Microtomography at 3SR Lab for the study of snow

Frédéric Flin
frederic.flin@meteo.fr
Centre d'Etudes de la Neige

CEN: N. Calonne, A. Dufour, F. Flin, P. Hagenmuller, B. Lesaffre, L. Pézard, P. Puglièse, J. Roulle…
3SR: E. Ando, P. Charrier, C. Geindreau, S. Rolland du Roscoat…
IRSTEA/Etna: G. Chambon, M. Naaim

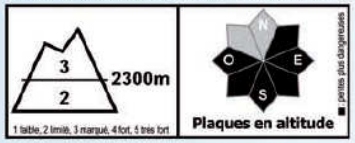
1. Context
2. Experimentation
3. Some applications
4. Recent development: dynamic observation of snow

Context – importance of a good knowledge of the snowpack

Societal issues
- Avalanche risk forecasting
- Climate studies
- Water ressources…

ESTIMATION DU RISQUE JUSQU'AU MERCREDI 19 DÉCEMBRE 2012 AU SOIR

Au-dessus de 2300 m : Risque marqué. En-dessous : Risque limité.



Départs spontanés : Coulées ou avalanches en pentes Sud.

Déclenchements skieurs : Près des crêtes, à l'abri du vent de Nord

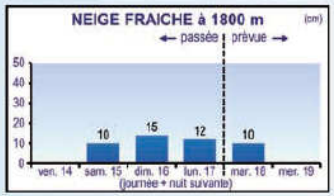
STABILITE DU MANTEAU NEIGEUX

RISQUE DE DECLENCHEMENT DE PLAQUE VERS LES CRETES D'ALTITUDE ; EN PENTES SUD, LA NEIGE RECENTE PEUT "COULER"....

La couche de neige récente est à surveiller ce mercredi de beau temps.

Vers les crêtes d'altitude, le skieur/randonneur se méfiera du travail du vent : des plaques (parfois friables, d'apparence poudreuse) on été formées par vent de Nord-ouest puis Nord-Est. Localement, le passage d'une personne peut entraîner une cassure de 30 cm, voire 50 cm au delà de 2300m. Rester vigilant car après la belle poudreuse des combes et couloirs, les pentes sommitales pourront être piégeuses.

En pentes sud réchauffées par le soleil, surtout près des rochers, on s'attend à des coulées superficielles voire à de petites avalanches de neige humidifiée (sous 2200m). Surveiller les horaires de passage près des longues pentes. Des fissures de reptations sont parfois visibles sur les alpages.



APERCU METEO

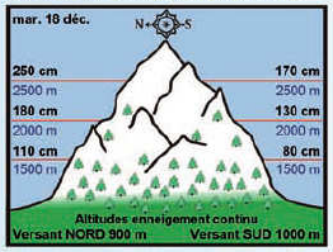
mercredi 19 déc.

nuit	matin	après-midi

Beau, quelques cirrus, douceur au Sud

pluie-neige			
iso 0°C	1000 m	1400 m	2200 m
vent 2000 m	30 km/h	20 km/h	nul
vent 3000 m	50 km/h	40 km/h	10 km/h

EPAISSEUR DE NEIGE HORS-PISTE



QUALITE DE LA NEIGE

Une couche de neige poudreuse dès 1100m repose sur de la vieille neige dense, parfois regelée. Elle va s'humidifier au soleil.

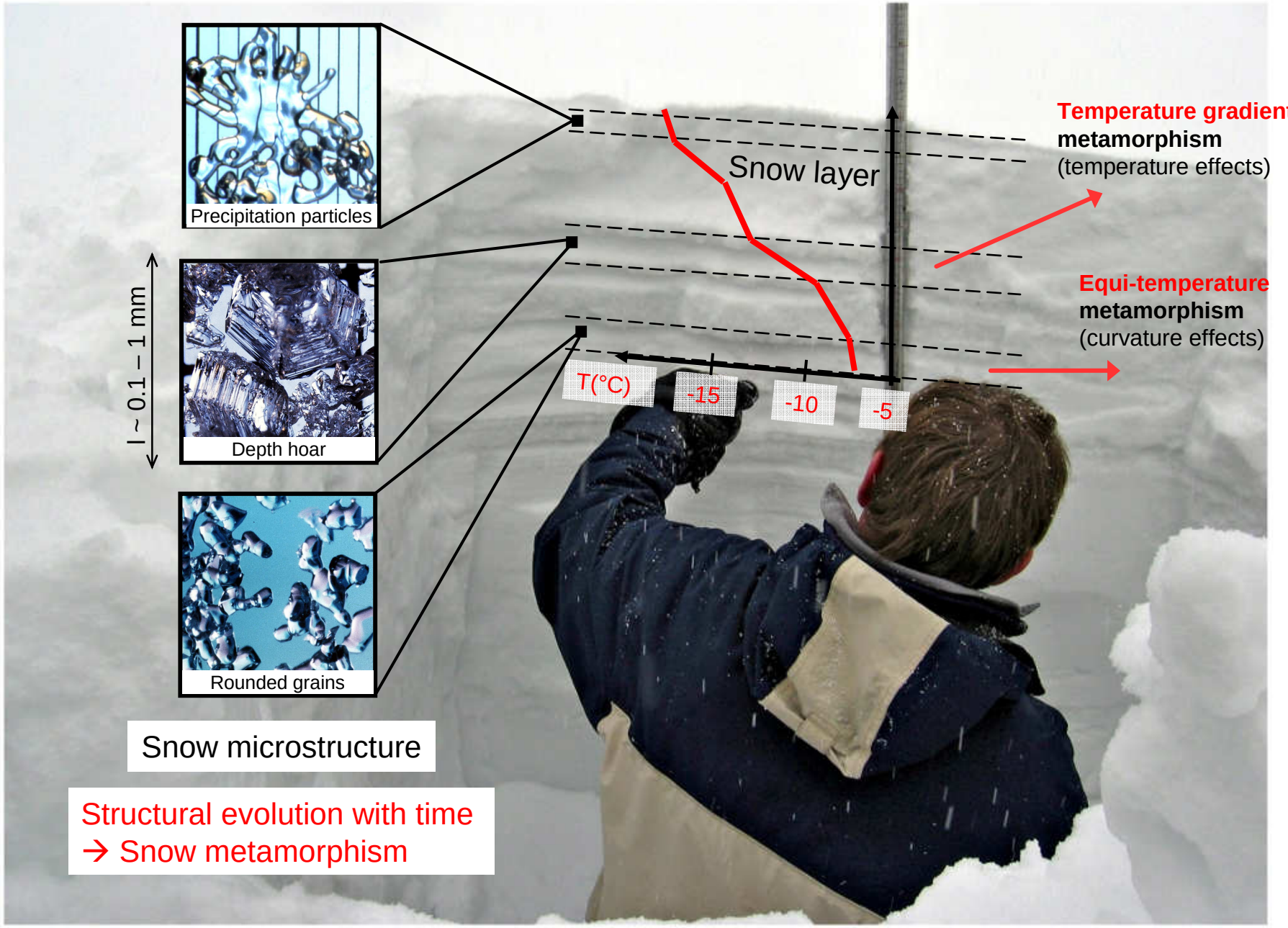
Au dessus de 1800m la couche de neige récente atteint 30/40 cm. Ski agréable dans les combes froides...

Près des crêtes la neige récente est plus ou moins soufflée/compactée par vent de Nord-Ouest puis Nord-Est.

