北京師範大學
BEIJING NORMAL UNIVERSITY

全球变化与地球系统科学研究院
College of Global Change and Earth System Science
GCESS

Simulating Antarctic subglacial hydrology processes beneath Pine Island Glacier, using GlaDS in Elmer/Ice

yufang zhang

John Moore[1 2] Mike Wolovick[1] Rupert Gladstone[2]
Thomas Zinger[3] Xiaoran Guo[1]

Ice dynamics, basal hydrology, Antarctica, GlaDS, Elmer/ice, PIG

PhD student
Email: 201831490020@mail.bnu.edu.cn

CSC

Why important to study (simulate) subglacial hydrology system?

- Subglacial drainage system influences basal sliding
- Contribute to SLR and have an impact on SLR prediction
- Previous work on ice dynamics involves little hydrology feedback
- Difficult to directly observe sub-environment
- Couple hydrology model to ice dynamics may give more specific SLR

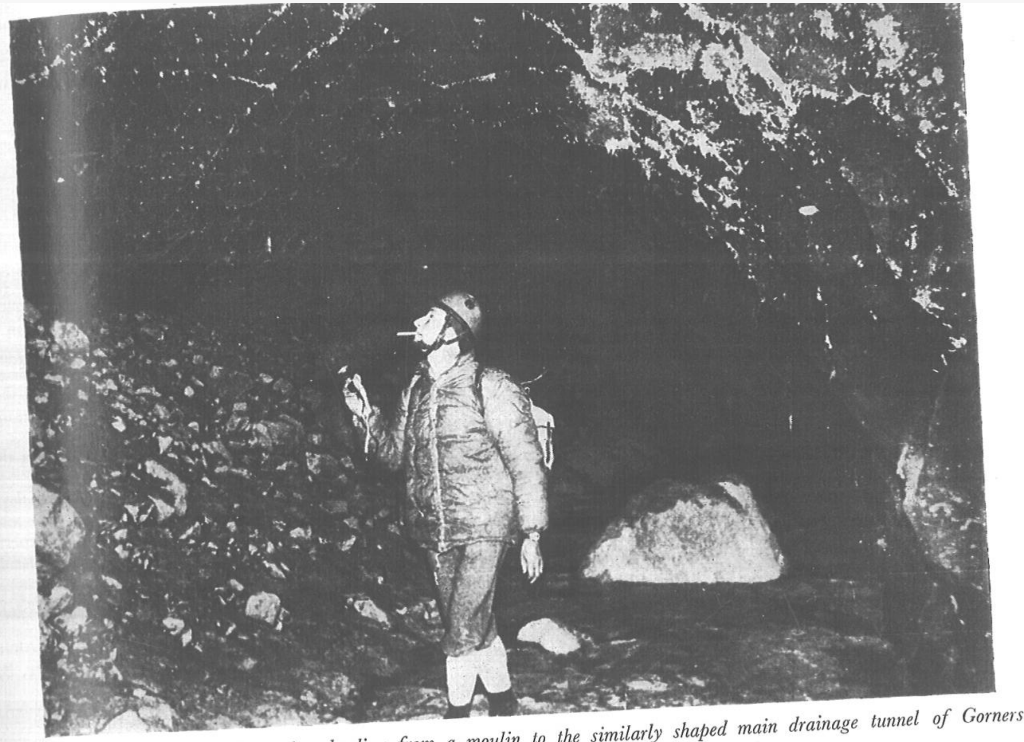


Fig. 11. *Typical section of the duct leading from a moulin to the similarly shaped main drainage tunnel of Gornersee.* (*Photograph by Luc Vuadens, Groupe St. Exupéry*).

Hydrology model developments

- Conduit model (Rothlisberger et al., 1972)
- Box model (Clarke et al., 1996)
- Flow-line model (Flowers et al., 2004)
- 2D network model (Schoof et al., 2012; Shugar et al., 2017)
- GlaDS, coupled distributed and continuous drainage model (Werder et al., 2013; Dow et al., 2016; Dow et al., 2020)

GlaDS model in Elmer/Ice

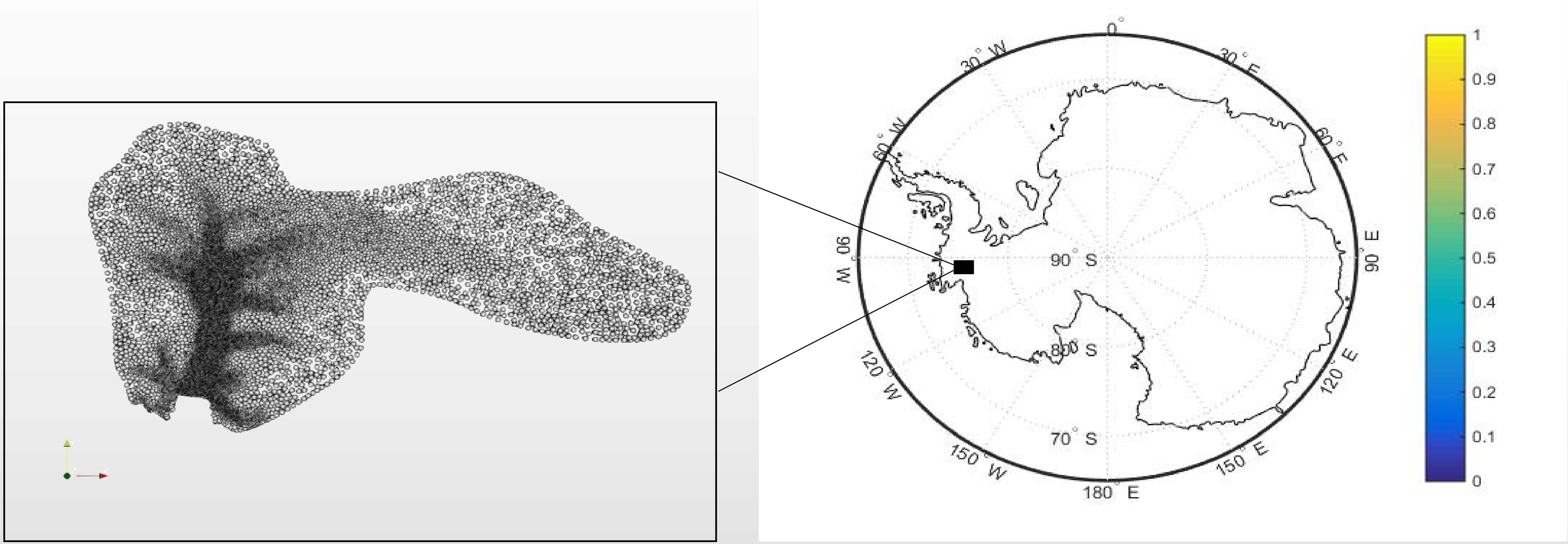
- Oliver Gagliardini, Mauro A. Werder., 2018
- de Fleurian et al., SHMIP project, 2017

My research work focus on applying GlaDS in Elmer/Ice to a marine-terminating glacier, Pine Island Glacier, West Antarctica, to reveal realistic hydrology system and test centurial timescale evolution under climate senarios.

