

**Blocking the Sun: Earth's External Heat Engine
and the Earth's Atmosphere**

SPN LESSON #34



TEACHER INFORMATION

LEARNING OUTCOME

After analyzing graphs, charts, and maps, students describe the types of electromagnetic energy present in sunlight, explain how various wavelengths are affected by the atmosphere, and cite the mechanisms that absorb, scatter, and refract incoming radiation.

LESSON OVERVIEW

This lesson is the conclusion of a three-lab sequence that investigates the factors controlling the amount of insolation reaching Earth. Students analyze displays of data and draw conclusions regarding energy from sunlight; determine how wavelengths are affected by the atmosphere; and contemplate mechanisms at work in the absorbing, scattering, refracting, and reflecting of radiation. In addition, they chart the movement of frontal systems across New York State through the use of Internet sites and the SPN network of solar collector sites.

GRADE-LEVEL APPROPRIATENESS

This Level II and III Physical Setting lesson is designed for Earth science students in grades 8–12.

MATERIALS

Computer terminal having Internet access
Pencil
Ruler

SAFETY

No special safety considerations are necessary.

TEACHING THE LESSON

This lesson is to be taught in increments. Have students follow the directions on the worksheets, working in small groups or individually, completing one or

two sections at a time in class and/or for homework. Follow the completion of each section with a debriefing discussion to ensure that they comprehend the material.

You may want to include several of the lesson extensions that follow as clarifying laboratory activities.

LESSON EXTENSIONS

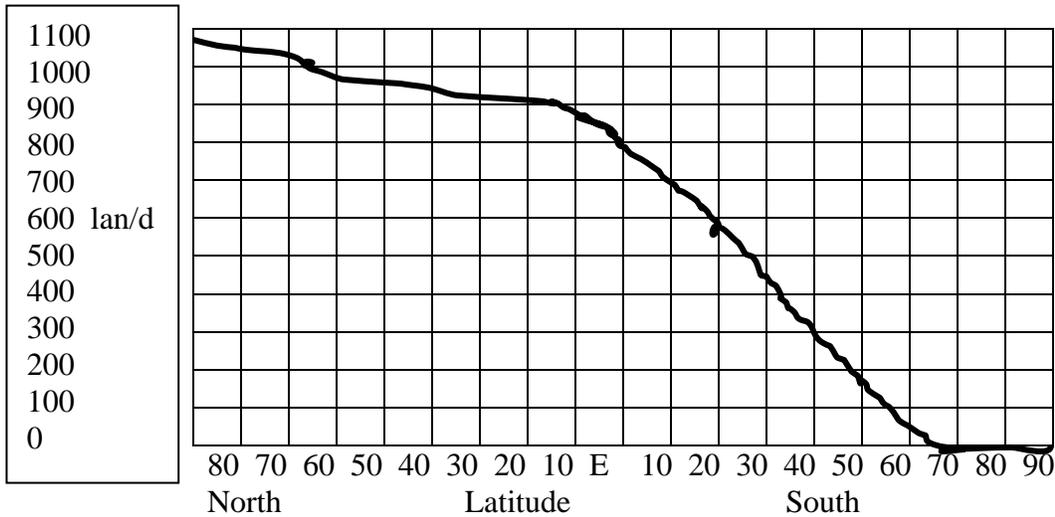
Several standard Earth science laboratory activities you might use that fit well with this lesson's concepts follow:

1. Black can – white (silver) can lab (demonstrates the characteristics of good absorbers/reflectors)
2. Cloud formation bell jar lab (demonstrates condensation nuclei / adiabatic cooling) (Note: This lab may be modified by passing a beam of light through the cloud chamber to observe the absorption and reflection of the light beam.)
3. Angle of refraction lab (demonstrates refraction of light)
4. Diagnostic weather maps (demonstrate fronts, clouds, and precipitation)
5. In addition, the University of Massachusetts has a radiative balance lesson at the following website that allows students to determine the changes in Earth surface temperatures caused by varying Earth albedo, incident insolation, and greenhouse effect of the atmosphere.
<http://www.geo.umass.edu/courses/climate/radbal.html>

ACCEPTABLE RESPONSES FOR DEVELOP YOUR UNDERSTANDING SECTION [Numbers in brackets are NYSED Intermediate Science Core Major Understandings.]

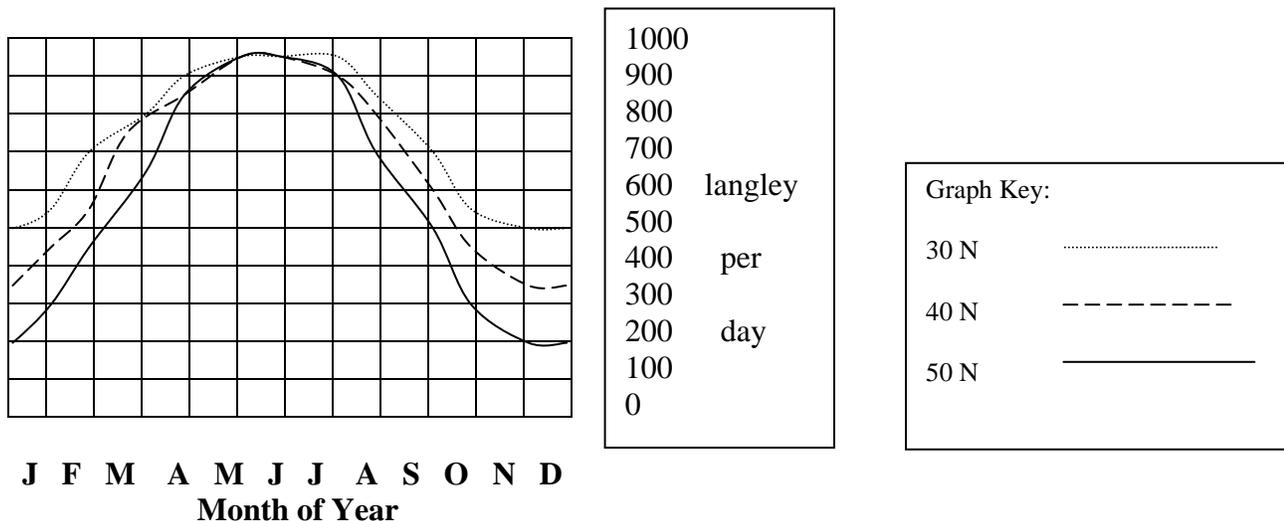
1. Acceptable responses should be between .4 and .7 microns. (The actual answer is .475 microns or 4.75×10^{-5} centimeters as per Earth Science Reference Tables.) [Std 6, KI 2]
2. (a) blue/green; (b) 4.75×10^5 centimeters [Student responses will vary, but most will probably be around 4.9×10^5 in value.] [You might want to discuss the nature of logarithmic scales at this point, if that topic has not already been addressed.] [Std 6, KI 3]
3. The peak of atmospheric absorption occurs at a shorter wavelength at the approximate boundary between visible and ultraviolet light at about .4 microns. [Std 6, KI 3]
4. (a) X ray and ultraviolet; (b) infrared (Students could successfully argue that visible light is also greatly affected.) [Std S1, KI 1]
5. Student graphs should be similar to the one provided below. [Std 6, KI 5]

