

Métamorphoses de neige et migrations de bulles: expériences et premières analyses

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Tâche 2.3 : « Modélisation des métamorphoses: validation expérimentale »

CEN: N. Calonne, R. Caneill, A. Dufour, F. Flin, P. Hagenmuller, B. Lesaffre, L. Pézard, A. Philip,
P. Puglièse, J. Rouille...

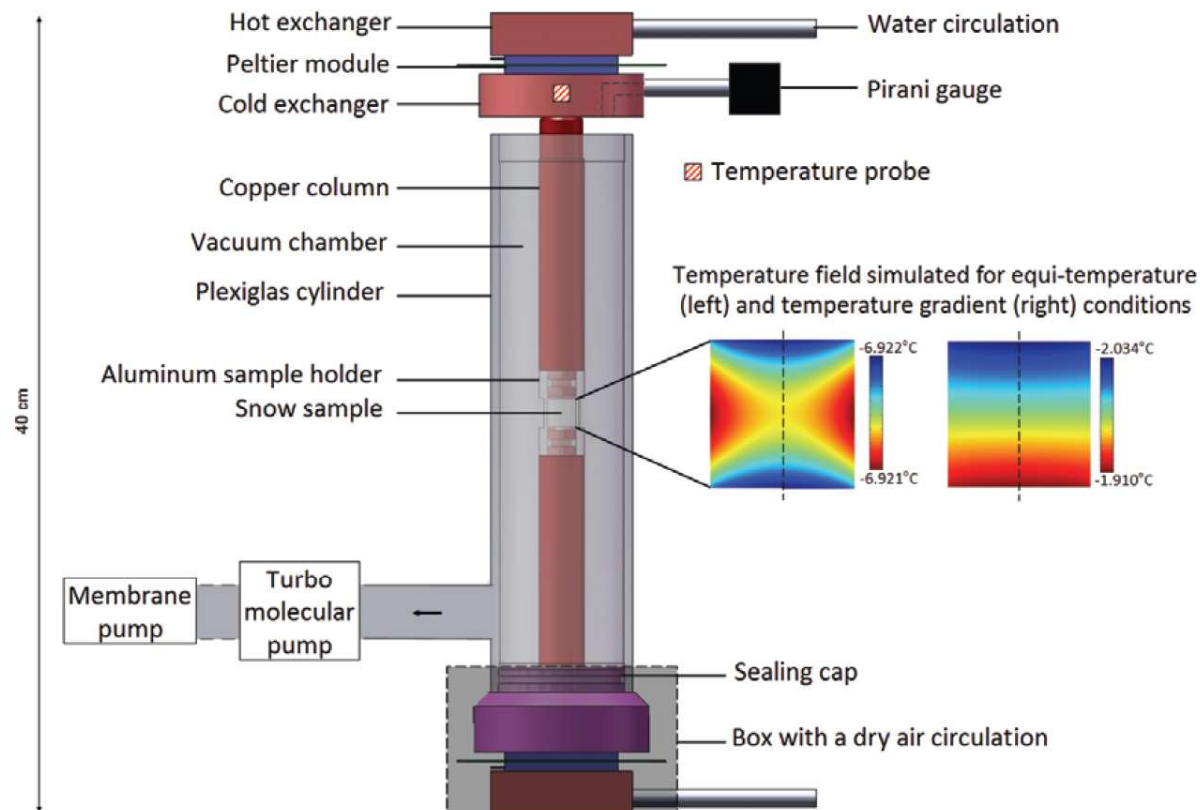
3SR: E. Ando, P. Charrier, C. Geindreau, S. Rolland du Roscoat...



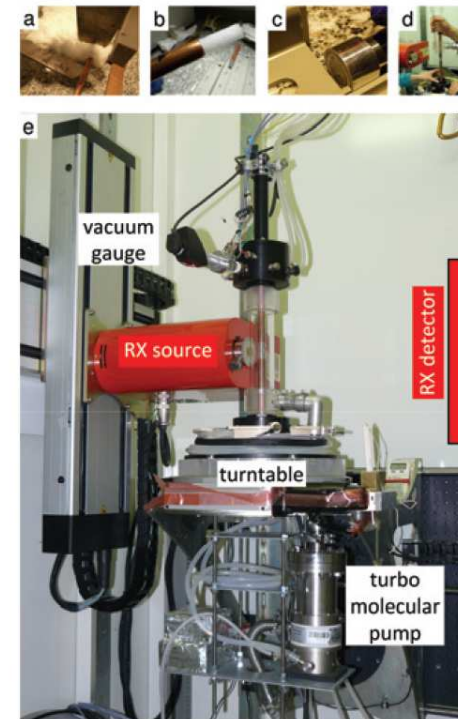
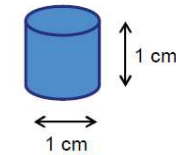
1. CellDyM: a Cryogenic Cell for Time-lapse Tomography at Room-Temperature

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 amovable conductive sample holder that protects specimens during their installation into the cell



