Intro to CMIP, the WHOI CMIP5 community server, and planning for CMIP6

Caroline Ummenhofer, PO

Overview
- Background on IPCC & CMIP
- WHOI CMIP5 server
  - Available model output
  - How to access files
- Planning for CMIP6
Intergovernmental Panel on Climate Change

Panel of scientists that synthesizes published research on climate change including observations, modeling, and paleoclimate

1990    First Assessment Report (FAR)
1995    Second Assessment Report (SAR)
2001    Third Assessment Report (TAR)    CMIP1 & CMIP2
2007    Fourth Assessment Report (AR4)    CMIP3
2013/14 Fifth Assessment Report (AR5)    CMIP5

Coupled Model Intercomparison Project

- Defines the set of standard experiments (with IPCC guidance)
- Coordinates with modeling groups around the world who choose to participate
- Groups run the specified set of experiments with their model and contribute the output to the CMIP data base following protocols for uniform data conventions
Evolution of climate models

- AGCM: Prescribed ocean and land surface
- OGCM: Prescribed atmosphere
- LSM: Prescribed atmosphere

60s | 70s | 80s | 90s | 00s | 10s

Atmospheric/Land Surface/Vegetation
Ocean

Courtesy of Kris Karnauskas
Evolution of climate models

Courtesy of Kris Karnauskas
Evolution of climate models

The World in Global Climate Models

- **Mid-1970s**
  - CO₂
  - Rain

- **Mid-1980s**
  - Land Surface
  - Prescribed Ice
  - Clouds

- **FAR**
  - Volcanic Activity
  - Sulphates
  - “Swamp” Ocean

- **SAR**
  - Ocean

- **TAR**
  - Carbon Cycle
  - Aerosols
  - Overturing Circulation

- **AR4**
  - Chemistry
  - Interactive Vegetation

- **FAR**
  - 500 km (T21)

- **SAR**
  - 250 km (T42)

- **TAR**
  - 180 km (T63)

- **AR4**
  - 110 km (T106)

IPCC AR4
Computational resources – CMIP3-5

**CMIP3:** 17 institutes (groups) and 25 models  (40 TB)
- Total years simulated: 70,000
- Individual models simulated 500 to 8,400 years (mean: 2,800 yr)
- Individual groups simulated on average $\frac{70,000}{17} = 4,100$ yr

**CMIP5:** 26 institutes (groups) and 60 models  (2 PB)
- Total years simulated: 330,000 (estimate Oct 2014)
- Individual models simulated on average $\frac{330,000}{60} = 5,500$ yr
- Individual groups estimated on average $\frac{330,000}{26} = 13,000$ yr

