Visco-elastic ice-flow model

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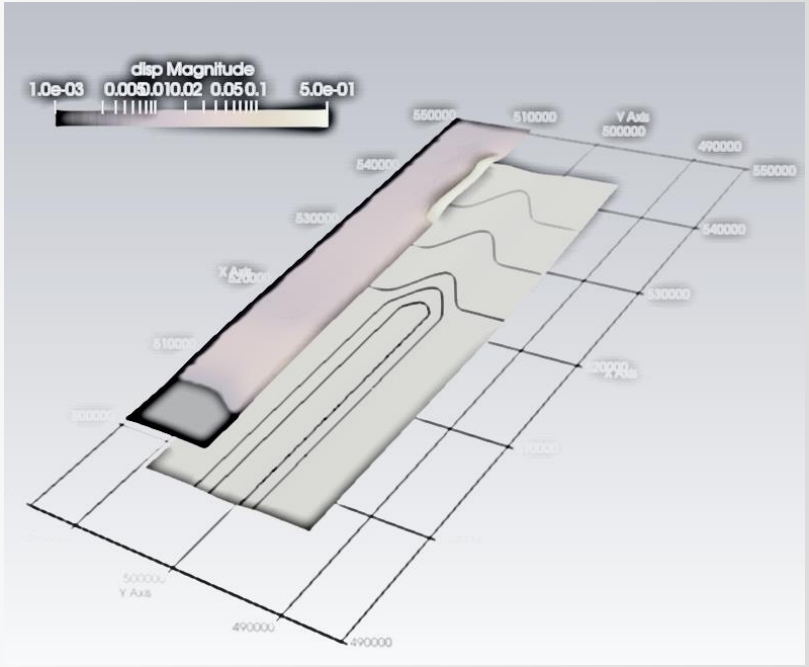
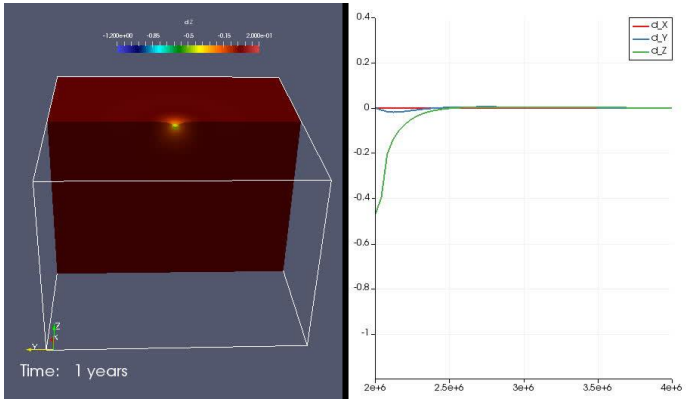


Visco-elastic ice-flow model



- Visco-elastic Maxwell model
- Introduction of visco-elastic stress (P. Wu, 2004)

$$\nabla \cdot \boldsymbol{\tau} = \rho \mathbf{g} \qquad \frac{\partial \boldsymbol{\tau}}{\partial t} = \frac{\partial \boldsymbol{\tau}_0}{\partial t} - \frac{\mu}{\eta}(\boldsymbol{\tau} - \Pi \mathbf{1}) \qquad \boldsymbol{\tau}_0 = \Pi \mathbf{1} + 2\mu\boldsymbol{\epsilon}$$

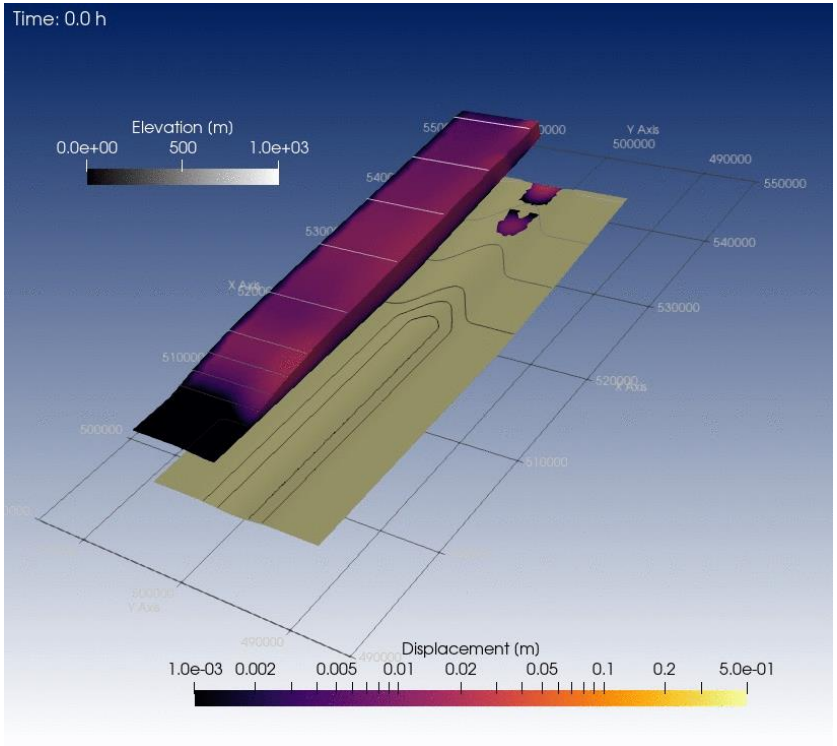
  - At the same time, we introduce pressure Π to enable incompressibility
  - Effective viscosity, $\eta(\dot{\epsilon})$, expressed as shear thinning (Glen) using time derivatives of deformation (strain), $\dot{\epsilon} = \frac{\partial \epsilon}{\partial t}$
  - Mind, the factor: $\frac{\mu}{\eta} = 1/t_m$ (large viscosity → dominating elasticity)

