NetLogo: Exploring Stocks and Flows for Climate Change: A Netlogo Model

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This note describes a model of stocks and flows in the climate problem. Students should read the note, install the NetLogo software on their computers following the instructions provided in a separate reading, and then perform the exercise described here. All students should be prepared to discuss their experiences with the exercise.

Stocks and flows are one of the fundamental building blocks of complex systems and are present in systems of many different types (Sweeney and Sterman, 2000; Sterman, 2002). For the nature-society systems at the heart of our study of sustainable development, the "capital assets" are themselves stocks, which are affected over time both by environmental flows and by anthropogenic flows (see Part I of this course).

Despite their pervasiveness, as well as their importance in systems thinking, research has found that stocks and flows are often not well understood. For example, Sweeney and Sterman (2000) asked two groups of graduate business students at the Massachusetts Institute of Technology to draw the time path of a stock given a varying input flow and a constant output flow. In one scenario, students were presented with a "square wave" pattern for the inflow, where a correct solution would illustrate a stock that rises at a constant rate, then declines at a constant rate, and then repeats. In another scenario, students were shown a "sawtooth" pattern for the inflow, where a correct solution would depict sinusoidal behavior for the stock. In both cases, the problems involved no feedbacks or time delays, and all values were given as round numbers. Surprisingly, the authors found that **only** 63 percent and 37 percent of the students answered correctly for the first and second scenarios, respectively. Sterman (2002) notes that these results were replicated with Austrian university students, graduate business students at the University of Chicago, and undergraduates at the California Institute of Technology.

Our purpose in exploring "Stocks and Flows" through a NetLogo model is to provide an introduction to these concepts in a climate change setting, while abstracting from real-world features of social and natural systems to keep the exercise simple. The model focuses on stocks and flows as important and fundamental concepts as part of a larger curriculum on systems thinking.

Model Overview

The Stocks and Flows model you will use for this unit simulates the stock of carbon dioxide (CO_2) in the atmosphere, based on changes in flows, specifically emissions due to human activities and net absorption of CO_2 by the environmental system (mostly forests). The problem addressed in the class exercise, as in the world today, is to manage the system through time in a way that achieves a desired goal, where the goal is a stock but the management controls can only change flows.

For simplicity, stocks and flows in the model are reported in terms of carbon (C) rather than CO_2. The students' goal is to stabilize the stock of "atmospheric carbon" (and thus CO_2) near—but below—a given target level by the year 2080. For the purposes of the exercise, the model begins in the year 2015, and the "target" carbon stock is taken to be 1,000 gigatons (Gt) of carbon in the world atmosphere – approximately the level that scientists have determined is consistent with keeping global warming below the danger level of 1.5^{o}C in 2100.

To accomplish this goal, the model allows students to make incremental adjustments to society's annual global carbon emissions rate (flows). The model starts at 10 GtC/y emissions, which is approximately the actual 2015 value). Specifically, in each year, students (acting as unitary world decision makers) adjust emission flows anywhere from -5 percent to +5 percent relative to current emissions levels. The model interface provides a "slider" for this purpose, with units denominated in percentage points per year. Moving the slider to the extreme left will cause emissions to decrease by 5 percent of current levels; moving the slider to the extreme right will cause emissions to increase by 5 percent of current levels. Other values (at a resolution of tenths of a percentage point) can be chosen by moving the slider between these two extremes. The current emissions rate in GtC/y is shown in a "monitor" text box as well as in a figure for the students to see.

The net amount of carbon absorbed by the environment each year (the "out-flow" from the stock of carbon in the "bathtub" of the atmosphere) is positive but fluctuates due to natural variation. We follow the current science in assuming that this flow has a long-term mean of 5 GtC/year and a standard deviation of 1 GtC/y. Information about the distribution of this absorption rate of flow is provided to students in the model documentation (though it is not modifiable). The model's current year value of the absorption flow rate in GtC/y, which varies year-to-year, is presented in a monitor text box for students to see. (In the real world, the net environmental carbon sink is mostly due to flows into growing plants, especially forests, due to the fertilization effect of rising CO2. This rate may be affected by climate warming, but such impacts are not included in this model.

After students make their adjustment to the emission flow for a given year and press the button labeled "go," the simulation moves forward by one year and a new level of the atmospheric carbon stock —based on the current flows of emissions and absorption—is calculated. The historical stock of atmospheric carbon from 1960 to the present model year is displayed in a figure as part of the interface, with a horizontal red line indicating the danger level of 1,000 Gt. The current stock of atmospheric carbon in GtC is also displayed in a monitor text box. When the model reaches the year 2100, a message is presented stating that the model has come to an end and that students may restart the exercise if desired.

The objective of your work with the model is to discover a strategy for managing annual flows in emissions that keeps the total stock of carbon in the atmosphere below the danger level. But there is a constraint: large annual changes in carbon emissions (flows into the atmospheric stock) represent potentially substantial disruptions to the global energy system and economy (and in addition, may be difficult or impossible to achieve in practice). While the only actual restriction in terms of your choice set is that the annual percentage change in emission flows must fall between -5 percent and +5 percent of the current emissions rate, your overall goal is to manage the atmospheric stock of C, while minimizing distributions to the global energy system and economy. Note that during the last half century the greatest reductions in emission flows that have been achieved at the national level for periods of a decade or more are on the order of -4%/year (achieved by France in the 1980s as it moved out of oil and into nuclear energy as its primary source for electric power). Higher rates are possible and may be necessary to avoid climate disaster. But achieving them will be very hard. What you should aim for is a management strategy that keeps your annual reductions in flows as small and as regular as possible, consistent with keeping the total stock just below the danger level. Once you have figured out an optimal strategy, write it down and be prepared to present and defend it.

Obtaining and running the model: This model has been written (by Stu Iler) specifically for this course, so is not in the NetLogo public library. Rather, you can download it from the Library for this class; it will have the name Iler, 2021 ("Stocks and Flows v6.nlogo"). Once you have it on your computer, run the NetLogo program you previously installed. Go to the "File" tab at the top left, click it, and pick "Open" from the dropdown. Browse your computer for the file you saved (Stocks and Flows v6.nlogo), highlight it, and click "open." The model should appear on the screen of your NetLogo program. Click the "Info" tile at the top left of the model page, read about the model, then go back to the Interface tile (next to "Info"), click the 'setup' tile and you are ready to go. Each year you should adjust the slider under the graphs to adjust your emission flows, then click 'go'. Once you see the result, think about it, and make your emissions (flow) adjustment choice for the next year. Click 'go' again. And so on.)

References

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- Sterman, J. D. (2002). All models are wrong: Reflections on becoming a systems scientist. *System Dynamics Review*, *18*(4), 501–531. https://doi.org/10.1002/sdr.261
- Sweeney, L. B., & Sterman, J. D. (2000). Bathtub dynamics: Initial results of a systems thinking inventory. *System Dynamics Review*, *16*(4), 249–286. https://doi.org/10.1002/sdr.198.