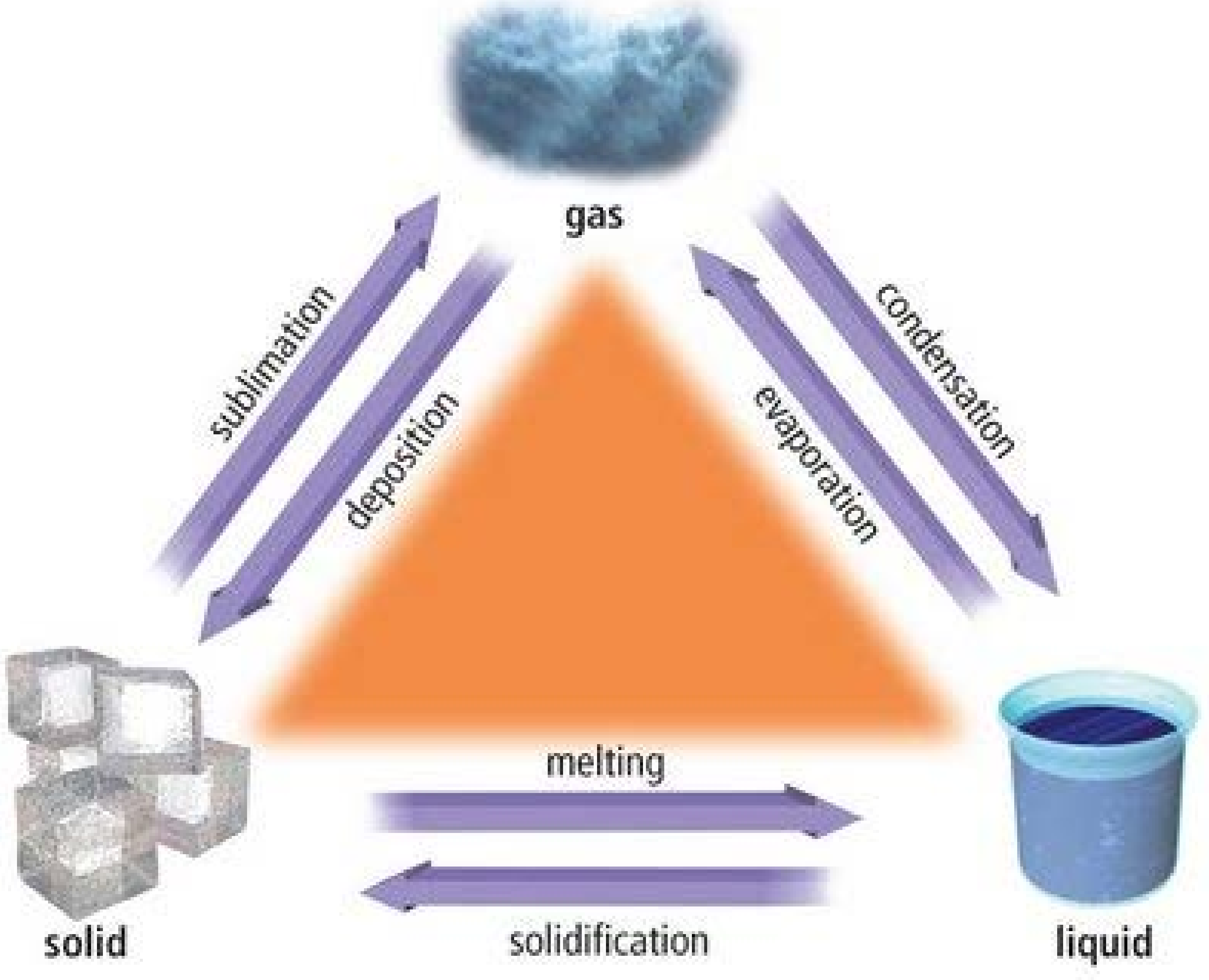
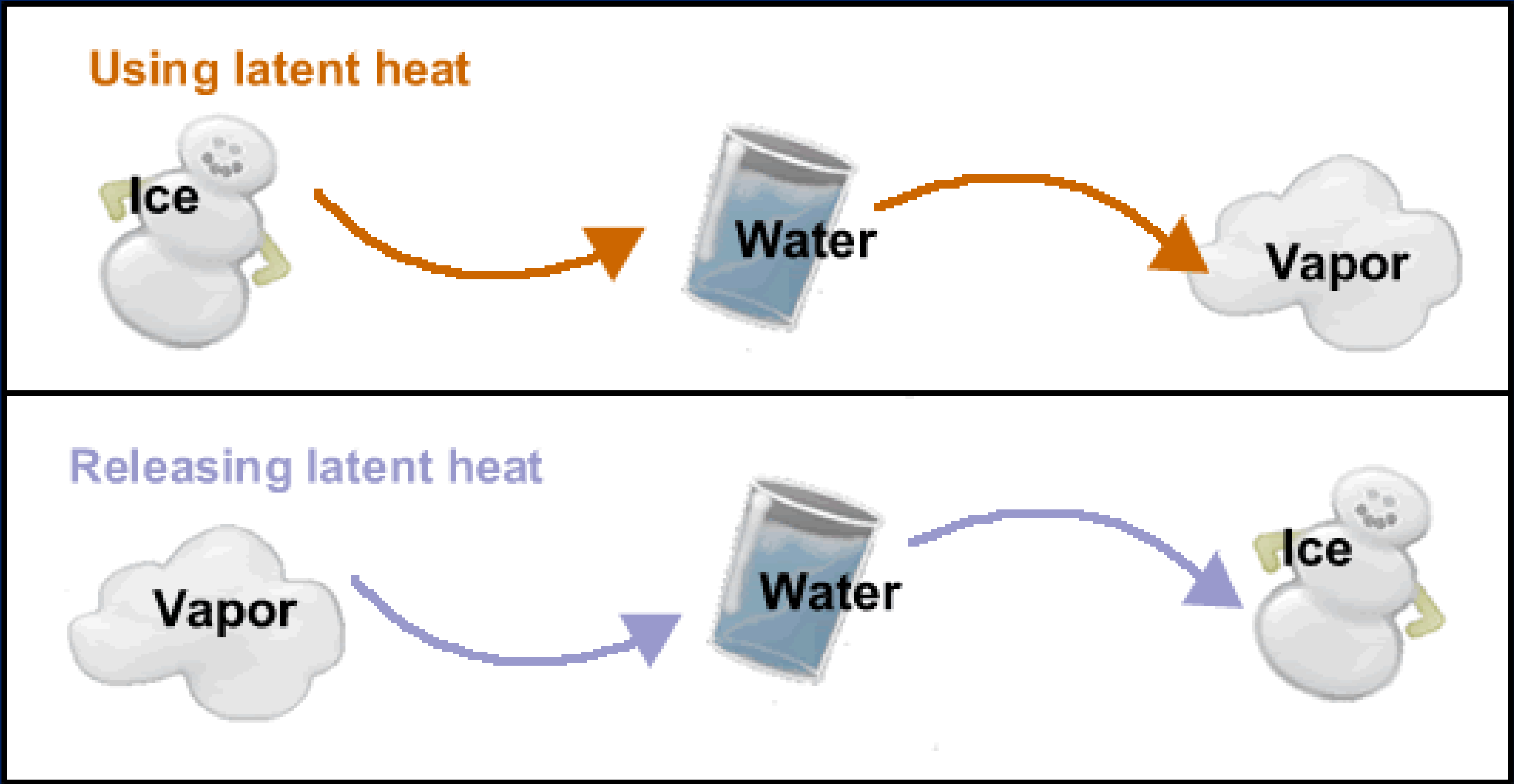


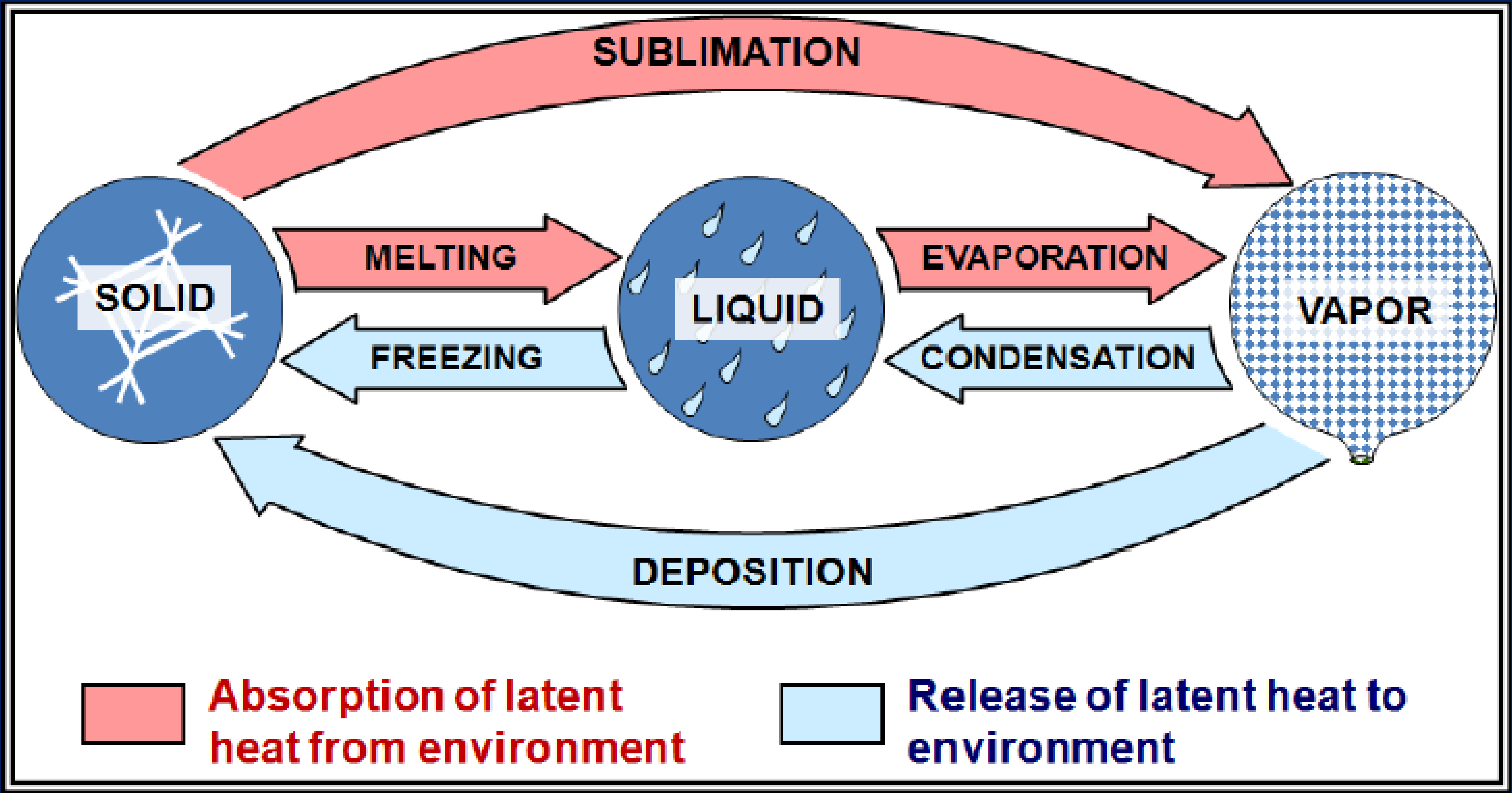
Figure 7.5A Changes of state

Latent Heat. Latent heat is the quantity of heat energy either released or absorbed by a unit mass of a substance when it undergoes a phase transition (change of state). Units are typically expressed in terms of joules per gram (J/g).



Heat is exchanged between water and its environment during phase transition. Although the temperature of the environment changes in response, the temperature of the water undergoing the phase transition remains constant until the phase change is complete; that is, the available heat, latent heat, is involved exclusively in changing the phase of water and not in changing its temperature.

There are six phase transitions, three of which are associated with the absorption of latent heat by water from the environment (melting, evaporation, and sublimation), and three of which are associated with the release of heat energy by water to the environment (freezing, condensation, and deposition).


SUBLIMATION
SOLID
MELTING
FREEZING
LIQUID
EVAPORATION
CONDENSATION
VAPOR
DEPOSITION
Absorption of latent heat from environment
Release of latent heat to environment

Melting is the phase transition by which a solid is changed to a liquid. During melting, water absorbs 334 joules per gram due to the latent heat of fusion. Freezing, the reverse process, releases 334 joules per gram back to the environment.

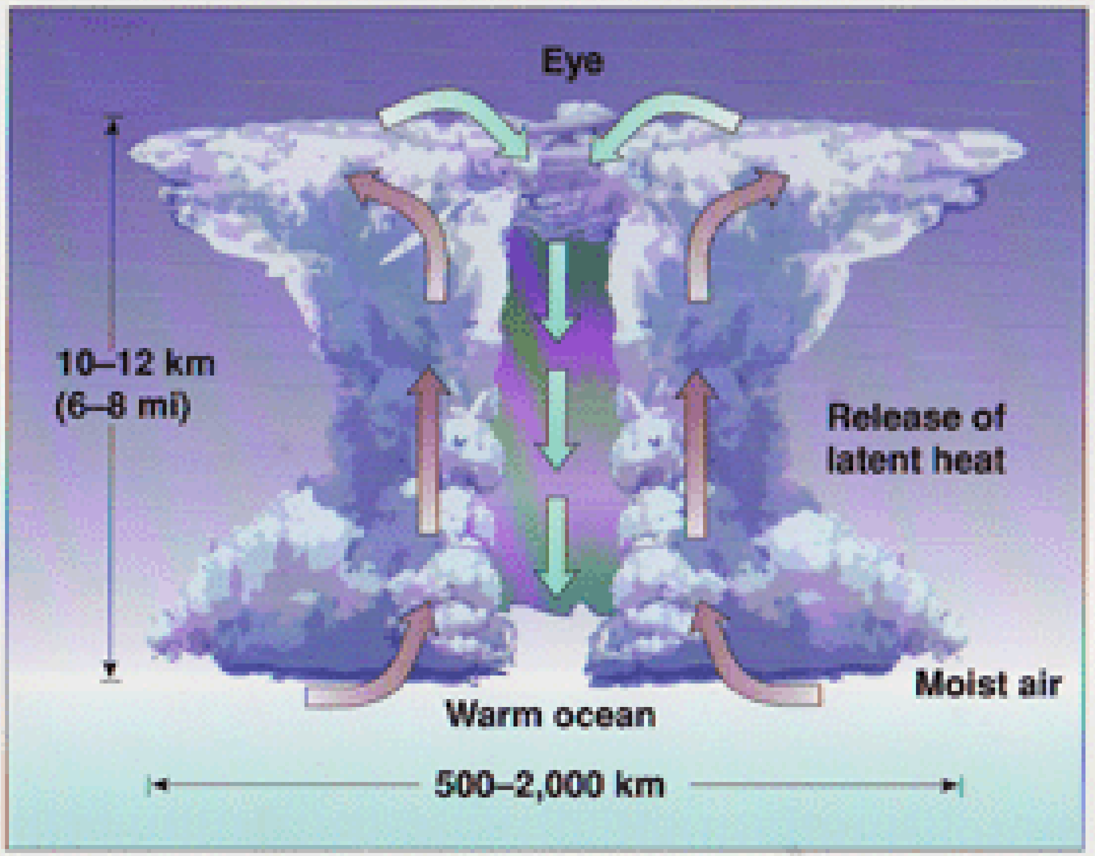
Evaporation is the phase transition by which a liquid is changed to a vapor. During evaporation, water absorbs 2,501 joules per gram due to the latent heat of vaporization.

Condensation, the reverse process, releases 2,501 Joules per gram back to the environment.

Sublimation is the phase transition by which a solid is changed to a vapor. During sublimation, water absorbs 2,834 joules per gram due to the latent heat of sublimation. Deposition, the reverse process, releases 2,834 joules per gram back to the environment.

The amount of energy associated with latent heat exchange should not be understated. An average hurricane releases 52 million trillion (5.2 x 1019) joules per day as water vapor condenses into clouds and precipitation.

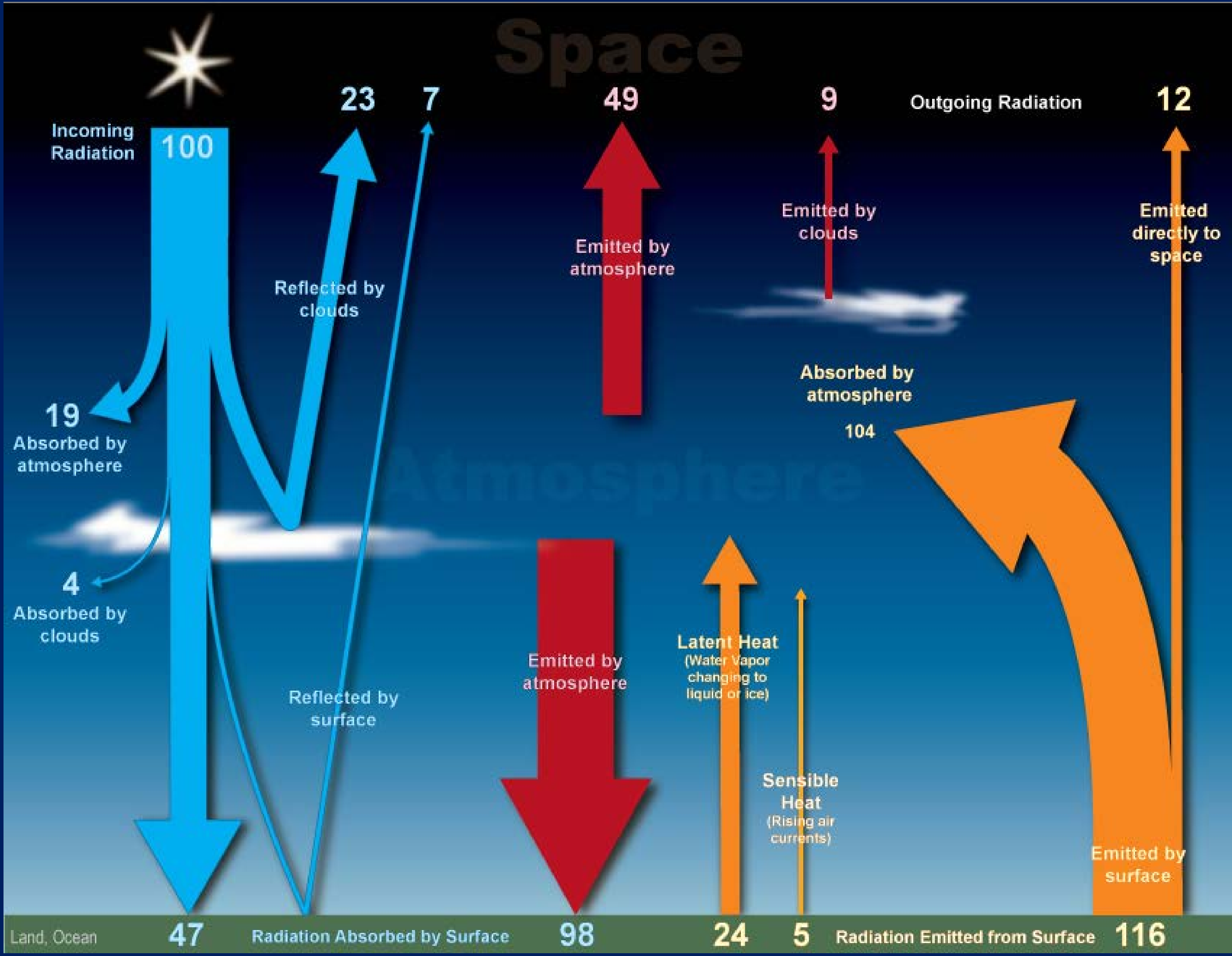
<u>This is equivalent to about 40 times the total worldwide energy consumption per day in 2016!</u>



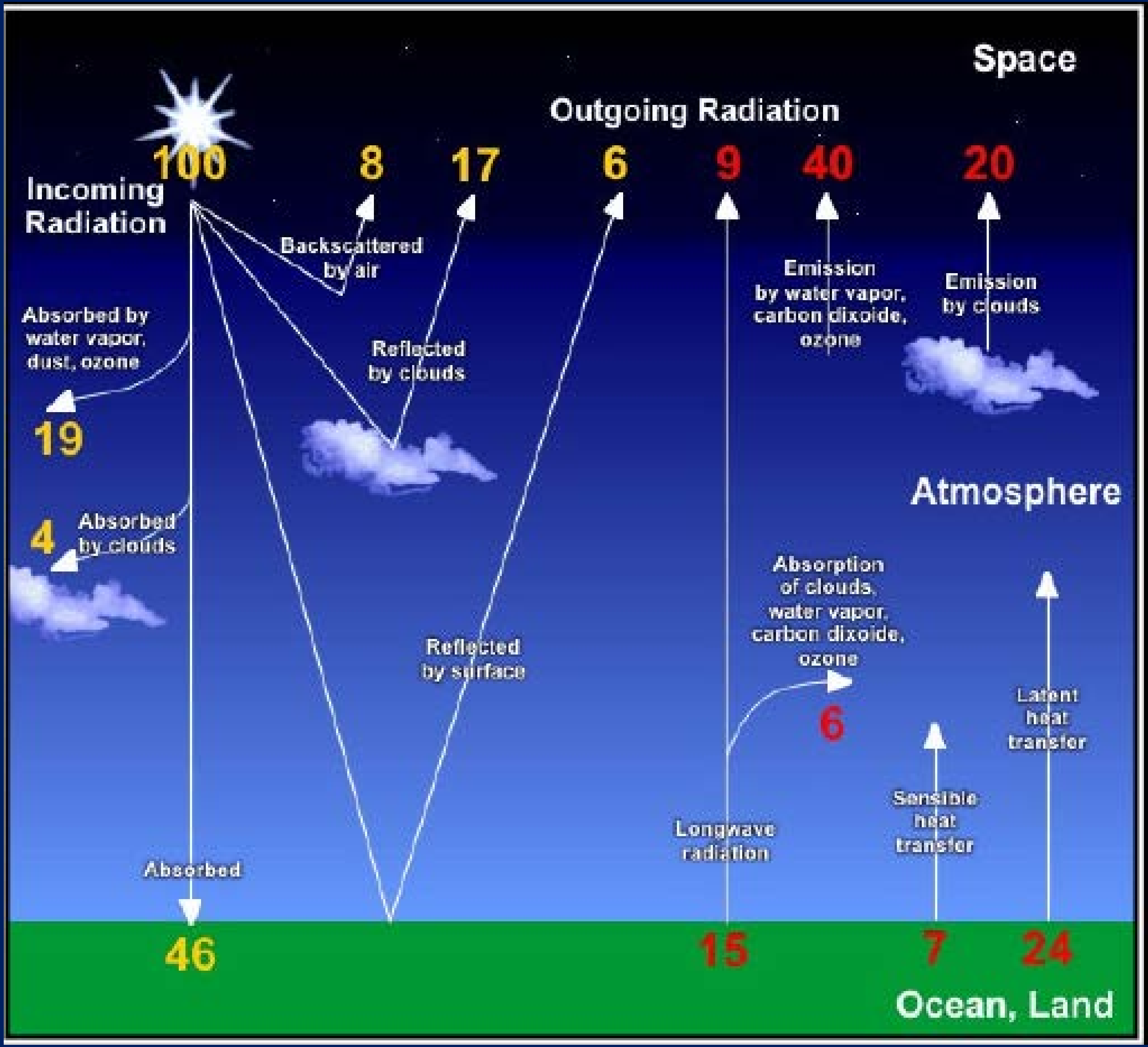
The Internal Structure of a Hurricane

EARTH-ATMOSPHERE HEAT IMBALANCES

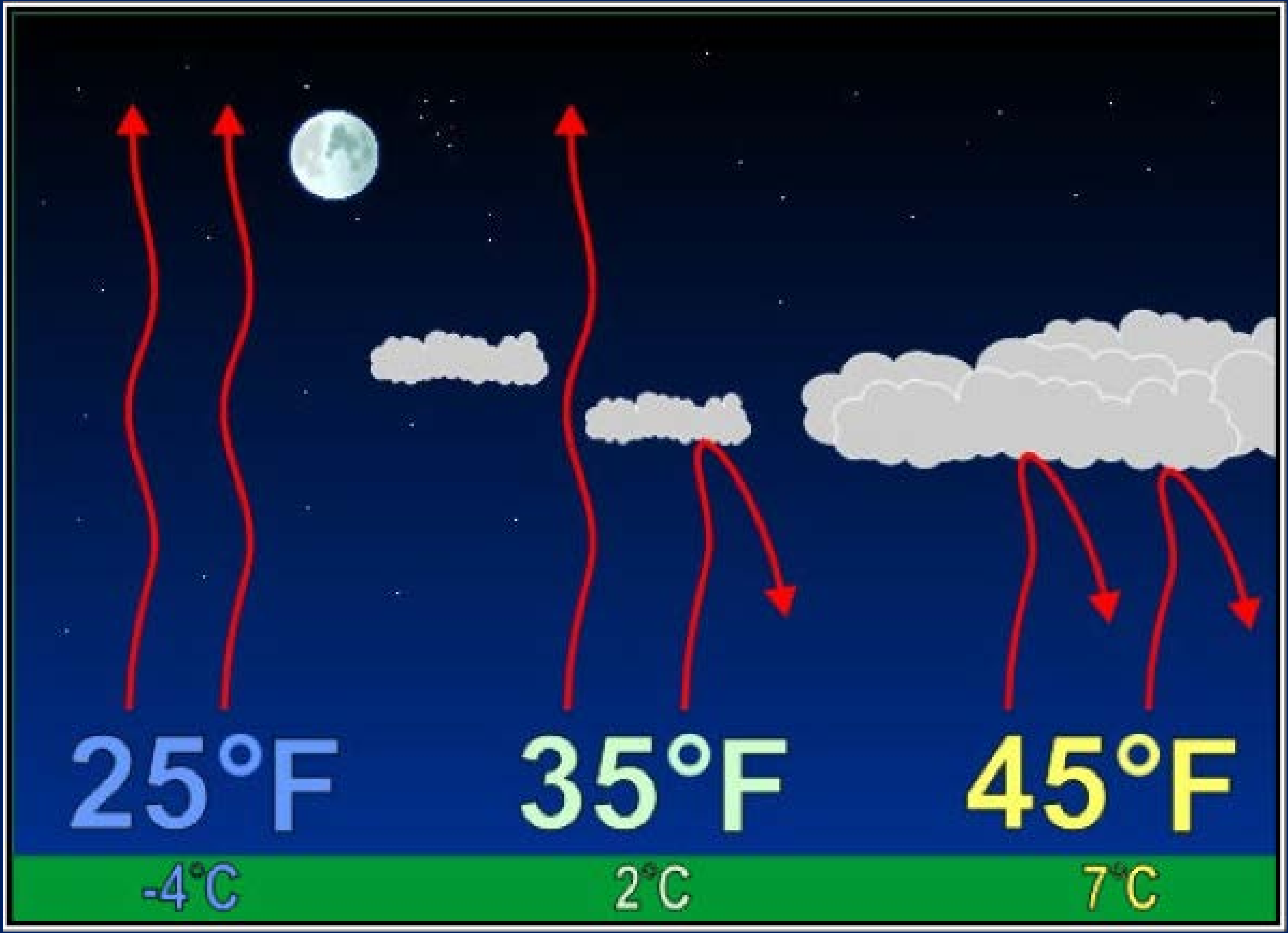
Introduction. Weather is not a capricious act of nature, but rather the atmosphere's response to unequal rates of radiational heating and cooling across the surface of the Earth and within its atmosphere. The absorption of incoming solar radiation causes heating, while the emission of outgoing terrestrial radiation causes cooling. However, imbalances in the rate of heating and cooling create temperature gradients.2 Atmospheric circulations and weather are the atmosphere's never-ending attempt to redistribute this heat and achieve equilibrium.



The Earth-Atmosphere Energy Balance. The Earth-atmosphere energy balance is the balance between incoming energy from the sun (solar radiation) and outgoing energy from the Earth (terrestrial radiation. When solar radiation reaches the Earth, some is reflected back to space by air (8 percent), clouds (17 percent), or the surface (6 percent). Some is absorbed by water vapor/dust/ozone (19 percent) or by clouds (4 percent). The remainder is absorbed by the Earth's surface (46 percent).



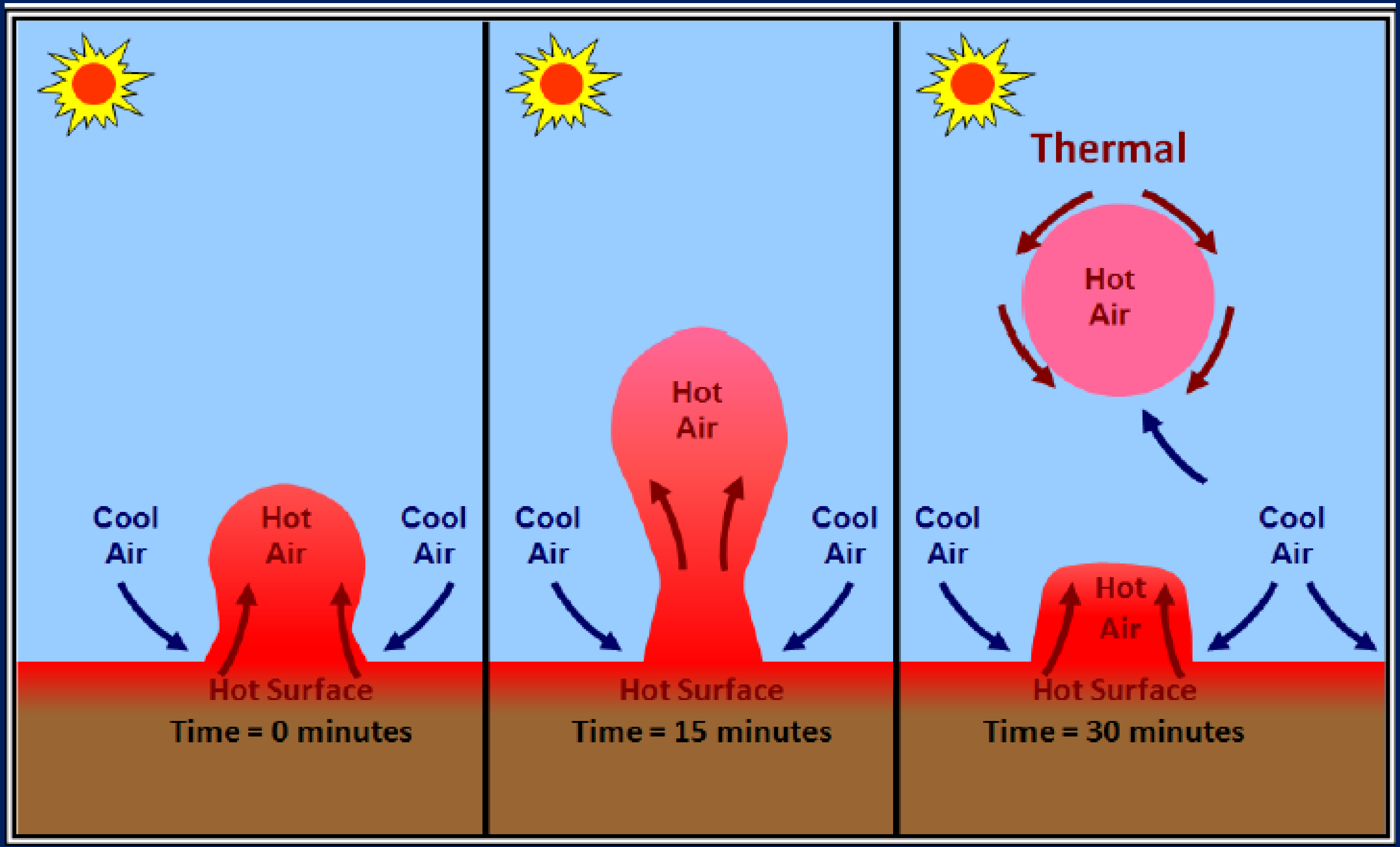
Greenhouse warming is enhanced during nights when the sky is overcast. Heat energy from the Earth can be trapped by clouds, leading to higher temperatures as compared to nights with clear skies. The air is not allowed to cool as much with overcast skies. Under partly cloudy skies, some heat is allowed to escape, and some remains trapped. Clear skies allow for the most cooling to take place



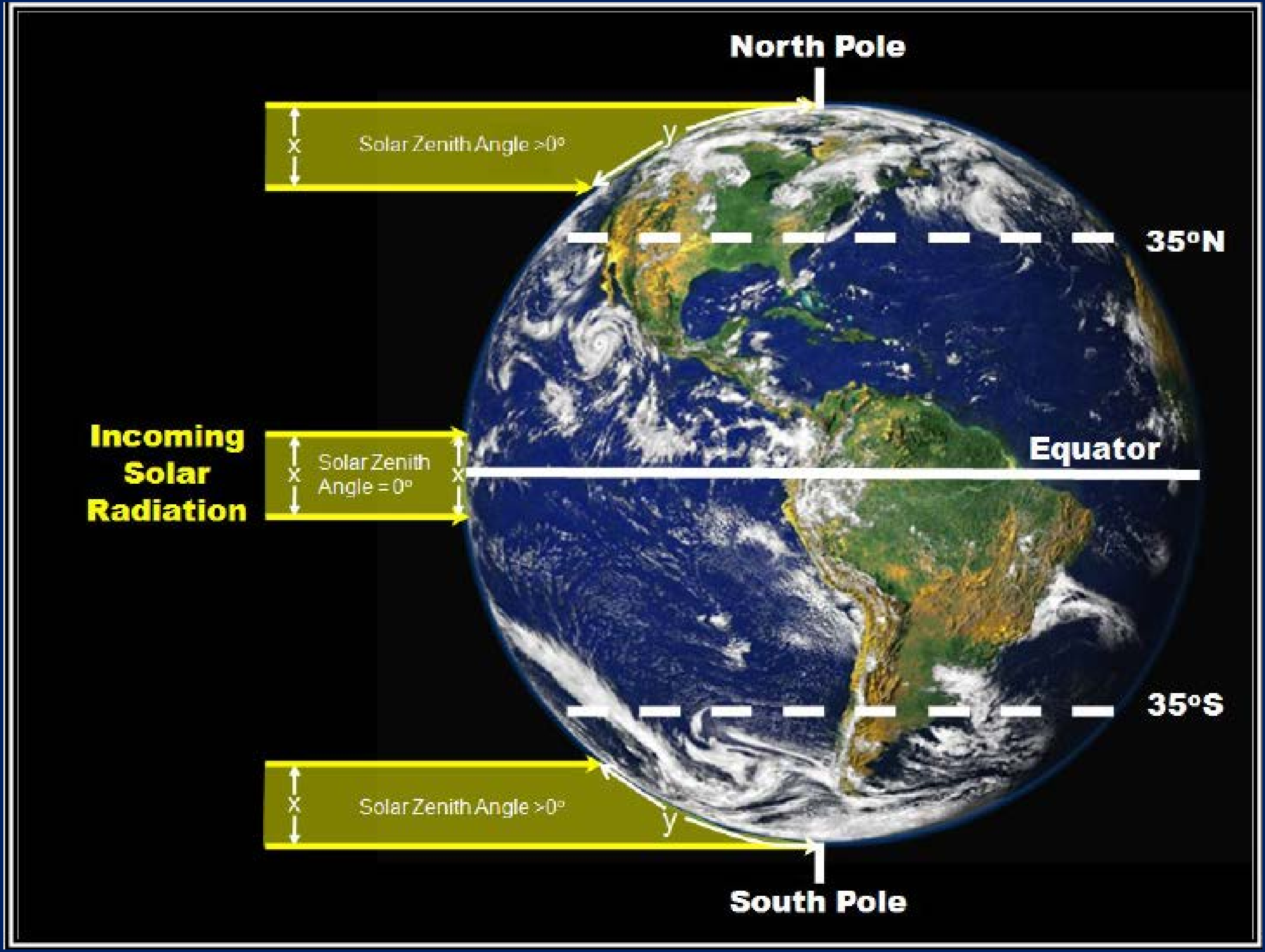
Sensible Heating. Sensible heating involves both conduction and convection. It occurs due to differences in air density. Warm air is less dense than cool air.

On warm sunny days, the Earth’s surface is heated by incoming solar radiation or insolation. However, the heating is somewhat uneven because certain areas of the Earth’s surface absorb more heat from the sun than others. Heat is conducted from the relatively warm ground to the cooler overlying air, which warms a shallow layer of air near the ground. The heated air expands, becomes less dense than the surrounding cooler air, and rises. Through this process, a large bubble of warm air called a thermal rises and transfers heat energy upwards. Cooler, denser air sinks toward the ground to replace the rising air. This cooler air becomes heated in turn, rises, and repeats the cycle.

In this manner, convection transports heat from the Earth's surface into the atmosphere. Because air is a poor conductor of heat, convection is much more important than conduction as a heat transport mechanism within the atmosphere.



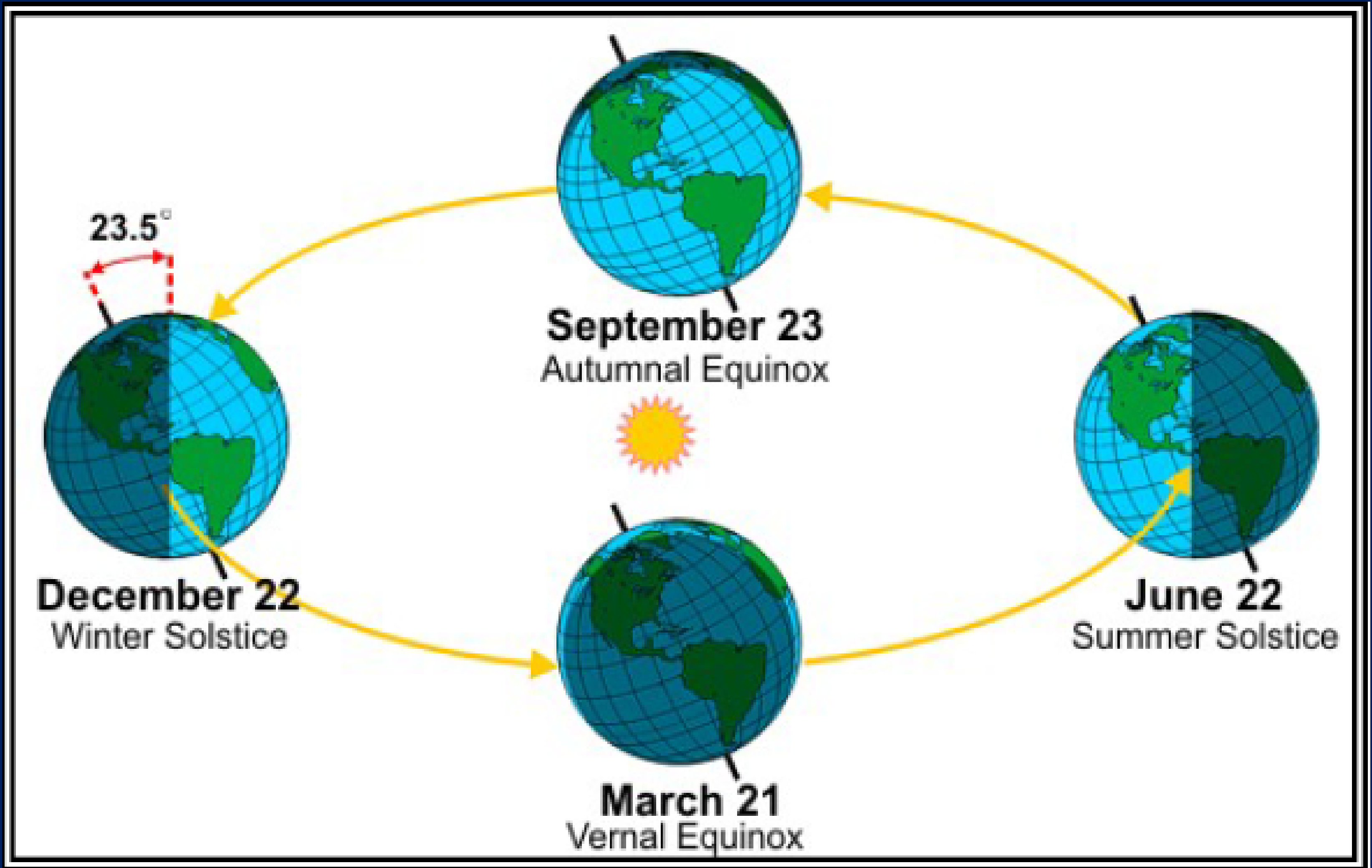
Latent Heat. The phase transition of water and associated latent heat exchanges are largely responsible for transferring the excess heat from the surface of the Earth into its atmosphere. As the Earth's surface absorbs radiation, some of the heat produced is used to evaporate (vaporize) water from oceans, lakes, rivers, soil, and vegetation. The water absorbs heat energy due to the latent heat of vaporization. Some of this water vapor condenses to microscopic water droplets or deposits as ice crystals that are visible as clouds. During cloud formation, the water vapor changes state, and latent heat is released into the atmosphere. During this process, the excess heat is transferred from the Earth's surface into its atmosphere.


North Pole
Solar Zenith Angle >0°
x
y
35°N
Incoming Solar Radiation
Solar Zenith Angle = 0°
x
Equator
35°S
Solar Zenith Angle >0°
x
y
South Pole

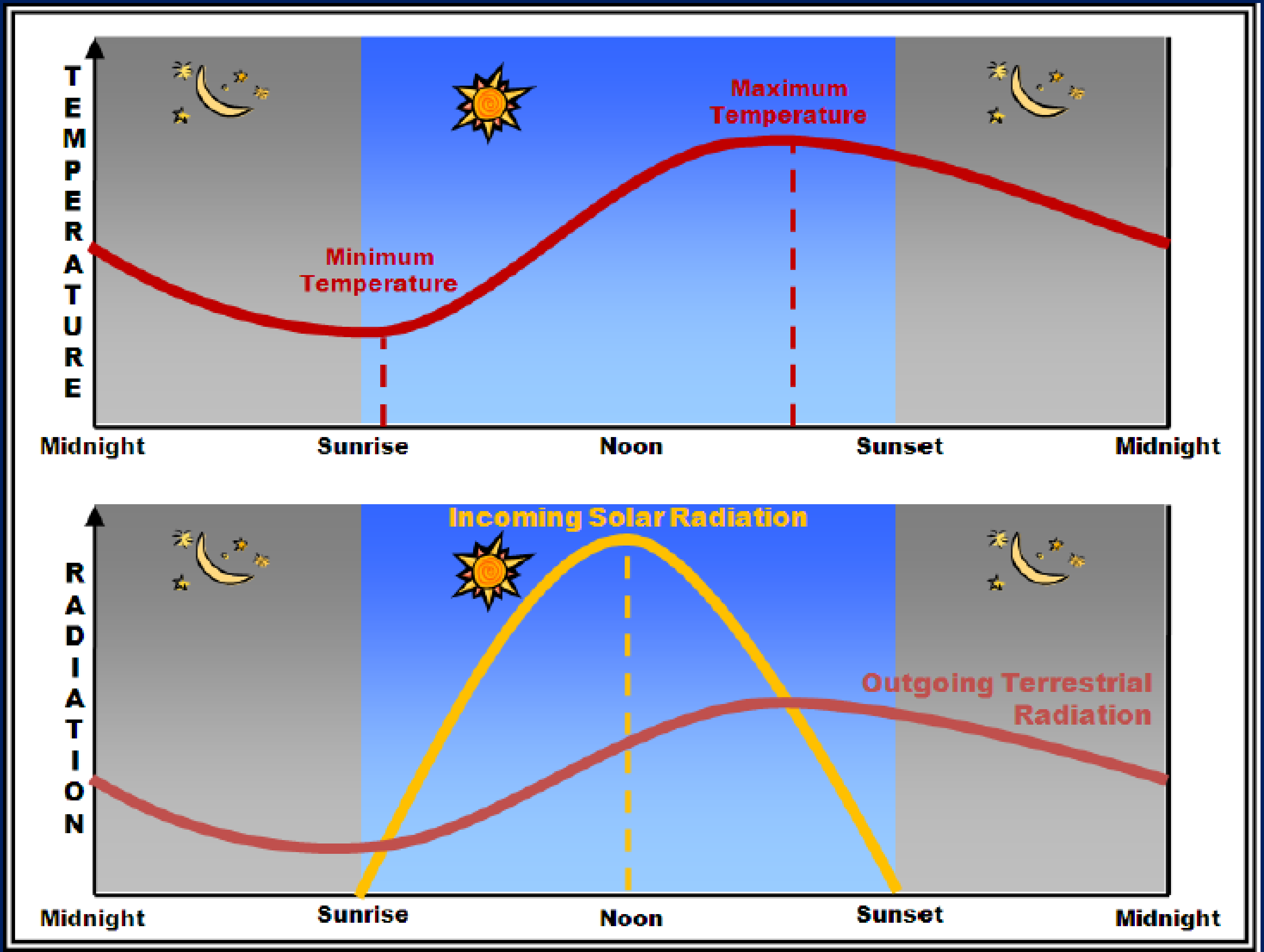
Seasons. Seasons are caused by the tilt of the Earth's rotational axis as the Earth orbits the sun. The Earth's rotational axis is tilted by 23½° from the perpendicular drawn to the plane of the Earth's orbit about the sun and points the same direction in space all year long.

The North Pole is tilted most directly toward the sun Solstice (~December 22). Thus, in the Northern Hemisphere, the longest day of the year (lowest solar zenith angle) occurs on the Summer Solstice, while the shortest day of the year (highest solar zenith angle) occurs on the Winter Solstice. Day and night are of equal length (12 hours) worldwide on the Vernal Equinox (~March 21) and the Autumnal Equinox (~September 23).

The average seasonal temperature variation in the Northern Hemisphere for both maritime and continental locations. Note that the warmest (coldest days) of the year occur after the summer (winter) solstice. This is due to the time lag necessary for heat flow processes to fully heat (cool) the surface of the Earth.



Diurnal Temperature Variation. Diurnal temperature variation is the daytime maximum and nighttime minimum of air temperature due to variations of insolation caused by the rising and setting of the sun (variations of solar zenith angle) as the Earth rotates around its axis.

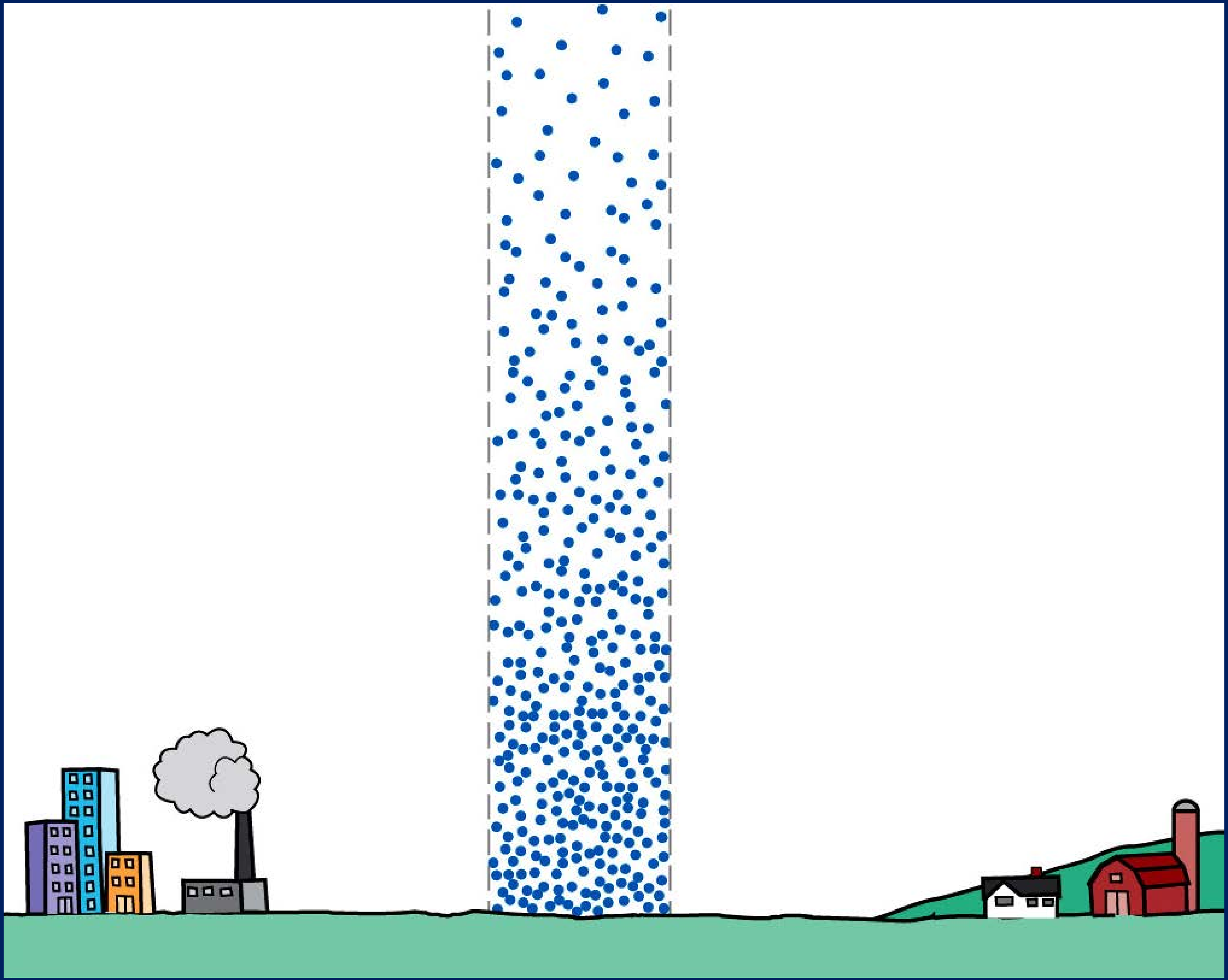


ATMOSPHERIC PRESSURE AND ALTIMETRY

Atmospheric pressure is one of the most basic variables used to describe the state of the atmosphere and is commonly reported in weather observations. Unlike temperature and relative humidity, changes in atmospheric pressure are not as readily sensed by people. However, variations of pressure across the Earth are associated with pressure centers (either high pressure centers or low pressure centers) that cause the wind to blow and can bring important weather changes. Density, which is directly related to pressure, is a property of the atmosphere which can be used by pilots to help determine how their aircraft will perform at various altitudes.

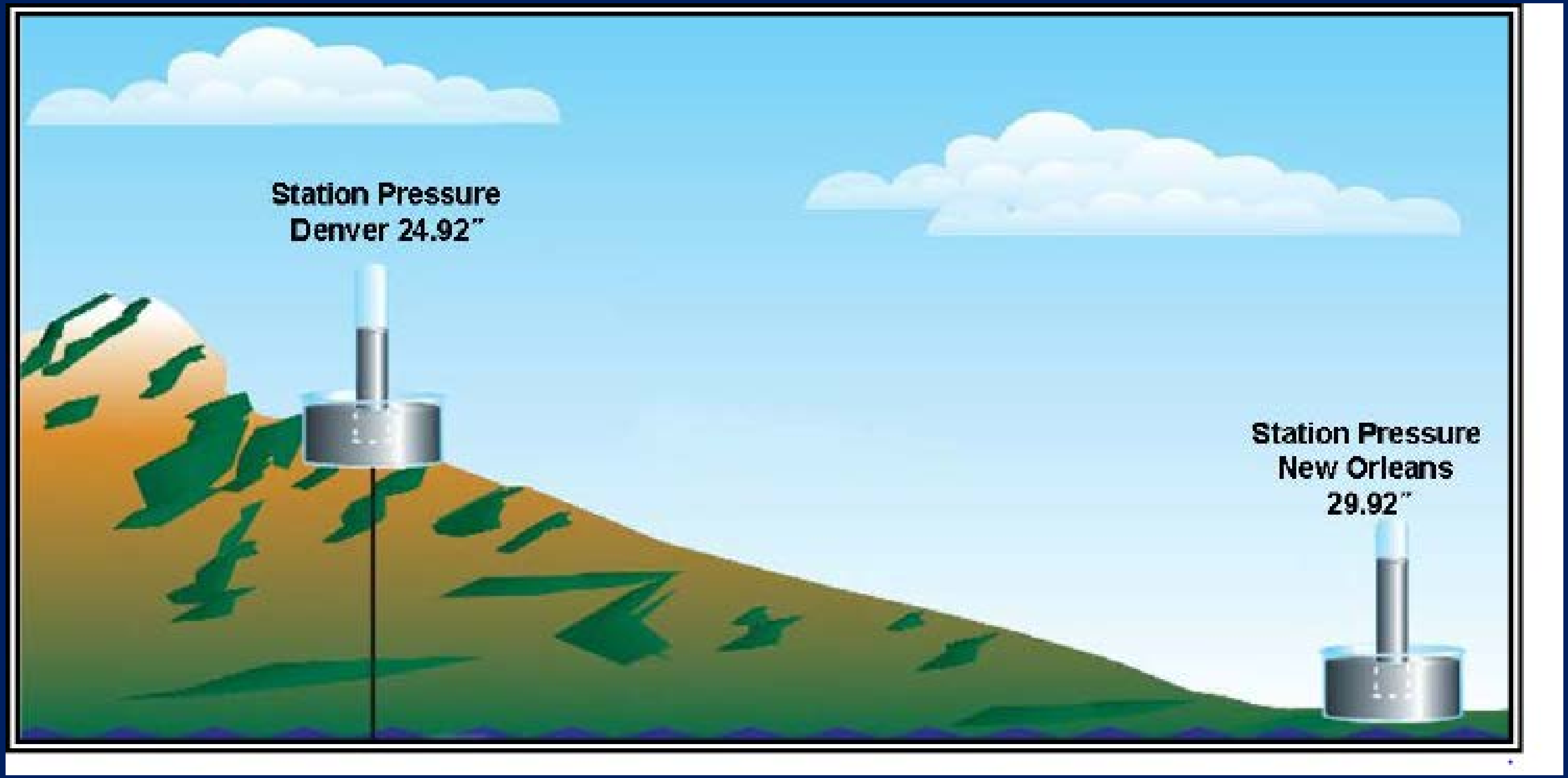
Atmospheric Pressure. The atoms and molecules that make up the various layers in the atmosphere are always moving in random directions. Despite their tiny size, when they strike a surface they exert pressure.

