

**MEA 717 Advanced Weather Analysis**  
**Exam 2 (Take Home), Distributed Saturday, 4 April, due Friday, 10 April**

Instructions: Please type your answers to discussion questions, but you are welcome to use hand-drawn diagrams for #1d, and you can neatly write out answers for questions requiring equations. For #5, please write your answers on the exam page itself. You are expected to work on this exam independently, meaning that you are not to discuss the questions or answers with your classmates (I know, I don't need to say this). I would suggest that the entire exam should take you approximately 6 hours to complete, depending on how much you need to dig back into earlier materials. If you need to make additional assumptions for answering any questions, simply state what assumptions you made and proceed.

1. [31 points] We discussed Davis and Emanuel 1991 (hereafter DE91), a pioneering study on the use of PV to quantify and better understand processes acting in midlatitude cyclones. However, DE91 state that additional case studies are needed in order to better understand the role of diabatic processes in cyclogenesis. A major part of this exam will be to read and summarize three additional papers on this topic, and summarize the role of these processes within the context of baroclinic instability theory.
  - a.) [6] Davis 1992 (hereafter D92) presents analysis of 2 additional cyclone events, from December 1987 and February 1988. (i) **Compare and contrast the interactions of the primary cyclonic PV elements between the DE91 case, and the two cases from Davis (1992).** (ii) **Specifically, what role do diabatic processes play in these different cases?**
  - b.) [9] Davis et al. 1993 (DSK93) add two additional cases to the December 1987 event. (i) **In what ways does this paper differ from or extend the results of the DE91 and D92 studies?** (ii) **What different or additional tools of analysis were used?** (iii) **What are the direct and indirect roles of diabatic processes in these cyclone events?**
  - c.) [6] Stoelinga 1996 (S96) also addressed the roles of diabatic processes and friction in a midlatitude cyclone. (i) What was different about the approach in this paper relative to DE91, D92, and DSK93? (ii) What does this paper add to our knowledge that we didn't know from the other papers?
  - d.) [10] Now, we will assimilate this information into a schematic conceptual model for mid-latitude cyclones. Hoskins (1990) presented the schematic I have often shown in class, included at the top of the following page. **Based on the results of DE91, D92, DSK93, and S96, draw a revised schematic that includes the role of diabatic processes.** You may wish to draw 2 or more schematics to cover different possibilities spanning the spectrum of events from the papers. These diagrams should capture the essence of midlatitude cyclogenesis in the real atmosphere, extending the Eady view.

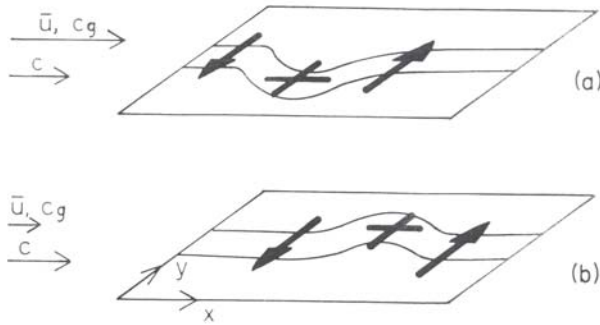


FIG. 5.6. A schematic showing neutral and interacting Rossby waves in the Northern Hemisphere. (a) At an upper level, PV contours on a  $\theta$ -surface (or  $\theta$ -contours on a PV surface) with values increasing (decreasing) with  $y$ . An equatorward displacement as shown corresponds to a positive (negative), "cyclonic" anomaly and meridional winds as indicated. These act to transfer the displacement upstream so that the phase speed ( $c$ ) is less than the flow speed ( $\bar{u}$ ). The group velocity ( $c_g$ ), however, will be larger than the phase speed. These speeds are indicated on the left-hand side. (b)  $\theta$ -contours on the lower boundary. The warm cyclonic anomaly leads to a tendency to transfer the displacement downstream but the group velocity will be less than this. The induced velocities will extend through some depth of the atmosphere. With the relative phases shown, the velocity field induced by each anomaly acts to increase the displacement and thus the size of the other anomaly.

