Exploring Solar Energy Variations on Earth: Changes in the Length of Day and Solar Insolation Through the Year

Purpose
To help students understand how solar radiation varies (duration and intensity) during the year and relate this to phenomenon on the Earth's surface.

Overview
Students will do hands-on activities to explore how the incident solar energy on the Earth varies through the year. They will examine how solar angle and length of day change during the year at several points on the Earth's surface using provided data sets. They will construct a length of day and solar angle data set for their location and compare it to the provided data. They will form an understanding of the impact of these changes on the Earth's surface.

Student Outcomes
Students will be able to,

- Interpret a graph of annual length of day
- Recognize aspects of seasonal change
- Relate local seasonal changes to conventional equinox and solstice dates
- Create a profile of local seasonal variation

Science Concepts
Physical Sciences

- The sun is the major source of energy for changes on the Earth's surface.

Scientific Inquiry Abilities

- Compile and organize data into tables and graphs
- Use of appropriate tools and techniques, including mathematics
- Develop explanations and predictions using evidence
- Communicate results and explanations

Time
Several class periods

Level
Intermediate, Advanced

Materials and Tools

- Gridded/graph paper or computer graphing application
- Large globe or "balloon/beach ball" Earth
- Large flashlight
- Small flashlight
- Large piece of gridded paper (or multiple sheets taped together)
- String
- Tape
- Protractor
- Ruler
- Pens, colored pencils and crayons

Preparation
The instructor may wish to obtain and graph the local data for this activity beforehand.

Prerequisites
It is recommended that the ***Exploring Solar Energy Variations on Earth: Time and Seasons*** activity be done in preparation for this activity.

Some knowledge of graphing principles for students who will be making graphs of the local data.

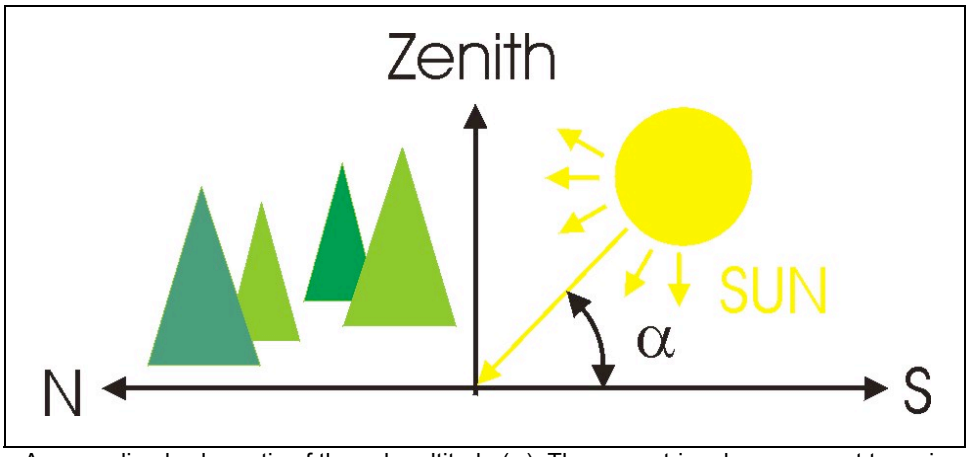
Background

The ***Exploring Solar Energy Variations on Earth: Time and Seasons*** activity looks at the Earth's rotation and time (24 hour day), the Earth's revolution and orbit characteristics, the tilt of the Earth's axis, and seasonal milestones (equinox and solstice). These are important basic concepts that help students orient themselves in relation to other locations on the Earth and in relation to the Sun. They help the students understand changes they see on a daily (day/night) and yearly (seasons) basis.This activity extends these concepts by exploring variations in solar altitude, length of day and the incident insolation. All of these variables contribute to the seasonal changes in our local environment.

Tilt of the Earth's Axis and Solar Altitude

The annual change in the relative position of the Earth's axis in relationship to the Sun causes the height of the Sun to vary in the sky. The ***solar altitude*** is the angle of sun above the horizon from the view of the observer. Above the horizon, the value is positive; below the horizon, the value is negative. At sunrise/sunset the solar angle equals zero; that is, the Sun is directly on the horizon. Maximum solar altitude occurs when the Sun is directly overhead and has a value of 90° (i.e., Equinox on the Equator). The total variation in maximum solar altitude for any location on the Earth over a one-year period is 47° (Earth's tilt 23.5° x 2 = 47°) (Source: http://www.physicalgeography.net/fundamentals/6h.html). ***Solar noon*** occurs when the Sun is at its highest solar altitude during a specific day.

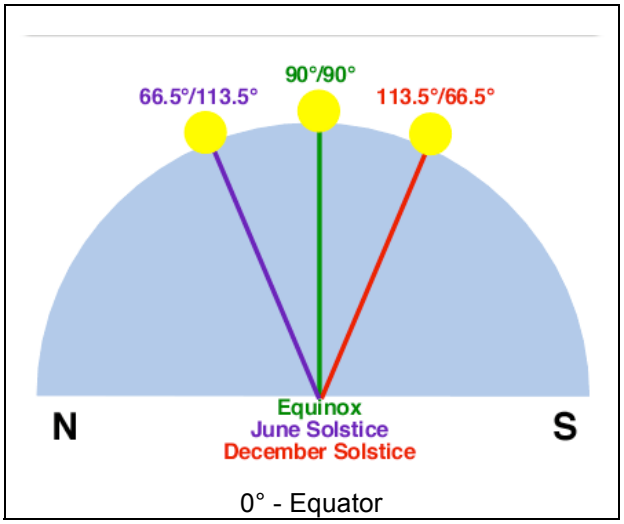
The figure below shows a simple example of solar altitude.



A generalized schematic of the solar altitude (α). The green triangles represent trees in the landscape. (Source: http://www.pvresources.com/en/location.php)

In the figure at right, the variation in the solar altitude at the Equator at solar noon is shown. Maximum solar height at the equator goes from 66.5° above the northern end of the horizon during the June solstice, to directly overhead on the September equinox, and then down to 66.5° above the southern end of the horizon during the December solstice. Note that the horizon is the point at which the visible edge of the Earth's surface meets the sky. It has 180° from true North to true South (i.e., not magnetic north/south).

The table below summarizes the same data for various latitudes. Note that at the North and South poles, there is a period of time when the sun does not rise above the horizon (demonstrated by the December solstice at the North Pole and June solstice at the South Pole).



