SIA vs Higher Order: Greenland tests, and thoughts on Antarctica

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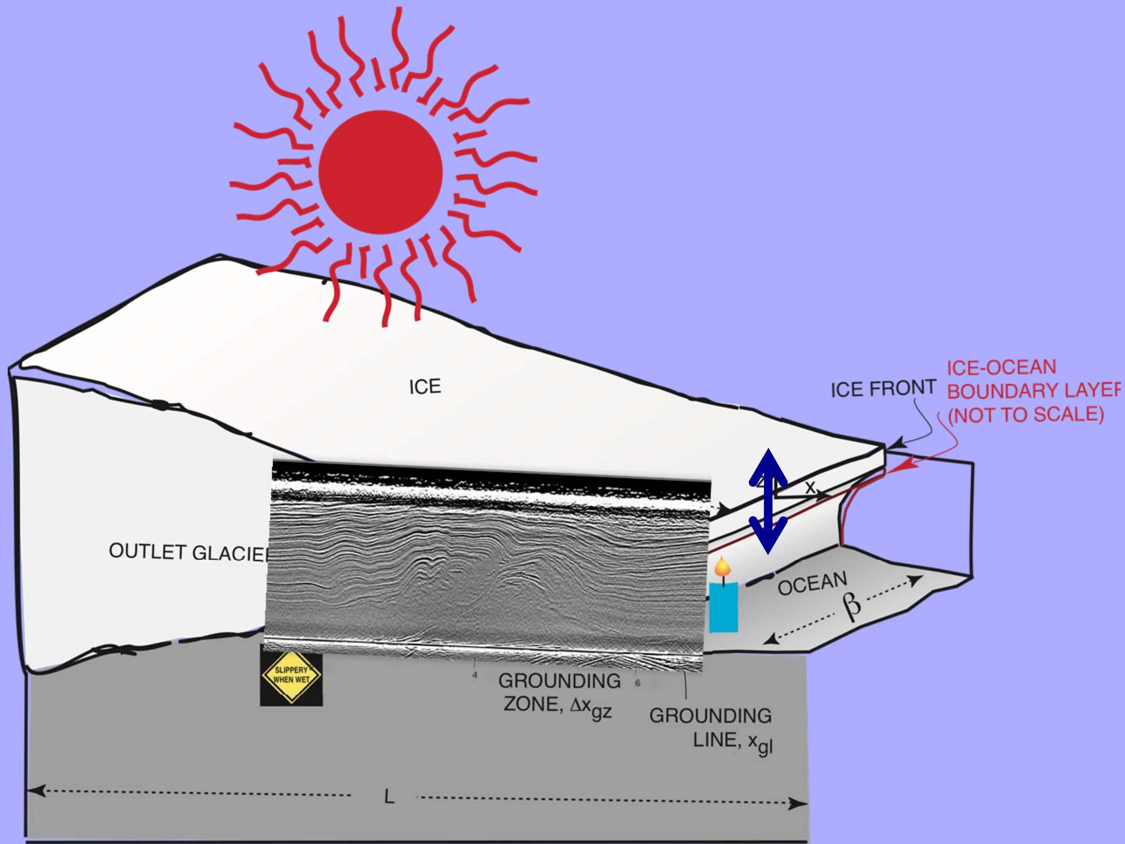

We are learning much from observing the surface, coring, imaging and probing the ice and bed, sampling the ocean, etc., … and developing models for each.

Do you find yourself asking:
What happened?
What's happening?
Why?
How?

What if…?

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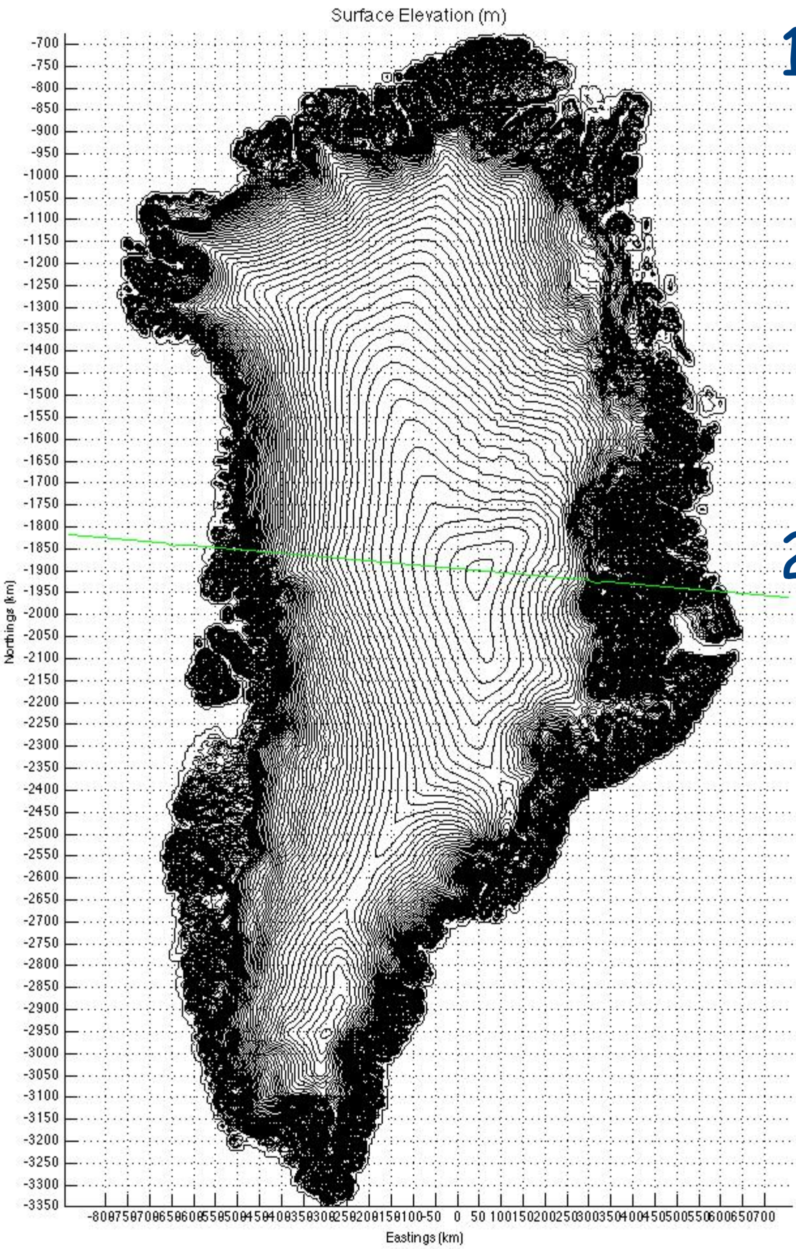
"In fact, every year there was [is] a new discovery…" --Robert Bindschadler, 10/1/13

And along the way to discovery, we need to remember that:

“Old time stuff still works.”

--Reed Scherer, 9/30/13

Patrick's two questions



1. How does uncertainty about input parameter values affect sea level rise projections from models of Greenland Ice Sheet behavior?

