NUMERICAL MODELING OF OCEAN CURRENTS (MAR 761)

4 credits (combined lecture and computer laboratory format)

Instructors: Vladimir M. Kamenkovich and Dmitri A. Nechaev

Office hours are by appointment

Bulletin Description: 4 hours. Basic knowledge of calculus and FORTRAN is required. General aspects of ocean modeling and numerical algorithms are discussed based on the Princeton Ocean Model.

Abbreviated Title: Ocean Modeling

Course Description.

We will base our course on the thorough analysis of the Princeton Ocean Model. The Princeton Ocean Model is one of the most popular community models of the ocean circulation. The model incorporates reasonably complete physics and reliable (and simple) numerical algorithms. The model has been verified against observations for a wide range of model configurations. It is recognized by oceanographic community that the model performs well especially in coastal regions. The curvilinear orthogonal coordinates of the model are quite flexible and allow generation of efficient variable-resolution grids for the regions with complicated coastline. The model is popular mainly because (i) the model code, which is written in a straight Fortran, is user-friendly, platform independent and can be easily modified by the users; (ii) the installation of the model is simple and does not require running Unix-type command interface; (iii) the model code is tested and optimized by the community of several hundred users who also develop model-oriented supplementary software; (iv) model manuals and extended publications describing the model and model results are available. All this makes the model a perfect tool for the beginners who want to start learning numerical modeling, and for physical oceanographers who are involved in studying the ocean processes.

We believe that the study of any numerical model, and especially the application of a model to practical problems, along with the interpretation of model results, require some level of understanding of physics and numerical aspects of the model. That is why the proposed course reviews some topics of ocean dynamics, coordinate transformations, and numerical analysis. The study of the model is impossible without some practical examples. The students will use toy models code to acquire experience in dealing with numerical models.

The course is directed toward graduate students in physical oceanography, and to those students in math, physics and computer science who are interested in application of their skill in geophysics. It will also be useful for qualified personnel with the various agencies located at the Stennis Space Center.

The course requires basic knowledge of calculus and Fortran programming

Course Objectives

- To provide the basic concepts of numerical modeling and numerical algorithms used in the community ocean general circulation models.
- To analyze numerical schemes, grids and coordinate systems commonly used in the ocean general circulation models
- To teach skills in applying the general principles of numerical modeling to the analysis of particular problems.

Text:

G. L. Mellor 2004: Users guide for a three-dimensional, primitive equation, numerical ocean model. See http://www.aos.princeton.edu/WWWPUBLIC/htdocs.pom .

Grading

Class participation (15%); 3 term papers (36%); final exam (49%). The final exam is organized as a scientific report on a special topic that contains a research component.

Detailed Syllabus

Introduction (1 lecture)

Why do we need numerical modeling? What is the difference between models of atmospheric and ocean circulation? Brief overview of the history of ocean modeling.

Ch. I. Numerical analysis of inertial oscillations equation (2 lectures; 2-3)

1. Inertial oscillations equation and its exact solution. Basic concepts of numerical analysis. Finite-difference approximations.
2. Two-time levels and three-time levels difference schemes (leapfrog and Adams-Bashworth schemes). Computational mode. The analysis of stability.

Ch. II. Numerical analysis of advection-diffusion equation (6 lectures; 4-9)

1. Advection-diffusion equation. Analytical solution to 1D advection-diffusion equation with constant coefficients. Numerical methods for solving advection-diffusion equation. Examples of finite-difference schemes for advection-diffusion equation and analysis of these schemes.
2. Approximation and stability of the difference scheme. Error and stability analysis of the numerical scheme. Illustration of the von Neumann method. Computational mode in the leapfrog scheme for advection equation. Grid separation problem. Robert-Asselin filter. Artificial dispersion and diffusion. Courant-Friedrichs-Levy (CFL) condition. Explicit and implicit finite-difference schemes. Smolarkiewicz iterative upstream scheme with anti-diffusion velocity.

