

Quantifying Feedbacks of Climate Intervention under Climate Change

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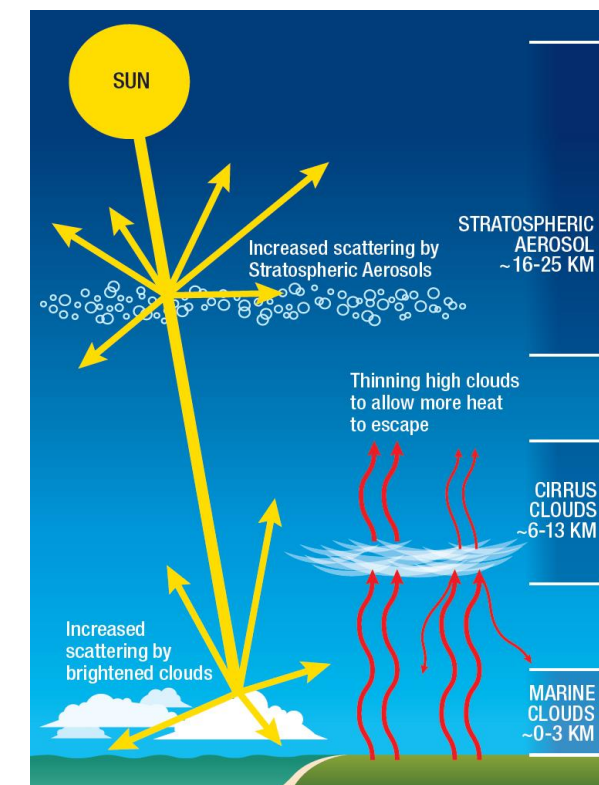
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Background

- As climate change impacts worsen, especially extreme weather events, there is a rising demand to explore **climate intervention / geoengineering** technologies to stabilize or lower Earth's surface temperature.

- Solar radiation management (SRM)** is one approach to partially reduce warming by reflecting some of the incoming solar radiation to maintain resilience of the Earth system.

