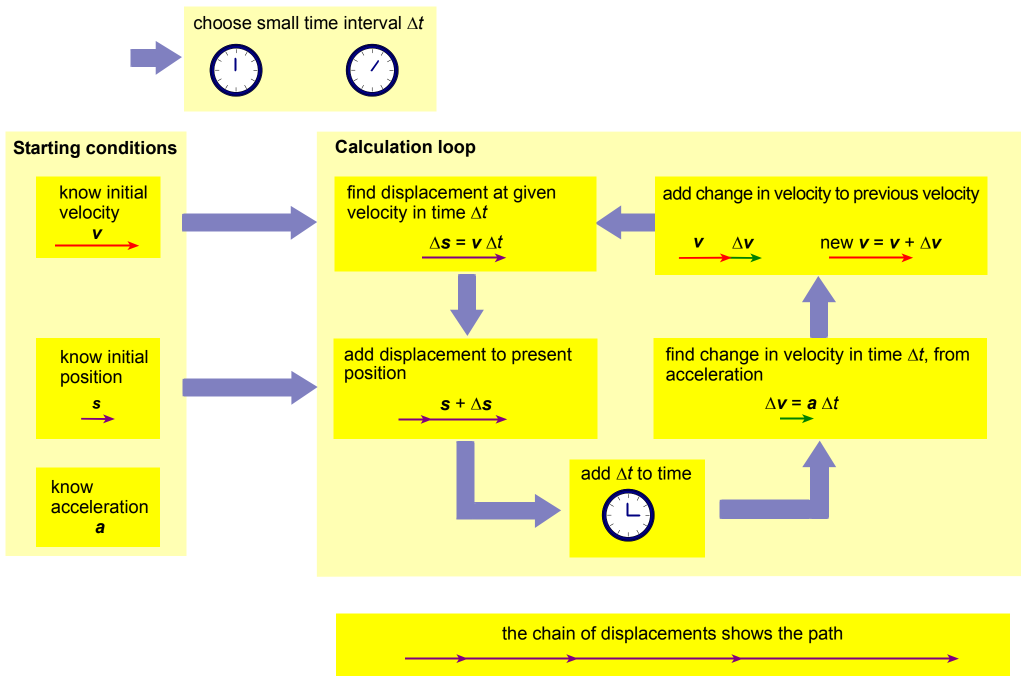
Climate Modelling using Modellus

In Chapter 9 of *Advancing Phsics* you were introduced to modelling simple motion; by breaking a motion into many short and regular time intervals and knowing the starting position and speed of an object it is possible to calculate where it will go to using iterations:

Computing rules for accelerated motion



Advancing Physics AS CD-ROM, 9D40O

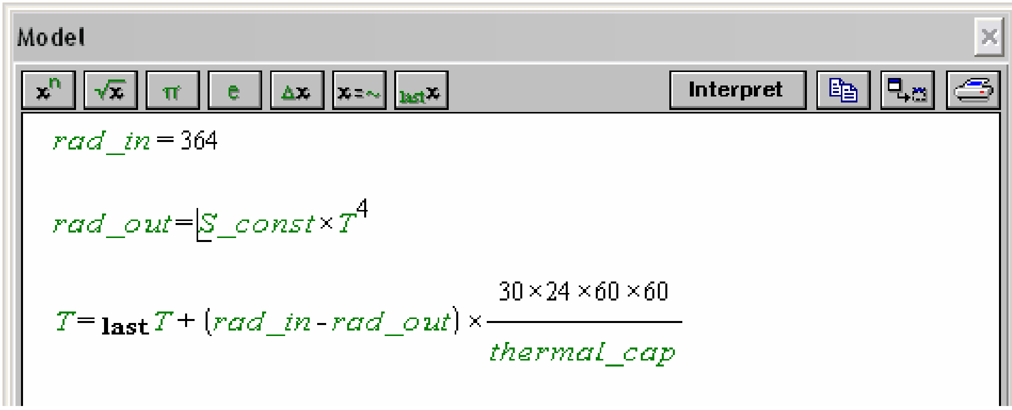
The same process, breaking time down into short periods and applying the same calculations over and over again can be used to ‘predict’ many different physical processes. By the time you reach the end of Chapter 10 you will have used it to model radioactive decay, capacitor circuits and simple harmonic oscillators.

