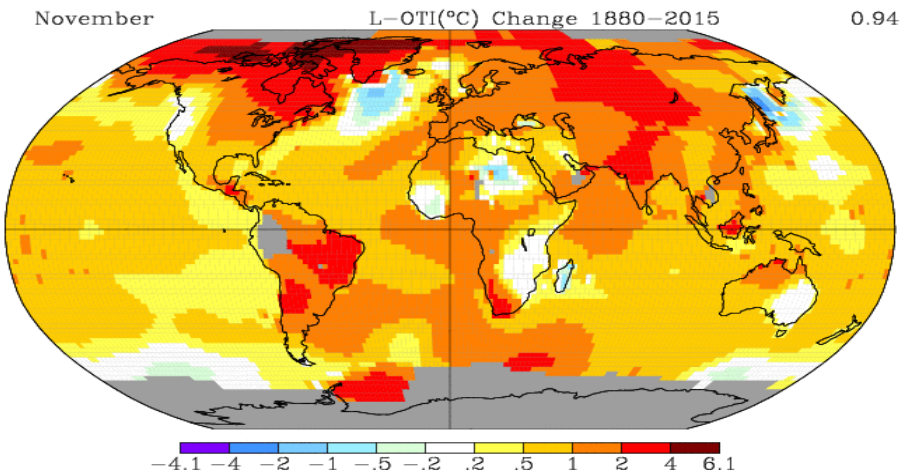
National Aeronautics and Space Administration
Goddard Institute for Space Studies
New York, N.Y.

NASA Goddard Institute for Space Studies (GISS)
Climate Change Research Initiative (CCRI)
Applied Research STEM Curriculum Unit Portfolio

Unit Title: Earth's Energy Budget
NASA STEM Educator / Associate Researcher: Nicole Dulaney
NASA PI / Mentor: Dr. Allegra LeGrande
NASA GSFC Office of Education – Code 160



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I. Executive Summary Goals and Overview of Unit:

The title of this unit is Earth's Energy Budget and the goal of the unit is for the students to learn about each component of the energy budget formula and how the contribution of each component changes based on the location and the time of the year. The energy budget formula components the students will be introduced to are incoming solar radiation, outgoing longwave radiation, outgoing shortwave radiation, and net energy. The students will also make connections in each lesson to climate change by making predictions as to how different components of the energy budget will be impacted due to the changing climate.

The students will begin the unit by deriving the formula for Earth's energy budget based on information provided in a NASA Earth Observatory Article titled Climate and Earth's Energy Budget. The students will complete a graphic organizer as they read the article that allows the students to derive formulas for the incoming and outgoing components of the energy budget. In the next lesson, the students are able to analyze data from the NASA CERES satellite that represents each component of Earth's energy budget. Specifically, the students will use a NASA GISS program called Panoply that reads and displays data in the form of netCDF to determine how incoming solar radiation, outgoing longwave energy, outgoing shortwave energy, and net energy data from the CERES satellite differ based on changing latitudes and seasons. The students will answer analysis questions that allow them to evaluate how each component can change so drastically when the latitudes and the seasons change. In the third lesson, the students will learn how to code using a program called RStudio that allows users to perform simple statistical data analysis and analysis of data in netCDF files. The students are expected to complete a step-by-step guide that shows them how to use basic commands in RStudio. Lesson #3 is essential for a successful completion of lesson #4 in which the students will use RStudio to explore and evaluate each component of the energy budget for specific locations and seasons on Earth. The students will explore the values for each component of the energy budget of New York City, Summit, Greenland, Quito, Ecuador, and a city of their choice. The students will also evaluate each component of the budget through analysis questions and they will make predictions as to how the energy budgets for the cities will be impacted in the future as a result of climate change.

As Earth's climate continues to change, it is essential for the general public to understand that climate change will impact locations differently. This unit plan allows students to learn how and why the energy budget differs from one location to the next and more specifically, how climate change might alter the energy budget in the future. Educating this current generation of students about climate change is crucial as we head towards a global debate regarding impacts and mitigation strategies. If educators can effectively communicate how climate change will impact different regions of the world, our global society can be better equipped to make social, economic, and political changes regarding climate change.

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III. NASA Education Resources Utilized in Unit

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Schmunk, R. B. (2016, July 13th). *Global Equilibrium Energy Balance Interactive Tinker Toy (GEEBITT).* Retrieved from https://icp.giss.nasa.gov/education/geebitt/

Schmunk, R. B. (2017, February 27th). *Panoply netCDF, HDF, and GRIB Data Viewer*. Retrieved from https://www.giss.nasa.gov/tools/panoply/

IV. Unit Pre and Post Standards Based Assessment:

Pre & Post-Unit Assessment: Earth's Energy Budget

In order to truly measure student growth after the completion of the unit, the pre-assessment will be the same as the post-assessment.

The pre and post-unit assessment is based on New York State Earth Science Regents questions and standards. Since students taking part in these lessons are also likely taking Regents Earth Science, students need to be familiar with answering Regents-style questions. The following New York State Earth Science standards are assessed:

1.1f - Earth's changing position with regard to the Sun and the moon has noticeable effects.
- Earth revolves around the Sun with its rotational axis tilted at 23.5 degrees to a line perpendicular to the plane of its orbit, with the North Pole aligned with Polaris.
- During Earth's one-year period of revolution, the tilt of its axis results in changes in the angle of incidence of the Sun's rays at a given latitude; these changes cause variation in the heating of the surface. This produces seasonal variation in weather.

2.2a - Insolation (solar radiation) heats Earth's surface and atmosphere unequally due to variations in:
- the intensity caused by differences in atmospheric transparency and angle of incidence which vary with time of day, latitude, and season
- characteristics of the materials absorbing the energy such as color, texture, transparency, state of matter, and specific heat
- duration, which varies with seasons and latitude.

2.2d - Temperature and precipitation patterns are altered by:
- natural events such as El Niño and volcanic eruptions
- human influences including deforestation, urbanization, and the production of greenhouse gases such as carbon dioxide and methane

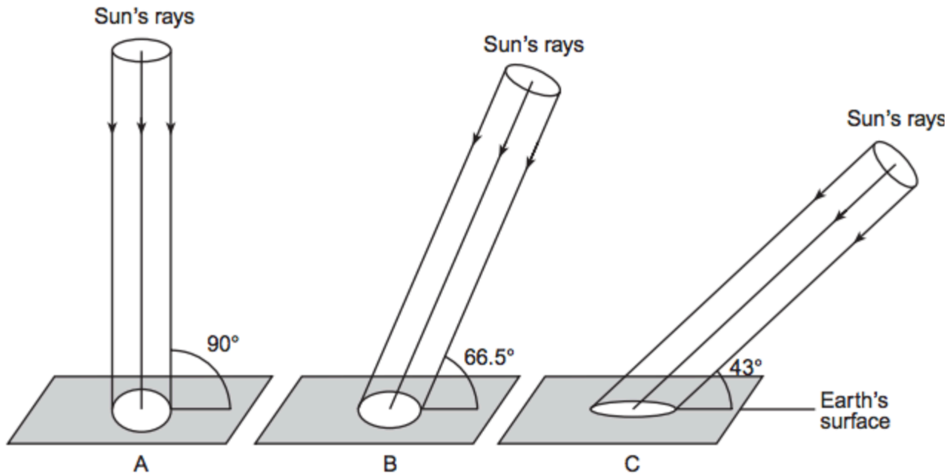
______**1.** In which region of the electromagnetic spectrum is most of Earth's outgoing terrestrial radiation?

(1) infrared	(3) visible
(2) ultraviolet	(4) x rays

______**2.** The average temperature at Earth's equator is higher than the average temperature at Earth's South Pole because the South Pole

(1) receives less intense insolation
(2) receives more infrared radiation
(3) has less land area
(4) has more cloud cover

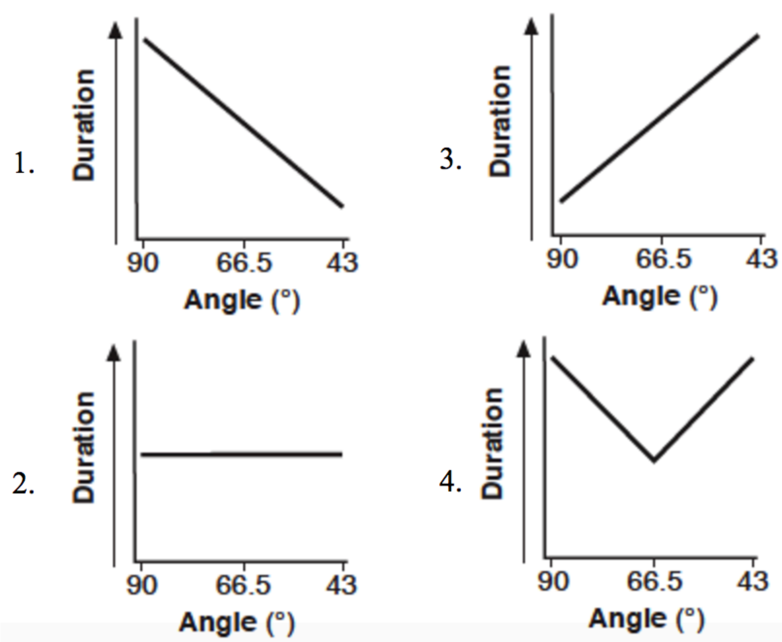
Base your answer to the questions 3 and 4 on the diagrams below and on your knowledge of Earth science. The diagrams, labeled *A*, *B*, and *C*, represent equal-sized portions of the Sun's rays striking Earth's surface at 23.5° N latitude at noon at three different times of the year. The angle at which the Sun's rays hit Earth's surface and the relative areas of Earth's surface receiving the rays at the three different angles of insolation are shown.



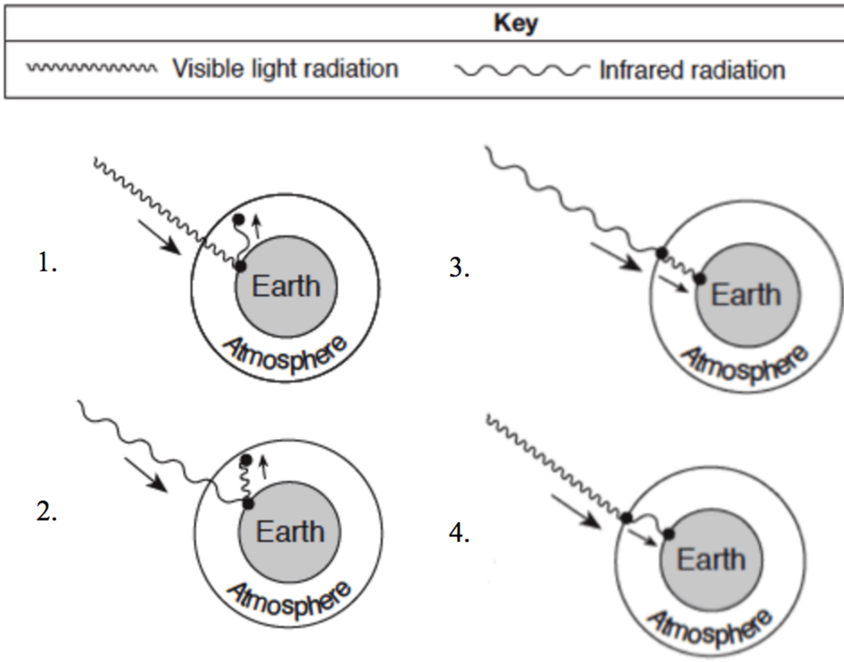
______**3.** As viewed in sequence from *A* to *B* to *C*, these diagrams represent which months and which change in the intensity of insolation?

(1) December → March → June; and decreasing intensity
(2) December → March → June; and increasing intensity
(3) June → September → December; and decreasing intensity
(4) June → September → December; and increasing intensity

______**4.** Which graph best shows the duration of insolation at this location as the angle of insolation changes?



_____**5.** Which diagram best represents how greenhouse gases in our atmosphere trap heat energy?



_____**6.** Equal areas of which surface will absorb the most insolation?

(1) partially melted snowfield
(2) white sand beach
(3) blacktop parking lot
(4) lake surface

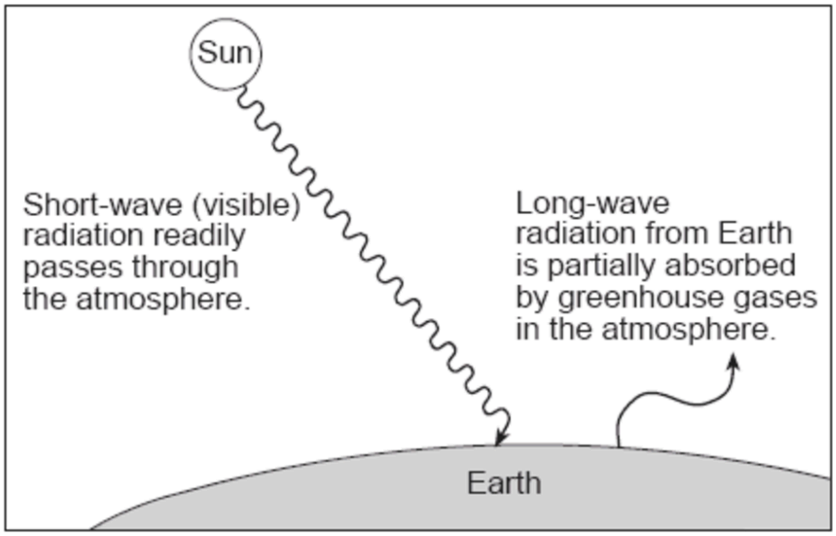
_____**7.** Compared to a light-colored rock with a smooth surface, a dark-colored rock with a rough surface will

(1) both absorb and reflect less insolation
(2) absorb less insolation and reflect more insolation
(3) both absorb and reflect more insolation
(4) absorb more insolation and reflect less insolation

_____**8.** Most insolation striking a smooth, light-colored, solid surface is

(1) refracted (2) transmitted (3) reflected (4) absorbed

Base your answer to this question on the diagram below, which represents the greenhouse effect in which heat energy is trapped in Earth's atmosphere.

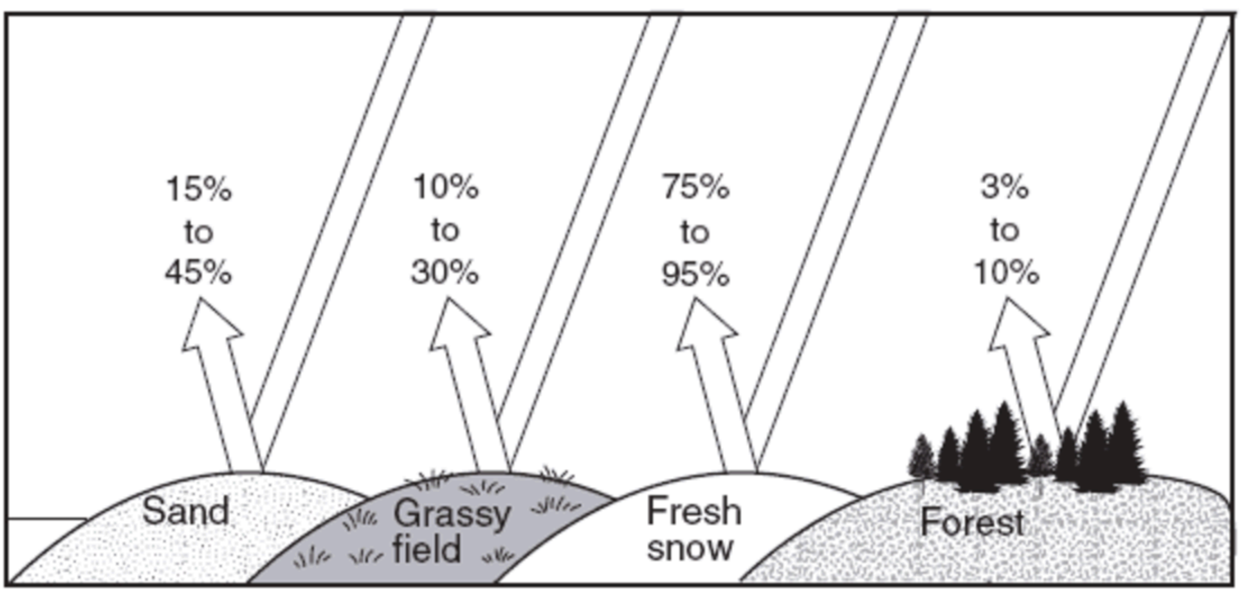


(Not drawn to scale)

______**9.** The Earth surface that best absorbs short-wave solar radiation has which characteristics?

(1) black and rough (2) black and smooth (3) white and rough (4) white and smooth

The diagram below indicates the amount of solar radiation that is reflected by equal areas of various materials on Earth's surface.



______**10.** Which material absorbs the most solar radiation?

(1) grassy field (2) fresh snow (3) sand (4) forest

Pre & Post-Unit Assessment: Earth's Energy Budget - Answers

In order to truly measure student growth after the completion of the unit, the pre-assessment will be the same as the post-assessment.

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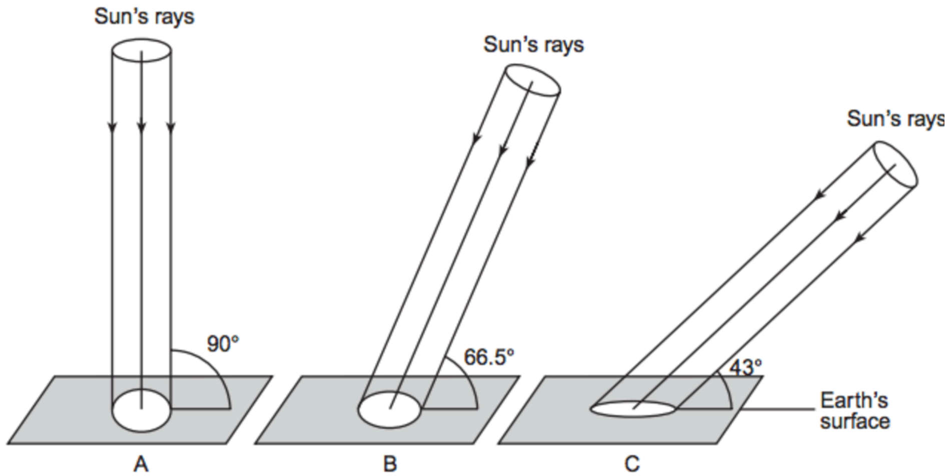

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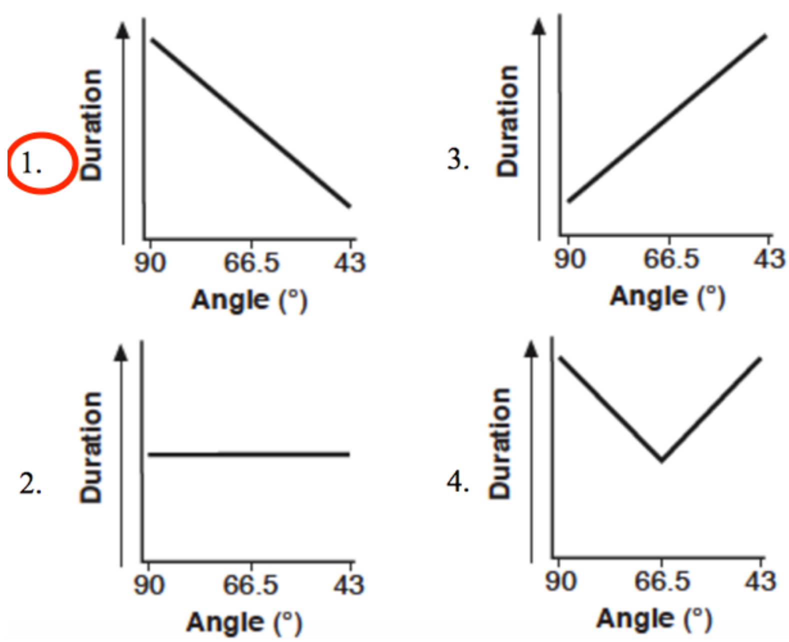
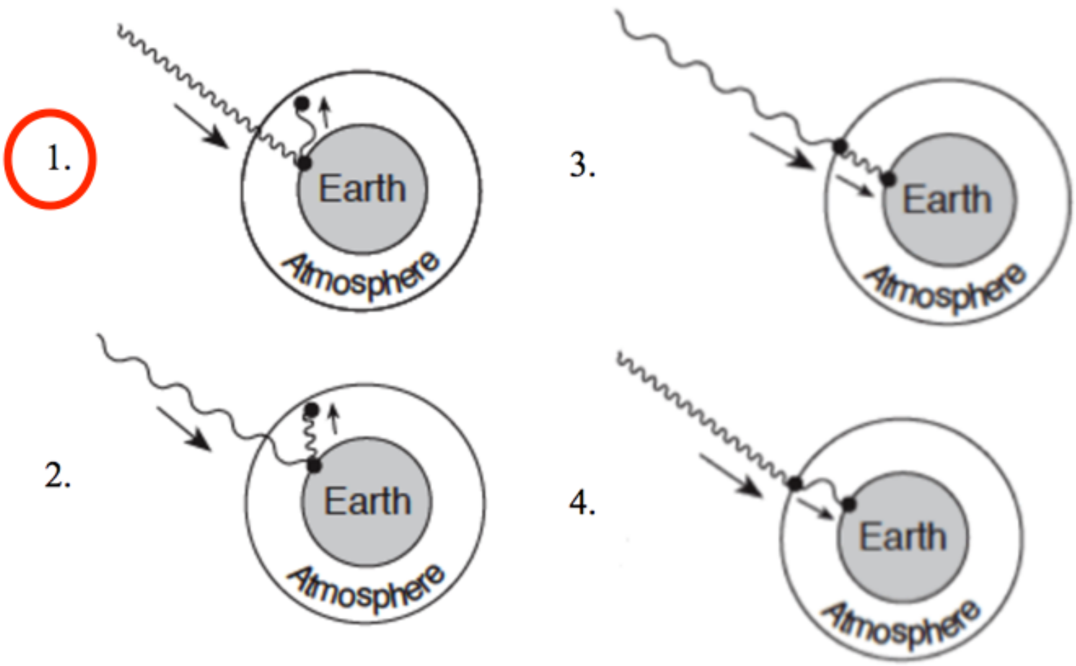


_____**5.** Which diagram best represents how greenhouse gases in our atmosphere trap heat energy?

Key		
Visible light radiation	Infrared radiation	• Absorbed energy



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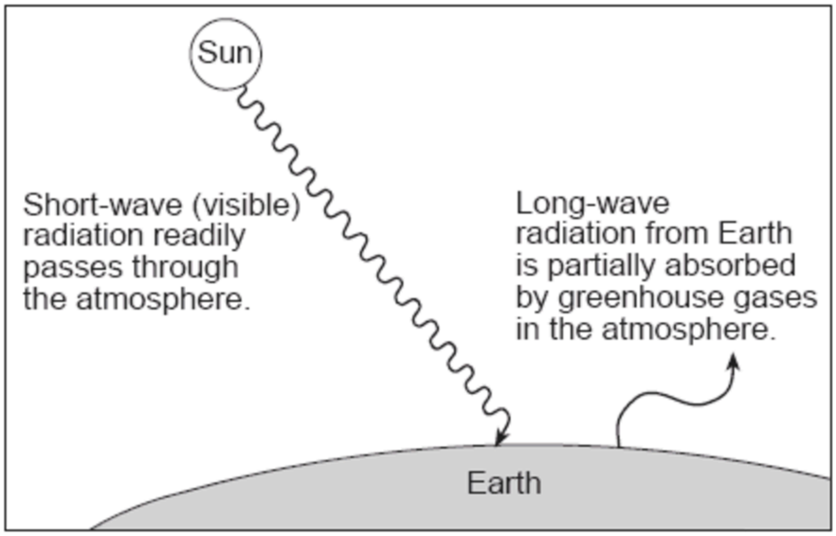

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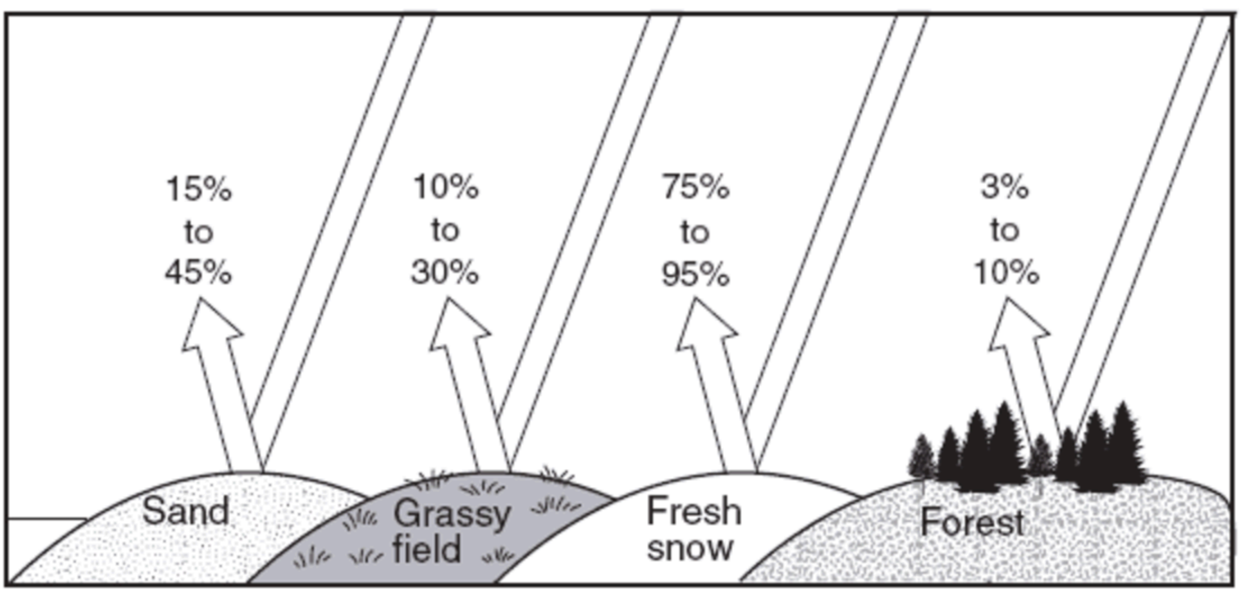

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Unit Title: Earth's Energy Budget
Lesson #1 Title: Deriving Earth's Energy Budget Equation
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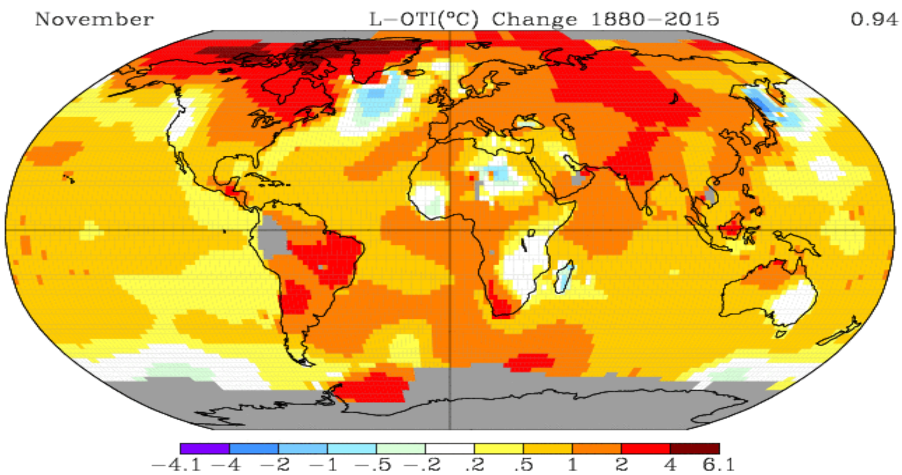

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V. Lesson 1: Title: Deriving Earth's Energy Balance Equation

A. Summary and Goals of Lesson

The goal of this lesson is for the students to learn how to derive the formula that represents Earth's radiative equilibrium, also known as the energy budget. The formula is $\frac{S_o}{4}(1 - \alpha) = \sigma T^4$ and represents how incoming energy needs to be equal to outgoing energy in order for Earth to maintain a stable temperature. In order for students to truly have an understanding of the energy balance equation, it is important for the students to learn how the formula is derived.

Derivations at the high school level can be daunting and therefore the students will learn how to derive the formula with a graphic organizer that outlines the NASA Earth Observatory article titled Climate and Earth's Energy Balance. The article describes the derivation through words and images that represent the balance of incoming and outgoing energy. While reading the article, the students will use the graphic organizer that outlines each section of the article and provides the most important facts accompanied by questions about the content. The graphic organizer also introduces the students to the mathematical equations that accompany each section of the article so the students can deepen their understanding through numerical data. By the completion of the graphic organizer, the students will have one final equation that represents Earth's energy budget based on the balance of incoming and outgoing energy.

The activity will culminate in a student-led class discussion regarding the theme of different factors that can disrupt the balance of the mathematical model and the possible implications. The students will contribute to the discussion by creating two discussion questions related to the theme by using the Depth of Knowledge (DOK) chart. Students will be evaluated throughout the discussion with a rubric based on their knowledge of the content, citation of information from the article, and professionalism.

B. Table of Contents for lesson

A. Summary and Goals of Lesson **14**
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F. Conclusion and overview of linkages to next lesson and unit goals. **40**

C. 5 E lesson model template:

STEM Earth Science Research

Unit: Earth's Energy Budget **Topic**: Deriving Earth's Energy Budget Equation

Prior Learning: Prior to this lesson, the students should have knowledge of Earth's tilt and how the tilt influences the angle of insolation that hits the surface of the Earth at different latitudes at different times of the year. The students should also have knowledge of the term albedo and how different surfaces have a different value for albedo based on how much energy the surface reflects. The students will now use this knowledge of tilt, angle of insolation, and albedo to learn how to derive an equation that describes Earth's energy budget at the top of the atmosphere.

Do Now (Pre-Assessment):
1. Describe the distribution of insolation on the surface of the Earth in both the Northern and Southern Hemispheres on the following two dates: December 21st and June 21st.

Aim: How can we derive the equation for Earth's radiative equilibrium (energy budget)?

New York State Standards:

1.1f - Earth's changing position with regard to the Sun and the moon has noticeable effects.
- Earth revolves around the Sun with its rotational axis tilted at 23.5 degrees to a line perpendicular to the plane of its orbit, with the North Pole aligned with Polaris.
- During Earth's one-year period of revolution, the tilt of its axis results in changes in the angle of incidence of the Sun's rays at a given latitude; these changes cause variation in the heating of the surface. This produces seasonal variation in weather.

2.2a - Insolation (solar radiation) heats Earth's surface and atmosphere unequally due to variations in:
- the intensity caused by differences in atmospheric transparency and angle of incidence which vary with time of day, latitude, and season
- characteristics of the materials absorbing the energy such as color, texture, transparency, state of matter, and specific heat
- duration, which varies with seasons and latitude.

Next Generation Science Standards:

HS - ESS2-4 - Use a model to describe how variations in the flow of energy into and out of Earth's systems result in changes in climate.

HS - ESS3-5 - Analyze geoscience data and the results from global climate models to make an evidence-based forecast of the current rate of global or regional climate change and associated future impacts to Earth systems.

Common Core State Standards: (This unit is also connected to the 11-12 grades of the same standards).

CCSS: 9-10.RST.1 - Cite specific textual evidence to support analysis of science and technical texts, attending to the precise details of explanations or descriptions.

CCSS: 9-10.RST.2 - Determine the central ideas or conclusions of a text; trace the text's explanation or depiction of a complex process, phenomenon, or concept; provide an accurate summary of the text.

CCSS: 9-10.RST.7 - Integrate and evaluate multiple sources of information presented in diverse formats and media (e.g., quantitative data, video, multimedia) in order to address a question or solve a problem.

CCSS:Math.Content.HSA.SSE.A.1.B - Interpret complicated expressions by viewing one or more of their parts as a single entity.

NASA System Engineering Behavior:

Attitudes and Attributes:
1a. Seeks Information and Uses the Art of Questioning
1b. Advances Ideas
Problem Solving & Systems Thinking:
2a. Thinks Systematically
2b. Possess Creativity and Problem Solving Abilities

Performance Objective: Students will be able to derive the formula that describes Earth's radiation equilibrium (energy budget) by reading, analyzing, and completing a graphic organizer based on the content in a NASA Earth Observatory article titled Climate and Earth's Energy Budget.

Materials: NASA Earth Observatory Article; Deriving Earth's Energy Balance Equation organizer; NASA GEEBITT model (see the For Further Exploration section of this lesson plan)

NASA Earth Observatory Article: http://earthobservatory.nasa.gov/Features/EnergyBalance/

NASA GEEBITT Model: https://icp.giss.nasa.gov/education/geebitt/

Vocabulary: Albedo; Insolation; Incoming energy (shortwave); Outgoing energy (longwave); Stefan-Boltzmann Constant; Solar Constant

Anticipatory Opening: After the Do Now, talk to the students about what it means to maintain a budget based on their allowance, the money they make with a part-time job, etc.

Development of the Lesson: **Two-Day Lesson (Approximately two 50-minute periods).**

What the teacher does	What the student does	Time
1. Write down the Do Now, Aim, and the HW on the blackboard.		
2. Circulate the room while the students complete the Do Now questions. Determine how much the students remember from the previous units and determine by responses how much needs to be reviewed concerning angle of insolation.	The students answer the Do Now questions in their notebooks to determine how much is remembered about Earth's tilt (in relation to angle of insolation).	**5 min**

Assessment Opportunity #1 (Student prior knowledge from previous units)		
3. ENGAGE Discuss with the students what it means to maintain a budget based on their income. Have the students make a list of their expenses and have them compare that to their income. ***Assessment Opportunity #2 (Student discussions regarding budgets)*** ***Assessment Opportunity #3 (Student connections between a monetary budget and an energy budget).***	The students discuss what it means to maintain a budget based on their income and expenses. The students make connections between a monetary budget and an energy budget for Earth.	**10 min**
4. EXPLORE & EXPLAIN Introduce the students to the NASA Earth Observatory Article. Circulate the room as the students read the article and complete the graphic organizer that allows students to derive the energy budget equation. Look for common challenges and misconceptions. Pay special attention to student calculations. ***Assessment Opportunity #4 (Student answers to questions in the graphic organizer).***	The students read and analyze the contents of the NASA Earth Observatory article. The students complete the graphic organizer by answering questions based on the content of each section of the article. The students derive the formula for Earth's energy budget.	**50 min**
5. ELABORATE & EVALUATE Model for the students how to use the DOK chart to come up with discussion questions for the following theme: *How could the energy budget become out of balance?* Begin the discussion for the students but slowly leave the discussion so the students are the facilitators. Assess the students on their discussion based on the attached rubric. ***Assessment Opportunity #5(Student-led discussions regarding an imbalance of the energy budget).***	The students use the DOK chart to create discussion questions based on the following theme: *How could the energy budget become out of balance?* The students lead a discussion based on their discussion questions. The students will discuss ways that the energy budget can be out of balance and any implications of the imbalance.	**30 min**

6. Administer the Daily Formative Assessment (DFA) to the students. ***Assessment Opportunity #6 (Student answers to the DFA).***	The students individually answer questions for the Daily Formative Assessment. The students will submit their answers at the end of class.	**5 min**

Summary/Conclusion: The students individually answer questions on the Daily Formative Assessment. The students will submit their answers at the end of class.

Higher Order Questions:
1. Why doesn't Earth's surface temperature infinitely rise?

2. Why do you think the amount of energy that reaches the Earth ($\boldsymbol{I}$) is less than the amount of energy that the sun emits ($\boldsymbol{I_S}$)?

3. How would the amount of energy received by Earth at the TOA change if Earth's albedo was .50 instead of .29?

Differentiated Instruction:
- The students are exposed to content in written, oral, and visual forms (multiple modalities exist).
- Students can use colored pencils to draw diagrams and annotate notes in a way that is meaningful to them.
- Students are asked both higher and lower level questions so all students can answer questions at their particular academic level.
- Students are given time to answer questions during think pair share/group activities.
- Students will be using a graphic organizer to break down the derivation of Earth's energy budget formula.
- Students will have access to highlighters when reading the NASA Earth Observatory article.

Daily Formative Assessment:
1. Assuming Earth's albedo is .30, calculate the temperature at which Earth emits energy based on the energy budget formula you derived today.

2. How would the amount of incoming energy for Earth change if Earth's albedo were to increase due to an increase in cloud cover around the Earth?

Next Lesson: The next lesson the students will analyze four datasets that make up each component of the energy budget at the top of Earth's atmosphere (TOA) from the NASA CERES satellite mission.

For Further Exploration: Go to https://icp.giss.nasa.gov/education/geebitt/ and click on the link titled "GEEBITT – Full Version". Clicking will download an Excel file that allows users to change inputs, such as date of the year and distance from the Sun, to determine how the amount of solar energy reaching the top of Earth's atmosphere will change due to those changing parameters.

Notes For Revision:

Derived Energy Budget Formula: $\frac{S_o}{4}(1 - \alpha) = \sigma T^4$

D. Content template:

NGSS Standard:	State Earth Science Content Standard:	Common Core Standard:	NASA Science:
HS - ESS2-4 - Use a model to describe how variations in the flow of energy into and out of Earth's systems result in changes in climate. **HS - ESS3-5 -** Analyze geoscience data and the results from global climate models to make an evidence-based forecast of the current rate of global or regional climate change and associated future impacts to Earth systems.	**1.1f** - Earth's changing position with regard to the Sun and the moon has noticeable effects. • Earth revolves around the Sun with its rotational axis tilted at 23.5 degrees to a line perpendicular to the plane of its orbit, with the North Pole aligned with Polaris. • During Earth's one-year period of revolution, the tilt of its axis results in changes in the angle of incidence of the Sun's rays at a given latitude; these changes cause variation in the heating of the surface. This produces seasonal variation in weather. **2.2a** - Insolation (solar radiation) heats Earth's surface and atmosphere unequally due to variations in: • the intensity caused by differences in atmospheric transparency and angle of incidence which vary with time of day, latitude, and season • characteristics of the materials absorbing the energy such as color, texture, transparency, state of matter, and specific heat • duration, which varies with seasons and latitude.	**CCSS: 9-10.RST.1** - Cite specific textual evidence to support analysis of science and technical texts, attending to the precise details of explanations or descriptions. **CCSS: 9-10.RST.2** - Determine the central ideas or conclusions of a text; trace the text's explanation or depiction of a complex process, phenomenon, or concept; provide an accurate summary of the text. **CCSS: 9-10.RST.7** - Integrate and evaluate multiple sources of information presented in diverse formats and media (e.g., quantitative data, video, multimedia) in order to address a question or solve a problem. **CCSS:Math.Content.HSA.SSE.A.1.B** - Interpret complicated expressions by viewing one or more of their parts as a single entity.	Earth: Earth's Energy Budget
Content Area: Earth & Space Sciences **Grade Level:** High School	**Name of Project-Based Activity or Theme:** Deriving Earth's Energy Budget Equation	**Estimated Time Frame to Complete (days/weeks):** Lesson #1 = Two 50-minute class periods	

Overall Investigation Question(s): How can we derive the equation for Earth's radiative equilibrium (energy budget)?
Overall Project Description/Activity: Students will be able to derive the formula that describes Earth's radiation equilibrium (energy budget) by reading, analyzing, and completing a graphic organizer based on the content in a NASA Earth Observatory article titled Climate and Earth's Energy Budget.

