



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

Suggested Level: Grades 8 through 12, especially students who are enrolled in Regents Earth Science

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 the 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.

MATERIALS

- Computer terminal with 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

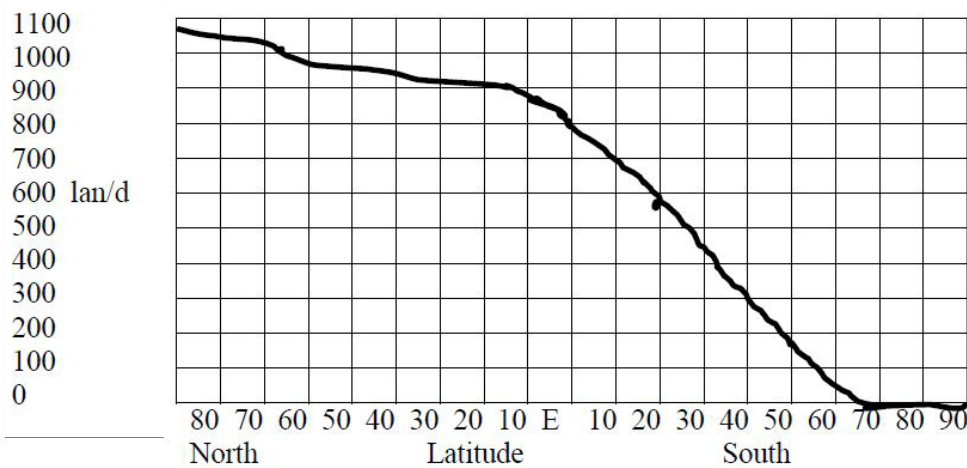
Following are several standard Earth Science laboratory activities you might use that fit well with this lesson's concepts:

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)

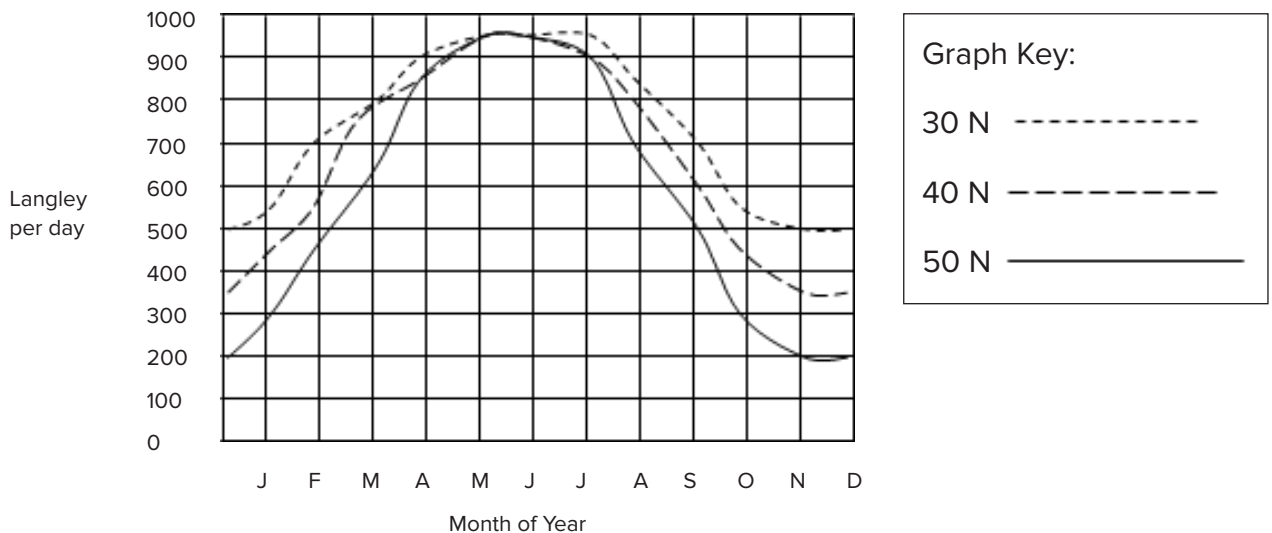
ACCEPTABLE STUDENT RESPONSES

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.)
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.]
3. The peak of atmospheric absorption occurs at a shorter wavelength at the approximate boundary between visible and ultraviolet light at about .4 microns.
4. (a) X ray and ultraviolet; (b) infrared (Students could successfully argue that visible light is also greatly affected.)
5. Student graphs should be similar to the one provided below.