Reason of choosing Pine Island Glacier, West Antarcitca

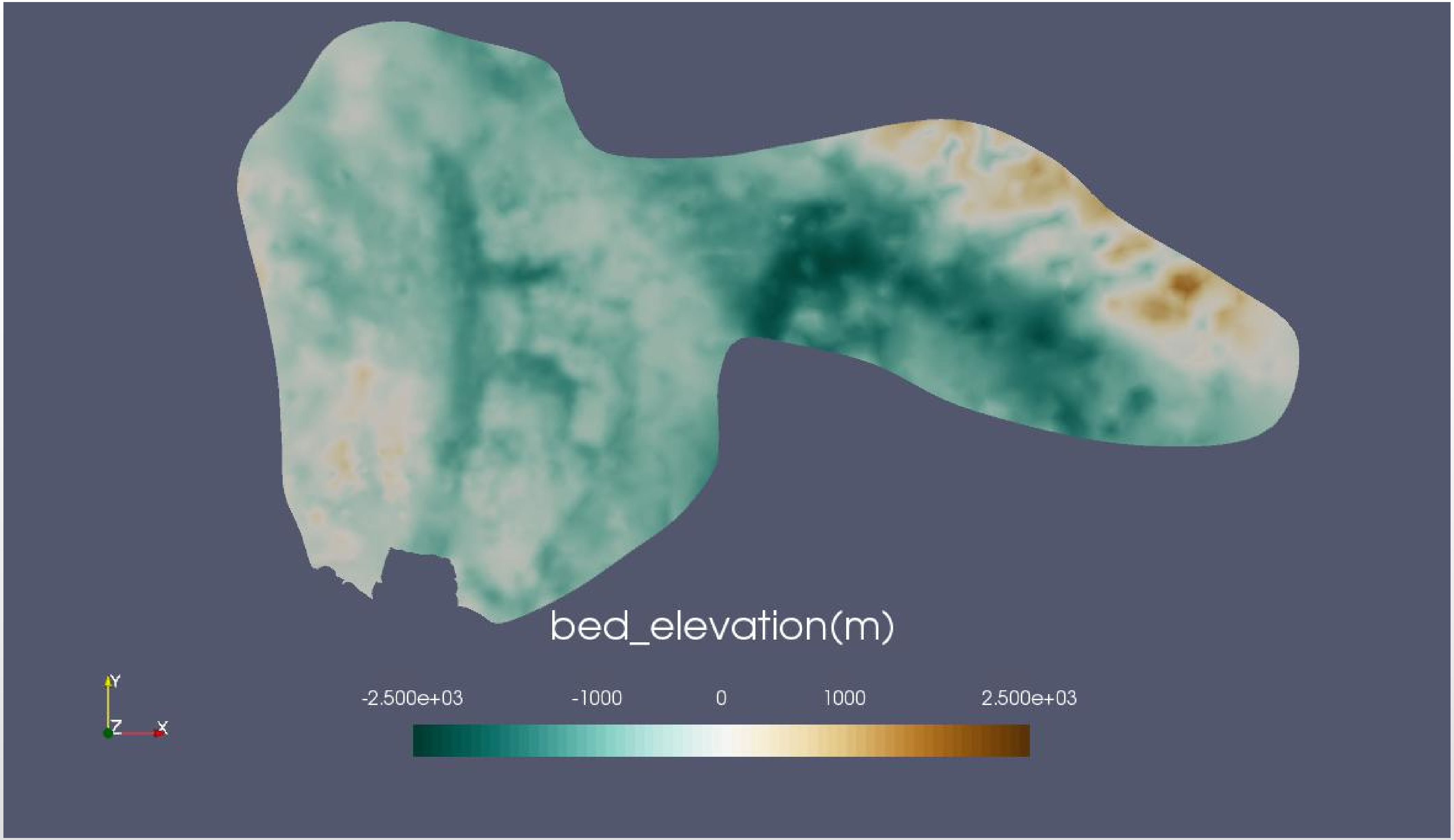
- One of the biggest mass loss and contribution to SLR.

