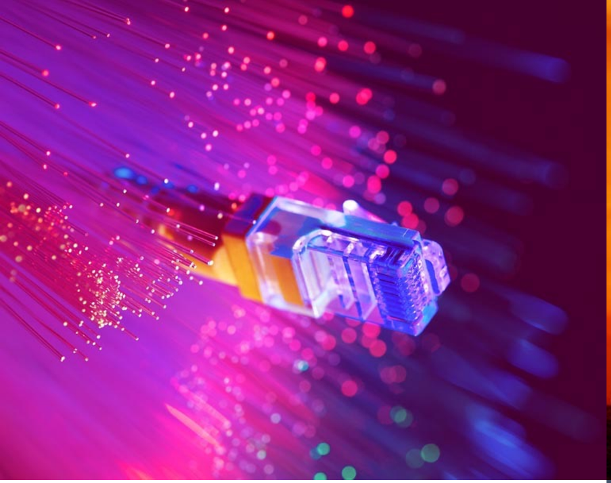


Elmer/Ice User meeting Nov. 2023

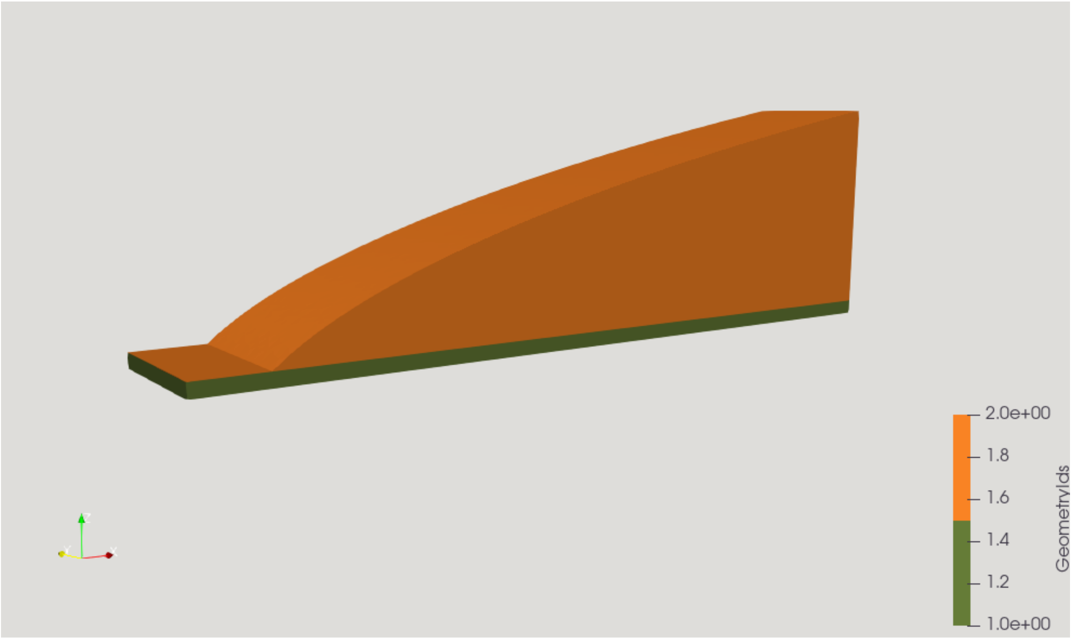
Thomas Zwinger, CSC – IT Center for Science Ltd.

CSC – Suomalainen tutkimuksen, koulutuksen, kulttuurin ja julkishallinnon ICT-osaamiskeskus

Changes in internal extrusion

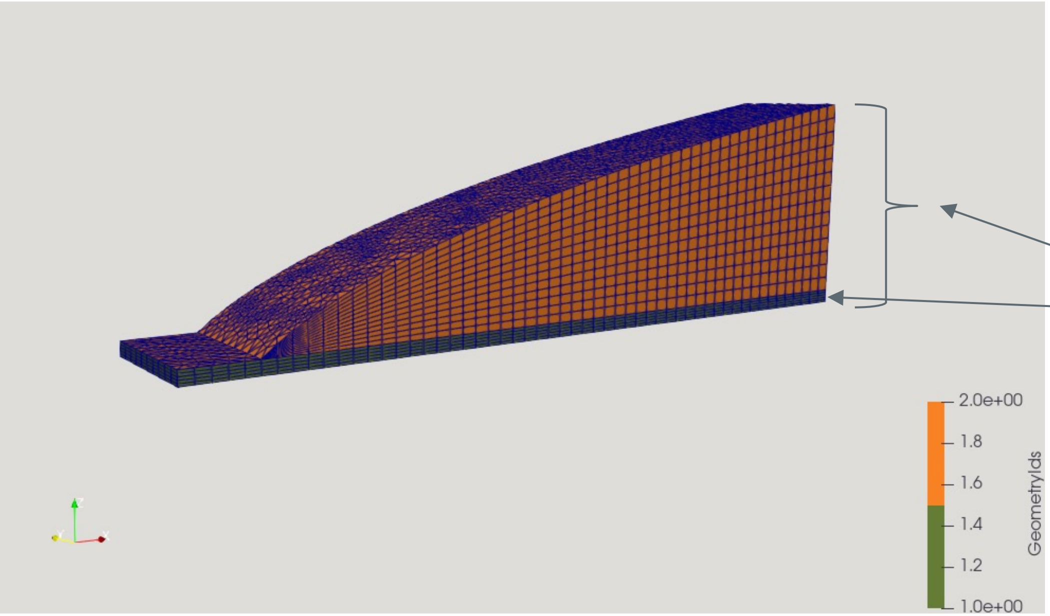
Thomas Zwinger

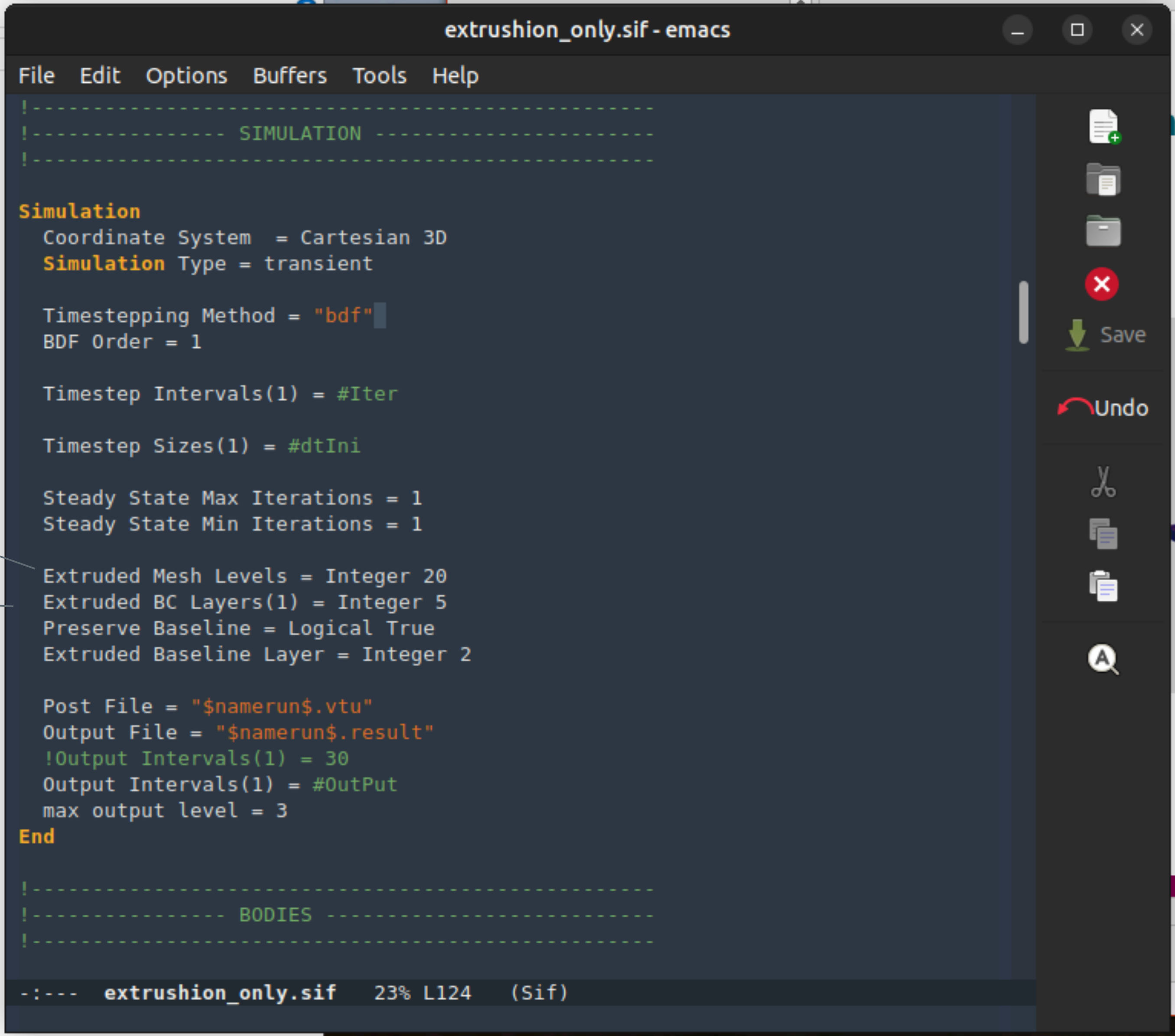
Changes in internal extrusion



- Possibility to include midlayer
- For instance, if one wants to add bedrock underneath ice-sheet/glacier
- Starting from 2D footprint
- Declaration in Simulation section

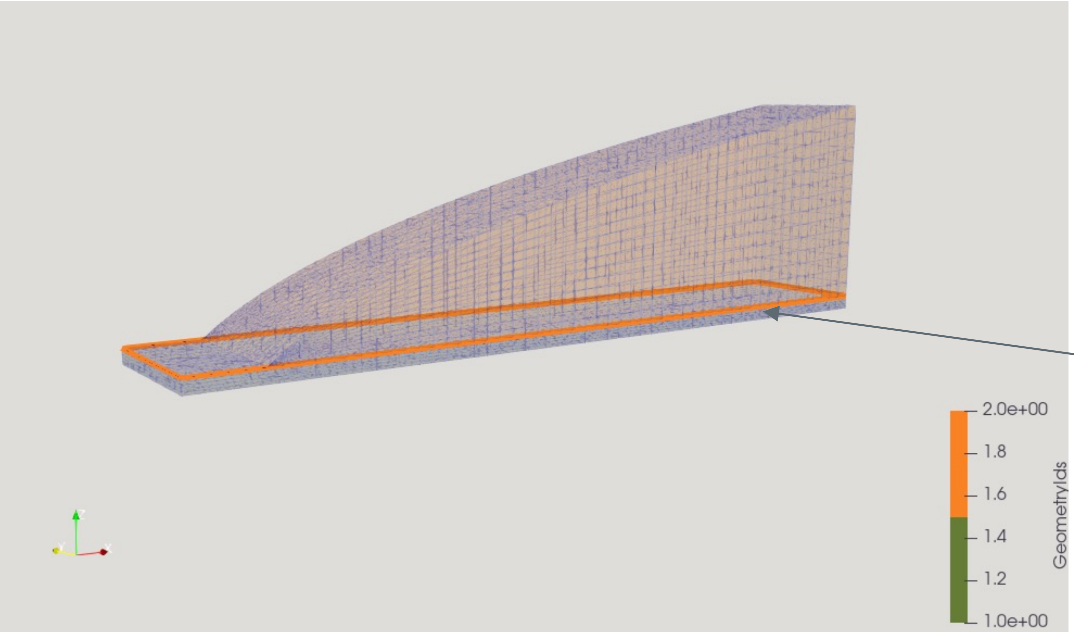
Changes in internal extrusion






```
!----------------------------------------------------
!--------------- SIMULATION ------------------------
!----------------------------------------------------

Simulation
  Coordinate System  = Cartesian 3D
  Simulation Type = transient

  Timestepping Method = "bdf"
  BDF Order = 1

  Timestep Intervals(1) = #Iter

  Timestep Sizes(1) = #dtIni

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

  Extruded Mesh Levels = Integer 20
  Extruded BC Layers(1) = Integer 5
  Preserve Baseline = Logical True
  Extruded Baseline Layer = Integer 2

  Post File = "$namerun$.vtu"
  Output File = "$namerun$.result"
  !Output Intervals(1) = 30
  Output Intervals(1) = #OutPut
  max output level = 3
End

!----------------------------------------------------
!--------------- BODIES ----------------------------
!----------------------------------------------------
```

