Toward an ice sheet initial condition for coupled climate simulations

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Goal: pre-industrial initial condition for ice sheets

General concept

Basic steps in model tuning procedure

Iterative tuning of sliding parameters

Caveats

Example: Greenland Ice Sheet

Goal: pre-industrial initial condition for ice sheets

Concept:

(1) from SMB and geometry, compute balance velocities
(= target velocity field)
(2) from model, calculate ss, diagnostic velocities (no sliding)
(3) compare velocities from (1) and (2), estimate sliding parameter, $\beta(x,y)$, to bring model and target fields into agreement
(4) where step (3) requires sliding, set basal $T=T_{pmp}$
(5) run model to new ss using updated estimate of sliding parameters

… iterate on steps (3)-(5) until model-target mismatch is small

Necessary inputs:

ice sheet geometry - from modern day observations
pre-ind surface mass balance (SMB) - from CESM
pre-ind surface temperature (T_s) - from CESM
geothermal flux - current best guess

Tuning Procedure

(1) Calculate steady-state, thermomechanical, diagnostic velocity field[1] …

[1]Using 3d, higher-order flow model

Diagnostic Velocity Field

Momentum Balance BCs:

surface:	free surface	
bed:	u=v=0	
sides:	u=v=0	(we can improve on this)

Energy Balance BCs:

surface:	specified T	(CESM)
bed:	specified dT/dz	(Q_{geo} = ~55 mW)
sides:	upwinding	

Calculation:

- hold geometry, T_{surf}, Q_{geo}, and momentum bcs steady …
- step forward in time …
- allow $B(T)$, $\boldsymbol{u}$, and η_{eff} to evolve to steady state …

Tuning Procedure

(1) Calculate steady-state, thermomechanical, diagnostic velocity field[1]

(2) Calculate $\Delta U = U_{target} - U_{model}$ and use τ_b from (1), sliding law $\tau_b = \beta u_b$, and target velocity field, to calculate $\beta(x,y)$ field …

$$\beta(x,y) = \tau_b / u_b, \text{ where } u_b = U_{target} - U_{def\_model}$$

… run to new steady-state

(3) Return to step (2), continue updating β until ΔU is small

Are there other ways to update the $\beta(x,y)$ field?

[1]Using 3d, higher-order flow mode

NOTE: U is depth-averaged velocity field

Tuning Procedure - updating β field

(3a) Calculate $\Delta U = U_{target} - U_{model}$ and use τ_b from (1), sliding law $\tau_b = \beta u_b$, and target velocity field, to calculate $\beta(x,y)$ field …

$$\beta^* = \tau_b / u_{b,} \text{ where } u_b = U_{target} - U_{def\_model}$$

(3b) Calculate ratio $R = (U_{model} / U_{obs})$ and nudge $\beta(x,y)$ field;

$$\beta^* = R\ \beta_{old}$$

(3c) use flux divergence residual: $r = \nabla \cdot (\bar{\mathbf{u}} H) - \dot{b}$

Regardless of β^* calculation, convergence ($U_{model} / U_{target} \sim 1$) requires under relaxation: $\beta_{new} = \alpha\beta^* + (1-\alpha)\ \beta_{old}$, for $0 \leq \alpha \leq 1$

Caveats

For this initial condition to be useful for prognostic runs, the following assumptions must hold:

(1) tuned, basal traction field is held static
- ok for simulations over the next ~100 yrs? (but perhaps we can improve on this)

(2) tuning to fit the modern-day geometry is more important than tuning to fit viscosity
- to first order, both equally important to dynamics, but the latter is more poorly constrained

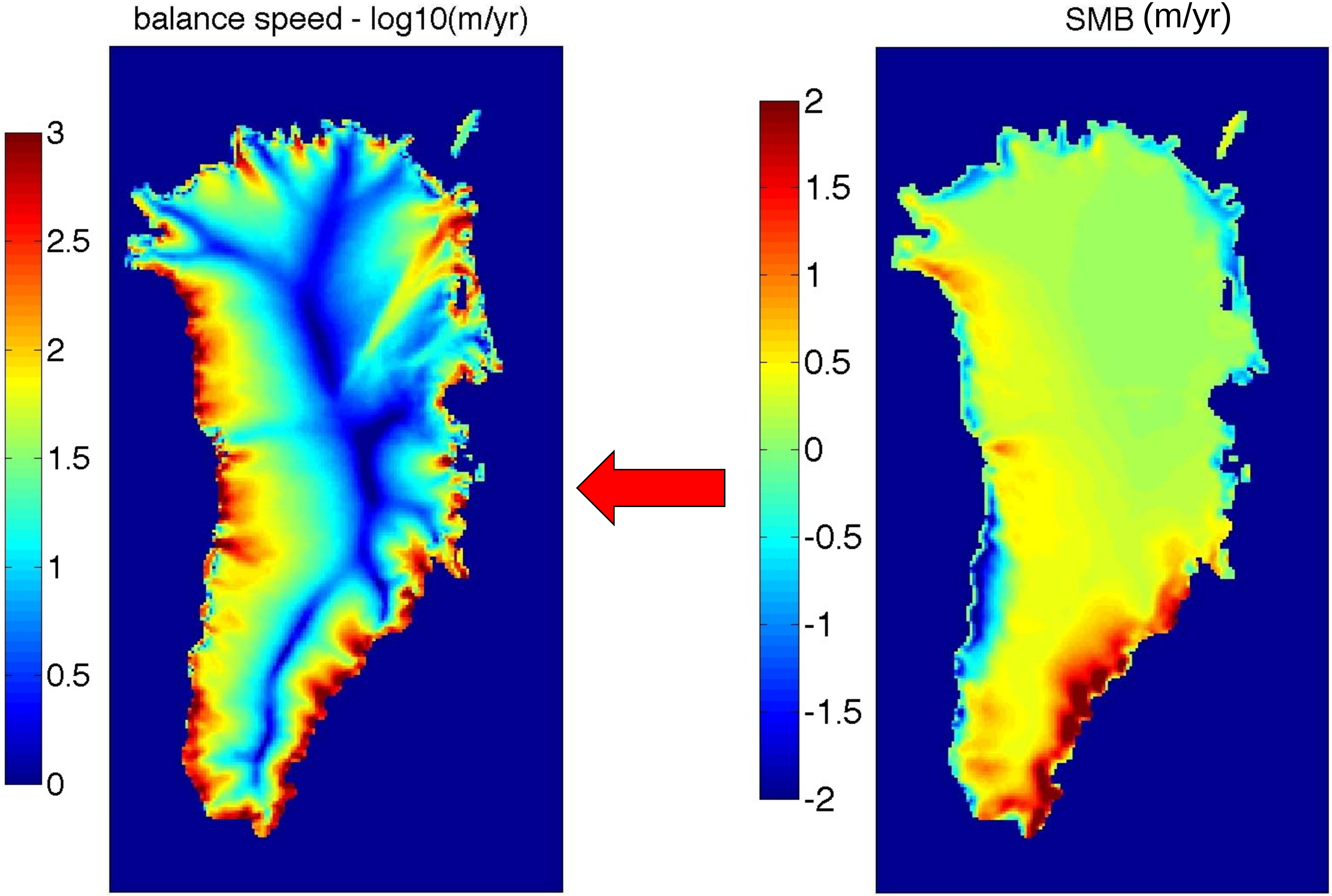
(3) pre-industrial ice sheet is assumed to be in a steady state; pre-ind geometry is assumed to be same as modern

(4) currently considers only atmos. coupling; simplified bcs at margins

Caveats (cont.)

Pros and cons of using balance velocities for target field

… first, what are balance velocities?



balance speed - log10(m/yr)
3
2.5
2
1.5
1
0.5
0
SMB (m/yr)
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2

Caveats (cont.)

Pros and cons of using balance velocities for target field:

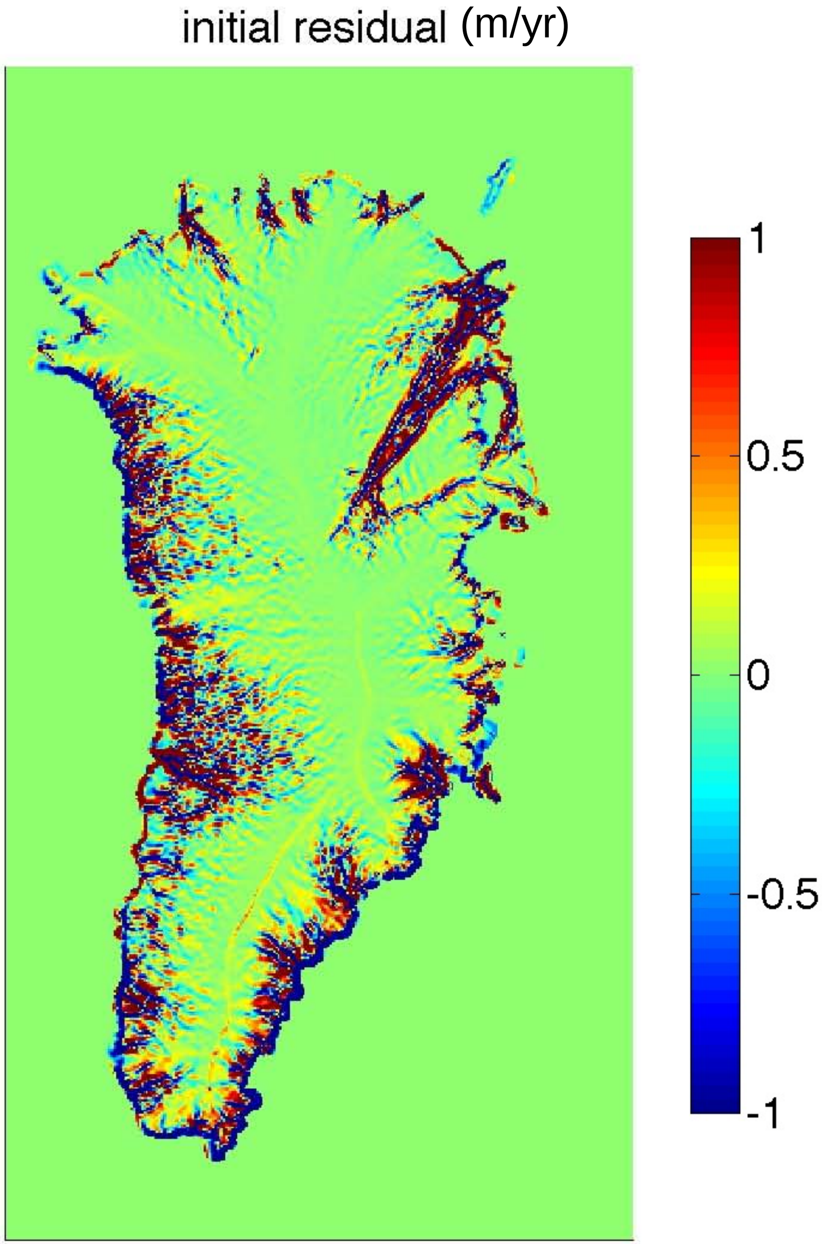
- Balance velocities *are* in equilibrium with current, known geometry and SMB.

