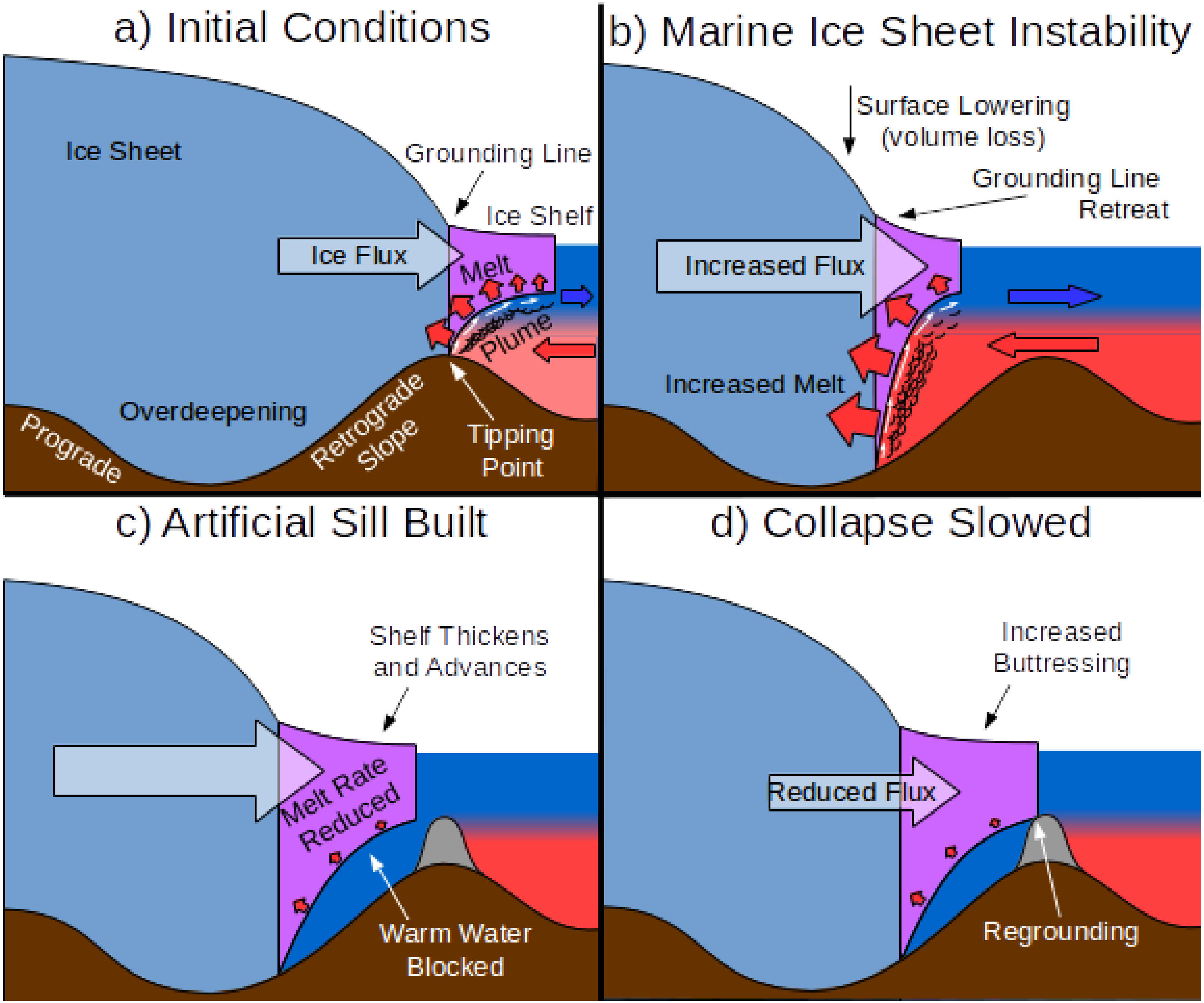
Fast and Slow: Two Very Different Problems that I Might Use Elmer/Ice On

