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Global Change Explorer—A Web-Based Tool for Investigating the Complexities of Global Change †

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Abstract: The Global Change Explorer (GCE) is an interactive web-based tool for investigating the complexities of global change (https://www.globalchange-uwo.ca/). The GCE is using the ANEMI simulation model developed at the University of Western Ontario, Canada. ANEMI simulates system dynamics to offer information on Earth's dynamic processes and the behaviours that instigate change. The ANEMI model is an integrated assessment model of global change that emphasizes the role of water resources. The model sectors that comprise the ANEMI3 (the current version of the model) are that of the climate system, carbon, nutrient, and hydrologic cycles, population dynamics, land use, food production, sea level rise, energy production, global economy, persistent pollution, water demand, and water supply development. The GCE is designed to allow the use of ANEMI to simulate various future scenarios related to five main themes: climate change; population dynamics; food production; water quality and water quantity. The users are presented with the opportunity to ask different questions, select simulation runs, and evaluate model outputs.

Keywords: global change; system dynamics; water; decision support

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1. Introduction

In the early 1950s, the concept of global change entered the international stage with a clear indication that Earth is a closed system in which natural resources and the environment determine the boundaries of population growth and economic development. This paper starts with a simple assumption that global change problems require a systems approach. Global change research mostly uses integrated assessment, defined as an interdisciplinary process of bringing together knowledge from different disciplines.

There are a limited number of tools that allow users to assess, analyze and adapt to global change. The Global Change Explorer (GCE) is an attempt to bring global change and its consequences closer to decision-makers, scientists and the general public [1]. The GCE allows interactive investigation of global change complexities. It is using ANEMI, system dynamics simulation model developed at the University of Western Ontario [2], [3], and [4]. ANEMI is named after the Greek ANEMOI gods of the four winds: Boreas the North-Wind (bringing the cold breath of winter), Zephryos the West (the god of spring breezes), Notos the South (the god of summer rain-storms), and Euros the East (associated with the season of autumn).

ANEMI simulates system dynamics to offer information on Earth's dynamic processes and the behaviours that instigate change. It is an integrated assessment model of global change that emphasizes the role of water resources. The main thrust of ANEMI is to explicitly integrate various sectors (natural, physical and socioeconomic) into a single model, providing effective consideration of the high-level feedback relationships between the physical environment and social adaptation. At lower levels, this relationship ends in thousands of feedbacks between various model sectors and variables.

The ANEMI model is developed using Vensim system dynamics simulation environment [5]. The entire model code is archived using Zenodo (https://doi.org/10.5281/zenodo.4025424) and is available to everyone. Details on how to run the model, modify inputs, and view the outputs in graphical or tabular formats are provided in the repository.

The GCE is designed to allow use of ANEMI to simulate various future scenarios related to five main themes: climate change; population dynamics; food production; water quality and water quantity. The users are presented with the opportunity to ask different questions, select simulation runs, and evaluate model outputs.

The main objective of the paper is (i) a brief description of the ANEMI model and (ii) an illustrative presentation of the GCE. The next section of the paper provides a brief description of the ANEMI model. It is followed by the graphical description of the GCE use. The paper ends with a summary statments.

2. The ANEMI Model

The development of the ANEMI model is done using the system dynamics simulation (SD) approach. The SD is one of the systems analysis tools specifically designed to analyze the dynamic nature of systems that are composed of feedback loops [6] and [7]. A structure is essential for the interpretation of complex interactions occurring in models of global change. Learning the structure of a system is learning how things are related [6]. The concept of feedback systems emerged as the basis for structuring the observations of global change. The feedback is defined as a closed path connecting in sequence a decision that controls the action, the state of the system, and information about the state of the system [7]. The feedback provides a direct link between the system structure and its dynamic behaviour. The language of system dynamics includes a powerful tool of causal diagraming to capture the system structure (express what we know about a system) and mathematical simulation to generate dynamic system behaviour.

2.1. The ANEMI Model Description

The model sectors that comprise the ANEMI model are climate, carbon, nutrient, and hydrologic cycles, population dynamics, land use, food production, sea level rise, energy production, global economy, persistent pollution, water demand, and water supply development (detailed descriptions of each model sector are available in [4]. The high-level model structure is shown in Figure 1. The selection of model sectors is made to capture the dynamics of global change with an emphasis on water resources. The main strength of the ANEMI model is its highly endogenous structure and tight coupling of all twelve sectors. This allows for studying global change from a feedback-based perspective to understand the dynamic behavior of global issues (e.g., climate change, food-water-energy resource limitations, and development of water supply to support a growing population). Figure 1 depicts the main feedback relationships between the sectors.