- Observed velocities (InSAR) *are not* in equilibrium with known or actual geometry, or SMB

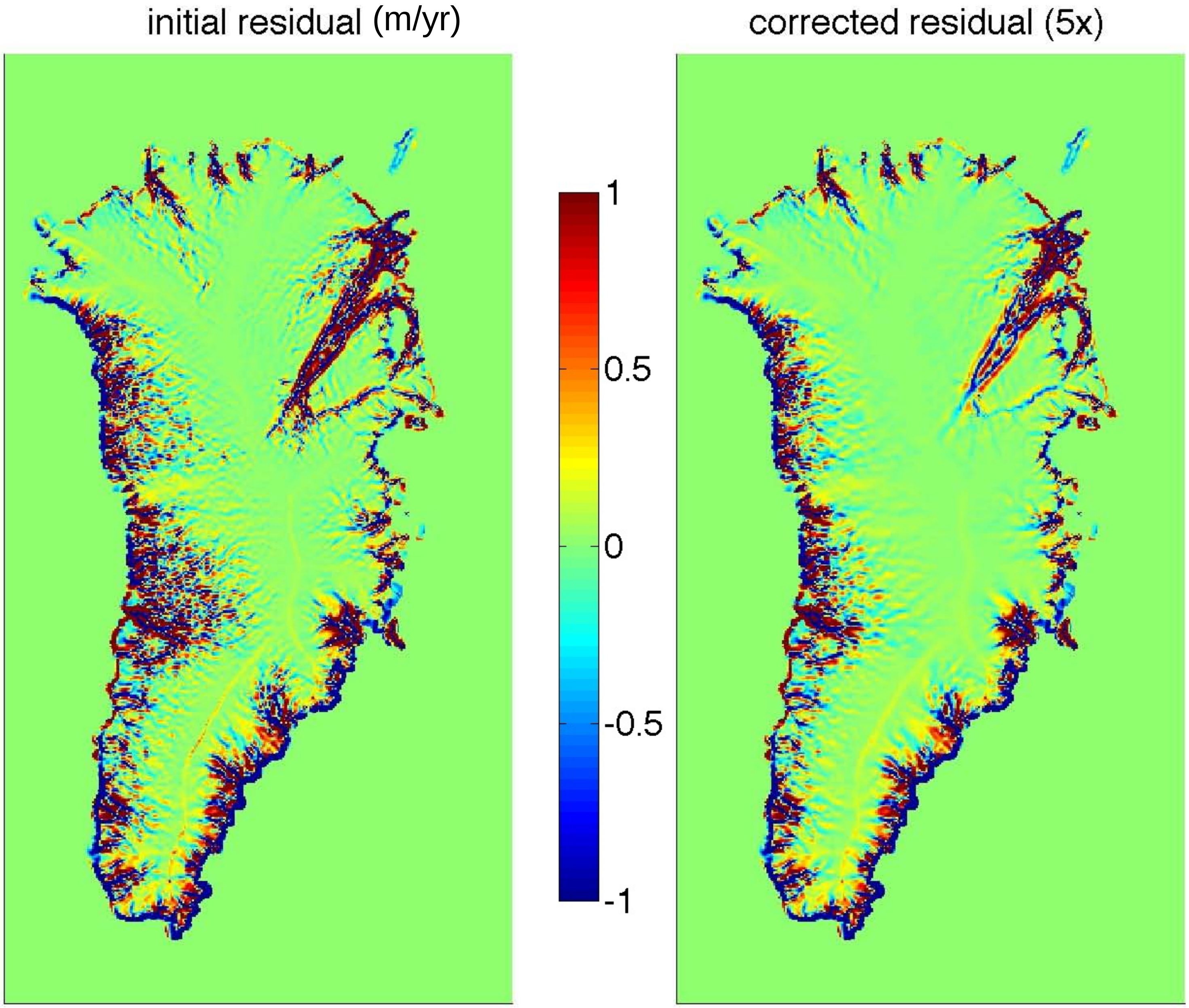
- InSAR vels are at a much higher resolution than our current geometry data, and so resolve features our model cannot.

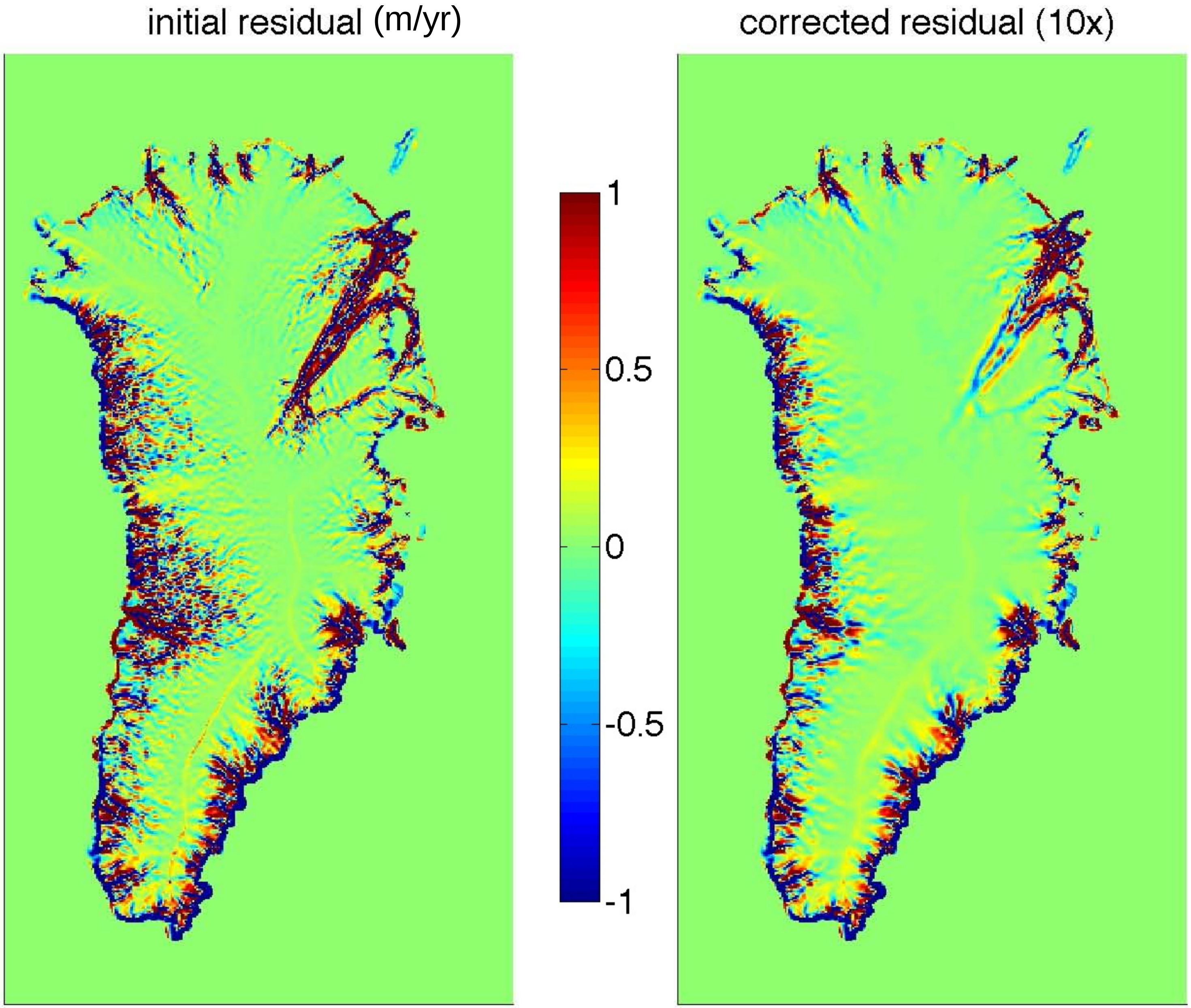
- Arguably, better to tune sliding to (more conservative) ss velocities than to (more erratic) transient observed velocities (e.g. accelerated fields from Jak., Kang., and Hel. glaciers).

