Earth's Global Energy Budget Teacher Guide

Lesson Overview: Students will explore how energy from the sun is absorbed, reflected and radiated back out into space. They will complete a short lab investigating the effect of surface color, type of material (land or water) or clouds on temperature change to begin to think about how Earth's varying surfaces might affect overall temperature. Then they will explore Earth's Energy Budget through a video, demonstration activity, and interactive animation. As an extension, students will look at NASA data about absorbed and reflected energy and look for seasonal and geographical patterns.

Lesson is expected to take two 45-minute periods or one 90-minute block

Learning Objectives:

- Students will be able to describe how surface material type and color, as well as clouds above the surface, affect how the sun's radiation is absorbed on Earth's surface.
- Students will be able to describe what the Global Energy Budget is and how energy flows through the various parts of the Earth system.

National Standards:
ESS2.D - The ocean exerts a major influence on weather and climate by absorbing energy from the sun, releasing it over time, and globally redistributing it through ocean currents. Greenhouse gases in the atmosphere absorb and retain the energy radiated from land and ocean surfaces, thereby regulating Earth's average surface temperature and keeping it habitable.

MS-ESS2-6. Develop and use a model to describe how unequal heating and rotation of the Earth cause patterns of atmospheric and oceanic circulation that determine regional climates. *[Clarification Statement: Emphasis is on how patterns vary by latitude, altitude, and geographic land distribution. Emphasis of atmospheric circulation is on the sunlight-driven latitudinal banding, the Coriolis effect, and resulting prevailing winds; emphasis of ocean circulation is on the transfer of heat by the global ocean convection cycle, which is constrained by the Coriolis effect and the outlines of continents. Examples of models can be diagrams, maps and globes, or digital representations.] [Assessment Boundary: Assessment does not include the dynamics of the Coriolis effect.]*

From the Next Generation Science Standards, available at http://www.nextgenscience.org/.

Background Information:

The global energy budget describes the ways solar radiation from the sun is used in the various parts of the Earth system: atmosphere, hydrosphere, biosphere and geosphere. Depending on factors such as clouds and surface albedo (how much of the radiation hitting a surface is reflected versus being absorbed), the balance of the system can change. In a monetary budget, "balancing the budget" means knowing where all the money is spent, and having an equal amount coming in as going out. In the Earth system, instead of money, we think of energy. For the system to be balanced, all the energy coming from the sun must be accounted for, and the energy coming into the system must equal the energy leaving the system. An imbalance in the system (such as what has happened with the increase in greenhouse gases) can cause changes to temperature, precipitation patterns and sea level, among other effects. Although the lab activities described here are intended to help students grasp the way the system works and do not directly address these results, part of NASA's mission is to help understand and predict these environmental changes, both natural and human-caused.

For more detailed information, and an alternative activity see:
http://education.gsfc.nasa.gov/experimental/all98invproject.site/pages/trl/inv2-1.abstract.html

Materials:

Land vs. Water Lab (per group)	Albedo Lab (per group)	Clouds Lab (per group)
Thermometers (2) Lamp with heat bulb and stand Stopwatch Beakers or cups (2) Sand or soil Water Clothespins or binder clips (2)	Thermometers (2) Lamp with heat bulb and stand Stopwatch Large cups or other containers such as soda cans (2) Foam lids or caps Dark and light construction paper	Thermometers (2) Lamp with heat bulb and stand Stopwatch Black construction paper Two-liter soda bottles (2) Aluminum foil

Note: Each student will not complete all three labs, but instead be part of an "expert group" on one investigation, to share with their home group (or the whole class) at the end of the activities. Therefore, only two to three sets of each lab's materials will be need, depending on the size of the class.

Other materials – projector and computer to show videos, pie chart of energy budget (printed on large poster paper if possible) and labels (Figures A – E)

Slide page numbers refer to the *GPM Global Energy Budget Power Point*.

Engage: Discuss important vocabulary for the lesson: absorption, reflection, and radiation (*slide 3*). Look at an image of Earth and think about and discuss any factors that might affect how energy is absorbed, reflection or radiated from Earth *(slide 4).* To facilitate discussion, you may wish to show the animation of reflection and absorption *(slide 5).* Additional words that might need to be addressed if unfamiliar to students: albedo, conduction, convection, infrared *(slide 6). Optional:* create a word splash for absorption, reflection and radiation, especially with English Language Learners or other students who need additional vocabulary support. Slides for this purpose can be found at the end of the PowerPoint in the "Differentiation and Re-Teaching" section *(slides 28-30)*.

