Experiments with Tim Osborn's simple climate model: hints and outcomes

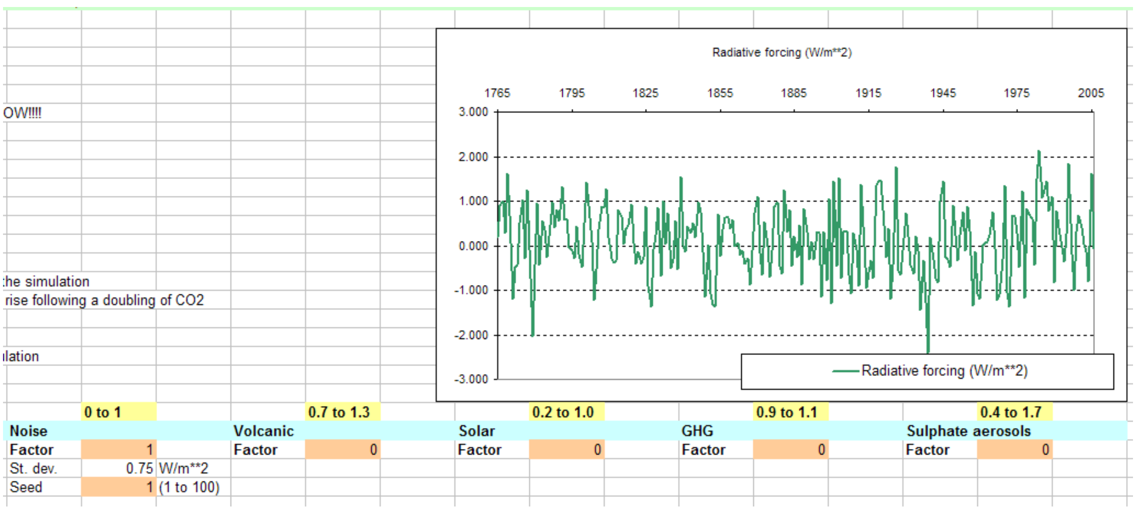
Sensitivity experiment (1)

Hints: set all forcing factors to 0 except that of the sine-wave, which you could set to, say, 6.6 (or any positive value, but if you choose something too small then it will be difficult to see the results accurately in the graphs). Set the period to 100 years, and try climate sensitivities of 1.5 and 4.5. The overall range of the simulated temperature is 0.75 degC for sensitivity of 1.5, which more than doubles to a range of 1.6 degC for a tripling of climate sensitivity to 4.5. For a sinusoid with a period of 50 years, the equivalent simulated temperature ranges are 0.7 and 1.4 degC, while for the faster-varying forcing of a 10 year period sinusoid, the simulated temperature range is little different between sensitivities of 1.5 and 4.5 (being 0.6 and 0.7 degC).

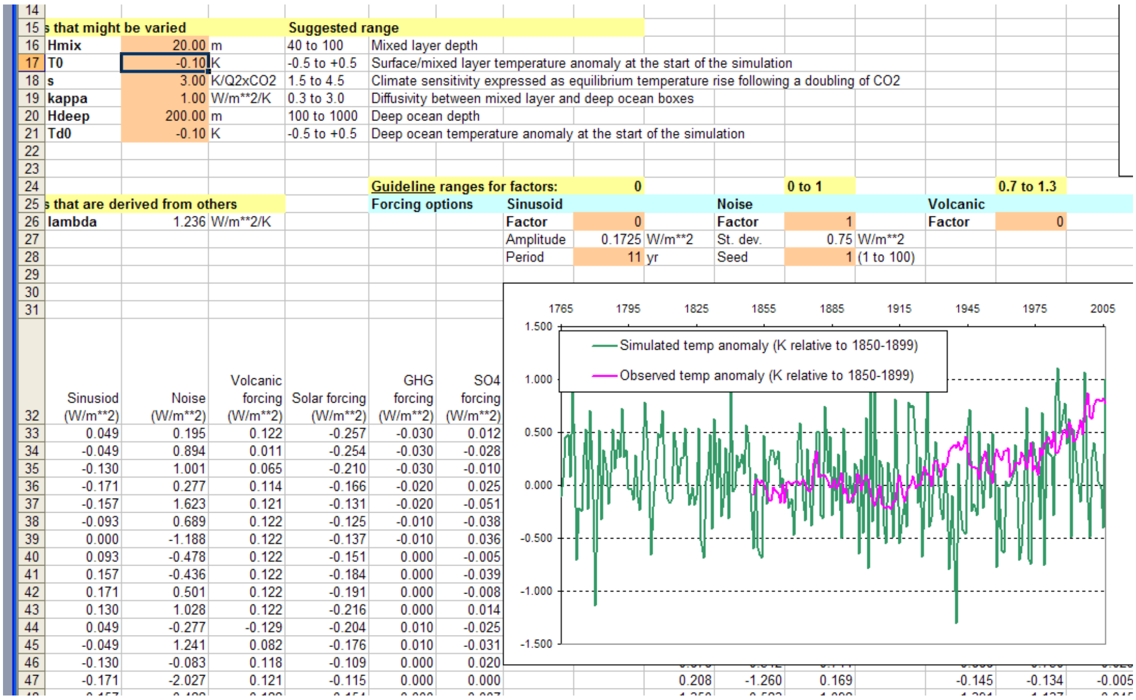
Learning outcome: the effect of climate sensitivity on temperature response is demonstrated to be smaller for the sine waves with shorter periods than for those with longer periods. The implication is that if we wish to estimate climate sensitivity by observing the real-world temperature response to some known external forcing changes, it may be better to focus on the response to forcings that last for long periods of time (e.g. the forcing trends over the 20th century) rather than those that are shorter-lived (e.g. the annual cycle), because the response to the latter depend only weakly on the climate sensitivity.

