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Melt rates and their sensitivities underneath Pine Island Ice Shelf, Antarctica, derived from fitting a regional circulation model observations

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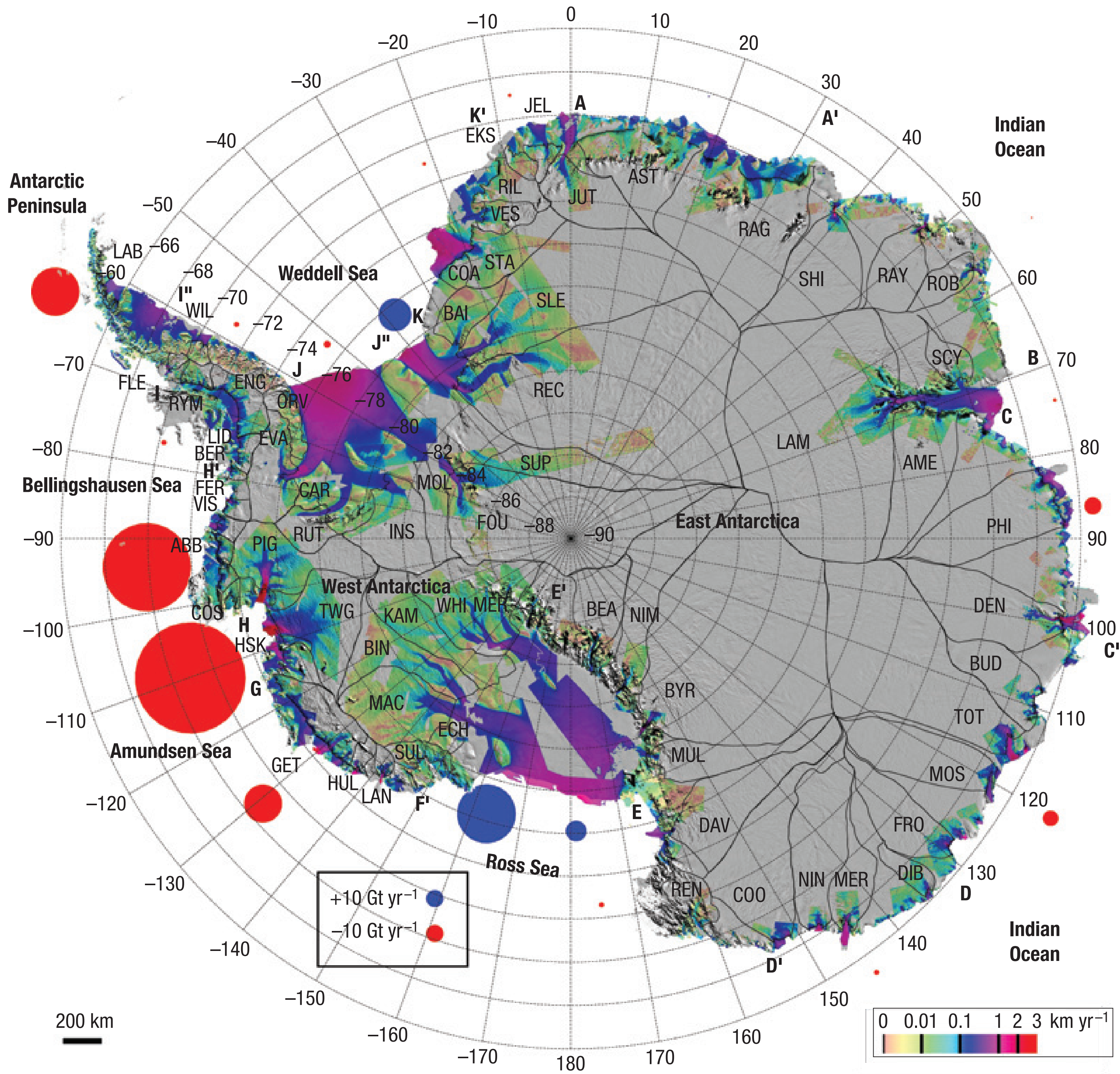
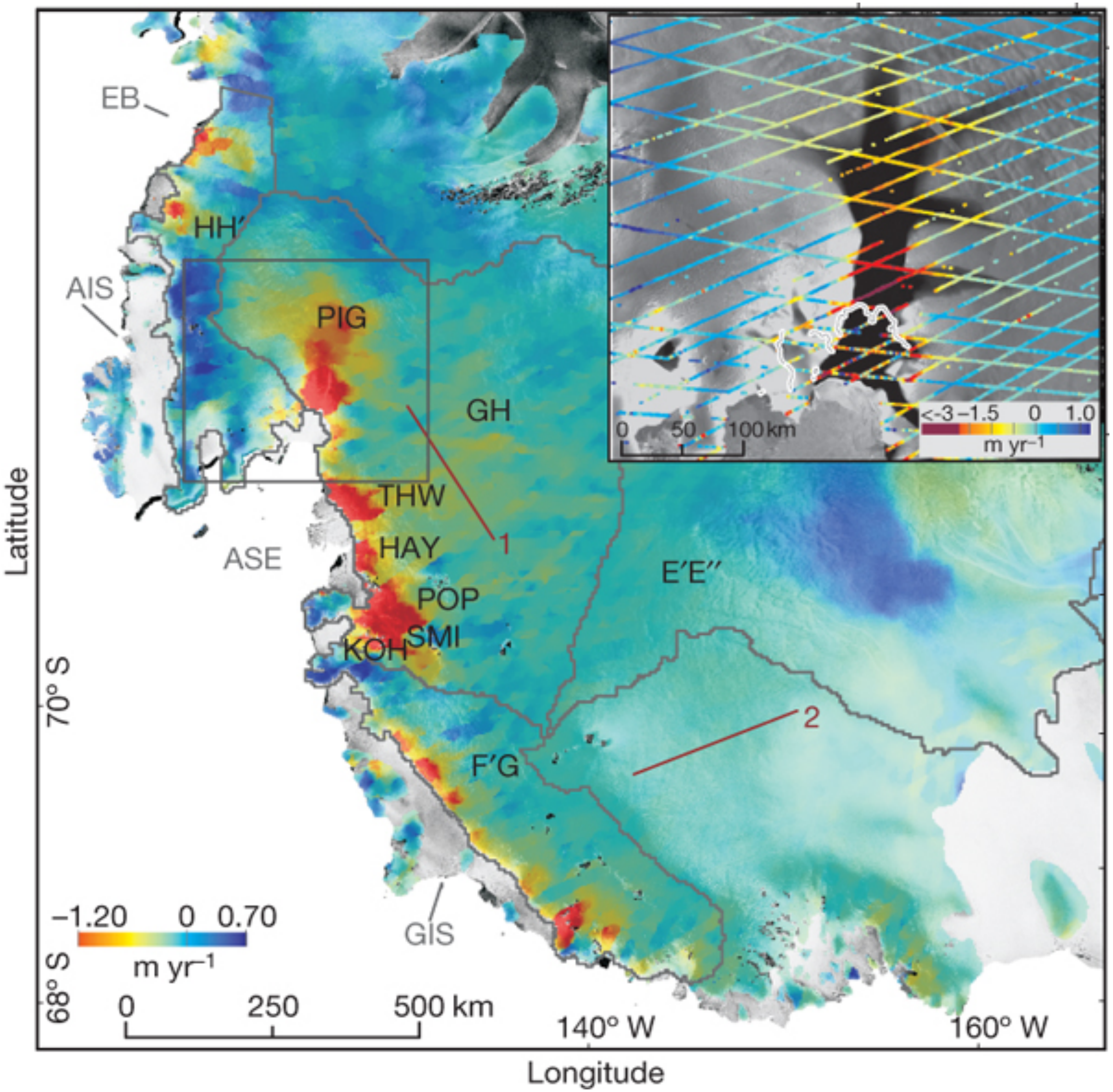
Why is this interesting?



