

GEOG15010 – Physical Geography

'Oceans' practical

November 2015

This practical is TWO hours long. It is not assessed but will give you the necessary knowledge to do your portfolio and the assessed practical of Biogeography (early 2016). Feel free to use the end of the hours to start on your portfolio part or to escape prior to the two hours being up if you have finished.

The practical exercises are based on a simple computer model, using (and helping reinforce) concepts introduced in the 5 Oceans lectures. You will also be making a brief comparison with a web-hosted observational dataset (the same datasets used in the lectures).

Read all of the instructions and the introduction section CAREFULLY and BEFORE attempting any of the exercises. Read the information about the model as directed. The handout might look l o n g ... but this is only so that there is sufficient information provided to help you. This is not a race to the death and there is PLENTY of time to complete the practical exercise.

If you are not completely sure whether the model has run 'correctly' – ASK.

The questions you are expected to answer are **highlighted in bold**.

As a rough guide: just a couple of sentences will generally be perfectly sufficient for answers which are indicated in the instructions as only needing to be '*brief*'. Don't forget to include units (where relevant).

Work 'individually' (i.e., one bum per computer!).

You can refer to the lecture (or other) material (on-line) if you like.

DO IT NOW!!!!

0. Introduction

- 0.1 For some of you, using numerical models of the climate system and/or global biogeochemical cycles might seem about as much fun as sticking your tongue in an electrical outlet ...

However, the model you are going to use has a relatively simple (maybe *too* simple!) graphical interface to understand configuration and comes with a graphical interface for setting up experiments and viewing the results.

In a web browser, go to: http://www.noc.soton.ac.uk/jmodels/wiki/index.php/Carbon_model

You should be looking at a page entitled 'Carbon model' (as below).

Click on: 'Launch Carbon Model'.

(If in a 'pop-up' window you are asked what you want to 'do' with the file – you want to open the file in 'Java'. ASK at this stage if you are confused and cannot make anything 'happen' ...)

You should now have the following (Carbon Model) window on your screen:

- 0.2 Click on View Model Description button and read the brief description contained there (and look at the cartoon illustration).
From the webpage, click on [Click here for a more detailed description of the carbon model.](#) and read through what is 'in' the model. Don't worry about the section on Carbon isotopes (not covered in your lectures) and don't overly worry about what 'State variables and equations' really means – at this point you are simply looking to get an overview and rough appreciation about what is in the model (i.e., how 'realistic' is it?, are all the most important processes included, and in what ways does the model configuration look or not look like 'reality'?).
The most important information you need about the model is encapsulated in the figure (RH side of the webpage) **Physical structure of the carbon model** (click on this to make it bigger). Basically, you are using a model that represents the entire global ocean as just 3 boxes – one for the surface, one for the intermediate depths, and one for the deep ocean. The only 'circulation' in the model is accomplished by mixing between the boxes. (There are also boxes for the atmosphere and the underlying sediments – again, globally averaged and lacking any spatial resolution.) Maybe this degree of spatial simplification might 'matter' (i.e., influence the predictions)?
- 0.3 In essence, this model includes many of the processes described in the lectures. Hence, by 'playing' with this model and changing some of the processes, one should be able to get a better feel for how biogeochemical cycles 'work' and how important they are (or not) to atmospheric $p\text{CO}_2$. This is one of the best uses of numerical models – improving your understanding of the Earth system (climate and global biogeochemical cycles). Numerical models are also a tool to answer 'what if ...' questions you might have (and some of the brief exercises will be doing just this).

1. Interrogating the (pre-industrial) model

- 1.0 To start off, you are going to quickly familiarize yourselves with the relevant controls and outputs of the model and assess to what extent the model is capable of representing the ‘real World’.
- 1.1 Without *changing anything* in the model: simply run it (click on the Run Model button in the main Carbon Model window). A pop-up window will open and show the model progress – it should take about 15 seconds or so to complete. (Note that the model does not solve all the equations in an instant – the solution is accomplished by taking little steps in time, one after another, and calculating the change in carbon cycle properties after each and every time step.)
When it finishes, a new Window (Carbon Model Plots) should appear containing 6 plots. There are in fact 3 pages of plots – you can move forward to the next page of plots via the Next button at the top of the screen, and back again (via Back).
NOT ALL of the plots are relevant and some show things that you have not been taught in the lectures – DON’T PANIC – you will be explicitly directed to and asked questions only on plots and properties of the global carbon cycle that have been discussed during the course.
- 1.2 First ... note that all the lines either go straight across or are almost straight – i.e., they don’t change with time (Time is on the x -axis and is in units of ky, i.e., thousands of years). This simply reflects that the initial values chosen for the various properties in the model (e.g., nutrient concentrations in the ocean boxes, atmospheric $p\text{CO}_2$) are about the same as the values reached after simulating thousands of years of nothing new happening, i.e., the model was already initial at (or close to) *steady state* (equilibrium). In the default setup of the model, it runs for 3000 years (i.e., the lines in the plots end at a value of 3.0 ky on the x -axis).
- 1.3 From the main Carbon Model control window – click on the Show Final State button. A window opens (called C_Model Final States) which provides a simple summary of some of the properties of the model reached at the end of the simulation. Again, there are several pages of values (contained in different ‘tabs’ – Summary, State Variables, and State Variables Cont), and again, DON’T PANIC – some of the ocean properties listed in this window have not been covered in the lectures and there will be no questions on these. You will be clearly directed to the properties that you should be familiar with and on which questions will be asked.
- Q1.** From the C_Model Final States window (Summary tab), **write down the value of ‘Atmospheric $p\text{CO}_2$ ’ (concentration of CO_2 in the atmosphere) in the atmosphere predicted by the model.**