Variations in solar altitude at solar noon during the June solstice, equinox and December solstice at the equator. The first measurement represents the angle from the northern side of the horizon, while the second measurement is from true south. Note that these two numbers sum to 180°, the full extent of the horizon

(Source: http://www.physicalgeography.net/fundamentals/6h.html)

Maximum Sun altitudes for selected latitudes during the two soltices and equinoxes. All measurements are in degrees (the horizon has 180 degrees from true North to true South) and are measured from either True North or True South (whatever is closer). (Source: http://www.physicalgeography.net/fundamentals/6h.html)

Latitude	Approximate Location	Equinox March 20/21	Solstice June 21/22	Equinox Sept. 22/23	Solstice Dec. 21/22
90°N	North Pole	0.0°	23.5°	0.0°	-23.5°
70°N		20.0°	43.5°	20.0°	-3.5°
66.5°N	Arctic Circle	23.5°	47.0°	23.5°	0.0°
60°N		30.0°	53.5°	30.0°	6.5°
50°N		40.0°	63.5°	40.0°	16.5°
23.5°N	Tropic of Cancer	66.5°	90.0°	66.5°	43.0°
0°	Equator	90.0°	66.5°	90.0°	66.5°
23.5°S	Tropic of Capricorn	66.6°	43.0°	66.6°	90.0°
50°S		40.0°	16.5°	40.0°	63.5°
60°S		30.0°	6.5°	30.0°	53.5°
66.5±S	Antarctic Circle	23.5°	0.0°	23.5°	47.0°
70°S		20.0°	-3.5°	20.0°	43.5°
90°S	South Pole	0.0°	-23.5°	0.0°	23.5°

The Sun is directly overhead when its altitude is 90°, on the horizon at 0° and below the horizon when the value is negative (i.e., no sunlight).

What To Do and How To Do It

- Review your results from the ***Exploring Solar Energy Variations on Earth: Time and Seasons*** activity. Recall the discussion about Equinox and Solstice.
- Ask students what they have observed about the position of the Sun in the sky (Is it the same all day? Is it the same from day-to-day?)
- Ask the students if sunrise and sunset occurs at the same time everyday (what is their experience of this – winter vs summer, etc)?
- Ask students what they know about what causes changes in the length of day.
- Ask the students what they know about the strength of sunlight during the year. Is it the same or does it change? Does it appear brighter in summer or in winter?
- Ask students to predict what impact(s) the changing length of day might have on the Earth's surface.
- Go to the Sun or Moon Altitude/Azimuth Table (Daily) web site (see ***Resources***).
- Enter the Year, Month, Day and Location data for your site.
- This creates a list that includes the time, degrees of altitude and azimuth. What does the data tell us? (Notice that the Sun's altitude changes during the course of the day as the Sun rises, transits the sky and sets. Solar noon occurs when the Sun is at its highest altitude.)
- Determine the maximum Sun altitude for several days during the year – start with the equinoxes and solstices. Are the maximum Sun altitudes the same?
- Now look at some other dates of interest (holidays, birthdays, etc.).
- Ask the students if they see a pattern in the changes in Sun altitude. (Can they relate the angles they have looked at to the Equinoxes and Solstices?)
- Have the students graph the daily Sun altitudes for several days, including the Equinoxes and Solstices, for their location, in order to confirm their prediction about the daily and annual patterns of change in the Sun angle.

Note: Students can also gain an understanding of the movement of the Sun through the sky and determine local solar noon by doing the GLOBE activity: Making a Sundial (http://www.globe.gov/tctg/atla-sundial.pdf?sectionId=22&lang=EN).

Example: **BARROW, ALASKA - W156° 47, N71° 17 (71°17′N, 156°47′W)**

Two examples of Daily Solar Altitude data sets for Barrow, AK, USA in 2008.

Solar Altitude – Daily

(http://aa.usno.navy.mil/data/docs/AltAz.php)

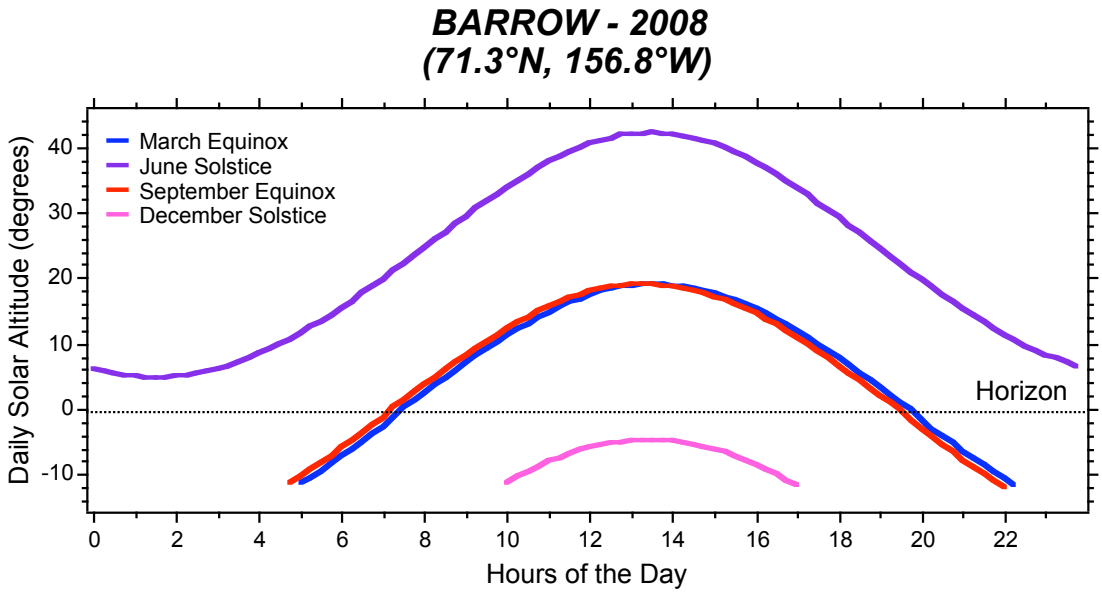
Year: **2008**, Month: **January**, Day: **1**
State or Territory: **Alaska**
City or Town Name: **Barrow**

Year: **2008**, Month: **July**, Day: **1**
State or Territory: **Alaska**
City or Town Name: **Barrow**

