LESSON 15: STIFLING, OPPRESSIVE, SWELTERING, OH MY!
The Science Behind Heat Waves and their Effect on Human Health

PURPOSE/QUESTION
Students will analyze temperature and outgoing long-wave radiation data to identify heat waves.

GRADE LEVEL
9-12

TIME TO COMPLETE
2-3 – 50 minute time periods

STANDARDS
See appendix below-page 8

LEARNING OUTCOMES
- Students will compare various temperature data sets, over a series of years at a specific location.
- Students will know that the Earth emits radiation at a rate that is proportional to its temperature.
- Students will learn how heat waves affect human health.
- Students will know what populations are most vulnerable to heat waves.

STUDENT OBJECTIVES
- Access air temperature and long-wave radiation data.
- Convert from radiation to temperature using the Stefan-Boltzmann equation.
- Learn the relationship between hot weather and unhealthy amounts of ground-level ozone.
- Analyze and draw conclusions about how heat waves affect different populations.

TEACHER BACKGROUND
In August 2007, a severe heat wave affected much of the central, southeast, and east parts of the United States. This lesson will give students an opportunity to explore how the heat wave progressed and learn about the impacts on human health. These sorts of heat waves are projected to become more frequent and more severe if climate change continues unabated, so can be thought of as an example of what to expect from climate change.

My NASA Data only includes monthly average temperatures. To explore the shorter term variations in temperature, we use daily observations of upward longwave radiation from the surface. Because the Earth can be approximated as a black body, we can use the Stefan-Boltzmann equation to convert radiation to temperature.

$$T = \sqrt[4]{\frac{\phi}{\sigma}}$$

Where… T = temperature in K

φ = energy flux density in W/m^2

σ = Stefan-Boltzmann constant = 5.67e-8 $\frac{W}{m^2 K^4}$

This conversion will give an approximation of average daily temperature because we are calculating it using only the integrated long-wave radiation. To be more accurate, we would use a value that integrates all the radiation (short- and long-wave) emitted by the surface. Even so, this approximation is reasonable because most of the radiation emitted by the Earth is in the long-wave part of the spectrum.

Extremely hot weather is often accompanied by high levels of the ground-level ozone pollution. This is because ozone is formed in the atmosphere by chemical reactions involving hydrocarbons and nitrogen oxides, pollutants from fossil fuel combustion. These chemical reactions are more efficient during hot and sunny conditions, exactly what is common during heat waves. The actual ozone concentrations will depend both on the meteorological conditions and on the pollution emissions.

PREREQUISITES
- What is Ozone?
- Radiation Spectrum

MATERIALS & TOOLS
- Computer with Internet
- Microsoft Excel
- Color printer (optional)

VOCABULARY
- Longwave radiation
- Black body
- Radiation spectrum
- Meteorological observing station

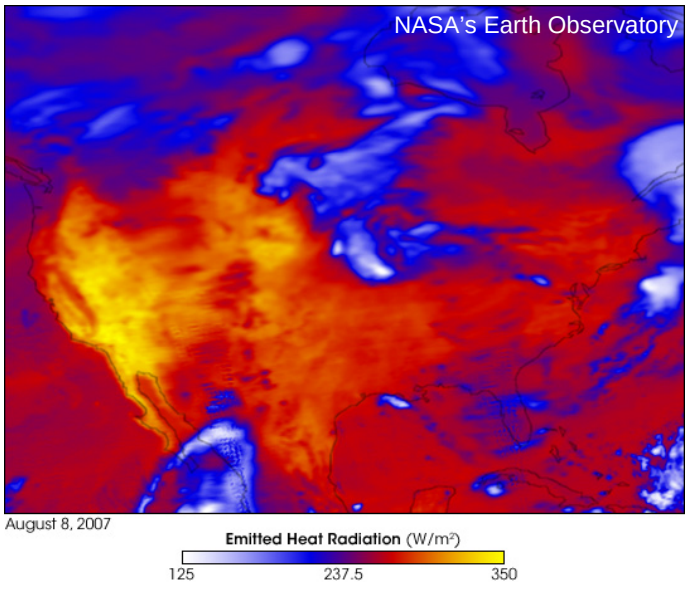
LESSON LINKS
- Live Access Server
- Opening MY NASA Data microsets in Microsoft Excel
- Special Report: Heat Wave August 2007
- NWF Reports: Extreme Weather-Heat Waves

