## Table of Contents

Lab #1: Geography and Time Zones Relevant to United States Weather and Climate .................................................5  
  Part 1: United States Geography and Selected North American Geographic Features ........................................6  
  Part 2: Time Zones ...................................................................................................................................................10  

Lab #2: The Composition of the Atmosphere ..............................................................................................................13  
  Part 1: Air Pressure and Density in the Troposphere ..............................................................................................14  
  Activity #1: Use Excel to Determine Air Density Changes with Altitude .............................................................14  
  Part 2: Temperature Lapse Rates and the Layers of the Atmosphere .................................................................17  
  Activity #2: Graph the Earth’s Atmospheric Temperature Layers .......................................................................17  
  Activity #3: Graph of Venus Atmospheric Temperature .....................................................................................18  
  Part 3: Lab Report ...................................................................................................................................................18

Lab #3 (Online Classes Only): Atmospheric Heating Processes and the Radiation Laws .............................................19  
  Part 1: Air Temperature Variability .........................................................................................................................19  
  Activity #1: Collecting Temperature Data from Soil and Surface Air ..................................................................19  
  Part 2: The Radiation Laws .......................................................................................................................................21  
  Activity #2: Applying the Stefan-Boltzmann Law to find the amount of energy emitted by the surface. ...........23  
  Activity #3: Applying the Wien’s Law to find the wavelength of energy emitted by different surfaces and the sun ........................................................................................................................................................................26

Lab #4 (In-Person): Atmospheric Heating Processes and the Radiation Laws .............................................................27  
  Part 1: Air Temperature Variability .........................................................................................................................27  
  Activity #1: Collecting Temperature Data from Soil and Surface Air ..................................................................27  
  Part 2: The Radiation Laws .......................................................................................................................................29  
  Activity #2: Applying the Stefan-Boltzmann Law to find the amount of energy emitted by the surface. ...........31  
  Activity #3: Applying the Wien’s Law to find the wavelength of energy emitted by different surfaces and the sun ........................................................................................................................................................................34

Lab #5: Seasons and Seasonality: How the Earth’s Tilt and Orbit Affect Solar Receipt ...............................................35  
  Part 1: Where is the sun? ........................................................................................................................................35  
  Activity #1: Measure the angle of sunlight hitting different latitudes at different times of the year. .................38  
  Activity #2: Direct and Angled Light Intensity over a Surface Area .......................................................................40  
  Activity #3: Using the Noon Sun Angle to Determine Solar Intensity ..................................................................42  
  Activity #4: Find the Solar Elevation Angle at Your Location ...............................................................................44  
  Part 2: Energy received at the surface ......................................................................................................................45  
  Activity #5: Determining Energy Receipt Where You Live for Different Times of the Year .................................47

Lab #6: Applications Using Temperature Data ............................................................................................................51
Part 1: Heating Degree Days and Cooling Degree Days .......................................................... 51
Activity #1: Heating Degree Days and Cooling Degree Days .................................................. 51
Activity #2: Growing Degree Days .......................................................................................... 54
Part 2: Radiosonde Air Temperature Data ............................................................................... 56
Activity #3: Collecting Air Temperature Data Online ............................................................. 56
Lab #7: Measuring Humidity ..................................................................................................... 61
Part 1: Background Information on Humidity ....................................................................... 61
Activity #1: Measuring Relative Humidity .............................................................................. 62
Activity #2: Measuring Humidity Using a Sling Psychrometer .............................................. 63
Part 2: Absolute Humidity and Mixing Ratios ...................................................................... 64
Activity #3: Calculating Absolute Humidity ........................................................................... 64
Activity #4: Calculating Relative Humidity using Mixing Ratios ........................................ 67
Activity #5: Mixing Two Unsaturated Air Parcels to form Fog ............................................. 69
Lab #8: Cloud Formation Processes and Cloud Identifications ............................................ 71
Part 1: Cloud Formation Processes ...................................................................................... 71
Part 2: Cloud Identifications .................................................................................................. 75
Lab #9: Atmospheric Stability ............................................................................................... 79
Part 1: Adiabatic Cooling ......................................................................................................... 79
Activity #1: Dry Adiabatic Lapse Rate .................................................................................... 80
Activity #2: Finding the Lifting Condensation Level Using Surface Temperature and Dew Point Measurements ........................................................................................................... 81
Activity #3: Using the Dry and Wet Adiabatic Lapse Rates to Compare Moisture Content of Air Parcels ................................................................. 82
Part 2: Orographic Uplift ....................................................................................................... 83
Activity #4: Adiabatic Temperatures of Air Rising and Falling Along a Mountain .............. 84
Part 3: Atmospheric Stability and Vertical Cloud Development ........................................... 85
Activity #5: Plot Environmental and Parcel Air Temeratures to Determine Stability and Vertical Cloud Development ................................................................. 85
Lab #10: Weather Map Interpretations ................................................................................... 89
Part 1: Weather Station Symbols .......................................................................................... 89
Activity #1: Decoding 3-digit Air Pressure Codes ............................................................... 91
Activity #2: Interpreting and Drawing Weather Station Models .......................................... 92
Part 2: Isolines on Weather Maps ........................................................................................ 94
Activity #3: Drawing Isolines on Weather Maps ................................................................. 95
Part 3: Identifying Air Masses and Weather Fronts on a Weather Map .................................. 97
Activity #4: Identify Air Masses and Weather Fronts on Weather Maps ............................. 97
Lab #11: Weather Fronts and Mid-Latitude Cyclones ............................................................ 99
Part 1: Air Masses and Fronts ................................................................................................................................. 99
  Activity #1: Air Masses ........................................................................................................................................ 99
  Activity #2: Weather Fronts .............................................................................................................................. 100
  Activity #3: Map the Moving Fronts ................................................................................................................. 103
Part 2: Mid-Latitude Cyclones ............................................................................................................................... 104
  Activity #1: Draw Converging and Diverging Winds around Low and High Pressure Systems ......................... 104
  Activity #2: How Air Aloft impacts developing Lows and Highs at the Surface ................................................ 105
  Activity #3: The Polar Front Theory .................................................................................................................. 106
  Activity #4: Interpreting Upper Air Charts ........................................................................................................ 109
Lab #12: The Impact of Tropical Cyclones on Human Society ................................................................................... 127
  Part 1: Key Ingredients of Tropical Cyclogenesis ................................................................................................... 127
    Activity #1: Answer the following questions based on the lecture material for Tropical Cyclones................. 127
  Part 2: Impacts of Hurricanes on Human Life and Civilization .............................................................................. 130
    Activity #1: Research a hurricane to find its impact on human life. ................................................................. 130
    Activity #2: Proofread a summary provided by another student. .................................................................... 131
    Activity #3: Rewrite your summary .................................................................................................................. 131
Lab #13: El Niño and the Southern Oscillation ......................................................................................................... 133
  Part 1: El Niño and the Southern Oscillation ......................................................................................................... 133
    Activity #1: El Niño and the Southern Oscillation ............................................................................................. 138
Lab #14: Paleoclimatology of the Western Pacific Warm Pool .................................................................................. 143
  Part 1: δ¹⁸O and Strontium/Calcium (Sr/Ca) ratios in Pteropod Shells ................................................................. 144
    Activity #1: The Western Pacific Warm Pool and ENSO ................................................................................. 146
  Part 2: Paleoclimate Records from Kau Bay, Indonesia ........................................................................................ 147
    Activity #1: Graph and Interpret δ¹⁸O paleoclimate data from Kau Bay, Indonesia ........................................ 147
    Activity #2: Strontium/Calcium Ratios in Pteropod Shells ................................................................................ 149
Lab #1: Geography and Time Zones Relevant to United States Weather and Climate

OBJECTIVES:
- Students will identify geographic features in North America and understand time zone conversions using a 24-hour clock, or “military” time to learn background tools required to read these features on weather maps.

INSTRUCTIONS:
- Print out these pages or use a graphics tablet to write in the areas provided.
- Email a copy of your completed lab to the instructor for feedback.
- Save the completed lab as a single PDF and upload to Brightspace.

MATERIALS:
- Pencil or Pen
- Colored pencils or markers
Part 1: United States Geography and Selected North American Geographic Features

Use Google Earth to find and label the following locations on the blank map on the next page (label using **abbreviations** only). *Hawaii is not located on the blank map.*

<table>
<thead>
<tr>
<th>US States</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Alabama AL</td>
<td>Louisiana LA</td>
<td>Ohio OH</td>
</tr>
<tr>
<td>Alaska AK</td>
<td>Maine ME</td>
<td>Oklahoma OK</td>
</tr>
<tr>
<td>Arizona AZ</td>
<td>Maryland MD</td>
<td>Oregon OR</td>
</tr>
<tr>
<td>Arkansas AR</td>
<td>Massachusetts MA</td>
<td>Pennsylvania PA</td>
</tr>
<tr>
<td>California CA</td>
<td>Michigan MI</td>
<td>Rhode Island RI</td>
</tr>
<tr>
<td>Colorado CO</td>
<td>Minnesota MN</td>
<td>South Carolina SC</td>
</tr>
<tr>
<td>Connecticut CT</td>
<td>Mississippi MS</td>
<td>South Dakota SD</td>
</tr>
<tr>
<td>Delaware DE</td>
<td>Missouri MO</td>
<td>Tennessee TN</td>
</tr>
<tr>
<td>Florida FL</td>
<td>Montana MT</td>
<td>Texas TX</td>
</tr>
<tr>
<td>Georgia, GA</td>
<td>Nebraska NE</td>
<td>Utah UT</td>
</tr>
<tr>
<td>Hawaii HI</td>
<td>Nevada NV</td>
<td>Vermont VT</td>
</tr>
<tr>
<td>Idaho ID</td>
<td>New Hampshire NH</td>
<td>Virginia VA</td>
</tr>
<tr>
<td>Illinois IL</td>
<td>New Jersey NJ</td>
<td>Washington WA</td>
</tr>
<tr>
<td>Indiana IN</td>
<td>New Mexico NM</td>
<td>West Virginia WV</td>
</tr>
<tr>
<td>Iowa IA</td>
<td>New York NY</td>
<td>Wisconsin WI</td>
</tr>
<tr>
<td>Kansas KS</td>
<td>North Carolina NC</td>
<td>Wyoming WY</td>
</tr>
<tr>
<td>Kentucky KY</td>
<td>North Dakota ND</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Canadian Provinces and Territories</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Alberta AB</td>
<td>Northwest Territories NT</td>
<td>Quebec QC</td>
</tr>
<tr>
<td>British Columbia BC</td>
<td>Nova Scotia NS</td>
<td>Saskatchewan SK</td>
</tr>
<tr>
<td>Manitoba MB</td>
<td>Nunavut NU</td>
<td>Yukon YT</td>
</tr>
<tr>
<td>New Brunswick NB</td>
<td>Ontario ON</td>
<td></td>
</tr>
<tr>
<td>Newfoundland and Labrador NL</td>
<td>Prince Edward Island PE</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Bodies of Water</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Pacific Ocean</td>
<td>Gulf of Mexico</td>
<td>Lake Michigan</td>
</tr>
<tr>
<td>Atlantic Ocean</td>
<td>Lake Huron</td>
<td>Lake Erie</td>
</tr>
<tr>
<td>Hudson Bay</td>
<td>Lake Ontario</td>
<td>Lake Superior</td>
</tr>
</tbody>
</table>
Use different colored pencils or markers to outline and label the following regions and mountain ranges on the map on the next page.

<table>
<thead>
<tr>
<th>US Regions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Northeast</td>
</tr>
<tr>
<td>New England</td>
</tr>
<tr>
<td>Mid-Atlantic</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>US Mountain Ranges</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rocky Mountains</td>
</tr>
<tr>
<td>Ozarks</td>
</tr>
<tr>
<td>Appalachians</td>
</tr>
</tbody>
</table>

Finally, use colored pencils to outline and label the U.S.-Canada and U.S.-Mexico borders on the map.
Part 2: Time Zones

Use the World Time Zones map included in this week’s lab folder online. Universal Coordinated Time (UTC) is the world’s primary standard time that is used to regulate time around the world. Time zones at other locations are set based on their distance to the UTC region. UTC time is also called “Zulu” or “Z” time.

1. What location (name of town or city and state) do you live in? What is the time zone?

2. How many hours behind Zulu (Z) time is Eastern Standard Time (EST)?

3. During daylight Savings Time (e.g., EDT instead of EST), the time zone becomes one hour closer to UTC time (“Z-time”). How many hours behind Zulu (Z) time is Eastern Daylight Time (EDT)?

4. Name a country that is in “Zulu Time.”

5. Name a country that is in a time zone three hours ahead of Zulu Time.
6. Weather maps use Z time to represent the time the map was created. These times are shown in “military” time based on a 24-hour clock. A 12-hour “AM/PM” clock uses a 12-hour scale repeated once with AM and PM. Convert all “AM/PM” times in the following table to military times. Some of the times are completed for you as an example.

<table>
<thead>
<tr>
<th>AM/PM Time</th>
<th>Military Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>12:00 AM</td>
<td>0000</td>
</tr>
<tr>
<td>1:00 AM</td>
<td>0100</td>
</tr>
<tr>
<td>2:00 AM</td>
<td>0200</td>
</tr>
<tr>
<td>2:15 AM</td>
<td>0215</td>
</tr>
<tr>
<td>4:45 AM</td>
<td></td>
</tr>
<tr>
<td>5:00 AM</td>
<td></td>
</tr>
<tr>
<td>6:23 AM</td>
<td>0623</td>
</tr>
<tr>
<td>7:00 AM</td>
<td></td>
</tr>
<tr>
<td>8:42 AM</td>
<td></td>
</tr>
<tr>
<td>9:00 AM</td>
<td></td>
</tr>
<tr>
<td>10:25 AM</td>
<td></td>
</tr>
<tr>
<td>11:05 AM</td>
<td>1105</td>
</tr>
<tr>
<td>12:00 PM</td>
<td>1200</td>
</tr>
<tr>
<td>1:45 PM</td>
<td>1345</td>
</tr>
<tr>
<td>2:00 PM</td>
<td></td>
</tr>
<tr>
<td>3:59 PM</td>
<td></td>
</tr>
<tr>
<td>4:16 PM</td>
<td></td>
</tr>
<tr>
<td>5:05 PM</td>
<td></td>
</tr>
<tr>
<td>6:00 PM</td>
<td></td>
</tr>
<tr>
<td>7:12 PM</td>
<td></td>
</tr>
<tr>
<td>8:36 PM</td>
<td></td>
</tr>
<tr>
<td>9:00 PM</td>
<td></td>
</tr>
<tr>
<td>10:15 PM</td>
<td></td>
</tr>
<tr>
<td>11:00 PM</td>
<td>2300</td>
</tr>
</tbody>
</table>
7. Use the “World Time Zones” map included in the lab folder documents for this week’s lab to complete the following table. The first two rows are completed for you as an example. Use military time for each example. You may use a separate piece of paper as scratch paper.

<table>
<thead>
<tr>
<th>UTC</th>
<th>EST</th>
<th>EDT</th>
<th>CST</th>
<th>CDT</th>
<th>MST</th>
<th>PST</th>
</tr>
</thead>
<tbody>
<tr>
<td>1200</td>
<td>1200-500=0700</td>
<td>1200-400=0800</td>
<td>1200-600=0600</td>
<td>1200-500=0700</td>
<td>1200-700=0500</td>
<td>1200-800=0400</td>
</tr>
<tr>
<td>0000</td>
<td>0000-500=1900</td>
<td>0000-400=2000</td>
<td>0000-600=1800</td>
<td>0000-500=1900</td>
<td>0000-700=1700</td>
<td>0000-800=1600</td>
</tr>
<tr>
<td>1500</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2300</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0600</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0715</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0022</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Lab #2: The Composition of the Atmosphere

OBJECTIVES:
- Students will become familiar with the layers and density of gases in the Earth’s atmosphere.
- Students will create and manipulate basic formulas in Excel.
- Students will create and analyze graphs on an Excel Spreadsheet from data sets.

