Comprehensive Final Exam
Mesoscale Meteorology (METR 4433)
Wednesday, May 11, 2005

Total 200 Points
Time to complete the test: 120 minutes

Please Read the Questions Carefully and Be Sure to Answer All Parts!
Use sketches to illustrate your points when necessary.

For the sake of time, be brief and to the point.

1. (20%) Explain, using schematics when necessary, the processes responsible for the diurnal oscillatory behavior of dryline propagation under quiescent weather conditions.

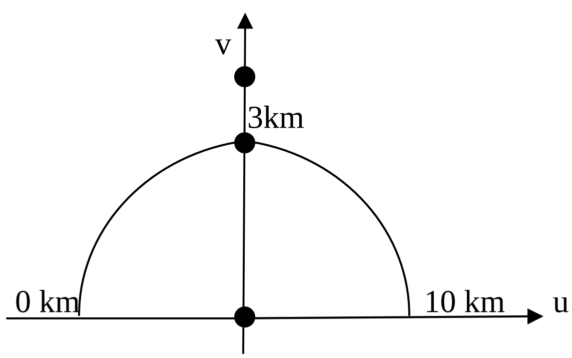
2. (30%) Describe the life cycle of a typical single-cell thunderstorm, using diagrams when necessary. Describe the environmental conditions conducive for single-cell thunderstorm formation. Contrast these conditions with those conducive to the development of multicell thunderstorms.

3. (30%) Consider a vertical cross section perpendicular to and through a mature squall line. Draw and label the following: a) front-to-rear inflow branch, b) rear-to-front inflow branch, c) gust front and cold pool, d) convective region, e) stratiform rain region, f) bright band in stratiform rain region. Give a brief physical description of each of these features.

4. (40% total) Consider the linear terms in the perturbation pressure equation, as given by

$$\nabla^2 p' = -\rho_0 \left[2\frac{\partial \bar{u}}{\partial z}\frac{\partial w'}{\partial x} + \frac{\partial \bar{v}}{\partial z}\frac{\partial w'}{\partial y} \right]$$

You are given a hodograph that is clockwise curved, like the following, and assume there is sufficient CAPE, answer the following two questions.



(a) (20%) Based on the effect of perturbation pressure, discuss why after the splitting of a convective storm, the right mover tends to have preferred development, even when the environment is horizontally homogeneous.

(b) (20%) Given the above hodograph, discuss the storm-relative environmental helicity (SREH) for the three cases, where the tip of the storm motion vector ends on one of the three black dots. Which situation is most favorable for cell growth and why?

5. (40%) Briefly describe the two theories of the source of low-level vorticity associated with supercell tornadogenesis.

6. (40% total) According to Emanuel's air-sea interaction theory for hurricane development and maintenance, the following equation can be used to determine the minimum attainable low-level central pressure in a hurricane.

$$\int_{r_a}^{r_c} \frac{RT_s}{p}\frac{dp}{dr}dr = -\varepsilon T_s(s_c - s_a) \text{ where } \varepsilon = \frac{T_s - T_o}{T_s}. \quad (1)$$

