Towards Interactive Analysis of Regional Ice Flow

Iulian Grindeanu, Jed Brown, Dmitry Karpeev, Barry Smith,
Tim Tautges, Jean Utke

Argonne National Laboratory

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Community Earth System Model CESM

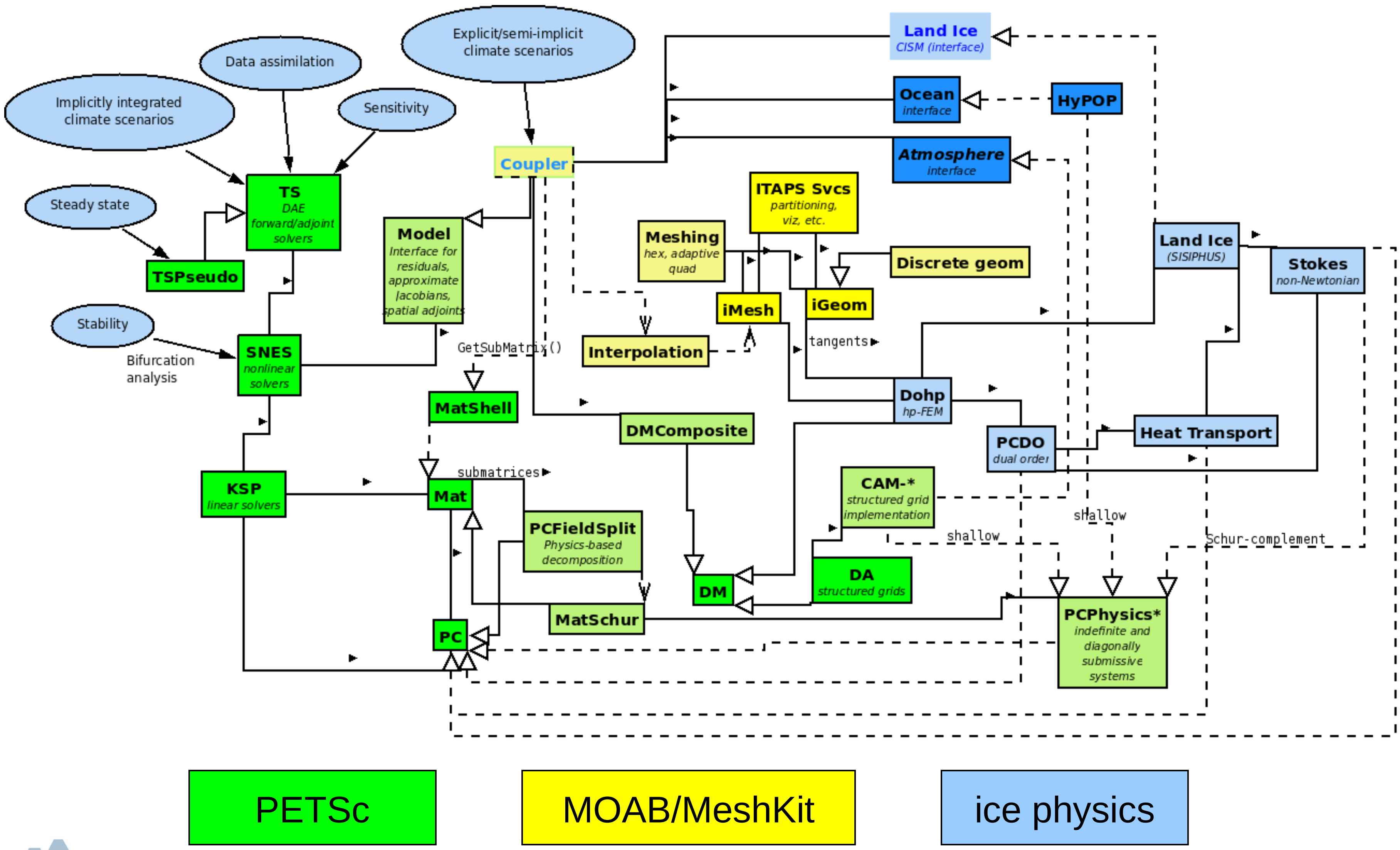
Motivation and objectives

Prescribing suitable domains and boundary conditions for regional ice flow models is typically a time-consuming process.

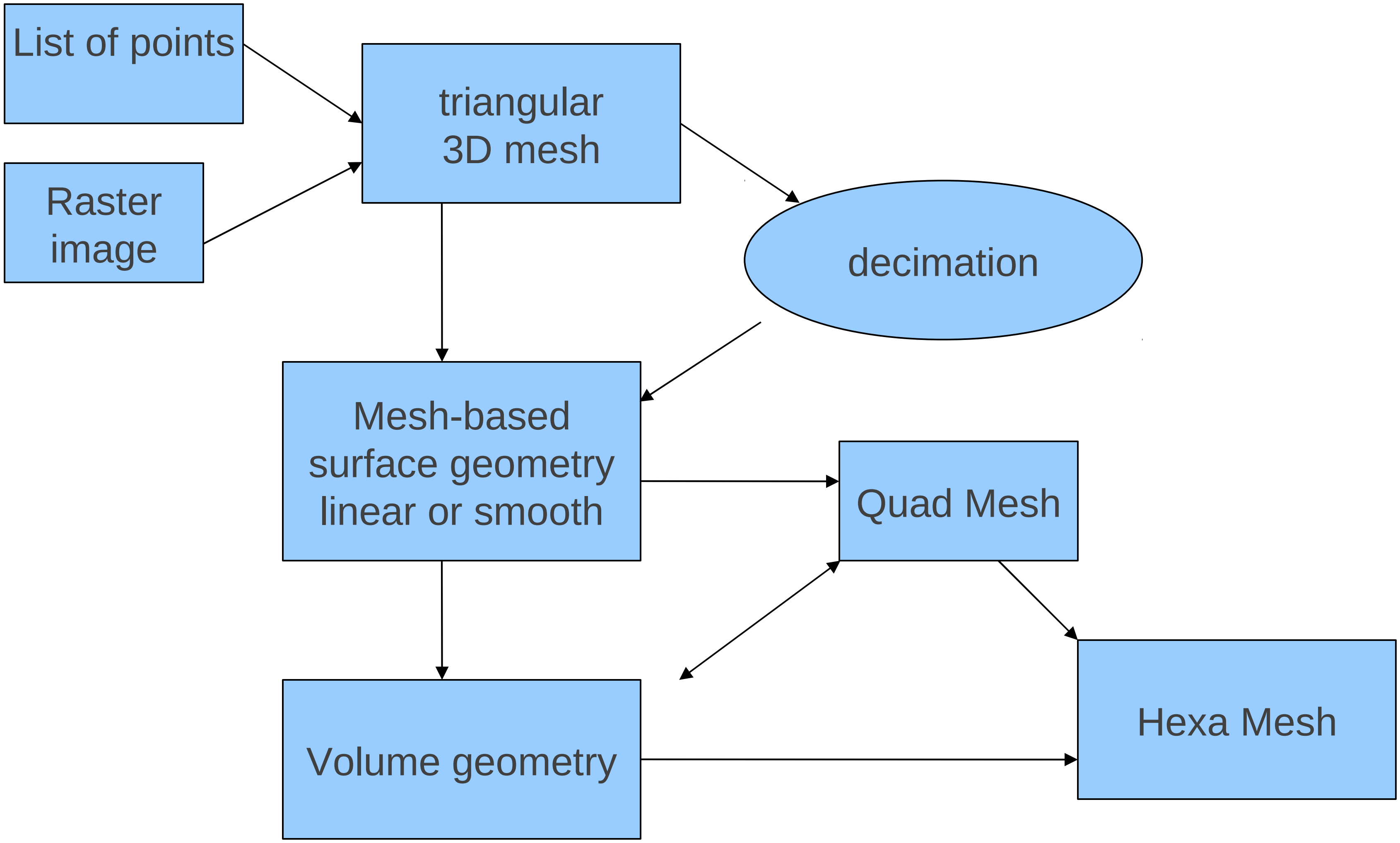
Field observations which will be used for boundary conditions or constraints for inverse modeling are often available in different formats, projections, sampling frequency, and with different conventions about missing data.

