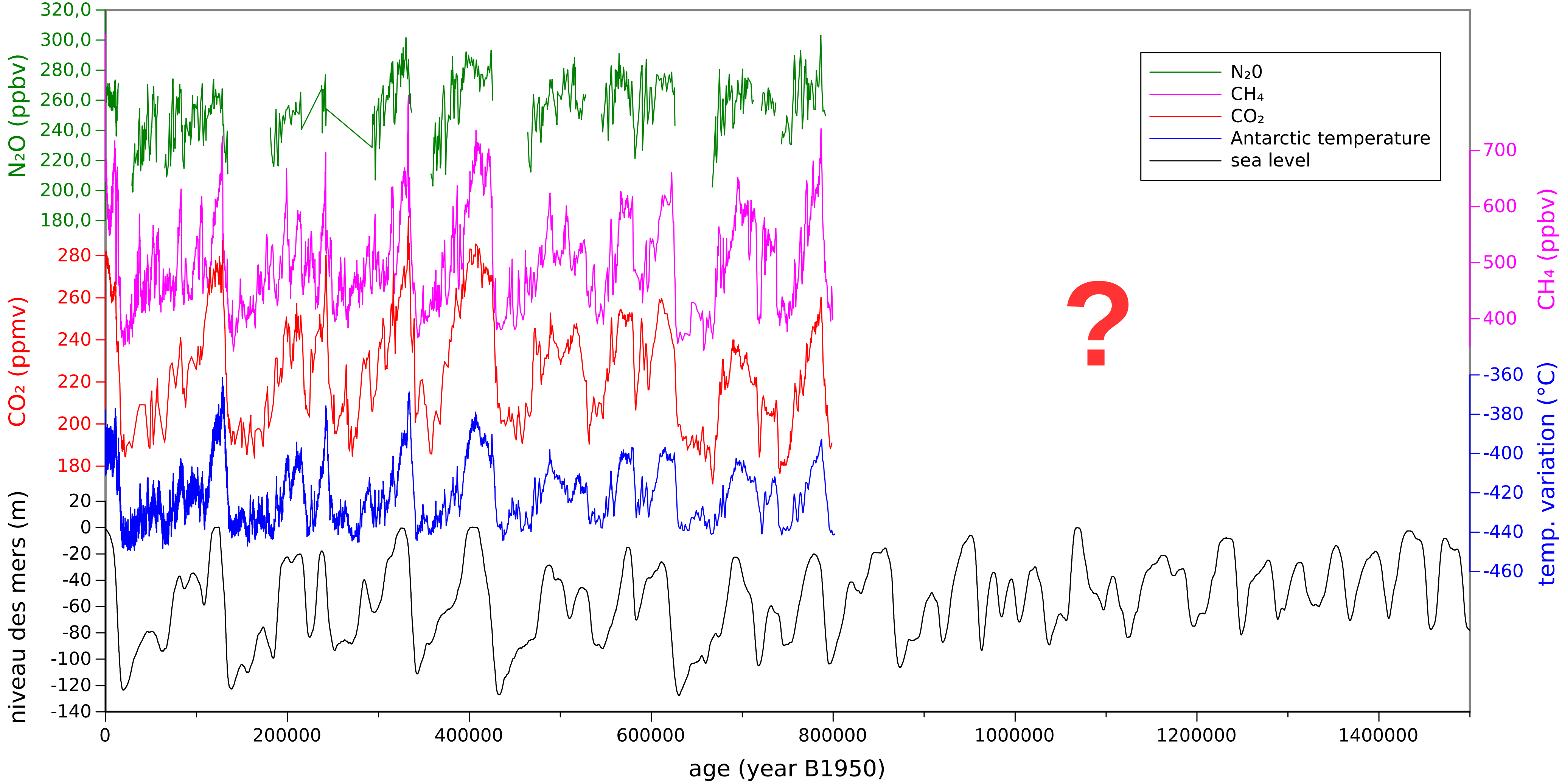
Seminar at BAS, October 2015

Is there 1.5 million-year old ice near Dome C, Antarctica?

F. Parrenin[1], M. G. P. Cavitte[2], D. D. Blankenship[2], J. Chappellaz[1], H. Fischer[3], O. Gagliardini[1], F. Gillet-Chaulet[1], V. Masson-Delmotte[4], O. Passalacqua[1], C. Ritz[1], M. J. Siegert[5], D. A. Young[2]

1) LGGE-UGA, Grenoble, France.
2) University of Texas, Austin, USA.
3) University of Bern, Switzerland.
4) LSCE-UVSQ, Gif-sur-Yvette, France.
5) Imperial College, London, UK.

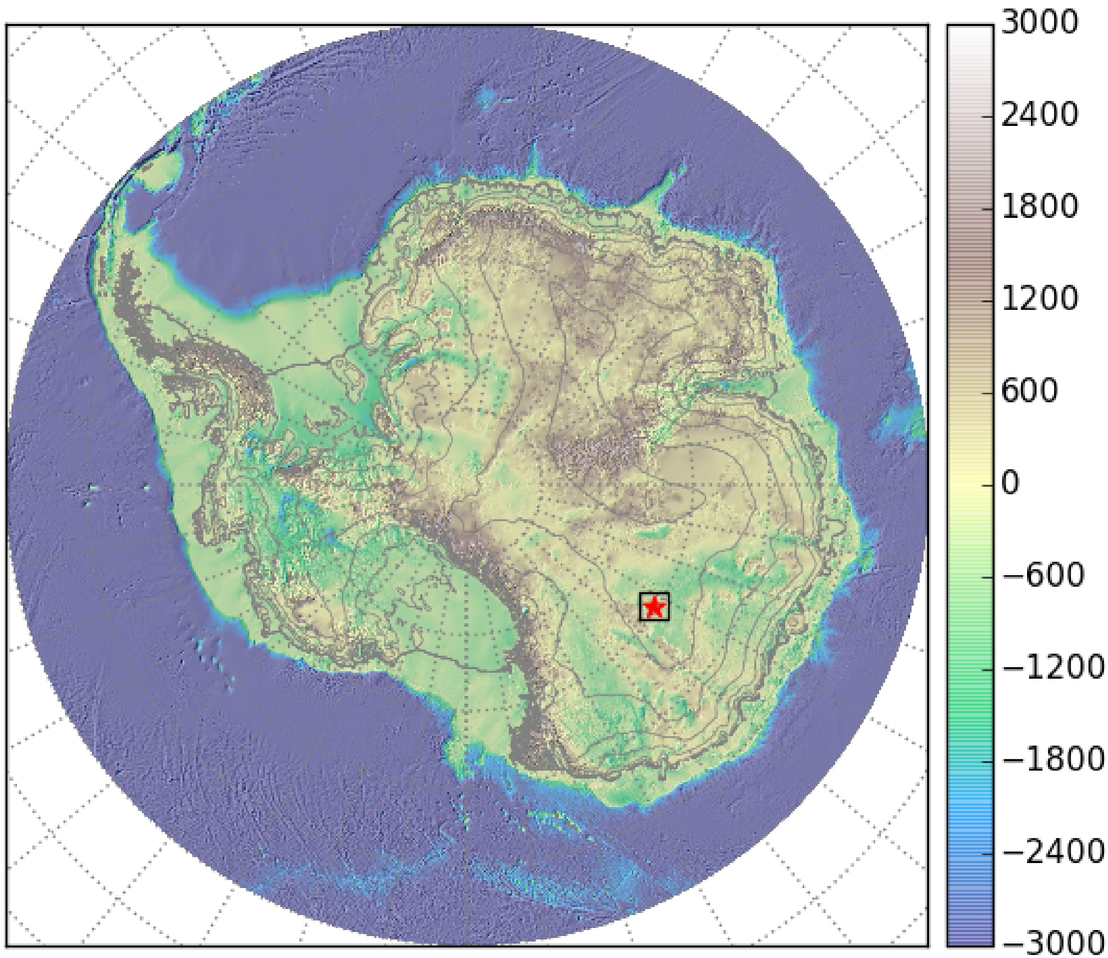
The OldestIce challenge



The OldestIce challenge

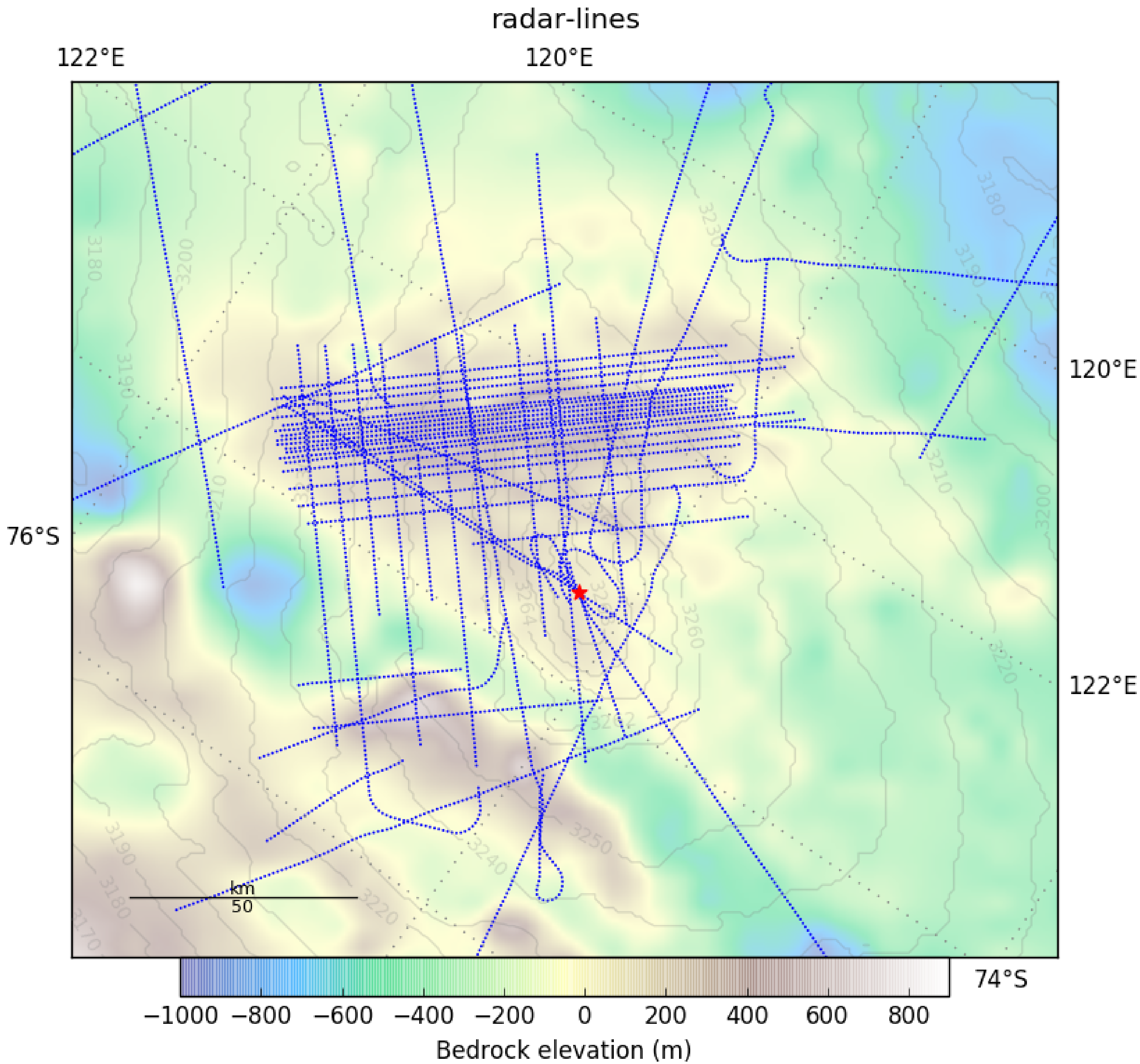
We want to obtain an un-disturb ice core record of the so-called '41 kyr' world, where the glacial cycles had shorter amplitude and duration than today

