SUNLIGHT AND SEASONS

TEACHER'S GUIDE

Project ATMOSPHERE

This guide is one of a series produced by Project ATMOSPHERE, an initiative of the American Meteorological Society. Project ATMOSPHERE has created and trained a network of resource agents who provide nationwide leadership in precollege atmospheric environment education. To support these agents in their teacher training, Project ATMOSPHERE develops and produces teacher's guides and other educational materials.

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This material is based upon work initially supported by the National Science Foundation under Grant No. TPE-9340055.

Foreword

This guide has been prepared to introduce fundamental understandings about the guide topic. This guide is organized as follows:

Introduction

This is a narrative summary of background information to introduce the topic.

Basic Understandings

Basic understandings are statements of principles, concepts, and information. The basic understandings represent material to be mastered by the learner, and can be especially helpful in devising learning activities in writing learning objectives and test items. They are numbered so they can be keyed with activities, objectives and test items.

Activities

These are related investigations. Each activity typically provides learning objectives, directions useful for presenting and completing the activity and questions designed to reinforce the learning objectives.

Information Sources

A brief list of references related to the guide topic is given for further study.

Introduction

Weather, the current state of the atmosphere, generally varies from day to day, and more so over the seasons. Climate, the long-term summary of weather conditions, follows patterns that remain nearly constant from year to year. Astronomical factors which govern the amount of sunlight received play a major role in predicting these weather and climate patterns.

Our solar system consists of the Sun and a series of planets orbiting at varying distances from the Sun. We can see other stars and we are have detected other planets. However, Earth is the only world on which we are sure life exists and it is the Sun's energy that makes all life possible. The variations in the amounts of solar energy received at different locations on Earth are also fundamental to the seasonal changes of weather and climate.

Essentially, all the energy received by Earth originates from thermonuclear reactions within the Sun. Energy from the Sun travels outward through the near-vacuum of space. The concentration of the Sun's emissions decreases rapidly as they spread in all directions. By the time they reach Earth, some 150 million kilometers (93 million miles) from the Sun, only about 1/2,000,000,000 of the Sun's electromagnetic and particle emissions are intercepted by Earth. This tiny fraction of solar energy is still a significant amount, with almost 2 calories falling each minute on each square centimeter (1370 Watts per square meter) of a surface oriented perpendicular to the Sun's rays above Earth's atmosphere. To the Earth system, this important life-giving amount of energy is called the "*solar constant*", even though it does vary slightly with solar activity and the position of Earth in its elliptical orbit. For most purposes, the delivery of the Sun's energy can be considered essentially constant at the average distance of Earth from the Sun.

Because of Earth's nearly spherical form, the incoming energy at any one instant strikes only one point on Earth's surface at a 90-degree angle (called the sub-solar point). All other locations on the sunlit half of Earth receive the Sun's rays at lower angles, causing the same energy to be spread over larger areas of horizontal surface. The lower the Sun in the sky, the less intense the sunlight received.

As shown in the accompanying Sunlight and Seasons diagram, **Figure 1**, Earth has two planetary motions that affect the receipt of solar energy at the surface, its once per day rotation and its once per year revolution about the Sun. These combined motions cause daily changes in the receipt of sunlight at individual locations. As Earth rotates and revolves about the Sun, its axis of rotation always remains in the same alignment with respect to the distant "fixed stars". Because of this, the North Pole points toward Polaris (North Star) throughout the year. This axis orientation is a steady 23.5-degree inclination from the year.