- One of the fatest retreated glacier, 4000 m s^{-1}



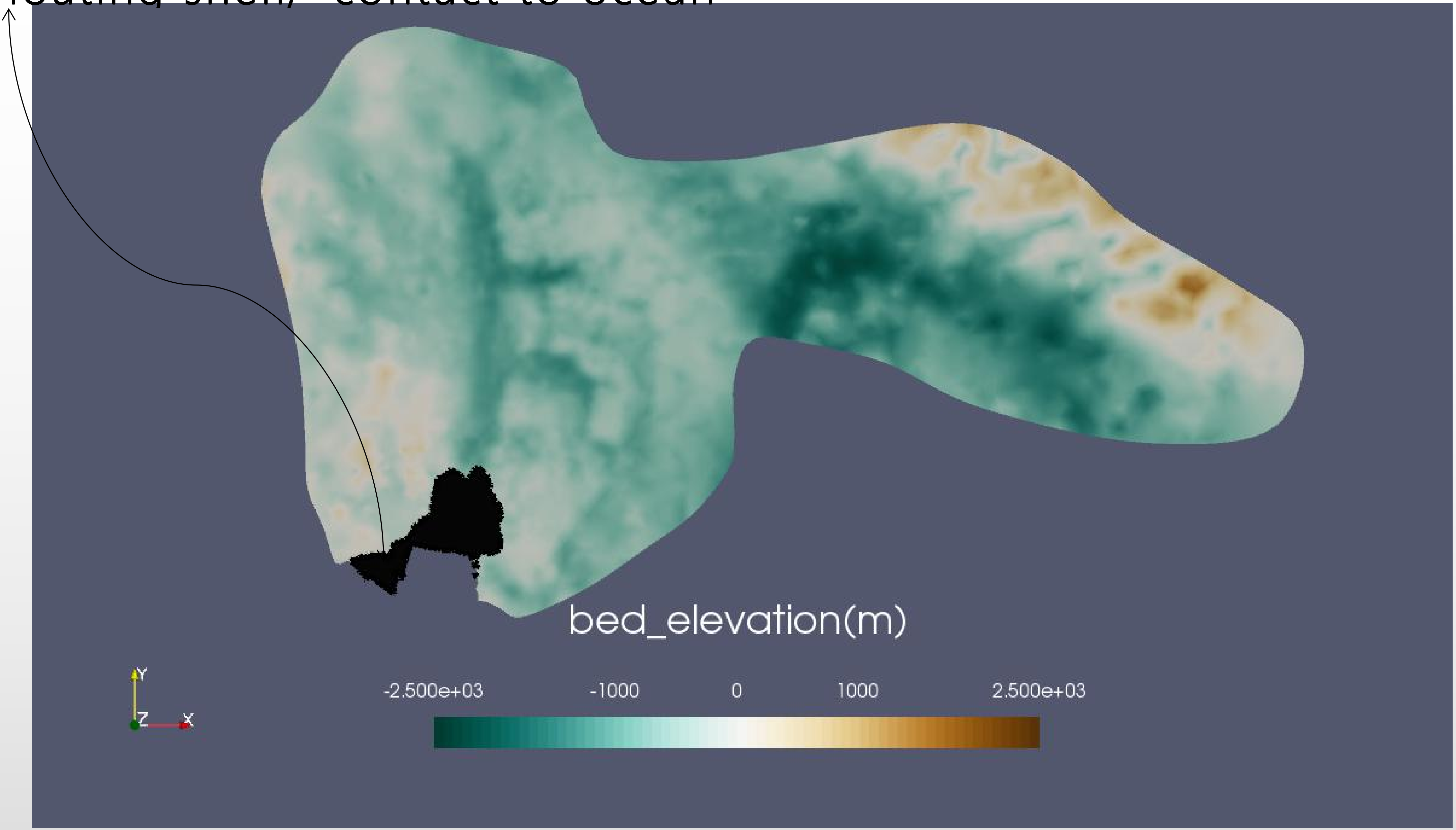
Domain & Topography

trough in the center of PIG



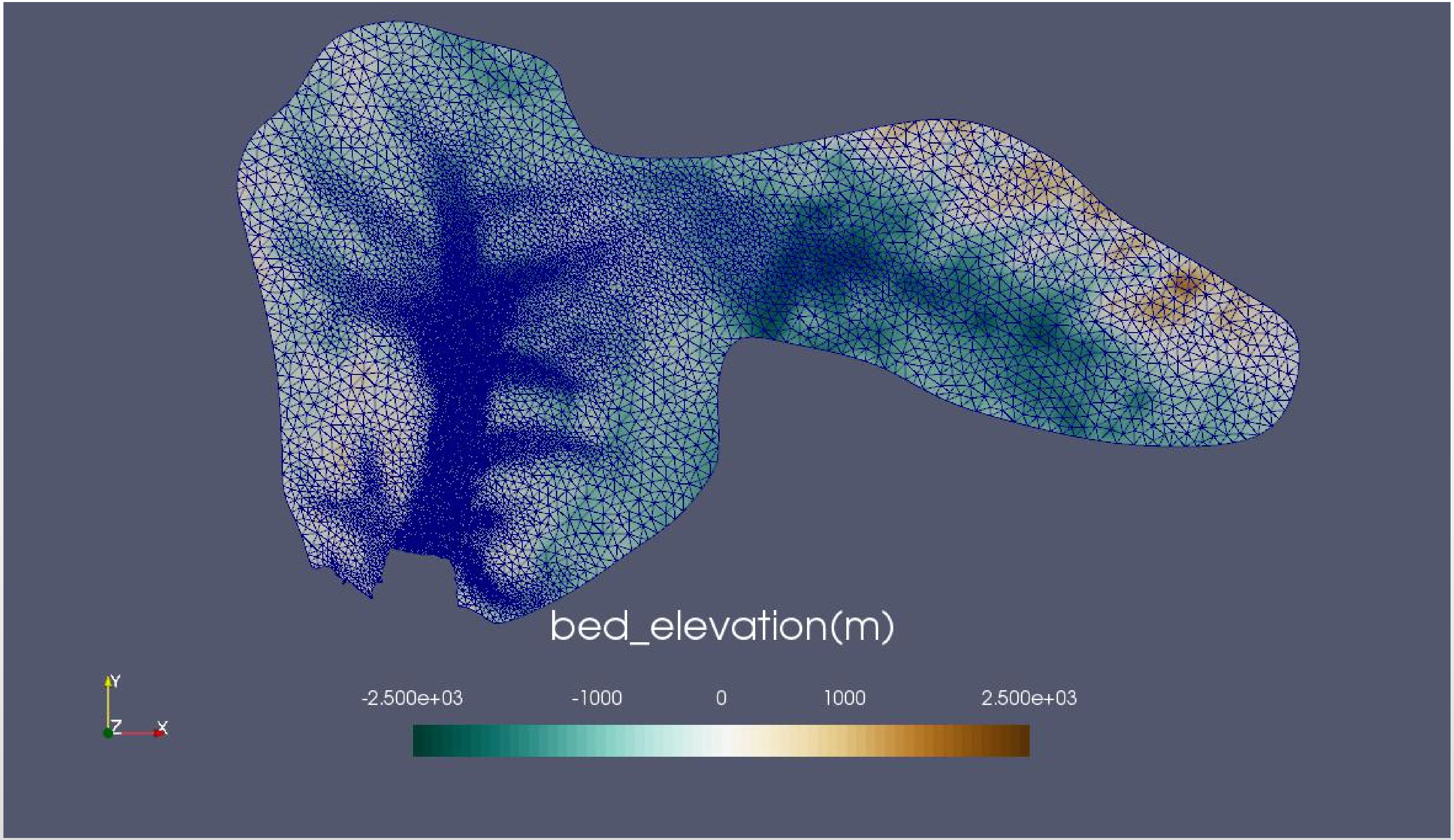
Domain & Topography

ice floating shelf, contact to ocean



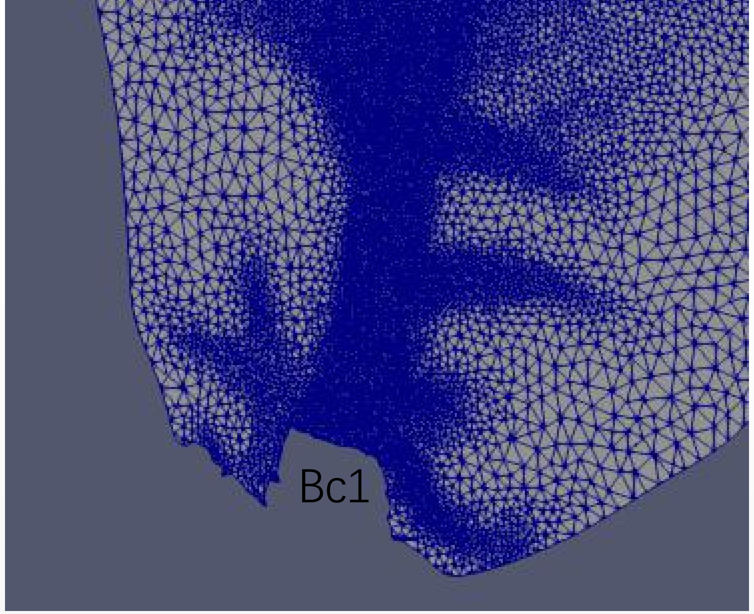
Unstructured triangle mesh; Different density

from Rupert Gladstone.



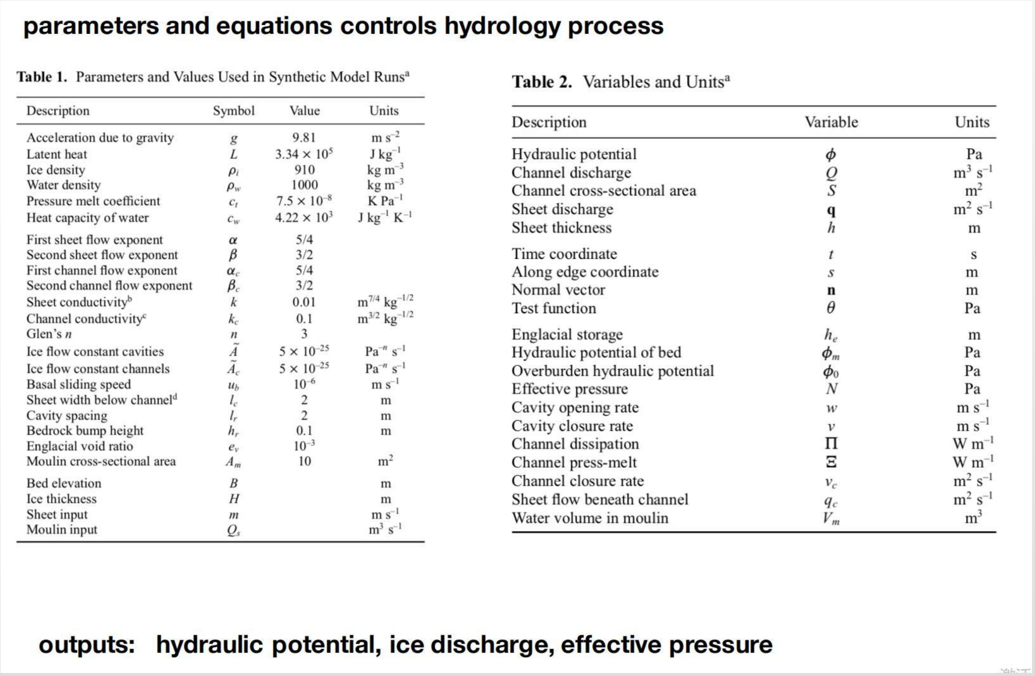
Bodys and Boundary Condition

- including 3 bodys, one shared body
- BC, set on lower surface, inland
- Direchelet BC: HP,N,Pw = 0
- Run 2000 days (over 4 years), output every 50 days
- waterinput1: Constant Water Input = 0.01m a^{-1}



Bc 1 is floating line boundary .

Parameters



parameters and equations controls hydrology process

Table 1. Parameters and Values Used in Synthetic Model Runs[a]

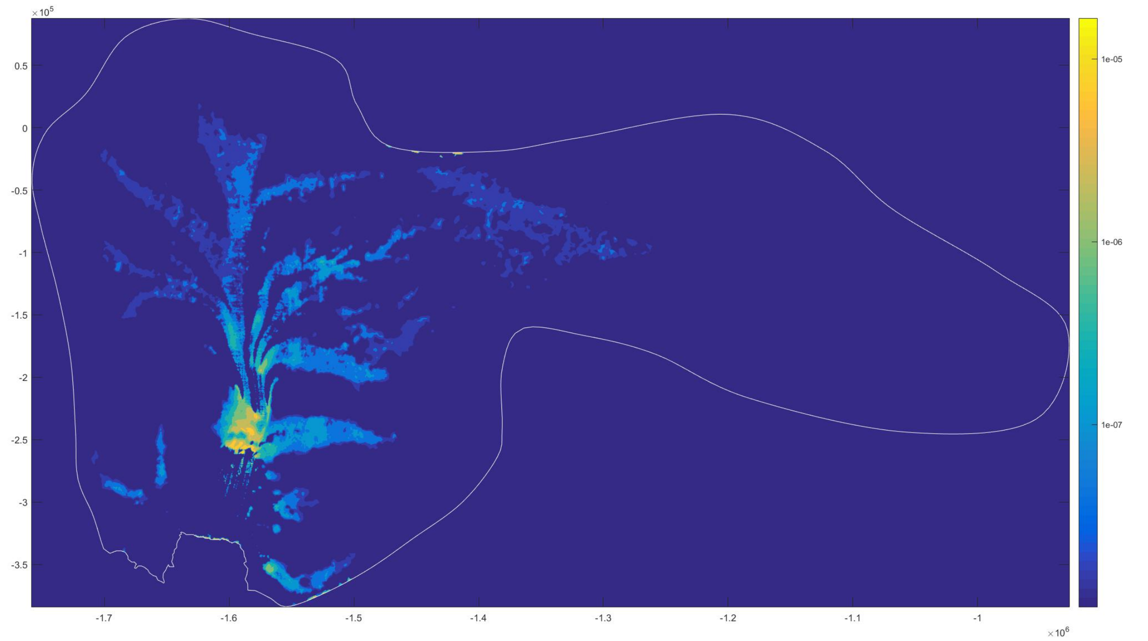
Description	Symbol	Value	Units
Acceleration due to gravity	g	9.81	m s^{-2}
Latent heat	L	3.34×10^5	J kg^{-1}
Ice density	ρ_i	910	kg m^{-3}
Water density	ρ_w	1000	kg m^{-3}
Pressure melt coefficient	c_t	7.5×10^{-8}	K Pa^{-1}
Heat capacity of water	c_w	4.22×10^3	J kg^{-1} K^{-1}
First sheet flow exponent	α	5/4	
Second sheet flow exponent	β	3/2	
First channel flow exponent	α_c	5/4	
Second channel flow exponent	β_c	3/2	
Sheet conductivity[b]	k	0.01	$m^{7/4}$ $kg^{-1/2}$
Channel conductivity[c]	k_c	0.1	$m^{3/2}$ $kg^{-1/2}$
Glen's *n*	n	3	
Ice flow constant cavities	$\tilde{A}$	5×10^{-25}	Pa^{-n} s^{-1}
Ice flow constant channels	$\tilde{A}_c$	5×10^{-25}	Pa^{-n} s^{-1}
Basal sliding speed	u_b	10^{-6}	m s^{-1}
Sheet width below channel[d]	l_c	2	m
Cavity spacing	l_r	2	m
Bedrock bump height	h_r	0.1	m
Englacial void ratio	e_v	10^{-3}	
Moulin cross-sectional area	A_m	10	m^2
Bed elevation	B		m
Ice thickness	H		m
Sheet input	m		m s^{-1}
Moulin input	Q_s		m^3 s^{-1}

