A physically-based formulation for texture evolution during dynamic recrystallization. A case study for ice. Supplementary

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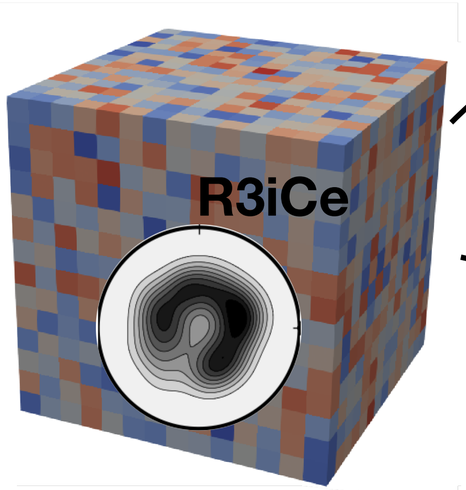
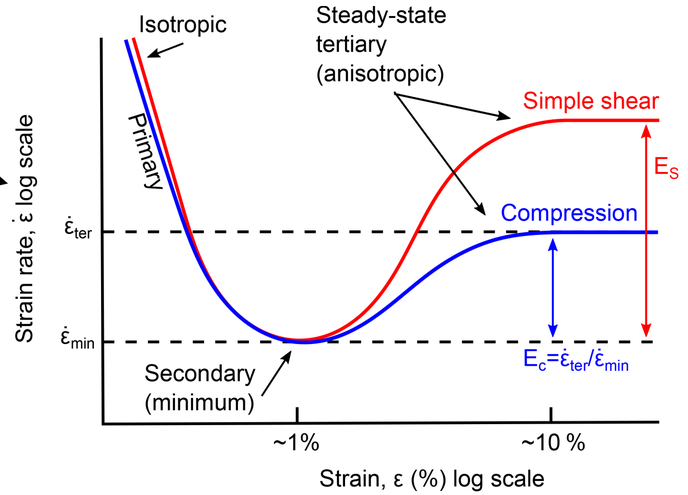
Center for Snow Study CEN, CNRM, Univ. Toulouse, France

Textures and large-scale ice flow





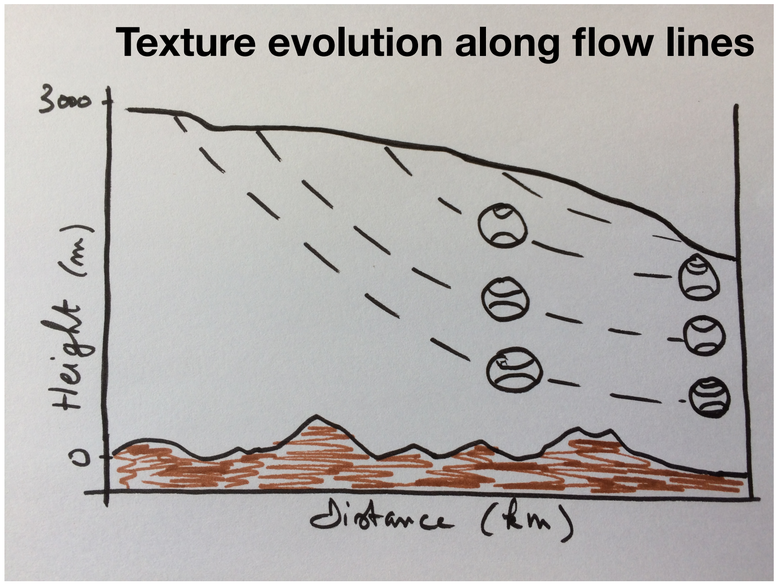
ESTAR

$$\dot{\varepsilon} = A\left(T'\right) E\left(\lambda_S\right) \tau_e^{n-1} \sigma',$$
$$E\left(\lambda_S\right) = E_C + \left(E_S - E_C\right) \lambda_S^2$$

