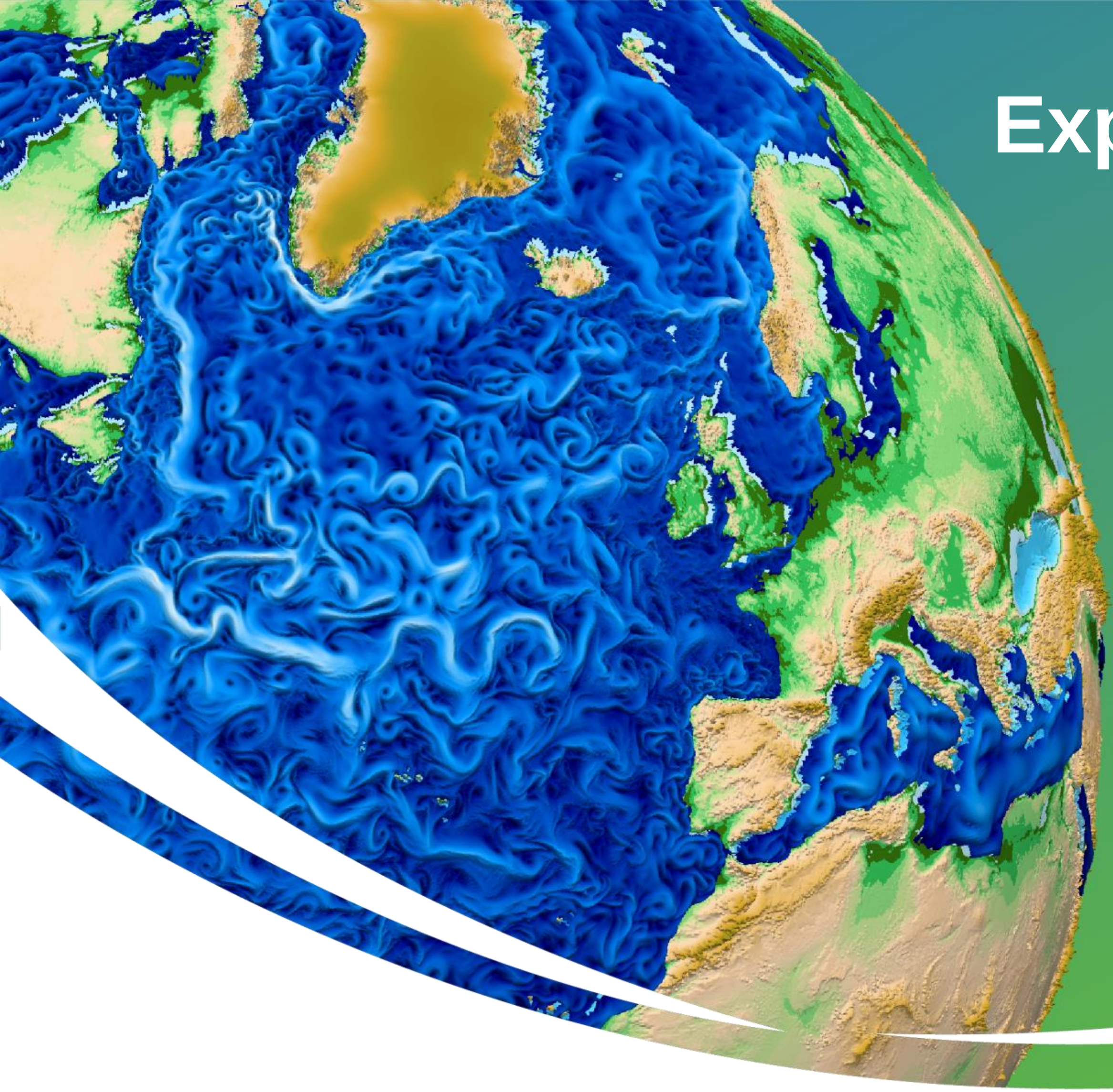

Exploration of Coupled-model Spin-up with Alternating Approach

Shixuan Zhang (PNNL)
Wuyin Lin (BNL)
Carolyn Begeman, Mathew Maltrud, Jon Wolfe, Andrew Roberts, Luke Van Roekel, Xylar Asay-Davis, (LANL)
Xue Zheng, Chris Golaz (LLNL)
E3SM Phase 3 Coupled Model Group