Table 2. Variables and Units[a]

Description	Variable	Units
Hydraulic potential	ϕ	Pa
Channel discharge	Q	m^3 s^{-1}
Channel cross-sectional area	S	m^2
Sheet discharge	$\mathbf{q}$	m^2 s^{-1}
Sheet thickness	h	m
Time coordinate	t	s
Along edge coordinate	s	m
Normal vector	$\mathbf{n}$	m
Test function	θ	Pa
Englacial storage	h_e	m
Hydraulic potential of bed	ϕ_m	Pa
Overburden hydraulic potential	ϕ_0	Pa
Effective pressure	N	Pa
Cavity opening rate	w	m s^{-1}
Cavity closure rate	v	m s^{-1}
Channel dissipation	Π	W m^{-1}
Channel press-melt	Ξ	W m^{-1}
Channel closure rate	v_c	m^2 s^{-1}
Sheet flow beneath channel	q_c	m^2 s^{-1}
Water volume in moulin	V_m	m^3

outputs: hydraulic potential, ice discharge, effective pressure

Water Input 2 from inversion model

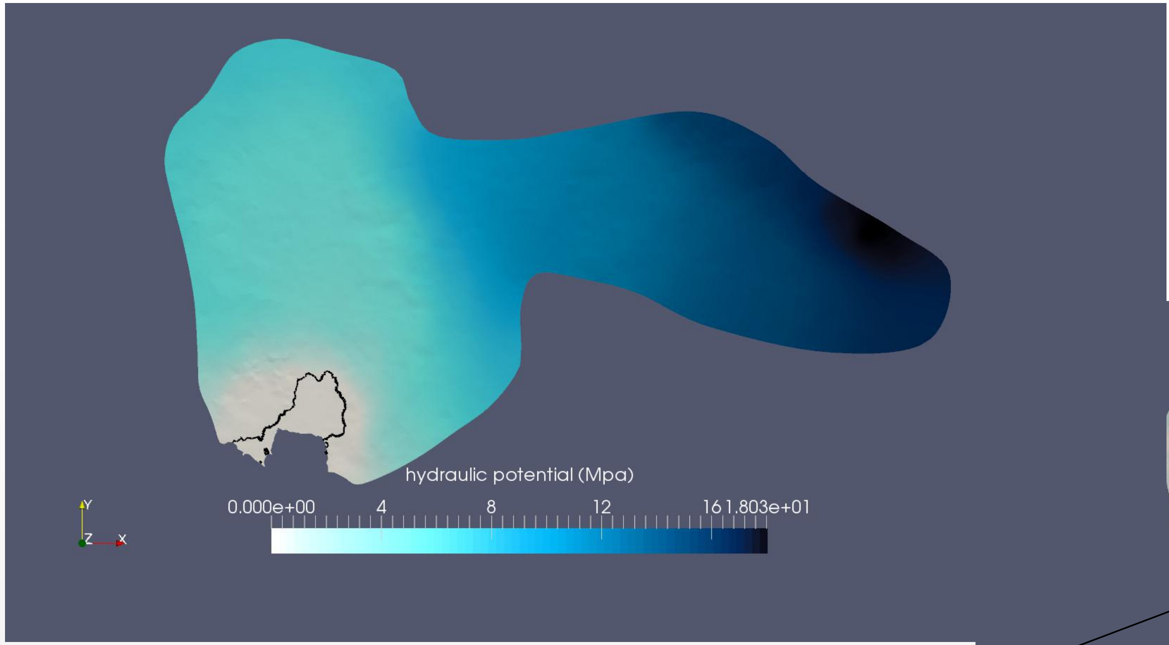


Results

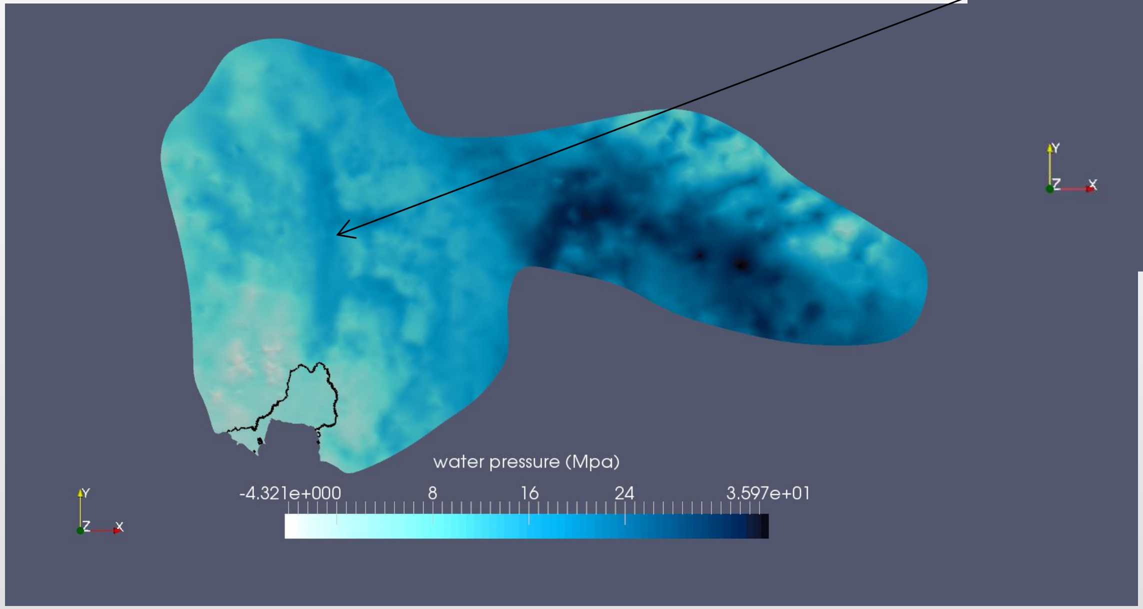
800days

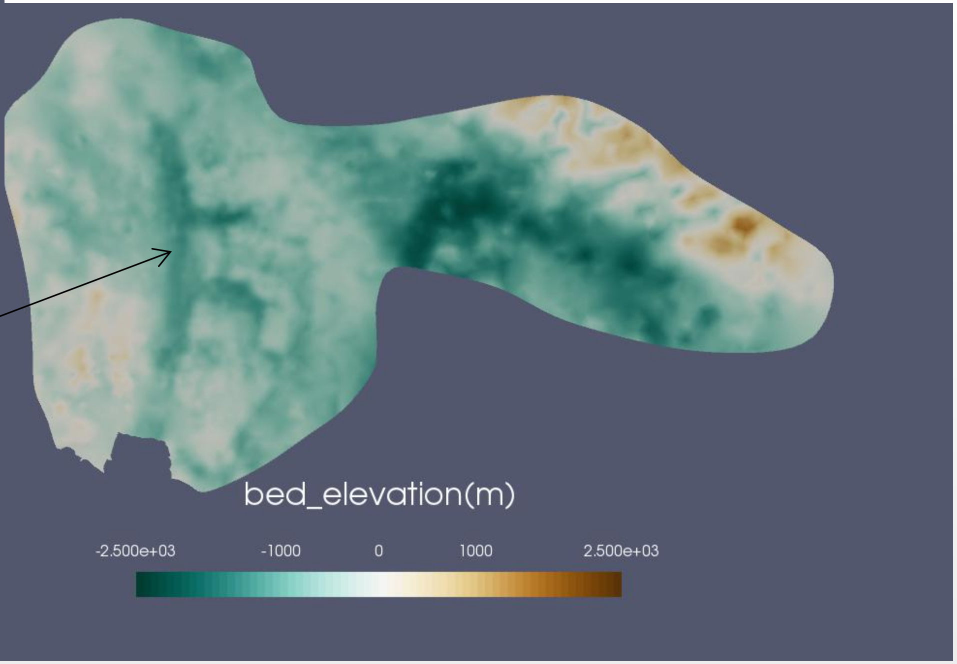
- When water pressure increases, the gradient of hydraulic potential increases.
- Strong correspondence in regions of faster sliding velocity with high water pressure. (along the troughs)

