This supplemental textbook is provided to students in the Acrobat Reader format through the course website. It provides students with an additional resource and is based on the course lectures. This is a work in progress.

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Explore the Skies

Studies in Meteorology

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Preface

Welcome. The Explore the Skies: Studies in Meteorology is an online educational series designed to provide upper level university students with conceptual understanding of the processes of the atmosphere as well as its impact on humanity. Throughout the semester you will learn the fundamentals of meteorology through the investigation of previous real-world weather scenarios and the daily acquisition of meteorological conditions for analysis and interpretation. To promote complete understanding of the processes of the atmosphere, a DVD has been provided that contains video lectures of the concepts. Since this course is administered via the Internet, it is suggested that you read the chapter assigned and then watch the associated video lecture. Each chapter has a review section that will be beneficial in your understanding of the material covered.

Cameron Douglas Craig
December 2005

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CHAPTER I

CHAPTER I: WEATHER AND HUMANITY

Throughout history humans have battled the elements. What is forgotten is that the natural world cannot be controlled. However, understanding how it functions will better prepare humanity for surprises. In this chapter, we explore the history of how weather has influenced humans and how humans have influenced the atmosphere.

Weather's Influence on Humanity

Scientific understanding was non-existent in the ancient world and the people of Mesopotamia believed that God communicated his agreement or disagreement through natural phenomena. When the rivers flooded, this was good because it provided a bountiful harvest at the end of the growing season. However, when a severe storm rolled through, God was not happy, which would result in a human or animal sacrifice in order to please God.

Hippocrates, ancient historian, believed that people who lived in warm climates were more apt to begin wars simply due to the extreme heat and people who lived in cooler environments were not as apt to promote wars. Although considered today as environmental determinism (a scapegoat for blaming the environment on the functions of society), there is some validity for this idea.

After 1000 A.D. humans were constantly struggling to survive the natural environment. The Black Plague in the 1400s was enhanced by unfavorable weather conditions causing widespread death. In addition, agriculture often failed throughout history due to extreme weather conditions. If a developing civilization was to prosper, the inhabitants had to understand weather. Most often weather for the season ahead was foretold by folklore, which at that time was accepted. Failure to prepare for the oncoming winter would result in the death of the inhabitants. Essentially, weather was most important in the future of developing societies.

Weather has played an important role in the outcome of battles. The harsh cold winters often found in Russia helped the Russian army defeat Napoleon in 1812. Thousands of French soldiers froze to death as they began their march back to Western Europe. In the same manner, Hitler's armies attempted to take control of Volgograd without success. The Soviets were better prepared for winters touch—at the end of the day, they would drain the oil from their tanks and keep it warm near a fire. The next morning, they refilled the engines with the warmed oil that allowed the tanks to start right up while the Germans struggled to start theirs.

With the recent war in Iraq, weather is most influential in the military campaigns across the deserts. Dust carried by whirlwinds creates havoc for technology and daily living conditions. In some cases, soldiers would spend two to three hours in the blinding dust storms trying to find their way back to the living quarters that were just 300 feet away. The exhausting heat drains the energy from soldiers unprepared for the extreme climate. Imagine the effect of wearing battle gear throughout the day in near 106°F conditions.

Although weather is not as important to today's societies as it was prior to the modern period concerning agriculture, it is still important to our daily lives and forecasts are readily available with only a point and click. People dress and work according to the weather forecast. However, what is often missed is how humans influence the atmosphere with regard to the daily activities.

Human Modification of the Environment

Modification of the environment influences the atmosphere. When vegetation is removed from a vast area, the result can be devastating. The Dust Bowl event in the 1930s is an excellent example of how modifying the land enhanced the already dry atmospheric conditions. Many years before the dry spell of 1934-39, humans began to migrate from the East to the rich fertile lands of the Great Plains. They saw profit from this virgin land. The eastern farmers removed the protective blanket of grass that exposed the soils to the harsh baking Sun. When they realized that the soil was dry, they would again plow to bring moist soil to the surface. Again, the soil would bake in the Sun. The plowing also created another effect, soil compaction from the constant trampling from livestock and machinery. Now a fine powder, the winds would begin to gust and carry the topsoil across the vast land. Together with already dry conditions created by a persistent high-pressure cell over the Great Plains and the baking and compaction of the soil, the drought of the 1930s was enhanced by human modification.

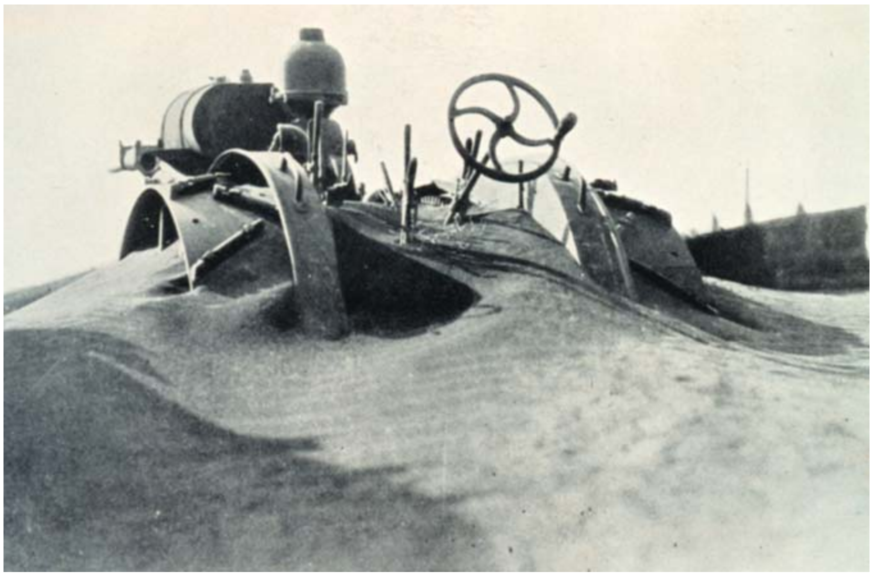


Figure 1.1 Result from Soil Exhaustion during the Dust Bowl. Photo from NOAA Photo Library.

Urban expansion creates serious problems when heavy rains fall from the skies. Significant flooding of small streams and large waterways is a result of humans leveling the land and removing trees for development. Essentially, trees help to protect the soil from becoming too saturated all at once. When removed, the compacted leveled soil can no longer absorb rain and creates runoff.

Another major example of modifying the land is the development of urban environments along coastlines influences hurricane destruction. After Hurricane Katrina in August 2005 destroyed much of New Orleans, urban planners, geologists, and atmospheric scientists are questioning whether humans were responsible. The building of a city below sea level, the removal of vegetation for development, and the stability of the levies to hold back the Mississippi River supports the notion that humans enhanced the destruction. Moreover, concern of anthropogenic influence of the atmosphere through pollution is raising concern that continued warming will also enhance the frequency and power of future hurricanes.

Lessons Learned

Severe weather has always been a serious matter and protection from nature's fury has not always been an important aspect in the evolution of the progress of civilization, until the skies let loose the whirlwinds on April 11, 1965.

Figure 2.1. Twin Tornadoes outside Elkhart, Indiana, April 11, 1965. Photo by Paul Huffman. Archived by NOAA Photo Library.

The winter of 1965 had been a somewhat harsh season in regards to the extreme cold conditions and snow that fell. Palm Sunday, April 11, 1965 was a day that broke the winter harshness with warm afternoon temperatures and gentle breezes. Most people were celebrating the religious holiday outdoors unaware that the skies would unleash great destruction. In the early afternoon hours, tornadoes began to strike the Earth in Iowa. As the day progressed, 47 whirlwinds would rip through the Great Lakes region until late evening killing 271 people and injuring 3,400.

This event caused a significant change in which the National Weather Service functioned. Essentially, the warning system had failed to inform people of the danger. Through an investigation led by the U.S. Weather Bureau Disaster Survey Team that interviewed witnesses, survivors, and employees of the forecast offices conclusions were made that would ultimately change the manner in which people were warned of dangerous situations.

First, the civil defense warning sirens would be utilized to warn people outdoors. Prior to the day of destruction, the widespread use of warning sirens was not considered except for the Great Plains region where tornadoes most often occurred. In addition, the public were not well educated in what the sirens were indicating. Most often when the sirens whined, people would go venture outdoors out of curiosity only to find that a tornado was a few miles away. Today, all communities throughout the United States have warning sirens installed and tested every week.

Second, the use of the Weather Wire Teletype System was expanded to all counties. In 1965, only a handful of institutions had the system installed that allowed hardcopies of warnings to be printed and broadcasted to the public. Since most of the institutions, such as television and radio stations did not have the system, they had to relay warnings over the telephone. In some cases, warnings were issued but due to the length of the phone call list, the warnings were issued one hour late. Although the Weather Wire Teletype System has long been obsolete, the Internet, NOAA radio, and other means of broadcasting severe weather information originally developed from this recommendation.

Third, RADAR systems were greatly improved as well as the placement of RADAR repeaters to all National Weather Service forecast offices. In 1965, many of the RADAR installations were outdated or not working. Many of the units that were not used because of disrepair were used to fix the near working units. In one particular situation, the South Bend RADAR unit was not working and the meteorologist would call the Chicago forecast office to determine where the tornadoes were. This caused problems for both meteorologists. The Chicago meteorologist would be unable to describe accurately the position of a tornado to the South Bend meteorologist. Moreover, the South Bend meteorologist would be unable to accurately determine the strength or direction first-hand. Overall, the lack of first-hand knowledge caused unnecessary delay in determining what locations were in danger.

Fourth, FM radio frequencies would be set aside for the dissemination of severe weather information. Today, the National Weather Service broadcasts weather information over the same expanded network to NOAA radios that further notifies people of severe weather.

Fifth, the number of severe weather spotters would be increased to help meteorologists located and confirm severe weather events. Prior to 1965, the U.S. Weather Bureau decided that the money for training spotters could be used elsewhere. Essentially, administrators believed that trained spotters outside the Great Plains were not necessary. Today, the use of trained spotters is essential and an important necessity to disseminating severe weather information.

Finally, educating the public of the possibility of severe weather is vital. In 1965, the public was essentially confused by what was being issued by the forecast offices. Prior to the change, a tornado warning today was called a tornado forecast in 1965 and people did not know exactly what to do. When the sirens did sound, people were curious why and did not take the necessary precautions. Furthermore, when the severe weather information was issued over the radio or television, instructions were not given as to what the public should do. Today, anytime a warning or watch is issued, the broadcaster must include instructions on what to do. For example, “National Weather Service in Indianapolis has issued a Tornado Warning for Greene County, Indiana. Go to the lowest level of the structure or interior room for cover immediately.” Although great strides to educate the public of the procedures of what to do in the event of severe weather has occurred since 1965, there are still a large number of people who do not know what to do.

The Palm Sunday Tornado Outbreak changed the way National Weather Service functions today. Had the 1965 event not occurred, it is believed that the Super Outbreak of April 3-4, 1974 would have resulted in higher fatalities and injuries. These are lessons learned and will continue to be learned for the protection of humanity from nature’s fury.

The Future and the Reasons for Studying Meteorology

As we progress through the current century, humans will begin to see patterns of how we are influencing the atmosphere that reciprocates in destruction. Further investigation as well as educating the future population of the globe will promote an understanding and better protection of the environment. The environment does evolve naturally; however, we need to understand that our activities do enhance the evolution of the atmosphere. Remaining ignorant of the influence will only provide further destruction and unnecessary death.

Multimedia Applications

Watch the following documentaries on the accompanying website.

- Human Modification of the Environment: Water Resources (2005)
- The Plow that Broke the Plains (1936)

Chapter Review

1. What do you think is the psychology behind humans and weather?
2. What are other examples of humans believing that the environment could be controlled?
3. From the documentary, “Explore the Skies: Human Modification of the Environment-Water Resources,” provide a summary of the debate between consumers and producers.
4. The documentary, “The Plow that Broke the Plains,” was produced by the U.S. Government. What, do you believe, was the overall purpose of this film?

CHAPTER II

CHAPTER II: HISTORY OF METEOROLOGY

The study of meteorology originates in Greece in the year 340 B.C. with Aristotle's work, *Meteorologica*. Aristotle (figure 2.1) is considered the father of meteorology with this particular work. In his writing, he speculates on the functions of the atmosphere through philosophical observations. Although primitive in form, his understanding of the atmosphere is accurate. During this period, anything that fell from the sky or in the sky was called, in Greek, *meteoros*, hence the term meteorology.

Assuming Aristotle's role, Theophrastus (figure 2.2), a student of Aristotle, wrote a book on weather forecasting called, "Book of Signs." Within the text, Theophrastus provides information on general weather indicators.

The Dawn of Meteorology

Meteorology did not become an accepted science until the invention of weather instruments. Instruments are very important in any field of science as it allows the observer or investigator to record measurements for testing. Once the test is repeated successfully without change, it becomes a scientific fact. The first instrument invented in the 1500s was the thermometer by the Italian physicist and astronomer, Galileo (figure 2.3). Later in 1714, Gabriel Daniel Fahrenheit created a scale to be affixed to the thermometer that allowed the accurate measurement of temperature. Fahrenheit's scale established 32° as the melting point and 212° as the boiling point. Anders Celsius in 1742 further established another scale that is commonly used today throughout the world. In this scale, 0° is the melting point and 100° is the boiling point. The Celsius scale is considered the scientific standard in recording temperature for scientific purposes due to its simplicity. Evangelista Torricelli, an Italian mathematician and physicist, invented the barometer in 1643. Later, René Descartes and Blaise Pascal,

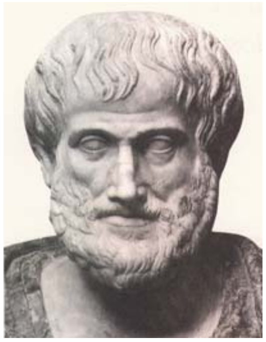


Figure 2.1. Aristotle.

Figure 2.2. Theophrastus.

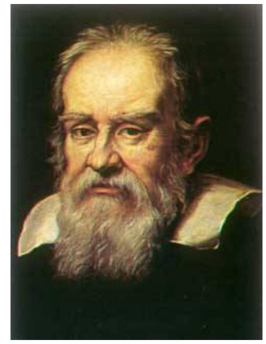


Figure 2.3. Galileo.

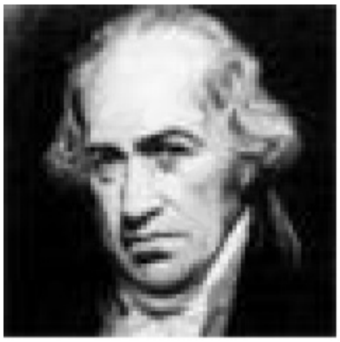


Figure 2.4. Gabriel Daniel Fahrenheit.

Figure 2.5. Anders Celsius.

Figure 2.6. Evangelista Torricelli.

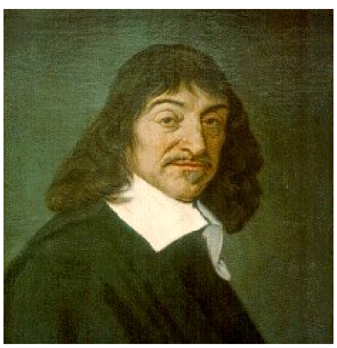


Figure 2.7. René Descartes.

Figure 2.8. Blaise Pascal.

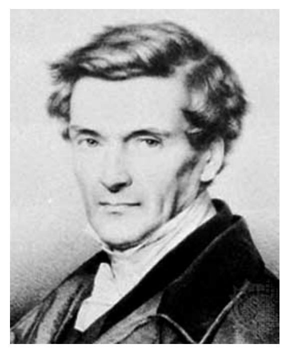


Figure 2.9. Gaspard de Coriolis.

Figure 2.10. Vilhelm Bjerknes.

Figure 2.11. Sir Robert Watson-Watt

Figure 2.12. Theodore Fujita.

French mathematician-philosophers, used the barometer in determining that pressure decreases with altitude.

Conceptual Meteorology

The concepts of atmospheric circulation can be attributed to several scientists over the last 300 years. George Hadley, in 1735, discovered a strong convection system within the Tropics where heat rises around the Equator inducing a low pressure known today as the Inter-tropical Convergence Zone split near the Tropopause. As the air cooled around 30°, it sank to form a zone of high pressure at the surface called today the Sub-tropical High Pressure belt. Furthermore, in 1835, the concept that explains that a free parcel unattached to the surface of the Earth will be influenced by Earth's rotation called the Coriolis Effect was discovered by French physicist Gaspard de Coriolis.

In the 1920s, considerable advancement in meteorology occurred when a group of Norwegian scientists, known as the Bjerknes School, including Vilhelm Bjerknes and Tor Bergeron, worked together to investigate a model of cyclogenesis or the development of mid-latitude cyclones. Their findings have provided meteorologists and atmospheric scientists with important information of how storm systems evolve as well as established the symbols displayed on maps people see on television or the Internet. Prior to the work of the Bjerknes School, frontal systems, and wind streams were not well known. As the discoveries of the school were disseminated, forecasting of storm systems became more accurate. Later in the 1940s, the use of upper air observations from weather balloons further provided scientists with a three-dimensional view of the atmosphere, which resulted in better forecasts as well as detailed information of atmospheric evolution on a smaller scale.

Meteorology Since World War II

Prior to World War II, Sir Robert Watson-Watt (1892-1973) invented a RADAR instrument that could detect thunderstorms with considerable distance. His work also allowed the Allies to detect German bombers crossing the English Channel. Today, RADAR is one of the most important instruments used in detecting rotation in storm systems to help warn people of a possible tornado.

Although tornadoes are still a mystery in atmospheric science, great strides in better understanding them came from the investigations of Theodore Fujita (1920-1998).

History of Weather Observations

Meteorology would not have become vastly important without the primary use of instruments for observations. Weather observations were most important throughout the Chinese civilization. Approximately 6000 years of weather observations were recorded for governmental purposes to determine prosperity. In imperial Russia, Peter the Great, wanting to bring knowledge from the west, established the first Russian weather observation network in order to learn more about the land Russia held. In the United States, weather observations were of importance to Benjamin Franklin and Thomas Jefferson. Each day they would keep the daily temperature, barometer reading, precipitation, and general weather conditions. Thomas Jefferson essentially fostered the importance of weather observations in the United States, which culminated in the establishment of the Smithsonian Weather Observation Network.

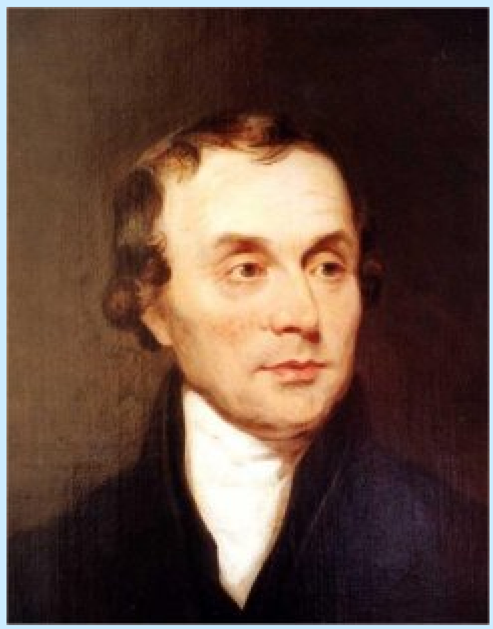
Although the Smithsonian network was a good effort in recording the weather, it was not accurate and contained errors. Weather conditions were recorded with non-standardized instruments and observed at different times throughout the day, which made a mess for the analyst. In an effort to correct errors, Congress passed legislation in 1870 that established the National Weather Bureau under the control of the Signal Corp. Once established, the observations were standardized meaning the instruments were the same from the same manufacturer, and the observations were taken at specific times throughout the day by trained observers. In addition, observation stations would cover more areas than the previous network.

Today, the weather observation network is maintained by the National Weather Service Cooperative Observation Network. Throughout the United States, a observation station can be found every 15 miles providing an extremely dense network of weather information. In central Indiana alone, there are over 150 weather observation stations. Each station records the temperature, precipitation, and overall weather conditions and submits them via the Internet to the regional forecast office where the information is tabulated and analyzed by meteorologists and climatologists in determining what is considered normal. This network, which can be found in any nation in the world, is vital to the future condition of the climate as well as discovering further information about the evolution of our atmosphere.

Luke Howard (1772-1864)

By Cameron Douglas Craig

From *Encyclopedia of World Climatology*, edited by John E. Oliver. 2005.



Luke Howard was born in 1772 in London, England. Although by profession he was a manufacturing chemist and pharmacist, he was also an amateur meteorologist who is credited with the first successful and logical classification of clouds based on appearance. Howard was educated at a Quaker school in Burford, Oxfordshire and became a devout Quaker and family man – Mariabella (Eliot) Howard, his wife, and three children. Although his professional life was that of a chemist, he stated that “meteorology was my real penchant”.

In his attempt to classify clouds, Howard believed that the terms should describe the appearance of the clouds and use a common language that Europeans and non-Europeans could understand – Latin – rather than the vernacular, which was attempted by Jean-Baptiste Lamarck of France. Lamarck’s classification of clouds was not unlike Howard’s basic idea that clouds have distinct appearances. However, there were three reasons that Lamarck’s scheme failed – first, the use of the scheme, which did not use the Linnaean style of nomenclature; second, the language was French not Latin, which would only be useful to French-speaking people; and third, it was too difficult to understand. Howard’s success of classifying clouds came about when he used a similar method of classifying plants and animals by the Swedish taxonomist Carl von Linné (Linnaeus). The style of nomenclature used identified the genus and further specified the species. Howard’s scheme was widely accepted for two reasons: similar clouds occur globally, which allowed the use of an internationally accepted language, and the proper use of nomenclature.

In his book, *On the Modification* (classification) *of Clouds* (1804), Howard presented three distinct basic forms of clouds: *stratus* meaning layered, *cumulus* having a stacked appearance, and *cirrus* regarding the appearance of an angel’s hair. In addition, four cloud forms were introduced: *cirro-cumulus*, *cirrostratus*, *cumulo-stratus*, and *cumulo-cirro-stratus*. Howard believed, from his study of cloud formations, that one could predict the weather through observing clouds.

Howard's classification scheme and detailed descriptions from republished essays inspired a few Romantic painters such as John Constable and Joseph M. W. Turner in the accuracy of illustrating clouds in their works of art (Thornes, 1984; Heidorn, 1999). In addition to Howard's book, *On the Modification of Clouds*, he further presented a range of papers and lectures on meteorological topics, including *Average Barometer* (1800), and *Theories of Rain* (1802). In 1806 Howard began a register of meteorological observations, which were regularly published in the *Athenaeum Magazine* in 1807. A series of *Seven Lectures in Meteorology* (presented in 1817) that Howard gave were later published as a textbook on meteorology in 1837. Howard began a study of London's urban climate that culminated into two volumes, *The Climate of London* (1818–1819). In 1821 Howard became a member of the Royal Society, an organization of scientists and inventors, and later published his final work, *Barometrographia* (1847).

Although not much has been written about Howard's life and his classification of the clouds, Richard Hamblyn's book, *The Invention of the Clouds: how an amateur meteorologist forged the language of the skies*, provides a history into the life of Luke Howard and his creation of the classification of clouds. On 17 April 2002 English Heritage of England awarded a plaque to be placed on the home of Howard to honor his achievements to the study of meteorology and climatology. Although Howard's original classification has been modified and further cloud types added, such as *cumulus congestus*, *cumulus fractus*, *cumulonimbus calvus*, and *stratocumulus undulates*, his concept is still used around the world in meteorological and climatological studies.

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Chapter Review

1. What do you think would result in society today if these significant historical figures did not investigate the atmosphere?
2. Why are weather observations important to scientific discovery?
3. What was the single reason Luke Howard's method of classifying clouds is widely accepted?
4. What is conceptual meteorology?

CHAPTER III

CHAPTER III: OBSERVING THE WEATHER

The most important aspect of understanding atmospheric evolution is in the recording of conditions. Prior to 1870, weather observations were not standardized. Although networks throughout Europe and the United States were established to record weather conditions, their accuracy was less than desirable. In some cases, observations were recorded sporadically or even not at all. The instruments used were not accurate or calibrated to specific specifications. Through an act of Congress, the Secretary of War was given authorization to create a weather observation network for the systematic and synchronous observation of weather in the United States. The Signal Corp was the agency within the Department of War responsible for this important task.

As part of the organization of the network, all equipment used in recording weather conditions had to be of the same manufacturer to guarantee accurate and similar recordings. Moreover, the observers would be expected to record the weather at specific times throughout the day and transmit the conditions via telegraph to the national headquarters in Washington D.C.

Today, the National Weather Service oversees the Cooperative Observer Network that derives from the 1870 act of Congress. The only difference is in the participants and the number of observation stations. The Cooperative Observer Network no longer employs trained specialists to record daily weather conditions. Volunteers in all occupations are given the equipment to observe the weather at their home and submit the data to the regional forecast office. Most of the volunteers are those who are simply interested in the weather. Some families have been part of the network for many generations. A region, such as Central Indiana, will contain over 150 stations. Each station covers an area of 15 miles radius. Within this area, no other station will be established to reduce errors in the recordings.

There are two types of stations that are maintained by volunteers: a climatological station (figure 3.1), and a hydrological station. The climatological station records the temperatures and precipitation. A hydrological station records temperatures, precipitation, river height, soil temperatures, and evaporation.

Figure 3.1. National Weather Service Cooperative Observing Station located on the Indiana State University Campus in Terre Haute, Indiana.

Instruments of the Cooperative Observation Station

Every morning throughout the United States observers will record the weather conditions using standardized equipment provided to them from National Weather Service. The typical time that weather conditions are recorded is 0800 local standard time (LST). Some stations observe at 0600 LST or 0700 LST depending on the regional forecast office. Moreover, since weather does not stop, observations are recorded everyday of the year regardless of holidays. The instruments that are used are standardized and are analog, not automated. In other words, the weather conditions are recorded by human eyes for accuracy.

The Stevenson Screen (figure 3.2) is a box that houses the maximum and minimum thermometers. It is painted white to reflect the sunlight in order to reduce the inflation of temperature readings. Slats on all four sides allow the air to freely flow through the screen to provide accurate readings. Moreover, the screen is placed approximately 4.5 feet above the ground so that there is no influence of heat from the ground.

Figure 3.2. The Stevenson Screen that houses the thermometers.

Within the screen on a Townsend mount (figure 3.3) is placed the maximum and minimum thermometers 5 feet above the ground. The maximum thermometer is most often mercury filled and has a unique feature in its design—a constriction of the column near the bulb. The constriction allows the maximum temperature to be recorded. Once the maximum temperature occurs, the heavy metal, mercury, is kept at its current position until it is reset. To reset the maximum thermometer, the mercury must be forced back into the bulb. This is accomplished through centrifugal force or a spinning of the thermometer. The minimum thermometer is filled with alcohol that contains a special object that allows the observer to record the minimum temperature—an index rod. The rod sits within the alcohol column and as the temperature drops the miscues of the liquid pushes the rod toward the bulb. When the temperature rises, the index stays put until it is reset. Resetting the minimum thermometer simply involves gravity by tilting the bulb of the thermometer up to allow the index to slide back to the end of the alcohol column.

Three temperatures are recorded daily—the maximum temperature is recorded by the maximum thermometer and the observation (current) temperature and minimum temperature are recorded by the minimum thermometer.

Figure 3.3. The Townsend mount that holds the Maximum and Minimum Thermometers.

Daily precipitation is recorded by the use of an eight-inch rain gauge (figure 3.4). There are four parts to the gauge, funnel (figure 3.5), collection tube (figure 3.6), overflow can, and a rosewood measuring stick. As melted precipitation falls, it is funneled into the collection tube. If enough precipitation fills the collection tube, any more overflows into the overflow can. During the observation period, the observer will remove the funnel and measure the amount of precipitation using the rosewood measuring stick that is calibrated with the width of the overflow can (eight-inch). Although the measuring stick is approximately 2.5 feet in length it will only record up to two inches of rain. If more than two inches of rain fell, what is held within the collection tube is measured first and dumped and the precipitation that is in the overflow can is funneled into the collection tube and measured then all partial measurements are added together to get the total amount of precipitation for the previous day.

Figure 3.4. Eight inch Rain Gauge.

Figure 3.5. Funnel being removed from the overflow can.

Figure 3.6. Collection tube inside the overflow can.

During the winter season, the can will collect the frozen precipitation without the funnel and collection tube attached. The overflow can acts as the collection tube. Frozen precipitation is recorded by taking hot water and measuring it in the collection tube then poured into the overflow can to melt the frozen precipitation. The funnel is then attached to the collection tube and the melted precipitation is measured with the rosewood measuring stick. After the value is recorded, the hot water value is subtracted to obtain the total amount of melted precipitation. In addition to the amount of water held within the frozen precipitation, snow depth is recorded for the last 24 hours and total on the ground. To record the 24 hours snowfall, a snowboard is placed on the ground at the start of the winter season. After a snowfall, the observer will record the depth of snow on the board with a regular ruler and reset the board by removing the snow and placing it on top of the old snow to record the next 24 hours snowfall. The total depth of snow on the ground is also recorded. The observer makes three measurements in three different locations where there is no drifting then take an average from the observations. This daily measurement records the total accumulation of snow on the ground until it melts.

