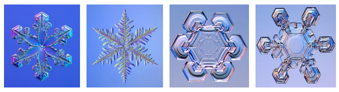

Written exam, 31.01.2025, 09:15 – 11:15, CE 1 106, (120 min); total: 60 Points

Instructions / Rules / Information:

Open book exam - permitted resources and tools: course slides, personal notes, exercises and solutions, pocket calculator. Personal laptop/tablet **exclusively** for browsing the slides, your notes, and any other course material of this class. The use of smartphones is not authorized. Any type of communication and exchange (e.g., phone, SMS, chat, email, etc.) is NOT allowed and considered as cheating. Rules are enforced according to the 'Internal directive concerning examinations at EPFL', LEX 2.6.1, Article 6.
Each question has a point value (shown in red, "**X P**") and an **indicative** time for answering (shown in blue, "**X min**"). The small red circles ° in the questions indicate the distribution of points. Please use a black or blue ball-pen for writing. Provide the correct/appropriate units of your results where applicable. Document intermediate steps leading to your final answer. In case of questions, give a sign; exam supervisors will assist.

→ Please answer Questions 1-2, Questions 3-4, and Question 5, respectively, on separate sheets.
→ Please write your name on all sheets you return.

Good luck ! *Hendrik, Michi, Grégoire, Yael, Liza, Francesca, Adrien*

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Values of variables or constants to be used:

- Specific heat capacity of ice — 2.11e3 J kg^{-1} K^{-1}
- Latent heat of fusion of ice/water — 3.34e5 J kg^{-1}
- Thermal conductivity of snow — 0.3 W m^{-1} K^{-1}
- Extinction coefficient of old snow — 10 m^{-1}

1. Energy balance (17 P – 34 min)

A 40 cm deep homogeneous snowpack has a temperature of -10°C at the surface and -2°C at the base. The density of the snow is 308 kg m^{-3} and the albedo is equal to 0.76.

(a) Calculate the conductive heat flux at the snow surface assuming a liner temperature profile. °°

(b) Assume a constant net radiation of 50 W m^{-2} and a constant heat loss via the sum of the turbulent heat fluxes of 34 W m^{-2} at a given reference time. Calculate (approximatively) the temperature of the top 1 cm of the snowpack after one hour. °°°

(c) Why is the calculation only approximative? Give at least 3 reasons. °°°

(d) A radiometer at the base of the snowpack measures a downward shortwave radiation flux of 3 W m^{-2}. What is the corresponding incoming SW radiation at this moment? °°°

(e) Now assume the snowpack was only 2cm deep and isothermal at 0°C. After 8h of sunshine all snow has melted. Calculate the corresponding mean net heat flux that led to the melting of the snow. °°°

(f) When comparing the calculated mean net heat flux from (e) to the magnitude of the net radiation in (b), which other heat flux contributions are included but neglected in (e)? Assume a daytime mean air temperature of $T_a >> 0$°C. °°°

2. Snow microstructure and metamorphism (8 P – 16 min)

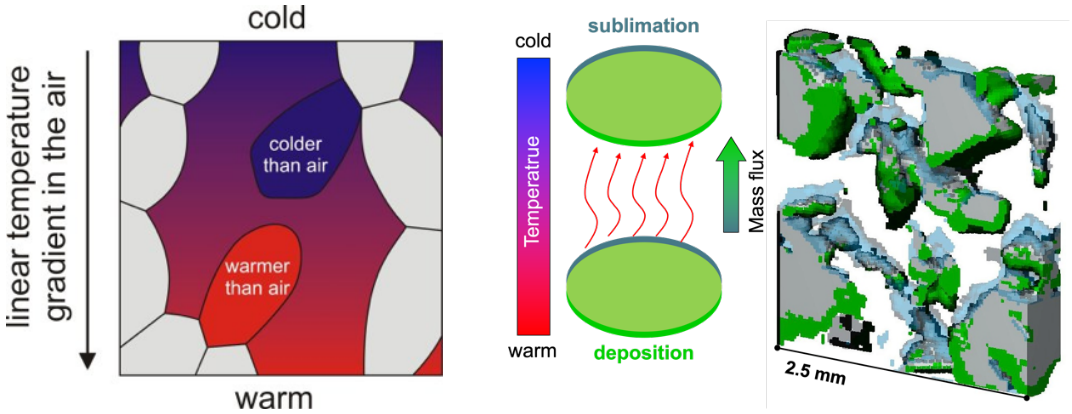


Figure 1.

Consider the schematics of a small volume in a snowpack given in Figure 1. Briefly explain and discuss:

(a) the effective thermal conductivity, °°°

(b) water vapor dynamics, °°

(c) the relative age of the ice composing an ice grain. °°°

3. Blowing snow sublimation and isotopes (20 P – 40 min) [*please answer questions 3 and 4 on a separate sheet*]

Assume, you are in the complex terrain of Flüelapass and under strong wind conditions from the South (Föhn). It is afternoon and the wind transports blowing snow particles from the sun-exposed south-eastern part of the pass towards the frozen Lai da la Scotta (lake), which is in the shade (see Figure 2 for the topography).

