State of CESM

Jean-François Lamarque
CESM Chief Scientist
NCAR
Community support

Adding approx. 900 registered users per year

Discuss CESM:
- 35,000 User sessions May 1, 2015 - YTD
- 21,000 Returning user sessions May 1, 2015 - YTD
- 18,500 New User sessions May 1, 2015 - YTD

CESM Tutorial: 10-14 August 2015
Led by C. Shields
Approx. 80 participants

CESM Tutorial: 8-12 August 2016
Led by A. Philips and S. Bates

- Made possible through DOE and NSF funding!
BRACE: Benefits of Reduced Anthropogenic Climate change

- Explore differences in physical and societal impacts between RCP8.5 and RCP4.5 using CESM ensembles
- 21 papers, special issue of *Climatic Change* (in progress)
- 50+ participants, from NCAR and 18 other institutions

Avoided Impacts

<table>
<thead>
<tr>
<th>Biophysical &amp; Societal Impact Models</th>
</tr>
</thead>
<tbody>
<tr>
<td>Health</td>
</tr>
<tr>
<td>Ag. and Land use</td>
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<tr>
<td>Heat extremes</td>
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<tr>
<td>Tropical cyclones</td>
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<tr>
<td>Drought</td>
</tr>
<tr>
<td>Sea-level rise</td>
</tr>
</tbody>
</table>
Decadal prediction

Predicted rate of global warming from 2013 initial year greater than during early-2000s slowdown and greater than uninitialized:

Observed 2001-2014: $+0.08 \pm 0.05^\circ\text{C}/\text{decade}$

Predicted 2013-2022: $+0.22 \pm 0.13^\circ\text{C}/\text{decade}$

Uninitialized 2013-2022: $+0.14 \pm 0.12^\circ\text{C}/\text{decade}$

(Meehl et al., 2016, Nature Communications)

With funding from DOE RGCM program
ROAD TO CESM2
Timeline for CESM2 (as of June 2015)

- **Spring 2015**: Decision on CAM5.5
- **June 2015**: CAM5.5 to developers
  - Interim versions of CLM5, POP2, CICE5, BGC, Chemistry, WACCM, Others
  - CAM6 development (SE dycore)
  - Coupled simulations
- **Oct 1 2015**: All components for FV-1° frozen by Oct. 1 2015
- **Spring 2016**: Coupled simulations
- **June 2016**: CESM2 FV-1°

- **Code delivery**
  - Potential code delivery
  - Potential code development
  - Assembling and optimizing coupled model

**AMWG meeting in Jan-Feb 2016 to freeze CAM6**
Where we were in Feb. 2016

• 4-day all-WGs meeting in Boulder
• Had generated 100+ year control and 20th century simulation w/ intermediate configurations
• Identified 3 main areas of strong concern
  – > Amazon precipitation
  – > Surface wind over ice sheet
  – > Arctic ocean warming at depth
Amazon problem
Parameter and physics exploration – Amazon DJF Rainfall

Amazon - (15S-5N; 290W-310E)

PRECT (TRMM) - mm/day

TREFHT (LEGATES) - K

Observed
CESM1.5 (79)
CESM1.5 (66)
CESM1.5 (41)
CESM1.5 (28)
CFSM1 (LENS)

mm/day
Improved MJO Lag-correlations (precip./U850mb, JJA)

- 20-100-day band pass filtered fields
- Lag correlation of rainfall (colors) and 850-mb zonal wind (contours) with rainfall at 90E
- Improved MJO in response to convection buoyancy change (capeten)

Obs. (TRMM/NCEP)

CAM5.5+Capeten

CAM5.5
Reduced surface biases for ice sheets

• CESM2 can now generate a realistic surface mass balance for either Greenland or Antarctica.
  – However, surface melting is sensitive to snow physics. Still working on uniform physics that gives good results for both ice sheets.
• Surface winds over both ice sheets are much improved.
• CAM still generates too much liquid precipitation in cold regions.
Arctic ocean bias: not much improvement