In this work, we present recently developed tools to "close the loop" between defining a problem in GIS and visualizing results from an ice flow model.

SISIPHUS Software Component View

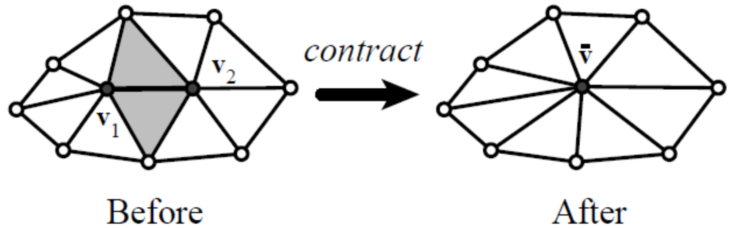


Geometry and Mesh Generation



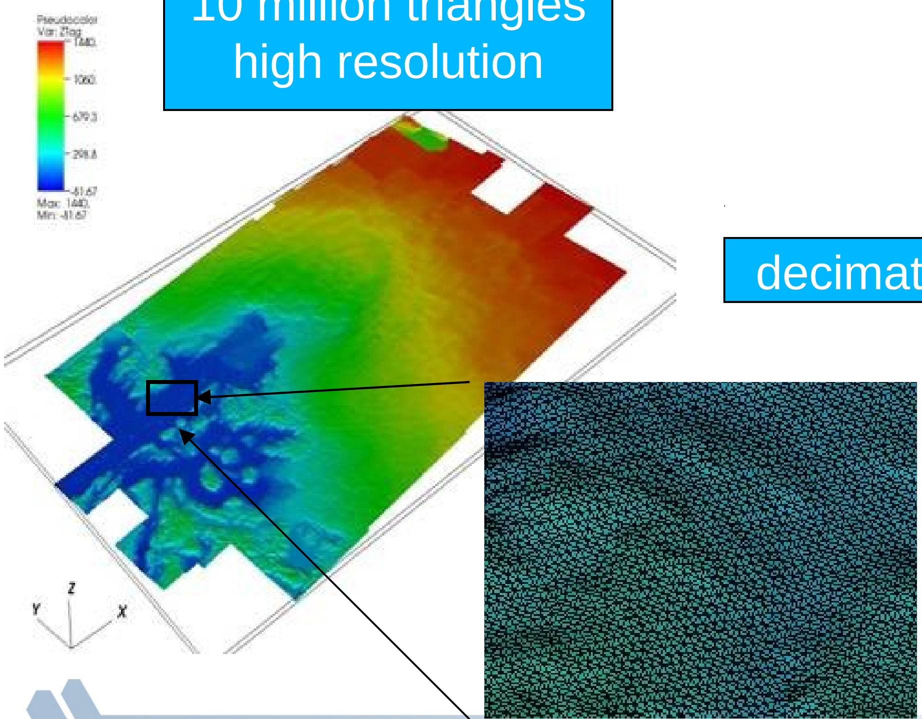
Decimation

- For surface simplication, qslim algorithm is implemented in MeshKit:
  http://mgarland.org/software/qslim10.html
- Main method of decimation: Edge Contraction
- Minimize certain error (quadrics)



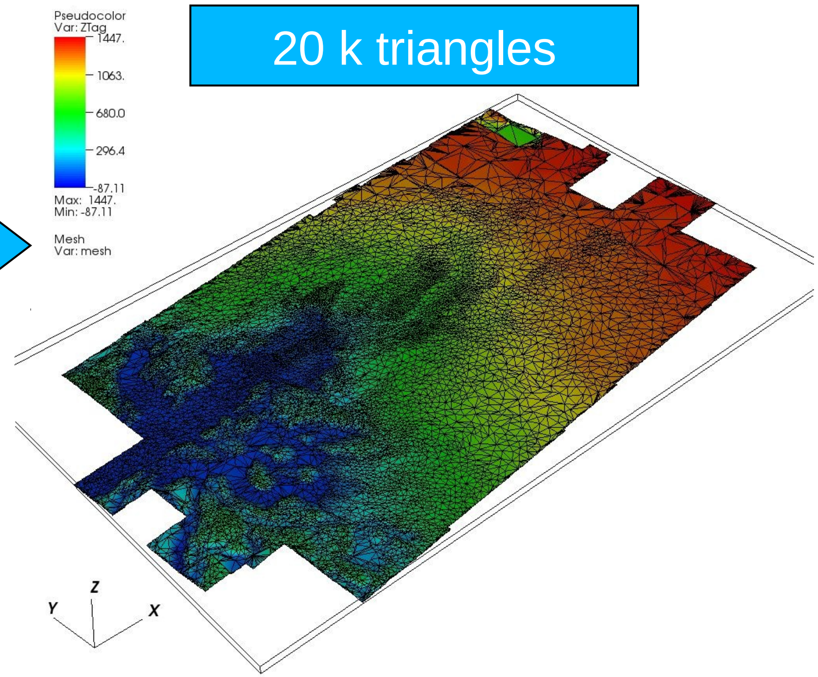
- Example of use: Surface Elevation data for Ice Sheets