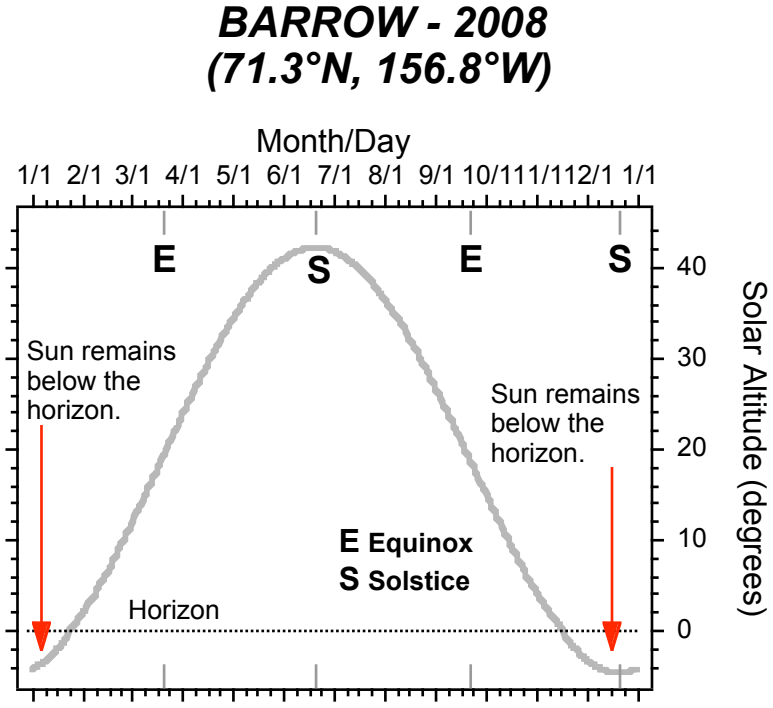
January 1, 2008 Alaska Standard Time			**July 1, 2008** Alaska Standard Time								
h m	Altitude degrees	Azimuth (E of N) degrees	h m	Altitude degrees	Azimuth (E of N) degrees	h m	Altitude degrees	Azimuth (E of N) degrees	h m	Altitude degrees	Azimuth (E of N) degrees
09:50	-11.6	129.5	00:00	5.8	339.0	08:00	24.1	89.0	16:00	37.3	224.4
10:00	-11.0	131.8	00:10	5.6	341.3	08:10	24.9	91.4	16:10	36.7	227.2
10:10	-10.4	134.1	00:20	5.3	343.6	08:20	25.7	93.7	16:20	36.1	229.9
10:20	-9.9	136.3	00:30	5.1	345.9	08:30	26.5	96.1	16:30	35.5	232.6
10:30	-9.3	138.6	00:40	4.9	348.2	08:40	27.3	98.6	16:40	34.8	235.3
10:40	-8.8	140.9	00:50	4.8	350.5	08:50	28.1	101.0	16:50	34.2	238.0
10:50	-8.3	143.1	01:00	4.7	352.8	09:00	28.9	103.5	17:00	33.5	240.7
11:00	-7.8	145.4	01:10	4.6	355.1	09:10	29.6	105.9	17:10	32.8	243.3
11:10	-7.4	147.7	01:20	4.6	357.4	09:20	30.4	108.5	17:20	32.0	245.9
11:20	-7.0	150.0	01:30	4.5	359.8	09:30	31.2	111.0	17:30	31.3	248.4
11:30	-6.6	152.3	01:40	4.5	2.1	09:40	31.9	113.5	17:40	30.6	250.9
11:40	-6.2	154.5	01:50	4.6	4.4	09:50	32.6	116.1	17:50	29.8	253.5
11:50	-5.9	156.8	02:00	4.7	6.7	10:00	33.3	118.7	18:00	29.0	255.9
12:00	-5.6	159.1	02:10	4.8	9.0	10:10	34.0	121.4	18:10	28.2	258.4
12:10	-5.3	161.4	02:20	4.9	11.3	10:20	34.7	124.0	18:20	27.5	260.9
12:20	-5.1	163.7	02:30	5.1	13.6	10:30	35.4	126.7	18:30	26.7	263.3
12:30	-4.9	166.0	02:40	5.3	15.9	10:40	36.0	129.4	18:40	25.9	265.7
12:40	-4.7	168.3	02:50	5.5	18.2	10:50	36.6	132.2	18:50	25.1	268.1
12:50	-4.6	170.6	03:00	5.8	20.5	11:00	37.2	135.0	19:00	24.3	270.4
13:00	-4.4	172.9	03:10	6.0	22.8	11:10	37.7	137.8	19:10	23.5	272.8
13:10	-4.4	175.2	03:20	6.4	25.1	11:20	38.2	140.6	19:20	22.7	275.1
13:20	**-4.3**	177.5	03:30	6.7	27.3	11:30	38.7	143.5	19:30	21.9	277.5
13:30	**-4.3**	179.8	03:40	7.1	29.6	11:40	39.2	146.4	19:40	21.1	279.8
13:40	**-4.3**	182.2	03:50	7.5	31.9	11:50	39.6	149.3	19:50	20.3	282.1
13:50	**-4.3**	184.5	04:00	7.9	34.2	12:00	40.0	152.3	20:00	19.5	284.4
14:00	-4.4	186.8	04:10	8.4	36.5	12:10	40.4	155.2	20:10	18.7	286.7
14:10	-4.5	189.1	04:20	8.9	38.7	12:20	40.7	158.2	20:20	18.0	289.0
14:20	-4.7	191.4	04:30	9.4	41.0	12:30	41.0	161.3	20:30	17.2	291.3
14:30	-4.8	193.7	04:40	9.9	43.3	12:40	41.2	164.3	20:40	16.5	293.5
14:40	-5.1	196.0	04:50	10.5	45.5	12:50	41.4	167.3	20:50	15.8	295.8
14:50	-5.3	198.3	05:00	11.0	47.8	13:00	41.5	170.4	21:00	15.0	298.1
15:00	-5.6	200.6	05:10	11.6	50.1	13:10	41.7	173.5	21:10	14.4	300.3
15:10	-5.9	202.9	05:20	12.3	52.3	13:20	41.7	176.6	21:20	13.7	302.6
15:20	-6.2	205.2	05:30	12.9	54.6	**13:30**	**41.8**	179.6	21:30	13.0	304.9
15:30	-6.5	207.4	05:40	13.6	56.8	13:40	41.7	182.7	21:40	12.4	307.1
15:40	-6.9	209.7	05:50	14.2	59.1	13:50	41.7	185.8	21:50	11.7	309.4
15:50	-7.3	212.0	06:00	14.9	61.4	14:00	41.6	188.9	22:00	11.1	311.7
16:00	-7.8	214.3	06:10	15.6	63.6	14:10	41.4	191.9	22:10	10.5	313.9
16:10	-8.2	216.6	06:20	16.4	65.9	14:20	41.2	195.0	22:20	10.0	316.2
16:20	-8.7	218.8	06:30	17.1	68.2	14:30	41.0	198.0	22:30	9.4	318.5
16:30	-9.2	221.1	06:40	17.8	70.5	14:40	40.7	201.1	22:40	8.9	320.7
16:40	-9.8	223.4	06:50	18.6	72.8	14:50	40.4	204.1	22:50	8.4	323.0
16:50	-10.3	225.6	07:00	19.4	75.0	15:00	40.1	207.0	23:00	8.0	325.3
17:00	-10.9	227.9	07:10	20.1	77.3	15:10	39.7	210.0	23:10	7.5	327.5
17:10	-11.5	230.2	07:20	20.9	79.6	15:20	39.3	212.9	23:20	7.1	329.8
Note that -4.3° altitude means the Sun is still below the horizon.			07:30	21.7	82.0	15:30	38.8	215.8	23:30	6.7	332.1
			07:40	22.5	84.3	15:40	38.4	218.7	23:40	6.4	334.4
			07:50	23.3	86.6	15:50	37.8	221.6	23:50	6.1	336.7

Notice that the Sun altitude is different but occurs at the same time of day (***Solar Noon is indicated in RED - 13:30 or 1:30 p.m. Alaska Standard Time***).

A graph showing the time series of daily ***Solar Angles*** for a selection of dates in 2008 at Barrow, AK., USA.