TENDANCE ULTERIEURE DU RISQUE

jeudi 20 ↗ vendredi 21 →

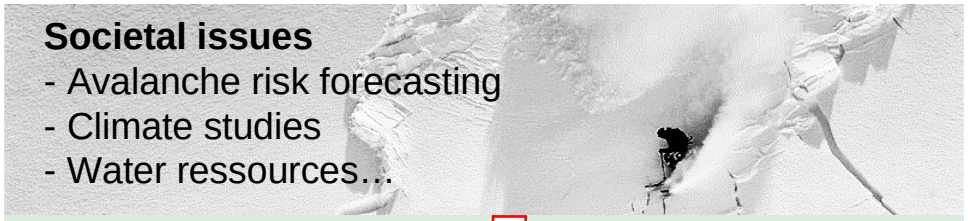
Context – snowpack properties are changing with time



Snow microstructure

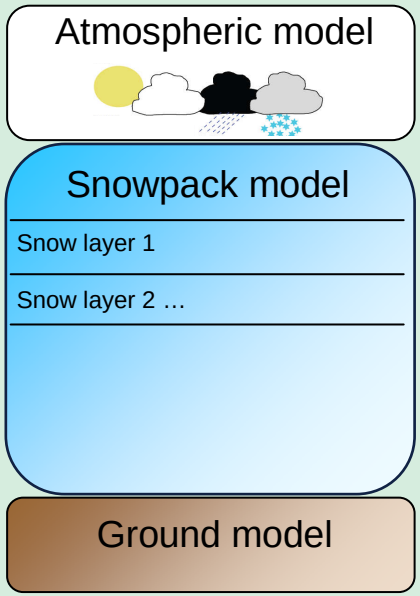
Structural evolution with time
→ Snow metamorphism

Context – need of microscale observations



Societal issues
- Avalanche risk forecasting
- Climate studies
- Water ressources…

Snowpack models for the prevision of the time evolution of the macroscopic properties (temperature, mechanical properties…)

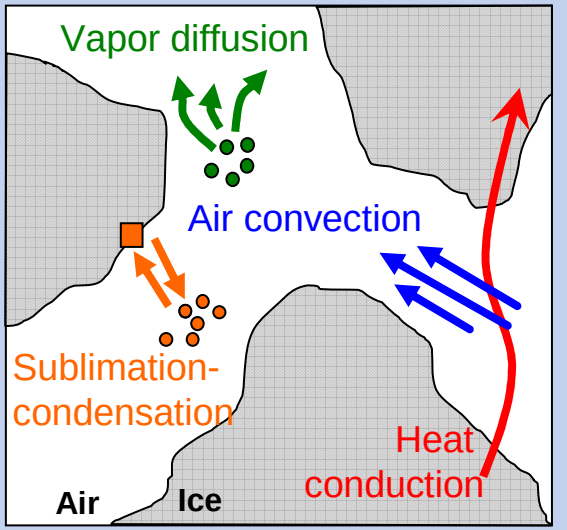


- Physical processes
  - Heat conduction
  - Vapor diffusion
  - Air convection
  - Phase change (source terms)
  - Compaction
  - …
- Effective properties = f (microstructure)

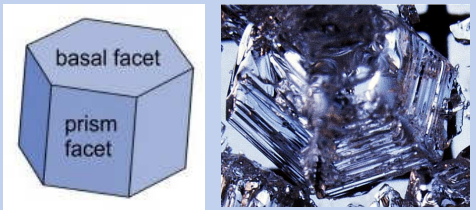
MACRO

Snow metamorphism

- Heat and mass transfer



- Ice crystal growth

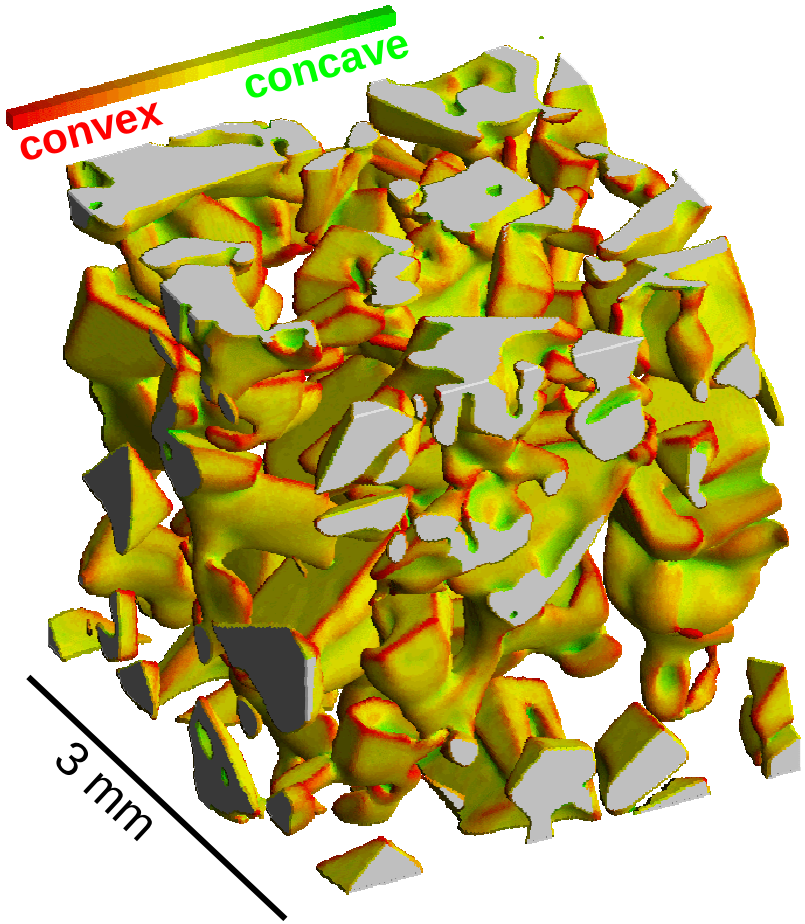


MICRO

→ Needs fine observations

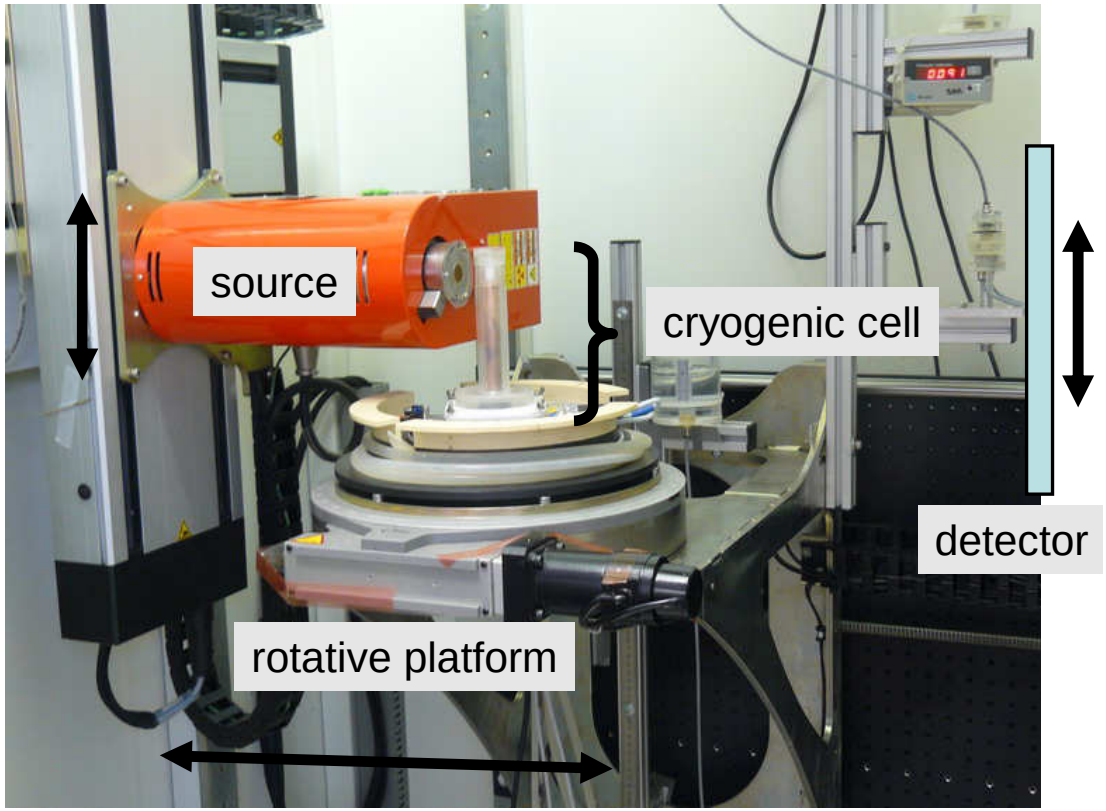
Experimentation – RX tomography: 3D images

