Simple Climate Model Extension

Simple Climate Model Goals

1) Introduce the Simple Model
   - -Discuss Climate Sensitivity
   - -Discuss how the carbon cycle influences the Model
2) Calibrate the Model to historical data
3) Look at future emission scenarios with the Model

The Math

$$T = T_0 + S \log_2 \left(C / C_0 \right)$$

- where, T = the new or current temperature
- T_0 = the temperature at some reference time
- S = the climate sensitivity factor (the temperature rise as a result of CO_2)
- C = the new or current temperature
- C_0 = the known atmospheric CO_2 concentration at some reference time

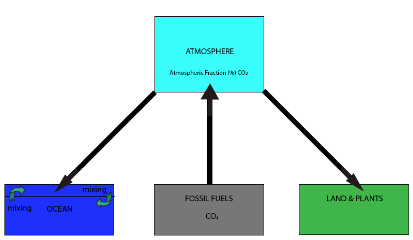
The Math

Example: CO_2 concentration in 2000 = 368 parts per million (ppm)
Average global temperature in 2000 = 14.3°C (57.7°F)

If the global CO_2 concentration increased to 600ppm, what temperature change could you expect?

T=14.3°C +[3°C * $\log_2$(600ppm/368ppm)]= 14.3°C +2.1°C=16.4°C

Simplified Carbon Cycle

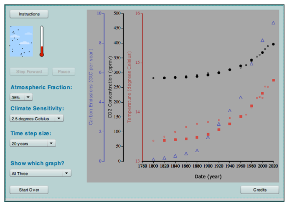


The Model

- The Past: http://eo.ucar.edu/staff/rrussell/climate/modeling/co2_climate_model_calibrate.html
- The Future:
  http://eo.ucar.edu/staff/rrussell/climate/modeling/co2_climate_model.html

The Model

- Historical Carbon Emissions △
- Historical CO_2 Concentration ●
- Model CO_2 Concentration ●
- Historical Temperature □
- Model Temperature ■



- Explore the Model
- Move to the worksheet . . .

The Past: Historical Data

- CO_2
  - Calibrate by adjusting the Atmospheric Fraction
  - Atmospheric Fraction is the percentage of CO_2 that remains in the atmosphere after fossil fuel emissions (the remaining percentage goes into the ocean and land)
- Temperature
  - Calibrate by adjusting the Climate Sensitivity
  - Climate Sensitivity measures how responsive the temperature of the climate system is to changes (i.e. a doubling of CO_2 concentration)

The Model

- The Past:
  http://eo.ucar.edu/staff/rrussell/climate/modeling/co2_climate_model_calibrate.html
- The Future:
  http://eo.ucar.edu/staff/rrussell/climate/modeling/co2_climate_model.html

The Future: Emissions Scenarios

- The International Panel on Climate Change (IPCC) has done many climate models runs based on different future fossil fuel scenarios.
- http://eo.ucar.edu/staff/rrussell/climate/modeling/ipcc_sres_scenarios.html
- We will pick a High, Medium, and Low emissions scenario to run on our model

The Future: Use the Model

- High: Set “Carbon Dioxide Emissions” to 18 Gt/year
- Medium: Set “Carbon Dioxide Emissions” to 11 Gt/year
- Low: Set “Carbon Dioxide Emissions” to 4 Gt/year

The Future: Use the Model

- Try a scenario where emission increase until mid-century and decrease thereafter . . .
- What do you see?!?

A Simple Climate Model - Worksheet

Part 1: The Past

This portion of the activity is focused on exploring past observations and calibrating the climate model to those observations.

1.) Use a computer with internet access and open up a web browser (Safari, Mozilla Firefox, etc.).

2.) Go to:
http://eo.ucar.edu/staff/rrussell/climate/modeling/co2_climate_model_calibrate.html

3.) Note the description of the different colors and shapes on the graph.