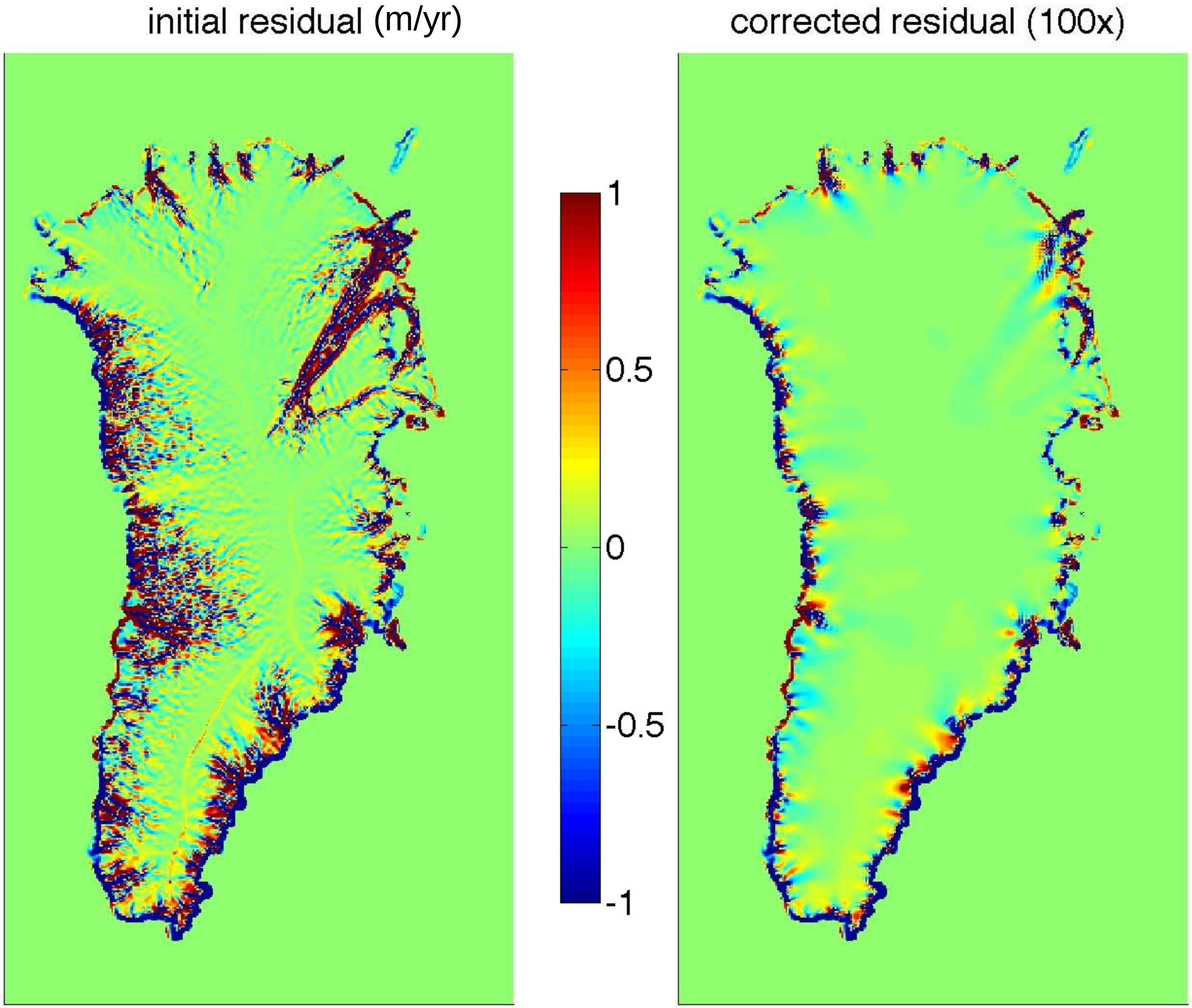
- In general, balance velocity algorithms do not give velocity field that obeys flux divergence



$$r = \nabla \cdot \left(\bar{\mathbf{u}} H \right) - \dot{b}$$


initial residual (m/yr)
corrected residual (5x)
1
0.5
0
-0.5
-1


initial residual (m/yr)
corrected residual (10x)
1
0.5
0
-0.5
-1



initial residual (m/yr)
corrected residual (100x)
1
0.5
0
-0.5
-1

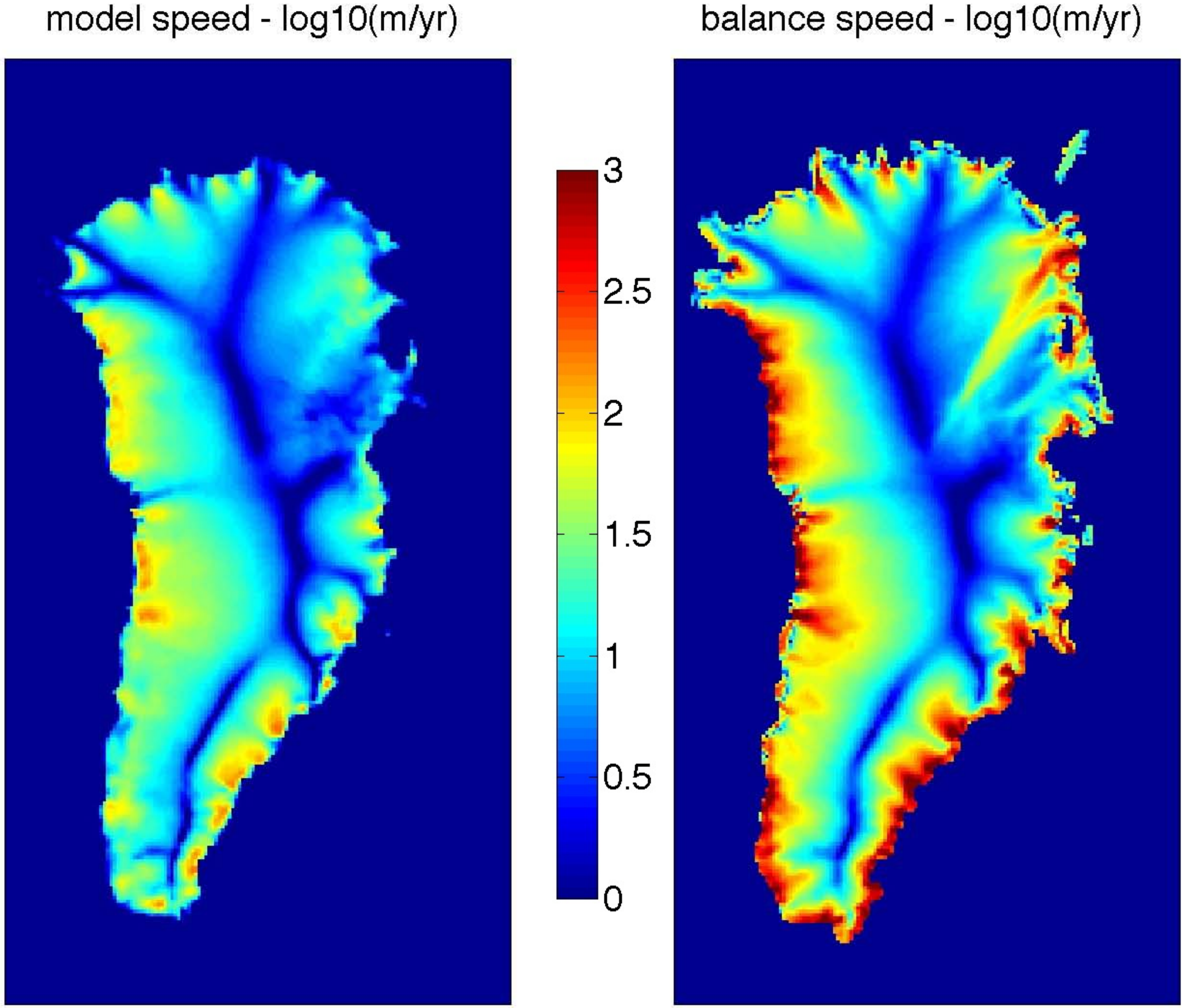
Example: Greenland Ice Sheet

target vs. model velocity fields (contour plots)

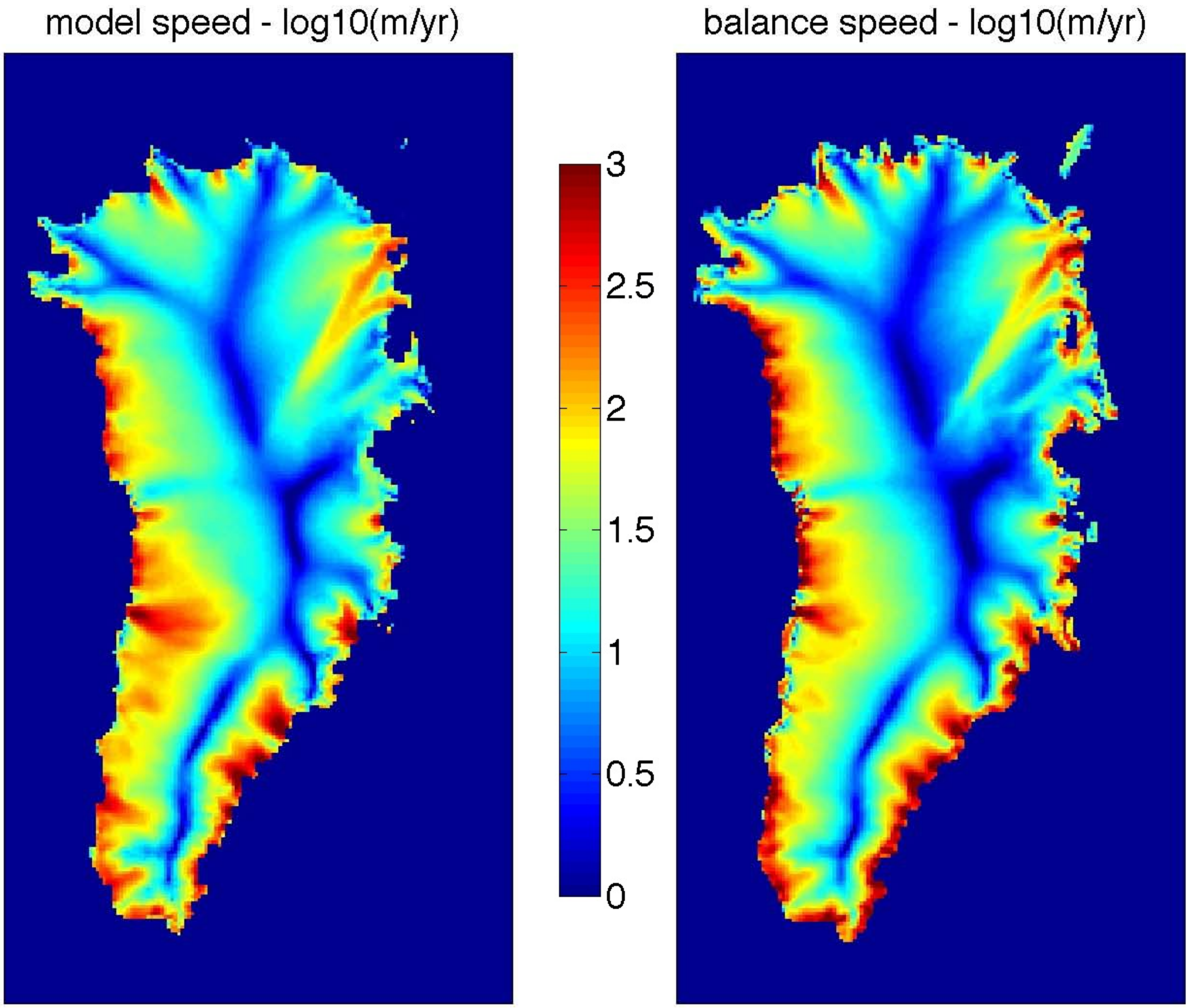
target vs. model velocity fields (1:1 plots)

