Computation of grain sizes from microtomographic images of snow

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METEO FRANCE
Toujours un temps d'avance

LIRIS

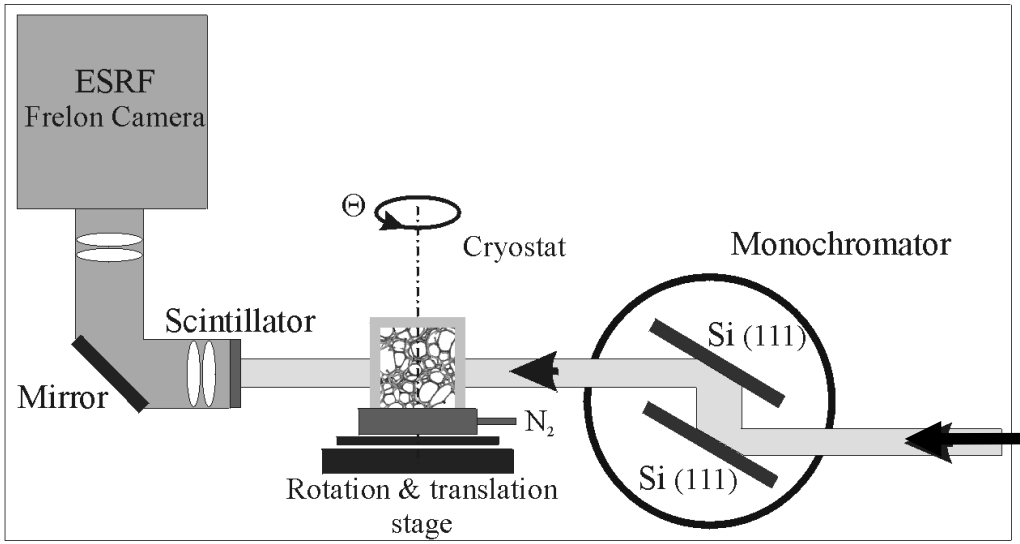
irstea

3S-R Laboratoire Sols Solides Structures Risques

ESRF

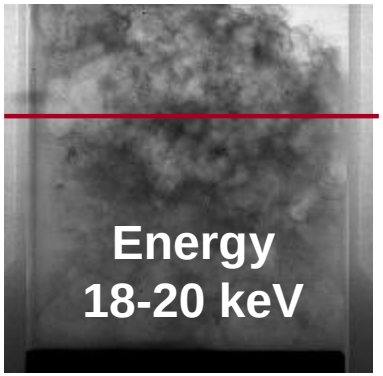
cnrs

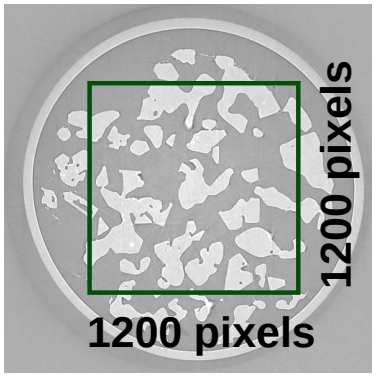
Method : X-ray Microtomography



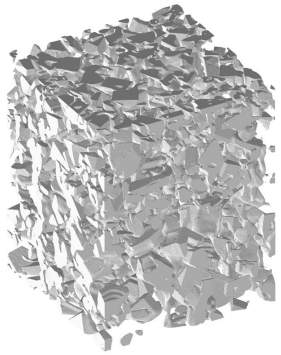
ESRF

Laboratoire
Sols
Solides
Structures
Risques





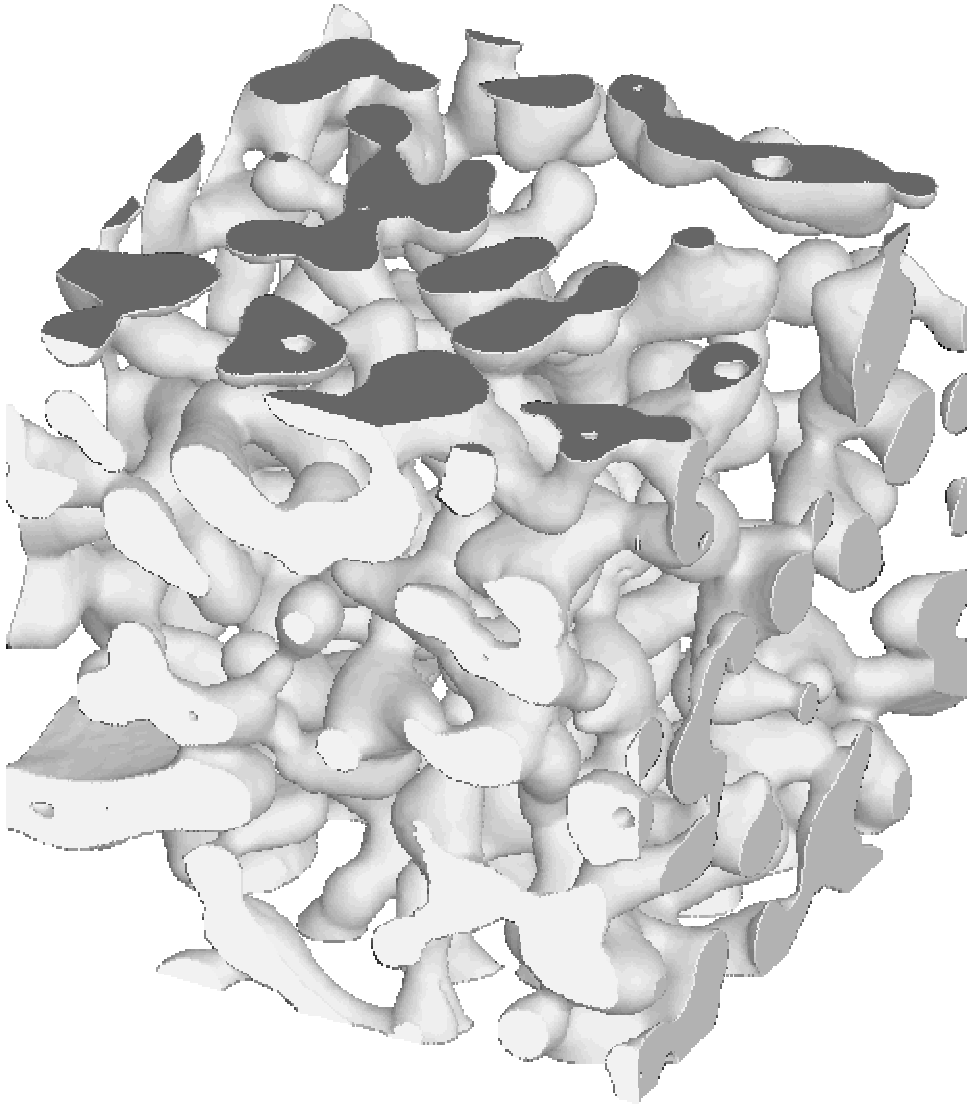
10 mm



Optimal resolution :
1 pixel
=
4.92 microns

Room temperature experiments:
A cold cell is needed

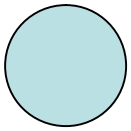
Grain sizes: 2 distinct definitions



Fierz et al 2009

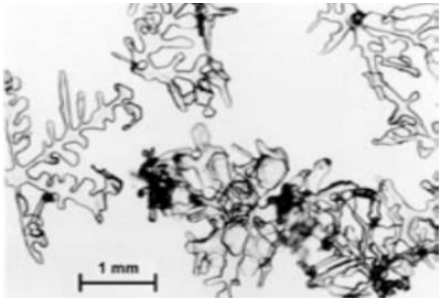
- Optical-equivalent grain size:

  Size of the sphere that has the same Surface / Volume ratio



- Classical definition: size of disaggregated particles

Mechanically detached



→Tomography: can estimate both of these grain sizes

Part 1:
Optical Grain Size and Specific Surface Area (SSA) from 3D images

Some reminders about SSA

- Definition

$$SSA = S / M$$

S: surface area (m^2)
M: mass (kg)

