ADVANCED OCEAN DYNAMICS (MAR 672)

3 credits

Instructor: **Vladimir M. Kamenkovich**

Office hours are by appointment

COURSE DESCRIPTION

This course is intended to develop the understanding of the basic physical mechanisms controlling the ocean circulation. The emphasis will be placed on the formation of vertical structure of the ocean circulation. Two physical mechanisms will be discussed. The first mechanism is connected with the formation of closed geostrophic contours and the ensuing intensification of motion. The second mechanism deals with the subduction of surface water in the area of outcropping of basic isopycnal surfaces. The needed concepts of fluid dynamics (basic equations, vorticity, etc) and ocean current theory (geostrophy, Sverdrup relation, Ekman boundary layers, western boundary currents, etc) will be properly reviewed. The course is directed toward graduate students in physical oceanography and meteorology, and also to those students in math, physics, and computer science, who are interested in the application of their skills in geophysics.

COURSE OBJECTIVES

1. To provide the basic concepts of ocean current theory required to understand the physical processes in the ocean and atmosphere.
2. To teach skills in applying the general results and methods of ocean current theory to the analysis of particular problems.
3. To explain relations between widely used simplified models of ocean currents and basic concepts of ocean current theory.

TEXT

Class notes with home assignments will be provided for each lecture.
The following book is recommended:

Pedlosky, J.: Ocean Circulation Theory. Springer-Verlag, 1996, 453pp.

GRADING

1. Class participation: 15%.
2. Home assignments: 55%.
3. Final exam: 30%

The final exam consists mainly of a term project. The term project is submitted in written form and is defended orally. It must contain a critical review of the published material with some elements of independent research.

PREREQUISITES

Basic courses on physics (PHY 351) and calculus (MAT 385) or permission of the instructor.

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DETAILED COURSE OUTLINE

Chapter I. Fundamentals of Fluid Dynamics (9 lectures)

We will start with the discussion of the first principles of fluid dynamics. The integral and differential formulations of these principles, independent of the choice of the coordinate system, will be given. The flux and evolution forms of the basic equations will be considered. The vorticity dynamics will be analyzed in detail.

I.1. Deformation and rotation of a fluid particle. The vorticity vector. Divergence of velocity vector.
I.2. The Stokes theorem.
I.3. Equation of mass conservation.
I.4. The flux - form equation.
I.5. Equation of salt diffusion. Fick’s law.
I.6. Newton's law of motion. Inertial and noninertial frames of reference. The Coriolis acceleration in a rotating frame. Integral formulation. Body or mass forces. Surface forces (stresses). External and internal forces. Differential formulation. Newton’s law of friction.
I.7. Angular momentum equation. The symmetry of the stress tensor.
I.8. Thermodynamics of sea water. Properties of sea water.
I.9. Equation of energy conservation.
I.10. Energy transformations. Equation for the mechanical energy. Equation for the internal energy.
I.11. Entropy equation. The Second Law of Thermodynamics. Adiabatic motion. Heat equations. Equations for temperature and potential temperature. Fourier’s law of thermal conduction.
I.12. Vorticity dynamics. Vortexlines and vortextubes. The vorticity equation. Generation of the vorticity caused by the deformation of vortextubes, baroclinic effect and friction. The influence of rotation. Absolute vorticity.
I.13. The concept of potential vorticity. Potential vorticity for the motion of homogeneous fluid with horizontal velocities, which do not depend on the vertical coordinate.
I.14. Overview of the basic equations.
I.15. Conditions at the interface. Boundary conditions.

Chapter II. Basic Approximations (8 lectures).

Based on the consideration of first principles of fluid dynamics, we will derive the basic equations of the meso- and large-scale ocean motions. The main approximations, widely used in ocean dynamics, will be thoroughly discussed. The special emphasis will be given to the analysis of the conservative properties of the approximate equations.