Each molecule is too small to feel and only exerts a tiny bit of pressure. However, when we add up all the pressures from the large number of molecules that strike a surface each moment, the total pressure is considerable. This is air pressure. As the density of the air increases, then the number of strikes per unit of time and area also increases..

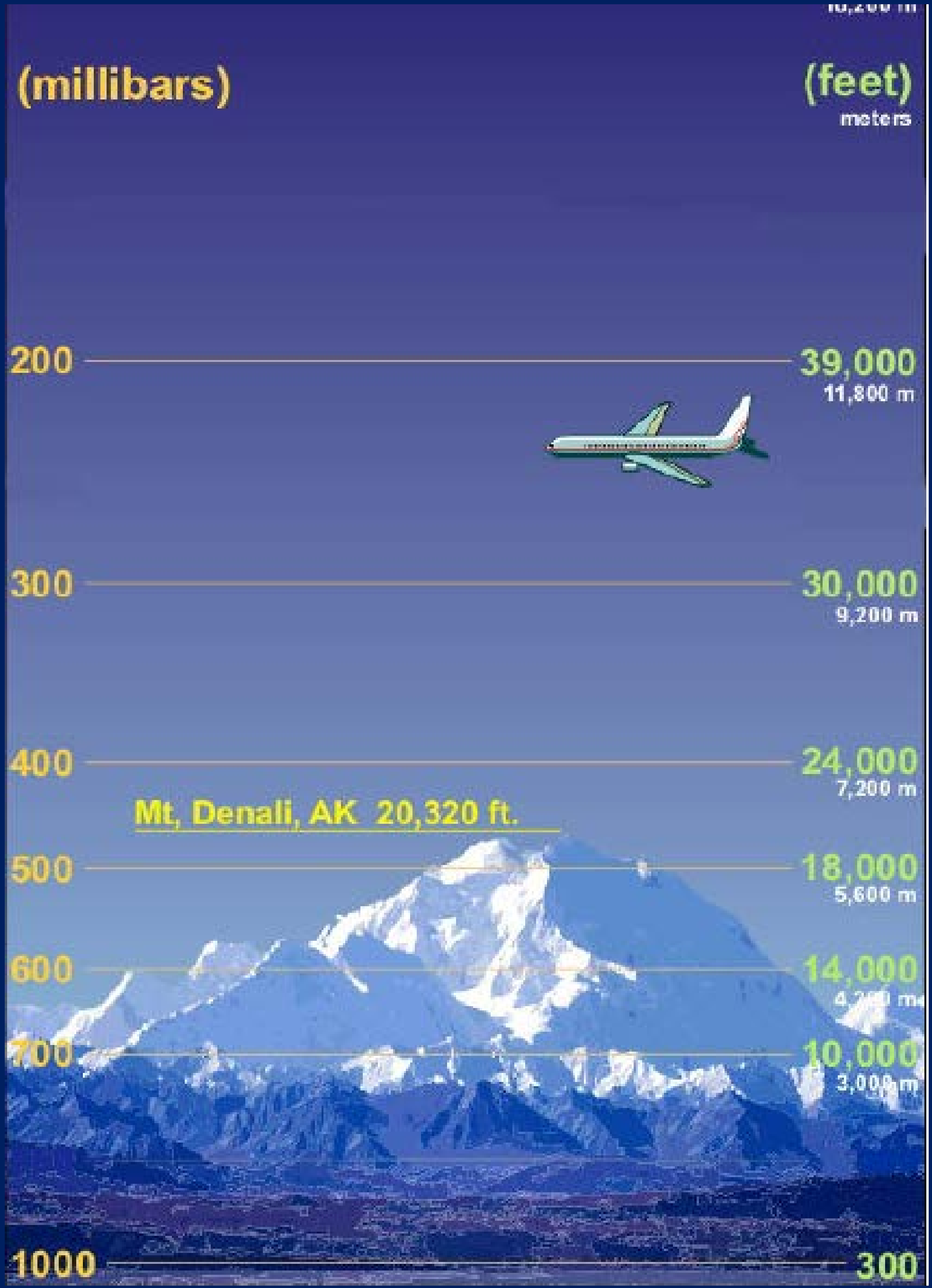


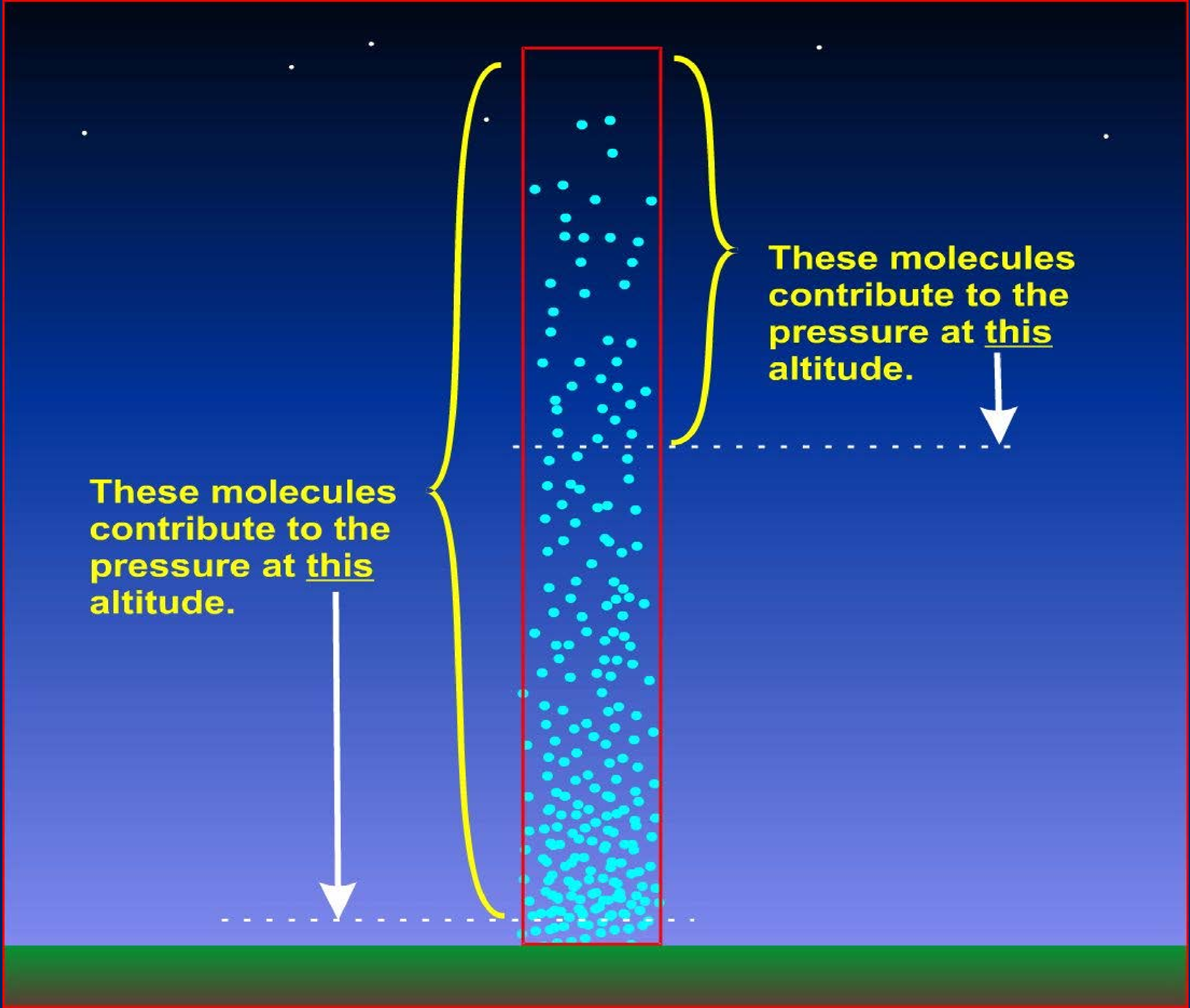
Atmospheric Pressure Units. Atmospheric pressure is expressed in many ways throughout the world. Meteorologists worldwide have long measured atmospheric pressure in millibars (mb or mbar), which denote pressure as a force per square centimeter. However, after the introduction of the International System of Units (SI) in 1960, the hectopascal (hPa) was adopted by most countries and is used in the Aviation Routine Weather Report (METAR)/Aviation Selected Special Weather Report (SPECI) code first developed in 1968. Many meteorologists prefer to use the term they learned during their education and work experience. Therefore, some continue to use the term millibars, while others use hectopascals (which are equivalent). The unit inch of mercury (inHg or Hg) is still used in the United States for altimetry.

Station Pressure. The pressure measured at an airport is called station pressure, or the actual pressure at field elevation. Pressure is lower at higher altitudes. Therefore, airports with higher field elevations usually have lower pressure than airports with lower field elevations. For instance, station pressure at Denver is less than at New Orleans

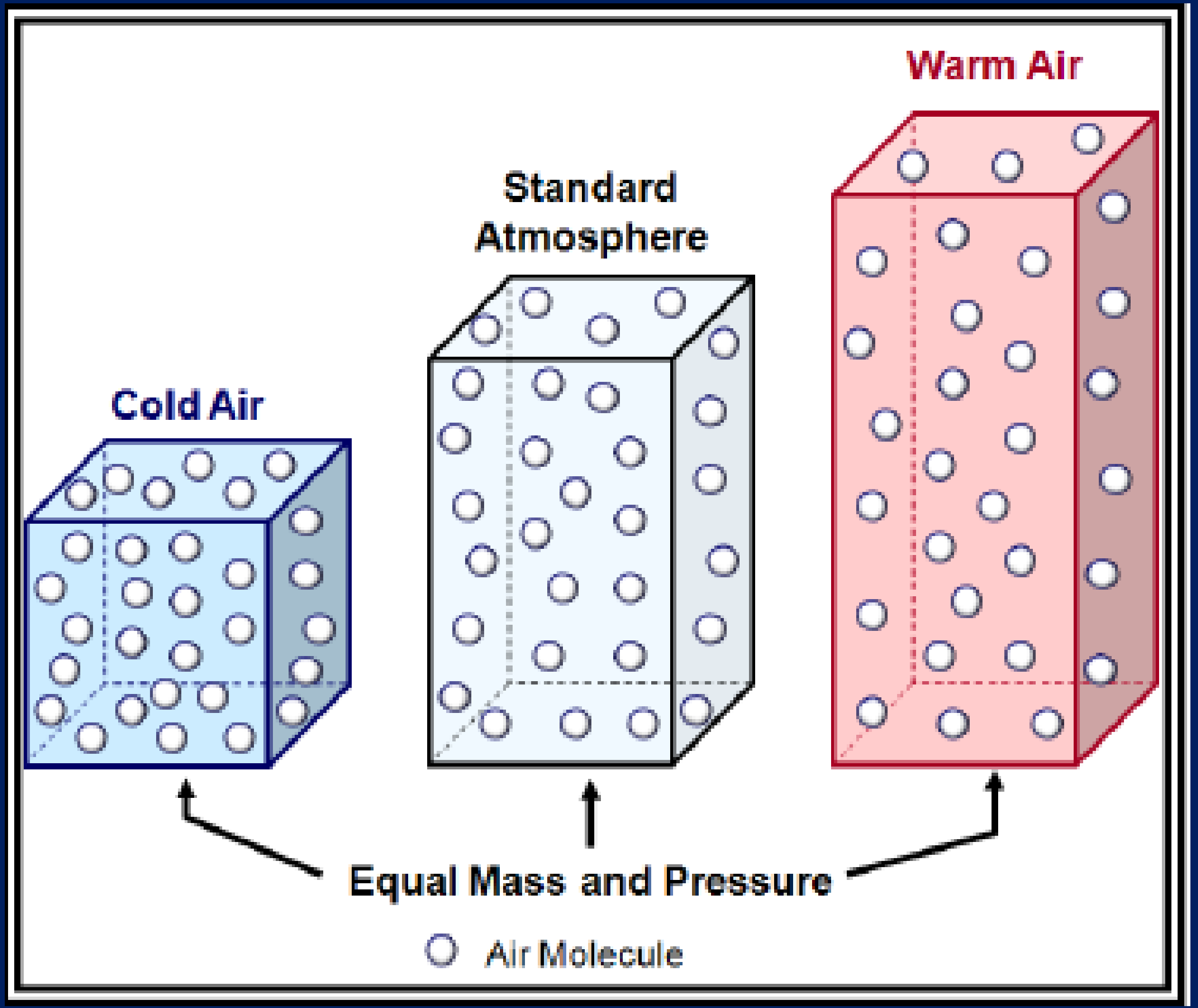


Pressure Changes with Altitude. As we move upward through the atmosphere, the weight of the air above us decreases. If we carry a barometer with us, we can measure a decrease in pressure as the weight of the air above us decreases.

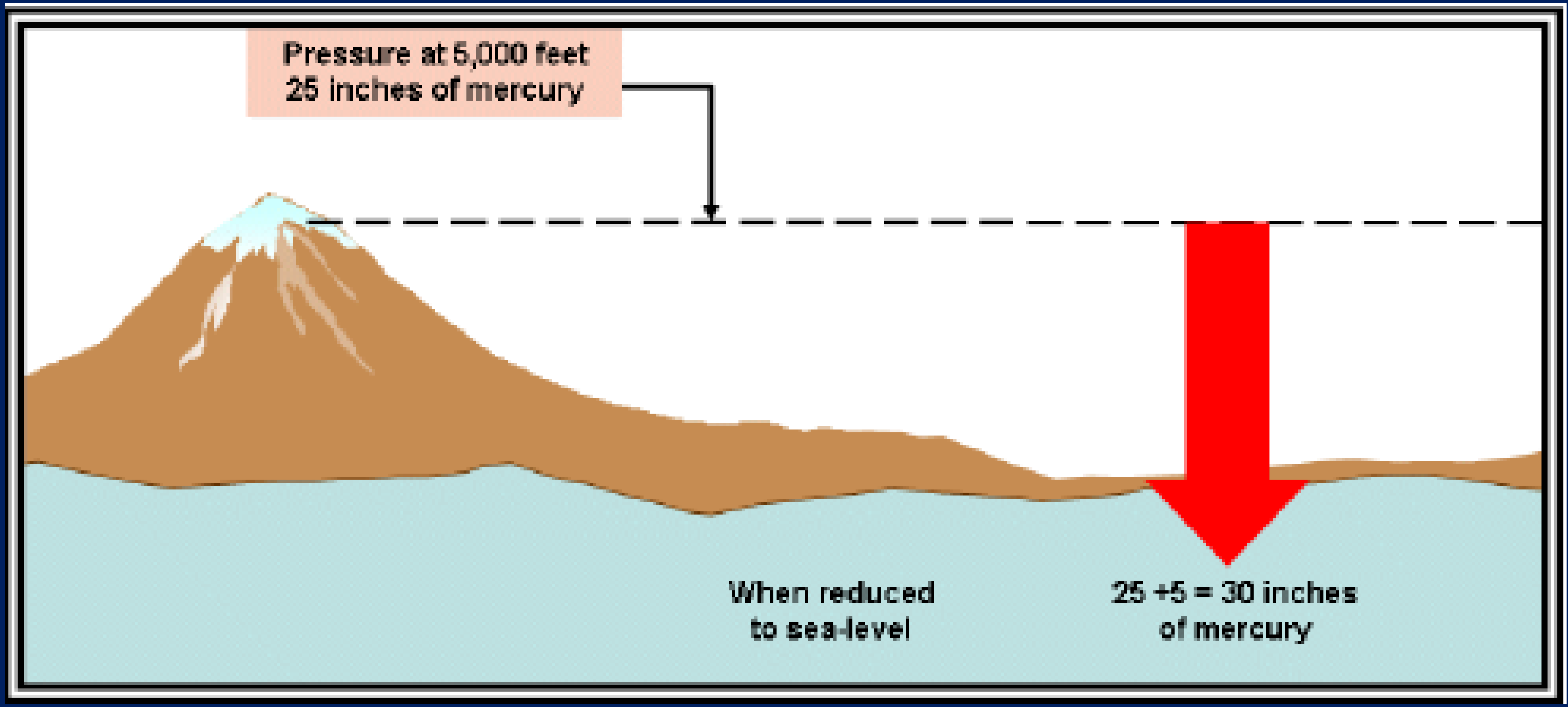



These molecules contribute to the pressure at this altitude.
These molecules contribute to the pressure at this altitude.

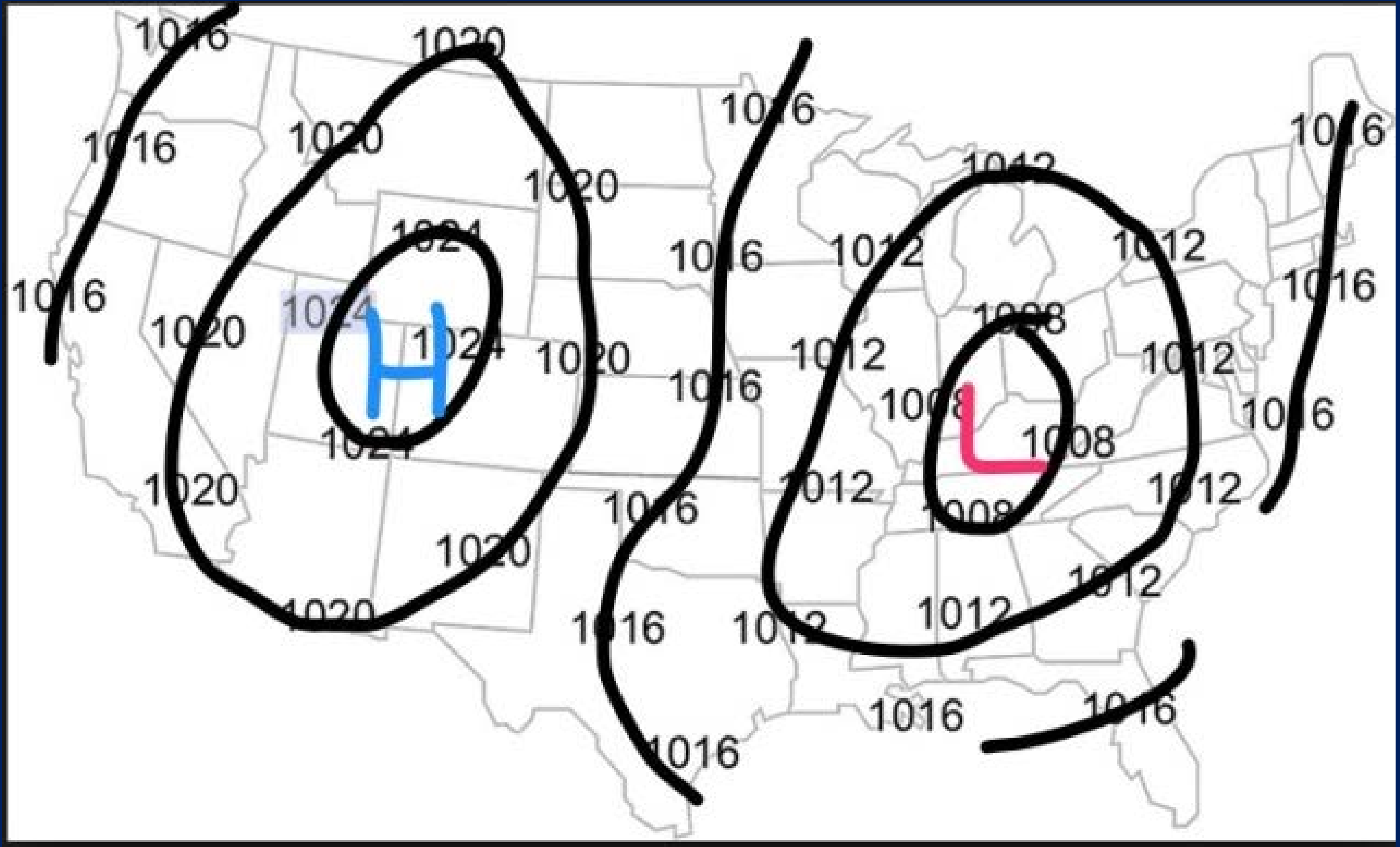
Temperature Effects on Pressure. Like most substances, air expands as it becomes warmer and contracts as it cools. Pressure is equal at the bottom and top of each column. Vertical expansion of the warm column has made it taller than the column at standard temperature. Contraction of the cold column has made it shorter than the standard column. Since the total pressure decrease is the same in each column, the rate of decrease of pressure with height in warm air is less than standard, while the rate of decrease in pressure with height in cold air is greater than standard.



Sea Level Pressure. Since pressure varies greatly with altitude, we cannot readily compare station pressures between stations at different altitudes. To make them comparable, we adjust them to some common level. Mean sea level (MSL) is the most useful common reference. In Figure 5-6 pressure measured at a station at a 5,000-foot elevation is 25 inches; pressure increases about 1 inch of mercury for each 1,000 feet, or a total of 5 inches. Sea level pressure is approximately 25 + 5, or 30 inches of mercury.

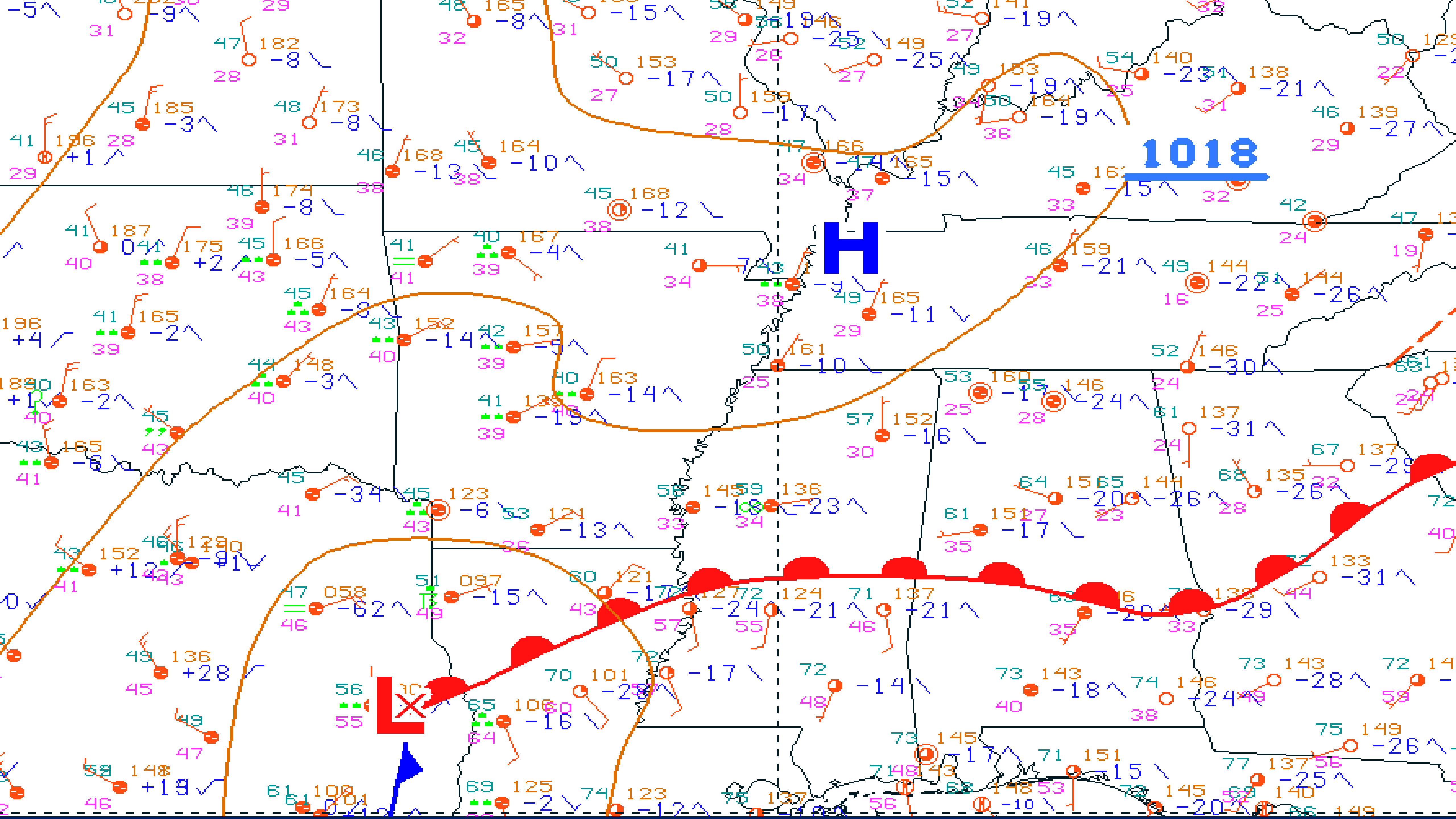


Sea level pressure is typically displayed on surface weather charts. Pressure continually changes across the Earth, so a sequence of surface charts must be viewed to follow these changing pressures.



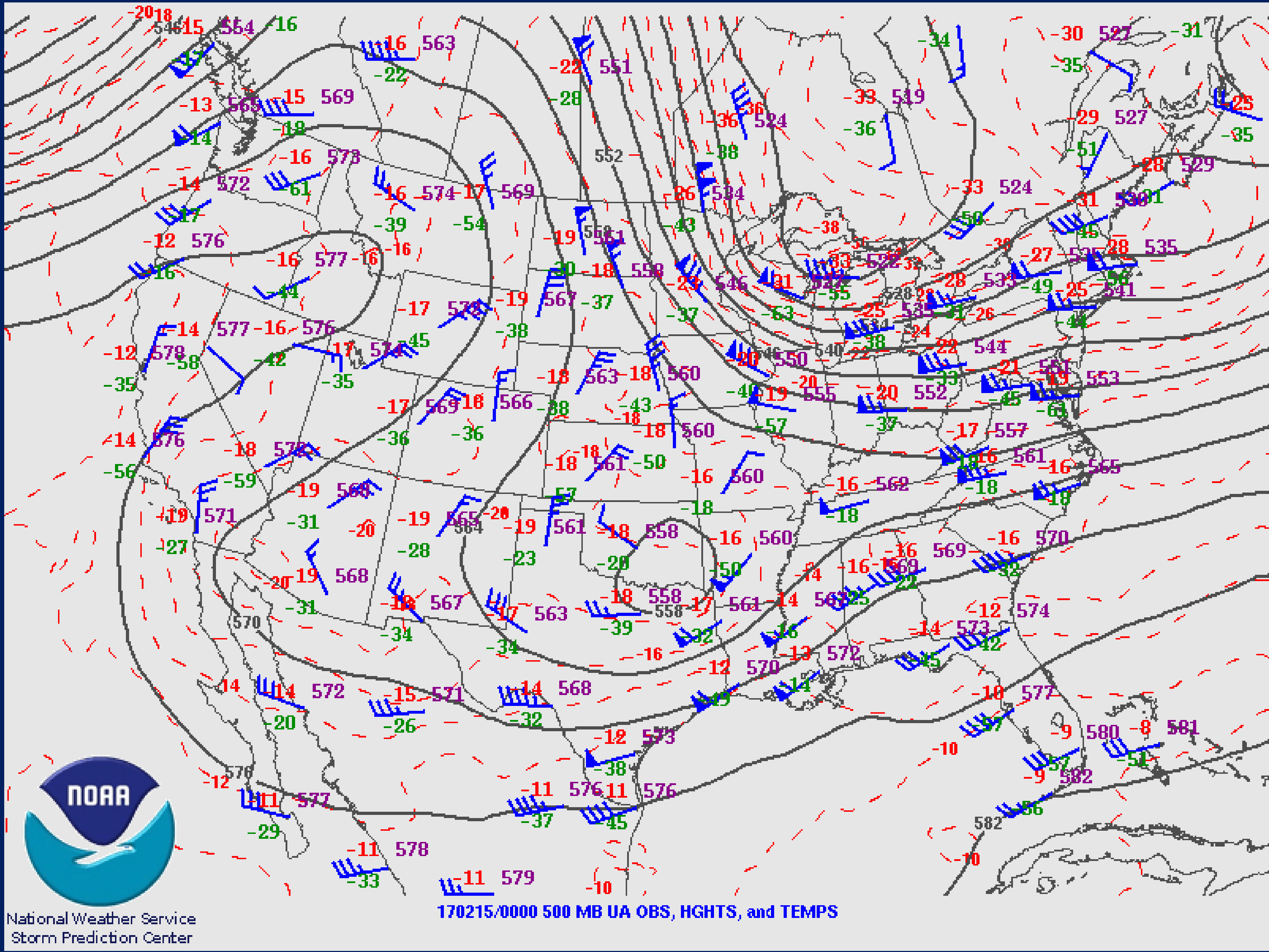
Sea Level Pressure Analyses (Surface Chart). After plotting sea level pressure on a surface chart, lines are drawn connecting points of equal sea level pressure. These lines of equal pressure are isobars. Hence, the surface chart is an isobaric analysis showing identifiable, organized pressure patterns. Four pressure systems are commonly identified: low, high, trough and ridge

Pressure System	Symbol	Definition
Low	L	A minimum of atmospheric pressure in two dimensions (closed isobars) on a surface chart, or a minimum of height (closed contours) on a constant pressure chart. Also known as a cyclone.
High	H	A maximum of atmospheric pressure in two dimensions (closed isobars) on a surface chart, or a maximum of height (closed contours) on a constant pressure chart. Also known as an anticyclone.
Trough		An elongated area of relatively low atmospheric pressure.
Ridge		An elongated area of relatively high atmospheric pressure.


1018
H
L

Rawinsonde Observations. The National Weather Service (NWS) takes routine scheduled upper air observations, usually referred to as soundings. A balloon carries a rawinsonde instrument, which consists of radio gear and sensing elements. While in flight, the rawinsonde transmits pressure, temperature, and relative humidity data. Wind speed and direction aloft are obtained by tracking the position of the radiosonde in flight using Global Positioning Satellites (GPS). Most stations around the world take rawinsonde observations. However, meteorologists and other data users frequently refer to a rawinsonde observation as a radiosonde observation.

Constant Pressure Surface Analysis (Upper Air Chart). These heights measured by the rawinsonde (and other types of instruments) are plotted on a constant pressure chart and analyzed by drawing a line connecting points of equal height. These lines are called height contours



A contour analysis shows highs, ridges, lows, and troughs aloft just as the isobaric analysis shows such systems at the surface. These systems of highs/ridges and lows/troughs are called pressure waves. These pressure waves are very similar to waves seen on bodies of water. They have crests (ridges) and valleys (troughs) and are in constant movement

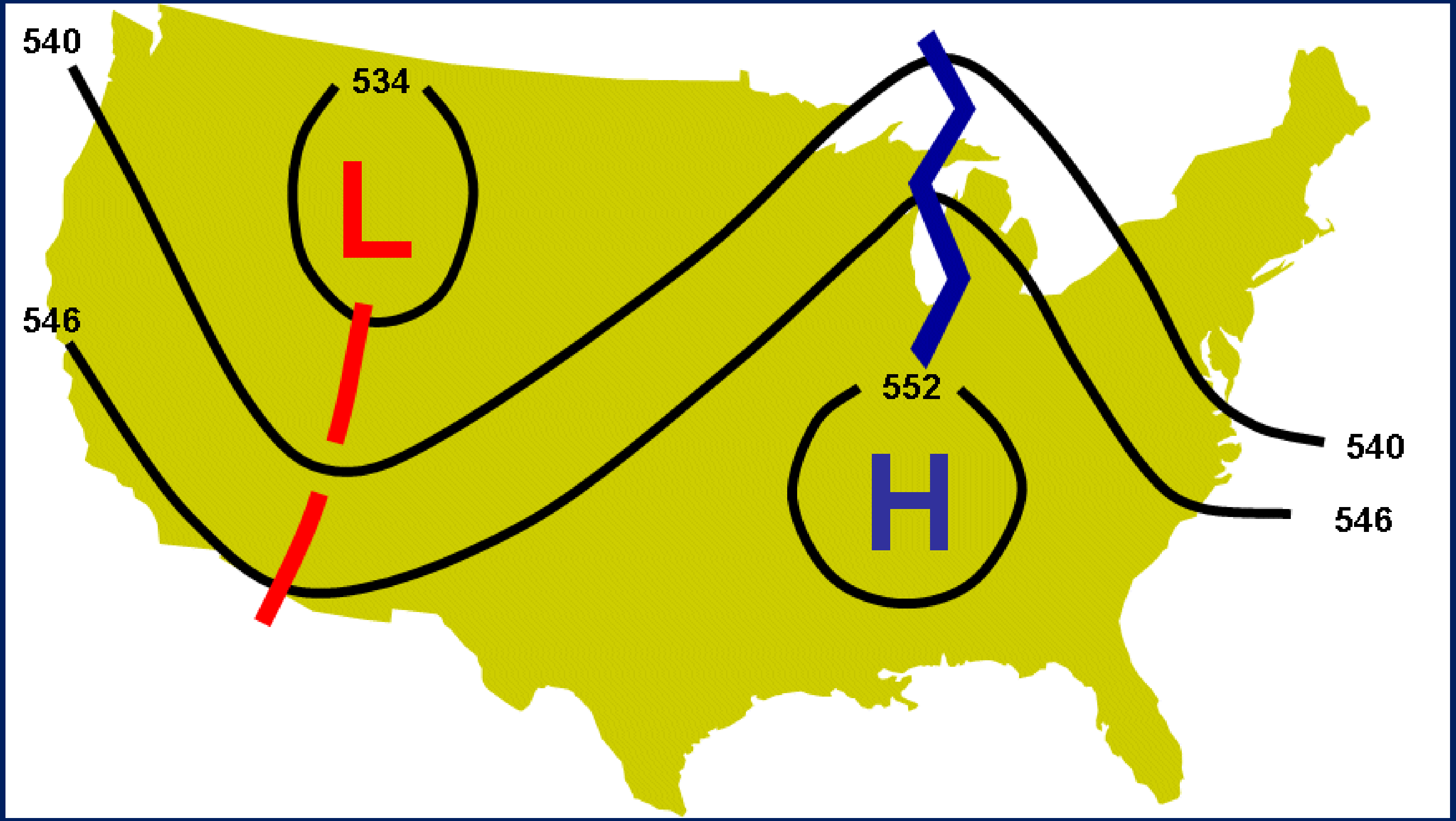
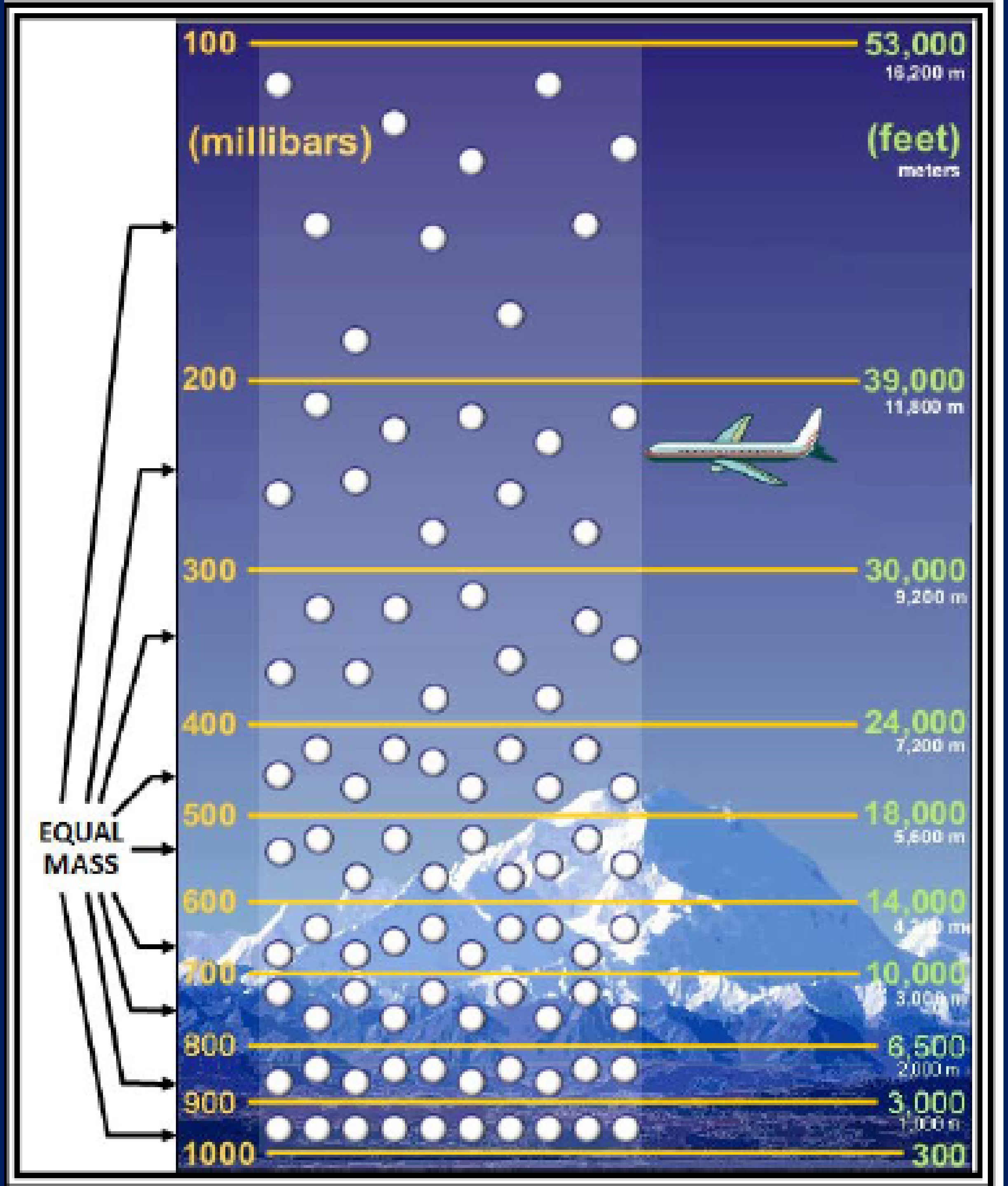


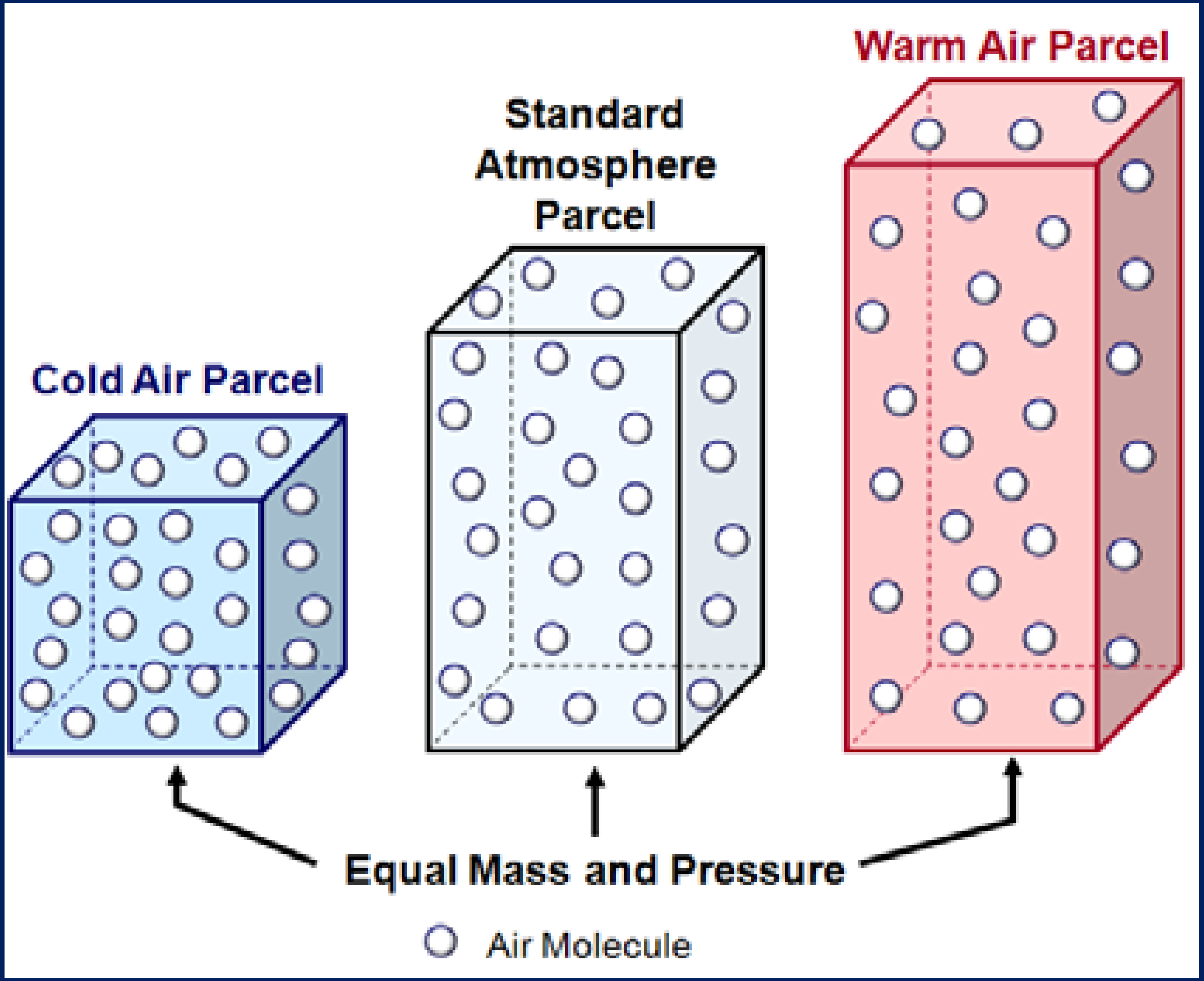
Chart	Pressure Altitude (approximate)	
	Feet (ft)	Meters (m)
100 mb	53,000 ft	16,000 m
150 mb	45,000 ft	13,500 m
200 mb	39,000 ft	12,000 m
250 mb	34,000 ft	10,500 m
300 mb	30,000 ft	9,000 m
500 mb	18,000 ft	5,500 m
700 mb	10,000 ft	3,000 m
850 mb	5,000 ft	1,500 m
925 mb	2,500 ft	750 m

Density Effects on Pressure. Density is directly related to pressure. Assuming constant mass and temperature, an air parcel with a higher pressure is denser than an air parcel with a lower pressure.

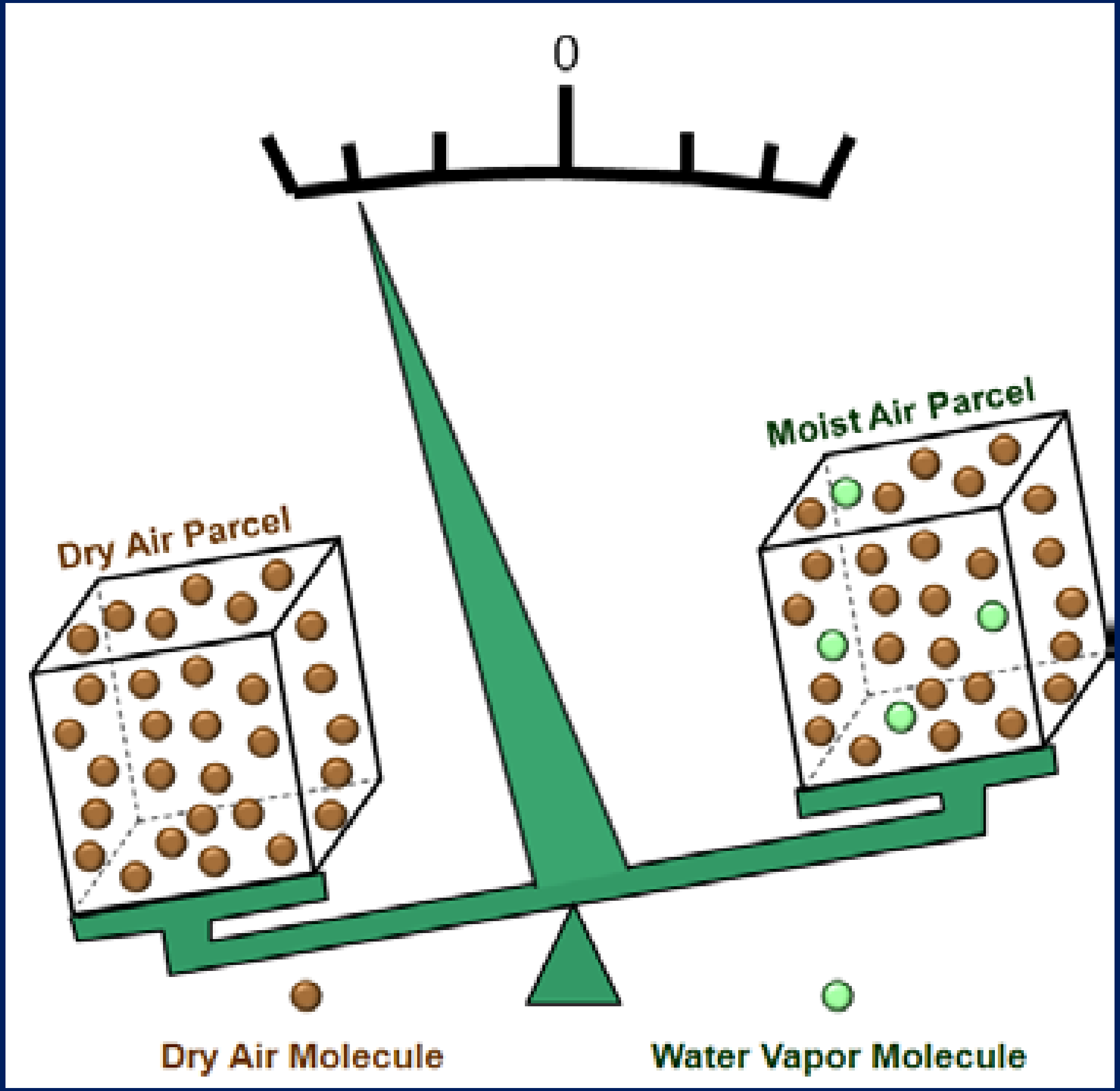
As we have already seen, air pressure decreases with height in the atmosphere. Therefore, the density also decreases with height. In the atmosphere, pressure has the greatest effect on density in the vertical direction.

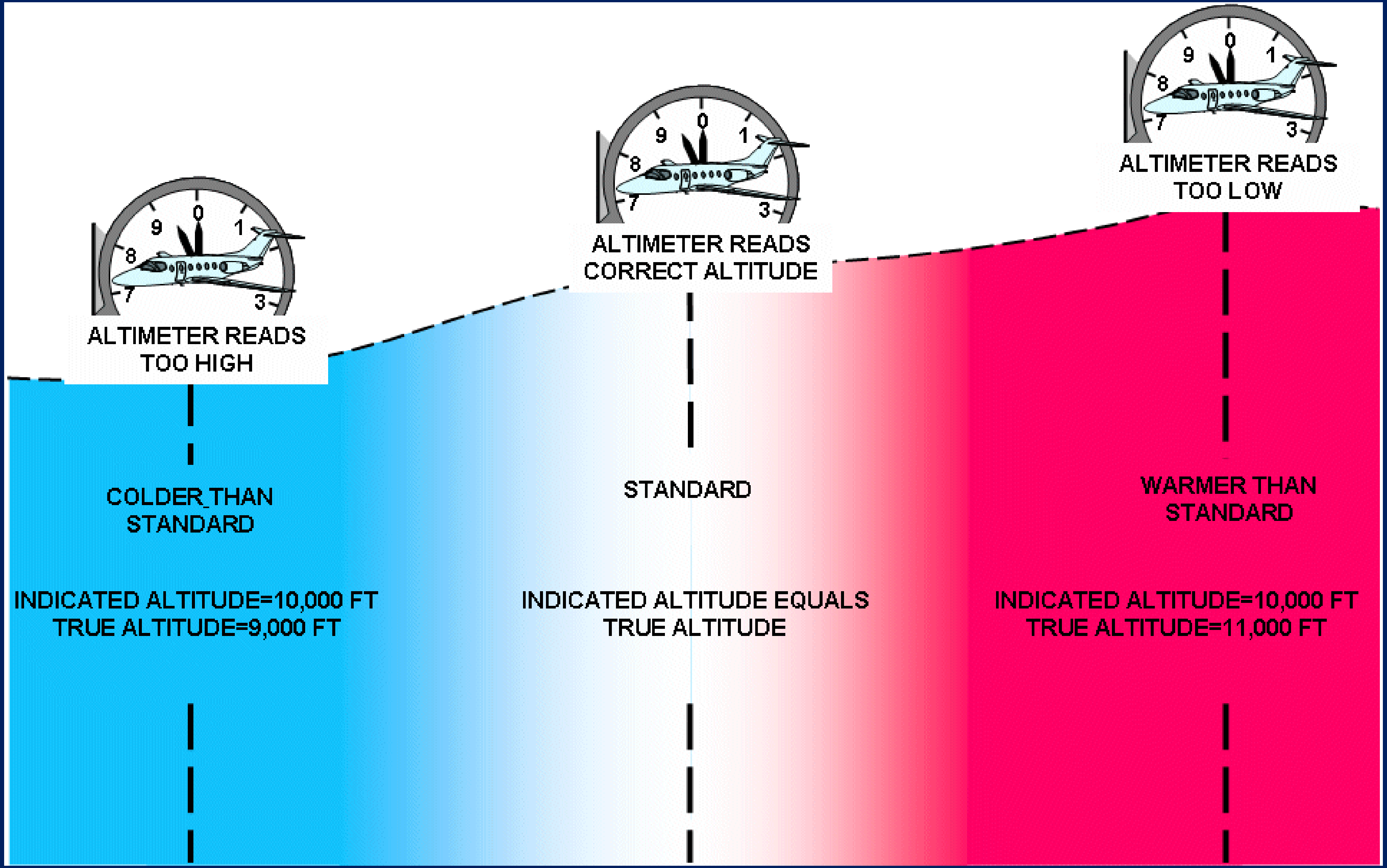


Temperature Effects on Density. Density is inversely related to temperature. Assuming constant mass and pressure, an air parcel with a higher temperature is less dense than an air parcel with a lower temperature. This is because the warmer air occupies a large volume.



Water Vapor Effects on Density. Density of an air parcel is inversely related to its quantity of water vapor. Assuming constant pressure, temperature, and volume, air with a greater amount of water vapor is less dense than air with a lesser amount of water vapor. This is because dry air molecules have a larger mass (weight) than water vapor molecules, and density is directly related to mass




ALTIMETER READS TOO HIGH
ALTIMETER READS CORRECT ALTITUDE
ALTIMETER READS TOO LOW
COLDER THAN STANDARD
STANDARD
WARMER THAN STANDARD
INDICATED ALTITUDE=10,000 FT
TRUE ALTITUDE=9,000 FT
INDICATED ALTITUDE EQUALS TRUE ALTITUDE
INDICATED ALTITUDE=10,000 FT
TRUE ALTITUDE=11,000 FT

Density altitude is an index to aircraft performance. Higher (lower) density altitude decreases (increases) performance. High density altitude is a hazard since it reduces aircraft performance in the following three ways:

1. It reduces power because the engine takes in less air to support combustion.

2. It reduces thrust because there is less air for the propeller to work with, or a jet has less mass of gases to force out of the exhaust.