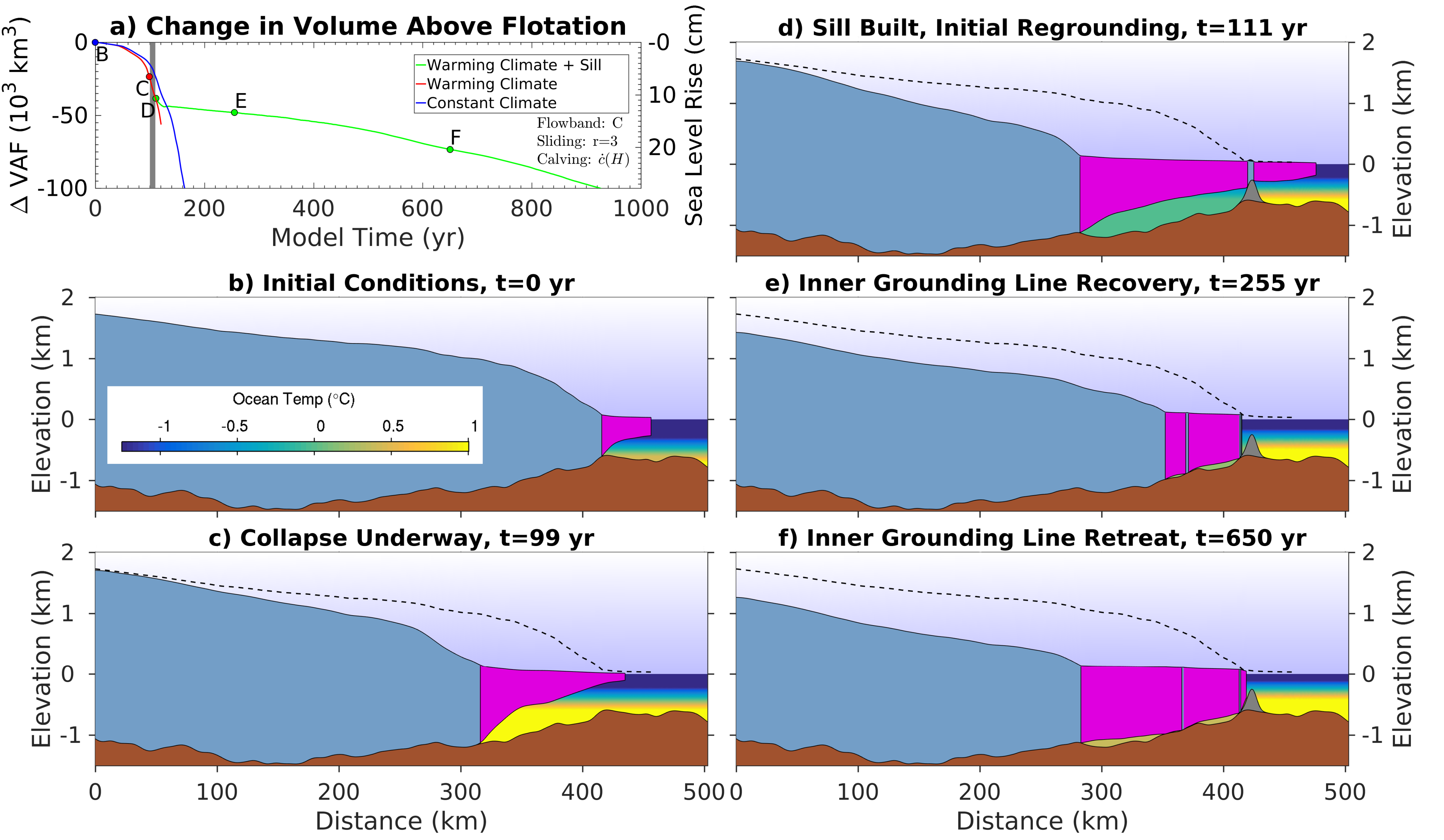
Mike Wolovick

Fast: Glacial Geoengineering



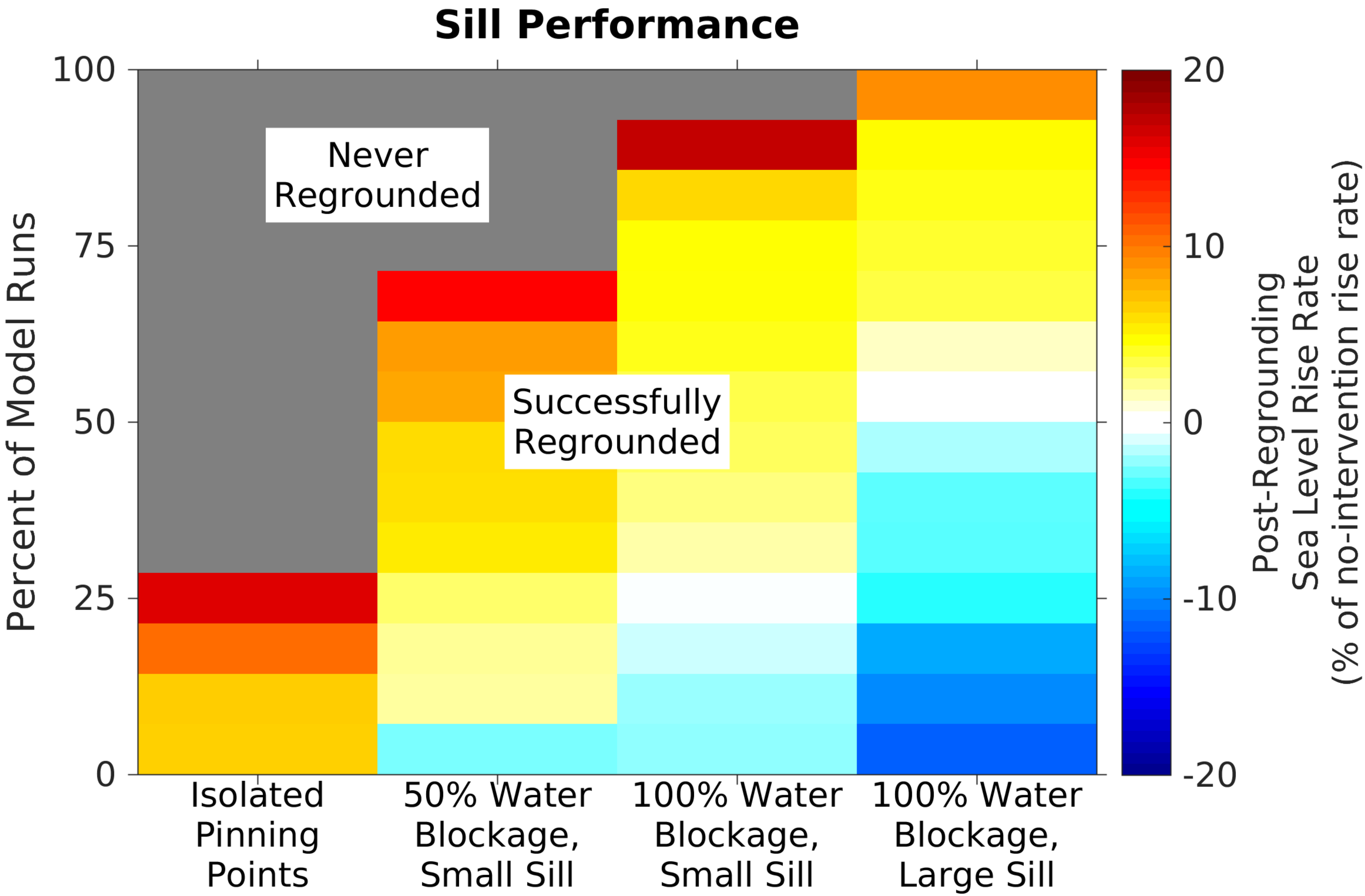
Wolovick and Moore, TC, 2018

Fast: Glacial Geoengineering