Changes in internal extrusion

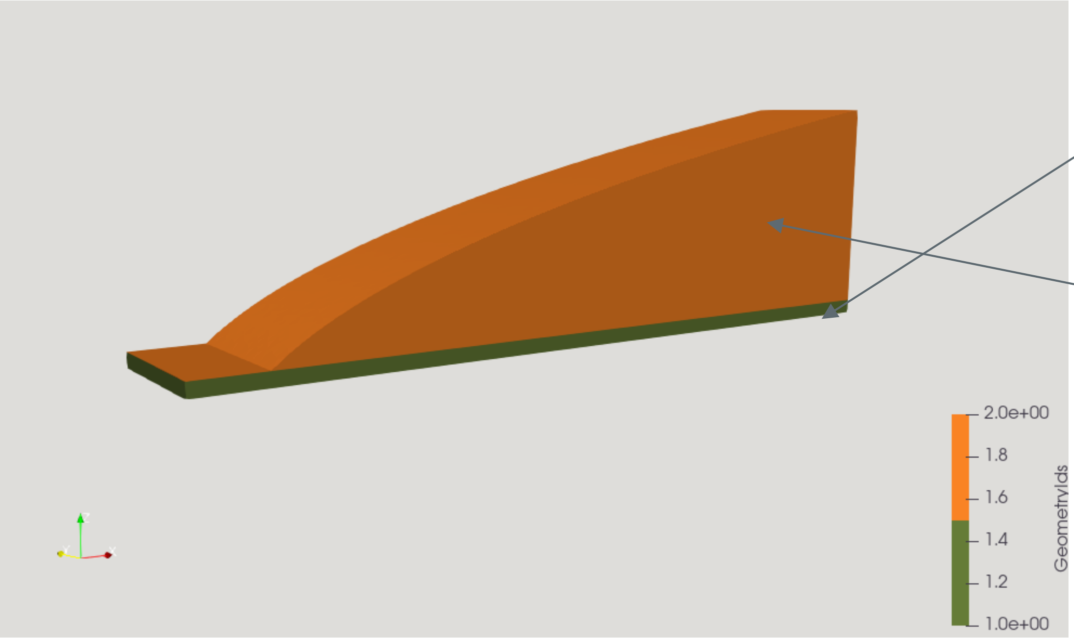


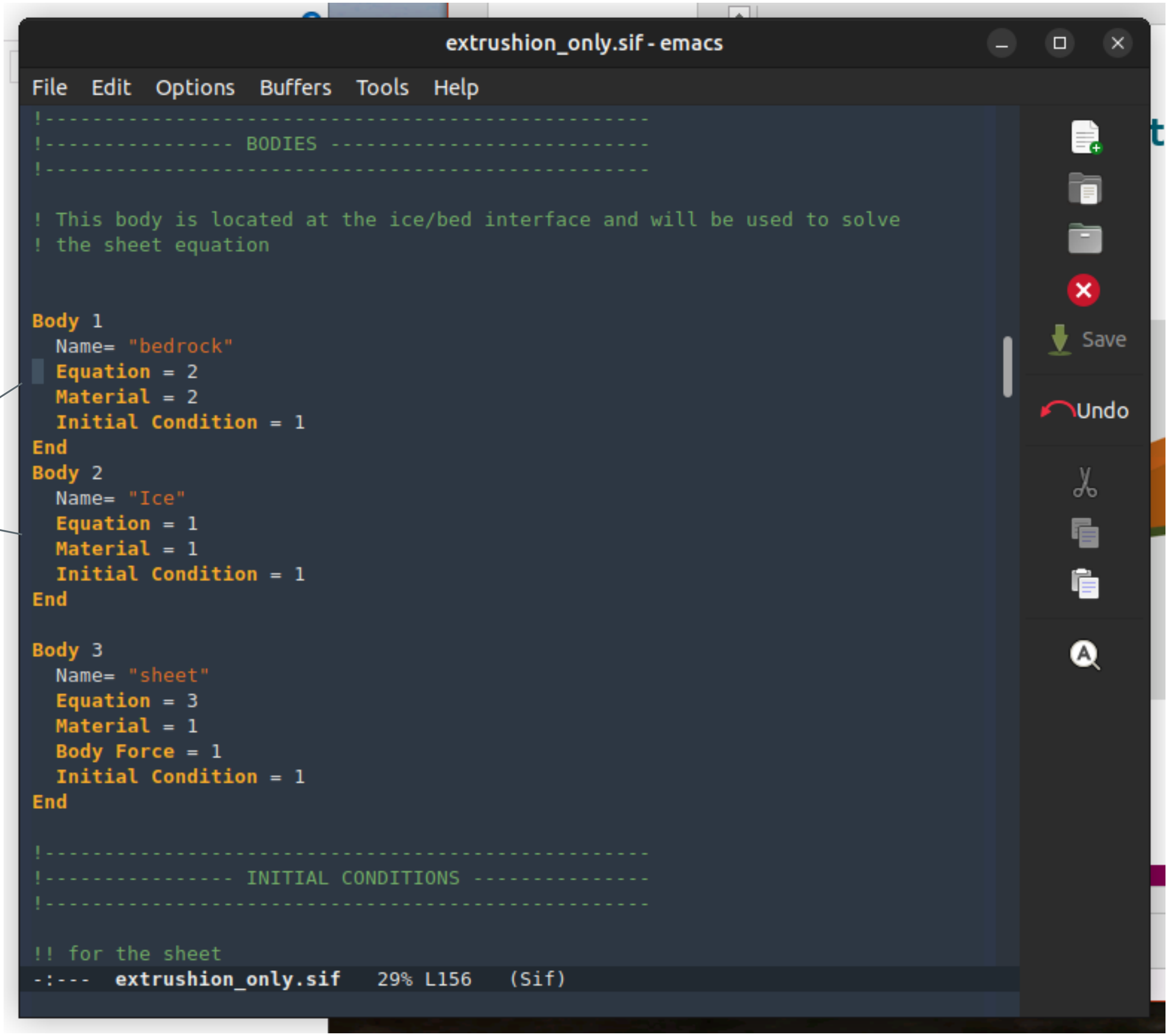
extrushion_only.sif - emacs

```
!----------------------------------------------------
!--------------- SIMULATION ----------------------
!----------------------------------------------------

Simulation
  Coordinate System  = Cartesian 3D
  Simulation Type = transient

  Timestepping Method = "bdf"
  BDF Order = 1

  Timestep Intervals(1) = #Iter

  Timestep Sizes(1) = #dtIni

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

  Extruded Mesh Levels = Integer 20
  Extruded BC Layers(1) = Integer 5
  Preserve Baseline = Logical True
  Extruded Baseline Layer = Integer 2

  Post File = "$namerun$.vtu"
  Output File = "$namerun$.result"
  !Output Intervals(1) = 30
  Output Intervals(1) = #OutPut
  max output level = 3
End

!----------------------------------------------------
!--------------- BODIES -------------------------
!----------------------------------------------------
```

-:--- extrushion_only.sif 23% L124 (Sif)

