ATMS/OCN/ESS 588 Global Carbon Cycle and Climate

Winter 2022

Problem Set 3 – Ocean Carbon Cycle

Overview:

You have already seen the land component of our coupled carbon cycle box model. For this problem set we will focus on the ocean component and leave the land turned off. To start, make sure you go to **`Section A`** and turn off land (set to 0) and turn on Ocean (set to 1). It should read:

```
# Choose if land and ocean should be active (1=active, 0=not active)
PS['DoOcn'] = 1 # include ocean
PS['DoTer'] = 0 # include land
```

Recall also that in Section A there is a place to give each experiment a name:

```
# Give your run a name
PS['runName'] = 'Ocean_noSol'
```

and this name is appended to all of the figures that get made (in this example a name I chose for a "No Solubility Pump" run).

The Ocean Model: A 7-box model of the ocean overturning circulation with nutrient and carbon cycles is provided, adapted from the study of [*Toggweiler*, 1999]. The ocean's meridional overturning circulation has 4 components: the thermocline is ventilated by wind-driven flow from the low latitude surface. Southern (Antarctic) and northern (North Atlantic) circulation into the deep ocean represent buoyancy-driven circulations discussed in class. An additional 2-way vertical exchange in the North Atlantic represents deep convective mixing. Surface biological productivity is parameterized by a linear function of surface nutrients, and extracts carbon in a fixed carbon:nutrient ratio (Rcp). The implied organic matter is then decomposed among underlying boxes. The alkalinity cycle is currently not represented. A diagram of the ocean box model and the equations governing it are at the end of this assignment.

Running the model:

To run the model you will, as before, specify some parameters and choose "Restart & Run all" from the "Kernel" menu. – for this problem set all parameters that you need to change are in **`Section A`**.

You are going to change two parameters by modifying a scaling factor. These are at the bottom of **`Section A`**. The two parameters are the piston velocity, kw, and Psi, the flux rate of water between boxes in our model. Remember that Psi is listed in Sverdrups (10^6 m^3/s), a convenient unit for tracking large scale flow in the ocean.

You will also change a number of switches (0=off, 1=on) to turn on and off different ocean components.

Problems:

1) We'd like to understand the uptake of anthropogenic CO_2 by the ocean. Specifically, let's find out which factor is most important in determining the rate of ocean CO_2 uptake - gas exchange or ocean circulation?

a. Run the model with the land component turned off (DoTer=0) and ocean turned on (DoOcn=1). The increase in ocean and atmospheric CO_2 (due to fossil fuel emissions) will automatically be plotted, as will the DIC for several ocean pools. Note the magnitude of the changes. Where is most of the anthropogenic CO_2 found (i.e. the increase over time due to fossil fuels)?

b. Now run the model with gas exchange that is faster or slower by a factor of 2. You can do this by changing the piston velocity (kw) by 2, using the "`kwScalar`" parameter in **`Section A`**. Note the new uptake rates. How much do they differ from the first case?

c. Repeat steb b, but reset the piston velocity to its initial value and instead change the circulation rates (Psi) by a factor of 2 using the "`PsiScalar`" parameter in **`Section A`**. You can also try turning circulation off entirely by setting `PS['DoOcnCirc'] = 0`.

d. Explain in simple terms why you got the answer that you did. You should consider the time it takes a surface "box" to equilibrate its CO_2, and compare that to the time that waters spend in that box.

2) We'd like to understand the relative importance of solubility and biology in creating the vertical variation of DIC in the ocean. We'll take the DIC difference between the deep ocean and the surface ocean in low latitudes as a measure of the strength of these "carbon pumps".

a. Run the model with the land component turned off (`PS['DoTer']=0`) and ocean turned on (`PS['DoOcn']=1`) and note the magnitude of the vertical DIC gradient in the ocean. How does it compare to what is observed? (We mostly want to know that the simple model is in the right ballpark, but if you'd like to think about reasons for discrepancies, that could be instructive). A plot of the vertical profile of DIC is included after the model diagram.

b. Now run the model with the biological pump turned off. This can be done by setting `PS['DoOcnBio']=0`, in **`Section A`**. (This just sets the uptake of nutrients to 0). What is the strength of the DIC gradient, and what does it represent?

c. Now run the model with the solubility pump turned off. This can be done by setting `PS['DoOcnSol']=0`, in **`Section A`**. (This sets the surface temperature and salinity in every box to the global average, so there are no variations in solubility). What is the strength of the DIC gradient, and what does it represent?

d. What fraction of the additional carbon storage in the deep ocean is due to biology, and what fraction is due to solubility? How does your answer compare to what we saw in class lectures based on complex ocean general circulation models (last figure on following page)?

