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Initializing the Greenland ice sheet to investigate its sensitivity to climate changes : a study with the GRISLI model.

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Introduction

Greenland Ice Sheet (GrIS) mass loss is expected to play a crucial role during the coming century. In this study we use the GRenoble Ice Shelf and Land Ice (GRISLI) model to study the GrIS evolution under different initialisations of the basal drag coefficient, obtained with climate forcings from the Modèle Atmosphérique Régional (MAR, Gallée & Schayes, 1994 and Gallée, 1995). The predominant atmospheric forcing field impacting GriS evolution is the annual climatology of Surface Mass Balance over Greenland. MAR is forced by ERA-Interim reanalyses for the period 1979-2014. We extract the most representative extreme year of the SMB for 7 different regions and for all Greenland, for the following characteristics : Annual minimun (2012 & 2010) , Annual maximum (1992 & 1983). Each SMB extreme year, as well as the average annual SMB between 1979-2014 are used as initial condition for a low computation cost spin-up method, based on a simple inverse method. Once the model initialized, results are analysed to determine the importance of initial climate forcing for GrIS evolution.

GRISLI

(GRenoble Ice Shelf and Land Ice model)

3D model (21 levels) 5 km x 5 km grid	Ice flow dynamics Mix of SIA and SSA	Characteristics of model
Topography (Bamber et al. 2013) Climatology (From MAR forced by ERA-Interim 1979 - 2014) Sliding surface velocities (Joughin et al, 2010)		Observations and GCM
Basal drag coefficient		Unknown

GrIS 3D time evolution :
(Resolve mass conservation equation)

Objectives

✔ Initialization of the basal drag coefficient with present-day observed GrIS under different climates forcings.

Reduction of the anomalies w.r.t observations

✔ Sensitivity of initialization to different extreme SMB years climate forcings extract from MAR.

How does the initial climate forcing using during initialization affect the GrIS evolution ?

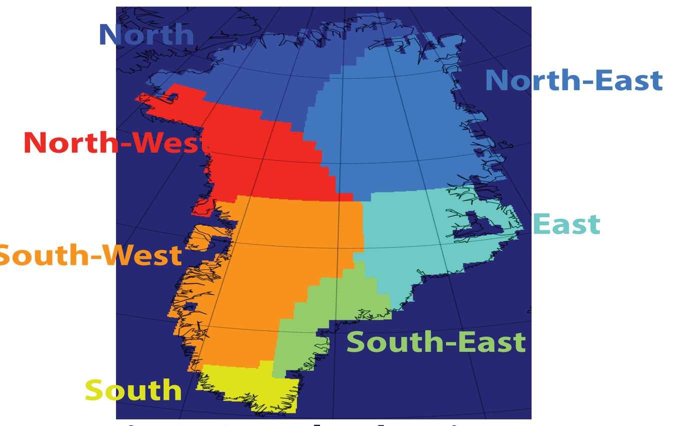


Fig 1 : Greenland regions.

1 Selection of the extreme SMB years

1- Greenland is cut in 7 different regions following major drainage basins (Fig 1).

2- For each region (Tab 1) : ➤ the SMB from MAR is annualy averaged.
➤ the extreme years of SMB are extracted (Table 1)

Table 1 : Extreme (min & max) years for the SMB extracted from MAR forced by ERA-Interim 1979-2014, after averaging by region.

SMB \ Region	All GrIS	South	South-West	North-West	North	North-East	East	South-East
Min	2012	2010	2010	2012	2012	2005	2010	2010
Max	1992	1992	1983	1996	1992	1992	1983	2002

3- Use the climatology of 2012, 2010, 1992, 1983 and the average between 1979 -2014.

3 Experimental design

✔ Initial conditions for initializing GRISLI for Step 1 and Step 2 are identical.
✔ Initial conditions for Final Step are extracted from the last time step of the step 2.
✔ Climate forcing (SMB and Surface temperature) are identical for all the steps.

GRISLI Spinup method are run with 2012, 2010, 1992, 1983 and 1979 - 2014 average climate forcing (hereafter "average").