Explore: Divide students into groups, each of which will become experts on one Heating Earth's Surface lab investigation and share back results to a home group or the whole class *(slides 7-9)*.

Students will complete a lab sheet with data tables and a graph – each lab has its own customized worksheet. (See associated documents *GPM Global Energy Budget – Albedo Lab*, *GPM Global Energy Budget – Clouds Lab*, and *GPM Global Energy Budget – Land vs. Water Lab*.) In addition, there is a general capture sheet (*GPM Global Energy Budget – Student Capture Sheet)* for all students to complete during the engage discussion of vocabulary and the summaries of the labs and discussion afterward. An answer key is available for the student capture sheet, as well for the *Analyze and Conclude* section of the labs on request via http://gpm.nasa.gov/education/contact.

Teacher notes for labs:

Heating Earth's Surface: Land versus Water

- Plastic cups (or the bottoms cut off of two liter bottles for the cloud lab) may be easily substituted for the beakers.
- If available, electronic temperature probes (such as with Vernier LabQuest or PASCO Spark units) may be used instead of manually recording the data.
- A heat bulb will provide a greater temperature difference, but be sure to warn students about the additional heat generated. A regular incandescent bulb (at least 75 watts) can also be used. The metal shade of any light can warm significantly, and should be discussed as a safety issue before starting the experiment.
- This particular lab was written to be done early in the school year, hence all of the scaffolding of problem statement, hypothesis, etc. The worksheet could be modified to be more open-ended, depending on the level and experience of your students.

Heating Earth's Surface: Albedo

- Preparation of cups for experiment: (If you have more class time, you could have students do these steps – just add them to the beginning of the procedures.)
  1. Cut strips of dark and light construction paper to fit around the cups (or soda cans), and tape on the outside, covering the entire surface.
  2. Cut two pieces of foam to firmly fit like caps inside the top of each of the containers. (Manufactured plastic drink lids are too flimsy.)
  3. Cut slots in the caps to fit the thermometers, making sure there is a snug fit.

Heating Earth's Surfaces: Clouds

- To prepare the 2-liter bottles: Turn each empty soda bottle, with the cap on, upside down on a hard, level surface. Using a ruler, mark a 3-inch line from the cap on each bottle and cut across the bottle. Save the cut-off bottle tops with caps on; discard the bottom pieces or use them for the land versus water experiment above. Tape the cloud cut-outs to the front of one bottle, leaving the back clear to read the thermometer. Cut black construction paper to fit in the bottom of the bottles.
- Digital LCD thermometers, found in the aquarium section of pet stores, work especially well here.

After the students complete the labs, you could take time for each group to summarize the key points for the lab they did, or complete the exercise as a class to make sure they have appropriate notes *(slide 10)*. Alternatively, you could split into groups of three, one student who did each lab, to share.

Expected results: In the albedo lab, we would expect that the cup covered in a lighter color will heat up more slowly than one covered in a darker color. Cooling rates may be similar. In the land versus water, we expect the land to heat up and cool down more quickly, but the water to heat and cool slowly. For clouds, the expected result is that the container with clouds will heat and cool more slowly than the one without. If these are not the results your students get, it can be a wonderful opportunity to discuss possible sources of error, and why scientists do multiple iterations of an experiment before drawing conclusions.

Explain:

1. What is a budget? *(slide 11)* Discuss ideas about a budget with students first to make connections with their prior experiences. You could discuss what they know about their family's household budget, what they would do if someone gave them $100 to spend, what happens if you go over a budget, etc. This is also a time to introduce the idea of a balanced budget if you wish, which is discussed further in the video.

NASA Video Clip (length-4:30) - Real World: Monitoring Earth's Energy Budget with CERES *(slide 12)*. Learn how NASA uses a data-collecting sensor, Clouds and Earth's Radiant Energy System, or CERES, to study clouds and make accurate measurements of energy leaving Earth (http://www.youtube.com/watch?v=D_Qmue54W14). As students watch, they should note the main ideas from the video *(slide 13)*.