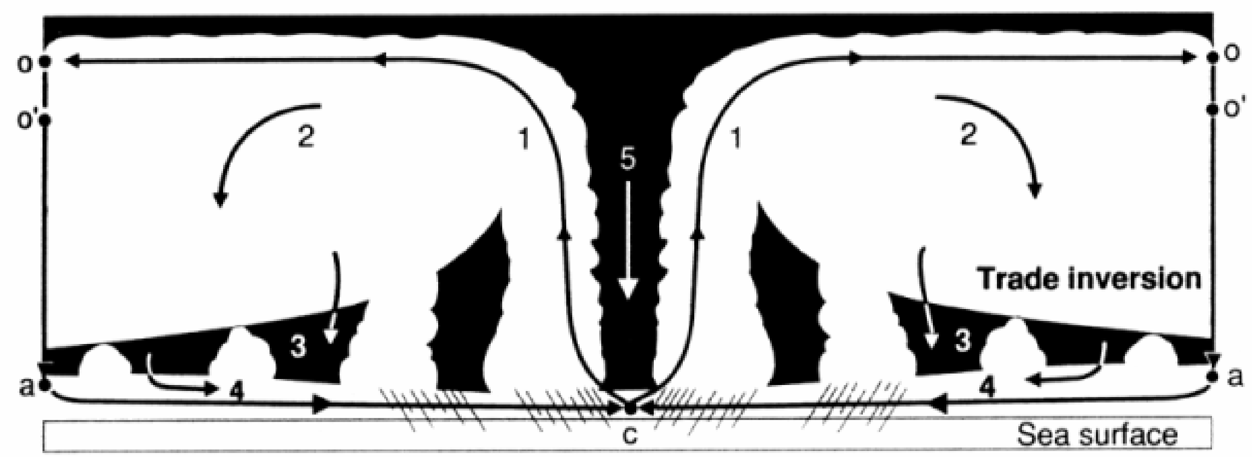


Fig. 9.14 Schematic cross section of the secondary meridional circulation in a mature hurricane. Air spirals in toward the eye (region 5) in the boundary layer (region 4), ascends along constant-*M* surfaces in the eyewall cloud (region 1), and slowly subsides and dries in regions 2 and 3. (After Emanuel, 1988.)

(a) (20%) Aided by the above diagram, interpret Eq. (1).

(b) (20%) After integrating the left hand side, Eq.(1) becomes $RT_s \ln\frac{p_c}{p_a} = -\varepsilon T_s(s_c - s_a)$ where the change in entropy ds is given by $ds = C_p\frac{dT}{T} + \frac{L\,dq_v}{T} - R\,d(\ln p)$.

Further, you are given: T_o = 200 K, T_s = 300 K, p_a = 100000 pa, the low-level environmental q_v = 0.014 kg kg^{-1} and q_v near the hurricane center is 0.018 kg kg^{-1}, and C_p = 1004 m^2/(s^2 K), R=287 m^2/(s^2 K), L=2.5×10^6 m^2/s^2, calculate the minimum attainable central pressure.

Hint: d[ln(x)]=dx/x, ln(x/y) = ln(x) - ln(y), ds between point c and a is s_c - s_a.

Solution:

Integrate the following equation from point a to c:

$$ds = C_p \frac{dT}{T} + \frac{L\ dq_v}{T} - R\ d(\ln p) \qquad (2)$$

$$\int_a^c ds = \int_a^c C_p \frac{dT}{T} + \frac{L\ dq_v}{T} - R\ d(\ln p)\,. \qquad (3)$$

Because the temperature of the near-surface air is equal to sea surface temperature T_s (due to heat exchange with the sea surface), which can be assumed constant from point a to c, dT=0 and T=T_s = constant, we have

$$s_c - s_a = \frac{L\ (q_{vc} - q_{va})}{T_s} - R \ln \frac{p_c}{p_a} \qquad (4)$$

therefore

$$RT_s \ln \frac{p_c}{p_a} = -\varepsilon T_s \frac{L\ (q_{vc} - q_{va})}{T_s} + \varepsilon T_s R \ln \frac{p_c}{p_a}$$

$$(1-\varepsilon) RT_s \ln \frac{p_c}{p_a} = -\varepsilon L\ (q_{vc} - q_{va})$$

$$\ln \frac{p_c}{p_a} = -\frac{\varepsilon L\ (q_{vc} - q_{va})}{(1-\varepsilon) RT_s}$$

$$= -\frac{1/3 \times 2.5 \times 10^6 \times (0.018 - 0.014)}{(1-1/3) \times 287 \times 300}$$

$$= -\frac{2.5 \times 10^3 \times 4}{2 \times 287 \times 300} = -\frac{100}{6 \times 287} = -0.058$$

$$p_c = p_a \exp(-0.058) = 100000 \times 0.9436 = 94365\text{Pa}\ .$$