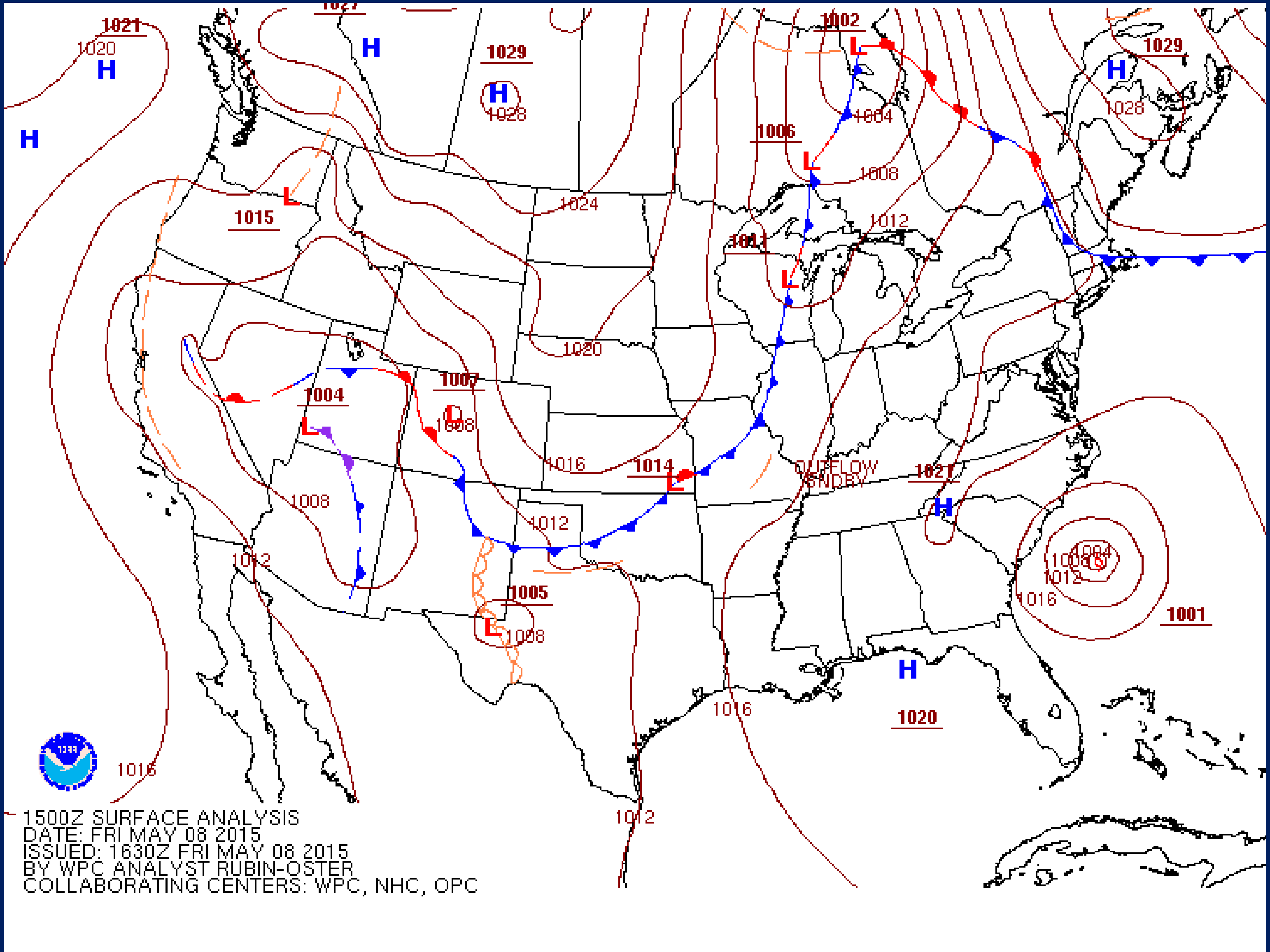
3. It reduces lift because the light air exerts less force on the airfoils.

WEATHER CHARTS

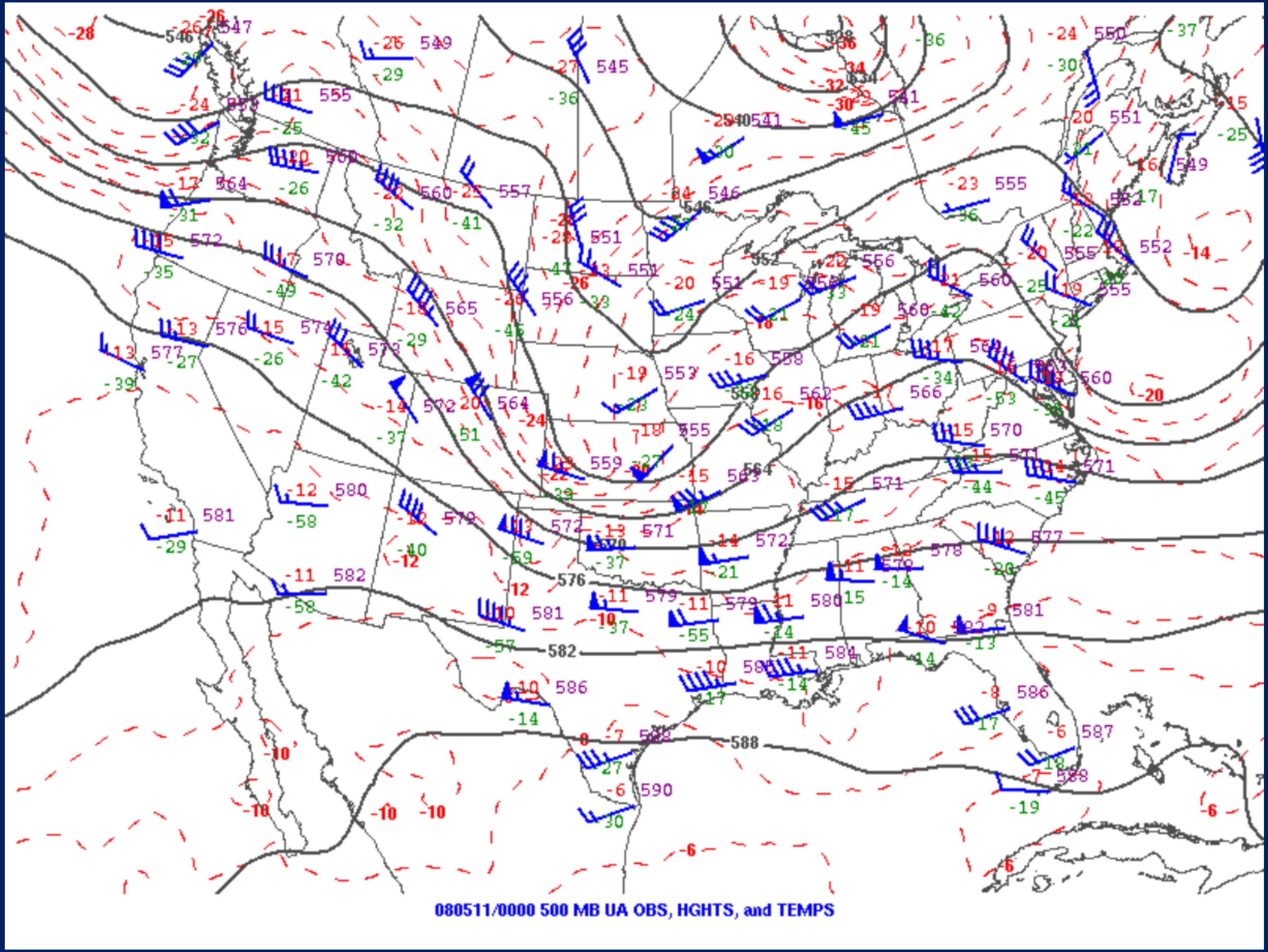
A weather chart is a map on which data and analyses are presented that describe the state of the atmosphere over a large area at a given moment in time.
The possible variety of such charts is enormous, but in meteorological history there has been a more or less standard set of charts, including surface charts and the constant pressure charts of the upper atmosphere. Because weather systems are three-dimensional (3-D), both surface and upper air charts are needed. Surface weather charts depict weather on a constant-altitude (usually sea level) surface, while upper air charts depict weather on constant-pressure surfaces.

Analysis is the drawing and interpretation of the patterns of various elements on a weather chart. It is an essential part of the forecast process. If meteorologists do not know what is currently occurring, it is nearly impossible to predict what will happen in the future. Computers have been able to analyze weather charts for many years and are commonly used in the process. However, computers cannot interpret what they analyze. Thus, many meteorologists still perform a subjective analysis of weather charts when needed.

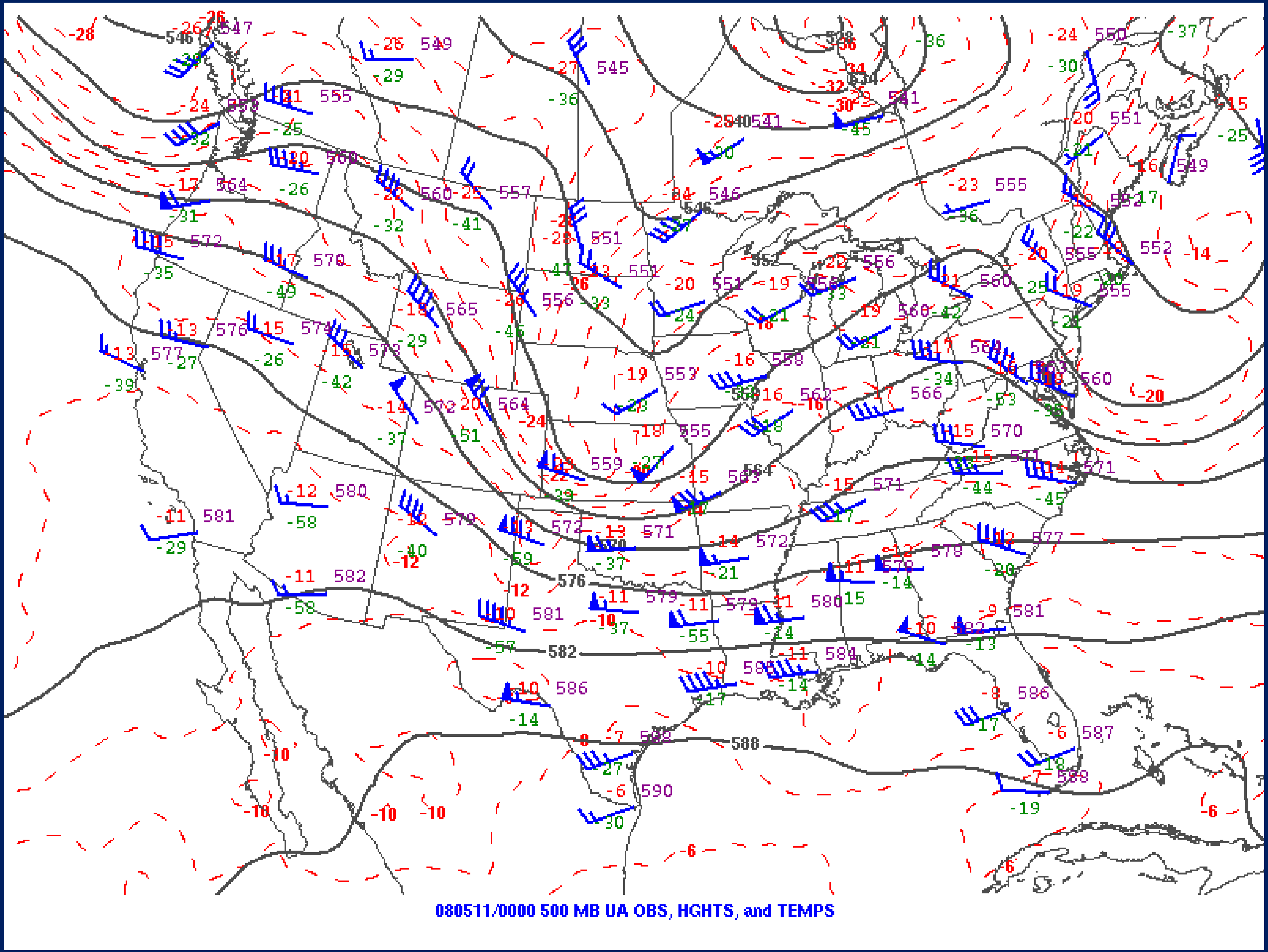
A surface chart (also called surface map or sea level pressure chart) is an analyzed chart of surface weather observations. Essentially, a surface chart shows the distribution of sea level pressure, including the positions of highs, lows, ridges, and troughs, and the location and character of fronts and various boundaries, such as drylines, outflow boundaries, and sea breeze fronts. Although the pressure is referred to as MSL, all other elements on this chart are presented as they occur at the surface point of observation. A chart in this general form is the one commonly referred to as the weather map.



A constant pressure chart (also called an isobaric chart) is a weather map representing conditions on a surface of equal atmospheric pressure. For example, a 500 millibar chart will display conditions at the level of the atmosphere at which the atmospheric pressure is 500 millibars. Constant pressure charts usually contain plotted data and analyses of the distribution of height of the surface (contours), wind (isotachs), temperature (isotherms), and sometimes humidity (isohumes). The height above sea level at which the pressure is that particular value may vary from one location to another at any given time, and also varies with time at any one location, so it does not represent a surface of constant altitude/height

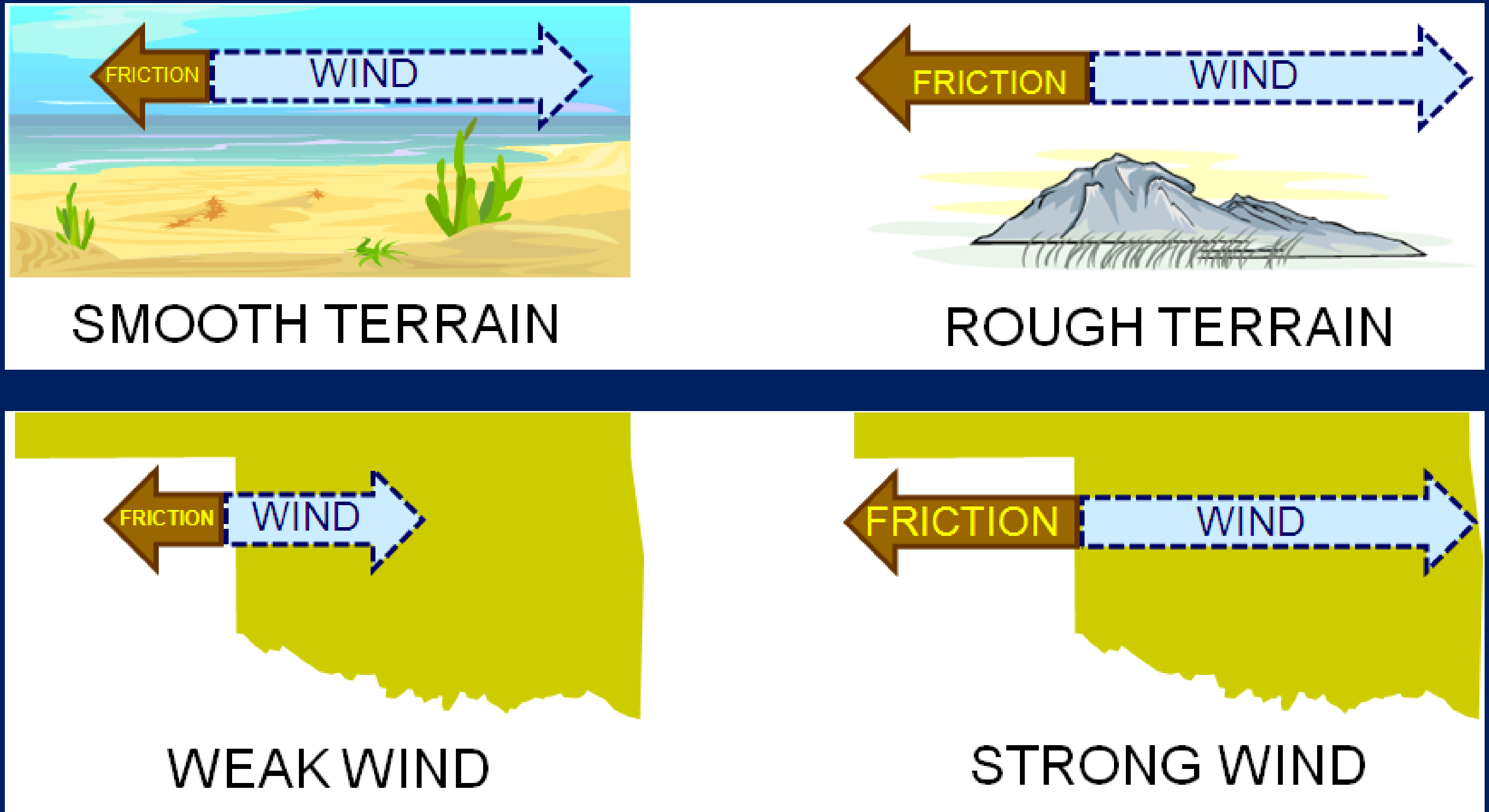


A contour analysis can reveal highs, ridges, lows, and troughs aloft just as the surface chart shows such systems at the surface. These systems of highs/ridges and lows/troughs are called pressure waves. These pressure waves are similar to waves seen on bodies of water. They have crests (ridges) and valleys (troughs).



Friction Force. Friction between the wind and the terrain surface slows the wind. The rougher the terrain, the greater the frictional effect. Also, the stronger the wind speed, the greater the friction. One may not think of friction as a force, but it is a very real and effective force always acting opposite to wind direction.

Friction between the wind and the terrain surface slows the wind. The rougher the terrain, the greater the frictional effect. Also, the stronger the wind speed, the greater the friction. One may not think of friction as a force, but it is a very real and effective force always acting opposite to wind direction.



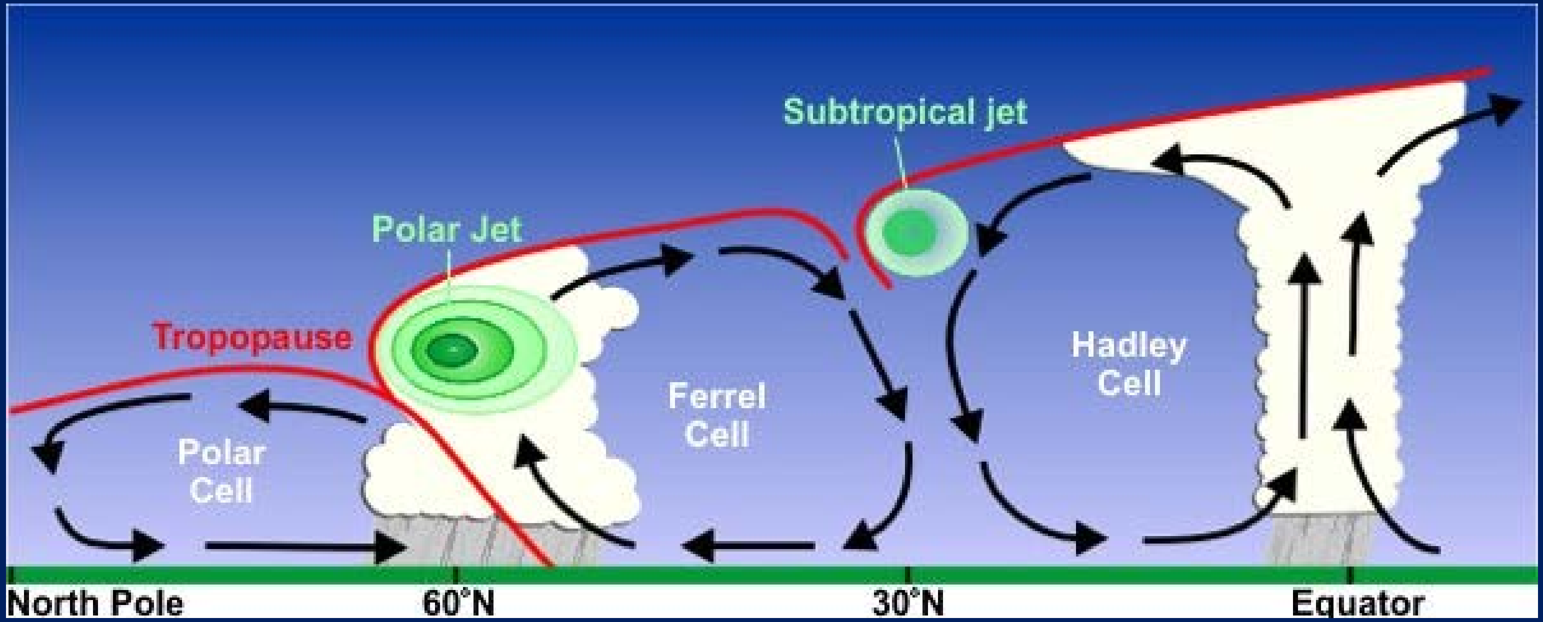
The frictional drag of the ground normally decreases with height and becomes insignificant above the lowest few thousand feet. However, this may vary somewhat since both strong winds and rough terrain extend the friction layer to higher altitudes.

The angle of surface wind to isobars is about 10° over water, increasing to as high as 45° over rugged terrain. The end result is, in the Northern Hemisphere, the surface wind spirals clockwise and outward from high pressure, and counterclockwise and inward into low pressure. In mountainous regions, one often has difficulty relating surface wind to pressure gradient because of immense friction, and also because of local terrain effects on pressure.

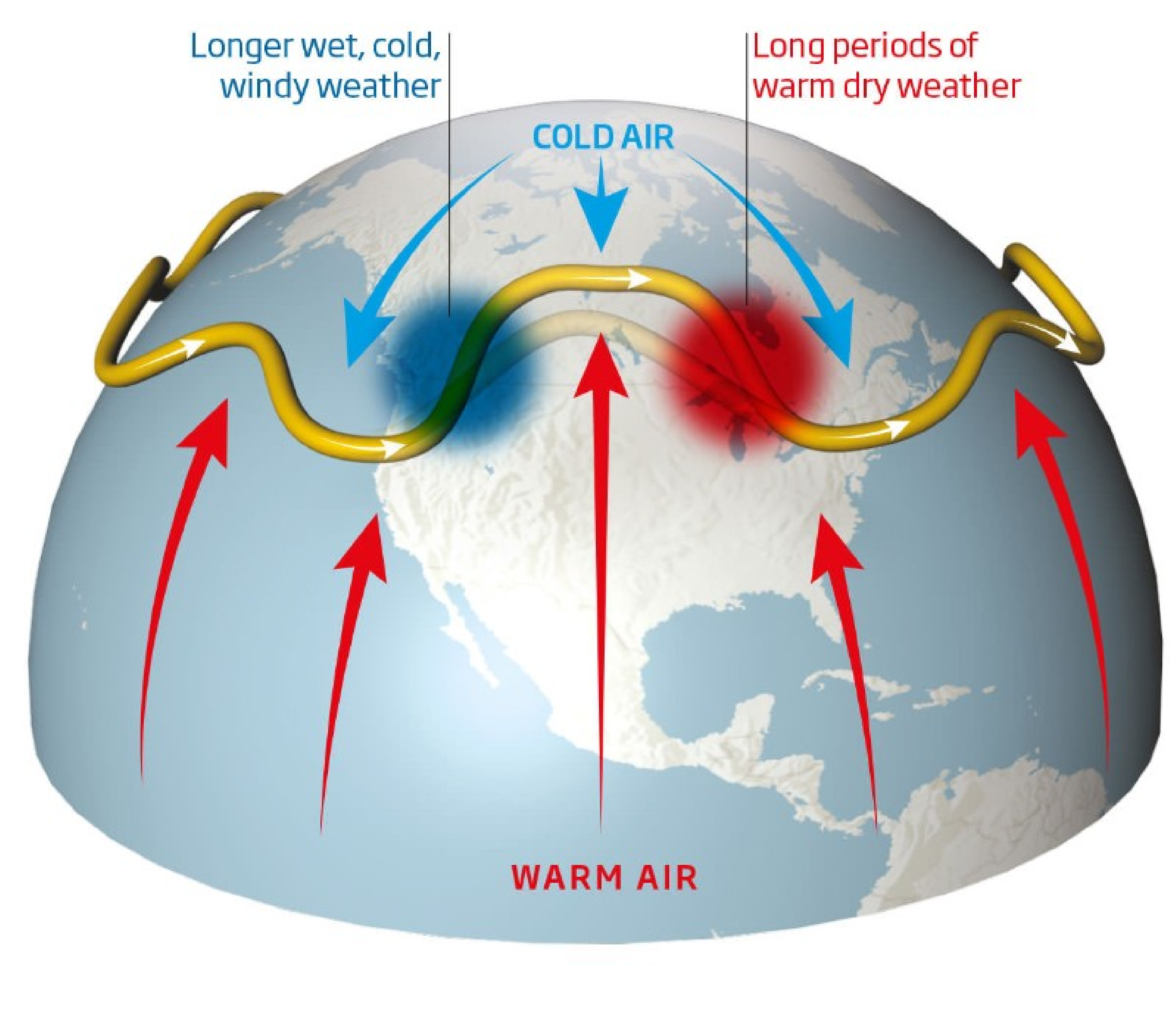
Jet Streams.

Jet streams are relatively narrow bands of strong wind in the upper levels of the atmosphere. The winds blow from west to east in jet streams, but the flow often meanders southward and northward in waves.

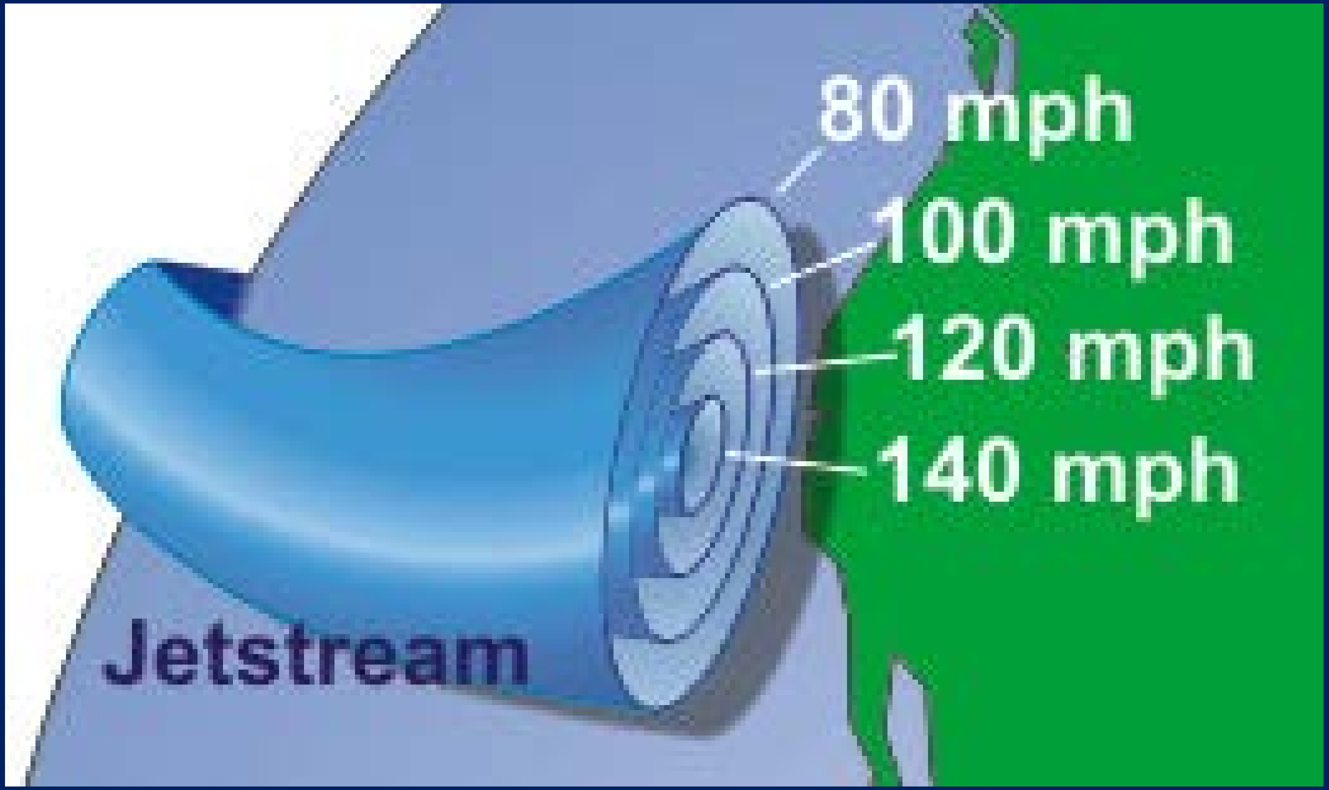
Jet streams follow the boundaries between hot and cold air. Since these hot and cold air boundaries are most pronounced in winter, jet streams are the strongest for both the Northern and Southern Hemisphere winters.



The actual appearance of jet streams results from the complex interaction between many variables, such as the location of high and low pressure systems, warm and cold air, and seasonal changes. They meander around the globe, dipping and rising in altitude/latitude, splitting at times and forming eddies, and even disappearing altogether to appear somewhere else.

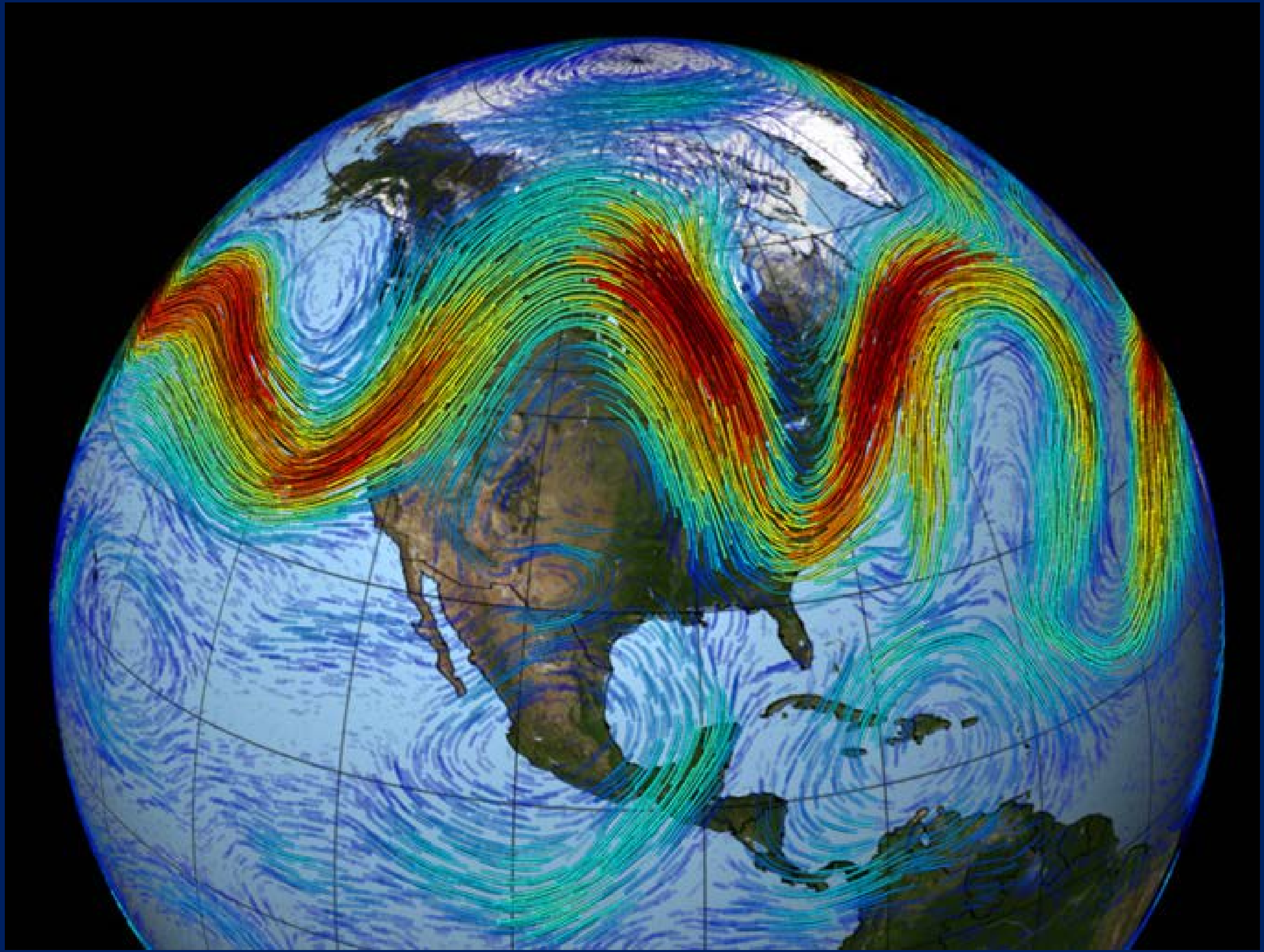


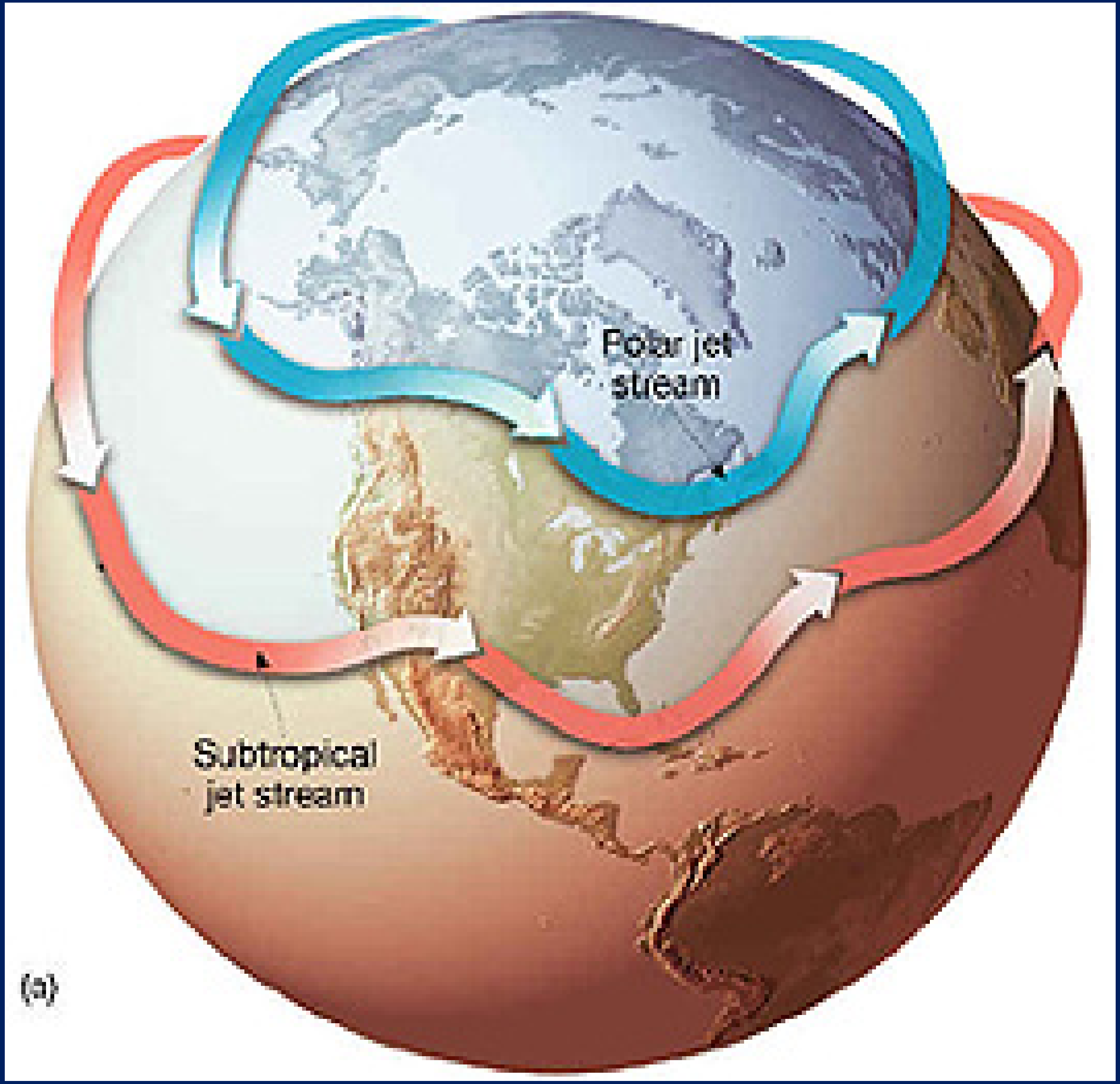
Jet streams also follow the sun, in that as the sun's elevation increases each day in the spring, the jet streams shift north moving into Canada by summer. As autumn approaches and the sun's elevation decreases, the jet stream moves south into the United States, helping to bring cooler air to the country.

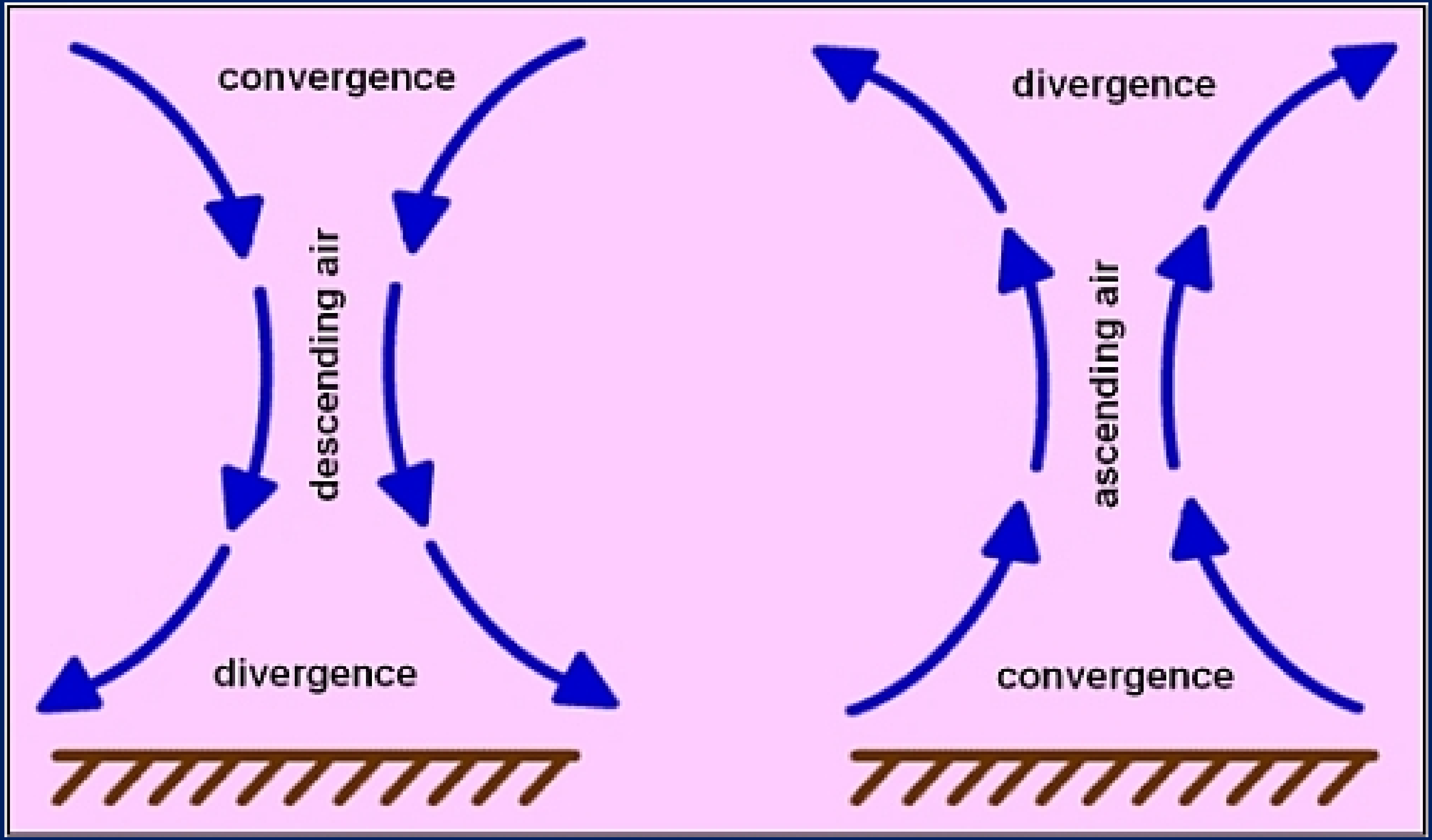


Also, the jet stream is often indicated by a line on maps, and shown by television meteorologists. The line generally points to the location of the strongest wind. In reality, jet streams are typically much wider. They are less a distinct location, and more a region where winds increase toward a core of highest speed.

One way of visualizing this is to consider a river. The river's current is generally the strongest in the center, with decreasing strength as one approaches the river's bank. It can be said that jet streams are rivers of air.

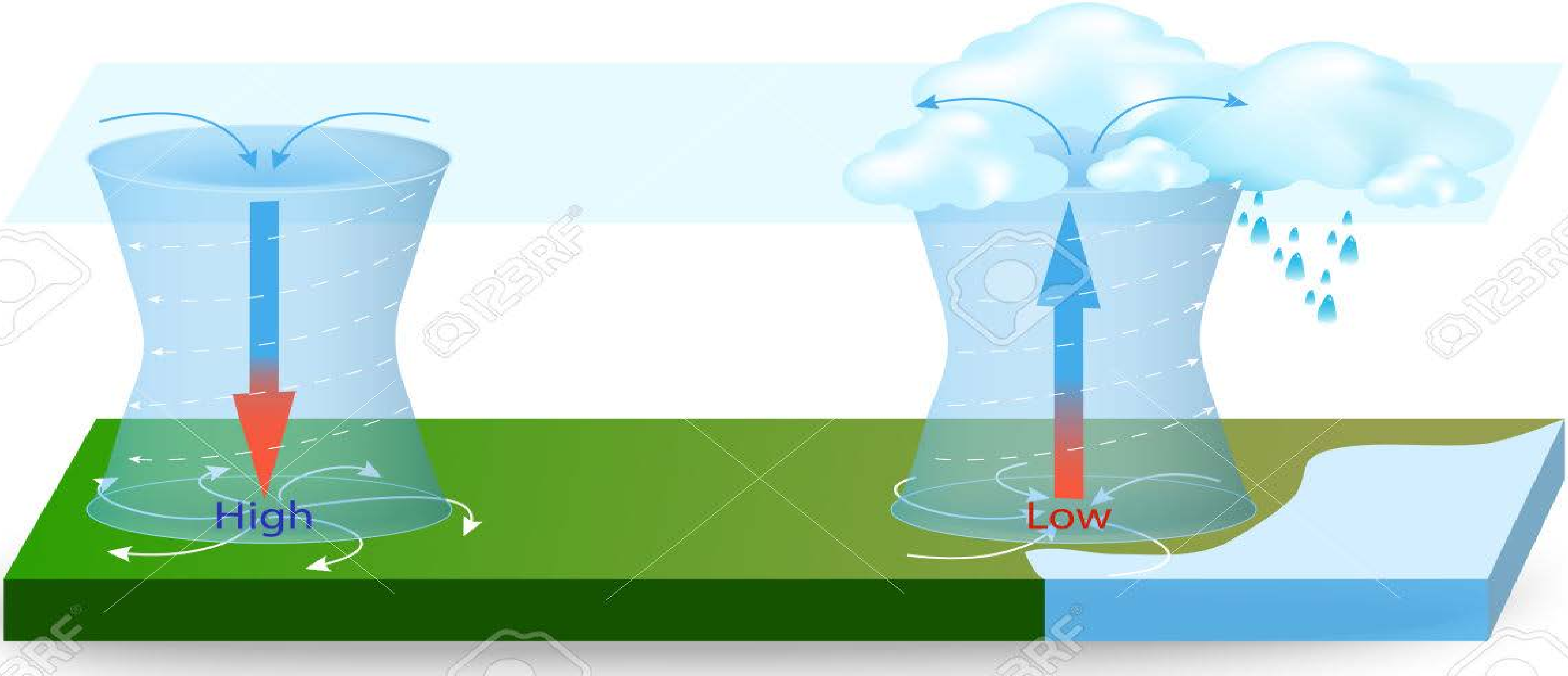



Polar jet
stream
Subtropical
jet stream
(a)

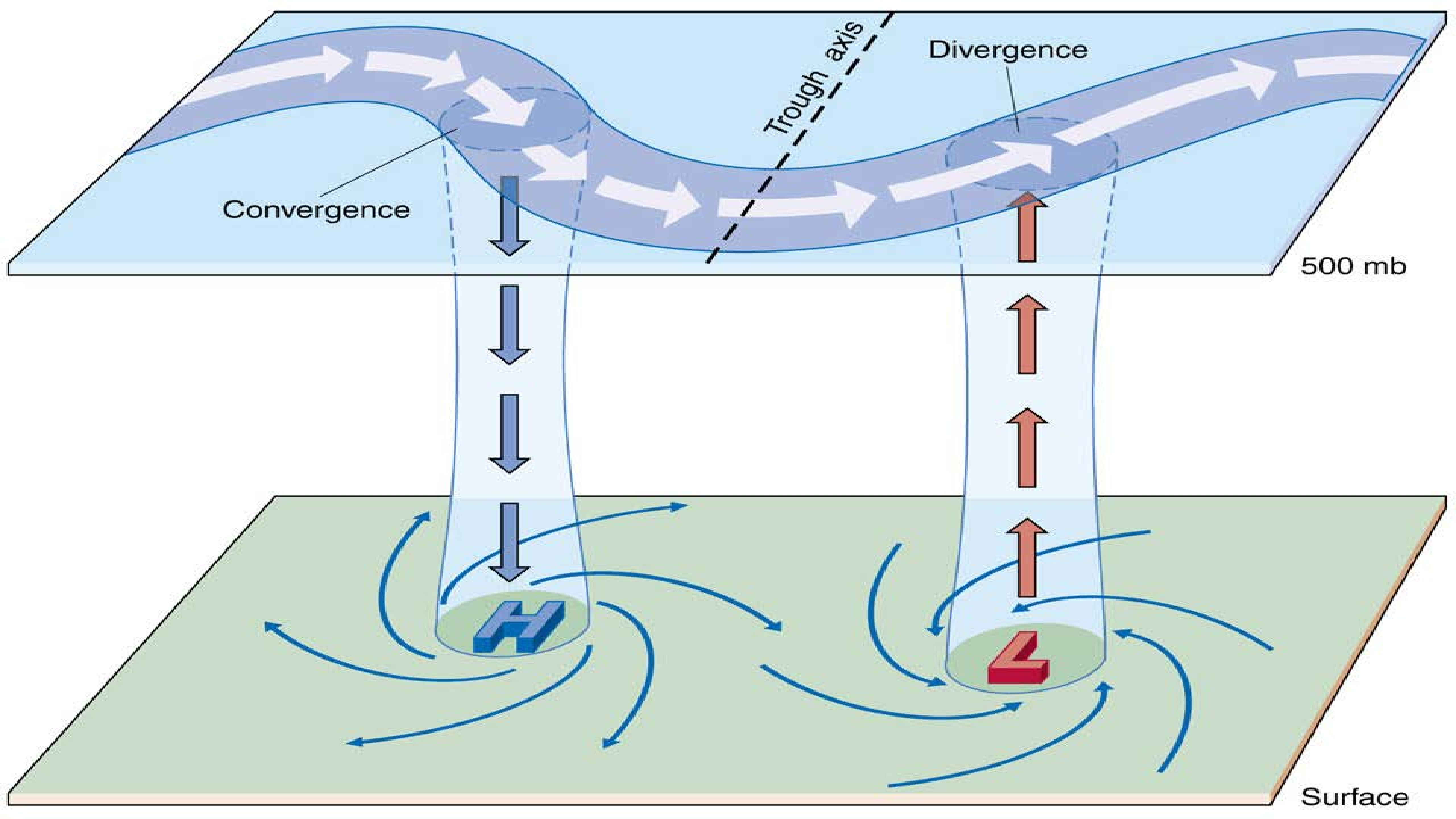


convergence
descending air
divergence
divergence
ascending air
convergence

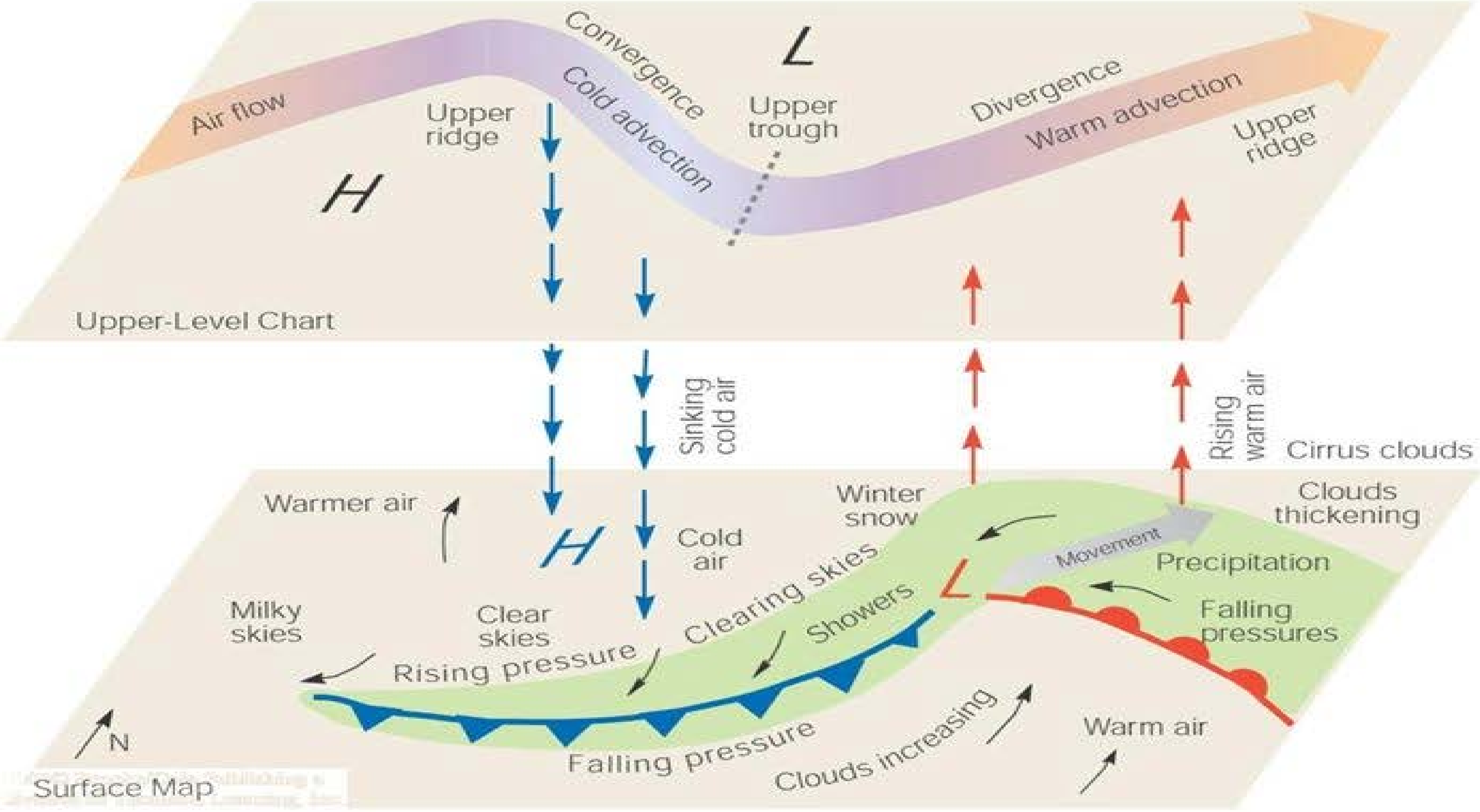
CYCLONES AND ANTICYCLONES



Anticyclones **Cyclones**


Trough axis
Divergence
Convergence
500 mb
Surface
H
L

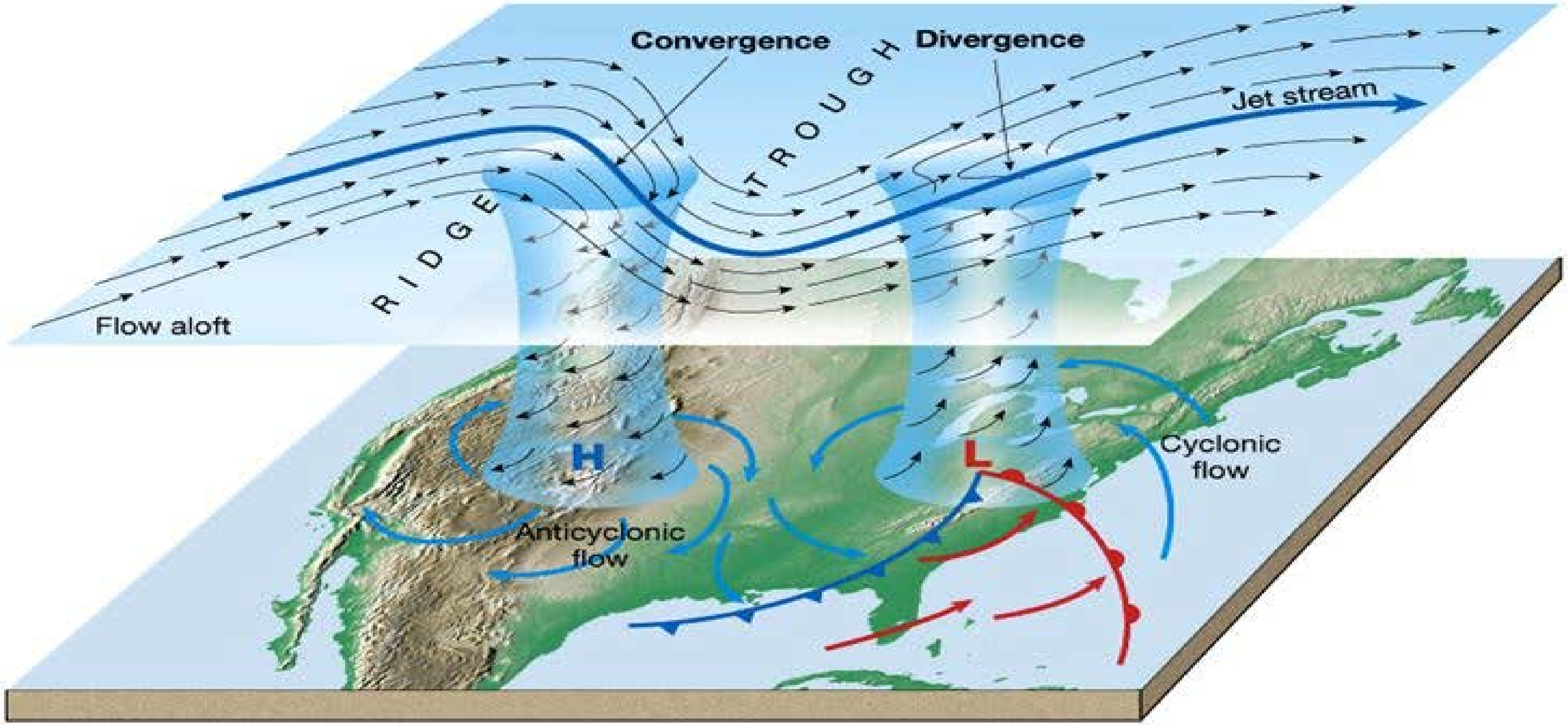
Summary of Cyclone Weather



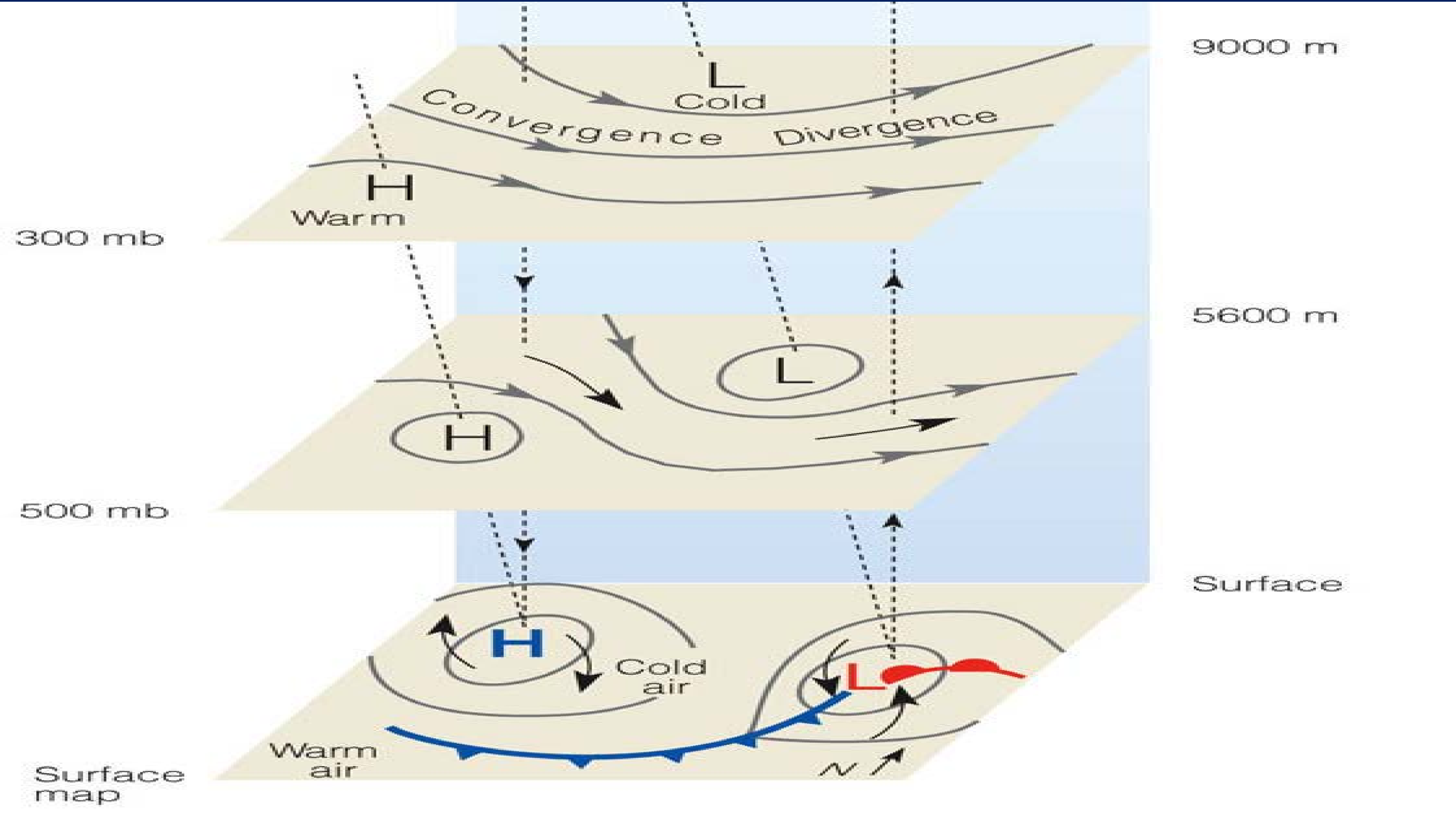
Roles of convergence and divergence aloft