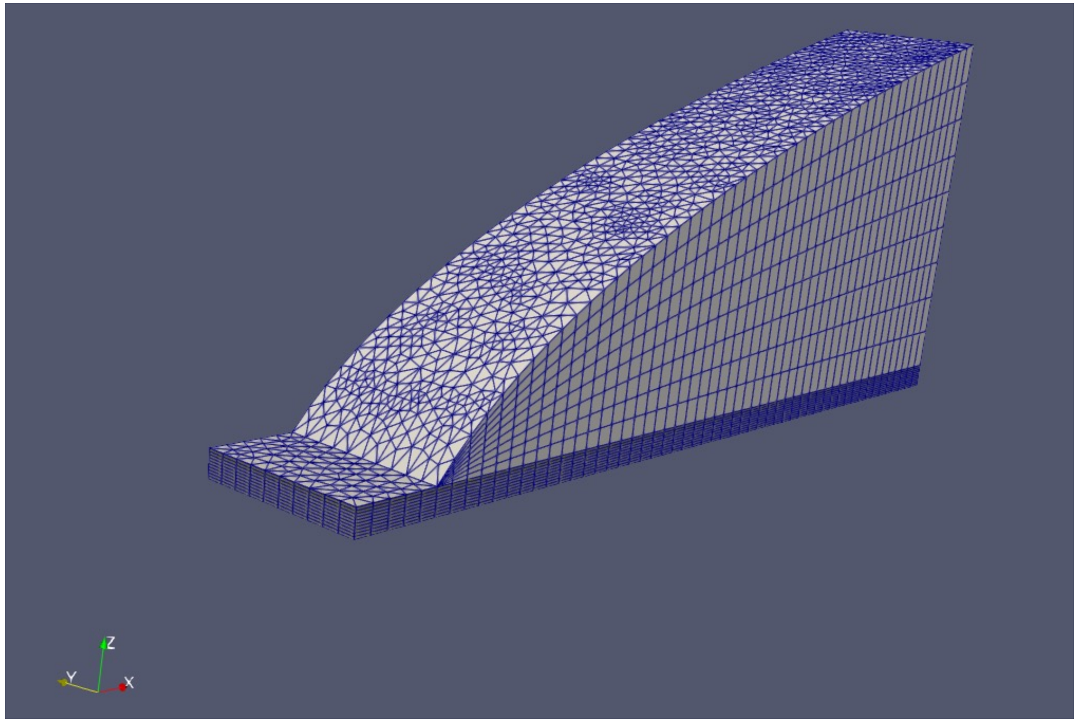
Changes in internal extrusion





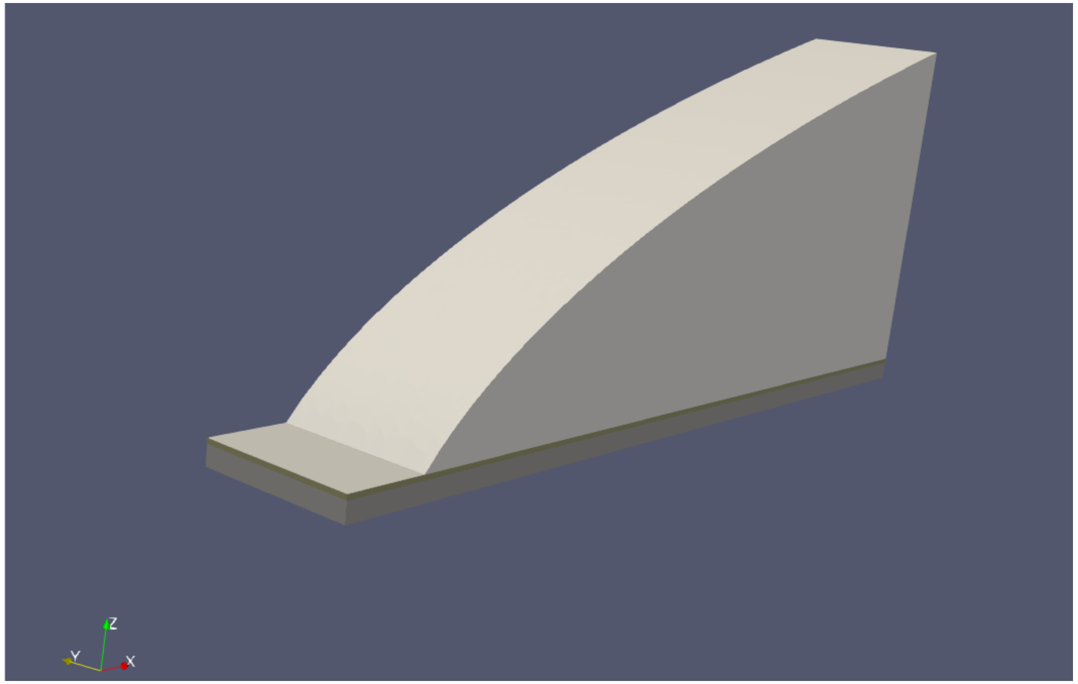

```
!---------------------------------------------------
!--------------- BODIES -------------------------
!---------------------------------------------------

! This body is located at the ice/bed interface and will be used to solve
! the sheet equation


Body 1
  Name= "bedrock"
  Equation = 2
  Material = 2
  Initial Condition = 1
End
Body 2
  Name= "Ice"
  Equation = 1
  Material = 1
  Initial Condition = 1
End

Body 3
  Name= "sheet"
  Equation = 3
  Material = 1
  Body Force = 1
  Initial Condition = 1
End

!---------------------------------------------------
!--------------- INITIAL CONDITIONS --------------
!---------------------------------------------------

!! for the sheet
-:---  extrushion_only.sif    29% L156    (Sif)
```

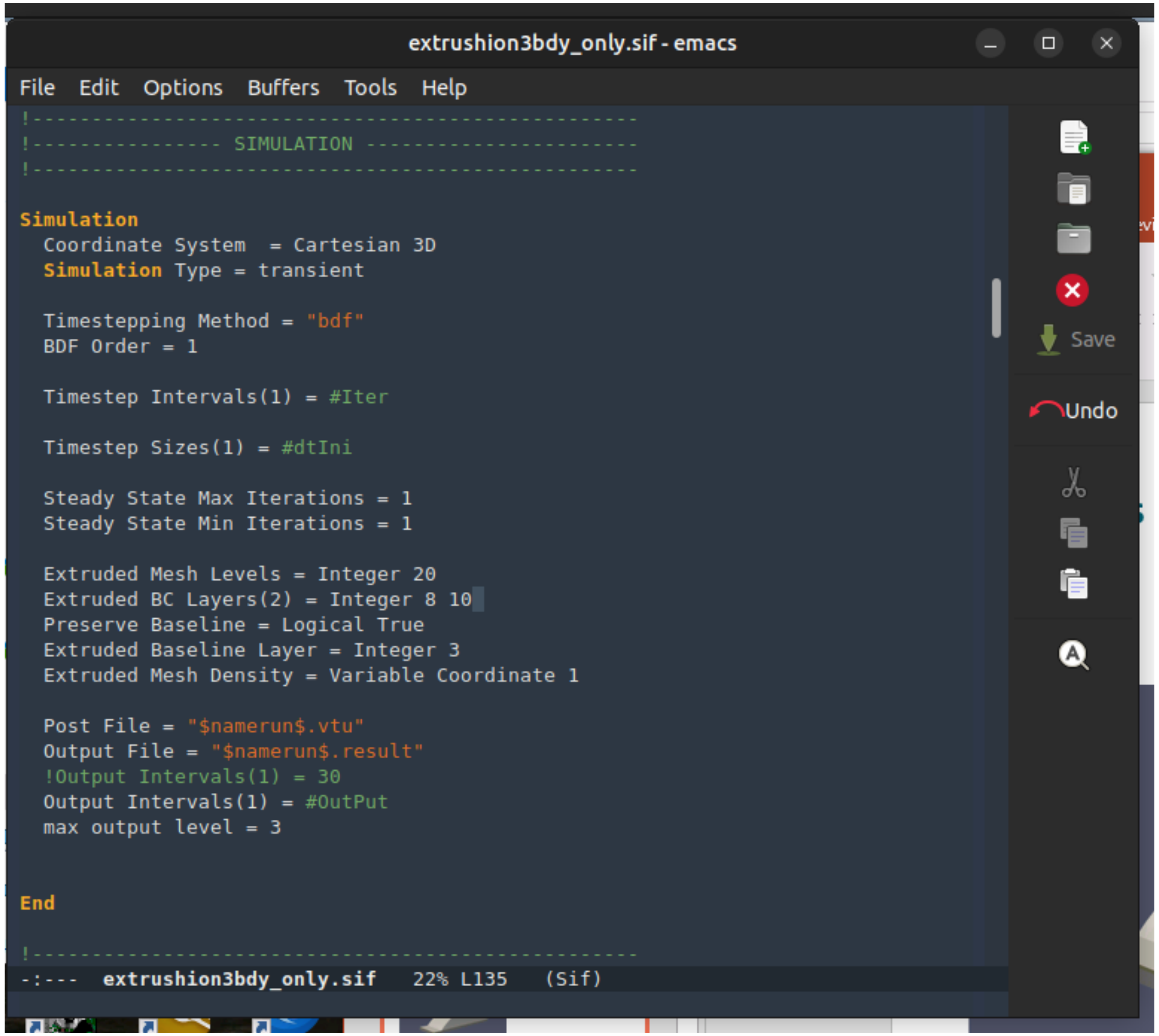
Changes in internal extrusion



- Even more layers
- Here with 3 layers (ice + sediment + bedrock)

Changes in internal extrusion





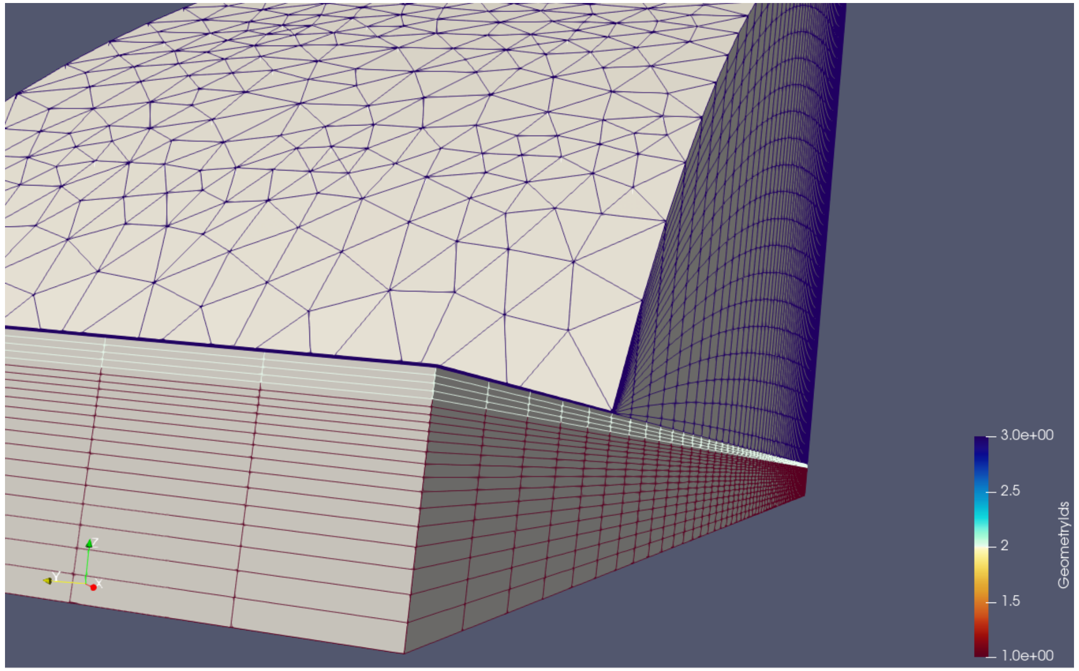
extrushion3bdy_only.sif - emacs

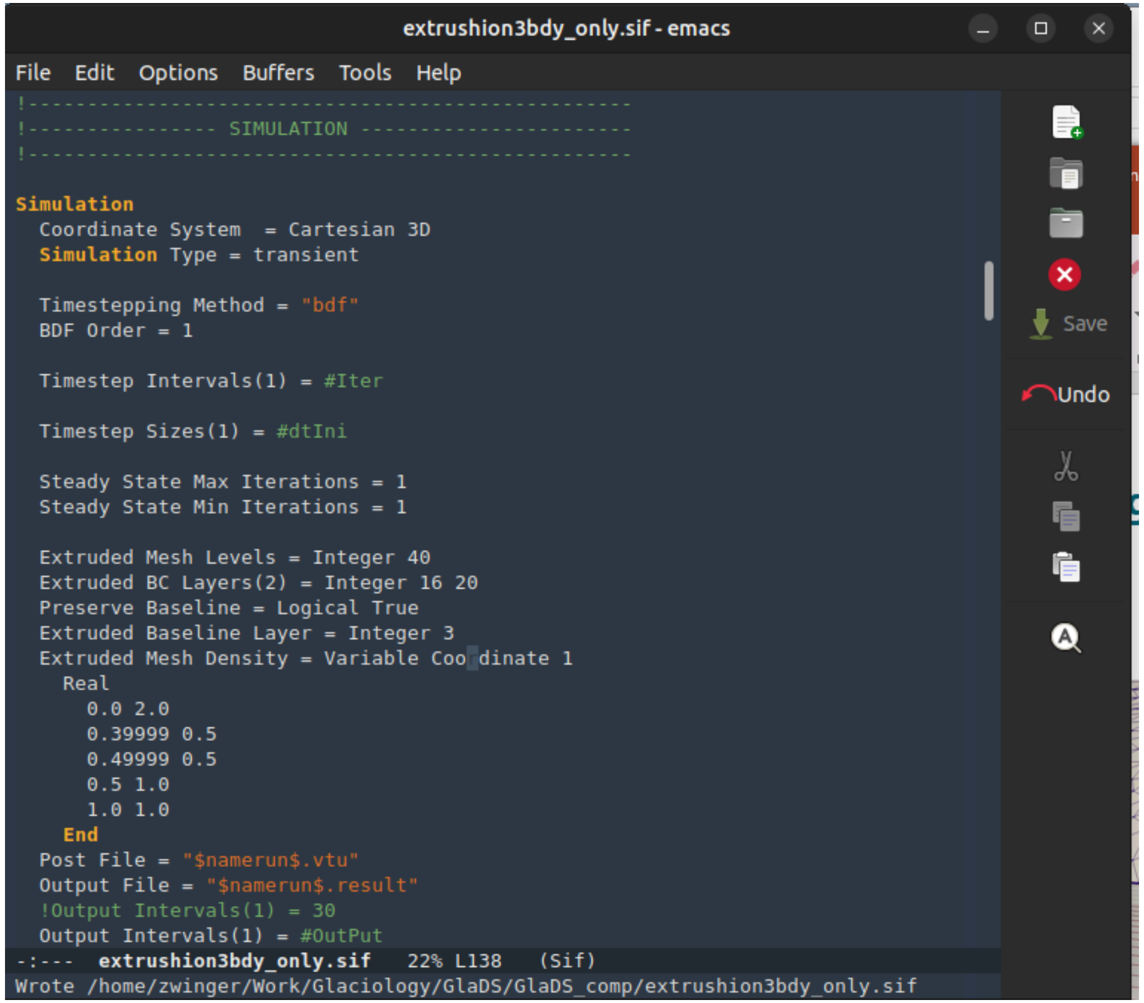
File Edit Options Buffers Tools Help

```
!-----------------------------------------------------
!---------------- SIMULATION ----------------------
!-----------------------------------------------------

Simulation
  Coordinate System  = Cartesian 3D
  Simulation Type = transient

  Timestepping Method = "bdf"
  BDF Order = 1

  Timestep Intervals(1) = #Iter

  Timestep Sizes(1) = #dtIni

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

  Extruded Mesh Levels = Integer 20
  Extruded BC Layers(2) = Integer 8 10
  Preserve Baseline = Logical True
  Extruded Baseline Layer = Integer 3
  Extruded Mesh Density = Variable Coordinate 1

  Post File = "$namerun$.vtu"
  Output File = "$namerun$.result"
  !Output Intervals(1) = 30
  Output Intervals(1) = #OutPut
  max output level = 3


End

!-----------------------------------------------------
```