EESM PI Meeting 2024
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U.S. DEPARTMENT OF ENERGY | Office of Science

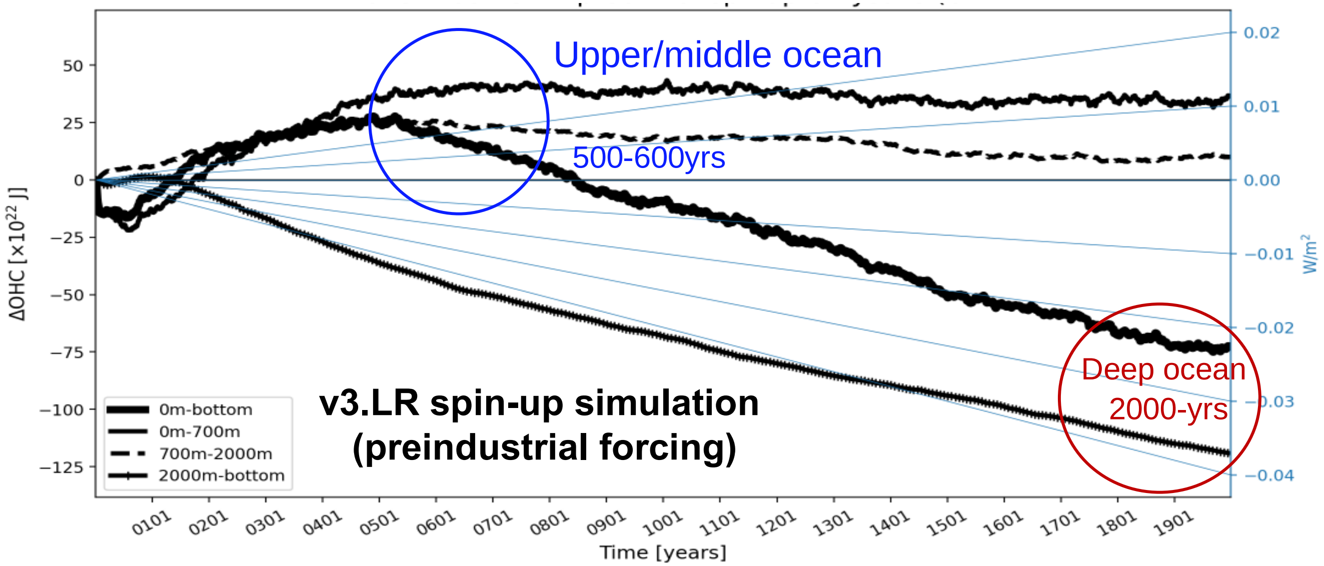
E3SM Energy Exascale Earth System Model

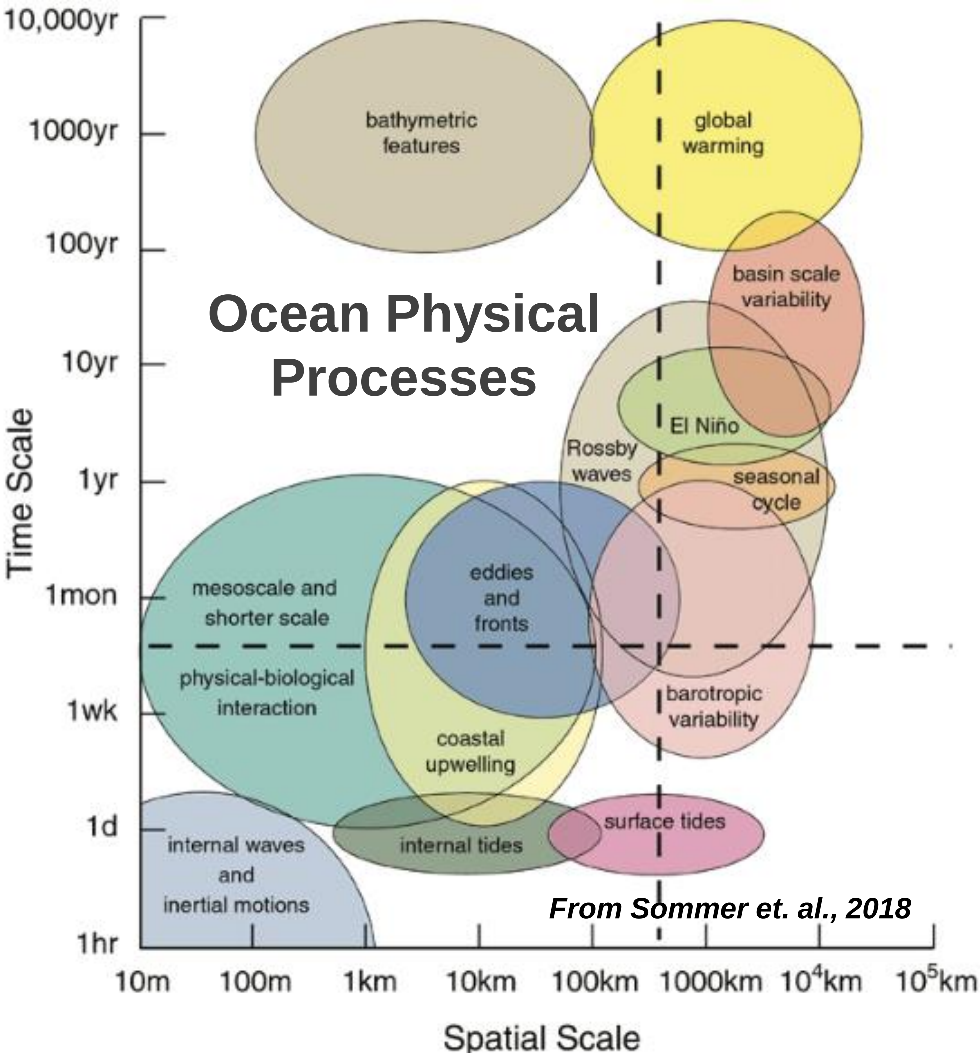
E3SM Coupled Model Spin-up Workflow: Challenge & Motivation

Earth System Model

- **Science Need:** Spin-up Earth System Models to a stable equilibrium representative of real-world conditions is critical for simulating response of atmosphere, land and ocean to climate change
- **Challenge:** An extremely slow process primarily due to the deep ocean's long adjustment timescale
  - Fully spun-up often requires 1000s years → heavy burden even for LR on powerful computers, formidable for high-resolution
  - Limiting factor for timely delivering simulation campaigns and high-res (ultra-high-res) coupled model development in E3SM Phases 3&4

