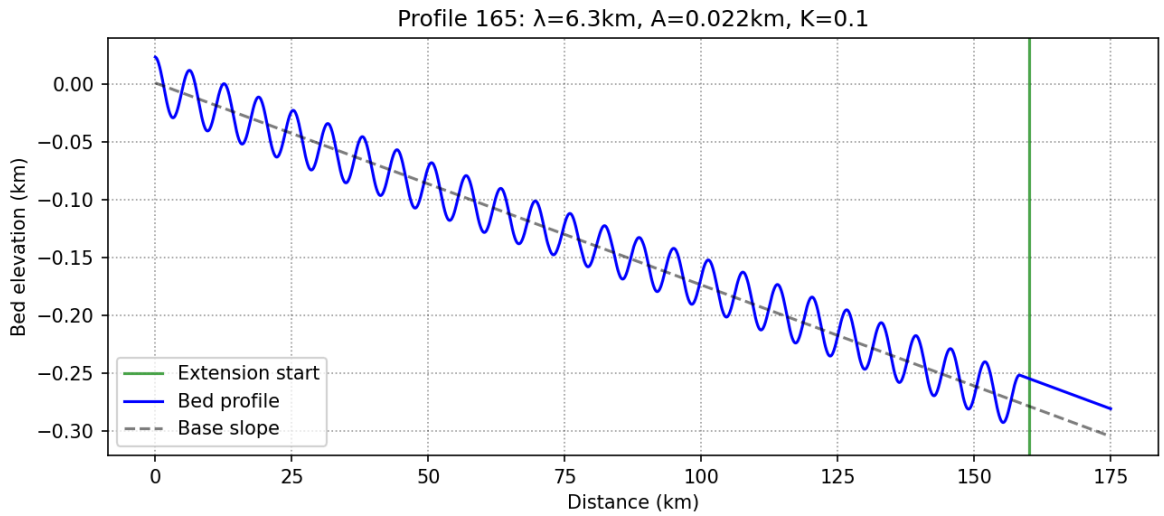
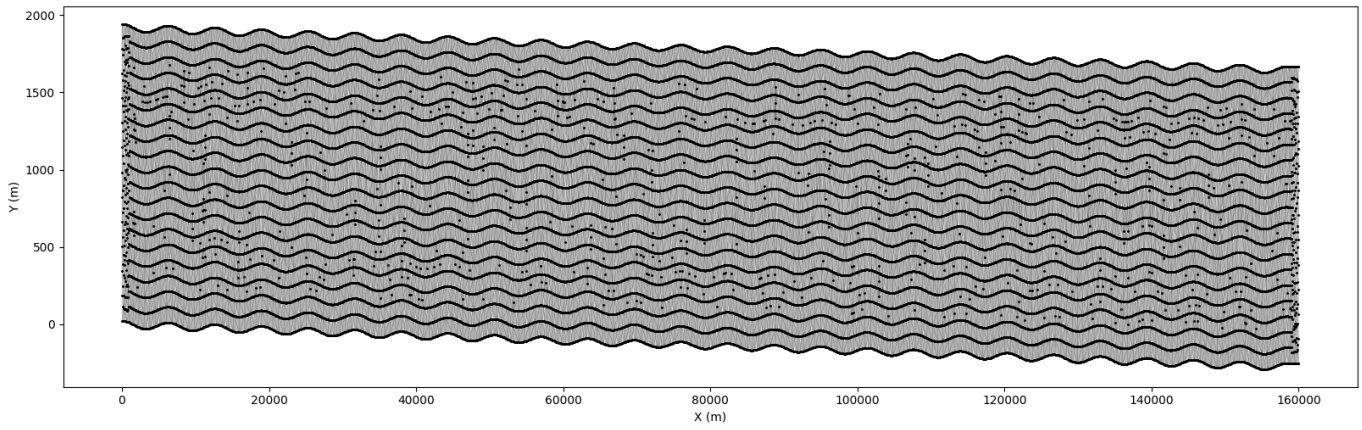
astronomical_terminus_acceleration (S4)

Testing `long_flowline.py` using bedrock profile 165 with `exp=S4` : Sliding + non-linear rheology

