Thermodynamics of Glaciers

Exercise

1 Climate history

Air temperatures in Alaska was oscillating with a period of about 50 years and an amplitude of about 2 °C between 1950 and 2000.

Question How deep down would you be able to detect such temperature variation in stagnant ice if the accuracy of your temperature sensors are 0.02 K assuming an ice temperature of $-3°$ C?

2 Cold content

Carl decided that snow is much more interesting than glacier ice. On a sunny morning in late March somewhere outside of Fairbanks, he measures the temperature profile in the snow pack after a cold night (Figure 1). During the day air temperatures increase above the freezing point and it starts raining. The cold content can be eliminated by release of energy from refreezing water.

Question How much melt in mm w.e. (water equivalent) or kg/m^2 is needed to completely eliminate the cold content? Hint: Make a reasonable guess for an anverage snow density.

3 Melting temperature depression

What is the pressure melting temperature at the base of Gornergletscher (Figure 2)? What does the Clausius-Clapeyron relation indicate in terms of air-saturation of the meltwater? The pressure p is the sum of the hydrostatic pressure and the atmospheric pressure, $p = \rho g H + p_{\text{atm}}$. Assume $p_{\text{atm}} = 75\,\text{kPa}$.

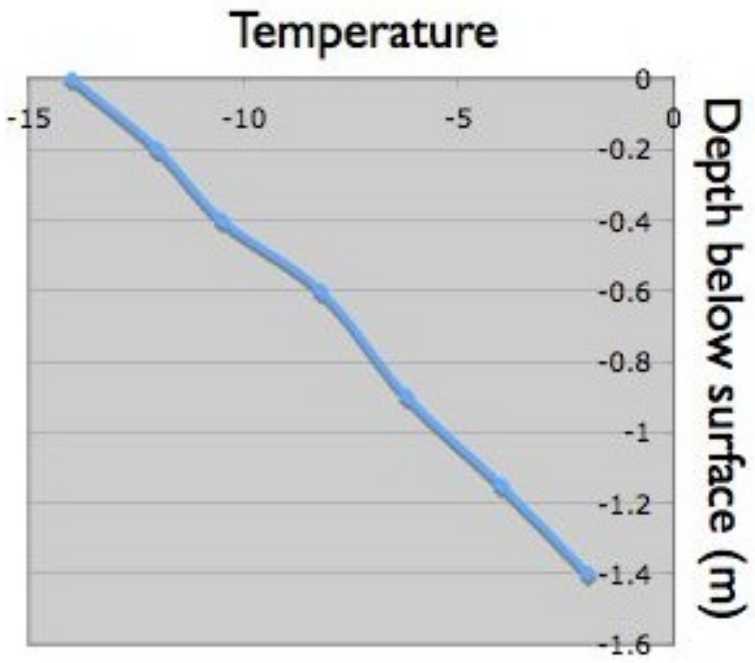

Figure 1: Snow temperature profile

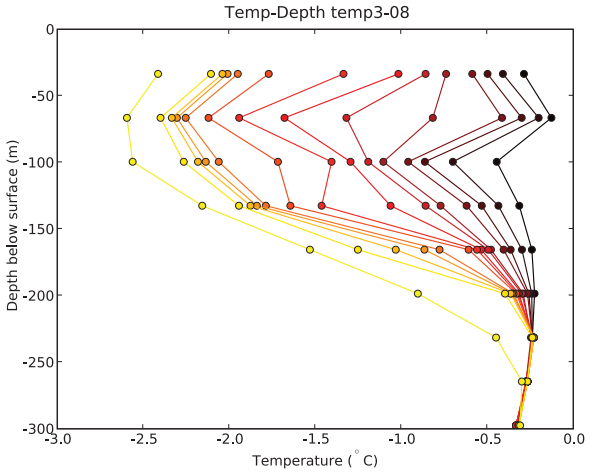

Figure 2: Cooling of a borehole drilled in the confluence area of Gorner-/Grenzgletscher. Temperatures measured every day after completion of drilling are shown in increasingly lighter colors, and after three months (leftmost yellow curve). Data from Ryser (2009).

4 Lake Vostok

1. Describe 2 different ways how heat can be moved through a polar ice sheet.
2. What is the Péclet Number, and how is it useful?
3. The coldest temperature ever recorded is -89° C at Vostok in East Antarctica (in July 1983). The mean annual temperature is -55° C. However, deep under the ice is lake Vostok, a lake of the size of lake Ontario. Calculate the minimum geothermal flux needed for a lake to form. Possibly relevant quantities:
   - Surface elevation 3488 m
   - Ice thickness 3300 m
   - Snow accumulation rate $2\,\mathrm{cm\,a^{-1}}$ (water equivalent)
   - A reasonable average thermal conductivity for the cold temperatures of the East Antarctic Ice Sheet is $k = 2.5\,\mathrm{W\,m^{-1}\,K^{-1}}$.

References

Ryser, C. (2009). *The polythermal structure of Grenzgletscher, Valais, Switzerland.* Master thesis, ETH Zurich.