SES4U

Video Questions

A) Solar Constant and Solar Intensity at Earth:
https://www.youtube.com/watch?v=416MgVibTZY

1) Why does the an object at earth's orbit only receive 1397 W/m^2 when the sun emits 65 MW/m^2? (you can check my calculation of the sun's output per square metre later)

2) Why does the atmosphere only receive 1/4 of that 1397 W/m^2 for each square metre of atmosphere?

3) a) Why does the surface of the earth only receive 244 W/m^2?
   b) What does the term "albedo" mean?

4) Before watching the next video, estimate the number of 13 W CF light bulbs that the room would need to simulate the brightness of a sunny day. How comfortable would this be to work in?

B) How Entropy Powers the Earth (MinutePhysics)
https://www.youtube.com/watch?v=sAMlGyaUz4M

1) What is the consequence of earth emitting less energy than it is taking in?

2) What is different about the photons of light that the earth receives from the sun and the ones that the earth emits into space (two points)?

C) Why is it Hot Underground? (MinuteEarth)
https://www.youtube.com/watch?v=mOSpRzW2i_4

1) Explain how the geothermal gradient (change in temperature / change in depth) can be used to estimate the age of a planet.

2) What fact did Lord Kelvin not appreciate and that caused him to severely underestimate our current understanding of the age of the earth?

3) What is the physical state of the lower mantle of the earth?

4) Based on what you learned in this video and the previous one, explain, in one short sentence, why are we able to do useful work with geothermal energy?

D) Go to the ***Yellowstone Volcano Observatory*** website.
https://www.usgs.gov/volcanoes/yellowstone/questions-about-heat-flow-and-geothermal-energy-yellowstone

1) a) What is meant by geothermal heat flow? What are its units?
   b) Based on lesson 5, what is the source of this energy?

2) a) What is the average geothermal heat flow power (W/m^2) at the earth's surface in North America?
   b) How does this compare to the solar input?
   c) Does geothermal energy contribute much to the Earth's surface temperature?

3) What is the average geothermal heat flow (W/m^2) for Yellowstone Park (which is a giant volcanic caldera about 60% of the area of Prince Edward Island, just in case you didn't pick up on this)?

4) Assume for sake of simplification that all of the current release of thermal energy is taking place in the core of the planet (it's not, but perhaps a majority is).
   a) Would the total energy per second released by the core have to equal the total energy per second radiated out at the earth's surface?
   b) If it were not so, what would happen to the temperature of the mantle?
   c) Given the radius of the outer core compared to that of the earth's surface, how many watts per square metre must be released by the core into the mantle?

5) How does the answer to question 4c compare to the heat flow rate for the Yellowstone caldera (question 3)?

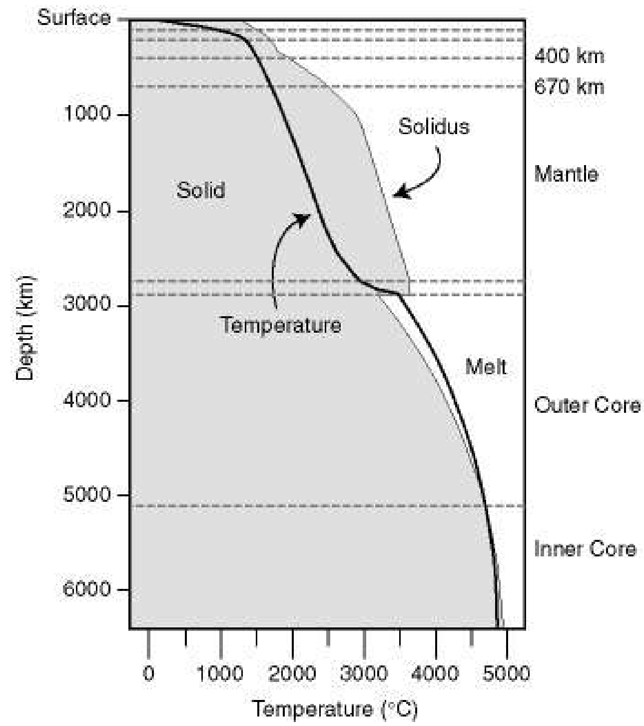
6) What could be responsible for the high heat flow at the Yellowstone caldera?

7) a) What is the difference between crust and lithosphere?
   b) What do we call the boundary between the crust and upper mantle?
   c) What about the rocks changes at the boundary between the crust and the upper mantle?
   d) What is our evidence of this change?
   e) Have we ever drilled a borehole deep enough to sample this transition?

8) The lithosphere, asthenosphere, and lower mantle are each different from the each other in terms of their physical properties. Outline the differences.

E) Geothermal Gradient

This is a measure of how much the temperature of the earth changes for every metre one descends below the surface. It is shown by the dark line in the graph to the right.