INSTRUCTIONS:
- Print out these pages or use a graphics tablet to write in the areas provided.
- Email a copy of your completed lab to the instructor for feedback.
- Save the completed lab as a single PDF and upload to Brightspace.

MATERIALS:
- MS Excel or compatible spreadsheet and graphing software
- Pencil or Pen
Part 1: Air Pressure and Density in the Troposphere

The force of gravity is responsible for keeping air molecules, atoms, and particles close to the earth. However, these particles have densities much lower than solids or liquids, which are “stuck” to the surface of the earth. Therefore, these particles float above the earth’s surface and are weakly held to the earth by gravity. The greatest gravitational force is closest to the surface of the earth. The force of gravity weakens further away from the surface of the earth. Therefore, most of the air molecules and particles are in the lower part of the earth’s atmosphere.

The density of atmospheric gases is the mass of the air divided by the volume of the atmosphere. Since there is greater mass closer to the surface of the earth due to gravity, the density drops with increasing altitude. The rate the density drops with altitude is roughly 50% every 5.6 km.

Activity #1: Use Excel to Determine Air Density Changes with Altitude

Procedure (see video for additional step-by-step instructions)

1. Open a blank workbook in Excel.
2. Type in Row #1: “Height (km)” at the top of column A, “% Above” at the top of column B, and “Pressure (mb),” at the top of column C:

3. In Row #2, enter the following information:
   - Height: 0
   - % Above: 100
   - Pressure: 1000 mb

4. In the “Height” column, enter the following formula into the third cell down:

   =SUM(5.6+)

   - Do not include spaces between any of the characters.
   - The “SUM” formula is used to add values.
Move the cursor so that it is in between the “+” and the closed parenthesis “)”. 

Click on cell #3 to add the cell number, “A2,” to the formula inside the parentheses, then hit enter:

The cell should “automatically” add 5.6 to 0.

5. “Carry” the formula down the Height column:

- A green box will appear around the cell that is selected.
- Select the cell with the formula to add 5.6 so that the green box is around that cell.
- On the lower right corner, there is a small square.

- Move the mouse over the green square and the cursor will turn into a “+” symbol.
- Use the left mouse button to click on the “+” and drag the formula down 3 additional cells.
6. Fill in the “% Above” column:
   - The first cell in the column should be entered as 100.
   - Fill in the second cell down with a formula to cut the value from the previous cell by half:
     - Enter the following formula into the cell:
       \[ =B2/2 \]
   - Finally, drag the formula down to the 6th row to fill in the numbers in the % Above column.

7. Fill in the Pressure (mb) column:
   - Enter 1000 into the top cell of the column.
   - The formula that relates pressure to altitude is:
     \[
     \text{Pressure (mb)} = 1000 \text{ mb} \times (0.5)^{x/5.6} \\
     x = \text{height (km)}
     \]
   - Calculate the air pressure, in mb, for each height and enter the values into the row for Pressure (mb).
   - Include a copy of your hand-written calculations at the end of this lab as an attached pdf document.

8. Graph the Data
   - Create a LINE graph using “XY Scatter” in Excel with Pressure (mb) on the x-axis and Height (km) on the y-axis. Make sure all axes are labeled with titles and units.
     - If you are unable to do this, please contact the instructor for help.
     - If you are unable to contact the instructor for help, use graph paper to create the line graph.

9. Save the graph as a picture by right-clicking anywhere on the graph and select “Save as Picture.”

10. Create a document using MS Word or compatible application and insert the jpeg of the graph into the document as a picture. If you used graph paper to create the graph, take a picture of the graph and insert the picture into the MS Word document.

11. Save the document with the lab number and your last name, for example, a student with the last name of “Smith” should save their file as “Lab_2_Smith.” This will be the working file you use to upload all answers for this lab assignment.
Part 2: Temperature Lapse Rates and the Layers of the Atmosphere

Activity #2: Graph the Earth’s Atmospheric Temperature Layers

1. Open the Excel file “Layers of the Earth’s Atmosphere.”
2. Use a graphing program (MS Excel, Google Sheets, or compatible application) or graph paper to plot a line graph of Earth’s atmospheric temperature (x-axis) vs. altitude (y-axis) using the data from the Excel Spreadsheet.
3. Label the following layers of the atmosphere on the graph by adding text boxes inside the chart area at the correct locations:
   a) Troposphere
   b) Tropopause
   c) Stratosphere
   d) Stratopause
   e) Mesosphere
   f) Mesopause
   g) Thermosphere
   h) Ozone Layer
4. Save the graph as a picture by right-clicking anywhere on the graph and select “Save as Picture.”
5. Insert the picture of the graph to your Word document file for this lab (from Part 1).
Activity #3: Graph of Venus Atmospheric Temperature

Procedure to create a graph of Venus’ Atmospheric Temperature in Excel:

2. Use a graphing program (MS Excel, Google Sheets, or compatible application) or graph paper to plot a line graph of Venus’ atmospheric temperature (x-axis) vs. altitude (y-axis) using the data from the Excel Spreadsheet.
3. Identify and Label the Troposphere and Tropopause on the graph of Venus’ atmospheric layers. If you are unsure where these layers should go, contact the instructor.
4. Save the graph as a picture.
5. Insert the picture into the Word document created in Activity #1.

Part 3: Lab Report

Write answers to the following questions in the Word document created in Part 1. Print the final report as a PDF document.

1. What is the temperature in Kelvin at the surface of Venus?
2. Convert the surface (sea level) temperature on Earth to Kelvin. How does this compare to the surface temperature on Venus (Show all mathematical work)?
3. Use the data on the spreadsheet to figure out the average lapse rate for the troposphere on Venus, or how many units in Kelvin the temperature drops for every 1 km of altitude.
4. Have the instructor check your answers before submitting.
5. Save the Lab Report as a PDF.
6. Upload the single PDF document to Brightspace.
Lab #3 (Online Classes Only): Atmospheric Heating Processes and the Radiation Laws

OBJECTIVES:
- Students will interpret the effects of moisture on air and soil temperature.
- Students will apply the radiation laws to temperature observations.

INSTRUCTIONS:
- Print out these pages or use a graphics tablet to write in the areas provided.
- Email a copy of your completed lab to the instructor for feedback.
- Save the completed lab as a single PDF and upload to Brightspace.

MATERIALS:
- MS Excel or compatible spreadsheet and graphing software
- Pencil or Pen

Part 1: Air Temperature Variability

Activity #1: Collecting Temperature Data from Soil and Surface Air

Procedure #1: The following temperature data (highlighted in the table below) was collected from three different containers—one temperature measurement in the soil of each container and one temperature measurement from the air space above the soil in each container. Container #1 contained soil saturated with water and was left open to the atmosphere for 2 hours. Container #2 contained soil saturated with water and closed to the environment. Container #3 contained dry soil and was closed to the environment.

Table 1: Results of Temperature Data Collection from Three Different Containers of Soil

<table>
<thead>
<tr>
<th>Container</th>
<th>Initial Soil Temperature (°C)</th>
<th>Initial Air Temperature (°C)</th>
<th>Final Soil Temperature (°C)</th>
<th>Final Air Temperature (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Container #1: Saturated and Open</td>
<td>25.8</td>
<td>24.3</td>
<td>25.0</td>
<td>24.1</td>
</tr>
<tr>
<td>Container #2: Saturated and Closed</td>
<td>26.4</td>
<td>24.3</td>
<td>30.7</td>
<td>30.7</td>
</tr>
<tr>
<td>Container #3: Dry Soil and Closed</td>
<td>26.3</td>
<td>24.3</td>
<td>31.6</td>
<td>30.5</td>
</tr>
</tbody>
</table>
Questions: Answer the following questions below:
1. Create a Table in MS Excel, Word, or compatible application with the data recorded on the table above.
2. Create a bar graph to show a visual comparison between the soil and air temperatures from each container. Make sure to designate on the graph which containers had wet or dry soil, and which containers were open or closed.
3. Which container had the highest air temperature at the end of the experiment?
4. Which container had the lowest air temperature at the end of the experiment?
5. Which container had the highest soil temperature at the end of the experiment?
6. Which container had the lowest soil temperature at the end of the experiment?
7. Use the data from this experiment to explain how latent heat is absorbed during the evaporation process.
Part 2: The Radiation Laws
Energy from the sun is emitted as radiation, or waves of light. Radiation energy is measured by wavelengths, frequency, and amplitude or intensity (Figure 1).

Figure 1: The Electromagnetic spectrum.³

<table>
<thead>
<tr>
<th>Wavelength (m)</th>
<th>$10^3$</th>
<th>$10^2$</th>
<th>$10^1$</th>
<th>$10^0$</th>
<th>$10^{-1}$</th>
<th>$10^{-2}$</th>
<th>$10^{-3}$</th>
<th>$10^{-4}$</th>
<th>$10^{-5}$</th>
<th>$10^{-6}$</th>
<th>$10^{-7}$</th>
<th>$10^{-8}$</th>
<th>$10^{-9}$</th>
<th>$10^{-10}$</th>
<th>$10^{-11}$</th>
<th>$10^{-12}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Approximate Scale of Wavelength</td>
<td>Buildings</td>
<td>Humans</td>
<td>Butterflies</td>
<td>Needle Point</td>
<td>Cells</td>
<td>Molecules</td>
<td>Atoms</td>
<td>Atomic Nuclei</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Radiation Type</td>
<td>Radio waves</td>
<td>Microwaves</td>
<td>Infrared</td>
<td>Ultraviolet</td>
<td>'Hard' X-rays</td>
<td>'Soft' X-rays</td>
<td>Gamma rays</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Frequency (Hz)</td>
<td>$10^6$</td>
<td>$10^7$</td>
<td>$10^8$</td>
<td>$10^9$</td>
<td>$10^{10}$</td>
<td>$10^{11}$</td>
<td>$10^{12}$</td>
<td>$10^{13}$</td>
<td>$10^{14}$</td>
<td>$10^{15}$</td>
<td>$10^{16}$</td>
<td>$10^{17}$</td>
<td>$10^{18}$</td>
<td>$10^{19}$</td>
<td>$10^{20}$</td>
<td></td>
</tr>
<tr>
<td>Sources</td>
<td>AM Radio</td>
<td>Microwave oven</td>
<td>Radar</td>
<td>Humans</td>
<td>Fluorescence bulbs</td>
<td>X-ray machines</td>
<td>Radioactive Elements</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Energy (eV)</td>
<td>$10^9$</td>
<td>$10^8$</td>
<td>$10^7$</td>
<td>$10^6$</td>
<td>$10^5$</td>
<td>$10^4$</td>
<td>$10^3$</td>
<td>$10^2$</td>
<td>$10^1$</td>
<td>$10^0$</td>
<td>$10^{-1}$</td>
<td>$10^{-2}$</td>
<td>$10^{-3}$</td>
<td>$10^{-4}$</td>
<td>$10^{-5}$</td>
<td>$10^{-6}$</td>
</tr>
</tbody>
</table>

Wavelengths of radiation are measured by the distance between two peaks. Frequency is measured as the number of waves per period, and the amplitude of a wave is the intensity, or height, of the wave (Figures 2-3). Electromagnetic energy in the visible light spectrum ranges from approximately 400 nanometers (nm) to 750 nm. The longest wavelength is red, the shortest wavelength is violet. Shorter wavelengths correspond to higher frequencies of waves, and vice versa, so that red light has the longest wavelength and lowest frequency, whereas violet has the shortest wavelength and the lowest frequency.
Figure 2 (right): A wavelength is measured as the distance from peak to peak on a wave, the intensity of the wave, $I$, is measured as the height of each peak.  

Figure 3 (left): Red light has the longest wavelength and lowest frequency, violet has the shortest wavelength and highest frequency in visible light.  

Wavelengths of light cannot be directly measured by standard laboratory equipment. However, heat energy is measured with thermometers, and we can apply the Stefan-Boltzmann law to determine the amount of energy emitted by matter based on its temperature. The Stefan-Boltzmann equation is:

$$E = \sigma T^4$$

where

- $E$ = energy ($\text{W/m}^2$)
- $\sigma$ = the Stefan-Boltzmann constant
  
  \[ (5.67 \times 10^{-8} \text{ W/m}^2 \text{ K}^4) \]
- $T$ = temperature (K)
Whereas the Stefan-Boltzmann Law gives us a mechanism to find the amount of energy being emitted from a surface from its temperature, Wien’s Law relates temperature to the wavelength of radiation emitted by an object. Mathematically, Wien’s Law is stated as:

$$\lambda_{\text{max}} = \frac{C}{T}$$

where

$$\lambda_{\text{max}} = \text{the wavelength of maximum emission in micrometers (\mu m)}$$

$$C = \text{Wien’s constant (2898 \mu m K)}$$

$$T = \text{Temperature (K)}$$

<table>
<thead>
<tr>
<th>Type of Energy</th>
<th>Wavelength (\mu m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ultraviolet</td>
<td>0.010-0.380</td>
</tr>
<tr>
<td>Visible</td>
<td>0.380 – 0.750</td>
</tr>
<tr>
<td>Near Infrared</td>
<td>0.750 – 4.000</td>
</tr>
<tr>
<td>Thermal Infrared</td>
<td>4.000 – 100.00</td>
</tr>
</tbody>
</table>

Activity #2: Applying the Stefan-Boltzmann Law to find the amount of energy emitted by the surface.

Use the data in Part 1 of this lab to determine the amount of energy emitted from different soil samples and at soils in different locations by using the Stefan-Boltzmann equation.

1. Convert the FINAL soil air temperatures from each container from °C to K by adding 273.15 to the measured temperature. Show your work below from each of the 3 soil containers:

   Container #1:

   Container #2:

   Container #3:
2. Use the Stefan-Boltzmann equation to find the amount of energy emitted from each of the three containers using the temperature in K calculated above:

Container with Dry Soil:

Container with Wet Soil/left open:

Container with Wet Soil/closed:
3. The surface of the sun is 5,778 K. Use the Stefan-Boltzmann equation to calculate the energy in W/m$^2$ emitted from the sun. Show all work below:

4. Which sample reemitted more energy, the dry sample or the wet sample? What does this say about the difference between energy emission to the lower atmosphere on a wet, rainy day vs. a dry day? (Hint: Explain your answer using clear, full sentences. You’re your answer out loud and then have a friend or relative read your answer and rewrite it using their feedback.)
Activity #3: Applying the Wien’s Law to find the wavelength of energy emitted by different surfaces and the sun

1. Use Wien’s Law to calculate the wavelength of energy emitted from the final soil temperatures in each of the containers from Activity #1. Show all work to receive credit. Use Table 1 to determine the type of electromagnetic energy emitted by each surface.

   **Container #1:**

   **Type of Energy:**

   **Container #2:**

   **Type of Energy:**

   **Container #3:**

   **Type of Energy:**

2. Use Wien’s Law to calculate the wavelength of energy emitted from the surface of the sun, which has a temperature of 5,778 K. Show all work to receive credit. Use Table 1 to determine the type of electromagnetic energy emitted by the sun.
Lab #4 (In-Person): Atmospheric Heating Processes and the Radiation Laws

OBJECTIVES:

- Students will collect temperature data from the air and soil samples with different moisture content.
- Students will apply the radiation laws to interpret the observed data.

INSTRUCTIONS:

- Print out these pages or use a graphics tablet to write in the areas provided. Save the completed lab as a pdf file and upload to the laboratory assignment portal.

