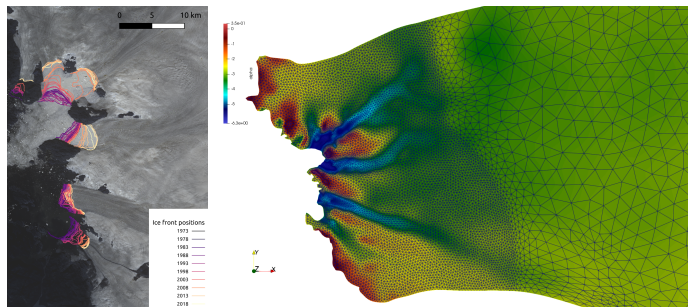


Data assimilation and ensemble method applied to Upernavik Isstrøm



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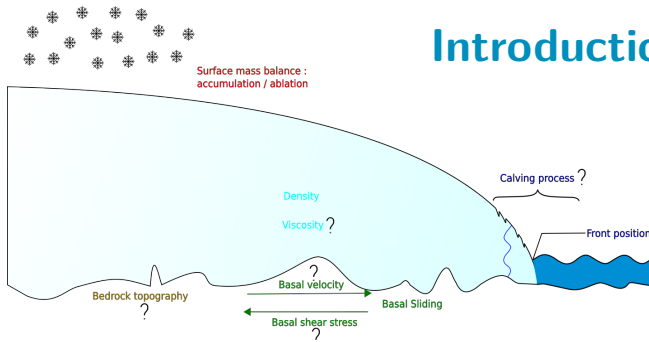
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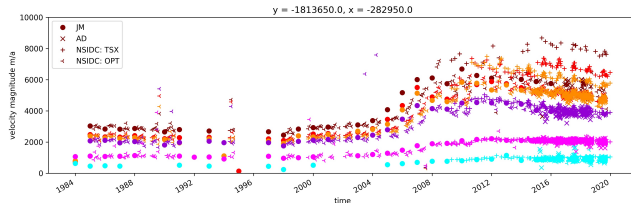
Introduction



Uncertainty for the input of our model :

- Ice viscosity
- Basal shear stress
- Bedrock topography
- Calving process

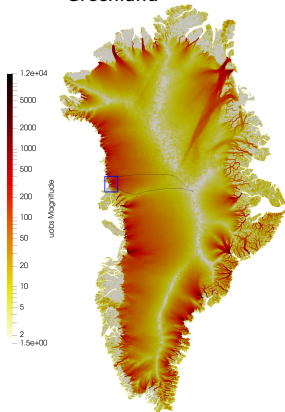
Velocity data from different source depending on time



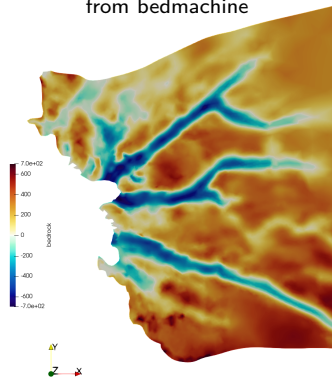
Increase of data amount in glaciology in the recent past years allows us to set up transient data assimilation as kalman filter

Overview of the data

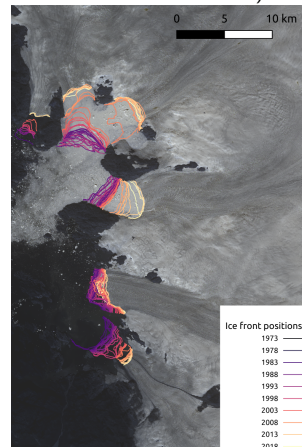
Upernavik Isstrøm's position in Greenland



Bedrock topography near the front from bedmachine

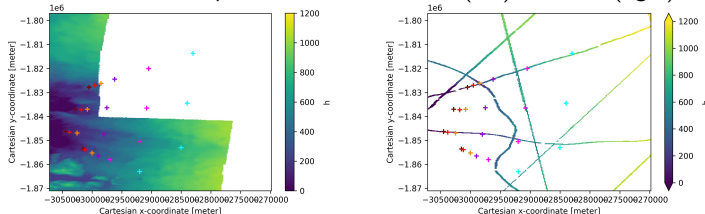


Front position of Upernavik Isstrøm between 1973 and 2018 (data from M. Wood et al. 2021)

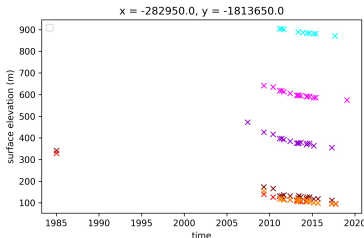


Overview of the data

Surface elevation of Upernavik Isstrøm for 1985 (left) and 2009 (right)



Surface elevation evolution depending on time. Colors correspond to the position on the graphs above.



