Modélisations du piégeage des gaz dans la glace polaire

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soutenance de thèse proche

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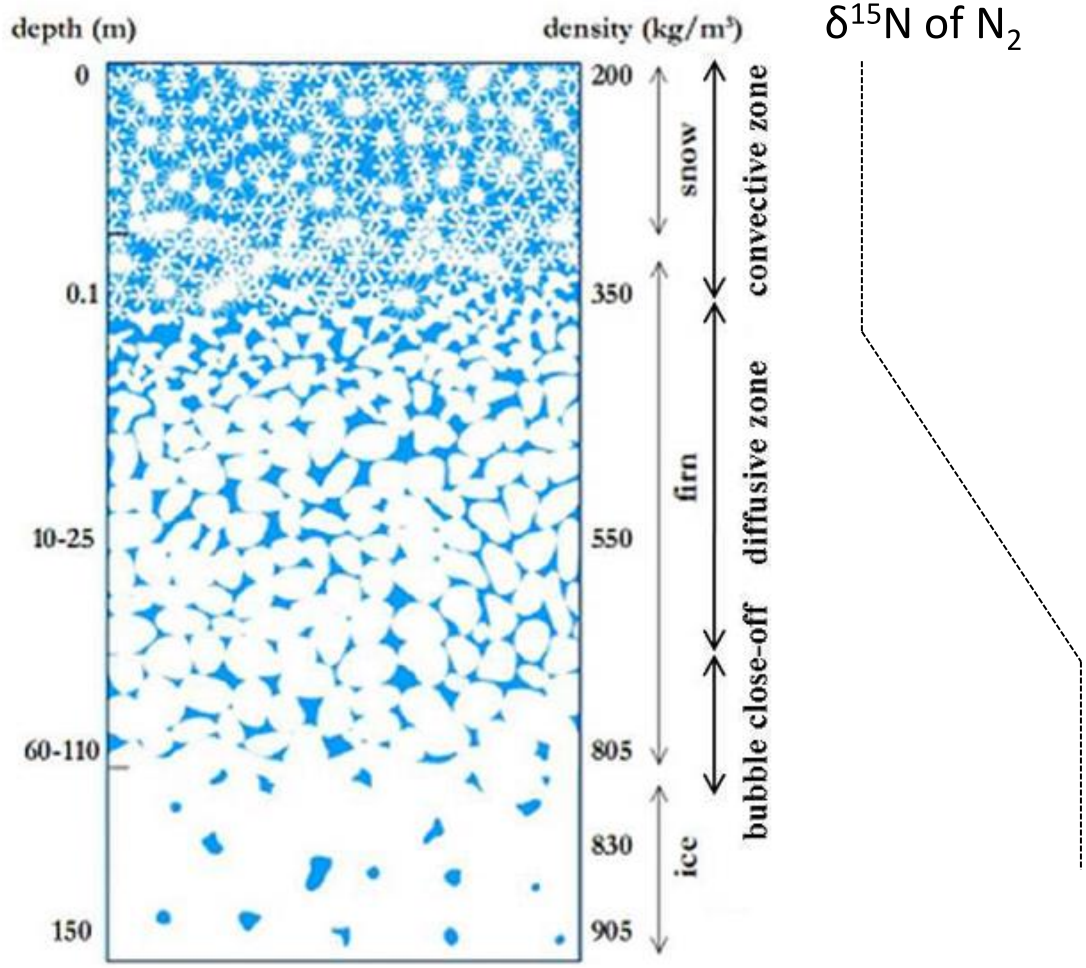
Début de 2ème année de thèse

Motivation :

constraining firn thickness with a combined model-data approach



<u>Isotopes of inert gases:</u>

Gravitational fractionation over most of firn thickness (diffusive zone)

Ice core records of $\delta^{15}N$ and/or $\delta^{40}Ar$ provide constraints on firn thickness

Mechanical models of firn densification aim at predicting firn thickness variations

Constraining the ice age at gas trapping depth is necessary to evaluate the phasing between temperature and greenhouse gas changes

Main model components

Goujon et al., JGR, 2003

1D ice flow module
W=f(Acc,m,Wbase, etc.)
Heat transfer module
T(z) = f(W,Tbase, etc.)
Densification module
$\Delta\rho/\Delta t$=f(T,Acc,etc.)
Gas age module
COD, Δage = f(ρ, etc.)
Isopic module
δ=f(T,Zconv,Zlid,etc)
Equilibrium state

