Uncertainties in Climate Projections: The Case for a Process-Oriented Evaluation of Earth System Models

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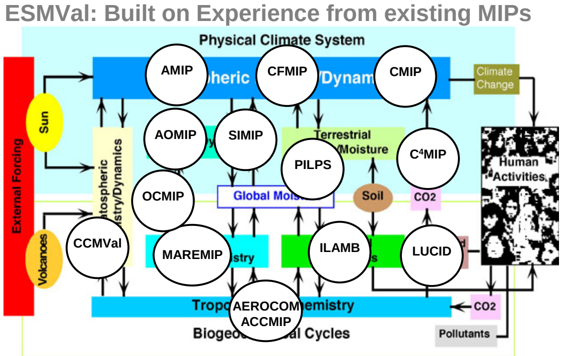
Abstract. The ability to understand and project future climate is fundamental to society. Currently, large uncertainties in climate projections exist due to uncertainties in physical climate feedbacks simulated by coupled Atmosphere-Ocean General Circulation Models (AOGCMs) and additional feedbacks that arise from complex interactions between climate and other components of the Earth System as simulated by Earth System Models (ESMs). Here we review important climate feedbacks and argue for a process-oriented evaluation in addition to the evaluation of Essential Climate Variables (ECVs). A set of core processes that are related to important feedbacks in the climate system is structured around three major topics (physical climate, global carbon cycle, and atmospheric composition). Each process is associated with one or more model diagnostics and with relevant observational datasets that can be used for the evaluation. Following this approach, outputs from individual component models and from coupled ESMs can be confronted with observations in a consistent and quantitative way. The review suggests that continued investment in systematic and consistent model evaluation will allow a rigorous assessment of the strengths and weaknesses of ESMs and should lead, on the long-term, to a more quantitative estimate of uncertainties in climate projections and to improved ESMs with demonstrably enhanced projection skills. This approach will also fully exploit the combined use of models and observations to better understand the climate system.

ESMVal: Built on Experience from existing MIPs

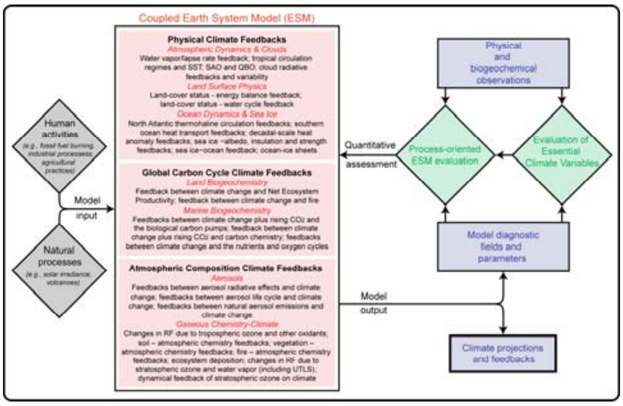


(from Earth System Science: An Overview, NASA, 1988)

Framework for ESM Evaluation

following the CCMVal approach (Eyring et al. 2005)

(1) evaluation of GCOS Essential Climate Variables (ECVs); (2) processes-oriented evaluation.



Example: Chemistry-Climate Model Validation Activity (CCMVal)

Performance Metrics (Waugh & Eyring, 2008)

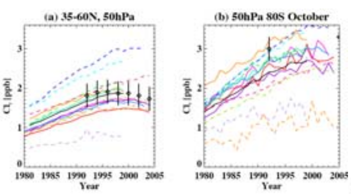
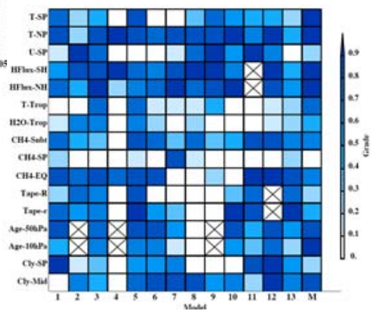


Figure 1. Times series of 50 hPa Cl_y for (a) annual mean 35-60N, and (b) October-mean 80S from CCMs (curves) and observations (symbols). Figure on the right shows grades for these two and other tests.