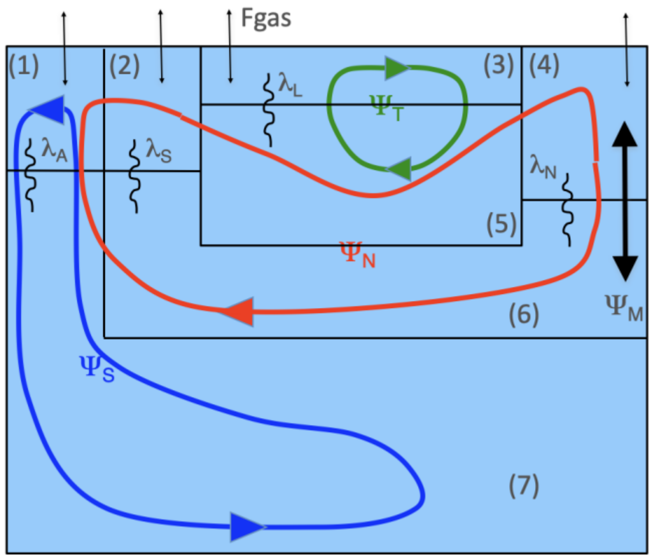
Model structure:

The ocean model predicts the distribution of 3 variables: nutrient concentrations (phosphate, P), dissolved inorganic carbon (C), and temperature (T, these are anomalies from a background mean state that is prescribed). Each variable is predicted in each box (i) according to a set of equations for the rate of change in that box:

$$V_i \frac{dT_i}{dt} = \sum_j \Psi_{ij} \Delta T_{ij} + RF - \lambda T_i$$

$$V_i \frac{dP_i}{dt} = \sum_j \Psi_{ij} \Delta P_{ij} - \lambda_i P_i$$

$$V_i \frac{dC_i}{dt} = \sum_j \Psi_{ij} \Delta C_{ij} - R_{cp} \lambda_i P_i + F_{GASX}$$



1=Antarctic
2=Subantarctic
3=Low latitude surface
4=North Atlantic surface
5=Thermocline
6=NADW
7=AABW (+NPDW)

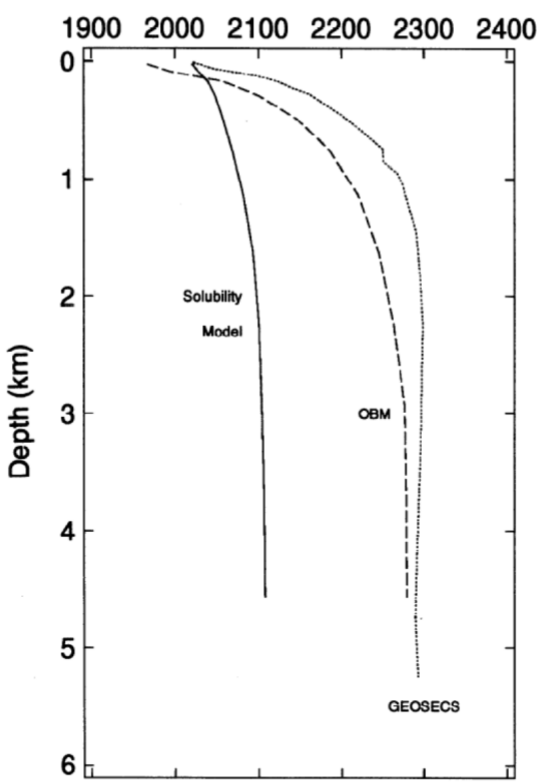


Figure 4 from Murnane et al. 1999, Global Biogeochemical Cycles: Global average DIC([umol kg-l) profiles for the preindustrial solubility model and Ocean Biogeochemistry Model (OBM) and for an average of Global Ocean Sections Study (GEOSECS) analyses.