Ocean Cryosphere Exchanges in Antarctica:

Impacts on Climate and the Earth System

Delivery of basal ice sheet melt flux

Milestone MS7

OCEAN:ICE is co-funded by the European Union, Horizon Europe Funding Programme for research and innovation under grant agreement Nr. 101060452 and by UK Research and Innovation
https://ocean-ice.eu/

Document information: Milestone report

Work Package	WP3 Ice sheet mass balance, forcing and dynamics
Milestone no. & title	MS7 Delivery of basal ice sheet melt flux WP3
Lead Beneficiary	PP14 – Northumbria University at Newcastle
Author	PP14- Northumbria University at Newcastle (UNN): Hilmar Gudmundsson
Contributors	All partners involved
Reviewer	PP1 - Danmarks Meteorologiske Institut (DMI): Chiara Bearzotti, Ruth Mottram
Version	Final
Due date	30 September 2023
Delivery date	14 September 2023
The image on the cover sheet	Photo Credit: Angie Agostino/AgostinoCreative on Pixabay

Table of contents

Means of verification of the achievement of the milestone:

Data on melt-water production has been made available and uploaded to the data servers. A detailed description of the new water-routing algorithm has been attached to this report, and circulated among project partners.

Work Performed

The work performed involved modelling basal meltwater production from the Antarctic Ice Sheet to the Southern Ocean. As ice slides over the bed, heat is generated and becomes available for basal melt. The initial task was to provide an estimate of the resulting water production. This is a non-trivial problem because it involves estimating both basal sliding velocities and basal drag, and can only be done by first performing a model inversion to estimate basal properties Once this has been done, a further objective is to establish a methodology for routing the resulting water production towards the grounding lines.

We have already produced new maps of basal melt water production, which we arrived at by performing a pan-Antarctic inversion of surface velocities. We found that the key areas of water production are those upstream of Pine Island and Thwaites glaciers.

Furthermore, we have made significant progress in developing a new and novel framework for routing the resulting water towards the grounding lines. A special emphasis has been placed on make sure that the resulting modelling framework is mass-conserving and the results mesh-independent. This issue of mesh-independence has been mentioned repeatedly in previous publications, but we know believe we have overcome this issue.

Looking ahead, we will perfume further model inversions at higher global mesh resolution. We have already performed such high-resolution inversions for the critical areas of the West Antarctic Ice Sheet.

A significant obstacle has been the inability to hire a suitable postdoc. We advertised the position twice, and the second time did find a highly skilled candidate. However, shortly before the planned starting date, the candidate declined the offer due to changes in personal circumstances. Hence, we have not been able to find a postdoc. As a results, the work originally planned was done by the UNN PI (Hilmar Gudmundsson).

Development of a subglacial water-routing algorithm:

A new water-routing algorithm has been developed and tested. It is based on solving

$$\partial_t h_w + \nabla \cdot (q_w) = a_w$$

where h_w

is a water-film thickness, q_w, the water flux vector, and $a_w$the subglacial water production. The water flux vector is related to the potential $\nabla\phi$ as follows

$$q_w = -k h_w \nabla \phi$$

where k is related to the (effective) permeability, and

$$\phi = g(\rho_w - \rho_i)B + g(\rho_w - \rho_i)h_w + g\phi_i s - N$$

where B, s, ρ_i, ρ_w, is the bedrock, upper surface, ice, and water densities, respectively, and N is the effective water pressure. The system is subject to the water-film thickness constraint

$$h_w > 0$$

The system was solved using finite elements, and a fully implicit non-linear solver with respect to h_w based on Newton-Raphson iteration. The water-film thickness constraint was fulfilled using the active-set algorithm.

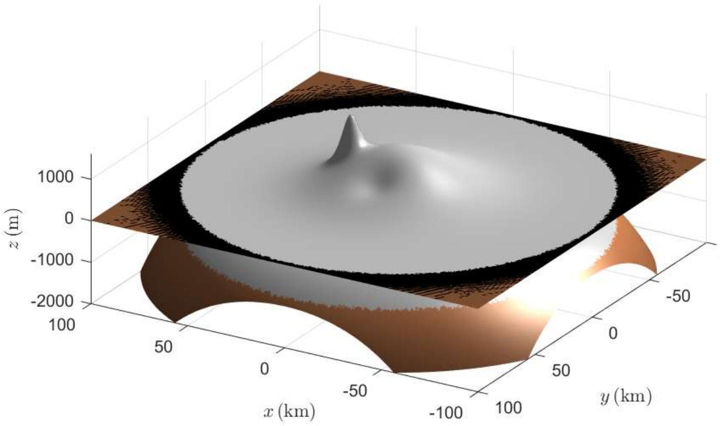

Fig 1: *Synthetic test geometry. The bedrock geometry includes retrograde sections and peaks and troughs in both upper and lower surfaces.*