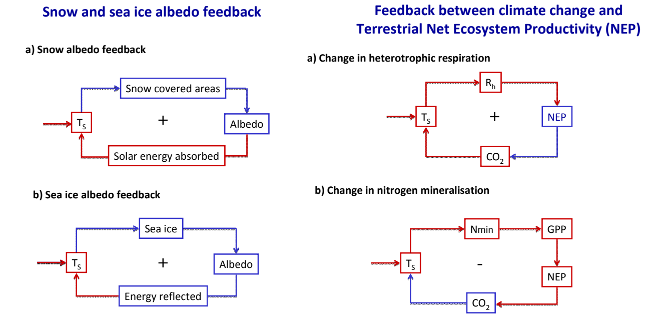
Climatological mean metric g:

$$g = 1 - \frac{1}{n_g}\frac{|\mu_{\rm model} - \mu_{\rm obs}|}{\sigma_{\rm obs}}$$



- ❑ Analysis quantifies several features noted in Eyring et al. (2006).
- ❑ Provides benchmark for evaluation of CCMVal-2 models (SPARC CCMVal Report, 2010).

Examples of Physical and Biogeochemical Climate Feedbacks



- **Physical climate feedbacks**, in particular fast cloud feedbacks, have been confirmed as a primary source for the spread of climate model estimates of the equilibrium warming for a doubling of CO_2 concentration.
- **Biogeochemical processes and feedbacks** also represent a major impediment to our ability to make reliable climate projections for the 21st century. The impact of climate change on carbon and nitrogen cycles processes on atmospheric CO_2 concentration is still a major source of uncertainty in the emission-concentration-climate pathways.
- **Atmospheric composition feedbacks** may emerge from climate impacts on methane emissions from wetlands or permafrost soils, on natural emissions of nitrous oxide from soils, on ozone concentrations mediated by multiple chemical pathways, and on emissions of natural aerosols.

Example: International Land Model Benchmarking (ILAMB)

1) Carbon Cycle Metrics (Cadule et al., 2010)

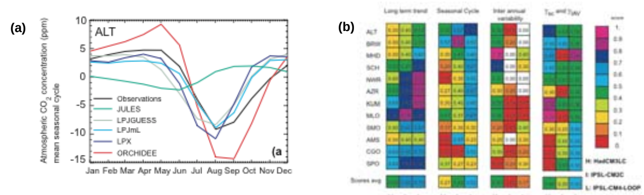
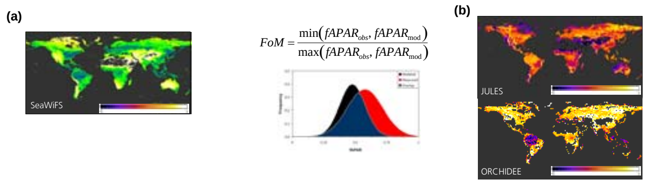


Figure 2. (a) Simulated vs. observed climatological seasonal cycle of atmospheric CO_2 at a high latitude station (Alert), representative of the mid- and hi-latitude terrestrial ecosystems carbon seasonal dynamic. (b) Coupled climate-carbon cycle models evaluation metric. Models are evaluated against atmospheric observations at 12 stations for seasonal, interannual and long term trends characteristics.

- ❑ CO_2 analysis quantifies land (and ocean in coupled mode) carbon cycle characteristics on multiple timescales.
- ❑ Other ILAMB diagnostics include vegetation phenology and surface water budget evaluation



$$FoM = \frac{\min(fAPAR_{obs}, fAPAR_{mod})}{\max(fAPAR_{obs}, fAPAR_{mod})}$$

Figure 3. Evaluation of leaf phenology through comparison of models with satellite derived fAPAR (a) SEAWIFS maximum fAPAR. (b) Figure of Merit (FoM) of simulated fAPAR for JULES and ORCHIDEE DGVMs.

References and Acknowledgement

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