3D image



Curvature field

Tomograph cabin



- conical X-ray microtomograph
- at ~+20℃
- acceleration voltage of 75 kV
- current intensity of 100 µA
- 1200 radiographies
- around 2 hours of acquisition
- precision: 10 µm/pixel

Experimentation – sample preparation and cryogenic cell

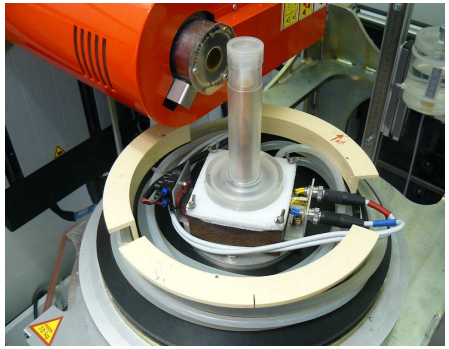
1. Sampling

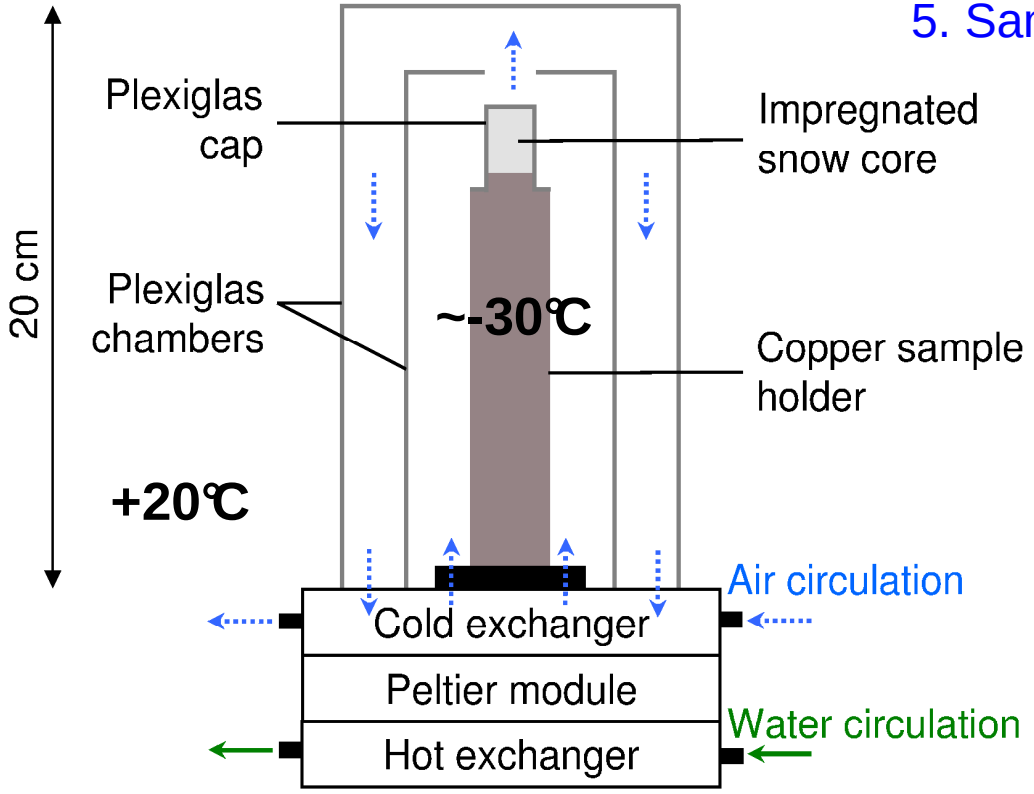
2. Impregnation

3. Freezing

4. Machining

Cryogenic cell

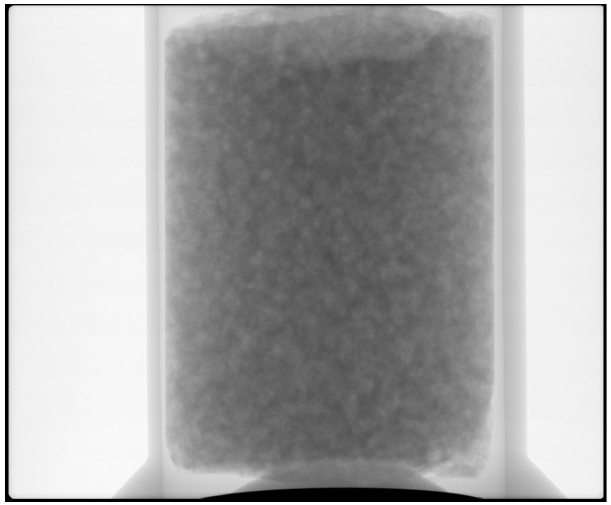




5. Sample holder

Experimentation – obtention of 3D binary images

Obtention of 1200 radiographies



Reconstruction
(Softwear DigiXCT)

Reconstructed cross-section

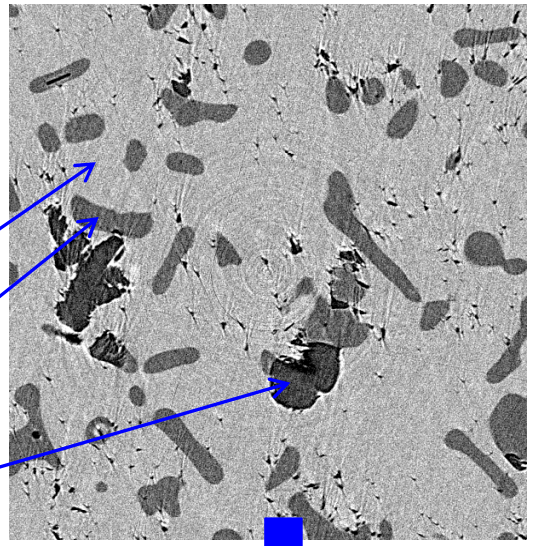
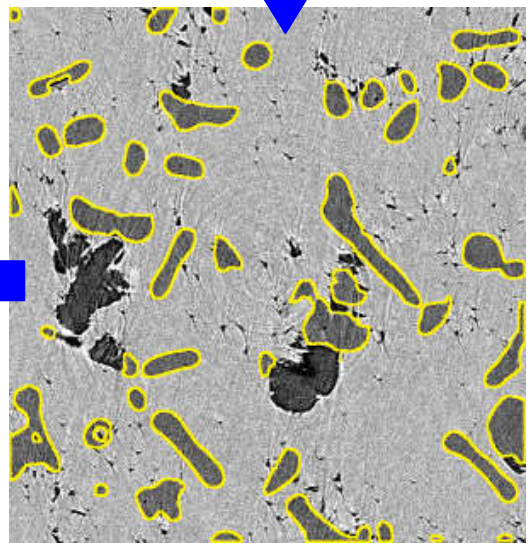
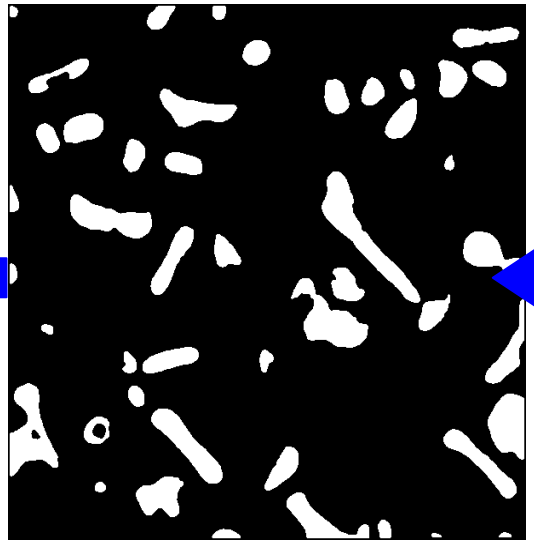