Zwinger, T., Nield, G. A., Ruokolainen, J., and King, M. A.: A new open-source viscoelastic solid earth deformation module implemented in Elmer (v8.4), Geosci. Model Dev., 13, 1155–1164, https://doi.org/10.5194/gmd-13-1155-2020, 2020.

Visco-elastic ice-flow model

- Elmer FE-modelling environment 
- Implementation of visco-elastic model inside linear elasticity solver
  - We can only deal with small deformations (in comparison with the dimensions of the glacier)
  - Recently: Shear-thinning viscosity (Glen) is implemented viscosity computed by `EffectiveViscosity` from `Materials.F90`; strain-rate from temporal derivative of deformations
- Contact problem solving variational inequality using residual based method
  - Constraining vertical component using library functionality
  - Currently, with the constraint that we neglect basal sliding during the passage of the jökulhlaup

Results of visco-elastic model



- The current model for Jökulhlaups (GLOFs) under development computes the response of the glacier to a prescribed pressure disturbance that travels downglacier.

A periodic visco-elastic model for crevasses propagation in ice shelves

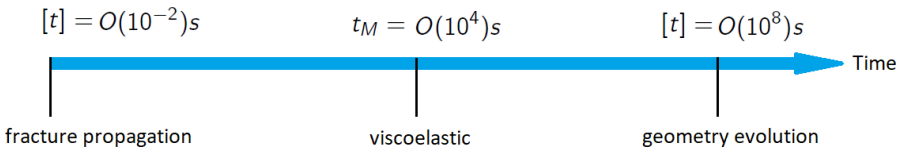
Maryam Zarrinderakht[1], Thomas Zwinger and Christian Schoof

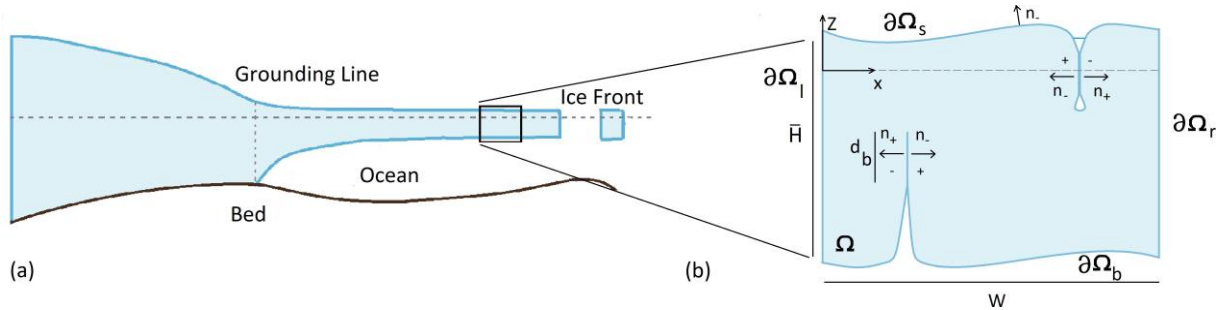
Ph.D., University of British Columbia
Canada

April 24, 2023

Viscoelasticity

Time scale separation:





Propagation criterion

The strength of the stress singularity predicted by the solution of the purely elastic problem is referred to as the **stress intensity factor**, K_I.

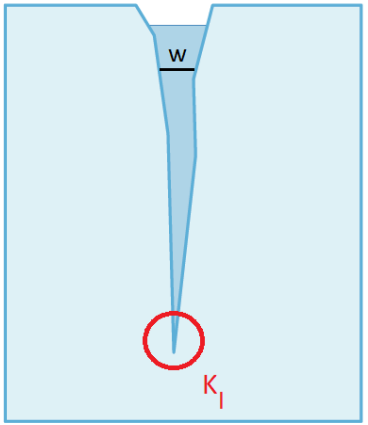
Crack growth occurs when the stress intensity factor reaches a critical value, the **fracture toughness**, K_{Ic}.