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

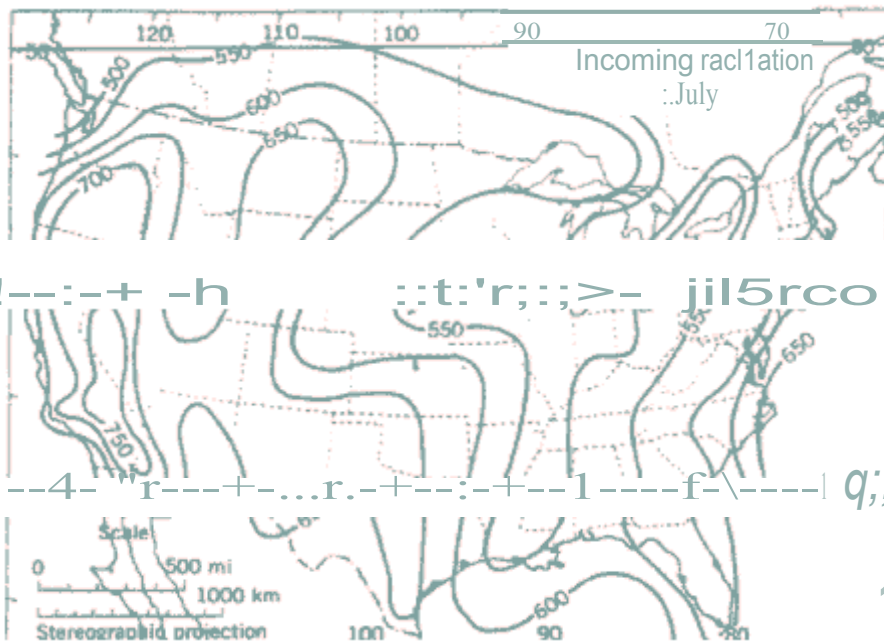
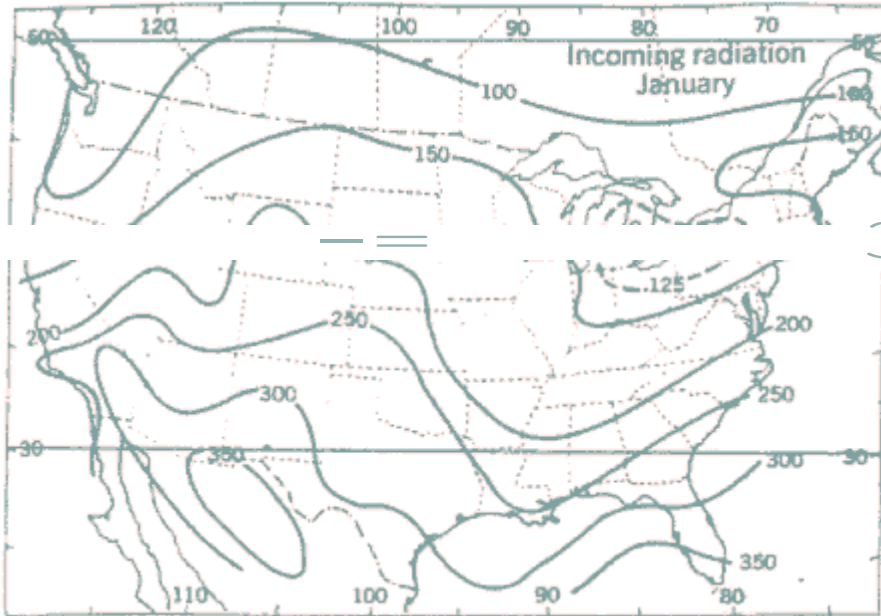


6. Because the earth's North Pole is tilted toward the sun on June 21, the North Polar region can receive 24 hours of daylight each day.
7. The three possible graphs are superimposed below.



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.

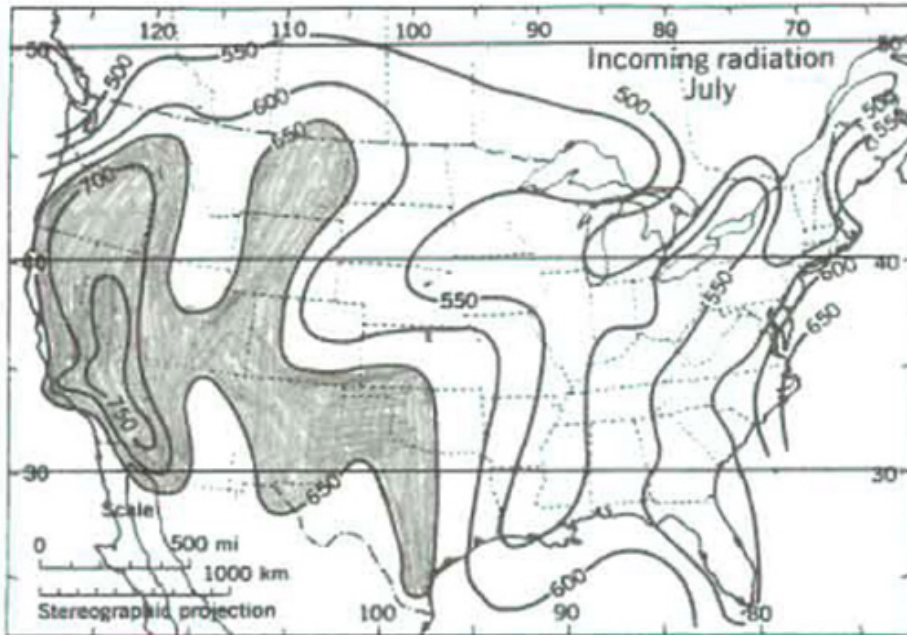
9. Student responses are likely to vary slightly. This would be a good time to emphasize the importance of reading graphs with accuracy (e.g., +/- 25 langleys per day). Students may have difficulty reading July values because of the southward bulging of the 900-langley isoline. You should remind them 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.