Materials Needed to Complete Project (put N/A as needed):	Stakeholders:	Hyperlinks Used: Visit the hyperlinks in the following order in the lesson:	Multimedia/Technology:	Classroom Equipment:
NASA Earth Observatory Article; Deriving Earth's Energy Balance Equation organizer	1. Earth & space science educators 2. Earth & space science students 3. Students engaged in science research 4. NYCDOE 5. NASA	1. NASA Earth Observatory Article: http://earthobservatory.nasa.gov/Features/EnergyBalance/	Website links: 1. NASA Earth Observatory Article: http://earthobservatory.nasa.gov/Features/EnergyBalance/	Highlighters; Calculators

NASA System Engineering Behaviors (2 behaviors per category)	**Category**	**Activities**	**Student Outcomes**	**Evaluation**
1a. Seeks Information and Uses the Art of Questioning 1b. Advances Ideas 2a. Thinks Systematically 2b. Possess Creativity and Problem Solving Abilities	1. Attitudes and Attributes 2. Problem solving & systems thinking	**How will student model engineering behaviors when learning science content?** **Describe student activities here.** 1a&b. Students will be seeking information through questioning and advancing ideas by participating in a student-led class discussion. Students will use the knowledge gained from the NASA Earth Observatory article titled Climate and Earth's Energy Budget and the DOK question chart to come up with discussion questions. The student-led discussion will be based on the theme of how and why would the Earth's energy budget become imbalanced. 2a. The students will read an article to help derive the equation that represents the balance of Earth's energy budget. The students will break down the equation into smaller manageable parts in order to ensure understanding. This will be done by completing a graphic organizer. 2b. The students will first read a long article that uncovers a different component of Earth's energy balance equation in each section of the article. The students will then have a 25-minute student-led discussion regarding the constraints of the equation and what could cause the equation to become imbalanced.	**How will you assess learning for each behavior:** 1a&b. Students will be assessed on these behaviors through their prepared DOK discussion questions and their participation in the student-led discussion. Students will be assessed with a rubric that evaluates their professionalism, knowledge of content, and ability to cite textual evidence. 2a. Student answers to questions in the graphic organizer will be assessed for accuracy. 2b. Student answers to questions in the graphic organizer will be assessed for accuracy. Students will also be assessed on their student-led discussion with a discussion rubric.	**Describe specific science content students understand as a result of engineering behavior.** 1a&b. Students will be able to explain how Earth's energy budget could become imbalanced and evaluate the implications of the imbalance. 2a. Students will be able to derive and explain the equation for Earth's energy budget. Specifically, students will be able to write a mathematical formula for incoming energy and a formula that represents outgoing energy. 2b. Students will be able to evaluate how an imbalance to the energy budget equation will impact climate on Earth.
List and attach all supportive documents for instructional activities.	Attachments? (circle) **Yes** or No	**List Attached Documents (if any):** 1. NASA Earth Observatory Article: Climate and Earth's Energy Budget 2. Deriving Earth's Energy Balance Equation Graphic Organizer 3. Student-led Class Discussion: Earth's Energy Budget activity description		
List and attach all rubrics for activity and assessment evaluation.	Attachments? (circle) **Yes** or No	**List Attached Rubrics (if any):** 1. Student-led Class Discussion Rubric		
Include comments or questions here:				

E. Supporting Documents: (order according to sequence of lesson)

Climate and Earth's Energy Budget

by Rebecca LindseyJanuary 14, 2009 http://earthobservatory.nasa.gov/Features/EnergyBalance/

*Please note that the subheadings of this article were changed in order to scaffold the information within the article

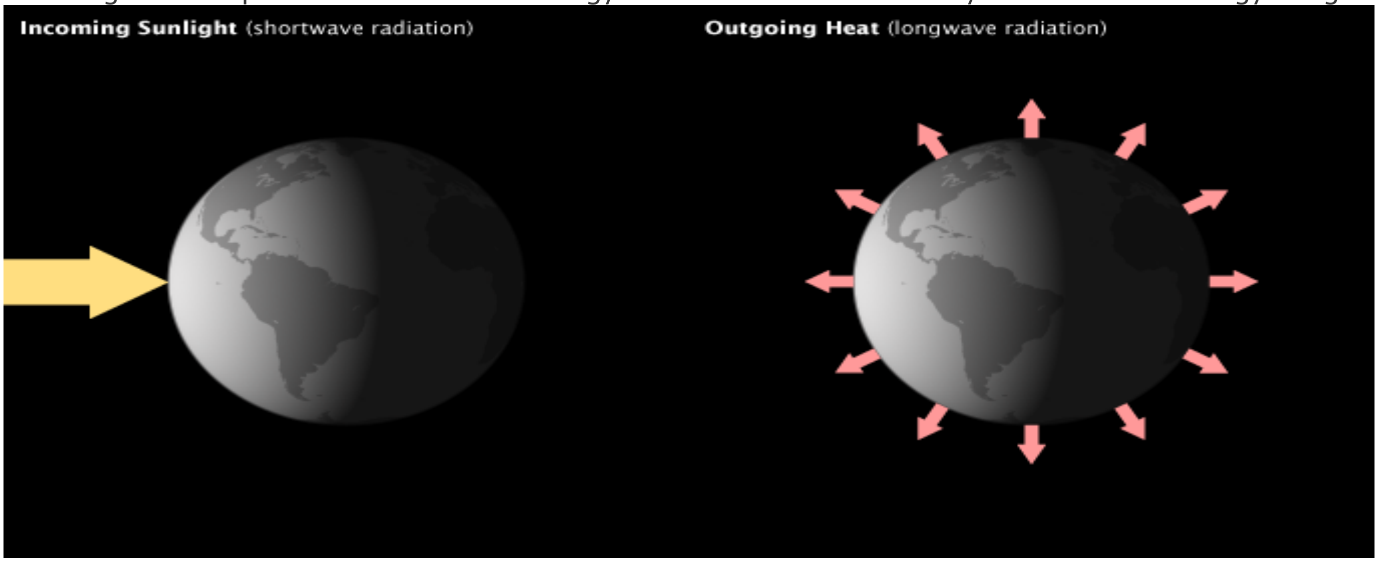
Introduction

The Earth's climate is a solar powered system. Globally, over the course of the year, the Earth system—land surfaces, oceans, and atmosphere—absorbs an average of about 240 watts of solar power per square meter (one watt is one joule of energy every second). The absorbed sunlight drives photosynthesis, fuels evaporation, melts snow and ice, and warms the Earth system.

Solar power drives Earth's climate. Energy from the Sun heats the surface, warms the atmosphere, and powers the ocean currents. (Astronaut photograph ISS015-E-10469, courtesy NASA/JSC Gateway to Astronaut Photography of Earth.)

The Sun doesn't heat the Earth evenly. Because the Earth is a sphere, the Sun heats equatorial regions more than polar regions. The atmosphere and ocean work non-stop to even out solar heating imbalances through evaporation of surface water, convection, rainfall, winds, and ocean circulation. This coupled atmosphere and ocean circulation is known as Earth's heat engine.

The climate's heat engine must not only redistribute solar heat from the equator toward the poles, but also from the Earth's surface and lower atmosphere back to space. Otherwise, Earth would endlessly heat up. Earth's temperature doesn't infinitely rise because the surface and the atmosphere are simultaneously radiating heat to space. This net flow of energy into and out of the Earth system is Earth's energy budget.

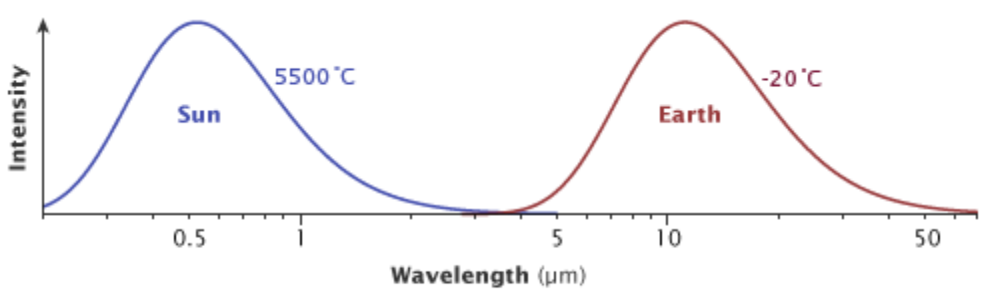


The energy that Earth receives from sunlight is balanced by an equal amount of energy radiating into space. The energy escapes in the form of thermal infrared radiation: like the energy you feel radiating from a heat lamp. (NASA illustrations by Robert Simmon.)

When the flow of incoming solar energy is balanced by an equal flow of heat to space, Earth is in radiative equilibrium, and global temperature is relatively stable. Anything that increases or decreases the amount of incoming or outgoing energy disturbs Earth's radiative equilibrium; global temperatures rise or fall in response.

Incoming Sunlight Part 1

All matter in the universe that has a temperature above absolute zero (the temperature at which all atomic or molecular motion stops) radiates energy across a range of wavelengths in the electromagnetic spectrum. The hotter something is, the shorter its peak wavelength of radiated energy is. The hottest objects in the universe radiate mostly gamma rays and x-rays. Cooler objects emit mostly longer-wavelength radiation, including visible light, thermal infrared, radio, and microwaves.



The Sun's surface temperature is 5,500° C, and its peak radiation is in visible wavelengths of light. Earth's effective temperature—the temperature it appears when viewed from space—is -20° C, and it radiates energy that peaks in thermal infrared wavelengths. (Illustration adapted from Robert Rohde.)

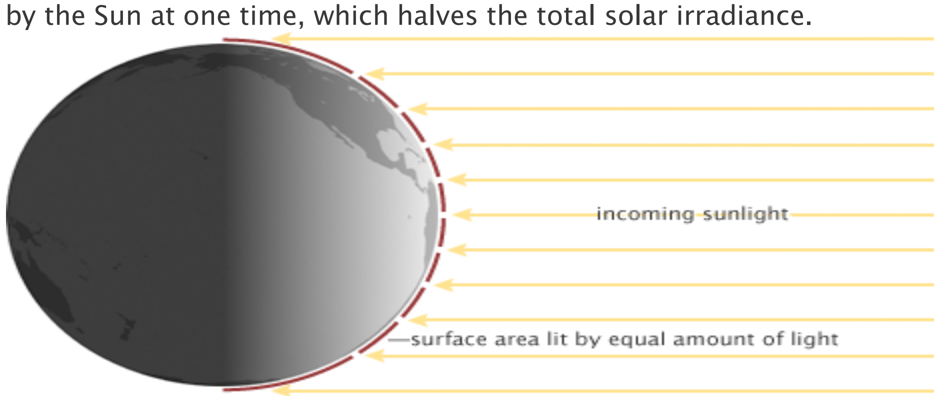
Incandescent light bulbs radiate 40 to 100 watts. The Sun delivers 1,360 watts per square meter. An astronaut facing the Sun has a surface area of about 0.85 square meters, so he or she receives energy equivalent to **19** 60-watt light bulbs. (Photograph ©2005 Paul Watson.)

Incoming Sunlight Part 2

The surface of the Sun has a temperature of about 5,800 Kelvin (about 5,500 degrees Celsius, or about 10,000 degrees Fahrenheit). At that temperature, most of the energy the Sun radiates is visible and near-infrared light. At Earth's average distance from the Sun (about 150 million kilometers), the average intensity of solar energy reaching the top of the atmosphere directly facing the Sun is about 1,360 watts per square meter, according to measurements made by the most recent NASA satellite missions. This amount of power is known as the total solar irradiance. (Before scientists discovered that it varies by a small amount during the sunspot cycle, total solar irradiance was sometimes called "the solar constant.")

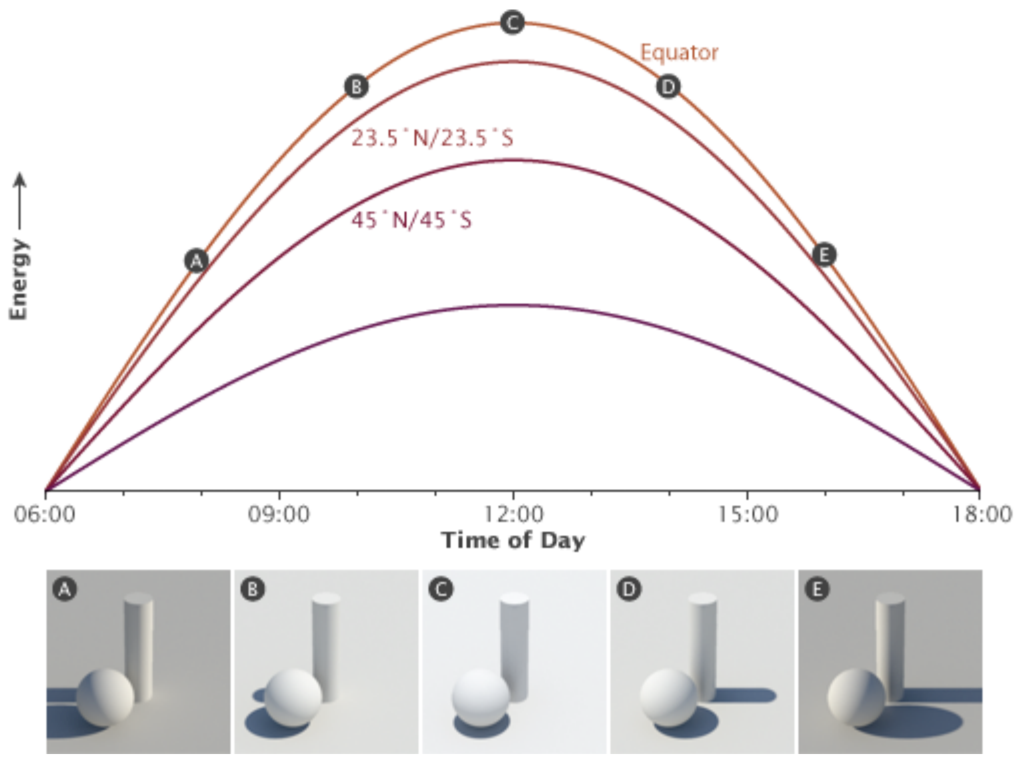
A watt is measurement of power, or the amount of energy that something generates or uses over time. How much power is 1,360 watts? An incandescent light bulb uses anywhere from 40 to 100 watts. A microwave uses about 1000 watts. If for just one hour, you could capture and re-use all the solar energy arriving over a single square meter at the top of the atmosphere directly facing the Sun—an area no wider than an adult's outstretched arm span—you would have enough to run a refrigerator all day.

The total solar irradiance is the maximum possible power that the Sun can deliver to a planet at Earth's average distance from the Sun; basic geometry limits the actual solar energy intercepted by Earth. Only half the Earth is ever lit by the Sun at one time, which halves the total solar irradiance.



Energy from sunlight is not spread evenly over Earth. One hemisphere is always dark, receiving no solar radiation at all. On the daylight side, only the point directly under the Sun receives full-intensity solar radiation. From the equator to the poles, the Sun' rays meet Earth at smaller and smaller angles, and the light gets spread over larger and larger surface areas (red lines). (NASA illustration by Robert Simmon.)

In addition, the total solar irradiance is the maximum power the Sun can deliver to a surface that is perpendicular to the path of incoming light. Because the Earth is a sphere, only areas near the equator at midday come close to being perpendicular to the path of incoming light. Everywhere else, the light comes in at an angle. The progressive decrease in the angle of solar illumination with increasing latitude reduces the average solar irradiance by an additional one-half.



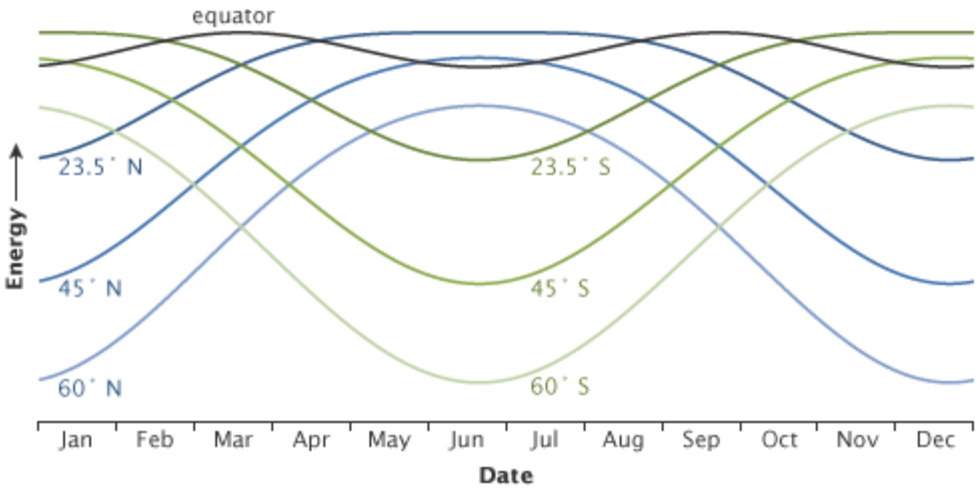
The solar radiation received at Earth's surface varies by time and latitude. This graph illustrates the relationship between latitude, time, and solar energy during the equinoxes. The illustrations show how the time of day (A–E) affects the angle of incoming sunlight (revealed by the length of the shadow) and the light's intensity. On the equinoxes, the Sun rises at 6:00 a.m. everywhere. The strength of sunlight increases from sunrise until noon, when the Sun is directly overhead along the equator (casting no shadow). After noon, the strength of sunlight decreases until the Sun sets at 6:00 p.m. The tropics (from 0 to 23.5° latitude) receive about 90% of the energy compared to the equator, the mid-latitudes (45°) roughly 70%, and the Arctic and Antarctic Circles about 40%. (NASA illustration by Robert Simmon.)

Averaged over the entire planet, the amount of sunlight arriving at the top of Earth's atmosphere is only one-fourth of the total solar irradiance, or approximately 340 watts per square meter.

When the flow of incoming solar energy is balanced by an equal flow of heat to space, Earth is in radiative equilibrium, and global temperature is relatively stable. Anything that increases or decreases the amount of incoming or outgoing energy disturbs Earth's radiative equilibrium; global temperatures must rise or fall in response.

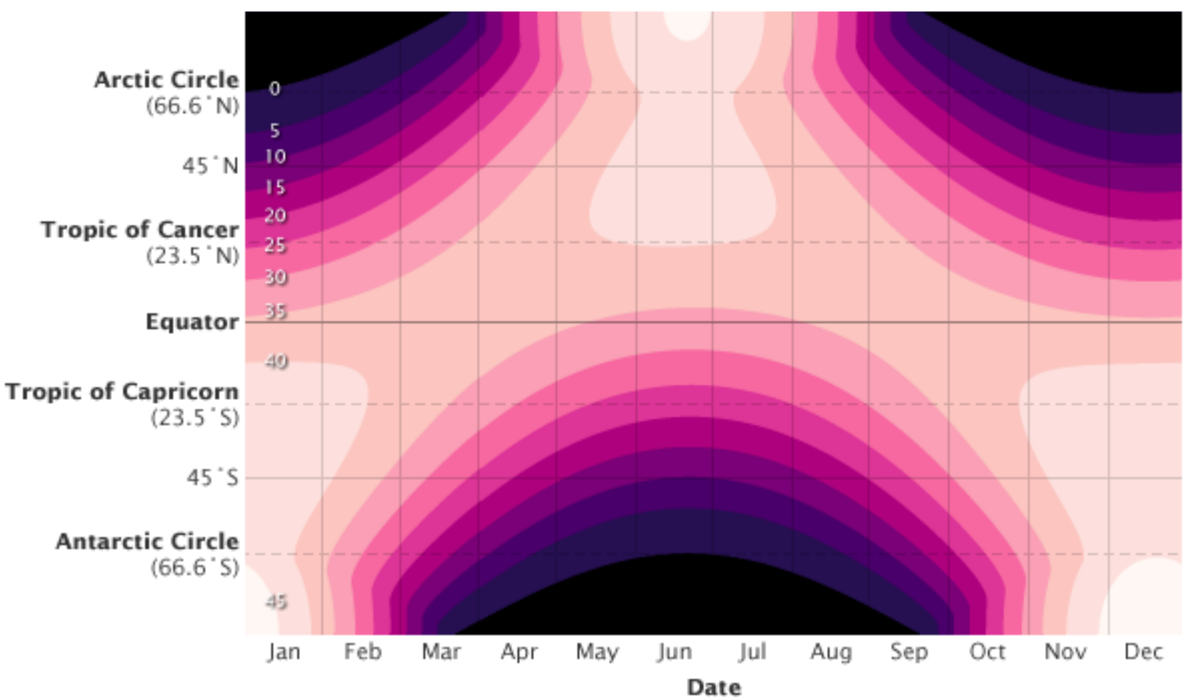
Heating Imbalances

Three hundred forty watts per square meter of incoming solar power is a global average; solar illumination varies in space and time. The annual amount of incoming solar energy varies considerably from tropical latitudes to polar latitudes (described on page 2). At middle and high latitudes, it also varies considerably from season to season.



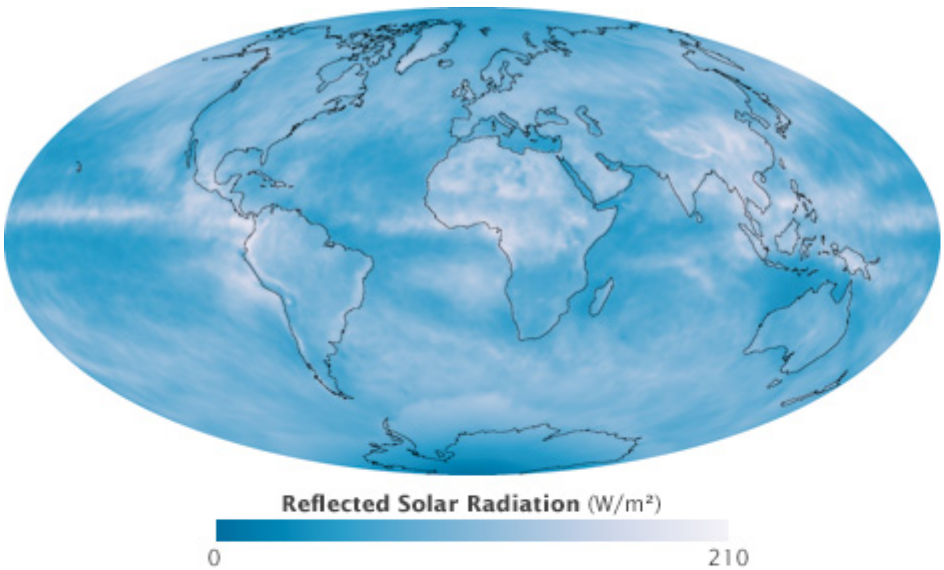
The **peak** energy received at different latitudes changes throughout the year. This graph shows how the solar energy received at local noon each day of the year changes with latitude. At the equator (gray line), the peak energy changes very little throughout the year. At high northern (blue lines) and southern (green) latitudes, the seasonal change is extreme. (NASA illustration by Robert Simmon.)

If the Earth's axis of rotation were vertical with respect to the path of its orbit around the Sun, the size of the heating imbalance between equator and the poles would be the same year round, and the seasons we experience would not occur. Instead Earth's axis is tilted off vertical by about 23 degrees. As the Earth orbits the Sun, the tilt causes one hemisphere and then the other to receive more direct sunlight and to have longer days.



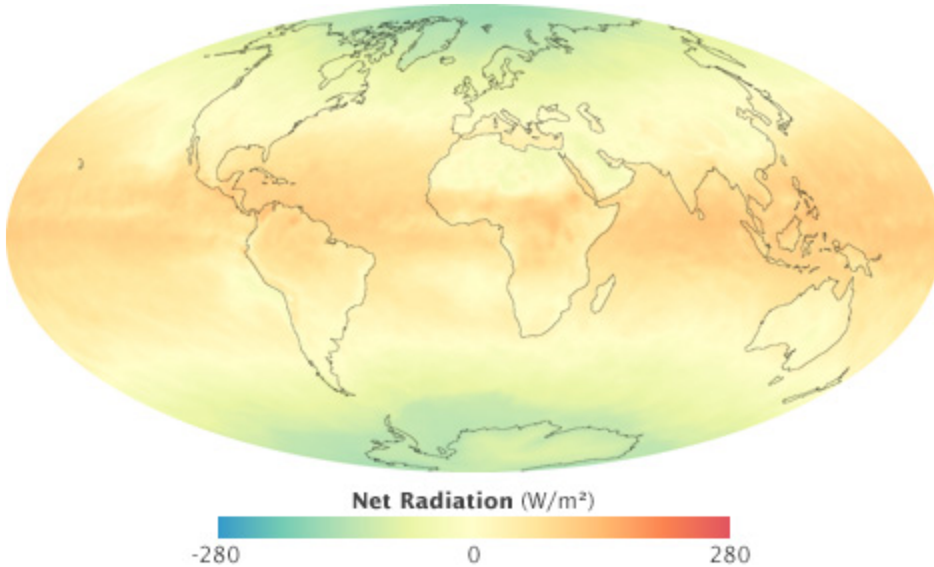
The **total** energy received each day at the top of the atmosphere depends on latitude. The highest daily amounts of incoming energy (pale pink) occur at high latitudes in summer, when days are long, rather than at the equator. In winter, some polar latitudes receive no light at all (black). The Southern Hemisphere receives more energy during December (southern summer) than the Northern Hemisphere does in June (northern summer) because Earth's orbit is not a perfect circle and Earth is slightly closer to the Sun during that part of its orbit. Total energy received ranges from 0 (during polar winter) to about 50 (during polar summer) megajoules per square meter per day.

In the “summer hemisphere,” the combination of more direct sunlight and longer days means the pole can receive more incoming sunlight than the tropics, but in the winter hemisphere, it gets none. Even though illumination increases at the poles in the summer, bright white snow and sea ice reflect a significant portion of the incoming light, reducing the potential solar heating.



The amount of sunlight the Earth absorbs depends on the reflectivness of the atmosphere and the ground surface. This satellite map shows the amount of solar radiation (watts per square meter) reflected during September 2008. Along the equator, clouds reflected a large proportion of sunlight, while the pale sands of the Sahara caused the high reflectivness in North Africa. Neither pole is receiving much incoming sunlight at this time of year, so they reflect little energy even though both are ice-covered. (NASA map by Robert Simmon, based on CERES data.)

The differences in reflectivness (albedo) and solar illumination at different latitudes lead to net heating imbalances throughout the Earth system. At any place on Earth, the net heating is the difference between the amount of incoming sunlight and the amount heat radiated by the Earth back to space (for more on this energy exchange see Page 4). In the tropics there is a net energy surplus because the amount of sunlight absorbed is larger than the amount of heat radiated. In the polar regions, however, there is an annual energy deficit because the amount of heat radiated to space is larger than the amount of absorbed sunlight.



This map of net radiation (incoming sunlight minus reflected light and outgoing heat) shows global energy imbalances in September 2008, the month of an equinox. Areas around the equator absorbed about 200 watts per square meter more on average (orange and red) than they reflected or radiated. Areas near the poles reflected and/or radiated about 200 more watts per square meter (green and blue) than they absorbed. Mid-latitudes were roughly in balance. (NASA map by Robert Simmon, based on CERES data.)

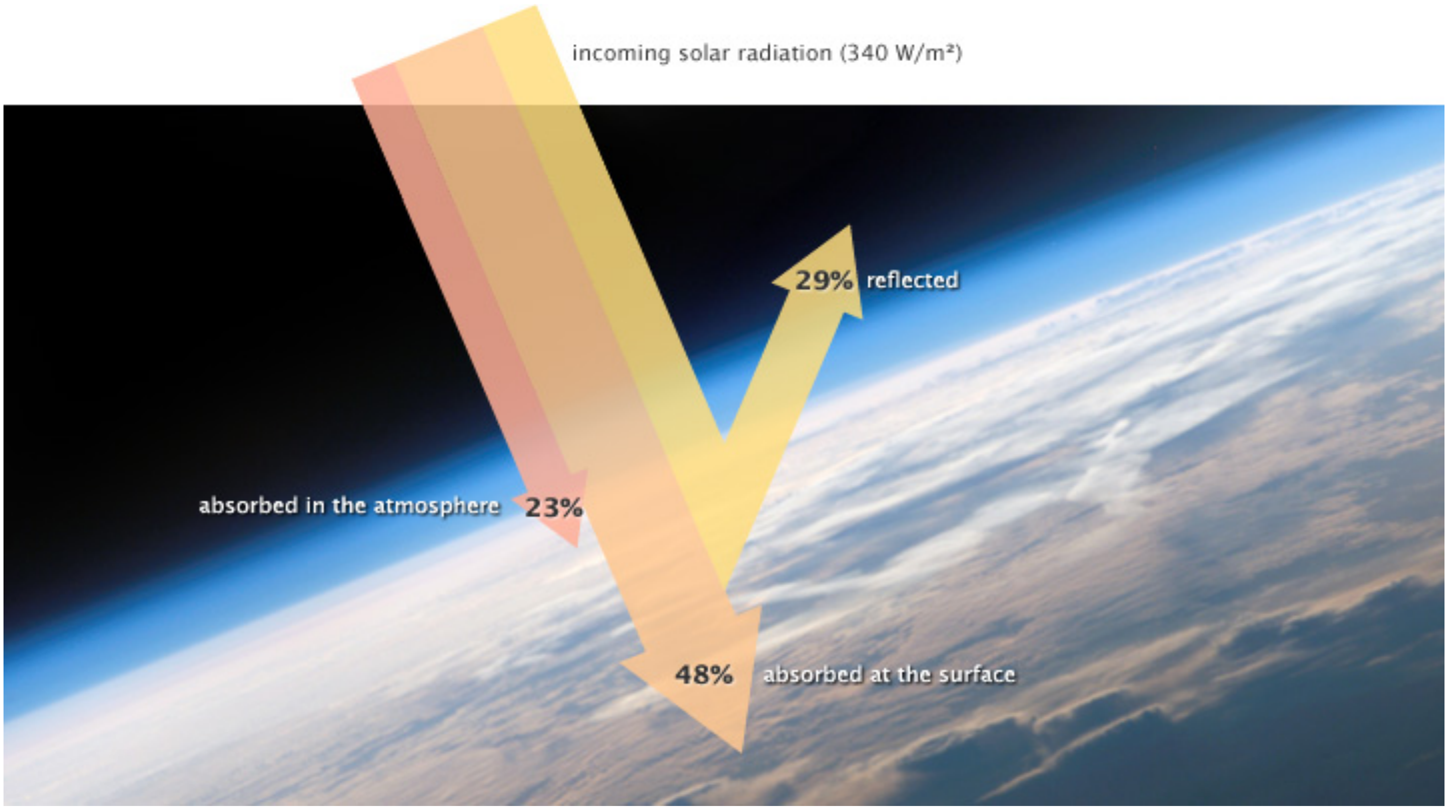
The net heating imbalance between the equator and poles drives an atmospheric and oceanic circulation that climate scientists describe as a "heat engine." (In our everyday experience, we associate the word engine with automobiles, but to a scientist, an engine is any device or system that converts energy into motion.) The climate is an engine that uses heat energy to keep the atmosphere and ocean moving. Evaporation, convection, rainfall, winds, and ocean currents are all part of the Earth's heat engine.

Earth's Energy Budget

Note: Determining exact values for energy flows in the Earth system is an area of ongoing climate research. Different estimates exist, and all estimates have some uncertainty. Estimates come from satellite observations, ground-based observations, and numerical weather models. The numbers in this article rely most heavily on direct satellite observations of reflected sunlight and thermal infrared energy radiated by the atmosphere and the surface.

Earth's heat engine does more than simply move heat from one part of the surface to another; it also moves heat from the Earth's surface and lower atmosphere back to space. This flow of incoming and outgoing energy is Earth's energy budget. For Earth's temperature to be stable over long periods of time, incoming energy and outgoing energy have to be equal. In other words, the energy budget at the top of the atmosphere must balance. This state of balance is called radiative equilibrium.

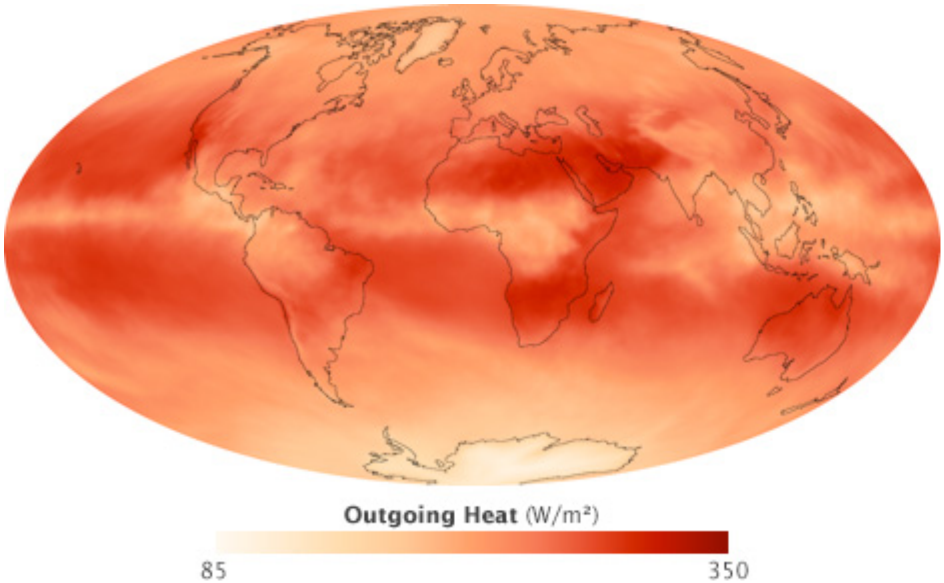
About 29 percent of the solar energy that arrives at the top of the atmosphere is reflected back to space by clouds, atmospheric particles, or bright ground surfaces like sea ice and snow. This energy plays no role in Earth's climate system. About 23 percent of incoming solar energy is absorbed in the atmosphere by water vapor, dust, and ozone, and 48 percent passes through the atmosphere and is absorbed by the surface. Thus, about 71 percent of the total incoming solar energy is absorbed by the Earth system.



Of the 340 watts per square meter of solar energy that falls on the Earth, 29% is reflected back into space, primarily by clouds, but also by other bright surfaces and the atmosphere itself. About 23% of incoming energy is absorbed in the atmosphere by atmospheric gases, dust, and other particles. The remaining 48% is absorbed at the surface. (NASA illustration by Robert Simmon. Astronaut photograph ISS013-E-8948.)

When matter absorbs energy, the atoms and molecules that make up the material become excited; they move around more quickly. The increased movement raises the material's temperature. If matter could only absorb energy, then the temperature of the Earth would be like the water level in a sink with no drain where the faucet runs continuously.

Temperature doesn't infinitely rise, however, because atoms and molecules on Earth are not just absorbing sunlight, they are also radiating thermal infrared energy (heat). The amount of heat a surface radiates is proportional to the fourth power of its temperature. If temperature doubles, radiated energy increases by a factor of 16 (2 to the 4th power). If the temperature of the Earth rises, the planet rapidly emits an increasing amount of heat to space. This large increase in heat loss in response to a relatively smaller increase in temperature—referred to as radiative cooling—is the primary mechanism that prevents runaway heating on Earth.



Absorbed sunlight is balanced by heat radiated from Earth's surface and atmosphere. This satellite map shows the distribution of thermal infrared radiation emitted by Earth in September 2008. Most heat escaped from areas just north and south of the equator, where the surface was warm, but there were few clouds. Along the equator, persistent clouds prevented heat from escaping. Likewise, the cold poles radiated little heat. (NASA map by Robert Simmon, based on CERES data.)

The atmosphere and the surface of the Earth together absorb 71 percent of incoming solar radiation, so together, they must radiate that much energy back to space for the planet's average temperature to remain stable. However, the relative contribution of the atmosphere and the surface to each process (absorbing sunlight versus radiating heat) is asymmetric. The atmosphere absorbs 23 percent of incoming sunlight while the surface absorbs 48. The atmosphere radiates heat equivalent to 59 percent of incoming sunlight; the surface radiates only 12 percent. In other words, most solar heating happens at the surface, while most radiative cooling happens in the atmosphere. How does this reshuffling of energy between the surface and atmosphere happen?

National Aeronautics and Space Administration
Goddard Institute for Space Studies
New York, N.Y.

Name: ____ Date: ____________________

Deriving Earth's Energy Balance Equation

Based on NASA Earth Observatory Article: Climate and Earth's Energy Budget by Rebecca Lindsey

http://earthobservatory.nasa.gov/Features/EnergyBalance/

Activity Description: The purpose of this activity is for students to learn how to derive the formula for Earth's energy budget by reading the NASA Earth Observatory Article titled Climate and Earth's Energy Budget.

Directions: Read the article **section by section.** At the ***end of each section***, complete the part of the table below that corresponds to that section. **Do not use the data table until you read the section!** Each section in the table includes important facts, supplemental information, and questions to answer.

Earth's Energy Budget: Incoming Energy = Outgoing Energy

Introduction Facts	Questions	Student Answers
The atmosphere and ocean work together to even out solar heating imbalances on Earth. This is known as Earth's heat engine. The heat engine also works to redistribute energy from Earth's surface and atmosphere back towards space.	1. Why doesn't Earth's surface temperature infinitely rise? 2. What would cause Earth's temperature to rise or fall?	1. 2.
Incoming Sunlight Part 1 Facts	**Questions**	**Student Answers**
All matter in the universe that has a temperature above absolute zero radiates (emits) energy at different wavelengths of the electromagnetic spectrum. The hotter an object is, the shorter the peak wavelength of radiated energy. **The following facts are not found in article but compliment the article** The sun emits 3.9 x 10^{26} Joules of energy each second (J/S) which is 3.9 x 10^{26} Watts (W). The amount of energy from the Sun that is sent	1. At what wavelength does the sun radiate the majority of its energy? 2. At what wavelength does the Earth emit majority of its energy? 3. Based on the formula provided, calculate the energy flux (***I***) that the Sun sends towards the Earth. The units of your answer will be in Watts per meter-squared (W/m^2).	1. 2. 3.

towards Earth depends on the distance Earth is from the Sun. This is modeled by the equation below: $I = I_S / 4\pi r^2$ • *I* is the energy flux based on Earth's distance from the Sun • I_S is the energy flux of the Sun which is 3.9×10^{26} Watts • $4\pi r^2$ is the surface area of the Earth at a distance ***r*** from the Sun • ***r*** is 1.5×10^{11}m	4. Why do you think the amount of energy that reaches the Earth (***I***) is less than the amount of energy that the sun emits (I_S)?	4.
Incoming Sunlight Part 2 Facts	**Questions**	**Student Answers**
This NASA Earth Observatory article specifies the solar constant (the amount of energy the sun sends towards Earth) as 1,360 W/m^2. This differs from the amount you calculated in question #3 in the previous section. For the remainder of this activity, we will use **1,360 W/m^2 as the solar constant**.	1. If only half of the Earth is receiving sunlight at a given time, calculate the amount of the Sun's energy that is intercepted by Earth. (**Hint**: Use the **solar constant value** which is the amount of energy the Sun sends towards the Earth).	1.
At a given time, only half of the Earth is receiving sunlight due to Earth's rotation. Use this information to answer question #1 in this section. When solar radiation hits the surface of the Earth, the amount of heating is unequal since Earth is a sphere. For instance, more energy	2. Due to the unequal heating of sunlight reaching Earth's surface, calculate the amount of solar energy that actually hits the top of Earth's atmosphere. (**Hint:** Use the answer from question #1 above to help with the calculation).	2.
hits the equator than the polar regions. The fact that solar radiation hitting the surface of the Earth decreases with increasing latitude, the amount of solar radiation reaching the Earth is reduced by an additional half. Use this information	3. Based on the amount of energy that reaches the top of Earth's atmosphere, how much energy does Earth need to radiate (emit) in order to maintain radiative equilibrium?	3.

to answer question #2 in this section. As a result of the information in this section, ***the amount of solar energy that reaches the top of Earth's atmosphere is 340 W/m²***.		
Heating Imbalances Facts	**Questions**	**Student Answers**
The value of 340 W/m^2 of incoming solar radiation is a global average and will differ based on latitude. For example, the equator receives a higher value of incoming solar radiation while the polar regions receive less.	1. Why is there an imbalance of heating on the surface of the Earth?	1.
	2. How does solar heating on Earth's surface in the Northern Hemisphere compare to solar heating in the Southern Hemisphere?	2.
The reflectiveness of Earth's surface is also known as albedo. In the Northern Hemisphere summer, the polar regions receive a large amount of solar radiation. However, there is a large amount of radiation reflected due to the white snow and ice surfaces.	3. Explain how snow and ice surfaces can influence the amount of energy absorbed by Earth.	3.
Since not all of the incoming energy reaching the Earth is absorbed due to albedo, the equation for Earth's incoming energy can be written as: ***Incoming Energy*** $= \frac{S_o}{4}(1 - \alpha)$ S_0 is the solar constant of 1,360 W/m^2 $S_0/4$ is equivalent to 340 W/m^2 α is the albedo (reflectiveness) of the planet.	4. What is the equation used to calculate the incoming solar energy for the Earth? What is the meaning of each variable in the equation?	4.

Earth's Energy Budget Facts	Questions	Student Answers
Earth's energy budget is defined by the flow of incoming energy and outgoing energy. Energy at the top of the atmosphere (TOA) must be in balance such that the energy coming in at the top of the atmosphere must equal the energy leaving.	1. Explain how the amount of energy received by Earth at the TOA changes if Earth's albedo was .50 instead of .29?	1.
Some of the energy entering the TOA is reflected back towards space due to Earth's planetary albedo. Earth's albedo is approximately .29 which means Earth reflects 29% of the incoming energy.	2. If 29% of the incoming solar energy is reflected back towards space, what percentage of energy is available for absorption by the atmosphere and the surface of the Earth?	2.
As Earth absorbs energy from the Sun, Earth is also radiating (emitting) infrared energy. This ensures Earth does not infinitely heat up since energy is going out as it is coming in.	3. What is the equation used to calculate the outgoing energy for the Earth? What is the meaning of each variable in the equation?	3.
The amount of energy Earth radiates is proportional to (related to) the fourth power of its temperature. This is also known as Earth's outgoing energy which is represented by the following equation:	4. Based on the equation for Earth's outgoing energy, how does an increase in temperature influence the amount of outgoing Energy?	4.
Outgoing energy = σT^4 ***σ*** is the Stefan-Boltzmann constant of $\mathbf{5.670367 \times 10^{-8}\ W \cdot m^{-2} \cdot K^{-4}}$ ***T*** is the temperature of the Earth	5. Based on the two equations for incoming energy and outgoing energy, write an equation used to balance Earth's energy budget.	5.

