C-ROADS: CLIMATE --RAPID OVERVIEW AND DECISION-SUPPORT SIMULATOR

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Motivation

Research shows that many people, including highly educated adults with substantial training in science, technology, engineering, or mathematics, misunderstand the fundamental dynamics of the accumulation of carbon and heat in the atmosphere (1, 2). Such misunderstandings can prevent decision-makers from recognizing the long-term climate impacts likely to emerge from specific policy decisions.

Furthermore, people charged with making decisions related to climate change – climate professionals, corporate and government leaders, and citizens – may understand the emissions reduction proposals of individual nations (such as those proposed under the United Nations Framework Convention on Climate Change process) but lack tools for assessing the likely collective impact of those individual proposals on future atmospheric greenhouse gas concentrations, temperature changes and other climate impacts.

These challenges to effective decision-making in regard to climate change are typical of the challenges facing decision makers in other dynamically complex systems. Research shows that people often make suboptimal, biased decisions in dynamically complex systems characterized by multiple positive and negative feedbacks, time delays, and nonlinear cause-and-effect relationships (3, 4, 5). In such situations computer simulations offer laboratories for learning and experimentation and can help improve decision-making (6, 7). Critical climate policy decisions will be made at the local, national, and global scales in the coming months and years. Key stakeholders need transparent tools grounded in the best available science to provide decision support for real-time exploration of different policy options (8).

Purpose and Use

We created the Climate Rapid Overview And Decision-support Simulator (C-ROADS) to provide a transparent, accessible, real-time decision-support tool that encapsulates the insights of more complex models. The simulator helps decision makers improve their understanding of the planetary system's responses to changes in greenhouse gas (GHG) emissions, including CO2 from fossil fuel use, emissions from land use practices, and changes in other greenhouse gasses (Figure 1). C-ROADS has been used in strategic planning sessions for decision-makers from government, business and civil society and in interactive role-playing policy exercises (9). An online version for broad use is currently under development.

C-ROADS provides a consistent basis for analysis and comparison of policy options, grounded in well-accepted science. By visually and numerically conveying the projected aggregated impact of national-level commitments to GHG emission reductions the model allows users to see and understand the gap between 'policies on the table' and actions needed to stabilize GHG concentrations and limit the risks of "dangerous anthropogenic interference" in the climate. In this way C-ROADS offers decision makers a way to determine if they are on track towards their goals, and to discover – if they are not on track – what additional measures would be sufficient to meet those goals.

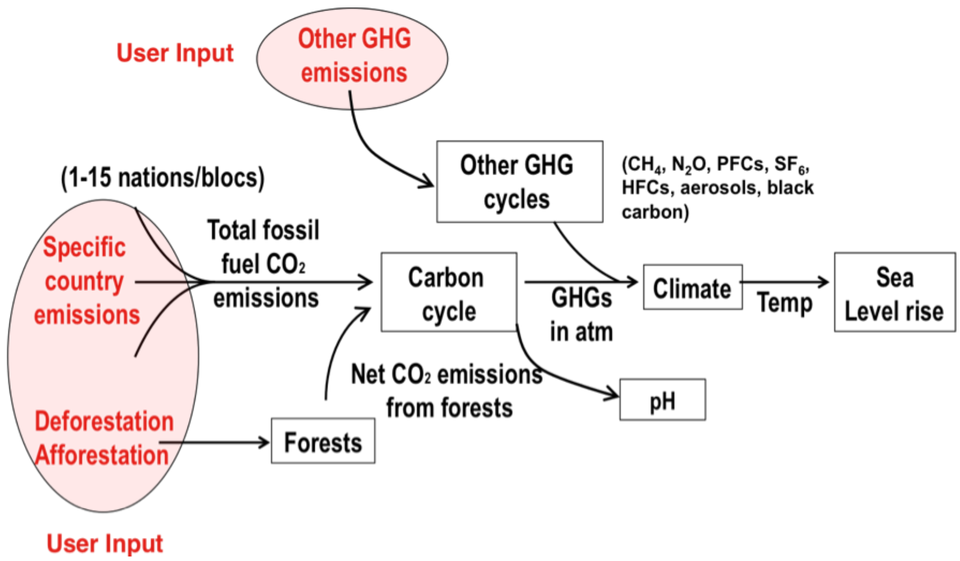


Figure 1. C-ROADS Structure

The Simulator

C-ROADS has been constructed using the tools of System Dynamics (7), a methodology for creating simulation models that help people improve their understanding of complex situations and how they evolve over time. The simulation model is based on the biogeophysical and integrated assessment literature and includes representations of the carbon cycle, other GHGs, radiative forcing, global mean surface temperature, and sea level change. Consistent with the principles articulated by, e.g., Socolow and Lam (10), the simulation is grounded in the established literature yet remains simple enough to run quickly on a laptop computer.

