

## Seismic Anisotropy Tomography from Glacial Microseismicity: an Antarctic Example

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<sup>1</sup>British Antarctic Survey, <sup>2</sup>University of Bristol, <sup>3</sup>University of Oxford; <sup>†</sup> now at KIT | DPT Karlsruhe | 25. Nov. 2022

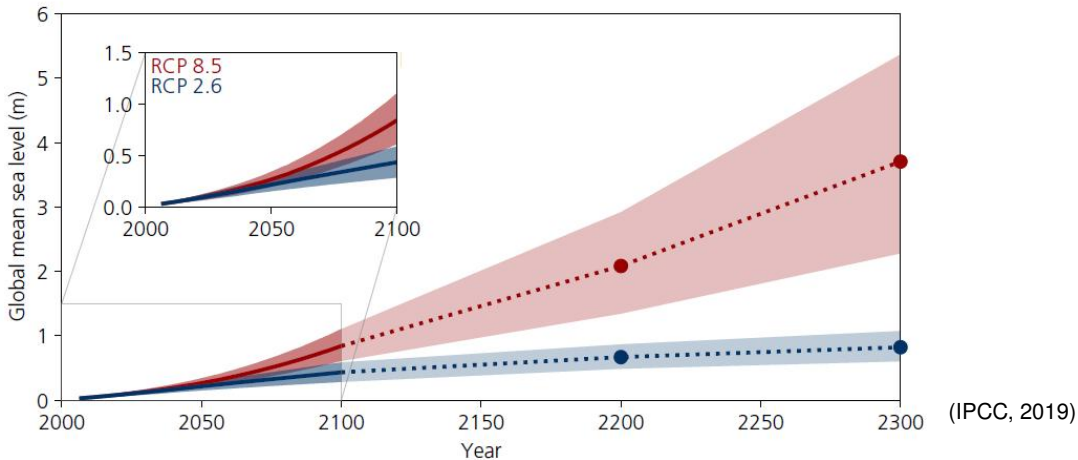


# Motivation

Projected sea level rise until 2300  
(Intergovernmental Panel on Climate Change)

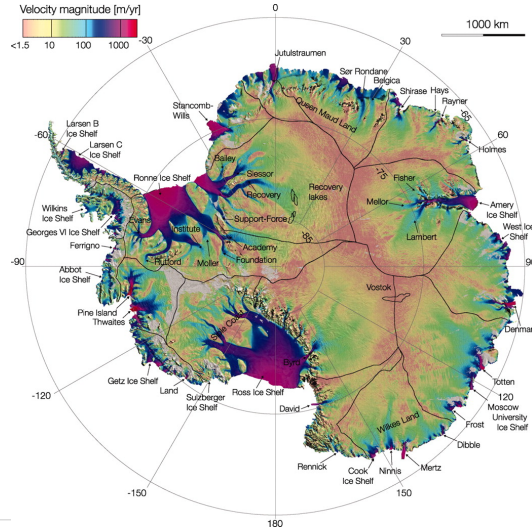


British  
Antarctic  
Survey



# Motivation

## Largest contribution to outflow from Ice Streams



(Rignot et al., 2011)

# Motivation



British  
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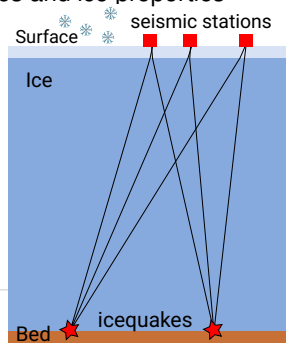
- **Largest uncertainty in sea level rise predictions from contribution of West-Antarctica**
  - → **Largest contribution to outflow of ice from ice-streams**
  - → → **Need to understand ice-stream dynamic!**
- 
- Ice-stream flow is is controlled by the frictional properties of the ice-bed interface & internal ice deformation



# Motivation

- **Largest uncertainty in sea level rise predictions from contribution of West-Antarctica**
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- → → **Need to understand ice-stream dynamic!**

- Ice-stream flow is controlled by the frictional properties of the ice-bed interface & internal ice deformation
  - Sliding of a ice-stream over its bed can induce **microseismicity**
  - Characteristics of these events carry information on bed properties and ice properties
- **Illuminate those through seismological studies**

