Earth System
Dynamics

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Discussions

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Interactive comment on "A User-friendly Earth System Model of Low Complexity: The ESCIMO system dynamics model of global warming towards 2100" *by* J. Randers et al.

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The authors present ESCIMO, a dynamic earth system model focused on climate change. ESCIMO is designed to run on laptop computers in seconds so it can be used interactively in education and policy contexts. ESCIMO replicates recent climate history and the output of complex Earth System Models (ESMs). It is used to explore the response of the climate to various policies designed to limit future warming and climate change.

Overall, the ESCIMO model helps to fill a great need: providing scientists, policymakers, business leaders, educators, the media and the public at large with the ability to explore for themselves the dynamics of the climate and its response to policies to mitigate anthropogenic climate change. The model is ambitious and the analysis pre-

sented in the paper shows that it is capable of replicating the historical data for a range of important climate variables and the behavior of larger, more complex models when driven with similar assumptions for future emissions. At the same time, there is clear room for improvement in the model, the analysis and testing to build confidence in it, and the model presentation and interface so that it can be more easily understood and used.

ESCIMO builds on the widely-used C-ROADS climate model developed by MIT and ClimateInteractive.org (Sterman et al. 2012, cited in the references), and it is useful to compare the two since they are both designed to run in seconds or faster on ordinary laptops and to be used interactively by a wide range of audiences. Like C-ROADS and other EMICs or EMLCs (Earth system models of intermediate or low complexity), ESCIMO aggregates key state variables such as the CO2 and heat content of the atmosphere and oceans into a small number of compartments rather than providing the spatial resolution as found in AOGCMs or complex Earth system models. The higher level of aggregation allows the model to replicate the historical behavior of the climate and simulations of complex ESMs while retaining the ability to run in seconds.

Like C-ROADS, ESCIMO is a physics-based model containing a representation of the carbon cycle, the energy balance of the Earth including radiative forcing and heat fluxes between the atmosphere and ocean, and other key elements of the climate. ESCIMO adds additional structure not explicit in C-ROADS relating, for example, to surface albedo and clouds, while offering less detail in other areas. For example, ES-CIMO includes explicit compartments for carbon in fossil fuel reserves, the atmosphere, biomass, permafrost, the surface ocean, and the deep ocean. It does not distinguish between C in biomass and soils, as C-ROADS does, and it treats the deep ocean as a single compartment, while C-ROADS and many other EMICS represent the ocean as consisting of a number of layers to capture slow and imperfect mixing. C-ROADS aggregates carbon in soils and permafrost into a single compartment, while ESCIMO represents C in permafrost separately while aggregating soil carbon together with C in

living biomass. ESCIMO represents CO2, CH4, N2O and aggregated compartments for the "Kyoto" gases and "Montreal" gases, while C-ROADS represents more individual species of non-CO2 GHGs, each with its own budget, atmospheric stock, lifetime and impact on radiative forcing. ESCIMO also includes a representation of arctic sea ice cover and some additional geophysical detail. These features allow ESCIMO to capture more of the positive feedbacks that may contribute to sink saturation and enhanced CO2/CH4 emissions that can amplify the impact of anthropogenic emissions, and positive feedbacks such as the ice-albedo feedback that leads to arctic amplification (even though the model does not capture spatial detail).

The behavior of the ESCIMO model fits historical data well, including global mean surface temperature, CO2 and CH4 concentrations, sea level rise, arctic ice extent, heat flux to the ocean, radiative forcing and ocean pH.

The authors also compare the behavior of the model to the behavior of the CMIP5 model ensemble for RCP4.5. The fit is good. However, the authors should compare the behavior of ESCIMO to a much wider range of scenarios, including all the RCPs, to demonstrate that ESCIMO remains reasonable across a much broader set of assumptions for GHG emissions.

Curiously, in the "base" run showing model behavior through 2100 global GHG emissions peak around 2040 and fall nearly to zero by 2100. Such large declines in emissions would require significant policy interventions in nations around the world or dramatic technical breakthroughs in low carbon energy, or a dramatically lower rate of global economic (and perhaps population) growth. The Paris agreement reached at COP21, even if fully implemented, does not come close to such large emissions reductions (see e.g. https://www.climateinteractive.org/programs/scoreboard/). It is unusual to define a base run in such models that assumes such strong policy actions, actions that no nations have committed to make. That said, it should be relatively easy to run ESCIMO using alternative assumptions for future emissions that would still allow the ESCIMO to be compared to the behavior of other ESMs.

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The policy and sensitivity experiments presented in the paper show the potential for the use of ESCIMO. These include various emissions pathways, as well as representations of carbon capture and sequestration, sulfate aerosol injection, and others. The model is also used to simulate the impact of alternative assumptions about insolation, cloud behavior, and so forth.

Technical issues:

Assessing model fit: I agree with the discussion on p. 22 that R2 is not particularly useful as a measure of goodness of fit for the model, but the claim that it is sufficient to say that the fit is "or the order of $\pm 20\%$" is not appropriate. The authors should provide goodness of fit statistics in addition to the graphs in Figure 5 comparing simulated and actual behavior. Relevant goodness of fit statistics would include the Mean Absolute Error or Root Mean Square Error (MAE/RMSE) and measures of bias (systematic differences between the data and model; there are some, for example, the model is consistently low compared to the data for arctic sea ice extent).

Documentation: The authors have provided the model, which is written in the Vensim simulation language, enabling anyone to download the model, examine the equations and run the model using the free Vensim Model Reader. They also provide the output of the Argonne National Laboratory model documentation tool, which provides an hyperlinked annotated summary of the model and equation listing. This is excellent practice.

However, the model does not fully conform to the documentation standards for dynamic models: the HTML documentation of the model shows that 64% of the equations/parameters in the model do not include explanatory comments or other documentation, and that 8% of the variables do not appear in any view of the Vensim model. The Vensim software returns 371 errors when the dimensional consistency check is run. These must be corrected. The model diagrams in Vensim are laid out poorly, making it more difficult to understand the structure of the model. The model should be divided into more views, each named appropriately, and the diagram showing the

structure of each view should be laid out to be more readable. There should be a much better dashboard or cockpit with key parameters and policy levers available for sensitivity and policy testing, along with the graphs showing the key outputs.