The model uses historical data through the most recent available figures, including country-level GDP and population (11, 12), CO2 emissions from fossil fuels (FF) and from changes in land use (13, 14, 15), and other well-mixed greenhouse gases (CH4, N2O,SF6, PFCs, and HFCs) (16). Scenarios for the future including Business As Usual GDP and emissions projections are calibrated to the IPCC 5th Assessment Report (AR5) scenarios (17, 18). Specifically, RCP projections are obtained from the IASSA website http://www.iiasa.ac.at/web-apps/tnt/RcpDb; RCP2.6 (19), RCP4.5 (20, 21, 22), RCP6.0 (23, 24), and RCP8.5 (default) (25). The user may also choose scenarios based on AR4 (26) and Energy Modeling Forum 22 (EMF22) Reference Scenarios (27). The model uses the population projections from the United Nations (28).

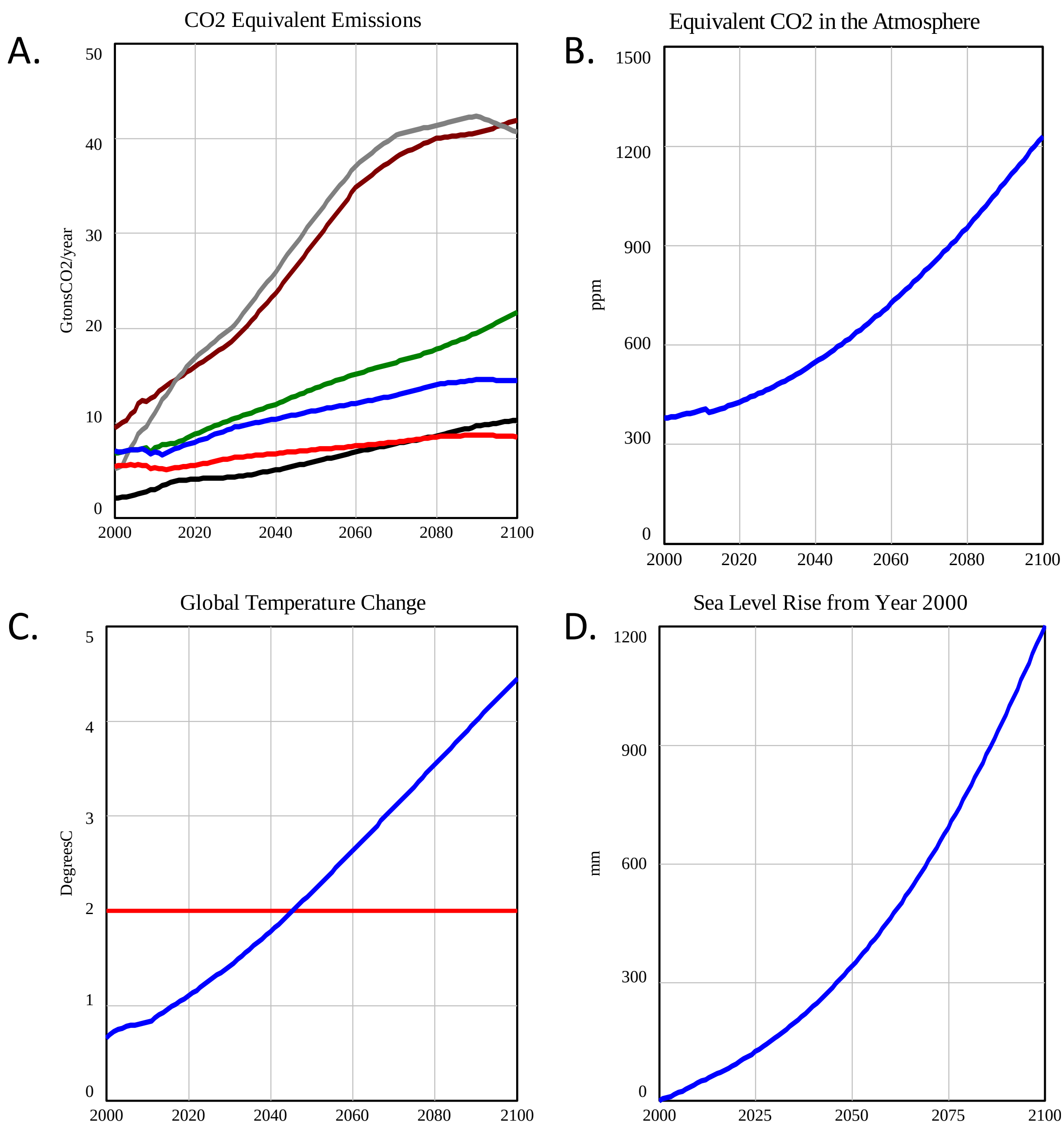


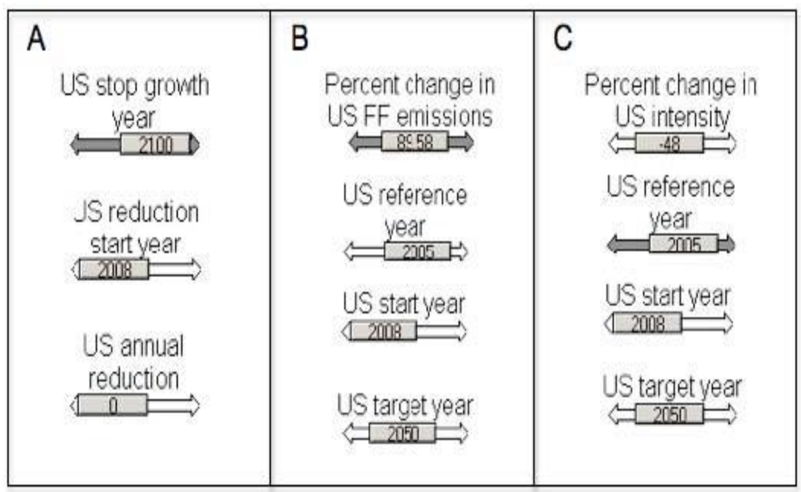
Figure 2. Representative C-ROADS behavior for a scenario based on the IPCC RCP8.5 emissions scenario. (A) Fossil fuel CO_2 emissions for the 6 regions represented in C-ROADS. (B) Resulting atmospheric CO_2 concentrations. (C) Resulting global temperature change relative to pre-industrial temperatures. (D) Resulting sea level rise. The model also allows Monte-Carlo simulations to generate the probability distributions of outcomes over important uncertainties such as climate sensitivity, carbon uptake, and sea level rise.

The core carbon cycle and climate sector of the model is based on Dr. Tom Fiddaman's 1997 MIT dissertation (29). The model structure draws heavily from Goudrian and Ketner (30) and Oeschger and Siegenthaler, et al. (31). The sea level rise sector is based on Rahmstorf (32, 33). In the current version of the simulation, temperature feedbacks to the carbon cycle are not included.

Model users determine the path of net GHG emissions (CO_2 from FF and land use, CH_4, N_2O, F-gases, and CO_2 sequestration, e.g, from afforestation), at the country or regional level, through 2100. The model calculates the path of atmospheric CO_2 and other GHG concentrations, global mean surface temperature, and sea level rise resulting from these emissions (Figure 2).

The user can choose the level of regional aggregation. Currently, users may choose to provide emissions inputs for one, three, six, or fifteen different blocs of countries, depending on the purpose of the session. Outputs may be viewed for any of these aggregation levels. Other key variables such as per capita emissions, energy and carbon intensity of the economy (e.g., tons C per dollar of real GDP), and cumulative emissions are also displayed.