$K_I < K_{Ic} \Rightarrow$ crack is stationary

$K_I = K_{Ic} \Rightarrow$ crack propagates

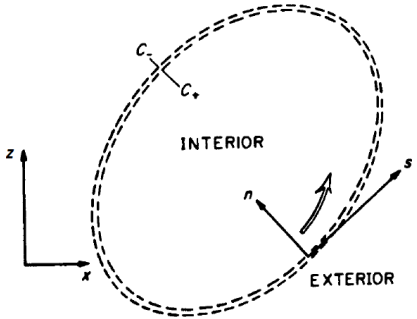
$$\dot{d} = \max\left(-\frac{K_{I,stat} - K_{Ic}}{K_{Ic}K'(0)}, 0\right)$$

Freund (1990)



Numerical Method

Displacement discontinuity boundary integral method [Crouch and Starfield (1983)]



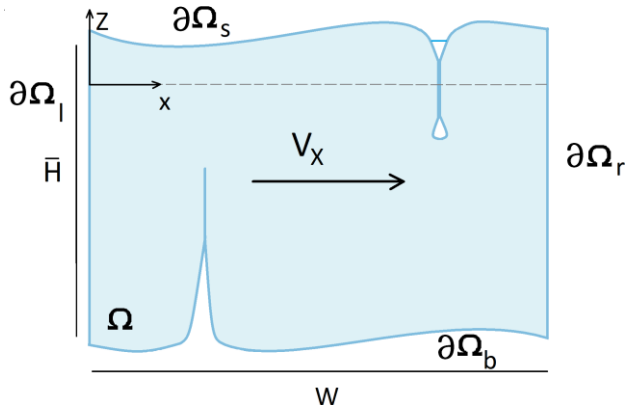
$$\mathbf{DD} = \mathbf{u}^{+} - \mathbf{u}^{-}$$

- Based on the use of a **Green's function**
- Summing the effects of **displacement discontinuities** at the **N** elements on the boundary
- Suitable for crack modeling
- Less expensive compared to the common numerical methods like finite elements

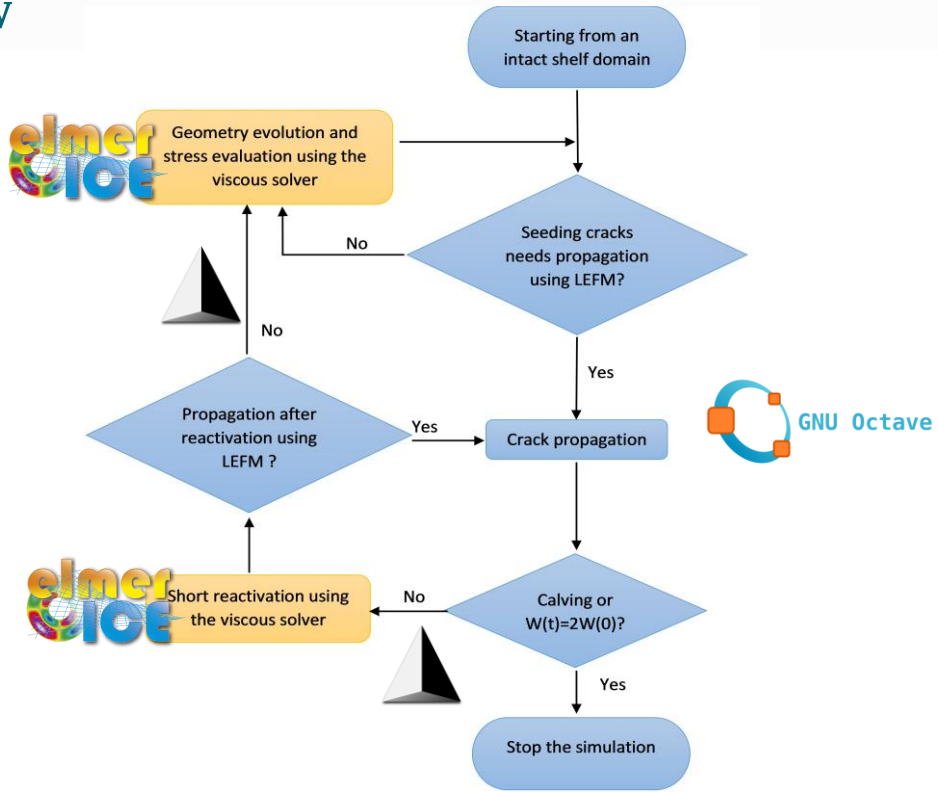
Conducted test cases and reproduced previously reported results by van der Veen's [1998] and Lai et al. [2020].