Hydraulic potential



Water Pressure

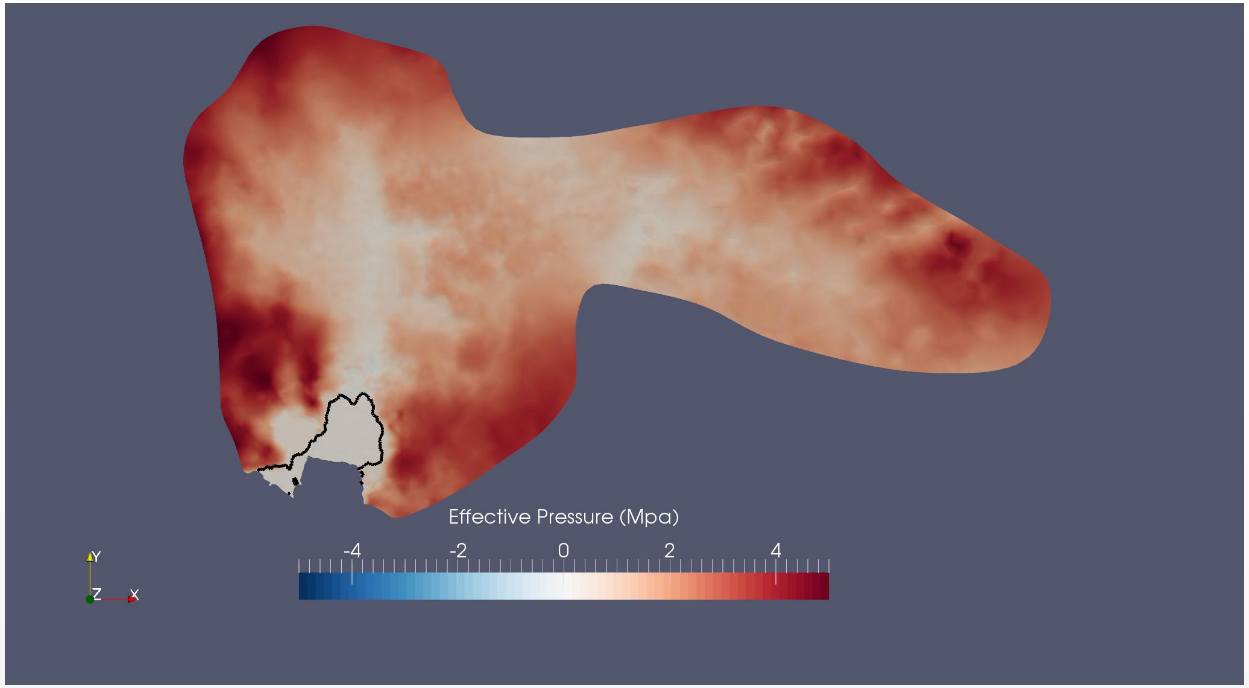




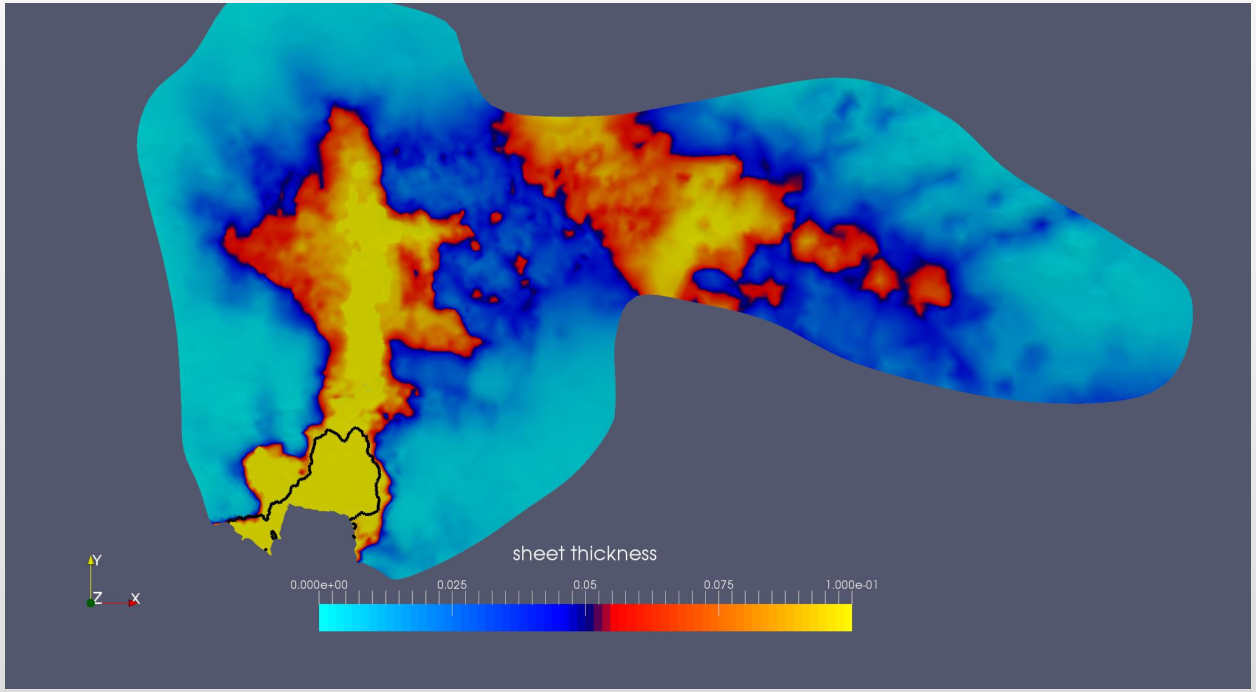
Results

800days

Effective Pressure



Sheet thickness



- Agreement of high water pressure with presnece of sheet thickness.
- Water pressure is basiclly the same with ice overburden pressure.

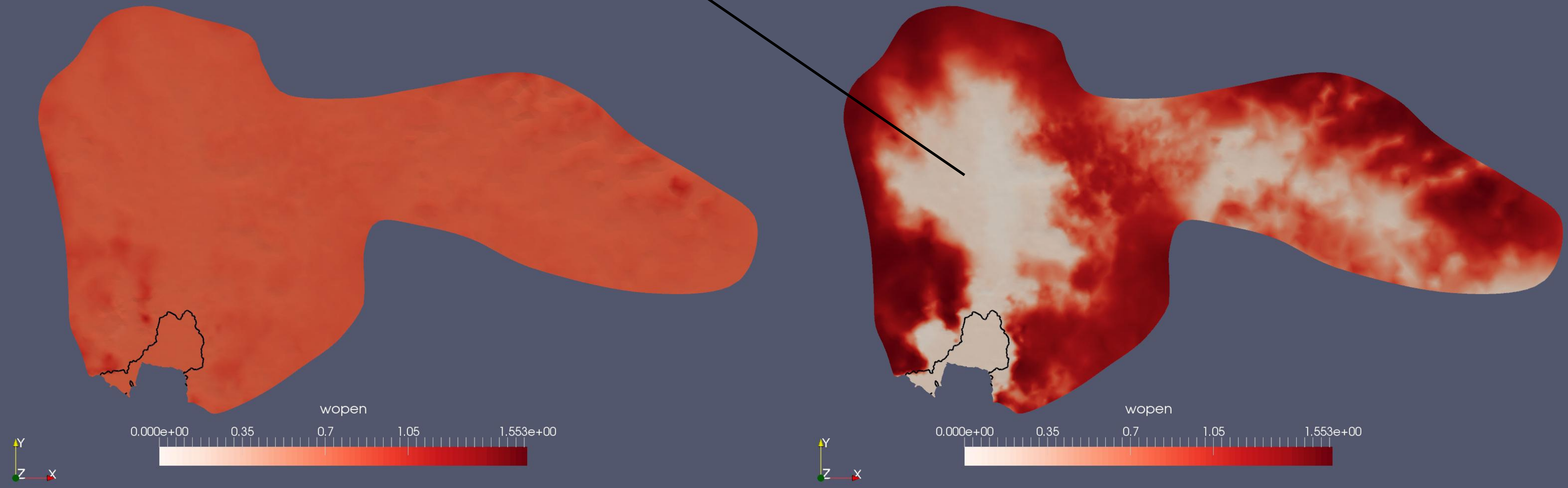
Results

cavity opening rate

$$w(h) = \begin{cases} \frac{u_b(h_r - h)}{l_r}, & h < h_r \\ 0, & otherwise \end{cases}$$

$h_r = 0.1(\mathrm{m}) \quad l_r = 2(m)$

sheet thickness is bigger than height of bed bump.