The model allows users to test a wide range of policy proposals for future emissions. Users can specify emissions reductions at a chosen annual rate (e.g., x%/year, beginning in a specified year), a target for emissions as a fraction of a specified base year (e.g., x% below 1990 by 2050), or reductions in emissions intensity (e.g., reducing emissions per unit of real GDP x% below today's level by 2050). Users can select the years in which the policies would go into force, the target years, and other attributes to capture a wide range of policy proposals (Figure 3). Users may also simulate specific sets of commitments, such as those under discussion by national governments, or those proposed by academic or advocacy groups.



Important Features

C-ROADS emphasizes:

- Transparency: equations are available, easily auditable, and presented graphically.
- Understanding: model behavior can be traced through the model structure to determine the causal factors contributing to results; we don't say "because the model says so."
- Flexibility: the model supports a wide variety of user-specified scenarios at varying levels of complexity.
- Consistency: the simulator is consistent with historic data, the structure and insights from larger models, and the IPCC AR5.
- Accessibility: the model runs with a user-friendly graphical interface on a laptop computer in real time.

Figure 3. User options for specifying policy proposals for future emissions for a representative nation (US). Users can specify emissions reductions at an annual rate (A), as a fraction of a specified base year (B), or as a reduction in emissions intensity (C).

- Robustness: the model captures uncertainty around the climate outcomes associated with emissions decisions through Monte-Carlo simulations.
- The model can be readily revised and expanded based on user feedback and new developments in climate science, and as new data become available.

Simulation Validation

C-ROADS is not a substitute for larger integrated assessment models or detailed General Circulation Models (GCMs) (34). Rather, C-ROADS is designed to capture the key insights from such models and make them available for rapid policy experimentation.

The model has been subjected to a suite of rigorous tests, documented in the C-ROADS reference guide. Model output compares well against the output of large, disaggregated models, e.g., MAGICC (35), BERN (36), and MERGE (37), all used by the IPCC (17, 18, 26, 38) and the EMF (27). Specifically, the resulting concentrations of each well-mixed greenhouse gas, radiative forcings, and temperature output of C-ROADS has been found to align very closely under a range of emissions scenarios with the output of these models, most notably with those in the IPCC's AR5 (17, 18).

The Team

C-ROADS was developed by Climate Interactive, the MIT System Dynamics Group, and Ventana Systems as part of a multi-organization effort to make climate simulations useful to decision makers, enabling effective action to stabilize the climate.

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