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

E3SM Energy Exascale Earth System Model

LLNL-PRES-829169
Work at LLNL was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.

U.S. DEPARTMENT OF ENERGY

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.

Future presentations

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**

Experiment	Years	Members	Notes
v2.LR : DECK + historical			
piControl-spinup	1000	1	• Complete
piControl	500	1	• Complete
abrupt-4xCO2	150	2	• Complete
1pctCO2	150	1	• Complete, but may add another member
historical	165 (1850-2014)	5	• Complete • Planning additional members as part of a large ensemble
amip	145 (1870-2014)	3	• Atmosphere • Complete
v2.LR : single-forcing coupled simulations (DAMIP-like)			
hist-GHG	165 (1850-2014)	5	• All well-mixed GHG forcing only • Complete
hist-aer	165 (1850-2014)	5	• Aerosol-related forcing only • Complete
hist-all-xGHG-xaer	165 (1850-2014)	5	• All other forcings • Complete
v2.LR : effective radiative forcing (RFMIP)			
piClim-control	50	1	• Atmosphere • Control simulation using SST and sea-ice derived from piControl • Complete
piClim-histall	165 (1850-2014)	3	• Atmosphere • All forcing • Complete
piClim-histaer	165 (1850-2014)	3	• Atmosphere • Aerosol-related forcing • Complete
v2.NARRM : DECK + historical			
piControl-spinup	1000	1	• Complete
piControl	500	1	• Complete
historical	165 (1850-2014)	1	• Complete • Planning additional members