PART 1 – Preliminary investigation of August 2007 heat wave

ESSENTIAL QUESTIONS
1. Does August 2007 especially stand out compared to past Augusts?
2. Why do you think the monthly average might not be a record breaker, even though there were several record-breaking hot days in Memphis?

PROCEDURE
Read NOAA summary of the August 2007 heat wave available in the Lesson Links above.

1. Look at monthly surface temperature time series to see how temperatures this August compare to past Augusts. We will focus on Memphis, TN (latitude = 35°N, longitude = 90°W) because people in this city especially suffered, with 15 deaths attributed to the heat.
   a. In Live Access Server (Advanced Edition), click on the ***Choose Dataset*** button. Then, choose ***Atmosphere > Atmospheric Temperature > Monthly Near-Surface Air Temperature (ISCCP)***. A map will be automatically generated.
   b. Under "LINE PLOTS", select: ***Time Series***
   c. Enter the latitude and longitude for Memphis into the appropriate boxes just below the small grey map on the left of the screen.
   d. Set the time settings in ***Date Range*** to be Jan 1994 to Dec 2007.
   e. Click ***Update Plot*** and a time series plot will appear.
   f. Print out or save the graph



PART 2 – Investigate daily variations in temperature for Memphis

ESSENTIAL QUESTIONS PART 2

1. What patterns do you notice in the map of radiation? Are the patterns consistent with what you expect based on the description of the summer 2007 heat wave?
2. The temperature conversion is an approximation. What factors are not accounted for?
3. Compare the average daily temperatures estimated from the LW satellite data to the surface observations of daily maximum temperatures. What are the similarities between the two datasets and what are the differences? How might you explain the differences?

PROCEDURE

1. The My NASA Data archive does not include daily temperature data. As an alternative, we'll use daily surface all-sky long-wave upward flux. The Earth emits radiation at a rate that is proportional to its temperature. Most of the radiation that the Earth emits is in the long-wave part of the radiation spectrum, making it a reasonable proxy for surface temperature. We'll start by mapping the data for one of the days during the heat wave to see the pattern of long-wave radiation emissions across the United States.
    a. In Live Access Server (Advanced Edition), click on the ***Choose Dataset*** button. Then, choose ***Atmospheric Radiation > Surface > Daily Surface All-sky LW Upward Flux (SRB)***. A time series chart will be automatically generated, but note that it may not be for the Memphis location.
    b. First let's examine a map of this variable for the continental United States. Under "MAPS", select ***Latitude-Longitude***. Then, use the small map to select a box that includes the continental United States (click on the little rectangle to enable the dynamic selection of a plot area). Enter the date of ***August 11, 2007***. Then click ***Update Plot***. A map will be automatically generated.
    c. Print out or save the graph
2. Now, we will use the longwave radiation data to create a daily temperature time series for Memphis for the month of August 2007.
    a. Continuing from the last data collection point in part one under "LINE PLOTS", select ***Time Series***. In the boxes under the small map, enter the latitude and longitude coordinates for Memphis. Select the date range of ***Aug 1, 2007*** to ***Aug 31, 2007***. Then click ***Update Plot***. A graph will be automatically generated.
    b. We want to access the data used to create this plot, so that we can do our own calculations. Click the ***Show Values*** button and then click ***OK*** to accept the defaults. The data will appear in the second window.
    c. Follow the instructions in the Eco-Schools CCC Tech Tips Sheet to import the data into the Microsoft Excel worksheet for this lesson. Put the raw data in the tab titled "Raw Data – LW Up".
    d. Copy and paste the LW radiation data into the tab titled "LW_Temp_Ozone_Data" in the column labeled "LW Up All-sky radiation (W/m^2)".
    e. The radiation values will be automatically converted to temperature in degrees Fahrenheit (F), using the Stefan-Boltzmann equation provided in the **Background** section and the conversion from Kelvin to Fahrenheit (F).
3. Finally, we will compare the daily average temperature we estimated from the satellite observations of long-wave radiation to direct measurements of maximum daily temperature from a meteorological observing station located at the airport in Memphis.
    a. The spreadsheet tab for "LW_Temp_Ozone_Data", includes a column labeled "TMAX (F) – Surface obs". This data and the temperature computed from the longwave radiation observations have been automatically plotted onto a time series chart in the tab titled "Temp_LW chart".

