Simulation of Global Warming in the Continental United States Using Agent-Based Modeling

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Abstract

It is a commonly accepted fact that as the population increases, the carbon footprint of the combined population of the United States increases. However, the more controversial result of this phenomenon is the further acceleration of the effects of global warming. However, this project was not conducted to determine whether or not the two are correlated; it has been assumed that they are. Not many studies have been constructed correlating the effects that global warming will have on the human population. The purpose of this experiment is to combine that effects that the increasing population will have on greenhouse gas output and then the effect that the resulting temperature and sea level changes will have on the population. The goal of the experiment is to show the detrimental effects that global warming will have on the population in the United States if nothing is done to limit the current greenhouse gas output. The results of this experiment would be useful to environmental scientists all over the world, not just in the United States, since similar population changes should be happening globally.

Keywords: global warming, greenhouse gases, agent-based modeling, netLogo, population changes

1 Introduction

I decided to use NetLogo, a cross-platform multi-agent programmable modeling environment, as the program running my experiment. NetLogo was created in 1999 by Uri Wilensky at NorthWestern University. It allows the user to run both a system dynamics and written code simultaneously, making it simple to use for event programming. It has its own easy-to-use programming language for which they provide tutorials online.

The running experiment will be shown on an interactive screen with a map of the

United States. The map is set up using two different variables, temperature and elevation. Each patch on the map has an elevation number which sets up a visual representation of the United States (figure 1) and also tells the program the elevation of a certain area of the map. The elevation map (numeric data) was the basis of the entire visual representation, and it was received from a previous project compiled by Josh Unterman, found in the Models Library of netLogo. The second variable gives each patch in the program a certain temperature, which is the current average temperature for the entire year of the area. The temperature was obtained from Weatherbase, which has annual average temperatures for nearly every city in the United States. The green house turtles on the map represent the largest cities of the Country, and linear interpolation was used to fill in the temperature data between these states, since accurately filling out every single temperature data point would be inefficient and time consuming. There is a fairly large margin of error in filling out the temperature data between the cities, since temperature does not increase and decrease linearly. However, it is extremely difficult to have an accurate and detailed representation of the entire Unites States based on temperature.

There are two changing agents in this experiment - the patches and the population. As the population increases, there is a general algorithm to calculate the greenhouse gas output. As the greenhouse gas composition in the atmosphere increases, the average surface temperature of the Earth (here, concentrated to the United States) also increases. The average global temperature increase and decrease is determined by a System Dynamics Model (figure 2) whose atmospheric absorption coefficient is the only variable being changed by the program itself. The sea levels will rise, and the visual representation of the map will change according to the new sea level. According to the Intergovernmental Panel for Climate Change, the estimated current sea level rise is 3 mm per year, which is the data used for this experiment. Also,the temperature of each patch will slowly start to increase. The second variable in this experiment are the people. One agent will represent a population of 10,000. Each person agent is given a salary according to the U.S. Census demographics information (the average annual salary and the percentage of people under the poverty line). At every single tick, they have the option of moving to a new location whose distance from the current patch is determined by how much money they have. For every 10,000 dollars available, an agent can move 10 patches in either direction. Each patch has a death rate which increases with increasing temperatures and sea levels, but decreases with decreasing sea levels. Also, as the sea levels increase, more and more people will die in that area, since the death rate will increase. If the agent runs out of money, it will stay in a certain area and has an increased chance of dieing of heat stroke or drowning.

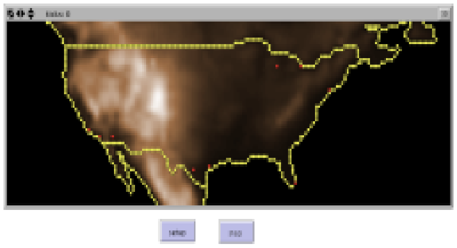

Figure 1: Image of the screen with the altitude map

2 Background

I learned the majority of information about global warming, climate change, and the greenhouse gas effect from geosystems class, where we used Stella to create a System Dynamics model of climate change and various representations of population change. Most of the common formulas come from these Stella models and from an online University of Michigan class based on global change. There are various versions of global warming models available on the internet, but none of them concentrate on the effects of people on global warming and climate change on the population. The basic elevation map was taken from a previous project by Josh Unterman on the Continental Divide. This project was provided by NetLogo in its Models Library, a set of previously completed experiments. The elevation map already had converted the different elevations of Northern America to color values that provided me with a useful map onto which I built a temperature map.

Agent-based modeling is a popular way to represent human behaviors through simple heuristics and basic societal rules. David Batten, in his paper "Are some human ecosystems self-defeating?" discusses the potential downfalls and problems of such modeling and proposes that the agents should be able to communicate with one another in addition to their environment. Each agent needs to have a set of values, which in this case is the temperature and elevation of the patch that they are currently inhibiting and of the ones around them. Romulus-Catalin Damaceanu performed his research on studying wealth distribution using NetLogo, which used similar parameters and private variables as will be used in my simulation of the global warming and population effects.

The Intergovernmental panel on Climate Change has been set up to include scientists from all over the world that work to combine data on the possible outcomes of climate change. They create various scenarios which account for possible population increase or decrease and also technological advancements. All of them propose different greenhouse gas compositions in the atmosphere and how they are increasing or decreasing. ("Global Climate Projections", Meehl, G.A., Stocker, T.F.)

3 Development

The elevation map from the Continental Divide project was the basis for the temperature map of the United States. After the approximate locations of large cities in the United States, linear interpolation was used to fill out the rest of the map. Basically, the two cities' temperatures were used as endpoints, and a linear model was created to estimate the data points in between the two, depending on how many there are.

$$dT = \frac{C1^2 - C2^2}{P1^2 - P2^2}$$

The C1 and C2 are representative of the temperatures of two end-point cities, and the P1 and P2 represent the patches that they were on. dT is the amount that the temperature would change for each patch between the two cities. At time, it was impossible to find out the horizontal interpolation of temperatures, since there are not enough major cities. In that case, vertical linear interpolation was used. All the code for the horizontal and vertical interpolation was written using Python.