- Flow speed estimates from radar interferometry (ERS-1/2)
- Mass loss estimates from satellite gravity (GRACE)

Rignot et al., Nature Geo., 2008

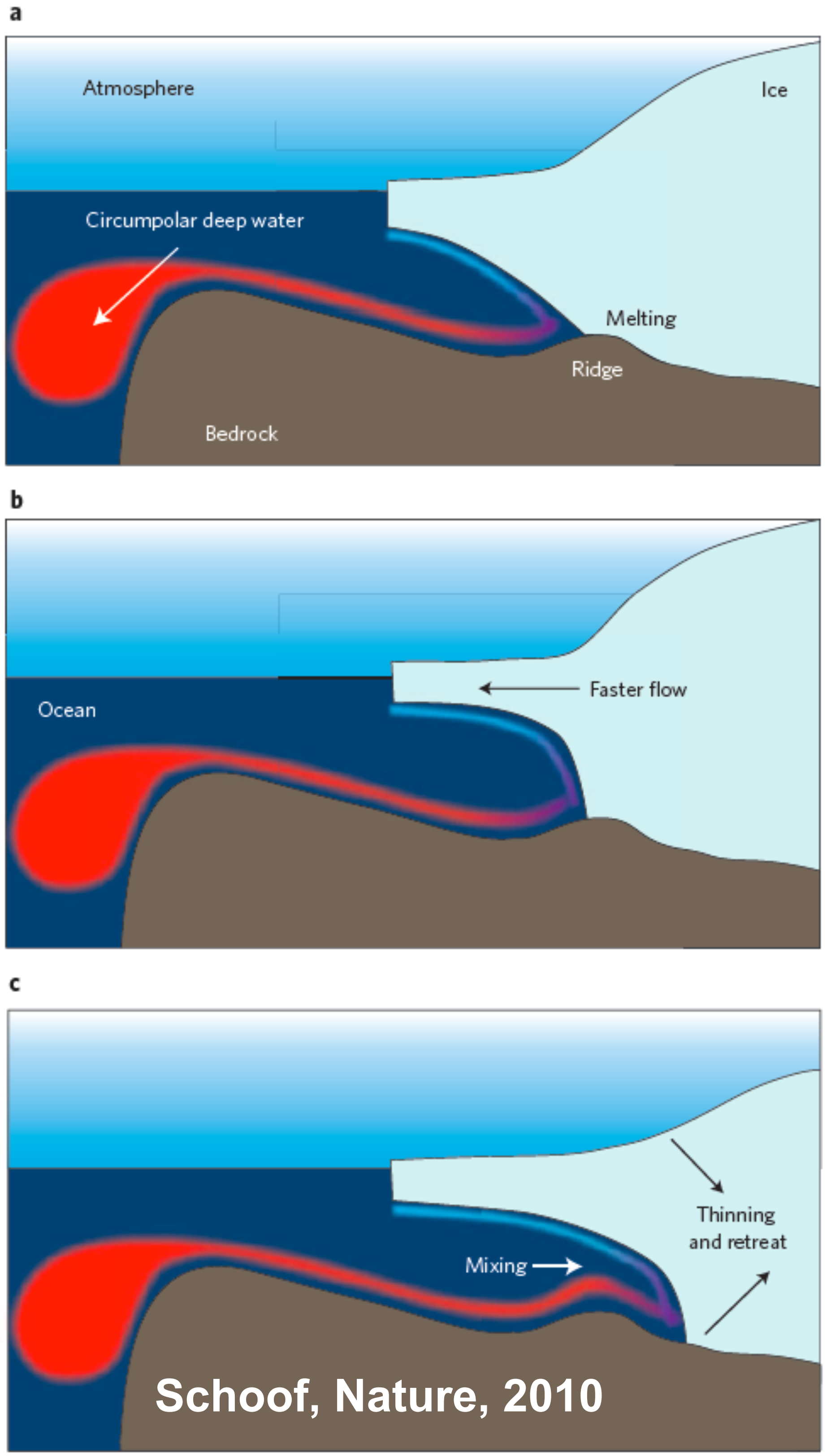
Pine Island Glacier: rapid dynamic thinning



