Exploring alternative possibilities for sublimation measurements over snow and ice surfaces

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(1) Motivation, background, objectives

In high mountain and polar regions sublimation from snow and ice surface can be a major component in the mass and energy balance. However, sublimation is challenging to measure and to quantify, especially in a spatially distributed and representative way. Both well-established measurement equipment and underlying theory is available but rather expensive and energy consuming, an issue for most remote sites in extreme environments. Cost and maintenance requirements limit the use of such technology to typically only one or very few measurement locations in vast areas.

This project attempts developing new methodological approaches suitable for distributed sublimation observation deploying less expensive or even low cost sensing equipment. A previous study has identified short-lived snow surface temperature signatures, recorded with a thermal camera (Figure 1).

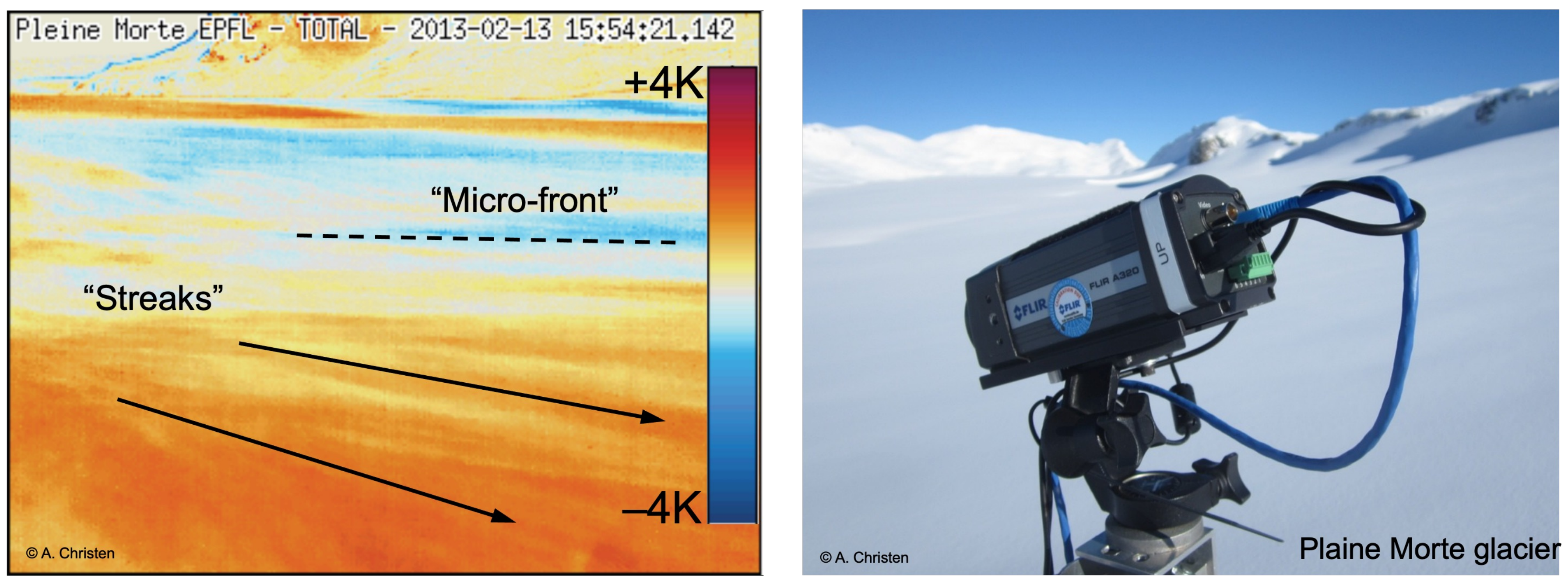

Figure 1: Thermal signature of the snow surface recorded in the absence of drifting snow (Plaine Morte, 2013).

(2) Ideas, approach, hypotheses, limitations

The proposed approach is based on fast-frequency IR surface temperature measurements. The instantaneous surface temperature is the result of the net surface energy balance, including short- and longwave radiative fluxes, turbulent sensible and latent heat fluxes and the conductive heat flux in the ice matrix. Sublimation cools the surface, which is counteracted by emitted longwave radiation and convective sensible heat fluxes. Changes in atmospheric radiative fluxes typically occur at time scales of seconds or larger. Thus, fluctuations in Ts at the second or sub-second time scale must result from different (non-radiative) forcing. Condensation/deposition and a melting snow/ice surface are not considered. Thermal conduction in ice is orders of magnitude slower than the thermal effects of phase change processes It is assumed below, that this attenuation or damping can be approximated as a linear response to changes in the surface temperature according to equation (X). The attenuation factor will be a function of various atmospheric state variables, cf. equation (4).

