Introduction to Meteorology

Spring 2011 Physics 187 Dr. Adam T. Whitten

Course Information

Lecture: 8:00-9:10 Days 135 in Pengl 167
Websites: (1) http://www.ametsoc.org/amsedu/login.cfm OR
http://amsedu.ametsoc.org/amsedu/login.cfm
(2) https://moodle.csbsju.edu/login/index.php
(3) http://www.physics.csbsju.edu/~awhitten/phys187.html

Introduction

This course introduces you to the excitement of weather as it happens while you learn the important physical concepts behind the science that makes the news and impacts everyone, every day. You access and work with current weather data and graphic products delivered via the Internet. You observe the workings of the dynamic atmosphere by following weather as it happens, in near real-time and/or by using recent real-world data and case studies, and observe the principles of meteorology in action. You employ the analysis and decision-making skills used by meteorologists to diagnose weather patterns, understand air motions, and predict future atmospheric conditions.

You must demonstrate the capability to download and print products from the AMS Weather Studies Course Website. The course has a fast pace that is timed to the Current Weather Studies delivery schedule, so you will need to keep current with the work. This course cannot be successfully completed with last minute catch-up. To take full educational advantage of the course, you must access online course materials frequently and according to a regular schedule.

Course Objectives

Students will be able to:

- describe the state of the atmosphere in terms of composition, pressure, temperature, dewpoint, and radiative properties.
- understand the origins of wind, precipitation, and cyclonic activity.
- construct weather maps given pressure, temperature, and wind data.
- interpret infrared satellite and doppler radar images.
- analyze climactic data.
- formulate a hypothesis, collect and plot data to test a hypothesis, and analyze experimental results to accept or reject a hypothesis.
- present the results of scientific inquiry in a clear and concise manner.

Grading

Your grade will be based on a weighted average of in-class assignments, quizzes, on-line lab exercises, on-site lab experiments, a midterm exam, and a final exam as follows:

<table>
<thead>
<tr>
<th>Item and Weight</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>In-class assignments</td>
<td>10%</td>
</tr>
<tr>
<td>Quizzes</td>
<td>10%</td>
</tr>
<tr>
<td>On-line laboratory exercises</td>
<td>15%</td>
</tr>
<tr>
<td>On-site laboratory experiments</td>
<td>15%</td>
</tr>
<tr>
<td>Midterm Exam</td>
<td>25%</td>
</tr>
<tr>
<td>Final Exam</td>
<td>25%</td>
</tr>
</tbody>
</table>

Grading Scale

<table>
<thead>
<tr>
<th>Grade</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>93-100</td>
</tr>
<tr>
<td>AB</td>
<td>88-92</td>
</tr>
<tr>
<td>B</td>
<td>83-87</td>
</tr>
<tr>
<td>BC</td>
<td>78-82</td>
</tr>
<tr>
<td>C</td>
<td>73-77</td>
</tr>
<tr>
<td>CD</td>
<td>68-72</td>
</tr>
<tr>
<td>D</td>
<td>60-67</td>
</tr>
<tr>
<td>F</td>
<td>0-59</td>
</tr>
<tr>
<td>Cycle.Day</td>
<td>Date</td>
</tr>
<tr>
<td>-----------</td>
<td>--------</td>
</tr>
<tr>
<td>1.1 – Mon</td>
<td>1/17</td>
</tr>
<tr>
<td>1.3 – Wed</td>
<td>1/19</td>
</tr>
<tr>
<td>1.5 – Fri</td>
<td>1/21</td>
</tr>
<tr>
<td>2.1 – Tue</td>
<td>1/25</td>
</tr>
<tr>
<td>2.3 – Thu</td>
<td>1/27</td>
</tr>
<tr>
<td>2.5 – Mon</td>
<td>1/31</td>
</tr>
<tr>
<td>3.1 – Wed</td>
<td>2/2</td>
</tr>
<tr>
<td>3.3 – Fri</td>
<td>2/4</td>
</tr>
<tr>
<td>3.5 – Tue</td>
<td>2/8</td>
</tr>
<tr>
<td>4.1 – Thu</td>
<td>2/10</td>
</tr>
<tr>
<td>4.3 – Mon</td>
<td>2/14</td>
</tr>
<tr>
<td>4.5 – Wed</td>
<td>2/16</td>
</tr>
<tr>
<td>5.1 – Fri</td>
<td>2/18</td>
</tr>
<tr>
<td>5.3 – Tue</td>
<td>2/22</td>
</tr>
<tr>
<td>5.5 – Thu</td>
<td>2/24</td>
</tr>
<tr>
<td>6.1 – Mon</td>
<td>2/28</td>
</tr>
<tr>
<td>6.3 – Wed</td>
<td>3/2</td>
</tr>
<tr>
<td>6.5 – Fri</td>
<td>3/4</td>
</tr>
</tbody>
</table>

