Project Atmosphere Canada

MODULE 10

Sunlight and Seasons

Teacher's guide

Canadian Meteorological and Oceanographic Society
La Société Canadienne de Météorologie et d'Océanographie

Environment Canada
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Canada

Project Atmosphere Canada

Project Atmosphere Canada (PAC) is a collaborative initiative of Environment Canada and the Canadian Meteorological and Oceanographic Society (CMOS) directed towards teachers in the primary and secondary schools across Canada. It is designed to promote an interest in meteorology amongst young people, and to encourage and foster the teaching of the atmospheric sciences and related topics in Canada in grades K-12.

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On behalf of
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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 determining 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 fairly certain other planets exist. However, Earth is the only world on which we are sure life exists and it is the Sun's energy that makes all life on Earth 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 the 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 the Earth, some 150 million kilometres (93 million miles) from the Sun, only about 1 / 2,000,000,000 of the Sun's electromagnetic and particle emissions are intercepted by the Earth. This tiny fraction of solar energy is still significant with about 1,365 watts per square metre of solar power falling on a surface oriented perpendicular to the Sun's rays at the top of the 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 the Earth from the Sun. About 31 percent of the solar energy reaching the top of the Earth's atmosphere is scattered back into space.

Because of Earth's nearly spherical form, the incoming energy at any one instant strikes only one point an the Earth's surface at a 90-degree angle (called the sub-solar point). All other locations on the sunlit half of the 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, Fig. 1, the 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 the 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, also called the North Star and *Alpha Ursae Minoris*, throughout the year. 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 the Earth's orbital plane, the Earth's axis is continuously changing position relative to the Sun's rays.

SUNLIGHT AND SEASONS

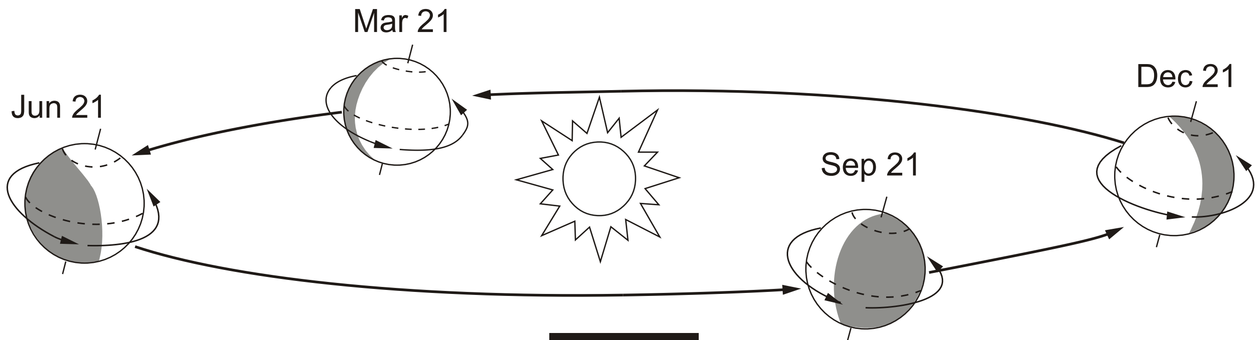

Figure 1

SKY VIEWS OF THE SUN

Daylight hours depicted for Brockport, NY (43.5^{o}N)

at the Equator

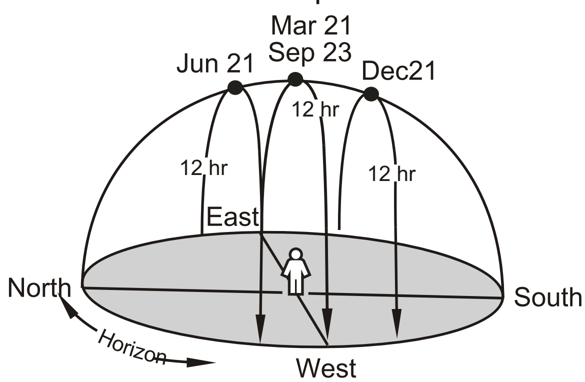

Figure 2a

at the North Pole

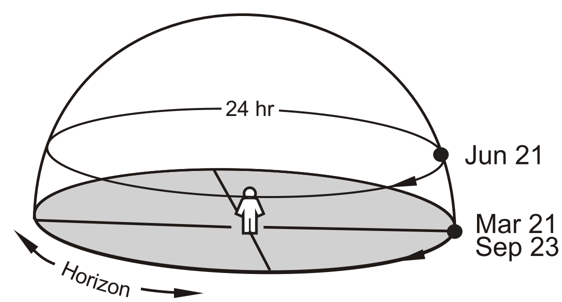

Figure 2b

at mid latitudes
(Northern Hemisphere)