National Aeronautics and Space Administration
Goddard Institute for Space Studies
New York, N.Y.

Name: **Answer Key** Date: ____________________

Deriving Earth's Energy Balance Equation

Based on NASA Earth Observatory Article: Climate and Earth's Energy Budget by Rebecca Lindsey

http://earthobservatory.nasa.gov/Features/EnergyBalance/

Activity Description: The purpose of this activity is for students to learn how to derive the formula for Earth's energy budget by reading the NASA Earth Observatory Article titled Climate and Earth's Energy Budget.

Directions: Read the article **section by section.** At the ***end of each section***, complete the part of the table below that corresponds to that section. **Do not use the data table until you read the section!** Each section in the table includes important facts, supplemental information, and questions to answer.

Earth's Energy Budget: Incoming Energy = Outgoing Energy

Introduction Facts	Questions	Student Answers
The atmosphere and ocean work together to even out solar heating imbalances on Earth. This is known as Earth's heat engine. The heat engine also works to redistribute energy from Earth's surface and atmosphere back towards space.	1. Why doesn't Earth's surface temperature infinitely rise? 2. What would cause Earth's temperature to rise or fall?	1. **Earth's surface and lower atmosphere radiates energy back towards space.** 2. **A disruption in Earth's energy budget (an imbalance in the budget).**
Incoming Sunlight Part 1 Facts	**Questions**	**Student Answers**
All matter in the universe that has a temperature above absolute zero radiates (emits) energy at different wavelengths of the electromagnetic spectrum. The hotter an object is, the shorter the peak wavelength of radiated energy. **The following facts are not found in article but compliment the article** The sun emits 3.9×10^{26} Joules of energy each second (J/S) which is 3.9×10^{26} Watts (W). The amount of energy from the Sun that is sent	1. At what wavelength does the sun radiate the majority of its energy? 2. At what wavelength does the Earth emit majority of its energy? 3. Based on the formula provided, calculate the energy flux (***I***) that the Sun sends towards the Earth. The units of your answer will be in Watts per meter-squared (W/m^2).	1. **Visible wavelengths (Short wavelengths)** 2. **Infrared wavelengths (Long wavelengths)** 3. **1,360 W/m^2**

towards Earth depends on the distance Earth is from the Sun. This is modeled by the equation below: $I = I_S / 4\pi r^2$ • I is the energy flux based on Earth's distance from the Sun • I_S is the energy flux of the Sun which is 3.9×10^{26} Watts • $4\pi r^2$ is the surface area of the Earth at a distance r from the Sun • r is $1.5 \times 10^{11}m$	4. Why do you think the amount of energy that reaches the Earth (***I***) is less than the amount of energy that the sun emits (I_S)?	4. **Answers will vary – steer the students towards the fact that by the time the sunlight reaches the Earth, the rays will not be as concentrated due to the large distance between the Earth and the Sun.**

Incoming Sunlight Part 2 Facts	Questions	Student Answers
This NASA Earth Observatory article specifies the solar constant (the amount of energy the sun sends towards Earth) as 1,360 W/m^2. This differs from the amount you calculated in question #3 in the previous section. For the remainder of this activity, we will use **1,360 W/m^2 as the solar constant.** At a given time, only half of the Earth is receiving sunlight due to Earth's rotation. Use this information to answer question #1 in this section. When solar radiation hits the surface of the Earth, the amount of heating is unequal since Earth is a sphere. For instance, more energy hits the equator than the polar regions. The fact that solar radiation hitting the surface of the Earth decreases with increasing latitude, the amount of solar radiation reaching the Earth is reduced by an additional half. Use this information	1. If only half of the Earth is receiving sunlight at a given time, calculate the amount of the Sun's energy that is intercepted by Earth. (**Hint**: Use the **solar constant value** which is the amount of energy the Sun sends towards the Earth). 2. Due to the unequal heating of sunlight reaching Earth's surface, calculate the amount of solar energy that actually hits the top of Earth's atmosphere. (**Hint:** Use the answer from question #1 above to help with the calculation). 3. Based on the amount of energy that reaches the top of Earth's atmosphere, how much energy does Earth need to radiate (emit) in order to maintain radiative equilibrium?	1. **1,360 W/m^2/ 2 = 680 W/m^2** 2. **680 W/m^2 / 2 = 340 W/m^2** 3. **340 W/m^2**

to answer question #2 in this section. As a result of the information in this section, ***the amount of solar energy that reaches the top of Earth's atmosphere is 340 W/m^2.***		
Heating Imbalances Facts	**Questions**	**Student Answers**
The value of 340 W/m^2 of incoming solar radiation is a global average and will differ based on latitude. For example, the equator receives a higher value of incoming solar radiation while the polar regions receive less.	1. Why is there an imbalance of heating on the surface of the Earth?	1. **The equator receives the more direct insolation (a high angle of insolation) while the polar regions receive less direct insolation (a low angle of insolation). As a result, the equatorial regions are heated more.**
The reflectiveness of Earth's surface is also known as albedo. In the Northern Hemisphere summer, the polar regions receive a large amount of solar radiation. However, there is a large amount of radiation reflected due to the white snow and ice surfaces.	2. How does solar heating on Earth's surface in the Northern Hemisphere compare to solar heating in the Southern Hemisphere?	2. **Due to the Earth's tilt of 23.5˚, when the north pole is tilted towards the Sun, the Northern Hemisphere receives more direct insolation compared to the Southern Hemisphere. There is an opposite effect when the north pole is titled away from the Sun.**
Since not all of the incoming energy reaching the Earth is absorbed due to albedo, the equation for Earth's incoming energy can be written as: ***Incoming Energy*** $= \frac{S_0}{4}(1-\alpha)$ S_0 is the solar constant of 1,360 W/m^2 $S_0/4$ is equivalent to 340 W/m^2 α is the albedo (reflectiveness) of the planet.	3. Explain how snow and ice surfaces can influence the amount of energy absorbed by Earth. 4. What is the equation used to calculate the incoming solar energy for the Earth? What is the meaning of each variable in the equation?	3. **Snow and ice have a high albedo which means they have a high reflectivity. Snow and ice reflect a large percentage of insolation that hits the surface, which reduces the amount of energy absorbed.** 4. ***Incoming Energy*** $= \frac{S_0}{4}(1-\alpha)$ **S_0 is the solar constant of 1,360 W/m^2** **α is the albedo of the planet of interest**

Earth's Energy Budget Facts	Questions	Student Answers
Earth's energy budget is defined by the flow of incoming energy and outgoing energy. Energy at the top of the atmosphere (TOA) must be in balance such that the energy coming in at the top of the atmosphere must equal the energy leaving. Some of the energy entering the TOA is reflected back towards space due to Earth's planetary albedo. Earth's albedo is approximately .29 which means Earth reflects 29% of the incoming energy. As Earth absorbs energy from the Sun, Earth is also radiating (emitting) infrared energy. This ensures Earth does not infinitely heat up since energy is going out as it is coming in. The amount of energy Earth radiates is proportional to (related to) the fourth power of its temperature. This is also known as Earth's outgoing energy which is represented by the following equation: ***Outgoing energy =*** σT^4 ***σ*** is the Stefan-Boltzmann constant of **5.670367×10**$^{-8}$ **W · m**$^{-2}$ **· K**$^{-4}$ ***T*** is the temperature of the Earth	1. Explain how the amount of energy received by Earth at the TOA changes if Earth's albedo was .50 instead of .29? 2. If 29% of the incoming solar energy is reflected back towards space, what percentage of energy is available for absorption by the atmosphere and the surface of the Earth? 3. What is the equation used to calculate the outgoing energy for the Earth? What is the meaning of each variable in the equation? 4. Based on the equation for Earth's outgoing energy, how does an increase in temperature influence the amount of outgoing Energy? 5. Based on the two equations for incoming energy and outgoing energy, write an equation used to balance Earth's energy budget.	1. **The amount of energy would decrease because a higher albedo leads to more of the Sun's energy reflected back towards space.** 2. **100% - 29% reflected = 71% absorbed** 3. ***Outgoing energy =*** σT^4 **T = Temperature of the Earth** ***σ*** **= Stefan-Boltzmann constant of 5.670367×10**$^{-8}$ **W · m**$^{-2}$ **· K**$^{-4}$ 4. **An increase in temperature would increase the amount of outgoing energy** 5. **A balanced equation would be:** **Incoming energy = Outgoing energy** $\frac{S_o}{4}(1-\alpha) = \sigma T^4$

National Aeronautics and Space Administration
Goddard Institute for Space Studies
New York, N.Y.

Student-led Class Discussion: Earth's Energy Budget

Directions: Students will use NASA Earth Observatory article titled Climate and Earth's Energy Budget and the DOK chart below to come up with **two discussion questions** based on the following theme:

How or why would Earth's energy budget become imbalanced? What are the implications of the imbalance?

Student should only pose questions using DOK levels 2 through 4 only. Students will use these questions to facilitate a student-led class discussion regarding the given theme. Students will be assessed with the Student-led Class Discussion Rubric.

DOK 1 • Can you recall______? • When did ____ happen? • Who was ____? • How can you recognize____? • What is____? • How can you find the meaning of____? • Can you recall____? • Can you select____? • How would you write___? • What might you include on a list about___? • Who discovered___? • What is the formula for___? • Can you identify___? • How would you describe___?	**DOK 2** • Can you explain how ____ affected ____? • How would you apply what you learned to develop ____? • How would you compare ____? Contrast_____? • How would you classify____? • How are____alike? Different? • How would you classify the type of____? • What can you say about____? • How would you summarize____? • How would you summarize___? • What steps are needed to edit___? • When would you use an outline to ___? • How would you estimate___? • How could you organize___? • What would you use to classify___? • What do you notice about___?
DOK 3 • How is ____ related to ____? • What conclusions can you draw _____? • How would you adapt____to create a different____? • How would you test____? • Can you predict the outcome if____? • What is the best answer? Why? • What conclusion can be drawn from these three texts? • What is your interpretation of this text? Support your rationale. • How would you describe the sequence of____? • What facts would you select to support____? • Can you elaborate on the reason____? • What would happen if___? • Can you formulate a theory for___? • How would you test___? • Can you elaborate on the reason___?	**DOK 4** • Write a thesis, drawing conclusions from multiple sources. • Design and conduct an experiment. Gather information to develop alternative explanations for the results of an experiment. • Write a research paper on a topic. • Apply information from one text to another text to develop a persuasive argument. • What information can you gather to support your idea about___? • DOK 4 would most likely be the writing of a research paper or applying information from one text to another text to develop a persuasive argument. • DOK 4 requires time for extended thinking.

DOK Questions:

1.

2.

Student-led Class Discussion Rubric

CATEGORY	4	3	2	1
Respect for Other Students	All statements, body language, and responses were respectful and were in appropriate language.	Statements and responses were respectful and used appropriate language, but once or twice body language was not.	Most statements and responses were respectful and in appropriate language, but there was one sarcastic remark.	Statements, responses and/or body language were consistently not respectful.
Information	All information presented in the discussion was clear, accurate and thorough.	Most information presented in the discussion was clear, accurate and thorough.	Most information presented in the discussion was clear and accurate, but was not usually thorough.	Information had several inaccuracies OR was usually not clear.
Use of Facts/Statistics	Every major point was well supported with several relevant facts, statistics and/or examples.	Every major point was adequately supported with relevant facts, statistics and/or examples.	Every major point was supported with facts, statistics and/or examples, but the relevance of some was questionable.	Every point was not supported.
Presentation Style	Student consistently used gestures, eye contact, tone of voice and a level of enthusiasm in a way that kept the attention of the audience.	Student usually used gestures, eye contact, tone of voice and a level of enthusiasm in a way that kept the attention of the audience.	Student sometimes used gestures, eye contact, tone of voice and a level of enthusiasm in a way that kept the attention of the audience.	Student had a presentation style that did not keep the attention of the audience.

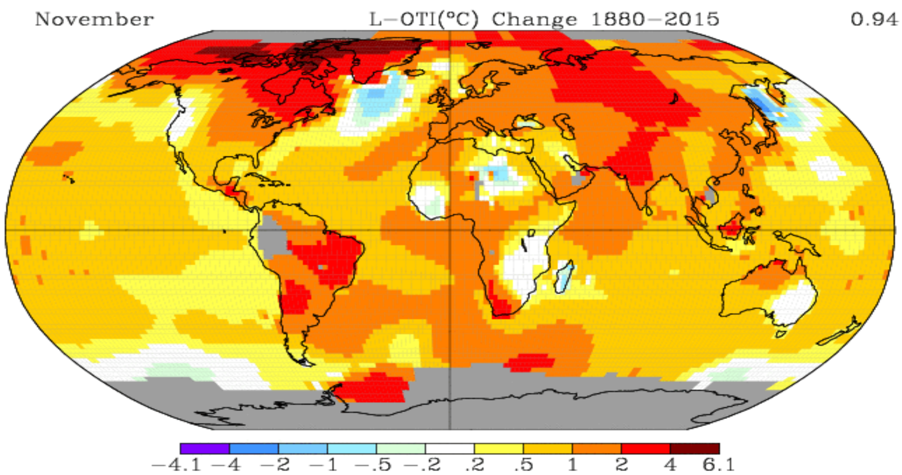
F. Conclusion and overview of linkages to next lesson and unit goals.

In this lesson, the students learned how to derive Earth's energy budget equation and were able to engage in a student-led discussion related to the factors that could cause an imbalance of the energy budget. In the next lesson, the students will apply their knowledge of the energy budget equation by learning how the NASA CERES satellite collects data on incoming and outgoing energy. The students will then use Panoply, a NASA GISS software, to analyze incoming solar radiation, outgoing longwave energy, outgoing shortwave energy, and net energy. The datasets contain monthly data from 2000 to 2015 and the goal is for the students to see how each component of Earth's energy budget formula changes based on latitude and season.

National Aeronautics and Space Administration
Goddard Institute for Space Studies
New York, N.Y.

NASA Goddard Institute for Space Studies (GISS)
Climate Change Research Initiative (CCRI)
Applied Research STEM Curriculum Unit Portfolio

Unit Title: Earth's Energy Budget
Lesson #2 Title: Analyzing NASA CERES Energy Budget Data
NASA STEM Educator / Associate Researcher: Nicole Dulaney
NASA PI / Mentor: Dr. Allegra LeGrande
NASA GSFC Office of Education – Code 160



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NASA Goddard Institute for Space Studies (GISS)
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VI. Lesson 2: Title: Analyzing NASA CERES Energy Budget Data

A. Summary and Goals of Lesson

The goal of this lesson is for the students to analyze data from the NASA CERES (Clouds and Earth's Radiation Energy System) satellite mission to learn more about the formula that represents Earth's energy budget at the top of the atmosphere. The CERES satellite orbits the Earth on a daily basis and records incoming and outgoing energy at the top of Earth's atmosphere. In the previous lesson, the students learned how to derive the energy budget formula, and in this lesson the students will be able to examine data that represents each component of the formula. The formula used in this lesson is a simplistic version of the one derived in the previous lesson. The formula present in this lesson is:

Net energy = Incoming Solar radiation – Outgoing Longwave – Outgoing Shortwave

Students will start the activity by downloading four data sets from the NASA CERES satellite mission: incoming solar radiation, outgoing longwave radiation, outgoing shortwave radiation, and net energy. The students will then use the NASA GISS Panoply software to analyze the contents of each dataset, specifically how incoming solar radiation, outgoing longwave energy, outgoing shortwave energy, and net energy change based on latitude and the time of year. After the students complete the activity, they will discuss results with a partner and use the knowledge from the activity to predict how climate change in the future will impact different components of the energy budget.

B. Table of Contents for lesson

A. Summary and Goals of Lesson **42**
B. Table of Contents for lesson **42**
C. 5 E lesson model template: **43**
D. Content Template **47**
E. Supporting Documents: (order according to sequence of lesson) **49**
F. Conclusion and overview of linkages to next lesson and unit goals. **80**

C. 5 E lesson model template:

STEM Earth Science Research

Unit: Earth's Energy Budget **Topic**: Analyzing NASA CERES Energy Budget Data

Prior Learning: For successful completion of this lesson, the students should have knowledge of the energy budget formula, and the meaning of the following terms: insolation, outgoing longwave energy and outgoing shortwave energy. In this lesson the students will download four datasets from the NASA CERES satellite in order to see how each component of the energy budget formula varies based on latitude and season. The students will be using a more simplistic version of the energy budget formula which is explained later in the lesson plan.

Do Now (Pre-Assessment):

1. Predict the relationship that exists between Northern Hemisphere latitudes and the amount of outgoing longwave energy during the following seasons: Winter and Summer. Justify your prediction with prior knowledge.

2. Predict the relationship that exists between Northern Hemisphere latitudes and the amount of outgoing shortwave energy during the following seasons: Winter and Summer. Justify your prediction with prior knowledge.

Aim: How can we utilize data from the NASA CERES satellite to analyze each component of Earth's energy budget formula?

New York State Standards:

1.1f - Earth's changing position with regard to the Sun and the moon has noticeable effects.

- Earth revolves around the Sun with its rotational axis tilted at 23.5 degrees to a line perpendicular to the plane of its orbit, with the North Pole aligned with Polaris.
- During Earth's one-year period of revolution, the tilt of its axis results in changes in the angle of incidence of the Sun's rays at a given latitude; these changes cause variation in the heating of the surface. This produces seasonal variation in weather.

2.2a - Insolation (solar radiation) heats Earth's surface and atmosphere unequally due to variations in:

- the intensity caused by differences in atmospheric transparency and angle of incidence which vary with time of day, latitude, and season
- characteristics of the materials absorbing the energy such as color, texture, transparency, state of matter, and specific heat
- duration, which varies with seasons and latitude.

Next Generation Science Standards:

HS - ESS2-4 - Use a model to describe how variations in the flow of energy into and out of Earth's systems result in changes in climate.

HS - ESS3-5 - Analyze geoscience data and the results from global climate models to make an evidence-based forecast of the current rate of global or regional climate change and associated future impacts to Earth systems.

Common Core State Standards:

CCSS: 9-10.RST.3 - Follow precisely a multistep procedure when carrying out experiments, taking measurements, or performing technical tasks.

CCSS: 9-10.RST.7 - Integrate and evaluate multiple sources of information presented in diverse formats and media (e.g., quantitative data, video, multimedia) in order to address a question or solve a problem.

NASA System Engineering Behavior:
Technical Acumen:
1a. Possesses Technical Competence and Has Comprehensive Previous Experience
1b. Learns from Successes and Failures
Problem Solving & Systems Thinking:
2a. Thinks Systematically
2b. Possess Creativity and Problem Solving Abilities

Performance Objective: Students will be able to analyze each component of Earth's energy budget formula by using NASA GISS Panoply software to read and display incoming solar radiation, outgoing longwave, outgoing shortwave, and net energy data from the NASA CERES satellite.

Materials: NASA CERES Satellite data; NASA GISS Panoply; NASA CERES article (from Daily Press); Computers

NASA CERES Satellite Data: https://iridl.ldeo.columbia.edu/SOURCES/.NASA/.ASDC-DAAC/.CERES/.EBAF-TOA/.Ed2p8/?Set-Language=en

NASA GISS Panoply: https://www.giss.nasa.gov/tools/panoply/

NASA CERES article: http://articles.dailypress.com/2012-02-14/news/dp-nws-cp-nasa-ceres-20120214_1_climate-scientists-nasa-scientist-climate-change

Vocabulary: Albedo; Insolation; Incoming energy (shortwave); Outgoing energy (longwave)

Anticipatory Opening: Discuss with the students what the NASA CERES satellite is and the type of data it collects.

Development of the Lesson: **Approximately Two to Three-Day Lesson (Two to Three 50-minute periods).**

What the teacher does	What the student does	Time
1. Write down the Do Now, Aim, and the HW on the blackboard.		
2. Circulate the room while the students complete the Do Now questions. Determine how much	The students answer the Do Now questions in their notebooks to determine	**5 min**

prior knowledge the students have about shortwave and longwave energy. The questions will also assess student's ability to predict how outgoing shortwave and longwave energy will differ based on latitude and season. ***Assessment Opportunity #1 (Student prior knowledge from previous units)***	how much prior knowledge they have about shortwave and longwave energy	
3. ENGAGE Discuss the NASA CERES satellite with the students and the goals of the mission. Introduce the students to a brief article about the NASA CERES satellite. Discuss the following energy budget formula with the students so they are aware of the components: ***Net energy = Incoming – Outgoing Longwave – Outgoing Shortwave*** ***Assessment Opportunity #2 (Student discussions about the goals of the NASA CERES satellite).***	The students learn about the NASA CERES satellite and the goals of the mission. The students read a brief article from the Daily Press about NASA CERES. The students write down the following energy budget formula: ***Net energy = Incoming – Outgoing Longwave – Outgoing Shortwave***	**15 min**
4. EXPLORE & EXPLAIN Introduce the students to the NASA GISS Panoply: Earth's Energy Budget activity. Circulate the room as the students begin the activity by downloading and saving all of the necessary datasets. Look for common challenges and misconceptions. Ensure the students are analyzing the proper datasets in each section of the activity. ***Assessment Opportunity #3 (Student answers to questions in the Panoply activity).***	The students begin the NASA GISS Panoply: Earth's Energy Budget activity by downloading and saving four CERES datasets from the Columbia IRI data library. The students complete the activity by analyzing the incoming solar radiation, outgoing longwave energy, outgoing shortwave energy, and the net energy datasets. The students will answer questions through Q31.	**60 min**
5. ELABORATE & EVALUATE Circulate the room as the students work with a partner to discuss answers to questions Q1 – Q30. Have each set of partners complete the questions Q31 and Q32 in the Elaborate & Evaluate section of the activity.	The students work with a partner to discuss answers to questions Q1 – Q30. The students work with a partner to discuss and complete the Elaborate and Evaluate questions at the end of the activity.	**30 min**

Assessment Opportunity #4(Student discussion of answers with a partner) ***Assessment Opportunity #5(Student answers to the elaborate & evaluate questions)***	The students make predictions as to how different components of the energy budget formula will be impacted due to climate change in the future.	
6. Administer the Daily Formative Assessment (DFA) to the students. ***Assessment Opportunity #6 (Student answers to the DFA).***	The students individually answer questions on the Daily Formative Assessment. The students will submit their answers at the end of class.	**10 min**

Summary/Conclusion: The students individually answer questions on the Daily Formative Assessment. The students will submit their answers at the end of class.

Higher Order Questions:

See all questions in the NASA GISS Panoply: Energy Budget Activity

Differentiated Instruction:
- The students are exposed to content in written, oral, and visual forms (multiple modalities exist).
- Students can use colored pencils to draw diagrams and annotate notes in a way that is meaningful to them.
- Students are asked both higher and lower level questions so all students can answer questions at their particular academic level.
- Students are given time to answer questions during think pair share/group activities.

Daily Formative Assessment:

1. Why do the higher northern latitudes have a high amount of outgoing shortwave energy in the summer season?

2. Why does the equatorial region have a high amount of outgoing longwave energy in the summer season?

Next Lesson: The next lesson the students will learn how to evaluate data from the CERES satellite in Rstudio by learning how to program with the R language.

For Further Exploration:

Go to https://icp.giss.nasa.gov/education/geebitt/ and click on the link titled "GEEBITT – Full Version". Clicking will download an Excel file that allows users to change inputs such as date of the year and distance from the Sun to determine how the amount of solar energy reaching the top of Earth's atmosphere will change due to those changing parameters.

Notes For Revision:

D. Content Template

NGSS Standard:	**State Earth Science Content Standard:**	**Common Core Standard:**	**NASA Science:**
HS - ESS2-4 - Use a model to describe how variations in the flow of energy into and out of Earth's systems result in changes in climate. **HS - ESS3-5 -** Analyze geoscience data and the results from global climate models to make an evidence-based forecast of the current rate of global or regional climate change and associated future impacts to Earth systems.	**1.1f** - Earth's changing position with regard to the Sun and the moon has noticeable effects. • Earth revolves around the Sun with its rotational axis tilted at 23.5 degrees to a line perpendicular to the plane of its orbit, with the North Pole aligned with Polaris. • During Earth's one-year period of revolution, the tilt of its axis results in changes in the angle of incidence of the Sun's rays at a given latitude; these changes cause variation in the heating of the surface. This produces seasonal variation in weather. **2.2a** - Insolation (solar radiation) heats Earth's surface and atmosphere unequally due to variations in: • the intensity caused by differences in atmospheric transparency and angle of incidence which vary with time of day, latitude, and season • characteristics of the materials absorbing the energy such as color, texture, transparency, state of matter, and specific heat • duration, which varies with seasons and latitude.	**CCSS: 9-10.RST.3** - Follow precisely a multistep procedure when carrying out experiments, taking measurements, or performing technical tasks. **CCSS: 9-10.RST.7** - Integrate and evaluate multiple sources of information presented in diverse formats and media (e.g., quantitative data, video, multimedia) in order to address a question or solve a problem.	Earth: Earth's Energy Budget

Content Area:	**Name of Project-Based Activity or Theme:**	**Estimated Time Frame to Complete (days/weeks):**
Earth & Space Sciences **Grade Level:** High School	Analyzing Earth's energy budget equation based on data from the NASA CERES satellite	Lesson #2 = Two to Three 50-minute class periods

Overall Investigation Question(s): How can we utilize data from the NASA CERES satellite to analyze each component of Earth's energy budget formula?

Overall Project Description/Activity: Students will be able to analyze each component of Earth's energy budget formula by using NASA GISS Panoply to read and display incoming solar radiation, outgoing longwave, outgoing shortwave, and net energy data from the NASA CERES satellite.

Materials Needed to Complete Project (put N/A as needed):	**Stakeholders:**	**Hyperlinks Used: Visit the hyperlinks in the following order in the lesson:**	**Multimedia/Technology:**	**Classroom Equipment:**
NASA CERES Satellite data; NASA GISS Panoply; NASA CERES article (from Daily Press); Computers	1. Earth & space science educators 2. Earth & space science students 3. Students engaged in science research 4. NYCDOE 5. NASA	1. NASA CERES Satellite Data: https://iridl.ldeo.columbia.edu/SOURCES/.NASA/.ASDC-DAAC/.CERES/.EBAF-TOA/.Ed2p8/?Set-Language=en 2. NASA GISS Panoply: https://www.giss.nasa.gov/tools/panoply/ 3. NASA CERES article: http://articles.dailypress.com/2012-02-14/news/dp-nws-cp-nasa-ceres-20120214_1_climate-scientists-nasa-scientist-climate-change	Website links: 1. NASA CERES Satellite Data: https://iridl.ldeo.columbia.edu/SOURCES/.NASA/.ASDC-DAAC/.CERES/.EBAF-TOA/.Ed2p8/?Set-Language=en 2. NASA GISS Panoply: https://www.giss.nasa.gov/tools/panoply/ 3. NASA CERES article: http://articles.dailypress.com/2012-02-14/news/dp-nws-cp-nasa-ceres-20120214_1_climate-scientists-nasa-scientist-climate-change	Computers; Highlighters; Calculators

NASA System Engineering Behaviors (2 behaviors per category) 1a. Possesses Technical Competence and Has Comprehensive Previous Experience 1b. Learns from Successes and Failures 2a. Thinks Systematically 2b. Draws on Past Experiences	**Category** 1. Technical Acumen 2. Problem solving & systems thinking	**<u>Activities</u>** **How will students model engineering behaviors when learning science content?** **Describe student activities here.** 1a&b. Students will be using the NASA GISS Panoply software to analyze four different components of the Earth's energy budget formula through four different data sets: incoming solar radiation, outgoing longwave energy, outgoing shortwave energy, and net energy. The students will then share their experiences and learn from their successes and failures by evaluating activity answers with a partner. 2a. The students will complete the NASA GISS Panoply activity by analyzing four different components of Earth's energy budget formula through four different data sets: incoming solar radiation, outgoing longwave energy, outgoing shortwave energy, and net energy. The students will look across the entire Earth system in order to determine how each dataset contributes to the energy budget differently, depending on the latitude and time of year. 2b. The students will use their knowledge of the Earth's energy budget derivation from the previous lesson in order to successfully complete the NASA GISS Panoply activity.	**Student Outcomes** **How will you assess learning for each behavior:** 1a&b. Students will be assessed based on their answers to the NASA GISS Panoply activity. Students will also be assessed based on their elaborate & evaluate questions that they discuss and answer with their partners. 2a&b. Students will be assessed based on their answers to the NASA GISS Panoply activity. Students will also be assessed based on their elaborate & evaluate questions that they discuss and answer with their partners.	**Evaluation** **Describe specific science content students understand as a result of engineering behavior.** 1a&b. Students will be able to explain how incoming solar radiation, outgoing longwave energy, outgoing shortwave energy, and net energy change based on latitude and time of the year. 2a&b. Students will be able to explain how incoming solar radiation, outgoing longwave energy, outgoing shortwave energy, and net energy change based on latitude and time of the year. Students will also be able to predict how changes to Earth's climate system in the future will impact Earth's energy budget through elaborate & evaluate questions near the end of the activity.
List and attach all supportive documents for instructional activities.	Attachments ? (circle) **Yes** or No	**List Attached Documents (if any):** 1. NASA CERES article (from Daily Press) 2. NASA GISS Panoply download instructions for PC and Mac 3. NASA GISS Panoply: Energy Budget Activity		
List and attach all rubrics for activity and assessment evaluation.	Attachments ? (circle) Yes or **No**	**List Attached Rubrics (if any):** None in this lesson.		
Include comments or questions here:				

E. Supporting Documents: (order according to sequence of lesson)

New NASA instrument measures Earth's energy budget

February 14, 2012|By Cory Nealon, cnealon@dailypress.com | 757-247-4760

If it could talk, the climate-monitoring instrument CERES might file a complaint.

Working nonstop, it orbits Earth 14 times a day taking millions of images that scientists will use to expand their knowledge of why the planet is warming.

"It's a lot of disc space," Norman Loeb, the NASA scientist leading the project, said with a chuckle about the reams of data being collected.

CERES, which stands for Clouds and Earth's Radiation Energy System, is one of five earth science experiments aboard Suomi NPP, a $1.5 billion satellite NASA launched into space Oct. 28 from Vandenberg Air Force Base in California.

Managed at NASA Langley Research Center in Hampton, CERES measures the amount of sunlight that enters Earth and how much sunlight and thermal radiation is reflected back to space. The concept is known as Earth's energy budget.

According to NASA, the sun annually provides the planet about 340 watts per square meter — roughly the energy radiated from six incandescent light bulbs. If the planet returned an equal amount of energy to space, temperatures would be constant, Loeb said.

That is not occurring. Instead, roughly 0.8 watts per square meter stays on Earth.

The energy is trapped by greenhouse gases, such as water vapor and carbon dioxide, that come from burning fossil fuels and other sources. Clouds also play a role; they reflect sunlight back into space and, depending on their height and thickness, prevent it from leaving the planet.

The imbalance helps explain why global temperatures increased 1.4 degrees since last century and sea levels are rising, Loeb said.

Cruising 512 miles above Earth, CERES constantly monitors fluctuations in the energy budget. It sends roughly 6 million images each day to a database in Norway, where the information is forwarded to Langley and other NASA centers.

NASA uses computer models to summarize the images into daily and monthly reports that date back to 1985. That's when another Langley instrument, ERBE, or Earth Radiation Budget Experiment, began monitoring the planet.

Four successive CERES instruments — the one launched in October is a fifth generation — followed, providing data used by, among others, the Intergovernmental Panel on Climate Change. The panel, which shared a Nobel Peace Prize with former Vice President Al Gore, wrote what many view as the definitive report on climate change.

The report has been criticized by fossil fuel companies, trade organizations and a minority of scientists as inconclusive. Their opposition helped keep Congress from enacting climate change legislation, such as a cap-and-trade program for greenhouse gases.

Most climate scientists say the data can be improved, which is why they continue to push for experiments like Suomi NPP. Other instruments on the satellite, which is a partnership with the National Oceanic and Atmospheric Administration and the Department of Defense, monitor the planet's oceans, clouds, vegetation and ice.

Jim Gleason, a scientist at NASA's Goddard Space Flight Center in Maryland, said in a statement that the variety of measurements will give scientists a "big picture" look at how the planet is changing.

"That will help us improve our computer models that predict future environmental conditions. Better predictions will let us make better decisions, whether it's as simple as taking an umbrella to work today or as complex as responding to climate change," he said

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New York, N.Y.

NASA GISS Panoply Download Instructions for macOS

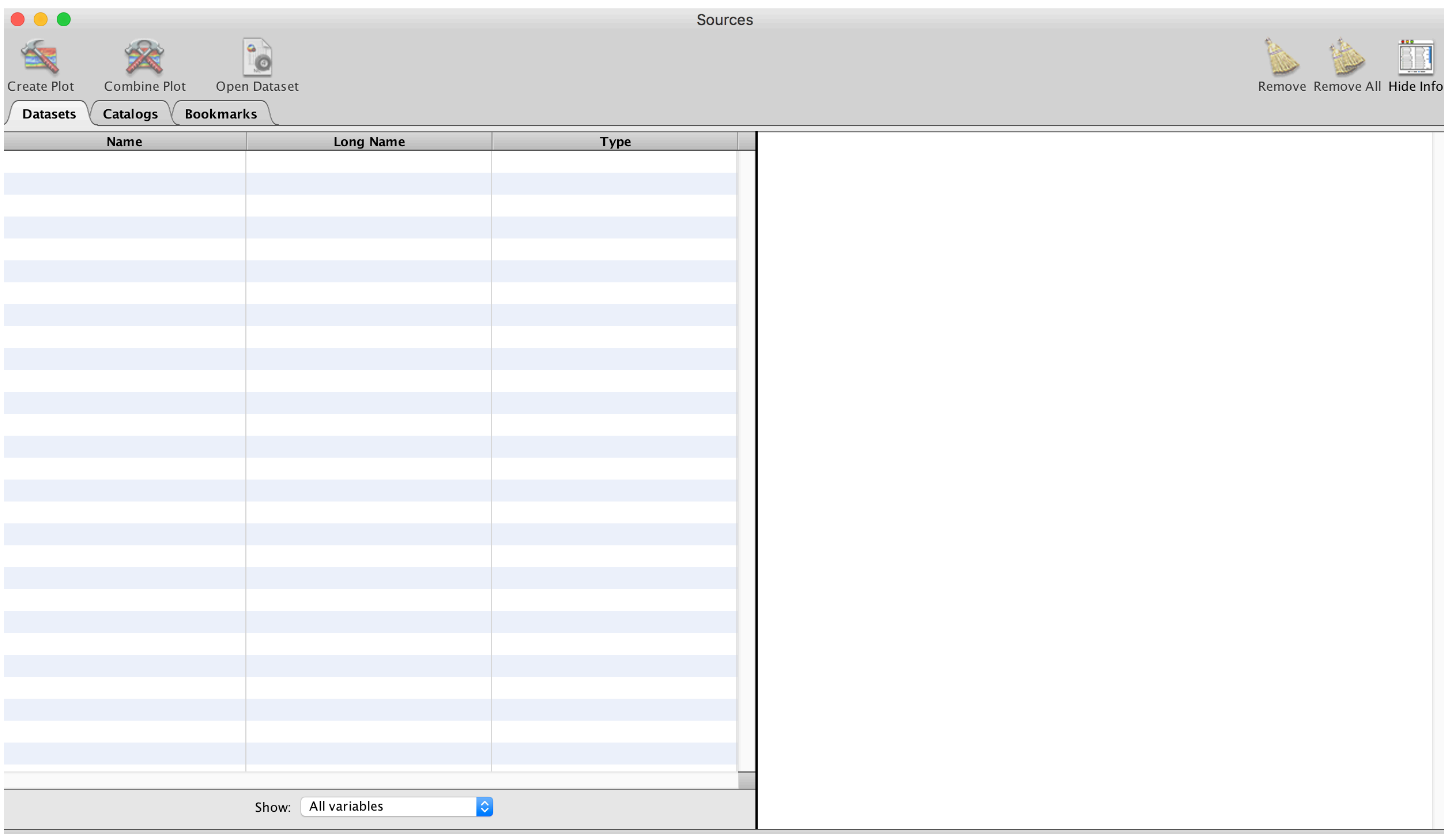
1. Make sure that the computer on which Panoply will be downloaded has Java SE 7 or 8 runtime environment installed.

2. Go to the following link http://www.giss.nasa.gov/tools/panoply/download.html and click on the option to download Panoply for macOS.

3. Once Panoply is done downloading, double-click the Panoply.dmg located on the Desktop. Then drag the Panoply application to where you keep applications, probably either your user Applications folder or else the system-wide Applications folder.

4. To run Panoply on macOS, just double-click on the Panoply application.

5. A window will pop-up that allows you to choose a dataset to open in Panoply. Since we do not have a dataset to analyze just yet, you can close out that window and then the Panoply Sources window will appear as shown below.



Once all teachers have Panoply downloaded we will begin to learn how to use it.

NASA GISS Panoply Download Instructions for Windows

1. Make sure that the computer on which Panoply will be downloaded has Java SE 7 or 8 runtime environment installed.

2. Go to the following link http://www.giss.nasa.gov/tools/panoply/download.html and click on the option to download Panoply for a Windows computer (this is the second option available as illustrated below).

Panoply netCDF, HDF and GRIB Data Viewer

Download Panoply

The current version of Panoply is 4.5.0 released 2016-04-20.

Panoply 4 for Mac OS X requires a computer with a Java SE 7 or 8 runtime environment installed.

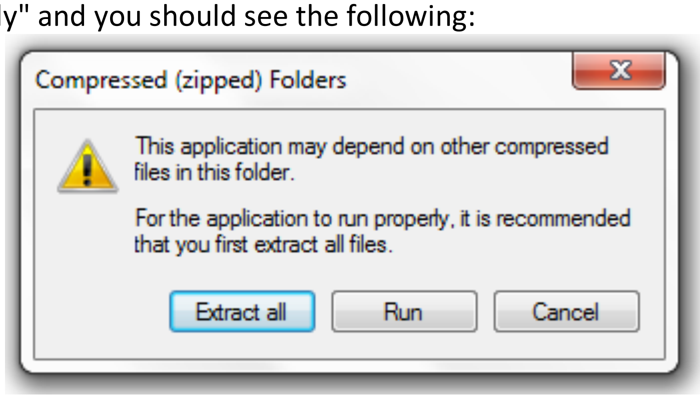
- Download Panoply 4.5.0 for Mac OS X, 35 MB DMG
- Download Panoply 4.5.0 for Windows, 32 MB ZIP
- Download Panoply 4.5.0 "generic" for Linux, etc., 32 MB ZIP
- Download Panoply 4.5.0 "generic" for Linux, etc., 32 MB TGZ
- View checksums: [MD5] [SHA1]

3. Once the program is downloaded, double click on the on the folder titled "PanoplyWin".

4. You should now see the following:

jars	File folder				
Panoply	Application	56 KB	No	130 KB	58%
README_Win	Text Document	2 KB	No	3 KB	51%

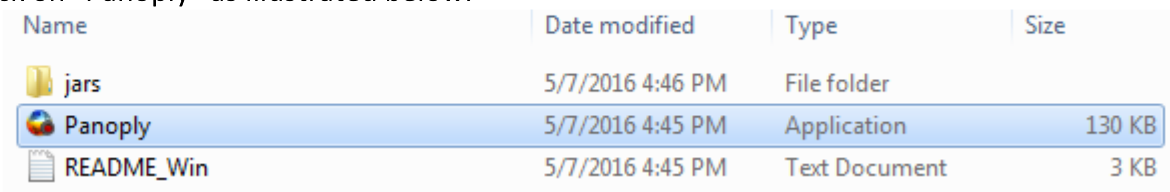
The "jars" folder needs to remain in this location in order for the Panoply program to work after download. Now double click on "Panoply" and you should see the following:



Click on "Extract all".

