## Climate Dynamics (NS 363B) (22 june 2008, 0900-1200)

**You may answer the questions either in Dutch or in English**

**In this test the symbols, if not explained, have their usual meaning.**

### 1 Planetary albedo

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. Which of these figures would you use to make an estimate of the average planetary albedo in December, January and February? Why?

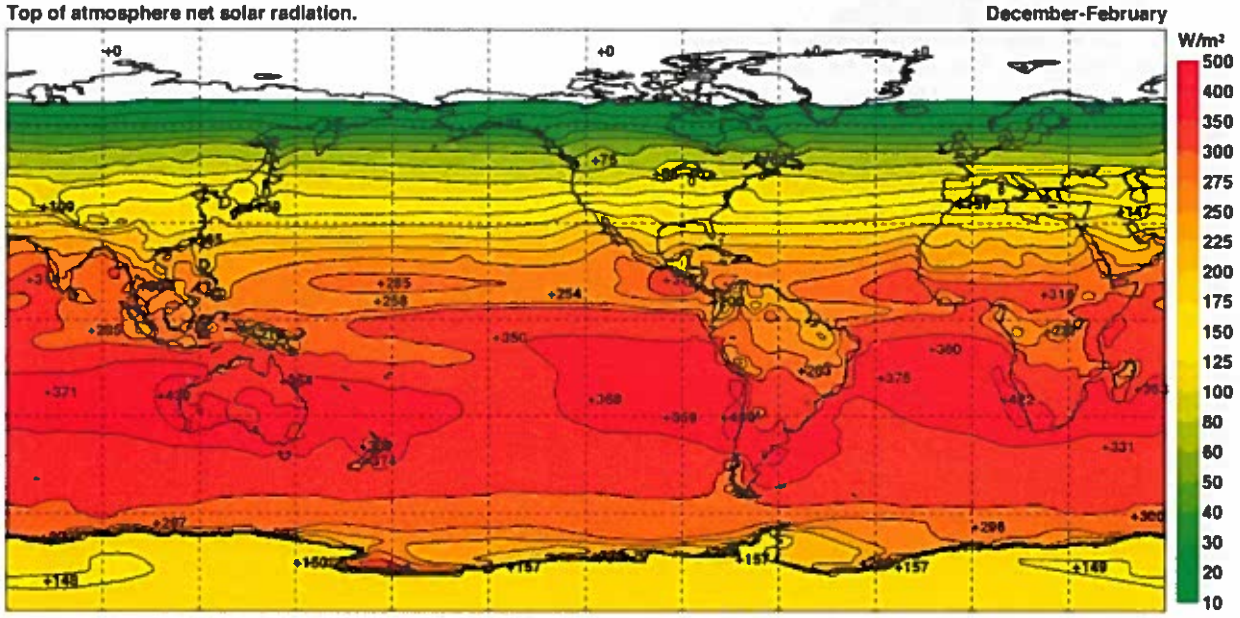


*Figure 1. Average net top of the atmosphere fluxes of Solar radiation in December, January and February (positive: downward). Labels in W m⁻².*

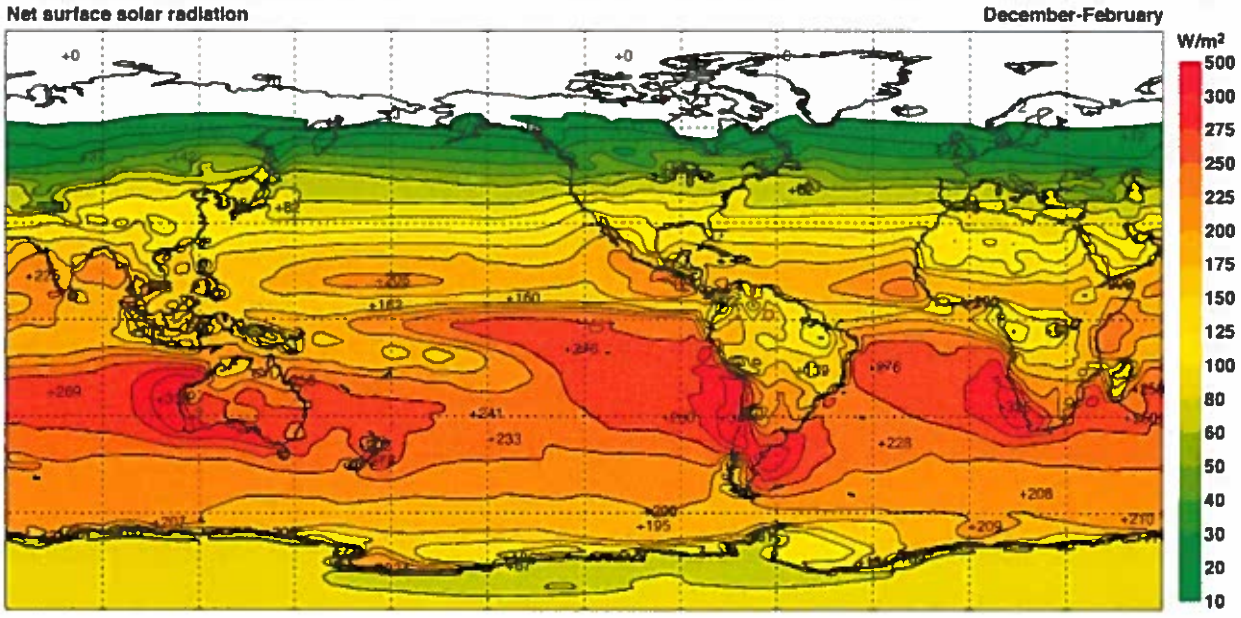


*Figure 2. Average net fluxes of Solar radiation at the Earth's surface in December, January and February (positive: downward). Labels in W m⁻².*

