Ocean Model Evaluation Web Site

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LONG-TERM GOAL

Our long-term goal is to to design, to implement and to maintain a World Wide Web site dedicated to the evaluation and intercomparison of numerical ocean circulation models and their component algorithms. Measures of evaluation on the WWW site will include verification against idealized, but analytically tractable, test problems, as well as assessment with respect to datasets obtained in realistic geophysical settings.

OBJECTIVES

There are at present within the field of ocean general circulation modeling four classes of numerical models which have achieved a significant level of community management and involvement, including shared community development, regular user interaction, and ready availability of software and documentation via the World Wide Web. These four classes are loosely characterized by their respective approaches to spatial discretization (finite difference, finite element, finite volume) and vertical coordinate treatment (geopotential, isopycnic, sigma, hybrid).

The earliest class of ocean models, and still the most widely applied, was pioneered by Kirk Bryan and his colleagues at GFDL utilizing low-order finite difference techniques applied to the oceanic primitive equations written in geopotential (z-based) coordinates. At present, variations on this first OGCM are in place at Harvard (Harvard Ocean Prediction System, HOPS), GFDL (Modular Ocean Model, MOM), Los Alamos National Lab (Parallel Ocean Program, POP), the National Center for Atmospheric Research (NCAR Community Ocean Model, NCOM), and other institutions. During the 1970's, two competing approaches to vertical discretization and coordinate treatment made their way into ocean modeling. These alternatives were based respectively on vertical discretization in immiscible layers (``layered" models) and on terrain-following vertical coordinates (``sigma" coordinate models). In keeping with 1970's-style thinking on algorithms, both these model classes used (and continue to use) low-order finite difference schemes similar to those employed in the GFDL-based codes.

Today, several examples of layered and sigma-coordinate models exist. The former category includes models designed and built at the Naval Research Lab (the Navy Layered Ocean Model, NLOM), the University of Miami (the Miami Isopycnic Coordinate Ocean Model, MICOM), GFDL (the Hallberg Isopycnic Model, HIM), and others. In the latter are models from Princeton (the Princeton Ocean Model, POM), and Rutgers University and UCLA (the Regional Ocean Modeling System, ROMS), to name the two most widely used in this class.

More recently, OGCM's have been constructed which make use of more advanced, and less traditional, algorithmic approaches. Most importantly, models have been developed based upon Galerkin finite element schemes -- *e.g.*, the triangular finite element code QUODDY (Dartmouth University) and the spectral finite element code SEOM (Rutgers). These differ most fundamentally from earlier models in the numerical algorithms used to solve the equations of motion, and their use of unstructured (as opposed to structured) horizontal grids.

Given the rapidly growing number of models (and algorithmic options within each of the various models), it is imperative that we understand the behavior, properties and limitations of alternate ocean models and their component methods. Several alternative approaches to model comparison and validation are conceivable. An affordable and easily interpreted means of contrasting model behavior is via an inexpensive set of process-oriented test problems. Several types of dynamically distinct, process-oriented test problems are available; our goal is to make such test problems readily available to the ocean modeling community, as described further below.

Next in order of complexity -- following idealized, analytically tractable test problems -- are quantitative comparisons between numerical and physical (*i.e.*,, laboratory) models of simplified oceanic flow processes. Since many important geophysical processes are amenable to laboratory simulation, and are more easily measured there than in nature, comparisons made between physical and numerical models offer more ready opportunities for quantification of ``realistic'' processes, particularly those involving non-linear and/or turbulent behavior. Comparative studies of this type have been performed -- *e.g.*, Perenne *et al.* (2000) -- and are presently being included in the test problem suite.

Ultimately, ocean circulation models must be intercompared in fully realistic settings. Recent examples of this approach in the North Atlantic Basin -- including the CME, DYNAMO and DAMEE programs (see, *e.g.*, Haidvogel and Beckmann, 1999) -- have been successful in beginning to identify systematic differences in model formulation; however, their success has been limited by the relative scarcity of data for initial and boundary conditions, high-resolution surface forcing, and verification. A model validation exercise based upon an intensive coastal dataset obtained at the LEO-15 National Littoral Laboratory in the New York Bight is being formulated to circumvent these difficulties.