It can be calculated as $\Delta T/\Delta depth$
$= (T_1-T_2) / (d_1-d_2)$

1) What is the geothermal gradient in the
   a) lithosphere (upper 200 km)?
   b) lower mantle (400 to 2500 km)

2) Why is the geothermal gradient so much larger for the lithosphere than the lower mantle?

3) What is the temperature of the asthenosphere and how does it compare to the melting point at that depth?

4) If the lower mantle was physically similar to the lithosphere.
   a) What would be the geothermal gradient from the surface to the base of the mantle, assuming the core was the same temperature as now?
   b) Would we still have an asthenosphere?
   c) If not, would plate tectonics still take place?
   d) If not, how do you think that the earth would look after 4 billion years?

5) Consider the previous question.
   a) Would the mantle conduct thermal energy to the surface as quickly as it does now?
   b) If the core was releasing thermal energy as fast as it is now, what would happen to the temperature of the core and lower mantle?

6) Thinking back to lesson 7, how are boreholes used to measure the geothermal gradient in earth's crust?

7) The geothermal gradient in the first few kilometres of the crust is affected by surface phenomena such as weathering and water flow. It can be as great as 25 to 30 ºC/km. This range often is mistakenly cited as the average gradient for the whole lithosphere. If this was true, what would be

F) Heat Flow Equation.

If you have a layer of some material that is different temperatures on one side and the other, thermal energy will flow from the hot side to the cold side at a rate (watts per square metre) that can be calculated by the equation

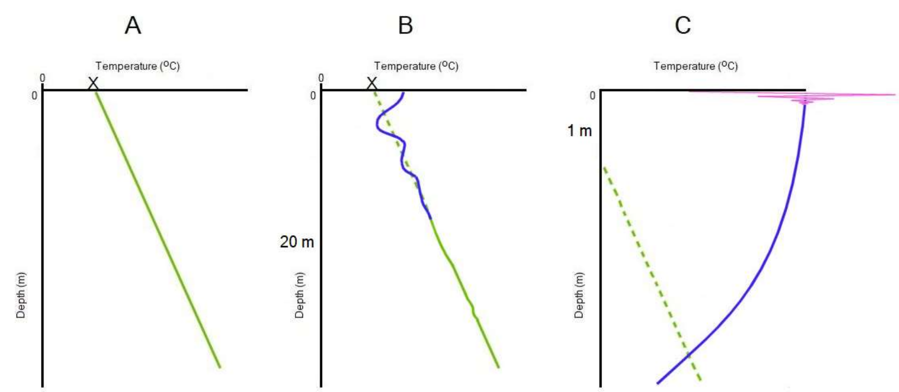
$P = k(\Delta T/\Delta depth)$ where P is the heat flow (W/m^2)
ΔT is the difference in temperature from one side to the other
$\Delta depth$ is the thickness of the layer
k is the thermal conductivity of the material of the layer

k for a typical bedrock at the surface is around 3 to 4.
The average k for the whole lithosphere is around 7.

1) a) Given your answer to question 1a) in section E, approximately what should the heat flow be through the lithosphere?
b) How does this compare to your answer to question 2a) in section D?

Rock has a fairly low thermal conductivity for a crystalline solid. As such, changes in temperature at the surface propagate very slowly into the bedrock. The amplitudeof fluctuations in surface temperature also attenuate (get weaker) rapidly with depth.

In graph A below we see a very uniform gradient of increasing temperature with depth. If the temperature at the surface is constant, one could extrapolate the temperature profile at depth to the surface to determine the atmospheric temperature X ºC.



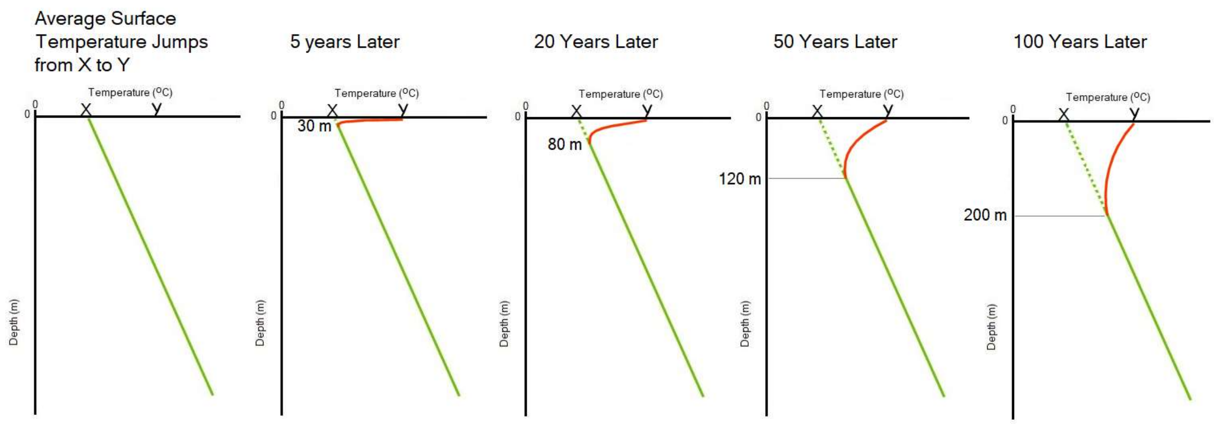
Graph B shows a zoomed-in view of the top 40 m of graph A. One can see the fluctuations in temperature over the past three years in the upper-most 20 m, but thermal energy flowing up from below causes each season's deflection to be reduced compared to what it was at the surface. Below 20 m, all of the seasonal fluctuations are dampened out - the temperature at any given depth is close to constant. Daily fluctuations are dampened out in the top few centimetres of depth (graph C above).