10 million triangles
high resolution



decimation

20 k triangles



Smooth Faceting

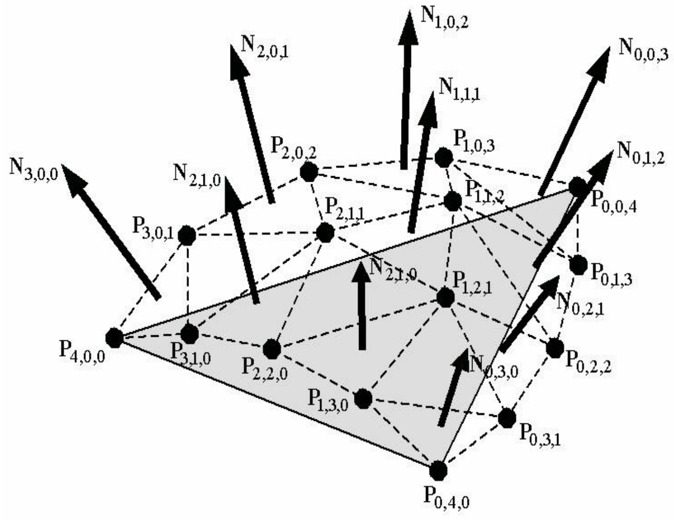
- C1-continuous facet-based geometric representation to support meshing
- compute the Bezier control points on each triangle such that the resulting surface, a reunion of smooth triangular patches, is continuous and differentiable
- Important for:

  - mesh generation

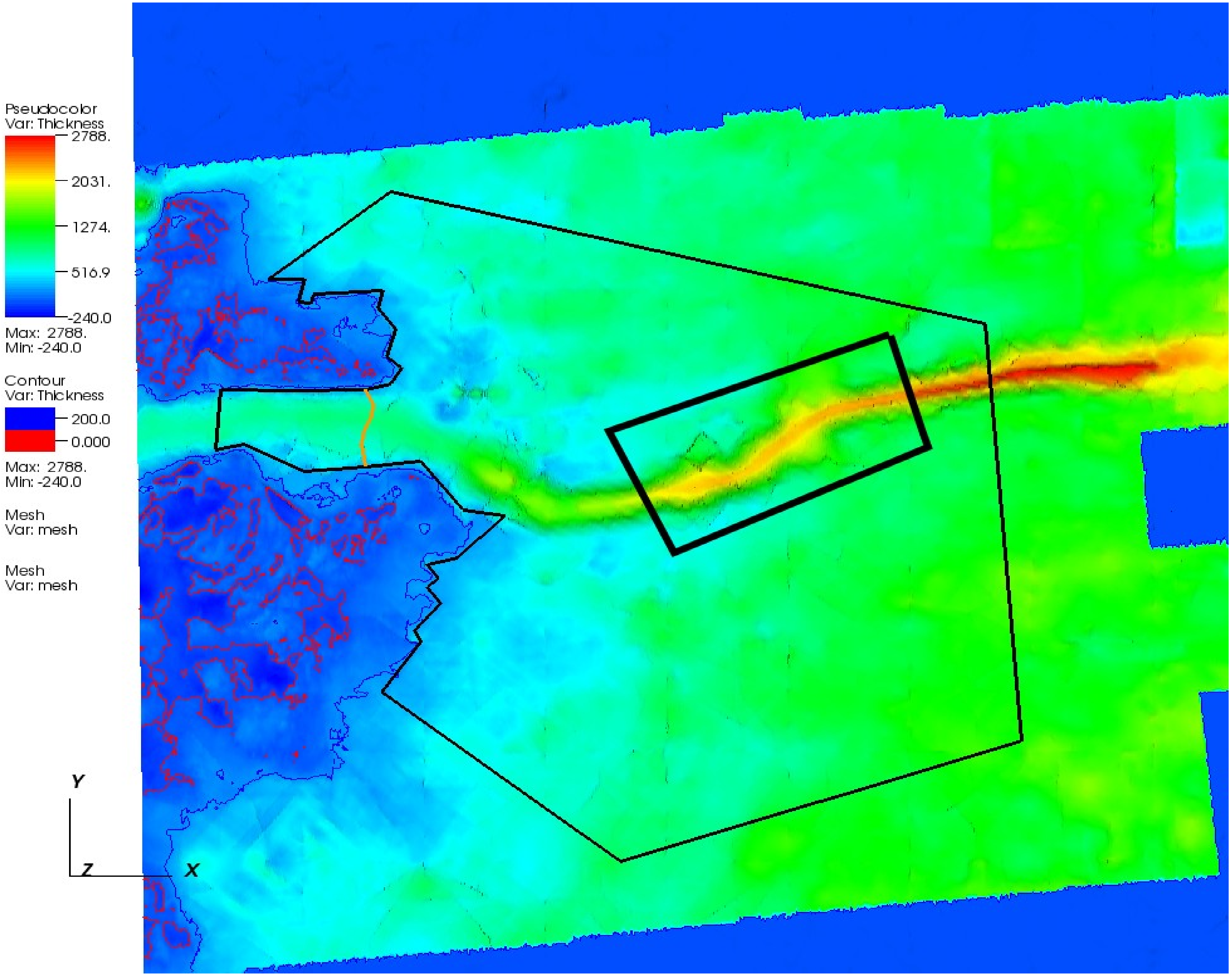
  - normal and tangent evaluation for boundary conditions

