Examination **ICE AND CLIMATE 2012/13 (28 January 2013, 14h^{00} – 17h^{00})**

1.

A simplified expression for the energy balance M at a melting glacier surface can be written as (fluxes towards the surface are positive):

$$M = (1-\alpha)Q - \varepsilon_s \sigma T_s^4 + \varepsilon_a \sigma T_a^4 + k(T_a - T_s)^2$$

In this expression α is the albedo, Q the incoming solar radiation, T_s the surface temperature, T_a the air temperature at a certain height, k a turbulent exchange coefficient, σ the Stefan-Boltzmann constant ($5.67 \cdot 10^{-8}\,\mathrm{W\,m^{-2}\,K^{-4}}$). The effective emissivities of the surface and the atmosphere are denoted by ε_s and ε_a, respectively. The last term in the equation describes the turbulent sensible heat flux due to the presence of katabatic flow.

a. On a summer day with significant melting we have $T_a > T_s$. In spite of this, the net longwave balance is often negative. Can you explain this?

b. By carrying out a perturbation analysis, find an expression for the sensitivity of M to a small change in air temperature (T_a'). Assume that $T_a' << T_a$.

c. On a warm summer day we have $T_a = 285\,\mathrm{K}$. If the air temperature now increases, both the net longwave balance and the turbulent heat flux increase. Which process is more important? [model parameters: $\varepsilon_a = 0.7$, $k = 0.5\,\mathrm{K^{-2}\,W\,m^{-2}}$]

2.

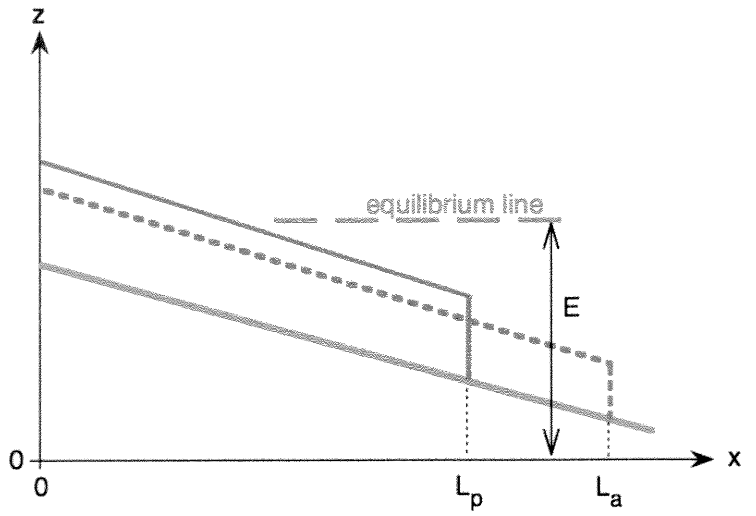
a. The orientation of crystals in an ice sample can be summarized in a so-called Schmidt-diagram. What does this diagram show? Draw a schematic Schmidt-diagram for ice in the centre of a large ice sheet; consider two cases: (i) ice close to the surface, (ii) ice near the base of the ice sheet.

b. The ice viscosity A in an ice sheet show significant variations. What are the most important factors that determine these variations? Where in an ice sheet do you expect the largest values of A ? How will this affect the vertical velocity profile due to deformation?

3.

Some glaciers surge at more or less regular intervals. During a surge ice velocities increase strongly, and the glacier front advances rapidly. It is believed that surges of temperate glaciers are associated with changes in the hydraulic system of a glacier. During a surge the efficiency of the system is insufficient to evacuate all meltwater, which results in pressurised water-filled cavities facilitating rapid sliding. Moreover, increased sliding velocity implies more frictional heating and additional production of meltwater.

To study this effect we consider a simple glacier of constant thickness H and constant width W resting on a bed with constant slope s (see figure below). The bed is given by $b(x) = b_0 - sx$. The glacier length before a surge is L_p, after the surge $L_a = \lambda L_p$. The total frictional heating can now be estimated from the loss of potential energy due to the surge.



a. Find an expression for the total frictional heating (dissipation) D during the surge. Denote ice density (constant) by ρ en the acceleration of gravity by g. Assume that ice volume is conserved.
b. Calculate the production of meltwater (total depth of water layer averaged over the glacier) if the glacier in pre-surge state is 20 km long, 5 km wide, 300 m thick, and has a slope of 0.05. The 'surge parameter' λ is 1.1; use standard values for ρ and g. The latent heat of fusion is 334 kJ kg^{-1}.

4.

An approximate force balance for a slab of ice in a flowband of width W of an ice sheet - ice shelf system can be written as

$$\frac{\partial}{\partial x}(2HW\bar{\tau}'_{xx}) + (\tau_{y2} + \tau_{y1})H + \tau_b W = -\rho g H \frac{\partial h}{\partial x} W$$

a. Explain what the terms in this equation represent.
b. Simplify this equation for a freely floating ice shelf of constant width and relate the longitudinal stress deviator to the ice thickness (water density is ρ_w). Denote the ice thickness and longitudinal stress at the grounding line by H_0 and $\bar{\tau}'_{xx,0}$.
c. Next consider a situation in which an ice shelf is confined and side drag dominates the force balance. Find an expression for the ice-sheet profile $H(x)$. The ice velocity at the grounding line is U_0.
d. In recent years large ice shelves have been broken up in the Antarctic Peninsula (Larsen Ice Shelf). Can you give an explanation for this rapid break-up ?