We obtain 5 set of differents results
Each result of extreme years is analysed by comparing with the "average" experiment.

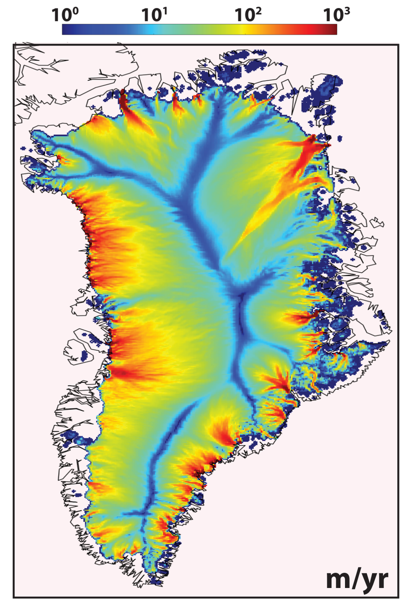
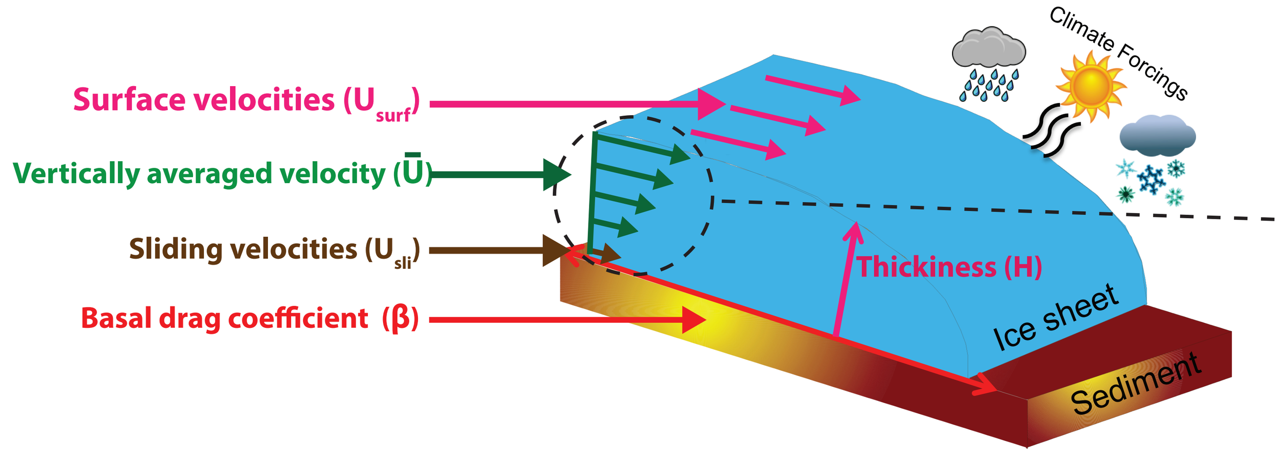


Fig 2 : modeled surface velocities

2 Spinup method



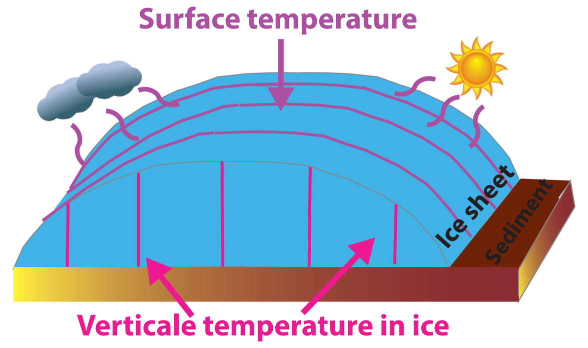
Objective of our spinup: to obtain modeled U^G_{surf} similar to observed U^{Obs}_{surf}

$U^G_{surf} = U^G_{def} + U^G_{sli}$
- SIA to compute ice deformation velocity (U^G_{def})
- SSA to compute sliding velocity (U^G_{sli})

