Elmer/Ice course

27-29 October 2014, IMO, Reykjavik

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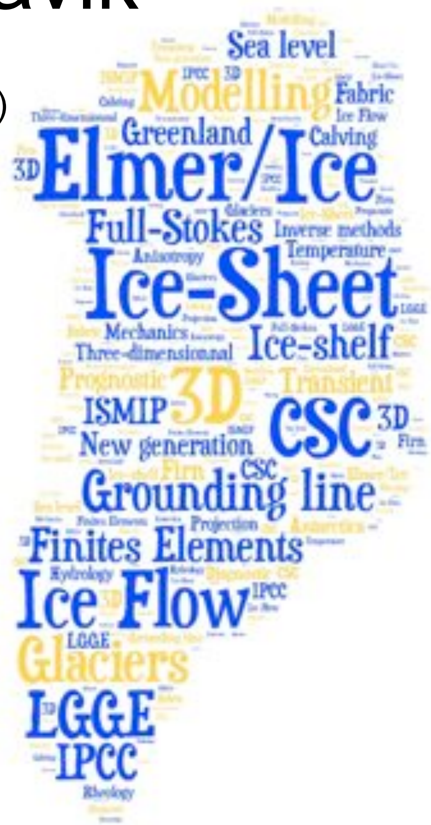


Introduction

(1) LGGE - Grenoble – France
(2) CSC – IT Center for Science Ltd. – Espoo - Finland

Program

Monday October 27

9:00-9:15 Welcome by T. Johannesson
9:15-9:45 Introduction (OG)
9:45-10:00 coffee break
10:00-12:00 Toy flow-line model – part 1 (TZ)
12:00-13:00 lunch (on own expenses)
13:00-14:30 Toy flow-line model – part 2 (TZ)
14:30 – 15:00 coffee break
15:00-17:00 Toy flow-line model – part 3 (TZ)
19:00 Dinner (on own expenses)

Tuesday October 28

9:00-10:00 Tête Rousse Introduction (OG)
10:00-10:15 User Defined Functions (TZ)
10:15-10:30 coffee break
10:30-11:00 TR Setup - Step 1 (OG)
11:00-12:00 TR Diagnostic – Step 2 (OG)
12:00-13:00 lunch
13:00 – 14:30 TR prognostic (Step 3) (OG)
14:30 – 15:00 coffee break
15:00- Open discussion - Questions

Wednesday October 29

9:00- Set up of your own Elmer/Ice simulations (OG)

Short history of Elmer/Ice (not anymore so short...) 1/2

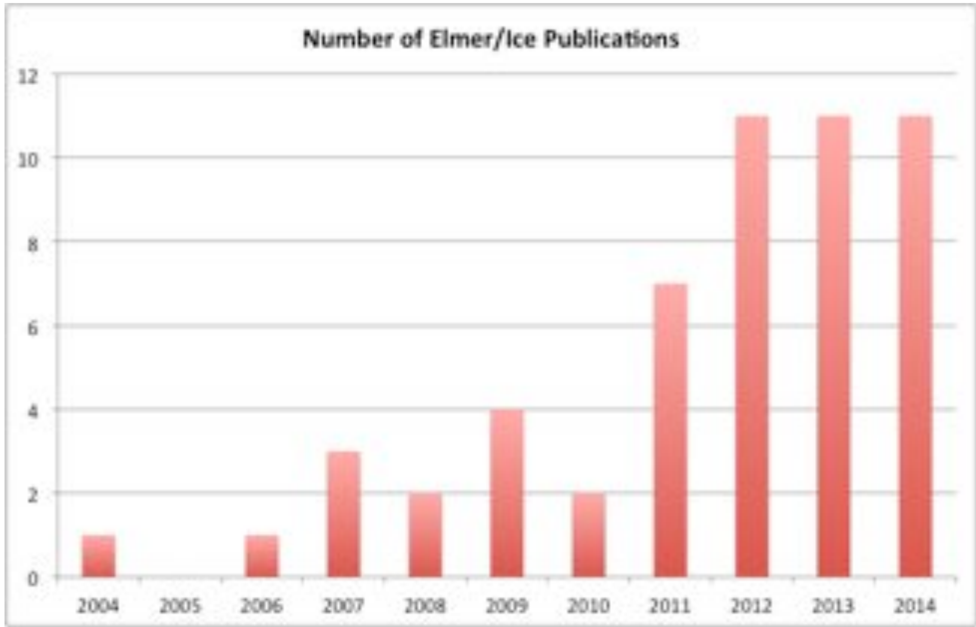
- ✓ EGU2002: OG was looking for a 3D FE code to model the flow of strain-induced anisotropic polar ice – meet TZ
- ✓ March 2003: OG visited CSC for few days: AIFlowSolver and FabricSolver partly implemented
- ✓ August 2005 – One year visit of OG at CSC (Anisotropy, cavity, glaciers, ISMIP tests, ...)
- ✓ February 2008 – First Elmer/Ice Course - Grenoble
- ✓ June 2011 – SVALI summer school – Finland
- ✓ 2012 – Elmer/Ice has now a website, a logo and a mailing list
- ✓ 2012 – Elmer/Ice comes as a Elmer Package – New wiki
- ✓ 2012 – Elmer/Ice course at UBC/SFU
- ✓ 2013 – Elmer/Ice courses at Univ. Washington and Univ. Alberta
- ✓ 9 April 2013 – First Elmer/Ice users meeting – EGU 2013

Short history of Elmer/Ice (not anymore so short...) 2/2

- ✓ May 2013 – Second SVALI summer school – Finland
- ✓ 2-day beginner Elmer/Ice course, 3-4 Oct. 2013, LGGE, Grenoble, France
- ✓ 3-day Elmer/Ice advanced workshop, 4-6 Nov. 2013, CSC, Espoo, Finland
- ✓ April 2014 – Second Elmer/Ice users meeting – EGU 2014

and now in Iceland...

A growing community



Since few years, first authors are not only anymore only from CSC or LGGE...

Elmer/Ice website

http://elmerice.elmerfem.org/

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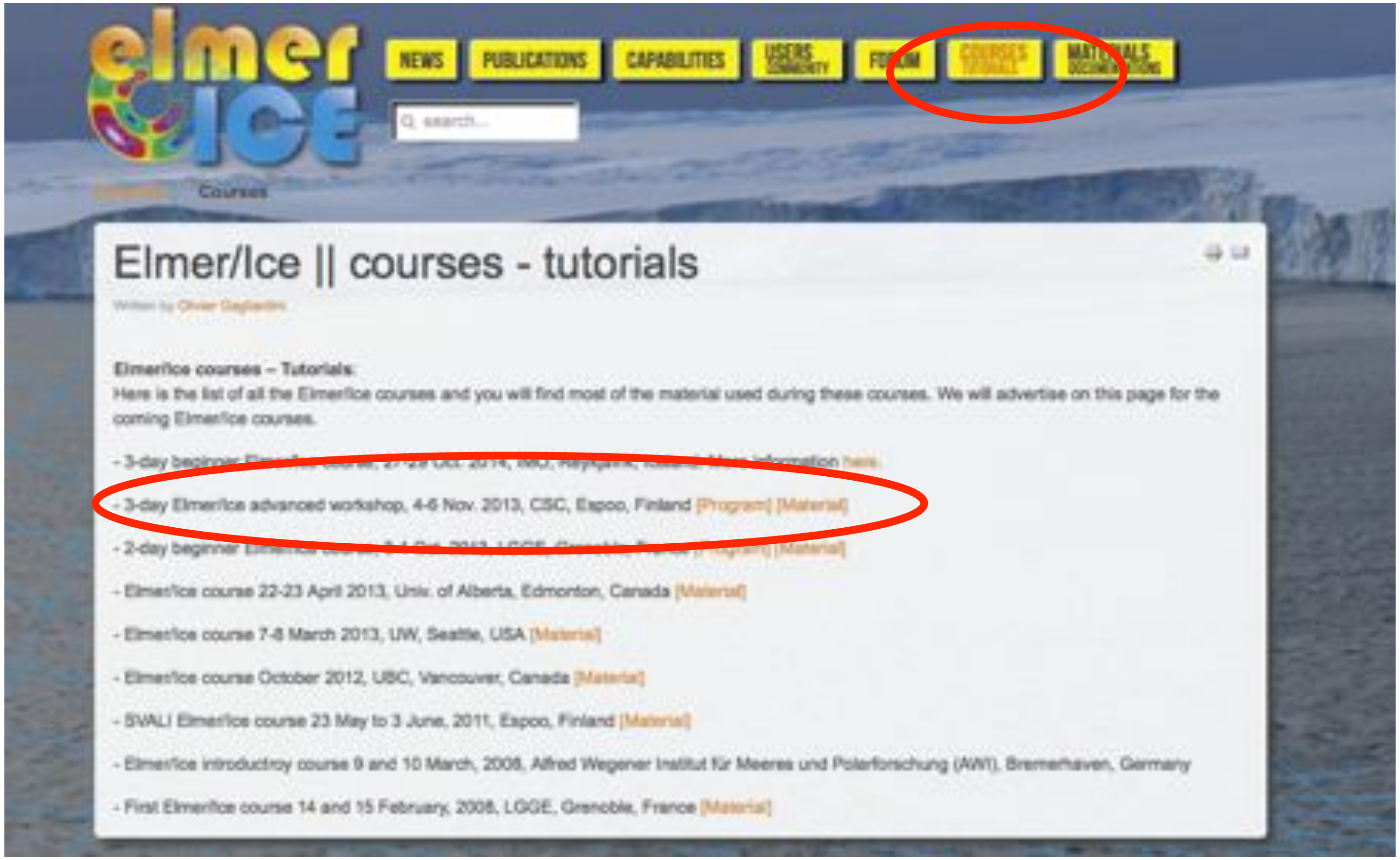
http://elmerice.elmerfem.org/



Much more material available than what we will present today

Elmer/Ice wiki http://elmerice.elmerfem.org/wiki/doku.php

[[start]] ELMER/ICE WIKI

Trace: • start

Show pagesource | Recent changes | Sitemap | Login

Search

- Home
- Problems
- Solvers
- User Functions
- Meshing Tools
- Tips and Tricks
- Meetings and Courses
- Compilation of Elmer/Ice
- Links

Welcome to the Elmer/Ice wiki

Elmer is an open-source, parallel, Finite Element code, mainly developed by the CSC-IT Center for Science Ltd. in Finland. Elmer/Ice builds on Elmer and includes developments related to glaciological problems. On this page you will find documentation and examples of the various solvers and user functions developed for **glaciological** applications using Elmer/Ice. Building Elmer/Ice on top of an existing Elmer installation is explained in the Compilation Section.