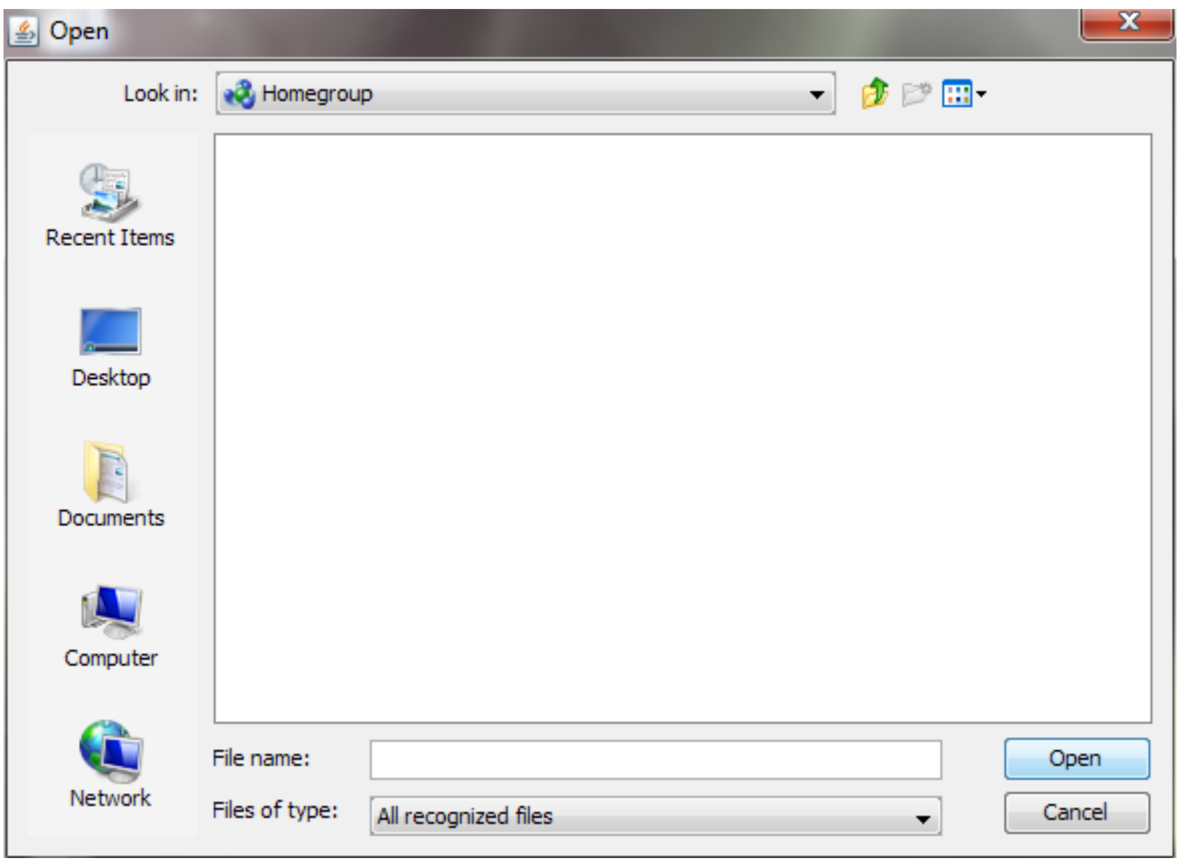
5. You will be prompted to select a destination to extract the files to. Input the path of the destination in which you want Panoply to be installed and then click "extract".
6. Panoply should now be installed in the location of the destination path you designated in Step #5.

7. Once you are in the location in which Panoply was installed, click on the folder titled "PanoplyWin" and then double click on "Panoply" as illustrated below.

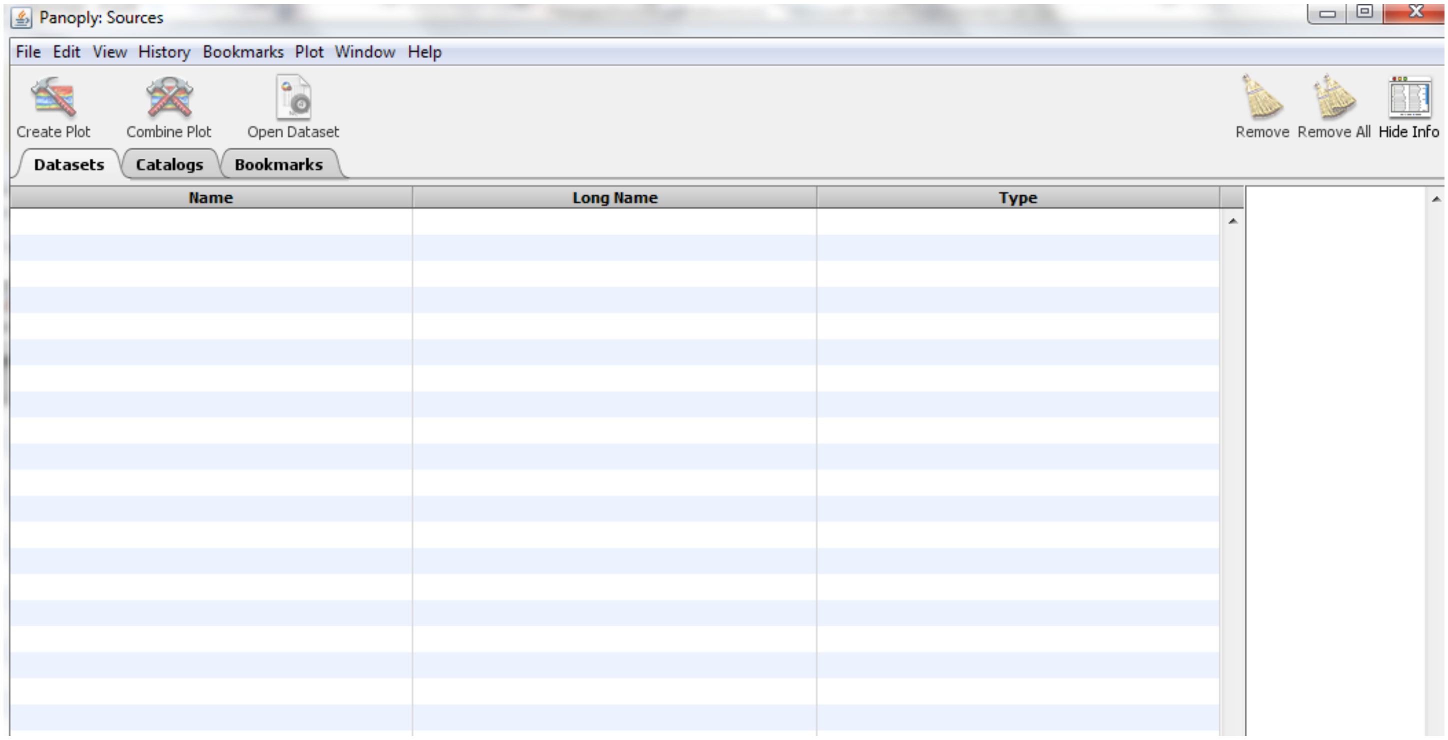


8. When prompted, click "run" to start Panoply.

9. If you do not see any new windows pop-up, minimize all open programs and browsers to get to your desktop. You should then see window with the Java emblem in the top left corner as shown below.



10. Click "Open" and you will see the following screen:



Once all teachers have Panoply downloaded we will begin to learn how to use it!

National Aeronautics and Space Administration
Goddard Institute for Space Studies
New York, N.Y.

Name: ______________________________________ Date: ___________________

NASA GISS Panoply: Earth's Energy Budget

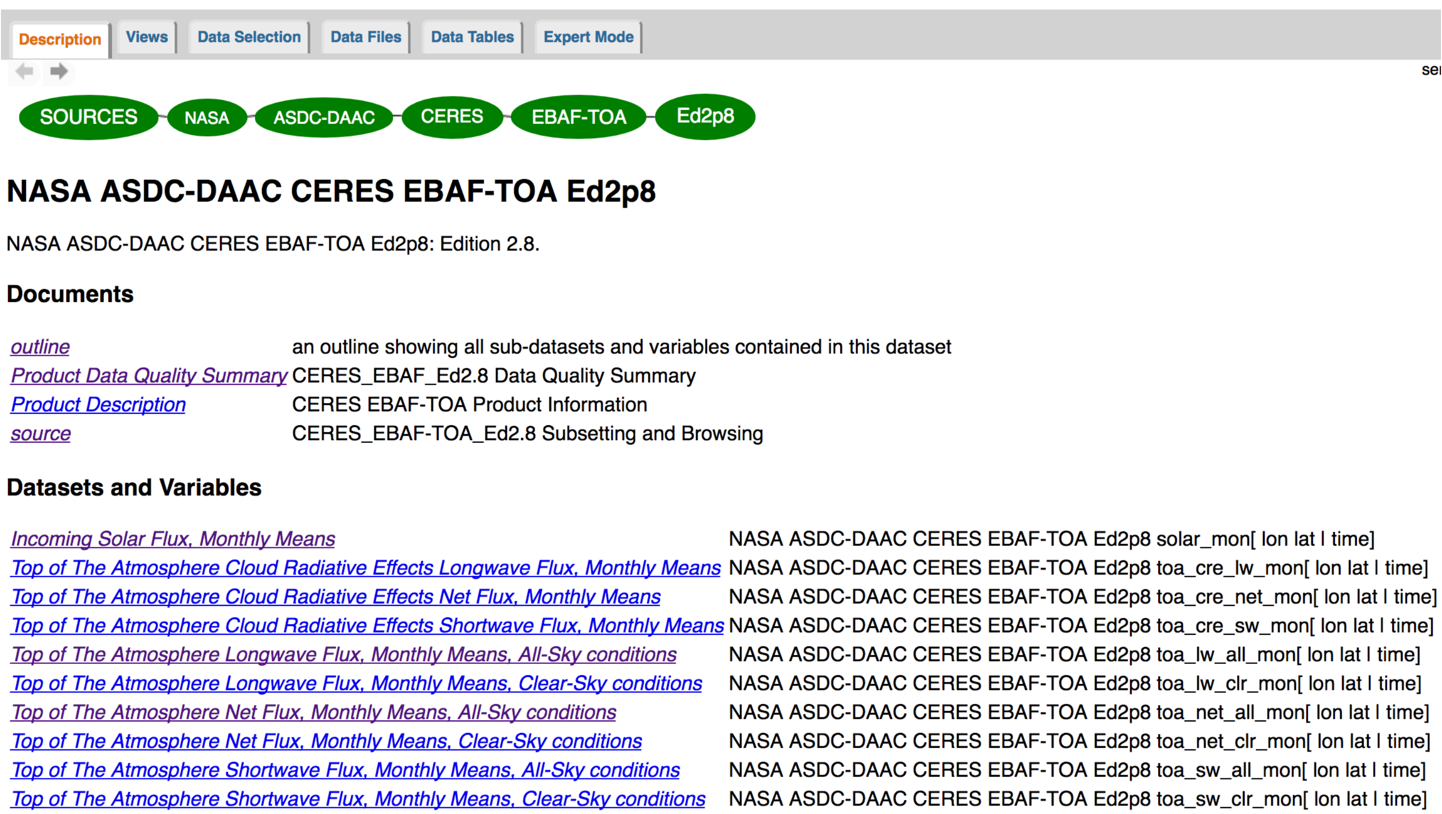
Activity Description: In this activity the students will use the IRI/LDEO Data Library sponsored by Columbia University to download data from the NASA CERES satellite that measures incoming and outgoing energy at the top of Earth's atmosphere. The students will download four datasets from CERES based on incoming solar energy, net solar energy at the top of the atmosphere, outgoing longwave radiation, and outgoing shortwave radiation.

Directions: Ensure Panoply (http://www.giss.nasa.gov/tools/panoply/) is downloaded onto each user's computer. There is a step-by-step download guide available for both Macs and PCs on the pages prior to this activity.

Net energy = Incoming Solar Radiation – Outgoing Longwave – Outgoing Shortwave

1. The activity will begin by downloading the four datasets necessary for the activity. Go to https://iridl.ldeo.columbia.edu/?Set-Language=en, click on the link titled ***"Data by Source"***, scroll down to and click the link that says ***"NASA"***, click on the first link that says **"ASDC-DAAC"**, click on the link that says ***"CERES"***, click on the link that says ***"EBAF-TOA"***, and finally click on the link that says ***"Ed2p8".***

You should now see a page that looks like this:


Description | Views | Data Selection | Data Files | Data Tables | Expert Mode

SOURCES – NASA – ASDC-DAAC – CERES – EBAF-TOA – Ed2p8

NASA ASDC-DAAC CERES EBAF-TOA Ed2p8

NASA ASDC-DAAC CERES EBAF-TOA Ed2p8: Edition 2.8.

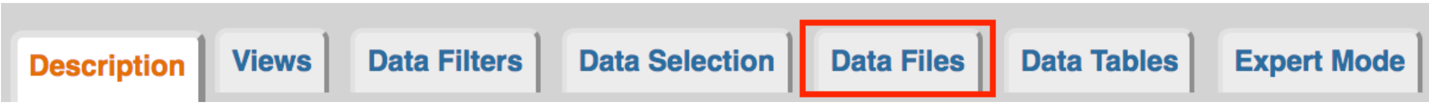
Documents

outline	an outline showing all sub-datasets and variables contained in this dataset
Product Data Quality Summary	CERES_EBAF_Ed2.8 Data Quality Summary
Product Description	CERES EBAF-TOA Product Information
source	CERES_EBAF-TOA_Ed2.8 Subsetting and Browsing

Datasets and Variables

Incoming Solar Flux, Monthly Means	NASA ASDC-DAAC CERES EBAF-TOA Ed2p8 solar_mon[lon lat l time]
Top of The Atmosphere Cloud Radiative Effects Longwave Flux, Monthly Means	NASA ASDC-DAAC CERES EBAF-TOA Ed2p8 toa_cre_lw_mon[lon lat l time]
Top of The Atmosphere Cloud Radiative Effects Net Flux, Monthly Means	NASA ASDC-DAAC CERES EBAF-TOA Ed2p8 toa_cre_net_mon[lon lat l time]
Top of The Atmosphere Cloud Radiative Effects Shortwave Flux, Monthly Means	NASA ASDC-DAAC CERES EBAF-TOA Ed2p8 toa_cre_sw_mon[lon lat l time]
Top of The Atmosphere Longwave Flux, Monthly Means, All-Sky conditions	NASA ASDC-DAAC CERES EBAF-TOA Ed2p8 toa_lw_all_mon[lon lat l time]
Top of The Atmosphere Longwave Flux, Monthly Means, Clear-Sky conditions	NASA ASDC-DAAC CERES EBAF-TOA Ed2p8 toa_lw_clr_mon[lon lat l time]
Top of The Atmosphere Net Flux, Monthly Means, All-Sky conditions	NASA ASDC-DAAC CERES EBAF-TOA Ed2p8 toa_net_all_mon[lon lat l time]
Top of The Atmosphere Net Flux, Monthly Means, Clear-Sky conditions	NASA ASDC-DAAC CERES EBAF-TOA Ed2p8 toa_net_clr_mon[lon lat l time]
Top of The Atmosphere Shortwave Flux, Monthly Means, All-Sky conditions	NASA ASDC-DAAC CERES EBAF-TOA Ed2p8 toa_sw_all_mon[lon lat l time]
Top of The Atmosphere Shortwave Flux, Monthly Means, Clear-Sky conditions	NASA ASDC-DAAC CERES EBAF-TOA Ed2p8 toa_sw_clr_mon[lon lat l time]

2. Click on the first link that says "Incoming Solar Flux, Monthly Means". Then, on the top left of the webpage, click on the tab titled "Data Files" as shown below.



Click on the link that says "**netCDF**" as shown below to download the dataset as a netCDF file.

NASA ASDC-DAAC CERES EBAF-TOA Ed2p8 solar_mon Data Files

This dataset has bytes (4.7433600E07 45.236206MB) of data in it, which should give you a rough idea of the size of any file that you ask for.

Download Data To Specific Software

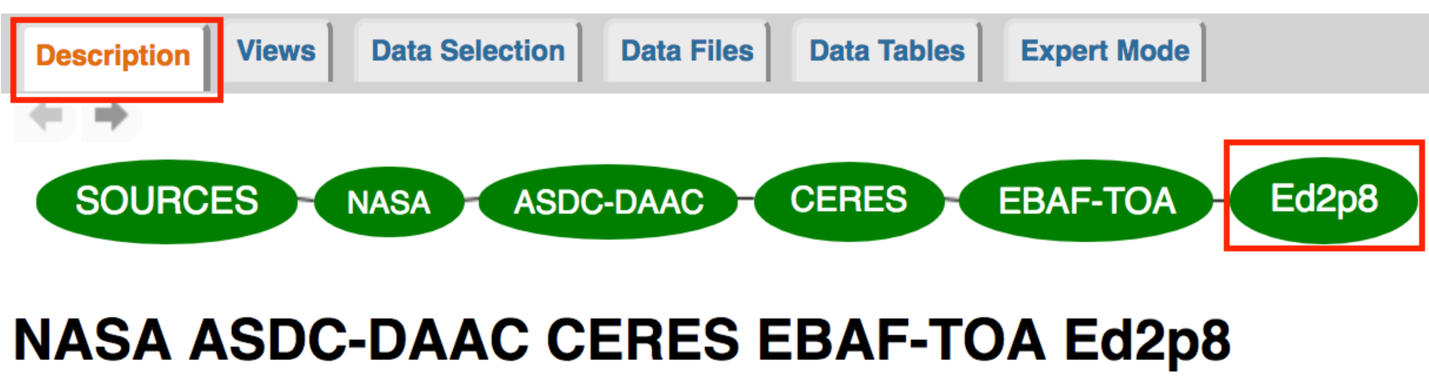
ingrid	The Postscript-based software on which the Data Library is built.
CPT	Climate Predictability Tool More information
ferret	Interactive computer visualization and analysis software. More information
GrADS	Grid Analysis and Display System More information
matlab	Data analysis and visualization software. More information
NCL	NCAR Command Language More information
WinDisp	A public domain software package for the display and analysis of satellite images, maps and associated databases, with an emphasis on early warning for food security. More information

Other Available File Formats

Full Information Formats These files contain all of the available metadata.	
OPeNDAP	A system which downloads data directly to software, such as matlab, Ferret, GrADS, etc. Specific instructions are available in the table above. Note: OPeNDAP was formerly known as DODS (Distributed Oceanographic Data System). More Information
netCDF (network Common Data Form)	A commonly supported self-describing data format. More Information

3. Go to the Downloads folder of your computer and change the name of the downloaded data to Insolation.nc (Make sure the file extension is .nc to indicate a netCDF file.) The name can be changed by right-clicking on the dataset and selecting "rename". The data that was just downloaded represents monthly incoming solar energy (insolation) from March 2000 to May 2015.

4. Click on the **"Description"** tab at the top of the webpage. Now, click on the **green ellipse titled "Ed2p8"** as illustrated below to go back to the list of datasets.



Click on the 5th **link** titled **"Top of The Atmosphere Longwave Flux, Monthly Means, All-Sky conditions"**, click on the **"Data Files"** tab at the top left of the webpage, and then click on the **"netCDF"** link to download the data.

Rename the dataset Outgoing_Longwave.nc (This dataset represents monthly outgoing longwave radiation from March 2000 to May 2015.)

5. Click on the **"Description"** tab at the top of the webpage. Now, click on the **green ellipse titled "Ed2p8"** to go back to the list of datasets.

Click on the 9th **link** titled **"Top of The Atmosphere Shortwave Flux, Monthly Means, All-Sky conditions"**, click on the **"Data Files"** tab, and then click on the **"netCDF"** link to download the data.

Rename the dataset Outgoing_Shortwave.nc (This dataset represents monthly outgoing shortwave radiation from March 2000 to May 2015.)

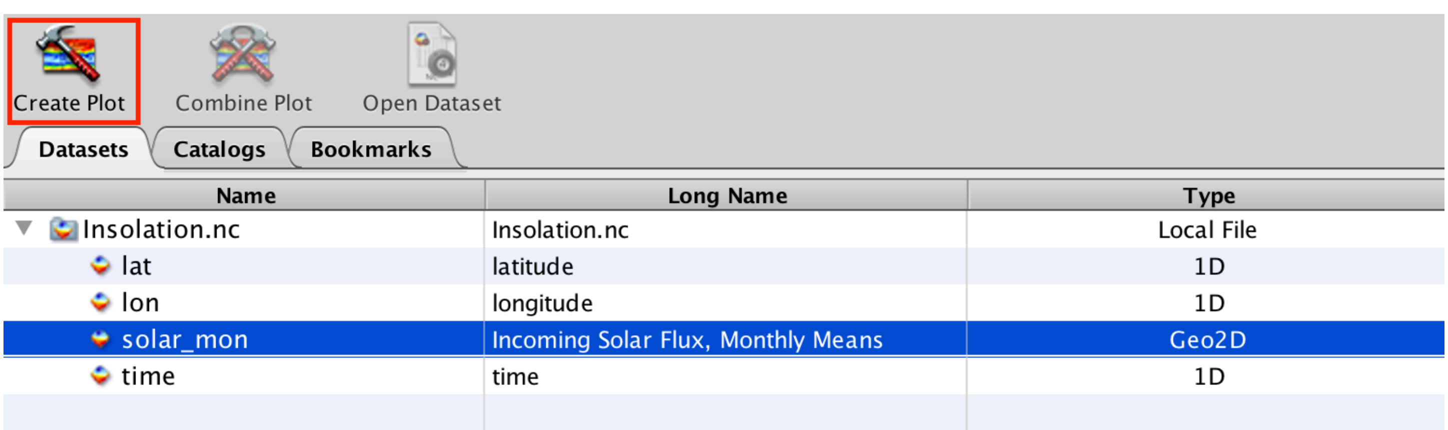
6. Click on the **"Description"** tab at the top of the webpage. Now, click on the **green ellipse titled "Ed2p8"** to go back to the list of datasets.

Click on the 7th **link** titled **"Top of The Atmosphere Net Flux, Monthly Means, All-Sky conditions"**, click on the **"Data Files"** tab, and then click on the **"netCDF"** link to download the data.

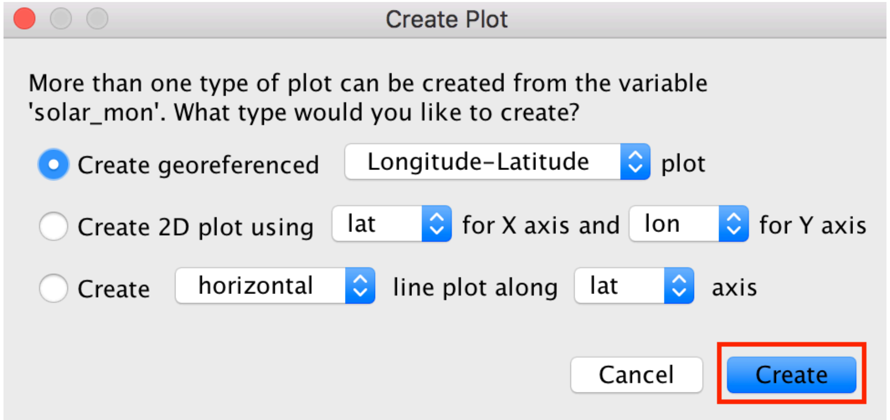
Rename the dataset Net_Energy.nc (This dataset represents the monthly net radiation (incoming – outgoing) at the top of Earth's atmosphere from March 2000 to May 2015.)

7. Open the Panoply program. Click on **"File"** on the top left of the program and then click on **"Open".** Locate the Insolation.nc file you saved in your downloads earlier and open it in Panoply. This dataset provides incoming solar energy values in W/m^2 for the entire Earth.

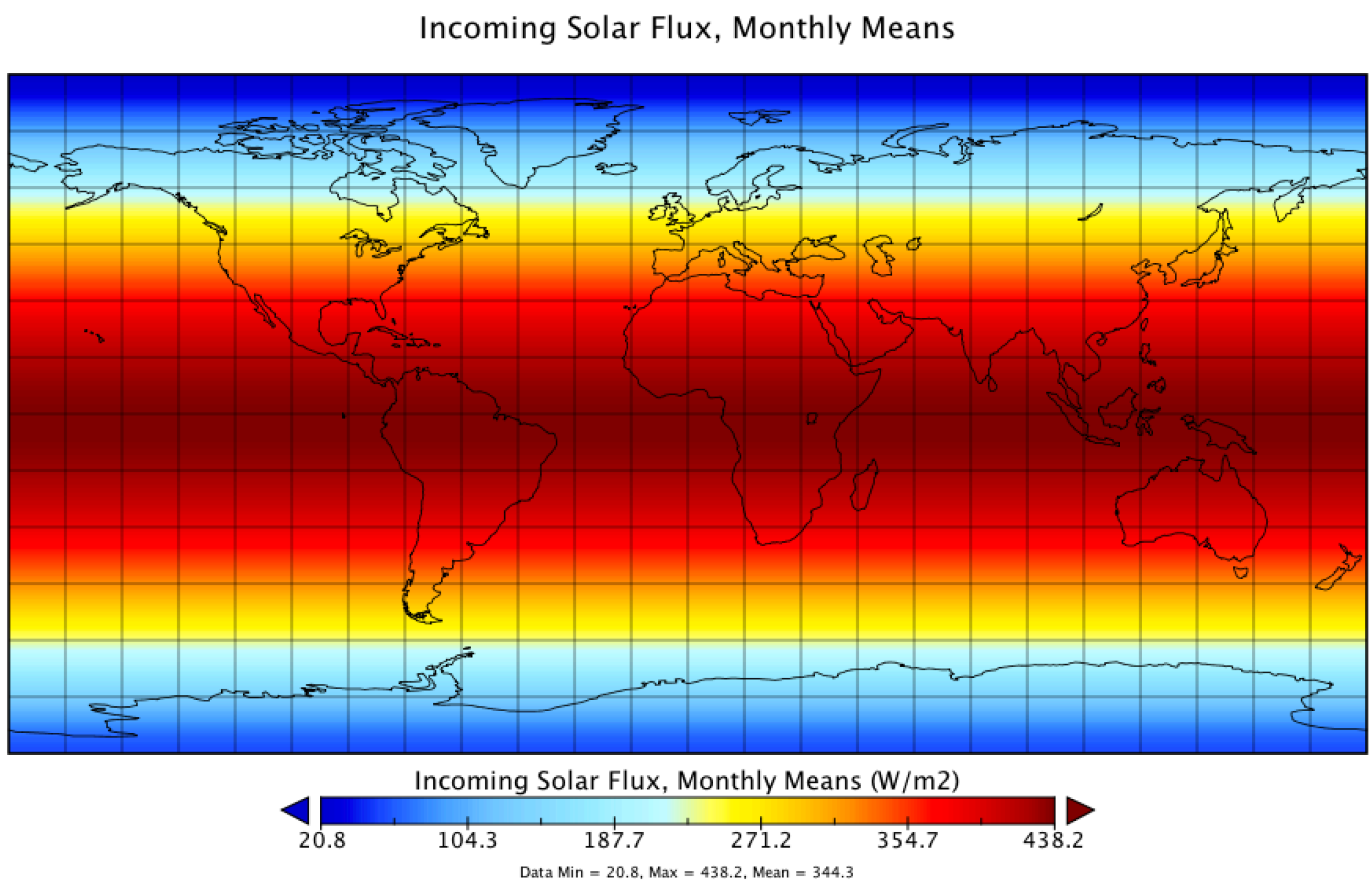
8. Click on the variable titled **"solar_mon"** and then click **"Create Plot"** in the top left corner as shown below:



The following window will appear. Do not change any of the settings and click **"Create"** as shown below.



You should now see a map that looks like this:



9. The map currently displayed is the average incoming solar radiation (solar flux) for the Earth during the month of March 2000.

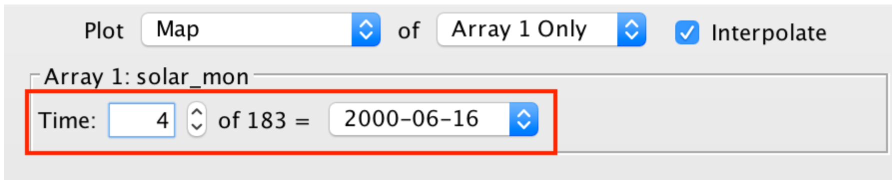
Q1. Describe the distribution of incoming solar radiation at the top of Earth's atmosphere during March 2000 (where is the most insolation, where is the least, etc).

____

Q2. How does the data displayed justify that the vernal equinox occurs during the month of March?

____

10. Locate the white "Time" box near the bottom of Panoply. Change the value in the white box to "4" and press enter as displayed below.



You will now be looking at average monthly insolation data for June 2000.

Q3. Describe the change in the distribution of insolation from March 2000 to June 2000.

____

Q4. Why was there a change in the distribution of insolation from March 2000 to June 2000?

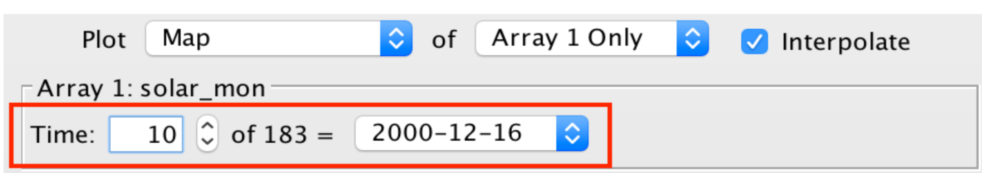
____

Q5. How would this change in insolation from March 2000 to June 2000 influence the balance of Earth's energy budget in the Northern Hemisphere? Why would the energy budget be impacted?

How: ____

Why: ____

11. Locate the white "Time" box near the bottom of Panoply. Change the value in the white box to "10" and press enter as displayed below.



You will now be looking at average monthly insolation data for December 2000.

Q6. Describe the change in the distribution of insolation from March 2000 to December 2000.

____

Q7. Why was there a change in the distribution of insolation from March 2000 to December 2000?

____

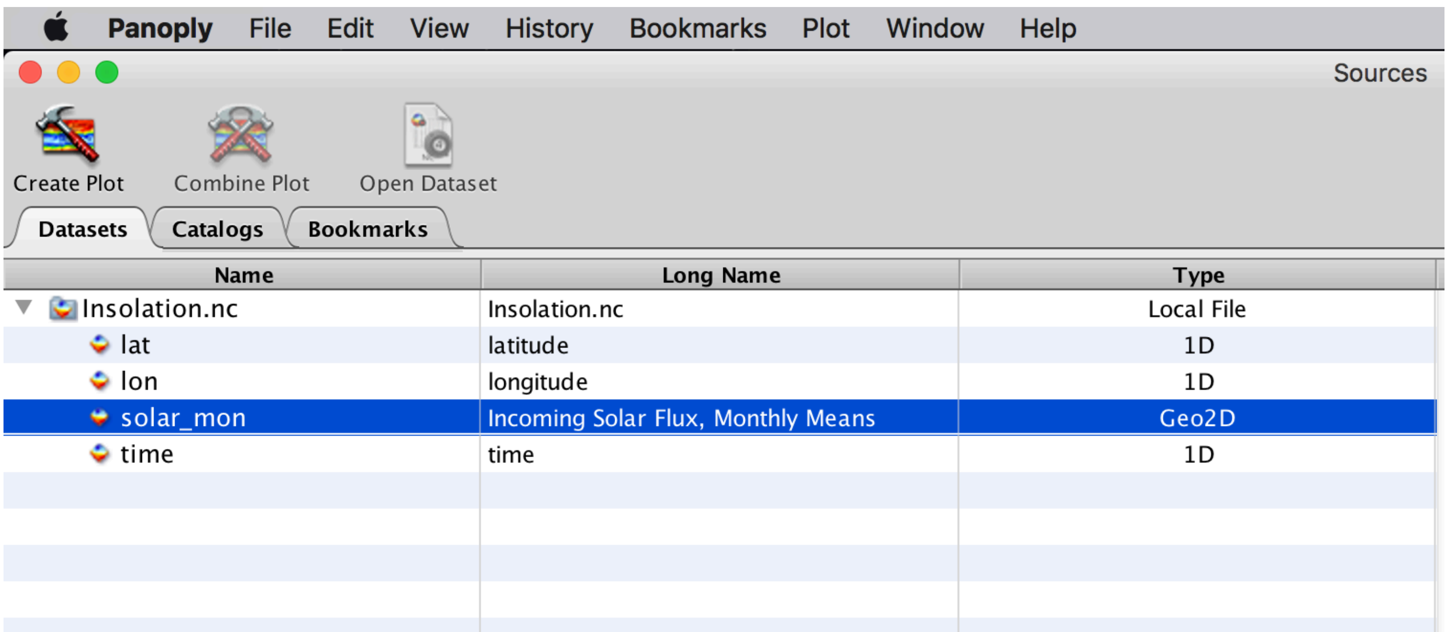
Q8. How would this change in insolation from March 2000 to December 2000 influence the balance of Earth's energy budget in the Northern Hemisphere? Why would the energy budget be impacted?

How: ____

Why: ____

You may now exit out of the insolation map.

12. Go back to the main Panoply window as shown below.



13. Click on **"File"** on the top left of the program and then click on **"Open".** Locate the Outgoing_Longwave.nc file you saved in your downloads earlier and open it in Panoply.

This dataset provides average monthly values of outgoing longwave radiation at the top of the atmosphere (TOA). Longwave radiation is characterized by energy with wavelengths in the infrared portion of the electromagnetic spectrum.

Q9. Briefly summarize the data that is available in the Outgoing_Longwave.nc dataset.

____

14. Click on the variable titled **"toa_lw_all_mon"** and then click on **"Create Plot"** at the top left of Panoply. When prompted, click **"Create".**

15. You are now viewing average outgoing longwave energy in W/m^2 for the month of March 2000.

Q10. Based on your knowledge gained from the previous lesson and the NASA Earth Observatory article titled Climate and Earth's Energy Budget, describe how the outgoing longwave energy is produced.

____

____

Q11. Why are the equatorial regions emitting the greatest amount of longwave radiation?

____

Q12. Why are the higher latitudes emitting the least amount of longwave radiation?

____

16. Change the value in the white time box to "4" and then press enter. You will now be viewing outgoing longwave energy during June 2000.

Q13. How did the amount of outgoing longwave energy on Earth change from March 2000 to June 2000? Why do you think there was a change?

How: ____

Why: ____

Q14. Why are outgoing longwave radiation values over Greenland lower than other locations at the same latitude?

____

17. Change the value in the white time box to "10" and then press enter. You will now be viewing outgoing longwave energy during December 2000.

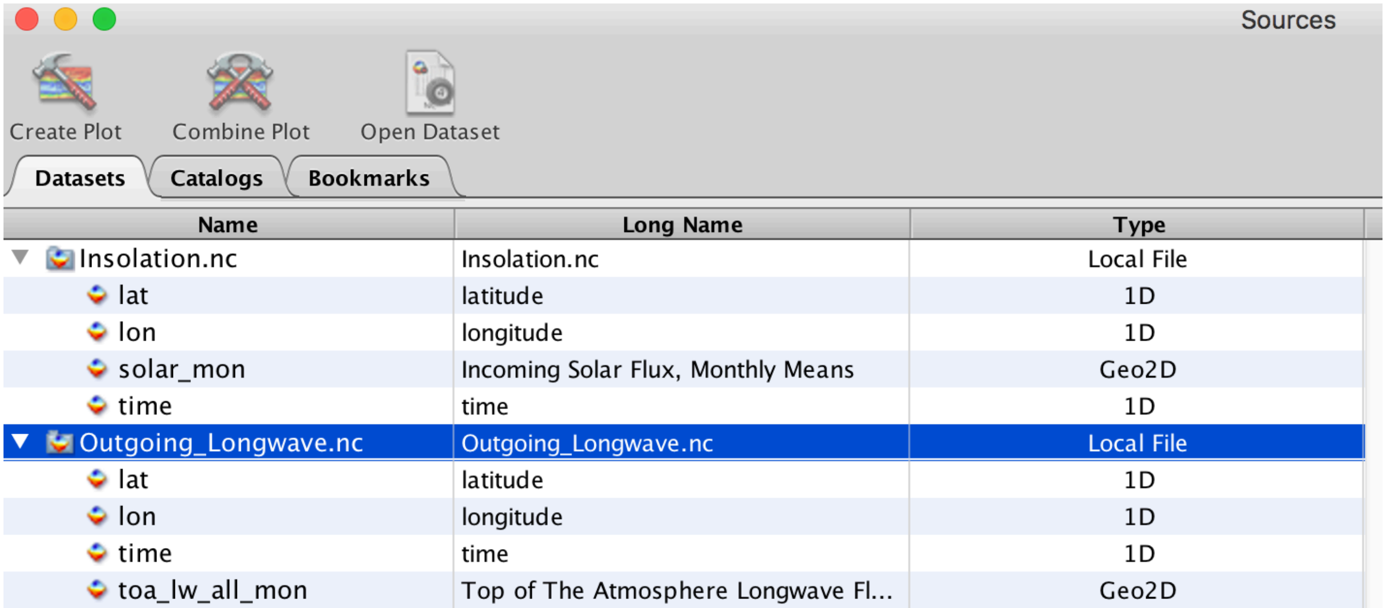
Q15. How did the amount of outgoing longwave energy on Earth change from June 2000 to December 2000? Why do you think there was a change?

How: ____

Why: ____

You may now exit out of the outgoing longwave map.

18. Go back to the main Panoply window as shown below.



19. Click on **"File"** on the top left of the program and then click on **"Open".** Locate the Outgoing_Shortwave.nc file you saved in your downloads earlier and open it in Panoply.

This dataset provides average monthly values of outgoing shortwave radiation at the top of the atmosphere (TOA). Shortwave radiation is characterized by energy with wavelengths in the visible portion of the electromagnetic spectrum.

Q16. Briefly summarize the data that is available in the Outgoing_Shortwave.nc dataset. Also, provide an example of outgoing shortwave energy (such as how is the outgoing shortwave energy produced?).

20. Click on the variable titled **"toa_sw_all_mon"** and then click on **"Create Plot"** at the top left of Panoply. When prompted, **click "Create".**

21. You are now viewing average outgoing shortwave energy in W/m^2 for the month of March 2000.

Q17. Why is there more outgoing shortwave radiation over land areas compared to ocean areas? Use the term ***albedo*** in your answer.

22. Change the value in the white time box to "4" and then press enter. You will now be viewing outgoing shortwave energy during June 2000.

Q18. How did the amount of outgoing shortwave energy on Earth change from March 2000 to June 2000? Why do you think there was a change?

How: ____

Why: ____

Q19. During June 2000, why is there more outgoing shortwave energy in the northern higher latitudes compared to the southern higher latitudes?

____

____

23. Change the value in the white time box to "10" and then press enter. You will now be viewing outgoing shortwave energy during December 2000.

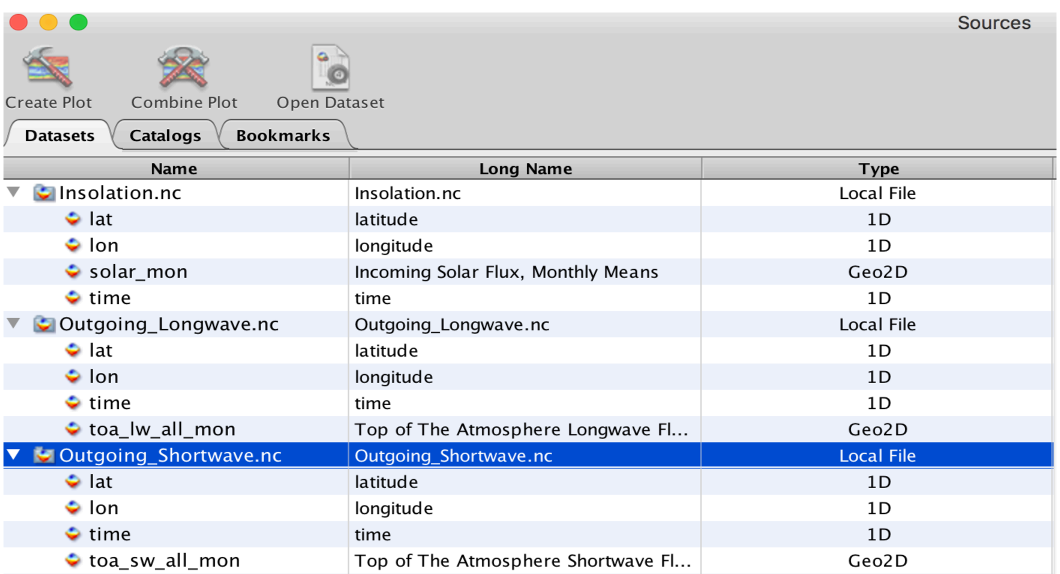
Q20. How did the amount of outgoing shortwave energy on Earth change from June 2000 to December 2000? Why do you think there was a change?