target vs. model flux divergence

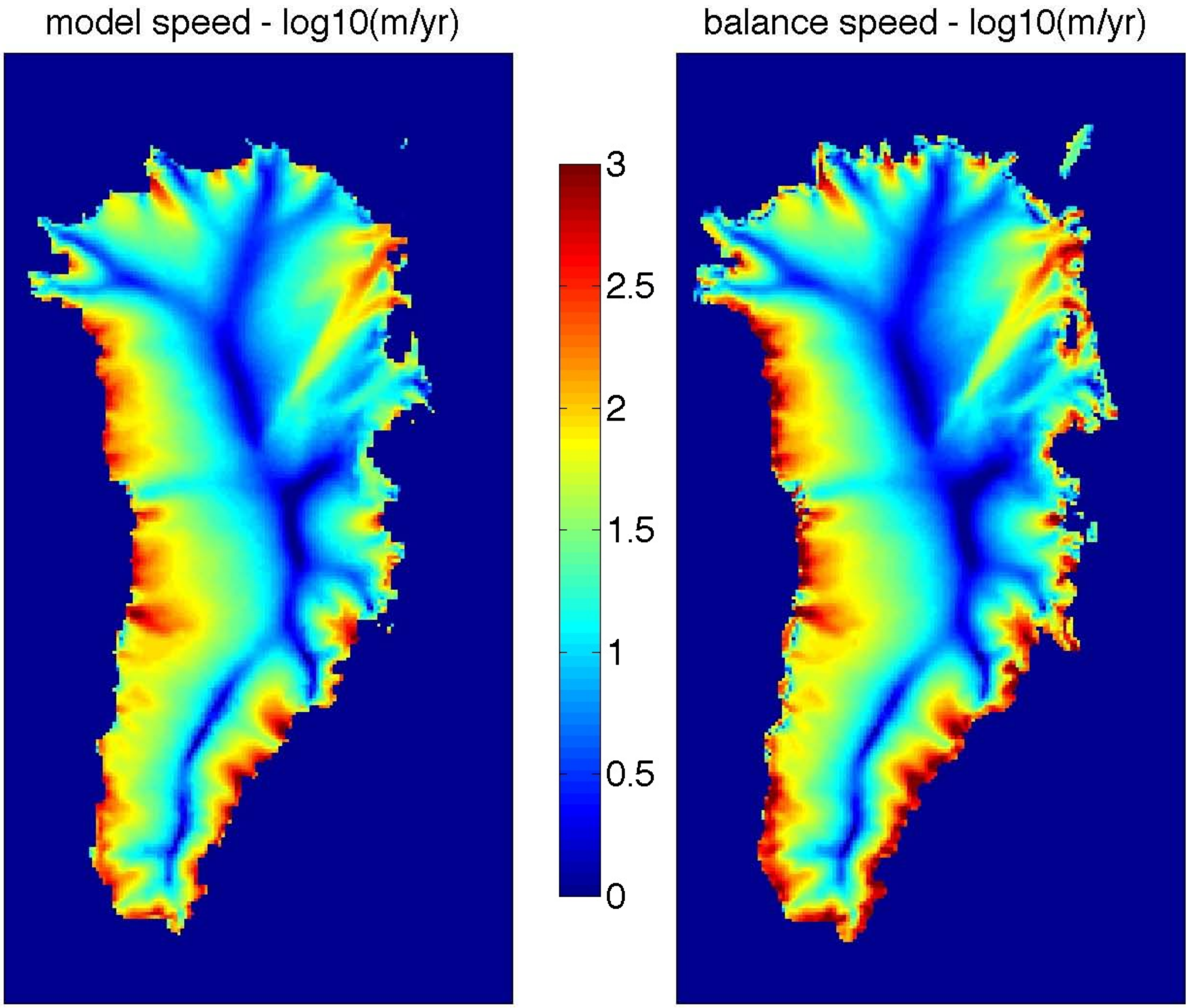
NOTE: relatively coarse (10km) resolution shown here