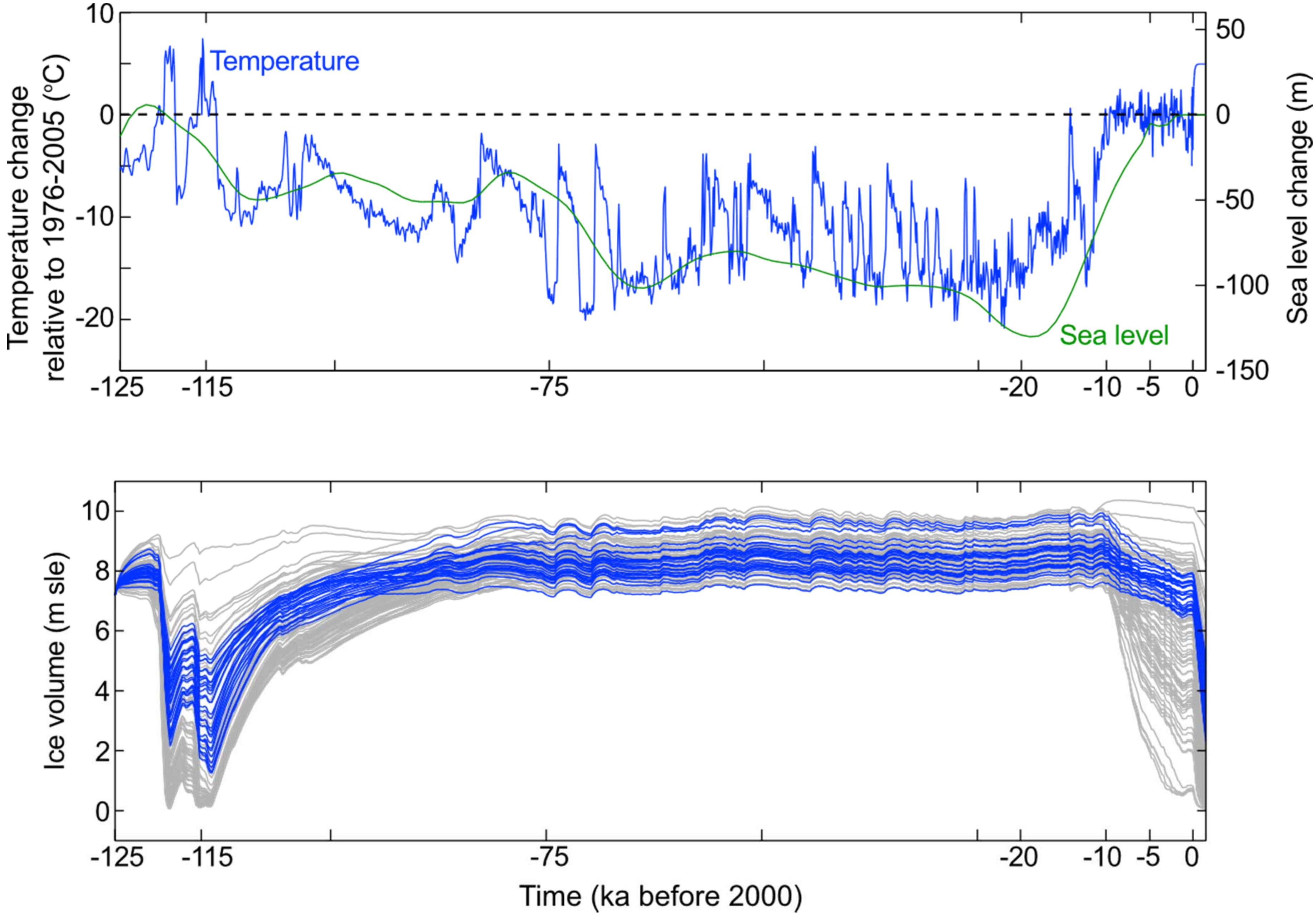
2. If surface air temperatures stabilize at a particular value, how much will the Greenland Ice Sheet eventually contribute to sea level rise ΔV, and over what time scale τ?

Applegate et al., *The Cryosphere*, 2012
Applegate et al., in prep.

Patrick's Recipe

(using SICOPOLIS; Greve, 1997; Greve et al., 2011; sicopolis.greveweb.net)

1. Establish 100 combinations of five model parameter values (perturbed-physics ensemble using Latin hypercube methods on ice/snow melt factors, ice flow factor, basal sliding factor, and geothermal heat flux; McKay, 1979; see also Stone et al., 2010).
2. "Spin up" the model over 125 kyr many times, using each of the parameter combinations from step #1.
3. Drive the spun-up model runs into the future.
4. Eliminate model runs that give unreasonable estimates of the modern ice volume.
5. For the "good" runs, compare the range of projections to the central estimate.



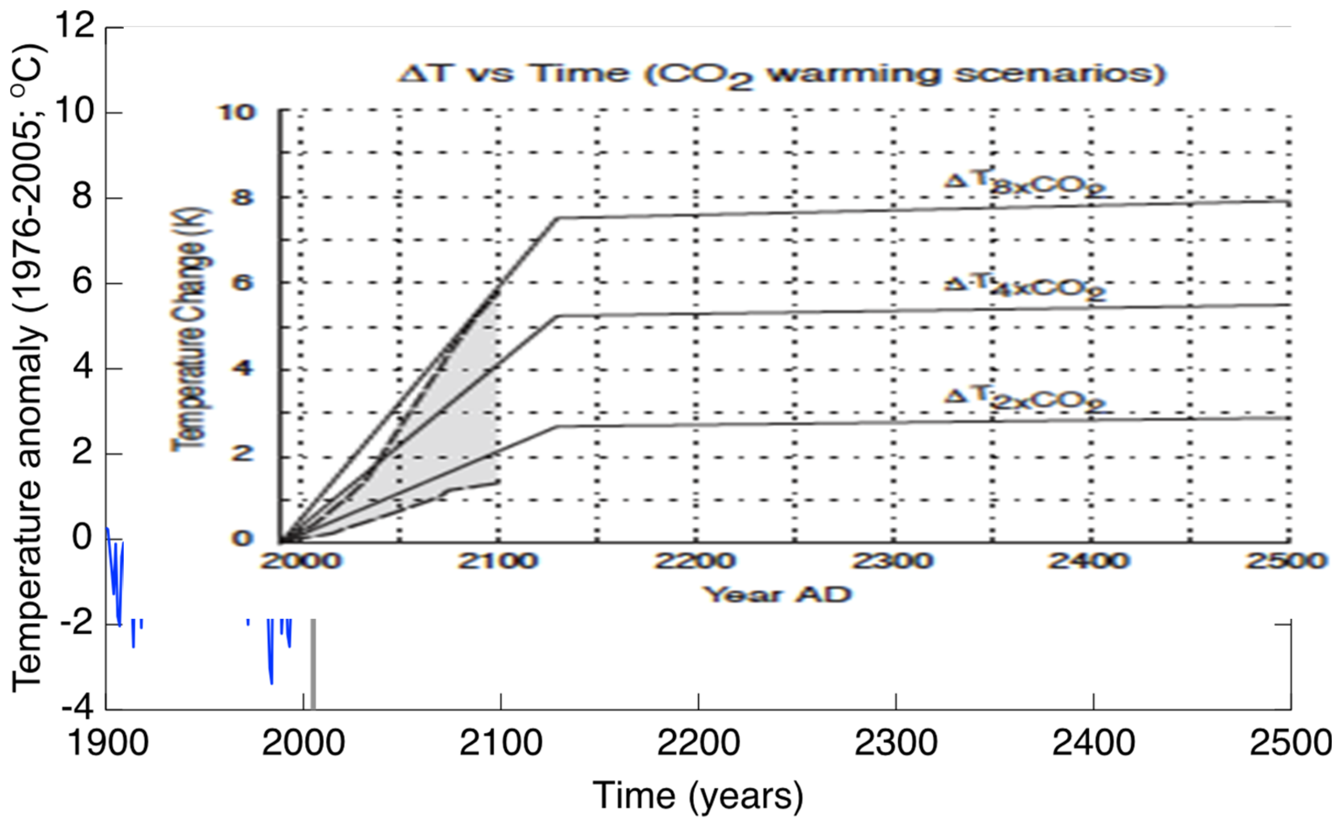
Applegate et al. (2012); temperatures, Dansgaard et al., 1993; sea levels, Imbrie et al. (1984)

Some answers

1. Uncertainty in model input parameter values leads to a substantial spread (40-70% of median value) in future projections of Greenland Ice Sheet volume changes.