**7.1 – Tue 3/8 Midterm Exam**

**Monday 3/14 – Friday 3/18 Spring Break**

<table>
<thead>
<tr>
<th>Cycle.Day</th>
<th>Date</th>
<th>Reading</th>
<th>Topics</th>
<th>Online Lab</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.3 – Thu</td>
<td>3/10</td>
<td>Ch. 7: p. 183-198</td>
<td>Clouds, Fog</td>
<td></td>
</tr>
<tr>
<td>7.5 – Mon</td>
<td>3/21</td>
<td>Ch. 7: p. 198-214</td>
<td>Precipitation</td>
<td>7A, 7B</td>
</tr>
<tr>
<td>8.1 – Wed</td>
<td>3/23</td>
<td>Ch. 8: p. 221-233</td>
<td>Wind Forces &amp; Models</td>
<td>8A</td>
</tr>
<tr>
<td>8.3 – Fri</td>
<td>3/25</td>
<td>Ch. 8: p. 233-240</td>
<td>Wind Continuity, Monitoring</td>
<td>8B</td>
</tr>
<tr>
<td>8.5 – Tue</td>
<td>3/29</td>
<td>Ch. 9: p. 249-261</td>
<td>Planetary &amp; Monsoon Circulations</td>
<td></td>
</tr>
<tr>
<td>9.1 – Thu</td>
<td>3/31</td>
<td>Ch. 9: p. 261-274</td>
<td>Westerlies, Jet Stream, ENSO</td>
<td>9A</td>
</tr>
<tr>
<td>9.3 – Mon</td>
<td>4/4</td>
<td>Ch. 9: p. 275-283</td>
<td>La Niña, ENSO</td>
<td>9B</td>
</tr>
<tr>
<td>9.5 – Wed</td>
<td>4/6</td>
<td>Ch. 10: p. 294-302</td>
<td>Air Masses, Frontal Weather</td>
<td></td>
</tr>
<tr>
<td>10.1 – Fri</td>
<td>4/8</td>
<td>Ch. 10: p. 302-313</td>
<td>Extratropical Cyclones</td>
<td>10A</td>
</tr>
<tr>
<td>10.3 – Tue</td>
<td>4/12</td>
<td>Ch. 10: p. 313-321</td>
<td>Anticyclones, Local/Regional Circulations</td>
<td>10B</td>
</tr>
<tr>
<td>10.5 – Thu</td>
<td>4/14</td>
<td>Ch. 11: p. 329-339</td>
<td>Thunderstorm Life Cycle</td>
<td></td>
</tr>
<tr>
<td>11.1 – Mon</td>
<td>4/18</td>
<td>Ch. 11: p. 339-349</td>
<td>Thunderstorm Hazards</td>
<td>11A</td>
</tr>
<tr>
<td>11.3 – Wed</td>
<td>4/20</td>
<td>Ch. 11: p. 349-360</td>
<td>Tornadoes</td>
<td>11B</td>
</tr>
</tbody>
</table>

**Thursday 4/21 – Monday 4/25 Easter Recess**

<table>
<thead>
<tr>
<th>Cycle.Day</th>
<th>Date</th>
<th>Reading</th>
<th>Topics</th>
<th>Online Lab</th>
</tr>
</thead>
<tbody>
<tr>
<td>12.1 – Fri</td>
<td>4/29</td>
<td>Ch. 12: p. 377-385</td>
<td>Hurricane Hazards</td>
<td>12A</td>
</tr>
<tr>
<td>12.3 – Tue</td>
<td>5/3</td>
<td>Ch. 12: p. 385-393</td>
<td>Trends, Forecasting</td>
<td>12B</td>
</tr>
</tbody>
</table>

**Wednesday 5/4 Scholarship & Creativity Day**

<table>
<thead>
<tr>
<th>Cycle.Day</th>
<th>Date</th>
<th>Reading</th>
<th>Topics</th>
<th>Online Lab</th>
</tr>
</thead>
<tbody>
<tr>
<td>12.5 – Fri</td>
<td>5/6</td>
<td>Review</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Thursday 5/12 Final Exam – 6:00-8:00 p.m. (Pengl 167)**

Specific learning goals for each chapter are listed on the following pages. It is recommended that you use them as a study guide when reading the textbook.
Chapter 15 – Climate and Climate Change