Number of Langleys per Day Received at Outer Edge of Earth's Atmosphere at All Latitudes on June 21

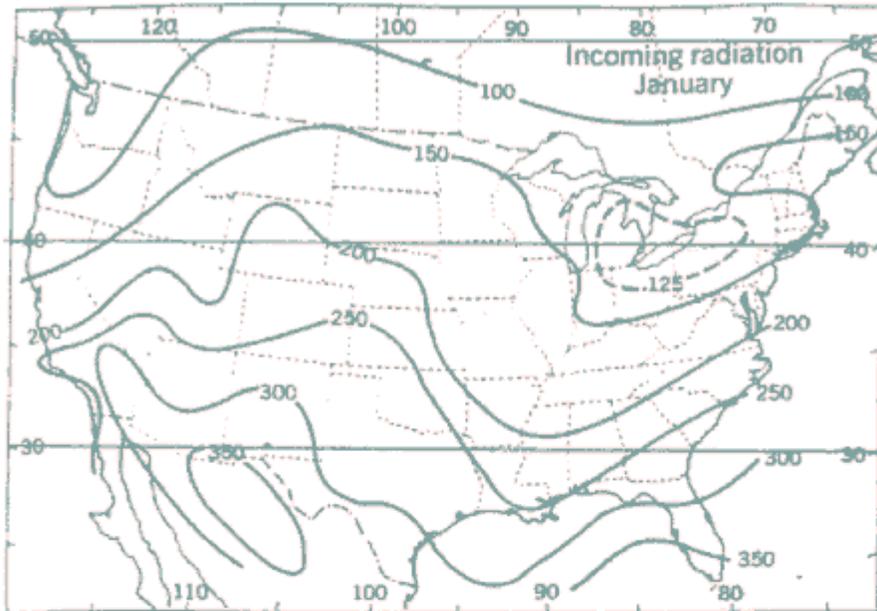


6. Since Earth's North Pole is tilted toward the Sun on June 21, the North Polar region can receive 24 hours of daylight each day. [Std 4, 1.1f]
7. The three possible graphs are superimposed below. [Std 6, KI 5]

Yearly Change in Insolation Received above Earth's Atmosphere at Latitude ____ North



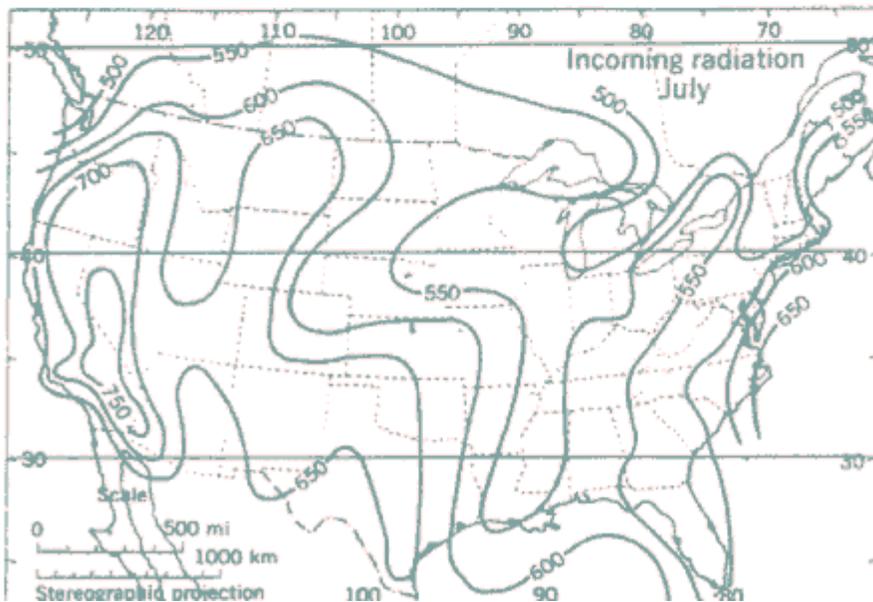
8. (a) Yes (hopefully); (b) In the winter, spring, and fall seasons, the controlling factor appears to be a combination of the angle of insolation and the duration of insolation. During the summer months, the pattern of steadily increasing duration of insolation occurring to the north appears to be most important. [Std 4, 2.2a]
9. Student responses are likely to vary slightly. This would be a good time to emphasize the importance of reading graphs with accuracy (e.g., +/- 25 langleys per day). Students may have difficulty reading July values because of the southward bulging of the 900-langley isoline. You should remind them that the values they are reading lie along the July 15 vertical line. Students might find it easier to determine these values by actually drawing this line on diagram 2. [Std S1, KI 1]



205
lang/day

360
lang/day

500
lang/day



950
lang/day

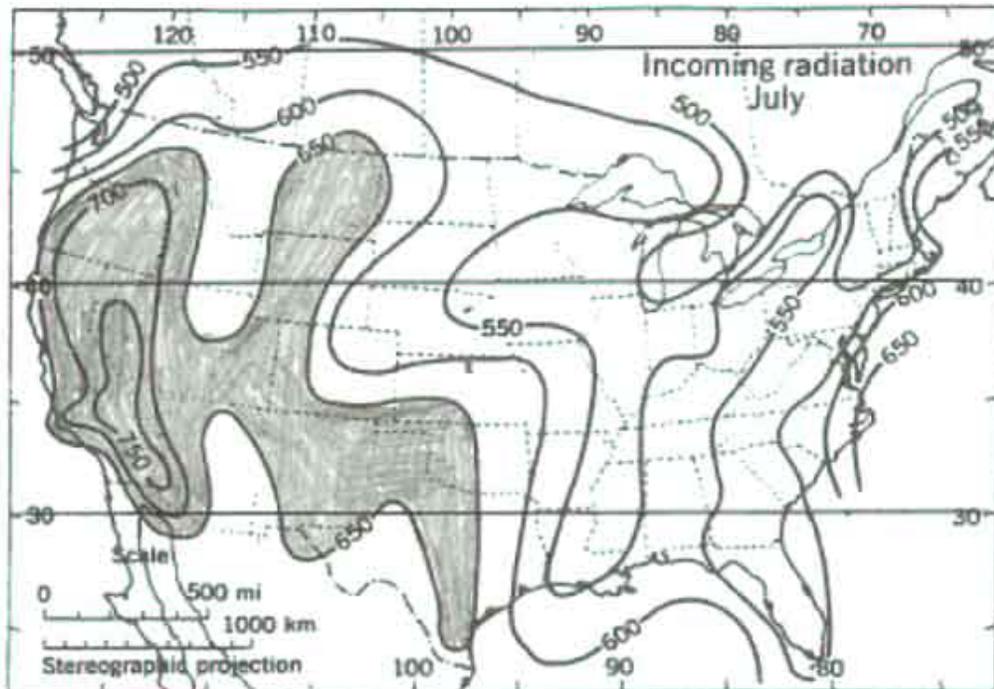
936
lang/day

924
lang/day

10. Responses will vary, but are likely to emphasize the following: [Std S1, KI 1]

- (1) Earth's surface pattern is much more irregular than that above the atmosphere.
- (2) Earth's surface receives only a portion of the amount received by the upper atmosphere.
- (3) Earth's surface pattern generally decreases to the north, but the July upper atmosphere insolation increases to the north.