Global Ocean Heat Content Anomaly

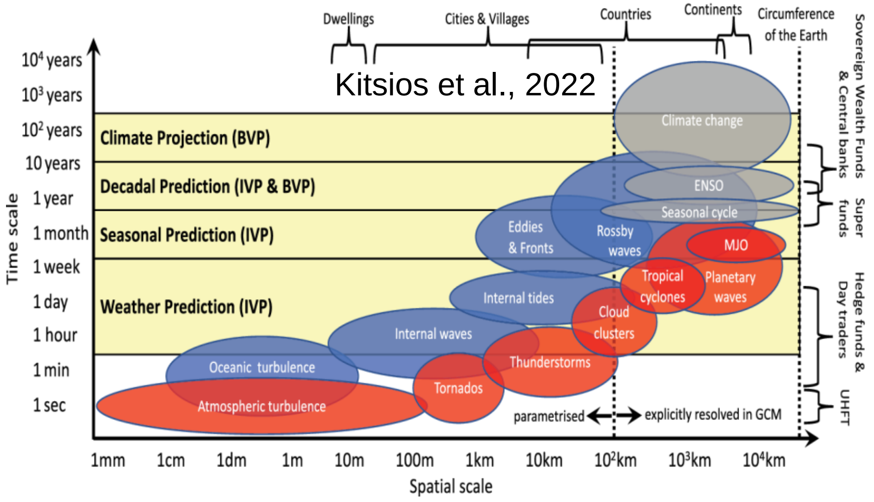




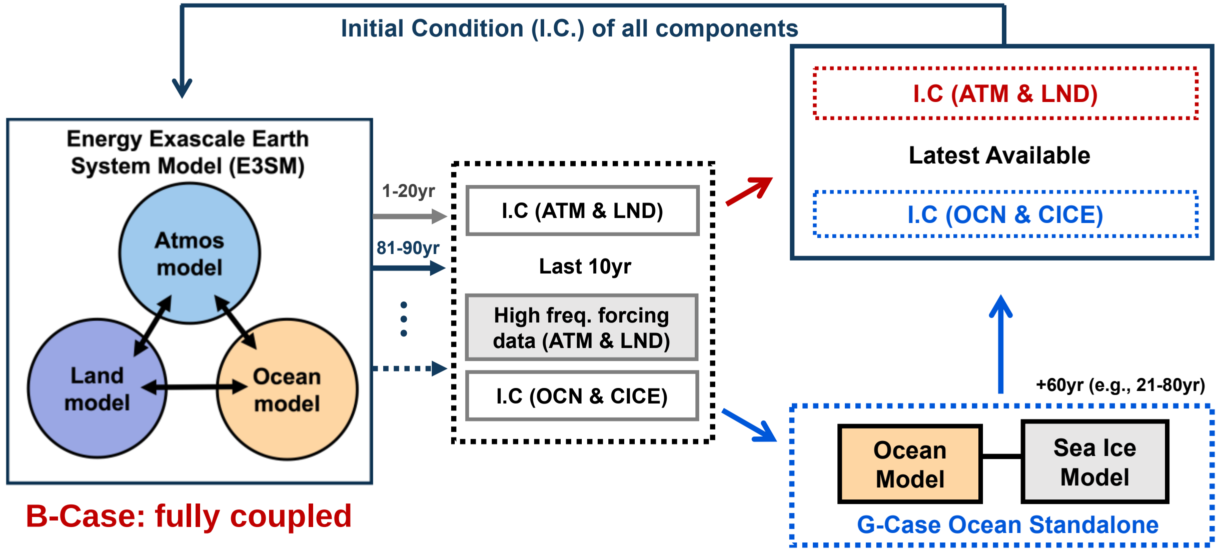
From Sommer et. al., 2018

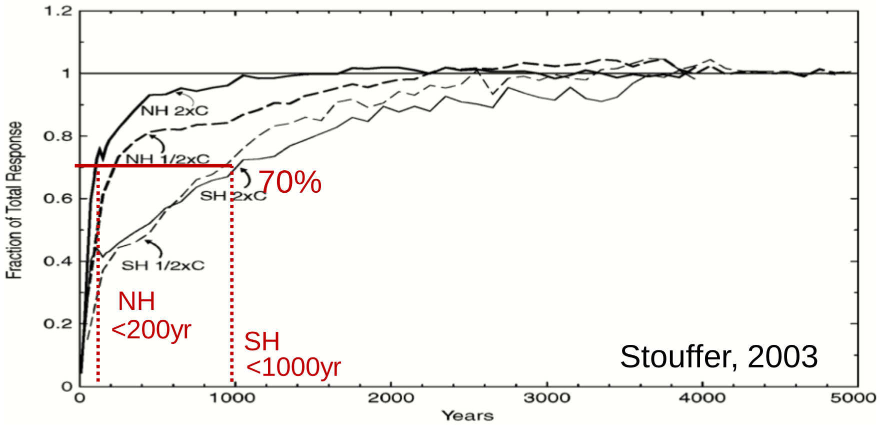
E3SM Coupled Model Spin-up Workflow: Conception & Justification