SUNLIGHT AND SEASONS

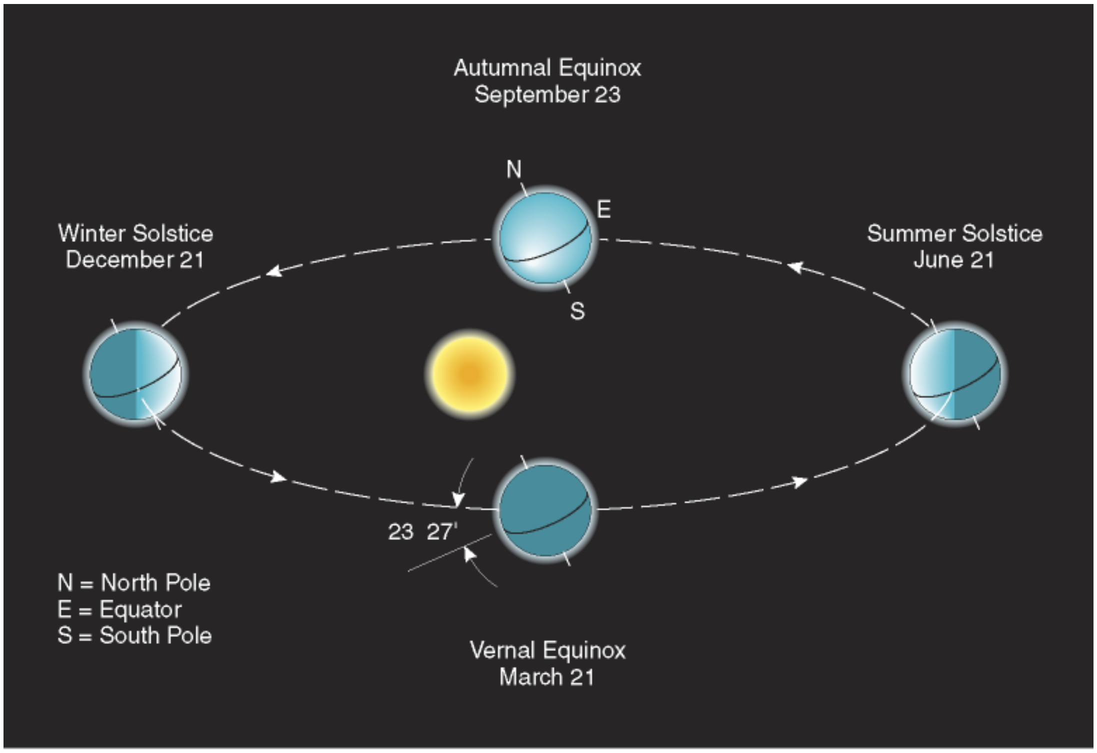

Figure 1. Earth's orbit relative to the Sun.

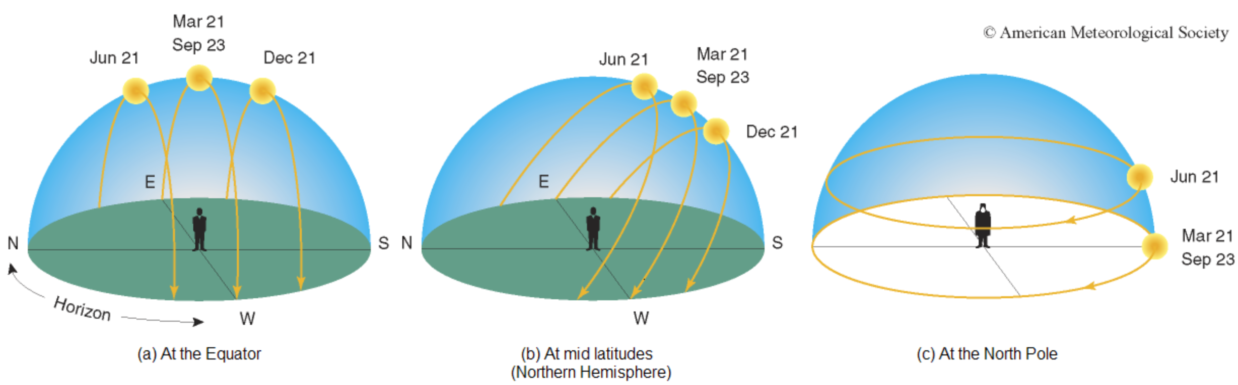

Figure 2. Path of Sun through the sky at equatorial, mid-latitude, and polar locations.