10. Responses will vary, but are likely to emphasize the following:

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

11. (a)



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

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 dew point where condensation takes place, changing water vapor to water droplets (or perhaps ice crystals). The droplets form clouds.

13. (a) 35%–80% (b) absorption and reflection (c) reflection

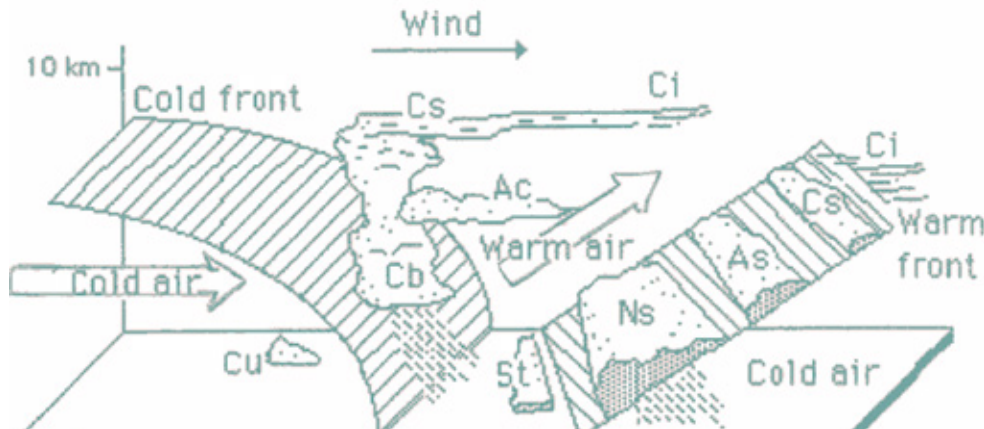
(d) Clouds appear white in color when reflecting sunlight, an indication that all wavelengths of visible light are being reflected.

14. (a) cumulonimbus, nimbostratus, or cumulus (b) These cloud types are thicker.

(c) Thicker clouds occur where large volumes of moist air are forced to rise.

- at frontal boundaries
- 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:



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.

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 schools with solar.

17. (a) Scattering and diffuse reflection and absorption by molecules and dust

(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.

(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.

19. (a) water vapor and carbon dioxide

(b) approximately 1.9, 1.2, 1.1, and 1.0 microns; infrared

(c) ozone and oxygen

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.]

(STUDENT HANDOUT FOLLOWS)

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

Topic: How does the earth's atmosphere affect the radiation coming from the sun to the surface of the 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, the 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 the earth and the amount that actually arrives at the earth's surface and becomes available:

- 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 needed:

- Student handout pages
- Ruler/straightedge
- Pencil

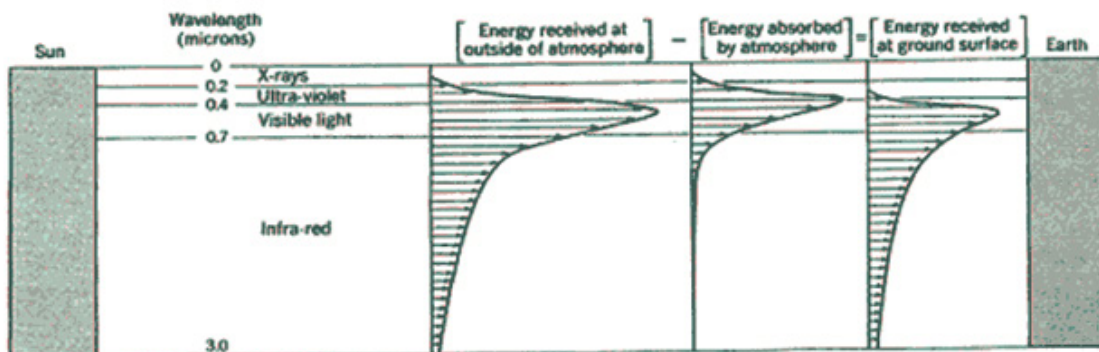
Procedure:

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. Because the atmosphere works in many different ways to alter the amount of radiation received on the 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 the Earth's Atmosphere, Removed by the Atmosphere, and Reaching the 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 the 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?