Use the Basal drag coefficient (β) to adapt U^G_{sli} allowing $U^G_{surf} = U^{Obs}_{surf}$

$$\beta_{t+1} = \beta_t * \left(\frac{U^G_{sli}}{U_{sli}}\right) \quad \text{With} \quad U_{sli} = U^{Obs}_{surf} - U^G_{def}$$

Equilibrium vertical temperature with surface temperature

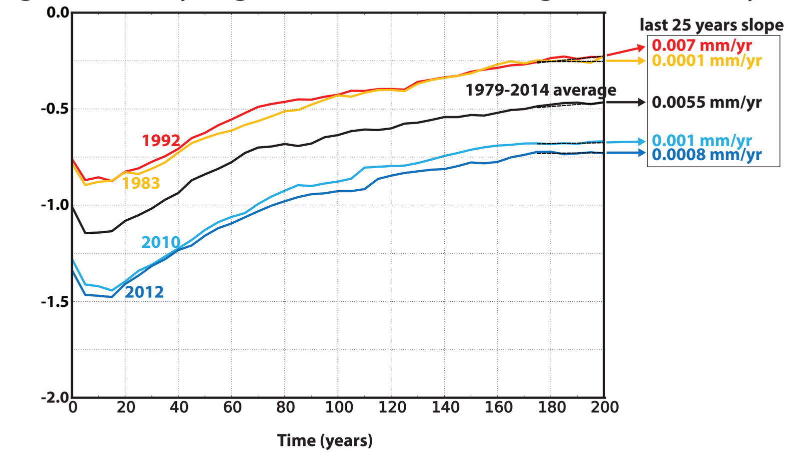


GRISLI spinup Process in 3 steps

- **Initialising GRISLI**: InitMIP process + Initial conditions
- **Step 1**: Compute β_t during 200 time steps → Import β_{200}
- **Step 2**: Equilibrium temperature profile during 30 000 years → Import β_{200}; Final cond. at t_{30000}
- **Step 3**: Compute β_t during 200 years (same method as step 1) → Import β_{200}; Final cond. at t_{30000}
- **Final step**: GRISLI free envolving

4 Results for final step

Fig 2: Tendancy of global ice volume average on GrIS (mm/year)