-:--- extrushion3bdy_only.sif 22% L135 (Sif)

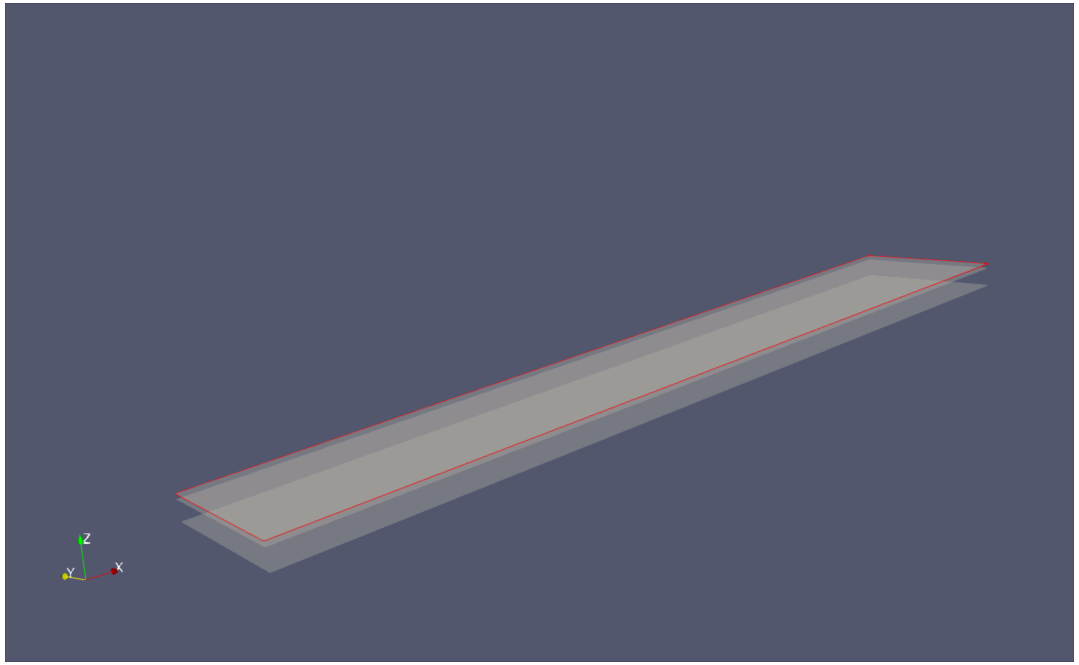
Changes in internal extrusion





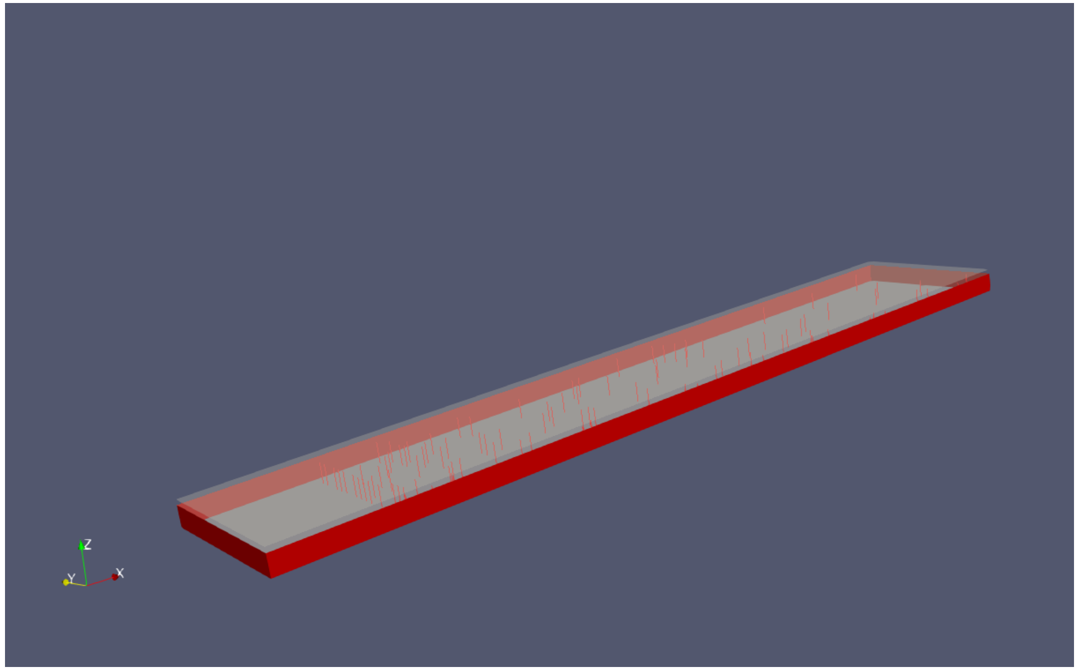
With mesh distribution

Changes in internal extrusion



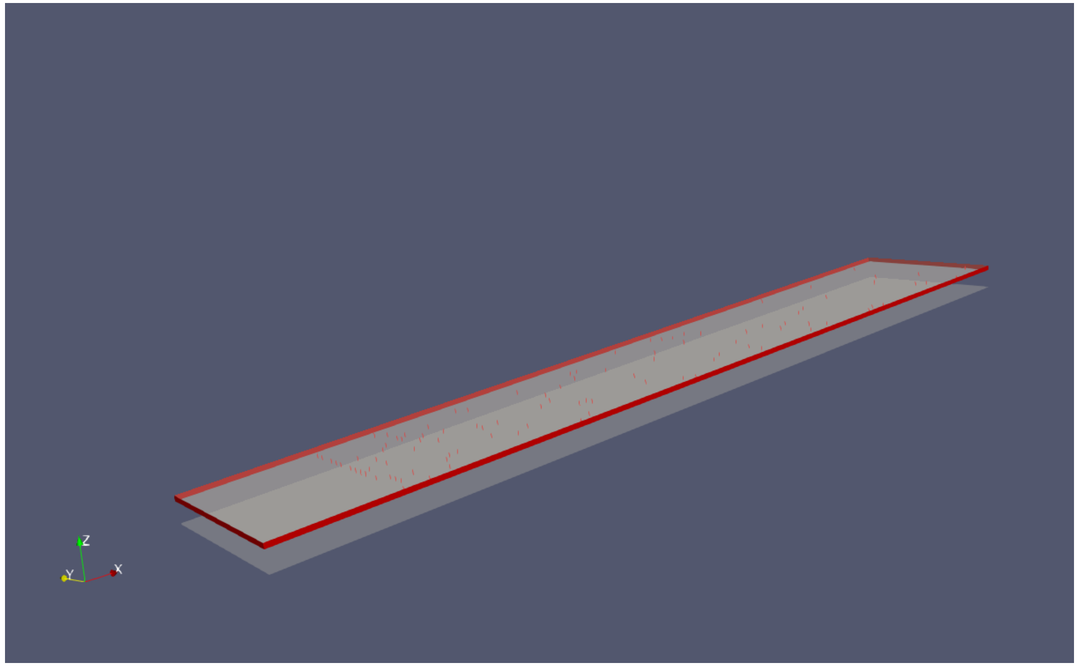
- Baseline (BC 1-4): 3 sides and moulins as points (not visible)

Changes in internal extrusion



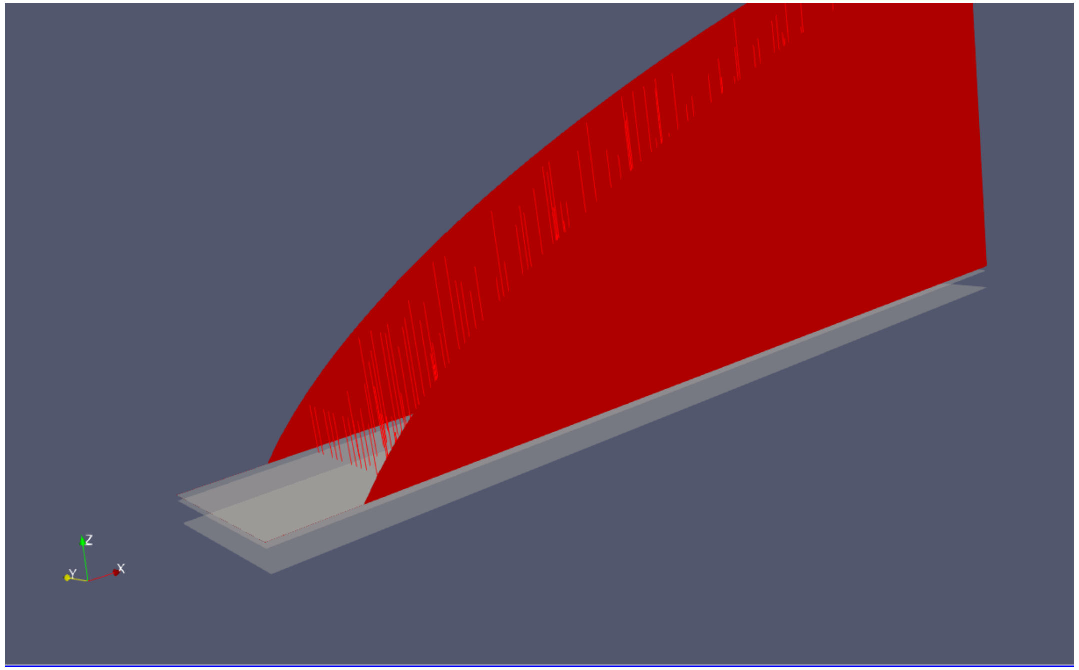
- Baseline (BC 1-4): 3 side-lines and moulins as points (not visible)
- Lowest part of extrusion (bedrock, BC 5-8): 3 sides + lines of moulins