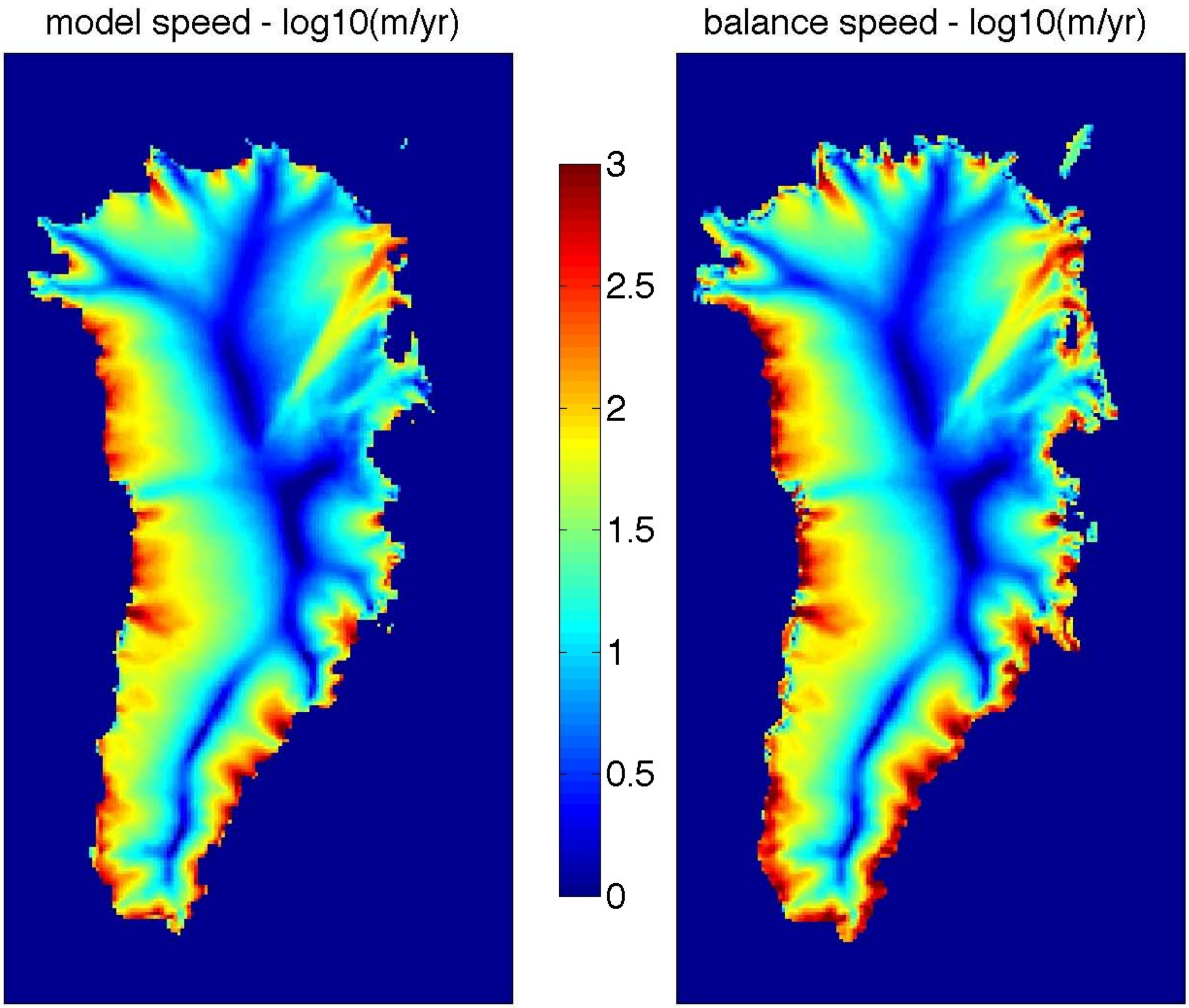
Iteration on β: 0x



Iteration on β: 1x

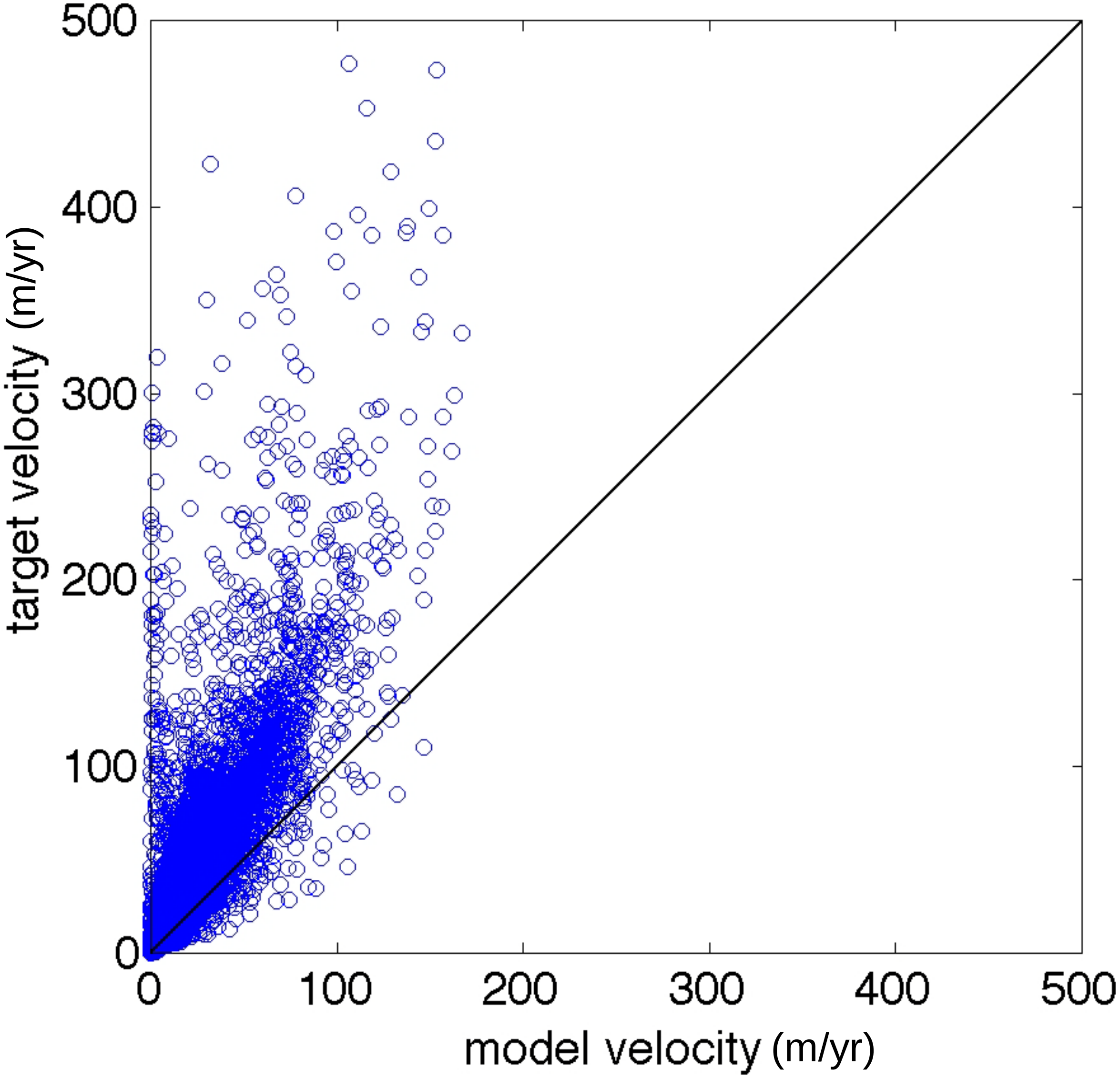


Iteration on β: 4x

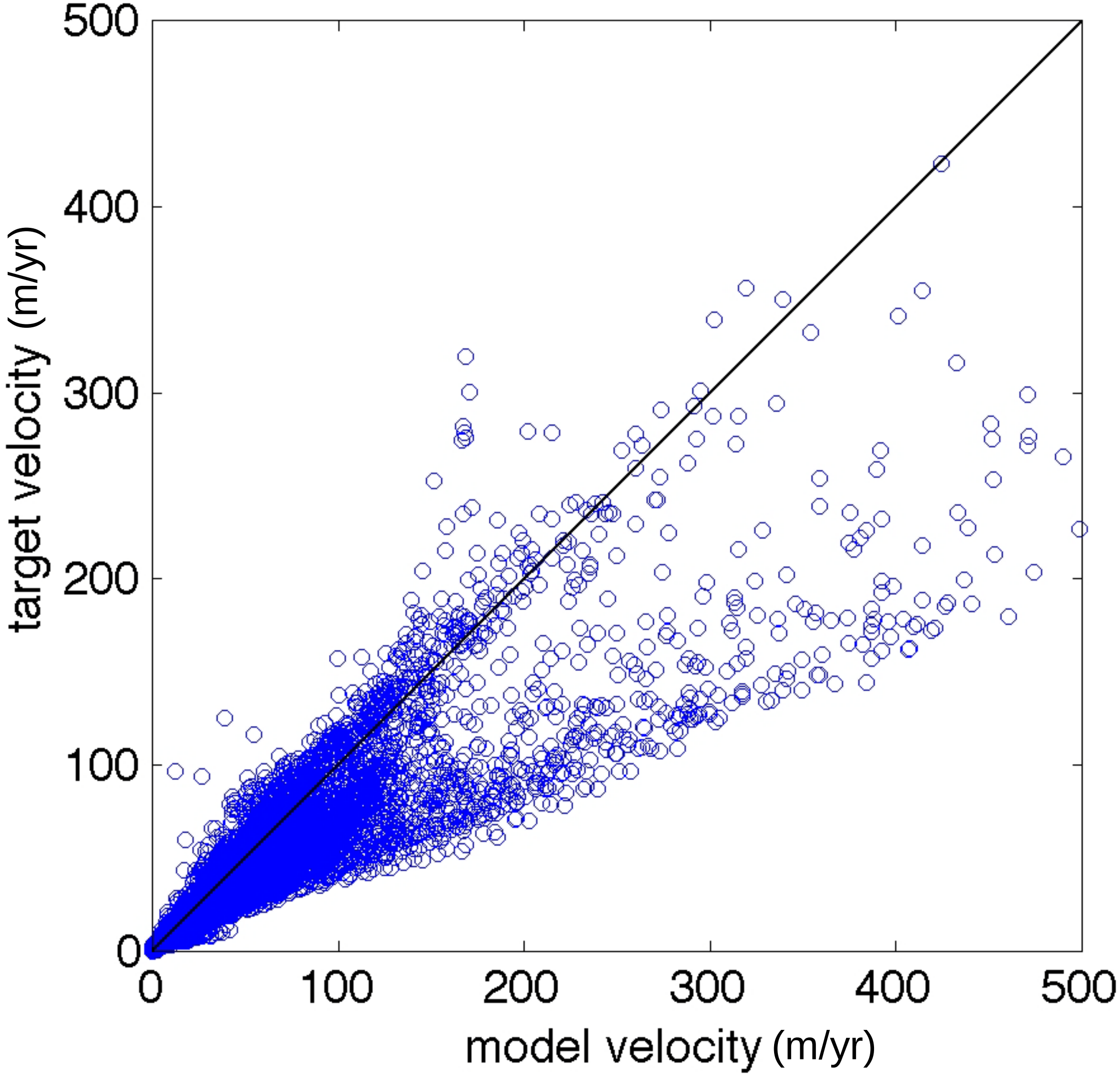


Iteration on β: 15x

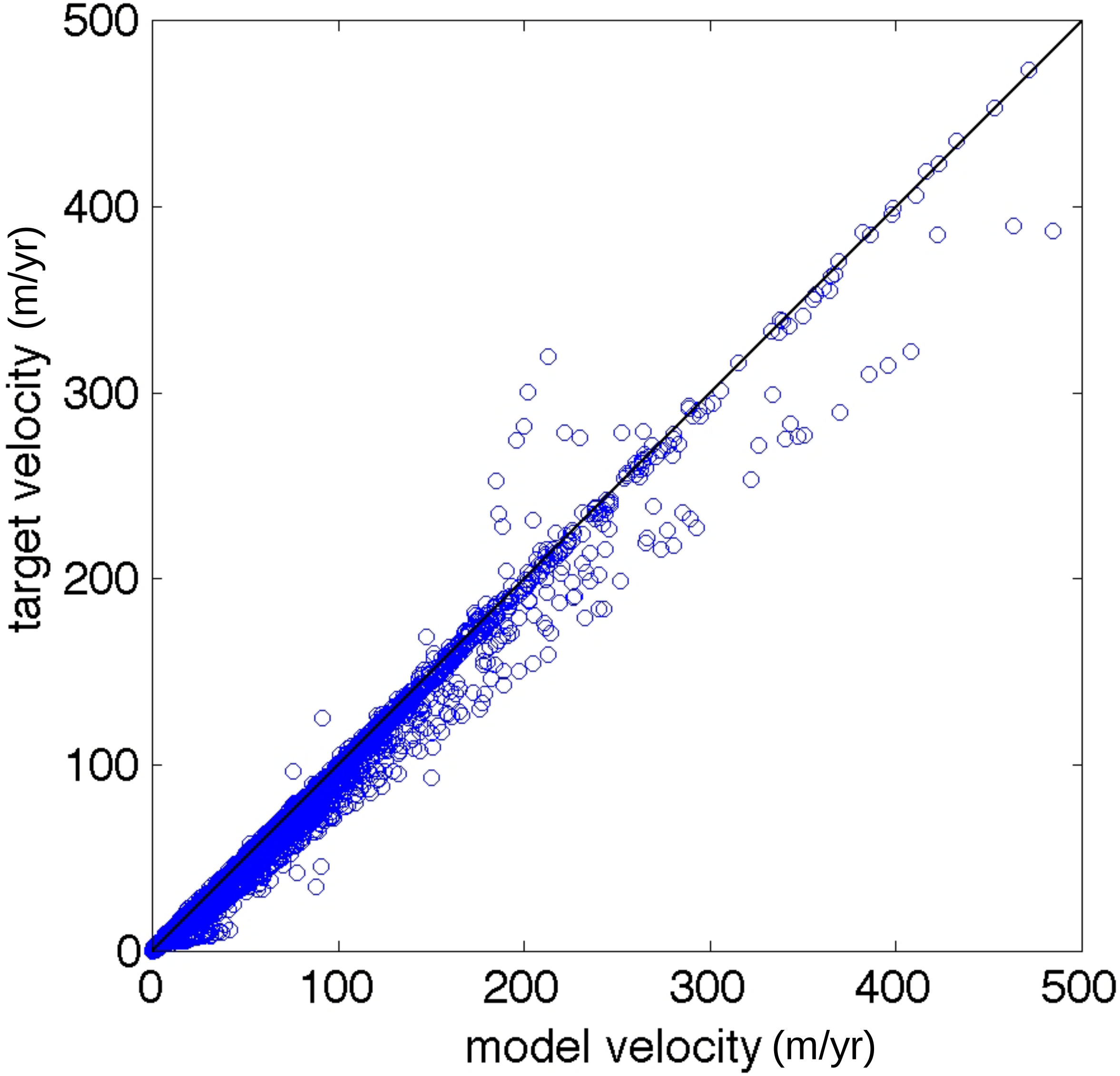