Figure 3.7. Soil thermometer for sod soil temperatures.

Soil temperatures are also an important variable of the Cooperative Observation Network; however, not all observing stations record the variable. The soil thermometers are placed in the ground at a four inch depth under bare soil and sod soil (figure 3.7). The thermometers record the daily maximum and minimum temperatures. The daily range in temperature for the bare soil will be greater than that of the sod soil. This is due to the fact grass (sod) acts as blanket and maintains heat better. Bare soil will release heat faster. The soil temperatures are extremely important for the agriculture industry in determining appropriate planting times. For example, in order to plant corn in spring, the temperature must be at least 50°F for approximately seven days.

Very few observing stations have evaporation pans for recording the daily evapo-transpiration. The instrument contains a large round pan for water, a hook gauge, a sixes thermometer, and an anemometer. During the observation period, the observer measures the height of the water and records how much water was removed during the previous 24-hour period. The maximum and minimum water temperatures are also recorded as well as the total number of miles the wind blew. All of these variables are used in determining the amount of evaporation for the agricultural industry. If the atmosphere is moist, not much evaporation will occur; however, if the atmosphere is relatively dry, a great deal of evaporation will occur. The evaporation pan is only used during the warm season.

The final instrument used in the daily recording of weather conditions is the human senses. During the observation period, the observer will record the relative amount of dew or frost on the ground, sky cover, relative temperature, and any other notes that complete the weather picture for the day. This information is very important because some weather conditions are simply not recorded from calibrated instruments.

Instruments of Digital Weather Stations

Digital weather stations are becoming more used throughout the United States. People who are interested in daily evolution of weather are purchasing affordable digital weather stations. These stations have many different sensors that record temperature, rain, solar radiation, ultraviolet radiation, humidity, barometric pressure, wind speed, wind direction, and so on (figure 3.8). The benefit of using digital weather stations is the recording resolution. Digital weather stations do not require human observations. These stations can record and archive weather data every minute and even every three seconds, which can be very important in micro-climatology and analyzing the evolution of storms.

Figure 3.8. The ISU2/CW1125 Digital Weather Station in Terre Haute, Indiana with Tipping Rain Collector, Stevenson Screen, Wind Vane, and Anemometer. Other meteorological sensors or housed within the Stevenson Screen.

Other Observing Instruments

Although there are specific variables required by the Cooperative Observation Network, there are other types of instruments used. These include the sling psychrometer, barometer, wind vane, and anemometer.

The sling psychrometer is a hand held instrument that is used to record the amount of moisture in the air. The instrument has two thermometers—one normal thermometer (dry-bulb) and another thermometer with a wick (wet-bulb). To make an observation of the amount of moisture in the air, the observer moistens the wick of the wet bulb, swings the psychrometer for approximately 45-60 seconds, and then records the two temperatures. The difference is determined by subtracting the wet-bulb temperature from the dry-bulb temperature then correlated with, for example, a relative humidity chart to determine the humidity of the air. As will later be discussed in detail, the wet-bulb temperature will be always be equal to or less than the dry-bulb temperature.

The barometer is an instrument that records the atmospheric pressure or the force of the atmosphere exerted via gravity. There are several different types of barometers used but two of the most used are the aneroid barometer and the mercury barometer. The aneroid barometer is a mechanical device that has a diaphragm that changes its size according to the pressure of the atmosphere. The mercury barometer records the force exerted on the heavy metal in a glass column, similar to a mercury thermometer.

The wind vane and anemometer are important instruments that record the wind parameters. The wind vane is a vertical blade that points to the direction the wind is coming. As the wind flows past the station, the blade is pushed with the flow allowing the pointer to indicate the wind direction. It is important to remember that wind direction is recorded as ‘coming from’ rather than ‘going to.’ The anemometer is an instrument that typically has three or four cups attached to a spinner. As the wind blows, the cups move with the wind to record its speed.

Variable Resolution

Not only are standardized instruments important in accurately recording weather conditions, but the resolution of the variables are also important. Table 1 displays the accepted resolution of particular weather variables. Although digital weather stations can record particular variables to a very fine resolution, the accepted resolution is to the whole degree. Human observations set the standard in that most thermometers are scaled to the whole degree. Providing anything smaller than a whole degree constitutes an error. In other words, without a greater resolution on a thermometer that is only incremented to the whole degree, a human cannot accurately record anything smaller than a whole degree. How does the observer know the temperature was 67.6°F unless the thermometer has tenths of a degree etched on the face? They do not. If the mercury is positioned halfway in-between the 67°F and 68°F, all the observer can do is to record 68°F instead of guessing that it is 67.6°F or 67.5°F. This is an important rule in weather observations, the standard.

Analog Stations vs. Automated Stations

Human observations of weather conditions using analog instruments are more reliable than observations from automated stations. Observers and hydrometeorologists know that analog instruments will work because anyone can fix them. If the mercury in a maximum thermometer is separated, the observer can easily fix the problem by applying centrifugal force to force the separation together. However, automated stations require a technician to fix the problem. For example, a NWS representative called a Cooperative Observation Network volunteer to determine how much precipitation fell during a storm. The nearby automated station recorded 18 inches of precipitation for the event. The observer looked over the data and determined that only 2.51 inches of precipitation fell during the storm. The Weather Channel broadcasted the amount the automated station recorded as the highest amount of precipitation in the region. In this particular example, the automated station inaccurately recorded the precipitation, which caused great confusion and provided an important reason why NOAA/NWS only uses human observations.

The Purpose of Weather Observations

The primary purpose of having a weather observation network is not to provide a forecast. The daily recording of weather conditions in the Cooperative Observation Network is to establish what is normal. Automated stations do not provide the National Oceanic and Atmospheric Administration (NOAA) with ‘what is a normal temperature,’ but the human observation of the weather. Determining what is normal is very important in determining the state of the climate for the future. This is only done through human observations not automated stations.

Multimedia Applications

Watch the following documentaries on the accompanying DVD.

- Observing the Weather

Chapter Review

1. Why does NWS require the same or close observation times for the whole country?
2. Why is the resolution of the weather variable important?
3. Describe the importance of using human observations.
4. Why is a standardized system of weather observations extremely important? Why not let observers use their own instruments?

Meteorological Exercise

1. Complete Laboratory Exercise 1 in the Explore the Skies: Studies in Meteorology Laboratory Book. Time required for completing this exercise is approximately 1.5 hours.

CHAPTER IV

CHAPTER IV: OBSERVING THE ATMOSPHERE

In addition to observing the weather at the surface through a weather station, observation of the atmosphere is also important. Observing the atmosphere requires the use of radiosondes, radar, and satellites. From these sophisticated instruments, meteorologists and atmospheric scientists can interpret the weather picture from above or vertically through the atmosphere. Moreover, these instruments along with surface observations help to create important weather charts used in communicating weather conditions at different levels.

Weather Satellites

The National Oceanic and Atmospheric Administration (NOAA) maintains several different satellites used in gathering and interpreting weather data. The main satellite system used is the Geostationary Operational Environmental Satellite (GOES). Referred as geosynchronous, these satellites remain stationary (orbit at the same speed as the Earth's rotation) with the Earth's rotation to allow scientists to view current weather such as hurricanes, mid-latitude cyclones, and tornadoes throughout the course of the day.

Another satellite system that sun-synchronous is the Polar Operational Environmental Satellite (POES). Essentially, the POES system observes the Earth longitudinally passing over the North and South Poles. This system observes a swath of the Earth's surface of a few miles to 1500 miles in width. The major satellites used in this system are the LANDSAT and IKONOS.

The GOES system will be of great importance for observing the overall character of the atmosphere. Three primary data sets (visible, water vapor, and infrared) from GOES 8 and 10 (figure 4.1) will be used throughout this text to demonstrate how to analyze weather conditions across the United States.

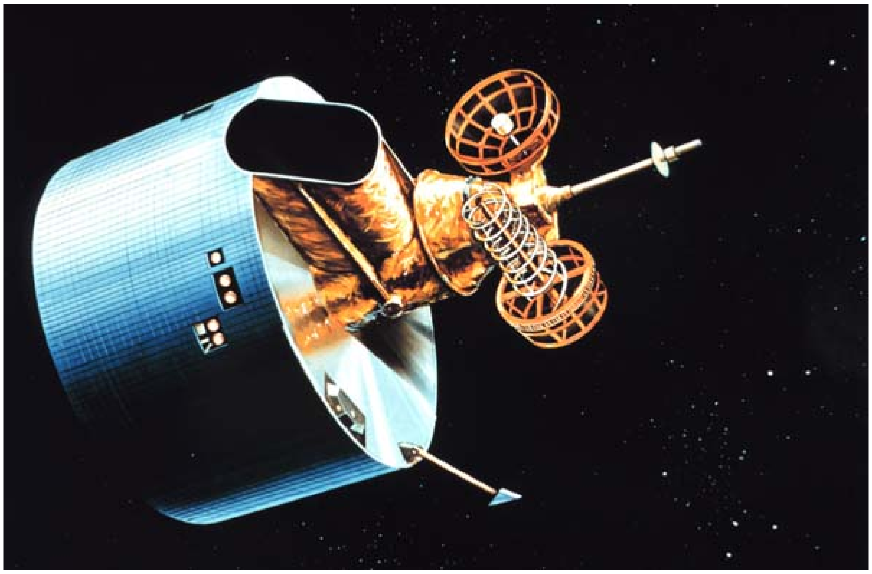


Figure 4.1. GOES 3. Photo from NOAA.

Observing the Weather through Images

Although meteorological observations from the surface are very important in forecasting, satellite images are also quite important for one particular reason—they provide meteorologists with a qualitative and quantitative view of the overall weather story. Essentially, these images provide analysts with the character of the atmosphere that would not otherwise be provided by numeric surface data. Clouds, moisture, and temperature are displayed through specific images that help to interpret what is actually occurring and what can be expected.

Visible Images

Visible images (Figure 4.2) are essentially photographs of the Earth just as you would take a photograph of a landscape. Visible images are only possible when the Sun is available to illuminate the surface because the sensor uses the sunlight like a camera flash. During hours of darkness, the images are black due to the absence of light from the Sun (Figure 4.3). These images provide analysts with specific cloud type information such as cirrus and cumulus, which allows some surface features to be seen, or cumulonimbus, which produces a shadow from the overshooting (percolating) top.

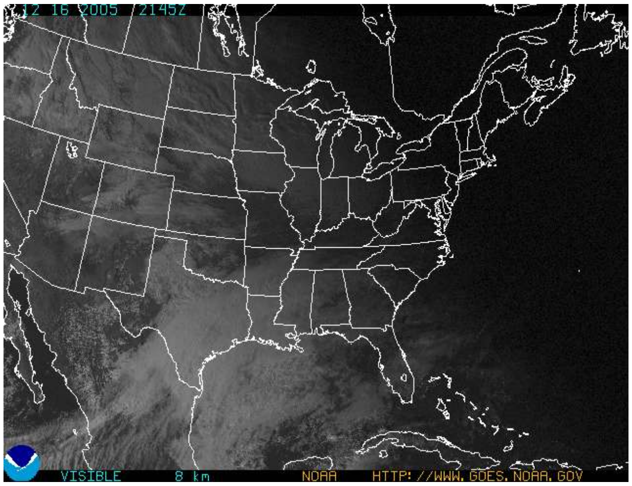


Figure 4.2. A visible image recorded during the day. Notice the circle of illumination (the separation of night and day). Image from NOAA.

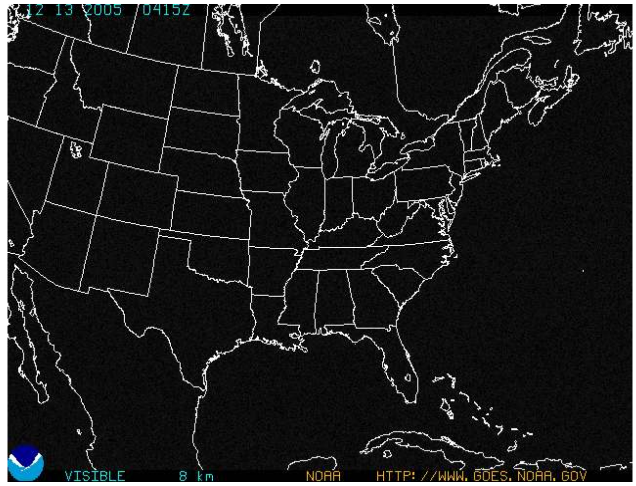


Figure 4.3. A visible image recorded during nighttime. Image from NOAA.

Figure 4.4. Percolating top of a cumulonimbus cloud. Indicates strong updrafts from the surface. Photo from Cameron Douglas Craig.

Water Vapor Images

Water vapor images (Figure 4.4) displays the relative amount of water vapor in the upper level. High levels of water vapor are indicated by bright white areas and darkened areas signify dry air aloft. Animated water vapor images are excellent in determining the location of low-pressure cells due to their apparent circulation. Since water vapor absorbs heat, we see only the areas that are warmer but only at the upper level. Swirls displayed throughout the image are only characteristic of water vapor images.

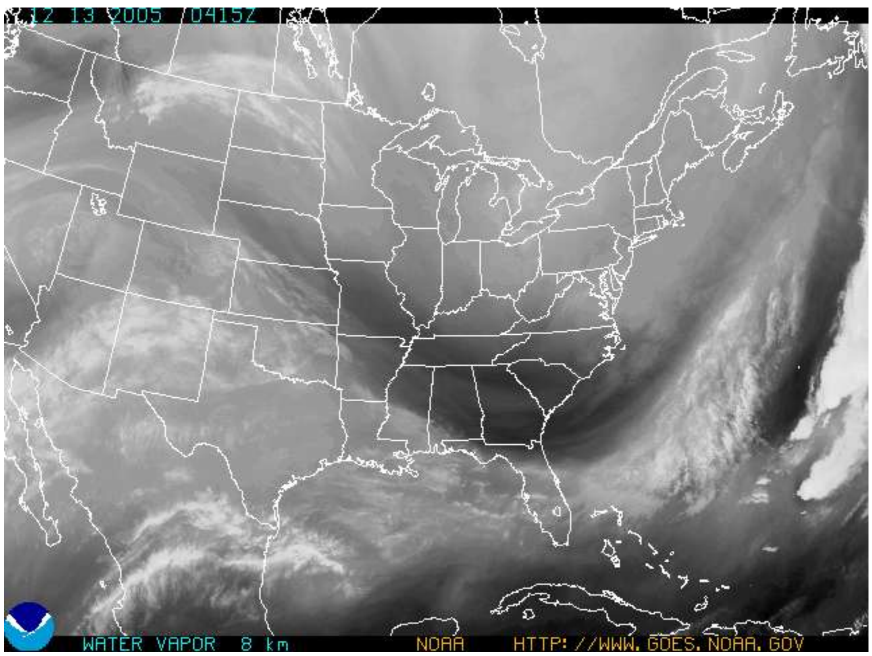


Figure 4.4. Water vapor images display moisture at the upper level. Image from NOAA.

Infrared Images

Infrared images (Figure 4.5) record what heat is being emitted through the atmosphere. Dark areas indicate greater heat, which is being absorbed by the sensor. The primary function of infrared images is to provide analysts with the temperature of clouds tops. Since temperature decreases with altitude, high-level clouds or clouds that have vertical extent such as the cumulonimbus will be displayed as white. In other words, the higher the cloud, the colder the temperature. This is indicated by bright white areas on the image.

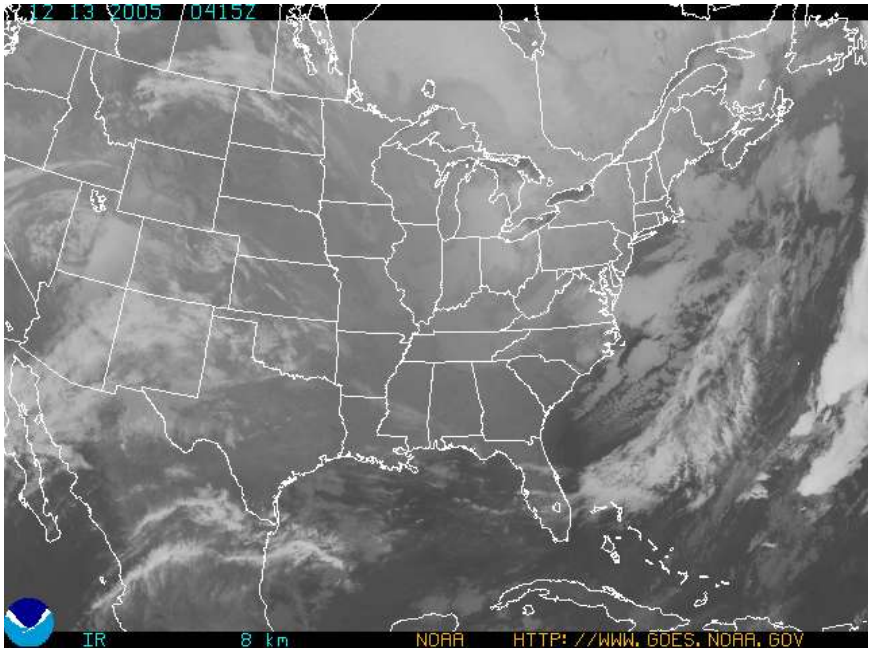


Figure 4.5. Infrared images display cloud top temperatures (cold). Image from NOAA.

Determining the Difference between Images

The following passage describes how to differentiate between the three images. To determine the difference between infrared and visible images, it is important to look for shadows. If there are shadows between the cloud and the surface, this is a visible image. In addition, ripples and shadows on clouds will also indicate visible images. Infrared images are essentially gray, where visible images look like a typical black and white photograph of the Earth.

Water vapor and infrared images are sometimes confused among students. In order to differentiate the difference between these images it is important to understand that water vapor images only show the moisture content of the *upper level* where infrared images display surface and upper air characteristics. If the image displays very dark areas with white swirls, this is a water vapor image. Imagine a glass of milk and pouring chocolate syrup into it, the result is a swirl—a water vapor image is similar in context. Infrared images will essentially be milky showing land surfaces or water surfaces as a grayscale without swirls.

Radio Detection and Ranging

One of most important observational tools is the radar. Sir Robert Watson-Watt, a meteorologist at the Royal Aircraft Factory in Farnborough, England, found a way to use radio waves to warn pilots of approaching storms in 1915. His work helped win victory against the German bombers during the Battle of Britain. Today, his work in radio detection and ranging is still used throughout the world for identifying approaching severe thunderstorms and notifying the public of tornado formation.

The radar system allows weather analysts to view the size, intensity, and distance of precipitation within the range of a radar tower. As a beam of radiation is sent out from a dish (receiver), the energy bounces off the precipitation back to the dish recording its size in decibels. Essentially, the heavier precipitation indicates more severe situations where the raindrop has made a long journey from the top of a towering cumulonimbus cloud. Nimbostratus clouds produce lighter precipitation that is displayed on radar screens as finer decibels. In the radar image displayed in figure 4.6, larger moisture droplets are indicated in red where smaller drops are displayed in green.

Radar images also provide meteorologists with wind velocities in identifying rotation above the surface such as the possible development of a tornado. Radars cannot acquire wind velocities without the presence of moisture. Since moisture is an important ingredient of a cloud, the radar can determine whether that moisture droplet moves toward the receiver or away from it. Thus, indicating wind velocity.

Unlike radar images that have colors indicating precipitation intensity, figure 4.6 displays a radar velocity image where green colors indicate winds flowing toward the receiver and red showing winds flowing away from the receiver. In this example, two tornadoes were identified by the radar's ability to differentiate the wind flow coming or going away from the receiver. In normal, non-severe weather situations where the wind field is from one direction, the velocities would not be spiral or isolated as in figure 4.7.

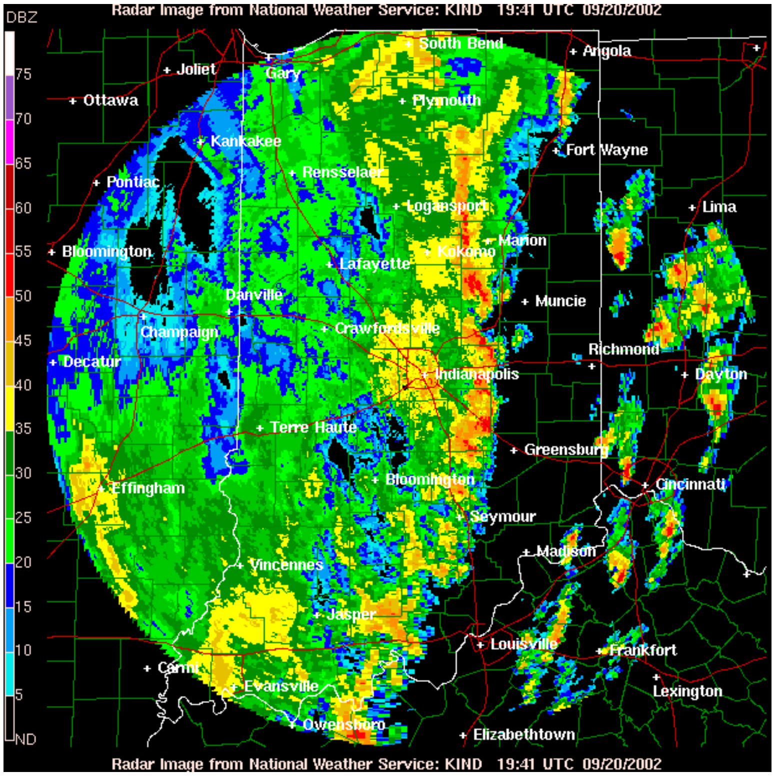


Figure 4.6. Radar image from Indianapolis, Indiana indicating areas of heavy and light precipitation.

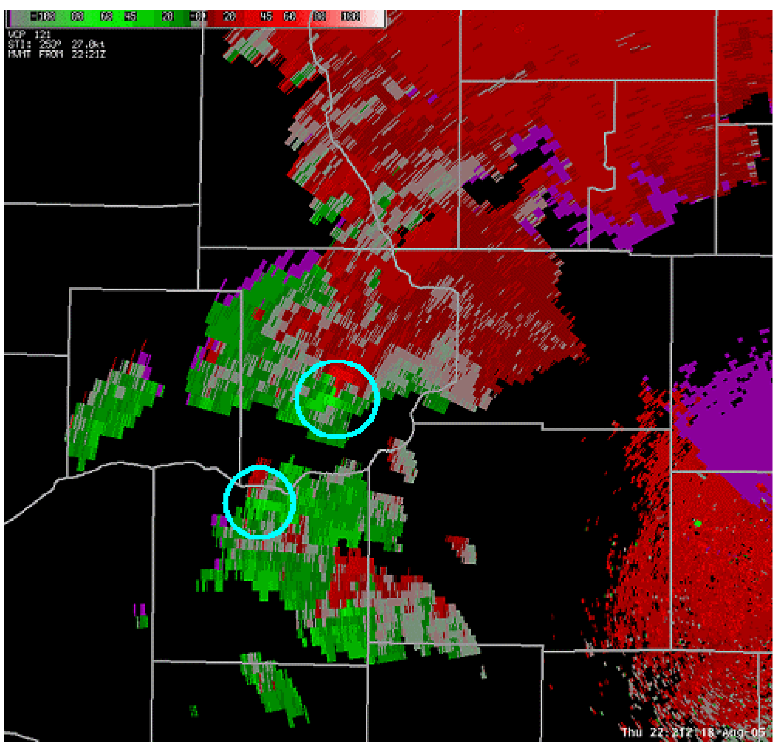


Figure 4.7. Radar image displaying wind velocities. Blue circles indicate the presence of rotation. Image from NWS Milwaukee/Sullivan, Wisconsin.

Radiosondes

Radiosondes (figures 4.8 and 4.9) are very important in observing the vertical profile of the atmosphere. As it was in the 1930s, radiosondes, attached to an eight-foot or sixteen-foot diameter helium filled balloon, are released twice everyday into the air recording the temperature, dew point, humidity, wind speed and direction, and barometric pressure. As they fly into the sky, they transmit data to receivers at the surface. The data are displayed in thermodynamic charts or skew-Ts (figure 4.10) that provide meteorologists with the vertical profile of the atmosphere. Analysts use these charts to determine the extent of moisture in the upper for cloud formation, as well as wind shear and stability for thunderstorm forecasting. After the balloon expands the higher it travels and breaks, the radiosonde returns safely to the surface with the attached parachute. When the instrument is found, the finder returns the instrument in the prepaid mailing envelope to a NWS Forecast Office to be refurbished for future collections.

Figure 4.8. Radiosonde being released. Photo from NOAA Photo Library.

Figure 4.9. The radiosonde records upper air meteorological parameters. Photo from NWS Upper Air Observations Program.

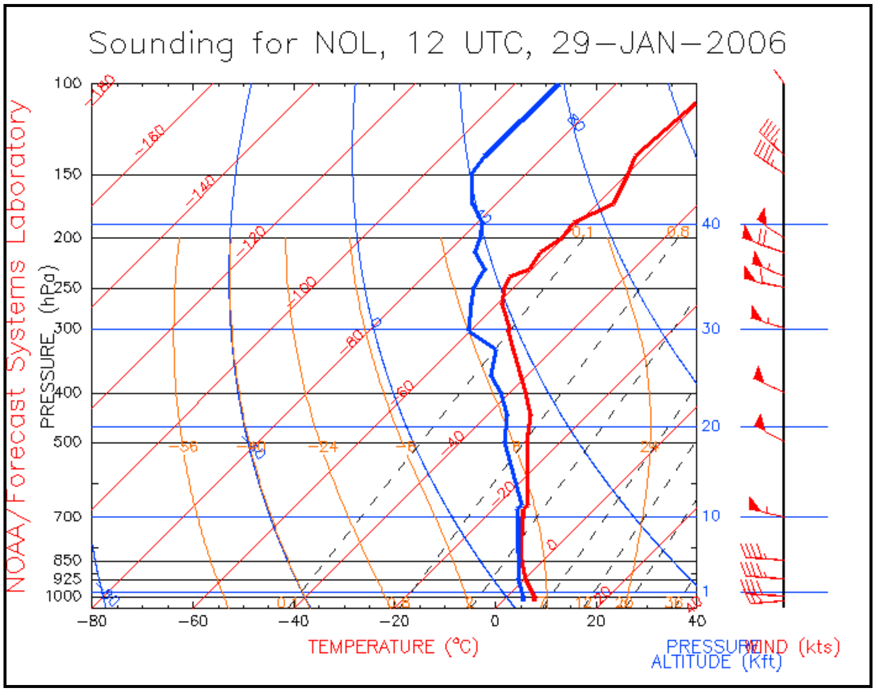


Figure 4.10. Skew-T for Orlando, Florida showing the vertical profile of the atmosphere. The wind direction, wind speed, temperature, and dew point were recorded from a radiosonde. Chart acquired from NOAA FSL Database.

Chapter Review

1. Briefly describe the difference between the GOES and POES satellite systems maintained by NOAA.
2. What are the key characteristics of visible, infrared, and Water vapor images?
3. Describe what kinds of data are acquired from radar systems.
4. Why, in your opinion, are radiosonde data important to meteorologists? Why not just use surface stations?

Meteorological Exercise

1. Complete Laboratory Exercise 2 in the Explore the Skies: Studies in Meteorology Laboratory Book. Time required for completing this exercise is approximately 1.5 hours.

CHAPTER V

CHAPTER V: FUNDAMENTALS OF METEOROLOGY PART I

Studying meteorology requires complete understanding of the basic concepts of atmospheric processes. In this chapter, a review of the essential concepts is presented.

Pathways of Energy

The most important aspect of meteorology is the concept of energy transportation on Earth. There are three main types of transfers of energy—conduction, convection, and advection. Conduction (figure 5.1) is the transfer of energy where one molecule begins to vibrate induced by heat and influences the adjacent molecule to vibrate as well until all molecules vibrate. Conduction is similar to the domino effect where one domino falls and causes the next to fall as well until all dominos have fallen.

Convection is the vertical transfer of energy (figure 5.2). A source of heat is necessary to begin the process. As heat causes the atmosphere is become less dense, it rises. Then it is restricted by a barrier such as the tropopause where it begins to cool. As the air cools, it begins to become more dense and sinks to the surface to begin the process again. The everyday example is a pot of boiling water. The element of the stove provides the heat that heats the water, decreases its density, rises, cools near the surface, sinks toward the bottom of the pot, and begins the process again.

Concerning atmospheric processes, convection occurs in cloud development and thunderstorm development (i.e. popcorn thunderstorms). The source of heat is the surface of the Earth. Continued rising of the parcels will eventually cool, become denser, and sink back to the surface.

The final transfer of energy is advection. Advection is the lateral or horizontal movement of energy. As cold air moves into an area of warm air, the cold air subtly changes the warm air. An example of this transfer of energy is when a drop of red dye falls into clear water. At first, the red dye streams within the water, after a short time, the red dye disperses equally throughout the water changing the clear water to a reddish color without the presence of streams.