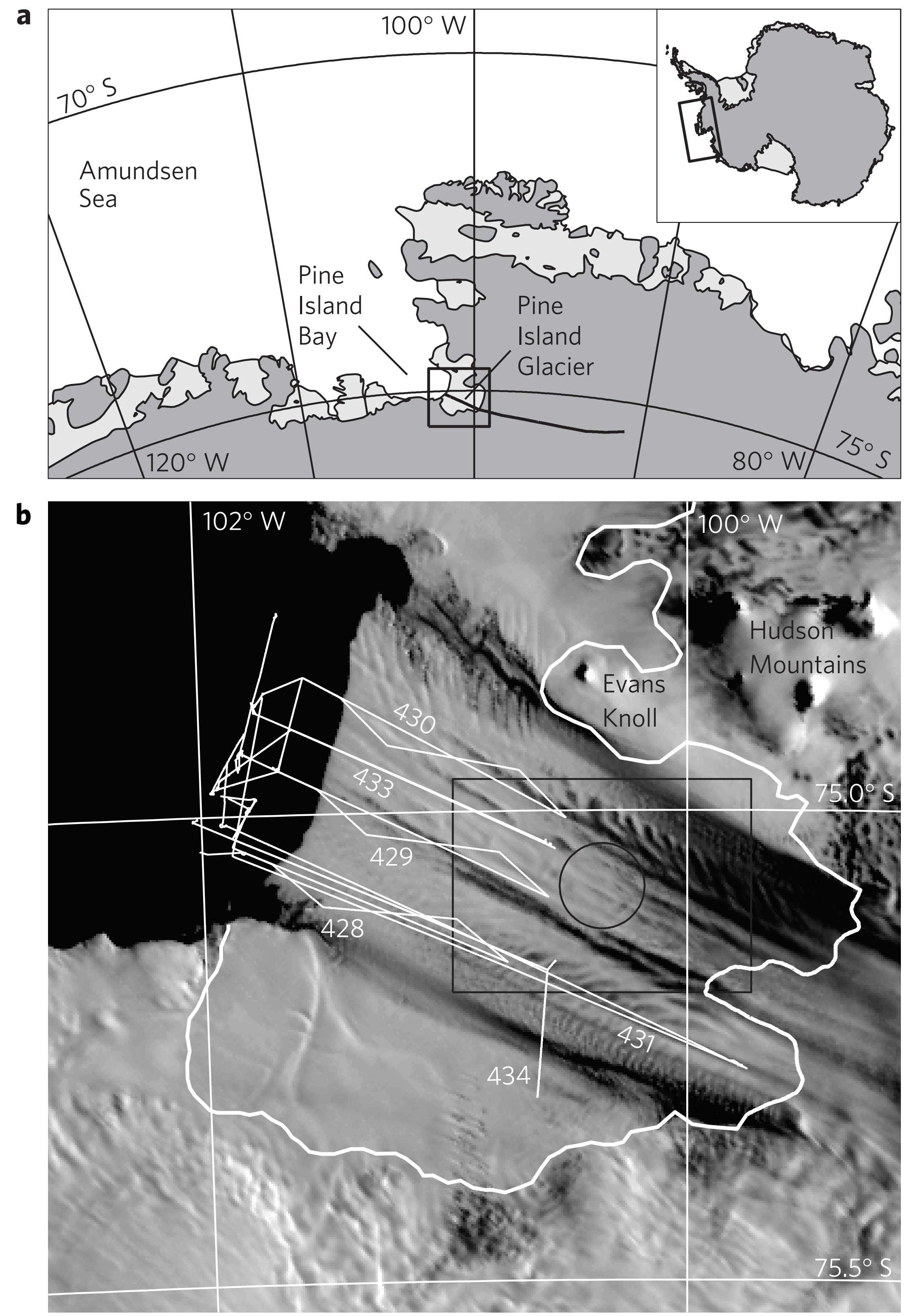
Pritchard et al., Nature (2009)

Thinning rates inferred from laser altimetry (ICESat-1)

Why is this interesting?



Schoof, Nature, 2010



Jenkins et al. 2010

Melt rates: What do the others say?

Jacobs et al. (1996), 3 in-situ CTD casts in 1994, water mass analysis	10-12 m/a 28 Gt/a	
Hellmer et al. (1998), numerical model	6−12.5 m/a	
Rignot et al. (2008), radar interferometry, regional climate model	Grounding line flux of 237±4 Gt/a (PIG and Thwaites) 37±4 m/a (not clear where this comes from)	
Jacobs et al. (2011), in-situ CTD observations, water mass analysis and inverse model	2009: 80 to 85±6 km^3/a (ice) (33 m/a) 1994: 53 to 53±7 km^3/a (ice) (22 m/a)	
Bindschadler et al. (2011), observations from satellite and airborne platforms combined with model calculations	19.1 m/a (44.5 km^3/a of ice) 50.4 m/a (42.5 km^3/a of ice) near grounding line	
Schodlok et al. (2012), MITgcm/ECCO2	28.28 m/a water 117.89 Gt/a ice (IceBridge topography)	20.32 m/a water 84.39 Gt/a ice (BEDMAP topogr.)