MATERIALS:

- Soil samples
- Beakers
- Petri dishes to cover the beakers
- Water
- MS Excel or compatible spreadsheet and graphing software
- Pencil or Pen

Part 1: Air Temperature Variability

Activity #1: Collecting Temperature Data from Soil and Surface Air

Procedure #1:
1. Use masking tape to label each container #1-5. Include a “team name” or initials for your group’s containers.
2. Add at least 3 inches thick of soil into 3 of the 5 containers.
3. Add enough water to 2 of the containers with soil to saturate the soil, so that it “jiggles” when it shakes. Leave one soil container dry.
4. Measure and record both the soil and air temperature from inside of each container. Create a table in your notebook or note paper to record the data.
5. Cover one of the wet soil containers and the dry container tightly after recording the initial temperature data.
6. Add approximately 1-2 cups of water to the empty containers, record the air and water temperatures separately, and tightly cover ONE of these containers after recording the temperatures. Leave one container open, this will be the “control” container.
7. Note which containers contain wet soil, dry soil, no soil, and which containers were left open or closed.
8. Leave the containers outside in the sun or by a window for at least 1 hour.
9. Measure and record the soil and air temperatures in each container after 1 hour.
10. Enter all data into the data table below:

<table>
<thead>
<tr>
<th>Container</th>
<th>Initial Temperature of Soil (°C)</th>
<th>Initial Air Temperature (°C)</th>
<th>Final Soil Temperature (°C)</th>
<th>Final Air Temperature (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>#1: Open</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>#2: Closed</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>#3: Closed</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Questions:** Answer the following questions below:
1. Create a Table in MS Excel, Word, or compatible application with the data recorded on the table above.
2. Create a bar graph to show a visual comparison between the soil and air temperatures from each container. Make sure to designate on the graph which containers had wet or dry soil, and which containers were open or closed.
3. Which container had the highest air temperature at the end of the experiment?
4. Which container had the lowest air temperature at the end of the experiment?
5. Which container had the highest soil temperature at the end of the experiment?
6. Which container had the lowest soil temperature at the end of the experiment?
Part 2: The Radiation Laws
Energy from the sun is emitted as radiation, or waves of light. Radiation energy is measured by wavelengths, frequency, and amplitude or intensity (Figure 1).

**Figure 1:** The Electromagnetic spectrum.\(^5\)

Wavelengths of radiation are measured by the distance between two peaks. Frequency is measured as the number of waves per period, and the amplitude of a wave is the intensity, or height, of the wave (Figures 2-3). Electromagnetic energy in the visible light spectrum ranges from approximately 400 nanometers (nm) to 750 nm. The longest wavelength is red, the shortest wavelength is violet. Shorter wavelengths correspond to higher frequencies of waves, and vice versa, so that red light has the longest wavelength and lowest frequency, whereas violet has the shortest wavelength and the lowest frequency.
Figure 2 (right): A wavelength is measured as the distance from peak to peak on a wave, the intensity of the wave, $I$, is measured as the height of each peak. 

Figure 3 (left): Red light has the longest wavelength and lowest frequency, violet has the shortest wavelength and highest frequency in visible light.

Wavelengths of light cannot be directly measured by standard laboratory equipment. However, heat energy is measured with thermometers, and we can apply the Stefan-Boltzmann law to determine the amount of energy emitted by matter based on its temperature. The Stefan-Boltzmann equation is:

$$E = \sigma T^4$$

where

- $E$ = energy ($W/m^2$)
- $\sigma$ = the Stefan-Boltzmann constant
  
  \[ (5.67 \times 10^{-8} \text{ W/m}^2 \text{ K}^4) \]
- $T$ = temperature (K)
Whereas the Stefan-Boltzmann Law gives us a mechanism to find the amount of energy being emitted from a surface from its temperature, Wien’s Law relates temperature to the wavelength of radiation emitted by an object. Mathematically, Wien’s Law is stated as:

\[ \lambda_{\text{max}} = \frac{C}{T} \]

where

\[ \lambda_{\text{max}} = \text{the wavelength of maximum emission in micrometers (\(\mu m\))} \]
\[ C = \text{Wien’s constant (2898 \(\mu m\ K\))} \]
\[ T = \text{Temperature (K)} \]

<table>
<thead>
<tr>
<th>Type of Energy</th>
<th>Wavelength ((\mu m))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ultraviolet</td>
<td>0.010-0.380</td>
</tr>
<tr>
<td>Visible</td>
<td>0.380 – 0.750</td>
</tr>
<tr>
<td>Near Infrared</td>
<td>0.750 – 4.000</td>
</tr>
<tr>
<td>Thermal Infrared</td>
<td>4.000 – 100.00</td>
</tr>
</tbody>
</table>

Activity #2: Applying the Stefan-Boltzmann Law to find the amount of energy emitted by the surface.

Use the data in Part 1 of this lab to determine the amount of energy emitted from different soil samples and at soils in different locations by using the Stefan-Boltzmann equation.

1. Convert the FINAL soil temperatures from each container from °C to K by adding 273.15 to the measured temperature. Show your work below from each of the 3 soil containers:

   Container #1:

   Container #2:

   Container #3:
2. Use the Stefan-Boltzmann equation to find the amount of energy emitted from each of the three containers using the temperature in K calculated above:

   **Container with Dry Soil:**

   **Container with Wet Soil/left open:**

   **Container with Wet Soil/closed:**
3. The surface of the sun is 5,778 K. Use the Stefan-Boltzmann equation to calculate the energy in W/m² emitted from the sun. Show all work below:

4. Which sample reemitted more energy, the dry sample or the wet sample? What does this say about the difference between energy emission to the lower atmosphere on a wet, rainy day vs. a dry day?
Activity #3: Applying the Wien’s Law to find the wavelength of energy emitted by different surfaces and the sun

3. Use Wien’s Law to calculate the wavelength of energy emitted from the final soil temperatures in each of the containers from Activity #1. Show all work to receive credit. Use Table 1 to determine the type of electromagnetic energy emitted by each surface.

Container #1:

Type of Energy:

Container #2:

Type of Energy:

Container #3:

Type of Energy:

4. Use Wien’s Law to calculate the wavelength of energy emitted from the surface of the sun, which has a temperature of 5,778 K. Show all work to receive credit. Use Table 1 to determine the type of electromagnetic energy emitted by the sun.
Lab #5: Seasons and Seasonality: How the Earth’s Tilt and Orbit Affect Solar Receipt

OBJECTIVES:
- Students will demonstrate how the tilt of the earth and earth’s orbit around the sun affect insolation at different latitudes for different seasons.
- Students will determine the amount of energy hitting the earth at any latitude for specific dates including estimates of radiation reflected by clouds.

INSTRUCTIONS:
- Print out these pages or use a graphics tablet to write in the areas provided. Save the completed lab as a pdf file and upload to the laboratory assignment portal.

MATERIALS:
1. Protractor
2. Scientific Calculator
3. Pencil
4. Flashlight
5. Round object (softball, basketball, bowl, melon, etc.)
6. Notebook paper
7. Tape
8. Permanent Marker
9. Ruler

Part 1: Where is the sun?
The earth is approximately 93 million miles away from the sun (150 million kilometers). As the earth revolves around the sun, it rotates at an angle of 23.5° from the perpendicular of the planar orbital path. The sun’s rays hit the earth in a straight path, but due to the angle of the earth’s axis of rotation, direct rays of sunlight hit different latitudes depending on the earth’s position in its orbit. The northern hemisphere is pointed towards the sun during the northern hemisphere’s summer, and the northern hemisphere is pointed away from the sun during the northern hemisphere’s winter (see Figure 1). This tilt is called the solar declination. The equinoxes are the two days during the year when the northern and southern hemispheres receive equal amounts of sunlight. This variability creates the seasons.

The subsolar point is the latitude on earth that is receiving direct rays of sunlight at a 90° angle to the surface (Figure 2). Solar noon is the time of day when the sun is at its highest angle in the sky.
Figure 1: This schematic (above) shows how the northern and southern hemispheres are illuminated at different angles at different points on the earth’s orbit around the sun.\textsuperscript{9}

Figure 2: The sun’s rays are striking the earth’s surface at a 90° angle at the subsolar point.\textsuperscript{10}
The angle of the sunlight hitting any point on earth will vary depending on that point’s distance from the subsolar point.

**Figure 3:** The angle of sunlight hitting the earth at solar noon on an Equinox date. The sun hits the equator at a 90° angle, 45° N at a 45° angle, and 65° S at a 25° angle.
Activity #1: Measure the angle of sunlight hitting different latitudes at different times of the year.

Instructions: Use a protractor to measure the inside angle of the sun’s rays hitting the earth at the equator, 30° N, and 45° S latitudes for each of the following dates (Figures 4-6). See the tutorial for using a protractor to measure and draw angles posted as a separate attachment if you need guidance.

1. March 21

![Figure 4: Representation of sunlight hitting the Earth on the Boreal Equinox.](image)

2. June 21

![Figure 5: Representation of sunlight hitting the Earth on the Boreal Summer Solstice, June 21.](image)
3. December 21

Figure 6: Representation of sunlight hitting the Earth on the Boreal Winter Solstice, December 21.
Activity #2: Direct and Angled Light Intensity over a Surface Area

Instructions: Use the following materials to complete this activity:
   1. Flashlight
   2. Round object (softball, basketball, bowl, melon, etc.)
   3. Notebook paper
   4. Tape
   5. Permanent Marker

Procedure:
   1. Use tape to wrap notebook paper around your round object. The paper does not have to cover the entire object if it is too large, but it should cover at least half. See the examples in the photograph below (Figure 7, below).

   ![Figure 7: Examples of several round objects wrapped with notebook paper.](image)

   2. **Figure 8:** Place your flashlight a few inches away from the round object so it is shining directly towards the object:
3. **Figure 9:** Use the marker to draw a line around the lit area on the paper:

![Figure 9](image)

4. **Figure 10:** Tilt the flashlight up at a slight angle, you may use a notebook or another object to prop the flashlight up:

![Figure 10](image)

5. **Figure 11:** Draw a line around the lit area on the paper from the tilted flashlight:

![Figure 11](image)

6. **Record your observations below or on a separate page attached to your final submission:**
   a. What was the difference in the amount of area covered by the directly shining light vs. the tilted light?
   b. Which light was brighter on the paper?
Activity #3: Using the Noon Sun Angle to Determine Solar Intensity

As shown in Activity #2, direct sunlight at a 90° angle covers a smaller area, but is more intense, than light that hits the surface at an angle lower than 90°. The amount of surface area covered by a beam of light can be calculated using trigonometry:

![Diagram of the sun angle \( \alpha \), with surface area “c,” beam of light “a,” and line “b” connecting the beam of light to the surface at a 90° angle.]

**Figure 12:** The geometry of the sun angle \( \alpha \), with surface area “c,” beam of light “a,” and line “b” connecting the beam of light to the surface at a 90° angle.

Given this geometry:

\[
\sin \alpha = \frac{b}{c}
\]

and

\[
c = \frac{b}{\sin \alpha}
\]

The distance of line b can be determined by the distance between two arbitrary beams of light coming from the source.
Figure 13: The geometry from Figure 12 created with two beams of light that are one unit of distance apart (b) and spread out over a surface area (c).

The surface area, c, can now be calculated using an arbitrary distance of 1 unit between the two beams of light hitting the surface.

If the sun angle is 45°, the surface area is calculated by:

\[ c = \frac{b}{\sin \alpha} \]

or,

\[ c = \frac{1 \text{ unit}}{\sin 45} \]

and

\[ c = \frac{1 \text{ unit}}{0.71} \]

\[ c = 1.41 \text{ units} \]
1. Use the sun angles determined from Activity 1 to find the surface area spread of light between two light beams that are 1 meter apart (line “b” in the triangle example on figures 12 and 13). **Show all math on separate paper.** Enter your answers in the data table below:

<table>
<thead>
<tr>
<th></th>
<th>Latitude 30°N</th>
<th>Equator</th>
<th>Latitude 45°S</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Sun Angle</td>
<td>Surface Area Spread</td>
<td>Sun Angle</td>
</tr>
<tr>
<td>March 21</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>June 21</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dec 21</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Activity #4: Find the Solar Elevation Angle at Your Location**

This activity must be completed close to the solar noon time for your day. If you are unable to take the measurement at solar noon, write down the time of day and complete the following steps to approximate the solar elevation angle.

**Materials**
1. Pole: Any long, slender object will work (pen/pencil, tall glass, stick, etc.)
2. Ruler or tape measure

**Procedure**
1. Measure the length of your pole-object using any units of measurement (inches, cm)

   __________________________________________

2. Place your pole-object vertically on a flat surface outside.
3. Measure the length of its shadow using the same units used for #1:

   __________________________________________
4. Divide the pole length by the length of its shadow:

____________________________

5. Find the inverse of the tangent (tan⁻¹) of the numerical value calculated in #4. This is equal to the solar noon angle:

____________________________

Part 2: Energy received at the surface

The sun emits 1341 Watts per square meter (W/m²) of energy. In this activity, the amount of solar energy received at your latitude for different times of the year will be calculated. Follow the steps in the example below to complete the problems:

September 21, Poughkeepsie, NY 42°N latitude

- Step 1: Find the Subsolar Point:

  Subsolar Point = 23.5 sin(n)
  where n = the number of days from the nearest equinox
  For dates between March and September, “n” is positive.
  For dates between September and March, “n” is negative.

  - How many days are there to the nearest equinox?
    - Use a calendar to count the days between the given date and either March 21 or September 21. Use the smaller number.
    - Since September 21 is an equinox, so n = 0

  - Find the sin of the “n” value: sin (0) = 0
    *** Make sure that your calculator is set to degrees, NOT radians!

  - Multiply 23.5 x 0 = 0

  The subsolar point for September 21 is 0° latitude, or the equator.

- Step 2: Figure out how many degrees of latitude separate the location at 42° N and the latitude of the subsolar point. For this example, 42°N is exactly 42° away from the subsolar point at 0° latitude. If the subsolar point is located in a southern latitude, you will need to add the total number of latitude degrees including the degrees from the equator to
the subsolar point. For example, if the subsolar point is -15° and your location is at 42°N, there are 42° between your location and the equator, and then an additional 15° between the equator and the subsolar point, so the total number of degrees separating your location and the subsolar point are 42° + 15° = 57°.

- **Step 3:** Find the *solar elevation angle* for the given date by subtracting 90° - answer from step 2: 90° - 42° = 48°

- **Step 4:** Multiply 1341 W/m² x 1m² to find the amount of energy emitted over a 1 m² area at solar noon at the latitude receiving direct sunlight at a 90° angle:

  \[
  1341 \text{ W/m}^2 \times 1\text{m}^2
  \]

  Here, the m² cancels out, leaving *1341 W*.

- **Step 5:** Calculate the spread of energy at this latitude using the method from Activity 3:

  \[
  \alpha = 48° \\
  \sin \alpha = \sin (48) = 0.743 \\
  1/0.743 = 1.35
  \]

  The distance will be spread out to *1.35 m²* at the surface at this latitude.

