Baroclinic Instability

Basic idea: For wave growth to occur, need sufficient warm air advection east of trough, cold air advection west of trough to overcome cooling of rising motion east of trough (due to adiabatic expansion) and warming of sinking motion west of trough due to adiabatic compression. "UWDC"

In others words, a sufficient ∇T is needed, which by thermal wind arguments is manifested by a strong vertical wind shear (VWS).

Reference:
Carlson,
"Mid-latitude
Weather
Systems"

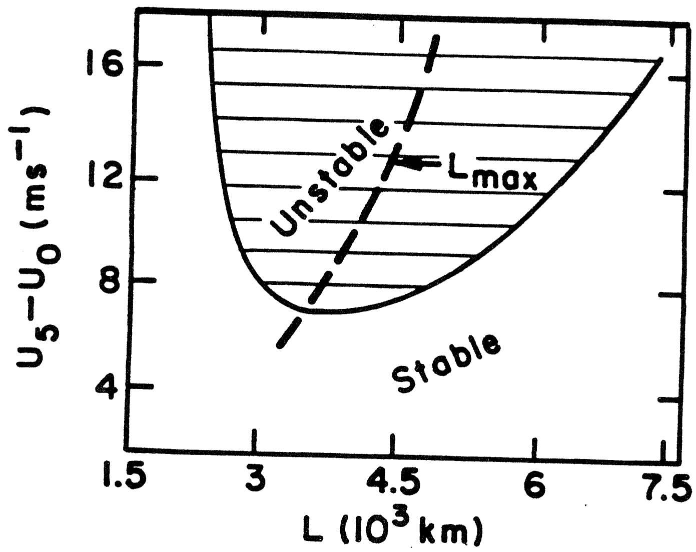


Figure 11.2 Baroclinic stability regimes as a function of wavelength (L) and thermal wind ($U_5 - U_0$) for a two-level model. L_{max} is the wavelength of maximum growth rate. (Based on a figure by Haltiner, 1971.)

(a) Growth rate is sensitive to VWS (∇T)

(b) Larger VWS yields larger growth rates (and, by implication, more intense disturbances) and longer wavelengths

(c) Below a critical VWS no growth occurs.

(d) Optimum growth rate at about 3000-4000 km (wavenumber 7 to 8)

(e) Growth fails to occur below a minimum wavelength (≈ 2000 km). Whether this "short-wave cut-off" exists is controversial

(f) Except for extraordinary VWS, there is an effective "long-wave cut-off" at about 8000 - 10,000 km.

Other non-linear and modeling studies have
shown:

a) * "Short-wave cutoff" is not related to friction, but to how much a model is stratified (two-level, ten-level, twenty-level). In some highly stratified linear models, there is no SW cutoff.

* However, others argue it does exist. Some say a SW is advected by $\bar{U}$ too fast to "feel" the effects of baroclinicity.

* Dr. Gray says $w \propto \frac{1}{L^{1.5}}$, and the very fast ascent

[redacted] experiences large adiabatic cooling which cannot be compensated by warm air advection.

* Effect of friction is not understood.

b) Baroclinic instability is manifested simultaneously as $A_Z \rightarrow A_E$ and $A_E \rightarrow K_E$

c) The maximum growth rate, which occurs at L_{max}, increases with decreasing static stability

d) L_{max} decreases with decreasing static stability

e) Growth rate is more sensitive to stability in lower troposphere than upper troposphere.

f) Condensation and latent heating increases the growth rate.

g) * The "Long-wave cutoff" is related to the beta effect

Recall the 1D barotropic equation

$$\frac{\partial \zeta_r}{\partial t} = -u \frac{\partial \zeta_r}{\partial x} - \beta v$$

Also recall that PVA is associated with $-u \frac{\partial \zeta_r}{\partial x} > 0$

$-\beta v < 0$

Beta effect increases with L. If the Beta effect dominates over PVA, $\frac{\partial \zeta_r}{\partial t} < 0$

* Likewise, if u is too weak, $\frac{\partial \zeta}{\partial t} < 0$

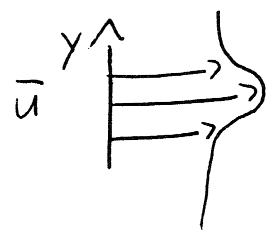
* Linear models show LW cutoff $\propto \sqrt{U}$, and $\propto \frac{1}{\sqrt{\beta}}$

* Dr. Gray says since $w \propto \frac{1}{L^{1.5}}$, the ascent will be too weak for baroclinic instability to occur.