The Dome C area

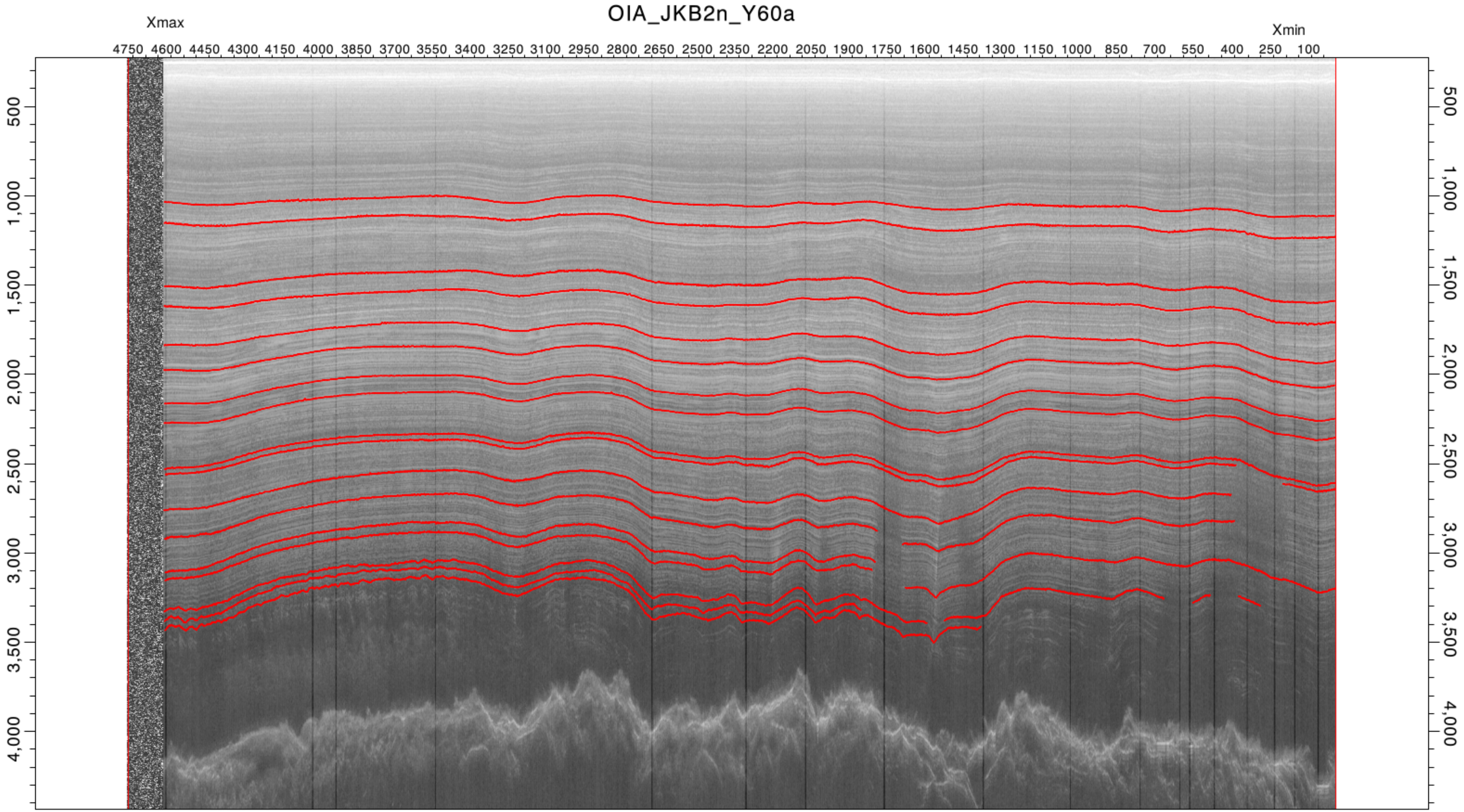


- Close to a topographic dome
- The longest record so far with 800,000 years
- Many geophysical data
- Logistic facility

The UTIG data



Example of radar profile



The age model used

- Eulerian age formulation

$$\chi(z)=\int_{z}^{H}\frac{D(z')}{a(z')\tau(z')}dz'$$

Number of annual
Layers per depth unit

- z: depth of ice
- χ: age of ice
- D: relative density
- a: surface accumulation
- τ: vertical thinning function

The thinning model used

- 1D, pseudo-steady velocity model

$$\tau = (1-\mu)\omega + \mu \qquad \mu = m/a$$

- m/a is assumed constant in time
- ω, the flux shape function, is assumed constant in time
- ω based on Lliboutry analytical SIA solution:

$$\omega(\zeta) = 1 - \frac{p+2}{p+1}(1-\zeta) + \frac{1}{p+1}(1-\zeta)^{p+2}$$

$$\zeta = \frac{z-B}{H}$$ Reduced depth

The accumulation model used

- Accumulation reconstructed from the isotopic content of ice at EDC :

$$a = A^0 \exp\left(\beta \Delta\left(\delta D\right)\right)$$

- The steady problem is solved with an average accumulation

$$a = R\left(t\right)\bar{a}$$

- The stationnary ages are converted to real ages using :

$$d\,\bar{t} = R\left(t\right)dt$$

The thermal model used

- 1D, steady thermal model :

$$k_{\mathrm{T}} \frac{d^2 T}{dz^2} - c \rho u_z \frac{dT}{dz} = 0$$

- Boundary condition at surface :

$$T \big|_{z=H} = T_S$$

- Boundary condition at bedrock :

$$T \big|_{z=0} = T_f$$

$$-k_{\mathrm{T}} \frac{dT}{dz}\bigg|_{z=0} = G_0$$

- 5 iterations to solve the thermo-mechanical coupling

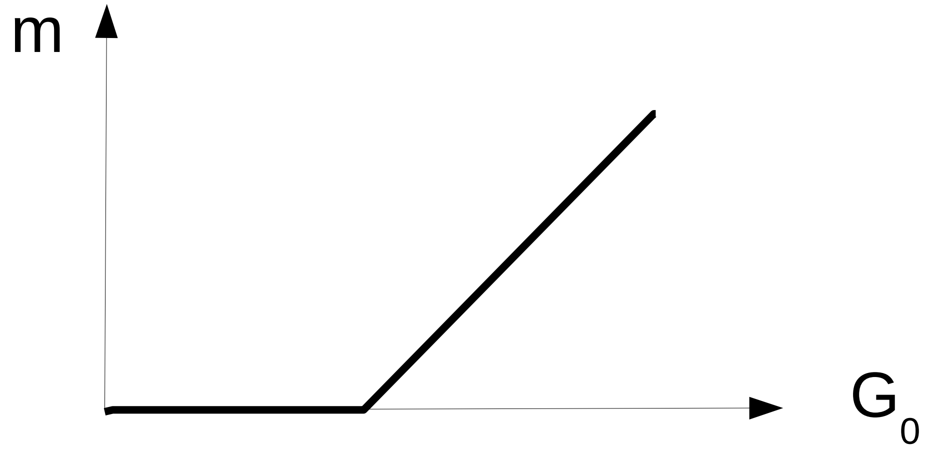
Model fitting to isochrones

$$S = \sum_{i=1}^{N} \frac{\left(\chi_i^{iso} - \chi^{mod}\left(d_i^{iso}\right)\right)^2}{\left(\sigma_i^{iso}\right)^2} + \frac{\left(p'_{prior} - p'\right)^2}{\left(\sigma^{p'}\right)^2} + \frac{\left(G_{0,prior} - G_0\right)^2}{\left(\sigma^{G_0}\right)}$$

- Least-squares cost function
- Prior value of ln(3)±2 for p'=ln(p+1)
- Prior value of 60±20 mW/m^2 for G_0
- Fit on 17 isochrones
- 3 free parameters: a, p', G_0

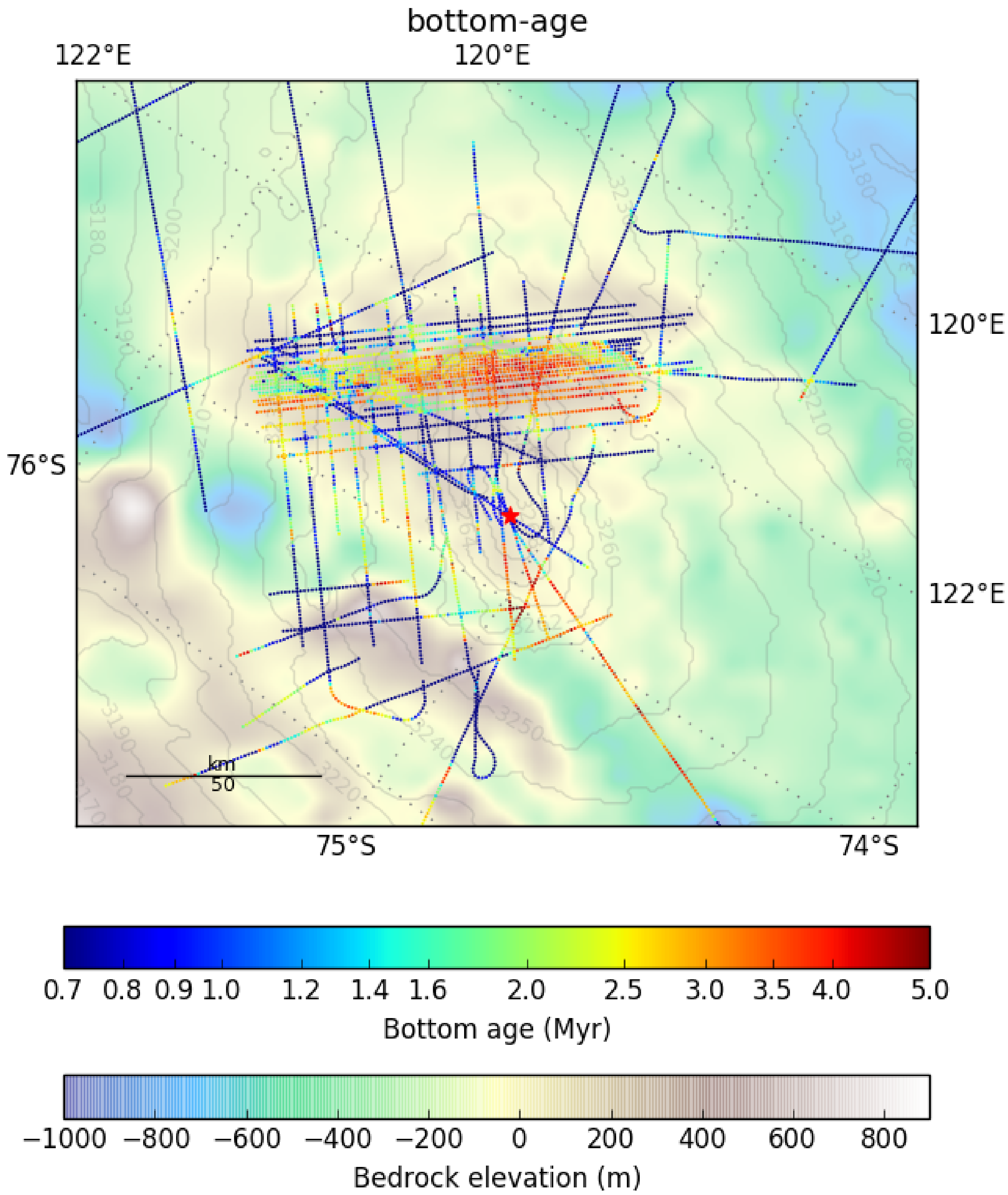
Solving the inverse problem

- The forward model is very non-linear:

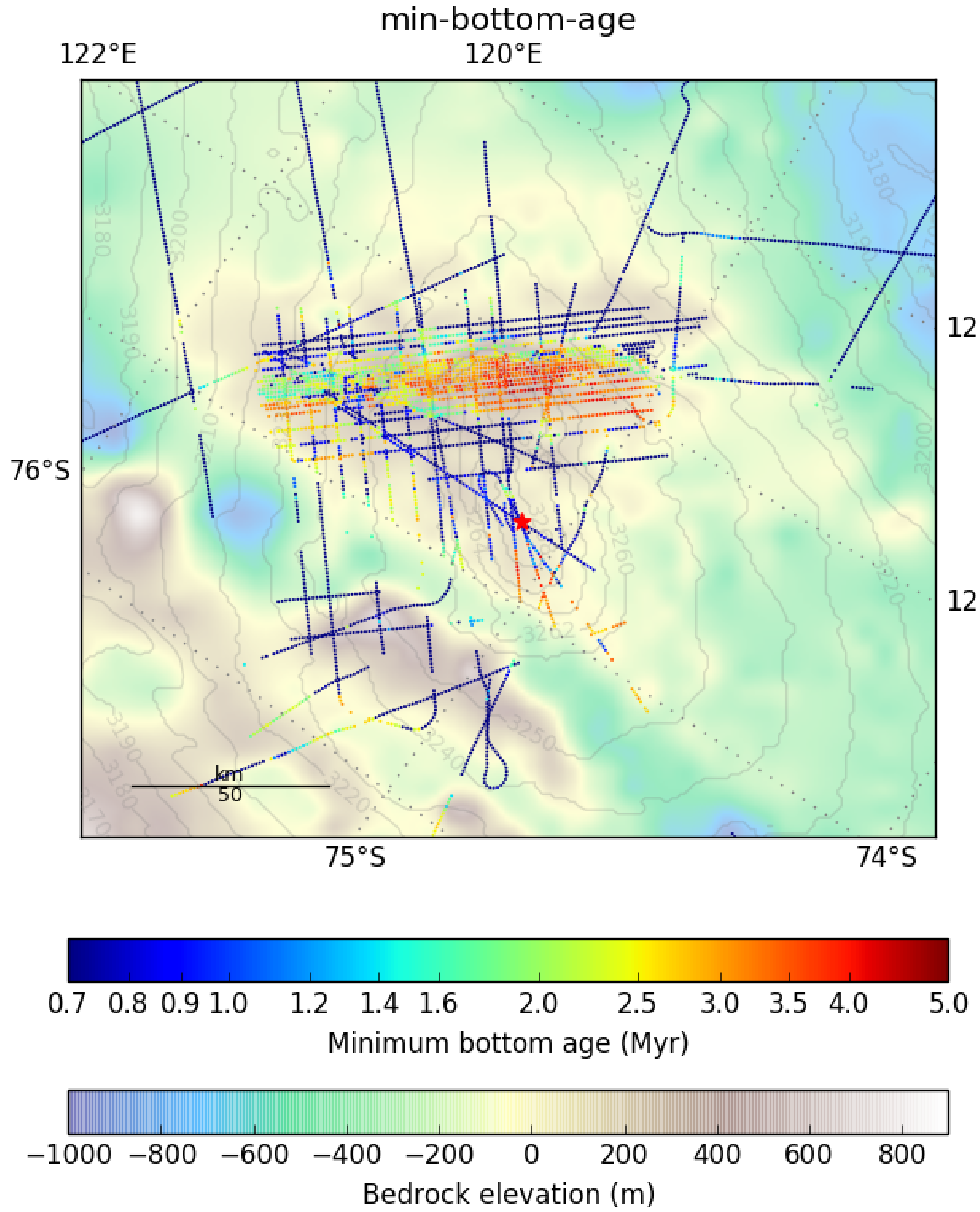


- MCMC Method (Metropolis-Hastings)
- 1000 scenarios
- Step function and initial scenario determined using a quasi-linear solution (Levenberg-Marquardt)