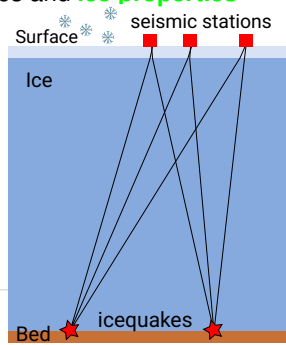


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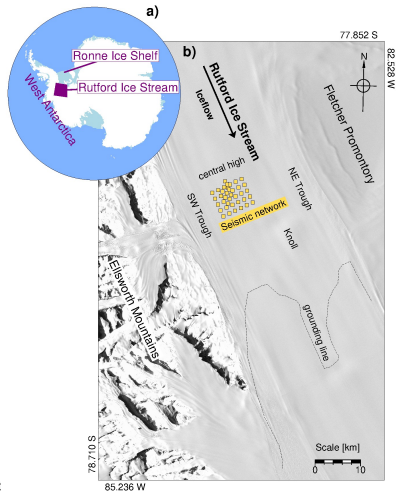
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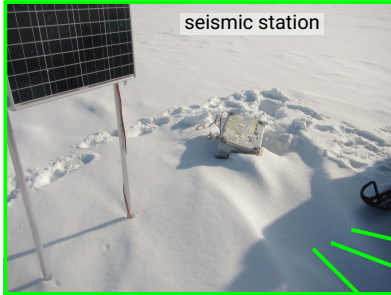


# Study Area: Rutford Ice Stream

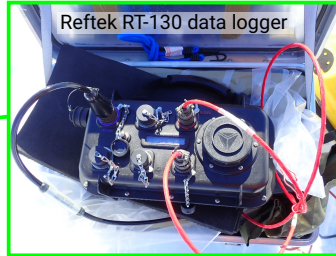
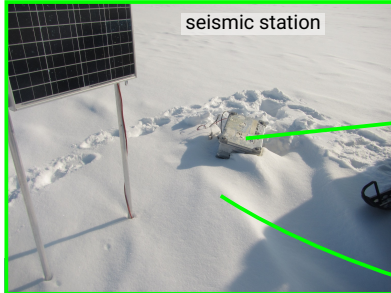


- Study area located  $\sim 40$  km upstream the grounding line
- Flow speeds of  $\sim 1.1$  m/day
- Ice thickness of  $\sim 2.2$  km
- 35-station seismic network, operated during the 2018/19 field season for  $\sim 3$  months

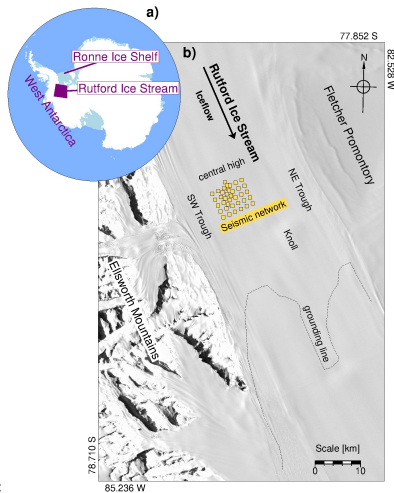
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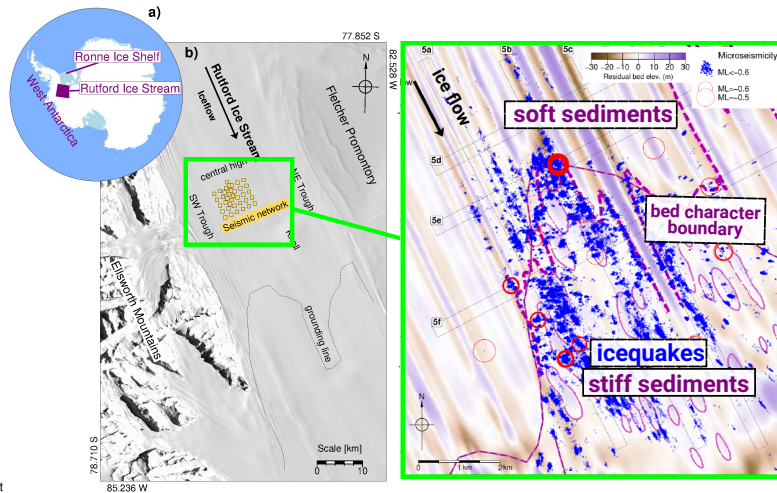


