Atmospheric Physics Convergence Project Overview

(PI: H. Wan, PNNL; Co-lead: C. S. Woodward, LLNL)

The Gap to Fill

Time integration issues such as numerical accuracy and solution convergence have largely been overlooked in the development of atmospheric physics parameterizations, not only in E3SM but also by other modeling groups worldwide.

Specific Goals

Understanding the causes of poor time step convergence in EAM (Figure 1). Improving solution accuracy. Establishing a numerically more robust model.

Why It Matters

- Poor convergence means the code is behaving unexpectedly. Furthermore, the accuracy gain from future reduction of time step size in high-resolution models will be much less than expected (Figure 1)
- EAM-simulated long-term climate is sensitive to model step size, implying uncertainties in the model's predictions (Figure 2)

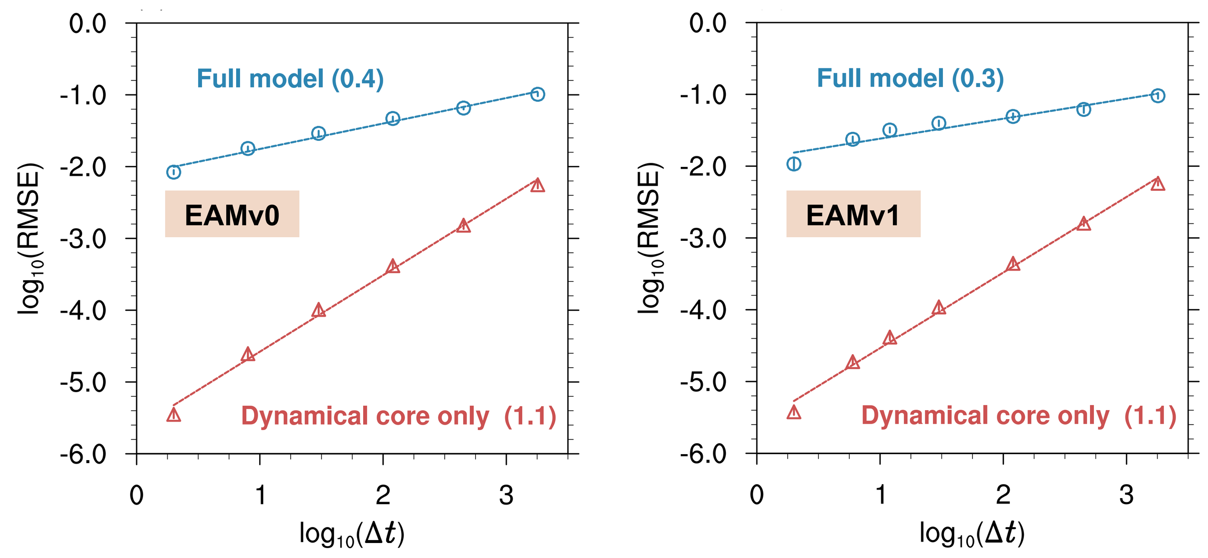
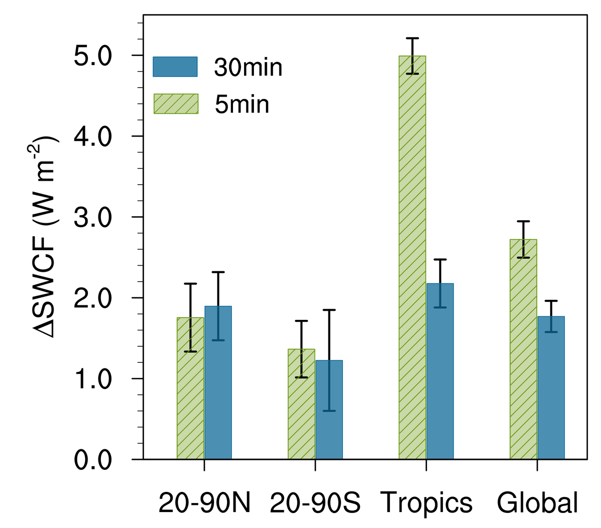


Figure 1. Time integration error and solution self-convergence in 1 h simulations conducted with EAMv0 and v1.