Applegate et al., *The Cryosphere*, 2012
Applegate et al., in prep.

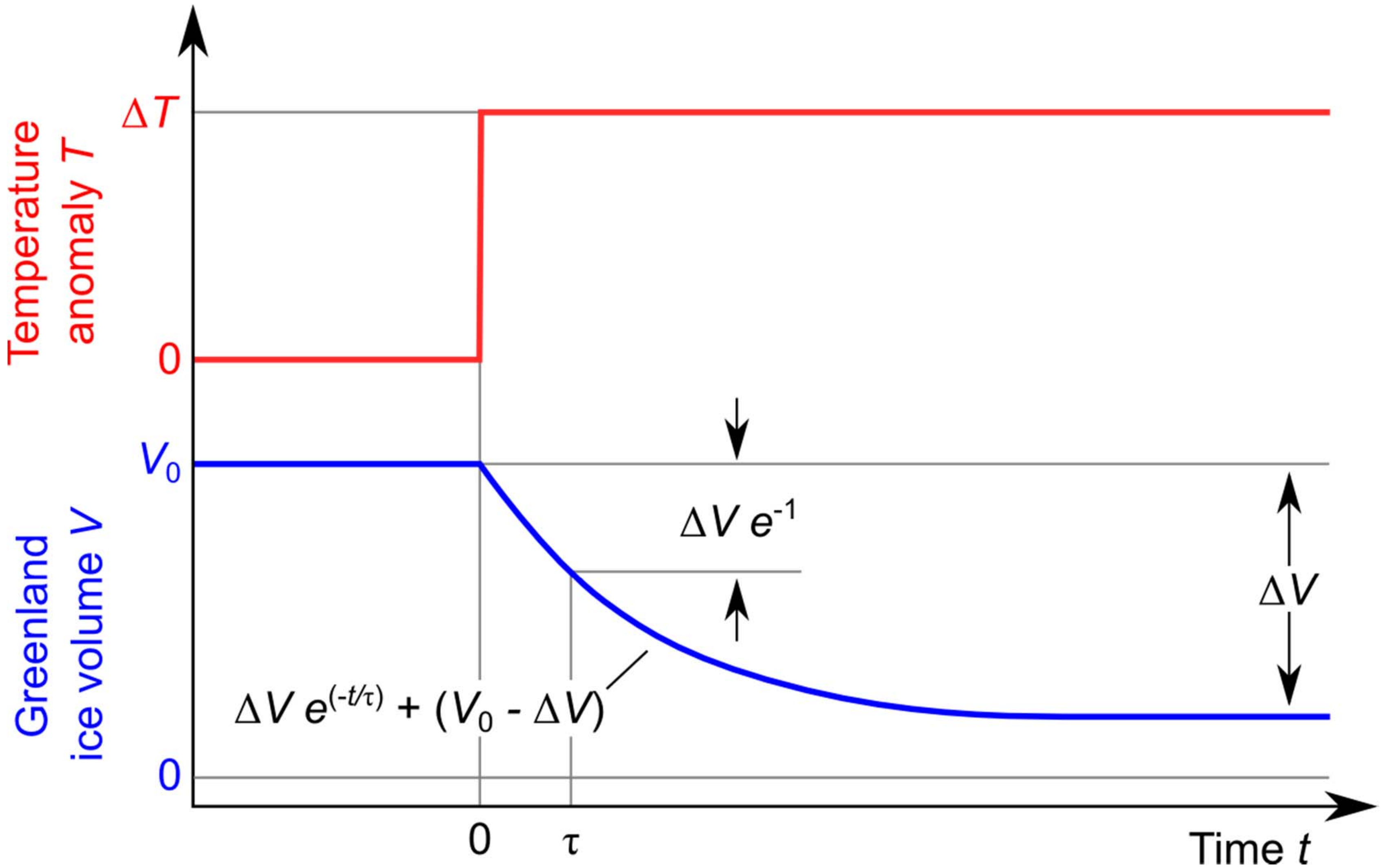
Now impose instantaneous, permanent temperature increases (ΔT = 0, 1, 2, 3, 4.5, 6, 9, 12 ^{o}C) on each of the "good" model runs.



Historical temps, Vinther et al. (2006); future temps, Schewe et al. (2011)

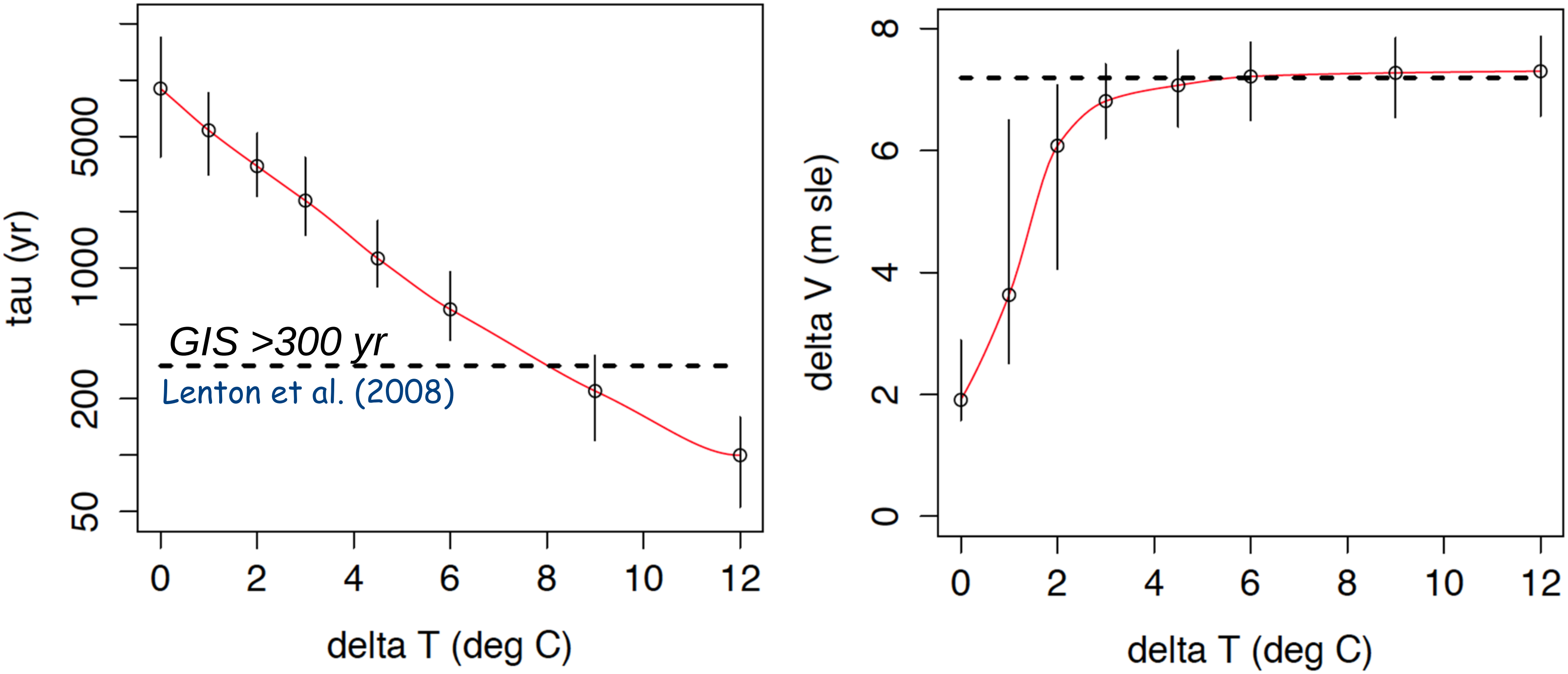
Applegate et al., in prep.