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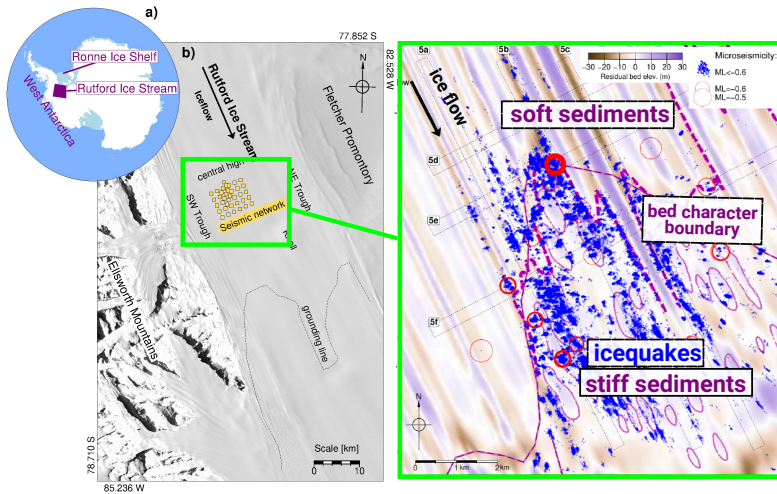
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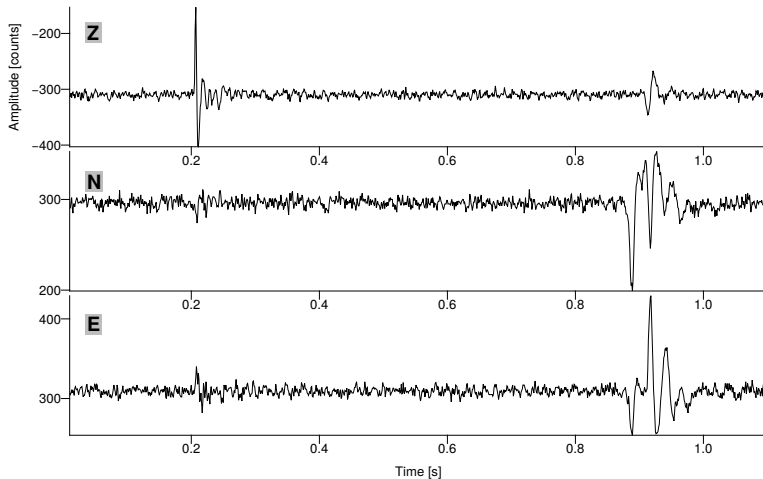
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- **Icequakes carry information on bed properties**  
(Kufner et al., 2021; Hudson et al., 2021; Hudson & Kufner, 2022)