Figure 2. Shortwave cloud forcing changes caused by 4K sea surface warming, predicted by EAMv0 using two different time step sizes.



Key Outcomes

- New insights on causes of convergence problems
- Methods for improving convergence in both deterministic and stochastic systems
- Demonstration of the impact of improved convergence on climate simulations
- New methods for assessing solution correctness for HPC applications
- Bug fixes for E3SM
- Increased awareness of the issues by E3SM and related communities

Components of the Math-Climate Collaboration

Core Activities: Identifying and Addressing Convergence Bottlenecks

A Deterministic PDE Perspective

- Addresses issues in *current* EAM
- Formal error analysis confirms expected convergence rate and reveals potential pitfalls
- Short-term convergence tests and sensitivity experiments pinpoint problematic code
- Alternative numerical methods improve convergence and accuracy

(See poster by Woodward et al.)

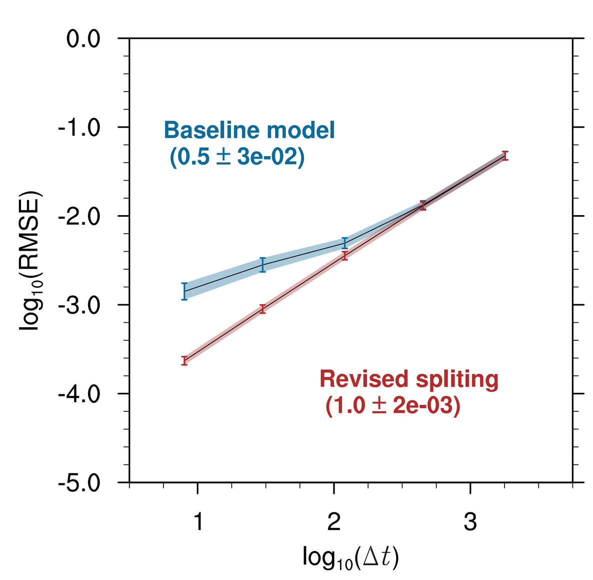


Figure 3. Solution error and self-convergence in 1 h simulations using EAM's dynamical core coupled with a simplified cloud parameterization. Vertical bars indicates ensemble spread.

A Stochastic PDE perspective

- Helps to explain causes of convergence problems in the *current* EAM
- Develops new time integration methods for *future* stochastic parameterizations in E3SM and ensemble modeling
- Provides higher numerical accuracy and computational efficiency

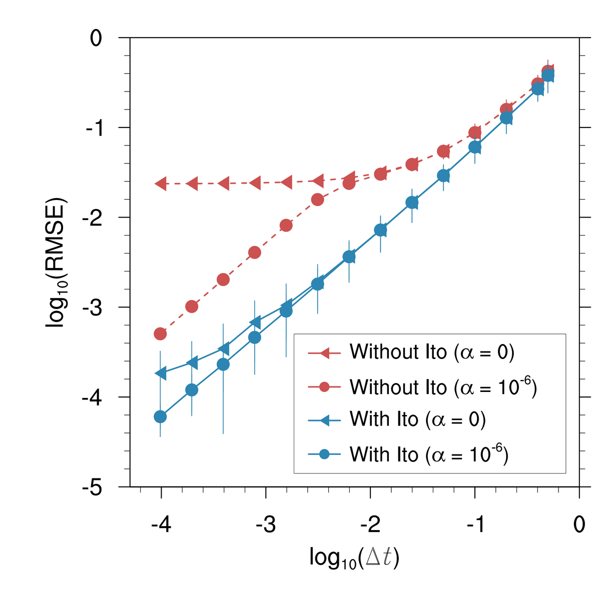


Figure 4. New time integration method improves solution accuracy and convergence in an advection-diffusion problem regardless of the characteristics of the stochastic forcing. (See poster by Stinis et al.).

Connections to Climate

- Climate simulations demonstrate the impact of new methods developed in core activities
- Numerical artifacts in climate simulations motivate further development of new time integration methods.