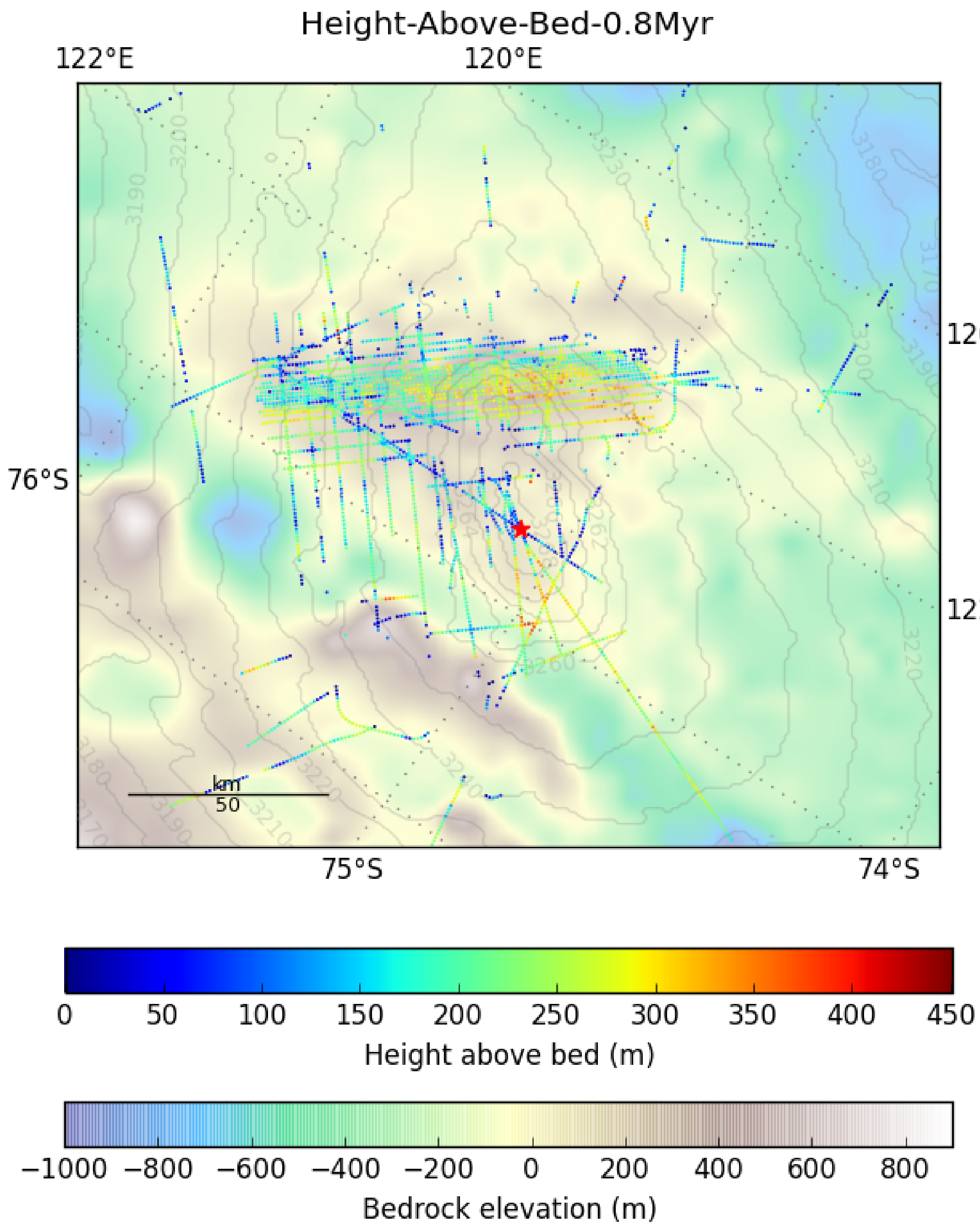
Age at 60 m above bedrock



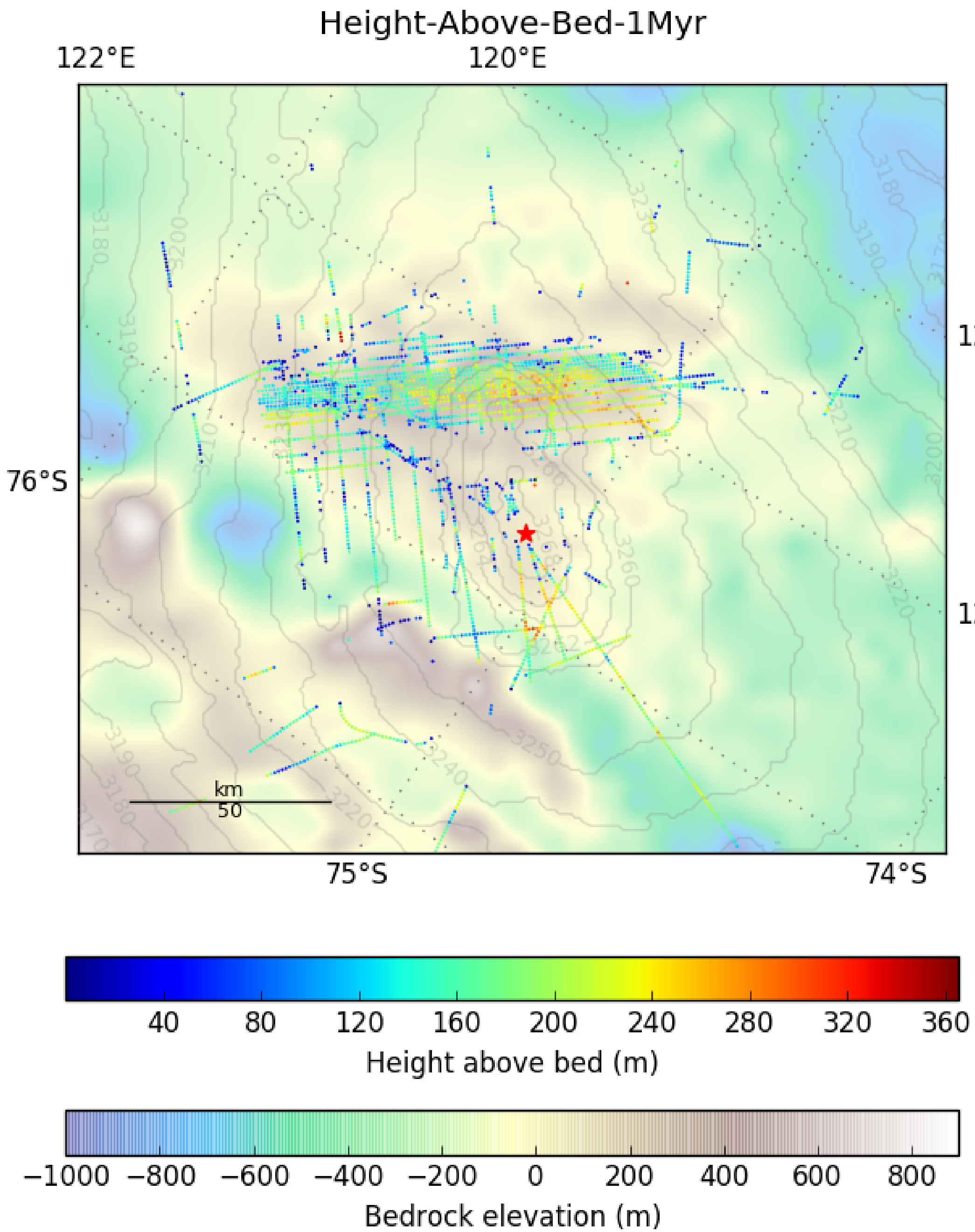
Min Age (85%) at 60 m above bedrock



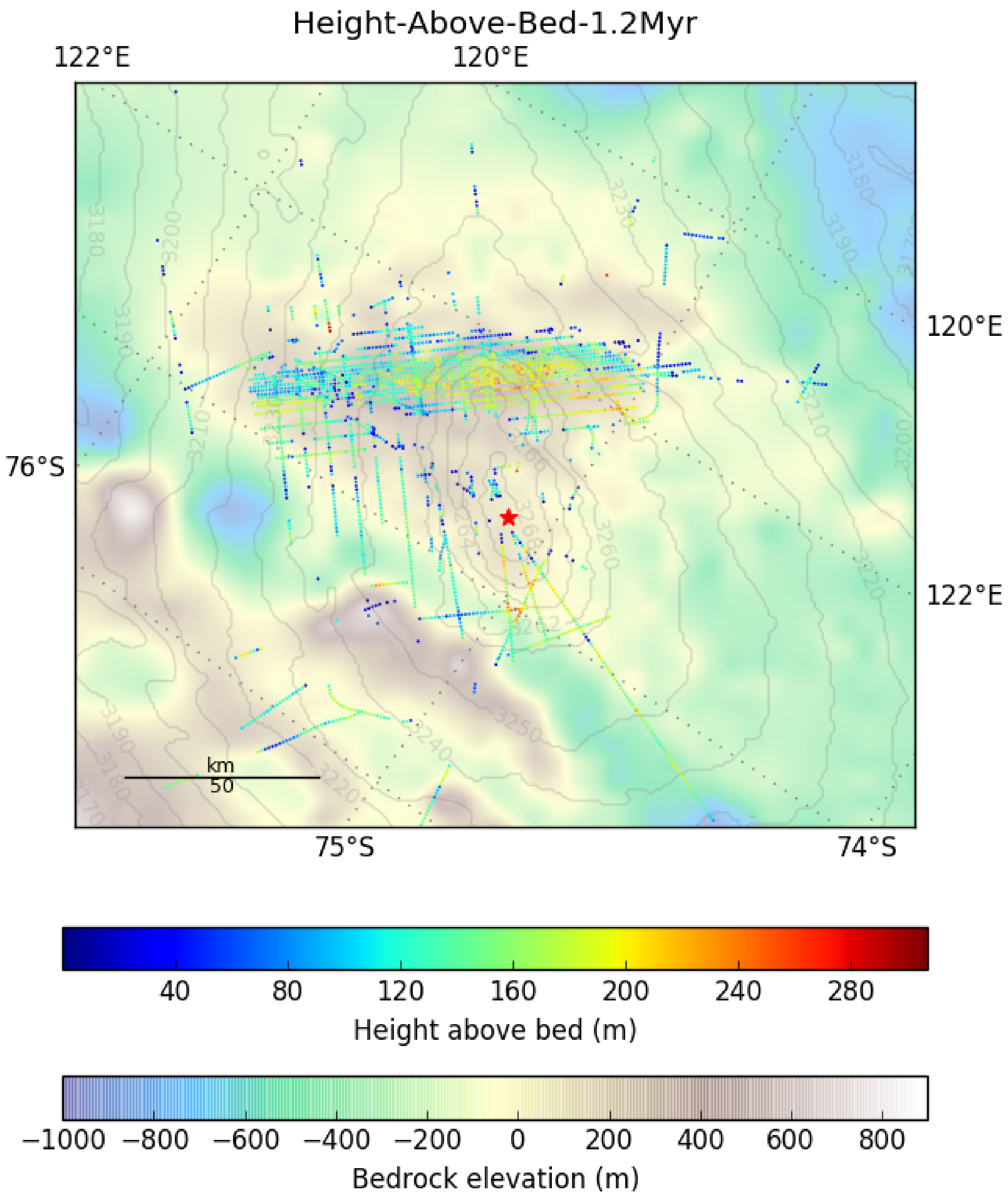
Height above bed – 0.8 Myr



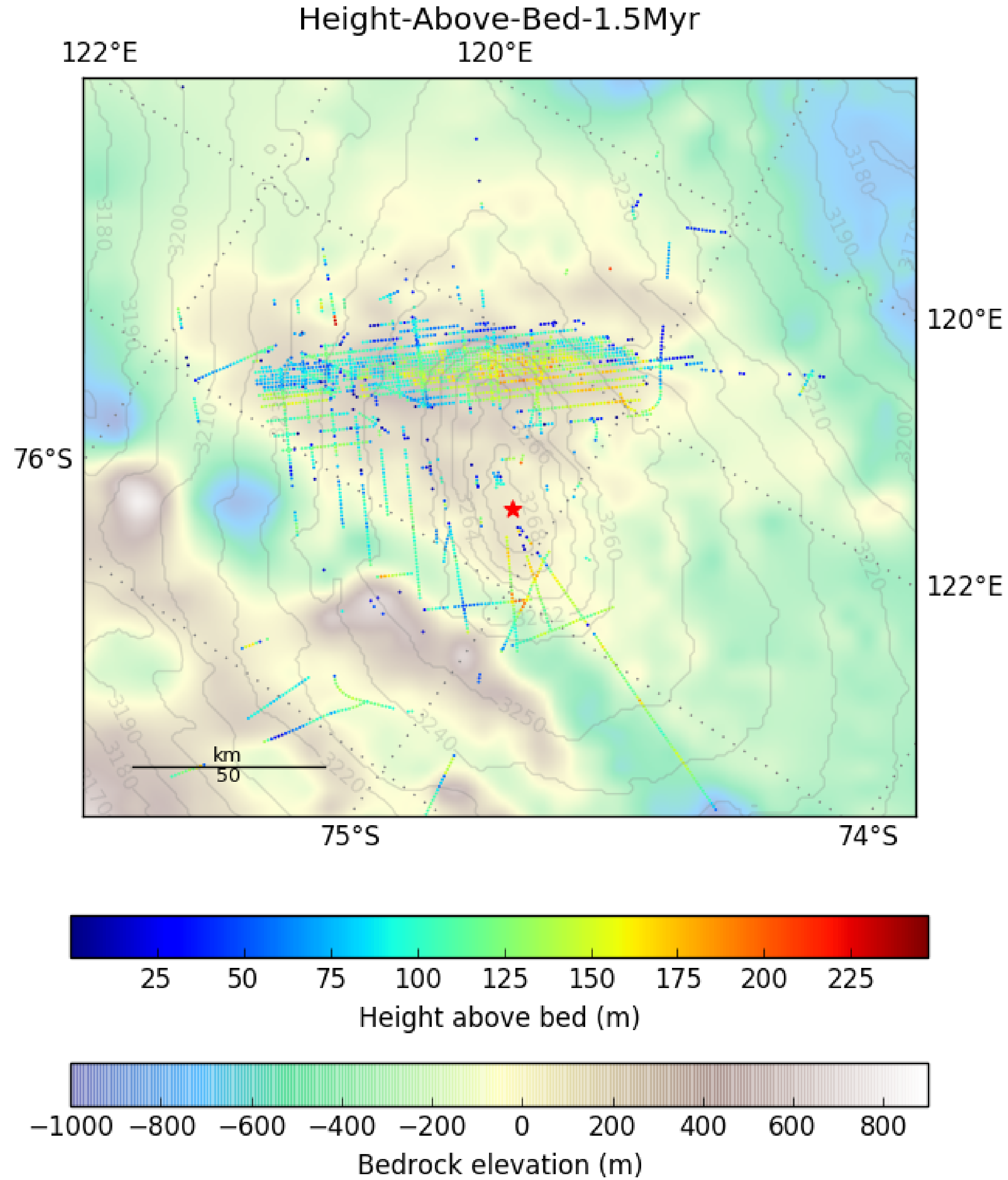
Height above bed – 1 Myr



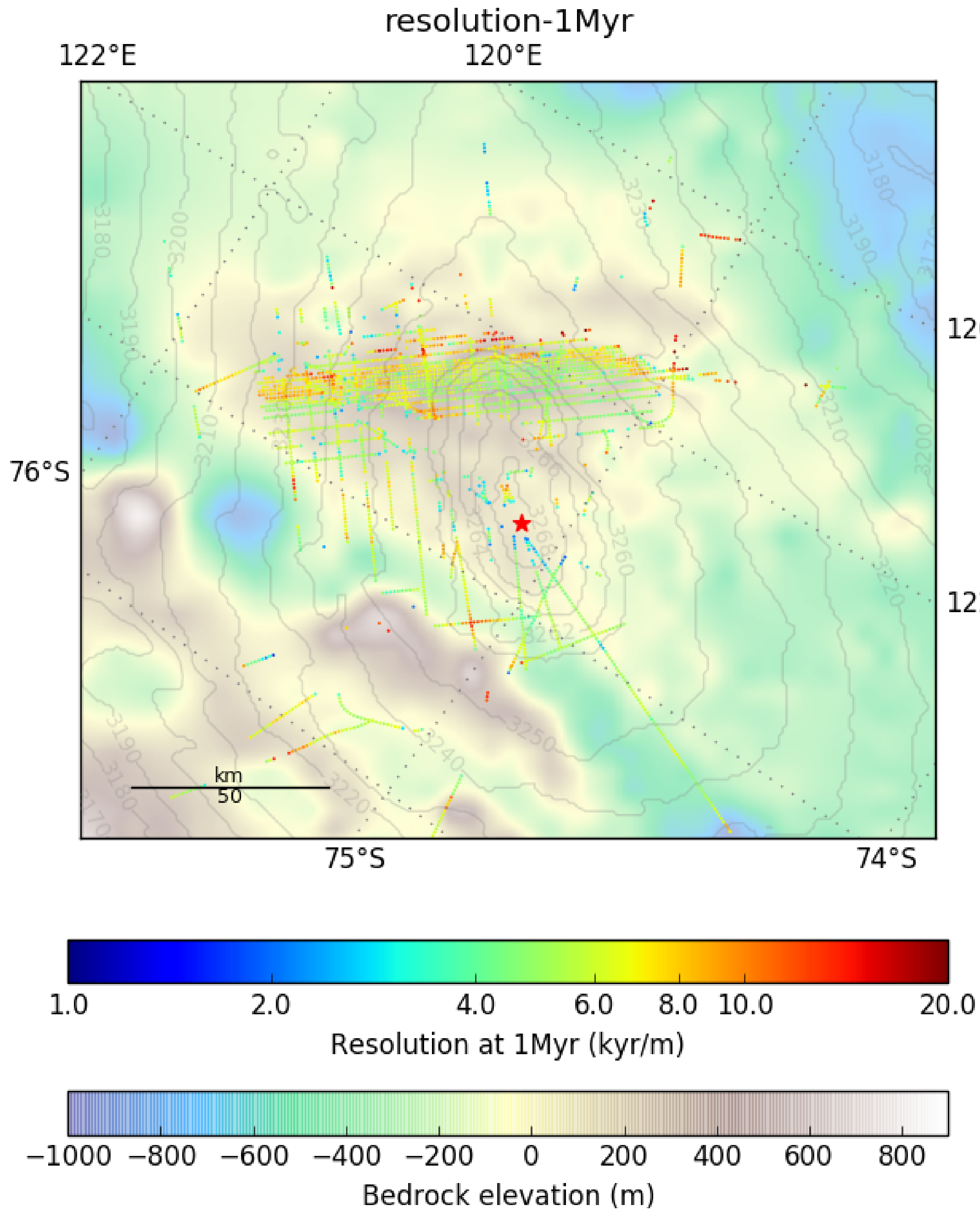