$$S(u,v,w)=\sum_{i+j+k=4} P_{i,j,k}\frac{4!}{i!j!k!}u^i v^j w^k$$

$$u,v,w\geq 0,\ \ u+v+w=1,\ \ i,j,k\geq 0$$



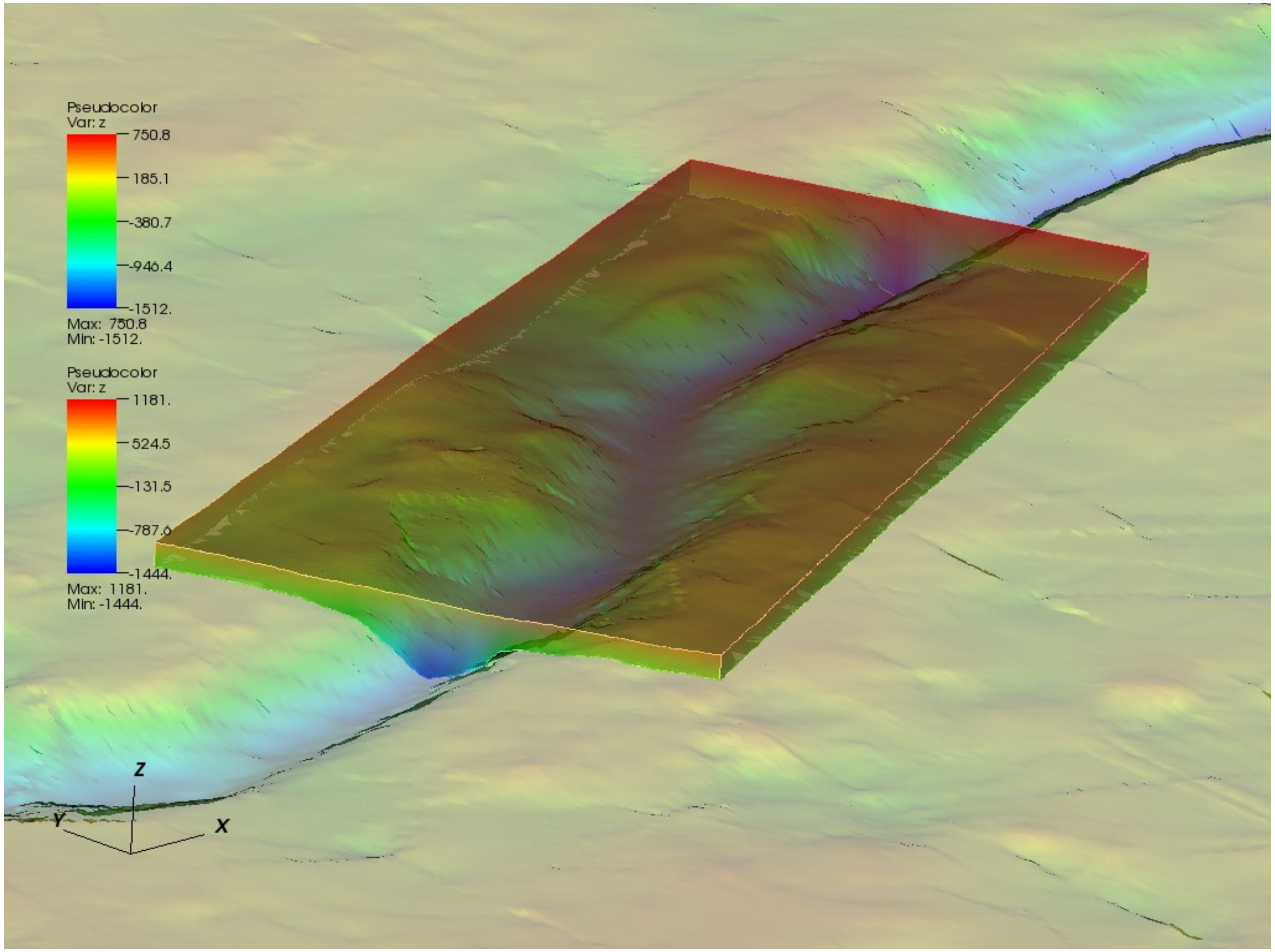
What is the region of interest?



