

1. (45%) In natural coordinates, the geostrophic forcing term in the Sawyer-Eliassen frontogenesis equation is  $Q_g = 2\gamma \frac{\partial u_g}{\partial s} \left| \frac{\partial \theta}{\partial n} \right|$ . Here natural coordinates are used, with unit vector  $\mathbf{n}$  pointing to the warm air, and  $\mathbf{s}$  normal to  $\mathbf{n}$ , turned  $90^\circ$  counterclockwise.

- Use this to graphically show that if cold air advection dominates across a jet streak, variations in  $Q_g$  can explain the tendency for descent to occur along the axis of the jet, and ascent both on the cyclonic and the anticyclonic sides of the jet.
- Draw a vertical cross section across the jet streak, showing some isotachs and isentropes, to show that this secondary circulation tightens the upper-level front on the cyclonic side of the jet.
- Show, by means of the Trenberth approximation of the omega equation, that this secondary circulation is consistent with QG theory. (Clearly the QG secondary circulation and resulting frontogenesis would be weaker and broader than the one inferred from the Sawyer Eliassen frontogenesis equation, but that is not the issue here.)

2. (30%) Problem 8.7 in Martin (2006).

3. (25%) Problem 8.8 in Martin (2006). Clearly mark the cold and warm frontal surfaces (a  $\theta_e$  line) (you can use the schematic below, or draw your own copy). Hint: the feature of interest is discussed in Section 8.6 in the textbook.

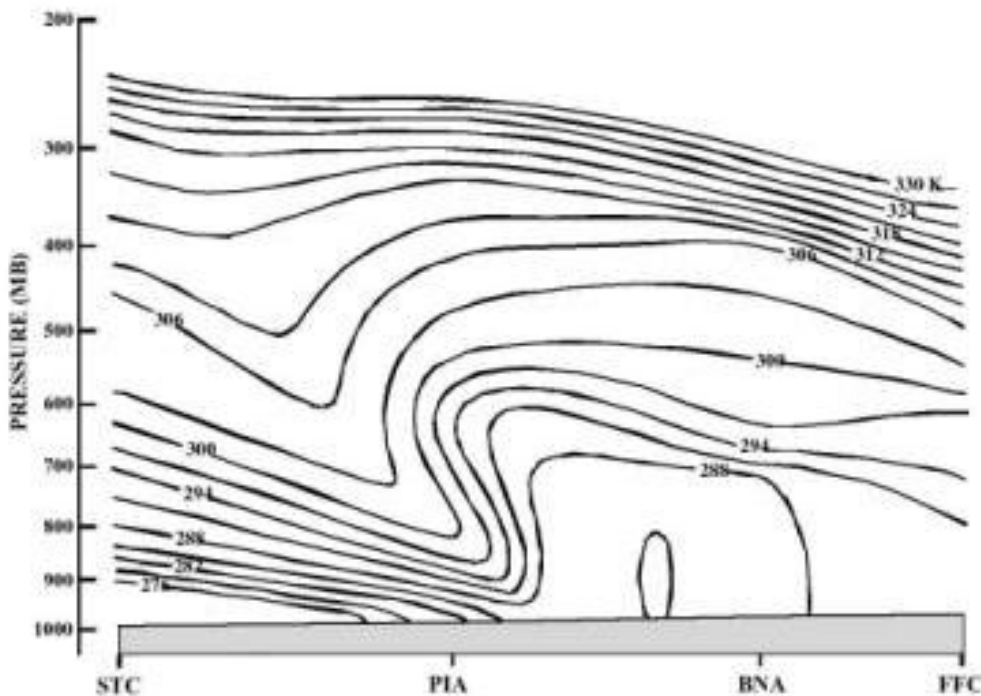


Figure 8.3A