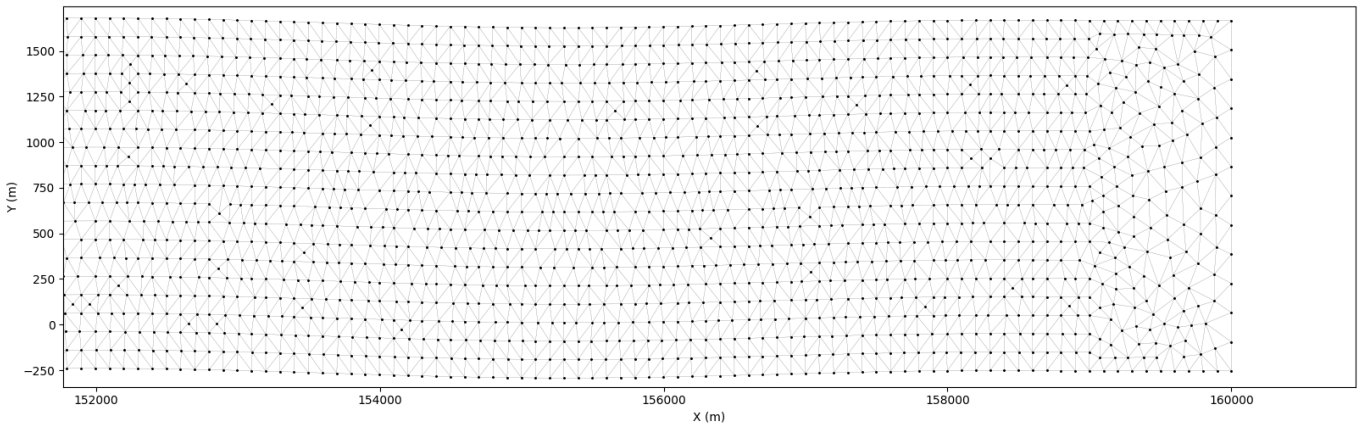
Bedrock



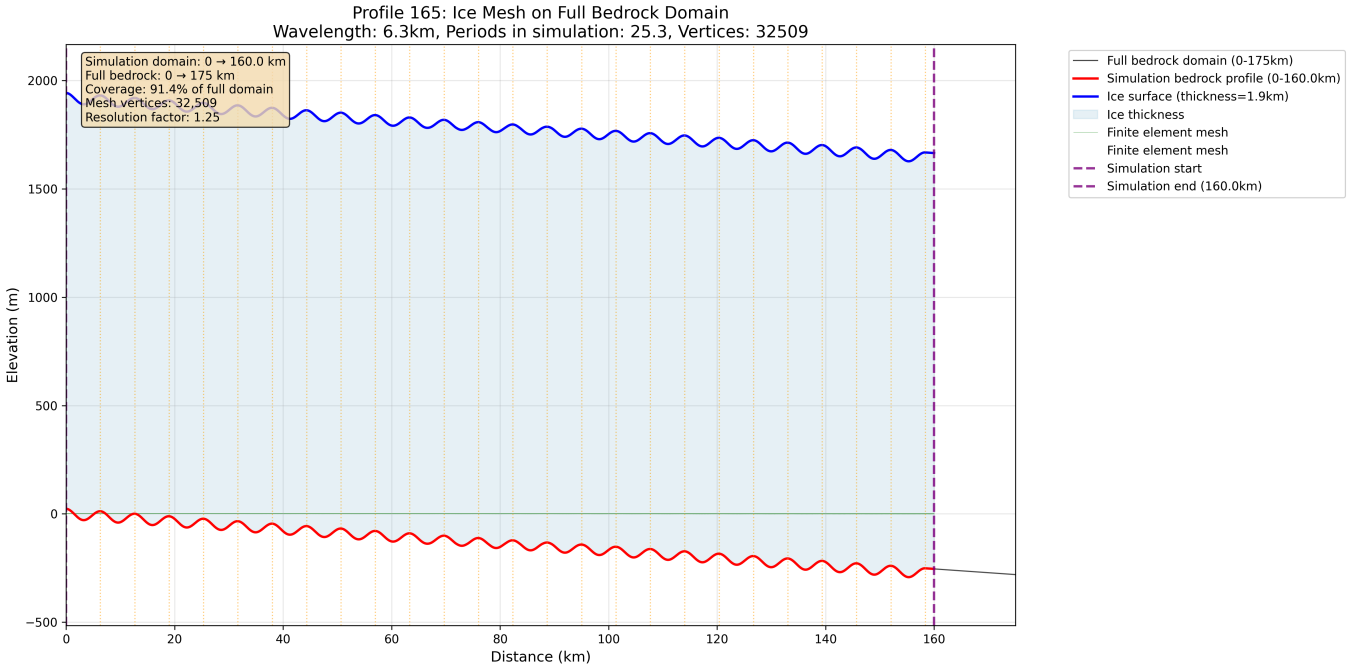
Mesh



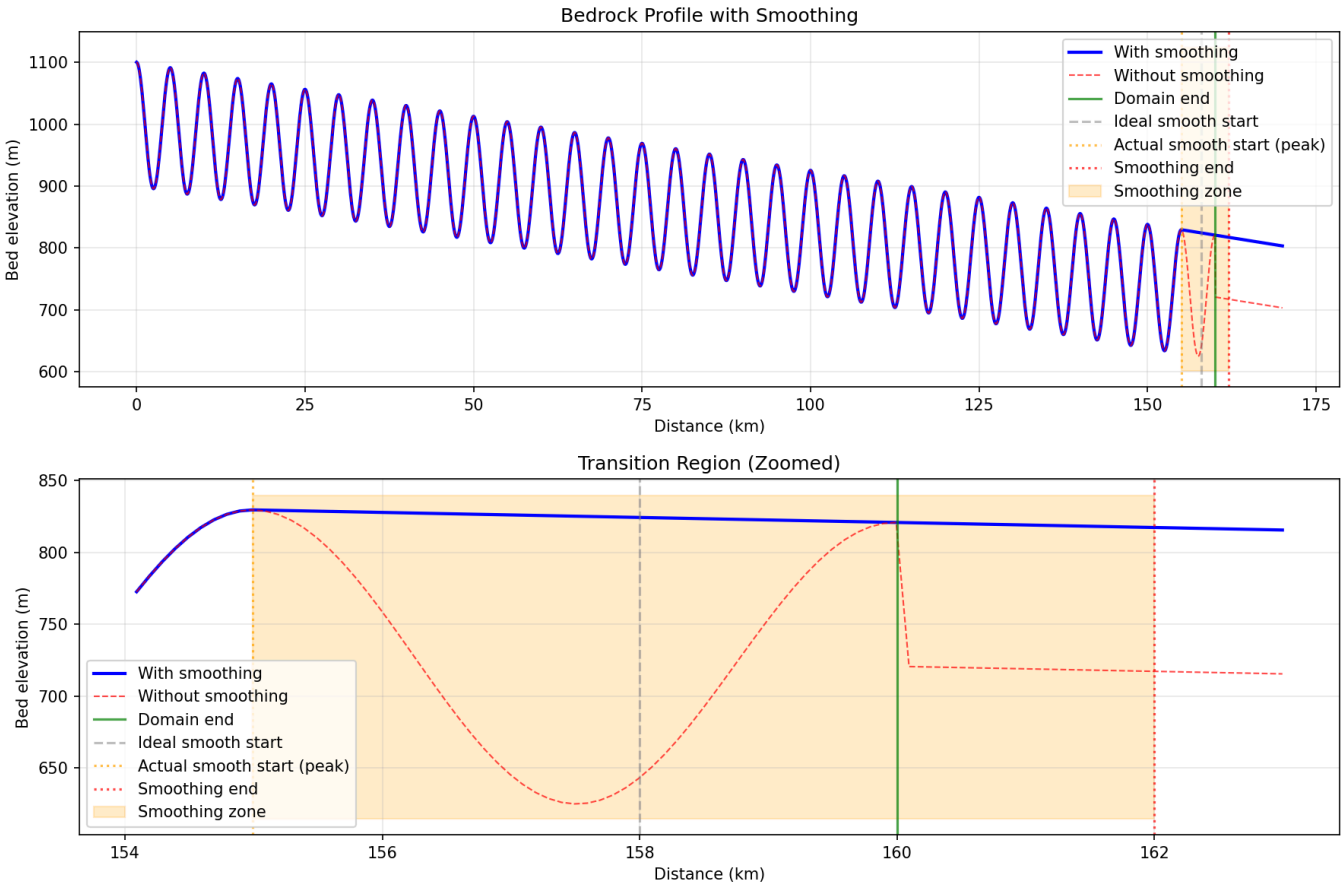
Mesh at Terminus



Mesh Over the Full Bedrock



Terminus Smoothing



terminal output for long_flowline.py

```
Loaded bedrock profile 165 with parameters:
  amplitude: 22.400000000000002
  wavelength: 6336.0
  skewness: 0.0
  kurtosis: 0.10000000000000003
  noise_level: 0.0
  initial_elevation: 1.0

============ SETTING MESH==============
Construction of a mesh from a given geometry

[ADAPTIVE_BAMG] FINAL Mesh statistics:
  wavelength_thickness_ratio: 3.3
  hmax: 158.4
  resolution_factor: 1.25
  refinement_factor: 50
  Total vertices: 32509
  Elements: 61794
```