The Problems Section presents the various categories of glaciological problems that can be solved using Elmer/Ice.

The Solvers Section and the User Functions Section describe the glaciology related solvers and user functions, respectively, that can be used to solve these problems.

Tools that can be used to mesh glacier and ice-sheet geometry are presented in the Meshing Section.

The Tips and Tricks Section gives some useful demo of MATC, Post-treatments of results and more.

The Courses Material Section contains presentation as well as material proposed in the framework of the Elmer/Ice courses dispensed since 2008.

Some useful links are given in the Links Section.

Scientific publications presenting glaciological applications with Elmer/Ice are listed in the Elmer/Ice website.

Elmer/Ice mailing list

To subscribe to the Elmer/Ice list *elmerice@elmerfem.org*, just sent an email to *majordomo@elmerfem.org*, with in the body the text:

subscribe elmerice

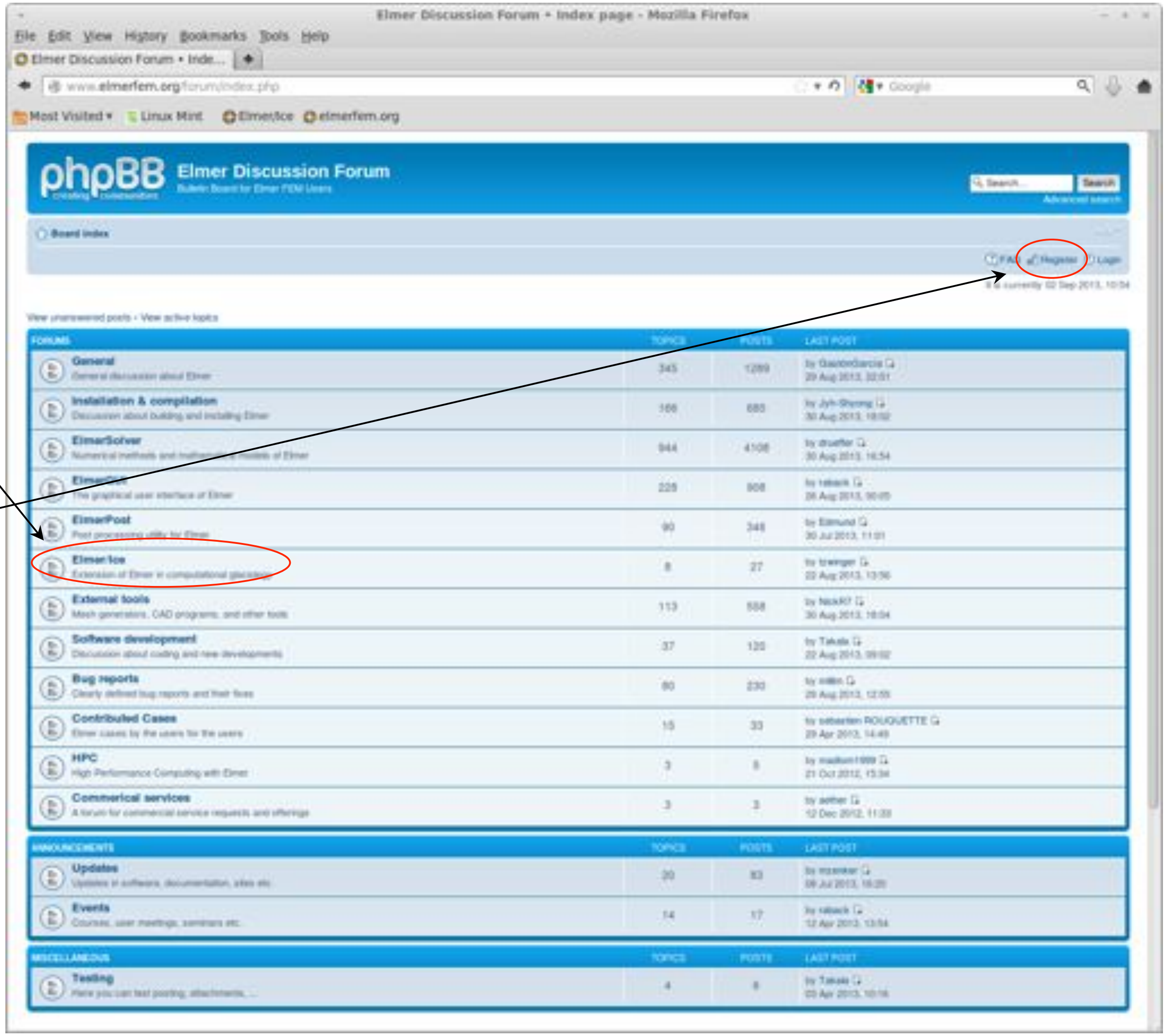
If you do not know how to use mailing lists run by majordomo you may sent a mail with "help" in the message body.

Elmer/Ice Forum

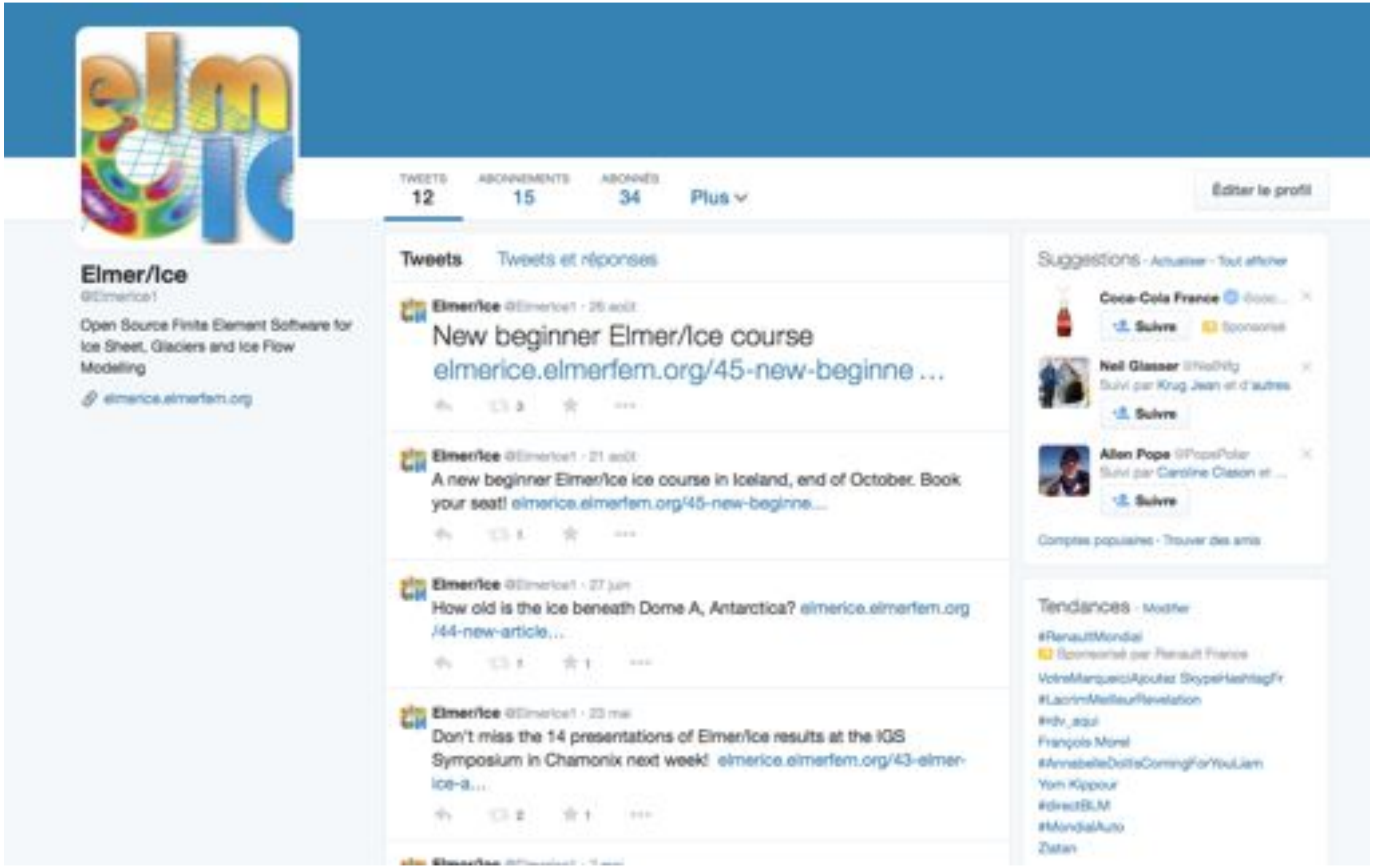
Under

http://www.elmerfem.org :

- Go to **Elmer Forum:** find answers on all aspects of Elmer
- Click on **Elmer/Ice** link: find answers specific to Elmer/Ice
- To get access: **Register** in upper right corner



Elmer/Ice on Twitter @ElmerIce1



Important links (summary)

Elmer at CSC (documentation, how to install, …)
http://www.elmerfem.org/
http://www.csc.fi/english/pages/elmer

Elmer Forum
http://elmerfem.org/forum/

Elmer/Ice webpage
http://elmerice.elmerfem.org/

Elmer/Ice wiki
http://elmerice.elmerfem.org/wiki/doku.php?id=start

Elmer/Ice in relation to Elmer

Elmer is an open-source, parallel, Finite Element code, mainly developed by the CSC-IT Center for Science Ltd. in Finland.