This axis orientation is a steady 23.5-degree inclination from the perpendicular to the plane of the orbit. While the inclination remains the same relative to Earth's orbital plane, Earth's axis is continuously changing position relative to the Sun's rays.

Figure 2, (a), (b), and (c), **Sky Views of the Sun**, shows the effects of rotation, revolution, and orientation of Earth's axis on the path of the Sun through the sky at equatorial, mid-latitude and polar locations at different time of the year.

Twice each year as Earth makes its journey around the center of the solar system, Earth's axis is oriented perpendicular to the Sun's rays. This happens on the Spring (Vernal) Equinox – on or about March 21, and the Fall (Autumnal) Equinox – on or about September 23 (terminology being a Northern Hemisphere bias!). On these days, the sub-solar point is over the Equator. Exactly one half of both Northern and Southern Hemispheres are illuminated and everywhere (Except the pole itself) received 12 hours daylight in the absence of atmospheric effects. From the perspective of a surface observer located anywhere except at the poles, the Sun would rise in the due East position and set due West. At the Equator, the Sun would be directly overhead at local noon.

There are two times when Earth's axis is inclined the most from the perpendicular to the Sun's rays. These are the solstices, approximately midway between the equinoxes. For the Summer Solstice, on or about June 21, the North Pole is inclined 23.5 degrees from the perpendicular and tipped toward the Sun. The sub-solar point is at 23.5 °N. At this time, more than half of the Northern hemisphere is illuminated at any instant and thus, has daylight lengths greater than 12 hours. The day length increases with increasing latitude until above 66.5 °N (Arctic circle) there is 24 hours of sunlight.

Conversely, for the Winter Solstice, on or about December 21, Earth's axis is also inclined 23.5 degrees from the perpendicular to the Sun's rays. However, at this time of the year the sub-solar point is at 23.5 °S. The North Pole tips away from the Sun and no sunlight reaches above the Arctic Circle (66.5 °N). Less than half of the Northern Hemisphere is illuminated and experiences daylight periods shorter than 12 hours.

Sunlight variability due to astronomical factors in the Southern Hemisphere is the reverse of the Northern Hemisphere patters. The seasons are also reversed.

Together, the path of the Sun through the local sky and the length of daylight combine to produce varying amounts of solar energy reaching Earth's surface. The energy received is one of the major factors in determining the character of weather conditions and, in total, the climate of a location. Generally, the higher the latitude, the greater the range (difference between maximum and minimum) in solar radiation received over the year and the greater the difference from season to season.

Astronomical factors do not tell the whole story about sunlight and seasons. The daily changes of solar energy received at Earth's surface within each season come primarily from the interaction of the radiation with the atmosphere through which it is passing. Gases within the atmosphere scatter, reflect and absorb energy. Scattering of visible light produces the blue sky, while clouds and hazy gray days. Ozone formation and dissociation absorb harmful ultraviolet radiation while water vapor absorbs infrared. Clouds strongly reflect and scatter solar energy as well as absorbing light depending on their thickness. Haze, dust, smoke, and other atmospheric pollutants are also scatterers of solar radiation.

Basic Understandings: Sunlight and Seasons

Solar Energy

1. Practically all the energy that makes Earth hospitable to life and determines weather and climate comes from the Sun.

2. The Sun, because of its high surface temperatures, emits radiant energy throughout the electromagnetic spectrum. Most is in the form of visible light and infrared (heat) radiation.

3. Earth, on average some 150 million kilometers (93 million miles) away, intercepts a tiny fraction (1/2,000,000,000) of the Sun's radiation.

4. The rate at which solar energy is received outside Earth's atmosphere on a flat surface placed perpendicular to the Sun's rays, and at the average distance of Earth from the Sun, is called the *solar constant*. The value of the solar constant is about 2 calories per square centimeter per minute (1370 Watts per square meter).

5. Solar radiation is not received the same everywhere at Earth's surface, due primarily to astronomical and atmospheric factors.

Astronomical Factors – The Spherical Earth

6. At any instant of time, one-half of the nearly spherical Earth is in sunlight and one-half is in darkness.

7. The total amount of solar energy received by Earth is limited to the amount intercepted by a circular area with a radius equal to the radius of Earth.