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

Faster - coupled

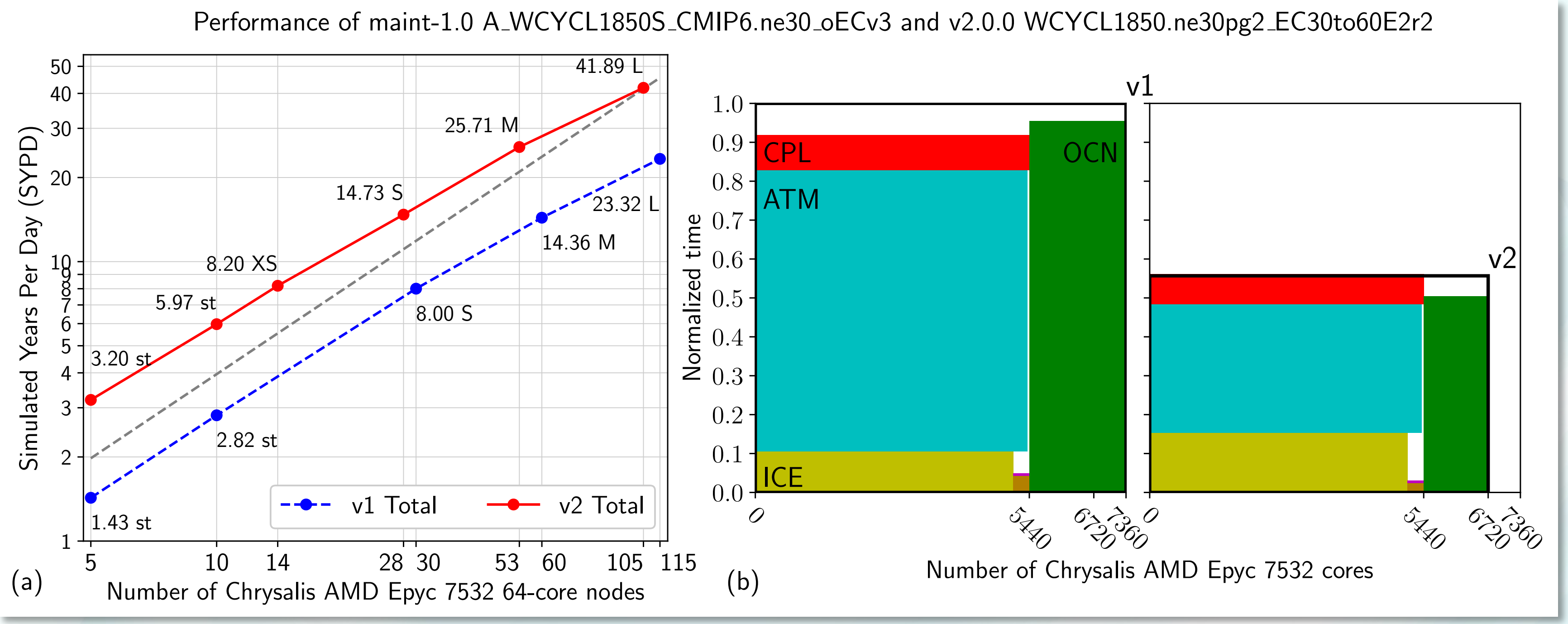


Figure courtesy Andrew Bradley

Faster - atmosphere

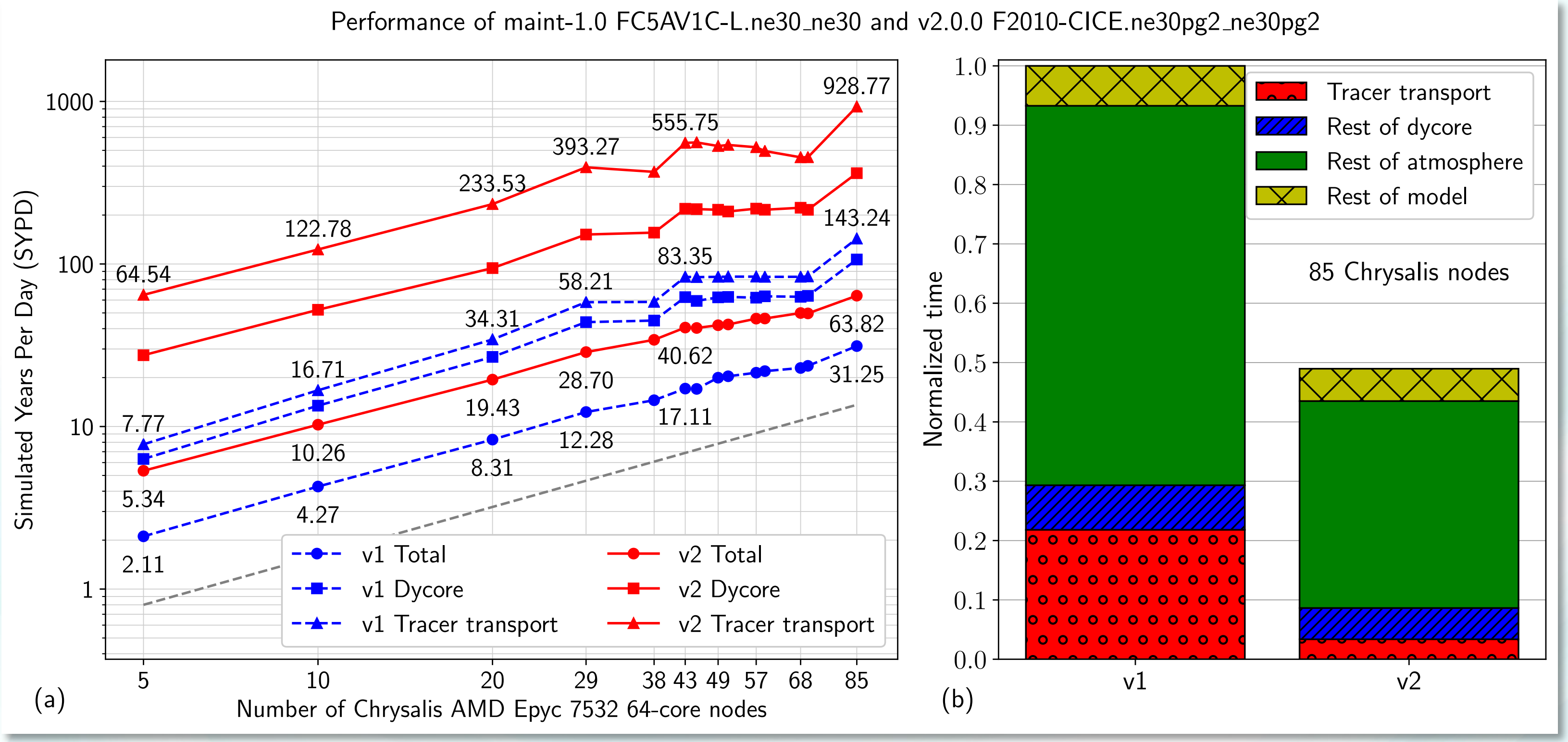
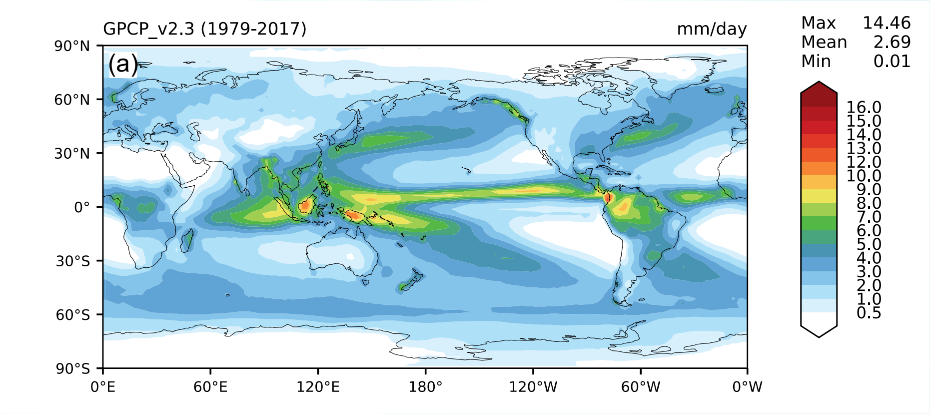
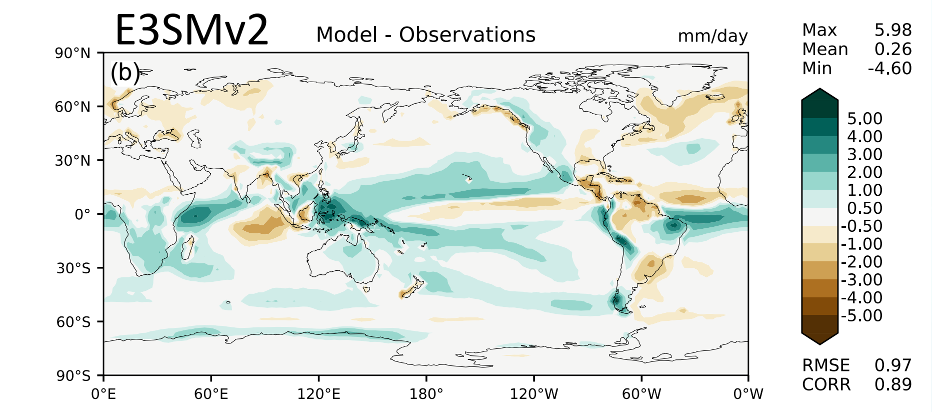
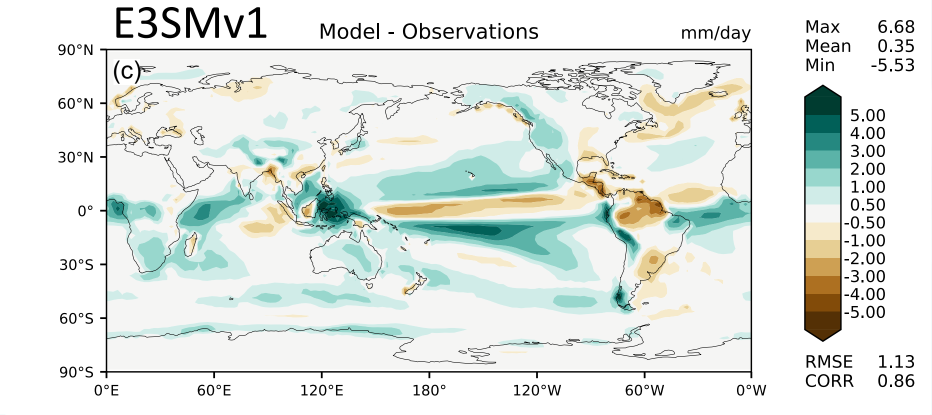


Figure courtesy Andrew Bradley

Precipitation – historical ensemble (1985-2014)







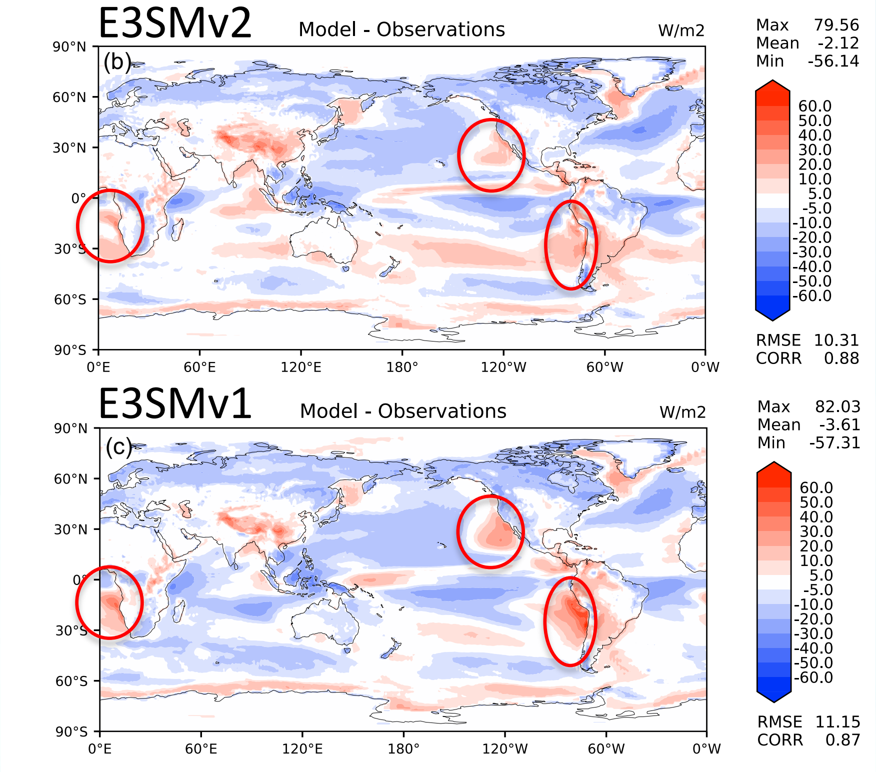
15% reduction in RMSE

Notable regional improvements:

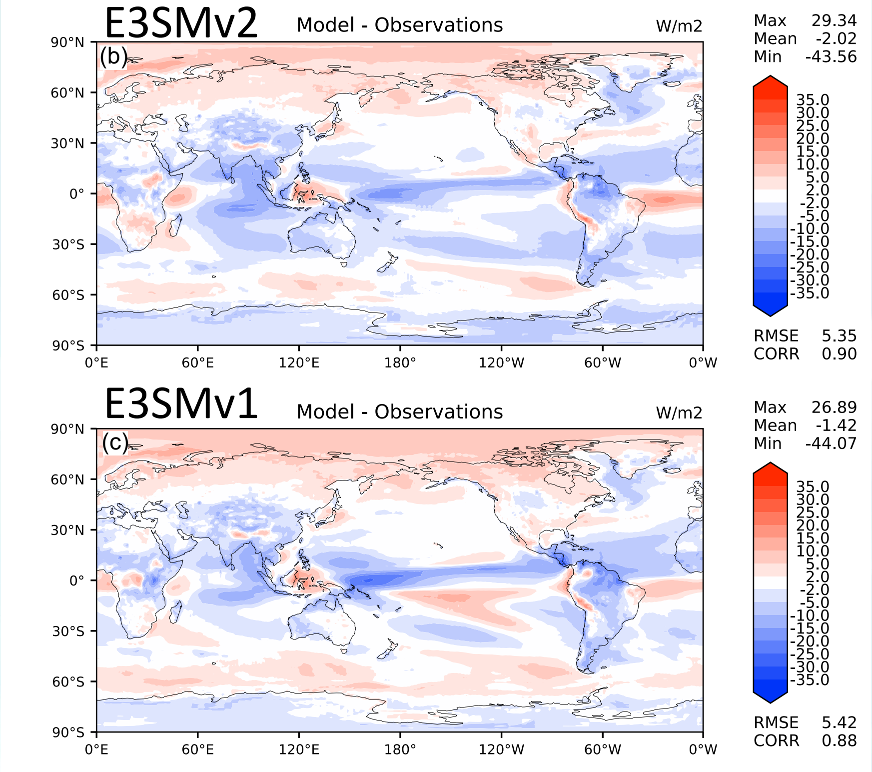
- Double ITCZ
- Amazon dry bias
- Tropical Warm Pool
- Western N America
- High elevations

Cloud radiative effects – historical ensemble

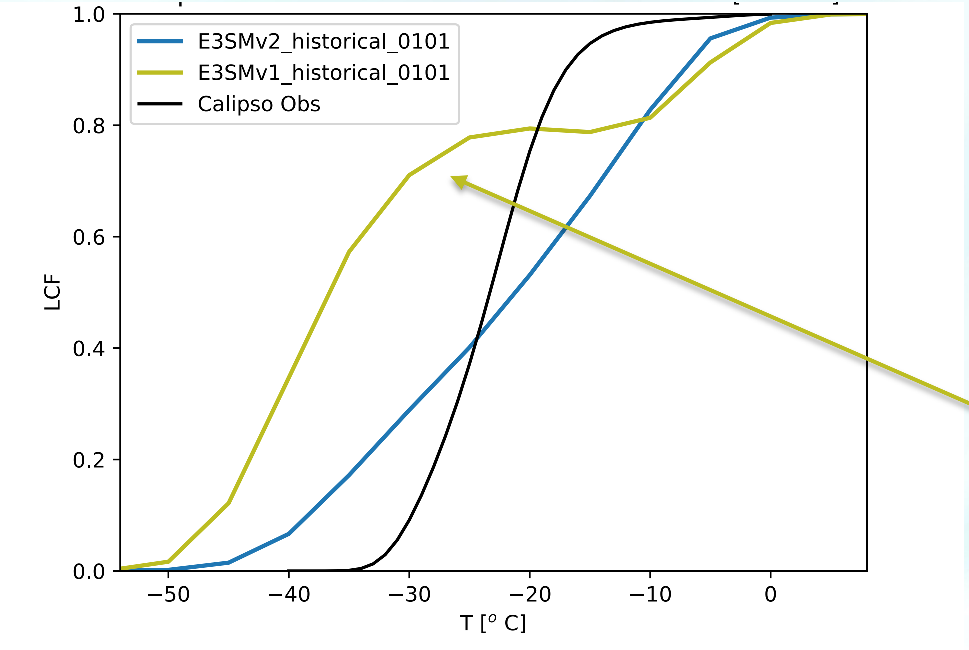
SW CRE



LW CRE



Clouds – liquid cloud fraction (LCF)

