Written exam, 29.01.2024, 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 **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 (indicated in red, "**XP**") and an indicative time for answering (given in blue, "**Xmin**"). 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 1-3, Questions 4-5, and Question 6, respectively, on separate pages.
→ Please write your name on all sheets you return.

Good luck !

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Values of variables or constants:

- Specific heat capacity of ice at 0°C — 2.11e3 J kg^{-1} K^{-1}
- Latent heat of fusion of ice/water — 3.34e5 J kg^{-1}
- Extinction coefficient of fresh and old snow — 20; 10 m^{-1}

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1. Energy balance, radiation (9 P – 18 min)

A 20 cm deep fresh alpine snow cover has an albedo of 0.75, and SW = 400 Wm^{-2} is the incoming shortwave radiation at this location at a given time.

(a) Compute the energy flux of transmitted solar radiation at the base of the snowpack, expressing it as a faction of the net SW radiation. °°°

(b) If the snowpack of (a) was composed of old, consolidated snow, how would the repartitioning of the net SW radiation change with respect to SW radiation absorption within the snow and at the soil surface? °°°

(c) A few days later, a Sahara sandstorm transports dust and deposits it on the snow cover of (b) changing its albedo to 0.6. What are the implications for the amount of radiation reaching the (soil or rock) surface below the snow pack? °°°

2. Energy balance, snow melt (6 P – 12 min)

The snowpack of Question (1a) has a mean density of 126 kg m^{-3}, and a linear temperature profile. The temperature at the surface is -9°C and -1°C at the base. Compute (a) the snowpack cold content, (b) the amount of energy required to melt it, and (c) the time this would take for a constant net energy input of 100 W m^{-2} present during 8 hours per day (express your result in days, hours, minutes, seconds).

3. Climate change and Snow (10 P – 20 min)

Consider Figure 1 (see separate page) recently published by the BBC on the occasion of the globally warmest year since the beginning of temperature records. Comparing the two years 1976 and 2023, which differences of the global snow cover do you infer for these years? Reply, considering (a) seasonality and timing,°°° (b) precipitation,°° (c) geography and climate,°° and (d) interaction with other cryospheric components.°°°

4. Snow Transport, Turbulent Fluxes and Isotopes (20 P – 40 min)

Figure 2 (see separate page), which has been shown in class during the snow transport and isotopes lectures, presents measurements taken during a snowstorm in Antarctica.

(a) Name the quantities measured in panels (a), (c) and (d) and provide one or two key words for the measurement principle, for example for relative humidity (f) it would be capacitance changes or for temperature (h) it would be speed of sound or metal expansion respectively. °°°

(b) Explain how the data shown by the two different curves in each of the panels (g) and (i) are calculated. First, name the calculated quantity; second, mention the measurements needed for its calculation and at which temporal resolution; and third, briefly explain how the fluxes in question are calculated. You may give the equations if considered helpful. °°°°°°

(c) Explain why during situations of drifting and blowing snow the Monin-Obukhov Similarity Theory (MOST) may underestimate the turbulent sensible and latent heat fluxes. °°°°

(d) From the data shown in Figure 2, identify two of the most intense blowing snow events and approximately say when they occurred. While during most drifting and blowing snow conditions LE is positive, there are also periods with negative latent heat flux when the latter is computed with the Eddy Covariance (EC) method. What does this mean and how do you explain it? °°°

(e) Why do negative latent heat flux values help explaining isotopic fractionation (oxygen and hydrogen stable water isotopes) in drifting and blowing snow? °°°°

5. SNOWPACK and avalanche danger (5 P – 10 min)

A SNOWPACK simulation for the station "Les Collines" above Champéry, VS, in most Western Switzerland is shown in Figure 3 (see separate page). With the information that the most active avalanche period of that winter was in December, please answer the following questions.