Height above bed – 1.2 Myr



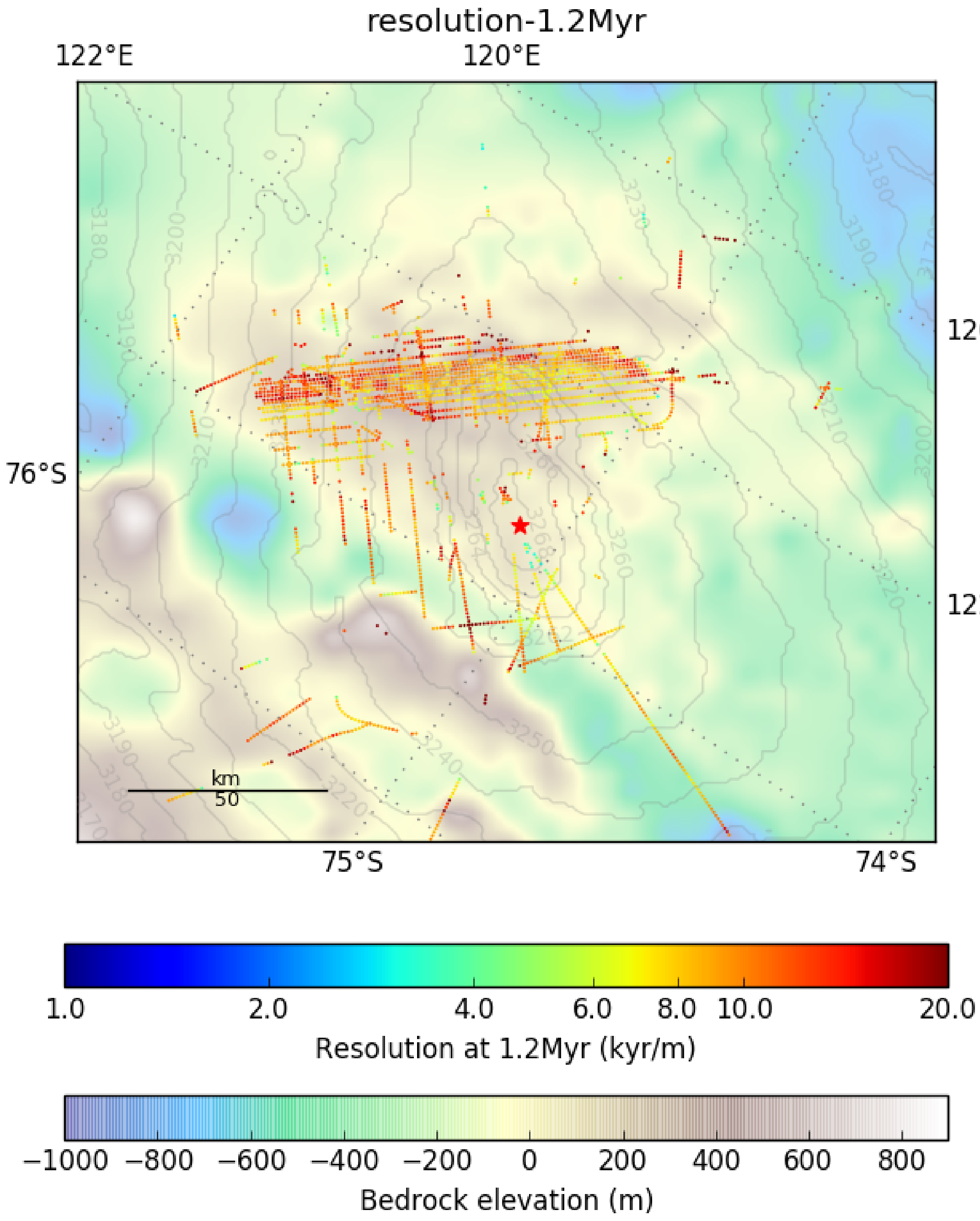
Height above bed – 1.5 Myr



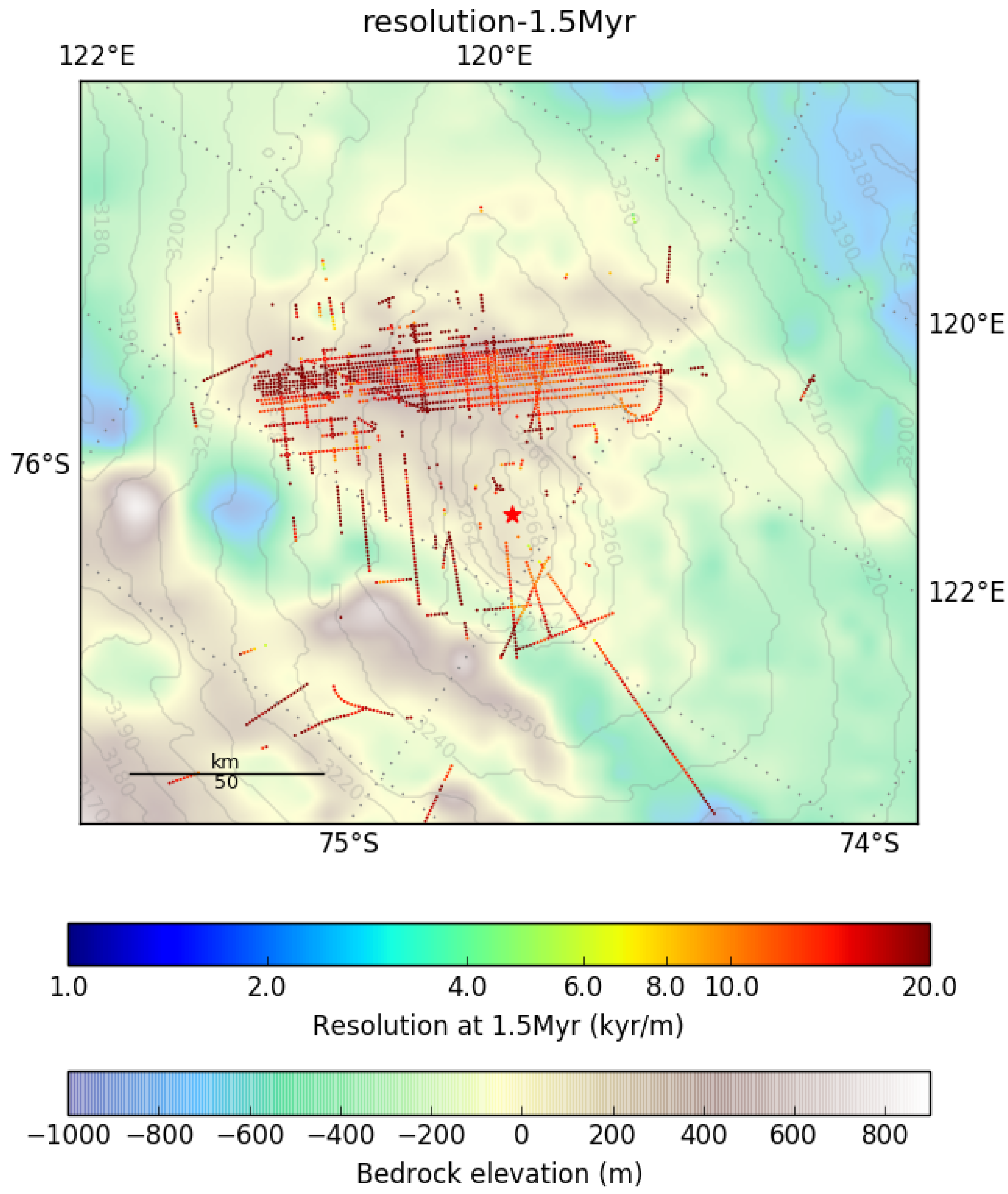
Resolution at 1 Myr



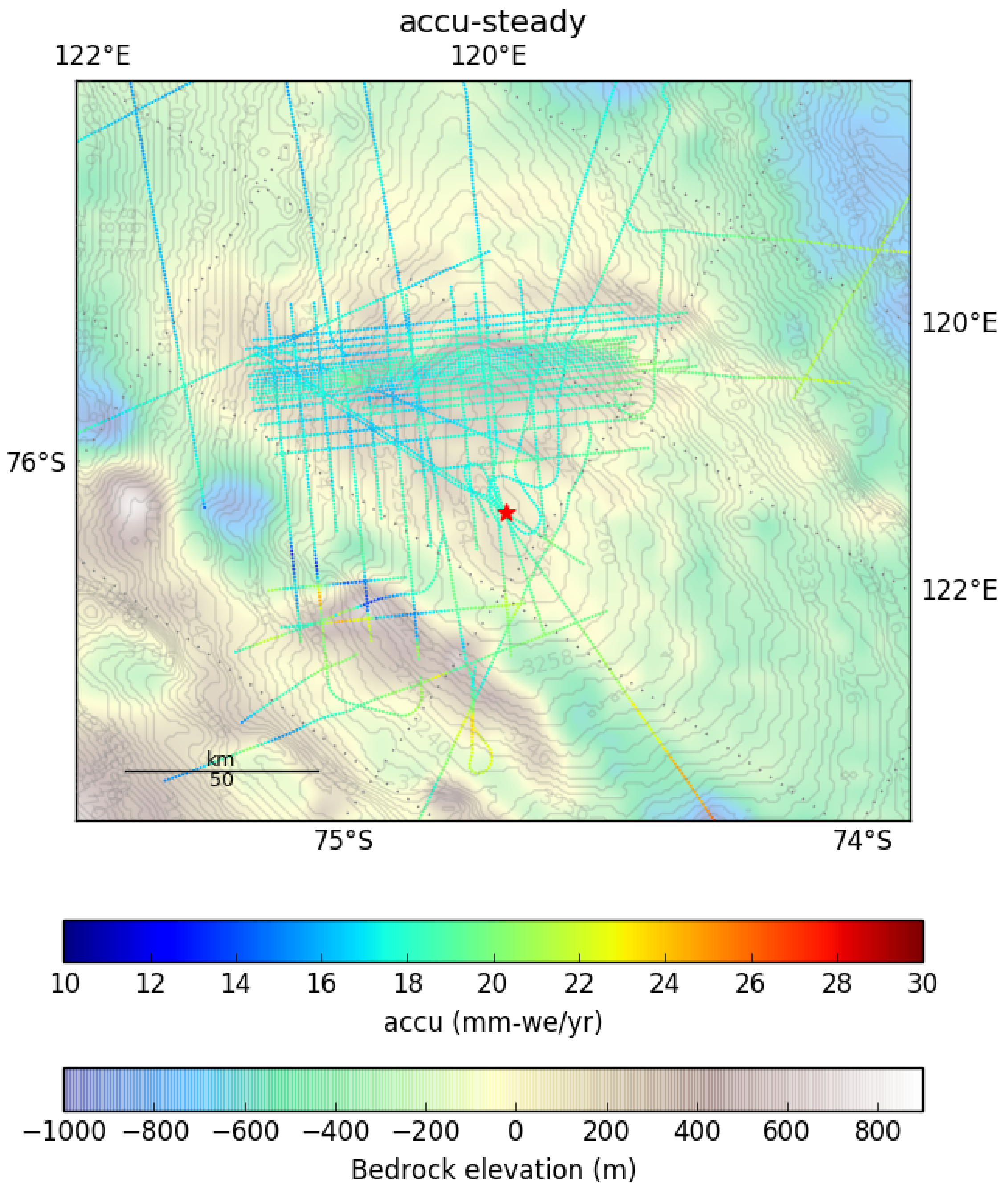
Resolution at 1.2 Myr



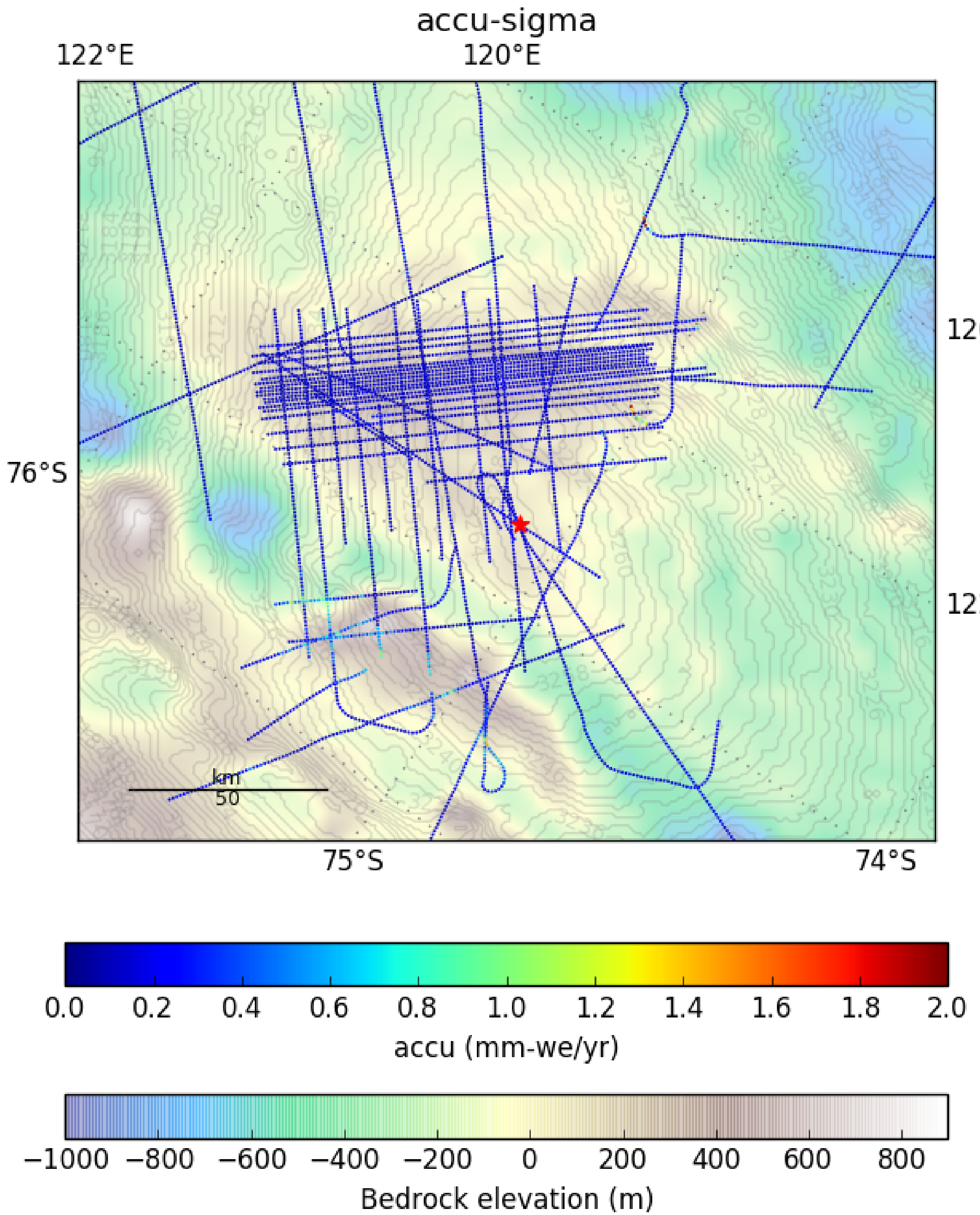
Resolution at 1.5 Myr



