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

- Application to Isothermal Metamorphism and Comparison with a Phase-Field Model -

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1. Introduction

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.

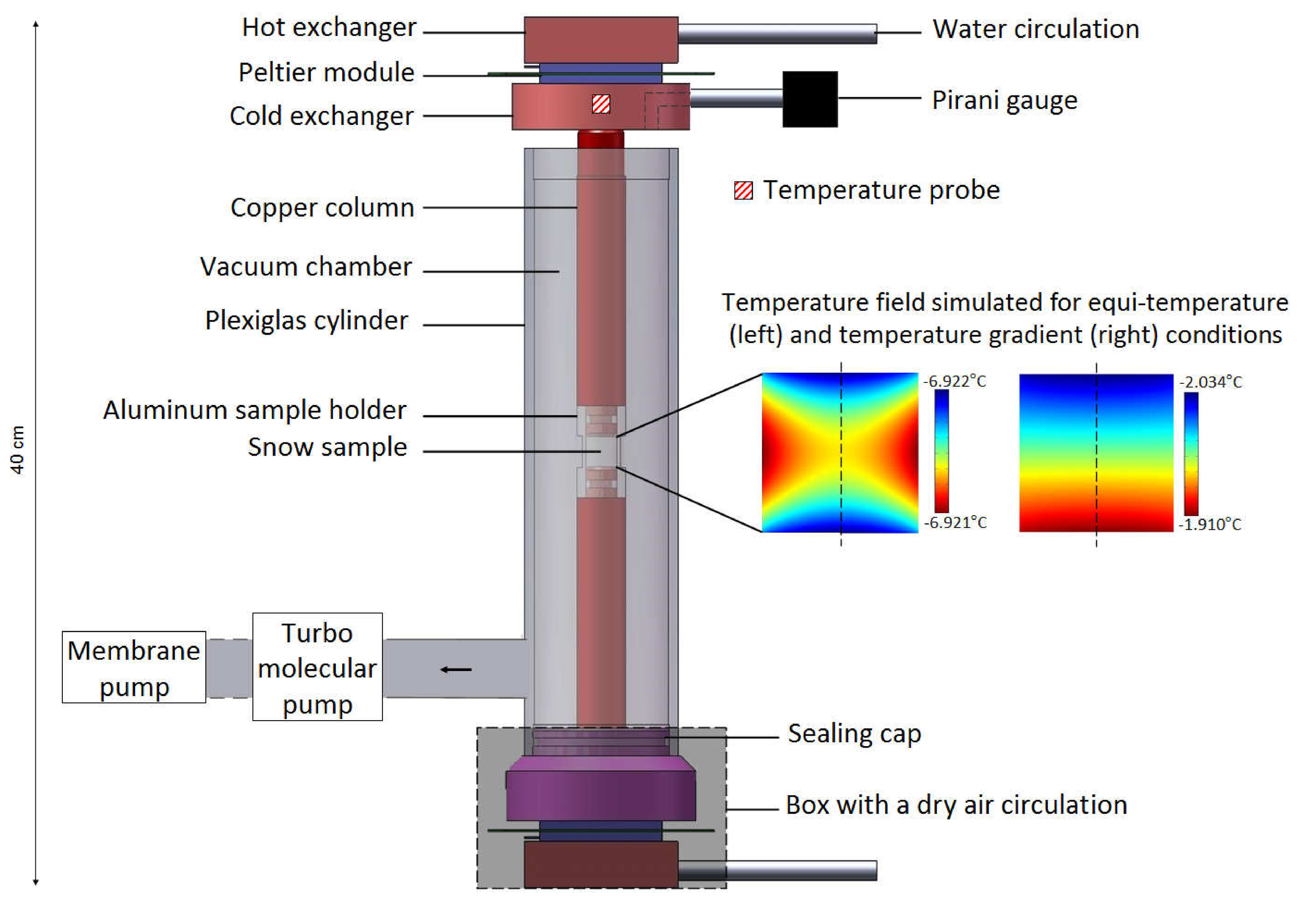
To address this problem, several investigations combining X-ray tomography and 3D micro-modeling have been carried out (e.g. Flin et al, 2003; Kaempfer and Plapp, 2009; Pinzer et al, 2012) but precise comparisons between experimentation and modeling remain difficult. One of the difficulties comes from 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.