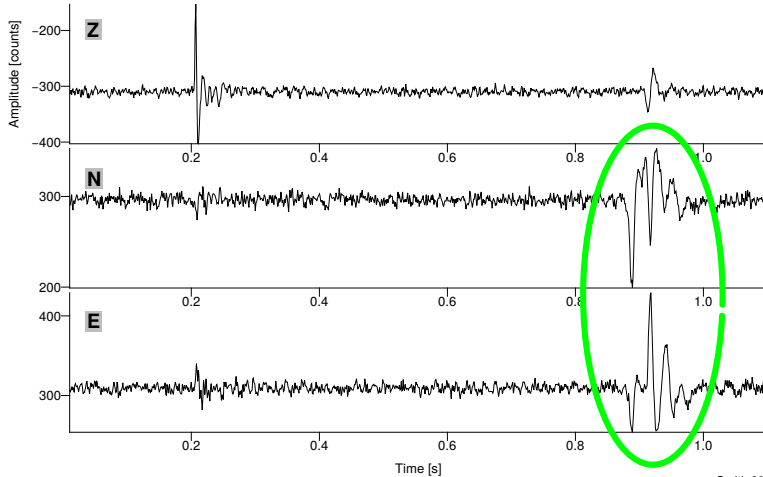
# Icequakes



- **Frequency range:** P-waves - 10 and 200 Hz & S-wave - 30 and 100 Hz

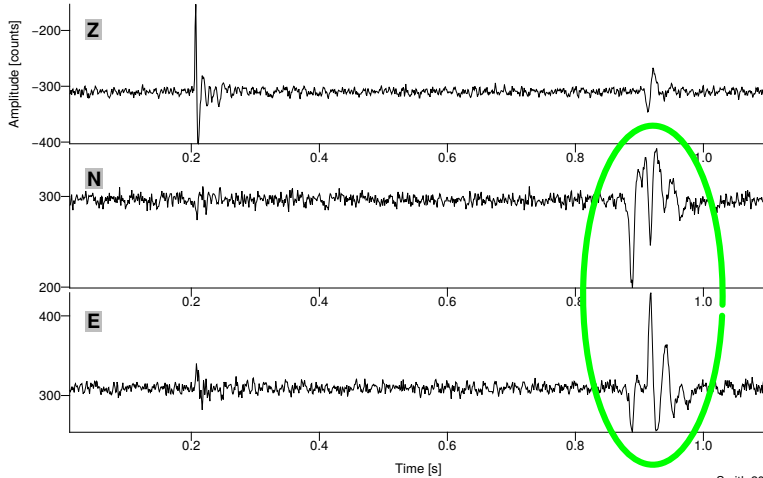
# Icequakes

## Shear wave splitting

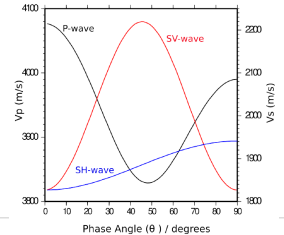
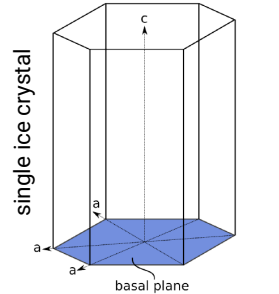


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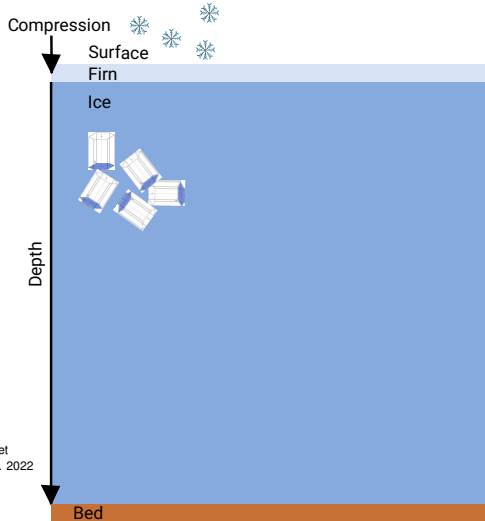
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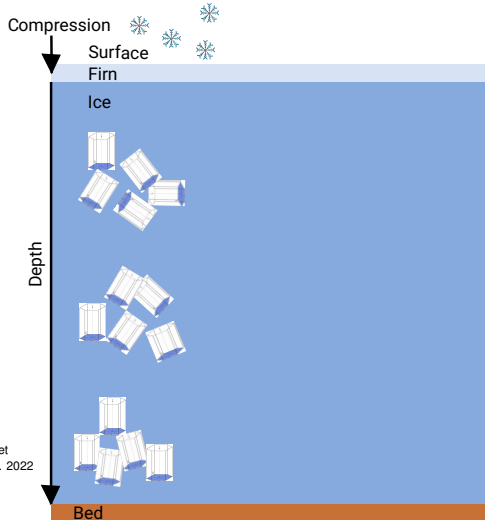
Smith 2015



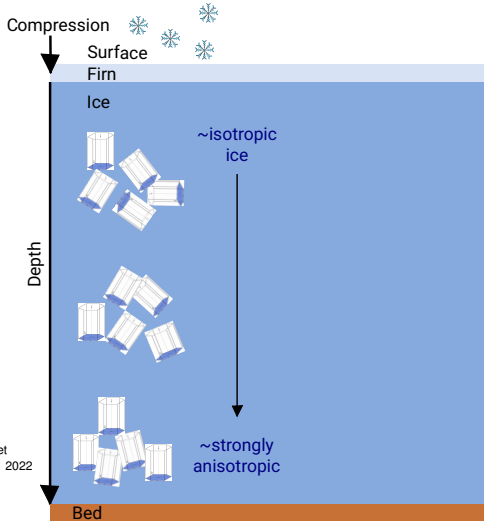
# Background: Polycrystalline anisotropy development of Ice Fabric