Some ideas students might write down:

- *Balancing Earth's radiation budget is like balancing a money budget – you need to keep track of where everything goes*
- *Satellites can measure the amount of energy Earth receives, and the amount it sends back into space using temperature estimates – ideally those two should be equal, giving a balanced radiation budget*
- *About 50% of the sun's energy is reflected by clouds or absorbed by the atmosphere.*
- *Darker surfaces (like oceans or rainforests) absorb more heat*
- *Lighter surfaces (like deserts and the polar regions) reflect more heat*
- *Energy absorbed by Earth's surface is converted to heat, some of which gets sent back out toward space (although some is trapped by the atmosphere due to the greenhouse effect)*
- *Satellite sensors and instruments on the ground show that Earth's temperature is rising due to the increase in greenhouse gases in the atmosphere caused by human activity.*
- *When ice melts, more ocean is exposed, which absorbs more radiation and increases the temperature.*

During the discussion is an opportunity to bring up a term the students will probably have heard: the Greenhouse Effect *(slide 14)*. It's important for students to realize that the

Greenhouse Effect is what allows us to sustain life on Earth. Without the atmosphere insulating heat, the planet would be very cold and life might not be able to survive. However, the issue with global warming is that there are MORE greenhouse gases in the atmosphere now that are causing the Earth to heat up faster than natural processes can regulate. The idea of balance is an important theme to reinforce throughout the lesson. For more information on climate change, and the most recent report of the Intergovernmental Panel on Climate Change, see http://www.ipcc.ch/. For further lessons to expand upon this topic, see GPM Climate Change Labs Teacher Guide and GPM Current Climate Change Evidence Teacher Guide.

2. Pie chart of Earth's Energy Budget *(slide 15)*

Preparation: If possible, make a large poster-sized version of the pie chart (Figure A), one per class. Trim the outside of the chart, leaving just a circle, before class to save time. Print Figures B-E. It may be useful to print them on cardstock and laminate them, and/or attach them to large craft sticks or dowels for students to hold.

Give four different students each one of the cards with the locations where energy can travel throughout Earth's system: Atmosphere, Clouds, Earth's Surface and Space. Assign a fifth student to be the "Energy Messenger."

The circle of the pie chart represents all the energy coming from the sun. The teacher, or another student, cuts each segment of the chart, and the Energy Messenger takes it on its path. For example, the 6% reflected by the atmosphere would start at the "Sun," be taken to the student holding the Atmosphere label to bounce off, and then be handed to the student holding the Space label.

The main idea is that students see a visualization of all the ways the energy travels, and note that while the energy gets used within the Earth's systems, and may say there for some time, it all eventually ends up back out in space for a balanced energy budget.

Important points for discussion:

- When the 51% that gets absorbed by the surface (land and oceans) is reached would be a good time to discuss what happens to that energy in the Earth's system, especially relating it to the water cycle and other needs of life on Earth (photosynthesis, etc.)
- The 4% that bounces off of the surface (as well as the absorption in the previous note) can easily be related to the previous lab. Which surfaces on Earth absorb more? Which reflect more?
- The absorption and reflection of clouds can be discussed. What would happen if there were more cloud cover on Earth? Less cloud cover?

3. After students have an idea about how the energy travels, they will look at a chart of the Global Energy Budget *(slide 16)*.

Questions to start the conversation:

- What is absorbing and reflecting the sun's energy? *Clouds, atmosphere and Earth's surface (land and oceans) all do both, but in different percentages.*
- Where is most of the energy being absorbed? *The greatest single place energy is absorbed is into the land and oceans, Earth's surface (51%)*
- What carries a large percentage of heat back into the atmosphere? *Latent heat in water vapor (the energy carried with the water when it evaporates) carries 23% of the energy back into the atmosphere. Radiation from Earth's surface is also absorbed into the atmosphere, heating it.*

If sufficient computers are available, or as a class, students can review an animated version of the Energy Budget available at http://earthguide.ucsd.edu/earthguide/diagrams/energybalance/, either as a replacement or extension of the original diagram.

4. To make the connection to satellite data, have students examine images of incoming and reflected radiation from MY NASA DATA (http://mynasadata.larc.nasa.gov/) and observe differences in seasons and surface material *(slide 17-20)*. For specific questions to guide the discussion, see the notes in the PowerPoint.