- Importance
  - Related to grain size (spherical approximation) [L^{-1}]
  - Characterize snow metamorphism evolution
  - Surface available for chemical reactions

- Measurements
  - CH4 adsorption (Legagneux et al, 2002; Kerbrat et al 2008)
  - Near Infra Red methods (Gallet et al, 2009; Arnaud et al, 2011)
  - Tomography (Flin et al, 2004; Schneebeli and Sokratov, 2004)

Why studying SSA measurements from 3D images ?

- An important physical parameter that can be measured from field measurements AND from 3D images → **link between microscale experiments and snowpack studies**

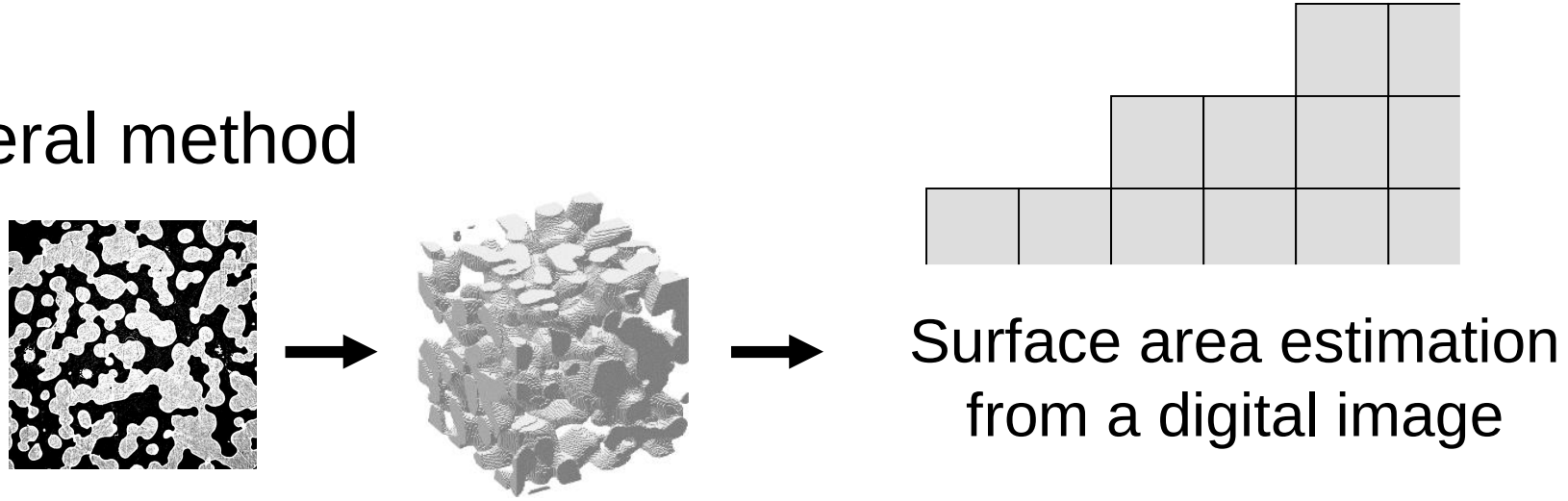
- Increasing number of tomographs and SSA computation methods in the world (SLF, AWI, Dartmouth College & CRREL, UAF, SASEé)

- Questions:

  Do all the numerical methods give the same results and is a minimal image resolution necessary to compute accurate SSA ?