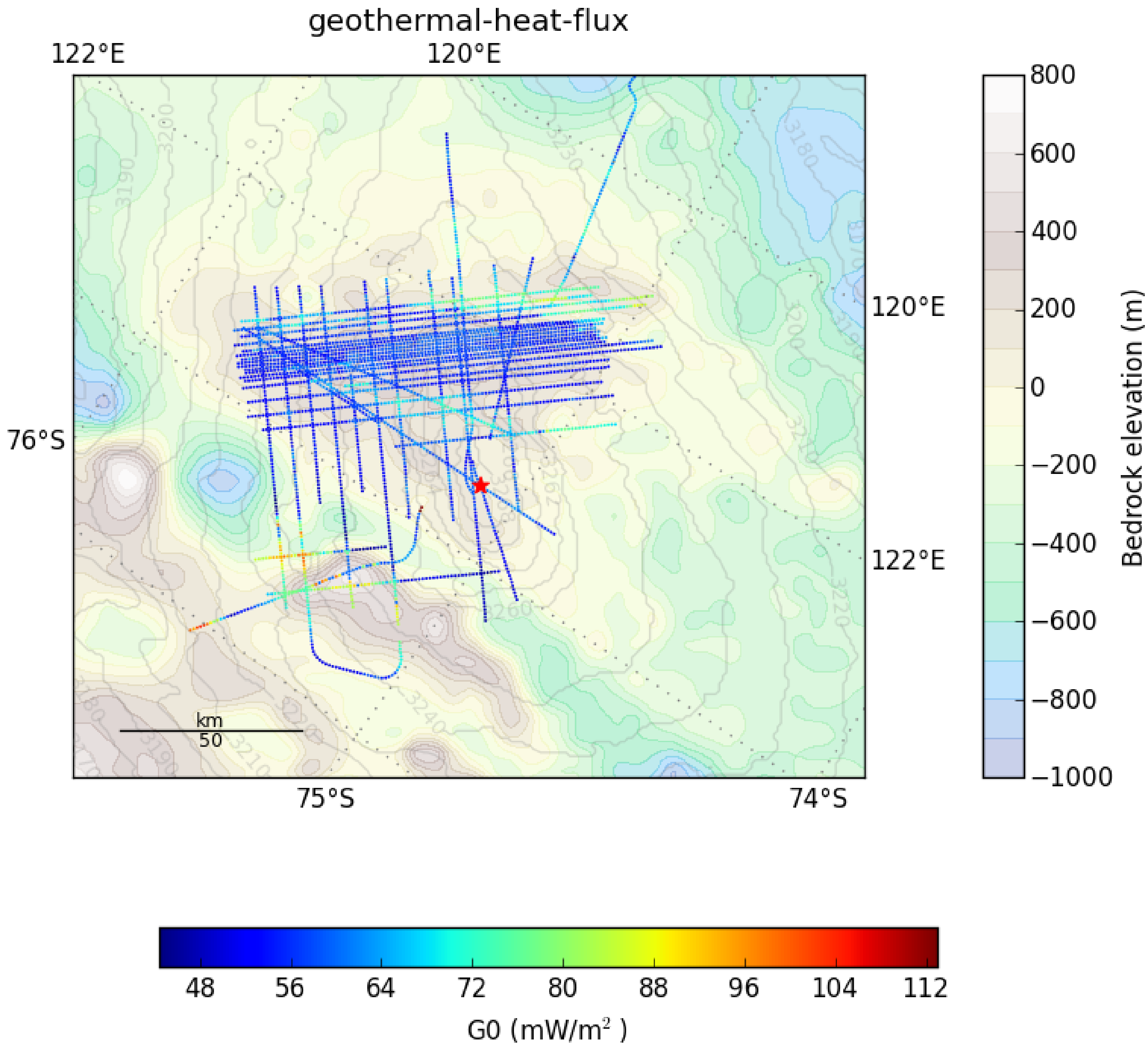
Accumulation



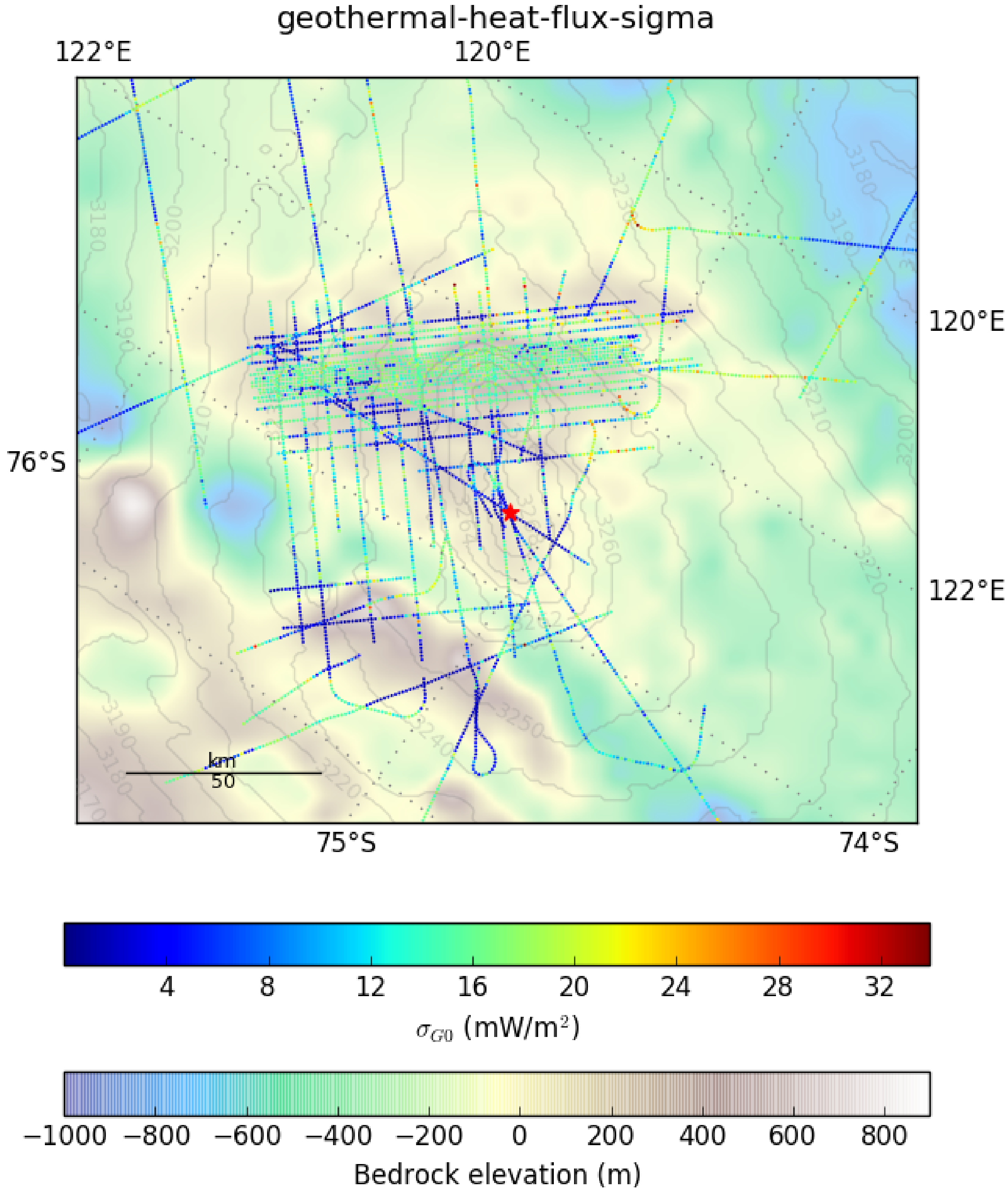
Uncertainty in accumulation



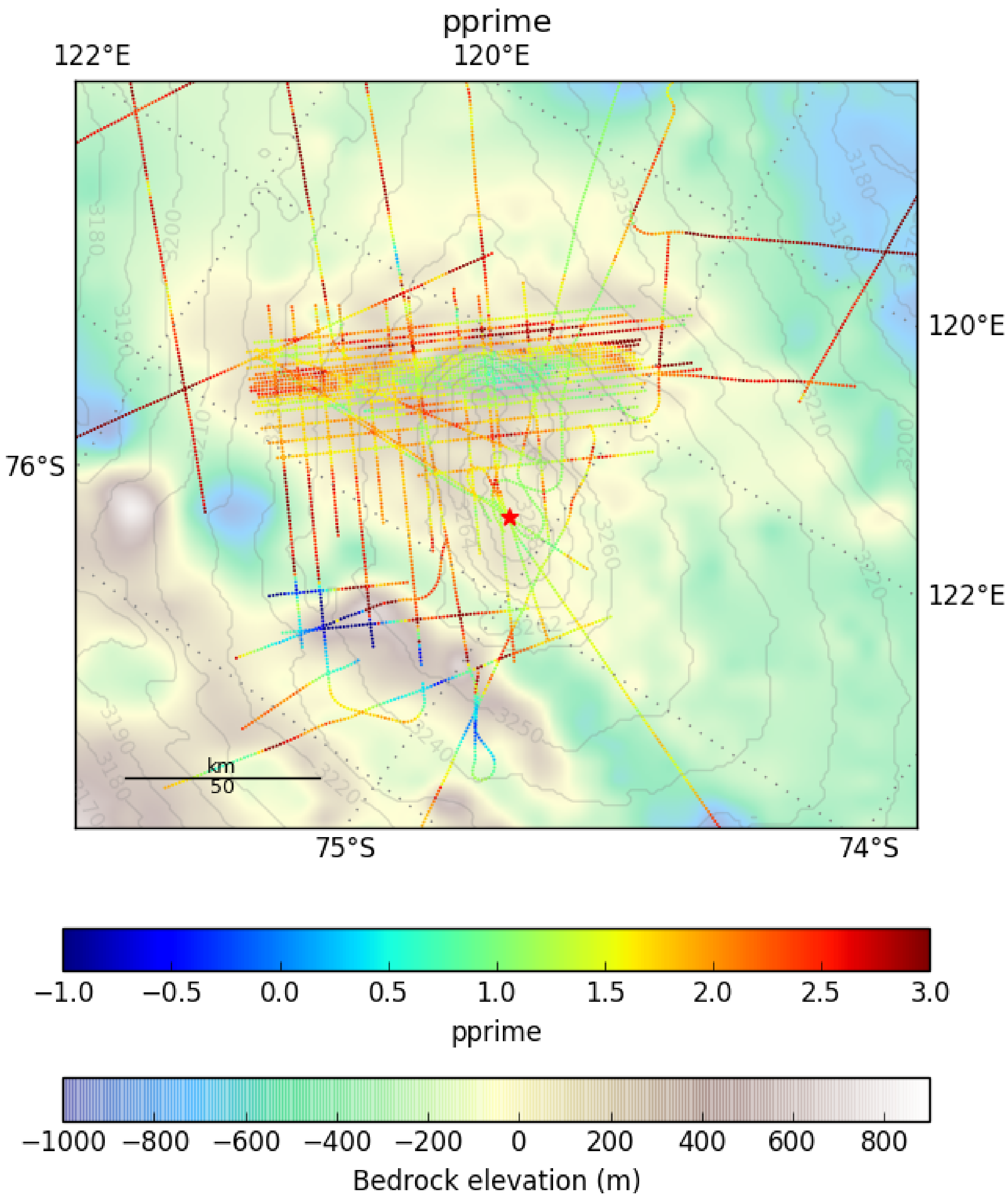
G_0


geothermal-heat-flux
122°E
120°E
120°E
122°E
76°S
75°S
74°S
km
50
800
600
400
200
0
−200
−400
−600
−800
−1000
Bedrock elevation (m)