II.1. Boussinesq approximations.
II.2. Basic equations in spherical coordinates.
II.3. The thin-layer approximation. Local Cartesian coordinates. The quasi-static approximation.
II.4. Vorticity equation in the quasi-static approximation.
II.5. Parameterization of turbulent mixing. Coefficients of turbulent mixing.
II.6. Geostrophic relations. Thermal wind relations.
II.8. Ekman boundary layers. Straightforward analysis for the homogeneous ocean. Asymptotic analysis of the general case.
II.9. The Ekman transports. The Ekman pumping.
II.10. Buoyancy frequency.
II.11. Quasi-geostrophic approximations: the homogeneous ocean. Potential vorticity equation. Beta plane approximation.
II.12. Quasi-geostrophic approximations: the continuously stratified ocean. Potential vorticity equation. Rossby radii of deformation.

Chapter III. Layer Models (4 lectures).

The layer (isopycnal) model of the ocean circulation will be considered and the derivation of the continuity and momentum equations for such a model will be given. The vertical resolution provided by layer models will be analyzed by the comparison of layer and continuously stratified models.

III.1. Continuity equation. Cross-interface velocities.
III.2. Momentum equations.
III.3. Potential vorticity equation.
III.4. Quasi-geostrophic approximations.
III.5. Some widely-used layer models.
III.6. Vertical modes: the two-layer model.
III.7. Vertical modes: the three-layer model. Generalization for n-layer models.
III.8. Vertical modes: the continuously stratified ocean.

Chapter IV. The Sverdrup Relation (2 lectures).

Based on the properties of Rossby waves, we will demonstrate that the boundary layer occurs near the western coast only. The approximate form of the vorticity equation for the large-scale flow will be presented. The Sverdrup relation will be derived and its adequacy will be discussed.

IV.1. Rossby-wave mechanism of western boundary-layer formation.
IV.2. Sverdrup relation: the continuously stratified ocean.
IV.3. Sverdrup relation: the 2.5-layer model.
IV.4. On the validity of the Sverdrup relation.

Chapter V. Homogenization of Potential Vorticity (2 lectures).

To understand how the momentum penetrates into the depth of the ocean, we will, first, inroduce the concept of geostrophic contours. Then we will show the intensification of the circulation in the region of closed geostrophic contours. The homogenization of the potential vorticity in such a region will be considered in detail. Finally, the theory of the subtropical gyre based on the hypothesis of the potential-vorticity homogenization will be outlined.

V.1. Geostrophic contours. Blocked and closed contours.
V.2. Rhines and Young's example.
V.3. Determination of the recirculation.
V.4. Homogenization of potential vorticity.
V.5. Theory of the subtropical gyre based on the homogenization hypothesis.
V.6. Numerical and observational evidence.

Chapter VI. Theory of the Ventilated Thermocline in the Subtropical Gyre (4 lectures).

Here we will consider another mechanism of the vertical penetration of momentum into the depth of the ocean, dealing with outcropping of isopycnal surfaces. The two-and-a-half layer model of the ventilated thermocline will be thoroughly analyzed. The special attention will be given to the discussion of such concepts as thermocline ventilation, subduction of water masses, shadow zone and so on. A combined theory of the subtropical gyre, based on concepts of thermocline ventilation and homogenization of potential vorticity in unventilated layers, will be developed.

VI.1. Midocean approximations.
VI.2. Sverdrup relation.
VI.3. Two-and-a-half layer model of the ventilated thermocline. Subduction. Shadow zone. Pool of constant potential vorticity.
VI.4. Three-and-a-half layer model of the subtropical gyre.
VI.5. Ventilation and homogenization in the subtropical gyre.
VI.6. Numerical and observational evidence.

Chapter VII. Dynamics of the subpolar gyre.(1lecture)

The sketch of the theory is outlined.

VII.1. Cross-gyre flow.

VII.2. The analysis of the subpolar gyre.

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 <mailto:Suzanne.Hebert@usm.edu> .