(a) Name the phase change process that is impacting the mass of snow grains in the blowing snow cloud and say how this process influences temperature and humidity. °°°°

(b) As the cloud moves into the shade, things may change; describe how the phase change may change and what that means for the mass of the grains as well as for temperature and humidity. °°°°

(c) Name the type of fractionation that happens in the situations described above and whether situation a) or b) leads to stronger fractionation. °°°

(d) Let's assume (pretty crazy) the gulf stream shuts down because of climate change and President Trump moving Greenland towards the American continent. Europe falls into an ice age and a new glacier forms on Flüelapass, at the place the blowing snow cloud from b) has finally deposited on the edge of Lai da la Scotta. 20'000 years later, a scientist takes an ice core at this location and analyzes the isotopic composition of the very crystals (molecules) that had settled there 20'000 years earlier. If this scientist does not know about blowing snow fractionation, would they over- or underestimate the temperature of the age of snow deposition (our time)? Name the reason. °°°°

(e) Figure 3 (from the lecture notes) shows measurements and derived quantities for a period of blowing snow in Antarctica. Circle the times that would correspond to situation a) and b), respectively. °° This tells you that spatial dynamics can be similar to temporal dynamics. Note that the time series in Figure 3 describe the situation at a specific height above ground. What sign/direction do you expect the latent heat flux to have when (if?) you could measure it above the blowing snow cloud? °°°

Figure 2: Topographic setting at the Flüelapass near Davos, GR, Switzerland.

