

Advanced Numerical Methods for Numerical Weather Prediction (NWP)

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LONG-TERM GOAL

The long-term goal of this research is to construct the Navy's next generation global numerical weather prediction (NWP) model using new numerical methods specifically for distributed-memory computers. To take full advantage of the new computer architectures, the spherical global domain must be partitioned into local sub-domains, or elements, which can then be solved independently on the multiple processors of these computers. The numerical methods used on these sub-domains must be not only local in nature but also high-order in accuracy and highly efficient. Thus the final objective of this project is to construct a new global NWP model which is as accurate as the current spectral model (NOGAPS) while much more efficient, thereby allowing for finer resolution forecasts.

OBJECTIVES

The objective of this project is to construct high-order local methods for the Navy's next generation global NWP model. The high-order accuracy of these methods will ensure that the new model yields the same accuracy as the current spectral model while the locality of these methods will ensure that the efficiency of the model increases.

APPROACH

To meet our objectives we explore:

1. spectral element methods (SEM),
2. spectral elements in space with a semi-implicit semi-Lagrangian scheme in time (SESL),
3. Fast matrix solvers on distributed-memory computers.

The power of spectral element methods is that they are high order accurate, like spectral transform methods (i.e., spherical harmonics), yet are completely local in nature – meaning that the equations are solved independently within each individual element and processor. Semi-Lagrangian methods are also being considered because these methods, like high-order methods, have minimal dispersion errors. This property is important for properly capturing atmospheric phenomena. In addition, semi-Lagrangian methods offer vast improvements in efficiency due to the longer time steps that they permit.

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14. ABSTRACT The long-term goal of this research is to construct the Navy???s next generation global numerical weather prediction (NWP) model using new numerical methods specifically for distributed-memory computers. To take full advantage of the new computer architectures, the spherical global domain must be partitioned into local sub-domains, or elements, which can then be solved independently on the multiple processors of these computers. The numerical methods used on these sub-domains must be not only local in nature but also high-order in accuracy and highly efficient. Thus the final objective of this project is to construct a new global NWP model which is as accurate as the current spectral model (NOGAPS) while much more efficient, thereby allowing for finer resolution forecasts.					
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After validation of the spectral element and semi-Lagrangian discretization methods, the vertical integration scheme for the full 3D NWP model was included. The hydrostatic 3D SEM primitive equation model was then ported to the message-passing interface (MPI) to show exactly what types of performance we can expect with these new high-order local methods. The final stage for the dynamics is to include performance-enhancing features such as Helmholtz solvers for the semi-implicit semi-Lagrangian method and port the SESL scheme to MPI.

WORK COMPLETED

To test the discretization methods (SEM and SESL) we have applied them to the shallow water equations on the sphere. These methods have been tested extensively and three papers have been written concerning these innovative approaches (Ref. [1,3,4]). The new spectral element 3D NWP model is undergoing extensive validation and performance testing. Six test cases have been applied to the new 3D model and this work was presented at a conference in Toronto (Ref. [5]) and at invited talks at NCAR (August 2002), NCEP and NRL-DC (September 2002).

RESULTS

Shallow Water Equations. To show the accuracy of the spectral element discretization method we show results for nonlinear zonal geostrophic flow (Case 2 in Ref. [1]). Figure 1 shows the spectral convergence of the method.