Then, calculate ΔV and the e-folding time, τ, resulting from ΔT



Note that τ is *much shorter* than the equilibration time!

After Rahmstorf (2007)



Some answers

2. The equilibrium ice volume change ΔV and the time scale of response τ depend strongly on the imposed temperature change.

Applegate et al., in prep.

More questions

1. Are there significant differences between a SIA and Higher Order Model in this setting?

2. Why this dependence of τ on ΔT?

Applegate et al., in prep.

Atmosphere: 250-kyr GRIP forcing following EISMINT with PDD ablation scheme + prescribed warming (Braithwaite and Thomsen, 1984; Reeh, 1991; Huybrechts et al., 1991; Ritz and Grenoble Team Members, 1997)

$$\dot{P} = \dot{P}_i 1.0533^{(T_s - T_{s_i})}, \quad (6)$$

$$\dot{F} = \dot{P} - \alpha_s N_{\mathrm{PDD}} \frac{\rho_w}{\rho}, \quad (7)$$

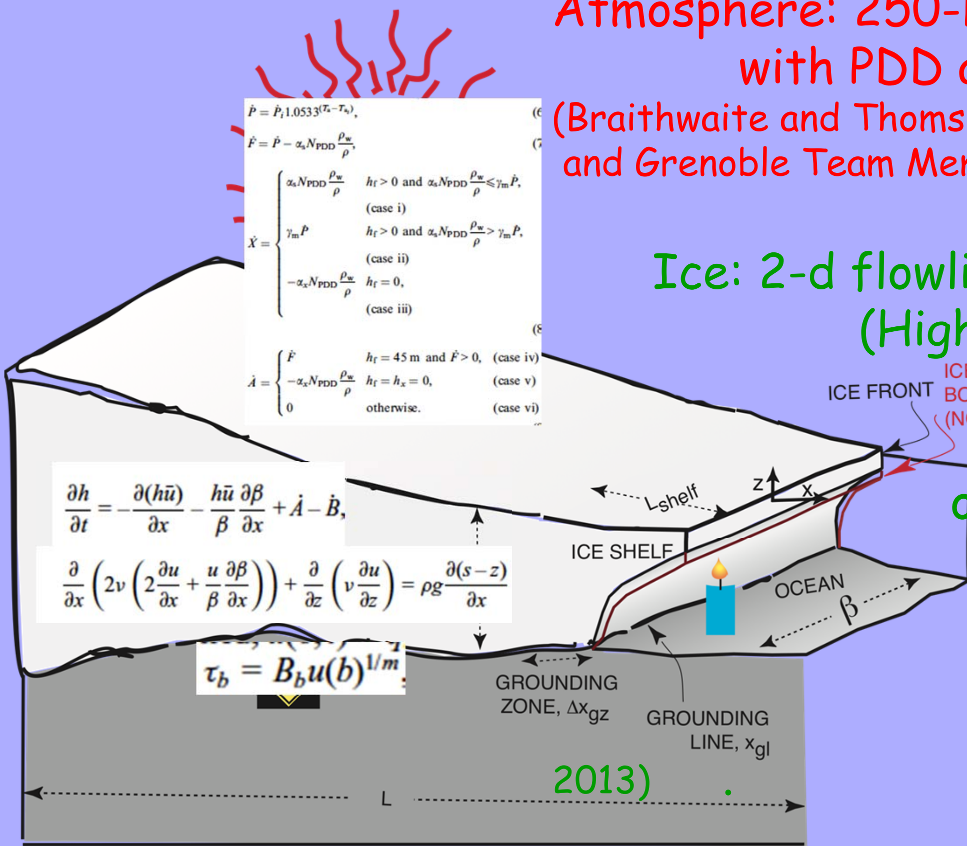
$$\dot{X} = \begin{cases} \alpha_s N_{\mathrm{PDD}} \frac{\rho_w}{\rho} & h_f > 0 \text{ and } \alpha_s N_{\mathrm{PDD}} \frac{\rho_w}{\rho} \leqslant \gamma_m \dot{P}, \\ & \text{(case i)} \\ \gamma_m \dot{P} & h_f > 0 \text{ and } \alpha_s N_{\mathrm{PDD}} \frac{\rho_w}{\rho} > \gamma_m \dot{P}, \\ & \text{(case ii)} \\ -\alpha_x N_{\mathrm{PDD}} \frac{\rho_w}{\rho} & h_f = 0, \\ & \text{(case iii)} \end{cases} \quad (8)$$

$$\dot{A} = \begin{cases} \dot{F} & h_f = 45\,\mathrm{m} \text{ and } \dot{F} > 0, \quad \text{(case iv)} \\ -\alpha_x N_{\mathrm{PDD}} \frac{\rho_w}{\rho} & h_f = h_x = 0, \quad \text{(case v)} \\ 0 & \text{otherwise.} \quad \text{(case vi)} \end{cases}$$

$$\frac{\partial h}{\partial t} = -\frac{\partial (h\bar{u})}{\partial x} - \frac{h\bar{u}}{\beta}\frac{\partial \beta}{\partial x} + \dot{A} - \dot{B},$$

$$\frac{\partial}{\partial x}\left(2\nu\left(2\frac{\partial u}{\partial x} + \frac{u}{\beta}\frac{\partial \beta}{\partial x}\right)\right) + \frac{\partial}{\partial z}\left(\nu\frac{\partial u}{\partial z}\right) = \rho g \frac{\partial (s-z)}{\partial x}$$

$$\tau_b = B_b u(b)^{1/m}$$



Ice: 2-d flowline [Δx=300:3000 m] with longitudinal (Higher Order; without-Shallow Ice) and vertical shear stresses, parameterized flowband width over linear-viscous bed, with h<=1400m sliding zone; thermomechanical spin-up using SIA (Parizek and Alley, 2004; Parizek et al., 2010; Parizek and Walker, 2010; Parizek et al., 2013).

