Contribution of Greenland and Antarctica to future sea level change

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From Ice to High Seas

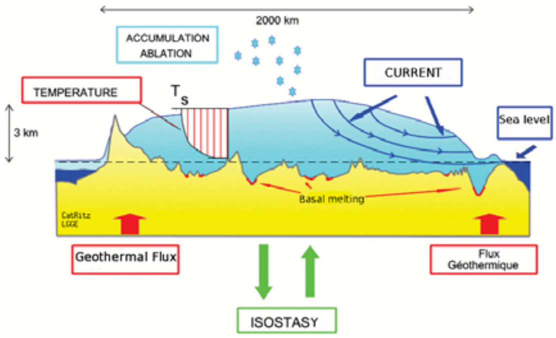
Sea-level rise and European coastlines

www.ice2sea.eu

Ice sheet modelling what for ?

- **Modelling is the major mean to evaluate the future of ice sheets**
- **Processes**
  - Surface mass balance
  - Ice flow
  - Feedbacks and instabilities
- **Models and their limitations**
- **Observations of the present state and projections**

Major processes

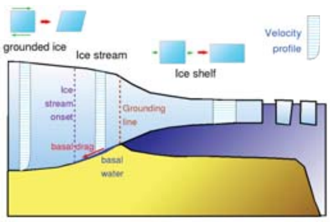


Focus here on:

- **Ice flow**
- **Surface mass balance**

Solving Mechanical Equations for ice flow

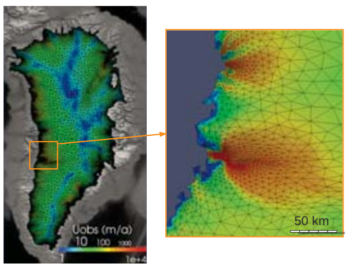
- **A hierarchy of models with various approximations exists**
  - Thin layers approximations
  - Full resolution (full Stokes models)
- **Strongly dependent on basal boundary condition**
  - Basal drag function of
    - Sediment properties
    - Basal hydrology



- **Strong impact of model resolution**
  - Ice streams are a few km wide

GIS prognostic simulations for Ice2Sea

State of the art: Models incorporating necessary physics resolved at sufficient small scale are capable of reproducing observed ice flow and recent changes (thinning)



- Model ELMER/Ice
- Data from Ice2sea database
- temperatures from Sicopolis
- Velocities from Joughin et al., 2010, JOG
- inversion of the basal drag using surface velocities
- Mesh resolution from 1 km to 30 kms
- ~440,000 nodes

Gillet-Chaulet et.al, 2012, TCD

Run 200 years prognostic simulations for different SMB scenarios

Surface mass balance (SMB) and global warming

- **Two major components with opposite response**
  - Surface mass balance = Precipitation - Ablation
  - Ablation rate (melting) increases with higher temperatures
  - Precipitation rate (snow) is likely to increase because it is linked to atmospheric moisture content.
  - But if really warm, rain replaces snow.
- **Response to warming: the net effect on SMB depends on regions**
  - Greenland : centre governed by precipitation, edges by ablation
  - Antarctica : almost no ablation at present → SMB increase
- **Possible changes in atmospheric circulation**
- **Polar amplification**

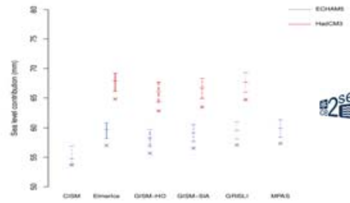
Elevation feedback should be small for the next 100 years

- **Possible instability : Thinning of the ice sheet enhances ablation**
- **Experiment in the framework of ice2sea**
  - 2 AO-GCM A1B scenario -> MAR (regional atm. Model) → 6 ice sheet models
  - Surface elevation feedback parametrized (statistical approach)
  - **Contribution to sea level due to SMB changes ~ 55-70 mm in 2100**
  - **feedback < 10 mm**

X: no feedback

Bars: 95 % credibility intervals of parametrization

central tick: best estimates



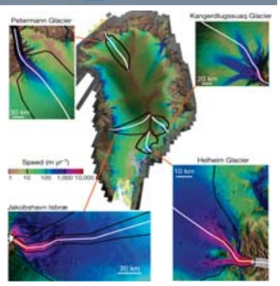
Edwards et al, TCD 2013

- **But the instability is not ruled out on longer time scale or more dramatic scenario**

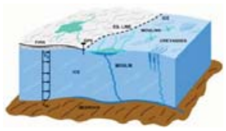
Dynamical processes affecting the Greenland ice sheet