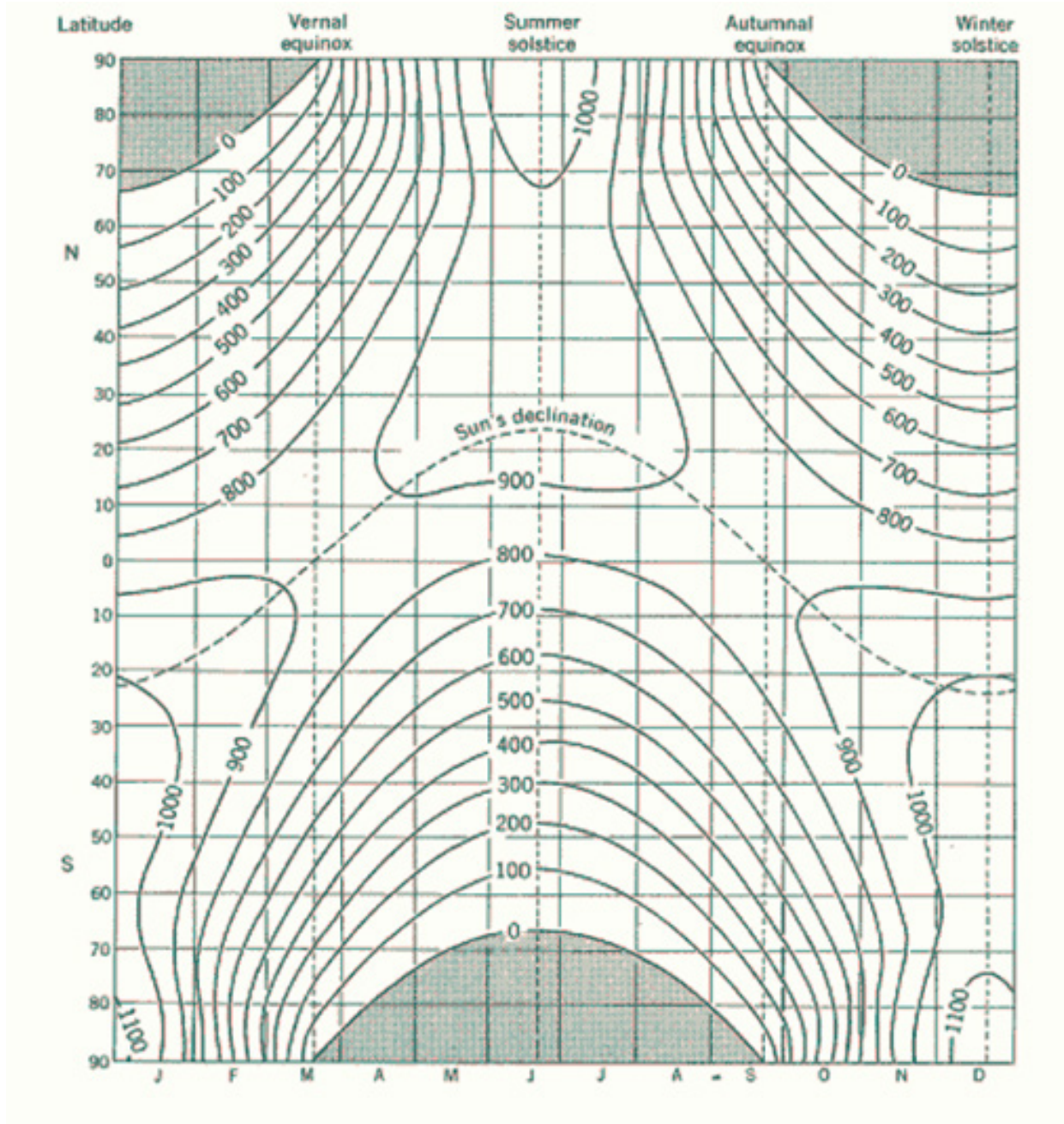
_____ and _____

(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.

