# MODELLING THE EARTH'S TEMPERATURE

**The vast majority of the energy on Earth comes from the Sun, and therefore the Sun is a good starting point when it comes to building a model of the Earth's temperature and climate. A particular class of models are known as *energy balance models*. They predict the average temperature on Earth by looking at the Earth's total energy budget. So let's build our very own energy balance model and predict how greenhouse gases and the melting of the Arctic ice caps impact on temperature.**

> **"Our predictions of the future climate of the Earth rely on sophisticated mathematical models."**
>
> **Peter Wadhams, Professor of Ocean Physics, University of Cambridge**

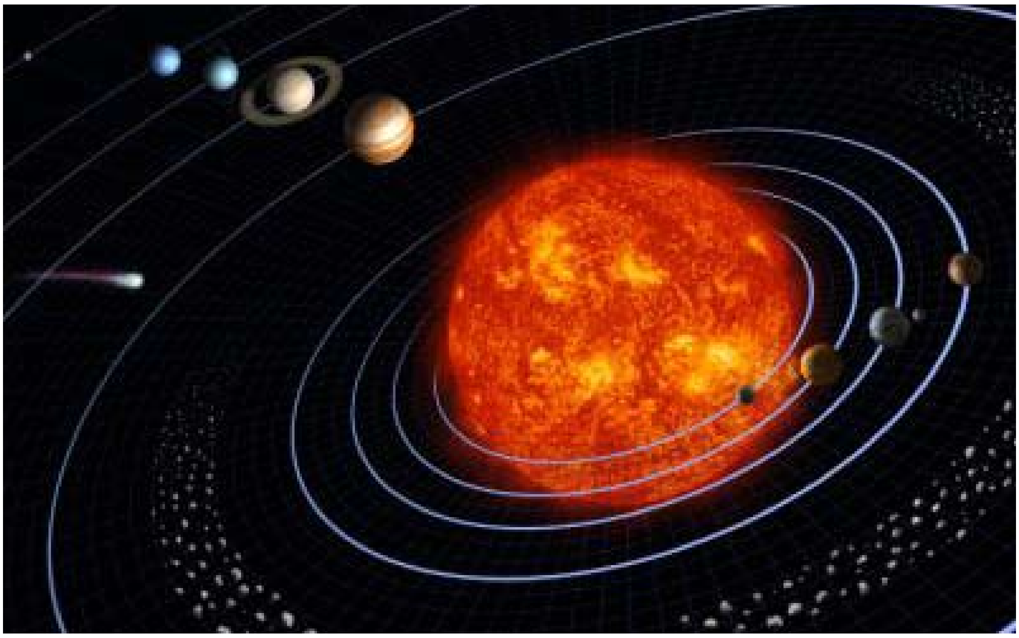

Image courtesy NASA

*The Earth receives its energy from the Sun*

The Sun emits energy into space in the form of radiation. About half of this energy arrives on Earth as visible sunlight, but it also includes energy from the ultraviolet and infrared parts of the spectrum, as well as microwaves and other wavelengths. Some of the solar energy is absorbed by the Earth, which in turn radiates energy back into space in the form of heat – just like an object placed near a fire heats up and starts to radiate heat into its surroundings. As the object heats up, the energy it radiates increases, until the energy radiated by the object exactly balances the energy absorbed by the object. When this happens, the object is said to be in *thermal equilibrium*. The basic assumption of energy balance models is that the Earth is also in thermal equilibrium: the amount $A$ of solar energy it absorbs is equal to the amount $R$ it radiates back into space.

Using measurements from satellites, scientists have been able to estimate the average amount $S$ of solar energy that arrives on Earth per second. It is around

$S=175{,}000{,}000{,}000\ MW$, which scientists write as
$S=1.75 \times 10^{11}\ MW$

Here $MW$ stands for megawatt, and a megawatt is equal to one million watts. That's a very large number – (most coal fired power stations generate only a few hundred to a few thousand megawatts) it shows just how strong the Sun is.

