Modelling and measurements of vertical strain-rates under ice domes and ridges

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Where, why and when should the next deep ice core in West Antarctica be drilled?

- We are usually looking for a **long and undisturbed** stratigraphy
- Ice **domes and ridges** are usually preferred locations

We need **good ice flow models** to choose the good locations and make the chronology of the cores, but the **ice flow law is not well constrained**

=> **Model** and **measure** strain-rates under ridges and domes to give clues to the where and why

Outline

I. Introduction:

- Ice flow law
- Raymond Effect
- Some examples of ice domes

II. 3D modelling of the flow of ice under ridges and domes

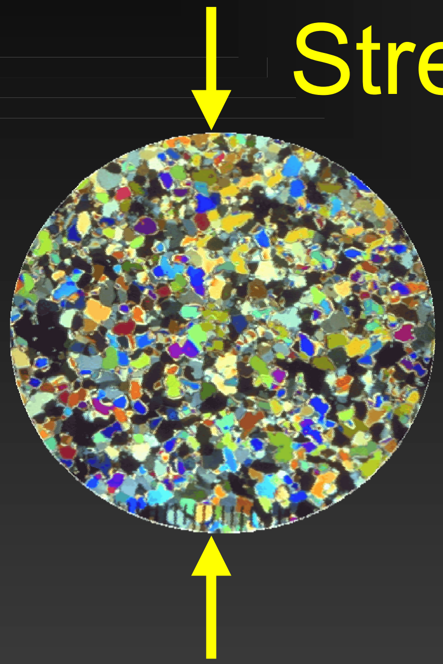
- Triple junctions
- Curved Ridges

III. In situ strain-rate measurements using a phase sensitive radar

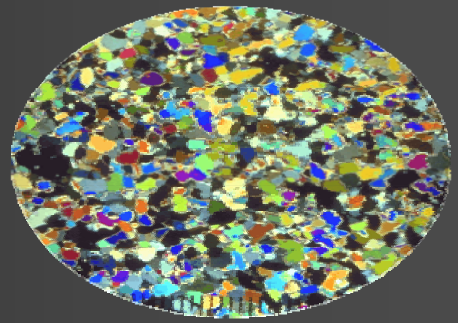
- Summit - Greenland
- NEEM - Greenland
- Fuchs Ice Rise - Antarctica

I Introduction: Ice flow law

Stresses S



Strain-rates D



$$\boldsymbol{S} \propto f(\gamma_{\boldsymbol{D}}^{1/n-1})\boldsymbol{M} : \boldsymbol{D}$$

