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Small-scale disturbances in the stratigraphy of the NEEM ice core: observations and numerical simulations

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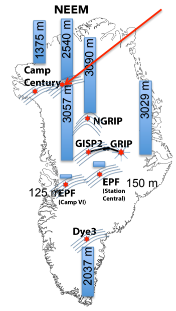
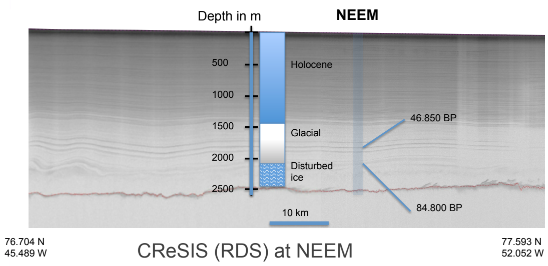
NEEM ice core



- „North Greenland Eemian Ice Drilling“
- 2008–2010
- Position:77.45°N, 51.07°W
- Mean annual temperature -29°C
- Accumulation rate 0.22 m/a
- Core until bedrock, 2540 m

NEEM ice core



CReSIS (RDS) at NEEM

Observations: Methods

Line scan stratigraphy:

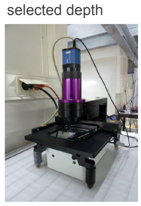
- Dark field method, light is scattered at dust particles, bubbles.
- Transparent ice appears black in the record.
- Continuous except for brittle zone

Svensson et al., 2005

Problem: Disturbances and folding only visible when the impurity content is high (cloudy bands)

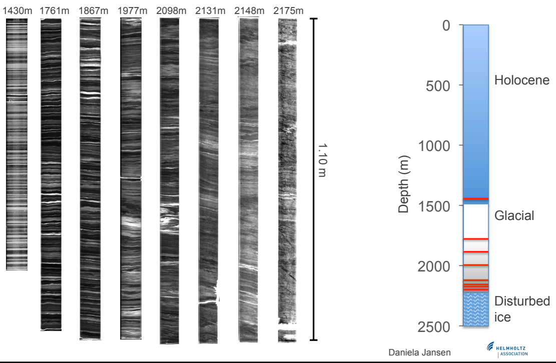
Measuring c-axes orientation:

- Polarized light microscopy on thin sections
- Not continuous, but for NEEM measured for entire core segments in selected depth



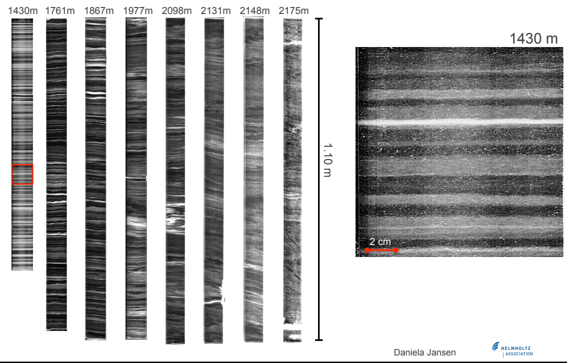
G50 Fabric Analyser, photo by Anneke Tammen

Observations: LineScan



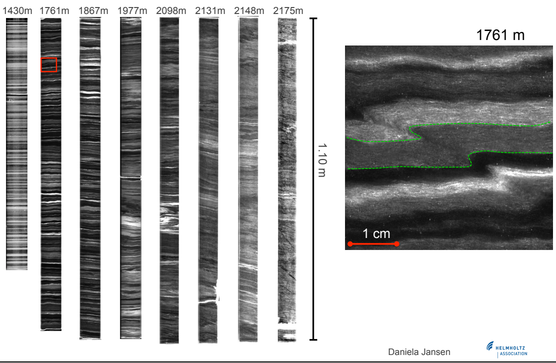
Daniela Jansen

Observations: LineScan



Daniela Jansen

Observations: LineScan



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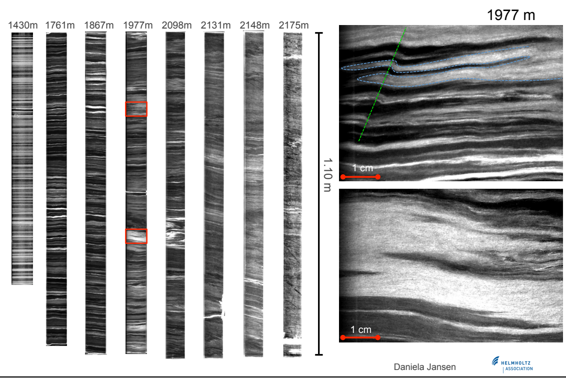
Observations: LineScan