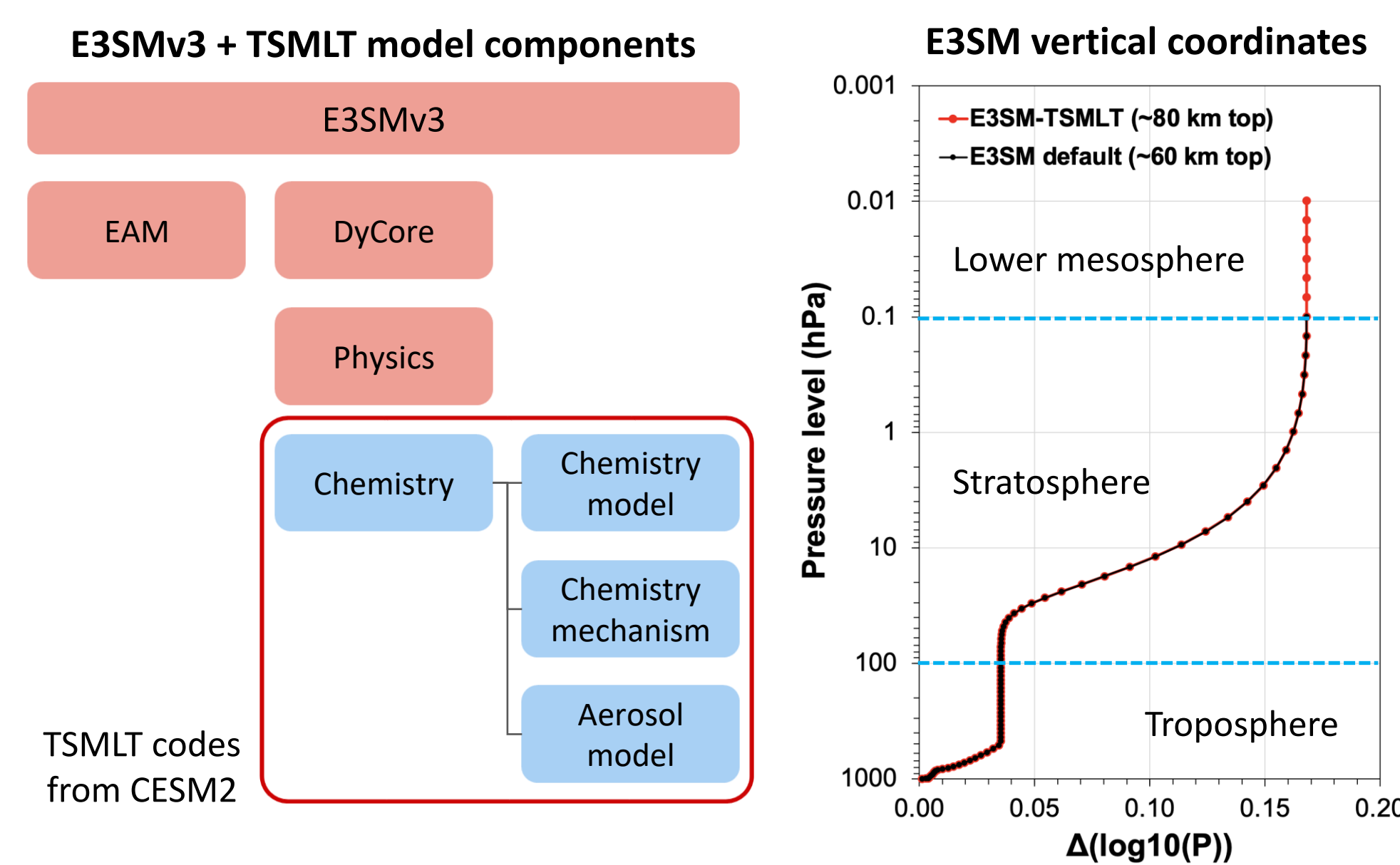


Reflecting Sunlight: Recommendations for Solar Geoengineering Research and Research Governance (2021)

- Brighten low clouds
 - Reduce high clouds
 - Stratospheric Aerosol Injection (SAI)**
- SAI, achieved by injecting sulfur directly into the lower stratosphere, is seen as the most practical and cost-effective way of implementing SRM.
- Our project aims to evaluate the benefits and risks of SAI under future scenarios using **DOE's Energy Exascale Earth System Model (E3SM)**:
 - Extend the capabilities of E3SM in simulating the impacts of geoengineering technologies
 - Quantify global and regional effects of SAI in scenarios with and without **CO₂ removal (CDR)**
 - Assess whether SAI would be a carbon-negative process to enhance CDR