Evaluate: As a summary activity, have students respond to the questions: *Describe what the Global Energy Budget is and how it works. What would happen if the surface of Earth changed to be more or less reflective? If there were more or less clouds all the time? How are the oceans and other water on Earth important to the Global Energy Budget? (slide 21).*

Answers may vary. Sample answer: "The global energy budget is how Earth 'spends' its energy, basically where and how it gets absorbed for use in the Earth system, radiated into the atmosphere or back into space, or reflected. If Earth's surfaces become more reflective (surfaces such as ice, snow or desert), less energy will be absorbed, making the temperature cooler. If Earth's surfaces become less reflective (more oceans and forests), more energy will be absorbed, making the temperature warmer. Clouds tend to reflect energy back into space, so more clouds would tend to reduce the temperature, while fewer clouds could increase the temperatures. Oceans absorb a lot of heat, so they are a key part of the global energy budget. When ice melts and reveals the ocean (or land) underneath, that changes the way energy is absorbed and affects the budget."

Elaborate/Extend:

- The video "Aqua CERES: Tracking Earth's Heat Balance" *(slide 23)* discusses similar themes as the video on slide 12, but with a few more details added (length – 3:25, http://youtu.be/gW-CNX6koM8). However, it is not geared specifically toward students. For more on CERES, see http://ceres.larc.nasa.gov/.

- Animations on *slide 24* and *slide 25* relate to the maps on *slide 19* and *slide 20*, but show the progression through the months for several years. It may be helpful for students to be able to see more continuous data, but you may need to use your web browser to zoom in to make the animation more easily visible. For more information, see the PowerPoint notes or go to: http://svs.gsfc.nasa.gov/goto?3096 and: http://svs.gsfc.nasa.gov/goto?3089.

- For another way to look at the seasonal patterns in albedo, see the composited image on *slide 25*. Students should be able to notice the increased reflectivity in the northern winter months, and also see that there is some variation year to year. For more detailed information on this diagram see the PowerPoint notes or go to http://photojournal.jpl.nasa.gov/catalog/PIA0437 8

- To differentiate for students who need more vocabulary background, you might spend time doing a word splash/word web for the key vocabulary terms, radiation reflection, and absorption (*slide 28-30*).

- If students are having trouble with the complex Global Energy Budget diagram viewed previous, a much simpler version is available (*slide 31-32*). This diagram is designed to be used interactively on a smart board - drag each statement to the corresponding arrows/areas. Being able to move around the phrases may help some students get a better grasp of the energy budget. See the end of the student capture sheet for a worksheet for students to record where the various percentages belong.

- The discussion of the lab results could lead very naturally into a discussion of other reasons for temperature differences – specifically, latitude and its effect. For example, the conclusion questions for the Land vs. Water lab ask students to compare two cities at a similar latitude, but one close to water (Seattle), and the other far inland (Bismarck). A continuation of that discussion about the absorption of solar radiation by difference surfaces could be to ask how those results may vary between places with a widely varying latitude such as Florida and Alaska or during summer versus winter, leading to a conversation about the influence of latitude and Earth's tilt. The albedo of Earth's surface will also change significantly due to latitudinal differences in land cover (for example jungles near the equator versus temperate deciduous forests at higher latitudes, or seasonal differences in ice cover near the poles). Cloud cover can also vary by latitude and season (for example, the heavy cloud cover during winter for Seattle, compared to the relatively clearer sky in summer, or the generally cloudier latitude belts such as around the equator). Another aspect of the discussion could be water vapor, considered a 'wild card' in terms of global warming. Water vapor is a greenhouse gas – in fact, the most abundant greenhouse gas on Earth. More heat in the Earth system means more evaporation and more water vapor, but also means more clouds that reflect radiation back into space cooling Earth, making the effect of water vapor on climate change difficult to predict.

Additional Resources:
Earth's Albedo and Global Warming - This interactive activity adapted from NASA and the U.S. Geological Survey illustrates the concept of albedo—the measure of how much solar radiation is reflected from Earth's surface.
http://www.pbslearningmedia.org/resource/ipy07.sci.ess.watcyc.albedo/earths-albedo-and-global-warming/

MY NASA DATA Lesson Plan –Variables Affecting Earth's Albedo
https://mynasadata.larc.nasa.gov/lesson-plans/lesson-plans-middle-school-educators/?page_id=474?&passid=63

MY NASA DATA Lesson Plan – Comparing Graphs of Temperature and Radiation
https://mynasadata.larc.nasa.gov/lesson-plans/lesson-plans-middle-school-educators/?page_id=474?&passid=70

To extend the discussion about balancing Earth's energy budget, here is a video discussing how the greenhouse effect keeps more of the sun's heat and energy with Earth's atmosphere causing temperatures on Earth to rise. http://gpm.nasa.gov/education/videos/launchpad-global-warming-how-humans-are-affecting-our-planet