With the power of modern computers and their ability to do millions of calculations per second, iterative modelling is used in all branches of physics and engineering. Our understanding of a great number of things – explosives, stars, aircraft, the weather etc – has improved by building models and comparing their results to reality. The climate*prediction*.net experiment is trying to do the same – build a viable model of the atmosphere and its weather to try and predict accurately what our future climate might be.

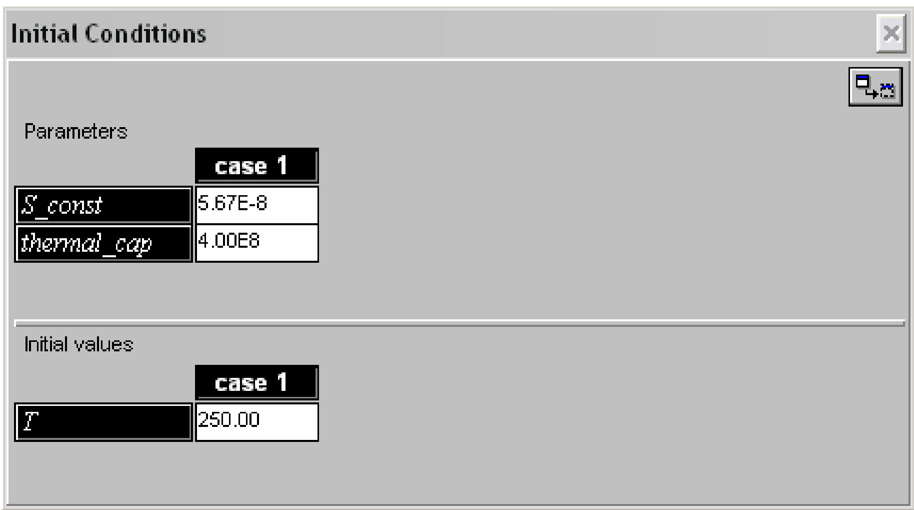
The climate*prediction*.net experiment can be downloaded from the internet and run as a background process on any modern PC – it will make use of unused time on the computer’s processor to do its calculations. Several thousand people around the world have already downloaded the model and are allowing the climate*prediction*.net team, based at the University of Oxford, to try out many different versions of their model to see which ones can accurately reproduce today’s climate and which are therefore most likely to be able to make sensible predictions about the future.

But how do you model the climate? Certainly not by applying the iterative process to the motion of each particle in the atmosphere! There are far too many of them for that to be a sensible method but the basic principle of one calculation being repeated over and over again is used. You can understand the principles of this using *Modellus*.

A simple model
Open the Modellus file *climate.mdl* and select the MODEL window. You should see this:



Look at the INITIAL CONDITIONS window. You should see this:



Run the model and see what happens to the temperature. Try changing the starting temperature, T; does it change what happens? What if you try extreme values? Is this a sensible temperature for the Earth?

Understanding the model

rad_in: the amount of energy from the Sun reaching each square metre of the Earth's surface per second in W/m^2. In this model the value shown is based on how far the Earth is from the Sun, the luminosity of the Sun, the amount of energy that is reflected or absorbed by the atmosphere and the greenhouse effect.

rad_out: the amount of energy radiating away from each square metre of the Earth's surface per second. This is calculated using Stefan's law:
the power emitted as radiation per square metre = $5.67\times10^{-8} \times T^4$

The temperature of the Earth's surface, T, is calculated by taking the difference between the *amount of energy landing* on each square metre and the *amount radiated away* and calculating the effect that this amount of energy has on the Earth's surface. The (30×24×60×60) is the number of seconds in 30 days so the model's time step is about a month. Because the Sun's radiation does not penetrate very far into the Earth the thermal capacity is not that of the whole Earth, but rather a thin surface layer of rock and is measured in $J/m^2/K$.

Using the model to make predictions

Over its lifetime the Sun's luminosity, the amount of energy it emits each second, has increased and it will continue to do so. Suppose the Sun suddenly increased its luminosity by 5% - what would happen to the Earth's temperature and how long would this take?

Change the initial value of the *T* to 283 K (the average temperature of the Earth today) and *rad_in* to 382 W/m^2. Run the model and see what happens to the temperature. Does it increase? By 5%? How long does it take – remember the time units are months.

What would happen to Earth if the Sun were to suddenly stop shining? How long would it be before water started freezing? How dim could the Sun get and still keep water liquid on Earth?