Snow sample

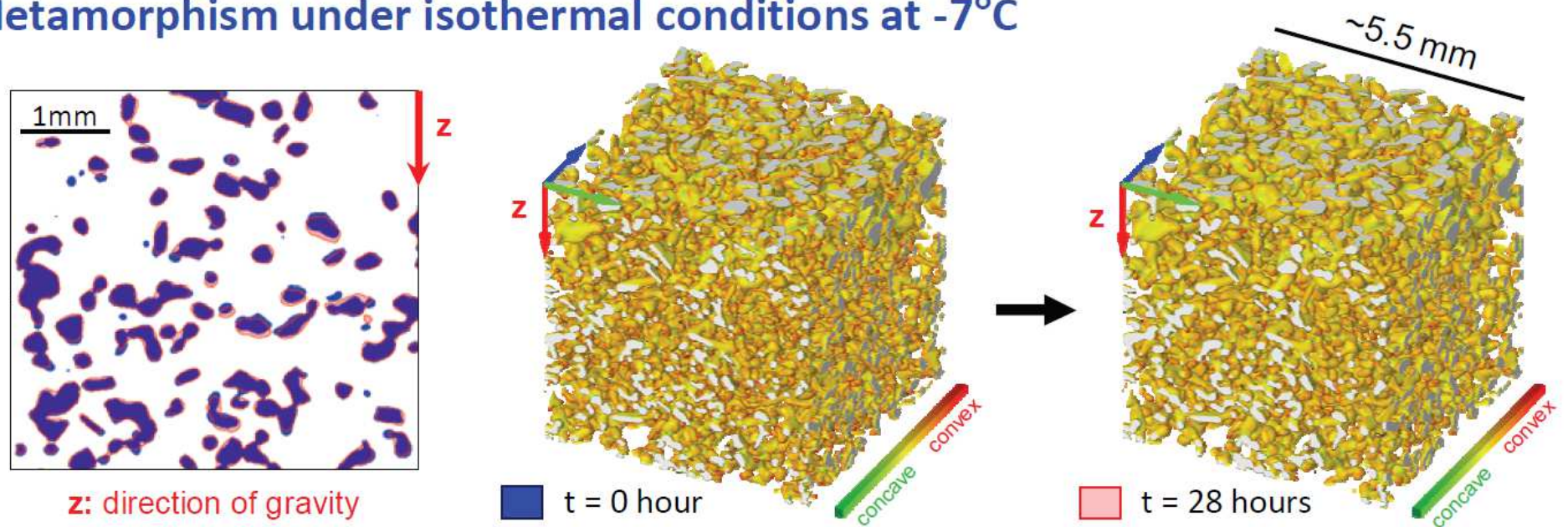


→ **Results:** 3D time-lapse series with :

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

2. Experiments and Available Time-lapse Series

Metamorphism under isothermal conditions at -7°C



<https://svn.liris.cnrs.fr/dsnow/Data/Binary>

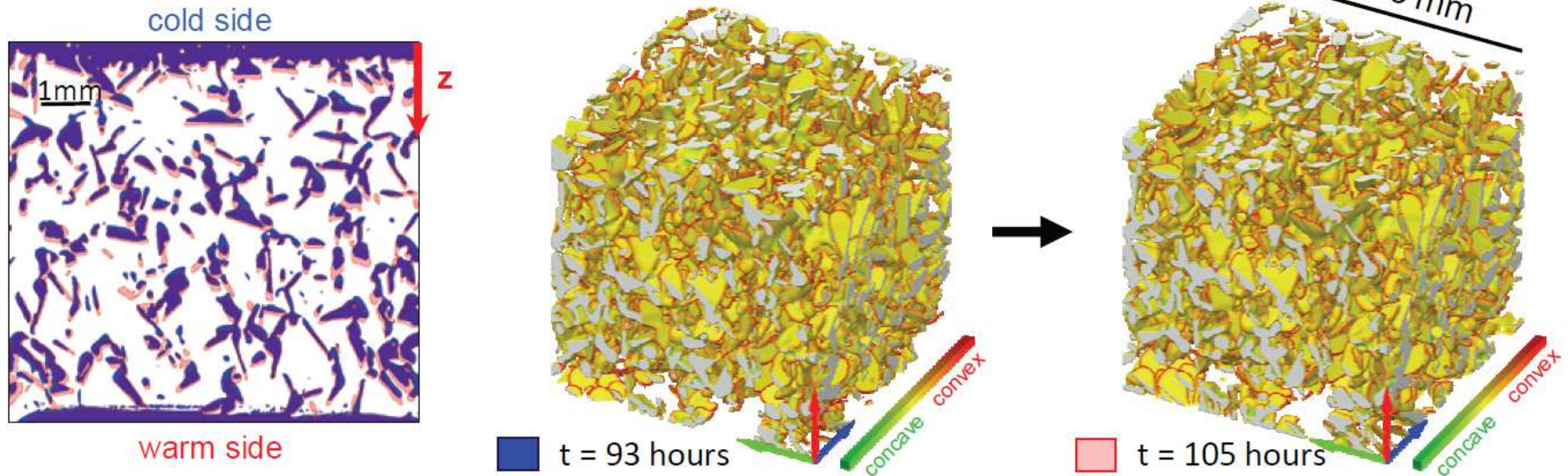
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2. Experiments and Available Time-lapse Series