Synopsis
This chapter focuses on Earth’s climate system. We cover some basic properties of climate, controls of climate, global patterns of climate, the reconstructed and instrument-based climate record, lessons of the climate record, and possible causes of climate change. Climate is defined as average weather plus extremes in weather, and climate is viewed as specific to a particular location over some time interval. Earth is a mosaic of many climate types. The reliable instrument-based record dates back only 100 years or so and may not include the full range of climatic variability. For information on prior climate regimes, scientists rely on a variety of proxy climate indicators. In this way, scientists have pieced together a generalized picture of the climate of the past two million years. Perhaps the most important conclusions to be drawn from this record are that climate varies over a wide range of time scales and our present climate is unusually mild. Possible causes of temporal variations in climate are phenomena that shift the radiative equilibrium of the Earth-atmosphere system. Considered are forces that alter the solar constant (sunspots, astronomical changes), the planetary albedo (volcanism), Earth’s surface characteristics, or the gas and aerosol composition of the atmosphere. Human activity appears to be playing a significant role in global climate change by contributing to the build up of atmospheric carbon dioxide, a greenhouse gas. Some observed and reconstructed climatic variations closely match oscillations of certain climate forcing phenomena. But establishment of cause-effect relationships is made difficult by the complexity of processes operating within Earth’s climate system. Nonetheless, a general consensus in the scientific community holds that an overall global-scale warming trend has prevailed since the end of the Little Ice Age. The most reasonable scientific explanation is the steady build-up of carbon dioxide and other infrared-absorbing gases in the atmosphere (primarily because of combustion of fossil fuels) and the consequent enhancement of the natural greenhouse effect. Continuation of the upward trend in the concentration of greenhouse gases inevitably will lead to global warming throughout this century and perhaps beyond.

Learning Objectives
After reading this chapter, you should be able to:
☐ explain why climate encompasses both average and extreme weather.
☐ define the climatic norm.
☐ identify the many interacting factors that shape global climates.
☐ describe the general global patterns of temperature and precipitation.
☐ explain why precipitation is distinctly seasonal in some regions of the world.
☐ list some of the methods of climate reconstruction.
☐ explain how plate tectonics and mountain building may have contributed to climate shifts in the geological past.
☐ sketch the principal features of the global climate record over the past 2 million years.
☐ explain the significance of polar amplification for future climate change.
☐ describe the climatic significance of the Medieval Warm Period and the Little Ice Age.
☐ list the principal lessons of the climate record.
☐ describe the results of efforts to isolate cycles in the climate record.
☐ describe the short-term variations in solar energy output.
☐ explain how Milankovitch cycles might explain large-scale fluctuations in the planet’s glacial ice cover.
☐ describe the type of volcanic eruption that is most likely to impact global climate.
☐ explain how changes in properties of the Earth’s surface can influence climate.
☐ describe the historical trends in concentrations of greenhouse gases.
☐ summarize the role of human activity in the upward trend of greenhouse gases.
☐ explain how an enhanced greenhouse effect and global warming impact society.
☐ describe how aerosols might impact the global radiation budget.
☐ discuss the validity of various scenarios of the climatic future.
Chapter 1 – Monitoring the Weather

Synopsis
The purpose of this opening chapter is to provide the student with an overview of basic characteristics of weather. We open by distinguishing between weather and climate and then cover some of the sources of weather information including television, the Internet, and NOAA Weather Radio. Using the surface weather map as a reference, we describe the most common weather systems, including lows, highs, air masses, and fronts. We then list and define the various parameters that are commonly used to describe the state of the atmosphere (e.g., maximum and minimum temperature, relative humidity). The chapter closes with a brief description of satellite images, radar displays, and some advice on observing clouds and the changing conditions of the sky.

Learning Objectives
After reading this chapter, you should be able to:

☐ distinguish between weather and climate.
☐ list some sources of daily weather information.
☐ identify the principal weather systems that are plotted on surface weather maps.
☐ describe some of the properties of weather systems including highs, lows, and fronts.
☐ define the common parameters used to describe the state of the atmosphere.
☐ distinguish between geostationary and polar-orbiting satellites.
☐ distinguish between visible and infrared satellite images.
☐ explain the advantages of satellite observation of the atmosphere.
☐ present the basic principle of weather radar.
☐ provide some examples of how observations of the sky provide indications of future weather.
Chapter 2 – Atmosphere: Origin, Composition, and Structure