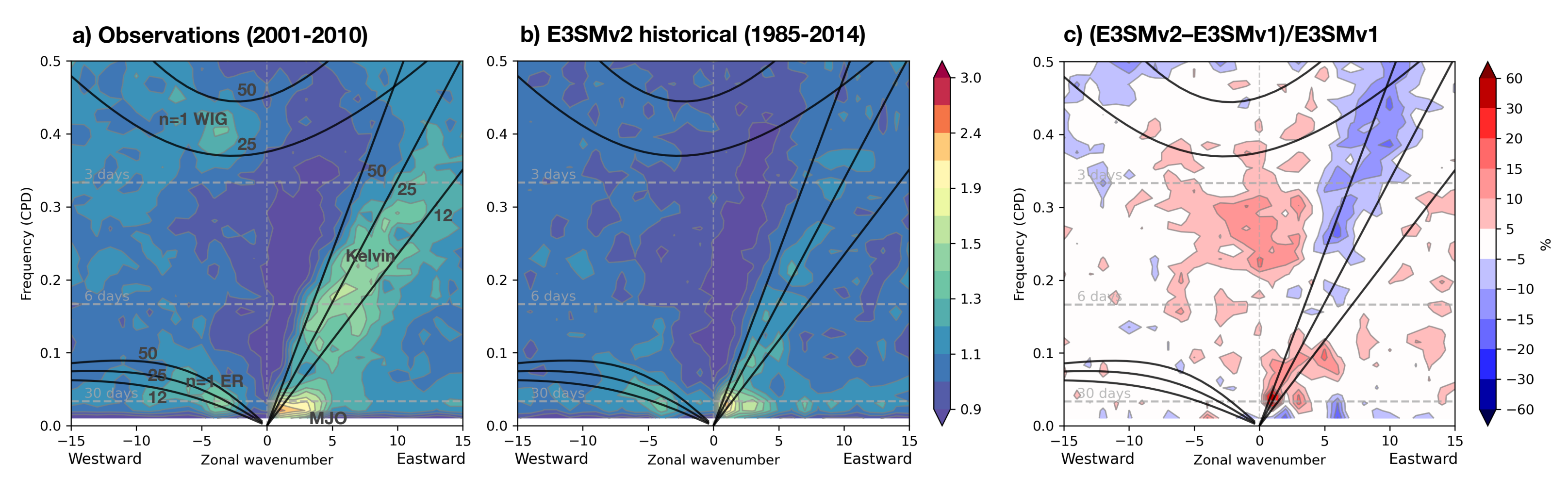


corrected unrealistic behavior in v1

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

Figure courtesy Xue Zheng

Tropical variability: Wheeler-Kiladis

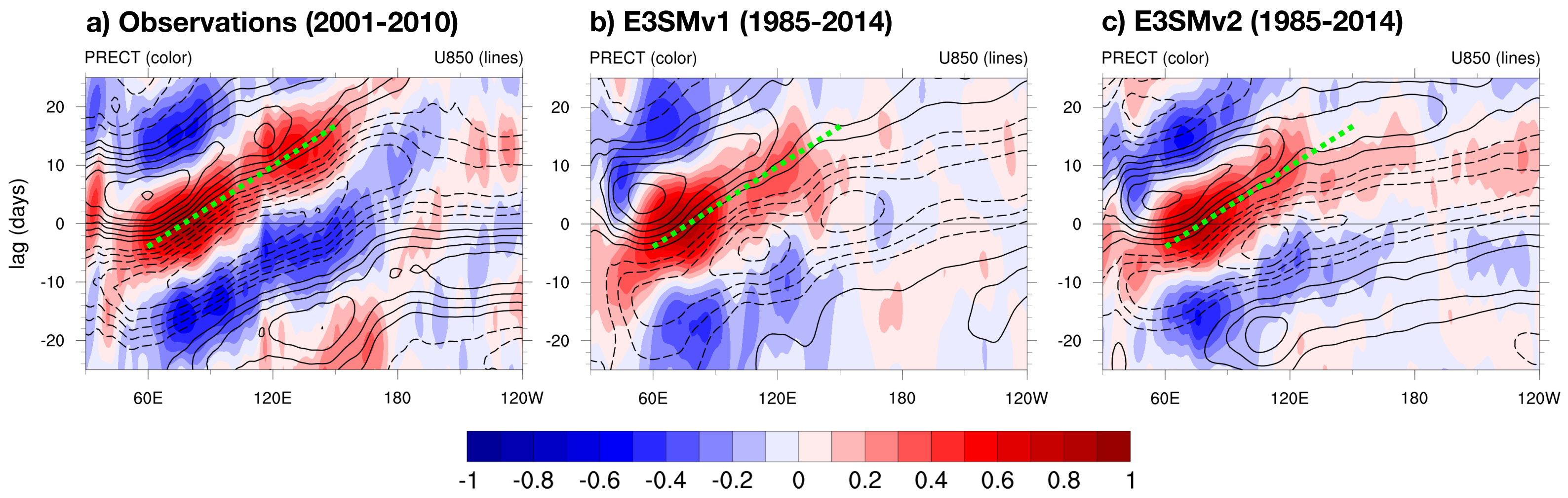


Distribution of **tropical precipitation spectral power**, normalized by a smoothed background spectrum, in zonal wavenumber-frequency space.

- 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

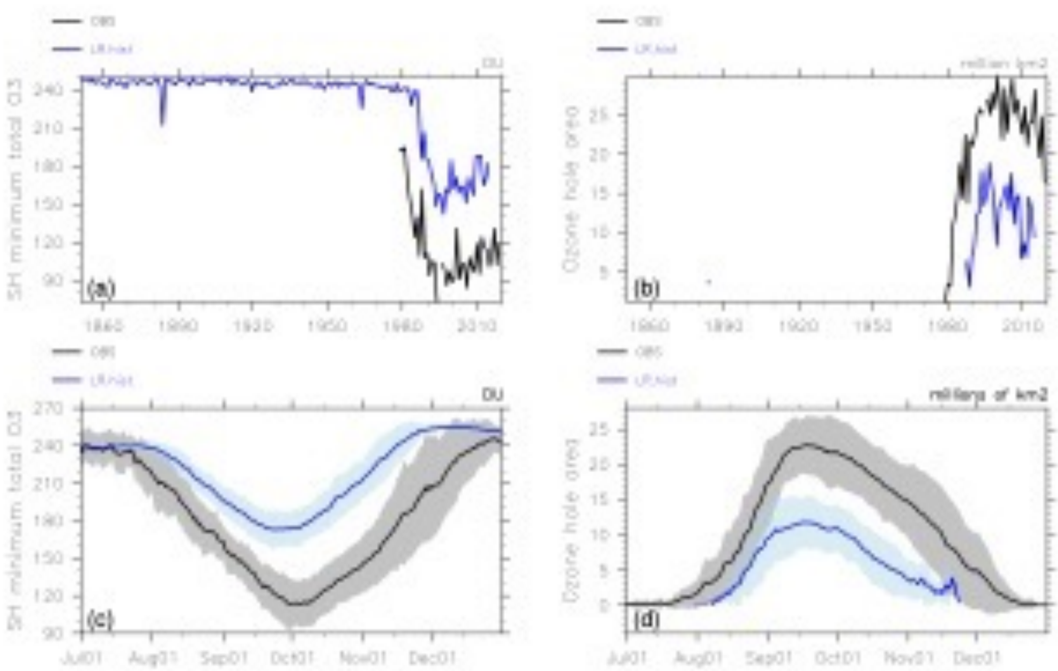


Lag correlations of equatorial precipitation zonal wind with Indian Ocean precipitation.

- **Improvement in MJO propagation** across the Maritime Continent in E3SMv2 compared to E3SMv1, as evidenced by more consistent red shading **eastward to 125 ºE**.
- 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 120ºE** and especially in E3SMv2.