Time-lapse isothermal metamorphism						
36-t01	2013_04_18_AI 1_t1_Bin _Filtree_1 495x1423 x1000_13 1_-100	DF/ RG	Time-lapse observation of isothermal metamorphism at -7° C. Initial state (0h): t1 Calonne et al., 2015	131	7.64592	3SR
36-t08	2013_04_18_AI 1_t8_Bin _Filtree_1 495x1423 x1000_x- 5_y+10_z - 23_131_- 100	DF/ RG	Time-lapse observation of isothermal metamorphism at -7° C. Final state (28h): t8 Calonne et al., 2015	131	7.64592	3SR
36-1-t01	2013_04_18_AI 1_t1_Bin _Filtree_1 495x1423 x1000_0_ 700_150 xmin_150 ymin_150 zmin	DF/ RG	Time-lapse observation of isothermal metamorphism at -7° C. Initial state (0h): t1 Calonne et al., 2015	700	7.64592	3SR
36-1-t08	2013_04_18_AI 1_t8_Bin _Filtree_1 495x1423 x1000_x- 5_y+10_z - 23_1000_ 0_700_15 0xmin_15 0ymin_15 0zmin	DF/ RG	Time-lapse observation of isothermal metamorphism at -7° C. Final state (28h): t8 Calonne et al., 2015	700	7.64592	3SR

2. Experiments and Available Time-lapse Series

Metamorphism under a TG of 18 K/m at -2°C



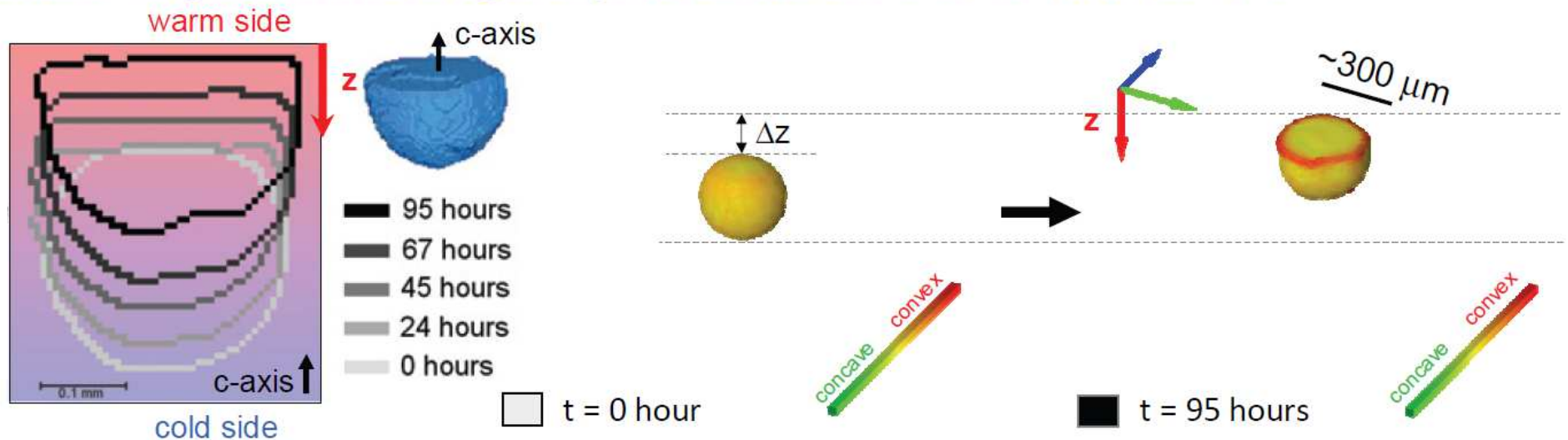
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https://svn.liris.cnrs.fr/dsnow/Data/2015_06_11_Tableau_infos_images_binaires

→ To be uploaded

2. Experiments and Available Time-lapse Series

Bubble migration in a single crystal under a TG of 45 K/m at -4°C



<https://svn.liris.cnrs.fr/dsnow/Data/Binary>

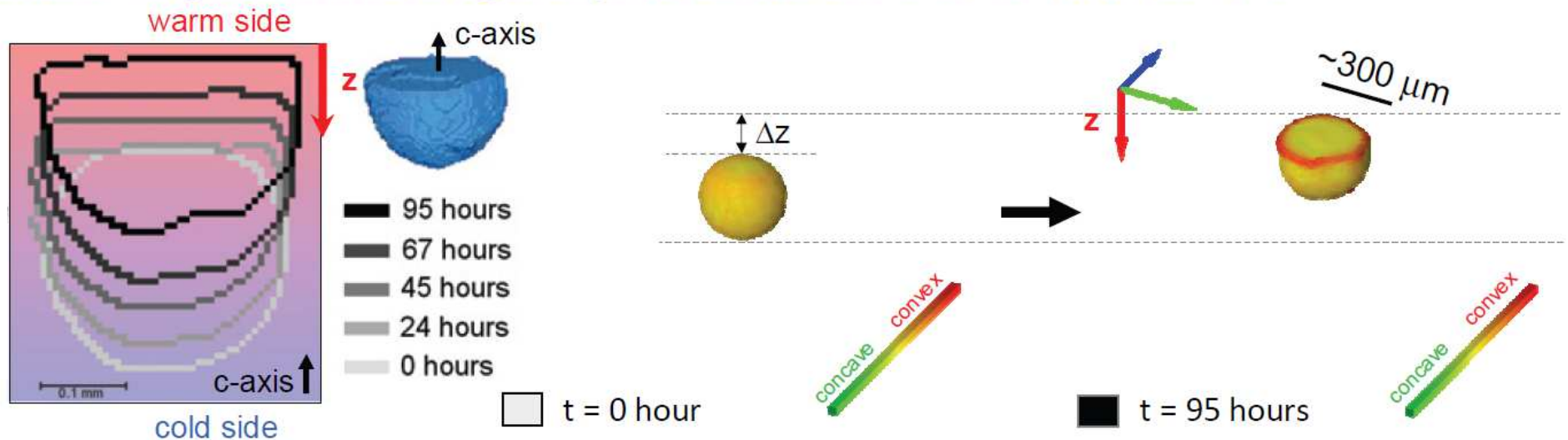
https://svn.liris.cnrs.fr/dsnow/Data/2015_06_11_Tableau_infos_images_binaires

