CLIMATE CHANGE TOOLKIT

Solar Energy & Soil Temperature

Standards
NGSS PS3.D Energy in everyday life
NGSS ESS3.D Global climate change
Grade Level: Middle & High School

Equipment:
Soil-filled terrarium, flowerpot or field site
6" metal-stem digital thermometers (2-3)
Clip lamp w/ high intensity bulb (if indoors)

Why?

One hundred seventy-four thousand terrajoules of solar energy strike the surface of the Earth every second. This greatly exceeds every other energy source available to Earth. For example, Earth's internal energy – the power behind earthquakes and volcanoes – flows across the surface at only 44 terrajoules per second. Some of the incoming solar energy is absorbed by Earth surface materials, warming them, before eventually re-radiating back to space. The warm subsurface of the solid Earth and ocean is a critical component of all of Earth's ecosystems.

What?

Incoming solar energy diffuses from the surface downward, creating a temperature gradient that we can measure. Because sunlight varies both seasonally and diurnally the temperature gradient is not constant, and it is not linear. An easily accessible place to measure & examine the subsurface temperature gradient is in soil. We can graph our measured data to better understand the flux of energy through the subsurface, and to explore how natural and human communities can take advantage of this energy source.

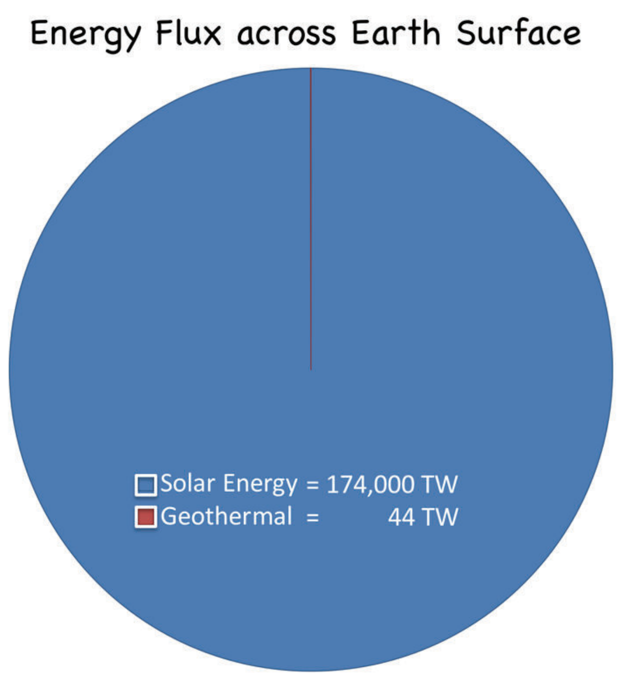


Figure 1: Pie chart comparison of solar and geothermal energy flux across Earth's surface.

How?

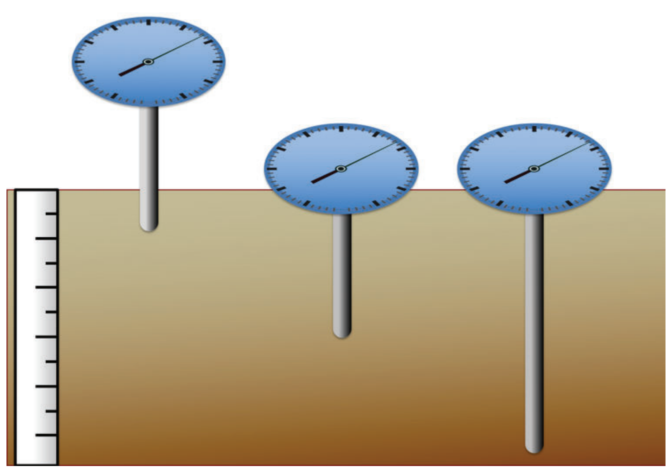
This activity is best done outdoors, although a terrarium or flowerpot of soil can substitute for a field site if none are available. These measurements can be done in any season (unless the ground is frozen very hard), and a series of measurements in different seasons will provide a better understanding of the changes in solar energy flux throughout the year. A minimum of two thermometers is required to measure soil temperature near the surface and at a depth of 5-6"; a third thermometer can be added to create a more data-rich result – or – a compost thermometer with a longer stem will allow you to measure temperature at greater depth. Ideally the thermometers can be installed in the morning and then checked periodically throughout the school day. This gives us both spatial and temporal data sets.