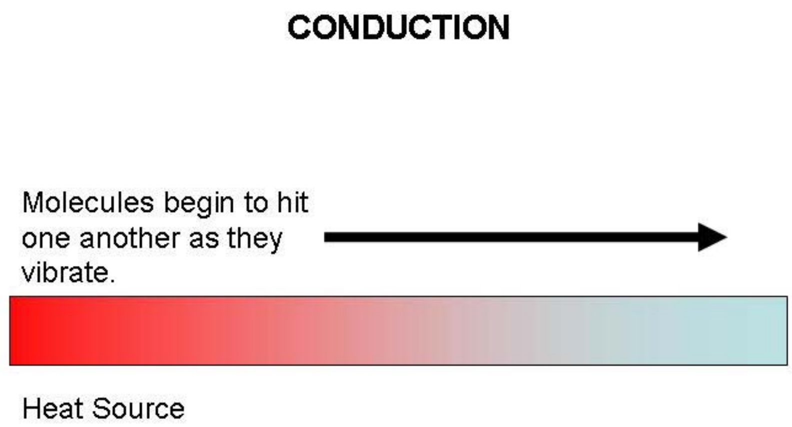


Figure 5.1. Conduction is the transfer of energy where one atom vibrates from a heat source and make the next atom vibrate until all atoms vibrate to transfer energy throughout the object.

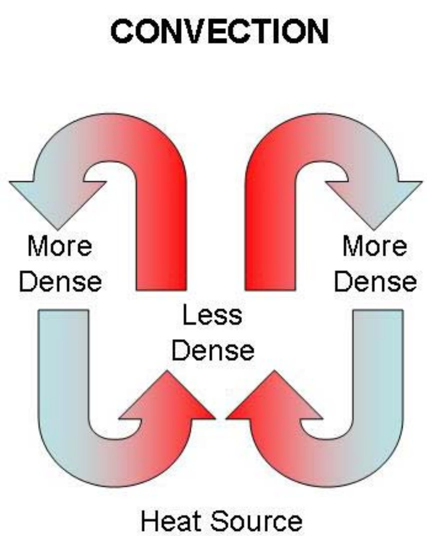


Figure 5.2. Convection is the vertical transfer of energy where a heat source causes rising due to expansion (less dense) and then it begins to cool and shrink (denser) to return to the heat source to start once again.

Radiation Essentials

The Sun is the foundation of meteorology. Without the Sun, weather simply would not occur. Throughout the day, the Sun emits a spectrum of radiation in all sorts of sizes based on wavelength. Radiation types are classified according to their measured properties (figure 5.3). Wavelength is the first measurement that is used to classify types of radiation. Essentially, wavelength is a measure of the length of the wave from crest to crest or trough to trough. Shortwaves have shorter distances between crests or troughs. Longer distances between crests or troughs are known as longwaves. The second method to measure radiation is by its amplitude. Amplitude is measured by determining the distance between the crest top to the mid-line or wave mean. More distance between the crest/trough and the mid-line indicates strong amplitude. If the distance is shorter, the amplitude is weak. The third measure of radiation is its frequency. Frequency is determined by the number of times a crest/trough passes a given point in a specific period of time. The more crests/troughs that pass a given point classify the radiation type with a higher frequency. Fewer crests/troughs passing a point indicate a lower frequency.

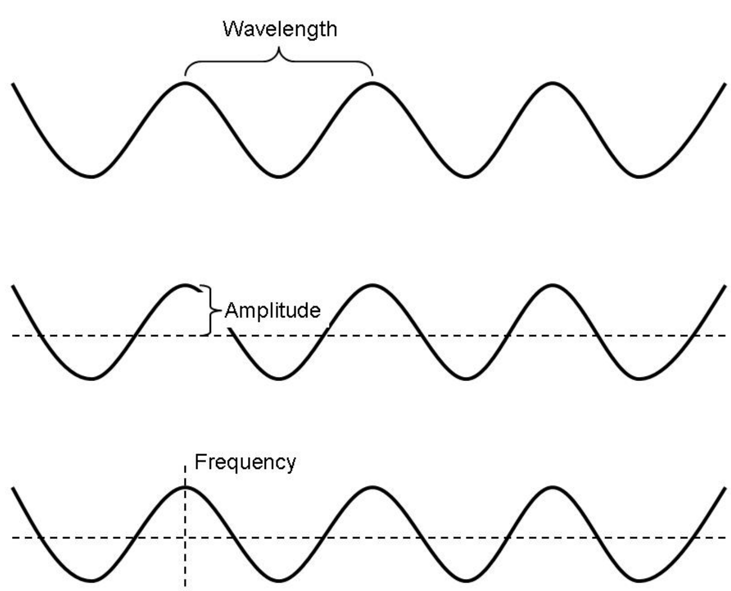


Figure 5.3. Three methods radiation is measured.

Radiation is divided into bands according to wavelength. The order of radiation into wavelengths is called the Electromagnetic Spectrum (EMS). The spectrum is divided into three categories: shortwave, visible, and longwave (figure 5.4). The shortwave portion of the spectrum, from shortest to longest, contains gamma rays, x-rays, and ultraviolet. The visible portion, from shortest to longest, includes violet, blue, green, yellow, orange, and red. Infrared, microwave, and radio waves make up the longwave portion of the spectrum.

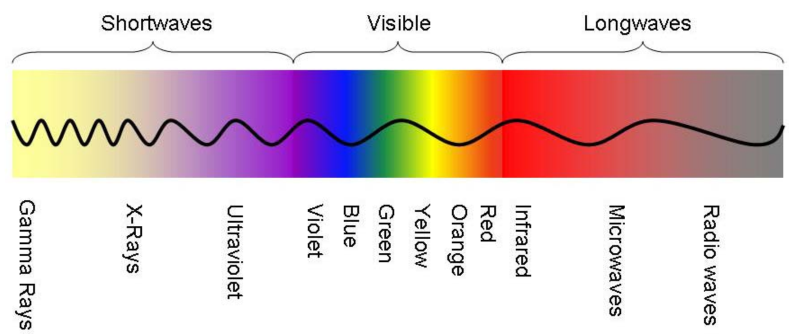


Figure 5.4. The Electromagnetic Spectrum.

Alternate terms can be applied to shortwave and longwave radiation. Shortwave radiation is often referred to as solar radiation and terrestrial radiation for longwave. Shortwaves are the most powerful and as the wavelength increases, the power decreases. Although all radiation types are emitted as heat, longwave radiation is the portion of the spectrum that can be measured with normal thermometers. Shortwaves maintain temperatures far above what normal thermometers can measure.

Laws of Radiation

There are a few laws that help to explain how radiation functions with regard to its intensity. The temperature of an object determines the amount of radiation it emits. This concept is the central theory of the Stefan-Boltzmann Law that states the radiation emitted by an object is proportional to the fourth power of the absolute temperature of the blackbody. The Stefan-Boltzmann Law is written where *E* is the emittance (intensity) of an object, σ is the Stefan-Boltzmann constant (5.670×10^{-8} Wm^{-2} K^{-4}), and T is the absolute temperature of the object to the fourth power.

$$E = \sigma T^4$$

Blackbodies are theoretical objects in helping to explain how a celestial object such as the Sun or Earth emits radiation.

Wien's Law describes the peak level of emission where λ_{max} is the maximum wavelength emitted by an object, the constant (2900), and T is the temperature of the object.

$$\lambda_{\max} = 2900 / T$$

This law helps to explain that hotter objects emit shorter wavelengths than cooler ones. Since the Sun is extremely hot, the wavelengths emitted will be very short. On the other hand, longer wavelengths are primarily emitted by the Earth due to its cooler temperature in comparison to the Sun.

Altering Radiation

Radiation can change depending on an objects albedo. Albedo is the reflectance value of an object. An object that has a high albedo, such as snow, will reflect solar radiation somewhat unchanged. However, an object that has a low albedo, such as an asphalt road, will absorb the solar radiation where it changes from shortwave to longwave radiation. Simplified, shortwave radiation is like someone passing a basketball to another person without it bouncing (figure 5.5a). The energy is unchanged during the pass. If the ball bounces between the two people, the energy is less when the person receives the ball due to most of the energy being absorbed at the point where the ball it the ground (figure 5.5b). If a person simply throws the ball without another to catch it, the ball bounces with the height of the bounce decreasing with time (figure 5.5c). Every hit the ball makes on the ground, more energy is absorbed by the ground until all the energy is used, which results in the ball simply rolling. Radiation acts in the same manner. Shortwave radiation hits an object with low albedo and gets absorbed by the object, and then the object emits longwave radiation. The by-product of used energy is heat. Once the shortwave radiation is absorbed, the object radiates heat. For example, a television will import electricity (shortwave radiation), use it, and emit heat (longwave radiation). If the television is on, the housing becomes warm due to the energy it is using. The Earth acts the same way. Shortwave radiation enters through the atmosphere hits an object with low albedo, gets absorbed, and radiates longwave radiation (heat).

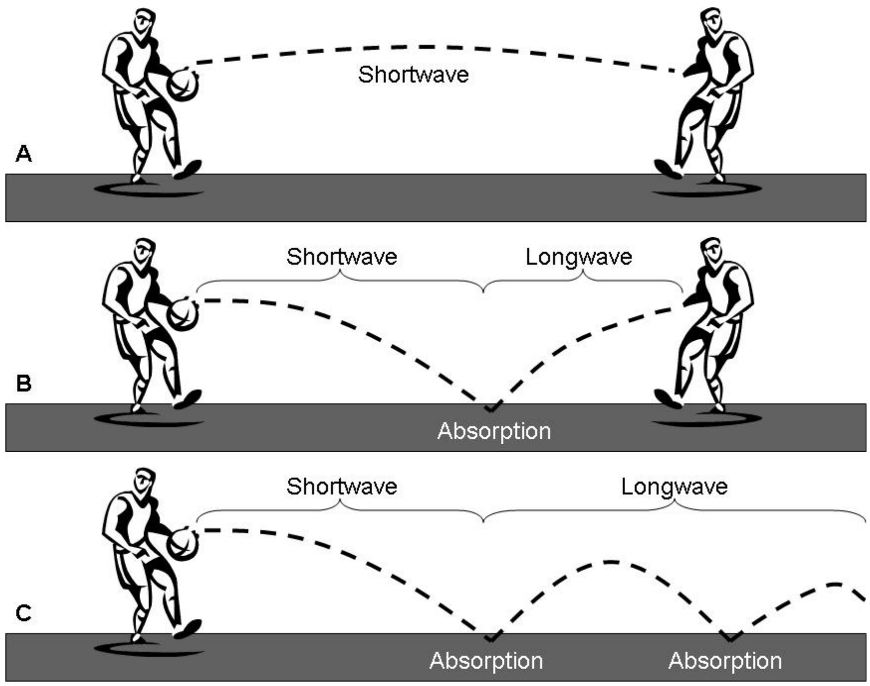


Figure 5.5. Concept of how energy changes from shortwave to longwave: A) shows that the energy is unchanged since the ball does not hit the surface, B) demonstrates the ball is now longwave energy due to the absorption of energy at the surface, and C) after the first absorption, the ball's bounce continues to decrease in height indicating the continued absorption of energy at the surface.

Surface temperatures are a result of the differences in albedo. If the albedo of a surface is high, the temperature will be low due to the lack of adequate absorption. On the other hand, if the albedo of a surface is low, the resultant temperature will be high. Take for example the Polar Regions. Since there is a great deal of ice and snow on the surface, the temperature is low due to the lack of absorption caused by high albedo. In the Tropical Regions, the overall albedo is low, which results in high temperatures. Water can have two albedos depending on the angle of the Sun striking the surface of the water. If the Sun is directly over the water with a 90° angle, the albedo of the water is low. Insolation (incoming shortwave radiation) will penetrate deeper into the water. Inversely, if the angle of the Sun is low, such as during sunset, the albedo is high.

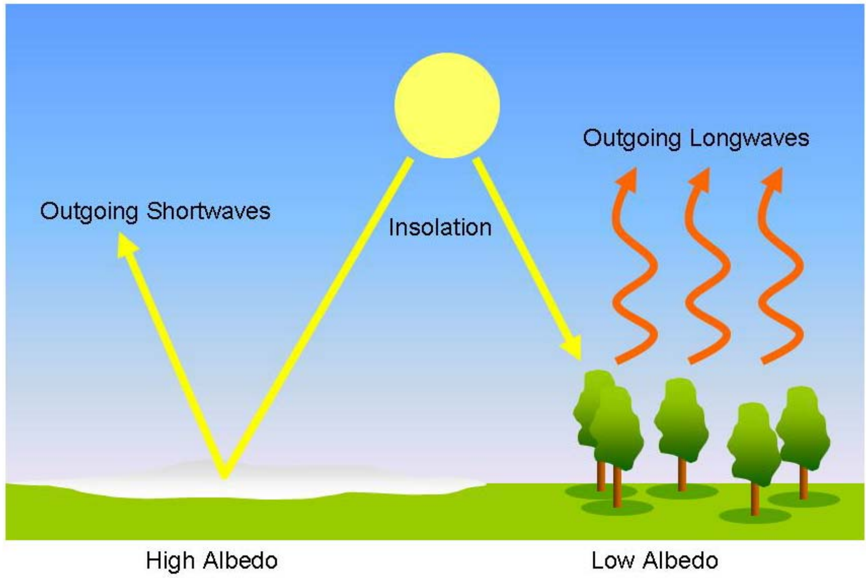


Figure 5.6. Snow has a high albedo that results in outgoing shortwave radiation. Vegetation or low albedo surfaces absorb the insolation, change it into longwaves, and emits heat.

Direct vs. Oblique Rays of the Sun

It is important to remember that albedo is an important aspect in Earth's energy balance, but also, is the angle of insolation. There are two angles of the Sun that determine the distribution of energy across the globe. Direct rays of the Sun are those that occur between 23.5°N and 23.5°S. The spatial concentration of energy from the direct ray is contained within a small area due to the higher angle from the Sun. Oblique rays of the Sun occur north of 23.5°N and south of 23.5°S. A lower angle of the Sun in these regions causes the spatial concentration to be less due to the larger area. The concept of these distinct rays is the character in which energy is distributed. Most of the Earth's energy is received in the Tropics due to the direct ray while most energy is lost at the Poles (figure 5.6). In addition, this concept supports the concept of albedo and temperature. If the angle of the Sun is oblique and the surface albedo is high, the resultant temperature is low. On the other hand, if the angle of the Sun is direct, the surface albedo is low, which results in a higher temperatures.

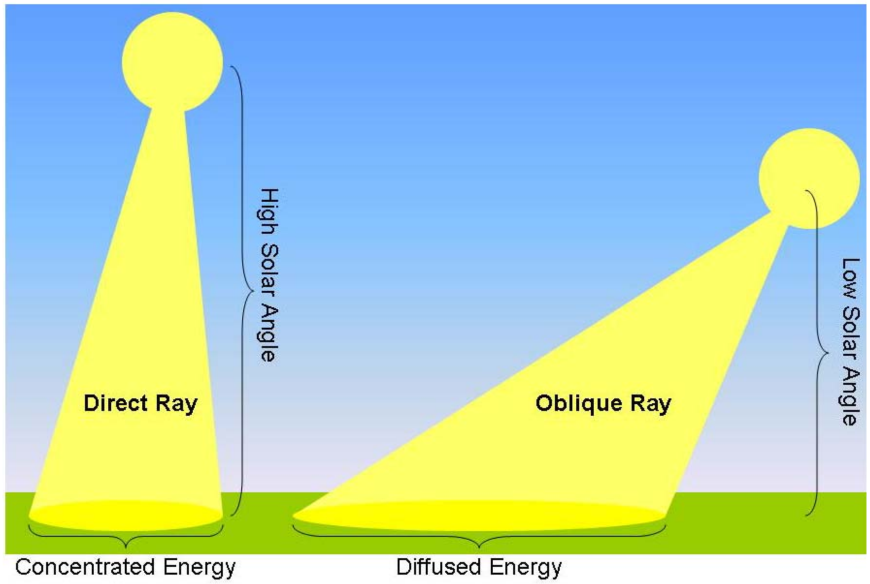


Figure 5.5. The difference between direct and oblique rays of the Sun in regards to received energy.

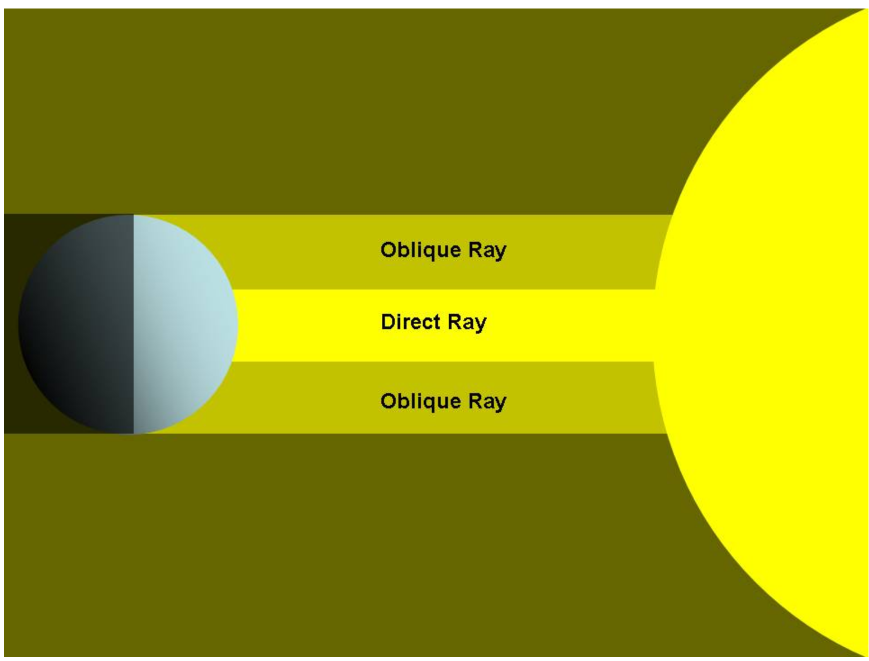


Figure 5.6. The difference between direct and oblique rays of the Sun across the globe. Most energy is received in the Tropics resulting in higher temperatures. Less energy is received north and south of the Tropics, which results in cooler temperatures.

Earth's Seasons

Taking the concepts of energy pathways, radiation, albedo, and rays of the Sun in concert with one another can be used to describe a further concept of energy distribution, the seasons. Throughout the year, the Earth revolves around the Sun. The Earth's orbit, contrary to common belief, is not a simple circle where the Sun is in the exact center but an elliptical orbit with the Sun off center. There are two points throughout the year where the Earth is actually closer and farther away from the Sun (figure 5.7). Aphelion is the point when the Earth is farthest away, approximately 94.5 million miles, from the Sun on July 1 (approximate dates). Perihelion is the point when the Earth is closest, approximately 91.5 million miles, to the Sun on January 1. Even though the Earth is at perihelion, the amount of radiation is less in the Northern hemisphere due to the *tilt* causing a drop in temperatures rather than an increase in temperatures. In addition, the Southern hemisphere actually receives more radiation during this period than does the Northern hemisphere when the Earth is at aphelion.

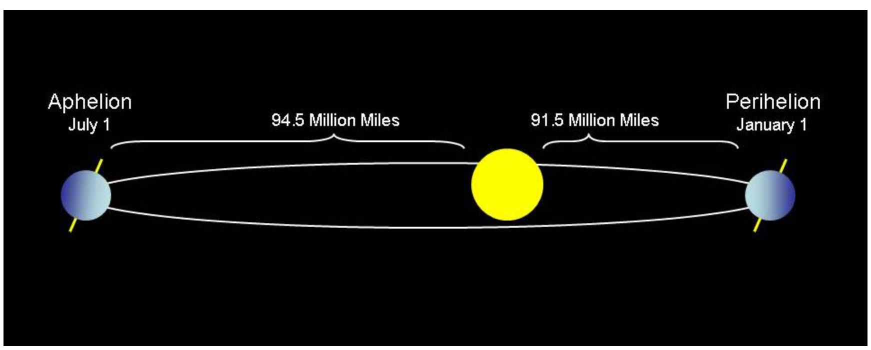


Figure 5.7. Earth's distance from the Sun at two positions during the year.

Throughout the year, the Earth's axis points in the same direction referred to as axial parallelism. Figure 5.8 demonstrates axial parallelism throughout the year. Note that all of the axis' points in the upper right corner of the image. The primary reason the Earth has seasons is the tilt of the Earth. If the northern axis always pointed away from the Sun, the northern hemisphere would always be cold. On the other hand, if the southern axis always pointed toward the Sun, the southern hemisphere would always be warm. Axial parallelism maintains the change of seasons for both the northern and southern hemispheres.

Figure 5.8 also displays the position of the Earth at each climatological season. When the Earth is closest to the Sun but the northern hemisphere is tilted away from the Sun, the northern hemisphere's Winter Solstice occurs on December 21 (figure 5.9). Here the northern hemisphere's day length is short with the 24 hours of darkness occurring at the North Pole. The southern hemisphere has a longer day length with the South Pole receiving 24 hours of daylight. As the year progresses, the Earth travels along its orbit to the next season, March 21, Vernal Equinox or Spring Equinox (figure 5.10). Equinox is translated as equal nights from Latin. Essentially, it means that every location on Earth will receive 12 hours of daylight and 12 hours of darkness. Continuing along Earth's orbit to the next season is Summer Solstice, June 21 (figure 5.11). Here the northern hemisphere is pointed toward the Sun and the southern hemisphere is tilted away from the Sun. The northern hemisphere has a longer day length with the North Pole receiving 24 hours of daylight. The South Pole is opposite with regard to daylight. The last season is Autumnal or Fall Equinox that occurs on September 21 (figure 5.12). Again, every location on Earth will receive 12 hours of daylight/darkness.

As stated above, the direct ray of the Sun extends only from 23.5°N to 23.5°S. Thus, a location at or near the Equator will have a day length of 12 hours throughout the year. Moreover, the energy from the Sun during the day will remain nearly the same value throughout the year.

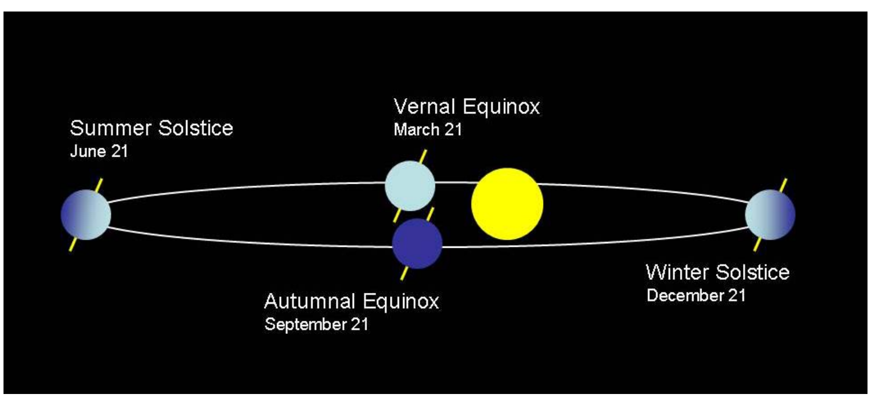


Figure 5.8. Earth's position throughout the year. Note the axial parallelism throughout the year.

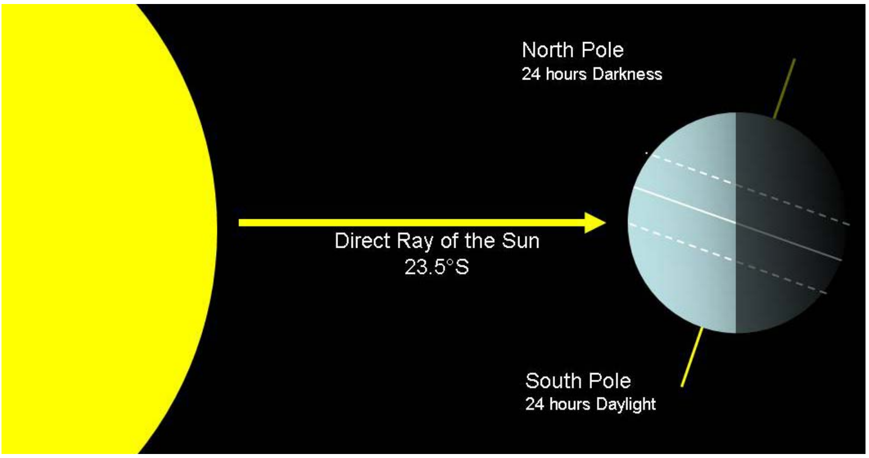


Figure 5.9. Winter Solstice, December 21.

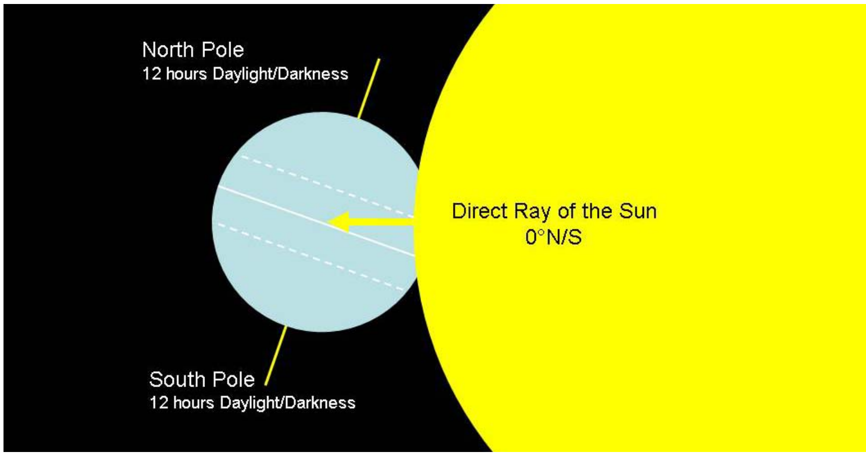


Figure 5.10. Vernal (Spring) Equinox, March 21.

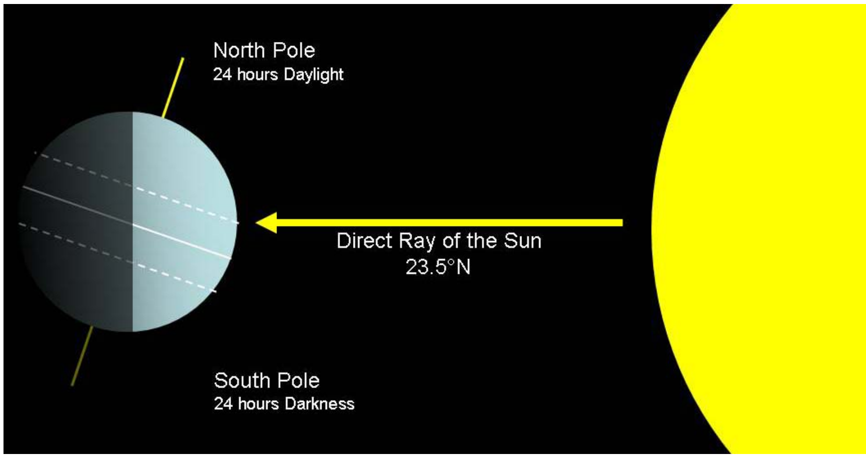


Figure 5.11. Summer Solstice, June 21.

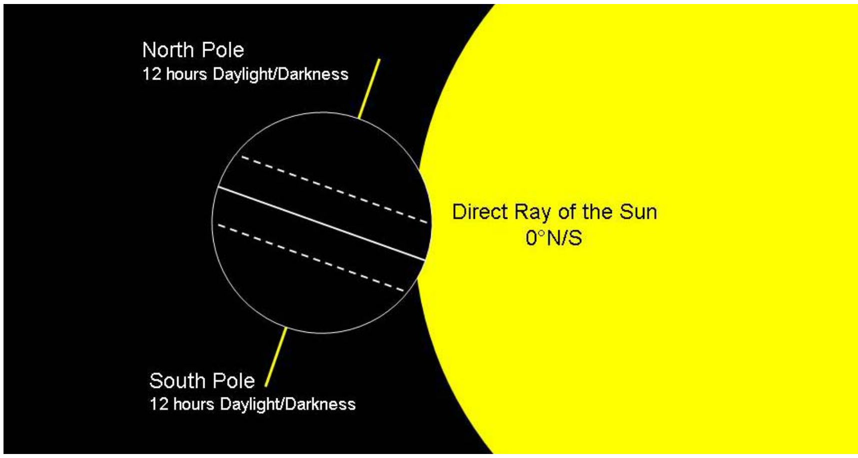


Figure 5.12. Autumnal (Fall) Equinox, September 21.

The Modern Atmosphere

The atmosphere is composed of constant gases and variable gases. The constant gases are those that do not change in volume. Nitrogen, oxygen, hydrogen, argon, and many other element gases are constant. Although nitrogen is the most abundant of the constant gases, it is relatively inactive. However, the most active gas, oxygen, is important for sustaining biological processes at the surface. Variable gases are those that do change in volume depending on the time, place, and specific environment. Water vapor, carbon dioxide, and methane are gases that do not remain constant. Table 5.1 displays the gases and their associated volumes.

Constant Gases		*Variable Gases*
Nitrogen	78.1%	Water Vapor
Oxygen	20.9%	Carbon Dioxide
Argon	0.9%	Ozone
Others	>0.1%	Others

Table 5.1. Constant Atmospheric Gases and Variable Atmospheric Gases.