Synopsis
We begin our study of weather and climate by examining the origins and properties of Earth’s atmosphere, the arena in which weather and climate take place. Our present atmosphere is the product of a lengthy evolutionary process and consists of a mixture of gases (mostly nitrogen and oxygen) in which is suspended a variety of tiny solid and liquid particles (collectively called aerosols). In investigating the atmosphere, scientists apply the scientific method and make extensive use of models. Much of what is known about the atmosphere’s composition and structure is derived from direct measurements by instruments borne by kites, balloons, aircraft, rockets, and Earth-orbiting satellites. One finding of these efforts is that the atmosphere can be subdivided into layers based on the vertical profile of average air temperature. The lowest of these layers, the troposphere, is the site of virtually all weather. A portion of the upper atmosphere, known as the ionosphere, contains a relatively high concentration of electrically charged particles and is the site of the aurora (northern and southern lights).

Learning Objectives
After reading this chapter, you should be able to:

- describe the principal events and processes in the evolution of Earth’s atmosphere.
- explain the important role of the ocean in the evolution of the atmosphere.
- distinguish between the homosphere and the heterosphere.
- explain the significance of minor components of the atmosphere.
- illustrate the scientific method.
- demonstrate the value of models in scientific investigations.
- distinguish among the various types of scientific models
- explain how meteorologists monitor surface and upper-atmospheric conditions.
- sketch the average vertical temperature profile of the atmosphere.
- distinguish between the troposphere and the stratosphere.
- describe the origin and significance of the ionosphere.
- explain how solar activity influences the ionosphere.
Chapter 3 – Solar and Terrestrial Radiation

Synopsis
The principal focus of this chapter is the flow of electromagnetic radiation into and out of the Earth-atmosphere system. Electromagnetic radiation is described in terms of its basic properties and spectrum of types. Earth intercepts solar radiation as the planet rotates on its axis and revolves about the sun. Changes in solar altitude and length of daylight that accompany the march of the seasons produce a regular annual cycle in the amount of solar radiation that reaches any locality on the surface of the planet. As solar radiation travels through the atmosphere, some is scattered or reflected back to space and some is absorbed (that is, converted to heat). Absorption of ultraviolet (UV) radiation during the natural formation and destruction of ozone in the stratosphere shields us from potentially lethal intensities of UV. Nonetheless, some UV reaches Earth’s surface and over-exposure may cause sunburn or even skin cancer. Solar radiation that strikes Earth’s surface is either reflected or absorbed, depending on the surface albedo. In response to solar radiational heating, the Earth-atmosphere system emits infrared radiation. The greenhouse effect, however, slows the loss of infrared radiation to space and causes Earth’s surface to be considerably warmer than the upper atmosphere. Water vapor is the principal greenhouse gas. Unless compensated for by other climate forcing mechanisms, enhancement of Earth’s greenhouse effect by upward trends in the concentrations of other infrared-absorbing gases, especially carbon dioxide, is likely to cause further global warming.

Learning Objectives
After reading this chapter, you should be able to:

- identify the principal characteristics of radiation and the electromagnetic spectrum.
- distinguish among the various forms of electromagnetic radiation.
- explain how solar altitude influences the intensity of solar radiation received at Earth’s surface.
- describe the cause of the astronomical seasons.
- define the solar constant.
- describe the interactions that take place as solar radiation travels through the atmosphere.
- explain the significance of the stratospheric ozone layer for life on Earth.
- identify the principal threat to the stratospheric ozone shield.
- describe the interactions that take place when solar radiation strikes Earth’s surface.
- explain the role of the ocean in the global solar radiation budget.
- contrast solar radiation with terrestrial infrared radiation.
- identify the gases responsible for the greenhouse effect.
- explain how the continued buildup of greenhouse gases is likely to cause further global warming.
- list some of the possible societal implications of global warming.
Chapter 4 – Heat, Temperature, and Atmospheric Circulation

Synopsis
This chapter distinguishes between temperature and heat, how the two quantities are related and measured, basic heat transfer processes operating within the Earth-atmosphere system, and controls of air temperature. Temperature is a measure of the average kinetic-molecular energy whereas heat is the name given to the energy that is transferred between objects at different temperatures. Heat is transferred within and between substances through radiation, conduction, convection, and phase changes of water. The temperature of a substance changes in response to a gain or loss of heat, with the magnitude of temperature change depending on the specific heat of the substance. In response to the same heat gain, substances with relatively low specific heats (such as land surfaces) warm up more than substances with relatively high specific heats (such as the ocean surface). The greater thermal inertia of the ocean means that downwind localities have maritime climates with less temperature contrast between summer and winter compared to continental localities located well inland. Within the Earth-atmosphere system, absorption of solar radiation causes warming whereas emission of infrared radiation causes cooling. Imbalances in rates of radiational heating and radiational cooling occur between Earth’s surface and the troposphere and between the tropics and higher latitudes. In response, the atmosphere circulates so that heat is redistributed from locations of net radiational heating to locations of net radiational cooling. Excess heat at the Earth’s surface is transferred to the troposphere via latent heating and sensible heating. Excess heat in the tropics is transferred to higher latitudes via air mass exchange, latent heating in storm systems, and ocean currents. Air temperature at any location is governed by local radiational conditions plus air mass advection.