OUTDOORS: Select a sunny location with at least six inches of reasonably soft soil (a lawn or grassy field is perfect). An undisturbed location will be necessary of the thermometers will be left in place all day. Press one 6" thermometer into the soil so that the entire stem is buried. Press the second thermometer ony about 1" into the soil (so that most of the stem is above the surface). The temperature sensor is at the bottom of the metal stem. If using three thermometers, press the third one halfway into the soil. Allow a few minutes for the thermometers to reach thermal equilibrium with the surrounding soil. Record the time and temperatures. Return periodically to record temperatures throughout the day.

DATA TABLE

Time	**Depth**	**Temperature**

Figure 2: (Photo) Thermometer at 6" (lower L) records a soil temperature of 66.7F, while the thermometer at 1" (upper R) records a temperature of 88.7F.



INDOORS: Add a 6-8” layer of soil to a terrarium or flower pot, pressing the soil to create a firm substrate (loose soil with air pockets will not allow energy to diffuse evenly and will produce wonky results). If the soil is excessivley dry, add a little misture and allow time for it to percolate through. The indoor experiment requires you to provide your own sunlight – or – you could place the apparatus in a sunny window. A reptile lamp from a pet store is good for quickly warming the soil surface. Clip the lamp to the side of the pot and turn it on to start warming the soil about 10 minutes before installing the thermometers. Place the thermometers as described above. When doing this activity indoors you can run the experiment just once, or you can try turning the lamp on in the morning and off at the end of the day to simulate the effect of daily sunlight variations. Record the data as before.

Graph the Data

The more data we collect the more interesting this experiment becomes. If we record the soil temperatures just once (e.g. if we run the experiment indoors with artificial light) we can compile a soil temperature profile for the time we made our measurements. A typical 3-point profile to a depth of 40cm (16”) is shown in Figure 3, below. Notice that for this graph, depth is plotted on the vetical axis, and that the values increase downward. This arrangement is unusual in two ways, first, y-axis values usually increase upward, and second, the dependent variable (temperature) is plotted here on the horizontal axis. These choices have been made because these data represent an actual physical space, thus the graph layout reflects that physical space as well.

Notice also that the temperature does not change as a linear function of depth. We are often tempted to draw straight lines through data – and we could make a “best fit” line here – but in this case the physical process that controls temperature at depth is not linear. The soil temperature is periodically changed by the daily appearance of the Sun (or lamp), thus the surface temperature is very dymanic, but the diffusion of the heat through the soil is slow, creating a curved temperature profile.

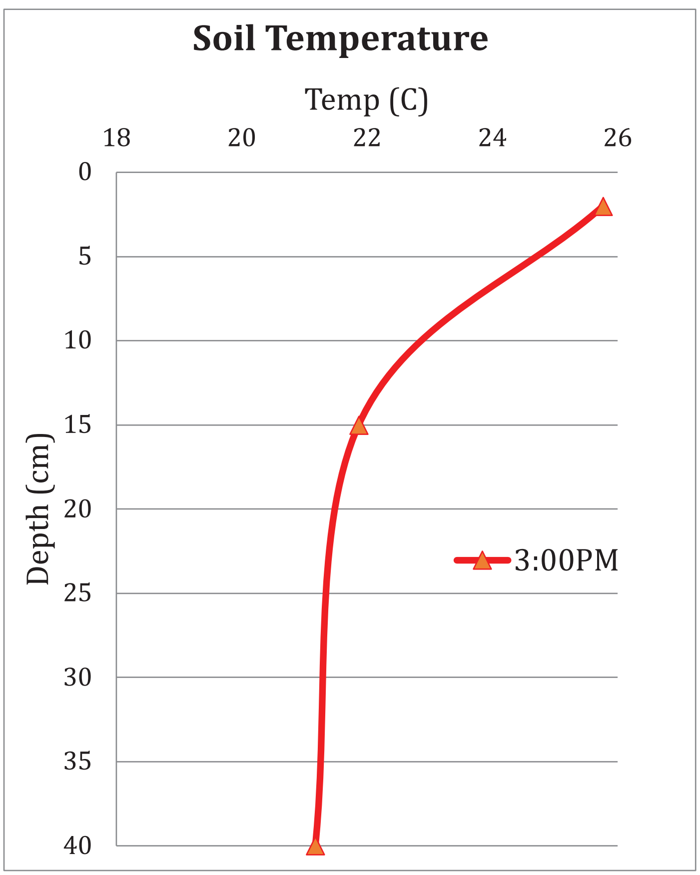


Figure 3: Soil temperature 0-40cm, August, Ithaca NY

If we repeat our measurements across the course of a school day we can make two graphs; one showing the spatial change of temperature in the soil and a second graph showing the temporal variation of temperature at each depth (Figure 4).