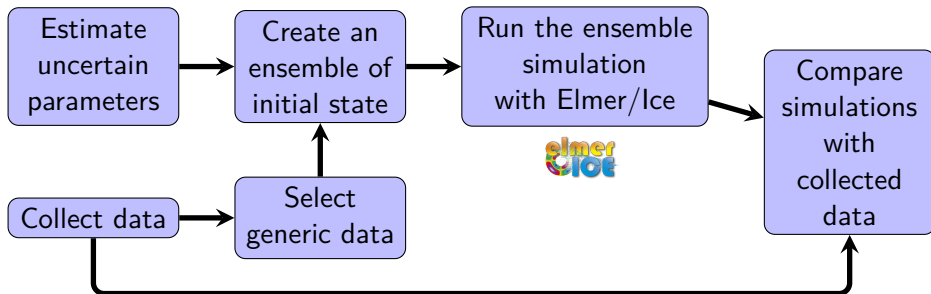
What kind of data do we have?

- Velocities
- Surface elevation
- Ice front position
- Bedrock topography

Which data is constant over time ? Only the bed topography!

How to use these data ?

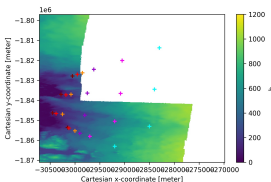
Diagram illustrates a generic method to prepare an ensemble simulation for data assimilation



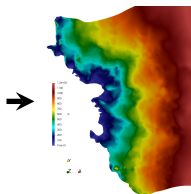
How to use these data to reduce uncertainty of our model inputs? The goal here is to create a generic method which could be apply to other glaciers than Upernavik Isstrøm.

Changes in parameters

Take the oldest data elevation



Complete year by year with more complete data



Run a relaxation simulation with different sets of parameters.

You have created a realistic ensemble of initial states

Diagram illustrates a generic method to create an ensemble of initial states

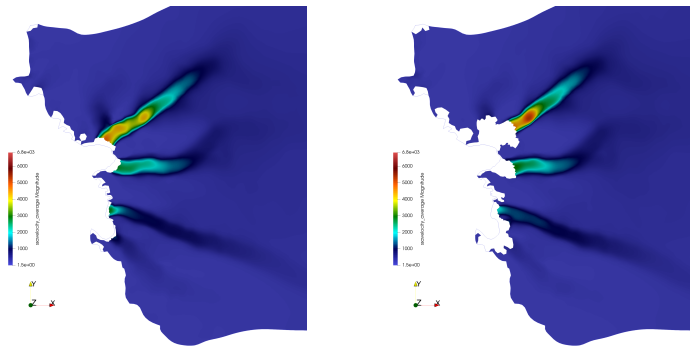
To do realistic sets of parameters, you have to catch the entire uncertainty of each parameters. We introduce here an uncertainty on the surface mass balance and the time relaxation to represent the unknown history of the glacier. The relaxation simulation allow us to smooth the surface.

Changes in parameters

During the relaxation simulation, we have 5 different parameters which are following different probability laws :

- Surface mass balance : random draw of a 10-year average (60's,70's,80's,90's and 2000's)
- Relaxation duration : random draw of a number of years (between 5 and 10 years)
- Exponent of the friction law $\tau_b = \cdot ||\underline{u}||^{\frac{1}{m}}$, random draw of m between 1 and 5
- Friction coefficient : random draw of a field obtain with ensemble inversion simulation on the full Greenland
- Enhancement factor $\nu \propto E^{\frac{1}{n}}$, random draw of E between 0.5 and 5

Transient simulation

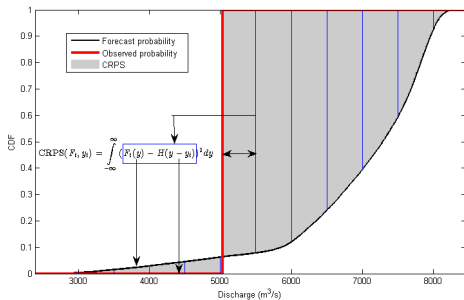


Velocity of the average simulation at the initial and final step. See the video to go further

Characteristics of our simulation runs with the Finite Element code Elmer/Ice :

- Shallow Shelf Approximation
- External forcing : changes of the front position, constant SMB
- Initial condition : End of the relaxation simulation
- Boundary conditions : Free-slip at the sides and fixed calving front.