Changes in internal extrusion



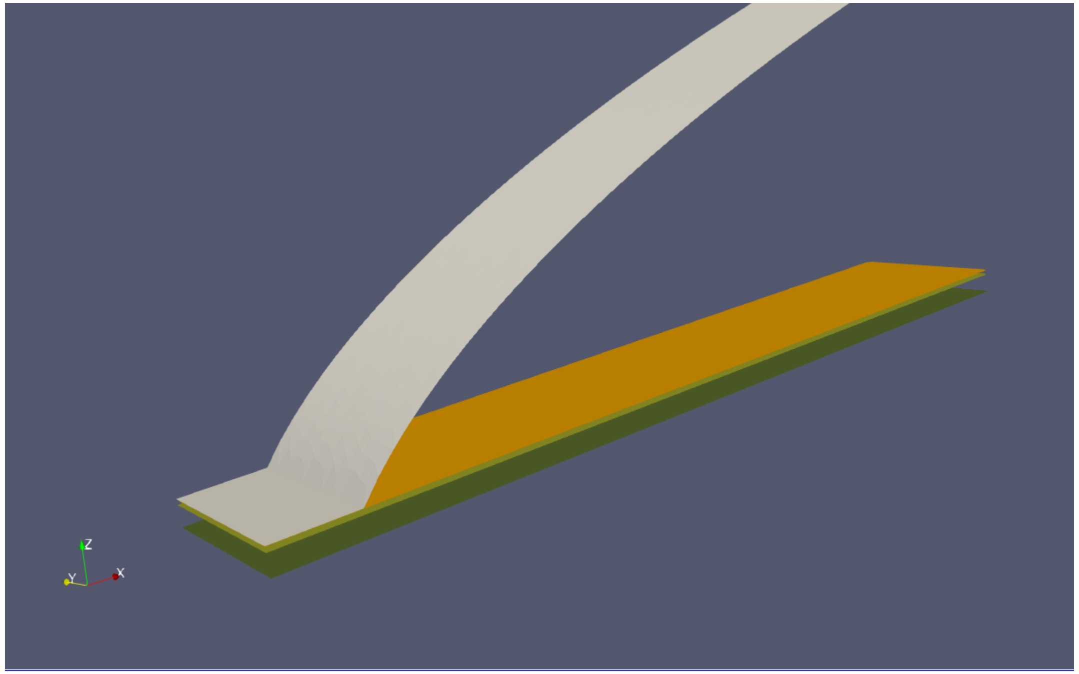
- Baseline (BC 1-4): 3 side-lines and moulins as points (not visible)
- Lowest part of extrusion (bedrock, BC 5-8): 3 sides + lines of moulins
- Middle part of extrusion (sediment, BC 9-12): 3 sides + lines of moulins

Changes in internal extrusion



- Baseline (BC 1-4): 3 side-lines and moulins as points (not visible)
- Lowest part of extrusion (bedrock, BC 5-8): 3 sides + lines of moulins
- Middle part of extrusion (sediment, BC 9-12): 3 sides + lines of moulins
- Upper part of extrusion (ice, BC 13-16): 3 sides + lines of moulins

Changes in internal extrusion



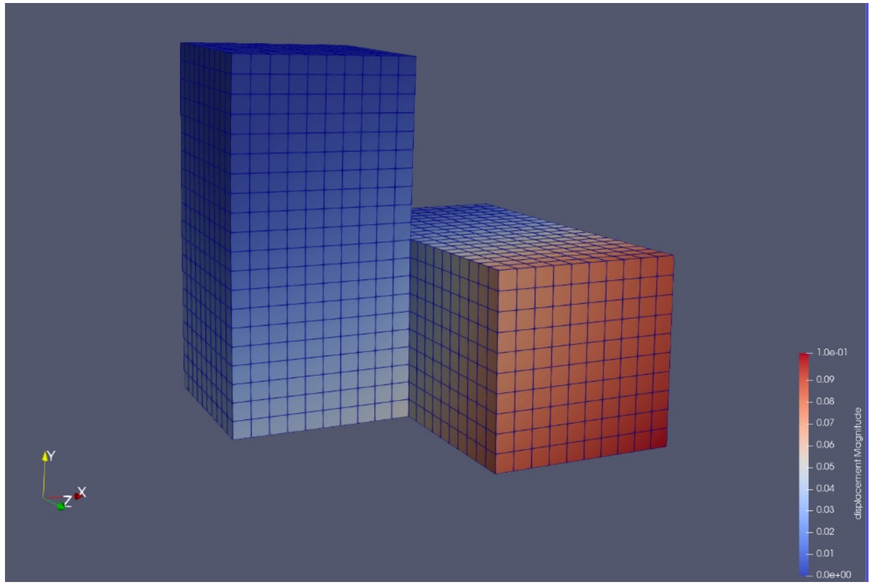
- Baseline (BC 1-4): 3 side-lines and moulins as points (not visible)
- Lowest part of extrusion (bedrock, BC 5-8): 3 sides + lines of moulins
- Middle part of extrusion (sediment, BC 9-12): 3 sides + lines of moulins
- Upper part of extrusion (ice, BC 13-16): 3 sides + lines of moulins
- Horizontal surfaces (BC 17-20): bottom until free surface

AMGX now included in devel branch

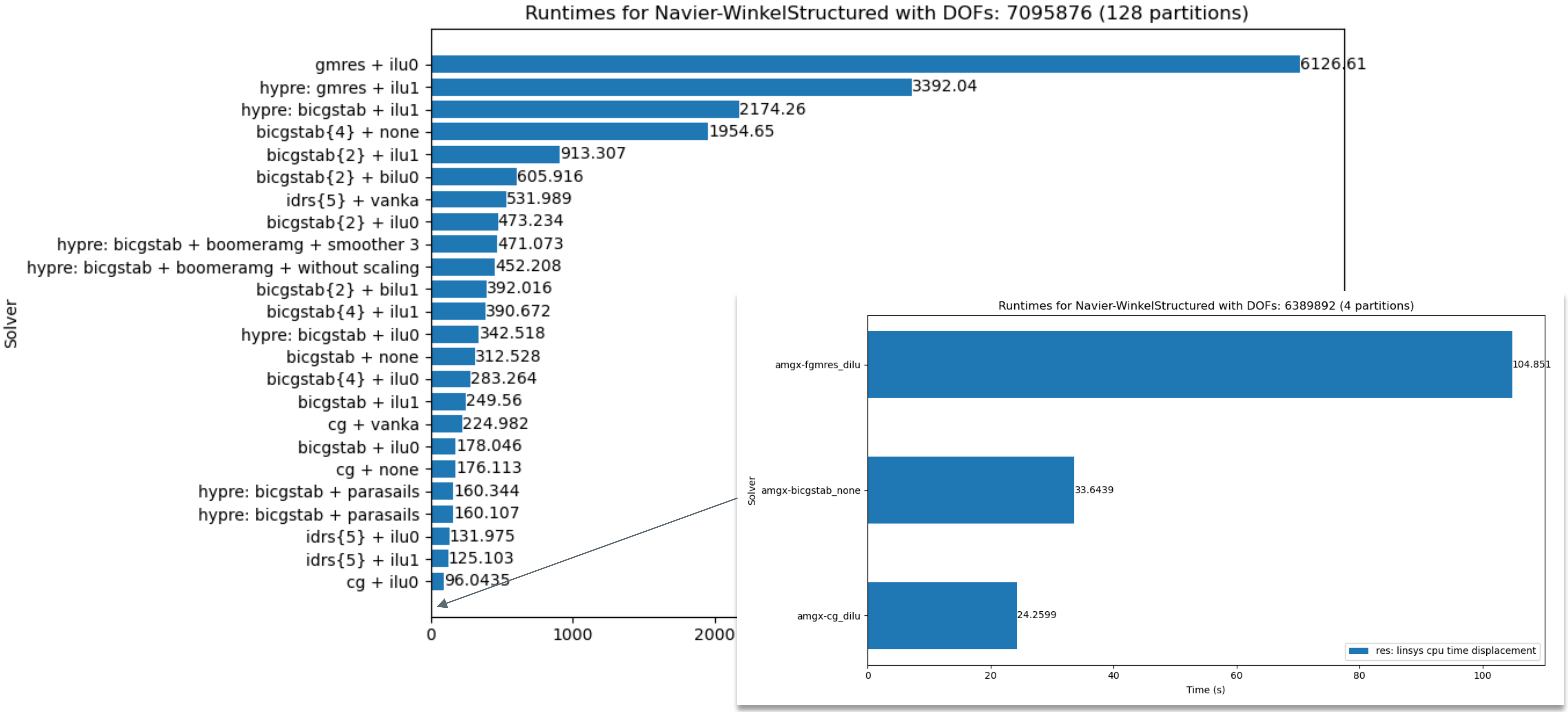
Thomas Zwinger

AMGX now included in devel branch

- Tested systematically
  https://github.com/ElmerCSC/elmer-linsys
- Navier problem on slightly more complex geometry
- Tests on mahti.csc.fi (1 node has 2x64 cores AMD Rome and 4 Nvidia Ampere A100 GPUs)
- Compared to tests on CPU-only nodes

