

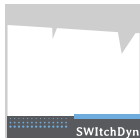
The meltwater feedbacks on ice dynamics, influence of melt amplitude, duration and extent.

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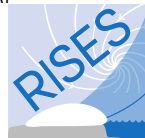
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Evolution of glacier velocities around Greenland

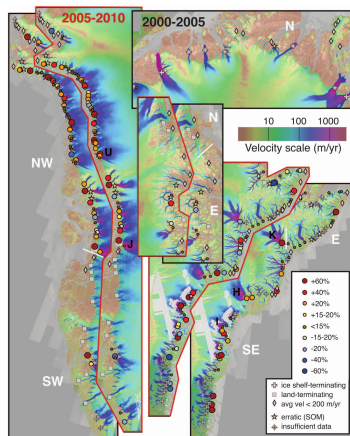


Figure from Moon et al. (2012)

Greenland currently provides half of the sea level rise rate.

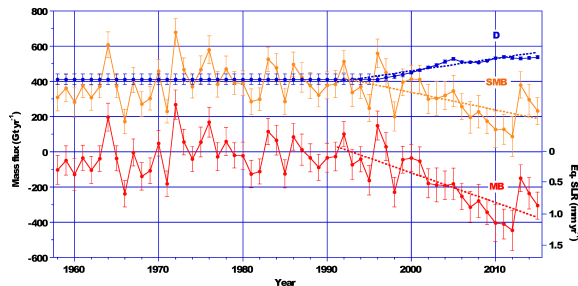


Figure from van den Broeke et al. (2016)

Greenland contribution has two components

The discharge of glaciers.

The decrease of the surface mass balance.

How are glaciers losing mass, and increasing sea-level

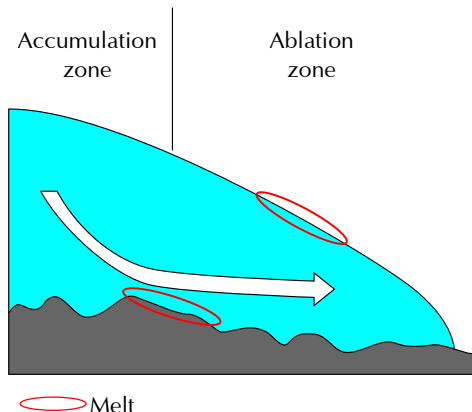
We focus on this study on land terminating glaciers.

There is no discharge to the ocean

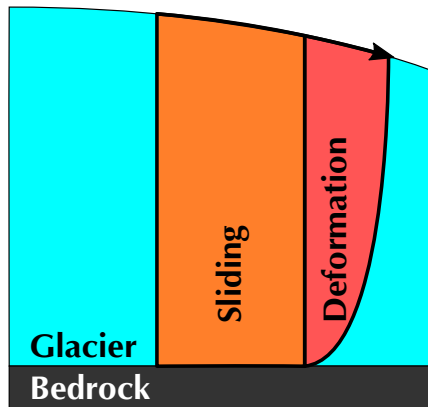
Only mass loss is through melt

Dynamics has a role in moving ice to lower elevations

Mass loss of land terminating glaciers



The main components of ice dynamics.



Surface velocity
is made of :

Glacier sliding

Represent the bulk
of fast glaciers
velocities

Shows short and
long term variations

The process of the
variations are poorly
known

Ice deformation

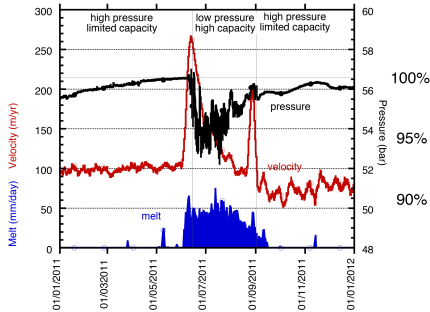
Only a small part of
fast glaciers
velocities

No short term
variation

Long term
variations are well
known



The link between subglacial hydrology and ice dynamics



Basal pressure, surface velocity and runoff at 700m elevation on Russell glacier (West Greenland).

Figure from van de Wal et al. (2015)

We will focus on the sliding velocities which are mainly driven by the availability of water at the base of the glacier.

The link between melt and sliding is however not straightforward and largely unknown on longer timescales.

On a seasonal timescale

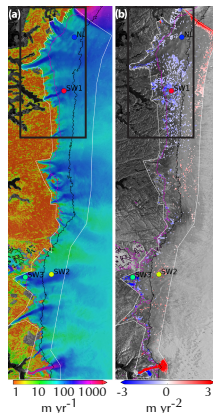
High water pressure leads to faster velocities

High melt does not translate directly into high runoff

The link between subglacial hydrology and ice dynamics

Surface velocities in 2017 **(a)** and velocity trends from 2000 to 2017 **(b)**.