- Blue Triangle: carbon emissions - how much carbon we add to the atmosphere each year
- Black Circle, Hollow: historical, measured CO_2 concentration – how much carbon has accumulated in the atmosphere
- Black Circle: model CO_2 concentration – the accumulation of carbon the model predicts
- Red Square, Hollow: historical, measured temperature
- Red Square: model temperature – the global temperature the model predicts

CO_2 Emission Rate

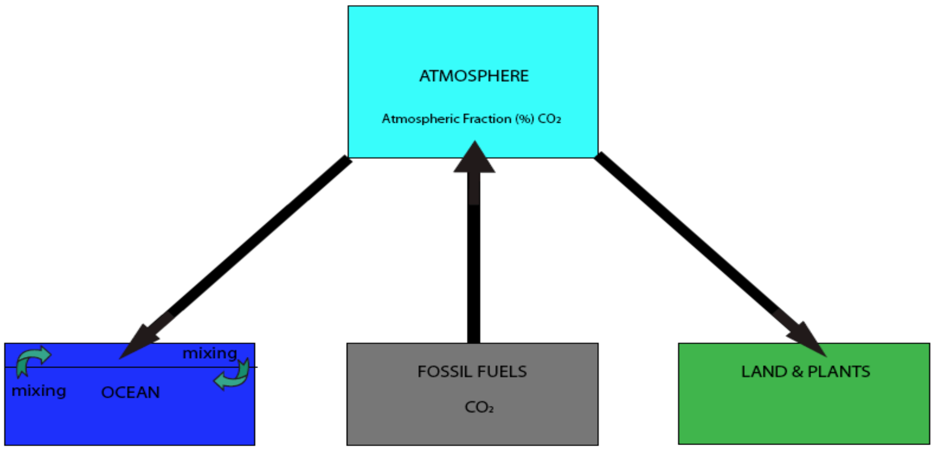
4. Switch temperature to Fahrenheit in the drop down menu at the bottom of the model. You may leave time step size at 20 years for the entirety of this exercise.
5. Select "CO_2 Emission Rate" under the "Show which graph?" menu (lower left).
6. Click play and watch the actual, historical, measured CO_2 emissions from 1800-2010 appear.

CO_2 Concentration

7. Click "Start Over" (lower left).
8. Select "CO_2 Concentration" under the "Show which graph?" menu (lower left). The actual, historical, measured CO_2 concentration from 1800-2010 should be visible on the graph.
9. Click play and watch the model results for CO_2 concentration appear.
10. Note that the two sets of data do not match. You can fix this by calibrating the model!

Calibrate the Model – CO_2 Concentration
11. Click “Start Over.”
12. To calibrate the model to match CO_2 concentration you must change the “Atmospheric Fraction” (drop down menu underneath the “Play” button) to a value other than 100% and click “Play.”

The “Atmospheric Fraction” indicates how much CO_2 remains in the atmosphere after fossil fuel emissions (with the remainder residing in the ocean and land).



Which “Atmospheric Fraction” did you first decide to try? Was it a good match?

13. Repeat steps 11 and 12 until you find the best possible match.

Which “Atmospheric Fraction” gives you the closest match?

Leave your model at this value. You have now calibrated the model for CO_2 concentration!

Temperature
14. Click “Start Over.”
15. Select “Temperature” under the “Show which graph?” menu (lower left).
16. Click play and watch the model results for Temperature appear.
17. Note that the two sets of data do not match. You can fix this by calibrating the model again!

Calibrate the Model – Temperature
18. Click “Start Over.”
19. To calibrate the model to match Temperature you must change the “Climate Sensitivity” (drop down menu underneath the “Atmospheric Fraction” menu) to a value other than 3°C and click “Play.”

Climate Sensitivity measures how responsive the temperature of the climate system is to changes (i.e. a doubling in CO_2 concentration). Which "Climate Sensitivity" did you first decide to try? Was it a good match?

20. Repeat steps 18 and 19 until you find the best possible match.

Which **"Climate Sensitivity"** gives you the closest match?

Leave your model at this value. You have now calibrated the model for Temperature!

Part 2: The Future

This portion of the activity is focused on exploring future possible emissions scenarios using our calibrations from above.