Pattern of clouds, precipitation, and temperatures on the ground

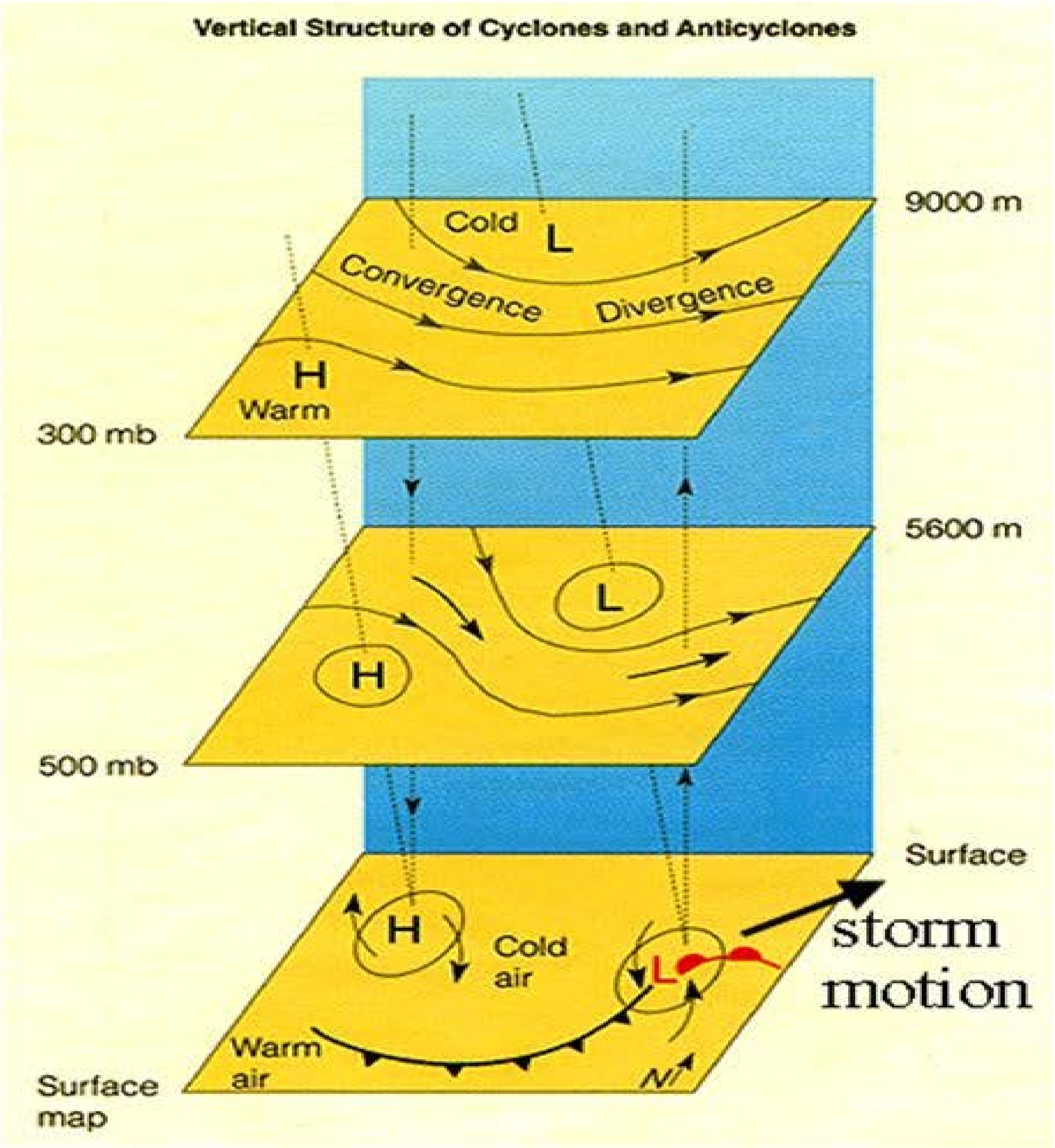
3-D view of atmospheric wave

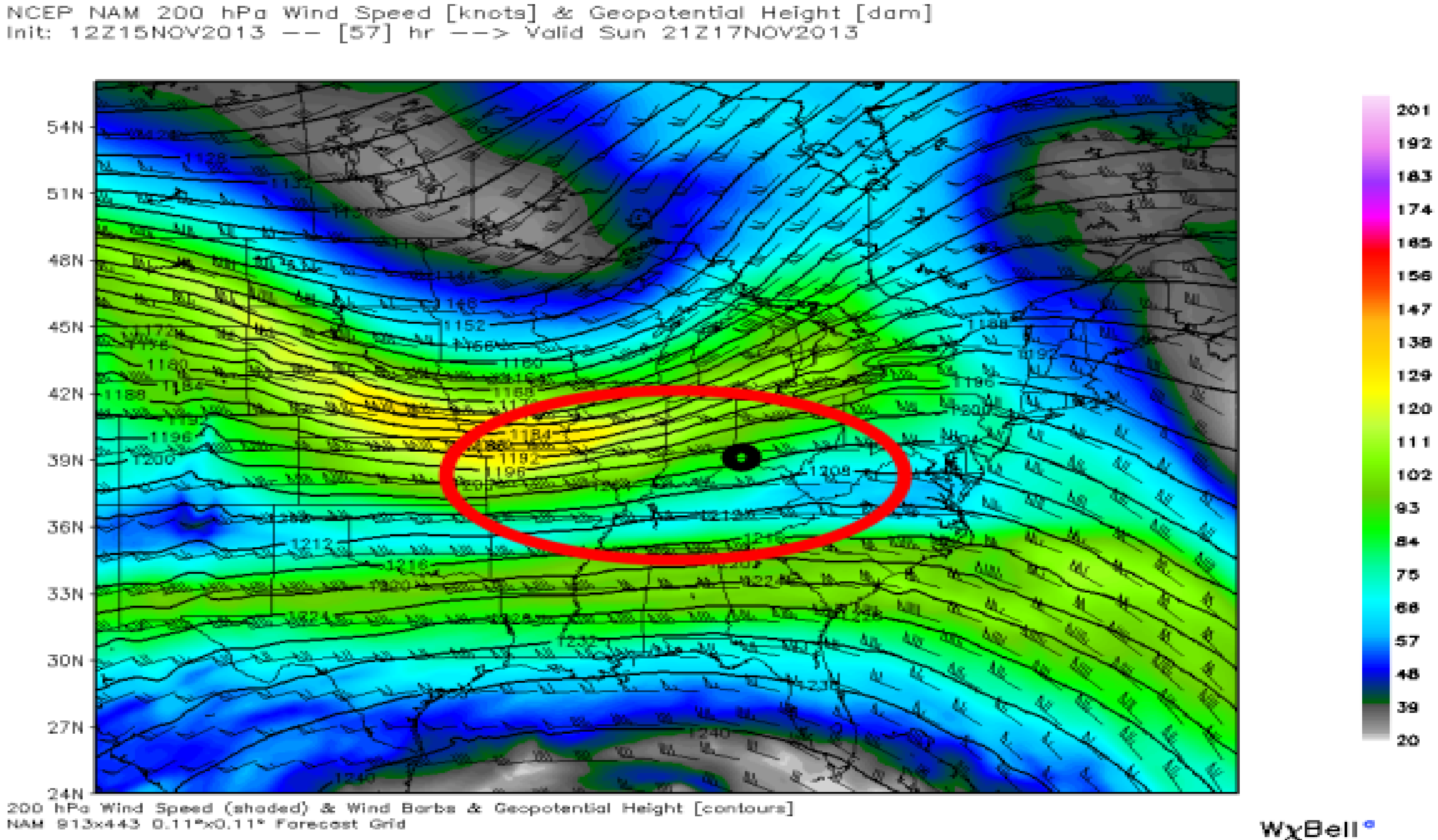


Idealized depiction of the support that convergence and divergence aloft provide to anticyclonic and cyclonic circulation at the surface.


9000 m
L
Cold
Convergence
Divergence
H
Warm
300 mb
5600 m
L
H
500 mb
Surface
H
Cold
air
L
Warm
air
Surface
map

- The diverging air aloft allows more air to flow upward from the surface
- The divergence aloft acts as an exhaust system for the surface low
- This is a mechanism for storm intensification

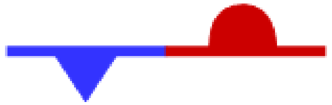



NCEP NAM 200 hPa Wind Speed [knots] & Geopotential Height [dam]
Init: 12Z15NOV2013 -- [57] hr --> Valid Sun 21Z17NOV2013
54N
51N
48N
45N
42N
39N
36N
33N
30N
27N
24N
201
192
183
174
165
156
147
138
129
120
111
102
93
84
75
66
57
48
39
20
200 hPa Wind Speed (shaded) & Wind Barbs & Geopotential Height [contours]
NAM 913x443 0.11°x0.11° Forecast Grid
WxBell

Air Masses. An air mass is a large body of air with generally uniform temperature and humidity. The area from which an air mass originates is called a source region.

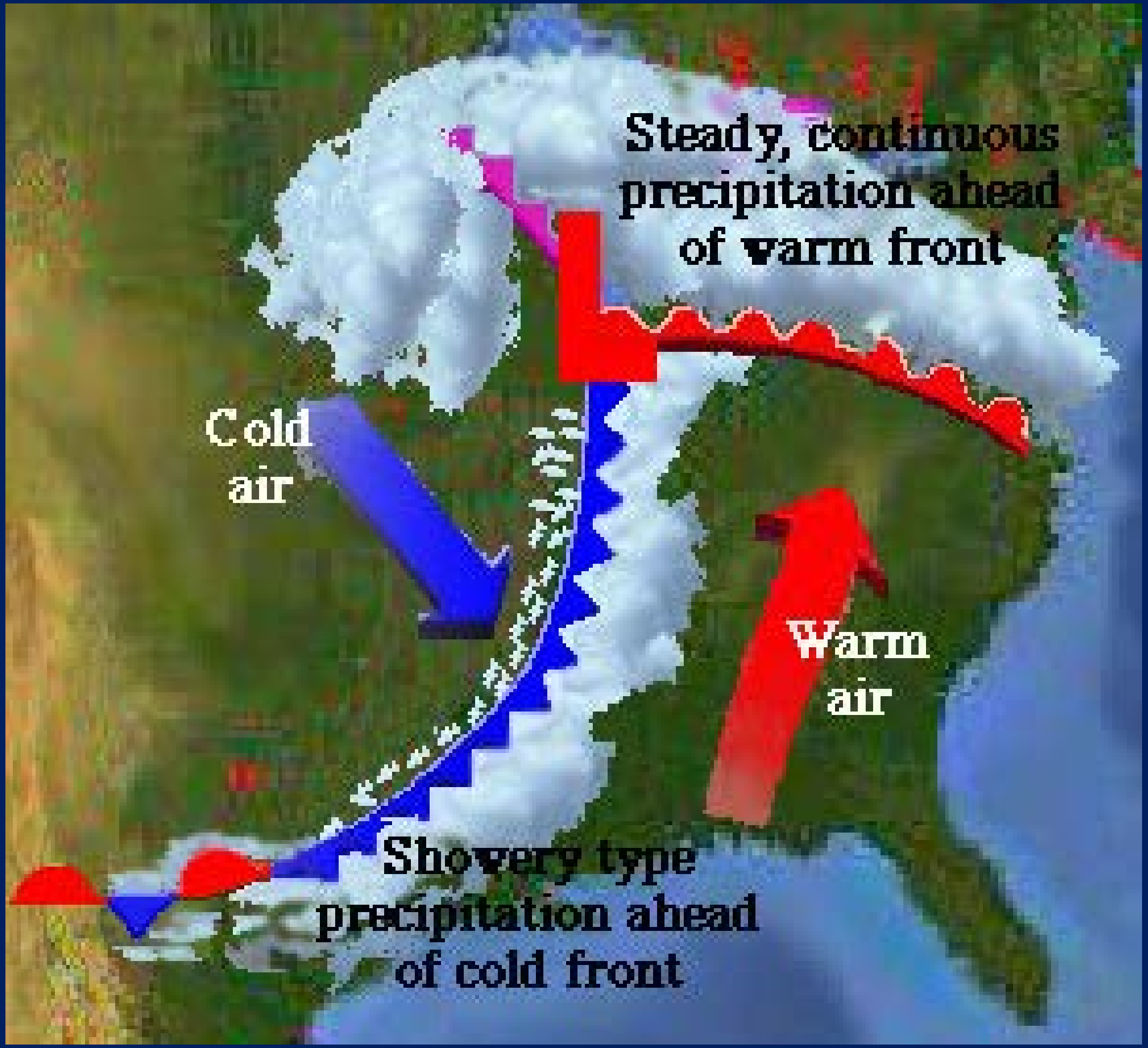
Air mass source regions range from extensive snow-covered polar areas to deserts to tropical oceans. The United States is not a favorable source region because of the relatively frequent passage of weather disturbances that disrupt any opportunity for an air mass to stagnate and take on the properties of the underlying region. The longer the air mass stays over its source region, the more likely it will acquire the properties of the surface below.

Air masses can control the weather for a relatively long time period ranging from days to months. Most weather occurs along the periphery of these air masses at boundaries called fronts. A front is a boundary or transition zone between two air masses. Fronts are classified by which type of air mass (cold or warm) is replacing the other

FRONT	CHART SYMBOL	DEFINITION
Cold Front		A front that moves in such a way that colder air replaces warmer air.
Warm Front		A front that moves in such a way that warmer air replaces colder air.
Stationary Front		A front which is stationary or nearly so.
Occluded Front		A composite of two fronts as a cold front overtakes a warm front or stationary front.

Note: Frontal symbols point in the direction of frontal movement.

Fronts are usually detectable at the surface in a number of ways: significant temperature gradients, or differences, exist along fronts (especially on the cold air side); winds usually converge, or come together, at fronts; and pressure typically decreases as a front approaches and increases after it passes.

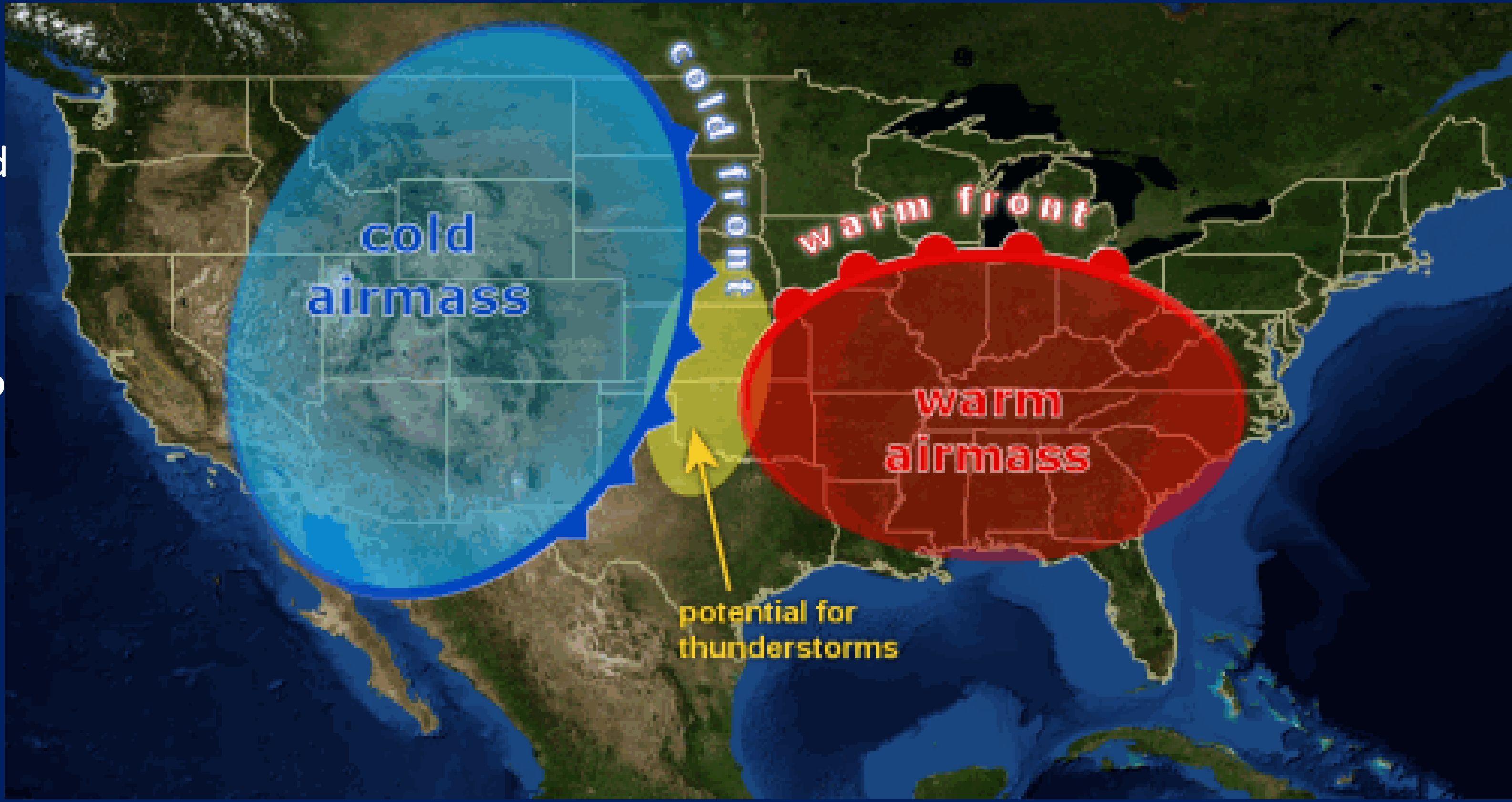


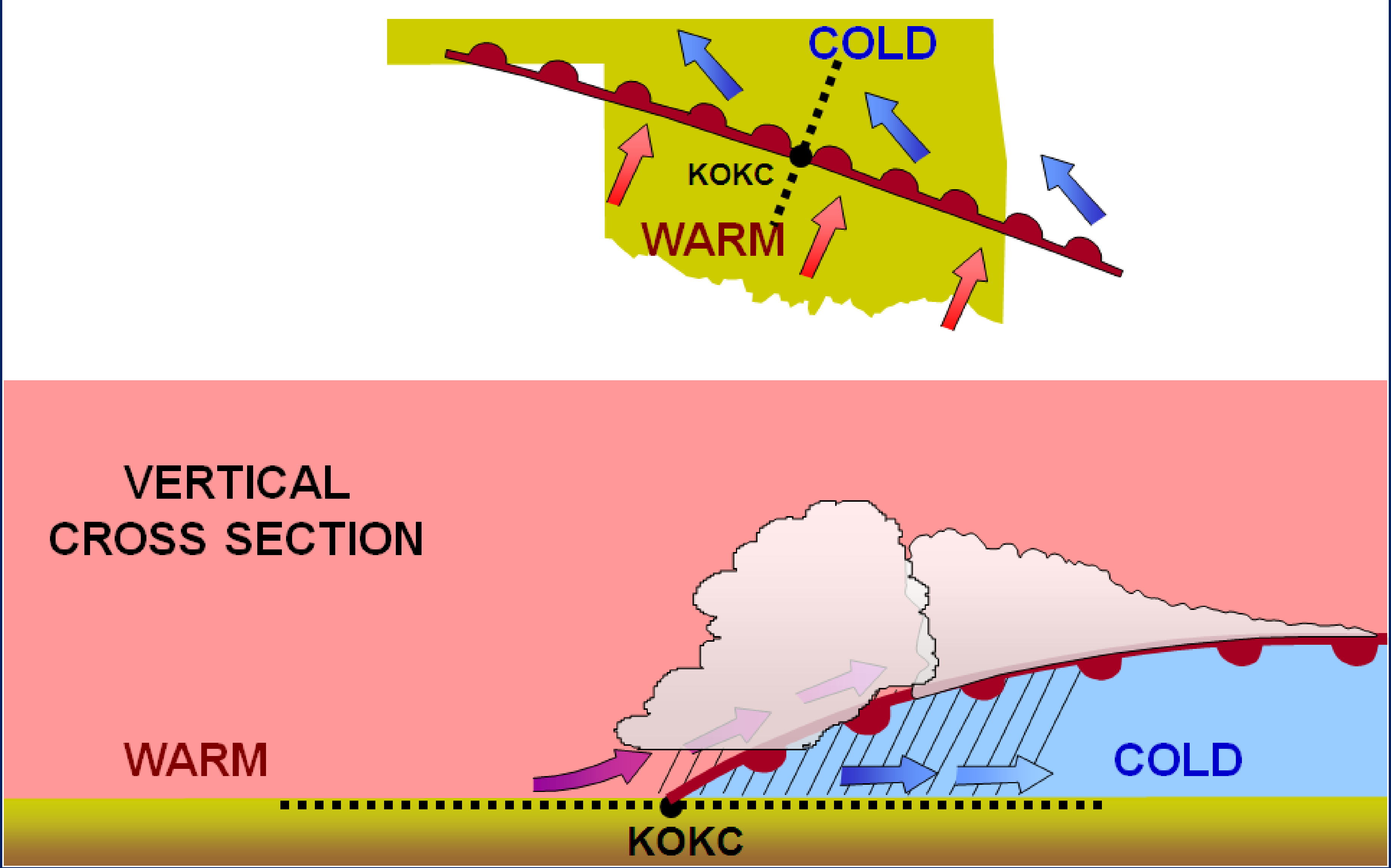
Fronts do not exist only at the surface of the Earth; they have a vertical structure in which the front slopes over the colder (denser) air mass.

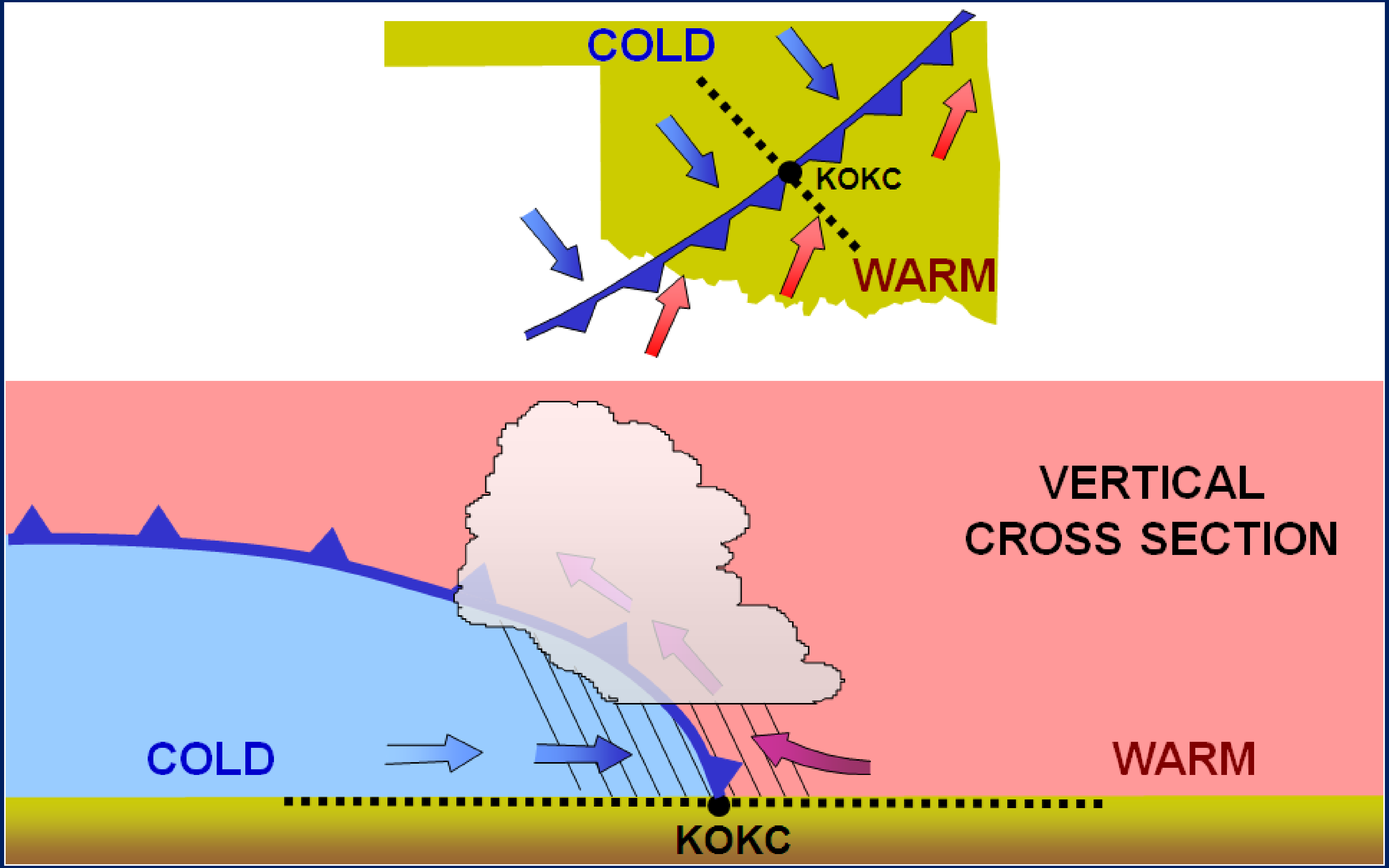
Cold fronts have a steep slope, and the warm air is forced upward abruptly. This often leads to a narrow band of showers and thunderstorms along, or just ahead of, the front if the warm rising air is unstable.

Warm fronts typically have a gentle slope, so the warm air rising along the frontal surface is gradual. This favors the development of widespread layered or stratiform cloudiness and precipitation along, and ahead of, the front if the warm rising air is stable.

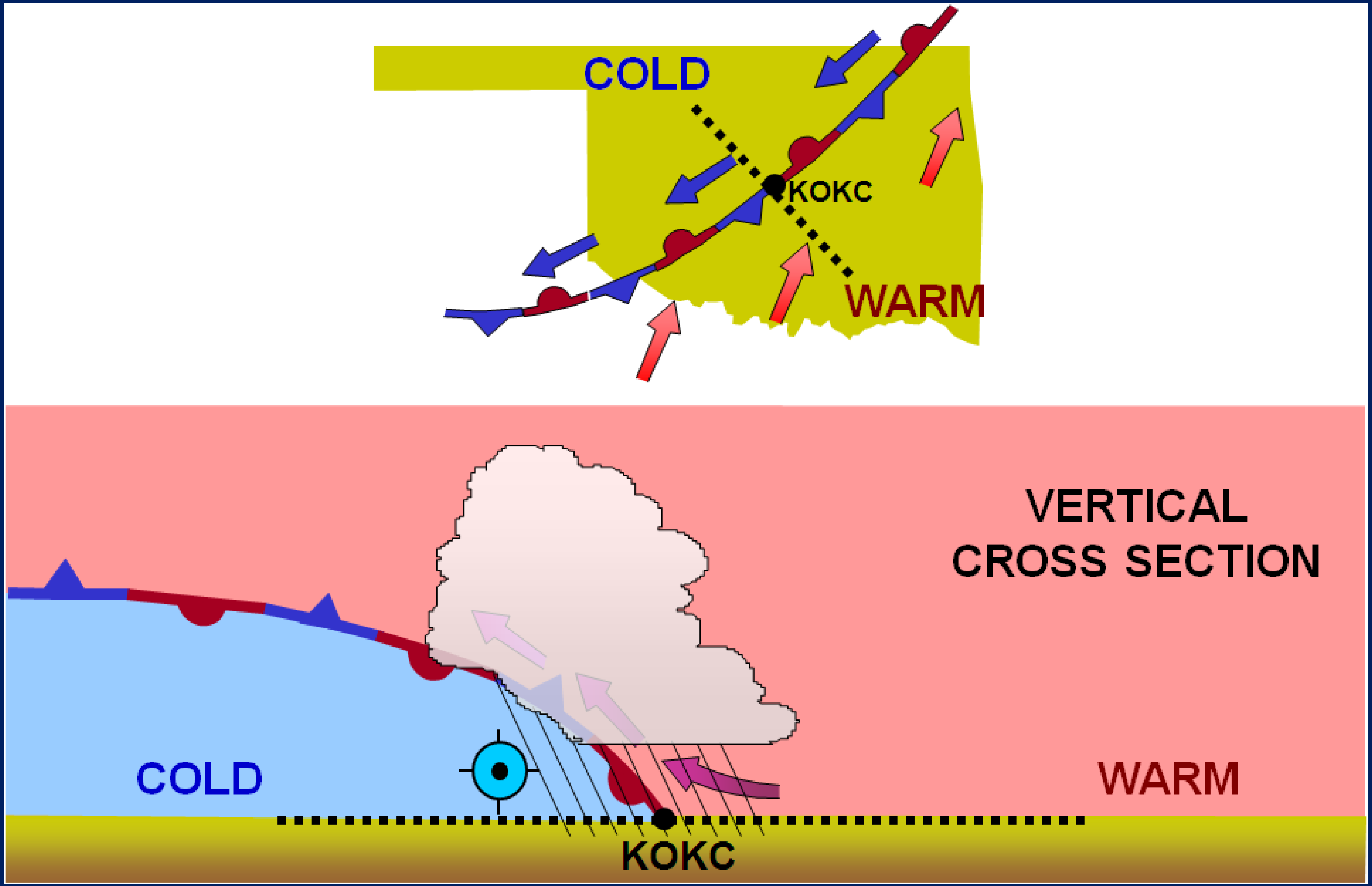
Stationary frontal slope can vary, but clouds and precipitation would still form in the warm rising air along the front.




COLD
KOKC
WARM
VERTICAL
CROSS SECTION
WARM
COLD
KOKC



COLD
KOKC
WARM
VERTICAL
CROSS SECTION
COLD
WARM
KOKC



COLD
KOKC
WARM
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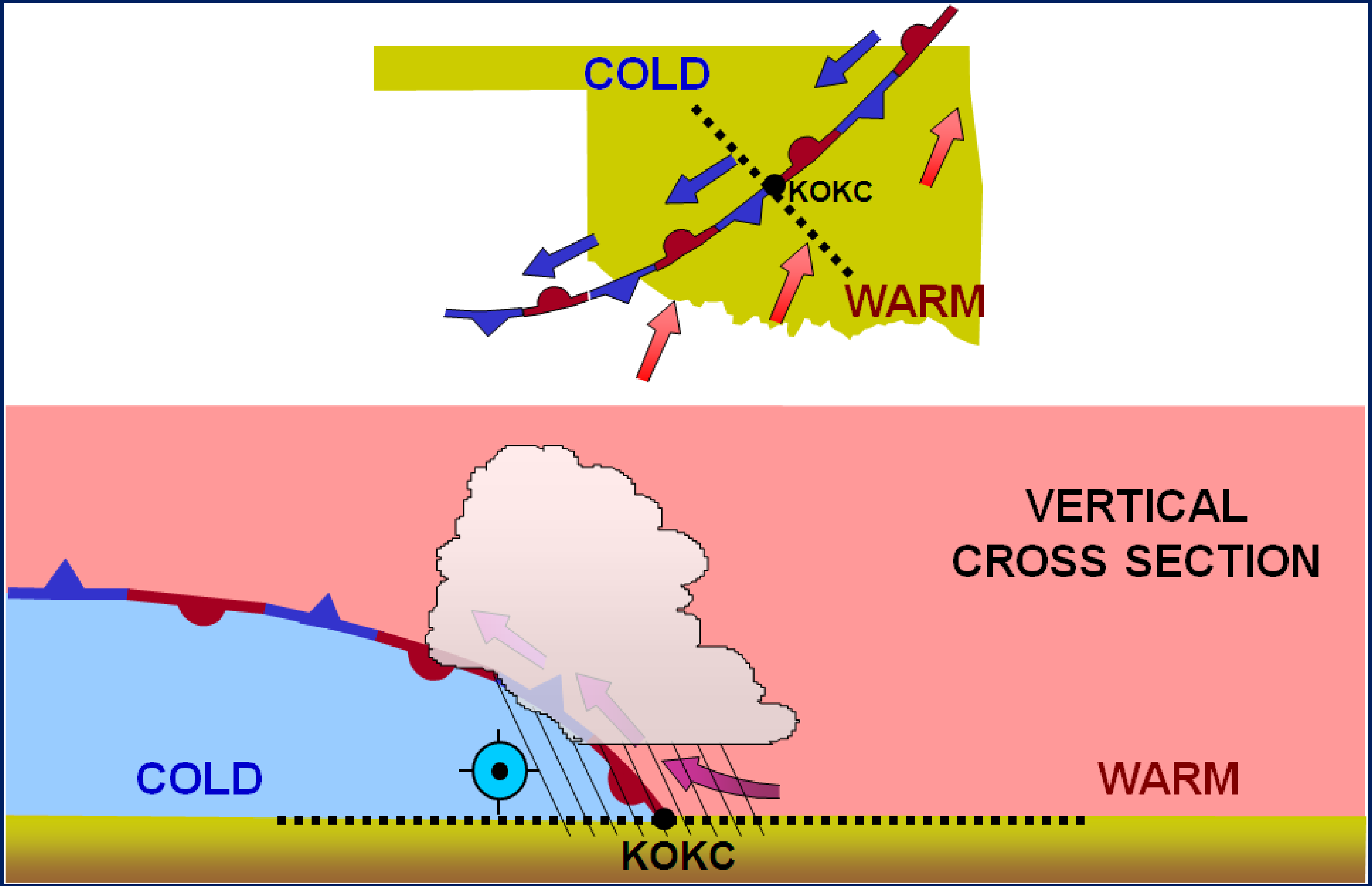
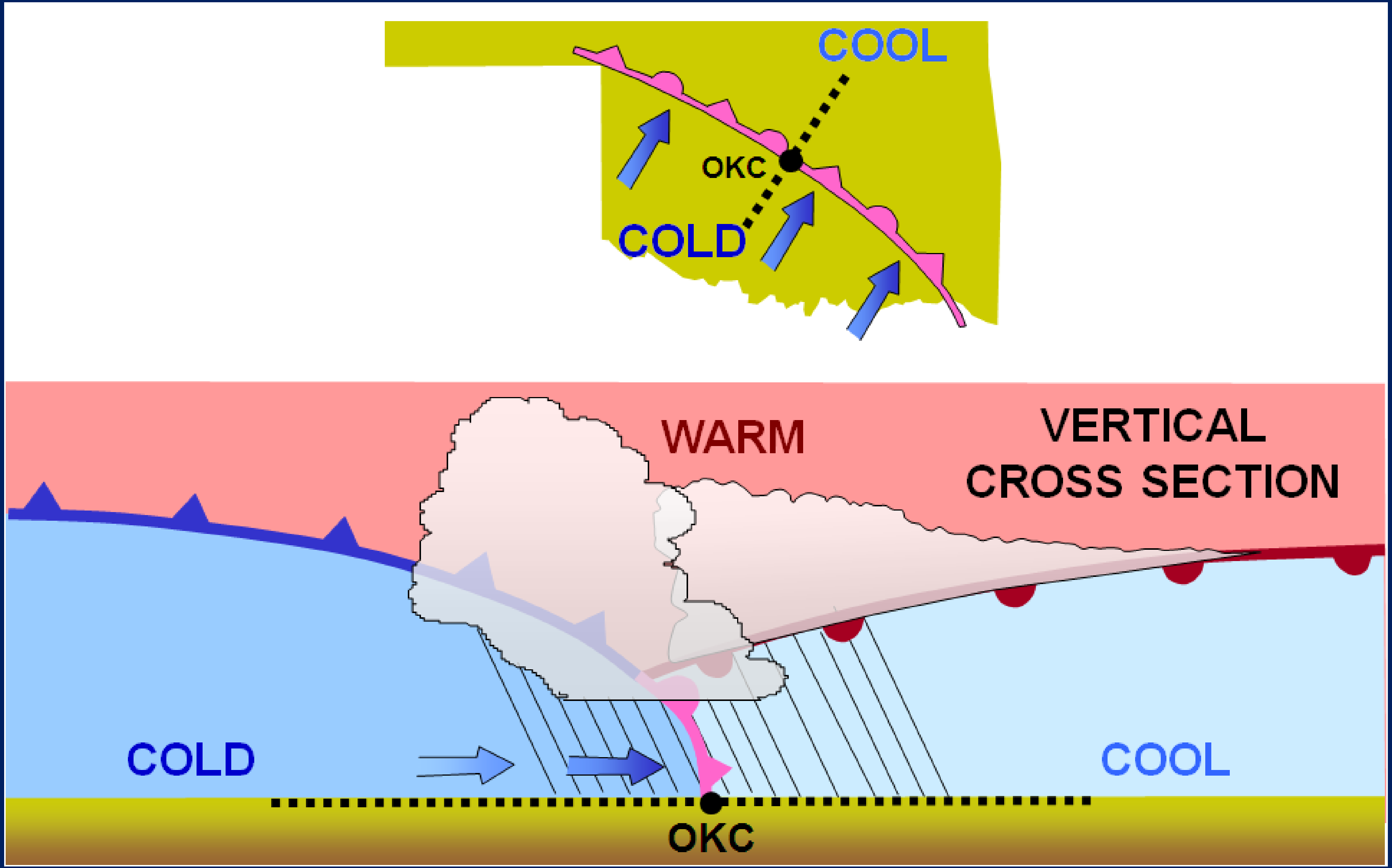
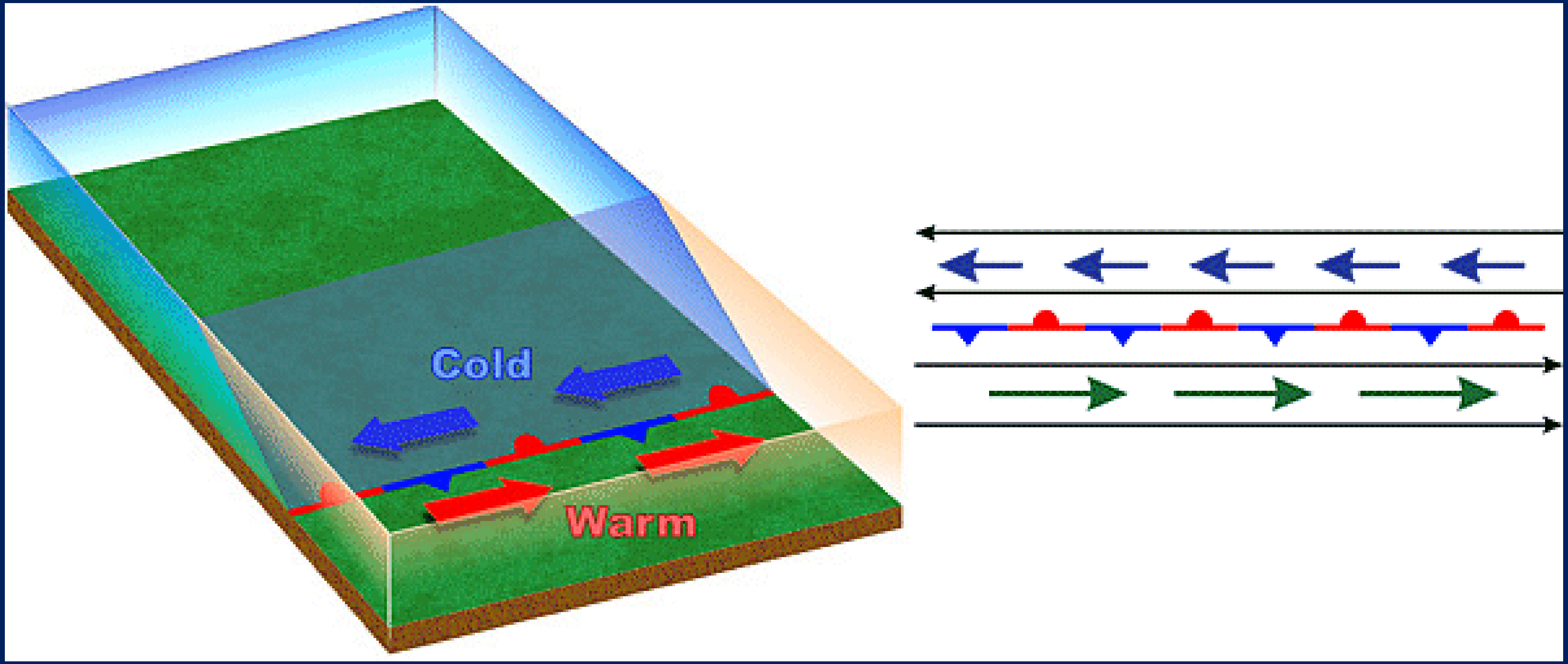
CROSS SECTION
COLD
WARM
KOKC

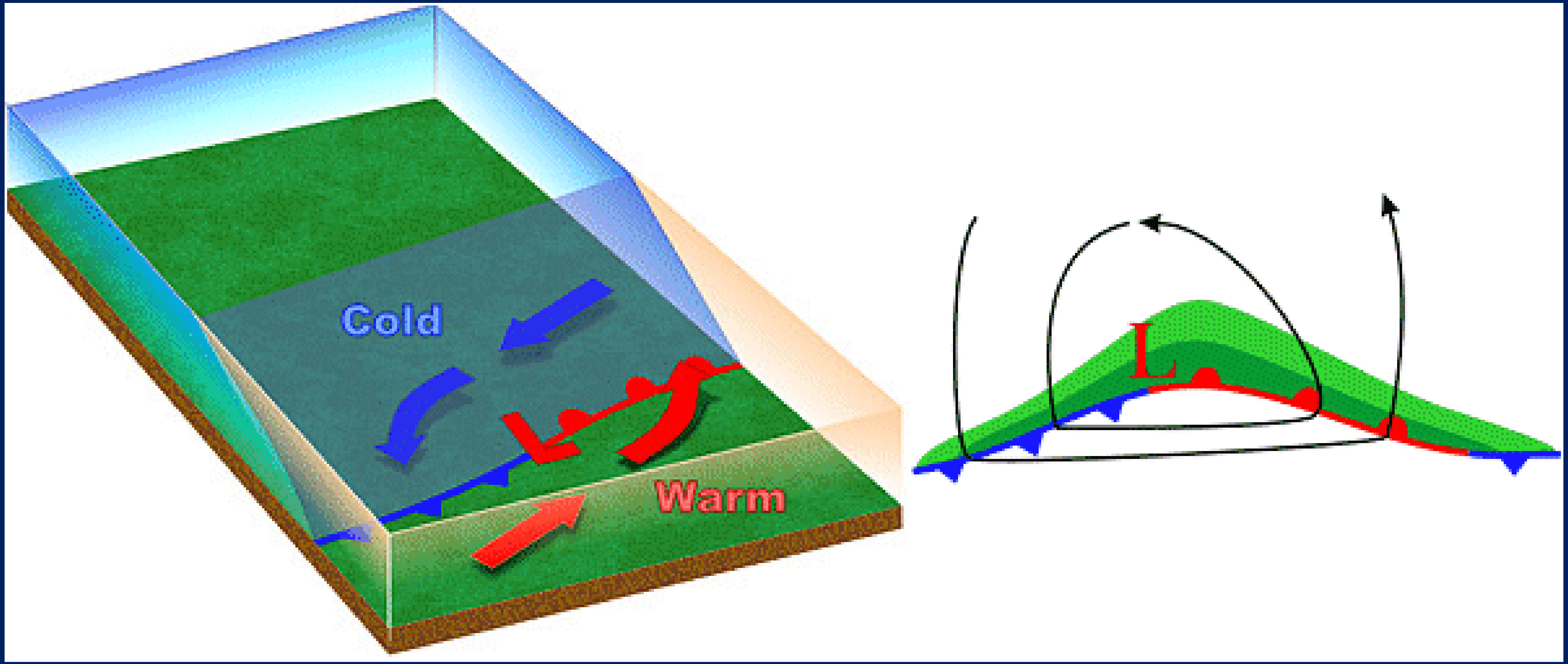

COLD
KOKC
WARM
VERTICAL
CROSS SECTION
COLD
WARM
KOKC


COOL
OKC
COLD
WARM
VERTICAL
CROSS SECTION
COLD
COOL
OKC

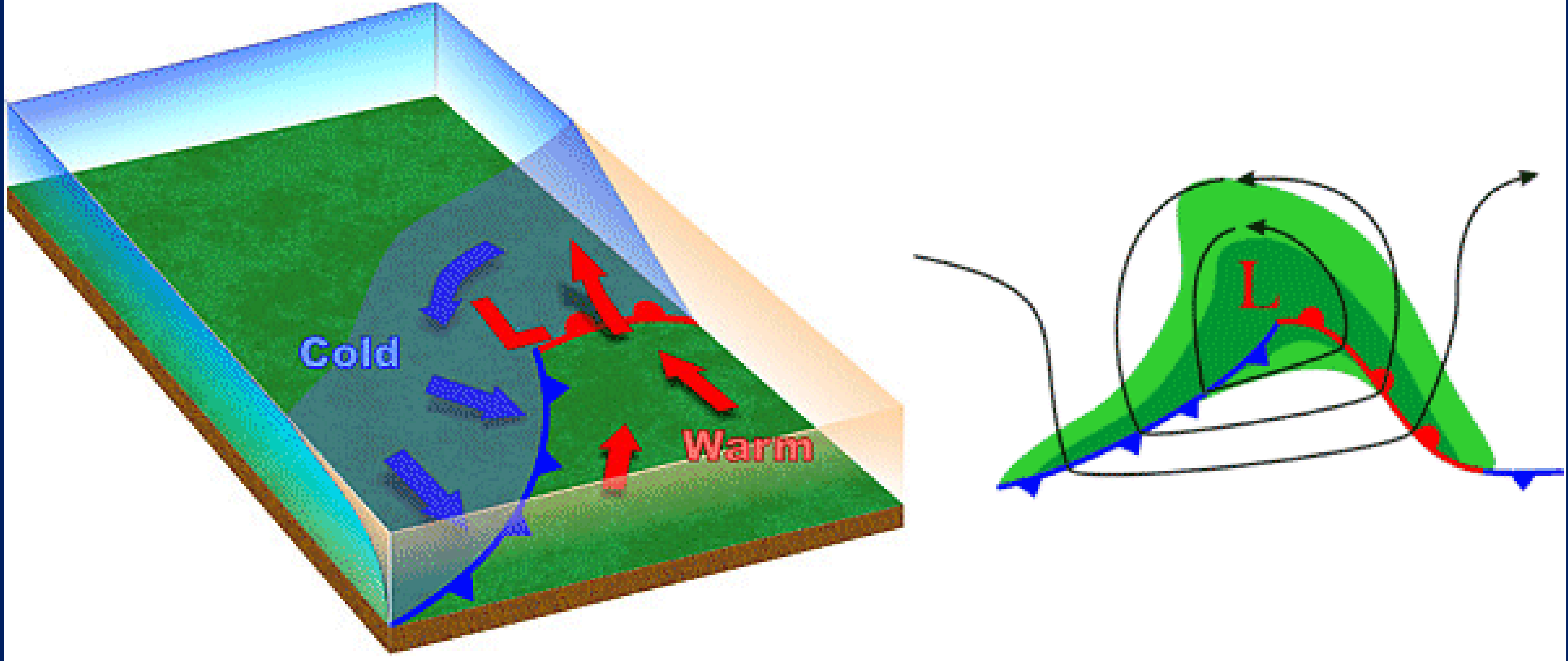
A wave cyclone is a low pressure circulation that forms and moves along a front produced by the polar front jet located over the stationary boundary. The circulation about the cyclone center tends to produce a wavelike kink along the front. Wave cyclones are the primary weather producers in the mid-latitudes. They are large lows that generally travel from west to east along a front. They last from a few days to more than a week.