$$d(SWE)/dt = P - (S \text{ or } E) - O\,, \ [\mathrm{mm\ s^{-1}}] \qquad (1), \qquad \text{cf. Figure (2)}$$

$$Q_{SW*} + Q_{LW*} + Q_H + Q_{LE} + Q_G = 0\,, \ [\mathrm{W\ m^{-2}}] \qquad (2), \qquad \text{cf. Figure (2)}$$

$$Q_{LE} = r_s\, dT_s / dt\,; \ \text{for } dT_s/dt < 0\,, \ [\mathrm{W\ m^{-2}}] \qquad (3), \qquad \text{cf. Figure (3)}$$

$$r_s = f\,(T_a, RH, \rho)\,, \ [\mathrm{J\ K^{-1}\ m^{-2}}] \qquad (4)$$

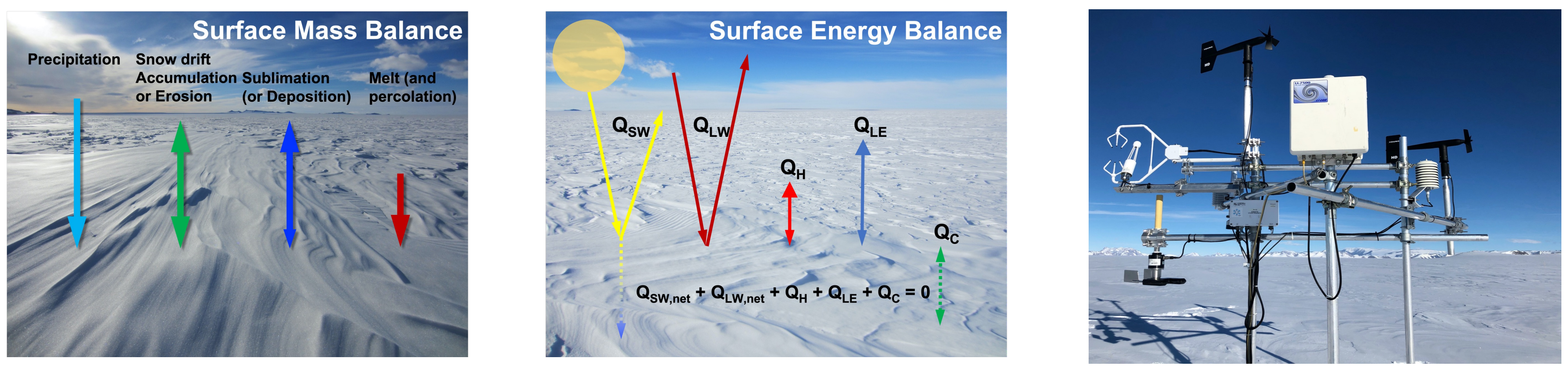

Figure 2: Schematic of surface mass (Eq.1) and energy (Eq.2) balance and a complete M-E-B measurement station.

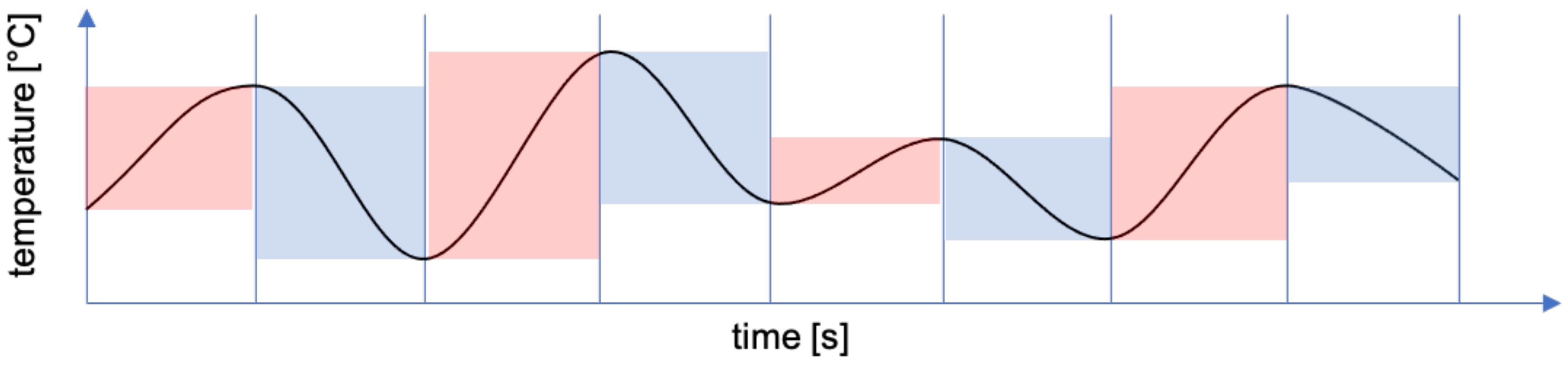

Figure 3: Schematic of surface temperature fluctuations. Blue shaded periods: cooling due to phase change (*LE* dominates over *H*), red shaded periods: warming when *H* dominates over *LE*

(3) Proof of concept and verification of hypotheses

(A) What are the characteristic fluctuations in incident short wave radiation? Fast frequency radiation measurements.