SSA numerical measurements

Å General method



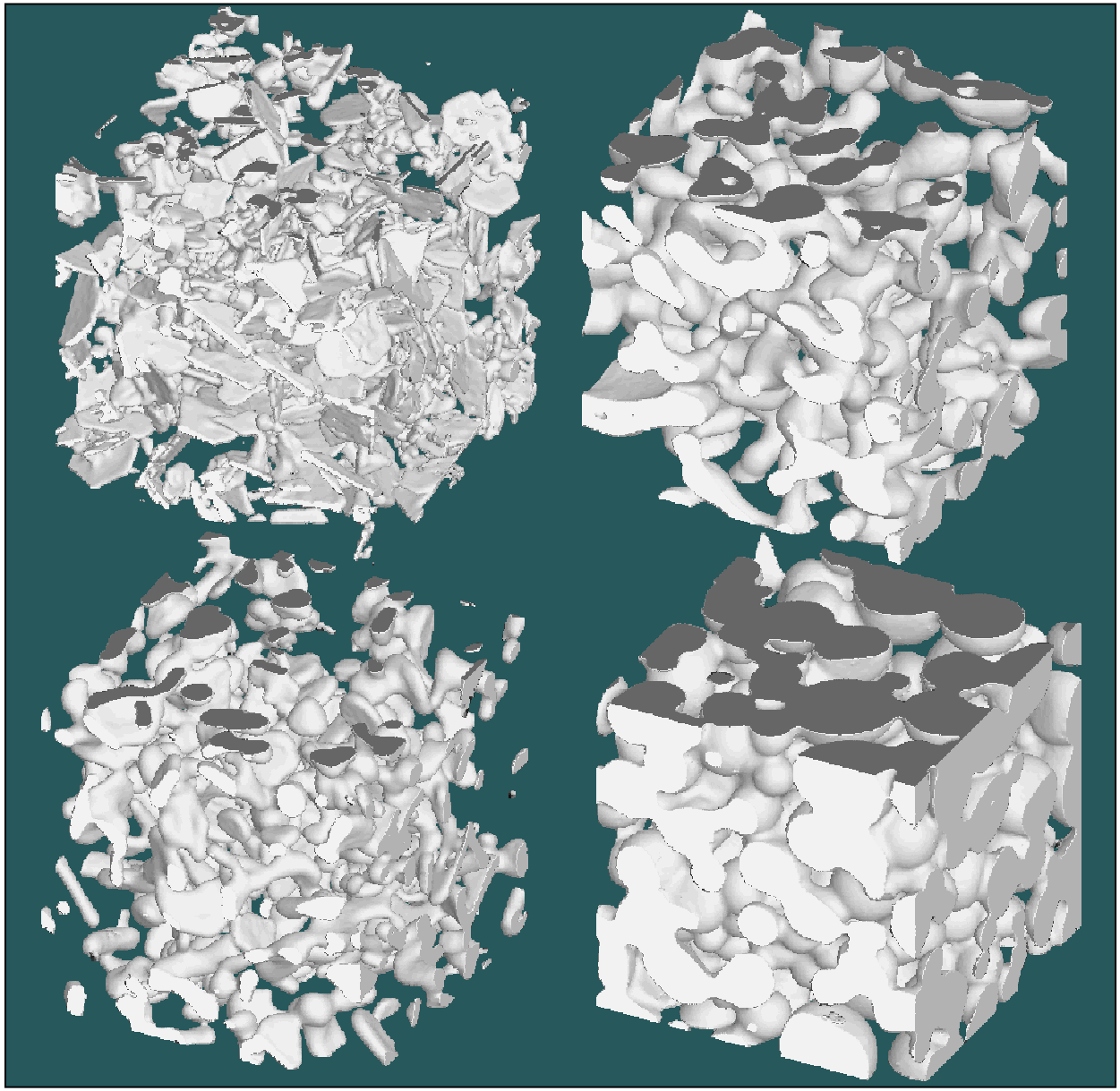
Surface area estimation from a digital image

Å 4 different approaches for surface computation

- ï Method 1: stereology (Underwood, 1970)
- ï Method 2: triangulation (Lorensen and Cline, 1987)
- ï Method 3: projection methods (Flin et al, 2005)
- ï Method 4: graph-cut approach (Hagenmuller et al, 2013)

Tests on diverse snow types :