Learning Objectives
After reading this chapter, you should be able to:
- distinguish between temperature and heat.
- compare and contrast the various temperature scales.
- describe how temperature is measured.
- explain how heat is transported via conduction and convection.
- explain how heat is transported via phase changes of water.
- demonstrate how heat and temperature are related through specific heat.
- contrast a continental climate with a maritime climate.
- describe the imbalances in radiational heating and cooling within the Earth-atmosphere system.
- distinguish between sensible heating and latent heating.
- explain why latent heating is more important than sensible heating on a global scale.
- describe the significance of the Bowen ratio.
- identify the various processes responsible for poleward heat transport.
- distinguish between radiational controls and air mass controls of air temperature.
- explain the seasonal and diurnal lag between radiation and temperature.
- describe how properties of Earth’s surface influence air temperature.
Chapter 5 – Air Pressure

Synopsis
Now that we have examined the various controls of air temperature, we turn to another important variable of the atmosphere, air pressure. It is desirable to examine air pressure before considering vapor pressure and atmospheric stability in the next chapter. Air pressure can be thought of as the weight per unit area of a column of air that extends to the top of the atmosphere. The mercury and aneroid barometers are standard instruments for monitoring air pressure and the air pressure tendency. Air pressure (and air density) declines rapidly with increasing altitude and, after reduction to sea level, exhibits important changes from one place to another and with time. Spatial and temporal variations in air pressure arise from changes in air temperature, water vapor concentration, and divergence and convergence of horizontal winds. At Earth’s surface, air pressure tends to increase with declining air temperature and decreasing water vapor concentration. Air pressure, temperature, and density are related through the gas law. Ascending air expands and cools whereas descending air is compressed and warms. Expansional cooling and compressional warming of an air parcel moving vertically in the atmosphere are examples of adiabatic processes as long as water undergoes no phase change.

Learning Objectives
After reading this chapter, you should be able to:

☐ define air pressure.
☐ identify the advantages of an aneroid barometer over a mercury barometer.
☐ explain the significance of air pressure tendency for local weather forecasting.
☐ describe how air pressure and air density change with altitude.
☐ explain how and why meteorologists adjust air pressure readings to sea level.
☐ describe how air temperature and water vapor concentration influence the density of air and air pressure at the Earth’s surface.
☐ show how divergence and convergence of horizontal winds can cause changes in air pressure.
☐ discuss how surface air pressure varies with different types of air masses.
☐ show how the gas law applies to the atmosphere.
☐ explain why ascending air cools whereas descending air warms.
☐ define an adiabatic process.
☐ distinguish between the dry adiabatic lapse rate and the moist adiabatic lapse rate.
Chapter 6 – Humidity, Saturation, and Stability

Synopsis
This is the first of two chapters on moisture in the atmosphere. In this chapter, we present some fundamental concepts: the global water cycle, the global water budget, various ways of expressing the water vapor concentration of air, the nature of saturation, methods for monitoring humidity, achieving saturation through expansional cooling, stability of air, and lifting processes. On Earth, water occurs in all three phases and is distributed among oceanic, terrestrial, and atmospheric reservoirs. Water is transferred between the atmosphere and the other reservoirs through evaporation, transpiration, condensation, sublimation, deposition, and precipitation. The water vapor concentration of air is most commonly described in terms of vapor pressure, mixing ratio, and relative humidity. Dewpoint and precipitable water are also measures of the water vapor component of air. Water vapor is monitored directly by instruments and remotely (above 3000 m) by satellite sensors. Water vapor satellite imagery is especially useful in tracking plumes of moisture over broad geographical areas. Uplift and expansional cooling bring air to saturation and clouds develop. Stability of the air either enhances or suppresses uplift that is triggered by convection, fronts, topography, and converging surface winds.