Wolovick and Moore, TC, 2018

Fast: Glacial Geoengineering



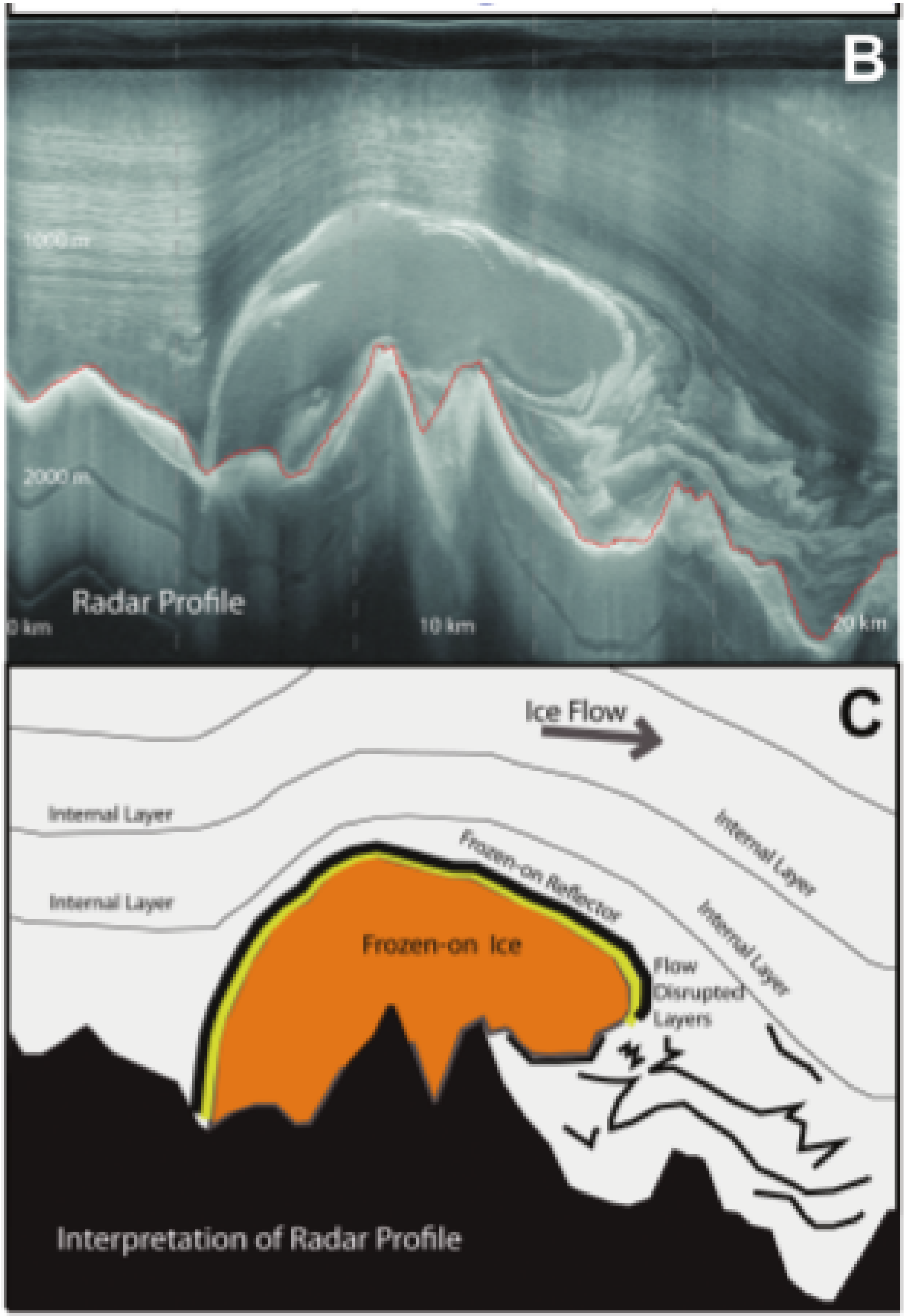
Wolovick and Moore, TC, 2018

Fast: Glacial Geoengineering

Potential Future Work:

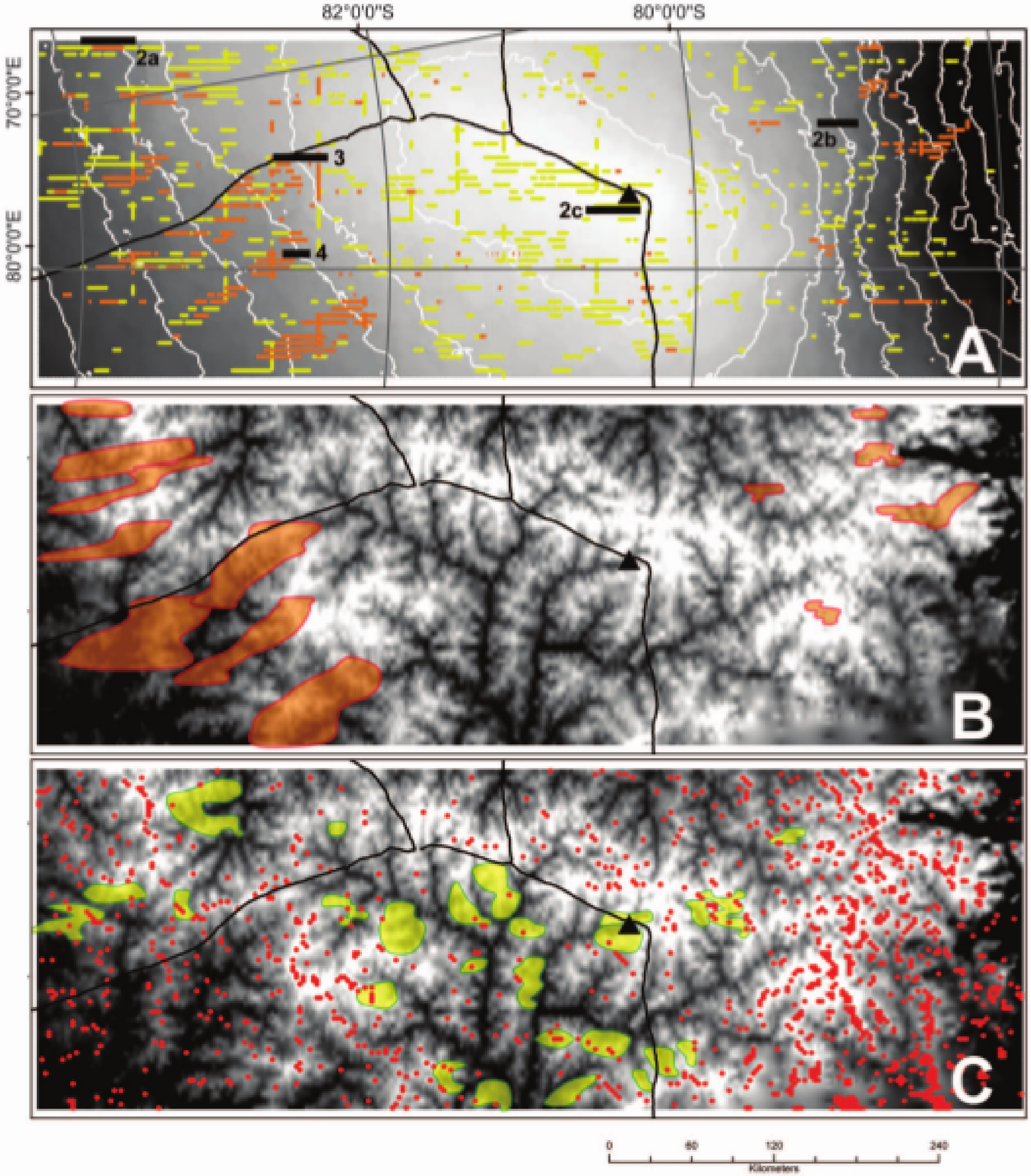
1. Better ice models (2D, 3D)
2. Ocean Model
3. Ice/Ocean coupling??
4. Other Possible Interventions:
   a) Subglacial drying
   b) Seawater pumping
   c) ...

Slow: Dome A



Bell et al., 2011

Slow: Dome A



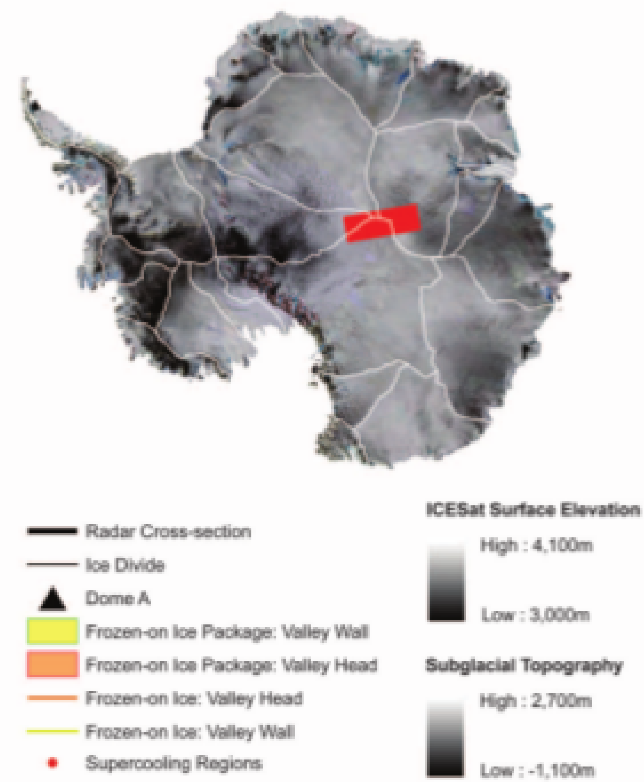


Fig. 1. Distribution of frozen-on ice in the Dome A region. (**A**) Surface elevation with location of frozen-on ice (orange, valley head; yellow, valley wall). Contours of 50 m show surface elevation from ICESat (Ice, Cloud, and land Elevation Satellite). A black triangle marks Dome A. (**B**) Valley head, strong reflector–bounded, freeze-on ice packages (orange) overlain on subglacial topography. (**C**) Valley wall freeze-on ice packages (yellow) overlain on subglacial topography with regions of supercooling (red dots). (Inset, top right) Location of survey (red bar), along with major Antarctic Ice Divides.