Scores



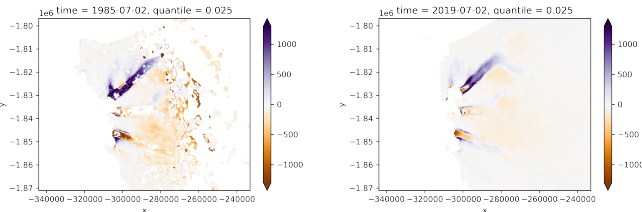
Calculation of the CRPS (source :
Matlab site, by Durga Lal Shrestha)

Two different scores for simulation :

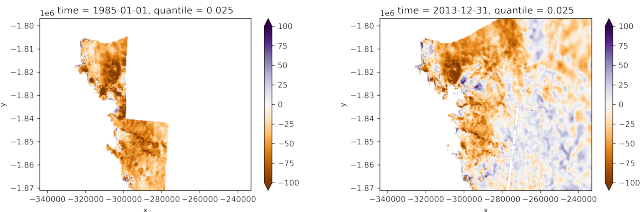
- The Root Mean Square Error allow us to compare simulations one by one
- The Continuous Rank Probability Score allow us to compare different ensemble of simulation : if we are overconfident, we will have a bad score if the observation is outside of the spread. However, if we catch the observation, a thinner spread will have a better score.

Map results

- It seems that the errors of the average decrease when we get closer to the moment when we made the inversions of the friction fields
- We don't have a general bias (a little positive bias for surface elevation).



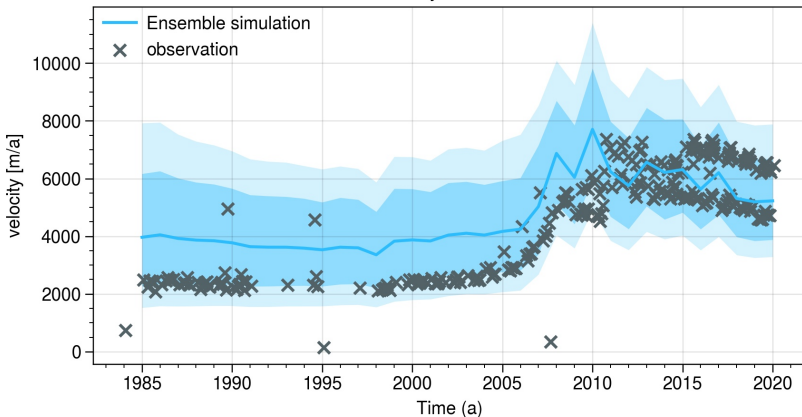
Difference between average velocity of our ensemble and observed velocity for 1985 and 2019



Difference between average surface elevation of our ensemble and observed surface elevation for 1985 and 2013

Local results

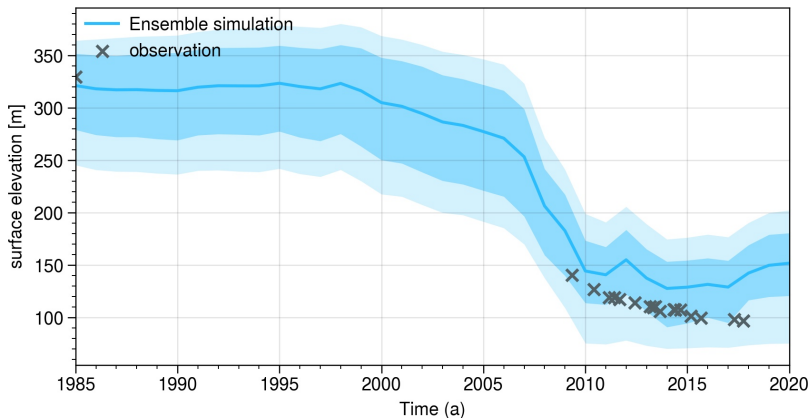
velocity over time



- Some simulations seem better than others, so some combination of parameters better represent the reality
- Data assimilation can be relevant here to decrease the spread and select the best combinations of parameters.

