CESM2 development simulations: Are we there yet?

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CESM 2 development at a glance

• Huge team effort started in Mid November 2015
• 2 co-chair meetings/week
CESM 2 development simulations
http://www.cesm.ucar.edu/working_groups/Atmosphere/development/cesm1_5/

Nov 2015: First coupled
• First coupled simulation

Feb 2016: Winter Working Group Meeting
• 34 experiments (“cases”)
• 1300+ years of simulations + diagnostics

June 2016: Breckenridge workshop
• 94 experiments (“cases”)
• 2890+ years of simulations + diagnostics

Feb 2017: Winter Working Group Meeting
• 150 experiments (“cases”)
• Thousands of simulated years + diagnostics

And also
• Many standalone simulations in individual working groups
CESM 2 development simulations

Are you lost in translation?

Simplified terminology for this talk

<table>
<thead>
<tr>
<th>CESM1</th>
<th>Large Ensemble (2013)</th>
<th>LENS</th>
</tr>
</thead>
<tbody>
<tr>
<td>CESM1.5</td>
<td>Winter Working Group (Feb 2016)</td>
<td>28 or 36</td>
</tr>
<tr>
<td>CESM2_dev</td>
<td>Breckenridge (June 2016)</td>
<td>63, 64, 66, 79</td>
</tr>
<tr>
<td>CESM2</td>
<td>Winter Working Group (Feb 2017)</td>
<td>125</td>
</tr>
</tbody>
</table>

Caveat: 125 is not the “final” version of CESM2 but no major change in climate.
What happened since Breckenridge?

At Breckenridge: we had a preliminary version of CESM2

FAQ: “I thought CESM2 was almost ready at Breckenridge, what happened since then?”

Can you spot the difference? The word “Almost”
Houston, we have a problem: The Labrador Sea is freezing

Sea-ice extent (ANN)

CESM1.5

Sea-ice extent (black line)

CESM2_dev (Breckenridge)

Labrador sea

Sea-ice extent is close to obs
Labrador sea is ice free
(This is also true for LENS)

Extensive sea-ice cover
Labrador sea sea is ice covered
Trouble in the Labrador Sea

Timeseries of sea ice thickness in Labrador sea

Sea ice is building up in Labrador sea
This can happen after 1 yr, 40 yr, 100+ yr
SST and salinity bias

**LENS**  
Too warm and salty

**CESM1.5**

**CESM2_dev (Breckenridge)**  
Too cold and too fresh

**CESM2_dev:** Too cold and too fresh South of Greenland. Fresh water pool prevent further mixing
Solving the Labrador Sea problem

After Breckenridge, multiple attempts to solve the issue

We found out it is a very robust feature in CESM2_dev
Estuary Box Model (EBM) to the rescue!

EBM – CONTROL (COUPLED)

Sea surface salinity

Sea surface temperature

EBM – CONTROL (COUPLED)

Courtesy: Gokhan Danabasoglu
What happened since Breckenridge?

It was not only fixing the Labrador Sea.
Quick glance at CESM milestones

The rest of the talk will highlight some differences between:

**CESM1**
- LENS
- 2014

**CESM1.5**
- Feb 2016

**CESM2**
- Feb 2017
Taylor score was degraded in CESM1.5
CESM2 is better than LENS
Sea Surface Temperature (SST) bias (ANN)

LENS
Bias = -0.24K
RMSE = 0.91

CESM1.5
Bias = -0.62K
RMSE = 1.12

CESM2
Bias = -0.32K
RMSE = 0.98

RMSE improves in CESM2 compared to CESM1.5 but not as good as in LENS.
**Precipitation bias versus GPCP (ANN)**

**LENS**
- Bias = 0.37
- RMSE = 1.13
  (mm/day)

**CESM1.5**
- Bias = 0.19
- RMSE = 1.12
  (mm/day)

**CESM2**
- Bias = 0.18
- RMSE = 0.89
  (mm/day)

**Improved precip RMSE**
Precipitation bias versus GPCP (ANN)

**LENS**
- Bias = 0.37
- RMSE = 1.13 (mm/day)

**CESM1.5**
- Bias = 0.19
- RMSE = 1.12 (mm/day)

**CESM2**
- Bias = 0.18
- RMSE = 0.89 (mm/day)

Improved precip RMSE
Better precip over Amazon
Precipitation bias versus GPCP (ANN)

**LENS**
Bias = 0.37
RMSE = 1.13
(mm/day)

**CESM1.5**
Bias = 0.19
RMSE = 1.12
(mm/day)

**CESM2**
Bias = 0.18
RMSE = 0.89
(mm/day)

Improved precip RMSE
Better precip over Amazon
Improved tropical precip
Precipitation bias versus GPCP (ANN)

LENS
Bias = 0.37
RMSE = 1.13
(mm/day)

CESM1.5
Bias = 0.19
RMSE = 1.12
(mm/day)

CESM2
Bias = 0.18
RMSE = 0.89
(mm/day)
SWCF bias versus CERES-EBAF (ANN)

LENS
Bias = -1.18
RMSE = 13.7
(W/m²)

CESM1.5
Bias = -0.98
RMSE = 10.9
(W/m²)

CESM2
Bias = -1.43
RMSE = 8.97
(W/m²)

CESM1.5: improved SWCF
CESM2: even better
Sea-level pressure versus MERRA (ANN)

**LENS**
Bias = 0.29  
RMSE = 1.61 (mbar)

**CESM1.5**
Bias = 0.09  
RMSE = 3.02 (mbar)

**CESM2**
Bias = 0.29  
RMSE = 1.86 (mbar)

Improved SLP in Southern Ocean

RMSE improves in CESM2 compared to CESM1.5 but not as good as in LENS
Greenland and Antarctica surface winds

Greenland

Obs (RACMO2.3)

CESM1.5

CESM2

Antarctica

Courtesy Lenaerts
Climate sensitivity

- Climate sensitivity in Slab Ocean Model experiments
- Qfluxes computed from 1850 control
- \( CS = T_{\text{equilibrium}} (2\times\text{co2}) - T_{\text{equilibrium}} (1\times\text{co2}) \)
## Aerosol indirect effect

<table>
<thead>
<tr>
<th></th>
<th>Direct (W/m²)</th>
<th>Indirect (W/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>IPCC values</td>
<td>-0.5 [-0.9 to -0.1]</td>
<td>-0.7 [-1.8 to -0.3]</td>
</tr>
<tr>
<td>LENS</td>
<td>-0.2</td>
<td>-1.4</td>
</tr>
<tr>
<td>CESM1.5</td>
<td>-0.4</td>
<td>-1.8</td>
</tr>
<tr>
<td>CESM2</td>
<td>-0.3</td>
<td>-1.6</td>
</tr>
</tbody>
</table>

CESM1.5: aerosol indirect effect were too strong
CESM2: New autoconversion reduced indirect effect
20th century warming

**CESM1.5**
- not enough warming over 20thC
- too much cooling during dimming period

**CESM2**
- warmer 20th century
- aerosol effect reduced during dimming period
Are we there yet? Yes, we are.
This has been 15 months of intense work

We had good days

We had bad days

We always found the cause of our problems
Extra slides
Beyond 125

Changes for final version:

• Subgrid-scale topography representation around Greenland (different scale due to very strong winds)
• Caspian sea: from ocean model to land model (lake)
• Update to land vegetation parameters (little climate impact, mostly for carbon-cycle improvements)
• Crop improvement
• CMIP6 emissions
• Robert Filter
• 1 hour coupling atm $\leftrightarrow$ ocn
• Ocean initial conditions from LENS
• Dust tuning
• Ocean biogeochemistry