According to Taylor & Balaji (2015)
CMIP5 experiments

Taylor et al. (2012)
<table>
<thead>
<tr>
<th>Experiment description</th>
<th>CMIP5 label</th>
<th>AOGCM</th>
<th>ESM or EMIC</th>
<th>High resolution</th>
<th>Major purposes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Preindustrial control run</td>
<td>piControl</td>
<td></td>
<td></td>
<td></td>
<td>Evaluation, unforced variability</td>
</tr>
<tr>
<td>Past ~1.5 centuries (1850–2005)</td>
<td>historical</td>
<td></td>
<td></td>
<td></td>
<td>Evaluation</td>
</tr>
<tr>
<td>AMIP run (observed SSTs and sea ice prescribed for 1979–present)</td>
<td>amip</td>
<td></td>
<td></td>
<td>X</td>
<td>Evaluation</td>
</tr>
<tr>
<td>Future projection (2006–2300) forced by RCP4.5</td>
<td>rcp45</td>
<td>X</td>
<td></td>
<td></td>
<td>Projection</td>
</tr>
<tr>
<td>Future projection (2006–2300) forced by RCP8.5</td>
<td>rcp85</td>
<td>X</td>
<td></td>
<td></td>
<td>Projection</td>
</tr>
<tr>
<td>Future projection (2006–2300) forced by RCP2.6</td>
<td>rcp26</td>
<td>X</td>
<td></td>
<td></td>
<td>Projection</td>
</tr>
<tr>
<td>Future projection (2006–2100) forced by RCP6</td>
<td>rcp60</td>
<td>X</td>
<td></td>
<td></td>
<td>Projection</td>
</tr>
<tr>
<td>Benchmark 1% yr⁻¹ increase in CO₂ (to quadrupling)</td>
<td>IpctCO2</td>
<td>X</td>
<td></td>
<td></td>
<td>Climate sensitivity, feedbacks</td>
</tr>
<tr>
<td>Quadruple CO₂ abruptly, then hold fixed</td>
<td>abrupt4xCO2</td>
<td>X</td>
<td></td>
<td></td>
<td>Climate sensitivity, feedbacks, fast responses</td>
</tr>
<tr>
<td>Climatological SSTs and sea ice imposed from piControl</td>
<td>sstClim</td>
<td></td>
<td></td>
<td></td>
<td>Fast responses</td>
</tr>
<tr>
<td>As in sstClim, but with 4XCO₂ imposed</td>
<td>sstClim4xCO2</td>
<td>X</td>
<td></td>
<td></td>
<td>Fast responses</td>
</tr>
<tr>
<td>Historical simulation but with natural forcing only</td>
<td>historicalNat</td>
<td>X</td>
<td></td>
<td></td>
<td>Detection and attribution</td>
</tr>
<tr>
<td>Historical simulation but with GHG forcing only</td>
<td>historicalGHG</td>
<td>X</td>
<td></td>
<td></td>
<td>Detection and attribution</td>
</tr>
<tr>
<td>Mid-Holocene conditions (as called for by PMIP)</td>
<td>midHolocene</td>
<td>X</td>
<td></td>
<td></td>
<td>Evaluation</td>
</tr>
<tr>
<td>Last Glacial Maximum conditions (as called for by PMIP)</td>
<td>lgm</td>
<td>X</td>
<td></td>
<td></td>
<td>Evaluation</td>
</tr>
<tr>
<td>Natural forcing for 850–1850 (as called for by PMIP)</td>
<td>past1000</td>
<td>X</td>
<td></td>
<td></td>
<td>Evaluation, natural variability</td>
</tr>
</tbody>
</table>
Selected model output available:

√ All available models

√ Experiments of broad interest to WHOI community (past, present, future)

X Multiple ensemble members

√ Comprehensive set of ocean variables (selected atmosphere, land, sea-ice, BGC)

√ Monthly physical variables

√ Annual selected BGC variables

X high-frequency variables (e.g., daily)

