ATM S 442/504: Atmospheric Motions II

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Energetics of Baroclinic Instability

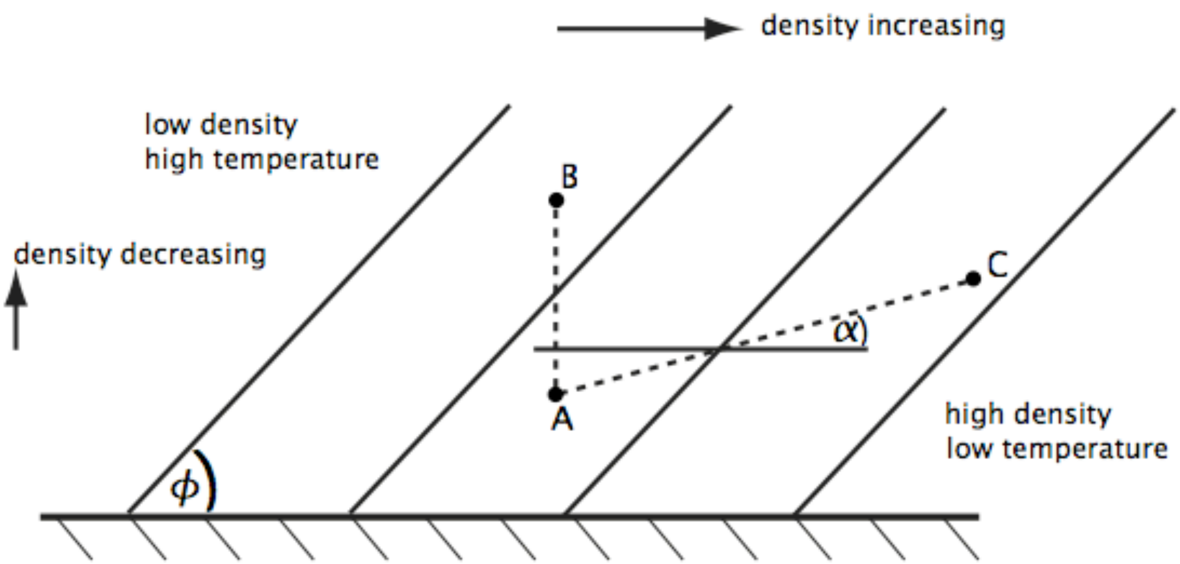


Fig. 6.9 A steady basic state giving rise to baroclinic instability. Potential density decreases upwards and equatorwards, and the associated horizontal pressure gradient is balanced by the Coriolis force. Parcel 'A' is heavier than 'C', and so statically stable, but it is lighter than 'B'. Hence, if 'A' and 'B' are interchanged there is a release of potential energy.

Switching parcels A and B moves heavy stuff up and light stuff down: This requires energy!

However C is lighter than A, but is above it: Switching these releases energy!

This is the ultimate energy source for baroclinic instablity

Available Potential Energy (APE)

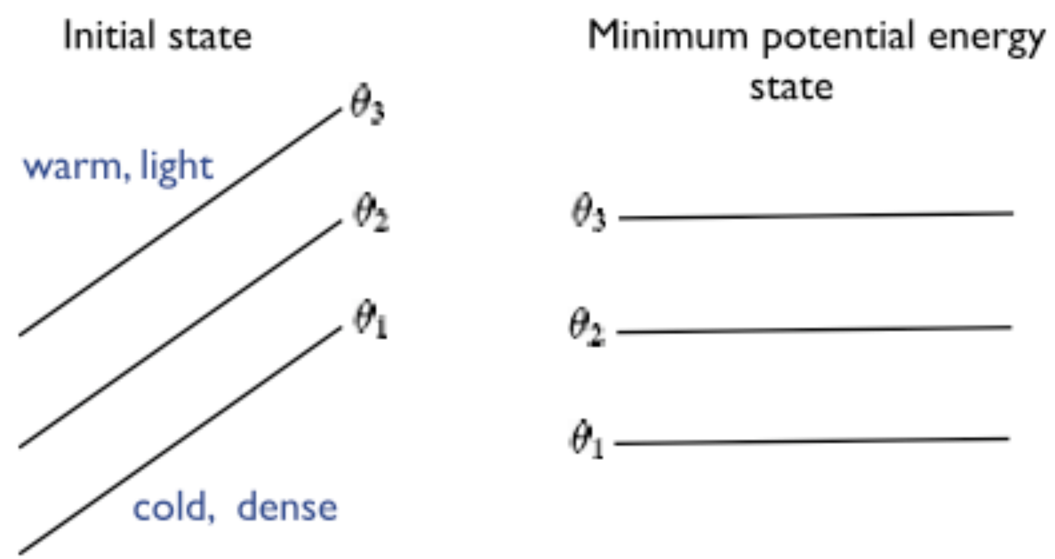


Fig. 3.11 If a stably stratified initial state with sloping isentropes (left) is adiabatically rearranged then the state of minimum potential energy has flat isentropes, as on the right, but the amount of fluid contained between each isentropic surface is unchanged. The difference between the potential energies of the two states is the *available potential energy*.

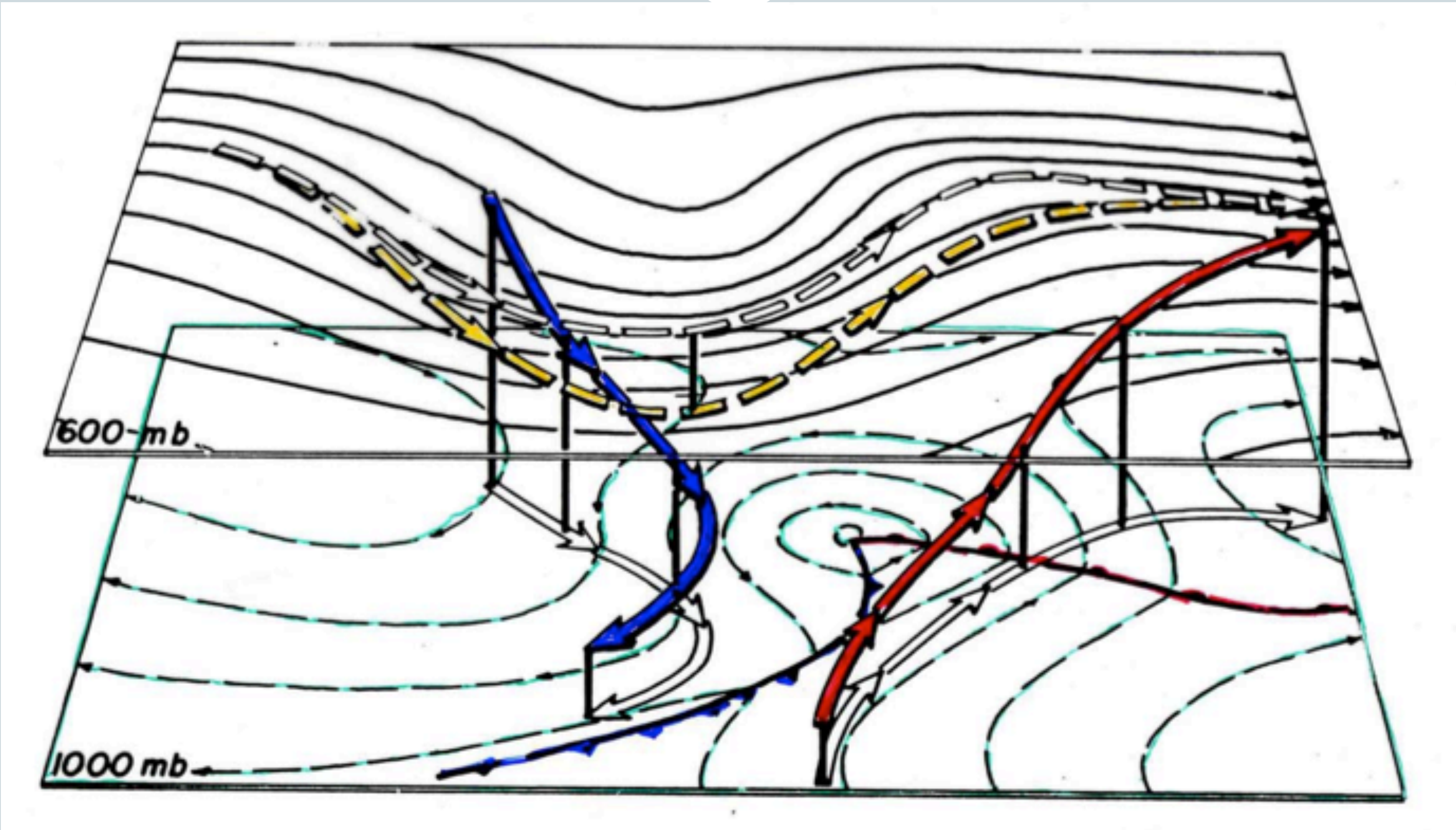
Equations can be derived for the APE of the mean state and of eddies – let's look at one of these equations…

Energy Conversion

- So turns out when there's **heat flux down a temperature gradient** then there's conversion from **mean APE to eddy APE**
- When there's **vertical motion correlated with temperature**, there's conversion from **eddy APE to eddy kinetic energy**

- Do either of these happen in baroclinic instability in the atmosphere, or in the Eady model?

Baroclinic Instability Parcel Trajectories



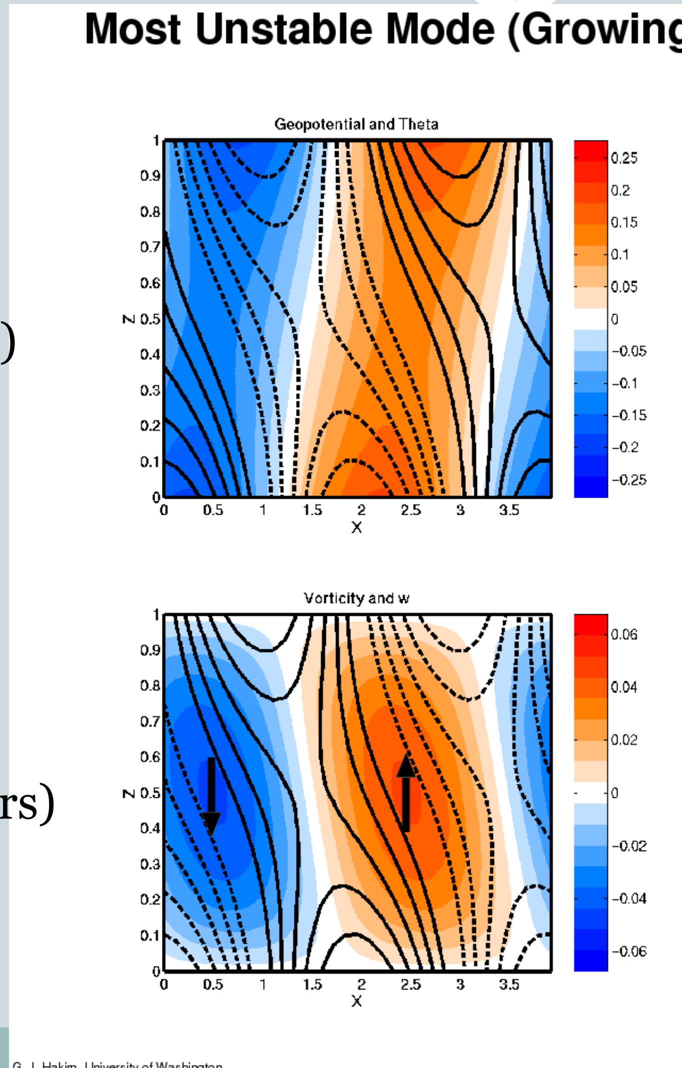
Both conversions happen, of course!

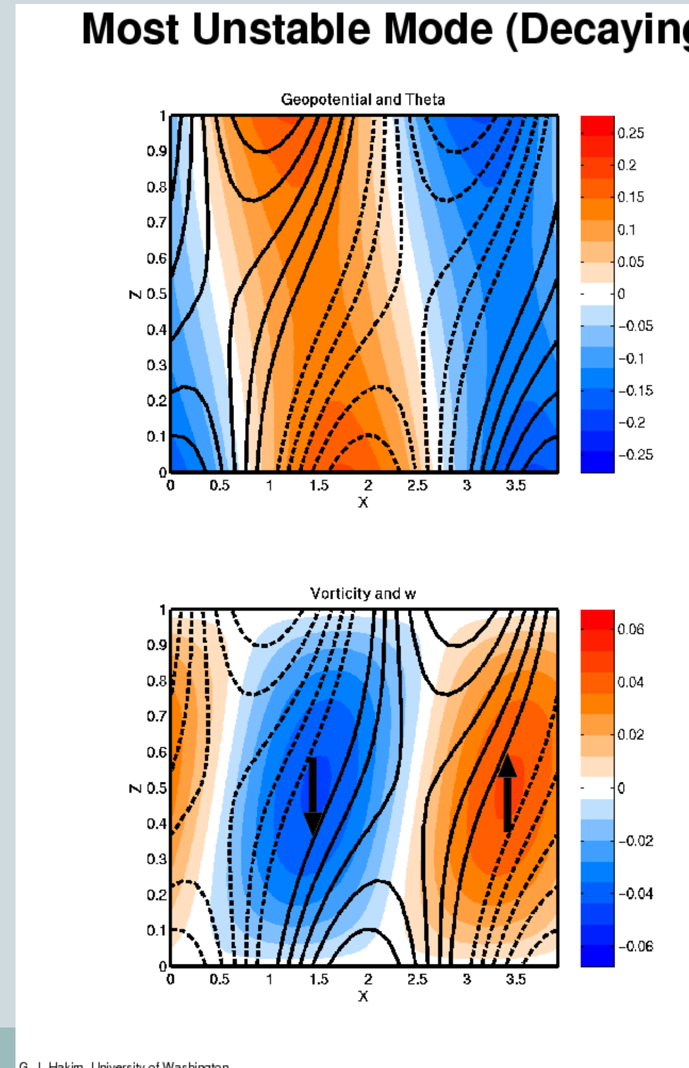
Structure of Modes in Eady Model

Remember these plots?

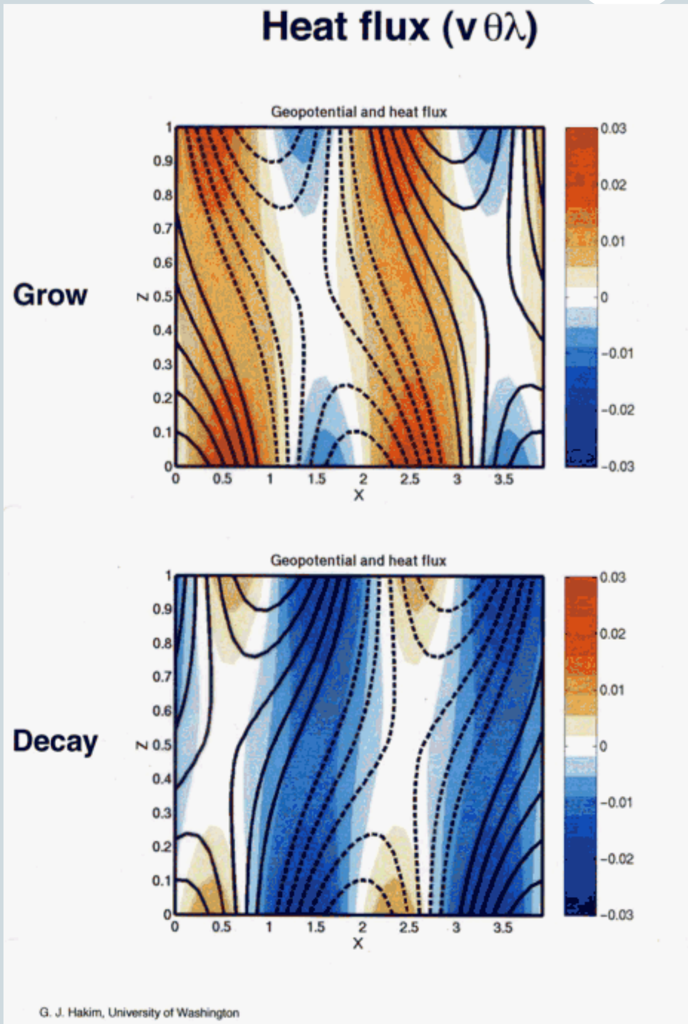
Height (contours) & theta (colors)

Vorticity (contours) & w (colors)





Eady Model Heat fluxes



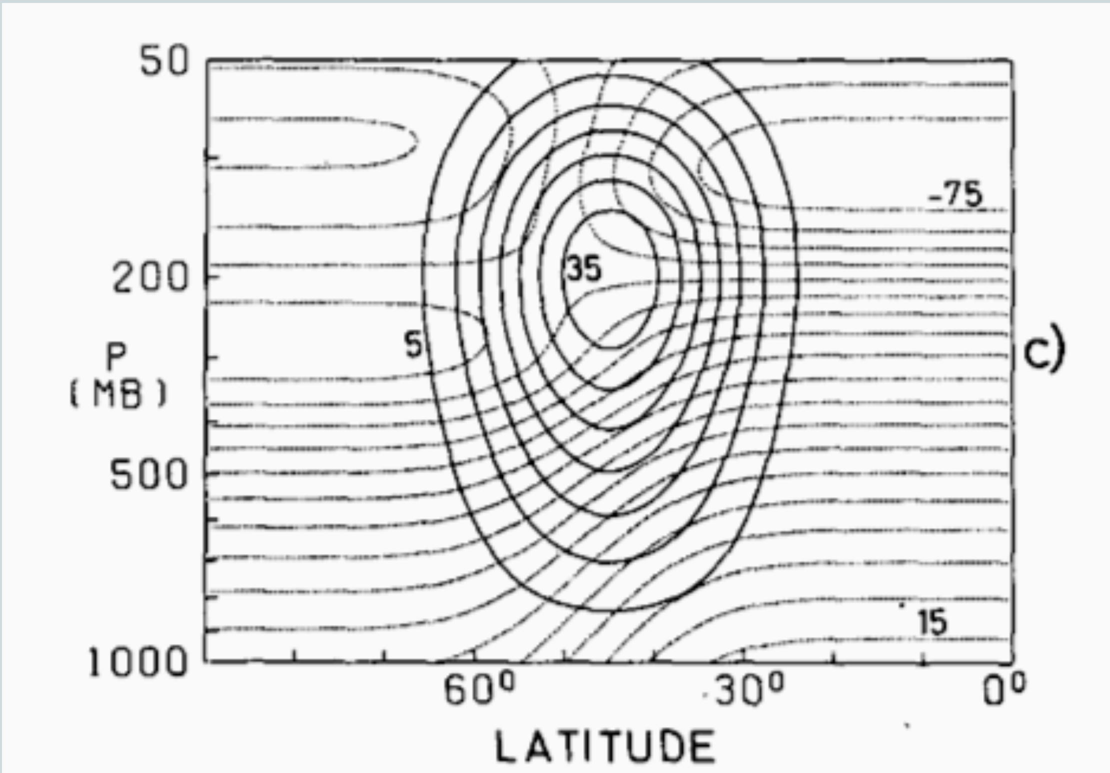
Growing mode has heat flux poleward – warm air moving poleward and cold air moving equatorward

Decaying mode has equatorward heat flux (upgradient!). Converts **from eddy APE to mean APE**
(so eddies won't last long…)

Eady model also has w'T' > 0…

Nonlinear Baroclinic Instability

What about that other term in the eddy kinetic energy equation? It transfers energy between eddy kinetic energy and mean kinetic energy.
Let's look at it in a simulation of baroclinic instability.



Initial conditions: jet centered at 45 degrees

Simmons and Hoskins 1977

Nonlinear evolution

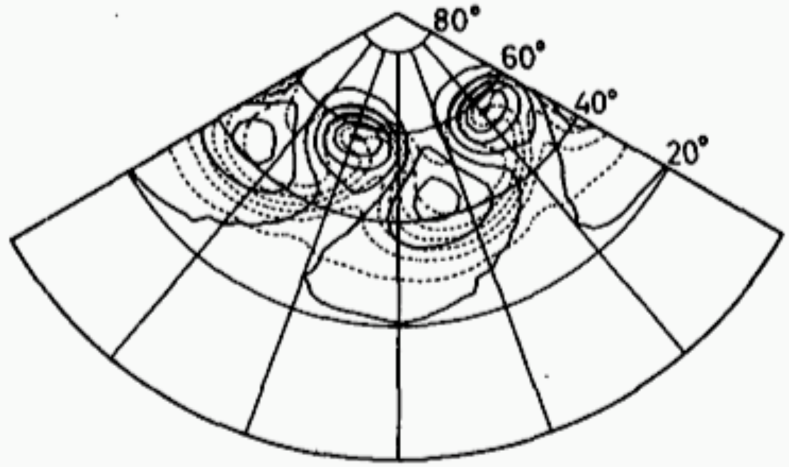


FIG. 1. North polar stereographic plot showing surface pressure (solid contours) and low-level temperature ($\sigma = 0.985$, broken contours) after seven days of integration for the wavenumber 6 perturbation to the 45° jet. Contours are drawn at intervals of 8 mb and 4°C using linear interpolation between values on the computational grid comprising 32 "Gaussian" latitudes and 32 regularly spaced points per 60° longitude. Background lines of latitude and longitude are drawn at intervals of 20°.

After 7 days, perturbation has grown from 1 hPa to 32 hPa within the low

More nonlinear evolution

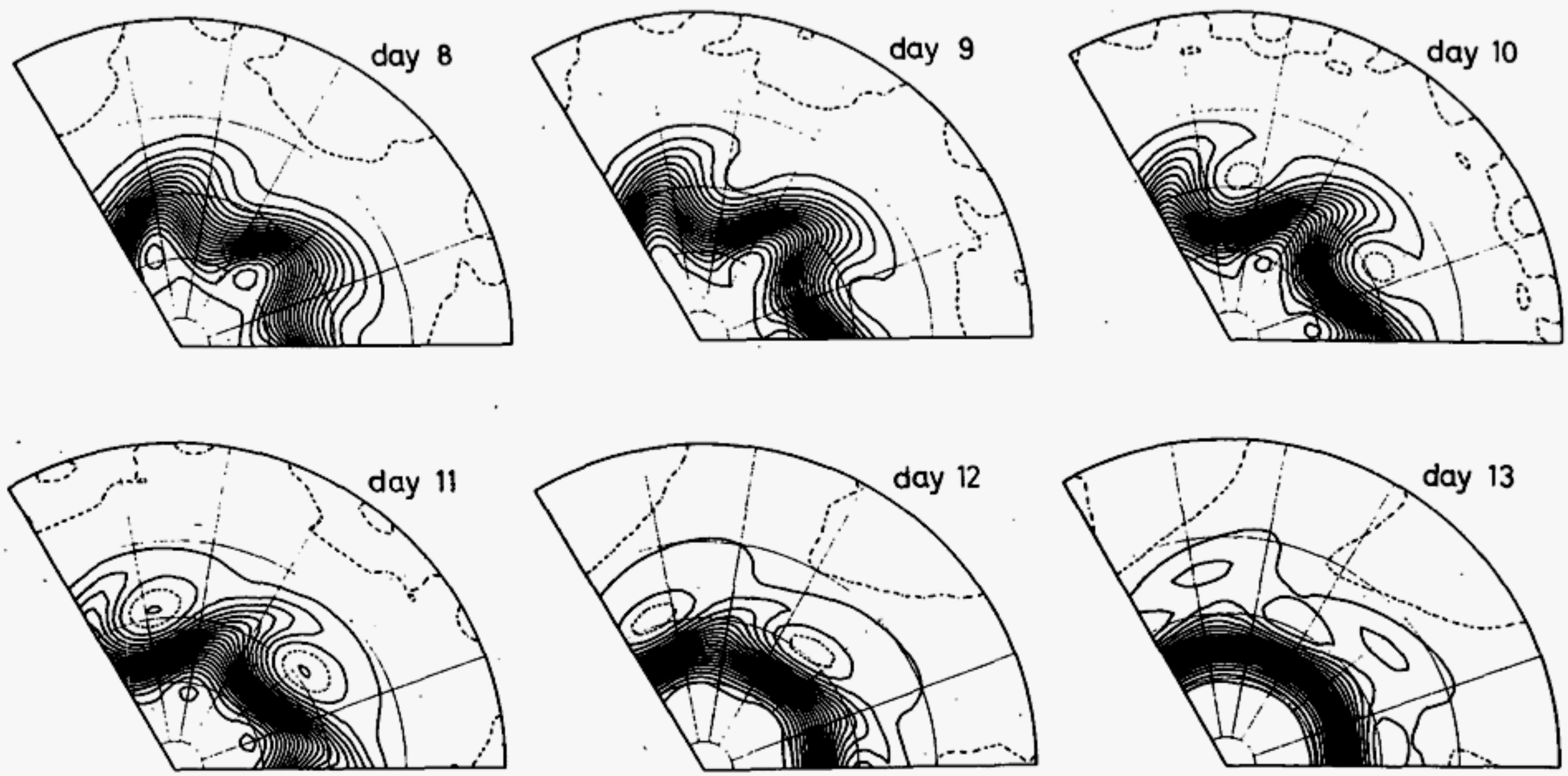


FIG. 2. Streamfunction at $\sigma=0.321$ at daily intervals from day 8 to day 13 for the wavenumber 6 perturbation to the 45° jet. The zero contour is dashed to avoid emphasis of insignificant small-amplitude variability close to the equator, and the contour interval is $1.5\times10^{-3}\ a^2\Omega$, where a is the radius of earth and Ω its angular velocity.

Energetic Terms

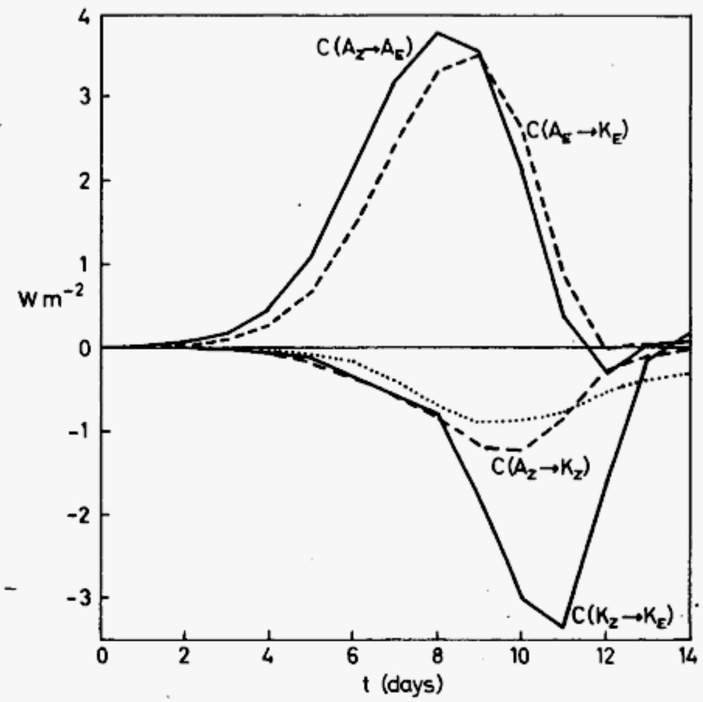


FIG. 5. Variation with time of various energy conversions and the net rate of energy dissipation (dotted curve) for the wavenumber 6 disturbance to the 45° jet. A_Z and A_E are the zonal and eddy available potential energies, and K_Z and K_E the corresponding kinetic energies. Positive values of $C(A_Z \rightarrow A_E)$ imply a transfer from A_Z to A_E, and negative values imply a reversed transfer.

So in a baroclinic lifecycle, kinetic energy is *returned* to the mean flow!!

The mean flow ends up being *stronger* after the lifecycle.

This process is associated with a momentum transport into the jet stream. It ultimately leads to surface westerlies in the midlatitudes and surface easterlies in the tropics.

So baroclinic instability is also very important for the structure of the mean winds on Earth…