48
56
64
72
80
88
96
104
112
G0 (mW/m²)

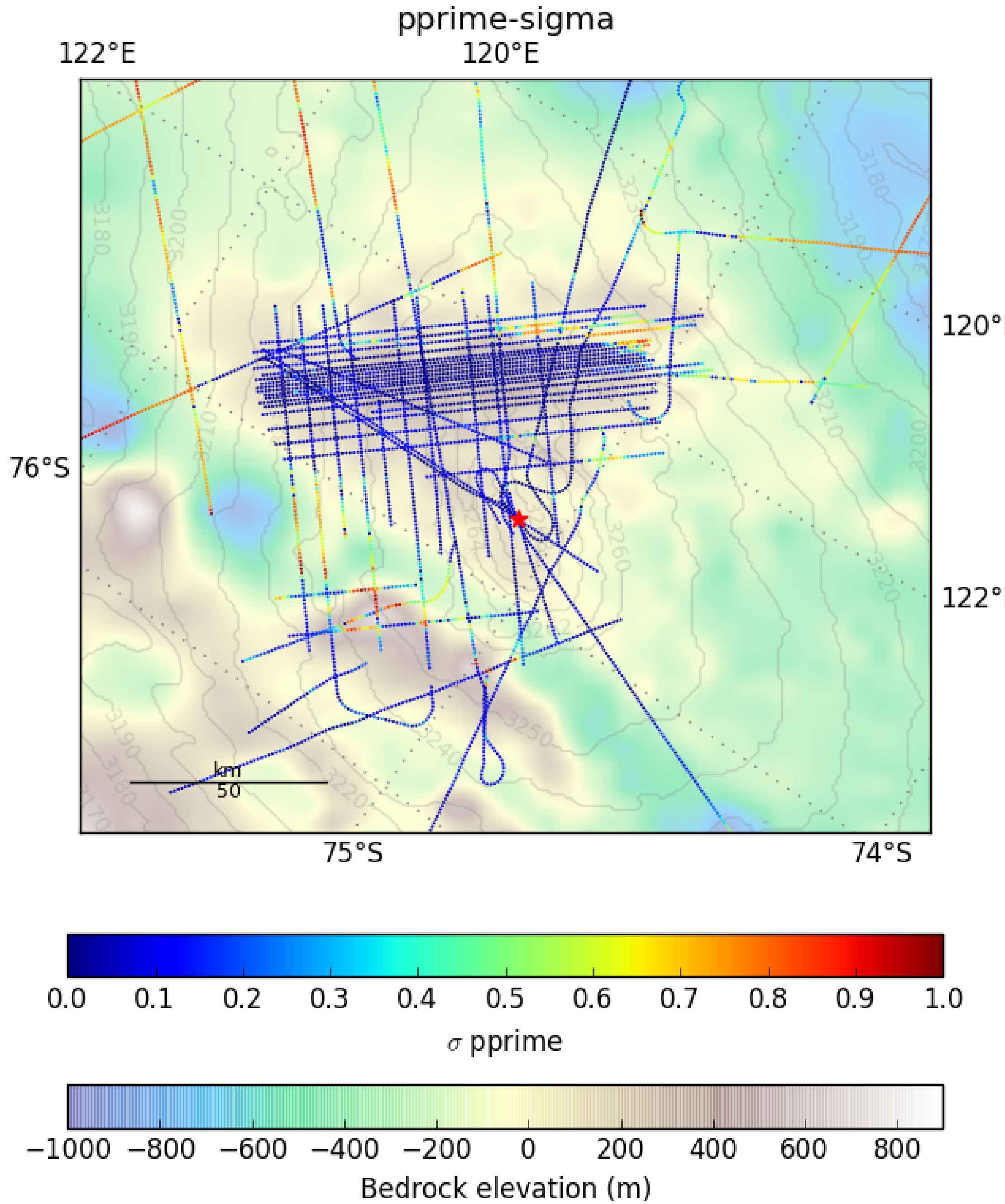
Uncertainty in G_0



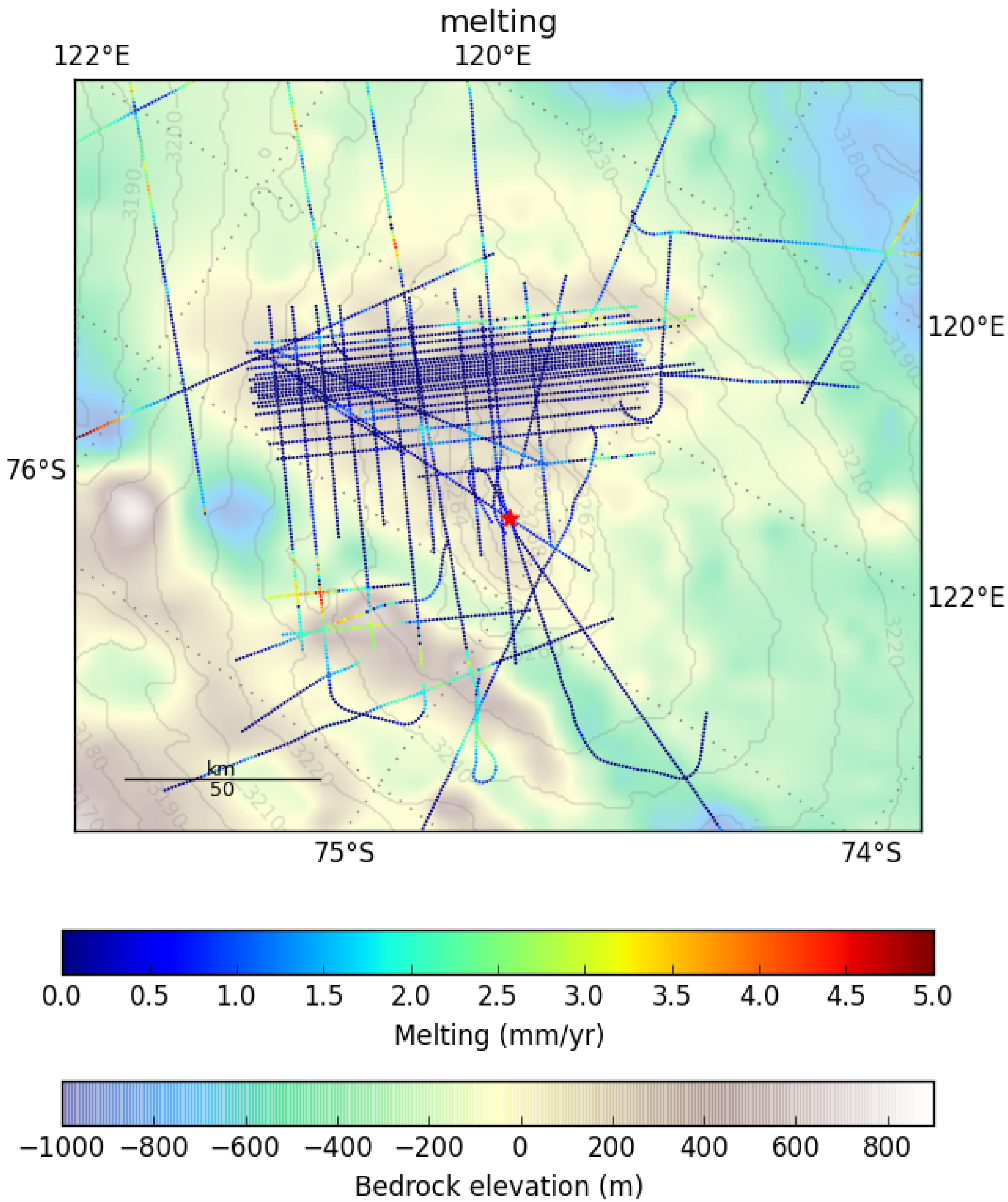
p’


pprime
122°E
120°E
120°E
122°E
76°S
75°S
74°S
km
50
−1.0
−0.5
0.0
0.5
1.0
1.5
2.0
2.5
3.0
pprime
−1000
−800
−600
−400
−200
0
200
400
600
800
Bedrock elevation (m)