Graham et al. 2018

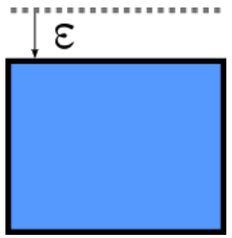
elmer ice

http://elmerice.elmerfem.org/
Gagliardini et al. 2013



Modeling texture evolution with DRX

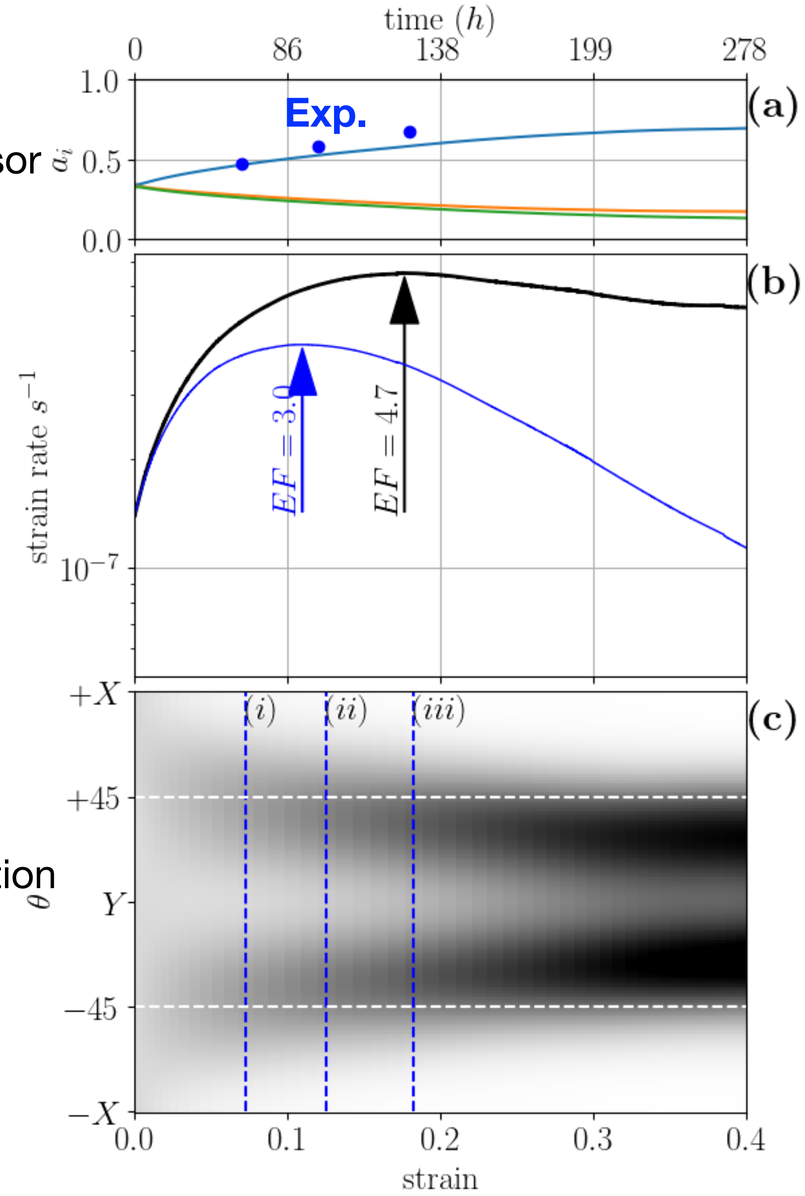
Results : uniaxial compression

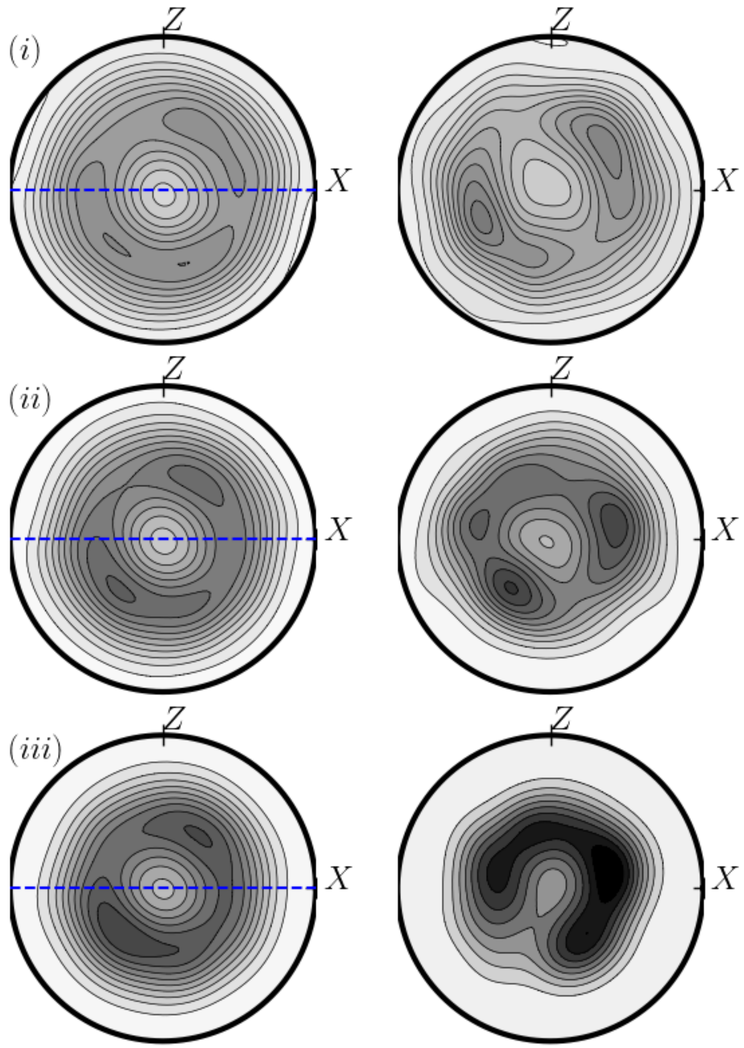


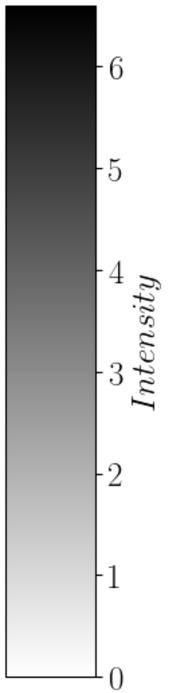
2d order orientation tensor

Strain rate

Texture evolution with strain





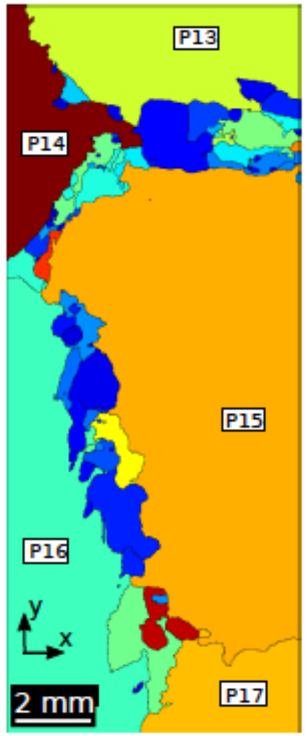


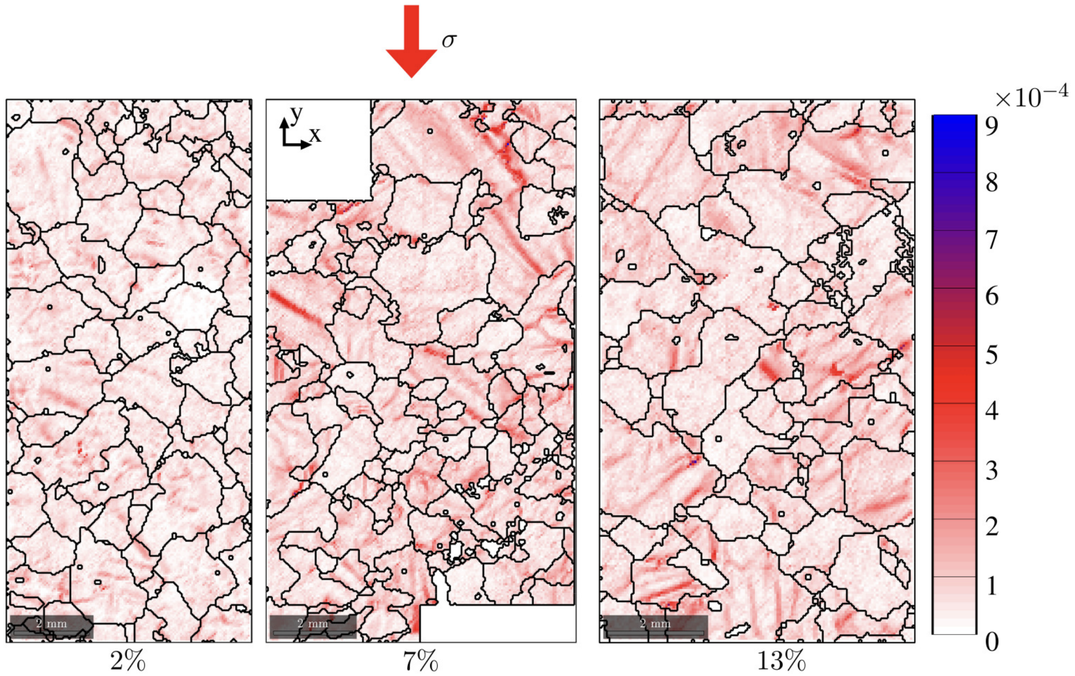
(d) Simulation (e) Experiment

Experimental results from Montagnat et al. 2015

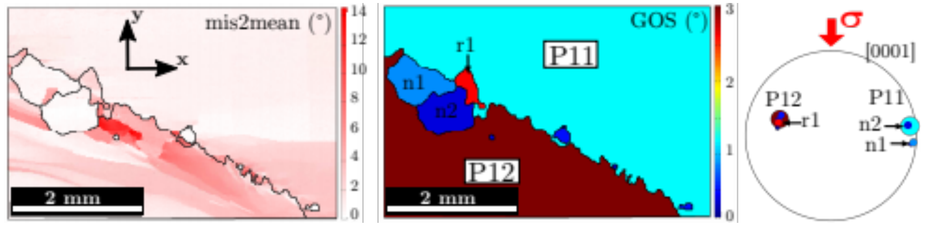
Dynamic recrystallization in the lab