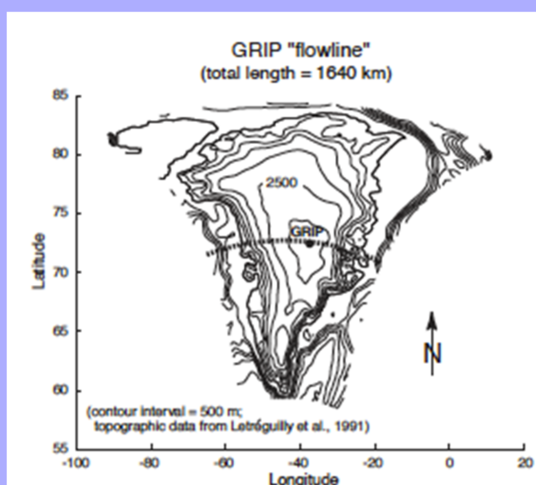
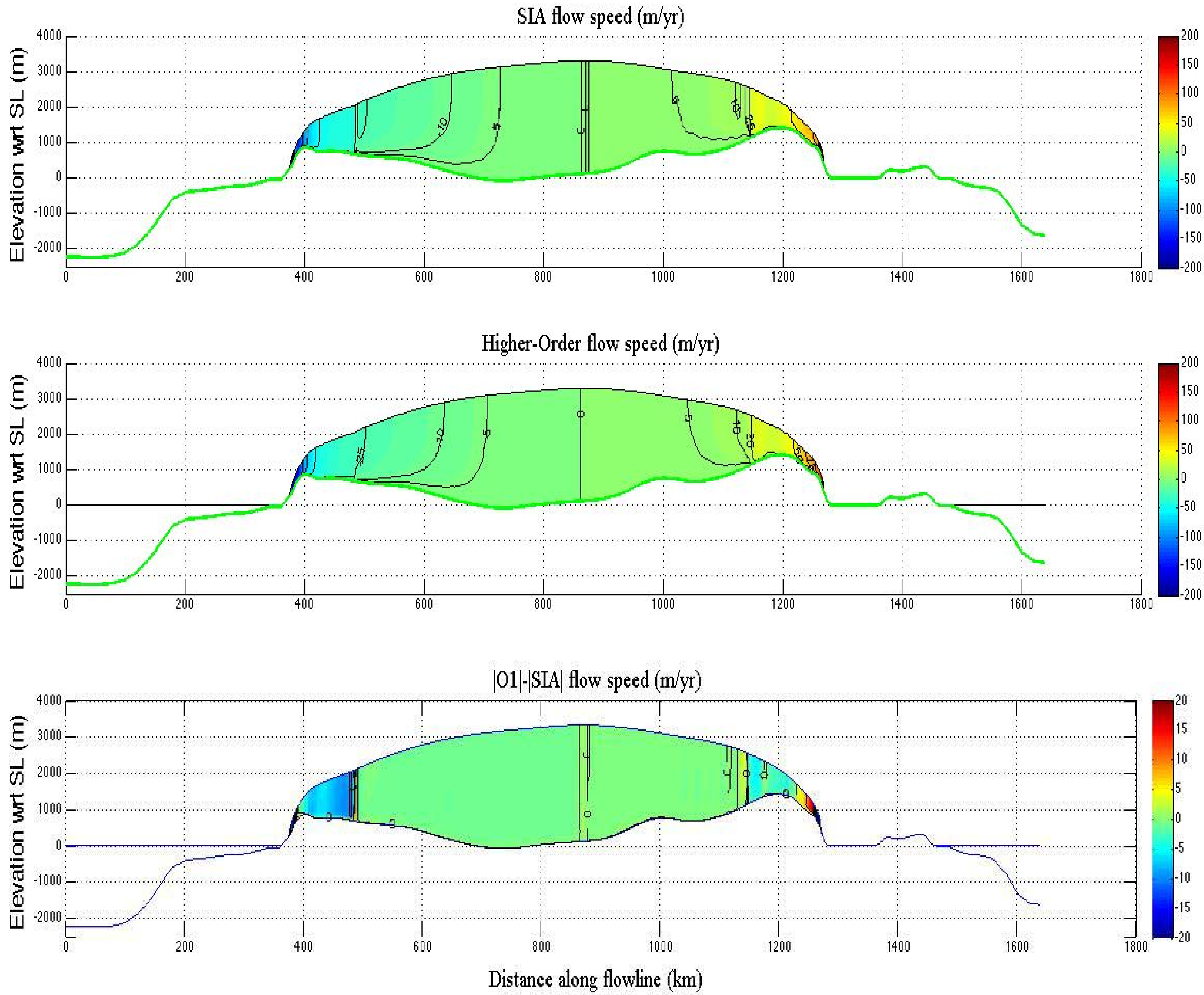
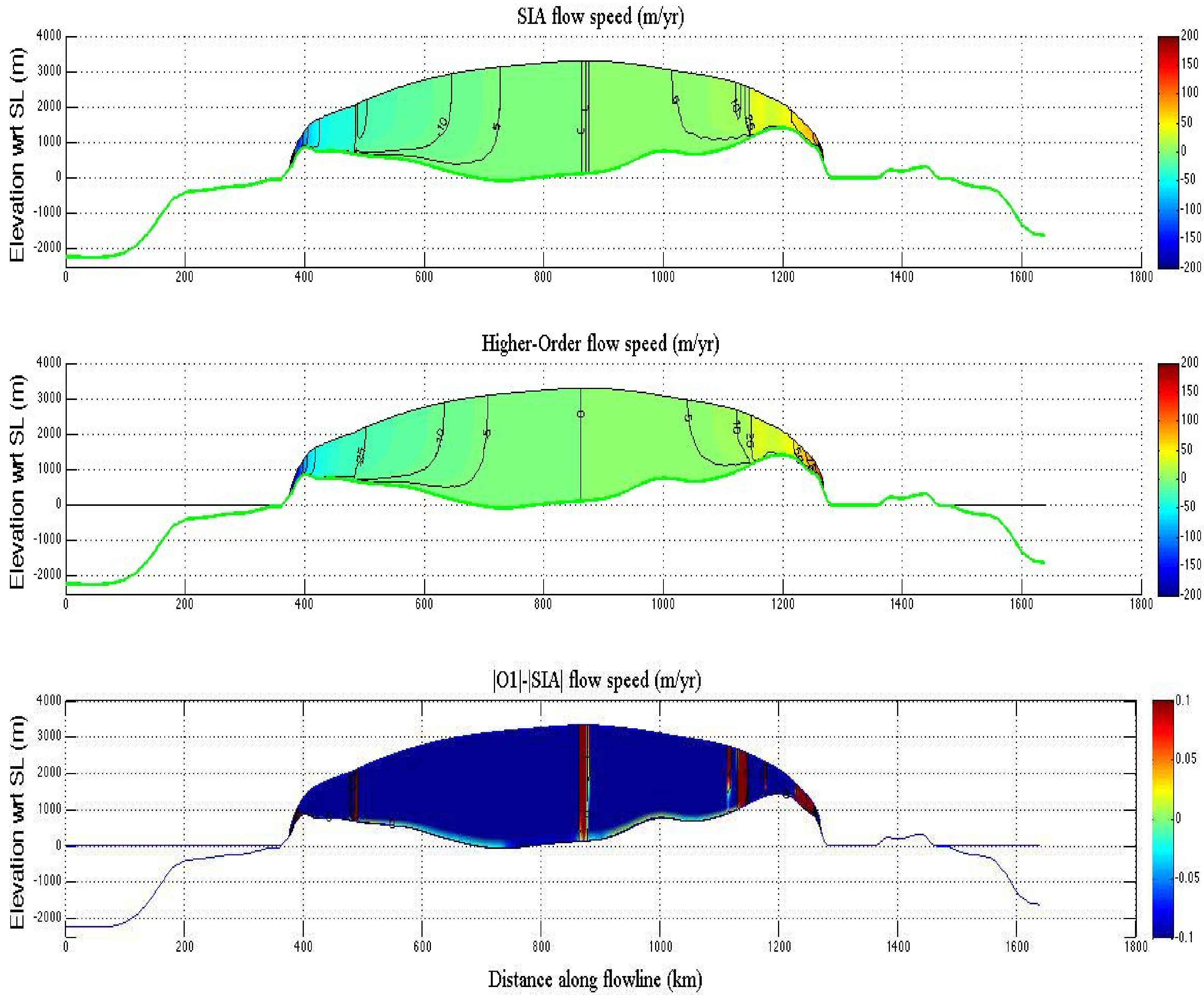