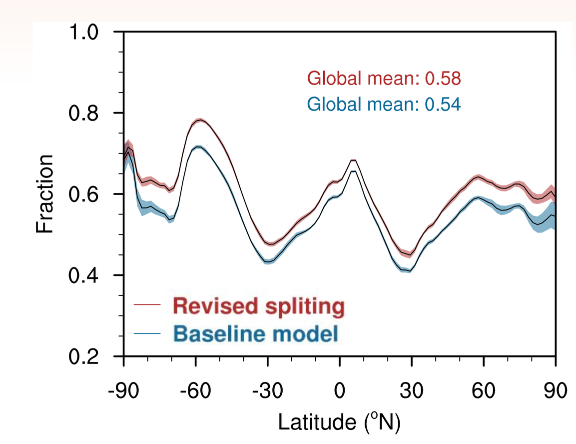


Figure 5. Code changes that restored convergence in Figure 3 lead to substantial changes in the zonal and annual mean cloud fraction.

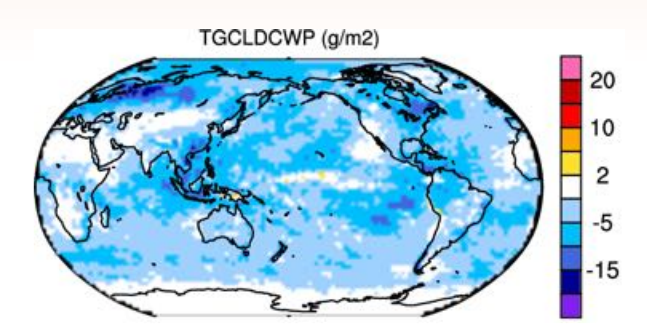
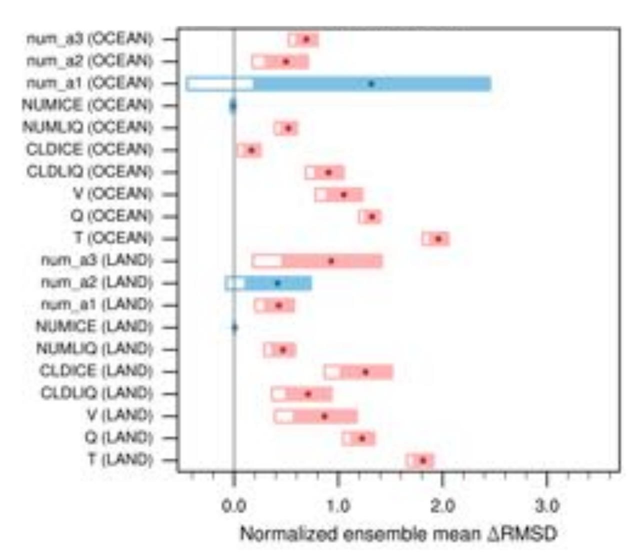


Figure 6. More substeps for cloud macro- and microphysics in EAMv1 lead to substantial decrease of cloud amount (total cloud water path), suggesting these parameterizations need more accuracy.

HPC Applications



Convergence-based testing methods are developed to objectively assess solution correctness on new HPC platforms (e.g., software environment, new hardware, reduced or mixed-precision arithmetic). Low cost and fast turnaround make the methods particularly attractive for high-resolution E3SM.

Figure 7. Intel compiler v15 with -O3 optimization was found to give incorrect results. (See poster by Zhang et al.)

Ongoing and Future Work

- Addressing convergence issues in EAM's turbulence and cloud parameterizations
- Improving numerical coupling of interacting physical processes (e.g., clouds, aerosols and radiation, boundary layer and surface)
- Further development of new methods for stochastic problems

The team: Hui Wan[1], Carol S. Woodward[2], Michael Brunke[3], Vince Larson[4], Huan Lei[1], Jing Li[1], Phil Rasch[1], Balwinder Singh[1], Jeremy Sousa[3], Panos Stinis[1], Chris Vogl[2], Xubin Zeng[3], and Shixuan Zhang[1] ([1]PNNL, [2]LLNL, [3]U. Arizona, [4]U. Wisconsin – Milwaukee)

This work was performed under the auspices of the U.S. Department of Energy by Pacific Northwest National Laboratory under Contract DE-AC05-76RL01830 and by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.