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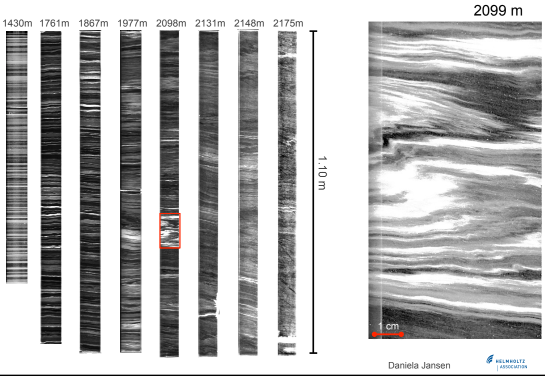
Observations: LineScan



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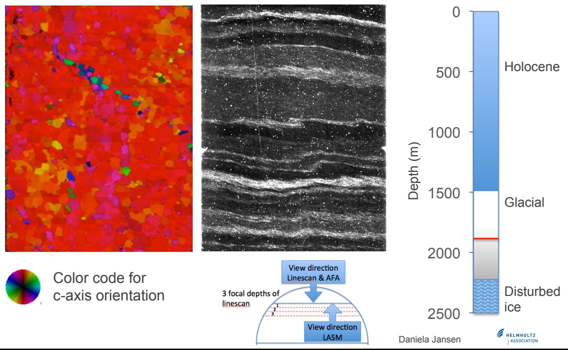
Observations: Fabric

Depth: 1803 m



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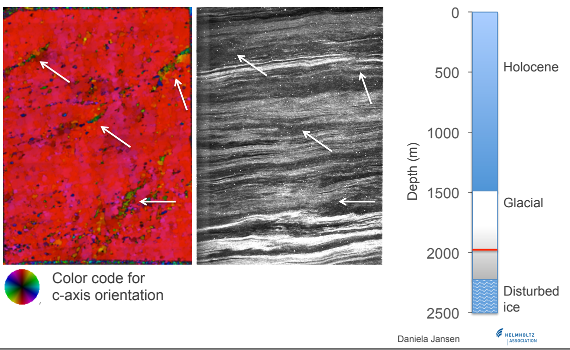
Observations: Fabric

Depth: 1978 m



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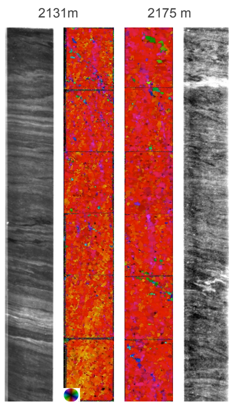

Observations: Fabrics

- Striking of the bands is consistent throughout core sections (0.55 cm)
- Tilted layers indicate folding on a larger scale
- c-axes tilt with the layers

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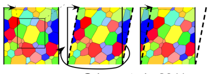
Modelling: Elle FFT

FFT code (Lebensohn 2001, Lebensohn et al., 2008), purely viscoplastic dislocation glide



Griera et al., 2011

Simulation Setup

- resolution of 256x256 Fourier points (unodes)
- Each unode represents a small area or crystallite with a certain lattice orientation and dislocation density
- Wrapping boundaries
- Initial misorientation between grains <5º from vertical, randomly distributed
- 10 steps of dynamic recrystallization (GBM and recovery) per deformation (FFT) step (γ=0.04)

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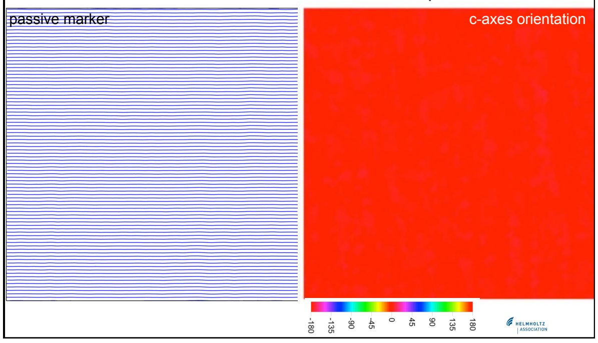
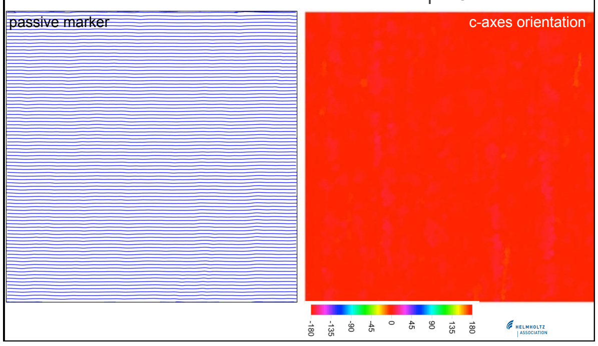
Modelling: Elle FFT

