CESM OMWG Development Timeline – Path Towards CESM2

Focus Topics

Algorithmic Developments
- z*; Robert filter; Natural boundary conditions
- New horizontal and vertical grids

Diabatic Processes
- CVMix in POP2
- IDEMIX (?)
- Tidal mixing; Near-inertial wave mixing; KPP changes; Additional CPT parameterizations
- Langmuir (WaveWatch) Phase I (prognostic)
- Langmuir (WaveWatch) Phase II (ustokesdiag, but not u*)

Adiabatic Processes
- mesoscale parameterization modifications; Anisotropic mesoscale (constant diffusivity)
- Anisotropic mesoscale

Coupling
- Diurnal cycle for upper ocean
- Estuary parameterization

Metrics and Diagnostics

01/14 — 06/14 — 01/15 — 06/15 — 01/16

Arrows indicate completion points for more detailed evaluation with BGCWG

Algorithmic Developments [Participants: Bryan (lead), Danabasoglu, Hecht, Lindsay, Maltrud, Tseng, Yeager]:

i) Introduction of a conservative Robert time filter to replace the time-averaging time step;

ii) Implementation of a new vertical coordinate system, z*;

iii) Elimination of virtual salt fluxes in favor of true freshwater surface fluxes;

iv) Making partial bottom cell (PBC) treatment fully operational;

v) Considering both slightly finer horizontal resolution than currently used and increased vertical resolution.

vi) New barotropic solvers

Diabatic Processes [Jayne (lead), Bryan, Danabasoglu, Fox-Kemper, Gent, Jochum, Large, Levy, Long]:

i) New and modified tidal mixing and near-inertial wave mixing parameterizations;

ii) Langmuir mixing parameterization;

iii) Development and incorporation of the CVMix (Community ocean Vertical Mixing) modules into POP2;

iv) Revisiting and modifying some parts of the K-Profile Parameterization (KPP);

v) Considering incorporation of additional (and new) parameterizations emerging from the Climate Process Team (CPT) activities on internal mixing or from the general OMWG community, e.g., Internal Wave Dissipation, Energy, and Mixing (IDEMIX).

Adiabatic Processes [Gent (lead), Danabasoglu, Fox-Kemper, Long, Moore]:

i) changes in the prescriptions for both the isopycnal and thickness diffusivity coefficients used in the Gent and McWilliams mesoscale mixing parameterization;

ii) implementation of an anisotropic version of this parameterization.

Coupling and Boundary Conditions [Large (lead), Bailey, Bryan, Tseng]:

i) evaluation and use of a newly developed coupler scheme for diurnal cycling of the near-surface ocean temperature;

ii) incorporation of an estuary parameterization.

Metrics and Diagnostics [Danabasoglu (lead), Bertini, Mickelson, Levy]: In response to an earlier request from the CESM SSC, the OMWG had prepared and submitted (to the SSC) a short document summarizing our current practice of model evaluation along with a list of desired redesign and improvements of the OMWG metrics and diagnostics. The goal here is to start making some progress.

Status

Robert Filter (RF), z*, and PBC

Mathew Maltrud (LANL) and Tony Craig

Accomplishments:

- RF and z* modifications added to the "rfzstar_ncar" branch based on cesm1_3_beta10,
- Branch is bit-for-bit with trunk tag for out-of-the-box configurations,
- RF and z* exact restarts working,
- RF and z* tested with compiler DEBUG flags,
- z* leverages (requires) the partial bottom cells (PBC) code; PBC code testing ongoing with a goal to migrate to the PBC-based code for use in all cases even when full bottom cells are on and z* is off. This provides a much cleaner implementation.

Status

Robert Filter (RF), z*, and PBC

Mathew Maltrud (LANL) and Tony Craig

Still to be done:

- Science validation for RF and z*,
- Continue validation of PBC code with the goal of merging PBC and non-PBC implementations (likely needs some modifications to overflows, mesoscale and submesoscale parameterizations),
- Get z* and PBC working with overflows,
- Get z* working with freshwater boundary conditions,
- Test and validate z* and PBC with other code features,
- Review and consider removing non-z* code branch to simplify implementation (needs a non-z* capability within the z* code),
- Code cleanup:
  - Formatting (indentation) of new code
  - PBC logic when PBC code is validated with all features
  - z* logic if z* code can support non-z* mode

Community Ocean Vertical Mixing (CVMix) Project

Michael Levy, Gokhan Danabasoglu, and Bill Large

NCAR

Stephen Griffies, Alistair Adcroft, and Robert Hallberg

GFDL

Todd Ringler and Doug Jacobsen

LANL

CVMix

- CVMix is a software package that aims to provide transparent, robust, flexible, well documented, and shared Fortran source codes for use in parameterizing vertical mixing processes in numerical ocean models.
- The project is focused on developing software for a consensus of first-order closures that return a vertical diffusivity, viscosity, and a non-local transport (if needed), with each variable dependent on prognostic model fields.
- CVMix modules are written as kernels designed for use in a stand-alone manner or in a variety of Fortran ocean model codes such as MPAS-O, MOM, and POP.
- Code development occurs within a community of scientists and engineers who make use of CVMix modules for a variety of ocean codes and research needs.

Status

- CVMix in POP2, MPAS-O, and MOM6
- Round-off differences between the KPP versions in POP2 and POP2+CVMix
- Performing idealized test case simulations across all three models
- Beta version has been available upon request

- Document to be finalized
- Enhanced error checking and message logging

Status

evaluation and use of a newly developed coupler scheme for diurnal cycling of the near-surface ocean temperature …… DONE

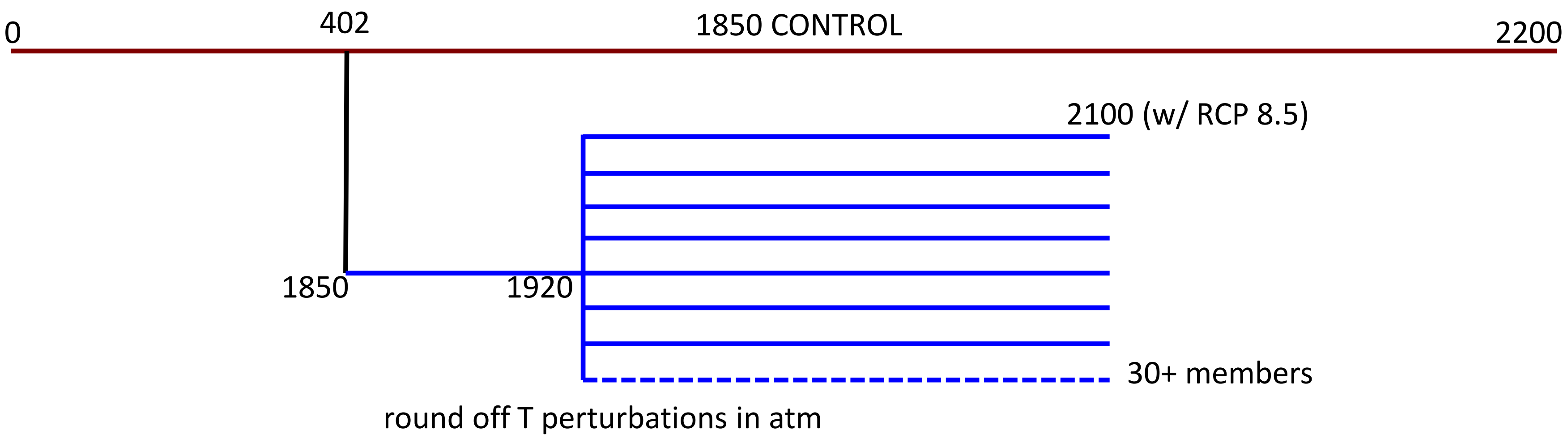
Large and Caron, 2015: Diurnal cycling of sea surface temperature, salinity, and current in the CESM coupled climate model. *J. Geophys. Res.* (submitted)

- The implementation impacts only the coupler.
- Tested and evaluated in AMIP-style integrations.
- Evaluation in fully-coupled configurations will be performed.

A Community Project: Extending Large Ensemble Simulations to Include Uncertainty due to Ocean Initial Conditions

Background: A set of CESM1 Large Ensemble (LE) simulations have been performed as a CESM community project (Kay et al., 2015, *BAMS*). The primary goal was to investigate climate change in the presence of internal climate variability.

- CESM1-CAM5; nominal 1^{o} resolution models; with passive BGC



Spread and uncertainty in the LE simulations are expected to be larger when also the oceanic initial conditions are varied.

A new CESM community project has been proposed to perform a set of ensemble experiments to complement our existing LE by including uncertainty resulting from initialization with different ocean states.

An allocation equivalent to integrating CESM-LE configuration for 2500 years has been awarded.

Largely follows the already-established protocol for running such LE simulations.

A proposal for initialization of the ocean model:

- Simply start from 1850 CONTROL initial conditions for all component models.
- Consider initial states within ~100 years of year 402 to use similar mean states as in the existing LE simulations.
- Because AMOC is thought to play a major role in climate variability, particularly on decadal time scales, choose ocean initial conditions to sample various AMOC states, e.g., strong, weak, declining from strong, increasing from weak, and near-neutral AMOC states.
- 10 members integrated for the 1851 – 2100 period.

U.S. CLIVAR Climate Process Teams (CPTs)

CPTs are highly collaborative projects involving teams of theoreticians, observationalists, process modelers, and coupled climate modelers formed around specific issues or key uncertainties in coupled climate model systems and their components.

Climate Process Modeling and Science Teams: Motivation and Concept, U.S. CLIVAR SSC, 2002, U.S. CLIVAR Office Report 2002-1.

CPT Objectives

- Expedite the transfer of theoretical and practical process-understanding into improved treatment of those processes in climate model systems, and demonstrate, through testing and diagnostics, the (climate) impact of these improvements;
- Parameterizing missing unresolved processes / physics in climate models and advancing our understanding of how particular processes impact the climate system;
- Identify additional process study activities necessary to further refine climate model fidelity;
- Develop requirements for sustained observations needed by climate model systems.

Some Guidelines:

- For maximal impact and assessment of robustness, CPTs should explicitly involve more than one climate model; but the number of models should not be so large that CPTs would result in an inter-comparison project, i.e., CPTs are not just another MIP!
- No new observations;
- Success of the CPTs will be measured not only by advances in knowledge, i.e., publications, but more importantly by its practical productivity as evidenced by development of new capabilities and products;
- Readiness element.

CPT Awards

First Round - 2003:

1. Low-Latitude Cloud Feedbacks on Climate Sensitivity
2. Ocean Eddy Mixed-Layer Interactions
3. Gravity Current Entrainment

Second Round 2010:

1. Internal-Wave Driven Mixing in Global Ocean Models
2. Ocean Mixing Processes Associated with High Spatial Heterogeneity in Sea Ice and the Implications for Climate Models
3. Cloud Parameterization and Aerosol Indirect Effects
4. Stratocumulus to Cumulus Transition

In anticipation of a third round of CPTs .....

CPT Review Committee of the US CLIVAR Process Study Model Improvement (PSMI) Panel: Amala Mahadevan, Aneesh Subramanian, and Caroline Ummenhofer;

Questionnarie to seven modeling centers / groups:

- NCAR,
- NOAA GFDL,
- NOAA NCEP,
- NASA GISS,
- NASA GMAO,
- DoE ACME,
- ONR NRL

Responses received from all (summarized here);

A CPT scoping workshop under consideration;

Anticipating call for proposals in 2015.

Coupled Model Inter-comparison Project phase 6 (CMIP6): Organization, Design, and Timeline

Based on information and slides from
- Veronika Eyring (CMIP Panel chair)
- Meehl et al. (2014, EOS, vol. 95, 77-84)
- discussions at the WGCM (Working Group on Coupled Modeling) meeting (October 2014)

Please see the CMIP Panel website for additional information and updates:
http://www.wcrp-climate.org/index.php/wgcm-cmip/about-cmip

Contact for questions: CMIP Panel Chair Veronika Eyring
e-mail: Veronika.Eyring@dlr.de

Scientific Background for CMIP6 Design

The scientific background for CMIP6 is the six WCRP Grand Challenges plus a theme encapsulating questions related to biogeochemical forcings and feedbacks:

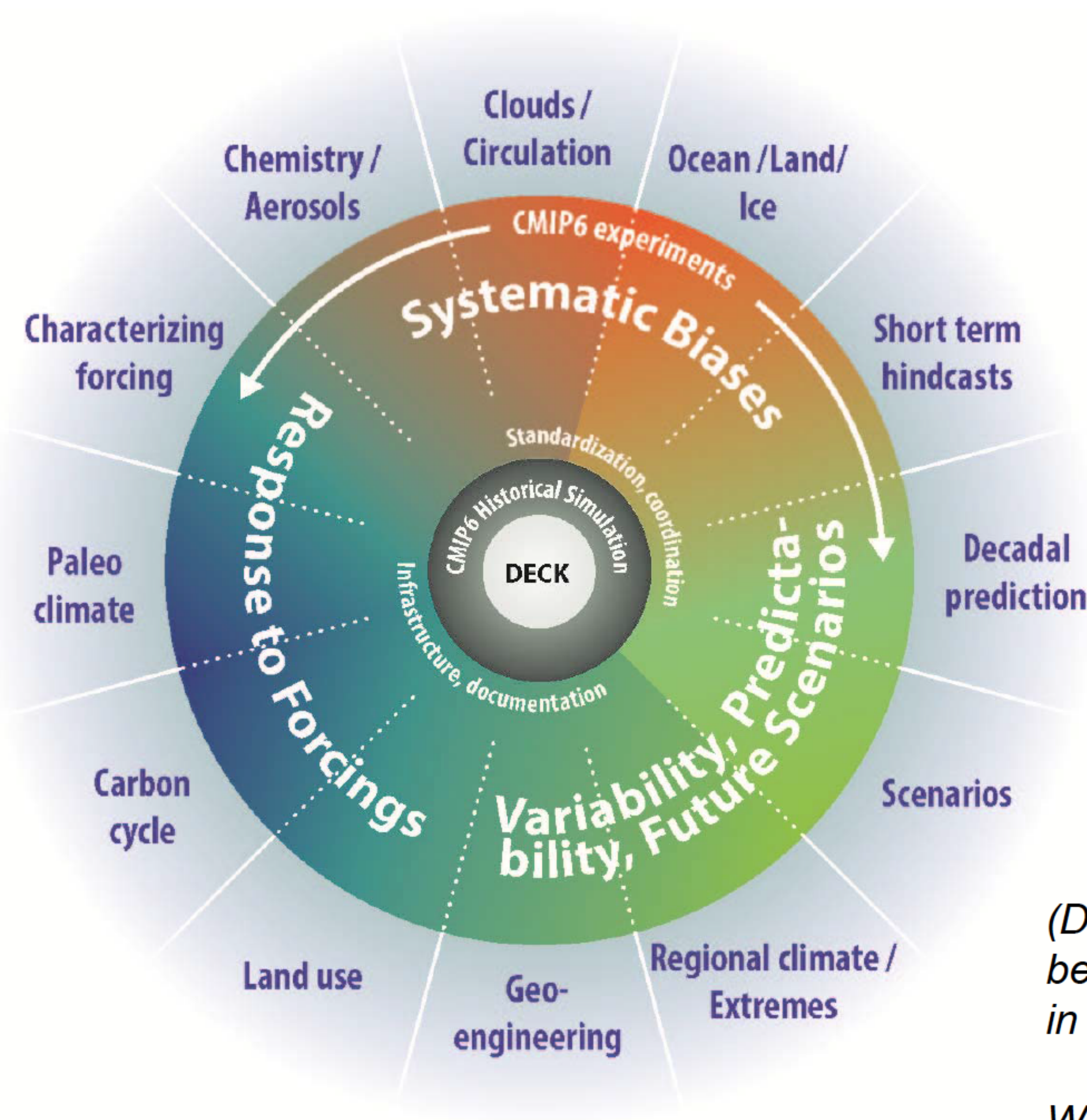
1. Clouds, Circulation, and Climate Sensitivity
2. Changes in Cryosphere
3. Climate Extremes
4. Regional Climate Information
5. Regional Sea Level Rise
6. Water Availability
7. Biogeochemical forcings and feedbacks (AIMES & WGCM)

The specific experimental design is focused on three broad scientific questions:

1. How does the Earth System respond to forcing?
2. What are the origins and consequences of systematic model biases?
3. How can we assess future climate changes given climate variability, predictability, and uncertainties in scenarios?

AIMES: Analysis, Integration, and Modeling of the Earth System

DECK: Diagnosis, Evaluation, and Characterization of Klima



DECK (entry card for CMIP)

i. AMIP simulation (~1979-2014)
ii. Pre-industrial control simulation
iii. 1%/yr CO_2 increase
iv. Abrupt $4xCO_2$ run

CMIP6 Historical Simulation (entry card for CMIP6)

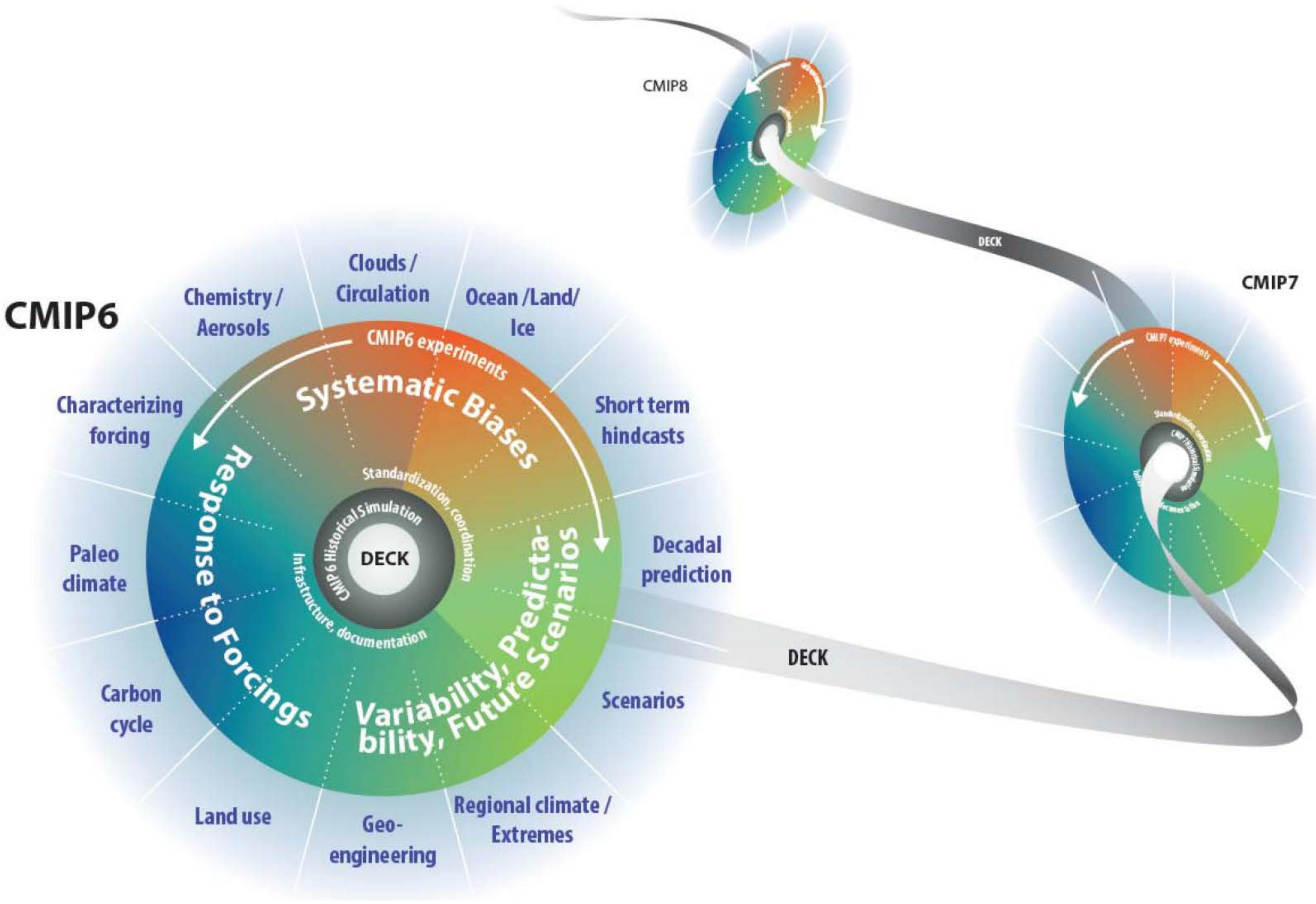
v. Historical simulation using CMIP6 forcings (1850-2014)

(DECK & CMIP6 Historical Simulation to be run for each model configuration used in the subsequent CMIP6-Endorsed MIPs)

With proto-DECK experiments (LMIP,OMIP etc.) in CMIP6 Tier1

Note: *The themes in the outer circle of the figure might be slightly revised at the end of the MIP endorsement process*

CMIP Continuity



The DECK experiments are chosen to

1. provide continuity across past and future phases of CMIP,
2. evolve as little as possible over time,
3. be well-established,
4. be part of the model development cycle.

The CMIP Phase X Historical Simulation is chosen to

1. serve as a benchmark for CMIP6-Endorsed MIPs
2. use the specific forcings consistent with Phase X of CMIP
3. be decoupled from model development cycle if needed.

MIPs that have applied for CMIP6 endorsement (02 December 2014)

	Short Name of MIP	Long Name of MIP
1	**AerChemMIP**	Aerosols and Chemistry Model Intercomparison Project
2	**C4MIP**	Coupled Climate Carbon Cycle Model Intercomparison Project
3	**CFMIP**	Cloud Feedback Model Intercomparison Project
4	**DAMIP**	Detection and Attribution Model Intercomparison Project
5	**DCPP**	Decadal Climate Prediction Project
6	**ENSOMIP**	ENSO Model Intercomparison Project
7	**FAFMIP**	Flux-Anomaly-Forced Model Intercomparison Project
8	**GeoMIP**	Geoengineering Model Intercomparison Project
9	**GMMIP**	Global Monsoons Model Intercomparison Project
10	**HighResMIP**	High Resolution Model Intercomparison Project
11	**ISMIP6**	Ice Sheet Model Intercomparison Project for CMIP6
12	**LS3MIP**	Land Surface, Snow and Soil Moisture
13	**LUMIP**	Land-Use Model Intercomparison Project
14	**OCMIP6**	Ocean Carbon Cycle Model Intercomparison Project, Phase 6
15	**OMIP**	Ocean Model Intercomparison Project
16	**PDRMIP**	Precipitation Driver and Response Model Intercomparison Project
17	**PMIP**	Palaeoclimate Modelling Intercomparison Project
18	**RFMIP**	Radiative Forcing Model Intercomparison Project
19	**ScenarioMIP**	Scenario Model Intercomparison Project
20	**SolarMIP**	Solar Model Intercomparison Project
21	**VolMIP**	Volcanic Forcings Model Intercomparison Project
	Diagnostic MIPs (i.e., no proposed experiments rather requesting that certain output is archived and/or contributing to the evaluation and analysis in a coordinated manner)	
22	**CORDEX**	Coordinated Regional Climate Downscaling Experiment
23	**DynVar**	Dynamics and Variability of the Stratosphere-Troposphere System
24	**GDDEX**	Global Dynamical Downscaling Experiment
25	**SIMIP**	Sea-Ice Model Intercomparison Project
26	**VIAAB**	VIA Advisory Board for CMIP6

Ocean Model Inter-comparison Project (OMIP)
a.k.a. Coordinated Ocean – ice Reference Experiments phase II, CORE-II
CLIVAR Ocean Model Development Panel (OMDP) & Friends

An experimental protocol for ocean – sea-ice coupled simulations forced with inter-annually varying atmospheric data sets for the 1948-2007 period (Large and Yeager 2009). This effort is coordinated by the CLIVAR Ocean Model Development Panel (OMDP).

These hindcast simulations provide a framework for

- evaluation, understanding, and improvement of ocean models,
- investigation of mechanisms for seasonal, inter-annual, and decadal variability,
- evaluation of robustness of mechanisms across models,
- complementing data assimilation in bridging observations and modeling and in providing ocean initial conditions for climate (decadal) prediction simulations.

Ocean Model Inter-comparison Project (OMIP)
a.k.a. Coordinated Ocean – ice Reference Experiments phase II, CORE-II

Addresses “What are the origins and consequences of systematic model biases?”

Tier 1: One 300+ year experiment

CORE-II Special Issue of Ocean Modelling
(20+ participating models)

- North Atlantic and Atlantic meridional overturning circulation (AMOC)
  Part I: Mean states (Danabasoglu & Yeager), PUBLISHED
  Part II: Variability (Danabasoglu & Yeager),
- Global and regional sea level (Griffies & Yin), PUBLISHED
- Southern Ocean water masses, ventilation, and sea-ice (Downes & Farneti),
- Antarctic Circumpolar Current and Southern Ocean overturning circulation (Farneti & Downes),
- Arctic Ocean and sea-ice (Gerdes, Wang, & Drange),
- South Atlantic simulations (Farneti),
- Ocean circulation in temperature and salinity space (Nurser & Zika),
- Indian Ocean (Ravichandran, Rahaman, Harrison, Swathi, & Griffies),
- Pacific Ocean circulation and its variability (Tseng),
- Indonesian Throughflow (England & Santoso).

Sampling the Physical Ocean in CMIP6 Simulations

CLIVAR Ocean Model Development Panel (OMDP)
Committee on CMIP6 Ocean Model Output

Stephen M. Griffies (NOAA Geophysical Fluid Dynamics Laboratory, USA)
Alistair J. Adcroft (NOAA/GFDL and Princeton University, USA)
V. Balaji (NOAA/GFDL and Princeton University, USA)
Gokhan Danabasoglu (National Center for Atmospheric Research, USA)
Paul J. Durack (LLNL/Program for Climate Model Diagnosis and Intercomparison, USA)
Peter J. Gleckler (LLNL/Program for Climate Model Diagnosis and Intercomparison, USA)
Jonathan M. Gregory (Hadley Centre and University of Reading, UK)
John P. Krasting (NOAA Geophysical Fluid Dynamics Laboratory, USA)
Trevor J. McDougall (University of New South Wales, AUS)
Ronald J. Stouffer (NOAA Geophysical Fluid Dynamics Laboratory, USA)
Karl E. Taylor (LLNL/Program for Climate Model Diagnosis and Intercomparison, USA)

Version 1.0
November 25, 2014

Abstract

We present recommendations for sampling physical ocean fields for the World Climate Research Program (WCRP) Coupled Model Intercomparison Project #6 (CMIP6), including its suite of satellite MIPs such as the Ocean Model Intercomparison Project (OMIP). We motivate the diagnostics by presenting salient scientific reasons for their relevance, and present a practical framework for meaningful comparisons across climate models and observational based measurements. We focus on diagnostics related to physical properties and processes within the simulated ocean, along with associated ocean boundary fluxes. The audience for this document includes the WCRP Working Group for Coupled Modeling (WGCM), the CMIP panel, CLIVAR Scientific Steering Group (SSG), CLIVAR Ocean Model Development Panel (OMDP), scientists contributing model results to CMIP, and scientists analyzing ocean climate simulations.

https://dl.dropboxusercontent.com/u/38722087/CMIP6_ocean/version1p0/CMIP6_ocean_version1p0.pdf

OCMIP6: Ocean Carbon Cycle Model Inter-comparison Project phase 6

James Orr

OCMIP is an open international collaboration that aims to improve and accelerate development of global-scale, three-dimensional, ocean biogeochemical models that include the carbon cycle and related biogeochemical and ecosystem components.

Proposed experiments

OCMIP6 will exploit results from the planned CMIP6 experiments. In addition, new OCMIP6 protocols will be developed i) to run CMIP6 ocean dynamical-biogeochemical models in stand-alone mode, forced by data-based historical forcing (reanalysis data) and ii) to update protocols to evaluate circulation models with passive tracers, namely CFCs and SF_6.

Proposed evaluation/analysis of the CMIP DECK and CMIP6 experiments

- Compare results from the ocean biogeochemical components of the CMIP6 earth system models;
- Analyze the analogous forced ocean simulations with the CMIP6 ocean biogeochemical models, focusing in part on how internal variability differs between coupled and forced simulations;
- Validate the CMIP6 ocean model components by comparing their simulations of 2 passive tracers (CFC and SF_6) to a large global observational database.

MIP Endorsement Process Timeline

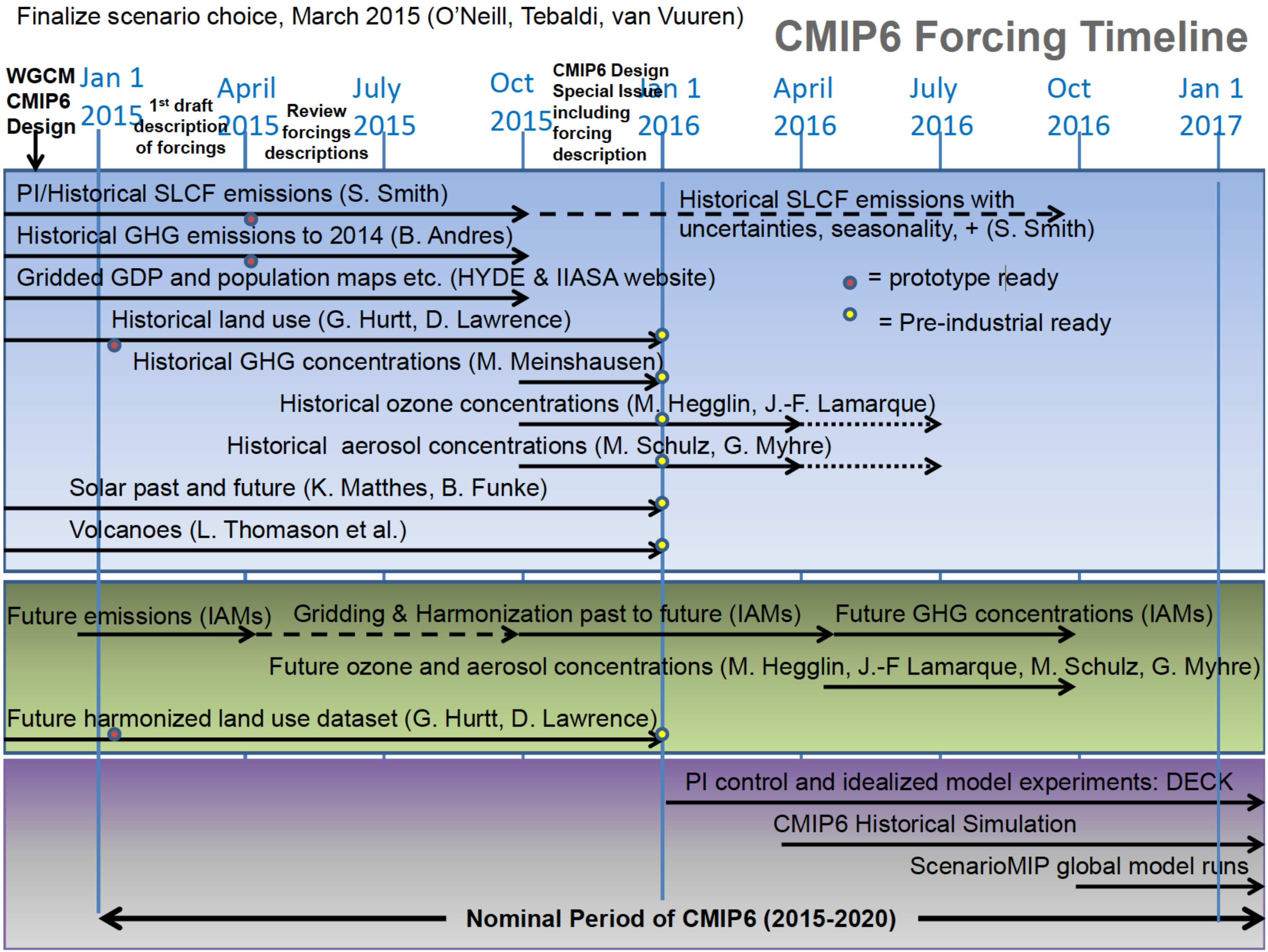
- October 2014: First feedback from WGCM and modeling groups on their September proposals sent to MIP co-chairs (CMIP Panel)
- 29 November 2014: MIP proposal (except for information of the data request) scientifically revised and harmonized with other MIPs (MIP co-chairs)
- 30 November 2014: Revised proposals sent to WGCM, WCRP GCs, biogeochemical forcing theme & projects (WGCM co-chairs), MIP co-chairs and modeling groups for review (CMIP Panel)
- 15 January 2015: review process finished
- 15 February 2015: Synthesis of comments and recommendations for each MIP finished and sent to MIP co-chairs (WGCM members organized by WGCM co-chairs)
- 31 March 2015: Final MIP proposals with all information (including data request) sent to CMIP Panel and WIP co-chairs (MIP co-chairs)
- 30 April 2015: MIP endorsement (CMIP Panel and WGCM co-chairs)
- April - December 2015: Special Issue on the CMIP6 experimental design opens with envisaged submission of the endorsed MIPs and the CMIP6 forcings.

CMIP6 Data Request Timeline

- 15 December 2014: Template for CMIP data request sent to MIP co-chairs (WIP co-chairs)
- 31 January 2015: Experiment and variable list sent to WIP co-chairs (MIP co-chairs)
- 15 March 2015: Synthesized data request ready (WIP co-chairs in collaboration with CMIP Panel)
- 30 April 2015: Data request reviewed and sent to WIP co-chairs and CMIP Panel chair (Model groups and MIP co-chairs)
- 15 July 2015: Final data request published

CMIP6 Forcing Datasets Timeline

- 31 January 2015: Initial description of each forcing dataset sent to CMIP Panel chair (Forcing Group)
- 31 March 2015: Initial description reviewed (Model groups)
- 31 December 2015: Description of forcing datasets in CMIP6 Special Issue (Forcing Group)
- Early 2016: Forcing datasets available (Forcing group)



Finalize scenario choice, March 2015 (O'Neill, Tebaldi, van Vuuren)
CMIP6 Forcing Timeline
WGCM CMIP6 Design
Jan 1 2015
1st draft description of forcings
April 2015
Review forcings descriptions
July 2015
Oct 2015
CMIP6 Design Special Issue including forcing description
Jan 1 2016
April 2016
July 2016
Oct 2016
Jan 1 2017
PI/Historical SLCF emissions (S. Smith)
Historical SLCF emissions with uncertainties, seasonality, + (S. Smith)
Historical GHG emissions to 2014 (B. Andres)
Gridded GDP and population maps etc. (HYDE & IIASA website)
= prototype ready
= Pre-industrial ready
Historical land use (G. Hurtt, D. Lawrence)
Historical GHG concentrations (M. Meinshausen)
Historical ozone concentrations (M. Hegglin, J.-F. Lamarque)
Historical aerosol concentrations (M. Schulz, G. Myhre)
Solar past and future (K. Matthes, B. Funke)
Volcanoes (L. Thomason et al.)
Future emissions (IAMs)
Gridding & Harmonization past to future (IAMs)
Future GHG concentrations (IAMs)
Future ozone and aerosol concentrations (M. Hegglin, J.-F Lamarque, M. Schulz, G. Myhre)
Future harmonized land use dataset (G. Hurtt, D. Lawrence)
PI control and idealized model experiments: DECK
CMIP6 Historical Simulation
ScenarioMIP global model runs
Nominal Period of CMIP6 (2015-2020)

Summary of Responses to the Questionnarie
(based on input from Mahadevan, Subramanian, and Ummenhofer)

Two sections:

1. Lessons from past CPTs (NCAR & GFDL)
2. Model improvement needs and opportunities

CPT Strengths (NCAR and / or GFDL):