Fresh Snow edge: 2.5 mm

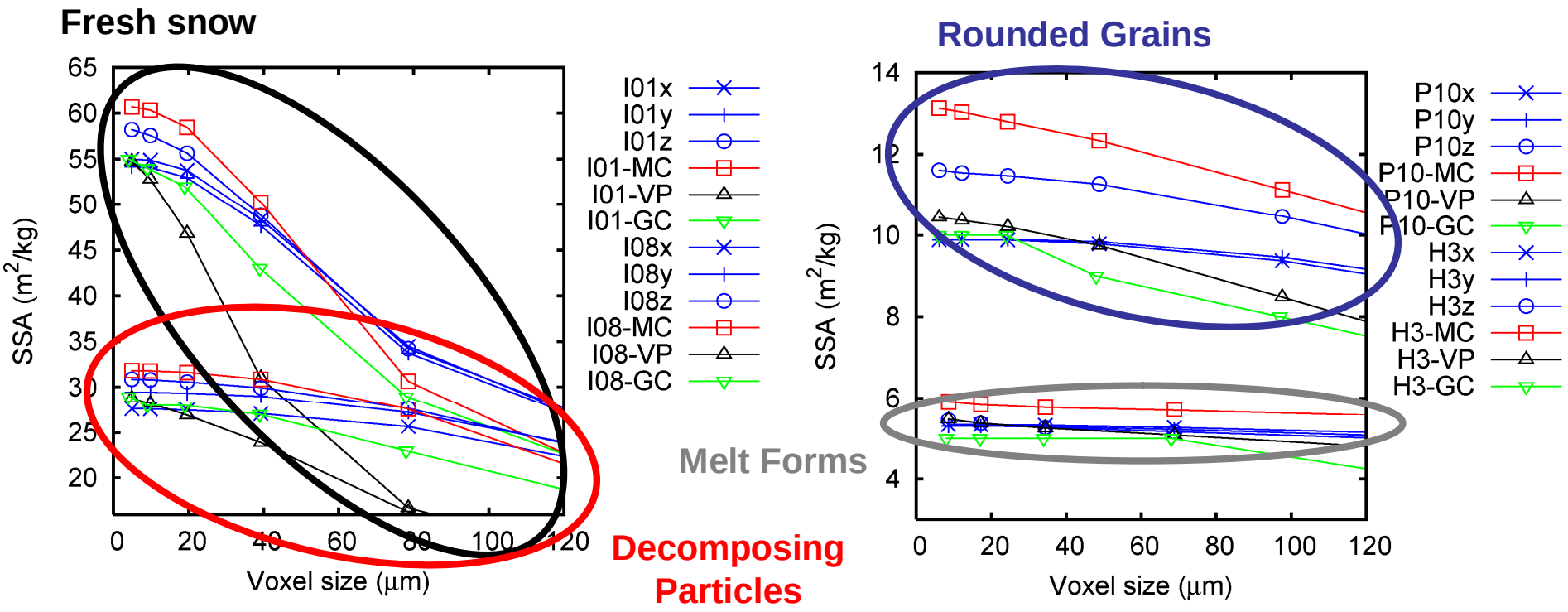


Rounded Grains edge: 2.5 mm

Decomposing Particles edge: 2.5 mm

Melt Forms edge: 4.5 mm

Impact of Methods and Resolution



→ At high resolution, all methods agree within **± 15%**

→ Results strongly depend on the snow type

→ **ST** methods give different estimations between z and x-y directions

→ **Marching Cubes** systematically overestimates SSA

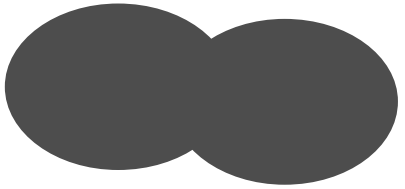
→ **VP** is particularly sensitive to resolution decrease

→ **Graph-cut** method is close to **VP** but is less sensitive to resolutions issues

Part 2:
Classical Grain Size and Specific Grain Contact Area (SGCA) from 3D images