8. In the absence of atmospheric effects, sunlight is most intense at the place on Earth where the Sun is directly overhead, that is, at the zenith for that location. As the Sun's position in the sky lowers, the sunlight received on horizontal surfaces decreases.

9. Due to our planet's rotation and revolution, the place on Earth where the Sun's position is directly overhead is constantly changing.

Astronomical Factors – The Inclination of Earth's Axis

10. Throughout Earth's annual journey around the Sun, the planet's rotational axis remains in the same position relative to the background stars. The North Pole points in the same direction toward Polaris (the North Star) throughout the year.

11. Earth’s rotational axis is inclined 23.5 degrees from the perpendicular to the plane of Earth’s orbit. The orientation of Earth’s axis relative to the Sun and its rays changes continuously as our planet speeds along its orbital path.

12. Twice a year Earth’s axis is positioned perpendicular to the Sun’s rays. In the absence of atmospheric effects, all places on Earth except the poles experience equal period of daylight and darkness. These times are the equinoxes — the first days of spring and fall, and they occur on or about March 21 and September 23, respectively.

13. Earth’s rotational axis is positioned at the greatest angle from its perpendicular equinox orientation to the Sun’s rays on the solstices. On or about June 21, our Northern Hemisphere is most tipped toward the Sun on its first day of summer. On or about December 21, the Northern Hemisphere is most tipped away from the Sun on its first day of winter.

14. As Earth orbits the Sun, the inclined axis causes the Northern Hemisphere to tilt toward the Sun for half of the year (our spring and summer seasons). During this time, more than half of the Northern Hemisphere is in sunlight at any instant of time. During the other half of the year (our fall and winter seasons), the axis tilts away and less than half of the Northern Hemisphere is in sunlight.

15. The tilting of the Southern Hemisphere relative to the Sun’s rays progresses in opposite fashion, reversing its seasons relative to those in the Northern Hemisphere.

16. The changing orientation of Earth’s axis to the Sun’s rays determines the length of daylight and the path of the Sun as it passes through the sky at every location on Earth.

17. The continuous change in the angular relationship between Earth’s axis and the Sun’s rays causes the daily length of daylight to vary throughout the year everywhere on Earth except at the equator.

18. From day to day in a perpetually repeating annual cycle, the path of the Sun through the sunlit sky changes everywhere on Earth, including at the equator.

19. In the latitudes between 23.5 degrees North and 23.5 degrees South, the Sun passes directly overhead twice each year.

20. At latitudes greater than 23.5 degrees, the maximum altitude the Sun ever reaches in the local sky during the year decreases as the latitude increases. At either pole the maximum altitude is 23.5 degrees above the horizon, occurring on the first day of the hemisphere’s summer.

Energy Received

21. In the absence of atmospheric effects, the length of the daylight period and the path of the Sun through the local sky determine the amount of solar radiation received at Earth’s surface.

22. Ignoring atmospheric effects, the variation in the amount of sunlight received over the period of a year at the equator is determined by the path of the Sun. The Sun’s path is highest in the sky on the equinoxes and lowest on the solstices. This results in two periods of maximum sunlight centering on the equinoxes and two period of minimum sunlight at solstice times each year.

Seasons

23. At the equator the daily period of daylight is the same day after day. The changing path of the Sun through the sky produces over the year a cyclical variation in the amounts of solar radiation received that exhibit maxima near the equinoxes and minima near the solstices. The relatively little variation in the amounts of solar energy received over the year produces seasons quite different from those experienced at higher latitudes.

24. Away from the tropics, the variation in the amounts of solar radiation received over the year increase as latitude increases. The amounts of sunlight received exhibit one minimum and one maximum in their annual swings. The poles have the greatest range since the Sun is in their skies continuously for six months and then below the horizon for the other half year.

25. In general, the variations in solar radiation received at the surface over the year at higher latitudes create greater seasonal differences.