- 2.) [10 pts] In class, we derived various forms of the PV-tendency equation. We neglect friction for the moment, and write this equation with only the diabatic heating terms:

$$\frac{dQ}{dt} = -g\zeta_{a\theta} \frac{\partial \dot{\theta}}{\partial p} + g \frac{\partial \theta}{\partial p} \left[ \frac{\partial v}{\partial \theta} \frac{\partial \dot{\theta}}{\partial x} - \frac{\partial u}{\partial \theta} \frac{\partial \dot{\theta}}{\partial y} \right]$$

We also utilized the Emanuel et al. (1987) formula for estimation of condensational heating:

$$\dot{\theta} \approx \omega \left( \frac{\partial \theta}{\partial p} - \frac{\gamma_m}{\gamma_d} \frac{\theta}{\theta_e} \frac{\partial \theta_e}{\partial p} \right)$$

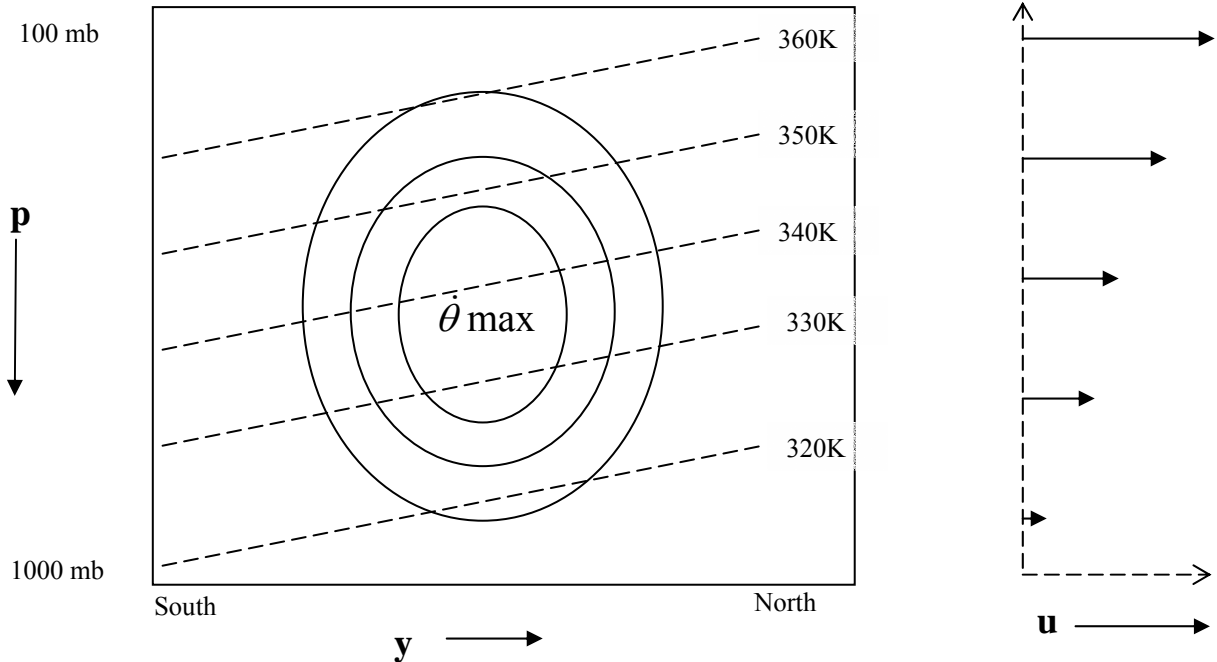
Perform a **scale analysis** for a typical marine cyclone event for (a) the condensational heating (express in units of degrees per hour), and (b) the condensational PV tendency (express in units of PVU per hour).

3. [10 pts] Eady's graduate student, John. Green, found that by adding  $\beta$  to the Eady (1949) problem (relaxing the f-plane assumption) that the shortwave cutoff vanished. ***Within the context of Bretherton (1966) and "necessary conditions" for baroclinic instability, how and why does adding  $\beta$  destabilize all wavelengths?***

4.) [25 points, 5 each but 10 for part d] This is a repeat of the extra credit question from the previous exam. Some of you have already completed most of this! Again, we will only consider barotropic instability and the lateral shear, ignoring any vertical shear. You will need a domain that is periodic in  $x$ , and with rigid boundaries at  $y = 0, L_y$ .

- State any assumptions you wish to use.
- Derive or write the governing equation for the interior of the flow, and the equations you would use for the boundary conditions.
- Write an expression for a basic-state lateral shear profile (of the westerly flow) that may be barotropically unstable. You may wish to consult the first page of Bretherton (1966a) for ideas.
- Assume a wavelike solution, and proceed with a solution to this problem. Keep things as simple as possible, but remember- we are seeking a dispersion relation, relating the phase speed  $c$  to the wavenumber  $k$ .