γ = 0.2



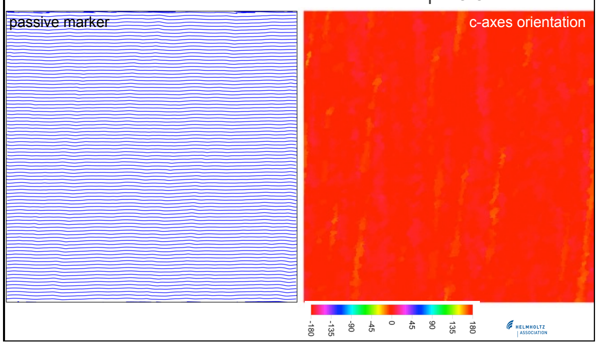
Modelling: Elle FFT

γ = 0.4



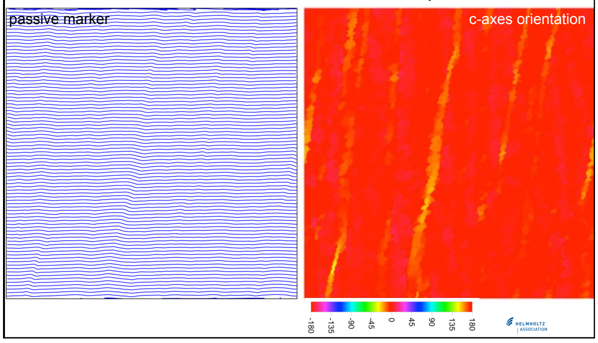
Modelling: Elle FFT

γ = 0.6



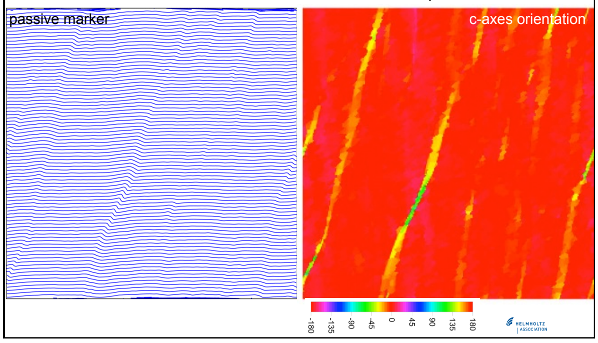
Modelling: Elle FFT

$\gamma = 0.8$



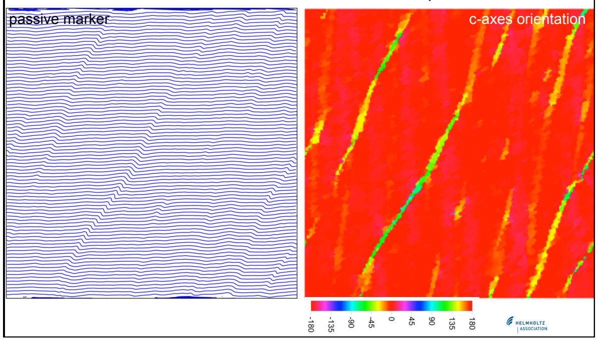
Modelling: Elle FFT

$\gamma = 1$



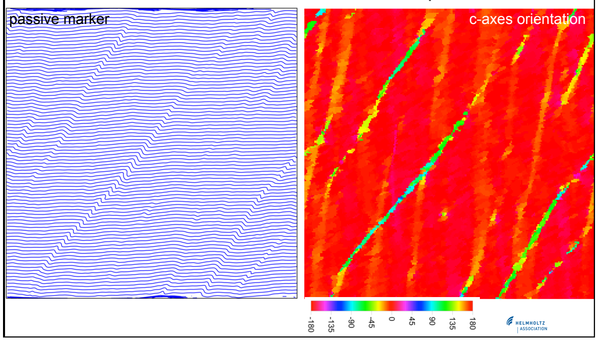
Modelling: Elle FFT

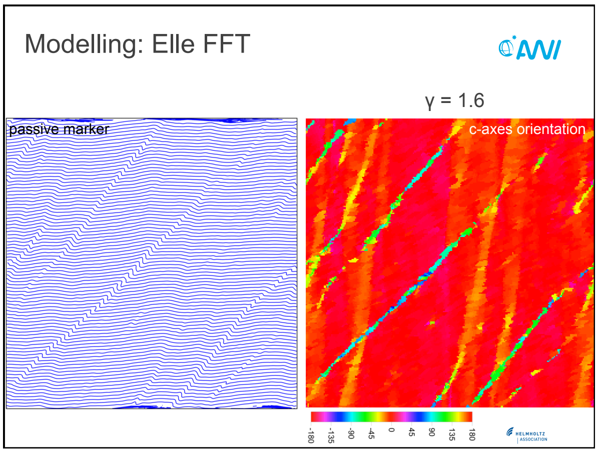