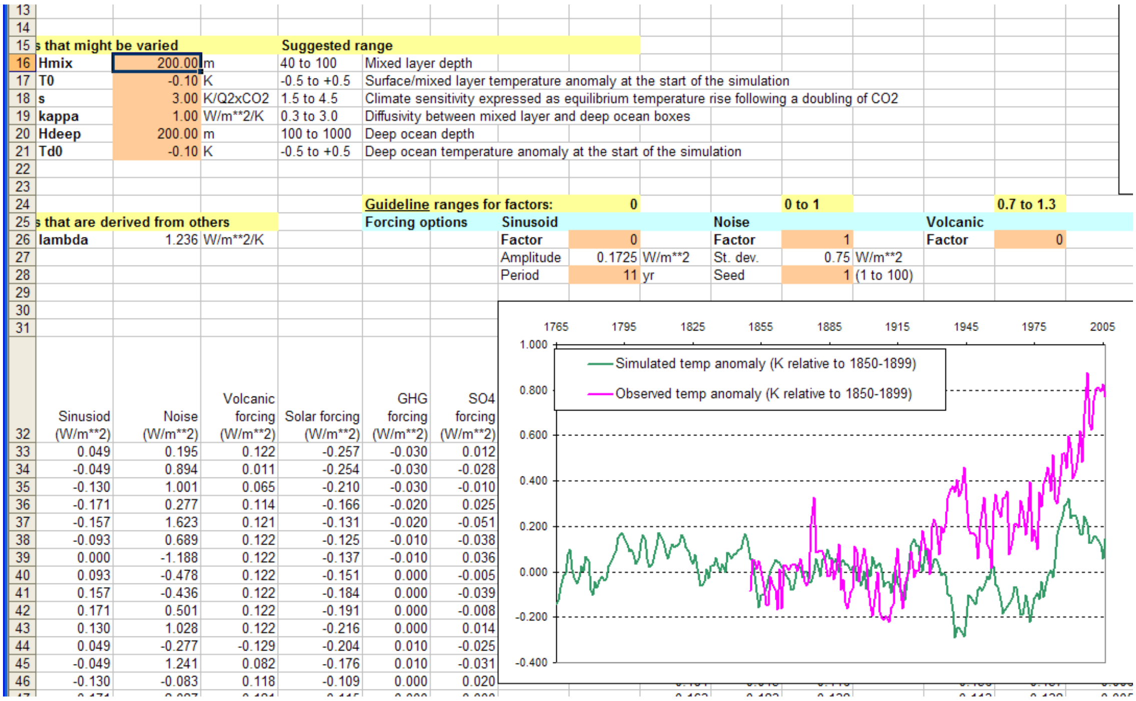
Sensitivity experiment (2)

Hints: setting all forcing factors to zero except the noise factor will result in a random sequence of year-by-year forcing fluctuations, such as those shown below. The exact sequence will depend on which random series you select; this one is for seed=1.



Learning outcome: For a mid-range climate sensitivity of 3 degC (for the equilibrium warming following a double of [CO_2]), the response to this random forcing series is shown below for two cases: a mixed-layer depth of 20 m and of 200 m. The difference in simulated temperature (green curves) is clear to see (note that the vertical scale has changed, but the pink curve is identical in each case and acts as a useful indicator of the two ranges). The 200m ocean mixed layer has a heat capacity 10 times that of the 20m ocean mixed layer and the more rapid forcing fluctuations do not last long enough to noticeably warm or cool the Earth's surface temperature in the 200m case. Forcing fluctuations that last longer, such as the sequence of positive forcings from 1983–1989, are not damped so much and drive prominent warming in the 200m case. These experiments demonstrate the importance of climate system heat capacity (which arises primarily from the oceans) in determining the strength of multi-decadal variations relative to inter-annual temperature variations.

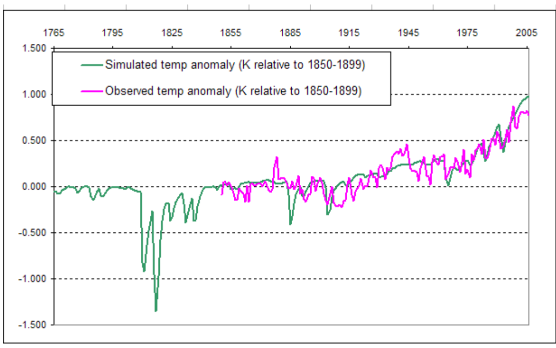


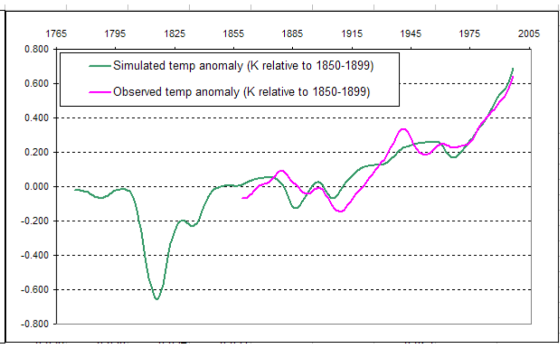


Simulation experiment (1)

Hints: set all forcing factors to 1 (volcanic, solar, GHG and sulphate aerosol factors) except that of the sine-wave and the noise which are set to zero. Set the mixed layer depth back to 60 m, diffusivity to 1 W m^{-2} K^{-1} and "deep" ocean depth to 200m. Now vary the climate sensitivity within the range 1.5 to 4.5 until you obtain a close match between the simulated (green) and observed (pink) global-mean temperatures.

Learning outcome: although there is some subjectivity in determining the best fit, values between 2 and 2.5 degC (for a doubling of [CO_2]) give a reasonable match for this particular model. The graphs below show the outcome for a climate sensitivity of 2.2 degC (for a doubling of [CO_2]). Does this mean that we can use the observed record to "tune" our model and hence diagnose the real climate sensitivity? Unfortunately the uncertainties in the forcing factors, and the influence of internally-generated variability, mean that we cannot be confident that the real climate sensitivity is close to 2.2 degC. The remaining two exercises explore this uncertainty further.