2. Experiments and Available Time-lapse Series

Time lapse migration of Bubble 1 under TG						
38-t00	140616_bulle1_t 0_BinFiltre e_1700x17 00x1061_1 35_925xmi n_725ymin _435zmin	Air bubble	Time-lapse observation of an air bubble under a vertical TG of 45 K/m, $T_{\text{mean}} = -4^{\circ}$ C. The c-axis is vertical. Initial state (0h): t0	135	7.43349	3SR
38-t01	140616_bulle1_t 1_BinFiltre e_1700x17 00x1061_1 35_925xmi n_725ymin _435zmin	Air bubble	Time-lapse observation of an air bubble under a vertical TG of 45 K/m, $T_{\text{mean}} = -4^{\circ}$ C. The c-axis is vertical. Initial state (2h40): t1	135	7.43349	3SR
38-t02	140616_bulle1_t 2_BinFiltre e_1700x17 00x1061_1 35_925xmi n_725ymin _435zmin	Air bubble	Time-lapse observation of an air bubble under a vertical TG of 45 K/m, $T_{\text{mean}} = -4^{\circ}$ C. The c-axis is vertical. Initial state (15h35): t2	135	7.43349	3SR
...	...					
38-t18	...					

2. Experiments and Available Time-lapse Series

Bubble migration in a single crystal under a TG of 45 K/m at -4°C

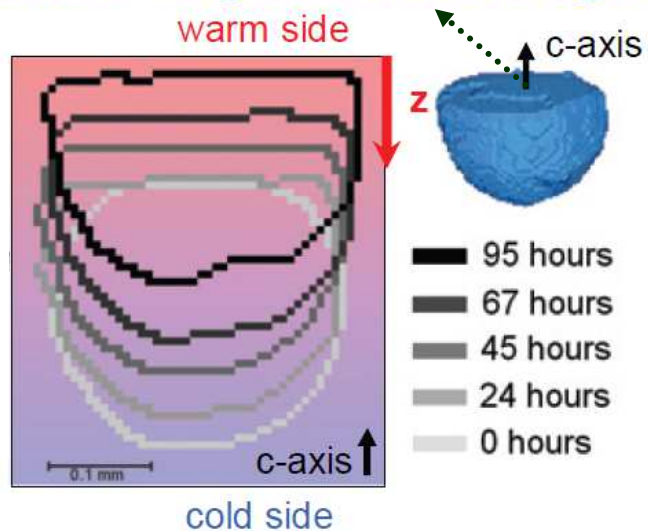


<https://svn.liris.cnrs.fr/dsnow/Data/Binary>

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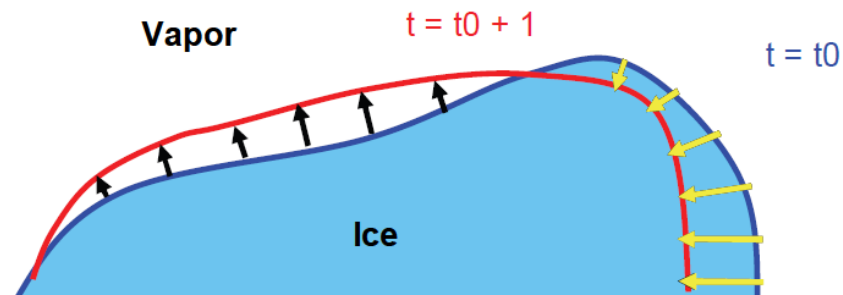
2. Experiments and Available Time-lapse Series

Bubble migration in a single crystal under a TG of 45 K/m at -4°C



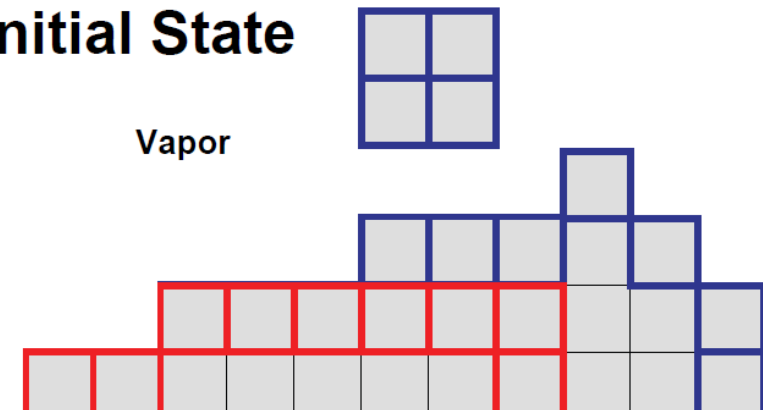
Experiment with **c-axis not along the TG direction**: done
→ Image processing: to be done