PART 3 – Examine ground-level ozone concentrations during Aug. 2007

ESSENTIAL QUESTIONS

1. What are the health impacts of exposure to extreme heat? to elevated ozone? What populations are especially vulnerable to ozone pollution and to the combined exposure to heat and ozone?
2. What is the relationship between ozone and temperature? What might explain the times when the two variables are well correlated and those times when they are not?

PROCEDURE

1. Read the NWF report *More Extreme Heat Waves: Global Warming's Wake-Up Call* to learn about how heat waves affect human health.
2. Extremely hot weather is often accompanied by high levels of ground-level ozone pollution. We will examine to what extent this was the case in Memphis for the August 2007 heat wave. Notice that the "LW_Temp_Ozone_Data" tab of your spreadsheet also includes data for "Daily Ozone Maximum (ppb)". These data are averaged from air quality observing stations located at 3 different sites in the greater Memphis area.
3. The ozone data has been plotted along with the two temperature measurements in the tab titled "LW_Temp_Ozone Timeseries Chart".

TOOLS FOR ASSESSMENT

- **Concept Quiz – found on pg. 14**
- **Essay – found on pg. 11**
- **Foldables®**
- **Student Reading and Science Notebook Assessment Tools – found in the *Rubrics* folder**

WEBSITES FOR FURTHER LEARNING

- **Earth Observatory – From Green to Brown**
- **Urban Heat Island - EPA**
- **How Stuff Works – What is the Urban Heat Island Effect?**

STUDENT READING RESOURCES

- **Heat Waves Across the United States**
- **Beating the Heat-In the World's Big Cities**
- **Heat Waves Could Become Commonplace…**
- **Climate Change to Bring a Wave of New Health Risks**
- **Heat Waves – CDC: Climate and Health Program**
- **Report Predicts Urban Meltdown from Heat Waves**


Photo Credit: Bukutgirl

LESSON 15-APPENDIX

Tech Tips for Eco-Schools USA Climate Change Connections Curriculum

How do I import data into an Excel spreadsheet?