High-resolution observations from electronic microscopy - EBSD

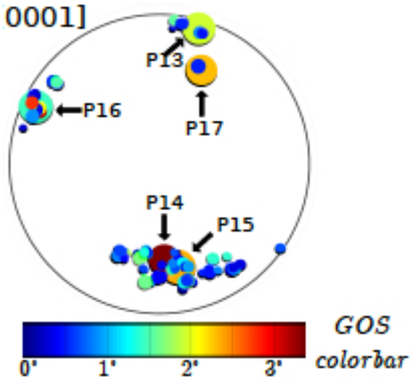




Lattice misorientations
(Kernel Average Misorientation)



Observation and orientation of new grains



Orientation of
new / parent grains

Nucleation by bulging
Impact of subgrain misorientations

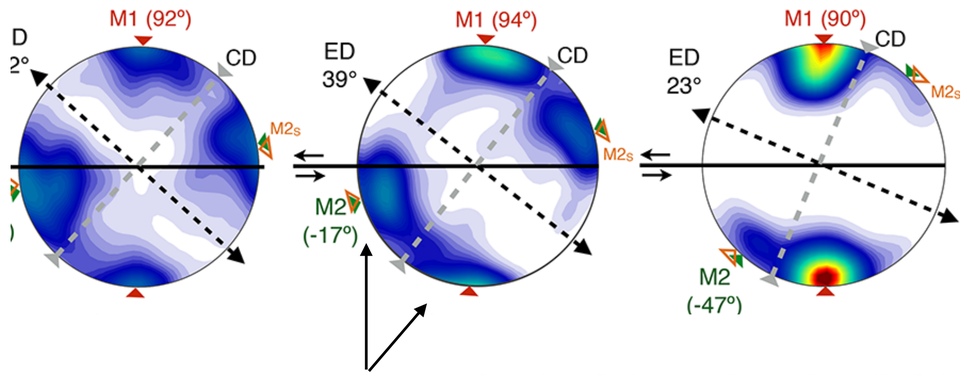
-> nucleus orientation close to parent grains one
-> impact of the local stress field

Chauve et al. 2017

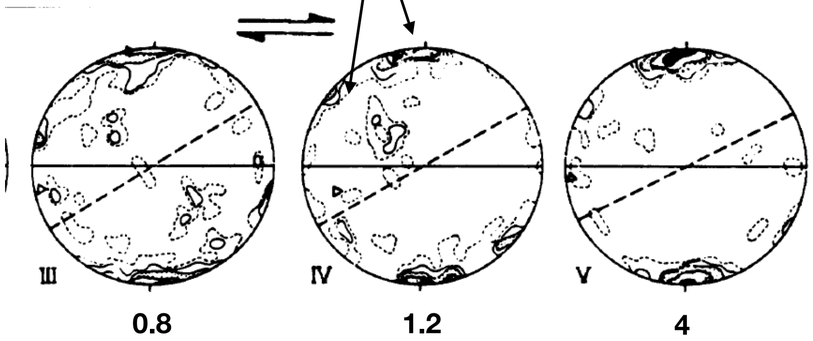
Modelling of DRX texture - issues

Textures resulting from simple shear are not well simulated so far

Lab experiments (Journaux et al. 2019)