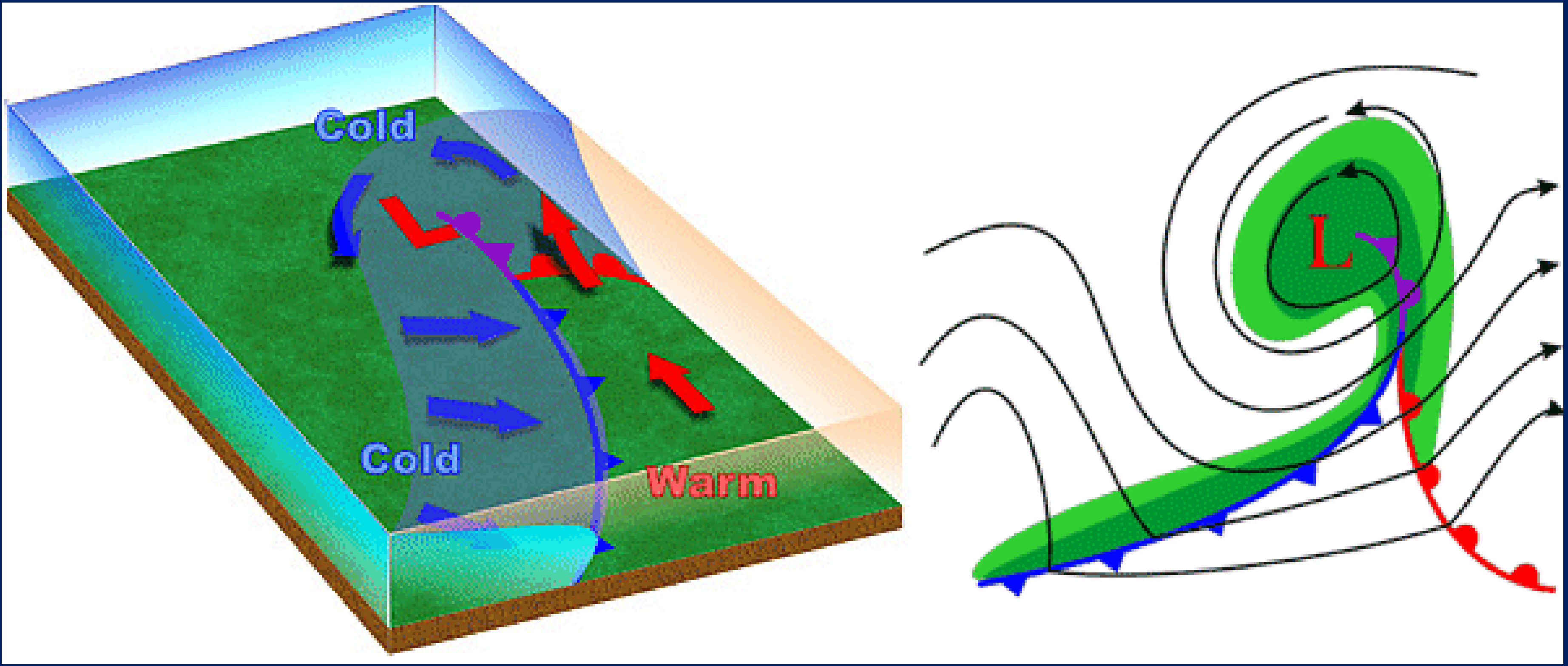
A low pressure wave forms on the front. The front develops a kink where the wave develops. Precipitation develops with the heaviest intensity (dark green) located in the zone of lift along the front



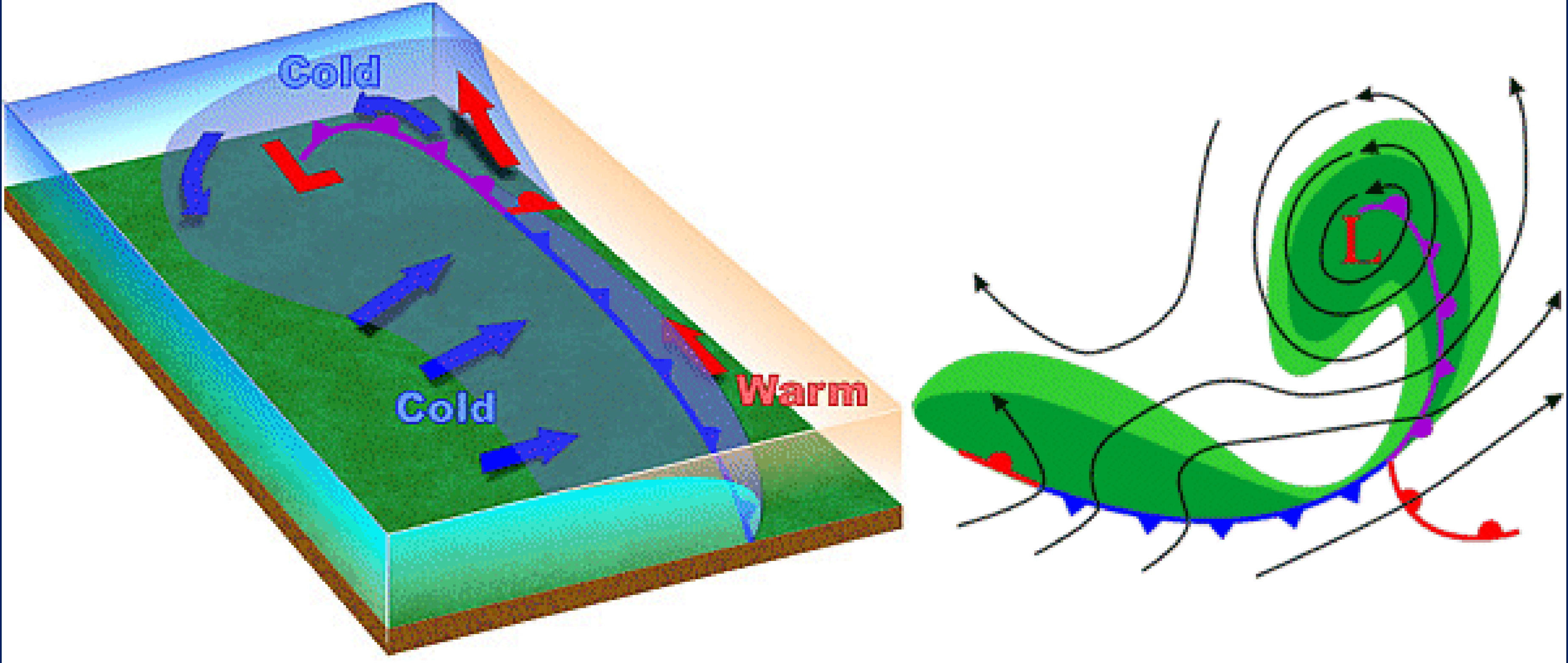
As the wave intensifies, both the cold and warm fronts become better organized



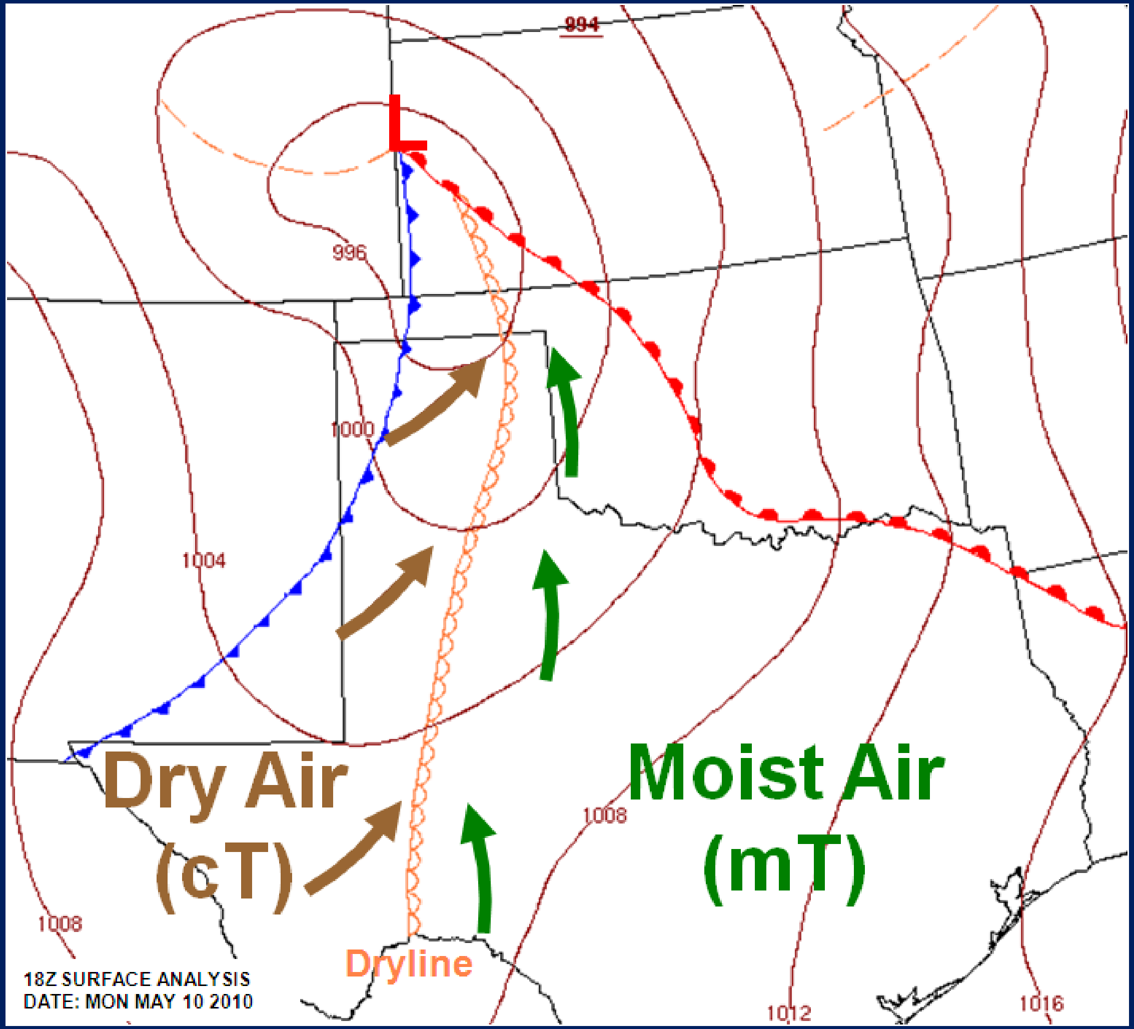
In the fourth stage, the wave becomes a mature low. The occluded front forms as the cold front overtakes the warm front



As the cold front continues advancing on the warm front, the occlusion increases and eventually cuts off the supply of warm moist air. This causes the low to gradually dissipate.

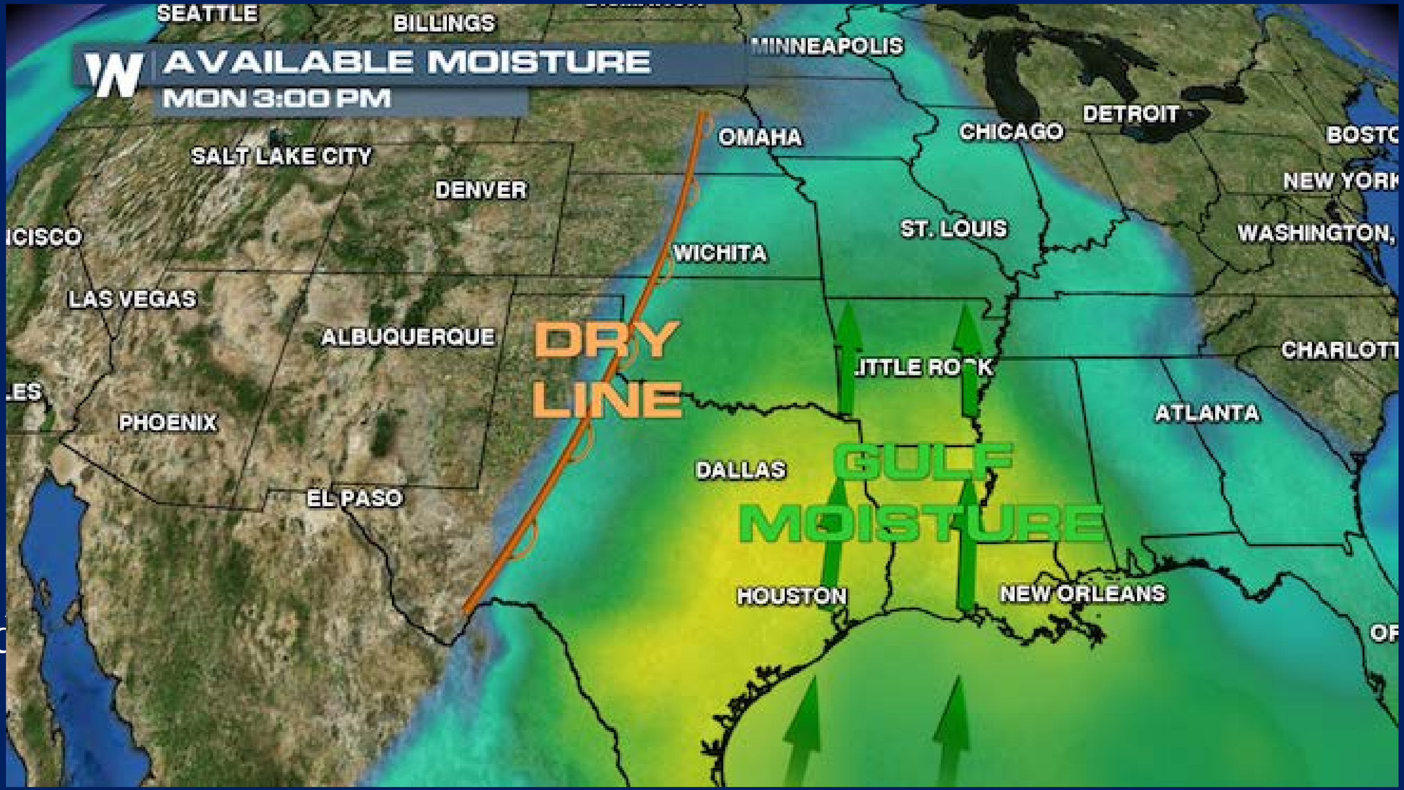


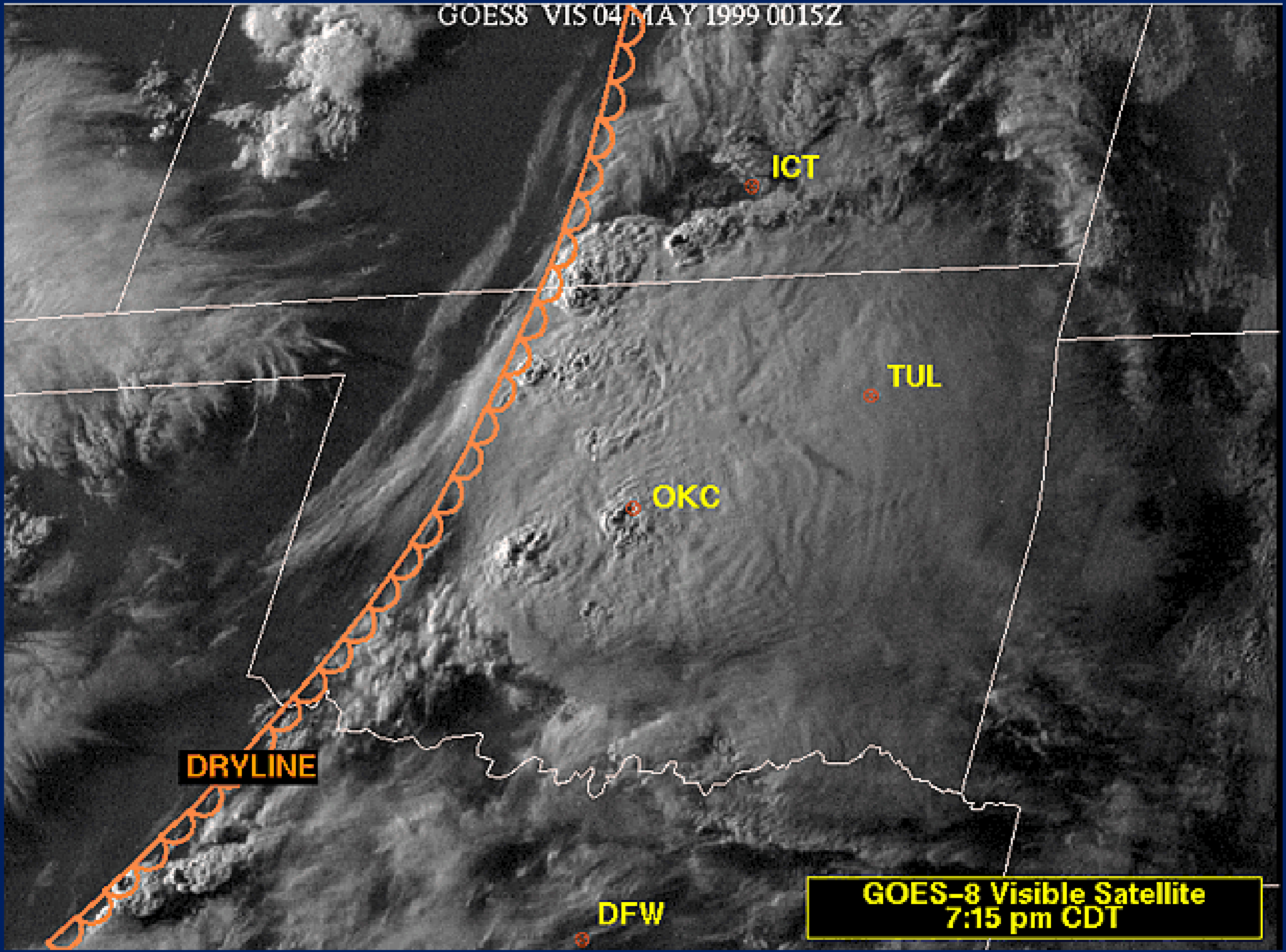
Dryline. A dryline is a low-level boundary hundreds of miles long separating moist and dry air masses. In the United States, it typically lies north-south across the southern and central High Plains during the spring and early summer, where it separates moist (mT) air from the Gulf of Mexico to the east and dry desert (cT) air from the southwestern states to the west (



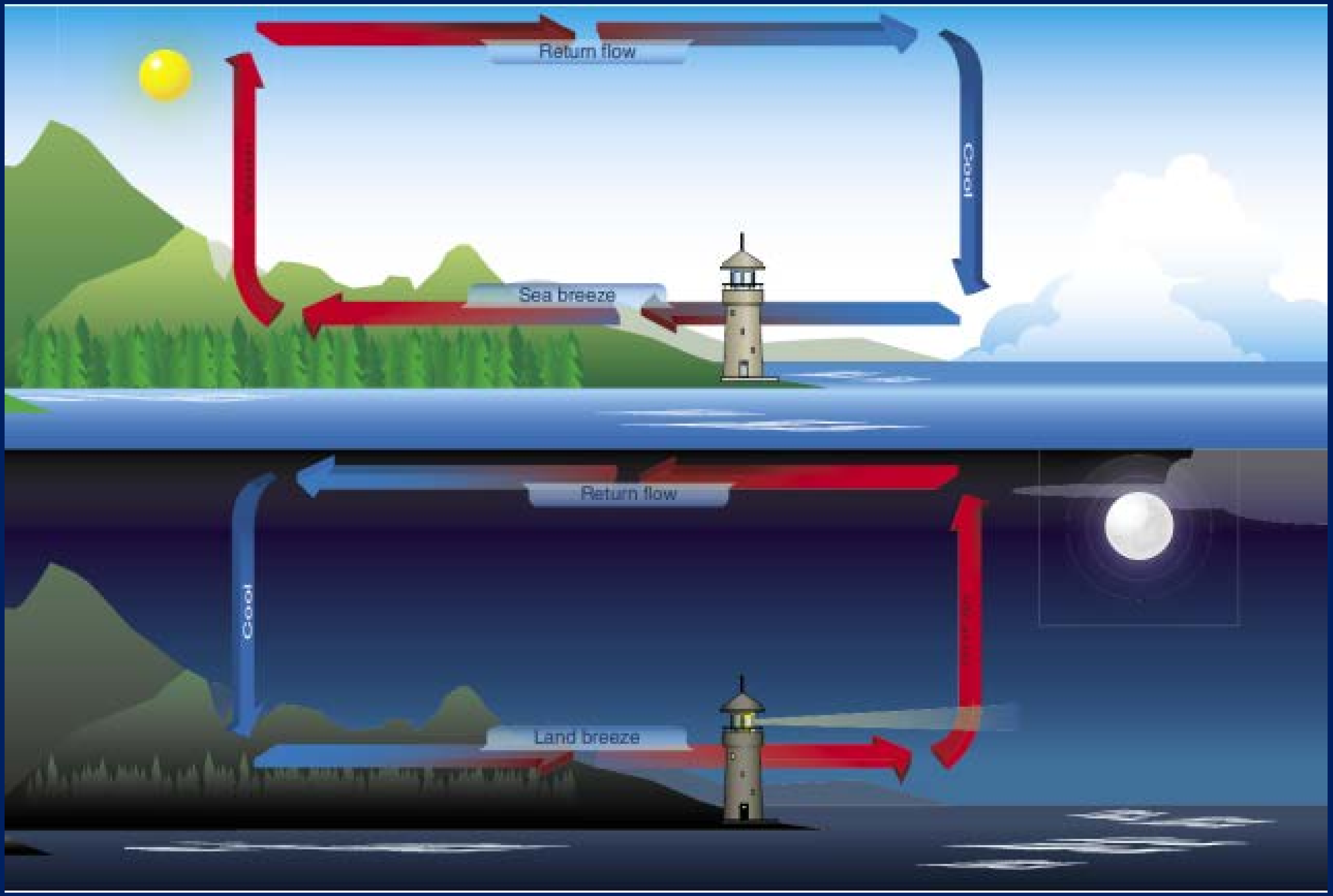
The dryline typically advances eastward during the afternoon and retreats westward at night. However, a strong wave cyclone can sweep the dryline eastward into the Mississippi Valley, or even further east, regardless of the time of day. Low-level clouds and early morning fog often prevail in the moist air, while generally clear skies mark the dry side. Severe and sometimes tornadic thunderstorms often develop along a dryline or in the moist air just to the east of it, especially when it begins moving eastward.

A typical dryline passage results in a sharp drop in humidity (hence the name), clearing skies, and a wind shift from south or southeasterly to west or southwesterly. Blowing dust and rising temperatures also may follow, especially if the dryline passes during the daytime. These changes occur in reverse order when the dryline retreats westward.




GOES8 VIS 04 MAY 1999 0015Z
ICT
TUL
OKC
DRYLINE
DFW
GOES-8 Visible Satellite
7:15 pm CDT

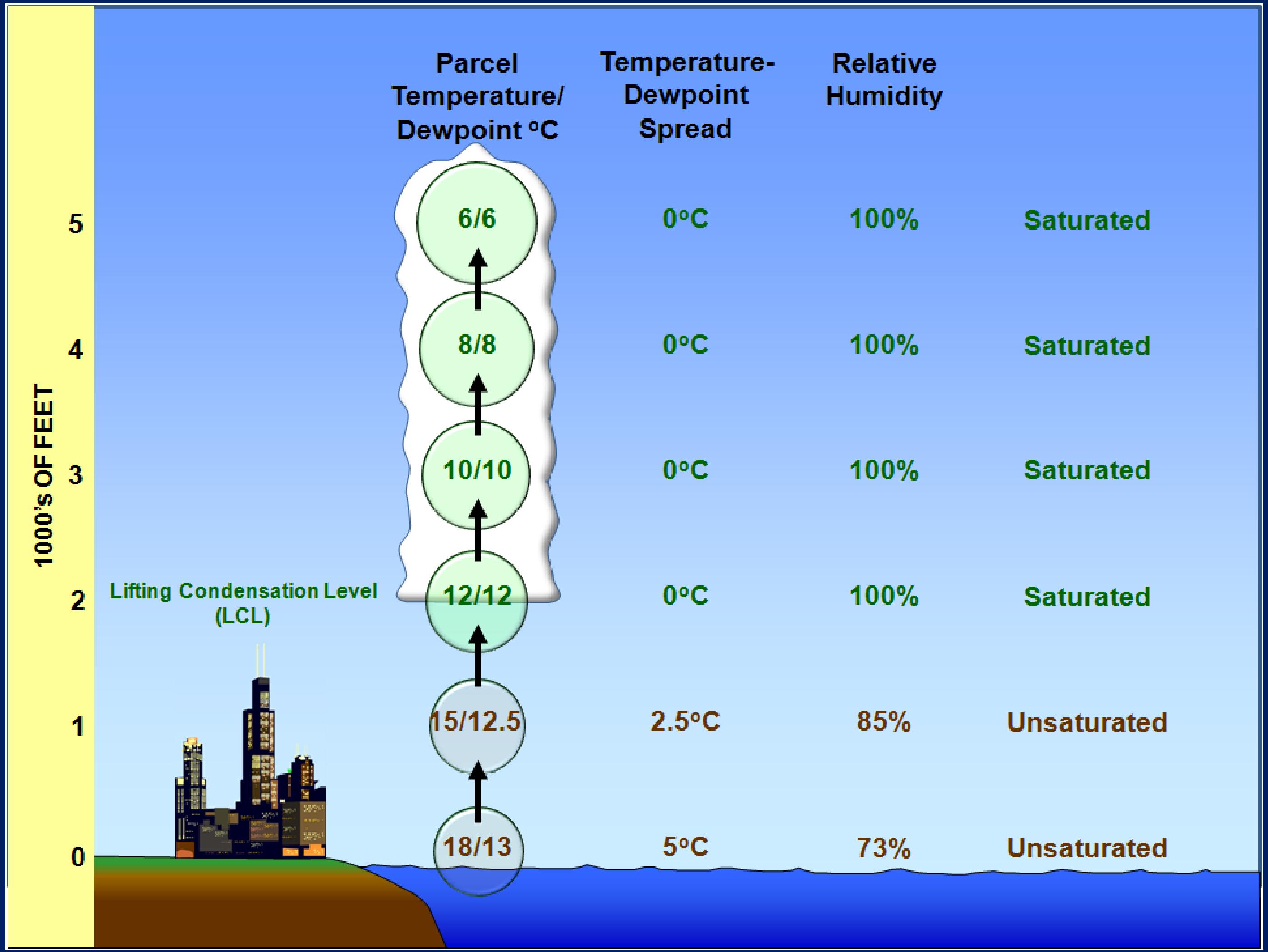
Local winds include: sea breeze, land breeze, lake breeze, lake effect, valley breeze, mountain-plains wind circulation, and mountain breeze.



Clouds form in the atmosphere as a result of condensation of water vapor in rising currents of air, or by the evaporation of the lowest layer of fog. Rising currents of air are necessary for the formation of vertically deep clouds capable of producing precipitation heavier than light intensity.

Vertical Motion Effects on a Saturated Air Parcel. The Lifting Condensation Level (LCL) is the level at which a parcel of moist air lifted dry adiabatically becomes saturated. At this altitude, the temperature-dewpoint spread is zero and relative humidity is 100 percent. Further lifting of the saturated parcel results in condensation, cloud formation, and latent heat release. Because the heat added during condensation offsets some of the cooling due to expansion, the parcel now cools at the moist adiabatic lapse rate, which varies between approximately 1.2 °C per 1,000 feet (4 °C per kilometer) for very warm saturated parcels to 3 °C per 1,000 feet (9.8 °C per kilometer) for very cold saturated parcels. Concurrently, the parcel's dewpoint decreases at an identical rate. For simplicity, examples shown in this AC use a moist adiabatic lapse rate of 2 °C per 1,000 feet. Regardless of temperature, the relative humidity remains constant at about 100 percent

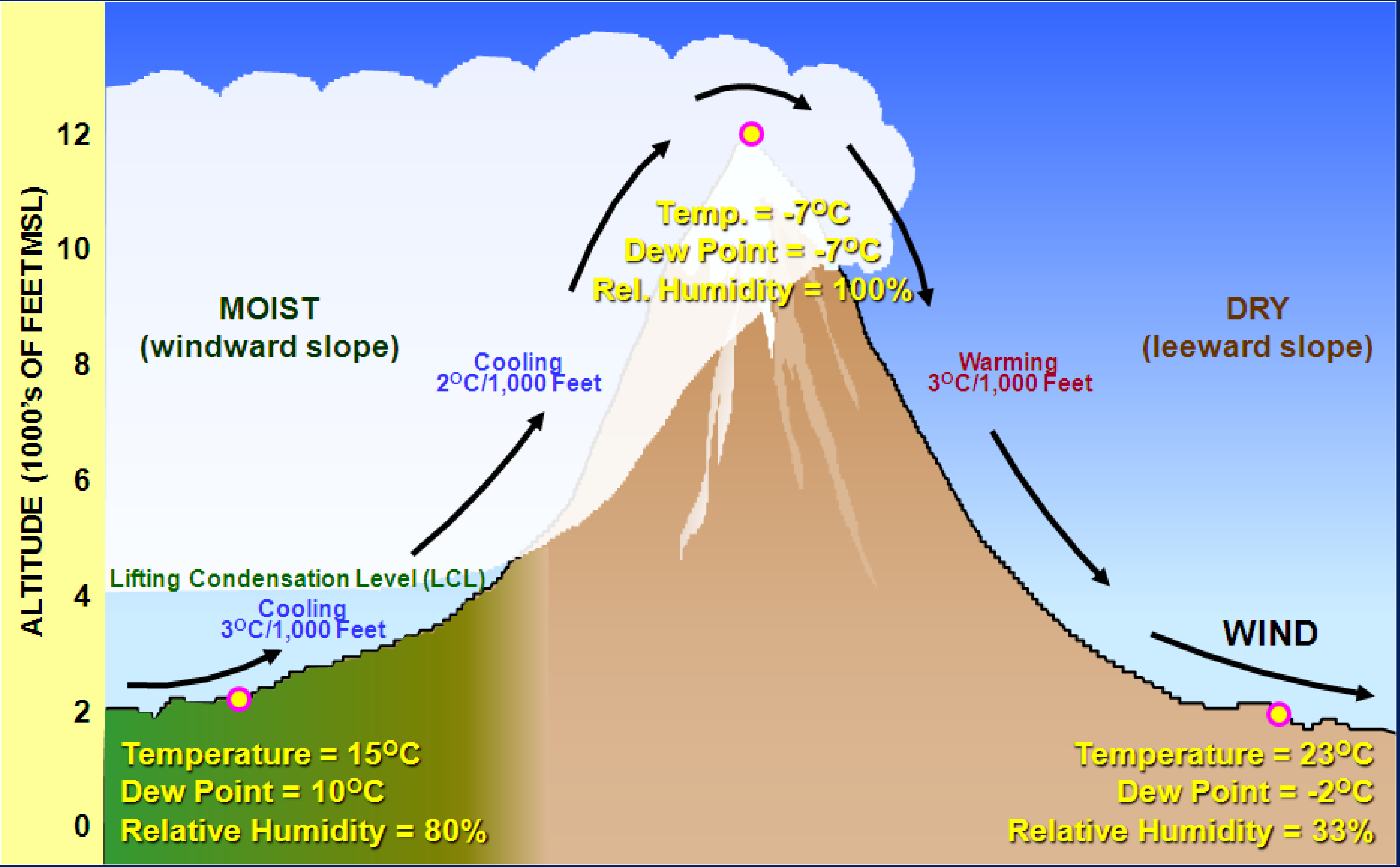
As the saturated air parcel expands and cools, however, its water vapor content decreases. This occurs because some of the water vapor is condensed to water droplets or deposited into ice crystals to form a cloud. This process is triggered by the presence of microscopic cloud condensation (and ice) nuclei, such as dust, clay, soot, sulfate, and sea salt particles. The cloud grows vertically deeper as the parcel continues to rise.



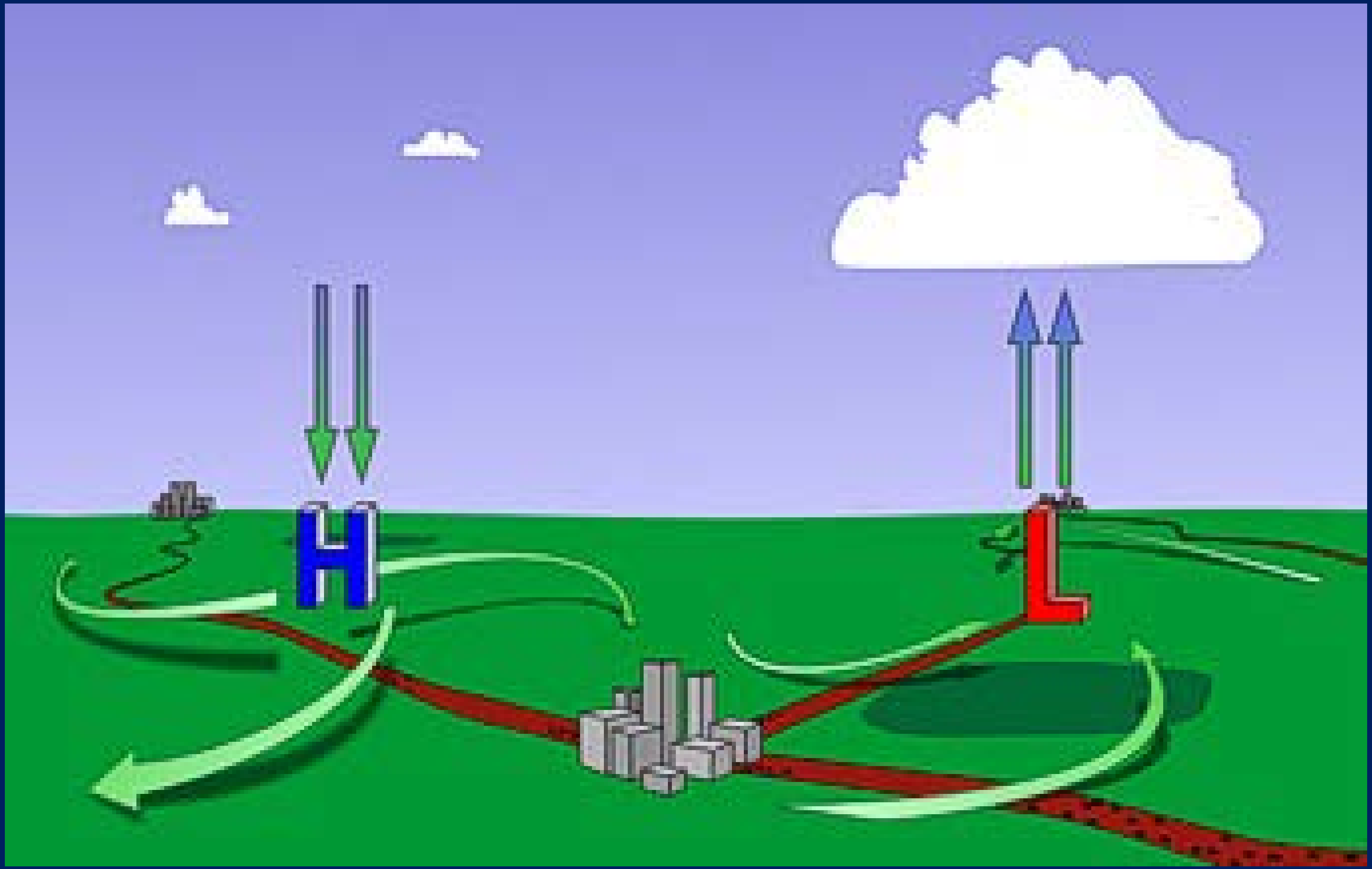
Common Sources of Vertical Motion. There are many sources of vertical motion in the atmosphere. Four of the most common types of vertical motion are orographic effects, frictional effects, frontal lift, and buoyancy.

Orographic Effects. Winds blowing across mountains and valleys cause the moving air to alternately ascend and descend. If relief is sufficiently great, the resulting expansional cooling and compressional warming of air affects the development and dissipation of clouds and precipitation.

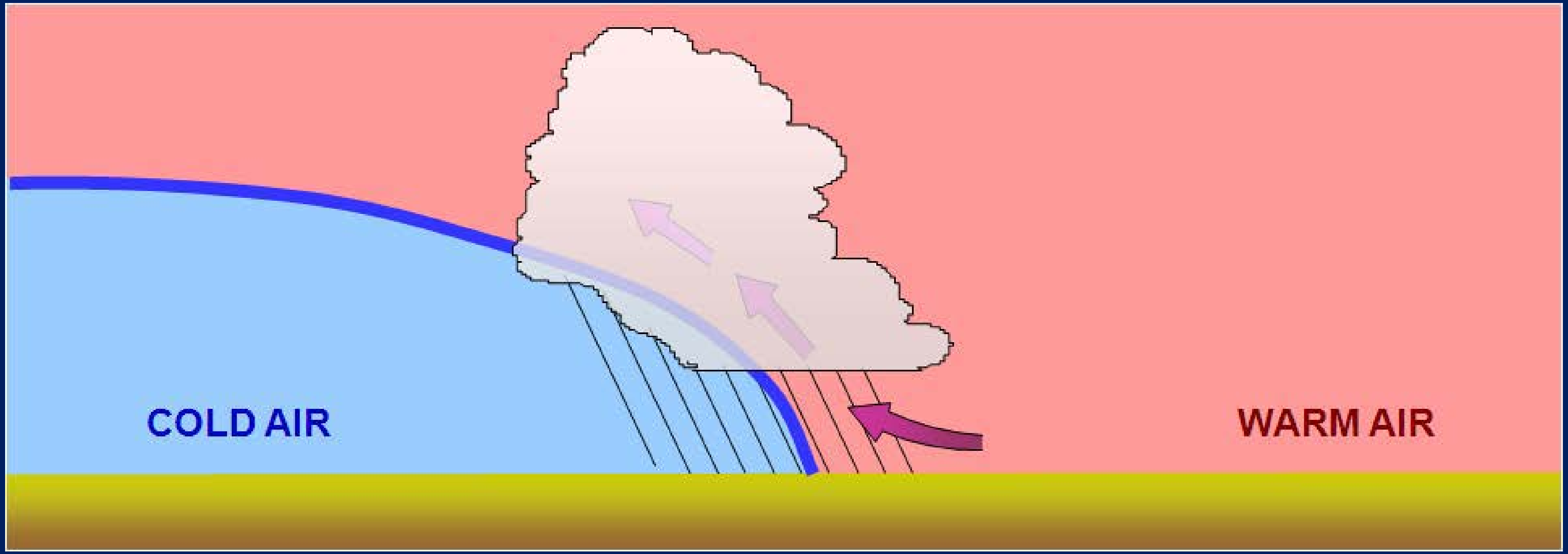
For example, a mountain range that is oriented perpendicular to the prevailing wind flow forms a barrier that results in a cloudier and wetter climate on one side of the range than on the other side. As air is forced to rise along the windward slope, it expands and cools, which increases its relative humidity. With sufficient cooling, clouds and precipitation develop at and above the LCL. Conversely, on the mountain's leeward slope, air descends and warms, which reduces its relative humidity, and tends to dissipate clouds and precipitation. In this way, mountain ranges induce two contrasting climatic zones: a moist climate on the windward slope and a dry climate on the leeward slope. Dry conditions often extend hundreds of miles to the lee of a prominent mountain range in a region known as rain shadow.


ALTITUDE (1000's OF FEET MSL)
12
10
8
6
4
2
0
MOIST
(windward slope)
DRY
(leeward slope)
Temp. = -7OC
Dew Point = -7OC
Rel. Humidity = 100%
Cooling
2OC/1,000 Feet
Warming
3OC/1,000 Feet
Lifting Condensation Level (LCL)
Cooling
3OC/1,000 Feet
WIND
Temperature = 15OC
Dew Point = 10OC
Relative Humidity = 80%
Temperature = 23OC
Dew Point = -2OC
Relative Humidity = 33%

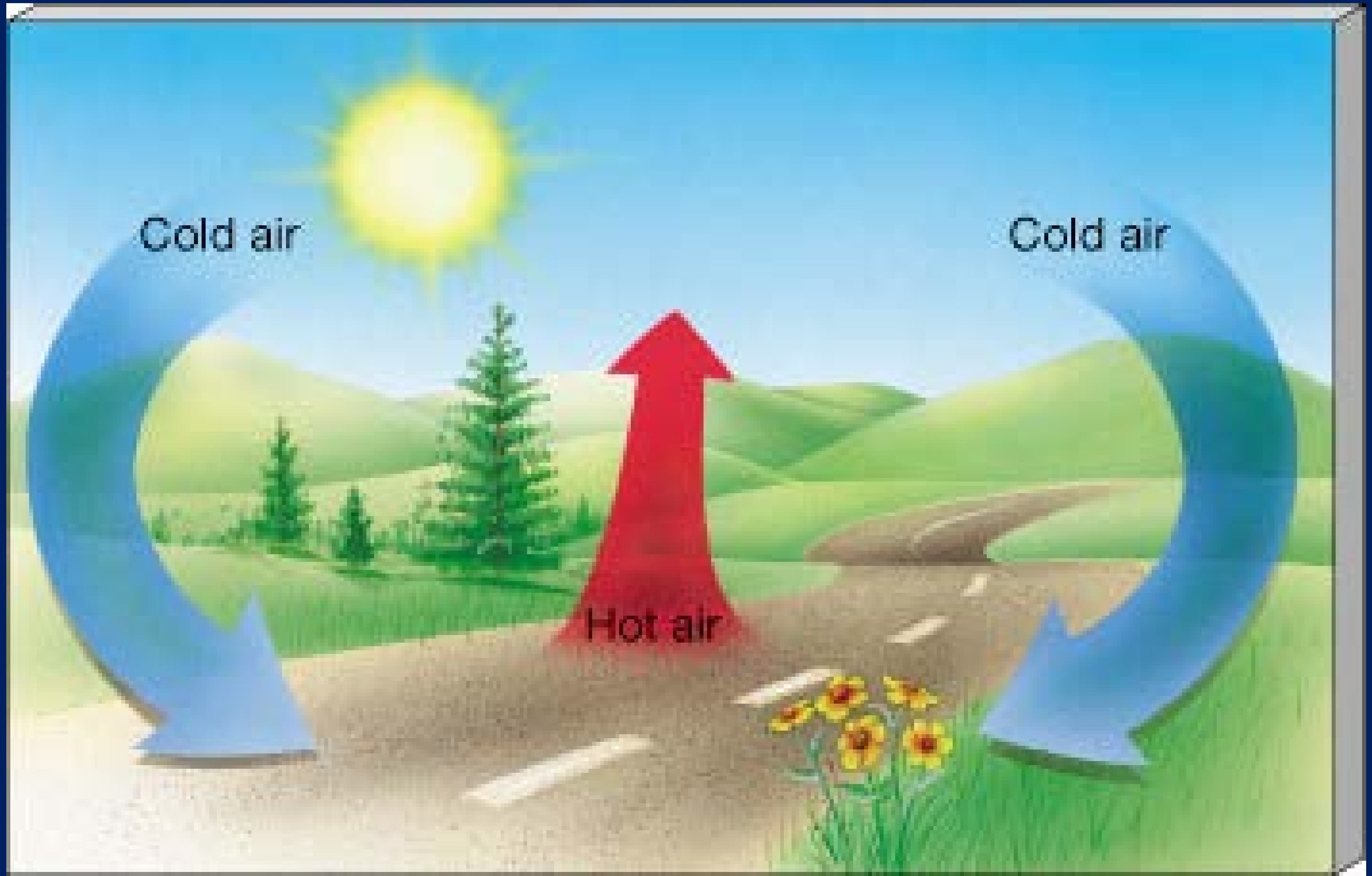
Frictional Effects. In the Northern Hemisphere, the surface wind spirals clockwise and outward from high pressure, and counterclockwise and inward into low pressure due to frictional force. The end result is that winds diverge away from surface high pressure, causing the air to sink, compress, and warm, which favors the dissipation of clouds and precipitation. Conversely, winds converge into surface low pressure, causing the air to rise, expand, and cool, which favors the formation of clouds and precipitation given sufficient moisture



Frontal Lift. Frontal lift occurs when the cold, denser air wedges under the warm, less dense air, plowing it upward, and/or the warmer air rides up and over the colder air in a process called overrunning. Cloud and precipitation will form given sufficient lift and moisture content of the warm air.

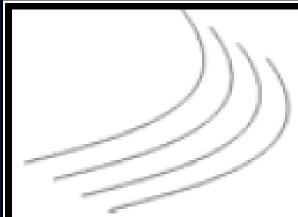
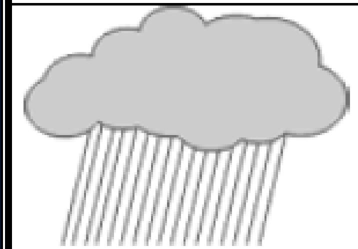


Buoyancy. Air near the ground can warm at different rates depending on the insular properties of the ground with which it is in contact. A newly plowed field will warm faster than an adjacent lake. These temperature differences result in different densities, allowing the warm air to become buoyant. The denser cool air will tend to push (i.e., lift) the less dense warm air aloft. On a grand scale, the tendency of air to rise due to heating, and how high it will rise



A cloud is a visible aggregate of minute water droplets and/or ice particles in the atmosphere above the Earth’s surface. Fog differs from cloud only in that the base of fog is at the Earth’s surface while clouds are above the surface. Clouds are like signposts in the sky that provide information on air motion, stability, and moisture. Clouds help pilots visualize weather conditions and potential weather hazards.

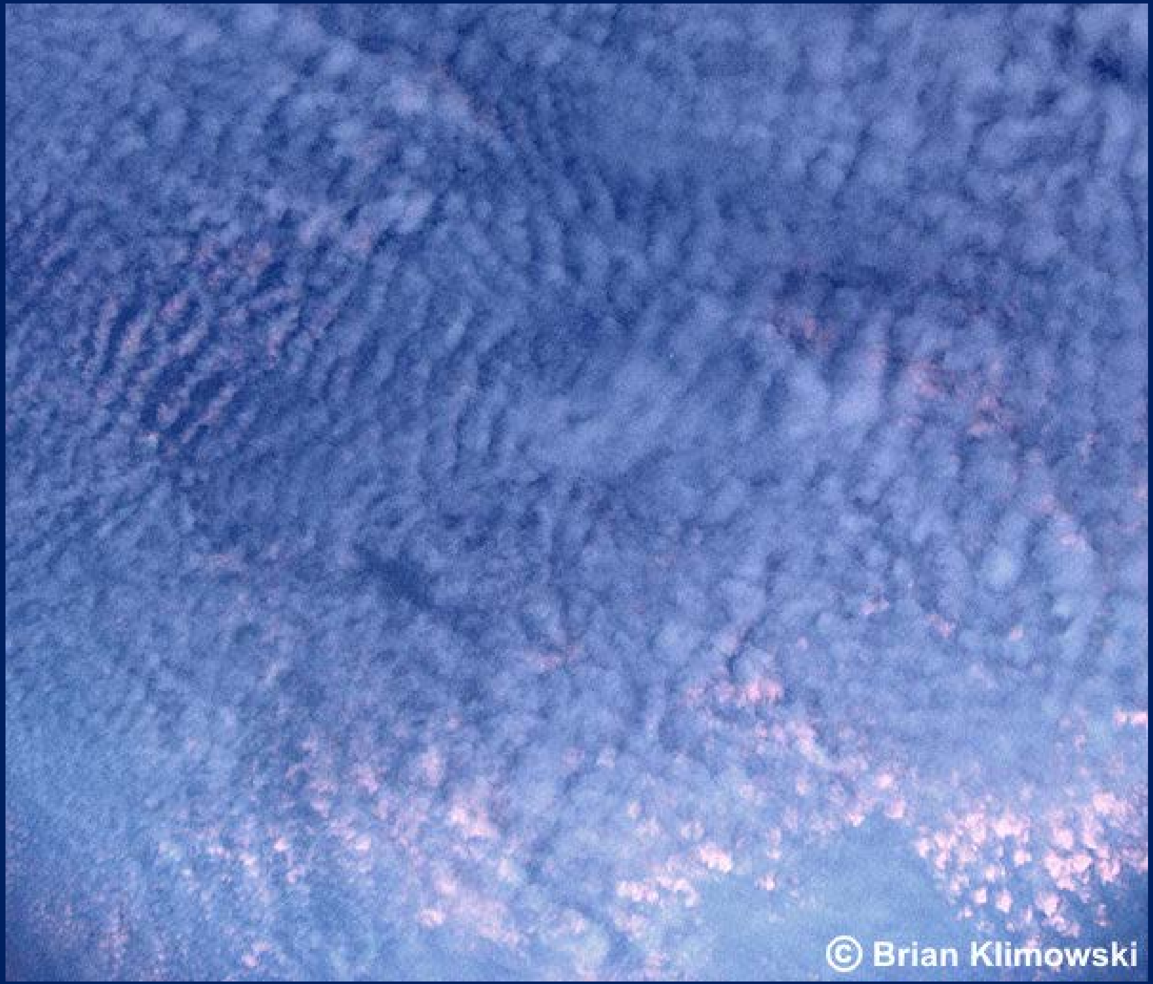
Clouds form in the atmosphere as a result of condensation of water vapor in rising currents of air, or by the evaporation of the lowest layer of fog. Rising currents of air are necessary for the formation of vertically deep clouds capable of producing precipitation heavier than light intensity,

 **Cirriform**	High-level clouds that form above 20,000 feet (6,000 meters) and are usually composed of ice crystals. High-level clouds are typically thin and white in appearance, but can create an array of colors when the sun is low on the horizon. Cirrus generally occur in fair weather and point in the direction of air movement at their elevation.
 **Nimbus**	Nimbus comes from the Latin word meaning "rain." These clouds typically form between 7,000 and 15,000 feet (2,100 to 4,600 meters) and bring steady precipitation. As the clouds thicken and precipitation begins to fall, the bases of the clouds tend to lower toward the ground.
 **Cumuliform**	Clouds that look like white, fluffy cotton balls or heaps and show the vertical motion or thermal uplift of air taking place in the atmosphere. The level at which condensation and cloud formation begins is indicated by a flat cloud base, and its height will depend upon the humidity of the rising air. The more humid the air, the lower the cloud base. The tops of these clouds can reach over 60,000 feet (18,000 meters).
 **Stratiform**	Stratus is Latin for "layer" or "blanket." The clouds consist of a featureless low layer that can cover the entire sky like a blanket, bringing generally gray and dull weather. The cloud bases are usually only a few hundred feet above the ground. Over hills and mountains, they can reach ground level when they may be called fog. Also, as fog lifts off the ground due to daytime heating, the fog forms a layer of low stratus clouds.

Cirrus (Ci). Cirrus (Ci) is a cloud type composed of detached cirriform elements in the form of white, delicate filaments of white (or mostly white) patches, or of narrow bands. These clouds have a fibrous (hair-like) appearance and/or a silky sheen. Many of the ice crystal particles of cirrus are sufficiently large to acquire an appreciable speed of fall; therefore, the cloud elements often trail downward in well-defined wisps called mares' tails. Cirrus clouds in themselves have little effect on aircraft and contain no significant icing or turbulence.

Cirrocumulus (Cc). Cirrocumulus (Cc) is a cirriform cloud type appearing as a thin, white patch, sheet, or layer of cloud without shading, and is composed of very small elements in the form of grains, ripples, etc. The elements may be merged or separate, and more or less regularly arranged; they subtend an angle of less than 1° when observed at an angle of more than 30° above the horizon.

Cirrocumulus may be composed of highly supercooled4 water droplets, as well as small ice crystals, or a mixture of both; usually, the droplets are rapidly replaced by ice crystals. Pilots can expect some turbulence and icing.



Cirrostratus (Cs) is a cloud type appearing as a whitish veil, usually fibrous (hair-like) but sometimes smooth, that may totally cover the sky, and that often produces halo phenomena, either partial or complete. Cirrostratus occasionally may be so thin and transparent as to render it nearly indiscernible, especially through haze or at night. At such times, the existence of a halo around the sun or moon may be the only revealing feature.

The angle of incidence of illumination upon a cirrostratus layer is an important consideration in evaluating the identifying characteristics. When the sun is high (generally above 50° elevation), cirrostratus never prevents the casting of shadows by terrestrial objects, and a halo might be completely circular. At progressively lower angles of the sun, halos become fragmentary, and light intensity noticeably decreases. When near the horizon, cirrostratus may be impossible to distinguish from cirrus.

Cirrostratus clouds are composed primarily of ice crystals and contain little, if any, icing and no turbulence.

Altocumulus (Ac) is a cloud type, white and/or gray in color, that occurs as a layer or patch with a waved aspect, the elements of which appear as laminae, rounded masses, rolls, etc. These elements usually are sharply outlined, but they may become partly fibrous or diffuse; they may or may not be merged.
Small liquid water droplets invariably compose the major part of the composition of altocumulus. This results in a sharp outline and small internal visibility. At very low temperatures, however, ice crystals may form. Pilots flying through altocumulus can expect some turbulence and small amounts of icing.

Altocumulus Lenticularis. Altocumulus Lenticularis, commonly known as Altocumulus Standing Lenticular (ACSL), are an orographic type of cloud. They often appear to be dissolving in some places and forming in others. They also often form in patches in the shape of almonds or wave clouds. These formations are caused by wave motions in the atmosphere and are frequently seen in mountainous or hilly areas. They may be triggered off by hills only a few thousand feet high and may extend downwind for more than 60 miles (100 kilometers). The cloud elements form at the windward edge of the cloud and are carried to the downwind edge where they evaporate. The cloud as a whole is usually stationary or slow moving. These clouds often have very smooth outlines and show definite shading.

The ACSL clouds indicate the position of the wave crests, but they do not necessarily give an indication on the intensity of turbulence or strength of updrafts and downdrafts. This is because the clouds depend on both lifting and moisture. A well-defined wave may be visible (i.e., ACSL cloud) in weak updrafts where there is an adequate supply of moisture, but may not be visible when the environment is very dry, even if the wave is intense.