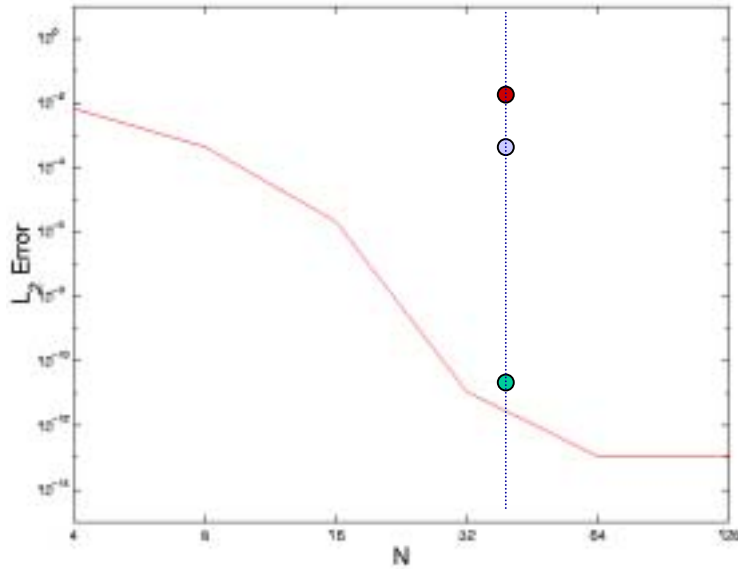


Figure 1: *L2 error as a function of basis function order N for the spectral element method (red line), Japanese earth simulator finite volume code (red dot), CSU finite volume code (purple dot), and the NCAR spectral transform model (green dot).*

Note the high-order spectral accuracy achieved by the SEM model. In addition, this figure shows that the SEM model is currently the most accurate numerical scheme as is evident by comparing this model to three other models: 2 finite volume models (red and purple dots) and a spectral transform model

(green dot). This pattern is repeated for many other test cases and in Ref. [5] we show that the spectral element method is indeed more accurate than all currently existing methods.

A similar result is obtained with SESL except that now we can use time-steps 10 times larger with SESL as compared to SEM.

3D NWP Equations. As a first test to validate the new 3D NWP model Rossby-Haurwitz waves number 1 and 4 were run both with the spectral element Eulerian atmospheric model (SEE-AM) and NOGAPS. These test cases were run for 5 days using a T80 horizontal resolution with 24 vertical levels.

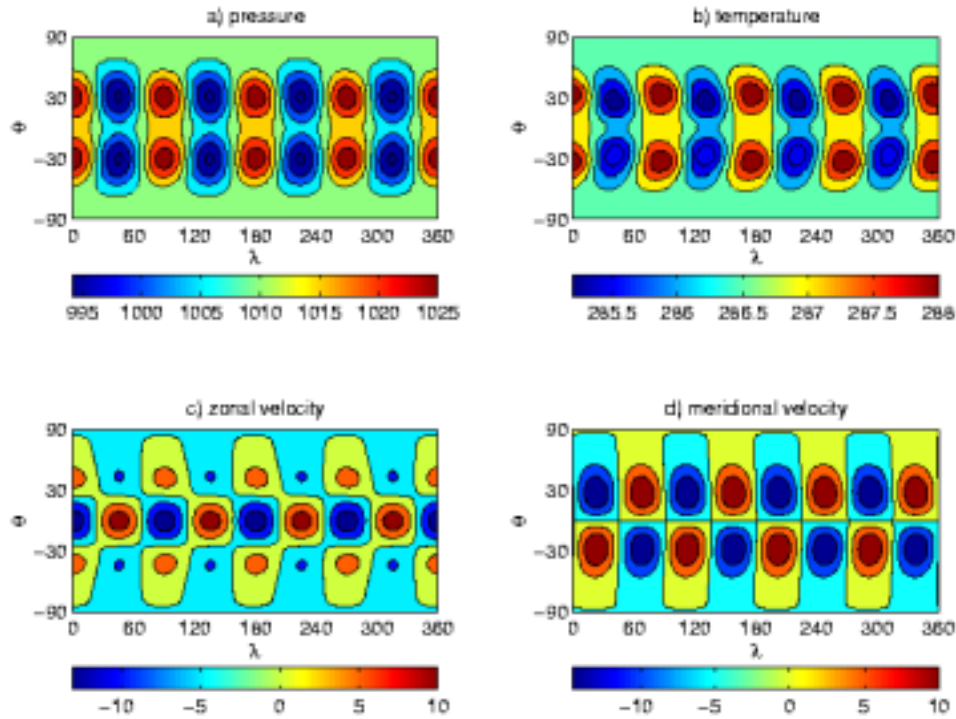


Figure 2: Surface contours for Rossby-Haurwitz wave 4 for SEE-AM with T80 L24 for a 5 day integration.