Improvements in Ocean Physics Parameterizations Reduce Denitrification, Improving the Global Ocean Nitrogen Balance
Overall score

ANN: SPACE–TIME

Reference Grids Used

- / +  Bias
\[\downarrow \triangle >20\%\]
\[\downarrow \triangle 10–20\%\]
\[\downarrow \triangle 5–10\%\]
\[\downarrow \triangle 1–5\%\]
\[\triangledown \triangle <1\%\]

Black: Large Ensemble
Red: CESM2

RMSE Bias
- 1.00 1.00
- 0.86 0.72

0 – Sea Level Pressure (ERAi)
1 – SW Cloud Forcing (CERES–EBAF)
2 – LW Cloud Forcing (CERES–EBAF)
3 – Land Rainfall (30N–30S, GPCP)
4 – Ocean Rainfall (30N–30S, GPCP)
5 – Land 2–m Temperature (Willmott)
6 – Pacific Surface Stress (5N–5S,ERS)
7 – Zonal Wind (300mb, ERAi)
8 – Relative Humidity (ERAi)
9 – Temperature (ERAi)
Where we are now:

- Nearing completion of **ALL** components
- Targeted coupled issues identified in Feb.
  - CESM2 is improved over LENS
  - Additional work going on
    - Secondary-organic aerosols
    - Land optimization
Exploration of CLM5 parameters

Amazonia Latent Heat Climatology

- Optimal (predicted)
- Default
- Observations (FLUXNET)

Latent Heat (Wm^-2)

J F M A M J

50 55 60 65 70 75 80 85 90 95 100

high low

high low
Where we are now:

- Nearing completion of **ALL** components
- Targeted coupled issues identified in Feb.
  - CESM2 is improved over LENS
  - Additional work going on
    - Secondary-organic aerosols
    - Land optimization
    - Performance optimization (20+ sypd!)
    - ...

Breckenridge June 20 2016
Stratospheric AOD at Northern Mid-Latitudes

Prognostic stratospheric aerosols with volcanic SO\textsubscript{2} database match lidar observations much better than existing climatologies.
Sea-ice issue in very recent experiments
Timeline until release

- **Feb 2016**: WG meetings
- **Mar. 1 2016**: All WGs define
- **Jun. 2016**: Definition of CESM2
- **Jul. 1 2016**: Code Freeze
- **Sep. 1 2016**: CESM2.0 Release
  - Full release, incl. WACCMX and simpler models
  - CMIP6 1°
- **Dec 2016**: Start CMIP6 simulations
- **Jun. 2016**: CESM2 Sessions at Breckenridge
- **Mar. 1 2016**: Definition of CESM2
- **Jul. 1 2016**: Code Freeze
- **Jun. 2016**: Definition of CESM2
- **Mar. 1 2016**: Definition of CESM2

**Document impacts in coupled simulations**

**Code available through developers’ access**
Upcoming CSL proposal: 2016-2018

• Proposal will be due in mid Sept. 2016
• Expected targets:
  – 2017: ≈3x (330M core-hours: Yellowstone + Cheyenne)
  – 2018: ≈2x (220M core-hours: Cheyenne)
• Use CSL Yellowstone allocation (110M) with supplement (in discussion with CISL) to cover CMIP6 DECK and Tier 1 1-degree runs
• Use Cheyenne for everything else, including high-resolution CMIP6 simulations
CMIP Analysis Platform

• Up and running: https://www2.cisl.ucar.edu/resources/cmip-analysis-platform

• Tutorial (20 students and early-career scientists) scheduled for Aug. 16-18: agenda and registration available at link above

• Will be a critical component to support CMIP6 analysis (combined with LENS, LME, ME, ...)
Ocean

- Issue #1: POP is no longer being supported by LANL (has been used since CCSM2!)
- Issue #2: Not state-of-the-art anymore
  - Opportunity to identify
    - New model framework
    - New mode of development and collaboration
  - Has been discussed at Feb. OMWG meeting and Ocean Sciences (New Orleans)
  - RFI sent to 6 groups (MOM6, MPAS-O, HYCOM, ROMS, MITgcm, and NEMO); all responded and will participate in the discussions
Questions?