- **Step 6:** Divide the energy emitted from the sun by the amount of spread at the surface calculated in step 5:

  \[
  1341 \text{ W}/1.35 \text{ m}^2 = 993 \text{ W/m}^2
  \]
Activity #5: Determining Energy Receipt Where You Live for Different Times of the Year

1. Find your latitude: ____________________

2. Find the Subsolar Point for the following dates (Use Step 1 in the above instructions and show all work below each date):
   a. June 21
   
   b. December 21
   
   c. Today’s Date: ____________

3. Find the solar elevation angle at your location for each date (Use Steps 2-3 in the above instructions and show work below each date):
   a. June 21
   
   b. December 21
   
   c. Today’s Date: ____________
4. Calculate the energy spread at your location for each date (Use the formula from Step 5 or Activity #3 and show all work below each date):
   a. June 21

   b. December 21

   c. Today’s Date: ____________

5. Given 1341 W/m² energy emitted by the sun, how much energy is hitting 1 m² at the surface at your location without any energy lost or scattered by atmospheric gases and clouds for each date (Use Step 6 from the above instructions and show all work below each date)?
   a. June 21

   b. December 21

   c. Today’s Date: ____________
6. How much energy would hit 1 m$^2$ surface area if 40% of the energy emitted by the sun is lost due to scattering by atmospheric gases and reflection by clouds for each date (show all work)?
   
a. June 21

   b. December 21

   c. Today’s Date: ______________

7. Estimate the percentage of clouds covering the sky when you completed the experiment in Activity #4. For example, if half the sky was covered by clouds, use 50%. If there were only a few clouds, use 10%.

   ______________ %

8. Calculate the amount of energy hitting the ground at your location based on the solar elevation angle found in Activity #4. Use the subsolar point for today’s date (Activity #5, question 2c) to find the total amount of energy hitting 1 m$^2$ area including the percentage of cloud coverage. Show all work below.
Lab #6: Applications Using Temperature Data

OBJECTIVES:
- Students will use Heating Degree Days, Cooling Degree Days, and Growing Degree Days data from different online databases to determine how these data have varied over time.
- Students will interpret lower troposphere stability using radiosonde temperature data acquired from the National Weather Service.

INSTRUCTIONS:
- Print out these pages or use a graphics tablet to write in the areas provided.
- Email a copy of your completed lab to the instructor for feedback.
- Save the completed lab as a single PDF and upload to Brightspace.

MATERIALS:
- Excel or compatible graphing software

Part 1: Heating Degree Days and Cooling Degree Days
Heating Degree Days (HDD) are a quantifiable measurement of the amount of energy required to heat buildings. To find the number of heating degree days for a single day, subtract 65°F – the average temperature of that day. The total number of heating degree days for a month is found by adding up all the heating degree days in that month.

Cooling Degree Days (CDD) are a quantifiable measurement of the amount of energy required to cool buildings on hot days. To find the number of cooling degree days for a single day, subtract the average temperature of that day – 70°F. The total number of cooling degree days for a month is found by adding up all the cooling degree days in that month.

Heating and Cooling degree days data for New York State can be found on NYSERDA’s website (this link is provided within the Brightspace assignment): [Monthly Cooling and Heating Degree Day Data - NYSERDA](#)

Activity #1: Heating Degree Days and Cooling Degree Days
1. Calculate the number of Heating Degree Days for a day with an average temperature of:
   a. 40°F

   b. 25°F
2. Find the total number of NY statewide heating degree days for each of the following months from this link: [Monthly Cooling and Heating Degree Day Data - NYSERDA](#) and insert them into the table below in the “HDD” column. Next, use this link: [Monthly Average Home Heating Oil Prices - NYSERDA](#) to find the historical average monthly cost of heating oil in New York State and add these prices to the table below in the column for “Heating Oil Price.” These links are also provided as separate links within the assignment on Brightspace if you are unable to open them from this document.

<table>
<thead>
<tr>
<th>Month</th>
<th>HDD</th>
<th>Heating Oil Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>December, 2018</td>
<td></td>
<td></td>
</tr>
<tr>
<td>January, 2019</td>
<td></td>
<td></td>
</tr>
<tr>
<td>February, 2019</td>
<td></td>
<td></td>
</tr>
<tr>
<td>March, 2019</td>
<td></td>
<td></td>
</tr>
<tr>
<td>December, 2019</td>
<td></td>
<td></td>
</tr>
<tr>
<td>January, 2020</td>
<td></td>
<td></td>
</tr>
<tr>
<td>February, 2020</td>
<td></td>
<td></td>
</tr>
<tr>
<td>March, 2020</td>
<td></td>
<td></td>
</tr>
<tr>
<td>December, 2020</td>
<td></td>
<td></td>
</tr>
<tr>
<td>January, 2021</td>
<td></td>
<td></td>
</tr>
<tr>
<td>February, 2021</td>
<td></td>
<td></td>
</tr>
<tr>
<td>March, 2021</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
3. Based on the monthly total HDDs for each winter season listed in the above table, which winter season must have been the coldest, 2018-2019, 2019-2020, or 2020-2021?

4. Which winter season had the highest oil price?

5. Based on this information, does the general cost of oil follow a “supply-and-demand” type of pattern, wherein higher number of heating degree days lead to higher prices of oil?

6. Calculate the number of Cooling Degree Days for the following average daily temperatures:
   a. 85°F
   b. 92°F

7. Viewing the Cooling Degree Day Data, which were the hottest 5 months from the period of 2012-2022?

8. Add up the total number of cooling degree days for each year from 2013-2022 (see link from question #2) and enter the information in the spaces below. Which year from 2013-2022 had the highest number of cooling degree days?
   2013 Total CDD: _______________________
   2014 Total CDD: _______________________
   2015 Total CDD: _______________________
   2016 Total CDD: _______________________
   2017 Total CDD: _______________________
   2018 Total CDD: _______________________
   2019 Total CDD: _______________________
   2020 Total CDD: _______________________
   2021 Total CDD: _______________________
   2022 Total CDD: _______________________
9. Is there an observable trend in CDD or HDD during this 9-year period—towards steadily rising or falling numbers of CDD and/or HDD? Describe any trends that you observe from the data.

Activity #2: Growing Degree Days
Use this link to read about Growing Degree Days (link also provided within the Brightspace assignment): Landscape: Growing Degree Days for Management of Insect Pests in the Landscape | Center for Agriculture, Food, and the Environment at UMass Amherst

1. What are growing degree days used to determine?

2. Calculate the average daily temperatures based on the maximum and minimum daily temperatures in the table below. Then, calculate the Growing Degree Days based on a baseline temperature of 40°F.

<table>
<thead>
<tr>
<th>Daily Maximum Temperature</th>
<th>Daily Minimum Temperature</th>
<th>Daily Average Temperature</th>
<th>GDD</th>
</tr>
</thead>
<tbody>
<tr>
<td>65°F</td>
<td>40°F</td>
<td></td>
<td></td>
</tr>
<tr>
<td>55°F</td>
<td>45°F</td>
<td></td>
<td></td>
</tr>
<tr>
<td>86°F</td>
<td>67°F</td>
<td></td>
<td></td>
</tr>
<tr>
<td>98°F</td>
<td>84°F</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Use the NEWA Degree Day Calculator—see the left hand side of this website (link also provided within the Brightspace assignment): Degree Day Calculator | NEWA (cornell.edu) to find the Growing Degree Days at Appleton, NY (Russell Farms) for a baseline temperature of 50°F over the period of April 1, 2022 – April 30, 2022 and from May 1, 2022 – May 31, 2022. Write down the total number of degree days for these two periods below:

a. April, 2022:

b. May, 2022:
3. Based on the NEWA website About Degree Days | NEWA (cornell.edu), name three organisms that grow with a base of 50°F.

4. What crops are most affected by the three organisms you listed in the previous answer? (Hint: you may use an internet search to find out!)
Part 2: Radiosonde Air Temperature Data

Activity #3: Collecting Air Temperature Data Online

Procedure:
1. Visit these websites to learn about how weather information is collected and interpreted from radiosondes (clicking the “next” button at the bottom of the first page listed below will take you to the links that follow). Hit “Control-Mouse Button” to open the following links, or find the links in the assignment on Brightspace under “Activity 3 Links”:

   https://www.weather.gov/jetstream/radiosondes
   https://www.weather.gov/jetstream/skewt
   https://www.weather.gov/jetstream/skewtplots
   https://www.weather.gov/jetstream/skewt_samples

2. Copy and paste the following link into your browser to find the Skew-T Plots for different US weather stations:

   https://www.spc.noaa.gov/exper/soundings

   Each star on this site’s U.S. map represents a different weather station. Try clicking on different stars to obtain Skew-T plots for different stations. For example, the star circled in red in the image to the right is the Albany, NY station, station code ALB:
- An interpreted Skew-T plot showing temperature, dew point, wind, and precipitation information for the Albany, NY Weather Station is shown below. For this activity, only use the temperature data, shown in red on the Skew-T plot below as an example:

3. Copy and paste 5 different Skew-T plots into the bottom of your lab report document by right-clicking on the image of the Skew-T plot from the website, select “Copy Image,” and then paste below on a blank new page of the document. Save your lab report with your last name_Temperature. For example, “Smith_Temperature.”
4. Open a blank Excel Worksheet (or compatible program) and set the worksheet with the following information. Replace “Station #1-5” with the 3-letter city code for each of the stations for which you copied Skew-T plots:

<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elevation above Sea Level (km)</td>
<td>Station #1 Temperature C</td>
<td>Station #2 Temperature C</td>
<td>Station #3 Temperature C</td>
<td>Station #4 Temperature C</td>
<td>Station #5 Temperature C</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Environmental Lapse Rate 0-3km (C/km)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Stability</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Lower Troposphere Inversion Y/N?</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

5. Example weather station Skew-T plots are entered for you in the example below. The thick red plotted line is the temperature, elevations are shown on the left side of the Skew-T plot in red numbers. Plot temperatures for the same elevations for the 5 additional Skew-T plots you copied to the Word document. Change “Station 1, Station 2,” etc., to the 3-letter city station codes for your Skew-T plots.

6. Calculate the “Environmental Lapse Rate” for the lower troposphere, from 0 – 3 km. To find the environmental lapse rate, subtract the temperature at the surface (0 km elevation) – the temperature at 3 km above the surface and divide by 3 for each station using Celsius temperatures.

Lapse rates for different parts of the atmosphere are also given in a box below each Skew-T plot, check your data to make sure it is similar to what is given in the box. In the ALB station example shown here, the lower Troposphere lapse rate is 4.4°C/km:

7. Environmental lapse rates with values less than 5°C/1000 m indicate an absolutely stable environment, with no chance of rain clouds forming at the specified time. Lapse rates between 5-10°C/1000 m indicate a conditionally stable atmosphere, in which storms may form in some conditions. Lapse rates above 10°C/1000 m are absolutely unstable and storms will likely form. In the row underneath the Environmental Lapse Rate row, indicate the stability condition for each weather station as “Stable,” “Conditionally Stable,” or “Absolutely Unstable.” If the lapse rate is negative, follow to Step #8:
8. A thermal inversion in the lower troposphere is found when the surface temperature is **lower** than the temperature at 3km and the lapse rate from 0 – 3 km is a negative value, for example, see the BUF and GYX stations below:

<table>
<thead>
<tr>
<th>Elevation above Sea Level (km)</th>
<th>ALB Temperature °C</th>
<th>BUF Temperature °C</th>
<th>GYX Temperature °C</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>18</td>
<td>15</td>
<td>12</td>
</tr>
<tr>
<td>1</td>
<td>17</td>
<td>20</td>
<td>15</td>
</tr>
<tr>
<td>3</td>
<td>16</td>
<td>18</td>
<td>18</td>
</tr>
<tr>
<td>6</td>
<td>15</td>
<td>10</td>
<td>12</td>
</tr>
<tr>
<td>9</td>
<td>5</td>
<td>5</td>
<td>9</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Environmental Lapse Rate 0-3km (°C/km)</th>
<th>Absolutely Stable</th>
<th>Absolutely Stable</th>
<th>Absolutely Stable</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>-1</td>
<td>-2</td>
</tr>
</tbody>
</table>

| Lower Troposphere Inversion Y/N? | N     | Y    | Y    |

9. Copy and paste the information from the spreadsheet to your lab report Word document.
10. Save the entire lab report as a single PDF document and submit to Brightspace.
Lab #7: Measuring Humidity

OBJECTIVES:
- Collect and interpret humidity data.

INSTRUCTIONS:
- Print out these pages or use a graphics tablet to write in the areas provided.
- Email a copy of your completed lab to the instructor for feedback.
- Save the completed lab as a single PDF and upload to Brightspace.

MATERIALS:
- Calculator
- Textbook: Essentials of Meteorology, Ahrens and Henson, 8th Ed. 2018

Part 1: Background Information on Humidity
Some people describe humid weather as muggy. When the air is humid, it has a lot of water vapor in it. Water as a gas in the atmosphere is called water vapor. The maximum amount of water vapor that can be in the air depends on the air temperature. Warmer air can hold more water vapor than cooler air. As the temperature goes down, the air can hold less vapor and some of it turns into liquid water, forming fog.

The amount of water vapor in the air is called absolute humidity. The percentage of water vapor in the air as compared with the amount of water that the air could hold at any given temperature is called the relative humidity. This amount of space in air that can hold water changes depending on the temperature and pressure. For example, on a warm 76°F day, you measure that there is half a gram of water vapor for each cubic yard of air. At that temperature, air can hold 1 gram of water for each cubic yard of air. If the air is able to hold twice the amount of water that it does hold, then the relative humidity is 50%. The air becomes saturated when it is holding the most amount of vapor it can at any given temperature. Since warmer air can carry more water vapor than cooler air, as a warm parcel of air cools, the relative humidity will go up with the same amount of water vapor.

Why are there water droplets on the grass on a cool summer morning, even though it did not rain the night before? The water most likely came from water vapor which formed liquid water droplets when it cooled to the dew point. The dew point is the temperature at which water will start to condense out of the air. When air is saturated as much as possible with water vapor it is at the dew point.
Activity #1: Measuring Relative Humidity

1. Choose two indoor and two outdoor locations. Write down these locations in the spaces below:
   Indoor #1: __________________________
   Indoor #2: __________________________
   Outdoor #1: __________________________
   Outdoor #2: __________________________

2. Write any and all possible sources of water vapor for each location. Water must be open and available to evaporate in each location. Examples can include a lake, ocean, or river or even living animals or plants that are actively respiring water vapor. Think of as many sources of water as possible. Some locations might not have obvious sources of water.

   Indoor #1:  _____________________________________________
              ______________________________________________
              ______________________________________________

   Indoor #2:  ______________________________________________
              ______________________________________________

   Outdoor #1:  ______________________________________________
              ______________________________________________

   Outdoor #2:  ______________________________________________
              ______________________________________________
3. Which location probably has the **highest** relative humidity?

___________________________________________________________

Explain why:

4. Which location probably has the **lowest** relative humidity?

___________________________________________________________

Explain why:

**Activity #2: Measuring Humidity Using a Sling Psychrometer**

A sling psychrometer was used to collect the dry and wet bulb temperature data shown in Table 1, below. The dry bulb thermometer measures the air temperature and the wet bulb thermometer measures the temperature of evaporation. Use the Relative Humidity Chart in your textbook, Appendix F, Table F.2, page 474 to find the Relative Humidity %. This chart gives the relative humidity percentage based on the difference between the air temperature (dry bulb) and the temperature of evaporation (wet bulb). The difference between the dry bulb and wet bulb temperatures is called the **wet bulb depression**.

1. Find the **wet bulb depression** and **relative humidity** for the examples given in Table 1, below:

<table>
<thead>
<tr>
<th>Dry Bulb Temperature °C</th>
<th>Wet Bulb Temperature °C</th>
<th>Wet Bulb Depression</th>
<th>Relative Humidity %</th>
</tr>
</thead>
<tbody>
<tr>
<td>26</td>
<td>25</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>35</td>
<td>20</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2. Which dry bulb temperature in the above table had the highest relative humidity percentage?