Why do Greenland glaciers accelerate

- **Calving**
  - Flow line model applied to 4 major glaciers →**40-85 mm** sea level contribution by 2100. (*Nick et al. Nature 2013*)
  - Implemented as a forcing in a 3D model → **7-15 mm** *(Goelzer et al. J. Glac, in press)*
  - Contribution stops when the glaciers retreat enough to be no longer connected to the ocean



- **Basal lubrication**
  - Due to runoff water reaching bedrock through crevasses and moulins.
  - Small contribution 1.4 mm (*Goezler et al, J. Glac, in press*)

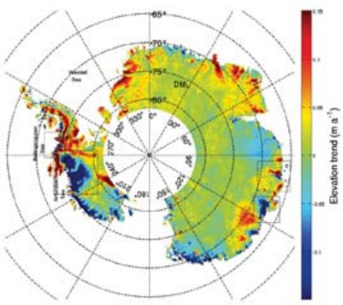


Summary for the Greenland ice sheet

- **Observation 2003-2009** *(Hanna et al. Nature 2013)*
  - Loss -238±29 Gt/yr (GRACE) and -260±53 Gt/yr (mass budget). ~ **0.7 mm/yr**
  - Seems to be accelerating
- **For the future: largest uncertainty comes from the spread among global climate models and from emission scenario**
  - A1B → 55-70 mm sea level rise by 2100 ((in the ice2sea study)
  - But the surface temperature perturbation is about twice as large for RCP8.5 compared to A1B
- **Amplifications exists but calving impact remains difficult to predict**
  - Calving 7-85 mm sea level rise by 2100
  - Lubrication 1.4 mm by 2100
  - Elevation feedback ~ 10 mm by 2100

Observation of changes in the Antarctic ice sheet

- **Some thickening in East Antarctica and Peninsula**
  - Attributed to an Increase in precipitation rate.
  - Could be impacted by the decadal variability.
  - Shut down of ice stream C
- **Important thinning in some drainage basins.**
  - Especially Amundsen sea sector and is accelrating there
  - Totten glacier in EAIS

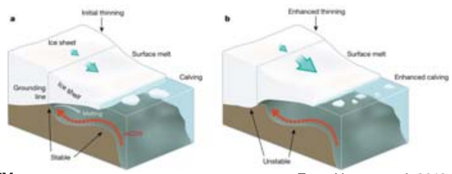


Flament-Rémy, J. Glac, 2012. Rate of surface elevation change (m/yr)

2002-2010 (Envisat)

Marine Ice Sheet instability : grounding line migration

- **Strongly suspected for PIG** (Pine Island Glacier)



From Hanna et al. 2013

- **Topographical instability**
  - Where the bedrock is deeper inland , modulated by 3D effect
  - In the unstable region, perturbation in any of the terms of force balance may result in grounding line migration backward or forward.
- **Can be triggered by ice shelf melting or collapse**
  - Ocean : due to warming ocean or change in circulation
  - Atmosphere : ponding of surface melt water opens crevasses

Difficulties to model Marine Ice sheet instability

- **Numerical treatment requires very small grids (0.1-1 km)**
  - Theoretical point (*Schoof 2007*)
  - Checked in intercomparison projects MISMIP2D and 3D (*Pattyn et al. 2012, 2013*)

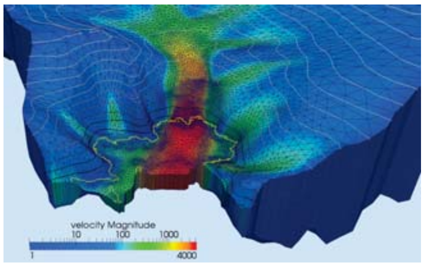
- **Parametrization based on analytical solution** *(Schoof 2007)*
  - Allows for larger grid size (10-40 km) compatible with ice sheet scale modelling (*Pollard et de Conto, 2009*)
  - But fail in simulating transient behavior at time scale 100 yr *(Drouet et al. 2012)*

New generation of sophisticated models can deal with this process and is applied to restricted areas (example next slides)

But simulation of the whole ice sheet for the next century is still a challenge.