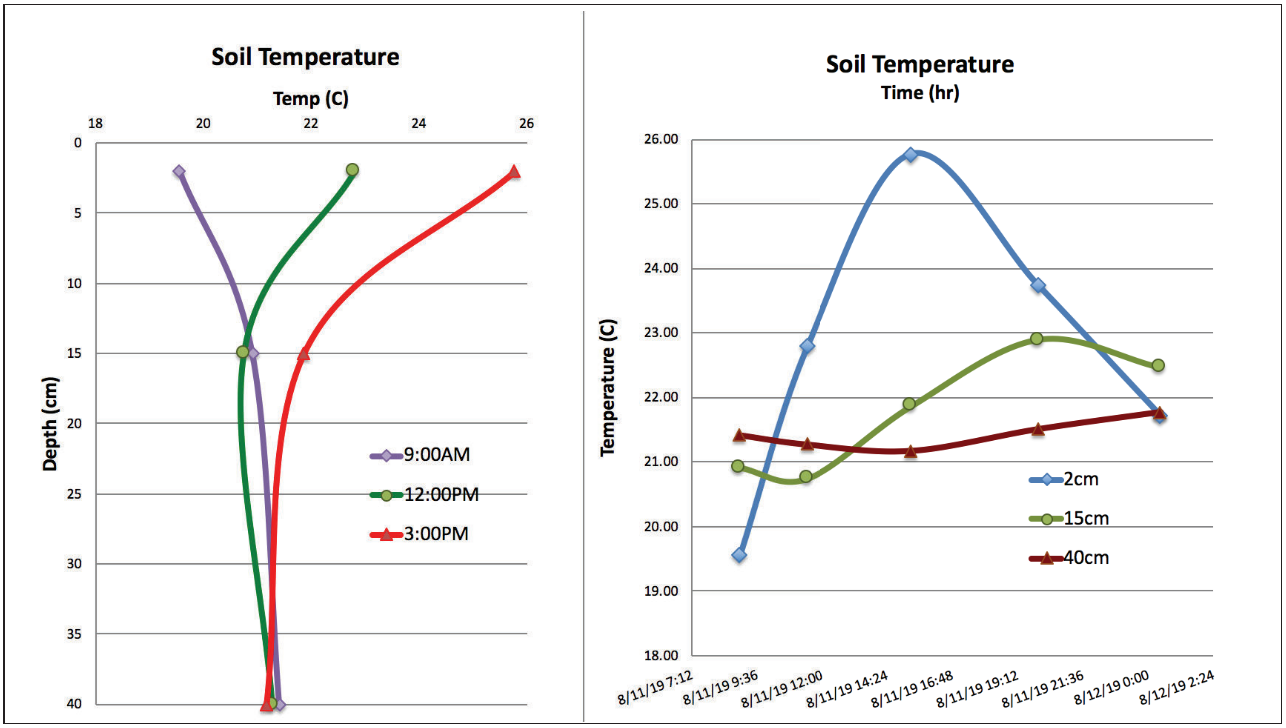


Figure 4: (Left) Summer soil temperature profiles from Ithaca NY at 9:00am, 12:00pm and 3:00pm. The 3pm data are the same as Figure 3. (Right) The same measurements plotted as a time series of soil temperatures at 2cm, 15cm, 40cm, from 9:00am to midnight.

The first graph (left) shows the effect of daily heating and cooling of the Earth surface by sunlight. The first measurement of the day, at 9:00am, shows that the surface has not yet warmed up, and in fact the shallowest thermometer records the coolest temperature in the soil profile. Three hours later at 12:00pm the surface has warmed somewhat – but notice the change at 15cm depth. Here the soil is still "feeling" the coolness of the evening diffusing downward, and the temperature has decreased slightly, even as the shallow temperature increases. By 3:00pm the surface is quite warm, and the warmth is moving downward through the soil, but does not yet affect the deepest thermometer at 40cm (in fact the evening coolness has just now arrived at 40cm, depressing the temperature a tiny amount).

