GEOGM1405: Assignment 1

Analysing Global Climate Model Data

Deadline for submission: 14:00 Friday 28th November 2014

Background information on GCMs

General circulation models or global climate models (GCM's) are the primary tools used in predicting the future climate. GCMs represent the atmosphere and ocean systems and are based on fundamental physics, specifically Newton's Laws of Motion, the first and second laws of thermodynamics, the conservation of energy, mass, and momentum, and the ideal gas law. State-of-the-art GCMs, increasingly called Earth System Models (ESMs), incorporate sub-models that represent additional aspects of the Earth System such as the terrestrial and marine carbon cycle, the chemistry of the atmosphere and ice sheet dynamics.

Accurately solving the equations that govern the dynamic behaviour of the climate system is neither theoretically nor practically possible given current knowledge and the limitations inherent in modeling the climate system. We require vast computers that solve these equations on a grid. Current grid resolutions, constrained by computing capacity, are much too coarse (typically 100 to 250km horizontal resolution) to represent some key physical processes, such as clouds, and aspects such as the coastline and orography become distorted. As a response, "parameterisation schemes" have been developed in an attempt to represent sub-grid scale physics but the parameters chosen for such schemes are often not well constrained and this adds a layer of uncertainty to complicate our interpretation of model output. Therefore, even for a single climate model, there are a number of possible future realisations that depend on our model setup choices.

In addition to the uncertainties introduced as a consequence of how we model the climate system, we are faced with additional uncertainties arising from an imperfect initialisation (i.e. starting state) of the model and unknown future "forcings" – i.e. external factors that affect the Earth's radiative balance. The former is especially important for near-term predictions, such as seasonal to decadal forecasts. For longer predictions, particularly those for the late 21st century, the forcing uncertainty becomes dominant. We sample this uncertainty by incorporating different scenarios; the most recent IPCC assessment uses Representative Concentration Pathways (RCPs) which correspond to different levels of human greenhouse gas (GHG) emissions.

"*All models are wrong but some are useful*" (George Box, early 20th century statistician)

Any representation of the climate system is a *model* and in order to have any confidence in the model output we must evaluate whether or not the model is realistic. The "realism" of climate models depends on many factors, such as whether or not the model includes all important processes and whether or not these processes are accurately represented. An important first step in evaluating the utility of a climate model is to compare the output of hindcast simulations (i.e. simulations of the recent past) to the observed climate. However, while high skill in simulating the past and present climate is an important precursor to using the model to simulate the future climate, it is not a sufficient test; a model might poorly represent climate change processes and be too strongly constrained on the present day climate. Therefore, additional experiments are required to examine how well a model can simulate *changes* in the climate.

GCMs produce huge volumes of model output. A single GCM simulation can produce more than 1Tb of data (and can take months to run). Analysing such data rigorously requires a major research effort. Synthesising and translating the data into "usable" information is one of the most significant challenges facing climate modellers.

The Assignment

Aims

- **Investigate the reliability of hindcast simulations from a GCM**
- **Explore the climate predictions from a GCM**
- **Interpret the output of climate data and report the results**

The practical is highly structured at the start but then you have the freedom to make choices about what aspects of the model data you wish to analyse. There is a huge amount of model output to potentially examine but you will only look at a small subset. By analysing the model output, you should aim to improve your understanding of the processes important for climate change, as well as evaluate whether or not the model is successfully simulating the climate system. Ultimately this assignment provides a basis for interrogating real climate model data. Think about how such data might inform our understanding of future climate change.

Data

In this practical, you will not run a GCM to generate new data. Rather, you will examine model output from a set of already completed simulations. The data comes from different versions of the UK Met Office Hadley Centre climate model. The model data can be found at: http://www.bridge.bris.ac.uk/resources/simulations. Go to "Old System" and use the following username "course8" and password "mscepm12". The set of simulations available for analysis are as follows:

(a) **Present day conditions, atmosphere only model - "xajpa"**. Using an atmosphere only model, forced by climatological mean observed present day (1961-1990) sea surface temperatures and modern vegetation patterns, the simulation does not aim to predict ocean temperatures. Rather it uses observed ocean temperatures to constrain predictions of atmospheric variables, such as land temperatures and precipitation.

(b) **"Control" conditions, coupled atmosphere-ocean model - "xefka"**. Similar to above but using a fully dynamic ocean model so that the ocean temperatures are also predicted and here GHG concentrations are set at pre-industrial values (280 ppm) - i.e. conditions as in the year 1750.

(c) **Climate change experiments**. Finally, a set of simulations explore different levels of climate change into the future. In these simulations, CO_2 is increased to a fixed amount above that observed in the preindustrial climate. The data is taken from the resulting climate at the end of a 400 year simulation (by averaging over the period 300-400 years). Note, in the real world CO_2 changes more gradually over time and the transient response of the climate system is of utmost interest. However, for understanding the system, there is value in running these hypothetical experiments. The four sets of output are outlined below:

i.	**xefkb**	As xefka but assumes modern CO_2 concentrations (390 ppm) – the "present day" climate
ii.	**xefkc**	As above but assumes 2x pre-industrial CO_2 concentrations (560 ppm)
iii.	**xefkd**	As above but assumes 3x pre-industrial CO_2 concentrations (840 ppm)
iv.	**xefke**	As above but assumes 4x pre-industrial CO_2 concentrations (1120 ppm)