Estimation of Grain Contact Area

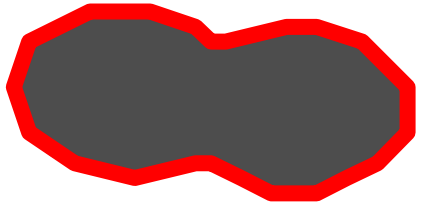
- Idea: estimating the size of the contact area between grains



- Method:

Estimation of Grain Contact Area

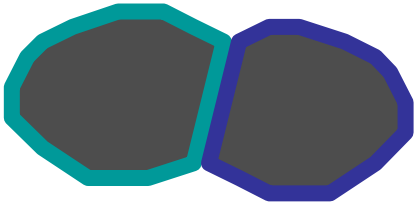
- Idea: estimating the size of the contact area between grains



- Method:
  - Estimate the SSA of the snow sample

Estimation of Grain Contact Area

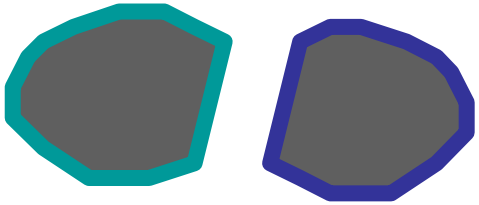
- Idea: estimating the size of the contact area between grains



- Method:
  - Estimate the SSA of the snow sample
  - Estimate the average SSA for the grains constituting the snow sample (SSA_{tot})

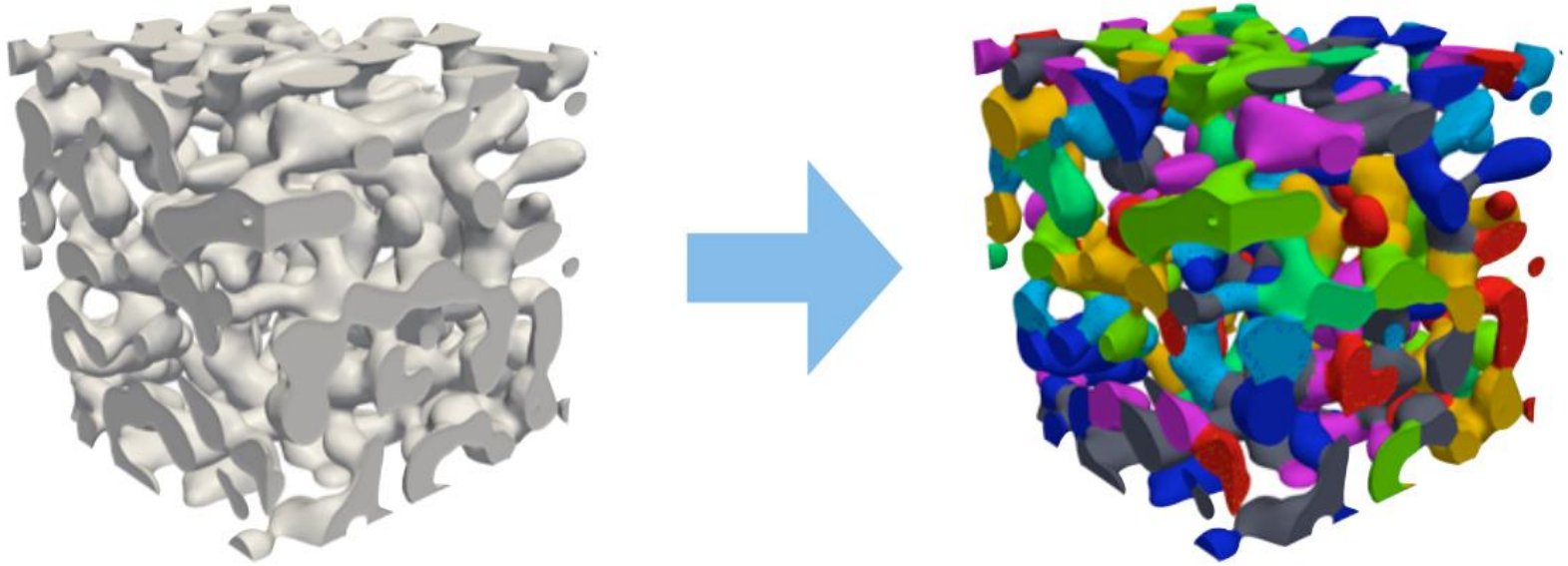
Estimation of Grain Contact Area

- Idea: estimating the size of the contact area between grains



- Method:
  - Estimate the SSA of the snow sample
  - Estimate the average SSA for the grains constituting the snow sample (SSA_{tot})
  - 2*SGCA = SSA_{tot}-SSA is the SSA that would be released by neck breaking