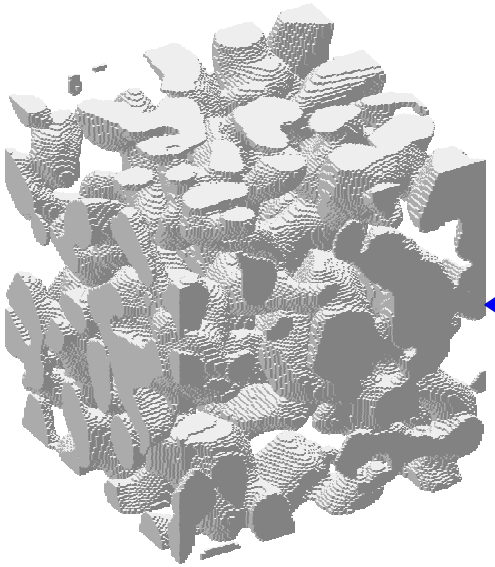
Image processing



Thresholded cross-section

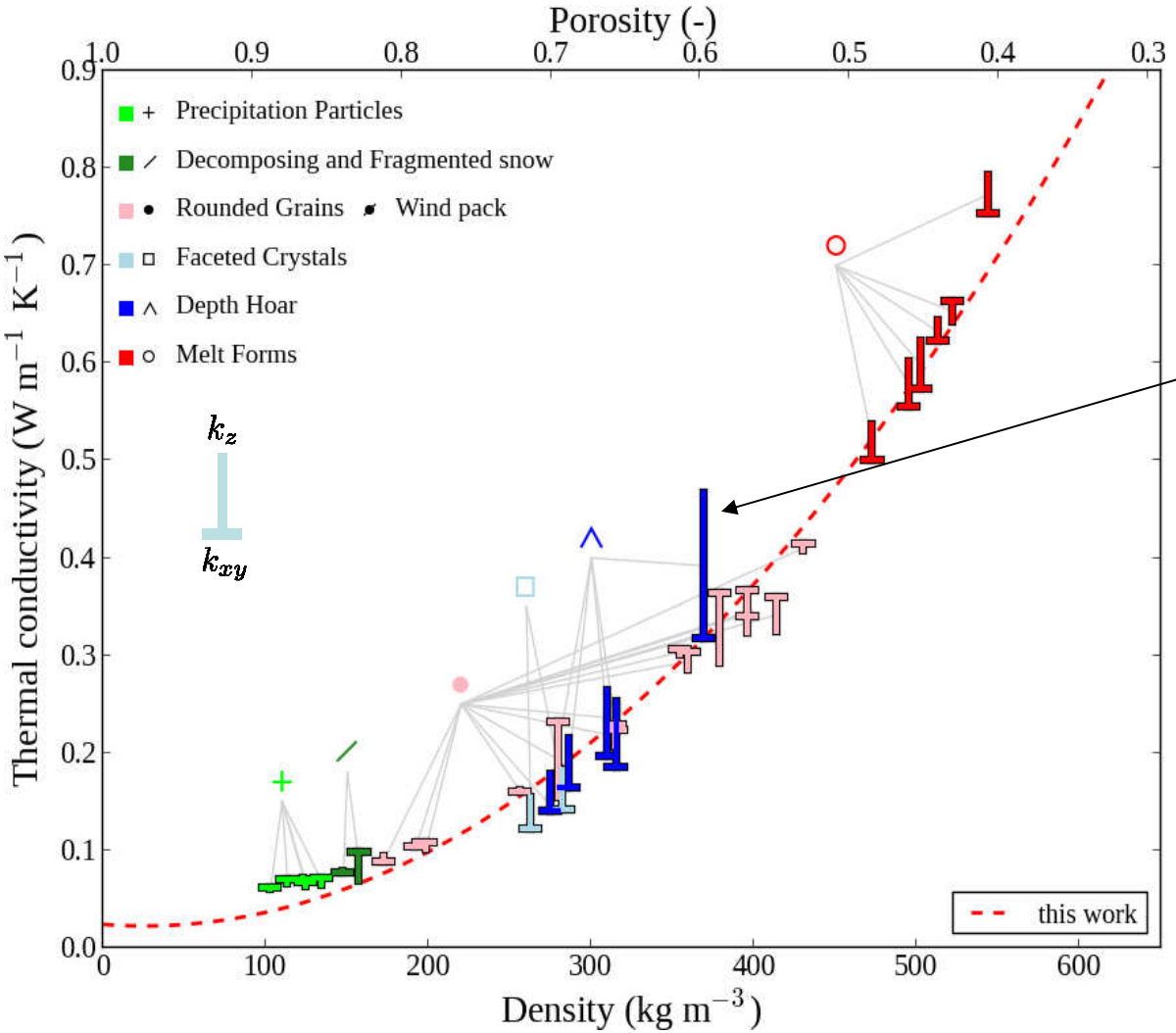


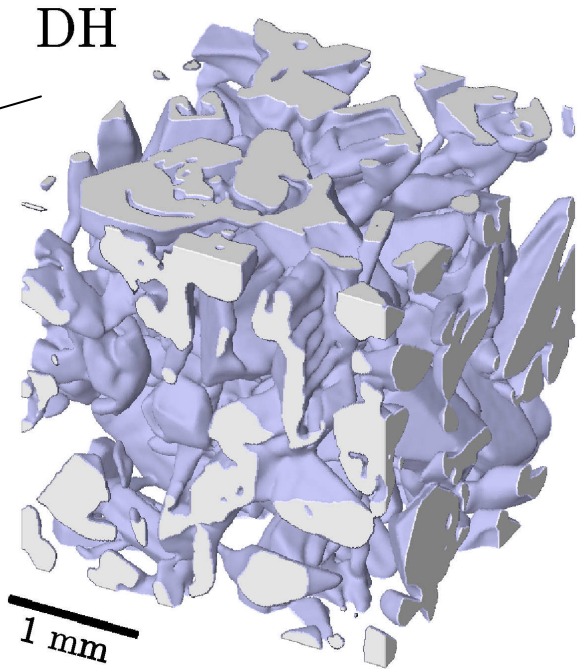
Binary cross-section



3D images

Some applications – Effective thermal conductivity

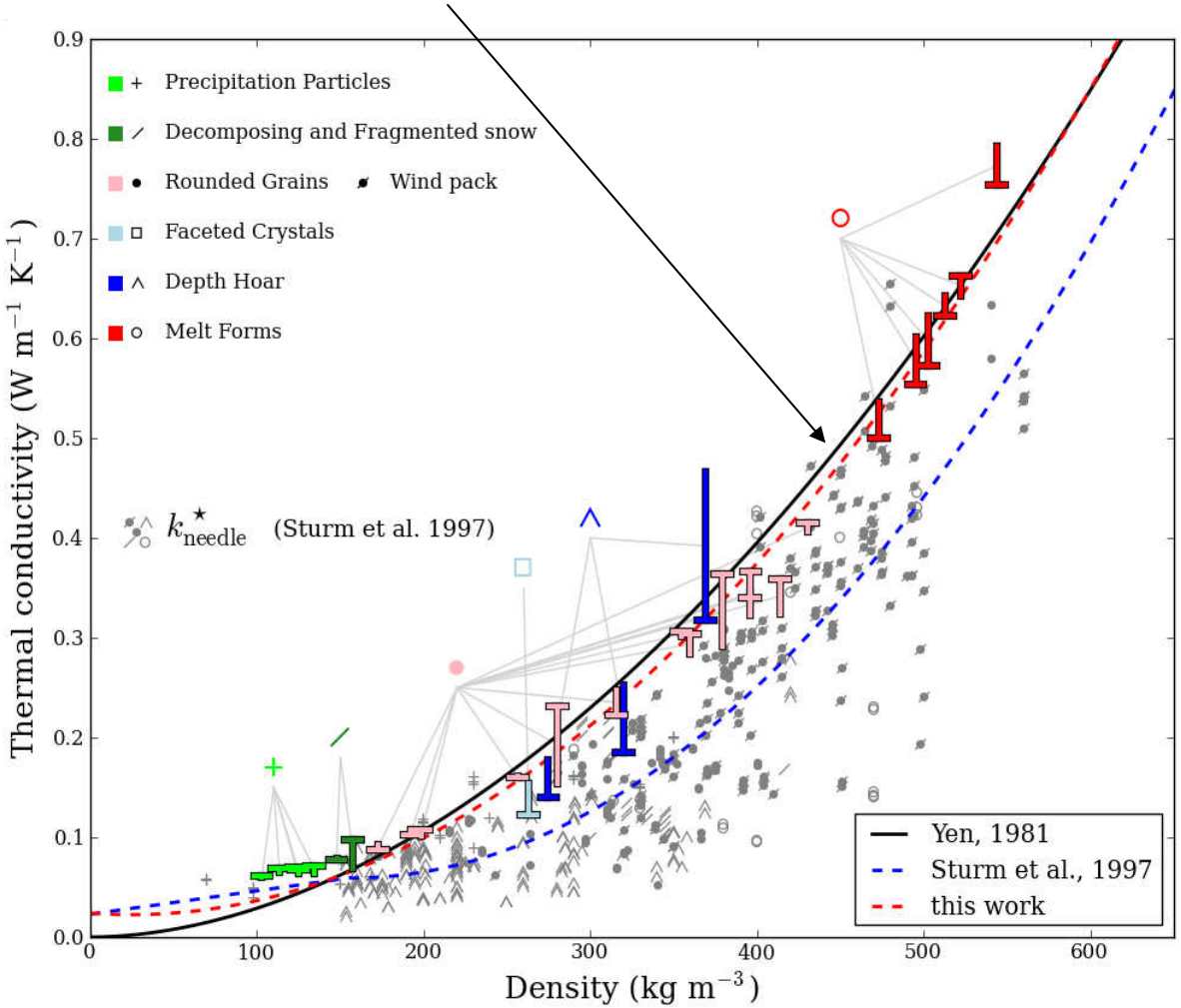




$$\kappa_i = 2.107\ \mathrm{W\,m^{-1}\,K^{-1}}$$
$$\kappa_a = 0.024\ \mathrm{W\,m^{-1}\,K^{-1}}$$

Some applications – Effective thermal conductivity

Fit used in CROCUS



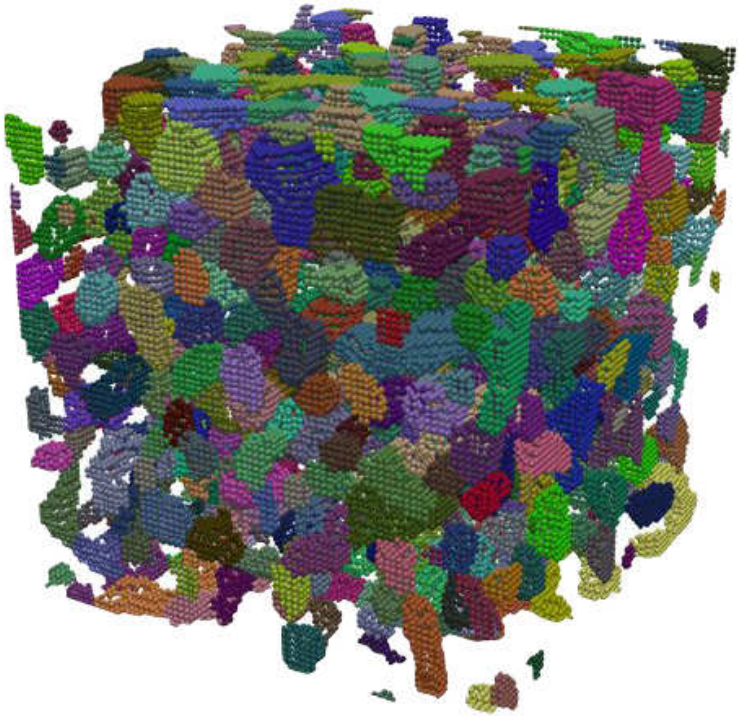
- Needle probe measurements are significantly lower than computed values.

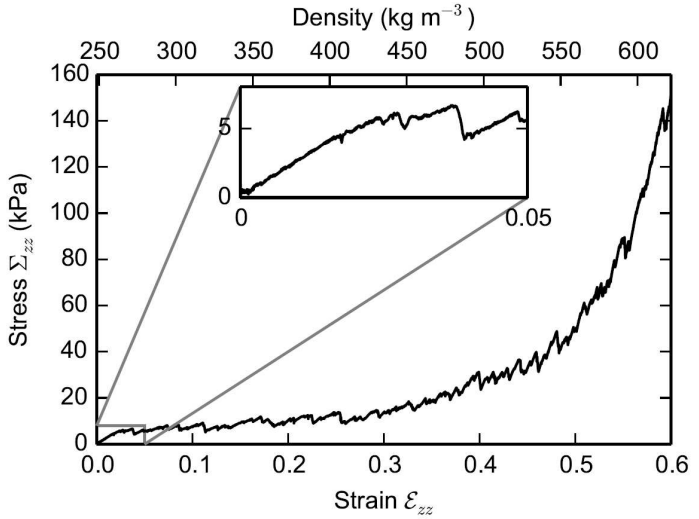
- Consistent with Yen's fit (CROCUS model)

Some applications – Mechanics using DEM

- Conversion into grains :
  - Binary segmentation