This stability of the geothermal gradient can be useful for heat exchanger heating and cooling systems for houses. Colder fluids can be pumped down to be warmed in the winter and warmer fluids can be pumped down to be cooled in the summer.

2) Given that rock is a relatively poor thermal conductor, what would happen if a heat exchange system tried to add or remove thermal energy from a zone of subsurface rock too quickly? In other words, can you build a geothermal plant anywhere, or does it have to be in a place with high heat flow.

The other advantage of the stability of the deep geothermal gradient is that it can be extrapolated to the surface to get a good estimate of the true average surface temperature for the location of the bore hole (graph B above).

Yet another utility of the geothermal gradient is to be able to track changes in average surface temperature. These changes produce divergences in the gradient. Both the old and new average temperature can be determined. The time since the change can be estimated from the depth of the divergence.



Read the NASA / Penn State University article on borehole temperatures.
https://www.e-education.psu.edu/earth103/node/752

3) Using their data, estimate the pre- and post-change average temperatures at the three eastern Canadian bore holes and how long ago the change occurred (their figure 1).

4) Would you expect the gradient divergence to migrate down at the same rate if the size of the temperature change was greater?

5) a) Does this effect require a change to the climate over a broad area? Would the effect be similar if the borehole area had been forested and then clear-cut at some time in the past?
b) How would you know that a global climate change effect was at work?

6) Looking at the last figure in the article, how well do the temperature-change conclusions from borehole data compare to those from other data?

G) How Do Greenhouse Gases Work? (MinutePhysics)
https://www.youtube.com/watch?v=sTvqIijqvTg

1) What is the moon's and earth's average surface temperatures?

2) What properties do molecules need in order to absorb infrared photons?

3) What happens, on average, to an infrared photon that is emitted by the surface of the earth before it is lost to space?

After Video Questions

Thermal Geophysics: all temperature calculations must be in Kelvins rather than Celsius degrees.

Kelvins = °C + 273

The Stefan-Boltzmann equation, also called the Blackbody Equation, to calculate the heat flow (as light) from a surface based on its temperature. A perfect black body is a surface that has zero reflectance.

$P = eST^4$ P is the energy emitted (W/m^2)
e is a variable called emissivity
S is the Stefan-Boltzmann constant is 5.67×10^{-8} W/m^2T^4
T is the temperature in kelvins

1) If the earth's surface absorbs 244 W/m^2 and is at equilibrium, it must be radiating the same 244 W/m^2 back into space. According to the equation above, what temperature would the earth's surface need to have to emit that heat flow? (This assumes no atmosphere to intercept any of this outgoing radiation)

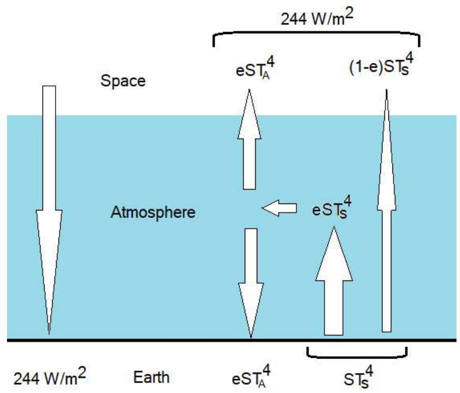
2) How does this compare to the average temperature of the moon from the third video?

3) How much infrared energy must the earth actually emit per second (watts) per square metre if it has the temperature given in the video?

4) a) How much energy must the atmosphere radiate back towards earth based on question 3?
b) What average temperature would the atmosphere need to have to do this if its emissivity is 0.75?

A more detailed calculation of the earth's energy balance can be based on the diagram below. The proportion of the infrared light that passes directly through the atmosphere is equal to 1-e, where is is the emissivity of the atmosphere (0.75). This is the value that is affected by CO_2 and methane in the atmosphere. As these concentrations rise, so does the emissivity for infrared light. T_S is the average temperature of the earth's surface. T_A is the average temperature of the atmosphere.

5) Write a pair of equations that can be used to calculate these two temperatures.



A more detailed, multi-layered atmosphere model would look as follows: