Overview of CMIP6 at GFDL

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on behalf of the GFDL CMIP6 Community

Geophysical Fluid Dynamics Laboratory Review

October 29-31, 2019

Background

- The Coupled Model Intercomparison Project (CMIP) is a project of the World Climate Research Programme (WCRP)'s Working Group on Coupled Modelling (WGCM).
- International, multi-model framework designed to better understand past, present, and future climate change.
- Defines common experiment protocols, forcings, and output.
- Publicly available model output supports
  - national and international assessments; scientific research in diverse arenas; multi-model intercomparisons
- GFDL has provided leadership and participated in all past CMIPs and contributed to all IPCC assessments to date:
  - Coupled and Earth System Models (increasing resolution/comprehensiveness)
  - diverse leadership and participatory roles in IPCC assessments
  - currently participating in *CMIP6/AR6*

CMIP6 Scientific Design

https://www.wcrp-climate.org/grand-challenges/grand-challenges-overview

The WCRP Grand Challenges are the scientific backdrop for CMIP6.

CMIP6 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 change given climate variability, predictability, and uncertainty in scenarios?

CMIP6 Scope

- *Greatly expanded scope and scale of CMIP6 compared to CMIP5*
  - 296 experiments, 120 registered models (CMIP5: 39 experiments, 59 models)
  - 10-50 PB model output expected (~2 PB in CMIP5)
- *More continuous and distributed organization*
  - Core simulations performed routinely
    - DECK = Diagnosis, Evaluation, and Characterization of Klima: AMIP (1979-2014), Preindustrial Control, 1% yr^{-1} CO_2 increase, abrupt 4xCO_2
  - Historical simulation (1850-2014) is also needed to participate in CMIP6.
- *23 Model Intercomparison Projects (MIPs) endorsed*
- *Comprehensive Data Request for model output*
  - *(~4000 unique variables, multiple frequencies)*
- *New requirements ensure provenance and traceability*
  - *Quality Assurance of data.*
  - *Routine benchmarking and evaluation.*
  - *Earth System Documentation (ES-DOC) of models.*
  - *Digital Object Identifiers (DOIs) for data citation.*
  - *Errata/Retraction.*

GFDL contributions to CMIP6

- Led/Contributed to Special Issue in *Geoscientific Model Development* (18 authors)
- Five models: **CM4**, **ESM4**, **CM4C192**, **OM4p5B**, **ESM2M**
  - CM4 and ESM4 perform DECK and Historical simulations with new CMIP6 forcings.
- 18 MIPs: 13 unique, 5 participating using two GFDL CMIP6-generation models.
- Model documentation papers submitted/in preparation.
  - Hundreds of manuscripts will use publicly served data.

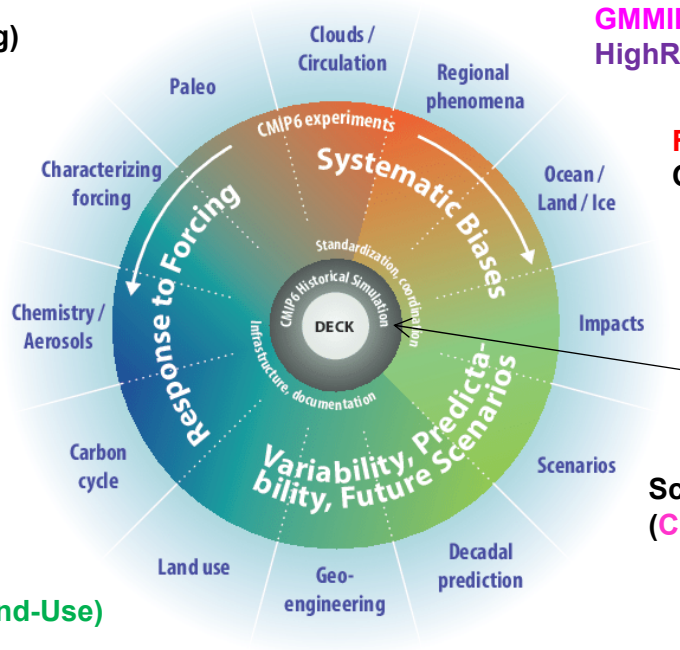
CFMIP (Cloud Feedback)
DynVarMIP (Dynamics and Variability) (CM4, ESM4)

