Elmer/Ice course

7-8 March 2013 – UW - Seattle

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Introduction

(1) LGGE - Grenoble - France

Program

Day 1 : March 7th 2013 (8:30am-5:00pm)

- A brief introduction of the main tools
  - What is Elmer/Ice?
  - How to get a mesh
  - Solver input file
  - How to visualise results

- A step by step exercise using ISMIP tests B and C

  2D flow line applications, diagnostic and prognostic

Day 2: March 8th 2013 (8:30am-3:00pm)

- Short presentation of what you would like to do with Elmer/Ice in the next future (5mn)
- A real world application: Tête Rousse glacier

  3D application, diagnostic and prognostic

Short history of Elmer/Ice

- 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, ...)

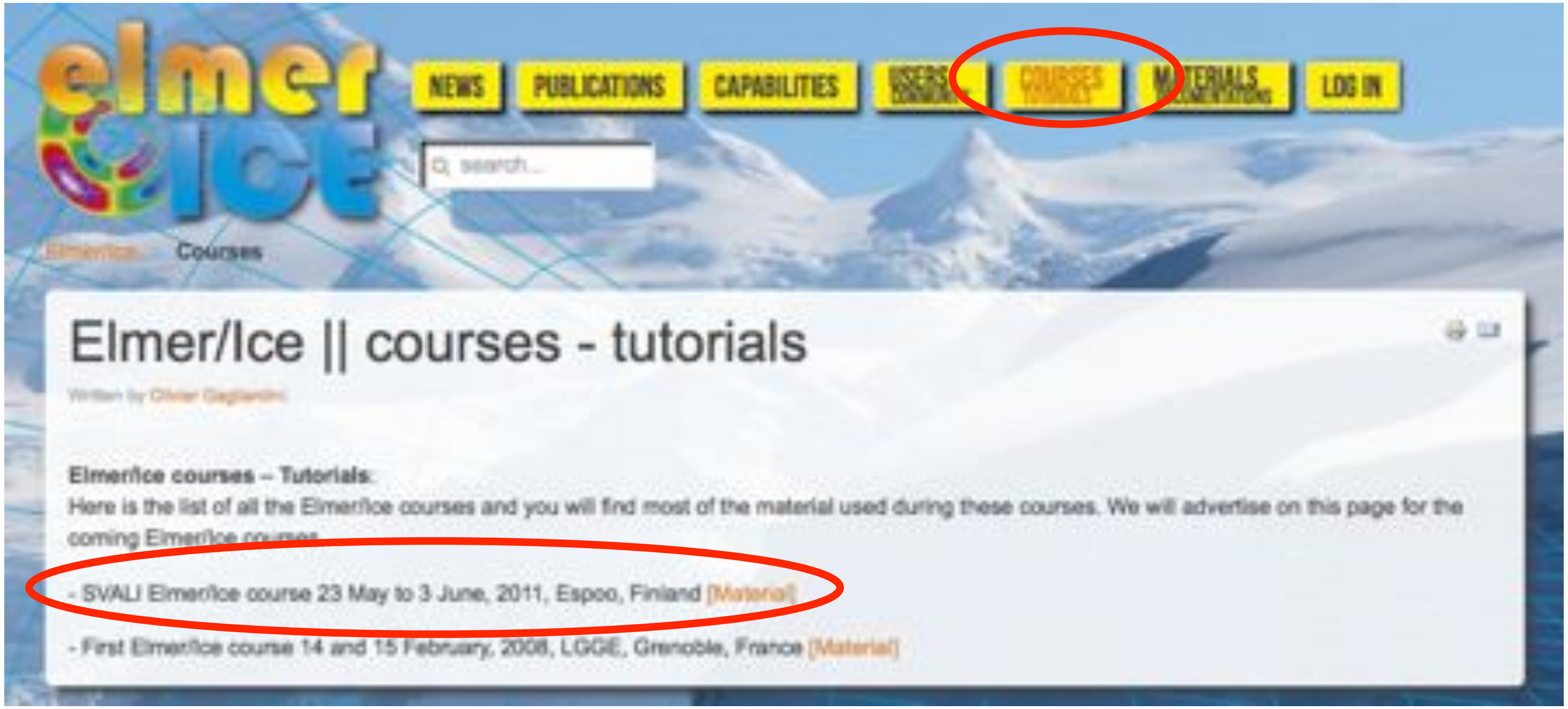
- February 2008 – First Elmer/Ice Course - Grenoble

- June 2011 – Second Elmer/Ice Course – Finland

- 2012 – Elmer/Ice has now a website, a logo and a mailing list
- 2012 – Elmer/Ice comes as a Elmer Package

http://elmerice.elmerfem.org/

http://elmerice.elmerfem.org/



Much more material available than what I will present today

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 versus Elmer

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.

Elmer/Ice includes a variety of dedicated solvers and user functions for glaciological applications.

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 `elmerfem/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 links

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

Important notices

In this course

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

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

What I expect from this course ?

- some fruitful collaborations to begin !