Elmer is constantly developed towards improved performance, utilizing international projects such as FP7 PRACE and HPC Europa2.

Elmer/Ice builds on Elmer and includes developments related to glaciological problems.

Elmer/Ice includes a variety of dedicated solvers and user functions for glaciological applications and its development is supported by various groups and funding...

Elmer/Ice Package

All the Solvers, User Functions and Meshers presented on the Elmer/Ice wiki comes as an Elmer/Ice package on the Elmer distribution (in `elmerice/`)

To compile the package, go in `elmerice/` directory

```
$ make compile
$ make install
```

To use it (in the SIF file):

```
Procedure = File "ElmerIceSolvers" "NameSolver”
```

or

```
Procedure = File "ElmerIceUSF" "NameUSF”
```

Important notices

In this course

- We will not teach finite element method (can give references)

- We will focus on some technical aspects of using Elmer for glaciological applications

What we expect from this course ?

- giving you a kick-start in Elmer/Ice
- some fruitful collaborations to begin

Elmer/Ice capabilities

- **Full-Stokes** equations but also SIA, SSA, diagnostic or transient
- Various **rheologies** (Glen's law, firn/snow and anisotropic flow laws)
- **Temperature** solver accounting for the upper limit at melting point
- **Transport equations** for density, fabric, age …
- **Post-processing solver** for strain-rate and stress fields
- Various **friction laws** (Weertman, effective-pressure dependent friction law)
- **Free surface evolution** as a contact problem (Grounding line dynamics)
- **Inverse methods** (linear adjoint and Arthern and Gudmundsson 2010 methods)
- Tools or plug-ins for **meshing** (YAMS, external and internal extrusion of footprint)
- **Highly parallel** Stokes solver
- **Basal hydrology** (2 approaches, one in the distribution)
- **Calving** (3 approaches, not yet in the distribution)
- **Damage mechanics** (not yet in the distribution)

Elmer/Ice applications

53 publications using Elmer/Ice since 2004

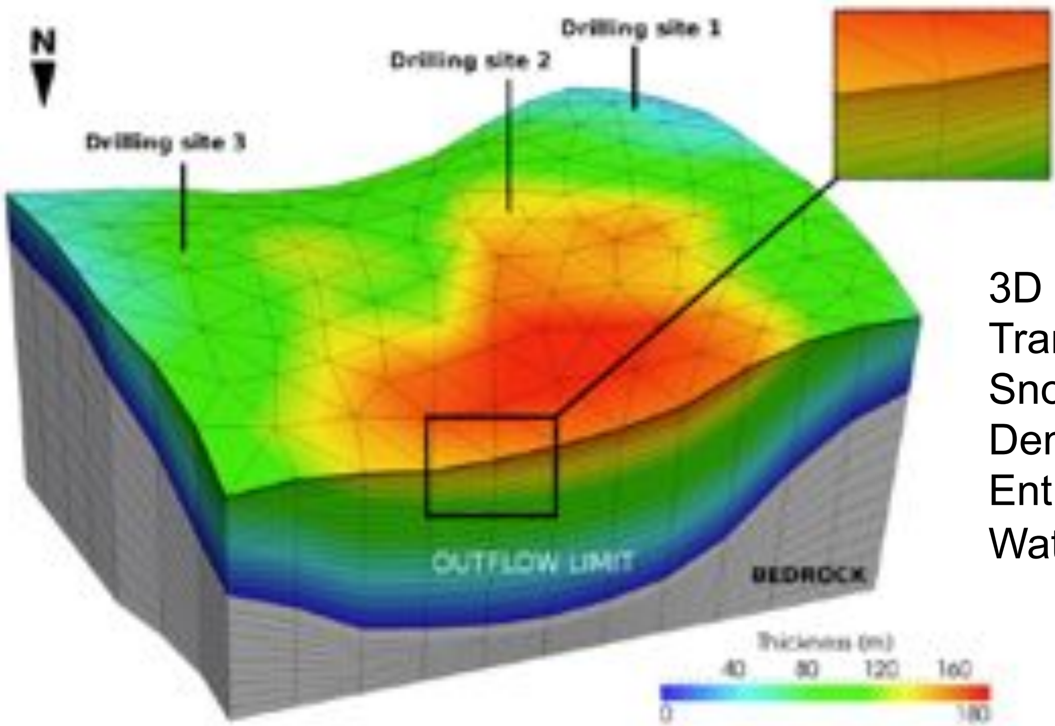
- ISMIP, MISMIP, MISMIP-3d
- 2D and 3D Grounding line dynamics
- Ice2sea and SeaRISE contributions (Greenland)
- Inverse methods (Variegated, Vestfonna ice-cap, GIS)
- Flow of anisotropic ice
- Glaciers

- 9 cited references including results from Elmer/Ice in the 5th IPCC report

see http://elmerice.elmerfem.org/publications

Few recent examples (2014 publications)

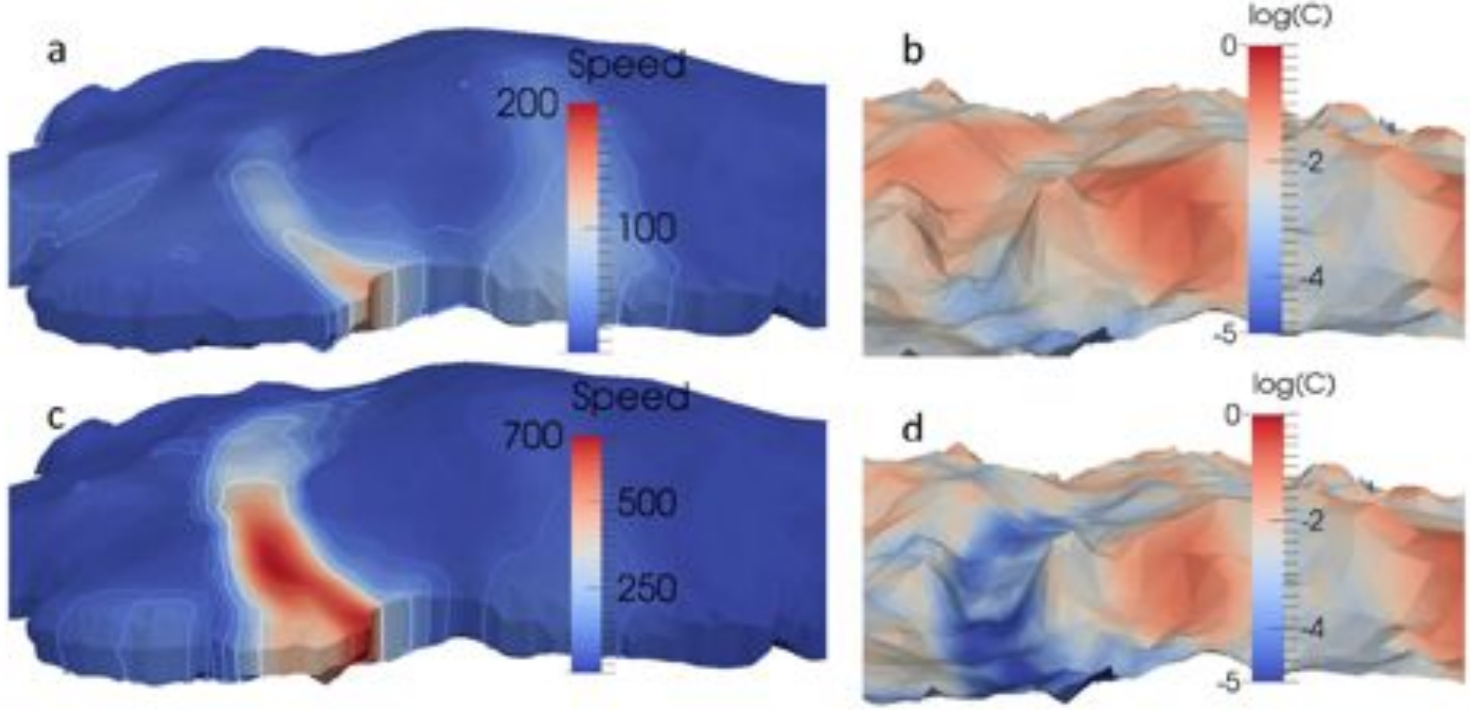
Gilbert, A., O. Gagliardini, C. Vincent, and P. Wagnon, 2014. A 3-D thermal regime model suitable for cold accumulation zones of polythermal mountain glaciers, J. Geophys. Res. Earth Surf., 119, doi: 10.1002/2014JF003199.