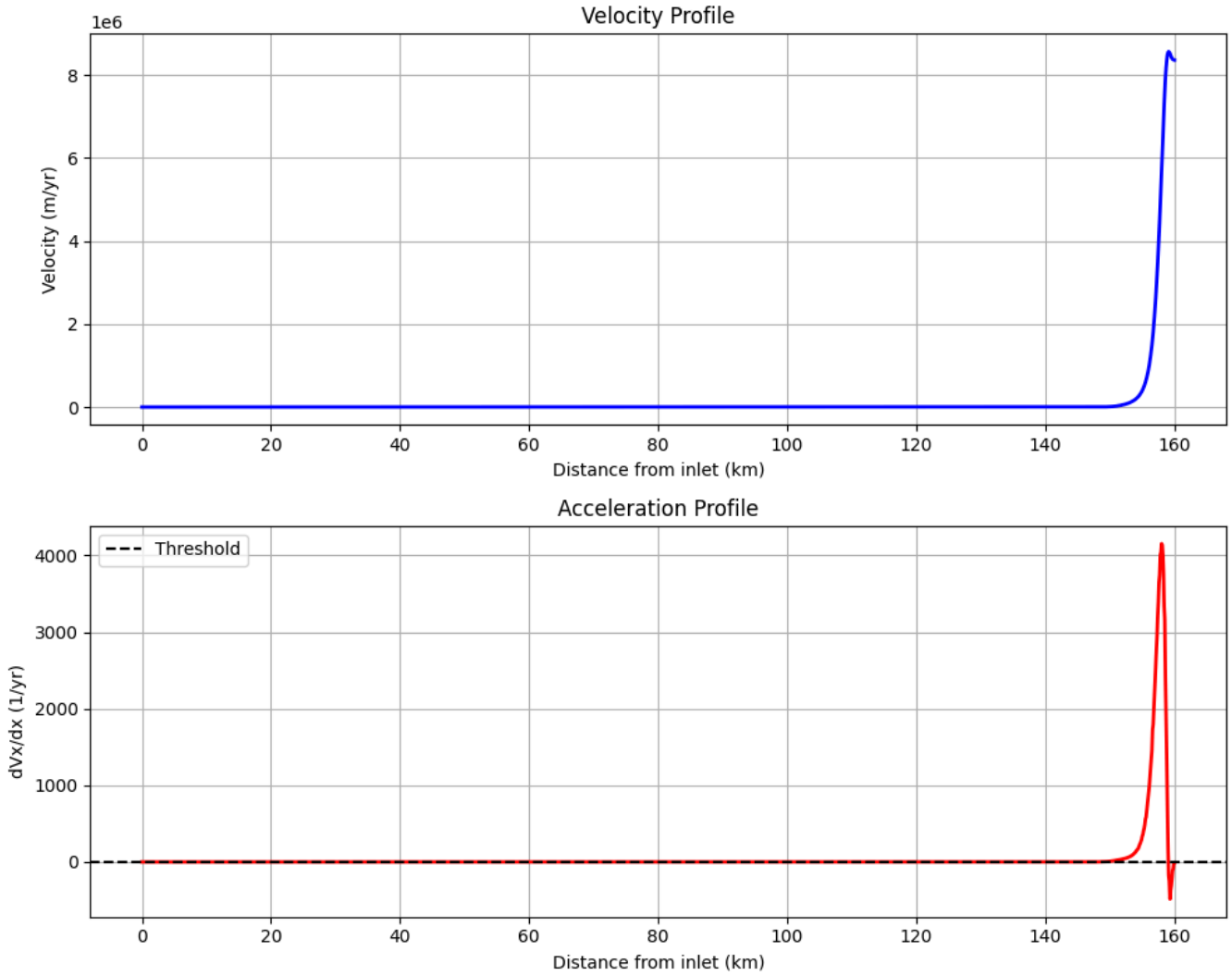
```
  inlet vertices: 13
  terminus vertices: 13
=======================================

============ SETUP FRICTION ==============

Experiment S4: β² = 1500 field
β² field statistics:
  Array size: 1
  Range: [1500.0, 1500.0] Pa·a·m⁻¹
  Mean: 1500.0 Pa·a·m⁻¹

Final friction coefficient:
  Array size: 32509
  Range: [0.0, 217567.0] Pa·s·m⁻¹

============ FRICTION DIAGNOSTIC ==============
INTENDED FRICTION:
  β² = 1500 Pa·a·m⁻¹
  β² (ISSM) = 4.73e+10 Pa·s·m⁻¹
  friction coeff = 217567 Pa·s·m⁻¹

ACTUAL FRICTION:
  friction coeff range = [217567, 217567]
  β² (ISSM) range = [4.73e+10, 4.73e+10]
  β² (annual) range = [1500, 1500]

============ SETTING NON-PERIODIC BCS ==============
 inlet nodes shape: (13,)
 terminus nodes shape: (13,)

============ BCS DIAGNOSTIC ==============
Vertices with prescribed vx: 13
Vertices with prescribed vy: 0
Total vertices: 32509

Terminus nodes: 13
Terminus vx range: [NaN, NaN] m/s (all values are NaN)

===== Solving Diagnostic Stressbalance =====
```

```
checking model consistency
marshalling file '165_S4_1.25'.bin
uploading input file and queuing script
launching solution sequence on remote cluster

Ice-sheet and Sea-level System Model (ISSM) version  4.24
(website: http://issm.jpl.nasa.gov forum: https://issm.ess.uci.edu/forum/)

call computational core:
   computing new velocity
computing slope...
   extruding SurfaceSlopeX from base...
   computing slope
   computing basal mass balance
write lock file:

   FemModel initialization elapsed time:   0.407334
   Total Core solution elapsed time:       26.5968
   Linear solver elapsed time:             12.6127 (47%)

   Total elapsed time: 0 hrs 0 min 27 sec
loading results from cluster

===== DIAGNOSING ACCELERATION =====
Debug info:
  Surface nodes: 1600
  x shape: (1600,)
  vx shape: (1600, 1)
  x range: [0.0, 160000.0] m
  vx range: [0.000, 8561881.022] m/yr
  dvx_dx range: [-4.84e+02, 4.15e+03] 1/yr
Acceleration problem starts at 160.0 km
✗ Problem starts beyond 15km - issue is not buffer length

=== SAVING STATIC OUTPUT ===
Available results in md.results:
  md.results.StressbalanceSolution
  md.results.checkconsistency
  md.results.marshall
  md.results.setdefaultparameters
```

```
Available results in md.results.StressbalanceSolution:
  BedSlopeX: shape (32509, 1)
  Pressure: shape (32509, 1)
  SolutionType: length 21, type <class 'str'>
  StressbalanceConvergenceNumSteps: shape (1,)
  SurfaceSlopeX: shape (32509, 1)
  Vel: shape (32509, 1)
  Vx: shape (32509, 1)
  Vy: shape (32509, 1)
  checkconsistency: <class 'method'>
  errlog: length 0, type <class 'list'>
  getfieldnames: <class 'method'>
  getlongestfieldname: <class 'method'>
  marshall: <class 'method'>
  outlog: length 0, type <class 'list'>
  setdefaultparameters: <class 'method'>
  step: <class 'int'>
  time: <class 'float'>
Coordinate ranges: x_hat=[0.000, 1.000],y_hat=[-0.002, 0.012]
Warning: No Vz field found, using zeros
Surface velocity ranges (m a⁻¹):
  vx: [0.00000, 8561881.02184]