Elmer/Ice capabilities

- Full-Stokes equation but also SIA, SSA, Diagnostic or transient
- Various rheology (Glen's law, firn/snow and two anisotropic flow laws)
- Temperature solver accounting for the upper limit at melting point
- Evolution equations for density, fabric, …
- Dating, evaluation of strain-rate and stress fields
- Various friction laws (Weertman, effective-pressure dependent friction law)
- Grounding line dynamics as a contact problem
- Inverse methods (linear adjoint and Arthern and Gudmundsson 2010 methods)
- Tools to mesh glaciers (YAMS, extrusion of footprint)
- Highly parallel Stokes solver

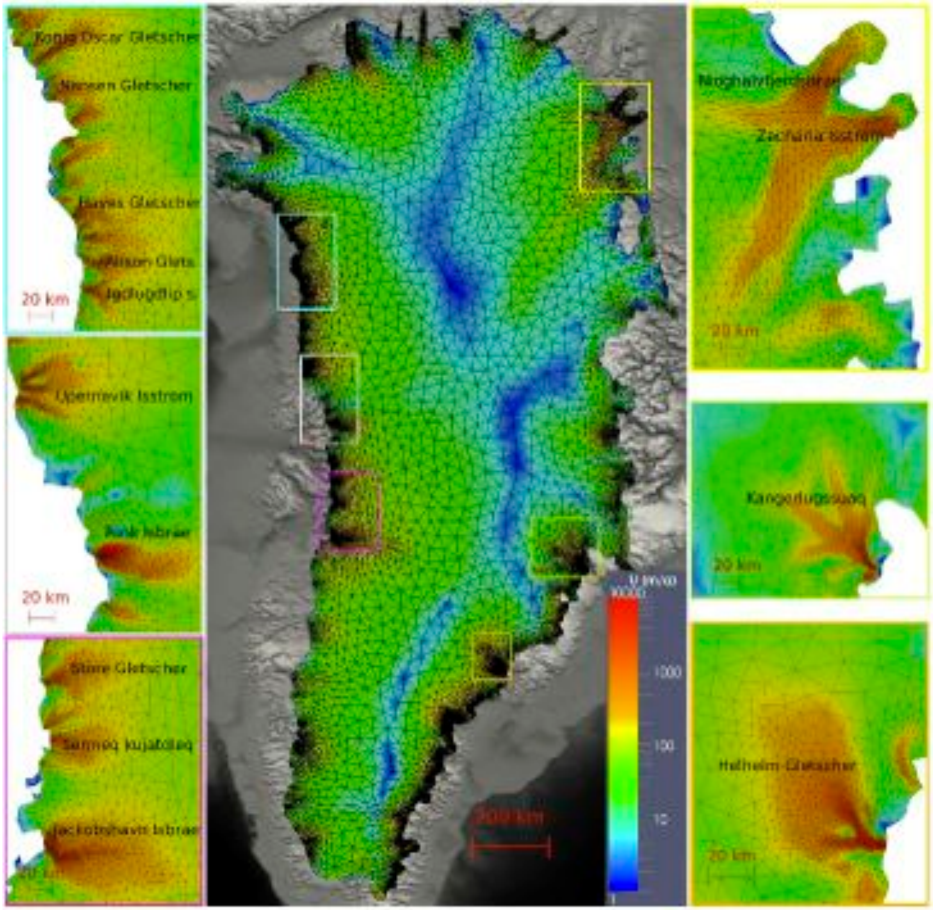
Elmer/Ice applications

More than 30 publications using Elmer/Ice since 2004

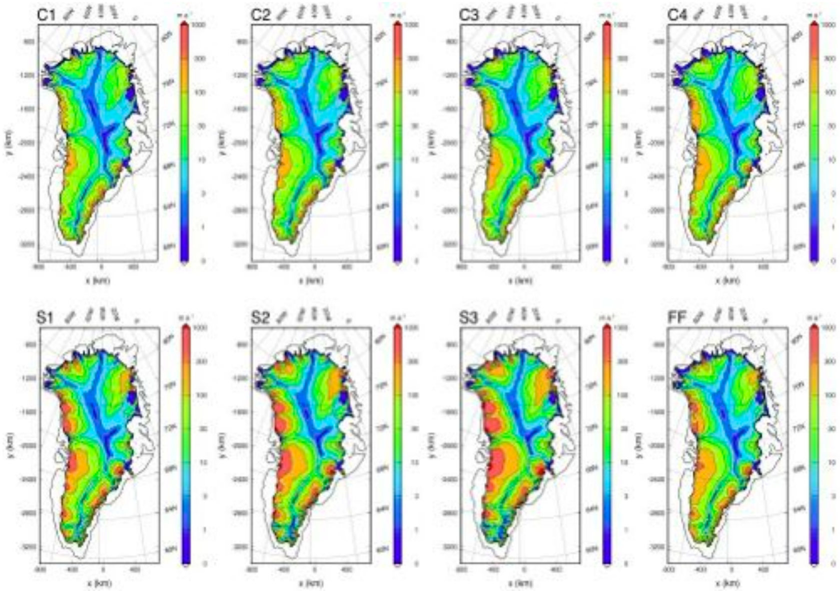
- ISMIP, MISMIP, MISMIP-3d
- 2D and 3D Grounding line dynamics
- Ice2sea and SeaRISE contributions (Greenland)
- Inverse methods (Variegated, Vestfonna ice-cap, GIS)
- Flow of anisotropic ice