The second graph (right) shows how heating and cooling vary as a function of time. Because the shallowest thermometer is closest to the source of heat it responds first and the magnitude of change is largest. As the heat diffuses downward the 15cm thermometer responds, with a ***phase lag*** that follows the appearance of the Sun. The temperature here never gets as warm as the surface temperature because there isn't enough time; the soil at 15cm is still warming up when the Sun sets and the surface begins to cool again. The deepest thermometer at 40cm shows these effects even more strongly. The phase lag is longer, and the magnitude of change is very small. In fact, notice that the temperature at 40cm is warmest in the middle of the night!

Seasonal Variation – How to stay warm in winter and cool in summer

Soil temperature probes at 2cm and 40cm depth show the transition from summer to fall

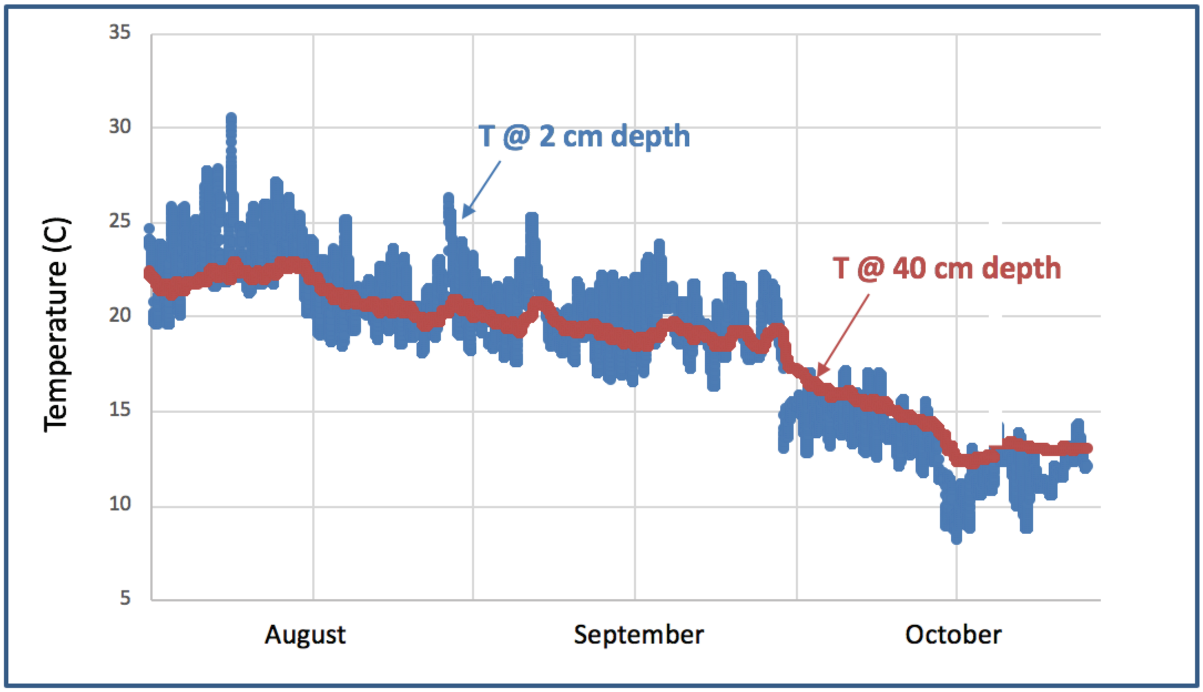


Figure 5: Three months of soil temperature data at 2cm and 40cm, Ithaca, NY.

Just as the Sun changes the soil temperature on a daily basis, the seasonal change in sunlight intensity changes soil temperature over the course of the year. As with the daily variation that we observed above, the seasonal surface changes are largest, and the temperature change becomes smaller with increasing depth. In fact at temperate latitudes, there is very little change at all below a depth of about 2 meters (6 ft); the soil maintains a temperature equal to the annual average air temperature (55.7F in Washington DC). In Figure 5 we can see the transition from summer to fall in the soil temperature data. The surface temperature variation is always larger than the variation at a depth of 40cm, but in the summer the near-surface soil is most often warmer than the deeper soil. As the seasons advance the surface soil becomes cooler than the deeper soil. At latitudes where the average annual air temperature is above freezing, the subsurface does not freeze. This is incredibly important for living organisms that need to hibernate through the winter. It is also very useful for human communities trying to keep warm in the cold months. Ground-sourced geothermal heat systems take advantage of sunlight stored as heat in soil to warm residential and commercial buildings far more efficiently than conventional fossil-fuel powered heating systems. And ground-sourced heat pumps also work to cool buildings in the summer, when subsurface temperatures are reliably cooler than the air.

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