 Consider the ocean as being made up of three well-mixed boxes: a “warm surface” box at low latitudes, a “cold surface” box at the highest latitudes of both hemispheres, and a “deep” box isolated from contact with the atmosphere. Above the ocean is a single well-mixed atmosphere with a mean surface pressure of 101325 Pascals. The atmosphere receives CO2 from fossil fuel (*FF*), which is assumed to instantly mix with the whole mass of the atmosphere. The surface boxes exchange CO2 (*FW* and *FC*) with the atmosphere but the deep box only interacts with the surface boxes and does not exchange CO2 with the atmosphere.

Let there be a slow thermohaline overturning circulation *T* = 20 Sv and let there be a constant net downward biological carbon flux (*BW* and *BC*) from each surface box that represents sinking organic particles.

Assume that the ocean covers 70% of the Earth’s surface, and that 85% of the ocean surface is “warm” while 15% of the ocean surface is “cold.” Let the warm ocean have a temperature of 21.5 **°**Cwith a mean wind speed of 5 m s-1 and the cold ocean have a temperature of 1.5 **°**C with a mean wind speed of 12 m s-1. Assume that the ocean is 4000 m deep, that the warm surface layer is 75m deep, and that the cold surface layer is 250 m deep.

Initialize the model for preindustrial conditions as we did in homework #3, with salinity = 34.78‰, pCO2 = 278 ppm, average surface DIC = 2002 mmol kg-1 and average Titration Alkalinity = 2311 mmol kg-1. You will need to adjust DIC in each surface box to get a preindustrial pCO2 = 278 ppm because their temperatures are so different. Initialize the deep ocean with DIC = 2288 mmol kg-1.

**WARNING: keeping track of the units in this model is critical and difficult! I suggest you stick to “mks” units (meters, kilograms, seconds) throughout the arithmetic, and only change to more useful units (like GtC/yr) for diagnostic output.**

[Continued on page 2]

1. Write a system of ordinary differential equations for the time rate of change of the mass of carbon in each box. You will have four equations: one for each ocean box and one for the atmosphere.
2. Write expressions for *BW* and *BC* that allow your model to achieve steady state under preindustrial conditions by balancing the mass of carbon in each box. Solve for the actual values of these fluxes (in kg C per second).
3. Write expressions for the air-sea gas exchange fluxes (*FW* and *FC*), in terms of the “piston velocity,” wind speed, and difference in pCO2 between the water and the overlying air.
4. Discretize your model by replacing the time derivative terms on the left-hand side of each equation with a finite difference D/D*t*. Plug in some numbers and verify that you have a balanced steady state when the atmospheric CO2 is 278 ppmv and the fossil fuel emissions (*FF*) are zero.
5. Download a file of historical and projected future fossil fuel emissions in GtC/yr form the class website for the years 1800 – 2300.
6. Run your model forward in time starting with your steady-state initial conditions in 1800 up through the year 2300. Use a time step of 1 year, but remember to convert to seconds in your calculations!
7. Turn in the following:
   1. your model code
   2. plot of fossil fuel emissions from 1800 – 2300 (GtC/yr)
   3. a graph of the net uptake of fossil fuel by the oceans (GtC/yr)
   4. a graph of atmospheric CO2 (ppmv)

**NOTE: This assignment is hard!**

I will be available to help you both indivudally and in groups, and I will be posting my solution as a toy model on the class website. You are encouraged to work in groups on this, and to copy-paste from my code as you wish. You will need your code from Assignment #3 to do this, and you will need the code you write here for the final assignment in which we put air, ocean, and land carbon together in a single model!