26. While the receipt of solar energy is the major cause of seasonal swings of weather and climate at middle and high latitudes, other factors such as nearness to bodies of water, topographical features, and migrations of weather systems play significant roles as well.

Atmospheric Factors

27. The atmosphere reflects, scatters, and absorbs solar radiation, reducing the amount of sunlight that reaches Earth’s surface.

28. Some atmospheric gases absorb specific wavelengths of solar radiation. Water vapor is a strong absorber of incoming infrared energy, causing a significant reduction in the amount of solar radiation reaching the ground during humid conditions. Ozone, during its formation and dissociation, absorbs harmful ultraviolet radiation that can lead to sunburn and skin cancer.

29. Haze, dust, smoke, and air pollutants in general block incoming solar energy to some extent wherever present.

30. Clouds strongly reflect, scatter, and absorb incoming sunlight. High, thin cirrus absorb some sunlight while dense clouds, if thick enough, can produce almost nighttime conditions.

Activity: Sunlight Throughout the Year

Introduction

All weather and climate begin with the Sun. Solar radiation is the only significant source of energy that determines conditions at and above Earth's surface. Earth receives about 1/2,000,000,000 of the Sun's radiant energy production.

The average amount of solar radiation reaching Earth's orbit (top of the atmosphere) and falling on a flat surface perpendicular to the Sun's rays at that distance is about 2 calories per square centimeter per minute. This rate is called the ***solar constant***.

However, the amount of solar radiation that reaches the Earth's surface can be quite different. The nearly-spherical Earth, rotating once a day on an axis inclined as it is to the plane of its orbit, presents a constantly changing face to the Sun. Everywhere on Earth the path of the Sun through the sky changes during the year. Everywhere on Earth, except at the Equator, the lengths of daily daylight periods change.

In addition, the atmosphere acts to reflect, absorb, and scatter the solar radiation passing through it. Clouds, especially, can reflect and scatter much of the incoming radiation.

The purpose of the activity is to investigate the variability of sunlight received at Earth's surface over the period of a year.

Upon completing this activity, you should be able to:

- Investigate the receipt of solar energy over the period of a year at equatorial, mid-latitude, and polar regions.

- Describe annual solar radiation patterns at different locations and relate then to the astronomical factors that cause them.

- Estimate and compare average daily radiant energy totals received at a mid-latitude location on the first days of the seasons.

Procedure

Examine the accompanying graph entitled Variation of Solar Radiation Received on Horizontal Surfaces at Different Latitudes. Data points plotted on the graph represent solar radiation received daily on horizontal surfaces averaged over each month for equatorial, mid-latitude, and polar locations. These values were determined from actual observations and include the effects of clouds. Time is plotted along the horizontal axis while average daily incident radiant energy in calories per square centimeter per day is plotted vertically.

Questions

1. Construct an annual solar radiation curve for each of the three locations. Do this by drawing a smooth curved line connecting adjacent months of average daily radiation values for the locations that have already been plotted. Note that at the South Pole (90 degrees South Latitude) the Sun rises on or about September 23 and sets on or about March 21. Draw each curve to the edges of the graph. December appears twice to more clearly display the annually repeating radiation cycles.

2. At which latitude shown does the rate at which solar energy is received vary the least throughout the year? _______________

3. The annual radiation curve for Singapore shows two maxima and two minima even though the daily period of daylight remains nearly 12 hours throughout the year. Explain the astronomical cause of the two maxima and minima by referring to Fig. 2(a) in the Sunlight and Seasons diagram.
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____
____
____

4. Refer to Fig. 2(b) in the Sunlight and Seasons diagram. At such a middle latitude location, both the path of the sun through the sky and the daily length of daylight change from day to day. Use these two factors to explain why during the May-August period the mid-latitude location receives more solar radiation on a daily than does the equatorial location.
____
____
____
____

5. Refer to your graph. At which latitude is there an extended period of darkness over the year? ____________ How long is it? ____________

6. On your graph, the maximum daily solar radiation amount for Brockport occurred in late June. Why does it peak six months later at Antarctica?
____
____

7. Draw and label an estimated annual solar radiation curve for the North Pole. Assume North and South Pole radiation values to be the same, but reversed,

over the period of a year. Fill in the North Pole (NP) column of the radiation table and then draw the North Pole curve.

