Solar Radiation vs Latitude: Teacher Guide

Level: Intermediate

Subject: Geography

Duration: 40 minutes

Type: Classroom discussions

Learning Goals:

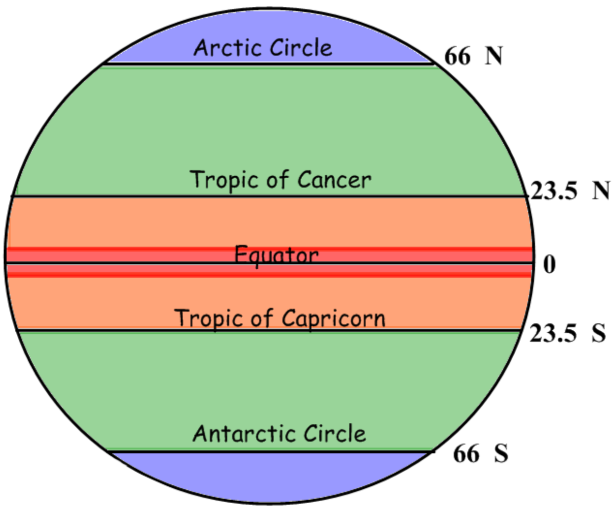
- Define the lines of latitude
- Understand how the sun shines on different parts of the globe based on the shape of Earth
- Make calculations on potential solar panel energy for different locations

Materials:

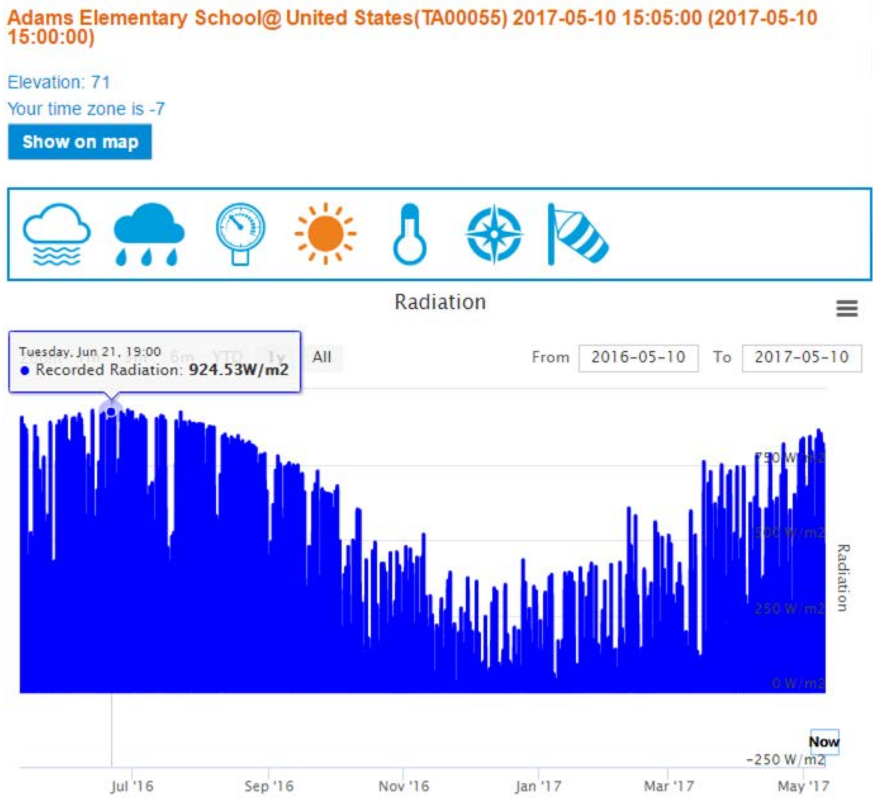
- Internet access- navigation to the School-2-School website
- Optional visualizations at http://profhorn.meteor.wisc.edu/wxwise/radiation/sunangle.htm

Methods:

- Ask the students what latitude is the equator? Tropic of Cancer? Tropic of Capricorn? Arctic Circle? Antarctic Circle?
  (Figure from http://msblaszak.cmswiki.wikispaces.net/Climate+Latitude)



- With the class, discuss the climate zones on Earth and at what latitudes are they found? [Answer: The tropics are between the Tropic of Cancer and the Tropic of Capricorn, which includes the Equator. The temperate zone is between the Tropic of Cancer and the Arctic Circle, and also between the Tropic of Capricorn and the Antarctic Circle. The polar zone is between the Arctic Circle and the North Pole, and between the Antarctic Circle and the South Pole.]
- Compare maximum solar radiations for multiple different stations. On the graph, zoom to view different dates of data to identify the maximum solar radiation. Use the “show on map” button to view the location of the station. Either estimate the latitude based on the map or use google maps to find the exact latitude. [Example viewing the 1 year time range : Adams Elementary school is in Corvallis, Oregon USA at a latitude of 44.6° N and the approximate maximum solar radiation is 920 W/m^2. St. Scholastica Catholic School is located in Nairobi, Kenya at a latitude of 1.3°S and the approximate solar radiation of 1,030 W/m^2]



- Make observations about the trends of maximum solar radiation at different latitudes. Do stations with higher maximum solar radiations tend to be closer to the equator or closer to the poles?
- Considering the Earth is a globe, how would this affect the incoming solar radiation? (Figure from https://www.nature.com/scitable/knowledge/library/introduction-to-the-basic-drivers-of-climate-13368032). [Answer: At the equator the sun is perpendicular to the surface, allowing maximum solar radiation to be distributed over a small surface area. Closer to the poles, the incoming solar radiation is the same but the light is spread over a larger surface area so the intensity is lower at a particular location.]