(a) Which event on which date contributed most to the de-stabilization of the snow cover? °°

(b) Based on the simulations shown in Figure 3, which type of avalanche do you expect? °

(c) What would be the most likely release depth of an avalanche (and why) if it were to start at the elevation of the station "Les Collines" and how would this change if it were to start at much higher elevation (which actually was the case for many avalanches during this period). °°

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

(a) Recall three different avalanche types. °

(b) One of the three types of (a) is responsible for more than 90% of the fatalities. Recall the three necessary ingredients for releasing this avalanche type. °°

(c) Recall and explain the process steps required for releasing avalanche type in (b). °°°

(d) Back-calculate the weak layer shear strength τ_p from the Natural Stability Index of 1.3 and the following properties: °°°

$\rho_{slab} = 290\ kg \cdot m^{-3}$	Rounded grain slab density.
$H_{slab} = 52\ cm$	Slab height.
$g = 9.8\ m \cdot s^{-2}$	Gravitational force equivalent.
$\psi = 43°$	Slope angle.

(e) Is this value in line with experimental data? Please give your opinion and discuss this result. °

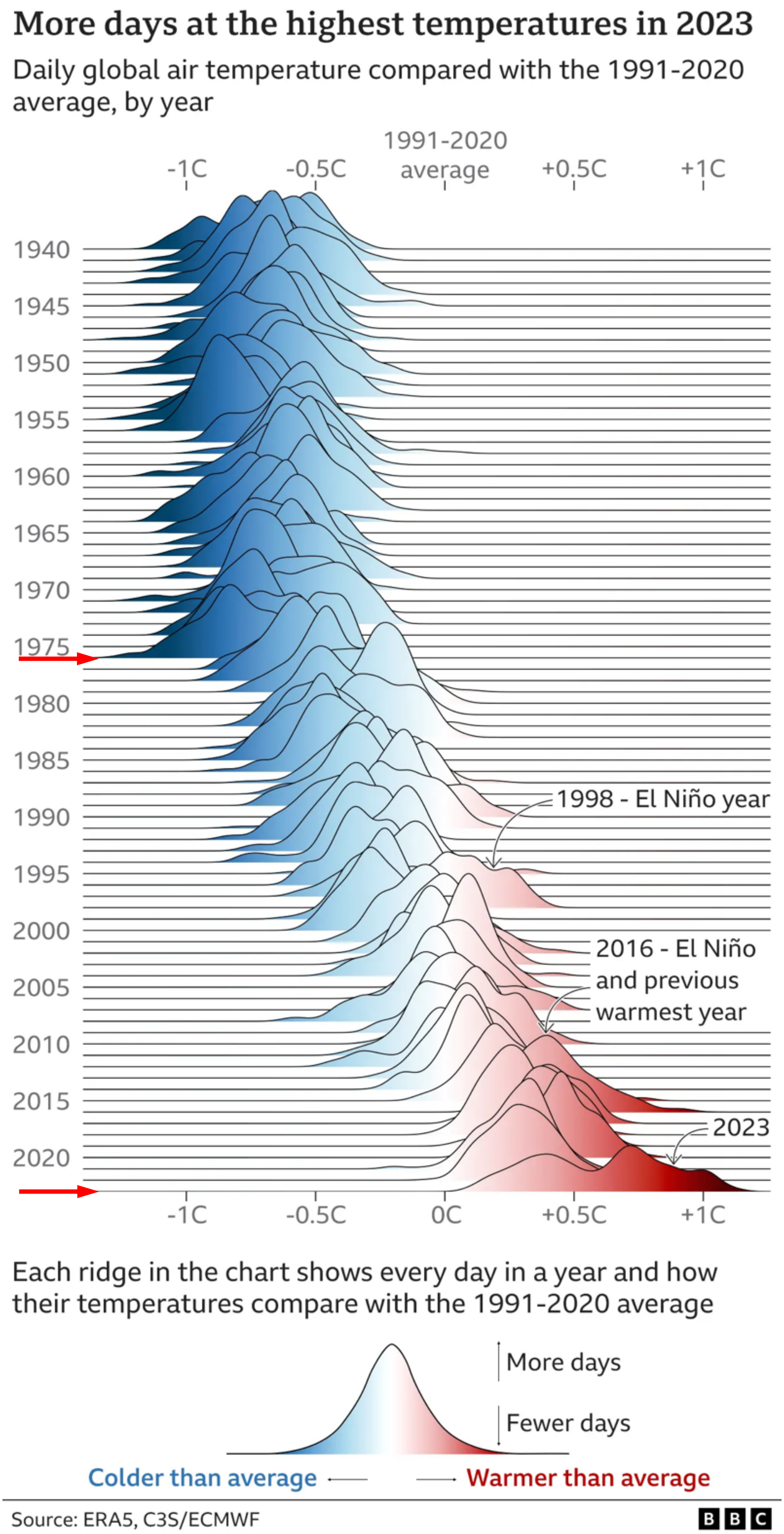

Figure 1: *Distributions of daily global air temperature anomalies by year with respect to the 1991-2020 reference period.*

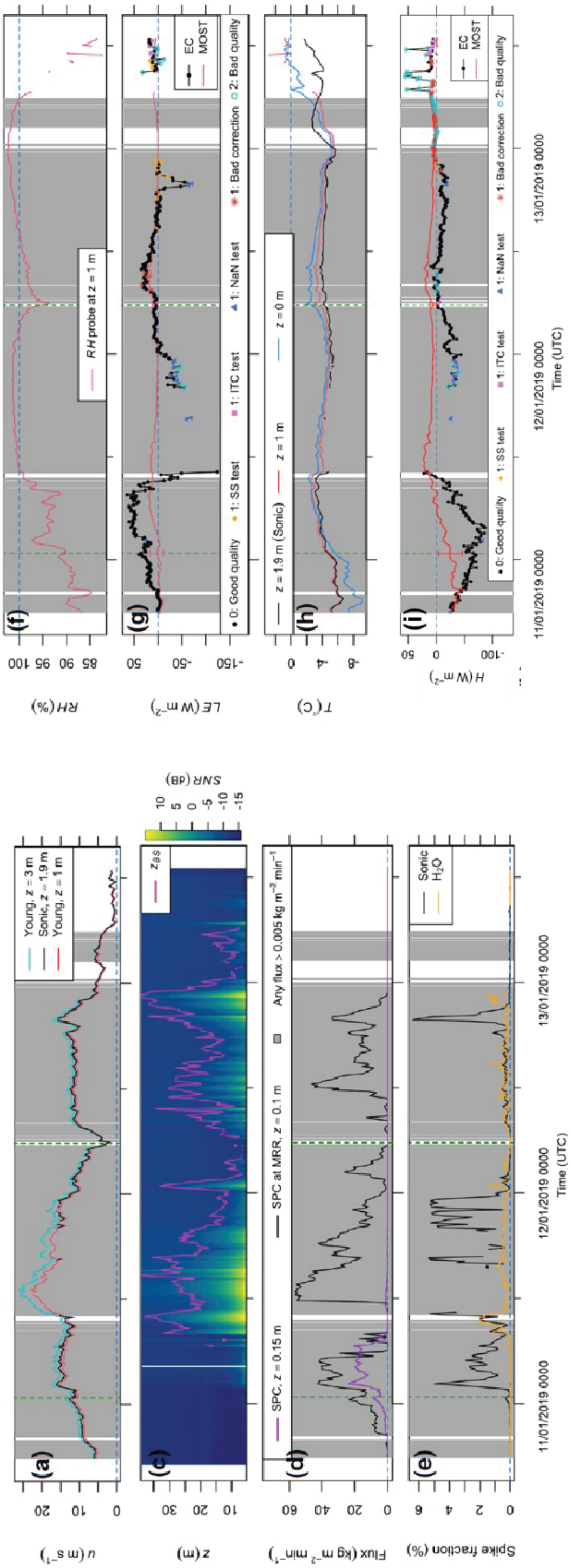

Figure 2: Measurements from Syowa, Antarctica. [NB: there is no panel (b).]