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



Continuous problem

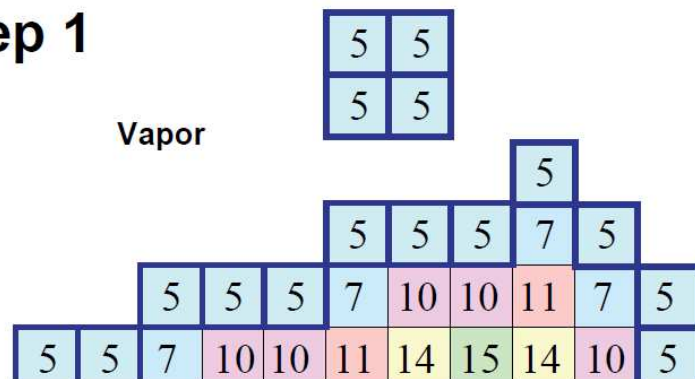
Initial State



Binary image – interface in blue
In red: new position of the interface

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

Step 1



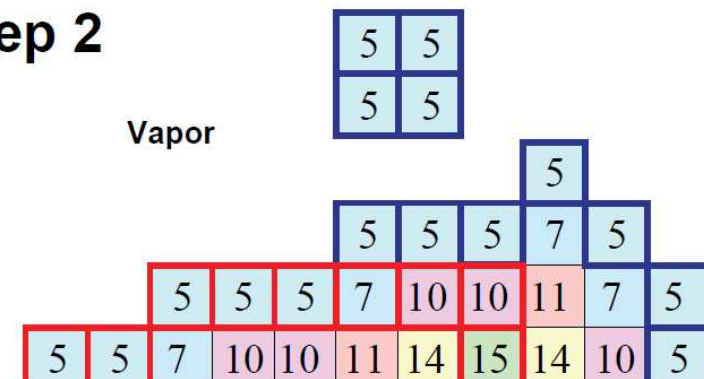
Binary image – interface in blue

Distance map ϕ : proportional to the distance of the background (pores)