3. Insert the missing values for relative humidity, wet bulb depression, and wet bulb temperature into Table 2 on the next page:
<table>
<thead>
<tr>
<th>Dry Bulb Temperature °C</th>
<th>Wet Bulb Temperature °C</th>
<th>Wet Bulb Depression</th>
<th>Relative Humidity %</th>
</tr>
</thead>
<tbody>
<tr>
<td>25</td>
<td>21</td>
<td></td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>3.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>82%</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Part 2: Absolute Humidity and Mixing Ratios
Absolute Humidity is the direct measurement of the amount of water vapor in the air, whereas relative humidity is the percentage of the water vapor in the air compared to the total amount of water vapor the air could potentially carry. The amount of water vapor in a volume of air can be measured by the vapor pressure of the air or by the mass of the water vapor in the air. Absolute humidity is measured as the mass of the water vapor compared to the volume of the air sample or parcel. The absolute humidity is expressed in units of kilograms of water vapor per cubic meters of air, or kg/m³. The mixing ratio of air is a comparison of the mass of the water vapor to the mass of the remaining dry air in the volume of air. The mixing ratio of the air is expressed in units of grams of water/kilograms of air, or g/kg.

Activity #3: Calculating Absolute Humidity
Follow these steps to calculate the absolute humidity of the air:
1. Find the wet bulb depression and relative humidity of the air using the measurements of dry bulb and wet bulb temperatures and Appendix F.2 on page 474 of your textbook. Enter these values into Table 3.
2. Estimate the Saturation Vapor Pressure for each of the dry bulb temperatures using Figure 4.5 on page 83 of your textbook.
3. Rearrange the formula:
   \[ RH = \frac{\text{Actual Vapor Pressure}}{\text{Saturation Vapor Pressure}} \times 100\% \]
   So that \textbf{Actual Vapor Pressure} = \frac{RH \times \text{Saturation Vapor Pressure}}{100\%}

   Enter the Actual Vapor Pressures into \textbf{Table 4}. Show All Work on scratch paper, inserted as a picture to the end of your final lab report document.
4. Convert the dry bulb temperatures to Kelvin and enter these values into \textbf{Table 4}.
5. Multiply the value for the actual vapor pressure x 100 to convert to units of Pascals (Pa).
6. Use the Ideal Gas Law to find the absolute humidity. The absolute humidity is the density of water vapor in g/m^3:

The Ideal Gas Law is expressed mathematically as:

\[ \text{Pressure} = \text{density} \times \text{gas constant} \times \text{temperature} \]

Rearrange the Ideal Gas Law formula to find density so that:

\[ \text{AH} = \frac{\text{Pressure}}{R \times T} \]

Wherein:

- \( \text{AH} = \) Absolute Humidity in kg/m^3
- \( \text{Pressure} = \) Vapor Pressure in Pa
- \( R = \) The gas constant for water vapor, 461.5
- \( T = \) Dry Bulb Temperature in Kelvin

1. Complete the two tables below (Tables 3-4) to find the absolute humidity of 2 different air parcels. Show all work on separate scratch paper.

<table>
<thead>
<tr>
<th>Air Parcel</th>
<th>Dry Bulb Temperature °C</th>
<th>Wet Bulb Temperature °C</th>
<th>Wet Bulb Depression</th>
<th>RH %</th>
<th>Saturation Vapor Pressure (mb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>20</td>
<td>12.5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>2.5</td>
<td>2.0</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 4

<table>
<thead>
<tr>
<th>Air Parcel</th>
<th>Dry Bulb Temperature, K</th>
<th>Actual Vapor Pressure (mb)</th>
<th>Actual Vapor Pressure (Pa)</th>
<th>AH (kg/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2. Which air parcel, A or B, has higher relative humidity?

3. Which air parcel, A or B, has higher Absolute Humidity?

4. Explain why relative humidity does not accurately show the amount of water vapor present in an air parcel.
Activity #4: Calculating Relative Humidity using Mixing Ratios

The relative humidity of an air parcel can be found using the mixing ratio of the parcel using the following formula:

\[
\text{RH} = \frac{\text{mixing ratio of parcel}}{\text{Saturation mixing ratio}} \times 100\%
\]

The saturation mixing ratio is the mixing ratio of a parcel at 100% humidity. The units for mixing ratio are grams of water vapor/kg of dry air, or g/kg.

1. Table 6 (next page) lists saturation mixing ratios as a function of temperature. Give the saturation mixing ratio for each of the air parcels with the given temperatures, then calculate the Relative Humidity (RH) % for each parcel listed in Table 5 below. Show all work for each parcel on separate scratch paper for full credit. The first air parcel, “D,” was completed for you as an example.

<table>
<thead>
<tr>
<th>Air Parcel</th>
<th>Temperature °C</th>
<th>Saturation Mixing Ratio (g/kg)</th>
<th>Parcel Mixing Ratio (g/kg)</th>
<th>RH %</th>
</tr>
</thead>
<tbody>
<tr>
<td>D</td>
<td>10</td>
<td>7.762</td>
<td>3.415</td>
<td>44</td>
</tr>
<tr>
<td>E</td>
<td>16</td>
<td></td>
<td>3.511</td>
<td></td>
</tr>
<tr>
<td>F</td>
<td>16</td>
<td></td>
<td>10.890</td>
<td></td>
</tr>
<tr>
<td>G</td>
<td>32</td>
<td></td>
<td>30.000</td>
<td></td>
</tr>
<tr>
<td>H</td>
<td>32</td>
<td></td>
<td>10.890</td>
<td></td>
</tr>
</tbody>
</table>

2. Which parcel(s) on Table 5 have the highest relative humidity?

3. Which parcel(s) on Table 5 contain the most water vapor?
Table 6: Saturation Mixing Ratio values as a function of air temperature.

<table>
<thead>
<tr>
<th>Temperature (°C)</th>
<th>Saturation Mixing Ratio (g/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>-40</td>
<td>0.118</td>
</tr>
<tr>
<td>-35</td>
<td>0.195</td>
</tr>
<tr>
<td>-30</td>
<td>0.318</td>
</tr>
<tr>
<td>-25</td>
<td>0.51</td>
</tr>
<tr>
<td>-20</td>
<td>0.784</td>
</tr>
<tr>
<td>-18</td>
<td>0.931</td>
</tr>
<tr>
<td>-16</td>
<td>1.102</td>
</tr>
<tr>
<td>-14</td>
<td>1.3</td>
</tr>
<tr>
<td>-12</td>
<td>1.529</td>
</tr>
<tr>
<td>-10</td>
<td>1.794</td>
</tr>
<tr>
<td>-8</td>
<td>2.009</td>
</tr>
<tr>
<td>-6</td>
<td>2.45</td>
</tr>
<tr>
<td>-4</td>
<td>2.852</td>
</tr>
<tr>
<td>-2</td>
<td>3.313</td>
</tr>
<tr>
<td>0</td>
<td>3.819</td>
</tr>
<tr>
<td>2</td>
<td>4.439</td>
</tr>
<tr>
<td>4</td>
<td>5.12</td>
</tr>
<tr>
<td>6</td>
<td>5.894</td>
</tr>
<tr>
<td>8</td>
<td>6.771</td>
</tr>
<tr>
<td>10</td>
<td>7.762</td>
</tr>
<tr>
<td>12</td>
<td>8.882</td>
</tr>
<tr>
<td>14</td>
<td>10.14</td>
</tr>
<tr>
<td>16</td>
<td>11.56</td>
</tr>
<tr>
<td>18</td>
<td>13.162</td>
</tr>
<tr>
<td>20</td>
<td>14.956</td>
</tr>
<tr>
<td>22</td>
<td>16.963</td>
</tr>
<tr>
<td>24</td>
<td>19.21</td>
</tr>
<tr>
<td>26</td>
<td>21.734</td>
</tr>
<tr>
<td>28</td>
<td>24.557</td>
</tr>
<tr>
<td>30</td>
<td>27.694</td>
</tr>
<tr>
<td>32</td>
<td>31.213</td>
</tr>
<tr>
<td>34</td>
<td>35.134</td>
</tr>
<tr>
<td>36</td>
<td>39.502</td>
</tr>
<tr>
<td>38</td>
<td>44.381</td>
</tr>
<tr>
<td>40</td>
<td>49.815</td>
</tr>
</tbody>
</table>
Activity #5: Mixing Two Unsaturated Air Parcels to form Fog

“Mixing Fog,” also known as evaporation fog, forms when two unsaturated parcels of air with different temperatures mix together and create the right temperature to raise the relative humidity of the mixed parcel to 100%. This activity will demonstrate how mixing fog forms.

1. Plot and label air parcels E, F, G, and H from Table 5 (two pages back) onto the graph of saturation mixing ratios in Figure 1 on the next page. Point D was plotted for you as an example. Notice how each point is to the right of the Saturation Mixing Line.

Points that plot directly on the Saturation Mixing Line have 100% humidity. The temperature for any points that plot directly on the mixing line are equal to the dew point temperature. To find the dew point temperature for an unsaturated air parcel, start from the plotted point and go to the left until you hit the saturation mixing line. Then, read the temperature value on the bottom axis. Point “D” was completed for you as an example.

2. Use Figure 1 on the next page to find the Dew Point Temperatures for points E, F, G, and H:

D: -2°C
G: __________
E: __________
H: __________
F: __________

3. Let’s say air parcels F and G mix together to form a new parcel, parcel “X.” Use the average temperature and mixing ratios from parcels F and G to find the air temperature and mixing ratio of parcel X. Show all math work on separate scratch paper.

Air Temperature of Parcel X: __________
Mixing Ratio of Parcel X: __________

4. Plot parcel X on Figure 1 on the next page.

5. Is Parcel X saturated, unsaturated, or supersaturated?

6. If parcels F and G mix together at the surface, will fog form?
Figure 1: Graph of saturation mixing ratios, plotted along the blue line. Values that plot to the right of the saturation mixing line are unsaturated, values that plot to the left of the line are supersaturated. Air parcel “D” is plotted in red. The red arrow points to the saturation mixing ratio for this parcel along the dotted blue line, and the dew point temperature for the parcel is approximately -2°C read from the bottom axis.
Lab #8: Cloud Formation Processes and Cloud Identifications

OBJECTIVES:
- Students will determine the main processes that build different clouds.
- Students will identify different types of clouds.

INSTRUCTIONS:
- Print out these pages or use a graphics tablet to write in the areas provided.
- Email a copy of your completed lab to the instructor for feedback.
- Save the completed lab as a single PDF and upload to Brightspace.

Part 1: Cloud Formation Processes

Clouds are made of water droplets or ice crystals that are so small and light that they can stay suspended in the air. But how does the water and ice that makes up clouds get into the sky? And why do different types of clouds form?

The water or ice that in clouds travels into the sky within the air as water vapor. Water vapor gets into air mainly by evaporation – some of the liquid water from the ocean, lakes, and rivers turns into water vapor and travels in the air. As air rises in the atmosphere it gets cooler and expands. When air cools, it can no longer hold as much water. The vapor condenses into small water droplets or ice crystals and a cloud is formed.

It is easier for water vapor to condense into water droplets when it has a particle to condense onto. These particles, such as dust and pollen, are called condensation nuclei. Eventually, enough water vapor condenses onto pieces of dust, pollen or other condensation nuclei to form a cloud.
Cloud Formation Process #1: Convective uplift

**Figure 1:** Some clouds form as air warms up near the ground and rises (Figure 1). Heated by sunshine, the ground heats the air just above it. That warmed air starts to rise because, when warm, it is lighter and less dense than the air around it. As it rises, its pressure and temperature drop causing water vapor to condense. Eventually, enough moisture will condense out of the air to form a cloud. Several types of clouds form in this way including cumulus, cumulonimbus, mammatus, and stratocumulus clouds.

Cloud Formation Process #2: Lifting along topography

**Figure 2:** Some clouds, such as lenticular and stratus clouds, form when wind blows into the side of a mountain range or other terrain and is forced upward, higher in the atmosphere. The side of the mountains that the wind blows towards is called the windward side. The side of the mountains where the wind blows away is called the leeward side. This can also happen without a dramatic mountain range, just when air travels over land that slopes upward and is forced to rise. The air cools as it rises, and eventually clouds form. Other types of clouds, such as cumulus clouds, form above mountains too as air is warmed at the ground and rises.
Cloud Formation Process #3: Convergence of Air Masses

**Figure 3:** Two air masses with converging wind will force air to rise at the boundary between the two air masses.

Cloud Formation Process #4: Uplift along weather fronts

**Figure 4:** At a warm front, a warm air mass is lifted above a cold air mass at a gradual angle. The warm air is pushed upward forming stratus-type clouds including low stratus clouds (St) and nimbostratus clouds (Ns) near the surface, midlevel altostratus clouds (As), and high cirrostratus (Cs) clouds.
**Figure 5:** At a cold front, a dense, cold air mass pushes a warm air mass upward, creating cumulus clouds. They often grow into cumulonimbus clouds, which produce thunderstorms.

**Question #1:** Describe the process that causes clouds to form on the windward side of mountains.

**Question #2:** Describe the conditions that can cause a warm air parcel to rise and form a cloud.

**Question #3:** How do clouds form from converging air?

**Question #4:** Describe how cumulus congestus clouds can form along a cold front.
Part 2: Cloud Identifications

In this section of the laboratory assignment, you will need to go outside to look at clouds in the sky.

Weather Conditions (you may use a weather app to look these up online):

Outdoor Air Temperature: _________________ Celsius

Surface Pressure: _________________ mb

1. Draw sketches of at least 3 different cloud types. You may need to look outside several times throughout the day or the week to see different cloud shapes. Write the date and time of your observations on each sketch. Use the extra pages at the end of this lab to draw sketches if more space is needed.
2. Write a description of and identify the clouds that you sketched. Use descriptions from pages Chapter 4 and the cloud guide in the back of your textbook.

3. Use Table 4.2 in your textbook to determine the approximate height of these clouds in feet above sea level.

4. Describe the processes that most likely caused these clouds to form –see Figures 1-5 and the background information at the beginning of this exercise for examples. Hint: You may want to look at an online map to see if you are near any elevated regions, like the Taconics, Catskills, or Mount Beacon.

5. Refer to the surface air temperature and think about adiabatic temperature changes with altitude to determine the composition of each of the clouds you identified.
Lab #9: Atmospheric Stability

OBJECTIVES:
- Students will determine the stability of the troposphere by interpreting examples of atmospheric temperature and dew point conditions.

INSTRUCTIONS:
- Print out these pages or use a graphics tablet to write in the areas provided.
- Email a copy of your completed lab to the instructor for feedback.
- Save the completed lab as a single PDF and upload to Brightspace.

MATERIALS:
- Calculator
- Graph Paper OR Excel or compatible software

Part 1: Adiabatic Cooling
Adiabatic cooling is the process of a parcel of air cooling as it rises and expands without mixing with its surrounding environment. Therefore, the temperature of the parcel will change independently from the environment.

The rate of cooling for a dry parcel of air as it rises in the atmosphere is called the dry adiabatic lapse rate, or DALR. A parcel of air is considered as dry if it contains no condensed water droplets and the relative humidity of the parcel is less than 100%. For all parcels of air with relative humidity less than 100%, the DALR is 1°C/100 m or 10°C/km. The temperature will drop by 1°C for every 100 m the parcel rises, and for every 1,000 m or 1 km the parcel rises, its temperature will drop adiabatically by 10°C.

The rate of cooling for a wet parcel of air as it rises in the atmosphere is called the wet adiabatic lapse rate, or WALR. A parcel of air that has 100% humidity is considered wet, or saturated. The WALR is between 5-10°C/1000 m. A saturated air parcel will cool adiabatically at a lower rate than a dry parcel because of the release of latent heat as water vapor condenses to liquid water droplets within the parcel. The wet adiabatic lapse rate will vary between 5°C and 10°C depending on the amount of moisture present in the parcel.