  - Grain segmentation
  - Clumps

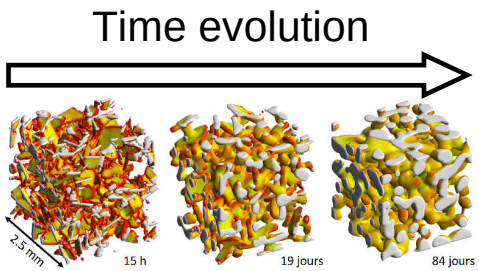
- DEM simulation (YADE)
  - Grains_png_Hagenmuller.mov



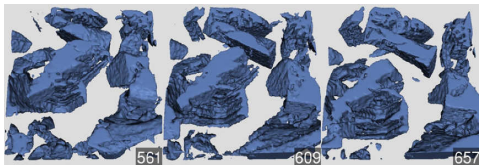


Recent development – dynamic observation of snow

GOAL – Monitor the snow metamorphism by RX micro-tomography



Flin et al. 2004



Pinzer et al. 2009

- Static approach: Monitor the evolution of a **snow slab** in cold-room or in the field by sampling at regular time interval for tomography

- Dynamic approach: Monitor the evolution of the **same snow sample** set up in a cryogenic cell for time-lapse tomography, up to now only in a cold-room

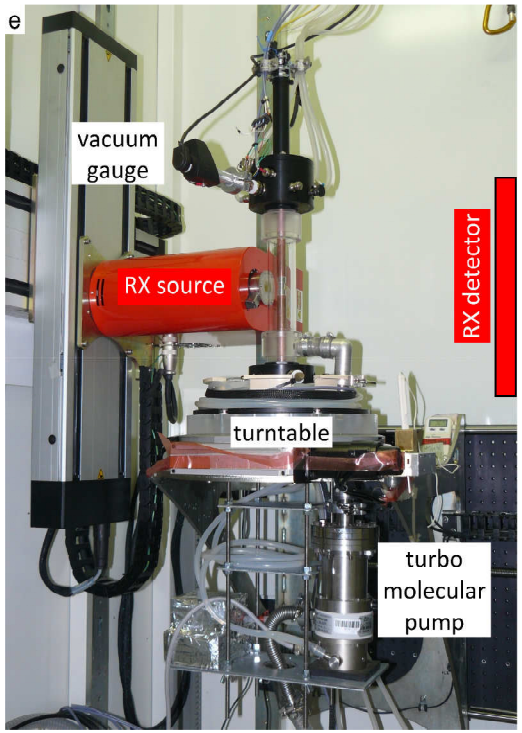
Dynamic approach: a new cryogenic cell for the dynamic monitoring of metamorphism