  vy: [-9433511.46469, 556.35585]
  vz: [0.00000, 0.00000]
Basal velocity ranges (m a⁻¹):
  vx_basal: [-3093.62535, 28645.83828]
✓ Saved 165_S4_1.25_static.txt with shape (1600, 4)
First 5 rows:
[[1.00000000e+00 8.35879158e+06 0.00000000e+00 0.00000000e+00]
 [9.99374609e-01 8.35943316e+06 0.00000000e+00 3.86282101e+00]
 [9.98749218e-01 8.36803657e+06 0.00000000e+00 7.76874657e+00]
 [9.98123827e-01 8.37946262e+06 0.00000000e+00 1.14453318e+01]
 [9.97498437e-01 8.40237355e+06 0.00000000e+00 1.51709443e+01]]
✓ output saved: 165_S4_1.25_static.txt

=== DRIVING STRESS DIAGNOSTIC S4 ===
Surface elevation: 1943.400 to 1665.643 m
Bed elevation: 23.400 to -254.357 m
Ice thickness: 1920.000 to 1920.000 m
```

```
Systematic trends over 160 km:
  Surface: -277.757 m (-1.736 m/km)
  Bed: -277.757 m (-1.736 m/km)
  Thickness: 0.000 m (0.000 m/km)

Driving stress at boundaries:
  Left (x=0): 51290.6 Pa
  Right (x=L): 29915.0 Pa
  Difference: 21375.6 Pa

=====================================

===== Solving Transient Full-Stokes =====
sb_coupling_frequency: 1
output_frequency: 1
isstressbalance: 1
Δt (yr): 0.05208333333333333 Tfinal (yr): 1 ≈nsteps: 19
checking model consistency
marshalling file '165_S4_1.25'.bin
uploading input file and queuing script
launching solution sequence on remote cluster

Ice-sheet and Sea-level System Model (ISSM) version  4.24
(website: http://issm.jpl.nasa.gov forum: https://issm.ess.uci.edu/forum/)

call computational core:
iteration 1/20  time [yr]: 0.05 (time step: 0.05)
   computing new velocity
computing slope...
   extruding SurfaceSlopeX from base...
   computing slope
   computing basal mass balance
   computing basal mass balance
   computing mass transport
   call free surface computational core
   extruding Base from base...
   extruding solution from top...
   extruding solution from top...
   extruding solution from top...
```

```
   updating vertices positions
   computing transient requested outputs
   saving temporary results
iteration 2/20  time [yr]: 0.10 (time step: 0.05)
   computing new velocity
computing slope...
   extruding SurfaceSlopeX from base...

[0] ??? Error using ==> ./classes/Elements/TriaRef.cpp:117
[0] GetJacobianDeterminant error message: negative jacobian determinant!

--------------------------------------------------------------------------
Primary job  terminated normally, but 1 process returned
a non-zero exit code. Per user-direction, the job has been aborted.
--------------------------------------------------------------------------
--------------------------------------------------------------------------
mpiexec detected that one or more processes exited with non-zero status,
thus causing
the job to be terminated. The first process to do so was:

  Process name: [[6295,1],0]
  Exit code:    1
--------------------------------------------------------------------------
loading results from cluster
Solving complete - saving results
field md.solidearth.external is None
qmu is skipped until it is more stable
```