Other nifty instability stuff for "PV people"

Necessary but not sufficient conditions for

(a) "Barotropic instability": $\frac{\partial \zeta_a}{\partial y} = 0$ | $\frac{d^2 \bar{u}}{dy^2} - \beta = 0$ | $\frac{d}{dy}\left(-\frac{d\bar{u}}{dy} + f\right) = 0$



The meridional gradient of ζ_a must change sign in the basic current $\bar{u}$.

If $\frac{du}{\partial y} > f$, this can occur.

Example: easterly jet over Africa, where easterly waves form. Contributes 50% to easterly wave formation

(b) "Combined barotropic/baroclinic instability"

$$\frac{d(PV)}{dy} = 0$$

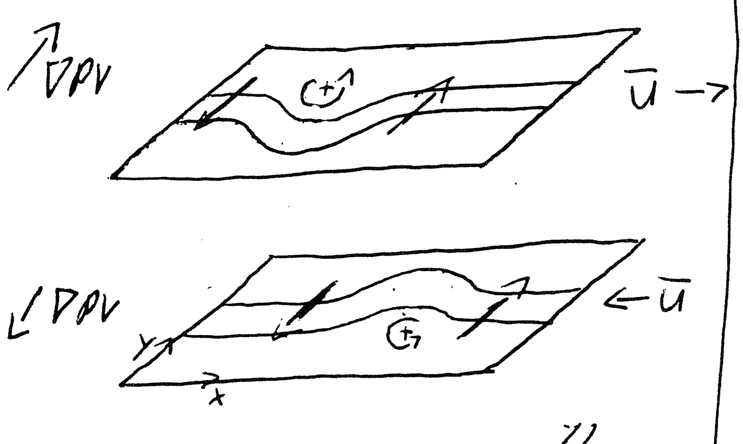
. Explains easterly wave formation.

(c) "Baroclinic instability"

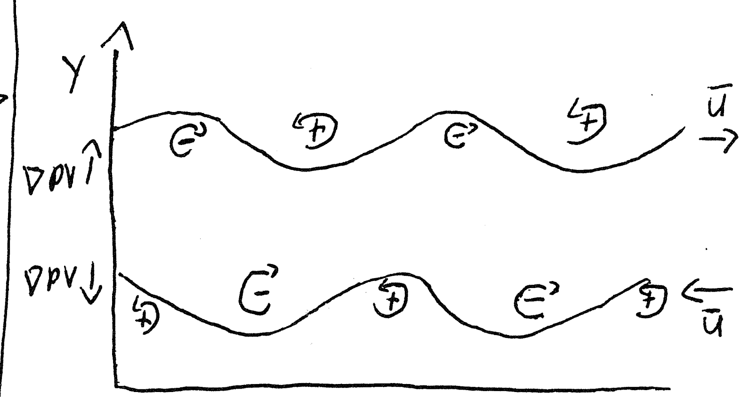
$\frac{d(PV)}{dy}$ changes sign in the vertical

(d) PV "induction theory"

- Have two "counter-propagating" Rossby waves. If they are sufficiently close to one another and they are not too long or too short, they will slow each other down. They will "phase lock" and cause each other to grow.
- This interaction ~~~~ increases for decreased stability and diabatic heating sources (convection).
- If these two waves are in vertical, have "baroclinic instability"
- If these two waves are in horizontal, have "combined baroclinic/barotropic" instability.



"Baroclinic instability"



"Combined baroclinic/barotropic instability"

References: Bluestein, "Synoptic-Dynamic Meteorology in Mid-latitudes" pg 180-219
AT602, AT704