→ Storage requirements ultimately limiting factor at this stage

→ Feedback from users about interest in additional data

http://cmip5.whoi.edu/
<table>
<thead>
<tr>
<th>Experiment description</th>
<th>CMIP5 label</th>
<th>AOGCM</th>
<th>ESM or EMIC</th>
<th>High resolution</th>
<th>Major purposes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Preindustrial control run</td>
<td>piControl</td>
<td>✔</td>
<td>✔</td>
<td></td>
<td>Evaluation, unforced variability</td>
</tr>
<tr>
<td>Past ~1.5 centuries (1850–2005)</td>
<td>historical</td>
<td>✔</td>
<td>✔</td>
<td></td>
<td>Evaluation</td>
</tr>
<tr>
<td>AMIP run (observed SSTs and sea ice prescribed for 1979–present)</td>
<td>amip</td>
<td>✔</td>
<td>✔</td>
<td>X</td>
<td>Evaluation</td>
</tr>
<tr>
<td>Future projection (2006–2300) forced by RCP4.5</td>
<td>rcp45</td>
<td>✔</td>
<td>✔</td>
<td></td>
<td>Projection</td>
</tr>
<tr>
<td>Future projection (2006–2300) forced by RCP8.5</td>
<td>rcp85</td>
<td>✔</td>
<td>✔</td>
<td></td>
<td>Projection</td>
</tr>
<tr>
<td>Future projection (2006–2300) forced by RCP2.6</td>
<td>rcp26</td>
<td>✔</td>
<td>✔</td>
<td></td>
<td>Projection</td>
</tr>
<tr>
<td>Future projection (2006–2100) forced by RCP6</td>
<td>rcp60</td>
<td>✔</td>
<td>✔</td>
<td></td>
<td>Projection</td>
</tr>
<tr>
<td>Benchmark 1% yr⁻¹ increase in CO₂ (to quadrupling)</td>
<td>IpctCO2</td>
<td>✔</td>
<td>✔</td>
<td></td>
<td>Climate sensitivity, feedbacks</td>
</tr>
<tr>
<td>Quadruple CO₂ abruptly, then hold fixed</td>
<td>abrupt4xCO2</td>
<td>✔</td>
<td>✔</td>
<td></td>
<td>Climate sensitivity, feedbacks, fast responsesb</td>
</tr>
<tr>
<td>Historical simulation but with natural forcing only</td>
<td>historicalNat</td>
<td>✔</td>
<td>✔</td>
<td></td>
<td>Detection and attribution</td>
</tr>
<tr>
<td>Historical simulation but with GHG forcing only</td>
<td>historicalGHG</td>
<td>✔</td>
<td>✔</td>
<td></td>
<td>Detection and attribution</td>
</tr>
<tr>
<td>Historical simulation but with other individual forcing agents or combinations of forcings</td>
<td>historicalMisc</td>
<td>✔</td>
<td>✔</td>
<td></td>
<td>Detection and attribution</td>
</tr>
<tr>
<td>Mid-Holocene conditions (as called for by PMIP)</td>
<td>midHolocene</td>
<td>✔</td>
<td>✔</td>
<td></td>
<td>Evaluation</td>
</tr>
<tr>
<td>Last Glacial Maximum conditions (as called for by PMIP)</td>
<td>lgm</td>
<td>✔</td>
<td>✔</td>
<td></td>
<td>Evaluation</td>
</tr>
<tr>
<td>Natural forcing for 850–1850 (as called for by PMIP)</td>
<td>past1000</td>
<td>✔</td>
<td>✔</td>
<td></td>
<td>Evaluation, natural variability</td>
</tr>
</tbody>
</table>
Available data

Data Distribution by Experiment

- **paleo**
  - lgm
  - midHolocene
  - past1000
  - piControl
  - historical

- **future**
  - rcp85
  - rcp45
  - past1000
  - piControl
How to find data
Data access methods

- Advanced Dataset Search
- File Transfer Protocol (FTP)
  - host: ftp://cmip5.whoi.edu/
  - username: anonymous or ftp

- Hypertext Transfer Protocol (HTTP)
  - http://cmip5.whoi.edu/data/

- Network File System (NFS) Mount
  - hostname: //cmip5.whoi.edu/

→ Copy files to local storage
  + Easy to access/search & download files
  + Ability to modify files
  - Local storage requirements

→ Access files as if located locally, but without local storage requirement
  + No local storage requirements
  - Files are read-only

→ Detailed step-by-step instructions on webpage
→ Access only works internally (or via VPN)
CMIP6 experiments and beyond

→ continuity through DECK simulations
→ additional experiments to address specific scientific questions
• **Diagnosis, Evaluation and Characterization of Klima (DECK)** – benchmark CMIP runs

  → Include:
     - AMIP (~1979-2014)
     - Pre-industrial control
     - 1%/yr CO$_2$ increase
     - Abrupt change to 4xCO$_2$

  → Performed whenever a new model is developed (no deadlines)
  → “Entry card” for participation in CMIP

• **Historical run**
  → Historical forcing updated for each CMIP phase
  → Required for CMIP6 participants