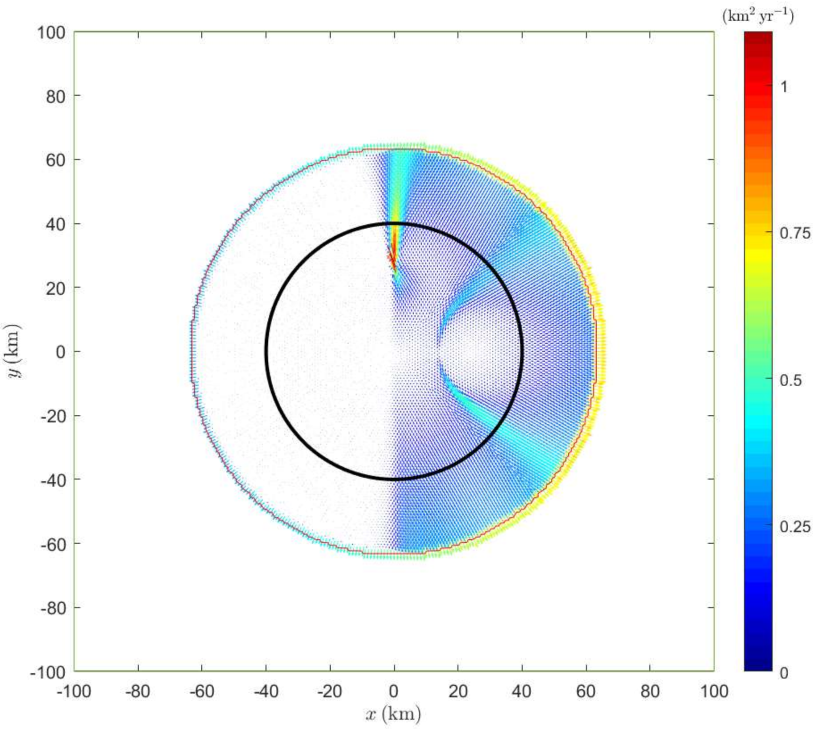

Fig 2: *Modelled water fluxes based on geometry in Fig. 1. The arrows indicate flux vectors. The thick back circle is the flux gate for which the fluxes shown in Fig. 3 were calculated.*

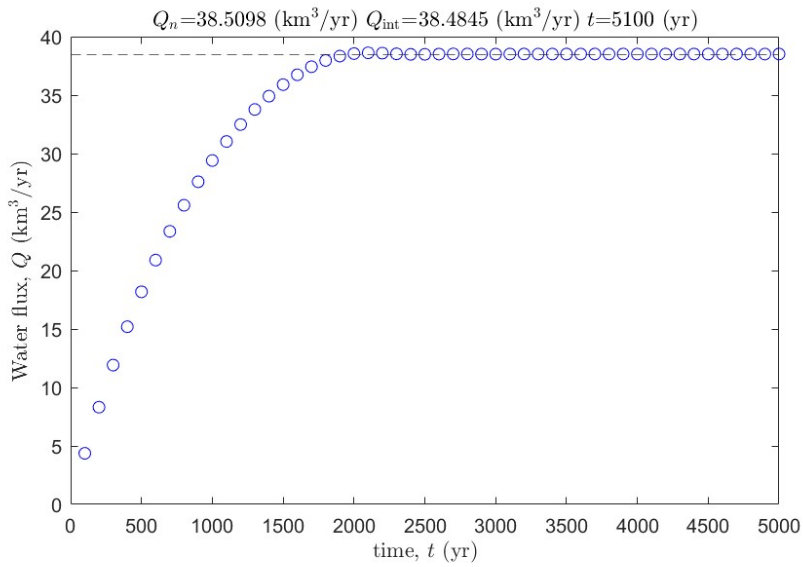

Fig 3: *Example of a test where total flux through a flux gate is compared to total integrated basal water production upstream of the flux gate. In steady state these numbers must be equal. The figure shows excellent agreement between calculated flux values (circles) and total integrated updates melt-water production (dashed line). The analytical steady state value is* $\pi r^2\ a$*, where* r *is the radius of the flux gate shown in Fig 2, and* $a = 10\ m/yr$ *is the prescribed meltwater production.*

Basal meltwater production of Antarctic:

New pan-Antarctic surface-to-bed inversions were performed using the ice-sheet model *Úa*. We found that Pine Island and Thwaites glaciers produce up to 1 to 1.2 m/yr of meltwater over significant areas upstream of their respective grounding lines. This is several orders of magnitude larger than the often-quoted value of about 1 mm/yr (e.g. see the widely-used textbook for glaciology *Physics of Glaciers*, Paterson).