Habitable zones

So far as we know, a fundamental necessity for life to evolve on a planet is liquid water. Although the state of water depends on the atmospheric pressure as well as the temperature (you may know that the boiling point of water lowers as you go up a mountain and is higher for water in a pressure cooker) the next model will assume that the pressure does not change – is this reasonable? Even if the temperature changes?

The Earth orbits the Sun in a narrow distance band called the habitable zone – any closer and it would be too hot for life, and further away and it would be too cold.

Open the *Climate2.mdl* model. This has the same basic logic as the first model but you can change several of the values:

luminosity can be varied between 0.5 and 1.0 times the current value of the Sun's luminosity.

albedo the amount of radiation from the Sun that is reflected back into space by the Earth's atmosphere. 1 = total refection and 0 = total absorption

thermal capacity if the Sun's energy falls on water about the top 10 metres are heated. The thermal capacity of a $1 m^2$ by 10 m deep column of water, is 4.2×10^7 $J/m^2/K$.

If the Sun's energy falls on rock then only the first 10cm are heated. This gives a thermal capacity of about 8×10^5 $J/m^2/K$.

distance the Earth is 1 AU (astronomical unit) from the Sun. Mercury is about 0.4 AU away and Pluto is out at 40 AU.

In the MODEL window, the line:

$$rad\_in = lum \times \frac{1}{4 \times \pi \times dist^2} \times (1 - albedo)$$

calculates the amount of energy landing on each square metre of Earth by (i) spreading the total energy emitted by the Sun out over the surface of a sphere of radius equal to the distance of the Earth from the Sun using the inverse square law and (ii) compensating for how much is reflected using the albedo.

Run the model: it starts with *T* = 283 K but the Earth quickly cools to 247 K, below the melting point of water. This highlights a very important effect of the Earth's atmosphere – the greenhouse effect.

Use the slider bars in the ANIMATION window to change various values. So long as you don't change them too suddenly you should get temperature changes that make sense – moving away from the Sun makes the Earth cooler as does making the albedo bigger.

Changing the values too radically sometimes produces strange and meaningless values – infinite or even negative temperatures. Use the TABLE window to investigate why the model failed. If you think you have identified the problem, try changing values in the model or the initial conditions to stop the failure. If it works, is there a downside?

What affect does changing the thermal capacity have? Does that make sense? With the 'rock' setting, is it harder or easier to get the model to fail? Why?

Modelling the real Earth

As you can see, although this model does give its results a lot faster than the climate*prediction*.net model, it is not very useful – for example, it does not give the correct temperature for the Earth as it takes no account of the atmosphere's greenhouse effect, just the reflection of sunlight from clouds etc. Involving the atmosphere properly makes the model much more complicated.

Look at http://www.climateprediction.net/schools/docs/Energy_Budget.ppt to see how the atmosphere interacts with the energy flowing into and out of the Earth. As well as looking at the slides, read the notes carefully. Any model that includes the atmosphere will have to have 3 bodies exchanging energy – the Sun, the Earth's surface (land and oceans) and its atmosphere.

Obviously the surface and the atmosphere interact differently where there is water or high land etc and the atmosphere varies with height. The amount of sunlight falling on each square metre of the Earth varies with latitude, season and time of day as well as weather conditions.

In order to incorporate all these factors, the whole planet/ atmosphere system is divided into small blocks called cells. Each cell has its own "energy in" and "energy out" calculation at each time step and cells interact with each other as weather develops and moves across the globe and so this makes for a huge amount of calculation work. http://climateprediction.net/science/model-intro.php describes some of these details.

If your computer is running the climate*prediction*.net model, run the TASK MANAGER by pressing ALT, CONTROL and DELETE. Select the "Processes" tab and look for "Model.exe" - see how much of the computer's CPU (Central Processing Unit) time the model is taking. Open the Climate*prediction*.net window and wait for the "Timestep" to increase by 1 unit (half an hour of model time). Your computer can perform millions of calculations each second; this should give you some idea of how complicated the model is!

Each downloaded version of the climate*prediction***.**net program has the same model controlling it but each one has its own starting conditions (parameters). The conditions you download may turn out to give a very good simulation of the weather in the early 19th Century in which case we can place some faith in its predictions about the future weather. By having thousands of different variations of the initial conditions, the team can see which parameters affect the model's climate (and therefore hopefully Earth's climate) most significantly.

Read http://climateprediction.net/newsb.php to get the latest news of how the project is progressing.