# Climate Dynamics (NS-363-B) (test 1, 17 April 2013, 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

Figures 1, 2 and 3 show, respectively, the net Solar radiation flux at the *top of the atmosphere* as a function of latitude and longitude averaged for the months of December, January and February, the net Solar radiation flux at the *Earth's surface* as a function of latitude and longitude averaged for the months of December, January and February, and the daily average *maximum insolation* as a function of month and latitude. What information in these figures would you use to make an estimate of the average planetary albedo in December, January and February? Why?

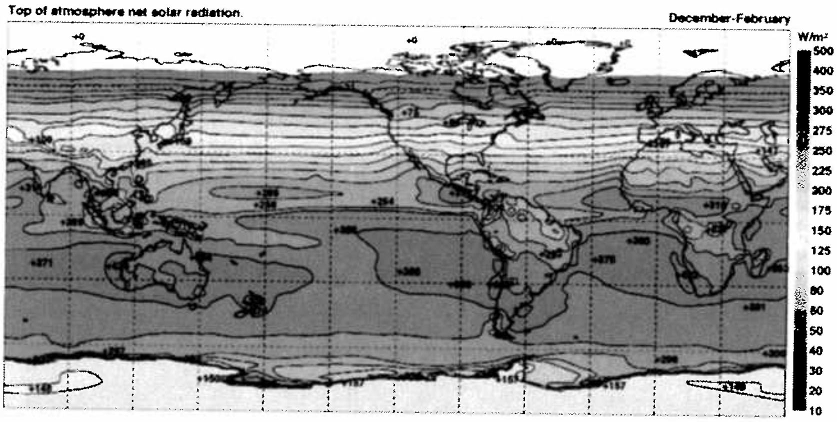


**FIGURE 1. Net top of the atmosphere fluxes of Solar radiation averaged for the period 1958-2002 for December, January and February (positive downwards). Labels in W m$^{-2}$.**

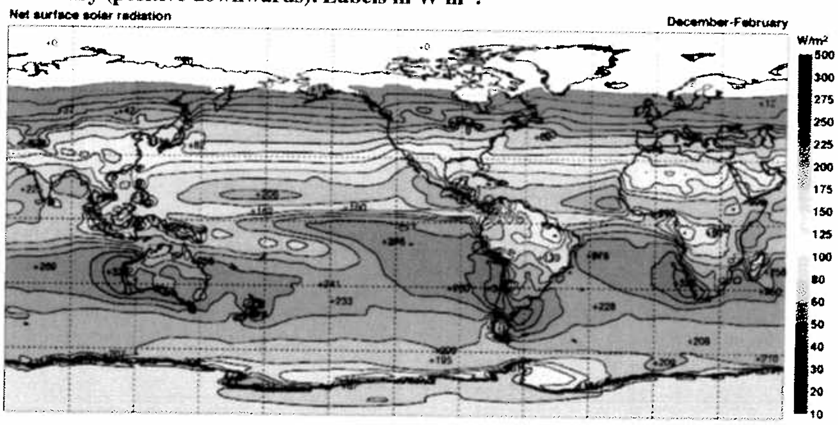


**FIGURE 2. Net fluxes of Solar radiation at the Earth's surface for the period 1958-2002 for December, January and February (positive downwards). Labels in W m$^{-2}$.**

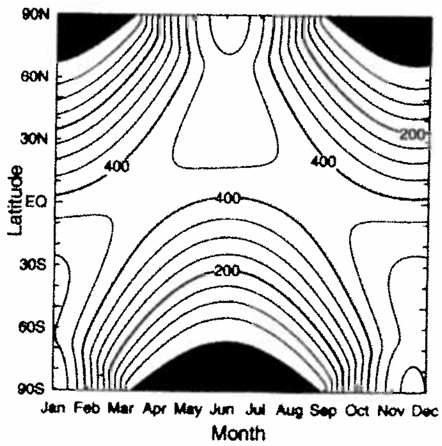


**FIGURE 3. Daily mean incident Solar radiation at the top of the atmosphere as a function of latitude and month. Labels in units of W m$^{-2}$. Contour interval is 50 W m$^{-2}$.**

## Problem 2

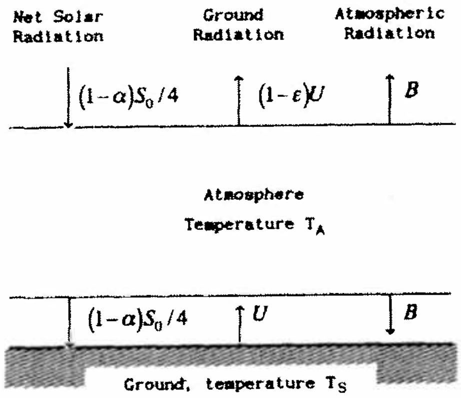


**FIGURE 4. Simplified model of the climate system.**

Let us adopt a single slab model of the Earth-atmosphere system (see figure 4). The parameter, $\alpha$, is the albedo of the Earth's surface. The parameter, $\varepsilon$, is the emissivity of the atmosphere. The parameter $S_0$ is the Solar constant (=1366 W m$^{-2}$). Assume that 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 $\sigma$=5.67·10$^{-8}$ W m$^{-2}$K$^{-4}$). Assume that the earth is a black body.