APPROACHES

An ONR-based web site containing explicit examples of these test problems has been developed by the PI's. Our approach is to take existing test problems and geophysical datasets, to define test problems based upon these, to verify the usefulness of the test problems by solving the problems with one or more different models, and finally to prepare the results thus obtained in a form appropriate to the world wide web. Each problem is described in detail, so as to allow replication by viewers of the WWW site. Sample results from one or more of the model classes mentioned above are included for illustration. Measures of accuracy (``metrics'') are fully defined to allow cross-model comparison.

The accompanying numerical simulations thus far conducted at IMCS have utilized two different models -- the Spectral Element Ocean Model (SEOM), and the Regional Ocean Modeling System (ROMS). The two models differ primarily in their respective approaches to spatial discretization (high-order finite element and low-order finite difference respectively), but are terrain-following so that in principle both should offer convergent solutions to flow problems featuring strong topographic variations and stratification. Haidvogel and Beckmann (1999) give a concise description of both model classes.

WORK COMPLETED

Idealized processes addressed in the first phase (FY99-00) of site development included Rossby solitons, gravitational adjustment of a vertical density front, wind-driven western boundary currents and coastal-trapped waves on curving coastlines. The results of these test problems follow closely the exposition in the recent monograph by Haidvogel and Beckmann (1999). Figure 1 shows a schematic diagram of the web site contents as envisioned here, including test problems currently available on the WWW site and those scheduled for future installation. Three other idealized tests are scheduled for inclusion in FY02, all of which consider the joint effects of stratification and bottom topography: a test of static pressure gradient errors for non-geopotential coordinate system models, downslope flow of a density current, and supercritical flow in a channel.

In addition to these web site enhancements, FY01 has seen the collection of an intensive model validation dataset at the LEO-15 National Littoral Laboratory during its annual coastal predictive skill experiment in July 2001. In contrast to prior years, the regional weather in summer 2001 was unusual, featuring several abrupt transitions from upwelling-favorable to downwelling-favorable winds. An integrated dataset -- based upon a subset of the data collected in July, and emphasizing the CTD, CODAR, AUV, and moored thermistor systems -- is being assembled to provide the basis for a quantitative hindcast/forecast test problem. Installation of this test problem is scheduled for FY02.

RESULTS

Implementation and debugging of the ROMS canyon simulations began in July 2001, and the central calculation reported in Perenne *et al*. (2000) has now been replicated. This exercise proved to be a valuable "learning exercise" for use of the rapidly evolving (and still rather untested) ROMS code. In particular, we have identified what appears to be a parallel bug in the north/south periodicity option (required to replicate the annular geometry), and weak instabilities in the rotated mixing tensors. Minor modifications of the experimental design were necessary to get ROMS to run. Interestingly, similar modifications were not required in SEOM. This emphasizes the additional utility of these test problems for rapidly evolving -- and incompletely tested -- ocean models.