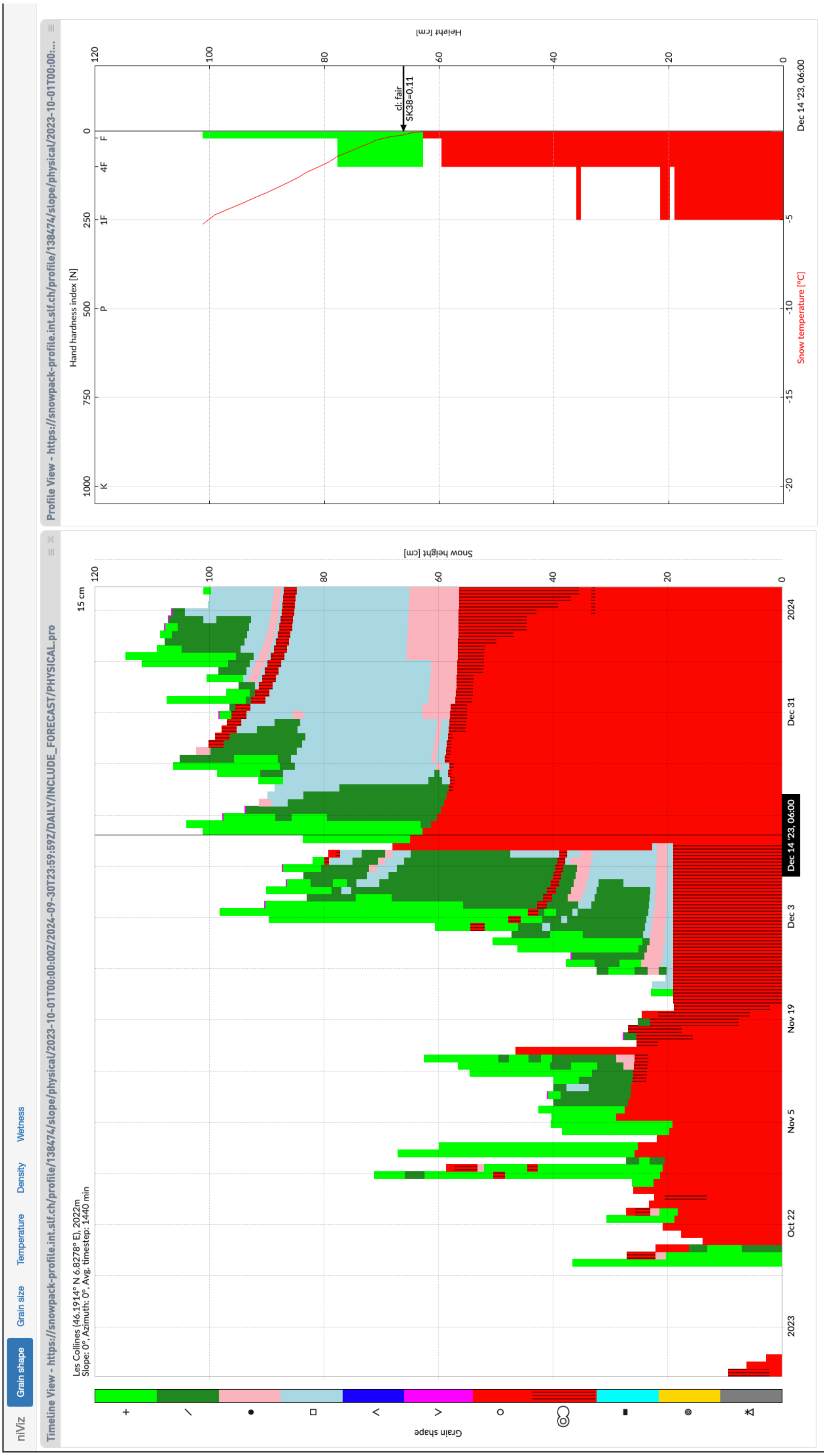

Figure 3: *SNOWPACK snow profile showing grain types for the IMIS station " Les Collines " close to the " Portes du Soleil " ski area.*