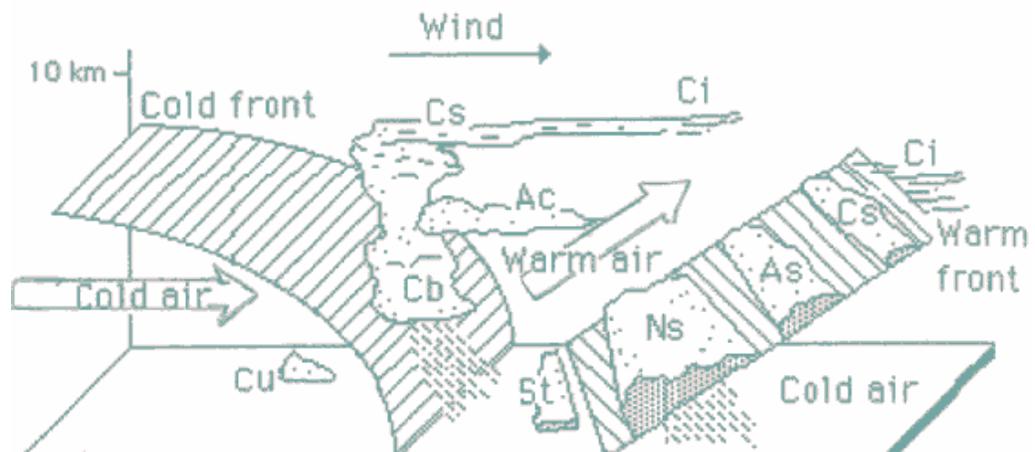
11. (a) [Std 6, KI 2]



(b) The high insolation area has a generally warm-to-hot climate, and the climate is dry. [Std 4, 2.2b]

12. When humid air is forced to rise (as when it encounters a frontal surface, mountain, or low-pressure center), the air expands and cools to the dewpoint where condensation takes place changing water vapor to water droplets (or perhaps ice crystals). The droplets form clouds. [Std 4, 2.1f]

13. (a) 35%–80% [Std 6, KI 2]
 (b) absorption and reflection
 (c) reflection
 (d) Clouds appear white in color when reflecting sunlight, an indication that all wavelengths of visible light are being reflected.
14. (a) cumulonimbus, nimbostratus, or cumulus [Std 6, KI 2]
 (b) These cloud types are thicker. [Std 6, KI 5]
 (c) Thicker clouds occur where large volumes of moist air are forced to rise. [Std S1, KI 1]
 - at frontal boundaries [Std S1, KI 1]
 - at the center of a low air pressure
 - on the windward side of mountains
 (d) Responses will vary according to the circumstances chosen by the student. Typical responses are likely to be for warm and cold fronts as shown in the figure below: [Std 6, KI 2]



15. There should be a sharp reduction in electrical output from those solar collectors that are under a heavy cloud cover associated with low-pressure centers and the associated fronts. [Std M1, KI 2]
16. Responses will vary greatly. However, the presence and movement of heavy cloud cover should be readily apparent from the drop in energy collection/output from school sites in the SPN statewide solar network. [Std 6, KI 1]
17. (a) Scattering and diffuse reflection and absorption by molecules and dust [Std 6, KI 2]
 (b) Blue-colored sky
18. (a) removing the 18% of the blue and 32% of the violet makes the Sun appear more yellowish than it is. [Std S1, KI 3]
 (b) blocked sunlight means darker days with less radiation for photosynthesis in green plants; plants and the herbivores that depend on

them might die, and the carnivores might die as well; mass extinction might occur as it did in the dinosaur extinction event at the end of the Mesozoic Era. [Std.4, 1.2d]

19. (a) water vapor and carbon dioxide [Std 6, KI 2]
(b) approximately 1.9, 1.2, 1.1, and 1.0 microns; infrared
(c) ozone and oxygen

ADDITIONAL SUPPORT FOR TEACHERS

SOURCE FOR THIS ADAPTED ACTIVITY

This lesson is a compilation from many sources, although mainly from the two sources listed in the References for Background Information section below.

BACKGROUND INFORMATION

Scattering is the term used to describe the reflection of light rays from molecules in the atmosphere. *Rayleigh scattering* is the proper term for this phenomenon. Blue light is greatly scattered because of the “fit” between its wavelength and the diameter of gas molecules in the atmosphere. Therefore, the sky usually appears blue because our eyes see all this scattered blue radiation from the Sun coming from all points in the atmosphere. Therefore, the Sun appears yellow instead of white, because the blue component has been removed by scattering. [See appendix for additional information.]

REFERENCES FOR BACKGROUND INFORMATION

Strahler, Arthur. *The Earth Sciences*, Harper & Row, 1971. This book in any of its many editions is an invaluable reference.

Sorbjan, Zbigniew. *Hands on Meteorology*, American Meteorological Society, 1996.

Any of several Earth science texts and review books are likely to be helpful to you.

LINKS TO MST LEARNING STANDARDS AND CORE CURRICULA

Standard 1—Analysis, Inquiry, and Design: Students will use mathematical analysis, scientific inquiry, and engineering design, as appropriate, to pose questions, seek answers, and develop solutions

Mathematical Analysis Key Idea 2: Deductive and inductive reasoning are used to reach mathematical conclusions.

Scientific Inquiry Key Idea 1: The central purpose of scientific inquiry is to develop explanations of natural phenomena in a continuing, creative process.

Scientific Inquiry Key Idea 3: The observations made while testing proposed explanations, when analyzed using conventional and invented methods, provide new insights into phenomena.

Standard 4—The Physical Setting: Students will understand and apply scientific concepts, principles, and theories pertaining to the physical setting and living environment and recognize the historical development of ideas in science.

Key Idea 1: The Earth and celestial phenomena can be described by principles of relative motion and perspective.

1.1: Explain complex phenomena, such as tides, variations in day length, solar insolation, apparent motion of the planets, and the annual traverse of the constellations.

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.

Key Idea 2: Many of the phenomena that we observe on Earth involve interactions among components of air, water, and land.

2.1: Use the concepts of density and heat energy to explain observations of weather patterns, seasonal changes, and the movements of Earth's plates.

2.1e: Weather variables are interrelated. For example:

- Temperature and humidity affect air pressure and probability of precipitation.
- Air pressure gradient controls wind velocity.

2.1f: Air temperature, dewpoint, cloud formation, and precipitation are affected by the expansion and contraction of air due to vertical atmospheric movement.

2.2: Explain how incoming solar radiation, ocean currents, and land masses affect weather and climate.

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.

2.2b: The transfer of heat energy within the atmosphere, the hydrosphere, and Earth's surface occurs as the result of radiation, convection, and conduction.

- Heating of Earth’s surface and atmosphere by the Sun drives convection within the atmosphere and oceans, producing winds and ocean currents.

Standard 6—Interconnectedness: Common Themes: Students will understand the relationships and common themes that connect mathematics, science, and technology and apply the themes to these and other areas of learning.

Key Idea 1: Through systems thinking, people can recognize the commonalities that exist among all systems and how parts of a system interrelate and combine to perform specific functions.