Altostratus (As) is a cloud type in the form of a gray or bluish (never white) sheet or layer of striated, fibrous, or uniform appearance. Altostratus very often totally covers the sky and may, in fact, cover an area of several thousand square miles. The layer has parts thin enough to reveal the position of the sun, and if gaps and rifts appear, they are irregularly shaped and spaced. Pilots can expect little or no turbulence, but light to moderate icing in the supercooled water regions.

Nimbostratus is composed of suspended water droplets, sometimes supercooled, and of falling raindrops and/or snow crystals or snowflakes. It occupies a layer of large horizontal and vertical extent. The great density and thickness (usually many thousands of feet) of this cloud prevent observation of the sun. This, plus the absence of small droplets in its lower portion, gives nimbostratus the appearance of dim and uniform lighting from within. It also follows that nimbostratus has no well-defined base, but rather a deep zone of visibility attenuation. Frequently a false base may appear at the level where snow melts into rain. It is officially classified as a middle cloud although it may merge into very low stratus or stratocumulus. Other cloud classification systems may identify it as a low-level cloud. Nimbostratus produces very little turbulence, but can pose a serious icing problem if temperatures are near or below freezing.

Cumulus is composed of a great density of small water droplets, frequently supercooled. Within the cloud, larger water drops are formed that may, as the cloud develops, fall from the base as rain or virga.5 Ice crystal formation will occur within the cloud at sufficiently low temperatures, particularly in upper portions as the cloud grows vertically.

For cumulus with little vertical development, pilots can expect some turbulence and no significant icing. However, for towering cumulus (i.e., cumulus of moderate/strong development) pilots can expect very strong turbulence and some clear icing above the freezing level (where temperatures are negative). Towering cumulus is also referred to as the first stage of a thunderstorm.

Stratocumulus is composed of small water droplets, sometimes accompanied by larger droplets, soft hail, and (rarely) by snowflakes. Under ordinary conditions, ice crystals are too sparse even to give the cloud a fibrous aspect; however, in extremely cold weather, ice crystals may be numerous enough to produce abundant virga, and sometimes even halo phenomena. The highest liquid water contents are in the tops of these clouds where the icing threat is the greatest, if cold enough. Virga may form under the cloud, particularly at very low temperatures. Precipitation rarely occurs with stratocumulus.

Pilots can expect some turbulence and possible icing at subfreezing temperatures. Ceiling and visibility are usually better than with low stratus.

Stratus (St) is a cloud type in the form of a gray layer with a fairly uniform base. Stratus does not usually produce precipitation, but when it does occur, it is in the form of minute particles, such as drizzle, ice crystals, or snow grains. Stratus often occurs in the form of ragged patches or cloud fragments, in which case rapid transformation is a common characteristic. When the sun is seen through the cloud, its outline is clearly discernible. In the immediate area of the solar disk, stratus may appear very white. Away from the sun, and at times when the cloud is sufficiently thick to obscure it, stratus gives off a weak, uniform luminance.

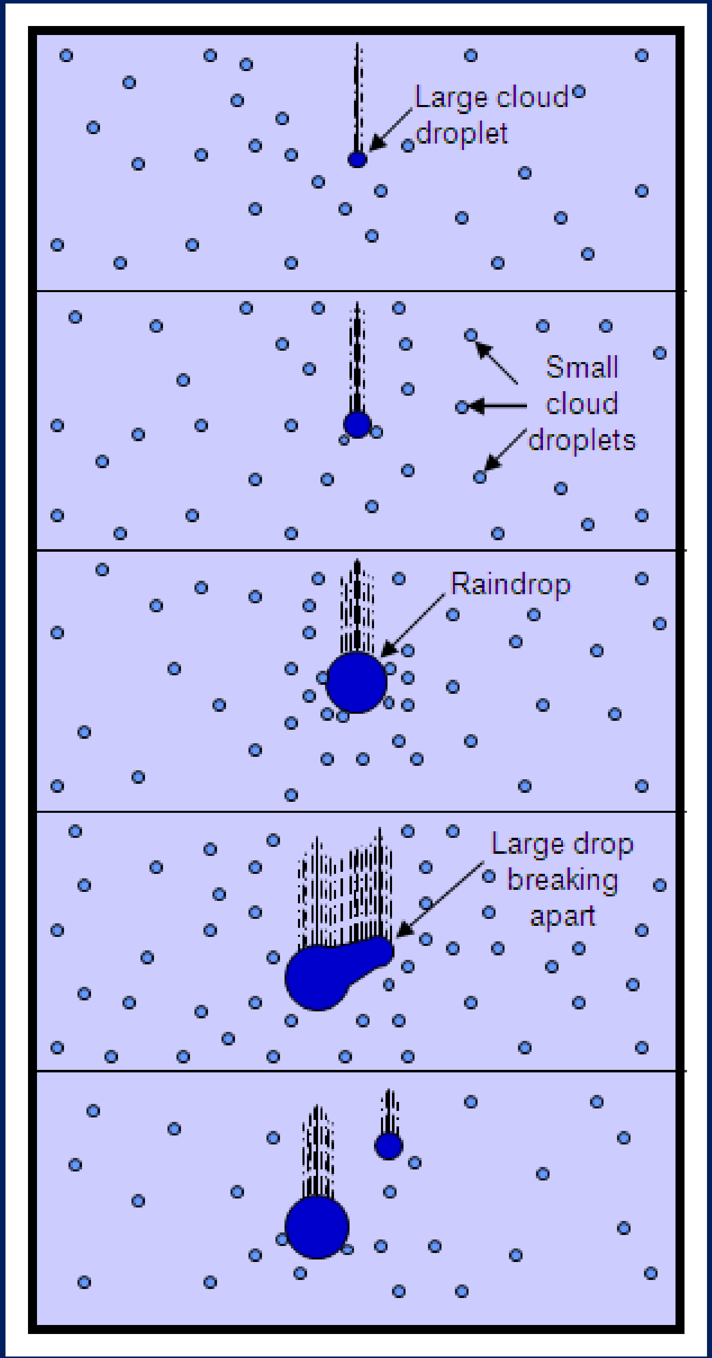
The particulate composition of stratus is quite uniform, usually of fairly widely dispersed water droplets and, at lower temperatures, of ice crystals (although this is much less common). Halo phenomena may occur with this latter composition.

Stratus produces little or no turbulence, but temperatures near or below freezing can create hazardous icing conditions. When stratus is associated with fog or precipitation, the combination can become troublesome for visual flying.

A cumulonimbus (Cb) is a cloud type, exceptionally dense and vertically developed, occurring either as isolated clouds or as a line or wall of clouds with separated upper portions. These clouds appear as mountains or huge towers, at least a part of the upper portions of which are usually smooth, fibrous, or striated, and almost flattened as it approaches the tropopause. This part often spreads out in the form of an anvil or vast plume. Under the base of cumulonimbus, which is often very dark, there frequently exist virga, precipitation, and low, ragged clouds, either merged with it or not. Its precipitation is often heavy and always of a showery nature. The usual occurrence of lightning and thunder within or from this cloud leads to its popular appellations: thundercloud, thunderhead (the latter usually refers only to the upper portion of the cloud), and thunderstorm.

Cumulonimbus is composed of water droplets and ice crystals, the latter almost entirely in its upper portions. It also contains large water drops, snowflakes, snow pellets, and sometimes hail. The liquid water forms may be substantially supercooled. Cumulonimbus contains nearly the entire spectrum of flying hazards, including extreme turbulence.

Necessary Ingredients for Formation. Precipitation formation requires three ingredients: water vapor, sufficient lift to condense the water vapor into clouds, and a growth process that allows cloud droplets to grow large and heavy enough to fall as precipitation. Significant precipitation usually requires clouds to be at least 4,000 feet thick. The heavier the precipitation, the thicker the clouds are likely to be. When arriving or departing from an airport reporting precipitation of light or greater intensity, expect clouds to be more than 4,000 feet thick.



The other process is the ice crystal process. This occurs in colder clouds when both ice crystals and water droplets are present. In this situation, it is easier for water vapor to deposit directly onto the ice crystals so the ice crystals grow at the expense of the water droplets. The crystals eventually become heavy enough to fall. If it is cold near the surface, it may snow; otherwise, the snowflakes may melt to rain. This is thought to be the primary growth process in mid- and high-latitudes.

Precipitation Types. The vertical distribution of temperature will often determine the type of precipitation that occurs at the surface. Snow occurs when the temperature remains below freezing throughout the entire depth of the atmosphere

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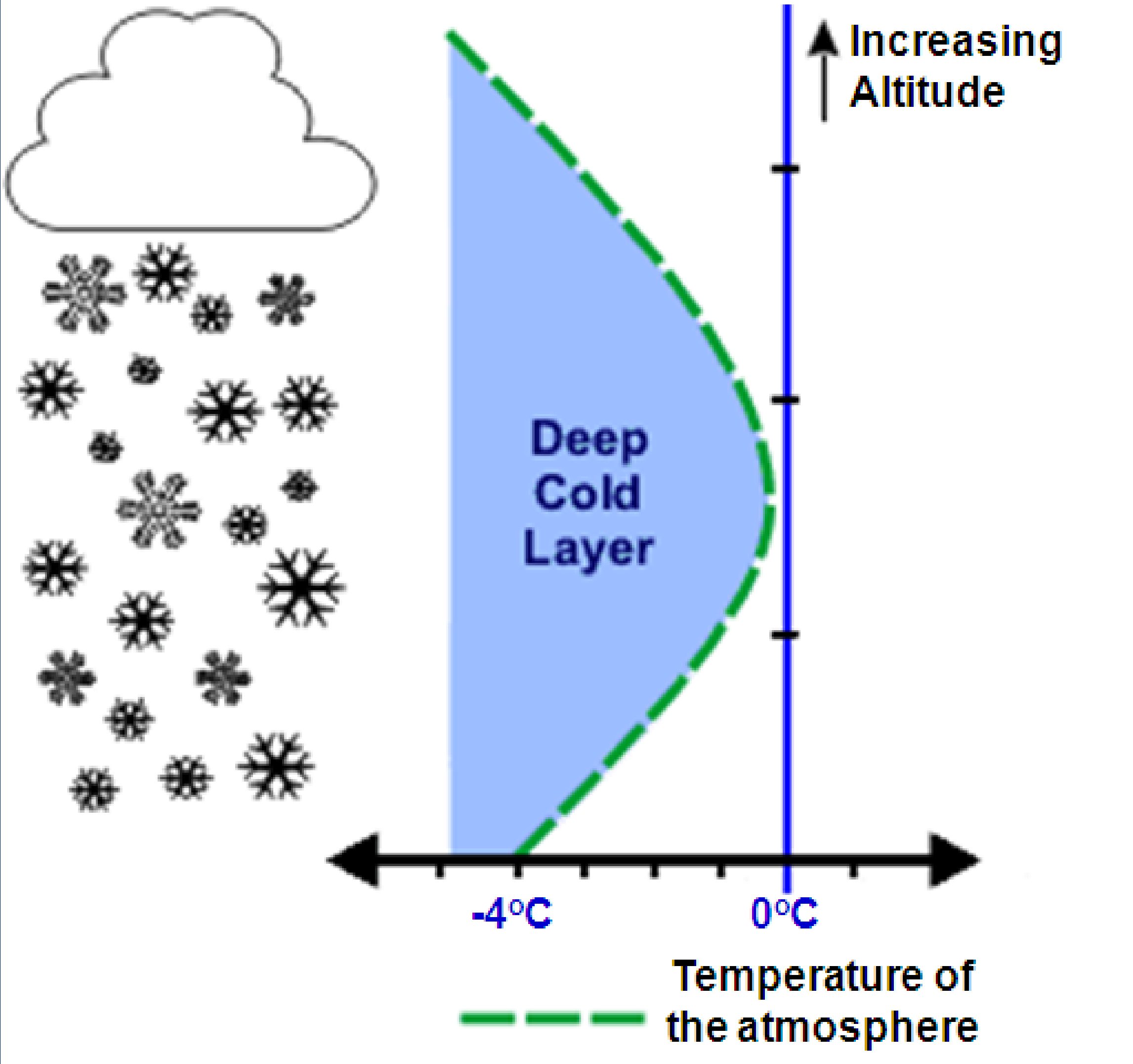
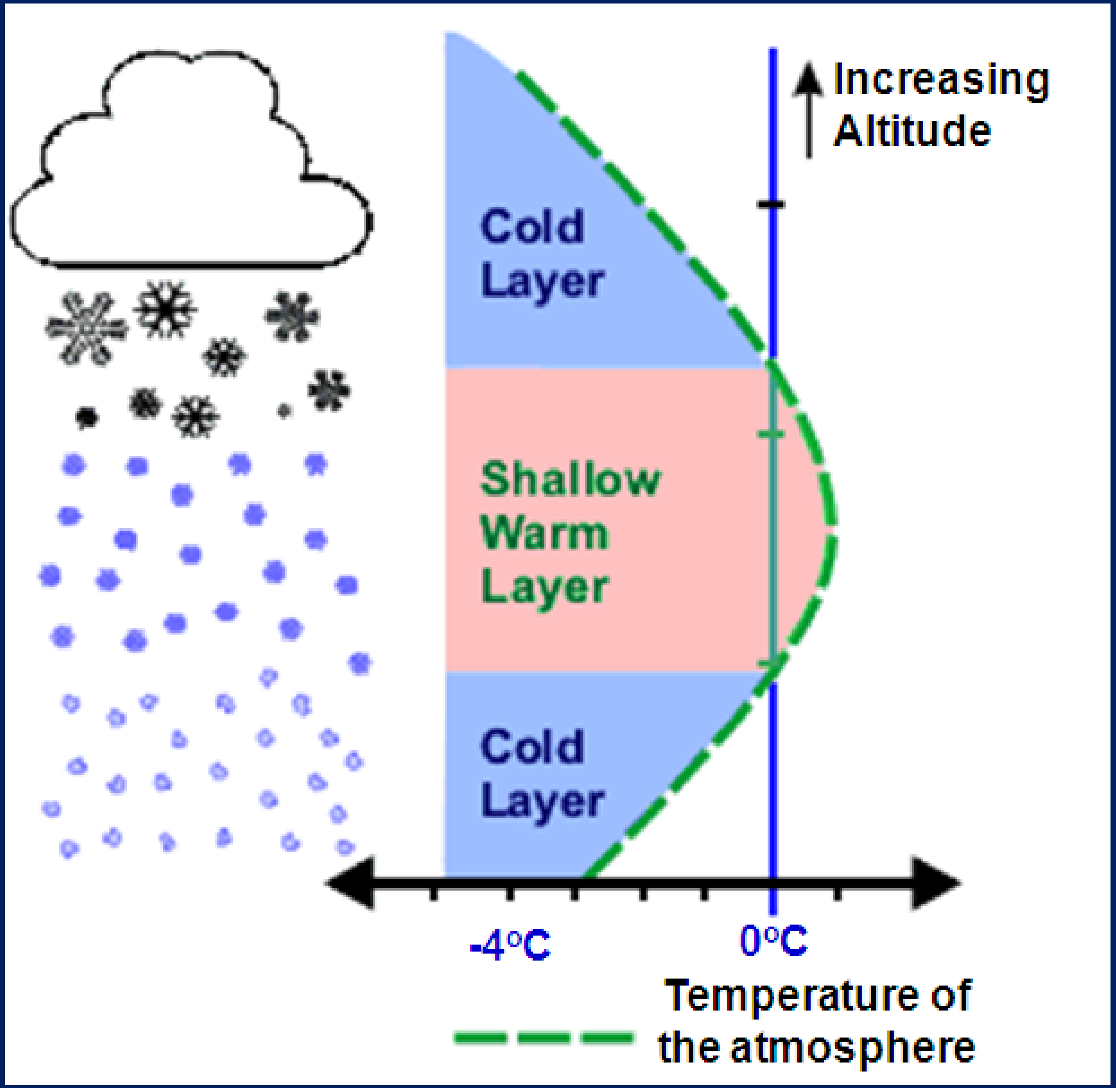
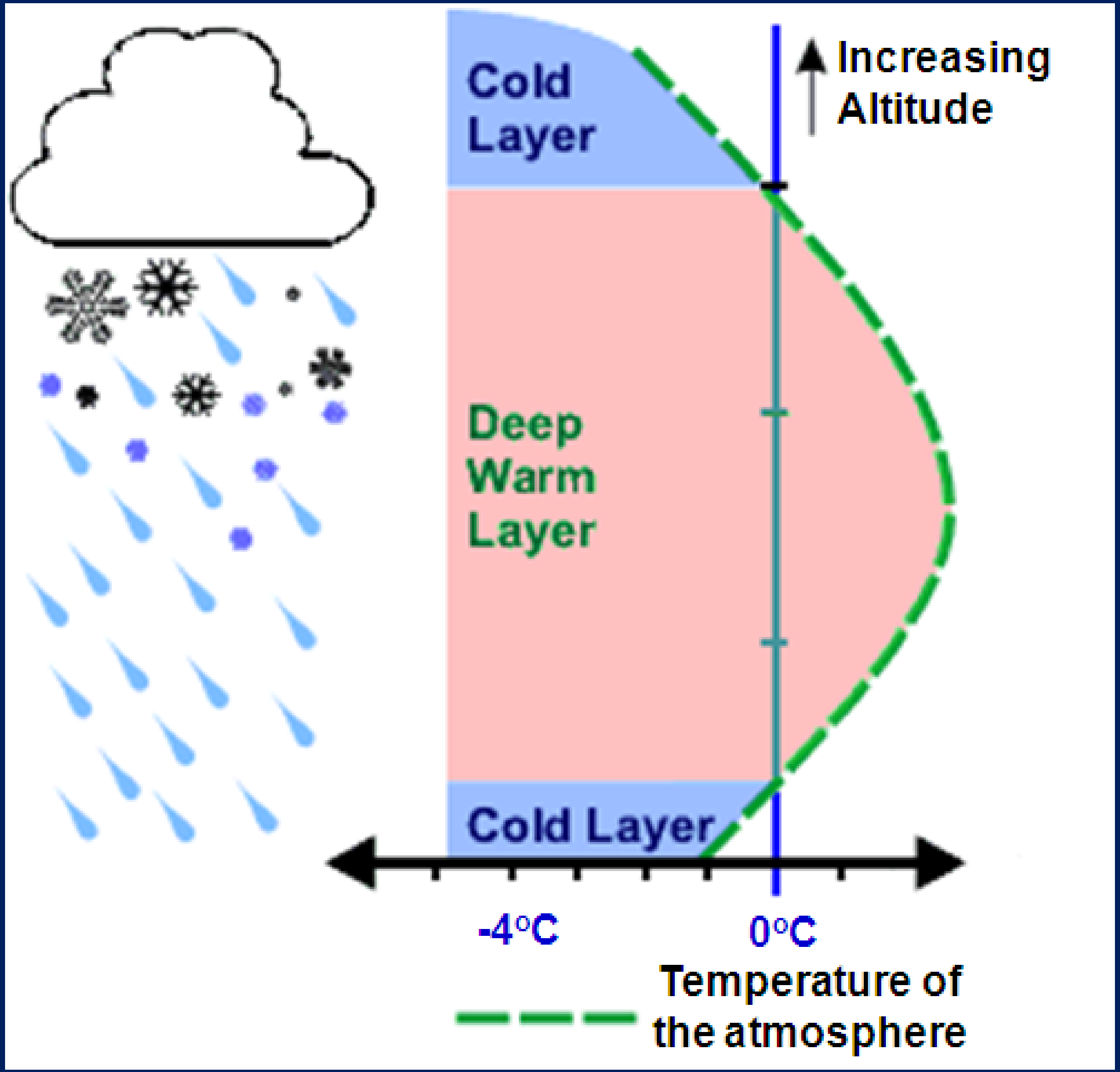


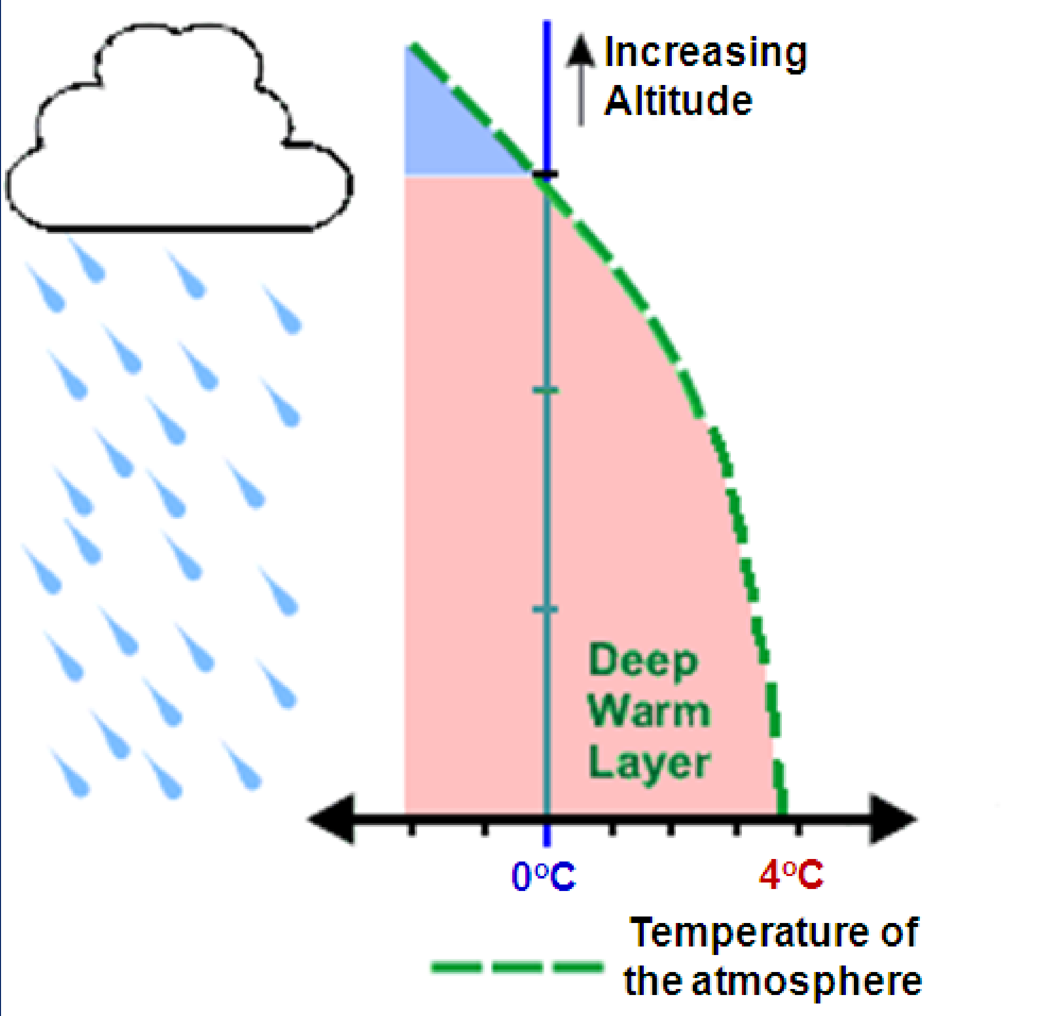
Ice pellets (sleet) occur when there is a shallow layer aloft with above freezing temperatures and with a deep layer of below freezing air based at the surface. As snow falls into the shallow warm layer, the snowflakes partially melt. As the precipitation reenters air that is below freezing, it refreezes into ice pellets



Freezing rain occurs when there is a deep layer aloft with above freezing temperatures and with a shallow layer of below freezing air at the surface. It can begin as either rain and/or snow, but becomes all rain in the warm layer. The rain falls back into below freezing air, but since the depth is shallow, the rain does not have time to freeze into ice pellets. The drops freeze on contact with the ground or exposed objects



Rain occurs when there is a deep layer of above freezing air based at the surface



Adverse wind is a category of hazardous weather that is responsible for many weather-related accidents. Adverse winds include: crosswinds, gusts, tailwind, variable wind, and a sudden wind shift. Takeoff and landing are the most critical periods of any flight and are most susceptible to the effects of adverse wind. The most at-risk group is General Aviation (GA) pilots flying aircraft with lower crosswind and tailwind threshold values.

A gust is a fluctuation of wind speed with variations of 10 knots or more between peaks and lulls.

Even if the airplane is oriented into the wind, gusts during takeoff and landing cause airspeed fluctuations which can cause problems for pilots. A gust increases airspeed, which increases lift, and may cause an aircraft to briefly balloon up. Once the gust ends, a sudden decrease of airspeed occurs, which decreases lift and causes the aircraft to sink. Gusty winds at the point of touchdown provide significant challenges to a safe landing.

A tailwind is a wind with a component of motion from behind the aircraft.
A tailwind can be hazardous during both takeoff and landing. A longer takeoff roll is necessary because a higher groundspeed is required to generate sufficient lift, and the aircraft may roll off the end of the runway before lift-off. Also, a smaller initial climb gradient occurs during takeoff, which may be insufficient to clear obstacles at the end of the runway. During a landing, a longer landing roll is required because the aircraft will touch down at a higher groundspeed. Wind should always be considered in takeoff performance planning.

Wind shear is the change in wind speed and/or direction, usually in the vertical. The characteristics of the wind shear profile are of critical importance in determining the impact for an aircraft on takeoff or landing.

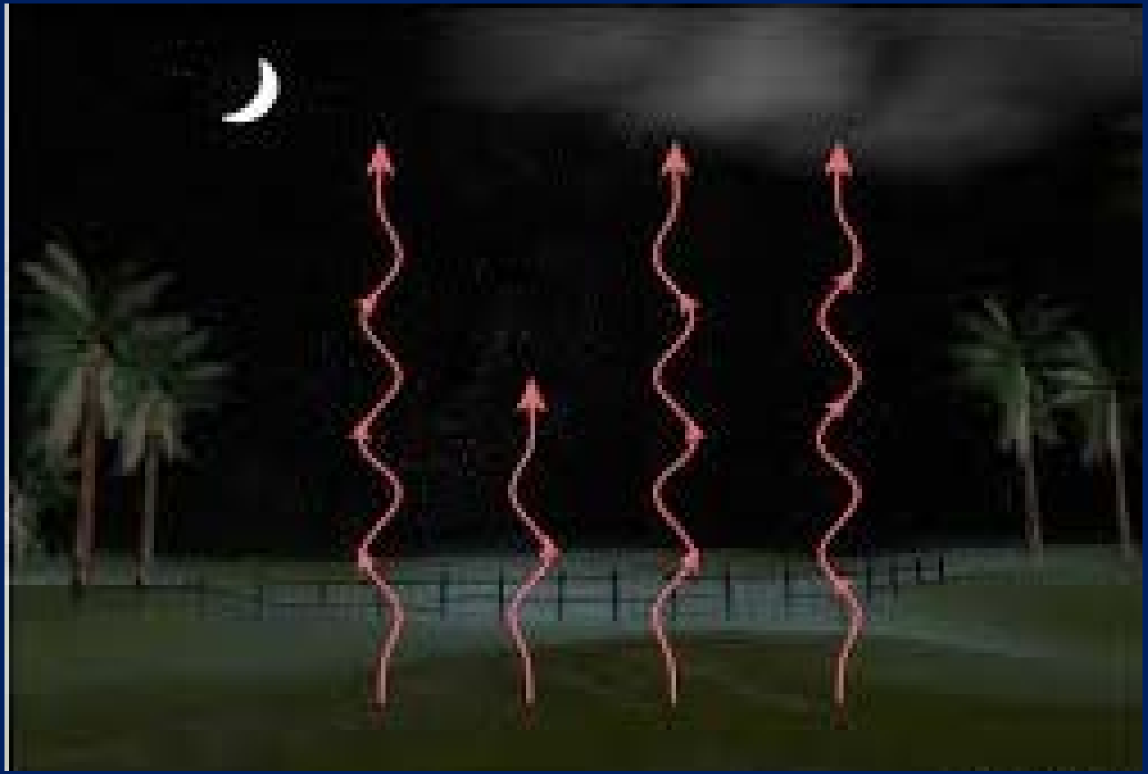
WEATHER, OBSTRUCTIONS TO VISIBILITY, LOW CEILING, AND MOUNTAIN OBSCURATION

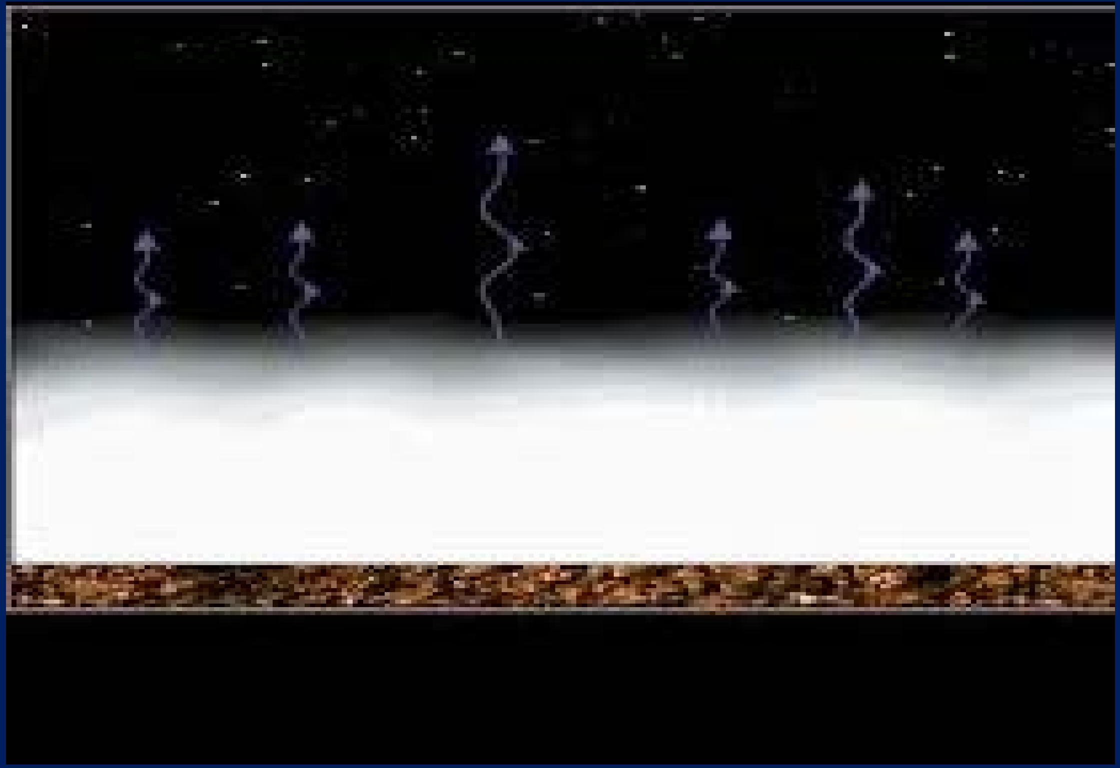
Weather and Obstructions to Visibility. Weather and obstructions to visibility include: fog, mist, haze, smoke, precipitation, blowing snow, dust storm, sandstorm, and volcanic ash.

Fog is a visible aggregate of minute water droplets that are based at the Earth’s surface and reduces horizontal visibility to less than 5/8 statute mile (1 kilometer); unlike drizzle, it does not fall to the ground. Fog differs from cloud only in that its base must be at the Earth’s surface, while clouds are above the surface.
Cloud droplets can remain liquid even when the air temperature is below freezing. Fog composed of water droplets and occurring with temperatures at or below freezing is termed freezing fog. When fog is composed of ice crystals, it is termed ice fog. If fog is so shallow that it is not an obstruction to vision at a height of 6 feet (2 meters) above the surface, it is called simply shallow (ground) fog.

Fog forms when the temperature and dewpoint of the air become identical (or nearly so). This may occur through cooling of the air to a little beyond its dewpoint (producing radiation fog, advection fog, or upslope fog), or by adding moisture and thereby elevating the dewpoint (producing frontal fog or steam fog). Fog seldom forms when the temperature-dewpoint spread is greater than 2 °C (4 °F).

Fog types are named according to their formation mechanism.
Radiation Fog. Radiation fog is a common type of fog, produced over a land area when radiational cooling reduces the air temperature to or below its dewpoint. Thus, radiation fog is generally a nighttime occurrence and often does not dissipate until after sunrise.





Radiation fog is relatively shallow fog. It may be dense enough to hide the entire sky or may conceal only part of the sky. Ground fog is a form of radiation fog that is confined to near ground level.

Factors favoring the formation of radiation fog are:

1) a shallow surface layer of relatively moist air beneath a dry layer,

2) clear skies, and

3) light surface winds. Terrestrial radiation cools the ground; in turn, the ground cools the air in contact with it. When the air is cooled to its dewpoint, fog forms.

4) When rain soaks the ground, followed by clearing skies, radiation fog is not uncommon the following morning.

Radiation fog is restricted to land because water surfaces cool little from nighttime radiation. It is shallow when wind is calm. Winds up to about 5 knots mix the air slightly and tend to deepen the fog by spreading the cooling through a deeper layer. Stronger winds disperse the fog or mix the air through a still deeper layer with stratus clouds forming at the top of the mixing layer.

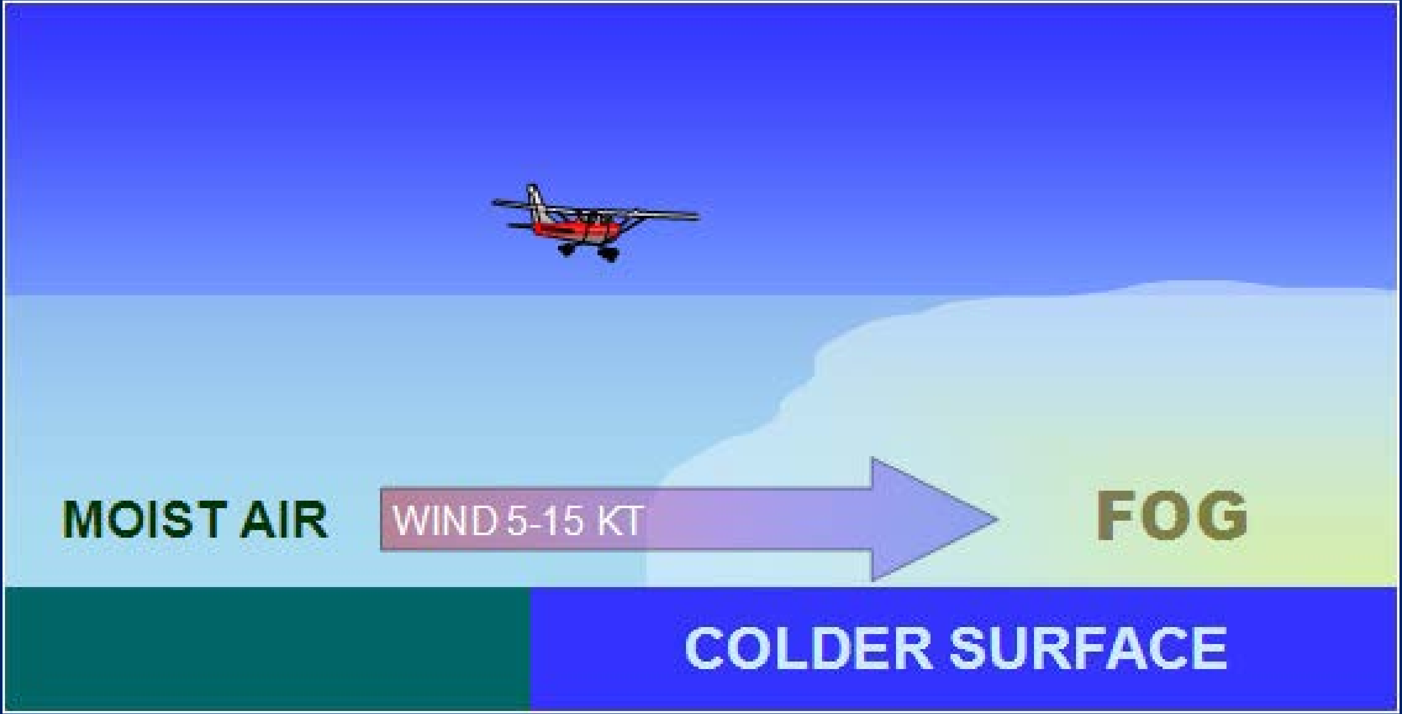
Ground fog usually burns off rather rapidly after sunrise. Other radiation fog generally clears before noon unless clouds move in over the fog. It can be difficult at times to differentiate between this and other types of fog, especially since nighttime cooling intensifies all fogs.

Advection fog forms when moist air moves over a colder surface, and the subsequent cooling of that air to below its dewpoint. It is most common along coastal areas, but often moves deep in continental areas. At sea, it is called sea fog. Advection fog deepens as wind speed increases up to about 15 knots. Wind much stronger than 15 knots lifts the fog into a layer of low stratus or stratocumulus clouds.

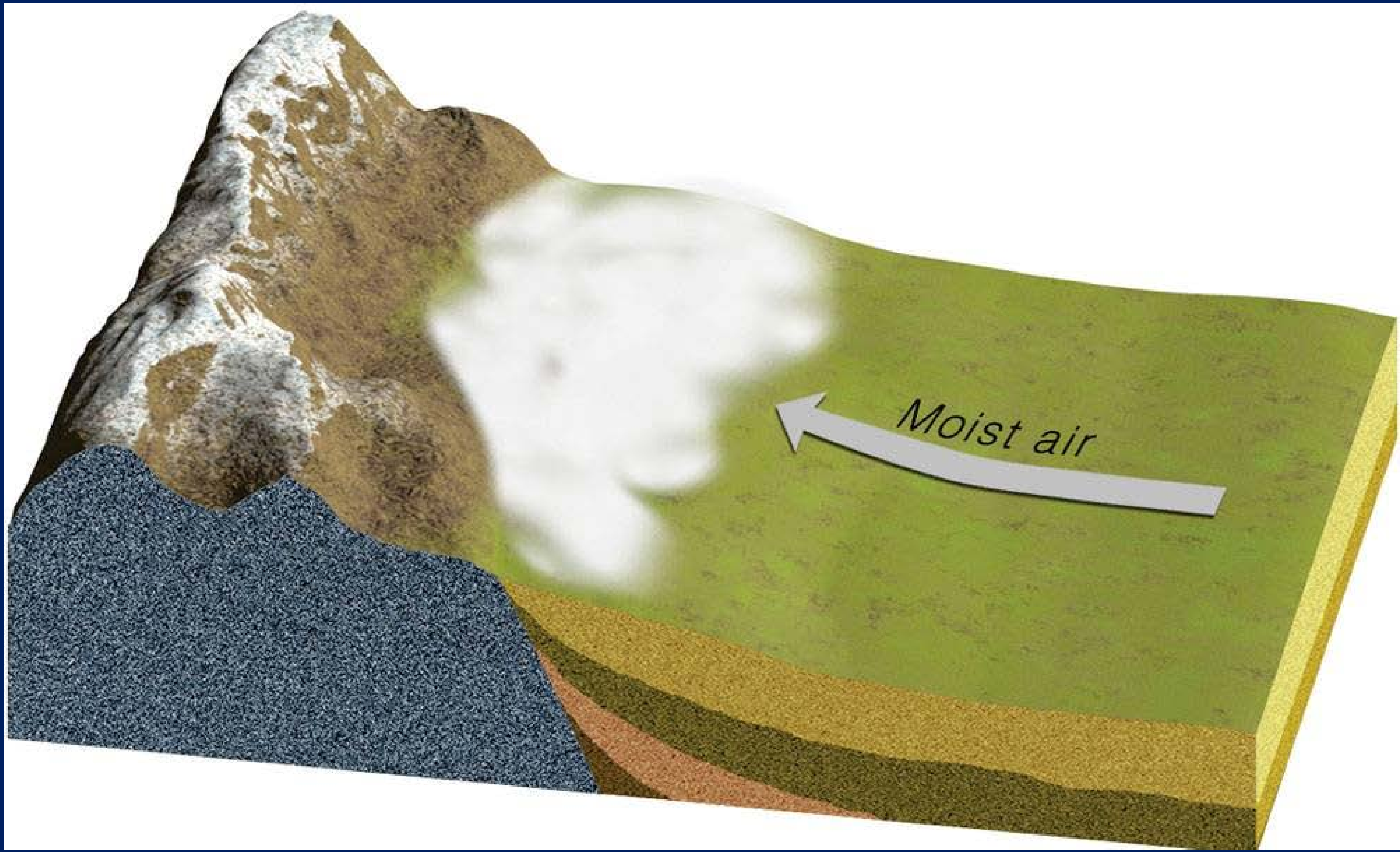
The west coast of the United States is quite vulnerable to advection fog. This fog frequently forms offshore as a result of cold water and then is carried inland by the wind. It can remain over the water for weeks, advancing over the land during night and retreating back over the water the next morning.

During the winter, advection fog over the central and eastern United States results when moist air from the Gulf of Mexico spreads northward over cold ground. The fog may extend as far north as the Great Lakes. Water areas in northern latitudes have frequent dense sea fog in summer as a result of warm, moist, tropical air flowing northward over colder Arctic waters.

A pilot will notice little difference between flying over advection fog and over radiation fog. Also, advection fog is usually more extensive and much more persistent than radiation fog. Advection fog can move in rapidly regardless of the time of day or night.

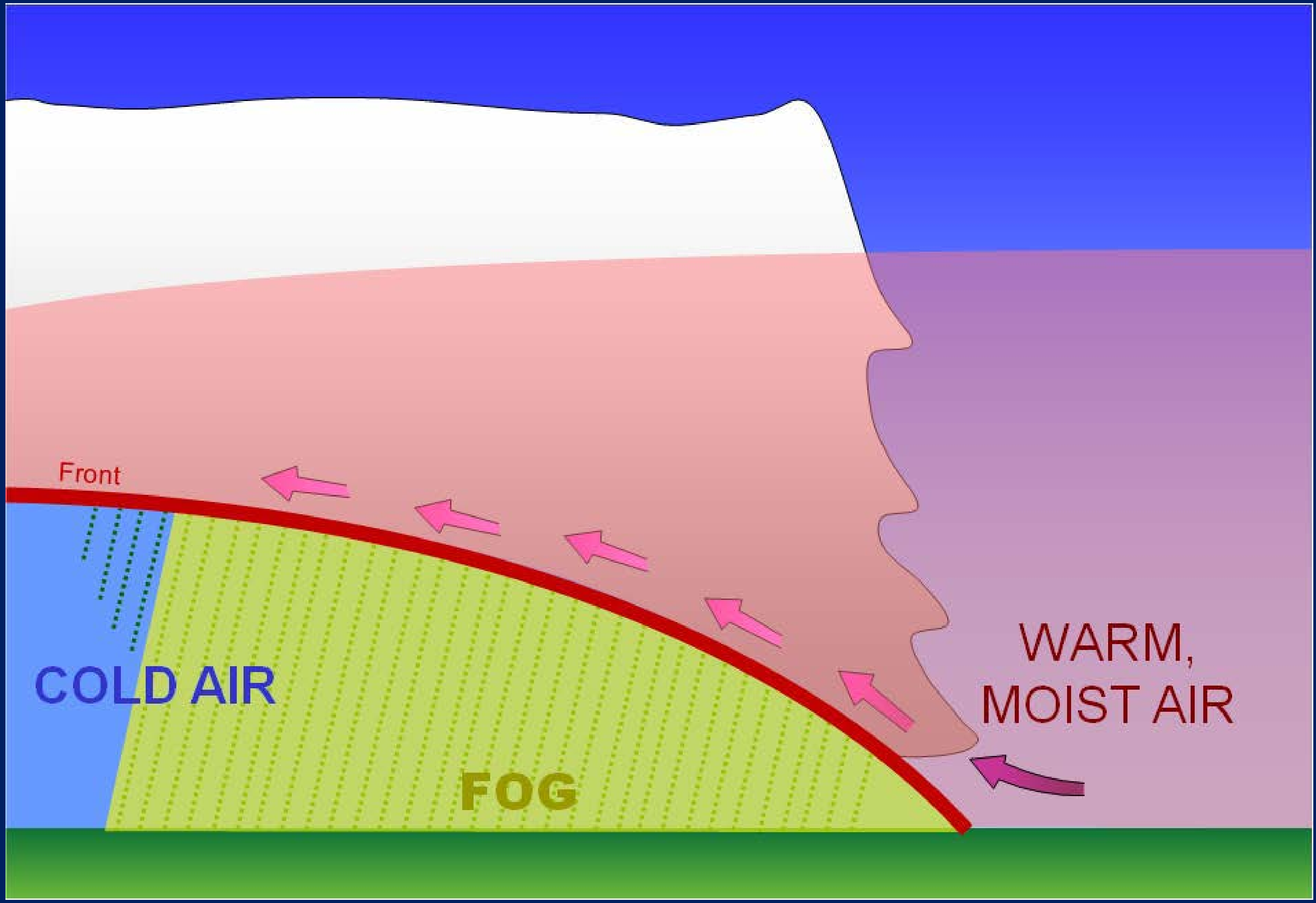


Upslope Fog. Upslope fog forms as a result of moist, stable air being adiabatically cooled to or below its dewpoint as it moves up sloping terrain. Winds speeds of 5 to 15 knots are most favorable since stronger winds tend to lift the fog into a layer of low stratus clouds. Unlike radiation fog, it can form under cloudy skies. Upslope fog is common along the eastern slopes of the Rockies, and somewhat less frequent east of the Appalachians. Upslope fog is often quite dense and extends to high altitudes.



Frontal Fog. When warm, moist air is lifted over a front, clouds and precipitation may form. If the cold air below is near its dewpoint, evaporation (or sublimation) from the precipitation may saturate the cold air and form fog

A fog formed in this manner is called frontal (or precipitation-induced) fog. The result is a more or less continuous zone of condensed water droplets reaching from the ground up through the clouds. Frontal fog can become quite dense and continue for an extended period of time. This fog may extend over large areas, completely suspending air operations. It is most commonly associated with warm fronts, but can occur with other fronts as well.



Steam Fog. When very cold air moves across relatively warm water, enough moisture may evaporate from the water surface to produce saturation. As the rising water vapor meets the cold air, it immediately recondenses and rises with the air that is being warmed from below. Because the air is destabilized, fog appears as rising filaments or streamers that resemble steam. This phenomenon is called steam fog. It is commonly observed over lakes and streams on cold autumn mornings, and over the ocean during the winter when cold air masses move off the continents and ice shelves. Steam fog is often very shallow, for as the steam rises, it reevaporates in the unsaturated air above. However, it can be dense and extend over large areas.

Steam fog is associated with a shallow layer of unstable air. Thus, pilots can expect convective turbulence flying through it. On occasion, columns of condensed vapor rise from the fog layer, forming whirling steam devils, which appear similar to the dust devils on land.

Mist. Mist is a visible aggregate of minute water droplets or ice crystals suspended in the atmosphere that reduces visibility to less than 7 statute miles (11 kilometers), but greater than, or equal to, 5/8 statute mile (1 kilometer). Mist forms a thin grayish veil that covers the landscape. It is similar to fog, but does not obstruct visibility to the same extent.

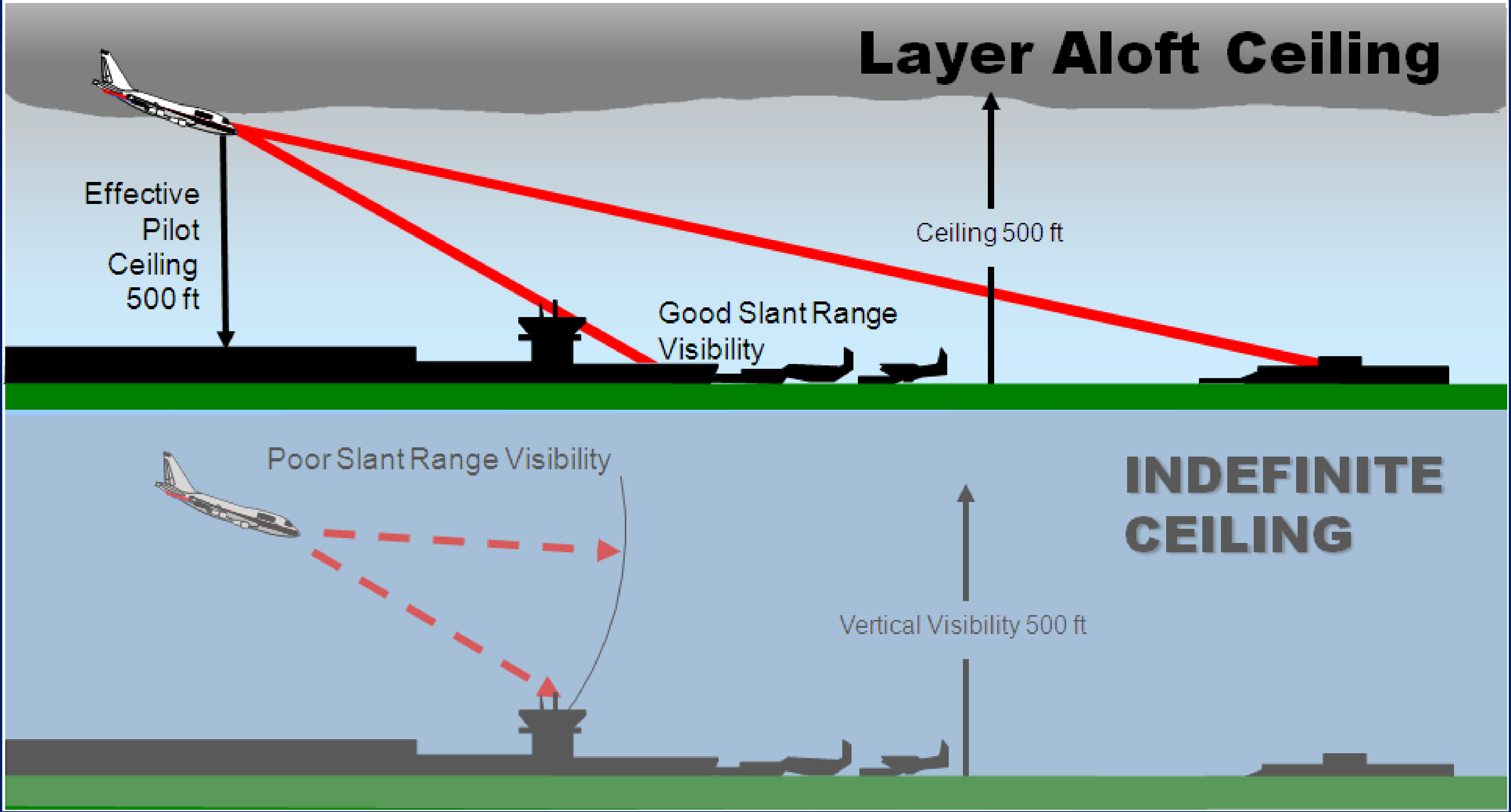
Mist may be considered an intermediate between fog and haze. It has lower relative humidity (95-99 percent) than fog and does not obstruct visibility to the same extent. However, there is no distinct line between any of these categories.

Haze. Haze is a suspension in the air of extremely small particles invisible to the naked eye and sufficiently numerous to give the air an opalescent appearance. It reduces visibility by scattering the shorter wavelengths of light. Haze produces a bluish color when viewed against a dark background and a yellowish veil when viewed against a light background. Haze may be distinguished by this same effect from mist, which yields only a gray obscuration. Certain haze particles increase in size with increasing relative humidity, drastically decreasing visibility. While visibility is a measure of how far one can see, including the ability to see the textures and colors therein, haze is the inability to view a similar scene with equal clarity.

Haze occurs in stable air and is usually only a few thousand feet thick, but may extend upwards to 15,000 feet (4,600 meters). A haze layer has a definite ceiling above which in-flight (air-to-air) visibility is unrestricted. At or below this level, the slant range (air-to-ground) visibility is poor. Visibility in haze varies greatly, depending on whether the pilot is facing into or away from the sun.

Stratus is the most frequent cloud associated with low ceilings. Stratus clouds, like fog, are composed of extremely small water droplets or ice crystals suspended in air. An observer on a mountain in a stratus layer would call it fog. Stratus and fog frequently exist together. In many cases, there is no real line of distinction between the fog and stratus; rather, one gradually merges into the other. Flight visibility may approach zero in stratus clouds. Stratus over land tends to be lowest during night and early morning, lifting or dissipating due to solar heating by late morning or early afternoon. Low stratus clouds often occur when moist air mixes with a colder air mass, or in any situation where temperature-dewpoint spread is small.

Not all ceilings are equally hazardous to a pilot. An indefinite ceiling is more hazardous than an equal ceiling caused by a layer aloft. Once a pilot descends below a ceiling caused by a layer aloft, the pilot can see both the ground below and the runway ahead. However, an indefinite ceiling restricts the pilot’s slant range (air-to-ground) visibility. Thus, the pilot may not see the runway ahead after he descends below the indefinite ceiling


Layer Aloft Ceiling
Effective Pilot Ceiling 500 ft
Ceiling 500 ft
Good Slant Range Visibility
Poor Slant Range Visibility
INDEFINITE CEILING
Vertical Visibility 500 ft

A mountain obscuration is a condition in which mountains or mountain ridges are obscured due to clouds, precipitation, smoke, or other obscurations.