As a dry air parcel rises and expands, its dew point will change, as well. The dew point lapse rate is 2°C/1000 m.
Activity #1: Dry Adiabatic Lapse Rate

1. Calculate the temperature of a rising parcel for every 100 m it rises from the surface to 1000 m (1 km) in Figure 1, below. Enter the temperatures in the spaces provided on the figure below. The surface temperature is 28°C and the temperature at 100 m above sea level is given.

![Figure 1: A parcel of air is rising at the dry adiabatic lapse rate.](image)

2. What will the temperature of the parcel of air from question #1 be at the following altitudes using the dry adiabatic lapse rate:

   1500 m: _________________________
   2000 m: _________________________
   2500 m: _________________________
Activity #2: Finding the Lifting Condensation Level Using Surface Temperature and Dew Point Measurements

The lifting condensation level (LCL) is the height at which water vapor will condense to liquid droplets and clouds can form. This level is reached when the air temperature of a parcel equals the dew point temperature, and the relative humidity is 100%. The height of the LCL can be calculated using the surface temperature and dew point with the following formula:

\[ \text{LCL} = \frac{\text{Temperature} - \text{Dew Point}}{8^\circ C} \times 1000 \text{ m} \]

The height of the LCL can also be found by using the adiabatic lapse rates of the parcel air temperature and dew points to locate the elevation where the air temperature is equal to the dew point.

1. Calculate the LCL for each of the following air parcel temperature and dew point data. Show all work.

a) Surface temperature = 30°C, Dew Point = 14°C

b) Surface temperature = 15°C, Dew Point = 7°C

c) Surface temperature = 25°C, Dew Point = 8°C
2. Use the dry adiabatic lapse rate to find the parcel air temperatures and the dew point lapse rate to find the dew point temperatures at each elevation in Table 1. Start from the surface temperature and dew points at the bottom of the table.

**Table 1: Temperature and Dew Points from the Surface to 4000 m elevation**

<table>
<thead>
<tr>
<th>Height (m)</th>
<th>Temperature (°C)</th>
<th>Dew Point Temperature (Td, °C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1500</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>500</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>32</td>
<td>0</td>
</tr>
</tbody>
</table>

3. At what height does the air temperature equal the dew point temperature? What is the relative humidity at this elevation?

**Activity #3: Using the Dry and Wet Adiabatic Lapse Rates to Compare Moisture Content of Air Parcels**

Whereas the dry adiabatic lapse rate is always the same, an air parcel may cool at different rates once it reaches saturation depending on its water vapor content. More water vapor will release more heat once it reaches saturation, which reduces the lapse rate. A parcel with less water vapor will not release as much heat because there will be less condensation of water vapor to liquid water droplets.

1. Table 2 contains air temperature information for three different air parcels, Parcel #1, Parcel #2, and Parcel #3. Each parcel starts with the same surface temperature, but each parcel has a different water vapor content and, therefore, different wet adiabatic lapse rates. The LCL for all parcels is located at 2km elevation.
   a. Draw a line across the table at 2km and label it “LCL.”
   b. Use the Dry Adiabatic Lapse rate to figure out the air temperatures for each parcel UP TO the LCL at 2km.
   c. Use the following wet adiabatic lapse rates for each of the parcels to fill in the temperatures ABOVE the LCL:
      - Parcel #1: 6°C/1000 m
      - Parcel #2: 5°C/1000 m
      - Parcel #3: 7°C/1000 m
Table 2: Air Temperature Data for Three Parcels from 0 – 5000 m elevation

<table>
<thead>
<tr>
<th>Height (m)</th>
<th>Parcel #1 Temperature (°C)</th>
<th>Parcel #2 Temperature (°C)</th>
<th>Parcel #3 Temperature (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1500</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>500</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>30</td>
<td>30</td>
<td>30</td>
</tr>
</tbody>
</table>

2. Based on the wet adiabatic lapse rates of each parcel, which parcel had the highest water vapor content?

Part 2: Orographic Uplift
When wind hits an obstruction, such as a building or a mountain, the air cannot go through it, so it is forced upwards. The geologic term for a large mountain range is “orogeny.” **Orographic uplift** is the lifting of air from wind hitting the windward side of a mountain range and being forced to rise. This air may not have time to sit and mix with the surrounding environment as it rises, so it cools adiabatically. The air rising on the windward side of a mountain will cool at the dry adiabatic lapse rate of 10°C/1000 m until it reaches its lifting condensation level (LCL). Above the LCL, if the air continues to be forced upwards, the temperature will cool by the wet adiabatic lapse rate, which varies based on the moisture content of the parcel. All the moisture is usually released on the windward side of a mountain as fog, clouds, and precipitation. When the wind rises to the top of the mountain, it is dry and falls down the leeward side of the mountain from the force of gravity pushing it down. As the parcel of air falls, it compresses and warms adiabatically. Since the parcel of air is no longer saturated, as it falls, it heats up by the dry adiabatic lapse rate, or 10°C/1000 m. The lapse rate of the falling air is much larger than the wet lapse rate by which it rose, so by the time it reaches the bottom of the leeward side of the mountain, the wind is much hotter and dryer than the wind going up the windward side of the mountain. The falling, warm, dry air creates high pressure at the surface. Therefore, the lee-side of mountain ranges are often arid climates. Deserts that form on the leeward side of mountains are called **“Rain Shadow”** deserts because the air is dried from traveling over the mountain range.
In the following example, fill in the blanks for temperature and dew point temperature as air rises up the windward side of the mountain and falls down the leeward side of the mountain.

**Activity #4: Adiabatic Temperatures of Air Rising and Falling Along a Mountain**

1. For the following mountain example, the surface air temperature is 25°C and the surface dew point is 17°C. Calculate the LCL and label it on the windward side of the mountain.

2. Fill in the temperatures and dew points at letters A through G, assume that the air is steadily rising up the windward side at the dry adiabatic rate until it reaches the LCL. The dew point temperature will drop by the dew point lapse rate of 2°C/1000 m until the LCL. Above the LCL, the temperature and dew point will drop by the wet adiabatic lapse rate of 6°C/1000 m until point D. After point D, the air will fall and its temperature will rise by the dry adiabatic lapse rate and the dew point will rise by the dew point lapse rate.

**Figure 2:** Orographic uplift of air along a mountain.

3. Draw a cloud where it might form on Figure 2.

4. What are the differences between the moisture contents of Point A and Point G?

5. What is the term used for the type of desert that may form at Point G?
Part 3: Atmospheric Stability and Vertical Cloud Development

In each of the previous sections, we considered air parcels being forced upwards and their temperature dropping adiabatically—that is, without mixing with the air of the surrounding environment.

However, the continual rising of an air parcel in the absence of any other force (for example, once the air reaches the top of a mountain) depends on the stability of the surrounding environment. A parcel of air will continue to rise if the temperature of the surrounding environment is lower than the parcel’s temperature. If the surrounding environment is stable, the air temperature of the parcel will always be cooler than the environment, so it will not be able to rise without any force pushing it up. If the surrounding environment is absolutely unstable, then the parcel temperature will always be higher than the surrounding environment and no additional force is necessary for it to continue to rise. In a conditionally unstable environment, the environment may be stable close to the surface, but its lapse rate will change with greater instability with height. In this case, the amount of water vapor in the air parcel will determine whether or not its temperature will be high enough to continue to rise through the stable part of the environment and into the unstable height. If the parcel is able to rise past the stable environment, it will continue to rise through the unstable environment without additional force.

The environmental temperature change is determined by measuring the temperatures at different altitudes with a radiosonde. The environmental lapse rate (ELR) is the rate that the temperature cools with elevation. The stability of the environment is determined by the ELR as follows:

\[
\begin{align*}
\text{ELR} &< 5°C/1000 \text{ m} & \text{Absolutely Stable} \\
\text{ELR} &\text{ between } 5°C - 10°C/1000 \text{ m} & \text{Conditionally Unstable} \\
\text{ELR} &> 10°C/1000 \text{ m} & \text{Absolutely Unstable}
\end{align*}
\]

Activity #5: Plot Environmental and Parcel Air Temperatures to Determine Stability and Vertical Cloud Development

1. Complete the missing parcel temperatures and dew point temperatures in Tables 3 through 5. Use a wet adiabatic lapse rate of 6°C/1000m for each parcel.
2. Create a line graph with graph paper or a graphing program (MS Excel or Google Sheets) to plot the environmental air temperature, the parcel air temperature, and the parcel dew point temperature for Tables 3 through 5 as separate lines connecting points. Label each plot separately (you may use different colors and/or symbols for each plot).
3. Label the LCL on each of the three graphs.
4. Determine the stability of each of the environments—Absolutely Stable, Conditionally Unstable, or Absolutely Unstable and write it on the graph.
5. Draw clouds on the graphs at the locations they will form.
Table 3: Environment and Parcel Example #1, WALR = 6°C/1000m

<table>
<thead>
<tr>
<th>Height, m</th>
<th>Environmental Temperature, °C</th>
<th>Parcel Temperature, °C</th>
<th>Parcel Dew Point Temperature, °C</th>
</tr>
</thead>
<tbody>
<tr>
<td>5000</td>
<td>15</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4000</td>
<td>18</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3000</td>
<td>21</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2000</td>
<td>24</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1000</td>
<td>27</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>30</td>
<td>30</td>
<td>14</td>
</tr>
</tbody>
</table>

Table 4: Environment and Parcel Example #2, WALR = 6°C/1000m

<table>
<thead>
<tr>
<th>Height, m</th>
<th>Environmental Temperature, °C</th>
<th>Parcel Temperature, °C</th>
<th>Parcel Dew Point Temperature, °C</th>
</tr>
</thead>
<tbody>
<tr>
<td>5000</td>
<td>-25</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4000</td>
<td>-14</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3000</td>
<td>-3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2000</td>
<td>8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1000</td>
<td>19</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>30</td>
<td>30</td>
<td>14</td>
</tr>
</tbody>
</table>
Table 5: Environment and Parcel Example #3, WALR = 6°C/1000m

<table>
<thead>
<tr>
<th>Height, m</th>
<th>Environmental Temperature, °C</th>
<th>Parcel Temperature, °C</th>
<th>Parcel Dew Point Temperature, °C</th>
</tr>
</thead>
<tbody>
<tr>
<td>5000</td>
<td>-9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4000</td>
<td>-2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3000</td>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2000</td>
<td>12</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1000</td>
<td>19</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>26</td>
<td>26</td>
<td>18</td>
</tr>
</tbody>
</table>
Lab #10: Weather Map Interpretations

OBJECTIVES:
- Students will interpret weather station symbols.
- Students will draw weather station symbols for various weather elements.
- Students will interpret and compile weather maps based on weather station data.

INSTRUCTIONS:
- Print out these pages or use a graphics tablet to write in the areas provided.
- Email a copy of your completed lab to the instructor for feedback.
- Save the completed lab as a single PDF and upload to Brightspace.

MATERIALS:
- Printer or graphics tablet with stylus

Part 1: Weather Station Symbols
Symbols used on weather maps can be found in Appendix C of your textbook.

Wind direction is determined by the direction the wind is traveling from. If you stand facing the wind and you are facing due north, the wind is a north wind. If you stand facing the wind and you are facing due south, the wind is a south wind.

Wind direction is plotted on a weather station point with a straight line going towards the weather station. Figure 1 demonstrates how different wind directions are plotted on a weather map. The weather station symbol is a circle and the line designates the wind direction. The “wind rose” in Figure 2 shows wind directions on a compass.

**Figure 1 (Right):** Wind direction symbol showing a wind coming from the north.
Figure 2: Wind rose showing compass directions of winds.

Wind speeds are shown on the end of a wind direction line and are referred to as “barbs.” Appendix C in your textbook, page 469, shows the symbols for wind barbs in miles per hour, knots, and kilometers per hour.
**How to Decode Air Pressure on a Weather Station Model:**

Air pressure in mb is coded as a 3-digit symbol on most weather station models. Follow these steps to “decode” the 3-digit pressure symbol:

A. Start with the 3-digit code, e.g., 999
B. Place a decimal point in between the two digits on the right: 99.9
C. Add either a “9” or a “10” to the left of the three digits, so the number becomes either 999.9 OR 1099.9.
D. Select the decoded value that is in between 950 and 1050. In this case, 1099.9 is too high, but 999.9 is in between 950 and 1050. Therefore, the correctly decoded air pressure is 999.9 mb.

To decode the **pressure tendency**, insert a decimal point in between the two digits given. For example, if the pressure tendency on the weather station model is “-22,” the actual air pressure has dropped 2.2 mb in the last three hours.

**Activity #1: Decoding 3-digit Air Pressure Codes**

Decode the following 3-digit codes for air pressure:

1. 301 _________ 3. 980 _________
2. 890 _________ 4. 026 _________
Activity #2: Interpreting and Drawing Weather Station Models

1. Use Appendix C in your textbook or the National Weather Service Weather Map Symbols (separate attachment online) to interpret the wind direction, speed (miles per hour), and cloud coverage on the following weather station models:

   a) Direction: _______    Speed: _______    Clouds: _______

   b) Direction: _______    Speed: _______    Clouds: _______

   c) Direction: _______    Speed: _______    Clouds: _______

2. Use Appendix C in your textbook or the National Weather Service Weather Map Symbols (separate attachment online) to interpret the wind direction, speed, temperature, dew point, precipitation, cloud coverage, decode air pressure, and pressure tendency for the following weather station models.

   a) Wind Direction: __________

      Wind Speed: __________

      Cloud Coverage: __________

      Temperature: __________

      Dew Point: __________

      Precipitation: __________

      Air Pressure: __________

      Pressure Tendency: __________
b) Wind Direction: __________
   Wind Speed: __________
   Cloud Coverage: __________
   Temperature: __________
   Dew Point: __________
   Precipitation: __________
   Air Pressure: __________
   Pressure Tendency: __________

c) Wind Direction: __________
   Wind Speed: __________
   Cloud Coverage: __________
   Temperature: __________
   Dew Point: __________
   Precipitation: __________
   Air Pressure: __________
   Pressure Tendency: __________
3. Use Appendix C in your textbook or the National Weather Service Weather Map Symbols (separate attachment online) to fill in the empty weather station model with the given information:

Wind Direction: WSW

Wind Speed: 16 mph

Cloud Coverage: Broken

Temperature: 45°F

Dew Point: 10°F

Precipitation: Light drizzle

Air Pressure: 1012.6

Pressure Tendency: Rising 1.0 mb in the last three hours

Part 2: Isolines on Weather Maps

**Isolines**, or contour lines, are lines on a map that connect points of equal value from different weather stations on a map.

**Figure 3 (Left): Isotherms** are isolines that connect weather stations or areas with the equal temperature. These lines may be solid, dashed red, or color coded on a weather map. The isotherms are labeled on the left side of this map and have an interval of 10°F.

**Figure 4 (Right): Isodrosotherms** are isolines that connect weather stations or areas with equal dew points. These lines are often drawn as dashed red lines on a weather map.
**Figure 5 (Right): Isobars** are isolines that connect weather stations or areas with equal air pressure. Isobars are drawn for every 4 mb from 1000 mb. In this example, the isobars are drawn with solid black lines and labeled in blue. Weather station air pressure measurements are shown in black numbers for millibars. For this example, the isobars form circles around high and low pressure systems.