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

$$d = (5 - \phi)/5 \quad (\text{pixels})$$

Step 2

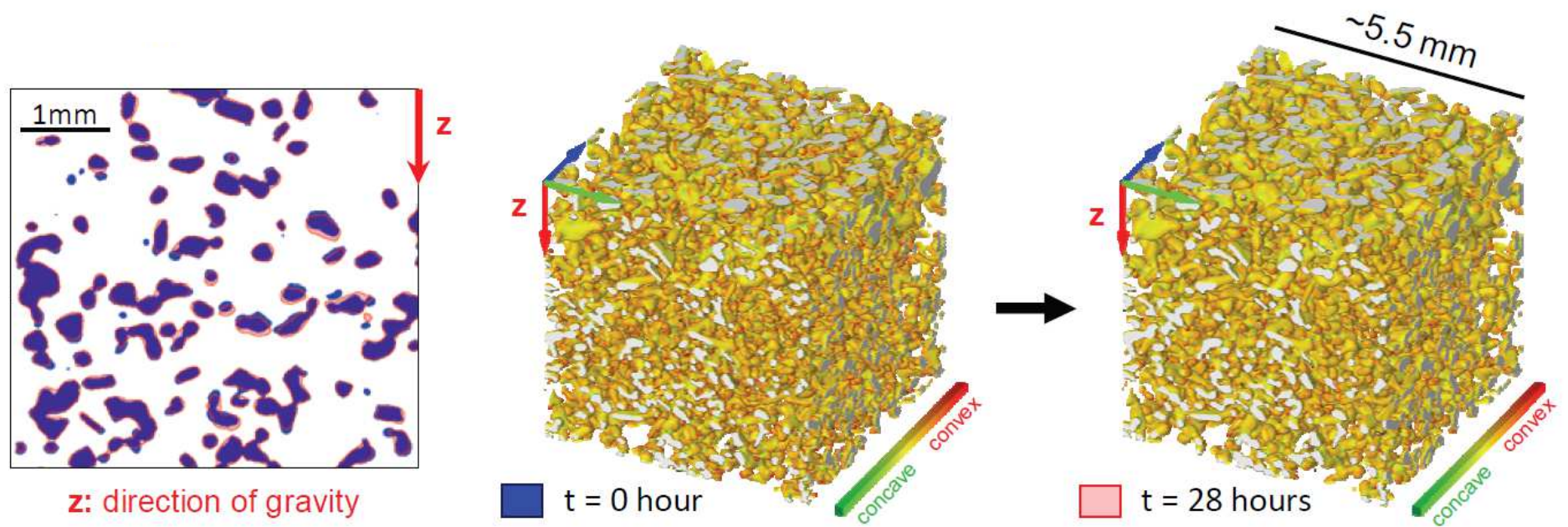


→ local growth (and sublimation) rates r

→ local fluxes $\dot{j} = r \cdot \rho_{ice}$ at the interface

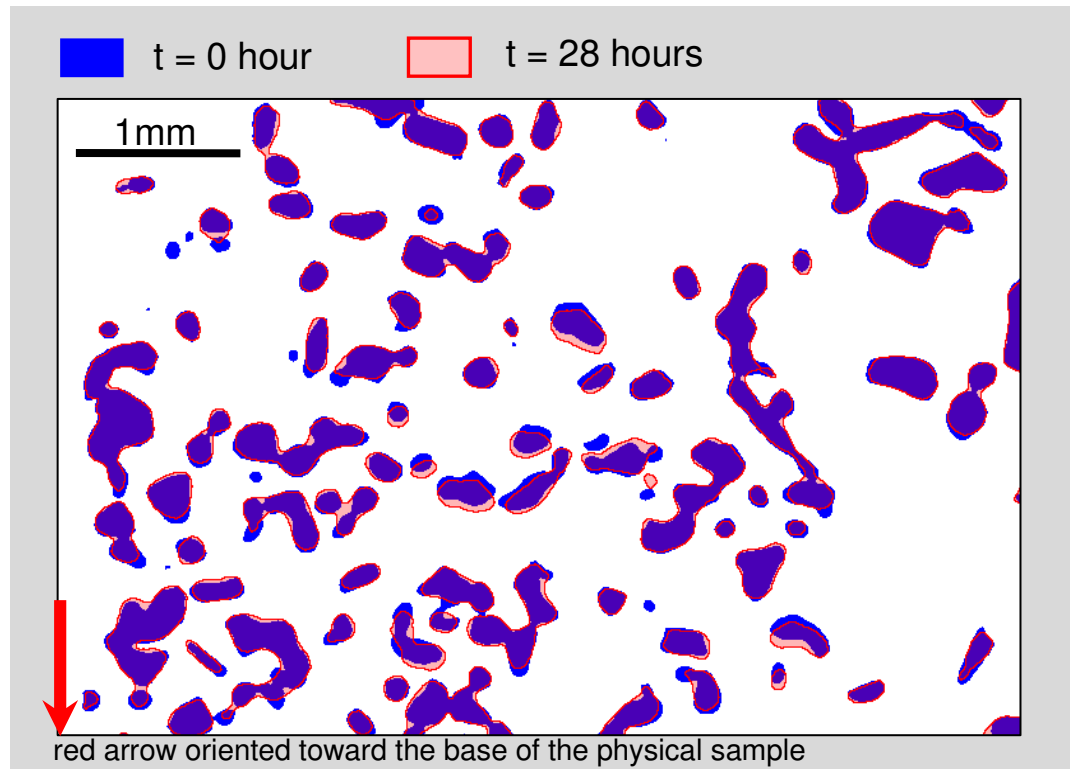
4. Preliminary Results for Isothermal Metamorphism

Equi-temperature metamorphism at -7°C



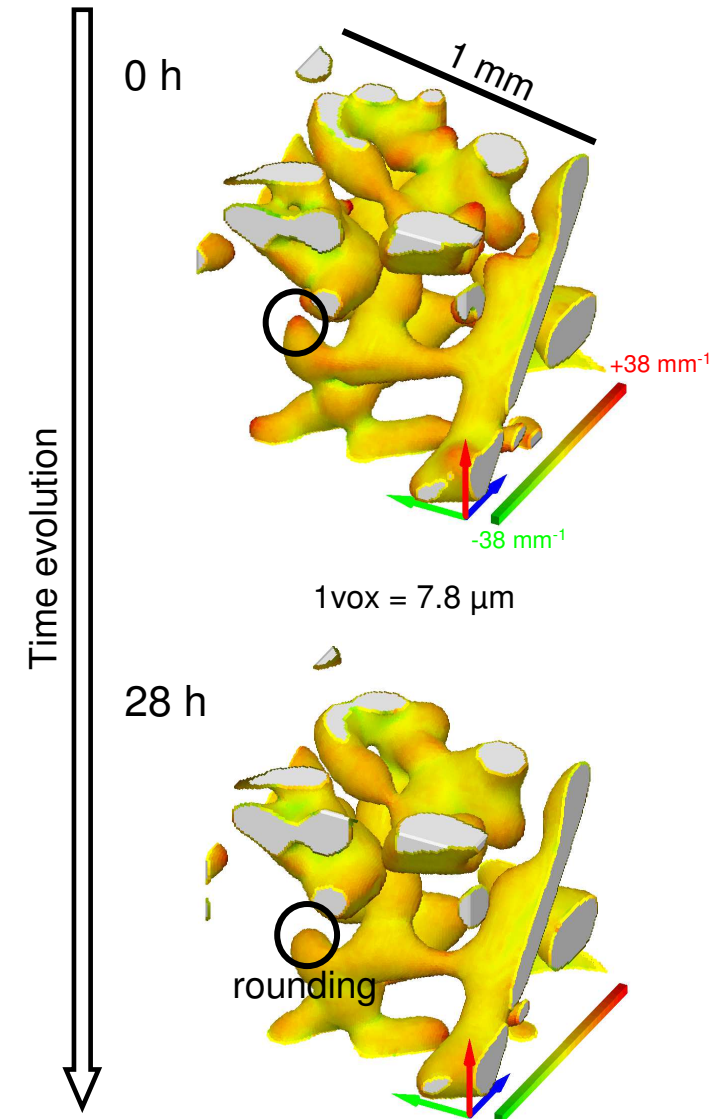
4. Preliminary Results for Isothermal Metamorphism