Few recent examples

Grenland within ice2sea
@Fabien Gillet-Chaulet, LGGE



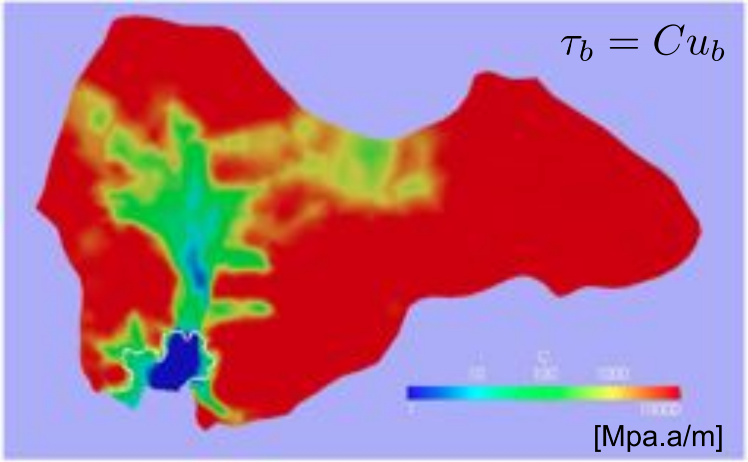
Grenland within SeaRise
@Hakime Seddik, ILTS



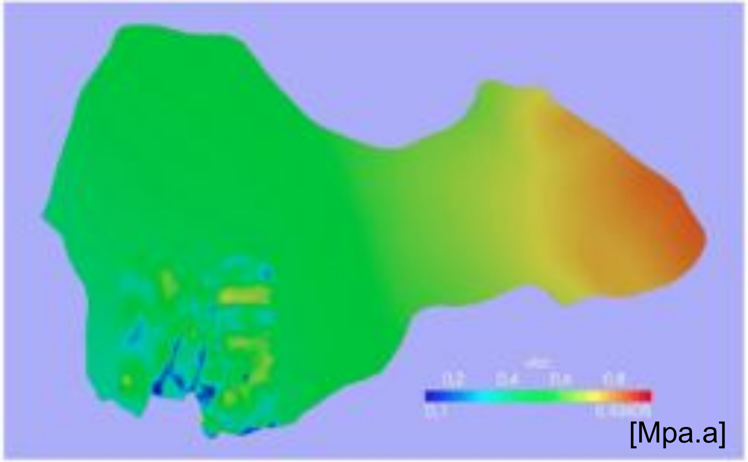
Few recent examples

Grounding line 3D @Lionel Favier, LGGE

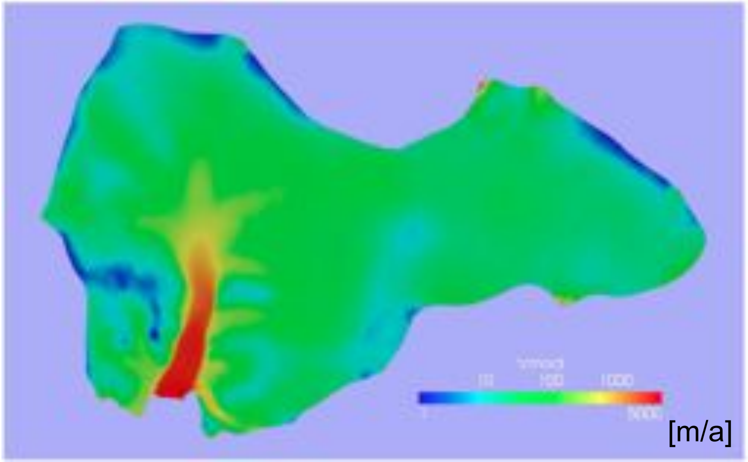
Inverted **basal friction** parameter



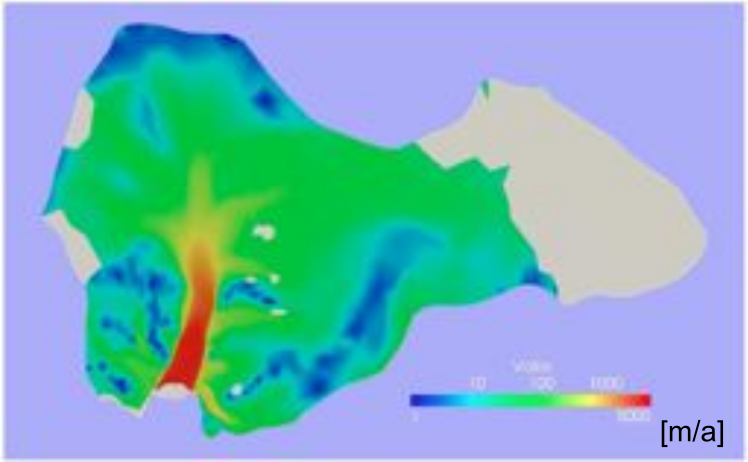
Inverted surface **effective viscosity**