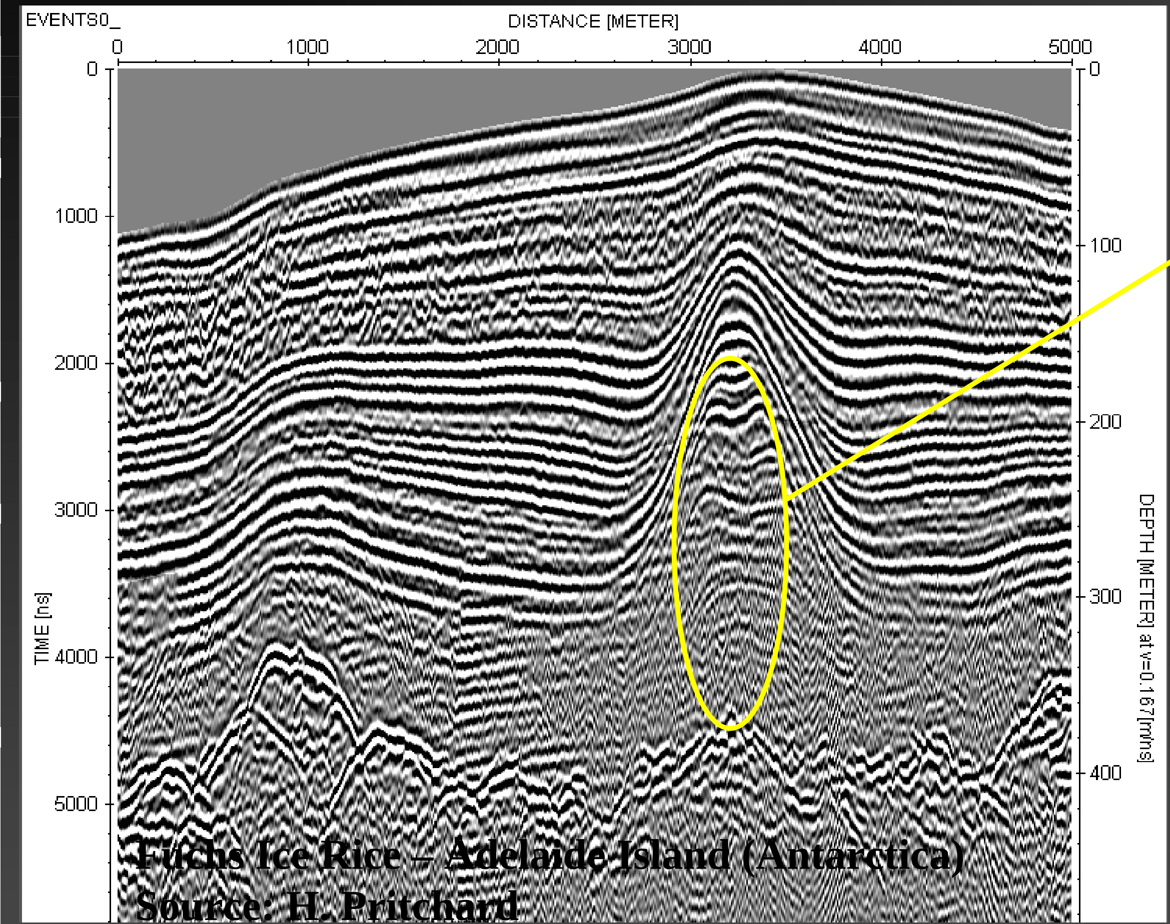
<u>Non-linearity</u>

Usually n=3 but values less than 2, possibly close to 1 have been reported

<u>Anisotropy</u>

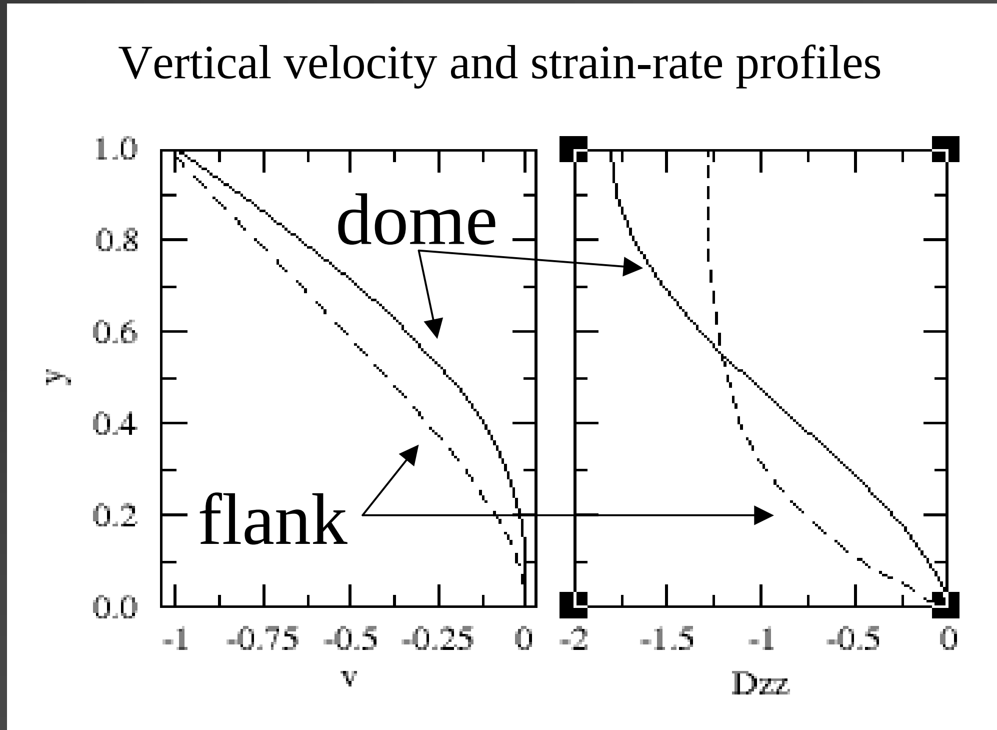
Usually isotropic Glen's flow law

I Introduction: Raymond Effect



$$\gamma_D^{1/n-1} \to \infty$$

Stiff ice area

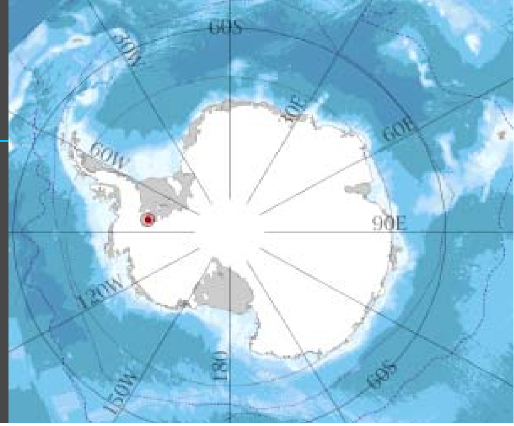


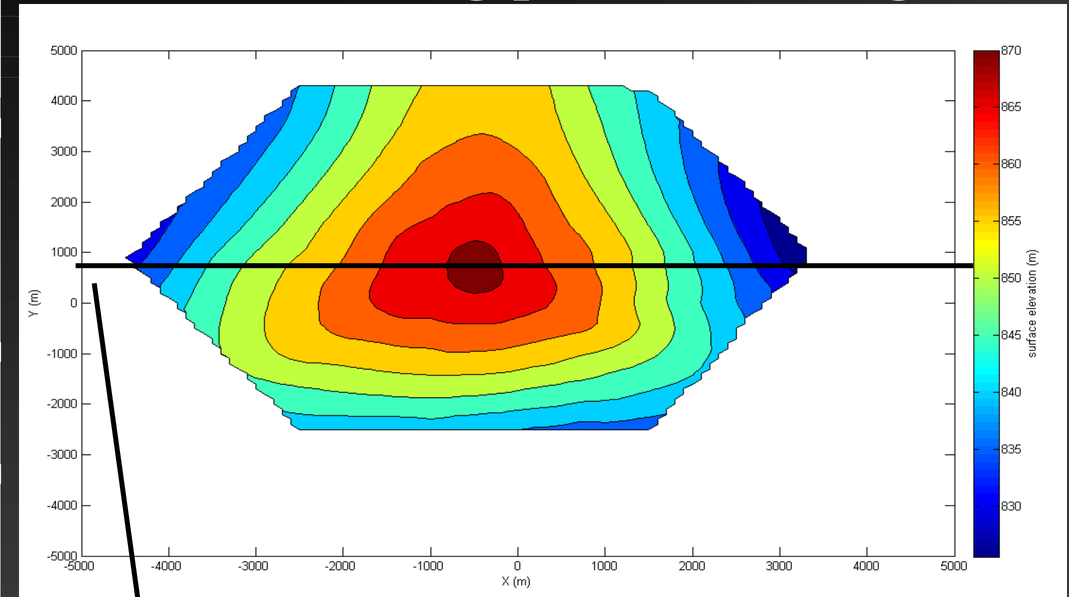
Raymond bumps depend of the ice rheology **but also** of the **divide history => need direct measurements**

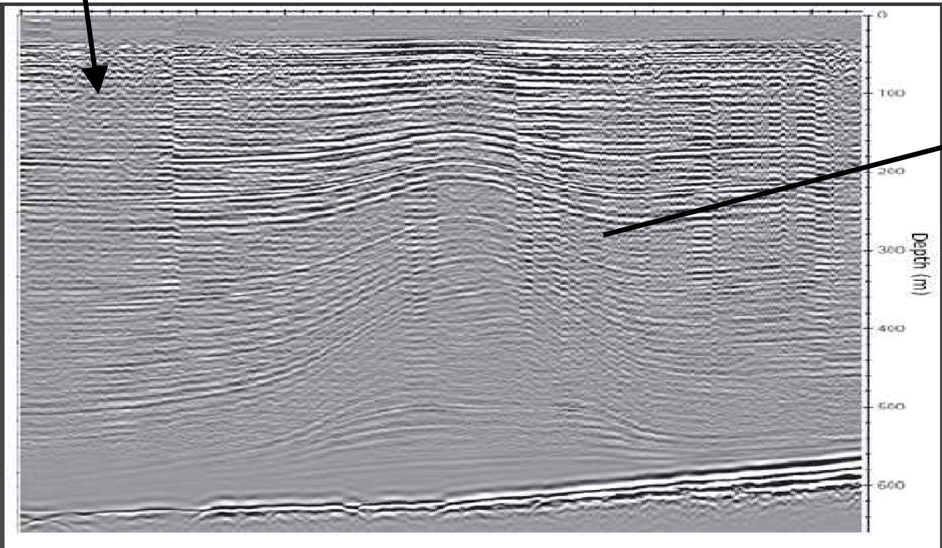
Many studies **but mainly in 2D => often 3D effects can't be neglected**