Equi-temperature metamorphism at -7°C



Typical features of the evolution under curvature effects:

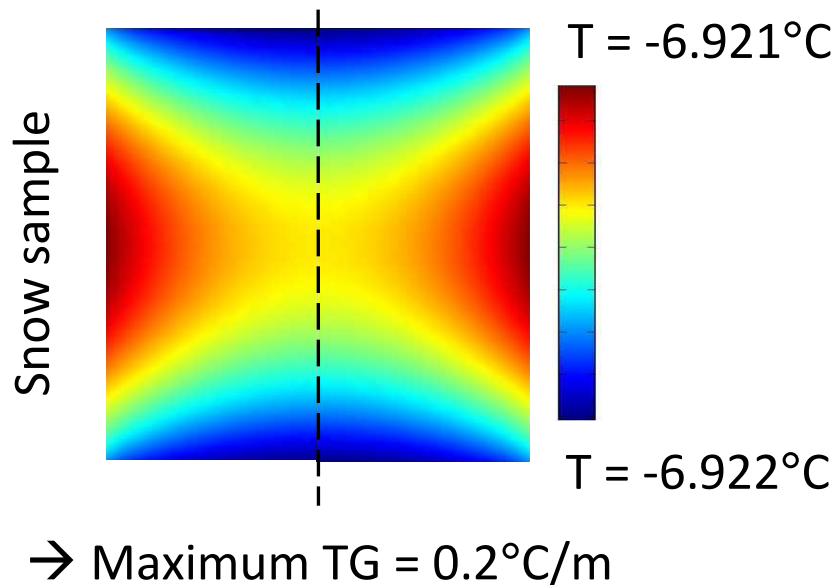
- Slow evolution
- Settlement
- Grain rounding
- Growth/decay of bonds



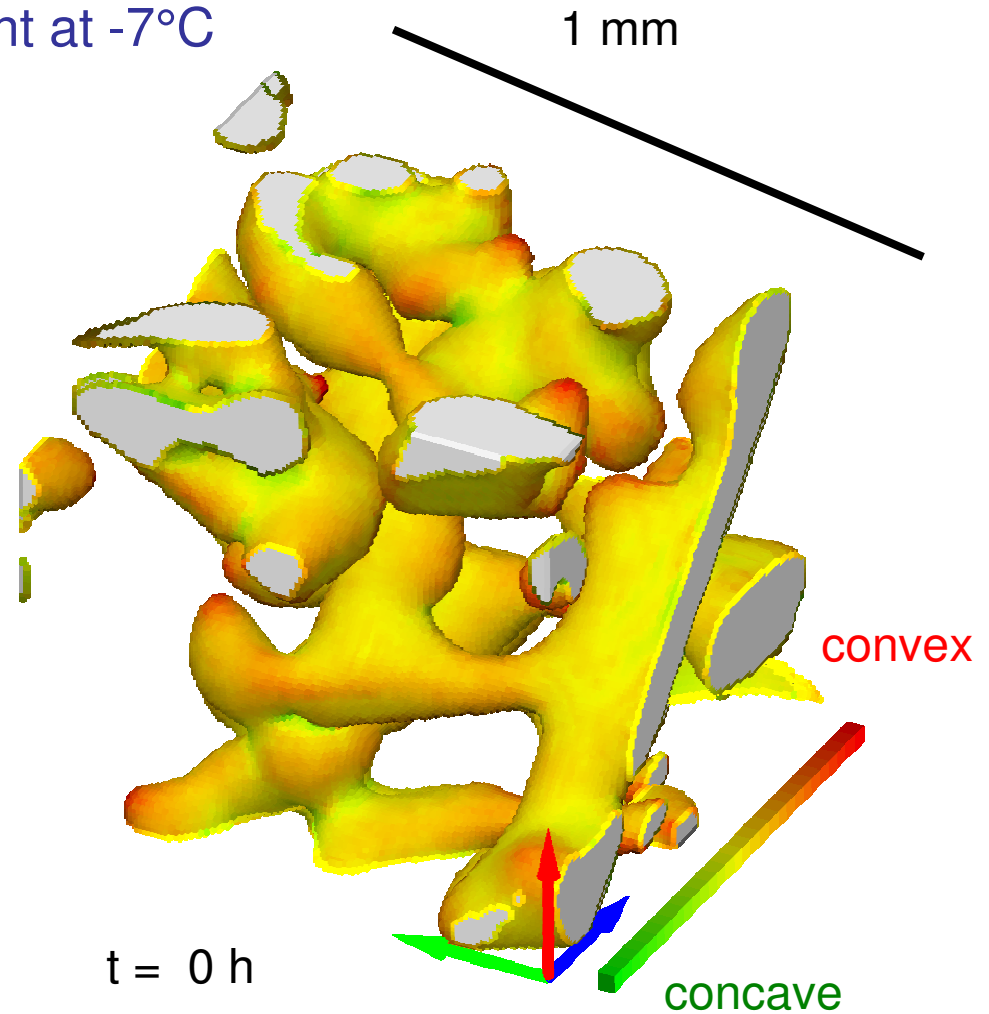
4. Preliminary Results for Isothermal Metamorphism

