Student Worksheet

CLIMATE CHANGE TOOLKIT
Solar Energy & Soil Temperature

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 (10^{12} joules) 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.

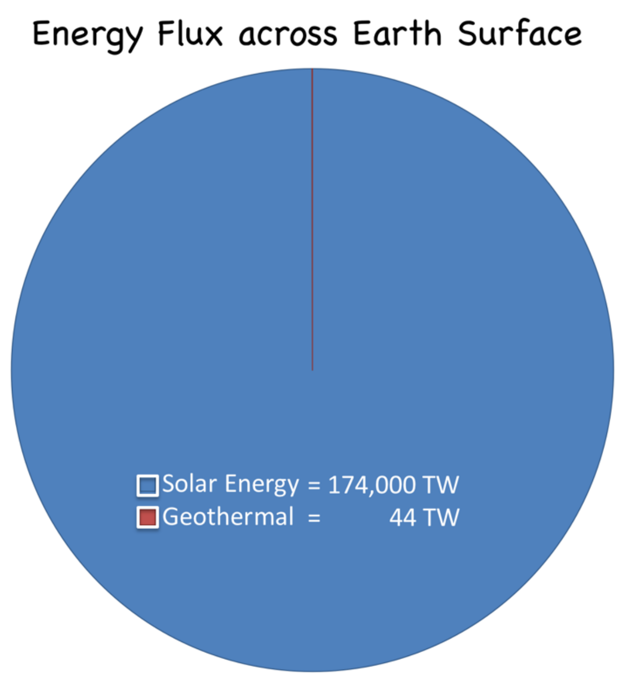


Figure 1: Pie chart comparison of solar and geothermal energy flux across Earth's surface.

How?

This activity can be done indoors or outdoors, but outdoors is better if you have access to a good site. Work with your teacher and classmates to design the set-up of this experiment:

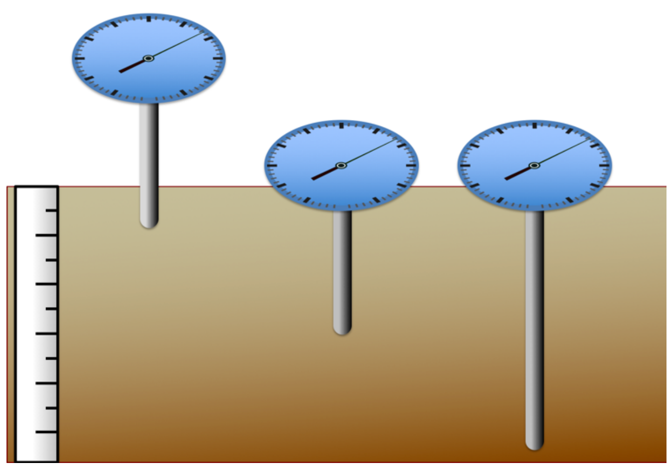
- Is your site indoors or outdoors?
- Will you use 2 thermometers or 3 thermometers?
- How often will you record data?
- Over what period of time will you record data?

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 if 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 only 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.

SAMPLE DATA TABLE – *SEE FULL TABLE ON LAST PAGE*

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.