Bell et al., 2011

Slow: Dome A

My Model:
1. Steady State, SIA
2. Balance Velocity + Shape Functions (downhill integration)
   - All components of strain rate enter viscosity
3. Basal Hydrology (with freeze-on!)
   - Also a downhill integration (in hydraulic potential)
   - Hydrology equations:

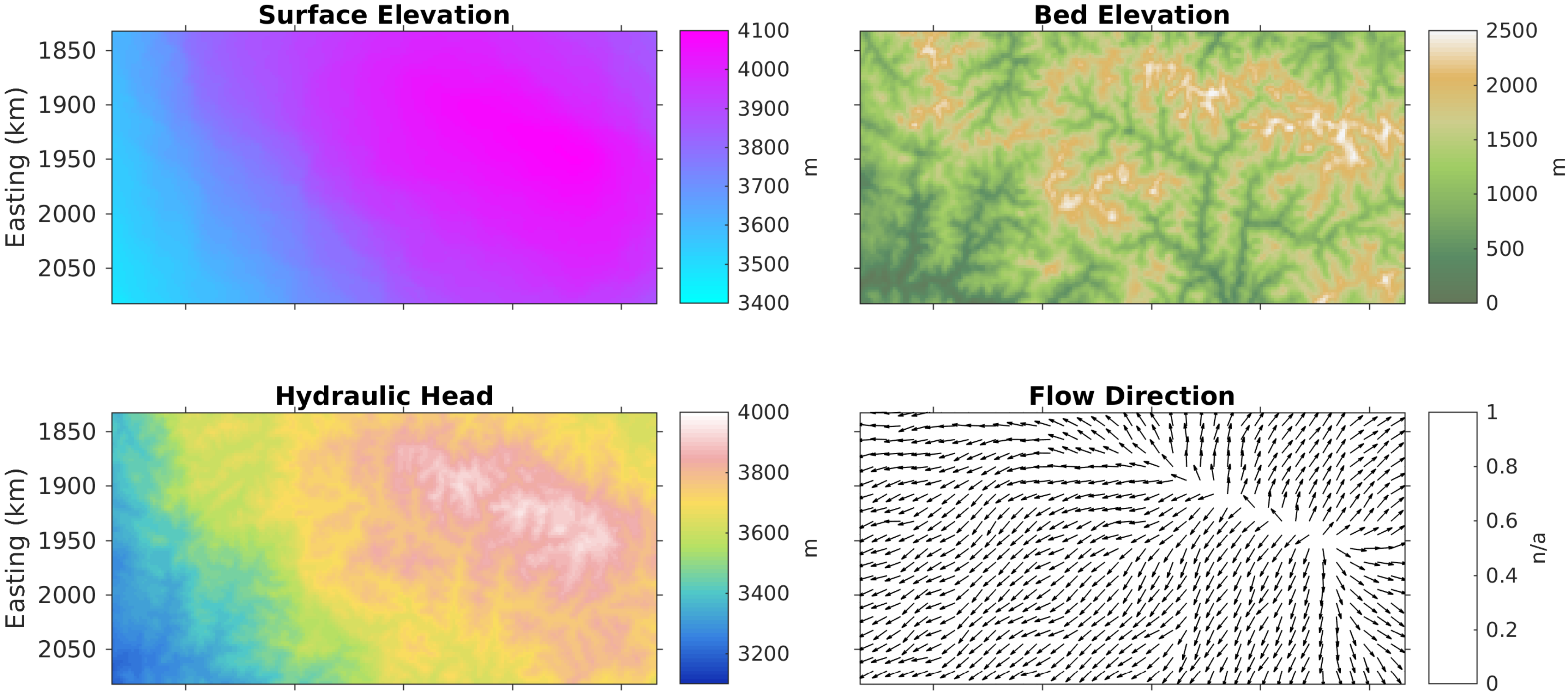
$$\nabla \cdot \vec{q} = \dot{m}$$

Mass conservation