3D application
Transient
Snow/firn rheology
Densification
Enthalpy (Temperature/water contents)
Water percolation and refreezing

Few recent examples (2014 publications)

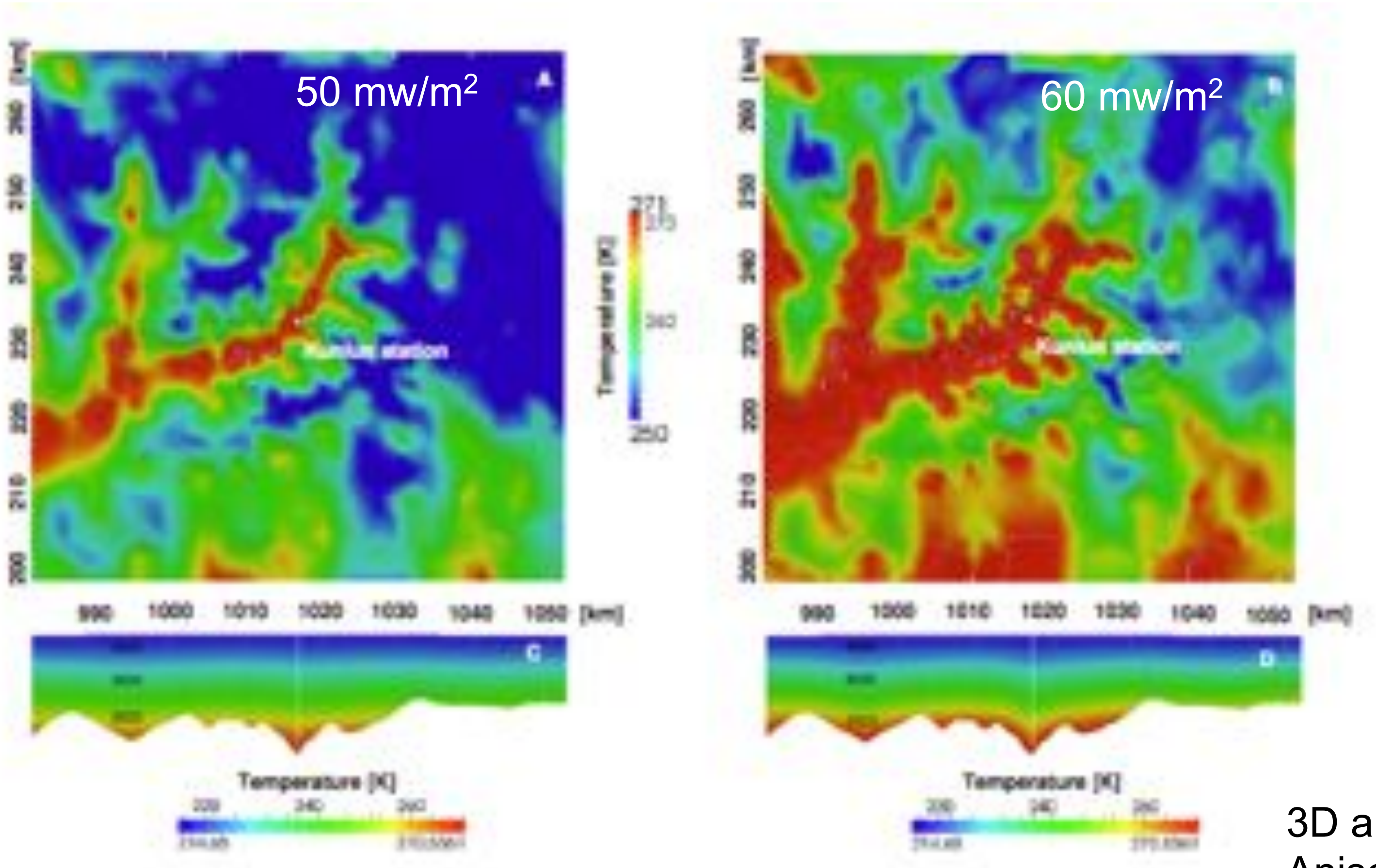
Gladstone, R., M. Schäfer, T. Zwinger, Y. Gong, T. Strozzi, R. Mottram, F. Boberg, and J.C. Moore, 2014. Importance of basal processes in simulations of a surging Svalbard outlet glacier, The Cryosphere, 8, 1393-1405, doi:10.5194/tc-8-1393-2014



3D application
Diagnostic/Transient
Inverse methods
Temperature

Few recent examples (2014 publications)

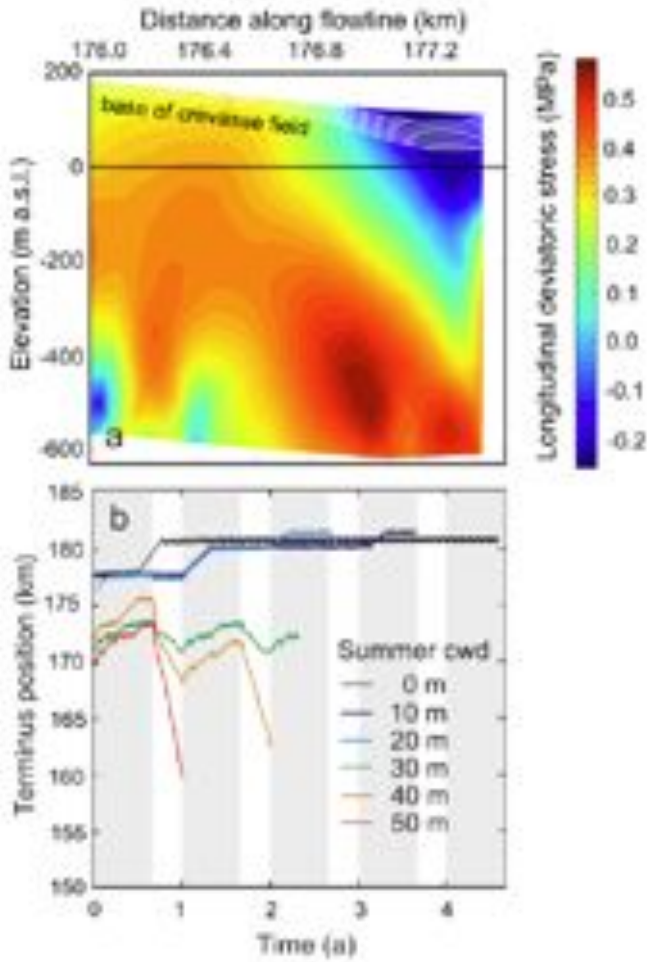
Sun, B., Moore, J. C., Zwinger, T., Zhao, L., Steinhage, D., Tang, X., Zhang, D., Cui, X., and Martín, C., 2014. How old is the ice beneath Dome A, Antarctica?, The Cryosphere, 8, 1121-1128, doi:10.5194/tc-8-1121-2014.



3D application
Anisotropic ice rheology
Temperature

Few recent examples (2014 publications)

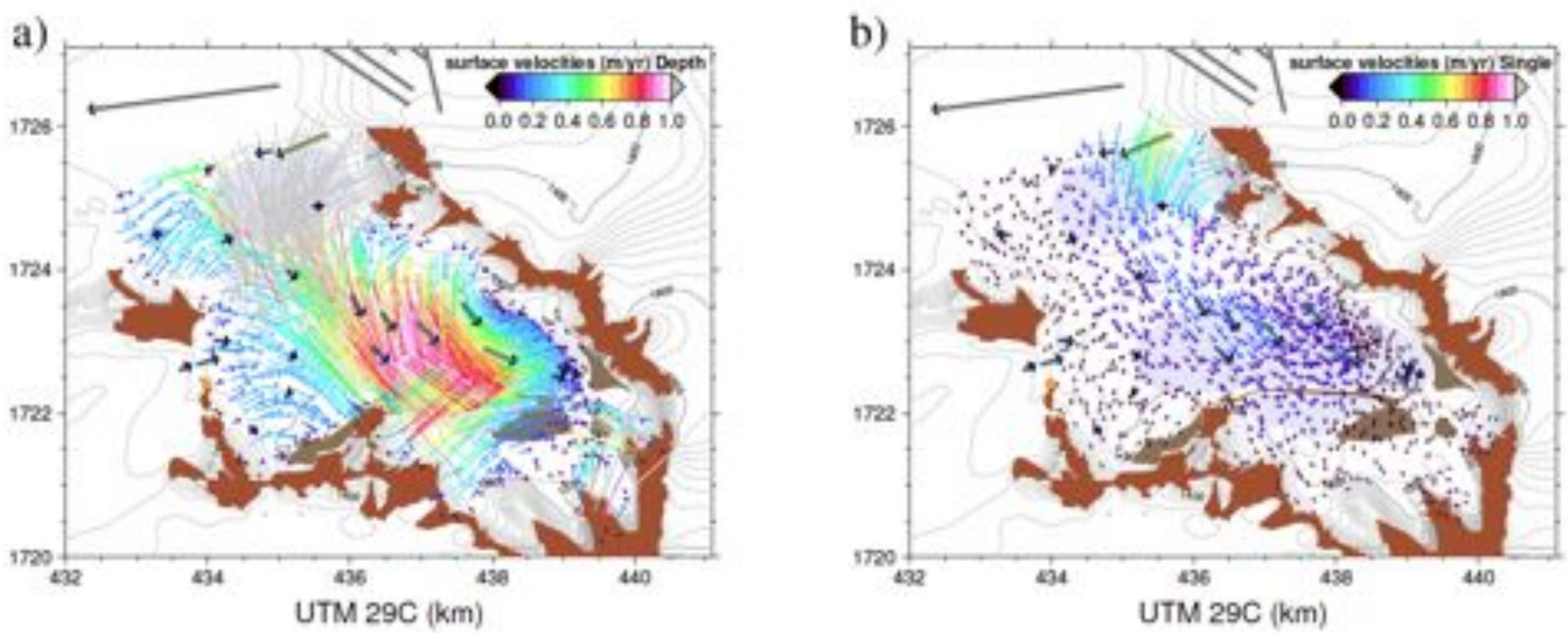
Cook, S., I.C. Rutt, T. Murray, A. Luckman, T. Zwinger, N. Selmes, A. Goldsack, and T.D. James, 2014. Modelling environmental influences on calving at Helheim Glacier in eastern Greenland, The Cryosphere, 8, 827-841, doi:10.5194/tc-8-827-2014