Multidisciplinary

Deep-firn oriented

800 000 years run in a few minutes

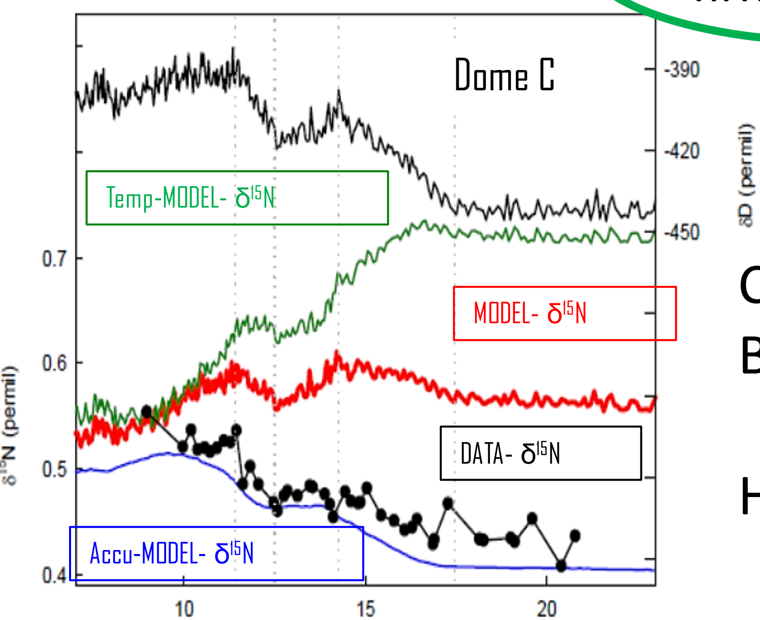
A balance between opposite effects

Deglaciation

Increasing temperature → Accelerated densification → Decreasing firn thickness

Increasing accumulation → Accelerated firn sinking → Increasing firn thickness

≠

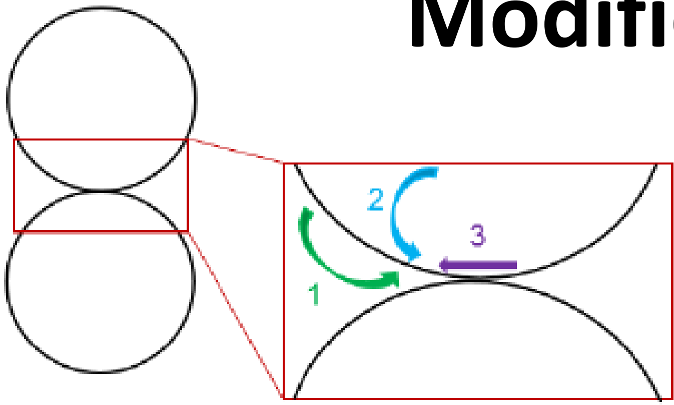


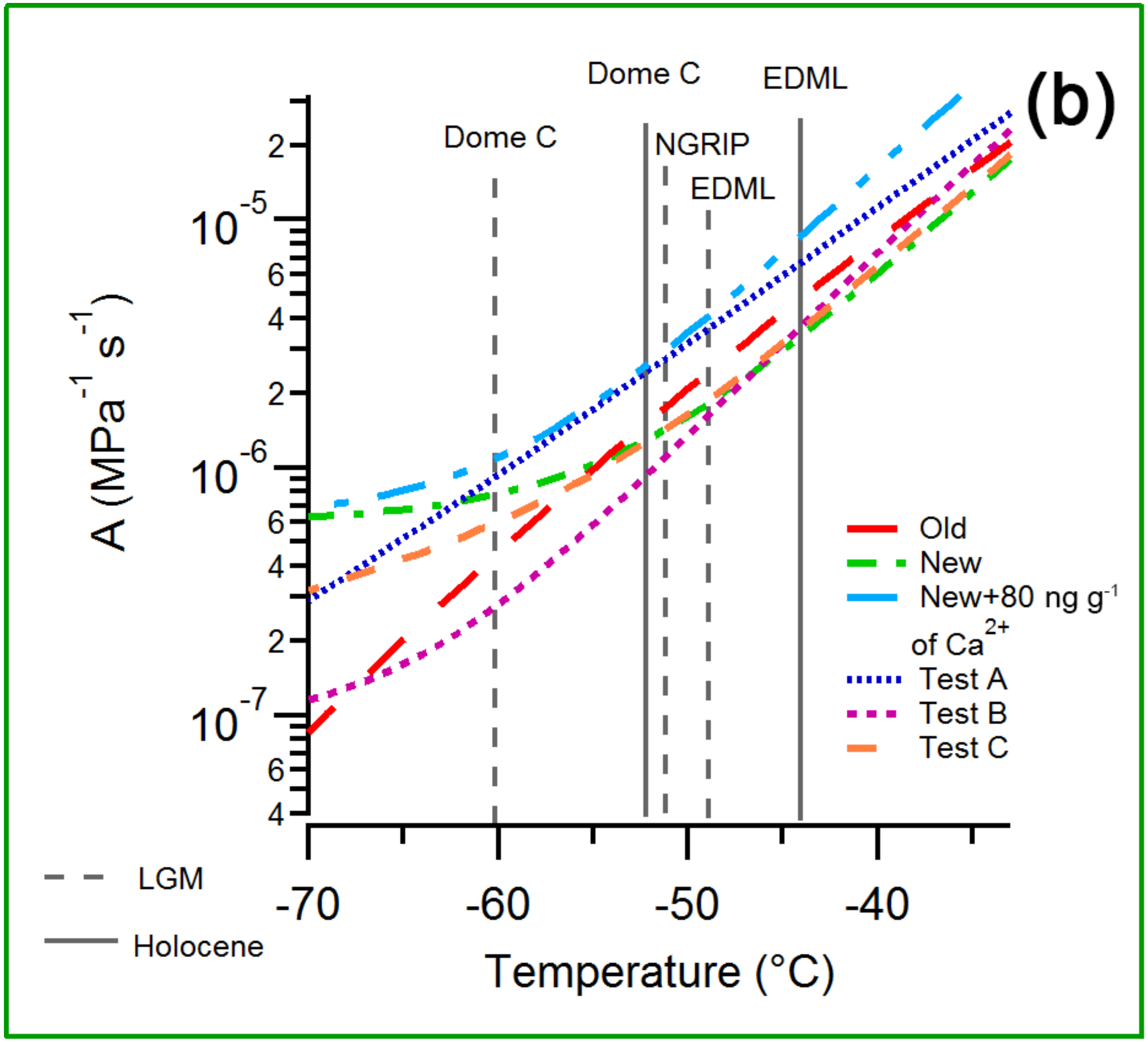
Capron et al., 2013

Can the model sensitivity to temperature Be overestimated ?