- Coordinated multi-institutional and multi-agency research efforts;
- Provides pathway for translating observationally, theoretically, and numerically derived process understanding to climate models; effective in making use of existing (and costly) observational programs;
- Topic choice for CPT determined by ‘readiness’ of process understanding from community, rather than by modeling center needs; topics that can be addressed within 3-5 years with existing observational data and (mostly) existing process modeling frameworks;
- Encourages multiple different approaches/ideas within a team, which mitigates risks, explores innovative approaches, and facilitates cross-fertilization; effective in building bridges between modeling centers and broader community;
- Collaboration between centers, rather than competition, building bridges among the community and modeling centers;

CPT Strengths (NCAR and / or GFDL):

- Goes beyond diagnosing model problems/biases, but seeks connection between biases and model physics, which is difficult and time consuming; process-focused, not bias-focused;

- Early-mid career CPT leaders and dedicated postdoc and scientific support personnel, all clearly invested in success of CPT; effective training of early career scientists;

- Annual workshop crucial for enhancing and establishing (new) collaborations; such exchange leverages more than what is directly funded;

- Most support going to community, not modeling centers;

- CPTs represent great value: The whole is greater than the sum of its individual components.

CPT Weaknesses (NCAR and / or GFDL):

- Unclear how to fund international collaborations;
- With thematically/temporally overlapping CPTs, key modeling center personnel can be over-taxed;
- Overly narrow proposal categories can lead to funding of weak CPTs;
- Productivity, as measured by publication output, potentially not so great (publication count should not be the metric for success for CPTs);
- Challenge to keep collaborations going after CPTs;
- Funding agency priorities can lead to complications.

How to make CPTs more effective (NCAR and / or GFDL):

There are many more ways that changes could make CPTs less effective and diluted, rather than more effective. Care is needed to build on demonstrated strengths.

- Encourage budgeting for dedicated project manager and technical support (e.g., website, cross-group communication, timely exchange of data, outreach, organizing conference session) to allow the lead-PI to focus on CPT topic. Such a model ensures success/lasting legacy of CPT, rather than funding a collection of loosely connected individual projects;
- Ensure support for annual workshops;
- Allow international collaborators to be funded (strongly suggested by only GFDL);
- Consider coordinating funding mechanisms across agencies;
- Ensure CPTs have focused scientific goals/models, without narrowly confining proposal categories.

Would you recommend CPTs to encompass the cryosphere, land surface, and biogeochemistry, in addition to the ocean and atmosphere?

In principle supportive, but …. not through a single solicitation, which would be too broad and involve too many agency programs, with a great risk of destructive competition within centers, agencies, and the community.

The agencies should decide on the scope of each CPT solicitation so that there are meaningful contributions to their programs and constituents.

An exception might be needed for multi-disciplinary processes.

What aspects of the Earth System Model require most attention?

Earth System Modeling aspects requiring most attention often cite processes at interfaces between different realms, e.g.:

- Ice-ocean interactions and sea-ice dynamics (glacier-fjord models, sea-ice thermodynamics);
- Air-sea interactions (atmospheric boundary processes, near-surface ocean processes);
- All aspects of hydrological cycle and convective parameterizations;
- Coastal/marginal sea processes (estuarine mixing, coastal upwelling);
- Vertical transports and surface processes in ocean (overturning, upwelling, waves);
- Polar feedbacks (ice-albedo, cloud radiative);
- Biogeochemistry (carbon cycle and climate feedbacks, ocean biology, dynamic vegetation);
- Interaction between land (canopy) and atmosphere;
- …….

Strongest model biases (varies across models):

- Double ITCZ, precipitation intensity distribution across all spatio-temporal scales, tropical cyclones;
- Ocean heat uptake, storage, and redistribution, e.g., Southern Ocean;
- biases in tropical ocean SSTs;
- ENSO (e.g., amplitude, periodicity), MJO and other modes of climate variability (PNA, NAO, AO, AMV);
- Coastal upwelling and stratus decks (eastern boundary regions, including ocean biogeochemistry);
- Clouds (e.g., aerosol-cloud interactions, low-level clouds, liquid/ice water content);
- Diurnal cycle over land and ocean;
- Subtropical cloud radiative effects in the Southern Ocean;
- Ice-sheet dynamics and discharge;
- ……

Challenges with modeling climate variability:

Problems seen as emergent phenomena in climate models arising from difficulty in simulating specific processes;

challenging phenomena include internal climate variability (e.g., AMV, ENSO, MJO, monsoon) and distinguishing the variability signal from the model trend;

not enough observations for describing long term climate variability

Specific climate processes with potential to improve models in 3-5 years:

- Meso- and submeso-scale mixing in ocean (waves, tidal mixing); Southern Ocean mixing;
- Cloud microphysics (including aerosols), atmospheric turbulence, aspects of convection modeling (such as convective detrainment, cold pool triggering), cloud-radiation interaction;
- Interaction between marginal seas and open ocean (including freshwater discharge);
- Upwelling (coastal, equatorial) and links to stratus decks (clouds);
- Multi-decadal internal climate variability (AMV), and QBO to be resolved in the stratosphere;
- Increased model resolution and scale-aware parameterizations for various processes;
- Diurnal-to-annual surface processes (land and ocean);
- Ice-sheet atmospheric interactions, ice-sheet dynamics, ice-ocean interactions;
- Terrestrial carbon stores and land surface (surface/subsurface hydrological processes);
- ……