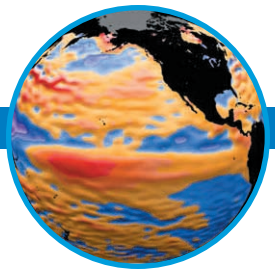
Educational Product	
Educators	Grades 5–8



Investigating the Climate System

CLOUDS

And the Earth's Radiant Energy System

PROBLEM-BASED CLASSROOM MODULES

Responding to National Education Standards in:

English Language Arts ◆ Geography ◆ Mathematics
Science ◆ Social Studies

Investigating the Climate System

CLOUDS

And the Earth's Radiant Energy System

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NOTE: This module was developed as part of the series "Investigating the Climate System." The series includes five modules: **Clouds, Energy, Precipitation, Weather,** and **Winds.** While these materials were developed under one series title, they were designed so that each module could be used independently. They can be freely downloaded at:
http://www.strategies.org/CLASS.html

June 2003

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Investigating the Climate System

CLOUDS

And the Earth's Radiant Energy System

SCENARIO ***After accepting appointments to work as weather interns in the State Climatology Office, students will be given their first task—to find answers and respond to a letter from a very frustrated third-grade student requesting help with an unwanted assignment about clouds. (See Activity Six on p. 11.) In order to help the younger student, the interns will need to conduct preliminary investigations to gain knowledge on: cloud formation, cloud classification, and the role of clouds in heating and cooling the Earth; how to interpret TRMM images and data; and the role clouds play in the Earth's radiant budget and climate.***

GRADE LEVELS

Grades 5–8

TIME REQUIRED

45 minutes per investigation

OBJECTIVES

The students will:

- Model and explain cloud formation.
- Sketch and classify clouds according to height, shape, and optical thickness.
- Calculate and compare incoming and outgoing radiation.
- Describe how cloud properties affect the Earth's radiant budget.
- Identify aerosols in the Earth's atmosphere.
- Make climate predictions based on future increases or decreases of certain cloud types.
- Respond to the third-grade student's letter, answering specific questions asked by the student.

DISCIPLINES ENCOMPASSED

Earth science, space science, math, language arts

KEY TERMS & CONCEPTS

aerosols
albedo
climate
clouds, cloud formation and classification
collision coalescence
condensation
condensation nuclei
evaporation
greenhouse gases
insolation
latent heat of condensation
latent heat of vaporization
net radiation
nuclei
optical depth
precipitation
radiant budget
water cycle
water vapor

PREREQUISITE KNOWLEDGE

CLOUD FORMATION

When liquid water (L) is heated by sunlight, the water often evaporates, becoming **water vapor** (V):

$H_2O_{(L)}$ + heat = $H_2O_{(V)}$

liquid water + heat = water vapor

The water vapor is carried high in the sky by warm air rising from the Earth's surface. As the air rises, it cools, and eventually turns back into water. The process of water changing from gas to liquid is called **condensation**. Heat is released into the environment when this happens.

Scientists have found that liquid water in the air and cold temperatures are not enough to form **clouds.** Microscopic particles of dust, pollen, or salts, called **condensation nuclei,** are also necessary because they provide a surface for the water molecules to collect on. As the water molecules become larger, they get heavier and gravity causes them to fall to the Earth as **precipitation,** such as rain, snow, or ice. This whole process of **evaporation**, condensation, precipitation, and accumulation of water on the Earth is commonly referred to as the **water cycle.**

CLOUD CLASSIFICATION

Clouds are generally classified according to their appearance, composition, and height. Words from the Latin language are used to describe the shape of clouds. Clouds that appear in layers are called "stratus," which in Latin means "layered." Clouds that look puffy are called "cumulus," which is Latin for "heap." High, thin, wispy clouds are called "cirrus," which is Latin for "curl of hair." Clouds may also be classified according to their height—as high, mid-level, or low, depending on how high the bottom of the cloud, called the base, is from the surface of the Earth. The amount of water vapor in a cloud, its composition, and its height all affect the amount of the Sun's radiation that reaches the Earth's surface.

CLOUDS AND THE EARTH'S RADIANT BUDGET

The Earth constantly tries to maintain a balance between the energy that it receives from the Sun and the energy it emits back out to space. The balance between incoming and outgoing energy is referred to as the Earth's **radiant budget.** Clouds play an important role in maintaining this energy balance because they can reflect, absorb, and radiate energy. Whether a cloud will act to warm or cool the Earth depends on the cloud's altitude, composition, thickness (or, **optical depth**—a measure of the amount of sunlight that passes through), and size.

Cloud cover affects both incoming solar radiation, or **insolation,** and outgoing infrared radiation (reflected and radiated by the Earth), playing an important role in the heating and cooling of the Earth. Understanding cloud effects requires some knowledge of how clouds absorb and reflect incoming shortwave solar energy (insolation), as well as how they absorb and reemit outgoing infrared longwave energy.

The Clouds and the Earth's Radiant Energy System (CERES) instrument, carried by the TRMM (Tropical Rainfall Measuring Mission) satellite, is designed to measure reflected and radiant energy coming from the Earth's surface and atmosphere, including clouds. Using data from CERES, scientists hope to better understand the Earth's energy balance. Using very high-resolution cloud-imaging instruments, CERES can help scientists determine the cloud properties mentioned before, including cloud-fraction (percentage of the sky covered by clouds), altitude, thickness, and the size of cloud particles—all of which affect the amount of radiation transmitted, reflected, or absorbed by clouds.

CLOUDS AND CLIMATE CHANGE

Studying clouds is a top priority among many atmospheric scientists because clouds are one of the greatest unknown factors in predicting changes in the Earth's climate. **Climate** is the weather at a particular place averaged over a long period of time, at least thirty years. Clouds can affect climate because they influence the amount of solar energy reaching the Earth and the amount of outgoing infrared radiation leaving the Earth. The Earth's climate also affects cloud formation. Both nature and human activities cause changes in the Earth's atmosphere. For example, a change in climate can increase or decrease the amount of heat that causes water to evaporate, or, increased pollution can cause an increase in condensation nuclei. Clouds can form, change, or break up in seconds. Not knowing in advance which type of clouds will form makes it difficult to predict the future climate of the Earth. As you probably already have observed, different types of clouds normally exist simultaneously. What cloud combination will appear depends on factors such as current weather conditions at different levels of the atmosphere.

Nature gave scientists an example of how even a small change in cloud cover could have a significant effect on the Earth's climate with the volcanic eruption of Mt. Pinatubo in the Philippines in June of 1991. During the eruption, huge clouds of gas and tiny particles of ash were sent high into the atmosphere, which kept sunlight from hitting and warming the surface of the Earth. Winds helped carry the cloud particles all over the globe, and during this period the overall climate of the Earth cooled.

Student Weather Intern
TRAINING ACTIVITIES

In order to find answers for the third-grade student's questions about clouds, you, the student weather interns, will: 1) share what you think the answers are to the following questions; and then 2) conduct a series of hands-on experiments and online weather studies. All observations and investigations should be recorded in your journal.

Activity One: **Brainstorming**

Brainstorm together to answer the following questions:

- What are clouds?
- Where do they come from?
- Why don't they look the same?
- Why are there sometimes clouds in the sky that don't rain or snow?
- How do I study clouds if I can't reach them?
- Why is it even important to study clouds?