Professional development modules for teachers about various aspects of climate change, from a discussion of human responsibility for climate change, to coastal consequences of sea level rise, and including engineer and STEM career connections (a collaboration between NASA and PBS). http://www.pbs.org/teachers/stem/professionaldevelopment/

Global Energy Budget Pie Chart

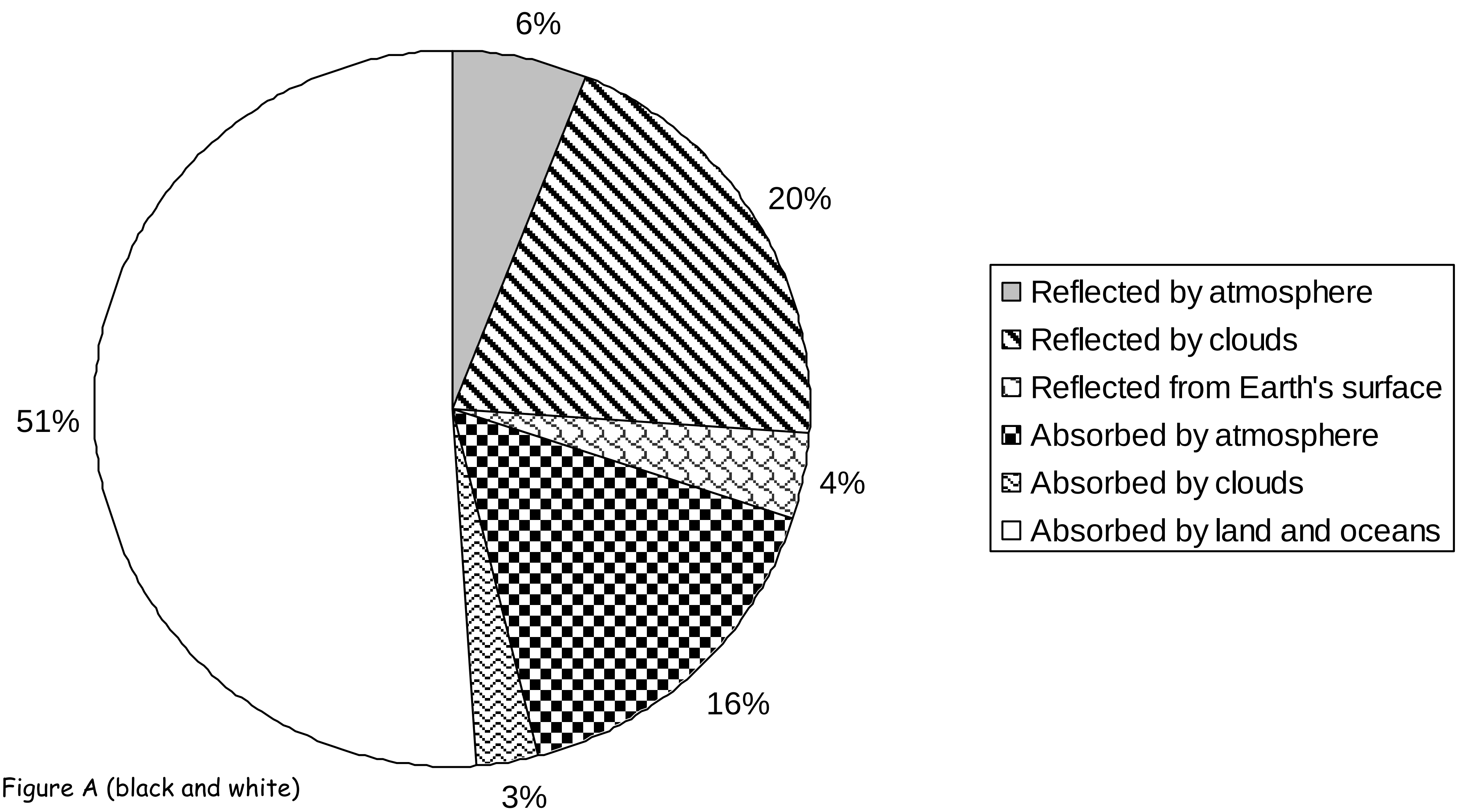

Figure A (black and white)

