3D Growth Rates from Tomographic Images: Local Measurements for a Better Understanding of Snow Metamorphism

F. Flin[1], N. Calonne[1, 2, 3], R. Caneill[1], B. Lesaffre[1], A. Dufour[1], A. Philip[1], J. Roulle[1], S. Rolland du Roscoat[2], C. Geindreau[2]

frederic.flin@meteo.fr

[1] Météo-France - CNRS, CNRM - GAME UMR 3589 / CEN, Saint Martin d'Hères, France
[2] Laboratoire 3SR UMR 5521, CNRS UJF G-INP, Grenoble, France
[3] now at WSL, Institute for Snow and Avalanche Research SLF, Davos, Switzerland

Acknowledgments:
F. Dominé, M. Dumont, F. Karmous, F. Lahoucine, J-M. Panel, P. Puglièse and G. Vian for their help with the cryo-cell development, E. Ando, J. Desrues and P. Charrier for tomography at 3SR
Funding: ANR DigitalSnow (ANR-11-BS02-009-03); 3SR is part of the Labex Tec 21 (ANR-11-LABX-0030), CEN is part of the Labex OSUG@2020 (ANR-10-LABX-56)

1. Abstract

Once deposited on the ground, snow forms a complex porous material whose microstructure constantly transforms over time. These evolutions, which strongly impact the physical and mechanical properties of snow (e.g. Srivastava et al, 2010; Löwe et al, 2013; Calonne et al, 2014) need to be considered in details for an accurate snowpack modeling. However, some of the physical mechanisms involved in metamorphism are still poorly understood.

To address this problem, several investigations combining X-ray tomography and 3D micro-modeling have been carried out (e.g. Flin et al, 2003; Kaempfer and Plapp, 2009; Pinzer et al, 2012) but precise comparisons between experimentation and modeling remain difficult. One of the difficulties comes from the lack of high resolution time-lapse series for experiments occurring with very well-defined boundary conditions, and from which precise measurements of the interfacial growth rates can be done.

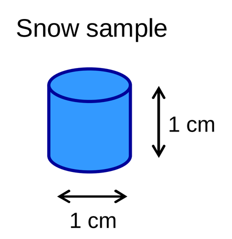
Using **CellDyM, a recently developed cryogenic cell** (Calonne et al, 2015), we conducted **in situ time-lapse tomographic experiments** on several snow and ice samples under various conditions (isothermal metamorphism at -7°C, temperature gradient metamorphism at -2°C under a TG of 18 K/m, air bubble migration in a single crystal at -4°C under a TG of 45 K/m). The non-destructive nature of X-ray microtomography yielded series of 8 micron resolution images that were acquired with time steps ranging from 2 to 12 hours. An image analysis method was then developed to estimate the **normal growth rates on each point of the ice-air interface** and applied to the series obtained.