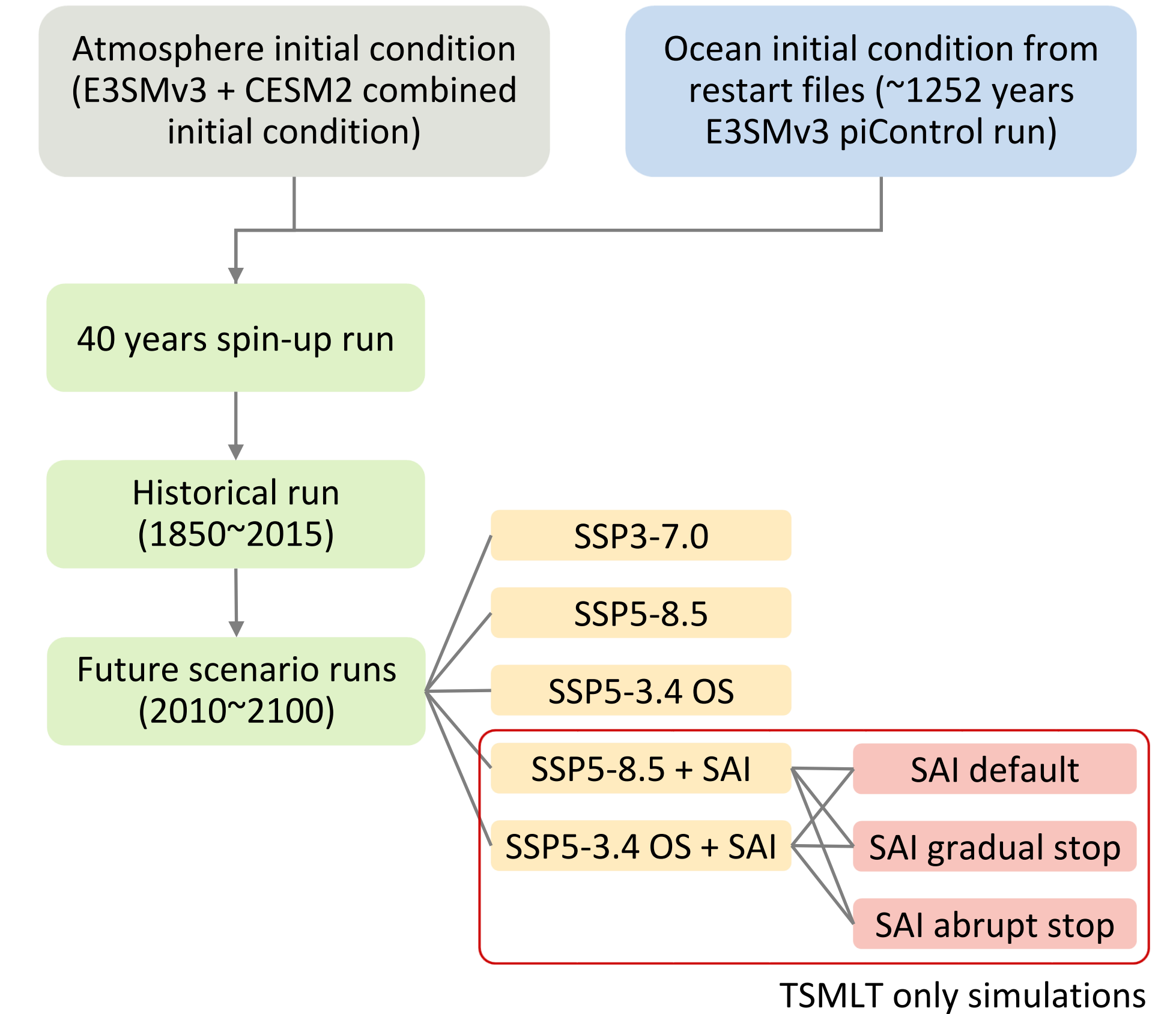
New Model Development

- We implement the **Whole Atmosphere Community Climate Model (WACCM) Troposphere, Stratosphere, Mesosphere, and Lower Thermosphere (TSMLT)** chemistry mechanism into E3SM version 3 because TSMLT has:
 - Enhanced chemical reactions: ~ 220 chemical species are involved
 - Prognostic stratospheric aerosols and higher model top: more realistic stratospheric chemistry
- Step 1: Port detailed TSMLT chemistry package and associated physics package into E3SMv3
- Step 2: Set up the vertical coordinate to improve the model top from 60 km to 80 km
 - 1000 hPa - 0.1 hPa: Same initial conditions as E3SMv3
 - 0.1 hPa - 0.01 hPa: CESMv2-FW1850 data



Geoengineering Simulation Plans

- We have created a new atmospheric initial condition for our E3SMv3-TSMLT fully-coupled simulation by combining E3SMv3 and CESM FW1850 atmospheric initial conditions.
- We leverage the long-term (~1,252 years) spin-up ocean and sea-ice fields from E3SMv3 piControl simulation.
- We will turn on the **land biogeochemistry** once its initial condition is ready.

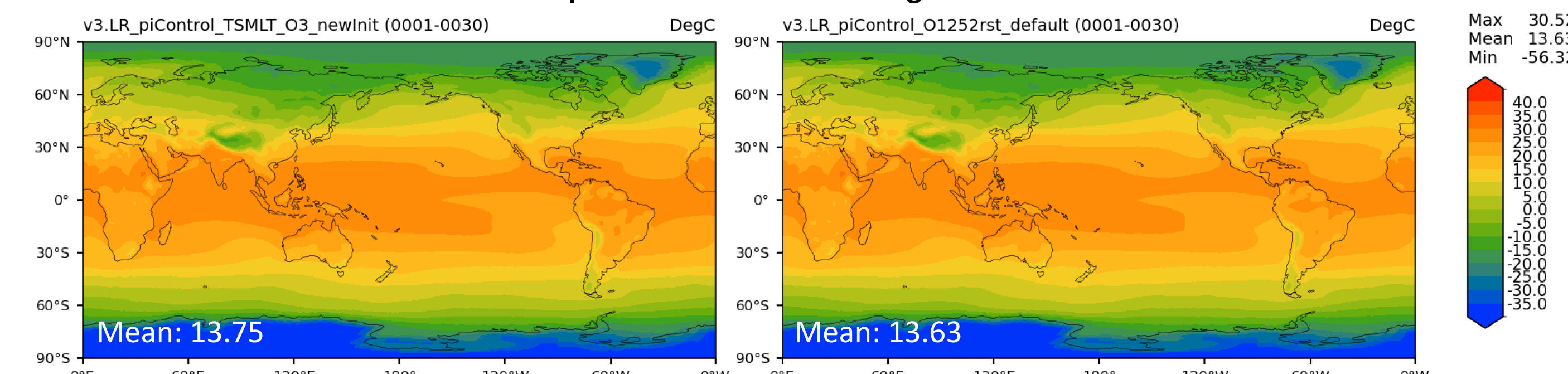


Preliminary Results (spin-up runs for 30 years)