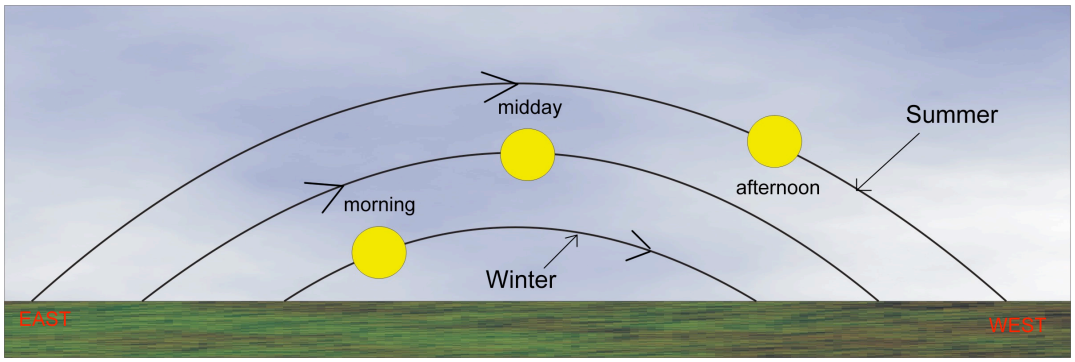
A graph showing the daily maximum daily Solar Angles for every day in 2008 at Barrow, AK., USA.



Tilt of the Earth's Axis, Latitude and Length of Day

Length of day refers to the time each day from the moment the upper limb of the Sun's disk appears above the horizon during sunrise to the moment when the upper limb disappears below the horizon during sunset. Low levels of daylight may be visible even after the sun has gone below the horizon due to the diffusion and refraction of the sunlight by the atmosphere (twilight).

In general, the length of a day varies throughout the year, and depends upon latitude (see figure below). This variation is caused by the tilt of the earth's axis of rotation with respect to the ecliptic plane of the earth around the sun. (Source: http://en.wikipedia.org/wiki/Length_of_day)



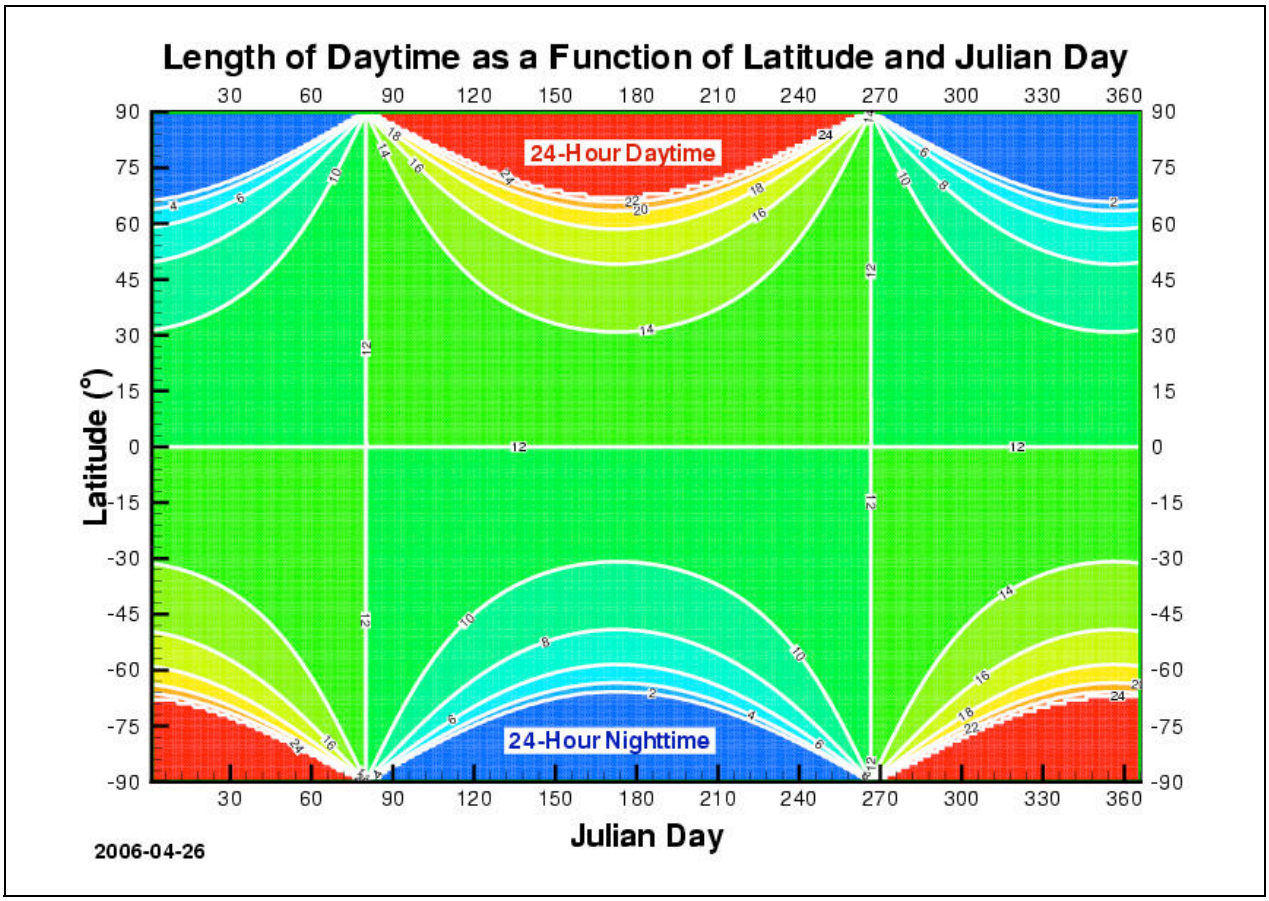
A generalized schematic of the differences in length of day and solar altitude during the year at a mid-latitude site in the Northern Hemisphere (looking south).
(Source: http://www.skinnerscience.com/lesson_hw_docs/year8/unit_7l/week1.htm)

Examples of the minimum and maximum length of day for specific degrees of latitude are seen in the table at right. The continuous changes in the length of day for the entire globe are illustrated in the graph below.

LENGTH OF DAY

Region	*Latitude (N or S)*	*Shortest Day (hh:mm)*	*Longest Day (hh:mm)*
	00	12:07	12:07
TROPICS	10	11:32	12:42
	20	10:56	13:20
	30	10:14	14:04
	40	09:20	14:00
TEMPERATE	50	08:05	16:21
	60	05:54	18:49
	70	00:00	24:00
POLAR	80	00:00	24:00
	90	00:00	24:00

(Source: http/www.hort.purdue.edu/newcrop/tropical/lecture_02/lec_02.html)



Day length as a function of latitude and the day of the year running from 1 (January 1) to 365 (December 31) in an ordinary year or 1 to 366 in a leap year. The lines represent the length of the day in hours.
(Source: http://en.wikipedia.org/wiki/Length_of_day)

What To Do and How To Do It

- Review your results from the ***Exploring Solar Energy Variations on Earth: Time and Seasons*** activity. Recall the discussion about Equinox and Solstice.
- Ask the students if sunrise and sunset occurs at the same time everyday (what is their experience of this – winter vs summer, etc)?
- Ask students what they know about what causes changes in the length of day.