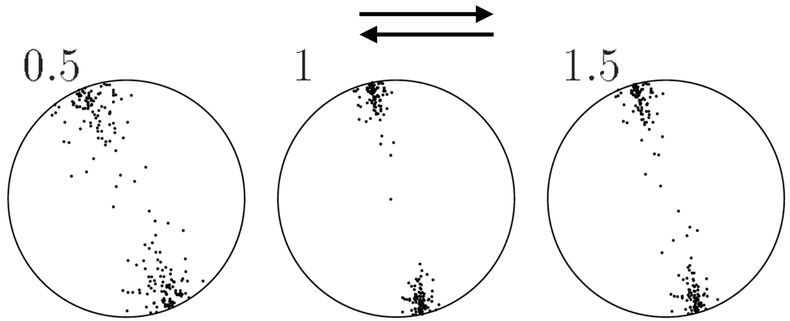
In the lab and in the field:
2 maxima texture



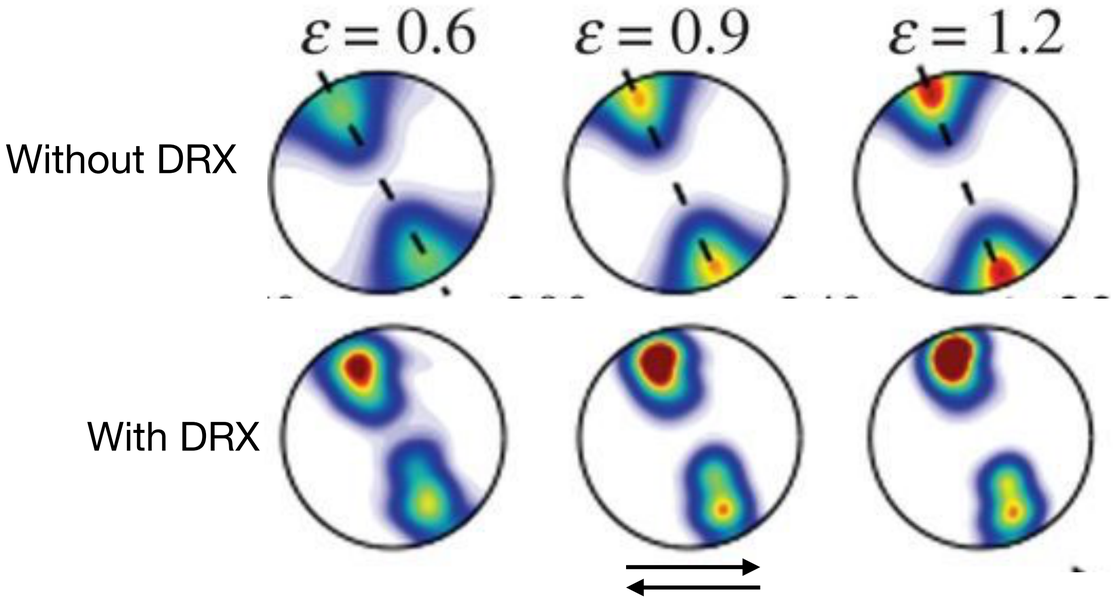
Natural shear zone Barnes Ice Cap (Hudelston 1977)

Mean-field modeling VPSC (Montagnat 2001)

Without DRX



Full-field modeling (Llorens et al. 2017)

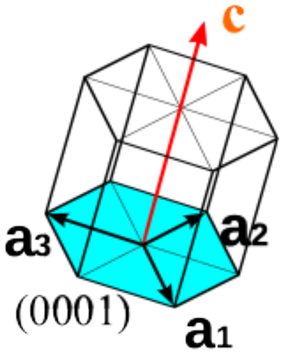


Modeling texture evolution with DRX

DRX -> rotation of c-axis toward an attractor c0

c0 is the orientation that maximizes the plastic strain for a given stress state **S**

-> **c0** maximizes the Resolved Shear Stress on the basal plane (0001)



$$RSS(\mathbf{a},\mathbf{c},\mathbf{S}) = \mathbf{S} : \mu$$

$$\mu = \frac{1}{2}\left(\mathbf{c}\otimes\mathbf{a} + \mathbf{a}\otimes\mathbf{c}\right)$$

maximum for

$$\mathbf{c_0} = \frac{1}{2}\left(\mathbf{e_1} \pm \mathbf{e_3}\right)$$

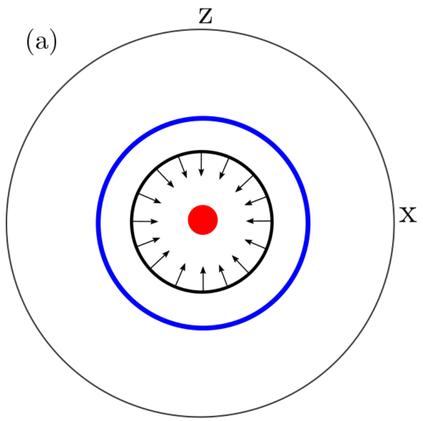
ei eigenvectors of **S**

Solutions of $\mathbf{Wc} - \lambda\left[\mathbf{Dc} - \left(\mathbf{c}^T\mathbf{Dc}\right)\mathbf{c}\right] = \mathbf{0}$

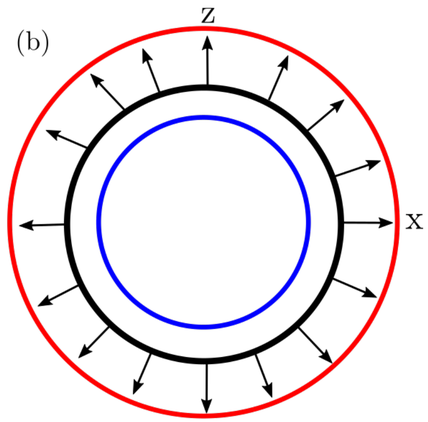
Solutions of $\frac{1}{\Gamma_{RX}}\left(\mathbf{c_0} - \mathbf{c}\right) = \mathbf{0}$