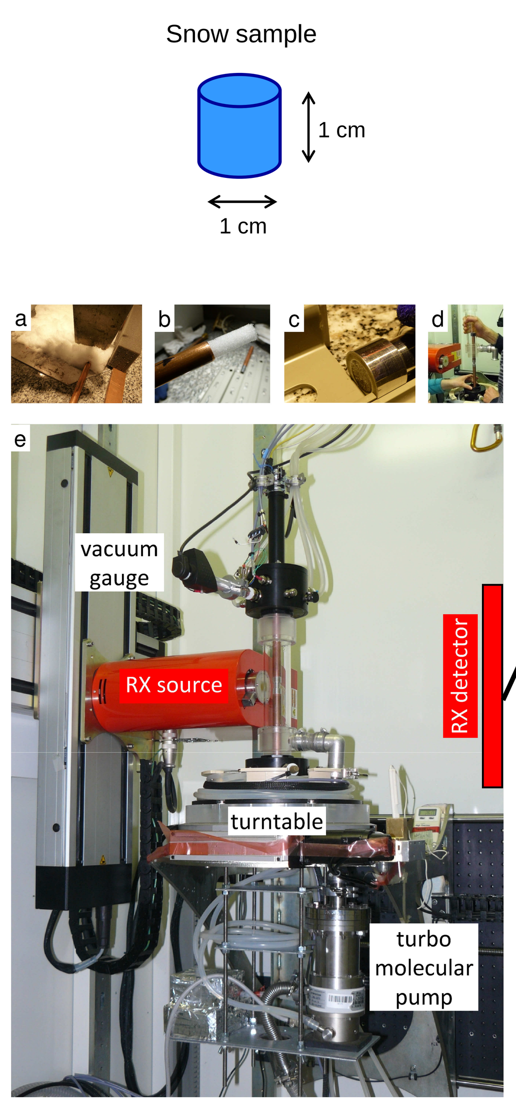
Using **CellDyM, a recently developed cryogenic cell** (Calonne et al, 2015), we conducted **in situ time-lapse tomographic experiments** on several snow and ice samples under various conditions (isothermal metamorphism at -7°C, temperature gradient metamorphism at -2°C under a TG of 18 K/m, air bubble 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.

Here, we focus on isothermal metamorphism at -7°C, where the results obtained and their comparison to those of existing models (e.g. Flin et al, 2003; Bretin et al, 2015) give **interesting outlooks for the understanding of the physical mechanisms involved**.