$\gamma = 1.2$

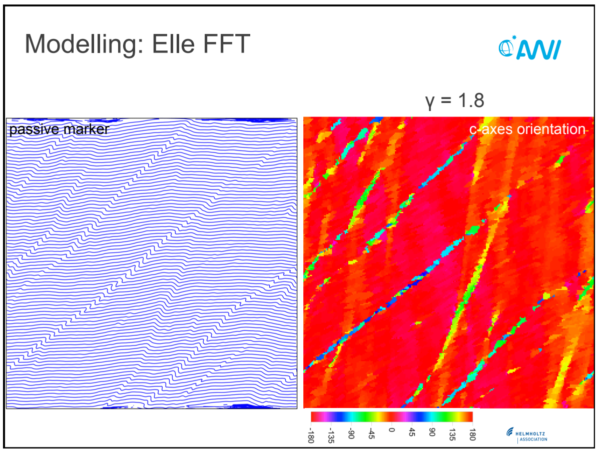


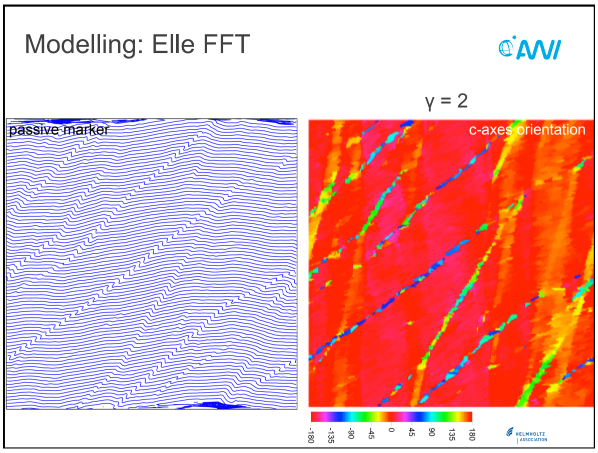
Modelling: Elle FFT

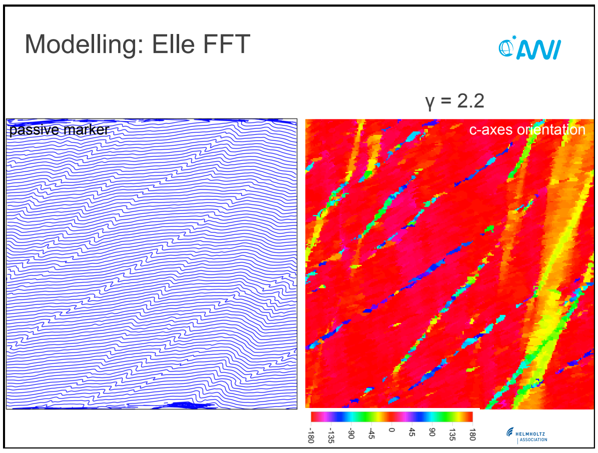
$\gamma = 1.4$




Modelling: Elle FFT
γ = 1.6
passive marker
c-axes orientation
-180 -135 -90 -45 0 45 90 135 180

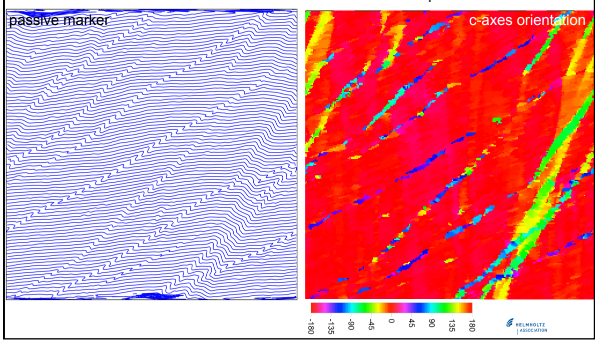

Modelling: Elle FFT
γ = 1.8
passive marker
c-axes orientation
-180 -135 -90 -45 0 45 90 135 180