- Problem: Melt rates are difficult to observe/measure directly
- Solution: use inverse methods to infer melt rates from available marine observations and dynamical constraints (here an OGCM)

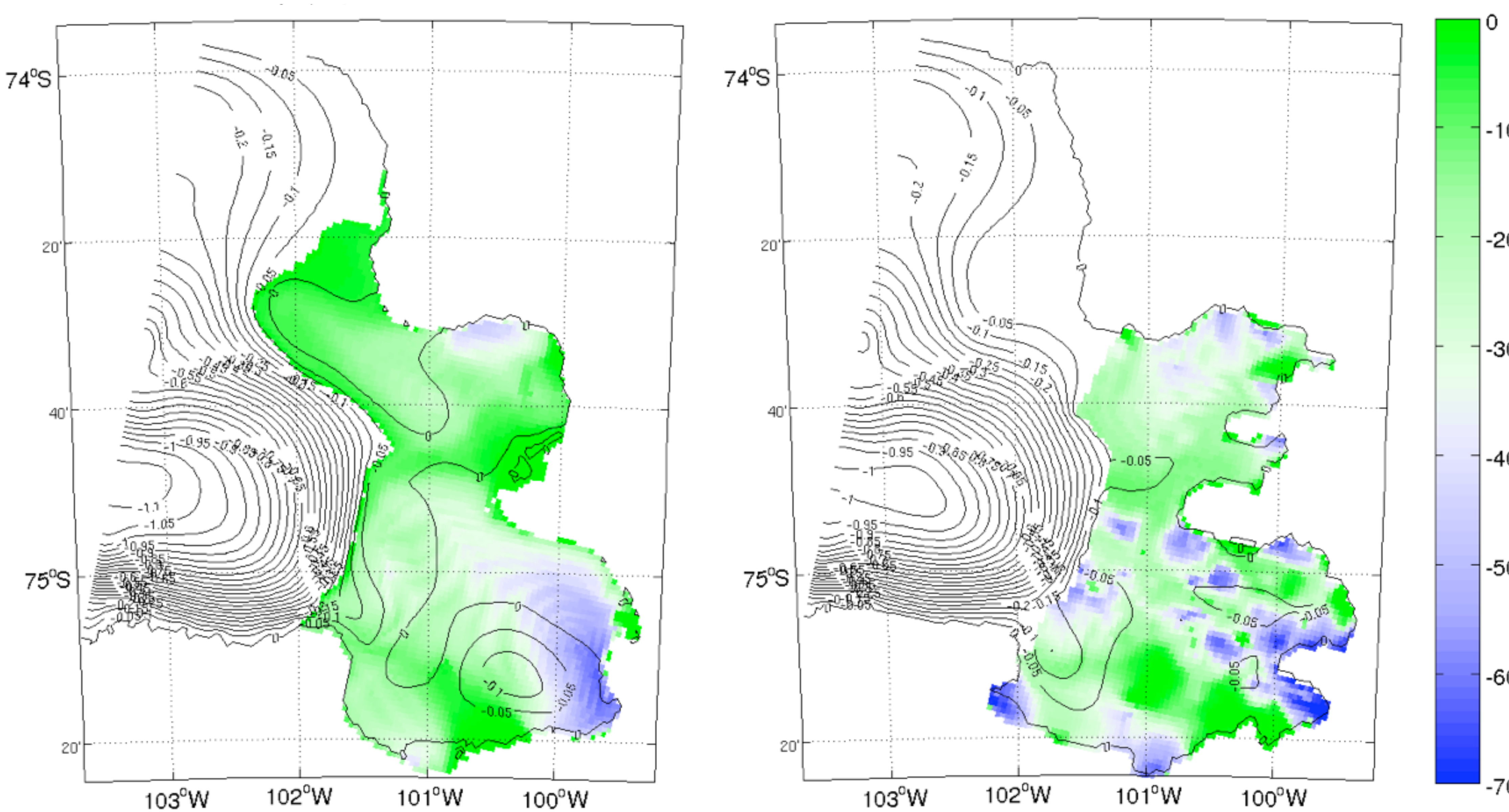
Approach

- Given an OGCM with …
  1. (parameterized) ice shelf-ocean interation,
  2. an adjoint model
- you can calculate gradients/sensitivities of objective functions, such as
  - melt rates
  - least-squares model - data misfits

Reproducing Schodlok et al. (2012)