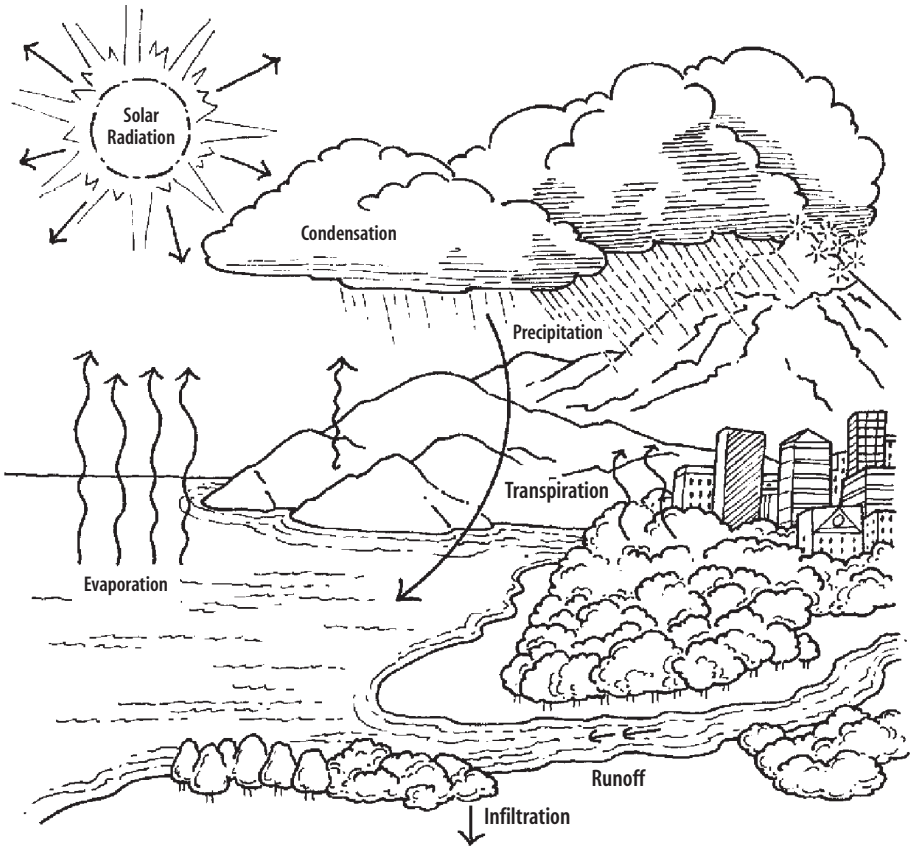
Activity Two: **Cloud Formation**

FOCUS QUESTION:
What are clouds and how do they form?

DESCRIPTION

As student weather interns, you need to understand the water cycle and **cloud formation**. After conducting the "Cloud in a Bottle" experiment on the next page, you should have a clearer understanding of both. Keep a log of your studies and find a creative way to share your findings, which explain the water cycle and the process of cloud formation, to your supervisor.

In your journal, identify and describe each process illustrated in the water cycle diagram below.



EXPERIMENT:

Cloud in a Bottle

By conducting this experiment, you will witness the processes of cloud formation firsthand. Think about how you will share this information with your third-grade student, who wants to know how clouds are formed.

Materials

- Clear plastic bottle with cap
- Enough water to wet the bottom of the bottle
- Incense stick (or you can use a paper match)
- Matches

Procedure

1. Pour water into the bottle, place the cap on, and shake for 30 seconds.
2. Squeeze the bottle—What effect does this have on the environmental conditions inside the bottle? Now release the pressure on the bottle. What effect does this have on the environmental conditions inside the bottle? Did a cloud form?
3. After smoke from the incense or paper match is placed in your bottle, quickly place the cap on and then repeat Step 2.

   This time, did the cloud appear when you squeezed or when you released the bottle?

   What's happening when you do this (i.e., what condition has been provided for clouds to form)?

Using the knowledge you gained from your experiment, provide a written explanation to your supervisor on how clouds form in the atmosphere.

Activity Three: **Cloud Classification**

FOCUS QUESTION:
Why don't all clouds look the same?

DESCRIPTION

As an intern, you have been asked by your supervisor to classify the clouds outside your school over a three-day period. What do you need to know in order to do this? Where would you go to find this information? In your journal include:

1. What you need to know.
2. How/where you will get that information.
3. The information you have gained.
4. Your observations after applying this information. Be sure to include date, time, location, cloud type, cloud altitude, percent cloud cover, and any additional atmospheric conditions necessary.

EXTENSIONS

1. Students can participate in CERES studies by conducting surface cloud observations as a CERES satellite instrument passes over their school. Students can send their cloud data to NASA's Langley Archive Center, where the data will be stored for analysis by the CERES science team. For further information about the S'COOL (Students' Cloud Observations On-line) project, visit their Web site: ***http://asd-www.larc.nasa.gov/SCOOL.*** You can download the S'COOL Report Form at: ***http://asd-www.larc.nasa.gov/SCOOL/forme-ol.pdf***
2. Log onto the site below to interact with a GOES satellite image and see the effects of changing a cloud's height and temperature: ***http://cimss.ssec.wisc.edu/wxwise/satir/IRCloud.html***

Activity Four: Clouds and the Earth's Radiant Budget

FOCUS QUESTION #1:
Do clouds affect the temperature and atmosphere of the Earth?

DESCRIPTION

Your supervisor is giving a presentation on the role clouds play on the Earth's radiant budget and needs help researching the topic. After conducting the following experiment, you need to provide your supervisor with a description of the Earth's radiant budget and the role clouds play.

EXPERIMENT:
Clear Vs. Cloudy

Materials

- Two empty 2-liter soda bottles with caps. 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.
- Infrared heat lamp
- Two pieces of black construction paper, cut into circles, that will fit under each bottle
- Two LCD thermometers (found in most pet supply stores in the aquarium section)

- Thermometer to record the air temperature of the room
- Enough cloud patterns cut out of white copy paper to cover the front side of one soda bottle
- Tape to adhere the cloud patterns onto the front of one bottle

Setup

1. Tape the cloud pattern cutouts to the front of one bottle.
2. Place the infrared heat lamp approximately 8–10 inches in front of the bottles, but do not turn it on. Place the lamp so that the light will shine on the front of the bottles, not down on them, leaving the back of the cloud bottle clear for reading temperature changes.
3. Position the bottles so that each will receive an equal amount of light from the lamp. Make sure the clouds covering the front of one bottle face the lamp, blocking some or all of the lamp's light.
4. Under each bottle, place a black construction paper circle, with a thermometer positioned on top of the circle. Make sure you can read the temperature while looking through the backs of the bottles (i.e., the numbers aren't upside down).
5. Position the air temperature thermometer away from the heat lamp and any other direct heat sources.

Procedure

1. In your journal, record the starting time and temperature for all three thermometers.
2. Turn on the light source and in 5 minutes, record the time and temperature for all three thermometers.
3. Turn off the light source, move it away from the bottles, and observe the changes in the thermometer readings. In 5 minutes, record the time and temperature for all three thermometers.
4. Describe the similarities and differences between the two bottles. Are the results the same or different? Why? What condition would each bottle represent in the natural environment?

EXTENSIONS

No. 1: MATH

Construct and analyze a line graph comparing clear and cloudy sky (day and night) temperature data.

MATERIALS (per group)

- Stopwatch with a second hand
- Student-constructed chart, used to record day and night temperatures for clear and cloudy sky data
- Seven students, each assigned to time, monitor, or record specified data

STUDENT JOBS

1. Assign a student to call out "time" every 20 seconds during the experiment.
2. Assign a student to monitor and call out temperatures every 20 seconds for:
   - The clear sky thermometer
   - The cloudy sky thermometer
   - The room air temperature thermometer
3. Assign a student to record temperatures for:
   - The clear sky thermometer
   - The cloudy sky thermometer
   - The room air temperature thermometer

ALTERNATE: Follow the "Clear vs. Cloudy" experiment procedures, with the modification of collecting data every 20 seconds instead of after 5 minutes. Then, construct a line graph to demonstrate what happens to temperatures under clear and cloudy sky conditions during the day and night. A key should be included as well as an analysis of the data graphed.