Figure courtesy Jim Benedict

Ozone hole

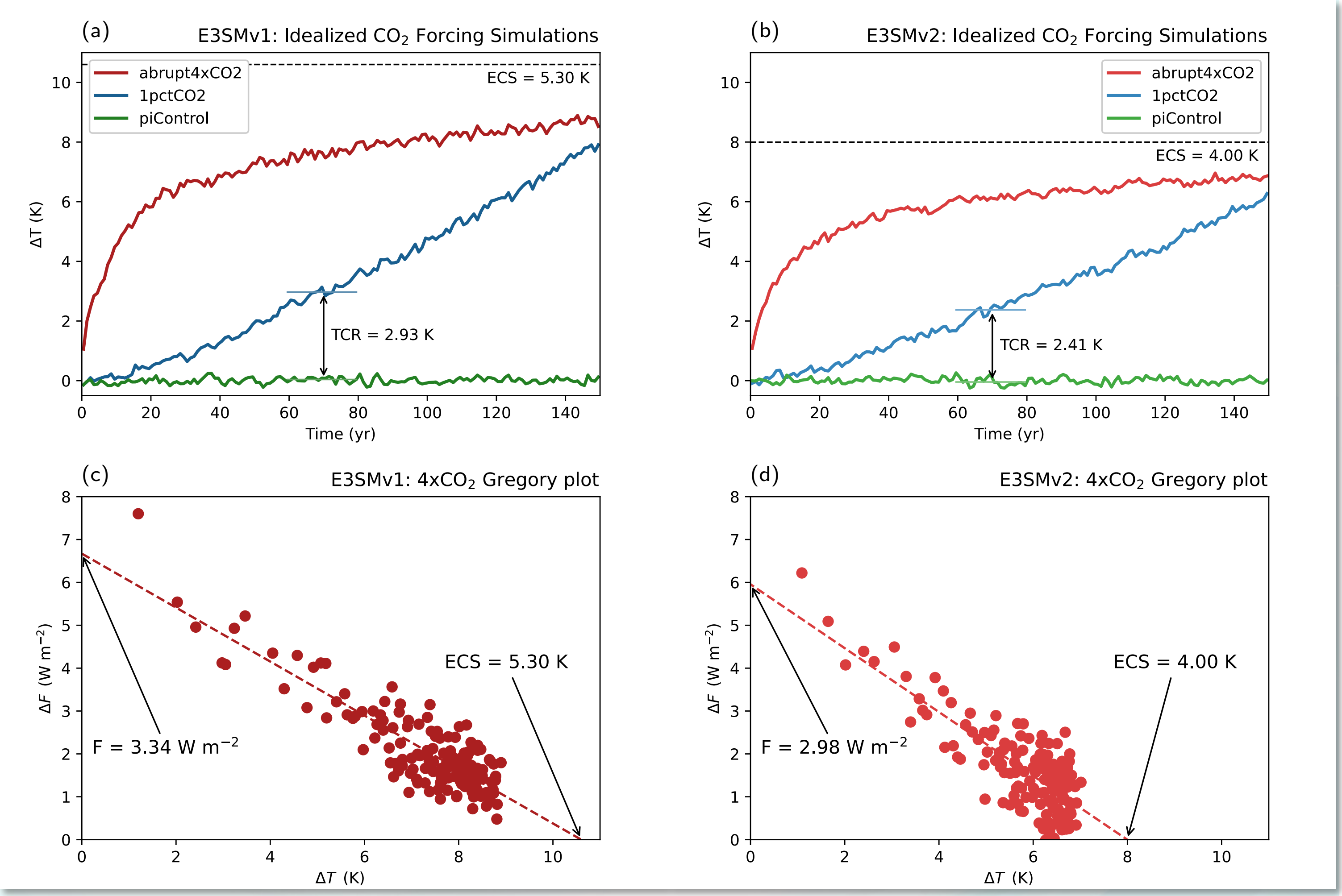


Ozone hole in the historical time series (top) and **daily mean climatology** and variance (bottom) of the **SH minimum total column ozone** (left, unit: DU) and the **SH maximum ozone hole area** (right, area with total ozone<220 DU, unit: million km2) based on the daily data from July 1 to December 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

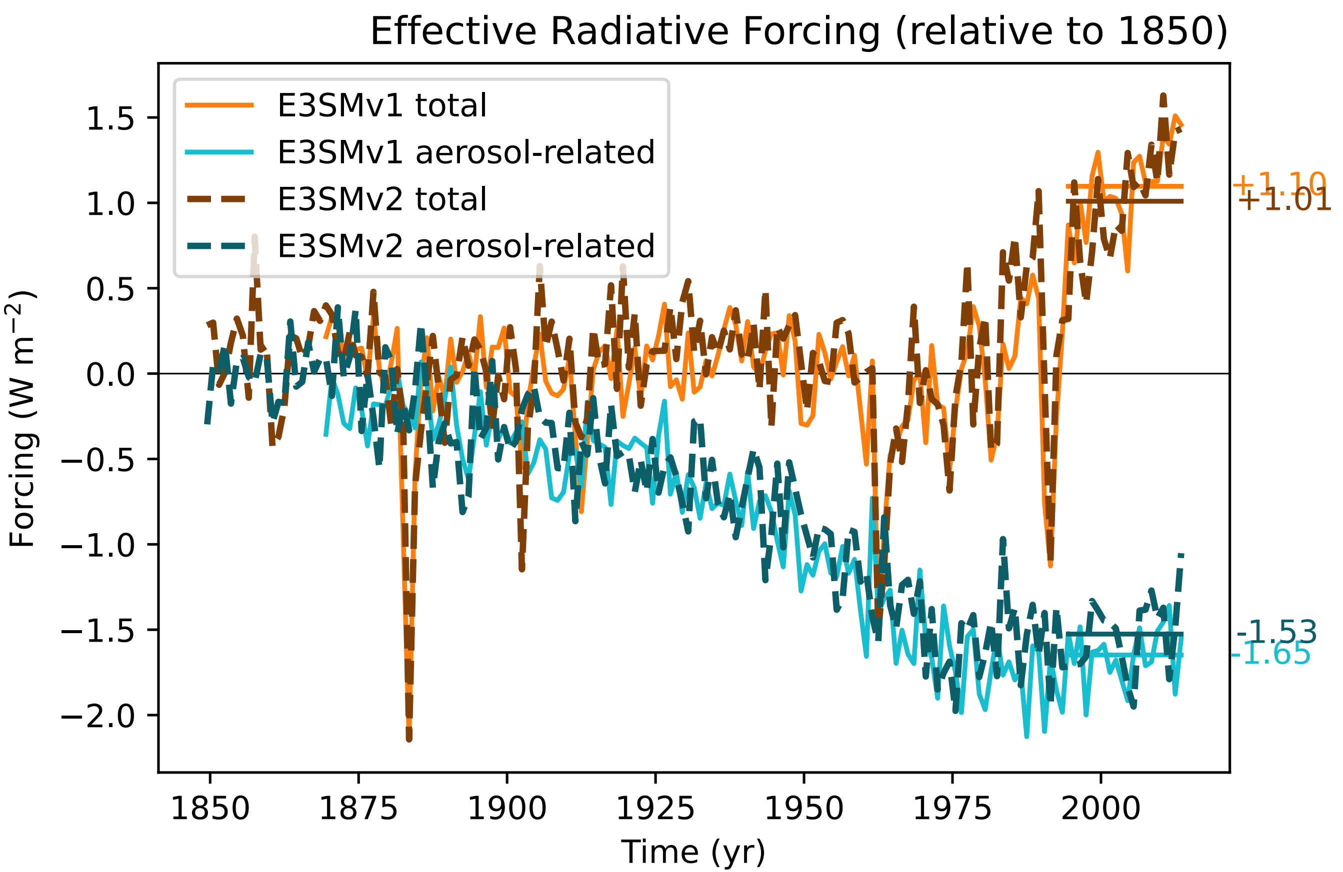
Equilibrium Climate Sensitivity
Transient Climate Response



Sherwood et al. (2020)
ECS estimate (66%)
2.6 – 3.9 K (baseline)
2.3 – 4.7 K (robustly)