1. Access data from My NASA Data:
    a. Once you have all the parameters set for your desired data set (and have clicked "Update Plot" to have your preferences processed), click the "Show Values" button. A new window will pop up with a Table of Values.
    b. The first several lines of the Table will provide information that describes the data set, often called "metadata", such as the name of the variable, what subset of the data is included in the file, and what time range. Make sure to keep this metadata with the rest of the data when you copy it into Excel. This way you'll be able to easily keep track of which data you have!
2. Copy the data from the browser (note that these instructions are for Internet Explorer running on a PC, and may need to be modified for other platforms):
    a. In this new window, select all. You can do this by clicking anywhere in the window and then typing "Ctrl-A". Or you can right-click in the window, which will pop up a menu, and then choosing "Select All" from the options.
    b. Next, copy this data. Again there are two options. You can use the keyboard shortcuts, and type "Ctrl-C". Or you can right-click and choose "Copy" from the pop-up menu.
3. Paste the data into Excel:
    a. Now open your Excel worksheet and go to the tab where you want to put the raw data. Click in the A1 cell.
    b. Paste the data, either by typing "Ctrl-V", by clicking "Paste" (located at the left under the "Home" tab), or by right-clicking in the A1 cell and choosing "Paste".
4. Convert the data from text to columns:
    a. Now, we have the data in Excel, but we can't manipulate it very well because all the data for each row is lumped into one cell. We want to split out each data value into its own cell.
    b. Starting at the row where the column headers are located (probably around row 7), highlight the A column down to the end of the data.
    c. Click on the Data tab at the top of the window, and then choose the "Text to Columns" wizard (located a little to the right of center).
    d. A dialogue box will pop up to help you through the process.
    e. The first page of the wizard asks you to identify whether the data is "Delimited" or "Fixed width". In most cases, the My NASA Data data will be "Fixed Width", so select that option and click "Next".
    f. The next page of the wizard gives you a chance to check whether the column breaks make sense and to adjust them as necessary. Make any changes that are needed. Or, go back and switch to "Delimited" on page 1 if you notice that the columns are not lining up as you expected. Once you are satisfied with the columns, click "Next".
    g. The final page of the wizard allows you to designate what kind of data values are in each column and a destination for the data. For the purposes of the CCC curriculum, we'll just accept the defaults and click "Finish".
    h. Now your data should be in beautiful columns and the values should make sense. It's always a good idea to double check that nothing crazy happened!

My NASA Data isn't working! What should I do?

1. Double check that you entered everything correctly. Especially check that you have the right data set and that you have entered dates and latitude/longitude values within the range of available data. Usually the user interface will prevent you from entering invalid data ranges, but sometimes there are glitches.
2. Refresh the browser and/or restart the browser. Occasionally, a fresh start is the easiest way to clear out any mistakes or glitches.
3. Update your browser and/or JAVA. If you have older versions of the software, then you might find that some functionality is lost.
4. If you're still struggling, consider whether problem might be at the My NASA Data website. It might be a temporary problem, in which case taking a break and returning to the site at a later time could be a good choice. Or it could be a more significant problem, in which case you'll want to explore the "help" resources provided by My NASA Data (link in upper right hand corner of page).
5. Ask your Eco-Schools contact for help or email eco-schoolsusa@nwf.org!

How do I print or save a map or graph?

1. Use the "Print" button to generate a version of your map or graph that is suitable for saving or printing. Once you click on the "Print" button, a new window will pop up with your map or graph.
2. Print a map or graph by using the print option on your browser.
3. Save a map or graph in one of two ways:
    a. By choosing "Save as" in the browser. Use the defaults to save as a "Web Archive, single file (*.mht)".
    b. By right clicking and choosing "Save picture as…" Use the defaults to save as a *.png file.
4. When saving, make sure to give your new file a descriptive name and put it somewhere that you'll remember!

How do I find my latitude and longitude?

A number of sites help you find your latitude and longitude. For example:

1. http://itouchmap.com/latlong.html
2. http://www.findlatitudeandlongitude.com/

HYPERLINKS WEB ADDRESSES

PREREQUISITES

- **What is Ozone?**
  http://ozonewatch.gsfc.nasa.gov/facts/ozone.html
- **Radiation spectrum**
  http://imagine.gsfc.nasa.gov/docs/science/know_l1/emspectrum.html

VOCABULARY

- **Longwave radiation**
  http://mynasadata.larc.nasa.gov/science-glossary/?page_id=672?&letter=L
- **Black body**
  http://mynasadata.larc.nasa.gov/science-glossary/?page_id=672?&letter=B
- **Radiation spectrum**
  http://mynasadata.larc.nasa.gov/science-glossary/?page_id=672?&letter=R
- **Meteorological observing station**
  http://www.thefreedictionary.com/weather+station

