Overview of Energy Exascale Earth System Model (E3SM)
a new model from US Department of Energy
from Ruby Leung, E3SM Chief Scientist
• E3SM (formerly ACME) started with CESM v1 as E3SM v0
• E3SM v1 model components:
  – Atmosphere (EAM): A fork of CAM5.3; increased vertical levels from 30 to 72; CLUBB + MG2; MAM4 aerosols; other minor improvements
  – Ocean (MPAS-Ocean): A free surface ocean model with unstructured grid for variable resolution modeling
  – Sea ice (MPAS-Sea Ice): An unstructured grid model with CICE physics
  – Land ice (MPAS-Land Ice): An unstructured grid model with ice-ocean interactions beneath Antarctic ice sheet
  – Land (ELM): A fork of CLM4.5; new soil hydrology; CNP cycle and other new biogeochemistry representations
  – River (MOSART): A scale adaptive river transport model
E3SM v1 model configurations

• Three model configurations:
  – Low resolution: ~100 km (ne30) atmosphere/land; 60-30 km ocean/ice
  – High resolution: ~25 km (ne120) atmosphere/land; 18-6 km ocean/ice
  – Low resolution BGC: low resolution model + land and ocean BGC

• Model release:
  – E3SM v1 will initially be released with (1) a low resolution model configuration and DECK simulations and (2) a high resolution model configuration with a 1950s simulation – tentatively April 2018
  – E3SM v1 low resolution BGC will be released after completion of low resolution BGC experiments (TBD)
Planned simulations

- CMIP6 DECK experiments using low resolution configuration for ~3 ensemble members – tentatively completed by March 2018

- Water cycle experiments:
  - Full transient forcing simulations at low and high resolution for 1950-2050 (similar to HighResMIP)
  - Single transient forcing simulations at low and high resolution for 1950-2050

- BGC experiments (estimate carbon-climate and carbon-CO2 feedbacks):
  - (1) Preindustrial control simulation – 1850 for 250 years
  - (2) Transient forcing 1850-2100 with 1850 GHG concentrations
  - Same as (2), except including BGC influence of transient atmospheric CO2 concentration
  - Same as (2), except including full radiative effects of GHG
Community Earth System Model (CESM) for CMIP6
Target CESM2 and CMIP6 versions (2018-2019):

**DECK and most MIP simulations:**
1. AOGCM physical climate (atmos $1^\circ$, ocean $1^\circ$, low-top) with biogeochemistry ($CO_2$ emission and/or concentration driven)
2. + atmospheric chemistry (atmos $1^\circ$, ocean $1^\circ$, high-top; WACCM)

**DECK + ScenarioMIP tier 1 simulations:**
1. AOGCM physical climate (atmos $1/4^\circ$, ocean $1^\circ$, low-top)
   (currently with CESM1 at this resolution: time slice, PI control 100 years, 20th century; planning on RCP8.5 and RCP2.6 in 2017)

   **Low-top:** 32 levels up to 40 km  
   **High-top:** 72 levels up to 150 km

2019-2020: simulations with AOGCM atmos $1/4^\circ$, ocean $1/10^\circ$: 50 year PI control; 20C and RCP8.5
   (currently with CESM1 at this resolution have 50 year perpetual 2000 and RCP8.5 to 2050)
CESM2 participation in CMIP6

<table>
<thead>
<tr>
<th>MIP acronym</th>
<th>MIP name</th>
<th>Name of primary sponsor(s)</th>
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<tbody>
<tr>
<td>AerChemMIP</td>
<td>Aerosols and Chemistry Model Intercomparison Project</td>
<td>Lamarque/Emmons/Liu (Wyoming)</td>
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<tr>
<td>C4MIP</td>
<td>Coupled Climate Carbon Cycle Model Intercomparison Project</td>
<td>Lindsay</td>
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<tr>
<td>CFMIP</td>
<td>Cloud Feedback Model Intercomparison Project</td>
<td>Medeiros/Kay (CU)/Klein (LLNL)</td>
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<td>DAMIP</td>
<td>Detection and Attribution Model Intercomparison Project</td>
<td>Tebaldi/Arblaster</td>
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<td>DCPP</td>
<td>Decadal Climate Prediction Project</td>
<td>Danabasoglu/Meehl</td>
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<td>GeoMIP</td>
<td>Geoengineering Model Intercomparison Project</td>
<td>Tilmes/Mills</td>
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<td>Global Monsoons Model Intercomparison Project</td>
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<td>HighResMIP</td>
<td>High Resolution Model Intercomparison Project</td>
<td>Neale/Bacmeister</td>
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<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>
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<td>LUMIP</td>
<td>Land-Use Model Intercomparison Project</td>
<td>D. Lawrence/P. Lawrence</td>
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<td>OMIP/OCMIP</td>
<td>Ocean Model Intercomparison Project</td>
<td>Danabasoglu/Lindsay</td>
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<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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<td>VolMIP</td>
<td>Volcanic Forcings Model Intercomparison Project</td>
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<td>CORDEX</td>
<td>Coordinated Regional Climate Downscaling Experiment</td>
<td>Mearns/Gutowski</td>
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<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>
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<td>Flux-Anomaly-Forced Model Intercomparison Project</td>
<td>Aixue Hu</td>
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<td>NonlinMIP</td>
<td>Nonlinear climate responses to CO2</td>
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OMIP: ocean - sea-ice simulation at 1/10 degree resolution forced with the JRA-55 atmospheric data sets (in addition to 1 deg ocean)
Improved performance for CESM2 on current and upcoming supercomputers has been a focus over the last year

Throughput estimates for CESM2:

1. 1 deg atmos 1 deg ocean standard CESM2: ~20 model years per calendar day on NCAR Yellowstone (climate sensitivity ~4.5°)

2. 1/4 deg atmos 1 deg ocean CESM2: ~2.4 model years per calendar day (on Blue Waters and Mira)

3. high top 1 deg WACCM, 72 layers ~6 model years per day on NCAR Yellowstone.

