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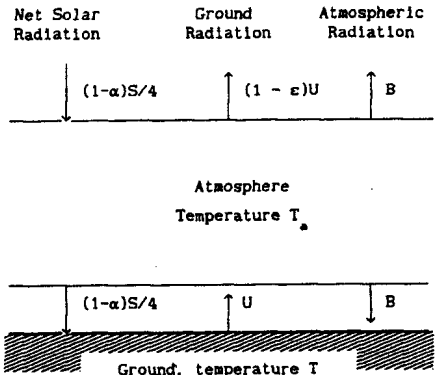
In 2005/2006, the course NS-MO429 was given by R.S.W. van de Wal.

Climate Dynamics (NS-MO429)
2 februari 2006

Question 1

Let us adopt a single slab model of the earth-atmosphere system (see the figure). The parameter, α, is the albedo of the earth. The parameter, ϵ, is the emissivity of the atmosphere.



a) Derive an expression for the bolometric temperature (also called 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) Show that, in radiative equilibrium,

$$T_{a0} = \left(\frac{\epsilon}{2-\epsilon}\right)^{\frac{1}{4}} T_e$$

where the subscript 0 denotes the equilibrium state.

c) If the emissivity, $\epsilon = 0.5$, show that in radiative equilibrium $\frac{T_{a0}}{T_{g0}} = \frac{1}{\sqrt{2}}$

d) Now, suppose that for some reason the atmospheric temperature is disturbed slightly away from the radiative equilibrium such that $T_a = T_a \Delta T_a$, with $\Delta T_a \ll T_{a0}$. Derive an approximate expression [1] for the time-rate of change of ΔT_a in terms of T_{a0} and ΔT_a. Assume that $\frac{c_p p_s}{g}$ is the thermal capacity of an atmospheric column of unit cross-sectional area. Here p_s is the pressure at the earth's surface; c_p is the specific heat at constant pressure (= 1004 J K^{-1}kg^{-1}), and g is the acceleration due to gravity.

e) According to the expression derived in (d) the temperature perturbation decays exponentially towards zero with a timescale called the radiative equilibrium timescale. Give an estimate in days of this timescale for the earth's atmosphere.

Question 2

Stable isotopes are widely used in paleoclimatology.

a) Explain why stable isotopes are used in paleoclimatology.

[1] Use the following approximation of Taylor's formula:// $f(x) \cong f(x_0) + (x - x_0) f'(x_0)$

b) Explain the difference in the physical interpretation of marine benthic isotopes and isotopes in an ice sheet?

c) Explain how the benthic isotopes and ice core isotopes are related and provide typical values for the present-day climate and during the Last Glacial Maximum.

d) Sketch the $d^{18}O$ value over the last 50 kyr for an ice core from Antartica, one from Greenland an a marine benthic core and explain the differences.

Question 3

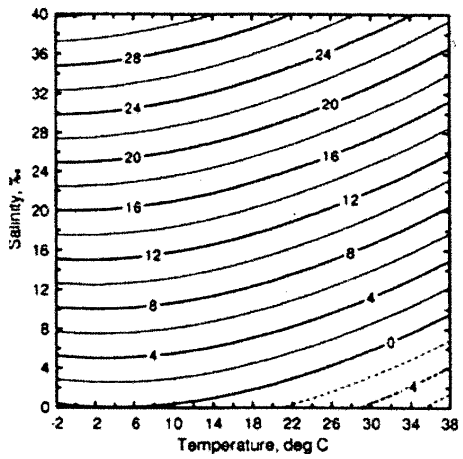
What dynamical process is taken into account (in parametrized form), next to in- and outgoing radiation, in the one-dimensional energy-balance model introduced first by Budyko and Sellers?

Question 4

Describe in words the global thermohaline circulation and explain what role it plays for the climate

Question 5

Estimate from the figure below the initial and final density of a kilogram of water that starts in the tropics with a temperature of 28 °C and a salinity of 35‰and flows on the surface in the Gulf stream to the Norwegian Sea, where it arrives with a temperature of -1 °C. Assume that the water conserves its salinity on its way and loses heat by sensible heat transfer.



Contours of seawater density anomalies ($\rho_t - 1000$ kg m^{-3})

Question 6

Explain what is meant by a Heinrich event and give a possible mechanism that involves the ocean circulation. What can be learned from the (simple) Stommel box model to explain Heinrich events?