The velocity&acceleration diagnostic shows:

- "Acceleration problem starts right before 160.0 km"
  My mesh is 160km long (even though my bedrock is 175km long) it looks like I have a terminus acceleration problem that's causing the massive velocity spike right before the boundary.

Investigating causes:

Hypothesis 1: Root Cause: Inadequate Back-Pressure at Terminus ?

From investigating ISSM FS boundary conditions:
FS terminus BC: only water pressure below sea level
pressure = rho_water $\times$ gravity $\times$ min(0., z - sealevel)

For fully grounded ice:

- sea level is likely at/below the bed elevation
- Most of ice column has z > sealevel
- So pressure ≈ 0 for most of the terminus face: pressure = rho_water × gravity × min(0) = 0
- Result: Almost no back-pressure to resist ice flow

The Physics Problem:

1. Driving stress: 148 kPa difference between inlet/terminus
2. No resistance: FS terminus BC provides almost zero back-pressure for grounded ice
3. Acceleration: Ice accelerates uncontrollably toward the "free" boundary
4. Mesh failure: Extreme velocities cause negative Jacobian determinants

Solutions for Terminus Boundary Condition:

1. Add back-pressure at the terminus (ice-front load)

Right now I set `spcvx=NaN` at the terminus → essentially stress-free outflow. For grounded ice that's "no resistance." I need to mark the downstream vertical face as an ice front and let ISSM apply hydrostatic water pressure below sea level (and zero above).
In a 2D flowband this is done via levelsets, not Dirichlet vx. This is a minimal pattern from CG

```
# mark last vertical face as ice front
md.mask.ice_levelset[:] = -1     # ice present
md.mask.ocean_levelset[:] = +1   # grounded by default

# find nodes on the terminus vertical face and set icefront there
terminus = np.where(md.mesh.vertexflags(2))[0]
md.mask.ice_levelset[terminus] = 0          # ice front at face
md.mask.ocean_levelset[terminus] = -1       # "ocean" at the front so
hydrostatic load applies
```

What those two level-set lines actually *do*

- `md.mask.ice_levelset` : **ice vs "outside"**. Negative = ice; zero on the **ice front**; positive = outside.
- `md.mask.ocean_levelset` : **grounded vs ocean**. Positive = grounded; zero on the grounding line; negative = **ocean present**.

I don't WANT ocean at the front though.... I want air. That means that I can't have something stopping my ice from runaway effect???
By default you set the whole domain to "ice present & grounded" (−1 and +1). That's fine inside, but it leaves the **downstream boundary** with no special treatment, so it behaves like a stress-

free outflow.
IF I SET Ocean at the front to test this method:

terminal output for long_flowline.py (after fix)

```
Loaded bedrock profile 165 with parameters:
  amplitude: 22.400000000000002
  wavelength: 6336.0
  skewness: 0.0
  kurtosis: 0.10000000000000003
  noise_level: 0.0
  initial_elevation: 1.0

============ SETTING MESH==============
Construction of a mesh from a given geometry

[ADAPTIVE_BAMG] FINAL Mesh statistics:
  wavelength_thickness_ratio: 3.3
  hmax: 158.4
  resolution_factor: 1.25
  refinement_factor: 50
  Total vertices: 32509
  Elements: 61794
  inlet vertices: 13
  terminus vertices: 13
========================================
Number of front nodes: 13
Number of ocean-contact nodes: 13
Number of ice-front segments: 14
Front segment x-range: 159899.9374609131 → 160000.0
Front segment z-range: -254.35730883494688 → 1665.8173332415504
Front nodes on boundary: 13/13
x-range of front nodes: 160000.0 160000.0
x.max(): 160000.0
x-range of front nodes: 160000.0 → 160000.0

============ SETUP FRICTION ==============

Experiment S4: β² = 1500 field
β² field statistics:
  Array size: 1
  Range: [1500.0, 1500.0] Pa·a·m⁻¹
  Mean: 1500.0 Pa·a·m⁻¹
```

```
Final friction coefficient:
  Array size: 32509
  Range: [0.0, 217567.0] Pa·s·m⁻¹

============ FRICTION DIAGNOSTIC ==============
INTENDED FRICTION:
  β² = 1500 Pa·a·m⁻¹
  β² (ISSM) = 4.73e+10 Pa·s·m⁻¹
  friction coeff = 217567 Pa·s·m⁻¹

ACTUAL FRICTION:
  friction coeff range = [217567, 217567]
  β² (ISSM) range = [4.73e+10, 4.73e+10]
  β² (annual) range = [1500, 1500]

============ SETTING NON-PERIODIC BCS ==============
 inlet nodes shape: (13,)
 terminus nodes shape: (13,)

============ BCS DIAGNOSTIC ==============
Vertices with prescribed vx: 13
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Terminus nodes: 13
Terminus vx range: [NaN, NaN] m/s (all values are NaN)

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(website: http://issm.jpl.nasa.gov forum: https://issm.ess.uci.edu/forum/)

call computational core:
   computing new velocity
computing slope...
   extruding SurfaceSlopeX from base...
   computing slope
   computing basal mass balance
write lock file:

   FemModel initialization elapsed time:   0.407501
   Total Core solution elapsed time:       25.9303
```

```
   Linear solver elapsed time:             12.3326 (48%)

   Total elapsed time: 0 hrs 0 min 26 sec
loading results from cluster

===== DIAGNOSING ACCELERATION =====
Debug info:
  Surface nodes: 1600
  x shape: (1600,)
  vx shape: (1600, 1)
  x range: [0.0, 160000.0] m
  vx range: [0.000, 8753262.318] m/yr
  dvx_dx range: [-4.96e+02, 4.25e+03] 1/yr
Acceleration problem starts at 160.0 km
x-range of front nodes: 160000.0 160000.0
Pressure at front nodes: -4175.80894975889 11797927.063947653
Median dP/dz at front (Pa/m): -551.9511576238838

=== SAVING STATIC OUTPUT ===
Available results in md.results:
  md.results.StressbalanceSolution
  md.results.checkconsistency
  md.results.marshall
  md.results.setdefaultparameters

Available results in md.results.StressbalanceSolution:
  BedSlopeX: shape (32509, 1)
  Pressure: shape (32509, 1)
  SolutionType: length 21, type <class 'str'>
  StressbalanceConvergenceNumSteps: shape (1,)
  SurfaceSlopeX: shape (32509, 1)
  Vel: shape (32509, 1)
  Vx: shape (32509, 1)
  Vy: shape (32509, 1)
  checkconsistency: <class 'method'>
  errlog: length 0, type <class 'list'>
  getfieldnames: <class 'method'>
  getlongestfieldname: <class 'method'>
  marshall: <class 'method'>