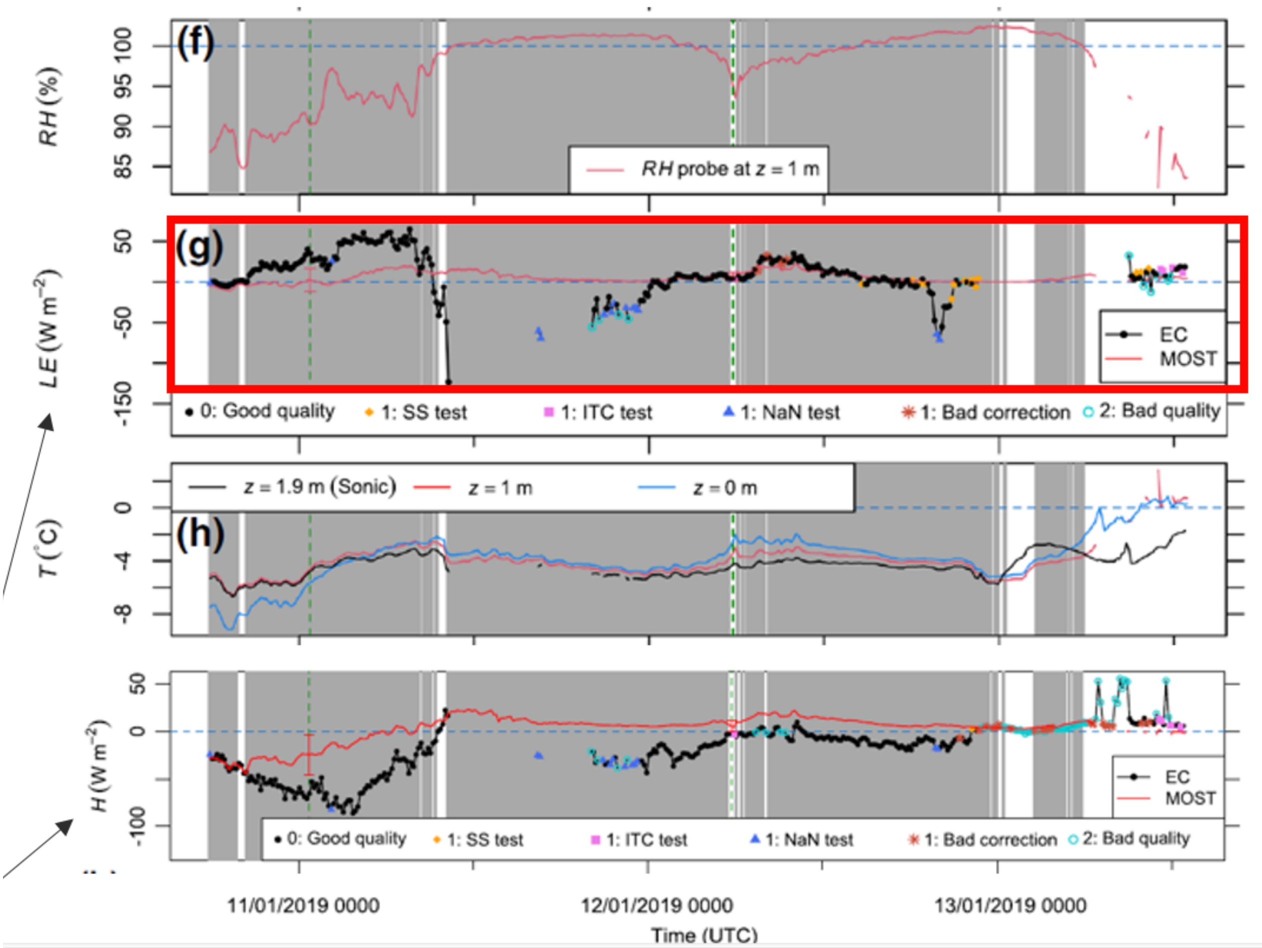


Figure 3: Time series of measured and calculated atmospheric quantities during blowing snow in Antarctica.

4. Snow and vegetation (5 P – 10 min) [*please answer questions 3 and 4 on a separate sheet*]

Figure 4 shows part of a slide from the lecture.

(a) Name what K_S stands for and explain which process it governs. °°

(b) Explain how the two different snow microstructures have developed and how this relates to canopy characteristics. °°°

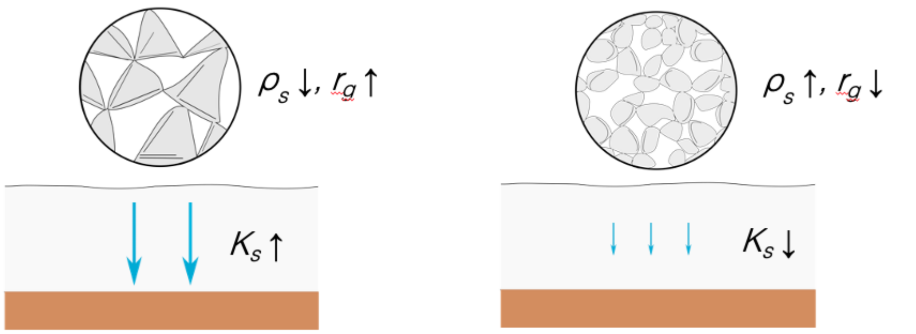


Figure 4: Different snow types and characteristic quantities

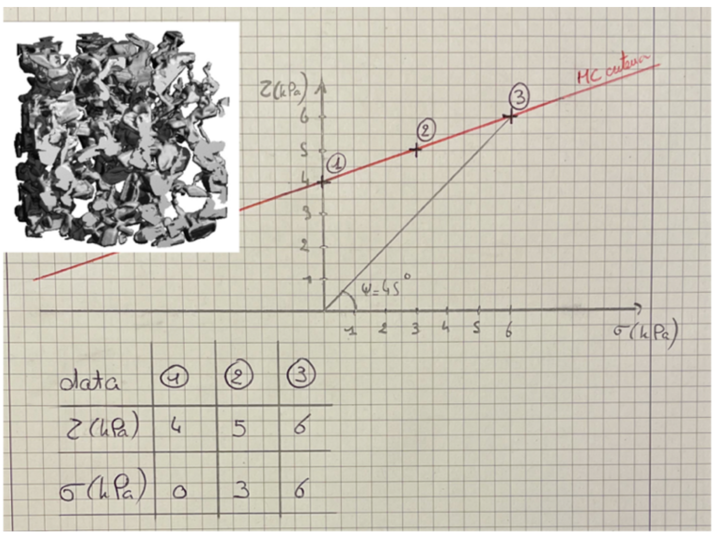
5. Snow mechanics and avalanches (10 P – 20 min) [*please answer question 5 on a separate sheet*]

a) Glide-Snow Avalanche °°°
Describe the conditions (necessary ingredients) and the step-by-step process required for triggering a glide-snow avalanche. In addition, discuss whether it is possible to trigger a glide-snow avalanche in flat terrain, and if so, how.

b) Slab Avalanche °°°
Describe the conditions (necessary ingredients) and the step-by-step process required for triggering a slab avalanche. In addition, discuss whether it is possible to trigger a slab avalanche in flat terrain, and if so, how.

c) Snow cohesion °
A weak layer was sampled and tested, revealing three strength values (1, 2, and 3) corresponding to different loading angles (see Figure 5). The Mohr-Coulomb failure criterion was interpolated based on these data (red line). What is the cohesion of the tested weak layer?

Figure 5.



d) Stability index °°°
Over the season, this weak layer has been buried on a steep slope with an angle of $\psi = 45°$. The slab resting on top of this weak layer currently has a thickness of $H_{slab} = 137\ cm$ and an average density of $\rho_{slab} = 316\ kg \cdot m^{-3}$. Assuming the gravitational acceleration is $g = 9.8\ m \cdot s^{-2}$, calculate the current natural stability index.