Inverted surface velocity

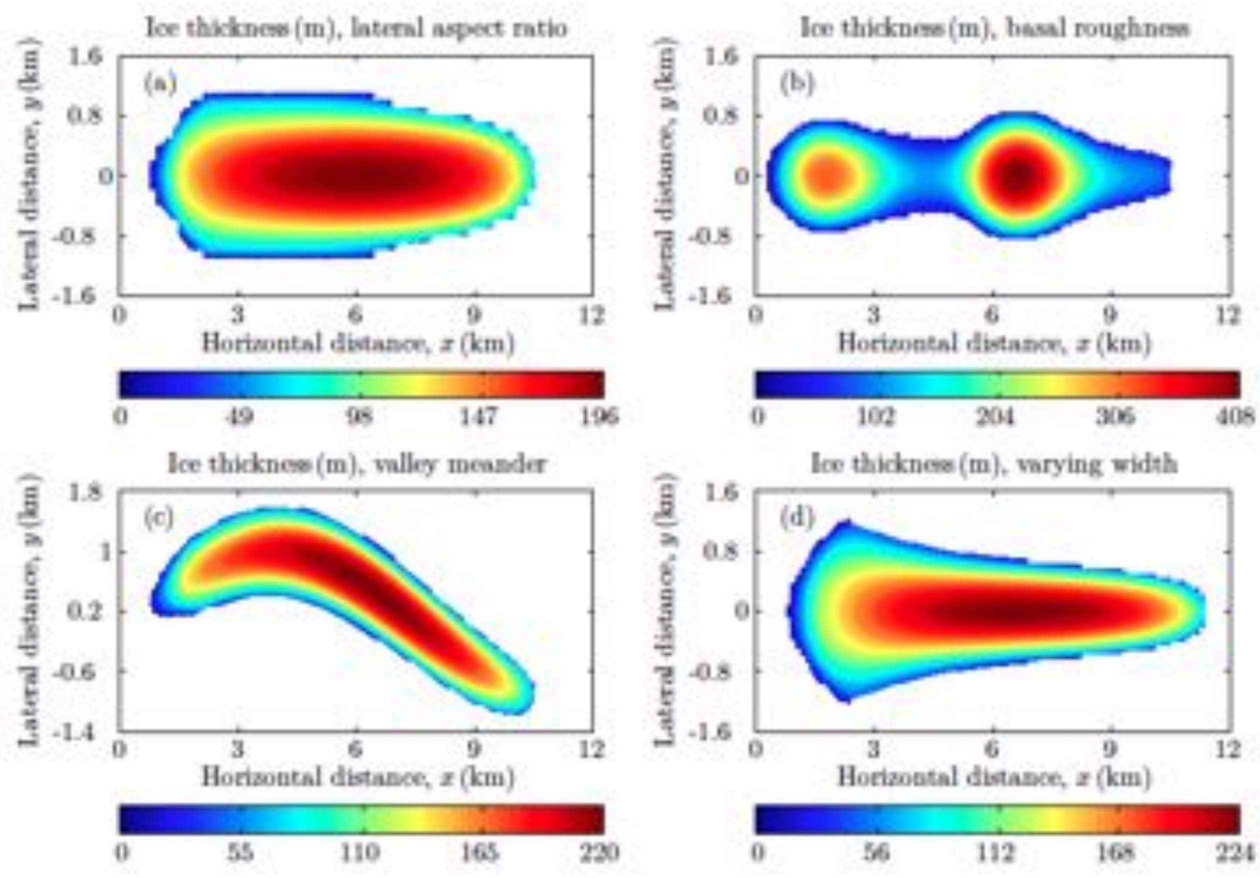


Observed surface velocity (Rignot et al., 2011)