How: ____

Why: ____

24. Change the value in the white time box back to "1" and then press enter in order to view outgoing shortwave data from March 2000. ***Do not exit out of this map.***

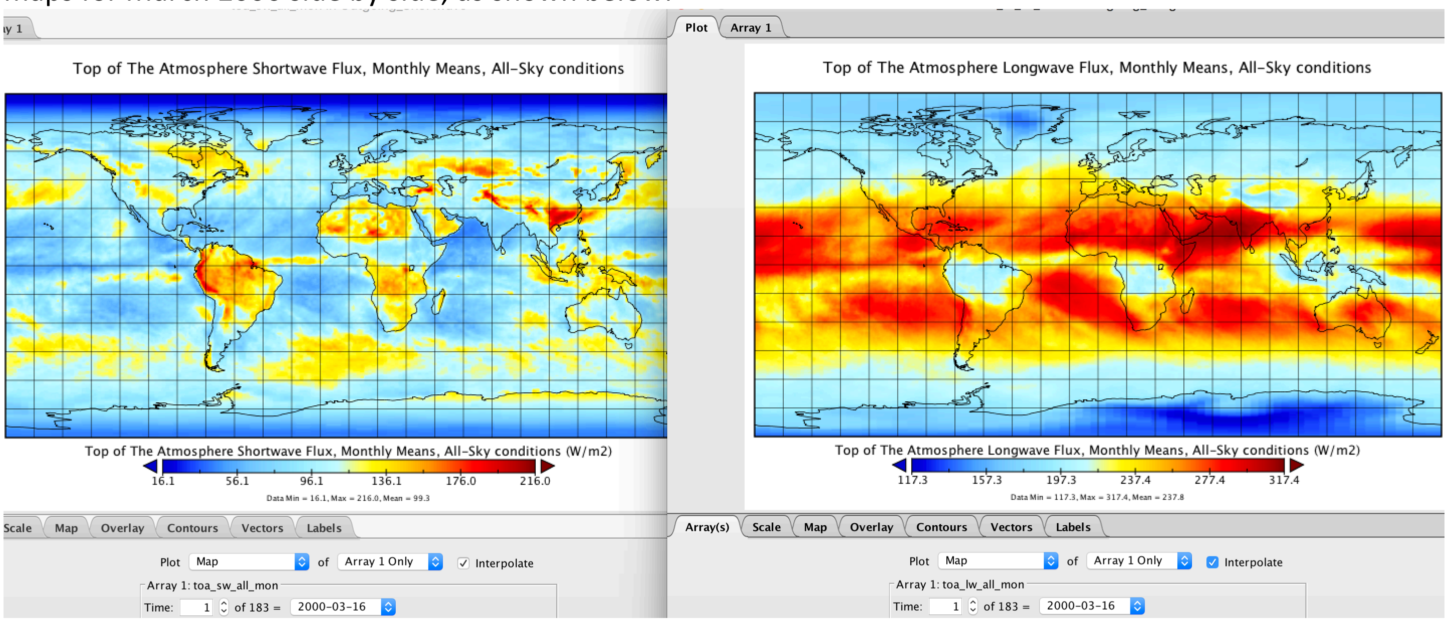
25. Go back to the main Panoply window as shown below.



26. Go to the Outgoing_Longwave.nc dataset that is already uploaded into Panoply. Click on the **"toa_lw_all_mon**" variable and then click on **"Create Plot"** at the top left of Panoply. When prompted, click **"Create".**

27. You are now viewing average outgoing longwave energy in W/m^2 for the month of March 2000.

28. Position your open Panoply windows so you are viewing the outgoing shortwave and outgoing longwave maps for March 2000 side by side, as shown below.



29. On both maps, change the white time box value to "4" and press enter to show outgoing shortwave and outgoing longwave values for June 2000.

Q21. Describe the main differences in outgoing longwave and outgoing shortwave radiation in June 2000.

Q22. Why is there more outgoing longwave radiation coming from the equatorial ocean compared to outgoing shortwave?

Q23. Why is there more outgoing shortwave radiation coming from the higher northern latitudes, specifically Greenland, when compared to the outgoing longwave radiation?

Q24. Based on your observations from today's activity, describe the regions on Earth that experience, in general, the greatest and least amount of outgoing longwave radiation in June.

Greatest: ____

____

Least: ____

____

Q25. Based on your observations from today's activity, describe the regions on Earth that experience, in general, the greatest and least amount of outgoing shortwave radiation in June.

Greatest: ____

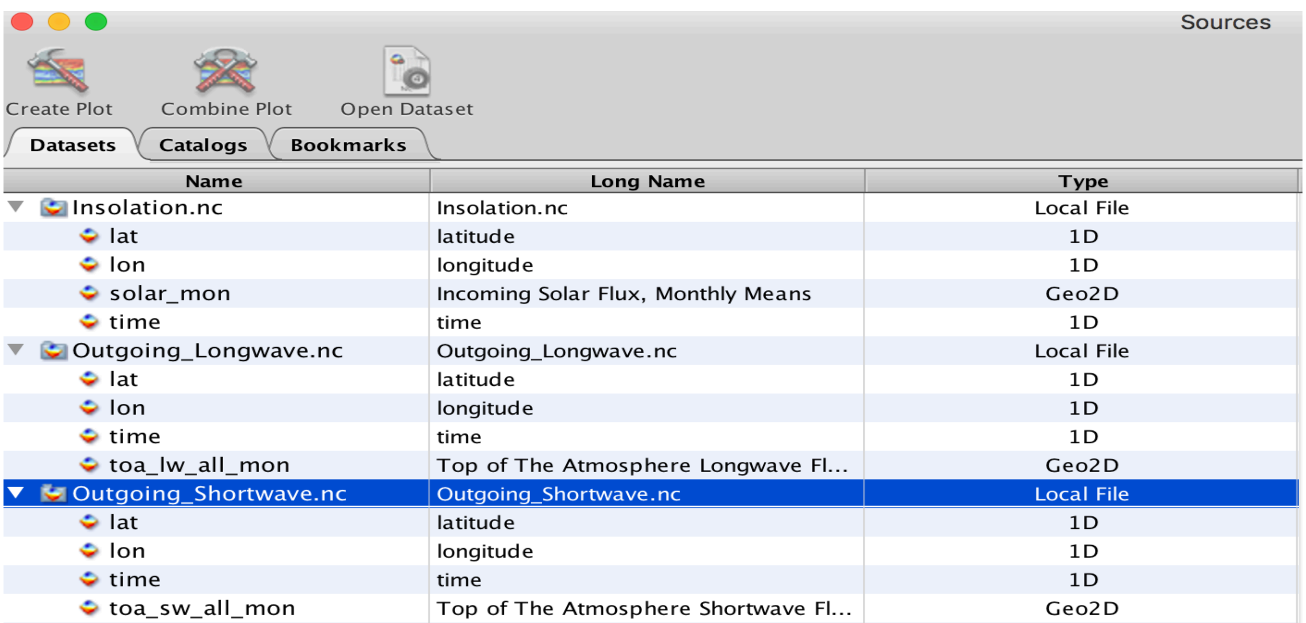
____

Least: ____

____

You may now exit out of the outgoing longwave and outgoing shortwave plots.

30. Go back to the main Panoply window as shown below.



31. Click on **"File"** on the top left of the program and then click on **"Open"**. Locate the Net_Energy.nc file you saved in your downloads earlier and open it in Panoply.

This dataset provides average monthly values of net energy at the top of the atmosphere (TOA). Net energy is described by comparing the total amount of outgoing energy and the total amount of incoming energy. A formula to calculate Earth's net energy is:

Net Energy = Incoming – Outgoing Shortwave – Outgoing Longwave

Q26. Briefly summarize the data that is available in the Net_Energy.nc dataset.

____

32. Click on the variable titled **"toa_net_all_mon"** and then click on **"Create Plot"** at the top left of Panoply. When prompted, click **"Create"**.

33. You are now viewing average net energy in W/m^2 for the month of March 2000.

Q27. Describe the general regions that have the greatest and least net energy at the top of Earth's atmosphere in March 2000.

Greatest: ____

Least: ____

34. Change the white time box value to "4" and press enter to show net energy values for June 2000.

Q28. Describe the general regions that have the greatest and least net energy at the top of Earth's atmosphere in June 2000.

Greatest: ____

Least: ____

Q29. How did the net energy change from March 2000 to June 2000?

____

____

Q30. During June, the start of the Northern Hemisphere Summer, there is a higher amount of incoming solar energy (insolation) in the higher latitudes of the Northern Hemisphere (this can be verified by opening the **"solar_mon"** variable in the **Insolation.nc** dataset in Panoply, and changing the month to June 2000). Why do locations at the higher latitudes, such as Greenland, have a negative net amount of energy? Use the energy budget formula provided in Step #31 in order to specify which component of the budget has the greatest impact on net energy.

____

____

Elaborate & Evaluate Questions

Q31. Predict how you would expect the amount outgoing longwave energy over equatorial regions to change in the future as average global temperatures on Earth continue to warm. Explain your prediction.

Prediction: ____

Explanation: ____

____

Q32. Predict how you would expect net energy over Greenland to change in the future as the ice sheets in Greenland are expected to melt. Explain your prediction using the terms longwave and shortwave energy.

Prediction: ____

Explanation: ____

____

Name: **Answer Key** Date: ____________________

NASA GISS Panoply: Earth's Energy Budget

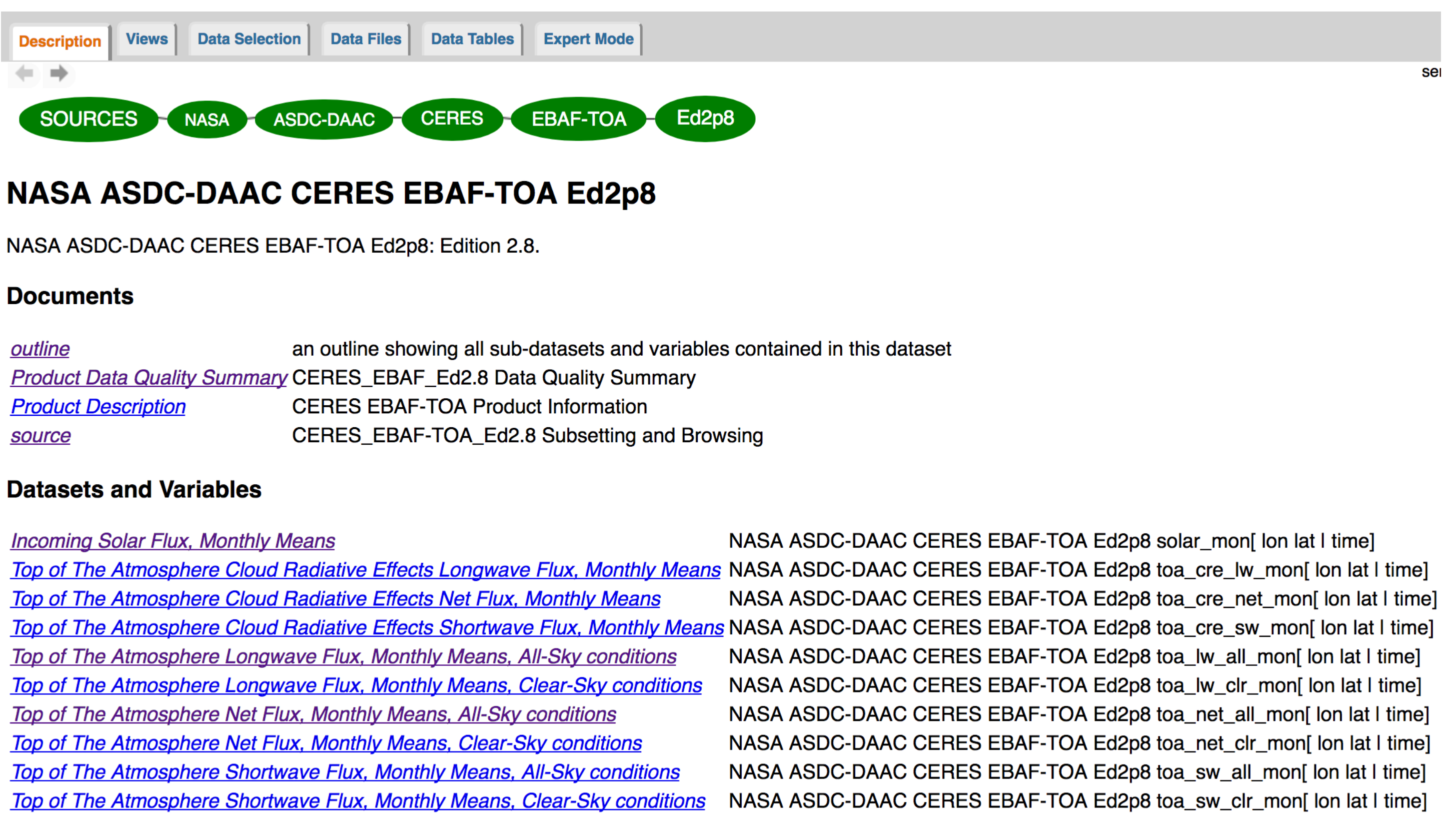
Activity Description: In this activity the students will use the IRI/LDEO Data Library sponsored by Columbia University to download data from the NASA CERES satellite that measures incoming and outgoing energy at the top of Earth's atmosphere. The students will download four datasets from CERES based on incoming solar energy, net solar energy at the top of the atmosphere, outgoing longwave radiation, and outgoing shortwave radiation.

Directions: Ensure Panoply (http://www.giss.nasa.gov/tools/panoply/) is downloaded onto each user's computer. There is a step-by-step download guide available for both Macs and PCs on the pages prior to this activity.

Net energy = Incoming Solar Radiation – Outgoing Longwave – Outgoing Shortwave

1. The activity will begin by downloading the four datasets necessary for the activity. Go to https://iridl.ldeo.columbia.edu/?Set-Language=en, click on the link titled ***"Data by Source"***, scroll down to and click the link that says ***"NASA"***, click on the first link that says **"ASDC-DAAC"**, click on the link that says ***"CERES"***, click on the link that says ***"EBAF-TOA"***, and finally click on the link that says ***"Ed2p8".***

You should now see a page that looks like this:


Description | Views | Data Selection | Data Files | Data Tables | Expert Mode

SOURCES · NASA · ASDC-DAAC · CERES · EBAF-TOA · Ed2p8

NASA ASDC-DAAC CERES EBAF-TOA Ed2p8

NASA ASDC-DAAC CERES EBAF-TOA Ed2p8: Edition 2.8.

Documents

outline	an outline showing all sub-datasets and variables contained in this dataset
Product Data Quality Summary	CERES_EBAF_Ed2.8 Data Quality Summary
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source	CERES_EBAF-TOA_Ed2.8 Subsetting and Browsing

Datasets and Variables

Incoming Solar Flux, Monthly Means	NASA ASDC-DAAC CERES EBAF-TOA Ed2p8 solar_mon[lon lat l time]
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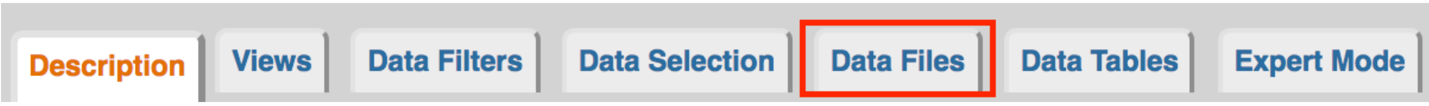
Top of The Atmosphere Net Flux, Monthly Means, All-Sky conditions	NASA ASDC-DAAC CERES EBAF-TOA Ed2p8 toa_net_all_mon[lon lat l time]
Top of The Atmosphere Net Flux, Monthly Means, Clear-Sky conditions	NASA ASDC-DAAC CERES EBAF-TOA Ed2p8 toa_net_clr_mon[lon lat l time]
Top of The Atmosphere Shortwave Flux, Monthly Means, All-Sky conditions	NASA ASDC-DAAC CERES EBAF-TOA Ed2p8 toa_sw_all_mon[lon lat l time]
Top of The Atmosphere Shortwave Flux, Monthly Means, Clear-Sky conditions	NASA ASDC-DAAC CERES EBAF-TOA Ed2p8 toa_sw_clr_mon[lon lat l time]

2. Click on the first link that says “Incoming Solar Flux, Monthly Means”. Then, on the top left of the webpage, click on the tab titled “Data Files” as shown below.



Click on the link that says “**netCDF**” as shown below to download the dataset as a netcdf file.

NASA ASDC-DAAC CERES EBAF-TOA Ed2p8 solar_mon Data Files

This dataset has bytes (4.7433600E07 45.236206MB) of data in it, which should give you a rough idea of the size of any file that you ask for.

Download Data To Specific Software

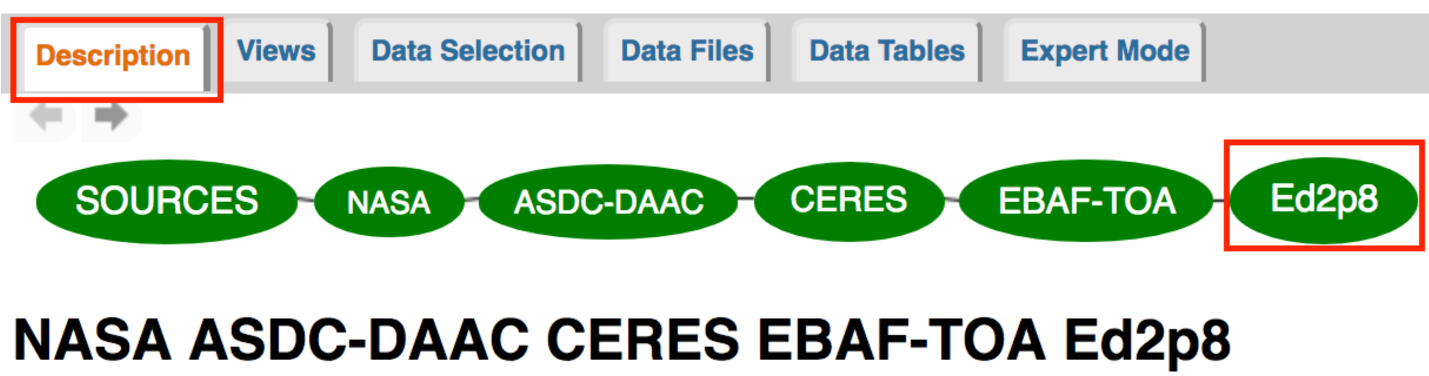
ingrid	The Postscript-based software on which the Data Library is built.
CPT	Climate Predictability Tool More information
ferret	Interactive computer visualization and analysis software. More information
GrADS	Grid Analysis and Display System More information
matlab	Data analysis and visualization software. More information
NCL	NCAR Command Language More information
WinDisp	A public domain software package for the display and analysis of satellite images, maps and associated databases, with an emphasis on early warning for food security. More information

Other Available File Formats

Full Information Formats These files contain all of the available metadata.	
OPeNDAP	A system which downloads data directly to software, such as matlab, Ferret, GrADS, etc. Specific instructions are available in the table above. Note: OPeNDAP was formerly known as DODS (Distributed Oceanographic Data System). More Information
netCDF (network Common Data Form)	A commonly supported self-describing data format. More Information

3. Go to the Downloads folder of your computer and change the name of the downloaded data to Insolation.nc (Make sure the file extension is .nc to indicate a netCDF file.) The name can be changed by right-clicking on the dataset and selecting “rename”. The data that was just downloaded represents monthly incoming solar energy (insolation) from March 2000 to May 2015.

4. Click on the **“Description”** tab at the top of the webpage. Now, click on the **green ellipse titled “Ed2p8”** as illustrated below to go back to the list of datasets.



Click on the 5th **link** titled **"Top of The Atmosphere Longwave Flux, Monthly Means, All-Sky conditions"**, click on the **"Data Files"** tab at the top left of the webpage, and then click on the **"netCDF"** link to download the data.

Rename the dataset Outgoing_Longwave.nc (This dataset represents monthly outgoing longwave radiation from March 2000 to May 2015.)

5. Click on the **"Description"** tab at the top of the webpage. Now, click on the **green ellipse titled "Ed2p8"** to go back to the list of datasets.

Click on the 9th **link** titled **"Top of The Atmosphere Shortwave Flux, Monthly Means, All-Sky conditions"**, click on the **"Data Files"** tab, and then click on the **"netCDF"** link to download the data.

Rename the dataset Outgoing_Shortwave.nc (This dataset represents monthly outgoing shortwave radiation from March 2000 to May 2015.)

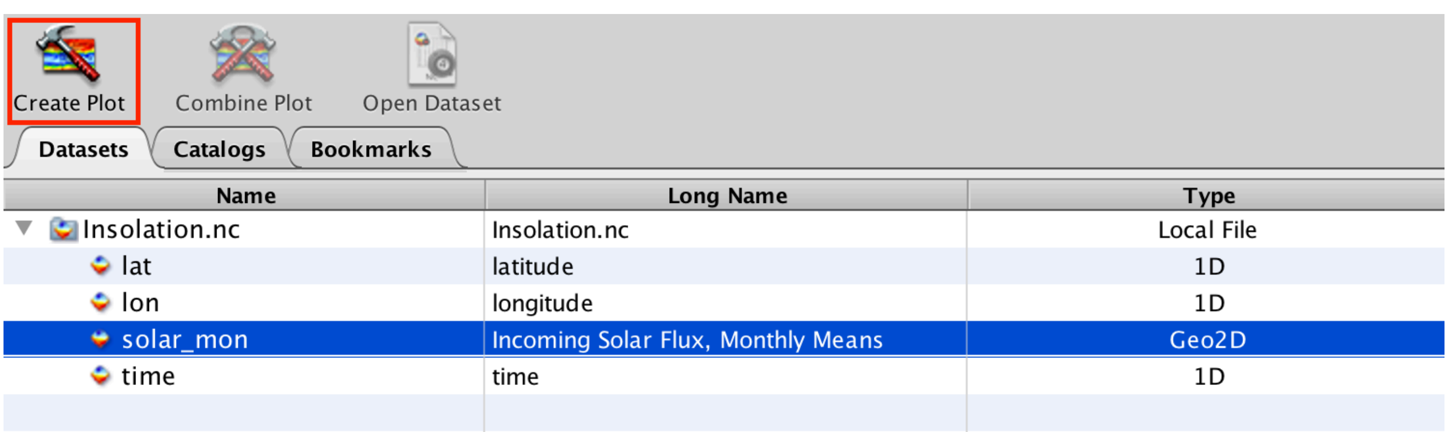
6. Click on the **"Description"** tab at the top of the webpage. Now, click on the **green ellipse titled "Ed2p8"** to go back to the list of datasets.

Click on the 7th **link** titled **"Top of The Atmosphere Net Flux, Monthly Means, All-Sky conditions"**, click on the **"Data Files"** tab, and then click on the **"netCDF"** link to download the data.

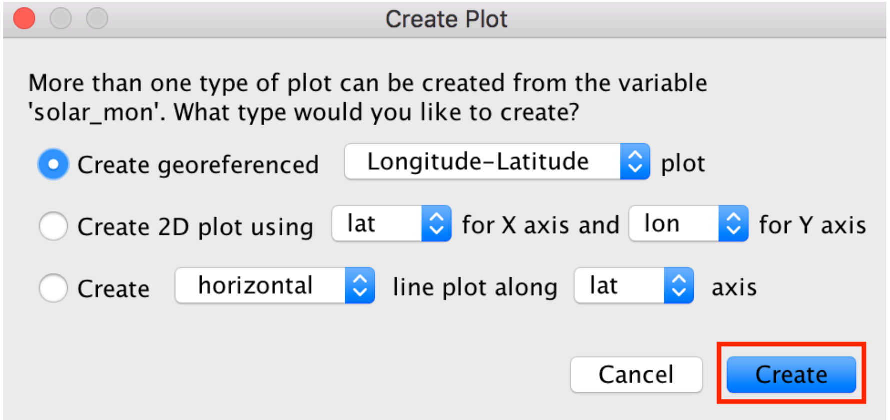
Rename the dataset Net_Energy.nc (This dataset represents the monthly net radiation (incoming – outgoing) at the top of Earth's atmosphere from March 2000 to May 2015.)

7. Open the Panoply program. Click on **"File"** on the top left of the program and then click on **"Open".** Locate the Insolation.nc file you saved in your downloads earlier and open it in Panoply. This dataset provides incoming solar energy values in W/m^2 for the entire Earth.

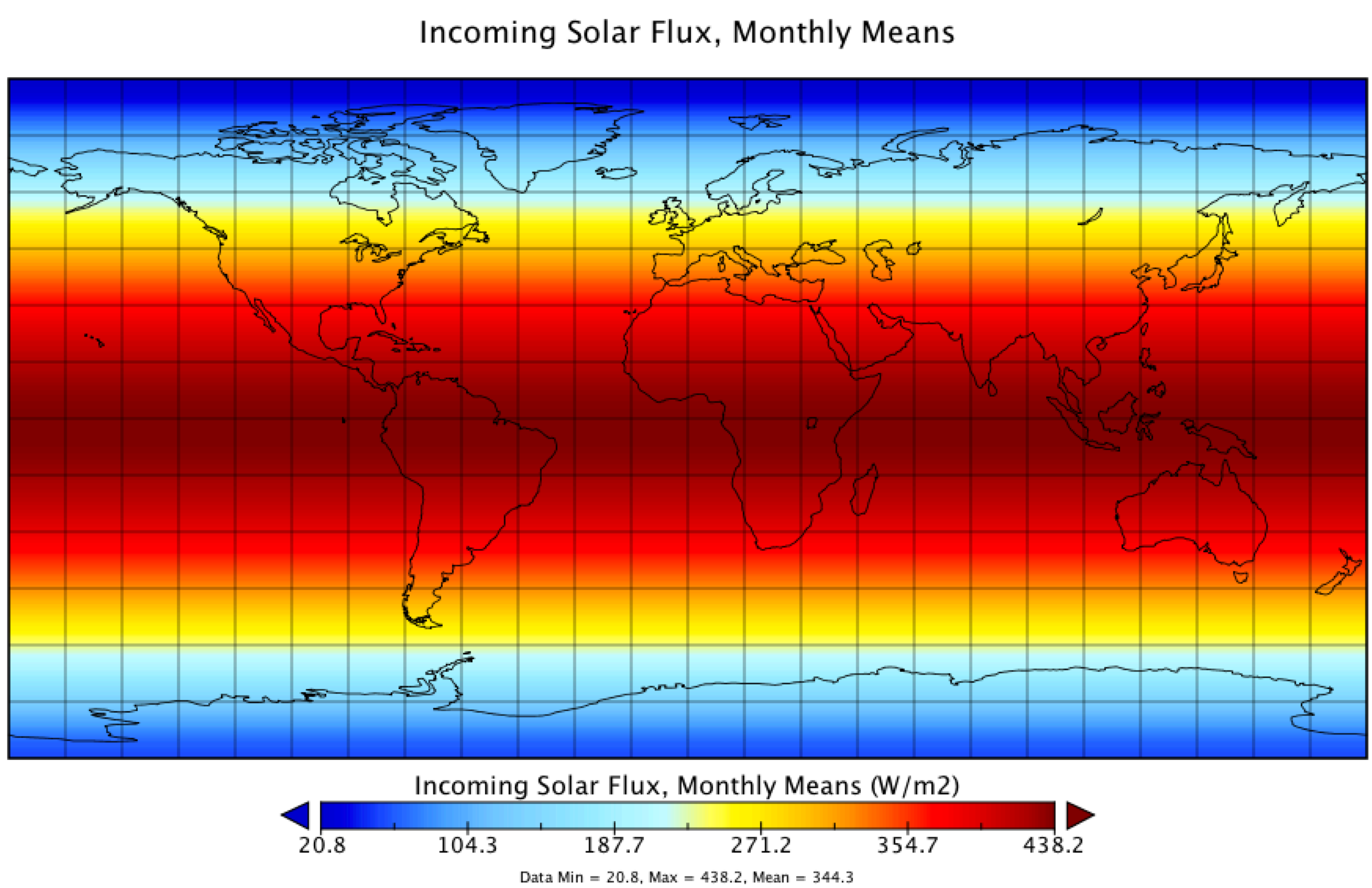
8. Click on the variable titled **"solar_mon"** and then click **"Create Plot"** in the top left corner as shown below:



The following window will appear. Do not change any of the settings and click **"Create"** as shown below.



You should now see a map that looks like this:



9. The map currently displayed is the average incoming solar radiation (solar flux) for the Earth during the month of March 2000.

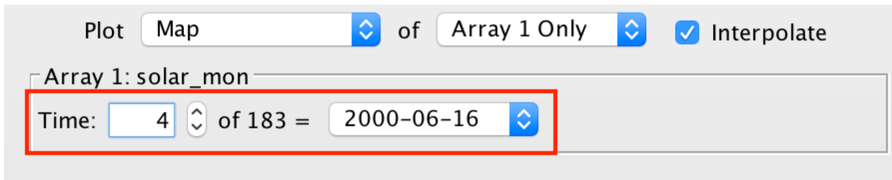
Q1. Describe the distribution of incoming solar radiation at the top of Earth's atmosphere during March 2000 (where is the most insolation, where is the least, etc).

The greatest insolation is near the equatorial regions and the least is in the polar regions.

Q2. How does the data displayed justify that the vernal equinox occurs during the month of March?

<u>**During an equinox the sunlight is directly on the equator and in the map above, the equator is receiving the greatest and most direct sunlight.**</u>

10. Locate the white "Time" box near the bottom of Panoply. Change the value in the white box to "4" and press enter as displayed below.



You will now be looking at average monthly insolation data for June 2000.

Q3. Describe the change in the distribution of insolation from March 2000 to June 2000.

<u>**The insolation is now greatest in the NH**</u>

Q4. Why was there a change in the distribution of insolation from March 2000 to June 2000?

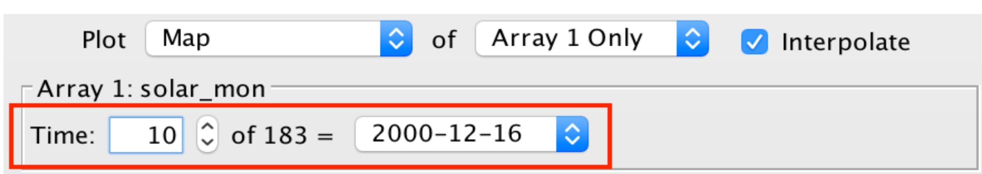
<u>**From March to June the greatest angle of insolation shifts from the equator to 23˚N latitude because in June the NH is tilted towards the Sun**</u>

Q5. How would this change in insolation from March 2000 to June 2000 influence the balance of Earth's energy budget in the Northern Hemisphere? Why would the energy budget be impacted?

How: <u>**The net energy budget for the NH would increase**</u>

Why: <u>**There is an increase in incoming solar radiation and more energy would be coming in than going out**</u>

11. Locate the white "Time" box near the bottom of Panoply. Change the value in the white box to "10" and press enter as displayed below.



You will now be looking at average monthly insolation data for December 2000.

Q6. Describe the change in the distribution of insolation from March 2000 to December 2000.

<u>**The greatest insolation is now in the SH and there is lower insolation in the NH**</u>

Q7. Why was there a change in the distribution of insolation from March 2000 to December 2000?

In December the greatest angle of insolation hits a latitude of 23˚S, which means the greatest insolation is in the SH since the SH is tilted towards the Sun in December

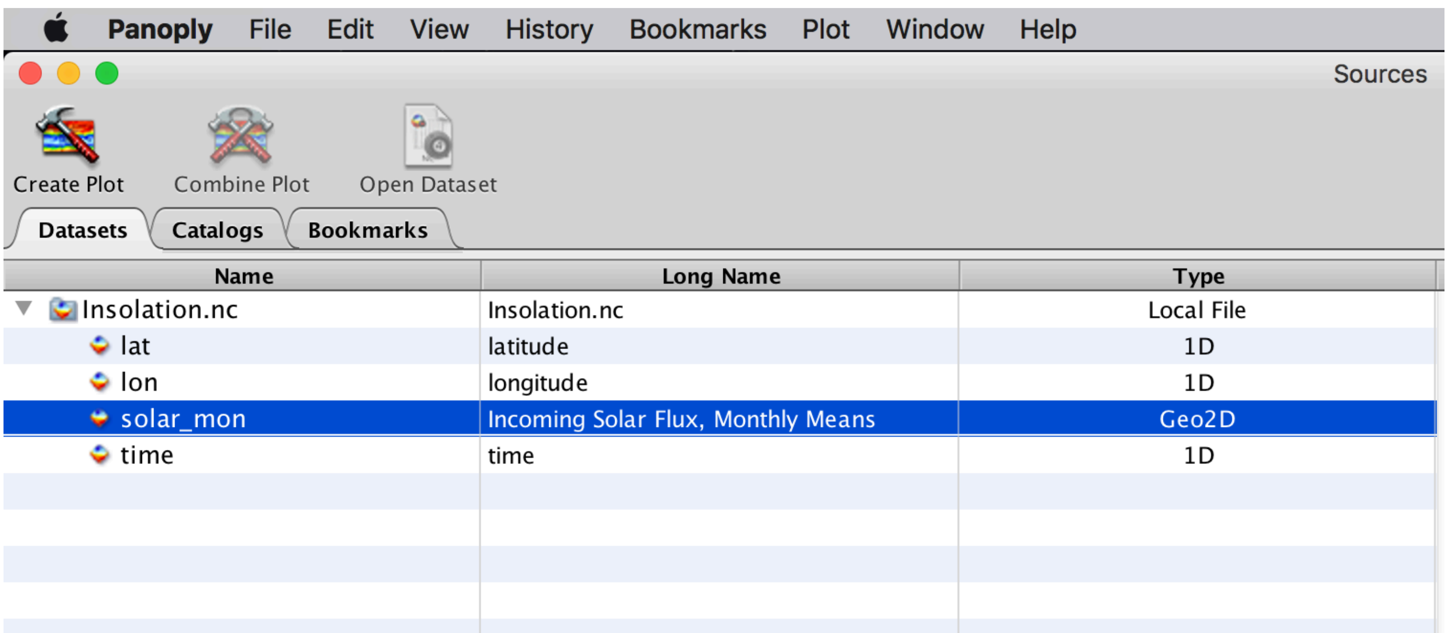
Q8. How would this change in insolation from March 2000 to December 2000 influence the balance of Earth's energy budget in the Northern Hemisphere? Why would the energy budget be impacted?

How: **The net energy budget for the NH would decrease**

Why: **There is a decrease in incoming solar radiation and less energy would be coming in than going out**

You may now exit out of the insolation map.

12. Go back to the main Panoply window as shown below.



13. Click on **"File"** on the top left of the program and then click on **"Open".** Locate the Outgoing_Longwave.nc file you saved in your downloads earlier and open it in Panoply.

This dataset provides average monthly values of outgoing longwave radiation at the top of the atmosphere (TOA). Longwave radiation is characterized by energy with wavelengths in the infrared portion of the electromagnetic spectrum.

Q9. Briefly summarize the data that is available in the Outgoing_Longwave.nc dataset.

Average monthly values of outgoing longwave radiation for the globe

14. Click on the variable titled **"toa_lw_all_mon"** and then click on **"Create Plot"** at the top left of Panoply. When prompted, click **"Create".**

15. You are now viewing average outgoing longwave energy in W/m^2 for the month of March 2000.

Q10. Based on your knowledge gained from the previous lesson and the NASA Earth Observatory article titled Climate and Earth's Energy Budget, describe how the outgoing longwave energy is produced.

Outgoing longwave energy is infrared energy emitted (radiated) by the surface of the Earth and parts of the lower atmosphere and sent back towards space. This energy is re-radiated from the surface that absorbs insolation.

Q11. Why are the equatorial regions emitting the greatest amount of longwave radiation?

The equatorial regions absorb the greatest amount of insolation in March and since they are receiving a great amount of energy, they are able to emit (give back) a great amount of the energy as infrared.

Q12. Why are the higher latitudes emitting the least amount of longwave radiation?

The higher latitudes absorb the least amount of insolation and since they are not absorbing a lot of energy, they therefore cannot emit (give back) a lot of energy as infrared.

16. Change the value in the white time box to "4" and then press enter. You will now be viewing outgoing longwave energy during June 2000.

Q13. How did the amount of outgoing longwave energy on Earth change from March 2000 to June 2000? Why do you think there was a change?

How: The greatest amount of outgoing longwave infrared shifted northward into the NH

Why: In June the NH receives more direct insolation and therefore absorbs more energy. The NH is able to emit (give back) the absorbed energy as infrared.

Q14. Why are outgoing longwave radiation values over Greenland lower than other locations at the same latitude?

Greenland is covered in ice which has a high albedo. The increased insolation in the NH gets reflected rather than absorbed and does not get absorbed and emitted by the surface as infrared.

17. Change the value in the white time box to "10" and then press enter. You will now be viewing outgoing longwave energy during December 2000.

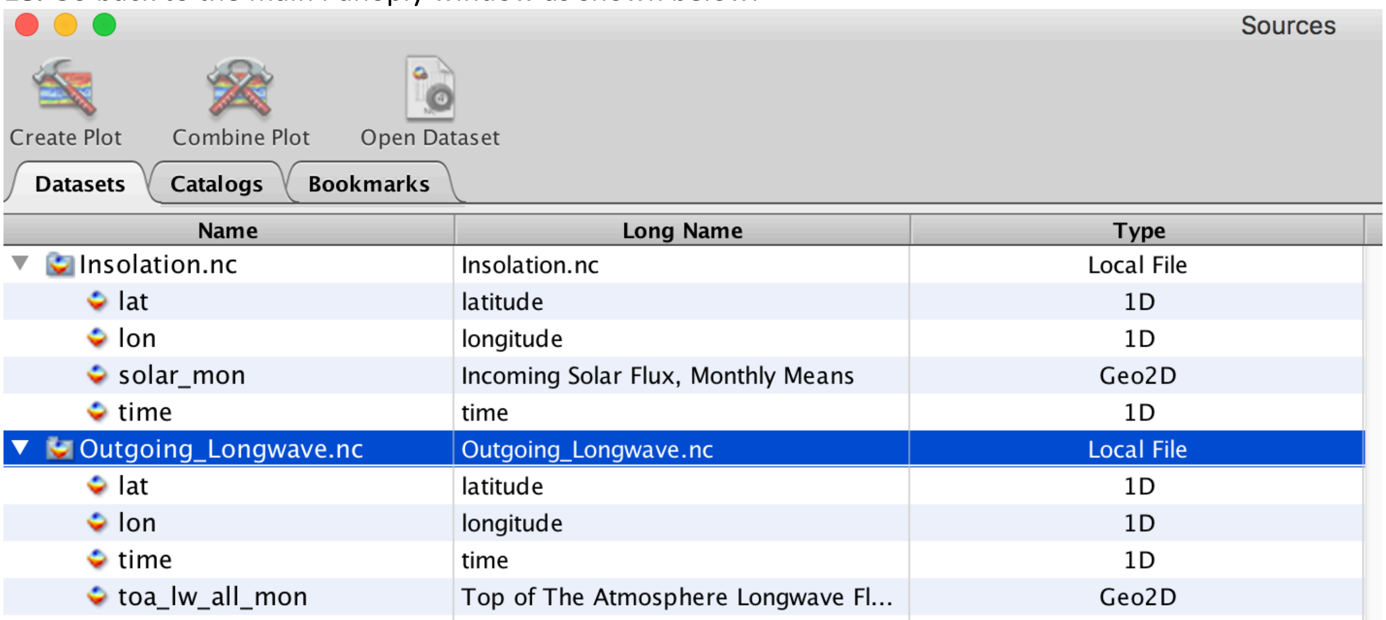
Q15. How did the amount of outgoing longwave energy on Earth change from June 2000 to December 2000? Why do you think there was a change?

How: The greatest amount of outgoing longwave infrared shifted southward to the SH

Why: In December the SH receives more direct insolation and therefore absorbs more energy. The SH is able to emit (give back) the absorbed energy as infrared.

You may now exit out of the outgoing longwave map.

18. Go back to the main Panoply window as shown below.



19. Click on **"File"** on the top left of the program and then click on **"Open".** Locate the Outgoing_Shortwave.nc file you saved in your downloads earlier and open it in Panoply.
This dataset provides average monthly values of outgoing shortwave radiation at the top of the atmosphere (TOA). Shortwave radiation is characterized by energy with wavelengths in the visible portion of the electromagnetic spectrum.

Q16. Briefly summarize the data that is available in the Outgoing_Shortwave.nc dataset. Also, provide an example of outgoing shortwave energy (such as how is the outgoing shortwave energy produced?).

The dataset contains average monthly outgoing shortwave energy values for the globe. Outgoing shortwave energy is produced when insolation (also shortwave energy) is reflected off of a surface or a cloud top. The energy is not absorbed and emitted as infrared and is therefore outgoing shortwave rather than outgoing longwave.

20. Click on the variable titled **"toa_sw_all_mon"** and then click on **"Create Plot"** at the top left of Panoply. When prompted, **click "Create".**

21. You are now viewing average outgoing shortwave energy in W/m^2 for the month of March 2000.

Q17. Why is there more outgoing shortwave radiation over land areas compared to ocean areas? Use the term ***albedo*** in your answer.
Land surfaces have a higher albedo compared to oceanic surfaces, which means land surfaces reflect more insolation back towards space, which is now outgoing shortwave energy. Absorbed energy over the oceans would be emitted as outgoing longwave infrared.

22. Change the value in the white time box to "4" and then press enter. You will now be viewing outgoing shortwave energy during June 2000.

Q18. How did the amount of outgoing shortwave energy on Earth change from March 2000 to June 2000? Why do you think there was a change?