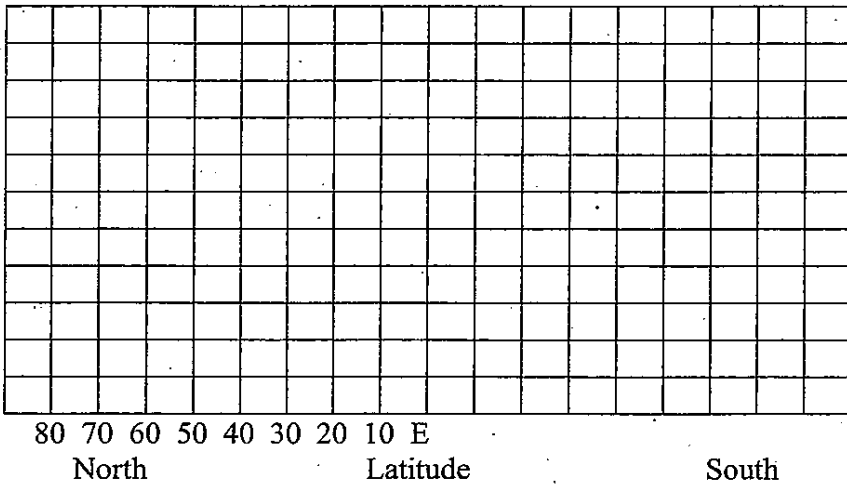
Diagram 2 below consists of a complex graph. It shows the amount of solar radiation energy received on a horizontal surface during the year for all latitudes at the outside of the earth's atmosphere. In other words, the graph shows the amount of radiation energy the earth's surface would receive if no atmosphere were present. Units of energy shown on the graph are in langley's 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



5. 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 the earth on June 21 (the summer solstice). Complete the horizontal and vertical scales and graph the energy data.

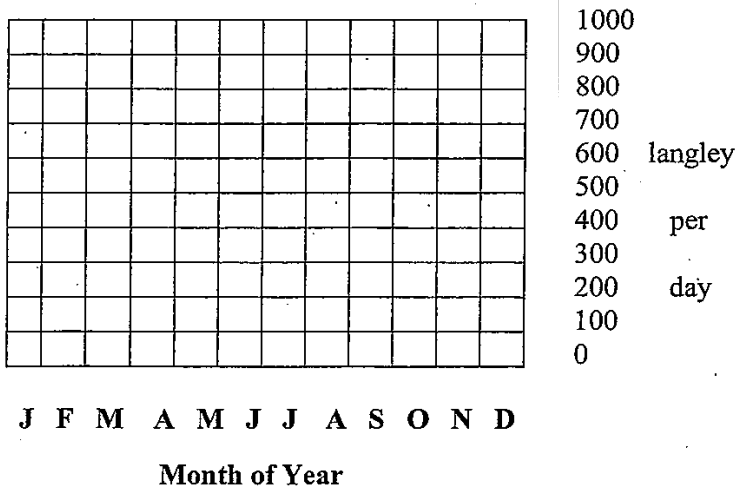
Number of Langleys per Day Received at Outer Edge of the Earth's Atmosphere at All Latitudes



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

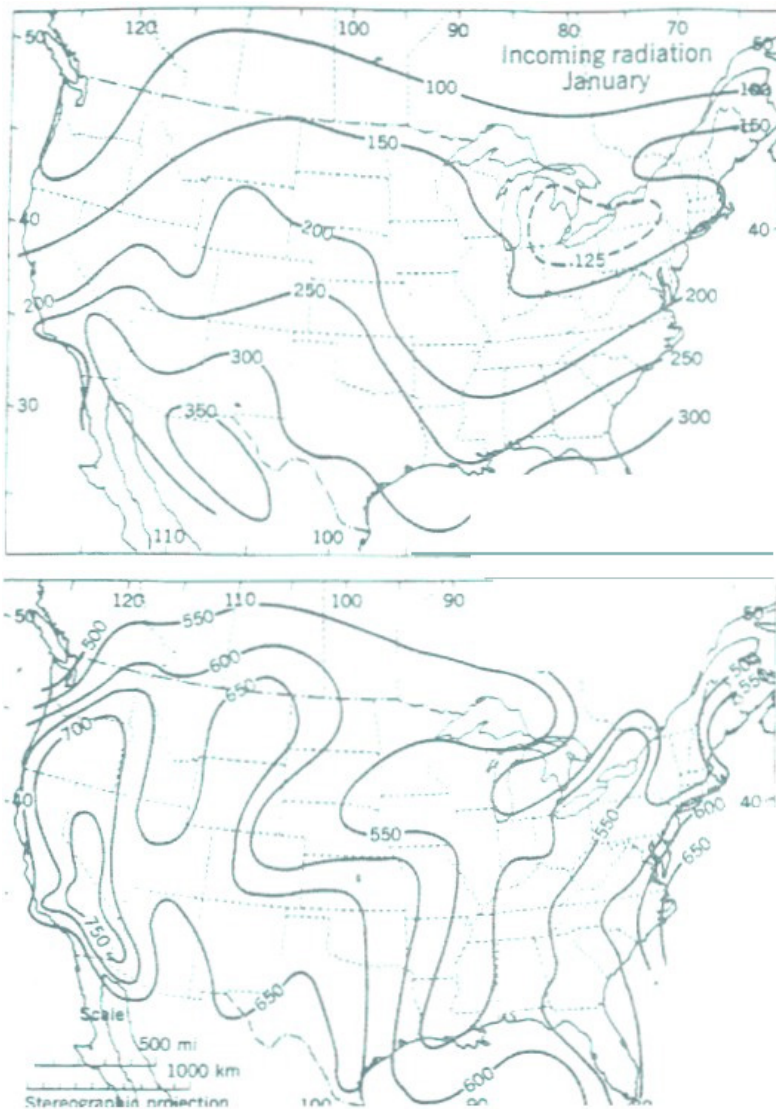


8. (a) Compare the results of your graph with those of classmates who graphed data for different latitudes. Is the pattern of radiation at the top of the atmosphere consistent with your earlier graphs?