Iteration on β: 0x



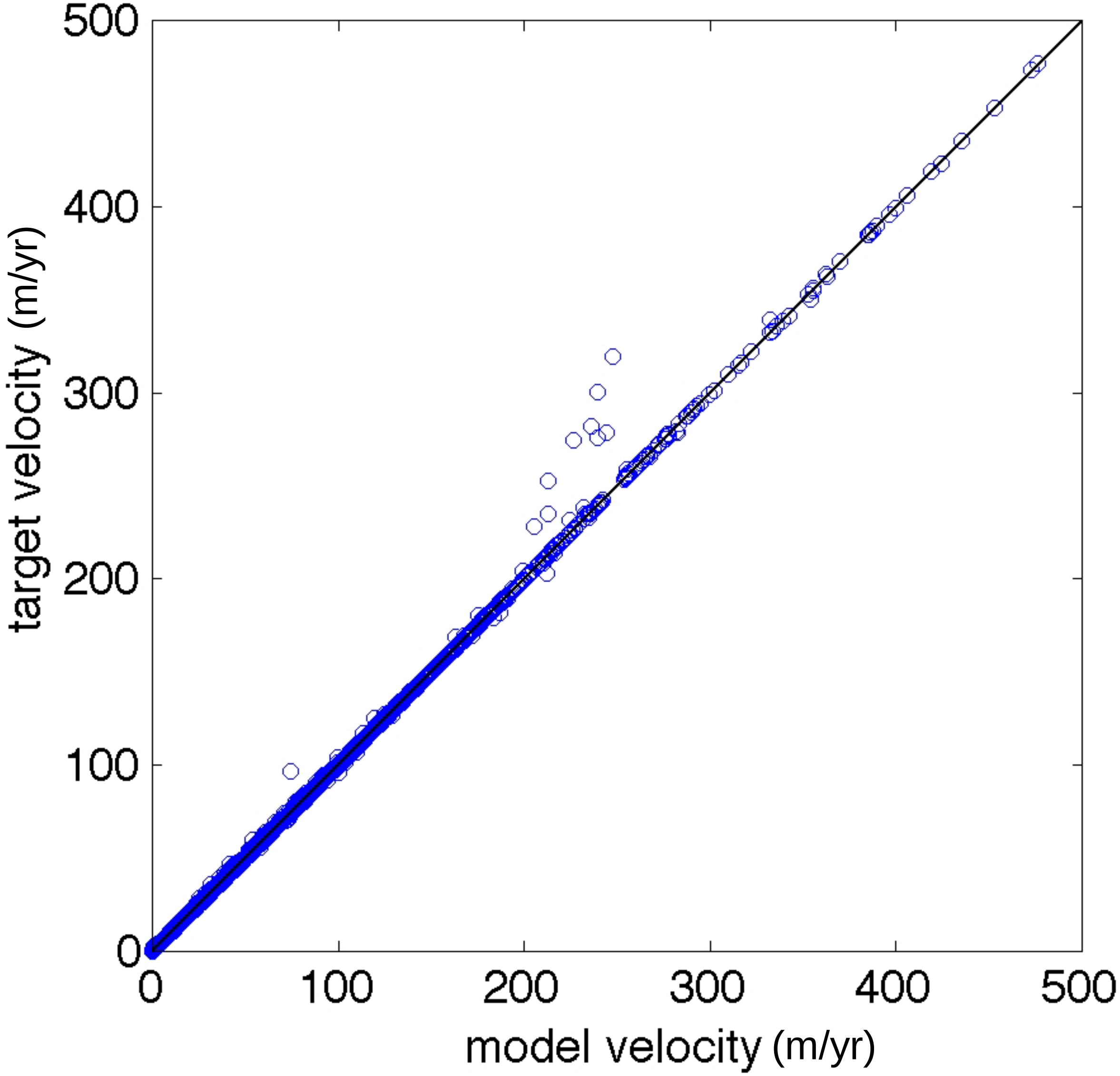
Iteration on β: 1x

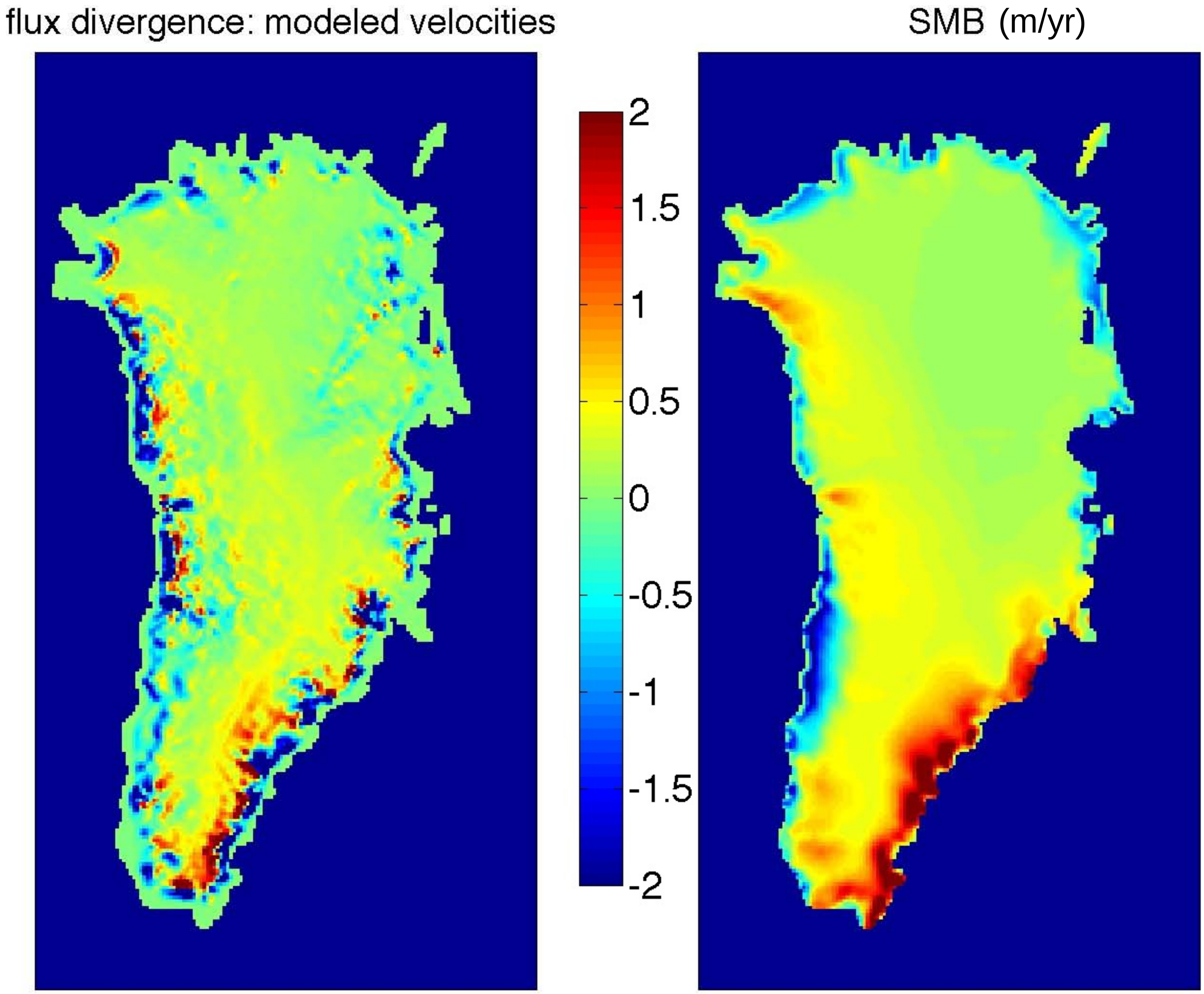


Iteration on β: 4x

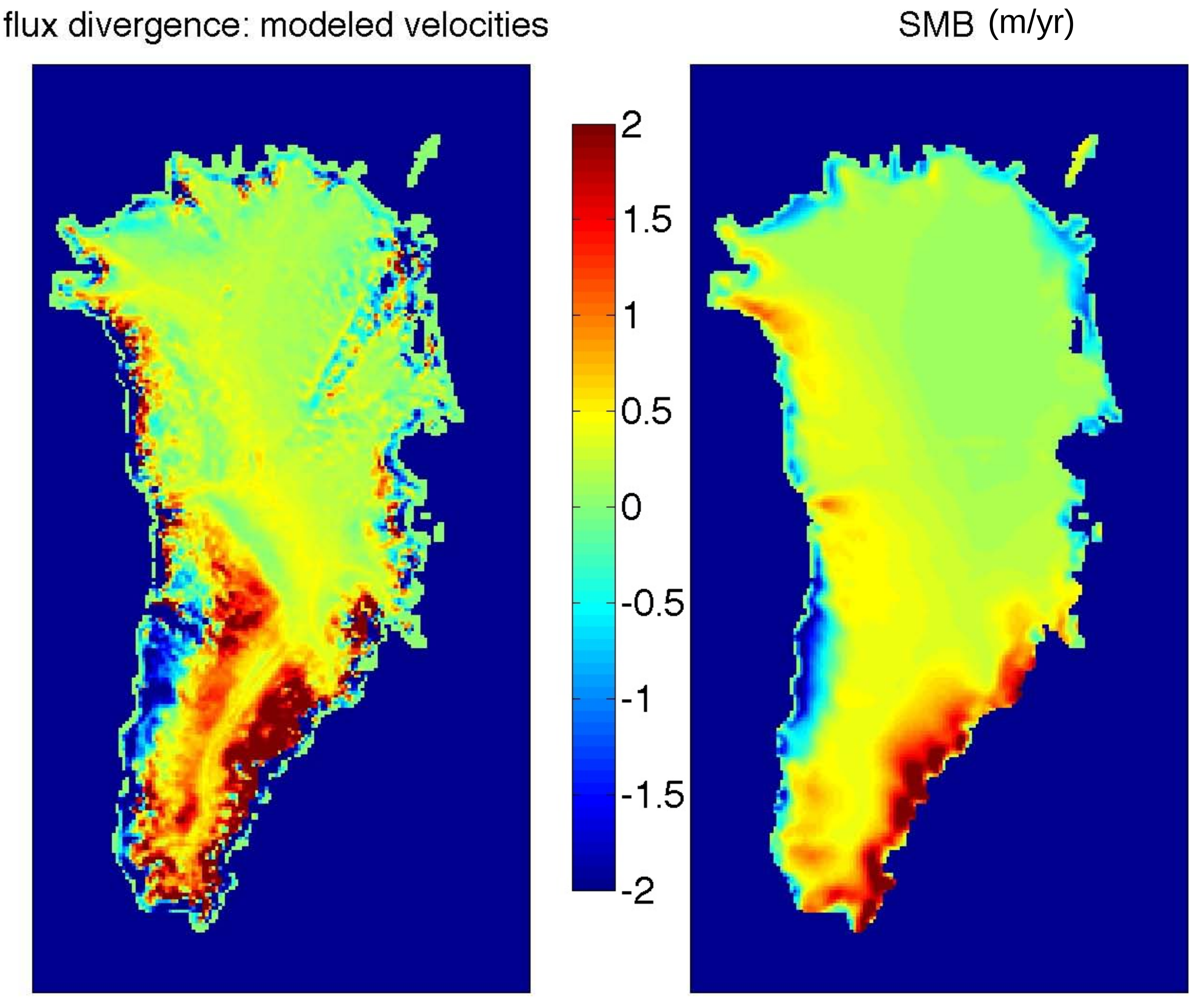


Iteration on β: 15x