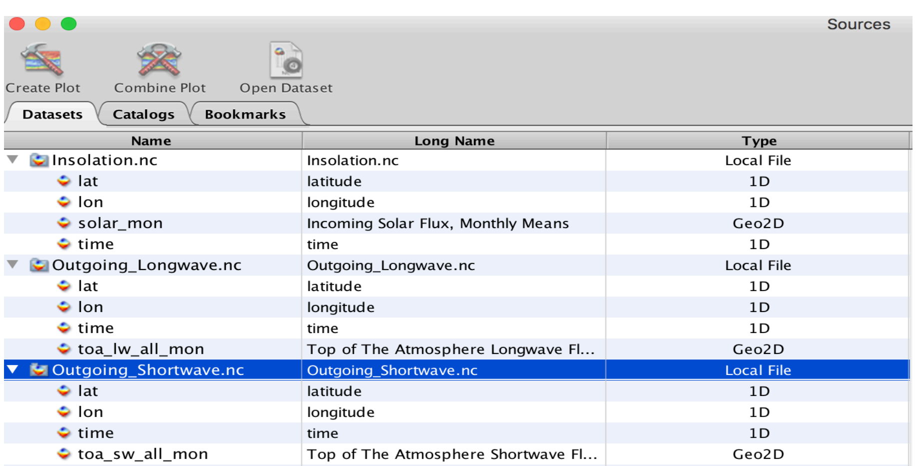
How: **The greatest amount of outgoing shortwave energy shifted northward towards the NH. The highest values are at the highest northern latitudes.**
Why: **In June the NH receives more direct insolation and therefore has more energy available that could be reflected and sent back to space as outgoing shortwave energy.**

Q19. During June 2000, why is there more outgoing shortwave energy in the northern higher latitudes compared to the southern higher latitudes?
In June the northern higher latitudes are receiving more direct sunlight. These locations are also snow and ice covered which means the land has a high albedo, leading to more reflectivity and greater outgoing shortwave energy. In the SH the south pole is titled away from the Sun and therefore little to no insolation is received. Therefore, there is neither an opportunity for absorption nor reflection of insolation.
23. Change the value in the white time box to "10" and then press enter. You will now be viewing outgoing shortwave energy during December 2000.

Q20. How did the amount of outgoing shortwave energy on Earth change from June 2000 to December 2000? Why do you think there was a change?

How: **The greatest amount of outgoing shortwave energy shifted southward to the high latitudes of the SH.**
Why: **In December the SH receives more direct insolation and therefore has more energy available that could be reflected and sent back to space as outgoing shortwave energy.**
24. Change the value in the white time box back to "1" and then press enter in order to view outgoing shortwave data from March 2000. ***Do not exit out of this map.***

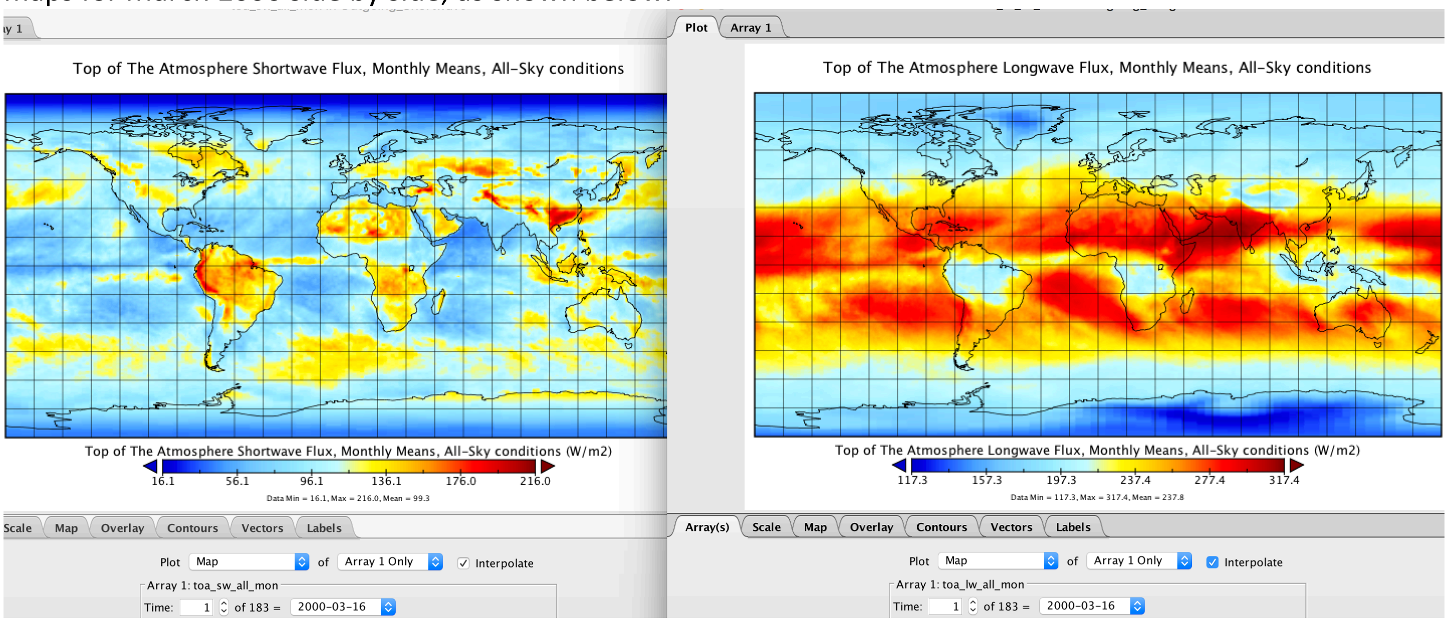
25. Go back to the main Panoply window as shown below.



26. Go to the Outgoing_Longwave.nc dataset that is already uploaded into Panoply. Click on the **"toa_lw_all_mon**" variable and then click on **"Create Plot"** at the top left of Panoply. When prompted, click **"Create".**

27. You are now viewing average outgoing longwave energy in W/m^2 for the month of March 2000.

28. Position your open Panoply windows so you are viewing the outgoing shortwave and outgoing longwave maps for March 2000 side by side, as shown below.



29. On both maps, change the white time box value to "4" and press enter to show outgoing shortwave and outgoing longwave values for June 2000.

Q21. Describe the main differences in outgoing longwave and outgoing shortwave radiation in June 2000.

In June the greatest outgoing longwave energy is near the equatorial regions while the greatest outgoing shortwave energy is near the higher latitudes of the NH.

Q22. Why is there more outgoing longwave radiation coming from the equatorial ocean compared to outgoing shortwave?

The equatorial regions receive and absorb more insolation which is re-radiated as outgoing longwave infrared energy. The equatorial regions also have a large amount of water, which has a lower albedo than land surfaces, leading to more absorption of energy.

Q23. Why is there more outgoing shortwave radiation coming from the higher northern latitudes, specifically Greenland, when compared to the outgoing longwave radiation?

Greenland has more outgoing shortwave energy because it has a higher albedo due to the snow and ice cover. Much of the insolation is not absorbed and rather reflected as outgoing shortwave energy.

Q24. Based on your observations from today's activity, describe the regions on Earth that experience, in general, the greatest and least amount of outgoing longwave radiation in June.

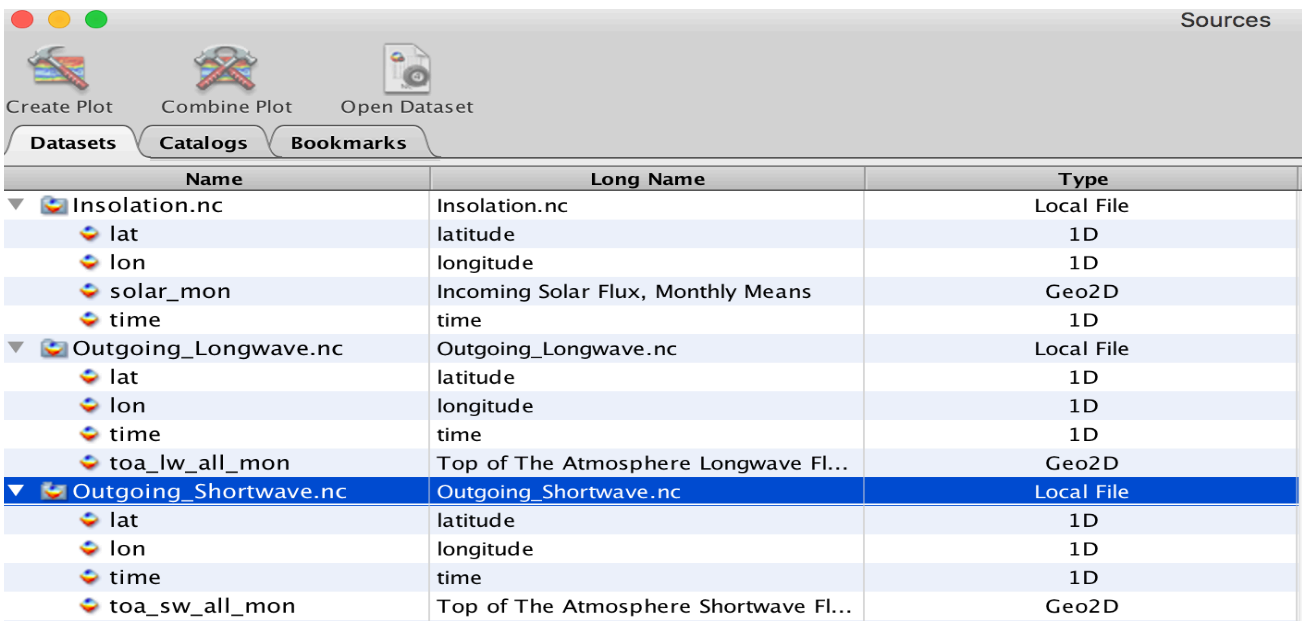
Greatest: In June, the greatest amount of outgoing longwave energy is in the equatorial regions and the NH.
Least: In June, the least amount of outgoing longwave energy is in the higher latitudes of the SH.

Q25. Based on your observations from today's activity, describe the regions on Earth that experience, in general, the greatest and least amount of outgoing shortwave radiation in June.

Greatest: In June, the greatest amount of outgoing shortwave energy is in the higher latitudes of the NH.
Least: In June, the least amount of outgoing shortwave energy is in the higher latitudes of the SH.

You may now exit out of the outgoing longwave and outgoing shortwave plots.

30. Go back to the main Panoply window as shown below.



31. Click on **"File"** on the top left of the program and then click on **"Open"**. Locate the Net_Energy.nc file you saved in your downloads earlier and open it in Panoply.
This dataset provides average monthly values of net energy at the top of the atmosphere (TOA). Net energy is described by comparing the total amount of outgoing energy and the total amount of incoming energy. A formula to calculate Earth's net energy is:

Net Energy = Incoming – Outgoing Shortwave – Outgoing Longwave

Q26. Briefly summarize the data that is available in the Net_Energy.nc dataset.

Average monthly values of net energy for the globe at the top of the atmosphere.

32. Click on the variable titled **“toa_net_all_mon”** and then click on **“Create Plot”** at the top left of Panoply. When prompted, click **“Create”**.

33. You are now viewing average net energy in W/m^2 for the month of March 2000.

Q27. Describe the general regions that have the greatest and least net energy at the top of Earth’s atmosphere in March 2000.

Greatest: **The greatest net energy is near the equatorial regions.**

Least: **The least net energy is near the higher latitudes of both the NH and SH.**

34. Change the white time box value to “4” and press enter to show net energy values for June 2000.

Q28. Describe the general regions that have the greatest and least net energy at the top of Earth’s atmosphere in June 2000.

Greatest: **The greatest net energy is in the NH.**

Least: **The least net energy is near the higher latitudes of the SH.**

Q29. How did the net energy change from March 2000 to June 2000?

The net energy shifted northward to greater values in the NH.

Q30. During June, the start of the Northern Hemisphere Summer, there is a higher amount of incoming solar energy (insolation) in the higher latitudes of the Northern Hemisphere (this can be verified by opening the **“solar_mon”** variable in the **Insolation.nc** dataset in Panoply, and changing the month to June 2000). Why do locations at the higher latitudes, such as Greenland, have a negative net amount of energy? Use the energy budget formula provided in Step #31 in order to specify which component of the budget has the greatest impact on net energy.

Although Greenland is experiencing a greater amount of insolation in June, the high albedo of the surface of Greenland leads to a greater amount of outgoing shortwave, resulting in a negative net energy.

Elaborate & Evaluate Questions

Q31. Predict how you would expect the amount outgoing longwave energy over equatorial regions to change in the future as average global temperatures on Earth continue to warm. Explain your prediction.

Prediction: **The amount of outgoing longwave energy would decrease over the equatorial regions.**

Explanation: **As Earth continues to warm, greenhouse gases, including water vapor, are expected to be higher, which will trap the outgoing longwave energy in Earth’s atmosphere. This will reduce the amount of energy leaving the atmosphere going towards space. Although the amount of longwave energy might increase, the energy will not be outgoing since it will be absorbed in Earth’s atmosphere.**

Q32. Predict how you would expect net energy over Greenland to change in the future as the ice sheets in Greenland are expected to melt. Explain your prediction using the terms longwave and shortwave energy.

Prediction: **Net energy over Greenland will increase**

Explanation: **As the ice sheets melt, albedo in Greenland will decrease, leading to more absorption of insolation in the summer months. The decrease in outgoing shortwave energy will allow the net energy to increase.**

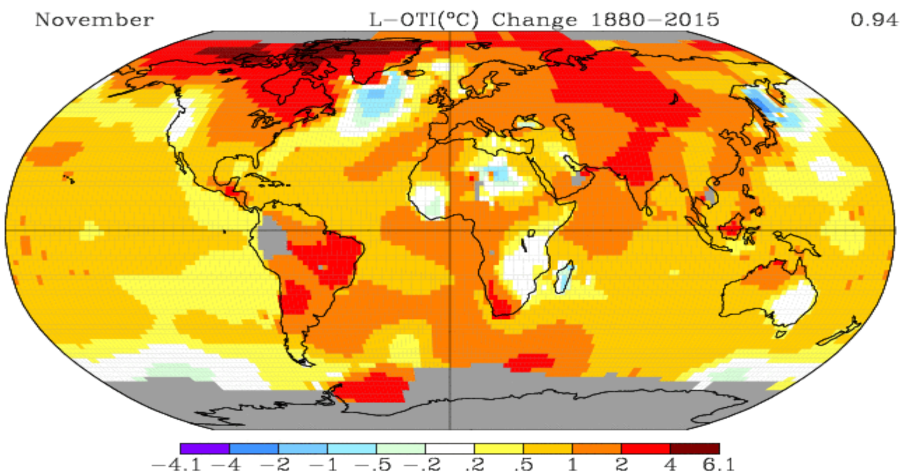
F. Conclusion and overview of linkages to next lesson and unit goals.

In this lesson the students analyzed four different components of Earth's energy budget formula in order to determine how the contribution of each component varies based on latitude and season. The students used NASA GISS Panoply software to analyze datasets from the NASA CERES satellite mission. In the next lesson, the students will learn how to write a code in the R language using Rstudio in order to analyze dataset values from specific latitude and longitude coordinates. Specifically, the students will learn how to read netCDF data into Rstudio, extract variables of interest, and extract data values based on a given time slice and grid box. The goal is to teach students how to use Rstudio to analyze data from the NASA CERES satellite (as an alternative to Panoply) in order to prepare for the culminating project of this unit. During the project, the students will use CERES data and Rstudio to balance the energy budget for specific locations on Earth.

National Aeronautics and Space Administration
Goddard Institute for Space Studies
New York, N.Y.

NASA Goddard Institute for Space Studies (GISS)
Climate Change Research Initiative (CCRI)
Applied Research STEM Curriculum Unit Portfolio

Unit Title: Earth's Energy Budget
Lesson #3 Title: Learning RStudio for NASA CERES Data Analysis
NASA STEM Educator / Associate Researcher: Nicole Dulaney
NASA PI / Mentor: Dr. Allegra LeGrande
NASA GSFC Office of Education – Code 160



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VII. Lesson 3: Title: Learning RStudio for NASA CERES Data Analysis

A. Summary and Goals of Lesson

The goal of this lesson is for the students to learn how to write a code in RStudio. RStudio is a program that utilizes the R programming language, which is used for data analysis. The students will first learn how to write a code that assigns variables to numerical values so simple operations such as addition and subtraction can be performed. The students will also learn how to compute the mean of a group of numbers. The students will then learn how to write a second code that will load in netCDF data. In lesson #2 of this unit, the students downloaded four netCDF datasets from the NASA CERES satellite. The students will learn how to load the Insolation.nc dataset from lesson #2 into RStudio so data analysis can be performed on the insolation data. The students will also learn how netCDF datasets and climate models use grid boxes to describe locations rather than latitude and longitude values. Each grid box corresponds to specific latitude and longitude coordinates and the students are provided with a data table that allows them to associate specific grid box values to latitude and longitude values. The students will end the lesson evaluating how a changing latitude or changing longitude influences insolation values at the top of Earth's atmosphere through data analysis in RStudio.

Students need to learn how to use RStudio in this lesson so they can successfully complete the capstone project in lesson #4. The students will be using RStudio and the energy budget formula that was evaluated in lessons #1 and #2 to calculate the net energy at the top of Earth's atmosphere for different locations on Earth.

B. Table of Contents for lesson

A. Summary and Goals of Lesson **82**
B. Table of Contents for lesson **82**
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D. Content template: **87**
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F. Conclusion and overview of linkages to next lesson and unit goals. **113**

C. 5 E lesson model template:

STEM Earth Science Research

Unit: Earth's Energy Budget **Topic**: Learning RStudio for NASA CERES Data Analysis

Prior Learning: For success in this lesson, the students need to have an understanding of the contents of the four netCDF datasets from the NASA CERES satellite from the previous lesson that included incoming solar radiation, outgoing longwave energy, outgoing shortwave energy, and net energy data. Each dataset represented a different component of Earth's energy budget formula and the students analyzed each dataset through the NASA GISS software Panoply. Today the students will begin a lesson to learn how to write a code in RStudio in order to ultimately use RStudio to also analyze the NASA CERES data and calculate the energy budget for different locations on Earth in the next lesson.

Do Now (Pre-Assessment):

1. Predict the relationship that exists between ***latitude*** and incoming solar radiation the top of Earth's atmosphere during an equinox.

2. Predict the relationship that exists between ***longitude*** and incoming solar radiation the top of Earth's atmosphere during an equinox.

Aim: How can we write a code and analyze data in RStudio?

New York State Standards:

1.1f - Earth's changing position with regard to the Sun and the moon has noticeable effects.

- Earth revolves around the Sun with its rotational axis tilted at 23.5 degrees to a line perpendicular to the plane of its orbit, with the North Pole aligned with Polaris.
- During Earth's one-year period of revolution, the tilt of its axis results in changes in the angle of incidence of the Sun's rays at a given latitude; these changes cause variation in the heating of the surface. This produces seasonal variation in weather.

2.2a - Insolation (solar radiation) heats Earth's surface and atmosphere unequally due to variations in:

- the intensity caused by differences in atmospheric transparency and angle of incidence which vary with time of day, latitude, and season
- characteristics of the materials absorbing the energy such as color, texture, transparency, state of matter, and specific heat
- duration, which varies with seasons and latitude.

Next Generation Science Standards:

HS - ESS2-4 - Use a model to describe how variations in the flow of energy into and out of Earth's systems result in changes in climate.

HS - ESS3-5 - Analyze geoscience data and the results from global climate models to make an evidence-based forecast of the current rate of global or regional climate change and associated future impacts to Earth systems.

Common Core State Standards:

CCSS: 9-10.RST.3 - Follow precisely a multistep procedure when carrying out experiments, taking measurements, or performing technical tasks.

CCSS: 9-10.RST.7 - Integrate and evaluate multiple sources of information presented in diverse formats and media (e.g., quantitative data, video, multimedia) in order to address a question or solve a problem.

NASA System Engineering Behavior:
Technical Acumen:
1a. Possesses Technical Competence and Has Comprehensive Previous Experience
1b. Learns from Successes and Failures
Problem Solving & Systems Thinking:
2a. Thinks Systematically
2b. Possess Creativity and Problem Solving Abilities

Performance Objective: Students will be able to write a code in RStudio that loads and displays netCDF insolation data from the NASA CERES satellite by completing a step-by-step guide that shows students how to perform calculations and other analyses in RStudio.

Materials: NASA CERES Satellite data; Rstudio; Class set of computers

NASA CERES Satellite Data: https://iridl.ldeo.columbia.edu/SOURCES/.NASA/.ASDC-DAAC/.CERES/.EBAF-TOA/.Ed2p8/?Set-Language=en

RStudio Download Link: https://www.rstudio.com/products/rstudio/download/

Vocabulary: Insolation; Incoming energy (shortwave); Outgoing energy (longwave)

Anticipatory Opening: Discuss with the students what a climate model is and how climate scientists write codes to make data analysis more efficient.

Development of the Lesson: **Approximately Three to Four-Day Lesson (Three to four 50-minute periods).**

What the teacher does	What the student does	Time
1. Write down the Do Now, Aim, and the HW on the blackboard.		
2. Circulate the room while the students complete the Do Now questions. Determine how much prior knowledge the students have about the relationship between latitude and longitude and insolation.	The students answer the Do Now questions in their notebooks to determine how much prior knowledge they have regarding the relationship between latitude and longitude and insolation.	**5 min**

The questions will also assess student's ability to predict how insolation is dependent on latitude and longitude. ***Assessment Opportunity #1 (Student prior knowledge from previous units)***		
3. ENGAGE Discuss how scientists use climate models and coding to efficiently analyze an abundant amount of data.	The students learn how scientists use climate models and coding to efficiently analyze an abundant amount of data.	**10 min**
4. EXPLORE & EXPLAIN Introduce the students to RStudio. Circulate the room as the students complete the guided activity that shows them how to write a code and perform calculations in RStudio. Look for common challenges and misconceptions in the guided activity. ***Assessment Opportunity #2 (Student discussions about the RStudio guided activity).*** ***Assessment Opportunity #3 (Student answers to the RStudio guided activity).***	The students begin the RStudio guided activity by learning how to write a code. The students perform simple operations in RStudio such as addition, subtraction, and calculating the mean. The students learn how to load a netCDF dataset into RStudio, specifically the Insolation.nc dataset that was downloaded in lesson #2 of this unit. The students learn how climate models and climate datasets use grid boxes in place of latitude and longitude coordinates. The students analyze the contents of the Solar_mon variable of the Insolation.nc dataset.	**Two to Three class periods**
5. ELABORATE & EVALUATE Circulate the room as the students use RStudio to answer the Elaborate and Evaluate questions at the end of the RStudio guided activity. ***Assessment Opportunity #4(Student answers to the elaborate & evaluate questions)***	The students use the RStudio Console to evaluate the relationship between latitude and insolation when longitude and time are kept constant. The students use the RStudio Console to evaluate the relationship between longitude and insolation when latitude and time are kept constant.	**15 min**
6. Administer the Daily Formative Assessment (DFA) to the students. This DFA will show whether the students learned from/expanded on their answers to the Do Now. ***Assessment Opportunity #5 (Student answers to the DFA).***	The students individually answer questions for the Daily Formative Assessment. The students will submit their answers at the end of class.	**10 min**

Summary/Conclusion: The students individually answer questions for the Daily Formative Assessment. The students will submit their answers at the end of class.

Higher Order Questions:

See the Elaborate & Evaluate questions at the end of the RStudio guided activity.

Differentiated Instruction:
- The students are exposed to content in written, oral, and visual forms (multiple modalities exist).
- Students can use colored pencils to draw diagrams and annotate notes in a way that is meaningful to them.
- Students are asked both higher and lower level questions so all students can answer questions at their particular academic level.
- Students are given time to answer questions during think pair share/group activities.

Daily Formative Assessment:

1. During the month of March, how does a location's latitude influence the amount of insolation at the top of Earth's atmosphere?

2. During the month of March, how does a location's longitude influence the amount of insolation at the top of Earth's atmosphere?

Next Lesson: The next lesson the students will use their new knowledge of RStudio to engage in a small project where they use RStudio to calculate Earth's energy budget for different locations on Earth's surface based on the four NASA CERES datasets downloaded in lesson #2 (incoming solar radiation, outgoing longwave energy, outgoing shortwave energy, and net energy).

For Further Exploration:

Continue changing the parameters for the Solar_mon variable in the Console in RStudio to determine how the time of year (month) impacts insolation for different latitude and longitude grid boxes on the surface of the Earth.

Notes For Revision:

National Aeronautics and Space Administration
Goddard Institute for Space Studies
New York, N.Y.

D. Content template:

NGSS Standard: **HS - ESS2-4 -** Use a model to describe how variations in the flow of energy into and out of Earth's systems result in changes in climate. **HS - ESS3-5 -** Analyze geoscience data and the results from global climate models to make an evidence-based forecast of the current rate of global or regional climate change and associated future impacts to Earth systems.	**State Earth Science Content Standard:** **1.1f** - Earth's changing position with regard to the Sun and the moon has noticeable effects. • Earth revolves around the Sun with its rotational axis tilted at 23.5 degrees to a line perpendicular to the plane of its orbit, with the North Pole aligned with Polaris. • During Earth's one-year period of revolution, the tilt of its axis results in changes in the angle of incidence of the Sun's rays at a given latitude; these changes cause variation in the heating of the surface. This produces seasonal variation in weather. **2.2a** - Insolation (solar radiation) heats Earth's surface and atmosphere unequally due to variations in: • the intensity caused by differences in atmospheric transparency and angle of incidence which vary with time of day, latitude, and season • characteristics of the materials absorbing the energy such as color, texture, transparency, state of matter, and specific heat • duration, which varies with seasons and latitude.	**Common Core Standard:** **CCSS: 9-10.RST.3** - Follow precisely a multistep procedure when carrying out experiments, taking measurements, or performing technical tasks. **CCSS: 9-10.RST.7** - Integrate and evaluate multiple sources of information presented in diverse formats and media (e.g., quantitative data, video, multimedia) in order to address a question or solve a problem.	**NASA Science:** Earth: Earth's Energy Budget
Content Area: Earth & Space Sciences **Grade Level:** High School	**Name of Project-Based Activity or Theme:** Learning RStudio for NASA CERES Data Analysis	**Estimated Time Frame to Complete (days/weeks):** Lesson #3 = Three to Four 50-minute class periods	
Overall Investigation Question(s): How can we write a code and analyze data in RStudio?			
Overall Project Description/Activity: Students will be able to write a code in RStudio that loads and displays netCDF insolation data from the NASA CERES satellite by completing a step-by-step guide that shows students how to perform calculations and other analyses in RStudio.			

Materials Needed to Complete Project (put N/A as needed): NASA CERES Satellite data; Rstudio; Class set of computers	**Stakeholders:** 1. Earth & space science educators 2. Earth & space science students 3. Students engaged in science research 4. NYCDOE 5. NASA	**Hyperlinks Used:** **Visit the hyperlinks in the following order in the lesson:** 1. NASA CERES Satellite Data: https://iridl.ldeo.columbia.edu/SOURCES/.NASA/.ASDC-DAAC/.CERES/.EBAF-TOA/.Ed2p8/?Set-Language=en 2. RStudio Download Link: https://www.rstudio.com/products/rstudio/download/	**Multimedia/Technology:** Website links: 1. NASA CERES Satellite Data: https://iridl.ldeo.columbia.edu/SOURCES/.NASA/.ASDC-DAAC/.CERES/.EBAF-TOA/.Ed2p8/?Set-Language=en 2. RStudio Download Link: https://www.rstudio.com/products/rstudio/download/	**Classroom Equipment:** Computers; Highlighters; Calculators

NASA System Engineering Behaviors (2 behaviors per category)	**Category**	**Activities** **How will student model engineering behaviors when learning science content?** **Describe student activities here.**	**Student Outcomes** **How will you assess learning for each behavior:**	**Evaluation** **Describe specific science content students understand as a result of engineering behavior.**
1a. Possesses Technical Competence and Has Comprehensive Previous Experience 1b. Learns from Successes and Failures 2a. Thinks Systematically 2b. Draws on Past Experiences	1. Technical Acumen 2. Problem solving & systems thinking	1a&b. The students will learn how to write a code in RStudio with the ultimate goal of loading and analyzing netCDF data into RStudio for further analysis. Here, the students will demonstrate an understanding of engineering principles and computer programming in order to be able to analyze climate data from the NASA CERES satellite in a more efficient way. The students will then share their experiences and learn from their successes and failures by evaluating how their answer to the Do Now changed from the beginning of the activity when they answer the Daily Formative Assessment. 2a. The students will learn how to write a code in RStudio with the ultimate goal of loading and analyzing netCDF data into RStudio for further analysis. The students will look across the entire Earth system in order to determine through RStudio how a changing latitude or longitude can influence insolation values at the top of Earth's atmosphere. 2b. The students will use their knowledge of Earth's energy budget from the previous lesson in order to learn how to use RStudio through the example Insolation.nc dataset.	1a&b. Students will be assessed based on their answers to the RStudio guided activity. Students will be assessed based on their elaborate & evaluate questions at the end of the RStudio activity. Students will also be assessed based on their answers to the Do Now and Daily Formative Assessment questions. 2a&b. Students will be assessed based on their answers to the RStudio guided activity. Students will be assessed based on their elaborate & evaluate questions at the end of the RStudio activity. Students will also be assessed based on their answers to the Do Now and Daily Formative Assessment questions.	1a&b. Students will be able to evaluate how latitude and longitude each play a role in influencing the insolation reaching the top of Earth's atmosphere during the march equinox. 2a&b. Students will be able to evaluate how latitude and longitude each play a role in influencing the insolation reaching the top of Earth's atmosphere during the march equinox.
List and attach all supportive documents for instructional activities.	Attachments? (circle) **Yes** or No	**List Attached Documents (if any):** 1. RStudio Download Instructions 2. Using RStudio Guided Activity: Earth's Energy Budget		
List and attach all rubrics for activity and assessment evaluation.	Attachments? (circle) Yes or **No**	**List Attached Rubrics (if any):** None in this lesson.		
Include comments or questions here:				

E. Supporting Documents: (order according to sequence of lesson)

RStudio Download Instructions

1. In order to download RStudio, the computer must have a program called R installed first. To download R, go to the following link: https://cran.rstudio.com/ and you should see the following:

The Comprehensive R Archive Network

Download and Install R

Precompiled binary distributions of the base system and contributed packages, **Windows and Mac** users most likely want one of these versions of R:

- Download R for Linux
- Download R for (Mac) OS X
- Download R for Windows

R is part of many Linux distributions, you should check with your Linux package management system in addition to the link above.

Choose the download option based on the computer you have.

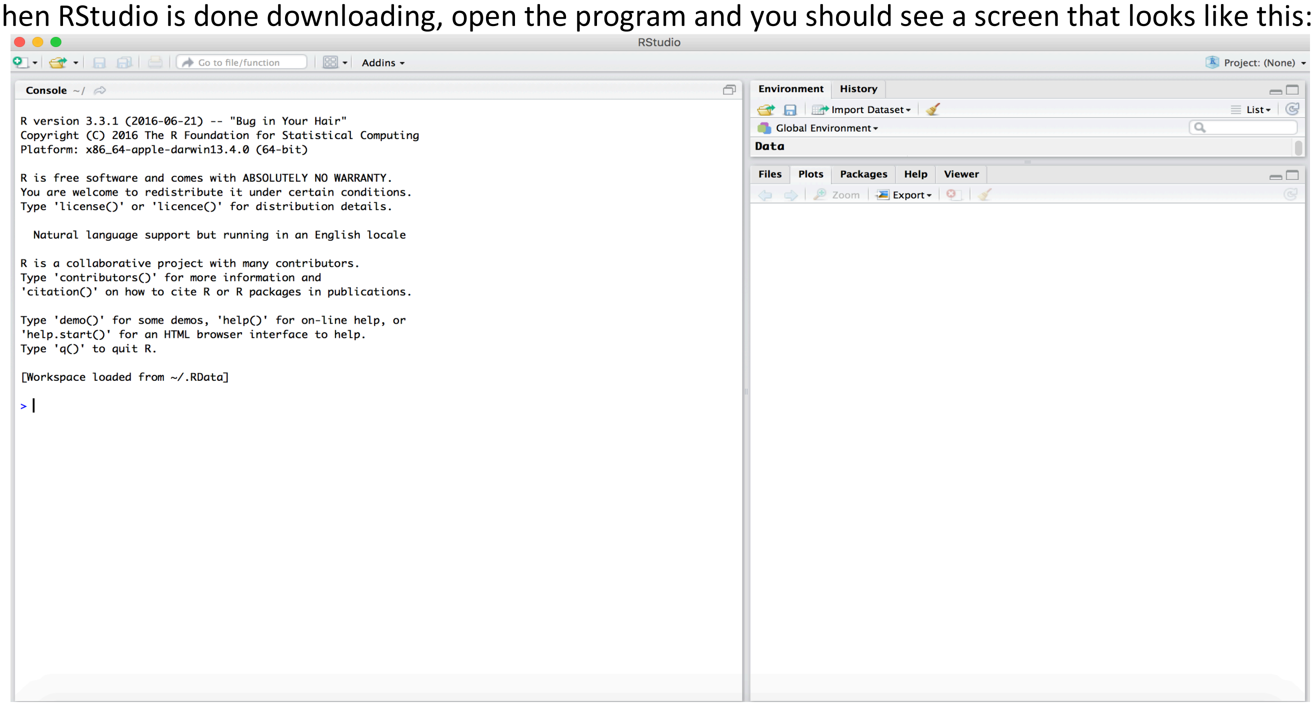
2. Once R is downloaded and installed, go to the following link:
https://www.rstudio.com/products/rstudio/download/

Scroll down to the section on the page titled **Installers for Supported Platforms** and focus on the section labeled **Installers** as shown below:

Installers	Size	Date	MD5
RStudio 1.0.136 - Windows Vista/7/8/10	81.9 MB	2016-12-21	93b3f307f567c33f7a4db4c114099b3e
RStudio 1.0.136 - Mac OS X 10.6+ (64-bit)	71.2 MB	2016-12-21	12d6d6ade0203a2fcef6fe3dea65c1ae
RStudio 1.0.136 - Ubuntu 12.04+/Debian 8+ (32-bit)	85.5 MB	2016-12-21	0a20fb89d8aaeb39b329a640ddadd2c5
RStudio 1.0.136 - Ubuntu 12.04+/Debian 8+ (64-bit)	92.1 MB	2016-12-21	2a73b88a12a9fbaf96251cecf8b41340
RStudio 1.0.136 - Fedora 19+/RedHat 7+/openSUSE 13.1+ (32-bit)	84.7 MB	2016-12-21	fa6179a7855bff0f939a34c169da45fd
RStudio 1.0.136 - Fedora 19+/RedHat 7+/openSUSE 13.1+ (64-bit)	85.7 MB	2016-12-21	2b3a148ded380b704e58496befb55545

Click on the option based on the computer that you have.

3. When RStudio is done downloading, open the program and you should see a screen that looks like this:



National Aeronautics and Space Administration
Goddard Institute for Space Studies
New York, N.Y.

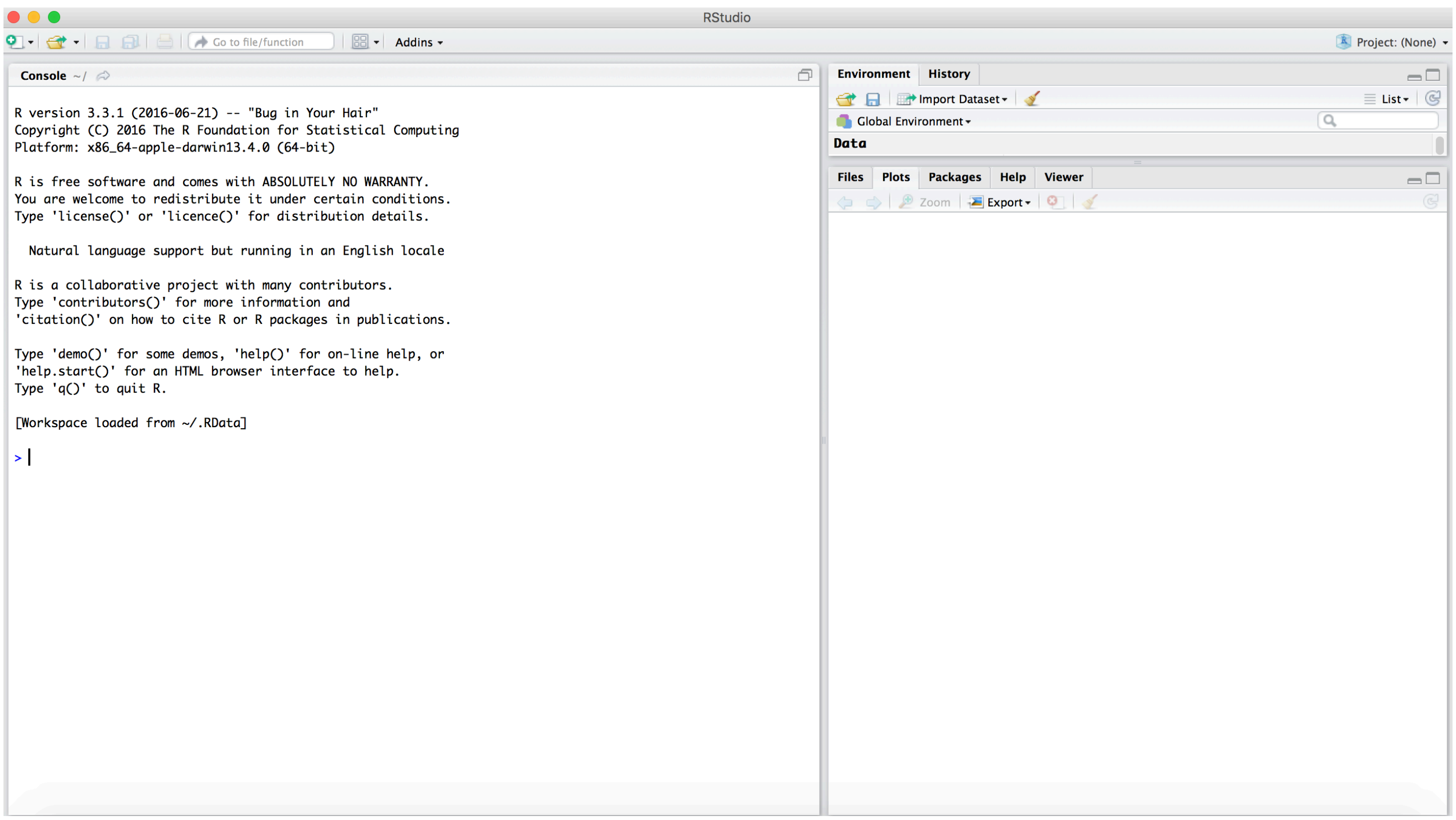
Using RStudio Guided Activity: Earth's Energy Budget

Activity Description: The purpose of this activity is for the students to learn how to write a code in RStudio. The students will first learn how to perform simple calculations such as addition and subtraction. The students will then learn about commands and arguments in RStudio, such as the command to calculate the mean of a dataset. Finally, the students will learn how to load netCDF data into RStudio for further data analysis.

NOTE: Lesson #2 titled ***Analyzing NASA CERES Energy Budget Data*** needs to be completed prior to this activity. Teachers and students need to have the CERES datasets used in lesson #2 already downloaded onto the computer.

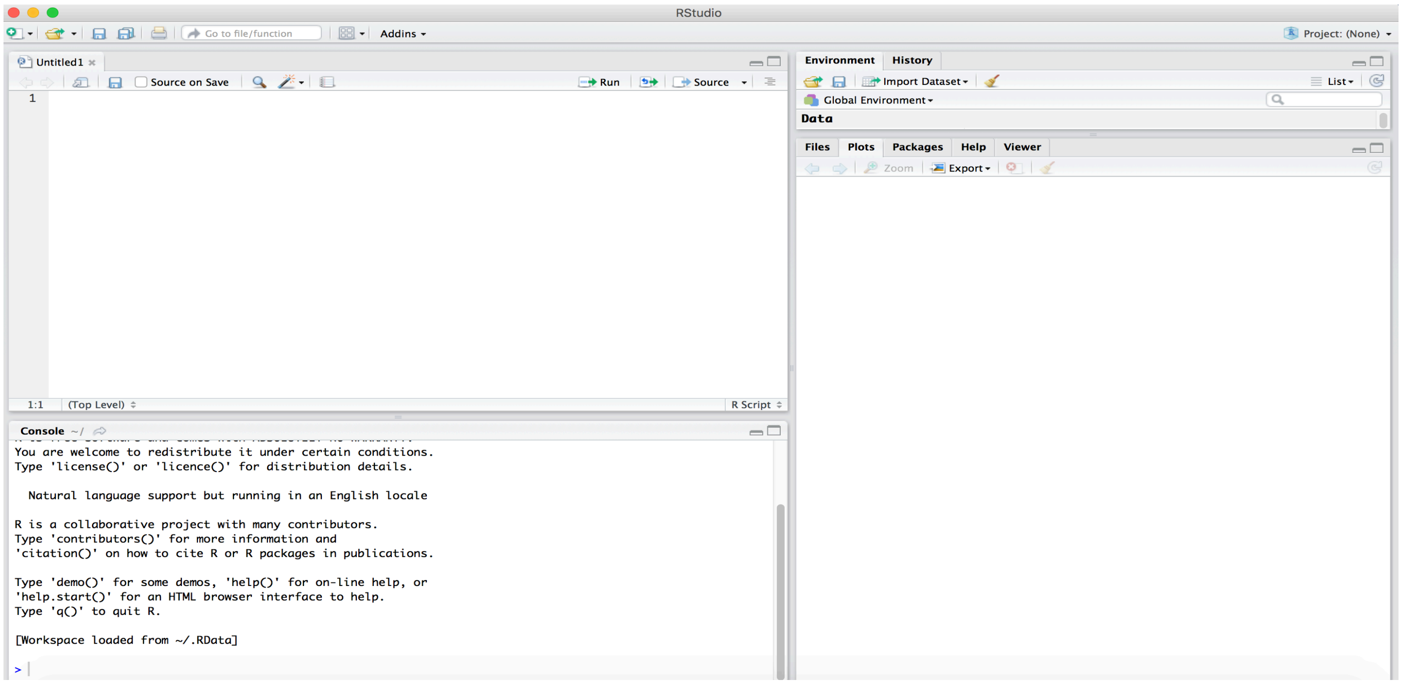
1. Ensure that Rstudio is installed on your computer. If RStudio is not downloaded on your computer, please view the download instructions provided before this activity.

