1 Scientific context

The Geophysical High Order Suite for Turbulence (GHOST) is a highly scalable Fortran 90-95 pseudo-spectral code that solves a variety of PDEs that are often encountered in turbulence studies. The use of pseudo-spectral methods has a long and distinguished history in the turbulence community that hardly needs expounding upon. The numerics employ a Galerkin-Fourier spectral method and nonlinear terms are solved using a parallel fast Fourier transform (FFT). For continuous, infinitely differentiable and periodic functions, numerical convergence is exponential (spectral). These methods have found widespread use in the turbulence community primarily because of their spectral accuracy, which often makes them useful—indeed even indispensable—for direct numerical simulation (DNS; XXX), but also increases the accuracy of turbulence models (XXX). Typically, pseudo-spectral methods require only $\frac{1}{8}$ or fewer of the spatial points required by many low (e.g., 2nd-4th) order finite difference schemes for comparable accuracy, and are optimal in periodic geometry in terms of computational and memory costs.

GHOST contains solvers to numerically integrate the various hydrodynamic, magnetohydrodynamic, or Hall-magnetohydrodynamic equations in three dimensions with periodic boundary conditions. Somewhat more specifically, solvers are provided to study neutral and conducting fluids, rotating flows, conducting flows with external magnetic fields, and stratified flows. Subgrid models for turbulence are also available, including Lagrangian average models for hydrodynamics and magnetohydrodynamics, the Leray (tensor-diffusivity) model, and the Clark model (4)-(7) and recent extensions of spectral eddy-viscosity closures (incorporating helicity and eddy noise) (8; 9) could be included as well.

The pseudo-spectral method is used to compute spatial derivatives, while a Runge-Kutta method of adjustable order is used to evolve the system in the time domain (10). A non-blocking parallel fast Fourier transform (FFTP) is provided with the code, which uses serial FFT libraries to compute FFTs in each node. Several FFT libraries are supported, including versions 2.X and 3.X of FFTW.

The code is highly portable and compiles with several compilers in many platforms including the Portland suite, the XLF compilers, Compaq/HP, ABSoft, INTEL, GNU, and G95 compilers. Several flavors of MPI are regularly tested for compatibility. Both POSIX and MPI I/O are supported. Technical details of the code and of the parallelization techniques used can be found in (1; 2).
2 FY2008 accomplishments

We have invested effort this year into providing support for rotating flows by including a Coriolis force and rigorously probing the results of rotating turbulent simulations. A number of important fundamental results on rotational turbulence have emerged from these GHOST simulations, that will have broad applicability to other regimes (e.g., understanding hurricane observations). Rotational effects are expected to become important when the Rossby number, Ro, (the ratio of the convective to the Coriolis acceleration) is sufficiently small. We have explored with DNS rotating non-magnetic flows at high Reynolds number, Re, down to Ro=0.03 (note that Ro≈ 0.1 in the atmosphere). It is found that in the non-helical case (i.e. in the absence of correlation between the velocity field and its curl, the vorticity), energy transfer between wavemodes parallel to the rotation is strongly quenched, so that the direct transfer of energy to small scales is mediated by interactions with eddies whose wave vectors are perpendicular to the rotation direction. For rapid rotation, direct and indirect cascades appear to take place simultaneously. For the helical case, it is found that at small Ro, there is a direct cascade of energy (as expected), but that helicity can dominate the cascade to small scales and alter the dynamics.

As a final note, GHOST was recently selected for an Accelerated Scientific Discovery award, to make a high resolution (1536^3) study of turbulent rotational flows, and these simulations have begun in order to extend some of the work discussed above.

3 2009 plans

Currently, GHOST uses a slab domain decomposition method in which the N^3 computational cube is decomposed into N- N^2 sized slabs and distributed to the processors. This decomposition will prevent us from running jobs on systems with processor counts greater then N.

Thus, we will begin in FY2009 to modify this distribution method to allow for a pencil distribution, in which the cube is decomposed into 1D arrays of length N and distributed. In this way we will be prepared to run on the large processor, small memory footprint petascale systems that will be available in the near future.

In addition, we will begin the modifications necessary in GHOST to allow the code to be operated in single and double precision so that roundoff errors at extremely small scale do not adversely impact the solution in very high Re computations afforded by this new generation of systems.

4 References

References