Hard to modify the amplitude of modelled $\delta^{15}N$

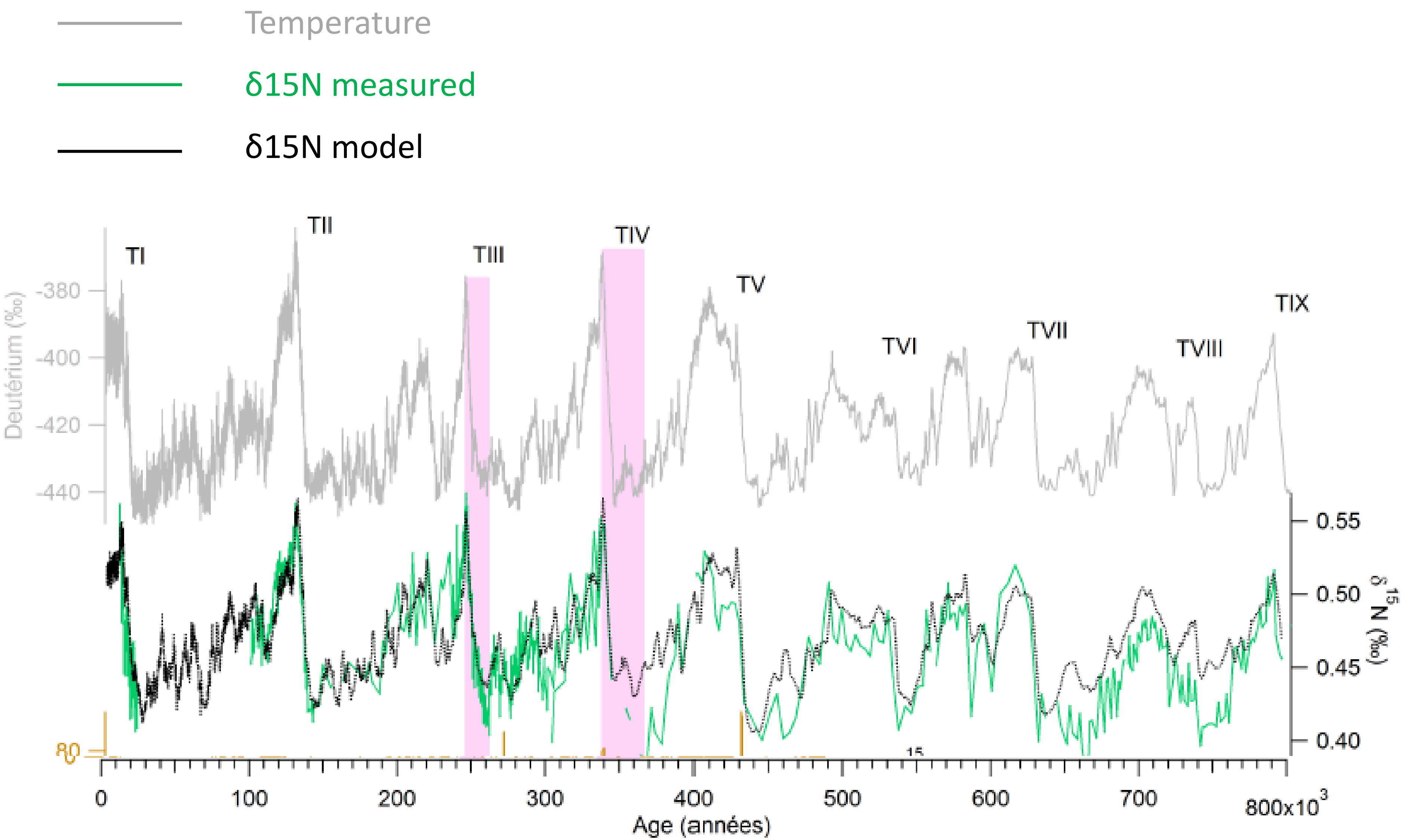
Modified activation energies





Bréant et al., Clim. Past., 2017

Very good results although the physics is rough



Bréant, PhD, 2017

Some possible perspectives

Possible amplifiers of the accumulation effect ?
(Radiation ? Impurities ?)

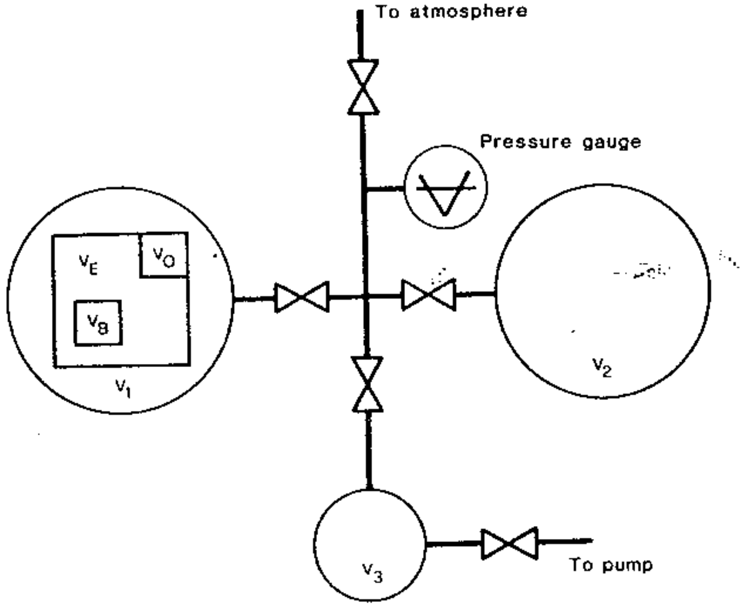
Need for better understanding what controls densification speed in the ~0.5 to ~0.8 g/cm^3 density range