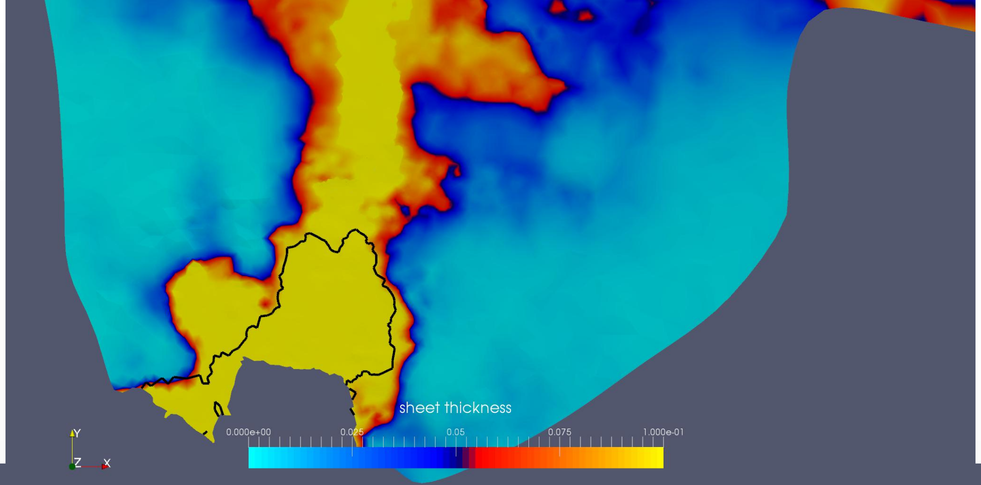
water input1

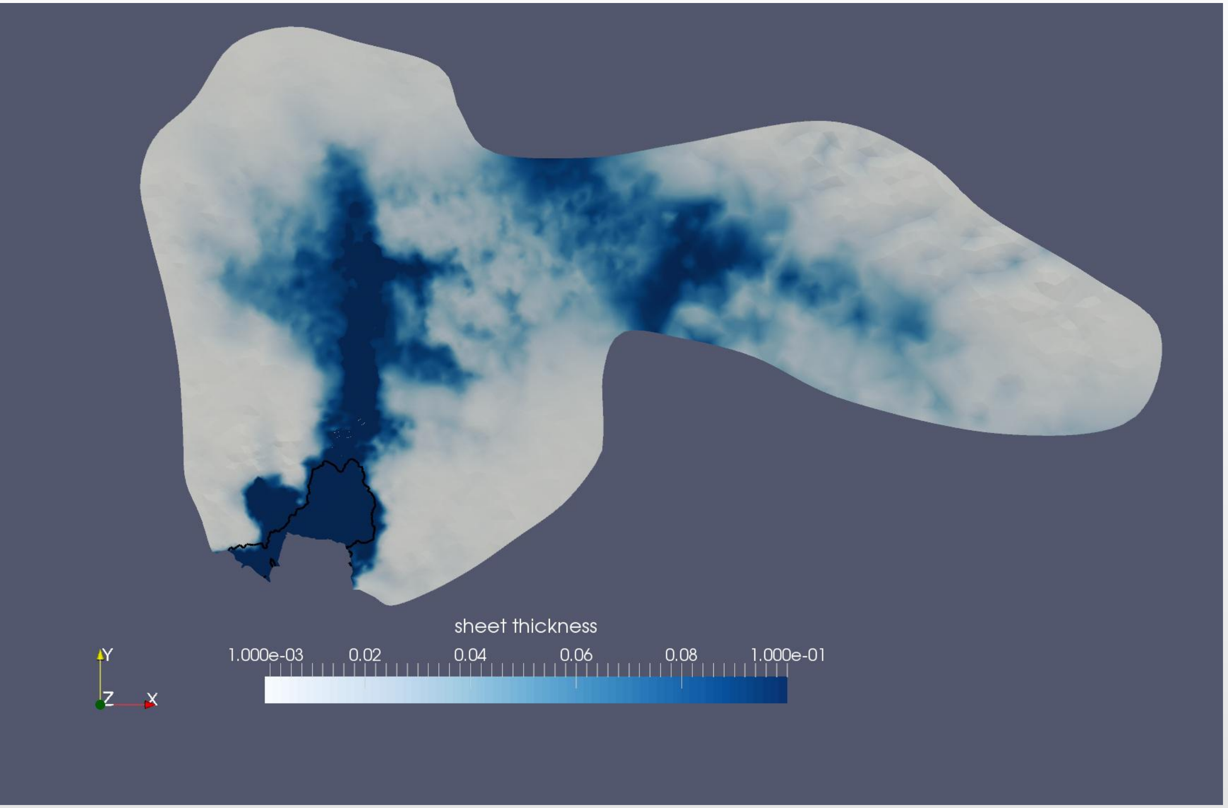
Results

Sheet thickness

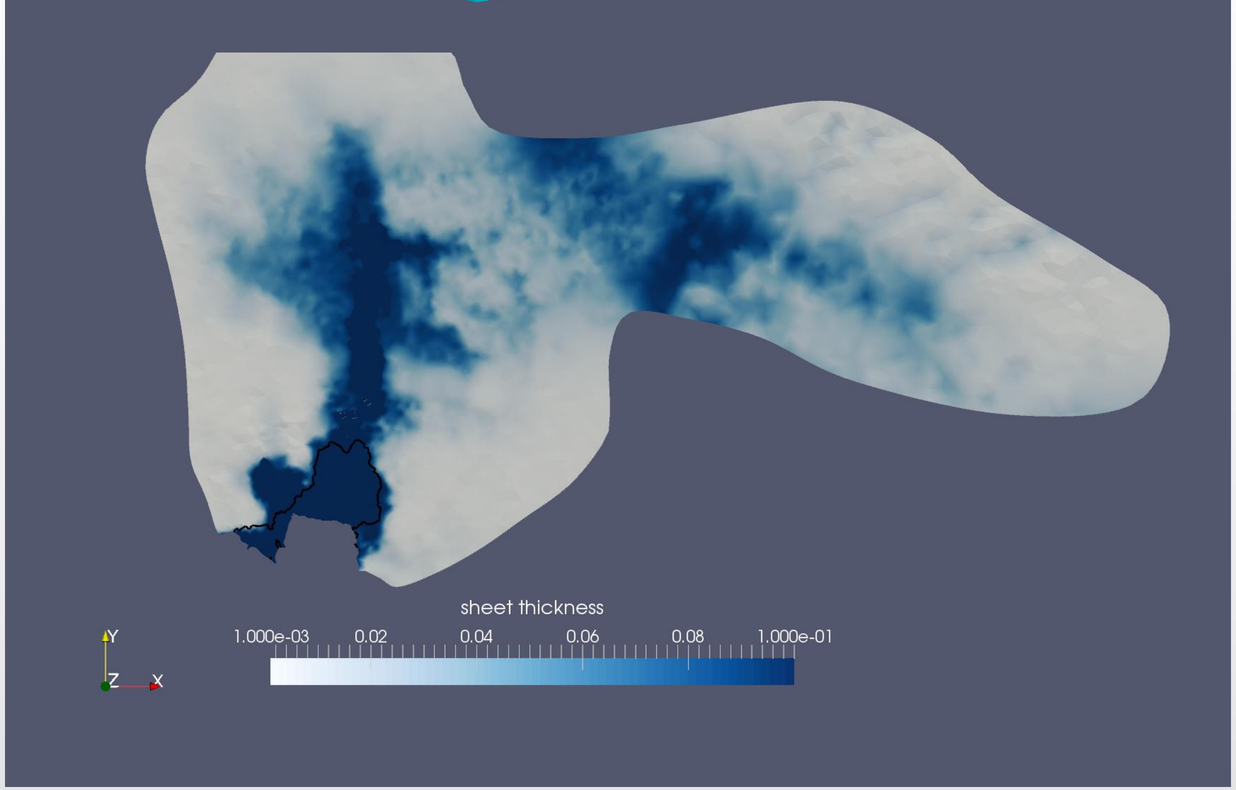
h [0.001,0.1] m

$$\frac{\partial h}{\partial t} = w - v$$





800days



850days

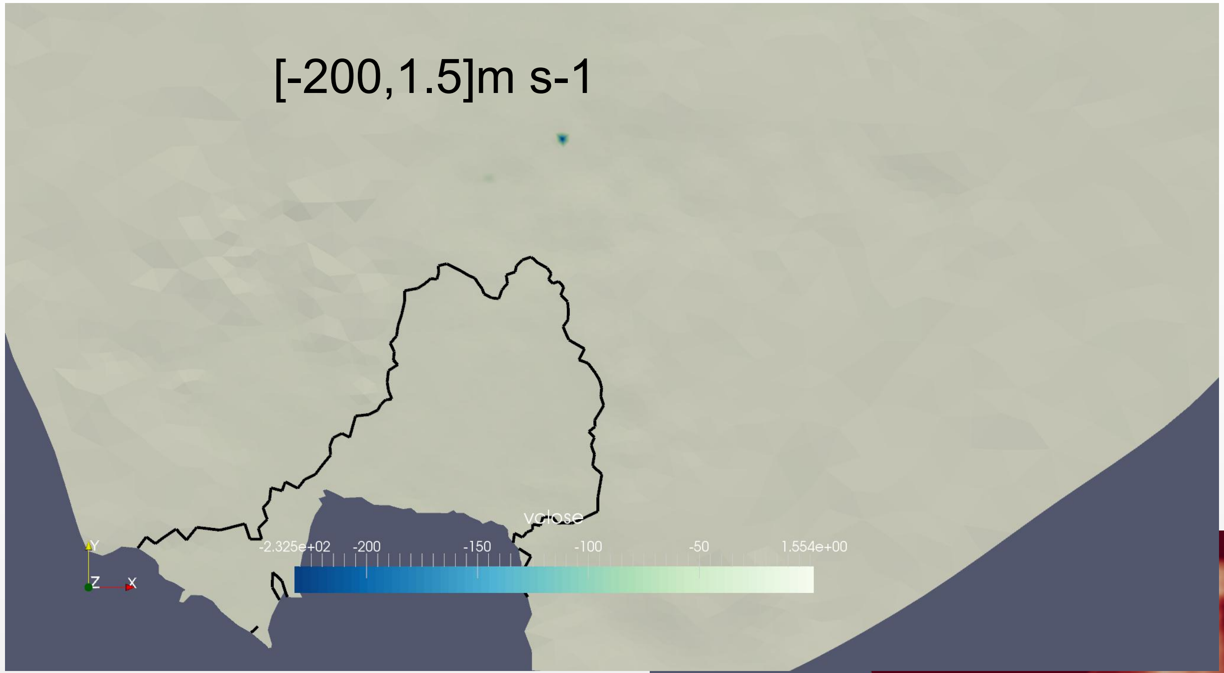