- **Science Question:** Can we find an alternative approach to address (at least partially) the challenge of model spin-up?
  - Most coupled earth system (interested to climate prediction) processes operated on time scales that are much faster than slowing deep ocean processes
  - Focus on spinup of upper/middle ocean (above 2km) to equilibrium
    - much shorter conceptual equilibrium time scale → can be well spun-up with hundred instead of thousand years simulations
    - trends due to the continuing drift in the deep ocean (below 2km) can be partially removed via linear regression (e.g., Streffing et. al., 2022)



- **Partial (and simple) solution:** explore approach to reduce computational burden from long-term spinup simulation
  - Alternating coupled (B-Case) and uncoupled ocean (G-Case) spin-up





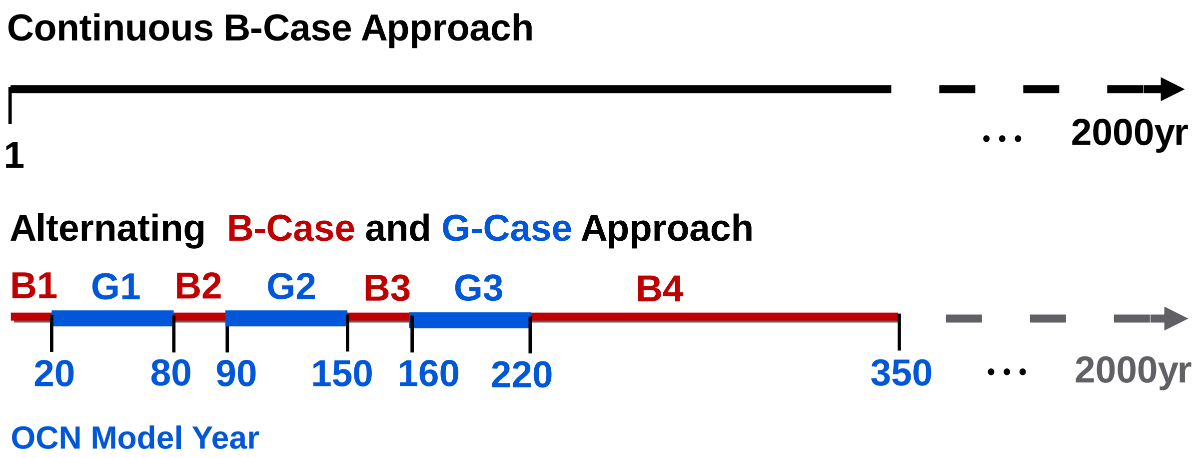
Spatiotemporal scales of motion in the coupled Earth system (Top), and time series of the fraction of total equilibrium hemispheric mean surface air temperature response (Bottom)