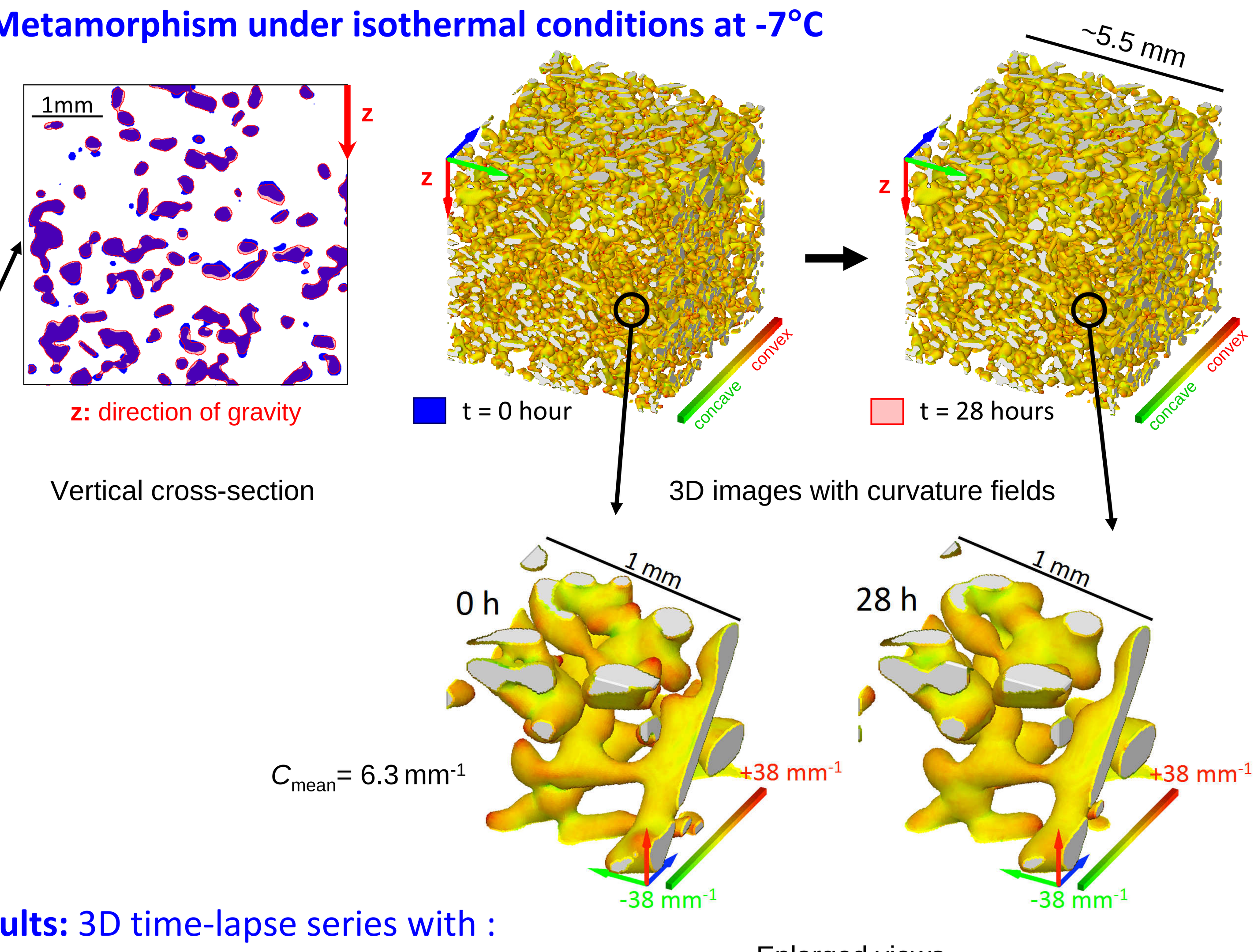
2. CellDyM: a Cryogenic Cell for Time-Lapse Tomography at Room-Temperature

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





Metamorphism under isothermal conditions at -7°C

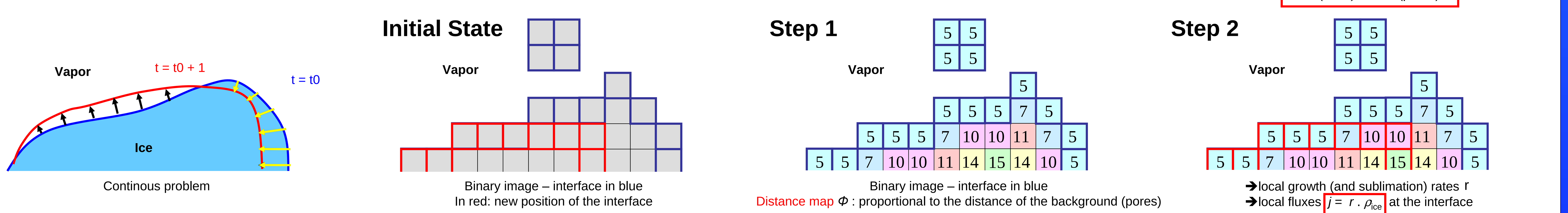


➔**Results:** 3D time-lapse series with :
- high spatial and temporal resolution
- well-defined thermal conditions