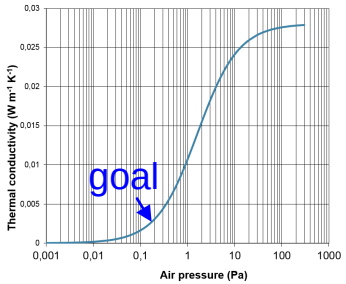
- operating at room temperature conditions
- adaptable to a large panel of tomographic scanner

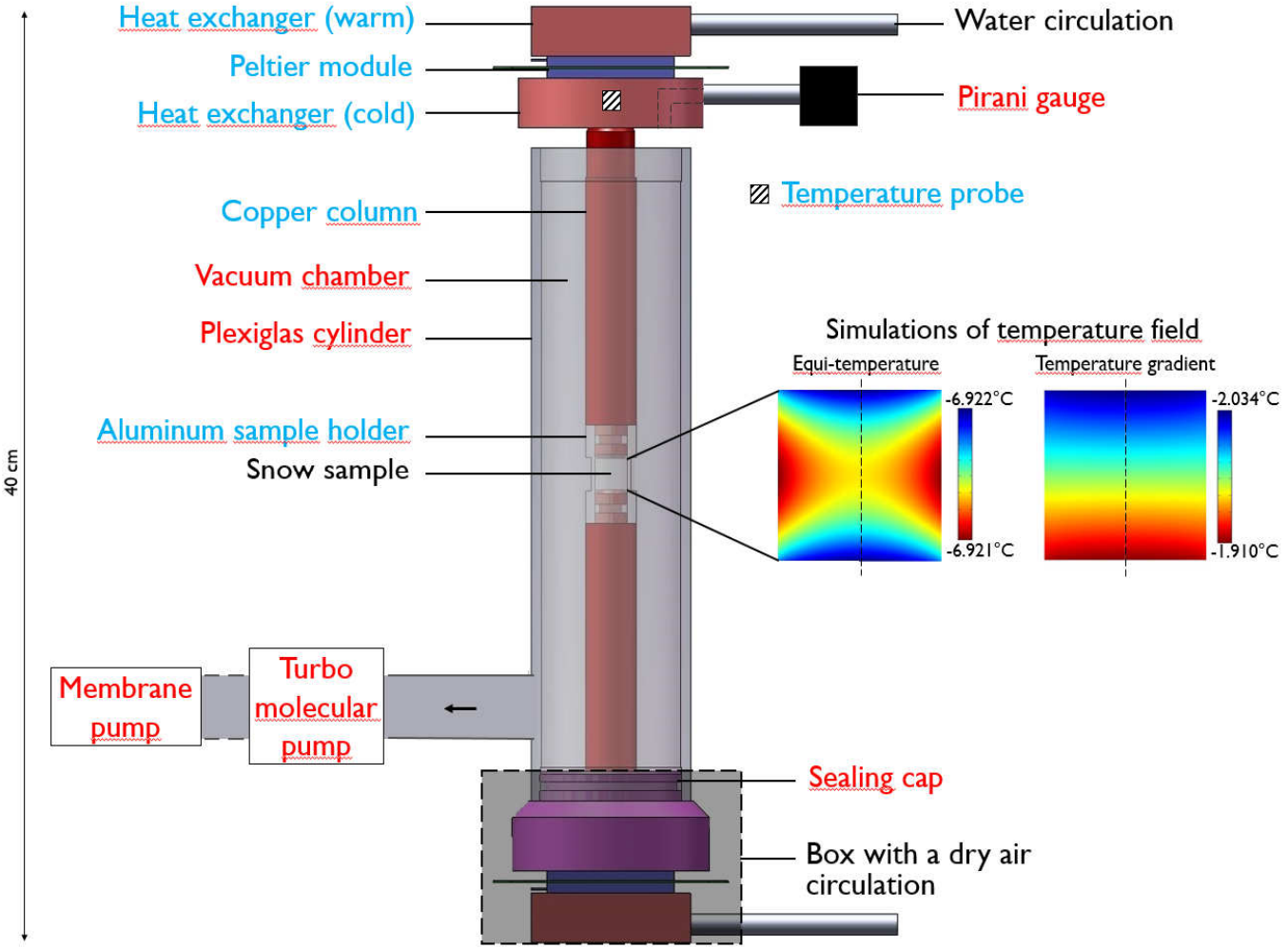
Recent development – new cryogenic cell

Insulation from the outside ➔ vacuum system
Pressure of about 0.1 Pa, leading to a thermal conductivity of air ~ 0.0015 $Wm^{-1}K^{-1}$ (reduced by 28 compared to that at atmospheric pressure).

Cold production and conduction ➔ 2 Peltier modules
Precision of Pt100 about +/- 0.03℃ (between 0 and – 10℃)
Regulation of Peltier modules about +/- 0.01℃



