Elements: Cyberinfrastructure for streamlining coupled, simplified climate modeling within the Community Earth System Model

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Introduction

With the increasing pressure to accurately project the future of our climate system, global climate models have increased dramatically in their complexity over the last few decades to become the Earth System Models (ESMs) of today. They now represent a massive array of complex atmospheric, oceanic, cryospheric, biospheric and chemical processes. The inclusion of such complexity is critical for the accurate projection of future climate and associated impacts. However, this complexity has a number of drawbacks. It adds substantial computational expense, making it increasingly challenging for an individual researcher to perform targeted experiments to probe a particular feature. The massive complexity also makes it challenging to design a reasonable experiment to isolate individual mechanisms or processes. The overall result is that as complexity increases, so too does the gap between simulation and understanding.

For fundamental climate science, simpler models and idealized experimentation have advantages over state-of-the-art simulations with prediction-capable ESMs in several regards (**Figure 1**). Simpler models are often easier to analyze and can take advantage of more advanced and specialized numerical methods. In addition to their scientific utility they are also often well-suited for the development and testing of diagnostic tools.

Community Land Model (CLM), version 5 | **Simple Land Interface Model (SLIM)**

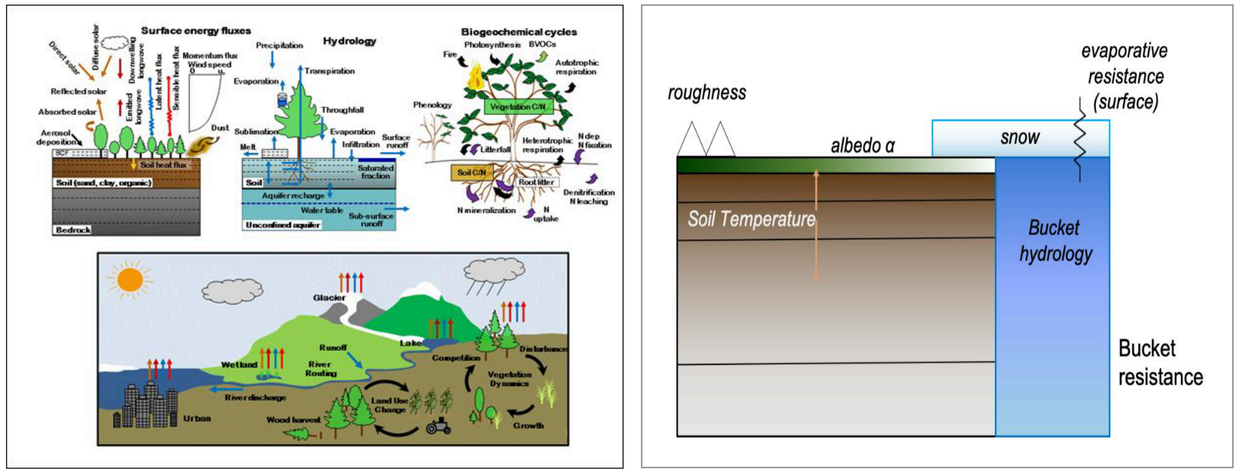

Figure 1: State-of-the-art earth system model components like the CLM (left panel) simulate a large number of processes and their physical and chemical couplings. For fundamental climate science many of these features are unnecessarily complex and expensive, and cheaper and simpler alternatives like SLIM (right panel) are sufficient.

Motivation

The community of simpler model users is broad, engaged, and highly multidisciplinary. However, this community presently lacks a rallying point for developing a sustainable modeling suite that can seamlessly switch between minimalist and state-of-the-art dycores and physics packages. NCAR is the center of open-source Earth System Modeling in the U.S.A. and has a long history of facilitating the development of community models that are used both for state-of-the-art climate projections and as research tools by the university community. The Community Earth System Model (CESM) is one of NCAR's flagship models and forms a nexus for NCAR's strong links with the university community. Through the development of cyberinfrastructure and research tools, CESM represents the ideal platform on which to build idealized configurations of the coupled ocean-land-atmosphere system with a range of simplifications (**Figure 2**).

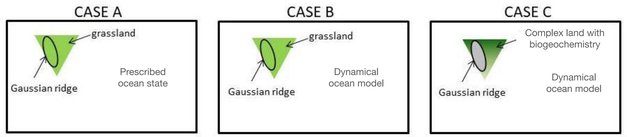

Figure 2: Example hierarchical configuration of an idealized Earth system with simplified land and ocean dynamics.