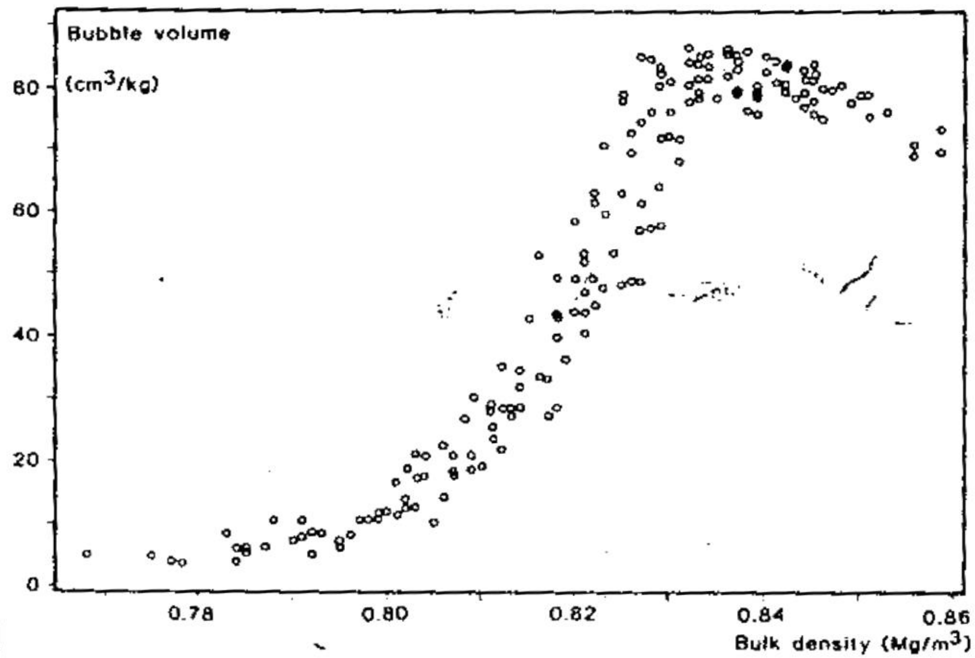
"Cold sintering of ceramics" (2016-2017)
https://www.mri.psu.edu/mri/news/research-breakthrough-cold-sintering
Most sintering processes occur at temperatures >1000°C
Cold sintering achieves dense ceramic solids at < 300°C
Using impurities, liquid-solid interface and external pressure