Fig. 1 Parizek and Alley, 2004

Ocean: Prescribed melt rates (0 or 1.4 m/yr)



SIA flow speed (m/yr)
Higher-Order flow speed (m/yr)
|O1|-|SIA| flow speed (m/yr)
Elevation wrt SL (m)
Distance along flowline (km)



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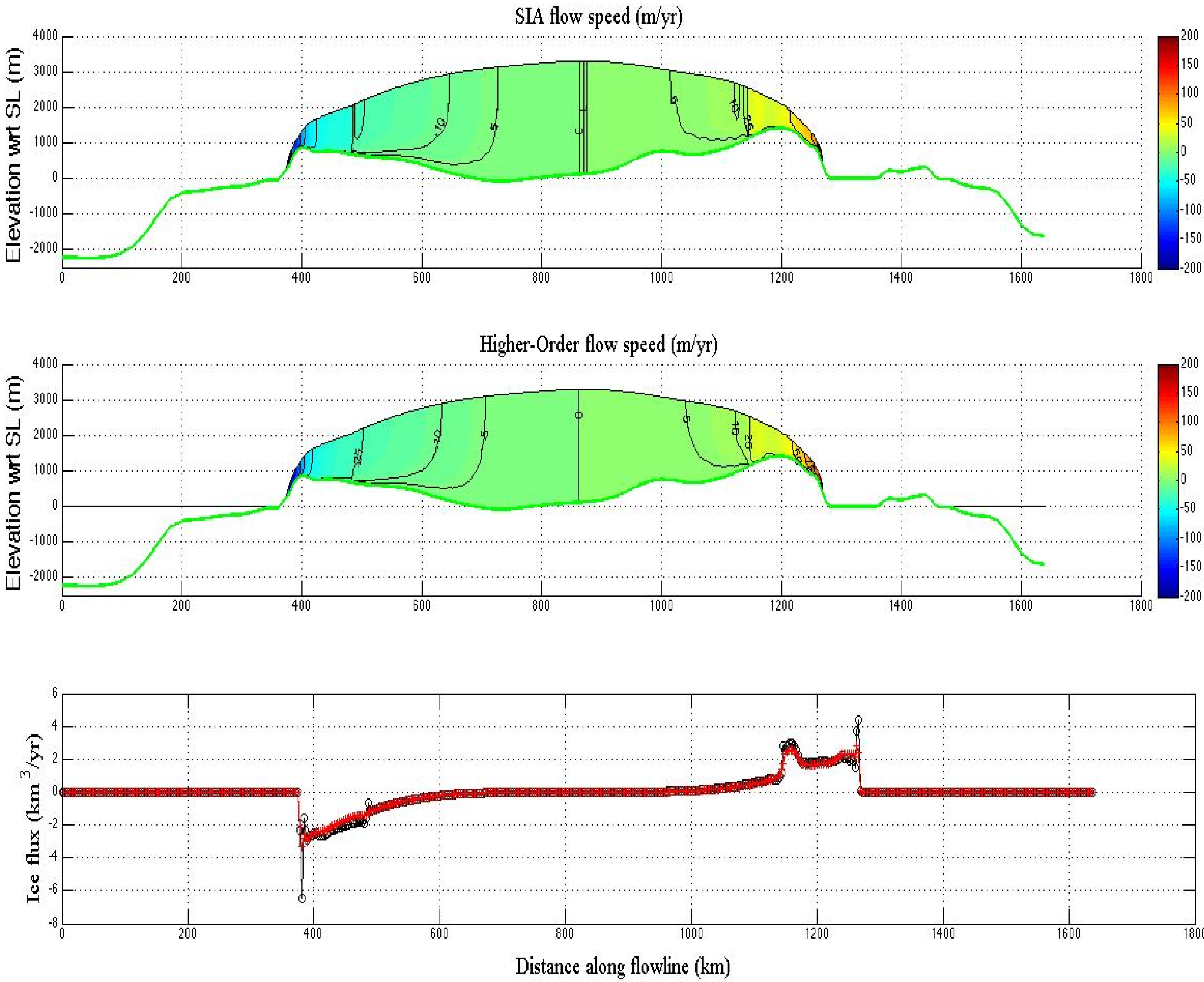
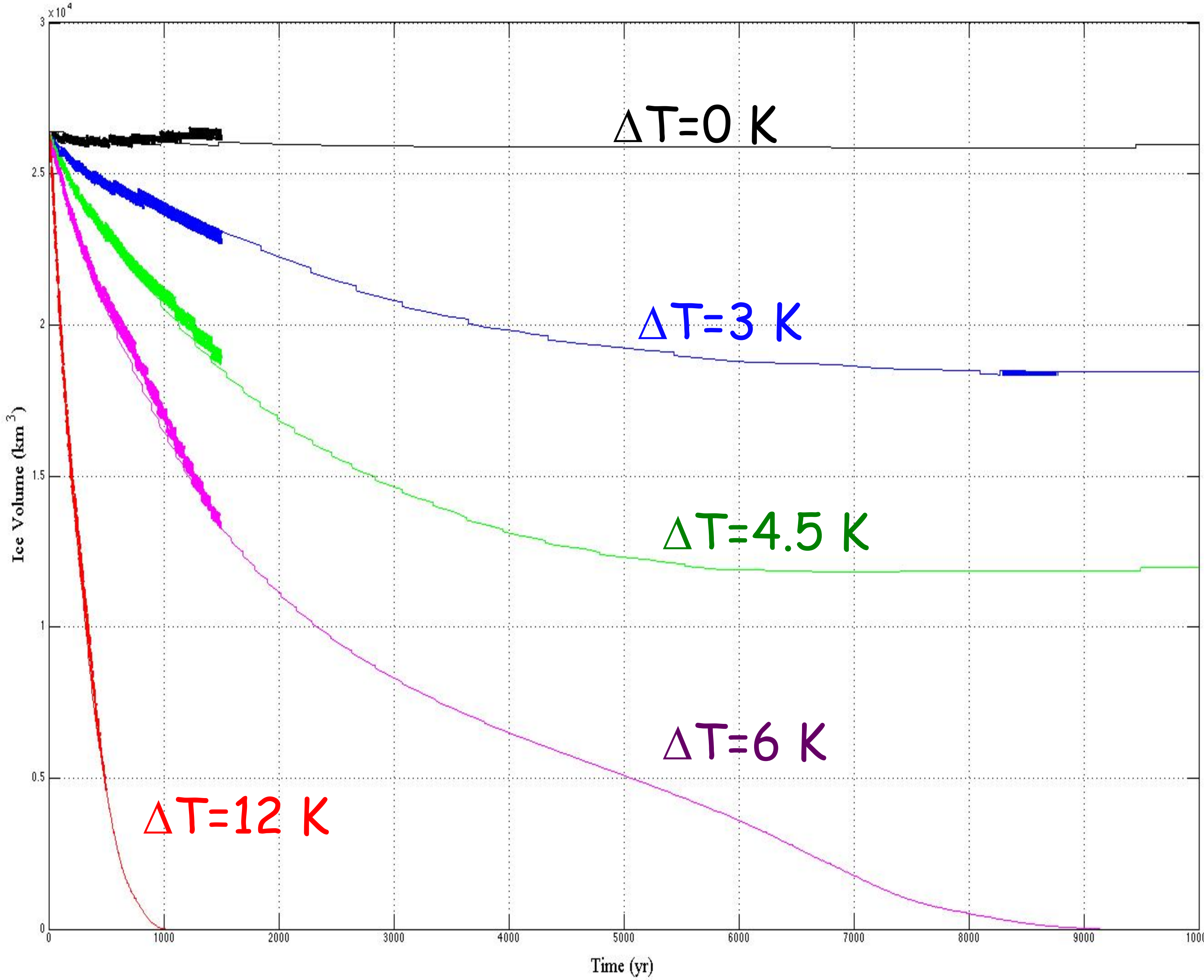
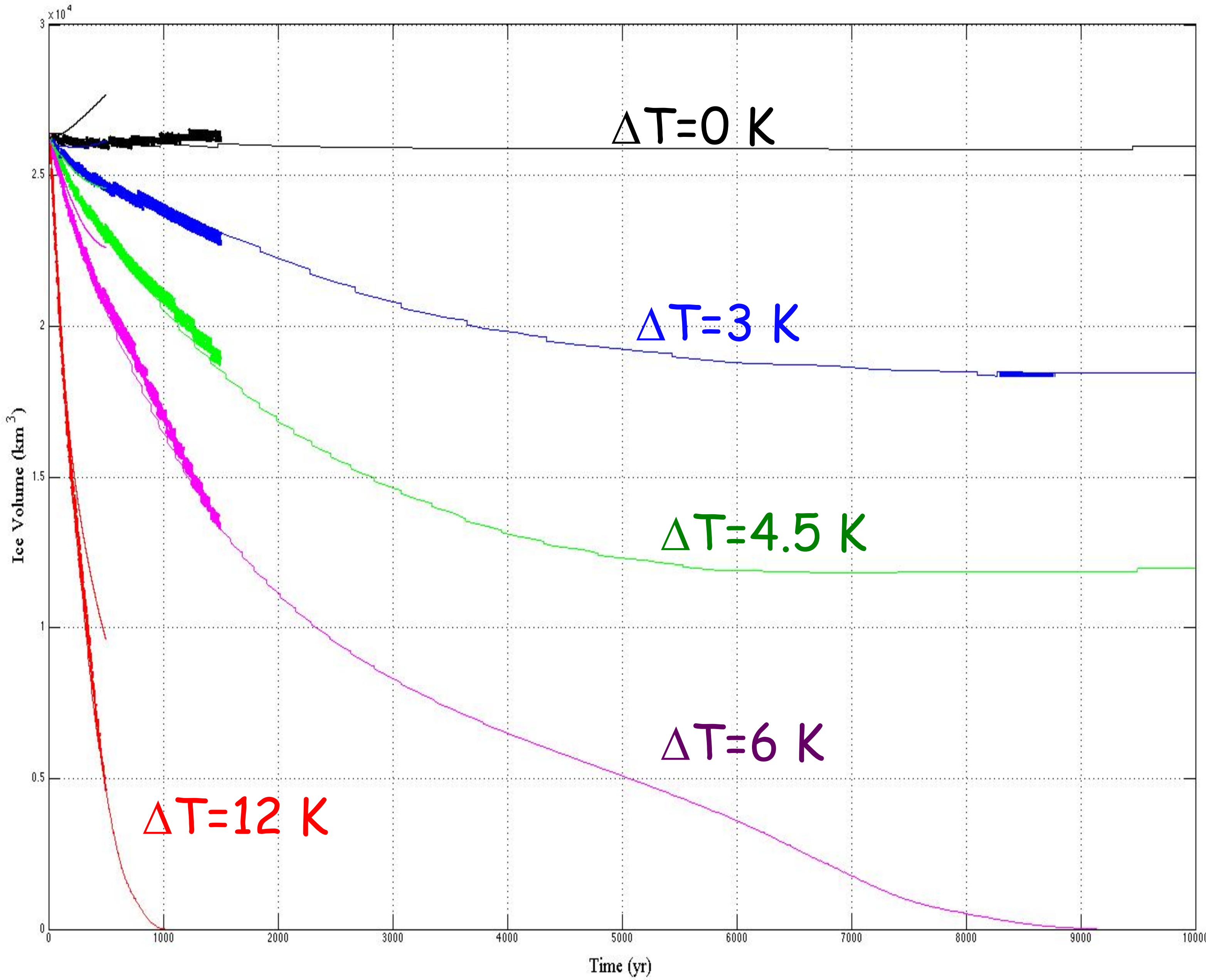