Key Idea 2: Models are simplified representations of objects, structures, or systems used in analysis, explanation, interpretation, or design.

Key Idea 3: The grouping of magnitudes of size, time, frequency, and pressures or other units of measurement into a series of relative order provides a useful way to deal with the immense range and the changes in scale that affect the behavior and design of systems.

Key Idea 5: Identifying patterns of change is necessary for making predictions about future behavior and conditions.

Produced by the Research Foundation of the State University of New York with funding from the New York State Energy Research and Development Authority (NYSERDA)

www.nyserda.org

Should you have questions about this activity or suggestions for improvement, please contact Bill Peruzzi at billperuz@aol.com

(STUDENT HANDOUT SECTION FOLLOWS)

Name _____

Date _____

Blocking the Sun: Earth's External Heat Engine and Earth's Atmosphere

Topic: How does Earth's atmosphere affect the radiation coming from the Sun to the surface of Earth? [Before you continue, write a brief hypothesis that suitably addresses this question.]

Introduction

Because it is such a small target compared to the rest of space, Earth receives only a tiny amount of the Sun's total energy output. There is also a very large difference between the amount of incoming solar radiation (insolation) that approaches Earth and the amount that actually arrives at Earth's surface and becomes available for

- 1) providing the heat energy that drives our weather systems, and
- 2) generating electric power from photovoltaic systems.

A variety of gases and particulate matter in the atmosphere disrupt the flow of insolation by refracting, scattering, absorbing, and reflecting various wavelengths of solar radiation. These disruptions in the flow of energy partially act as a shielding mechanism. Indeed, this mechanism protects life on Earth from the harmful parts of the solar spectrum.

Materials

Student handout pages
Ruler/straightedge
Pencil

Procedure

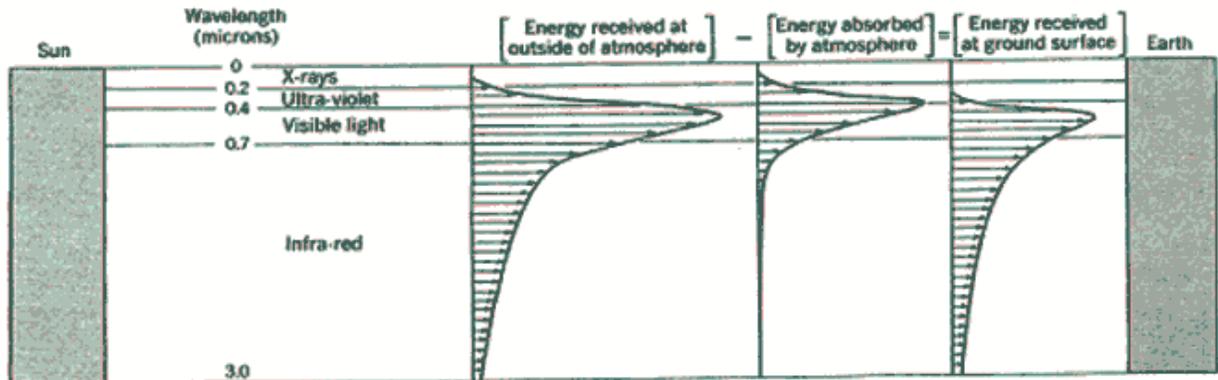
1. Work in groups as assigned by your teacher.
2. Follow directions as you read and analyze the information provided.

DEVELOP YOUR UNDERSTANDING

As you began work on this packet, you made up a hypothesis concerning how the atmosphere affects incoming solar radiation. Since the atmosphere works in many different ways to alter the amount of radiation received on Earth, chances are that almost every hypothesis will be supported. Let's see.

Energy from the Sun peaks in the visible wavelength region of the solar spectrum. Those visible wavelengths account for 41% of total radiation. Yet, the majority of solar output (50%) is in the infrared region of the spectrum. The remainder falls in the X ray, gamma ray, and ultraviolet region (9%). The graphs below show what happens to radiation that enters the Earth's atmosphere.

Diagram 1: Insolation (Showing Types of Radiation) at the Top of Earth's Atmosphere, Removed by the Atmosphere, and Reaching Earth's Surface



1. At what wavelength does the Sun produce the greatest amount of radiation energy? _____ microns (a micron is one ten-thousandth of a centimeter, or 0.0001 cm)
2. (a) According to the chart on page 14 of the New York State Earth Science Reference Tables, what color light does this represent?

(b) How does this chart express this wavelength?

_____ How does the peak wavelength absorbed by the atmosphere differ from the greatest amount of radiation energy wavelength?

3. Compare the wavelength of maximum solar radiation to the wavelength of maximum absorption by Earth's atmosphere.

(a) How does the absorption differ? _____

(b) Determine the approximate wavelength of maximum absorption of sunlight by the atmosphere.

4. (a) Which types of radiation from the Sun seem most reduced by the Earth's atmosphere?