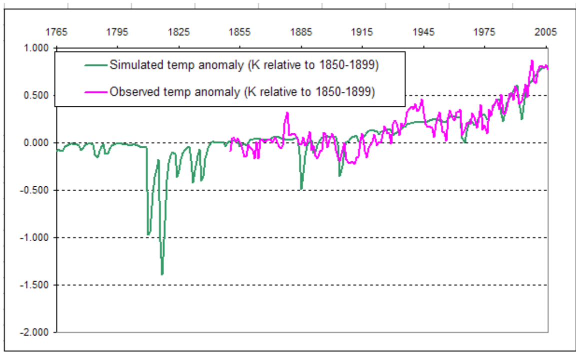


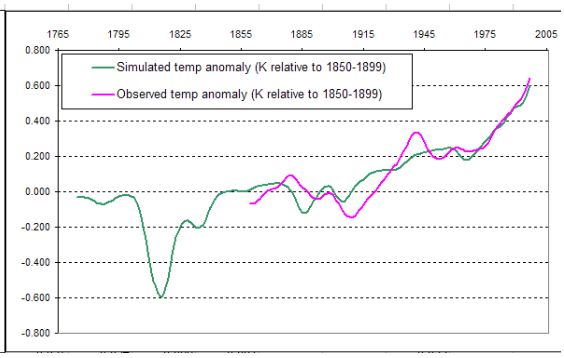


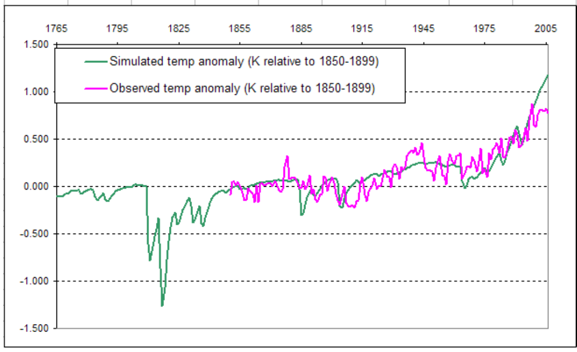
Simulation experiment (2)

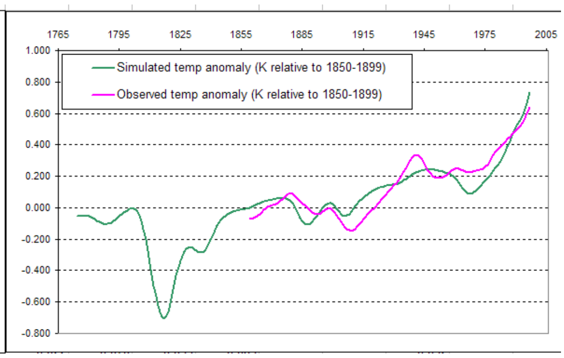
Hints: set the climate sensitivity to 1.5 degC (for a doubling of [CO_2]), and vary the forcing factors (within the guideline ranges of what is plausible, indicated on the spreadsheet) until a reasonable fit between simulated and observed temperatures is obtained. Repeat the process, having first set the climate sensitivity to 4.5 degC (for a doubling of [CO_2]).

Learning outcome: there are a range of possible solutions. In general, a good simulation of the observed warming can be obtained with lower climate sensitivity if the cooling forcing due to tropospheric sulphate aerosols is in the weaker part of its plausible range (and natural forcings are relatively strong). The example shown below was obtained with a sensitivity of 1.5 degC, solar and GHG factors of 1, sulphate aerosols factor of 0.7 and a volcanic factor of 1.2. A good simulation of the observed warming can also be obtained with higher climate sensitivity by strengthening the sulphate aerosol cooling effect, while weakening the GHG forcing (within its rather narrow uncertainty range) and the natural forcings. The second example shown below was obtained with a sensitivity of 4.5 degC, volcanic factor of 0.8, solar factor of 0.3, GHG factor of 0.95 and sulphate aerosols factor of 1.2. It should be clear that the uncertainties in the strengths of past forcings represent a significant limitation in our ability to estimate the real sensitivity of the climate system.









Simulation experiment (3)

<u>Hints:</u> set the climate sensitivity to 3.0 degC, GHG and sulphate aerosol forcing factors to zero, and volcanic and solar forcing factors to 1. Then set the internally-generated noise factor to 1, and try as many different realisations of noise as possible by typing different values (between 1 and 100) for the noise "seed" in cell M28. Do any of them result in a good fit between the simulated and observed temperatures?

<u>Learning outcome:</u> you should find that some realisations of noise make the fit between model and observations worse (e.g. seed=38), while some make it better (e.g. seed=54). It is almost impossible, however, to obtain a close fit for the post-1980 warming. Many cases do reasonably well up until 1980 (e.g. seed=25), but every single case under-predicts the final warming observed. Perhaps the best is seed=22, shown below, which simulates some of the recent warming. The implication is that, if the climate sensitivity is around 3 degC for a doubling of [CO_2], and the various other assumptions in this experiment are correct (e.g. the strength of the internal variability, as represented here by a random forcing term, and the strength of the natural forcings), then it is not possible to explain the recently observed warming without a contribution from an anthropogenic enhancement of the greenhouse effect. This type of analysis is one piece of evidence that led IPCC (2007) to conclude that "most of the observed increase in global average temperatures since the mid-20th century is very likely due to the observed increase in anthropogenic greenhouse gas concentrations".