LEARNING LINKS

- **Live Access Server, LAS**
  http://mynasadata.larc.nasa.gov/live-access-server/
- **Opening My NASA DATA mircrosets in Excel**
  http://mynasadata.larc.nasa.gov/excel.html
- **Special Report: Heat Waves 2007**
  http://www.ncdc.noaa.gov/special-reports/2007-aug-heat-event.html
- **NWF Reports – Extreme Weather: Heat Waves**
  http://www.nwf.org/Global-Warming/What-is-Global-Warming/Global-Warming-is-Causing-Extreme-Weather/Heat-Waves.aspx

WEBSITES FOR FURTHER LEARNING

- **Earth Observatory – From Green to Brown – This page on NASA's Earth Observatory site explains the radiation spectrum from the Aqua satellite with great visuals.**
  http://earthobservatory.nasa.gov/IOTD/view.php?id=79332
- **Urban Heat Island – A section of the EPA website dedicated to the understanding of the urban heat island effect. Information includes heat island impacts and mitigation as well as activities in your state or community.**
  http://www.epa.gov/heatisld/
- **How Stuff Works – What is the Urban Heat Island Effect?**
  http://science.howstuffworks.com/environmental/green-science/urban-heat-island.htm

STUDENT READING RESOURCES

- **Heat Waves Across the United States**
  http://earthobservatory.nasa.gov/IOTD/view.php?id=7968
- **Beating the Heat – In the World's Largest Cities**
  http://earthobservatory.nasa.gov/Features/GreenRoof/
- **Heat Waves Could Become Common Place**
  http://earthobservatory.nasa.gov/Newsroom/view.php?id=44646
- **Climate Change to Bring a Wave of New Health Risks**
  http://earthobservatory.nasa.gov/Newsroom/view.php?id=26198
- **Heat Waves – CDC: Climate and Health Program**
  http://www.cdc.gov/climateandhealth/effects/default.htm
- **Report Predicts Urban Meltdown from Heat Waves**
  http://www.scientificamerican.com/article.cfm?id=heat-waves-urban-climate-change-poor-elderly

LESSON 15-STANDARDS

National Science Education Standards

Unifying Concepts and Processes

- Systems, Order, and Organization
- Evidence, Models, and Explanations
- Change, Constancy, and Measurement

Standard A – Science as Inquiry

- Abilities necessary to do scientific inquiry
- Understanding about scientific inquiry

Standard C – Life Science

- Matter, energy, and organization in living systems

Standard D – Earth and Space Science

- Energy in the earth system
- Geochemical cycles

Standard E – Science and Technology

- Abilities of technological design
- Understandings about science and technology

Standard F – Science in Personal and Social Perspectives

- Personal and community health
- Environmental quality
- Natural and human induced hazards
- Science and technology in local, national, and global challenges

Standard G – History and Nature of Science

- Science as a human endeavor
- Nature of scientific knowledge
- Historical perspectives

National Education Technology Standards

- Understand and use technology systems.
- Select and use applications effectively and productively.
- Use models and simulations to explore complex systems.
- Identify trends and forecast possibilities.
- Apply digital tools to gather, evaluate, and use information.

National Council of Teachers of Mathematics Education Standards

- Compute fluently and make reasonable estimates.
- Analyze change in various contexts.
- Understand measurable attributes of objects and the units, systems, and processes of measurement.
- Formulate questions that can be addressed with data and collect, organize, and display relevant data to answer them.
- Solve problems that arise in mathematics and in other contexts.
- Recognize and apply mathematics in contexts outside of mathematics.
- Use representations to model and interpret physical, social, and mathematical phenomena.

Climate Literacy Principles

Principle 1: The sun is the primary source of energy for Earth's climate system.
Principle 2: Climate is regulated by interactions among components of the Earth system.
Principle 3: Life on Earth depends on, is shaped by, and affects climate.
Principle 4: Climate varies over space and time through both natural and man-made processes.
Principle 5: Our understanding of the climate system is improved through observations, theoretical studies, and modeling.
Principle 6: Human activities are impacting the climate system.
Principle 7: Climate change will have consequences for the Earth system and human lives.