Governing equations-viscous model

- Full Stokes equations.
- Periodic boundary conditions on stresses.
- Domain stretches in time by the stretching rate V_X and is quasi-periodic on velocities.
- Coupling between viscous flow and elastic fracturing takes the forms of: viscous **geometry**. **update** of the ice, and **pre-existing viscous stress** at the time of fracture initiation.

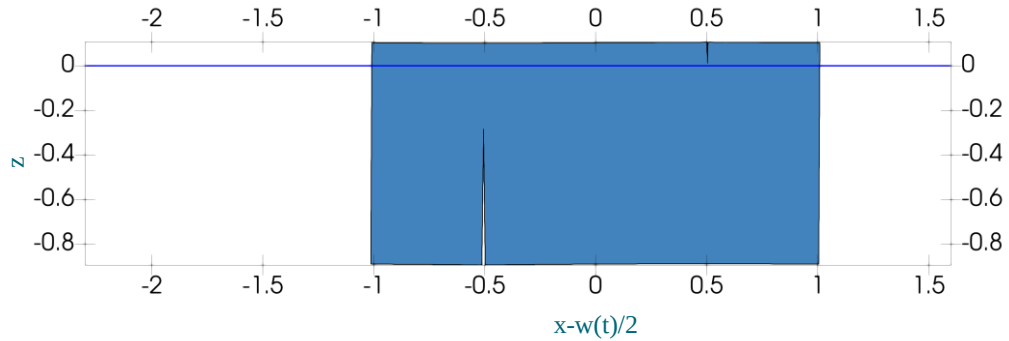


Overview


Starting from an intact shelf domain
Geometry evolution and stress evaluation using the viscous solver
Seeding cracks needs propagation using LEFM?
No
No
Yes
Propagation after reactivation using LEFM ?
Yes
Crack propagation
GNU Octave
Short reactivation using the viscous solver
No
Calving or W(t)=2W(0)?
Yes
Stop the simulation