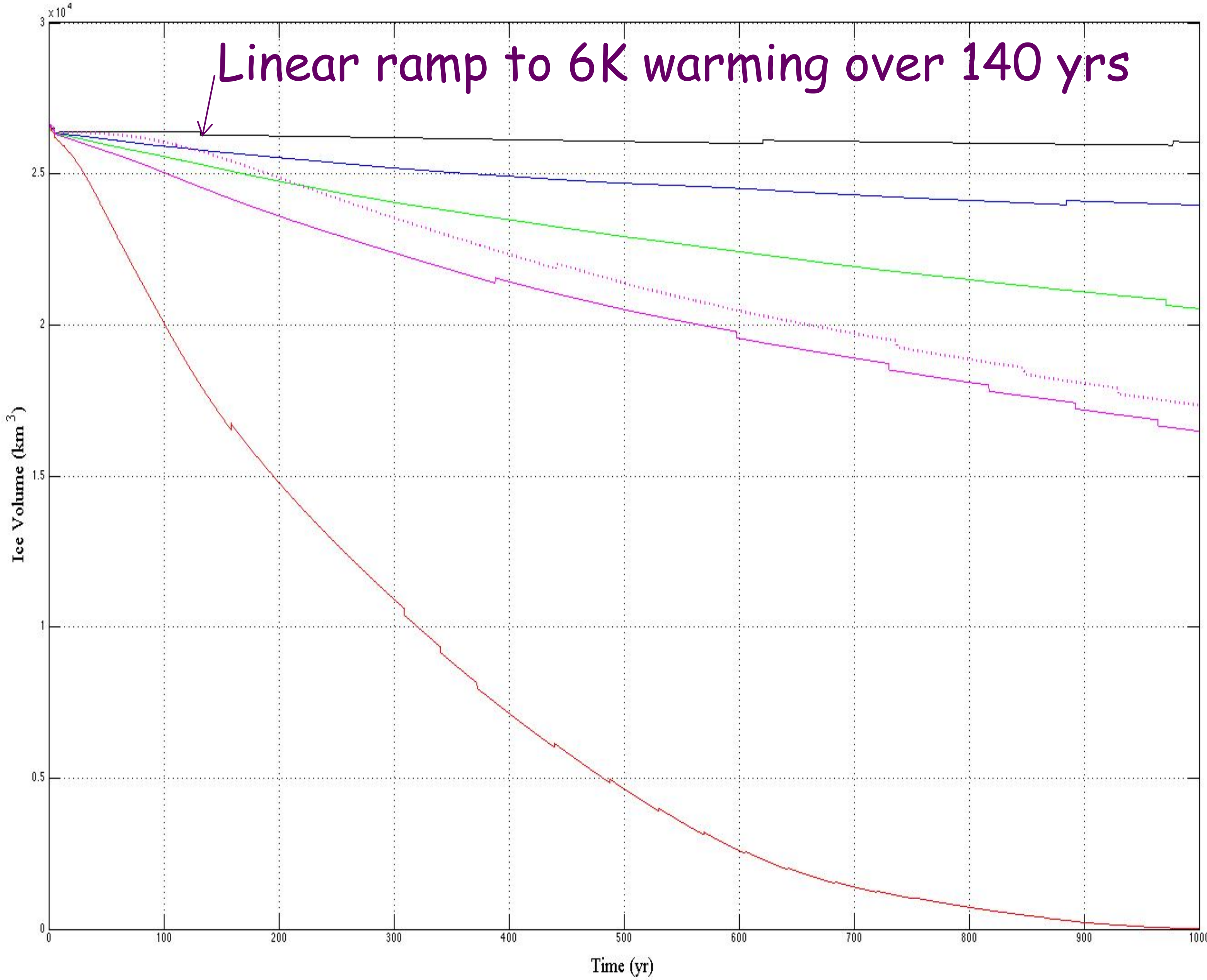
Also see SeaRISE results (Bindschadler et al., 2013; Nowicki et al., 2013a,b)