This CSSI grant (**NSF Award# 2004575**) is funding the development of new capabilities in the cyberinfrastructure of NCAR's Community Earth System Model (CESM) to enable scientists to easily create and configure coupled experiments. This infrastructure includes a new simpler model query tool and user-friendly toolchain that allows idealized CESM experiments to be readily accessed and experiments to be easily customized.

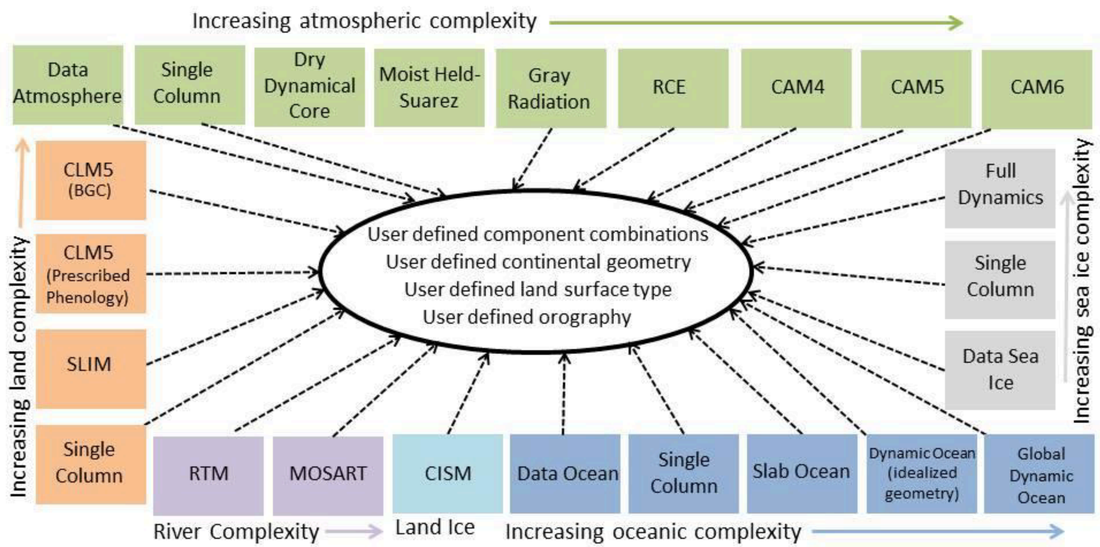

Figure 3: CESM model components ranked by complexity. The toolchain being supported by this CSSI grant enables mix-and-match capability for performing novel climate science research.

The CESM coupling framework provides the ideal software infrastructure on which to build a "rally point" for simpler model users, as it is actively maintained, officially supported by NCAR, is connected with a very large user base in the academic community, and offers an inherent mix-and-match capability that enables fundamental research across all branches of climate science (**Figure 3**). A Python-based toolchain is currently under development that will enable rapid setup and customization across many levels of complexity (**Figure 4**).

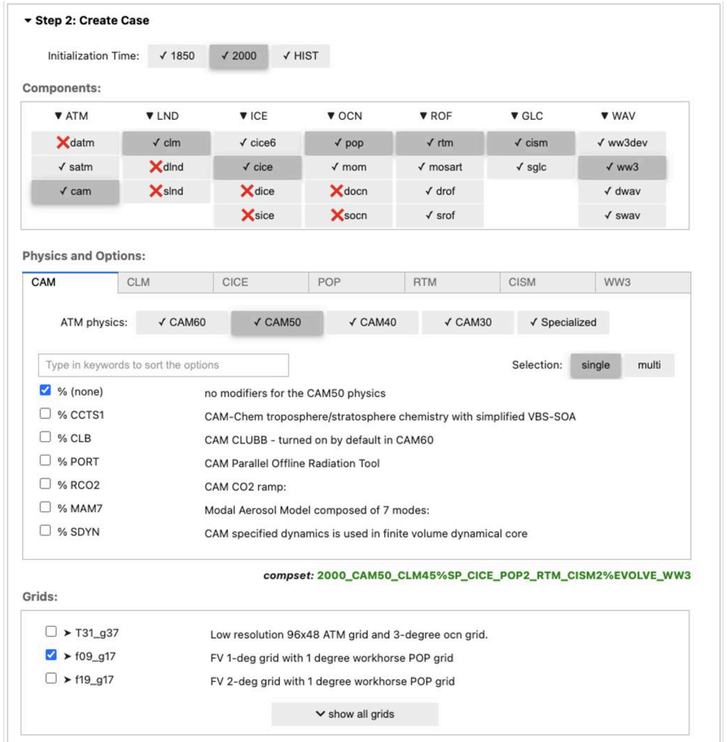

Figure 4: Prototype graphical user interface for CESM model query tool and customization toolchain.

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