- Introduce the idea that the length of the day changes as the Earth revolves around the Sun.
- Go to the Complete Sun and Moon Data for One Day web site (see ***Resources***).
- Enter the Year, Month, Day and Location data for your site.
- This creates a list that includes the time of the Sunrise and Sunset. The time from sunrise to sunset is the Length of Day.
- Determine the Length of Day for several days during the year – start with the equinoxes and solstices. Are the days' lengths the same?
- Ask the students if they see a pattern in the changes in Length of Day. (Can they relate the angles they have looked at to the Equinoxes and Solstices?)

- Now, go to the Sun or Moon Rise/Set Table for One Year web site (see ***Resources***).

- Have the students study the table and confirm their ideas about the pattern of change in the Length of Day.

If you wish to graph these data, do the following:

- Assign one month of data to individuals or small groups.
- Convert the Sunrise and Sunset to decimal hours (6:23 am = 6.383 (23/60 = 0.383); 4:47 pm = 16:47 = 16.783 (47/60 = .0.783)).
- Subtract the Sunrise from Sunset value to determine Length of Day.
- Assemble the values into an annual data set.
- Graph Sunrise and Sunset values on the same graph.
- Graph the Length of Day.
- Discuss the strengths and weaknesses of each graph. Which is easier to understand/more informative?

Two examples of daily Sunrise and Sunset data sets for Barrow, AK, USA in 2008.

U.S. Naval Observatory Astronomical Applications Department

Sun and Moon Data for <u>One Day</u>

The following information is provided for Barrow, North Slope Borough, Alaska (71.3°N, 156.8°W):

Tuesday, 1 January 2008 Alaska <u>Standard</u> Time

SUN	
Begin civil twilight	11:47 a.m.
End civil twilight	3:15 p.m.
MOON	
Moonset	11:38 a.m. on preceding day
Moonrise	5:08 a.m.
Moon transit	8:14 a.m.
Moonset	10:56 a.m.

Note: Missing Sun phenomena indicate Sun below horizon for extended period of time.
Phase of the Moon on 1 January: waning crescent with 35% of the Moon's visible disk illuminated.
Last quarter Moon on 30 December 2007 at 10:52 p.m. Alaska Standard Time.

The following information is provided for Barrow, North Slope Borough, Alaska (71.3°N, 156.8°W):

Friday, 1 August 2008 Alaska <u>Daylight</u> Time

SUN	
Sunrise	**2:43 a.m**.
Sun transit	2:33 p.m.
Sunset	**1:54 a.m.** on following day
MOON	
Moonset	2:03 a.m.
Moonrise	3:31 a.m.
Moon transit	3:02 p.m.
Moonset	12:21 a.m. on following day

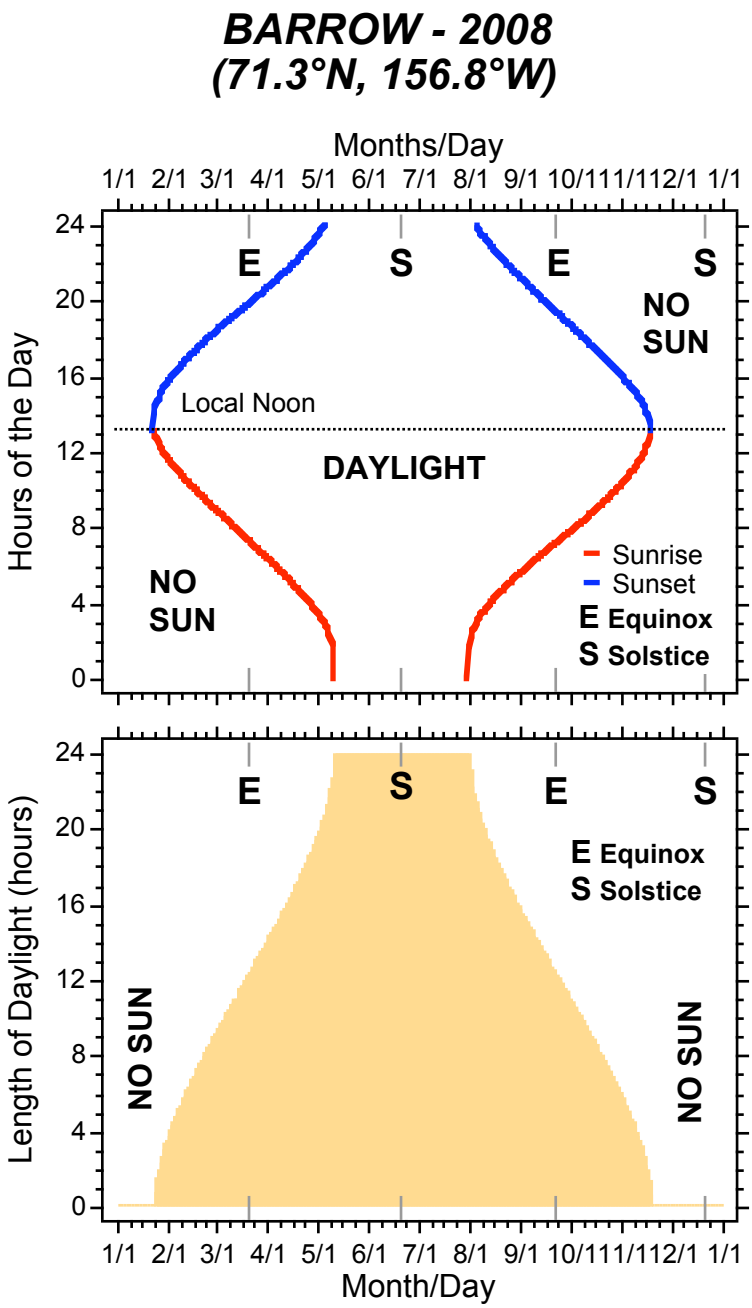
New Moon on 1 August 2008 at 2:13 a.m. Alaska Daylight Time.

An example of Sunrise, Sunset and Length of Day calculations for for Barrow, AK, USA, February, 2008.

Sun or Moon Rise/Set Table for One Year
(http://aa.usno.navy.mil/data/docs/RS_OneYear.php)