2. Open RStudio and you will see a screen that looks like this.



3. At the top left of Rstudio, click on **File**, then **New File,** and then click **R Script**.

4. You should now see the following on your screen:



5. The ***top left panel*** of RStudio contains the **R Script** that will be used to write code with the R programming language. Once a script is created, a user can run the entire script or run the script line by line or section by section.

The ***bottom left panel*** of RStudio contains the **Console** which displays the lines of code that the user selects to run. Users can also type commands and perform calculations directly in the **Console** for a quick answer rather than writing a script and waiting for an answer after running the script.

The ***top right side*** of RStudio contains an **Environment tab** which lists all of the datasets that have been loaded into RStudio. There is also a **History tab** that contains the history of everything that was typed into the **Console**.

The ***bottom right side*** of RStudio contains a **Plot tab** that allows users to look at any plots that are created. There is a **Packages tab** that allows users to download packages that are needed for specific R tasks, and there is a **Help tab** that allows users to search how to use specific commands in R.

6. The next few steps are designed to help users become familiar with coding and the R programming language.

7. You will start working in the R Script you opened in step #3. Most coders (individuals who write code) begin the code by writing at the top of the script what the code will be about. The description of the code needs to be "commented out", which means the writing will not be part of the code when the code is later running.

In the R language, the symbol "#" needs to be placed in the beginning of each line of the code that is meant to be commented out. For example:

#This statement is written to teach students how to comment out a line in a R code.

Later when the code you write is running, RStudio will not include any line that is commented out in the calculations or procedures you are performing in your code.

8. Let's begin writing your first line of code! In the R Script, write the following comment on line #1:

#This code will teach students how to perform basic functions in RStudio. Students will learn how to add, subtract, and calculate the mean (average) of a dataset.

On line #2, write:

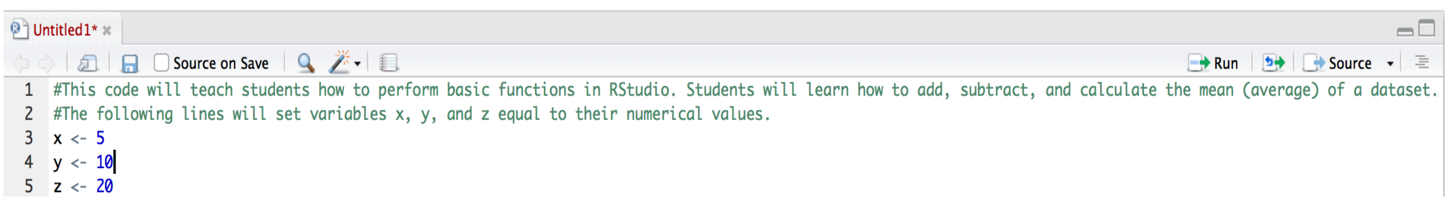
#The following lines will set variables x, y, and z equal to their numerical values.

Please note in RStudio, any commented out line will be in a light green color.

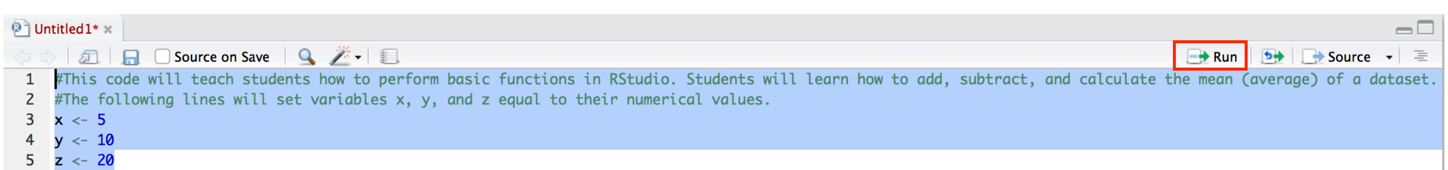
9. On the next line (line #3), type x <- 5 (In R, **<-** is equivalent to **=**) This is setting the x variable equal to the number 5.

10. On line #4, type y <- 10 and on line #5, type z <- 20

11. Your R Script should now look like the script displayed below:



12. Using your cursor, highlight the first five lines in the code as shown below. Then, click the "Run" button as outlined below.



Clicking "run" will take all of the lines of code that are highlighted and run it through RStudio.

If you look in the **Console** in the bottom left of R Studio, you will see all of the lines of code you just ran as shown below.

```
Console ~/

Type 'demo()' for some demos, 'help()' for on-line help, or
'help.start()' for an HTML browser interface to help.
Type 'q()' to quit R.

[Workspace loaded from ~/.RData]

> #This code will teach students how to perform basic functions in RStudio. Students will learn how to add, subtract, and calculate the mean (average) of a dataset.
> #The following lines will set variables x, y, and z equal to their numerical values.
> x <- 5
> y <- 10
> z <- 20
```

If you do not see any red error messages, that means your code ran successfully.
Please note that font in the Console is blue in color.

13. Now that you ran the first five lines of your code and that RStudio knows the values of the x, y, and z variables, you can view your data in the **Console**.

In the **Console**, type x and then press enter. By typing x and pressing enter, you are asking RStudio to tell you the value of x, which is 5 based on your code. This process is shown below:

```
> x
[1] 5
> |
```

14. Type y and z into the **Console** as well to make sure the variables have the values you assigned in the code.

15. Go to your R Script and add a comment on line #7 as written below:

#The following lines will teach you how to perform mathematical operations in RStudio

16. Go to line #8 in the script and type A <- x + y + z

This operation sets variable A equal to the value of x + y +z. You can use any variable name to set equal to x + y + z. The letter A was chosen as an example and can be interchanged with anything the coder would like.

Your R Script should now look like this:

```
PracticingRStudio.R ×
Source on Save                                   Run    Source
1  #This code will teach students how to perform basic functions in RStudio. Students will learn how to add, subtract, a
2  #The following lines will set variables x, y, and z equal to their numerical values.
3  x <- 5
4  y <- 10
5  z <- 20
6
7  #The following line will teach you how to perform mathematical operations in RStudio.
8  A <- x + y + z
```

17. Highlight lines 7 and 8 in the script and press Run. Now RStudio has the data and calculations you coded for in those two lines.

Make sure there are no red error messages in the **Console**.

18. In the **Console**, type A and then enter to see the value of x + y + z. The value of 35 should appear after you press enter, as shown below.

```
> #The following line will teach you how to perform mathematical operations in RStudio.
> A <- x + y + z
> A
[1] 35
>
```

19. There are tasks you can perform in the **Console** without running your code. Since RStudio already knows the values of x, y, and z, you can perform calculations directly in the **Console**.

Type x + z in the **Console** and then press enter. You should see a value of 15.

Type z – y in the **Console** and then press enter. You should see a value of 10. You can also set z – y equal to a variable, such as B. Type B <- z – y in the **Console** and then press enter. Then, type B and then press enter. The value of z – y will appear.

*Please note that RStudio is case sensitive, which means capital and lower case letters matter. For example, after typing B <- z – x in the **Console**, upper case B needs to be used because lower case b will not work. This is demonstrated in the image below.

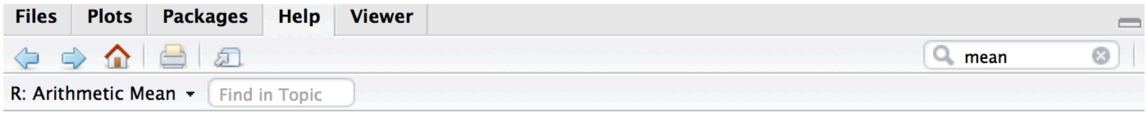
```
> B <- z - y
> b
Error: object 'b' not found
> B
[1] 10
```

20. Go to line #10 and type the following comment:

#The following line will teach you how to find the mean (average) of a group of numbers.

21. You will now learn about commands and arguments in RStudio. Commands can help users accomplish tasks or calculations that are not simple addition and subtraction.

We will now learn how to use the ***mean*** command. To learn how to use a specific command, go to the right side of RStudio and click on the "**Help**" tab. In the search bar to the right of the "**Help**" tab, type mean, and then press enter. You should now see the following screen:



mean {base} R Documentation

Arithmetic Mean

Description

Generic function for the (trimmed) arithmetic mean.

Usage

```
mean(x, ...)

## Default S3 method:
mean(x, trim = 0, na.rm = FALSE, ...)
```

Arguments

`x`	An R object. Currently there are methods for numeric/logical vectors and date, date-time and time interval objects. Complex vectors are allowed for `trim = 0`, only.
`trim`	the fraction (0 to 0.5) of observations to be trimmed from each end of `x` before the mean is computed. Values of trim outside that range are taken as the nearest endpoint.
`na.rm`	a logical value indicating whether `NA` values should be stripped before the computation proceeds.
`...`	further arguments passed to or from other methods.

Under the **Usage** section, RStudio shows users how to use the command.

All commands, like the mean command, are written with the name of the command followed by parentheses. Inside the parentheses are **arguments** that can be used along with the command. The structure of the mean command is provided below:

mean(x, ...)

The first argument inside the parentheses is an object arbitrarily called "x". This <u>specific location after the parentheses is reserved for the name of the dataset you</u> will be calculating the mean of.

In the **Argument** section of the help tab, there are other arguments listed that could be used in the mean command. We will not be using any other arguments today with the mean command.

22. In order to properly use the mean command, the first argument "x" needs to be a dataset consisting of data values. We need to take the values of x, y, and z we inputted earlier **and create one dataset.**

In order to put values into one list or dataset, the command ***c*** is needed. This command takes all of the values that are inputted as arguments and combines them into one list of data values.

Type the following into line #11 of the R Script: Data_xyz <- c(x,y,z)

The ***c*** command is taking the value of x, y, and z and making one list with all three values.

The name **Data_xyz** was chosen as the name of the new dataset containing the values of x, y, and z. Any name can be chosen for the new data set and feel free to change the name. However, it is important to choose a name that makes sense based on your data and your code.

You R Script should now look like this:

PracticingRStudio.R

Source on Save | Run | Source

```
1  #This code will teach students how to perform basic functions in RStudio. Students will learn how to add, subtract, a
2  #The following lines will set variables x, y, and z equal to their numerical values.
3  x <- 5
4  y <- 10
5  z <- 20
6  
7  #The following line will teach you how to perform mathematical operations in RStudio.
8  A <- x + y + z
9  
10 #The following line will teach you how to find the mean (average) of a group of numbers.
11 Data_xyz <- c(x,y,z)
```

23. Highlight the contents of lines 10 and 11 and click **Run**. Once the lines are run successfully and there are no errors in the **Console**, type Data_xyz into the **Console** and press enter to see the dataset you created. You should now see the following in your **Console**:

```
> #The following line will teach you how to find the mean (average) of a group of numbers.
> Data_xyz <- c(x,y,z)
> Data_xyz
[1]  5 10 20
> 
```

24. We will now use the mean command to find the mean (average) of Data_xyz. Finding the mean is the same as finding the average of a group of numbers.

Type the following into line #12 of the R Script: Mean_Data_xyz <- mean(Data_xyz)

The name Mean_Data_xyz was chosen to represent the calculated mean of Data_xyz. Data_xyz is the first and only argument of the mean command.

*Remember, you can change the names of the name representing the mean calculation and the dataset to whatever you like.

25. Highlight and run line #12 of the R Script.

26. In the **Console**, type Mean_Data_xyz and press enter. You will now see the mean (average) of the x, y, and z values from the dataset is 11.66667.

27. Go to the very top left of RStudio and click on "File", and then click "Save As" to save the file. Name the file PracticingRStudio.R

The .R extension is needed when saving an R Script.

28. We will now learn how to load netCDF data into RStudio. Open a new R Script by clicking "**File**" at the top left of RStudio, and then click "**New File**", and then "**R Script**".

29. When RStudio is first downloaded, it comes with a default set of commands, such as the command to calculate the mean. To work with netCDF data in Rstudio, users need to install the **ncdf4** library.

Go to the **Console** and type install.packages("ncdf4") and then press enter. The ncdf4 library package will download in the **Console**.

30. Once a library is downloaded, it does not need to be downloaded again. However, it does need to be referenced at the top of every R Script that uses the ncdf4 library. It is always a great idea to reference the libraries needed in each script at the top of the code.

On line #1 of your R Script, type library(ncdf4). Library is a command in line #1 and there, you are referencing the ncdf4 library with the library command.

31. We will now write a comment in line #2 to describe the purpose of the code. Type the following into line #2:

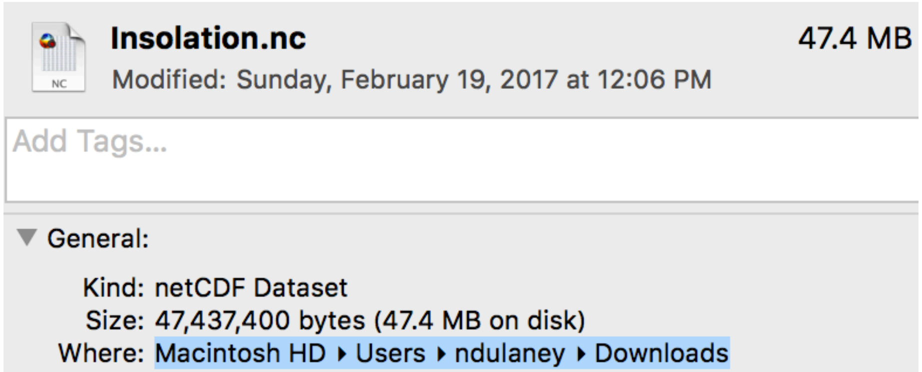
#This code will teach students how to read in data from netCDF files and extract variables from the dataset.

32. We will first learn how to load a dataset into RStudio. The first dataset we will load is the Insolation.nc dataset we used in the previous lesson titled ***Analyzing NASA CERES Energy Budget Data***. This dataset provides values of incoming solar radiation at the top of Earth's atmosphere in W/m^2.

Before we can load the Insolation.nc data into RStudio, we need to know the file pathway. The file pathway describes the location of the file. For example, the file pathway for my Insolation.nc file is **/Users/ndulaney/Downloads/Insolation.nc**

This means the Insolation.nc file is located in the Downloads folder under the ndulaney user.

If your computer is a Mac, to determine the file pathway, you need to right-click on the filename wherever the file is located and then click "**Get Info**". There will be a section named "**General**" and in that section next to the word "**Where**:" you will see the pathway. If you highlight the section as emphasized below, and the copy and paste it into a blank document, the path name will be provided.



When I copy and paste the highlighted section as shown above, the result is **/Users/ndulaney/Downloads**

You will need to add /Insolation.nc to the end of the file path in order to make the pathway complete. A complete file pathway is **/Users/ndulaney/Downloads/Insolation.nc**

If your computer is a PC, to determine the file pathway, you need to right-click on the filename wherever the file is located and then click "**Properties**". Find where it says **"Location:"** and after location is the file pathway. Highlight the pathway and copy and paste it into a document. The result **could be** a pathway such as **C:\Users\ndulaney\Downloads**

You will need to add \Insolation.nc to the end of the file path in order to make the pathway complete. You will also need to change all of the \ to /. A complete and correct file pathway example for a PC is **C:/Users/ndulaney/Downloads/Insolation.nc**

33. Once you know the pathway of the Insolation.nc file, you are ready to load the dataset into RStudio.

In line #4, write the following comment:

#We will now learn how to load a netCDF file into RStudio.

34. We first need to determine what to name the dataset once it is loaded in RStudio. I am choosing to name the dataset **Data_Insolation**, but feel free to name the dataset anything you wish.

In order to load a netCDF file in R, we need to use the **nc_open** command. To learn more about the **nc_open** command, type **nc_open** in the search bar of the **Help** tab on the right side of RStudio. The **nc_open** command uses multiple arguments, but we will only be using the first argument named "**filename**". In this case, filename will be the file pathway we determined in step #32.

In line #5, type the name of the dataset you are choosing and set it equal to the **nc_open** command. An example of what to type is given below:

Data_Insolation <- nc_open("/Users/ndulaney/Downloads/Insolation.nc")

Data_Insolation is the name of the dataset that will be loaded into RStudio, **nc_open** is the command used to open netCDF files, and "/Users/ndulaney/Downloads/Insolation.nc" is the filename pathway for the Insolation.nc file.

Note: Please be aware that you will need to change the file pathway to match the pathway that is specific for you.

Note: You need to keep your filename in quotations as shown in the example above.

35. An example of my R Script is shown below. Remember, your line #5 will look different due to your different file pathway and if you chose to name the loaded dataset something different from my example.

```
1 library(ncdf4)
2 #This code will teach students how to read in data from netCDF files and extract variables from the dataset.
3
4 #We will now learn how to load a netCDF file into RStudio.
5 Data_Insolation <- nc_open("/Users/ndulaney/Downloads/Insolation.nc")
```

36. Highlight the first five lines of code and then click **Run**. Check the **Console** to ensure there are no error messages. If there are no error messages, your **Console** should look similar to this:

```
> library(ncdf4)
> #This code will teach students how to read in data from netCDF files and extract variables from the dataset.
>
> #We will now learn how to load a netCDF file into RStudio.
> Data_Insolation <- nc_open("/Users/ndulaney/Downloads/Insolation.nc")
>
```

If there are error messages, they appear in red font. If there are error messages, it could be due to the fact that the ncdf4 library was not installed correctly, or the file pathway is wrong. It can also be helpful to copy and paste the error message into Google to learn more about your error.

37. The Insolation.nc dataset that was loaded into RStudio is now called **Data_Insolation.** We now need to extract the variable from the dataset that we want to explore. In order to determine the proper name of the variable in the dataset, we can use a command in RStudio called **names.**

In the **Console**, type names(Data_Insolation$var) and press enter. This will provide the name of the variable in the Data_Insolation dataset. The variable named **solar_mon** should appear in the **Console** as shown below:

```
> #We will now learn how to load a netCDF file into RStudio.
> Data_Insolation <- nc_open("/Users/ndulaney/Downloads/Insolation.nc")
> names(Data_Insolation$var)
[1] "solar_mon"
```

Note: If you named the dataset something other than Data_Insolation, you will need to use that name instead of Data_Insolation when using the names command.

38. We will now learn how to extract the **solar_mon** variable from **Data_Insolation**. Type the following comment in line #7:

#We will now learn how to extract a variable from a dataset.

In order to extract a variable from a dataset, we need to use the command **ncvar_get.** To learn more about this command, go to the **Help** tab on the right ride of RStudio and in the search bar type **ncvar_get** and press enter.

In the **ncvar_get** command, the first argument is named **nc**, which is the netCDF dataset we loaded in line #5 of the code. The first argument we will type in the **ncvar_get** command is **Data_Insolation.** The second argument for **ncvar_get** is called **varid**, which is the name of the variable we want to extract, **solar_mon**.

When you are extracting the **solar_mon** variable with the **ncvar_get** command, you need to set the extracted variable equal to a name. I will name the extracted variable **Solar_mon** to be consistent with the actual name of the variable.

In line #8 of the code, type Solar_mon <- ncvar_get(Data_Insolation, "solar_mon")

***Remember that R is case sensitive! Uppercase and lowercase letters matter and you need to pay special attention to this!**

Your R Script could now look like this:

PracticingNetCDF.R

Source on Save — Run — Source

```
1 library(ncdf4)
2 #This code will teach students how to read in data from netCDF files and extract variables from the dataset.
3
4 #We will now learn how to load a netCDF file into RStudio.
5 Data_Insolation <- nc_open("/Users/ndulaney/Downloads/Insolation.nc")
6
7 #We will now learn how to extract a variable from a dataset.
8 Solar_mon <- ncvar_get(Data_Insolation,"solar_mon")
```

39. Highlight lines 7 and 8 and click **Run.** Check the **Console** to ensure there are no error messages. If there is an error message, the most likely error is due to a typo in the **varid** argument of the **ncvar_get** command.

40. We now need to figure out how many dimensions are in the dataset. In the **Console**, type dim(Solar_mon) and press enter. Your **Console** should look like the following:

```
> Solar_mon <- ncvar_get(Data_Insolation,"solar_mon")
> dim(Solar_mon)
[1] 360 180 183
>
```

The command **dim** provides the number of dimensions and the amount in each dimension. The result of dim(Solar_mon) is **360 180 183**. This means there are three dimensions in the dataset.

- The first dimension represented by 360 is longitude, which means there are 360 longitude values in **Solar_mon.**
- The second dimension represented by 180 is latitude, which means there are 180 latitude values in **Solar_mon.**
- The third dimension represented by 183 is time, which means there are 183 time values in **Solar_mon.**

If you multiply 360 x 180 x 183, the result is 11,858,400. This means there are 11,858,400 data values in Solar_mon.

41. Data in the form of netCDF (which is the format for most climate-related datasets) is structured in terms of grid boxes. For example, for the **Solar_mon** variable, there are 360 longitude grid boxes and 180 latitude grid boxes that span the entire surface of the Earth.

Each grid box is assigned a data value from **Solar_mon** which corresponds to a specific latitude and longitude value measured in degrees. The following will help explain how grid box values correspond to specific latitude and longitude values.

Longitude: There are 360 longitude grid boxes in variable **Solar_mon**. In reality, there are 180 east longitudes and 180 west longitudes, which corresponds to a total 360 degrees of longitude on Earth. This means that each grid box in **Solar_mon** consists of data representing 1 degree of longitude. In this dataset, longitude values start at a value of 0.5 degrees east and increase by a value of 1 degree for each grid box. For example, longitude grid box #1 represents a **Solar_mon** value at 0.5 degrees east longitude, grid box #2 represents a **Solar_mon** value at 1.5 degrees east longitude, grid box #3 represents a value at 2.5 degrees east longitude, etc.

Latitude: There are 180 latitude grid boxes in variable **Solar_mon**. In reality, there are 90 north latitudes and 90 south latitudes, which corresponds to a total of 180 degrees of latitude on Earth. This means that each grid box in **Solar_mon** consists of data representing 1 degree of latitude. In this dataset, latitude values start at a value of -89.5 degrees north (which is equivalent to 89.5 degrees south). Latitude values increase by a value of 1 degree for each grid box. For example, latitude grid box #1 represents a **Solar_mon** value at -89.5 degrees north latitude, grid box #2 represents a **Solar_mon** value at -88.5 degrees north latitude, grid box #3 represents a value at -87.5 degrees north latitude, etc.

42. There are 183 time components of the **Solar_mon** variable. Time component #1 corresponds to **Solar_mon** data from March 2000, time component #2 corresponds to **Solar_mon** data from April 2000, time component #3 corresponds to **Solar_mon** data from May 2000, etc. The last time component 183 corresponds to May 2015.

On the next few pages, there is a data table that provides longitude, latitude and time grid box numbers that correspond to the actual longitude and latitude measurements in degrees and time value in month and year format.

Data Table for Longitude, Latitude, and Time Grid Boxes

Please note that positive longitudes represent degrees east and negative longitudes represent degrees west.
Please note that positive latitudes represent degrees north and negative latitudes represent degrees south.

Longitude Grid Box #	Longitude in °	Latitude Grid Box #	Latitude in °	Time Grid Box #	Month & Year
1	0.5	1	-89.5	1	Mar-00
2	1.5	2	-88.5	2	Apr-00
3	2.5	3	-87.5	3	May-00
4	3.5	4	-86.5	4	Jun-00
5	4.5	5	-85.5	5	Jul-00
6	5.5	6	-84.5	6	Aug-00
7	6.5	7	-83.5	7	Sep-00
8	7.5	8	-82.5	8	Oct-00
9	8.5	9	-81.5	9	Nov-00
10	9.5	10	-80.5	10	Dec-00
11	10.5	11	-79.5	11	Jan-01
12	11.5	12	-78.5	12	Feb-01
13	12.5	13	-77.5	13	Mar-01
14	13.5	14	-76.5	14	Apr-01
15	14.5	15	-75.5	15	May-01
16	15.5	16	-74.5	16	Jun-01
17	16.5	17	-73.5	17	Jul-01
18	17.5	18	-72.5	18	Aug-01
19	18.5	19	-71.5	19	Sep-01
20	19.5	20	-70.5	20	Oct-01
21	20.5	21	-69.5	21	Nov-01
22	21.5	22	-68.5	22	Dec-01
23	22.5	23	-67.5	23	Jan-02
24	23.5	24	-66.5	24	Feb-02
25	24.5	25	-65.5	25	Mar-02
26	25.5	26	-64.5	26	Apr-02
27	26.5	27	-63.5	27	May-02
28	27.5	28	-62.5	28	Jun-02
29	28.5	29	-61.5	29	Jul-02
30	29.5	30	-60.5	30	Aug-02
31	30.5	31	-59.5	31	Sep-02
32	31.5	32	-58.5	32	Oct-02
33	32.5	33	-57.5	33	Nov-02
34	33.5	34	-56.5	34	Dec-02
35	34.5	35	-55.5	35	Jan-03
36	35.5	36	-54.5	36	Feb-03
37	36.5	37	-53.5	37	Mar-03

38	37.5	38	-52.5	38	Apr-03
39	38.5	39	-51.5	39	May-03
40	39.5	40	-50.5	40	Jun-03
41	40.5	41	-49.5	41	Jul-03
42	41.5	42	-48.5	42	Aug-03
43	42.5	43	-47.5	43	Sep-03
44	43.5	44	-46.5	44	Oct-03
45	44.5	45	-45.5	45	Nov-03
46	45.5	46	-44.5	46	Dec-03
47	46.5	47	-43.5	47	Jan-04
48	47.5	48	-42.5	48	Feb-04
49	48.5	49	-41.5	49	Mar-04
50	49.5	50	-40.5	50	Apr-04
51	50.5	51	-39.5	51	May-04
52	51.5	52	-38.5	52	Jun-04
53	52.5	53	-37.5	53	Jul-04
54	53.5	54	-36.5	54	Aug-04
55	54.5	55	-35.5	55	Sep-04
56	55.5	56	-34.5	56	Oct-04
57	56.5	57	-33.5	57	Nov-04
58	57.5	58	-32.5	58	Dec-04
59	58.5	59	-31.5	59	Jan-05
60	59.5	60	-30.5	60	Feb-05
61	60.5	61	-29.5	61	Mar-05
62	61.5	62	-28.5	62	Apr-05
63	62.5	63	-27.5	63	May-05
64	63.5	64	-26.5	64	Jun-05
65	64.5	65	-25.5	65	Jul-05
66	65.5	66	-24.5	66	Aug-05
67	66.5	67	-23.5	67	Sep-05
68	67.5	68	-22.5	68	Oct-05
69	68.5	69	-21.5	69	Nov-05
70	69.5	70	-20.5	70	Dec-05
71	70.5	71	-19.5	71	Jan-06
72	71.5	72	-18.5	72	Feb-06
73	72.5	73	-17.5	73	Mar-06
74	73.5	74	-16.5	74	Apr-06
75	74.5	75	-15.5	75	May-06
76	75.5	76	-14.5	76	Jun-06
77	76.5	77	-13.5	77	Jul-06
78	77.5	78	-12.5	78	Aug-06
79	78.5	79	-11.5	79	Sep-06
80	79.5	80	-10.5	80	Oct-06

81	80.5	81	-9.5	81	Nov-06
82	81.5	82	-8.5	82	Dec-06
83	82.5	83	-7.5	83	Jan-07
84	83.5	84	-6.5	84	Feb-07
85	84.5	85	-5.5	85	Mar-07
86	85.5	86	-4.5	86	Apr-07
87	86.5	87	-3.5	87	May-07
88	87.5	88	-2.5	88	Jun-07
89	88.5	89	-1.5	89	Jul-07
90	89.5	90	-0.5	90	Aug-07
91	90.5	91	0.5	91	Sep-07
92	91.5	92	1.5	92	Oct-07
93	92.5	93	2.5	93	Nov-07
94	93.5	94	3.5	94	Dec-07
95	94.5	95	4.5	95	Jan-08
96	95.5	96	5.5	96	Feb-08
97	96.5	97	6.5	97	Mar-08
98	97.5	98	7.5	98	Apr-08
99	98.5	99	8.5	99	May-08
100	99.5	100	9.5	100	Jun-08
101	100.5	101	10.5	101	Jul-08
102	101.5	102	11.5	102	Aug-08
103	102.5	103	12.5	103	Sep-08
104	103.5	104	13.5	104	Oct-08
105	104.5	105	14.5	105	Nov-08
106	105.5	106	15.5	106	Dec-08
107	106.5	107	16.5	107	Jan-09
108	107.5	108	17.5	108	Feb-09
109	108.5	109	18.5	109	Mar-09
110	109.5	110	19.5	110	Apr-09
111	110.5	111	20.5	111	May-09
112	111.5	112	21.5	112	Jun-09
113	112.5	113	22.5	113	Jul-09
114	113.5	114	23.5	114	Aug-09
115	114.5	115	24.5	115	Sep-09
116	115.5	116	25.5	116	Oct-09
117	116.5	117	26.5	117	Nov-09
118	117.5	118	27.5	118	Dec-09
119	118.5	119	28.5	119	Jan-10
120	119.5	120	29.5	120	Feb-10
121	120.5	121	30.5	121	Mar-10
122	121.5	122	31.5	122	Apr-10
123	122.5	123	32.5	123	May-10

124	123.5	124	33.5	124	Jun-10
125	124.5	125	34.5	125	Jul-10
126	125.5	126	35.5	126	Aug-10
127	126.5	127	36.5	127	Sep-10
128	127.5	128	37.5	128	Oct-10
129	128.5	129	38.5	129	Nov-10
130	129.5	130	39.5	130	Dec-10
131	130.5	131	40.5	131	Jan-11
132	131.5	132	41.5	132	Feb-11
133	132.5	133	42.5	133	Mar-11
134	133.5	134	43.5	134	Apr-11
135	134.5	135	44.5	135	May-11
136	135.5	136	45.5	136	Jun-11
137	136.5	137	46.5	137	Jul-11
138	137.5	138	47.5	138	Aug-11
139	138.5	139	48.5	139	Sep-11
140	139.5	140	49.5	140	Oct-11
141	140.5	141	50.5	141	Nov-11
142	141.5	142	51.5	142	Dec-11
143	142.5	143	52.5	143	Jan-12
144	143.5	144	53.5	144	Feb-12
145	144.5	145	54.5	145	Mar-12
146	145.5	146	55.5	146	Apr-12
147	146.5	147	56.5	147	May-12
148	147.5	148	57.5	148	Jun-12
149	148.5	149	58.5	149	Jul-12
150	149.5	150	59.5	150	Aug-12
151	150.5	151	60.5	151	Sep-12
152	151.5	152	61.5	152	Oct-12
153	152.5	153	62.5	153	Nov-12
154	153.5	154	63.5	154	Dec-12
155	154.5	155	64.5	155	Jan-13
156	155.5	156	65.5	156	Feb-13
157	156.5	157	66.5	157	Mar-13
158	157.5	158	67.5	158	Apr-13
159	158.5	159	68.5	159	May-13
160	159.5	160	69.5	160	Jun-13
161	160.5	161	70.5	161	Jul-13
162	161.5	162	71.5	162	Aug-13
163	162.5	163	72.5	163	Sep-13
164	163.5	164	73.5	164	Oct-13
165	164.5	165	74.5	165	Nov-13
166	165.5	166	75.5	166	Dec-13

167	166.5	167	76.5	167	Jan-14
168	167.5	168	77.5	168	Feb-14
169	168.5	169	78.5	169	Mar-14
170	169.5	170	79.5	170	Apr-14
171	170.5	171	80.5	171	May-14
172	171.5	172	81.5	172	Jun-14
173	172.5	173	82.5	173	Jul-14
174	173.5	174	83.5	174	Aug-14
175	174.5	175	84.5	175	Sep-14
176	175.5	176	85.5	176	Oct-14
177	176.5	177	86.5	177	Nov-14
178	177.5	178	87.5	178	Dec-14
179	178.5	179	88.5	179	Jan-15
180	179.5	180	89.5	180	Feb-15
181	-179.5			181	Mar-15
182	-178.5			182	Apr-15
183	-177.5			183	May-15
184	-176.5				
185	-175.5				
186	-174.5				
187	-173.5				
188	-172.5				
189	-171.5				
190	-170.5				
191	-169.5				
192	-168.5				
193	-167.5				
194	-166.5				
195	-165.5				
196	-164.5				
197	-163.5				
198	-162.5				
199	-161.5				
200	-160.5				
201	-159.5				
202	-158.5				
203	-157.5				
204	-156.5				
205	-155.5				
206	-154.5				
207	-153.5				
208	-152.5				
209	-151.5				

210	-150.5				
211	-149.5				
212	-148.5				
213	-147.5				
214	-146.5				
215	-145.5				
216	-144.5				
217	-143.5				
218	-142.5				
219	-141.5				
220	-140.5				
221	-139.5				
222	-138.5				
223	-137.5				
224	-136.5				
225	-135.5				
226	-134.5				
227	-133.5				
228	-132.5				
229	-131.5				
230	-130.5				
231	-129.5				
232	-128.5				
233	-127.5				
234	-126.5				
235	-125.5				
236	-124.5				
237	-123.5				
238	-122.5				
239	-121.5				
240	-120.5				
241	-119.5				
242	-118.5				
243	-117.5				
244	-116.5				
245	-115.5				
246	-114.5				
247	-113.5				
248	-112.5				
249	-111.5				
250	-110.5				
251	-109.5				
252	-108.5				

253	-107.5				
254	-106.5				
255	-105.5				
256	-104.5				
257	-103.5				
258	-102.5				
259	-101.5				
260	-100.5				
261	-99.5				
262	-98.5				
263	-97.5				
264	-96.5				
265	-95.5				
266	-94.5				
267	-93.5				
268	-92.5				
269	-91.5				
270	-90.5				
271	-89.5				
272	-88.5				
273	-87.5				
274	-86.5				
275	-85.5				
276	-84.5				
277	-83.5				
278	-82.5				
279	-81.5				
280	-80.5				
281	-79.5				
282	-78.5				
283	-77.5				
284	-76.5				
285	-75.5				
286	-74.5				
287	-73.5				
288	-72.5				
289	-71.5				
290	-70.5				
291	-69.5				
292	-68.5				
293	-67.5				
294	-66.5				

295	-65.5				
296	-64.5				
297	-63.5				
298	-62.5				
299	-61.5				
300	-60.5				
301	-59.5				
302	-58.5				
303	-57.5				
304	-56.5				
305	-55.5				
306	-54.5				
307	-53.5				
308	-52.5				
309	-51.5				
310	-50.5				
311	-49.5				
312	-48.5				
313	-47.5				
314	-46.5				
315	-45.5				
316	-44.5				
317	-43.5				
318	-42.5				
319	-41.5				
320	-40.5				
321	-39.5				
322	-38.5				
323	-37.5				
324	-36.5				
325	-35.5				
326	-34.5				
327	-33.5				
328	-32.5				
329	-31.5				
330	-30.5				
331	-29.5				
332	-28.5				
333	-27.5				
334	-26.5				
335	-25.5				
336	-24.5				
337	-23.5				

338	-22.5				
339	-21.5				
340	-20.5				
341	-19.5				
342	-18.5				
343	-17.5				
344	-16.5				
345	-15.5				
346	-14.5				
347	-13.5				
348	-12.5				
349	-11.5				
350	-10.5				
351	-9.5				
352	-8.5				
353	-7.5				
354	-6.5				
355	-5.5				
356	-4.5				
357	-3.5				
358	-2.5				
359	-1.5				
360	-0.5				

43. Now we will try extracting **Solar_mon** values from different grid boxes. If we are interested in the monthly insolation value for 15.5 degrees east longitude and 42.5 degrees north latitude during March 2000, you need to use the data table above to determine the appropriate longitude grid box number, latitude grid box number, and time component number.

- For a longitude of 15.5 degrees east, the grid box number is **16**.
- For a latitude of 42.5 degrees north, the grid box number is **133**.
- For the month March 2000, the time component number is **1**.

To determine the **Solar_mon** (insolation) value associated with these grid box values, type the following into the **Console**: Solar_mon[16,133,1] and press enter. Remember, the longitude value is first, then the latitude, and then the time.

The value in the **Console** should be equal to **310.6**. This means that at a latitude of 42.5 degrees north and a longitude of 15.5 degrees east during March 2000, the amount of insolation reaching the top of the atmosphere is **310.6 W/m^2**.

44. Let's practice some more. If we are interested in the monthly insolation value for 75.5 degrees west longitude and 10.5 degrees south latitude during September 2007, you need to use the data table on the previous pages to determine the appropriate longitude grid box number, latitude grid box number, and time component number.

Remember that west longitudes are negative in the data table and south latitudes are also negative.

- For a longitude of 75.5 degrees west, the grid box number is **285**.
- For a latitude of 10.5 degrees south, the grid box number is **80**.
- For the month September 2007, the time component number is **91**.

To determine the **Solar_mon** (insolation) value associated with these grid box values, type the following into the **Console** Solar_mon[285,80,91] and press enter. The value in the **Console** should be equal to **415 W/m^2**.

45. Now you will need to determine the grid box numbers on your own. Determine the amount of insolation from **Solar_mon** at a longitude of 84.5 degrees east and a latitude of 50.5 degrees north during April 2012.

The resulting value in the **Console** should be **366.8 W/m^2**.

46. We now need to save the R Script for future use. Click on "**File**" at the very top left of RStudio, then click "**Save As**". Name the file PracticingNetCDF.R

Elaborate & Evaluate Questions

47. In the **Console**, change the latitude grid box value while keeping the longitude value and time value the same for **Solar_mon**. For example, determine the value for **Solar_mon[1,1,1]**, and then determine the value for **Solar_mon[1,10,1]**, then **Solar_mon[1,20,1]**, and so on. Be sure to leave the longitude value on 1 and the time value on 1 to represent the March equinox. The goal is to determine how a changing latitude influences the **Solar_mon** value, and therefore the amount of insolation at the top of the atmosphere.

Q1. By changing the latitude and keeping longitude and time constant, evaluate the relationship between latitude and insolation at the top of Earth's atmosphere. Then, justify the relationship using the term angle of insolation. ***Remember:*** *Use the Data Table for Longitude, Latitude, and Time Grid Boxes to help determine actual latitude values that are associated with the changing grid box values.*

Relationship: ____

Justification: ____

48. Repeat step #48 but this time keep latitude and time constant while only changing longitude in **Solar_mon**. Be sure to leave the latitude value on 1 and the time value on 1 to represent the March equinox.

Q2. By changing the longitude and keeping latitude and time constant, evaluate the relationship between longitude and insolation at the top of Earth's atmosphere. Then, justify the relationship using the term angle of insolation. ***Remember:*** *Use the Data Table for Longitude, Latitude, and Time Grid Boxes to help determine actual longitude values that are associated with the changing grid box values.*

Relationship: ____

Justification: ____

Elaborate & Evaluate Questions – Answer Key

47. In the **Console**, change the latitude grid box value while keeping the longitude value and time value the same for **Solar_mon**. For example, determine the value for **Solar_mon[1,1,1]**, and then determine the value for **Solar_mon[1,10,1]**, then **Solar_mon[1,20,1]**, and so on. Be sure to leave the longitude value on 1 and the time value on 1 to represent the March equinox. The goal is to determine how a changing latitude influences the **Solar_mon** value, and therefore the amount of insolation at the top of the atmosphere.