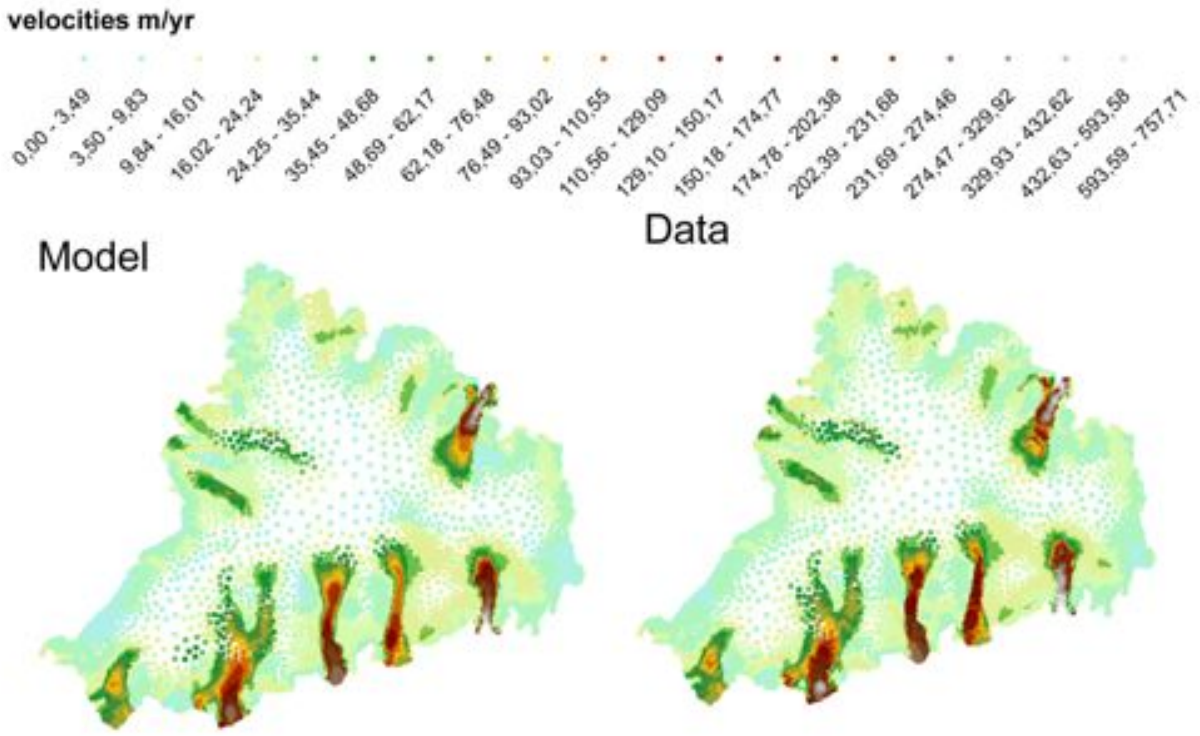
Few recent examples

Volume/Area relation @Surendra Adhikari, Univ. Calgary



Few recent examples

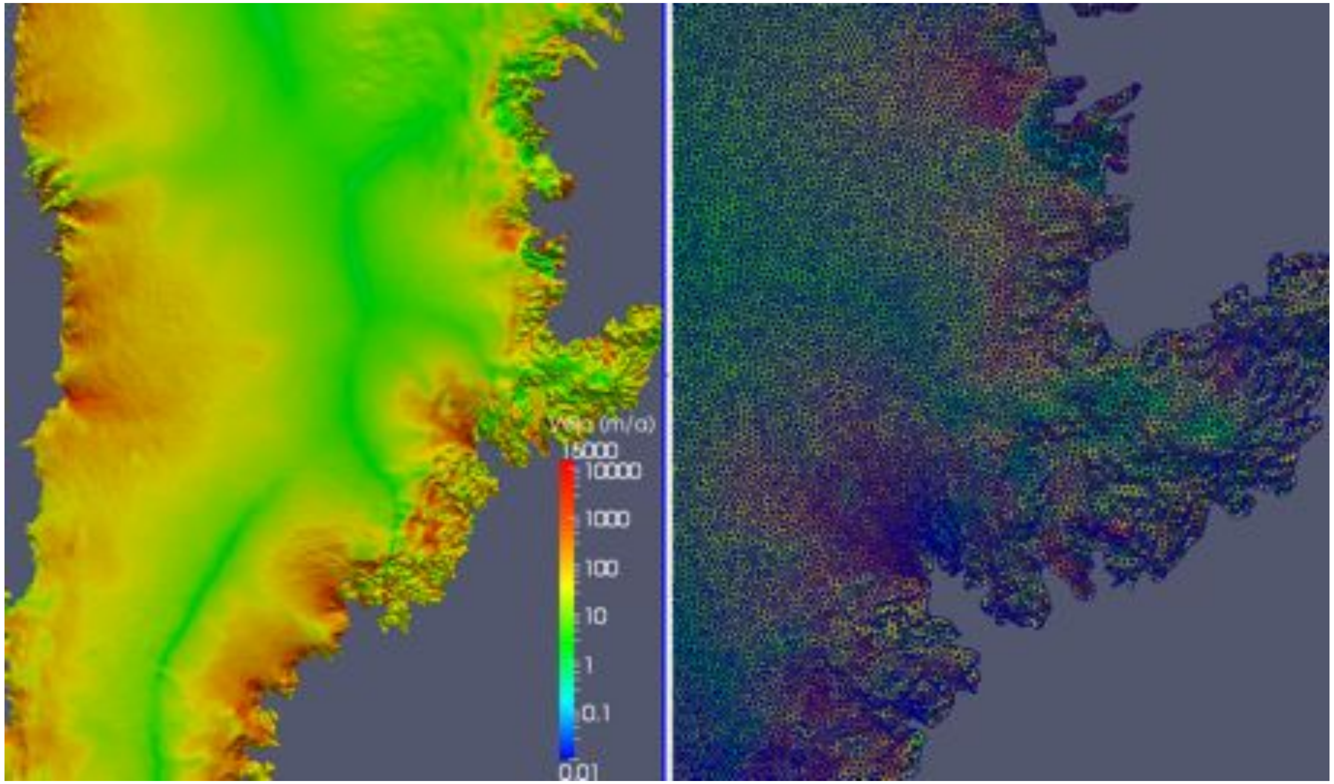
Vestfonna ice cap basal friction @Martina Schäfer, Univ. Lapland