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

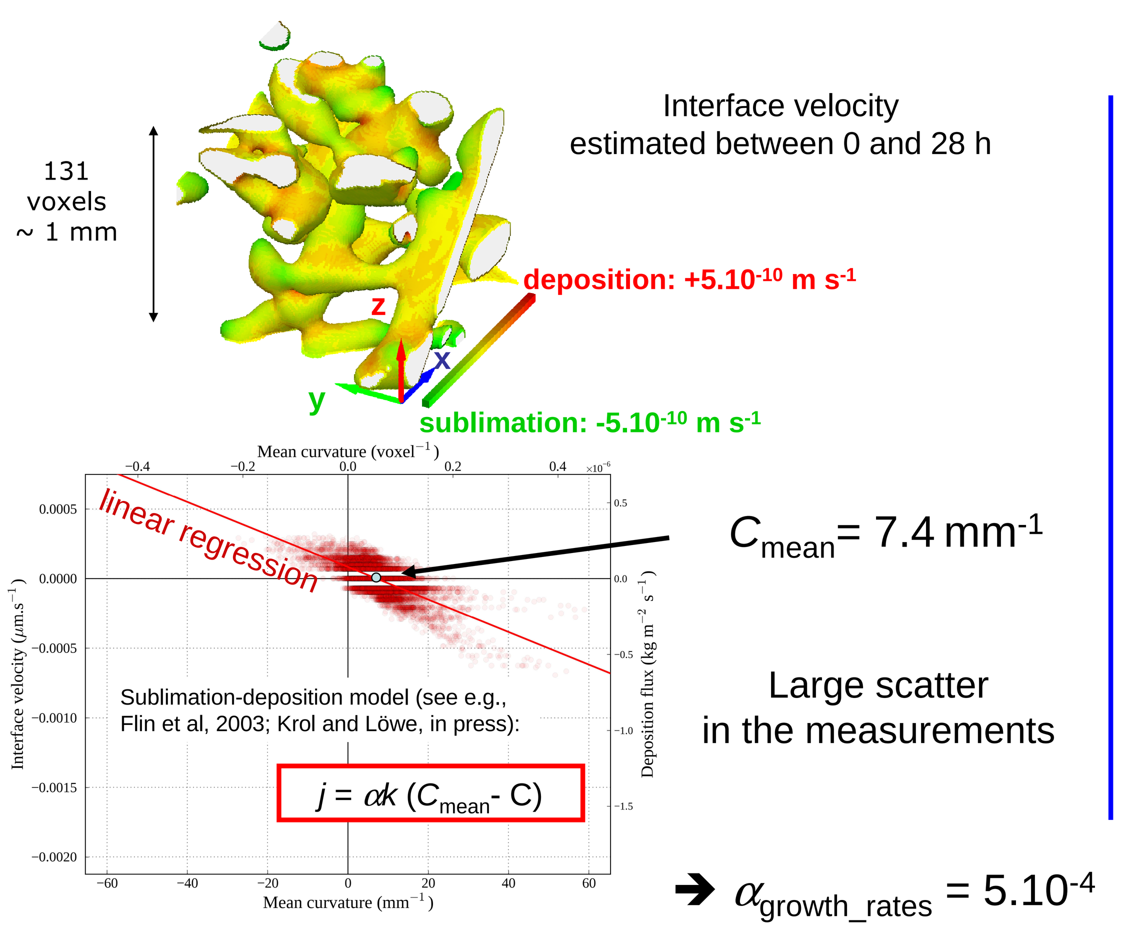
The (signed) distance of the red interface from the blue one is directly given by the distance map Φ as follows:

