Atmo Sci **Name:**

Very Simple Climate Model
Activity

Introduction

As noted on climate.gov, "models help us to work through complicated problems and understand complex systems. They also allow us to test theories and solutions. From models as simple as toy cars and kitchens to complex representations such as flight simulators and virtual globes, we use models throughout our lives to explore and understand how things work."

Climate models are based on well-documented physical processes to simulate the transfer of energy and materials through the climate system. Climate models, also known as general circulation models or GCMs, use mathematical equations to characterize how energy and matter interact in different parts of the ocean, atmosphere, land. Building and running a climate model is a complex process of identifying and quantifying Earth system processes, representing them with mathematical equations, setting variables to represent initial conditions and subsequent changes in climate forcing, and repeatedly solving the equations using powerful supercomputers.

Climate models separate Earth's surface into a three-dimensional grid of cells. The results of processes modeled in each cell are passed to neighboring cells to model the exchange of matter and energy over time. Grid cell size defines the resolution of the model: the smaller the size of the grid cells, the higher the level of detail in the model. More detailed models have more grid cells, so they need more computing power.

Once a climate model is set up, it can be tested via a process known as "hind-casting." This process runs the model from the present time backwards into the past. The model results are then compared with observed climate and weather conditions to see how well they match. This testing allows scientists to check the accuracy of the models and, if needed, revise its equations. Science teams around the world test and compare their model outputs to observations and results from other models.

Using Scenarios to Predict Future Climate

Once a climate model can perform well in hind-casting tests, its results for simulating future climate are also assumed to be valid. To project climate into the future, the climate forcing is set to change according to a possible future scenario. Scenarios are possible stories about how quickly human population will grow, how land will be used, how economies will evolve, and the atmospheric conditions (and therefore, climate forcing) that would result for each storyline.

In 2000, the Intergovernmental Panel on Climate Change (IPCC) issued its Special Report on Emissions Scenarios (SRES), describing four scenario families to describe a range of possible future conditions. Referred to by letter-number combinations such as A1, A2, B1, and B2, each scenario was based on a complex relationship between the socioeconomic forces driving greenhouse gas and aerosol emissions and the levels to which those emissions would climb during the 21st century. The SRES scenarios have been in use for more than a decade, so many climate model results describe their inputs using the letter-number combinations.

In 2013, climate scientists agreed upon a new set of scenarios that focused on the level of greenhouse gases in the atmosphere in 2100. Collectively, these scenarios are known as Representative Concentration Pathways or RCPs. Each RCP indicates the amount of climate forcing, expressed in Watts per square meter, that would result from greenhouse gases in the atmosphere in 2100. The rate and trajectory of the forcing is the pathway. Like their predecessors, these values are used in setting up climate models.

Source: https://www.climate.gov/maps-data/primer/climate-models

Using the Very, Very Simple Climate Model

This climate model is very simple. It knows nothing of changing wind or precipitation patterns that might accompany and in turn influence warming; it doesn't care where in the atmosphere the CO2 is; it ignores other greenhouse gases; and so on. In this simple model, the temperature is determined entirely by the atmospheric CO2 concentration via greenhouse warming of the atmosphere.

While the assumptions behind this model are limited, they are valid. The starting values for concentration, emission rate, and temperature are the actual values for the year 2015. The relationship between atmospheric CO2 concentration and temperature uses a well-established relationship; basically, temperature rises about 3° C for each doubling of CO2 concentration (the climate change sensitivity).

Learning Outcomes

- Students understand the impact of atmospheric carbon dioxide on Earth's global average temperature.
- Students understand that the amount of carbon dioxide in the atmosphere rises whenever emissions are greater than zero.
- Students understand how changes in the rate of carbon dioxide emissions impact the amount of carbon dioxide in the atmosphere and global average temperature.
- Students read and interpret graphs of data.
- Students develop an investigation using a model.
- Students present the results of an investigation to their peers.