The arrows represent causal relationships between the sectors and main connecting variables. Arrows with positive signs denote positive causality (change of connected sectors/variables in the same direction) and with a negative sign, negative causality (change of connected sectors/variables in the opposite direction). The causal links closed in a loop form the feedback relationships. The positive, reinforcing, feedbacks are formed by an even number of negative causal links. The negative, balancing, feedbacks are formed by an odd number of negative causal links.

Colored arrows in Figure 1 are used to illustrate thematic feedbacks between major model sectors. For example, the red arrows depict a feedback relationship between food production, population, energy-economy, carbon, and climate sectors. If food production decreases relative to the global population, this slows population growth and available labour to drive global economies. With less economic productivity, fewer emissions are anticipated, lowering greenhouse gas concentrations and slowing climate change. This has a positive effect on land yield, as global temperatures would not increase as much, having a positive influence on food production. This is an example of a negative or self-regulating feedback loop. The overall behaviour of the global system is governed by how strongly each feedback loop interacts with the system over time.

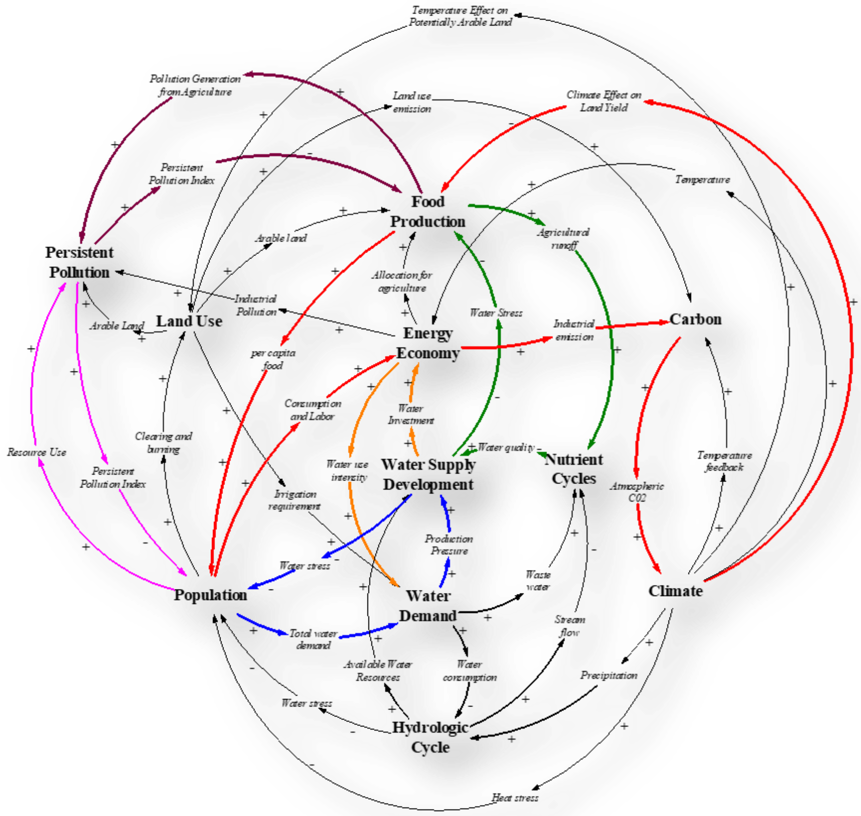

Figure 1. ANEMI model intersectoral feedback diagram (modified after [4]).

Feedback loops between sectors, or intersectoral feedback loops, are responsible for a global change in the Earth system. The ANEMI focuses on representing global scale feedbacks that are driving overall change and assessing their importance and influence within the Earth system. The highly endogenous structure of the model creates a very large number of feedbacks that are driving the dynamics of the Earth system.

The ANEMI model is developed using Venism systems dynamics simulation software [5]. The entire model code is available from the Zenodo archive (https://doi.org/10.5281/zenodo.4483736, accessed on 26 January 2023) with details on running the model, modifying inputs, and viewing the outputs.

2.2. The ANEMI Model Use

The ANEMI model is parameterized to simulate the Earth system over the period of 1980 to 2100 with an integration time step of 1/128th of year. Due to the rigid nature of the system equations, the simple Euler integration method is used. The model has been parameterized to capture the initial conditions in 1980 and reproduce the behaviour of key system variables in each sector.