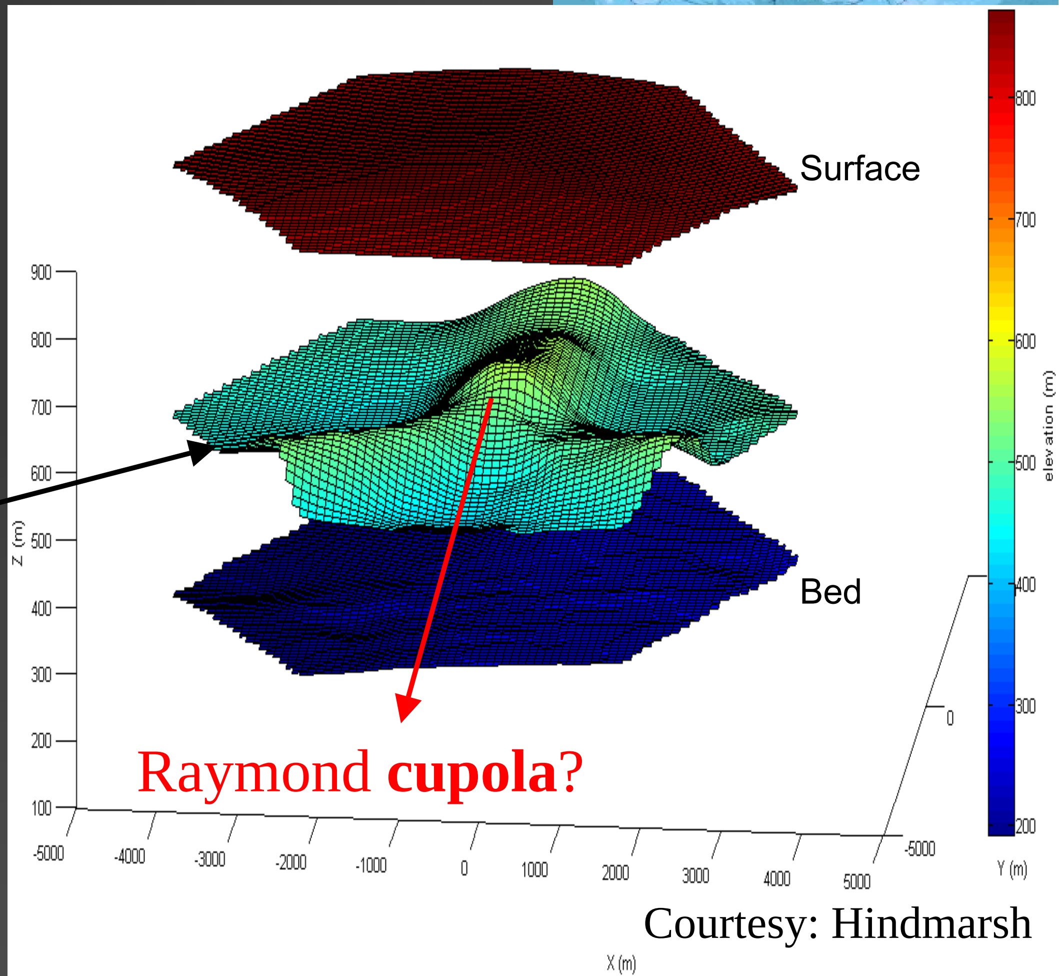
I Introduction: Fletcher Ice Rise

Dome = meeting point of 3 ridges, a **triple junction**







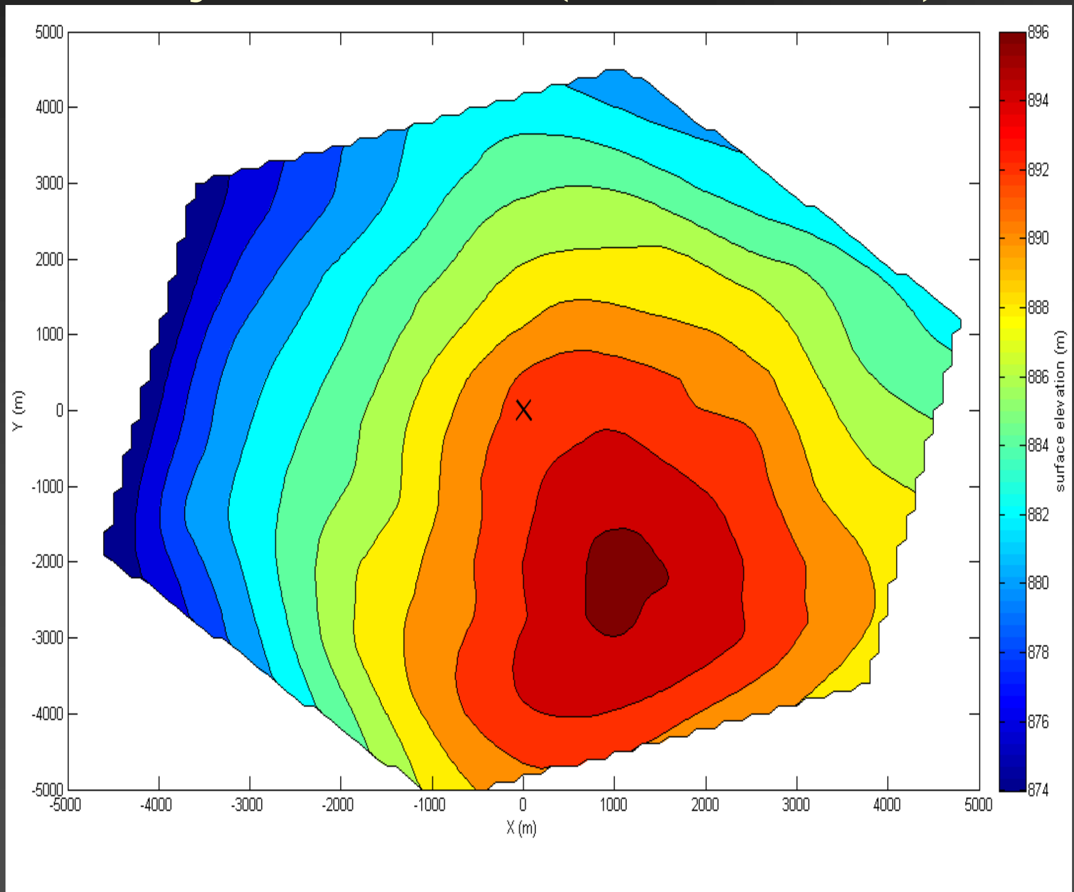


=> BAS project to drill a new ice core under the dome to study the elevation history of this area

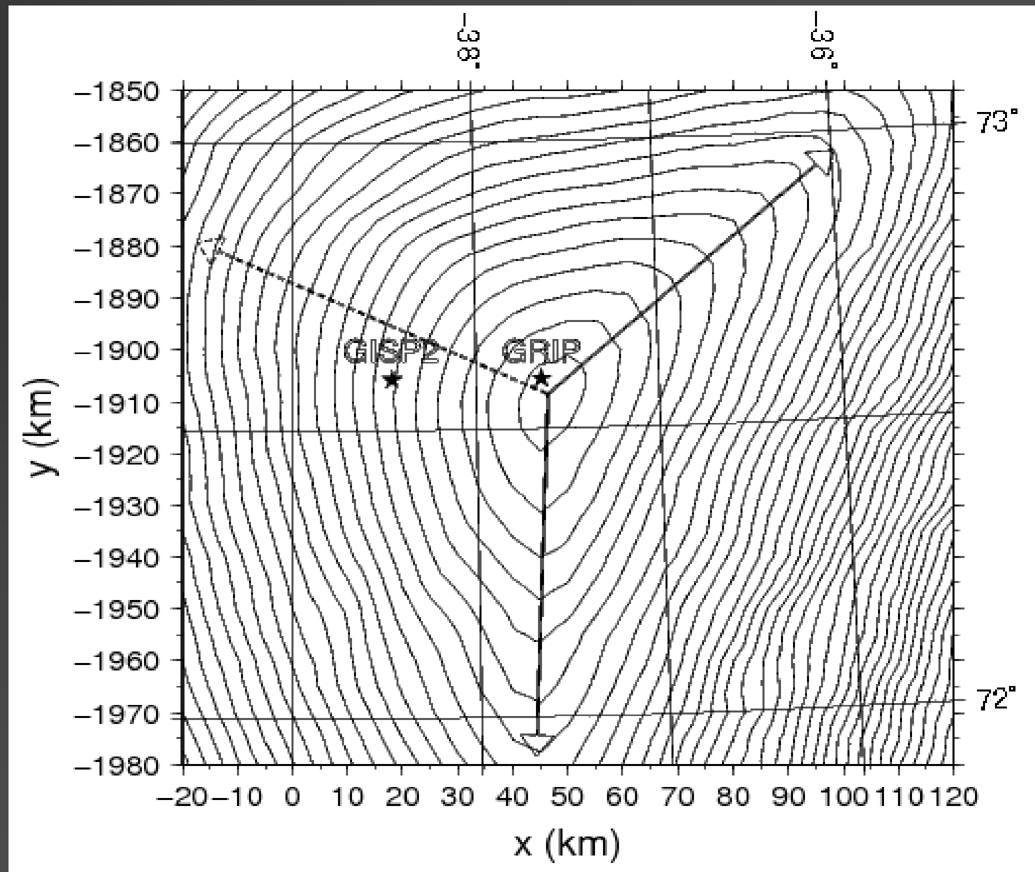
I Introduction: Berkner Island, Summit Greenland

2 examples of **elongated curved** ridges

Berkner Island
Thyssen Hohe (South dome)

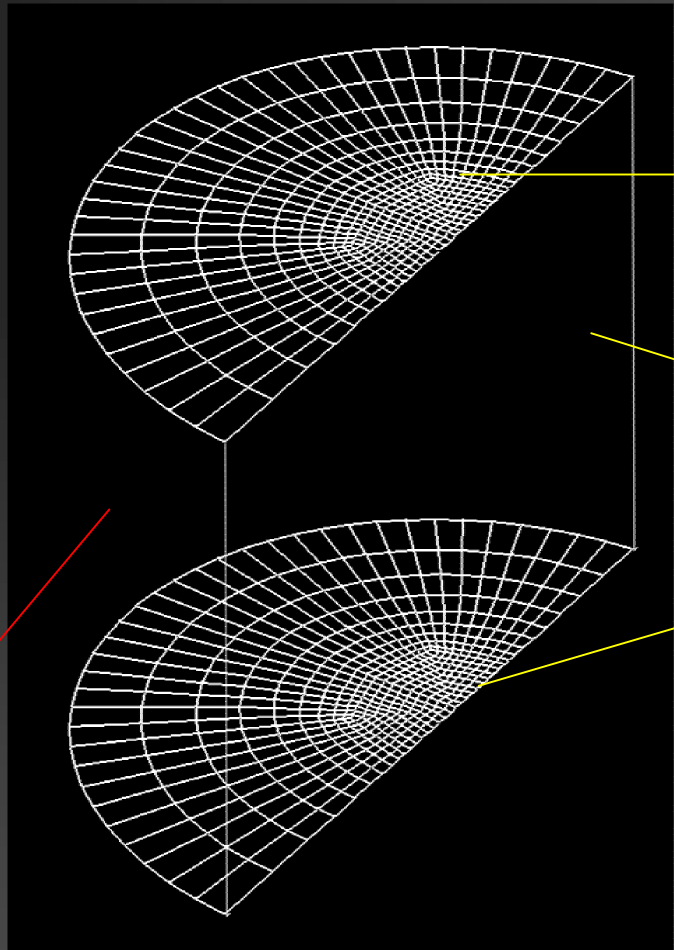


Greenland - Summit area
5km DEM (Bamber et al., 2001)



II 3D Modelling : Definitions

We use the finite element code ELMER to solve the set of the Stokes equation



-Free surface (initially axysymmetric)