8. Imagine you are the observer in Fig. 2(c) of the Sunlight and Seasons diagram. Explain in terms of the path of the Sun and the daily period of daylight, the placement of your North Pole annual radiation curve.

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____
____

9. Compare all the annual radiation curves. What is the relationship between latitude and the annual range of solar radiation received?

____
____

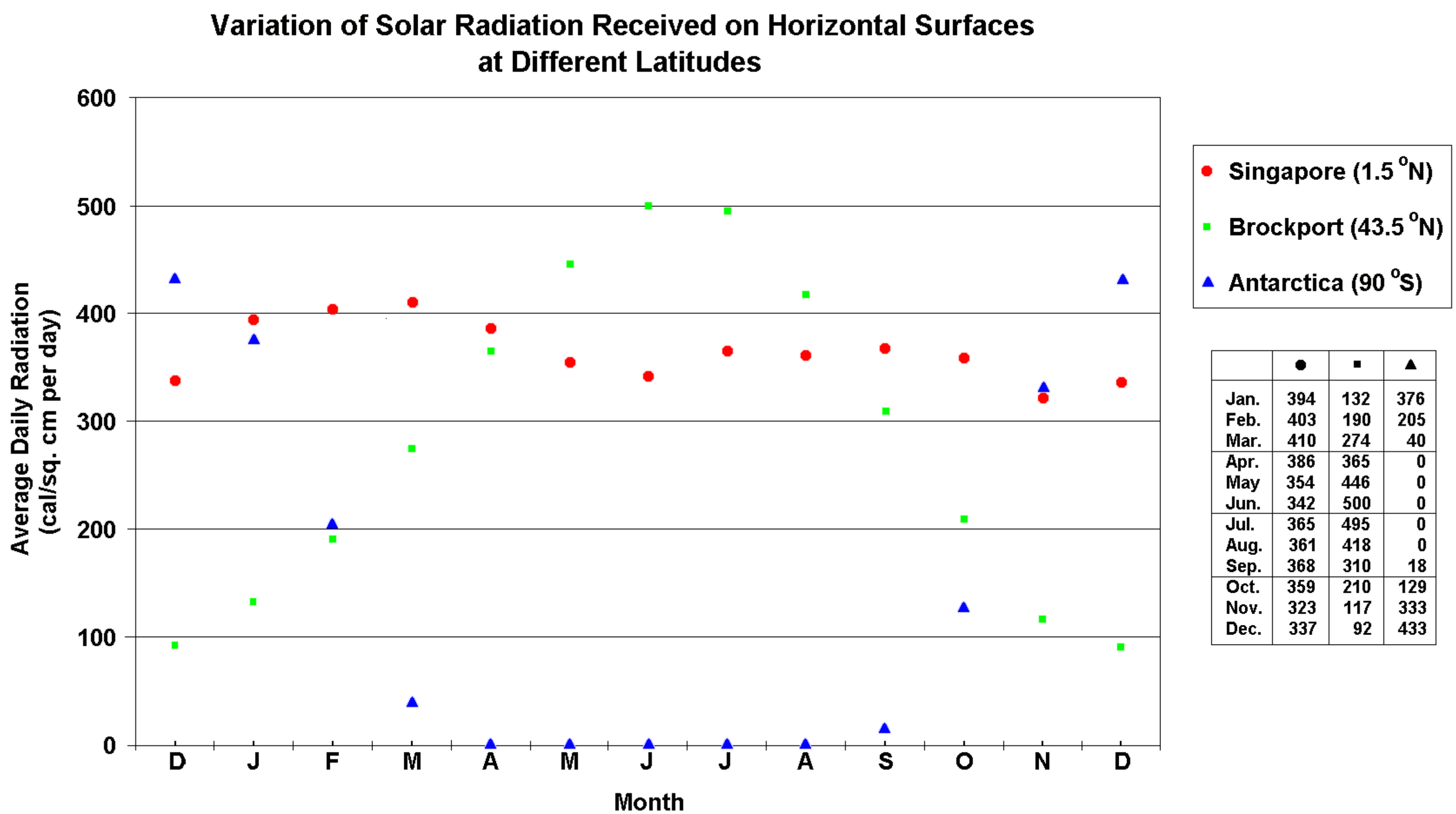
10. To mark the positions of the equinoxes and solstices, draw vertical lines on the graph at approximately March 21, June 21, September 23, and December 21. On the Equinoxes, the Sun is directly above the equator. while on the solstices the Sun is directly above 23.5 degrees North or South Latitude. Label the intervals between the lines as the Northern Hemisphere's Winter, Spring, Summer, and Fall seasons.

