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In 2005/2006, the course NS-MO427 was given by J. Oerlemans.

Ice and Climate (NS-MO427)
30 januari 2006

Question 1

Glaciers in the Alps are temperate: the ice temperature is at the freezing point everywhere in spite of the fact that the annual mean air temperature is well below 0°C.

a) How is this possible?

In the (sub)polar regions cold ice sheets are the rule.

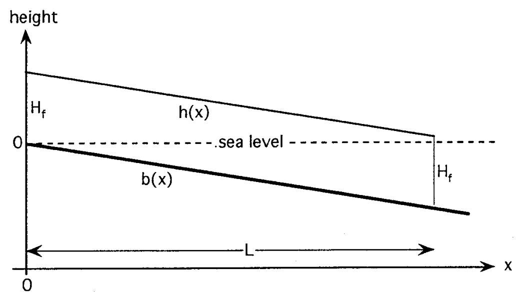
b) Which processes determine the temperature distribution in a polar ice sheet?

Question 2

We consider the response of a calving glacier with length L to climate change. The width and thickness of the glacier as well as the accumulation rate a do not depend on x (see figure). The glacier rests on a bed with a constant and small slope, given by

$$b(x) = -sx$$

So the highest point of the glacier bed is just at sea level. The volume of the glacier is denoted by V. The ice thickness (H_f) is determined by the flotation criterion at the glacier front. The ratio of water density to ice density is δ. The calving rate is proportional to the water depth at the glacier front (constant of proportionality c, with dimension [yr^{-1}]).



a) Formulate a continuity equation for this glacier $\frac{\mathrm{d}L}{\mathrm{d}t} = \ldots$

b) Solve for the equilibrium glacier length. What is the sensitivity of the normalized glacier length for changes in the accumulation rate?

c) When the glacier grows and gains height, it may capture more snow. We model this as $\dot{a} = \dot{a_0}\sqrt{\frac{L}{L_0}}$; where L_0 is a reference length. For this case, solve once more for the equilibrium glacier length. Is the glacier now more or less sensitive to the accumulation rate?

Question 3

The surface albedo of a glacier is a very important parameter with respect to the energy balance. It can be determined from radiance measurements done by satellites. Describe which steps have to be taken to convert an optical satellite image (e.g. Landsat, NOAA-AVHRR) into an albedo map?

Question 4

The earth crust may be considered as an elastic plate lying on a viscous mantle with density ρ_m. A load $q(x)$ can be opposed by buoyant forces and the elastic strength (rigidity) of the crust. The balance of forces reads

$$D\frac{\mathrm{d}^4\zeta(x)}{\mathrm{d}x^4} + \rho_m g\zeta(x) = q(x)$$

where D is the flexural rigidity of the Earth crust, and $\zeta(x)$ the vertical displacement of the crust with respect to a reference state.

a) Find an expression for the displacement $\zeta(x)$ when the load is periodical, i.e. $q(x) = q_0 \sin(\frac{2\pi x}{\lambda})$. What is the amplitude of the displacement?

b) Loads with an infinitly large wavelength λ are totally supported by buoyancy and not by rigidity of the crust (pure isostatic equilibrium). Loads with a very small wavelength are entirely supported by rigidity of the surface. Determine the amplitude for λ = infinite, and give an expression for the ratio of the amplitude for λ = infinite and the amplitude found in (a).
If $\rho_m = 3300$ kg m^{-3}, $g = 9.81$ m s^{-2} and $D = 2\ 10^{23}$ N m^{-2}, calculate for which wavelength 50% of the load is supported by rigidity of the crust.

c) Glacial erosion is very effective. In regions where large amounts of sediments are removed, there will be isostatic compensation by lifting of the crust. Can you make a theory that explains the widespread occurrence of fjord/mountain landscapes at the periphery of frequently glaciated areas?

Question 5

Glacial cycles are characterized by a slow build-up of ice volume and a relatively fast decrease. Can you describe a few processes that accelerate the decay of big ice sheets and the return of a glacial climate to interglacial conditions?