Application of a higher-order flow model to outlet glacier dynamics in Greenland

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Climate, Ocean, and Sea Ice Modeling Project

Outline

(1) Introduce a tuning procedure that provides a useful initial condition for a higher-order, stand alone ice sheet model (applied to the GIS).

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(3) From perturbation experiments, estimate SLR that is already “in” the ice sheet as a result of outlet glacier perturbations that have already occurred.

(4) Scale the model results in order to estimate the potential future SLR from *all* recent outlet glacier perturbations.

Show tuned GIS model and compare with target velocities

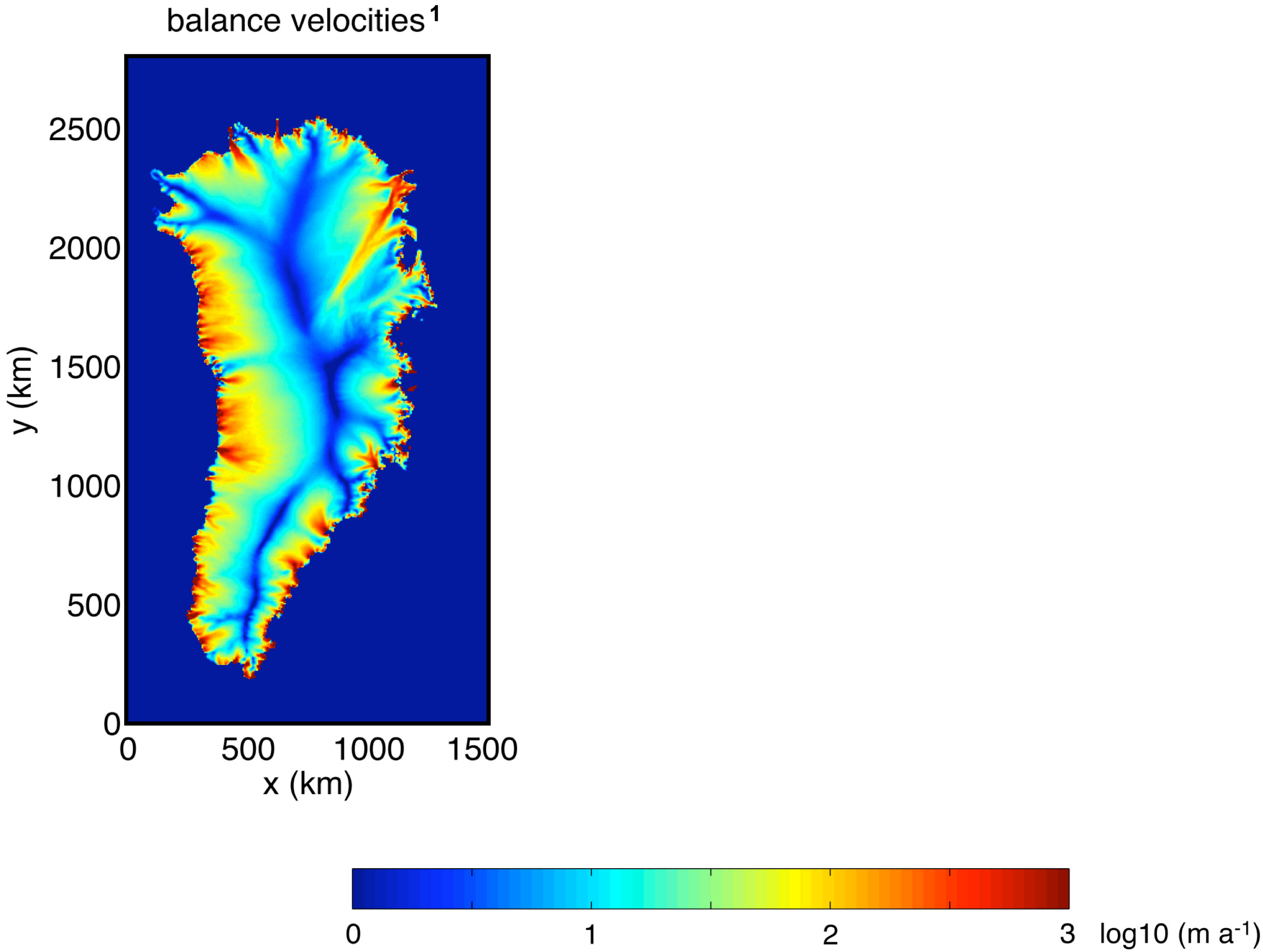
Apply model to outlet glacier perturbation experiments

Compare modelled and observed thinning rates

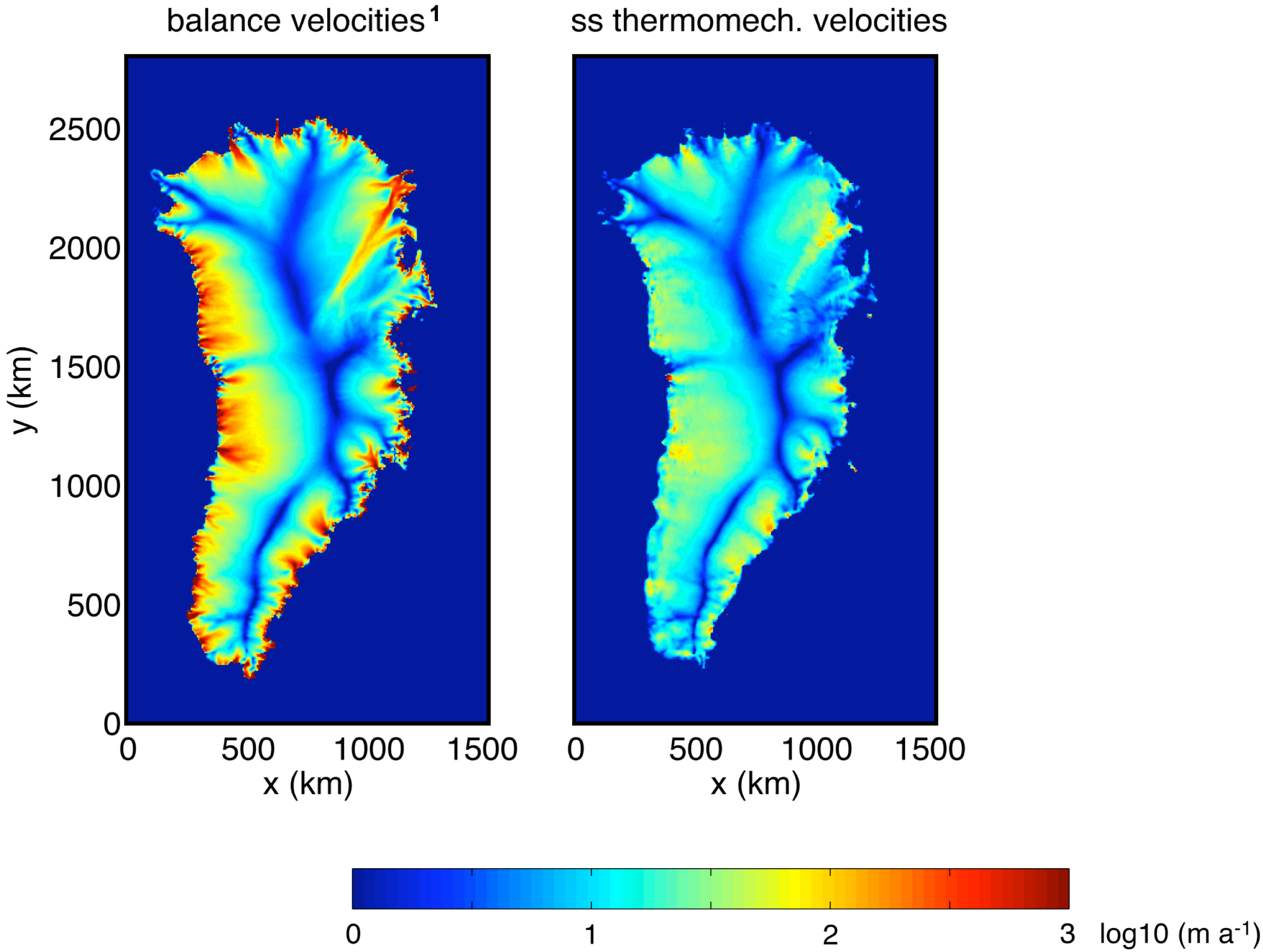
Estimate minimum future SLR from modelled glaciers

Scale estimate to entire ice sheet

field camp, central Greenland



[1]Bamber et al. (*J.Glac.*, **46**, 2000)



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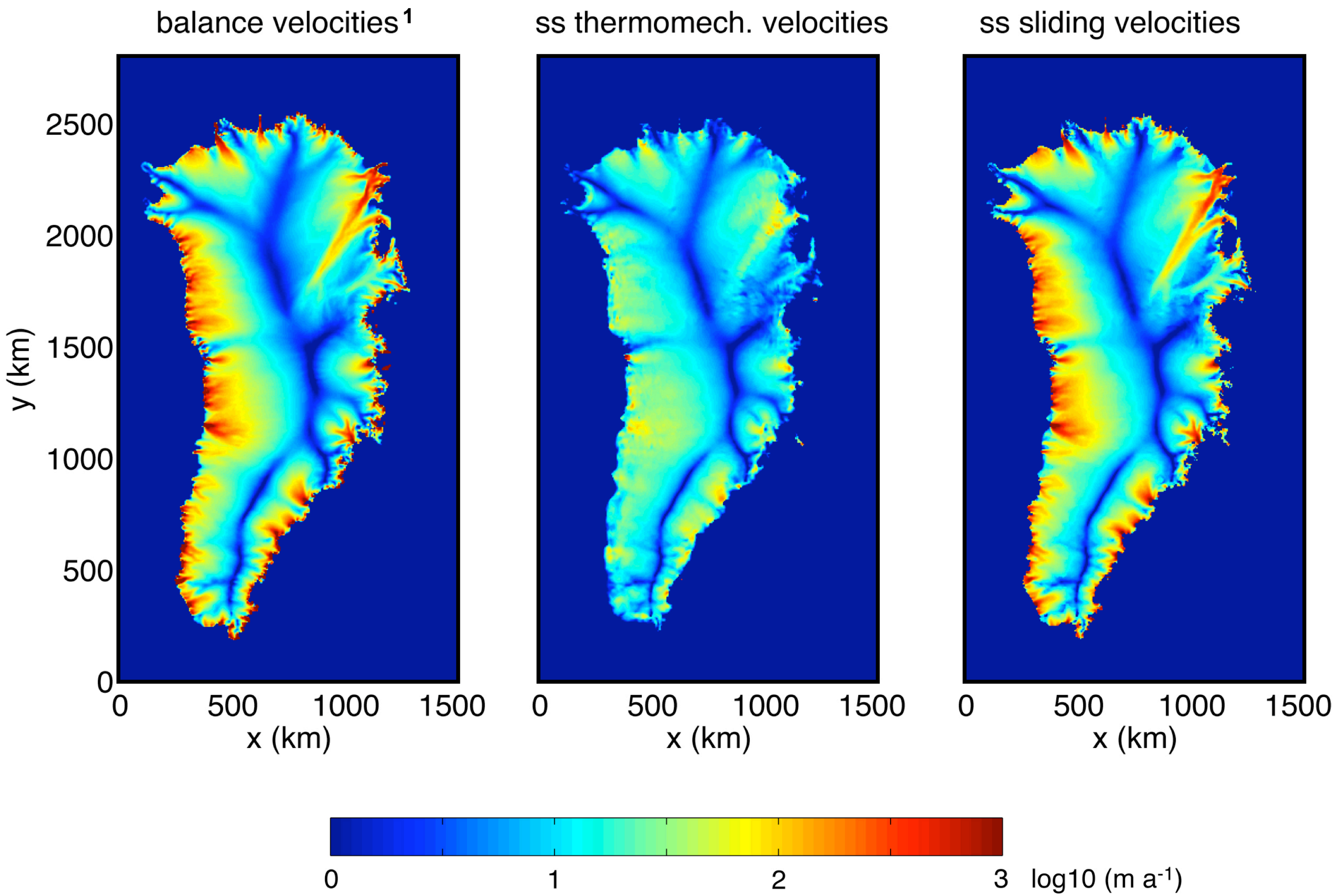

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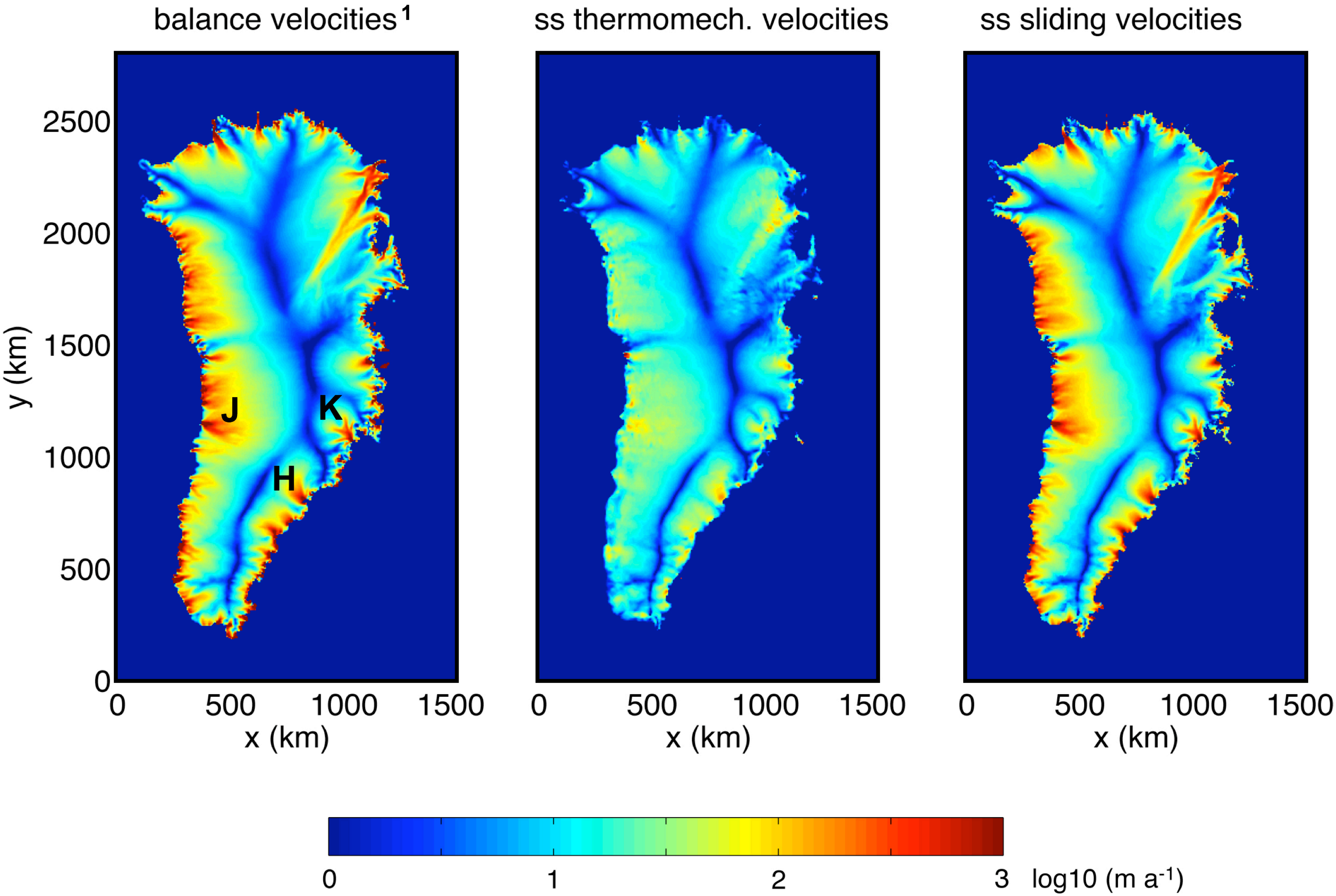