The atmosphere is divided into three categories (composition, temperature, and function), which describes how the atmosphere functions in different aspects. The atmosphere is divided into two shells that describe its overall composition (figure 5.13). The homosphere is the shell nearest to the surface of the Earth. In this shell, the gases mix very well, allowing biota to prosper. The heterosphere is the outer shell where gases do not mix but are layered according the atomic weight. Therefore, the heaviest gases, oxygen, will be at the lower layer of the heterosphere and the lightest, hydrogen, at the outer portion of the shell.

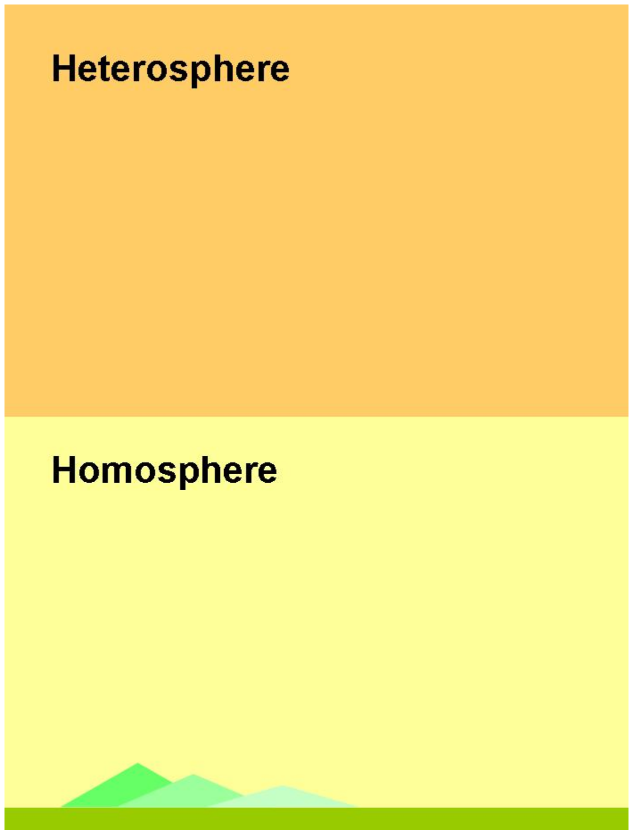


Figure 5.13. The Shells of Composition.

The second category, temperature, contains four major shells based on the increase or decrease of temperature (figure 5.14). In between these four shells are pauses where the temperature remains semi-constant for a short altitude before inverting. The major shell closest to the Earth's surface where our weather occurs is called the troposphere. The temperature in this shell decreases with altitude until it reaches the tropopause with a temperature of -57°C. After the pause, the temperature increases through the stratosphere and pauses at 0°C in the stratopause. The mesosphere is the shell where the temperature decreases drastically to -90°C at the mesopause. Then, finally, the temperature increases through the thermosphere. Although there is a thermopause, the exact temperature of this pause is not determined. Moreover, beyond a particular point the temperature in thermosphere cannot be measured due to the vast distance between molecules to measure temperature accurately. Essentially, temperature is measured by the speed at which molecules move around the sensor. If the molecules are less dense, temperature cannot be measured accurately due to the lack of molecules to register the speed of movement. Therefore, the exact temperature in the upper thermosphere cannot be measured.

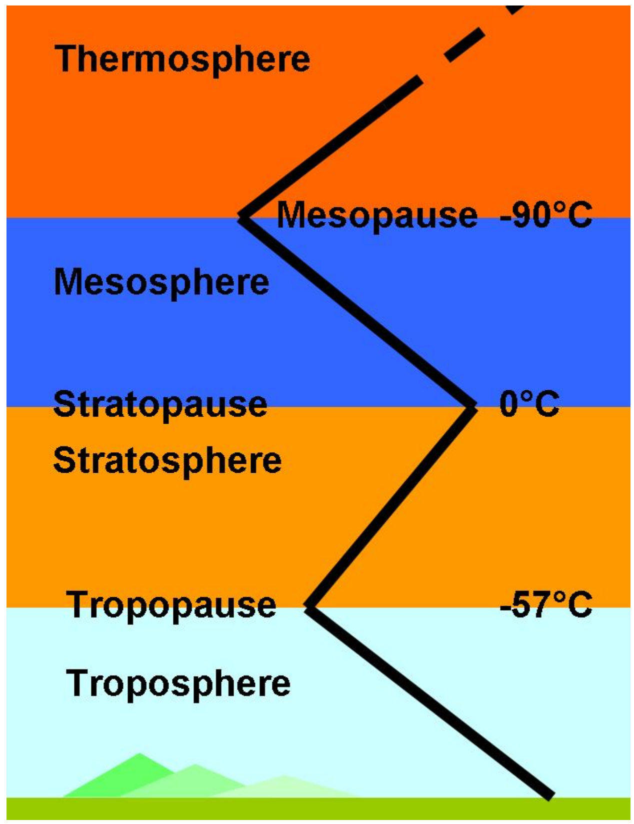


Figure 5.14. The Shells of Temperature.

The third and final category of the atmosphere is function (figure 5.15). There are two shells that describe how the atmosphere functions. The ozonosphere generally lies within the extent of the stratosphere. This shell functions to protect the biosphere from burning up from the incoming ultraviolet rays of the Sun. As UV-A, B, and C enter the Earth's atmosphere, ozone, within the ozonosphere, absorbs the harmful rays. The by-product of the absorption is heat, which accounts for the increase in temperature in the stratosphere. The ionosphere, which is layered above the ozonosphere, is the shell that describes the electronic function of the atmosphere. Negative electrons within the ionosphere help to provide beautiful displays of the aurora borealis, or northern lights, as well as help in the transfer of other electronic waves such as what are used in radios and televisions. For example, during the night hours, the ionosphere or the whole of the atmosphere shrinks toward the Earth due to the lack of the Sun heating the surface. The ionosphere, now closer to the surface, promotes Amplitude Modulation (AM) radio waves to be transported in great distances. During the height of the radio, people in extremely rural areas could hear broadcasts from New York or Chicago. However, during the daylight hours, the atmosphere would increase in height that caused the radio waves to travel less distance.

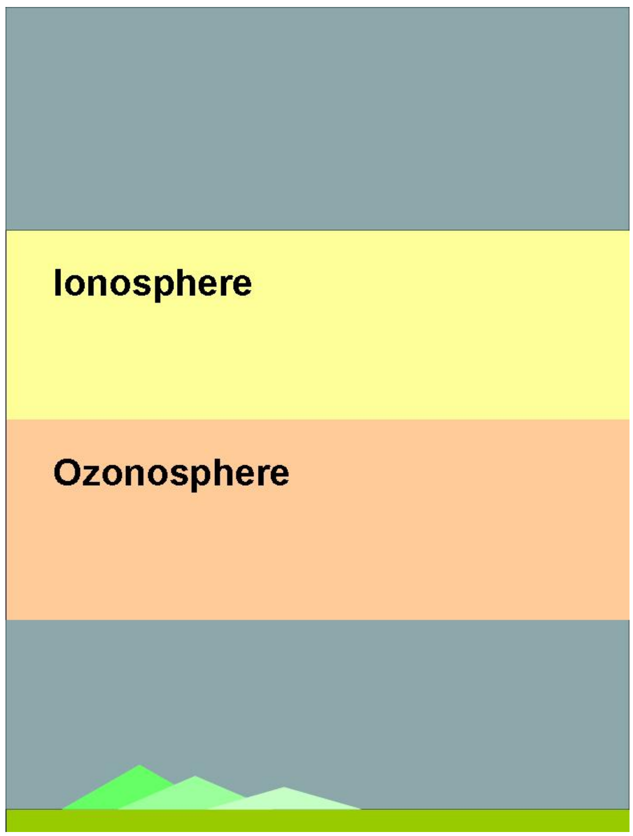


Figure 5.15. The Shells of Function.

Figure 5.16 displays all three categories with the respective shells (composition first, temperature second, and function third). It is important to remember that the real atmosphere is not vertically divided as diagramed but is one atmosphere with different properties based on the three criteria.

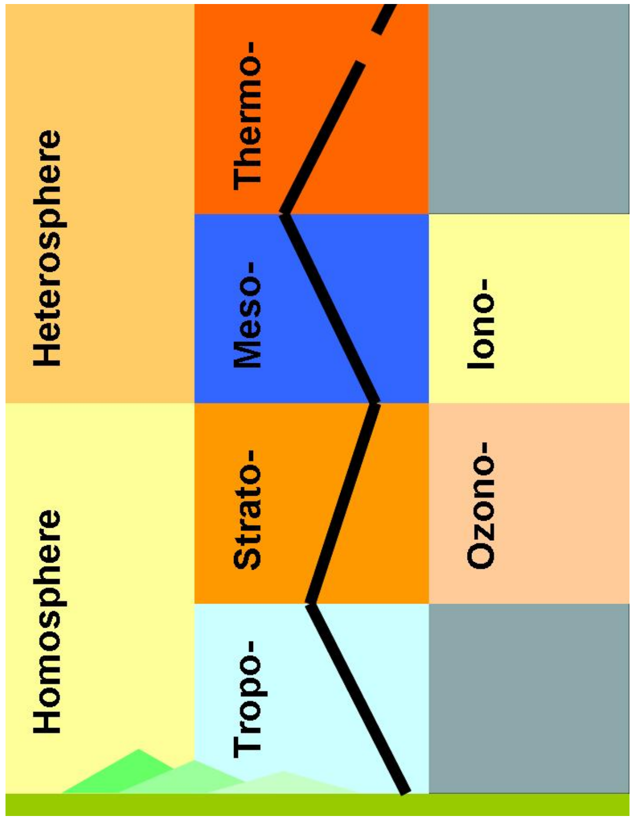


Figure 5.16. The Modern Atmosphere.

Earth's Energy Balance

Taking all aspect of radiation, Sun-Earth relationship, albedo and absorption, and pathways of energy, Earth's energy balance can be explained. Figure 5.17 displays Earth's energy balance in two scenarios—the high albedo scenario and low albedo scenario.

In scenario one, shortwave radiation enters the atmosphere called insolation (IN) (incoming shortwave radiation). If the surface has a high albedo, the insolation returns back to the atmosphere or space unchanged as outgoing shortwave (OSW) radiation. This scenario keeps temperatures down because of low absorption.

In scenario two, insolation (IN) enters the atmosphere and is absorbed by a low albedo surface. When shortwave radiation is absorbed, it turns into longwave radiation, which is felt as heat. These longwaves are then emitted by the surface into the atmosphere (OLW) where they are absorbed again by Greenhouse Gases (GHGs).

After absorption, the longwaves are then re-emitted back to the surface (ILW) as well as into the upper atmosphere or space (OLW).

Earth's energy balance is extremely important to the feedback system. If scenario one and scenario two are not balanced, the result would be; 1) extremely cold conditions over the globe due to an increase in albedo reflecting insolation back to the atmosphere, or 2) extremely hot conditions where a lack of high albedo would drive global warming, sea level rise, and massive continental flooding. As long as there is a balance between scenarios one and two, the global temperatures will remain steady.

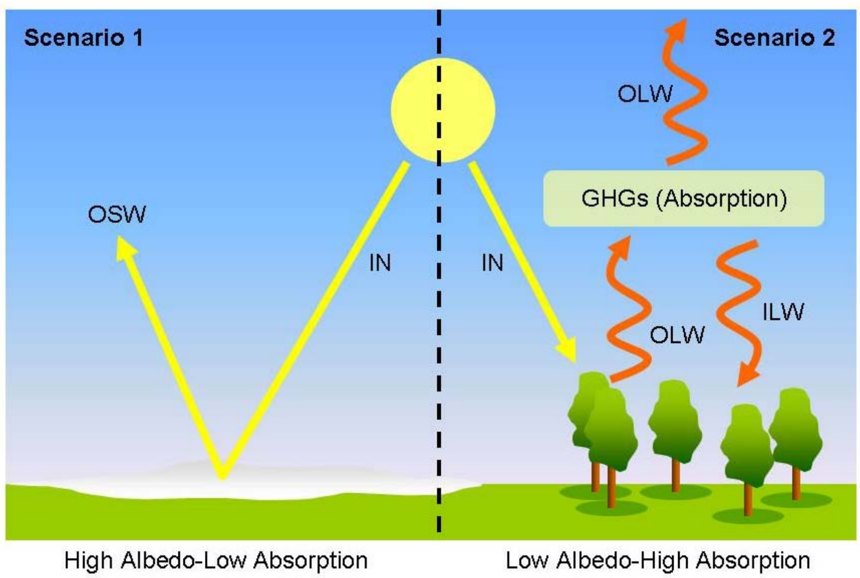


Figure 5.17. Earth's Energy Balance.

Chapter Review

1. Why is Georgia warmer than Alaska?
2. What is the reason why the northern hemisphere is not warmer if it is closer to the Sun during perihelion and why it is not colder if it is farthest from the Sun during aphelion?
3. If global warming continues, which scenario would there likely be an increase? What would specifically result from this imbalance?
4. What would be the relative (high or low) albedo, absorption, and resultant temperature of an asphalt surface and a concrete surface?

CHAPTER VI

CHAPTER VI: FUNDAMENTALS OF METEOROLOGY PART II

Studying meteorology requires complete understanding of the basic concepts of atmospheric processes. In this chapter, a continued review of the essential concepts is presented.

Solar Maxima, Maximum, and Minimum Temperatures

As the Sun rises, the surface of the Earth begins to accumulate longwave radiation. When the Sun approaches its zenith, the point the Sun is highest in the sky, it appears to slow in movement (figure 6.1). The zenith is the point of maximum insolation. After the Sun's zenith, the Sun begins its descent toward the horizon in the same speed as it rose in the East. During this phase, insolation decreases.

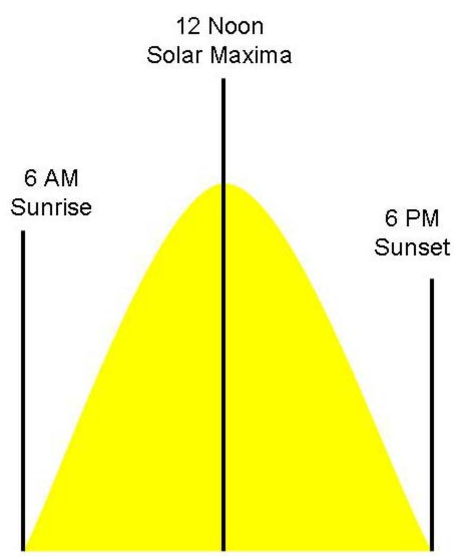


Figure 6.1. Solar Maxima.

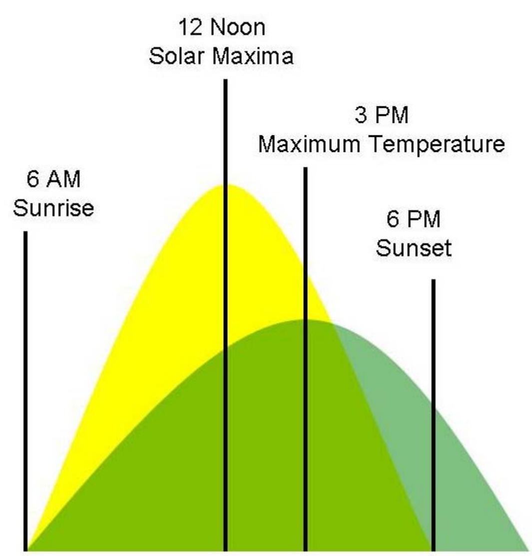


Figure 6.2. Occurrence of Maximum Temperature

Temperature is the product of insolation. Maximum temperatures will occur approximately 2-4 hours after the solar maxima or between 2 and 4 in the afternoon (figure 6.2). When insolation is no longer available, the surface temperature will decrease throughout the evening, night, and early morning hours. The minimum temperature occurs at the specific time before the Sun rises the next morning or between 5 and 7. If the Sun did not rise, the temperature would continue to fall until some type of energy changes the temperature trend.

Distribution of Temperature

The distribution of temperature is influenced by five controls—latitude, altitude, marine versus continental environments, ocean currents, and cloud cover. The geography of temperature is important as it determines the overall climate as well as the micrometeorological processes of a particular location.

Temperature controlled by latitude is primarily concerned with the distribution of energy from the Sun. Most of the energy, as stated in the previous section, is received in the Tropics that accounts for higher temperatures. As the latitude increases, energy decreases. The loss of energy toward the poles results in lower temperatures. The distribution of temperatures is mainly latitudinal in character. That is, the bands of temperatures are parallel with higher temperatures in the Tropics and lower temperatures in the Polar Regions. Figure 6.3 demonstrates the distribution of temperatures by latitude.

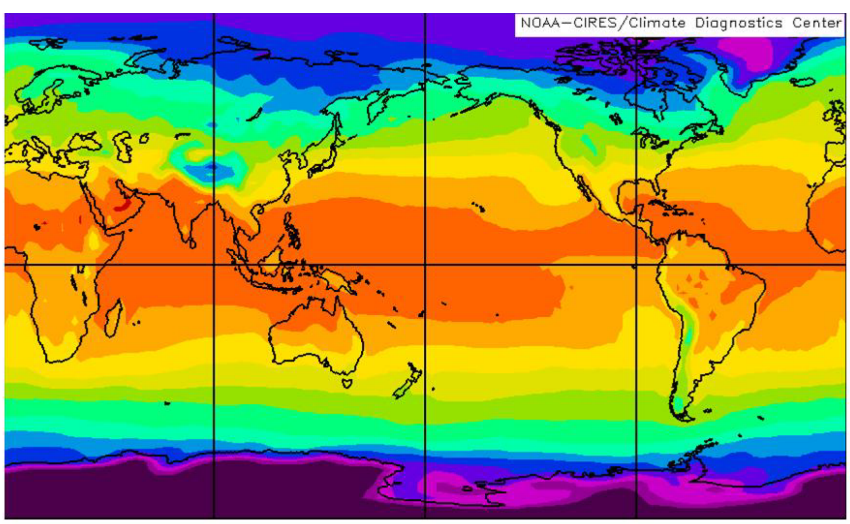


Figure 6.3. Distribution of Temperatures by Latitude.

Altitude is another control on temperature where the increase in elevation or altitude will result in a decrease in temperature. When referring to the character of the troposphere, insolation is absorbed at the surface. Although absorption of insolation by greenhouse gasses in the atmosphere, it is of minor influence. Therefore, the source of heat in the troposphere is the surface. With this in mind, if we climb a mountain or take-off in a plane, the temperature decreases as we increase the distance from the source of heat.

Two differentiating environments influence temperature based on the available moisture. Before delving into the environments a discussion on the principles of latent heat (LE) and sensible heat (T) must be introduced. Sensible heat is essentially heat felt as temperature. Latent heat is the storage of heat energy as in the process of evaporation. For latent heat to function, water must be present. When water evaporates, heat is stored, which results in lower temperatures. When you sweat on a hot summer day and a gentle breeze blows across your skin, the moisture on your skin will evaporate and you feel cooler. This is due to latent heat storing the heat energy during evaporation. If there is no moisture available, latent heat will be lower, which results in a higher temperature.

Consider two local environments—urban and rural. In the urban environment (figure 6.4a), civil engineers design the city in such a way to allow melted precipitation to runoff streets and highways quickly. This design keeps cities relatively dry resulting in the lowered latent heat and increasing the sensible heat (i.e. low moisture storage results in higher temperatures). In the rural environment (figure 6.4b), there is more soil to retain the precipitation, which results in higher latent heat values keeping sensible heat lower (i.e. higher moisture storage results in lower temperatures). The difference in latent heat values associated with moisture storage can also be seen as a small plane flies within the boundary layer (layer of the atmosphere directly influenced by the surface). If the soil has high moisture stored, the plane will experience a smooth flight due to the lowered temperatures. Latent heat in this situation keeps the uneven distribution of rising warm air to a minimum. On the other hand, a plane that experiences turbulence while flying is caused by the lack of moisture in the soil.

Uneven surface temperatures due to the lack of moisture to promote latent heat cause turbulent air (i.e. rising air from the surface and sinking air from aloft).

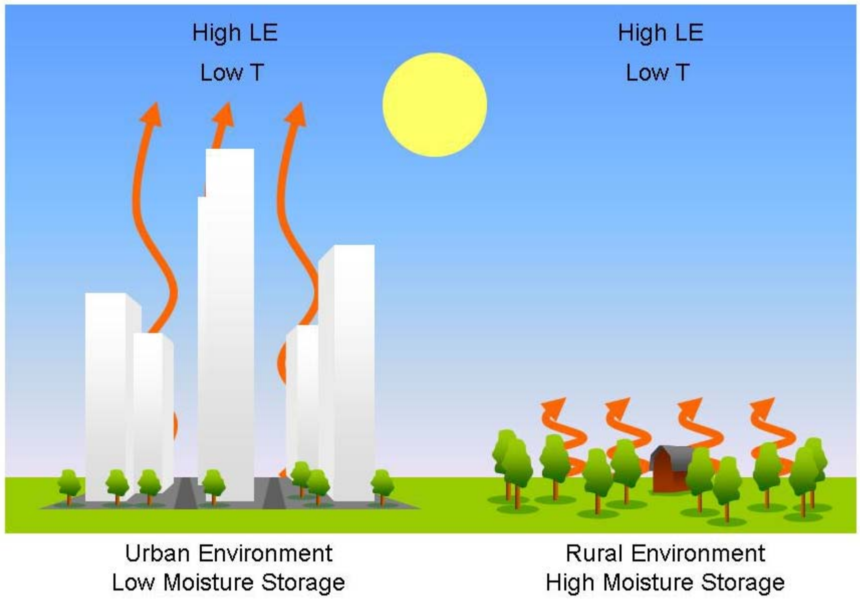


Figure 6.4. Differing environments due to moisture storage: a) urban environment and b) rural environment.

With the basic concept of how moisture controls temperature the difference between marine and continental environments can be described. Locations near large bodies of water are considered marine environments. These environments exhibit high latent heat values that keep temperatures down. In addition, the annual range of temperature will be low. There is a lack of extreme high and low temperatures in winter and summer in these locations due to the available moisture to maintain temperatures (i.e. low fluctuation in annual temperatures). Locations that exist in landlocked environments exhibit continental conditions. Lower overall latent heat values in continental environments increase the sensible heat, which causes the annual range in temperature to be high. Continental areas such as Fargo, North Dakota, experience extreme high temperatures in the summer and extremely low temperatures in the winter resulting in a high range in temperatures.

In addition to the difference between the marine and continental environments, a discussion on heat retention should be presented. Large bodies of water typically take approximately three months to heat up or cool down. Land heats and cools based on the diurnal variation of radiation. In other words, when the Sun rises, longwave radiation begins to accumulate energy for emission. Once the land can no longer retain the radiation it emits it as heat. After the Sun sets, the land begins to cool as longwave radiation dissipates from the surface. This cycle occurs daily. In conclusion, water takes much longer to cool or heat up than land—this is the oceanic temperature lag. Consider this concept throughout the year. In summer, the land temperatures peak around June-July. Ocean temperatures will not reach their maximum temperature until September-October. In December-January, the land will achieve its lowest temperature, but the ocean will not be cool until March-April. Evidence of this concept, in regard to the maximum temperature of the water, is the peak of the hurricane season occurring in September-October. Ocean temperatures will follow behind land temperatures by three months.

Ocean currents help to maintain coastal temperature fluctuations as well as moderate the temperatures in the Polar and Tropical Regions (figure 6.5). The United Kingdom has a temperate climate due to the existence of the Gulf Stream/North Atlantic Drift that brings warm water from the Tropics. The Gulf Stream is born in the warm central Atlantic waters. The current is fast moving, deep, and narrow. It travels north along the eastern coast of the United States between Iceland and the United Kingdom where it begins to cool and sink with increasing density of salinity. Another current, the Canary Current, is cold, slow moving, and wide flows southward from the Polar Region along the western European continent into the Tropical waters where it will again heat up. The overall purpose of the ocean currents throughout the world is to moderate the buildup of extreme high temperatures in the Tropics and extreme low temperatures in the Polar Regions.

When considering the current issue of global warming that is inserting glacial melt water in the North Atlantic, fresh water is less dense than salt water. If more fresh water is present in the North Atlantic, the thermohaline circulation will slow down. When this occurs, warm water will build up in the Tropics raising the sea surface temperatures. In addition, the cold arctic waters will continue to drop in temperature. When the circulation halts, it is possible that the globe will experience an ice age, but not immediately. The thermohaline circulation functions from high salinity. If this flow is diluted with the insertion of fresh water, it will begin to change the Earth's climate.

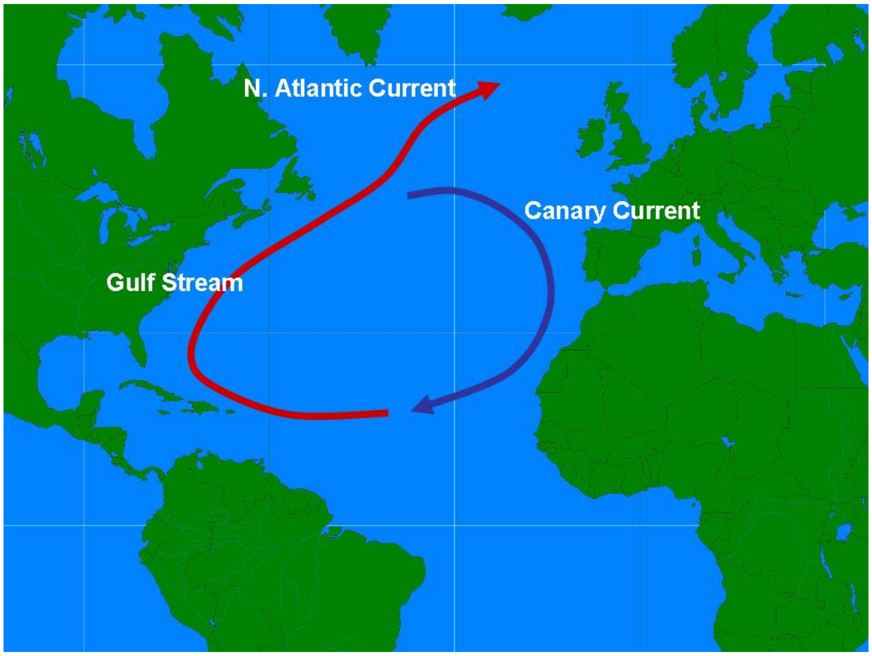


Figure 6.5. Ocean Currents in the North Atlantic Ocean.

Cloud cover is an important control on temperature on a daily time scale. Cloud albedo forcing is the concept that states clouds can reflect insolation from penetrating the surface. If insolation is not absorbed by the surface, the temperature will be lower. On the other hand, cloud greenhouse forcing is a cloud that acts as a blanket keeping temperatures elevated at the surface. Figures 6.6-6.9 shows the resultant relative temperature for the morning and afternoon determined by cloud cover. If the day remains clear, the relative temperature will be cool (figure 6.6). This scenario is due to the fact that a clear sky will allow sensible heat to escape into the upper atmosphere. When clouds enter the area during the afternoon (figure 6.7), cloud greenhouse forcing occurs increasing the relative temperature. The accumulation of longwave radiation from the absorption of insolation continues, then, is amplified by the clouds retaining the heat in the afternoon. Inversely, cloud cover in the morning will reduce the accumulation of longwave radiation; however, clear skies in the afternoon will allow some lag in energy accumulation for warm temperatures (figure 6.8). If cloud cover occurs throughout the day, cool conditions will result from the cloud albedo-forcing concept (figure 6.9). During the night, clear skies create colder surface conditions, while cloud cover maintains surface warmth.

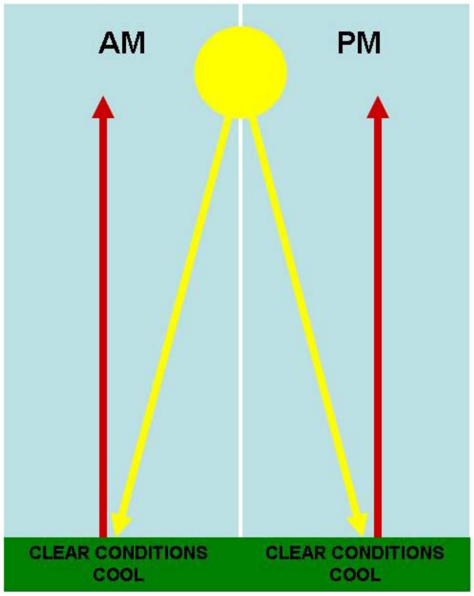


Figure 6.6.

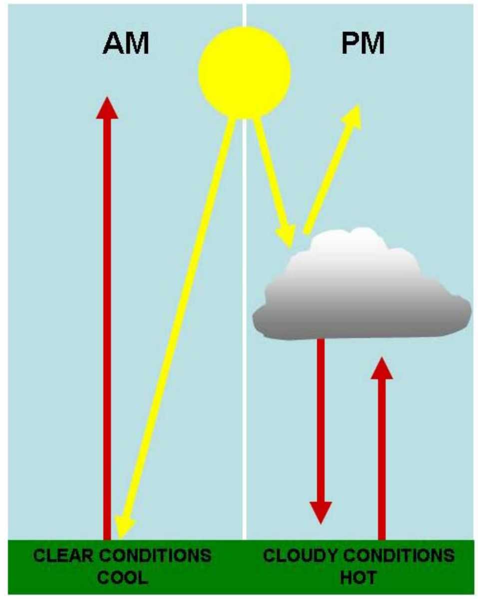


Figure 6.7.