Solutions of $\mathbf{Wc} - \lambda\left[\mathbf{Dc} - \left(\mathbf{c}^T\mathbf{Dc}\right)\mathbf{c}\right] + \frac{1}{\Gamma_{RX}}\left(\mathbf{c_0} - \mathbf{c}\right) = \mathbf{0}$

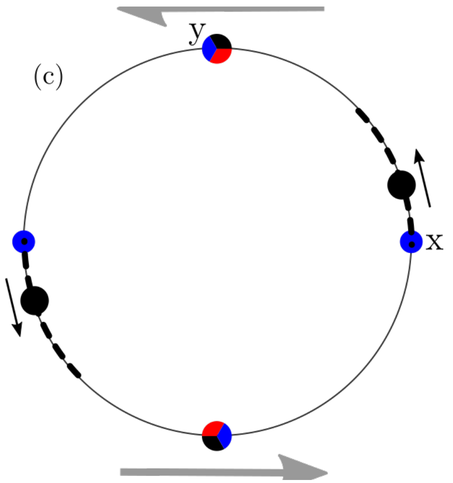
↑ Evolution of the solutions as Γ_{RX} increase



compression



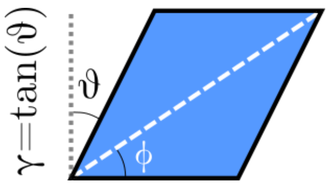
tension



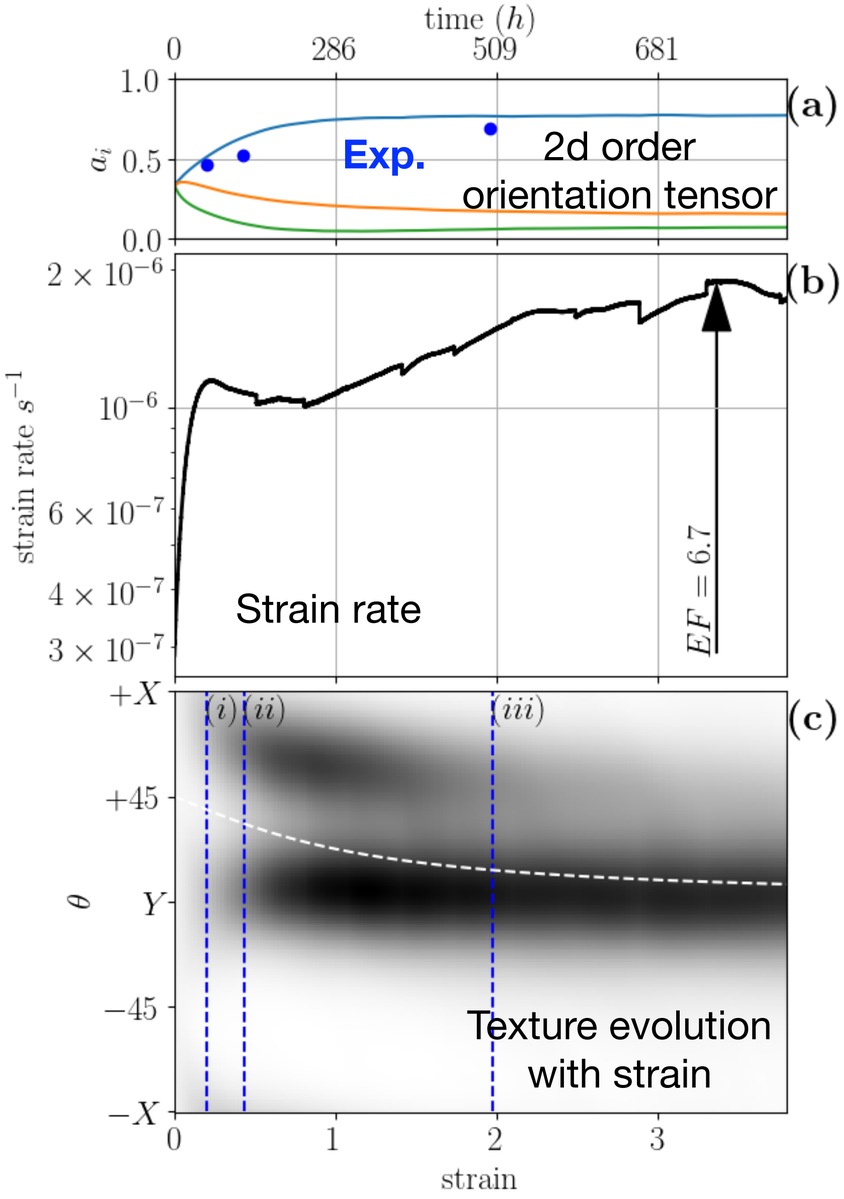
simple shear

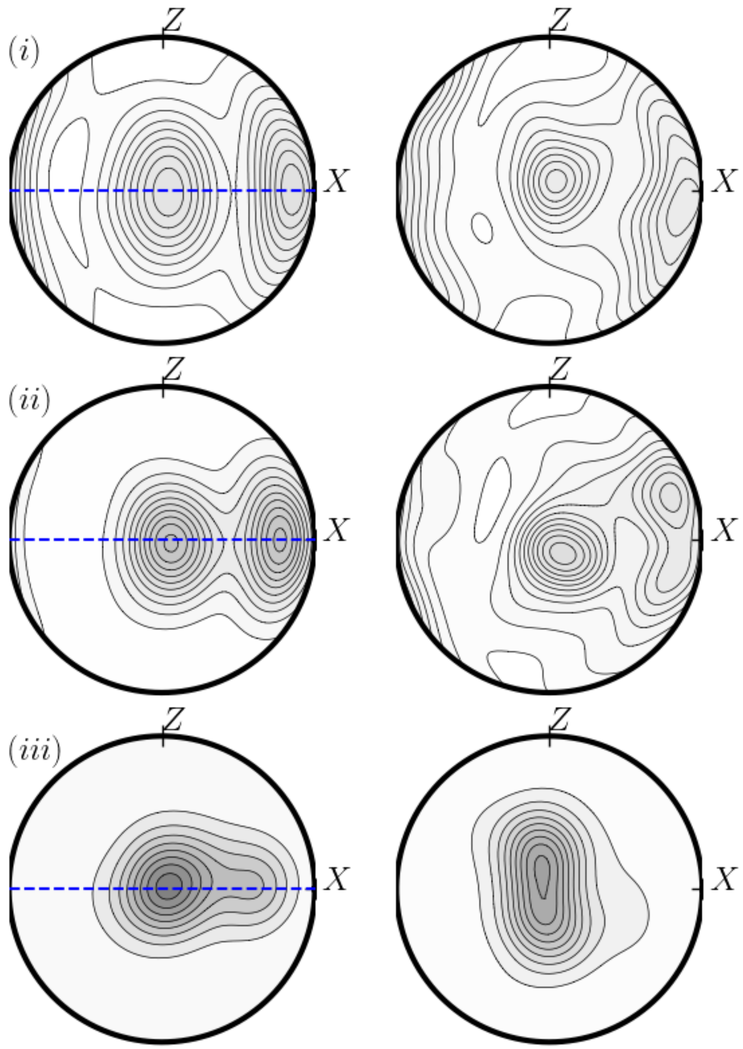
Modeling texture evolution with DRX

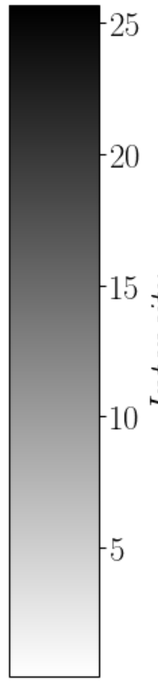