  outlog: length 0, type <class 'list'>
  setdefaultparameters: <class 'method'>
  step: <class 'int'>
  time: <class 'float'>
Coordinate ranges: x_hat=[0.000, 1.000],y_hat=[-0.002, 0.012]
Warning: No Vz field found, using zeros
Surface velocity ranges (m a⁻¹):
```

```
  vx: [0.00000, 8753262.31773]
  vy: [-9659206.66451, 569.16225]
  vz: [0.00000, 0.00000]
Basal velocity ranges (m a⁻¹):
  vx_basal: [-10.69541, 4578665.71335]
✓ Saved 165_S4_1.25_static.txt with shape (1600, 4)
First 5 rows:
[[1.00000000e+00 8.54598770e+06 0.00000000e+00 0.00000000e+00]
 [9.99374609e-01 8.54664463e+06 0.00000000e+00 3.86282101e+00]
 [9.98749218e-01 8.55532793e+06 0.00000000e+00 7.76874657e+00]
 [9.98123827e-01 8.56691900e+06 0.00000000e+00 1.14453318e+01]
 [9.97498437e-01 8.59017832e+06 0.00000000e+00 1.51709443e+01]]
✓ output saved: 165_S4_1.25_static.txt

=== DRIVING STRESS DIAGNOSTIC S4 ===
Surface elevation: 1943.400 to 1665.643 m
Bed elevation: 23.400 to -254.357 m
Ice thickness: 1920.000 to 1920.000 m

Systematic trends over 160 km:
  Surface: -277.757 m (-1.736 m/km)
  Bed: -277.757 m (-1.736 m/km)
  Thickness: 0.000 m (0.000 m/km)

Driving stress at boundaries:
  Left (x=0): 51290.6 Pa
  Right (x=L): 29915.0 Pa
  Difference: 21375.6 Pa

=======================================

===== Solving Transient Full-Stokes =====
sb_coupling_frequency: 1
output_frequency: 1
isstressbalance: 1
Δt (yr): 0.05208333333333333 Tfinal (yr): 1 ≈nsteps: 19
checking model consistency
marshalling file '165_S4_1.25'.bin
uploading input file and queuing script
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Ice-sheet and Sea-level System Model (ISSM) version  4.24
(website: http://issm.jpl.nasa.gov forum: https://issm.ess.uci.edu/forum/)

call computational core:
iteration 1/20  time [yr]: 0.05 (time step: 0.05)
```
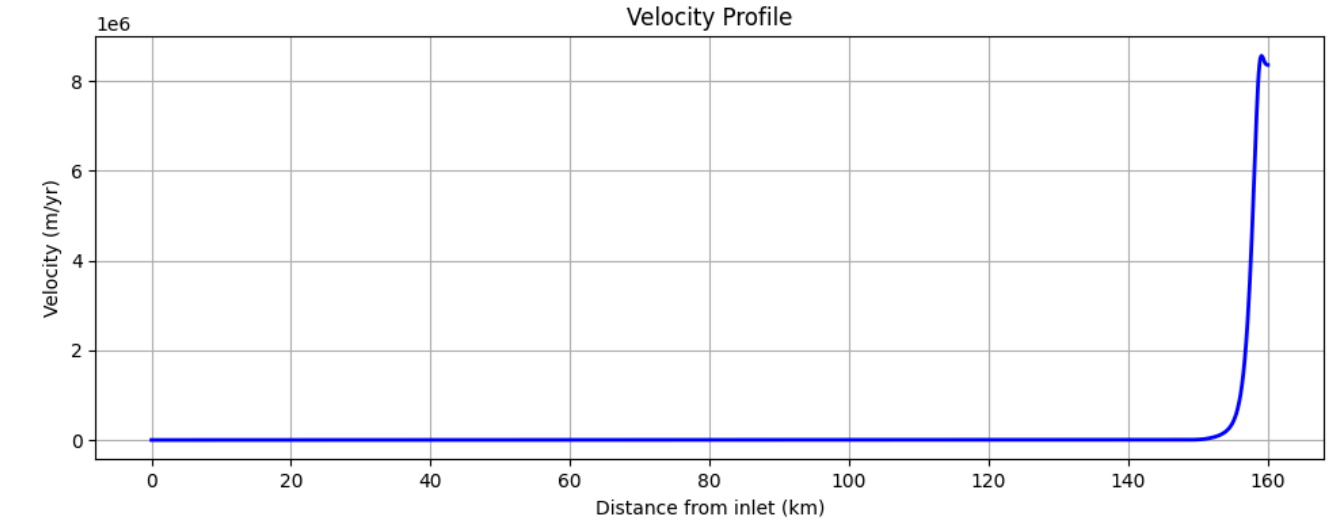
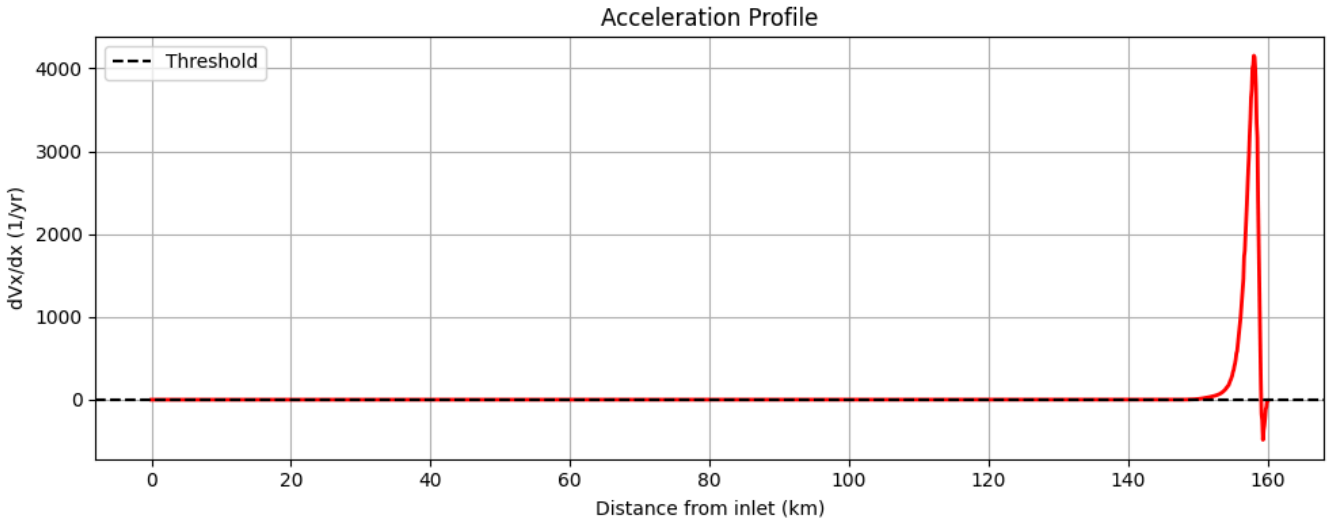
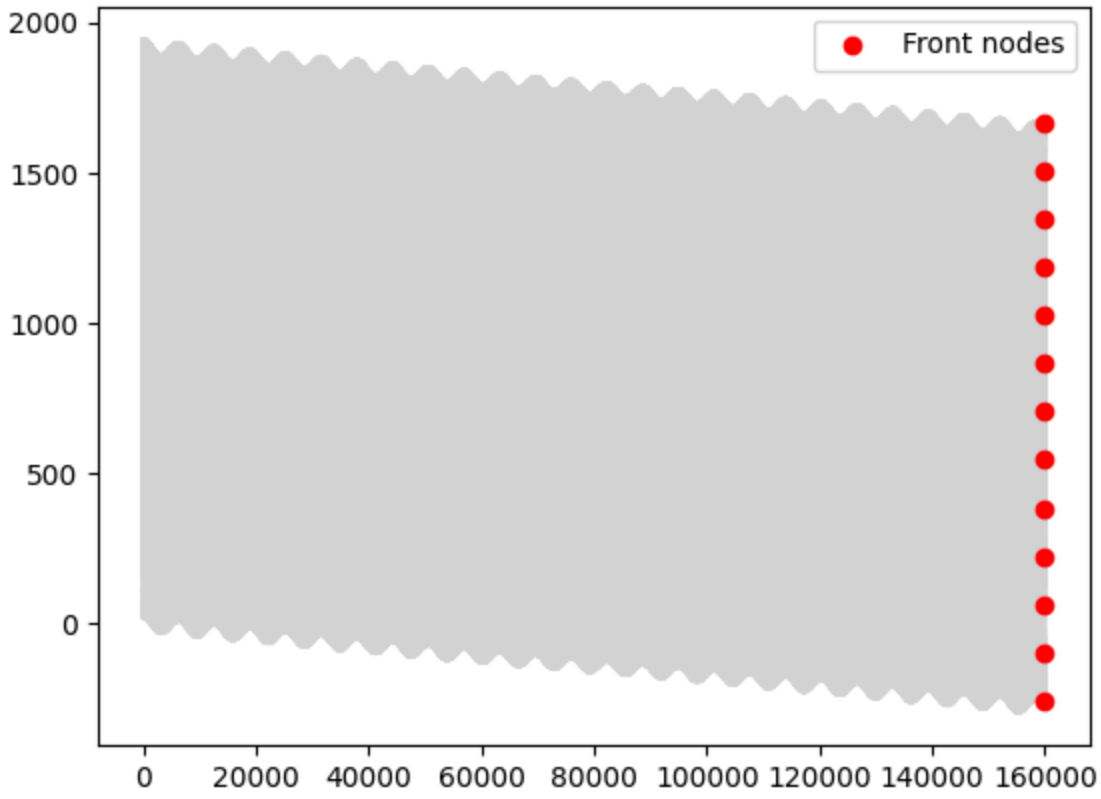

```
   computing new velocity
computing slope...
   extruding SurfaceSlopeX from base...
   computing slope
   computing basal mass balance
   computing basal mass balance
   computing mass transport
   call free surface computational core
   extruding Base from base...
   extruding solution from top...
   extruding solution from top...
   extruding solution from top...
   updating vertices positions
   computing transient requested outputs
   saving temporary results
iteration 2/20  time [yr]: 0.10 (time step: 0.05)
   computing new velocity
computing slope...
   extruding SurfaceSlopeX from base...

[0] ??? Error using ==> ./classes/Elements/TriaRef.cpp:117
[0] GetJacobianDeterminant error message: negative jacobian determinant!

--------------------------------------------------------------------------
Primary job  terminated normally, but 1 process returned
a non-zero exit code. Per user-direction, the job has been aborted.
--------------------------------------------------------------------------
--------------------------------------------------------------------------
mpiexec detected that one or more processes exited with non-zero status,
thus causing
the job to be terminated. The first process to do so was:

  Process name: [[15546,1],0]
  Exit code:    1
--------------------------------------------------------------------------
loading results from cluster
Solving complete - saving results
field md.solidearth.external is None
qmu is skipped until it is more stable
```



