Can Reduced Numerical Precision Improve Performance without Loss of Fidelity? A Case with A Global Ocean Model

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Abstract
High-resolution global ocean-climate models are often constrained by computational resources. Typically, ocean-climate models use double precision to represent their state variable arrays. However, initial conditions and forcing data in ocean-climate models are derived from observations that are not accurate to double precision. We examine the sensitivity of the Model for Prediction Across Scales ocean component (MPAS-Ocean) to the precision of its state variables. We compare the reduced-precision model with the standard double-precision model and evaluate it against observational data. We further analyze the performance gain in terms of memory access, storage, and message passing. By using the reduced-precision floating-point format, we can redistribute saved resources towards achieving higher resolution and more robust simulations in MPAS-ocean and other ocean-climate models.

MPAS-Ocean

MPAS-Ocean is a global ocean model jointly developed by the National Center for Atmospheric Research and Los Alamos National Laboratory. MPAS-Ocean is a finite-volume model based on variable-resolution spherical centroidal Voronoi tessellations (SCVT). These variable density SCVT are capable of enhancing resolution in regions of particular interest. Hence, MPAS-Ocean is particularly well suited to regional climate simulations.

Simulation Quality

Sea Surface Height (SSH) Averaged Over One Year

Double Precision

Single Precision

In MPAS-Ocean, four state variables are prognostic variables: layer thickness, normal velocity, salinity and temperature. In order to explore the effect of using reduced precision on MPAS-Ocean, we set prognostic variables to be single precision in one instance and double precision in another. We found no significant difference between the two levels of precision in terms of the simulation quality.

Numerical Stability

Stable Kinetic Energy

Unstable Kinetic Energy

In order to find the optimal (minimum) precision of the prognostic variables in MPAS-Ocean without the loss of fidelity, we set the prognostic variables to have between 3 to 15 significant digits. We choose values for the time step and the density of the mesh so that the Courant-Friedrichs-Lewy condition is satisfied in all cases. To examine the stability of model under varying levels of precision, we approximate the average kinetic energy over one year. We find that the average kinetic energy of the model using between 6 and 15 significant digits are similar. The kinetic energy becomes blows up quickly when the number of significant digits used drops below 6 and halts the model because of the NaN (not a number) error. These NaN errors appear to be caused by roundoff error, i.e. when two number get very close, there are not enough significant digits to tell them apart when taking the difference.

Conclusion

We find that most of the difference between simulation quality of double precision and reduced precision are concentrated on two regions, around the equator and the Antarctic. The error around the equator is a phase shift of the equatorial Kelvin wave.

The Antarctic Circumpolar Current.

Given the reduced demand on computational resources, we could further improve simulation quality through the use of higher density mesh.

Future work may examine the effect of reduced precision within specific subdomains in MPAS-Ocean. For example, we could identify the subroutines within MPAS-Ocean that produce NaN error when using less than 6 significant digits.

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References