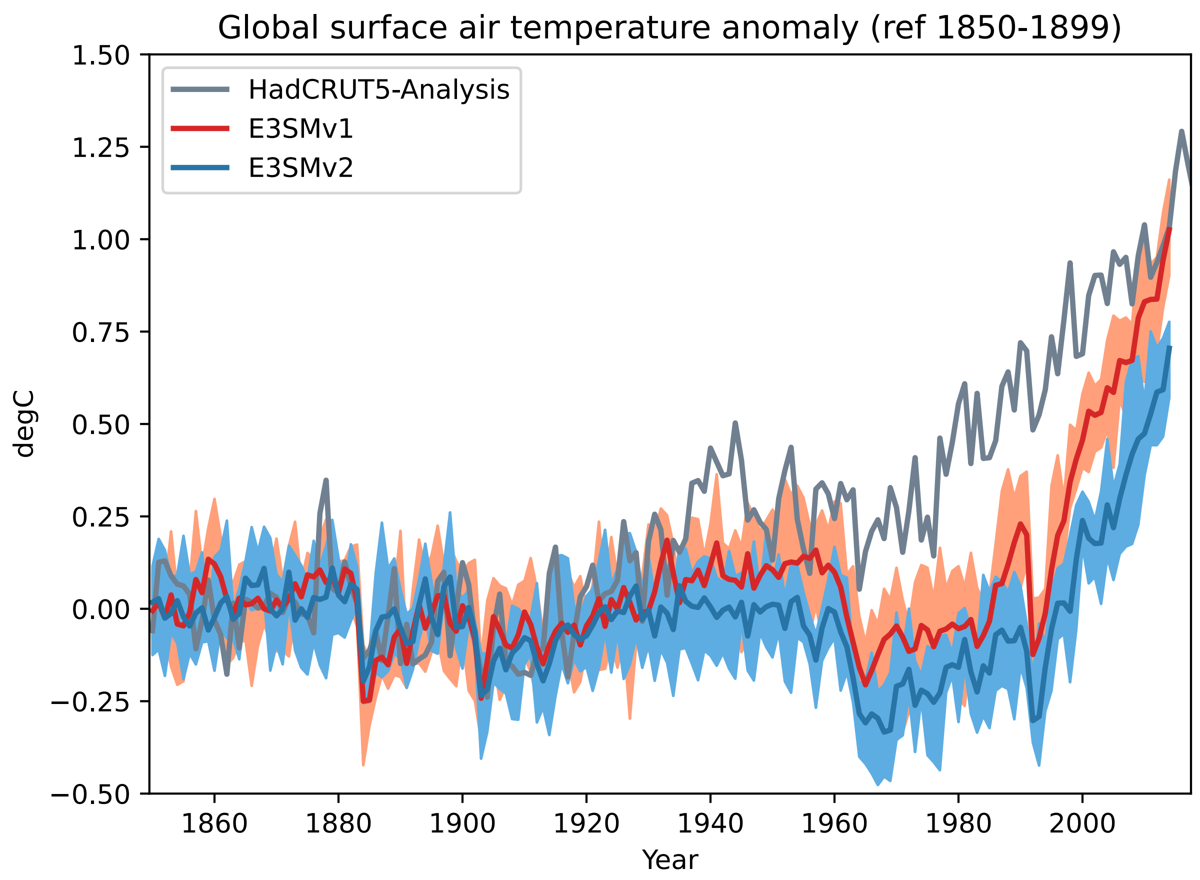
ERF

RFMIP simulations



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

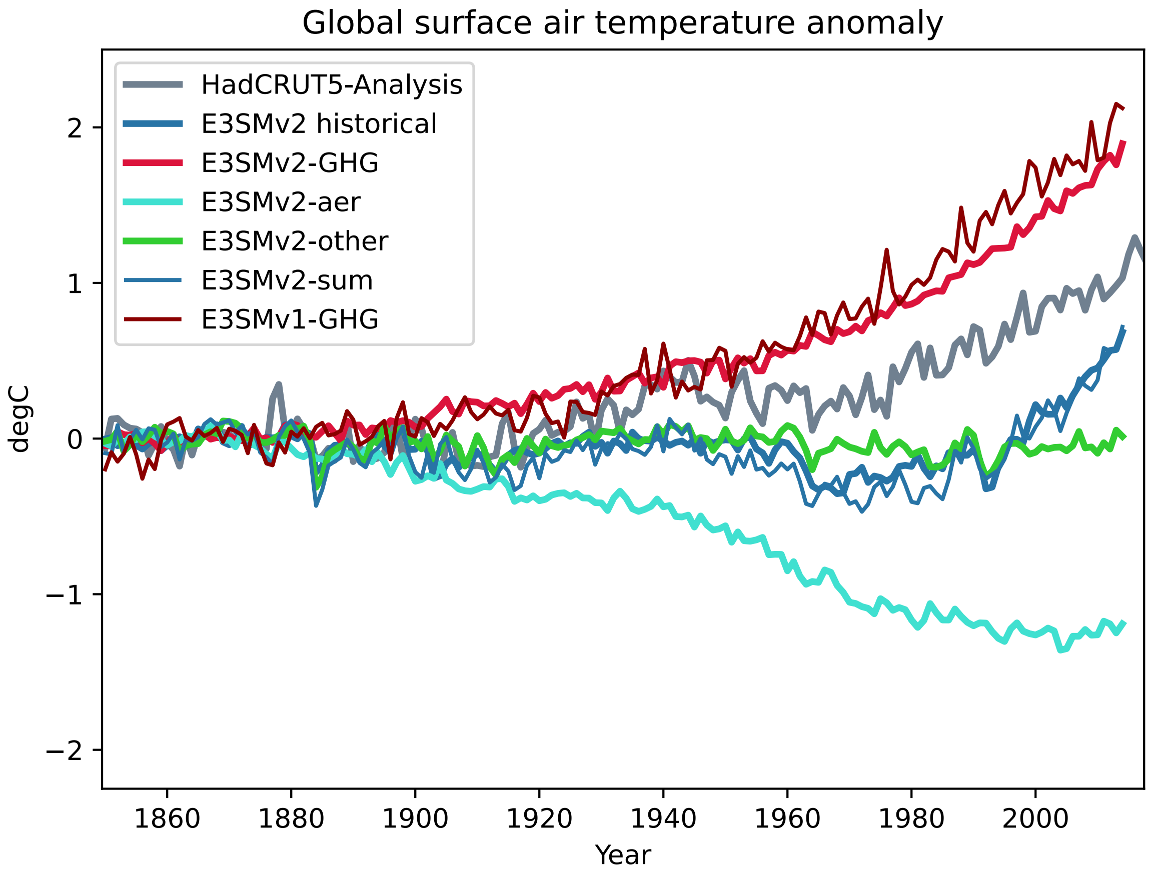


Single forcing ensemble

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:

$$\psi_{\text{all}} = \psi_{\text{piControl}} + \alpha_{\text{GHG}} \left(\psi_{\text{GHG}} - \psi_{\text{piControl}}\right) + \alpha_{\text{aer}} \left(\psi_{\text{aer}} - \psi_{\text{piControl}}\right) + \left(\psi_{\text{other}} - \psi_{\text{piControl}}\right)$$