E3SM Coupled Model Spin-up Workflow: Conception & Justification

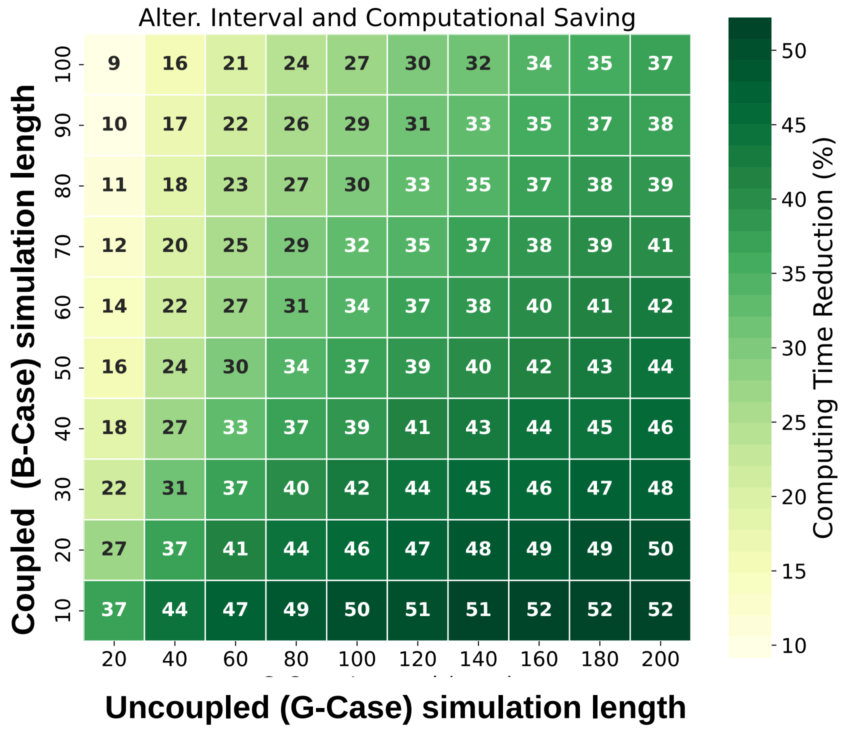
Earth System Model

- **Science Question:** Can we find an alternative approach to address (at least partially) the challenge of model spin-up?

- **Partial (and simple) solution:** explore approach to reduce computational burden from long-term spinup simulation
  - Alternating coupled (B-Case) and uncoupled ocean (G-Case) spin-up
  - Reducing the computational cost from the atmosphere model integration (occupies ~60-70% of total cost in B-Case) for ocean model spinup



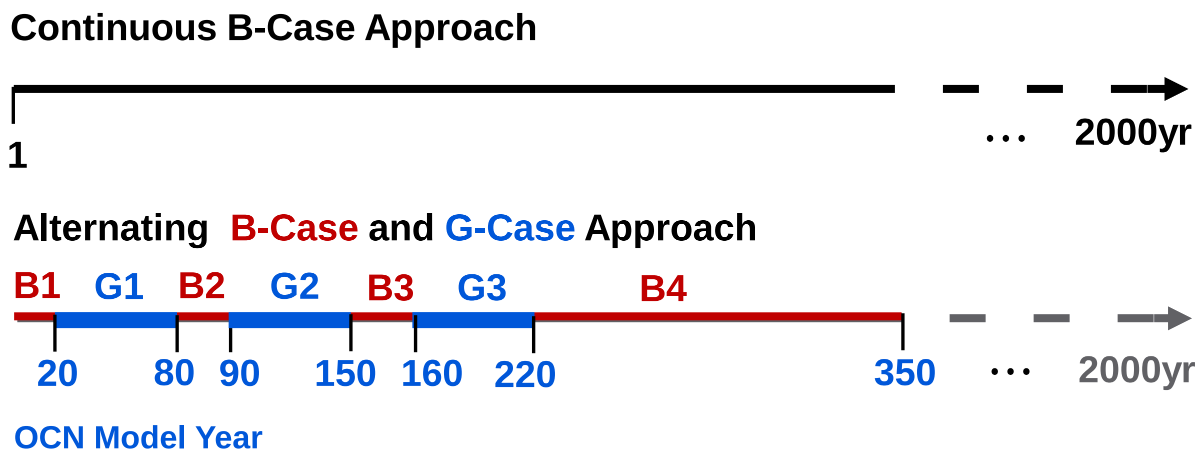
Percentage savings as a function of alternating design