1. Go to:
http://eo.ucar.edu/staff/rrussell/climate/modeling/co2_climate_model.html

2. This is the same model that we used for past observations; however, we are now looking into the future. Note the time scale (x-axis) has changed (we are now looking at 1990-2110 rather than 1800-2010) and we can now change the carbon dioxide emissions into the future (see the slide ruler). We can also now choose any combination of graphs by checking or unchecking the boxes next to CO_2 Emission Rate, CO_2 Concentration, and Temperature.

3. Switch temperature to Fahrenheit in the drop down menu at the bottom of the model. You may leave time step size at 5 years for the entirety of this exercise. Once you feel more comfortable with this model feel free to change it around.

4. Before you start running this model make sure to adjust it to your calibrations from Part 1. Click on "Change Settings" in the bottom left hand corner. Please leave the "Natural Rate of Decline of CO_2" at 0.1% per year, but make sure to adjust the "Climate Sensitivity" and "Ocean Absorption Rate" to your values from Part 1.

> **Note: The value listed here is "Ocean Absorption Rate" and not "Atmospheric Fraction." To account for the change please enter (100% – "Atmospheric Fraction") as your "Ocean Absorption Rate." For example, if you found an "Atmospheric Fraction" of 90% in Part 1 you would now enter an "Ocean Absorption Rate" of 10%.

5. Experiment with changing the carbon dioxide emissions. Pick a value for "Carbon Dioxide Emissions" and click "Play." The CO_2 Concentration and Temperature resulting from the Carbon Dioxide Emission value you chose will be displayed.

Let's do some exercises as a group. We'll designate three different emissions scenarios: Low, Medium, and High. Current carbon emissions are estimated at ~9 Gigatons of carbon per year (a gigaton equals one billion tons).

<u>High</u>

6. Click "Start Over."
7. This scenario assumes high economic growth and increased fossil fuel usage into the future. Set the Carbon Dioxide Emissions to 18 Gt/year. Click "Play."

What do you see?

Medium
8. Click “Start Over.”
9. This scenario assumes a steady economic growth and slightly increased fossil fuel usage into the future. Set the Carbon Dioxide Emissions to 11 Gt/year. Click “Play.”

What do you see?

Low
10. Click “Start Over.”
11. This scenario assumes decreased fossil fuel usage into the future (half of current). Set the Carbon Dioxide Emissions to 4 Gt/year. Click “Play.”

What do you see?

Thought Experiment
12. Click “Start Over.”
13. We can change emissions as the model runs. Attempt running the model with increasing emissions until mid-century. I.e. set the Carbon Dioxide Emissions as 11 Gt/year (medium) and then when the model reaches ~2050 drop the emissions to 4 Gt/year (low).

*Note: If you would like more precise control over when the emissions change you can use the “Step Forward” button as opposed to “Play.”

What do you see?

SIMPLE CLIMATE MODEL – Extra Information

What is a Climate Model? Computer models use math to describe how the earth works. They can describe how different elements of the Earth system (atmosphere, ocean, land, biosphere, ice, and energy from the Sun) affect each other and Earth's climate. The more complex models include a lot of calculations. For example, the Community Climate System Model used by the National Center for Atmospheric Research (NCAR) requires roughly three trillion calculations to simulate one day on Earth. These types of models are run on supercomputers and can take thousands of hours to complete.

For more information on Climate Models, see the *Windows to the Universe* webpage from the National Earth Science Teachers Association:

"What is a Climate Model?"
http://www.windows2universe.org/earth/climate/cli_models2.html

"How Climate Models Work"
http://www.windows2universe.org/earth/climate/cli_models3.html

"Accuracy and Uncertainty in Climate Models"
http://www.windows2universe.org/earth/climate/cli_models4.html

The Math

The Simple Climate Model is used to look at the relationship between average global temperature and carbon dioxide emissions.

$$T = T_0 + S \log_2 \left(C / C_0 \right)$$

where, T = the new or current temperature

T_0 = the temperature at some reference time

S = the climate sensitivity factor (the temperature rise as a result of CO_2 – a value has been estimated through research)

C = the new or current temperature

C_0 = the known atmospheric CO_2 concentration at some reference time

T_0 and C_0 should be from the same reference time, i.e. the year 2000

If you know the concentration, or have a good estimate of what the CO_2 concentration will be in the future, you can calculate Earth's temperature!