No. 2: TECHNOLOGY INTEGRATION

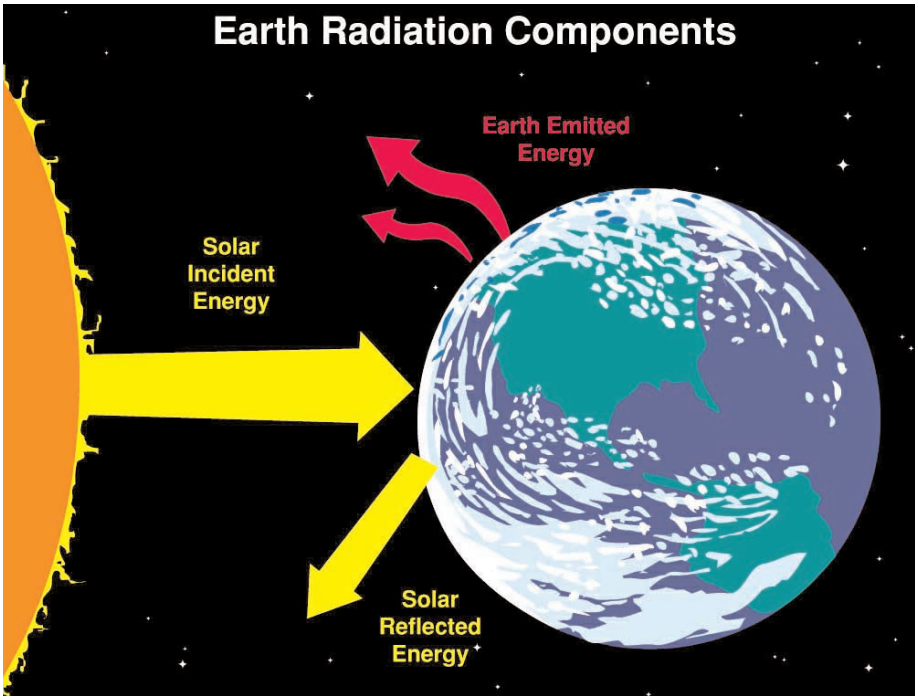
Insert temperature probes into tight holes in the bottle caps, which have been drilled prior to class. Use graphing calculators (if available) to record temperatures every 20 seconds, and after completing the experiment, analyze the graphed data.

No. 3: THE EARTH'S RADIANT BUDGET

The Earth's radiant budget is the amount of energy the Earth absorbs from the Sun compared to the amount of heat energy that escapes back into space.

THINK ABOUT IT

1. If the Earth receives more solar radiation than it sends back into space, what would happen to the temperature of the Earth?
2. What would happen to the temperature of the Earth if it released more energy into space than it received from the Sun?
3. What radiant energy situation is necessary in order to avoid a drastic change in the overall temperature of the Earth?



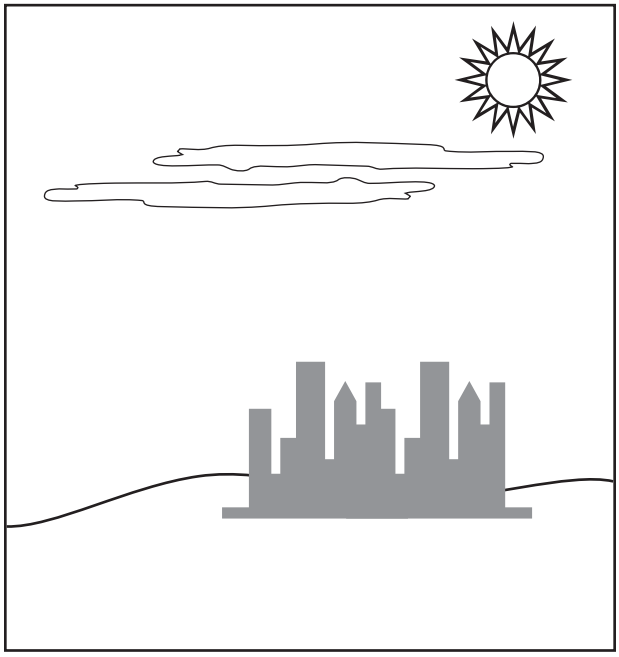
FOCUS QUESTION #2:
What role do clouds play in maintaining the energy balance of the Earth?

CLOUDS AND RADIATION

Insolation: Incoming Solar Radiation

High, thin cirrus clouds in the Earth's atmosphere are highly transparent to shortwave (or incoming) radiation and will transmit most of it to warm the Earth (insolation). However, these clouds readily absorb outgoing longwave radiation, reemitting both out to space and back to the Earth's surface.

DIAGRAM #1: DIRECTIONS
Draw arrows to mark the expected path of radiation coming from the Sun and Earth in the presence of high, thin cirrus clouds. Use yellow for shortwave radiation and red for longwave infrared radiation. Include this page in your journal. What is the overall effect of high, thin clouds on the Earth system?



YELLOW: shortwave (incoming) radiation

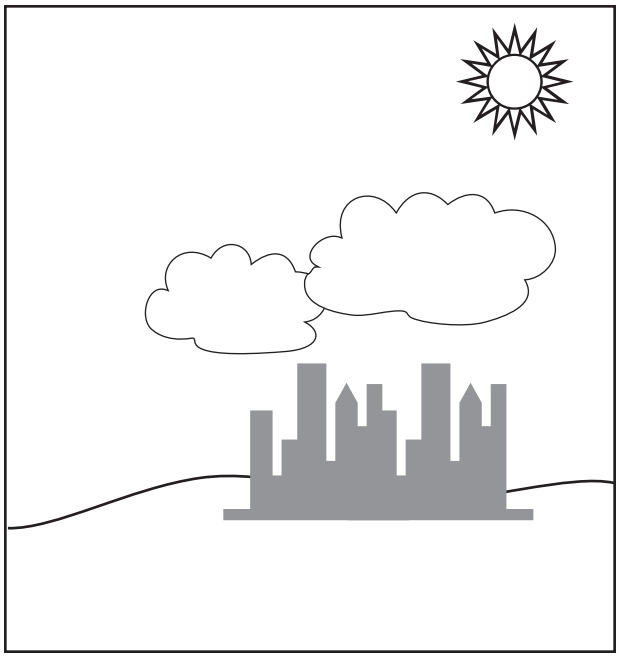
RED: longwave (outgoing) infrared radiation

The overall effect of high, thin cirrus clouds is warming of the Earth system.

Outgoing Radiation from the Earth System

Low, thick clouds such as stratocumulus clouds reflect incoming solar radiation back to space, causing cooling of the Earth system.

DIAGRAM #2: DIRECTIONS
Draw arrows to mark the expected path of radiation coming from the Sun and Earth in the presence of low, thick stratocumulus clouds. Use yellow for shortwave radiation and red for longwave infrared radiation. Include this page in your journal. What is the overall effect of low, thick clouds on the Earth system?



YELLOW: shortwave (incoming) radiation

RED: longwave (outgoing) infrared radiation

The overall effect of low, thick clouds is cooling of the Earth system.

CALCULATING THE EARTH'S RADIANT BUDGET

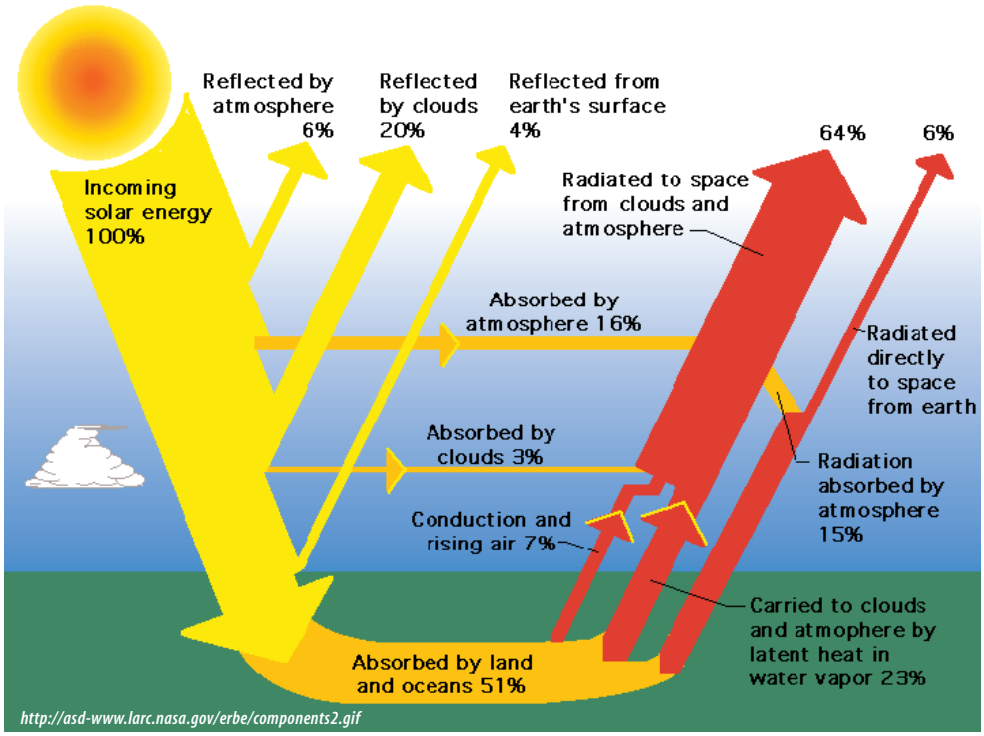
Directions

Using the diagram on the next page, ***determine if the Earth's radiant budget is in balance,*** meaning that the amount of insolation is equal to the amount of outgoing radiation. Show all your work in your journal. Is it balanced? Why or why not?