RFMIP (Radiative Forcing) (CM4, ESM4)

GMMIP (Global Monsoons)
HighResMIP (High-Resolution)

DAMIP (Detection and Attribution) (CM4, ESM4)

FAFMIP (Flux-Anomaly-Forced)
OMIP (Ocean) (CM4, OM4p5B)



AerChemMIP (Aerosols and Chemistry)

DECK and Historical (CM4, ESM4)

C4MIP (Coupled Climate Carbon Cycle)

ScenarioMIP (Future Scenarios) (CM4, ESM4)

LUMIP (Land-Use)

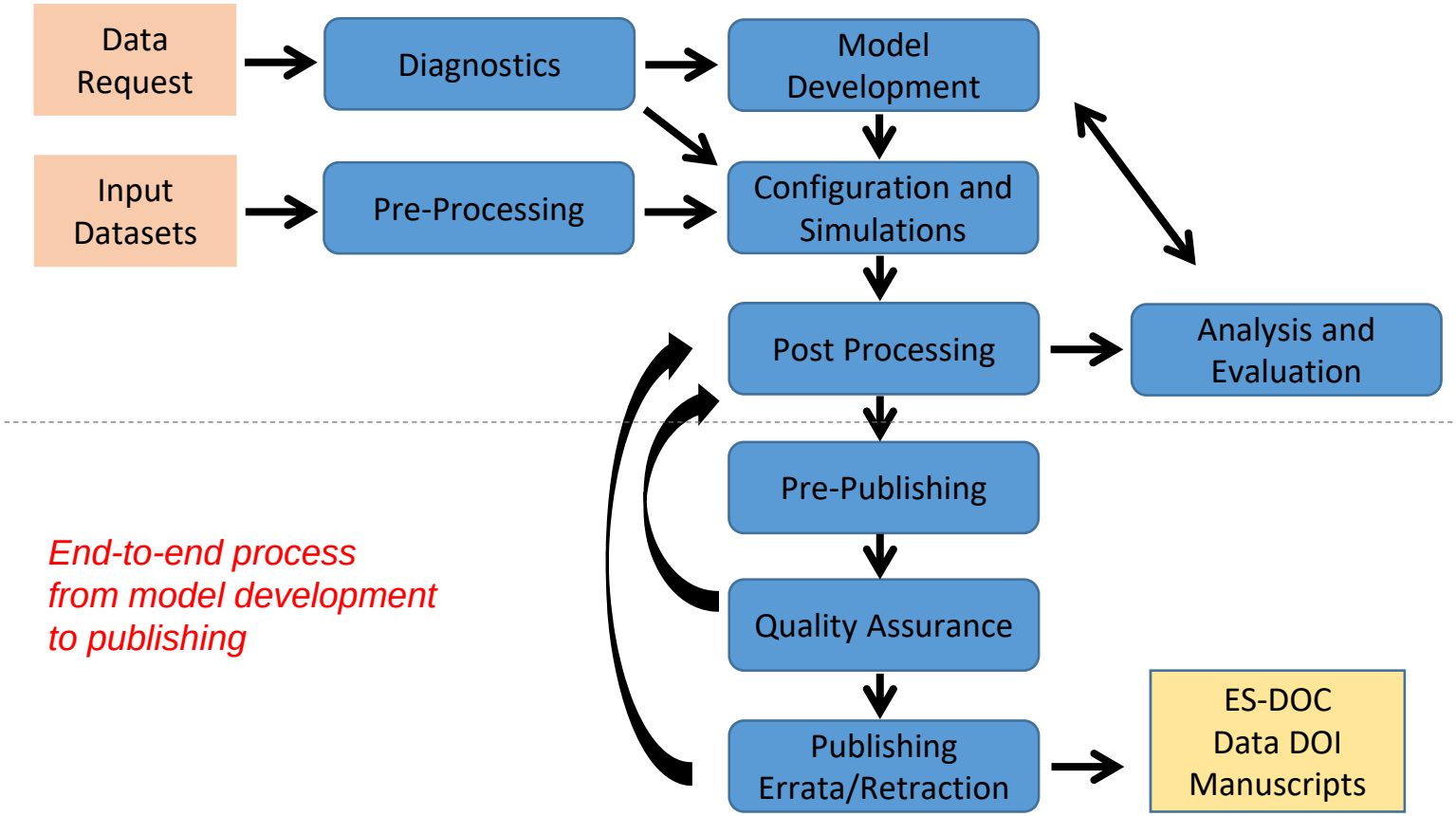
Adapted from
Eyring et al., GMD, 2016

CDRMIP (Carbon Dioxide Removal)

CMIP6 Resources and Workflow at GFDL

Comprehensive lab-wide efforts and resources to ensure GFDL's leadership and participation in CMIP6/AR6

- Roughly 7 year process from preparation of forcings to analysis of CMIP6 simulations.
- Delays can lead to compressed schedules/very tight timelines for modeling centers – *but* IPCC deadlines are fixed.



End-to-end process from model development to publishing

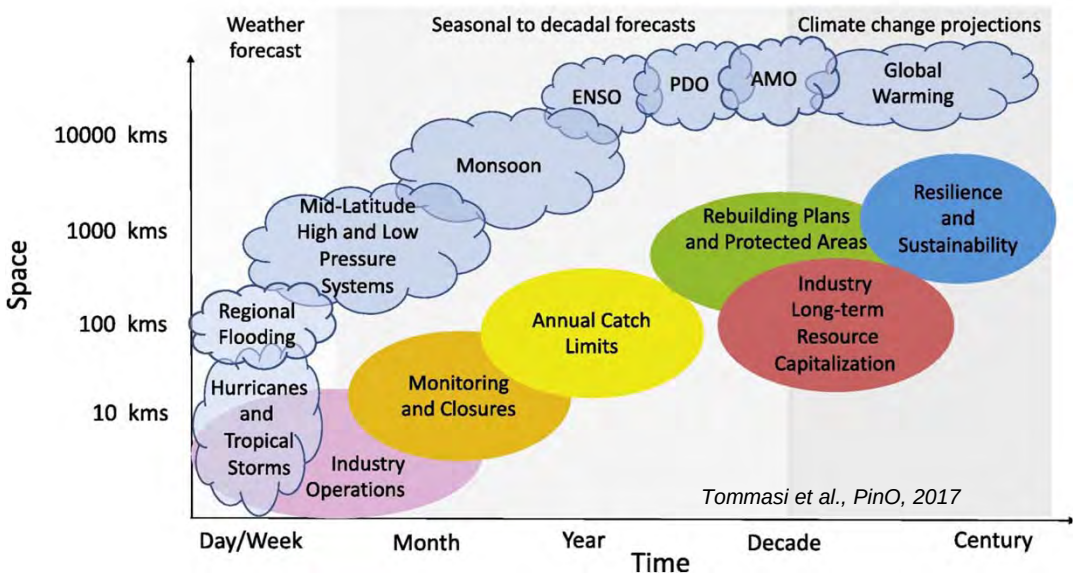
Major Accomplishments

- Advances in Earth System Model development
  - Successful development of four NOAA/GFDL CMIP6-generation models
- Advance understanding of Earth's climate system
  - Broad expertise at GFDL enabled participation in 13 MIPs
- Inform and support the Nation's efforts to adapt to the impacts of climate variability and change
  - Ongoing delivery of publicly served NOAA/GFDL CMIP6 data

CMIP6 by the numbers:

- 140 core experiments
- 18500+ production simulation years
- ~1 PB publicly served data (AR5:188Tb)

- Citation via CMIP6 data DOIs will provide enhanced visibility for NOAA/GFDL products
- Opportunities to collaborate across multiple disciplines over a range of spatial and temporal scales



Summary

- CMIP enables fundamental research
  - Data and research papers are used by the IPCC assessments, academia, NOAA, and other stakeholders.
  - CMIP6 MIPs address a broad range of science questions and fill scientific gaps of previous CMIPs, but scale and scope of current (future?) CMIPs is resource intensive.