Calculations:

Compare the energy potential for solar panels in two latitudes. If a school installs 5 m^2 solar panels on their roof, how many lightbulbs can that solar panel power?

$$E = A * H * PR$$

E = Energy (W)

A = Total solar panel Area (m^2)

H = Annual average solar radiation panels (W/m^2)

PR = Performance ratio of solar panel, coefficient for losses (default value = 0.22)

With this solar panel, we can then calculate how many lightbulbs can be powered by this solar panel. If we are using a lightbulb with a 100 watt rating for ½ of the day, we can calculate how many lightbulbs can be sustained.

 # lightbulbs = E / 100 watts

Adams Elementary at 44.6° N : E = 5 m^2 * (920 W/m^2) * 0.22 = 1012 Wh

Adams Elementary : E = 1012 W / 100 W = 10 light bulbs

St. Scholastica at 1.3°S : E = 5 m^2 * (1030 W/m^2)* 0.22 = 1133 Wh

St. Scholastica : E = 1133 W / 100 W = 11 light bulbs

Results:

Station	Max Solar Radiation (W/m^2)	Latitude	Solar Panel Energy Potential (Watts)	# lightbulbs that can be powered

Discussion:

Why do the maximum and minimum solar radiation change throughout the year? [Hint: Select different months from the dropdown menu on the webpage and take note of the axis of rotation - http://profhorn.meteor.wisc.edu/wxwise/radiation/sunangle.html. The Earth is on an axis that is 23.5^{o} from vertical which causes the seasons.]

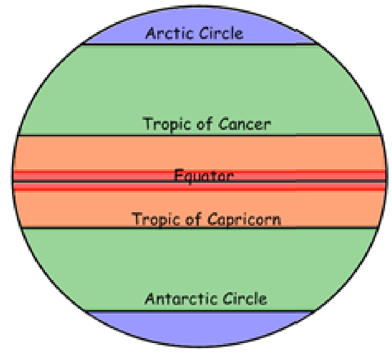
Based on what you have learned about solar radiation at different latitudes, where are the best places to locate solar panel farms? What angles do you think will give the greatest energy for panels located at the equator? What about panels located near 45 degrees latitude, like Corvallis, Oregon? [Answer: Think about the fact that the bigger the shadow the solar panel makes, the greater the energy it is receiving from the sun. So the panel should face the sun. At the equator the sun should point directly up, in the northern hemisphere the solar panel should face south, in the southern hemisphere the sun should point north]

If electricity is 0.20 USD per kWh, how much money can each solar panel produce? [Answer for Adams Elementary : 1.012 kWh * 0.20 USD/kWh = 0.20 USD per day = 73.88 USD per year]

Solar Radiation vs Latitude: Student Worksheet

What latitude is the:

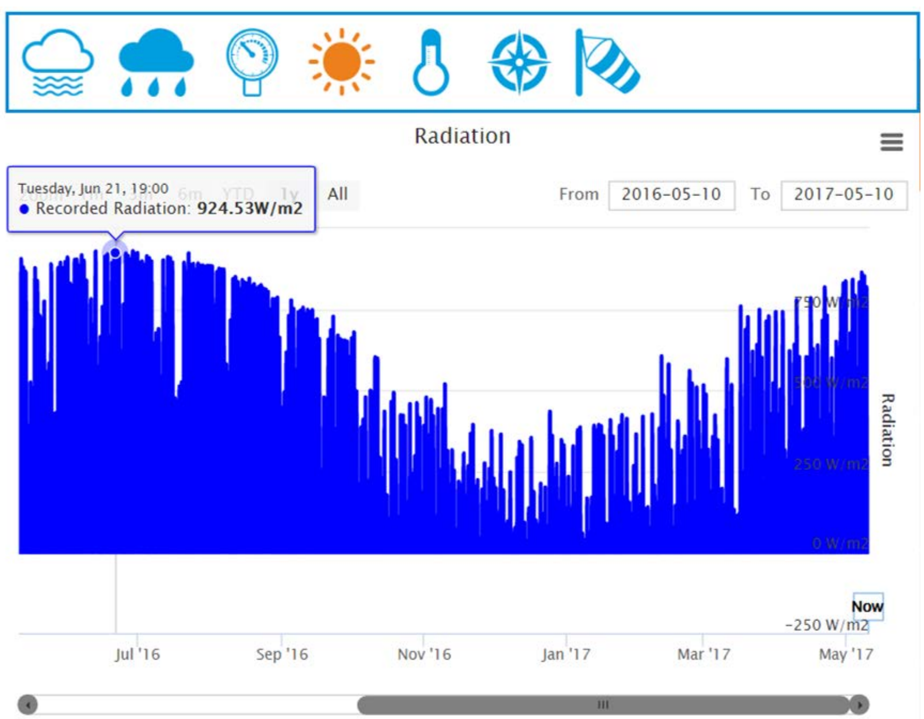
- Equator? ____________
- Tropic of Cancer? ____________
- Tropic of Capricorn? ____________
- Arctic Circle? ____________
- Antarctic Circle? ____________