- 5.) [24 points] Consider the heating associated with an idealized midlatitude convective system embedded in westerly flow, as shown below. Assume simple westerly shear as indicated at right, and that there are no north-south variations in this flow. The environmental meridional (N-S) wind component is zero. Outside the outermost contour shown,  $\dot{\theta}_{\max}$  is zero. The cross section at left is a northward oriented section.



- a.) Use the frictionless PV tendency equation below to deduce regions of PV growth and decay.
- First, indicate areas of positive and negative PV tendency *due to the first term on the right side*. Show your work, and shade and label regions of maximum PV growth or decay on the diagram above.
  - Now, consider the 2<sup>nd</sup> term on the right, again shading and labeling areas of PV growth or decay.

$$\frac{dQ}{dt} = -g \zeta_{a\theta} \frac{\partial \dot{\theta}}{\partial p} + g \frac{\partial \theta}{\partial p} \left[ \frac{\partial v}{\partial \theta} \frac{\partial \dot{\theta}}{\partial x} - \frac{\partial u}{\partial \theta} \frac{\partial \dot{\theta}}{\partial y} \right]$$

- b.) Determine the 3-D vorticity vector,  $\vec{\zeta} = f\hat{k} + \nabla_3 \times \vec{V}$ . Is the PV redistribution you found in a.) consistent with the projection of the heating gradient onto the vorticity vector? Briefly discuss, and sketch the vector on the diagram above.
- c.) Now, consider how the PV field might evolve. On the diagram on the following page, sketch a PV distribution that might result after sufficient time for PV anomalies to develop.
- d.) Assuming that diabatic effects are important to the motion and evolution of the system, sketch below a qualitative “track plot” for the local PV center that would accompany this convective system. Does the system propagate with respect to the flow? If so, your track plot should reflect this.

Diagram for c.) on previous page:

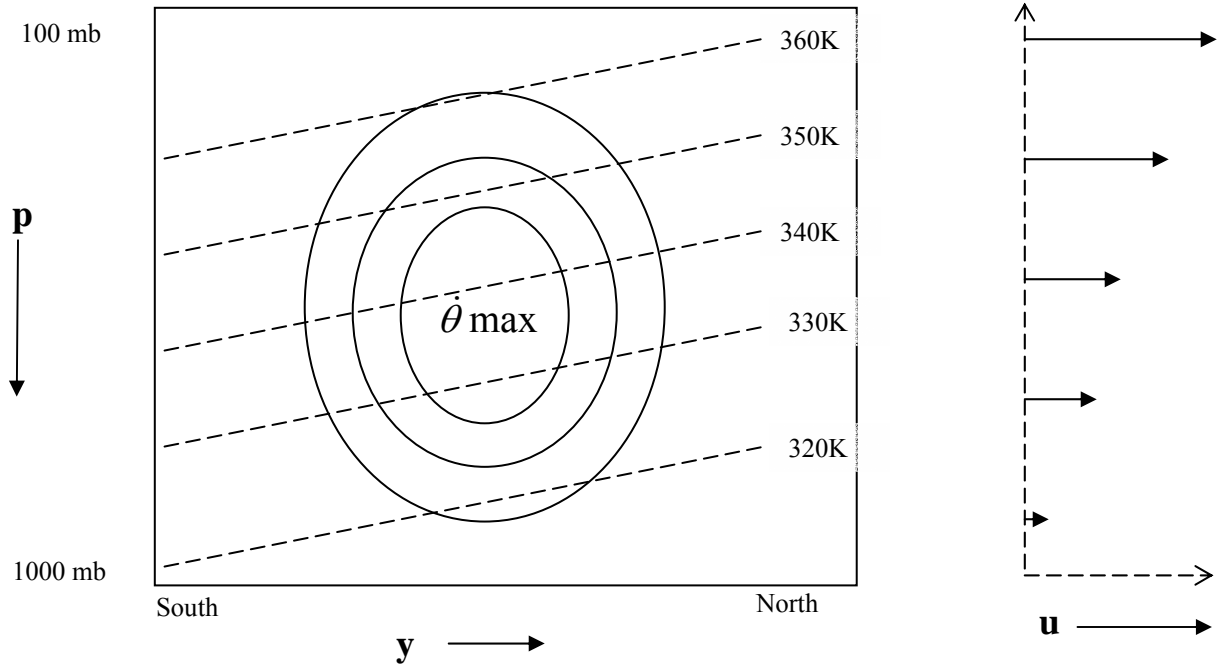


Diagram for d.) on previous page:

