THE ENERGY CYCLE

Definitions:

$A \equiv$ Available Potential Energy

$K \equiv$ Kinetic Energy

$G \equiv$ Generation Term from Diabatic Heating

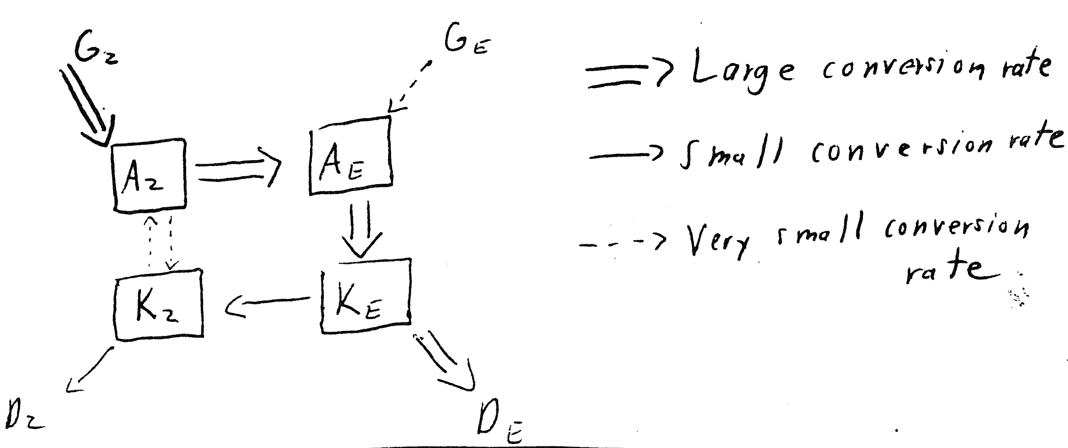
$D \equiv$ Frictional Dissipation

Subscripts: $z \equiv$ zonal
$E \equiv$ eddy

i.e.,
$A_E \equiv$ eddy Available Potential Energy

$K_z \equiv$ zonal Kinetic Energy

Book references on energy cycle:
Carlson, "Mid-latitude Weather System"
Oort, "Physics of Climate"



Furthermore, lets denote P as potential energy.

Basic definition of A:

P total − P reference which represents the realizable form of P that can be converted to K

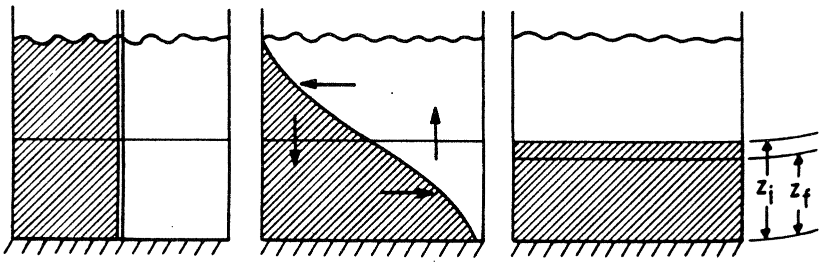


Figure 9.1 Schematic illustration of conversion of potential to kinetic energy and subsequent dissipation by friction in a tank of fluid. On the left, fluids of slightly differing densities (higher density shaded) are at rest and separated by a vertical partition (double line). The partition is removed and the denser fluid slides downward and toward the right, creating a circulation (middle figure). The rearrangement of the fluid involves a lowering of its center of mass from a height Z_i to Z_f above the base of the tank. In the final state (right-hand side), the fluid is once again at rest after having lost all its kinetic energy (an amount per unit mass of $g(Z_i - Z_f)$) to friction.

After rearrangement of mass, the fluid still possesses finite P, although further K generation is not possible

Now let us consider this sequence of events from the point of view of the energetics. In the initial configuration, the center of gravity of the fluid, denoted by the line, is exactly halfway between the top and bottom. After the partition is removed, the center of gravity drops as the denser liquid slides under the lighter one. Through the sinking of denser liquid and the rising of lighter liquid [indicated in (b)] potential energy is converted into the kinetic energy of fluid

motions. Frictional dissipation eventually converts all the fluid motions to random molecular motions so that, in the final state (c), the only evidence of the conversion that took place is the drop in the center of gravity of the system and a very slight increase in the temperatures (or internal energy) of the liquids. The energy cycle is summarized in Fig. 9.2. Here we have used the term *available potential energy* in recognition of the fact that only a small fraction of the potential energy of the initial state is really available for conversion to kinetic energy, since no matter what kind of motions develop the center of gravity cannot possibly drop below the level shown in Fig. 9.1c.

