Metrics for assessing ice sheet model performance

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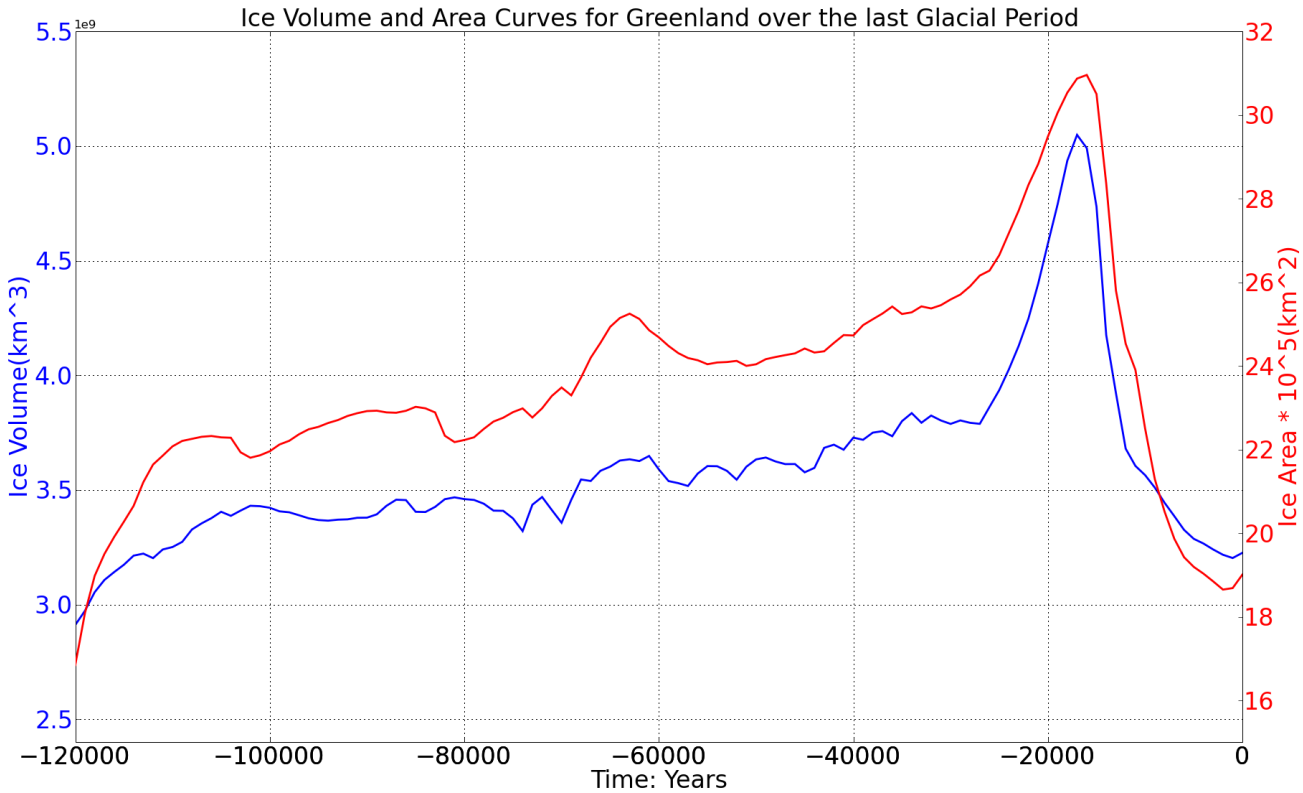