- Accumulation b=cst

Symmetry plan

Frozen bed

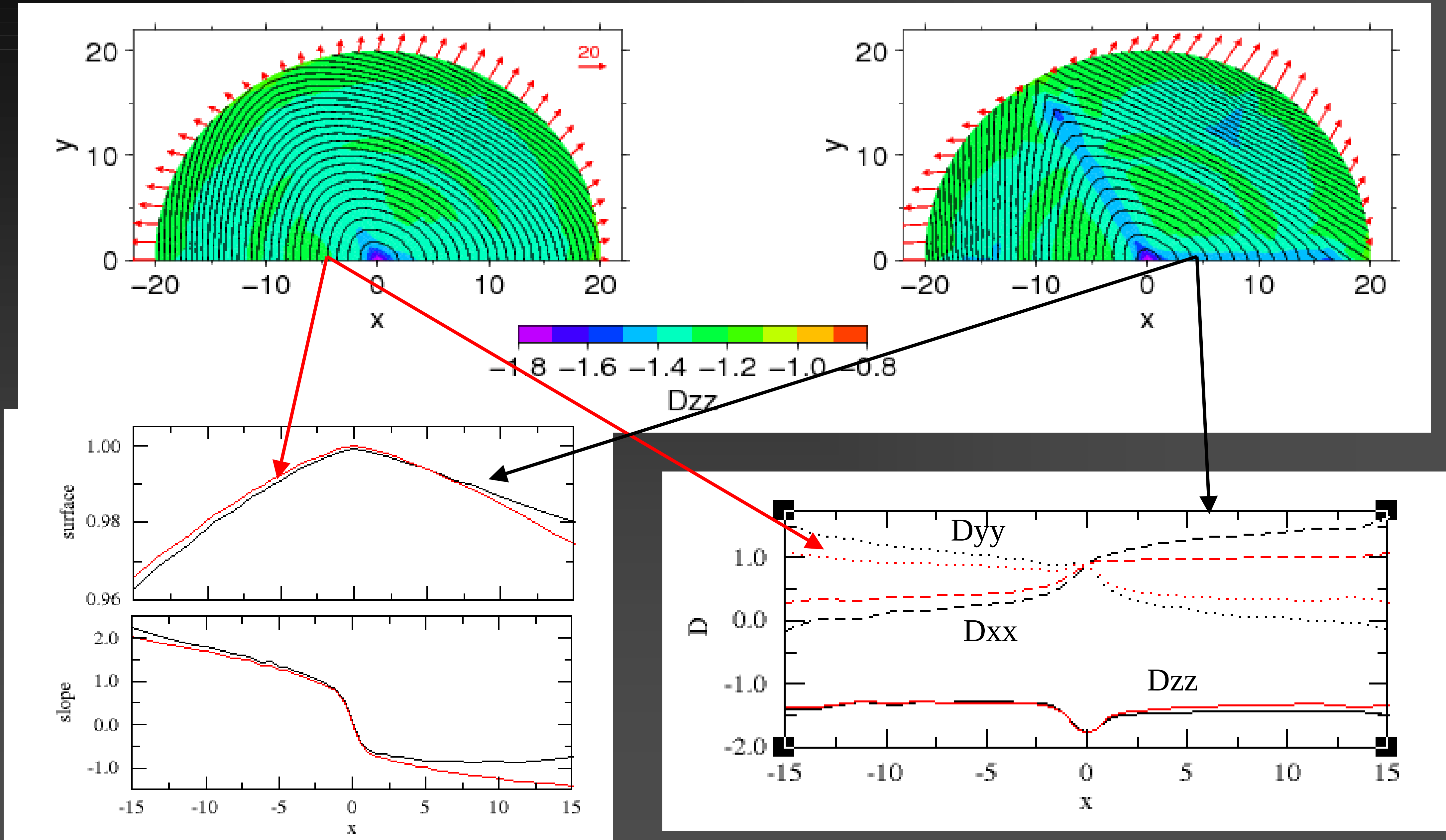
Horizontal velocity

$$\vec{u}.\vec{n} = \underbrace{\frac{1}{2}\frac{n+2}{n+1}(-H)^{-(n+2)}Rb}_{\text{mass conservation}}\underbrace{\left[(z-H)^{n+1} - (-H)^{n+1}\right]}_{\text{SIA profile}}\underbrace{f(\theta)}$$

