**Semester 1 Final Project: Modeling The Carbon Cycle and Climate Change.**

Name\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ Name \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

Name\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ Name \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

# 1. Background information

In this final project of the semester, you will experiment with a difference equation “compartment” model of the short-term carbon cycle, implemented as an Excel spreadsheet. This aims to capture some of the key features of the real-world short-term carbon cycle we have discussed in class. However, a disclaimer is certainly in order here: This is definitely a “toy” model that is much simpler than the climate models that scientists are currently using to try to understand the evolution of the Earth’s climate under the influence of anthropogenic sources of atmospheric CO2. For that reason*, you should not take any of the computed values as especially realistic predictions*. However, the results are suggestive, and the ideas used here are similar to what scientists are doing in this area (though on a much smaller scale) .

## 2. Getting started – understanding the spreadsheet

The spreadsheet file can be downloaded from the course homepage via the link for this assignment. It is called *ShortTermCarbonCycleModel.* Save on your computer andopen this file using Excel. Look over the organization. You will see that the first group of columns corresponds to the various reservoirs of carbon that we discussed in class on November 16:

## Column B – the year starting with 0 corresponding to 1990

## Column C – the mass of the carbon content of the atmosphere (in Gt)

## Column D—the mass of the carbon content of the terrestrial biosphere (in Gt)

## Column E –same for the surface ocean

## Column F – same for the deep ocean

## Column G – same for the soil

The next group of columns corresponds to the major fluxes between these reservoirs – gas exchange between the surface ocean and atmosphere, ocean upwelling and downwelling, respiration, death, decay, FFB = fossil fuel burning, de/re-forestation, photo=photosynthesis, and the ocean “biopump.” The important “outputs” are

* **Column Q** – the predicted atmospheric CO2 concentration in ppm
* **Column S** – an estimated global average temperature in degrees C

The numerical values in Row 3 are *initial conditions* derived from estimates of the various quantities in the year 1990 (with two key exceptions – see below). The contents of the cells in the subsequent rows *are formulas* that compute that quantity from the information for the previous year using the difference equation model we discussed in class. If you make a change in one of the initial conditions or change a formula, all the values in the spreadsheet will be recomputed to reflect the updated information.

When you download the spreadsheet you will notice that all the entries in columns N (fossil fuel burning) and O (de/reforestation) are zero.

1. What are the final CO2 concentration and temperature in year 50? What do you notice about the contents of all the columns in this case where there is essentially no human fossil fuel burning and no changes in human land-use leading to deforestation (or reforestation)? How realistic is this given what we know about the real history of CO2 levels over periods of 100’s or 1000’s of years (not over longer periods)?

2. Now let’s factor in what has really been happening with fossil fuel burning and deforestation.

1. As we said in class, in 1990, about 6 Gt of C was emitted into the atmosphere from fossil fuel burning. And in fact, from 1990 to 2008, fossil fuel burning was actually increasing by about 2.2% per year. Work out the appropriate *exponential* model for this by hand and enter here

FFB = (\_\_\_\_\_\_\_) (\_\_\_\_\_\_\_\_\_\_\_\_\_)^(years since 1990)

1. Next, the amount of C added to the atmosphere by deforestation was 1.64 Gt in 1990, but it had decreased to 1.20 Gt by 2008. Let’s be optimistic and assume that this trend will continue linearly (at least over the 50 years) covered by our spreadsheet model. Work out the appropriate *linear* model by hand and enter here:

De/reforestation = ( \_\_\_\_\_\_\_\_\_\_ )(years since 1990) + (\_\_\_\_\_\_\_\_\_\_\_)

1. Next, let’s incorporate these into our overall carbon cycle model. To do this, start by entering the initial value 6 in cell N3 and the initial value 1.64 in cell O3.

Then in cell N4 enter the formula

=$N$3\*(your multiplier value from part a)^B4

Copy and paste this formula into the other entries in column N (all the way down to the row for year 50). You should see all the other entries in the spreadsheet update when you do this. (*Technical note*: If you examine the contents of one of the cells you just pasted into, you will see that the formula *is not* the same as what you copied from – the row numbers will have been shifted to match the row you were pasting into in each case. That *is* what we want here, because we want to be using value from the corresponding row in column B in the formula each time. Excel uses what is called *relative addressing* of the cells in spreadsheets to make this sort of thing possible. But note also that there are times when we *do not* want that kind of shifting to be done. For instance, we always want the initial value 6 from cell N3 to be used in the exponential model formula. That is what the $N$3 does – the dollar signs say to Excel, “use the fixed cell N3 each time and do not shift the row number.”)

Now do something similar in Column O. You will need to enter a formula for the deforestation carbon contribution using your slope and intercept values from part b. In this case, you will use the entries from Column B as the years, and the same sort of shifting by relative addressing is what you want here too.

1. What are the final CO2 concentration and temperature now? How do those compare with the values from 1 above?
2. Also, how are the Terrestrial Biosphere values from Column D changing over the years? Does this make sense? (Recall that deforestation would remove trees and other plants and add their carbon to the atmosphere by way of burning. But more CO2 in the atmosphere also tends to promote the growth of surviving plants, at least to an extent, because of photosynthesis).

## 

Look at the temperature predictions in Column S. We can ask*: How do those predicted values depend on the year*? To answer this, fit linear, exponential, and power law models for Column S versus Column B (starting in row 4). Record the fitted equations in each case here and decide which one gives the best fit.  
  
  
  
 Linear: Temp = (\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_) (years since 1990) + (\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_)  
  
  
  
  
  
Exponential: Temp = (\_\_\_\_\_\_\_\_\_\_\_\_) (\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_)^(years since 1990)  
  
  
  
  
  
Power Law: Temp = (\_\_\_\_\_\_\_\_\_\_\_\_\_\_) (years since 1990)^(\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_)  
  
  
  
  
g) Finally, you are probably wondering just how the predicted global average   
temperatures are computed. To see, examine the contents of cells S4, S5, etc. What kind of model is being used here for the dependence of temperature on CO2 concentration? (*Note:* whether or not this is a reasonable model of how this works over decade time scales is controversial, and this toy model *does not* try to take into account how some of the fluxes between different carbon reservoirs *might depend on the temperature*. That is, you will see that none of the formulas for Columns H-M or R depend on the entries in Column S.)

3. What is past is past and we cannot change it. But we can use a model like the one incorporated in this spreadsheet to try to evaluate the effects of changes we might make in the future. For instance, we might ask: Suppose we were able to scale back fossil fuel burning to a constant level of 5.7 Gt per year and end all deforestation today. What would happen? To see, make all of the entries in columns N and O for years starting in 2012 equal to 5.7 Gt (this was the global target level established by the Kyoto Protocols in 1997). What does the model predict about CO2 concentration and temperature in 2041?   
  
  
  
  
  
  
  
  
  
  
  
  
  
  
  
  
What if continue the model into the future? Does the temperature look like it will ever return to current levels? If so how long does it take? (*Note:* To run the model over further years just copy all of the entries on row 53 in Columns B through S and paste them into the corresponding entries in any number of rows after 53.)

What is the largest constant (nonzero!) level for fossil fuel burning starting in 2012 that would yield decreasing atmospheric CO2 levels by the year 2100? (This will require some experimentation!)