Gas trapping criterion as a function of density

Closed porosity measurements: pycnometry

Stauffer et al., Ann Glaciol, 1985

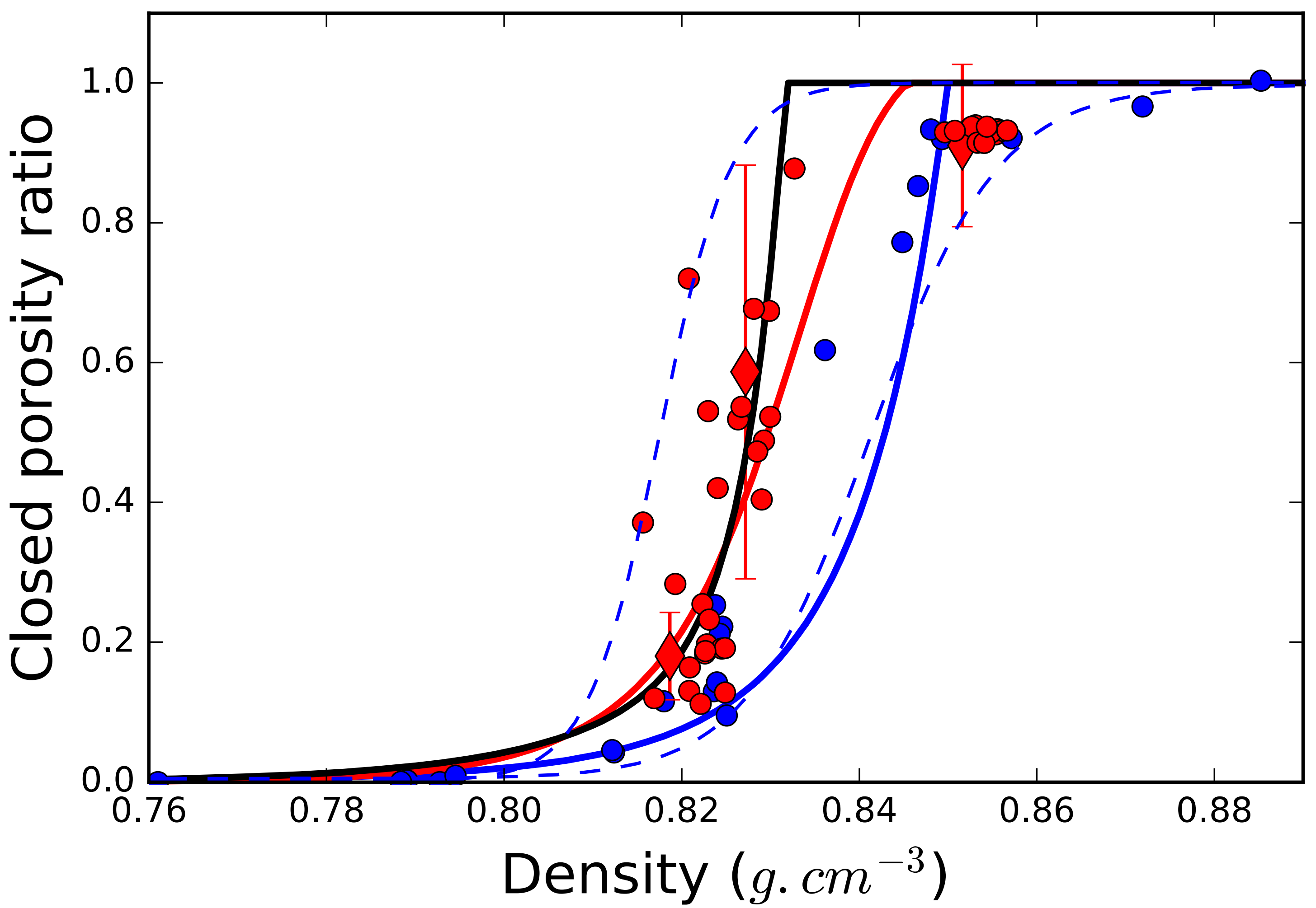




Data available only at a few sites, edge effects difficult to evaluate

Closed porosity estimates from tomographic images

Alexis Burr, PhD work



Cut bubble correction is sample size and image resolution dependent

Consistency with air content data

"air conservation" calculation based on Rommelaere et al., JGR, 1997

V	V_c	ρ_c	
0.0865	**0.1075**	0.840	DC data, Martinerie et al. 1992
0.093	0.112	0.838	Goujon et al., 2003
0.108	0.134	0.823	Schaller et al., CPD, 2017 (Dome Fuji)
0.116	0.143	0.816	Burr, PhD, minimum envelope
0.084	0.104	0.843	Burr, PhD, maximum envelope

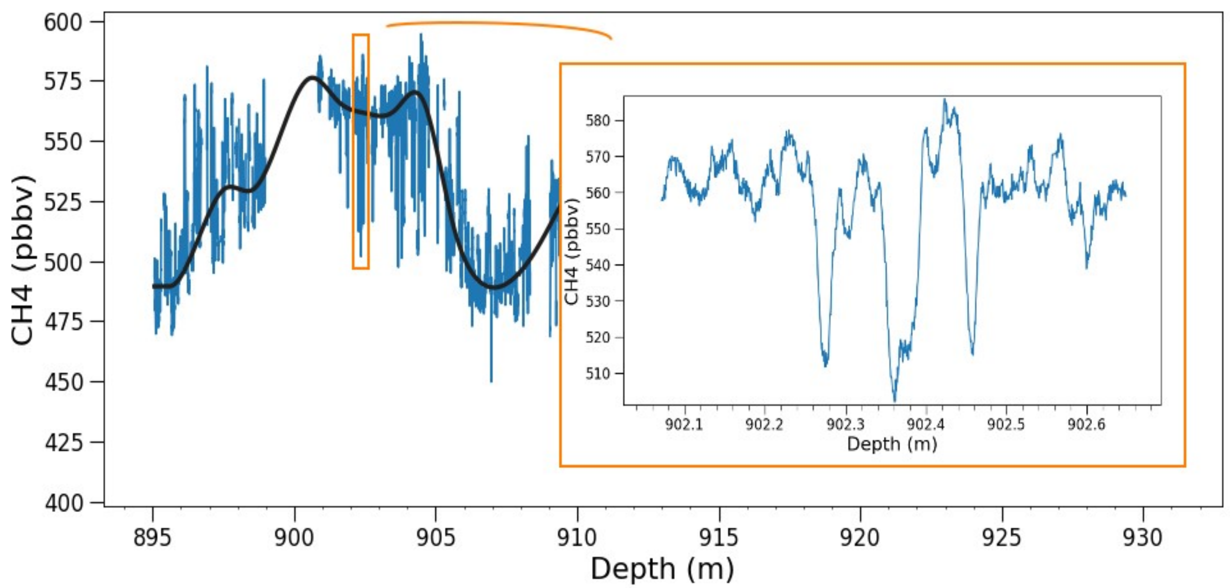
Tomography based data seem to underestimate the air trapping density
Similar result in Schaller et al., CPD, 2017 for the Antarctic Plateau

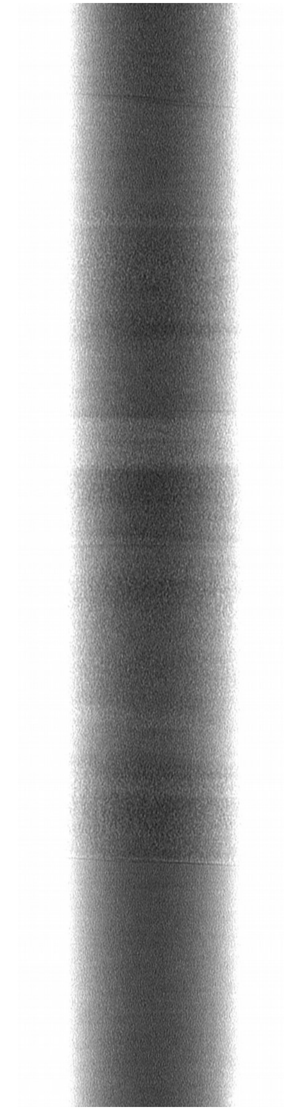
We wish to directly compare pycnometry and tomography (Kévin Fourteau)

Effects of fine scale trapping processes
Layering

Variations in pore structure and density are visible in the firn

This creates a layered trapping of gases
→ Gas stratigraphy is pertubed at the cm scale