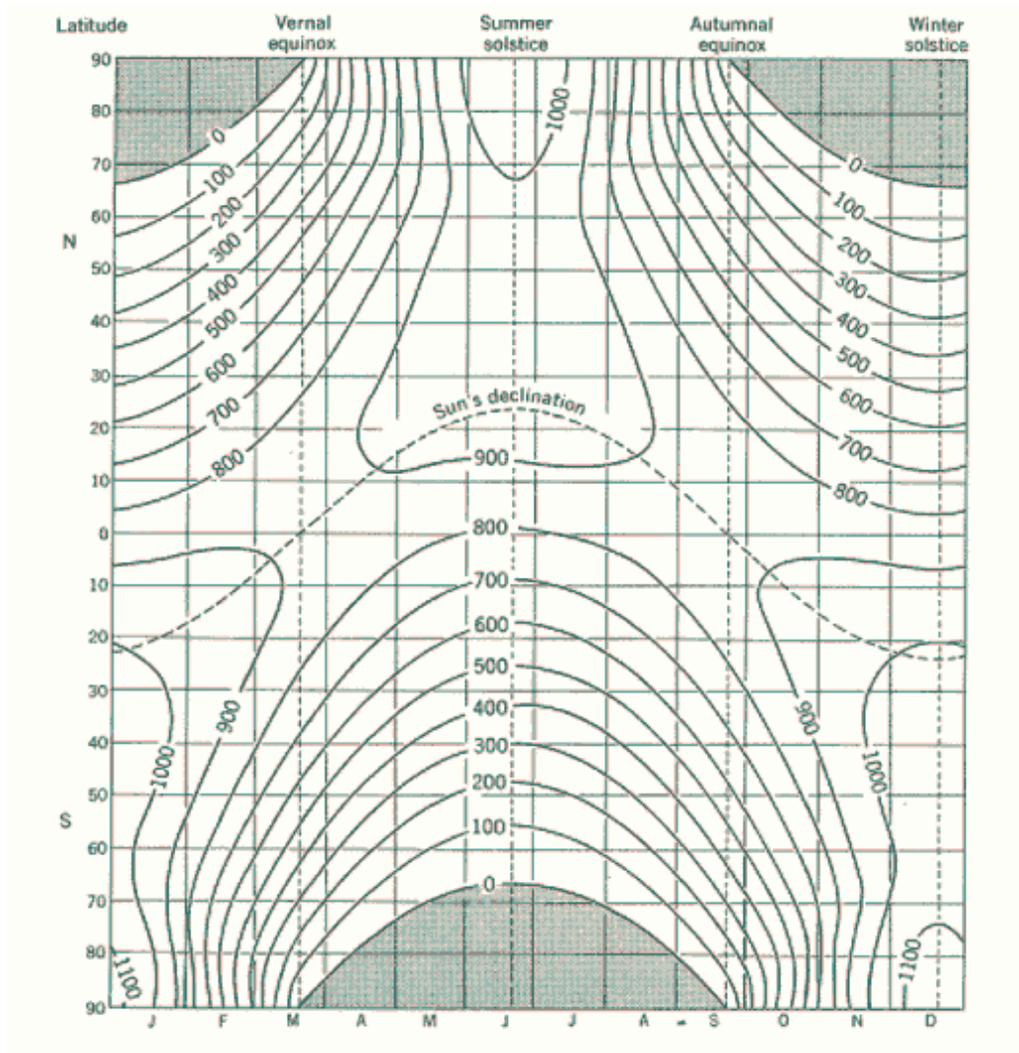
_____ and _____

(b) Which type of radiation seems least affected?

Soon you will investigate why and how these changes take place, but first these phenomena will be viewed from a slightly different perspective.

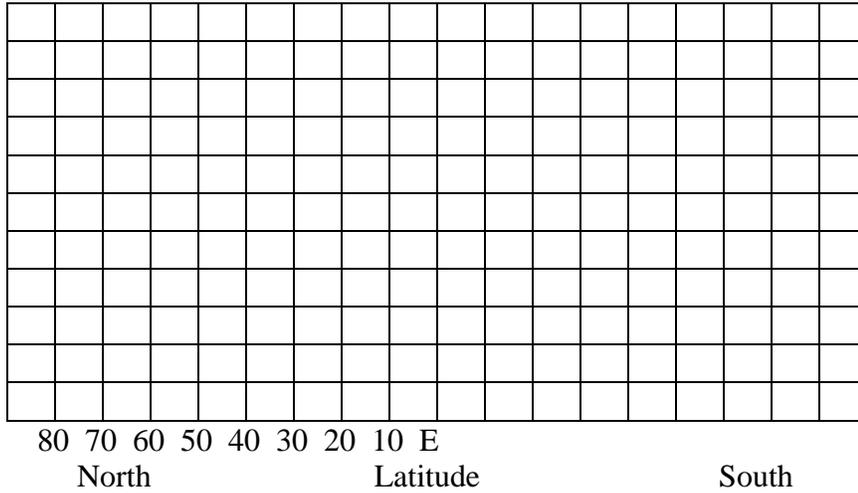
Diagram 2, below, consists of a complex graph. It shows the amount of solar radiation energy received on a horizontal surface during the year for all latitudes at the **outside** of Earth's atmosphere. In other words, the graph shows the amount of radiation energy Earth's surface would receive if no atmosphere were present. Units of energy shown on the graph are in langleys per day. One langley is equal to one calorie/minute/square centimeter. One calorie is the amount of heat needed to raise the temperature of one gram of water by one degree Celsius at sea level.

Diagram 2: Insolation Reaching the Top of Earth's Atmosphere



- To show that you understand the information on the graph above, construct a line graph on the form provided below that shows the amount of insolation that should be received at various latitudes on Earth on June 21 (the summer solstice). Complete the horizontal and vertical scales and graph the energy data.

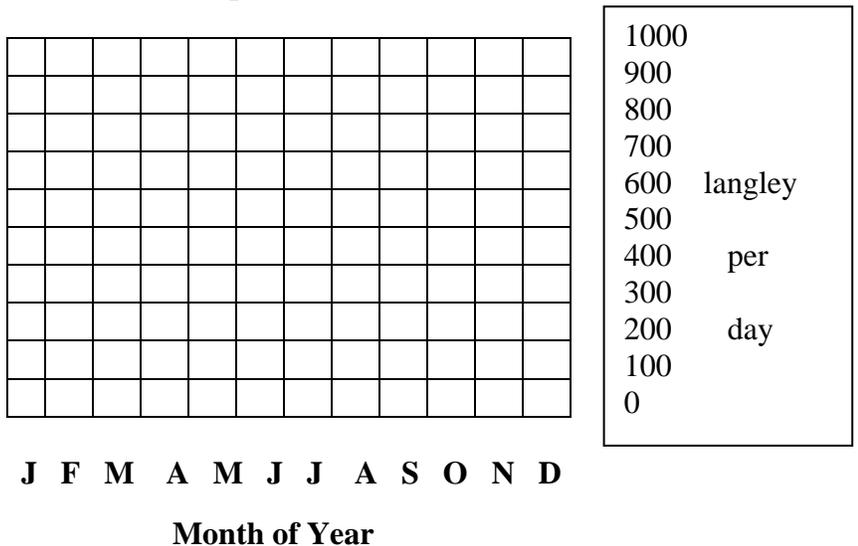
**Number of Langleys per Day Received at Outer Edge of
Earth's Atmosphere at All Latitudes**



6. Briefly describe the reasons why, on June 21, the greatest amount of the Sun's energy is received above the atmosphere in the North Polar region.

7. The graph shown in diagram 2 also can be used to determine the yearly pattern for insolation above the atmosphere at any particular latitude. Complete the graph that follows, using the langley/day data for 30, 40, or 50 degrees north latitude. Proceed according to your teacher's directions.

