11. Origin of Atmospheric Motions

11.1 Available Potential Energy

The total energy of the atmosphere can be devided into the

- internal energy
- gravitational potential energy
- kinetic energy.

Internal and gravitational potential energy are often summarized as total potential energy.

Internal energy E_i of a unit column of air:

$$E_i = c_v \int_0^\infty \rho T dz, \tag{11.1}$$

where c_v = 717 Jkg^{-1}K^{-1} is the specific heat of dry air at constant volume, ρ is the air density and T is the temperature. Generally, it is: $E_i = mc_vT$ with mass m.

Gravitational potential energy E_p of a unit column of air:

$$E_p = \int_0^\infty \rho g z dz = -\int_{p_0}^0 z dp = R \int_0^\infty \rho T dz, \tag{11.2}$$

where R = 287 Jkg^{-1}K^{-1} is the gas constant for dry air, g is the acceleration due to gravity, z is the height above ground and p_0 is the air pressure at the bottom of the column. Generally, it is: $E_i = mgh$.

With the specific heat at constant pressure c_p = 1004 Jkg^{-1}K^{-1} the total potential energy of the atmosphere (sum of internal and gravitational potential energy) can be written:

$$E_p + E_i = \frac{c_p}{R} E_p = \frac{c_p}{c_v} E_i. \tag{11.3}$$

Only a very small fraction of the total potential energy of the atmosphere is available for conversion to kinetic energy. The kinetic energy E_k of a unit column of air is:

$$E_k = \frac{1}{2} \int_0^\infty \rho v^2 dz. \tag{11.4}$$

The generation of available potential energy and kinetic energy in the atmosphere is demonstrated by the simple model atmosphere shown in Fig. 11.1. Two air masses at a different temperature are seperated by a wall. Across the wall horizontal gradients of p, ρ, T have been established.

Removing the wall leads to:

– rearrangement of the air masses
– stable hydrostatic balance
– warm air completely above cold air mass.

The difference between the total potential energy at start- and at end-point of the rearrangement is called the *available potential energy*.

High horizontal pressure gradient $\longrightarrow$ high available potential energy

11.2 Heat Balance of the Atmosphere

The radiation budget at the top of the atmosphere for the whole earth is balanced in the long time average. That is, the incoming short wave radiation equals the outgoing longwave radiation leading to a stable temperature regime for the earth-atmosphere system.

The differential heating of the earth results in an availability of parts of the total potential energy of the atmosphere for conversion into kinetic energy. An atmosphere which is in an hydrostatic equilibrium (i.e.: no horizontal gradients of p, ρ, T) has no kinetic energy. It is in rest!

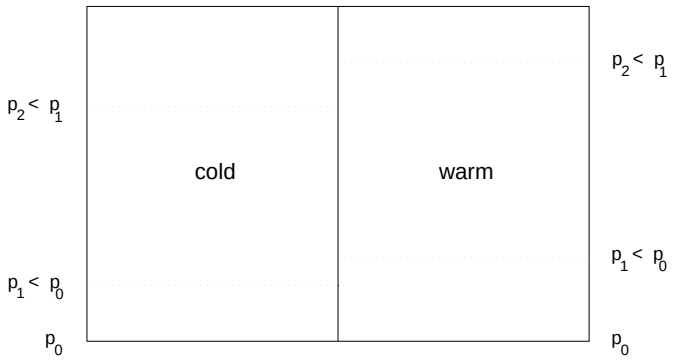

Fig. 11.1. Air columns of different temperatures resulting in a horizontal pressure gradient.

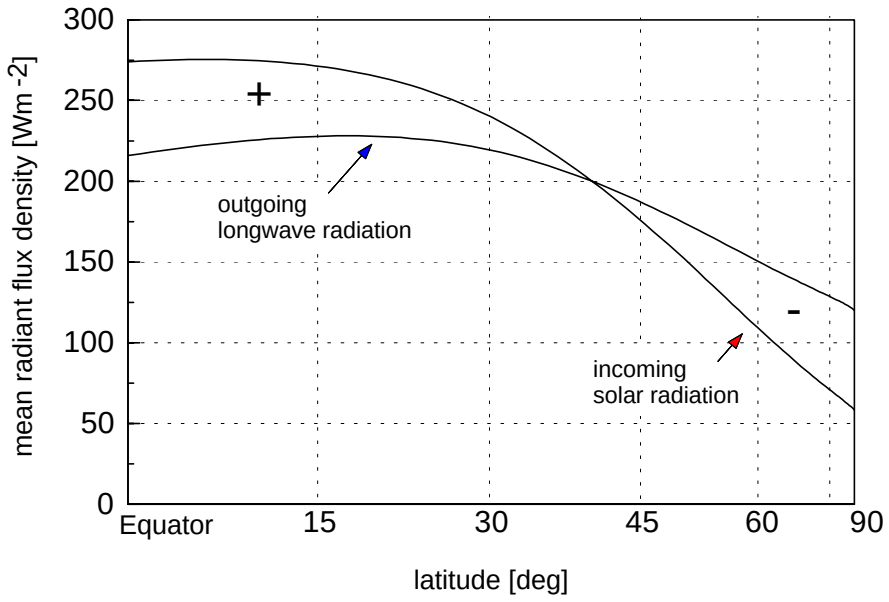

Fig. 11.2. Annual zonal mean estimates of absorbed solar radiation and outgoing longwave flux.