2e Toets Klimaatdynamica 27 Juni 2011 9-12

1. Ocean and Climate

An "iconic", but very simple, model of the thermohaline ocean circulation in a hemisphere is a model due to Stommel, which was later simplified by Taylor. This model assumes that an ocean consists of two reservoirs: a high latitude reservoir (1) and a low (subtropical) latitude reservoir (2). The water temperatures (T) and salinities (S) in both reservoirs are T_1, T_2, S_1, and S_2 (see the figure below). The flux of water between the two reservoirs is q at the surface and $-q$ at great depths, where q is positive if water is transported from reservoir 2 to reservoir 1. The salinity is affected by a "virtual" flux, H, of salt from the atmosphere. H is positive if salt is transported from the atmosphere to the ocean, i.e. if evaporation exceeds precipitation.

(Taylor, 2005)

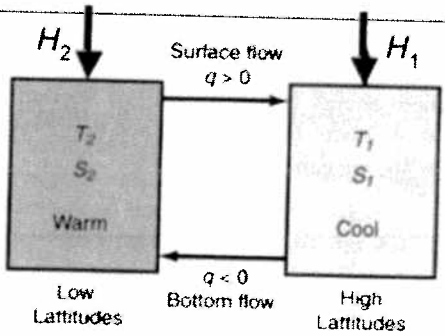

Fig. 11.6
A two-box model of the ocean circulation. The temperatures T_1 and T_2 are fixed so the principal variable is the salinity, S

Conservation of salt is expressed as

$$\frac{dS_1}{dt} = H_1 + |q|(S_2 - S_1); \quad \frac{dS_2}{dt} = H_2 + |q|(S_1 - S_2). \qquad (1)$$

The flux, q, is given by

$$q = k(X - Y),$$

where k is a constant and where

$$X \equiv \alpha(T_2 - T_1) \equiv \alpha\Delta T \text{ and } Y \equiv \beta(S_2 - S_1) \equiv \beta\Delta S,$$

where α is the thermal expansion coefficients and β is the haline "contraction" coefficient (α and β are both positive). Assume (following the simplification by Taylor) that X (i.e. the temperature contrast) is fixed or given.

(a) Reduce the system of two equations (1) to one equation for the time rate of change of Y. Assume that $H_2 = -H_1 = H > 0$.

(b) Suppose that at some point, due to an increase in the net salt flux,

$$H > \frac{k\alpha^2 \Delta T^2}{4\beta}.$$

How many different steady states does the system possess in this case, assuming that the low latitude reservoir is always saltier than the high latitude reservoir, consistent with a positive value of H?

(c) Analyze the linear stability of this or these steady state(s).

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

2. Sea Level Rise

The change in melt (ΔAbl) on a circular Greenland ice sheet depends strongly on the temperature (ΔT) via the following equation:

$$\Delta Abl = a\Delta T^2 + b\Delta T + c$$

Accumulation changes (ΔAcc) are approximated by:

$$\Delta Acc = c + \Delta T^{\beta}$$

and the surface profile (H) is a function of radial position (r):

$$H = \gamma\sqrt{r}$$

You may use the following constants:

$a = 1\ (m^3/K^2)$, $b = 2.41\ 10^{11}\ m^3/K$, $c = 10^{10}\ m^3$, $\beta = 2$, $\gamma = 0.44\ m^{0.5}$,

$A_{ocean} = 3.62\ 10^{14}\ m^2$

a. Give a physical justification for each of the three equations postulated above.

b. Calculate the contribution to sea level rise over a period of 50 years if the temperature increases instantaneous by 2K.

c. Calculate the change in radius of the ice sheet if the initial ice sheet equals 7 m of equivalent sea level. Explain why the change is small.

d. Estimate the sea level rise near Sydney, Australia due to the melt from Greenland as calculated under c and explain your answer.

e. Which other processes effect local sea level change, mention and explain briefly at least 4 others.

3. Paleo Climate

a. Which mechanisms explain the evolution of climate over the last 500 Myrs? Explain them briefly.

The waxing and waning of ice sheets in the Northern Hemisphere dominate climate over the last 3 Myr.

b. How do we usually explain this?

c. Sketch a power spectrum of ice volume over the period 2-3 Myr before present, and one over the last Myr. Explain the differences in the two spectra.

d. Explain from a meteorological perspective why ice ages have a so-called saw teeth character.

We know a lot about the climate of the last 1 Myr from ice cores.

e. Mention at least three key points and provide a short explanation.

f. What are the main remaining scientifical challenges in our understanding of the climate system over the last 1 Myrs?

4. Stable isotopes

Variations in stable isotopes ($\delta^{18}O$) are caused by fractionation. If we consider the isotopes in an ice core we can estimate the relation between temperature and isotopes if we make a few simple assumptions.

-Raleigh fractionation and mass conservation of isotopes.
-isobaric cooling evaporation at 20°C, condensation at 0°C.
-linear relation for fractionation coefficient with temperature.

a. Derive an equation for the change in $\delta^{18}O$ of ice for a temperature change based on the postulated assumptions.

b. Explain what the change in the seasonal cycle of the precipitation over time implies for the interpretation of the isotope record of an ice core.

The interpretation of the benthic $\delta^{18}O$ record in a marine sediment core depends on ice volume changes and temperature changes.

c. Formulate an expression for the change in $\delta^{18}O$ in a marine core taking ice volume changes into account.

Assume a change of 10 degrees in the atmosphere during the transition from an interglacial with no ice to full glacial conditions. During interglacial conditions the $\delta^{18}O$ value for the marine core is zero per mille and for the ice core an interglacial value of -35 per mille may be used.

d. Calculate the change you will observe in the benthic $\delta^{18}O$ of a representative marine core.

e. Compare your finding to the change of the $\delta^{18}O$ in an ice core and explain your finding.