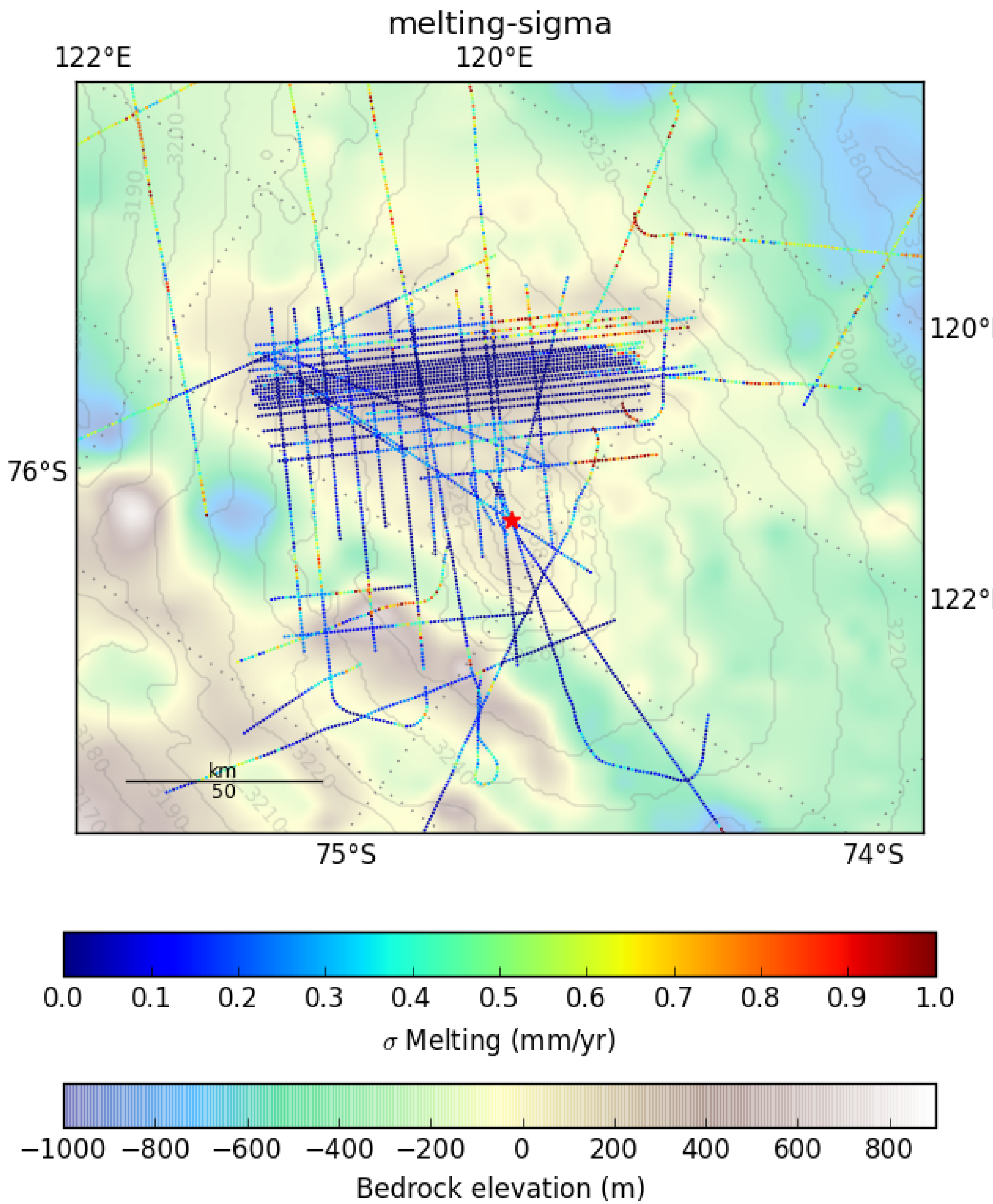
Uncertainty in p’



melting


melting
122°E
120°E
120°E
122°E
76°S
75°S
74°S
km
50
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
Melting (mm/yr)
−1000
−800
−600
−400
−200
0
200
400
600
800
Bedrock elevation (m)

Uncertainty in melting

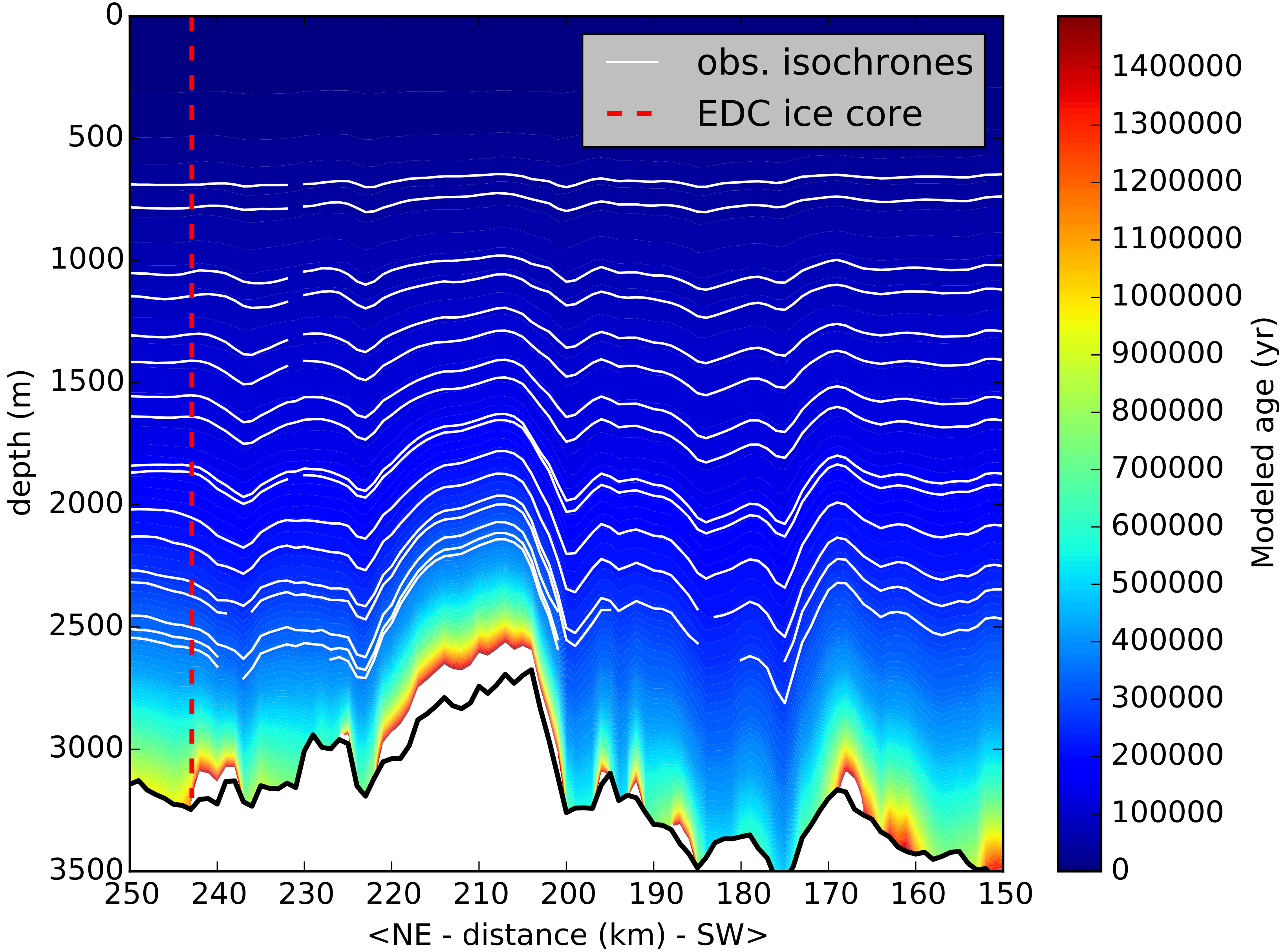


Conclusion/Perspectives

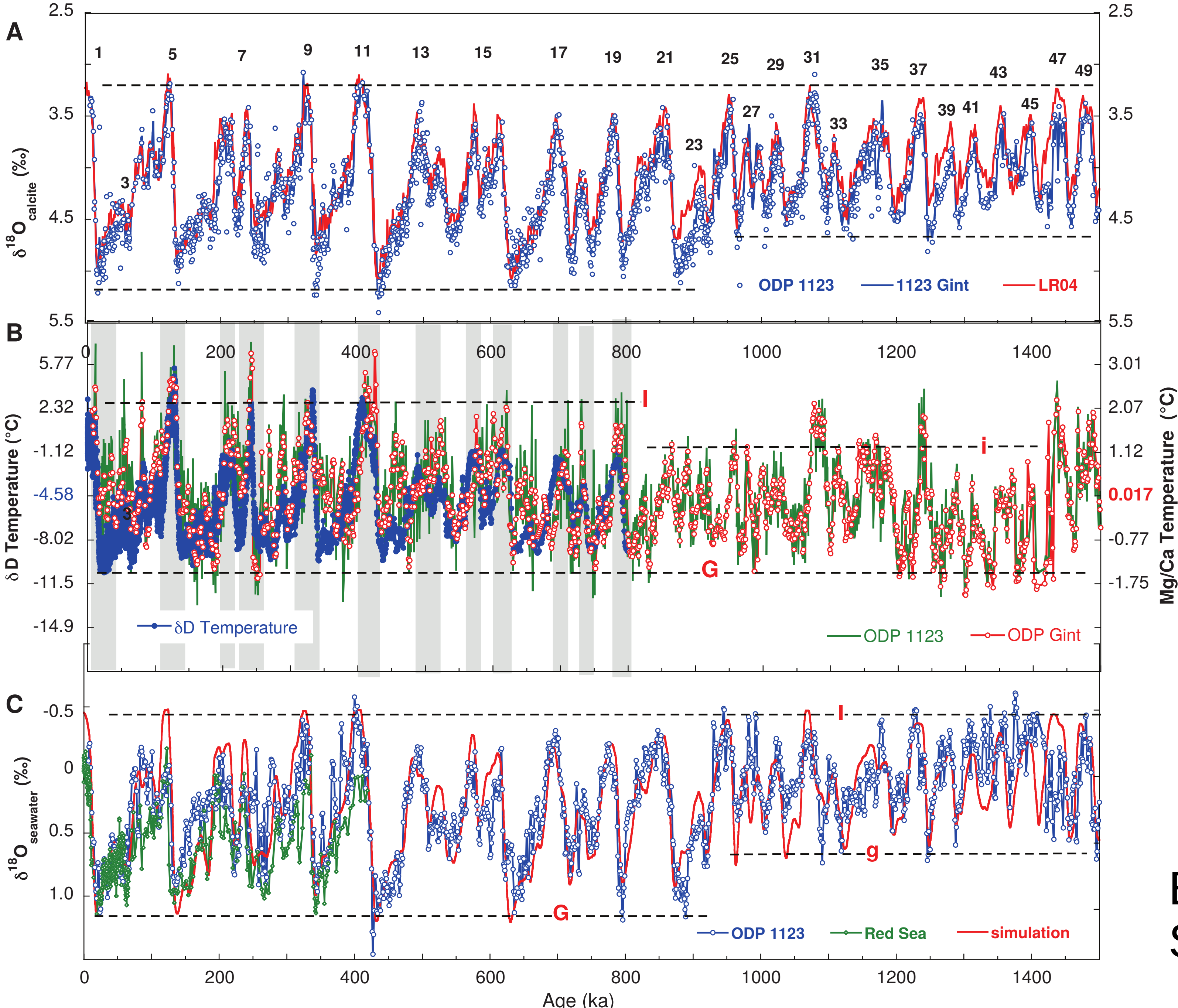
- Old Ice likely exist at two spots close to EDC
  - Blob A
  - Blob F
- => 3D modeling
  - Pb: sparsity of observations
- => Time dependent
  - Pb: under-constrained pb