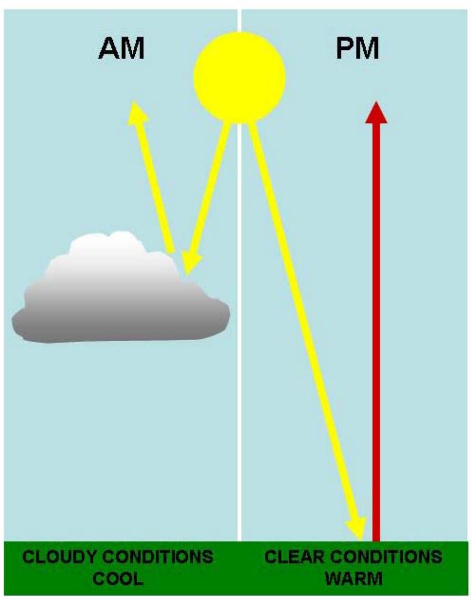


Figure 6.8.

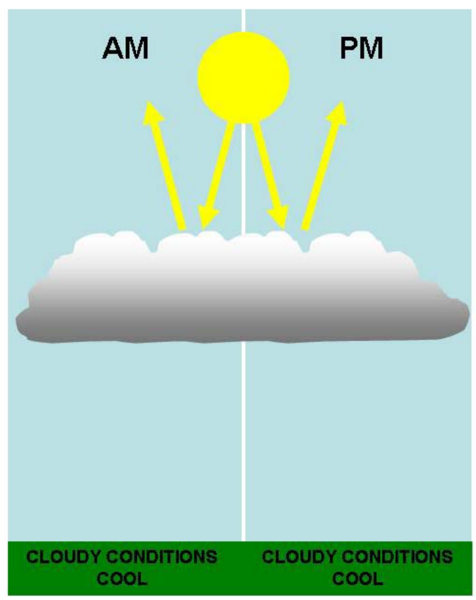


Figure 6.9.

Temperature and Density

Understanding how the atmosphere functions can be accomplished with a simple framework of interactions and influences (figure 6.10). The Sun controls temperature, which controls the density, dynamics (rising and sinking), and surface pressure in this order. These concepts form the framework that will be used in analyzing weather patterns in the latter chapters. Understanding the following sections is essential to build knowledge of atmospheric processes.

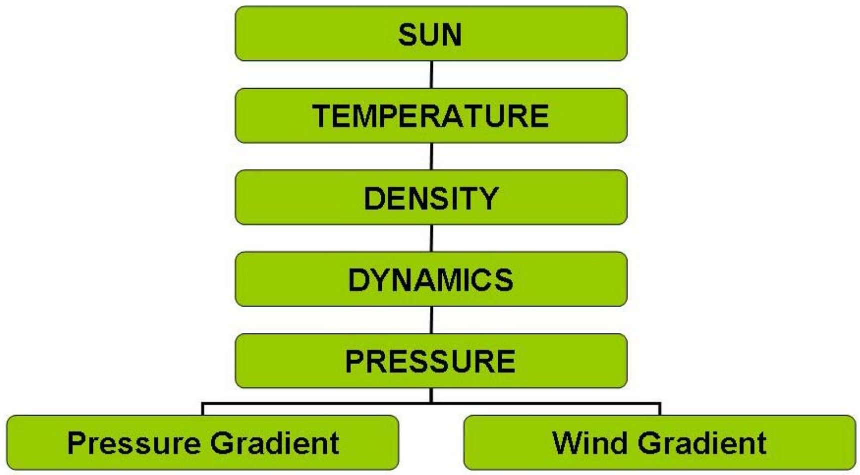


Figure 6.10, Framework of interactions and influences of atmospheric processes.

Density is a term that defines the concentration, in the context of the atmosphere, of parcels. For example, if a parcel is empty to start and sand is poured into it, it is becoming denser. Inversely, the parcel is full of sand and it is gradually taken out, it becomes less dense. In the atmosphere, density is influenced by temperature. A column air that is warmed expands upward, is less dense, and weighs less. Cold air shrinks a column of air, becomes denser, and is heavier. Looking at the global distribution of temperatures and associated density, the height of the tropopause will be higher in the tropics and decrease in height toward the poles.

Dynamics and Pressure

Temperature controls density and influences the dynamics (figure 6.11). If warm air is light, and less dense, the result is rising air because it is warm. On the other hand, if cold air is heavier due to it being denser, the outcome is sinking air. Rising air from the surface creates a low pressure at the surface. Essentially, the warm rising air creates a void near the surface. Air that sinks toward the surface creates a surface high pressure. This is the fundamental concept that explains how air moves throughout the atmosphere. Rising air creates low pressure near the surface and sinking air generates high pressure—all through differences in temperature.

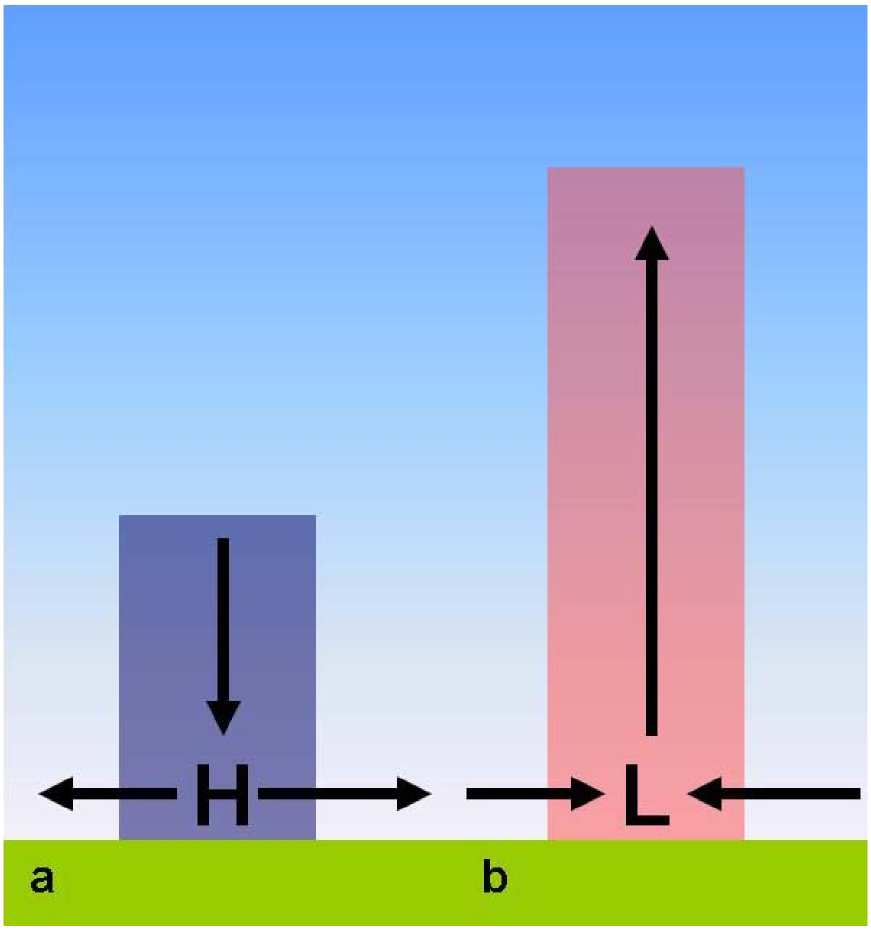


Figure 6.10. Density, dynamics, and resultant surface pressure.

As sinking air descends from aloft it creates a high pressure. High pressure at the surface is also an area of divergent air. Conversely, low pressure is an area of convergent air at the surface.

Determining which pressure cell is the strongest can be based on the pressure within the cell. If there are two low pressure cells in the United States and one has a central pressure of 978mb and the other has 1004mb, the lowest pressure will be the strongest simply due to the fact that more air is rising due to the warmth and density.

The cell with 1004mb is not as strong. Consider high pressure cell values 1024mb and 1051mb. The higher pressure will be the strongest cell due to cold dense air sinking.

When looking at a cross-section of the atmosphere, the height of a given level (figure 6.12a-b) would be lower for a high pressure due to the temperature, density, and dynamics. A low pressure would have a higher level due to the higher temperature, lower density, and rising effect.

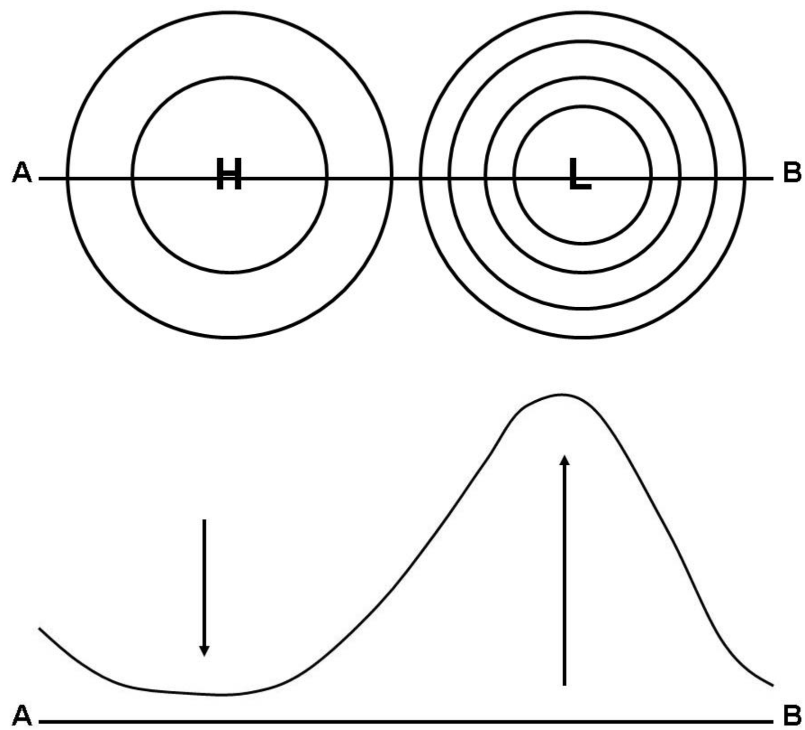


Figure 6.12. Basic cross-section of the atmosphere. Top image is a map view. Bottom image is the associated cross-section.

Pressure and Wind Gradients

Pressure and wind gradients are similar in function (figure 6.13). In other words, the pressure gradient determines the wind gradient. A gradient is the change in a physical quantity. For example, pressure gradient is the change in pressure over distance. Wind gradient is the change in wind speed over distance. Lines of equal pressure, isobars, which are drawn far apart, exhibit a weak gradient. In other words, a weak pressure gradient is the result of a change in pressure over a long distance. If the isobars are drawn close together, this indicates a strong pressure gradient or the change in pressure occurs within a short distance. Moreover, weak pressure gradients will provide weak winds and strong pressure gradients strong winds.

Cold air sinks and creates an area of divergence—high pressure. As the air descends, it is highly concentrated (dense). Since the air is highly concentrated it flows very slow—weak pressure and wind gradient. However, in a low pressure cell, air convergences due to the rising effect of warmth, which causes a lack of air. Therefore, air will move progressively faster toward the void—strong pressure and wind gradient.

A further example of the concept of gradient can be found in a construction site on a highway. As two lanes are required to merge into one lane before the construction area, the vehicles slow down because they are denser—weak gradient. As vehicles pass the construction site, they begin to increase in speed as a result in the decrease in density—strong gradient.

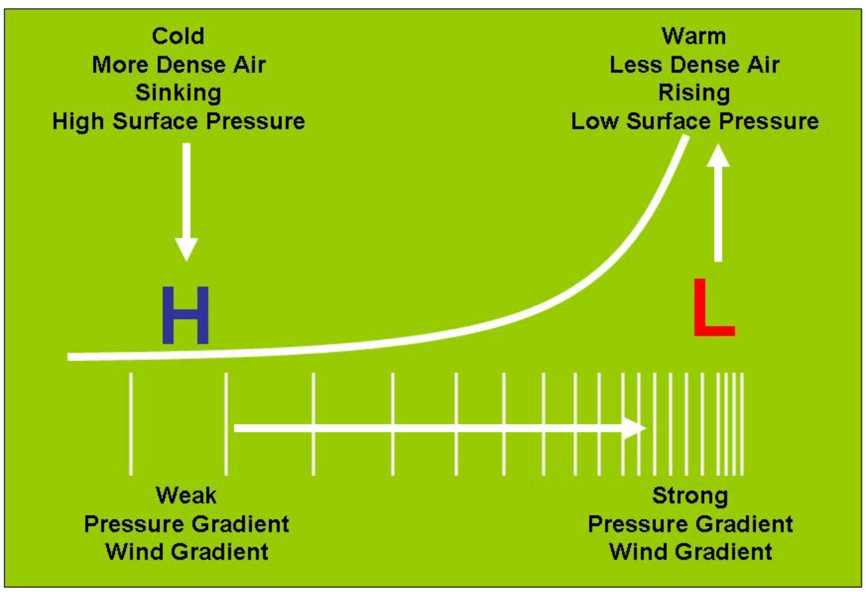


Figure 6.13. Temperature, density, dynamics, pressure, and pressure/wind gradient.

Forces that Drive Surface Winds

Air naturally desires to balance. The uneven balance of air in the atmosphere is primarily due to the differences in surface heating as described above. Understanding airflow requires a comprehension of the forces that drive surface winds.

For winds to occur there must be a difference in pressure. Furthermore, there must be a change in pressure over distance—the pressure gradient force (figure 6.14). Air moves from high to low. The second force is Coriolis. Coriolis is the influence of Earth's rotation on objects not attached to the surface. In the northern (southern) hemisphere, everything that can be influenced by Earth's rotation will be diverted to the right (left) (figure 6.15). One example of Coriolis is while flying from San Francisco to Washington, D.C. If the pilot does not correct for Coriolis, the plane would end up in Jacksonville, Florida. Another example can be seen in the swing pendulum in the Indiana State Museum or Chicago's Science and Industry Museum. The pendulum does not rotate but swings in the same position throughout the day. As the Earth rotates under the swinging pendulum, the pendulum knocks down pegs to the right. Within a 24 hours period, all pegs in the circle fall. The third and final force that drives surface winds is friction (figure 6.16). Friction on wind flow is due to topography, vegetation, structures, and various other obstacles. These degradations on the flow slow the wind further. If we put all the forces together, the resultant wind direction at the surface will be a 45° angle across isobars (figure 6.17).

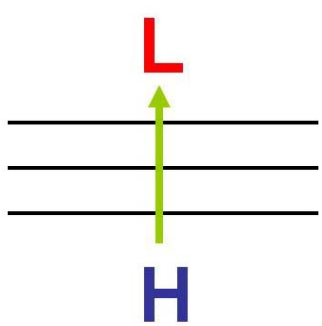


Figure 6.14. Pressure Gradient Force.

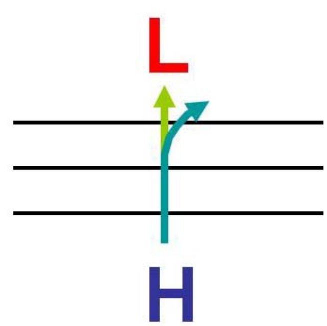


Figure 6.15. Coriolis Force.

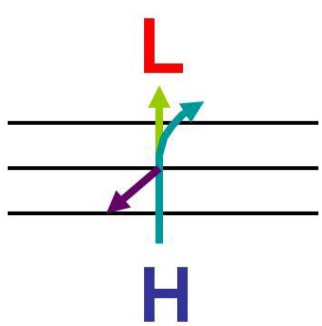


Figure 6.16. Friction Force.

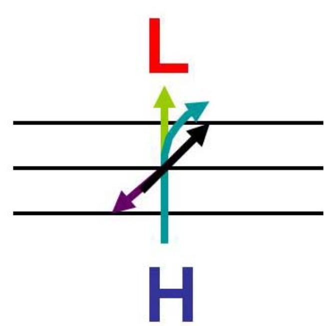


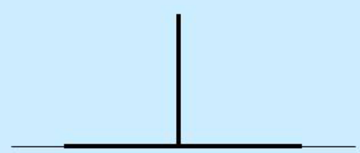
Figure 6.17. Resultant Winds at the Surface.

Determining Wind Direction: The CDC Method

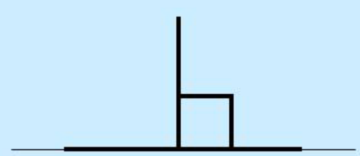
By Cameron Douglas Craig

Determining wind direction quickly will be important when it comes to weather analysis. On surface maps, some stations are provided with wind data. However, not all surface maps will have stations indicated. Therefore, it becomes important to be able to determine wind direction with only the use of isobars. The method below has been created to help you work out wind direction at the surface in the northern hemisphere. Practicing this method will promote quick recognition of wind direction without thinking about it in the future.

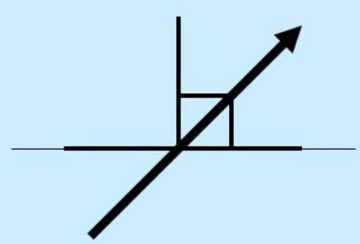
Step 1: Draw a perpendicular mark in the location you are interested in determining the wind direction with the base of the perpendicular mark on the isobar and the stem pointing toward the area of lower pressure. The stem indicates the pressure gradient force.



Step 2: Draw a right angle mark on the right side of the perpendicular mark. It must be on the right side of the perpendicular mark as it represents the Coriolis paramenter.



Step 3: Connect the intersecting point of the perpendicular mark with the corner of the right angle mark with an arrow where its head is on the right hand side pointing toward the area of lower pressure. This is the resultant wind—45° angle across the isobar.



Chapter Review

1. Briefly describe the patterns recognized in the January Mean Temperature map and July Mean Temperature map. Be sure to consider the controls on temperature in determining your answer.
2. Where on the surface of the Earth would you find the high annual range in temperatures and the low annual range in temperatures? Use the annual range in temperature map to determine your answer.
3. Describe the framework of interactions and influences for a high pressure cell and a low pressure cell.
4. Based on your understanding of this chapter, when would the atmosphere be more uniform and incoherent with regards to winter and summer?

Meteorological Exercise

1. Complete Laboratory Exercise 3 in the Explore the Skies: Studies in Meteorology Laboratory Book. Time required for completing this exercise is approximately 1.5 hours.

CHAPTER VII

CHAPTER VII: FUNDAMENTALS OF METEOROLOGY PART III

Studying meteorology requires complete understanding of the basic concepts of atmospheric processes. In this chapter, a continued review of the essential concepts is presented.

Surface Pressure Cells

Pressure cells at the surface are determined from the concepts in the previous chapter. In this chapter, a discussion on the wind patterns around surface pressure cells is also important especially in the discussion of mid-latitude cyclones later on. Wind flow around high-pressure cells spirals outwardly in a clockwise fashion. This is due to the cold sinking air diverging at the surface. Low-pressure cells are created by the rising effect of the warm less dense air at the surface. Wind flow around low-pressure cells will spiral inwardly counter-clockwise.

High pressure cells typically stifle cloud formation and creates beautiful days with relatively cooler conditions. Low pressure cells at the surface are typical for stormy weather due to the converging flow of air around in the region.

Air Flow Aloft

Airflow above the surface influences the conditions of the surface as discussed in the previous chapter. For example, cold dense air will sink to form a high-pressure cell at the surface. Why is this so?

Geostrophic wind flow above the surface is created by only two forces—pressure gradient force and coriolis force. Friction is not an influential force since there is nothing to perturb the flow of air such as what we find at the surface. Therefore, it is known that air will flow from high to low pressure; however, when coriolis is considered, the air aloft will flow parallel to the geopotential height lines.

Geopotential height lines are lines describe the height of an isobaric level at a particular location. An isobaric level is where every point on a horizontal plane is the same pressure. The 500-millibar chart, used in forecasting and meteorological analysis, is a chart that displays conditions at the 500mb pressure level. Geopotential height lines are used to show the change of heights in the 500mb chart. When looking at a 500mb chart, the northern portion of the chart will typically have lower geopotential heights due to the cold dense air that remains closer to the surface. On the other hand, warm air in the southern portion of the chart causes geopotential heights to increase (figure 7.1). Geopotential height lines are displayed in meters on charts. When a geopotential height line is labeled 534 it is the abbreviation for 5340m.

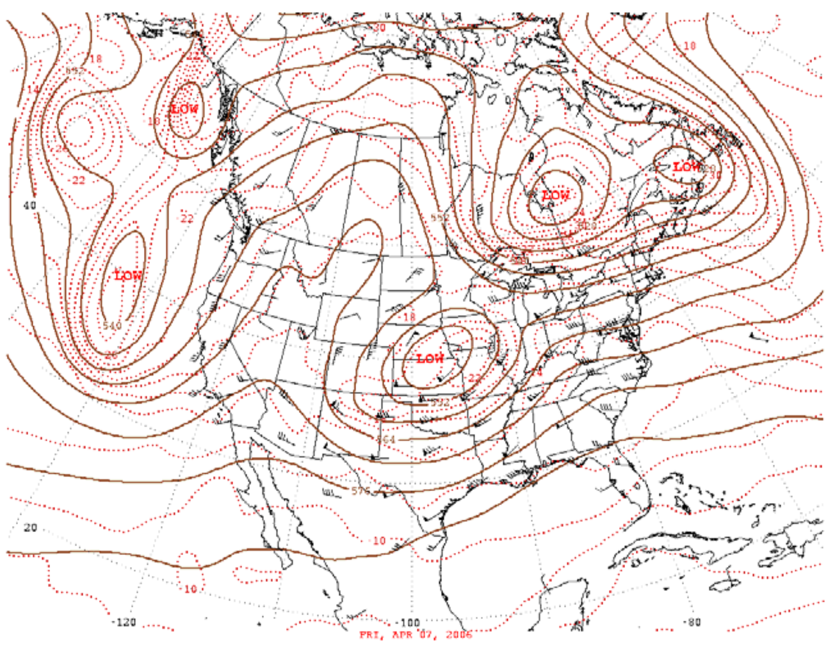


Figure 7.1. 500mb chart displaying geopotential height lines.

High heights are referred to ridges and low heights are called troughs. Warm air causes ridges or high heights. Cold dense air are found in troughs or areas of lower heights. Note in figure 7.1 that the a ridge of warm air at the 500mb level is positioned over the western portion of the United States. In addition, there are several troughs of colder air that are lower in height as described by the geopotential height lines. The word, ‘low,’ refers to the height of the 500mb level and is not describing pressure. However, this does not mean that lower pressure does not exist. For simplicity purposes, a trough that is labeled ‘low’ is referring to lower geopotential heights.

Geopotential Height Gradient

Geopontential height gradients are similar to pressure or temperature gradients. If geopotential height lines are drawn close together, this indicates a strong gradient. A weak gradient is displayed as geopotential height lines drawn far apart. Where you have a strong gradient, the change in the height is relatively great. This deepening creates higher winds known as jet streaks. Note in figure 7.1 that the wind speed in North Dakota is not as strong as the wind speed in Arkansas. The difference in wind speeds can be attributed to the geopotential height gradient. The weaker winds in North Dakota are due to the wide spacing of the two geopotential height lines where as the wind is much faster in Arkansas due to the height lines drawn closer together. The jet stream, the channel of high winds above the surface, can be identified by connecting the jet streaks together. For example, in figure 7.2, the subtropical jet stream is indicated in red while the polar jet stream is indicated in blue.

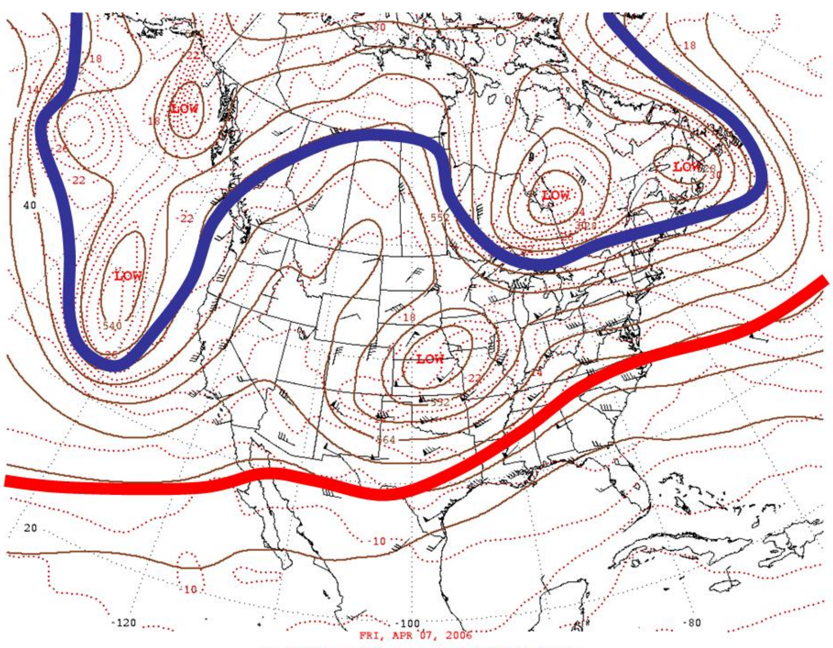


Figure 7.2. Jet streams indicated on the 500mb chart.

Converging and Diverging Geopotential Height Lines

Geopotential height lines can also provide meteorologists where a surface pressure cell will be located that is dependent upon the area of convergence and divergence. These areas are common to the trough. The area of convergent geopotential height lines is located west of the trough. Divergent height lines are typically located east of the trough. Note in figure 7.3a the trough positioned over the New England region. The area of convergence is located over the Midwest and the area of divergence is located over eastern Canada. If a comparison is made between these areas of convergence and divergence with the surface chart (figure 7.3b), we find that a high pressure is located just under the area of convergence and a low pressure is under the area of divergence.

The air that flows into an area of convergence begins to gain weight due to the increase in density and sinks to the surface to create a high pressure. On the other hand, the air will lose weight and allow air to flow from the surface in the area of divergence aloft creating a low pressure. It is also assumed that warm air from the surface can create divergence aloft.

The strength of the surface pressure cells is mainly determined by the strength of convergence and divergence. In other words, the more drastic the area of convergence is on the western side of a trough indicates a stronger high pressure at the surface. If the areas of convergence and divergence are not as pronounced, the surface pressure cells are weak.

Note also where the warm and cold air aloft are located. A jet that flows southeasterly will bring colder air on the north side into the trough that helps to support sinking air in the area of convergence. A jet that flows northeasterly will bring warmer air into the ridge that supports the placement of the surface low pressure. It is important to remember that the surface pressure cells are situated within the upper level trough, not the ridge.

When analyzing areas of convergence and divergence it is important to identify specific areas where the geopotential height lines display bends in the flow. Where the convergence and divergence aloft begins and ends indicates the probable placement of the surface cells.

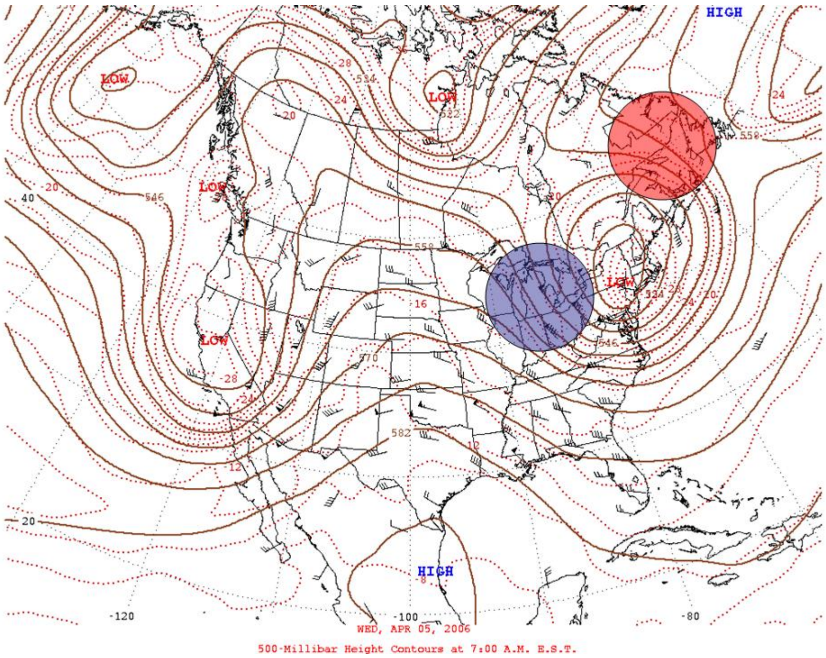


Figure 7.3a. 500mb chart showing area of convergence (blue) and divergence (red).