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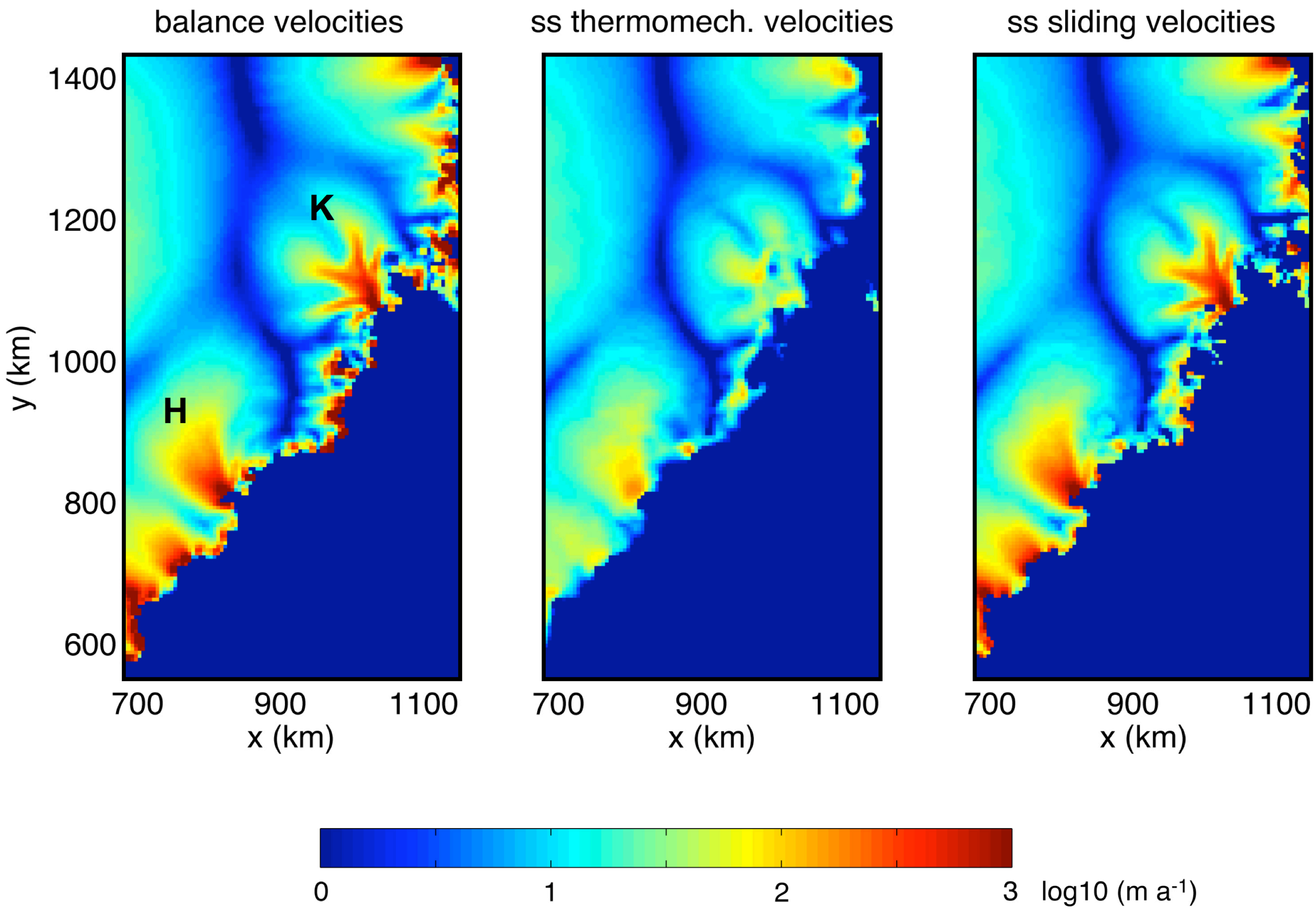
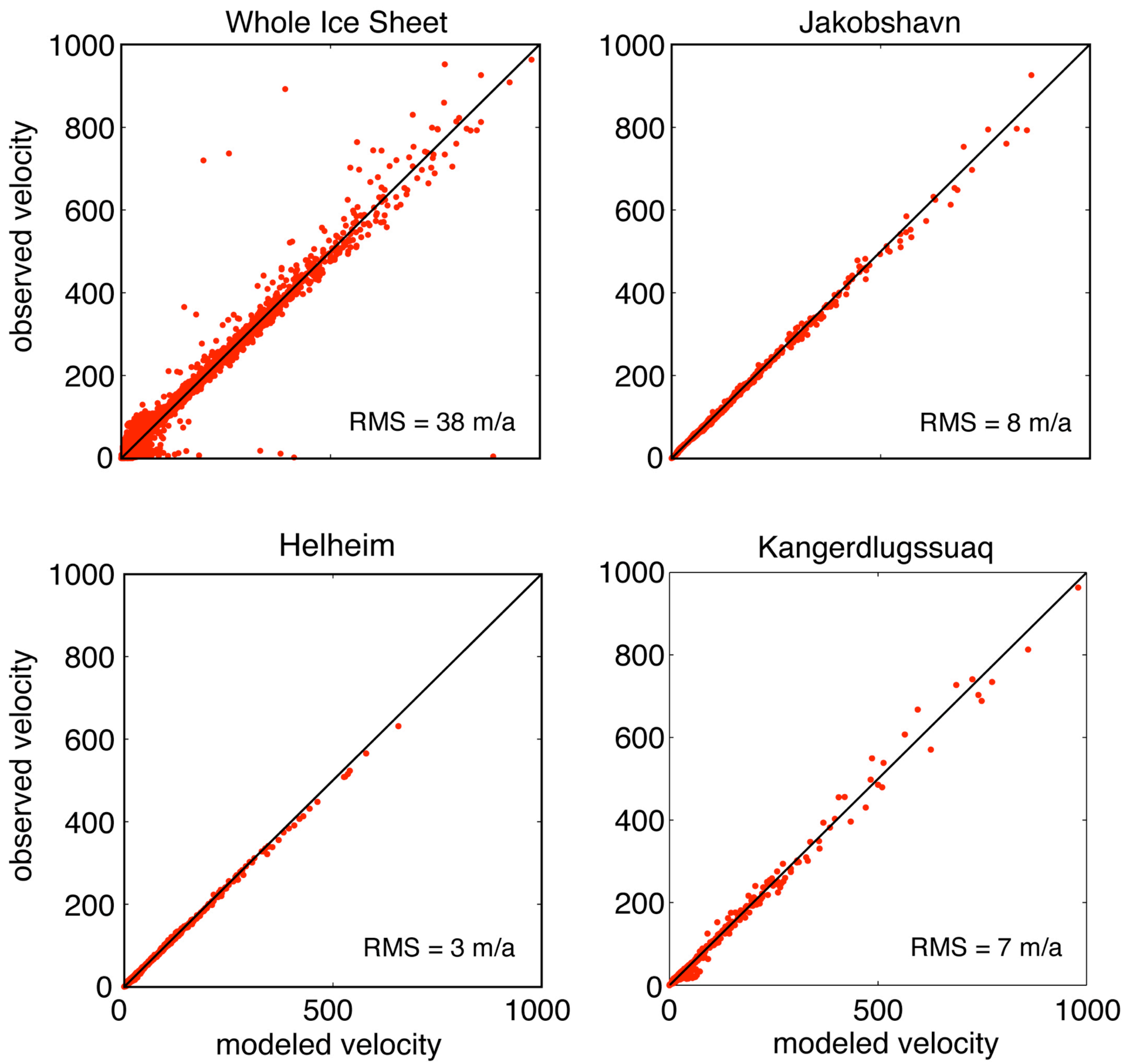

balance velocities
ss thermomech. velocities
ss sliding velocities
1400
1200
1000
800
600
y (km)
K
H
700
900
1100
x (km)
0
1
2
3
log10 (m a-1)

Tuning Statistics



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Scale estimate to entire ice sheet

field camp, Southern Greenland

Perturbation experiments

(1) Using initial condition, perturb outlet BC for select outlet glaciers (Jak, Hel, Kang)

Perturbation experiments: initial conditions

Assumed ~ss discharge ($km^3\ a^{-1}$) from select GIS basins:

Basin	*model (% error)*	*observations*[1]
Jakobshavn:	23.5 (<1)	23.6
Helheim:	25.8 (-2)	26.3
Kangerdlugssuaq:	27.8 (0)	27.8

[1] Rignot and Kanagaratnam (*Science*, **311**, 2006)

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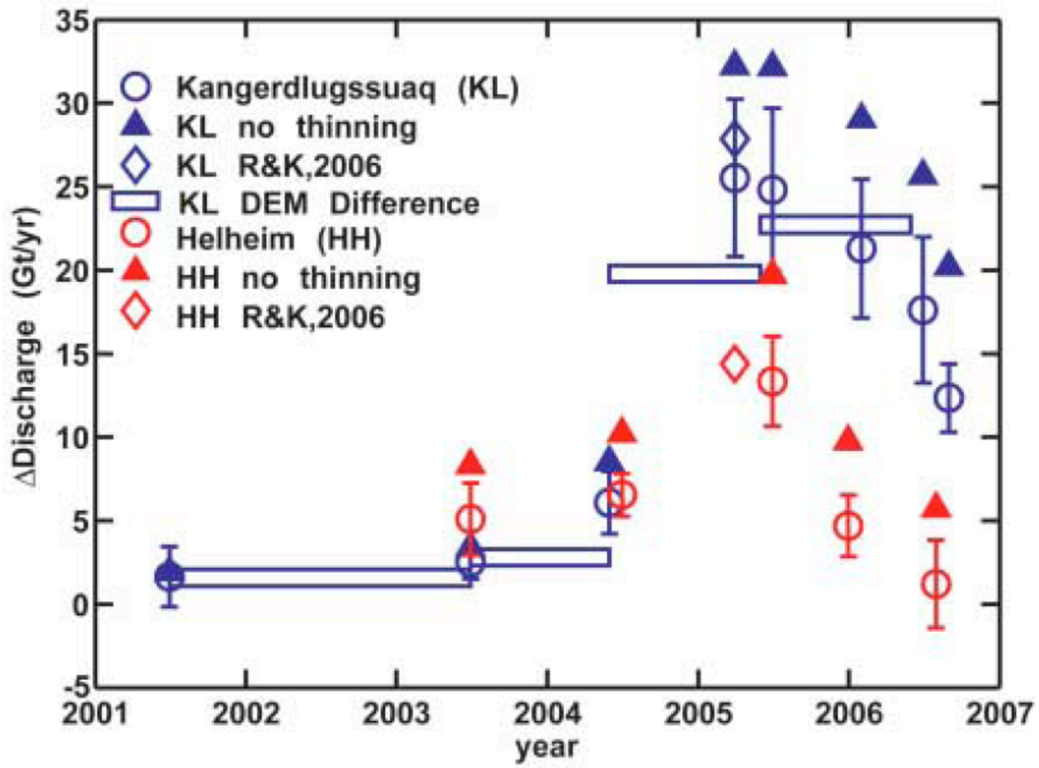
(2) perturbation: tune outlet BC so that flux change matches observations

Kang. and Hel.[1]



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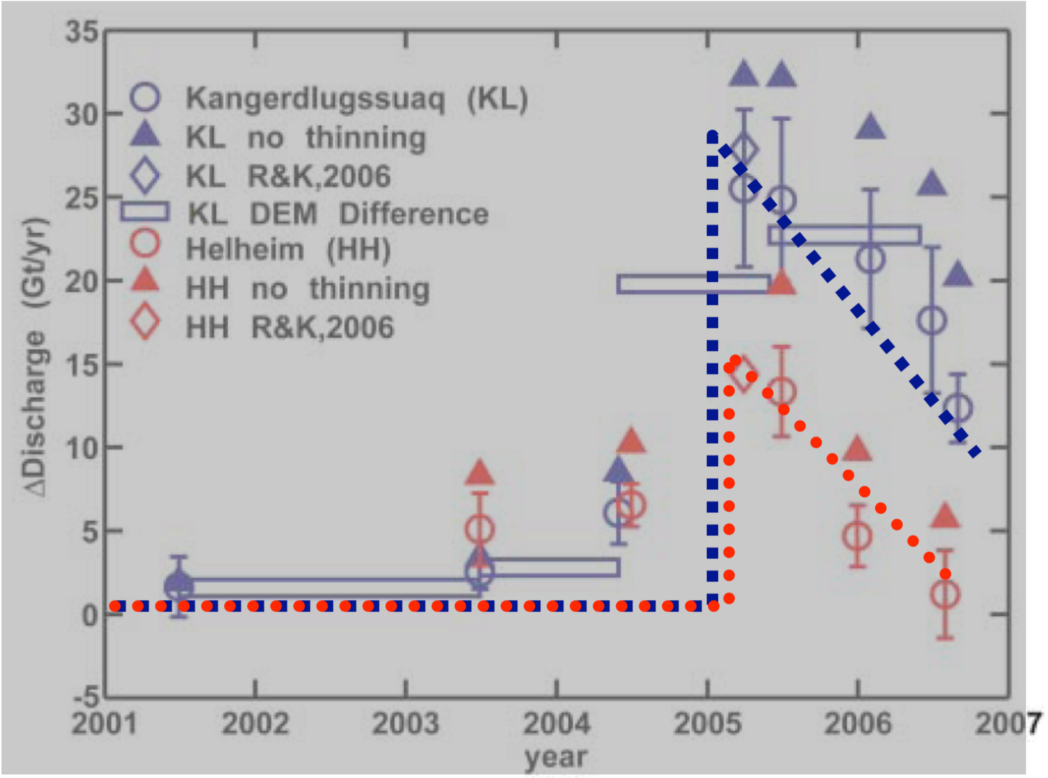