Atmospheric CO_2 is 281.7327 ppm

Easy, uh? (Did you remember to include the units ... ?)

- Q2.** Now look at the model values predicted for ocean nutrient (phosphate) concentrations in the surface and deep ocean ‘boxes’ in the model – Surface $[\text{PO}_4]$ and Deep $[\text{PO}_4]$ (refer to the Summary tab of the C_Model Final States window and/or Page 1 of the Carbon Model Plots window).
State how the PO_4 concentration values differ (e.g., is one higher than the other?) and briefly explain why (i.e., what physical and/or biological process(es) is likely to be responsible for this difference)?

Surface ocean (surface box) $[\text{PO}_4]$ (0.12 mmol m^{-3}) is lower than deep ocean (deep box) $[\text{PO}_4]$ (1.09 mmol m^{-3}).
The difference is due to uptake of PO_4 by phytoplankton at the ocean surface (in the surface box), the sinking (settling by gravity) of particulate organic matter into the ocean interior (the deep box), where it is decomposed by bacteria and PO_4 released back into solution. (Ocean mixing processes then returns PO_4 back to the surface.)

1.4 Open up the following website:

<http://iridl.ldeo.columbia.edu/SOURCES/.NOAA/.NODC/.WOA09/.Grid-1x1>

In Datasets and variables, choose **Annual** and under Datasets and variables on that page, choose **phosphate**.

You are now accessing a gridded dataset (based on the observations from World Ocean Atlas 2009) of ocean phosphate concentrations, as illustrate in the lectures.

The icon View at the top of the page allow you to visualize the data. Click on it and then on the left-most coloured icon (data as colors). You should see a map of surface phosphate concentrations appear.

Q3. Contrast the model predicted surface PO_4 concentration with the observations. Note that the model gives PO_4 concentrations ($[\text{PO}_4]$) in units of mmol m^{-3} whereas the plot is in units of micromolar ($\mu\text{mol kg}^{-1}$) – these can be assumed to be equivalent (i.e., 1 mmol m^{-3} in the model is approximately 1 micromolar in the plot). **Write down which region(s) of the real World surface ocean the model seems to be best at representing. Also, (briefly) list any physical and/or biogeochemical processes that you suspect (or guess!) that the model might be missing and that might explain why it does not instead represent the PO_4 concentration in some of other regions of the ocean.** (This is in effect asking you to remember the most important reasons why surface PO_4 concentrations differ ...) Refer to the model description and schematic to remind yourselves what physical and biogeochemical processes are ‘in’ the model (and which are not).

The model ocean surface (box) best reflects the nutrient concentrations observed in the subtropical gyre (mid latitude) regions of the real ocean.

The model lacks seasonal solar forcing and hence seasonal deep water formation and deep winter mixing, it lacks iron limitation, and it lacks any representation of the Equator and hence regions of nutrient upwelling.

2. A lifeless ocean

- 2.0 Now you are ready to ‘play’ with the model, and are going to use the mode to answer the question: How would atmospheric $p\text{CO}_2$ be affected if all life died in the ocean? First close both the Carbon Model Plots and C_Model Final States windows.
- 2.1 You can alter the assumptions in the model via the Model Parameters button (in the main, Carbon Model window). You will see 7 different ‘tabs’, each with a different set of values you can change: Physical, Rivers, Organic Carbon, Phosphorous, CaCO_3 , Biological, Isotopes.

Go to Biological, and for Algal maximum growth rate set a value of 0.001 (this is sufficiently close to zero to stop life, but a value of zero is not actually allowed by the model!). By doing this, you are in effect specifying an almost zero growth rate for phytoplankton.

Click on the Apply and Close button (NOT the Close one) to get your change accepted.

Run the model (Run Model). When it finishes, a new Carbon Model Plots window will appear.

- Q4.** Either by looking at the Phosphate plot (the 3 lines represent the concentration of PO_4 in the 3 different ocean boxes as a function of time) and/or the summary values provided in the C_Model Final States window (for which you will have to click on the Show Final State button to open up), answer (*briefly*): **How do the predicted concentrations of PO_4 in surface and deep ocean now compare and why (i.e., what processes are different compared to your answer to Q2)?**

Surface ocean (surface box) $[\text{PO}_4]$ (1.87 mmol m^{-3}) and deep ocean (deep box) $[\text{PO}_4]$ (1.83 mmol m^{-3}) are now (almost) identical.