Few recent examples

High parallel computing @Fabien Gillet-Chaulet, LGGE

1 900 000 nodes on 400 partitions
~7 000 000 dofs



Current developments

- Calving law (damage mechanics)
- Hydrology model to infer basal water pressure
- Moving margins
- Coupling with an ocean model / Implementation of a plume model
- Accounting for refreezing in the temperature equations
- Inversion of bedrock topography
- what you will implement yet after this course ?

Latest news

✓First Elmer/Ice user splinter meeting at next EGU

Tue, 09 Apr, 12:15 - 15:00 / Room Y3

✓GMD paper

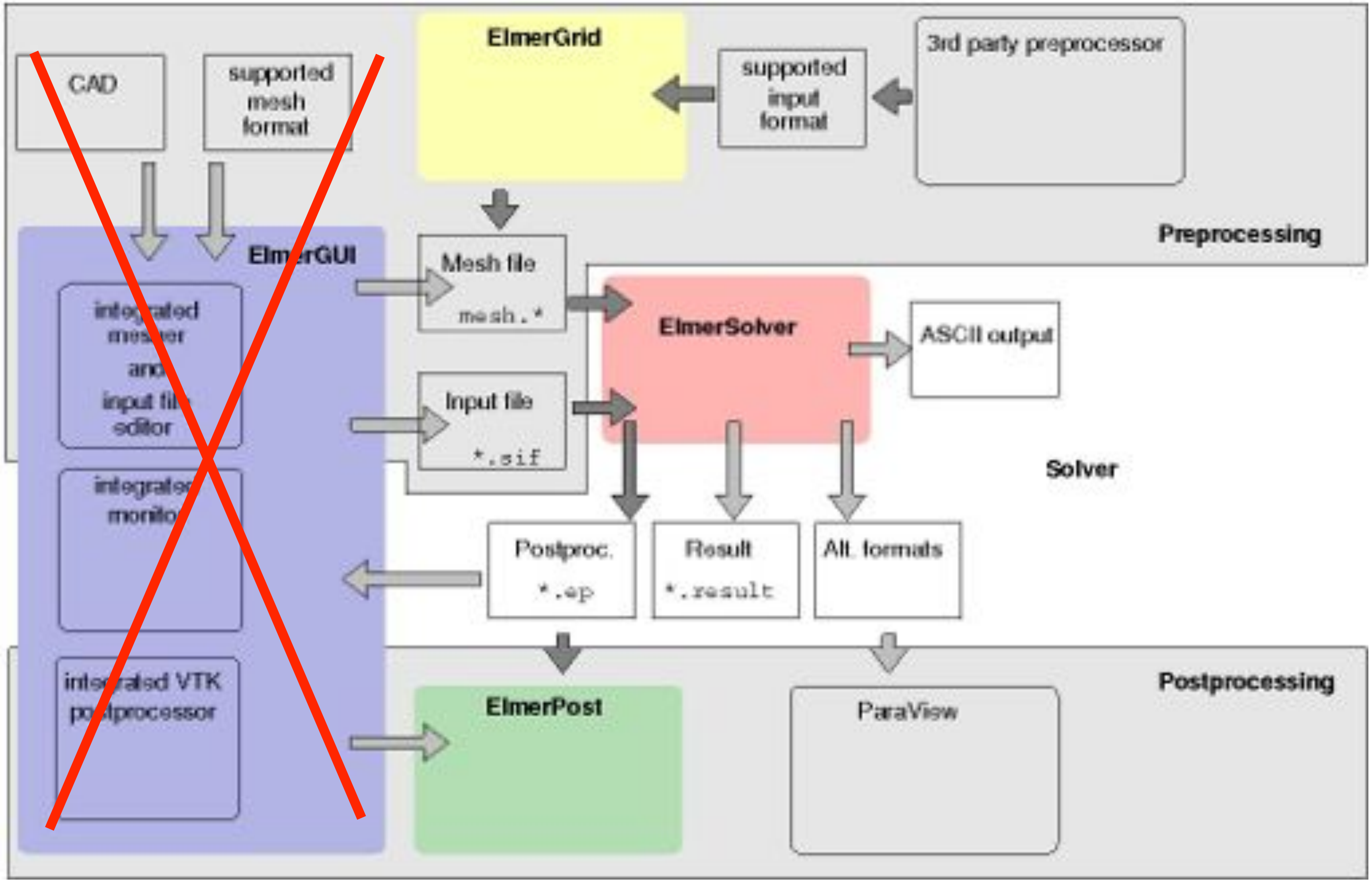
http://www.geosci-model-dev-discuss.net/6/1689/2013/gmdd-6-1689-2013.html

Capabilities and performance of Elmer/Ice, a new generation ice-sheet model

O. Gagliardini[1,2], T. Zwinger[3], F. Gillet-Chaulet[1], G. Durand[1], L. Favier[1], B. de Fleurian[1], R. Greve[4], M. Malinen[3], C. Martín[5], P. Råback[3], J. Ruokolainen[3], M. Sacchettini[1], M. Schäfer[6], H. Seddik[4], and J. Thies[7]

How does it work ?