28 h of equi-temperature experiment at -7°C

Simulated temperature field for a regulation of Peltier modules at -7°C



Heat conduction modeling
in the cold cell

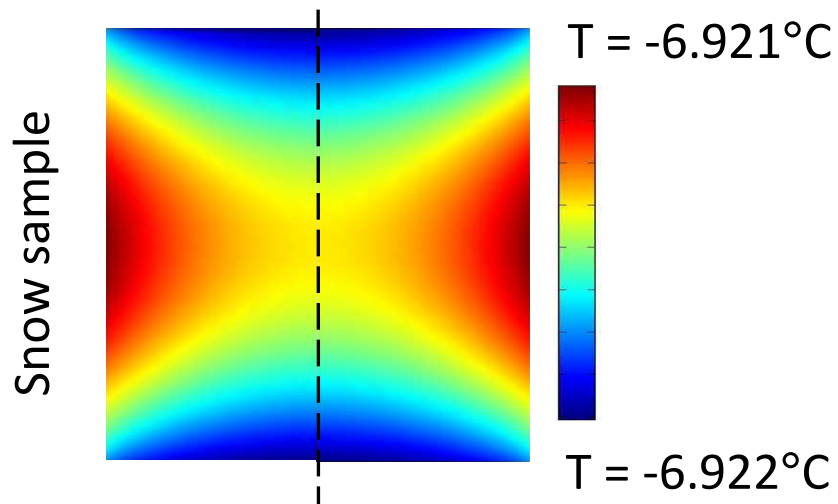


Experimental result

4. Preliminary Results for Isothermal Metamorphism

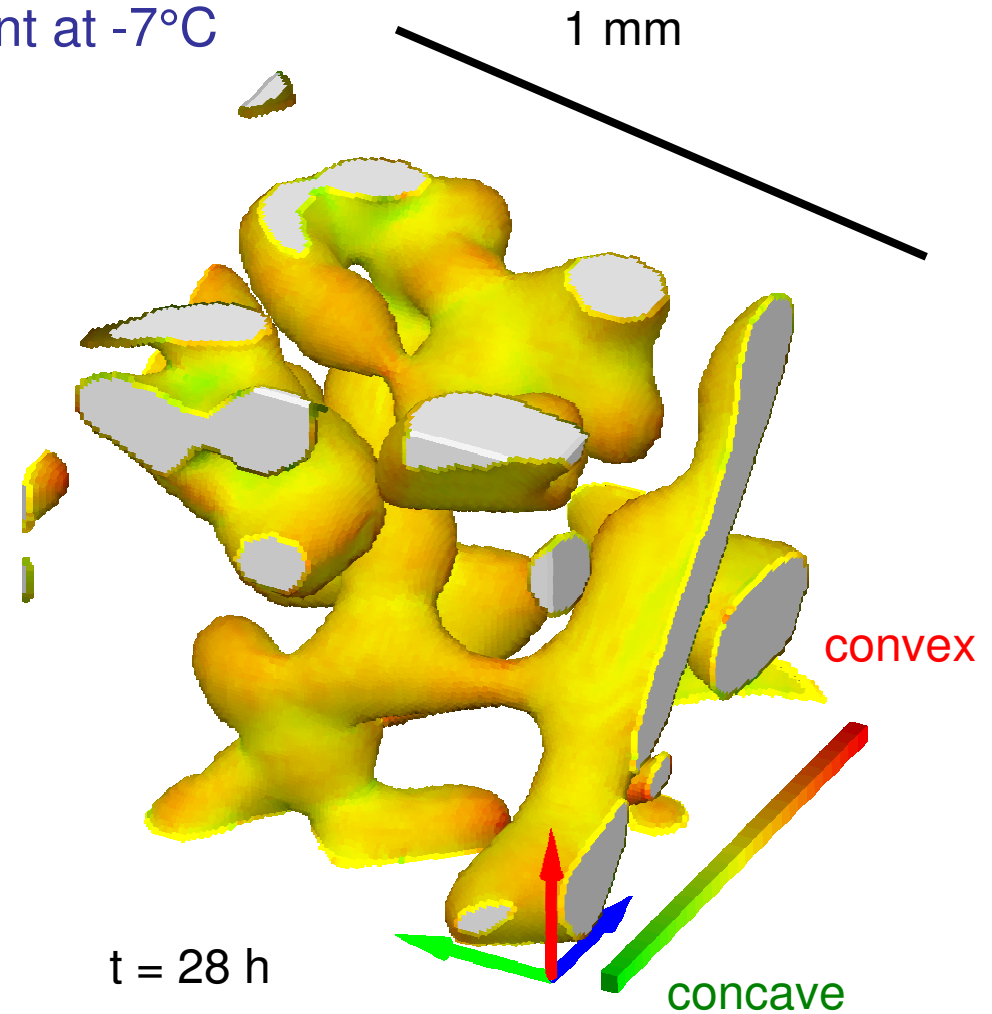
28 h of equi-temperature experiment at -7°C

Simulated temperature field for a regulation of Peltier modules at -7°C



→ Maximum TG = $0.2^{\circ}\text{C}/\text{m}$

Heat conduction modeling
in the cold cell



4. Preliminary Results for Isothermal Metamorphism