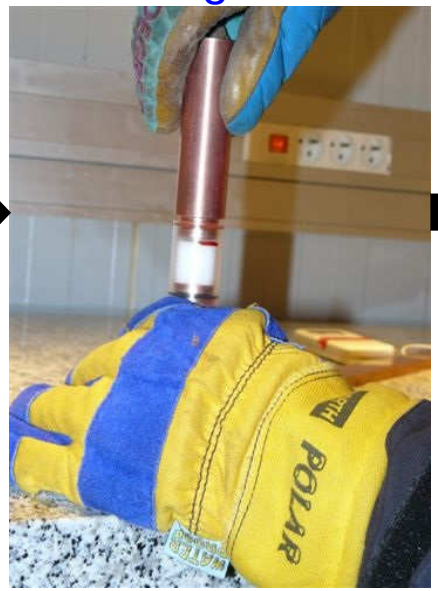




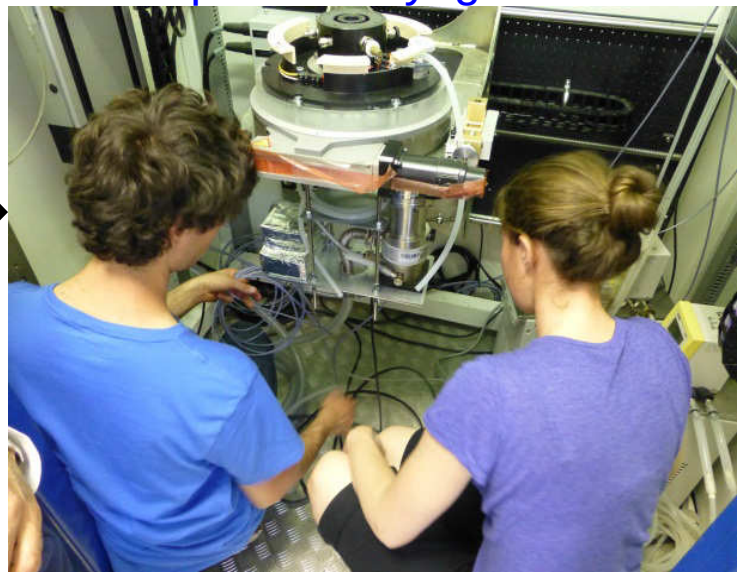
Recent development – experimental setup

1. Sampling

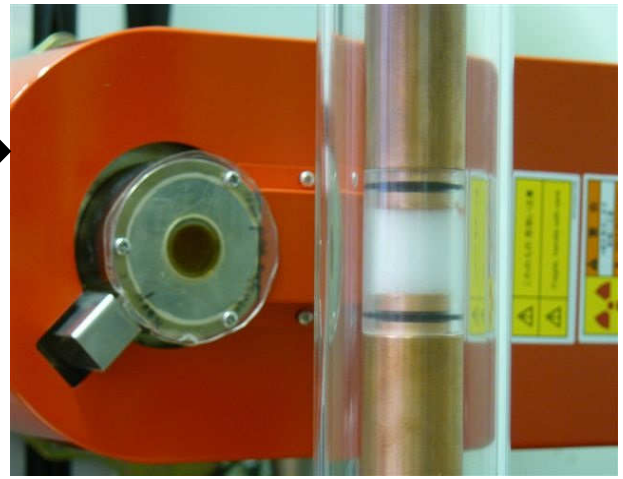
2. Storage



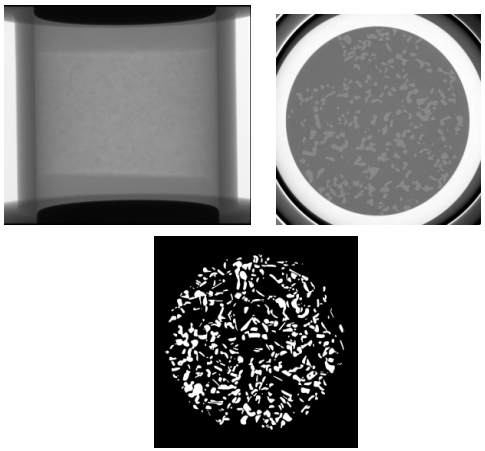
3. Set up of the cryogenic cell



4. Setup of the snow sample

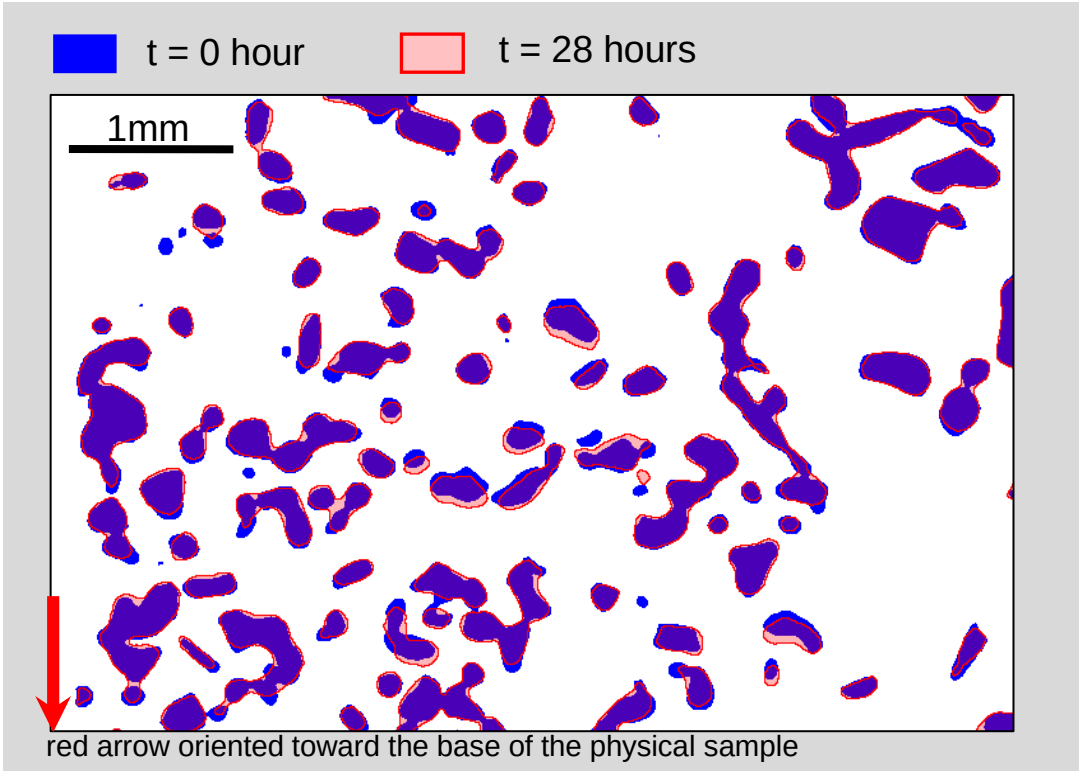


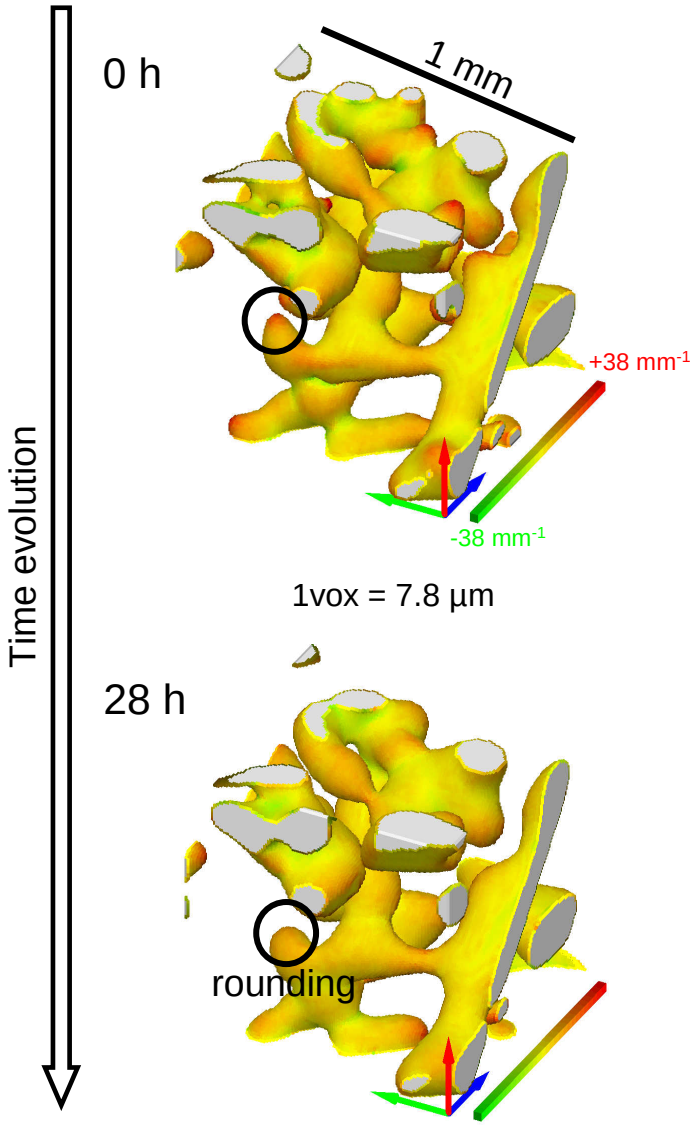
5. Tomography



Recent development – first results for equi-T metamorphism

Equi-temperature metamorphism at -7℃

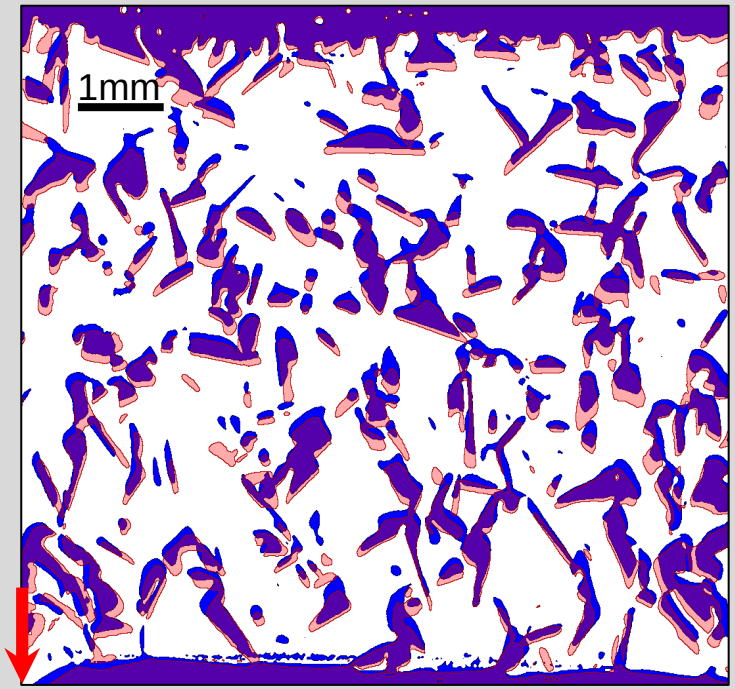




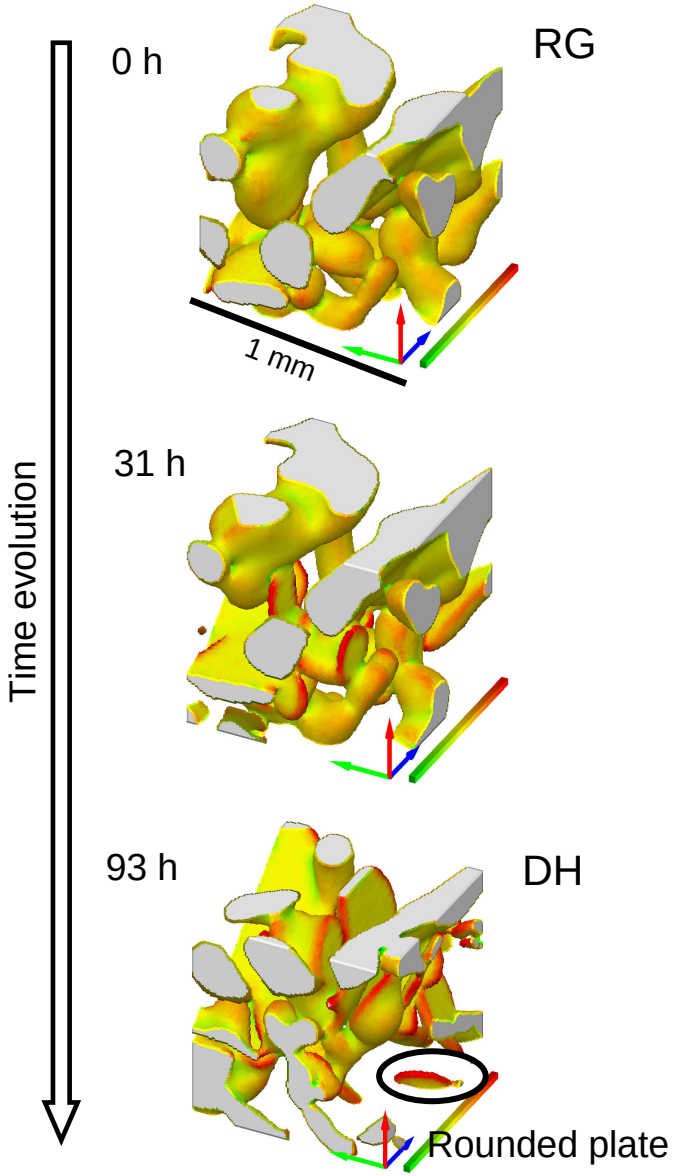
Typical features of the evolution under curvature effects:
-Slow evolution