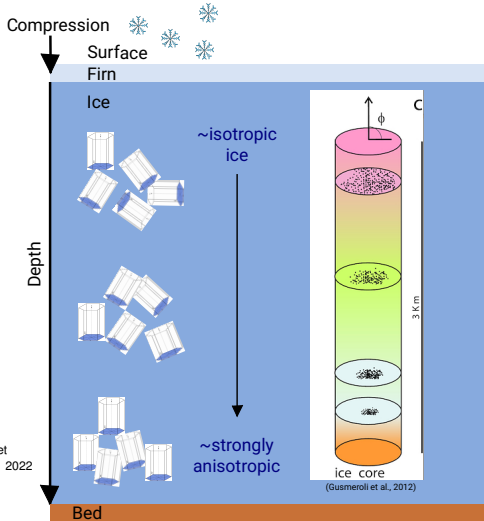
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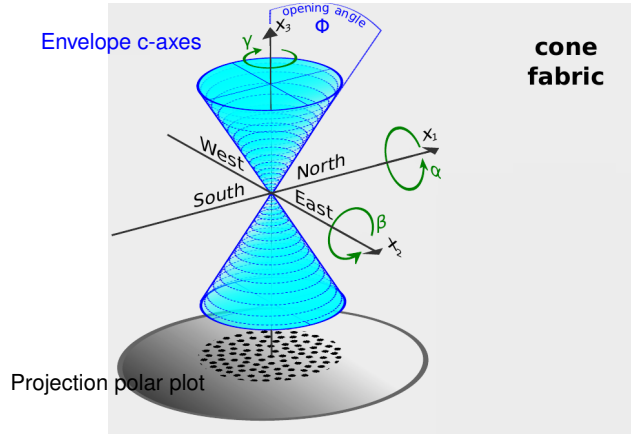
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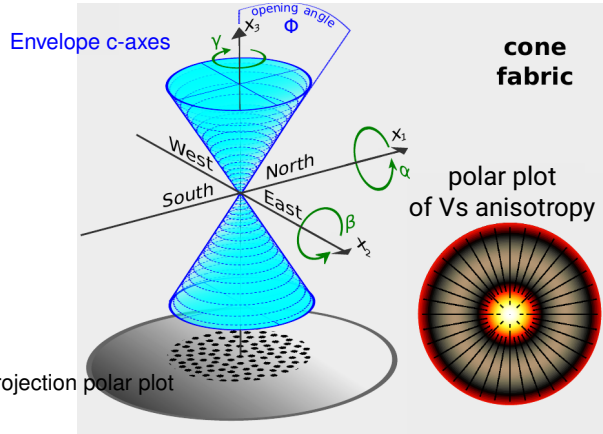
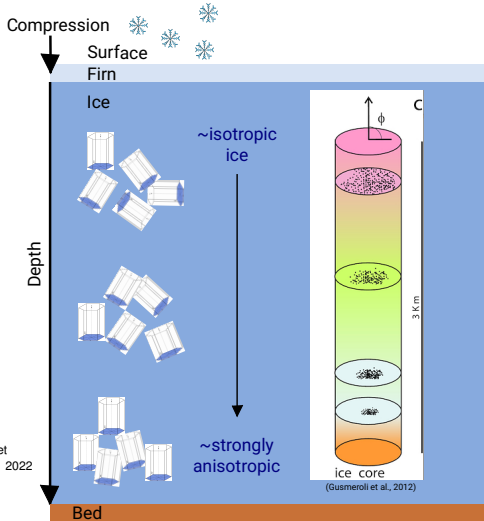
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Envelope c-axes

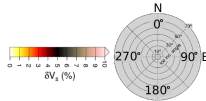
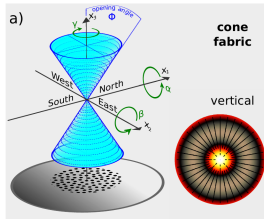


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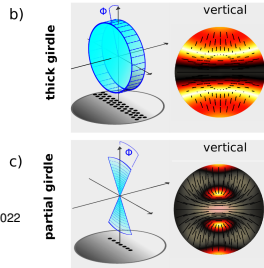




# Background: Polycrystalline anisotropy development of Ice Fabric



uniaxial  
compression

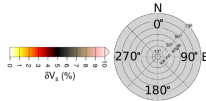
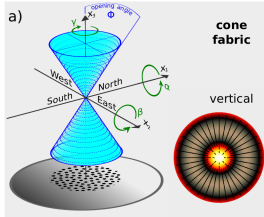


no lateral  
compression and  
pure longitudinal  
extension

combination of  
pure and simple  
shear

# Ice deformation

## a) Shear wave splitting analysis

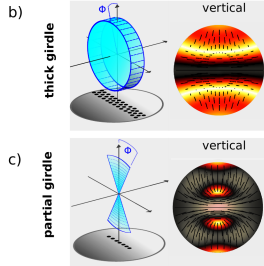
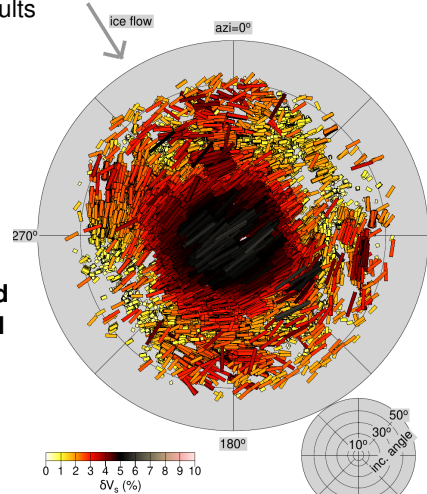