Think About It

What do you think would happen to the temperature of the Earth if outgoing infrared radiation were unable to escape to space?

Earth's Radiant Budget = Total of incoming energy from the Sun – the total energy leaving the Earth



EXTENSION

CERES Cloud Effects Animation

To see a short animation, which allows viewers to see how high and low clouds affect radiation entering and leaving the Earth, go to the NASA Langley Research Center Web site: ***http://lava.larc.nasa.gov.*** Enter "LV-1997-00003" as the search term. Play the animation several times.

OBSERVE: The high, thin clouds allow most solar radiation to pass through (as noted by the thick yellow arrow) and trap most of the infrared radiation leaving the Earth. The low, thick cloud primarily reflects most of the solar radiation and lets most of the infrared radiation pass through; because they are close to the surface of the Earth, low clouds are generally warmer compared to high clouds.

COMPARE OUTCOMES: Have student groups compare their results. Were they the same? Different? Why?

Activity Five: Clouds, Climate, and the Unpredictable Future

FOCUS QUESTION:
Why is it even important to study clouds?

DESCRIPTION

Each student intern is expected to make a presentation to your colleagues regarding information you have learned. Your supervisor has provided you with the following questions to guide you in your presentation. You must first provide written answers to your supervisor, with a resource list, and then prepare a presentation. Your only requirement for the presentation is that you accurately address the issues presented to you; how you do this is up to you. You can work with up to two additional interns.

Question #1: Speculate on what would happen to cloud formation and the future climate of the Earth if the temperature of the Earth increases. How would cloud types affect the Earth's temperature?

Question #2: Research TRMM aerosol/climate prediction data in order to investigate the theory that some **aerosols** inhibit cloud formation and, therefore, rainfall.

EXTENSIONS

Question #1: Speculate with Scientists—Scientists have observed that there is an increase of **greenhouse gases** in the atmosphere, and they know that greenhouse gases cause warming. These observations have led to a new scientific question to be answered. As a student weather intern, it is your job to help your supervisor answer the following question:

If the temperature of the Earth increases, how will this affect cloud formation and the future climate of the Earth?

Question #2: Speculate with Scientists—Another unknown is the effect increased aerosols (tiny particles suspended in the atmosphere, such as smoke, ash, and dust) will have on cloud formation. Whether an aerosol reflects or absorbs radiation depends upon the type and size of the aerosol. Generally, because aerosols are very small, they are unable to absorb a lot of radiation; instead, they tend to scatter the radiation, which causes cooling. Aerosols are important components to cloud formation; water vapor in the Earth's atmosphere needs those tiny particles to condense upon. If these particles were not in the atmosphere, clouds would not exist—a conclusion reached by scientists in laboratory studies. Without clouds, there would be no rain or other precipitation.

Scientists have collected data from the TRMM satellite indicating that there are clouds polluted with aerosols that are inhibiting rainfall. Microwave sensors have detected ample water within these clouds, but for some unknown reason, rain has been inhibited from falling. This leads to a new scientific question to be answered. As a student weather intern, it is your job to help your supervisor answer the following question:

If the clouds have sufficient water, why isn't it raining?

INVESTIGATION OR DEMONSTRATION:
Cloud/Water/Light

NASA Langley Research Center

Materials

- Two clear dessert-size dishes
- Equal amounts of ice cubes and crushed ice

Procedure

Take the two dishes and fill one with ice cubes and the other with an equal amount of crushed ice. Observe if there is any difference between the reflected light coming from each dish.

Analysis

1. Which form of ice, representing water droplet size, reflected more light?
2. How were you able to determine which dish of ice reflected more light?
3. Since there were equal amounts of ice in each of the dishes, how was it possible for one dish of ice to reflect more light?

WHAT'S NEXT?

For now, the role of clouds in regulating the climate of the Earth remains a mystery. However, through continued research, scientists hope to form a better understanding of the role clouds play in climate change, and how changes in the Earth system affect climate. Explain to the third-grade student what you have learned about the importance of studying clouds.

HOW YOU CAN HELP

1. Participate in NASA's S'COOL project (Students' Cloud Observations On-line) at: ***http://asd-www.larc.nasa.gov/SCOOL*** to help NASA scientists by providing "ground truth" used to confirm CERES satellite data.
2. Reduce aerosol use and the emission of greenhouse gases into the atmosphere.
3. Recycle to conserve the Earth's resources and to help prevent harmful changes in the Earth system.
4. Become informed about land-use issues.
5. Become informed by reading about global climate and environmental issues, often found in the world and local sections of the newspaper and in the environmental sections of news magazines.

Activity Six: **Final Student Weather Intern Project**

Well, you have worked hard this summer and have almost completed your internship. Your final task is below; use the information you have gained to complete the task. You can use any format you like (written, pictorial, video, etc.).

Office of Climatology Memorandum

Date: April 10
To: Student Interns
From: Intern Supervisor / Brian W. Smith
Subject: Response to student inquiry regarding clouds

Please demonstrate the knowledge you have gained as an intern to respond to the enclosed student letter requesting information about clouds. Keep in mind as you answer all of the student's questions that you are writing to a student on a third-grade level. Feel free to use creative ways to explain the information.

I hope you have enjoyed working as an intern in our office and look forward to reading your letter and reviewing presentation products in the near future.

CC: Your Teacher

March 31

Dear State Climatologist Office People,

My name is Mason and I'm in the 3rd Grade and my teacher, Miss Smith, said I have to do a report about clouds and I need some help!!! I looked at clouds and have a lot of questions. My mom says I should write to you. What I want to know is:

What are clouds made of? I haven't been able to touch any because they're too high.

Where do clouds come from?

How come clouds don't all look the same?

Why are there sometimes clouds in the sky that don't rain or snow?

How am I supposed to study clouds if I can't reach them?

Why is it even important to study clouds? Hey, are any real scientists studying clouds?

Please help me find answers to my questions and try to write back soon because my report's due next week. Thanks!

Your Friend,
Mason
Mason Robert Kane

APPENDIX A

Resources

Journals:

AMS Newsletter, published by the American Meterological Society

The Earth Scientist, published by the National Earth Science Teachers Association

Geotimes, published by the American Geological Institute

GSA Today, published by the Geological Society of America

Journal of Geography, published by the National Council for Geographic Education

Journal of Geoscience Education, published by the National Association of Geoscience Teachers

Nature, Macmillan Publishers

Science, published by the American Association for the Advancement of Science

Scientific American

Weatherwise, Heldref Publications

APPENDIX B

Assessment Rubrics & Answer Keys

Rubric: Activity One

SKILL	Outstanding	Very Good	Good	Fair	Poor
Actively participated in class					
Tried to answer					
Used creativity in answering					
Was polite and worked well with the others in the classroom					

Rubric: Activity Two

SKILL	Outstanding	Very Good	Good	Fair	Poor
Acted appropriately during experiment					
Was polite and worked well with others					
Actively participated					
Kept detailed log					
Log contained all the appropriate information					
Accurately identified the key parts of the water cycle					
Accurately described the water cycle					
Correctly answered questions posed					
Accurately described the process of cloud formation to supervisor					
Used creativity in describing the process of cloud formation to supervisor					

Rubric: Activity Three

SKILL	Outstanding	Very Good	Good	Fair	Poor
Gathered appropriate/accurate information					
Gathered detailed information					
Used multiple resources					
Used reliable resources					
Accurately classified observed clouds					
Included all appropriate information during cloud classification					

Rubrics: Activity Four

FOCUS QUESTION #1

SKILL	Outstanding	Very Good	Good	Fair	Poor
Acted appropriately during experiment					
Was polite and worked well with others					
Actively participated					
Kept detailed log					
Log contained all the appropriate information					
Provided a detailed and correct description of the similarities between the three bottles					
Provided a detailed and correct description of the differences between the three bottles					
Correctly applied knowledge to analyze the outcome of the experiment					
Accurately applied experiment to the natural environment					
Accurate definition/description of the Earth's radiant budget					
Accurate definition/description of the role of clouds in the Earth's radiant budget					