2D flow line application
Transient
Calving

Few recent examples (2014 publications)

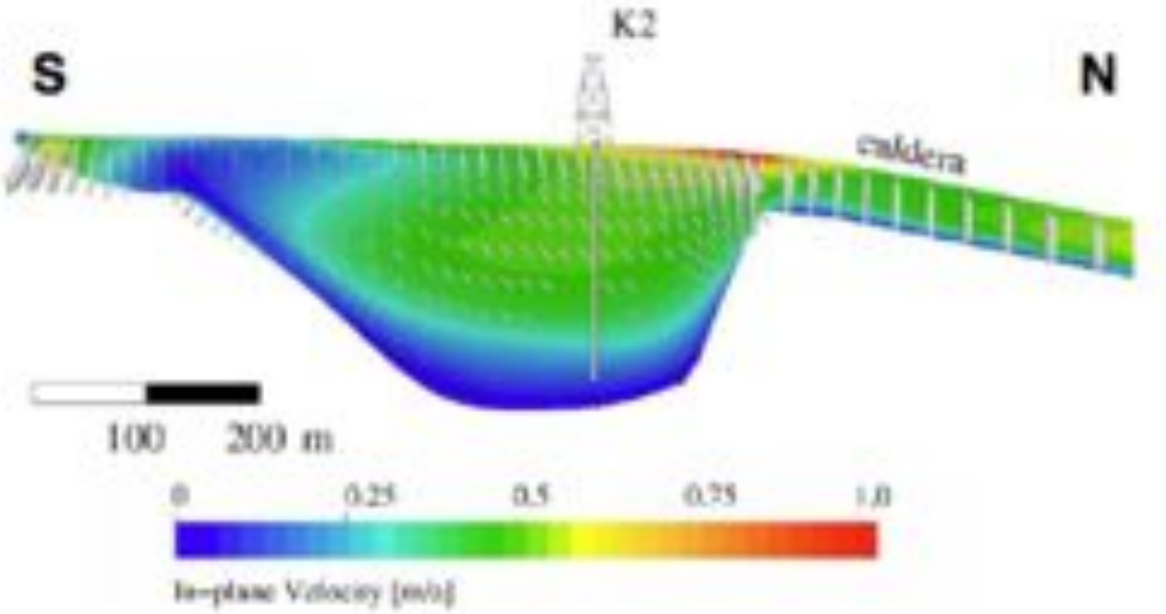
Zwinger, T., M. Schäfer, C. Martín, and J.C. Moore, 2014. Influence of anisotropy on velocity and age distribution at Scharffenbergbotnen blue ice area, The Cryosphere, 8, 607-621, doi:10.5194/tc-8-607-2014



3D application
Diagnostic
Anisotropic ice rheology

Few recent examples (2014 publications)

Sato, T., T. Shiraiwa, R. Greve, H. Seddik, E. Edelmann and T. Zwinger, 2014. Accumulation reconstruction and water isotope analysis for 1736–1997 of an ice core from the Ushkovsky volcano, Kamchatka, and their relationships to North Pacific climate records, Clim. Past, 10, 393-404, doi: 10.5194/cp-10-393-2014



3D application
Diagnostic
Snow/firn rheology

Few recent examples (2014 publications)

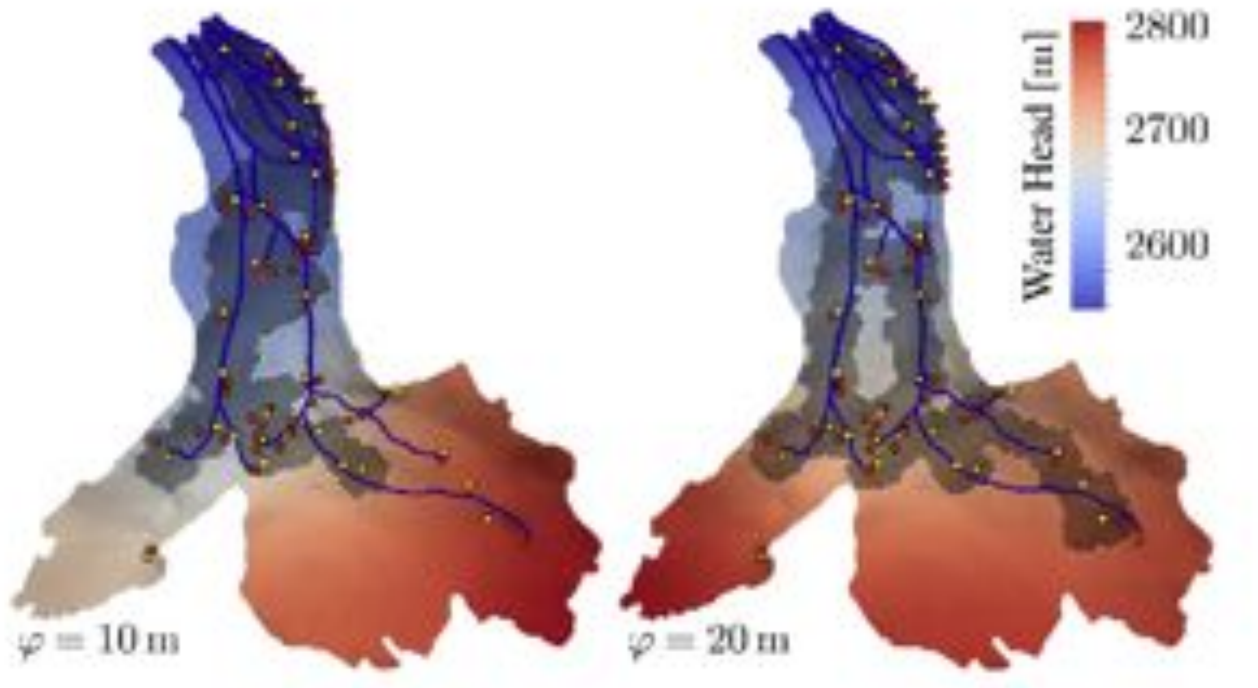
Edwards, T. L., X. Fettweis, O. Gagliardini, F. Gillet-Chaulet, H. Goelzer, J.M. Gregory, M. Hoffman, P. Huybrechts, A.J. Payne, M. Perego, S. Price, A. Quiquet and C. Ritz, 2013. Effect of uncertainty in surface mass balance–elevation feedback on projections of the future sea level contribution of the Greenland ice sheet, The Cryosphere, 8, 195-208, doi:10.5194/tc-8-195-2014.

	CISM	Elmer/Ice	GISM-HO	GISM-SIA	GRISLI	MPAS
PHYSICS						
Stokes equations	HO (P11, L11, E12)	Full	HO (F11, F13)	SIA	Hybrid SIA-SSA	HO (D10)
DERIVATION OF ICE TEMPERATURE						
Spin-up simulation	Quasi-SS; fixed geom. (B13)	One g–ig cycle with SICOPOLIS (G97)	Two g–ig cycles; IT rescaled to obs. thick.	Two g–ig cycles; IT rescaled to obs. thick.	Quasi-SS; fixed geom. (B13)	Quasi-SS; fixed geom. (B13)
Spin-up SAT	E09, constant	E09, constant	Two g–ig cycles, evolving	Two g–ig cycles, evolving	E09, constant	E09, constant

3D application (whole Greenland)
Transient
Inverse methods (Spin-up)
SMB from RGCM outputs

Few recent examples (2014 publications)