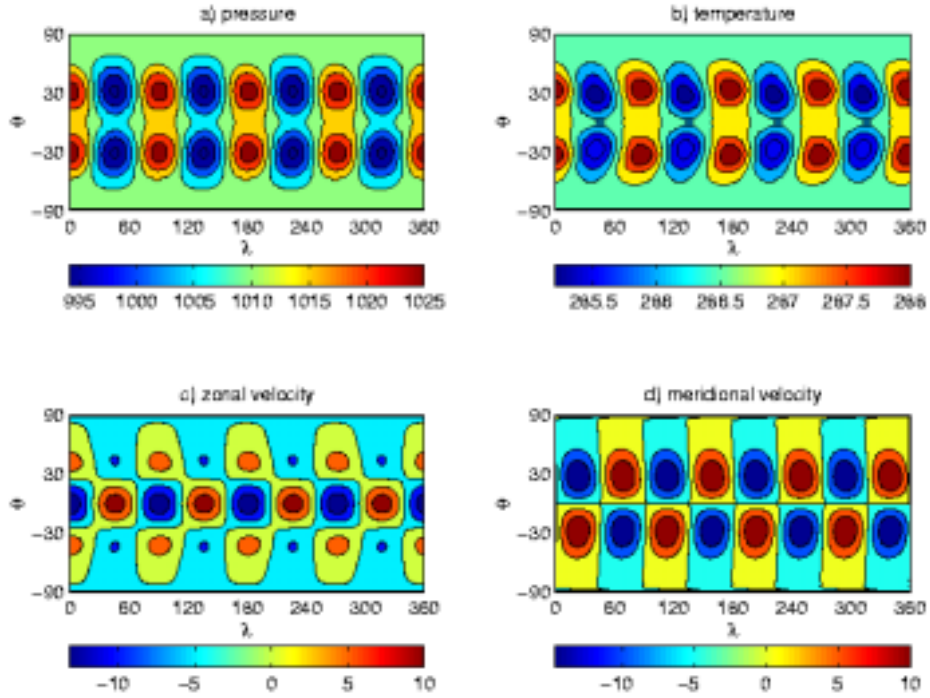


Figure 3: Surface contours for Rossby-Haurwitz wave 4 for NOGAPS with T80 L24 for a 5 day integration.

Note that the results between SEE-AM and NOGAPS are identical. This is also true for the wave 1 result (not shown). In addition, the spectral element semi-Lagrangian atmospheric model (SESLAM) also gives similar results for these test cases.

As a second test, the SEE-AM model was run with the Held-Suarez test case. This case is the primary test run by all new atmospheric models because it mimics a realistic atmosphere with full physics. Figure 4 shows the contour plot of the mean zonally-averaged zonal velocity as a function of latitude and vertical coordinate for T64 L20 for a 1200 day integration.

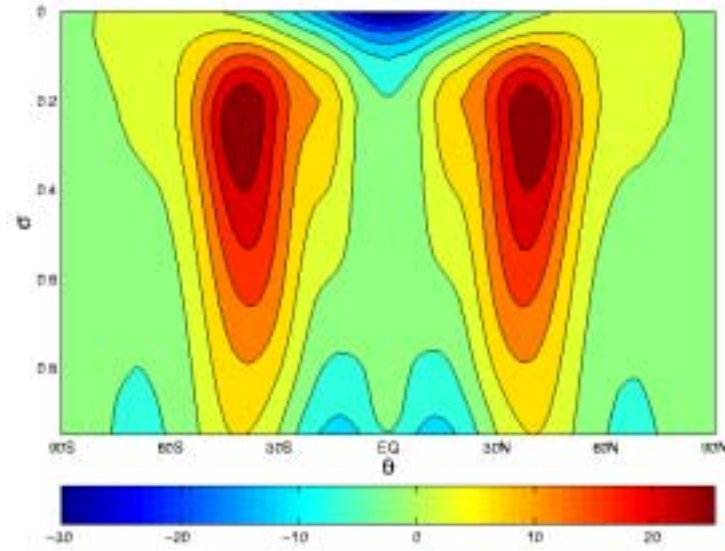


Figure 4: Zonally-averaged zonal velocity (U) for the Held-Suarez test case with T64 L20 as a function of latitude (θ) and vertical coordinate (σ) for a 1200 day integration.