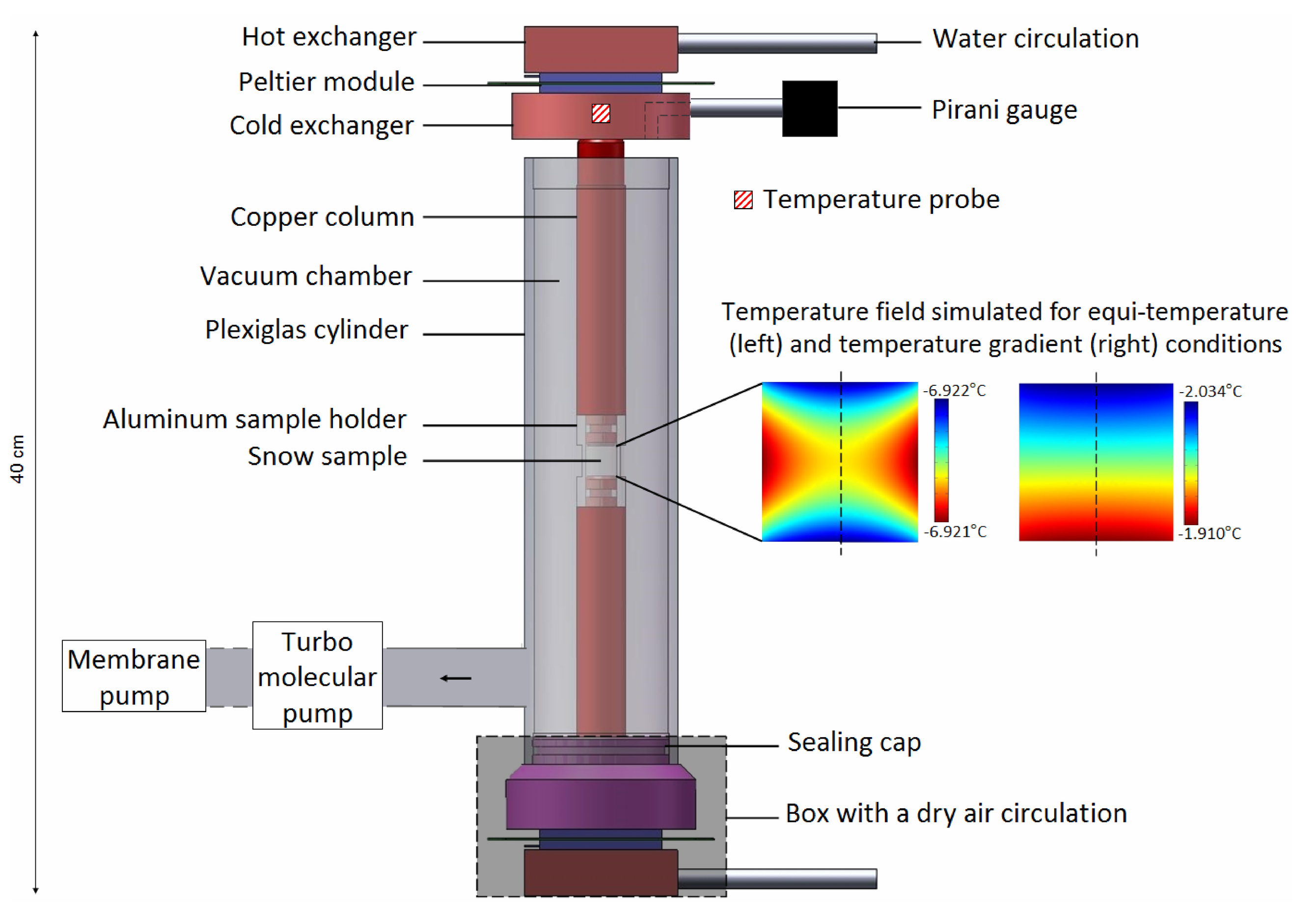
The analysis of the results and their comparison to those of existing experiments or models (e.g. Flin et al, 2003; Flin and Brzoska, 2008; Pinzer et al, 2012) give **interesting outlooks for the understanding of the physical mechanisms involved in snow metamorphism**.

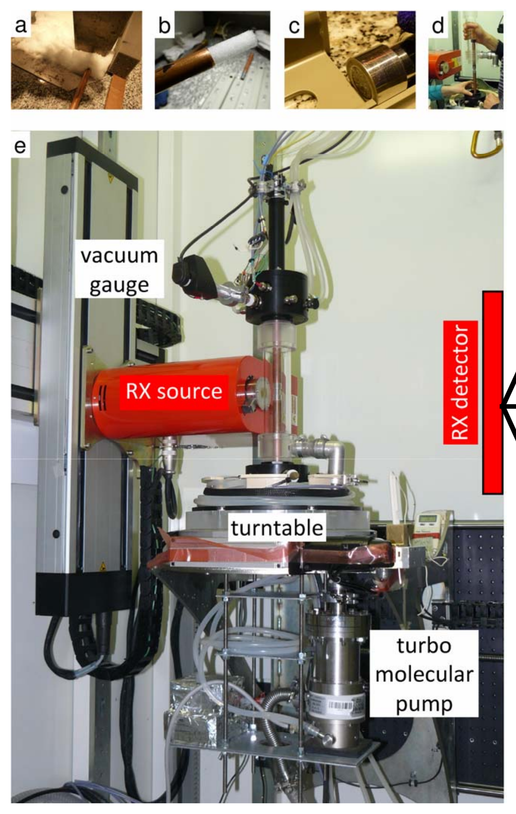
2. CellDyM: a Cryogenic Cell for Time-lapse Tomography at Room-Temperature