$$\frac{\vec{q}}{|q|} = \frac{\nabla \phi}{|\nabla \phi|}$$

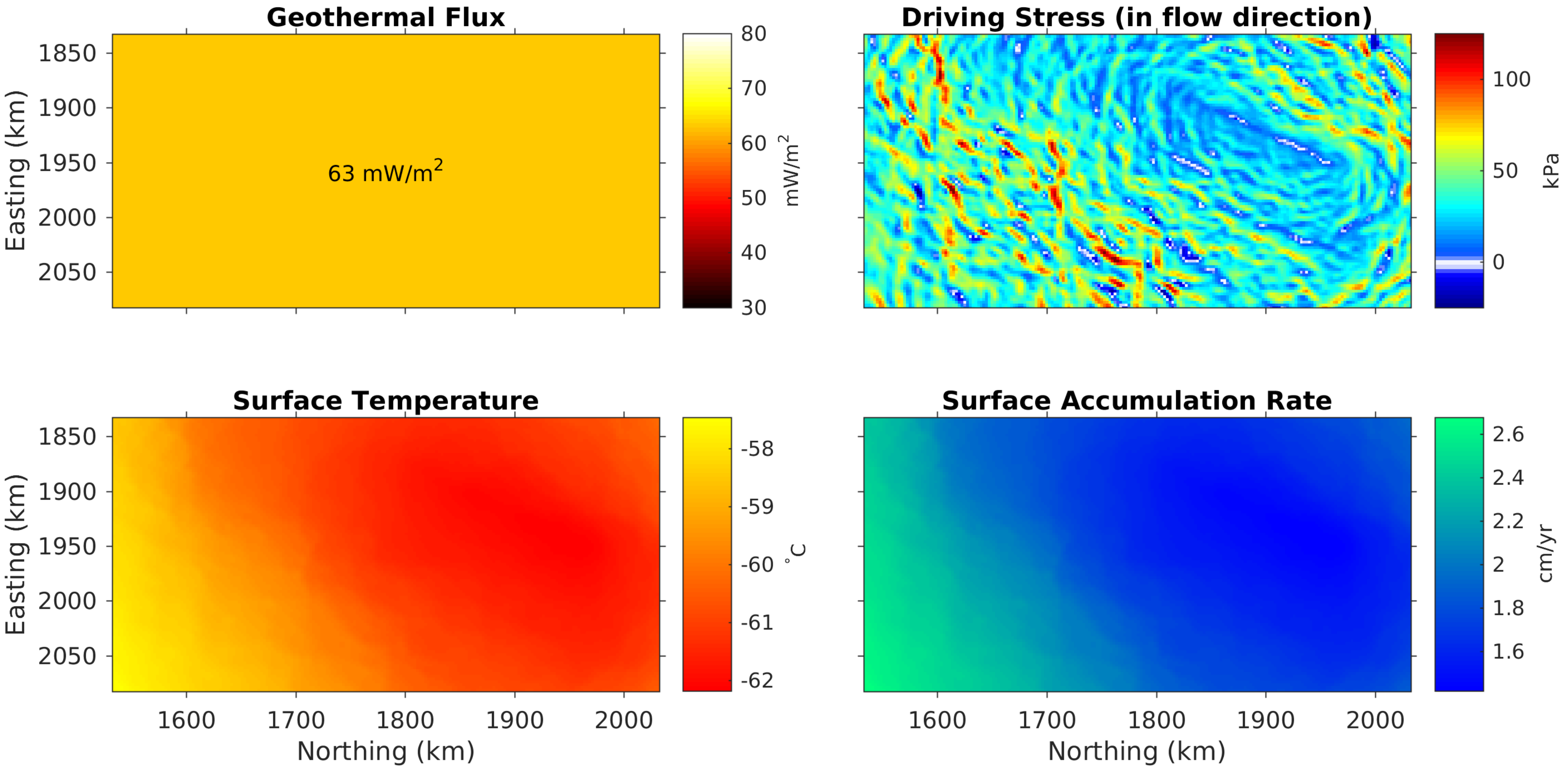
Flow aligned with gradient of hydraulic potential

Slow: Dome A



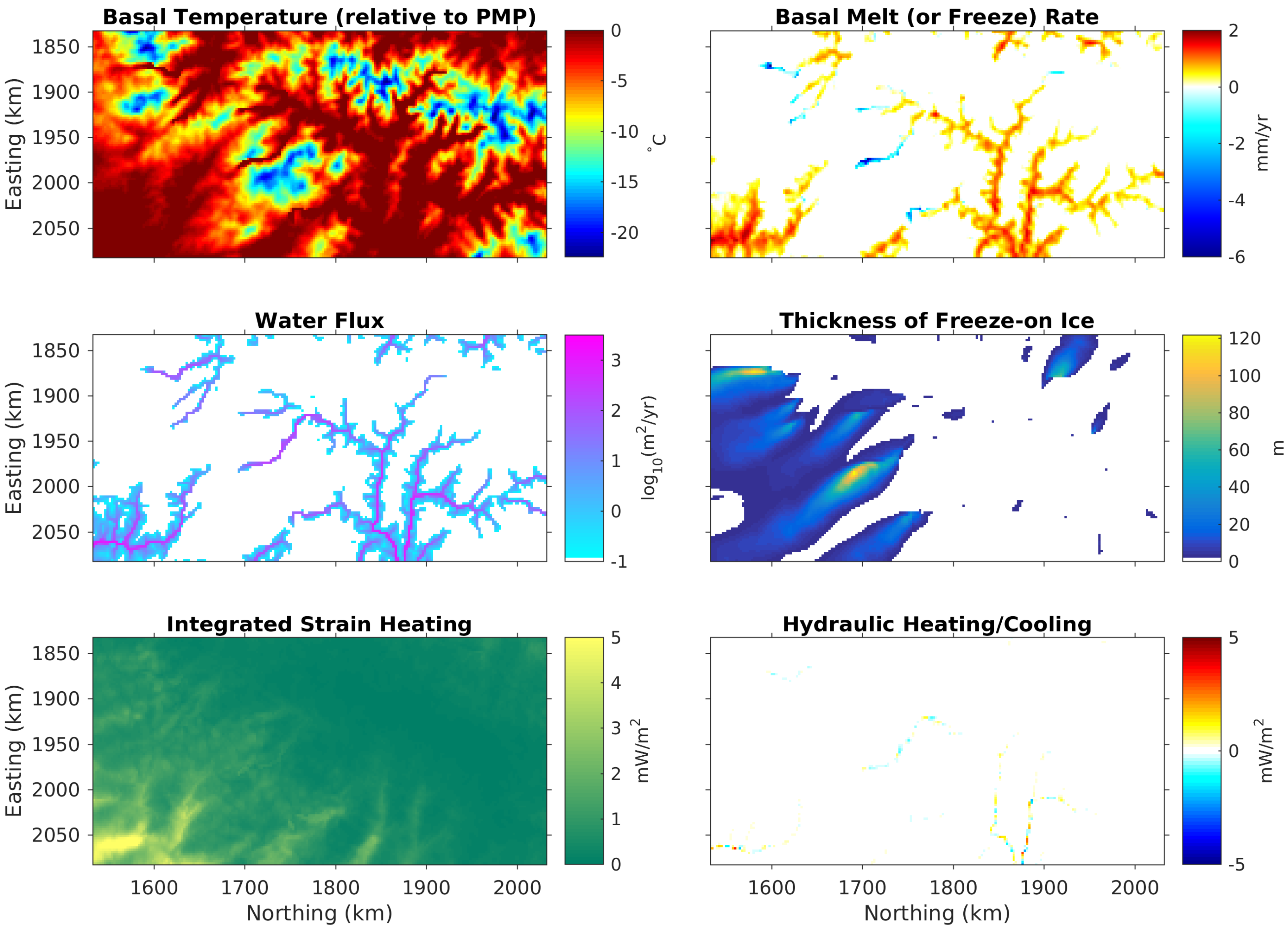
Surface Elevation
Bed Elevation
Hydraulic Head
Flow Direction
Easting (km)
1850
1900
1950
2000
2050
4100
4000
3900
3800
3700
3600
3500
3400
m
2500
2000
1500
1000
500
0
m
4000
3800
3600
3400
3200
m
1
0.8
0.6
0.4
0.2
0
n/a