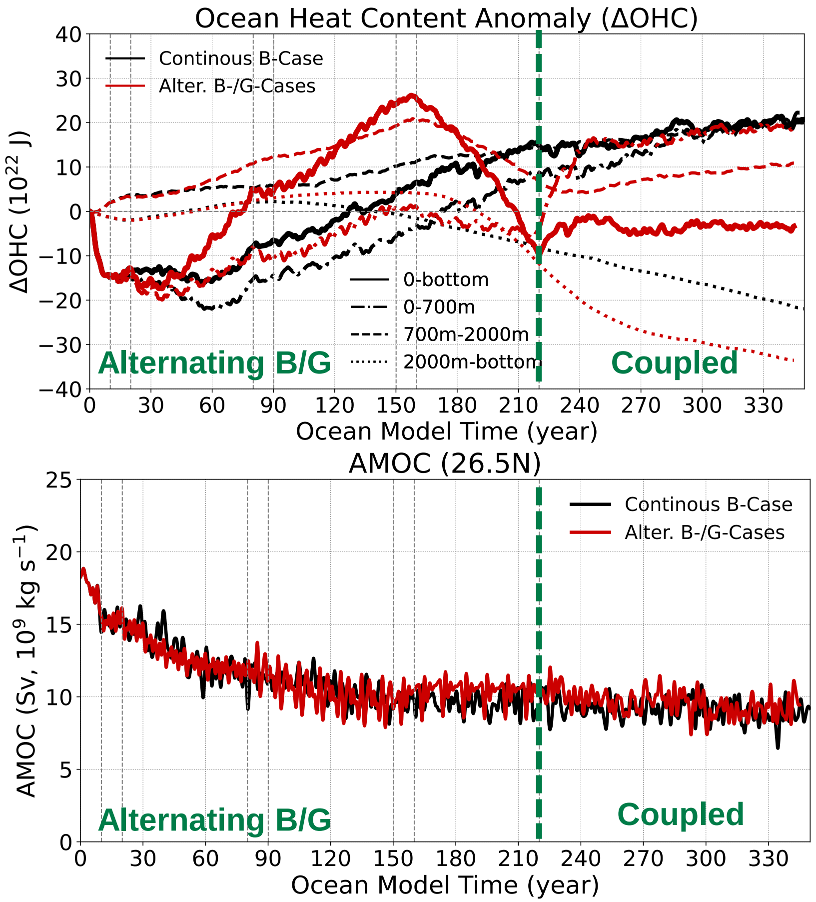
The key for "success" is to find optimal alternating design with maximum computing savings while still allowing all model components to evolve in a manner that mimics a fully coupled simulation

E3SM Coupled Model Spin-up Workflow: Verification & Validation

- **Alternating B-/G-Cases show the potential to reduce the computational cost, meanwhile maintaining the ocean model state to stay close to those from fully coupled configuration**



- **Short-term B-Case: 10-year** fully coupled v3 low-res simulations
  - Adjust and equilibrate coupled components
  - provide data atmosphere/land for G-Case
- **Long-term G-Case: 60-year** ocean model standalone simulations
  - Spin up Ocean and Sea Ice models
  - Provide initial conditions for B-Case
- **Cost Reduction:** ~40-45% savings if targeted for 2000-year spin-up



Time evolution of ocean heat content anomaly (ΔOHC), AMOC at 26.5N, over 350 years of piControl simulations with cycled 1850 external forcing data.

E3SM Coupled Model Spin-up Workflow: Summary & Future Work

- **Exploration from our study indicates that a well-designed simulation approach can potentially facilitate efficient coupled model spin-up**
  - Alternating B-/G-Cases approach effectively reproduces the climate of the atmosphere, land, and ocean (middle and upper layers) obtained from the Continuous B-Case approach
  - After three cycles of Alternating B-/G-Cases, coupled E3SMv3 achieved an acceptable equilibrium state in the upper and middle ocean with a reduced simulation time

- **Optimal simulation approach combined with other existing and emerging technologies could be needed to address challenges facing high-resolution model spinup**
  - Exploration on methods that can use existing simulations to speed up coupled model spinup
    - ✓ e.g. starting the model with interpolated state from existing well spunup runs
  - Data assimilation maybe helpful for coupled model spin-up and prediction
    - ✓ create more balanced first guess conditions for coupled model components to initialize the spinup simulation
    - ✓ reduce drifting errors due to insufficient equilibrium model spin-up with observations during the prediction stage (e.g. decadal predictions)

E3SM
Energy Exascale
Earth System Model