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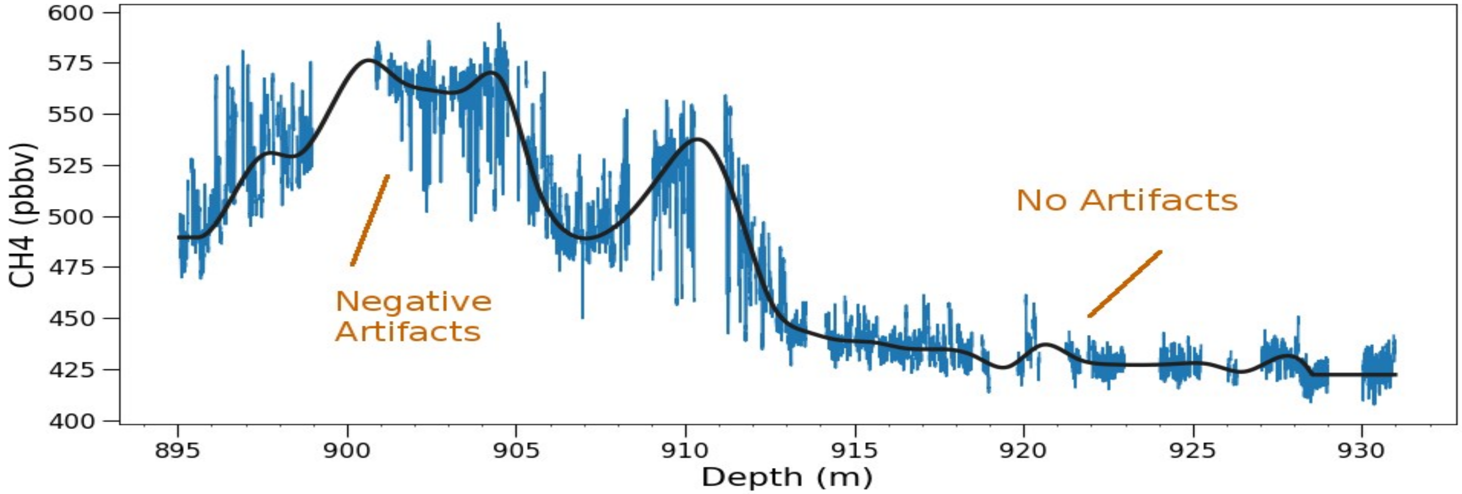
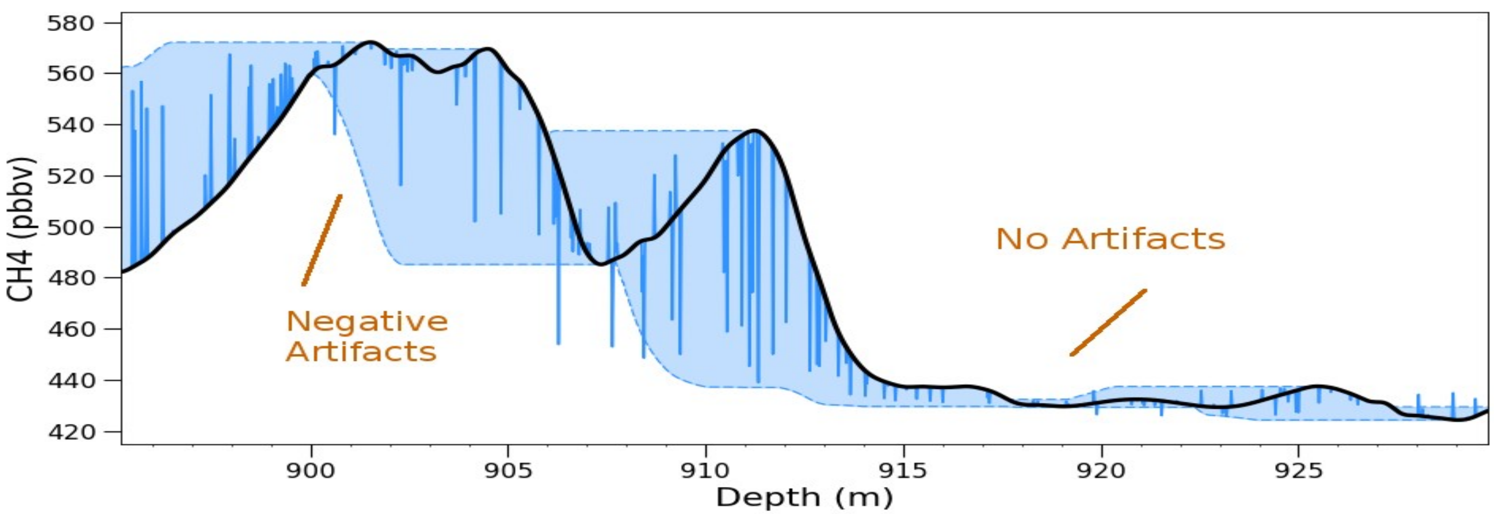