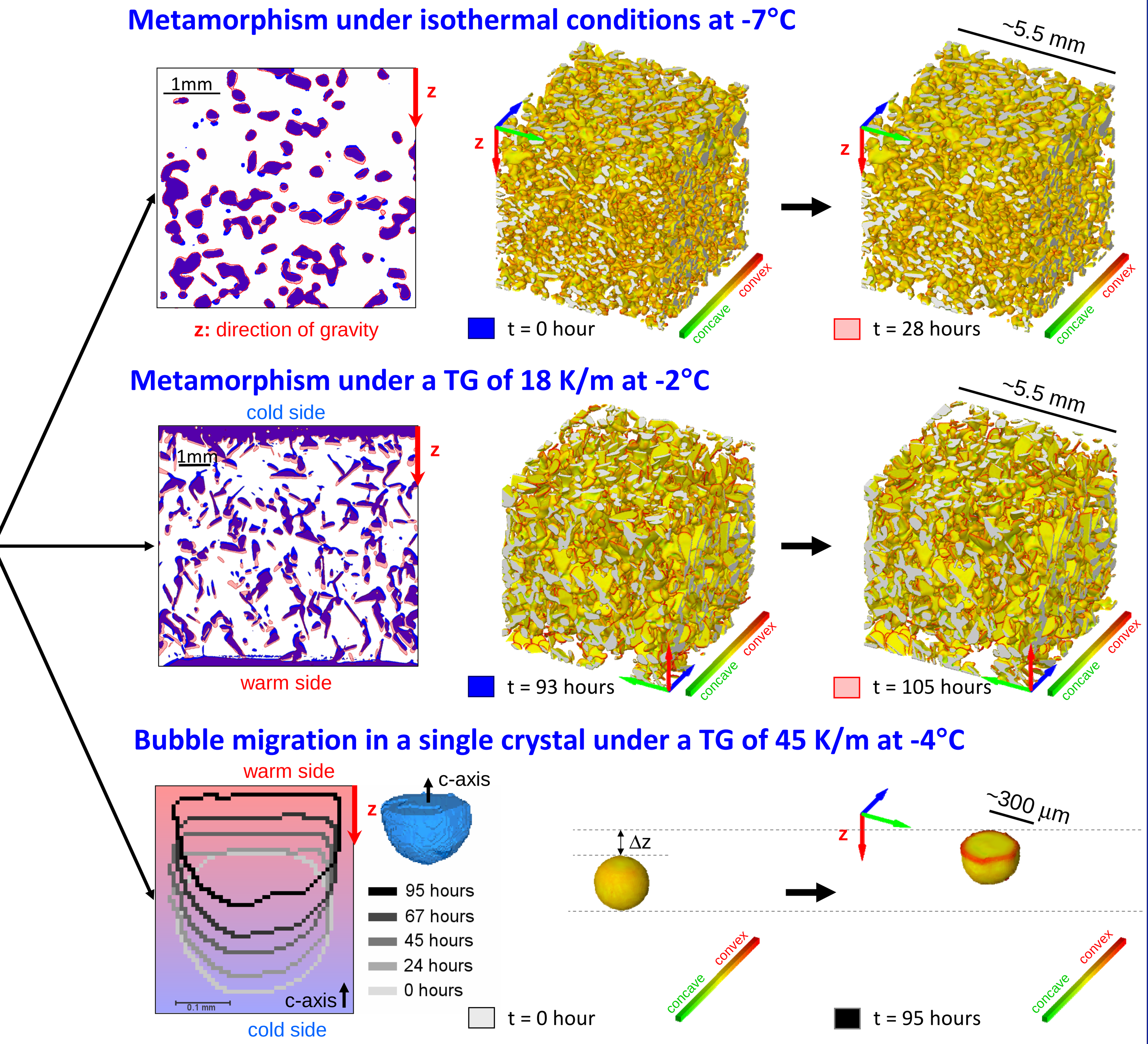
Based on the following principles:

- -thermal regulation using 2 Peltier modules at top and base of the sample
- -thermal insulation from room temperature using a vacuum chamber
- -an amovible conductive sample holder that protects specimens during their installation into the cell