The generalized, feedback-based structure of the ANEMI model allows the user to test policy scenarios related to global change. By altering one of the model parameters at a given point in time, all model sectors will respond through the driving feedback processes which govern the model structure. The output of the model using the baseline parameter set provides a reference scenario to which alternative policy scenarios may be compared. Different parameter sets have the potential to cause a shift in model behaviour compared to the reference scenario, as the dominance of feedback processes in the reference scenario may change. The large number of variables and sectors in the ANEMI model allows for the development of a wide variety of scenarios, each with a different focus. The main investigations conducted by the ANEMI model up to now focused on simulating various future scenarios related to five main themes: (i) climate change; (ii) population dynamics; (iii) food production; (iv) water quality and (v) water quantity. For a detailed description of the tested scenarios, please refer to [4].

3. Global Change Explorer (GCE)

The web version of the program, GCE (Global Change Explorer) [1] is designed as a smart interface that allows for the ANEMI model to be simulated through a series of interactive, user-defined scenarios. The GCE is available at https://globalchange-uwo.ca/ (accessed on 26 January 2023).

The communication with GCE starts by activating the *Scenarios* menu, as shown in Figure 2. The user is presented by five scenarios and questions related to each of them. Selection of the question and scenario sets in the background the ANEMI simulations and open possibilities for experimenting with the model by changing some input variables.

The smart interface automatically provides the *Variables* that can be experimented with based on the selected question and scenario. A variable selection screen for one scenario and one question is shown in Figure 3.

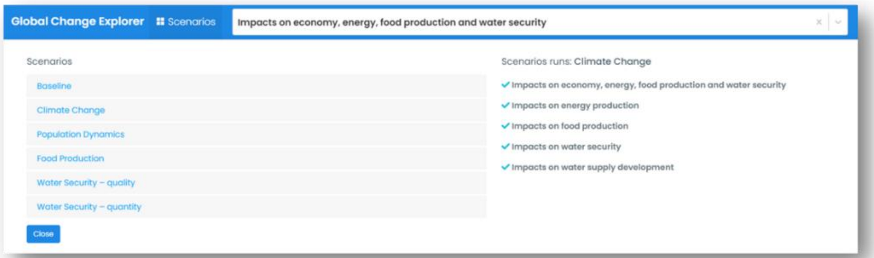

Figure 2. The GCE main menu.

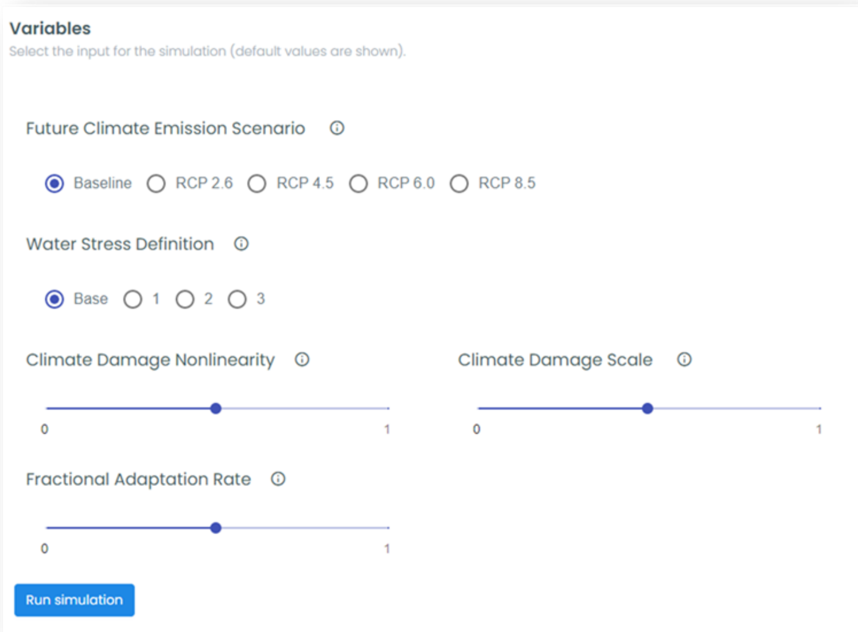

Figure 3. The GCE variable selection.

The GCE offers assistance in providing a *Description of the scenario and variables* that the user can experiment with, as shown in Figure 4.

Figure 4. The GCE variable description.

Upon selection of the variables, the ANEMI model is executed in the background and simulation results are stored for presentation in GCE. The left side of the GCE screen offers a graphical presentation of the results. Multiple options for downloading the results (graphs, tables, various image formats, etc) can be selected by choosing desired options under ≡ menue button.