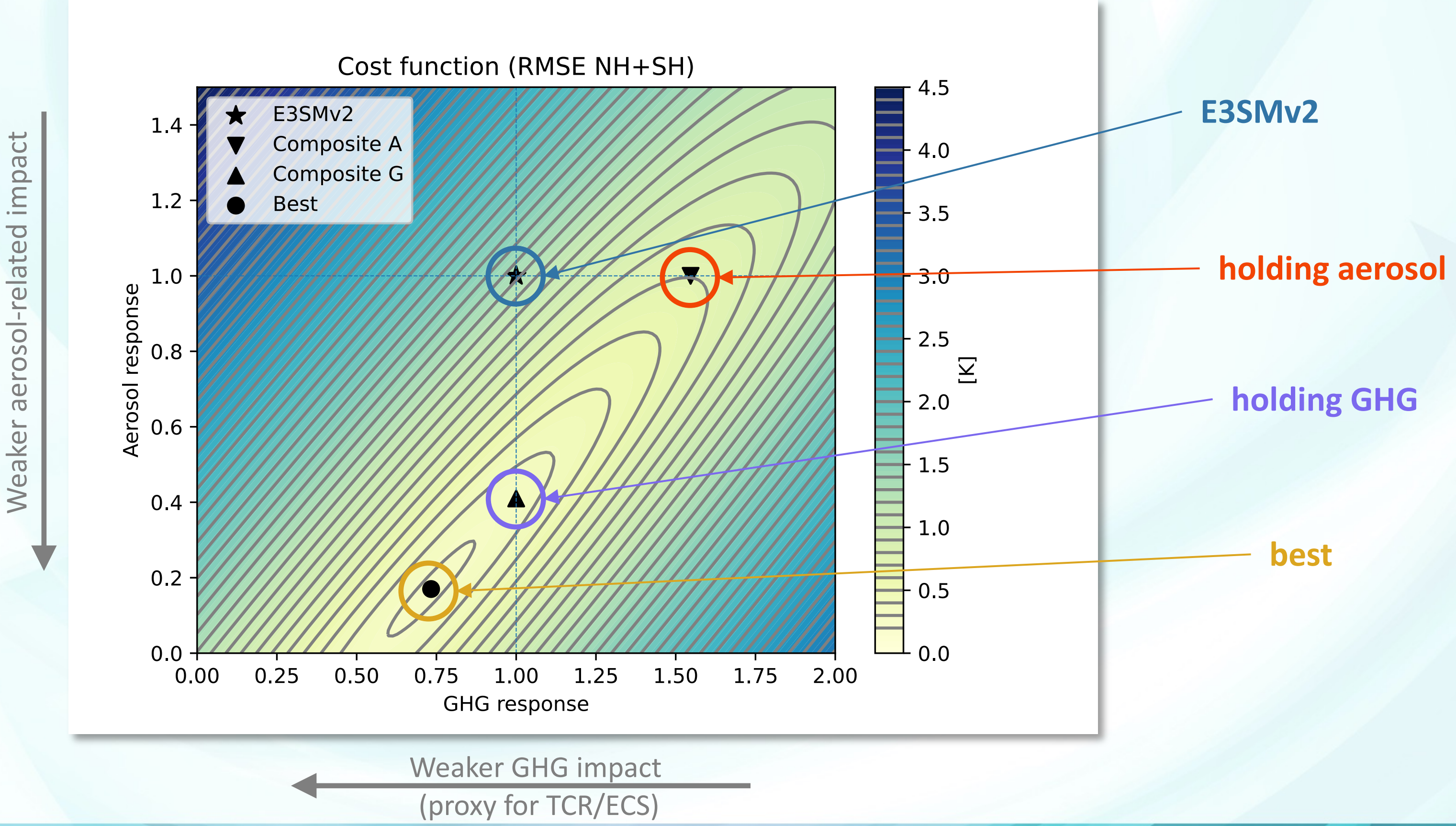
Baseline — Modulate GHG response — Modulate aerosol response — Keep the rest unchanged

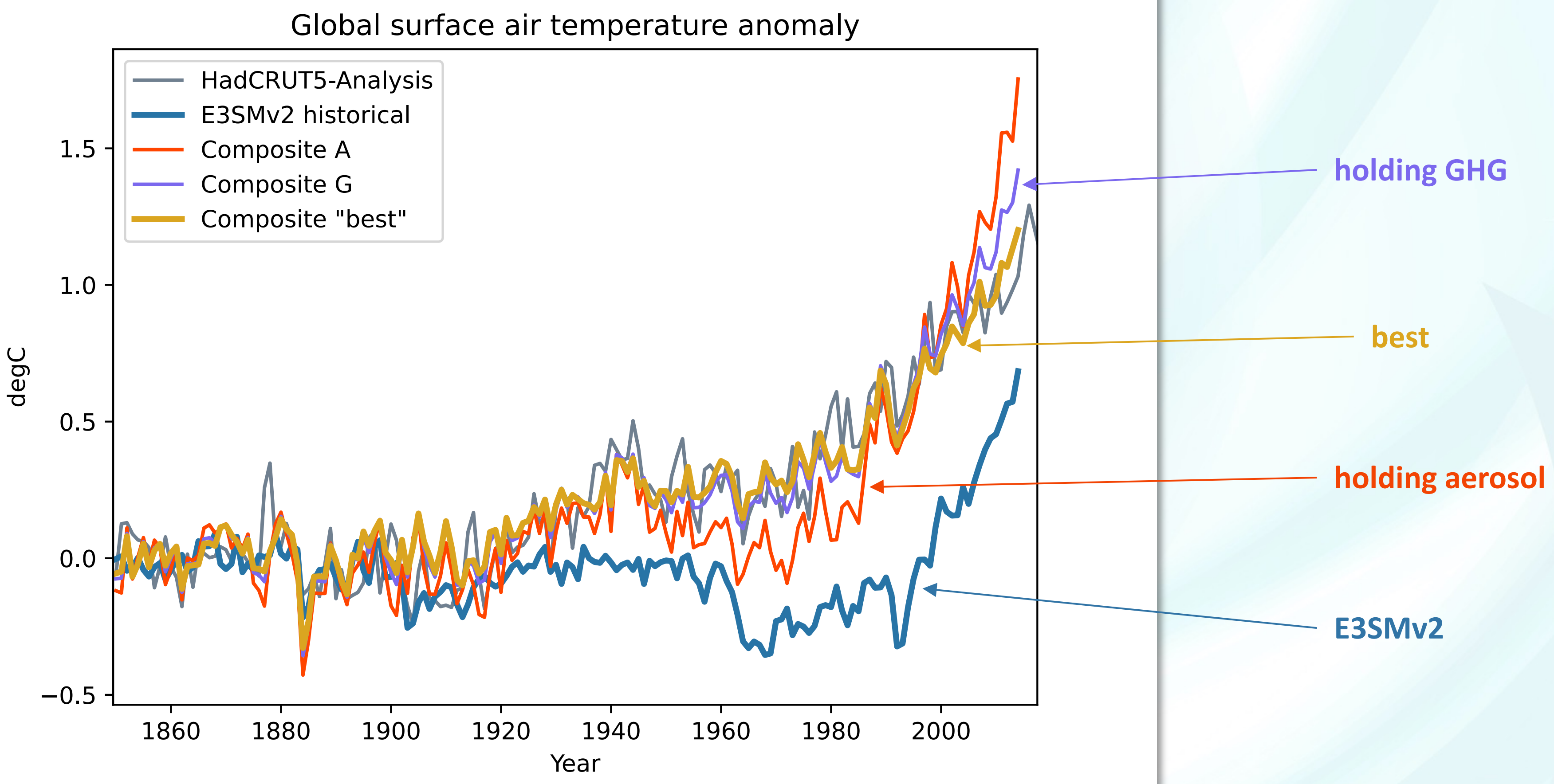
- Modulate strength of GHG response (proxy for TCR/ECS) and aerosol related to create alternate **composite configurations**.

- Applicable to any field; linear approximation holds well.