Learning Objectives
After reading this chapter, you should be able to:

- identify the principal reservoirs in the global water cycle.
- distinguish among the various phase changes of water.
- describe the role of latent heat in phase changes of water.
- list some of the implications of the global water budget.
- describe how the water vapor component of air is quantified.
- compute the relative humidity from either the mixing ratio or the vapor pressure.
- explain why and how relative humidity is temperature dependent.
- explain why the average precipitable water value generally decreases with increasing latitude.
- describe the operation of a sling psychrometer to determine relative humidity.
- explain how atmospheric stability is determined.
- plot a sounding on a Stve thermodynamic diagram.
- describe how atmospheric stability affects vertical motion of air and cloud formation.
- list the various lifting processes that operate within the atmosphere.
- describe how a mountain range can influence the pattern of clouds and precipitation.
Chapter 7 – Clouds, Precipitation, and Weather Radar

Synopsis
In this second of two chapters on moisture in the atmosphere, we consider cloud formation and classification, fog, precipitation processes, origins of the various forms of precipitation, acid deposition, and weather radar. Clouds are suspensions of water droplets or ice crystals formed when water vapor condenses or deposits on nuclei, tiny solid and liquid particles suspended in the atmosphere. Clouds are classified by general appearance, temperature (warm or cold), and by altitude of their base (high, middle, low, and vertical). Fog is a cloud in contact with Earth’s surface and forms through radiational cooling, advective cooling, vaporization of water, or ascent of humid air along a mountain slope. Most clouds do not produce precipitation because a special set of circumstances is required for cloud droplets or ice crystals to grow into raindrops or snowflakes. As a cloud droplet or ice crystal grows, its terminal velocity increases so that the particle of water or ice can survive a journey to Earth’s surface as precipitation. Principal growth mechanisms are the collision-coalescence process in warm clouds and the Bergeron-Findeisen process plus collision-coalescence in cold clouds. Unfrozen forms of precipitation are rain and drizzle; frozen forms of precipitation include snow, sleet (ice pellets), and hail; and freezing forms of precipitation are freezing rain or freezing drizzle. Precipitation dissolves carbon dioxide and thereby becomes slightly acidic but where air includes elevated levels of sulfur dioxide or nitrogen oxides, precipitation becomes excessively acidic. A weather radar continually emits pulses of microwave energy that are partially reflected (or scattered) by precipitation. Operating in the reflectivity mode, weather radar locates and tracks areas of precipitation. In the velocity (Doppler) mode, weather radar determines the movement of precipitation (or smaller particles) directly away from or toward the radar. In this way, weather radar is an important tool in monitoring the development and displacement of severe weather systems. Precipitation amounts are measured directly by rain and snow gauges and remotely by radar and satellite sensors.

Learning Objectives
After reading this chapter, you should be able to:
- explain the role of nuclei in cloud development.
- list the sources and types of cloud nuclei.
- explain the significance of hygroscopic nuclei.
- describe how clouds are classified.
- distinguish among the principal cloud types.
- identify the various fog-forming processes.
- list conditions required for extreme nocturnal radiational cooling.
- explain the significance of terminal velocity in the formation of precipitation.
- distinguish between warm clouds and cold clouds.
- describe the collision-coalescence process.
- describe the Bergeron-Findeisen process.
- distinguish among the various solid and liquid forms of precipitation.
- explain how weather radar detects precipitation.
- distinguish between the reflectivity and velocity modes for weather radar.
- describe how rain and snow are measured directly and remotely.
Chapter 8 – Wind and Weather

Synopsis
This chapter begins our discussion of atmospheric circulation and weather systems. We are concerned here with forces that initiate and shape the wind. The individual forces (pressure gradient, centripetal, Coriolis, friction, and gravity) are first described separately with special emphasis on the conditions under which each force operates. Individual forces are then combined in hydrostatic equilibrium, the geostrophic wind, the gradient wind, and surface winds. The air circulation within pressure cells (Highs and Lows) are linked to the general type of weather associated with each of these systems. In a High (or anticyclone), surface winds diverge and winds aloft converge so that air descends, the relative humidity decreases, and clouds dissipate. A High is a fair weather system. In a Low (or cyclone), surface winds converge and winds aloft diverge so that air ascends, the relative humidity increases, and clouds develop. A Low is a stormy weather system. We apply (and reinforce) concepts that were developed in the prior two chapters on moisture in the atmosphere.