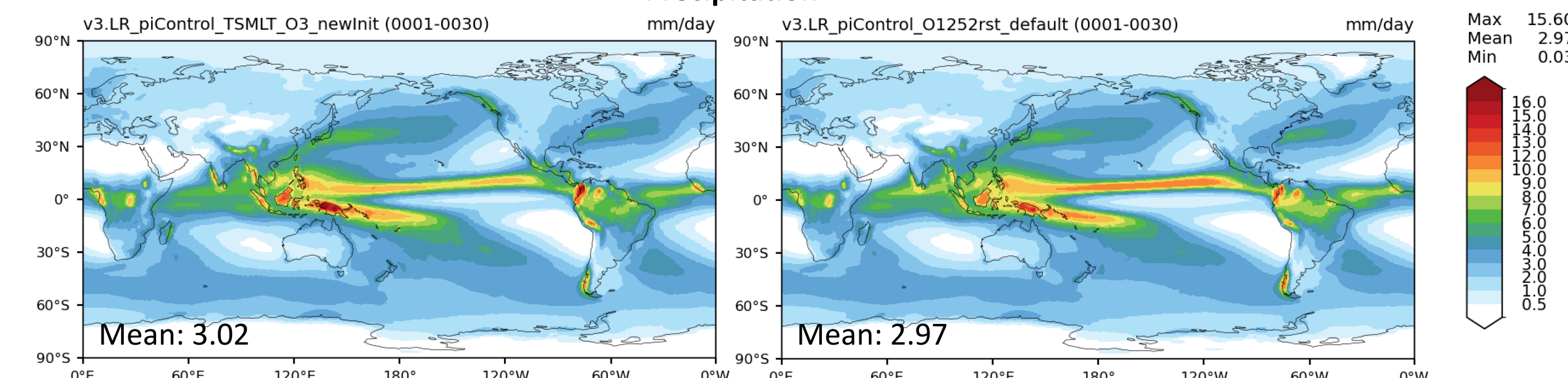
- We have integrated TSMLT and associated physics into E3SMv3 and got good agreement in most variables with the E3SMv3-default run.