Results : simple shear



Experimental results from Journaux et al. 2019

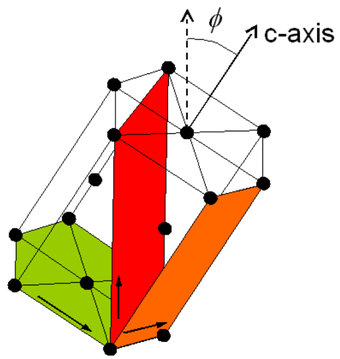




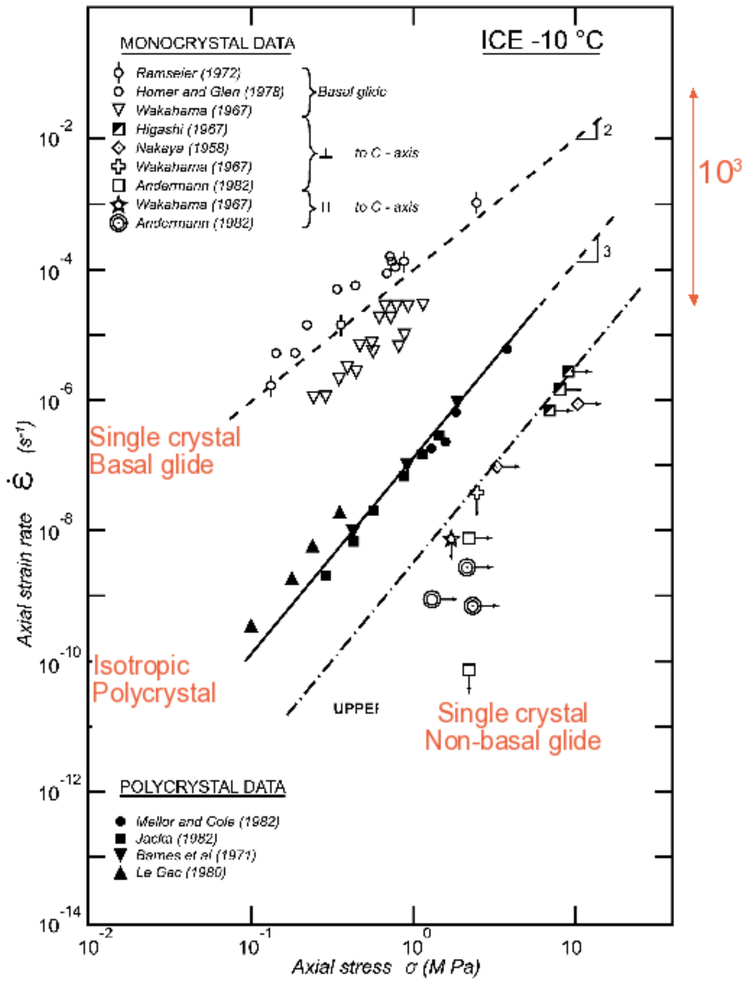


(d) Simulation (e) Experiment

Ice - strong viscoplastic anisotropy



Viscoplastic anisotropy

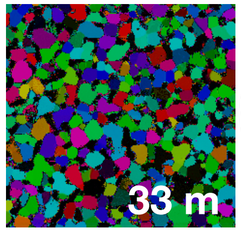


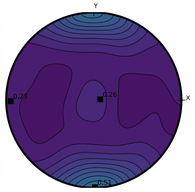
Duval et al. 1983

Texture-induced anisotropy

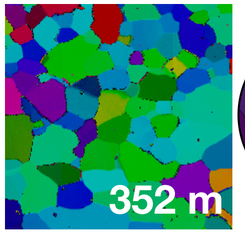
Ex. : Evolution along NEEM ice core (Greenland)