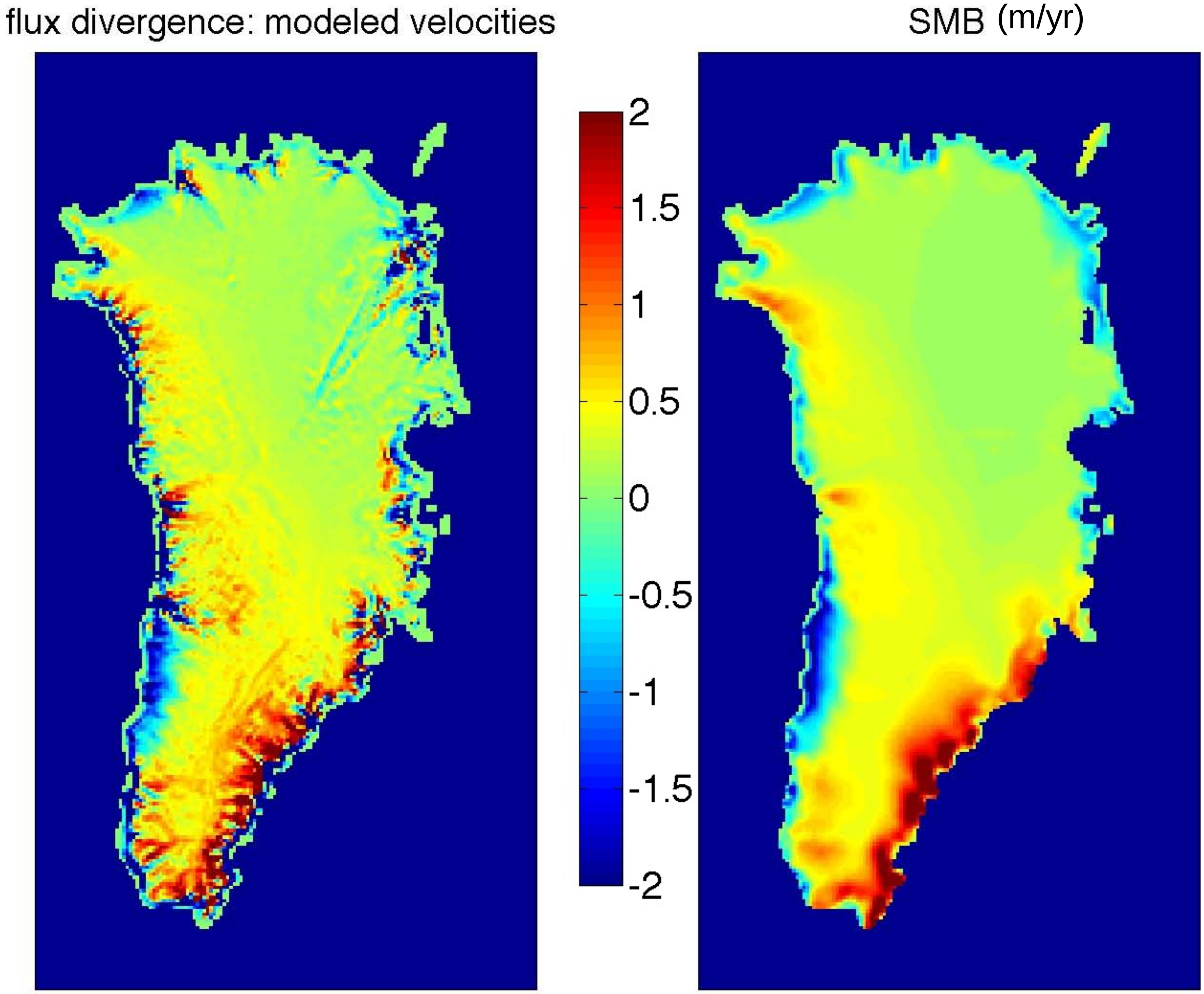




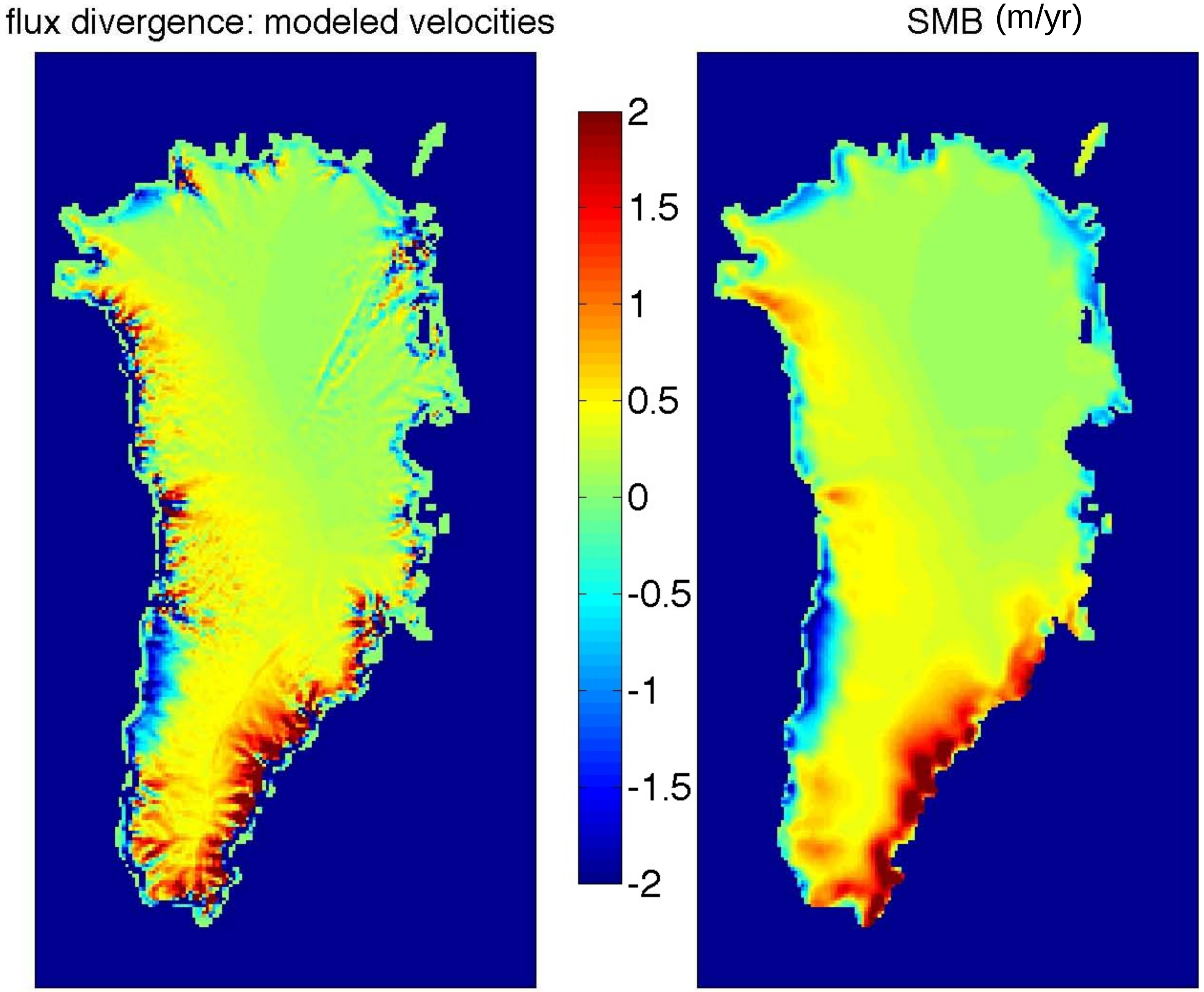
Iteration on β: 0x



Iteration on β: 1x



Iteration on β: 4x



Iteration on β: 15x

Discussion

Balance velocity algorithms don't know anything about continuity.

