August 2013

Knowledge Expectations for METR 3113
Atmospheric Dynamics I:
Introduction to Atmospheric Kinematics and Dynamics

Purpose: This document describes the principal concepts, technical skills, and fundamental understanding that all students are expected to possess upon completing **Atmospheric Dynamics I: Introduction to Atmospheric Dynamics and Kinematics (METR 3113)**. Individual instructors may deviate somewhat from the specific topics and order listed here.

Prerequisites: Grade of C or better in METR 2023/2021, MATH 2443 or 2934, PHYS 1215 or 2524.

Students should have a working knowledge of integration, total and partial differentiation, vector analysis, analytic geometry, notions of force, velocity, and acceleration, Newton's laws of motion, and basic thermodynamics. Prior to starting this course, they should also possess the basic knowledge of structure and physics of the atmosphere and principal atmospheric processes.

Goals of the course: to lay the foundation for the formal mathematical characterization of atmospheric motions, to provide descriptions of forces acting in the atmosphere and atmospheric energy transformations, and to introduce basic concepts and notions applied in atmospheric dynamics.

As a result of the course, students are expected to master the knowledge of the following notions, concepts, study techniques, mathematical formulations, and physical principles:

I. Units and Dimensions
- Standard techniques to operate with physical units.
- Conversions between SI and Imperial units used in atmospheric dynamics.
- Concept of dimension; idea of dimensional (scale) analysis and principle of dimensional homogeneity.

II. Coordinate systems
- Cartesian coordinates.
- Polar, spherical, and cylindrical coordinates.

III. Fundamentals of Vector Calculus
- Concepts of vector (versus scalar), unit vector, and vector decomposition basis.
- Properties of the vector dot and cross products, commonly employed vector identities and operations.
- Rules of vector differentiation.
- Properties and applications of ∇ (del, nabla) operator in vector analysis.
- Definitions and properties of divergence, gradient, curl, and Laplacian operations; physical meanings of these operations.
- Divergence theorem of vector calculus.

IV. Basics of Newtonian Mechanics
- Notions of inertial and non-inertial reference frames.
- Three Newton's laws of motion.
- Newton's law of gravitation.

- One-dimensional equation of motion in inertial frame with different forcing types.
- Notion of angular momentum.

V. Fundamental Atmospheric Forces

- Gravitational force.
- Notion of force per unit area.
- Pressure gradient force.
- Viscous (friction) force.
- Hydrostatic equation; geopotential and geopotential height.
- Pressure as vertical coordinate.
- Archimedes and buoyancy forces in the atmosphere; notion of the buoyancy.
- Apparent forces in a non-inertial reference frame.
- Centrifugal and gravity forces in a rotating reference frame.
- Coriolis force.

VI. Motion in Non-inertial Rotating Frame

- Lagrangian and Eulerian frames; concept of total differentiation.
- Differentiation of a vector in a rotating frame.
- Equation of motion in a rotating frame: vector form of the equation.
- Equation of motion in a rotating frame: components in a spherical coordinate system.
- Relative importance of individual terms in the equation of motion.
- Geostrophic approximation and geostrophic wind.
- Hydrostatic approximation in the equations of motion.
- Boussinesq approximation.

VII. Mass and Energy Conservation

- Conservation of mass; Lagrangian and Eulerian derivations of continuity equation; incompressible and anelastic forms of the continuity equation.
- Adiabatic process; potential temperature.
- Thermodynamic and mechanical energy equations.
- Scale analysis of mass and energy conservation equations.
- Mass and energy conservation equations in isobaric coordinates.

VIII. Balanced Flow in Natural Coordinates

- Natural coordinates.
- Gradient wind approximation; cases of geostrophic flow, inertial flow, and cyclostrophic flow.
- Solutions of gradient wind equation for northern and southern hemispheres.
- Notions of regular vs. anomalous, baric vs. antibaric, and cyclonic vs. anticyclonic gradient flows.