Figure from Joughin et al. (2018)



We will focus on the sliding velocities which are mainly driven by the availability of water at the base of the glacier.

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On a seasonal timescale

High water pressure leads to faster velocities

High melt does not translate directly into high runoff

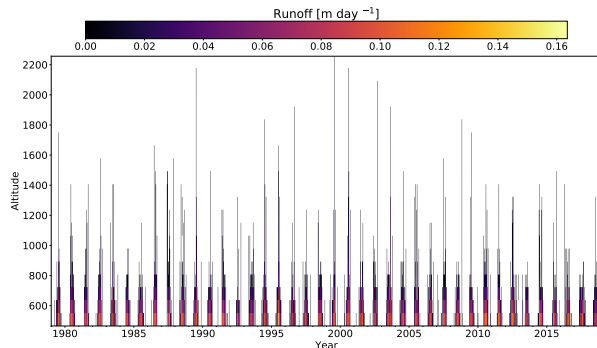
On a decennial timescale

Slight slowdown at lower elevations

Slight acceleration at higher elevations

The variability in melt in the Russell region.

The data from the ERA 5 reanalysis in the Russell Region shows a large interannual variability and not a clear trend.



This variability can be observed in:

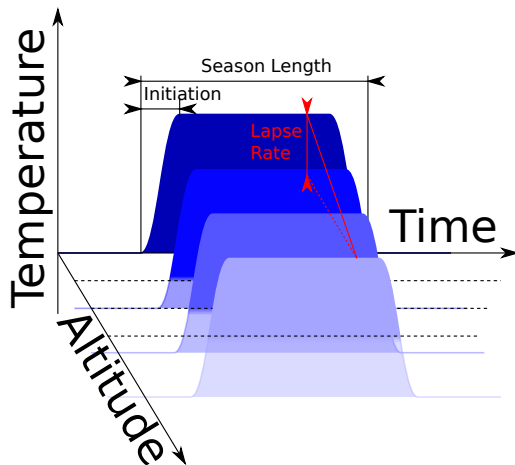
- In the amplitude of the melt (colour of the bars)
- In the maximum melt altitude (height of the bars)
- In the length of the melt season (thickness of the coloured zone)

Melt in the Russell glacier area computed with a PDD scheme and the ERA5 temperatures. The melt is given in function of time and ice elevation.

This study focuses on those different variability and their impact on ice dynamics.



Example from the ERA5 Reanalysis



The runoff is described by a synthetic temperature:

$$T = \frac{PDD_{ref}}{\Delta_{melt}} \left(\frac{1}{2} \tanh \left(\frac{t - t_{spr}}{\delta_i} \right) - \frac{1}{2} \tanh \left(\frac{t - t_{aut}}{\delta_i} \right) \right)$$

The temperature is defined at the front elevation and a lapse rate and PDD factor are used to compute melt on every grid point.

From the ERA5 data we define three parameters with [low, **standard** and high] values.

Season Length (Δ_{melt}) [109, **141**, 173] days

Lapse Rate (LR) [-6.88, **-7.26**, -7.63] $^{\circ}\text{C km}^{-1}$

Initiation length (δ_i) [5, **10**, 15] days

The perturbed forcings are designed such that the integrated runoff on the domain and over the year is always identical.

We use the DOuble COntinuum (DOCO) model as described in de Fleurian et al. (2016). The model uses two sediment layers to reproduce the inefficient and efficient components of the subglacial draining system. The runoff values computed as described are directly used as the water input of the model (no moulin, no surface routing)

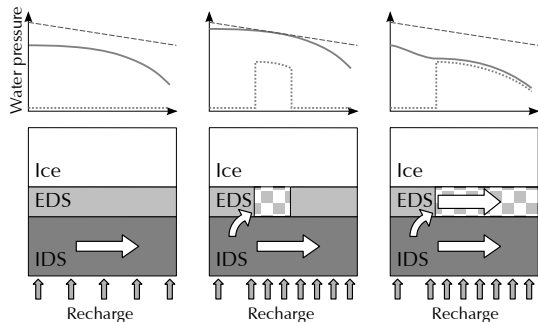


figure modified from de Fleurian et al. (2014)

Sketch of the activating mechanism of the efficient drainage system (EDS) in the DOCO model. Top row shows the water pressure in the inefficient system (IDS, solid grey), efficient system (dotted grey) and a pressure threshold (dashed black). The bottom row shows a sketch of the system with increasing recharge from left to right. IDS is always active and EDS is active (chequered) when the pressure in the IDS reaches the threshold. EDS activates downstream when its pressure reaches the threshold. When the EDS is active up to the glacier front it transfers more water and allow to drop the water pressure in the two systems.