Elmer structure



Sequence of a simulation

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

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

- 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)

- Visualise :

```
$ ElmerPost
```

We will see

- how to construct a simple mesh
- what is the contains 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 an other mesher (gmsh, gambit) and then transform it in Elmer format (ElmerGrid can do this for many other mesher formats)

- Glacier particularities :
  - Small aspect ratio (horizontally elongated elements)
  - In 3D, mesh a footprint with an unstructured mesh, and then vertically extrude it (same number of layer everywhere)

will see this later during the course…

ElmerGrid

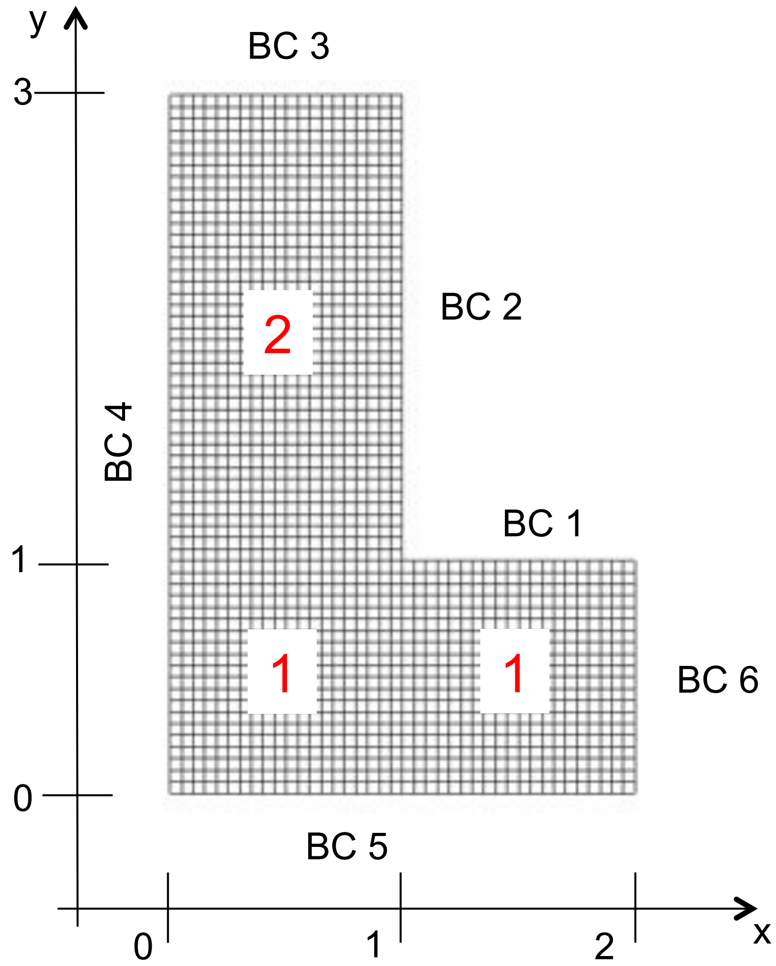
- command line tool for mesh generation
- native mesh format: `.grd`
- help : just execute : `ElmerGrid`
- possible to import meshes produced by other free or commercial mesh generators (Ansys, Abaqus, Gambit, Comsol, gmsh, …)

Examples :

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

Example of grd file

Mesh a L shape canal




```
$ ElmerGrid 1 2 Lshape.grd
$ ElmerGrid 1 3 Lshape.grd
$ ElmerGrid 1 3 Lshape.grd -bulktype 1 2 1
```

```
Coordinate System = Cartesian 2D
Subcell Divisions in 2D = 4 4
Subcell Limits 1 = -1.0 0.0  1.0  2.0 3.0
Subcell Limits 2 = -1.0 0.0  1.0  3.0 4.0
Material Structure in 2D
4 4 4 4
5 2 3 3
5 1 1 7
6 6 6 6
End
Materials Interval = 1 2
Boundary Definitions
! type     out      int
  1        3        1        1
  2        3        2        1
  3        4        2        1
  4        5        1        1
  4        5        2        1
  5        6        1        1
  6        7        1        1
End
Numbering = Horizontal
Coordinate Ratios = 1
Decimals = 12
Element Innernodes = False
Element Degree = 1
Triangles = False
Element Divisions 1 = 0 20 20 0
Element Divisions 2 = 0 20 40 0
```