(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 the earth's surface? Diagram 3 has two maps that show the average amounts of solar energy (in langley's/day) actually received at the earth's surface in the continental United States, northern Mexico, and southern Canada in January and July.

Diagram 3: Average Amounts of Insolation Striking the Earth's Surface (Langley's/Day)



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 the 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.

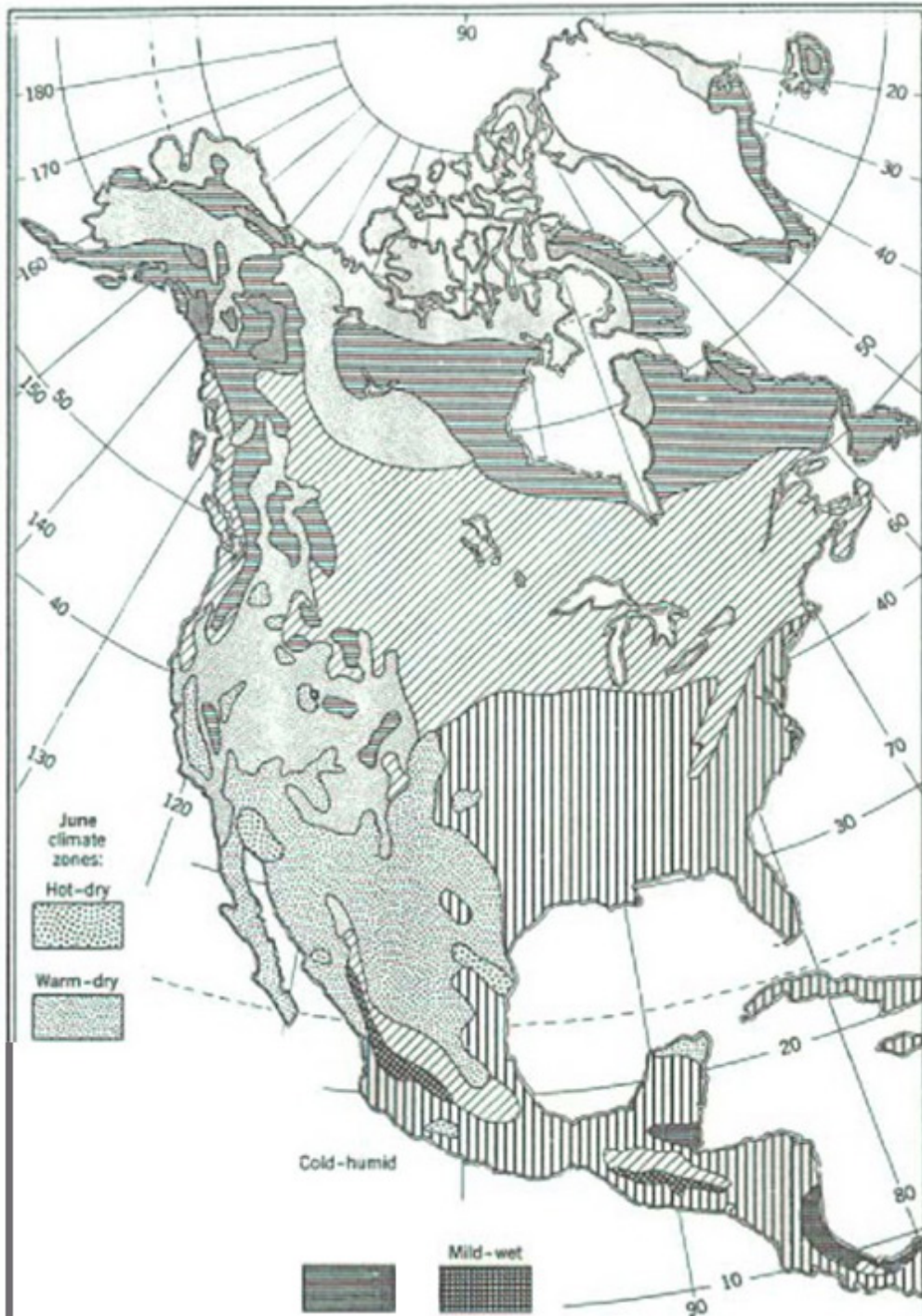
11. One particular pattern is especially visible on the July map of insolation reaching the earth's surface. Notice how irregular the isolines are on this map. The lines seem randomly scrambled, but perhaps there is a pattern.

