Baroclinic instability

Baroclinic cyclogenesis

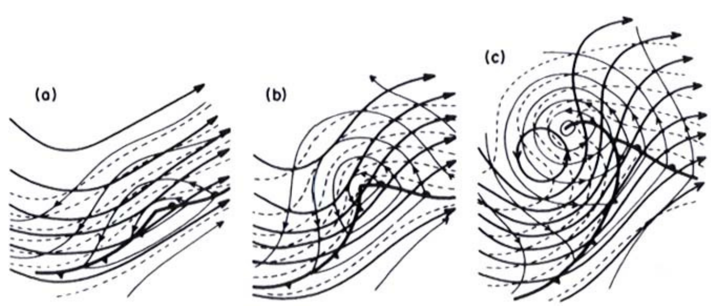
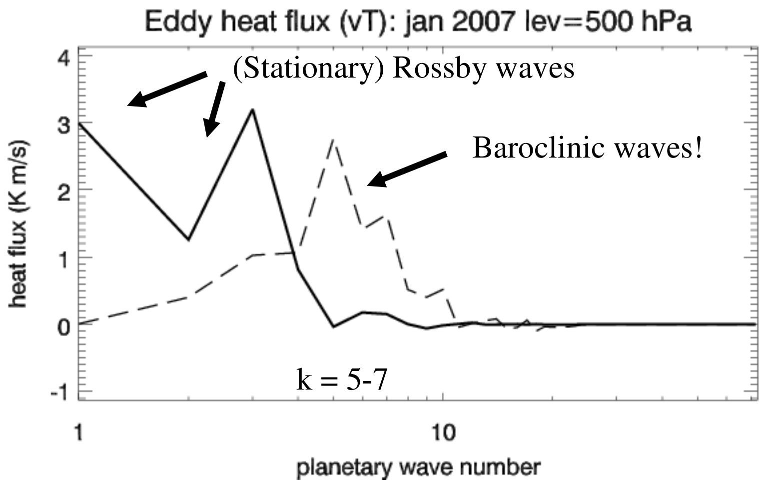


Fig. 6.5 Schematic 500-hPa contours (heavy solid lines), 1000-hPa contours (thin lines), and 1000–500 hPa thickness (dashed) for a developing baroclinic wave at three stages of development. (After Palmén and Newton, 1969.)

Heat flux by waves



Total stationary eddy heat transport = 8.5 K m/s

Total transient eddy heat transport = 9.5 K m/s

Normal mode analysis

Understand method way in which instabilities occur and develop

1. Come up with a/some wave equation(s)
2. Linearize (very small initial disturbance)
3. Assume solution

$$\psi' = A\exp[ik(x-ct)]$$

(i.e., construct wave equation knowing we want to do this)

4. Develop dispersion relationship: $c = c(k,u,\beta,f,\ldots)$
5. Examine conditions for growth
   defining k real and positive

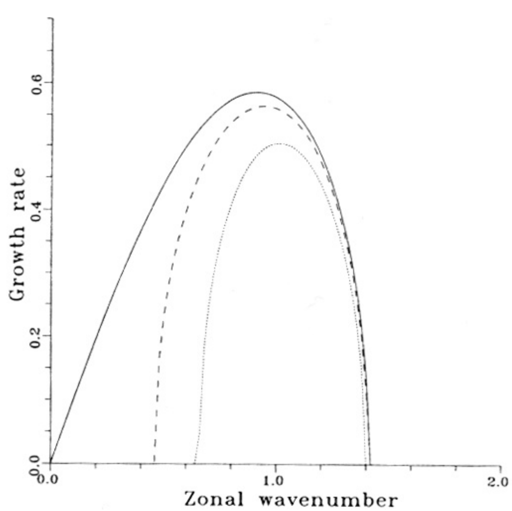


Fig. 5.23. Growth rate versus wavenumber for the two-level model for variou values of β, calculated from Eq. (5.59). Growth rates are scaled by $K_R \Delta U$ an wavenumbers by K_R. Basic parameters are for a β-plane centred at 45° wit $N^2 = 10^{-4}\,\mathrm{s}^{-2}$ and a vertical shear of $40\,\mathrm{m\,s}^{-1}$, roughly corresponding to norther hemisphere winter. Solid curve: $\beta = 0$. Dashed curve: $\beta = 8.1 \times 10^{-12}\,\mathrm{m}^{-1}\,\mathrm{s}^{-}$ Dotted curve: $\beta = 1.6 \times 10^{-11}\,\mathrm{m}^{-1}\,\mathrm{s}^{-1}$.