• **CMIP6-endorsed MIPs** – addressing specific science issues
  → Modeling groups will choose to participate in a subset, depending on scientific interest and resources

According to Taylor & Balaji (2015)
CMIP6 experiments and philosophy

The **scientific backdrop** for CMIP6 is the six **WCRP Grand Challenges**, and an additional 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?
Computational resources – CMIP6

CMIP3: 17 institutes (groups) and 25 models (40 TB)
- Total years simulated: 70,000
- Individual models simulated 500 to 8,400 years (mean: 2,800 yr)
- Individual groups simulated on average 70,000/17 = 4,100 yr

CMIP5: 26 institutes (groups) and 60 models (2 PB)
- Total years simulated: 330,000 (estimate Oct 2014)
- Individual models simulated on average 330,000/60 = 5,500 yr
- Individual groups estimated on average 330,000/26 = 13,000 yr
→ 4.3 Mio files

CMIP6: length of simulations similar to CMIP5, but higher resolution models, larger ensemble sizes, more diverse experiment structure
→ Factor of 20: 36 PB in 86 Mio files
→ Factor of 50: 90 PB in 215 Mio files

→ Careful planning required to determine subset of CMIP6 model output to best serve WHOI community

According to Taylor & Balaji (2015) and Denvil (2015)
Data access methods

- Advanced Dataset Search

- File Transfer Protocol (FTP)
  - host: ftp://cmip5.whoi.edu/
  - username: anonymous or ftp

- Via command line interface
- Via ftp client (FileZilla, WinSCP…)
- Via web browser
Data access methods

- Hypertext Transfer Protocol
  - http://cmip5.whoi.edu/data/
Data access methods

- Advanced Dataset Search

- File Transfer Protocol (FTP)
  - host: ftp://cmip5.whoi.edu/
  - username: anonymous or ftp

- Hypertext Transfer Protocol (HTTP)
  - http://cmip5.whoi.edu/data/

- Network File System (NFS) Mount
  - hostname: \cmip5.whoi.edu/
  - sharename: data
  - domain: WORKGROUP
What does model output look like

- Data format: netCDF (network Common Data Format)
  - platform independent data format
  - particularly useful for array-oriented scientific data
  - libraries for many different software products
  - incorporates metadata
What does model output look like

- Data format: netCDF (network Common Data Format)
  - platform independent data format
  - particularly useful for array-oriented scientific data
  - libraries for many different software products
  - incorporates metadata

- Gridded (at varying resolution)

- Multi-dimensional: e.g. thetao (time, depth, lat, lon)

- Supported by Matlab, R, IDL, NCL (amongst many others)
How to read netcdf files in Matlab

http://www.unidata.ucar.edu/software/netcdf/software.html

- CSIRO Matlab/netCDF Interface
- MEXNC and SNCTOOLS (a Matlab interface)
- nctoolbox (a MATLAB common data model interface)
How to read netcdf files in Matlab

MATLAB provides the following simple to use functions to read, write and create NetCDF data files.

- `ncdisp` - Display contents of a NetCDF file in the command window.
- `ncread` - Read data from a variable in a NetCDF file.
- `ncreadatt` - Read an attribute value from a NetCDF file.
- `ncwrite` - Write data to a NetCDF file.
- `ncwriteatt` - Write an attribute to a NetCDF file.
- `ncinfo` - Return information about a NetCDF file.
- `nccreate` - Create a variable in a NetCDF file.
- `ncwriteschema` - Add NetCDF schema definitions to a NetCDF file.
Assessing 21st century change with CMIP5 models – general approaches

1. Assess how well do models reproduce a certain metric in present-day climate conditions?
   • Compare to different observational/reanalysis products
   • What might affect/cause certain biases?

2. How does a metric change in future?
   • In all models/those models with a better representation of current/past climatic conditions?
   • Is the change consistent across models? (Multi-model mean vs individual models)

3. What drives projected change in metric?
   • What mechanisms can explain projected changes?

4. How sensitive are projected changes to model physics?