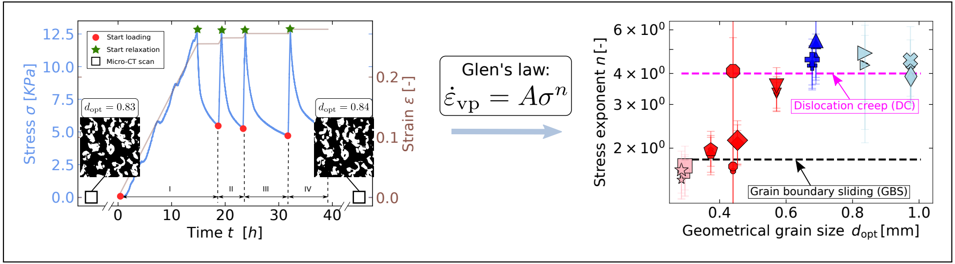
Examining the effect of snow type on effective viscoplastic properties in micro-compression experiments through repeated load-relaxation cycles



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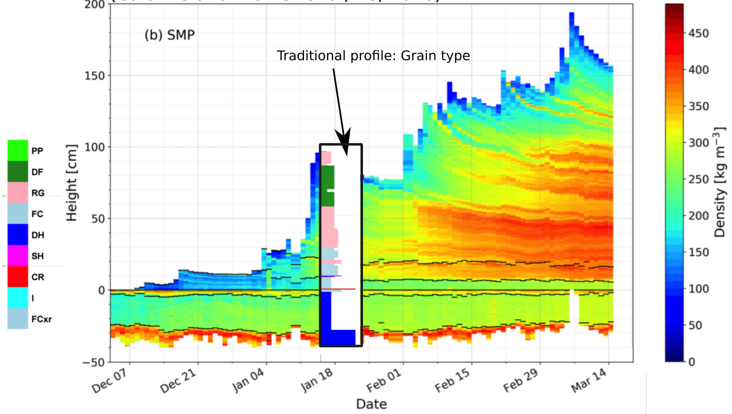
EGU General Assembly 2023, Monday, 10:55, PICO spot 3a

Motivation to study deformation mechanism in snow

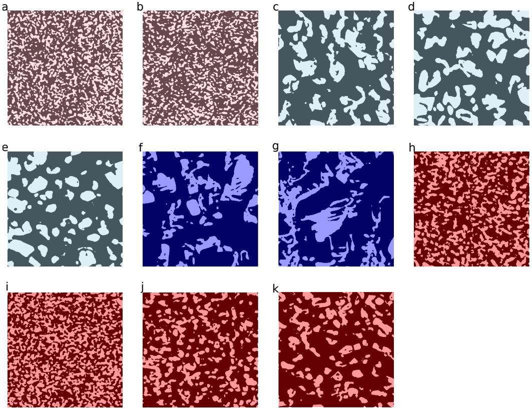
(Calonne and Richter et al, TC, 2020)



- Why does depth hoar (DH) have a different densification than other snow types?

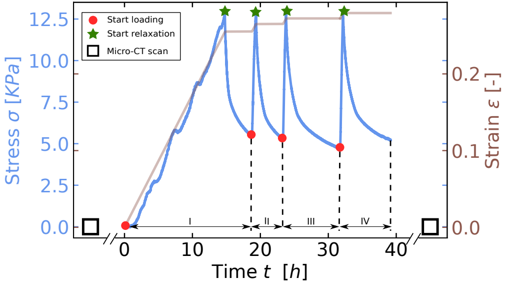
Experiments:

Snow samples:



- a to b: RG; c to e: FC; f to g: DH; h to k: MF
- Ice volume fraction ϕ: 0.18 to 0.43
- Geometrical (optical) grain size d_{opt}:0.28 to 0.97 $[\mathrm{mm}]$

Progressive loading-relaxation:



- Experiments done in micro-compression device
- I cycle: On average 75.6% of total strain; maximum microstructural deformation; non-homgeneous stress resposnse
- II, III, IV cylce: On average $< 1\%$ of total strain; minimum microstructural deformation; viscoplastic behavior of intact ice matrix

Parameter estimation:

Novel non-linear Maxwell model:

Strain superposition:

$$\dot{\varepsilon} = \dot{\varepsilon}_{el} + \dot{\varepsilon}_{\mathrm{vp}}$$

ODE:

$$\dot{\varepsilon} = \frac{1}{\lambda}\dot{\Sigma} + \frac{1}{\tau_{\mathrm{vp}}}\Sigma^n$$

