Introduction

It has become common to compare and contrast the output of multiple global climate models (GCMs), such as in the Climate Model Intercomparison Project 5 (CMIP5). However, intercomparisons of the software architecture of GCMs are almost nonexistent. In this qualitative study of seven GCMs from Canada, the United States, and Europe, we attempted to fill this gap in research. By examining the model source code, reading documentation, and interviewing developers, we created diagrams of software structure and compared metrics such as encapsulation, coupler design, and complexity.

Component-Based Software Engineering

A global climate model is really a collection of models (components), each representing a major realm of the climate system, such as the atmosphere or the land surface. They are highly encapsulated, for stand-alone use as well as a mix-and-match approach that facilitates code sharing between institutions.

This strategy, known as component-based software engineering (CBSE), pools resources to create high-quality components that are used by many GCMs. For example:

- IPSL uses a modified version of GFDL’s ocean model, MOM.
- HadGEM3 and CESM both use CICE, a sea ice model developed in a third institution (Los Alamos).

Contrary to CBSE goals, there is no universal interface for climate models, so components need to be modified when they are passed between institutions. Furthermore, the right to edit the master copy of a component’s source code is generally restricted to the development team at the hosting institution. As a result, many different branches of the software develop.

A drawback to CBSE is the fact that, in the real world, components of the climate system are not encapsulated. For example, how does one represent the relationship between sea ice and the ocean? Many different strategies exist:

- CESM: sea ice and ocean are completely separate components.
- IPSL: sea ice is a sub-component of the ocean.
- GFDL: sea ice is an interface to the ocean. All fluxes to and from the ocean must pass through the sea ice region, even if no ice is actually present.

Conclusions

While every GCM we studied shares a common basic design, a wide range of structural diversity exists in areas such as coupler structure, relative complexity between components, and levels of component encapsulation. This diversity can complicate model development, particularly when components are passed between institutions. However, the range of design choices is arguably beneficial for model output, as it inadvertently produces the software engineering equivalent of perturbed physics (although not in a systematic manner).

Additionally, architectural differences may provide new insights into variability and spread between model results. By examining software variations, as well as scientific variations, we can better understand discrepancies in GCM output.

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- COSMOS: Michael Eby (University of Victoria)
- GFDL: Gary K. Strand (NCAR), Arnaud Caudal, Marie-Alice Foujols, and Anne Cazet
- CESM: English, modern version of the model (code), and the ocean component.
- HadGEM3: ocean and ice coupling.
- GFDL: ocean and ice coupling.
- IPSL: ocean and ice coupling.
- COSMOS: ocean and ice coupling.

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