Solver Input File (sif)

Example of sif file

- Comments start with !
- Not case sensitive
- Do not use tabulators for indents

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

- Parameters 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
  - Output files (to restart a run) and ElmerPost file
  - Out put level : how verbose is the code
- 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 dependency of a variable

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

2/ MATC: a library for the numerical evaluation of mathematical expressions

```
Density = Variable Temperature
MATC "1000*(1-1.0e-4*(tx-273))"

Viscosity Exponent = Real $1.0/3.0
```

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

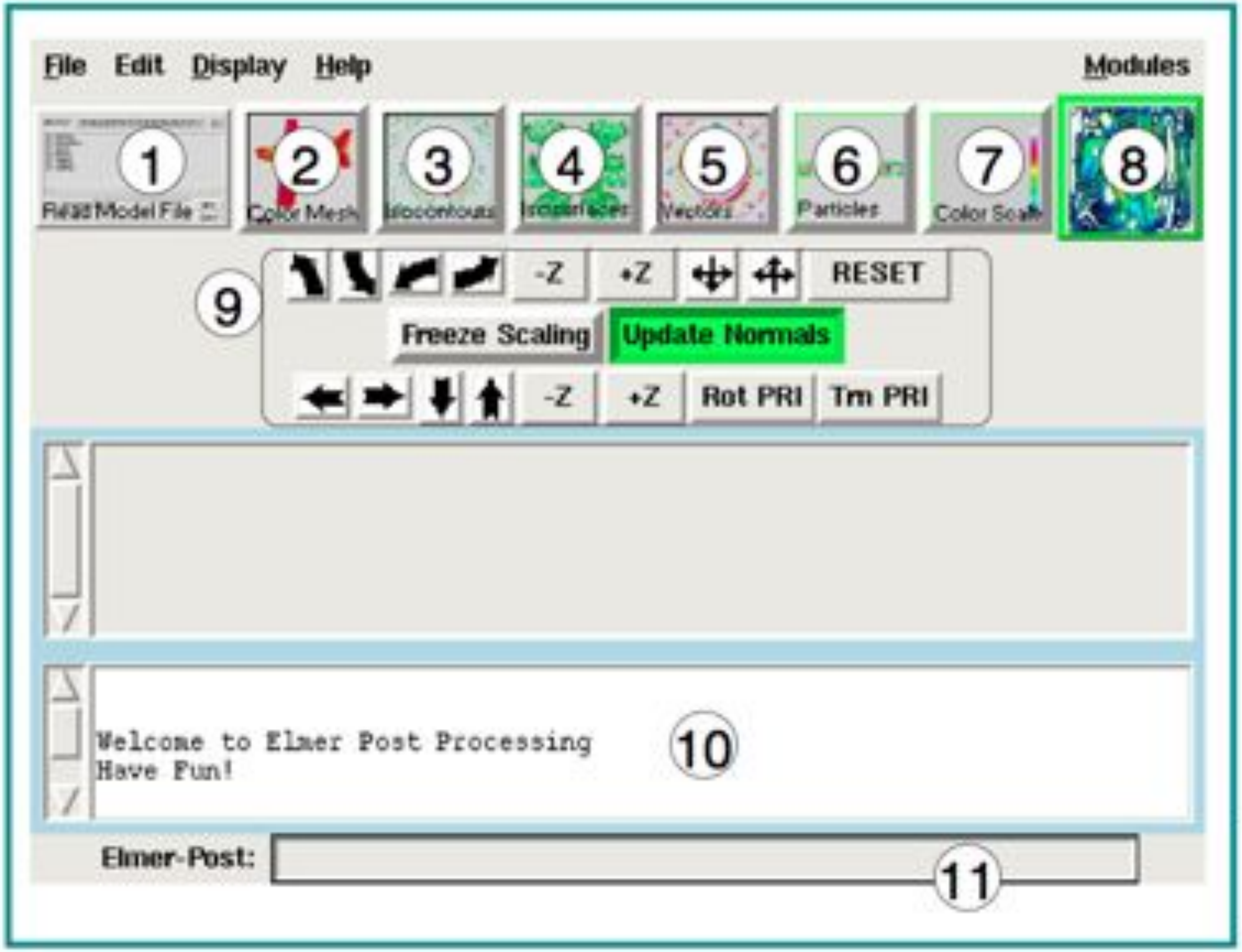
```
FUNCTION proc( Model, n, T ) RESULT(dens)
USE DefUtils
IMPLICIT None
TYPE(Model_t) :: Model
INTEGER :: n
REAL(KIND=dp) :: T, dens

dens = 1000*(1-1.0d-4(T-273.0_dp))
END FUNCTION proc
```

Compilation tools: `elmerf90`

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

How to visualise results

ElmerPost



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

`Output Format =`	`GID`	GID
	`Gmsh`	Gmsh
	`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
```

ASCII Based Output

`SaveScalars`	cpu time, mean, max, min of a variable
`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
```