Date	*Sunrise HH:MM*	*Sunset HH:MM*	*Length of day HH:MM*	*Sunrise Decimal*	*Sunset Decimal*	*Length of Day Decimal*
2/1/08	11:38	15:45	4:07	***11.633***	***15.750***	***4.117***
2/2/08	11:31	15:52	4:21	***11.517***	***15.867***	***4.35***
2/3/08	11:25	15:59	4:34	***11.417***	***15.983***	***4.567***
2/4/08	11:18	16:05	4:47	***11.300***	***16.083***	***4.783***
2/5/08	11:12	16:12	5:00	***11.200***	***16.200***	***5***
2/6/08	11:06	16:18	5:12	***11.100***	***16.300***	***5.2***
2/7/08	11:00	16:24	5:24	***11.000***	***16.400***	***5.4***
2/8/08	10:54	16:31	5:37	***10.900***	***16.517***	***5.617***
2/9/08	10:48	16:37	5:49	***10.800***	***16.617***	***5.817***
2/10/08	10:42	16:42	6:00	***10.700***	***16.700***	***6***
2/11/08	10:36	16:48	6:12	***10.600***	***16.800***	***6.2***
2/12/08	10:31	16:54	6:23	***10.517***	***16.900***	***6.383***
2/13/08	10:25	16:59	6:34	***10.417***	***16.983***	***6.567***
2/14/08	10:20	17:05	6:45	***10.333***	***17.083***	***6.75***
2/15/08	10:14	17:10	6:56	***10.233***	***17.167***	***6.933***
2/16/08	10:09	17:15	7:06	***10.150***	***17.250***	***7.1***
2/17/08	10:03	17:21	7:18	***10.050***	***17.350***	***7.3***
2/18/08	9:58	17:26	7:28	***9.967***	***17.433***	***7.467***
2/19/08	9:53	17:31	7:38	***9.883***	***17.517***	***7.633***
2/20/08	9:47	17:36	7:49	***9.783***	***17.600***	***7.817***
2/21/08	9:42	17:41	7:59	***9.700***	***17.683***	***7.983***
2/22/08	9:37	17:46	8:09	***9.600***	***17.767***	***8.15***
2/23/08	9:32	17:51	8:19	***9.533***	***17.850***	***8.317***
2/24/08	9:27	17:56	8:29	***9.450***	***17.933***	***8.483***
2/25/08	9:22	18:01	8:39	***9.367***	***18.017***	***8.633***
2/26/08	9:17	18:05	8:48	***9.283***	***18.083***	***8.8***
2/27/08	9:11	18:10	8:59	***9.183***	***18.167***	***8.983***
2/28/08	9:06	18:15	9:09	***9.100***	***18.250***	***9.15***
2/29/08	9:01	18:20	9:19	***9.017***	***18.333***	***9.317***

Graphs showing Sunrise and Sunset (top) and Length of Day (bottom) for every day in 2008 at Barrow, AK., USA (includes data from table above). What are the strengths/weaknesses of each graph?

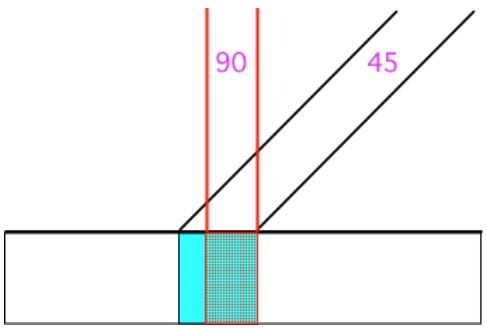


Insolation

The Sun's altitude variations influence the amount of energy received at Earth's surface in two ways:

- Energy concentration or intensity
- Atmospheric path length

Solar insolation is the intensity of solar radiation incident on the Earth's surface. It is largely a function of the angle of incidence, the angle at which the Sun's rays strike the Earth's surface. If the Sun is positioned directly overhead or 90° from the horizon, the insolation strikes the surface of the Earth at right angles and is most intense. If the Sun is 45° above the horizon, the insolation strikes the Earth's surface at an angle. This causes the rays to be spread out over a larger surface area reducing the intensity of the radiation (see figure below).
(Source: http://www.physicalgeography.net/fundamentals/6i.html)



The effect of the angle of incidence. The area of interception and the length of atmospheric path are both greater for the 45° case than the 90° one. This means that the solar intensity for the 45° case is lower than the 90° case.
(Image and data source: http://www.physicalgeography.net/fundamentals/6i.html)

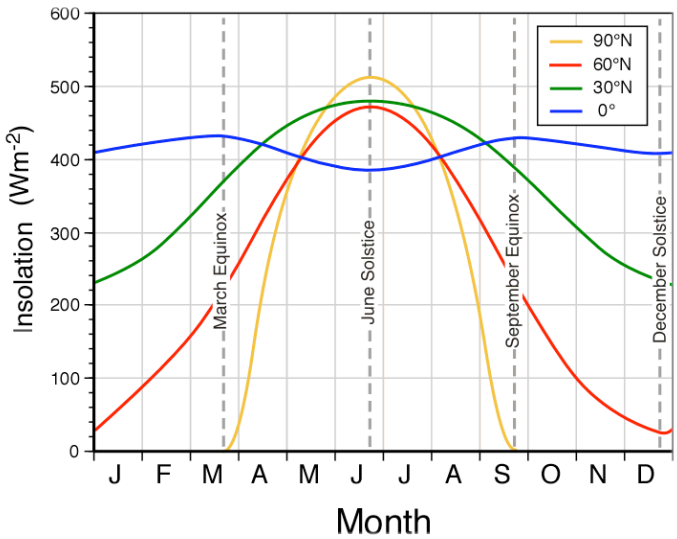
Solar Intensity = sine(**A**)

where: **A** is the angle of incidence
and **sine** is the sine function

Angle of Incidence	*Intensity*	*%*
sine(90)	1.00	100
sine(80)	0.98	98
sine(70)	0.94	94
sine(60)	0.87	87
sine(50)	0.77	77
sine(40)	0.64	64
sine(30)	0.50	50
sine(20)	0.34	34
sine(10)	0.17	17
sine(00)	0.00	0

The graph below illustrates the potential insolation available at several sites in the Northern Hemisphere over a one-year period. This graph takes into account the combined effects of angle of incidence and day length duration (number of hours of sunlight).

Locations at the equator show the least amount of variation in insolation because the day length is constant. The only source of variation is the angle of incidence. The extreme case occurs at 90°N where the daylight period varies from 0 to 24 hours during the year. On the June solstice, this location has more potential incoming solar radiation than any other location because the day is 24 hours long and the Sun remains at 23.5 degrees above the horizon for the whole day. From the September equinox to the March equinox, no insolation is received because the Sun does not rise above the horizon (0 hours of daylight).



Monthly values of available insolation in Wm^{-2} for the equator (0°), 30°N, 60°N, and 90°N. (Source: http://www.physicalgeography.net/fundamentals/6i.html)

What To Do and How To Do It

- Review your results from the ***Exploring Solar Energy Variations on Earth: Time and Seasons*** activity. Recall the discussion about Equinox and Solstice.
- Ask the students what they know about the strength of sunlight during the year. Is it the same or does it change? Does it appear brighter in summer or in winter?
- Ask students to predict what impact(s) the changing length of day might have on the Earth's surface.