Volume of interest

CAD-like
Boundary
Representation

meshable



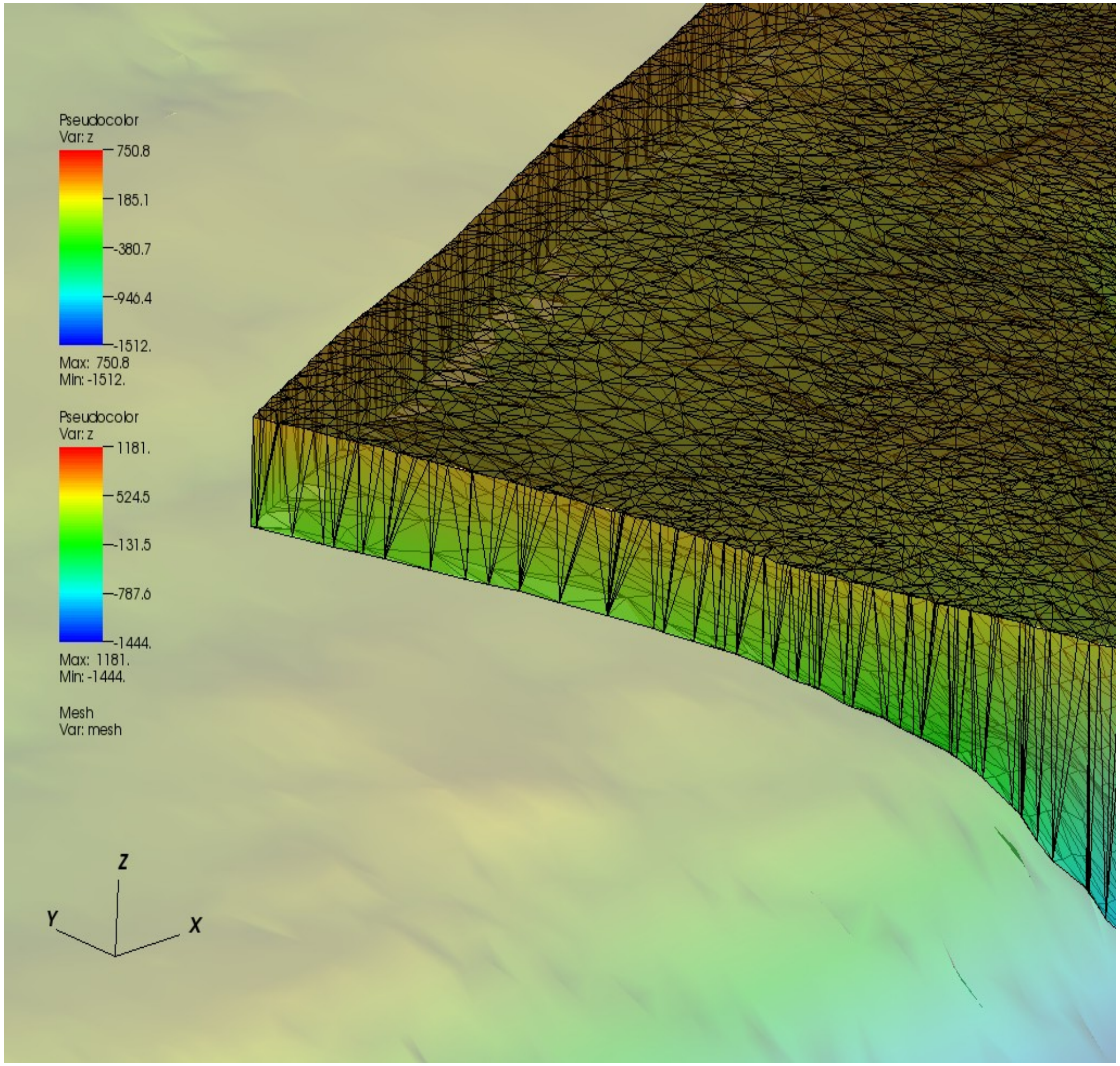
Volume of interest

Mesh-Based geometry
 Smooth or Linear

meshable with MeshKit

iGeom-like
Implemented in MOAB
  -volumes
    -surfaces
      -edges/curves

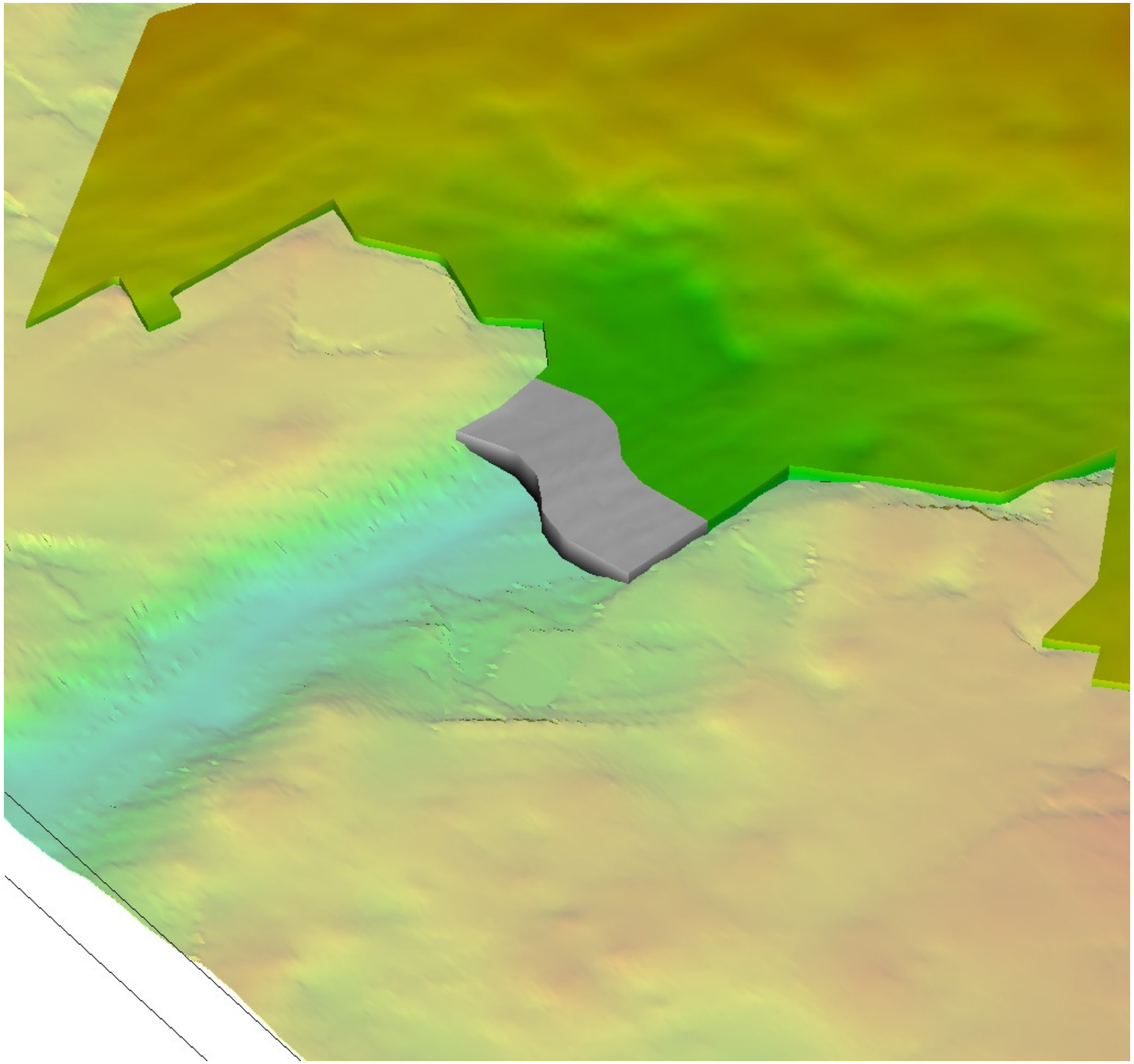
Topology and Geometry
tools developed for
 cutting/splitting/
 seaming