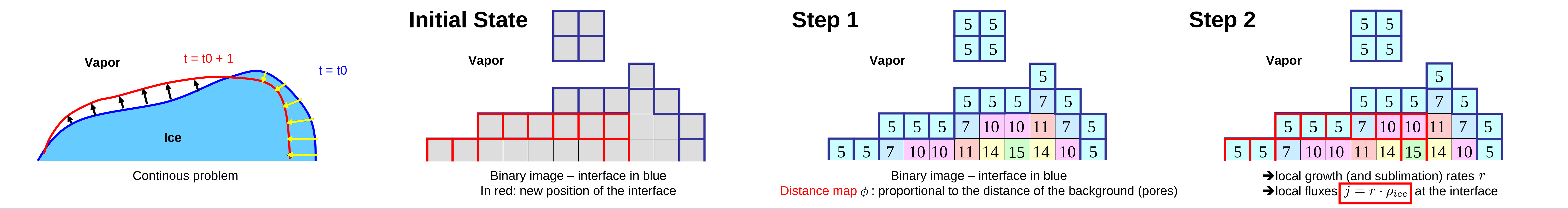
➔**Results:** 3D time-lapse series with :

- high spatial and temporal resolution
- well-defined thermal conditions

3. A Simple Method to Measure Normal Growth Rates from 3D Time-lapse Images

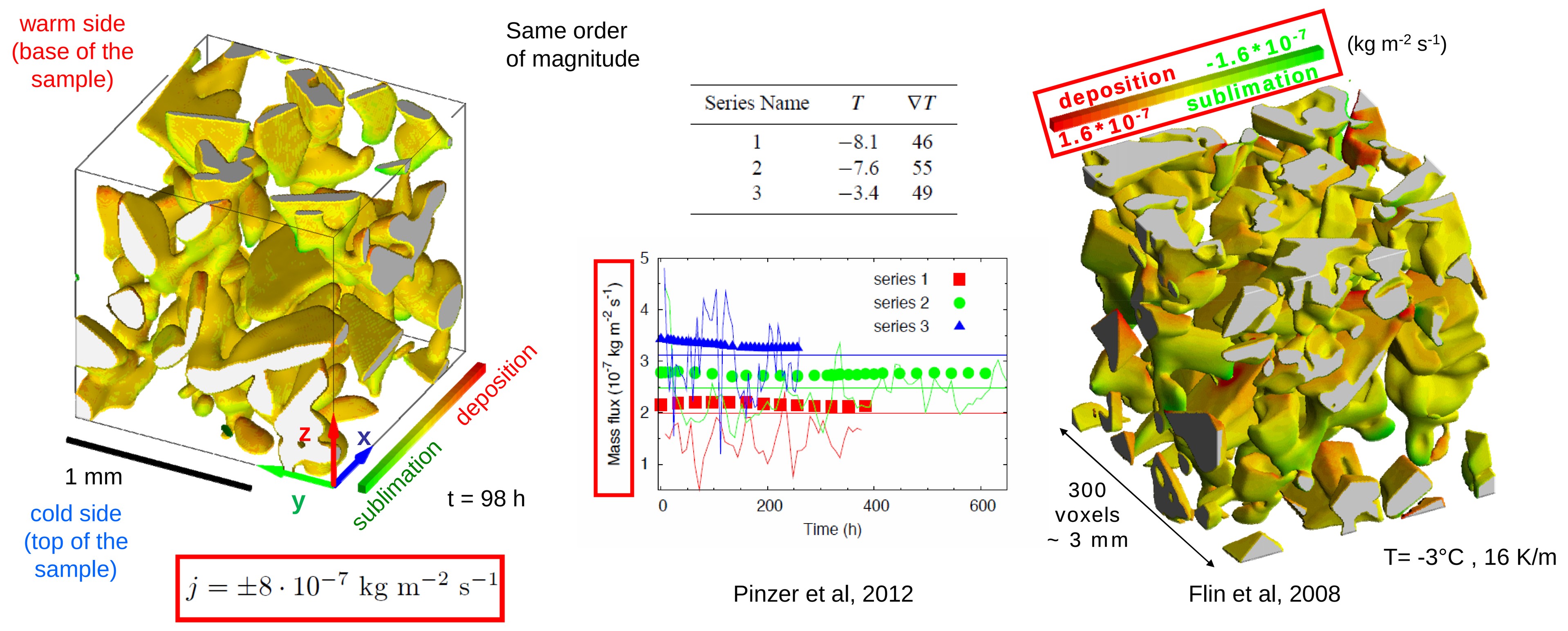
The (signed) distance of the red interface from the blue one is directly given by the distance map ϕ as follows:

$d = (5 - \phi)/5$ (pixels)