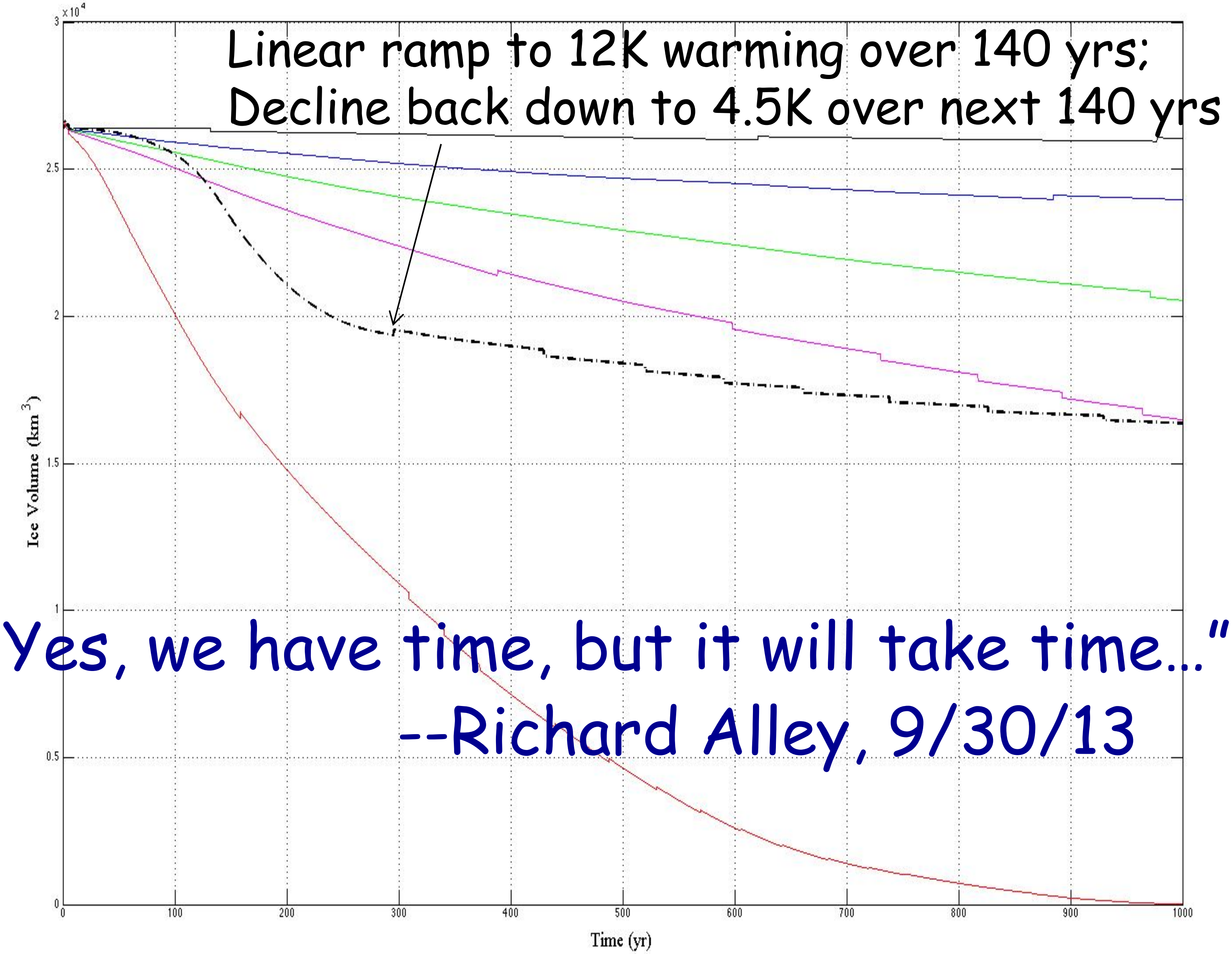
x 10^4
Ice Volume (km^3)
Time (yr)
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
0
0.5
1
1.5
2
2.5
3
ΔT=0 K
ΔT=3 K
ΔT=4.5 K
ΔT=6 K
ΔT=12 K



x 10^4
3
2.5
2
1.5
1
0.5
0
Ice Volume (km^3)
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
Time (yr)
ΔT=0 K
ΔT=3 K
ΔT=4.5 K
ΔT=6 K
ΔT=12 K



Linear ramp to 6K warming over 140 yrs
× 10^4
3
2.5
2
1.5
1
0.5
0
Ice Volume (km^3)
0
100
200
300
400
500
600
700
800
900
1000
Time (yr)



"Yes, we have time, but it will take time…"

--Richard Alley, 9/30/13

Conclusions:

- Process inclusion matters as much as the physics core (Often smart model selection can lead to justified efficiency… What questions? Which setting? We can still learn a lot from SIA and reduced-dimensional models.)

- Along the GIS flowline, higher-order physics initially leads to more rapid transmission of ice into the ablation zone, but with similar process inclusion in these SMB-dominated runs, overall volume histories are quite similar to SIA

- The rate and magnitude of warming matter not only to the quantity of mass loss, but also to the rate of loss (this one's for you, John Anderson)

"There is a lot that we don't know yet, but there is a lot that we can know…"

--Karen Alley, 10/1/13