Knowledge Expectations for METR 3123
Atmospheric Dynamics II: Theory of Atmospheric Flows

Purpose: This document describes the principal concepts, technical skills, and fundamental understanding that all students are expected to possess upon completing METR 3123, Dynamics II: Atmospheric Dynamics and Kinematics. Individual instructors may deviate somewhat from the specific topics and order listed here.

Pre-requisites: Grade of C or better in METR 3113, METR 3213, MATH 3113.

Students should be able to apply the mathematics from their prerequisite courses, including, calculus, vector analysis, ordinary differential equations (including use of complex exponential), geometry and trigonometry.

Goal of the Course: This course continues the study of basic concepts of atmospheric dynamics and kinematics begun in Dynamics I.

Topical Knowledge Expectations

I. Natural Coordinates and Idealized Flow Types

- Understand the qualitative meaning of trajectories and streamlines. Know how to derive their differential equations and know how to solve them in simple flows.
- Understand the two-dimensional natural coordinate system (e.g., center/radius of curvature, normal and tangential vectors). Work with the tangential and normal components of the equations of motion in natural coordinates. Demonstrate a qualitative and quantitative understanding of the force balances.
- Understand the approximations made in considering geostrophic, cyclostrophic, gradient and inertial flows, and understand the legitimacy of these approximations.
- Know how to derive the wind fields in these cases (quadratic equation), and solve problems using the associated wind/pressure fields

II. Thermal wind

- Have a qualitative and quantitative understanding of the thermal wind. Be able to explain its meaning and significance with and without equations.
- Know how to derive the thermal wind equation and be able to quantitatively solve problems related to the thermal wind.

III. Circulation and Vorticity

- Know the mathematical definition and physical meaning of circulation and vorticity, and be able to calculate them from information about the velocity field.
- Know how to derive the vertical component of the vorticity equation.
- Explain the meaning of terms in the vertical vorticity equation, and to use this equation to explain a variety of meteorological phenomena (e.g., thunderstorm rotation).
- Explain the meaning of analogous terms in the horizontal vorticity equation and apply the concepts to meteorological phenomena (e.g., baroclinic vorticity generation in gust fronts).
- Derive and understand the Bjerknes and Kelvin Circulation theorems, and be able to apply these theorems in quantitative problem solving.
- Derive the Rossby potential vorticity theorem, and understand its limitations. Be able to apply it to atmospheric flows (e.g., topographic Rossby waves).

IV. Viscosity and stress

- Understand the role of molecular viscosity as a stabilizing agent, and the nature of the no-slip boundary condition at the wall.
- Understand the relationships between the viscous stress and velocity deformation, and be able to distinguish between shear and normal components of viscous stress.
- Know the difference between laminar and turbulent flows, and develop an understanding of the transition to turbulence using the Reynolds number concept.

V. Turbulence closure problem

- Understand statistical ensemble and ensemble averaging, and apply these concepts to the Reynolds decomposition of flow fields in mean and fluctuating parts.
- Understand the impact of finite-interval averaging on flow statistics.
- Be able to apply Reynolds decomposition and averaging to the governing equations, and explain the new terms (turbulent stresses and fluxes) that appear after averaging.
- Know the expressions for turbulent stresses and fluxes, and distinguish between dynamic and kinematic turbulent fluxes.
- Understand similarities and differences between proportionality of stresses/fluxes to the gradients of flow fields as applied to laminar and turbulent flows
- Know the concepts of eddy viscosity and eddy diffusivity and realize their limitations for description of turbulent flows.

VI. Atmospheric Boundary Layer (ABL)

- Understand the nature of the Boussinesq and anelastic approximations. Be able to use these approximations to simplify the primitive equations.
- Know how to apply the Reynolds decomposition to the equations of boundary layer dynamics and thermodynamics.
- Understand the main features of the ABL under conditions of unstable, neutral, and stable stratification, and identify flow regions (sub-layers) within the ABL.
- Be able to schematically plot vertical distributions of mean-flow and turbulence quantities (turbulent fluxes, variances) in different types of boundary layers.
- Understand the roles of shear and buoyancy forcings in the boundary layer diurnal cycle.
- Know basic features of the process of turbulent mixing in a neutrally stratified, parallel, wall-bounded flow (neutral atmospheric surface layer).
- Be able to derive expression for the logarithmic near-surface wind profile based on scaling considerations and mixing-length theory, and know the concept of surface roughness length.
- Know the horizontal equations of motion for horizontally homogeneous large-scale frictional flow with constant eddy viscosity (Ekman boundary layer), and the derivation of solution for the mean wind profiles in the Ekman layer.
- Understand the concept of Ekman pumping and apply it to explain how friction helps enhance cloudiness and precipitation in low pressure systems.
- Understand the general notion of a hodograph as method of graphic presentation of vector fields and be able to use it for analysis of wind changes with height in the ABL.