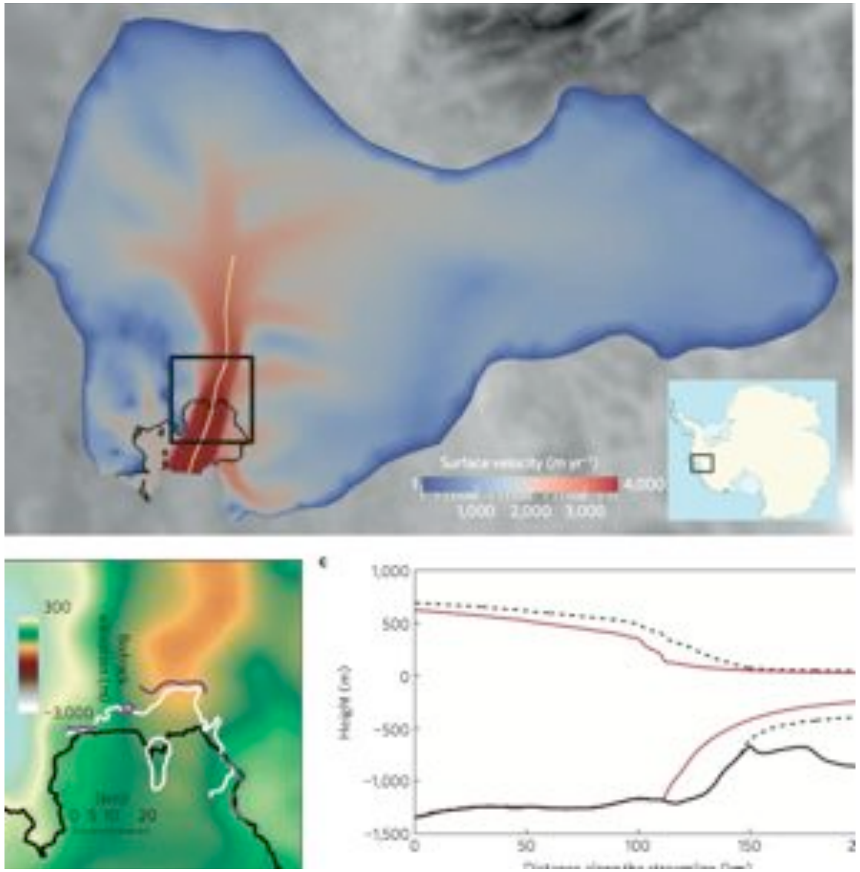
de Fleurian, B., O. Gagliardini, T. Zwinger, G. Durand, E. Le Meur, D. Mair, and P. Råback, 2014. A double continuum hydrological model for glacier applications, The Cryosphere, 8, 137-153, doi:10.5194/tc-8-137-2014



3D application
Transient
Basal hydrology
Coulomb friction law

Few recent examples (2014 publications)

Favier, L., G. Durand, S. L. Cornford, G. H. Gudmundsson, O. Gagliardini, F. Giller-Chaulet, T. Zwinger, A. J. Payne and A. M. Le Brocq, 2014. Retreat of Pine Island Glacier controlled by marine ice-sheet instability, Nature Climate Change, doi:10.1038/nclimate2094.

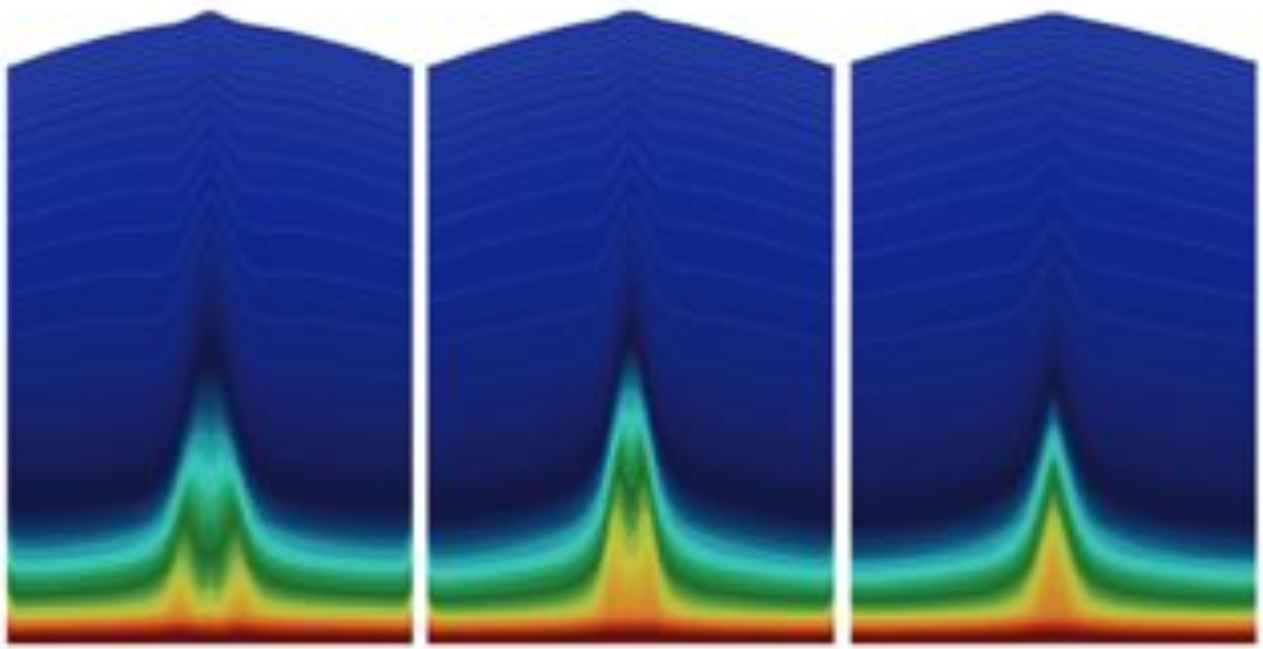


3D application
Transient
Grounding line (contact)

2 other models

Few recent examples (2014 publications)

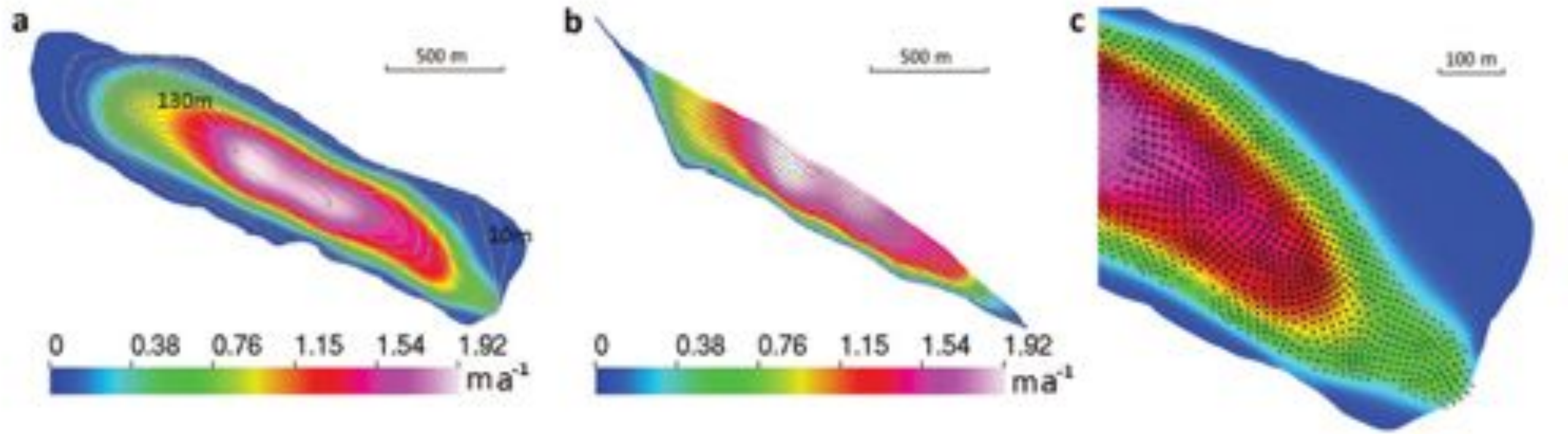
Martín, C., G.H. Gudmundsson and E.C. King 2014. Modelling of Kealey Ice Rise, Antarctica, reveals stable ice-flow conditions in East Ellsworth Land over millennia, J. Glaciol., 60, 139-146, doi: 10.3189/2014JoG13J089



2D flow line application
Transient
Anisotropic ice behaviour

Few recent examples (2014 publications)

Zhao, L., L. Tian, T. Zwinger, R. Ding, J. Zong, Q. Ye, and J.C. Moore, 2014. Numerical simulations of Gurenhekou Glacier on the Tibetan Plateau, J. Glaciol., 60, 71-82, doi:10.3189/2014JoG13J126.



3D application
Transient
Temperature

Current or planned developments

- **Calving law (damage mechanics)**
- **Hydrology model to infer basal water pressure**
- Moving margins / remeshing / adaptive mesh
- Coupling with an ocean model / Implementation of a plume model
- Accounting for refreezing in the temperature equations
- Inversion of bedrock topography
- Lower order Stokes models (SSA*)