Comments?
## Participation to MIPs

<table>
<thead>
<tr>
<th>MIP acronym</th>
<th>MIP name</th>
<th>Name of primary sponsor(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AerChemMIP</td>
<td>Aerosols and Chemistry Model Intercomparison Project</td>
<td>Lamarque/Emmons</td>
</tr>
<tr>
<td>C4MIP</td>
<td>Coupled Climate Carbon Cycle Model Intercomparison Project</td>
<td>Lindsay</td>
</tr>
<tr>
<td>CFMIP</td>
<td>Cloud Feedback Model Intercomparison Project</td>
<td>Medeiros/Kay (CU)/Klein (LLNL)</td>
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<tr>
<td>DAMIP</td>
<td>Detection and Attribution Model Intercomparison Project</td>
<td>Tebaldi/Arblaster</td>
</tr>
<tr>
<td>DCPP</td>
<td>Decadal Climate Prediction Project</td>
<td>Danabasoglu/Meehl</td>
</tr>
<tr>
<td>GeoMIP</td>
<td>Geoengineering Model Intercomparison Project</td>
<td>Tilmes/Mills</td>
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<tr>
<td>GMMIP</td>
<td>Global Monsoons Model Intercomparison Project</td>
<td>Fasullo/Kinter (COLA)</td>
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<td>HighResMIP</td>
<td>High Resolution Model Intercomparison Project</td>
<td>Neale/Bacmeister</td>
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<tr>
<td>ISMIP6</td>
<td>Ice Sheet Model Intercomparison Project for CMIP6</td>
<td>Lipscomb (LANL)/Otto-Bliesner</td>
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<tr>
<td>LS3MIP</td>
<td>Land Surface, Snow and Soil Moisture</td>
<td>D. Lawrence</td>
</tr>
<tr>
<td>LUMIP</td>
<td>Land-Use Model Intercomparison Project</td>
<td>D. Lawrence/P. Lawrence</td>
</tr>
<tr>
<td>OMIP/OCMIP</td>
<td>Ocean Model Intercomparison Project</td>
<td>Danabasoglu</td>
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<tr>
<td>PMIP</td>
<td>Palaeoclimate Modelling Intercomparison Project</td>
<td>Otto-Bliesner</td>
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<td>RFMIP</td>
<td>Radiative Forcing Model Intercomparison Project</td>
<td>Gettelman/Neale</td>
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<td>Scenario Model Intercomparison Project</td>
<td>Meehl/O'Neill/P. Lawrence</td>
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<tr>
<td>VolMIP</td>
<td>Volcanic Forcing Model Intercomparison Project</td>
<td>Mills/Otto-Bliesner</td>
</tr>
<tr>
<td>CORDEX</td>
<td>Coordinated Regional Climate Downscaling Experiment</td>
<td>Mears/Gutowski</td>
</tr>
<tr>
<td>DynVar</td>
<td>Dynamics and Variability of the Stratosphere\Troposphere System</td>
<td>Marsh</td>
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<td>SIMIP</td>
<td>Sea-Ice Model Intercomparison Project</td>
<td>Bailey/Holland/Jahn (CU)/Hunke (LANL)</td>
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<td>VIAAB</td>
<td>VIA Advisory Board for CMIP6</td>
<td>Mears/O'Neill</td>
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<td>FAFMIP</td>
<td>Flux-Anomaly-Forced Model Intercomparison Project</td>
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<tr>
<td>NonlinMIP</td>
<td>Nonlinear climate responses to CO2</td>
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</table>