202,651 SWS results

uniaxial compression

no lateral compression and pure longitudinal extension

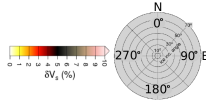
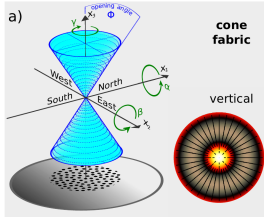
combination of pure and simple shear



Kufner et al. 2022

# Ice deformation

## a) Shear wave splitting analysis



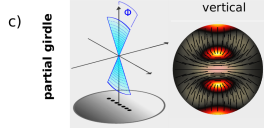
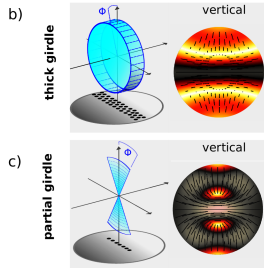
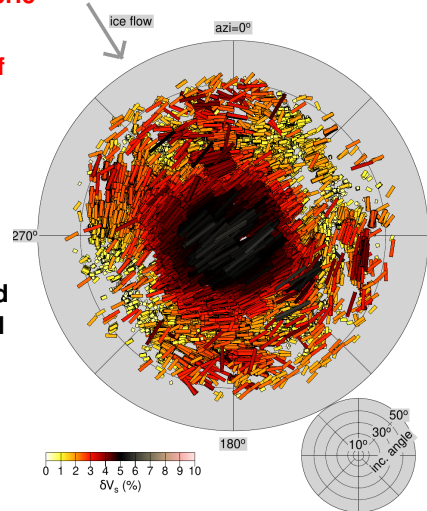
Mixing of two fabric types?

Multiple layers of distinct fabric?

uniaxial compression

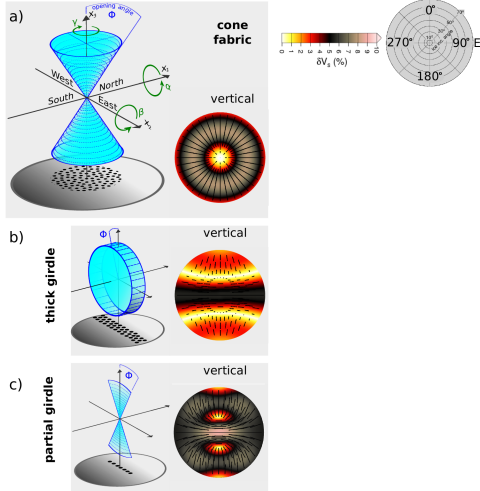
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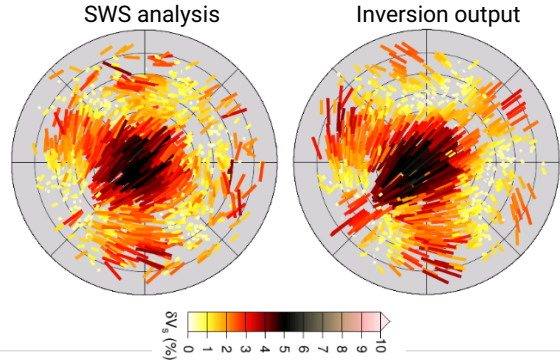


# Ice deformation

## b) Inversion for depth-variable ice fabric

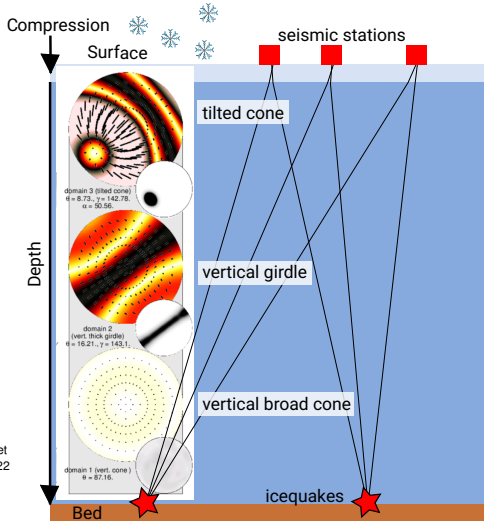


→ **Results from inversion for multiple-layer ice fabric** (neighbourhood algorithm; subsequently applying SWS-parameters to the original waveforms, following Wookey, 2012):