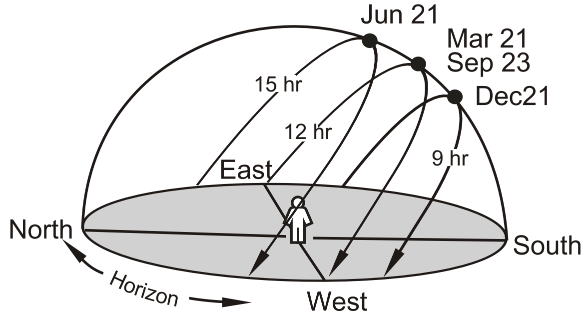

Figure 2c

In Figs. 2(a), 2(b), and 2(c), Sky Views of the Sun, the effects of rotation, revolution, and orientation of the Earth's axis on the path of the Sun through the sky at equatorial, mid-latitude and polar locations at different times of the year are depicted.

Twice each year as the Earth makes its journey around the centre of the solar system, the Earth's axis is oriented perpendicular to the Sun's rays. This happens on the Spring (or Vernal) Equinox - on or about March 21, and the Fall (or Autumnal) Equinox - on or about September 23 (terminology being a Northern Hemisphere bias!).

On these days, i.e. on or about March 21 and September 23, the sub-solar point is over the Equator. Exactly one half of both the Northern and Southern Hemispheres are illuminated and everywhere (except the pole itself) receives 12 hours of 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,

At the North Pole, the Spring Equinox marks the beginning of the transition period from 24 hours of darkness to 24 hours of daylight and vice versa from 24 hours of daylight to 24 hours of darkness for the Fall Equinox. In the Northern Hemisphere, this transition to 24 hour daylight which begins on the Spring Equinox at the North Pole progresses southward to reach 66.5 degrees North latitude (the Arctic Circle) at the Summer Solstice on or about June 21.

There are two times when the 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 towards the Sun. The sub-solar point is at 23.5 degrees North latitude which is also referred to as the Tropic of Cancer. 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 degrees North (the Arctic Circle) there is 24 hours of sunlight.

Conversely, for the Winter Solstice, on or about December 21, the 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 degrees South latitude which is also referred to as the Tropic of Capricorn. The North Pole tips away from the Sun and no sunlight reaches above the Arctic Circle (66.5 degrees 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 pattern. 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 the 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, white clouds and hazy grey days. Ozone formation and dissociation absorb harmful ultraviolet radiation while water vapour 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

Solar Energy

1. Practically all the energy that makes the 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 in the form of visible light and infrared (heat) radiation.

3. The Earth, on average some 150 million kilometres (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 the Earth's atmosphere on a flat surface placed perpendicular to the Sun's rays, and at the average distance of the Earth from the Sun, is called the solar constant. The value of the solar constant is about 2 calories per square centimetre per minute (1370 Watts per square meter).

5. Solar radiation is not received the same everywhere at the 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 the 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 a horizontal surface 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 the 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 towards Polaris, also called the North Star and Alpha Ursae Minoris, throughout the year.

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

12. Twice a year the 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 periods 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. The 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 towards 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 the Earth orbits the Sun, the inclined axis causes the Northern Hemisphere to tilt towards the Sun for half of the year, i.e. the spring and summer seasons in North America. 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, i.e. the fall and winter seasons in North America, 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 the 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 the 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 latitude increases. At either pole, the maximum altitude is 23.5 degrees above the horizon, occurring on the first day of that 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 the 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 periods 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 variations 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 the Earth's surface.

28. Some atmospheric gases absorb specific wavelengths of solar radiation. Water vapour 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 absorbs some sunlight while dense clouds, if thick enough, can produce almost night-time conditions.