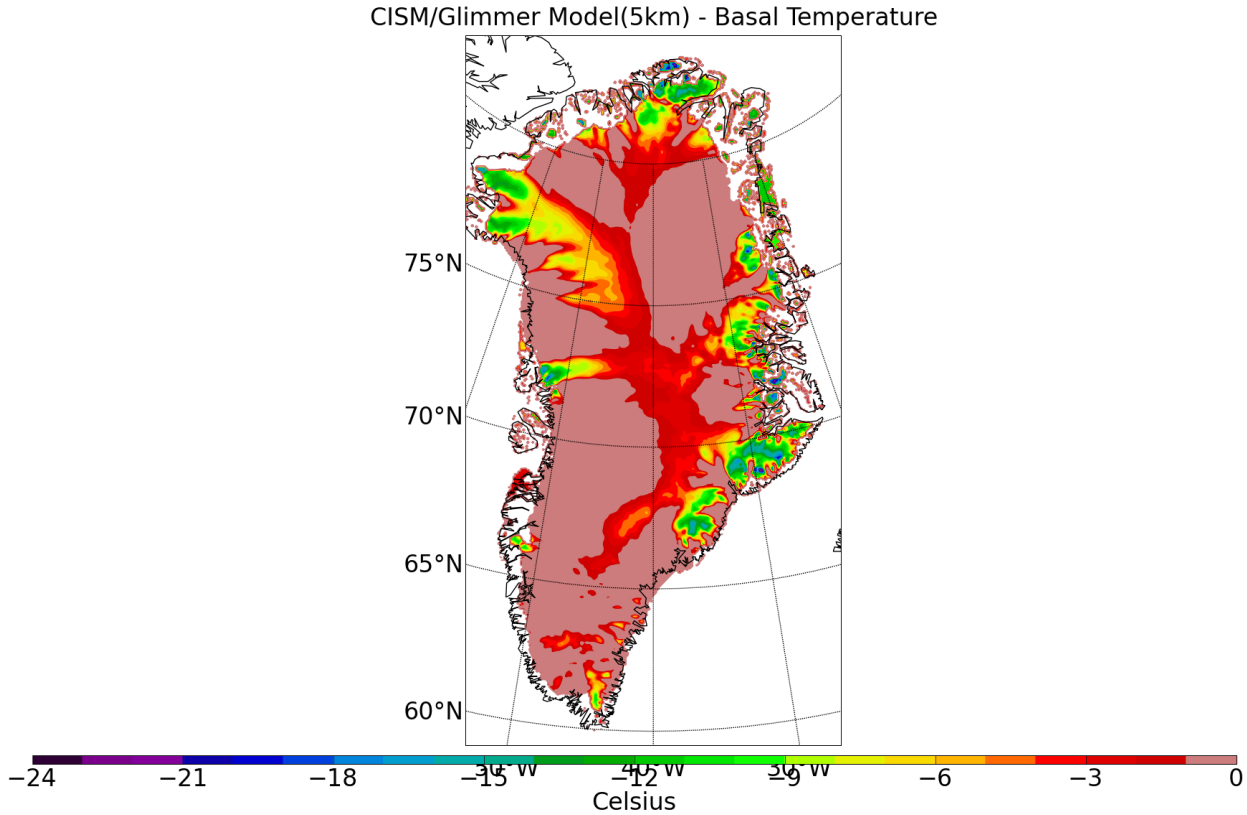
Land Ice Working Group, Paleo Climate Working Group Joint Session