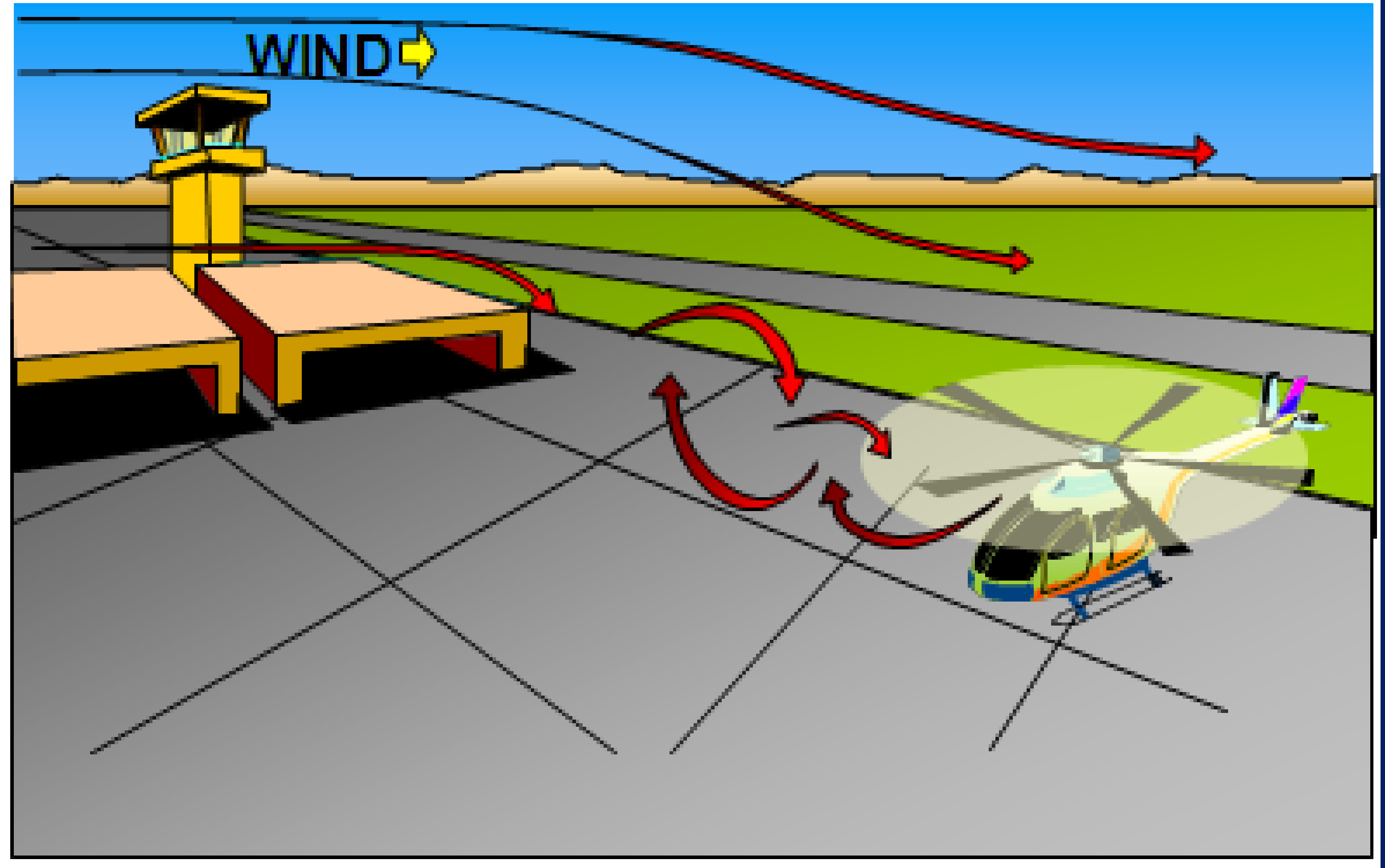
Flight can be especially hazardous over mountain routes when the mountains are obscured. The large elevation variations around mountains can cause surface weather observations to mislead. For example, a weather station located in a valley could report a visual flight rules (VFR) cloud ceiling, while a hiker in the mountains sees fog.

Aircraft turbulence is irregular motion of an aircraft in flight, especially when characterized by rapid up-and-down motion caused by a rapid variation of atmospheric wind velocities. Turbulence varies from annoying bumpiness to severe jolts which cause structural damage to aircraft and/or injury to its passengers.

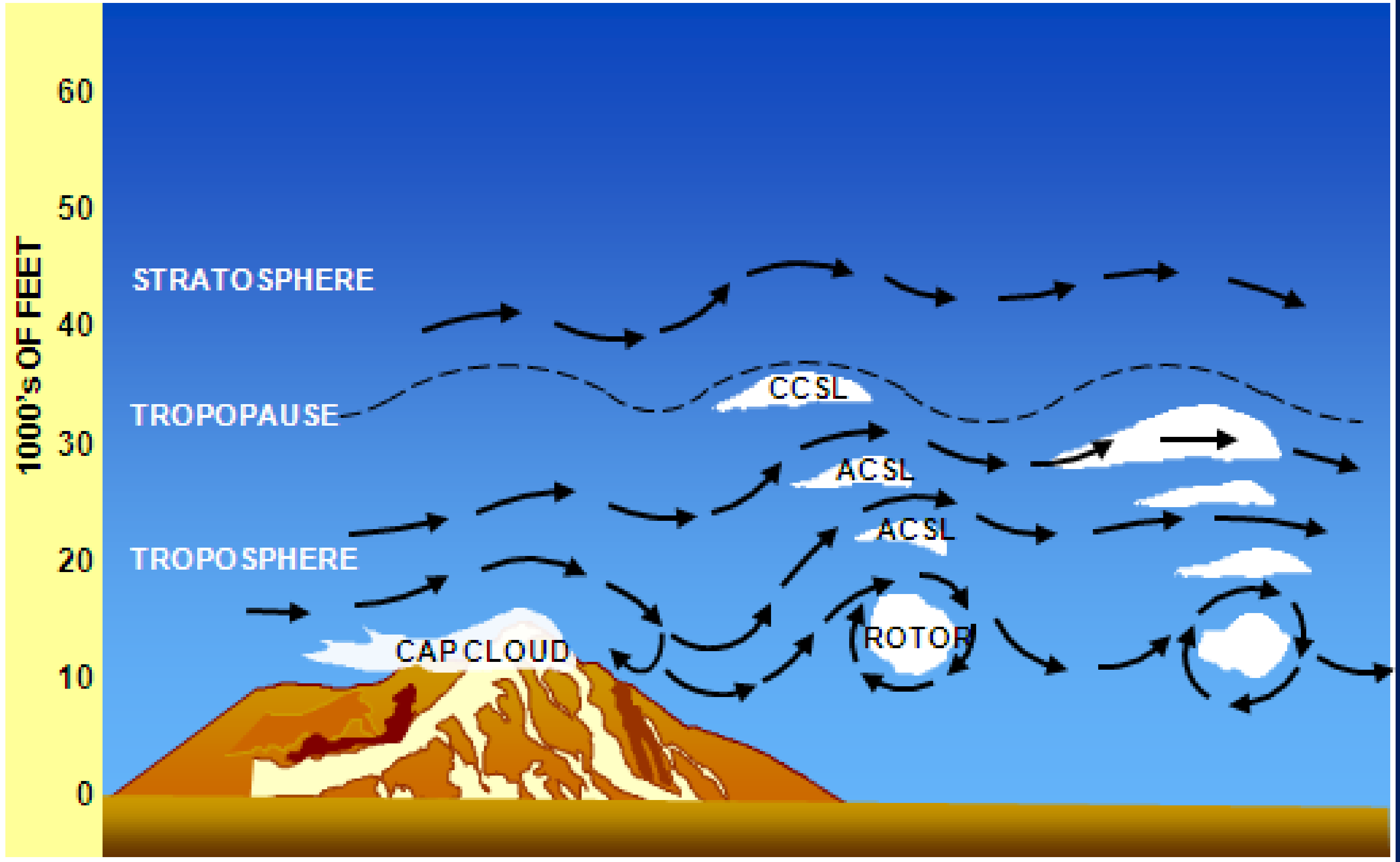
Causes of Turbulence. Turbulence is caused by convective currents (called convective turbulence), obstructions in the wind flow (called mechanical turbulence), and wind shear.

Convective Turbulence. Convective turbulence is turbulent vertical motions that result from convective currents and the subsequent rising and sinking of air. For every rising current, there is a compensating downward current. The downward currents frequently occur over broader areas than do the upward currents; therefore, they have a slower vertical speed than do the rising currents.

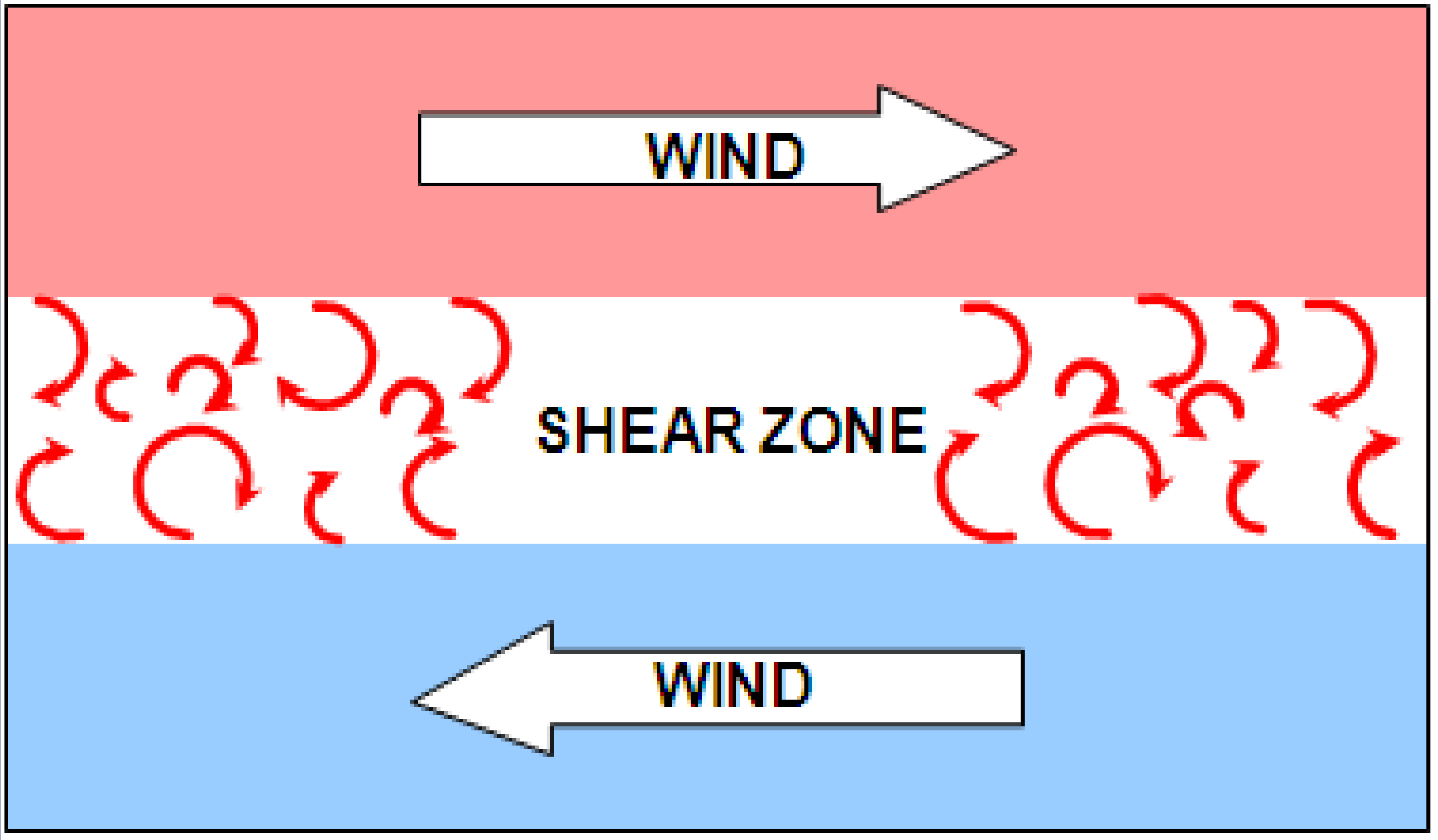
Mechanical turbulence is turbulence caused by obstructions to the wind flow, such as trees, buildings, mountains, and so on. Obstructions to the wind flow disrupt smooth wind flow into a complex snarl of eddies. An aircraft flying through these eddies experiences mechanical turbulence.



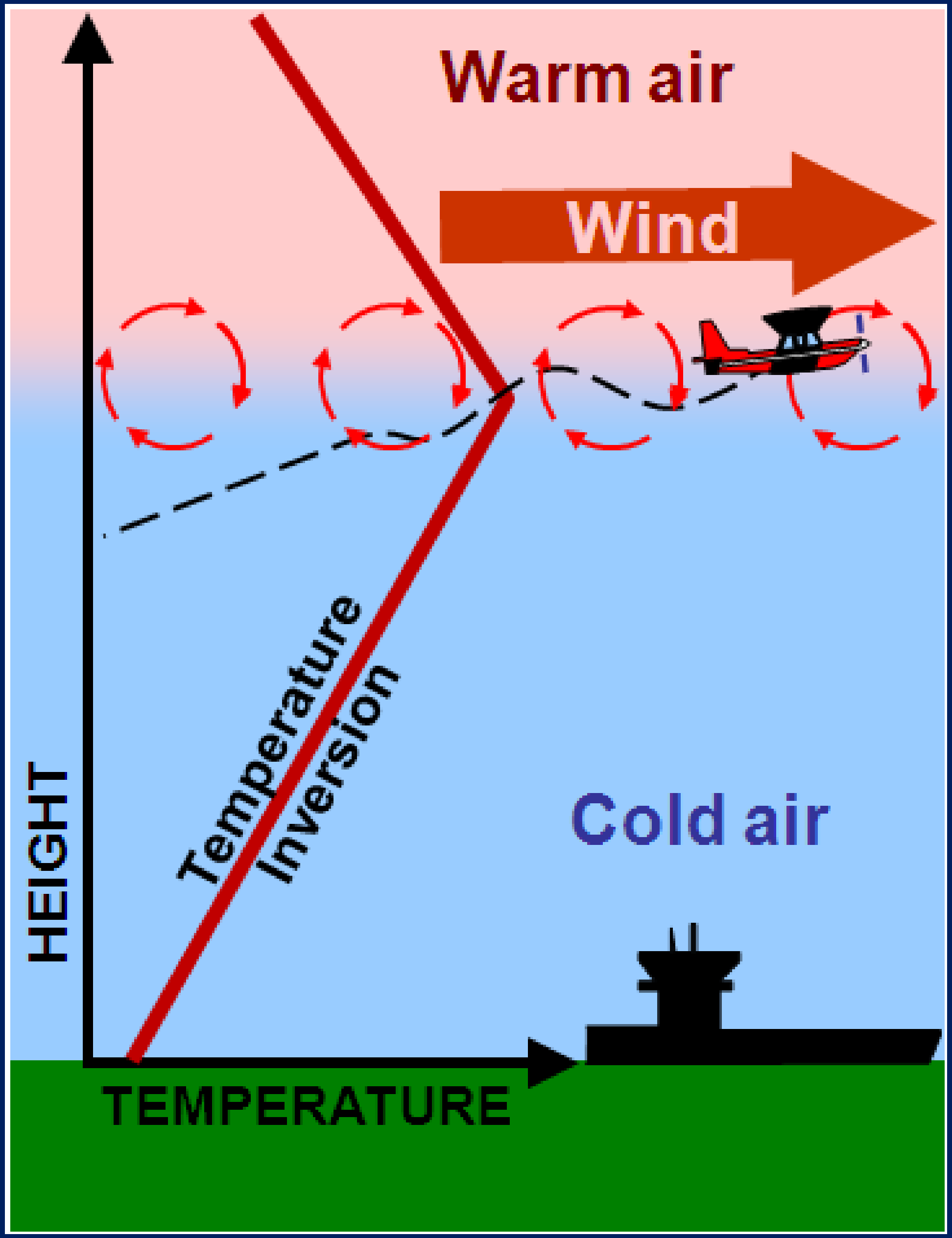
Mountain wave is an atmospheric wave disturbance formed when stable air flow passes over a mountain or mountain ridge. Mountain waves are a form of mechanical turbulence which develop above and downwind of mountains. The waves remain nearly stationary while the wind blows rapidly through them. The waves may extend 600 miles (1,000 kilometers) or more downwind from the mountain range. Mountain waves frequently produce severe to extreme turbulence. Location and intensity varies with wave characteristics. Incredibly, vertically propagating mountain waves have been documented up to 200,000 feet (60,000 meters) and higher.



Wind shear is the rate of change in wind direction and/or speed per unit distance. Wind shear generates turbulence between two wind currents of different directions and/or speeds. Wind shear may be associated with either a wind shift or a wind speed gradient at any level in the atmosphere.

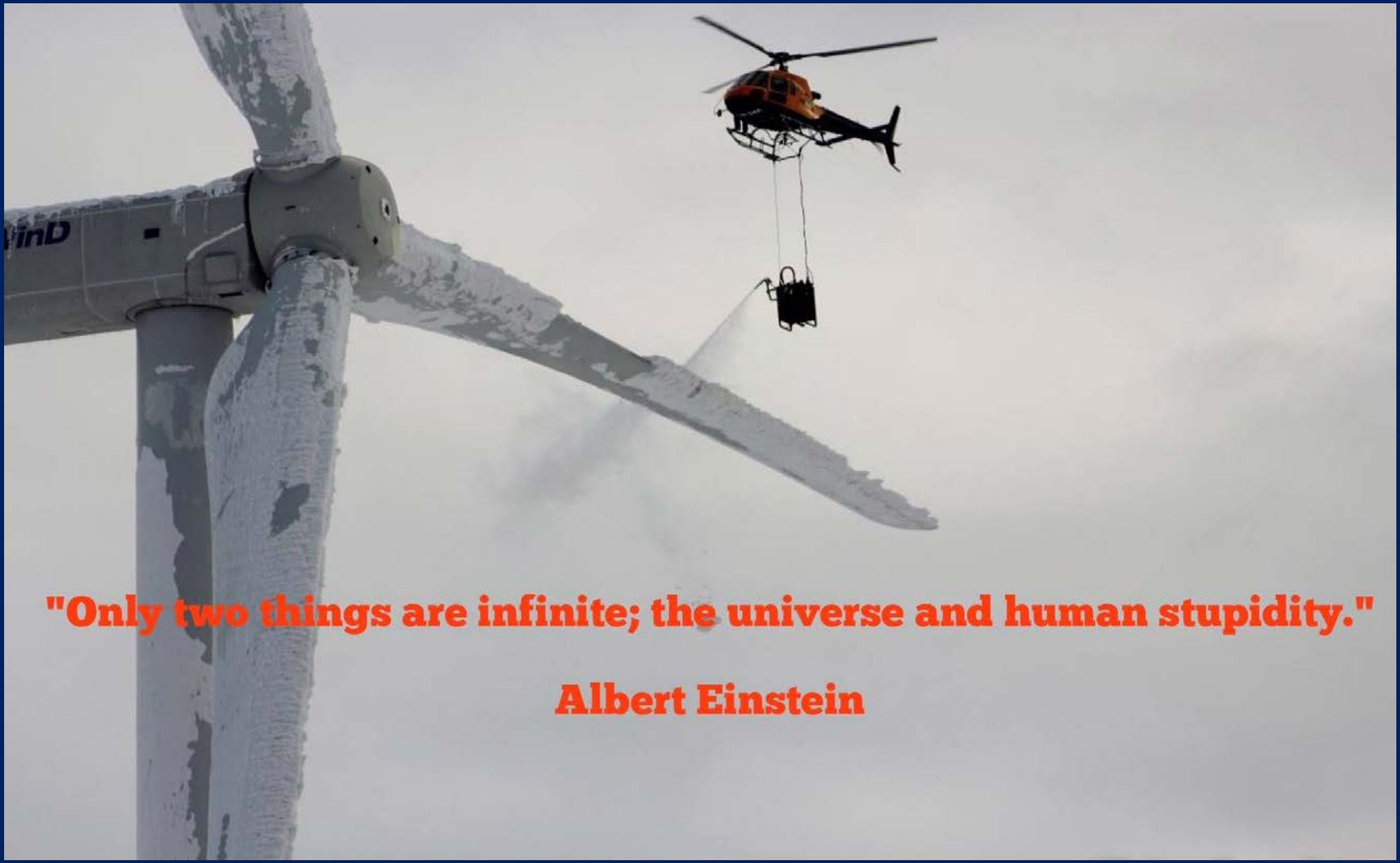


A temperature inversion is a layer of the atmosphere in which temperature increases with altitude. Inversions commonly occur within the lowest few thousand feet above ground due to nighttime radiational cooling, along frontal zones, and when cold air is trapped in a valley. Strong wind shears often occur across temperature inversion layers, which can generate turbulence



Clear Air Turbulence (CAT) is a higher altitude (~20,000 to 50,000 feet) turbulence phenomenon occurring in cloud-free regions associated with wind shear, particularly between the core of a jet stream and the surrounding air. It can often affect an aircraft without warning. CAT frequency and intensity are maximized during winter when jet streams are strongest.

Icing is any deposit of ice forming on an object. It is one of the major weather hazards to aviation. Icing is a cumulative hazard. The longer an aircraft collects icing, the worse the hazard becomes.



Supercooled Water. Freezing is a complex process. Pure water suspended in the air does not freeze until it reaches a temperature of -40 °C. This occurs because surface tension of the droplets inhibits freezing. The smaller and purer the water droplet, the more likely it is supercooled. Also, supercooled water can exist as large drops known as Supercooled Large Drops (SLD). SLDs are common in freezing rain and freezing drizzle situations

Notice how the wing's ice buildup is less on the leading edge's expandible rubber boot which had been employed prior to landing.

Supercooled water content of clouds varies with temperature. Between 0 and -10 °C clouds consist mainly of supercooled water droplets. Between -10 and -20 °C, liquid droplets coexist with ice crystals. Below -20 °C, clouds are generally composed entirely of ice crystals. However, strong vertical currents (e.g., cumulonimbus) may carry supercooled water to great heights where temperatures are as low as -40 °C.

Structural Icing. Structural icing is the stuff that sticks to the outside of the airplane. It occurs when supercooled water droplets strike the airframe and freeze. Structural icing can be categorized into three types: rime, clear (or glaze), and mixed.

Rime ice is rough, milky, and opaque ice formed by the instantaneous freezing of small, supercooled water droplets after they strike the aircraft. It is the most frequently reported icing type. Rime ice can pose a hazard because its jagged texture can disrupt an aircraft's aerodynamic integrity. Rime icing formation favors colder temperatures, lower liquid water content, and small droplets. It grows when droplets rapidly freeze upon striking an aircraft. The rapid freezing traps air and forms a porous, brittle, opaque, and milky-colored ice. Rime ice grows into the air stream from the forward edges of wings and other exposed parts of the airframe.

Clear ice (or glaze ice) is a glossy, clear, or translucent ice formed by the relatively slow freezing of large, supercooled water droplets. Clear icing conditions exist more often in an environment with warmer temperatures, higher liquid water contents, and larger droplets.

Clear ice forms when only a small portion of the drop freezes immediately while the remaining unfrozen portion flows or smears over the aircraft surface and gradually freezes. Few air bubbles are trapped during this gradual process. Thus, clear ice is less opaque and denser than rime ice. It can appear either as a thin smooth surface, or as rivulets, streaks, or bumps on the aircraft.

Clear icing is a more hazardous ice type for many reasons. It tends to form horns near the top and bottom of the airfoils leading edge, which greatly affects airflow. This results in an area of disrupted and turbulent airflow that is considerably larger than that caused by rime ice. Since it is clear and difficult to see, the pilot may not be able to quickly recognize that it is occurring. It can be difficult to remove since it can spread beyond the deicing or anti-icing equipment, although in most cases it is removed nearly completely by deicing devices.

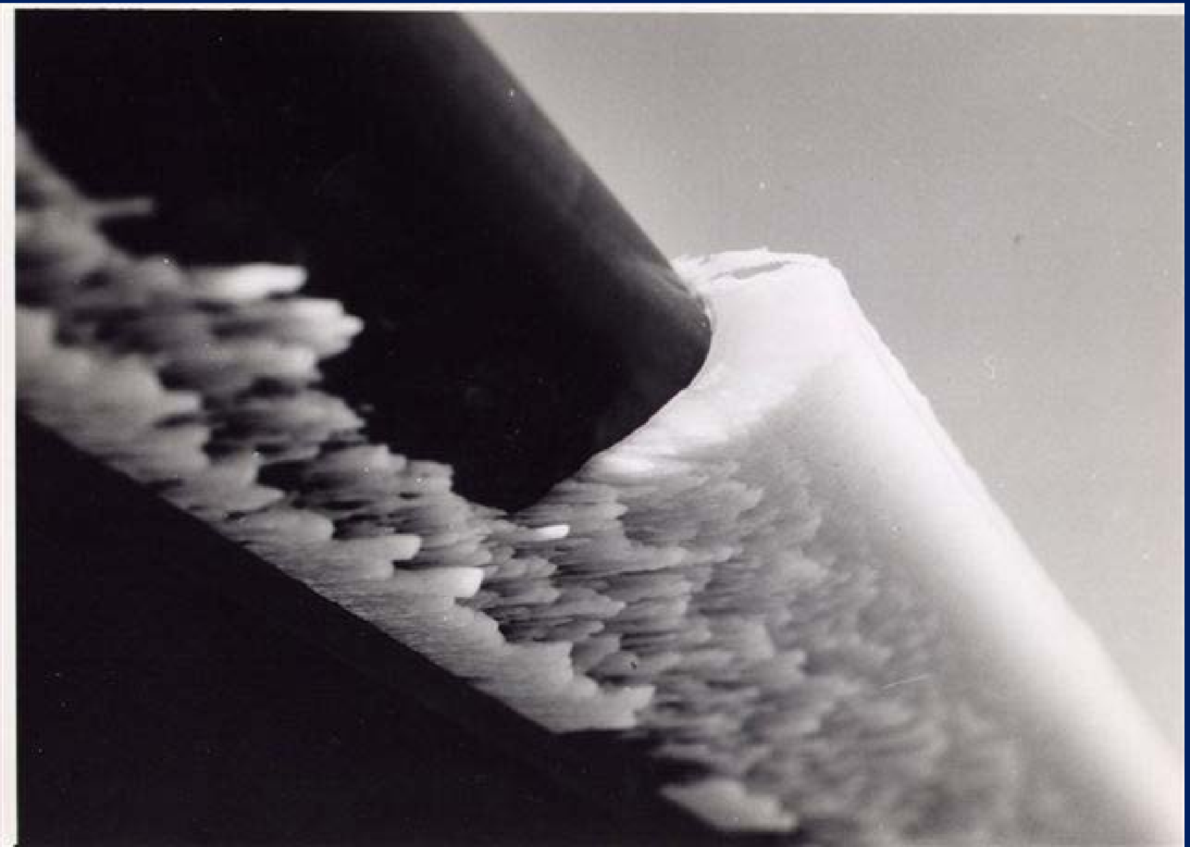
Supercooled Large Drops (SLD). A type of clear icing that is especially dangerous to flight operations is ice formed from SLDs. These are water droplets in a subfreezing environment with diameters larger than 40 microns, such as freezing drizzle (40 to 200 microns) and freezing rain (>200 microns). These larger droplets can flow along the airfoil for some distance prior to freezing. SLDs tend to form a very lumpy, uneven, and textured ice similar to glass in a bathroom window.

SLD ice tends to form aft, beyond the reach of deicing equipment. Thus, ice remaining on the airfoil continues to disrupt the airflow and reduce the aircraft’s aerodynamic integrity. Even a small amount of ice on the lower and upper surfaces of the airfoil can seriously disrupt its aerodynamic properties. The residual ice generates turbulence along a significant portion of the airfoil. This residual ice can act as a spoiler, a device actually used to slow an aircraft in flight. In extreme cases, turbulence and flow separation bubbles can travel along the airfoil and inadvertently activate the ailerons, creating dangerously unstable flying conditions.

Mixed ice is a mixture of clear ice and rime ice. It forms as an airplane collects both rime and clear ice due to small-scale (tens of kilometers or less) variations in liquid water content, temperature, and droplet sizes. Mixed ice appears as layers of relatively clear and opaque ice when examined from the side.

Mixed icing poses a similar hazard to an aircraft as clear ice. It may form horns or other shapes that disrupt airflow and cause handling and performance problems. It can spread over more of the airframe's surface and is more difficult to remove than rime ice. It can also spread over a portion of airfoil not protected by anti-icing or deicing equipment. Ice forming farther aft causes flow separation and turbulence over a large area of the airfoil, which decreases the ability of the airfoil to keep the aircraft in flight.

Icing in Stratiform Clouds. Icing in middle and low-level stratiform clouds is confined, on the average, to a layer between 3,000 and 4,000 feet thick. Thus, a change in altitude of only a few thousand feet may take the aircraft out of icing conditions, even if it remains in clouds. Icing intensity generally ranges from a trace to light, with the maximum values occurring in the cloud’s upper portions. Both rime and mixed are found in stratiform clouds. The main hazard lies in the great horizontal extent of stratiform clouds layers. High-level stratiform clouds (i.e., at temperatures colder than -20 °C) are composed mostly of ice crystals and produce little icing.



Icing in Cumuliform Clouds. The icing layer in cumuliform clouds is smaller horizontally, but greater vertically than in stratiform clouds. Icing is more variable in cumuliform clouds because many of the factors conducive to icing depend on the particular cloud's stage of development. Icing intensities may range from a trace in small cumulus to severe in a large towering cumulus or cumulonimbus. Although icing occurs at all levels above the freezing level in a building cumuliform cloud, it is most intense in the upper portion of the cloud where the updraft is concentrated and SLDs are plentiful. Icing can extend to great heights in towering cumulus and cumulonimbus where strong updrafts allow SLDs to exist at temperatures as cold as -40 °C. Icing in a cumuliform cloud is usually clear or mixed with rime in the upper levels.

Icing with Fronts. Most icing reports occur in the vicinity of fronts. This icing can occur both above and below the front .

For significant icing to occur above the front, the warm air must be lifted and cooled to saturation at temperatures below zero, making it contain supercooled water droplets. The supercooled water droplets freeze on impact with an aircraft. If the warm air is unstable, icing may be sporadic; if it is stable, icing may be continuous over an extended area. A line of showers or thunderstorms along a cold front may produce icing, but only in a comparatively narrow band along the front.

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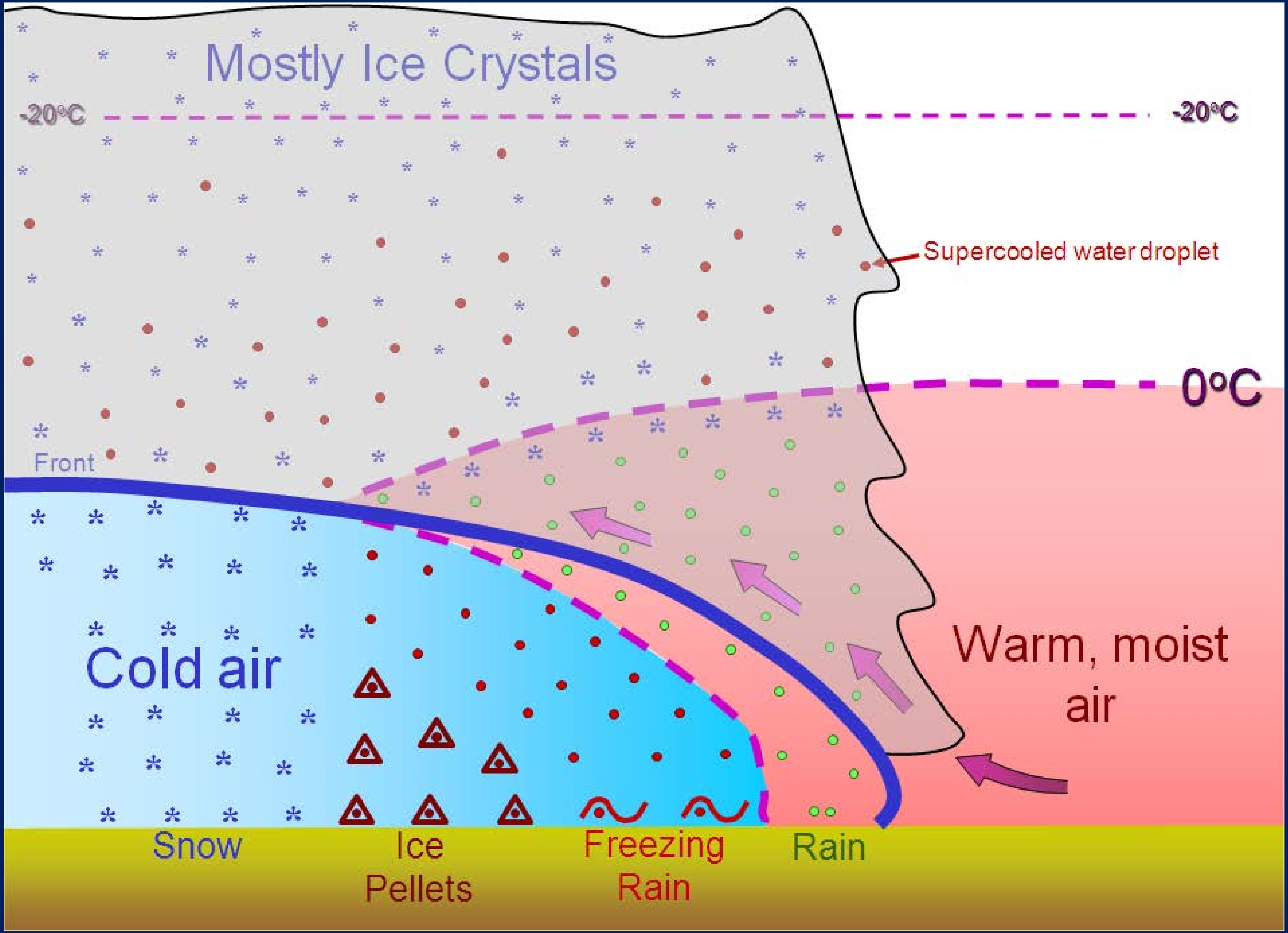


Mostly Ice Crystals
-20°C
-20°C
Supercooled water droplet
0°C
Front
Cold air
Warm, moist air
Snow
Ice Pellets
Freezing Rain
Rain

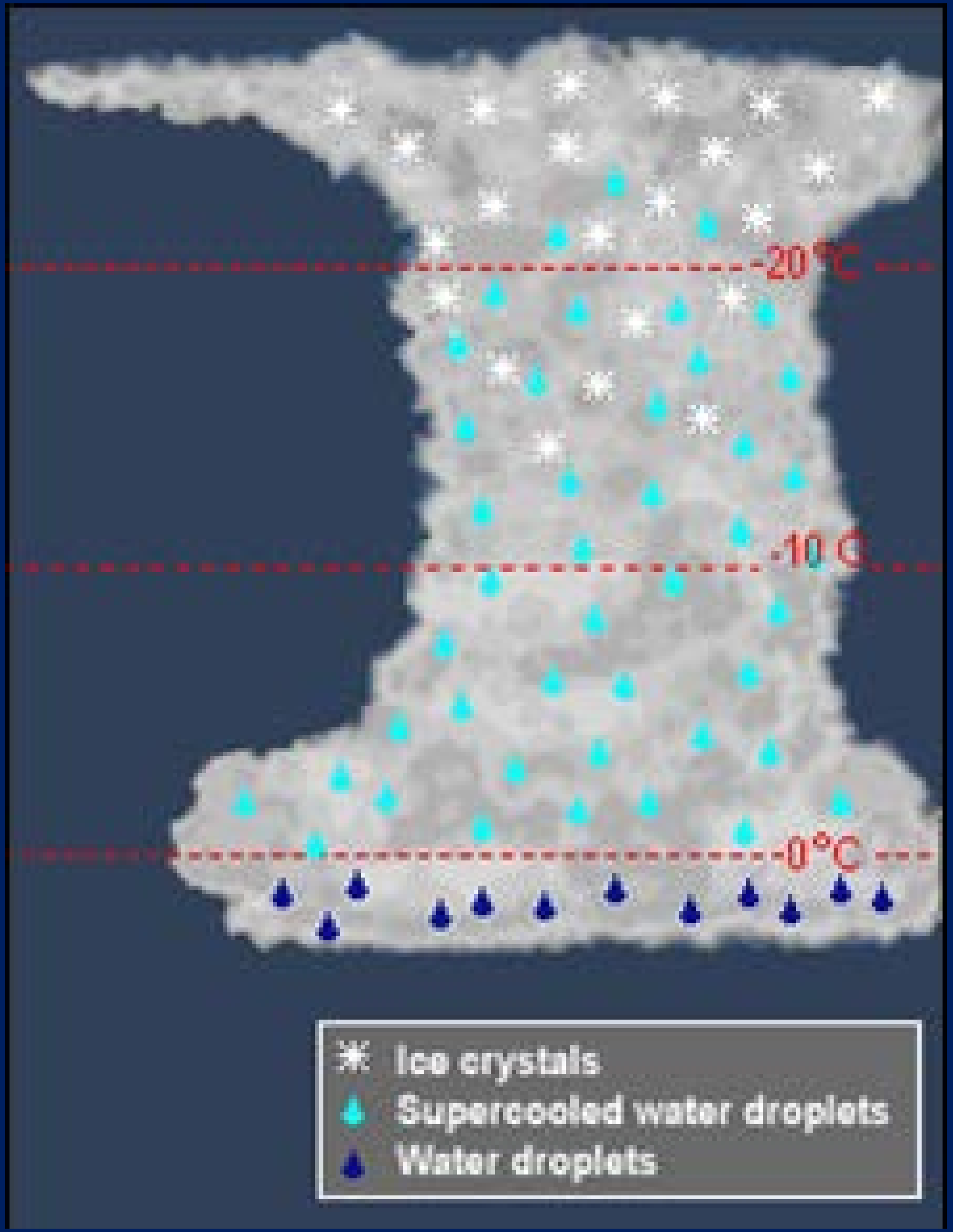
A favored location for severe clear icing is freezing rain and/or freezing drizzle below a front. Rain forms above the frontal surface at temperatures warmer than freezing. Subsequently, it falls through air at temperatures below freezing and becomes supercooled. The SLDs freeze on impact with an aircraft. If the below freezing layer is shallow, freezing rain will occur at the surface. If the below freezing layer is deep, the supercooled droplets may freeze into ice pellets. Ice pellets indicate icing above. The icing can be severe because of the large amount of supercooled water. Icing in freezing precipitation is especially dangerous because it often extends horizontally over a broad area and a pilot may be unable to escape it by descending to a lower altitude.

Icing Hazards. Structural icing degrades an aircraft's performance. It destroys the smooth flow of air, increasing drag while decreasing the ability of the airfoil to create lift. The actual weight of ice on an airplane is insignificant when compared to the airflow disruption it causes. As power is added to compensate for the additional drag, and the nose is lifted to maintain altitude, the angle of attack is increased. This allows the underside of the wings and fuselage to accumulate additional ice.

Wind tunnel and flight tests have shown that frost, snow, and ice accumulations (on the leading edge or upper surface of the wing) no thicker or rougher than a piece of coarse sandpaper can reduce lift by 30 percent and increase drag up to 40 percent. Larger accretions can reduce lift even more and can increase drag by 80 percent or more.

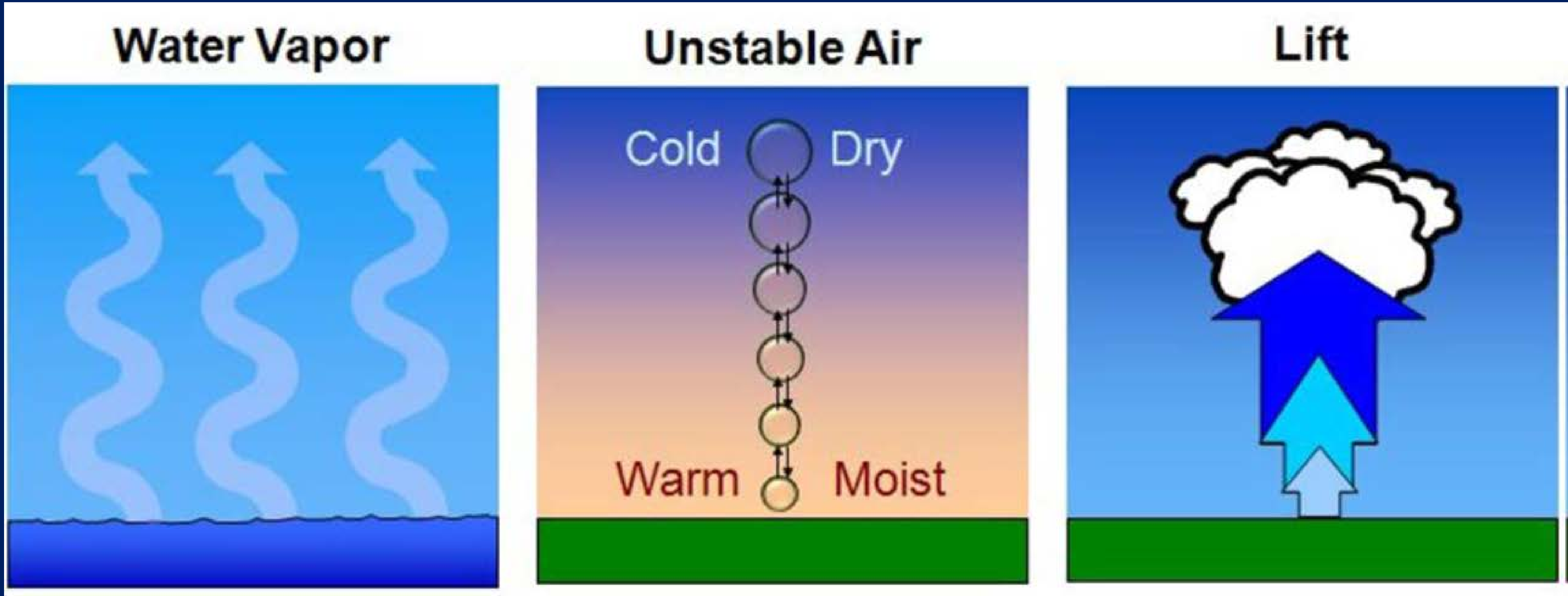
Ice accumulates on every exposed frontal surface of the airplane: wings, propeller, windshield, antennas, vents, intakes, and cowlings. It can build in flight where no heat or boots can reach it. It can cause antennas to vibrate so severely that they break. In moderate to severe icing, a light aircraft could be subject to enough ice accumulation or accretion that continued flight is impossible. The airplane may stall at much higher speeds and lower angles of attack than normal. It can roll or pitch uncontrollably, and recovery might be impossible.

Regardless of anti-ice or deice protection offered by the aircraft, a pilot's first course of action should be to leave the area of visible moisture. This might mean descending to an altitude below the cloud bases, climbing to an altitude that is above the cloud tops, or turning to a different course. If this is not possible, then the pilot must move to an altitude where the temperature is above freezing.



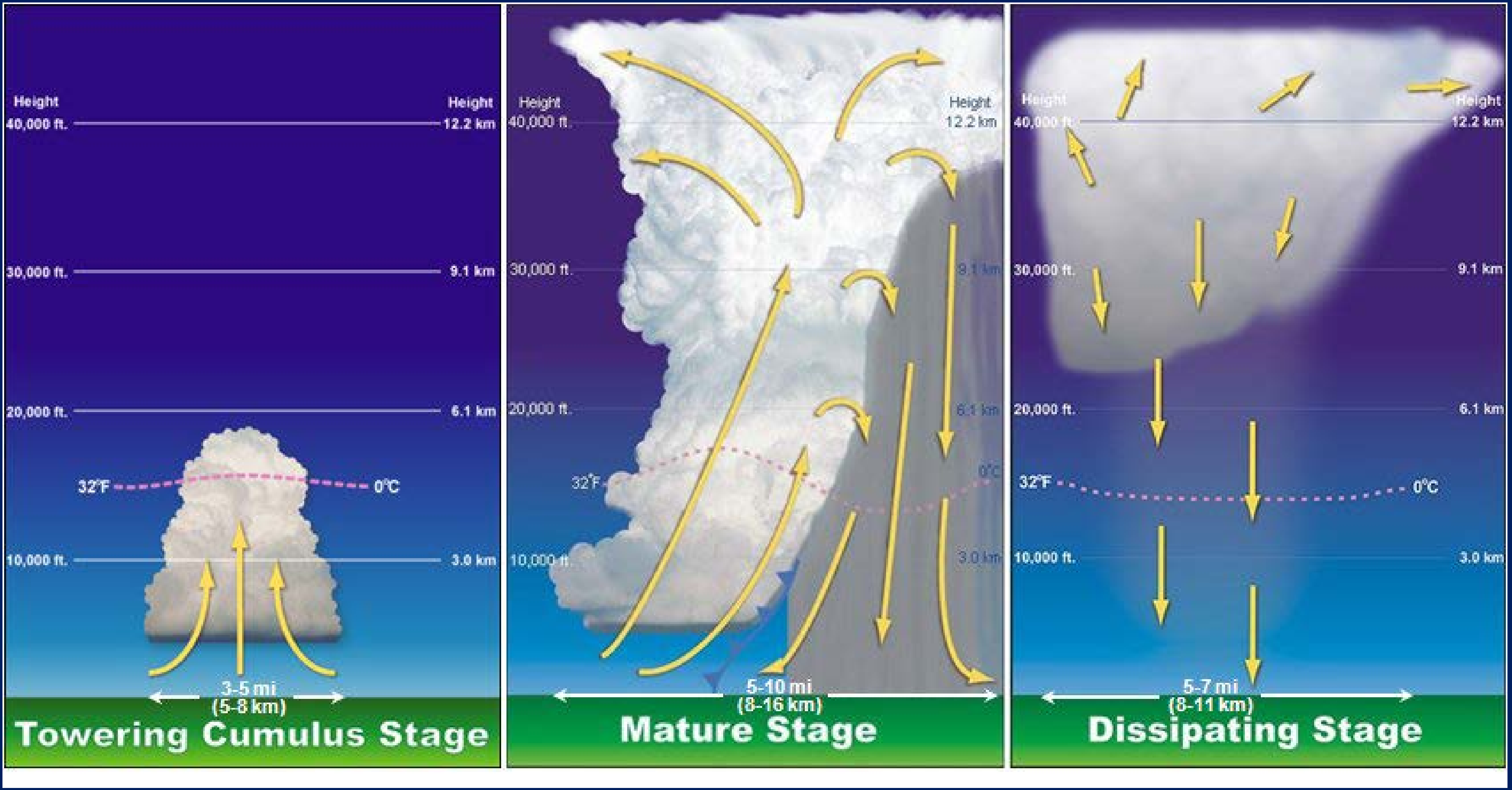
A thunderstorm is a local storm, invariably produced by a cumulonimbus cloud, and always accompanied by lightning and thunder, usually with strong gusts of wind, heavy rain, and sometimes with hail. There are as many as 40,000 thunderstorm occurrences each day worldwide, and the United States certainly experiences its share. Thunderstorms are barriers to air traffic because they are usually too tall to fly over, too dangerous to fly through or under, and can be difficult to circumnavigate.

Thunderstorm cell formation requires three ingredients: sufficient water vapor, unstable air, and a lifting mechanism. Sufficient water vapor (commonly measured using dewpoint) must be present to produce unstable air. Virtually all showers and thunderstorms form in an air mass that is classified as conditionally unstable. A conditionally unstable air mass requires a lifting mechanism strong enough to release the instability. Lifting mechanisms include: converging winds around surface lows and troughs, fronts, upslope flow, drylines, outflow boundaries generated by prior storms, and local winds, such as sea breeze, lake breeze, land breeze, and valley breeze circulations.



A thunderstorm cell is the convective cell of a cumulonimbus cloud having lightning and thunder. It undergoes three distinct stages during its life cycle: towering cumulus, mature, and dissipating. The total life cycle is typically about 30 minutes.

The distinguishing feature of the towering cumulus stage is a strong convective updraft. The updraft is a bubble of warm, rising air concentrated near the top of the cloud which leaves a cloudy trail in its wake. Updraft speeds can exceed 3,000 feet per minute.



Height
40,000 ft.
30,000 ft.
20,000 ft.
10,000 ft.
Height
12.2 km
9.1 km
6.1 km
3.0 km
32°F
0°C
3-5 mi
(5-8 km)
Towering Cumulus Stage
5-10 mi
(8-16 km)
Mature Stage
5-7 mi
(8-11 km)
Dissipating Stage

The cell transitions to the mature stage when precipitation reaches the surface. Precipitation descends through the cloud and drags the adjacent air downward, creating a strong downdraft alongside the updraft. The downdraft spreads out along the surface, well in advance of the parent thunderstorm cell, as a mass of cool, gusty air. The arc-shaped leading edge of downdraft air resembles a miniature cold front and is called a gust front. Uplift along the gust front may trigger the formation of new cells, sometimes well ahead of the parent cell. Cumulonimbus tops frequently penetrate into the lower stratosphere as an overshooting top, where strong winds aloft distort the cloud top into an anvil shape. Weather hazards reach peak intensity toward the end of the mature stage.

The dissipating stage is marked by a strong downdraft embedded within the area of precipitation. Subsiding air replaces the updraft throughout the cloud, effectively cutting off the supply of moisture provided by the updraft. Precipitation tapers off and ends. Compression warms the subsiding air and the relative humidity drops. The convective cloud gradually vaporizes from below, leaving only a remnant anvil cloud.