Segmentation Methods



Hagenmuller et al, 2013

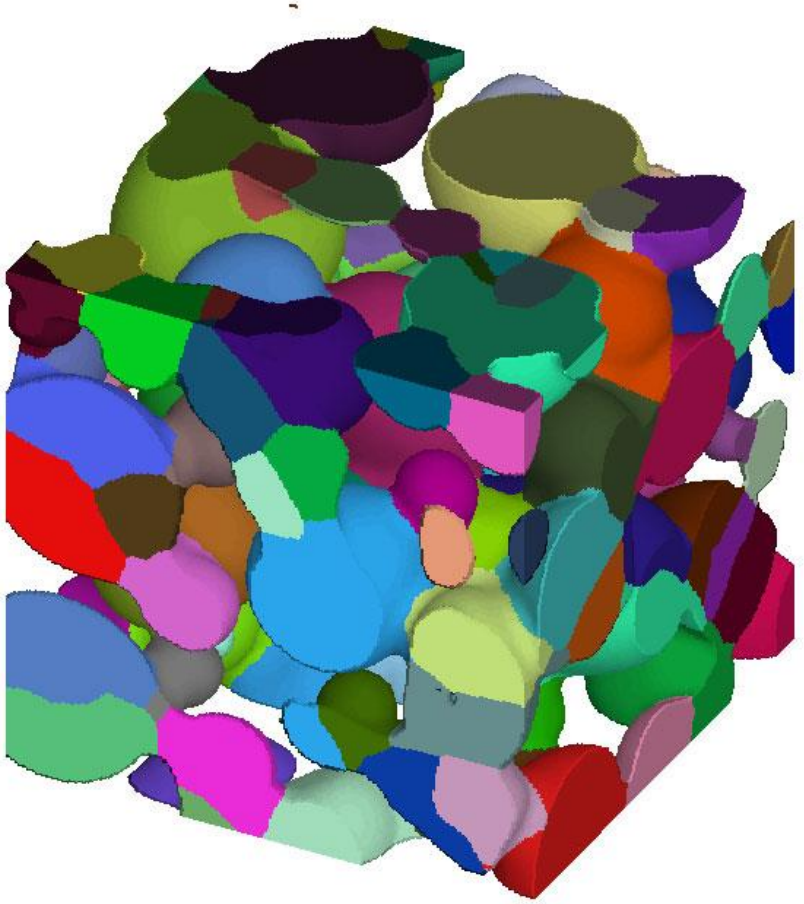
Å 2 curvature-based algorithms :

- ï CDGS : Wang et al, 2012
- ï Grain segmentation with 2 distinct parameters (Hagenmuller et al, 2013)