James. 1994

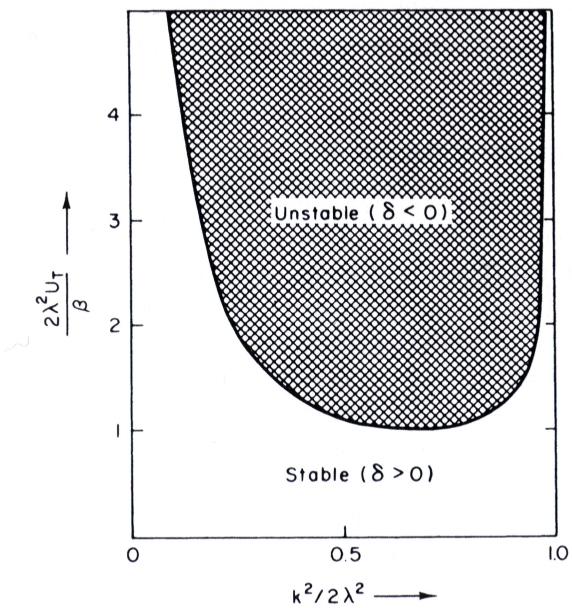
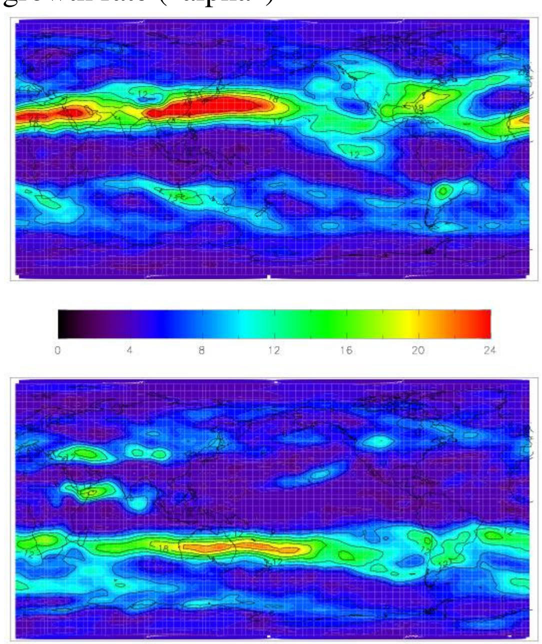


Fig. 8.3 Neutral stability curve for the two-level baroclinic model.

Baroclinic growth rate ("alpha")



January

24xday^{-1}

July

Baroclinic growth (predictions 1)

- Thermal wind balance (geostrophic/hydrostatic) continually maintained
- Vertical motion causes stretching, and vorticity generation at lower levels

1. Short waves always stable ($k^2 > 2k_R^2$)
2. Beta effect stabilizes flow for long waves (leads to a minimum U_T (or ΔT) for instability
3. For given stability, increasing U_T will give a wave number that becomes unstable first (the most unstable wave)

4. Depends on

- σ stability)
- F rotation rate, and
- U_T temperature gradient/difference

- Baroclinic waves in midlatitude typically on scale of most unstable wave ($k \sim k_R$ => L ~ 4000km, planetary wave 6-7)

Baroclinic cycle

- Warming in the tropics, cooling at poles: U_T increases
- For given stability (~moist adiabatic), U_T reaches critical value and most unstable wave grows
- Potential energy is converted to (eddy) kinetic energy
- Geopotential gradient is reduced, thus U_T is reduced below (to) critical threshold

Net effect is to transport heat poleward
(This avoiding "geostrophic paradox" in zonal mean)

Analogies with rotating annulus experiment?

What is β

What is f

What is "stability" σ

What is Rossby radius L_R or λ

1. What is the critical U_T for instability (ΔT, Ω, σ, ...)
2. What is the most unstable wave number/wave length? (for a given rotating rate and temperature difference)

First need to justify the analogy between the incompressible (Boussineq) case with the stratified atmosphere case from Chapter 8. Hints in chapter 10!