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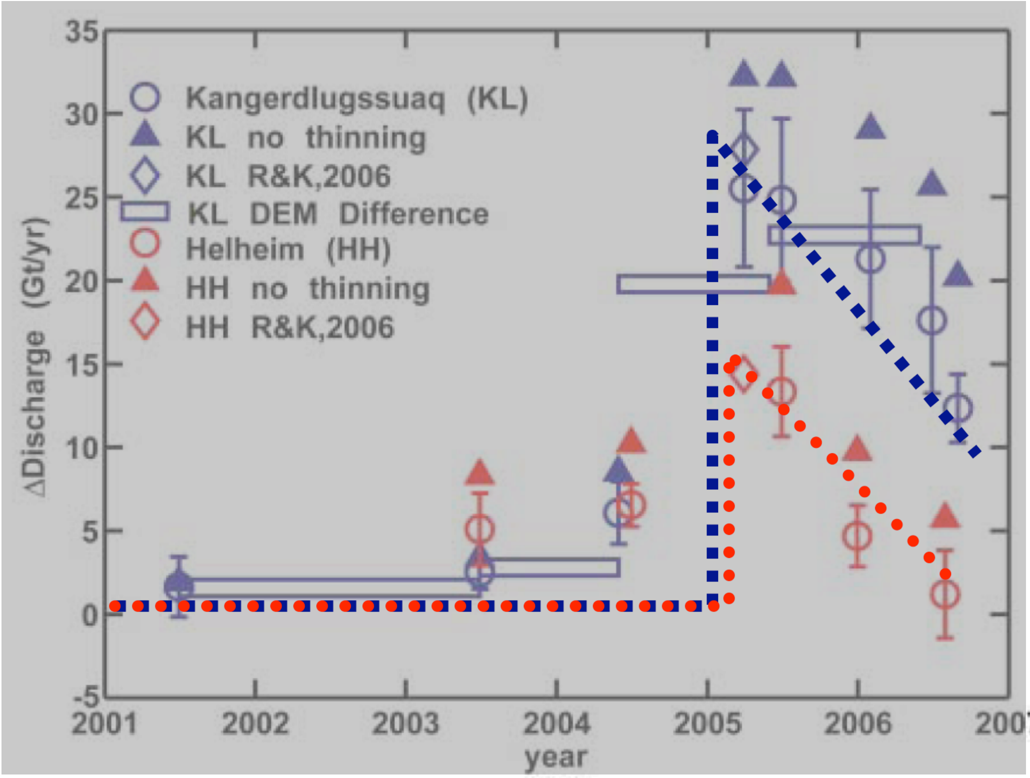


[1]Howat et al. (*Science*, **315**, 2007)

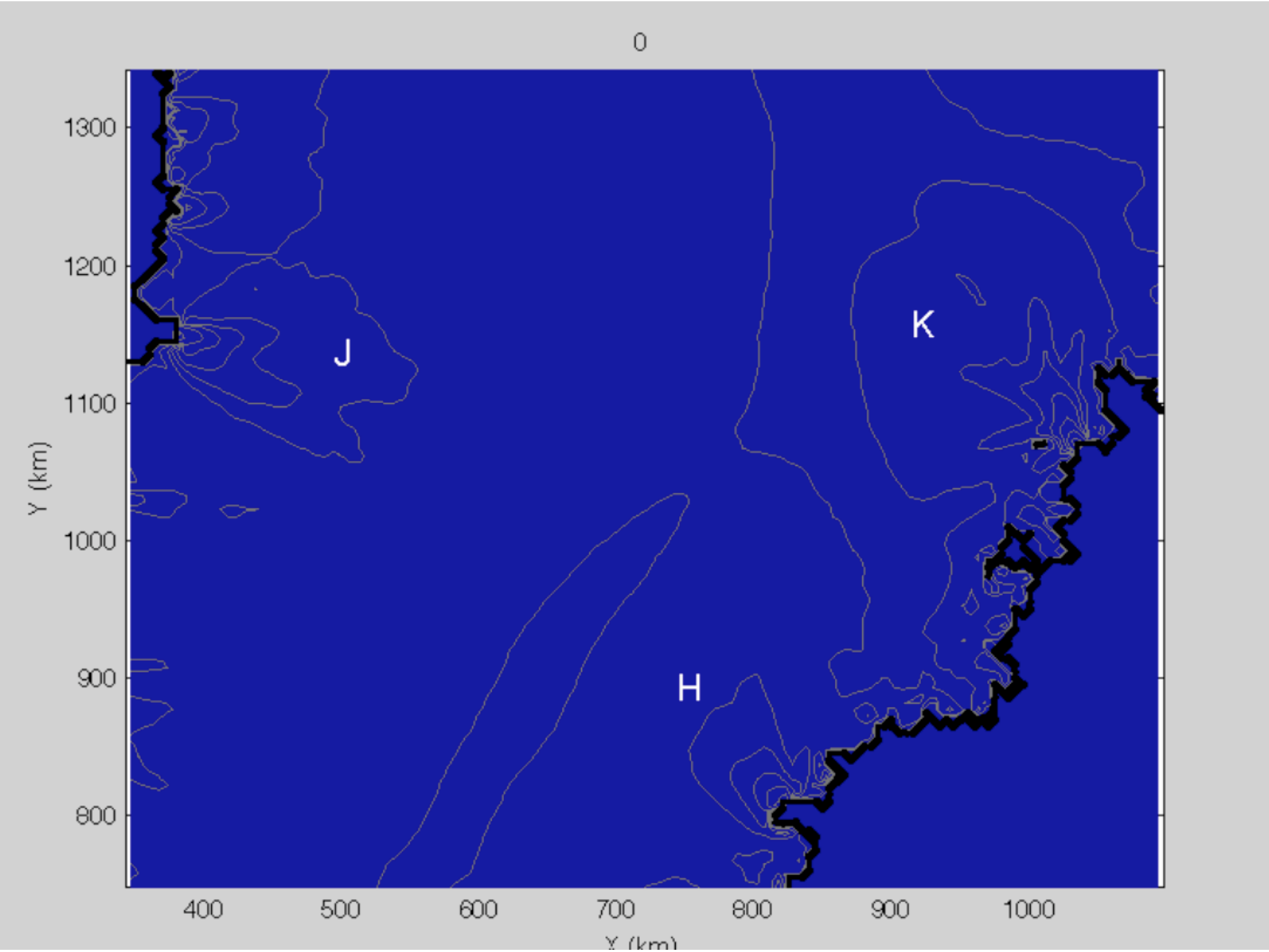
Jak:

Approx. flux doubling[2,3], from ~25-50 km^3 a^{-1},in the mid-late 90's

[2]Joughin et al. (*Nature*, **432**, 2004)
[3]Rignot and Kanagaratnam (*Science*, **311**, 2006)

Perturbation experiments (prognostic)

Next: movie of speed change over Jak., Kang. and Hel. glacier catchments from model years 0 to 25 (dt = 0.2 yrs) …


0
1300
1200
1100
1000
900
800
Y (km)
400
500
600
700
800
900
1000
X (km)
J
K
H

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(3) Step model forward in time, integrate thinning over basin area and over time.

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The result is an estimate for how past dynamic perturbations to these 3 basins will affect future GIS mass balance (i.e. long term, diffusive response).

This can be used to estimate a ***minimum*** future SLR contribution from GIS outlet glacier dynamics.

Show tuned GIS model and compare with target velocities

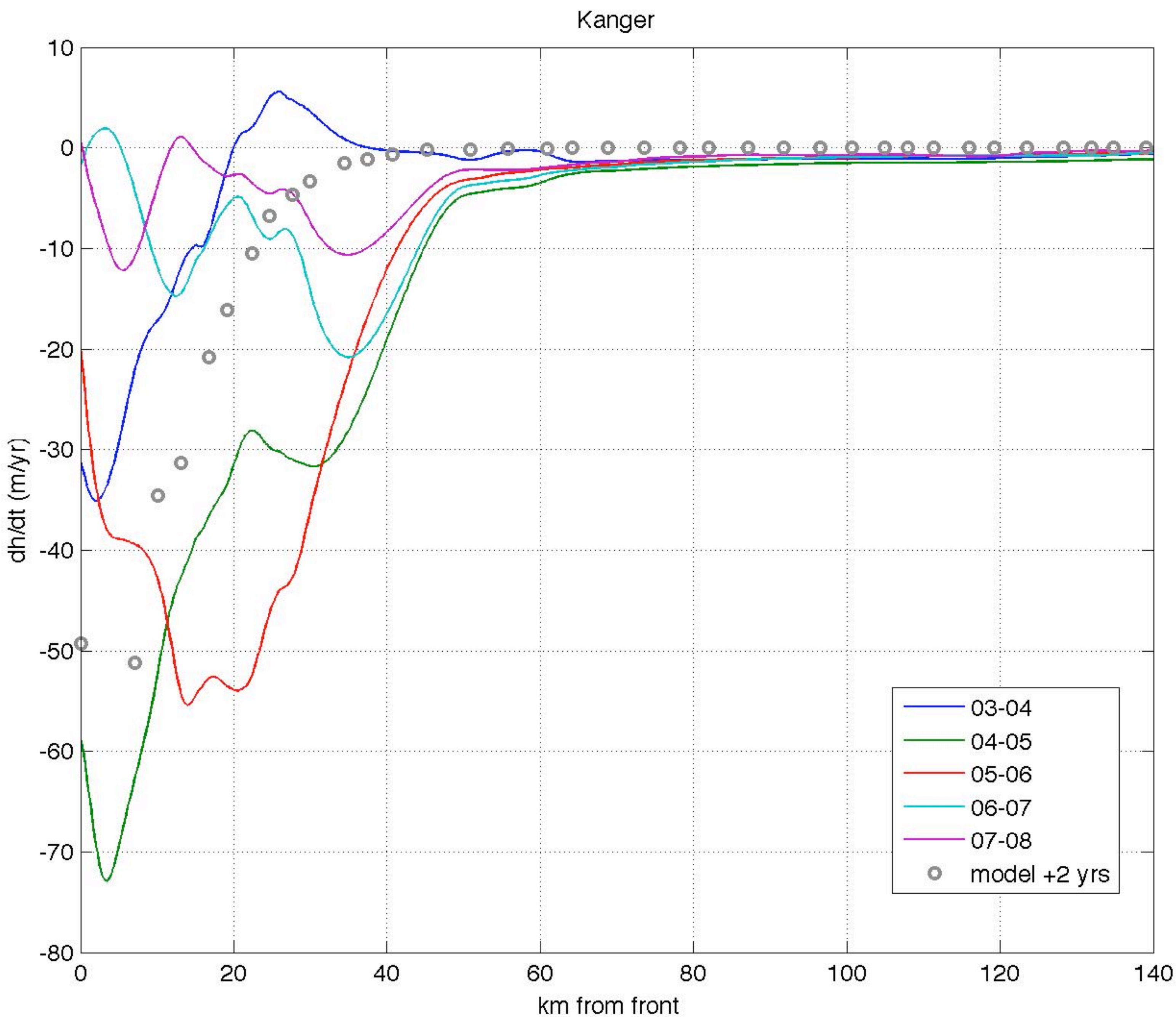
Apply model to outlet glacier perturbation experiments

Compare modelled and observed thinning rates

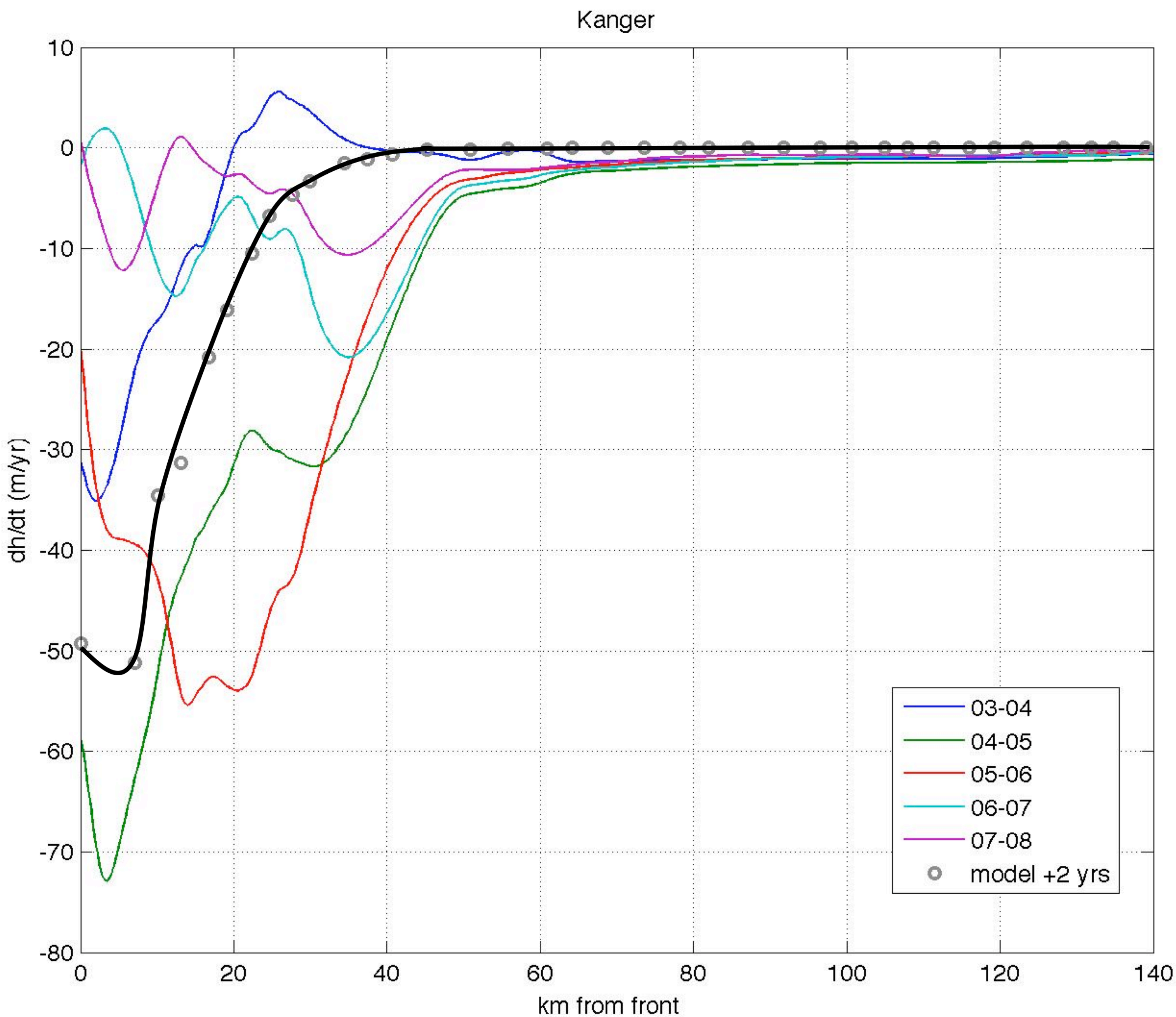
Estimate minimum future SLR from modelled glaciers