Modelling: Elle FFT
γ = 2
passive marker
c-axes orientation
-180 -135 -90 -45 0 45 90 135 180


Modelling: Elle FFT
γ = 2.2
passive marker
c-axes orientation
-180 -135 -90 -45 0 45 90 135 180

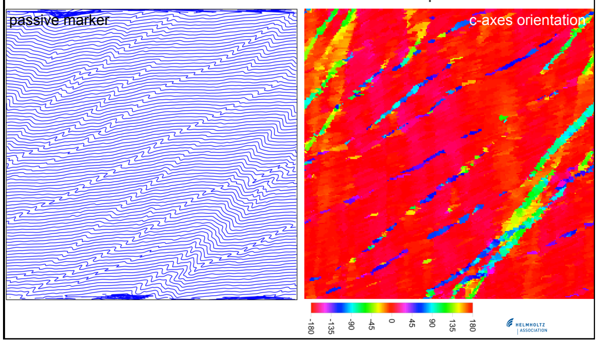
Modelling: Elle FFT

γ = 2.4



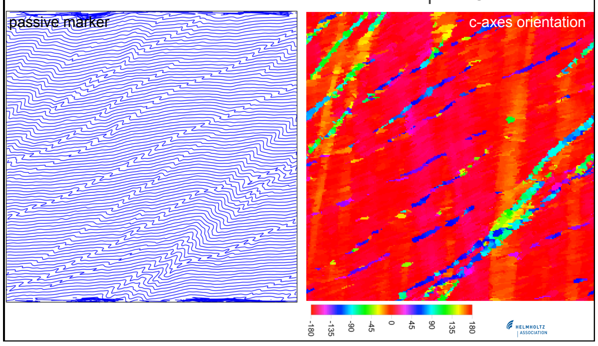
Modelling: Elle FFT

γ = 2.6



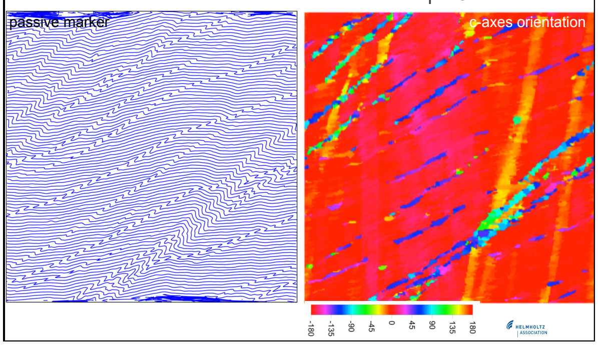
Modelling: Elle FFT

γ = 2.8

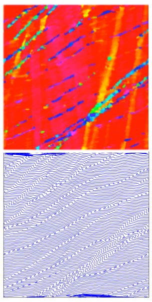


Modelling: Elle FFT

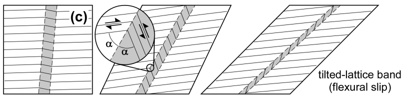
γ = 3



Modelling: Elle FFT



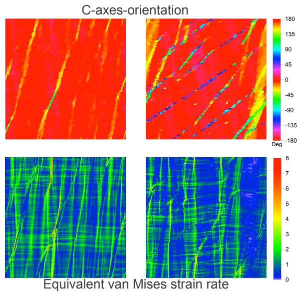
- Microstructure evolution model reproduces the development of the “tilted lattice” bands
- The bands form in different generations which interfere with each other
- If bands are eroded the disturbance is still visible in the passive marker



Kink- or chevron folds

Modelling: Elle FFT

Localization of strain



- Strain rate is highest at the margins of the bands where bending stresses are high
- This is most prominent for younger bands with steep inclination
- The localization intensifies with ongoing deformation

Summary

- Small scale folding in NEEM sets in at about 1500m, buckle folding unlikely
- Folding causes layer thickening and doubling, disturbances on the decimeter scale, maybe larger
- Microstructural modelling indicates that folding is initiated by “tilted lattice bands”, process similar to chevron folding
- Strong anisotropy is required (single maximum)
- Initial disturbance in the c-axes distribution is needed to seed the folds

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