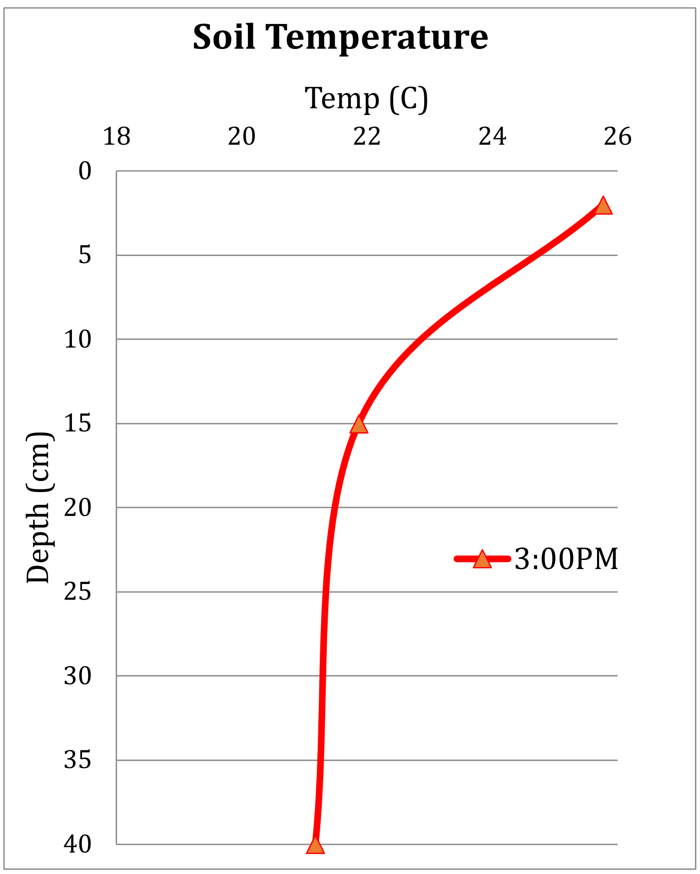


Figure 3: Soil temperature 0-40cm, August, Ithaca NY

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.

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.

- Record your temperature measurements according to the experimental design you created with your class on the data table on page 6.
- Make a graph of your temperature data. Plot temperature on the x-axis and depth on the y-axes (see page 7). If you measured the temperature more than once during the day, add the additional measurements to the same graph using a different color or different symbol for each dataset.
- Write a description of your data. Where is the soil warmer, where is it cooler?
- Draw a conclusion about the relationship between sunlight and soil temperature.