FOCUS QUESTION #2

SKILL	Outstanding	Very Good	Good	Fair	Poor
Correctly filled in first diagram (high, thin clouds)					
Clear and accurate description of the overall effect of high, thin clouds on the Earth's system					
Correctly filled in second diagram (low, thick clouds)					
Clear and accurate description of the overall effect of low, thick clouds on the Earth's system					
Work shown for calculation of the Earth's radiant budget					
Calculations for the Earth's radiant budget are correct					
Applied calculation to explain whether the Earth's radiant budget is balanced					

Rubric: Activity Five

SKILL	Outstanding	Very Good	Good	Fair	Poor
Conducted detailed research to answer questions					
Used previous knowledge gained in the answer to Question 1					
Used previous knowledge gained in the answer to Question 2					
Used previous knowledge gained in the answer to Question 3					
Included multiple resources					
Included reliable resources					
Provided detailed, accurate answers to all questions					
Included answers to all 3 questions in presentation					

Rubric: Activity Six

SKILL	Outstanding	Very Good	Good	Fair	Poor
Applied information gained from research to answer questions					
All questions were answered					
Answers provided accurate information					
Answers are thorough, including all important information					
Answers are appropriate for a third grader					

Answer Key: Activity Two

Clouds in a Bottle Experiment

2. What effect does squeezing the bottle have on the environmental conditions inside the bottle?
   Squeezing the bottle increases the air pressure inside the bottle—which increases the air temperature and will cause some of the water to evaporate and become water vapor.

   What effect does releasing the pressure on the bottle have on the environmental conditions inside?
   The air temperature will lower to aid in condensation.

   Did a cloud form?
   No.

3. After smoke was placed in the bottle, did the cloud appear when you squeezed or when you released the bottle?
   Released.

   What condition has been provided for clouds to form?
   When the water vapor condenses, there are now condensation nuclei present that promote cloud growth.

Answer Key: Activity Four

CLOUDS AND THE EARTH'S RADIANT BUDGET

Because most students have probably not had previous exposure to concepts related to the Earth's radiant budget and the effects of cloud cover, teachers may want to consider crediting student work that demonstrates a basic understanding of how clouds affect radiation coming to and leaving the Earth.

FOCUS QUESTION #1

Clear vs. Cloudy Experiment

The students should have observed:

1. The temperatures in both bottles increased and are higher than the air temperature; the light energy from the lamp warmed the surface and air in each bottle.
2. The temperature of the clear sky bottle rose more quickly than the cloudy bottle, and had a higher temperature.
3. With the light off (night)—the clear sky bottle cooled off faster than the cloudy sky bottle, which kept the heat longer.

FOCUS QUESTION #2

CLOUDS AND RADIATION

Insolation: Incoming Solar Radiation

Diagram #1

The student draws arrows showing that most sunlight passes through high, thin cirrus clouds but is primarily reflected by low, thick clouds. EXTRA CREDIT: student draws arrows of sunlight being reflected back to space by surfaces on the Earth.

Outgoing Radiation from the Earth System

Diagram #2

The student draws arrows indicating that most longwave radiation is trapped by high, cold cirrus clouds but easily passes through low, warm stratocumulus clouds. EXTRA CREDIT: student draws arrows showing longwave radiation returning to the Earth from the clouds.

Answer Key: Activity Five

CLOUDS, CLIMATE, AND THE UNPREDICTABLE FUTURE

Question #1

The students might speculate that with increased temperatures, there would be increased evaporation, and therefore an increase in cloud cover and rain. This sounds logical, but would an increase in nimbostratus (storm clouds) cause warming or cooling? As clouds form, latent heat (hidden heat) is released into the atmosphere. If there is an increase in clouds, then there will be an increase in latent heat. Will the overall result be a warming? Or because thick clouds primarily reflect incoming solar radiation, will an increase in storm clouds cause cooling? As you can see, it is

extremely difficult to predict what the future climate of the Earth might be until scientists better understand how changes in the Earth's temperature affect cloud formation.

Question #2

One theory is that water vapor in the atmosphere condenses around the numerous aerosols in the atmosphere, producing an abundance of small water droplets—instead of allowing the water droplets within the cloud to come together to form large droplets heavy and large enough to fall as rain.

Clouds with low aerosol concentrations have fewer but larger water droplets, which do not scatter light well. These clouds generally allow much of the Sun's light to pass through and reach the surface of the Earth.

Clouds with high aerosol concentrations produce many small water droplets, which do scatter light well. Up to 90% of sunlight is reflected to space by such clouds, and thus kept from reaching the Earth's surface.

Scientists have also observed that polluted clouds appear brighter than unpolluted clouds. Since clouds polluted with many aerosols contain smaller water droplets, they generally are able to reflect greater amounts of sunlight, which aids in cooling the Earth.

APPENDIX C

National Education Standards

SCIENCE

Content Standard: K–12

Unifying Concepts and Processes

Standard: As a result of activities in grades K–12, all students should develop understanding and abilities aligned with the following concepts and processes:

- Systems, order, and organization
- Evidence, models, and explanation
- Constancy, change, and measurement

Content Standards: 5–8

Science as Inquiry

Content Standard A: As a result of activities in grades 5–8, all students should develop:

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

Physical Science

Content Standard B: As a result of activities in grades 5–8, all students should develop an understanding of:

- Properties and changes of properties in matter
- Transfer of energy

Earth and Space Science

Content Standard D: As a result of activities in grades 5–8, all students should develop an understanding of:

- Structure of the Earth system

National Research Council. 1996. ***National Science Education Standards*** *p. 115, 143–171. Washington, DC: National Academy Press.*

MATH

Curriculum Standards for Grades 5–8

Standard 1: Mathematics as Problem Solving

Standard 4: Mathematical Connections

Standard 7: Computation and Estimation

Standard 9: Algebra

National Council of Teachers of Mathematics. 1989. ***Curriculum and Evaluation Standards for School Mathematics*** *p. 63–119. Reston, VA: The National Council of Teachers of Mathematics, Inc.*

GEOGRAPHY

National Geography Standards for Grades 5–8

Places and Regions

Standard 4: The physical and human characteristics of places.

Physical Systems

Standard 7: The physical processes that shape the patterns of Earth's surface.

Environment and Society

Standard 14: How human actions modify the physical environment.

American Geographical Society, Association of American Geographers, National Council for Geographic Education, and National Geographic Society. 1994. ***Geography for Life: National Geography Standards*** *p. 143–182. Washington, DC: National Geographic Research and Exploration.*

ENGLISH LANGUAGE ARTS

Standard 1: Students read a wide range of print and nonprint texts to build an understanding of texts, of themselves, and of the cultures of the United States and the world; to acquire new information; to respond to the needs and demands of society and the workplace; and for personal fulfillment. Among these texts are fiction and nonfiction, classic and contemporary works.

Standard 3: Students apply a wide range of strategies to comprehend, interpret, evaluate, and appreciate texts. They draw on their prior experience, their interactions with other readers and writers, their knowledge of word meaning and of other texts, their word identification strategies, and their understanding of textual features (e.g., sound-letter correspondence, sentence structure, context, graphics).

Standard 4: Students adjust their use of spoken, written, and visual language (e.g., conventions, style, vocabulary) to communicate effectively with a variety of audiences and for different purposes.

Standard 5: Students employ a wide range of strategies as they write and use different writing process elements appropriately to communicate with different audiences for a variety of purposes.

Standard 7: Students conduct research on issues and interests by generating ideas and questions, and by posing problems. They gather, evaluate, and synthesize data from a variety of sources (e.g., print and nonprint texts, artifacts, people) to communicate their discoveries in ways that suit their purpose and audience.

Standard 8: Students use a variety of technological and informational resources (e.g., libraries, databases, computer networks, video) to gather and synthesize information and to create and communicate knowledge.

Standard 12: Students use spoken, written, and visual language to accomplish their own purposes (e.g., for learning, enjoyment, persuasion, and the exchange of information).

National Council of Teachers of English and International Reading Association. 1996. ***Standards for the English Language Arts*** *p. 24–46. Urbana, Illinois and Newark, Delaware: National Council of Teachers of English and International Reading Association.*

SOCIAL STUDIES

Strand 3: *People, Places, and Environments.* Social Studies programs should include experiences that provide for the study of people, places, and environments.