Learning Objectives
After reading this chapter, you should be able to:

☐ distinguish among the directional components of the wind.
☐ identify the forces that initiate and govern the circulation of air.
☐ present the origins of horizontal air pressure gradients.
☐ describe how the pressure gradient force affects the motion of air.
☐ explain the source of the centripetal force.
☐ describe how the Coriolis Effect varies with latitude.
☐ explain why the Coriolis Effect is important only in large-scale circulation systems.
☐ show why gravity influences vertical motion and not horizontal motion.
☐ present Newton’s first and second laws of motion.
☐ describe the balance of forces in hydrostatic equilibrium.
☐ summarize the interaction of forces in geostrophic and gradient winds.
☐ explain how friction influences the magnitude and direction of surface winds.
☐ describe the circulation in cyclones and anticyclones.
☐ explain why stormy weather is associated with cyclones and fair weather with anticyclones.
☐ describe how winds are monitored.
Chapter 9 – Atmosphere’s Planetary Circulation

Synopsis
This and the next three chapters are concerned with the genesis and characteristics of a variety of weather systems. We examine these systems in order of decreasing spatial scale beginning with the largest scale, the global or planetary circulation. Semi-permanent pressure systems, wind belts, and the intertropical convergence zone (ITCZ) are principal features of the planetary-scale circulation. We show how these features are interrelated and how they change with the seasons. Special consideration is given to the westerlies of middle latitudes because the weather of middle latitudes is a major focus of Weather Studies. We describe wave patterns in the westerlies and properties of the jet stream with the objective of demonstrating how smaller scale weather systems are linked to the planetary-scale circulation. The final section of this chapter covers El Niño and La Niña, how these air-sea anomalies contrast with long-term average (neutral) conditions in the tropical Pacific, and the ramifications for weather conditions worldwide (teleconnections).

Learning Objectives
After reading this chapter, you should be able to:
- list the principal components of the atmosphere’s planetary-scale circulation.
- describe the linkage between the subtropical anticyclones and the trade winds.
- compare and contrast the planetary winds at the surface with those in the mid and high troposphere.
- describe the seasonal changes in the planetary-scale circulation.
- demonstrate how the prevailing planetary-scale circulation influences climate.
- describe how prevailing winds set up ocean surface currents.
- contrast weather patterns associated with zonal and meridional flow in the westerlies.
- explain the association between blocking circulation patterns and weather extremes.
- describe the linkage between the polar front and the middle latitude jet stream.
- explain the role of the jet stream and upper-air troughs in the development of extra-tropical cyclones.
- describe the connection between sea-surface temperature anomalies and changes in the planetary circulation.
- identify the changes that take place in the tropical Pacific ocean and atmosphere during El Niño and La Niña.
- describe the relationship between El Niño and the Southern Oscillation.
Chapter 10 – Weather Systems of Middle Latitudes

Synopsis
This chapter covers synoptic-scale weather systems plus selected regional and local circulation systems that affect the weather of middle latitudes. Air masses, fronts, cyclones, and anticyclones are plotted on surface weather maps. An air mass is a huge volume of air that is relatively uniform horizontally in temperature and humidity. Air masses modify as they travel away from source regions (where initial characteristics are acquired). Where contrasting air masses meet, fronts and frontal weather develop. Air that is forced to ascend along a front undergoes expansional cooling that often spurs formation of clouds and precipitation. The life cycle of an extra-tropical cyclone demonstrates how air masses, fronts, and pressure systems are interrelated. With upper-air support (horizontal divergence aloft), extra-tropical cyclones develop and are steered by the upper-level westerlies. From our description of the weather patterns associated with an extra-tropical cyclone, it is evident that the specific track of the cyclone determines the type of weather experienced at any locality in the storm’s path. Anticyclones follow cyclones. Anticyclones are fair-weather systems, may be warm or cold, and are accompanied by characteristic patterns of air mass advection. Land and sea (or lake) breezes, chinook winds, desert winds, and mountain and valley breezes are small-scale systems that are not significantly influenced by the Coriolis Effect. Planetary- and synoptic-scale winds set the boundary conditions for local and regional circulation systems.

Learning Objectives
After reading this chapter, you should be able to:

- identify the various air masses that regularly form over or invade North America.
- describe how and why air masses modify as they travel away from their source regions.
- identify and distinguish among the various types of fronts.
- distinguish between warm frontal weather and cold frontal weather.
- explain why fronts are associated with extra-tropical cyclones but not with anticyclones.
- sketch and describe the stages in the life cycle of an extra-tropical cyclone.
- describe the components of the conveyor-belt model of an extra-tropical cyclone.
- explain the linkage between a surface cyclone and the westerly flow aloft.
- identify the principal storm tracks across North America.
- distinguish between cold and warm lows and cold and warm highs.
- describe the air mass advection associated with an anticyclone.
- compare and contrast sea (or lake) breezes with land breezes.
- list the characteristics of a chinook wind.
- explain the diurnal variation of winds in deserts and mountainous areas.
Chapter 11 – Thunderstorms and Tornadoes