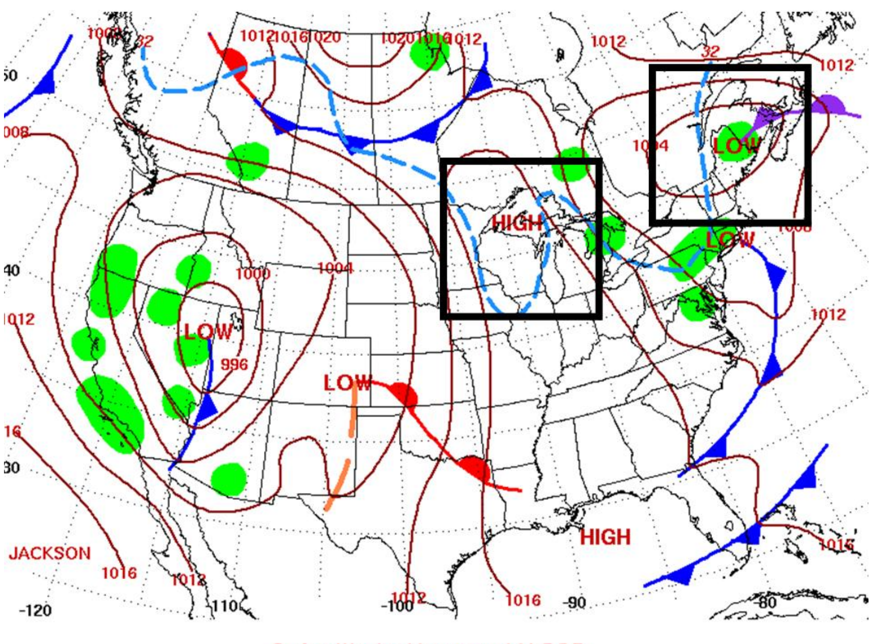


Figure 7.3b. Surface chart of the 500mb chart displaying the associated high and low pressure cells.

Chapter Review

Complete Chapter 7 Review on the Blackboard System.

CHAPTER VIII

CHAPTER VIII: FUNDAMENTALS OF METEOROLOGY PART IV

Studying meteorology requires complete understanding of the basic concepts of atmospheric processes. In this chapter, a continued review of the essential concepts is presented.

Global Circulation

From local and regional atmospheric circulation would not be complete without a detailed discussion of global circulation patterns. Global circulation involves the distribution of pressure and wind belts. Circulation is driven by the energy received from the Sun. Recall that most of the energy from the Sun is received at the equator and decreases toward the poles where most energy is lost. A hurricane demonstrates this unique concept. A hurricane is born from the warm sea surface temperature in the Tropical region of the Atlantic Ocean, which is indicative of high solar energy. As the hurricane makes its way toward the New World, it gains strength from the high energy input. When the hurricane shifts northward and then northeastward without making landfall, it begins to dissipate in the cooler waters of the North Atlantic due simply to the lack of energy available to maintain its strength. When investigating the strength of pressure and wind belts of global circulation the amount of energy available determines the overall strength of these belts.

Pressure Belts of Global Circulation

Starting at the Equator (figure 8.1) where most of the energy is received creates an area of extremely low pressure where the air is less dense and rises from the surface to the tropopause. This area of lower pressure is referred to as the Inter-Tropical Convergence Zone (ITCZ). Air is drawn into the low pressure belt rises and diverges just beneath the tropopause. The warm air cools, becomes more dense and begins to sink back to the surface around 30°N and 30°S where it creates a significant area of high pressure known as the Sub-Tropical High Pressure (STHP) belt back to the ITCZ. The primary vertical flow of the ITCZ and STHP is convective, which is the strongest convection of global circulation and is called the Hadley Cell. The biomes associated with the ITCZ and STHP are tropical rainforests and deserts respectively.

Air from the STHP flows northward (southward) to an area of lower pressure near 60°N (60°S) called the Sub-Polar Low Pressure (SPLP) belt. This belt is much weaker than the stronger ITCZ due to the primary fact that the energy received in this region is much less. The weakened strength of the SPLP is indicative of the lack of precipitation that does not promote the distribution of tropical rainforests, but instead, mixed deciduous and coniferous. Air rises from the SPLP into the upper atmosphere where it divergences just under the tropopause and begins to sink near the poles to great a Polar High (PH).

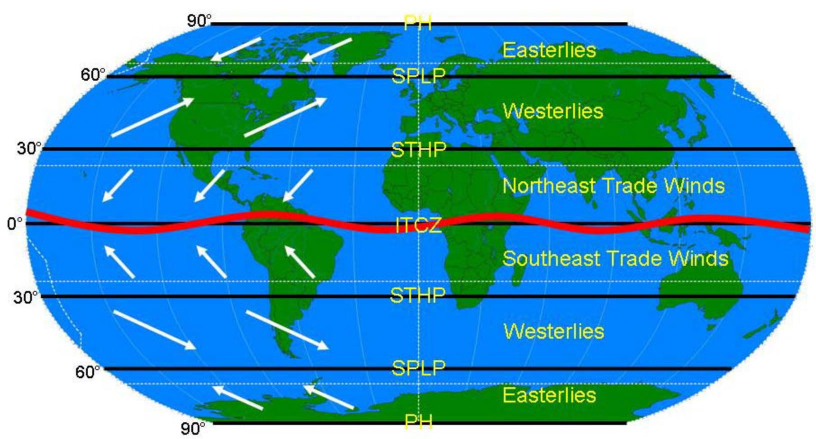


Figure 8.1. The Pressure and Wind Belts of Global Circulation.

Note that the height of the tropopause (figure 8.2) from the Equator to the Poles decreases with height due to the loss of energy to sustain temperature, which further promotes the upward expansion of the troposphere. The tropospause over the Equator is high due to the extreme heat that is generated by the intense solar radiation that is received. Over the poles the tropopause is closer to the surface due to the loss of energy that causes the column of air to shrink.

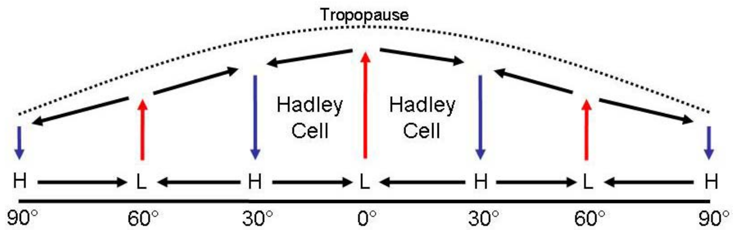


Figure 8.2. Cross-section of the atmosphere displaying the height of the tropopause and associated pressure belts.

Furthermore, the position of the pressure belts is dependent upon the placement of the Sun throughout the year (figure 8.3). In other words, the ITCZ will shift southward when the Sun is in the southern hemisphere during the northern hemisphere's winter. All pressure belts will thus shift southward with some latitudinal expansion in the northern hemisphere. In the northern hemisphere's summer the ITCZ and associated pressure belts will shift northward.

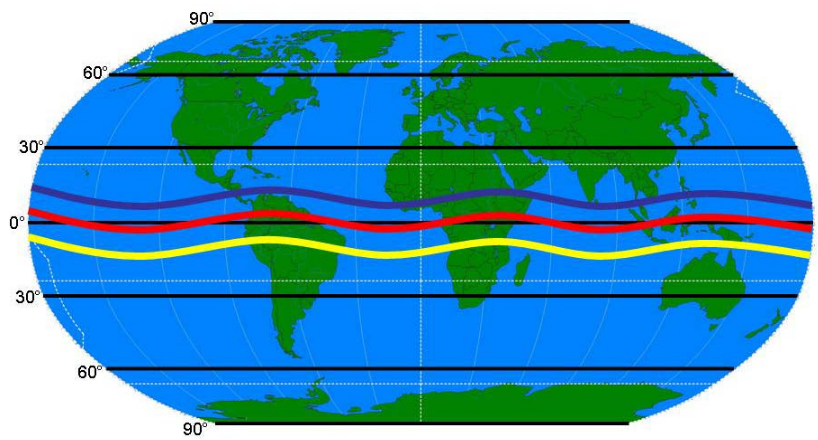


Figure 8.3. Migration of the ITCZ throughout the year. ITCZ during the northern hemisphere's winter (yellow). ITCZ during the northern hemisphere's summer (blue).

Global Wind Belts

The differentiating pressure belts cause global wind patterns (figure 8.4). Simply labeling the ITCZ as a low pressure with the STHP as a high pressure and considering pressure gradient (the chance in pressure over distance) and coriolis in the northern hemisphere the winds will flow from the northeast toward the low referring this wind belt as the Northeast Trade winds. In the southern hemisphere, the winds will flow from the southeast with regards to the distribution of the pressure belts also referred to as the Southeast Trade winds.

Traveling northward (southward) the pressure gradient remains consistent but the coriolis force strengthens a bit more. The wind belt between the STHP and SPLP is referred to as the Westerlies. Northward (southward) still the influence of coriolis is stronger where the wind flows from the Polar High toward the SPLP creating the Easterly wind belt.

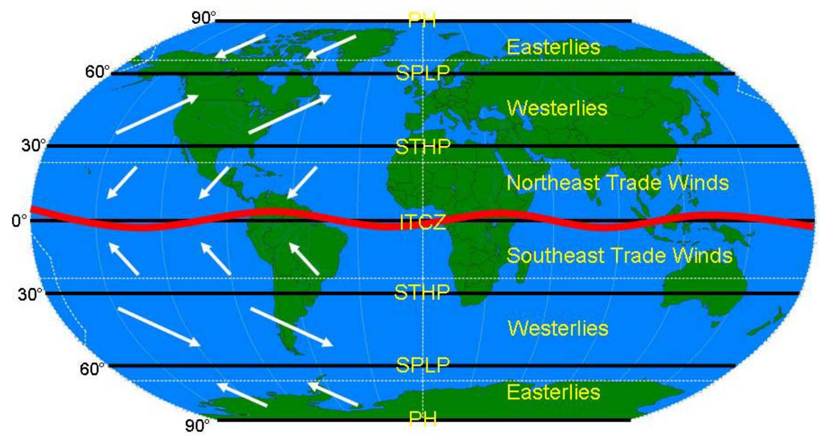


Figure 8.4. The Pressure and Wind Belts of Global Circulation.

Wind Flow in the Mid-Latitudes

Surface weather systems in the continental United States will be mainly influenced by the westerlies. All mid-latitude cyclones (low-pressure cells) will migrate from west to east with the westerlies driving their movement. The speed at which these systems move is dependent upon the temperature gradient in winter and summer.

Seasonal differences in temperature gradient will cause the Westerlies to strengthen in winter rather than in summer. This is primarily because when the Sun is in the southern hemisphere; the temperature gradient is stronger in the northern hemisphere. Without the Sun's influence on surface heating during the northern hemisphere's winter the Westerlies will be much stronger. The westerlies during the southern hemisphere's winter will not be a stronger as the northern hemisphere's winter because of the lack of significant landmass in the southern hemisphere where water is mainly in control of the temperature gradient.

Satellite View of Global Circulation

Satellite images can be used to determine the position of pressure and winds belts across the globe (figure 8.5). Note that the convective activity hovering around the Equator is the nature of the ITCZ (i.e. warm moist air rising from the intense energy received from the Sun to create thunderstorms). The STHP is influencing the dry conditions in North and South Africa. The westerlies can be identified by the manner in which the cloud formations surround regional low-pressure cells (mid-latitude cyclones) flow.

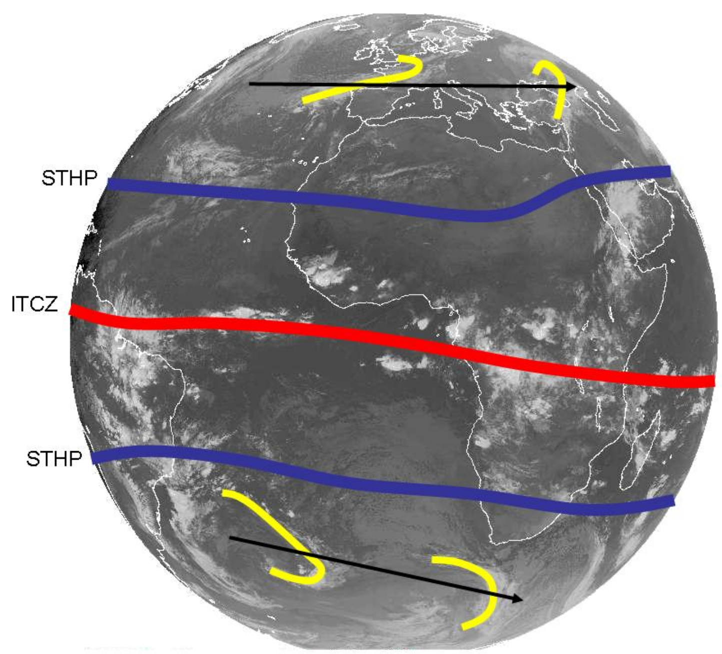


Figure 8.5. Infrared image showing the placement of the ITCZ (red) and the STHP (blue). The westerly wind belt can be identified by the distribution and cloud formations of the mid-latitude cyclones (yellow hooks). Image from NOAA.

Chapter Review

Complete Chapter 8 Review on the Blackboard System.

CHAPTER IX

CHAPTER IX: FUNDAMENTALS OF METEOROLOGY PART V

Studying meteorology requires complete understanding of the basic concepts of atmospheric processes. In this chapter, a continued review of the essential concepts is presented.

Phases of Water

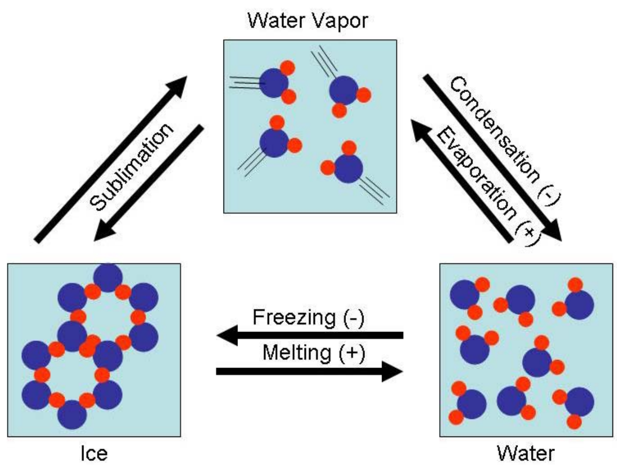


Figure 9.1. The phases of water (+ indicates the absorption of heat, - the release).

Water is an important component of the atmosphere. Water helps to maintain temperature between the Tropical and Polar Regions. It also modifies temperature on land in rural and urban environments. Energy changes the state of water between the three phases. In figure 9.1, if heat is added to ice, it melts to form water. If more heat is added, it begins to evaporate into water vapor. When heat is released, the process is reversed. Water vapor condenses when heat is released to form water. If more heat is released, the water molecules begin to arrange themselves into hexagonal crystals where air is trapped otherwise known as ice. The expansion of water during the frozen state is attributed to the arrangement of molecules during crystallization. The process of sublimation occurs between the solid state of water to the gaseous state. For example, dry ice, otherwise known as the solid form of carbon dioxide, will sublimate (the chemical process in which a solid is converted to a gas without passing through the liquid state) from the frozen state into a gas and vice versa.

Relative Humidity

Relative humidity is the relative volume of moisture in a parcel of air. It is often misused in accurately describing the specific amount of water in the air. Temperature and relative humidity are inversely related. For example, when temperature is high, the relative humidity is low and vice versa. Consider a parcel of dry air; if the temperature of the parcel is high the parcel expands. If the temperature of the air inside the parcel is cold, the parcel shrinks. Now add moisture to the parcel. For simplicity, moisture, in this example is not a gas as it would be in the real atmosphere, but 100ml of water. If the air temperature inside the parcel is high, the parcel expands and the level of the 100ml of water lowers. If the air temperature inside the parcel is low, the parcel shrinks, which causes the level of the 100ml of water to increase. Note that the volume of water does not change, only the volume of air.

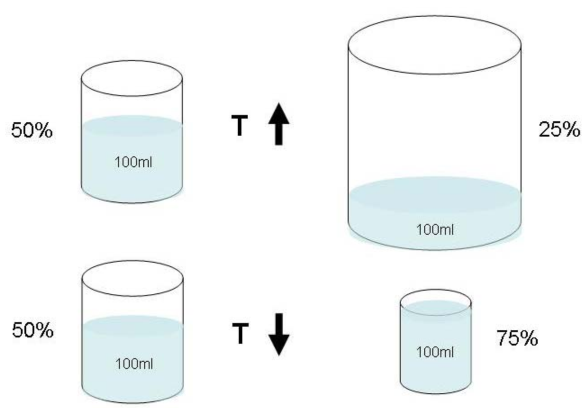


Figure 9.2. Diagram displaying the inverse relationship between temperature and relative humidity.

Figure 9.3 is a chart of different meteorological variables recorded from Charleston, Illinois (EIU1/CW5370). The temperature is a green line while the relative humidity is blue. Note that as temperature increases the relative humidity decreases during the day. At night, it is reversed. The temperature increases due to the influence of localized heating by insolation (olive colored hump). As the Sun sets, the temperature decreases causing relative humidity to increase.

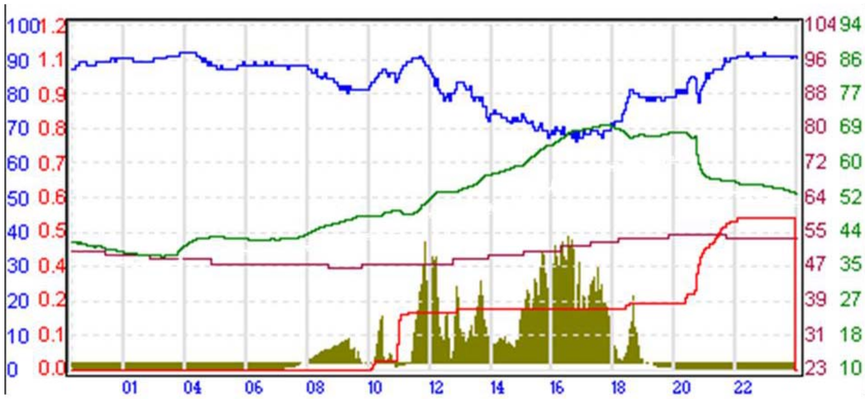


Figure 9.3. Chart displaying the inverse relationship between temperature (green) and relative humidity (blue). From Terre Haute, Indiana (ISU2/CW1125) 20060402.

People often confuse extremely hot days as being extremely humid. This is a common misconception. The relative humidity during extremely hot days is still lower compared to the nighttime hours. It is human perception that makes humans believe that it is more humid during the daytime than at night. This concept is referred to as the apparent temperature, which is determined by how humans feel temperature concerning relative humidity. Relative humidity can be high during the day but still lower than nighttime humidity.

Another misconception concerning relative humidity is that people believe it indicates when it will rain. If the relative humidity is 100%, people believe it will rain. If the relative humidity is near or at 100%, it has already begun to rain. The evaporation of water during a precipitation event increases the relative humidity of the air.

Dew Point

Dew point is the temperature when condensation occurs. If the temperature decreases and reaches the dew point temperature, condensation occurs. Take, for example, a glass of water with ice. The inside of the glass is cold due to the ice dropping the temperature of the water. On the outside of the glass, the temperature of the air adjacent to the glass is being cooled down. The air outside of the glass contains moisture. When the air adjacent to the glass is cooled to its dew point, sweat forms on the glass.

Dew point is a very important variable in meteorology because it determines when it will rain, where clouds will form, and determine the character of air masses. Meteorologists can identify when it will rain by using the dew point depression. The dew point depression (T_{dd}) is calculated by subtracting the dew point temperature (T_d) from the actual air temperature (T). If the dew point depression is less than 5°F, rain can be expected. If the dew point depression is 0°F, rain is most often occurring or fog is in the area. A dew point depression of 10°F or more indicates the atmosphere is relatively dry.

$$T_{dd} = T - T_d$$

Dew Point and the Rain Signature

A rain signature can be identified on a graph displaying temperature and dew point (figure 9.4). As temperature and dew point parallel each other, rain can be expected when there is a slight increase in the temperature and then a sudden drop. The dew point temperature increases to meet the temperature. Rain occurs where there is a drastic merging of the temperature and dew point temperature that precipitation occurs. If temperature and dew point already maintain a relatively low dew point depression and a slight merging occurs, the precipitation rate will be low (drizzle). If the two variables have a high dew point depression and merge significantly, the rate of precipitation is high (heavy rain).

Note that for precipitation to occur, the dew point depression should be relatively low. If the dew point depression is extremely high, precipitation is not expected as is the possibility of cloud formation. A higher dew point depression indicates that the local atmosphere is relatively dry.

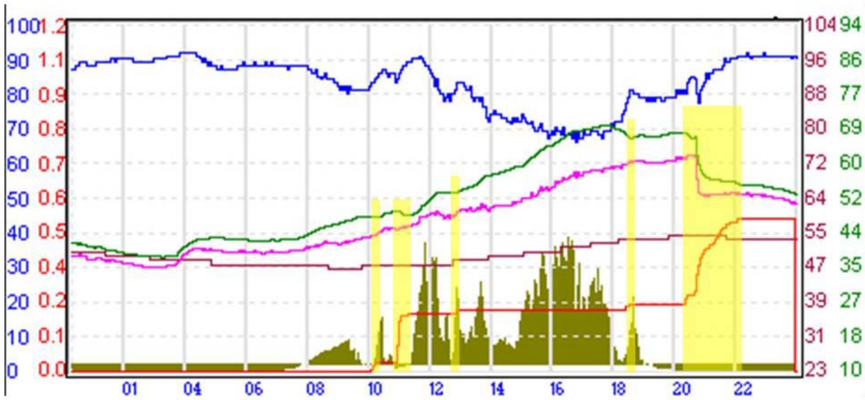


Figure 9.4. Graph displaying rain signature events (transparent yellow) with regards to temperature (green), dew point (pink), and precipitation amount (red). Note the amount of precipitation that occurs with the drastic change in temperature and dew point. The increased width of the yellow band indicates the more significant the change in the dew point depression. From Terre Haute, Indiana (ISU2/CW1125) 20060402.

Dew Point Depression and Cloud Height

Recall calculating dew point depression, temperature minus dew point temperature equals dew point depression. Cloud height can be determined by multiplying the dew point depression with the empirical (observed) value 255 feet. This calculation is relative to actual cloud height but can provide an estimate from two simple variables (software packages and meteorological models use other variables to get a more accurate cloud height). For example, to determine cloud height, a 10°F dew point depression is multiplied by 225 feet. The result is a cloud height of 2250 feet. No rain is occurring at this point. If the dew point depression is 3°F and multiplied by 225 feet, the cloud height is 675 feet above the surface. Rain is likely to occur. Consider a dew point depression of 0°F. Cloud height in this example would be 0 feet, which is fog. It is important to remember that this simple calculation can only be used to determine cloud height within or just above the boundary layer (the layer of air directly influenced by the surface).

$$Ch = (T - T_d)225$$

or

$$Ch = (T_{dd})225$$

Cloud Formation

Clouds form when a parcel of air rises, expands, and decreases in temperature. If the temperature of the parcel decreases, the relative humidity of the parcel of air increases to its saturation point or 100%, which causes the parcel to condense to form a cloud. The rising effect of the parcel is caused by convection, orographic lifting, frontal movement, or low-level convergence near the cloud base.

Cloud formation by convection is created by heat rising from the surface above the LCL. Clouds created by orographic lifting, refers to air being forced up by mountains. If a cold or warm front move into a region, the lifting effect of air causes cloud formation. Cold fronts are more drastic in nature due to the increased density of the air. As the cold air mass moves into a region of warm moist air, the lifting effect is great, causing significant lifting. The result of this significant lifting is the formation of cumulonimbus clouds. Warm air masses are gentle movers that glide over cool air. The result of this subtle movement creates stratiform clouds. In addition, areas of surface convergence creates clouds, but the effect is much weaker than convective cloud formations.

Precipitation Formation

Rain cannot form without a key ingredient—a condensation nucleus. A condensation nucleus is a microscope object that helps to increase condensation. This object can be a dust particle, sea salt, or pollutants. Most often dust particles or sea salts are the key ingredients in moisture droplets. Aerosol sea salts are created by the crashing of waves against cliffs. The extreme force of the waves actually releases salt molecules to become airborne.

If a condensation nucleus is available, water will begin to condense around this object to form a moisture droplet. Once the moisture droplet is created, the moisture droplet will fall to the surface in one of two processes (figure 9.5).

The first processes can be found in warm regions of the globe—the collision-coalescence process. In this process, the moisture droplet is in its liquid state in warm clouds. As the condensation nucleus continues to condense more water vapor from the surrounding air, it gains weight. When the weight of the moisture droplet out weighs the terminal velocity, the droplet falls. As the moisture droplet falls, it will eventually collide with another moisture droplet and coalesce (become one). The moisture droplet continues to fall colliding and coalescing with other droplets and increasing in speed toward the surface to fall as rain. A good example of the collision-coalescence process is when rain is falling on a windshield of a car not in motion. As the raindrops collide with other droplets, they gain weight and begin to move down the windshield. The droplets move faster when the moving droplet collides and coalesces with other droplets.

The second process can be found in colder upper atmosphere regions such as the Midwest. This process of precipitation is referred to as the Bergeron Process, which occurs in cold clouds. The process begins as an ice crystal where water vapor and moisture droplets freeze onto the ice crystal to form a larger crystal. As the crystal increases in weight, it begins to fall absorbing water vapor and other moisture droplets to increase its weight. If the melting point level is well above the surface, the ice crystal will melt below the melting point and fall as rain. If the melting point level is well below the surface, the crystal will fall as snow.

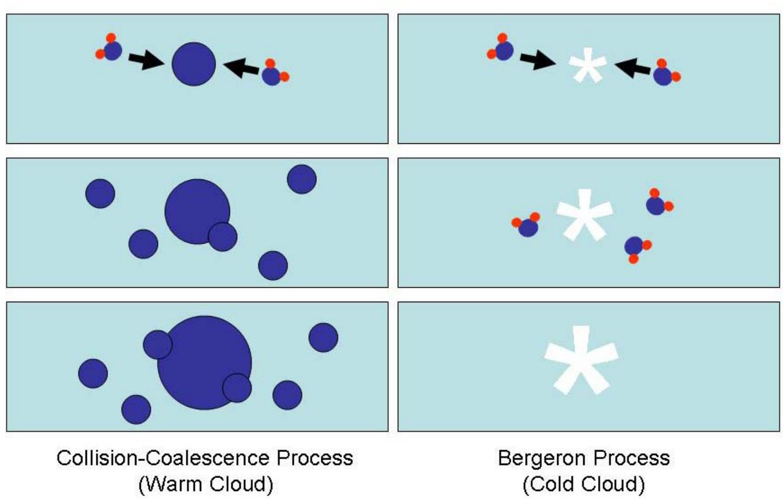


Figure 9.5. The processes of precipitation.

Chapter Review

Complete Chapter 9 Review on the Blackboard System.

CHAPTER X

CHAPTER X: ATMOSPHERIC STABILITY AND CLOUD DEVELOPMENT

Atmospheric stability refers to the state of the atmosphere in the development of clouds. This chapter focuses on three conditions of the atmosphere that influences or stifles cloud development.

Adiabatic Process

An air parcel will undergo changes depending on its own characteristics. In general terms, when a parcel of air rises, it will expand due to the decrease in pressure (i.e. pressure decreases with altitude) and cool. If it sinks toward the surface, the parcel will shrink under the increase in pressure and heat up. The term adiabatic refers to the change of the parcel when heat is not added or removed. In addition, the adiabatic process is constant when a parcel of air is dry but varies depending on the amount of moisture that it is holding.

A parcel that is dry will rise (cools) or sink (warms) at approximately 3°C/1000 ft. This is the change in temperature with altitude that is referred to as the lapse rate of the parcel. For example, dry adiabatic warming occurs when dry cold air sinks and undergoes compression and heating due to the increase in pressure as it sinks toward the surface. On the other hand, if the parcel contains moisture, it will release latent heat through condensation. However, the rate at which adiabatic cooling occurs is much slower than a dry parcel of air. The adiabatic cooling rate depends greatly on the dew point depression between the air temperature and dew point temperature.

Stable and Unstable Conditions

A stable and unstable condition (figure 10.1) refers to the ability of an air parcel to create clouds. If a parcel of air is warmer than its environment, it will continue to rise, cool, and condense when the parcel has reached its due point. This is causes clouds to form, which is referred to as an unstable environment. The important factor in this example is that convection occurred. However, when the parcel adiabatically cools more than the environment, it will return to the surface where convection is not created. If a parcel is the same temperature as the environment, it remains stationary until either it cools or warms adiabatically called conditionally unstable/stable.

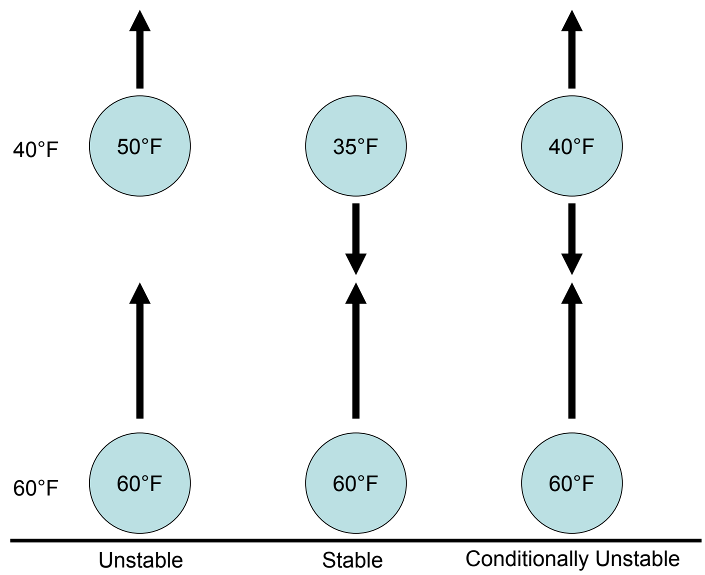


Figure 10.1. Parcels of air undergoing changes in different environments.