**Yearly Change in Insolation Received above Earth's
Atmosphere at Latitude _____ North**

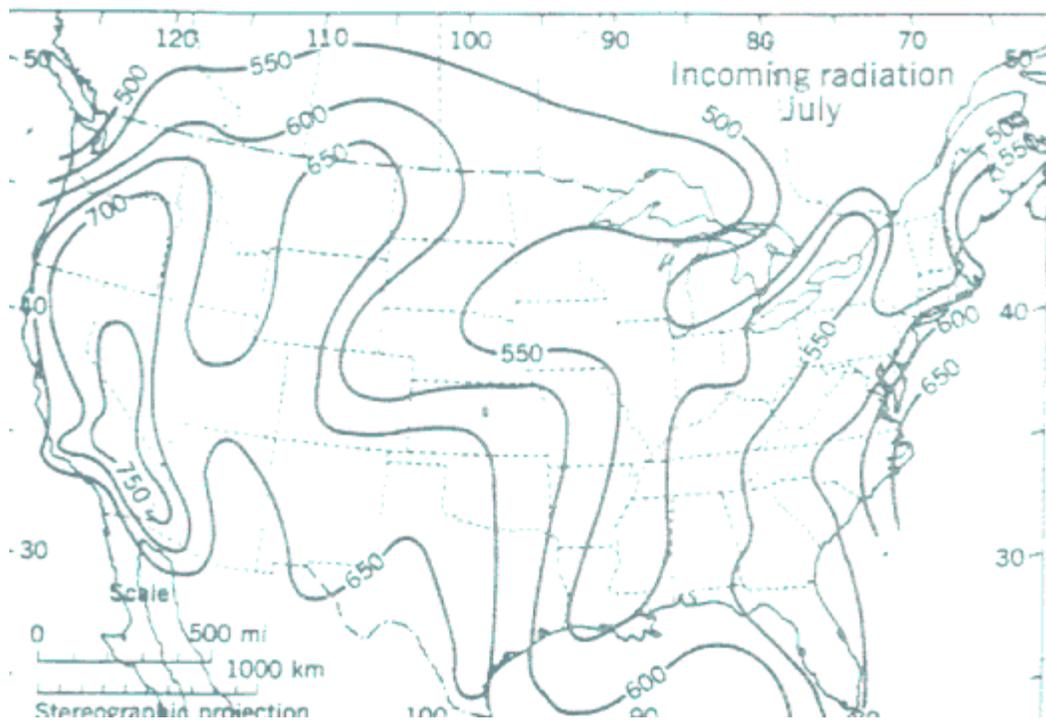
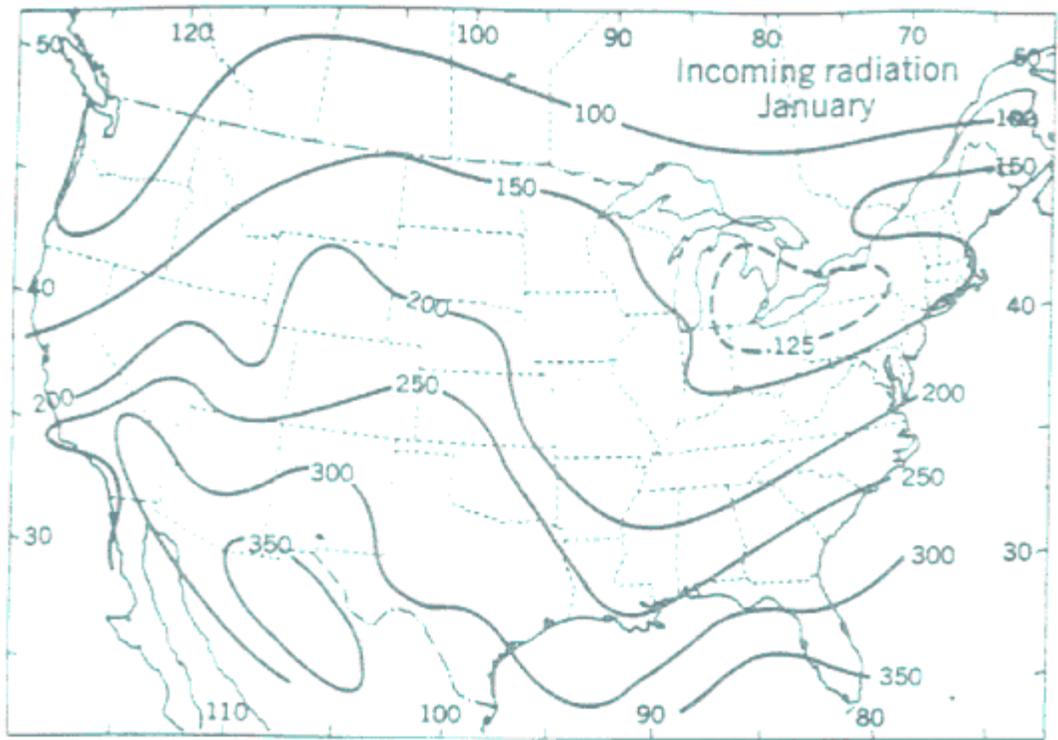


8. (a) Compare the results of your graph with those of classmates who graphed data for different latitudes. Is the pattern of radiation at the top of the atmosphere consistent with your earlier graphs?

(b) Explain these graphs on the basis of your knowledge of astronomy.

Now you have some data describing insolation above the atmosphere. But what happens by the time the Sun's energy goes through the atmosphere to Earth's surface? Diagram 3 has two maps that show the average amounts of solar energy (in langleys/day) actually received at Earth's surface in the continental United States, northern Mexico, and southern Canada in January and July.

Diagram 3: Average Amounts of Insolation Striking Earth's Surface (Langleys/Day) (Next Page)



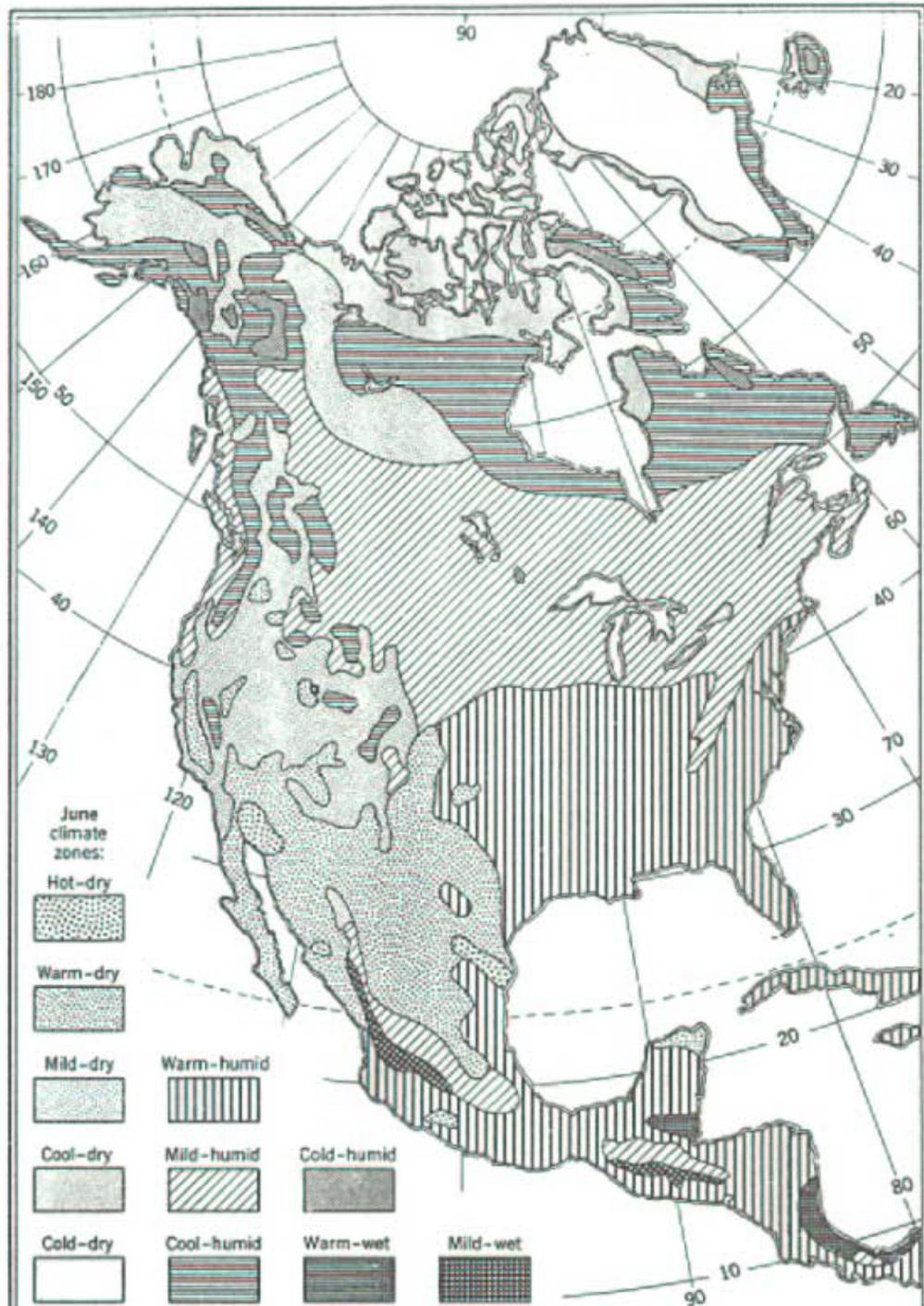
9. On both of these maps, use a ruler to draw latitude lines across the maps at 30, 40, and 50 degrees north. While these lines should actually sag southward a bit in the middle of the map, for our purposes they provide a close enough approximation of their actual location. Label each of the latitude lines with the value of insolation received above the atmosphere on these dates. Use the information shown on diagram 2 for these latitudes on January 15 and July 15 to obtain your values.
10. How do the values that you have written down for the insolation received just above Earth's atmosphere for each latitude compare to the values and patterns of the insolation data present on the maps? (List as many general differences as you find.)