Data only:

| CORDEX       | Coordinated Regional Climate Downscaling Experiment          | Mears/Gutowski                                   |
| DynVar       | Dynamics and Variability of the Stratosphere\Troposphere System | Marsh                                          |
| SIMIP        | Sea-Ice Model Intercomparison Project                        | Bailey/Holland/Jahn (CU)/Hunke (LANL)           |
| VIAAB        | VIA Advisory Board for CMIP6                                 | Mears/O'Neill                                    |

Not participating:

| FAFMIP       | Flux-Anomaly-Forced Model Intercomparison Project            |                                                 |
| NonlinMIP    | Nonlinear climate responses to CO2                          |                                                 |
Challenges to CESM

• Maintain flexibility with a increasingly complex code (simpler models, stand-alone configurations, multiple physics, ...)
• Code must run efficiently on multiple platforms
• Maintain multiple configurations (incl. resolution) but focus on a limited set of scientifically supported versions
• Enable community model development
Staging simulations for PI control

1. Use WACCM (F-case) to generate fields for CAM

   -> WACCM run with CMIP6 1850 specifications

2. Start CAM from Levitus and WACCM from stabilized climate
CMIP6
CMIP6 cost estimate

- **DECK experiments**
  - 1850 control: 1000 years
  - Instantaneous 4xCO$_2$: 150 years
  - 1% to 4x: 150 years
  - AMIP (1979-2015): 36 years

- **Historical simulation**: 165 years (3 members)

- **Tier 1 experiments**, as requested in MIP documents + ScenarioMIP Tier 2 ensemble
CMIP6 DECK + Tier 1 Requirements

• 1° versions
  – CAM: ≈ 5,000 years
  – CAM-BGC: ≈ 12,000
  – WACCM-BGC: ≈ 5,600
  – Total cost: ≈ 250M core-hours

• 1/4° resolution version
  – CAM: ≈ 1,500 years
  – Total cost: ≈ 250M core-hours

• Total I/O: ≈ 5PB (very rough estimate)

Yellowstone core-hours; 1 year ≈ 700M core-hours

1) A lot of interesting science resides in Tier 2/3 experiments
2) A large unknown is cost of high-resolution model.
Motivation: To increase the workflow performance in preparation for CMIP6

<table>
<thead>
<tr>
<th></th>
<th>CMIP5</th>
<th>CMIP6</th>
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<tbody>
<tr>
<td>Simulation Cost</td>
<td>~13M corehours</td>
<td>~500M corehours</td>
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<tr>
<td>Raw Size</td>
<td>2 PB</td>
<td>20-30* PB</td>
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<tr>
<td>Published Size</td>
<td>175 TB</td>
<td>5* PB</td>
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<tr>
<td>Time Line</td>
<td>18 Months</td>
<td>12-24 Months</td>
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</table>

* = rough estimate

Tools Currently in Development:

PyConform (Python Climate Output Formatter): Will replace the CMORization step. It will interpolate (vertical and horizontal), perform automatic unit conversion, add required attributes, perform validation checks, and perform calculations.

Workflow Automation and Management:

Automate the workflow and sync with the Run Database
Atmosphere

• Multiple dynamical cores available
  – > MPAS (non-hydrostatic)
  – > Spectral Element (currently used for high-resolution)
  – > Planning on a Evaluation process similar to CLUBB/UNICON
## Where we were a year ago

<table>
<thead>
<tr>
<th>Model</th>
<th>CAM4</th>
<th>CAM5.1 CESM1.0.3</th>
<th>CAM5.3 CESM1.2.0</th>
<th>CAM5.4</th>
<th>CAM5.5</th>
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<tbody>
<tr>
<td>PBL</td>
<td>HB</td>
<td>UW</td>
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<td>Shallow conv.</td>
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<td>UW</td>
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<td>FV</td>
<td>FV</td>
<td>SE</td>
<td>FV</td>
<td>FV</td>
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http://www.cesm.ucar.edu/working_groups/Atmosphere/development/cam6/CAM5.5_panel_rec_Jun15.pdf
http://www.cesm.ucar.edu/working_groups/Atmosphere/development/cam6/cam5.5-process/

= New parameterization/dynamics