After the temperature map was completed, the city agents (green houses) had to be added to the project. Each house agent has three different variables:

- Name
- Average Salary
- Percent Living Below Poverty Level (povpercent)

Since the average size of a family is 2.5 members, the poverty level annual salary is 15,800 per year. At the patch of each city, according to its private variables, people agents were made. The percentage determined by povpercent have a salary of a random number between 0 and 15800. Then, .5 - povpercent percent of people have a random salary between 15,800 and the city's average salary. Half of the people have a salary somewhere between the average salary and twice the average salary.

Each person agent has two variables

- Salary
- Money

Their salary figure is determined by which city they are created in, and their money is updated once at birth and then each year after that. The determination of how long a year is will be addressed later. Using the patches, agents, and cities, the program is able to run. However, the System Dynamics model runs the changes in the temperature of the model.

4 System Dynamics

The System Dynamics model for this program was taken from a model geosystems STELLA lab. It sets up the fundamental mathematical processes that determine the energy input and output of the Earth, taking into consideration both the surface of the Earth and the atmosphere around it. The relationships between the variables is as follows:

- Atmospheric Absorption Coefficient = .26
- Earth Albedo = .3
- Earth Diameter = 12742000
- Density of water = 1000

- Specific Head of Water = 4218
- Water Depth = 100
- Earth to Atmosphere = atmospheric absorption coefficient * surface radiation * dt
- Atmosphere to Earth =

$$atmosphericirradiation * \frac{1}{2} * dt$$

- Atmosphere to Space =

$$atmosphericirradiation * \frac{1}{2} * dt$$

- Solar to Earth =

$$solarconstant * (1 - earthalbedo) *$$

$$\Pi * ((\frac{earthdiameter}{2})^2) x dt$$

- Earth to Space =

$$1 - atmosphericabsorptioncoefficient$$

$$* surfaceradiation * dt$$

- Surface Radiation =

$$\Pi * (earthdiameter^2) * stefanboltzman$$

$$* earthtemperature^2$$

- Atmospheric IR Radiation =

$$\Pi earthdiameter^2 * stefanboltzman$$

$$* atmospherictemperature^4$$

Figure 2: Image of the screen with the temperature map

- Solar Constant =

$$1368 * 3.14476 * 10^7$$

- Atmospheric Heat Capacity =

$$5.14 * 10^1 8 * 1004$$

- Atmospheric Temperature

$$\frac{atmosphericenergy}{atmosphericheatcapacity}$$

- Earth Temperature

$$\frac{earthenergy}{heatcapacity}$$

- Stefan Boltzman

$$5.67 * 10^8 * 3.15576 * 10^7$$

- Heat Capacity

$$\Pi * earthdiameter^2 * waterdepth$$

$$* waterdensity * specificwaterheat$$

5 Results and Discussion

The main purpose of this experiment is to show a possible bleak future scenario of what will happen when nothing is done about global warming. The expected results are unknown, but will most likely show that over time, the population will first increase due to favorable conditions. However, as the population increases, more greenhouse gases are produced and thus the climate changes and heats up. As infectious diseases start to spread and sea-levels start to rise, the population will decrease, now decreasing the amount of greenhouse gases in the atmosphere. The climate will now cool down, and the death rate will once again decrease, enabling the birth of more agents. There should be a slow oscillating relationship between the population and greenhouse gases in the atmosphere. However, the majority of the population will move north, away from the coastal areas to escape high temperatures and flooded cities. The poorer population will not have as many options to move away from unfavorable conditions, and thus the people below the poverty level will have a harder time coping with climate change. More affluent agents will be able to move to favorable areas.

The Gaia Hypothesis states that the Earth acts as a controlling body. If there is a forcing in one area, then the Earth will change another to counterbalance it. The Earth will most likely try to get rid of the cause of the climate change - the humans. However, there are various problems that will conflict with the validity of this program. First of all, as technology and thus medicine improve, the rates of the increasing and decreasing death rates will change. It is possible that the increasing death rates due to the increasing temperature will be counterbalanced by the improving health care. Also, this program is assuming that the entire population of the United States is that of the major cities combined and that everyone starts out living in a large city.

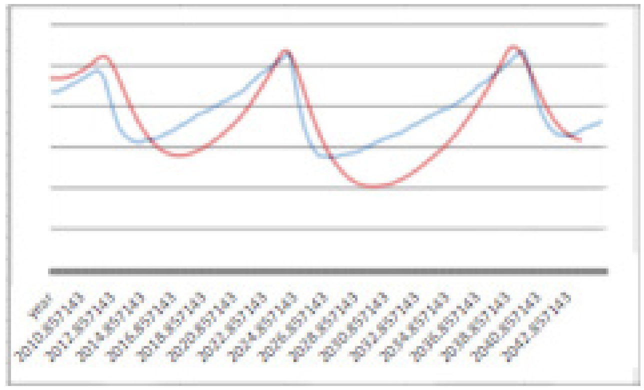

Figure 3: Graphs of temperature and population vs. Years

When the project is tested using only the original and current birth rate of .1418 and a 'dr' (the change in death rate as temperature increases or decreases) of 101, the data showed a clear oscillation. When the graph of the temperature was laid on top of the population graph, a clear connection was seen between the two, as shown by figure 3. It's important to note that the graph was set up with the Years on the X-axis instead of ticks. The intervals at which the year changes are separate for each scenario (determined by the birth rate and 'dr' variables).

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