11. The area enclosed under each curve between respective dates is directly proportional to the total energy received during that time period. At which location do all the seasons receive about the same total amount of solar radiation? _______________

12. At the mid-latitude location, which season(s) receive the most solar energy? ______________________________ Which receive the least? ______________________________

13. At the North Pole, which season(s) receive no solar radiation at all? ___________________________________

14. Calculate the annual amount of solar radiation received at the three locations. The equatorial and mid-latitude locations receive how many times more solar energy than either pole? ___________________________



	●	■	▲
Jan.	394	132	376
Feb.	403	190	205
Mar.	410	274	40
Apr.	386	365	0
May	354	446	0
Jun.	342	500	0
Jul.	365	495	0
Aug.	361	418	0
Sep.	368	310	18
Oct.	359	210	129
Nov.	323	117	333
Dec.	337	92	433

Real World Applications

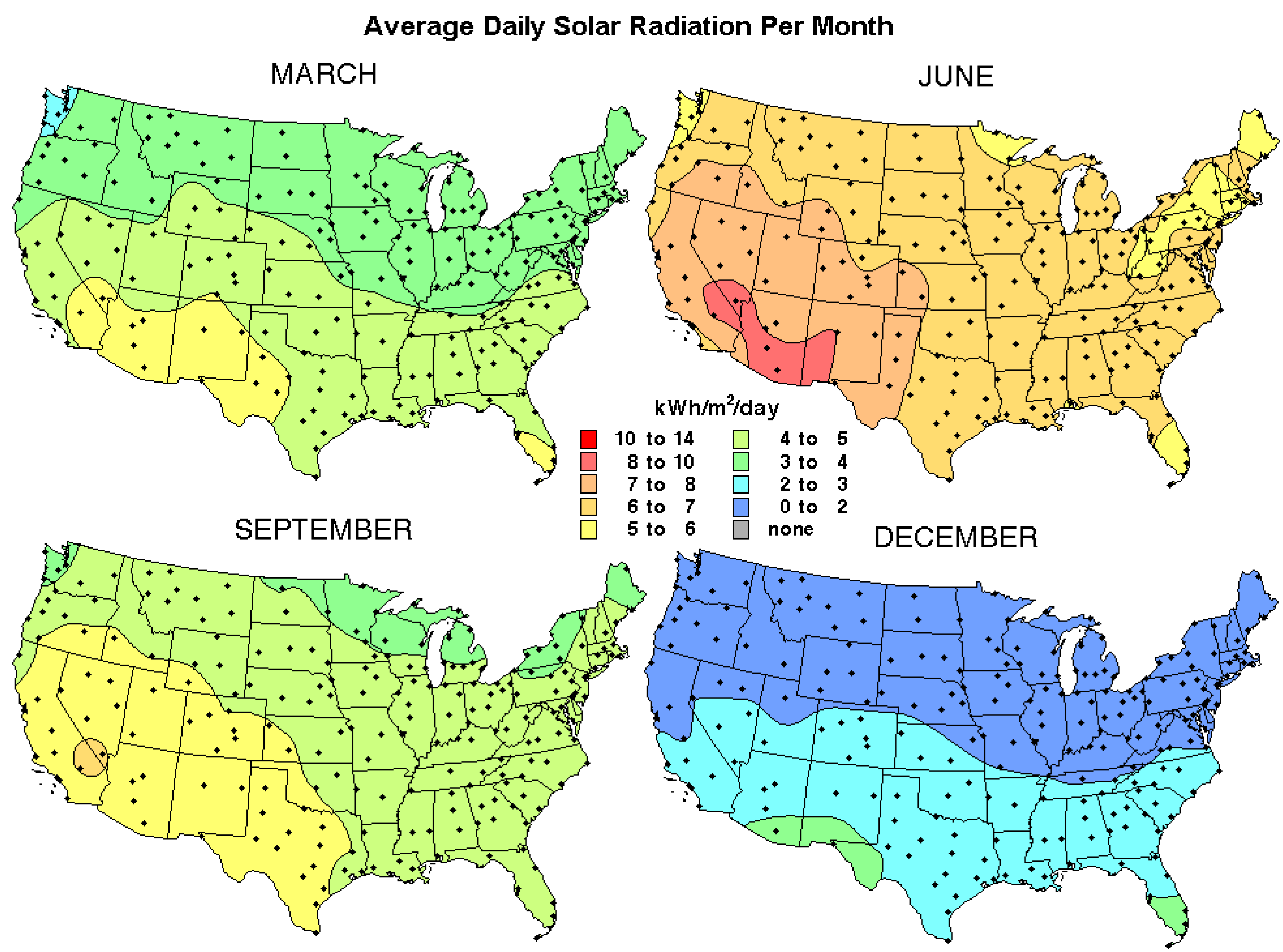
The following maps are based on data collected from 1961 – 1990 in the National Solar Radiation Database. These are considered for the use of implementing flat plate solar collectors. The data can be listed or mapped as either the average, maximum or minimum monthly or annual values for a variety of solar collector geometries. The map choices came from: *http://rredc.nrel.gov/solar/old_data/nsrdb/1961-1990/redbook/atlas/*. These data account for both the astronomical and atmospheric factors at the locations shown. Dots indicate the stations providing the data at these generally mid-latitude locations.