Strand 8: *Science, Technology, and Society.* Social Studies programs should include experiences that provide for the study of relationships among science, technology, and society.

National Council for the Social Studies. 1994. ***Expectations of Excellence: Curriculum Standards for the Social Studies*** *p. 19–30. Washington, DC: National Council for the Social Studies.*

APPENDIX D

Problem-Based Learning

What is Problem-Based Learning?

The Problem-Based Learning (PBL) model of teaching is a lot like it sounds; students learn by solving a problem. While this occurs in all classrooms to a different extent, the PBL learning model causes a drastic shift in the roles of students and teachers. In traditional teaching methods, the teacher acts as director of student learning, which is commonly passive. With PBL, these roles shift. Students become active and responsible for their own learning, and the activity is student-centered; the teacher becomes more of a facilitator or guide, monitoring student progress.

By using this model, the students gain information through a series of self-directed activities in which the students need to solve a problem. These problems drive the learning process and are designed to help students develop the skills necessary for critical thinking and problem solving. Students learn that in the real world, problems, and their solutions, are not always cut and dried, and that there may be different possible answers to the same problem. They also learn that as they continue to gain information, they need to readjust their plan. In other words, they must perform self-assessment.

A PBL lesson starts with a problem posed directly to the students. These problems are poorly structured to reflect real-world situations. Students (most commonly in small, cooperative groups) are then left to determine what steps need to be taken in order to solve the problem. The teacher does not give the students the information needed prior to the activity. However, the teacher does need to make sure the students have enough prior knowledge to be able to interpret the problem and determine a plan of action.

A key component of PBL is constant feedback. While the students are constantly assessing their work, and in turn adjusting their plan, teachers also need to provide continual, immediate feedback. Without feedback, students may be uncomfortable with this type of activity, because they do not know what is expected of them. Teacher feedback provides reinforcement for student learning. Feedback should be an authentic, performance-based assessment. Students need to continually evaluate their contributions. Rubrics provide a good guide for both teachers and students, to ensure that the students are continually kept on the right track.

Why use PBL?

Traditional teaching methods focus on providing students with information and knowledge. The PBL model also adds "real-world" problem-solving skills to the classroom. It teaches students that there is sometimes more than one possible answer, and that they have to learn how to decide between/among these answers.

Students and PBL

Students are broken up into groups and are presented with a poorly-structured, complex problem. Students should have enough background knowledge to understand the problem, but should not be experts. Any one, specific solution to the problem should not be evident. The students will need to determine what the problem is that they need to solve. Some organizational questions they may ask themselves are:

- What do we know about this problem?
- What do we need to know?
- How/where do we get the information needed to solve the problem?

The next step for the students is to determine a problem statement. From the information given to them in the problem, they should determine what they need to know and then plan a course of action to get the information they need to propose a solution. In implementing this plan, they will have to gather information to help them solve the problem. They will need to be sure that the resources they use are current, credible, accurate, and unbiased. As information is gathered and interpreted, they then apply their new knowledge, reevaluate what they know, and redetermine what they need to know to solve the problem. Once all the information is gathered, interpreted, and discussed, the group works together to propose a final solution.

Benefits of PBL

By using the Problem-Based Learning method, students gain more than just knowledge of facts. They develop critical thinking skills while working in collaborative groups to try to solve a problem. In doing this, they learn how to:

- interpret the question/problem,
- develop a problem statement,
- conduct research, reevaluating prior knowledge as new knowledge is gained,
- determine possible solutions, and
- pick the best possible solution based on the information they have gathered.

By providing immediate student feedback, the students can continually readjust their thinking, correcting any misconceptions or errors before moving on.

By using PBL, students become more familiar with "real-world" problems. They learn that there is not always only one correct answer, and that they need to work together to gather enough information to determine the best solution.

The PBL Classroom

When using the PBL model of instruction, it is best for students to work in small cooperative groups. The objective of this model is for students to work in a collaborative setting where they can learn social and ethical skills to determine how to answer the question presented. Students are expected to regulate themselves while in these working groups.

PBL Assessment

As the student groups work together to collect information, they will need to constantly assess their own progress and readjust their plan. As they do this, they will need continual, immediate feedback from the teacher. When they become more comfortable with this model, they will learn to rely less on the teacher and become more independent. By providing the students with the grading rubric, it will serve as a guide to ensure they are on the right track throughout the activity.

APPENDIX E

TRMM Introduction/Instruments

Introduction to the Tropical Rainfall Measuring Mission (TRMM)

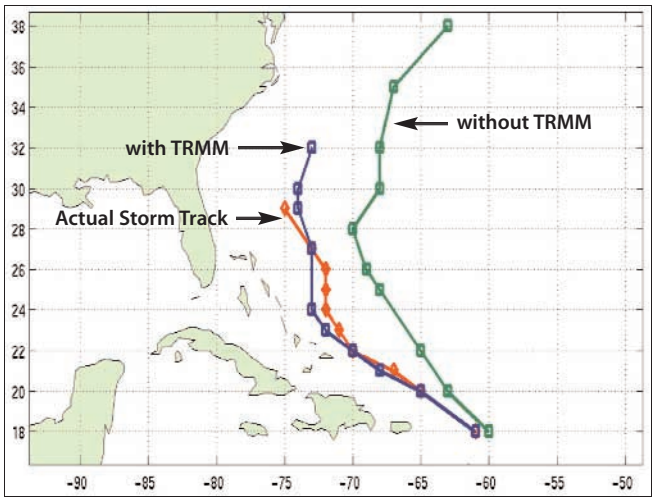
Rainfall is one of the most important weather and climate variables that determine whether mankind survives, thrives, or perishes. Water is so ubiquitous on planet Earth that we often take it for granted. Too much water results in devastating floods, and the famine caused by too little water (drought) is repsonsible for more human deaths than all other natural disasters combined. Water comprises more than 75 percent of our bodies and as much as 95 percent of some of the foods we eat.

Water is essential to life, as it nourishes our cells and removes the waste they generate. Water determines whether plants produce food, or whether they wither from drought or rot from dampness. Water is essential to our homes and factories, to our production of food, fiber, and manufactured goods, and to just about everything else we produce and consume. Although water covers more than 70 percent of the Earth's surface, only about 3 percent is fresh water—and about 75 percent of that is inaccessible because it is locked up in glaciers and icecaps.

Another important aspect of rainfall, or any other precipitation, is its role in redistributing the energy the Earth receives from the Sun. Evaporation of water from the Earth's surface, condensation of water vapor into cloud droplets or ice particles, precipitation, runoff of the precipitation, and melting of snow and ice constitute what is known as the water cycle, or the hydrological cycle. Evaporation, the process of changing water from liquid to gas form, absorbs 540 calories of energy per gram of water; while simply raising the temperature of a gram of water one degree Celsius—without changing its phase— requires only one calorie of energy. Thus, much of the Sun's energy that reaches the Earth's surface is used to evaporate water instead of raising the temperature of the surface. The resulting water vapor is carried upward by the atmosphere until it reaches a level where it is cooled to its condensation temperature. Then the water vapor releases the energy (540 calories per gram) it absorbed during the evaporation process. This "latent heat" release can occur thousands of kilometers from where the latent heat was originally absorbed.

Water plays an additional critical role in weather and climate: water vapor, it turns out, is the most abundant and most important greenhouse gas! Greenhouse gases trap some of the energy given off by the Earth's surface in the atmosphere. Therefore, the distribution and quantity of water vapor in the atmosphere are important in determining how well the Earth can emit the energy it absorbs from the Sun back into space. Unless the Earth loses as much energy as it receives, it will warm up. If the Earth loses more energy than it receives, it will cool down. The distribution of water vapor in the atmosphere also affects cloudiness; and clouds play an important role in determining how much solar energy reaches the Earth's surface, as well as how much heat can escape to space.

Perhaps it is now obvious that water, in all its forms, plays a critical role in determining what we call weather and climate. Our understanding of the complicated interactions involving water is insufficient to permit us to forecast, with much skill, weather beyond several days and climate beyond a few months. Because the occurrence of precipitation is highly variable in both time and space, and almost three-fourths of the Earth's surface has no rain gauges because it is covered by the oceans, we have never been able to adequately observe the global distribution of rain. Measurements from rain gauges on islands and satellite images of clouds have led to estimates of global precipitation. But TRMM—the first satellite to measure precipitation with the accuracy available from a radar in combination with other remote sensors—represents a breakthrough in our ability to monitor precipitation on a global scale.