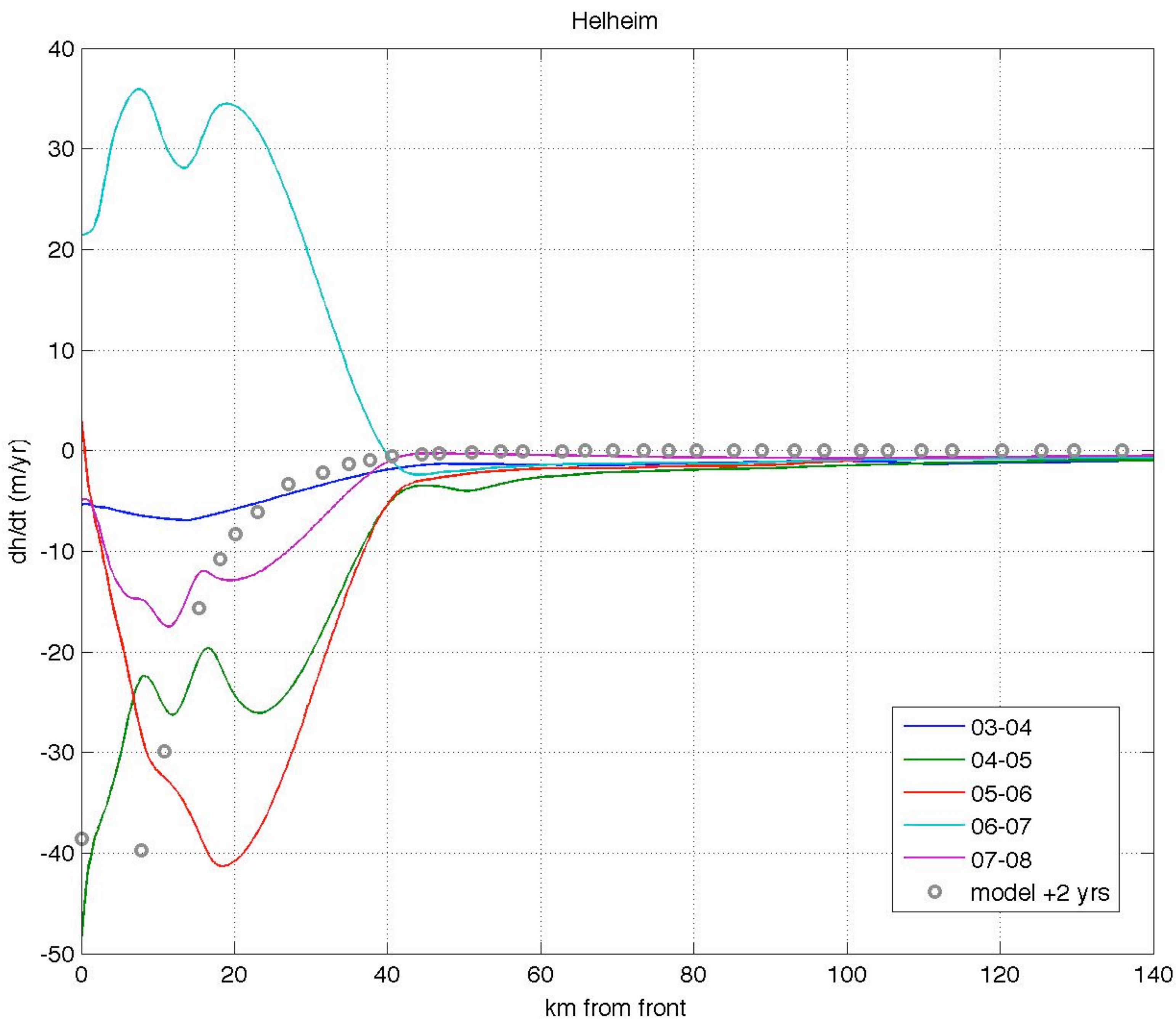
Scale estimate to entire ice sheet

Illulisat, Western Greenland

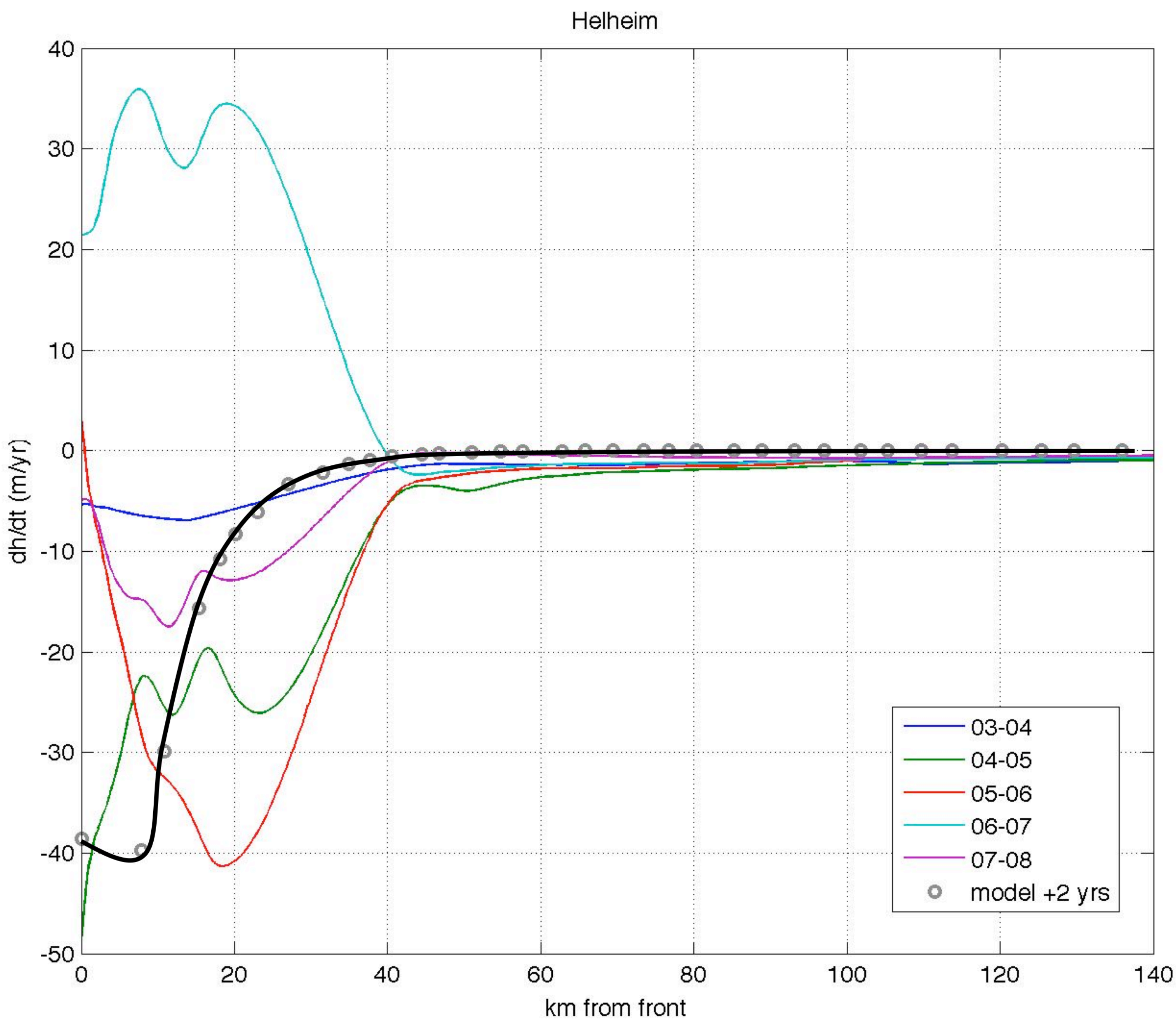


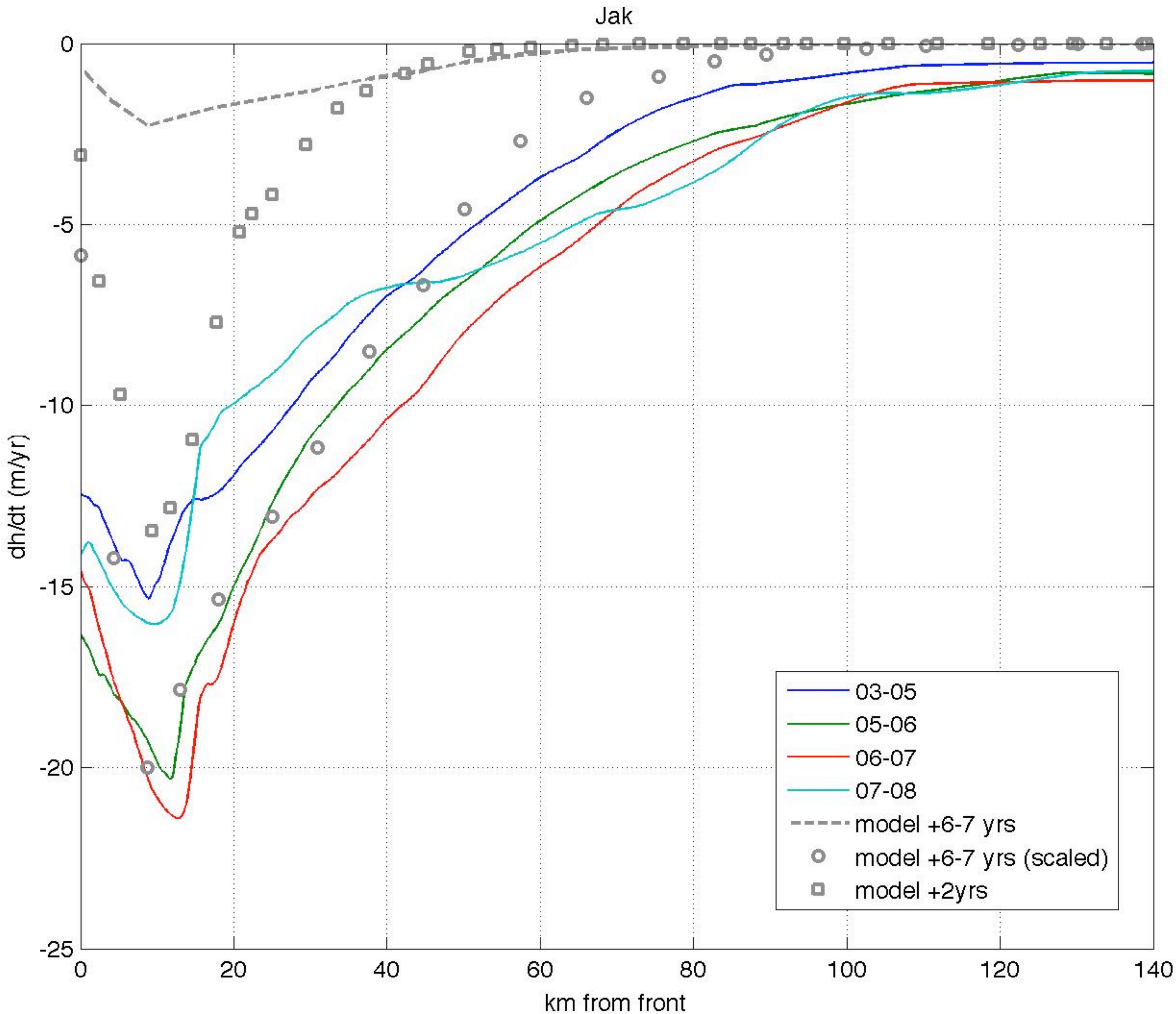
Kanger
10
0
-10
-20
-30
-40
-50
-60
-70
-80
dh/dt (m/yr)
0
20
40
60
80
100
120
140
km from front
03-04
04-05
05-06
06-07
07-08
model +2 yrs

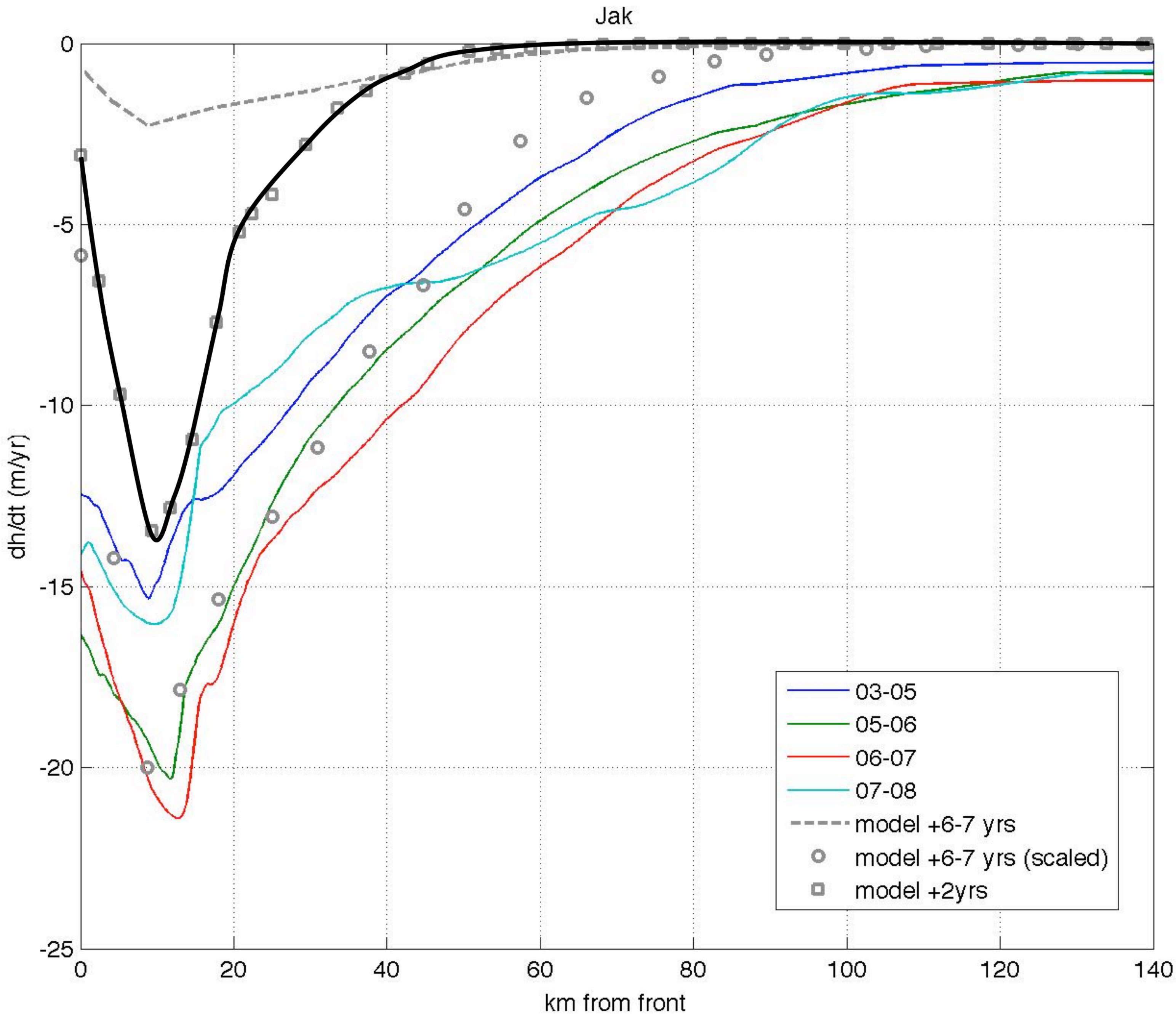

Kanger
dh/dt (m/yr)
km from front
10
0
-10
-20
-30
-40
-50
-60
-70
-80
0
20
40
60
80
100
120
140
03-04
04-05
05-06
06-07
07-08
model +2 yrs