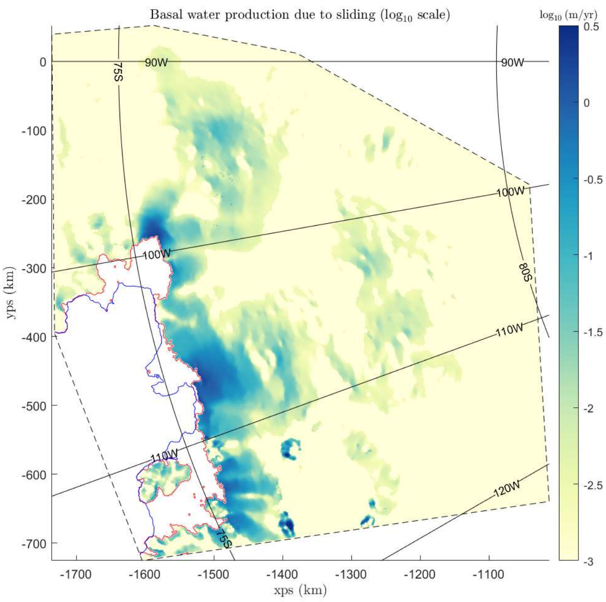

Fig 4: *Meltwater production for section of the West Antarctic Ice Sheet. Note the logarithmic scale. This area showed the largest meltwater production of all the sectors of the Antarctic Ice Sheet. Not that this is meltwater production due to basal sliding alone. While we have not routed this water production specifically yet, it is clear that the water will be routed directly downstream to the respective grounding lines.*

We have produced maps of basal ice-sheet water productions for Antarctica. Our next step will be do work with our partners within the project and estimate the most appropriate spatial resolution. Currently our products use spatially variable resolution as is typical of ice-flow modellers that can use unstr4uctued computational grids.

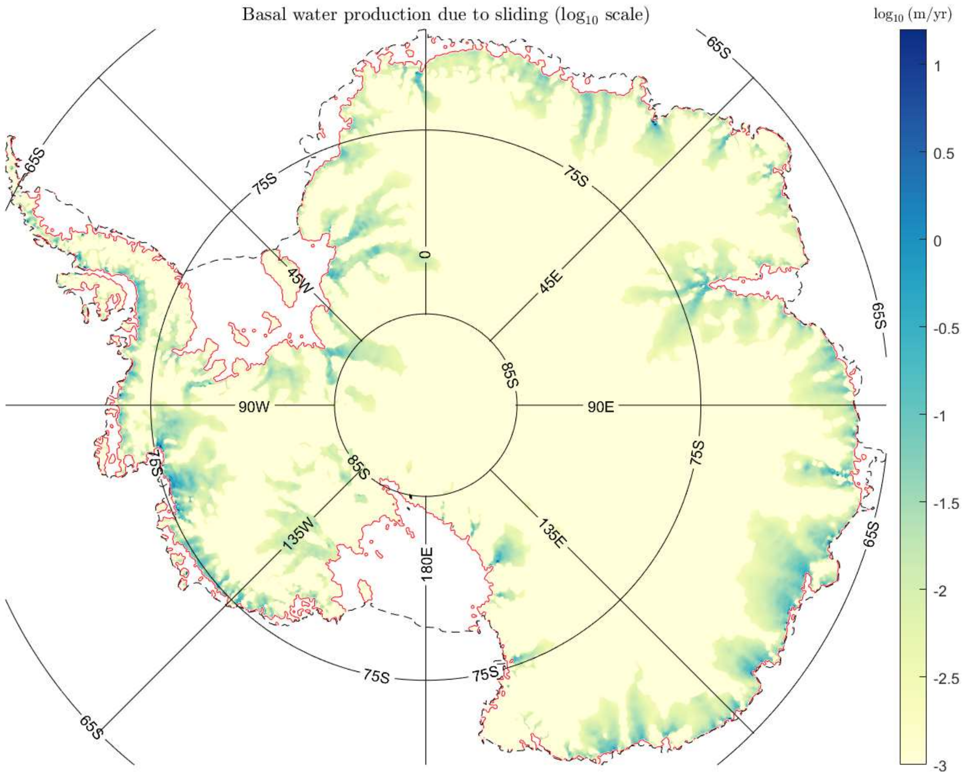

Fig 6: *Meltwater production for the whole of Antarctic Ice Sheet. Note the logarithmic scale. This results was based on performing a surface-to-bed velocity inversion for the basal slipperiness, and then calculating the generated heat flux generated through basal sliding.*

So far, our results have been obtained using Weertman sliding law, which is the most-commonly used sliding law in ice-sheet modelling. However, we can easily product further products using other types of sliding laws should that be of interest to the community. Having said that, although our modelling framework can provide such products, the model runs nevertheless take considerable amount of preparation, and further progress will depend on our ability to hire a postdoc.