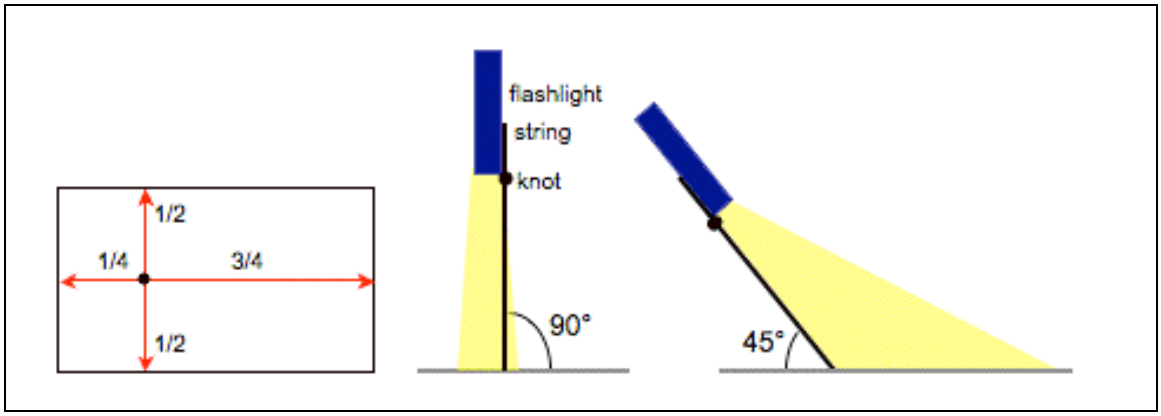
Incident Insolation

In this activity, the small flashlight is standing in for the Sun. The string and protractor will be used to determine its "solar altitude". The area that the flashlight illuminates will be traced onto the paper. The paper does not have to be gridded but it makes it easier to estimate the area of illumination.

Do the following:

- Spread out the paper on a flat surface and secure it to the surface with tape.
- Tape one end of the string to the paper approximately midway between the top and bottom of the paper and one quarter of the length (left to right) from one edge (see below).
- Tie a knot in the string. Remember the longer the distance between the paper and the knot, the larger the area of illumination will be.
- Hold the string straight up from the paper and measure the angle between the paper and the string with the protractor (90°).
- Turn on the small flashlight and hold it parallel to the string with the light source next to the knot pointing towards the paper.
- Trace out the area of illumination with one of the colored pencils and make note of the angle and the color of the pencil.

- Measure off a number of different angles (i.e., 70°, 50°, 30°, 10° or 67.5°, 45°, 22.5°, 0°, etc.) and trace out the areas of illumination making note of the angles and corresponding colored pencil (see below).



Placement of string on the paper (left) and varying angles of the flashlight (right).

- Compare the areas that are illuminated at different angles. (As the angle decreases from 90° towards 0° the area illuminated increases; in the lowest angles ~0°, the surface is not illuminated because the light is parallel to the paper's surface.)

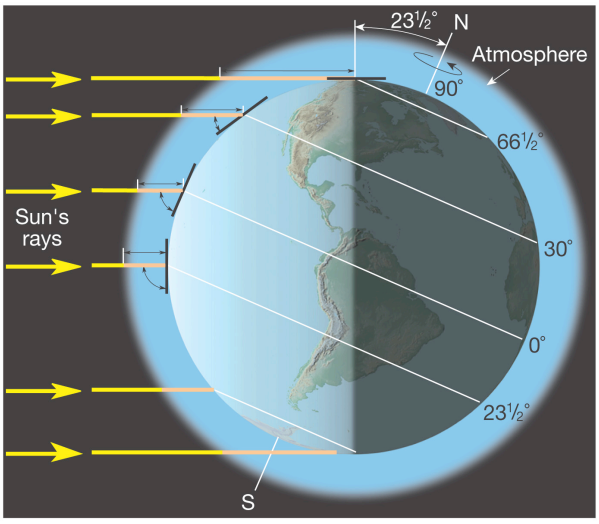
The same amount of energy (light) is spread over the various areas.

- What does this mean in terms of the amount of energy per unit area? (There is less energy per unit area as the area increases but the amount of energy is constant.)

Now, have the students gather around the large globe. If you are using a "beach ball" Earth, make sure it is tilted correctly.

- Dim the classroom lights so that the light is easily visible on the globe.
- Shine the flashlight on the globe with the light centered at the equator. Discuss the distribution of light on the Earth's surface. Talk about how the angle that the light strikes the globe's surface changes as you move from the equator to the poles. What can be said about the intensity of the solar energy hitting the Earth's surface at these various angles?

Use the graphic at right along with your results from the flashlight/string activity to facilitate this discussion.



Source:
http://www.eas.slu.edu/People/CEGraves/Eas138/fg02_04.jpg

Note that the zone of the Earth's surface that is illuminated by the Sun's rays "lengthens" and the angle of incidence of the Sun's rays (solar altitude) decreases from the Equator to the North Pole.

- Now, go to the Atmosphere-Ocean Model – Monthly Latitude Insolation web site (see ***Resources***). This creates a table of monthly insolation values for an entire year at a specified latitude increment (i.e., for every 5° of latitude, 10°, 15°, etc.). Compare the values.
- Go to the Atmosphere-Ocean Model – Insolation at Specified Location web site (see ***Resources***). This creates a table of the time of sunrise and sunset and the amount of daily average sunlight (W m^{-2}) for any month and year for a specified Latitude and Longitude.
- Compile the insolation values into an annual dataset and graph. (Note that the Sunrise and Sunset values are not exactly the same as those at the ones at the Sun or Moon Rise/Set Table for One Year web site. This is because the ones at the Atmosphere-Ocean Model – Insolation at Specified Location site are calculated (modeled) in a different way and are not based on observations.
- Graph these data and discuss.

- Compare all of the graphs produced in this activity. How are they related to each other?

Note: Students can also gain an understanding of the annual changes in the intensity of solar energy for a given location by reviewing the GLOBE Poster.

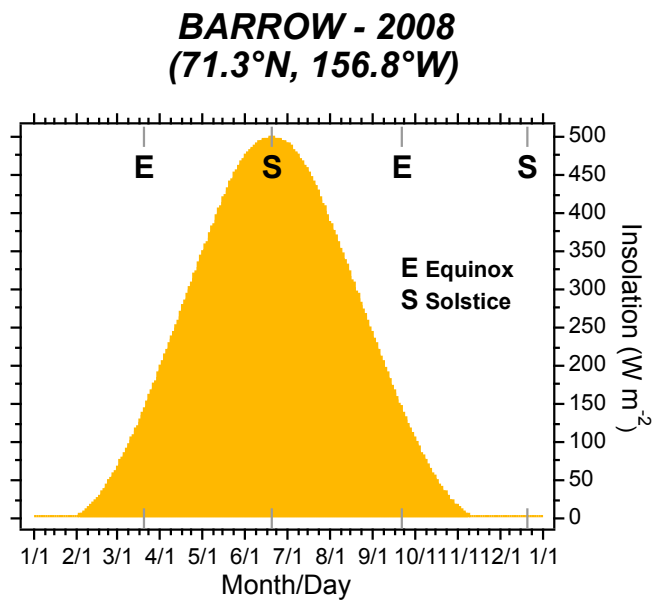
An example of daily Insolation data set for Barrow, AK, USA, February 2008.

Atmosphere - Ocean Model (NASA, GISS)
Daily Insolation Parameters
(http://aom.giss.nasa.gov/srlocat.html)

Latitude: 71.300 Longitude:-156.800
Time Zone: Hawaiian Standard Time (Longitudes -157.5 to -142.5)
Local Standard Time is used, not Daylight Time.
For Daylight Time add 1 hour to times reported in table below.