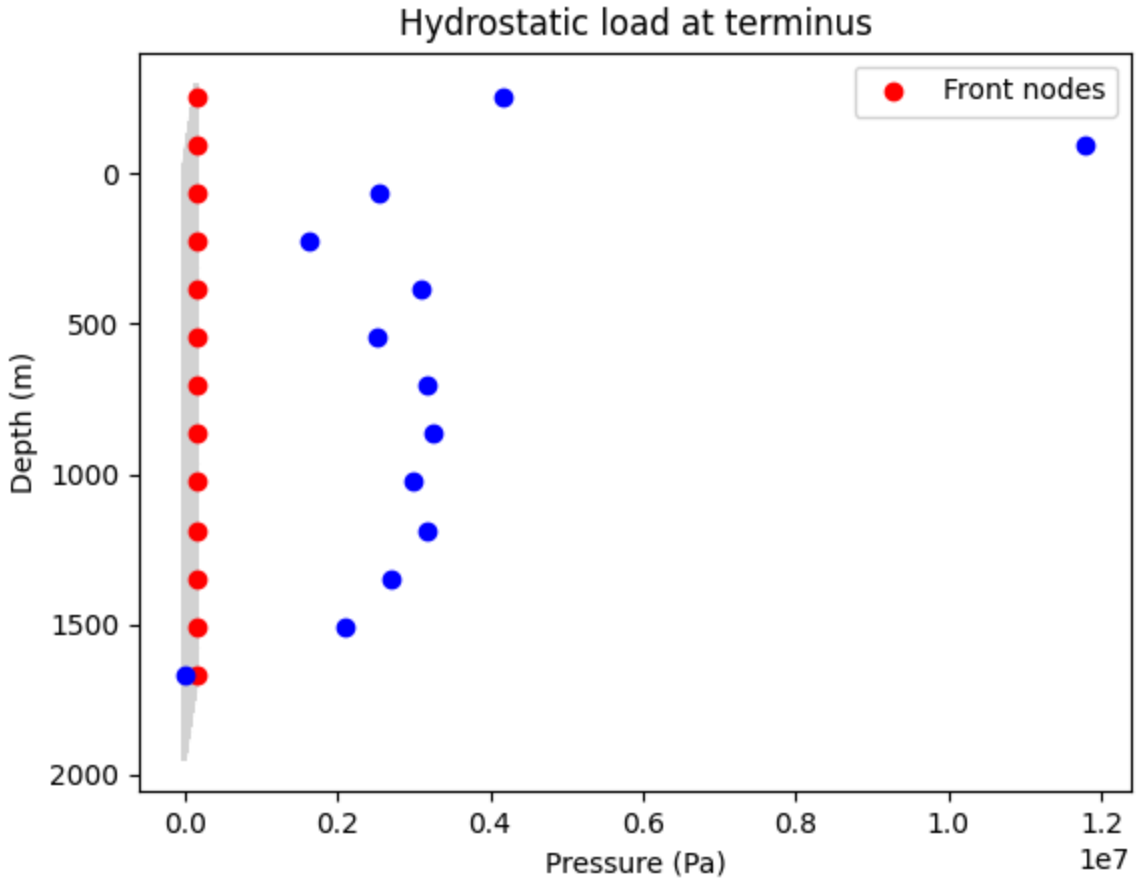


SIMULATION STILL CRASHES!

Icefront



Ocean Rressure at the Ice Front



OTHER ideas

Option 2: Extend Domain Further <<< JUST THE BEDROCK or SHOULD I ALSO EXTEND THE ICE MESH???? Might need 30-50km buffer????

Option 3: Impose Terminal Velocity Constraint