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

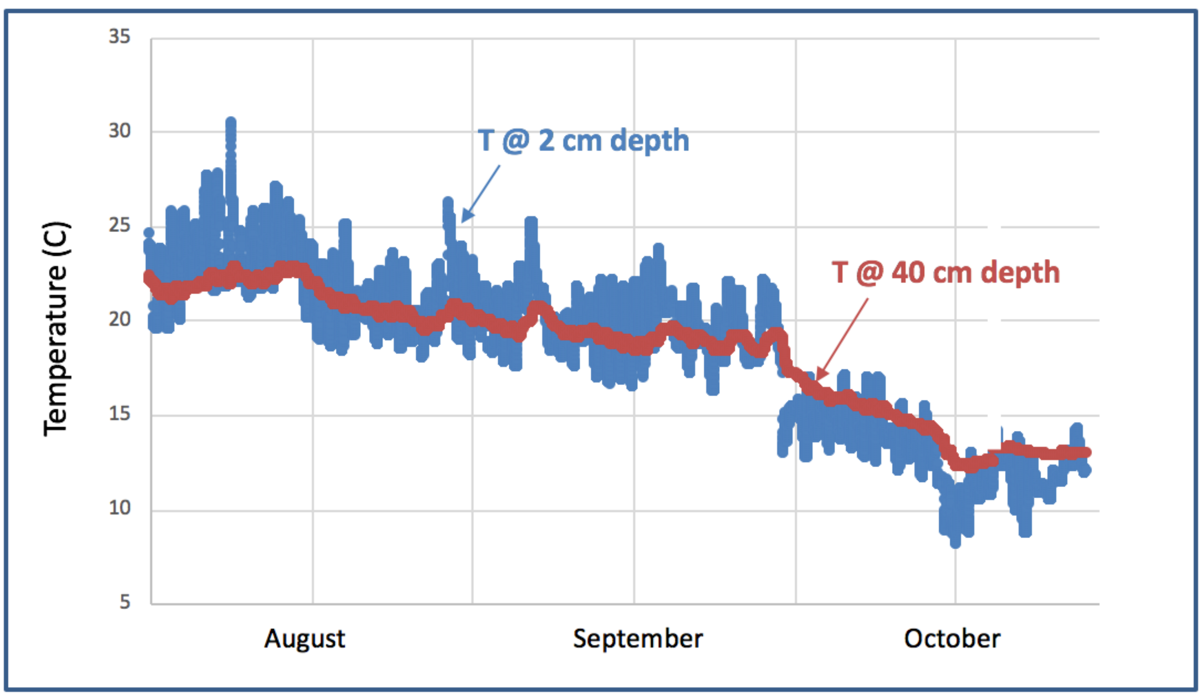


Figure 5: Three months of soil temperature data at 2cm and 40cm, Ithaca, NY.

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 (ex: 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.