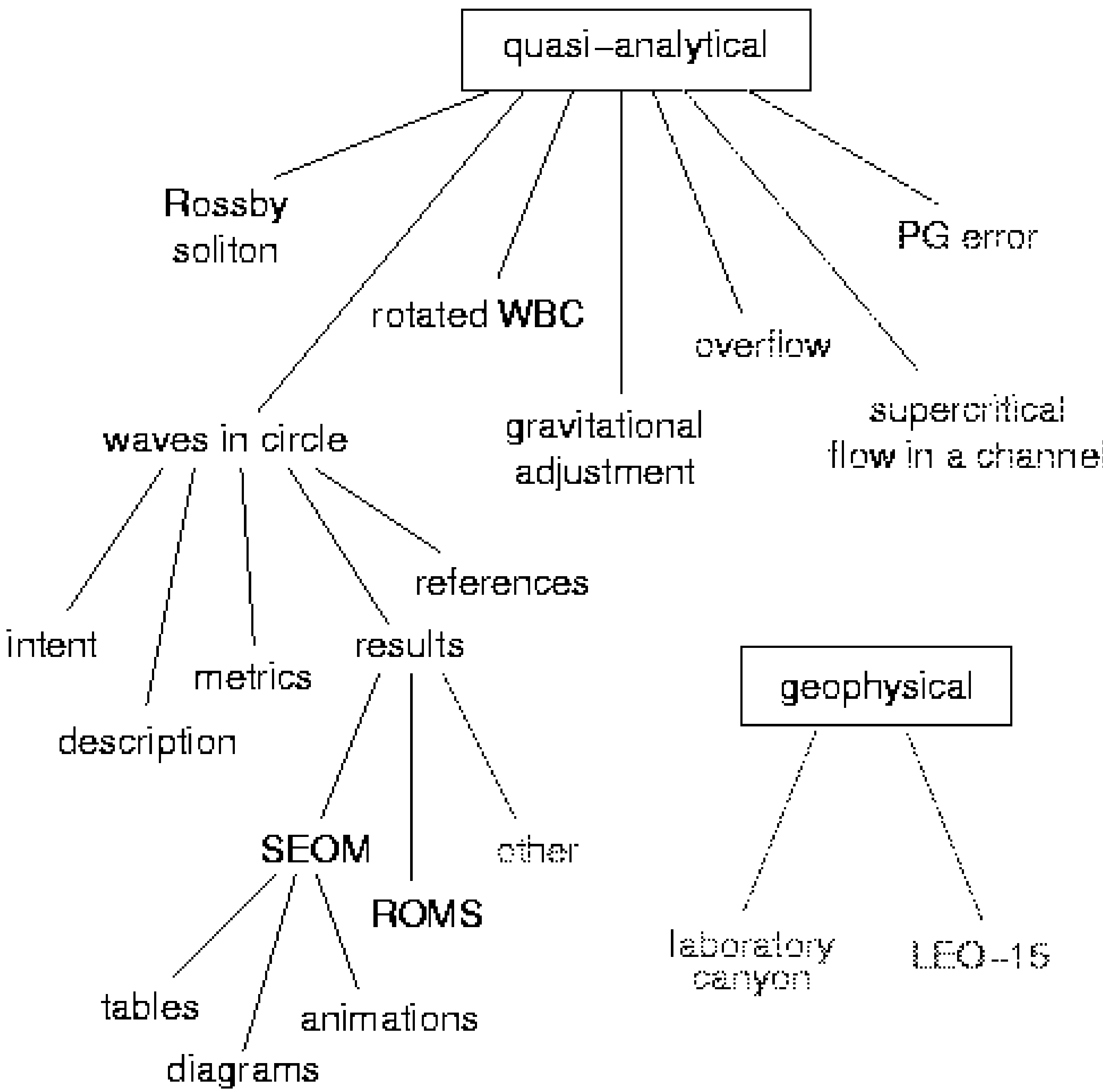

Figure 1: Hierarchy of model test problems on the web site. The currently existing components are shown in black. The test problems which will be available soon are shown in blue, while components which are planned for the future are shown in red.

IMPACT/APPLICATION

We have developed, for the first time, a centralized, integrated site containing documented test problems and metrics offering opportunities for systematic comparison across all classes of ocean models.

TRANSITION

The developers of several new ocean models -- e.g., HyCOM -- are utilizing these test problems, and their results will be added to the web site when available.

RELATED PROJECTS

Our principal model ``tools" for the illustration of these test problems continue to be the spectral finite element model SEOM and the generalized sigma coordinate model ROMS. Continued development of SEOM and ROMS benefits from support from several agencies including NSF, ONR and the NOPP program, and from the intellectual and technical contributions of colleagues at many institutions (*e.g.*, UCLA, JPL, SIO, USGS, etc.).

REFERENCES

D.B. Haidvogel and A. Beckmann, Numerical Ocean Circulation Modeling, Inperial College Press, 1999.

PUBLICATIONS

Pérenne, N., D.B. Haidvogel and D.L. Boyer, 2000: Laboratory - numerical model comparisons of flow over a coastal canyon. *J. Atm. Ocean. Tech.*, 18(2), 235-255.