MIDTERM EXAM 1 REVIEW
METR 5403/4403: Applications of Meteorological Theory to Severe-Thunderstorm Forecasting
Instructors: Dr. Ariel Cohen, Rich Thompson, and Dr. Steven Cavallo
Teaching Assistant: Andrew Moore

What are the necessary conditions for organized severe thunderstorms?

Explain the relationship between large-scale ascent and divergence ahead of mid-level short-wave troughs.

Consider two environmental vertical-wind profiles, each associated with 300 $m^2\ s^{-2}$ of storm-relative helicity. In Profile 1, the hodograph consists of a straight line. In Profile 2, the hodograph is curved. Which profile would be associated with an environment supporting more efficient and rapid mesocyclogenesis and possible tornadogenesis? Why? [*HINT: Consider the sources and ramifications of perturbation pressures in supercell thunderstorms.*]

Consider a shortwave trough preceded by mid-level height falls, and assume a steady-state, non-amplifying wave pattern characteristic of the mid-level geopotential height pattern. Use quasi-geostrophic theory to explain the relationship between trough-preceding height falls and ascent.

How can we decompose the true *horizontal* wind, $\vec{V}$, in terms of a geostrophic component ($\vec{V_g}$) and an ageostrophic component ($\vec{V_a}$)?

Derive an expression for the ageostrophic wind ($\vec{V_a}$) in terms of the acceleration of the *horizontal* wind (i.e., in terms of $\frac{D\vec{V}}{Dt}$).

Let $\vec{A}$ be a vector with nonzero horizontal components and a zero vertical component. Express $\hat{k} \times \hat{k} \times \vec{A}$ in terms of $\vec{A}$.

What factors distinguish between linear and discrete convective modes? Provided upper-air charts and surface charts, how would you go about assessing the most likely convective mode and related storm hazards? What role does forcing for ascent play in influencing convective mode?

Analyze a surface chart for pressure, temperature, dewpoint, and boundaries relevant for influencing deep convection.

Analyze 250-mb, 500-mb, 700-mb, and 850-mb charts.

Prove that the geostrophic wind is non-divergent.

What are the forcing terms for vertical motion and height tendency in the QG ω and QG χ equations, respectively? Be able to describe their spatial variability in tandem with mid-level waves.

How does large-scale ascent influence the propensity for thunderstorm occurrence and intensity?

What roles do hydrodynamic pressure perturbations play in influencing supercell intensity and motion? Be able to discuss the non-linear and linear contributions to perturbation pressure for a given hodograph, as covered in class and the homework. How does the background near-storm environment influence the eventual perturbation pressure distribution in deep convection?

Be able to plot a hodograph given wind direction and speed at various levels of the atmosphere. Be able to identify a bulk shear vector from the hodograph. Be able to identify storm-relative and boundary-relative flow at various levels within the atmosphere as represented on the hodograph.

Describe the characteristic environment of tropical-cyclone tornadoes.

What influences $\frac{\partial \gamma}{\partial t}$, where γ represents the environmental lapse rate? How are these influences represented mathematically? How do they physically arise and affect the risk for severe thunderstorms?

How can we use surface and upper-air charts to diagnose ascent? What physical concepts link surface pressure tendency to large-scale ascent? How can we use surface and upper-air charts to assess the severe-thunderstorm risk?

The quasi-geostrophic vorticity equation can be expressed as follows:

$$\vec{\nabla}^2\chi = -f_0\overrightarrow{u_g}\cdot\vec{\nabla}(\frac{1}{f_0}\vec{\nabla}^2\Phi + f) + {f_0}^2\frac{\partial\omega}{\partial p}.$$

The quasi-geostrophic thermodynamic energy equation can be expressed as follows:

$$\frac{{f_0}^2}{\sigma}\frac{\partial^2\chi}{\partial p^2} = -\frac{{f_0}^2}{\sigma}\frac{\partial}{\partial p}[\overrightarrow{u_g}\cdot\vec{\nabla}(\frac{\partial\Phi}{\partial p})] - {f_0}^2\frac{\partial\omega}{\partial p}.$$

Derive the quasi-geostrophic height-tendency equation using the two provided equations, and label the physical meaning of each term beneath the final equation.

The quasi-geostrophic vorticity equation can be expressed as follows:

$$\frac{\partial}{\partial p}\vec{\nabla}^2(\frac{\partial\Phi}{\partial t}) = f_0\frac{\partial}{\partial p}[-\overrightarrow{u_g}\cdot\vec{\nabla}(\zeta_g + f)] + {f_0}^2\frac{\partial^2\omega}{\partial p^2}.$$

The quasi-geostrophic thermodynamic energy equation can be expressed as follows:

$$-\frac{\partial}{\partial p}\vec{\nabla}^2(\frac{\partial\Phi}{\partial t}) = \vec{\nabla}^2[\overrightarrow{u_g}\cdot\vec{\nabla}(\frac{\partial\Phi}{\partial p})] + \sigma\vec{\nabla}^2\omega.$$

Derive the quasi-geostrophic omega equation using the two provided equations, and label the physical meaning of each term beneath the final equation.

Derive the lapse rate tendency equation in its entirety, beginning with the mathematical expression of conservation of energy

Prove the following relationship, making the assumption that vertical *velocity* vanishes:

$$\overrightarrow{\omega_h} = \hat{k} \times \frac{\partial \overrightarrow{u_h}}{\partial z}.$$

Using this relationship, how can horizontal vorticity be ascertained from a hodograph?

Describe the process of lee cyclogenesis.

Be able to sketch a hodograph, and then **calculate** storm motion for supercells in an environment characterized by the wind profile plotted in a hodograph. A calculator may be required.

Assume that the mean cloud-layer flow is from the east at 20 knots. Assume that there is a low-level jet from the north at 5 knots. A calculator may be required for this problem.

(a) Calculate the velocity vector magnitude and general direction corresponding to the motion of an upshear-propagating MCS.
[*HINT: Use basic vector analysis.*]

(b) Calculate the velocity vector magnitude and general direction corresponding to the motion of a downshear-propagating MCS.
[*HINT: Use basic vector analysis.*]

(c) Why does MCS motion vary between upshear-propagating and downshear-propagating MCSs?

Explain the motivations and goals of the "Forecasting a Continuum of Environmental Threats" initiative.