Within ISSM we use a shallow shelf approximation for the ice dynamics. The sliding component is computed with a friction law as developed by Schoof (2005); Gagliardini et al. (2007).

$$\tau_b + \frac{CN|\mathbf{u}_b|^{(1/n-1)}}{(|\mathbf{u}_b| + C^n N^n A_s)^{1/n}} \mathbf{u}_b = 0$$

τ_b : basal shear stress

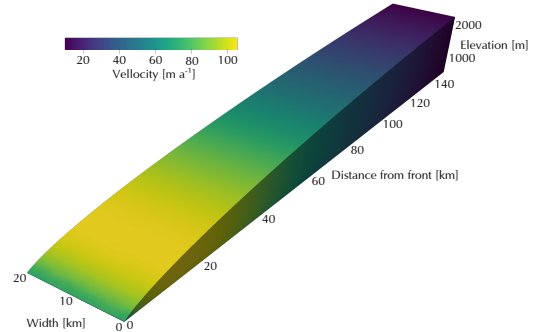
C : Iken's bound

N : effective pressure

$\mathbf{u}_b$: basal velocity

n : Glen exponent

A_s : sliding parameter



From the initial geometry the model is spun-up to achieve a pseudo steady state with all the different components.

Set-up of the forcing for the experiments

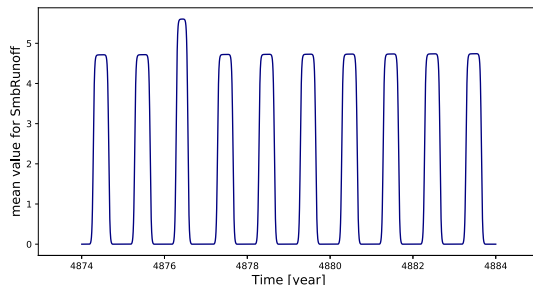
The experiment set-up is built around a series of ten year simulations.

The melt is set with its reference parameters for all the years but one.

In addition each simulation is run 10 times with slightly different starting times.

We end up with 90 simulations for each set of parameters.

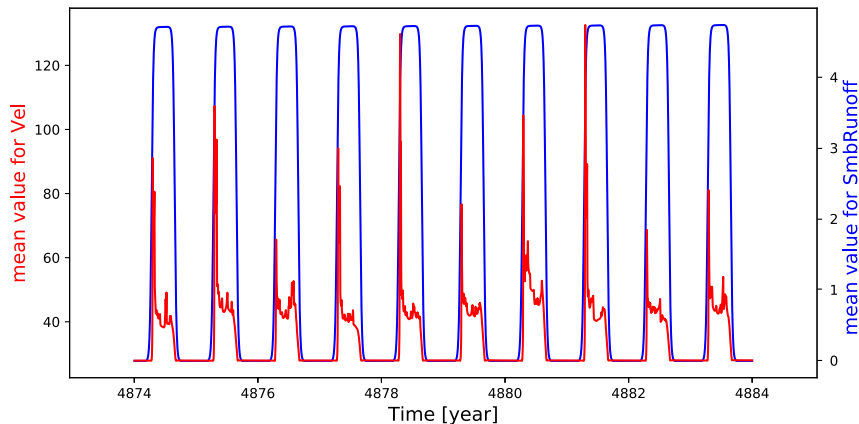
That allows to have more statistically significant results and to avoid issues related to the non linearity of the system and large interannual variations observed in the results.



Mean runoff on the whole domain for one simulation

Results interannual variability.

The mean velocities for the reference simulation (no perturbation) show a strong interannual variability

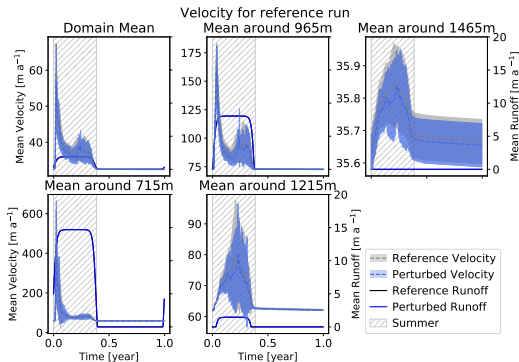


This is a result of both the threshold effect at the activation of the Efficient drainage system and the non linearity of the friction law. A similar interannual variability is observed when we shift the beginning of the simulation by a short amount of time.

Mean velocity over the whole domain for the reference experiment.



Results for the reference simulation.



Evolution of the velocities for the reference simulation

The figure shows the evolution of the mean velocity on the whole domain and at selected locations.

The blue (grey) dashed line shows the mean of all perturbed (unperturbed) years for the 90 simulations with this given parameter set.

The shading is the two standard deviation interval corresponding to this mean.