(d) **Observed data**. In addition to the model output, you are provided with two different "observed" climatology's. These are:

1. **"obslw"** - Legates and Willmott observed climatology (1951-1980) of surface air temperature and precipitation.
2. **"obsua"** - University of East Anglia observed climatology (1961-1990) of temperature and precipitation. only. This is called **obsua.**

STEP 1: Initial exploration

Carefully read the introductory webpage information: http://www.bridge.bris.ac.uk/resources/simulations.
To check that everything is working:

1.1 Select the *Part04 (CLIMATE)* page.
1.2 From the *first experiment* menu, select the Legates and Willmott observations (**obslw**).
1.3 Leave all other settings at their default value, and press the *get chart* button.
1.4 If everything is working, you should get an animation of the monthly cycle of the observed present day precipitation climatology. NOTE: the contour interval is not constant, since the tropics receive much more precipitation then mid-latitudes.

Describe the broad patterns you observe? Can you identify the names of some key climatic features, and what are the main causes/drivers of these features? Approximately, how much precipitation does Western Europe receive? How does this compare to other regions? What regions of the world exhibit the greatest seasonal variation in precipitation?

STEP 2: Comparison between observations and model output

2.1 Go to *options for second plot*, and select the experiment **xajpa**. Press the *get chart* button. After the plot has loaded, you should see two plots: observations on the left and model output on the right.

2.2 Visually comparing the two plots is a start, but a more rigorous quantitative way to compare the data is to take the difference fields (conventionally calculated as the model minus observations). In *options for first plot* select **xajpa** as the *first experiment*, and select **obslw** in the *difference with experiment* field.

2.3 It is tempting to be very critical of the model simulation but we should not forget that the observations are not perfect. To get a better idea about the magnitude of observational errors, go to the *options for second plot* and select **obsua** for the *first experiment*, and **obslw** for the *difference with experiment*.

Based on the output derived by selecting the above options, how well do you think the model simulates the observed climate? Where are the geographical regions of largest error? Are there particular regions where the errors are persistent for many months and over a large area? How well do the two different observational datasets compare? NOTE: the **obsua** data is not global coverage and, in particular, there is very little data coverage over the oceans. The output can be confusing as the same white colour denotes both missing data and small differences. You may want to take a look at the actual **obsua** data to get a better feel for the coverage and discuss the errors in this context.

2.4 Rather than relying on graphical output, you can also interrogate the numerical output. Go to *Part09 (The Numbers)*. First select **obsua** as the *experiment* and for the *time of data* field select *all months of year*. Enter your chosen longitude and latitude value in the *point value* field, and then click on *get chart*. You will get two columns, both with 12 numbers for each month of the year (starting from January). The first column displays data interpolated to your exact chosen location and the second column shows data from the nearest grid box. Make a note of the output as you may wish to cut and paste them into a spreadsheet.

Repeat the above procedure for other longitude/latitude locations, and do the same for the **xajpa** model output. Calculate the % errors for your selected locations. How do the errors vary across locations? For example, how do the errors at mid-latitude points compare to the errors at tropical locations?

STEP 3: The climate change experiment (the focus of the study!)

Now that you have some familiarity with the way that the web pages work, you can now begin looking at the coupled model climate change experiments. Analysis of these simulations forms the majority component of the assignment and reporting on the output of these experiments should be the focus of your report.

The aim of this exercise is to encourage you to utilise the web platform to examine the output from climate models. Based on your analysis of the output, you can then make some sensible deductions about how the climate is predicted to change (according to the models assessed) in a specific area of interest for a range of possible future CO_2 concentration levels.

One useful way to look at the output of the simulations is to explore the difference between the increased CO_2 simulations and the pre-industrial simulation (**xefka**); to help you, follow the procedure in 2.2 but use the coupled climate model experiments. For instance, if you are examining the 3xCO_2 simulation and want to see how much the climate has warms relative to modern day CO_2 forcing, in *options for first plot* select **xefkd** as the *first experiment* and **xefka** for the *difference with experiment*, and then choose your variable and month etc.

The Report

Write a scientific report of no more than 6 pages including all figures and text. The main text should not exceed 1,000 words. The report should detail your findings regarding the projected changes to climate in a particular geographical region of interest. Focus your analysis on the results from the coupled model predictions for the future climate change scenarios represented by experiments xefkb, xefkc, xefkd, and/or xefke. You cannot be exhaustive so focus on key results.

You are free to choose a region of the planet. Your report should include a brief discussion of the global scale climate model output and then focus on key variables that might be important in the chosen area. You should discuss the reliability of the model and the uncertainty associated with the predictions. For the purposes of this assessment, focus only on the physical climate model output. Avoid being tempted to elaborate on the potential impacts for society and Earth's ecosystems.

Some questions to consider:

- Has the climate warmed/cooled in your experiment relative to the "present day" conditions? Why?
- Where are the biggest regional differences? Why are some regions showing bigger changes than others? Are there changes to seasonality in your chosen region?
- Are the results what you expected? If not, why and how do they differ?

Carefully structure your report. Your report can include a few figures but focus only on the most relevant and do not place additional figures into an appendix. In the title or your report, please name the region of focus.

Have fun!!!