Knowledge Expectations for METR 4433
Mesoscale Meteorology

Purpose: This document describes the principal concepts, technical skills, and fundamental understanding that all students are expected to possess upon completing METR 4433 Mesoscale Meteorology. Individual instructors may deviate somewhat from the specific topics and order listed.

Pre-requisites: Grade of C or better in METR 4133, METR 4424.

Students should have a good understanding of the structure, dynamics, physics and thermodynamics of the atmosphere prior to starting this course.

Goal of the Course: This course teaches the structure and dynamics of convective and mesoscale phenomena, including mesoscale convective systems, severe thunderstorms, tornadoes, low-level jets, mountain waves and hurricanes. For most of these phenomena, the course discusses their general behaviors and characteristics, the dynamics of their formation and development, and the types of weather and hazards they produce, and in some cases their prediction. Specific topics and expected knowledge and understanding by the students after taking the course are given below.

1. Scale analysis and definition of scales

- Be able to perform scale analysis on the atmospheric equations of motion. Know the typical magnitude and relative importance of terms in the equations for the corresponding scales.
- Know the methods for categorizing atmospheric motion into various scales, and the general characteristics of such motion.

2. Dryline and mesoscale low-level jet

- Know the definition, spatial structure, and climatology of dryline. Understand the physical processes responsible for the formation and movement of dryline and the role of dryline in initiating convection.
- Know the definition and climatology of mesoscale low-level jet, and its role in moisture and heat transport in precipitating events. Understand the theories on the formation of nocturnal low-level jet.

4. Convection, single-cell storms and microburst

- Know the basic types of convective storms and their key characteristics, including their morphology, typical weather, and life cycles.
- Know the forces responsible for initiation, enhancement and suppression of the storms. Be able to apply the parcel theory to single cell storm development and estimate the maximum updraft speed based on environmental CAPE.
- Know the definitions, key features and hazard, and the conceptual model and life cycle of downbursts/microbursts. Know how they affect aircraft during takeoff and landing.

5. Organized convective systems, including multicell storms, squall lines and mesoscale convective complexes

- For multicell storms, know the ways by which multicell storms propagate. Understand the dynamic processes responsible for cell regeneration and its period.
- Know the source of cold pool in convective storms, understand its propagation along the ground in the form of density currents. Be able to derive and interpret the equation of cold pool / density current propagation and understand how cold pool propagation affects storm motion.

- Know the definition and general characteristics of squall lines. Know the conceptual models of squall lines that describe that typical internal circulation, thermal and perturbation pressure patterns and the distribution of precipitation in the systems.
- Know the ways by which squall lines form and understand the favorable environmental conditions that support long-lived squall lines.
- Know the phenomenon, characteristics, and significance of bow echoes. Know and understand the conceptual models of bow echo. Be able to describe the typical life cycle of bow echoes, and explain the formation of bookend vortices.
- Know the typical environment favorable for bow echoes, including shear and instability. Know the behaviors of derechos as a special form of bow echoes.
- Know the criteria for mesoscale convective complexes (MCC), their physical characteristics, associated weather and typical time evolution.

6. Supercell storms and tornadoes

- Know the distinguishing characteristics of supercell storms from other types of the storms.
- Be able describe the typical internal flow structure of supercell storms and be able to identify them according to radar echo patterns. Be able to explain the reason for such patterns.
- Know the 3D conceptual models of tornadic supercells. Be able to use the vorticity equation to explain the origin and intensification of updraft rotation.
- Know the phenomena, classification, damage as well as climatology of tornadoes. Know the kinematics and thermal structure inside tornadoes. Know the typical life cycles of tornadoes.
- Understand the generation of mid-level rotation and role of mid-level mesocyclones in tornadogenesis. Understand the theories for the generation of low-level rotation and tornadogenesis. Know the typical way that supercell storms transition into their tornadic phase.
- Understand and be able to use diagnostic pressure equation to explain the enhancement of rotating updraft, and why storms often split and how the hodograph curvature affects the behaviors of split cells.
- Be able to define various forms of vorticity, helicity and the Bulk Richardson number using both physical terms and equations. Understand and be able to explain the effects of these and other environmental parameters on storm types and storm behavior.
- Know how to use bulk Richardson number and various forms of helicity as the predictors of storm types, and their strength and weakness of these parameters for such a task.

7. Mesoscale rainbands, horizontal convective rolls and land-sea breezes

- Know the phenomena of rainbands and the conditional symmetric instability as a possible mechanism for their formation.
- Know the phenomena of horizontal convective rolls (HCR) and their role in convective initiation. Understand the theories of HCR formation.
- Know the causes and behaviors of land-sea breezes and their role in modulating convection.

8. Hurricanes

- Know the phenomena and climatology of hurricanes, the key factors and the necessary conditions for hurricanes formation. Know the flow and thermodynamic structures of hurricanes and the associated weather and damages.
- Understand the CISK and air-sea interaction theories of hurricane formation.

9. Gravity wave phenomena and downslope wind storms (optional topic)

- Be able to obtain the solution of internal gravity waves from linearized equations of motion and know how forced linear solution of mountain gravity waves can be obtained. Know the wave train patterns and wave energy propagation in forced mountain waves.

- Know how the stratification and wind shear, measured in terms of Score parameters, affects the vertical propagation of gravity waves, and the situations under which downslope winds can significantly intensify.
- Know the hydraulic jump theory for the development of severe downslope windstorms.