water input2

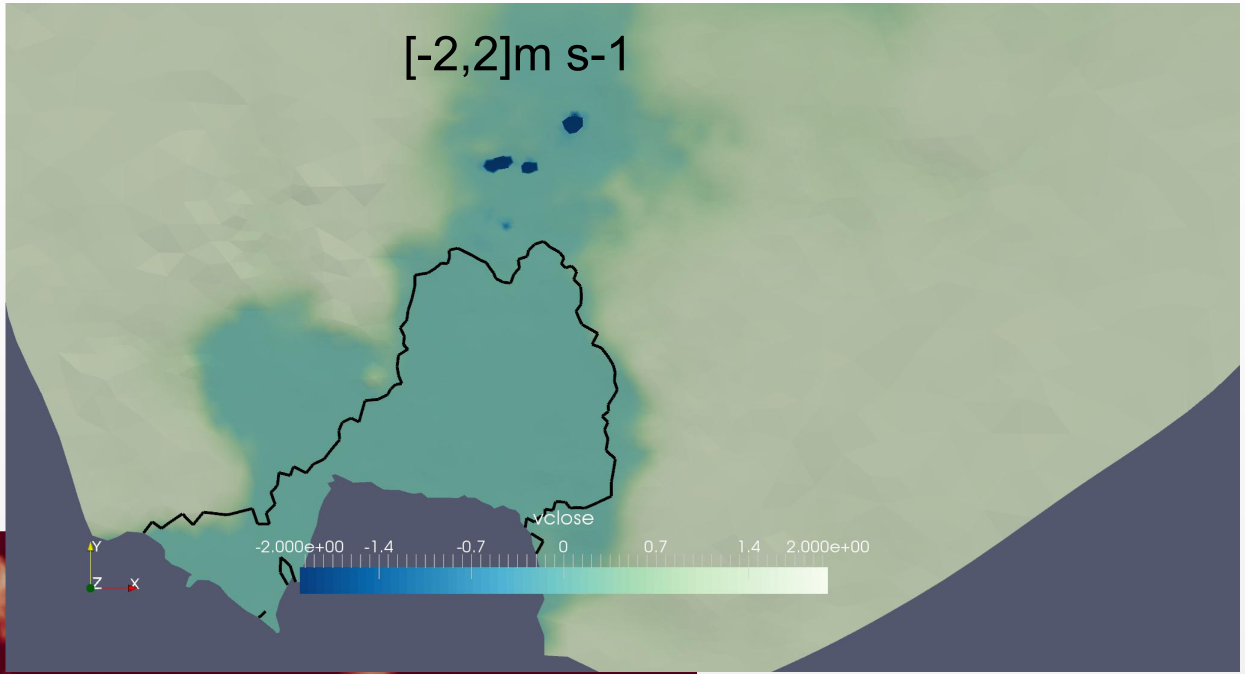
Results

cavity closure rate

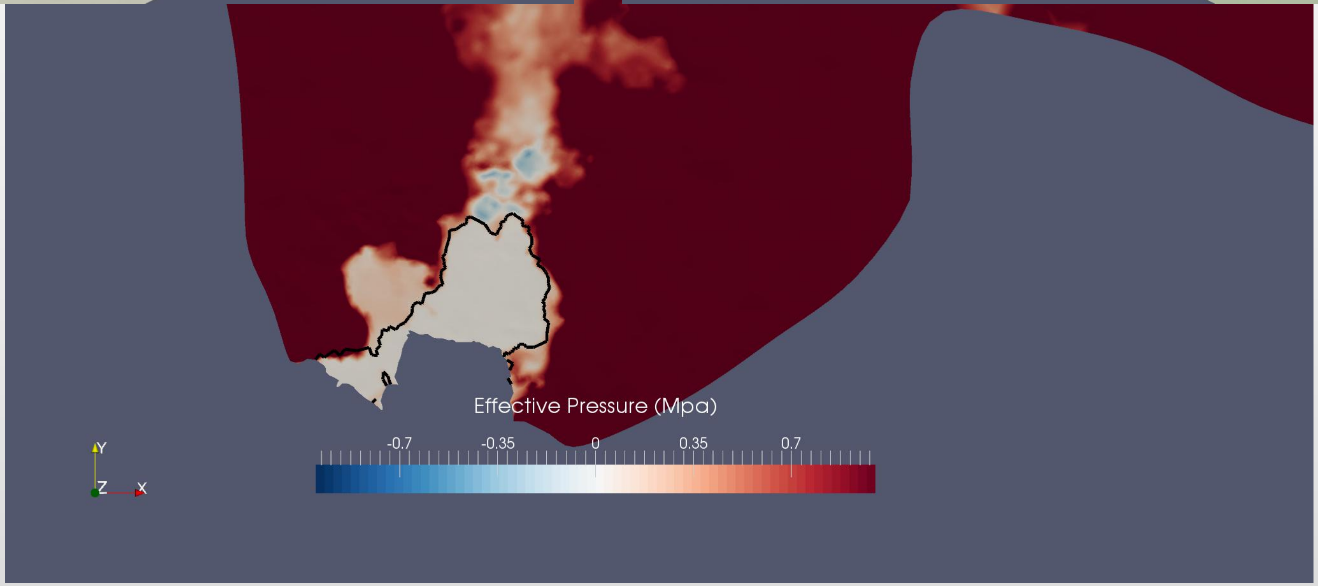
$$v(h, N) = Ah|N|^{n-1}N$$

800days





not reasonable due to water input



sticky points where shear heating accumulates.