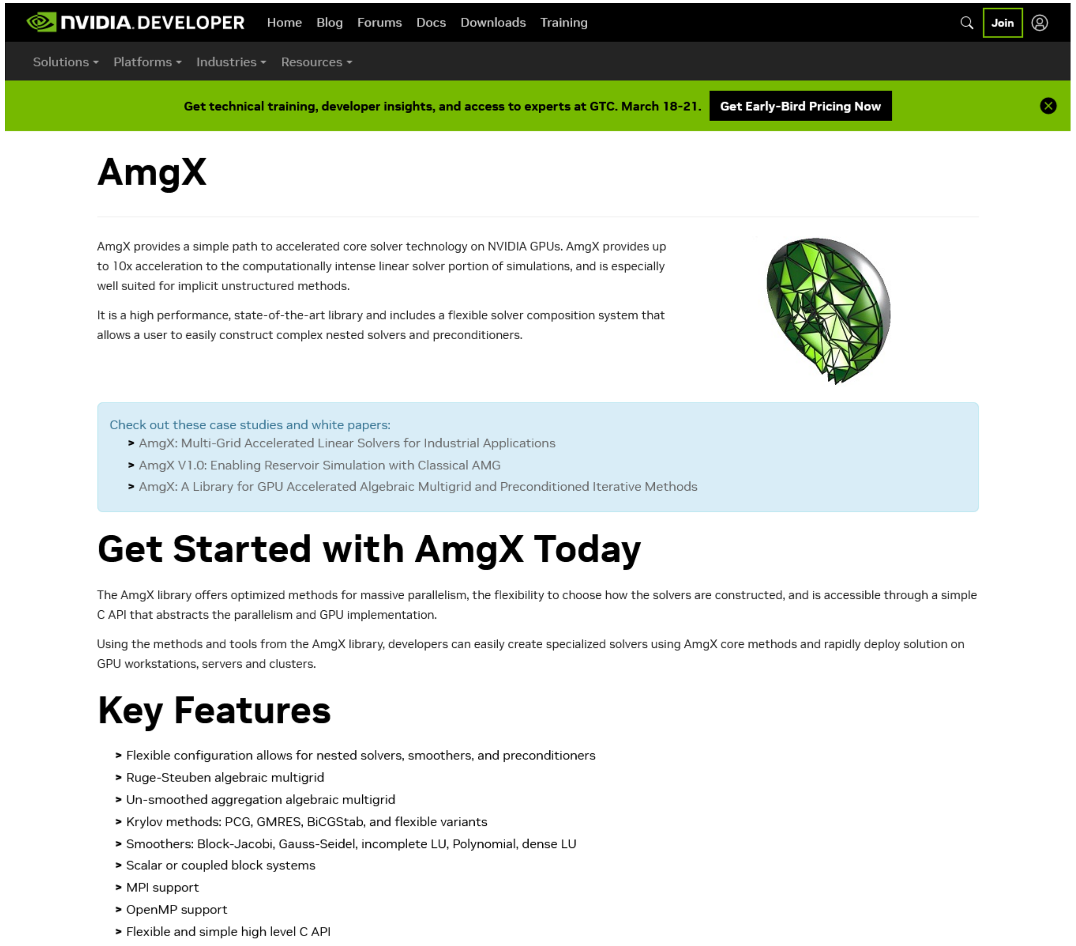


AMGX performance



AMGX

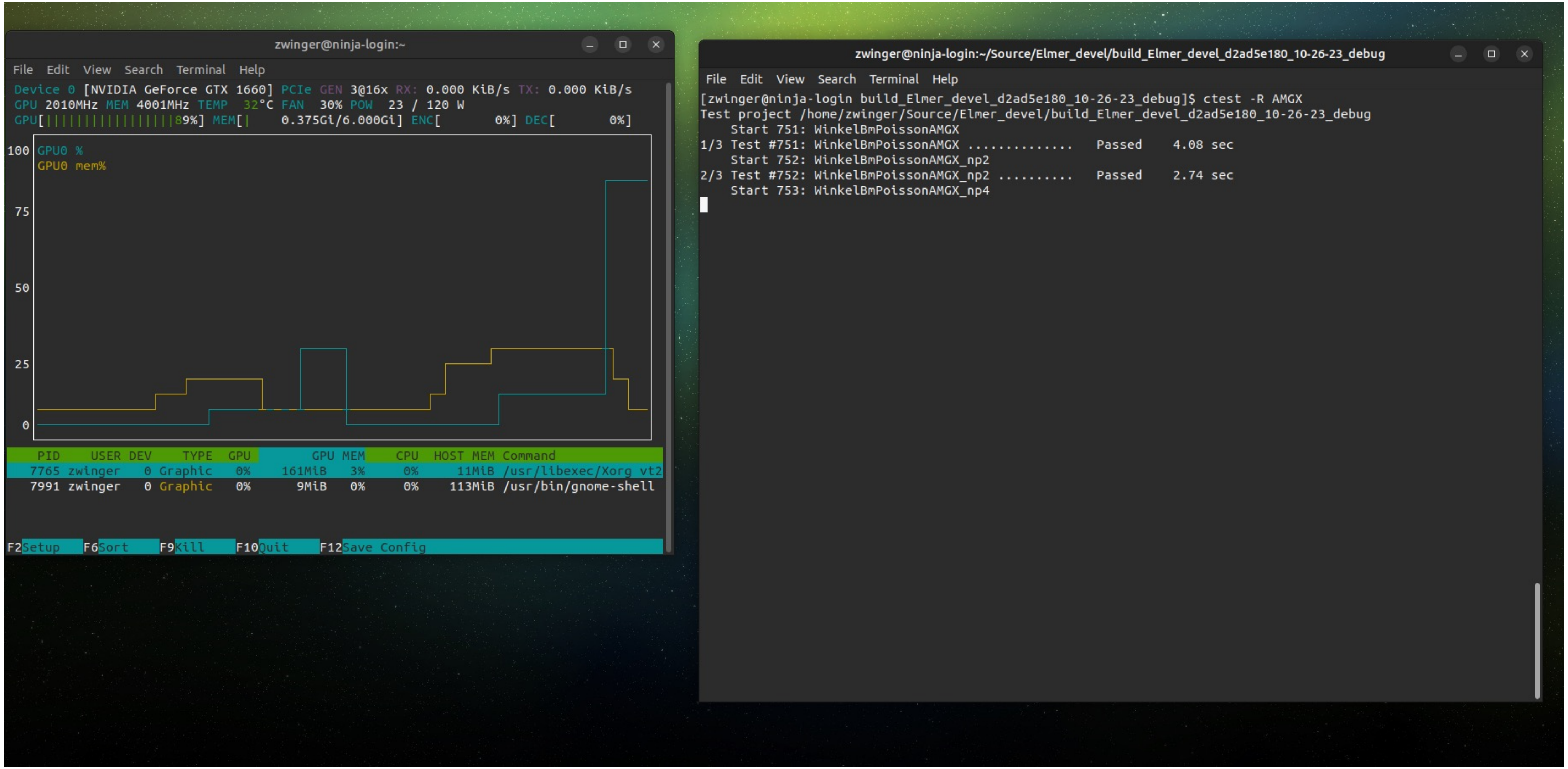
https://developer.nvidia.com/amgx



- Anyone with an Nvidia card (also consumer) can use it
- Downloadable under https://github.com/NVIDIA/AMGX
- Test: `WinkelBmPoissonAMGX`
- Needs special cmake flags

```
-DWITH_AMGX:BOOL=TRUE \
-DAMGX_ROOT="${AMGX_HOME}" \
-DAMGX_INCLUDE_DIR="${AMGX_HOME}/include/;${CUDAINC}" \
-DAMGX_LIBRARY="${AMGX_HOME}/lib/libamgx.a" \
-DCUDA_LIBRARIES="-L${CUDALIB} -lcusparse -lcublas -lcusolver -lcudart_static -
lnvToolsExt -ldl -lpthread /usr/lib64/librt.so" \
 -DCUDA_LIBDIR="${CUDALIB}"\
 -DCUDA_INCLUDE_DIR="${CUDAINC}"\
```

AMGX ctest testcase



Elmer GPU developments

- Porting to AMD world (ROCalution instead of AMGX)
- Started looking into OpenMP GPU offloading for matrix assembly (this is hard)
- Currently issues with data transfer between main and GPU memory - might go away with next gen hardware
- Final goal is that main Elmer/Ice solvers at some stage run on GPUs

Reporting unused keywords

- Ease of adding keywords in Elmer has a caveat
  - You can easily add unused keywords without realizing that they have no effect
- Typos may go unnoticed when casting
- Copy-pasting leaves history of previous sif file
- Not all keywords are futile, they just where not needed this time…

```
MAIN: Reporting unused list entries for sif improvement!
MAIN: If you do not want these lines undefine > DEVEL_LISTUSAGE < !
  Unused keywords:
     Simulation           debug element
     Constants            stefan boltzmann
     Boundary Condition 2  velocity 1
     Boundary Condition 2  velocity 2
     Boundary Condition 2  velocity 3
     Solver 2             flow model
     Solver 2             linear system abort not converged
     Solver 2             viscosity newton relaxation factor
     Solver 2             nonlinear system consistent norm
MAIN: *** Elmer Solver: ALL DONE ***
```

Report unused keywords

- Activatio & deactivation in `fem/config.h.cmake`
- + "`Max Output Level >= 6`"

```
/* Have these defined only for debugging or optimization purposes */
/* #define DEVEL_LISTCOUNTER */
#define DEVEL_LISTUSAGE
/* #define DEVEL_KEYWORDMISSES */
```

```
Unused keywords:
    Simulation          debug element
    Simulation          solver input file
    Simulation          timer: loadmesh real time
    Simulation          timer: meshstabparams real time
    Simulation          initialization phase
    Constants           stefan boltzmann
    Boundary Condition 1  name
    Boundary Condition 2  name
    Boundary Condition 2  velocity 1
    Boundary Condition 2  velocity 2
    Boundary Condition 2  velocity 3
    Material 1          name
    Solver 1            active mesh dimension
    Solver 1            no matrix
    Solver 2            flow model
    Solver 2            linear system abort not converged
    Solver 2            viscosity newton relaxation factor
    Solver 2            nonlinear system consistent norm
    Solver 2            active mesh dimension
    Solver 3            active mesh dimension
  Used keywords:
    Simulation          2     coordinate system
    Simulation          7     simulation type
    Simulation          1     steady state max iterations
    Simulation          1     steady state min iterations
    Simulation          1     initialize dirichlet conditions
    Simulation          1     max output level
    Simulation          2     extruded mesh levels
    Simulation          1     extruded max coordinate
    Constants           2     gas constant
    Constants           1     gravity
    Equation 1          3     active solvers
    Equation 1          3     mapcoordinate
    Equation 1          6     hydro-stokes
    Equation 1          3     resultoutput
    Body Force 1        4     flow bodyforce 1
    Body Force 1        4     flow bodyforce 2
    Body Force 1        4     flow bodyforce 3
    Boundary Condition 1  5     target boundaries
    Boundary Condition 2  13139 bottom surface
    Boundary Condition 2  78836 horizvelo 1
    Boundary Condition 2  78836 horizvelo 2
    Boundary Condition 3  13140 top surface
    Material 1          5     density
    Material 1          4     viscosity
    Material 1          4     viscosity model
    Material 1          3     glen exponent
    Material 1          3     critical shear rate
    Material 1          2     limit temperature
    Material 1          2     rate factor 1
    Material 1          2     rate factor 2
    Material 1          2     activation energy 1
    Material 1          2     activation energy 2
    Material 1          2     glen enhancement factor
    Material 1          2     set arrhenius factor
    Material 1          3     arrhenius factor
    Solver 1            4     exec solver
    Solver 1            9     equation
    Solver 1            4     procedure
    Solver 1            1     active coordinate
    Solver 1            1     mesh velocity variable
    Solver 1            1     mesh velocity first zero
    Solver 1            1     dot product tolerance
    Solver 2            16    equation
    Solver 2            4     procedure
    Solver 2            2     variable
    Solver 2            1     optimize bandwidth
    Solver 2            8     linear system solver
    Solver 2            2     linear system iterative me
    Solver 2            2     linear system max iteratio
    Solver 2            3     linear system residual out
    Solver 2            2     linear system convergence
    Solver 2            5     linear system precondition
```

HydrostaticNSVec

- Ref: Ralf Greve & Heinz Blatter: *Dynamics of Ice Sheets and Glaciers*
- Motivation
  - Missing piece between full 3D Stokes (IncompressibleNSVec) and 2D shell solvers
  - Much smaller linear system compared to full Stokes 2x2 vs 4x4
  - Pos.def. linear system - Not a saddle-point problem
    => large selection of good linear system strategies!?
- Implementation strategy
  - Copy-paste from IncompressibleNSVec
  - Use of same keywords as much as possible
  - Pre/post processing automated via internal use of structured mesh
- Additional assumption
  - 3D mesh with generated via extrusion