In figure 10.2a, stable conditions will occur when the temperature of the parcel is cooler than the environment. In unstable environments, the parcel is warmer than its environment (figure 10.2b) and is suitable for cloud development.

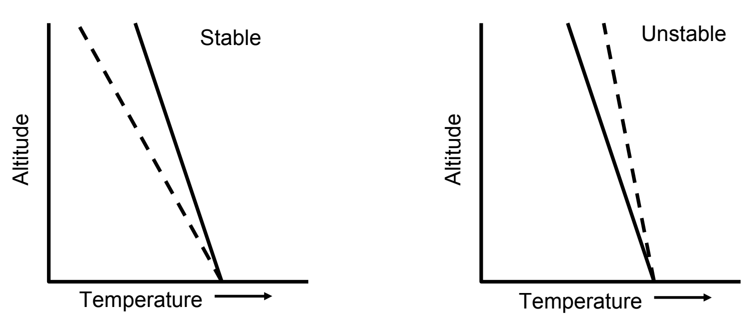


Figure 10.2. Graphs showing when an environment is stable or unstable.

Stable conditions limit convection. Therefore, if clouds are present they are stratiform due to the lack of convection. In other words, since there is no convection present and adiabatic cooling is occurring, layered clouds will be created. On the other hand, when convection occurs, unstable conditions will produce cumuliform clouds.

Unstable conditions will occur when the parcel of air continues to increase in height under the continued dropping of the temperature. In this process, convection is created and clouds will form with a stacked appearance (cumulus). Surface heating is usually the catalyst for unstable cloud development. Fair weather cumulus clouds will only develop to the point when the environmental temperature inverts (i.e. temperature inversion is the point at which the temperature shifts from cool to slightly warming with height). Cumulonimbus clouds will development through the entire troposphere as long as there are enough updrafts to support unstable conditions. The tropopause (the point of temperature inversion) will cap the top of the cumulonimbus cloud.

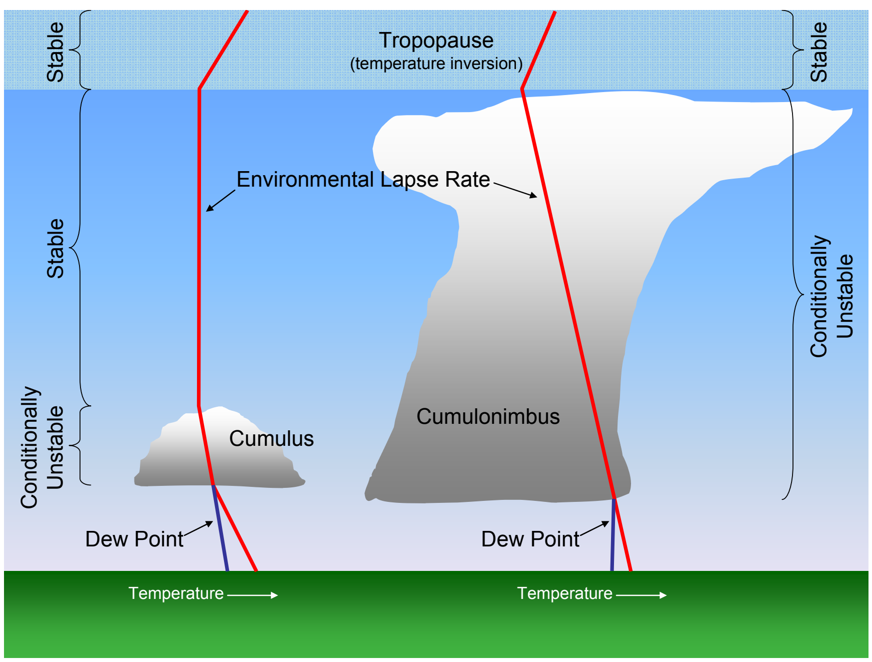


Figure 10.2. Cumuliform cloud development based on stable versus unstable environments.

In figure 10.2, a cumulus cloud will develop when the parcels of air are warmer than the environment. When the atmosphere above the cumulus is stable, convection and condensation halts. A cumulonimbus will develop when the parcels of air continue to condense well above the surface as long as the parcels are warmer than the environment. The convection will be blocked by temperature inversion otherwise known as the tropopause (stable air).

Chapter Review

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CHAPTER XI

CHAPTER XI: MID-LATITUDE CYCLONES

The mid-latitude cyclone is the weather system that is centered at the surface low-pressure cell. This system is the significant feature that meteorologists discuss on the evening news as it the foundation of differentiating weather conditions. In this chapter, we will look at the air masses, frontal systems, and cyclogenesis that are the essence of meteorology. Later, we will look at the elementary conditions that occur within regions of the mid-latitude cyclone that can be used in basic forecasting.

Air Mass Classification

Air masses are the fundamental component of mid-latitude cyclones. They are classified by two components—moisture content and temperature. These two components are dependent upon their source region. In other words, the region where the air mass originates is based on its characteristics. If an air mass is created over a major body of water that is in a cold region, it will be moist and cold. On the other hand, if the air mass originates over land in a warm region, it will be dry and warm.

The air mass classification scheme is a simple abbreviation of the moisture content and temperature of the air mass's source region. When the air mass originates over water, it is given a lower case 'm'. If it originates over land, a lower case 'c' is assigned. The moisture content abbreviation is first in the two-letter classification. The second letter is the temperature of the air mass. If the air mass originates in the Tropics, it is assigned a capital 'T'. On the other hand, if the air mass starts in the Polar Regions, it is given a capital 'P'. Figure 11.1 displays the air masses and their associated classifications based on the source region.

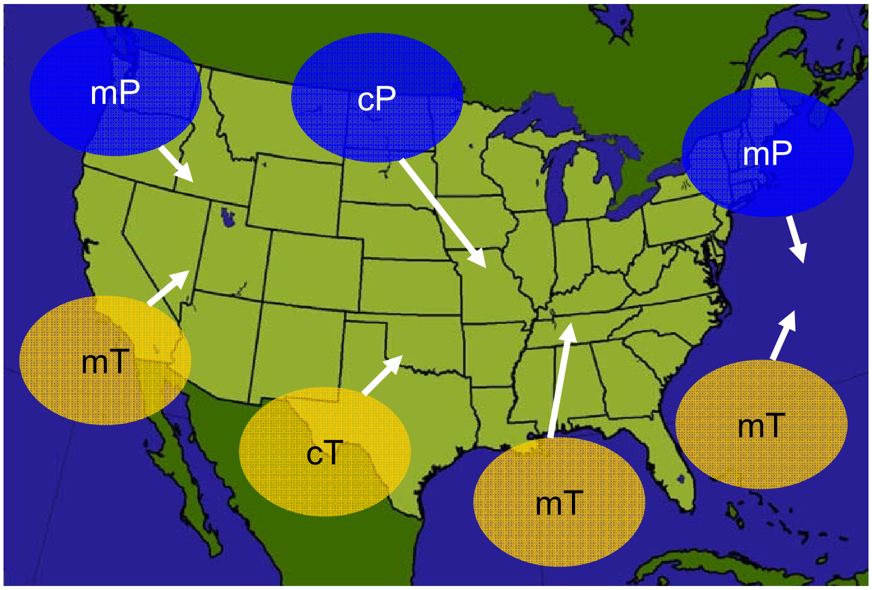


Figure 11.1. Air mass classification and the associated source regions.

Surface Fronts

With air masses comes their associated front symbol. The fronts are drawn on a surface chart where the leading edge of the air mass is touching the surface. Five different front symbols describe the characteristics of the air mass behind it. The stationary front (figure 11.2a) is a front with blue triangles and red semi-circles on opposite sides. This front describes that neither the cold nor the warm air masses are strong enough to dominate the other. Essentially, the stationary front is when there is no major movement of the differentiating air masses. A warm front (figure 11.2b) is colored red with semi-circles indicating the direction the air mass behind it is moving. The warm front symbol indicates a gentle movement due to its moisture content. The cold front symbol (figure 11.2c) is colored blue with triangles, which indicates the sharp abrupt movement of the cold air mass behind it. The occluded front symbol (figure 11.2d) is colored purple with alternating semi-circles and triangles on the same side, which is indicative of the merging of effect of the cold air mass into the warm air mass. The final front symbol is the dry line front (figure 11.2e), which is colored yellow with semi-circles drawn close together. The dry line front indicates a dry air mass (cT) and is most often located in the south-central United States.

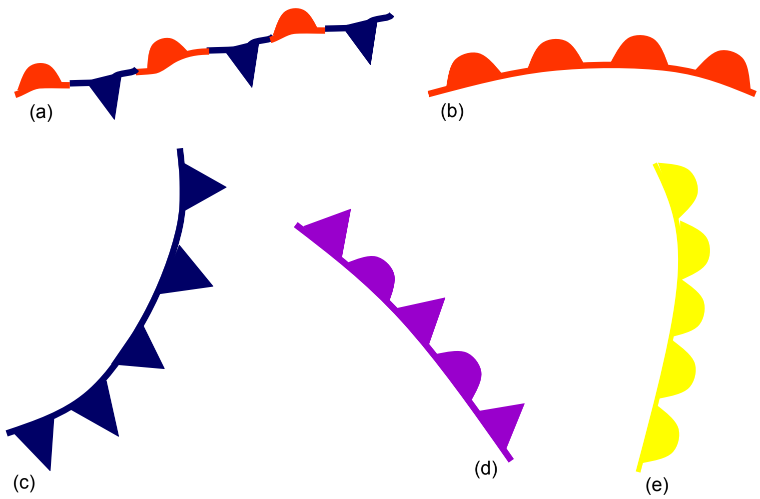


Figure 11.2. Front symbols. Stationary (a). Warm (b). Cold (c). Occluded (d). Dry line (e).

The Mid-Latitude Cyclone

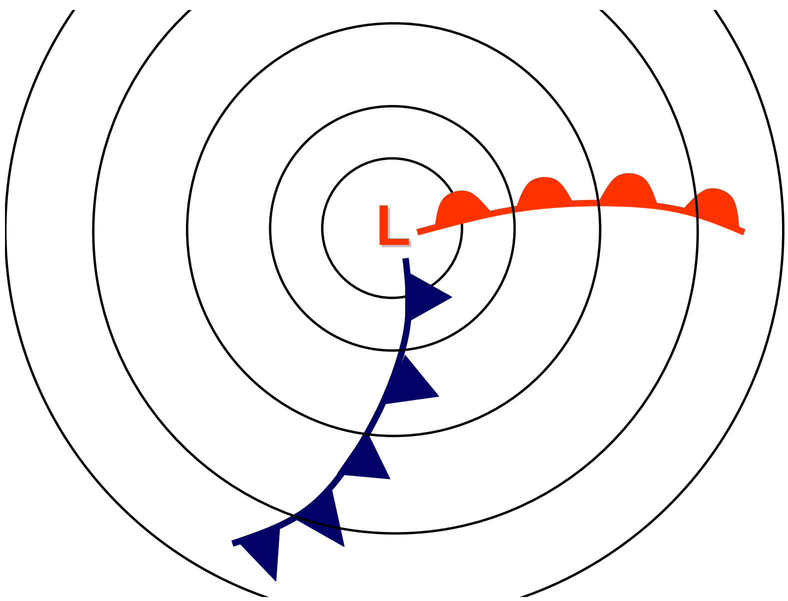


Figure 11.3. The mid-latitude cyclone.

The basic mid-latitude cyclone has a low-pressure cell at its center with a warm front extend to the east and a cold front to the south (figure 11.3). The general movement of a mid-latitude cyclone is west to east; however, movements that are more specific are based on components of vorticity that will be left to more advanced courses.

As the low pressure draws in air from the region in a counter-clockwise motion, the air masses and their associated fronts will be twisted inwardly as well. To understand how the mid-latitude cyclone evolves over-time, a discussion of cross-sections on an elementary level is necessary.

The cross-section of a warm front (figure 11.4) begins in the area ahead (north) of the warm front. The air ahead of the warm front is cool. If an observer looks at the clouds above their location, cirrus clouds would be seen. As the warm front approaches the observer, the warm air mass gently glides over the cool air at an gradual angle. As it glides overhead, stable air with adiabatic cooling creates stratiform clouds in the following order with the highest formation arriving first: 1) cirrostratus, 2) altostratus, 3) stratus, and 4) nimbostratus. The closer the warm air mass is to the surface the lower the clouds. Once the air mass is at the lowest altitude possible precipitation from nimbostratus clouds will fall near the warm front. After the warm front moves past the observer, nice conditions will prevail.

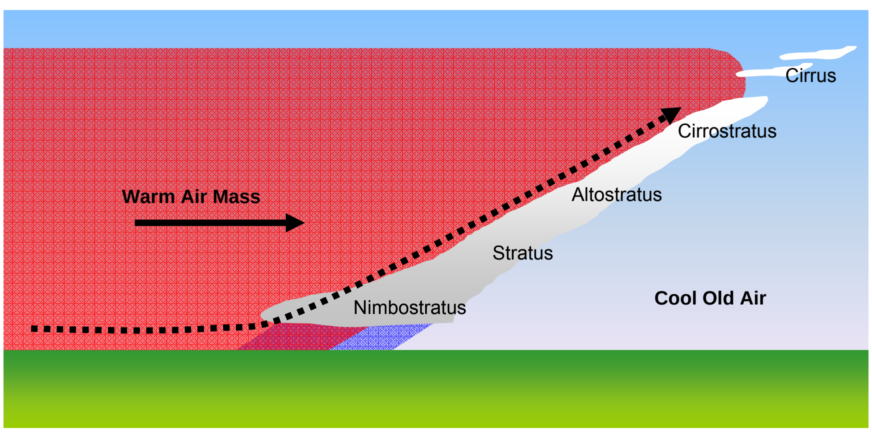


Figure 11.4. The cross-section of a warm front. Note that the warm front symbol is drawn where the leading edge of the air mass touches the surface.

The cross-section of a cold front (figure 11.5) is a bit easier to understand as it does not usually entail multiple cloud types. If an observer is ahead of the cold front, they will be in a warm air mass. As the cold front approaches the observer, cold air will abruptly push the warm moist air over the top of the cold air mass. This lifting effect creates unstable conditions resulting in cumuliform clouds. If the two air masses are extremely different as to their moisture continent and temperature, the abrupt lifting effect will increase the severity of the storms along the cold front. Once the cold front passes the observer, nice cold conditions relative to the season will prevail until another mid-latitude cyclone moves into the region.

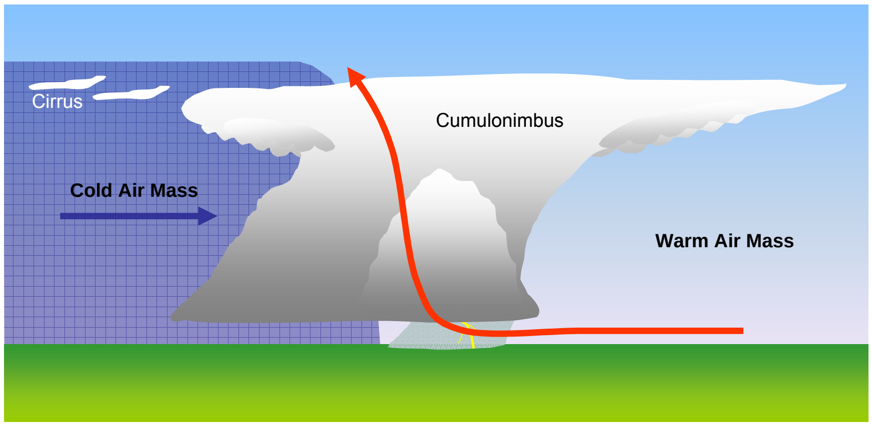


Figure 11.5. The cross-section of the cold front. Note that the cold front symbol is drawn where the leading edge of the cold air mass touches the surface.

Geography of a Mid-Latitude Cyclone

Six regions around a mid-latitude cyclone describe the basic current conditions. In addition, the current conditions in one region can provide a basic forecast for another as the mid-latitude cyclone moves into that region within the next 6-12 hours.

Referring to figure 11.6, the first region (A) is ahead of the warm front. In this region the temperature is cool as the warm front has yet to move into the region. The cloud type is stratiform, similar to the cross-section. Precipitation is possible but scattered. If precipitation is occurring, the intensity will be light or a drizzle and the duration will be long. The pressure tendency would be falling as the low pressure approaches a station within this region.

Intensity and duration of precipitation is based on the height of the cloud producing the precipitation. For example, since a nimbostratus is formed from stable conditions (i.e. lack of convection), the thickness of the nimbostratus cloud will be shallow. This shallowness causes precipitation to fall as small droplets due to the lack of height to allow the droplets to coalesce into larger ones. In addition, the shallowness of the nimbostratus cloud will decrease the intensity of the precipitation. On the other hand, if the cloud were a cumulonimbus, the intensity would be heavy due to the increased thickness of the cloud. Furthermore, the duration would be short, as most of the precipitable water would fall as large droplets. The spatial extent of the clouds is also a major factor in the duration. Since nimbostratus clouds can cover vast areas in and around the warm front, the duration will be long. On the other hand, the base of the cumulonimbus cloud is shorter causing the duration to be shorter.

Region B is located at the warm front. In this region, the temperature begins to rise. Precipitation is likely with a light intensity and long duration. The cloud type would be a nimbostratus if precipitation were falling. The pressure in this region would be falling as the low pressure slowly approaches the station.

Region C is located behind the warm front. The current conditions in this region are similar to a nice day. The temperature in this region is warm with steady to falling pressure. Precipitation is unlikely with cumulus or cirrus clouds or clear skies.

Region D is located ahead of the cold front and is only considered with possible severe weather. If severe weather is expected, the most severe conditions will occur within this region. If severe weather is not expected region C and D will become a larger region C.

Region E is located at the cold front. In this region, thunderstorms are possible. The intensity of the thunderstorms are dependent upon the differentiating characteristics of the air masses ahead and behind the cold front. For example, if the warm air mass has a high dew point and the cold air mass has a low dew point, thunderstorms could be severe. However, if the dew points are close to each other ahead or behind the front, the thunderstorms could be weakened or simply be a heavy downpour in a short period of time. The temperature will begin to drop and the pressure tendency will begin to rise as a high-pressure cell approaches behind the front.

Region F is located behind the cold front. The weather conditions in this region are much nicer than region C with high cirrus or fair weather cumulus clouds or even clear skies. The temperature lowers even more in this region without the possibility of precipitation. The pressure tendency will begin to rise with the oncoming high-pressure cell from the west.

Table 11.1 displays the associated conditions for each region for better viewing and interpretation.

Region	***Temperature***	***Pressure***	***Cloud Type***	***Precipitation***	***Intensity/Duration***
A	Cool	Falling	Ci, Cs, As, St	Possible	Light/long
B	Warming	Falling	St, Ns	Likely	Light/long
C	Warm	Falling/Steady	Cu, Ci, Clr	No	-
D	Warm	Steady/Rising	Cb	Severe	Heavy/Short
E	Cooling	Rising	Cb, Cu	Likely	Heavy/Short
F	Cold	Rising	Ci, Cu, Clr	No	-

Table 11.1. Conditions in the regions around a mid-latitude cyclone. Region D should only be considered during possible severe weather.

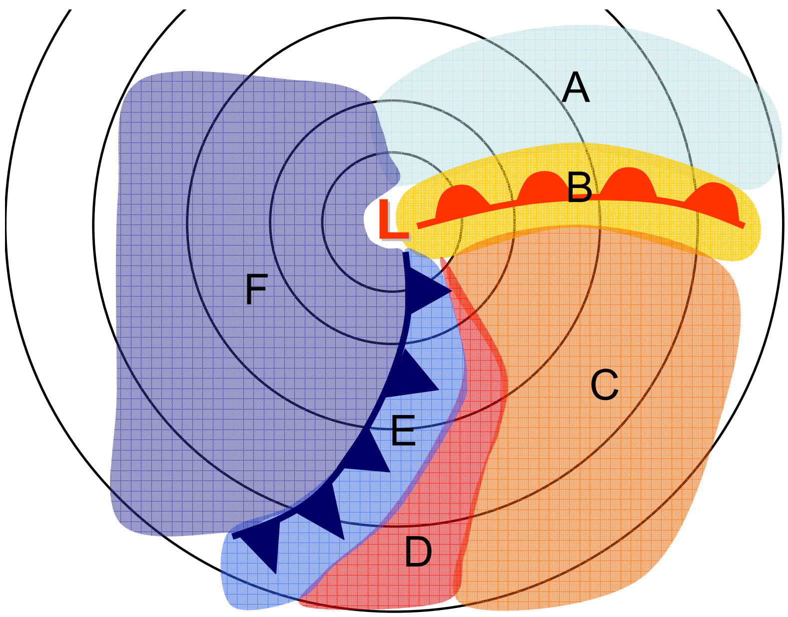


Figure 11.6. Regions within the mid-latitude cyclone for determining basic current conditions and forecasting.

Basic forecasting can be accomplished from this simple display of current conditions by considering the current region and moving to the next region. For example, if a station is located within region A, the forecast would be region B within 6 hours. In addition, if the station is located within region C, the forecast would be region D (if severe weather is highly probable) and then region E in 6-12 hours.

Cyclogenesis

Mid-latitude Cyclogenesis is essentially the development of the mid-latitude cyclone through time. There are five stages of cyclogenesis that progress slowly or quickly depending on the conditions of the upper level trough and the position of the jet streak/jetstream.

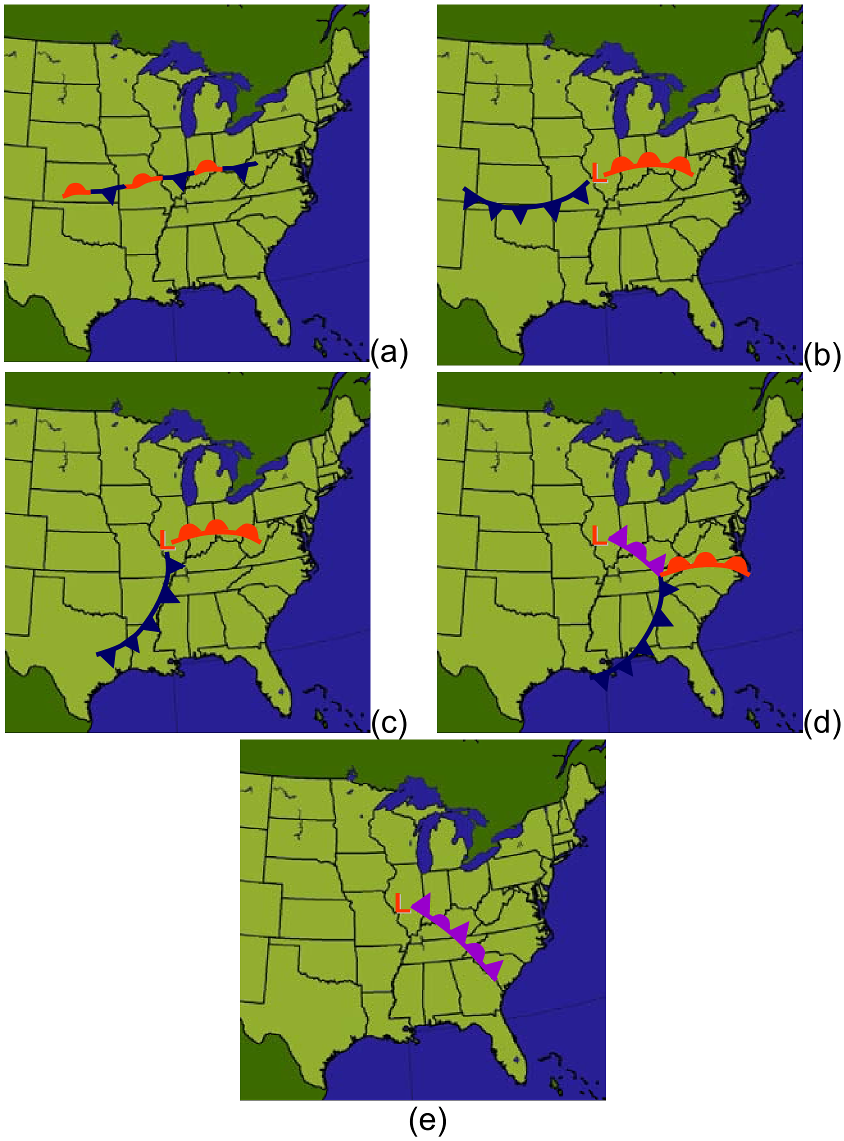


Figure 11.7. Stages of surface cyclogenesis.

The first stage of cyclogenesis is the stationary stage (figure 11.7a) where a stationary front divides the warm and cold air masses that are incapable of dominating each other. The wind flow in this stage converges in a parallel fashion. Sometimes if the conditions are favorable, severe weather is possible. Through time, a low-pressure cell will develop over the stationary front that will sort the cold and warm air masses through vorticity. As the low spins, cold air will begin to move southward on the western side of the low and warm air moves northward on the east side of the surface low. This is the wave stage of cyclogenesis (figure 11.7b). The third stage of cyclogenesis is the open stage and considered the mature stage (figure 11.7c). In this phase, the warm front moves gentle northward as the cold front rushes to the southeast. The occluded stage of cyclogenesis (figure 11.7d) is essentially the phase where the cold air mass begins to merge with the warm air mass, overtaking it—similar to a zipper. The final stage is dissipation (figure 11.7e). As the cold air is removing the warm air from the low-pressure cell, the system begins to fall apart. After the final stage, the stationary stage will again occur further downstream.

The essential ingredient needed for a mid-latitude cyclone to develop is the warm and cold air masses that promote the spin of the low-pressure cell. If warm air is removed, the system falls apart. Therefore, as long as warm air is in place, the system will continue to exist.

Storm Tracks

Mid-latitude cyclones will develop through three basic storm tracks within North America. The speed of movement and development is dependent upon the amount of moisture. A mid-latitude cyclone that has a great deal of moisture within the system will develop and move slowly. On the other hand, the lack of moisture will allow the cyclone to develop and move more quickly.

The Alberta Clipper storm track originates in Alberta, Canada (figure 11.8a). Since there is no major body of water in this region of Canada, the Alberta clipper will develop and move across the upper third of the United States quickly. Precipitation in the form of rain and snow will not be of great significance unless there is a strong inflow of moisture from the south. The track follows a path from Alberta, Canada southeasterly across the upper Great Plains and over the southern Great Lakes region out of the United States between the Canadian and United States border.

The Colorado Cyclone storm track originates in the Colorado region (figure 11.8b). This cyclone will have moderate development and movement as it is essentially balanced between low moisture and high moisture availability. The track extends from the Colorado area across the Ohio River Valley and out of the United States through New England.

The final storm track focused in this text is the Inside Leader (figure 11.8c). This cyclone develops over the southwestern United States region. The track follows a path across Texas toward the southern Gulf coast and then northward between Ohio and New York and out through New England. The Inside Leader is the slowest moving and developing cyclone due to the high moisture content from the Gulf of Mexico. Considerable precipitation amounts can be expected with this storm track.

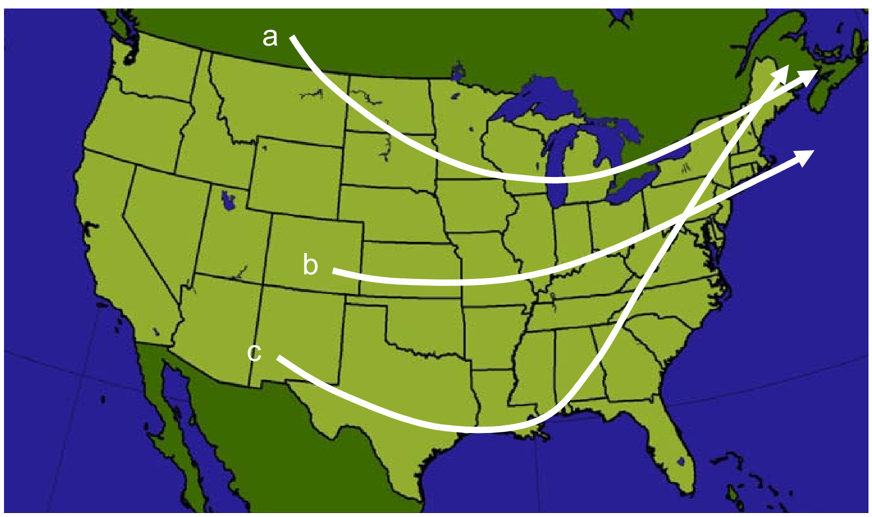


Figure 11.8. Three basic storm tracks that influence the eastern two-thirds of the United States. Alberta Clipper (a). Colorado Low (b). Inside Leader (c).