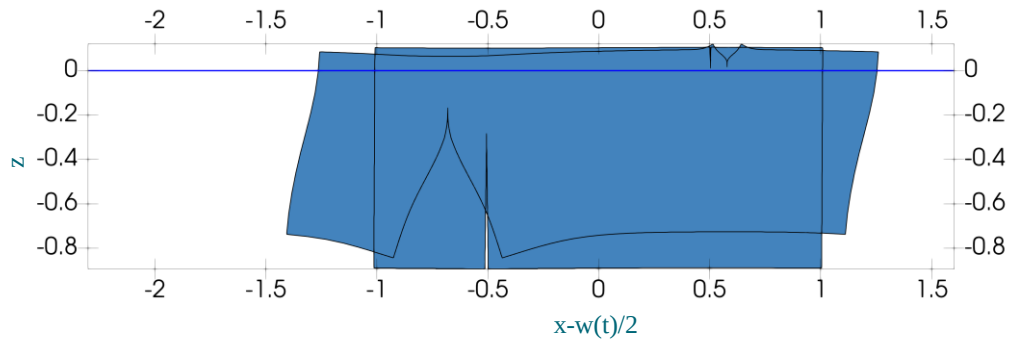
Results

Surface crevasse calving



Results

Surface crevasse calving



Results

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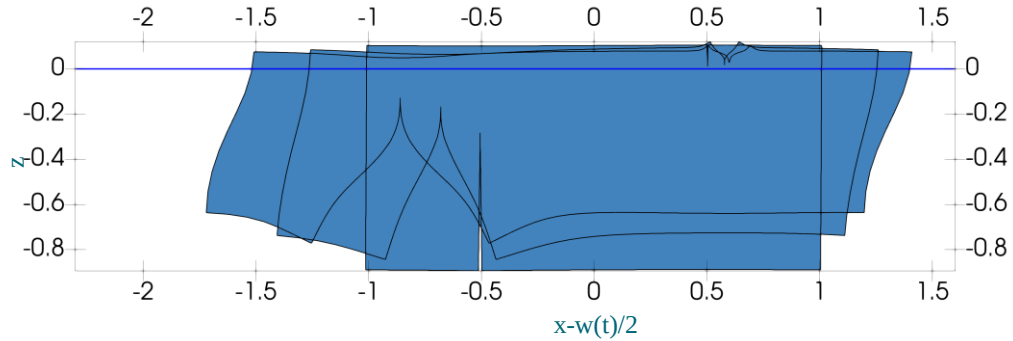
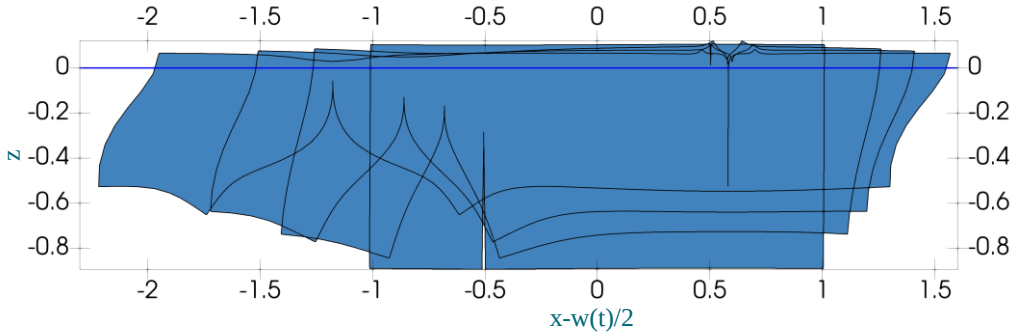
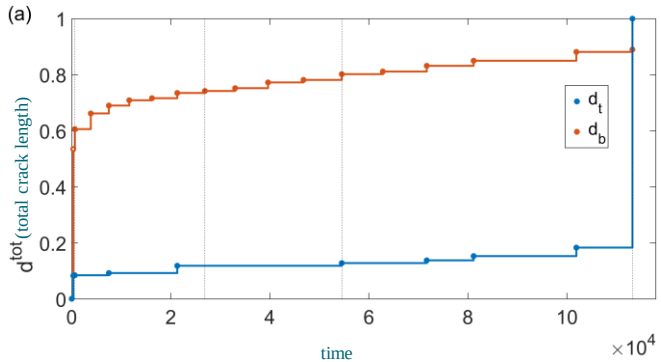
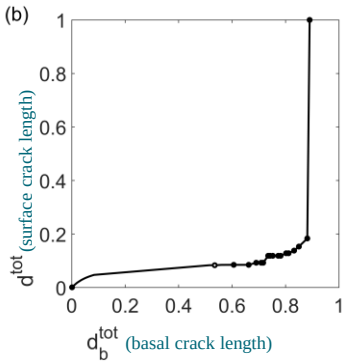


Results

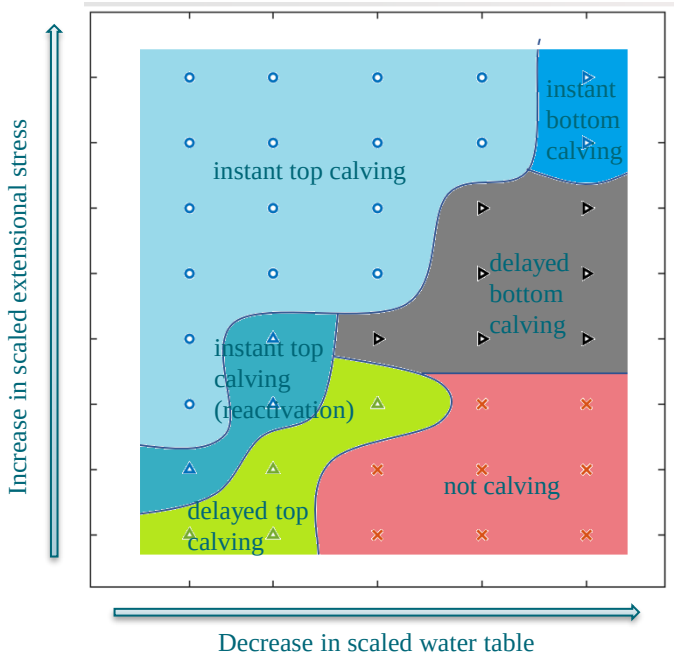
Surface crevasse calving







Calving types



Summary

Goal: Multiple basal and surface crevasses in **a viscoelastic domain**
Cracks deform viscously and forcing changes in time

Knowledge gaps covered:

- Developed a visco-elastic model that captures cracks geometry evolution in time
- Categorized different calving types
- Investigated the effect of controlling parameters

Not limited to tabulated functions for the parallel-sided ice slab with a single branch cut

A useful tool to train a low-dimensional representation calving law for an ice sheet model

Key conclusions:

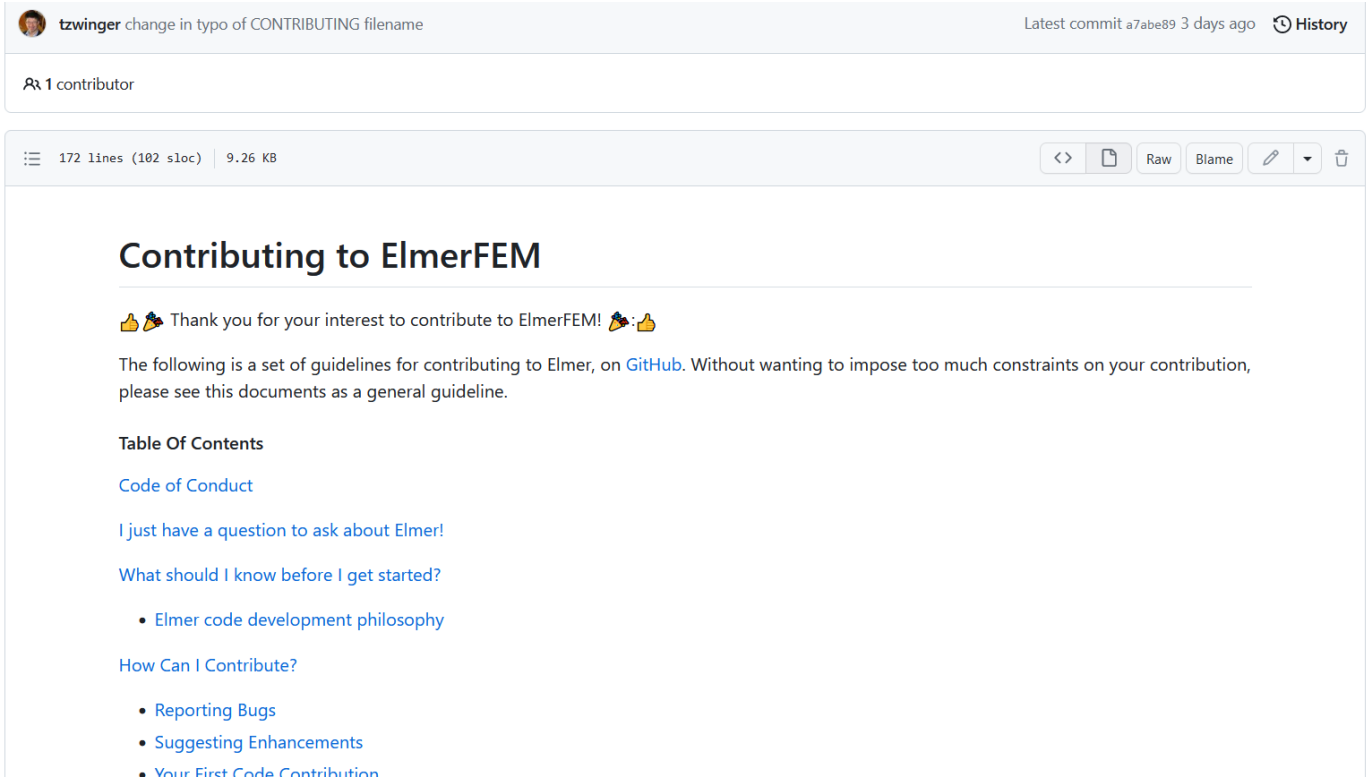
- Purely stress-based calving laws may not robustly describe the calving behaviour and a visco-elastic model is needed

✓ Maryam Zarrinderakht, Christian Schoof, Thomas Zwinger, *A leading-order viscoelastic model for crevasse propagation and calving in ice shelves*, The Cryosphere, Submitted.

Elmer Repository augmentations

- We need/want to make Elmer compliant with SQAaaS (Software Quality Assessment as a Service)
- This is about best practices on how HPC software is organized, tested, deployed
- It also contains certain rules on what has to be included in the repository and how repositories have to be organized
- Next few slides shall pick out what might be of interest – yet, I guess of limited direct impact – to you

Elmer Repository augmentations



tzwinger change in typo of CONTRIBUTING filename — Latest commit a7abe89 3 days ago — History

1 contributor

172 lines (102 sloc) | 9.26 KB — Raw | Blame

Contributing to ElmerFEM

👍🎉 Thank you for your interest to contribute to ElmerFEM! 🎉:👍

The following is a set of guidelines for contributing to Elmer, on GitHub. Without wanting to impose too much constraints on your contribution, please see this documents as a general guideline.

Table Of Contents

Code of Conduct

I just have a question to ask about Elmer!