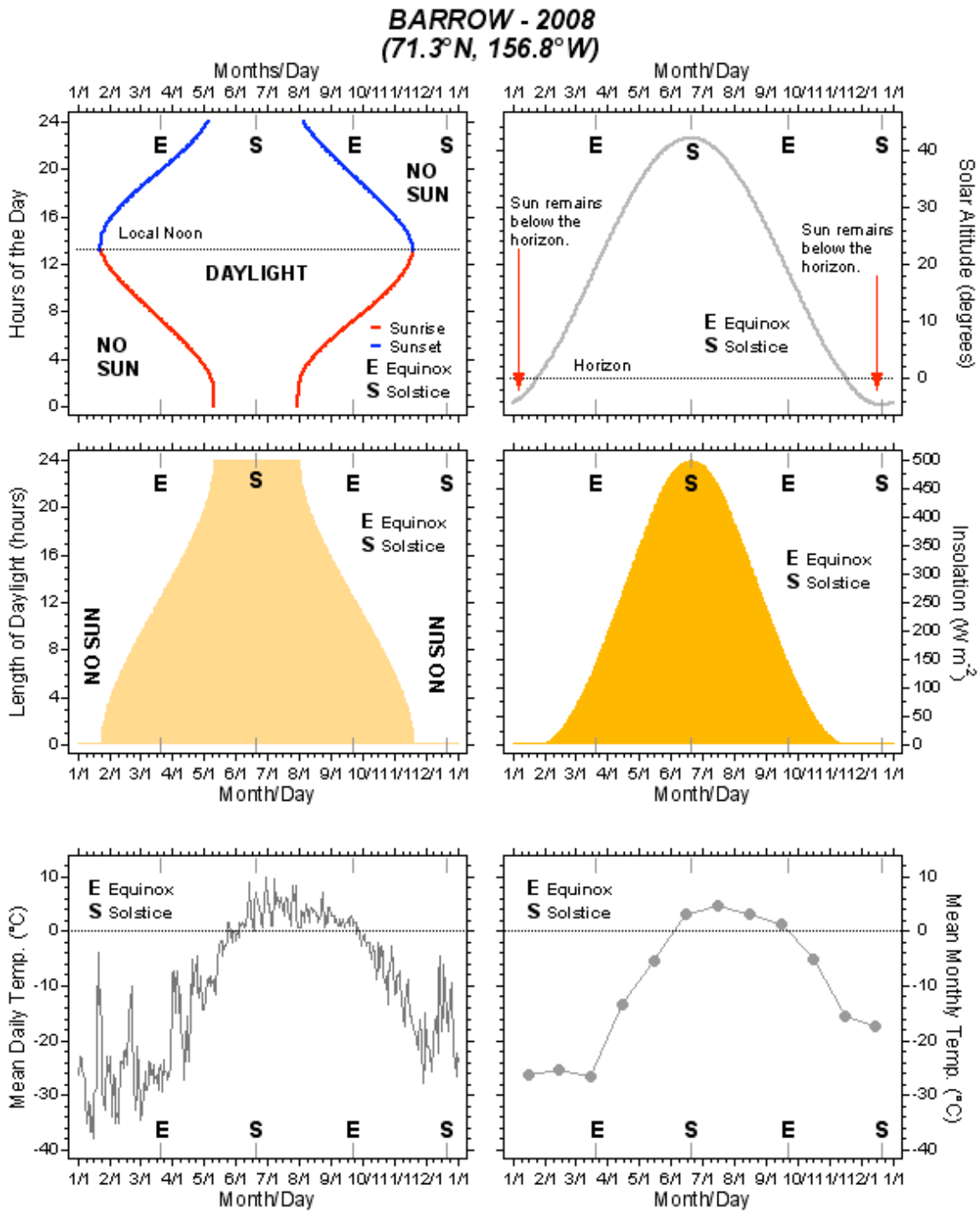
Data for February, 2008

Day	Sunrise (hh:mm)	Sunset (hh:mm)	Insolation (W/m²)
01	10:37	14:44	***3.67***
02	10:31	14:51	***4.68***
03	10:24	14:58	***5.79***
04	10:17	15:05	***7.00***
05	10:11	15:11	***8.30***
06	10:05	15:18	***9.69***
07	9:59	15:24	***11.17***
08	9:53	15:30	***12.75***
09	9:47	15:36	***14.41***
10	9:41	15:42	***16.16***
11	9:35	15:47	***18.00***
12	9:30	15:53	***19.93***
13	9:24	15:59	***21.94***
14	9:19	16:04	***24.03***
15	9:13	16:09	***26.21***
16	9:08	16:15	***28.48***
17	9:02	16:20	***30.83***
18	8:57	16:25	***33.26***
19	8:52	16:30	***35.77***
20	8:47	16:35	***38.36***
21	8:41	16:40	***41.03***
22	8:36	16:45	***43.78***
23	8:31	16:50	***46.61***
24	8:26	16:55	***49.51***
25	8:21	16:60	***52.49***
26	8:15	17:05	***55.55***
27	8:10	17:09	***58.68***
28	8:05	17:14	***61.88***
29	8:00	17:19	***65.15***



A graph showing the daily total insolation for every day in 2008 at Barrow, AK., USA (includes data from left).

Below is a summary of the Sun data compiled and graphed above (top four panels). The bottom two panels summarize daily and monthly mean temperatures at Barrow. Is there any relationship between patterns of the length of day, Sun altitude and insolation and air temperature? Why aren't the patterns exactly the same? (Air temperature is influenced by air masses moving into the region from elsewhere.) What other Earth phenomenon might be influenced by these Sun-Earth patterns? (plant phenology)



Further Investigations

- Ask the students what they think the consequences of shorter days and less intense sunlight on the Earth's surface are. How might they go about investigating these ideas?

Resources

See: *Real Reasons for the Seasons* (2000*)* from Lawrence Hall of Science, University of Califronia at Berkeley, for the original activity about what causes seasons and other related activities.

Atmosphere-Ocean Model – Insolation at Specified Location
http://aom.giss.nasa.gov/srlocat.html

Atmosphere-Ocean Model – Monthly Latitude Insolation http://aom.giss.nasa.gov/srmonlat.html

Complete Sun and Moon Data for One Day http://aa.usno.navy.mil/data/docs/RS_OneDay.php

Earth's Seasons - Equinoxes, Solstices, Perihelion, and Aphelion, 2000-2020
http://aa.usno.navy.mil/data/docs/EarthSeasons.php

Earth-Sun Geometry http://www.physicalgeography.net/fundamentals/6h.html

Earth-Sun Geometry (http://www.indiana.edu/~geog109/topics/02_earth_sun/Earth_sun.pdf)

Earth-Sun Relationships and Insolation http://www.physicalgeography.net/fundamentals/6i.html

The Solar Source of the Earth's Energy http://www.physicalgeography.net/fundamentals/6g.html

Sun or Moon Altitude/Azimuth Table (Daily)
http://aa.usno.navy.mil/data/docs/AltAz.php

Sun or Moon Rise/Set Table for One Year
http://aa.usno.navy.mil/data/docs/RS_OneYear.php

Weather Underground
http://www.wunderground.com/