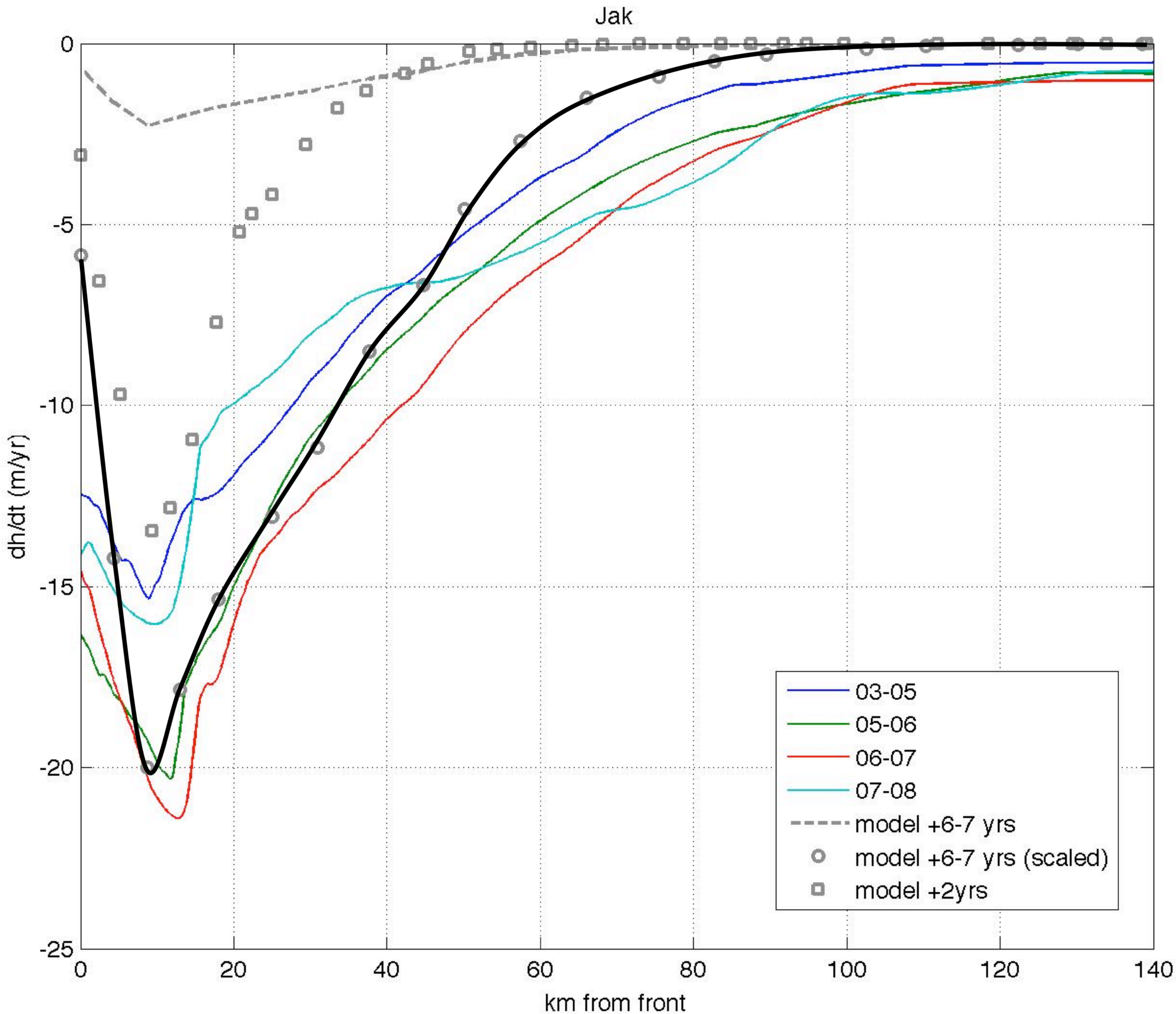
Helheim
40
30
20
10
0
-10
-20
-30
-40
-50
dh/dt (m/yr)
0
20
40
60
80
100
120
140
km from front
03-04
04-05
05-06
06-07
07-08
model +2 yrs


Helheim
40
30
20
10
0
-10
-20
-30
-40
-50
dh/dt (m/yr)
0
20
40
60
80
100
120
140
km from front
03-04
04-05
05-06
06-07
07-08
model +2 yrs


Jak
dh/dt (m/yr)
km from front
0
-5
-10
-15
-20
-25
0
20
40
60
80
100
120
140
03-05
05-06
06-07
07-08
model +6-7 yrs
model +6-7 yrs (scaled)
model +2yrs



Jak
0
-5
-10
-15
-20
-25
dh/dt (m/yr)
0
20
40
60
80
100
120
140
km from front
03-05
05-06
06-07
07-08
model +6-7 yrs
model +6-7 yrs (scaled)
model +2yrs



Jak
0
-5
-10
-15
-20
-25
dh/dt (m/yr)
0
20
40
60
80
100
120
140
km from front
03-05
05-06
06-07
07-08
model +6-7 yrs
model +6-7 yrs (scaled)
model +2yrs

Show tuned GIS model and compare with target velocities

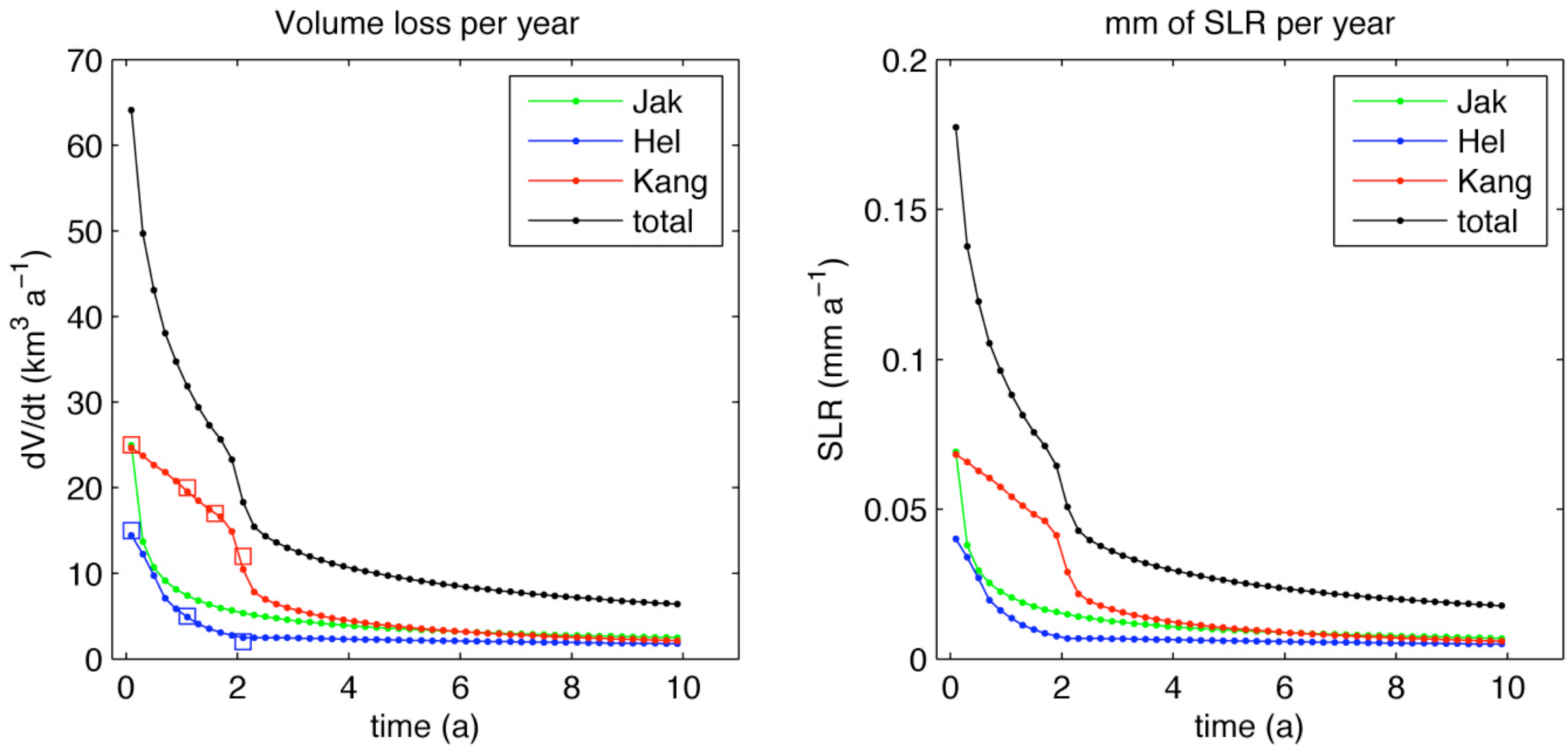
Apply model to outlet glacier perturbation experiments

Compare modelled and observed thinning rates

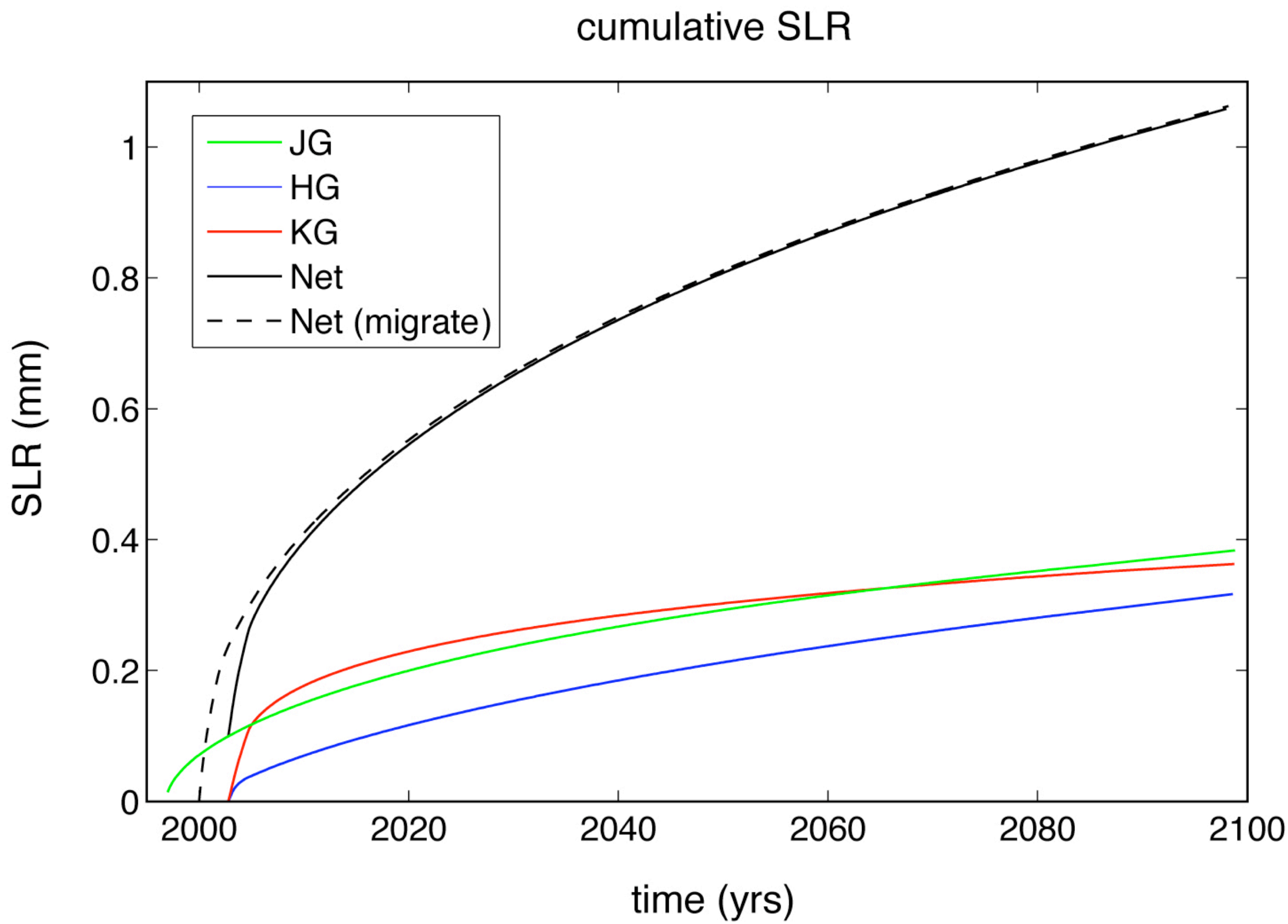
Estimate minimum future SLR from modelled glaciers

Scale estimate to entire ice sheet

field camp, central Greenland



[1]Kang., Hel, obs. from *Howat et al*. (*Science*, **315**, 2007)


cumulative SLR
JG
HG
KG
Net
Net (migrate)
SLR (mm)
time (yrs)
0
0.2
0.4
0.6
0.8
1
2000
2020
2040
2060
2080
2100