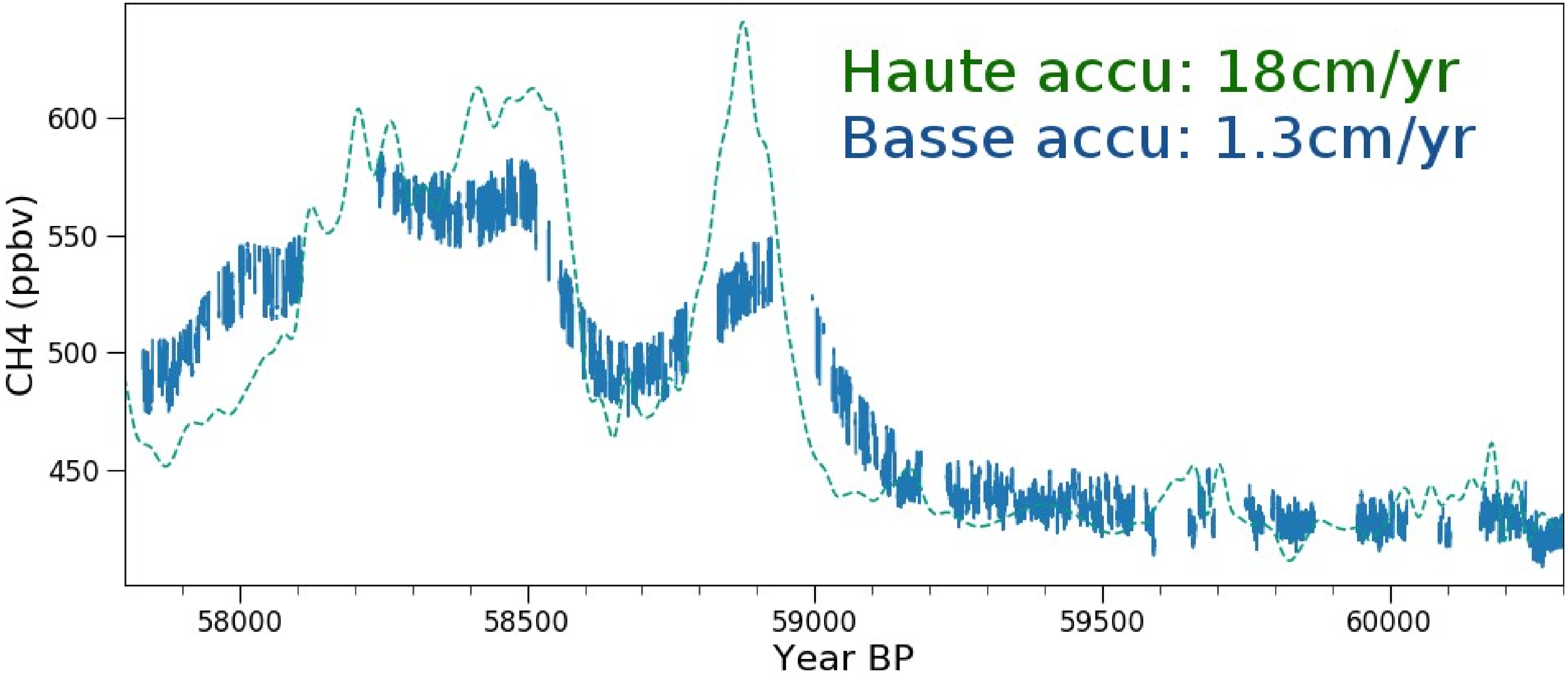


Effects of fine scale trapping processes
Smoothing

Gradual closure of porosity

→ Bubbles at the same depth close at different times

→ Gases of different ages are mixed in the same ice layer



Effects of fine scale trapping processes

These two phenomena vary strongly from site to site

Need to understand the fine scale effects of :

- Accumulation
- Temperature
- Initial pore structure
- Chemical impurities

Research article

04 Jul 2017

Analytical constraints on layered gas trapping and smoothing of atmospheric variability in ice under low accumulation conditions

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Review status

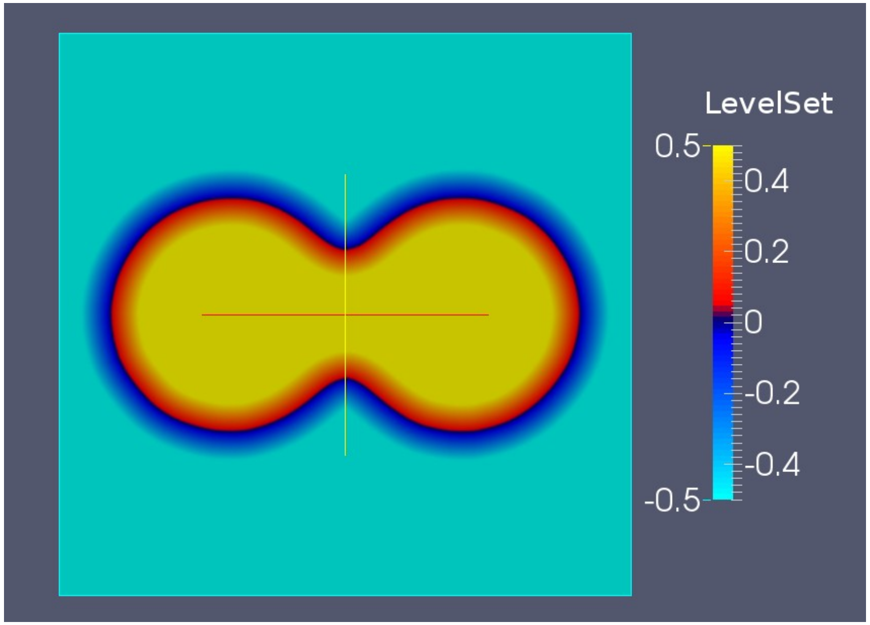
This discussion paper is a preprint. It is a manuscript under review for the journal Climate of the Past (CP).