Slow: Dome A

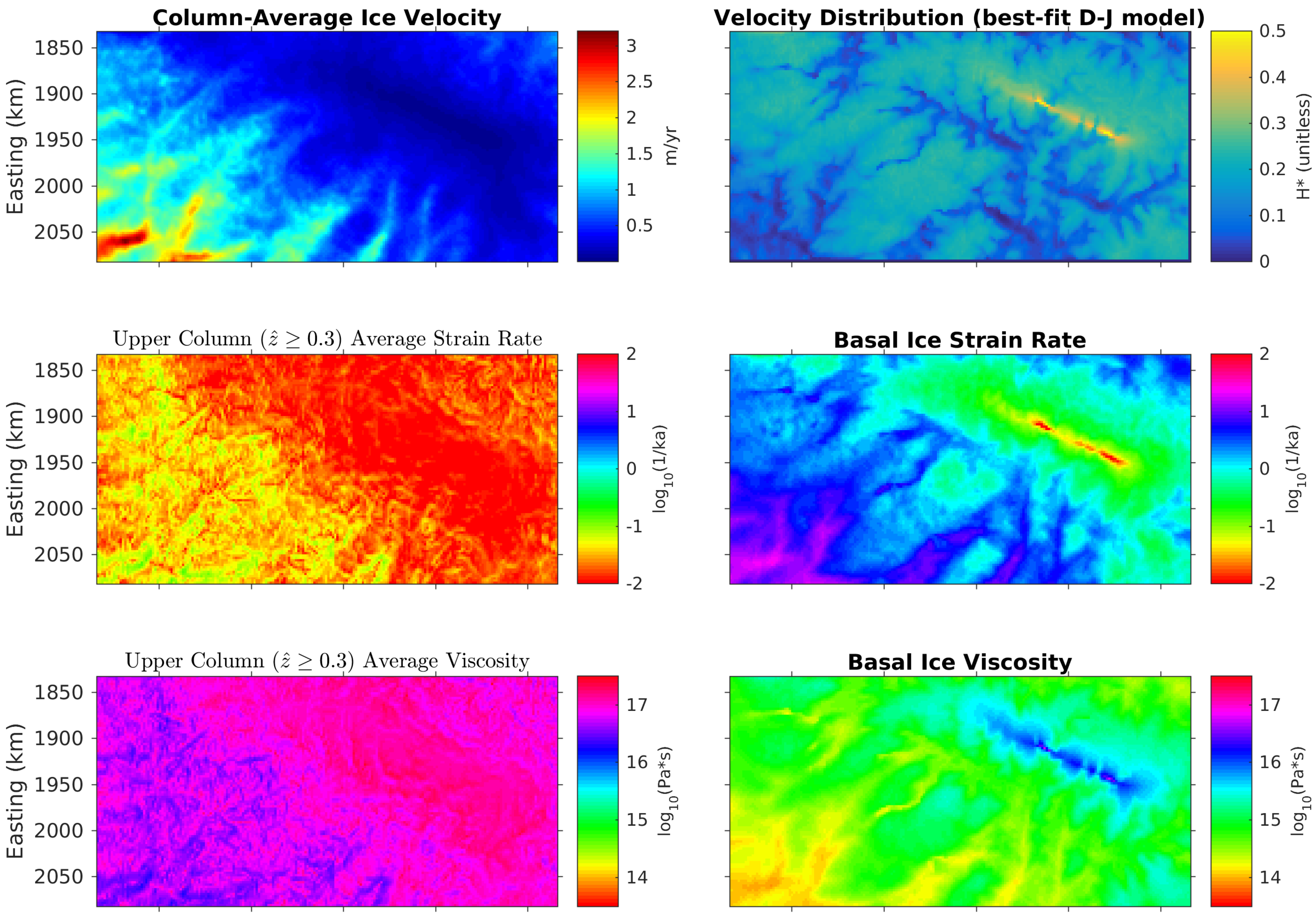


Geothermal Flux
63 mW/m²
mW/m²
80
70
60
50
40
30
Driving Stress (in flow direction)
kPa
100
50
0
Surface Temperature
°C
-58
-59
-60
-61
-62
Surface Accumulation Rate
cm/yr
2.6
2.4
2.2
2
1.8
1.6
Easting (km)
1850
1900
1950
2000
2050
Northing (km)
1600
1700
1800
1900
2000