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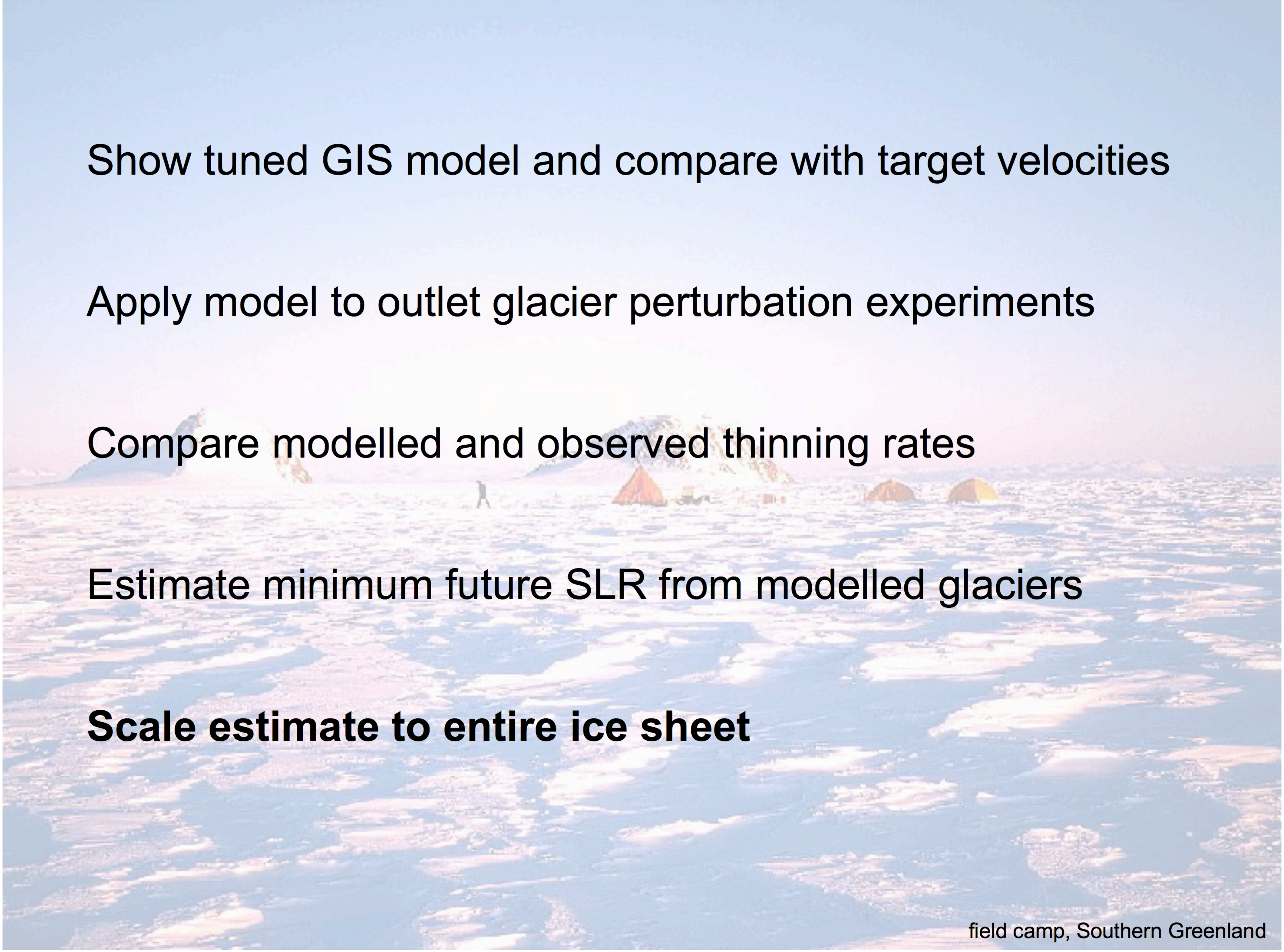
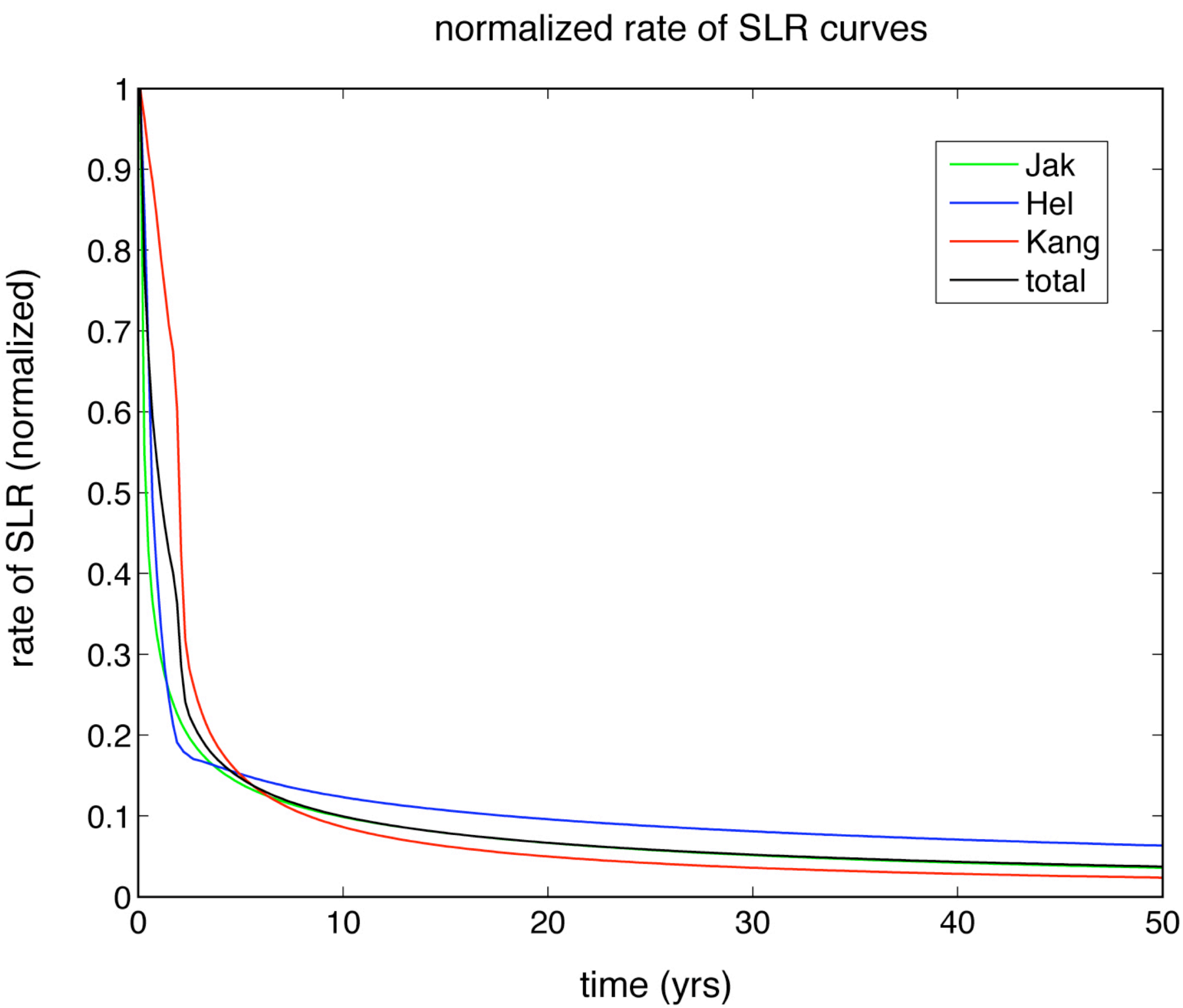


field camp, Southern Greenland

Can we scale these results?



normalized rate of SLR curves
rate of SLR (normalized)
time (yrs)
Jak
Hel
Kang
total
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
10
20
30
40
50

Can we scale these results?

Normalized *rate* of SLR curves have the form …

$$r(t) = r_0\left(\alpha t + 1\right)^{-\frac{1}{2}}$$

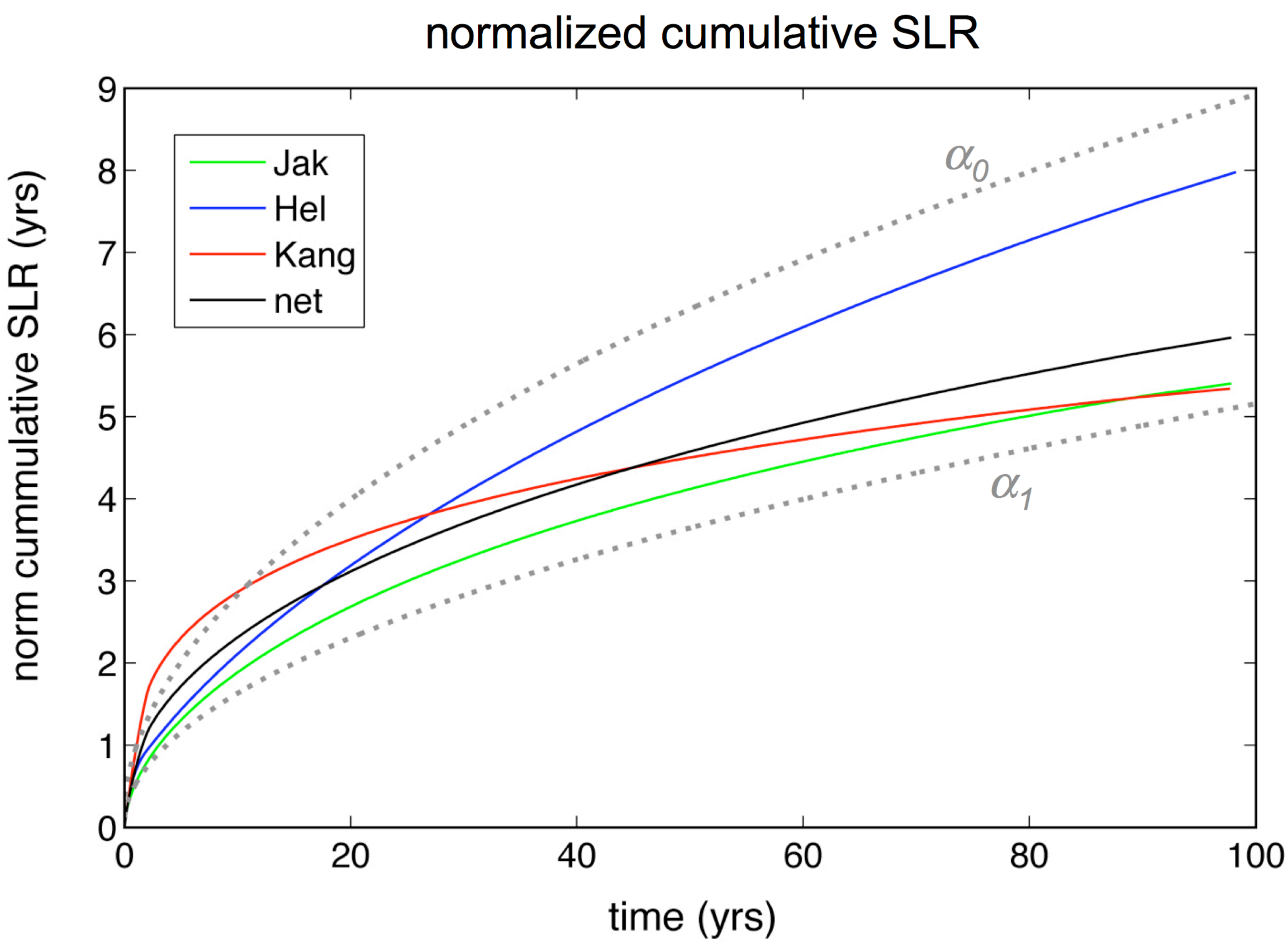
Can we scale these results?

Normalized *rate* of SLR curves have the form …

$$r(t) = r_0 \left(\alpha t + 1\right)^{-\frac{1}{2}}$$

Normalized SLR curves have the form …

$$SLR(t) = \int r_0 \left(\alpha t + 1\right)^{-\frac{1}{2}} dt \quad \ldots = r_0 \left[\frac{2}{\alpha} (\alpha t + 1)^{\frac{1}{2}} + c \right] \quad \ldots = r_0 f\left(t\right)$$


normalized cumulative SLR
norm cummulative SLR (yrs)
time (yrs)
Jak
Hel
Kang
net
α_0
α_1
0
20
40
60
80
100
1
2
3
4
5
6
7
8
9

Can we scale these results?

Over the last decade, the dynamic imbalance for the GIS is primarily due to perturbations at the marine termini of outlet glaciers.

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- Numerous marine-terminating outlet glaciers underwent acceleration and thinning between the mid-to-late '90's[1,2,3,4] and the present.

[1]Rignot and Kanagar. (*Science*, **311**, 2006); [2]Howat et al. (*J. Glaciol.*, **54**(187), 2009); [3]Sole et al. (*Cryosphere*, **2**, 2008); [4]Thomas et al. (*J. Glaciol.*, **55**(189), 2009); [5]Nick/Vieli et al. (*Nat. Geosc.*, **2**, 2009);

Can we scale these results?