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



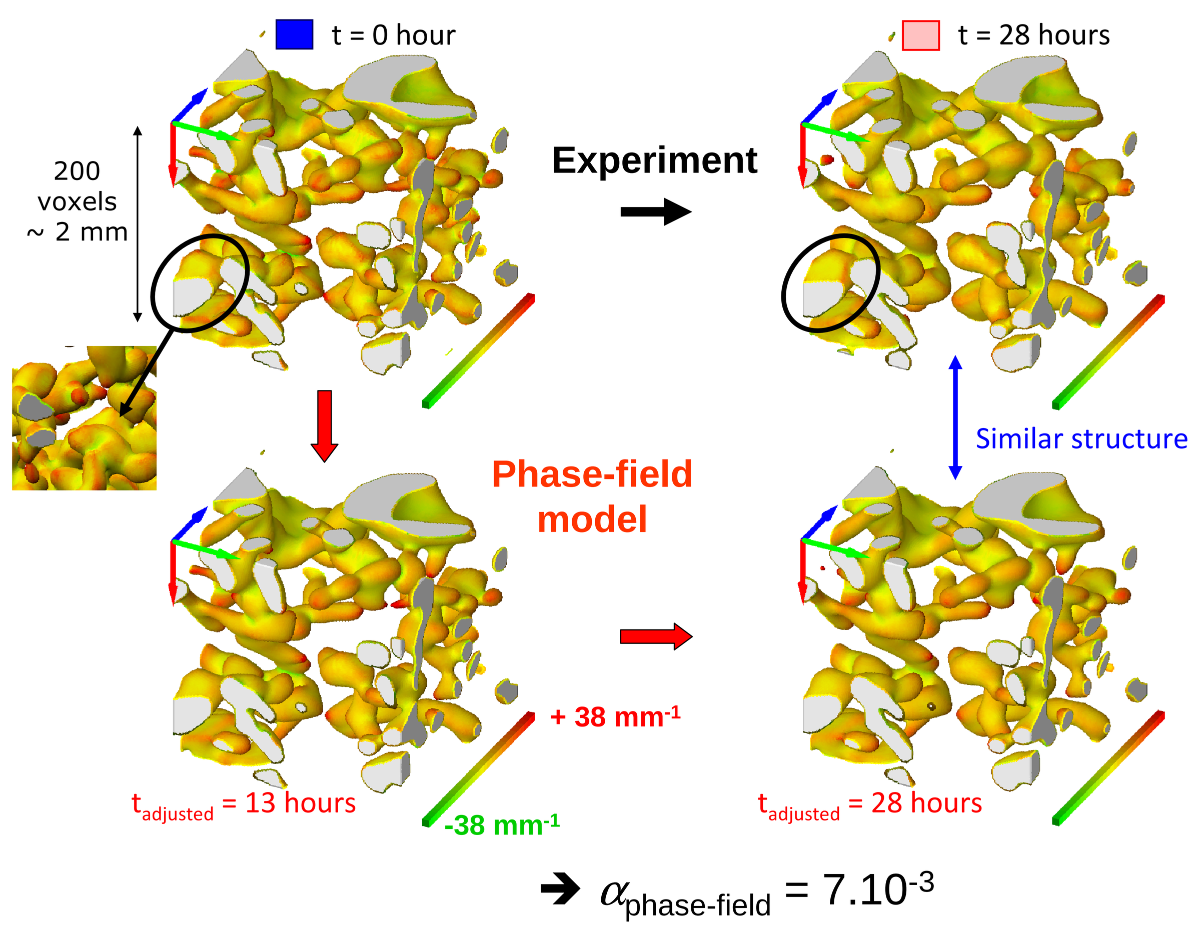
4. Preliminary Results: Is Sublimation-Deposition a Dominant Mechanism at -7°C? Which Value for α_{eff}?

Approach 1: Growth rates measurements



➔ $\alpha_{growth\_rates} = 5.10^{-4}$

Approach 2: Phase-field model



➔ $\alpha_{phase\text{-}field} = 7.10^{-3}$

Conclusions:

-A simple method has been developed to measure normal growth rates from time-lapse 3D images. It gives consistent results and can be used to better understand snow metamorphism.

-This method has been applied to snow to analyze the physical mechanisms occuring under isothermal metamorphism at -7°C. The obtained results have also been compared to an approach based on phase-field modeling: the sublimation-deposition appears as a possible mechanism with an effective accomodation coefficient about 10^{-3} but contributions of other mechanisms (vapor diffusion, grain boundary, mechanical effects…) seem difficult to neglect.

-Further analyses on larger datasets are now in progress.

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