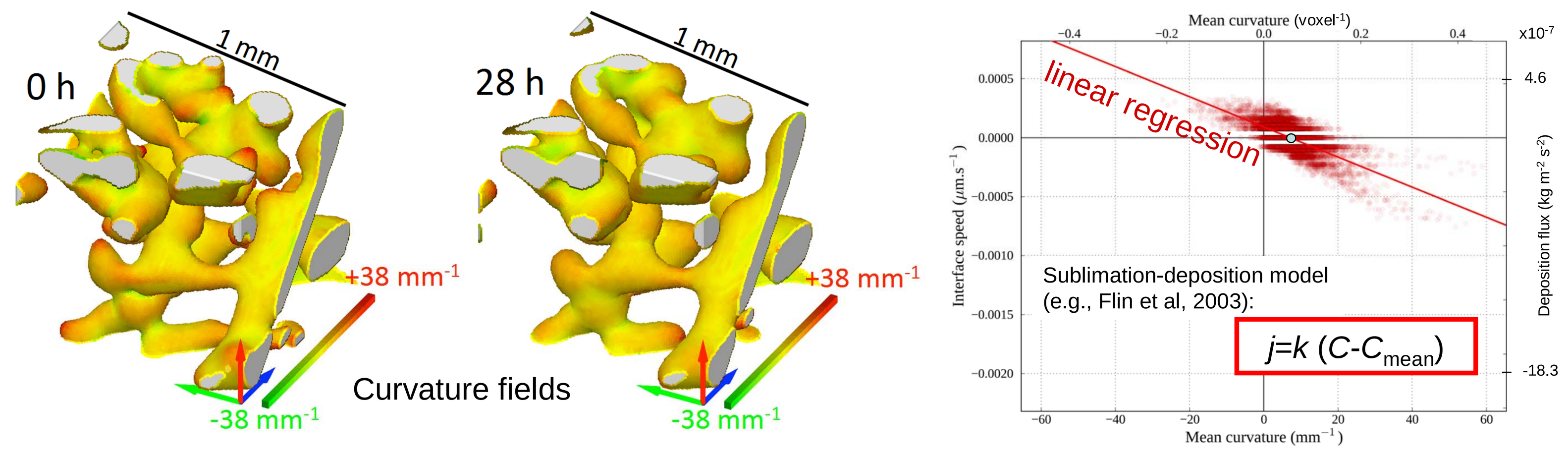


4. Preliminary Results

Metamorphism under a TG of 18K/m at -2°C:
Interface speed measurements at t = 98h, and comparisons with literature experiments and models



Isothermal conditions at -7°C: is sublimation-deposition the dominant mechanism ?



Conclusions : A simple method to measure normal growth rates from time-lapse 3D images has been developed. It gives consistent results with the literature and can be used to better understand the physics of snow metamorphism (sublimation-deposition vs diffusion, e.g.). Further analyses on the complete dataset are now in progress.

References:
Calonne, N., F. Flin, C. Geindreau, B. Lesaffre and S. Rolland du Roscoat (2014), The Cryosphere, 8(6), 2255–2274, doi:10.5194/tc-8-2255-2014.
Calonne, N., F. Flin, B. Lesaffre, A. Dufour, J. Roulle, P. Puglièse, A. Philip, F. Lahoucine, C. Geindreau, J.-M. Panel, S. Rolland du Roscoat and P. Charrier (2015), Geophys. Res. Lett., 42, doi: 10.1002/2015GL063541.
Flin, F., J.-B. Brzoska, B. Lesaffre, C. Coléou and R. A. Pieritz (2003), J. Phys. D. Appl. Phys., 36, A49-A54, doi: 10.1088/0022-3727/36/10A/310.
Flin, F. and J.-B. Brzoska (2008), Ann. Glaciol., 49, 17–21, doi:10.3189/172756408787814834.
Kämpfer, T. U. and M. Plapp (2009), Phase-field modeling of dry snow metamorphism, Phys. Rev. E, 79 (3), 031502, doi:10.1103/PhysRevE.79.031502.
Löwe, H., F. Riche and M. Schneebeli (2013), The Cryosphere, 7(5), 1473–1480, doi:10.5194/tc-7-1473-2013.
Pinzer, B., M. Schneebeli and T. Kämpfer (2012), The Cryosphere, 6, 1141–1155.
Srivastava, P., P. Mahajan, P. Satyawali and V. Kumar (2010), Ann. Glaciol., 51, 73–82.