Global Energy Budget Pie Chart

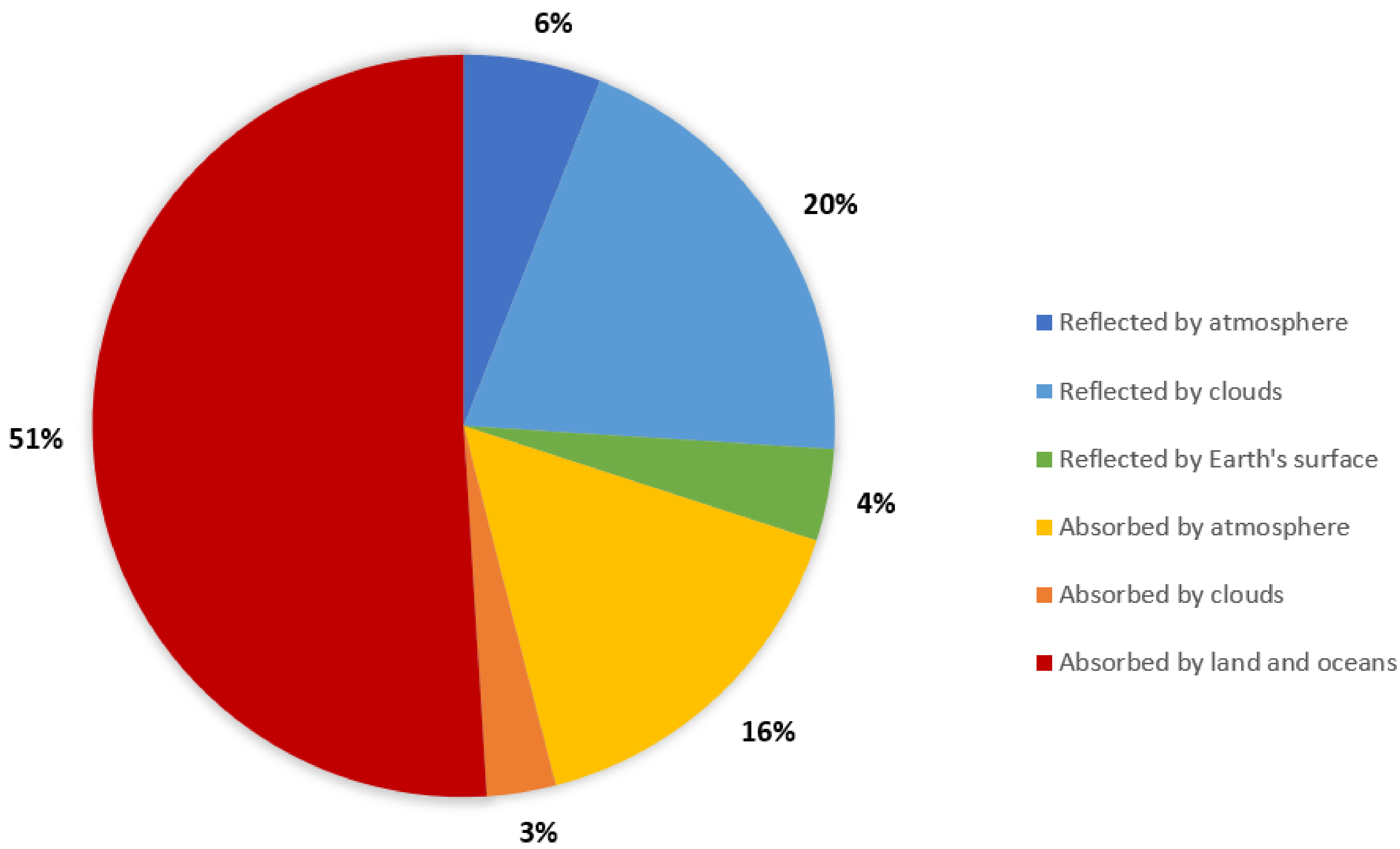

Figure A (color)

Atmosphere

Figure B – Image source: Expedition 13 Crew, International Space Station, NASA, http://apod.nasa.gov/apod/ap070320.html

Clouds

Figure C – Image source: NOAA/Historic NWS Collection, http://www.nasa.gov/centers/goddard/earthandsun/icesat_light.html

Earth's Surface

(land and oceans)

Figure D – Image source: NASA image courtesy Reto Stöckli and Robert Simmon, http://earthobservatory.nasa.gov/Features/BlueMarble/

Space

Figure E – Image source: NASA/JPL-Caltech, http://photojournal.jpl.nasa.gov/catalog/PIA09958