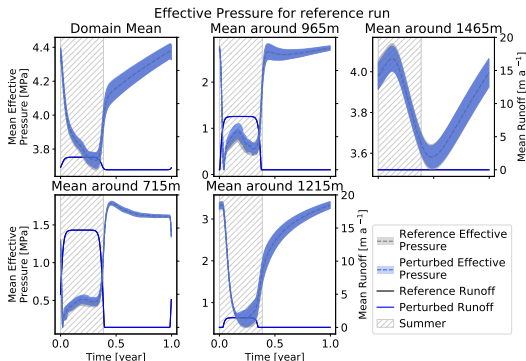
The blue (black) solid line correspond to the runoff on the perturbed (unperturbed) year.

The light grey dashed region correspond to the period of the standard melt season (141 days).

In this specific case there is a significant overlap between perturbed and unperturbed years as no perturbation is actually applied

Results for the reference simulation.

The effective pressure shows a clear demarcation between two zones on the glacier



Evolution of the effective pressure for the reference simulation

At lower elevations (below 1000m)

Sharp decrease in effective pressure in spring.

Marked “rebound” of the effective pressure.

Significantly higher effective pressure at the beginning of the fall.

At higher elevations

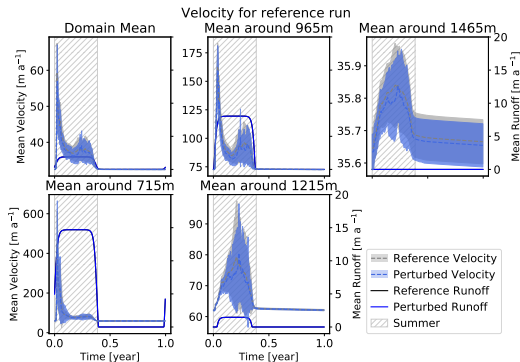
Slower decrease of the effective pressure

More gradual return to a winter effective pressure

The evolution gets smoother at higher altitude with a marked lag.

Results for the reference simulation.

Those results are translated in the Velocity evolution's



Evolution of the velocity for the reference simulation

At lower elevations (below 1000m)

Sharp “spring speed-up”

Faster velocity in the second half of summer where the pressure builds up again Around 1000m.

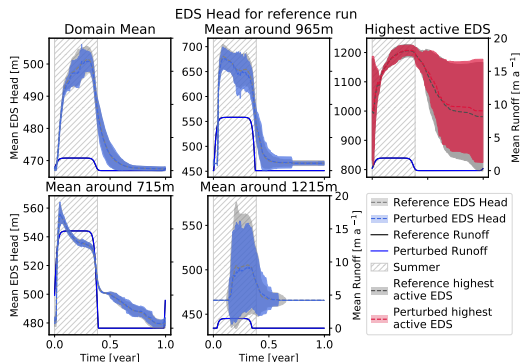
At higher elevations

More gradual acceleration

Maximum velocity at mid summer

Results for the reference simulation.

This is strongly driven by the Efficient system activity.



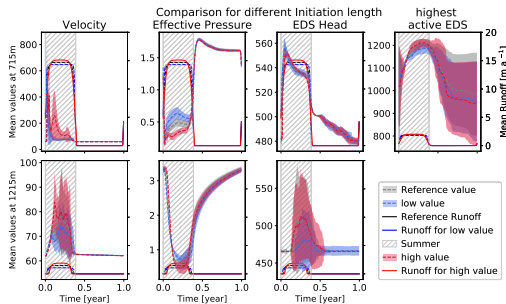
The top right panel show the location of the highest active efficient layer location (red). The regions where the efficient drainage system activates early in the season (roughly below 1100m) show a sharp rise of the EDS heads and then a slow decrease.

Above that point the efficient drainage activates more gradually and later into the melt season. The fast activation at lower altitude explains the rapid changes in effective pressure and velocities.

Evolution of the efficient system head for the reference simulation

Effect of the initiation length

The top row shows the evolution of the different variables at 715 m of elevation for short (blue) and long (red) initiation periods. The highest active EDS is a global value on the domain. Effective pressure is in MPa, all other variables are in meters above sea level.



Comparison of short and long initiation length for different variable at different altitudes.

At 715 m the long initiation leads to a delayed and less intense speed up but the low effective pressure mid-season drives higher velocities throughout summer

At 1215 m the velocities are higher throughout the melt season and there is only a slight delay in the spring acceleration.

At high elevation, the more sustain velocities are due to a slower development of the efficient drainage system.

The small difference in runoff amplitude needed to keep the same global runoff across all simulation seems to have a quite large impact on the effective pressure throughout summer but there may be other parameters involved such as the area covered by the efficient drainage system.



The system shows a strong interannual variability and investigating small changes require a lot of simulations

There is two different regimes on the glacier depending on the efficient system activation

The shape of the melt season definitely has an impact on the velocity evolution but the effect of each parameter still needs to be quantified

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