**(b)** Derive expressions for the temperature, $T_S$, of the Earth's surface and for the temperature of the atmosphere, $T_A$, in terms of $\varepsilon$ and $T_E$.

**(c)** Derive an expression for the *Outgoing Longwave Radiation at the Top of the Atmosphere (OLR-TOA)* in terms of $\sigma$, $\varepsilon$ and $T_S$, where $T_S$ is the surface temperature.

**(d)** Does climate-sensitivity at the Earth's surface to changes in incoming Solar radiation, according to the one-layer model, increase or decrease when $\varepsilon$ increases? Why?

## Problem 3

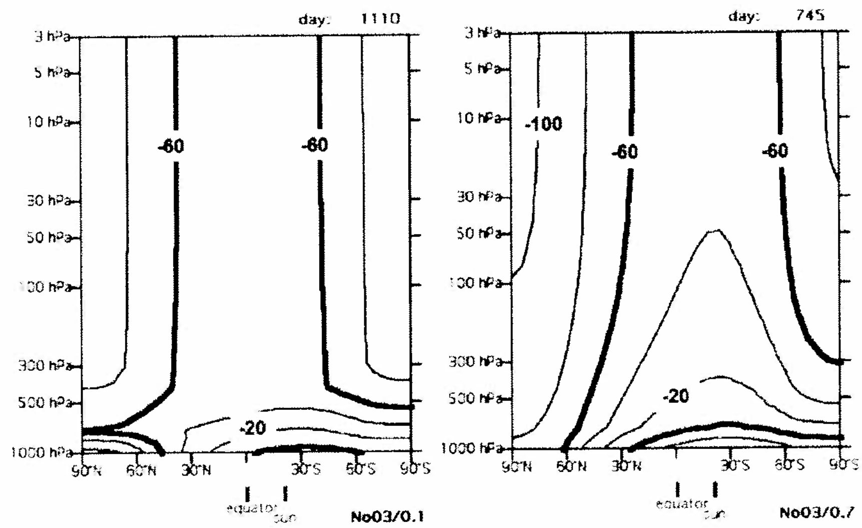


**FIGURE 5. Radiatively determined temperature as a function of latitude and pressure of a homogeneous atmosphere containing one well-mixed greenhouse gas and no ozone, on January 16, for $\varepsilon$=0.1 (left panel) and $\varepsilon$=0.7 (right panel) ($\varepsilon$ is the net atmospheric emission coefficient). Labels indicate temperature in °C. The Earth's surface radiates as a black body.**

Figure 5 shows the radiatively determined temperature on January 16 in two cases (see caption). Explain why the *upper* half (in terms of mass) of the atmosphere over the winter Polar cap is not or is hardly colder than the *upper* half of the atmosphere over the summer Polar cap, if $\varepsilon$=0.1, while the *lower* half (in terms of mass) of the atmosphere over the winter Polar cap is much colder than the *lower* half of the atmosphere over the summer Polar cap?

## Problem 4

The absorption length of visible (Sun-) light with wavelengths between 0.4 and 0.7 μm in water is 10 metres. What does this statement imply for the attenuation of radiation?

## Problem 5

Outgoing Long wave Radiation at the Top Of the Atmosphere ($I$) can reasonably well be approximated by the formula

$$I = I_0 + bT_S + cA_C,$$

where $A_C$ is the cloud cover fraction, $T_S$ is the temperature at the Earth's surface in °C(!!), and $I_0$, $b$ and $c$ are empirical constants. Budyko gave the following estimates of the values of these constants

$$I_0 = 226 \text{ W m}^{-2};\ b = 2.26 \text{ W m}^{-2}\,°\text{C}^{-1}..$$

The parameter, $c$, is (approximately) proportional to the temperature difference between cloud-top and the Earth's surface, i.e.

$$c \approx -1.7(T_S - T_C),$$

where $T_C$ is the cloud top temperature.

The equation that expresses the dependence of net absorbed Solar radiation (ASR) by the atmosphere and the Earth's surface on the two cloud parameters, the albedo, $\alpha_C$, of clouds ($\alpha_C$=0.45) and cloud cover cover fraction ($A_C$), is

$$\text{ASR} \equiv Q = \frac{S_0}{4}\left(1 - \alpha_C A_C - \alpha_G(1 - A_C)\right),$$

where $\alpha_G$, is the albedo of the Earth's surface (=0.1) and $S_0$ is the Solar constant (=1366 W m$^{-2}$).

For what range of values of the temperature difference between the Earth's surface and cloud top do clouds have a *warming* effect on climate?