TJHSST Computer Systems Lab Senior Research Project
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 United States increases, further accelerating the effects of global warming. However, not many studies have been constructed correlating the effects that global warming will have on population. The purpose of this experiment is to combine that effects that population will have on greenhouse gas output and then the effect that the resulting temperature and sealevel changes will have on the population. The goal of the experiment is to show the detrimental effects that global warming will have in the United States if nothing is done to limit the 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 - Elaboration on the problem statement, purpose, and project scope

1.1 Scope of Study

The main portion of the experiment will be shown on an interactive screen with a map of the United States. The map is set up using two different variables. Each patch on the map has an elevation number which sets up a visual representation of the United States and also tells the program the elevation of a certain area of the map. 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 red dots on the map represent the largest cities of the States, and linear interpolation is used to fill in the temperature data between these states. 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 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 sea levels will rise, and the visual representation of the map will change according to the new sea level. 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 1,000. If time allows, I can set up the population according to demographic data, giving each of these agents their own money variable. If the temperature in their area becomes unbearable, they will move somewhere with a more favorable temperature. Also, as the sea levels increase, more and more people will move from that area. 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. Also, I will try to add a variable to represent the increasing chance of infectious diseases spreading through a population in a warmer area.

1.2 Expected results

I expect the majority of the population to move towards the central-north area of the United States, away from the rising oceans and increasing tem-

peratures. However, if a large majority of the population dies, then the greenhouse gas output will decrease, decreasing the temperatures and once again lowering the sea-levels. There should be an oscillating representation between the greenhouse gas output and the population that attempts to reach an equilibrium.

The equilibrium that the graph approaches shows wether the population today will be able to survive with the same greenhouse gas output per person. The experiment will show if the real problem with global warming is the fact that the world is overpopulated and a smaller population will fix the problem. However, it is also possible that the only way of reaching an equilibrium is when all of the human population dies out. There is also a possibility that there is no equilibrium and the graph of climate change and population will forever be oscillating.

1.3 Type of research

This research project focuses on use-inspired basic research. I am writing this code to understand the fundamentals of agent-based research, but then proposing a futher use of the project: to understand how population and global warming are correlated and can change one another.

2 Background and review of current literature and research

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.

3 Procedures and Methodology

The entire project will be performed using NetLogo and its accompanying language. The main interface of the project has a map of the United States with the major cities and an underlying map of the temperatures. The interface will also include a reset button and a step button.With the use of Josh Unterman's map for his continental divide model, the altitude data for the continental United States was ready. All of the numerical altitude data (except for the data points that represented the ocean or the country's border) were removed and replaced with zeroes. The border between the United States and Canada and Mexico was drawn according to a map of the country and about 20 largest cities were plotted in their correct areas. The information from weatherbase.com provided the average yearly temperatures of the average cities, which surrounded the city on all four sides. Next, linear interpolation was used to fill in the missing data between the cities, and some smaller cities' temperatures were plotted as reference points to minimize possible errors. Each patch on the map now has two data points: the elevation and temperature.

Using current data on possible global warming effects, formulas about the global energy budget, the estimated temperature increase and sea-level increase, the map will change in temperature each time the 'step' button is hit on the interface to represent the passing of one year. Once this basic map change is programmed, the human agents will be added.

According to the demographics of each city according to the 2000 census, the representative amount of agents are added to each area surrounding the

city (perhaps one agent per every 10000 people). Every single agent gets a general annual salary according to the available data of the city, and as the temperatures and sea-levels start to increase, the agents will have the possibility of moving around and finding a patch with the most favorable conditions (that means lower temperature, sea-level and population) according to their financial status. If the agent has no more capital left, they must stay in the same spot where the chances of infectious diseases, heat stroke, and drowning will increase the death rate and over time, the agent may die.

The agents have their own set of heuristic rules that determine how they live or die. There is a continental birth rate for the entire country based on population, but the death rate depends on the conditions of each patch on the map. The global energy budget heuristics from geosystems will be used to determine the effects that the increase in CO2 output will have on the greenhouse gas effect and thus the temperature. The amount of greenhouse gas that each agent produces will be determined using available online data.

Every single time the interface is run, the agents should move to different locations. Each one has a chance of survival based on where they start out, what the other agents around them do, and how much money they have on hand. Since the current population of the United States is set, there will not be any variables that can be controlled in the project. It is designed to show the detrimental effects of global warming if the Kyoto protocol isn't followed, and nothing effective is done to reduce the amount of greenhouse gas output. Thus, the results should be similar on each test run.

Error analysis is difficult, and only time will show the real results of global warming. Also, it is highly unlikely that nothing will be done in the near future to control the possible deleterious effects.

4 Expected Results

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.