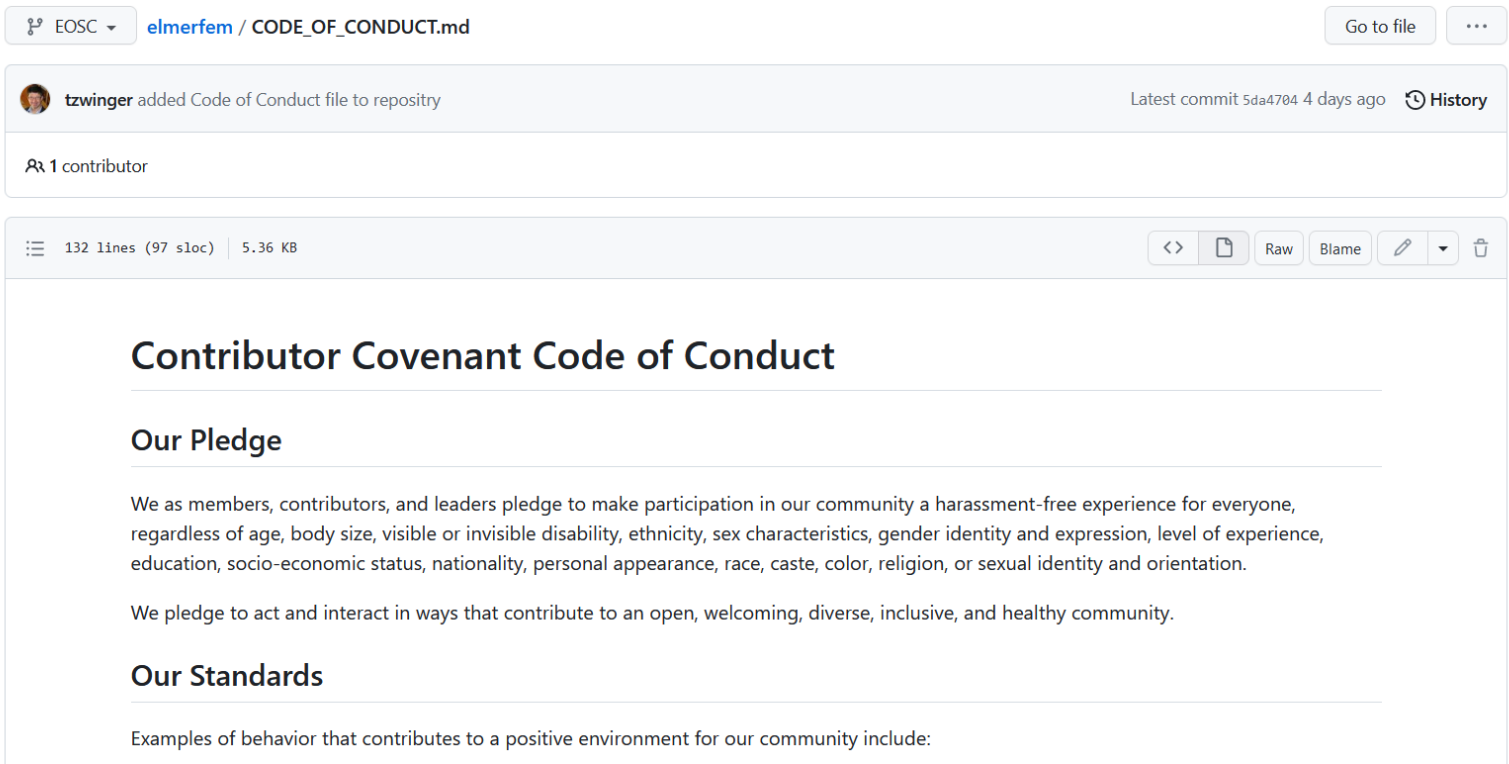
What should I know before I get started?

- Elmer code development philosophy

How Can I Contribute?

- Reporting Bugs
- Suggesting Enhancements
- Your First Code Contribution

Elmer Repository augmentations



Elmer Repository augmentations

- This **Code of Conduct** is adapted from the Contributor Covenant, version 2.1, available at https://www.contributor-covenant.org/version/2/1/code_of_conduct.html.
- Community Impact Guidelines were inspired by Mozilla's code of conduct enforcement ladder.
- For answers to common questions about this code of conduct, see the FAQ at https://www.contributor-covenant.org/faq. Translations are available at https://www.contributor-covenant.org/translations.

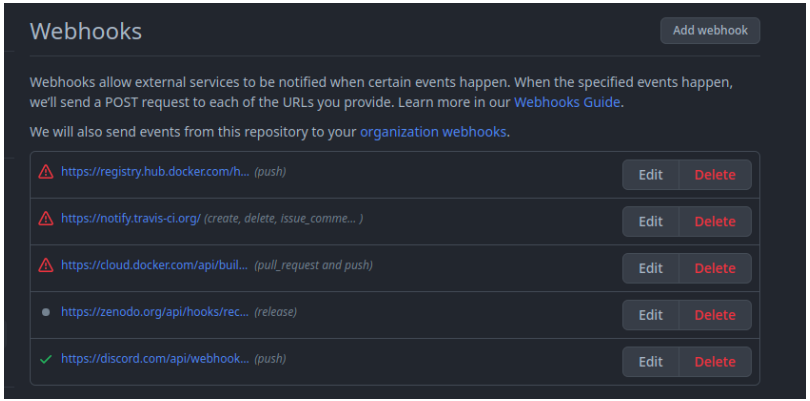
Elmer(/Ice) citeable repository

- Publications often demand DOI's (Digital Object Identifiers) to the used software
- We will need this for Elmer(/Ice)
- We have about 10 publications in average per year – so worst case is that we have 10 copies of Elmer on some DOI augmented repository (e.g., Zenodo)
- What should we do?
  - Everyone does their own citable copy of GitHub repository
  - We (=CSC) take care that citeable DOI is available?

