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 METR 3113, Introduction to 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 MATH 2443, PHYS 2524, and METR 2024 (or 2413).
Co-Requisite: MATH 3113.

Students should have a working knowledge of integration, total and partial differentiation, vectors, analytic geometry, force, velocity, acceleration, Newton's laws of motion, and basic thermodynamics. They also should understand the basic structure and physics of the atmosphere and the principal forces acting upon it prior to starting this course.

Goal of the Course: This course lays the foundation for characterizing the atmosphere mathematically, for identifying and expressing analytically the forces acting upon it, and for using various approximations to understand its behavior.

I. Basic Concepts of Calculus and Physics

- Understand the concept of a vector (especially how it differs from a scalar), unit vectors, and be able to take derivatives of vectors. Be able to operate on vectors and on appropriate products of vectors and scalars, using the scalar, vector, and inner products, as well as divergence, gradient, curl, and Laplace operators. Understand the mathematical and physical concepts of divergence, gradient, curl, and Laplacian and know and be able to apply the vector integral theorems of Stokes and Gauss.
- Be able to write down from memory and apply the Taylor series expansion and understand its meaning and practical use.
- Understand and be able to apply absolute and relative motion concepts, work with and convert between units (SI, Imperial), and understand notions of dimension, precision, accuracy and error.

II. Newton's Laws of Motion; Energy, Equilibrium and Stability

- Know from memory, both in equation form and from a physical understanding point of view, all three of Newton's laws of motion as well as the law of gravitation.
- Understand the concept of balanced and unbalanced forces as related to acceleration and be able to apply Newton's Second Law of Motion to one-dimensional problems of variable force and mass.
- Understand the basic physical and mathematical principles of linear versus nonlinear systems (e.g., the notion of feedback), and be able to apply in quantitative problems the concepts of work, potential and kinetic energy, energy equilibrium, energy conservation, and energy conversion.
- Understand the physical and mathematical concepts of one-dimensional simple harmonic motion, particularly as applied to parcel stability theory in the atmosphere, and be able to work associated problems in which the forcing is either constant or variable.
- Understand, both mathematically and physically, the concept of an eigenvalue in simple physical systems.

III. Coordinate Systems and Forces

- Understand the concept of a total differential, Eulerian and Lagrangian derivatives and frameworks, the difference between partial and total/material derivatives, as well as the concepts of steady state and material property conservation.
- Understand the formalism of the Cartesian coordinate system and be able to write wind components in this system in association with the concept of advection.
- Be able to work simple problems in which some terms of a total derivative are specified and others sought. It is important to note that substituting numbers into derivatives is incorrect, and that finite values of quantities can be used only once derivatives or differentials have been integrated to yield finite quantities.
- Know the mathematical definition and physical meaning of angular momentum and torque, their relationship, and the concept of angular momentum conservation, particularly as seen through atmospheric examples such as hurricanes and tornadoes.
- Understand and be able to derive the equations of motion in rotating coordinates (differentiation of a vector when the unit vectors are not constant), know the difference between real and apparent forces, and understand and be able to work problems involving apparent forces (centrifugal and Coriolis), knowing their vector forms from memory.
- Know the physical and mathematical properties of the pressure gradient force and its relationship to acceleration, and be able to write down the scalar and vector forms of the pressure gradient force from memory.
- Understand and be able to solve problems using the equations of atmospheric motion in spherical and isobaric coordinates, though memorization of this form of the equations is not required.

IV. Equations of Motion and Simple Force Balances

- Understand and be able to write down from memory the vector and component equations of atmospheric dynamics in Cartesian coordinates.
- Be able to apply scale analysis to identify the most important terms on highly contrasting scales (e.g., synoptic and storm), and understand physically and be able to apply quantitatively the geostrophic and hydrostatic approximations. In this regard, know the difference between diagnostic and prognostic systems and understand the physics and mathematics of geostrophic flow.
- Understand that exact solutions can be obtained from the governing equations under special assumptions, and in that regard know from memory and be able to apply Bernoulli's equation for steady flow.
- Understand the notion of a streamline, and the concept of static and dynamic pressure, and the conversion among terms in Bernoulli's theorm.

V. Mass and Energy Conservation

- Understand the concept of mass conservation and be able to write down from memory the compressible, anelastic, and incompressible forms of the continuity equation in height and pressure coordinates.
- Know the differences among these equations and understand physical situations in which they can and cannot be applied.
- Understand and be able to solve quantitative problems using simple forms of the thermodynamic energy equation, and understand the concepts of energy balance and exchange in atmospheric motions.
- Have a basic understanding of the diabatic term in the thermodynamic energy equation and be familiar with situations in which it can and cannot be neglected.