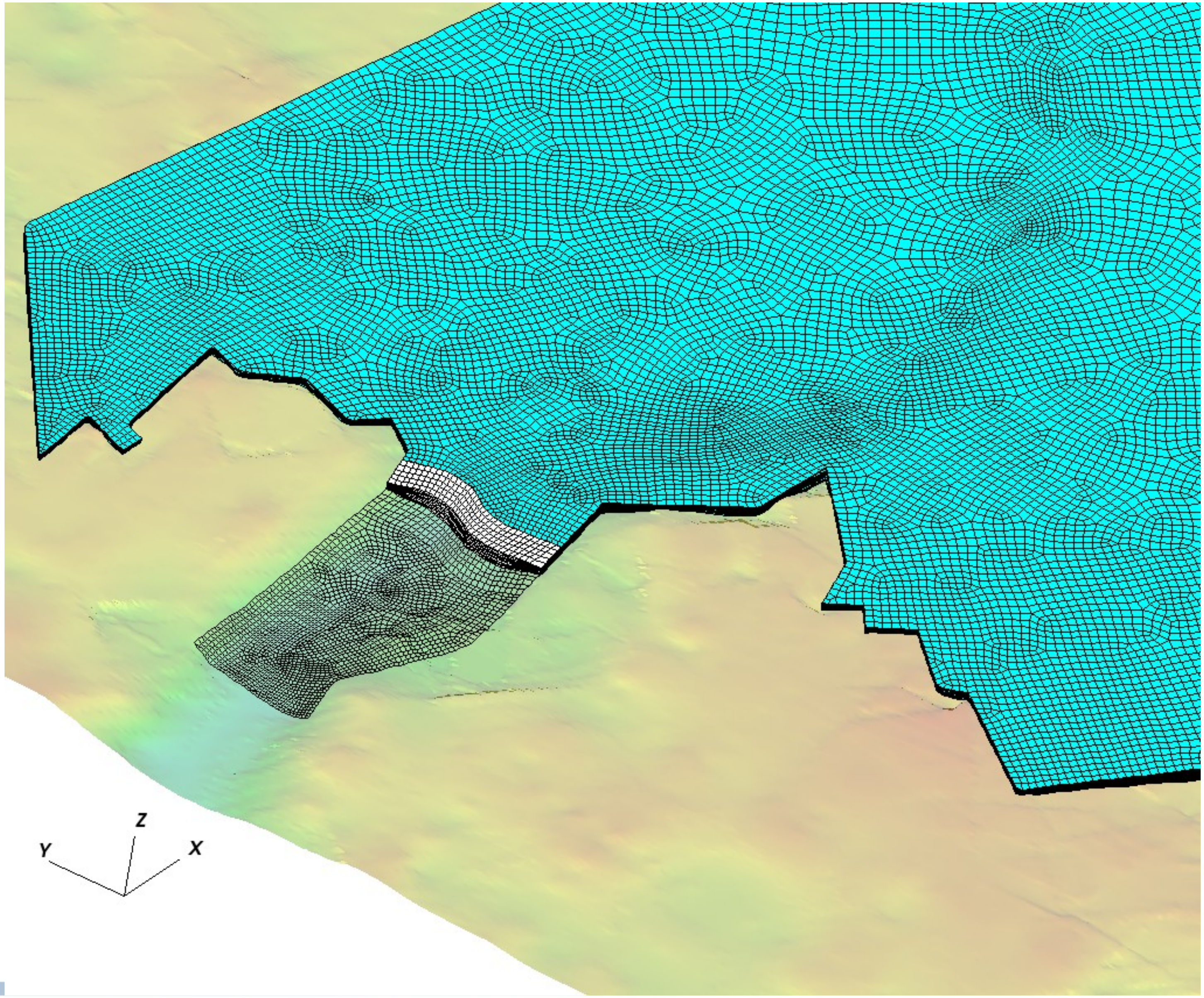
Topology and Geometry

Volume of ice
 - grounding line
 - CAD-like geometry

Different algorithms
 can be employed

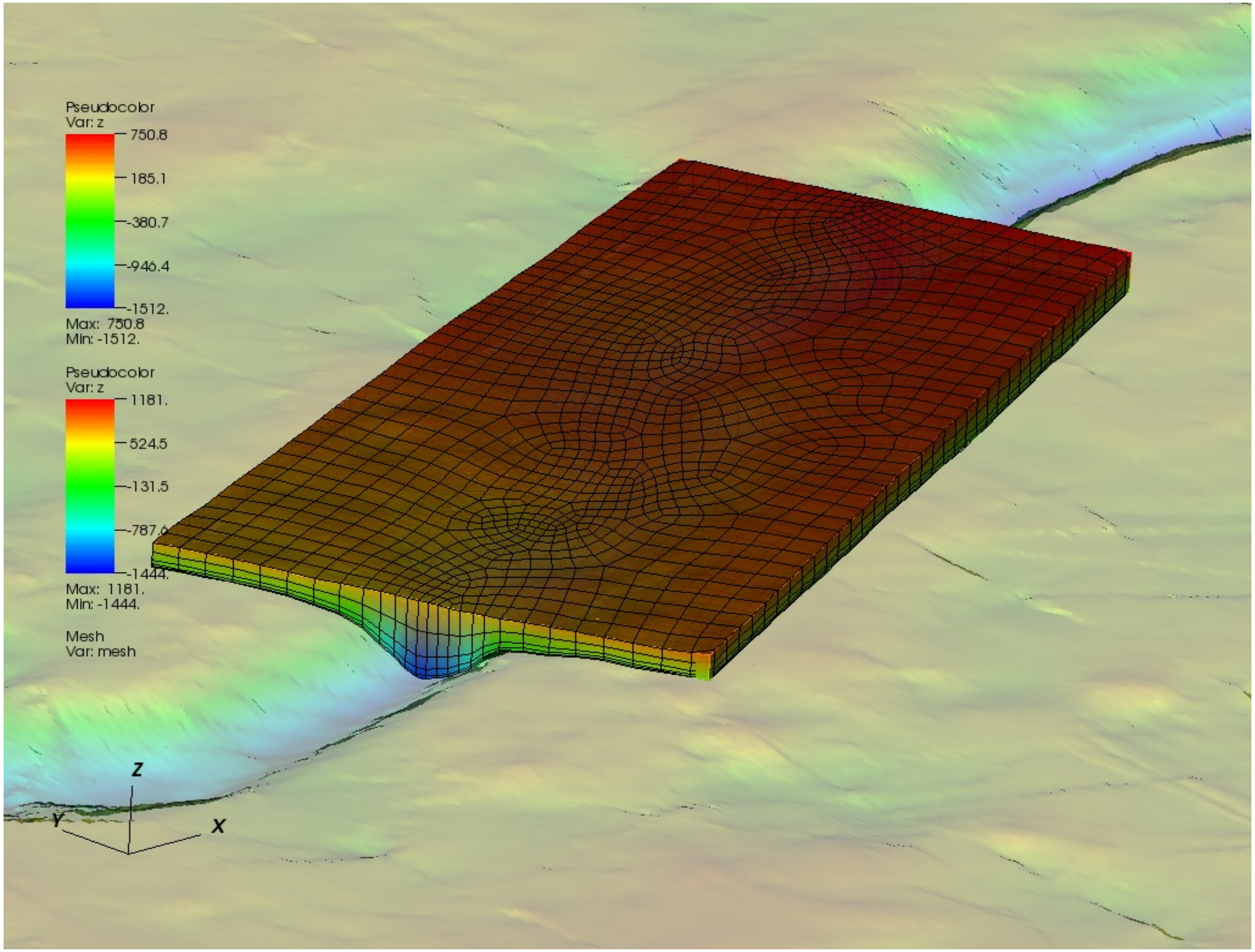


Meshes on volumes of interest



Hexa mesh

Quad mesh extruded



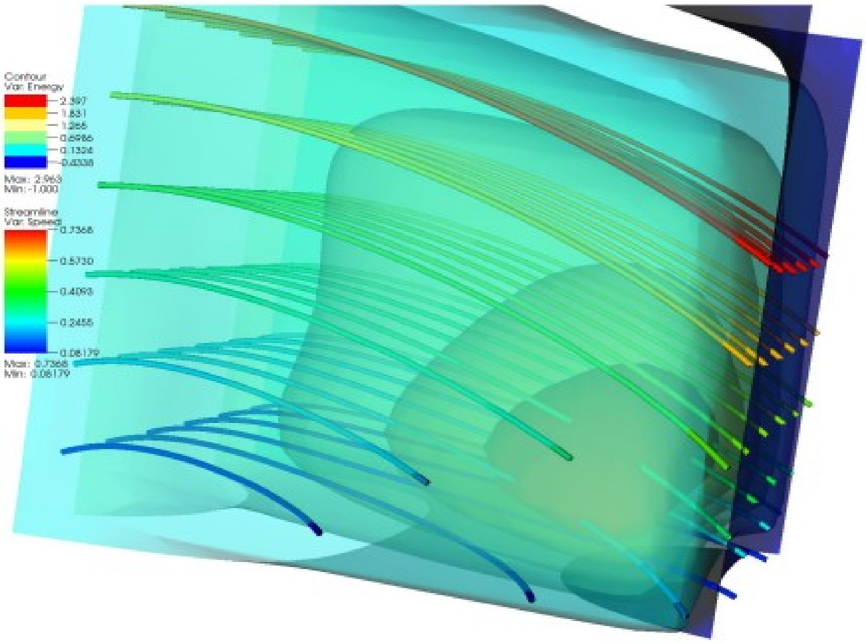
Conservative two-phase formulation

Find momentum density ρu, pressure p, and total energy density E:

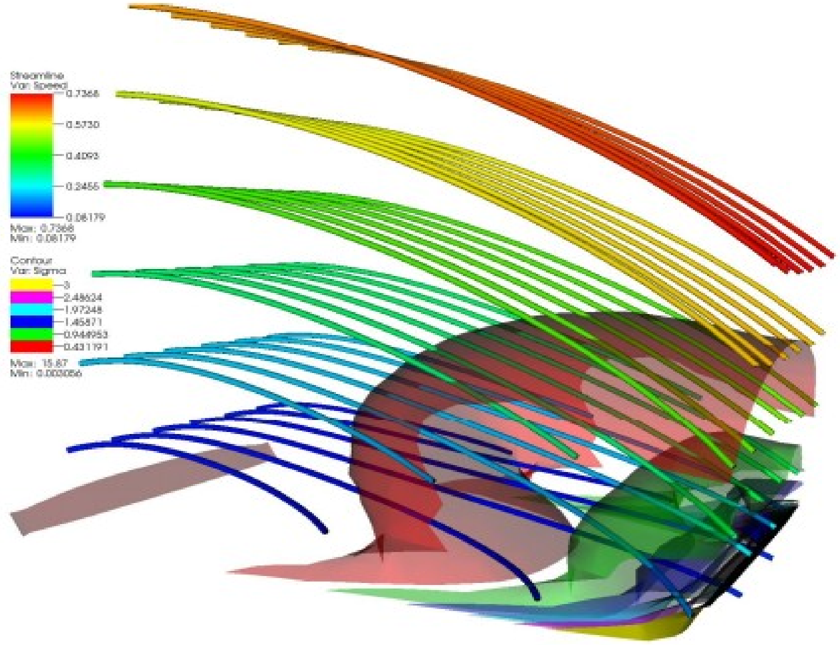
$$(\rho u)_t + \operatorname{div}(\rho u \otimes u - \eta D u_i + p 1) - \rho g = 0$$
$$\rho_t + \operatorname{div} \rho u = 0$$
$$E_t + \operatorname{div}((E + p)u - k_T \nabla T - k_\omega \nabla \omega) - \eta D u_i : D u_i - \rho u \cdot g = 0$$

- Solve for density ρ, ice velocity u_i, temperature T, and melt fraction ω using constitutive relations.
  - Simplified constitutive relations can be solved explicitly.
  - Temperature, moisture, and strain-rate dependent rheology η.
- DAEs solved implicitly after semidiscretizing in space.
- Newton solver converges quadratically.
- Thermocoupled steady state in one Newton solve
  - no time stepping needed, total cost similar to 3 semi-implicit steps
  - useful for inverse problems and stability analysis
- Robust preconditioning using nested field-split