Chapter Review

Complete Chapter 11 Review on the Blackboard System.

CHAPTER XII

CHAPTER XII: CONTINENTAL SEVERE WEATHER

Associated with the Mid-Latitude Cyclones, severe weather is probably the most fascinating among humans. In this chapter, a focus on phenomena that are unique to continental is presented such as supercell thunderstorms and tornadoes. The classification of continental severe weather identifies those weather events that originate over land.

Basic Thunderstorm Development

Air mass thunderstorms develop with the interaction of warm and cold air masses. Consider a station that is in the marine tropical (mT) air mass (region C in the mid-latitude cyclone) with a temperature of 78°F and a dew point of 68°F. As the cold front approaches the station, the air temperature of the air mass behind the cold front is 56°F with a dew point of 34°F. The difference between the qualities of the two air masses will promote the development of thunderstorms. In this situation, the atmosphere will become increasingly unstable as the warm air is forced upward as the cold dense air moves in. If the dew point depression spread (the depression between the two air masses) is less or nearly the same, thunderstorm development is reduced. For example, if the warm air mass' dew point depression is 5°F and the cold air mass has a depression of 8°F, then there is not enough difference between the two air masses to support strong thunderstorm development.

The first stage of thunderstorm development is the Cumulus Stage (figure 12.1a). Warm moist air rises in an unstable environment and rises above the LCL. At this point condensation occurs. If there are strong updrafts, the cumulus cloud will continue to grow with height into the Mature Stage (figure 12.1b) of thunderstorm development. In the Mature Stage, a towering cumulonimbus cloud develops as warm moist air continues to feed the cloud. Ice crystals form in the top portion of the cumulonimbus cloud and precipitation forms under the Bergeron process. As the crystals gain weight, they fall through the cloud creating downdrafts of wind and precipitation. If the updrafts are strong, precipitation will be forced back into the cloud to begin the cycle of hail formation—freezing a layer of moisture on the stone and slightly melting it as it returns to the base of the cloud. The size of the hailstones depends on the speed of the updrafts. If the updrafts have higher wind speeds, hailstones will continue to be tossed back into the upper portion of the cloud. Once the hailstones exceed the weight that the updrafts can handle, the hailstones fall to the surface. Once the balance between the updraft and downdraft changes to overwhelming downdrafts, the cloud begins to fall apart in the Dissipation Stage (figure 12.1c). Remember, for thunderstorms to continue to sustain development, warm moist air must be available. If the downdrafts gain strength, they cutoff the supply of warm moist air and the thunderstorm dissipates.

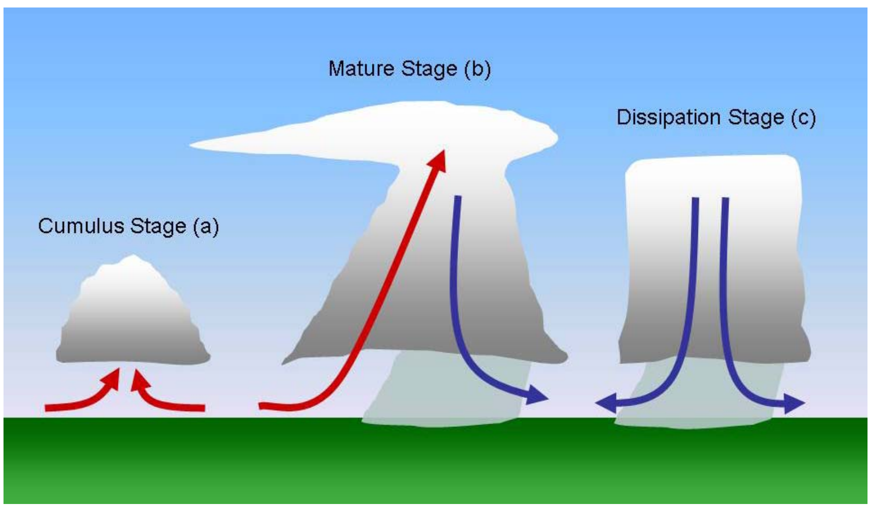


Figure 12.1. Stages of Thunderstorm Development.

Figure 12.2 displays the formation of towering cumulonimbus clouds just ahead of a cold front on March 31, 2006 in east-central Illinois between Westfield and Clarksville. As the cold air mass continues to migrate across the region, these clouds will continue to develop into thunderstorms. Once the front crosses the Illinois/Indiana state line, these cumulonimbus clouds will develop into supercell thunderstorms southeast of Terre Haute, Indiana (figure 12.3).

Figure 12.2. Thunderstorms developing over east-central Illinois between Westfield and Clarksville. Photo by Cheryl Birkhead.

Figure 12.3. Supercell developing southeast of Terre Haute, Indiana.

Supercell Thunderstorm Development

The cumulonimbus cloud is the king of all clouds and can form into a supercell (figure 12.4). The cumulonimbus cloud's vertical extent is impressive as it towers through the troposphere (the layer of the atmosphere between the surface and tropopause where all of our weather occurs). Born from the increased instability of the atmosphere the cumulonimbus cloud increases in height from warm moist air rising into a cold upper atmosphere. The stronger the updrafts, the higher the cloud will build. Sometimes, the updrafts are so strong that they actually poke through the tropopause to form an overshooting top. In addition, as the updrafts continue to provide more and more moisture, the cumulonimbus cloud begins to pile up under the tropopause to create the anvil portion of the cloud. Due to the weak return of air under the extended anvil head, mammatus clouds can form.

As the updrafts feed the cumulonimbus cloud, water vapor condenses to form ice crystals that gain weight by attracting water vapor and supercooled moisture droplets, which eventually fall toward the surface as a heavy rain. As more droplets begin to fall, a downdraft is created that flows through the base of the cumulonimbus toward the surface and ahead of the cloud as a gust front.

The upward spiraling effect of the updrafts can also create significant rotation causing a wall cloud to descend from the base of the cumulonimbus. This formation can set the stage for tornado development. Behind the storm cell, a flanking line can develop providing further development of another storm cell.

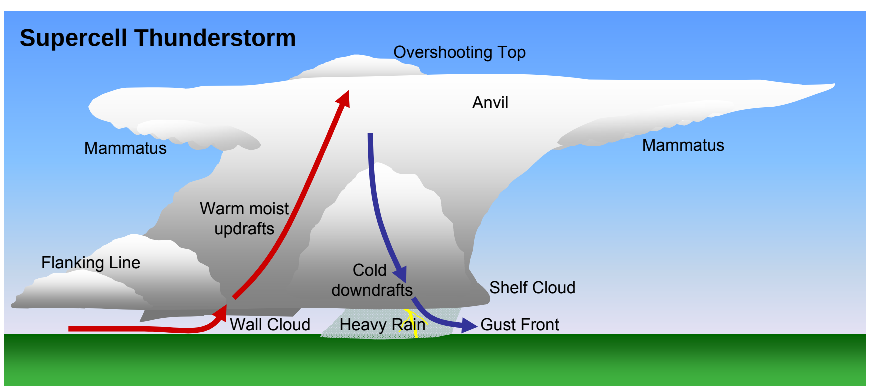


Figure 12.3. Anatomy of a Supercell.

Tornado Development

Tornadoes can develop from supercells as long as there are two primary ingredients available and the continued increase in instability—strong southwesterly winds aloft (500mb) and moderate southeasterly winds at the surface. In the basic formation of tornadoes, the horizontal rolling of air across the landscape is broken by a strong updraft that changes the rolling air into a vertical swirling column of air at the base of the wall cloud. If this continues, a tornado will develop through four stages within the rain-free zone.

The first stage of tornado development is the Funnel Cloud stage (figure 12.5a). When the updraft of a supercell forms the wall cloud and continued rotation is increased, a funnel cloud will begin to descend from the base of the wall cloud. The funnel cloud begins the formation of a tornado. It is not called a tornado until it touches the ground. Once the funnel cloud descends toward the surface and touches the ground it is called the tornado stage (figure 12.5b). At this point, the swirling mass begins to increase in size where it does the most damage in the mature stage (figure 12.5c). If the tornado begins to look like a spiraling wobbling rope, it is in the dissipation stage of development (figure 12.5d). In this stage, the updraft, which is the support of the tornado, begins to lose its axis and falls apart. It is important to keep in mind that even though the tornado appears to dissipate, another tornado could be developing upstream.

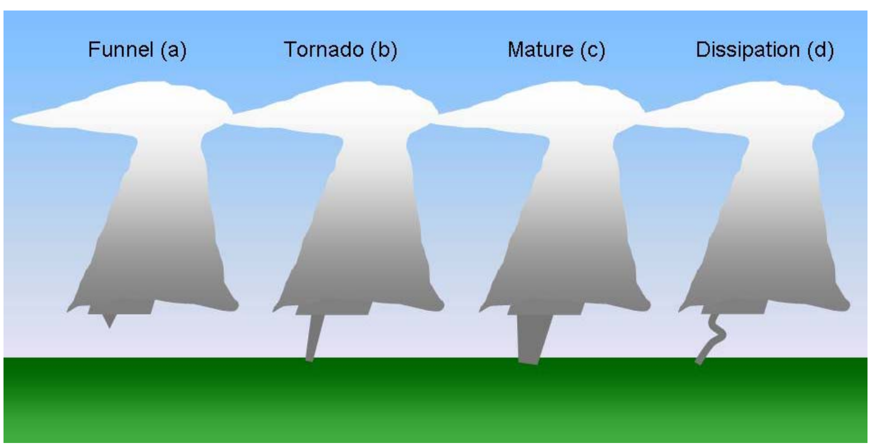


Figure 12.5. Stages of Tornado Development.

After a tornado has occurred, a damage survey team from National Weather Service will assess the damage caused by the twister. Once they have considered the data, the team will classify the tornado according to its damage path using the Fujita Scale (table 12.1) created by Dr. Theodore Fujita.

Scale	Wind Speed (mph)	Damage
F0	<73	Light
F1	73-112	Moderate
F2	113-157	Considerable
F3	158-206	Severe
F4	207-260	Devastating
F5	261-318	Incredible

Table 12.1. Fujita Scale based on Damage and Wind Speed.

On February 2, 2006, NOAA and NWS announced the implementation of an "Enhanced Fujita (EF) Scale" to replace the original Fujita Scale. NOAA identified the following weaknesses associated with the original scale as listed in table 12.2.

Over the years, the F-Scale has revealed the following weaknesses:

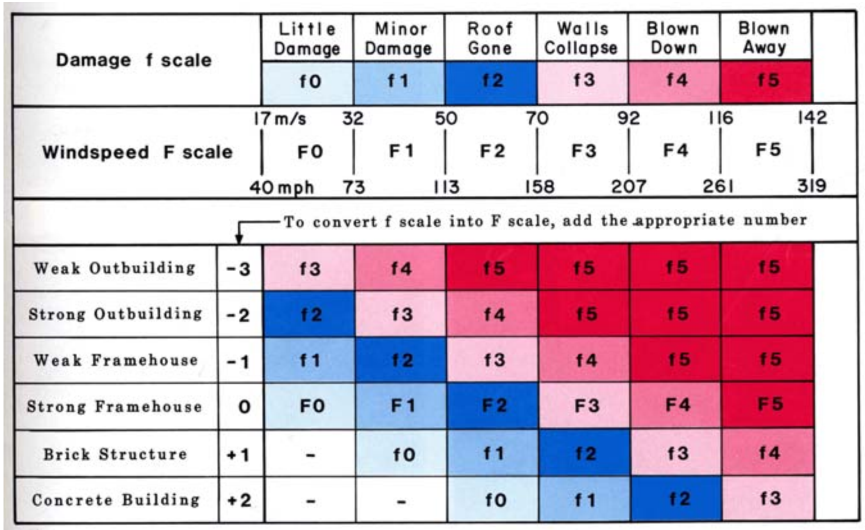
- It is *subjective* based solely on the damage caused by a tornado
- No recognition in difference in construction
- Difficult to apply with no damage indicators
    - if the 3/4-mile wide tornado does not hit any structures, what F-scale should be assigned?
- Subject to bias
- Based on the worst damage (even if it is one building or house)
- Overestimates wind speeds greater than F3

And the F-Scale has had its misuses over the years:

- Too much reliance on the estimated wind speeds
- Oversimplification of the damage description
- Judge the F-scale by the appearance of the tornado cloud
- Unrecognizing weak structures
    - mobile homes
    - modified homes

Table 12.1. Weaknesses identified by NOAA concerning the original Fujita Scale. From NOAA http://www.spc.noaa.gov/efscale/.

The new scale (figure 12.6), although complex upon first viewing, covers all aspects of damage according to the type of materials a structure is constructed. For example, if a buildings walls collapse it is classified as an f3. However, when considering the type of material that the exterior walls are made of such as brick, the scale is adjusted to an f2. Then to convert the result to the normal F Scale, you would add 1, which results in F3.



Damage f scale		Little Damage	Minor Damage	Roof Gone	Walls Collapse	Blown Down	Blown Away
		f0	f1	f2	f3	f4	f5
Windspeed F scale		17 m/s – 32 (40 mph – 73) F0	32 – 50 (73 – 113) F1	50 – 70 (113 – 158) F2	70 – 92 (158 – 207) F3	92 – 116 (207 – 261) F4	116 – 142 (261 – 319) F5
To convert f scale into F scale, add the appropriate number							
Weak Outbuilding	-3	f3	f4	f5	f5	f5	f5
Strong Outbuilding	-2	f2	f3	f4	f5	f5	f5
Weak Framehouse	-1	f1	f2	f3	f4	f5	f5
Strong Framehouse	0	F0	F1	F2	F3	F4	F5
Brick Structure	+1	-	f0	f1	f2	f3	f4
Concrete Building	+2	-	-	f0	f1	f2	f3

Figure 12.6. The Enhanced Fujita Scale (EF Scale). From NOAA http://www.spc.noaa.gov/efscale/.

Interpreting TVS on RADAR

Tornado Vortex Signature (TVS) is a feature of software programs that identifies rotation within a storm cell. Using a 0.5° tilt velocity image (the angle of the Doppler radar) with the associated composite image an analyst can determine rotation within a storm cell. Although a TVS can be identified automatically by software and indicate a strong possibility of tornadoes, not all signatures indicate the possibility of a tornado. However, a history of signatures does require concern and a higher probability of tornadic activity.

Figure 12.7a shows a composite radar image of the region northwest of Indianapolis on April 15, 2006 at 0107Z. Note the high decibel storm cell over Crawfordsville (storm cell identifier V6 and Y2). There is hail occurring in this cell due to the maximum decibel being 70. A decibel of 55 or higher requires the storm cell be monitored further. By analyzing the same region using the velocity 0.5° tilt (figure 12.7b), we can identify significant rotation in this cell, which is producing a tornado at this particular time. Green pixels indicate that the winds are flowing toward the radar in Indianapolis and red pixels show winds flowing away from the radar. When there is a couplet appearance in the wind field, we conclude that rotation is occurring and issue a tornado warning for these locations.

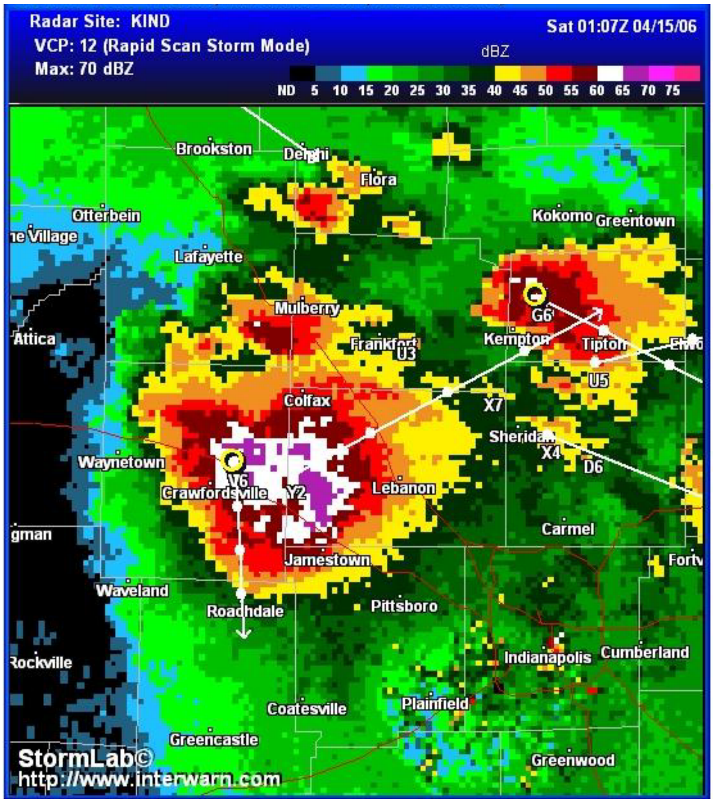


Figure 12.7a. Composite radar image showing precipitation, storm tracks, and storm cell identifiers.

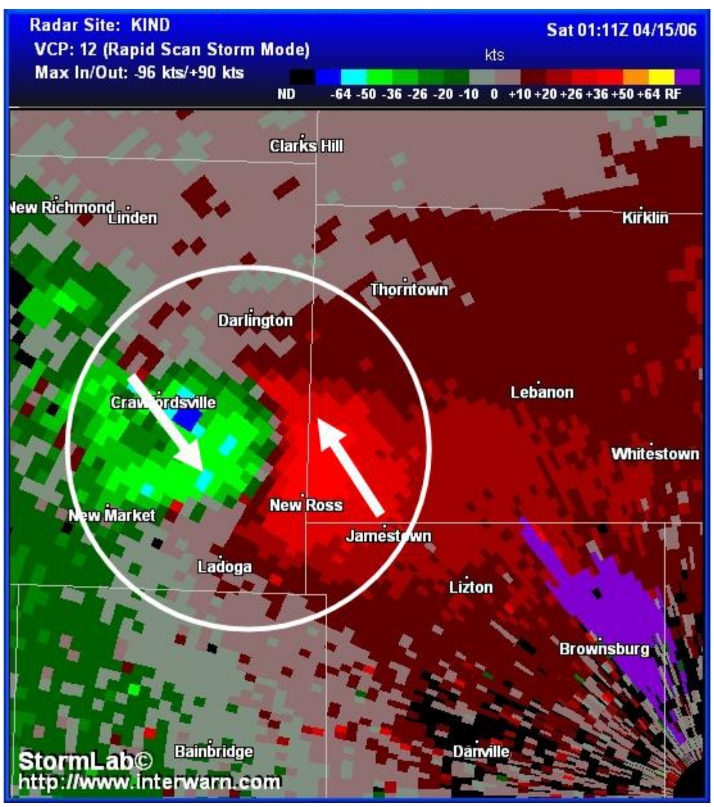


Figure 12.7b. Velocity image at 0.5° tilt showing wind flow.

Classifying Severe Weather

National Weather Service is the only agency that has the ability to issue watches and warnings for the United States. These issuances are determined by particular characteristics. If conditions are favorable for the formation of severe weather, a watch is issued. Although the skies appear that severe weather not possible, conditions can change within a short period. A watch box is placed over the region of concern to alert citizens of the potential danger of severe weather. It is a common that people disregard watches because it is not happening at that particular time. National Weather Service maintains that although a watch indicates that conditions are favorable for the development of severe weather, people should take this as seriously as if a warning has been issued.

Warnings are issued when severe weather phenomena have been sited and reported (i.e. currently happening). In this situation, warnings are normally issued when hailstones ¾ inch in diameter or greater are falling and/or wind speeds are 58mph or greater. These indicators are typical for severe thunderstorm warnings. Tornado warnings are issued when doppler radar velocity returns indicate a Tornado Vortex Signature (TVS).

When watches and warnings are mapped according to the county borders, this does not mean that severe weather is limited to those particular borders. Nature is not held by any human determined boundaries. Those counties in and around the counties under the watch or warning must also be aware that severe weather is extremely possible.

CHAPTER XIII: AIRMASS ADVECTION

The development of mid-latitude cyclones is dependent upon the strength of air mass advection. Airmass advection is determined by two qualities of advection—cold air advection (CAA) and warm air advection (WAA). This chapter discusses how to evaluate airmass advection using charts, which can be further analyzed in the development of mid-latitude cyclones.

Airmass Advection

Once a surface low develops in the late stationary stage of cyclogenesis, airmass advection begins and forms the wave stage. Advection is the horizontal transport of particular airmass by wind and changes the properties ahead of it. The rate of change depends on the speed of the wind that is doing the transporting. Consider to different airmasses—cool air ahead of a warm front and warm air behind the warm front. Southerly winds transport the warm moist air northward and change the cool air to warm air. If the wind is quite gusty, the change will occur rapidly.

There are two types of advection—cold air and warm air advection. Cold air advection occurs on the western side of a surface low and warm air advection on the eastern side. From our previous discussion on frontogenesis, cold air will move quicker than warm air due to its density, which results in an increase in advection than warm air.

Determining the Rate of Advection

There are two methods in determining the rate of advection. The first method, which is the easiest, is to use the 850mb chart that displays isotherms, geopotential heights, and wind vectors. The second method uses the 500-1000mb thickness chart.

When using the 850mb chart, isotherms and wind vectors will be of importance. Airmass advection increases when the wind vector becomes more perpendicular to the isotherms and the isotherms tighten. In figure 13.1 (b), the airmass advection is weak due to the low angle of the wind vector to isotherm. In addition, the isotherms are weak due to being drawn are apart. On the other hand, 'a' demonstrates how strong advection looks—the wind vectors are more perpendicular (or closer to right angles) to the isotherms. In addition, the isotherms are tighter indicating a stronger temperature gradient.

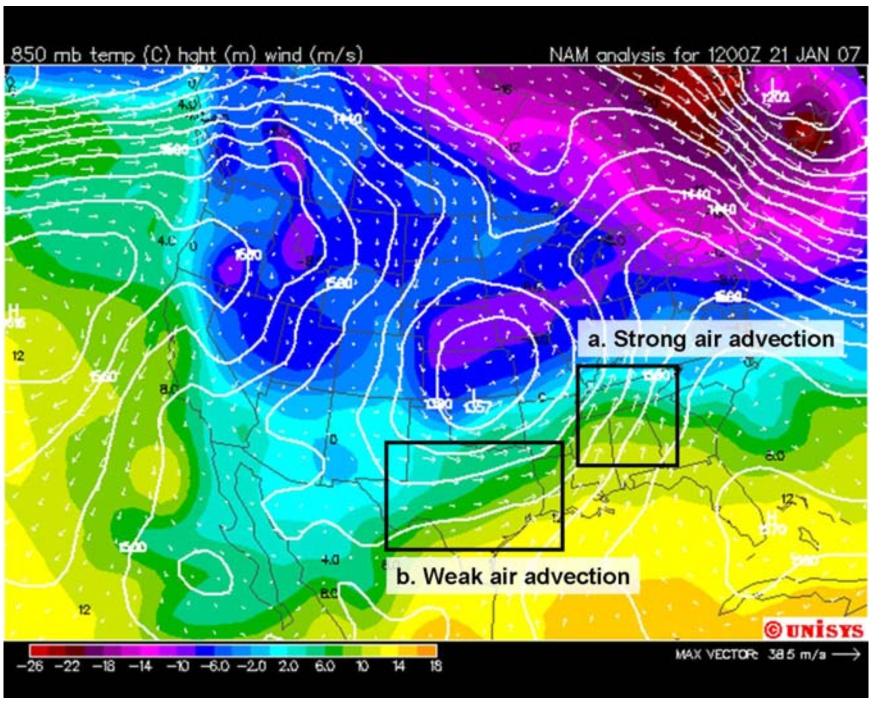


Figure 13.1. 850mb Chart. Areas of strong air advection (a) and weak air advection (b).

In figure 13.2, there is significant CAA than WAA. Note that the isotherms are tighter with wind vectors more perpendicular indicating a strong CAA. WAA is occurring but not as strong as displayed by the weaker temperature gradient and low angled wind vectors.

The second method uses a composite of the 500mb, 1000mb, and surface pressure charts to create the 500-1000mb thickness chart. Identifying airmass advection is a bit trickier as wind vectors and isotherms are not present in thickness chart. The composite chart merges the geopotential heights of the 500mb and 1000mb charts and the pressure at the surface. When determining airmass advection, boxes formed from the intersecting heights and isobars are identified. The more numerous and smaller the boxes indicates strong advection. Figure 13.3 is a thickness chart. Note that there are boxes to the west of the surface low pressure and the upper level trough. These boxes (a) are numerous and small indicating strong cold air advection. The same can be seen for warm air advection on the eastern side of the trough axis. If there are fewer and larger boxes, this indicates weak advection as seen in figure 13.3 (b).

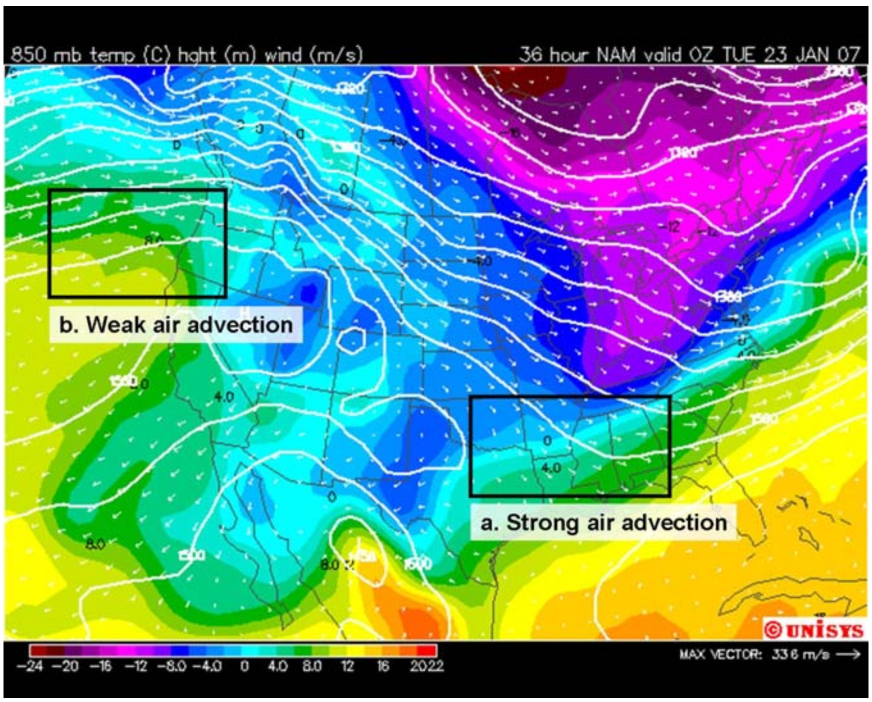


Figure 13.2. Difference between strong CAA and weak WAA.

Other Identifiers

Advection strength can also be used to identify the speed of cyclogenesis. If strong advection is evident, the mid-latitude cyclone will develop quickly. However, weak advection influences the retarded development of the mid-latitude cyclone.

Another piece of information that airmass advection can provide is the strength of a particular airmass and/or front. If strong advection is identified, the airmass behind the front is strong or the front itself is strong and significant. Weaker advection indicates slow moving air.

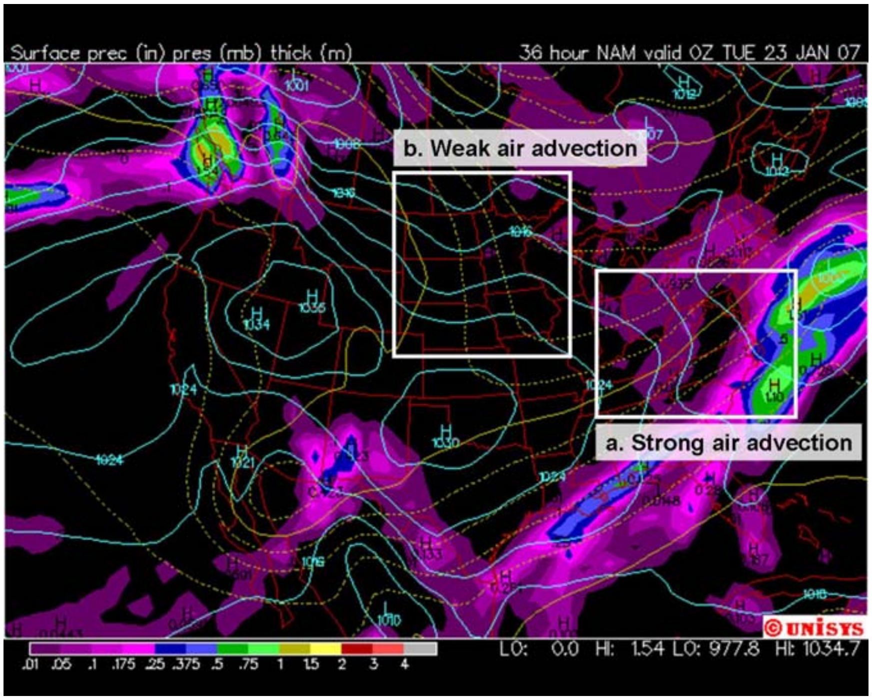


Figure 13.3. Thickness chart showing airmass advection as boxes. Surface pressure (isobars) in blue. Thickness heights in yellow (dashed and solid). Precipitation is multicolor.