Balance velocity calculation provides speed, which needs to be decomposed into vector components. Those components may not obey flux divergence.

If we tune β to match speed, we may not get flux divergence right. If we tune β to match flux divergence, we may not get physically reasonable vel field.

Next steps to try:

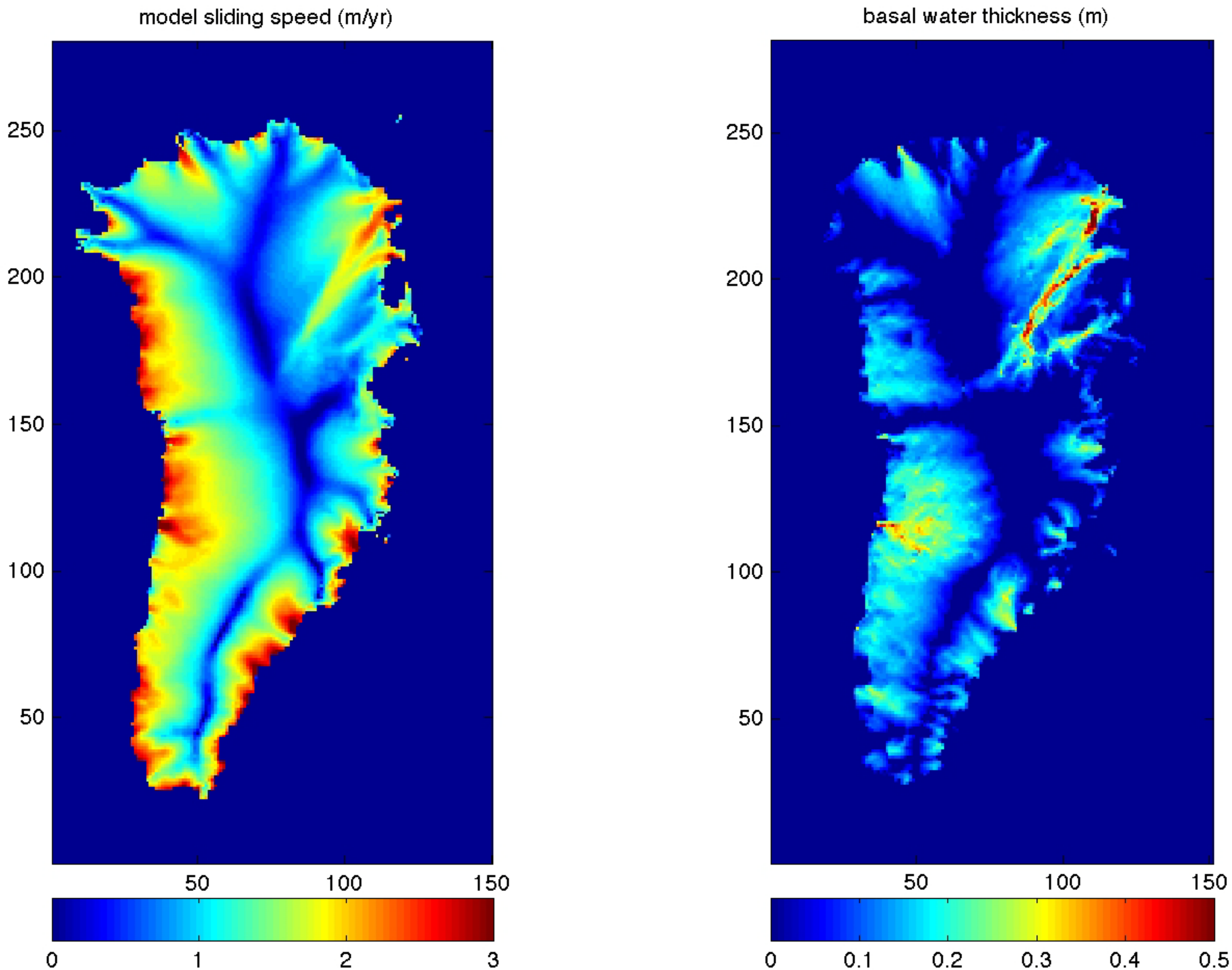
- tune model to *u*,*v* components of bal vels using two parameter sliding law, e.g. $\tau_b = \beta\, u_b^{\lambda}$

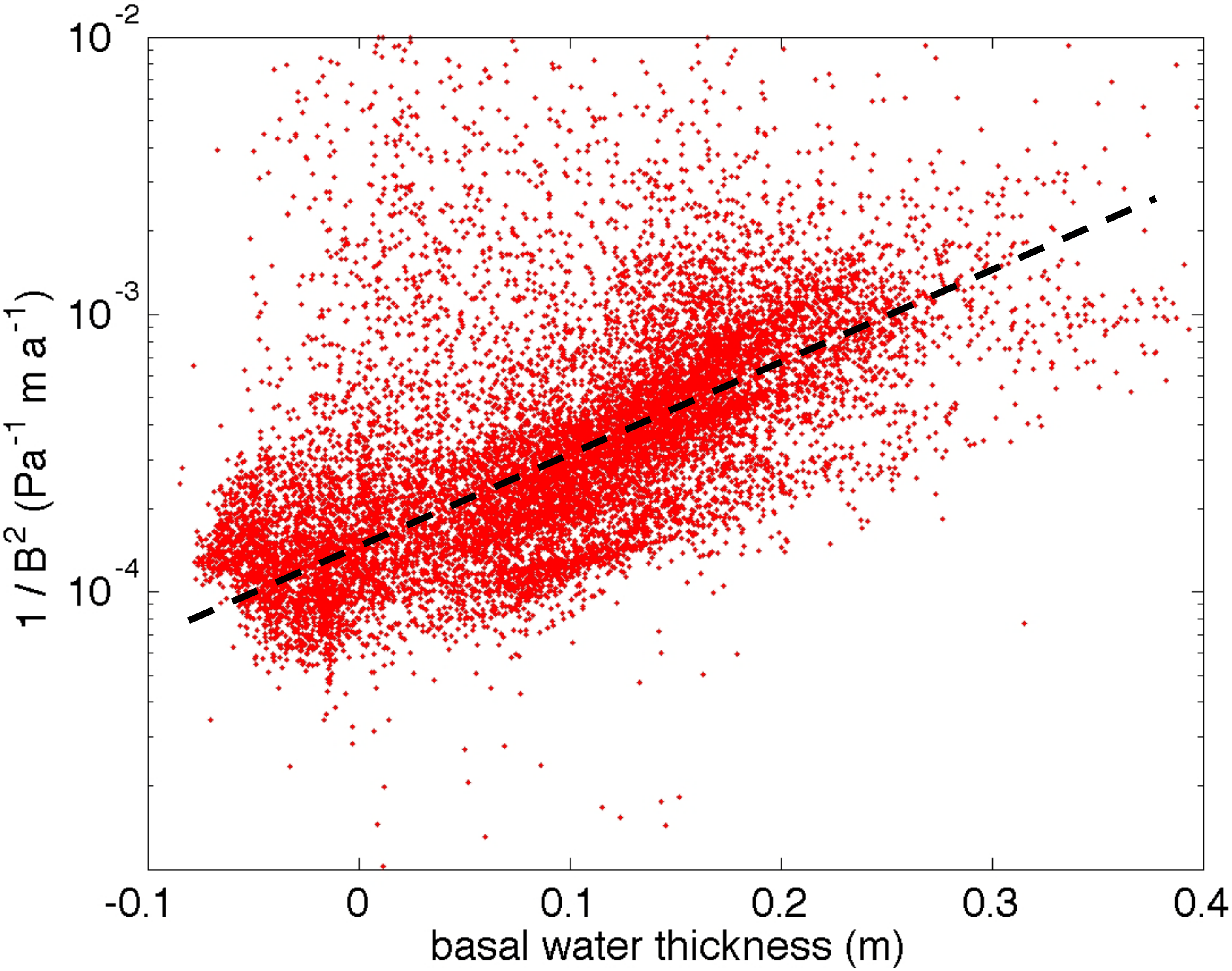
- more formal methods of solving for β field that matches bal vel and expected divergence

Is there a reasonable and simple way to evolve the tuned β field in time?

Is there a relationship between basal traction and basal water?

If so, can we use it to evolve β in time?


model sliding speed (m/yr)
basal water thickness (m)
250
200
150
100
50
50
100
150
0
1
2
3
250
200
150
100
50
50
100
150
0
0.1
0.2
0.3
0.4
0.5



10^{-2}
10^{-3}
10^{-4}
$1 / B^2$ (Pa^{-1} m a^{-1})
-0.1
0
0.1
0.2
0.3
0.4
basal water thickness (m)