$$\int_0^{\pi} f(\theta)\mathrm{d}\theta = \pi$$

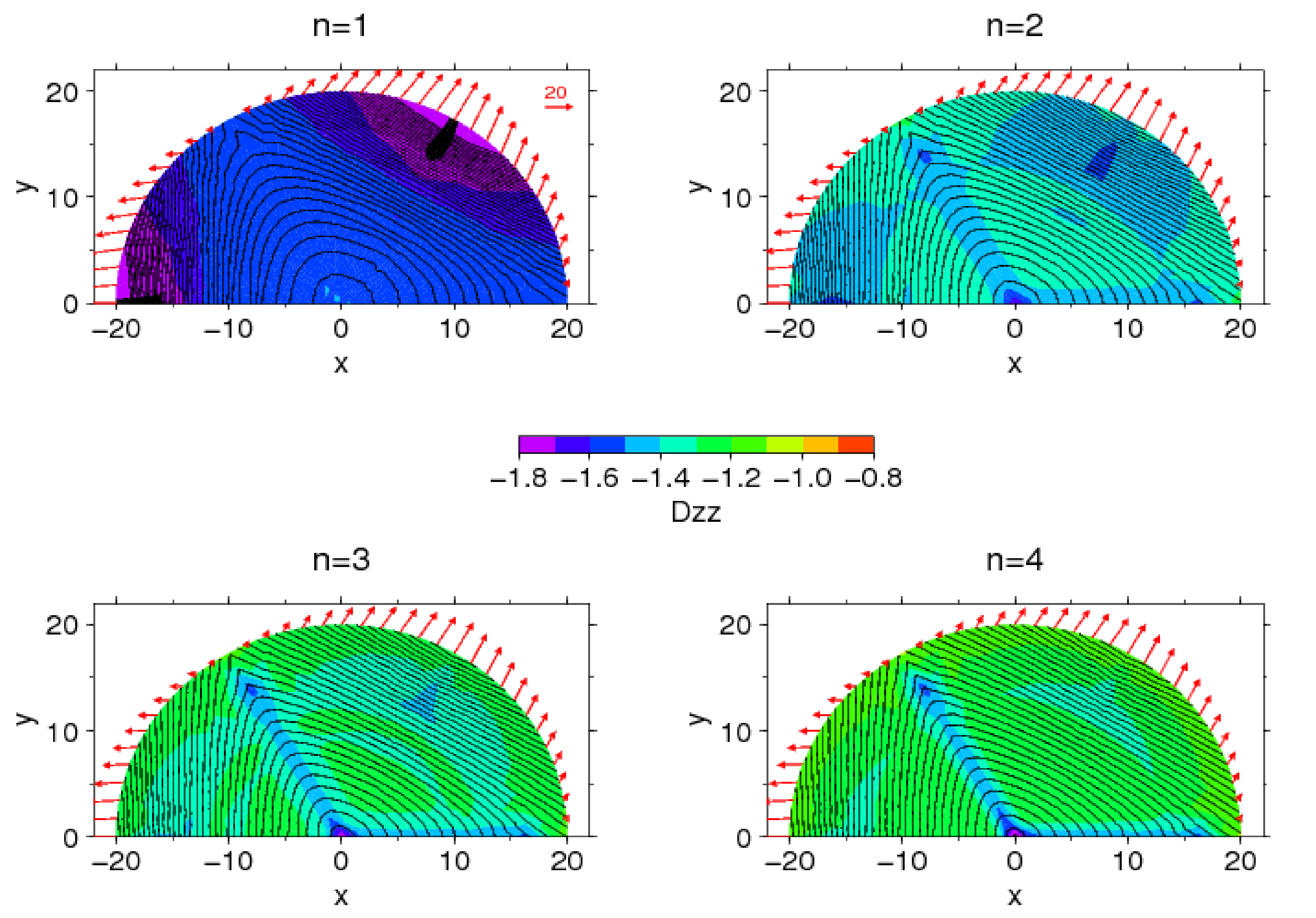
II 3D Modelling : Triple junctions

A 120º periodic forcing leads to a stable triple junction



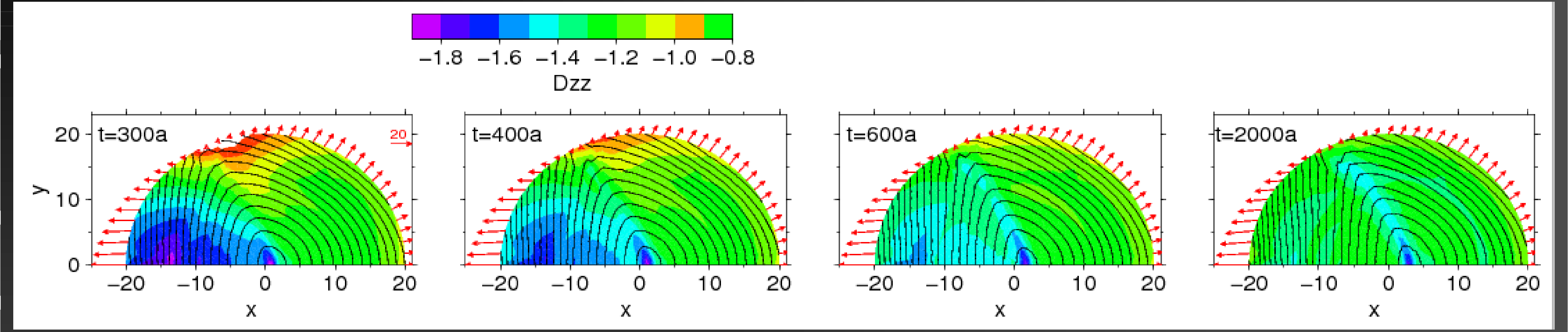
II 3D Modelling : Triple junctions

higher is n sharper is the ridge

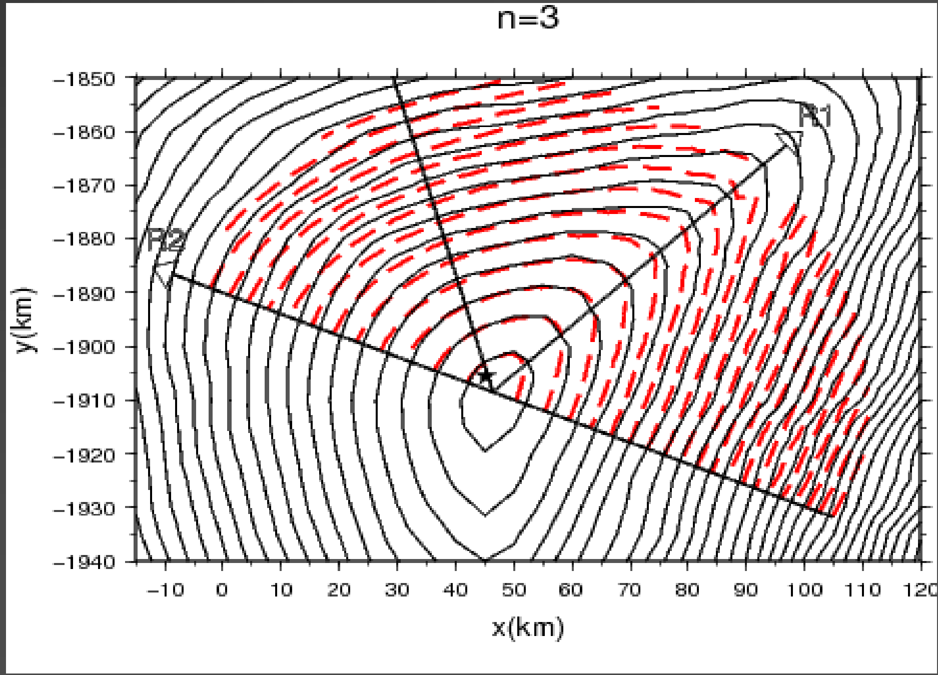