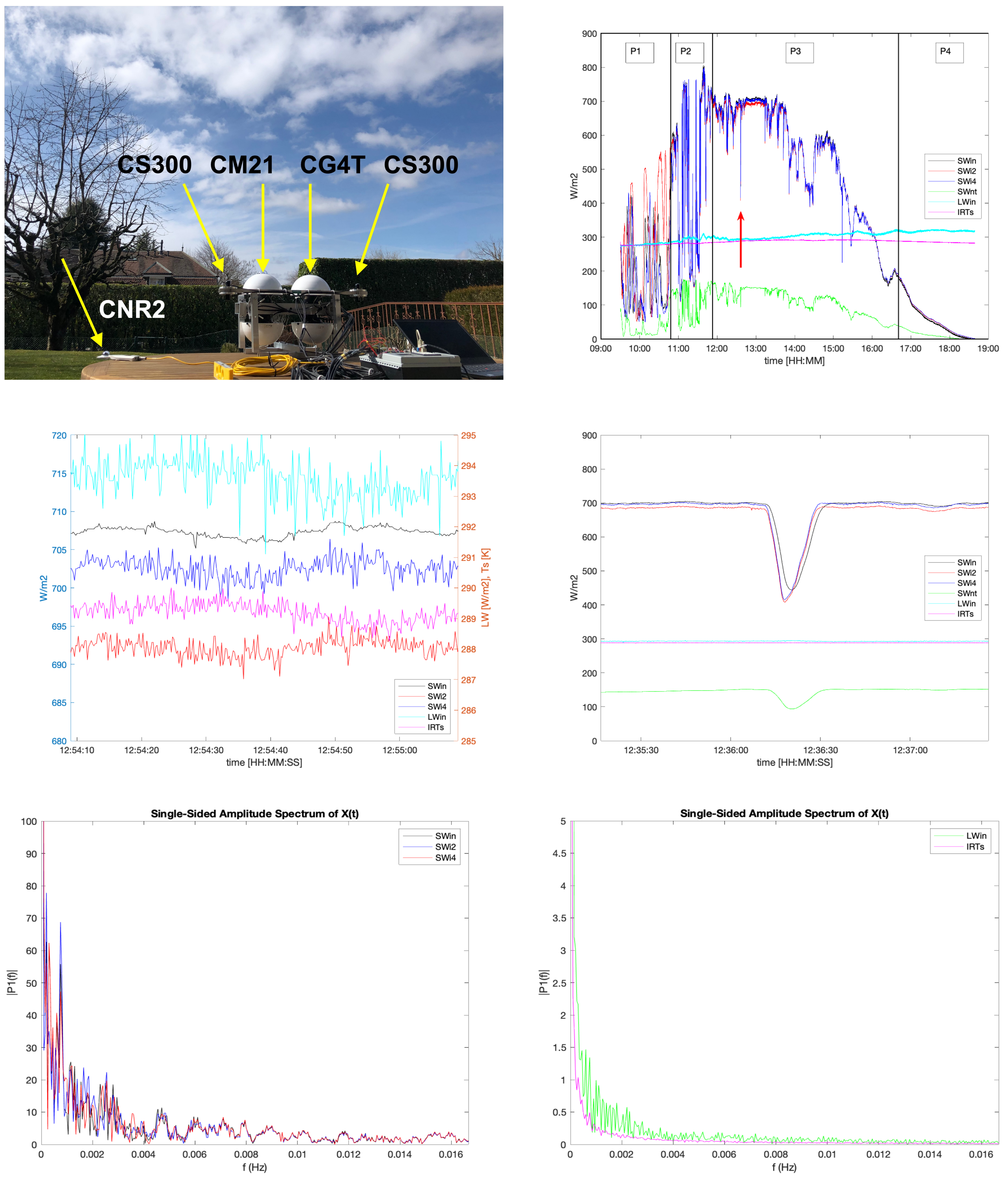

Figure 4: (a) Instruments and meteorological conditions during the radiative heat flux experiment. (b) Time series of all measured variables as indicated in the legend; (c) 1-min zoom into "plateau" in Period P3 just after the red arrow in (b), including incoming LW and IR surface temperature; (d) 2-min zoom in P3 including a "spike" indicated by red arrow in (a); (e) power spectra of incoming SW; (f) power spectra of incoming LW and IR surface temperature; the frequency axis is cropped at 1min, and the power axes to 100 and 5, respectively.