The amount $E$ of energy emitted per second by the Earth is related to the average temperature on the Earth's surface. A physical law known as the *Boltzmann law* allows scientists to estimate this relationship:

$$E=29T^4$$

where $T$ is temperature measured on the Kelvin scale. (To convert Kelvin into degree centigrade, simply subtract 273.15.)

Now assuming that the Earth absorbs all the energy that arrives from the Sun (so $S=A$), and that all of this is emitted back into space (so $E=R$), our energy balance assumptions gives the equation

$$1.75 \times 10^{11} = 29T^4$$

**Question 1: Solve this equation to find possible values for the Earth's average temperature *T*. Look up the real average temperature of the Earth – how does our model's prediction compare to this real value?**

**Question 2: Discuss how the model could be made more sophisticated.**

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*The vast areas of Arctic ice reflect sunlight and increase the Earth's albedo*

In our simple model we have made two important assumptions. The first assumption was that all the energy arriving at the Earth is actually absorbed by the Earth. But this isn't quite true – some of the energy is reflected right back into space, especially when it hits white areas like the polar ice caps. The proportion $a$ of the solar radiation that is reflected back into space is called the Earth's *albedo*. It is roughly equal to $a=0.32$. The proportion of solar radiation that is not reflected back into space is $(1-a)$. Consequently, the total average amount $A$ of solar radiation absorbed by the Earth is

$$A=(1-a)S.$$

*Any climate model must take into account the Earth's atmosphere*

The second assumption we made is that all the energy radiated by the Earth makes it back into space. But this ignores the fact that the Earth has an atmosphere in which energy can get trapped. In reality, greenhouse gases like water vapour, carbon dioxide, methane and ozone exist in the atmosphere and absorb energy. This leads to the well-known greenhouse effect, which is such an important factor in our climate, and which keeps us warm. The ratio $e$ comparing the radiation that is actually emitted by the Earth and the amount it would emit if there was no atmosphere is called the Earth's *emissivity*. It is roughly equal to $e=0.61$, showing that the amount of radiation emitted by the Earth is reduced by the presence of our atmosphere – that is, the atmosphere is absorbing energy.

Therefore, the amount $R$ of energy radiated by the Earth into space is

$$R=e\,E.$$

Since $A=R$, we get

$$(1-a) \times S = e \times 29T^4$$

**Question 3:** **Solve this equation to find new possible values for $T$ and compare to observed values.**

**Question 4:** **Now imagine that the temperature on Earth has risen, causing a large part of the Arctic ice caps to melt. What does this mean for the Earth's albedo, that is, the amount of sunlight that is reflected back into space, rather than being absorbed? How does this change in albedo in turn impact on temperature?**

**Question 5:** **Suppose that the Earth's albedo has decreased to $a=0.25$. How does this affect the average temperature as predicted by the model? How does this result tally with your answer to the previous question?**

**Question 6:** **Now imagine that the amount of greenhouse gases in the Earth's atmosphere increases. What does that mean for temperature? What happens to the Earth's emissivity?**

**Question 7:** **Suppose the Earth's emissivity has decreased to $e=0.55$. How does this effect temperature as predicted by our model (assuming that albedo remains the same at $a=0.32$)?**

As we've seen, our simple model accounts for two very important factors: the Earth's albedo and the effect of greenhouse gases. It also makes reasonably accurate predictions about the average temperature on Earth. This simple energy balance model forms the basis of many, more complex climate models.

More sophisticated energy balance models also take into account geographical variations of temperature on Earth – the Earth is divided into areas according to geographical features, for example oceans or mountain ranges, and individual models are built for these regions. There is almost no end to the layers of complexity that can be added to models like these – for example one can take into account the different layers of the Earth's atmosphere and circulation systems like the Gulf stream. However, simple models like the one we developed here are often used as basic components of more sophisticated models.