They have similar concentration of phosphate because there is no biological pump - no uptake of PO_4 by phytoplankton at the ocean surface (in the surface box), transport (settling by gravity) of particulate organic matter into the ocean interior (the deep box), and decomposition by bacteria releasing of PO_4 back into the deep ocean. With this, ocean mixing processes homogenize ocean PO_4 concentrations between the surface and the deep ocean.

- Q5.** Briefly describe how (i.e, what is the new value) and why (e.g., describe the carbon cycle process(es) that were operating in the original, default model, but are now different) atmospheric $p\text{CO}_2$ has changed

Atmospheric CO_2 is now 535.7497 ppm

As phytoplankton grow at the ocean surface they remove carbon from solution and incorporate it into their cells (as carbohydrates, fats, etc.). By subsequently dying and a proportion of this particulate organic carbon settling down through the water column before bacterial decomposition and CO_2 release into the deep ocean, CO_2 is reduced at the surface compared to in the deep ocean. Hence, when biological production stops (no biological pump in the ocean), this process that moves CO_2 from surface to deep stops. Atmospheric CO_2 then rises as the ocean mixes the higher CO_2 back to the surface (with now there being no plankton growth to draw it back down).

(refer to the Atmospheric $p\text{CO}_2$ plot and/or summary information). (“Reduced phytoplankton growth is an insufficient explanation on its own.”)

- 2.2 You can restore all the default value in the model from the C_Model Parameter window by clicking on the Default button (it does not matter which ‘tab’ of parameter values is currently displaying).

Do this now.

Also: to avoid confusion with the previous experiment, close both the Carbon Model Plots and C_Model Final States windows.

You are now going to see what happens if there is no mixing in the ocean. (In such a crude ‘box’ representation of the ocean, vertical mixing represents all the processes in the real ocean that lead to transport of salinity and carbon and other dissolved substances, e.g., wintertime convection at high latitudes, upwelling at the Equator, transport via the Atlantic Meridional Overturning Circulation, etc etc.)

In the Physical ‘tab’ of the C_Model Parameter window, under Ocean vertical mixing, set both values to 0.001 (again, for reasons best known to the programmer of the model, a value of zero is not allowed ...). Click on Apply and Close.

Re-run the model (Run Model).

- Q6.** By referring to the Carbon Model Plots and/or C_Model Final States, (*briefly*) answer the following: **What happens to Total Primary Production** (LH middle plot on the 1st page of Carbon Model Plots an) **in the ocean and why?** (Or you could look at Phytoplankton (upper LH plot), which you can take as related to the concentration of chlorophyll that you have seen maps for in the lectures. The story is much the same, either way.)

Total Primary Production falls (to near zero). This is because ocean mixing is no longer returning nutrients back to the surface.

3. Impacts of fossil fuel CO₂ release

- 3.0 Finally, you are going to get to release (fossil fuel) CO₂ to the atmosphere in the model and see what happens.
- 3.1 First off: close both the Carbon Model Plots and C_Model Final States windows.
Click on the Model Parameters button (Carbon Model window), then reset the default parameter values in the model by clicking on the Defaults button.
Close the window.
- 3.2 Click on the Add Fossil Fuels button (Carbon Model window).
Click on the On icon (in the Fossil Fuels box), then the Data icon (in the Specified According To: box).
Under Data Settings, you have the option of choosing different 'SRES' Future Emissions 2000 – 2100 CO₂ scenarios. (The SRES CO₂ emissions scenarios represent 'storylines' of development up until the year 2100. They "... describe divergent futures that encompass a significant portion of the underlying uncertainties in the main driving forces [and] cover a wide range of key "future" characteristics such as demographic change, economic development, and technological change".)
Keep the default selection of A1B.
Click on Apply and Close.
Before running the model, click on the Set Run Duration and Output Frequency button (main Carbon Model window). Set 2100 years as the Duration of run (so that the model finishes at year 2100 when the CO₂ emissions cease).
Click on Apply and Close.
Now run the model (Run Model).
From the results of this experiment, *briefly* answer the following questions (referring primarily to the plots on page 2 of the Carbon Model Plots window).

Q7. What happens to Surface pH?

Surface ocean pH falls after ca. year 1765 (to below 7.8 in year 2100).

Q8. What happens to Surface Carbonate Ion (CO₃²⁻) concentrations and why?

Q9. Why does surface Saturation State (Ω) change?

Saturation state, Ω, declines because the carbonate ion concentration declines. They are linked with the relationship: $\Omega = [\text{CO}_3^{2-}] [\text{Ca}^{2+}] / K_{sp}$

Q10. What is the main reason for the differences in the response of Deep pH and Deep Carbonate Ion change compared to surface response?

It takes hundreds of years for fossil fuel CO₂ to penetrate into the deep ocean. Hence they 'lag' in time behind surface changes.

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