You have seen what happens to incoming radiation; next, you will see why it happens.

11. One particular pattern is especially visible on the July map of insolation reaching Earth's surface. Notice how irregular the isolines are on this map. The lines seem randomly scrambled, but perhaps there is a pattern.
- (a) After studying the map for a moment, lightly shade in those regions receiving more than 650 langleys/day.
- b) What do areas of this region have that allows so much of the radiation from the Sun to reach Earth's surface?

_____ (Those of you who are familiar with this region of the country may know the answer, but if you don't, or are not quite sure, look at diagram 4, below, for a hint.)

Diagram 4: Early Summer Climate Zones of North America



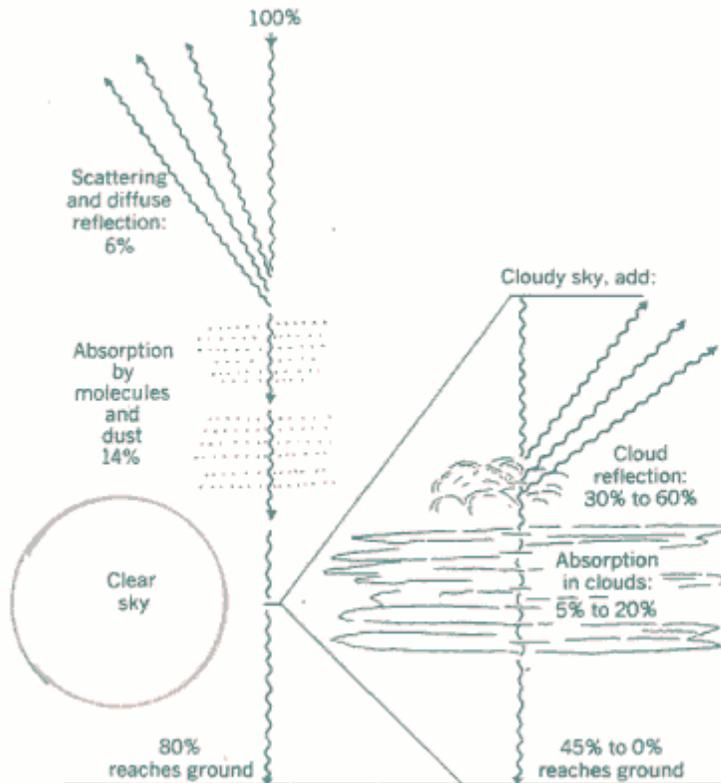
In diagram 4, notice that the eastern region of the United States has a mild-to-warm *humid* climate at this time of year. While this alone does not explain all of the interference with insolation for this region, the climate does play a major

role. Humid air can produce clouds easily, and clouds are a major solar energy blocker.

12. Explain how humid air produces clouds. Use all of these terms in your response: *mountains, water vapor, condensation, rise(s), frontal surface, ice crystals, dewpoint, clouds, water droplets.*

But, how much sunlight do clouds block? Look at diagram 5 below. The left side of the diagram shows the effects of the atmosphere on insolation on a cloudless day. Notice that, without clouds, on average 80% of radiation reaches Earth's surface. But let's focus on the right-hand side of the diagram.

Diagram 5: Effects of the Atmosphere on Insolation



13. (a) According to diagram 5, how much sunlight can a cloudy sky block from reaching Earth's surface? _____%

(b) What processes occur in the clouds to block the sunlight?

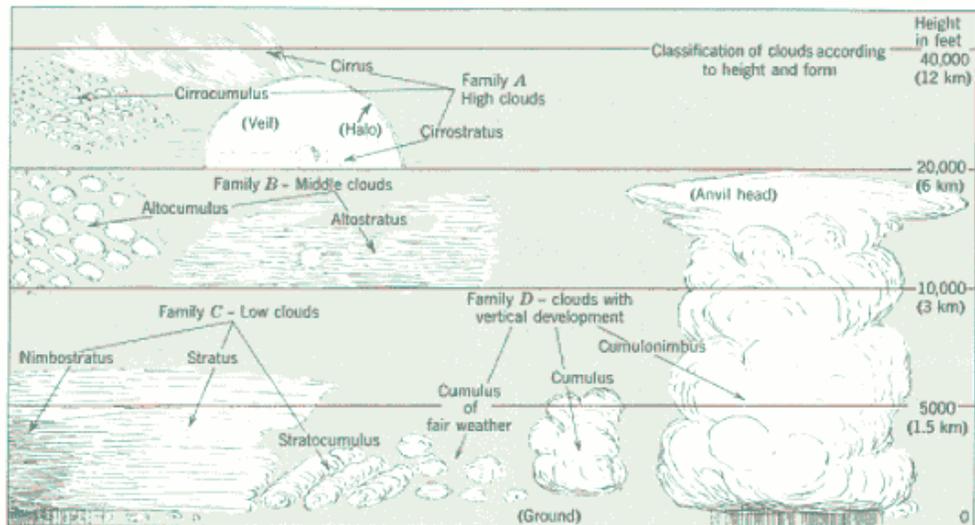
_____ and _____

(c) Which of these processes has the greatest effect on sunlight?

(d) From your personal observations of clouds, how do you know they are good reflectors of sunlight?

Obviously, some clouds are not as effective as others at blocking sunlight. Which types of clouds are most effective at doing so? Look at diagram 6 and make this judgment yourself. Diagram 6 names the major cloud types, separates them into groups called "families," and provides the normal altitudes where they form.

Diagram 6: Cloud Types and Altitudes of Formation



14. (a) Which cloud types should be the most effective at blocking sunlight?

_____ and _____

(b) What characteristic of the clouds caused you to select these types?

(c) Under what conditions do these thicker, sunlight-blocking clouds typically form?

(d) Where are such conditions most likely to be found in the atmosphere?

(e) In the space below, draw two cross-sectional diagrams to illustrate the conditions that would cause the formation of the cloud types you have selected as the answer to question 4a above. Use arrows to indicate air movements, and use words to label the features and clouds that you draw.

1.

2.