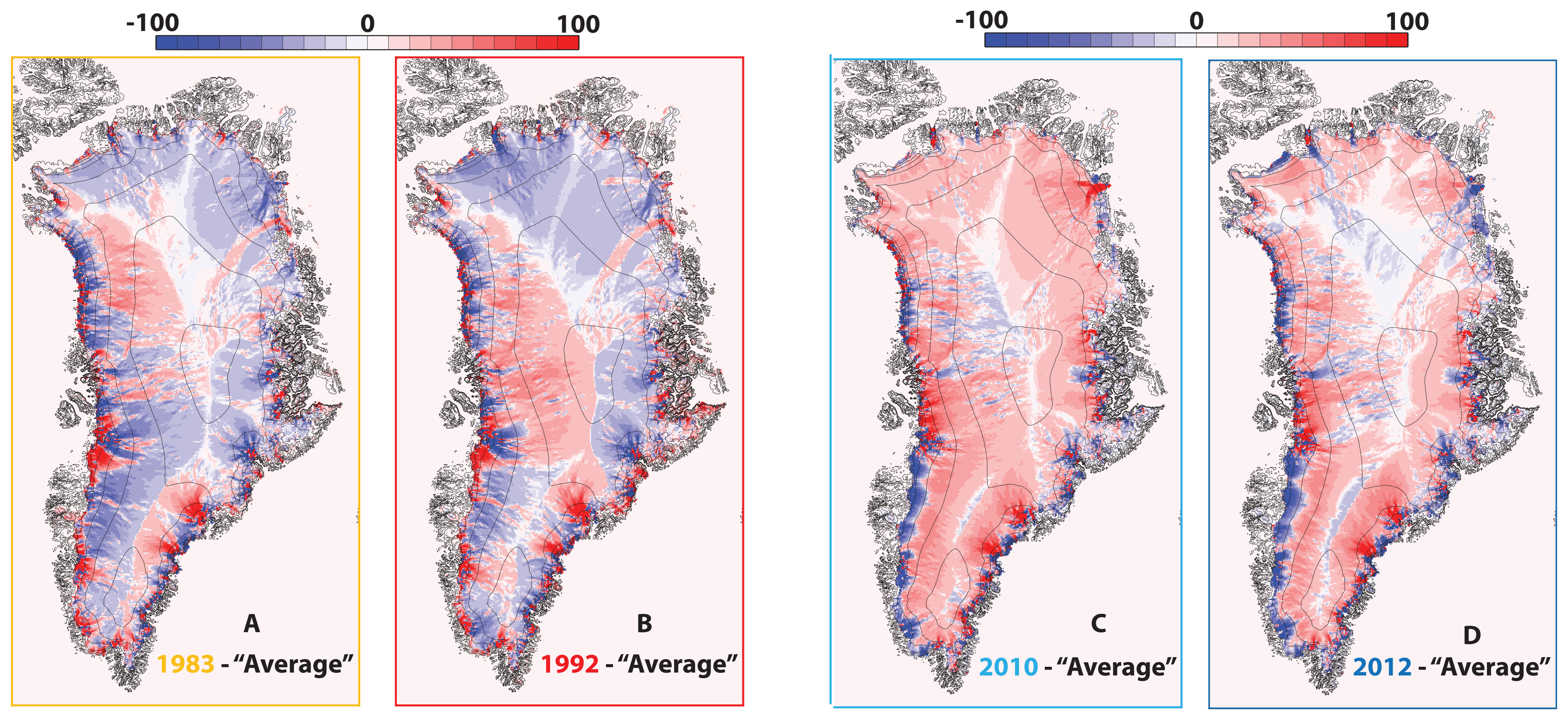


✔ GrIS melting for experiment initialisizing with the1979-2014 SMB forcing is equivalent to actual observed melting : 1mm/year (IPPC 2013).

✔ GrIS melting is proportional to the SMB applied : minimum (maximum) SMB lead to strong (low) melting.

✔ For all experiments, GRISLI takes about 180 years to find equilibrium between modeled velocity and climate forcing.

✔ At the end of all experiments, slope tends to 0.



✔ Long term simulation (Step 2) allows to propagate the surface temperature through the ice thus climate forcing impacts the entire column of ice. When we are forcing GRISLI with these new initial conditions (Final step of spinup method) model compute GrIS evolution take into account the effect of surface climate.

✔ For 1983 and 1992 (maximum SMB year) surface velocity globaly decreases on GrIS. During colder periods, basal drag coeffcient that has been calculate at Step 3 increases and causes the reduction of the sliding velocity and thus the surface velocity (Fig 3A et 3B).

✔ For 2010 and 2012 (minimum SMB year) surface velocity globaly increases on GrIS following the progation of surface temperature through the ice. In contrast to the cold periods, basal drag coeffcient calculate at Step 3 decreases and allows us to increase the sliding velocity and consequently the surface velocity (Fig 3C et 3D).

Fig 3 : Surface velocity difference (m/yr) between extreme climate year and "average" experiment : A- 1983 experiment minus "average"; B- 1992 experiment minus "average"; C- 2010 experiment minus "average"; D- 2012 experiment minus "average".

5 Conclusion

✔ The GRISLI spinup method uses the observed surface velocity to determine the basal drag coefficient. We don't use modeled surface velocity but observed surface velocity allowing us to ignore influence of SMB on initial velocity.

✔ The basal drag coefficient is impacted by initial climate forcing. Adjusted with a correct vertical temperature profile in the ice it allows us to find an equilibrium between climate forcing and modeled velocity. The GrIS evolution after our initialization method are constant (Fig 2).

✔ Warmer climates tends to increase surface velocity and colder climate tends to decrease surface velocity. Consequences of same climate forcing impact differently each GrIS regions (Fig 3).

✔ Climate forcing uses for initialization affects GrIS evolution however if we obtain an equilibrium between surface and basal conditions we can quantify this effect.

✔ We can use this initialization method with past, present and future climate.