3. Summary of the numerical schemes for the solution of the advection-diffusion equation.

Ch. III. Numerical analysis of the shallow water equation (SWE) (4 lectures; 10-13)

1. 1D linear shallow water equation and its analytical solution. Plane waves, phase speed and dispersion relation. Some numerical schemes for 1D SWE, possible grid layouts, staggered grids. Stability analysis for forward-backward and leapfrog schemes. Grid separation problem. Artificial dispersion and diffusion.
2. 2D linear shallow water equation. Analytical solution in the form of 2D plane wave. Numerical schemes for 2D SWE. Arakawa's classification of the rectangular grid layouts. Dispersion relations for grid A, E and C schemes. Analysis of dispersion errors. Grid separation problem.
3. Linear shallow water equation for rotating fluid. Analytical solution in the form of a plane wave. Dispersion relation. Rossby radius of deformation. Gravity-inertia waves, Poincare waves, and Kelvin waves. Some numerical schemes for SWE for rotating fluid. A, B, C, D, E Arakawa grids and their analysis. Numerical errors in phase and group velocities as functions of wavelength resolution, Rossby radius resolution, and propagation direction. C-grid dispersion problem at low Rossby radius resolution.

Ch. IV. Basic equations and boundary conditions (6 lectures; 14-19)

1. Basic fluid dynamical equations. General formulation in the integral form.
2. Boussinesq approximations.
3. Turbulence. The nature of turbulence. Averaging of the basic equations. An indirect estimate of the intensity of turbulent mixing.
4. Different coordinate systems. Sigma-coordinate system.
5. Differential form of basic equations in the sigma-coordinate system. Continuity equation. Salt diffusion equation. Heat equation. Momentum equations. The pressure gradient problem.
6. POM turbulence closure scheme. Turbulent fluxes. Coefficient of turbulent mixing and its parameterization. Turbulence in the main depth of the ocean. The effect of diffusion along sigma-surfaces. Equations for turbulence energy and scale.
7. Summary of the POM basic equations.
8. Vertical boundary conditions. Horizontal boundary conditions at the closed boundary.

Ch. V. Generation of the POM grid (3 lectures; 20-22)

1. Generation of 2D orthogonal curvilinear grid. Theoretical basis.
2. Grid.f program. Adaptation of the bottom topography. Interpolation of 2D fields onto the model grid and smoothing. Splines. Generation of horizontal grid. Arrays of horizontal grid parameters.
3. MATLAB implementation of the orthogonal curvilinear grid generation program.
4. Generation of vertical grid, setting sigma-levels. Arrays of vertical grid parameters. Interpolation of 3D fields onto model grid.

Ch. VI. Time splitting of slow and fast processes (3 lectures; 23-25)

1. The simplest 2-layer model. Plane-wave solution. Analysis of barotropic and baroclinic modes. Depth-averaged (external) and time-averaged (internal) modes. Numerical scheme.
2. Mode splitting in the POM. Equations for external mode and their difference approximation.
3. Formulation of the continuity equation on the internal time grid.
4. Equations for internal mode and their difference approximation

Ch. VII. Construction of the POM finite-difference scheme (6 lectures; 26-31)

1. General structure of the code (flow diagram of the code).
2. Description of the major POM code blocks. External mode loop.
3. Boundary conditions for external mode. Stencils for depth-averaged velocities and sea-surface elevation. Conditions at the closed boundary. Masking.
4. Open boundary conditions for external and internal modes. Clamped conditions. Radiation conditions: Flather and Orlanski open boundary conditions.
5. Description of the major POM code blocks. Internal mode loop.
6. Solving implicit schemes for “vertical” equations.

Home projects:

1. Experiments with toy advection-diffusion equation model. Time and space centered difference versus upstream schemes. Phase and amplitude errors. Dispersion and amplitude.
2. Experiments with toy 2D SWE model without rotation. Phase and amplitude errors.
3. Experiments with toy 2D SWE model for rotating fluid. Poincare waves, standing waves, Kelvin waves.
4. Experiments with 2-layer linear model. Time splitting of slow and fast processes. Surface and internal gravity waves.

ADA Compliance:

If a student has a disability that qualifies under the Americans with Disabilities Act (ADA) and requires accommodations, he/she should contact the Office for Disability Accommodations (ODA) for information on appropriate policies and procedures. Disabilities covered by ADA may include learning, psychiatric, physical disabilities, or chronic health disorders. Students can contact ODA if they are not certain whether a medical condition/disability qualifies.

Address:

The University of Southern Mississippi
Office for Disability Accommodations
118 College Drive # 8586
Hattiesburg, MS 39406-0001

Voice Telephone: (601) 266-5024 or (228) 214-3232 Fax: (601) 266-6035

Individuals with hearing impairments can contact ODA using the Mississippi Relay Service at 1-800-582-2233 (TTY) or email Suzy Hebert at Suzanne.Hebert@usm.edu.