Elmer(/Ice) citeable repository

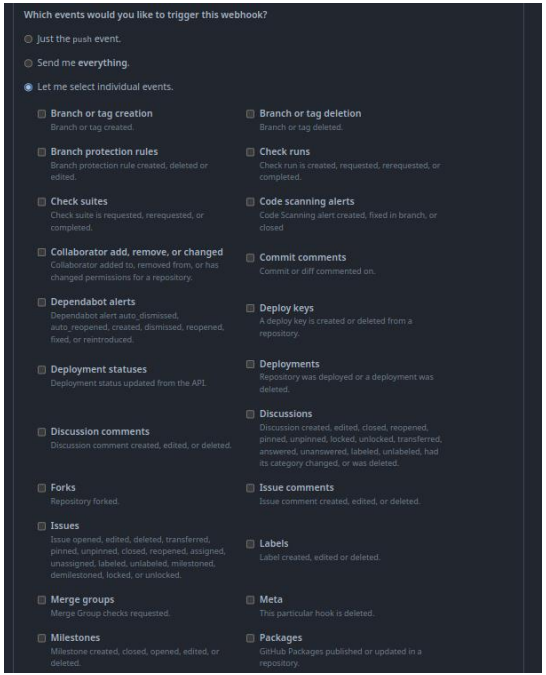
- We (=CSC) take care that citeable DOI is available?
  - We have several hundred commits per year
  - We have about one release every 2 years
- Is it enough to just put releases citeable to Zenodo?
  - Fewer disk-space going to waste
- Or: Should we add a tag to a certain Elmer version used in a paper and make that tag citeable?
  - Don't know whether Zenodo does incremental updates

Elmer(/Ice) citeable repository



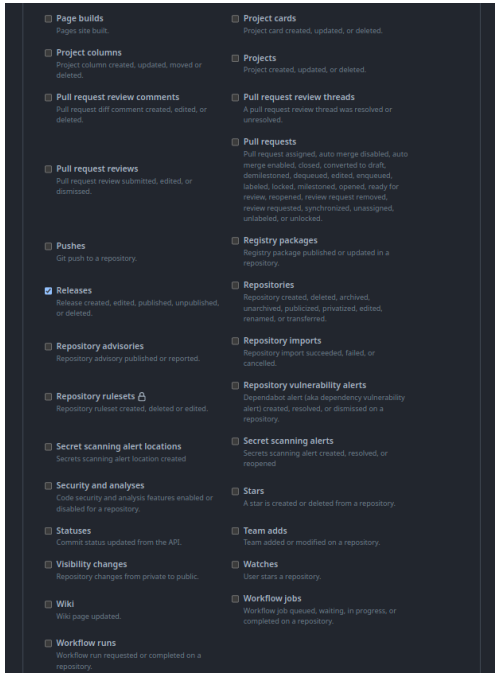
- We already have a Zenodo webhook at place

Elmer(/Ice) citeable repository



- We already have a Zenodo webhook at place
- Possibility to transfer everything
  - Or selectively new tags and branches
  - So, to our understanding we cannot selectively transfer tags to Zenodo

Elmer(/Ice) citeable repository



- We already have a Zenodo webhook at place
- Possibility to transfer everything
  - Or selectively new tags and branches
  - So, to our understanding we cannot selectively transfer tags to Zenodo
- At the moment only Releases
  - but we haven't releases in the GitHub sense, only tagged versions under a dedicated branch – so there's nothing from ElmerFEM GitHub at the moment

Elmer/Ice future plans

- Elmer/Ice is part of an EuroHPC CoE on natural hazards

Funded by the European Union. This work has received funding from the European High Performance Computing Joint Undertaking (JU) and Spain, Italy, Iceland, Germany, Norway, France, Finland and Croatia under grant agreement No 101093038.

ChEESE

- We contribute with GLOFs models and some aspects of calving
- Like for the existing implementation of GPU offloading using AMGX (Nvidia) we want to implement a similar solution for AMD GPUs (LUMI #3 Top500, hosted at CSC)
- We should have possibilities to port and test Elmer(/Ice) on ARM-based HPC installations (like Fugaku, #2 Top500)

MPI/GPU	5	10	20	40
1	Out of memory	11/25 s	27/35 s	AMGX exception
2	8/30 s	13/25 s	14/22 s	46/50 s
4	4/26 s	5/16 s	**6/12 s**	15/20 s

T. Zwinger, J. Ruokolainen & G. Gadeschi, 2020

Open source finite element software
for multiphysical problems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