(B) Is the response time of available sensors sufficiently fast? Experiments with alternating surface temperature.

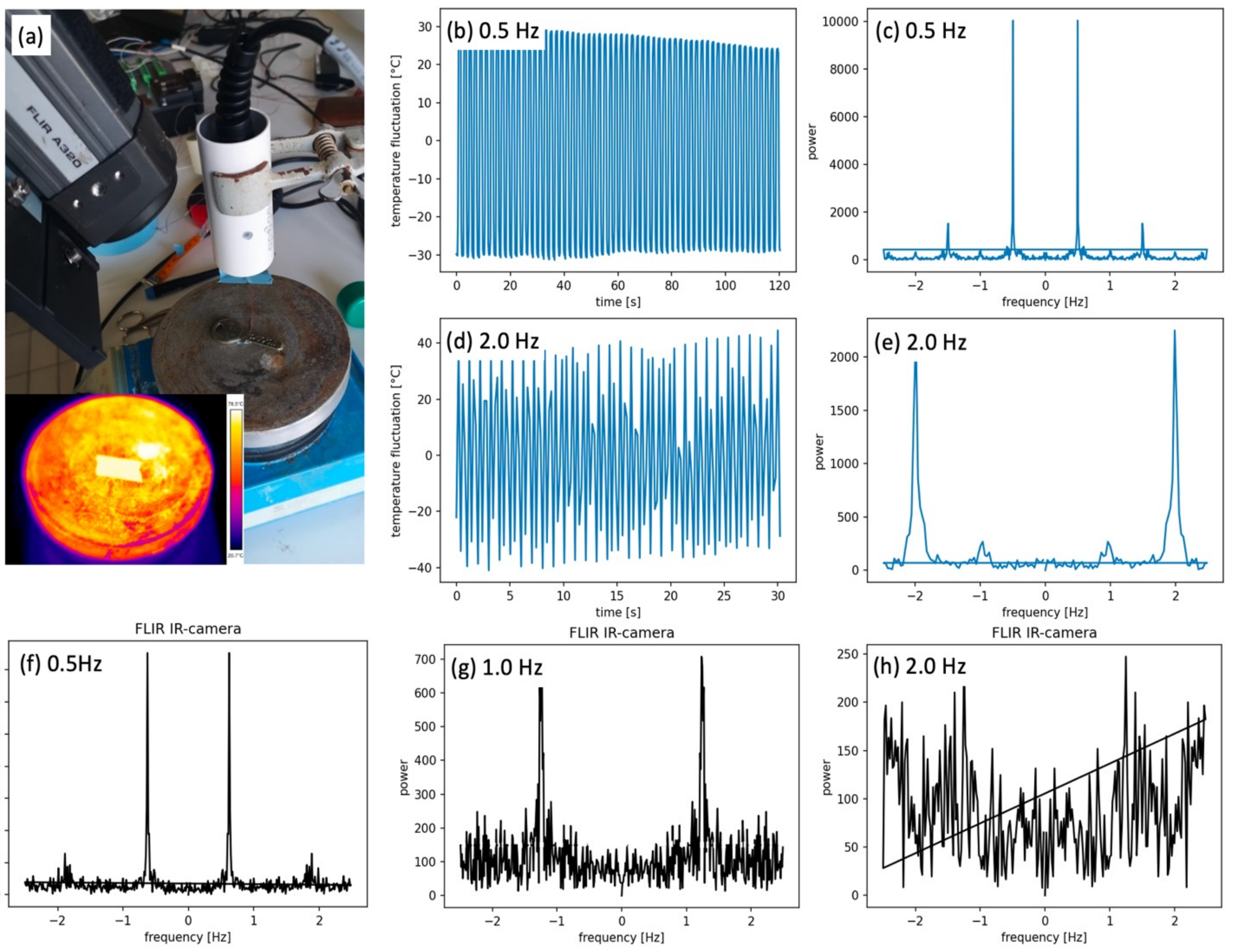

Figure 5: (a) Test setup of IRTS and IR camera; inset shows an IR image of the hotplate. (b)-(e): Temperature signal in the time and in the frequency domain (FFT) for temperature fluctuations at 0.5 and 2.0 Hz. (f)-(h): Temperature signal from the IR camera in the frequency domain (FFT) for temperature fluctuations at 0.5, 1.0, and 2.0 Hz.

(4) Outlook and next steps

- Further refinement of methodology.
- More laboratory tests, validation of approach.
- Field measurements over natural snow.