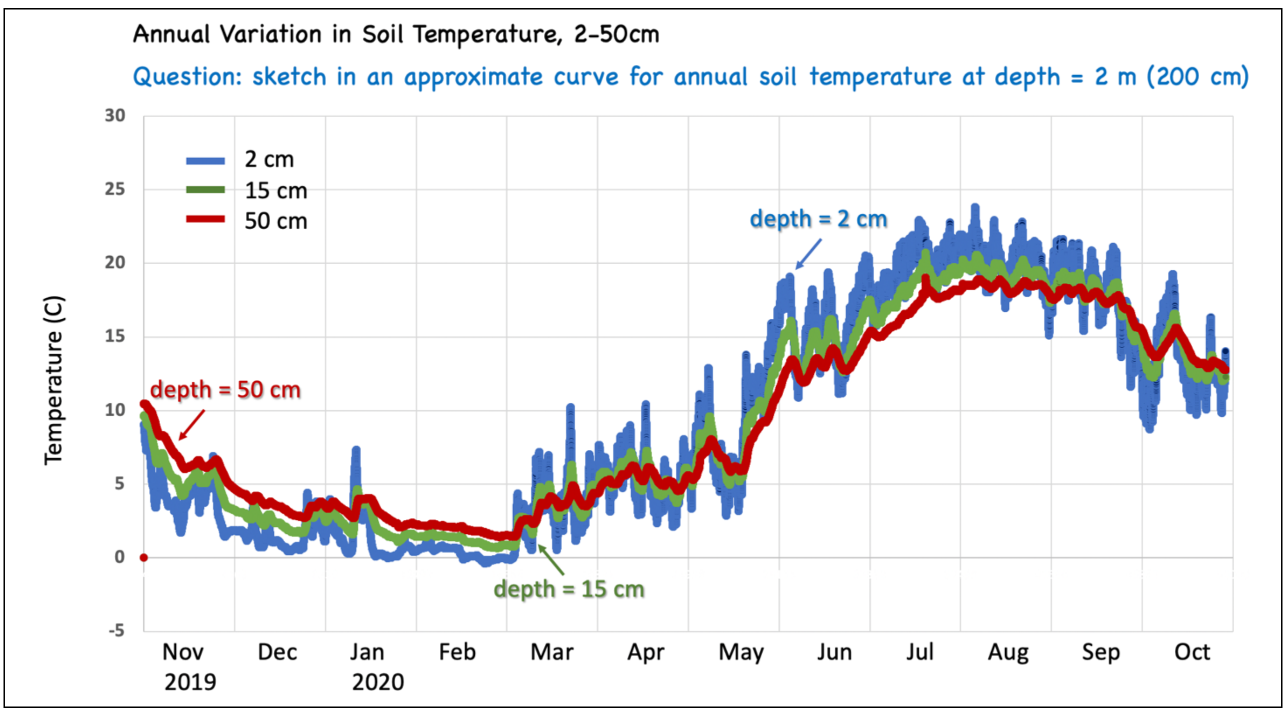
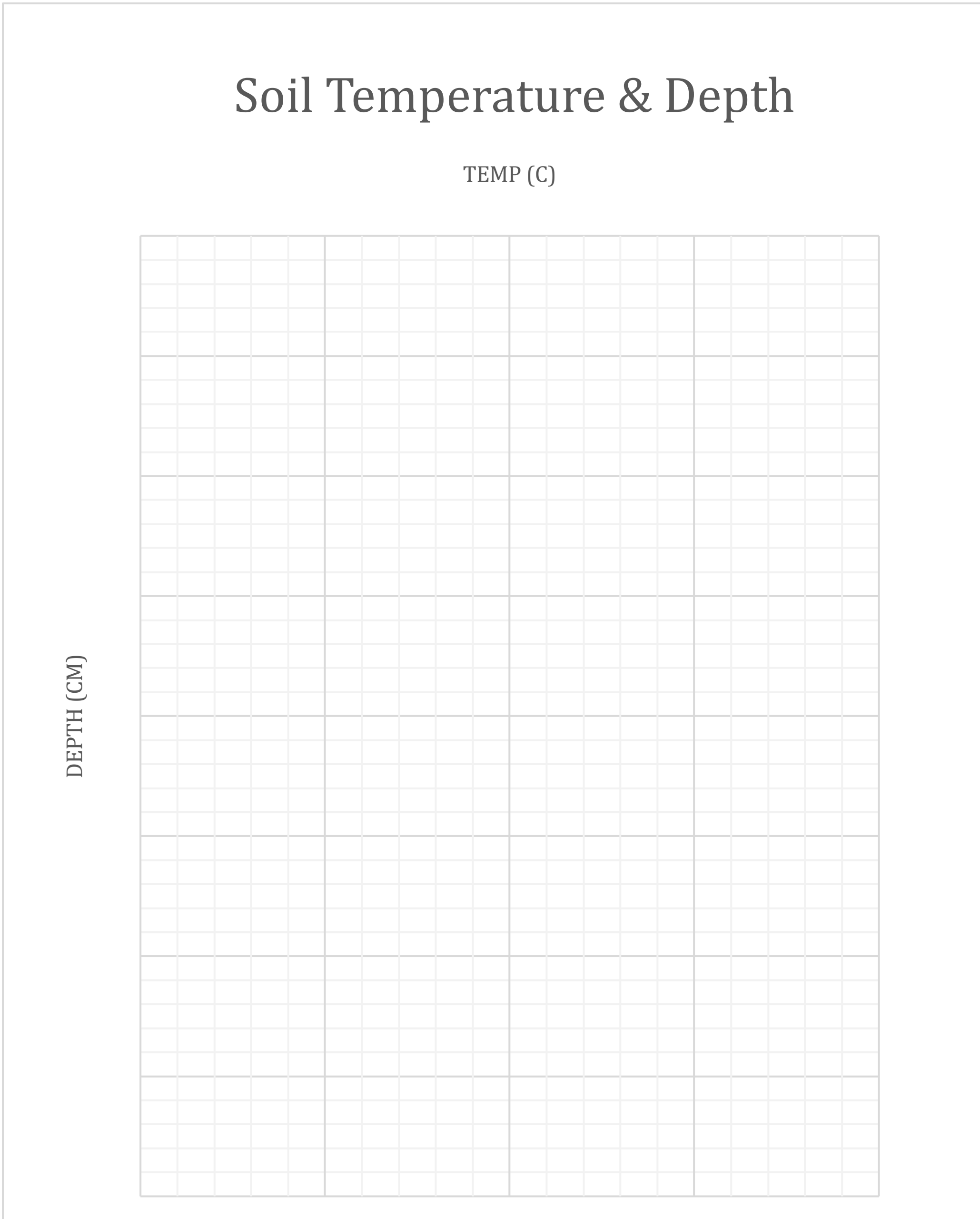


Figure 5: Twelve months of soil temperature data at the Cayuga Nature Center, Ithaca NY.

- On the graph in Figure 5, sketch in the approximate curve for annual soil temperature at a depth of 200cm.

DATA TABLE

Time	**Depth**	**Temperature**


Soil Temperature & Depth
TEMP (C)
DEPTH (CM)

Soil Temperature & Time