1. In general, the maximum monthly average solar radiation values occur in __________. The minimum values are in __________.

2. The values for March **[(*are*)(*are not*)]** generally comparable to those of September at the same locations.

3. The solar radiation values across the country in December and in March **[(*do*)(*do not*)]** generally run parallel to the latitudes, and **[(*decrease*)(*remain the same*)(*increase*)]** as the latitude increases.

4. Average monthly solar radiation values in June show a pattern of locally highest values in the U.S. desert Southwest. These higher values **[(*would*)(*would not*)]** likely be the result of atmospheric factors. That variation would most probably be due to the relative minimum of atmospheric **[(*water vapor*)(*clouds*)(*both of these*)]**.


Average Daily Solar Radiation Per Month
MARCH
JUNE
SEPTEMBER
DECEMBER
kWh/m2/day
10 to 14
8 to 10
7 to 8
6 to 7
5 to 6
4 to 5
3 to 4
2 to 3
0 to 2
none

Information Sources

Books

Moran, Joseph M. Weather Studies: Introduction to Atmospheric Science, 5th Ed. Boston, MA: American Meteorological Society, 2012.

Periodicals

Weatherwise. Bimonthly magazine written in association with the American Meteorological Society for the layperson. Weatherwise, 1319 Eighteenth St., NW, Washington, DC 20036.

USA Today. National newspaper with extensive weather page. Available at local newsstands and by subscription.

Radio and Television

NOAA Weather Radio. The voice of the National Weather Service and All Hazards Emergency Alert System. Local continuous broadcasts from over 1000 transmitting stations nationwide.

The Weather Channel. A continuous cable television program devoted to reporting weather. Includes frequent broadcast of local official National Weather Service forecasts.

Internet

DataStreme Atmosphere (*www.ametsoc.org/amsedu/dstreme/*). Atmospheric education distance-learning website of the AMS Education Program.

JetStream – Online School for Weather (*www.srh.noaa.gov/jetstream/*). Background weather information site from the National Weather Service.