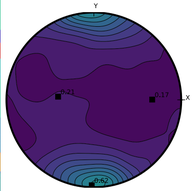
Montagnat et al. 2014



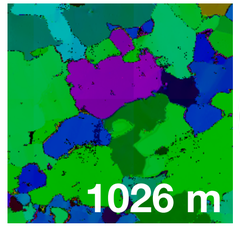


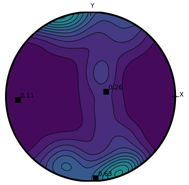
~ isotropic



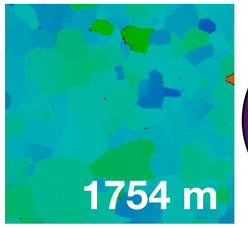


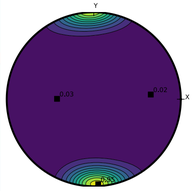
vertical compression



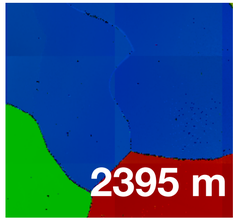


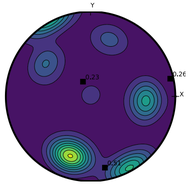
\+ dynamic recrystallization





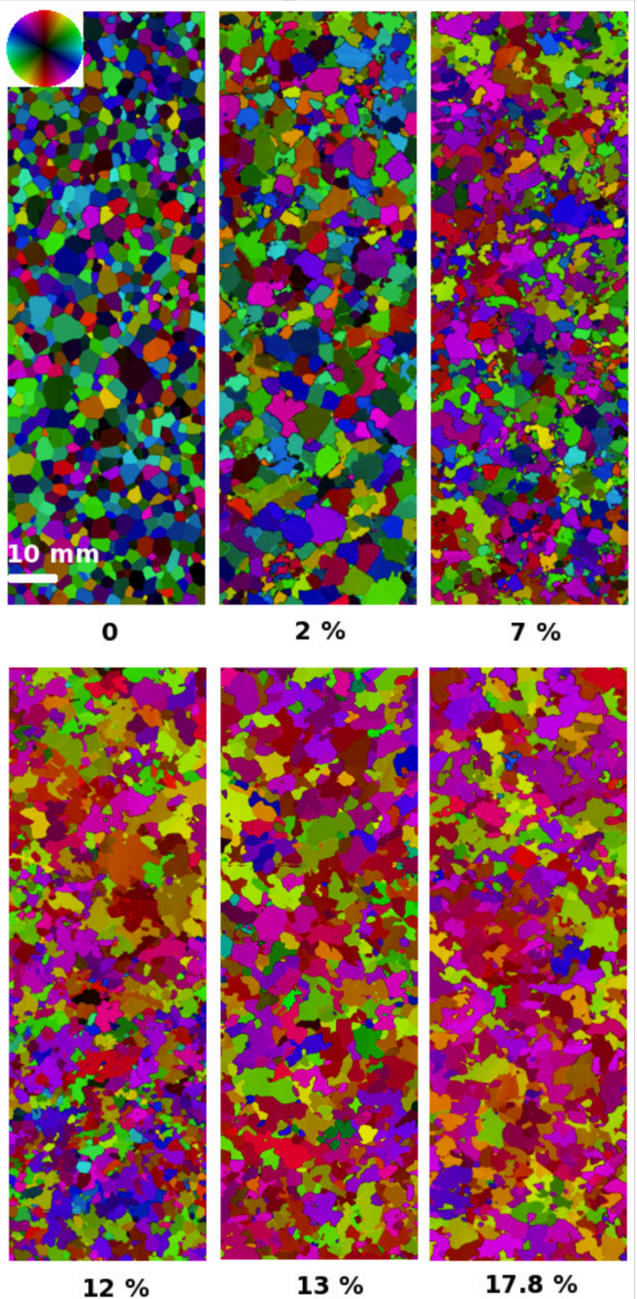
\+ horizontal shearing

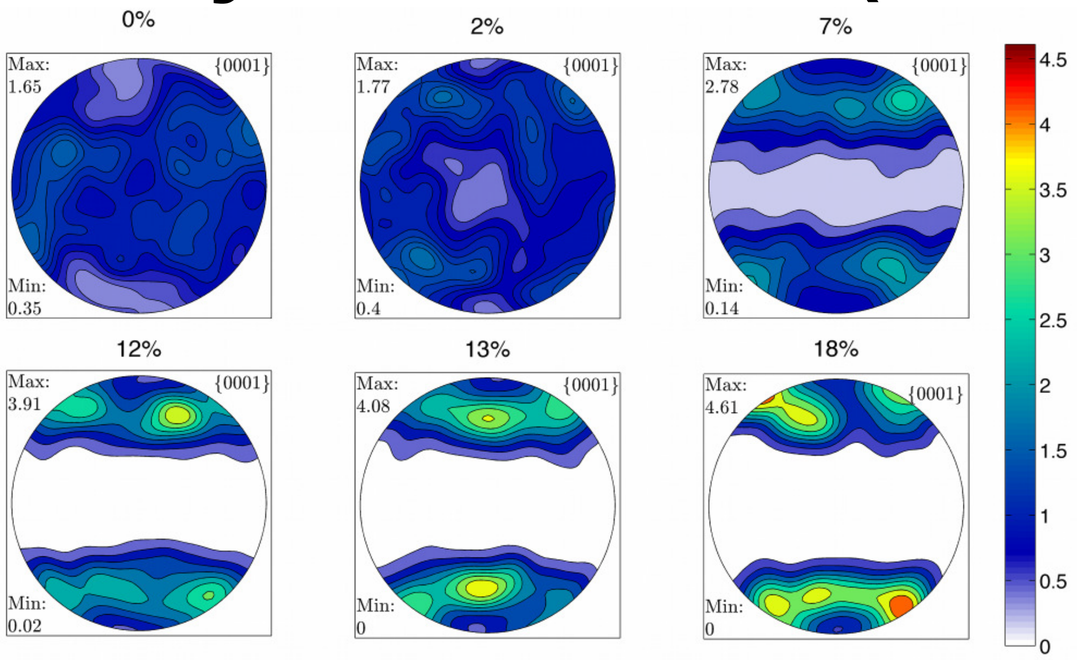


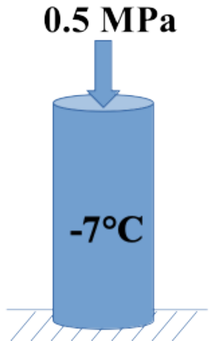


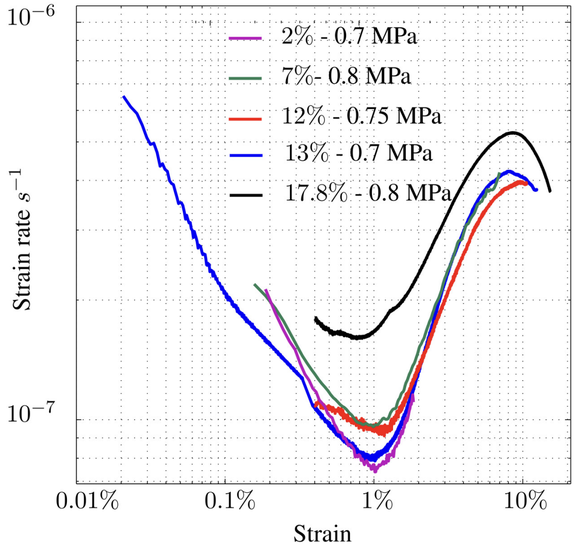
\+ high T and dynamic recrystallization