**Activity #3: Drawing Isolines on Weather Maps**

1. Draw and label isotherms using solid lines to connect points of equal temperature on the following map with an interval of 10°F between each line.
2. Draw and label isodrosotherms using dashed lines to connect areas of equal dew point on the following map with an interval of 10°F between each line:\[\text{Surface Dewpoint Map}\]

3. Draw and label isobars using solid lines to connect areas of equal pressure on the following map with an interval of 4 mb between each line. Label the region of highest pressure with an “H” and the region of lowest pressure with an “L”:\[\text{Surface Air Pressure Map}\]
Part 3: Identifying Air Masses and Weather Fronts on a Weather Map

Air masses are large parcels of air with similar temperature, humidity, pressure, and wind characteristics that span areas that can cover several states or an entire region on a map. Air masses develop in regions of stable pressure, but are pushed by upper air winds, like the polar jet stream, to different regions. The boundary between two air masses on a surface weather map is the location of a weather front.

Warm Front: A warm air mass is moving into a region of colder temperatures.

Cold Front: A cold air mass is moving into a region of warmer temperatures.

Activity #4: Identify Air Masses and Weather Fronts on Weather Maps

1. Draw circles around different air masses on the following map based on the wind barbs, temperatures, and dew points given at the weather stations. Note that air pressure is given in tenths of millibars (coded) at each weather station.
2. Draw large arrows within each air mass to show the general wind direction within each air mass on the following weather map.
3. Draw isobars for every 4 mb on the following map.
4. Use Appendix C in your textbook or the National Weather Service Weather Map Symbols (separate attachment online) to draw the correct symbols for one warm front and one cold front on the following weather map.
Lab #11: Weather Fronts and Mid-Latitude Cyclones

OBJECTIVES:
- Students will classify weather fronts based on temperature and humidity characteristics.
- Students will track and draw weather fronts on an idealized weather map.
- Students will assess cyclogenesis probability by interpreting surface and upper air conditions from weather maps.

INSTRUCTIONS:
- Use the lecture materials for Chapter 8 as background information and to reference while completing this lab.
- Print out these pages or use a graphics tablet to write in the areas provided.
- Email a completed draft of this lab to your instructor for feedback.
- Save the completed lab as a single pdf document and submit to Brightspace.

Part 1: Air Masses and Fronts

Activity #1: Air Masses
1. Complete the chart below by listing the full names of six different air masses, the two-letter abbreviations, and the relative temperature and humidity characteristics for each air mass (i.e., warm/cool/hot/cold; moist/dry).

<table>
<thead>
<tr>
<th>Full Name</th>
<th>2-letter Abbreviation</th>
<th>Relative Temperature/Humidity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Activity #2: Weather Fronts
For each of the following examples: Identify the type of weather front based on the air masses and relative motion given by arrows. Air temperatures and dew points may be included to help identify some of the fronts. Finally, draw the correct symbol for each front on the map.

1. Type of Front: _______________

2. Type of Front: _______________
3. Type of Front: _______________

![Diagram of Front cP and mT]

4. Type of Front: _______________

![Diagram of Front cP, mT, and L with mP]
5. For this example, use the temperatures and dew points (humidity) to determine the location of the boundary between the air masses and draw the symbol for the front in the correct location.

Type of Front: _______________
Activity #3: Map the Moving Fronts
The following map shows a cold front advancing at 300 miles per day to the northeast and a warm front advancing at 100 miles per day to the northeast. Use the scale at the bottom of the map to determine the locations of the fronts in one day. Draw the new locations of the warm and cold fronts on the map and any additional fronts that may develop if the cold front and warm front intersect.
Part 2: Mid-Latitude Cyclones

Mid-Latitude Cyclones are synoptic-scale spiraling systems in the extra-tropical regions of the earth. These systems are also referred to as extratropical cyclones because they develop in latitudes outside of the tropics. A cyclone is a system of converging wind that spirals inwards towards a point of low pressure. In the northern hemisphere, cyclones spiral inwards in a counterclockwise direction. In the southern hemisphere, cyclones spiral outwards in a clockwise direction. An anticyclone is a system of diverging wind that spirals outwards from a point of high pressure. In the northern hemisphere, anticyclones spiral outwards in a clockwise direction. In the southern hemisphere, anticyclones spiral outwards in a counterclockwise direction. The following set of activities will demonstrate the concepts of converging and diverging winds, convection systems, the polar front theory of extratropical cyclone development, and the “Norwegian Model” of mid-latitude cyclones.

Activity #1: Draw Converging and Diverging Winds around Low and High Pressure Systems

1. Draw arrows inside of each of the following boxes to show the surface wind direction around the “H” and “L,” for high and low pressure, respectively. Give the name of the type of wind (cyclonic or anticyclonic).

Northern Hemisphere:

Wind Name: _____________  _____________
Southern Hemisphere:

Activity #2: How Air Aloft impacts developing Lows and Highs at the Surface
Each of the following diagrams are cross-section profiles of different atmospheric conditions at the surface and aloft. The arrows show the direction of air advection, “H” represents a region of high pressure, and “L” represents a region of low pressure. Circle the diagram that will most readily support cyclogenesis.
Activity #3: The Polar Front Theory

1. Draw and Label each step of the Polar Front Theory in the following empty boxes. Describe each step on the lines beside each box. Use **only** lecture materials as reference.
Activity #4: Interpreting Upper Air Charts

1. For the following 500 mb upper air chart:
   a. Draw large arrows showing wind direction around the trough.
   b. Identify an area of convergence with a large “C.”
   c. Identify an area of divergence with a large “D.”
   d. Circle and area of cold air advection and write a “C” inside the circle.
   e. Circle and area of warm air advection and write a “W” inside the circle.

2. For the 300 mb upper air chart on the right:
   a. Circle the Jet Streak
   b. Draw arrows showing the movement of the Polar Jet Stream.
3. Interpreting Surface and Upper Air Charts

The following maps are surface and upper air charts that track a developing mid-latitude cyclone from 2/13/2021 to 2/17/2021. You may use this website to find the same archived maps to view a larger copy: [https://www.spc.noaa.gov/obswx/maps/](https://www.spc.noaa.gov/obswx/maps/). Answer the questions after each set of surface and 500mb maps for every 12 hours. No upper air charts are available for the time of 2/16/2021 1200Z so the 500mb map for this time not included in the following sequence.

Maps from 2/13/2021 1200Z:

**Surface**

![Surface Map](image)
1. Circle three “L’s” on the surface map from 2/13/2021 at 1200Z. Label them 1, 2, and 3 on the map.

2. What is the local time for each of the following time zones for these two maps:
   
   a. PST: ____________________
   
   b. MST: ____________________
   
   c. CST: ____________________
   
   d. EST: ____________________

3. Geostrophic wind follows elevation contour lines on upper air charts and is not slowed down by gravity. These winds push low pressure systems at the surface. For each of your labeled surface lows, draw arrows on the surface map to show the direction each low is pushed by the upper level (500mb) wind.
4. Upper level winds will push surface pressure systems at approximately 75% of their speed. Calculate 75% of each wind speed from the 500mb maps for the regions of surface lows #1, 2, and 3. Show all work next to your answers or in the space below.

#1: ______________________

#2: ______________________

#3: ______________________

5. Based on the wind speeds calculated in #3, approximately how long will it take for each low pressure system to travel 2,400 miles, the approximate distance from the Sierra Nevada Mountains to the Appalachian Mountains (show all math work in the space below for credit)?

6. What day should each low pressure system arrive in the Eastern U.S. if they continue to develop and move at the same rate?
Maps from 2/14/2021 0000Z:
Surface
7. Only two low pressure systems remain on the surface map for 2/14/2021 0000Z. Which low pressure systems (from #1, 2, and 3 on the surface map from 2/13/2021) continue to develop?
Maps from 2/14/2021 1200Z:
Surface
8. How many surface lows remain in the southwestern region? Circle the two new surface lows that developed in the eastern coastal region of the U.S. on the surface map from 2/14/2021 1200Z. Label them #1 and #2.
Maps from 2/15/2021 0000Z:
Surface Map:
500mb Map:
Maps from 2/15/2021 1200Z:
Surface Map:
Maps from 2/16/2021 0000Z:
Surface Map:
500mb Map:
Surface Map from 2/16/2021 1200Z (500mb chart unavailable):
Maps from 2/17/2021 0000Z:
Surface Map:
9. Find and circle 4 “L’s” on the surface map from 2/17/2021 000Z. On the surface map from 2/13/2021 1200Z (first surface map figure in this section), write a large “X” to show the locations of the low pressure systems that were circled on the surface map from 2/17/2021 0000Z. Use the locations from all of the maps in between these two times to draw arrows on the 2/13/2021 1200Z surface map to show the paths that any of the low pressure systems took to reach their final point. Note that not all of the Lows were present on 2/13/2021.

10. Label the following terms on every 500mb map with their abbreviations

   a. Trough Axis
   b. Ridge Axis
   c. Areas of strong convergence – CON
   d. Areas of strong divergence – DIV
   e. Circle regions of warm (W) and cold (C) air advection
11. Write the date and time of the 500mb map that has the strongest convergence and divergence.

12. Explain how surface lows were or were not supported by strong convergence and divergence aloft for at least two of the times shown from 2/13/2021 to 2/17/2021.
Lab #12: The Impact of Tropical Cyclones on Human Society

OBJECTIVES:
- Students will demonstrate the life cycle of a tropical cyclone.
- Students will research and discuss the impact of selected Category 5 tropical cyclones on human society.

INSTRUCTIONS:
- Use the lecture materials for Chapter 11 in the textbook.
- Submit the answers to this lab as a single PDF document.

Part 1: Key Ingredients of Tropical Cyclogenesis
Activity #1: Answer the following questions based on the lecture material for Tropical Cyclones.

1. What is the minimum sea surface temperature (in °C) required for cyclogenesis?

2. Circle the regions on the map in Figure 1 (next page) that have SSTs higher than the minimum required temperature for cyclogenesis.

3. View the wind shear map shown in Figure 2. Does the vertical wind shear align with areas of higher than minimum SST in Figure 1? If so, circle the region where cyclogenesis would be possible.
Figure 1: Global Sea Surface Temperatures from June 27, 2023.
Figure 2: Vertical Wind Shear tendency from June 28, 2023 – June 29, 2023
Part 2: Impacts of Hurricanes on Human Life and Civilization

Activity #1: Research a hurricane to find its impact on human life.
1. Use the school library or a search engine to find at least 2 articles on the impact of a hurricane or a hurricane season on humans.
2. Obtain approval from the instructor to use the chosen articles.
3. Write a 1-2 page summary about the hurricane or hurricane season of your choice using the following format:

   First Paragraph: 3-5 sentences that introduce the topic. Include the following information within the paragraph:
   1. Name and date of the hurricane.
   2. Locations impacted by the hurricane.
   3. Any other important, general information about the areas impacted by the hurricane.

   Middle Paragraph(s): 5-6 sentences that include more details about the information introduced in the first paragraph. Each “middle” paragraph should include information on ONLY one topic. Information may include the following:
   1. Demographic information about the people most heavily impacted by the hurricane (i.e., class, racial, gender, and any additional information about those affected by the hurricane).
   2. Total loss of resources, injuries, deaths directly and/or indirectly due to hurricane damage.
   3. Lasting impacts of the hurricane damage—how long did it take to recover losses, what were the total economic damages?

   Third Paragraph: Conclusion statement: Rewrite a summary of the information provided in the middle paragraphs.

Notes about scientific writing:
Scientific writing is in the third person. Do not include any personal statements containing the words “I,” “me,” “myself,” etc. Do not include information related to how you feel about the information, this is a report based on evidence and data, not feelings or emotions.
Activity #2: Proofread a summary provided by another student.
1. Always begin your review with at least one positive statement about something specific you read in their writing.
2. Check for statements that include personal information, the words “I,” “me,” “myself.” Give suggestions on how the student can change the sentence. For example:

   A student writes: “I feel like this was the worst hurricane ever to hit Puerto Rico.”

   Suggestion: “This hurricane resulted in large financial and personal losses in Puerto Rico because…”

3. Check that only general, introductory information is given in the first paragraph. Specific information and details should be given only in the middle paragraphs.
4. Check that each “middle” paragraph contains information about a single topic. If multiple topics or issues are covered within the same paragraph, they should be related or separated into different paragraphs.
5. Check the concluding paragraph to ensure that it is only a summary of what was stated in the middle paragraphs. New information should not be included in this paragraph.
6. Ask the writer for clarification on any sentence or statement that is unclear. Offer suggestions based on what you think the author meant.

Activity #3: Rewrite your summary.
1. Review the suggested revisions and recommendations from the student who reviewed your paper.
2. Remember that these are suggestions, not definite revisions that must be made. If you believe there is a better way to restate an argument or to clarify a sentence, go with what you, as the author, see as the best way to convey a message.
3. Submit your revised article review paper.
Lab #13: El Niño and the Southern Oscillation

OBJECTIVES:
- Track strong El Niño and La Niña events over the last century
- Identify ocean-atmosphere interactions in the equatorial Pacific that lead to the Southern Oscillation

INSTRUCTIONS:
- Print out these pages or use a graphics tablet to write in the areas provided.
- Email a copy of your completed lab to the instructor for feedback.
- Save the completed lab as a single PDF and upload to Brightspace.

MATERIALS:
- Pencil
- Dark marker
- Calculator

Part 1: El Niño and the Southern Oscillation

El Niño and the Southern Oscillation (ENSO)
El Niño and the Southern Oscillation is the term given to the changing climate phenomena, El Niño and La Niña. An oscillation is a backwards and forwards movement, like a moving fan. Therefore, ENSO is the movement from one climate extreme to another. The ENSO phenomenon is caused by the oscillation of warm water and atmospheric pressure differences from one side of the Pacific Ocean to the other as warm water is either contained in the western equatorial Pacific Ocean or moves across to the eastern equatorial Pacific Ocean. The warm water heats the air near the surface of the water, causing it to rise. As the air rises, it creates a gap or void in the air, creating low pressure at the surface. As air rises, it cools and condenses into liquid water droplets, forming clouds and stormy weather. Therefore, the location of the warm pool of water in the equatorial Pacific will generate low pressure and stormy weather in that region.

ENSO-Neutral Conditions
During “ENSO-Neutral” conditions, equatorial trade winds push warm water from east to west across the equatorial Pacific Ocean (Figure 1a). This creates a pool of warm water spread out across the Western Equatorial Pacific. Most of the atmospheric convection is centered around the Western Equatorial Pacific region. Surface water from the Eastern Equatorial Pacific is pulled towards the west, creating a void in the eastern surface water. This void causes cold deep water from below to be pulled upwards along the south and central American coasts, cooling the surface water.
**El Niño**
El Niño is considered the “warm” phase of ENSO (Figure 1b). Equatorial trade winds slacken, allowing the pool of warm water from the Western Equatorial Pacific to migrate eastward. Cold water is no longer pulled upwards, and the Eastern Equatorial Pacific surface water warms. Atmospheric convection is brought towards the central and eastern equatorial Pacific Ocean. There is higher pressure in the Western Equatorial Pacific, and lower pressure over the central and eastern Equatorial Pacific. This phenomena has a global effect by changing the position of semi-permanent high or low pressure zones, which can cause typically dry regions to become wet, and typically wet or humid climates to experience droughts. Meanwhile, the distribution of heat is also globally affected, and typically warmer regions may become cooler during an El Niño episode, while typically cooler regions may become warmer.

**La Niña**
During La Niña episodes, Pacific equatorial trade winds are stronger. Warm water is concentrated in the Western Equatorial Pacific, while colder water is pulled upwards in the Eastern Equatorial Pacific (Figure 1c). The surface ocean temperature and atmospheric pressure gradient between the eastern and western equatorial Pacific is enhanced, which can have an opposite global effect from El Niño episodes.

