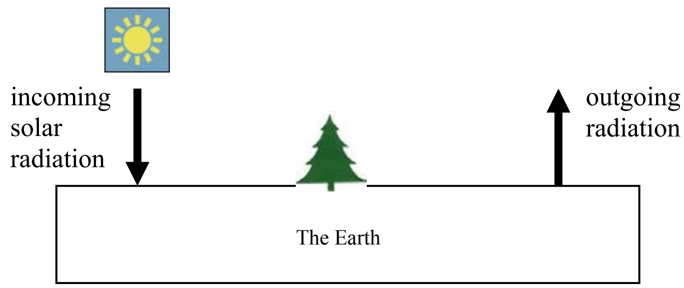
A very simple energy balance climate model Student sheet

The temperature of the Earth depends on the difference between the amount of **energy** the Earth receives from the Sun, and the amount of energy the Earth loses to space. For the Earth's average temperature to be steady, energy must leave at the same rate as it arrives. If energy arrives faster than it leaves, the Earth's temperature will rise.



Question 1

- Is the Earth's temperature constant?
- What might cause the Earth's temperature to change? Suggest as many factors as you can think of which might cause the Earth's temperature to increase or decrease.

Assumptions of the model

Using this very simple model you can see how the temperature of the Earth would change if the amount of incoming energy changed. The model is based on two assumptions:

- The average rate of incoming radiation is 364 joules per square metre per second.

  rate of incoming radiation = 364 $Jm^{-2}s^{-1}$

- The rate of outgoing radiation depends only on the temperature of the Earth, and is given by the Stefan-Boltzmann Law:

  rate of outgoing radiation = σT^4 where $\sigma = 5.67 \times 10^{-8}$ $Js^{-1}m^{-2}K^{-4}$

Question 2

- What might alter the rate at which energy arrives at the Earth?

Warming up

The change in temperature of the Earth depends on the difference between the rate at which radiation arrives and the rate at which it leaves. It also depends on the heat capacity of the Earth (how easily the Earth heats up).

The heat capacity of the Earth = **4×10^8 $JK^{-1}m^{-2}$**; i.e. it takes 4×10^8 J to raise the temperature of 1 m^2 by 1 K.

The change in temperature of the Earth over one year is given by:

temperature change = (incoming radiation – outgoing radiation) × time / heat capacity

and the temperature of the Earth after one year will be given by:

new temperature = old temperature + temperature change

Question 3

Suppose that energy arrived from the Sun at a greater rate.

- Suggest what effect a 5% increase in solar radiation would have on the temperature of the Earth.
- What effect would this have on the rate at which energy radiates from the Earth?

Using a spreadsheet model

We now have four equations, which represent our model. We can use these equations to calculate, for example, how the Earth's temperature will change if the rate at which energy arrives from the Sun changes.

Open the Excel spreadsheet climatemodel_worksheet.xls - you will see that most of the information is already in the spreadsheet. The model is set up assuming that at time 0 the incoming and outgoing radiation are in balance at an average temperature of 283 K (10 $^{\circ}$C).

Cell B5 contains the formula for the effect of increasing the incoming radiation by 5%.

Now run the model by copying the formula for time in cell A5 down at least 20 cells in the A column.

Copy the formula for incoming radiation in cell B5 down at least 20 cells in the B column.

You can now extend the series in columns C, D and E down to row 20 and see how temperature evolves in your model.

Question 4

- Describe how the Earth's temperature evolves.

- What temperature does the Earth reach, and after how long?

Plotting a graph

Use the chart wizard to plot an appropriate graph of temperature against time for the Earth.

Changing the time increment

Try playing with the time increment. You do this by changing the number in cell C1, which has been given as the number of seconds in half a year, 15768000.

Re-run the model with time intervals corresponding to, for example, one-quarter of a year, one year and five years. You may have to extend the columns further down, if the model doesn't reach an equilibrium.

Question 5

- Do you get the same new equilibrium temperature if you use a bigger or smaller time increment?
- Does it take more or less calculations to reach the final temperature?

Changing the incoming radiation

Try a different change in the rate of incoming radiation. You could increase it by more than 5%. Replace 1.05 in the formula in cell B5 with 1.08 for an 8% increase, and copy the new equation down the column. To reduce incoming radiation by 5%, replace the 1.05 by 0.95.

Question 6

- Does the model reach a new equilibrium, steady state temperature? If so, how does it compare with the old one?
- What is the advantage of drawing graphs to see how long it takes to reach a new steady state?

Question 7

Think about the model you have been exploring.

- Why do you think scientists use models like this to predict the future?
- Even as energy balance models go, this model is very simple. In what ways is the atmosphere different?

Notes on working the Excel spreadsheet

How to copy the formula down a column

Right click on the appropriate cell. When you move the cursor over the small square at the bottom right of the cell, it turns into a cross. Right click on this and drag down.

How to use chart wizard to plot a graph

Select the data you wish to plot ('x' and 'y' axis data) by holding the control button down and right clicking and dragging over the appropriate data. Launch the chart wizard by clicking on the bar graph icon. An XY scatter with data points connected by smoothed lines is appropriate for this exercise. Work your way through the wizard, entering appropriate words for 'x' and 'y' axis labels etc.

How the spreadsheet is set up

The constants are already defined:

σ in cell A1, the heat capacity of the Earth in cell B1 and the time increment in cell C1 (initially set to half a year, in seconds).

The table headings 'time', 'incoming radiation', 'outgoing radiation', 'temperature change' and 'temperature' are in cells A3 to E3.

At time 0, the initial temperature of the Earth is set to 283K.

How the spreadsheet calculates the Earth's changing temperature

Consider the time column first. After one time step, the time has increased by half a year, one time increment, so the formula in cell A5 adds the time in cell A4 (0) to the time increment. As this would display the time in seconds – a big and not very meaningful number, the formula (not the constant!) is divided by 60*60*24*365 to display the time in years.

Copy the formula down at least 20 cells in the A column. This should give you a series of times at half yearly intervals.

Now consider the outgoing radiation (column C) at time = 0.5years. The formula for the outgoing radiation based on the constant in cell A1 and the temperature of the Earth at time 0 is = σT^4. The formula for this is in cell C5.

If we assume the Earth is in a steady state (incoming energy = outgoing energy) before we do anything to the radiation, the incoming radiation at time 0 must equal this, so cell B4 is set equal to C5.

Consider the case where the incoming energy increases by 5% at time = 0.5 years, and then stays constant with time. We do this by putting =B4*1.05 in cell B5. Copy this expression down at least 20 cells.

Now, in cell D5, we can calculate the temperature change which results

= (incoming radiation – outgoing radiation) x time increment / heat capacity

Finally, in cell E5 we can calculate the new temperature

= old temperature + temperature change

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