TURBULENCE (MAR 664)

3 credits
Instructor: Vladimir M. Kamenkovich; office hours are by appointment

COURSE DESCRIPTION.

This is an introductory course on the theory of turbulent motions. It is directed toward graduate students in physical oceanography and meteorology, and also to those students and specialists in math, physics, and computer science, who are interested in the application of their skills in fluid mechanics and geophysics. The crux of turbulence theory is the closure problem: the number of unknowns always exceeds the number of equations. We will discuss various approaches to handle this problem. In Chapter I (Introduction) we discuss specific properties of the turbulent motion and some basic concepts used in the analysis of such motions. In Chapter II we review the basic principles of fluid dynamics needed for the discussion of properties of turbulent motion. Chapter III deals with general concepts of turbulence theory and the analysis of turbulent flow near a wall. Chapter IV presents the detailed analysis of isotropic and homogeneous turbulent motions. In Chapter V we review the Kolmogorov theory of the universal statistical regime of small-scale components of developed turbulence. Chapter VI deals with special properties of the two-dimensional turbulence and closely related properties of the geostrophic turbulence

COURSE OBJECTIVES.

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

TEXTS.

Class notes with home assignments will be provided for each lecture.
The following books are recommended for supplemental reading:

Monin, A. S. and A. M. Yaglom. Statistical Fluid Mechanics: Mechanics of Turbulence. Vol. 1, 1971, 769pp; Vol. 2, 1975, 874pp. The MIT Press (Translated from Russian).

Tennekes, H. and J. L. Lumley: A First Course in Turbulence. 1972, The MIT Press, 300pp.

Thorpe, S. The Turbulent Ocean. Cambridge University Press . 2005, 439pp.

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.

DETAILED COURSE OUTLINE.

Chapter I. INTRODUCTION (3 Lectures)

Characteristic properties of turbulent flows are discussed. Some approaches to studying such flows are introduced.

I.1. The Reynolds experiment. A model of valley river (Kolmogorov). Characteristic properties of turbulent flows. Random fields and ensemble (probability) means. The Reynolds decomposition of flow characteristics. Statistical moments.
The Reynolds rules of averaging.
I.2. Some estimates of the intensity of turbulent mixing
I.3. Molecular transport of momentum
I.4. Turbulent transport of momentum

Chapter II. FUNDAMENTALS OF FLUID DYNAMICS (10 Lectures)

We provide the discussion of general principles of fluid dynamics. Particular emphasis is given to the analysis of general laws governing the thermal conduction, salt diffusion, and friction in the fluid. For what follows it is of great value to disclose the physical basis of the relations between the corresponding fluxes and gradients of basic characteristics. Physical mechanisms responsible for the vorticity generation are discussed in detail.

II.1. Deformation and rotation of a fluid particle. The rate-of-strain tensor. Vorticity.
II.2. Stokes theorem.
II.3. Equation of mass conservation.
II.4.The flux and evolution forms of the basic equation.
II.5. Equation of salt diffusion.
II.6. Momentum equations (Newton’s law of motion). The stress tensor.
II.7. Angular momentum equations.
II.8. Thermodynamics of sea water.
II.9. Equation of energy conservation. The First Principle of thermodynamics.

II.10. Energy conversions. Equations for the mechanical and internal energies. The rate of dissipation of mechanical energy.
II.11. Entropy equation. The Second Principle of thermodynamics. Adiabatic motions.
II.12. Heat equation
II.13. Molecular thermal conduction, diffusion, and friction in the fluid. The relation between fluxes and gradients of basic characteristics
II.14. Vorticity dynamics. Vorticity equation. Mechanisms of vorticity generation.
II.15. Boussinesq approximations.

Chapter III. ANALYSIS OF TURBULENT MOTIONS (7 Lectures)

Some important characteristic processes (like stirring) are discussed. It is known that breaking of internal waves substantially contributes to the turbulence in the main depth of the ocean. So a very short review of internal waves properties is given. The general statistical formulation of the problems of turbulence theory will be introduced.
The factors that influence the intensity of temperature and velocity fluctuations are reviewed. The important nondimensional parameter - the Richardson number - will be introduced based on the energy consideration. The equations for the Reynolds stresses will be derived and the tendency toward isotropization caused by the pressure fluctuations will be analyzed. The physical mechanisms responsible for the enstrophy generation in turbulent flows will be thoroughly investigated.
The detailed analysis of the turbulent flow within a constant-stress layer near a rigid wall (without buoyancy effects) is considered. Then the buoyancy forces are included into consideration and the Monin-Obukhov scale is introduced. In conclusion, we will consider the dynamics of the planetary boundary layer. In this relation, we will discuss an approach to the closure of the system of governing equations, based on the incorporation of the equation for turbulence kinetic energy.

III.1. Processes that characterize the turbulence. Stirring. The effect of internal waves.
III.2. Statistical formulation of the problems of turbulence theory.
III.3. Averaging of the basic equations
III.4. Equation for the mean square of temperature fluctuations.
III.5. Equation for the kinetic energy of turbulence. The Richardson number. Taylor’s microscale.
III.6. Equations for the Reynolds stresses. Rotta’s hypothesis.
III.7. Equation for the enstrophy of turbulence
III.8. Turrbulent flow near a rigid wall
III.9. Planetary boundary layer
III.10. Stratified turbulent boundary layer.The Monin-Obukhov scale

Chapter IV. ISOTROPIC TURBULENCE (5 Lectures)

General concepts of spectral representations of random stationary functions and homogeneous fields are discussed. A way of experimental realization of the isotropic turbulence is considered. The structure of the velocity correlation tensor is analyzed. The von Karman-Howarth equation is introduced and some consequences of this equation are reviewed.

IV.1. Statistical formulation of the problems of turbulence theory.
IV.2. Stationary random functions and homogeneous fields. Ergodicity.
IV.3. Spectral representations of random stationary functions and homogeneous fields.
IV.4. Isotropic turbulence and its experimental realization.
IV.5. Velocity correlation tensor. The von Karman-Howarth equation.
IV.6. Some consequences of the von Karman-Howarth equation.
IV.7. Spectral form of the von Karman-Howarth equation.
IV.8. Kolmogorov's hypothesis on self-similarity of small scales.

Chapter V. STATISTICAL REGIME OF THE SMALL-SCALE COMPONENTS OF DEVELOPED TURBULENCE (2 Lectures)

We will analyze the turbulent flows with sufficiently large Reynolds numbers. The Kolmogorov theory of the universal statistical regime of the small-scale components of such flows will be outlined. The important concepts of the structure function and the spectrum of the locally isotropic motion are considered. We will conclude with the derivation and discussion of the famous "two-thirds" and "five-thirds laws".

V.1. The structure of developed turbulence.
V.2. Definition of locally isotropic turbulence.
V.3. Kolmogorov's similarity hypotheses.
V.4. Statistical characteristics of locally isotropic turbulence.
V.5. Local structure of the velocity fluctuations.

Chapter VI. TWO-DIMENSIONAL TURBULENCE (2 Lectures)

Due to the energy and enstrophy conservation laws, the properties of the two-dimensional turbulence differ substantially from those of the three-dimensonal turbulence. The specific properties of the energy and enstrophy fluxes and the corresponding spectra will be discussed in detail. Based on the consideration of the two-dimensional turbulence, we will thoroughly analyze the features of the geostrophic turbulence.

VI.1. Inviscid isotropic case.
VI.2. Spectra of 2D-turbulence.
VI.3. Energy transfer in 2D- and 3D-turbulence.
VI.4. Geostrophic turbulence. Macroturbulence.

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> .