Some of the cross-sectional diagrams you and your classmates have drawn represent weather-system fronts and low-pressure centers. Usually, the fronts and their associated clouds occur in distinct patterns. These patterns are

observable on radar images from weather satellites as seen on local weather forecasts, or at weather sites on the Internet. If you have not already done so, do a brief search for “weather” on the Internet and observe the cloud patterns associated with weather systems over North America.

15. The solar panels and other equipment from the network of 50 School Power Naturally schools provide another means of tracking the passage of weather systems across New York State. The electrical output from each solar collector site is available on the School Power Naturally website (www.SchoolPowerNaturally.org). How might you use this resource to track the movement of cloud-producing systems?

16. Using a map of New York State and the School Power Naturally website, identify state locations that are experiencing heavy cloud cover. Mark these locations on the map. If you find several clouded localities, see if you can tell whether a pattern exists. Speculate regarding the type of weather phenomena occurring. Check your conclusion by viewing a weather site on the Internet.

17. (a) Return to diagram 5 earlier in this activity. The left side of this diagram indicates that other processes besides reflection and absorption of solar energy within clouds interfere with insolation passing through the atmosphere. What are the other processes mentioned?

_____ and _____

- (b) On cloudless days, insolation encounters the gas atoms and molecules in Earth’s atmosphere, absorbing some radiation, but also causing much of the shorter wavelengths of the visible spectrum to scatter in all directions. This light is in turn reflected downwards toward Earth’s surface. What phenomenon do these processes cause us to see in the daytime sky?

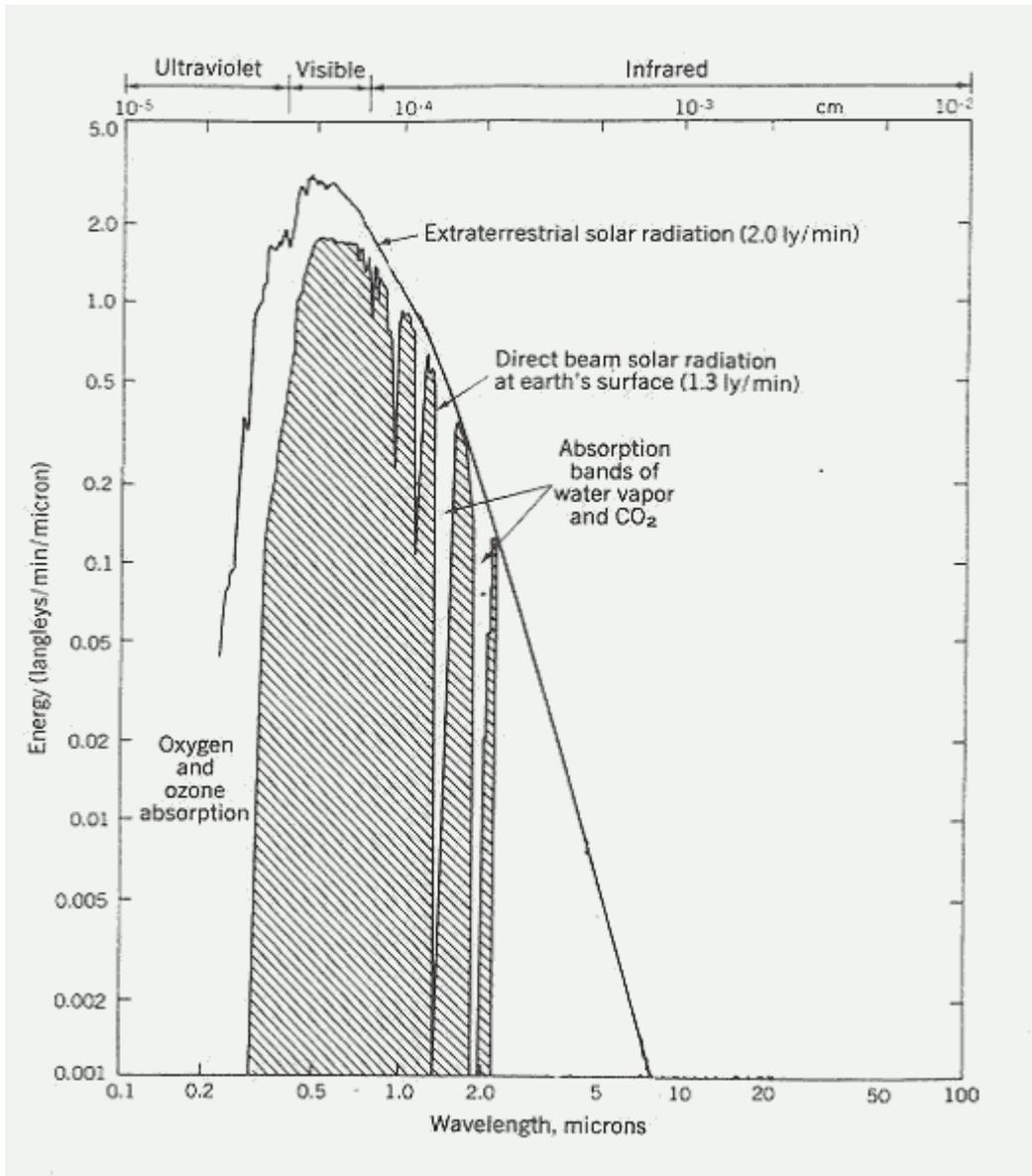
18. (a) Dust particles suspended in the atmosphere also affect the incoming radiation from the Sun, reflecting radiation back to space. The longer-wave visible radiation is less affected by both of these phenomena and more of it continues toward Earth’s surface. This selective removal of shorter visible

radiation affects the appearance of the Sun to our eyes. How do you think the appearance of the Sun is changed?

- (b) During times of major volcanic eruptions or large meteorite impact, tremendous quantities of ash and dust rise high in Earth's atmosphere, where much higher percentages of the insolation are reflected back into space. Describe some of the changes on Earth that the prolonged presence of these particles in the atmosphere would produce

19. The absorption of specific wavelengths of solar radiation by gases in the atmosphere is clarified by diagram 7, below. The upper graphed line shows the amount of Sun's radiation of each wavelength reaching our outer atmosphere. The amount of each wavelength reaching Earth's surface is shown by the line labeled "Direct beam solar radiation at Earth's surface." The space in between is the radiation amount that is blocked/absorbed by Earth's atmosphere.

Diagram 7: Absorption of Sunlight by Earth's Atmosphere



- (a) What materials in Earth's atmosphere absorb the longer wavelengths of the Sun's radiation?
- _____ and _____
- (b) There are four major absorption "valleys" in this section of the graph at approximate wavelengths of _____, _____, _____, and _____ microns. Since 1 micron equals 1×10^{-6} m (a)

(a) What materials in Earth's atmosphere absorb the longer wavelengths of the Sun's radiation?

_____ and _____

(b) There are four major absorption "valleys" in this section of the graph at approximate wavelengths of

_____, _____, _____, and _____ microns.

Since 1 micron equals 1×10^{-4} centimeters, what type of solar radiation is indicated by (absorbed within) these graph valleys?

_____ radiation

(c) What materials in Earth's atmosphere block much of the ultraviolet radiation?

_____ and _____