In Climate of the Past Discussion

A firn compression model

Aims to represent the compression of a firn slab
and the evolution of the porosity

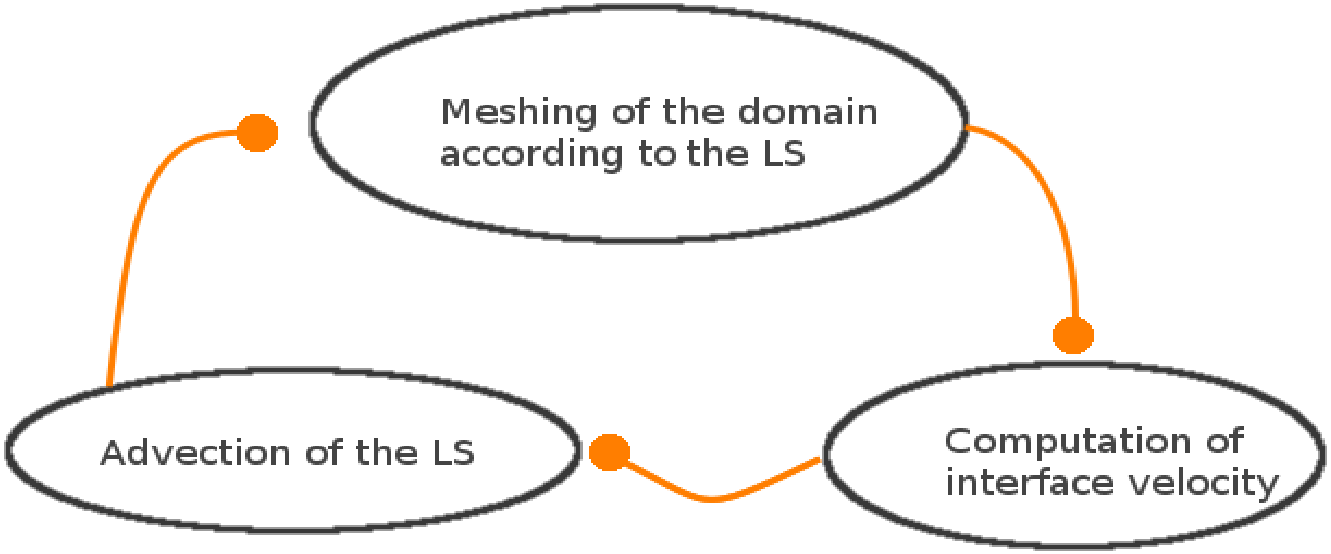
- Finite elements framework
- Levelset (LS) representation of the snow (ice + air)



A firn compression model

Remeshing at each time step :

→ Elements adapt to the LS



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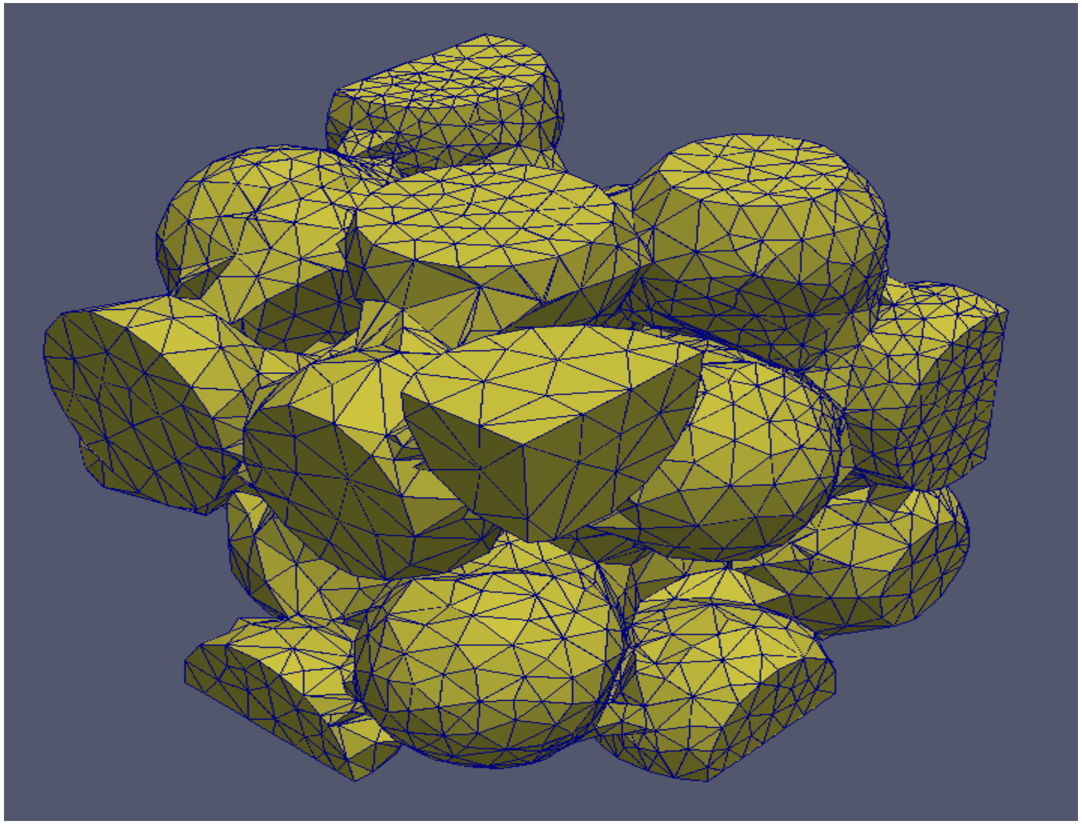

A firn compression model

The remeshing and its coupling with Elmer/Ice is done !
Problem of mass conservation to solve.