Block on inclined plate, nominal $Re = 0.24$, $Pe = 120$

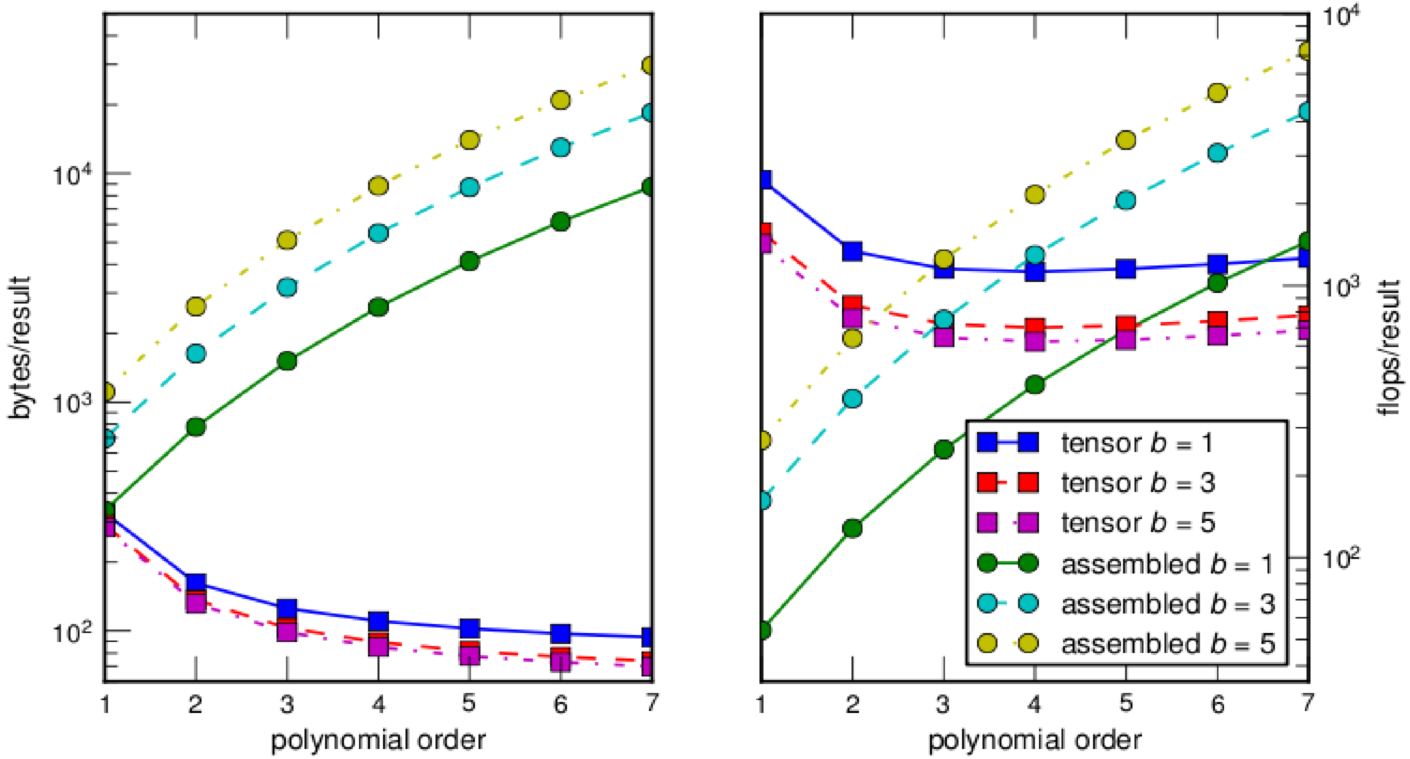


Contours of Energy, melt fraction up to 15%, density ratio 2.



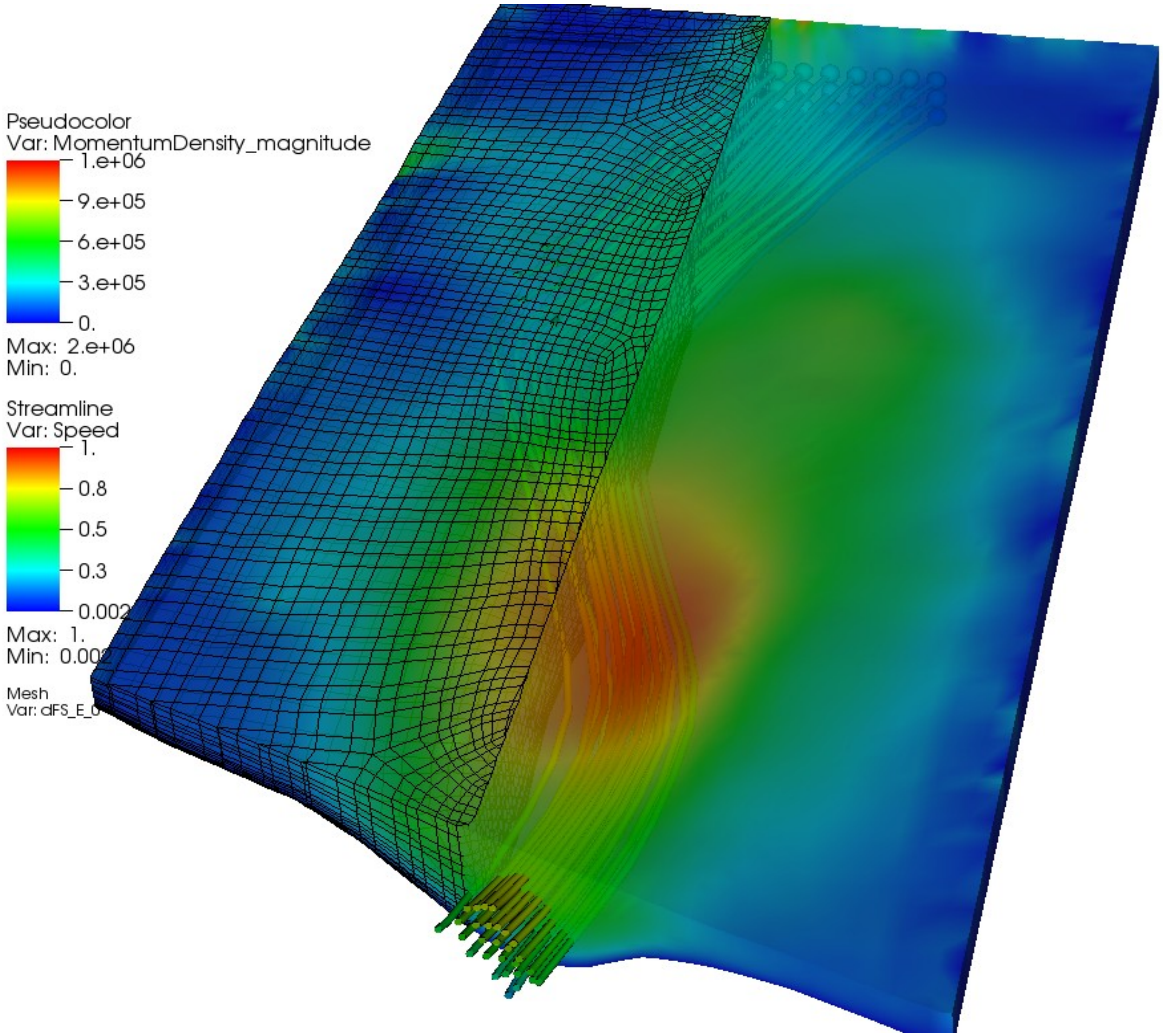
Contours of viscous heat production, $1/r$ singularity at corners.

Performance of assembled versus unassembled



- High order Jacobian stored unassembled using coefficients at quadrature points, can use local AD
- Approximation order is a run-time option
  choose independently for each field
- Precondition high order using assembled lowest order method

Some results



Thank you!