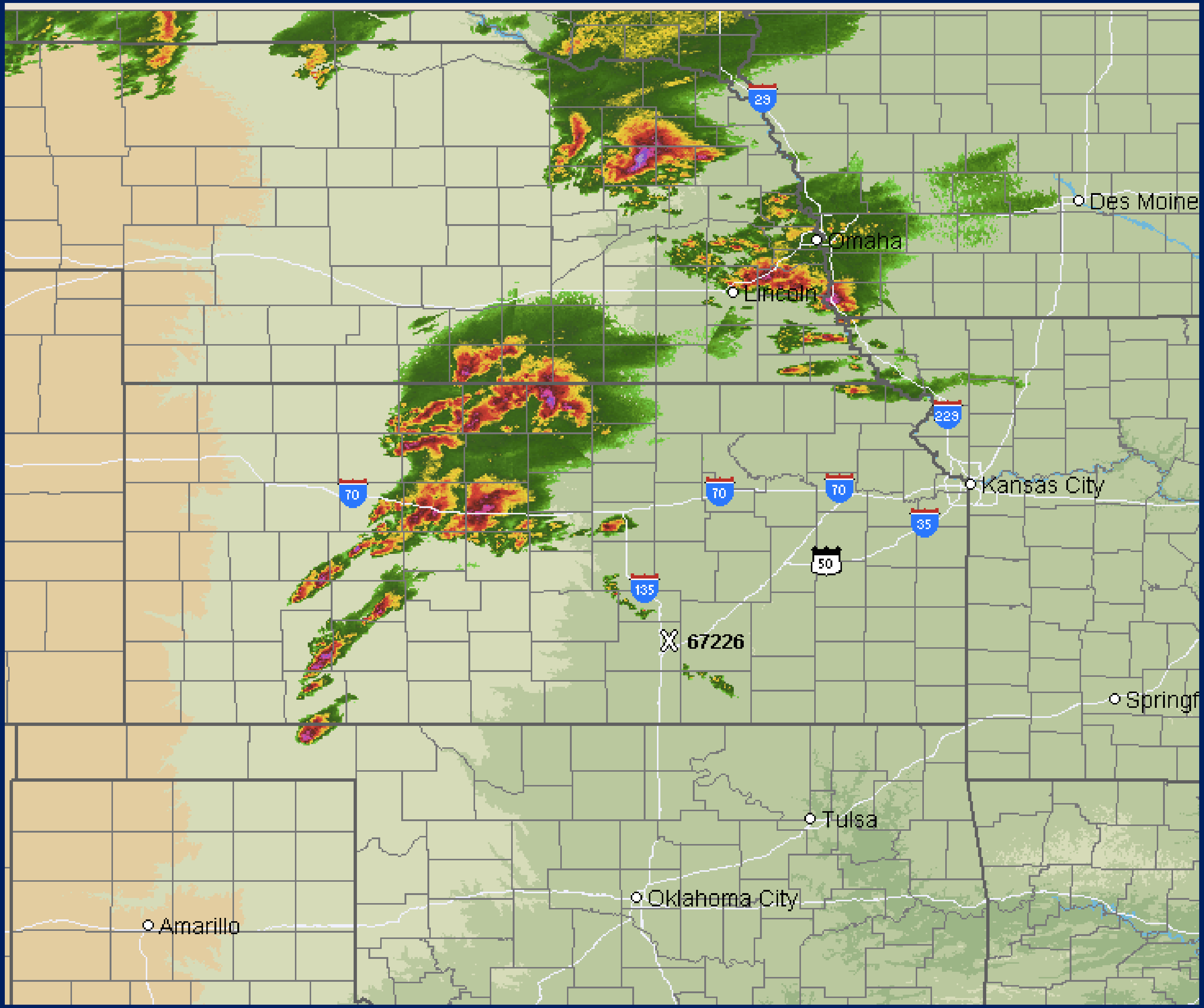
There are three principal thunderstorm types:

single cell,

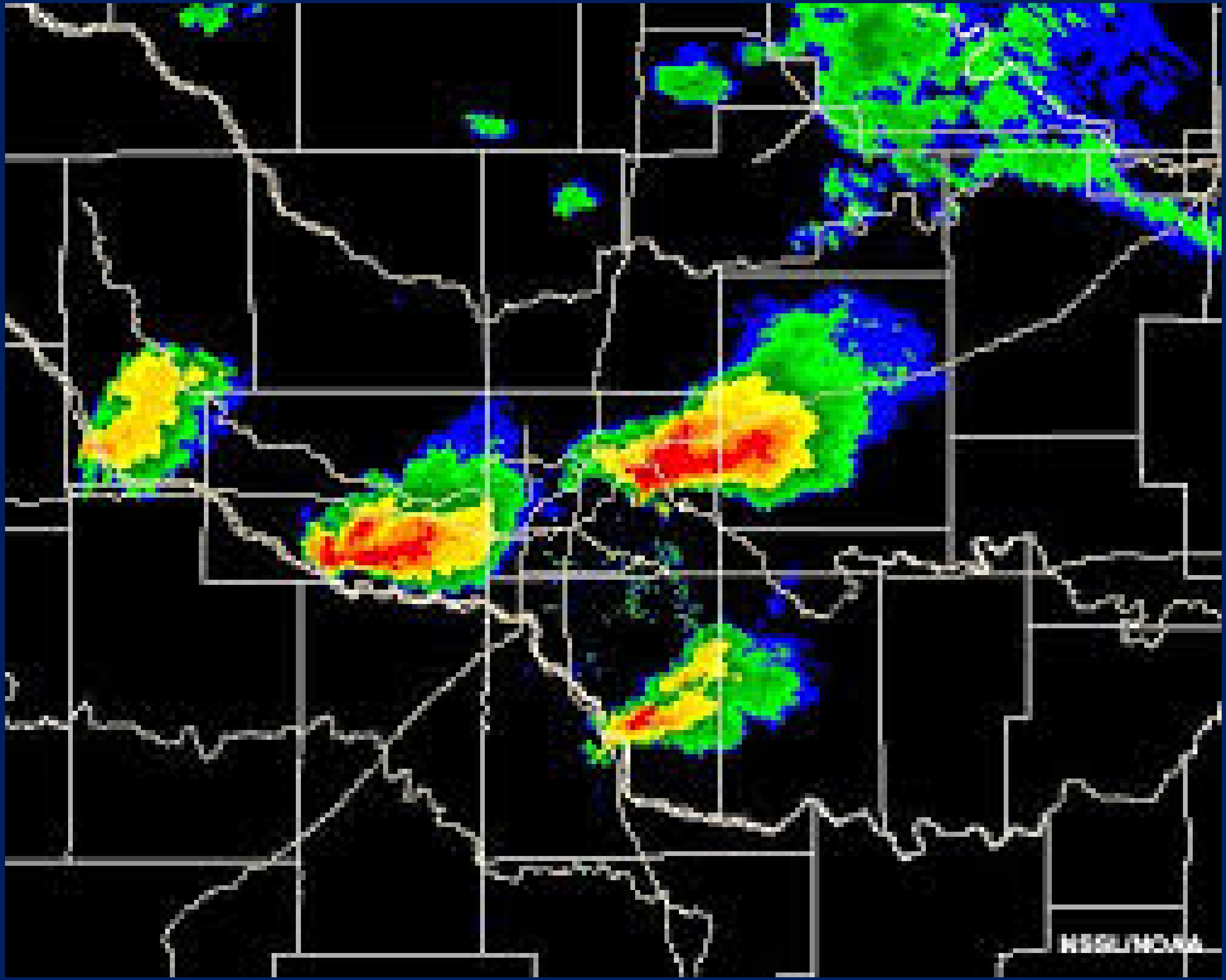
multicell (cluster and line), and

supercell.

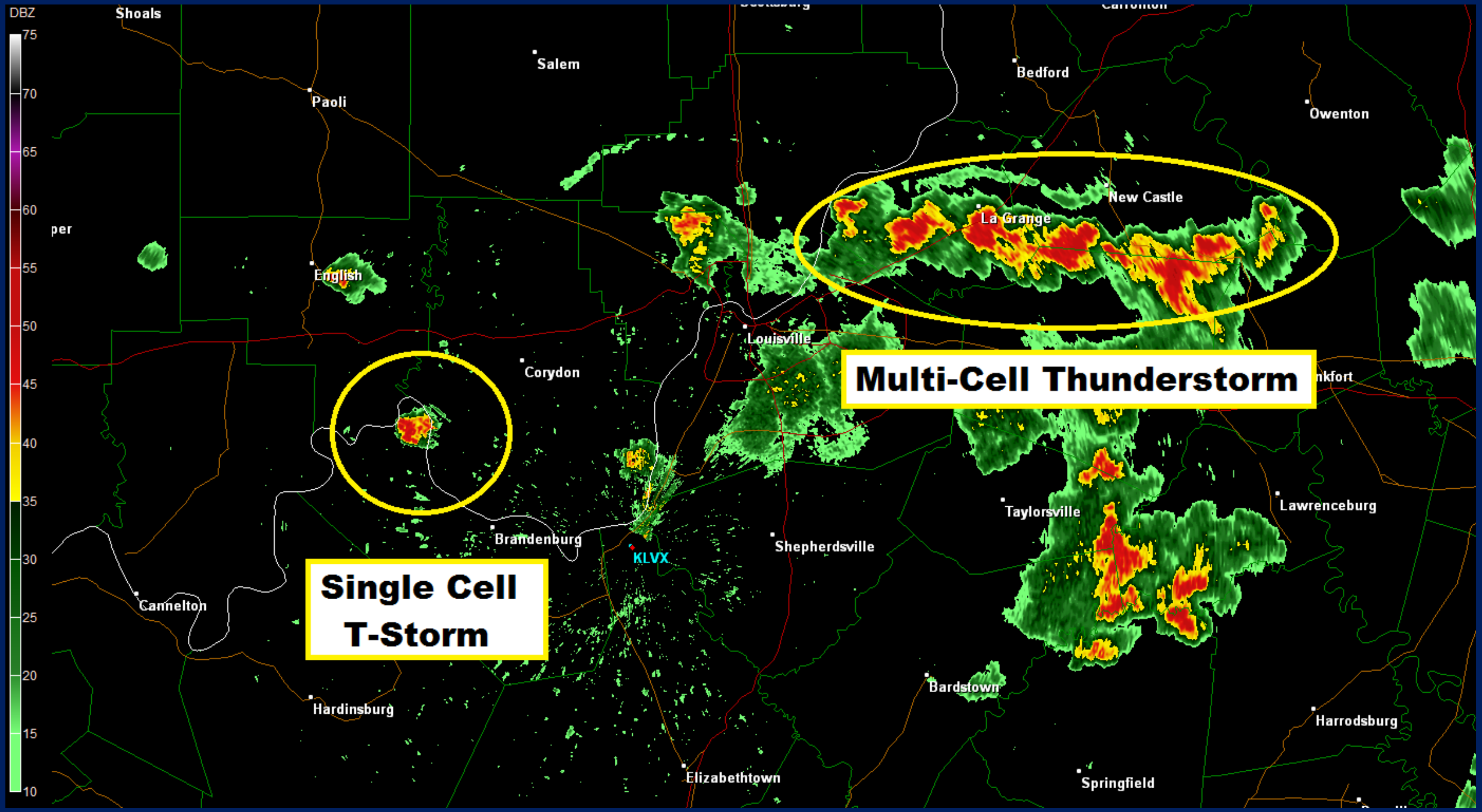
All thunderstorms are hazardous to aircraft.

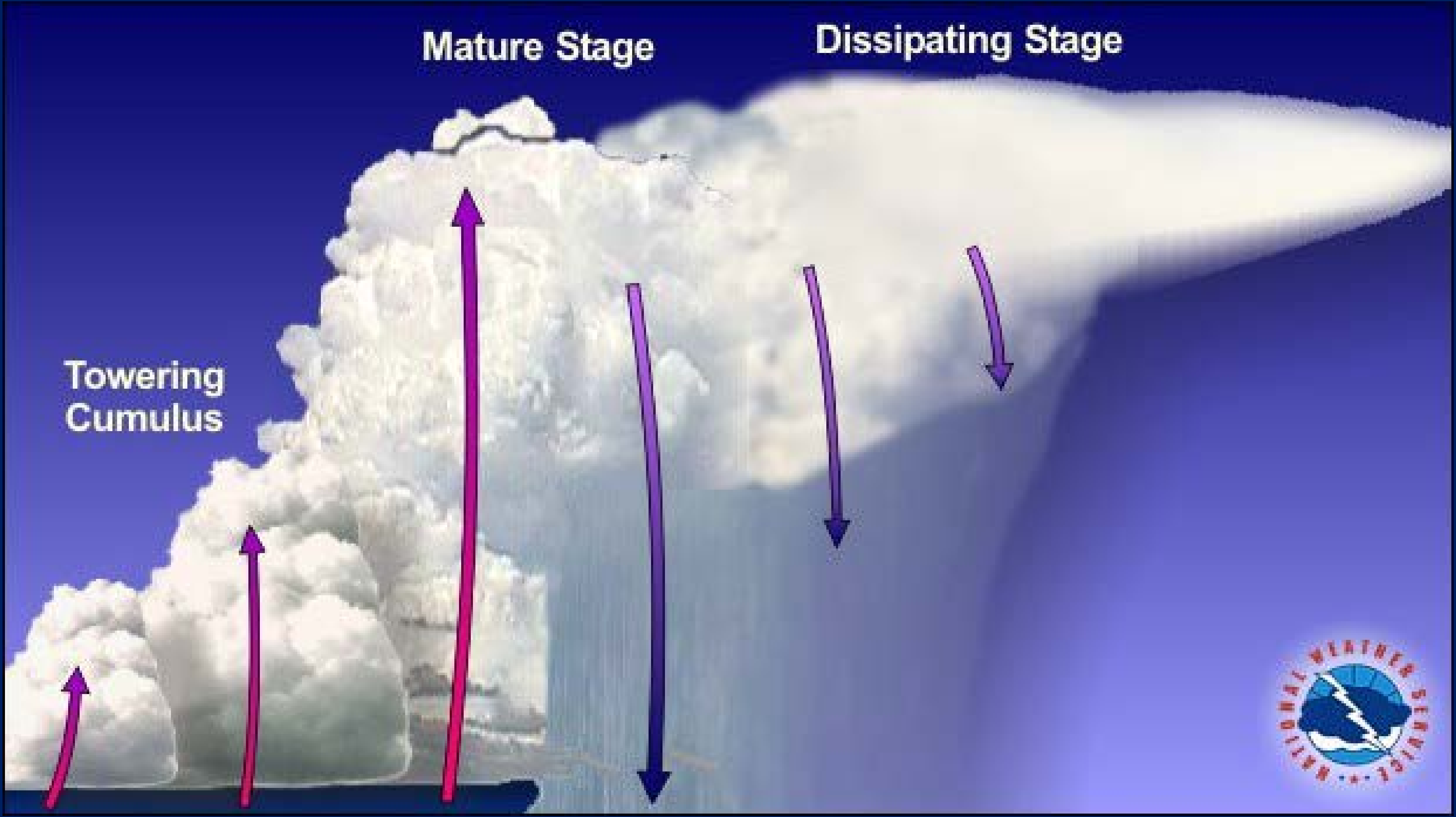


A single cell (also called ordinary cell) thunderstorm consists of only one cell. Its life cycle was covered in the previous section. It is easily circumnavigated by pilots, except at night or when embedded in other clouds. Single cell thunderstorms are rare; almost all thunderstorms are multicell.



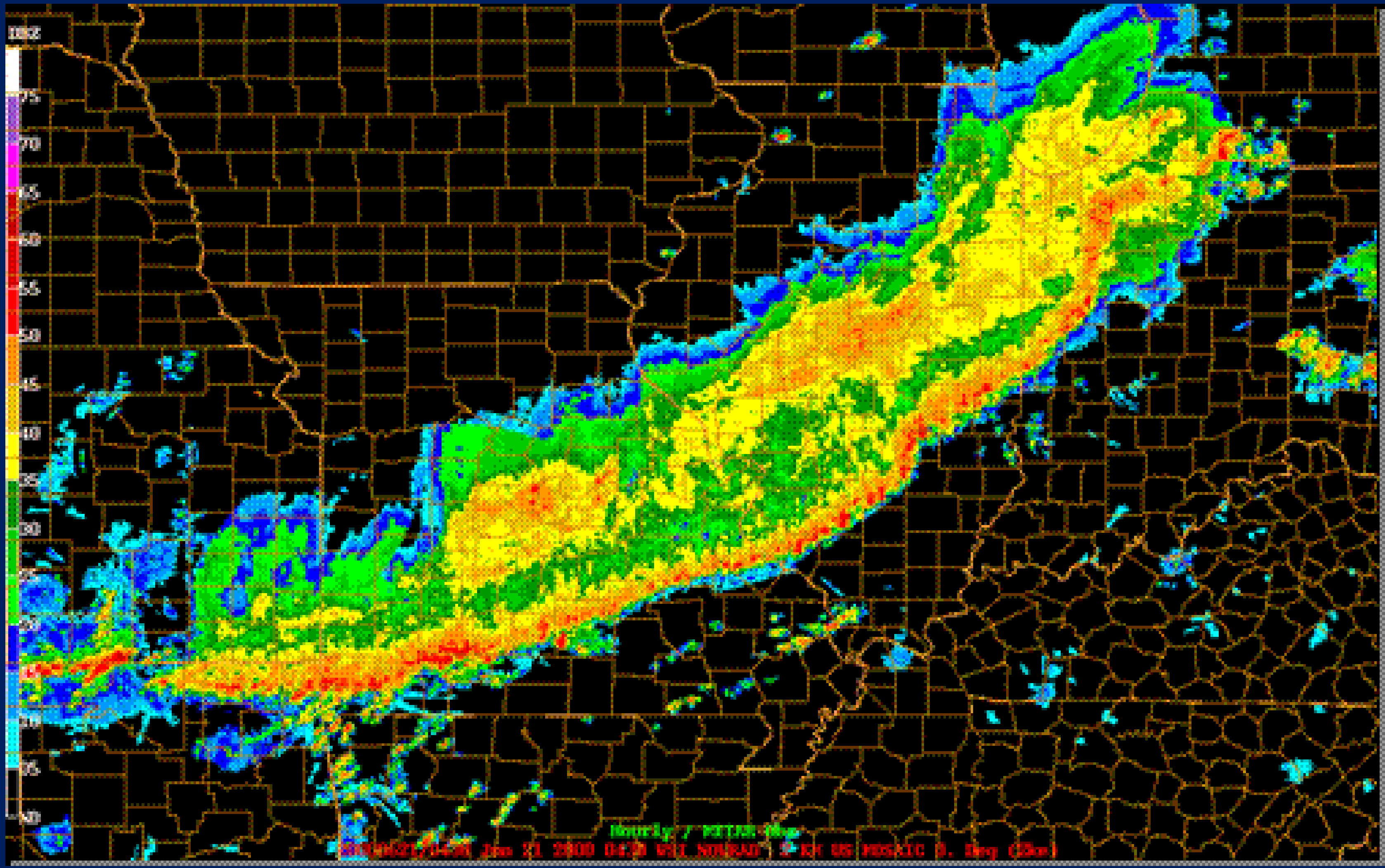
A multicell cluster thunderstorm consists of a cluster of cells at various stages of their life cycle. With an organized multicell cluster, as the first cell matures, it is carried downwind, and a new cell forms upwind to take its place. A multicell cluster may have a lifetime of several hours (or more). New cells will continue to form as long as the three necessary ingredients exist. Its size and persistence make it a bit tougher to circumnavigate than a single cell thunderstorm. An area of multicell cluster thunderstorms can be like a mine field for air traffic.



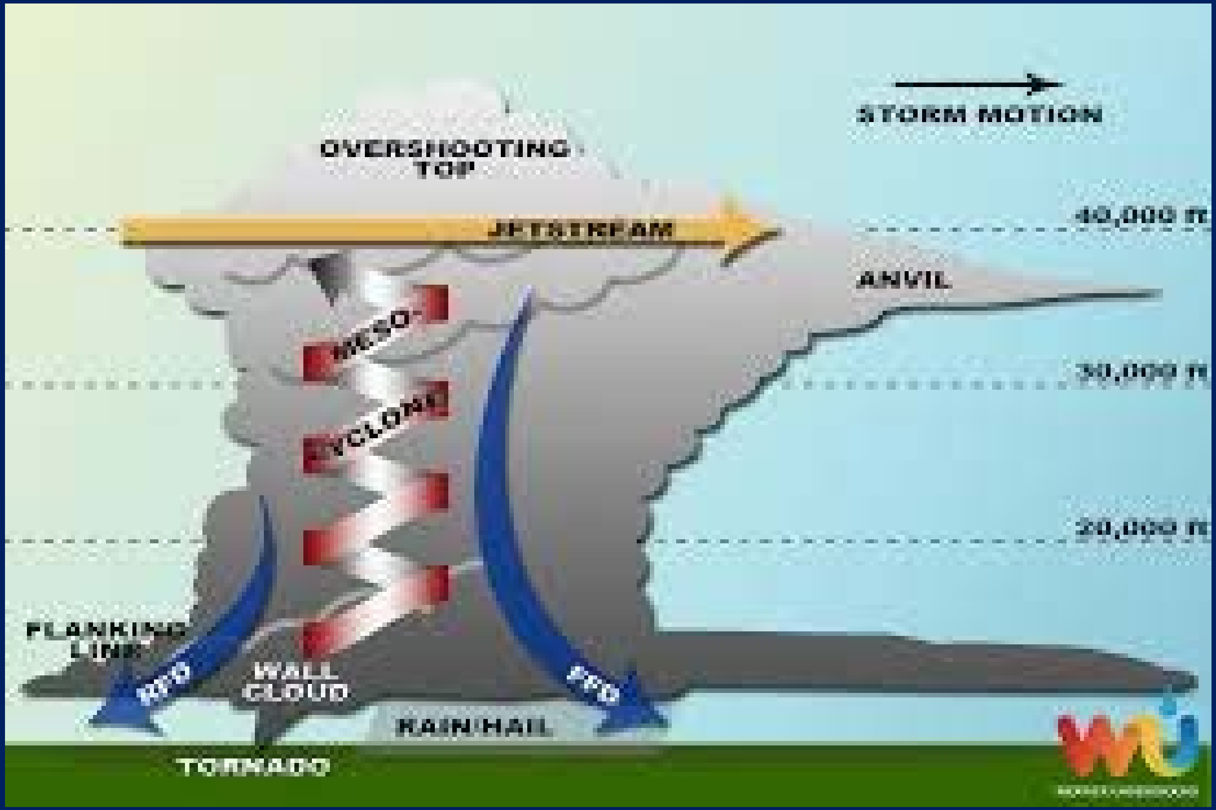


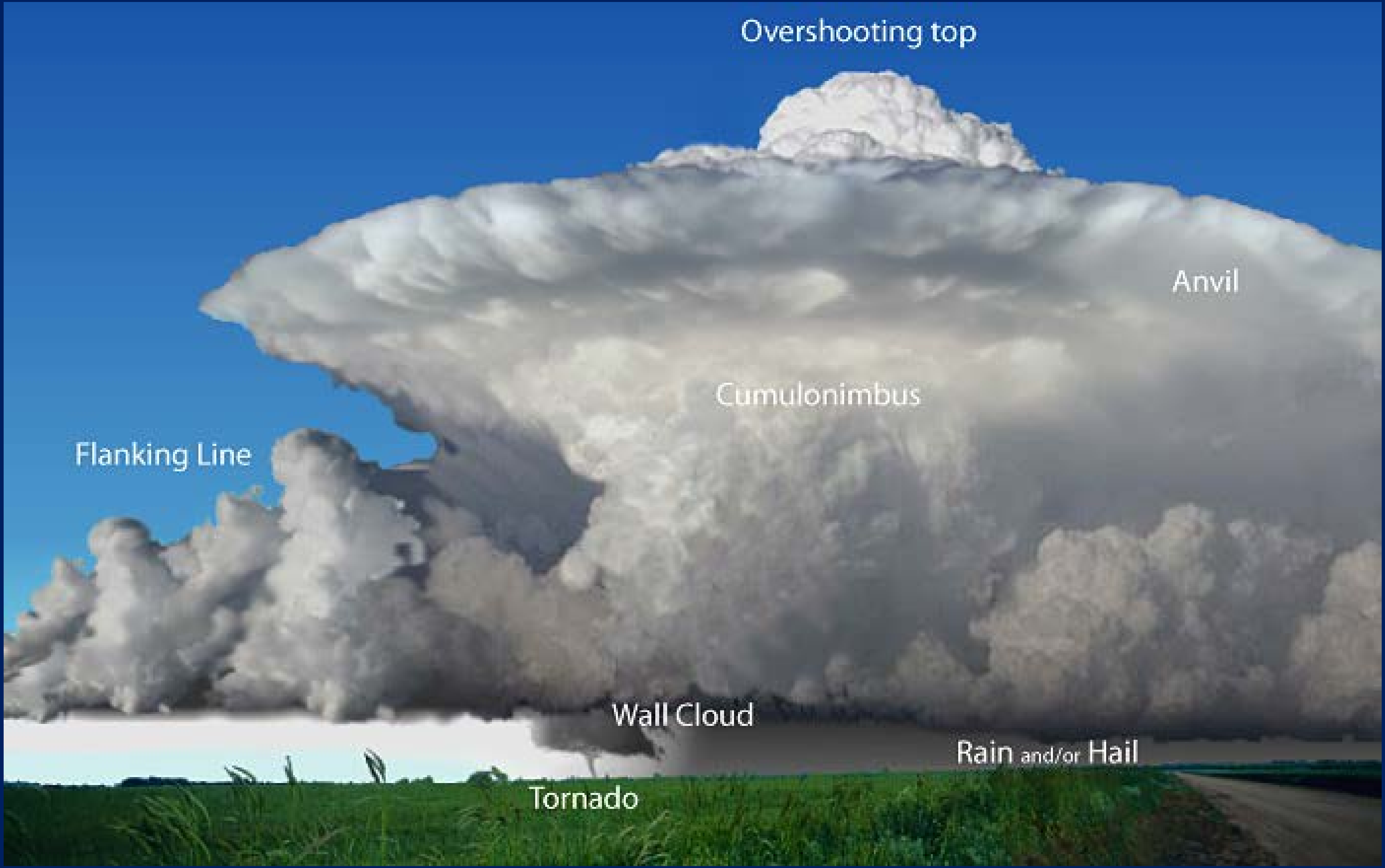
Mature Stage
Dissipating Stage
Towering
Cumulus
NATIONAL WEATHER SERVICE

Sometimes thunderstorms will form in a line that can extend laterally for hundreds of miles. New cells continually re-form at the leading edge of the system with rain, and sometimes hail, following behind. Sometimes storms which comprise the line can be supercells. The line can persist for many hours (or more) as long as the three necessary ingredients continue to exist. These squall lines are the thunderstorm type which presents the most effective barrier to air traffic because the line is usually too tall to fly over, too dangerous to fly through or under, and difficult to circumnavigate. About 25 percent of all U.S. tornadoes are spawned by squall lines.

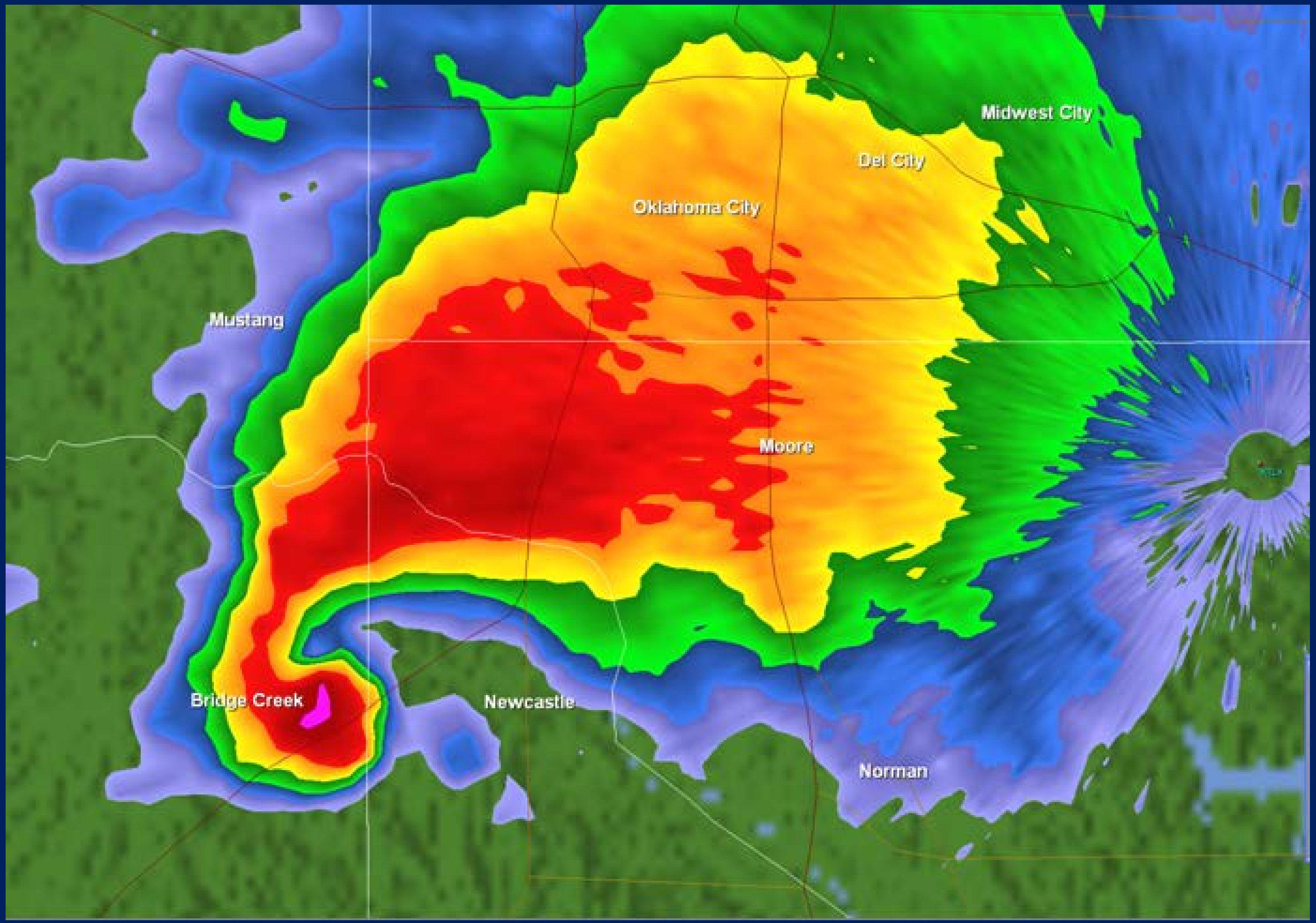


A supercell thunderstorm is an often dangerous convective storm that consists primarily of a single, quasi-steady rotating updraft that persists for an extended period of time. It has a very organized internal structure that enables it to produce especially dangerous weather for pilots who encounter them. Updraft speeds may reach 9,000 feet per minute (100 knots). This allows hazards to be magnified to an even greater degree. Nearly all supercells produce severe weather (e.g., large hail or damaging wind) and about 25 percent produce a tornado. A supercell may persist for many hours (or longer). New cells will continue to form as long as the three necessary ingredients exist

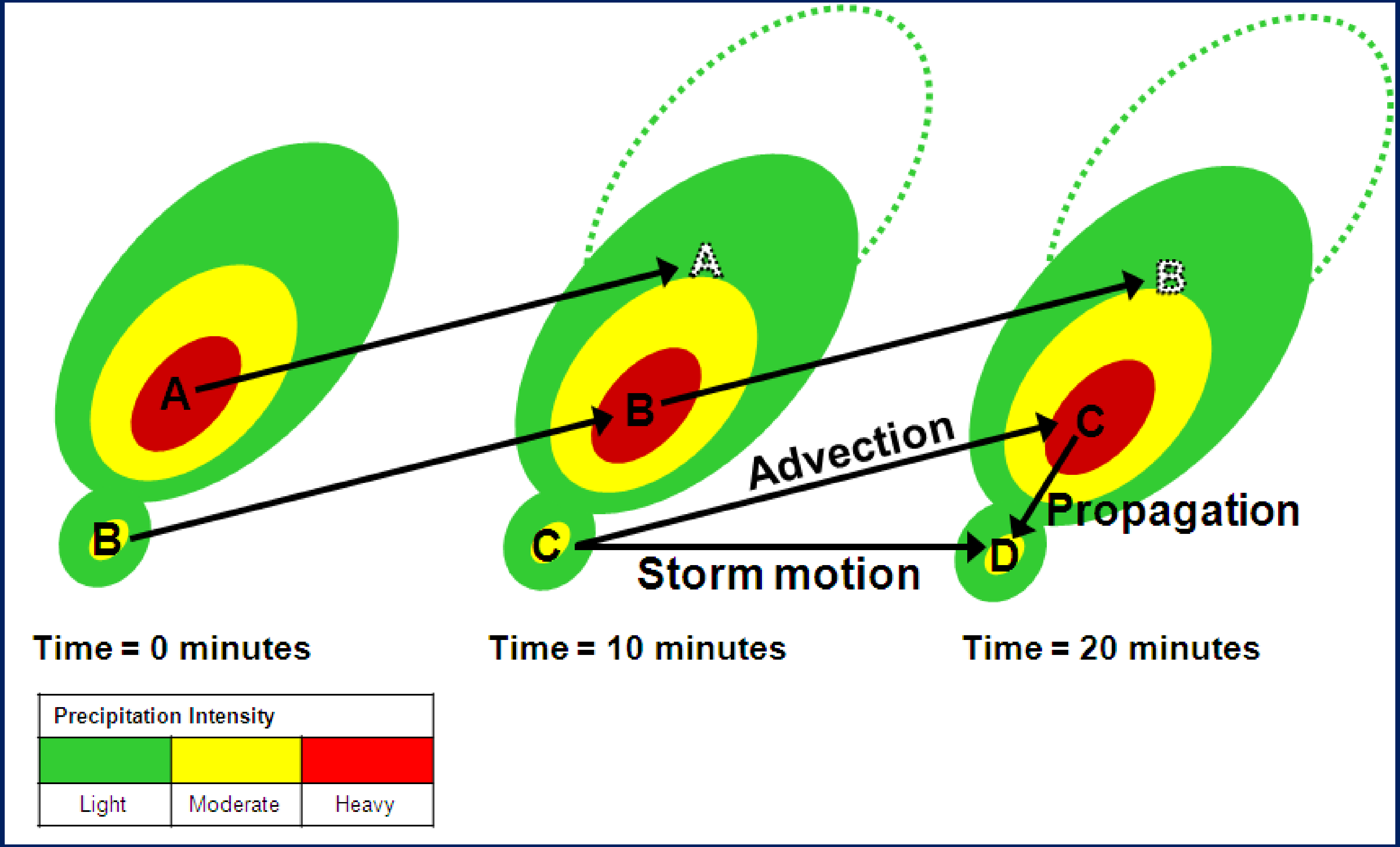



Overshooting top
Anvil
Cumulonimbus
Flanking Line
Wall Cloud
Rain and/or Hail
Tornado

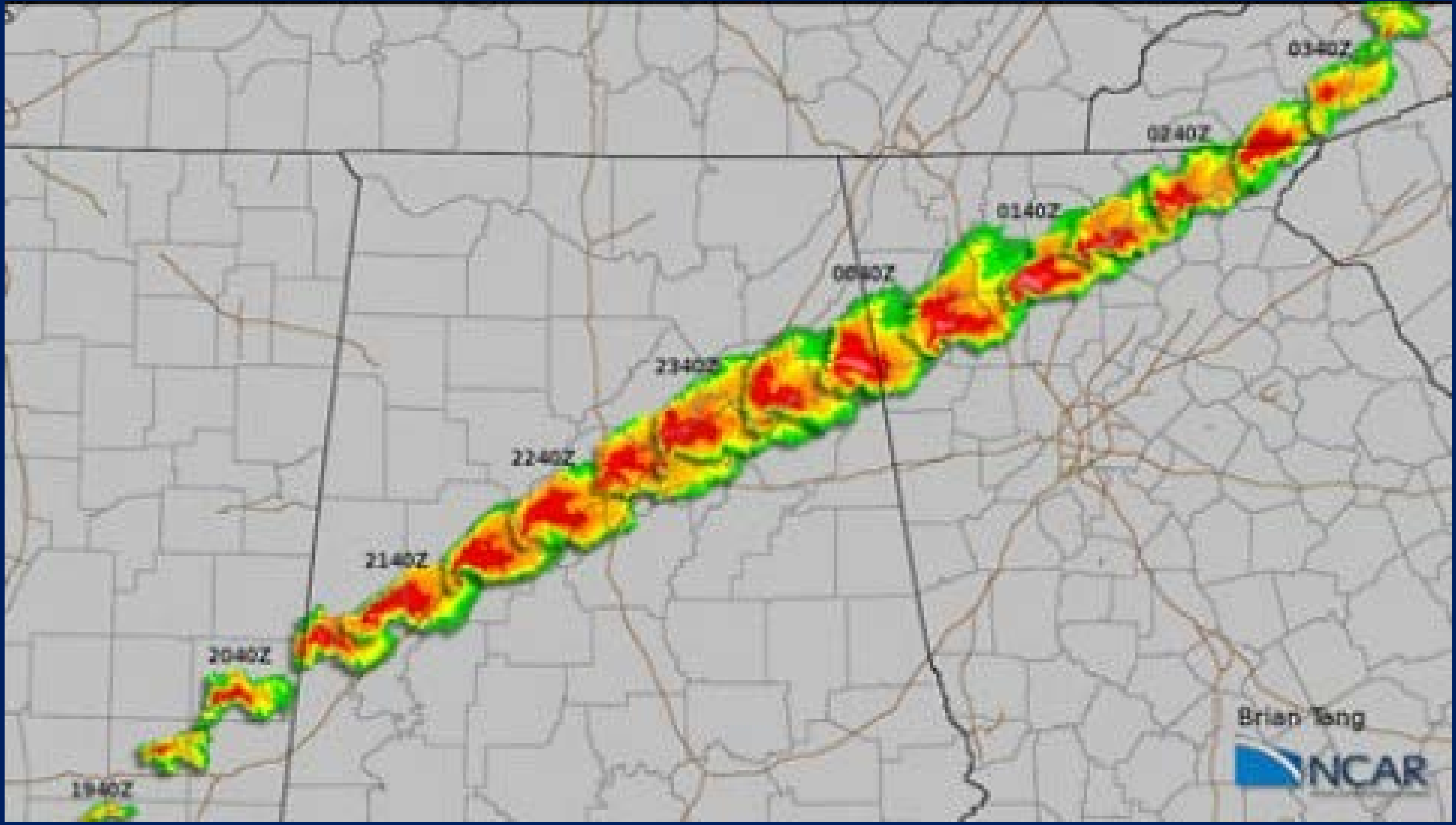
A thunderstorm is a process, not a solid object or block of wood. Storm motion equals the combined effects of both advection and propagation. Advection is the component of storm motion due to individual cells moving with the average wind throughout the vertical depth of the cumulonimbus cloud. The wind at FL180 (500 millibars) usually provides a good approximation. Propagation is the component of storm motion due to old cell dissipation and the new cell development. Storm motion may deviate substantially from the motion of the individual cells which comprise the storm.



Individual cells which comprise the storm move northeast (advection), but dissipate and are replaced by new cells (propagation). Storm motion equals the combined effects of both advection and propagation.



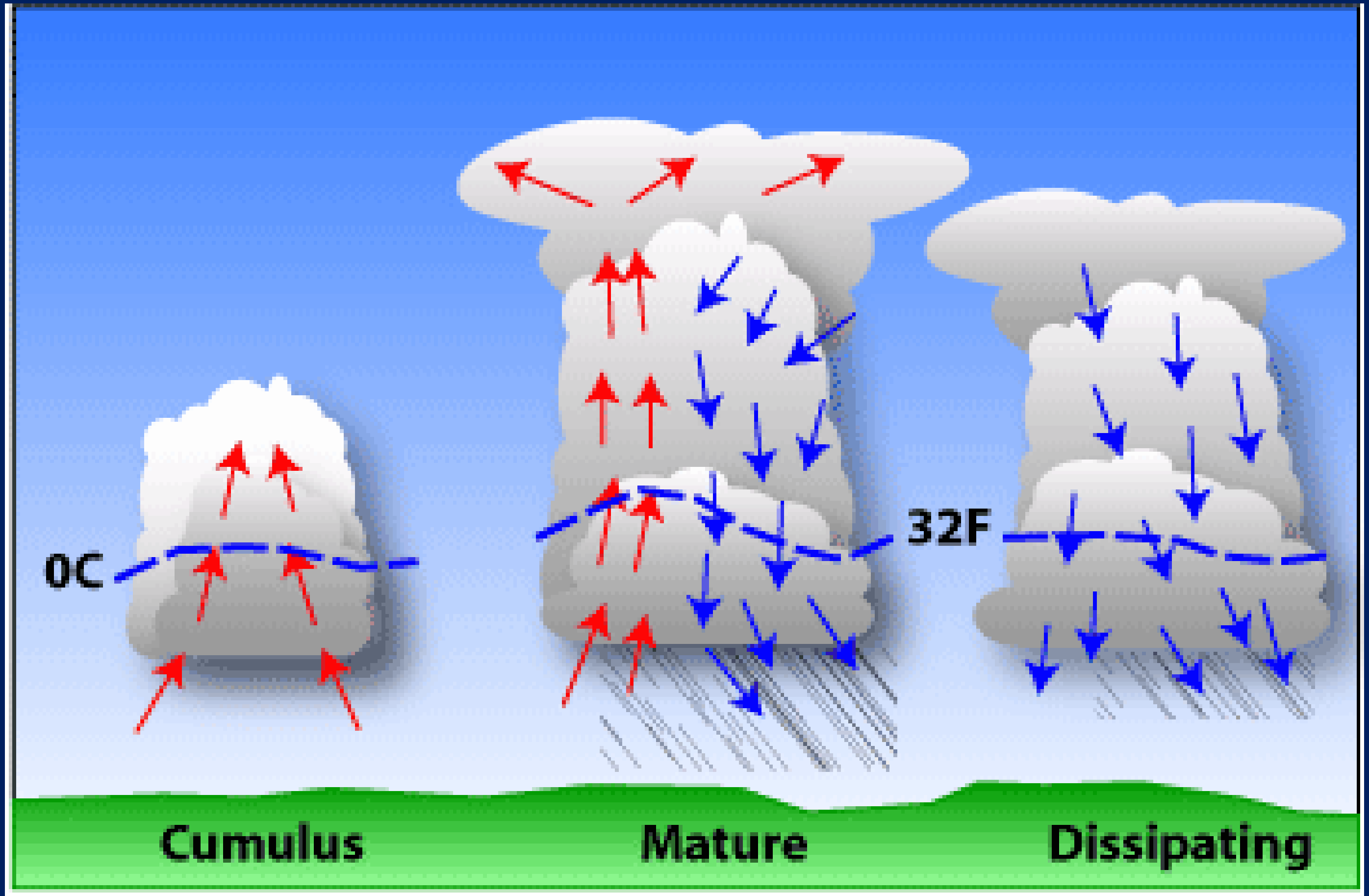
A thunderstorm can pack just about every aviation weather hazard into one vicious bundle. These hazards include: lightning, adverse winds, downbursts, turbulence, icing, hail, rapid altimeter changes, static electricity, and tornadoes.



Every thunderstorm produces lightning and thunder by definition. Lightning is a visible electrical discharge produced by a thunderstorm. The discharge may occur within or between clouds, between the cloud and air, between a cloud and the ground, or between the ground and a cloud

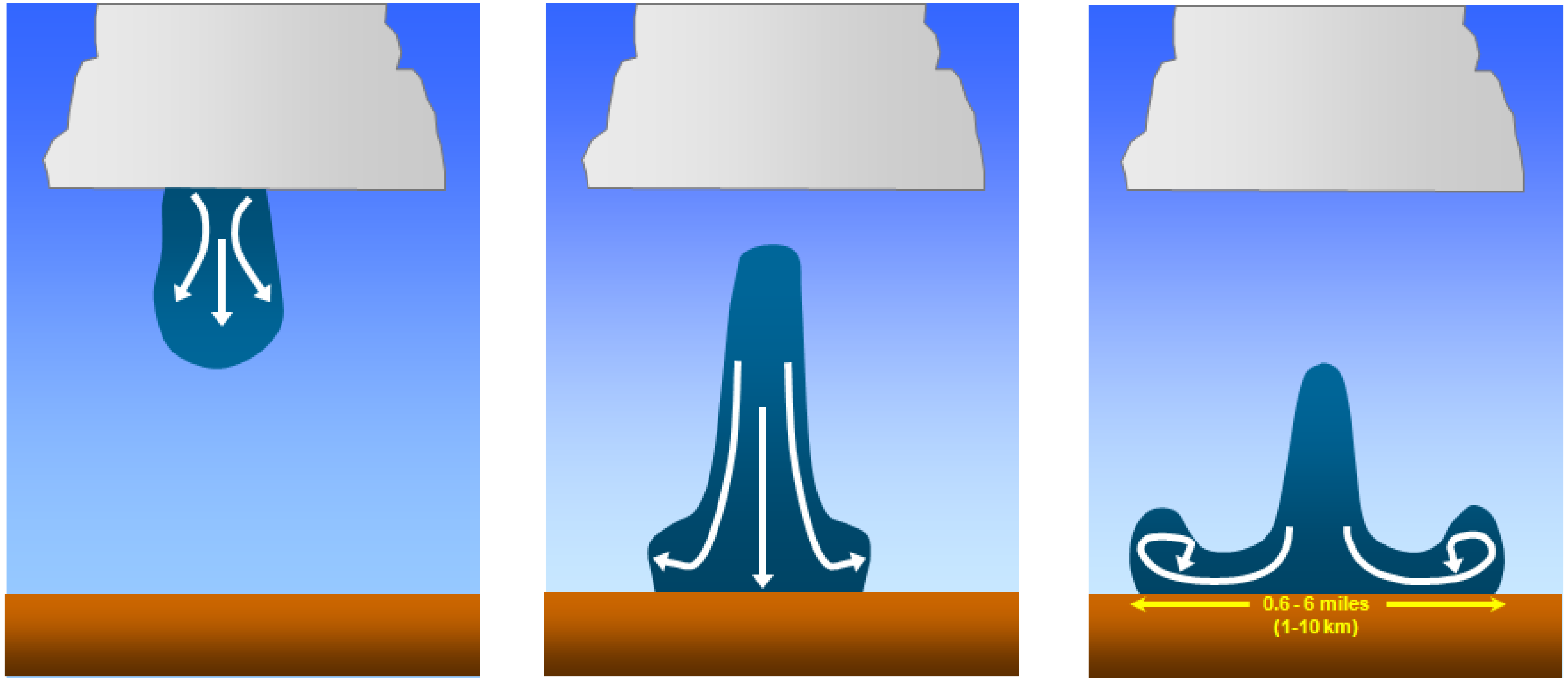
Lightning can damage or disable an aircraft. It can puncture the skin of an aircraft. It can damage communication and electronic navigational equipment. Nearby lightning can blind the pilot, rendering him or her momentarily unable to navigate either by instrument or by visual reference. Nearby lightning can also induce permanent errors in the magnetic compass. Lightning discharges, even distant ones, can disrupt radio communications on low and medium frequencies. Lightning has been suspected of igniting fuel vapors, causing explosion; however, serious accidents due to lightning strikes are extremely rare.

Adverse winds are always found within thunderstorms and often many miles away from the precipitation area. Crosswinds, gusts, and variable winds/sudden wind shifts can lead to a crash during takeoffs, approaches, and landings. The area along and immediately behind the gust front is particularly dangerous because this is where rapid and sometimes drastic changes in surface winds occur.



Shower and thunderstorm cells sometimes produce intense downdrafts called downbursts that create strong, often damaging winds. Downbursts can create hazardous conditions for pilots and have been responsible for many low-level wind shear accidents. Smaller, shorter-lived downbursts are called microbursts.

A downburst is especially dangerous to airplanes when it is encountered when climbing from takeoff or approaching to land. During this phase, the aircraft is operating at relatively slow speeds. A major change of wind velocity can lead to loss of lift and a crash.



FORMATION –

Evaporation and precipitation drag forms downdraft

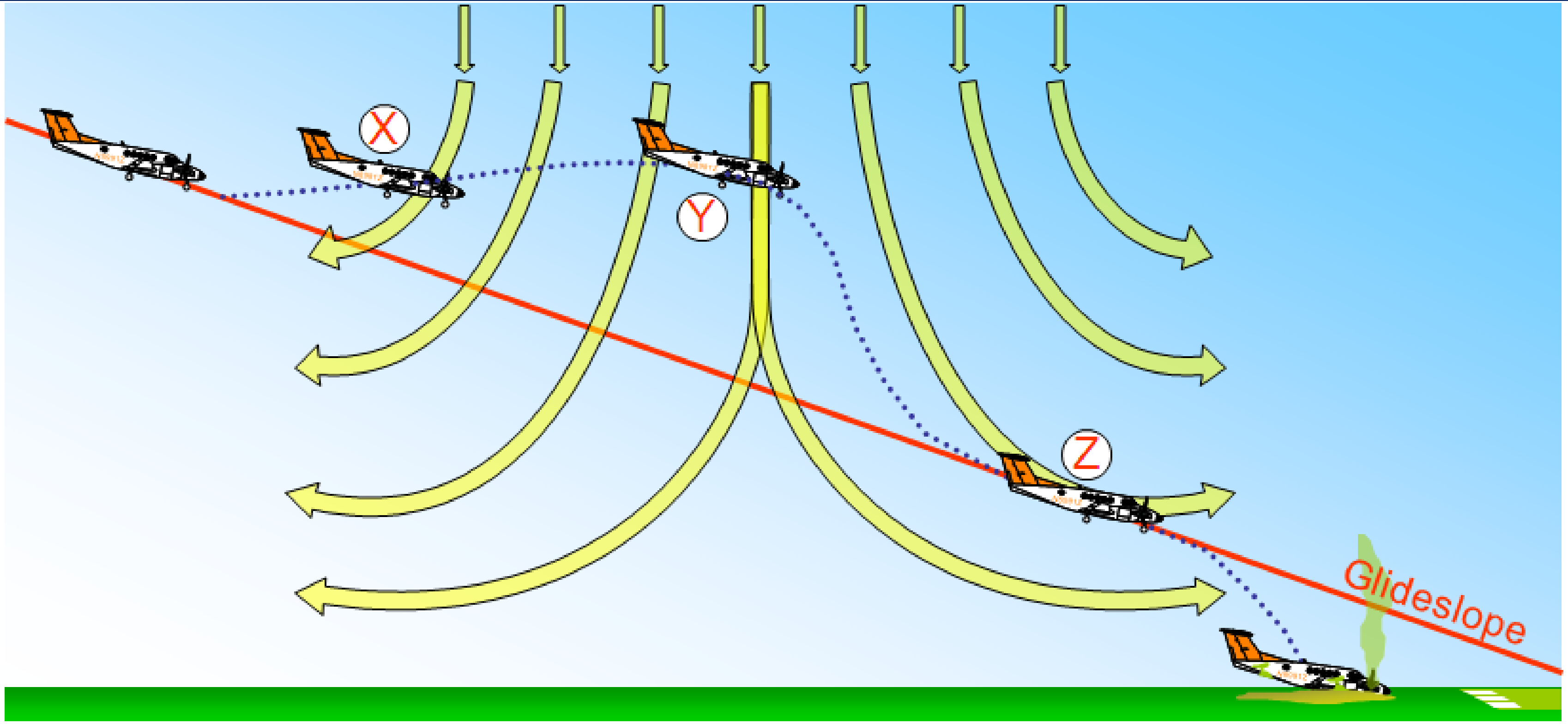
IMPACT –

Downdraft quickly accelerates and strikes the ground

DISSIPATION –

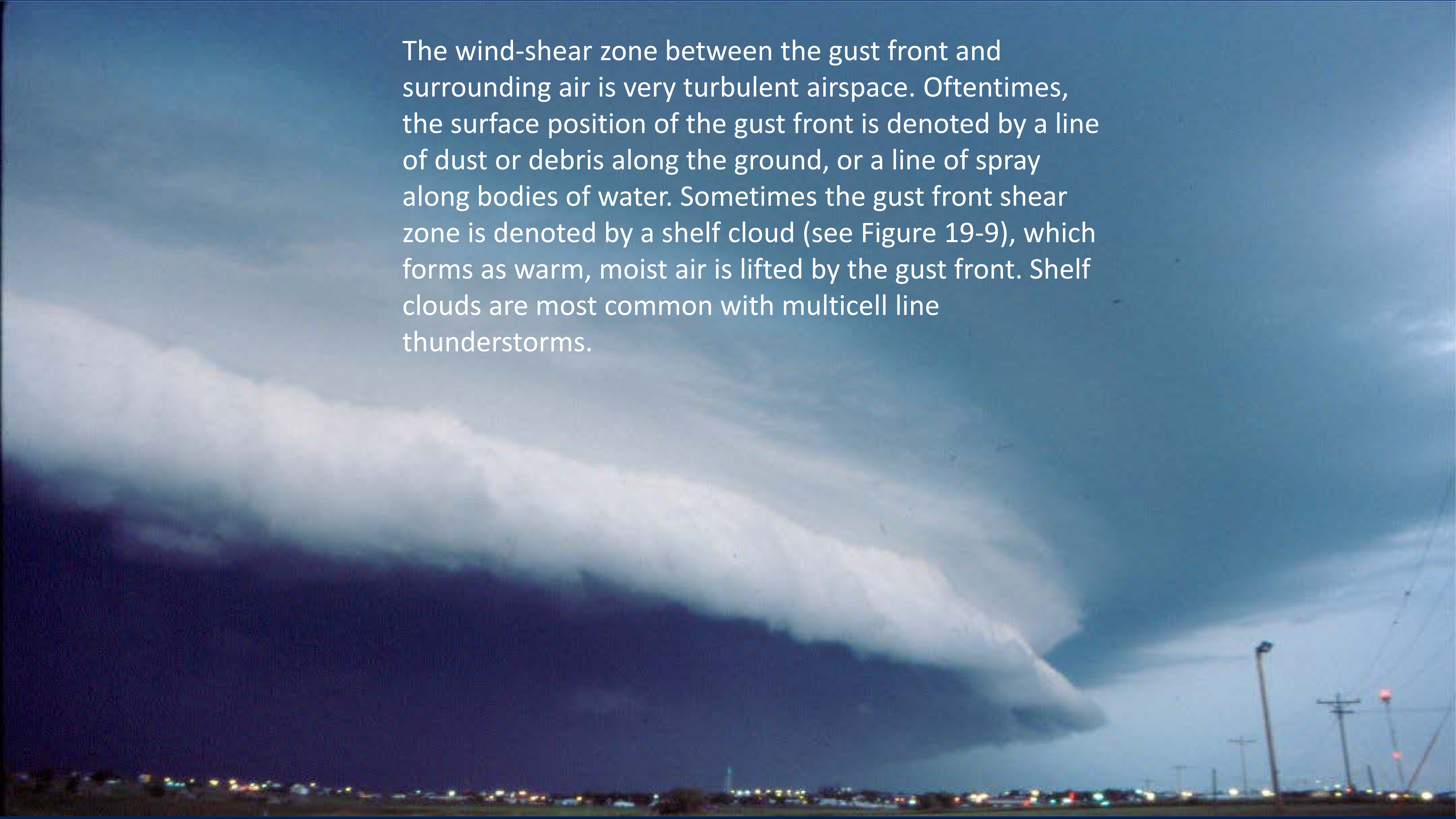
Downdraft moves away from point of impact

A microburst is particularly dangerous during landing if the pilot has reduced power and lowered the nose in response to the headwind shear. This leaves the aircraft in a nose-low, power-low configuration when the tailwind shear occurs, which makes recovery more difficult. It can cause the airplane to stall or land short of the runway.



At point X, the aircraft enters the microburst zone where a headwind causes it to balloon above the normal glideslope. At the center of the microburst, point Y, there is a downdraft which causes the aircraft to sink. At point Z, the aircraft enters the most lethal zone where a sudden tailwind causes the aircraft to lose airspeed.

The wind-shear zone between the gust front and surrounding air is very turbulent airspace. Oftentimes, the surface position of the gust front is denoted by a line of dust or debris along the ground, or a line of spray along bodies of water. Sometimes the gust front shear zone is denoted by a shelf cloud (see Figure 19-9), which forms as warm, moist air is lifted by the gust front. Shelf clouds are most common with multicell line thunderstorms.



Hail is precipitation in the form of balls or other irregular lumps of ice produced by thunderstorms. Thunderstorms that are characterized by strong updrafts, large supercooled liquid water contents, large cloud-drop sizes, and great vertical height are favorable to hail formation.