**The Southern Oscillation Index**
The Southern Oscillation Index (SOI) is a standardized index based on the observed sea level pressure differences between Tahiti and Darwin, Australia (Figure 2). The SOI is one measure of the large-scale fluctuations in air pressure occurring between the western and eastern tropical Pacific (i.e., the state of the Southern Oscillation) during El Niño and La Niña episodes. In general, smoothed time series of the SOI correspond very well with changes in ocean temperatures across the eastern tropical Pacific. The negative phase of the SOI represents below-normal air pressure at Tahiti and above-normal air pressure at Darwin. Prolonged periods of negative SOI values coincide with abnormally warm ocean waters across the eastern tropical Pacific typical of El Niño episodes and prolonged periods of positive SOI values coincide with abnormally cooler ocean waters across the eastern tropical Pacific, typical of La Niña episodes.
**Figure 1:** The phases of ENSO, Normal (a), El Niño (b) and La Niña (c).
**Figure 2:** The SOI generated from measured data, 1950-2018\(^{22}\).

**ENSO and North American Weather**

Figure 3 illustrates North American weather variability with different phases of ENSO\(^{23}\). During an El Niño phase, the Pacific Northwest experiences semi-permanent low pressure, which can cause more cloudiness and storms with warmer and wetter weather throughout Canada and the northern United States. Meanwhile, the southern Great Lakes region experiences high pressure and dryer weather. There are typically more storms across the U.S.-Mexico border with cooler and wetter weather from Southern California to Florida. During a La Niña phase, the Pacific Northwest experiences semi-permanent high pressure and clearer weather, creating cold, dry winters over Canada and the central United States. California to Florida is dryer and warmer, and there are warmer and wetter conditions in the northern United States.
Figure 3: Weather variability in North America during different phases of ENSO.24
Activity #1: El Niño and the Southern Oscillation
Use the following maps for questions 1-4.
1. Use a marker or pencil to label the Western Equatorial Pacific with “WEP” on the two maps on the previous page.

2. Use a marker or pencil to label the Eastern Equatorial Pacific with “EEP” on the two maps on the previous page.

3. Use Google Earth on a computer in the laboratory to locate the approximate area of Darwin, Australia. Label this location on both maps on page 6 with a large “D”.

4. Use Google Earth to locate Tahiti. Label this location on both maps on page 6 with a large “T”.

5. Use Google Earth to locate the island of Halmahera, Indonesia. Label this location on both maps on page 6 with a large “H”.

6. Which phase of ENSO, El Niño, or La Niña, spreads warm water across the entire equatorial Pacific?

7. Which phase of ENSO, El Niño or La Niña, is cooler across the eastern to central Pacific Ocean?
8. Which phase of ENSO is warmer in the Western Equatorial Pacific?

9. Which phase of ENSO is warmer in the Eastern Equatorial Pacific?

10. Refer to Figure 1 (page 3 of this lab) to fill in the following two boxes to illustrate the depth and longitudinal extent of the Western Pacific Warm Pool, the pool of warm water, for El Niño and La Niña across the Pacific Ocean. Use a red pencil for warm water and a blue pencil for cold water.

   a. **El Niño**

   ![Diagram of El Niño Warm Pool]

   b. **La Niña**

   ![Diagram of La Niña Warm Pool]
11. Looking at the Southern Oscillation Index in Figure 2 on page 4: Are El Niño episodes represented by positive or negative numbers?

12. Are La Niña episodes represented by positive or negative numbers on the SOI?

13. 1983-1984 was a strong El Niño episode. According to the SOI, this episode lasted from about 1983-1984. List 4 more periods from the SOI graph on page 4 when a strong El Niño episode occurred with greater than 2.5 units away from the central value—“ENSO Neutral” conditions (i.e., higher than 2.5 or lower than -2.5).

14. According to the SOI graph on page 4, about how long did the most intense (highest peak) El Niño episode last: 1-3 years, 3-5 years, or more than 10 years?

15. List at least 3 periods from the SOI graph on page 4 of this lab when a strong La Niña episode occurred with values that varied greater than 2.5 units from ENSO Neutral conditions.

16. Using the Southern Oscillation Index on page 4, what is the longest duration, in approximate years, of an El Nino episode from 1950 to present? What years did this episode occur? What was the SOI peak value for this episode?
17. For each of the following locations and time periods listed below:
   a. Indicate whether the period was during an El Niño or La Niña episode.
   b. Use Figure 3 (page 5 of this lab) to describe the typical weather (warmer, cooler, wetter, dryer, or a combination of these choices) at each location for the following examples. You may use a map of North America or Google Earth to find each location.

   Alaska, 1954-1956

   Indiana and Ohio, 1983-1984

   U.S. Southwestern Region, 1997-1998

   U.S. Pacific Northwest, 1971-1972

   U.S. Southeast, 2017-2018

18. Use this website: https://www.cpc.ncep.noaa.gov/products/analysis_monitoring/enso_advisory/ensodisc.shtml to determine the current state of ENSO. What is the current state of ENSO?
Lab #14: Paleoclimatology of the Western Pacific Warm Pool

OBJECTIVES:
- Graph and interpret paleoclimatological data.
- Identify changes in the Southern Oscillation.

INSTRUCTIONS:
- Print out these pages or use a graphics tablet to write in the areas provided.
- Email your completed lab to the instructor for feedback before submitting.
- Combine written answers to questions with graphs created by inserting images of the graphs to a Word (or compatible) document.
- Submit the answers to this lab as a single PDF document.

MATERIALS:
- Colored pencils
- Calculator
- Graph paper and tracing paper OR Excel/compatible graphing software
Part 1: $\delta^{18}$O and Strontium/Calcium (Sr/Ca) ratios in Pteropod Shells

Pteropods

Pteropods are types of snails, or gastropods, that swim in the ocean. Different species of pteropods create shells of all different shapes and sizes, as shown in Figure 1. Pteropods are also called Sea Butterflies because of their wing-like appendages used for swimming.

**Figure 1:** Different Pteropod Species, approximately 1 cm long$^{26,27}$:

Pteropods are ubiquitous in every ocean, that is, many species are found throughout all the oceans in most regions$^{28-29}$. They tend to live in the upper 900 meters of the water column, swimming up and down following prey. These organisms have a calcium carbonate shell of aragonite structure. Despite their abundance in the world oceans, shells of these organisms have been poorly studied because they do not survive after being captured and cannot be raised in a laboratory setting$^{30}$. However, pteropod shells are much larger than other microscopic shells typically used in paleoclimate studies, easily identifiable, and can be an ideal tool for researching paleoclimatology$^{31}$.

The Western Pacific Warm Pool is an area of higher temperature water that pools in the western equatorial Pacific region (Figure 2).
Figure 2: The location of the Western Pacific Warm Pool across the equatorial Pacific during a La Niña phase of ENSO.
Activity #1: The Western Pacific Warm Pool and ENSO

**Question #1:** Using your laboratory exercise on ENSO as a reference, what atmospheric condition causes warm water to pool in the western equatorial Pacific ocean?

**Question #2:** Use Google Earth to locate Halmahera, Indonesia on the map in Figure 3 below. In what part of the Pacific Ocean is Halmahera located? Circle the location of Halmahera on Figure 3 below:

![Figure 3: A map of the equatorial Pacific Ocean](image)

**Question #3:** Describe how an El Niño episode would change the water temperature in Kau Bay, which is located between the northern arms of the island of Halmahera, Indonesia.

**Question #4:** Describe how a La Niña episode would change the water temperature in Kau Bay, in Halmahera, Indonesia.
Part 2: Paleoclimate Records from Kau Bay, Indonesia

Activity #1: Graph and Interpret $\delta^{18}$O paleoclimate data from Kau Bay, Indonesia

Table 1 lists oxygen isotope data and ages based on radiocarbon dating of pteropod shells of the species *Creseis acicula* from sediment cores collected from Kau Bay, in Halmahera, Indonesia. $\delta^{18}$O has an inverse relationship with water temperature, which means that lower numbers for $\delta^{18}$O reflect warmer water temperatures.

**Question #1:** Use graph paper or a graphing application to construct a line graph using data from Table 1. Put Age (Years before Present) on the X-axis and $\delta^{18}$O on the Y-axis. Label the Y-axis equally spaced from 0 (on the bottom of the axis) to -2 (on the top of the axis).

**Table 1:** Selected pteropod oxygen isotope data ($\delta^{18}$O) from Kau Bay, Indonesia

<table>
<thead>
<tr>
<th>Radiocarbon Age (Years Before Present)</th>
<th>$\delta^{18}$O</th>
</tr>
</thead>
<tbody>
<tr>
<td>22</td>
<td>-1.6</td>
</tr>
<tr>
<td>86</td>
<td>-1.7</td>
</tr>
<tr>
<td>130</td>
<td>-1.8</td>
</tr>
<tr>
<td>162</td>
<td>-2.0</td>
</tr>
<tr>
<td>194</td>
<td>-1.8</td>
</tr>
<tr>
<td>227</td>
<td>-1.5</td>
</tr>
<tr>
<td>259</td>
<td>-0.9</td>
</tr>
<tr>
<td>291</td>
<td>-1.7</td>
</tr>
<tr>
<td>324</td>
<td>-1.3</td>
</tr>
<tr>
<td>356</td>
<td>-1.4</td>
</tr>
<tr>
<td>399</td>
<td>-1.0</td>
</tr>
<tr>
<td>432</td>
<td>-1.5</td>
</tr>
<tr>
<td>464</td>
<td>-1.4</td>
</tr>
<tr>
<td>529</td>
<td>-1.7</td>
</tr>
<tr>
<td>561</td>
<td>-1.7</td>
</tr>
<tr>
<td>605</td>
<td>-1.4</td>
</tr>
</tbody>
</table>

**Question #2:** Draw an up or down arrow on your graph next to the Y-axis to show the direction of rising water temperature.
These samples were collected in the year 2004. The youngest sample had a radiocarbon age of 22 years. To find the actual calendar age of the sample, subtract the radiocarbon age of the sample from the year that the sample was collected.

**Question #3:** What is the *calendar age* of the youngest sample in this record?

**Question #4:** What is the *calendar age* of the oldest sample, which has a radiocarbon age of 605 years before present?

**Question #5:** Write the calendar ages on the X-Axis of your graph below the Radiocarbon Ages. The first calendar age should be 2004, directly underneath the “0” year value on the X-axis.

**Question #6:** According to this graph, in what *calendar* year did Kau Bay have the coldest water temperature?

**Question #7:** Was this year probably during El Nino or La Nina?

**Question #8:** According to this graph, in what *calendar* year did Kau Bay have the warmest water temperature?

**Question #9:** Was this year probably during El Nino or La Nina?
Activity #2: Strontium/Calcium Ratios in Pteropod Shells

Strontium is an atom with similar characteristics to calcium. For this reason, strontium is sometimes used in the aragonite structure to replace calcium. The amount of strontium that is added to aragonite shells is relative to the amount of strontium in the seawater. As seawater temperature rises, it can carry more strontium. If pteropods incorporate strontium into their shells relative to the amount of total strontium available in the seawater, then the Strontium/Calcium ratio found in the pteropod shell should be directly relational to seawater temperature. Table 2 shows water temperatures derived from Sr/Ca ratios in pteropod shells from the same samples used for the δ¹⁸O analyses in Activity #1.

Question #1: Use scotch tape to attach a piece of tracing paper over your graph of oxygen isotope data OR create a second line graph in a graphing application. If using graph paper, use a ruler to copy the lines for the X and Y axes from the graph in Activity #1. Label the X-axis with the radiocarbon ages from the first graph. Label the Y-axis with the title, “Temperature °C.” Number the Y-axis equally spaced from 25 (at the bottom) to 30 (at the top). Graph the data from Table 2 on the tracing paper page.

Table 2: Pteropod Sr/Ca data from Kau Bay, Halmahera

<table>
<thead>
<tr>
<th>Radiocarbon Age (Years Before Present)</th>
<th>Temperature °C</th>
</tr>
</thead>
<tbody>
<tr>
<td>22</td>
<td>29.93</td>
</tr>
<tr>
<td>86</td>
<td>29.40</td>
</tr>
<tr>
<td>130</td>
<td>29.12</td>
</tr>
<tr>
<td>162</td>
<td>29.02</td>
</tr>
<tr>
<td>194</td>
<td>28.54</td>
</tr>
<tr>
<td>227</td>
<td>29.04</td>
</tr>
<tr>
<td>259</td>
<td>26.81</td>
</tr>
<tr>
<td>291</td>
<td>28.40</td>
</tr>
<tr>
<td>324</td>
<td>27.53</td>
</tr>
<tr>
<td>356</td>
<td>27.11</td>
</tr>
<tr>
<td>399</td>
<td>27.04</td>
</tr>
<tr>
<td>432</td>
<td>27.58</td>
</tr>
<tr>
<td>464</td>
<td>29.14</td>
</tr>
<tr>
<td>529</td>
<td>28.54</td>
</tr>
<tr>
<td>561</td>
<td>(no sample)</td>
</tr>
<tr>
<td>605</td>
<td>26.66</td>
</tr>
</tbody>
</table>

Question #2: According to the Sr/Ca temperature data, what calendar year did Kau Bay have the coldest water?

Question #3: How does your previous answer (#2) compare to your answer for question #6 in Part 2, Activity #1?
**Question #4:** According to the Sr/Ca temperature data, what calendar year did Kau Bay have the warmest water?

**Question #5:** How does your answer to #4 compare to your answer from question #8 from Part 2, Activity #1 of this lab?

**Question #6:** Use a blue pencil to outline possible strong El Niño episodes on the tracing paper graph.

**Question #7:** Use a red pencil to circle possible strong La Niña episodes on the line graph of the Sr/Ca data.

**Question #8:** The Little Ice Age was a period of cooler than average temperatures in the northern hemisphere from approximately 1400-1800 Common Era (C.E.). According to the Kau Bay data, is there any evidence of a change in climate during the same time period as the Little Ice Age? Explain.
1 Kaldari and Halava, CC BY-SA 3.0 <https://creativecommons.org/licenses/by-sa/3.0>, via Wikimedia Commons

2 Kaldari and Halava, CC BY-SA 3.0 <https://creativecommons.org/licenses/by-sa/3.0>, via Wikimedia Commons

3 DrSciComm, CC BY-SA 4.0 <https://creativecommons.org/licenses/by-sa/4.0>, via Wikimedia Commons

4 Ysangkok at the English-language Wikipedia, CC BY-SA 3.0 <http://creativecommons.org/licenses/by-sa/3.0/>, via Wikimedia Commons

5 No machine-readable author provided. LucasVB assumed (based on copyright claims)., Public domain, via Wikimedia Commons

6 DrSciComm, CC BY-SA 4.0 <https://creativecommons.org/licenses/by-sa/4.0>, via Wikimedia Commons

7 Ysangkok at the English-language Wikipedia, CC BY-SA 3.0 <http://creativecommons.org/licenses/by-sa/3.0/>, via Wikimedia Commons

8 No machine-readable author provided. LucasVB assumed (based on copyright claims)., Public domain, via Wikimedia Commons

9 Meniou, CC BY-SA 3.0 <https://creativecommons.org/licenses/by-sa/3.0>, via Wikimedia Commons

10 CaelusS, CC BY-SA 4.0 <https://creativecommons.org/licenses/by-sa/4.0>, via Wikimedia Commons

11 https://scied.ucar.edu/shortcontent/humidity

12 Brosen~commonswiki, CC BY-SA 3.0 <http://creativecommons.org/licenses/by-sa/3.0/>, via Wikimedia Commons


19 By Fred the Oyster - Own work, Public Domain, https://commons.wikimedia.org/w/index.php?curid=35206036
https://www.ncdc.noaa.gov/teleconnections/enso/indicators/soi/ Public Domain