Example: CO_2 concentration in 2000 = 368 parts per million (ppm)
Average global temperature in 2000 = 14.3°C (57.7°F)

If the global CO_2 concentration increased to 600ppm, what temperature change could you expect?

$T=14.3°C +[3°C * \log_2(600ppm/368ppm)]= 14.3°C +2.1°C=16.4°C$

The Online Simple Climate Model includes these Symbols

- Blue Triangle: carbon emissions - how much carbon we add to the atmosphere each year
- **Black Circle, Hollow:** historical, measured CO_2 concentration – how much carbon has accumulated in the atmosphere
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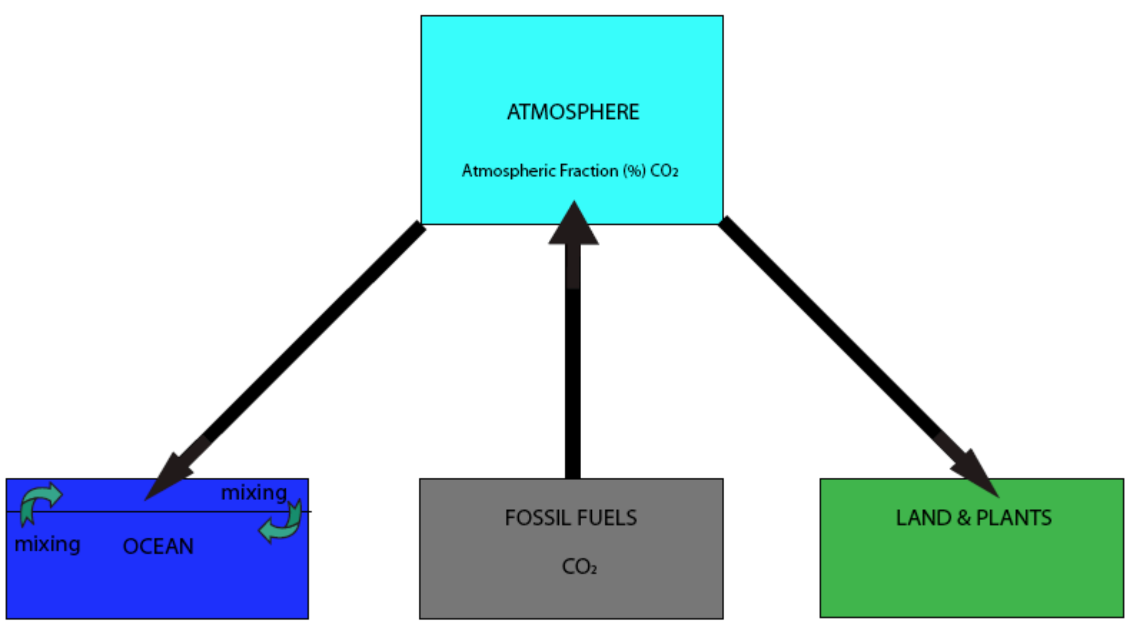
The Values we generally use with the Simple Climate Model

*Current best estimates of Climate Sensitivity (S) from the Intergovernmental Panel on Climate Change = 2-4.5°C, with a best estimate of 3°C.

*Current best estimates of Atmospheric Fraction = 35-40%.



Main Points

*Earth's temperature depends on the concentration of CO_2, which depends on CO_2 emissions.

*Cutting emissions completely will not cool the planet, it will only stop things from getting worse.

*Lowering the rate of emissions increases will not cool the planet either. It will only slow the rate of warming.

Other Helpful Simple Climate Model Links

- Activity Write-Up: http://eo.ucar.edu/staff/rrussell/climate/modeling/co2_climate_model_activity.html
- Test Drive the Climate Model: http://eo.ucar.edu/staff/rrussell/climate/modeling/co2_climate_model_test_drive.html
- Climate Modeling Education Resources: http://eo.ucar.edu/staff/rrussell/climate/modeling/climate_modeling.html