RTOPO (Timmermann et al. 2010)
melt rate 19.80 m/a
net mass loss 108.05 Gt/a

IceBridge (Studinger et al. 2010)
melt rate 26.07 m/a
net mass loss 119.23 Gt/a



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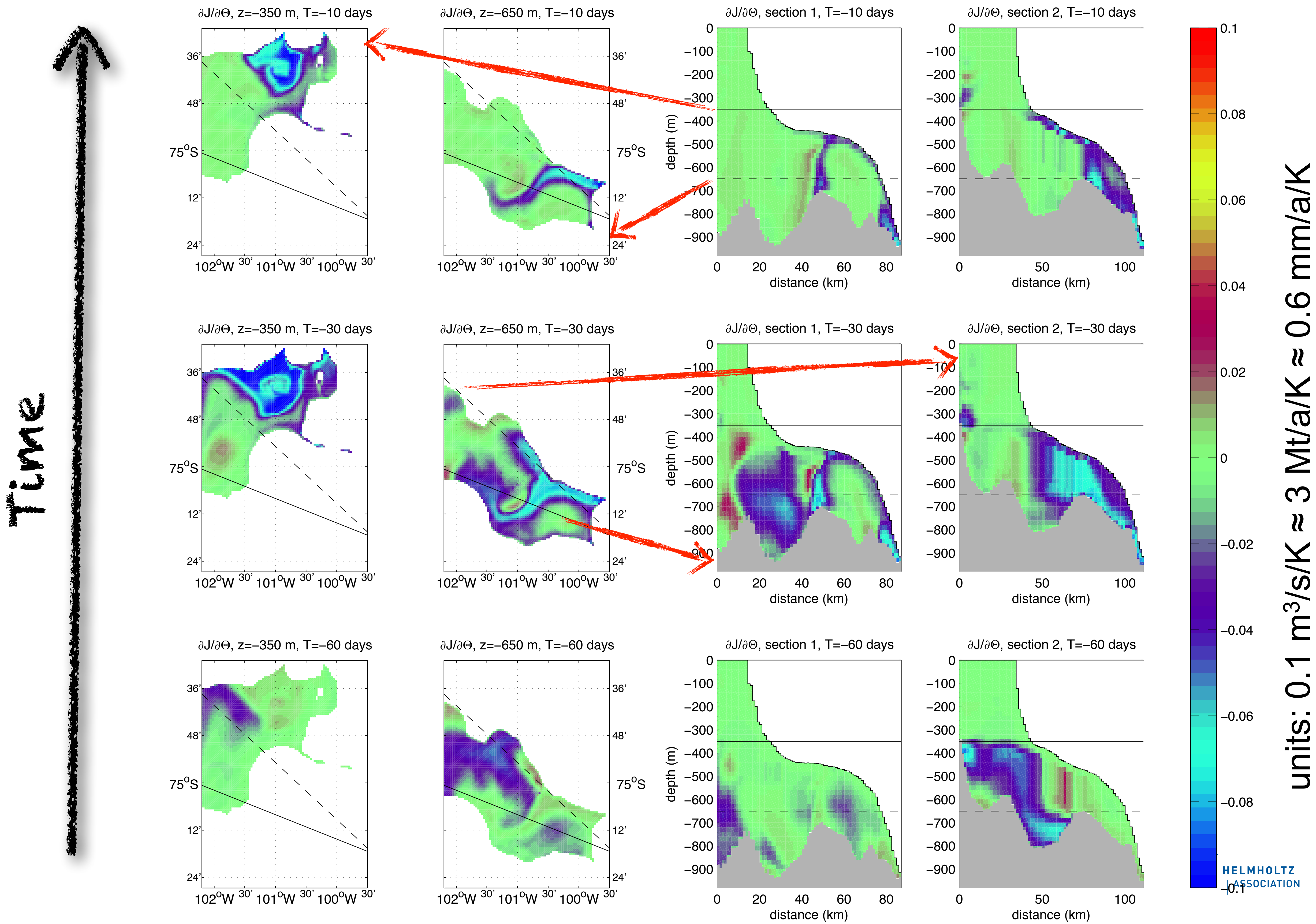