Hurricane Bonnie, August 1998:
5-Day Forecasts vs. Actual Storm Track
Improved forecasts can save money ($600K–$1M per mile of coast evacuated) and lives by more precisely predicting where the hurricane eye will be located at landfall. Source: Dr. A. Hou, NASA DAO

TRMM Instruments

TRMM Microwave Imager (TMI)

The TRMM Microwave Imager (TMI) is a passive microwave sensor that detects and images microwave radiation emitted by water droplets, ice particles, and the Earth's surface. TMI detects radiation at five different frequencies, which helps to distinguish between rainfall, bodies of water, and land. Data obtained from this instrument is used to quantify the water vapor, cloud water, and rainfall intensity in the atmosphere.

Precipitation Radar (PR)

The Precipitation Radar (PR), an active sensor, is the first space-based precipitation radar. PR emits radar pulses toward Earth, which are then reflected by precipitation particles back to the radar. By measuring the strength of the returned pulses, the radar is able to estimate rainfall rates. Among the three main instruments on TRMM, PR is the most innovative. Other instruments similar to TMI and the Visible and Infrared Scanner (VIRS) have operated in space before, but PR is the first radar launched into space for the purpose of measuring rainfall. Data obtained from this instrument:

- provides three-dimensional storm structures;
- helps to determine the intensity and three-dimensional distribution of rainfall over land and water, which can be used to infer the three-dimensional distribution of latent heat in the atmosphere;
- provides information on storm depth; and
- provides information on the height at which falling snow or ice particles melt into rain.

Visible Infrared Scanner (VIRS)

The Visible and Infrared Scanner (VIRS) measures radiance in five wavelength bands (from visible to infrared) emitted by clouds, water vapor, and the Earth's surface. The intensity of radiation from a cloud corresponds with the brightness or temperature of the cloud, which in turn indicates the height of the cloud—brighter (colder) clouds are higher in altitude, and darker (warmer) clouds are lower. In general, higher clouds are associated with heavier rain. By comparing VIRS observations with rainfall estimates from TMI and PR, scientists are able to better understand the relationship between cloud height and rainfall rate, and can apply this knowledge to radiation measurements made by other weather satellites.

Cloud and Earth's Radiant Energy System (CERES)

The Clouds and the Earth's Radiant Energy System (CERES) measures the amount of energy rising from the Earth's surface, atmosphere, and clouds. Clouds can have both a warming and cooling effect on the Earth, trapping energy emitted by the Earth's surface while blocking energy from the Sun. Similarly, water vapor also warms the Earth by trapping outgoing radiation, but also condenses to form clouds that sometimes have a cooling effect. Data from this instrument helps scientists learn more about how the Earth distributes the energy it receives from the Sun, as well as the effects of clouds and water vapor on the overall temperature and energy budget of the Earth. This information will help long-term climate models make more accurate predictions.

Lightning Imaging Sensor (LIS)

The Lightning Imaging Sensor (LIS) is a powerful instrument that can detect and locate cloud-to-ground, cloud-to-cloud, and intra-cloud lightning. The information gained from this instrument is used to classify cloud types and, together with other TRMM instruments, to correlate lightning flash rate with storm properties, including rainfall rate. It's also expected that the information provided from LIS will lead to future advances in lightning detection and forecasting.

APPENDIX F

Online Resources

At each of the following Internet sites, you may change the month and year to create animations and conduct comparative studies:

Aerosol Index
http://earthobservatory.nasa.gov/Observatory/Datasets/aerosol.toms.html

Cloud Fraction
http://earthobservatory.nasa.gov/Observatory/Datasets/cldfrc.isccp_c2.html

Radiation Sites:

Using real-time Earth Observatory satellite image data, you can monitor various types of radiation at the following Internet sites:

Reflected Solar Radiation
http://earthobservatory.nasa.gov/Observatory/Datasets/swflux.erbe.html

Outgoing Heat Energy
http://earthobservatory.nasa.gov/Observatory/Datasets/lwflux.erbe.html

Net Radiation
http://earthobservatory.nasa.gov/Observatory/Datasets/netflux.erbe.html

Other Web Sites:

The CERES S'COOL Project:
http://asd-www.larc.nasa.gov/SCOOL

Bad Clouds: ***http://www.ems.psu.edu/~fraser/Bad/BadClouds.html***

Cloud Climatology: ***http://www.giss.nasa.gov/research/intro/rossow_01/role.html***

Clouds and Climate Change, the Thick and the Thin of It: ***http://www.giss.nasa.gov/research/intro/delgenio_03***

Clouds and Precipitation: ***http://ww2010.atmos.uiuc.edu/(Gh)/guides/mtr/cld/home.rxml***

For Kids Only: ***http://kids.earth.nasa.gov***

NASA Langley Research Center Multimedia Repository:
http://lava.larc.nasa.gov

What does the brightness of a cloud mean on the TV weather shows?: ***http://cimss.ssec.wisc.edu/wxwise/satir/IRCloud.html***

Online Student Aerosol Investigation

NASA's Total Ozone Mapping Spectrometer is an instrument flown on satellites; it takes daily measurements of radiation so that scientists can estimate the location and amount of aerosols present in the atmosphere over the entire Earth. The following investigation allows you to collect and analyze the same real-time data scientists are currently studying.

PROCEDURE

1. Working with a partner, log onto the Internet at: ***http://earthobservatory.nasa.gov/Observatory/Datasets/aerosol.toms.html***
2. Enter the desired observation month and year (enter the same for "start" and "end"), as directed by your instructor. Use a world map, if necessary, to identify regions with aerosols. Using the site's color index scale, indicate the concentration of aerosols in selected regions as "high," "low," or "little to none."

Aerosol Index Observation for:

Month_____ Year_____

Region with Aerosols	Aerosol Concentration
1.	
2.	
3.	
4.	
5.	

3. Check your home region for Aerosols:

Home Region	Aerosol Concentration

EXTENSION

If you and your partner have time, you may create an animation to see how aerosol concentrations change in regions over a period of time. Or you may want to create animations to map the movement of aerosols.

Animation Procedures

Aerosol Animations:

1. Select: start month and year
2. Select: end month and year
3. Click: "Build Animation"

Comparison Animations:

1. Select: start month and year
2. Select: compare to start month and year
3. Click: "Build Animation"

Monitoring Solar Radiation Reflected from the Earth

Analyzing Real-Time Data from Earth Observatory Satellites

OBJECTIVE

Albedo is the amount of sunlight reflected by a body or surface. The surface of the Earth and composition of the atmosphere affect the amount of sunlight reflected. Surface areas that are flat and white can reflect great amounts of sunlight. Darker areas have lower albedo; they absorb radiation and reflect only a small amount.

In order to identify regions of the Earth with high and low albedo, you will examine Earth Observatory satellite data images, which display the amount of sunlight (shortwave radiation) that's reflected by the Earth's surface and atmosphere into space.

A color scale is used for these satellite data images, which show white as regions of high reflection values, green as regions of intermediate values, and blue as regions of low values.

PART 1: Make a Prediction

In what regions of the Earth would you expect to find (and why)…

- ***High reflection*** of sunlight?_____
- ***Low reflection*** of sunlight?_____

PART 2: Reflected Solar Radiation Monitoring Activity

Observation Date: _____ Observation Time: _____

Directions

1. Working with a partner, log onto the Internet at: ***http://earthobservatory.nasa.gov/Observatory/Datasets/swflux.erbe.html***
2. Using the site's color scale and if necessary, a world map, identify regions of the Earth with:
   - High solar reflection: _____
   - Low solar reflection: _____

PART 3: Animation

Create an animation to observe the poles of the Earth during the four seasons and note any changes in solar reflection.

Monitoring Outgoing Infrared Radiation Reflected from the Earth

Analyzing Real-Time Data from Earth Observatory Satellites

OBJECTIVE

Objects can only absorb but so much energy. If they continue to receive more energy, they will radiate it in the form of heat back to space. If heat were not sent back to space, the Earth system would warm up!