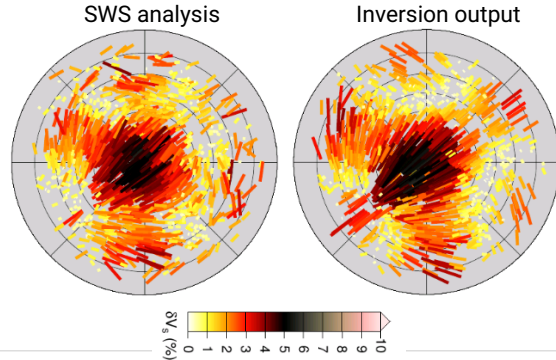


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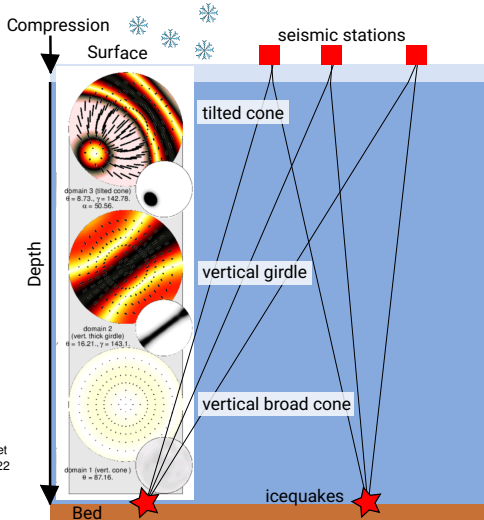


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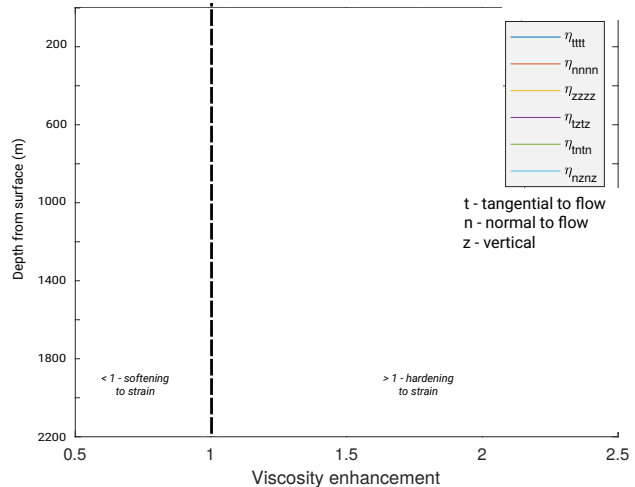
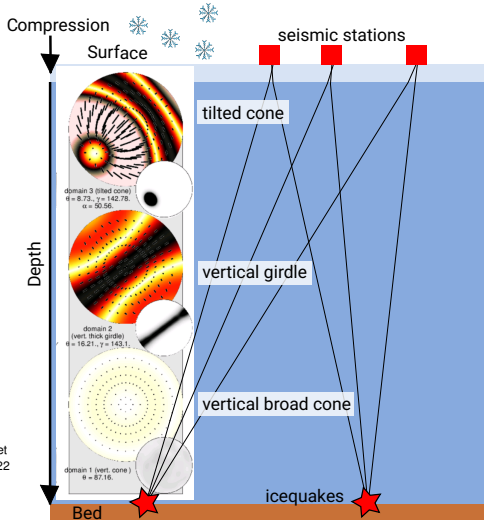
### → Results & Interpretations:

- top 400 m: mix of horizontal shearing across flow and compression
- center: extension along flow
- bottom 500 m: vertical compression & recrystallitation in basal unit

→ Ice fabric is a combination of ongoing deformation, the strain history and recrystallization processes