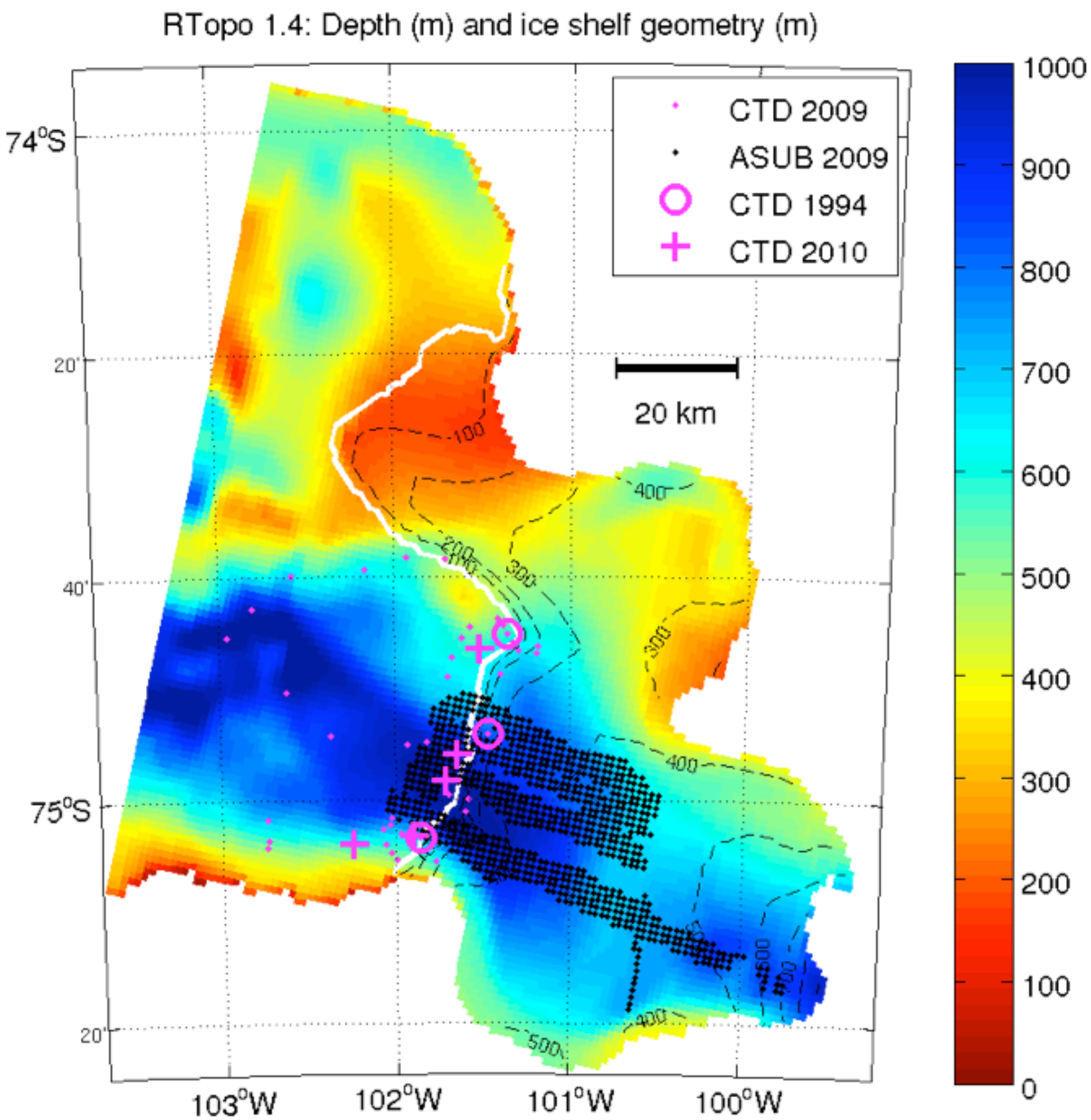
Transient melt rate sensitivities to current temperature (∂q/∂θ) control variables: initial and open boundary conditions (Heimbach and Losch, 2012)