Synopsis
This chapter covers the genesis, properties, and hazards of thunderstorms and tornadoes. We describe the three stages in the life cycle of a thunderstorm cell (towering cumulus, mature, and dissipating) and distinguish among single-cell and multi-cellular thunderstorms. The latter include squall lines and mesoscale convective complexes (MCCs). We describe the special synoptic situation that favors development of severe thunderstorms. Thunderstorm hazards include lightning, downbursts, flash floods, and hail. Our discussion of thunderstorms sets the stage for consideration of tornadoes, small but violent weather systems. We describe tornado characteristics, geographical and temporal distribution, and associated hazards. The special combination of atmospheric conditions that favors tornado development occurs most frequently in spring in the central United States. Based on rotational wind speeds reconstructed from property damage, tornadoes are rated from 1 to 5 on the Enhanced Fujita-scale. Most North American tornadoes are spawned by supercell thunderstorms that develop along or ahead of well-defined cold fronts. Tornadoes also spin off gust fronts and are associated with land-falling hurricanes.

Learning Objectives
After reading this chapter, you should be able to:
- describe each stage in the life cycle of a thunderstorm cell.
- distinguish among single cell and multi-cellular thunderstorms.
- describe the role of atmospheric stability in thunderstorm development.
- explain how and why thunderstorm frequency varies across North America.
- explain why some thunderstorms become severe whereas others do not.
- list the characteristics of a severe thunderstorm.
- sketch the synoptic weather pattern that favors severe thunderstorms.
- describe the atmospheric conditions that precede a lightning discharge.
- explain why lightning is dangerous.
- distinguish between a microburst and a macroburst.
- explain why a microburst can be hazardous to aviation.
- describe the characteristics of a thunderstorm cell that is most likely to produce flooding rains.
- explain why urban areas are particularly vulnerable to flash flooding.
- describe the origin and characteristics of hail.
- distinguish between a tornado and a funnel cloud.
- identify the principal force operating within a tornado.
- explain why tornadoes are most frequent in tornado alley.
- explain why tornadoes are most frequent in spring.
- identify and describe the hazards of tornadoes.
- present the basis for the EF-scale of tornado intensity.
- describe the linkage between severe thunderstorm cells and tornadoes.
- identify some weather phenomena that resemble funnel clouds.
Chapter 12 – Tropical Weather Systems

Synopsis
In this chapter we examine tropical weather systems with primary emphasis on hurricanes and tropical storms. Hurricanes are systems that develop in warm, humid air over tropical seas and feature sustained surface winds of 119 km (74 mi) per hour or higher. We describe the characteristics of hurricanes, their geographical and seasonal distribution, hazards associated with hurricanes, and the life cycle of tropical cyclones. Hurricanes originate over certain portions of tropical seas where sea-surface temperatures are high, vertical wind shear is weak, and the Coriolis Effect is sufficient to maintain a cyclonic circulation. Hurricanes develop principally in late summer and autumn. A hurricane originates from a tropical disturbance that strengthens into a tropical depression, then a tropical storm, and finally, a hurricane. Trade winds steer hurricanes and their precursors westward until eventually they are caught in the westerlies of middle latitudes. Then the system moves north and northeastward. Hazards of hurricanes are inland flooding from torrential rains, strong winds, and storm surge in low-lying coastal areas. Based on intensity, hurricanes are rated from 1 to 5 on the Saffir-Simpson Scale. In the final sections of this chapter, we describe recent trends in hurricane frequency, the hurricane threat to the southeast United States, long range forecasting of Atlantic hurricanes, and efforts to modify hurricanes.

Learning Objectives
After reading this chapter, you should be able to:

- describe the basic structure and characteristics of a hurricane.
- compare and contrast a hurricane with a typical extra-tropical cyclone.
- identify the oceanic and atmospheric conditions required for hurricane formation.
- locate the major hurricane breeding grounds.
- explain why hurricanes rarely strike the west coast of North America.
- explain why hurricanes are most common in late summer and autumn.
- identify and describe the hazards of hurricanes.
- describe the basis of the Saffir-Simpson Hurricane Intensity Scale.
- present the life cycle of a tropical cyclone.
- explain why the southeastern United States is particularly vulnerable to a destructive hurricane.
- describe the basis for long range forecasting of Atlantic hurricanes.
- discuss unsuccessful efforts to modify hurricanes.