Examination **ICE AND CLIMATE, 1 February 2011**

1. The surface albedo of a glacier surface varies strongly in time and space.

a. Give a brief description of the factors that determine this variability and give some characteristic albedo values.

b. A snowfall event always makes the net mass balance of a glacier more positive. In which time of the year is snowfall most effective?

c. It is possible to map the albedo from satellite images? What are the typical problems that have to be handled?

2. The orientation of crystals in an ice sample can be summarized in a so-called Schmidt-diagram.

a. What does this diagram show ? Draw a schematic Schmidt-diagram for an ice core from a large ice sheet; consider two cases: (i) ice close to the surface, (ii) ice near the base of the ice sheet.

The simplest mode of ice flow is pure shearing flow. In this case the shear stress is given by $\tau_{xz} = (H - z)\rho g s$, where H is the ice thickness, z height above the bed, ρ ice density, g gravity and s surface slope (small). In the absence of other stress deviators, Glen's law, relating du/dz to the shear stress, takes a simple form. Suppose that the viscosity depends linearly on z: $A = A_0 + \gamma(H - z)/H$.

b. Do you expect γ to be positive or negative? Motivate your answer.

c. Calculate the velocity profile $u(z)$ with Glen's law (suppose that all stress deviators except τ_{xz} are zero).

3. The macroscopic thermodynamic equation for a medium like ice or snow can be written as:

$$\frac{\partial T}{\partial t} = -v_i \frac{\partial T}{\partial x_i} + \frac{\partial}{\partial x_i}\left(K \frac{\partial T}{\partial x_i}\right) + \frac{\dot{\varepsilon}_{ij}\tau_{ij}}{J\rho c_p} + \frac{L_m}{\rho c_p}\dot{m}$$

a. Explain which processes are represented by the various terms.

Next we consider the steady-state temperature distribution in a two-layer system: a layer of snow of uniform thickness d_1 and thermal diffusivity K_{snow} overlying a layer of glacier ice of uniform thickness d_2 and thermal diffusivity K_{ice}. There is no flow or creep. The surface and bottom temperature of the system are denoted by T_s and T_b, respectively ($T_s < T_b < 0$ °C). The temperature at the snow-ice interface is denoted by T_{int}.

b. Simplify the thermodynamic equation for this case (write $x_3 = z$; now positive downwards), and express T_{int} in terms of T_s and T_b. Make a qualitative sketch of the temperature profile $T(z)$ in the ice-snow system.

c. In a thick snowpack the density, and as a conseqeunce also the thermal diffusivity, increases with depth. Find $T(z)$ in the snow pack for the case that $K_{snow} = K_0 + K_1 z$. Make a sketch of $T(z)$.

4. A first-order description of the shape of a perfectly plastic ice sheet can be obtained from the assumption of perfect plasticity, implying that (in polar coordinates) $-\rho g H \, \partial h / \partial r = \tau_0$ (g is the gravitational acceleration, ρ is the ice density, H is the ice thickness, h is the surface elevation, τ_0 is the yield stress; note that $\partial h / \partial r$ is always negative).

a. Derive the shape of the ice sheet, assuming local isostatic adjustment of the bed (mantle density is ρ_m). Assume zero ice thickness at the ice-sheet edge (i.e. at $r = R$).

b. Find an expression for the characteristic volume time scale of the ice sheet (suppose that the balance rate $\dot{a}$ is a positive constant).

5. The built-up and decay of ice sheets on the Northern Hemisphere (NH) continents has been a typical feature of the climate system during the last few million years (the Pleistocene).

a. Is this related to the configuration of the continents? What changes do you expect if the NH continents would be located more southward? And what if they would shift to the north?

b. Once an ice sheet attains a large size several processes tend to destabilize the ice mass. Can you describe these processes?