Model data comparison: cost function

cost function: squared model-data misfit, weighted by prior error estimates

$$J = \sum \frac{(T_{obs} - T_m)^2}{\sigma_T^2} + \sum \frac{(S_{obs} - S_m)^2}{\sigma_S^2}$$



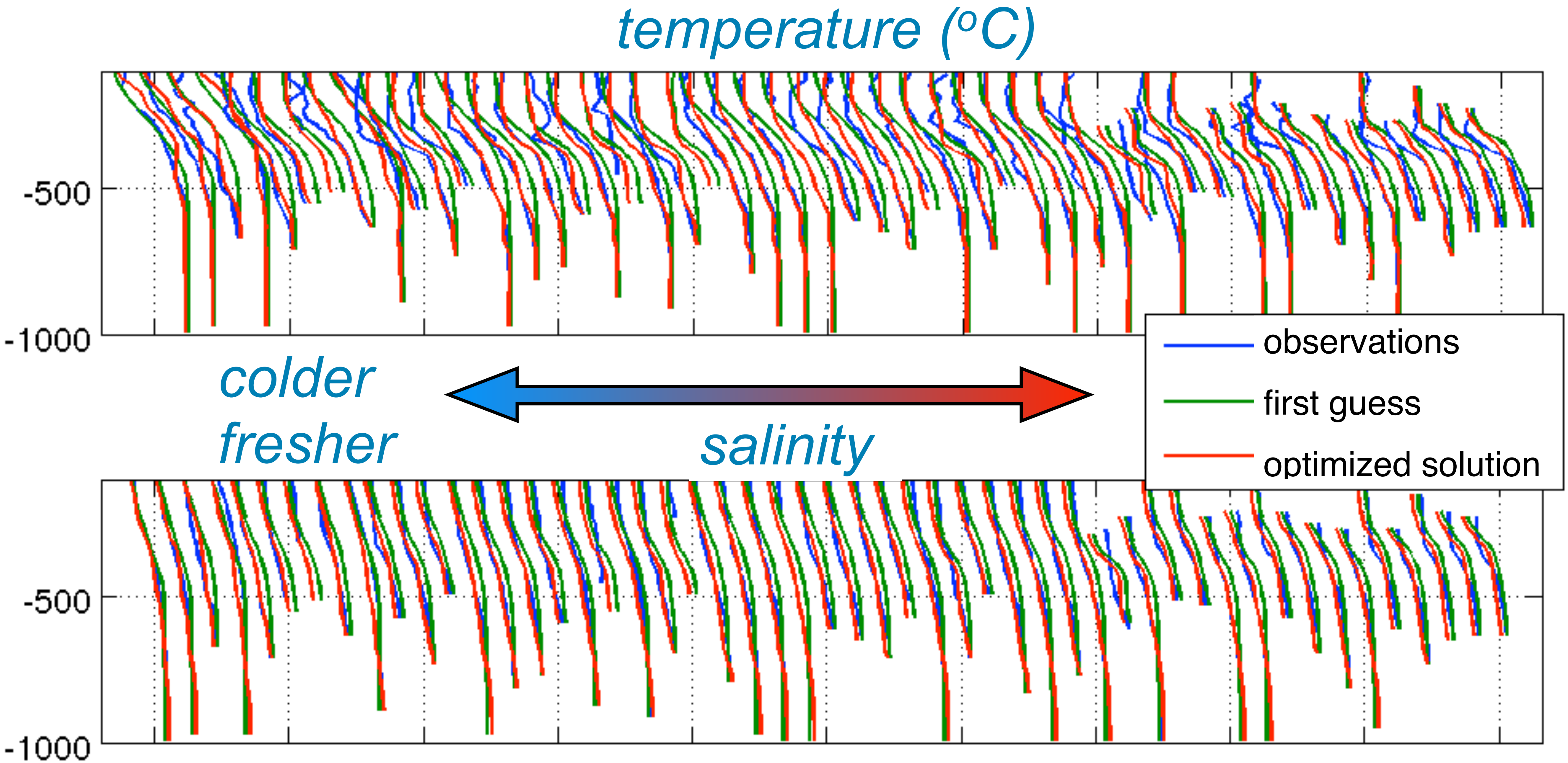
observational data:

- CTD data of 1994 cruise (3 casts)
- CTD and Autosub data of 2009 BAS cruise (Jenkins et al 2010), provided by P. Dutrieux
- CTD data of 2010 Polarstern cruise (5 casts, M. Schröder)

Melt rates and cost function values

	first guess	CTD + Autosub 2009	CTD 1994	CTD 2010
RTOPOv1.4 constant Γ	19.80 m/a 108.05 Gt/a	17.74 m/a 96.78 Gt/a J = 1477→1151	19.63 m/a 107.09 Gt/a J = 32→31	19.67 m/a 107.35 ma/ J = 70→69
IceBridge Topo constant Γ	26.36 m/a 120.67 Gt/a	24.35 m/a 111 Gt/a J =1543→1248		
RTOPOv1.4 velocity dependent Γ c_D = 0.0015	5.10 m/a 27.84 Gt/a	4.43 m/a 24.19 Gt/a J = 1367→1025	5.00 m/a 27.28 Gt/a J = 28→27	4.98 m/a 27.20 Gt/a J = 63→62

What's happening to the hydrography?



all CTD casts of 2009

Conclusions: Dilemma

- so far sensitivities to uncontrolled parameters/ parameterizations are large (topography, melt rate parameterization), much larger than to control parameters
- best fit to observations associated with very low melt rates (order 5 m/a or 27 Gt/a of melt water), much lower than previous estimates (except for very early estimates in the 1990s)
- first guess too warm and saline compared to observations, so that optimization reduces melt rates even further