AVAILABLE POTENTIAL ENERGY → KINETIC ENERGY → INTERNAL ENERGY

Fig. 9.2 The kinetic energy cycle.

Atmospheric definition: Difference between existing PE and that which would result if the temperature field were adiabatically rearranged to become that of the mean state.

$$\frac{A}{P_{total}} \sim \frac{1}{200}\ (0.5\%) \quad ; \quad \frac{K}{P_{total}} \sim \frac{1}{2000}$$

However, in a rotating atmosphere, it is difficult to convert all A to K because geostrophic adjustment occurs before that happens. In fact, $\frac{K}{A} \sim \frac{1}{10}$

Order of the hydrological cycle!

G_Z : Ultimate energy source is differential solar heating. However, to establish $\frac{\partial T}{\partial y}$ you need UMDD. This is to balance IR cooling plus a residual that warms the troposphere. This is manifested as fluxes from the surface in thunderstorms and the warming is actually obtained by broad-scale descent.

$\Downarrow$

$\boxed{A_Z}$

Generally speaking, want to "warm where it is warm, cool where it is cool" to establish $\frac{\partial T}{\partial y}$ (baroclinicity).

$\boxed{A_Z} \Rightarrow \boxed{A_E}$: Occurs when a wave is situated within $\frac{\partial T}{\partial y}$; warm air is carried poleward and cold air equatorward $\downarrow \zeta \uparrow$.

G_E ⇢ $\boxed{A_E}$: Generation by eddy diabatic heating is relatively small when averaged over the earth, but can play an important role in individual disturbances (rapid cyclogenesis generation). Might also play an important role in enhancing baroclinic instability.

$\boxed{A_E} \Downarrow \boxed{K_E}$: Occurs simultaneously with $\boxed{A_Z} \Rightarrow \boxed{A_E}$, and is associated with VWDC. A_E is transformed in kinetic energy of the growing disturbances (cyclones and anticyclones). A large part of K_E is directly dissipated (D_E) by friction or cascades in smaller eddies (turbulence)

$\boxed{K_E} \Rightarrow D_E$

The turbulence is finally eliminated by molecular viscosity. ④

$\boxed{K_2} \leftarrow \boxed{K_E}$, $K_2 \rightarrow D_2$

However, some K_E is converted into K_2 in a barotropic process leading to a decascade of energy from the small scales into larger scales which can be interpreted as a "negative viscosity" phenomenon.

In developing system, waves typically contain the following orientation:

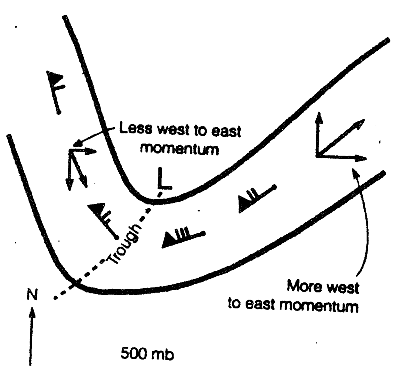


FIGURE 4
A well-developed surface storm usually shows up as a wave with a tilted trough (dashed line) on a 500-mb chart. The wave transports westerly momentum poleward because the winds east of the trough have a greater westerly component than do the winds west of the trough.

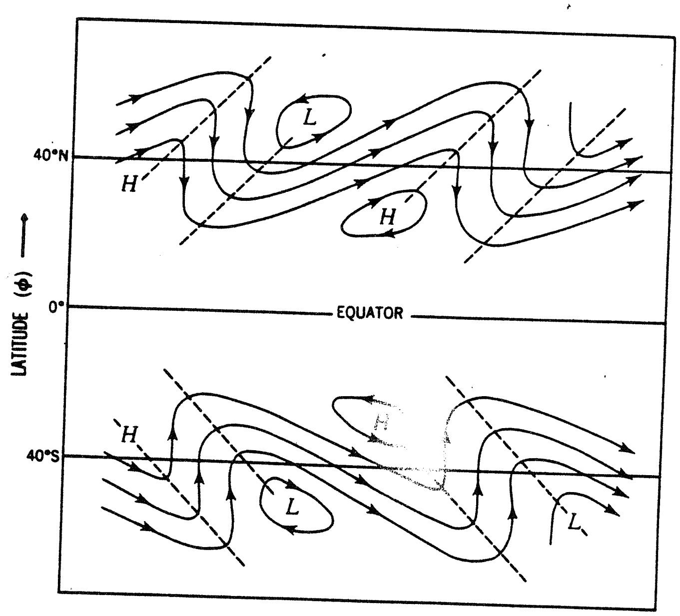
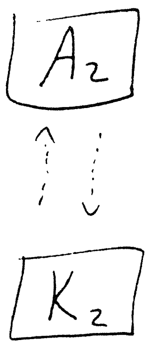