The End

Example of radar line

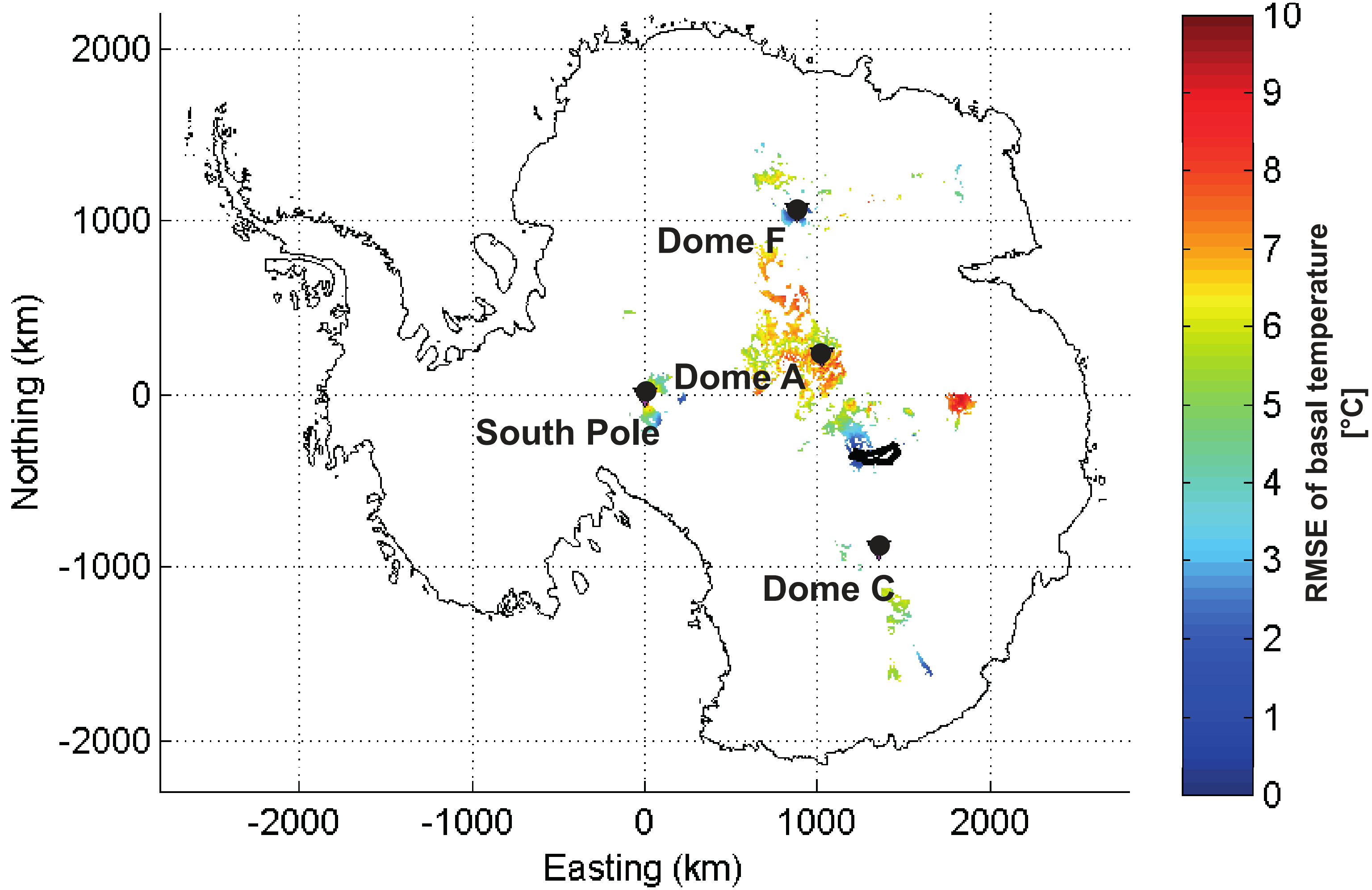


MPT may have happen quickly



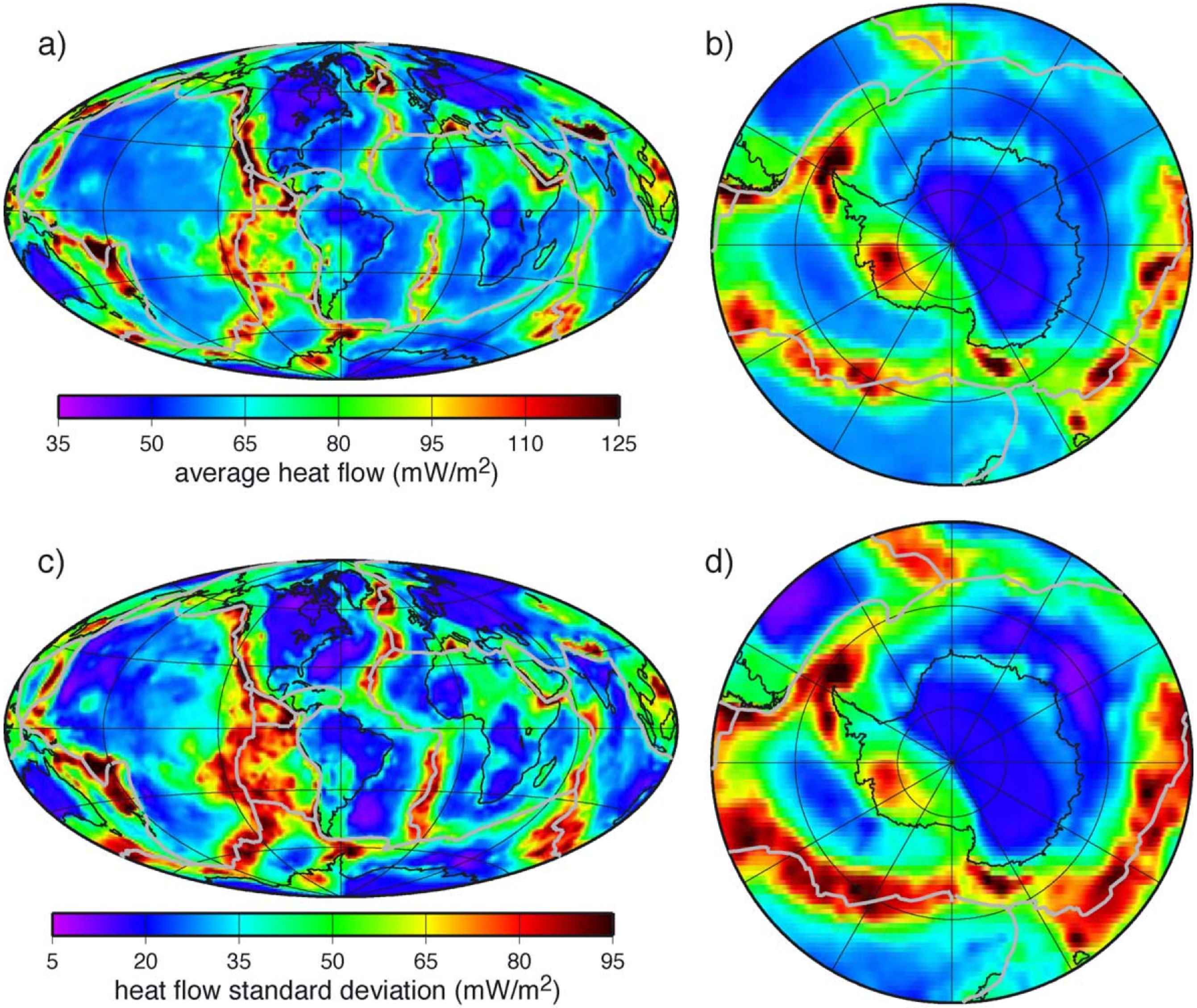
Elderfield et al., Science, 2012

Possible locations of Oldest Ice



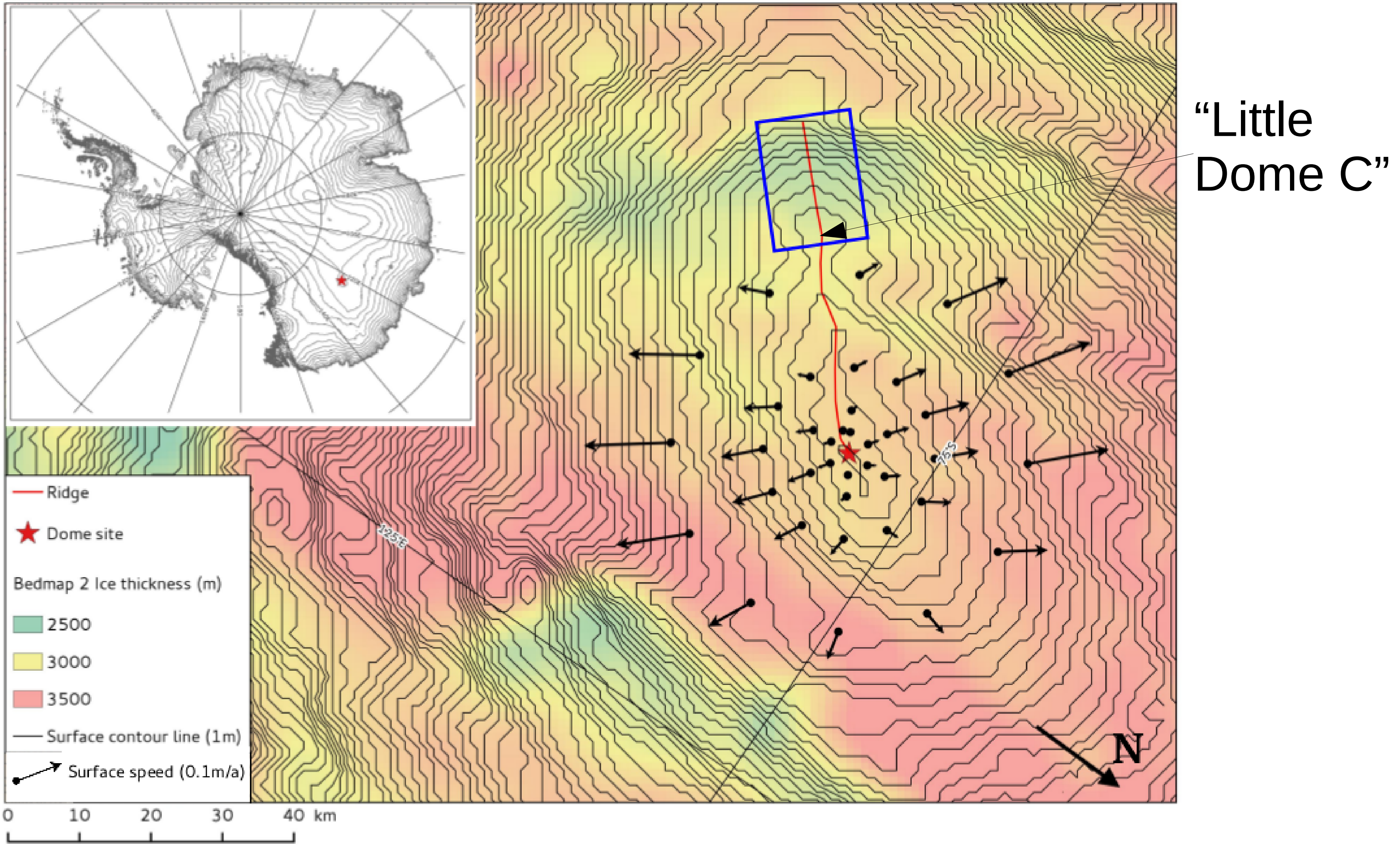
- Based on thermal modeling, horizontal velocity
- Fischer et al., CP, 2012.

But geothermal flux is poorly known...



- Shapiro and Ritzwoller, EPSL, 2004.

Toward more realistic simulations

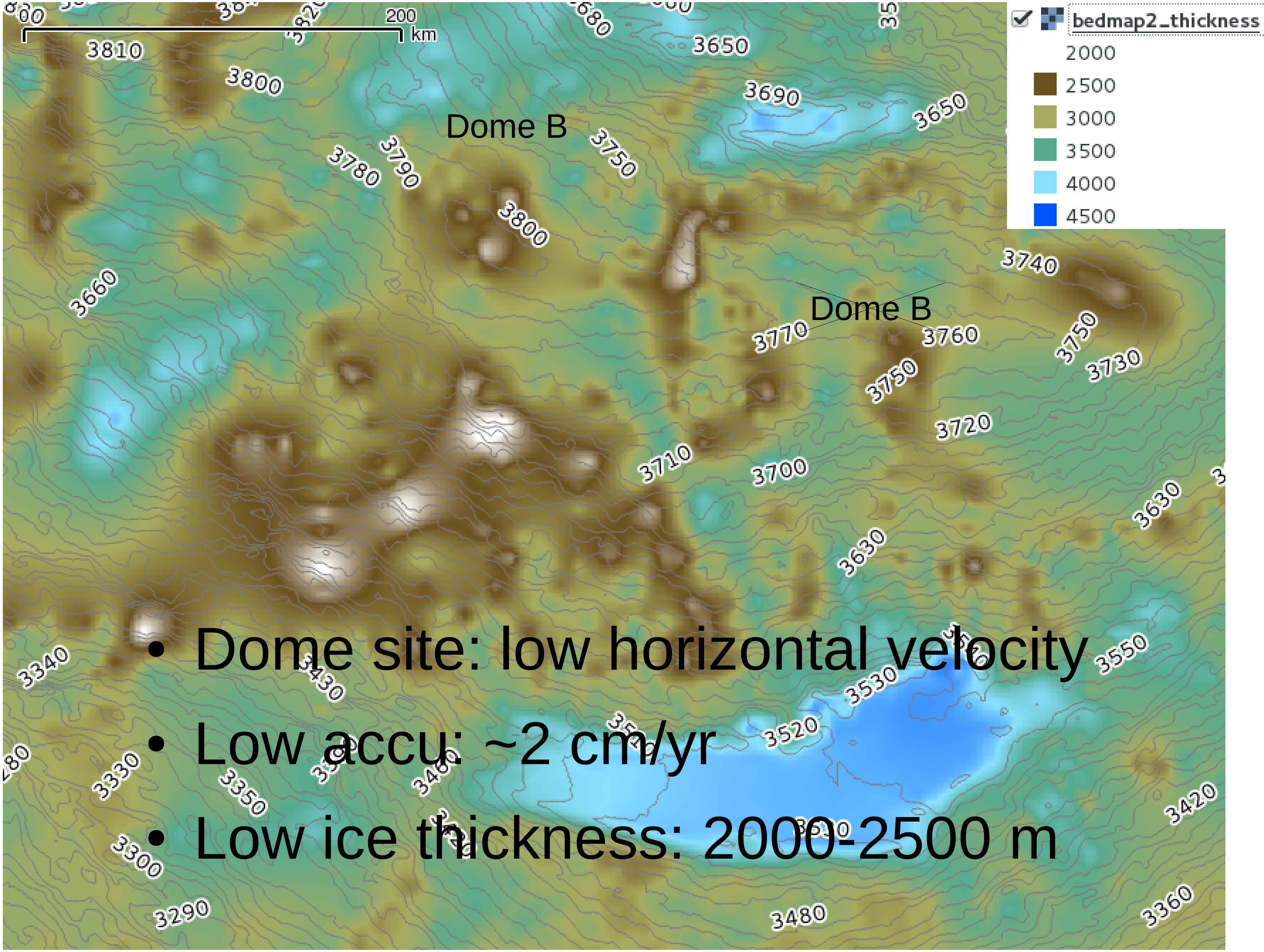


- 2.5D full-Stockes thermo-mechanical model

Perspectives

- Deeper isochrones layers are needed
- More realistic modelling studies are necessary (3D full-Stokes simulations are underway)
- Need to investigate other areas (e.g., Dome B, Dome A, Dome Fuji)
- Ultimately, it will be necessary to apply a rapid access drilling facility to confirm that old ice exists

Dome B: the perfect site?



- Dome site: low horizontal velocity
- Low accu: ~2 cm/yr
- Low ice thickness: 2000-2500 m