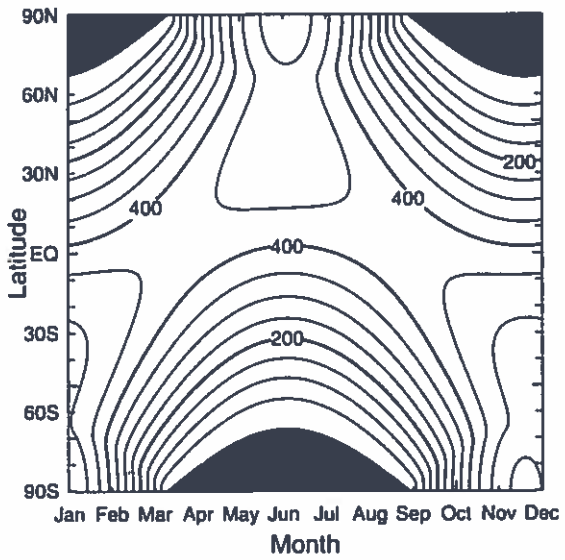


*Figure 3. Daily mean incident Solar radiation at the top of the atmosphere as a function of latitude and month. Labels in units of W m$^{-2}$. Contour interval is 50 W m$^{-2}$.*

## 2 Stratospheric cooling

In the past few decades a gradual cooling of the polar winter stratosphere has been observed. In which way could this be linked to the increase of greenhouse gas concentrations?

## 3 Ozone concentration

Explain why the ozone concentration in the lower stratosphere is highest poleward of ±60° latitude.

## 4 Water vapour distribution

The vertical dependence of the density, $\rho_v$, 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. How much precipitable water in the form of water vapour per square metre is contained in the atmosphere under such circumstances? Where does all this water vapour come from?

$PW = \rho_{g,v} \cdot H_v$

## 5 Clouds and climate

Explain why high clouds in Earth's atmosphere have a warming effect near the Earth's surface, whereas low clouds have cooling effect near the Earth's surface.

## 6 Thermohaline circulation and climate

In the Stommel model of the thermohaline ocean circulation, the ocean is represented as two reservoirs of well-mixed water connected by "pipes" (see the figure below).

(Taylor, 2005)

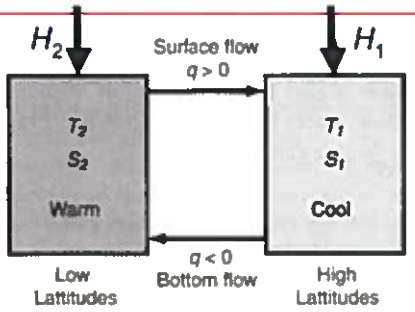


**Fig. 11.6**
A two-box model of the ocean circulation. The temperatures $T_1$ and $T_2$ are fixed so the principal variable is the salinity, $S$.

The two reservoirs represent the polar and equatorial regions of the ocean at temperatures $T_1$ and $T_2$ (fixed for simplicity).The principle variable is the salinity of the water, $S$, which is affected by a "virtual" flux $H$ of salt from the atmosphere. The flow of water $q$ between the boxes is proportional to the density difference. Conservation salt is expressed by

$$\frac{dS_1}{dt} = H_1 + |q|(S_2 - S_1)$$

$$\frac{dS_2}{dt} = H_2 + |q|(S_1 - S_2)$$

The flux is given by

$$q = \frac{k}{\rho_0}(\rho_1 - \rho_2)$$

$k$ is an unknown coefficient with the dimension [$s^{-1}$]. The equation of state for sea water is (approximately)

$$\rho = \rho_0(1 - \alpha T + \beta S)$$

$\alpha$ (>0) is the thermal **expansion** coefficient; $\beta$ (>0) is the haline **contraction** coeffient. Therefore

$$q = \frac{k}{\rho_0}\Delta\rho = k(\alpha\Delta T - \beta\Delta S), \text{ with } \Delta T = T_2 - T_1;\ \Delta S = S_2 - S_1$$

The atmosphere-ocean salt flux can be prescribed as follows

$$H_2 = -H_1 = H > 0$$

(a) Why is $H$>0?

(b) How many steady state solutions does this model have for fixed parameter values? 3

(c) Which of these steady state solutions represents a salt driven circulation. $\Delta S > \Delta T$

(d) Demonstrate that this salt driven steady state circulation is stable to small perturbations.

(e) Is the present day Atlantic thermohaline circulation salt driven? no

(f) In which way is the Atlantic thermohaline circulation relevant for the climate on Earth.