What are the climate zones on Earth and at what latitudes are they found?

- Tropics:____
- Temperate:____
- Polar:____

On the School2School.net website, look at the Map tab to view all stations across the globe. Choose two stations, one near the equator and one far from the equator. For each station view the solar radiation (the sun icon) and choose the zoom option to view 1 year of data (See Figure below). Use your cursor to float over the data, estimating the maximum value of solar radiation and recording it in the table.



If a school installs 5 m^2 solar panels on their roof, how many lightbulbs can that solar panel power?

To find this out use the following equations to find out how much energy the solar panel can produce, and how many lightbulbs can be powered by that energy.

$$E = A * H * PR$$

$$\# \text{ lightbulbs} = E / 100 \text{ watts}$$

E = Energy (W)

A = Total solar panel Area (m^2)

H = Annual average solar radiation panels (W/m^2)

PR = Performance ratio of solar panel, coefficient for losses (default value = 0.22)

Station	Max Solar Radiation (W/m^2)	Latitude	Solar Panel Energy Potential (Watts)	# lightbulbs that can be powered

Based on what you have learned about solar radiation at different latitudes, where are the best places to locate solar panel farms?

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What direction should the solar panel face? What angles do you think will give the greatest energy for panels located at the equator? What about panels located near 45 degrees latitude, like Corvallis, Oregon?

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Advanced Topics: Calculating the required solar panel size to power the TAHMO station

This advanced topic is intended for classes that want to continue to explore real-world applications of solar panels. This advanced topic is option and should be determined based on the skill level of the classroom. This activity is designed to be done after the main lesson plan is completed, and does use values obtained earlier. Allow an additional 20 minutes for this activity.

In the TAHMO ATMOS 41 station, the solar panel captures the solar radiation which is stored as energy in six 1.5 Volt batteries in series. The batteries are used to power the instruments and data logger on the weather station. By design the batteries will power the weather station for 3 months. This safeguard is to ensure the station continues to collect data even in the case that the solar panel breaks, the weather is cloudy, or any other malfunction with the solar panel. How big of a solar panel does the TAHMO station need to meet this power demand?

First we need to calculate the rate of discharge of the station. The current that the instruments draw energy and discharge from the battery can be calculated by knowing the rating of the battery and the total discharge time. The AA batteries are rated for 2.85 Amp-hours, and battery should power the station for 3 months, or 2160 hours.

Current = Rating/time = 2.85 Amp-hours/ 2160 hours = 0.001 Amp= 1 milliAmp

If the power draw is 1 milliAmp, then the power charge needs to be 2 milliAmp, assuming sun shines on the solar panel for 12 hours per day and the system uses power for 24 hours per day. The total voltage of the batteries is 1.5 Volts * 6 batteries = 9 Volts. With this information, we can calculate power requirement for the solar panel.

Power = Current * Voltage = 0.002 Amp * 9 Volts = 0.018 Watts

Finally we can calculate the size of solar panel required to meet the power requirement. Knowing the maximum incoming solar radiation, we can calculate the size of the solar panel required.

Solar Panel Size = Power / SR = 0.018 W / (920 W/m^2) = $1.96 * 10^{-5}$ m2 [Adams Elementary]

Solar Panel Size = Power / SR = 0.018 W / (1030 W/m^2) = $1.75 * 10^{-5}$ m^2 [For St. Scholastica]

The actual size of the solar panel is 3cm x 7cm= $2.1 * 10^{-3}$ m^2, which is two orders of magnitude larger than the required size. Why do you think it was designed this way? [Answer: Engineers design products with a safety of factor to ensure that the design will not fail. Often, there are uncertainties in some of the values used in the calculations that lead to uncertainties in the calculations for design. There are also assumptions used in the calculations that have associated uncertainties.]

What are the assumptions associated with our calculations? [Answer: our calculations make assumptions that the maximum solar radiation is present for 12 hours a day, which is an overestimate because of the effects of seasons and diurnal solar radiation. It also assumes that all 365 days a year the sun is shining on the solar panel, which does not account for cloudy days. We also are assuming that this system is 100% efficient and that no losses occur.]