Examples for CDGS algorithm

Wang et al, 2012

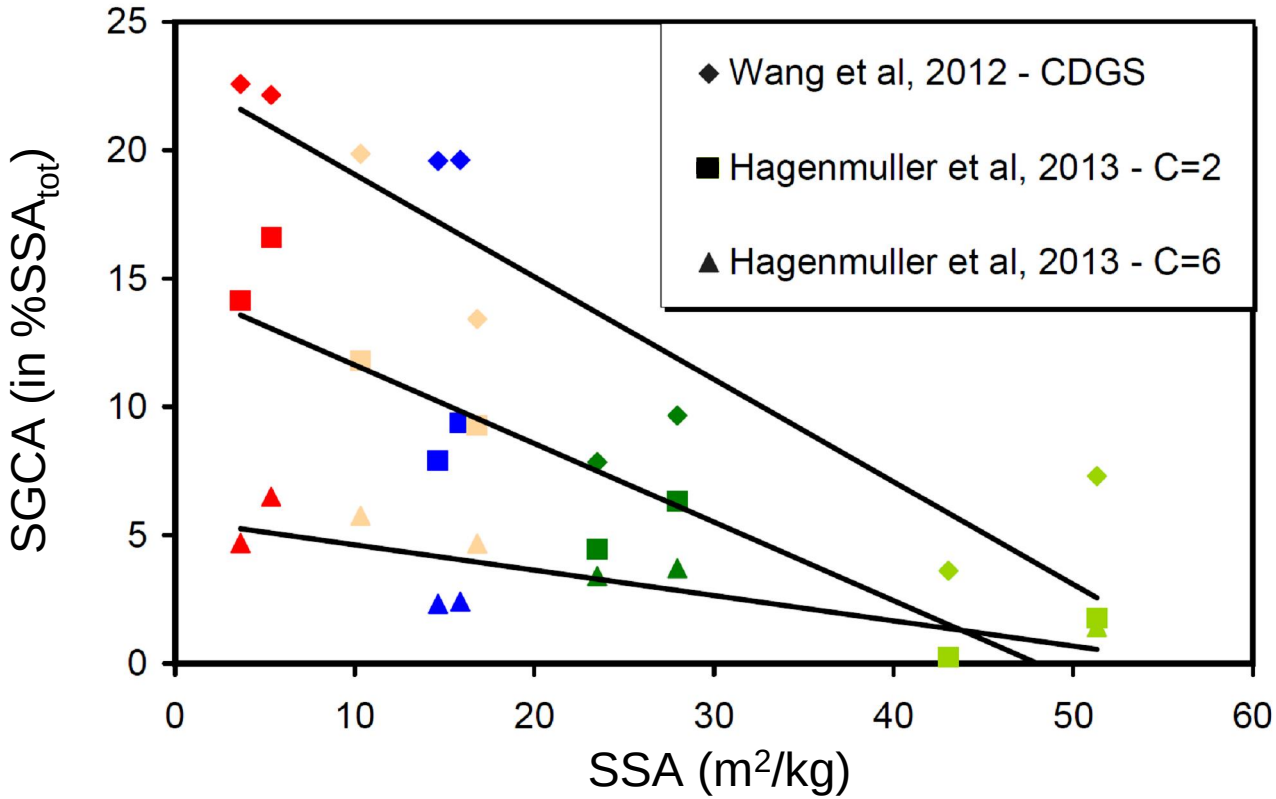
Decomposing Particles / Rounded Grains
Edge size = 2.5 mm - 604 grains



Melt Forms
Edge size = 4.5 mm -129 grains

Estimation of Grain Contact Area

Melt Forms
Depth Hoar
Rounded Grains
Decomposing and Fragmented precipitation particles
Precipitation Particles



→ Consistency of the methods: similar behavior with snow type
→ Relationship between SSA (grain size) and SGCA (neck size).
→ Mechanically processing ñoldòsnow samples could significantly increase SSA
→ SGCA seems a potential parameter to help in determining the snow type

Conclusions

- The main numerical methods that are commonly used to determine SSA from 3D images give slightly different results
- Each method has its own drawbacks: ST is not adapted to anisotropic media, MC overestimate SSA and VP is particularly sensitive to resolution decrease.
- Depending on the method, SSA estimation of recent snow require high resolution images (voxel size < 5 µm)
- Thanks to the combination of SSA and grain segmentation algorithms, SGCA values can be estimated: this opens new outlooks for the study of snow microstructure
- Segmentation methods do not give absolute estimations but give consistent results
- Grain size is closely linked to grain shape and grain connectivity

More information :

Calonne et al, **SSA metamorphism and other properties**, poster P4-21

Hagenmuller et al, **SGCA and Grain segmentation approaches**, poster P4-22

Wang et al, **Grain segmentation**, poster P4-19