Outline

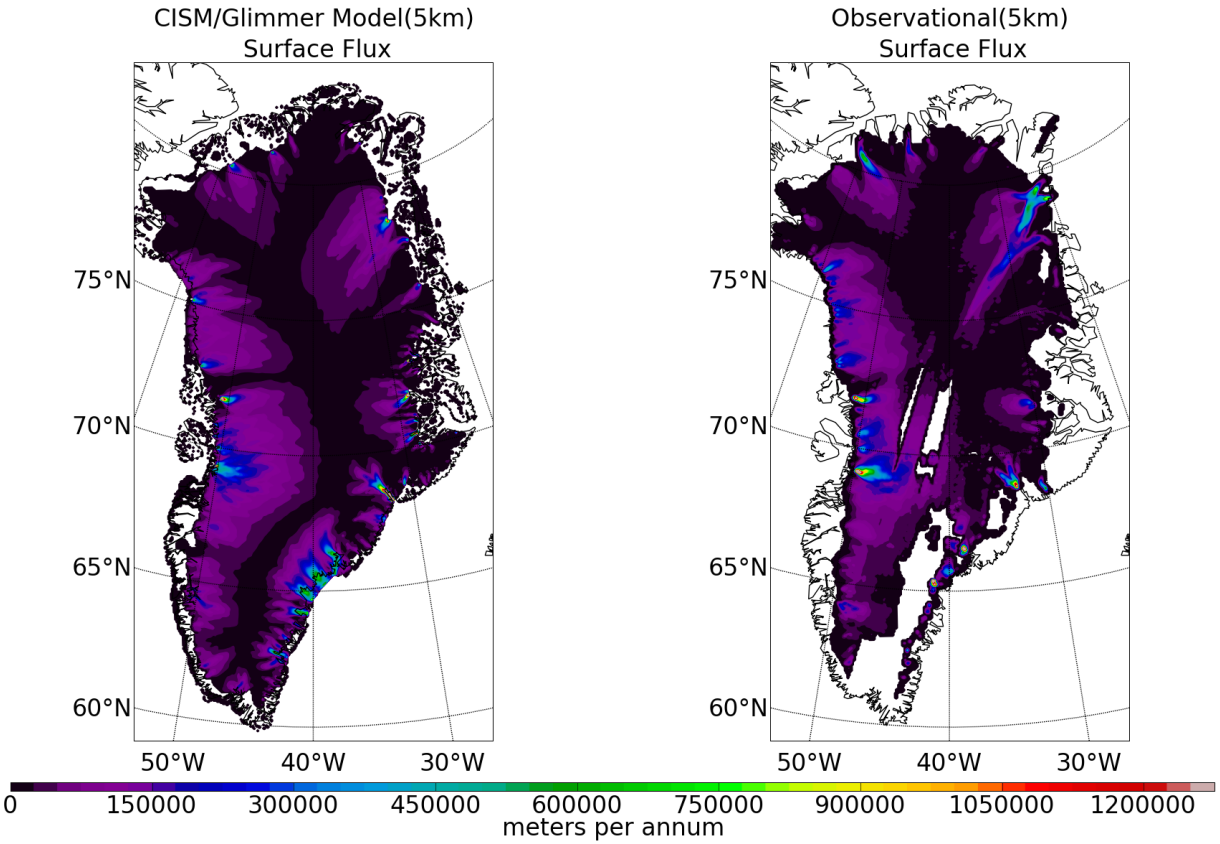
Model validation
Volume and Area



Model validation
Basal Temperature



Model validation
Surface Velocity



A brief history of ice sheet modeling
The Purpose

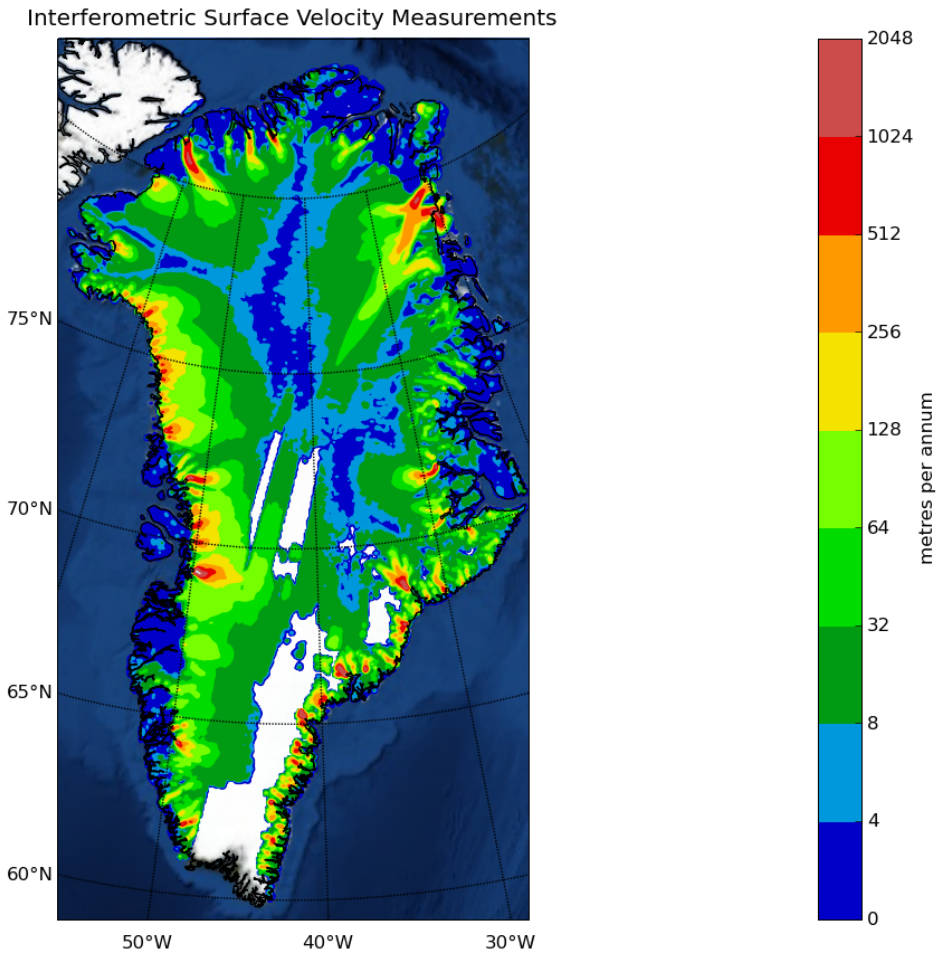
- ice sheet inception
- glacial-interglacial cycles
- a source for gravity models
- a source of freshwater for ocean models
- locating and dating ice cores