HydrostaticNSVec – the model

- Hydrostatic 1st order approximation

$$\frac{\partial v_z}{\partial x}\Big/\frac{\partial v_x}{\partial z},\quad \frac{\partial v_z}{\partial y}\Big/\frac{\partial v_y}{\partial z} \sim \frac{[W]}{[L]}\Big/\frac{[U]}{[H]} = \frac{[W]}{[U]}\frac{[H]}{[L]} = \varepsilon^2 \sim 10^{-6}$$

G&B (5.68)

- Resulting to:

$$\begin{aligned}
4\frac{\partial}{\partial x}\left(\eta\frac{\partial v_x}{\partial x}\right) + 2\frac{\partial}{\partial x}\left(\eta\frac{\partial v_y}{\partial y}\right) + \frac{\partial}{\partial y}\left(\eta\left(\frac{\partial v_x}{\partial y} + \frac{\partial v_y}{\partial x}\right)\right) \\
+ \frac{\partial}{\partial z}\left(\eta\frac{\partial v_x}{\partial z}\right) = \rho g\frac{\partial h}{\partial x}, \\
4\frac{\partial}{\partial y}\left(\eta\frac{\partial v_y}{\partial y}\right) + 2\frac{\partial}{\partial y}\left(\eta\frac{\partial v_x}{\partial x}\right) + \frac{\partial}{\partial x}\left(\eta\left(\frac{\partial v_x}{\partial y} + \frac{\partial v_y}{\partial x}\right)\right) \\
+ \frac{\partial}{\partial z}\left(\eta\frac{\partial v_y}{\partial z}\right) = \rho g\frac{\partial h}{\partial y}.
\end{aligned}$$

Elliptic operators
Diagonally dominated
2x2 block system

Easy!

G&B (5.70)

Nonlinear viscosity

- Nonlinear viscosity model exactly as in IncompresibleNSVec with strainrate velocity defined by

$$d_e = \left\{ \left(\frac{\partial v_x}{\partial x}\right)^2 + \left(\frac{\partial v_y}{\partial y}\right)^2 + \frac{\partial v_x}{\partial x}\frac{\partial v_y}{\partial y} + \frac{1}{2}\frac{\partial v_x}{\partial y}\frac{\partial v_y}{\partial x} + \frac{1}{4}\left(\frac{\partial v_x}{\partial y}\right)^2 + \frac{1}{4}\left(\frac{\partial v_y}{\partial x}\right)^2 + \frac{1}{4}\left(\frac{\partial v_x}{\partial z}\right)^2 + \frac{1}{4}\left(\frac{\partial v_y}{\partial z}\right)^2 \right\}^{1/2}.$$

G&B (5.71)

Postprocessing fields

- Vertical velocity

$$v_z = v_z\big|_{z=b} - \int_b^z \left(\frac{\partial v_x}{\partial x} + \frac{\partial v_y}{\partial y} \right) \mathrm{d}\bar{z}\,.$$

G&B (5.72)

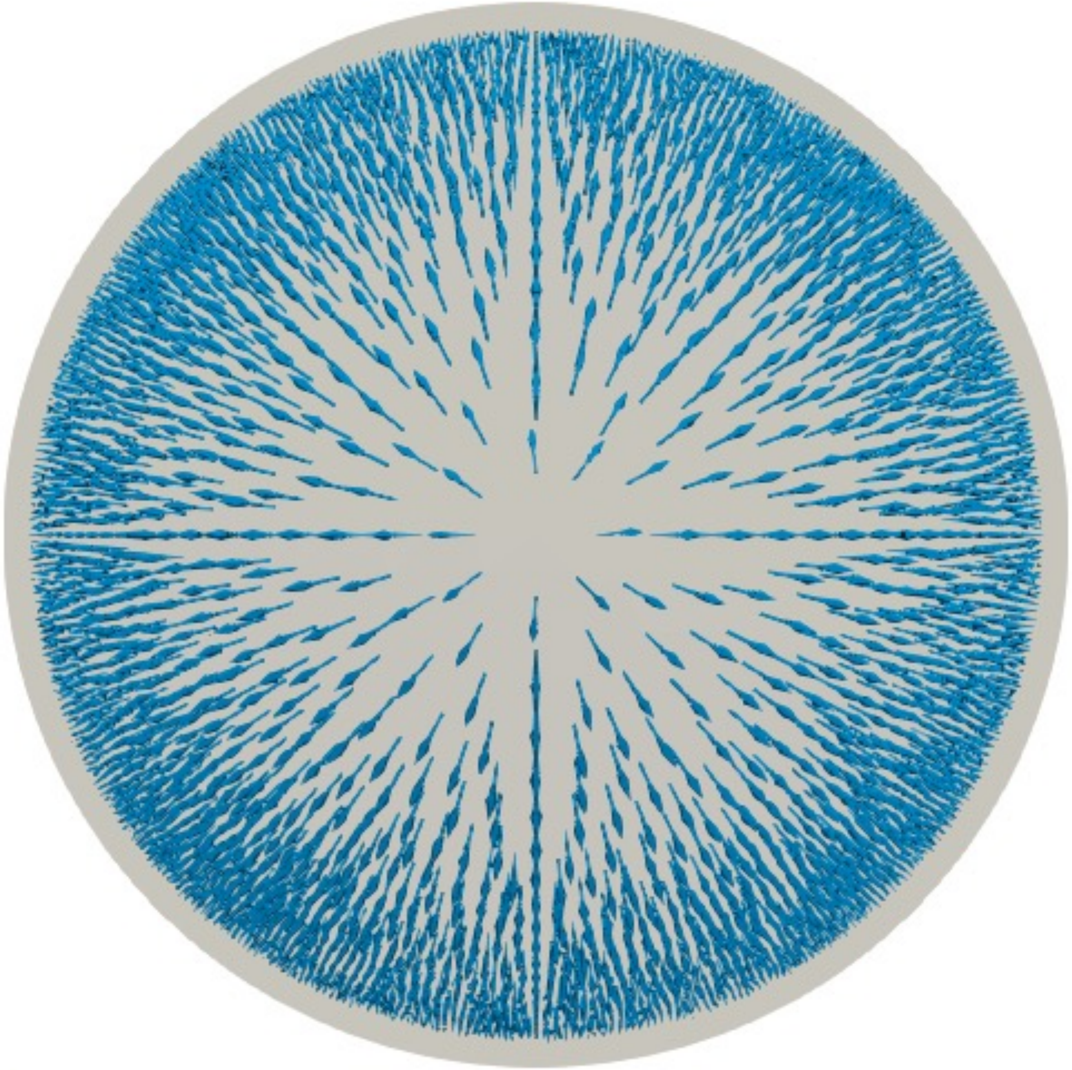
$$\frac{\partial b}{\partial t} + v_x \frac{\partial b}{\partial x} + v_y \frac{\partial b}{\partial y} - v_z = N_\mathrm{b} a_\mathrm{b}^\perp\,.$$

G&B (5.31)

- Derivatives appearing in postprocessing are averaged over elements!

HydrostaticNSVec: Buehler profile

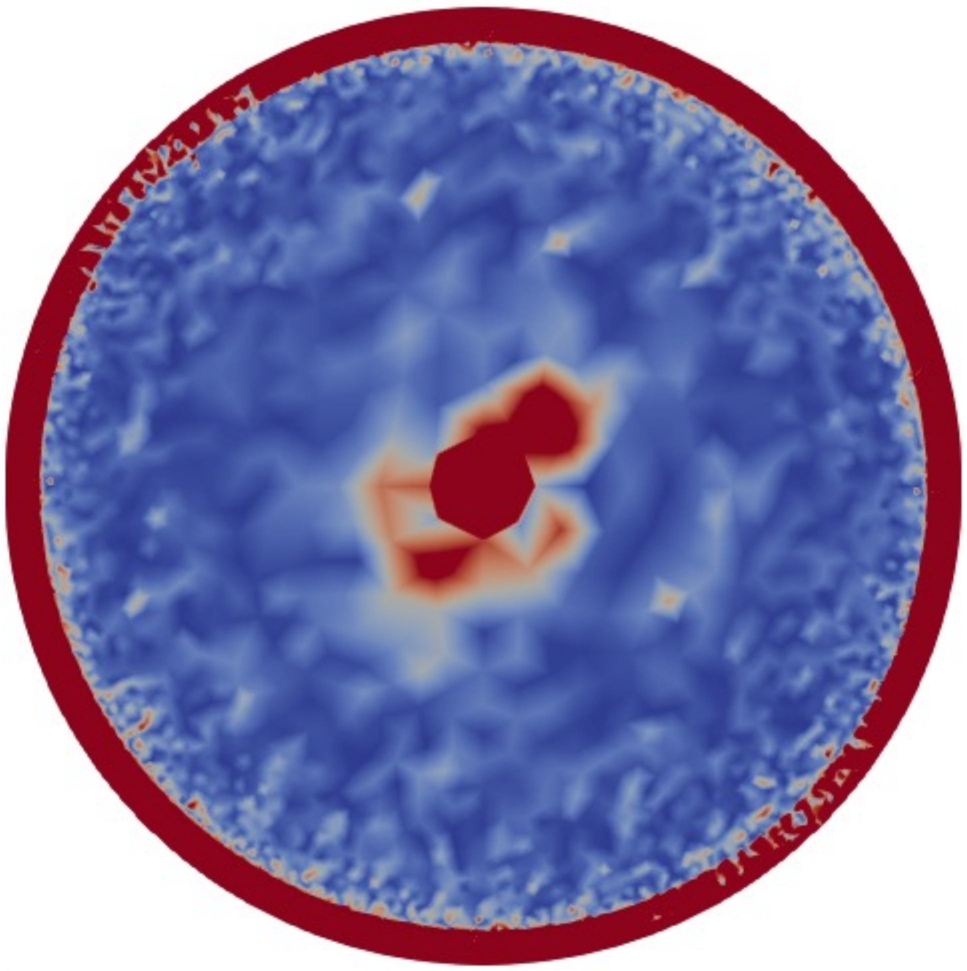
- This case should be straight-forward
- How to estimate the error?
- New operators for StructuredProjectToPlane
    - "error norm"
    - "error max"
    - "error projected"



