# Knowledge Expectations for METR 4133
# Atmospheric Dynamics III : Mid-Latitude Synoptic-Scale Dynamics

**Purpose**: This document describes the principal concepts, technical skills, and fundamental understanding that all students are expected to possess upon completing METR 4123, Mid-Latitude Synoptic-Scale Dynamics. Individual instructors may deviate somewhat from the specific topics and order listed here.

**Pre-requisites**: Grade of C or better in METR 3123, METR 3223.

Upon entering this course, students should have a working knowledge of real and apparent forces, the equations of motion and their simplified forms, coordinate systems, vorticity, circulation, angular momentum, moist and dry thermodynamics, and static stability.

**Goals of the Course**: This course combines concepts from kinematics, dynamics and thermodynamics to characterize the synoptic-scale atmosphere, with emphasis on quasi-geostrophic and baroclinic instability theory as the basis for understanding the structure, movement and evolution of extra-tropical weather systems including fronts and jets. Linear theory is used to describe a variety of atmospheric waves and to assess their role and relative importance in synoptic-scale meteorology.

**Topical Knowledge Expectations**

**I. Kinematics of the Wind and Pressure Fields**

- Understand the mathematical definition of ridges, troughs, highs, lows, cols and be able to express atmospheric wave motion in analytic form with an understanding of phase speed, wavelength, wave number, amplitude and phase.
- Understand and be able to apply formulae for the movement of pressure systems, and be able to explain their formation and intensification.
- Understand the expansion of the wind field about a point using Taylor series, rotational invariance, the physics and mathematics of pure fluid translation, divergence, rotation, and deformation in Cartesian and natural coordinates.
- Understand and be able to apply the concepts of streamfunction and velocity potential to two-dimensional flow.

**II. Quasi-Geostrophic and Baroclinic Instability Theory: Extratropical Cyclones**

- Understand the term “quasi-geostrophic” as applied to the synoptic scale and be able to apply scale analysis to the thermodynamic and vorticity equations, via quantitative waveform-based methods, to arrive at the quasi-geostrophic thermodynamic and vorticity equations.
- Understand how the vertical-p velocity relates to vertical-z velocity and be able to use the continuity equation to determine the vertical velocity at any level.
- Understand physically and mathematically the ageostrophic wind and its linkage with vertical motion, vertical motion in the context of horizontal motion in the presence of orography, and be able to compute vertical motion from the thermodynamic energy equation.
- Understand the methodology for deriving the quasi-geostrophic omega and height tendency equations and be apply them to determine height tendency and vertical motion fields. Further, understand how the atmosphere responds to perturbations to restore a state of quasi-geostrophic balance.
- Understand the concept of potential vorticity, be able to derive and explain physically the governing equation, and be able to apply potential vorticity in the context of synoptic-scale dynamics.

- Understand the location of and mechanisms by which surface and upper-level pressure systems form and move in the context of quasi-geostrophic theory and be able to apply the concepts to both idealized and real scenarios, including the influence of orography.
- Understand the classification of waves as long and short and be able to apply the associated concepts to the development and morphology of synoptic scale systems.
- Understand digging as well as baroclinic instability from physical points of view in the context of quasi-geostrophic principles.

**III. Fronts, Jets and the Dryline**

- Understand the physical and mathematical definition of surface fronts as well as the physical basis of synoptic scale jets and their relationship to the temperature field via the thermal wind.
- Be able to derive and interpret equations for the slope of fronts and understand physically why some fronts are steeper than others.
- Understand, mathematically and physically, the 3 mechanisms of surface frontogenesis and be able to interpret and apply quantitatively various forms of the frontogenesis function.
- Understand physically and mathematically the response of the atmosphere to frontal forcing such that hydrostatic and thermal wind balance are maintained. Students should be able to apply quasi-geostrophic thinking to upper-level fronts as well.
- Understand, be able to define, and also describe the physical origin of various types of jets in the atmosphere (Polar, sub-tropical, low-level) and describe their physical significance.
- Understand the structure of jet streaks, the mathematics of their secondary circulation, and their importance in forecasting.
- Understand the basic structure of the dryline, its mechanisms of formation and movement, and its physical significance.

**IV. Linear Perturbation Theory and Waves**

- Know the various types of waves in the atmosphere, the conceptual framework and assumptions associated with linear perturbation theory.
- Understand mathematically and physically the concept of a nonlinear process and be able to classify a mathematical operator as linear versus nonlinear.
- Have a physical and mathematical understanding of eigenvalues and eigenvectors in the context of wave theory; understand the basic concepts of Fourier analysis (students are not required to have taken a course in Fourier series); and be able to linearize an equation given a basic state.
- Know which systems of equations are necessary to represent, and be able to derive the frequency equation for, the following types of waves: acoustic, internal gravity, external gravity, inertial oscillations and Rossby. Also, understand the approximations made to isolate these pure types of waves in the full set of hydrodynamic equations.
- Be able to differentiate among these types of waves, give physical examples of each, and understand their importance in the atmosphere.