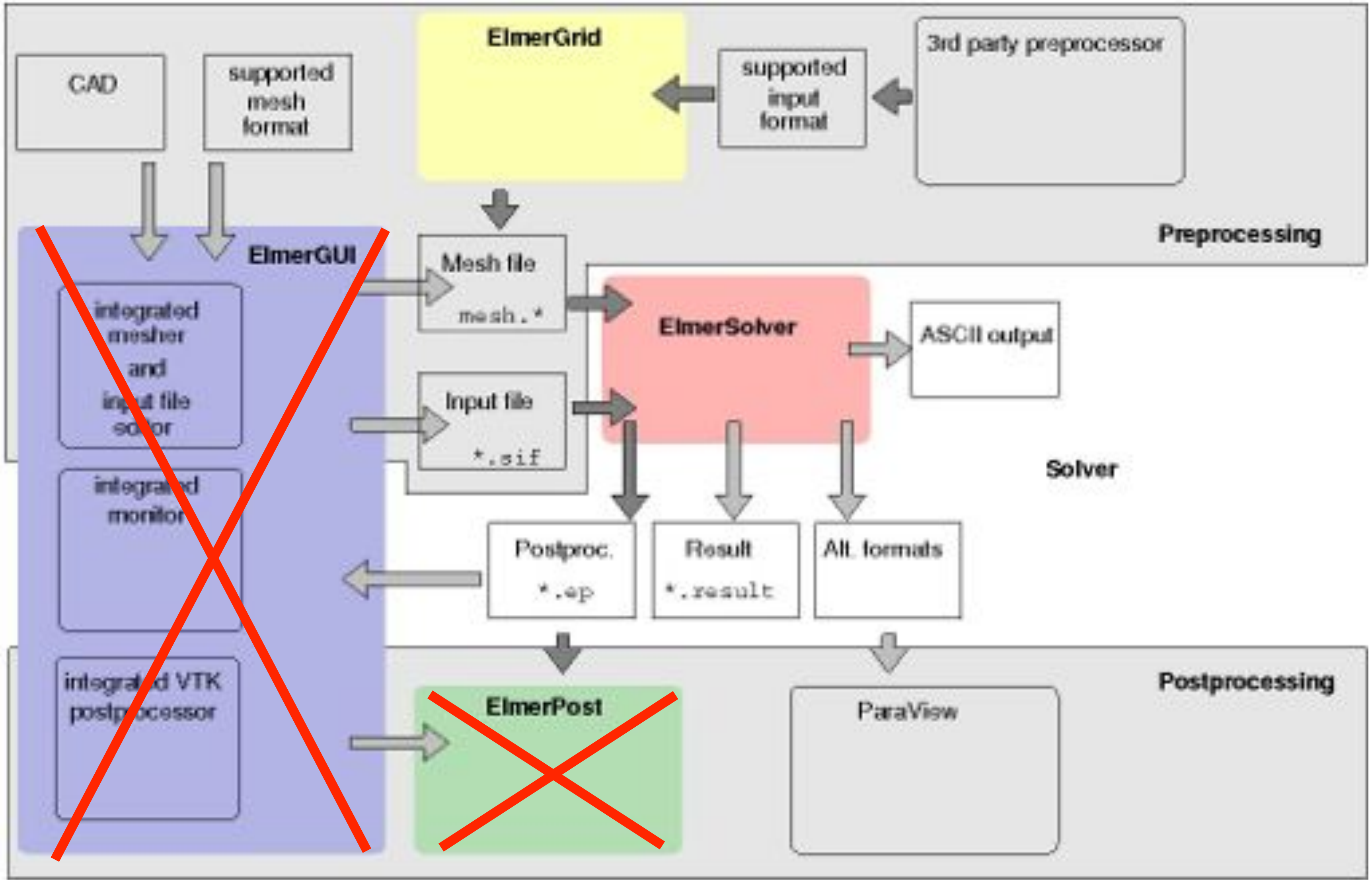
How to share developments?

Different groups are working on the development of new solvers or user functions (currently hydrology, calving, etc...)

When these developments have been published, solvers and/or user functions + examples + tests + documentation on the wiki should be made available for the community.

How does it work ?

Elmer structure



Sequence of a serial simulation

- build a mesh in Elmer format, i.e. a directory containing
  `mesh.header, mesh.nodes, mesh.element, mesh.boundary`

- file in a solver input file (`mysif.sif`)

- compile object files linked with Elmer of your user functions and solvers (if needed)

- Execute :

$ **`ElmerSolver mysif.sif`**

- Should create a *.ep file (ElmerPost format) or *.vtu file

- Visualise :

$ **`ElmerPost`** or $ **`paraview`**

We will see

- how to construct a simple mesh
- what is the content of a sif file
- how to execute
- how to visualise the results

How to get a mesh ?

Different possibilities to get a mesh

- use **ElmerGrid** alone

- use **another mesher** (gmsh, gambit) and then transform it in Elmer format - ElmerGrid can do this for many other mesh formats (just launch ElmerGrid without any argument to get list)

- Glacier particularities :
  - Small aspect ratio (horizontally elongated elements)
  - In 3D, mesh a footprint with an unstructured mesh, and then vertically extrude it (externally or internally)

will see this later during the course…

ElmerGrid

- command line tool for mesh generation
- native mesh format: `.grd`
- help : just execute : `$ ElmerGrid`
- possible to import meshes produced by other free or commercial mesh generators (Ansys, Abaqus, Fluent/Neutral, Comsol, gmsh, …)
- Examples :

```
$ ElmerGrid  1 2 my_mesh.grd
$ ElmerGrid 14 2 my_gmsh_mesh.msh
$ ElmerGrid 14 3 my_gmsh_mesh.msh
```

Solver Input File (sif)

Example of sif file

- Comments start with !
- Not case sensitive
- Avoid non-printable characters (e.g., tabulators for indents)

- A section always ends with the keyword `End` or use `::`

- Parameters not in the Keyword DB need to be casted by types:
  `Integer`, `Real`, `Logical`, `String` and `File`

- `Paremetername(n,m)` indicates a n×m array

- Sections are

```
Header
Constants
Simulation
Solver i
Body i
Equation i
Body Force i
Material i
Initial Condition i
Boundary Condition i
```

```
Body Force 1
Heat Source = 1.0
End
```

OR

```
Body Force 1 :: Heat Source = 1.0
```

Example of sif file

```
!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
!!                                       !!
!! Elmer/Ice Course - Application Step0  !!
!!                                       !!
!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
! Updated May 2011

check keywords warn
echo on

Header
  Mesh DB "." "square"
End

Constants
! No constant needed
End

!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
Simulation
  Coordinate System  = Cartesian 2D
  Simulation Type = Steady State

  Steady State Min Iterations = 1
  Steady State Max Iterations = 1

  Output File = "ismip_step0.result"
  Post File = "ismip_step0.ep"
  max output level = 100
End

!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
Body 1
  Equation = 1
  Body Force = 1
  Material = 1
  Initial Condition = 1
End

!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
Initial Condition 1
  Pressure = Real 0.0
  Velocity 1 = Real 0.0
  Velocity 2 = Real 0.0
End

!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
Body Force 1
  Flow BodyForce 1 = Real 0.0
  Flow BodyForce 2 = Real -1.0
End

!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
```

- **Header** declares where to search for the mesh
- If any **constants** needed (i.e. Gas constant)
- **Simulation**
  - Type of coordinate system
  - Steady or Transient
    - If transient: time stepping parameters
  - Output files (to restart a run) and ElmerPost/ VTU file
  - Output level : how verbose is the code?
  - Restart information (optional)
- In **Body** are assigned the Equation, Body Force, Material and Initial Condition
- In **Initial Condition** sets initial variable values
- In **Body Force** specify the body force entering the right side of the solved equation

Example of sif file

```
!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
Material 1
  Density = Real 1.0

  Viscosity Model = String "power law"
  Viscosity = Real 1.0
  Viscosity Exponent = Real 0.333333333333333333
  Critical Shear Rate = Real 1.0e-10
End

!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
Solver 1
  Equation = "Navier-Stokes"

  Stabilization Method = String Bubbles
  Flow Model = String Stokes

  Linear System Solver = Direct
  Linear System Direct Method = umfpack

  Nonlinear System Max Iterations = 100
  Nonlinear System Convergence Tolerance  = 1.0e-5
  Nonlinear System Newton After Iterations = 5
  Nonlinear System Newton After Tolerance = 1.0e-02
  Nonlinear System Relaxation Factor = 1.00

  Steady State Convergence Tolerance = Real 1.0e-3
End

!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!

Equation 1
  Active Solvers(1)= 1
End

!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
Boundary Condition 1
  Target Boundaries = 1
  Velocity 2 = Real 0.0e0
End

Boundary Condition 2
  Target Boundaries = 4
  Velocity 1 = Real 0.0e0
End

Boundary Condition 3
  Target Coordinates(1,2) = Real 0.0 1.0
  Target Coordinates Eps  = Real 1.0e-3
  Pressure = Real 0.0e0
End
```

- In **Material** sets material properties for the body (can be scalars or tensors, and can be given as dependent functions)
- In **Solver** specifies the numerical treatment for these equations (methods, criteria of convergence,…)
- In **Equation** sets the active solvers
- **Boundary Condition**
  - Dirichlet: `Variablename = Value`
  - Neumann: special keyword depending on the solver
  - Values can be given as function

Variable defined as a function

1) Tables can be use to define a piecewise linear (cubic) dependency of a variable

```
Density = Variable Temperature
Real cubic
   0  900
 273 1000
 300 1020
 400 1000
End
```

Outside range: Extrapolation!

2) MATC: a library for inline (in SIF) numerical evaluation of mathematical functions

```
Density = Variable Temperature
MATC "1000*(1 - 1.0e-4*(tx-273.0))"
```

Evaluated every time

or as constant expressions

```
Viscosity Exponent = Real $1.0/3.0
```

Evaluated once

3) Build your own user function

```
Density = Variable Temperature
Procedure "filename" "proc"
```

`filename` should contain a shareable (.so on Unix) code for the user function whose name is `proc`