Energy Literacy Principles

Principle 2: Physical Earth processes are the result of energy flow through the earth system.
Principle 3: Biological Earth processes depend on energy flow through the earth system.
Principle 5: Individuals and communities make energy decisions every day.
Principle 6: The amount of energy human society uses depends on many factors and can be reduced in many ways.
Principle 7: The energy choices made by individuals and societies affect quality of life.

LESSON 15-ESSENTIAL QUESTIONS ANSWER KEY

Essential Questions-1

1. Does August 2007 especially stand out compared to past Augusts?
   [August 2007 is high, but not the highest of this record.]

2. Why do you think the monthly average might not be a record breaker, even though there were several record-breaking hot days in Memphis?
   [The average monthly temperature includes the very hot days, but also all the other days. It's possible that other times during the month were cooler, bringing the average down.]

Essential Questions-2

1. What patterns do you notice in the map of radiation? Are the patterns consistent with what you expect based on the description of the summer 2007 heat wave?
   [Upward longwave radiation is relatively high in the central and southeast parts of the United States, as expected from the description of the heat wave. The highest values of upward long-wave radiation are in the arid regions of the southwestern United States, where there is relatively little vegetation and moisture to modulate the heat radiating off the surface.]

2. The temperature conversion is an approximation. What factors are not accounted for?
   [The Stefan-Boltzmann equation relates all the radiation emitted by a black body over the entire radiation spectrum to the temperature of that black body. We only used the radiation coming from the longwave part of the spectrum in our calculation, so we might expect the temperature to be slightly underestimated. The error would be relatively small because most of the radiation from a black body at the Earth's temperature falls in the long-wave part of the spectrum.]

3. Compare the average daily temperatures estimated from the LW satellite data to the surface observations of daily maximum temperatures. What are the similarities between the two datasets and what are the differences? How might you explain the differences?
   [Both datasets show a generally similar pattern with values peaking around August 9 – 17, and lower values near the beginning of the month, around August 20, and toward the end of the month. The temperature derived from the LW data is more variable, perhaps reflecting the interference of clouds.]