(a) After studying the map for a moment, lightly shade in those regions receiving more than 650 langley's/day.

b) What do areas of this region have that allows so much of the radiation from the sun to reach the 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, on the following page, for a hint.)

Diagram 4: Early Summer- Climate Zones of North America

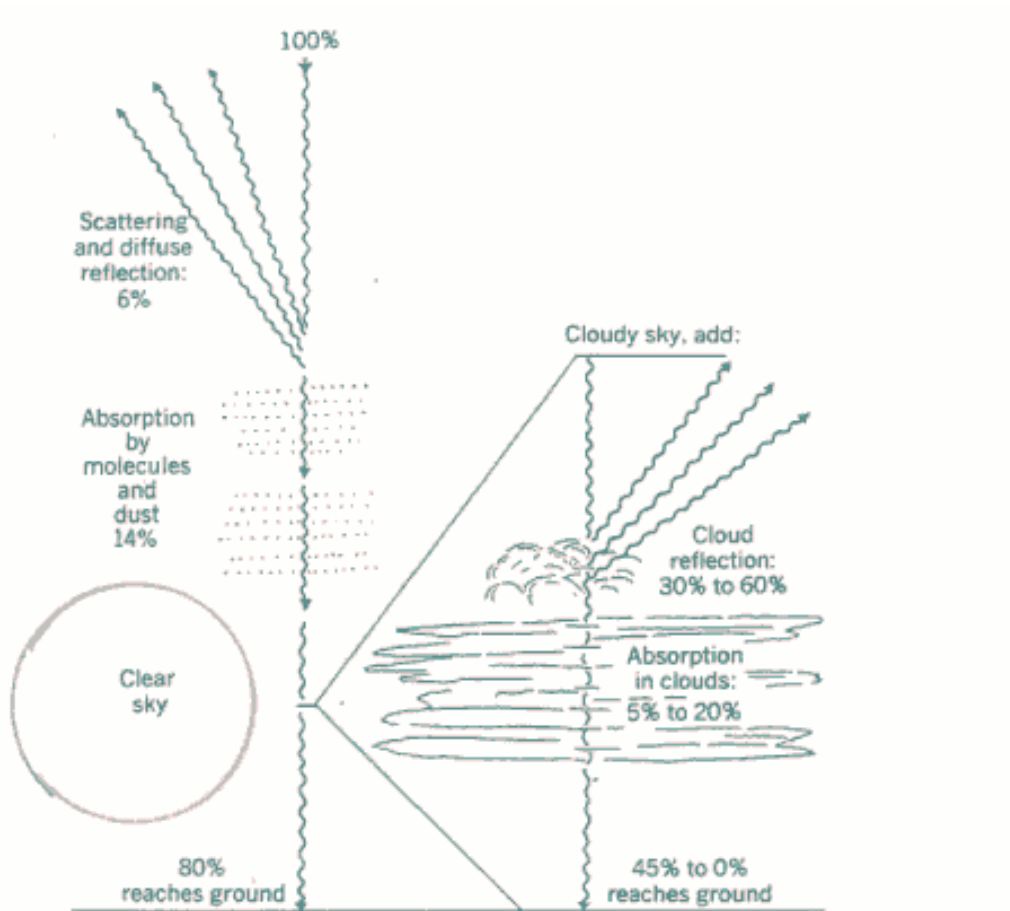


In Diagram 4, notice that the eastern region of the United States has a mild-to-warm *humid* climate at this time of year. While this alone does not explain all of the interference with insolation for this region, the climate does play a major role. Humid air can produce clouds easily, and clouds are 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, dew point, clouds, and 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 the 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 the earth's surface?