Q1. By changing the latitude and keeping longitude and time constant, evaluate the relationship between latitude and insolation at the top of Earth's atmosphere. Then. justify the relationship using the term angle of insolation. ***Remember:*** *Use the Data Table for Longitude, Latitude, and Time Grid Boxes to help determine actual latitude values that are associated with the changing grid box values.*

Relationship: **As latitude increases, the amount of insolation decreases.**

Justification: **Higher latitudes receive a lower angle of insolation.**

48. Repeat step #48 but this time keep latitude and time constant while only changing longitude in **Solar_mon**. Be sure to leave the latitude value on 1 and the time value on 1 to represent the March equinox.
Q2. By changing the longitude and keeping latitude and time constant, evaluate the relationship between longitude and insolation at the top of Earth's atmosphere. Then, justify the relationship using the term angle of insolation. ***Remember:*** *Use the Data Table for Longitude, Latitude, and Time Grid Boxes to help determine actual longitude values that are associated with the changing grid box values.*

Relationship: **As longitude changes, insolation remains the same.**

Justification: **Changing longitude does not change the angle of insolation. Angle of insolation is only dependent on latitude.**

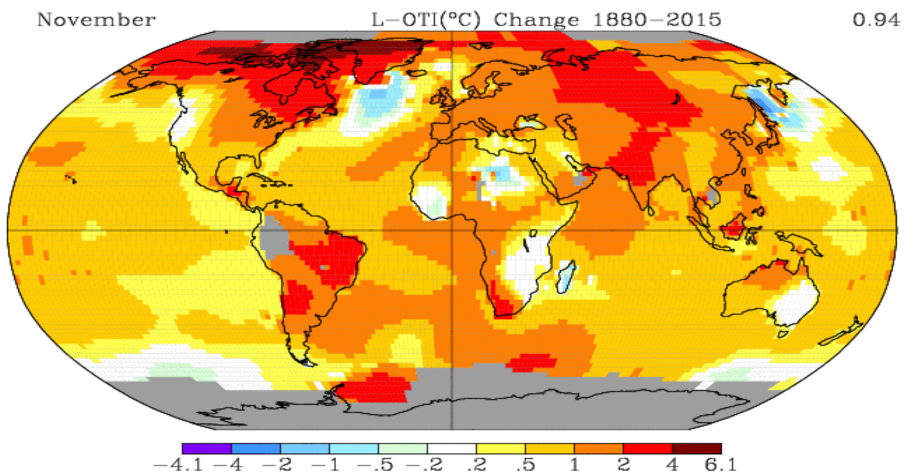
F. Conclusion and overview of linkages to next lesson and unit goals.

In this lesson, the students learned how to write two codes in RStudio. The first code taught students how to use basic commands in RStudio while the second code taught students how to load and analyze netCDF data. The goal of this lesson was to allow students to become comfortable with RStudio so they can successfully complete the capstone project in lesson #4. In the next lesson, the students will utilize RStudio in order to write a code that loads in incoming solar radiation, outgoing longwave energy, outgoing shortwave energy, and net energy data. The students will then use their knowledge of netCDF data and grid boxes from lesson #3 to calculate Earth's energy budget at different locations on Earth for different seasons.

National Aeronautics and Space Administration
Goddard Institute for Space Studies
New York, N.Y.

NASA Goddard Institute for Space Studies (GISS)
Climate Change Research Initiative (CCRI)
Applied Research STEM Curriculum Unit Portfolio

Unit Title: Earth's Energy Budget
Lesson #4 Title: Earth's Energy Budget Capstone Project
NASA STEM Educator / Associate Researcher: Nicole Dulaney
NASA PI / Mentor: Dr. Allegra LeGrande
NASA GSFC Office of Education – Code 160



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VIII. Lesson 4: Title: Earth's Energy Budget Capstone Project

A. Summary and Goals of Lesson

The goal of this lesson is for the students to write a code in RStudio that loads in the four NASA CERES satellite datasets representing each component of Earth's energy budget for further analysis. The students will be able to extract values of insolation, outgoing longwave energy, outgoing shortwave energy, and net energy for specific cities on Earth during March, June, and December 2000. These months were chosen so the students can see the energy budget values during an equinox, the Northern Hemisphere Summer Solstice, and the Northern Hemisphere Winter Solstice. The students will evaluate each component of the energy budget for New York City, Summit, Greenland, and Quito Ecuador. New York City was chosen so the students can learn about the energy budget in their own city. Summit, Greenland was chosen so the students can see how surface albedo can play a large role in the energy budget. Quito, Ecuador was chosen so the students can analyze the energy budget for a city that has positive net energy the entire year. Finally, the students are then asked to explore each component of the energy budget for a city of their choice.

In addition to determining values of the energy budget equation for specific cities, the students are expected to answer critical thinking questions based on the data for each city. The goal is for the students to learn how cities can be influenced differently by the components of Earth's energy budget. Students will also make predictions as to how the energy budget will change for different locations as Earth's climate changes in the future.

B. Table of Contents for lesson

A. Summary and Goals of Lesson **115**
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C. 5 E lesson model template:

STEM Earth Science Research

Unit: Earth's Energy Budget **Topic**: Earth's Energy Budget Capstone Project

Prior Learning: For successful completion of this lessons, the students need to have knowledge of the components of the energy budget formula derived in lesson #1, the contents of each NASA CERES satellite dataset analyzed in lesson #2, and the coding skills in RStudio developed in lesson #3. In this lesson, the students will use their new knowledge of RStudio to complete a capstone project in which they analyze the values for each component of Earth's energy budget (incoming solar radiation, outgoing longwave energy, outgoing shortwave energy, and net energy) for New York City, Summit, Greenland, Quito, Ecuador, and a city of their choice during March, June, and December 2000.

Do Now (Pre-Assessment):

1. Predict how the energy budget for New York City will differ from that of Summit, Greenland during March, June, and December 2000.

Aim: How can we use RStudio to analyze the energy budget of specific cities on Earth?

New York State Standards:

1.1f - Earth's changing position with regard to the Sun and the moon has noticeable effects.

- Earth revolves around the Sun with its rotational axis tilted at 23.5 degrees to a line perpendicular to the plane of its orbit, with the North Pole aligned with Polaris.
- During Earth's one-year period of revolution, the tilt of its axis results in changes in the angle of incidence of the Sun's rays at a given latitude; these changes cause variation in the heating of the surface. This produces seasonal variation in weather.

2.2a - Insolation (solar radiation) heats Earth's surface and atmosphere unequally due to variations in:

- the intensity caused by differences in atmospheric transparency and angle of incidence which vary with time of day, latitude, and season
- characteristics of the materials absorbing the energy such as color, texture, transparency, state of matter, and specific heat
- duration, which varies with seasons and latitude.

Next Generation Science Standards:

HS - ESS2-4 - Use a model to describe how variations in the flow of energy into and out of Earth's systems result in changes in climate.

HS - ESS3-5 - Analyze geoscience data and the results from global climate models to make an evidence-based forecast of the current rate of global or regional climate change and associated future impacts to Earth systems.

Common Core State Standards:

CCSS: 9-10.RST.3 - Follow precisely a multistep procedure when carrying out experiments, taking measurements, or performing technical tasks.

CCSS: 9-10.RST.7 - Integrate and evaluate multiple sources of information presented in diverse formats and media (e.g., quantitative data, video, multimedia) in order to address a question or solve a problem.

NASA System Engineering Behavior:
Technical Acumen:
1a. Possesses Technical Competence and Has Comprehensive Previous Experience
1b. Learns from Successes and Failures
Problem Solving & Systems Thinking:
2a. Thinks Systematically
2b. Possess Creativity and Problem Solving Abilities

Performance Objective: Students will be able to create a code in RStudio that allows them to analyze and compare the different components of Earth's energy budget for different cities and time slices on Earth.

Materials: NASA CERES Satellite data; Rstudio; Class set of computers

NASA CERES Satellite Data: https://iridl.ldeo.columbia.edu/SOURCES/.NASA/.ASDC-DAAC/.CERES/.EBAF-TOA/.Ed2p8/?Set-Language=en

RStudio Download Link: https://www.rstudio.com/products/rstudio/download/

Vocabulary: Insolation; Incoming energy (shortwave); Outgoing energy (longwave)

Anticipatory Opening: Discuss with the students how a global map of each component of Earth's energy budget does not allow you to evaluate the energy budget components of a specific city. Show the students a net energy map from Panoply in lesson #2 and ask them to provide the net energy value of New York City. Since the students will be unable to do this, this will show them how RStudio can be a great tool to obtain specific values for different cities.

Development of the Lesson: Approximately Two-Day Lesson (Two 50-minute periods).

What the teacher does	What the student does	Time
1. Write down the Do Now, Aim, and the HW on the blackboard.		
2. Circulate the room while the students complete the Do Now questions. Determine how much prior knowledge the students have about each component of Earth's energy budget. ***Assessment Opportunity #1 (Student prior knowledge from previous units)***	The students answer the Do Now questions in their notebooks to determine how much prior knowledge they have about each component of Earth's energy budget.	**5 min**

3. ENGAGE Discuss with the students how a global map of each component of Earth's energy budget does not allow you to evaluate the energy budget components of a specific city.	The students learn how RStudio can be a great tool to obtain specific energy budget values for different cities.	**5 min**
4. EXPLORE & EXPLAIN Introduce the students to Earth's Energy Budget capstone project. Circulate the room as the students complete the capstone project. Make sure the students are using the accurate grid box numbers for each city. Look for common challenges and misconceptions within the activity. ***Assessment Opportunity #2 (Student discussion about Earth's Energy Budget capstone project). Assessment Opportunity #3 (Student answers to the Earth's Energy Budget capstone project).***	The students begin the Earth's Energy Budget capstone project. The students evaluate each component of Earth's energy budget for specific cities by utilizing RStudio. The students make predictions as to how components of the energy budget will change as a result of climate change.	**60 min**
5. ELABORATE & EVALUATE Circulate the room while the students choose a city to evaluate in terms of Earth's energy budget. ***Assessment Opportunity #4(Student answers to the elaborate & evaluate questions)***	The students choose a city to evaluate in terms of Earth's energy budget. The students determine the latitude and longitude coordinates and the associated grid box values of their city. The students predict how each component of Earth's energy budget will change as a result of climate change in their city.	**20 min**
6. Administer the Daily Formative Assessment (DFA) to the students. This DFA will show whether the students learned from/expanded on their answer from the Do Now. ***Assessment Opportunity #5 (Student answers to the DFA).***	The students individually answer questions for the Daily Formative Assessment. The students will submit their answers at the end of class.	**10 min**

Summary/Conclusion: The students individually answer questions for the Daily Formative Assessment. The students will submit their answers at the end of class.

Higher Order Questions:

See the questions in the Earth's Energy Budget Capstone Project activity.

Differentiated Instruction:
- The students are exposed to content in written, oral, and visual forms (multiple modalities exist).

- Students can use colored pencils to draw diagrams and annotate notes in a way that is meaningful to them.
- Students are asked both higher and lower level questions so all students can answer questions at their particular academic level.
- Students are given time to answer questions during think pair share/group activities.

Daily Formative Assessment:

1. Explain how the energy budget for New York City was different from that of Summit, Greenland during March, June, and December 2000.

For Further Exploration:

Continue to choose cities in different continents to evaluate each component of Earth's energy budget.

Notes For Revision:

D. Content template:

NGSS Standard:	State Earth Science Content Standard:	Common Core Standard:	NASA Science:
HS - ESS2-4 - Use a model to describe how variations in the flow of energy into and out of Earth's systems result in changes in climate. HS - ESS3-5 - Analyze geoscience data and the results from global climate models to make an evidence-based forecast of the current rate of global or regional climate change and associated future impacts to Earth systems.	**1.1f** - Earth's changing position with regard to the Sun and the moon has noticeable effects. • Earth revolves around the Sun with its rotational axis tilted at 23.5 degrees to a line perpendicular to the plane of its orbit, with the North Pole aligned with Polaris. • During Earth's one-year period of revolution, the tilt of its axis results in changes in the angle of incidence of the Sun's rays at a given latitude; these changes cause variation in the heating of the surface. This produces seasonal variation in weather. **2.2a** - Insolation (solar radiation) heats Earth's surface and atmosphere unequally due to variations in: • the intensity caused by differences in atmospheric transparency and angle of incidence which vary with time of day, latitude, and season • characteristics of the materials absorbing the energy such as color, texture, transparency, state of matter, and specific heat • duration, which varies with seasons and latitude.	**CCSS: 9-10.RST.3** - Follow precisely a multistep procedure when carrying out experiments, taking measurements, or performing technical tasks. **CCSS: 9-10.RST.7** - Integrate and evaluate multiple sources of information presented in diverse formats and media (e.g., quantitative data, video, multimedia) in order to address a question or solve a problem.	Earth: Earth's Energy Budget

Content Area:	Name of Project-Based Activity or Theme:	Estimated Time Frame to Complete (days/weeks):
Earth & Space Sciences **Grade Level:** High School	Earth's Energy Budget Capstone Project	Lesson #4 = Two 50-minute class periods

Overall Investigation Question(s): How can we use RStudio to analyze the energy budget of specific cities on Earth?

Overall Project Description/Activity: Students will be able to create a code in RStudio that allows them to analyze and compare the different components of Earth's energy budget for different cities and time slices on Earth.

Materials Needed to Complete Project (put N/A as needed):	Stakeholders:	Hyperlinks Used: Visit the hyperlinks in the following order in the lesson:	Multimedia/Technology:	Classroom Equipment:
NASA CERES Satellite data; Rstudio; Class set of computers	1. Earth & space science educators 2. Earth & space science students 3. Students engaged in science research 4. NYCDOE 5. NASA	1. NASA CERES Satellite Data: https://iridl.ldeo.columbia.edu/SOURCES/.NASA/.ASDC-DAAC/.CERES/.EBAF-TOA/.Ed2p8/?Set-Language=en 2. RStudio Download Link: https://www.rstudio.com/products/rstudio/download/	Website links: 1. NASA CERES Satellite Data: https://iridl.ldeo.columbia.edu/SOURCES/.NASA/.ASDC-DAAC/.CERES/.EBAF-TOA/.Ed2p8/?Set-Language=en 2. RStudio Download Link: https://www.rstudio.com/products/rstudio/download/	Computers; Highlighters; Calculators

NASA System Engineering Behaviors (2 behaviors per category) 1a. Possesses Technical Competence and Has Comprehensive Previous Experience 1b. Learns from Successes and Failures 2a. Thinks Systematically 2b. Draws on Past Experiences	**Category** 1. Technical Acumen 2. Problem solving & systems thinking	**<u>Activities</u>** **How will student model engineering behaviors when learning science content?** **Describe student activities here.** 1a&b. The students will write a code in RStudio in order to analyze each individual component of Earth's energy budget formula. Here, the students will demonstrate an understanding of engineering principles and computer programming in order to be able to analyze climate data from the NASA CERES satellite in a more efficient way. The students will then share their experiences and learn from their successes and failures by evaluating how their answer to the Do Now changed from the beginning of the activity when they answer the Daily Formative Assessment. 2a. The students will write a code in RStudio in order to analyze each individual component of Earth's energy budget formula for different cities on Earth. 2b. The students will use their knowledge of Earth's energy budget from the previous lessons in order use RStudio to analyze the energy budget for specific cities on Earth.	**Student Outcomes** **How will you assess learning for each behavior:** 1a&b. Students will be assessed based on their answers to the Earth's Energy Budget Capstone Project. Students will be assessed based on their completed energy budget data tables for each city and the questions that accompany each table. Students will also be assessed based on their answers to the Do Now and Daily Formative Assessment questions. 2a&b. Students will be assessed based on their answers to the Earth's Energy Budget Capstone Project. Students will be assessed based on their completed energy budget data tables for each city and the questions that accompany each table. Students will also be assessed based on their answers to the Do Now and Daily Formative Assessment questions.	**Evaluation** **Describe specific science content students understand as a result of engineering behavior.** 1a&b. Students will be able to evaluate how latitude, longitude, and time of the year influence each component of Earth's energy budget (insolation, outgoing longwave energy, outgoing shortwave energy, and net energy) for different cities. 2a&b. Students will be able to evaluate how latitude, longitude, and time of the year influence each component of Earth's energy budget (insolation, outgoing longwave energy, outgoing shortwave energy, and net energy) for different cities.
List and attach all supportive documents for instructional activities.	Attachments? (circle) **Yes** or No	**List Attached Documents (if any):** 1. Using RStudio: Earth's Energy Budget Capstone Project		
List and attach all rubrics for activity and assessment evaluation.	Attachments? (circle) Yes or **No**	**List Attached Rubrics (if any):** None in this lesson.		
Include comments or questions here:				

E. Supporting Documents:

Name: ______________________________________ Date: ______________

Using RStudio: Earth's Energy Budget Capstone Project

Activity Description: The purpose of this activity is for the students to use RStudio to calculate the energy budget for different locations on Earth based on the following energy budget formula:

Net Energy = Incoming Solar Radiation – Outgoing Longwave Energy – Outgoing Shortwave Energy

The students will use the NASA CERES satellite data downloaded in lesson #2 to calculate the net energy at the top of Earth's atmosphere. Students will also make predictions as to how different components of Earth's energy budget will change as a result of climate change in the future.

NOTE: Lesson #2 titled ***Analyzing NASA CERES Energy Budget Data*** and Lesson #3 titled ***Learning RStudio for NASA CERES Data Analysis*** need to be completed prior to this activity. Teachers and students need to have the CERES datasets used in lesson #2 already downloaded onto the computer and students need to have a knowledge of RStudio introduced in lesson #3.

1. Open RStudio and open a new R Script by clicking **"File"** at the very top of RStudio, and then click **"New File"**, and then click **R Script.**

2. On the first line of your R Script, we need to use the **library** command we learned in lesson #3 to reference the **ncdf4** package. This can be done by typing **library(ncdf4)** on line #1 of the code.

3. On line #2 of your R Script, write a comment describing the goals of the activity. You may use the activity description above to help you write your comment. Remember, all comments in RStudio must start with ***"#"***.

4. On the next lines of your code, load in the four NASA CERES datasets we downloaded in lesson #2. These datasets are named Insolation.nc, Outgoing_Shortwave.nc, Outgoing_Longwave.nc, and Net_Energy.nc.

*Remember, to load in netCDF datasets you need to use the **nc_open** command. ***Be sure to find the correct file pathway using the strategies we learned in step #32 in the activity from lesson #3***.

You will need to load each of the four datasets individually as shown in the example below:

```
1  library(ncdf4)
2  #This code will allow students to calculate the net energy in Earth's energy budget for
3
4  #We will now load the four NASA CERES datasets into RStudio.
5  Data_Insolation <- nc_open("/Users/ndulaney/Downloads/Insolation.nc")
6  Data_OutgoingLongwave <- nc_open("/Users/ndulaney/Downloads/Outgoing_Longwave.nc")
7  Data_OutgoingShortwave <- nc_open("/Users/ndulaney/Downloads/Outgoing_Shortwave.nc")
8  Data_NetEnergy <- nc_open("/Users/ndulaney/Downloads/Net_Energy.nc")
```

Make sure to highlight and run all of your lines of code up until this point so you can ensure there are no errors in the **Console**. If there are errors, it is most likely due to an incorrect file path.

5. In the **Console**, use the **names** command for each of the four datasets you loaded into RStudio to determine the name of the variable in each dataset. ***Refer to step #37 in the activity from lesson #3 if you need***.

In the space provided below, write the name of the original dataset, the name you provided the loaded dataset, the command you need to type in the **Console**, and the resulting variable name. An example for the Insolation.nc dataset is provided for you.

Dataset Name	Dataset Name in RStudio	Command Typed in Console	Resulting Variable Name
Insolation.nc	*Data_Insolation*	*names(Data_Insolation$var)*	*solar_mon*

6. Using the variable names determined in step #5 above, extract the variables for each dataset by using the **ncvar_get** command. ***Refer to step #38 in the activity from lesson #3 if you need***. Use the information immediately below to help you name your extracted variable.

- Set the variable extracted from Data_Insolation equal to Solar_Insolation
- Set the variable extracted from Data_OutgoingLongwave equal to OutgoingLongwave
- Set the variable extracted from Data_OutgoingShortwave equal to OutgoingShortwave
- Set the variable extracted from Data_NetEnergy equal to NetEnergy

Use the image below as a guide. Your code should look similar to this at this point.

```
library(ncdf4)
#This code will allow students to calculate the net energy in Earth's energy budget for different

#We will now load the four NASA CERES datasets into RStudio.
Data_Insolation <- nc_open("/Users/ndulaney/Downloads/Insolation.nc")
Data_OutgoingLongwave <- nc_open("/Users/ndulaney/Downloads/Outgoing_Longwave.nc")
Data_OutgoingShortwave <- nc_open("/Users/ndulaney/Downloads/Outgoing_Shortwave.nc")
Data_NetEnergy <- nc_open("/Users/ndulaney/Downloads/Net_Energy.nc")

#We will now learn how to extract a variable from a dataset.
Solar_Insolation <- ncvar_get(Data_Insolation,"solar_mon")
OutgoingLongwave <- ncvar_get(Data_OutgoingLongwave, "toa_lw_all_mon")
OutgoingShortwave <- ncvar_get(Data_OutgoingShortwave, "toa_sw_all_mon")
NetEnergy <- ncvar_get(Data_NetEnergy, "toa_net_all_mon")
```

7. We will now use the data in Solar_Insolation, OutgoingLongwave, OutgoingShortwave to calculate the net energy at the top of Earth's atmosphere for different locations on Earth.

We will use the following energy budget formula:

Net Energy = Solar_Insolation – OutgoingLongwave – OutgoingShortwave

The components provided in the formula above represent the names of the extracted solar_mon variable (incoming solar radiation), the toa_lw_all_mon variable (outgoing longwave energy), and the toa_sw_all_mon variable (outgoing shortwave energy).

Q1. Compete the data table below for New York City for different time slices (March 2000, June 2000, and December 2000). The first example for March 2000 was done for you and an image of the **Console** showing where the answers came from is provided below.

```
> Solar_Insolation[286,131,1]
[1] 321.2
> OutgoingLongwave[286,131,1]
[1] 222.6
> OutgoingShortwave[286,131,1]
[1] 106.1
> NetEnergy[286,131,1]
[1] -7.476
```

To finish the data table, you will need to refer to the Data Table for Longitude, Latitude and Time Grid boxes that was introduced in lesson #3. The data table is provided at the end of this activity. ***Also, refer to steps #40 to #45 from the activity in lesson #3 if needed.***

Note: ***If your latitude or longitude value does not match a value in the Data Table for Longitude, Latitude and Time Grid boxes, choose the closest grid box. For example, the latitude of New York City of 40.7˚N corresponds to latitude grid box 131.***

Note: ***Remember that negative longitudes are west and negative latitudes are south.***

New York City Energy Budget

Net Energy = Solar_Insolation – OutgoingLongwave – OutgoingShortwave

Latitude & Longitude Coordinates and Month/Year	Longitude Grid Box #	Latitude Grid Box #	Time Slice #	Solar Insolation Value (W/m^2)	Outgoing Longwave Value (W/m^2)	Outgoing Shortwave Value (W/m^2)	Net Energy (W/m^2)
Longitude: *74.1˚W* ***Latitude:*** *40.7˚N* ***Time:*** *March 2000*	*286*	*131*	*1*	*321.2*	*222.6*	*106.1*	*-7.476*
Longitude: *74.1˚W* ***Latitude:*** *40.7˚N* ***Time:*** *June 2000*							
Longitude: *74.1˚W* ***Latitude:*** *40.7˚N* ***Time:*** *December 2000*							

Q2. After completing the New York City Energy Budget data table, describe how the net energy in New York City changed from March 2000, to June 2000, to December 2000.

____

____

Q3. Which component of the energy budget formula: Solar Insolation, Outgoing Longwave, or Outgoing Shortwave, would change the most for New York City as Earth continues to warm in the future? Why?

____

Why: ____

Q4. Predict how the net energy in New York City during each month would change as Earth's climate continues to warm in the future. Explain why using either the terms insolation, outgoing longwave energy, or outgoing shortwave energy.

____

Why: ____

Q5. Compete the data table below for Summit, Greenland (the location at the peak of the Greenland Ice Sheet) for different time slices (March 2000, June 2000, and December 2000).
***Note:* Remember that negative longitudes are west and negative latitudes are south.**

Summit, Greenland Energy Budget

Net Energy = Solar_Insolation – OutgoingLongwave – OutgoingShortwave

Latitude & Longitude Coordinates and Month/Year	Longitude Grid Box #	Latitude Grid Box #	Time Slice #	Solar Insolation Value (W/m^2)	Outgoing Longwave Value (W/m^2)	Outgoing Shortwave Value (W/m^2)	Net Energy (W/m^2)
Longitude: *38.5˚W* ***Latitude:*** *72.6˚N* ***Time:*** *March 2000*							
Longitude: *38.5˚W* ***Latitude:*** *72.6˚N* ***Time:*** *June 2000*							
Longitude: *38.5˚W* ***Latitude:*** *72.6˚N* ***Time:*** *December 2000*							

Q6. After completing the Summit, Greenland Energy Budget data table, describe how the net energy in Summit changed from March 2000, to June 2000, to December 2000.

____

____

Q7. Why does Summit, Greenland have a negative net energy in June 2000 even though it has a high amount of incoming solar radiation?

____

____

Q8. Which component of the energy budget formula: Solar Insolation, Outgoing Longwave, or Outgoing Shortwave, would change the most for Summit, Greenland as Earth continues to warm in the future? Why?

____

Why: ____

Q9. Compete the data table below for Quito, Ecuador (a city located on the equator) for different time slices (March 2000, June 2000, and December 2000).

***Note:* Remember that negative longitudes are west and negative latitudes are south.**

Quito, Ecuador Energy Budget

Net Energy = Solar_Insolation – OutgoingLongwave – OutgoingShortwave

Latitude & Longitude Coordinates and Month/Year	Longitude Grid Box #	Latitude Grid Box #	Time Slice #	Solar Insolation Value (W/m^2)	Outgoing Longwave Value (W/m^2)	Outgoing Shortwave Value (W/m^2)	Net Energy (W/m^2)
Longitude: *78.5˚W* ***Latitude:*** *0.2˚S* ***Time:*** *March 2000*							
Longitude: *78.5˚W* ***Latitude:*** *0.2˚S* ***Time:*** *June 2000*							
Longitude: *78.5˚W* ***Latitude:*** *0.2˚S* ***Time:*** *December 2000*							

Q10. After completing the Quito, Ecuador Energy Budget data table, describe how the net energy in Quito changed from March 2000, to June 2000, to December 2000.

____

____

Q11. Why is the net energy for each month in Quito positive?

____

____

Q11. Why do you think Quito has a high value for outgoing shortwave energy for March 2000, June 2000, and December 2000?

____

____

Q12. Compete the data table below for the ***city of your choice*** for different time slices (March 2000, June 2000, and December 2000). Write the name of your city at the top of the data table below. Also, write the latitude and longitude coordinates of your city in the first column of the data table.

Note: Remember that negative longitudes are west and negative latitudes are south.

_______________________ Energy Budget

Net Energy = Solar_Insolation – OutgoingLongwave – OutgoingShortwave

Latitude & Longitude Coordinates and Month/Year	Longitude Grid Box #	Latitude Grid Box #	Time Slice #	Solar Insolation Value (W/m^2)	Outgoing Longwave Value (W/m^2)	Outgoing Shortwave Value (W/m^2)	Net Energy (W/m^2)
Longitude: ***Latitude:*** ***Time:*** *March 2000*							
Longitude: ***Latitude:*** ***Time:*** *June 2000*							
Longitude: ***Latitude:*** ***Time:*** *December 2000*							

Q13. After completing the Energy Budget data table for your city, describe how the net energy in your city changed from March 2000, to June 2000, to December 2000.

____

____

Q14. How will each component of Earth's energy budget will be impacted as a result of climate change in your city? Be sure to explain your answer for each component.

Insolation: ____

Explanation: ____

Outgoing Longwave: ____

Explanation: ____

Outgoing Shortwave: ____

Explanation: ____

Net Energy: ____

Explanation: ____

National Aeronautics and Space Administration
Goddard Institute for Space Studies
New York, N.Y.

Teacher Answer Key

Dataset Name	Dataset Name in RStudio	Command Typed in Console	Resulting Variable Name
Insolation.nc	*Data_Insolation*	*names(Data_Insolation$var)*	*solar_mon*
Outgoing_Longwave.nc	*Data_OutgoingLongwave*	*names(Data_OutgoingLongwave$var)*	*toa_lw_all_mon*
Outgoing_Shortwave.nc	*Data_OutgoingShortwave*	*names(Data_OutgoingShortwave$var)*	*toa_sw_all_mon*
Net_Energy.nc	*Data_NetEnergy*	*names(Data_NetEnergy$var)*	*toa_net_all_mon*

New York City

Latitude & Longitude Coordinates and Month/Year	Longitude Grid Box #	Latitude Grid Box #	Time Slice #	Solar Insolation Value (W/m^2)	Outgoing Longwave Value (W/m^2)	Outgoing Shortwave Value (W/m^2)	Net Energy (W/m^2)
Longitude: *74.1˚W* ***Latitude:*** *40.7˚N* ***Time:*** *March 2000*	*286*	*131*	*1*	*321.2*	*222.6*	*106.1*	*-7.476*
Longitude: *74.1˚W* ***Latitude:*** *40.7˚N* ***Time:*** *June 2000*	*286*	*131*	*4*	*480.1*	*245.7*	*160.6*	*73.74*
Longitude: *74.1˚W* ***Latitude:*** *40.7˚N* ***Time:*** *December 2000*	*286*	*131*	*10*	*154.2*	*209.9*	*54.72*	*-110.4*

Q2. After completing the New York City Energy Budget data table, describe how the net energy in New York City changed from March 2000, to June 2000, to December 2000.
Net energy in New York City increased from March to June and then decreased from June to December.

Q3. Which component of the energy budget formula: Solar Insolation, Outgoing Longwave, or Outgoing Shortwave, would change the most for New York City as Earth continues to warm in the future? Why?
Outgoing longwave energy would change the most by decreasing

Why: Increasing greenhouse gases such as water vapor will cause the atmosphere to absorb more outgoing infrared energy, reducing the amount leaving the atmosphere travelling back towards space.

Q4. Predict how the net energy in New York City during each month would change as Earth's climate continues to warm in the future. Explain why using either the terms insolation, outgoing longwave energy, or outgoing shortwave energy.
Net energy would increase

Why: Decreasing outgoing longwave energy would allow for more energy to stay in the atmosphere, increasing net energy.

Summit, Greenland

Net Energy = Solar_Insolation – OutgoingLongwave – OutgoingShortwave

Latitude & Longitude Coordinates and Month/Year	Longitude Grid Box #	Latitude Grid Box #	Time Slice #	Solar Insolation Value (W/m^2)	Outgoing Longwave Value (W/m^2)	Outgoing Shortwave Value (W/m^2)	Net Energy (W/m^2)
Longitude: *38.5˚W* ***Latitude:*** *72.6˚N* ***Time:*** *March 2000*	*322*	*163*	*1*	*117*	*146.4*	*84.05*	*-113.45*
Longitude: *38.5˚W* ***Latitude:*** *72.6˚N* ***Time:*** *June 2000*	*322*	*163*	*4*	*493.1*	*203.9*	*331.7*	*-42.5*
Longitude: *38.5˚W* ***Latitude:*** *72.6˚N* ***Time:*** *December 2000*	*322*	*163*	*10*	*0*	*154.4*	*0*	*-154.4*

Q6. After completing the Summit, Greenland Energy Budget data table, describe how the net energy in Summit changed from March 2000, to June 2000, to December 2000.
Net energy in Greenland increased from March to June and then decreased from June to December.

Q7. Why does Summit, Greenland have a negative net energy in June 2000 even though it has a high amount of incoming solar radiation?
The ice and snow on Greenland increases the reflectively of the insolation, therefore increasing the outgoing shortwave energy. This reduces the net energy.

Q8. Which component of the energy budget formula: Solar Insolation, Outgoing Longwave, or Outgoing Shortwave, would change the most for Summit, Greenland as Earth continues to warm in the future? Why?
Outgoing shortwave energy would change the most by decreasing.

Why: As the ice on Greenland melts, surface albedo decreases, resulting in more absorption of energy and less reflection. This will reduce the amount of outgoing shortwave energy.

Quito, Ecuador Energy Budget

Net Energy = Solar_Insolation – OutgoingLongwave – OutgoingShortwave

Latitude & Longitude Coordinates and Month/Year	Longitude Grid Box #	Latitude Grid Box #	Time Slice #	Solar Insolation Value (W/m^2)	Outgoing Longwave Value (W/m^2)	Outgoing Shortwave Value (W/m^2)	Net Energy (W/m^2)
Longitude: *78.5˚W* ***Latitude:*** *0.2˚S* ***Time:*** *March 2000*	*282*	*90*	*1*	*438*	*207.1*	*199.4*	*31.5*
Longitude: *78.5˚W* ***Latitude:*** *0.2˚S* ***Time:*** *June 2000*	*282*	*90*	*4*	*384.7*	*227.6*	*155.3*	*1.8*
Longitude: *78.5˚W* ***Latitude:*** *0.2˚S* ***Time:*** *December 2000*	*282*	*90*	*10*	*414.6*	*244.3*	*169.9*	*0.4*

Q10. After completing the Quito, Ecuador Energy Budget data table, describe how the net energy in Quito changed from March 2000, to June 2000, to December 2000.

Net energy in Quito decreased from March to June and then again from June to December.

Q11. Why is the net energy for each month in Quito positive?

Quito is located on the equator and is always exposed to a high angle of insolation no matter that time of year.

Q11. Why do you think Quito has a high value for outgoing shortwave energy for March 2000, June 2000, and December 2000?

Answers will vary – students may need to do additional research. Potential reasons could be increased aerosols in the region, widespread cloud cover, or snow/ice on top of the mountains in that region. All of these factors can increase albedo, leading to more reflection and therefore more outgoing shortwave.

Data Table for Longitude, Latitude, and Time Grid Boxes

Please note that positive longitudes represent degrees east and negative longitudes represent degrees west.
Please note that positive latitudes represent degrees north and negative latitudes represent degrees south.

Longitude Grid Box #	Longitude in ˚	Latitude Grid Box #	Latitude in ˚	Time Grid Box #	Month & Year
1	0.5	1	-89.5	1	Mar-00
2	1.5	2	-88.5	2	Apr-00
3	2.5	3	-87.5	3	May-00
4	3.5	4	-86.5	4	Jun-00
5	4.5	5	-85.5	5	Jul-00
6	5.5	6	-84.5	6	Aug-00
7	6.5	7	-83.5	7	Sep-00
8	7.5	8	-82.5	8	Oct-00
9	8.5	9	-81.5	9	Nov-00
10	9.5	10	-80.5	10	Dec-00
11	10.5	11	-79.5	11	Jan-01
12	11.5	12	-78.5	12	Feb-01
13	12.5	13	-77.5	13	Mar-01
14	13.5	14	-76.5	14	Apr-01
15	14.5	15	-75.5	15	May-01
16	15.5	16	-74.5	16	Jun-01
17	16.5	17	-73.5	17	Jul-01
18	17.5	18	-72.5	18	Aug-01
19	18.5	19	-71.5	19	Sep-01
20	19.5	20	-70.5	20	Oct-01
21	20.5	21	-69.5	21	Nov-01
22	21.5	22	-68.5	22	Dec-01
23	22.5	23	-67.5	23	Jan-02
24	23.5	24	-66.5	24	Feb-02
25	24.5	25	-65.5	25	Mar-02
26	25.5	26	-64.5	26	Apr-02
27	26.5	27	-63.5	27	May-02
28	27.5	28	-62.5	28	Jun-02
29	28.5	29	-61.5	29	Jul-02
30	29.5	30	-60.5	30	Aug-02
31	30.5	31	-59.5	31	Sep-02
32	31.5	32	-58.5	32	Oct-02
33	32.5	33	-57.5	33	Nov-02
34	33.5	34	-56.5	34	Dec-02
35	34.5	35	-55.5	35	Jan-03
36	35.5	36	-54.5	36	Feb-03
37	36.5	37	-53.5	37	Mar-03

38	37.5	38	-52.5	38	Apr-03
39	38.5	39	-51.5	39	May-03
40	39.5	40	-50.5	40	Jun-03
41	40.5	41	-49.5	41	Jul-03
42	41.5	42	-48.5	42	Aug-03
43	42.5	43	-47.5	43	Sep-03
44	43.5	44	-46.5	44	Oct-03
45	44.5	45	-45.5	45	Nov-03
46	45.5	46	-44.5	46	Dec-03
47	46.5	47	-43.5	47	Jan-04
48	47.5	48	-42.5	48	Feb-04
49	48.5	49	-41.5	49	Mar-04
50	49.5	50	-40.5	50	Apr-04
51	50.5	51	-39.5	51	May-04
52	51.5	52	-38.5	52	Jun-04
53	52.5	53	-37.5	53	Jul-04
54	53.5	54	-36.5	54	Aug-04
55	54.5	55	-35.5	55	Sep-04
56	55.5	56	-34.5	56	Oct-04
57	56.5	57	-33.5	57	Nov-04
58	57.5	58	-32.5	58	Dec-04
59	58.5	59	-31.5	59	Jan-05
60	59.5	60	-30.5	60	Feb-05
61	60.5	61	-29.5	61	Mar-05
62	61.5	62	-28.5	62	Apr-05
63	62.5	63	-27.5	63	May-05
64	63.5	64	-26.5	64	Jun-05
65	64.5	65	-25.5	65	Jul-05
66	65.5	66	-24.5	66	Aug-05
67	66.5	67	-23.5	67	Sep-05
68	67.5	68	-22.5	68	Oct-05
69	68.5	69	-21.5	69	Nov-05
70	69.5	70	-20.5	70	Dec-05
71	70.5	71	-19.5	71	Jan-06
72	71.5	72	-18.5	72	Feb-06
73	72.5	73	-17.5	73	Mar-06
74	73.5	74	-16.5	74	Apr-06
75	74.5	75	-15.5	75	May-06
76	75.5	76	-14.5	76	Jun-06
77	76.5	77	-13.5	77	Jul-06
78	77.5	78	-12.5	78	Aug-06
79	78.5	79	-11.5	79	Sep-06
80	79.5	80	-10.5	80	Oct-06

81	80.5	81	-9.5	81	Nov-06
82	81.5	82	-8.5	82	Dec-06
83	82.5	83	-7.5	83	Jan-07
84	83.5	84	-6.5	84	Feb-07
85	84.5	85	-5.5	85	Mar-07
86	85.5	86	-4.5	86	Apr-07
87	86.5	87	-3.5	87	May-07
88	87.5	88	-2.5	88	Jun-07
89	88.5	89	-1.5	89	Jul-07
90	89.5	90	-0.5	90	Aug-07
91	90.5	91	0.5	91	Sep-07
92	91.5	92	1.5	92	Oct-07
93	92.5	93	2.5	93	Nov-07
94	93.5	94	3.5	94	Dec-07
95	94.5	95	4.5	95	Jan-08
96	95.5	96	5.5	96	Feb-08
97	96.5	97	6.5	97	Mar-08
98	97.5	98	7.5	98	Apr-08
99	98.5	99	8.5	99	May-08
100	99.5	100	9.5	100	Jun-08
101	100.5	101	10.5	101	Jul-08
102	101.5	102	11.5	102	Aug-08
103	102.5	103	12.5	103	Sep-08
104	103.5	104	13.5	104	Oct-08
105	104.5	105	14.5	105	Nov-08
106	105.5	106	15.5	106	Dec-08
107	106.5	107	16.5	107	Jan-09
108	107.5	108	17.5	108	Feb-09
109	108.5	109	18.5	109	Mar-09
110	109.5	110	19.5	110	Apr-09
111	110.5	111	20.5	111	May-09
112	111.5	112	21.5	112	Jun-09
113	112.5	113	22.5	113	Jul-09
114	113.5	114	23.5	114	Aug-09
115	114.5	115	24.5	115	Sep-09
116	115.5	116	25.5	116	Oct-09
117	116.5	117	26.5	117	Nov-09
118	117.5	118	27.5	118	Dec-09
119	118.5	119	28.5	119	Jan-10
120	119.5	120	29.5	120	Feb-10
121	120.5	121	30.5	121	Mar-10
122	121.5	122	31.5	122	Apr-10
123	122.5	123	32.5	123	May-10

124	123.5	124	33.5	124	Jun-10
125	124.5	125	34.5	125	Jul-10
126	125.5	126	35.5	126	Aug-10
127	126.5	127	36.5	127	Sep-10
128	127.5	128	37.5	128	Oct-10
129	128.5	129	38.5	129	Nov-10
130	129.5	130	39.5	130	Dec-10
131	130.5	131	40.5	131	Jan-11
132	131.5	132	41.5	132	Feb-11
133	132.5	133	42.5	133	Mar-11
134	133.5	134	43.5	134	Apr-11
135	134.5	135	44.5	135	May-11
136	135.5	136	45.5	136	Jun-11
137	136.5	137	46.5	137	Jul-11
138	137.5	138	47.5	138	Aug-11
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142	141.5	142	51.5	142	Dec-11
143	142.5	143	52.5	143	Jan-12
144	143.5	144	53.5	144	Feb-12
145	144.5	145	54.5	145	Mar-12
146	145.5	146	55.5	146	Apr-12
147	146.5	147	56.5	147	May-12
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169	168.5	169	78.5	169	Mar-14
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171	170.5	171	80.5	171	May-14
172	171.5	172	81.5	172	Jun-14
173	172.5	173	82.5	173	Jul-14
174	173.5	174	83.5	174	Aug-14
175	174.5	175	84.5	175	Sep-14
176	175.5	176	85.5	176	Oct-14
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350	**-10.5**				
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356	**-4.5**				
357	**-3.5**				
358	**-2.5**				
359	**-1.5**				
360	**-0.5**				

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