E3SMv2 Water Cycle

Model and Simulation Campaign
Part 1: Overview of coupled simulations at low-resolution

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2021-11-18 E3SM All-hands Webinar
E3SMv2 in a nutshell – faster and better (mostly)

• **Faster**
  – Approximately 2x on identical machines
  – Up to 40 SYPD

• **Better**
  – Improved clouds and precipitation
  – Plausible climate sensitivity (ECS = 4.0 K instead of 5.3 K)

• **Two configurations**
  – **v2.LR**: 100 km atmosphere and land; 1/2 deg river; 60 to 30 km ocean and sea-ice;
  – **v2.NARRM**: 25km atmosphere and land; 1/8 deg river; 14 km ocean and sea-ice over North America

• Some challenges remain.
Simulation campaign

- DECK + historical simulations for LR and NARRM.
- Additional simulations based on scientific needs.
- Simulations to date:
  - v2.LR : 6725+ years
  - v2.NARRM : 1665+ years

Special thanks to Ryan Forsyth, Qi Tang, Xue Zheng and Wuyin Lin
Faster - coupled

Performance of maint-1.0 A_WCYCL1850S_CMIP6.ne30_oECv3 and v2.0.0 WCYCL1850.ne30pg2_EC30to60E2r2

Figure courtesy Andrew Bradley
Faster - atmosphere

Performance of maint-1.0 FC5AV1C-L.ne30_ne30 and v2.0.0 F2010-CICE.ne30pg2_ne30pg2

Figure courtesy Andrew Bradley
15% reduction in RMSE
Notable regional improvements:
• Double ITCZ
• Amazon dry bias
• Tropical Warm Pool
• Western N America
• High elevations
Cloud radiative effects – historical ensemble

**SW CRE**

- **E3SMv2** Model - Observations
  - Max: 79.56
  - Mean: 2.12
  - Min: -56.14
  - RMSE: 10.31
  - CORR: 0.88

- **E3SMv1** Model - Observations
  - Max: 82.03
  - Mean: -3.61
  - Min: -57.31
  - RMSE: 11.15
  - CORR: 0.87

**LW CRE**

- **E3SMv2** Model - Observations
  - Max: 29.34
  - Mean: -2.02
  - Min: -43.56
  - RMSE: 5.35
  - CORR: 0.90

- **E3SMv1** Model - Observations
  - Max: 26.89
  - Mean: -1.42
  - Min: -44.07
  - RMSE: 5.42
  - CORR: 0.88
Clouds – liquid cloud fraction (LCF)

Diagnosed mixed-phase partitioning based on monthly model output in the 30–80° S latitude band

Figure courtesy Xue Zheng

corrected unrealistic behavior in v1
Tropical variability: Wheeler-Kiladis

Distribution of tropical precipitation spectral power, normalized by a smoothed background spectrum, in zonal wavenumber-frequency space.

- E3SMv2 historical simulation indicate slightly lower power values for equatorial Rossby waves and the MJO and a MJO peak that is at a higher frequency compared to observations.
- Both E3SMv2 and E3SMv1 dramatically underestimate precipitation variability associated with atmospheric Kelvin waves and other synoptic-scale disturbances.

Figure courtesy Jim Benedict
Tropical variability: MJO lag correlation

Lag correlations of equatorial precipitation zonal wind with Indian Ocean precipitation.

- **Improvement in MJO propagation** across the Maritime Continent in E3SMv2 compared to E3SMv1, as evidenced by more consistent red shading eastward to 125 °E.
- In both E3SMv2 and E3SMv1, the quadrature phasing of precipitation and zonal wind resembles that in observations, but the **MJO phase speed begins to exceed the observed 5.5 m s⁻¹ reference value (dashed green line) east of 120°E** and especially in E3SMv2.

Figure courtesy Jim Benedict
Ozone hole

Ozone hole in the historical time series (top) and daily mean climatology and variance (bottom) of the SH minimum total column ozone (left, unit: DU) and the SH maximum ozone hole area (right, area with total ozone<220 DU, unit: million km2) based on the daily data from July 1 to December 31. In the bottom panels, the lines indicate the multi-year average (observations in black from years 1990–2019 and models in blue from years 1990–2014), and shading covers ±1 standard deviation

Figure courtesy Qi Tang
**ECS and TCR**

Equilibrium Climate Sensitivity  
Transient Climate Response

Sherwood et al. (2020)  
ECS estimate (66%)  
2.6 – 3.9 K (baseline)  
2.3 – 4.7 K (robustly)
Bellouin et al. (2020)
Total aerosol ERF
-1.6 to -0.6 W m\(^{-2}\) (68%)
-2.0 to -0.4 W m\(^{-2}\) (90%)
Historical temperature record

Global surface air temperature anomaly (ref 1850-1899)
Single forcing ensemble

Single-forcing decomposition
- GHG
- Aerosol related
- Everything else (other)

Fully coupled simulations (1850-2014), 5 members for each forcing.

Special thanks to Dave Bader
### Composite configurations

- Treating single-forcing simulations as linear perturbations from the piControl, we can recompose them with alternate strengths:

\[
\psi_{\text{all}} = \psi_{\text{piControl}} + \alpha_{\text{GHG}} (\psi_{\text{GHG}} - \psi_{\text{piControl}}) + \alpha_{\text{aer}} (\psi_{\text{aer}} - \psi_{\text{piControl}}) + (\psi_{\text{other}} - \psi_{\text{piControl}})
\]

- Baseline | Modulate GHG response | Modulate aerosol response | Keep the rest unchanged

- Modulate strength of GHG response (proxy for TCR/ECS) and aerosol related to create alternate **composite configurations**.

- Applicable to any field; linear approximation holds well.

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Inspired from Neelin et al. (2010)
Looking for an optimum

Weaker aerosol-related impact

Weaker GHG impact (proxy for TCR/ECS)

E3SMv2

holding aerosol

holding GHG

best

Cost function (RMSE NH+SH)
Global surface air temperature anomaly

- HadCRUT5-Analysis
- E3SMv2 historical
- Composite A
- Composite G
- Composite "best"

Year:
- 1860
- 1880
- 1900
- 1920
- 1940
- 1960
- 1980
- 2000

degC:
- -0.5
- 0.0
- 0.5
- 1.0
- 1.5

Legends:
- holding GHG
- best
- holding aerosol
- E3SMv2
TOA net shortwave
Sea-surface temperature

E3SMv2
Model - Observations
degC
Max 6.46
Mean -0.21
Min -9.54

Composite "best"
Model - Observations
degC
Max 6.81
Mean 0.71
Min -7.33

Observations
HadiSST ( Climatology) (1982-2011)
Max 29.64
Mean 18.65
Min -1.71

Composite - E3SMv2
Difference
degC
Max 2.45
Mean 0.42
Min -0.57

RMSE
CORR 0.99

RMSE
CORR 1.00
Conclusion

- E3SMv2 improves upon v1 in many aspects
  - Substantially faster
  - Better clouds and precipitation
  - More realistic cloud feedback and equilibrium climate sensitivity (ECS).

- Some challenges remain
  - E3SMv2 fails to accurately simulate the late historical temperature record.
  - Correcting will require reducing aerosol-cloud impact between 60% to 80%.

- Much more to come
  - Ocean, sea-ice analysis.
  - North America RRM configuration.
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