_____ %

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

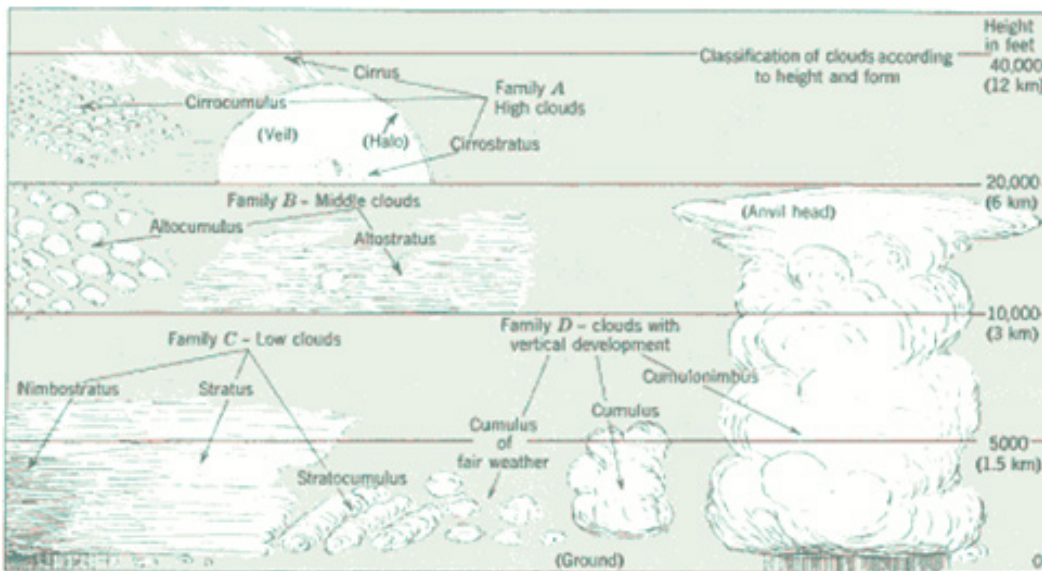
_____ and _____

(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 and on the following page, 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. Using a map of New York State, 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.

16. (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 _____

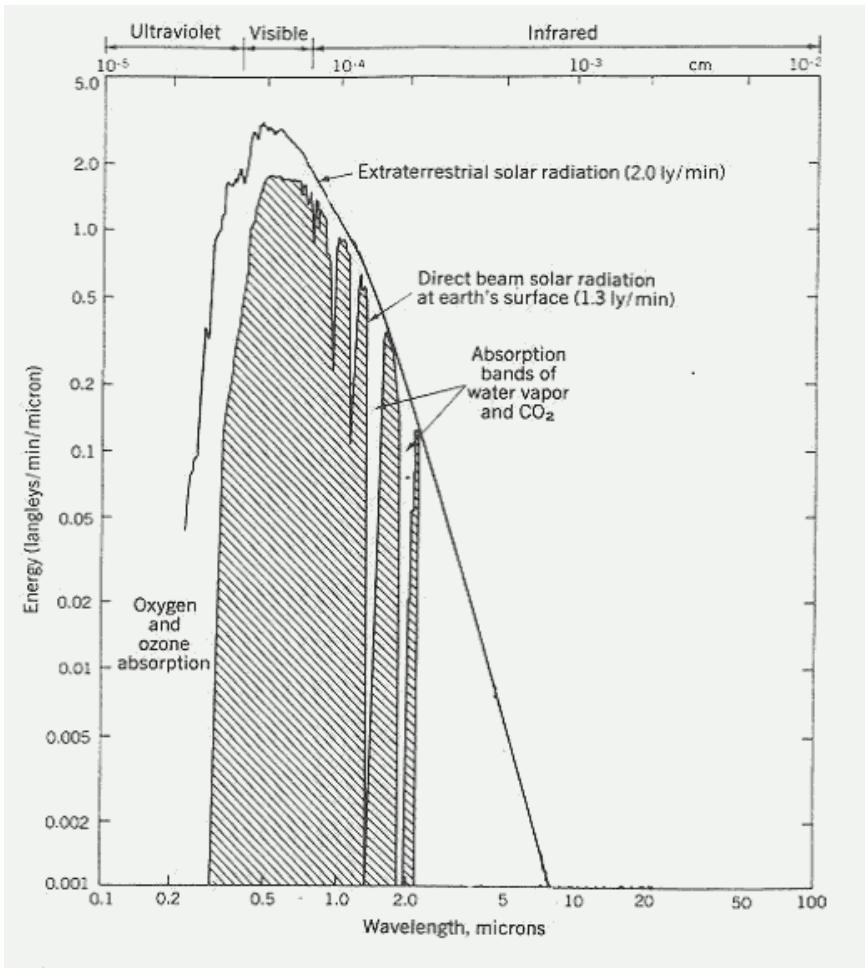
(b) On cloudless days, insolation encounters the gas atoms and molecules in the earth’s atmosphere, absorbing some radiation, but also causing much of the shorter wavelengths of the visible spectrum to scatter in all directions. This light is in turn reflected downwards toward the earth’s surface. What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

17. (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 the 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 the earth's atmosphere, where much higher percentages of the insolation are reflected back into space. Describe some of the changes on the earth that the prolonged presence of these particles in the atmosphere would produce.

18. 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 the sun's radiation of each wavelength reaching our outer atmosphere. The amount of each wavelength reaching the earth's surface is shown by the line labeled "Direct beam solar radiation at the earth's surface." The space in between is the radiation amount that is blocked/absorbed by the earth's atmosphere.

Diagram 7: Absorption of Sunlight by the Earth's Atmosphere



(a) What materials in the 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 the earth's atmosphere block much of the ultraviolet radiation?

_____ and _____