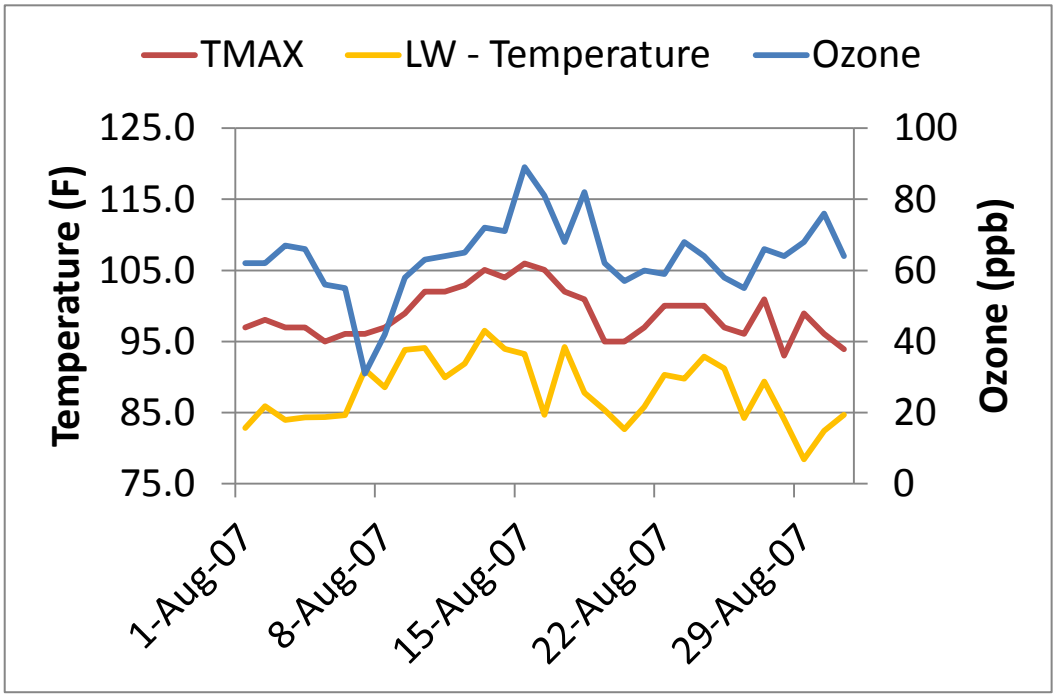
Essential Questions-3

1. What are the health impacts of exposure to extreme heat? to elevated ozone? What populations are especially vulnerable to ozone pollution and to the combined exposure to heat and ozone?
   [Exposure to extreme heat can lead to heat stroke and can exacerbate underlying health conditions, such as heart disease, stroke, or asthma. Ozone exposure can exacerbate the same diseases, as well as other respiratory diseases. The most vulnerable people are the very young, the very old, and those with pre-existing medical conditions.]

2. What is the relationship between ozone and temperature? What might explain the times when the two variables are well correlated and those times when they are not?
   [The ozone concentrations mostly track with the temperatures, although not always. The general correlation is because ozone is formed in the atmosphere by chemical reactions that happen more quickly on hot, sunny conditions. But, other factors also influence ozone concentrations, namely meteorological conditions and pollutant emissions. For example, a weather pattern might push clean air from over the Gulf of Mexico northward, causing there to be a dip in ozone levels for a day or more.]

Name: _____ Date: _____

Science Concept Quiz
Lesson 15: Stifling, Oppressive, Sweltering, Oh My!



What conclusions can be draw from the evidence in the line graph above?

A. As longwave temperature increases ozone also increases.
B. There is a direct relationship between on the ground daily maximum temperatures and satellite observing longwave temperatures.
C. Around August 15 ozone reached its maximum for the month while longwave temperature reached its minimum.
D. On the warmest day of August, ozone was at 90 ppb and longwave temperatures read around 85 degrees Fahrenheit.

_____ points out of 20

I. Answer

A.○ B.○ C.○ D.○

_____ points out of 15

II. What is the main concept behind the question?

1. Solar radiation
2. Drawing conclusions
3. Making measurements
4. Predicting changes in ozone

_____ points out of 25

III. Provide the reasoning for choosing your answer in part II.

_____points out of 40

IV. Why are the other responses in part I not the best answer choice?

1.

2.

3.

4.

Teacher Answer Key

1. D

2. 2

3. Answers will vary. The question asks one to draw a conclusion based on the information in the graph. You do not have to make measurements or understand ozone to answer the question correctly.

4. Answers will vary.

   A) The opposite occurs as longwave radiation increase ozone decreases.

   B) There is no direct relationship (inconsistent) between on the ground temperature maximums and longwave temperatures.

   C) Ozone did reach its maximum for the month on August 15th but longwave temperatures did not reach its minimum.

   D) This is the correct answer. On the warmest day of August the graph shows that the longwave temperature was 85°F and that ozone was 90 ppb.

Student Name
Teacher/Class
Date

Lesson 15: Stifling, Oppressive, Sweltering Oh My?
The Science Behind Heat Waves and their Effect on Human Health

Based on your analyses, collaborations, and writings provide evidence to convince your school board and district the need for action to reduce the effects of heat waves on citizens.

What Is the Expectation?

Accurate science relating to heat waves and future predictions, as well as its relating heat waves to human health concerns.

Evidence supporting your claims

Visual representations

Key vocabulary

Evidence of on grade level spelling and grammar usage