PIG grounding line simulation

- **Retreat is initiated by an enhanced melting below the ice shelf (***Favier et al. submitted***)**



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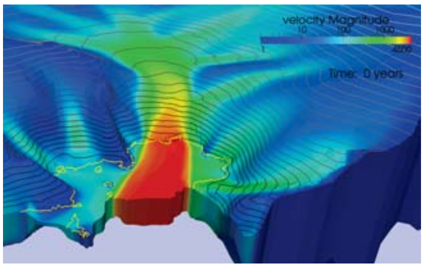

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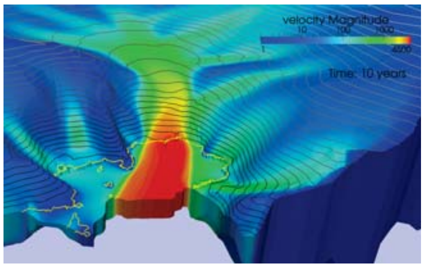

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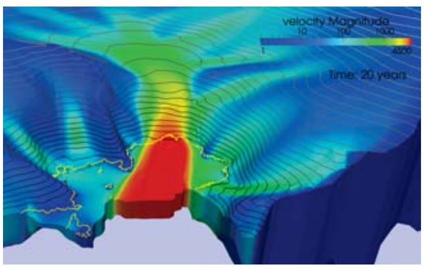

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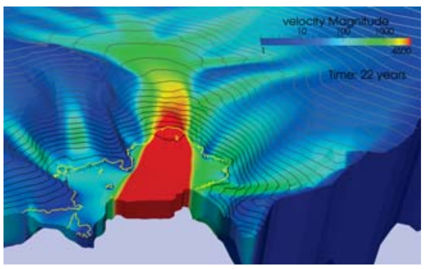

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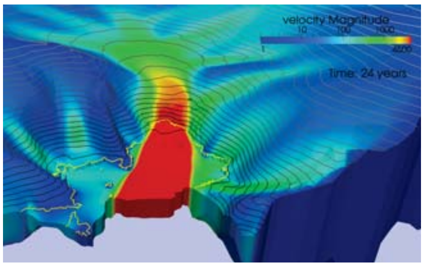

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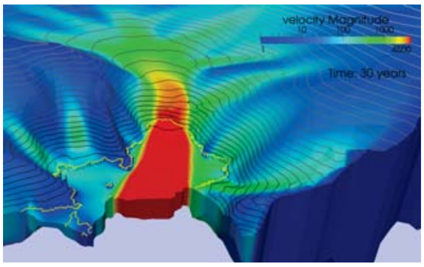

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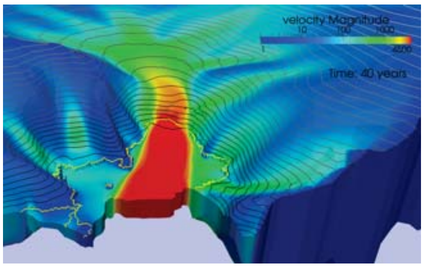

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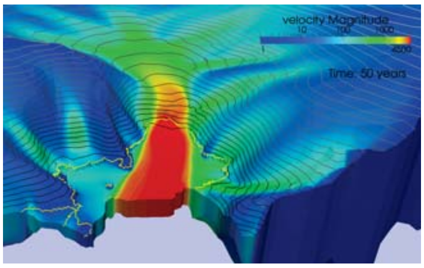
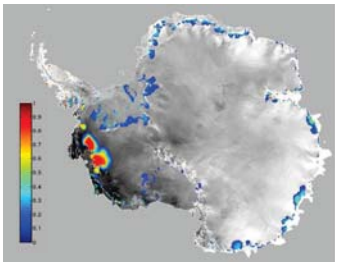


Conclusions on grounding line migration

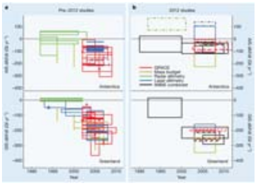
- **PIG is likely to continue retreating even if the basal melting stops**
- **Other regions that could be affected by MISI.** *(Ritz et al. In prep.)*
  - Here grounding line retreat is forced according to considerations on :
    - topography
    - glaciology
    - Ocean and atmosph. simulations
  - Ensemble method (1000 runs)
  - Keep only those that fit PIG observations (Shepherd et al. 2012)
  - Probability that a point is lowered by more than 100 m in 2200
  - Thwaites glacier ???



- **Global estimation in 2100 including surface mass balance change -8 + 32 mm of sea level in 2100** *(Payne et all PNAS, in press)*

Conclusions : Present and future of Greenland and Antarctica

- **Recent assessment has reduced uncertainty on present mass balance observations**
  - reconciled estimations
  - Greenland: still loosing mass at an increased pace.
  - Antarctica: half of previously estimated.



- **Models have improved since IPCC AR4 (grid, mechanics, methods)**
  - For the Greenland ice sheet, the major uncertainty comes from the spread of climate models. But modelling calving is still difficult.
  - In Antarctica, enhanced precipitation should partly compensate accelerated dynamics
  - Marine Ice Sheet instability seems active in PIG. Thwaites glacier ?


THANK YOU