II 3D Modelling : curved ridge

A non periodic forcing leads to a stable curved ridge

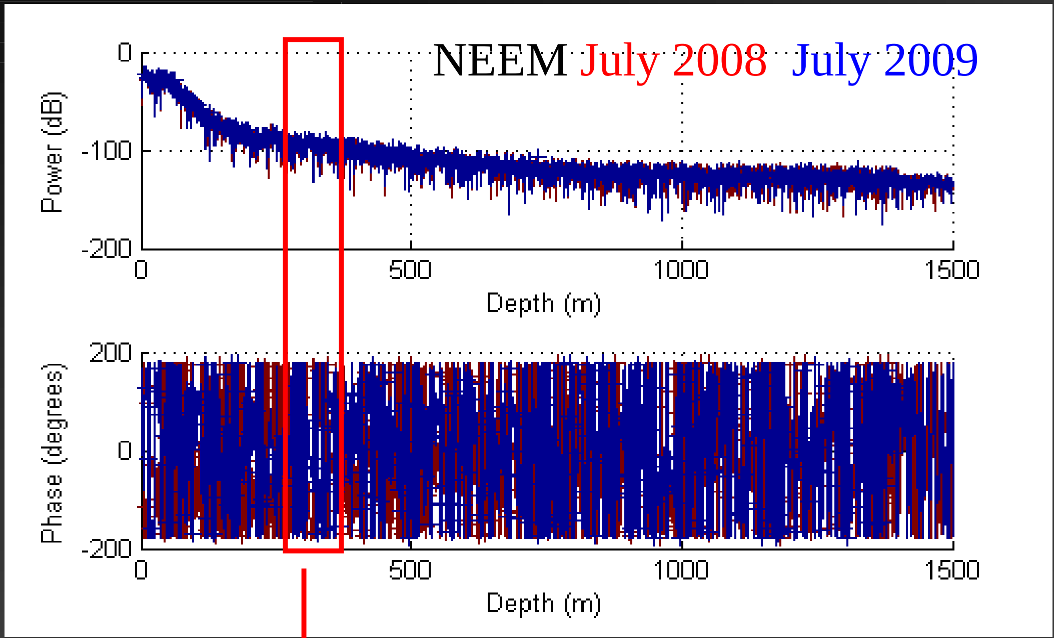


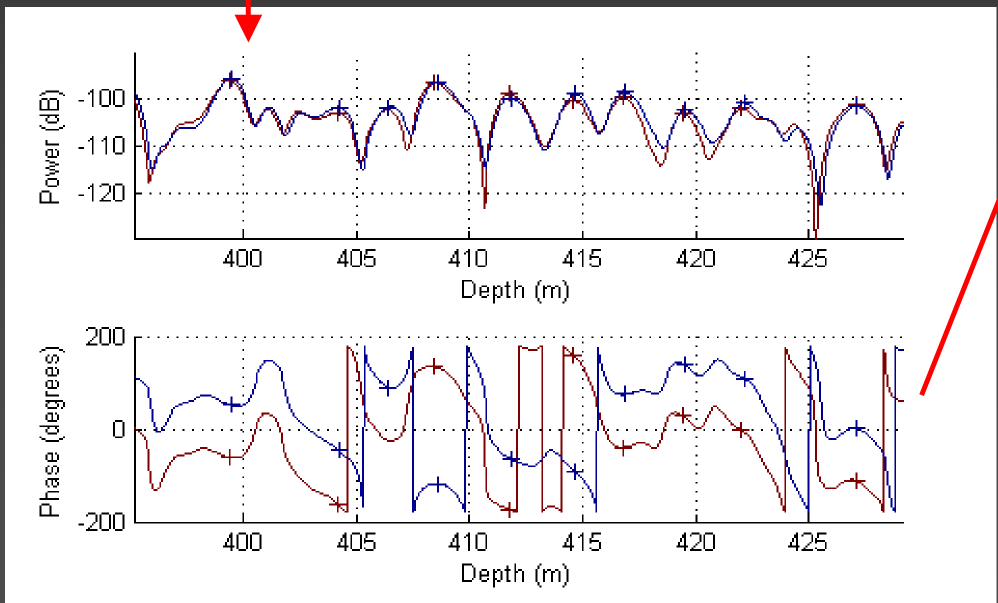
like the actual summit of Greenland

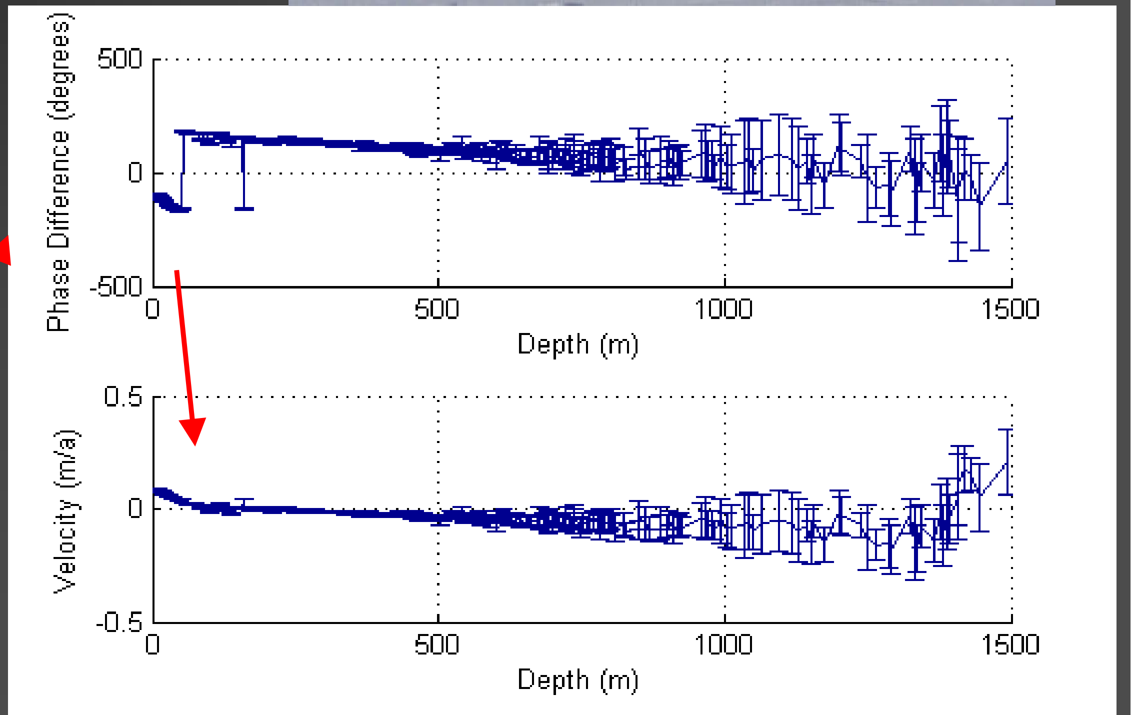


III Strain-rate measurement : Pres

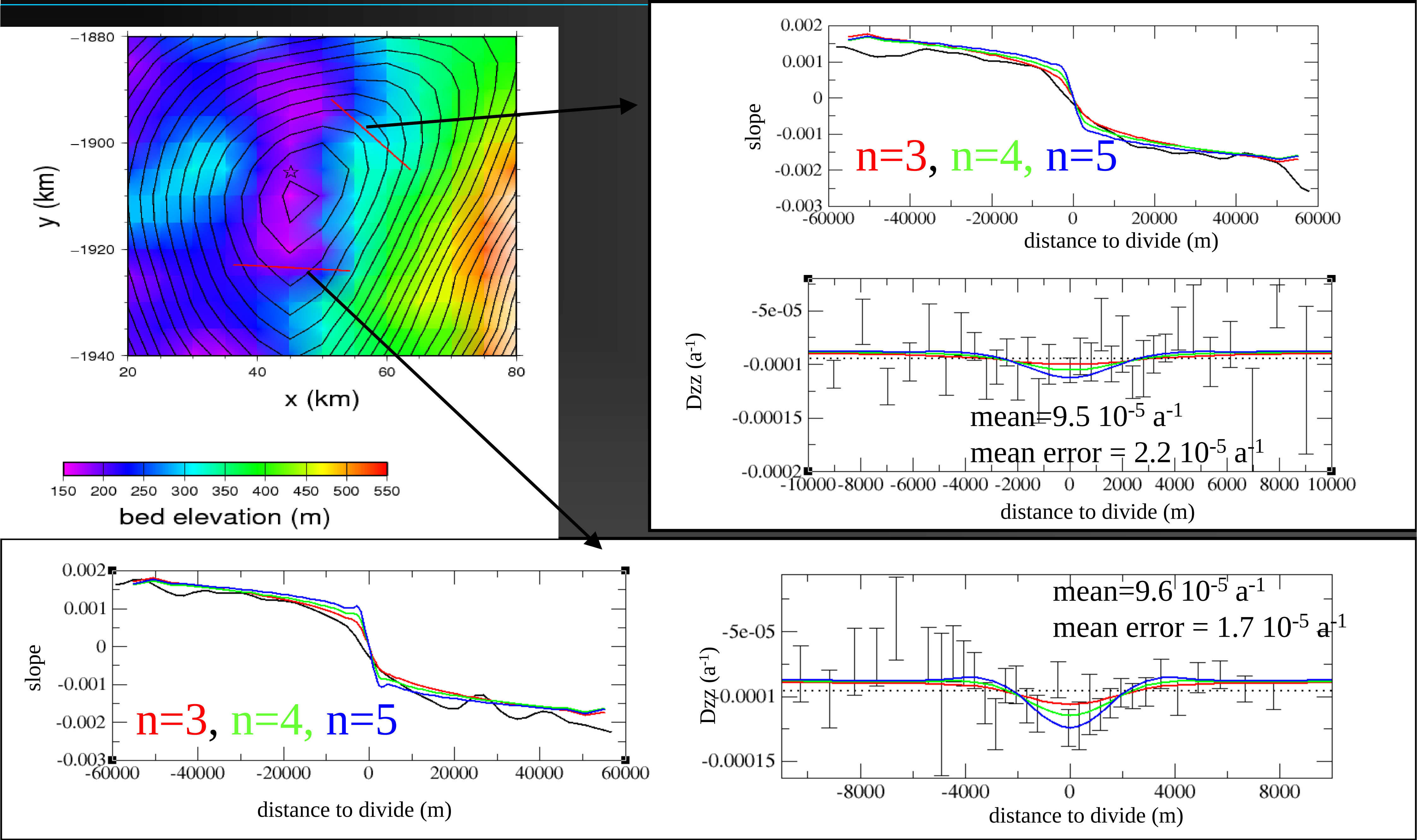
Phase sensitive radar