Local results

surface elevation over time



- Some simulations seem better than others, so some combination of parameters better represent the reality
- Data assimilation can be relevant here to decrease the spread and select the best combinations of parameters.

Summary

What have we done for the moment :

- Find main drivers of ice dynamics and its uncertainty.
- Separate generic data to inconstant data.
- Preprocessing to launch ensemble simulation.
- A lot of tools for the post-processing of simulations and to compare with data.

Prospects

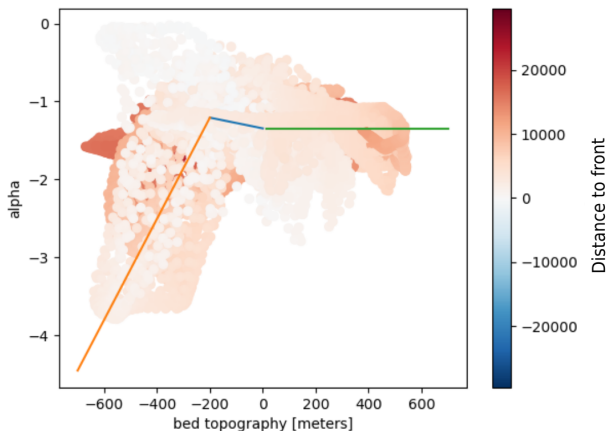
What are the next steps ?

- Find a better way to fill space where there is no data (friction and surface), maybe in link with correlation matrix.
- Move towards data assimilation : start to create initial step with correlation matrix.
- Begin to assimilate velocity and surface elevation observations to better estimate uncertain parameters with a Kalman Filter
- Try to switch to a full stokes model with Elmer/Ice

References

- Front positions : M. Wood et al. 2021
- Velocity : I. Joughin et al. 2018, Mouginot et al. 2017, Derkacheva et al. 2020
- Thickness : I. Howat et al 2017, I. Howat et al 2014, N.J. Korsgaard 2016, K.M. Brunt 2016, D. Moller 2019
- Bedmachine : M. Morlinghem et al. 2017
- Assimilation : Gillet-Chaulet 2020
- Elmer/Ice : Gagliardini et al. 2013
- Numerical environnement : All (or most of) the computations presented in this paper were performed using the GRICAD infrastructure (<https://gricad.univ-grenoble-alpes.fr>), which is supported by Grenoble research communities.

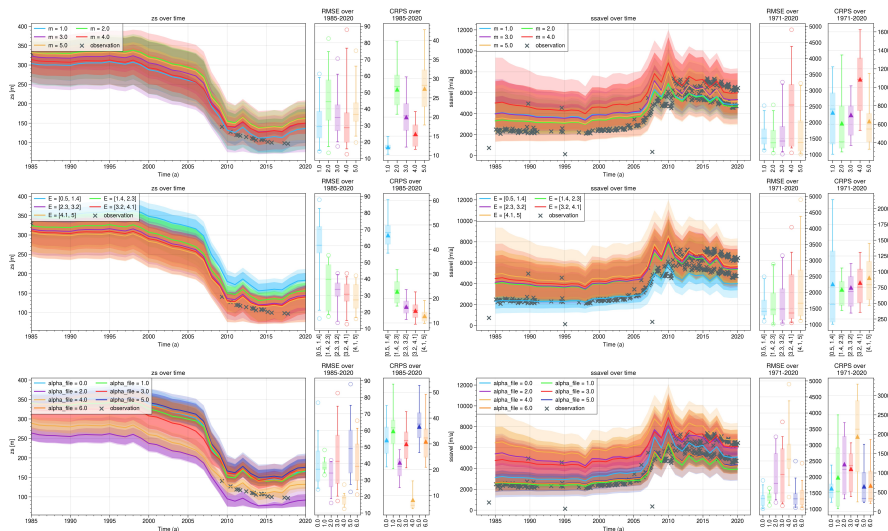
Ice free area



Alpha ($\alpha = \log \beta$) is approximately a function of bed topography.

To obtain friction coefficient, we have used results of inversion of the current state of the Ice sheet. Problem : we have ice free area that there is no in 1985. So how to fill data friction coefficient in these spaces ? We did a linear regression with the coefficient friction as a function of the topography.

Local results



Here we plot our complete graph : we have the trends of ensemble (mean, 68% and 95% confidence interval) for different parameter values. For each ensemble, we have the CRPS of each time step (mean Δ , median - and confidence intervals) and the RMSE over time of each simulation (median - and confidence intervals)