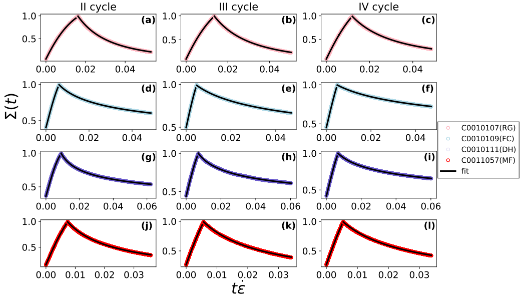
Relaxation phase: $\dot{\varepsilon} = 0$

$$\Sigma(t) = \Sigma(0)\left(\frac{1}{1+(n-1)(t/\tau)}\right)^{\frac{1}{n-1}}$$

Loading phase: $\dot{\varepsilon} \neq 0$; $t(\Sigma)$ can be solved

$$\dot{\varepsilon}(t-t_0) = \frac{1}{\lambda}\left\{\frac{\Sigma}{n}\Phi\left(\mu\Sigma^n, 1, \frac{1}{n}\right) - \frac{\Sigma_0}{n}\Phi\left(\mu\Sigma_0^n, 1, \frac{1}{n}\right)\right\}$$

Curve-fit:

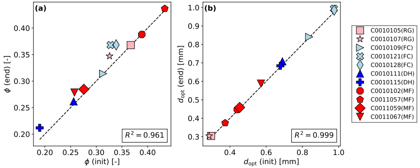


- Relaxation: n and τ
- Loading: μ, λ, and n from relaxation
- Loading: $\tau = \frac{1}{\lambda\mu\dot{\varepsilon}}$

- Sucessful estimation of parameters

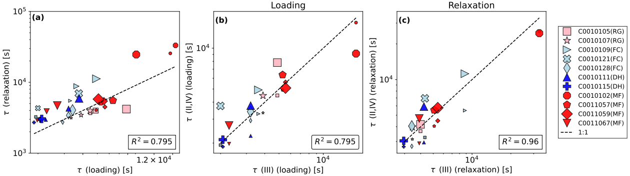
Inspection of results:

Intactness of microstructure:



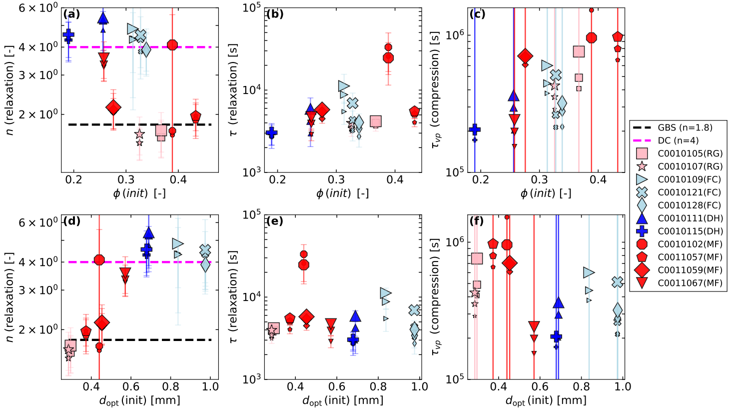
- Negligible structural changes
- Viscoplastic response of the intact ice matrix

Consistency of parameters:



- Increase of marker size from small to large: increase from II- to IV-cycles
- Fair agreement between independent estimates of τ
- High correlation of τ estimation from different cycles

Linking mechanical behavior with snow microstructure

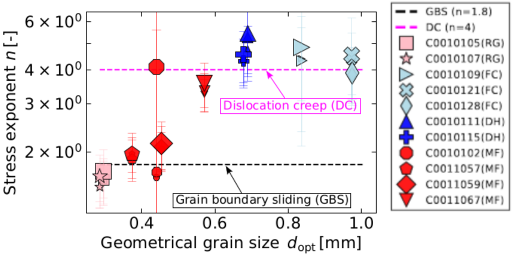


- Two, cleary separated groups of exponents: $n \approx 1.9$ and $n \approx 4.4$ (consistent with transition from GBS to DC, (Goldsby et al 2001)
- n does not depend on snow type and ϕ; n increment with grain size
- τ and τ_{vp} do not depend on d_{opt}; dependence on ϕ

Conclusion

Summary

- Access of viscoplastic behavior of intact ice matrix through deformation-controlled experiments; novel non-linear Maxwell model
- Geometrical grain-size driven transition in the snow deformation mechanism
- $\dot{\varepsilon}_{\mathrm{vp}} = \dot{\varepsilon}_{\mathrm{GBS}} + \dot{\varepsilon}_{\mathrm{DC}}$; $n \approx 1.9$ for GBS; $n \approx 4.4$ for DC



Discussion

- Grain size and density are highly correlated in nature (may conceal the grain size dependence)
- Results reconcile previous experiments: high sensitivity of compactive viscosity found in Wiese 2017 due to choice of optical diameters between 0.49 to 0.56

Limitations

- Indirect evidence on deformation mechanisms from the macroscopic mechanical response
- Indeterminate situation in loading phase

- DH has a different densification evolution due to it's geometrical grain size