Preliminary Results from a Pan-CMIP OSSE

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Outline

• Update on Strengthening International Collaborations.
• Overview and goals of a pan CMIP OSSE capability.
• Pan CMIP OSSE development update.
  – First phase models.
  – Vertical interpolation.
• Preliminary results from time-series analysis
• Summary.
• Discussion.
International Collaborations

- Building off PNAS (LBNL), GRL (Umich), and JC (Umich) papers on science value of surface emissivity measurements, collaboration with UK partners strengthened through a funded NERC proposal.

- Investigation will analyze CIRCCREX data over Greenland and the Denmark Strait and retrieve far-IR surface emissivity over ice-sheet and ocean.
  - Compare with calculations in emissivity database.

- Investigation will quantify ice-emissivity feedback within models.
  - Preliminary diagnosis using kernel techniques for CESM1.2 is +0.07 W/m$^2$/K (~1/3 ice albedo feedback), but is state-dependent and will decrease with increasing H$_2$O.
  - Framework for online feedback analysis within CESM has been built.

- Investigation will improve understanding of the controls on the polar radiative energy budget.
Pan CMIP5 OSSE Capability

• At Spring 2015 CLARREO meeting, Berkeley group received guidance to focus on development of a pan CMIP5 OSSE capability in support of CLARREO.

• Berkeley group will build off current OSSE, develop model-agnostic OSSE capability for SW reflectance and LW radiance for CMIP5 and CMIP6 models.

• Goals:
  • Determine relationship between model ECS and pan-spectral trends.
  • Establish pan-spectral variability across a broad range of climate models, with an eye towards observational constraint.
  • Support Decadal Survey 2017-2027 discussion.
The Coupled Model Intercomparison Protocol (CMIP5) is the basis for AR5. It includes a new set of simulations for the historical record: 1850 - 2005.
Progress Report

• First Phase Models Overview.

• Data Acquisition.

• Horizontal Interpolation.

• Vertical Interpolation.

• Preliminary Results.

• Execution on NAS facilities.
First Phase Models

- Model vertical-coordinate idiosyncrasies and data availability from Earth System Grid and mirroring servers have limited the feasible range of models for the first phase of the pan CMIP OSSE.
  - First phase contains nearly complete range of diagnosed ECS across full ensemble.

<table>
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<tr>
<th>Model Name</th>
<th>Diagnosed ECS (°K/2xCO2)</th>
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<tr>
<td>CESM1-CAM5</td>
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Data Acquisition

• Thermodynamic and condensate profiles downloaded from Earth System Grid and its mirrors.

• MODIS 16-day averages of 7 bands of BRDF and albedo, and 6 bands of emissivity gathered for 2003-2014.

• Model-agnostic NCL and Matlab routines developed to concatenate fields into appropriate input files for OSSE.
  • If you expect to work with multiple CMIP5 or CMIP6 fields, these routines will save you time.
Boundary Condition Horizontal Interpolation

• Key component of Berkeley’s pan-spectral OSSE is surface boundary conditions built off of MODIS land-surface products.
• Gridding required for MODIS Climate Modeling Grid (CMG) data for each model’s horizontal resolution.
  • Highly computationally-intensive, but parallelizable.
Vertical Interpolation

• OSSE is now model-agnostic for horizontal resolution, but it is less flexible for vertical resolution and inflexible on using layers, instead of levels.

• Vertical interpolation routines are required for thermodynamic and condensate profiles.
  • Routines need to be mathematically stable and mass-conserving with no edge cases.
  • Central challenge is that enormous heterogeneity used for vertical grids in climate model output.
Heterogeneous Vertical Grids Used in CMIP5

• Input to OSSE is CMIP5 climate model output assessed in the IPCC AR5.

• Difficulties in building complete thermodynamic + cloud profiles for OSSE from CMIP5:
  • Hi-res. thermodynamic profiles mapped to lo-res mandatory pressures
  • Hi-res. Cloud data is left on native model grid (differs model to model)

• We tried two alternates for interpolating these data to common grid:
  • Interpolate clouds to mandatory pressures
  • Interpolate thermodynamic profiles back to native model clouds

• Both interpolation schemes were strictly mass conservative.

• 1\textsuperscript{st} scheme failed, 2\textsuperscript{nd} scheme worked, and we are using 2\textsuperscript{nd} scheme.
Vertical Interpolation Interpolating Clouds to Mandatory Levels -- Reason for Failure

- Thermodynamic profiles = unphysical fill values where surface pressure less than mandatory level pressure in CMIP5 archive.
Model Differentiation: MIROC-ESM (4.7°) – MRI-ESM1 (2.1°)

- MIROC-ESM and MRI-ESM1 span the range of ECS diagnosed for CMIP5.
- Under RCP8.5, perfect broadband measurements starting in 2005 can begin to exclude one of these models with 15 years’ of data.
Model Differentiation: MIROC-ESM (4.7°) – CanESM2 (3.6°)

- MIROC-ESM and CanESM2 differ in ECS by 1°.
- Under RCP8.5, perfect broadband measurements starting in 2005 can begin to exclude one of these models with 20-25 years’ of data.
Model Differentiation: T85 CCSM3 (2.7°) – T31 CCSM3 (2.3°)

- Two resolutions of CCSM3 differ in ECS by 0.4°.
- Under RCP8.5, perfect broadband measurements starting in 2005 can begin to exclude one of these models with 20-25 years’ of data.
TOA Fluxes

- CMIP-model agnostic OSSE is mechanically working on NAS systems.
- Preliminary output of fluxes from CAM RT and MODTRAN show agreement in LW within 3 W/m² (clear-sky) and 10 W/m² (all-sky).
- More debugging on the timing system is still needed for the SW.
Benchmark Testing

• Multiple scattering line-by-line radiative transfer calculations (LBLRTM+CHARTS) coupled to a database of ice cloud optical properties enable versatile spectral flux calculations.

• NERSC and NAS resources take advantage of embarrassingly parallel nature of these calculations. Burst-buffer will address disk-limitations that hinder scaling.
Additional Opportunities with a Pan-CMIP OSSE

• The pan-CMIP OSSE produces radiometrically-rigorous radiative transfer calculations across the CMIP, thereby enabling additional science.

  • Realistic evaluation of the spatial distribution of radiative forcing from greenhouse gases and aerosols across a multi-model ensemble in realistic all-sky conditions.

  • Goal is to contribute to more realistic assessment of forcing for IPCC AR6.

• Recent 1M CPU-hour NASA supercomputing resources award for runs on Pleiades can enable this science.
Summary

• International collaboration with Imperial College and UMich partners yielding exciting science in the far-IR.

• A fully agnostic pan CMIP OSSE is now working.
  – Some additional testing and benchmarking still needed.
  – Preliminary time-series analysis suggests that CLARREO-like measurements will take less than 15 years’ to exclude a model where ECS is off by 2.5°K/2xCO₂.
  – Some debugging is still necessary in the SW.
  – Integration of SW and LW PCRTM will then proceed.

• Additional scientific opportunities enabled by the pan-CMIP OSSE, especially for IPCC AR6.

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