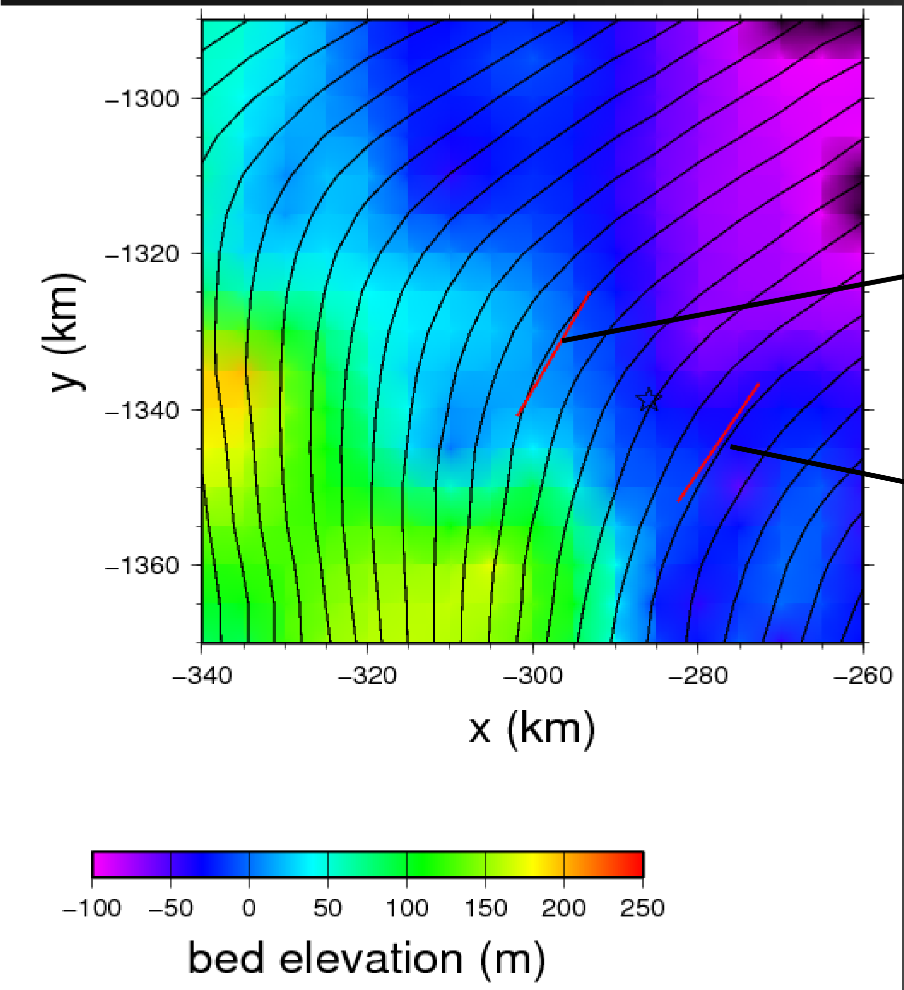


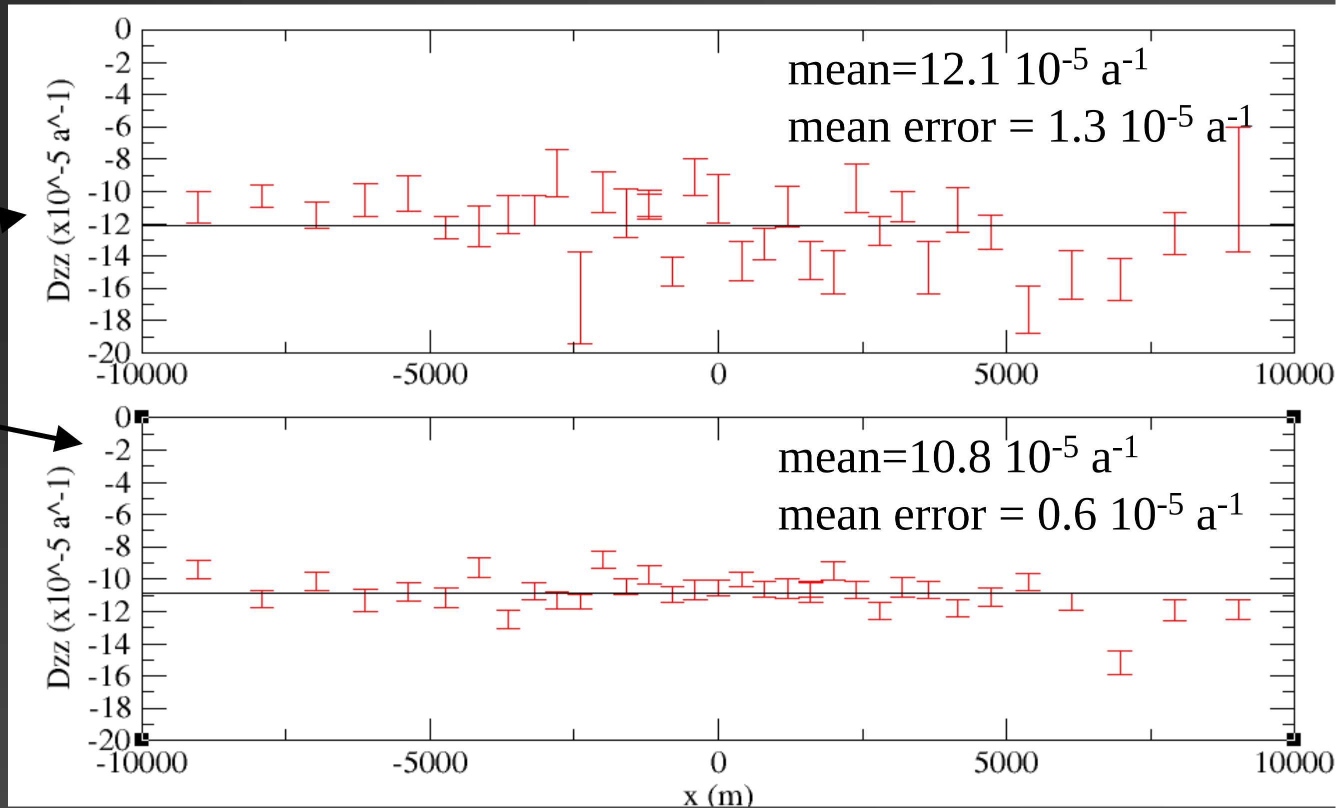
III SR measurement : Summit-Greenland



III SR measurement : NEEM-Greenland

Measurements taken **1 year** apart

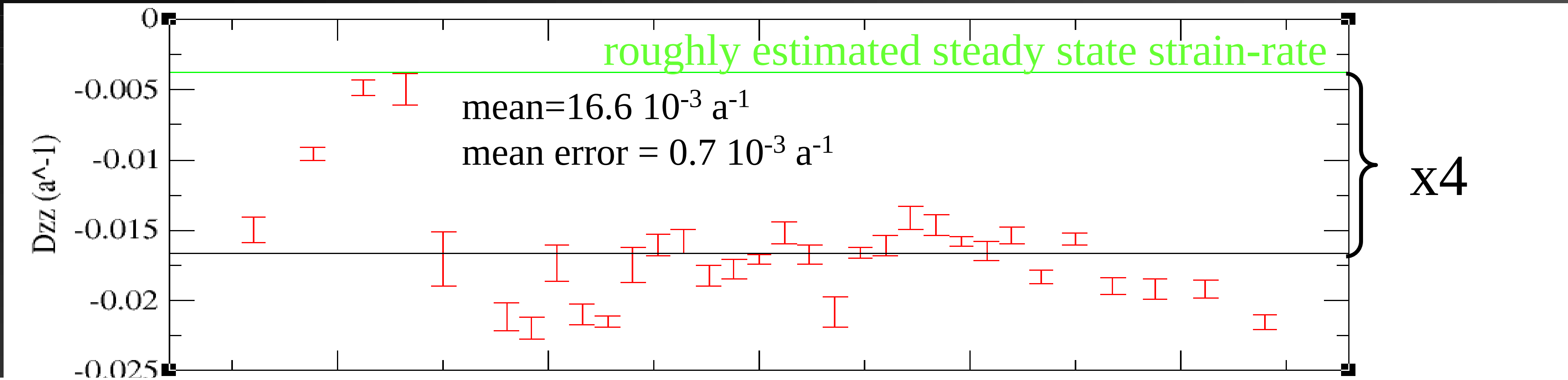


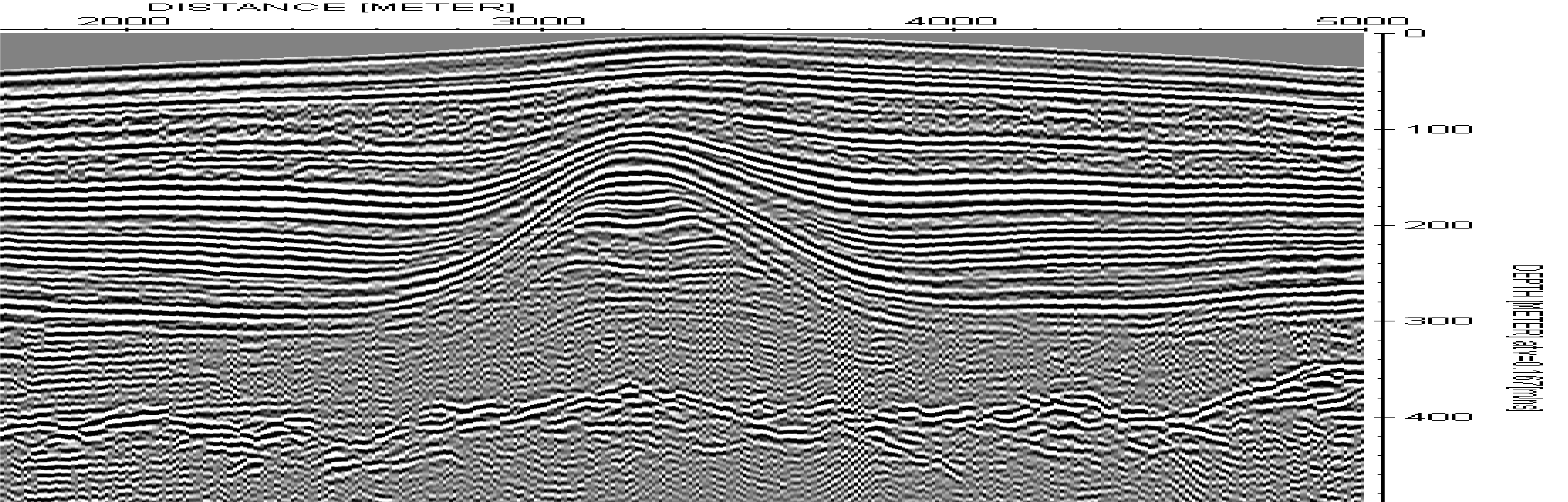


Flow mostly **along ridge** => no Raymond effect!!