The upper part of the results screen shows the Summary of model performance—the combined graph showing the dynamics of key variables associated with the selected scenario. An example output screen is in Figure 5.

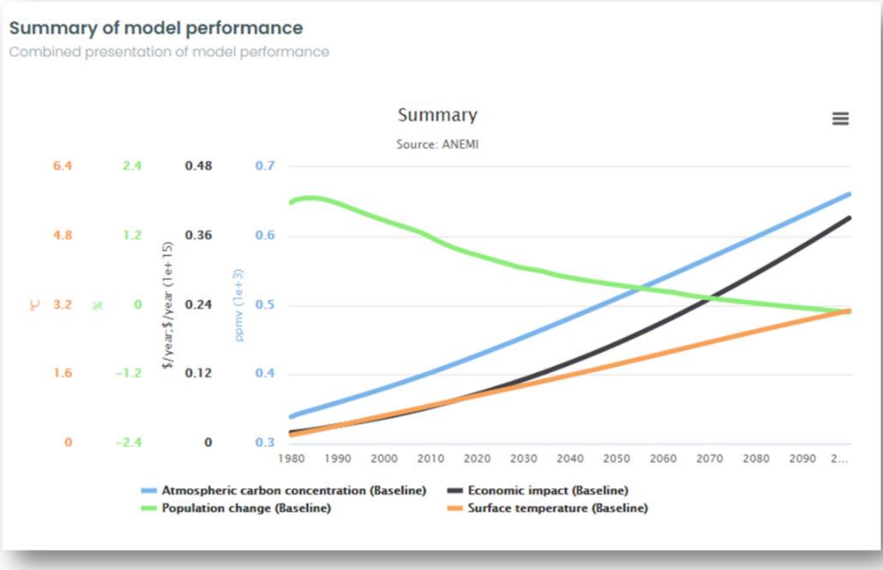

Figure 5. The GCE summary model performance.

The bottom part of the screen shows the *Individual performance metric*—individual graphs presenting the dynamic performance of the most significant variables for the selected scenario. As shown in Figure 6, the GCE provides these graphs in comparative form. Each user selection of input variables is memorized and presented as one line, and graphs show all experiments in the same place, allowing immediate communication of important answers to the user's questions.

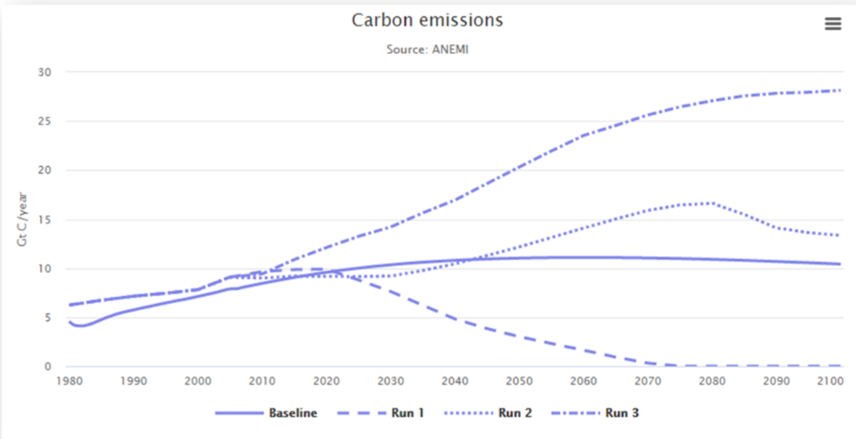

Figure 6. The GCE individual metric performance.

4. Summary

This paper has brieflydocumented the ANEMI model as a new tool for global change analysis. The feedback-based structure is designed to promote understanding of the feedbacks that drive Earth system behaviour and the process of global change occurring within it. The aggregated spatial scale of the model allows for examining global scale feedbacks through the development of scenarios that focus on individual or multiple model sectors.

An intelligent interface (GCE) is also presented as a mechanism to allow global change experimentation to the users with different skill levels necessary for the use of complex models like NAEMI.

The main limitation of GCE is in a limited number of preselected scenarios focusing on (i) climate change; (ii) population dynamics; (iii) food production; (iv) water quality and (v) water quantity. It is my hope that the future use of the model will eliminate this limitation. The interest of the community and various questions by potential users will guide future activities in expanding the ability of GCE.

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Data Availability Statement: Text of the article includes archive location of the ANEMI model and all the data and scenarios that were investigated up to now as well as theURL of GCE.

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