Dynamic recrystallization (DRX) in the lab









In lab conditions

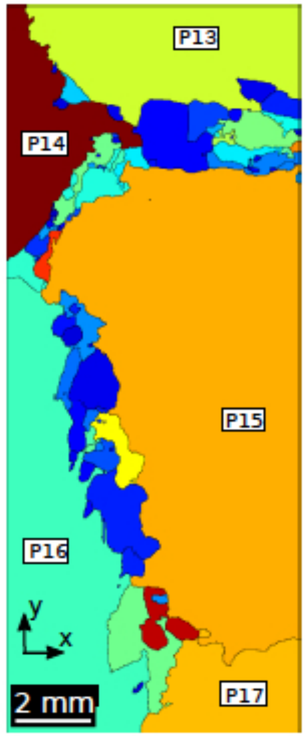
Dynamic recrystallization for $\varepsilon > 1\ \%$

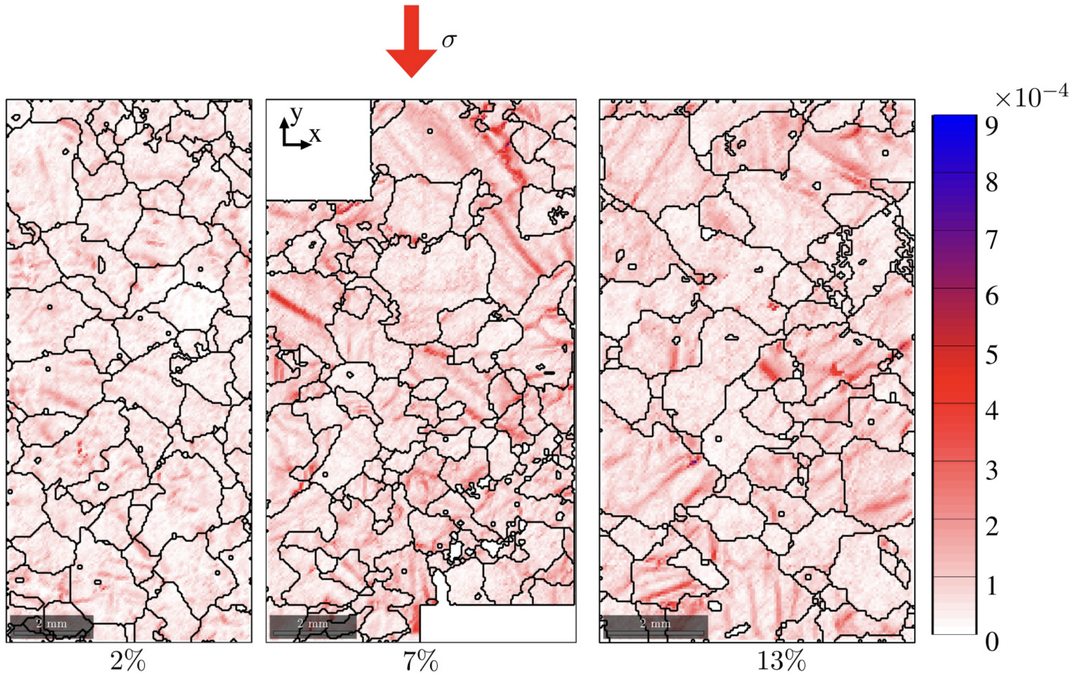
Well characterized DRX textures of girdle type in compression

Montagnat et al. 2015

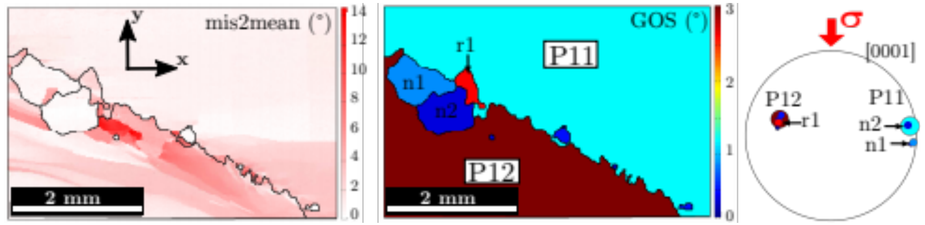
Dynamic recrystallization in the lab

High-resolution observations from electronic microscopy - EBSD

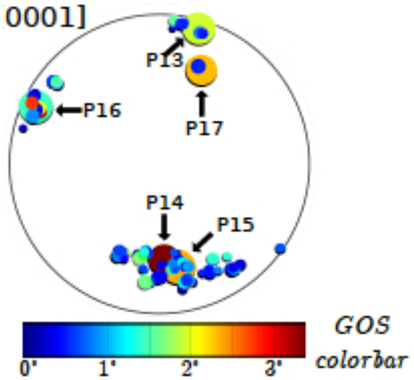




Lattice misorientations
(Kernel Average Misorientation)



Observation and orientation of new grains



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Chauve et al. 2017