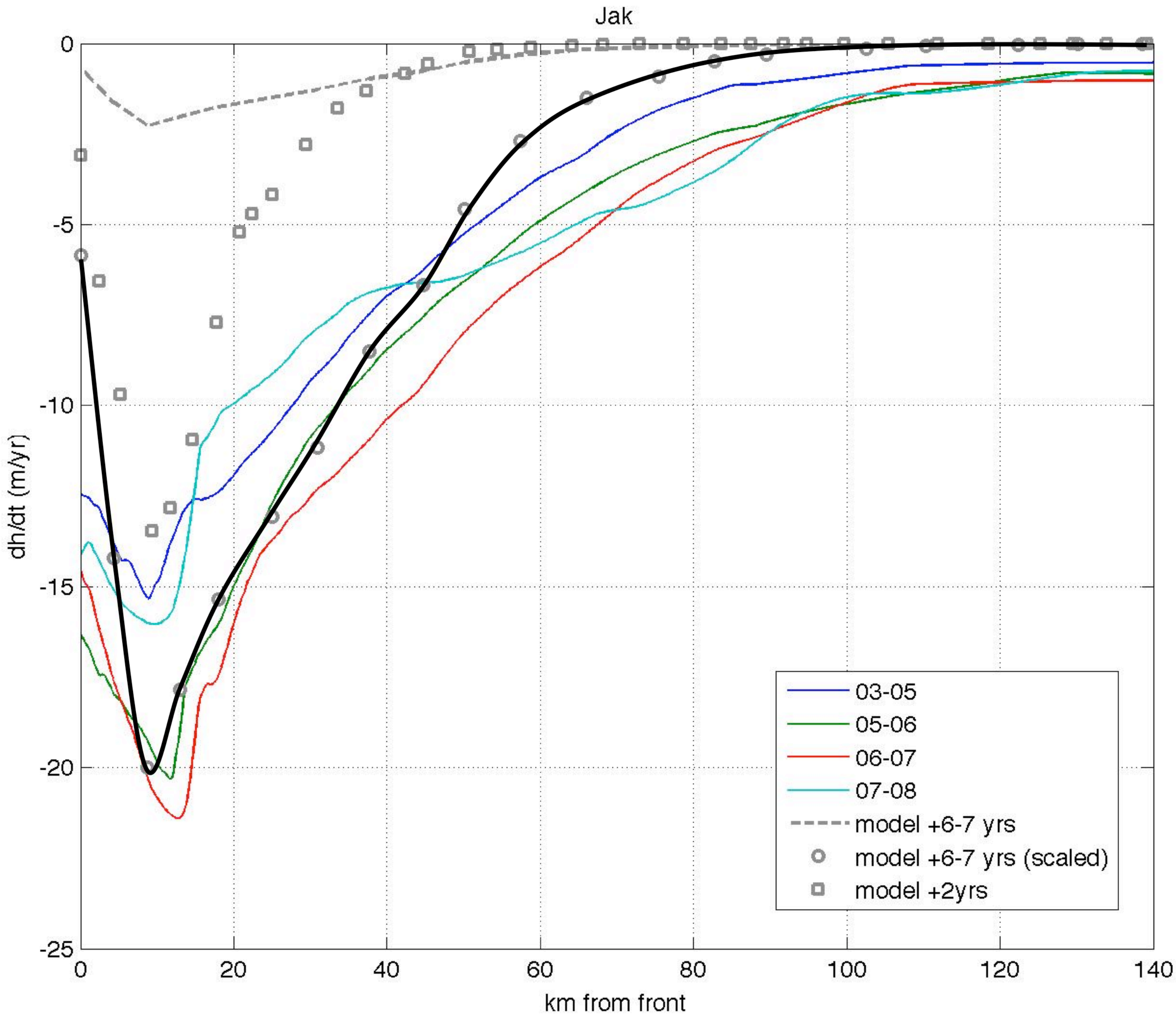
Over the last decade, the dynamic imbalance for the GIS is primarily due to perturbations at the marine termini of outlet glaciers.

- Numerous marine-terminating outlet glaciers underwent acceleration and thinning between the mid-to-late '90's[1,2,3,4] and the present.

- Where examined [2,3,4,5], acceleration and thinning are best explained by perturbations of the type explored here.

- The current modelling captures the long-term affects of this type perturbation.

[1]Rignot and Kanagar. (*Science*, **311**, 2006); [2]Howat et al. (*J. Glaciol.*, **54**(187), 2009); [3]Sole et al. (*Cryosphere*, **2**, 2008); [4]Thomas et al. (*J. Glaciol.*, **55**(189), 2009); [5]Nick/Vieli et al. (*Nat. Geosc.*, **2**, 2009);


Jak
0
-5
-10
-15
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-25
dh/dt (m/yr)
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20
40
60
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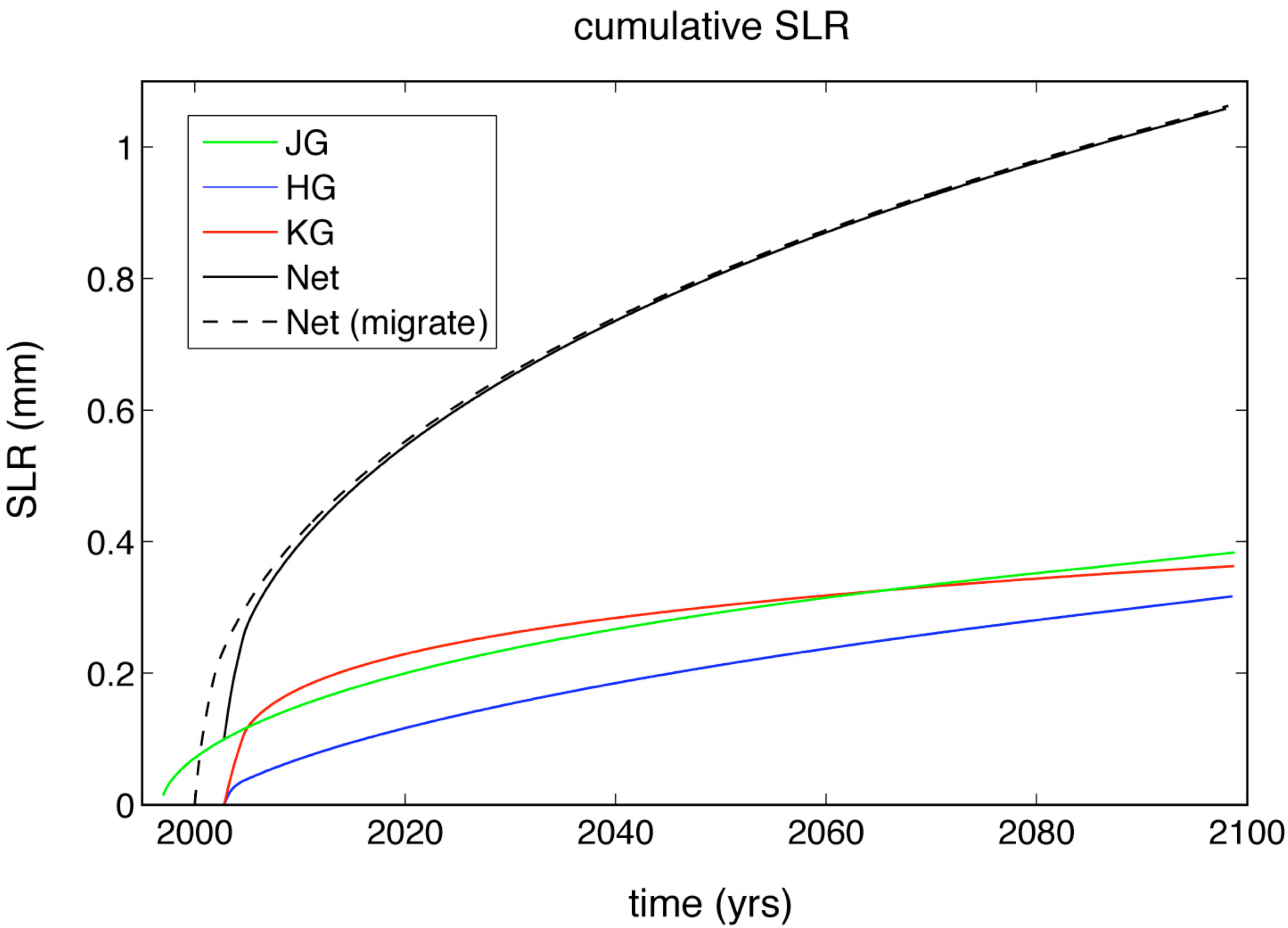
120
140
km from front
03-05
05-06
06-07
07-08
model +6-7 yrs
model +6-7 yrs (scaled)
model +2yrs

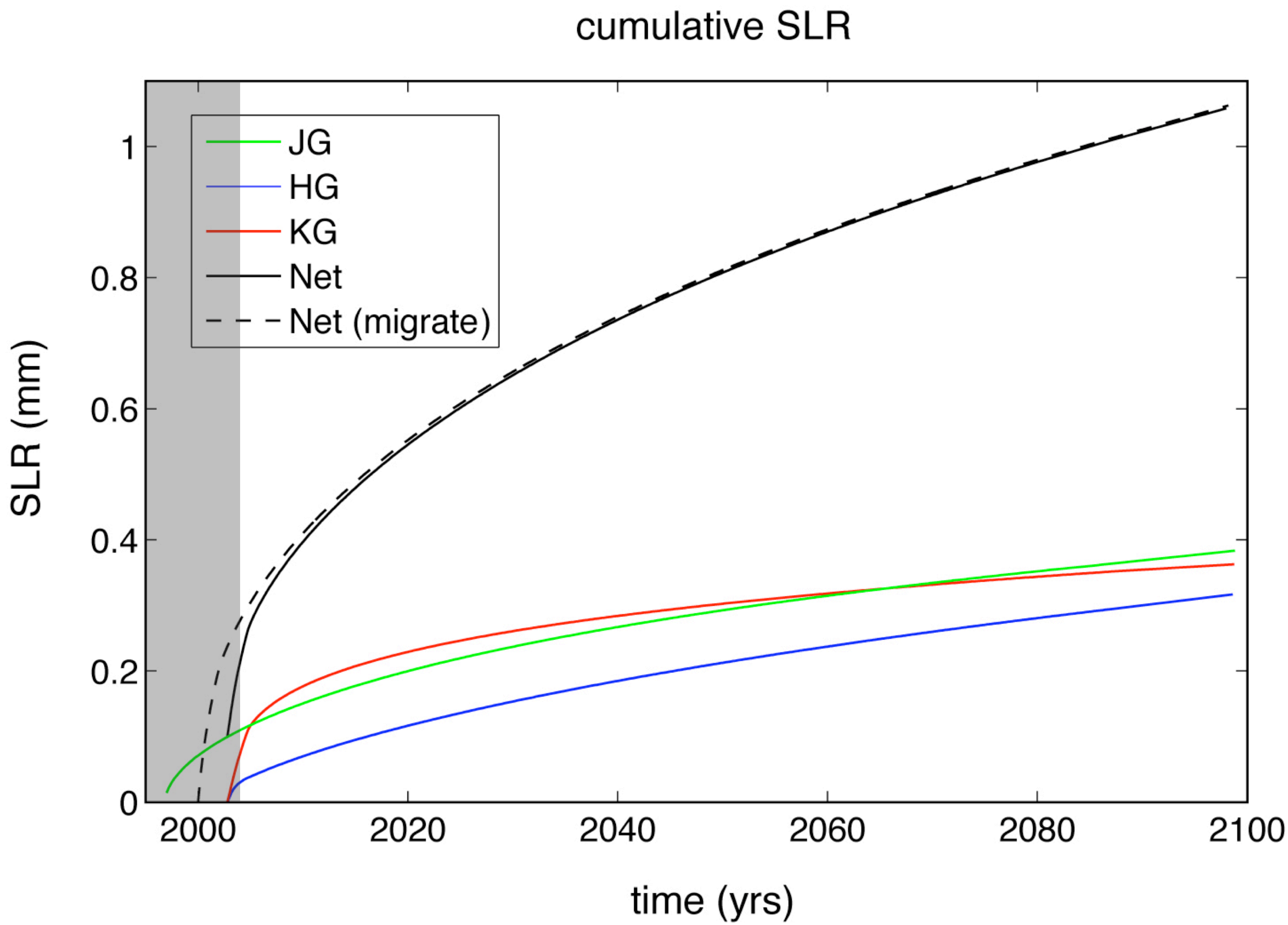
Can we scale these results?

The causative perturbations for this time period can be collapsed into a single, large perturbation.

Can we scale these results?



Can we scale these results?



Can we scale these results?

Normalized SLR curves have the form …

$$SLR(t) = \int r_0 (\alpha t + 1)^{-\frac{1}{2}}\, dt \quad \ldots = r_0 \left[\frac{2}{\alpha} (\alpha t + 1)^{\frac{1}{2}} + c \right] \quad \ldots = r_0 f(t)$$

Can we scale these results?

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For *n* perturbations contributing to SLR_{NET} over the next 100 yrs …

$$SLR(t)_{NET} = r_0^1 f^1(t) + r_0^2 f^2(t) + r_0^3 f^3(t) + ... + r_0^n f^n(t)$$

Can we scale these results?

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For *n* perturbations contributing to *SLR*$_{NET}$ over the next 100 yrs …

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If the general form of the perturbation response is the same …

$$f^1(t) \approx f^2(t) \approx f^3(t) \approx \ldots \approx f^n(t)$$

$$SLR(t)_{NET} \approx \left(r_0^1 + r_0^2 + r_0^3 + \ldots + r_0^n \right) f(t) = \left(\sum_1^n r_0^n \right) f(t)$$

Can we scale these results?

Normalized SLR curves have the form …

$$SLR(t) = \int r_0 (\alpha t + 1)^{-\frac{1}{2}}\, dt \quad \ldots = r_0 \left[\frac{2}{\alpha} (\alpha t + 1)^{\frac{1}{2}} + c \right] \quad \ldots = r_0 f(t)$$

For n perturbations contributing to SLR_{NET} over the next 100 yrs …

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The model gives us an estimate for the **blue** term. How do get an estimate for the **red** term?

Can we scale these results?

The magnitude of $\Sigma\ r_0$ is estimated from observations - require that modelled, mean thinning rate matches observations over some relevant time period.

