Climate Dynamics (NS-363-B) (test 1, 4 July 2012, 9:00-12:00)

In this test the symbols, if not explained, have their usual meaning. Answers may be given <u>Dutch or English</u>

Problem 1

FIGURE 1. High level layered (altostratus) clouds overlying non-layered (cumulus) clouds over the Wadden Sea and the island of Ameland (Netherlands) on 7 July 2011.

Which type of cloud, shown in the picture in figure 1, will most likely have a cooling effect on the climate near the Earth's surface? Why?

Problem 2

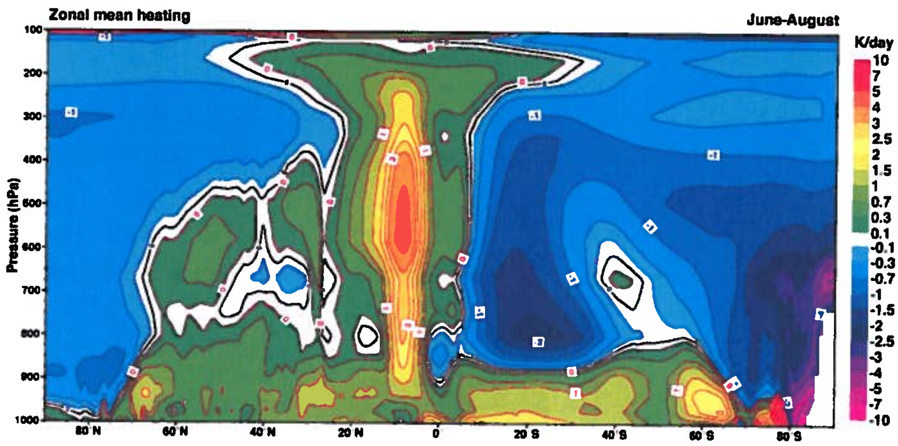

FIGURE 2. Zonal average diabatic heating rate in June, July and August as a function of pressure and latitude. The average is for the period 1979-2001.

(a) What is the reason for the strong diabatic heating (about 4 K per day) in the middle of the troposphere at approximately 10°N (figure 2).

(b) What is the reason for the strong cooling (about 2 K per day) in the sub-tropics of the southern hemisphere (around 20°S) at about 800 hPa (figure 2).

(c) What mechanism is the cause of the heating below 900 hPa at this latitude (around 20°S in figure 2)?

Problem 3

The long-wave optical path, δ, of a layer with thickness Δz in metres is given by

$$\delta = \kappa \Delta z .$$

Here, κ is the absorption coefficient.

(a) An absorption cross section, σ (units: m^2kg^{-1}), is frequently used in theory instead of an absorption coefficient. Write down the expression for δ in terms of σ.

(b) Assume that the layer contains one well-mixed greenhouse gas with a long wave absorption cross-section, σ=0.3 m^2kg^{-1}. The specific concentration, q, of this greenhouse gas is 400 ppmv. What is the optical depth for transmission of long-wave radiation of this layer if its mass per unit horizontal area is 1000 kg m^{-2}?

Useful equations are the following.

Hydrostatic equation: $\partial p/\partial z = -\rho g$.

Equation of state: $p = nkT$ or $p = \rho RT$. Here k is Boltzman's constant (=1.381×10^{-23} J K^{-1}), R is the specific gas constant and molecular number density, n (in units of m^{-3}). The specific gas constant for air is equal to 287 J $K^{-1}kg^{-1}$. The specific gas constant for the well-mixed greenhouse gas is equal to 188 J $K^{-1}kg^{-1}$.

Problem 4

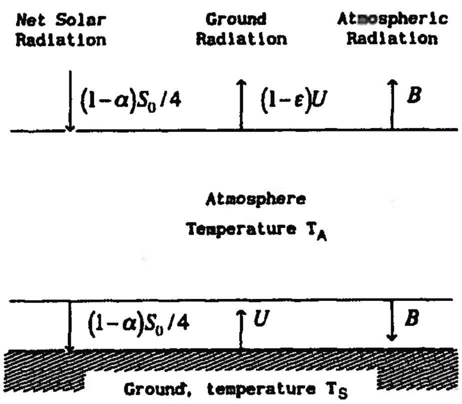

FIGURE 3. Simplified model of the climate system.

Let us adopt a single slab model of the Earth-atmosphere system (see figure 3). The parameter, α, is the albedo of the Earth's surface. The parameter, ε, is the emissivity of the atmosphere. The parameter S_0 is the Solar constant (=1366 W m^{-2}). The system is in radiative equilibrium.

(a) Derive an expression for the emission temperature, T_E of the Earth using Stefan-Boltzman's law, which states that the radiation emitted by a black body is proportional to the fourth power of the temperature of the emitting surface (constant of proportionality is σ=5.67·10^{-8} W $m^{-2}K^{-4}$). Assume that the earth is a black body.

(b) Derive an expression for the *back-radiation*, B (a measure of the strength of the greenhouse effect) in terms of σ, ε and T_E.

Problem 5

The vertical dependence of the density, ρ_v, of water vapour in the atmosphere can reasonably accurately be approximated by the following formula.

$$\rho_v = \rho_{g,v}\exp\left(\frac{-z}{H_v}\right)$$

Here $\rho_{g,v}$ is the density of water vapour at z=0 (the ground) and H_v is the so-called "scale height". During the Indian summer monsoon a typical value of $\rho_{g,v}$ is 0.024 kg m^{-3}. A typical value of H_v is 3000 m.

(a) How much precipitable water in the form of water vapour per square metre is contained in the atmosphere under such circumstances?

(b) Where does all this water vapour come from?