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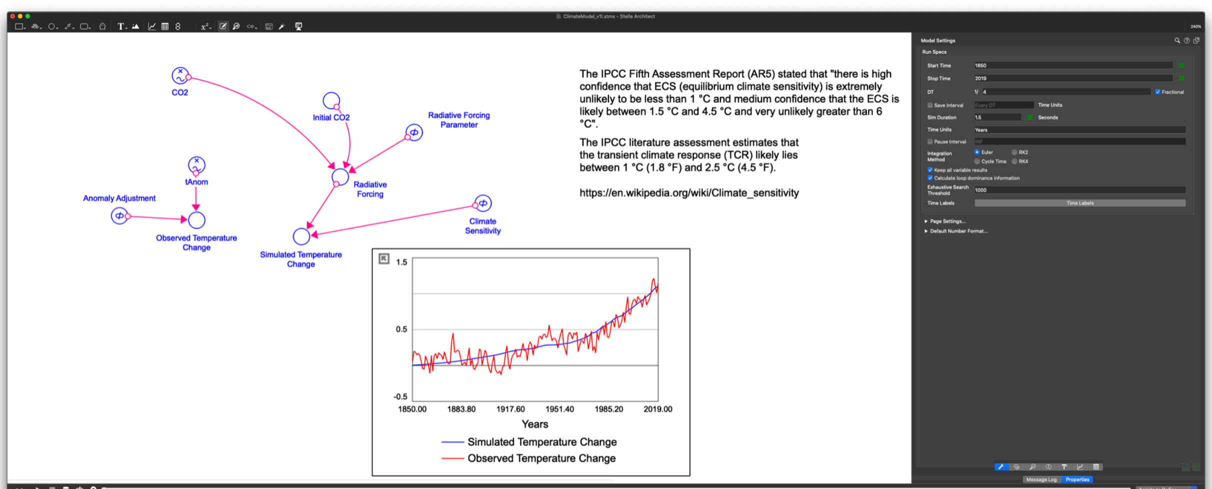
6. **Exercise: Simple climate model.** See the class Brightspace page for the due date.

Working with others. You are encouraged to work with others from class on this exercise but you must turn in your own model. If you do collaborate with others, you should build your own model through sharing ideas and techniques with others and not copying code.

We will build a simple Stella model of global mean temperature change from change in atmospheric CO_2. We will then use estimated atmospheric concentrations of CO2 from 1850 to 2019 to project global mean temperature. Finally, we will use the optimize functionality within Stella to choose the values of three of our model parameters that produce the best fit of our projected climate change to observed mean global temperature.

Our climate model will be based on the relationship between radiative forcing and atmospheric concentration of CO_2. We will combine the projected radiative forcing with a climate sensitivity parameter to project temperature change.

Here is a screenshot of what the model should look like.



1. Your time units should be Years and your start time should be 1850 and your end time should be 2019.
2. Radiative forcing is the change in energy balance of the Earth driven by a change in the concentration of a greenhouse gas such as carbon dioxide or CO_2.

We will use the following equation for radiative forcing (from Krauss 2021 chapter 7): Radiative forcing (RF in Watts/m^2) = 5.35 * ln(C/Co) where C is the current concentration of atmospheric CO_2, Co is the initial concentration of CO_2, and the radiative forcing parameter is 5.35.

3. The initial CO_2 should be 284 ppm.
4. Set the radiative forcing parameter to 5.35.
5. Set the climate sensitivity to 3.0
6. Simulated temperature change is radiative forcing * climate sensitivity.
7. Anomaly adjustment should be set to 0.
8. Observed temperature change should be tAnom (temperature anomaly) + Anomaly adjustment.
9. Here is a short video walking through this step. The CO_2 and tAnom (temperature anomalies) converters will contain the observed atmospheric CO2 concentrations and temperature anomalies. Download the csv file that contains these data: The link to the data is on the course schedule. **First**, make sure these converters are graphical functions: Select each converter, then select the second tab on the bottom right, then at the top of that tab, check the 'graphical' button. This must be done prior to importing the data. **Then** select Model->Import Data Then next to 'Source' browse to the downloaded csv file. Link type-> 'On demand' and Import Behavior->'Set parameters', then at top right, click on Import.
10. Then for both the CO_2 and tAnom converters, select the second bottom tab and when you click on the 'Points' tab, you should see the imported data.
11. Create a plot that includes both the simulated temperature change and the observed temperature change. How good is the model fit?
12. Let's try to optimize the model parameters. We will do this using the built in optimizer functionality. Here is a video implementing these steps.
    a. Double click anywhere inside the white canvas.
    b. Select the 3rd tab at the bottom--it should be a magnifying glass icon.
    c. Click the payoff tab at the top. Under 'payoff elements' click on the green plus and add 'Simulated temperature change'.
    d. Under comparison variable, select 'Observed temperature change'.
    e. Comparison run->Current run
    f. Comparison type->Squared error
    g. Under the Optimization tab, make sure the 'Choose a payoff definition'->Payoff
    h. Under Optimization parameters, click the green plus and add Climate Sensitivity, Anomaly Adjustment, and Radiative Forcing Parameter.
    i. Under Selected Optimization Parameter Options, for Climate Sensitivity select min value of 1, max value of 6; for Anomaly Adjustment select min

value of -1, max value of 1; for Radiative Forcing Parameter, select min value of 2, max value of 6;

j. Click the green check mark in bottom right.

13. Select the O-run in bottom left. Then a pop up optimization log should appear with the optimized values of the three parameters. In addition, the converters for these three parameters should be tuned to their optimized values. Also, notice the improved fit between the observed and simulated temperatures in the plot window.
14. After creating and optimizing the Stella model, please report the optimized values of Climate Sensitivity, Anomaly Adjustment, and Radiative Forcing Parameters in a text box within Stella.

Note that the data for model fitting comes from a few sources. Here are some sources for the data. CO_2 Emissions: Annual CO_2: 1800 to 2019; Atmospheric concentrations of CO_2: Mauna Loa CO_2: 1959 to 2020; CO_2: 0 to 2014. Mean global temperature: Temperature anomalies.

Krauss, L. M. 2021. The Physics of Climate Change. Head of Zeus.

What to turn in:

Please turn in a Stella file of your model through the Assignment tool in BrightSpace. **Attached files should be of the following format: YourLastName_Ex6_Climate.**

Grading rubric. I will assess this Stella exercise using a simplified numerical scale based on satisfactory or unsatisfactory progress. Satisfactory indicates that the student made a strong attempt to solve the problem and made substantial progress towards solving the problem, including arriving at or near the correct solution. Unsatisfactory means that low effort was made to solve the problem and limited progress was made towards solving the problem. A satisfactory will earn 10 of 10 points, and an unsatisfactory will earn 5 of 10 points. Intermediate effort will result in 8 points out of 10. Failure to turn in the model or very little effort invested in the model will result in 0 of 10 points.

Learning. We will go over the model in class as needed and I will post a solution. Please study the solution to address questions or uncertainties in your own proposed solution. Future exercises will build on the skills you develop in this exercise.

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