# Ice deformation

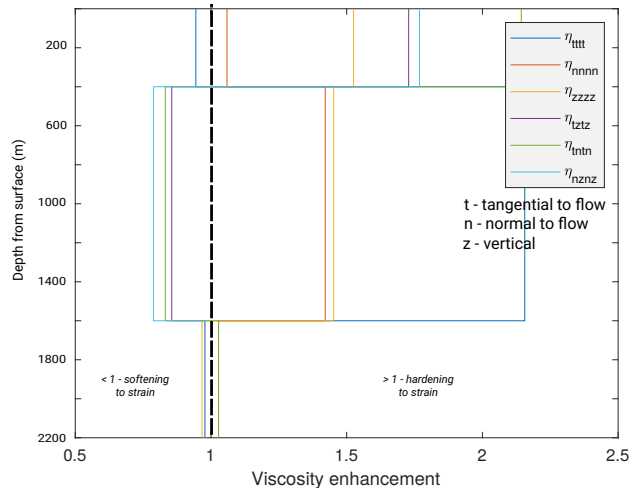
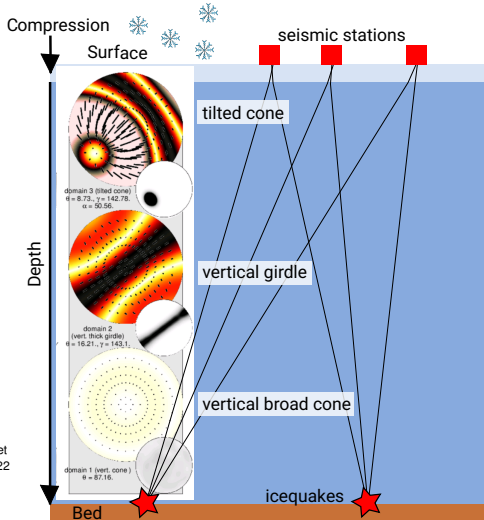
## b) Inversion for depth-variable ice fabric



Kufner et al. 2022

# Ice deformation

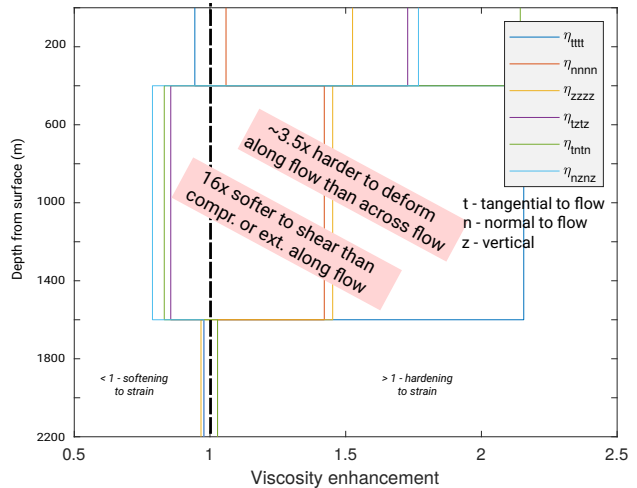
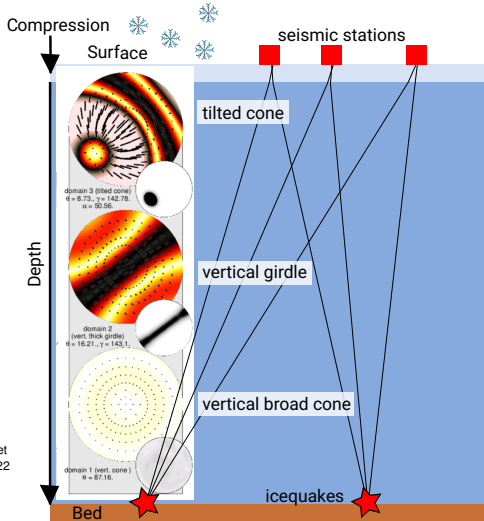
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Largest uncertainty in SLR from contribution of W-Antarctica

Largest contribution to outflow of ice from ice-streams



British  
Antarctic  
Survey



- Need to understand ice-stream dynamic!
- Illuminate those through seismological studies

## Bed properties:

- Icequake distribution illuminates type of bed character, which in turn feature distinct frictional properties (more info in Kufner et al., 2021)

## Ice properties:

- From SWS analysis: ice viscosity varies with depth, direction and component of deformation  
→ single enhancement factor not sufficient to describe ice-streams  
(more info in Kufner et al., 2022 - in review)

**Thank you for your attention  
& a big thanks to everybody who made this work possible!**



**British  
Antarctic  
Survey**



**BEAMISH field team  
2019/2020**