Figure 4 compares well with the results of Held-Suarez and those from the ECMWF spectral transform model and clearly shows the formation of the jet stream (in the mid-latitudes). This result shows that the model is stable for very long-time integrations while conserving mass and energy.

As a third test a baroclinic instability test was run. This case is a two part test: in the first part, the model is run for 30 days to ensure that the model retains the initial balanced state. The second part of the test involves adding a perturbation to this initial state and then tracing the evolution of the baroclinic instability. SEE-AM compared well with the NCAR spectral transform model (not shown).

Finally, to show the scalability of the new model we show a plot comparing NOGAPS to SEE-AM for a 1 day integration using the same time-step with the operational resolution T160 L24.

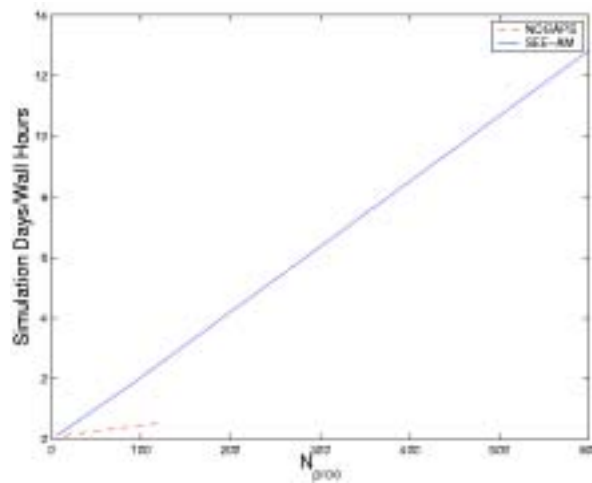


Figure 5: Scalability of the SEE-AM model (solid blue line) compared to NOGAPS (dotted red line). The SEE-AM model can use many more processors than NOGAPS.

This result clearly shows that SEE-AM can not only use far more processors than NOGAPS but that SEE-AM also scales better than NOGAPS on a per processor basis. At this spatial resolution SEE-AM can easily use 10,000 processors while NOGAPS can only accommodate 120 processors efficiently. Very few models will be able to scale at the rate that SEE-AM is scaling.

IMPACT

NOGAPS is run operationally by FNMOC and is the heart of the Navy's operational weather prediction support to nearly all DOD users worldwide. Our work here targets the next generation of this system for the next generation of computer architectures. These architectures are expected to be distributed-memory, commodity based systems. The new model has been designed specifically for these types of computer architectures while yielding the same high-order accuracy as the current model.

TRANSITIONS

Improved algorithms for model processes will be transitioned to 6.4 (PE 0603207N) as they are ready, and will ultimately be transitioned to FNMOC with future NOGAPS upgrades.

RELATED PROJECTS

Some of the technology developed for this project will be used immediately to improve the current spectral formulation of NOGAPS (NRL BE-35-2-18).

In addition, the work herein will complement the work done on constructing an efficient message passing NOGAPS as is being done in 6.3 Common High Performance Computing Software Support Initiative (CHSSI) (PE 0603704N).

SUMMARY

We have constructed a spectral element Eulerian atmospheric model (SEE-AM) and a spectral element semi-Lagrangian atmospheric model (SESLAM). Both models have been shown to yield spectral (exponential) convergence and are currently the most accurate methods for solving atmospheric flows. This high accuracy has been shown using shallow water and full 3D atmospheric test cases which show that the models compare well with NOGAPS and the NCAR spectral transform model. In addition, the SEE-AM model has been ported to distributed-memory computers and has been shown to scale linearly on these computers and will be able to outpace any model on these computer architectures for the foreseeable future. The goal for next year is to include physical parameterization into the model in order to run more realistic weather problems.

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