You will seek to answer this question: *How will the amount of carbon emissions released into the atmosphere affect the climate during this century?*

Model Details

- The carbon dioxide emissions rate is measured in gigatons of carbon dioxide per year.
- The emissions rate is initially set at 10.5 gigatons of carbon per year, which was the actual rate during 2015.
- The climate change sensitivity is initially set at 3 °C. The climate sensitivity represents the amount of temperature change estimated to occur when carbon dioxide doubles. There is some uncertainty about how the climate system will behave as carbon dioxide increases, so scientists test models with different climate sensitivities.
- The recommended temperature limit line (15.81 °C) reflects 2 °C of warming above pre-industrial times, after which scientists predict life on Earth will be significantly impacted and it will be difficult to adapt.

And

- The blue circles (emissions rate) represent how much carbon we add to the atmosphere each year. Since the rate stayed the same for this model run, the blue circles form a horizontal line on the graph.
- Black triangles represent how much carbon accumulates in the atmosphere over time. Units are "parts per million by volume" (ppmv). For reference, the actual concentration was 399.4 ppmv in the year 2015. In this run, the concentration rises from just under 400 ppmv to about 571 ppmv by the year 2100.
- Red squares represent average global temperature in degrees Celsius. For reference, this value was around 14.65 °C in the year 2015. In this model run, the temperature steadily rose to about 16.2 °C by the year 2100. This surpassed the recommended temperature limit by 0.4 °C.
    - In this simple model, the temperature is determined entirely by the atmospheric CO_2 concentration via greenhouse warming of the atmosphere.

The Three Scenarios

For this activity, you will complete three scenarios. Be prepared to discuss your results along with the “why” of your results.

Very Simple Climate Model

Scenario #1: What if we can reduce the rate that we add carbon dioxide to the atmosphere to 9 gigatons of carbon per year (9 GtC/yr)?

1. Set the carbon dioxide emissions rate to 9 GtC on the bar under "Select an emission rate".
2. Check the play button at the bottom of the left side. **What do you notice in the graph?**
3. Notice how the carbon emissions make a horizontal line since the rate stays the same over time. Do you see the CO_2 concentration increasing? Adding CO_2 at a steady rate causes the

concentration to climb. Take a look at the temperature line on the graph. In this model run, **how much did the temperature rise by the year 2100? Is it above the recommended limit?**

Scenario #2: What if our emissions get worse before they get better?
The glass is half full! People will rise to the challenge and limit the emissions of greenhouse gases in the atmosphere. Sure, it might take some time, but we will have new technologies and policies in place to limit the amount of carbon dioxide released. In this scenario, let's assume that people will keep emitting carbon dioxide at an increasing rate until 2050, and then we will have figured out how to stop polluting and the rate will fall.

1. Click the "Start Over" button to clean the slate.
2. Start with carbon emissions set at 10.5 GtC/yr, at or close to the current rate.
3. Click the "Step Forward" button (lower left) **twice** to advance "model time" by 10 years.
4. Increase emissions by 1 GtC/yr (to 10 GtC/yr) and advance another 10 years.
5. Continue to increase the emission rate by 1 GtC/yr (to 10 GtC/yr) for each decade, assuming it will take some time before we are able to take action, until you reach the year 2050.
6. Once you reach the year 2050, start **decreasing** the emission rate by 1 GtC/yr every 10 years.
7. Continue to decrease the emission rate by 1 GtC/yr for each decade until the model gets to the year 2100. What do you notice about the temperature?
8. Did you notice that emissions (blue) increased until 2050, then decreased through 2100? Did you see that CO2 concentration in the atmosphere (black) continued to rise even as emissions dropped? That's because we were still pouring CO2 into the atmosphere, just at a slower rate. Temperature (red) follows a trend similar to that for CO2 concentration - continuing to rise even as emissions drop, but at a slower pace.

Scenario #3: What does it take to stay below 2°C?
Do you see the red line labeled "recommended temperature limit?" What level of CO2 emissions do we need to stay within that limit during the 21st Century?

1. Start with carbon emissions set at 10.5 GtC/yr, close to present-day levels.
2. Play the simulation until the temperature line (red) crosses the recommended limit. Mouse over the data point to find out what year that would be.
3. Click the "start over" button to try again.
4. Select a different emissions rate that you think will keep temperature below the limit this century.
5. Play the simulation and see if it was enough.