HydrostaticNSVec: Buehler profile

```
Solver 4
  Equation = "ModelError"
  Procedure = "StructuredProjectToPlane"
"StructuredProjectToPlane"
  Active Coordinate = Integer 3
  Project to everywhere = Logical True

  Variable 1 = HorizVelo
  Error Variable 1 = String "Flow Solution"
  Operator 1 = "error norm"
  Target Variable 1 = "velo error"
End
```

$$err = |u - v|/(|u| + |v|)/2$$



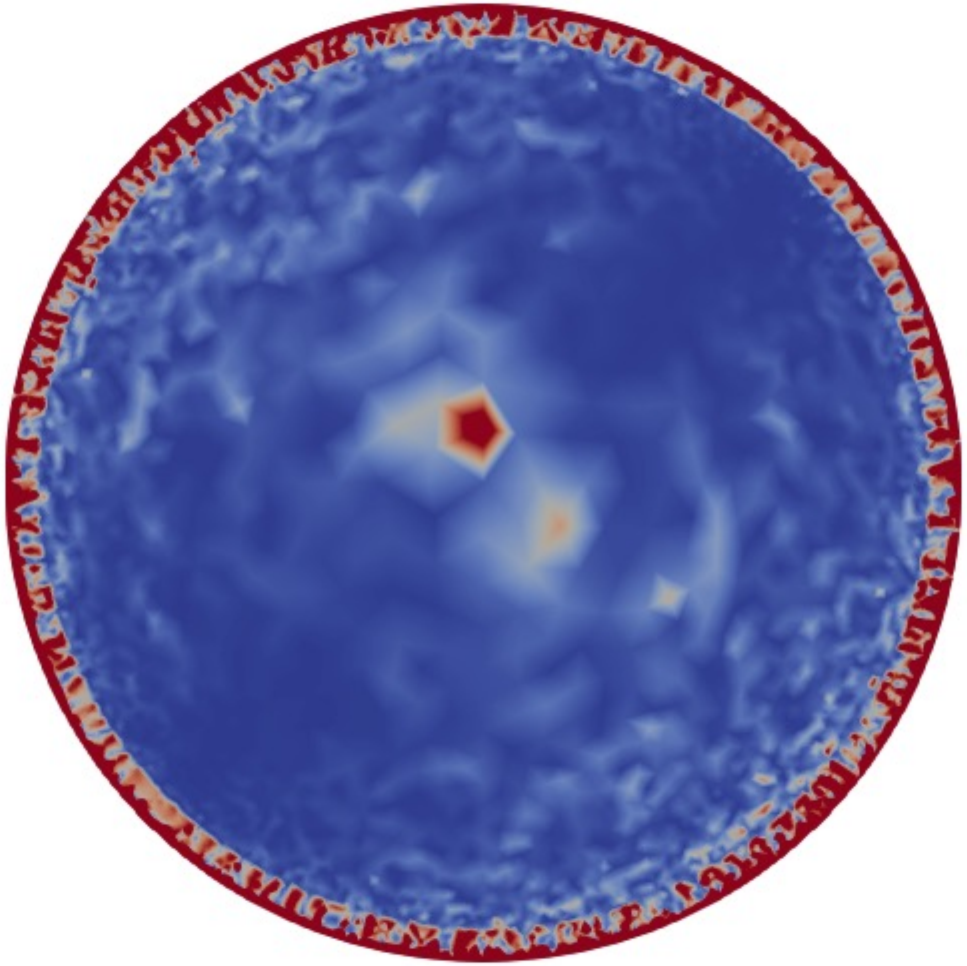
Error scaled to [0,0.001]

HydrostaticNSVec: Buehler profile

```
Solver 4
  Equation = "ModelError"
  Procedure = "StructuredProjectToPlane"
"StructuredProjectToPlane"
  Active Coordinate = Integer 3
  Project to everywhere = Logical True

  Variable 1 = HorizVelo
  Error Variable 1 = String "Flow Solution"
  Operator 1 = "error projected"
  Target Variable 1 = "velo projected error"
End
```

Find c that minimizes $|u\text{-}cv|$!

$$err = |u - cv|/(|u| + |cv|)/2$$

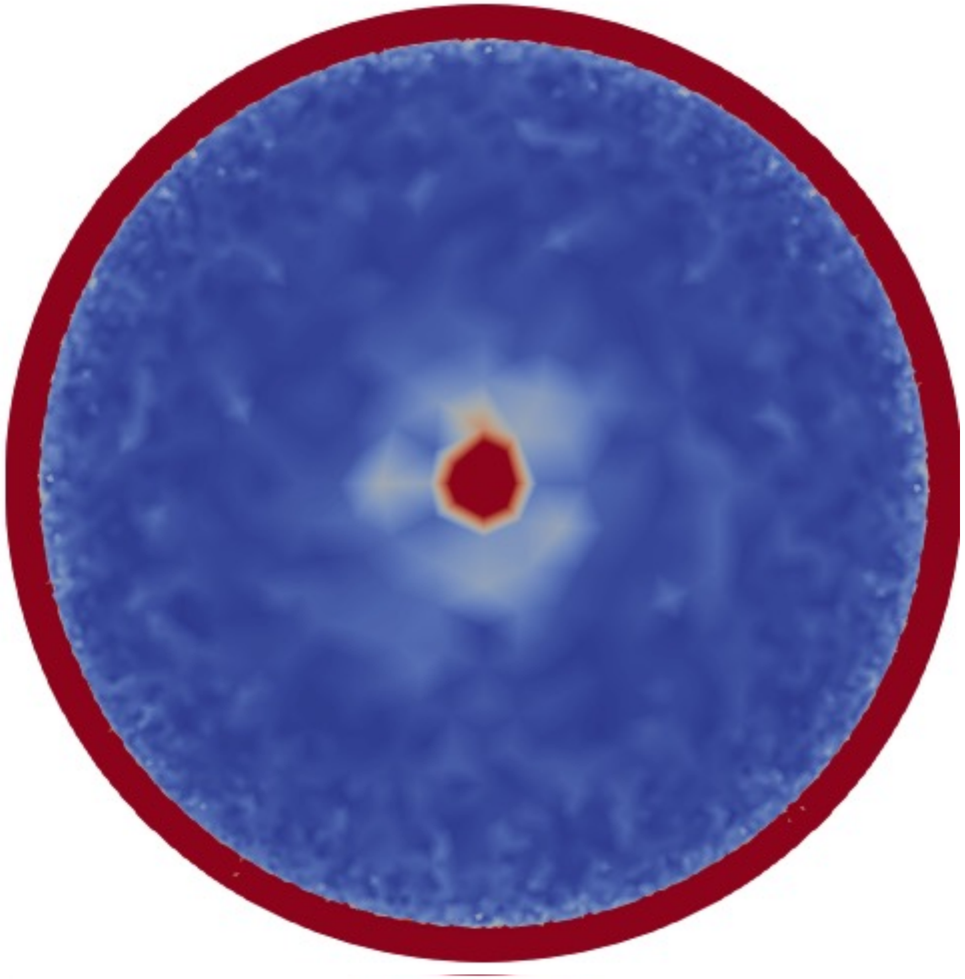


Error scaled to [0,0.001]

HydrostaticNSVec: Buehler profile

```
Solver 4
  Equation = "ModelError"
  Procedure = "StructuredProjectToPlane"
"StructuredProjectToPlane"
  Active Coordinate = Integer 3
  Project to everywhere = Logical True

  Variable 1 = HorizVelo
  Error Variable 1 = String "Flow Solution"
  Operator 1 = "error max"
  Target Variable 1 = "velo error max"
End
```

$$err = |u - v|_\infty / (|u|_\infty + |v|_\infty)/2$$

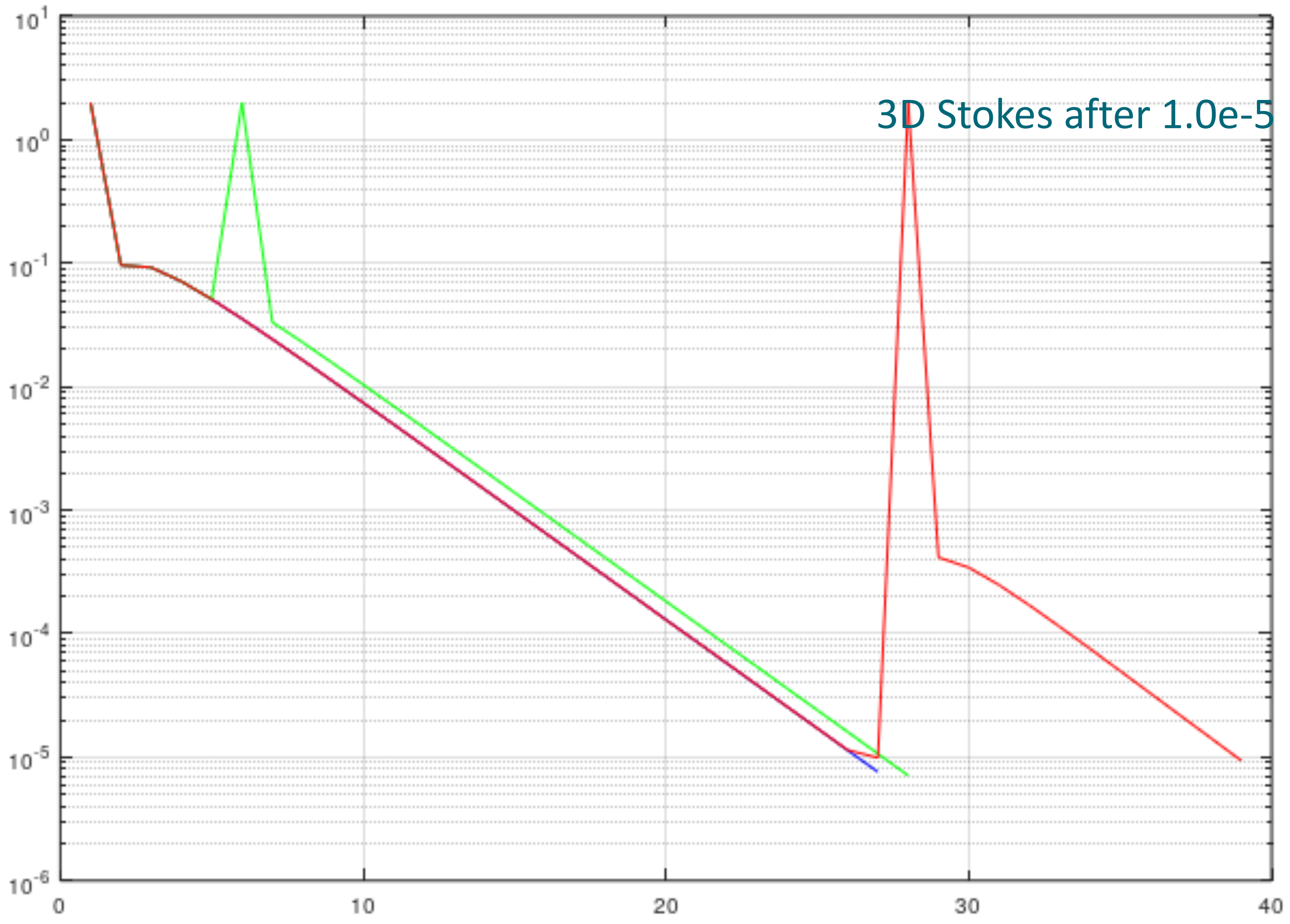


Error scaled to [0,0.001]

HydrostaticNSVec – initial guess for 3D Stokes

- We can run the two solvers in sequence
- Does this help in convergence?
- A simple case with Picard was studied
  - ”Constant-Viscosity Start = False”
- We may be able to replace more expensive iterations with cheaper ones
  - Effect is not dramatic even at best
- Might save initial convergence?

Relative error with combined iteration count



HydrostaticNSVec – using simpler model as preconditioner?

- For 3D Stokes: Au=b
- For Hydrostatic Stokes: Bv=c
- GCR sequence for Au=b
  - Compute r=Au-b
  - Project r to c
  - Solve Bv=c
  - expand v to dx

- Preliminary machinery in Elmer (for other problems)
- probably does not beat the block preconditioner…

HydrostaticNSVec – consistency test

- ISMIP HOM C