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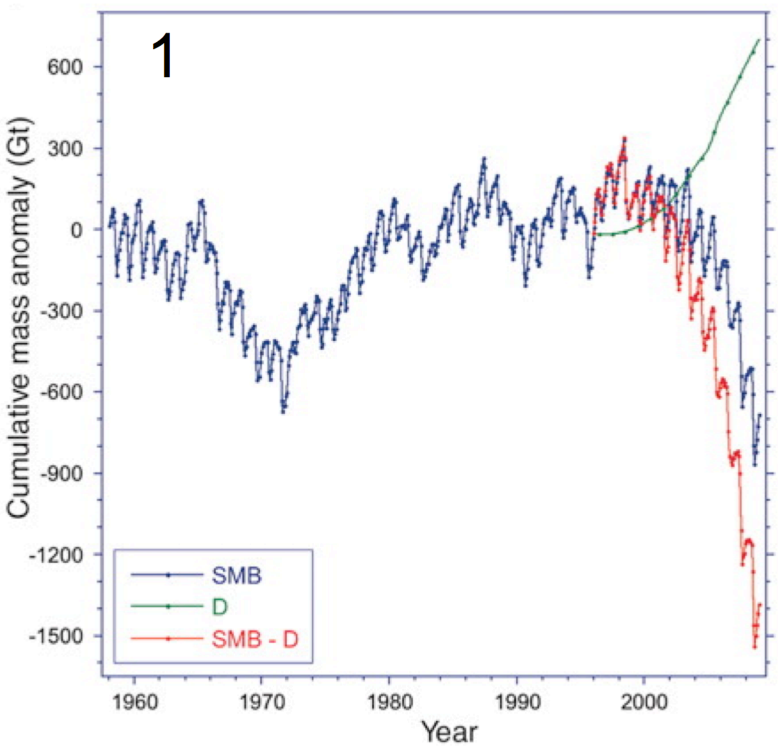

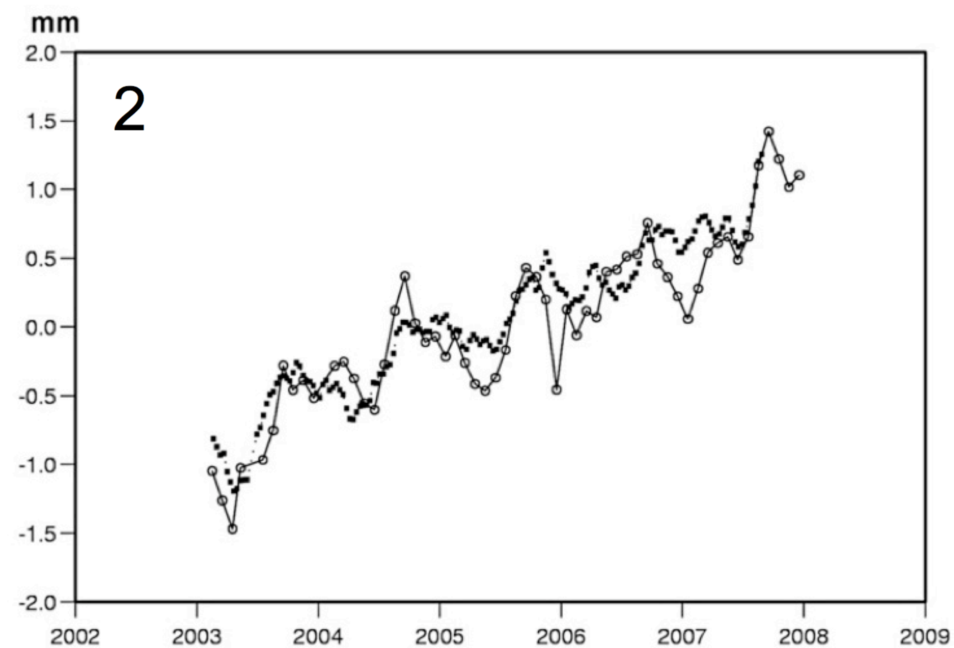

[1]van den Broeke et al. (*Science*, **326**, 2009);

[2]Cazenave et al. (*Global Planet. Change*, **65**, 2009);

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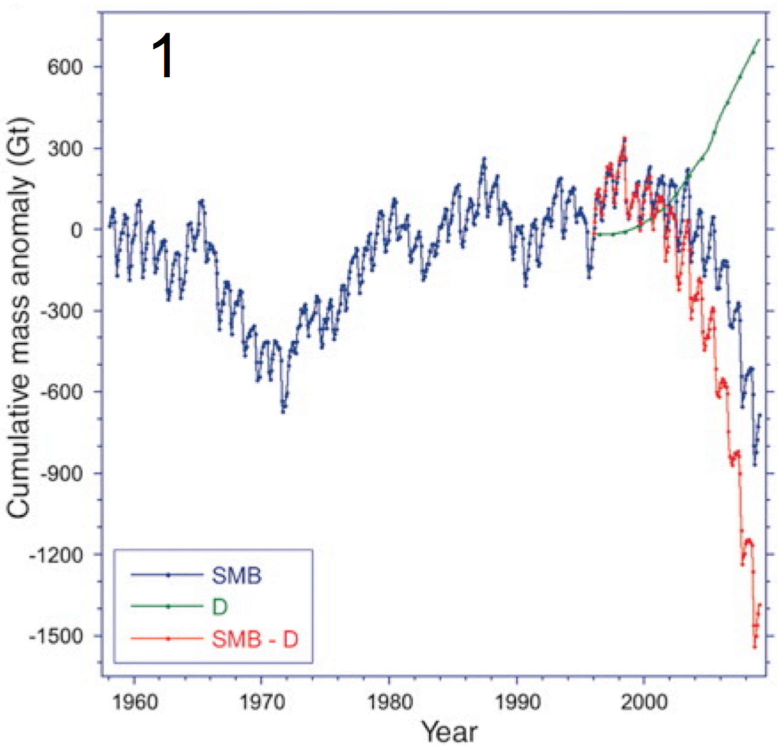
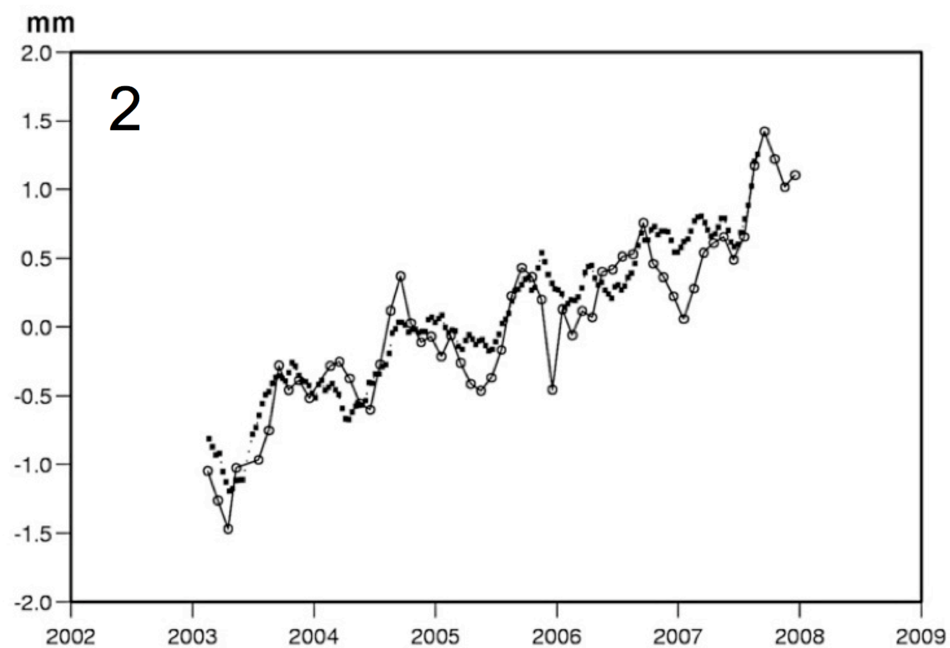


Mean rate of SLR from **2000-2008** is 0.46 mm yr^{-1}, ~1/2 due to dynamics

$\bar{r}_0$ **~0.23 mm yr^{-1}**

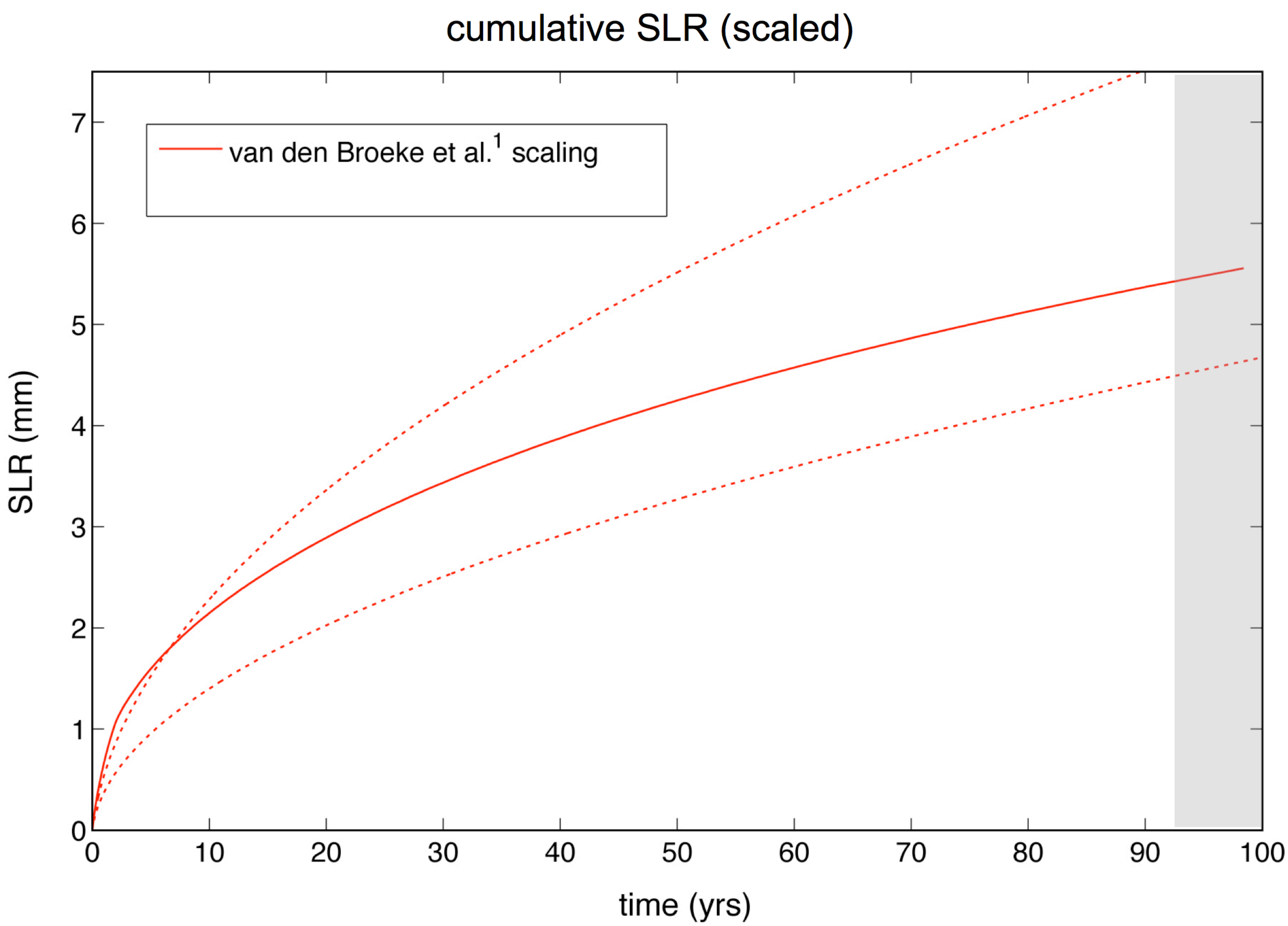


Mean rate of SLR from **2003-2008** is 0.38 mm yr^{-1} (assume 1/2 from dynamics)

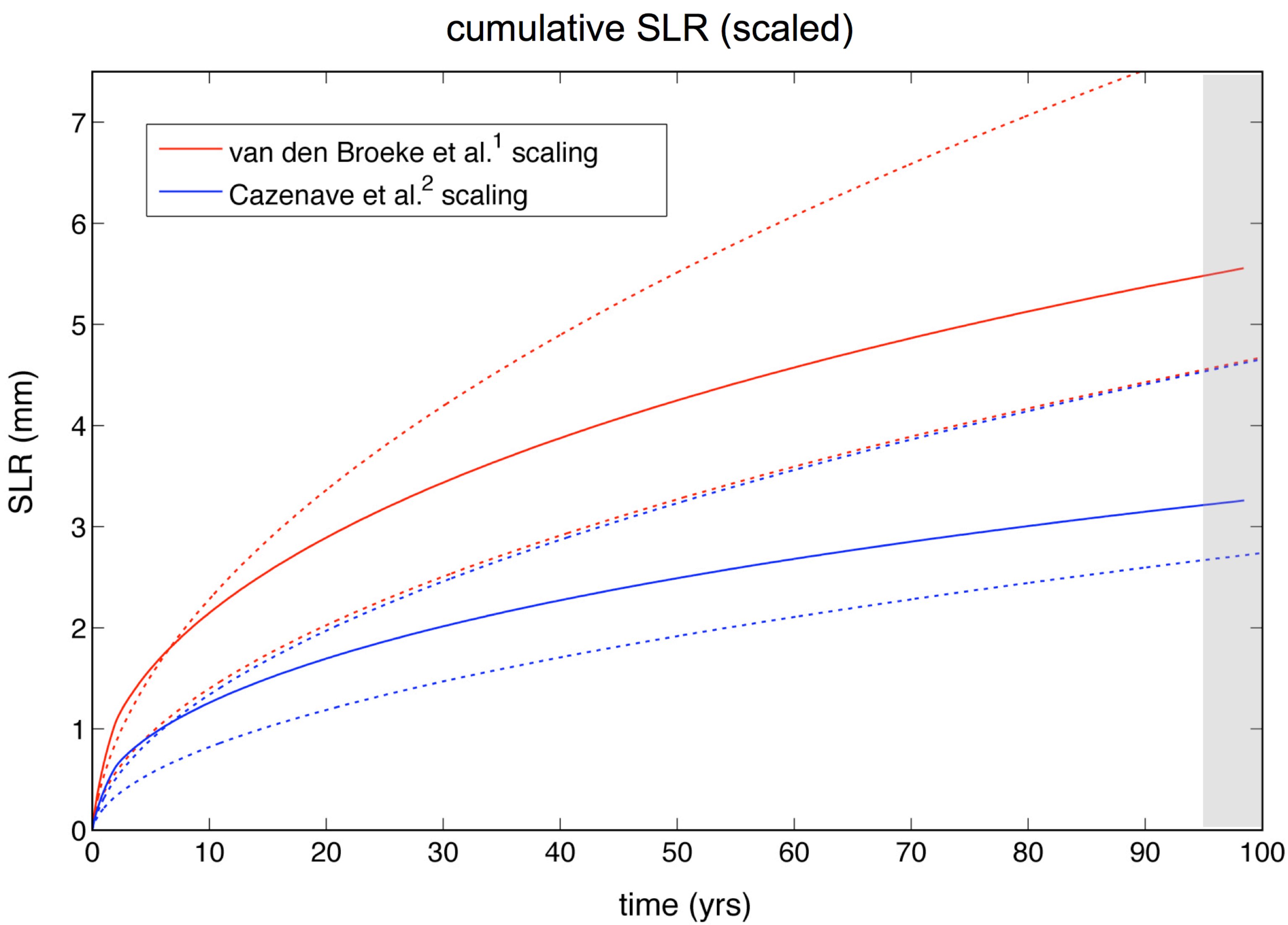
$\bar{r}_0$ **~0.19 mm yr^{-1}**

[1]van den Broeke et al. (*Science*, **326**, 2009);

[2]Cazenave et al. (*Global Planet. Change*, **65**, 2009);



[1]van den Broeke et al. (*Science*, **326**, 2009);



[1]van den Broeke et al. (*Science*, **326**, 2009); [2]Cazenave et al. (*Global Planet. Change*, **65**, 2009);

Conclusions

Conclusions

A straightforward tuning method provides an initial condition for the GIS that agrees (quantifiably) well with a target velocity field.

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Attributing all SLR from the 1st ~3 yrs (e-folding time) to the initial perturbation, 75% of the SLR in 100 yrs is from the diffusive response, yet to come.


END