Example of User Function

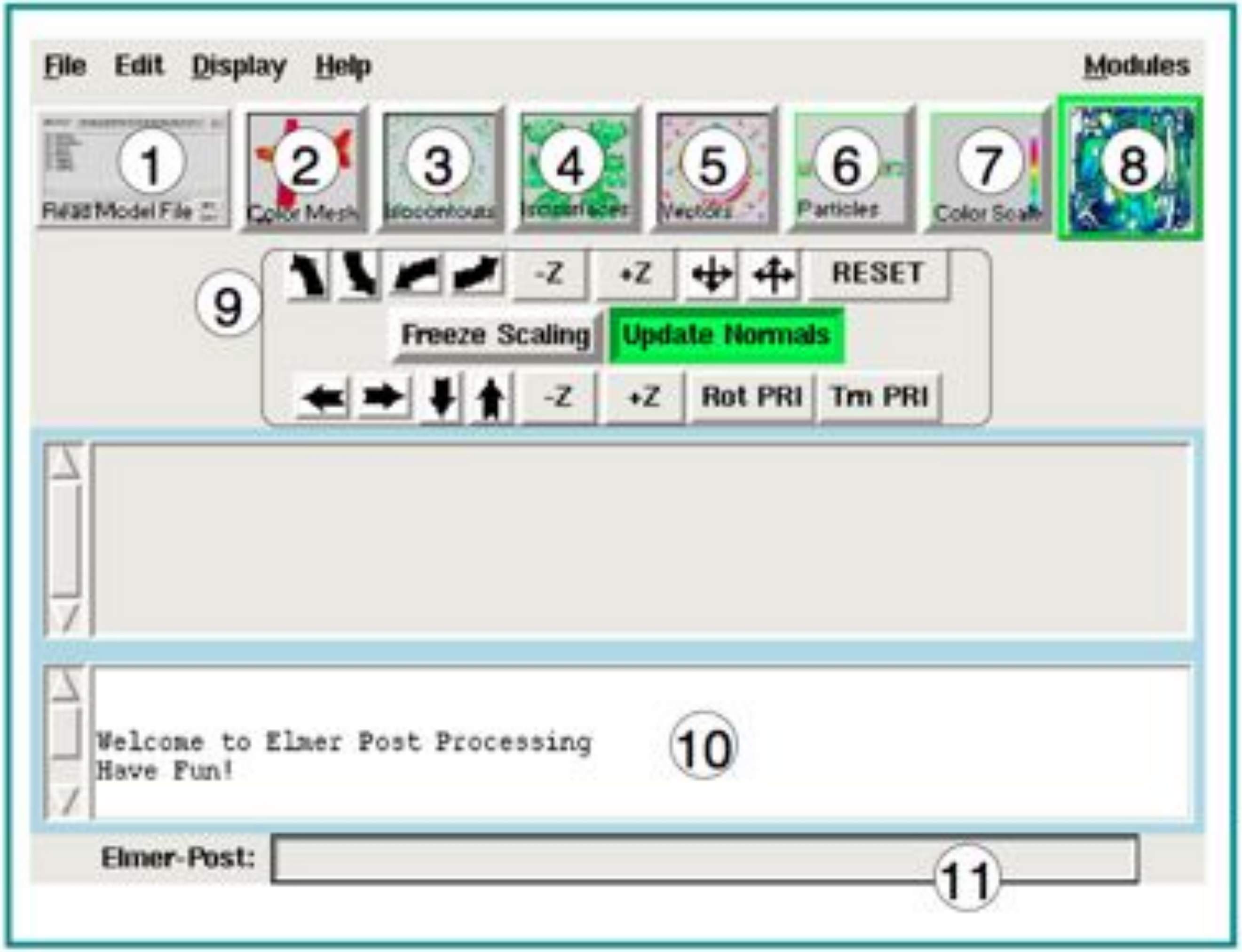
```
FUNCTION proc( Model, n, T ) RESULT(dens)
USE DefUtils
IMPLICIT None
TYPE(Model_t) :: Model
INTEGER :: n
REAL(KIND=dp) :: T, dens

    dens = 1000*(1-1.0d-4 *(T-273.0_dp))

END FUNCTION proc
```

Compilation tools: `elmerf90`

`$` **`elmerf90`** ***`filename`*** **`.f90 -o`** ***`filename`*** **`.so`**

How to visualise results

ElmerPost (legacy format)



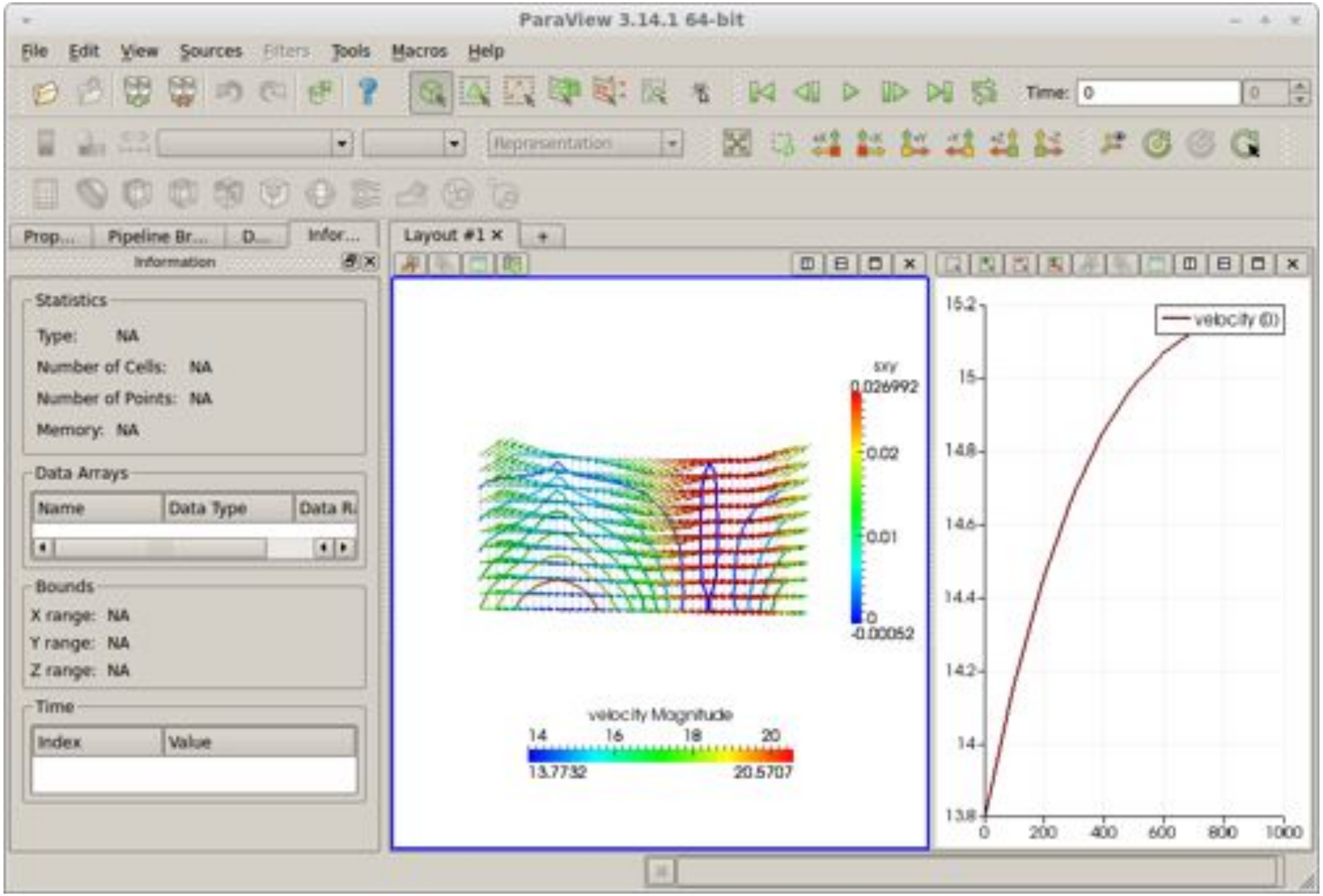
1. Read result
2. Mesh display
3. Iso-contours
4. Iso-surfaces
5. Vector-field
6. Particles
7. Color-bar
8. Refresh
9. View settings
10. Output
11. Command

Output for other post-processors

	`GID`	GID
	`Gmsh`	Gmsh
`Output Format =`	`Vtk`	VTK legacy
	`Dx Format`	Open DX
	`vtu`	ParaView

```
Solver 1
   Equation = "ResultOutput"
   Procedure = "ResultOutputSolve" "ResultOutputSolver"
   Output File Name = "test"
   Output Format = string "vtu"
   Scalar Field 1 = String "Temperature"
   Vector Field 1 = String "Velocity"
End
```

Paraview


ParaView 3.14.1 64-bit
File Edit View Sources Filters Tools Macros Help
Time: 0
Representation
Prop... Pipeline Br... D... Infor...
Information
Statistics
Type: NA
Number of Cells: NA
Number of Points: NA
Memory: NA
Data Arrays
Name Data Type Data R
Bounds
X range: NA
Y range: NA
Z range: NA
Time
Index Value
Layout #1
sxy
0.026992
0.02
0.01
0
-0.00052
velocity Magnitude
14 16 18 20
13.7732 20.5707
velocity (0)
15.2 15 14.8 14.6 14.4 14.2 14 13.8
0 200 400 600 800 1000

ASCII Based Output

`SaveScalars`	e.g. CPU time, mean, max, min of a variable, Flux
`SaveLine`	save a variable along a line (boundary or a given line)
`SaveMaterials`	save a material parameter like a variable

Example:

```
Solver 3
  Exec Solver =  After All
  Procedure = File "SaveData" "SaveLine"
  Filename =  "ismip_surface.dat"
  File Append = Logical False
End


Solver 4
  Exec Solver =  After TimeStep  ! For transient simualtion
  Procedure = File "./MySaveData" "SaveScalars"
  Filename =  "ismip_scalars.dat"
  File Append = Logical True     ! For transient simualtion

  Variable 1 = String "Flow Solution"
  Operator 1 = String "Volume"

  Variable 2 = String "Velocity 1"
  Operator 2 = String "Max Abs"

  Variable 3 = String "Flow Solution"
  Operator 3 = String "Convective flux"

  Variable 4 = String "cpu time"

  Variable 5 = String "cpu memory"
End
```

```
! Upper Surface
Boundary Condition 3
  Target Boundaries = 3
  Save Line = Logical True
  Flux integrate = Logical True
End
```