Inspired from Neelin et al. (2010)

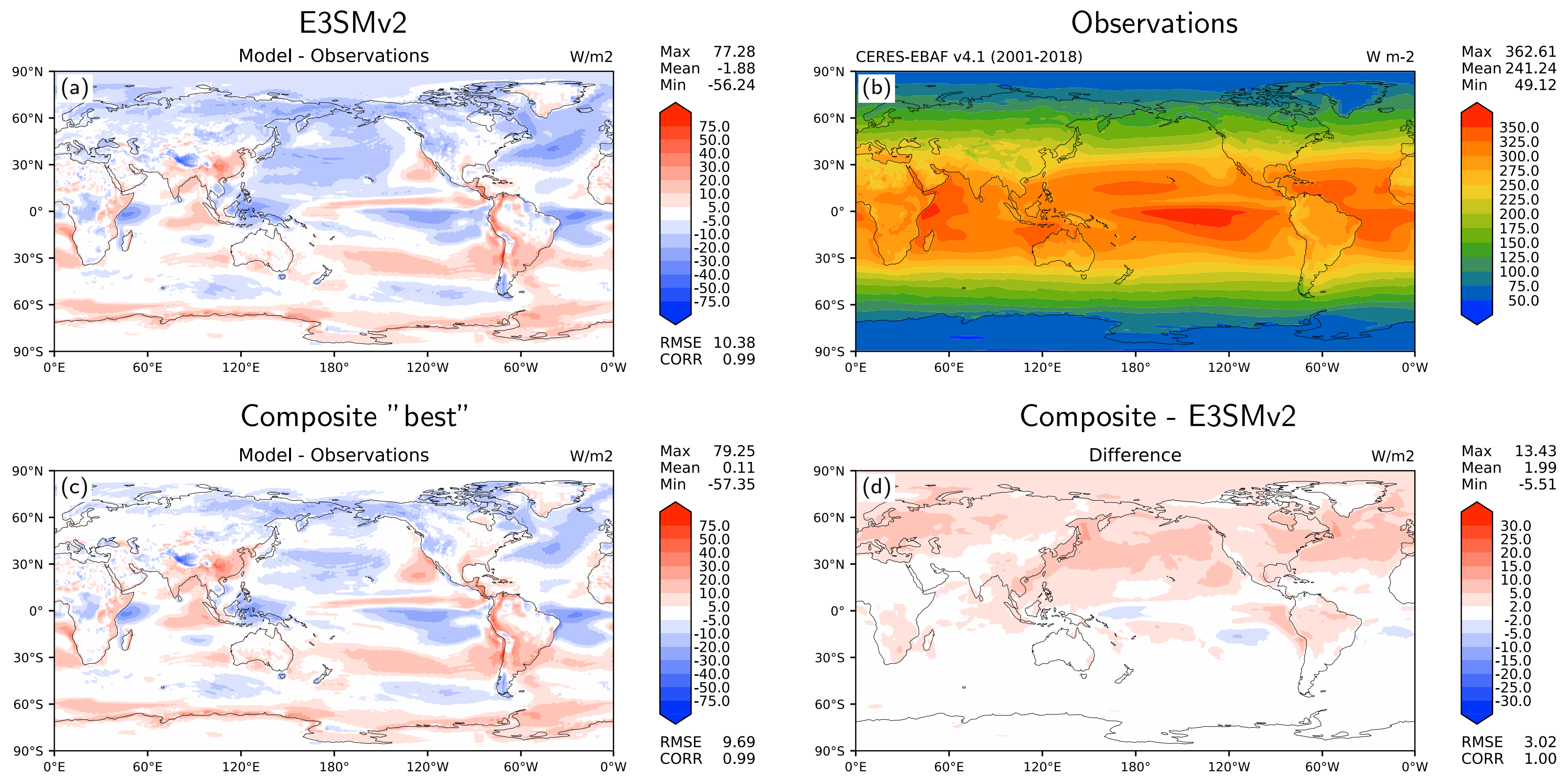
Looking for an optimum



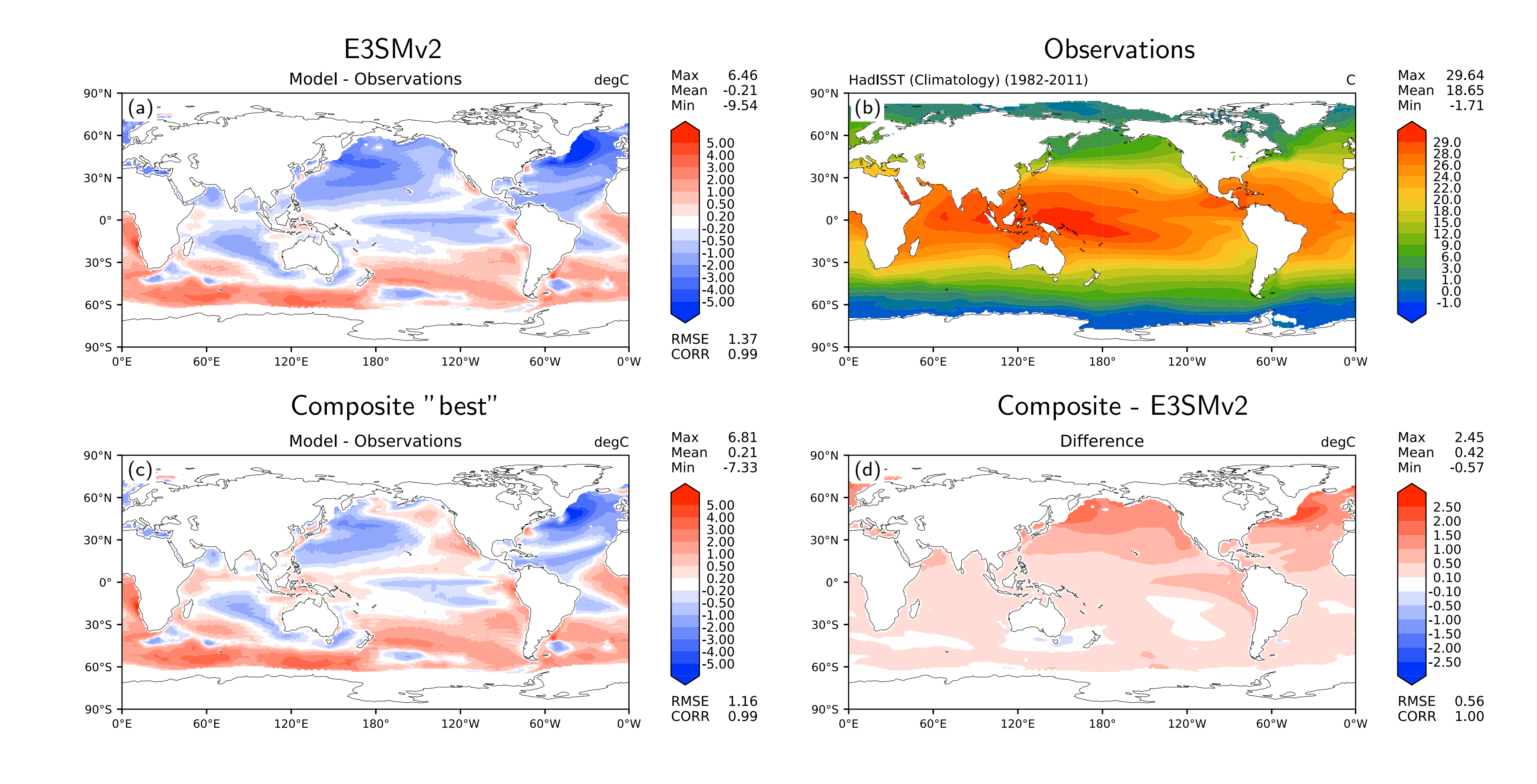


Global surface air temperature anomaly
HadCRUT5-Analysis
E3SMv2 historical
Composite A
Composite G
Composite "best"
1.5
1.0
0.5
0.0
−0.5
degC
1860
1880
1900
1920
1940
1960
1980
2000
Year
holding GHG
best
holding aerosol
E3SMv2

TOA net shortwave



Sea-surface temperature



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.