Results

Sheet thickness

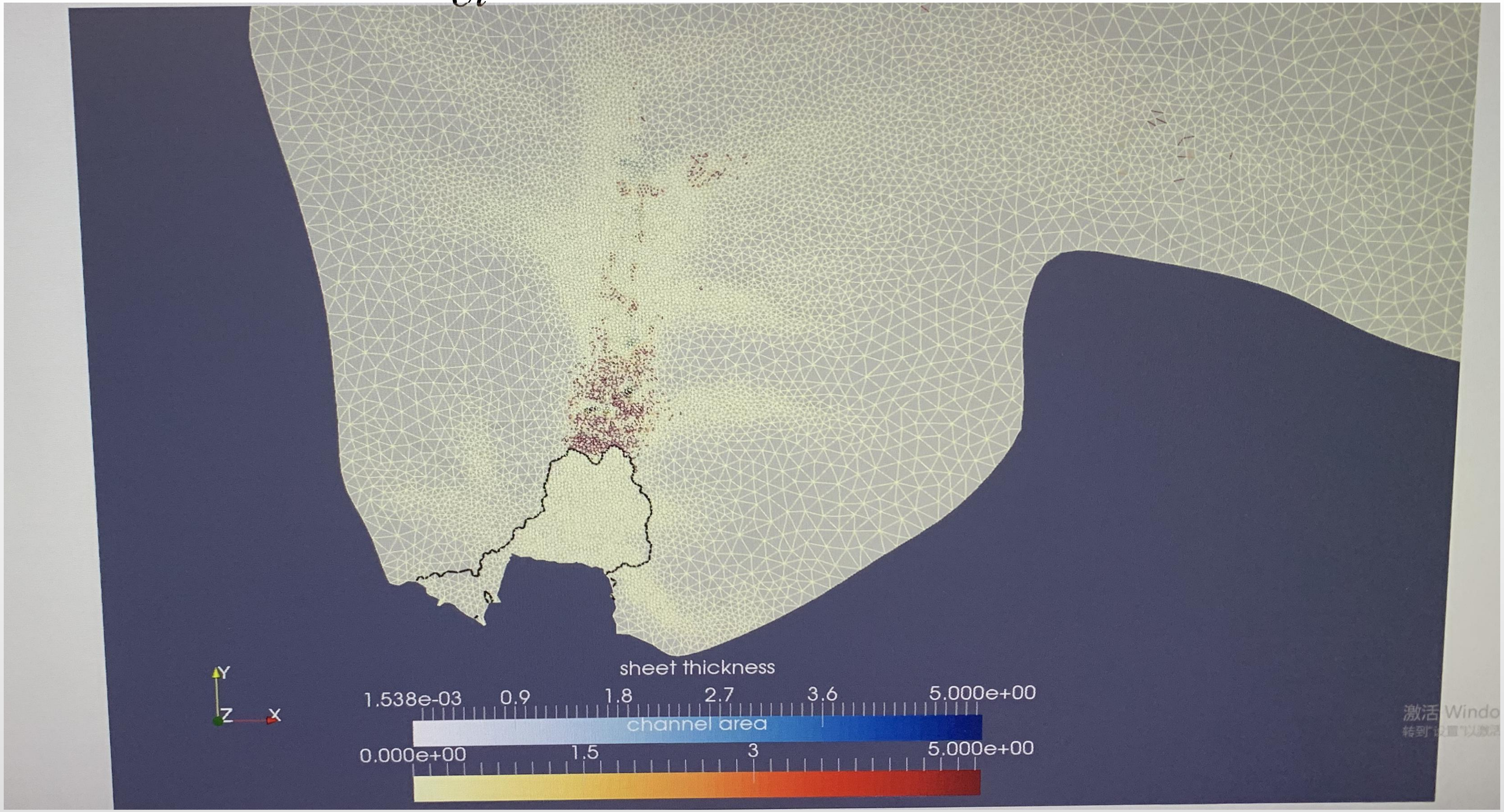
channel evoving

h [0.001,0.1] m

S [0,5] m^2

$$\frac{\partial h}{\partial t} = w - v$$

$$\frac{\partial h}{\partial t} + \nabla q = m$$



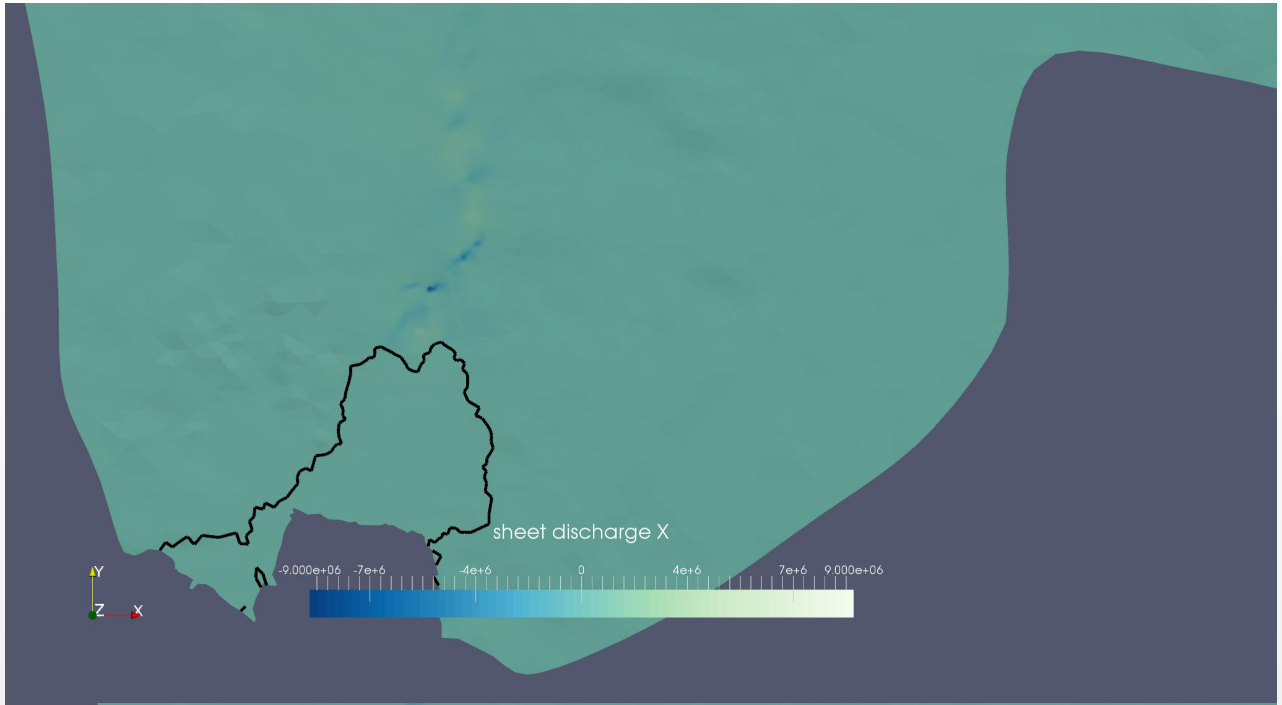
Results

800days

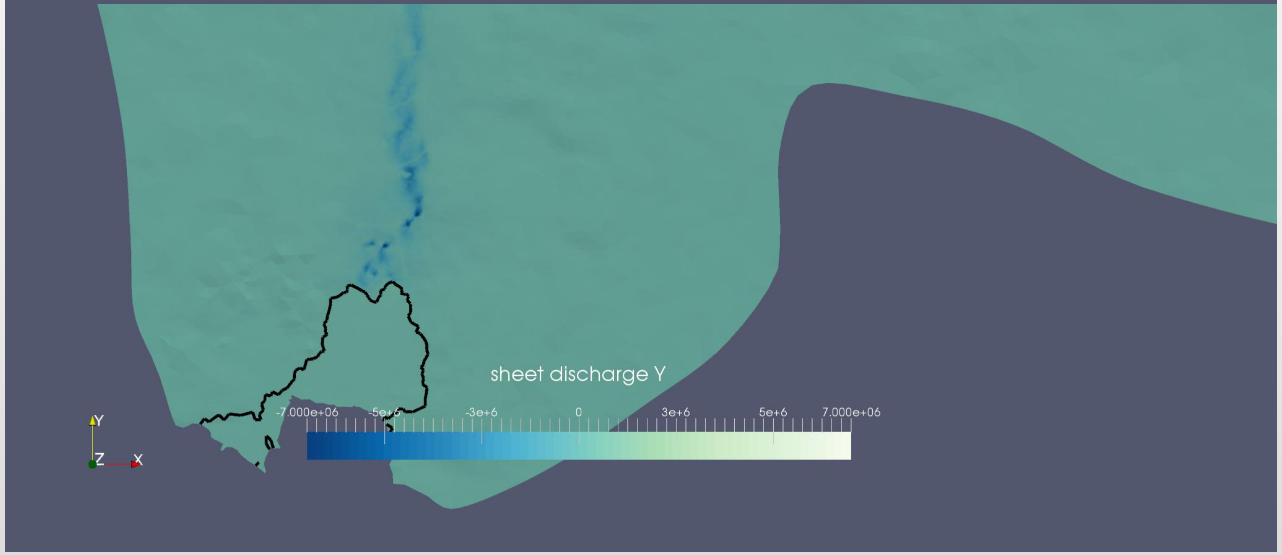
$$q = -\kappa h^{\alpha} \left|\nabla \phi\right|^{\beta-2} \nabla \phi$$

$$\frac{\partial h}{\partial t} + \nabla q = m$$

qx



qy



- High water pressure consistent with more sheet discharge.

Outlook

- Need further realistic water input to drive Glads from inversion model
- Need more results analysis and sensitivity tests
- Couple model with ice dynamics, give more realistic and detailed results.
- Couple to ocean model to simulate ocean circulation.

Thank you!

Yufang Zhang

PhD student

Email: 201831490020@mail.bnu.edu.cn

Wechat: xiaoyyzyf