E3SMv3-TSMLT Default

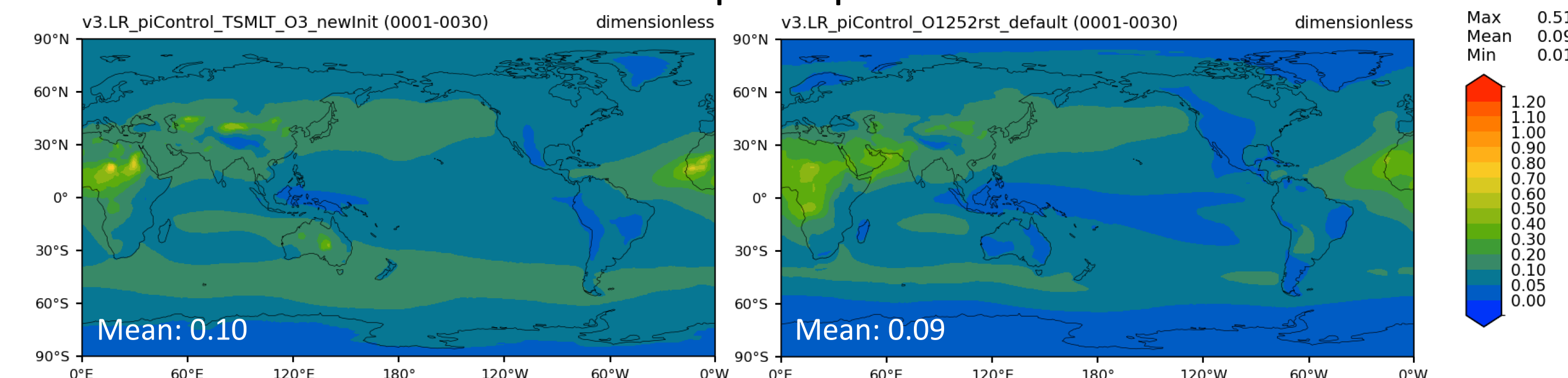
Temperature at reference height



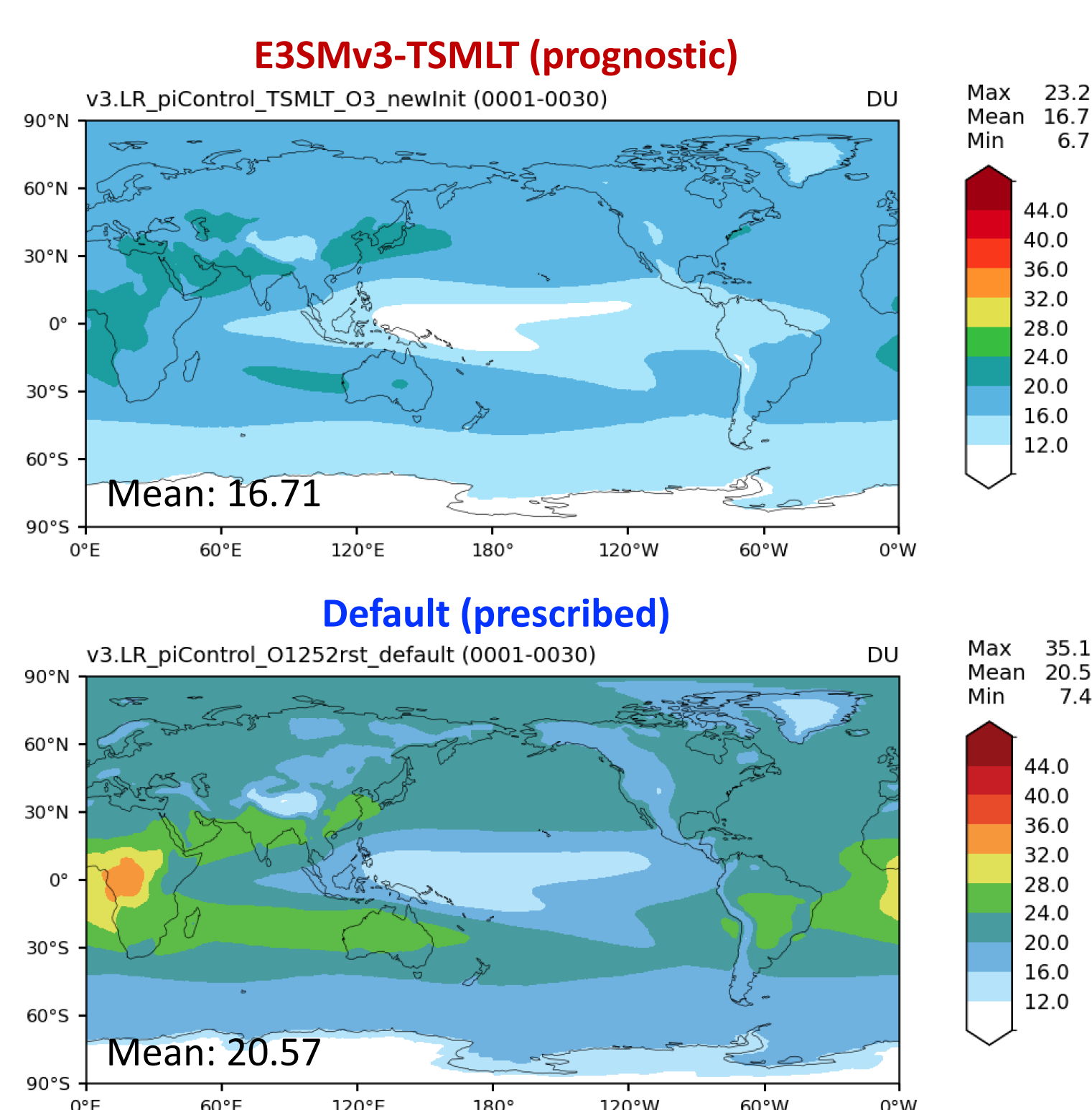
Precipitation



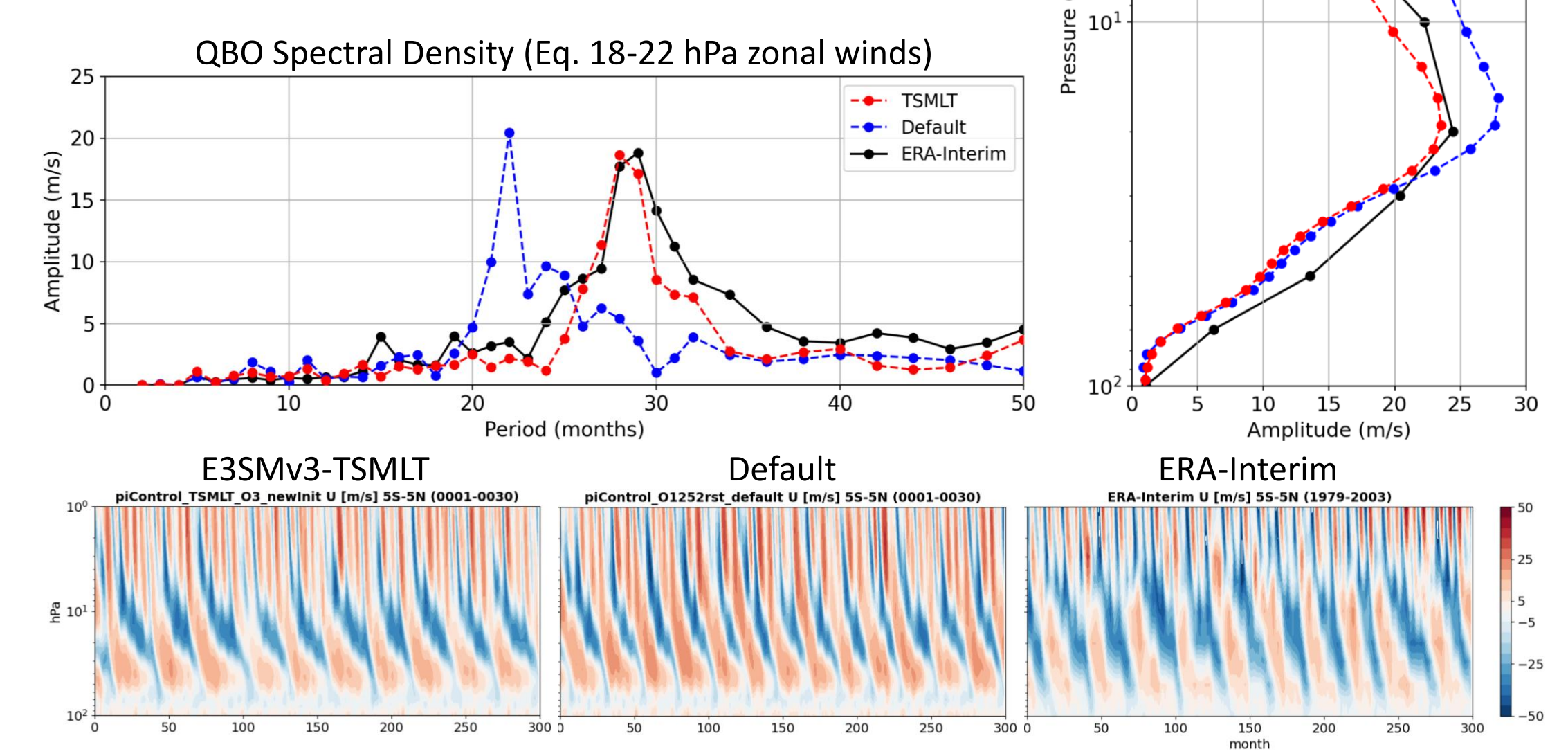
Aerosol Optical Depth



Tropospheric total column ozone



- Quasi-Biennial Oscillation (QBO) in the E3SMv3-TSMLT run (science_tuned) is improved compared to E3SMv3 default runs:
 - QBO affects residual circulation, temperature, and **chemical transport in the stratosphere**.
 - 30 years spin-up results are shown.



Future Works

- Plans in FY24:
 - Freeze E3SMv3-TSMLT new development
 - Conduct new SAI simulation experiments for SSP5-3.4-OverShoot-SAI and other scenarios
 - Analyze SAI and SAI+CDR simulations to document ecological, hydrological, and atmospheric impacts and their underlying mechanisms