4. 1/4 deg atmos 1/10 deg ocean CESM2: ~1 model year per day (on Blue Waters)
Current status of CESM2: issue when switching CMIP5 -> 6 emissions

Black: HadCRUT4
Red: #190: CMIP6
Blue: #192: CMIP5

CESM2 Global surface temperature (anomaly w.r.t. 1850-1880)

Prognostic aerosols
Same model (CESM2) run with CMIP5 SO2 emissions and CMIP6 SO2 emissions
CESM2
Red: CMIP6
Blue: CMIP5
5 year running mean
1961-1980 base period
Differences in emissions

SFSO2 [kg/m²/s], 01Jul1960

SO2 emissions N.Am.

30% increase

CMIP6
CMIP5

Same SO2 emissions in 1905 as in 2010
Michou, M.,
Geosci. Model Dev. Discuss.,
Differences in forcing CMIP5 -> CMIP6 (example for decade 1970-1980)

Annual SWCF (W/m²)  
Annual Low Clouds (%)
NCAR CMIP6 Planning

CMIP6 Simulations with CESM2
- Ramp-up (2018 Production)
- Production (2019, 2020)
- Ramp-down (2020)

CESM2 Validation

NCAR Yellowstone
- CESM 1° Release (January 2017)
- CESM 1° Release (January 2018)
- CESM 1° Release (January 2019)
- CESM 1/4° Release (January 2020)
- CESM 1/4° Release (January 2021)

NCAR Cheyenne

CMIP6 Data to ESGF
CMIP6 Post-Processing
CMIP6 Analysis and Papers (CMIP analysis platform)

1/4° CESM1 simulations

DOE (NERSC, Argonne); Univ. Illinois (Blue Waters)
END
Differences in emissions

SFS02 [kg/m²/s], 01Jul1960 00:00

Red: CMIP6
Blue: CMIP5
CMIP6 DECK + Tier 1 Requirements

- CESM2 1° coupled/uncoupled versions
  - CESM2-BGC: ≈18,000
  - CESM2 WACCM-BGC: ≈ 5,500
  - Total cost: ≈ 240M core-hours
- CESM2 1/4° coupled/uncoupled version
  - CESM2  1/4°: ≈ 400 years
  - Total cost: ≈ 50M core-hours
CESM2
Red: CMIP6
Blue: CMIP5
5 year running mean
1961-1980 base period
Model improvements (1): examples from MIROC6 (Update from MIROC5)

**AGCM (T85L81)**
- Shallow convection
- High-Top TOA (3hPa → 0.004 hPa)
- SOA, Oceanic organic Aerosol
- Scattering by non-spherical cloud ice
- Non-orographic GWD
- modified CMT, water leak fixed, etc.

**OGCM**
- Higher resolutions (1.4°L50 → 1°L63)
- Tripole coordinate
- Improved TKE estimate under sea-ice

**Land Surface Model**
- Subgrid snow cover distribution
- Wet land due to snow melting

Current status of CMIP6 experiments *(Done, On-going, Preparing)*

**DECK**
CMIP6 historical simulations using v6.0/v6.1 forcing datasets

**FAFMIP**

**DAMIP**

**OMIP**

**CFMIP**

**DCPP**

**HighresMIP**

**GMMIP**

**LS3MIP**

**RFMIP**

**ScenarioMIP**

Global-mean SAT (5yr running-mean; Ref: 1961/90)
Differences in emissions

SFS02 [kg/m²/s], 01Jul1960 00:00

CMIP6

CMIP5

S02 emissions N. Pac.
Transient volcanic forcing in CESM2 driven by emissions: comparison to CMIP6

![Graph showing transient volcanic forcing comparisons between CESM2 and CMIP6](image-url)
Current status of CESM2: issue when switching CMIP5 -> 6 emissions

Black: HadCRUT4
Red: #190: CMIP6
Blue: #192: CMIP5

Global surface temperature (anomaly w.r.t. 1850-1880)

Same model version used in both. Only differ in anthropogenic/bb emissions and continuous volcanoes

Currently working on understanding reason for differences and remedies: focus on cloud-aerosol interactions and background aerosols
CMIP6: revised timeline and workflow

- **WACCM** (fixed SSTs, 20 years)
- **CESM2** (coupled, 100 years)
- **WACCM** (fixed SSTs)
- **CESM2** (coupled)
- **Ocean only** (2500 years)
- **Land only** (800 years)
- **BGC spinup**
- **WACCM coupled 1850 control** (150 years)
- **CESM2 coupled 1850 control** (500 years)
- **CESM2 coupled 1850 control** (200 years)

**Days after model is frozen**

- Approximately 2 months before simulations other than PI control can get started

**CESM2**
- 20+ sypd (1°, 32L)
- WACCM: 6+ sypd (1°, 70L, 228 sp.)
- Ocean only: 100 sypd
- Land only: 150 sypd