III SR measurement : Fuchs-Antarctica

Measurements taken **2 months** apart





High thinning rate compatible with satellite measurements ($1.6ma^{-1}$, Pritchard (unpublished data))

Conclusion and outlooks

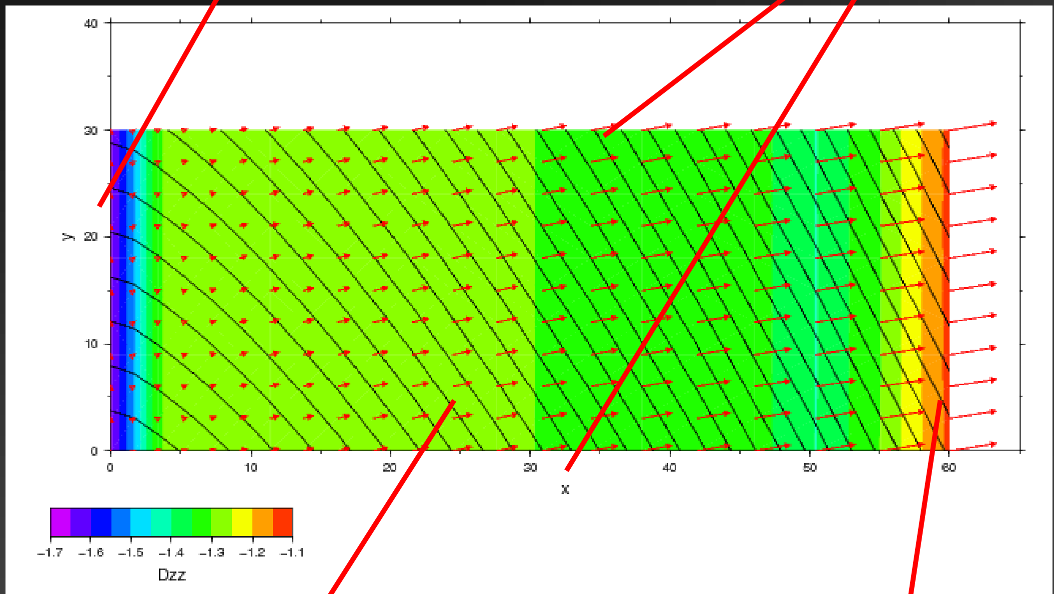
-The shape and position of ice domes depends of **the ice rheology <u>and</u> of large scale effects**
- Vertical strain-rate can "easily" be measured using a **phase sensitive radar** and complete surface and GPR data
- **Surface and Pres** data show a non-linear ice flow law for the central part of Greenland. What is the role of **anisotropy**?

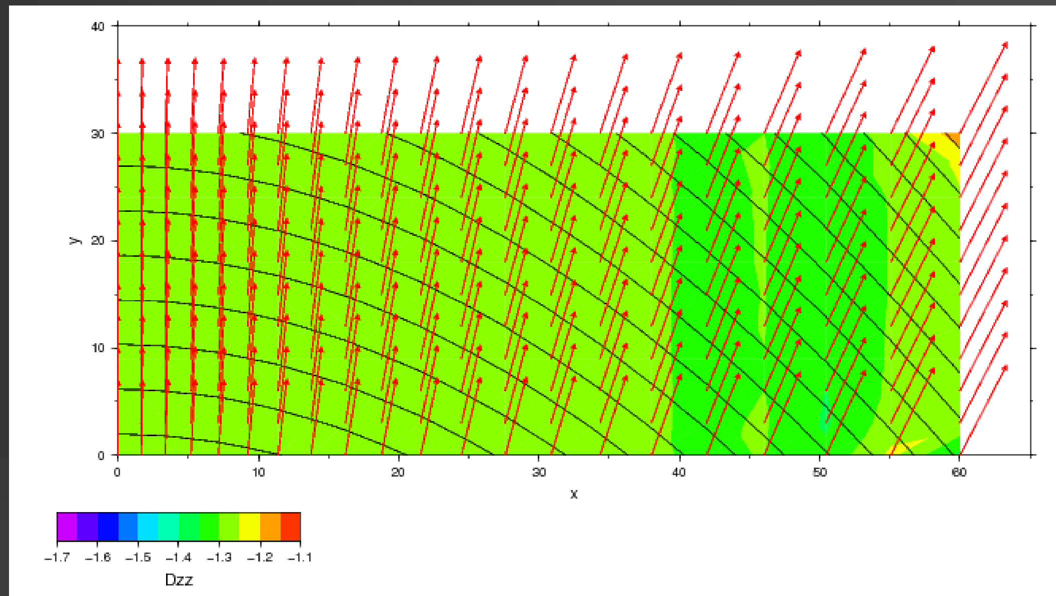
-The Pres will be used in Berkner Island this year, and can also be used to measure **melt rates** under the shelves

II 3D Modelling : Along ridge flow

Symmetry plan

Periodic velocity

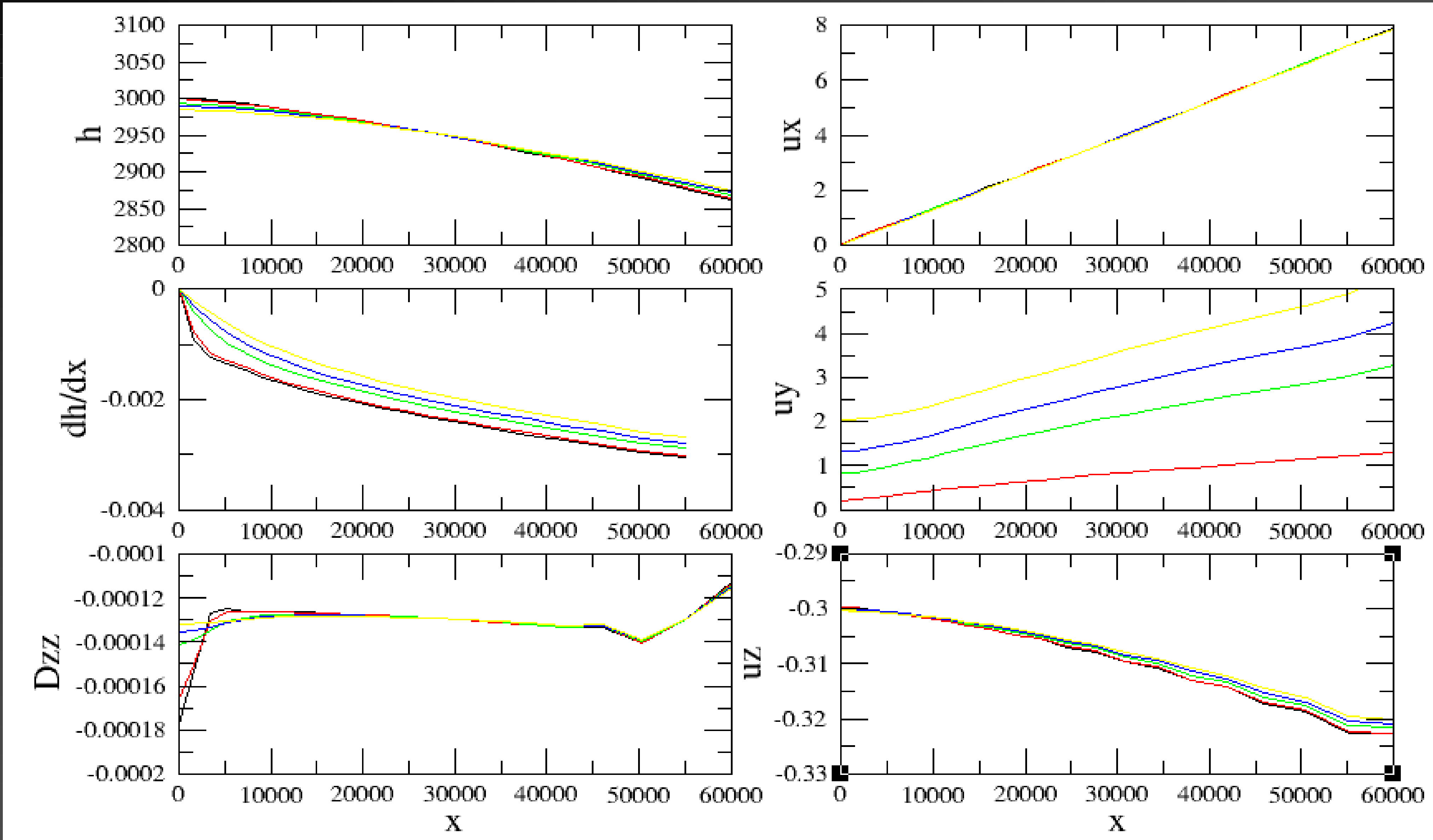




Free surface
Cst accumulation

SIA velocity mass
+ conservation

II 3D Modelling : Along ridge flow



III Strain-rate measurement : Pres

Phase sensitive radar

t1

t1+ dt