FIGURE 11.6. Schematic picture of the dominant mechanism of the upper air transport of westerly angular momentum by quasihorizontal eddies in midlatitudes. Note the preferred SW–NE tilt of the streamlines in the Northern Hemisphere, and the SE–NW tilt in the Southern Hemisphere leading to a net poleward transport of angular momentum in both hemispheres.

This transfer of westerly momentum maintains mid-latitude westerlies against turbulent dissipation D_2.

Note: $K_2 \rightarrow K_E$ is "barotropic instability"

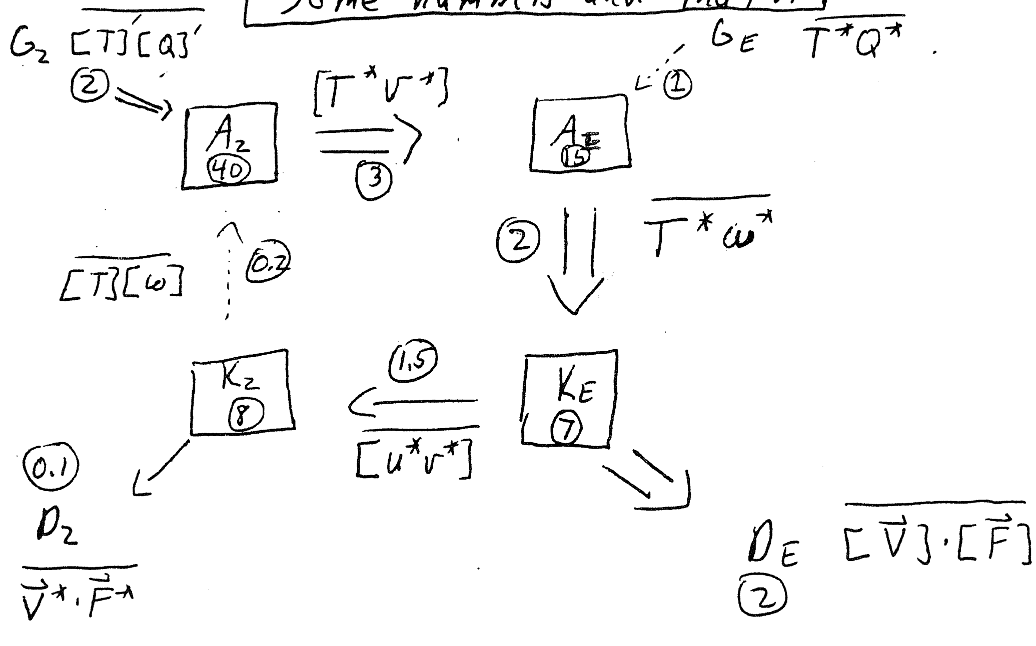
This is the breakdown of relatively zonal flow with $\frac{\partial \bar{u}}{\partial y}$ into a train of waves. Makes ~50% contribution to easterly waves in Africa.



: A small residual remains and conversion direction depends on the combined action of the direct meridional circulations ($A_Z \rightarrow K_Z$, Hadley Cell) and indirect meridional circulation ($K_Z \rightarrow A_Z$, Ferrell Cell).

Generally speaking, the Ferrell Cells consume K_Z slightly greater than the Hadley Cells produce K_Z; hence, $K_Z \dashrightarrow A_Z$

Some numbers and math!



$$[G, D, \text{conversion}] = \frac{W}{m^2}$$

$$[A, K] = 10^5 \frac{J}{m^2}$$

Definitions:

$\overline{(\;)}$ ≡ time mean

$[\;]$ ≡ zonal mean

$(\;)'$ ≡ Departure from time mean

$(\;)^*$ ≡ Departure from zonal mean