In order to identify regions of high and low outgoing infrared radiation escaping the Earth system to space, you will examine Earth Observatory satellite data images, which display the amount of longwave infrared radiation emitted by the Earth system.

A color scale is used for these satellite data images, which show bright yellows and oranges as areas with high values of infrared radiation emitted from the Earth back to space, purples and blues as areas with intermediate values, and whites as areas with low values.

PART 1: Make a Prediction

Which places on Earth would you expect to emit…

- The most heat? _____
  _____
  _____
- The least heat? _____
  _____
  _____

PART 2: Monitoring Outgoing Infrared Radiation (Heat Energy) Escaping to Space

Observation Date: _____ Observation Time: _____

Directions

1. Working with a partner, log onto the Internet at:
   http://earthobservatory.nasa.gov/Observatory/Datasets/lwflux.erbe.html
2. Using the site's color scale and if necessary, a world map, identify regions of the Earth that emit:
   - High amounts of infrared radiation back to space: _____
     _____
     _____
   - Low amounts of infrared radiation back to space: _____
     _____
     _____

PART 3: Animation

Create an animation of one year to observe if these regions consistently emit high and low values of infrared radiation.

Animation Start Date: _____ Animation End Date: _____

Observation Notes: _____
_____
_____

Monitoring Net Radiation within the Earth System

Analyzing Real-Time Data from Earth Observatory Satellites

OBJECTIVE

Net radiation is the total amount of sunlight that does not escape from the top of the Earth's atmosphere back into space.

In order to identify regions of the Earth with energy surplus and energy deficit, you will examine Earth Observatory satellite data images of net radiation.

A color scale is used for observing these satellite images, where green represents regions of the Earth that have an energy surplus (more than enough energy), and blue represents areas of energy deficit (not enough energy).

PART 1: Make a Prediction

Where on Earth would you expect to find an:

- Energy surplus? _____

- Energy deficit? _____

PART 2: Online Net Radiation Monitoring Activity

Observation Date: _____ Observation Time: _____

Directions

1. Working with a partner, log onto the Internet at: ***http://earthobservatory.nasa.gov/Observatory/Datasets/netflux.erbe.html***
2. Using the site's color scale and if necessary, a world map, identify regions of the Earth with an:
   - Energy surplus: _____
   - Energy deficit: _____
3. How would you explain occurrences of energy surpluses and deficits? _____

APPENDIX G

Glossary

aerosols—A collection of fine particles of a solid or a liquid suspended in a gas, such as air and smog.[1]

albedo—The percent of radiation returning from a surface compared to that which strikes it.[2]

climate—The average weather conditions in an area determined over a period of years.[3]

clouds, cloud formation and classification—A visible mass of water vapor sustained in the atmosphere above Earth's surface. Clouds form in areas where air rises and cools. The condensing water vapor forms small droplets of water (0.012 mm radius) that, when combined with billions of other droplets, form clouds. Clouds can form along warm and cold fronts, where air flows up the side of the mountain and cools as it rises higher into the atmosphere, and when warm air blows over a colder surface, such as a cool body of water.

Clouds fall into two general categories: sheet- or layer-like looking stratus clouds (stratus means layer) and cumulus clouds (cumulus means piled up). These two cloud types are divided into four more groups that describe a cloud's altitude.

High clouds form above 20,000 feet (6,096 meters) in the cold region of the troposphere, and are denoted by the prefix CIRRO or CIRRUS. At this altitude water almost always freezes so clouds are composed of ice crystals. The clouds tend to be wispy, are often transparent, and include cirrus, cirrocumulus, and cirrostratus.

Middle clouds form between 6,500 feet (1981.2 meters) and 20,000 feet (6,096 meters) and are denoted by the prefix ALTO. They are made of water droplets and include altostratus and altocumulus.

Low clouds are found up to 6,500 feet (1981.2 meters) and include the stratocumulus and nimbostratus clouds. When stratus clouds contact the ground they are called fog.

Vertical clouds, such as cumulus, rise far above their bases and can form at many heights. Cumulonimbus clouds, or thunderheads, can start near the ground and soar up to 75,000 feet (2286 meters).[3]

condensation—Change of a substance to a denser form, such as gas to a liquid. The opposite of evaporation.[3]

evaporation—Change from a liquid (more dense) to a vapor or gas (less dense) form. When water is heated it becomes a vapor that increases humidity. Evaporation is the opposite of condensation.[3]

greenhouse gases—A gaseous component of the atmosphere contributing to the greenhouse effect. Greenhouse gases are transparent to certain wavelengths of the Sun's radiant energy, allowing them to penetrate deep into the atmosphere or all the way into the Earth's surface. Greenhouse gases and clouds prevent some of the infrared radiation from escaping, trapping the heat near the Earth's surface where it warms the lower atmosphere. Altering this natural barrier of atmospheric gases can raise or lower the mean global temperature of the Earth. Greenhouse gases include carbon dioxide, methane, nitrous oxide, chlorofluorocarbons (CFCs), and water vapor. Carbon dioxide, methane, and nitrous oxide have significant natural and human sources while only industries produce chlorofluorocarbons. Water vapor has the largest greenhouse effect, but its concentration in the troposphere is determined within the climate system. Water vapor will increase in response to global warming, which in turn may enhance global warming.[3]

insolation—Solar radiation or heating received at the Earth's surface. The name is derived from INcoming SOLar radiATION.[4]

net radiation—The total amount of sunlight and heat energy that does not escape from the top of the Earth's atmosphere back into space.[5]

condensation nuclei/cloud nuclei—A particle upon which water vapor condenses. It may be either in a solid or liquid state.[4]

optical depth (optical thickness)—The degree to which a cloud prevents light from passing through it; the optical thickness then depends on the physical constitution (crystals, drops, and/or droplets), the form, the concentration, and the vertical extent of the cloud.[5]

precipitation—Moisture that falls from clouds. Although clouds appear to float in the sky, they are always falling, their water droplets slowly being pulled down by gravity. Because their water droplets are so small and light, it can take 21 days to fall 1,000 feet (30.5 meters) and wind currents can easily interrupt their descent. Liquid water falls as rain or drizzle. All raindrops form around particles of salt or dust. (Some of this dust comes from tiny meteorites and even the tails of comets.) Water or ice droplets stick to these particles, then the drops attract more water and continue getting bigger until they are large enough to fall out of the cloud. Drizzle drops are smaller than raindrops. In many clouds, raindrops actually begin as tiny ice crystals that form when part or all of the cloud is below freezing. As the ice crystals fall inside the cloud, they may collide with water droplets that freeze onto them. The ice crystals continue to grow larger, until large enough to fall from the cloud. They pass through warm air, melt, and fall as raindrops.

When ice crystals move within a very cold cloud (10°F/12.2°C and –40°F/-40°C) and enough water droplets freeze onto the ice crystals, snow will fall from the cloud. If the surface temperature is below 32 °F (0°C), the flakes will land as snow.[3]

radiant budget (energy budget)—A measure of all the inputs and outputs of radiative energy to a system, such as Earth.[3]

water cycle/hydrological cycle—The processes that cycle water through the Earth system. These include:

- Evaporation, changing from a liquid to a gas
- Condensation, changing from a gas to a liquid
- Sublimation, changing from a solid to a gas
- Precipitation, water molecules condensing to form drops heavy enough to fall to the Earth's surface
- Transpiration, moisture carried through plants from roots to leaves, where it changes to vapor and is released to the atmosphere
- Surface runoff, water flowing over land from higher to lower ground
- Infiltration, water filling the porous spaces of soil
- Percolation, groundwater moving in the saturated zone below the Earth's surface.

At ***http://watercycle.gsfc.nasa.gov*** you can download a water cycle movie.[9]

water vapor (aka moisture)—Water in a gaseous form.[3]

[1] USGS Glossary: ***http://interactive2.usgs.gov/glossary***

[2] Ahrens, C. Donald. 1994. *Meteorology Today.* St. Paul, MN: West Publishing Company

[3] *Looking at Earth From Space: Glossary of Terms,* 1993, NASA EP-302

[4] The Weather Channel Home Page: ***http://www.weather.com/glossary***

[5] The Earth Observatory Glossary: ***http://earthobservatory.nasa.gov/Library/glossary.php3***

[6] NASA Goddard Space Flight Center, Laboratory for Hydrospheric Processes: ***http://watercycle.gsfc.nasa.gov***