-Settlement
-Grain rounding
-Growth/decay of bonds

Recent development – first results for TG metamorphism

Temperature gradient metamorphism of 18℃/m at -2℃



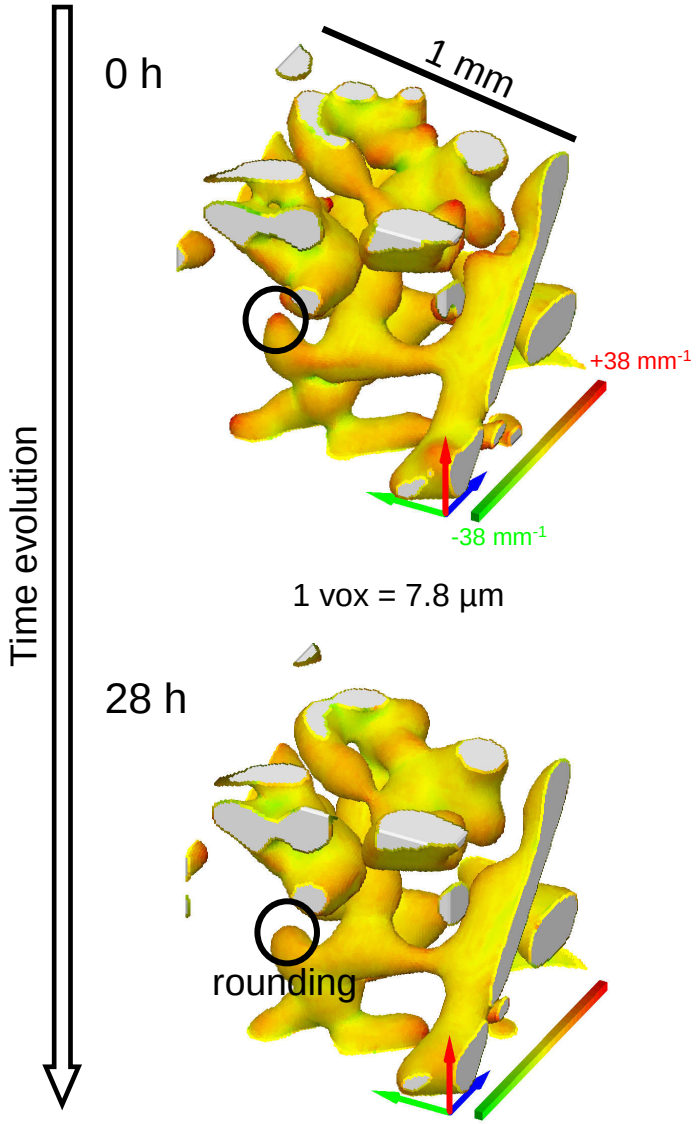
red arrow oriented toward the base of the physical sample



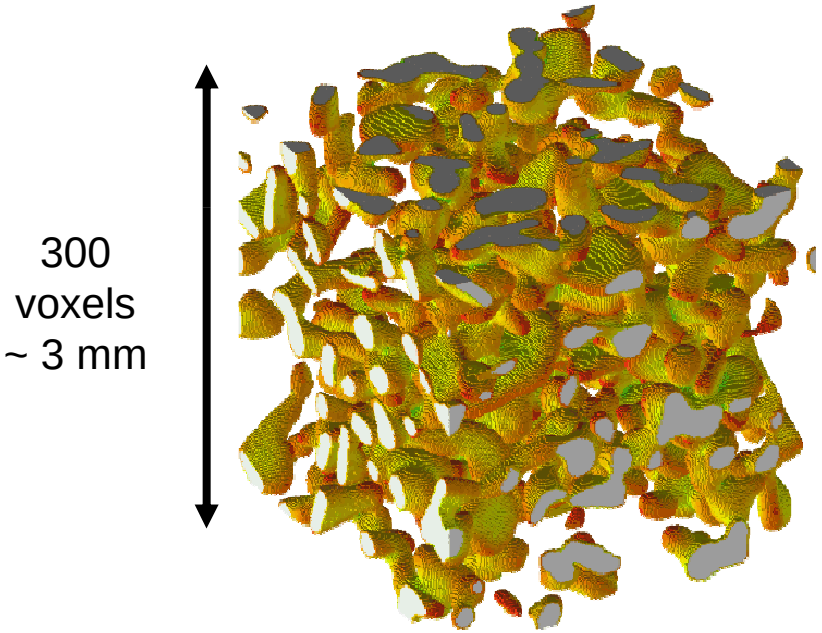
1 vox = 7.8 µm

Typical features of the evolution under temperature gradient effects:
-Deposition/sublimation at the base/top of grains
-Fast evolution from RG to DH
-General growth of the ice structures
-at -2℃: formation of rounded plates

Recent development - outlooks



experimentation



Numerical model

→Better understanding of physical processes