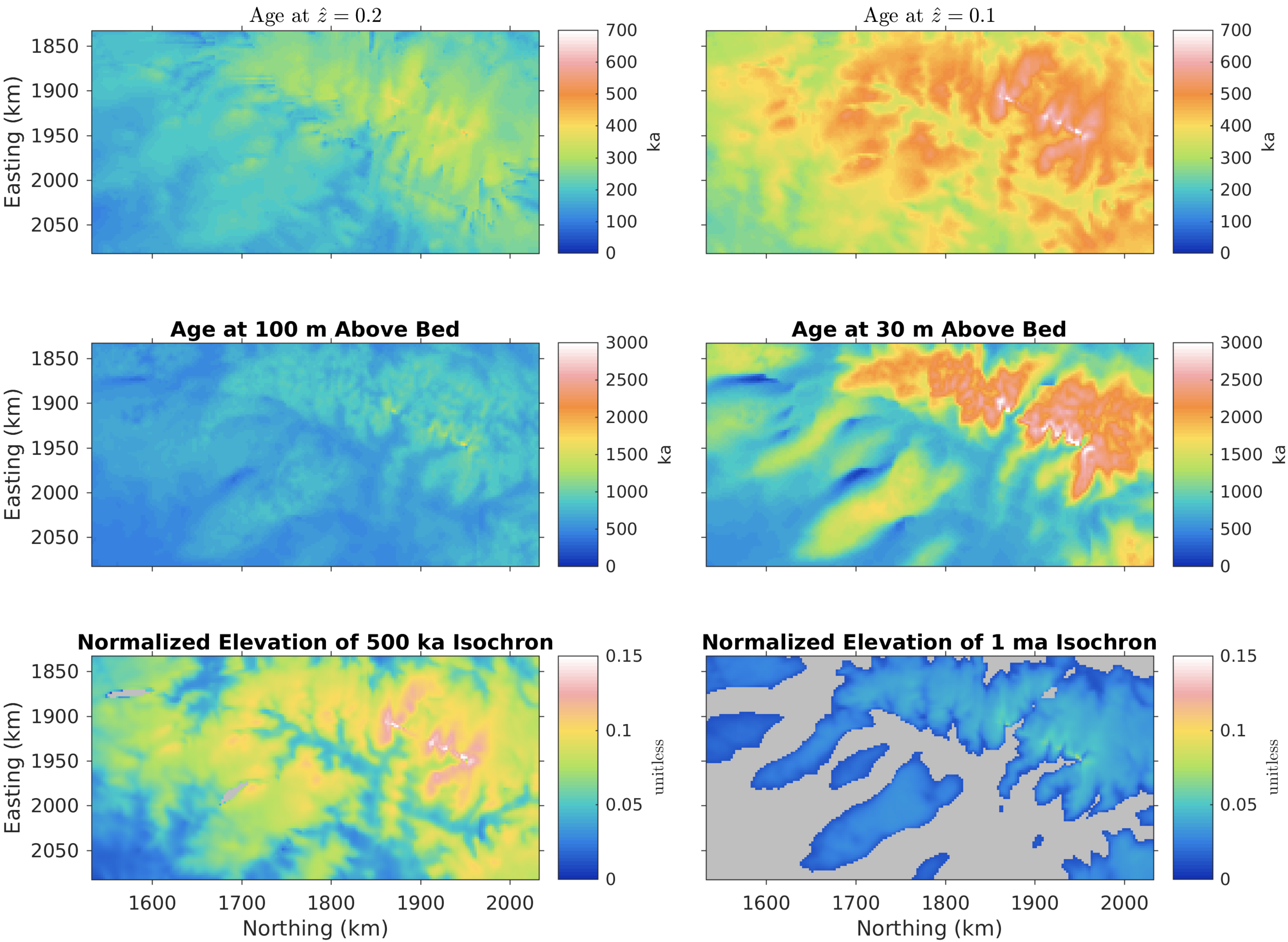
Slow: Dome A


Basal Temperature (relative to PMP)
Basal Melt (or Freeze) Rate
Water Flux
Thickness of Freeze-on Ice
Integrated Strain Heating
Hydraulic Heating/Cooling
Easting (km)
Northing (km)
1850
1900
1950
2000
2050
1600
1700
1800
1900
2000
°C
0
-5
-10
-15
-20
mm/yr
2
0
-2
-4
-6
log10(m2/yr)
3
2
1
0
-1
m
120
100
80
60
40
20
0
mW/m2
5
4
3
2
1
0
mW/m2
5
0
-5

Slow: Dome A


Column-Average Ice Velocity
Easting (km)
1850
1900
1950
2000
2050
3
2.5
2
1.5
1
0.5
m/yr
Velocity Distribution (best-fit D-J model)
0.5
0.4
0.3
0.2
0.1
0
H* (unitless)
Upper Column ($\hat{z} \geq 0.3$) Average Strain Rate
2
1
0
-1
-2
$\log_{10}$(1/ka)
Basal Ice Strain Rate
Upper Column ($\hat{z} \geq 0.3$) Average Viscosity
17
16
15
14
$\log_{10}$(Pa*s)
Basal Ice Viscosity

Slow: Dome A


Age at $\hat{z} = 0.2$
Age at $\hat{z} = 0.1$
Age at 100 m Above Bed
Age at 30 m Above Bed
Normalized Elevation of 500 ka Isochron
Normalized Elevation of 1 ma Isochron
Easting (km)
Northing (km)
1850
1900
1950
2000
2050
1600
1700
1800
1900
2000
0
100
200
300
400
500
600
700
ka
0
500
1000
1500
2000
2500
3000
ka
0
0.05
0.1
0.15
unitless

Slow: Dome A

Things Elmer/Ice Can Add to this Problem:

1. Full Stokes
2. Anisotropic rheology
3. Bedrock thermal conduction
4. Time dependence?