- Successful CMIP6 participation through lab-wide contributions
  - Expertise across multiple scientific and technical disciplines and diverse leadership and participatory roles.

- GFDL CMIP6-generation models and data will be used by a broad suite of stakeholders
  - Enhanced visibility of NOAA and GFDL via CMIP6 publications and citation of CMIP6 data.
  - New collaborations.

Future Plans & Challenges

- Level of CMIP participation – cost-benefit analysis
  - 7-8 years of investment from a broad spectrum of the lab from model development phase to publishing of data (human hours), IT/infrastructure (computing time, disk storage)
  - ***Does GFDL need to participate in every iteration of CMIP? To what extent?***
- Timelines
  - Cutting-edge model development/improvements may be curtailed in order to freeze models for participation in CMIP and meet IPCC deadlines.
  - ***Should GFDL tie its model development timeline to IPCC deadlines?***
- Expanded/new capabilities to address science objectives and balance with unprecedented scale of CMIP6
  - Model resolution sacrificed to make best use of compute resources, better understanding of new CMIP requirements
  - ***Model development - nested grids, regional modeling capabilities, ….***
  - ***Infrastructure, HPC, workflow - cloud computing, machine learning, ….***
  - ***Human resources - recruit, retain, and advance***
- Equity
  - Recognize/reward efforts equally (publish/perish vs service)
  - Remove science/technical distinction - data DOIs are a start.
  - ***Move to CRediT (Contributor Roles Taxonomy) "contributorship" model.***

GFDL CMIP6 Roles and Core Teams

- **CMIP6 Coordinator:** J. John
- **CMIP6 Model Development**
  - **Steering Committee:** Held, Balaji, Griffies, S.-J. Lin, Ming, Stouffer, Zhang, Ramaswamy
  - **Working Group Leads:** AWG (Held, Zhao), OWG (Adcroft), LWG (Shevliakova, Milly), CWG (Dunne, Winton), ESWG (Dunne, Horowitz), DET (Horowitz, Krasting)
- **MIP Design Leads/POCs:** AerChemMIP (Horowitz/Naik), C4MIP (Dunne/Krasting), CDRMIP (John), CFMIP (Ming/Silvers, Guo), DAMIP (Knutson; Horowitz), DynVarMIP (P. Lin), FAFMIP (Winton/Hurlin), GMMIP (Ming/B. Xiang), HighResMIP (Zhao), LUMIP (Shevliakova/Malyshev), OMIP (Griffies/Adcroft; Dunne/Krasting), RFMIP (Paynter), ScenarioMIP (Winton/Guo; John)
- **CMIP6 Forcings:** John, Malyshev, Naik, Paulot, Paynter, Schwarzkopf
- **CMIP6 Diagnostics core team:** Dunne, Adcroft, Griffies, Hallberg, Horowitz, John, Malyshev, Stock, Wyman
- **Model Runners and Publishers:** Adcroft, Guo, Horowitz, Hurlin, John, Krasting, P. Lin, Malyshev, Paynter, Ploshay, Sentman, Silvers, B. Xiang, Zadeh, Zhao
- **Quality Assurance core team:** Dunne, Dussin, Gauthier, Ginoux, Horowitz, John, P. Lin, Malyshev, Naik, Paynter, Ploshay, Silvers, Stock, Winton, Y. Zeng
- **Model Development Liaisons:** Dupuis, Robinson, Zadeh
- **Modeling Systems Data Portal Team:** Balaji, Blanton, Durachta, McHugh, Nikonov, Radhakrishnan, Rand, Vahlenkamp, Wilson
- **CMIP6 ES-DOC Liaison:** Blanton
- **CMIP6 Publication Liaison:** Radhakrishnan
- **Modeling Systems Division, Technical Services Group, Administrative Group**, and many more … (Apologies if anyone has been inadvertently missed)