A brief history of ice sheet modeling
"Validation"

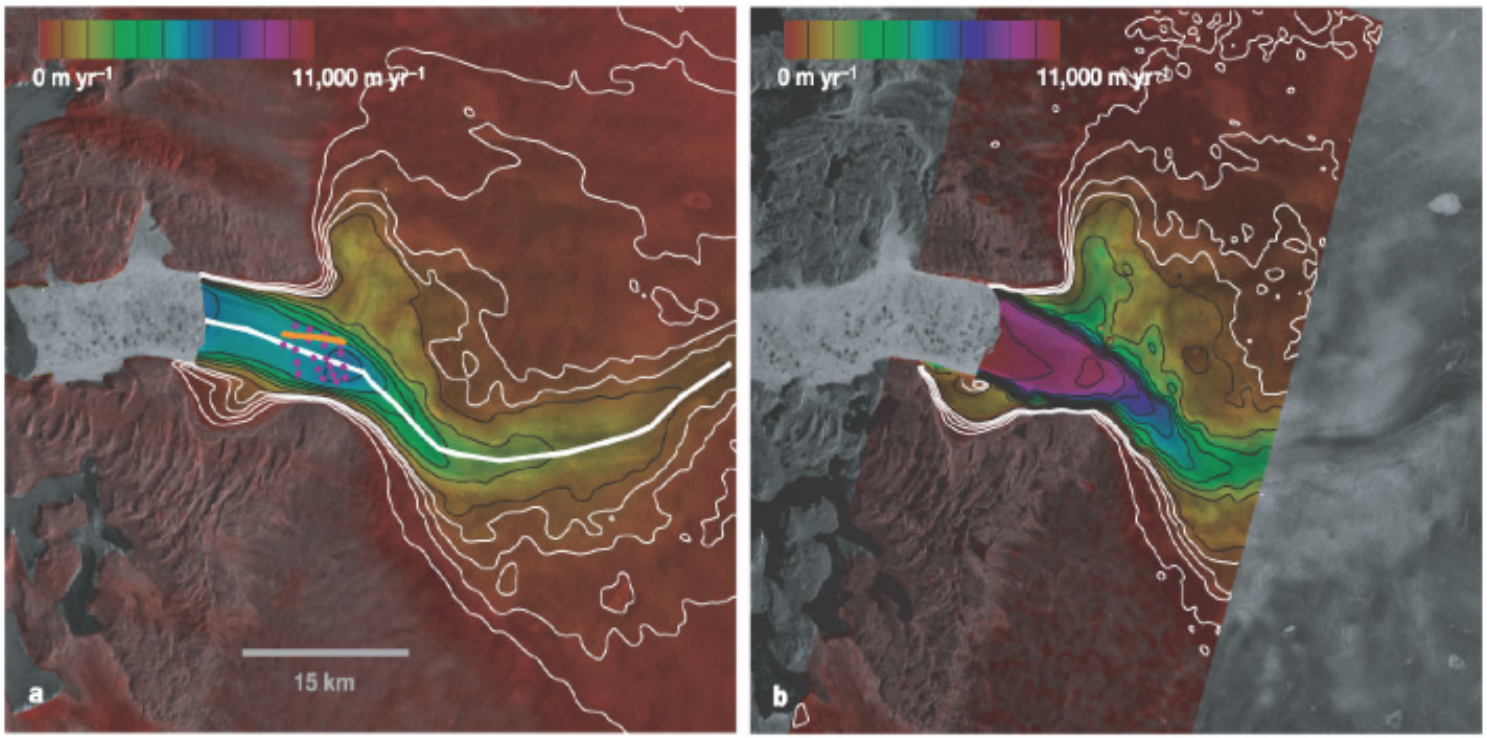
- *"Paucity of suitable test data..."*
- *"geological record is often ambiguous..."*
- *"Gross comparisons of the overall patterns..."*
- *"...look very reasonable"*
- *"...but not full exploited yet"*

Huybrechts. Numerical modelling of polar ice sheets through time. Glacier Science and Environmental Change, Chapter 80 (2006) pp. 1-12

Has the situation changed?
Rich data sources

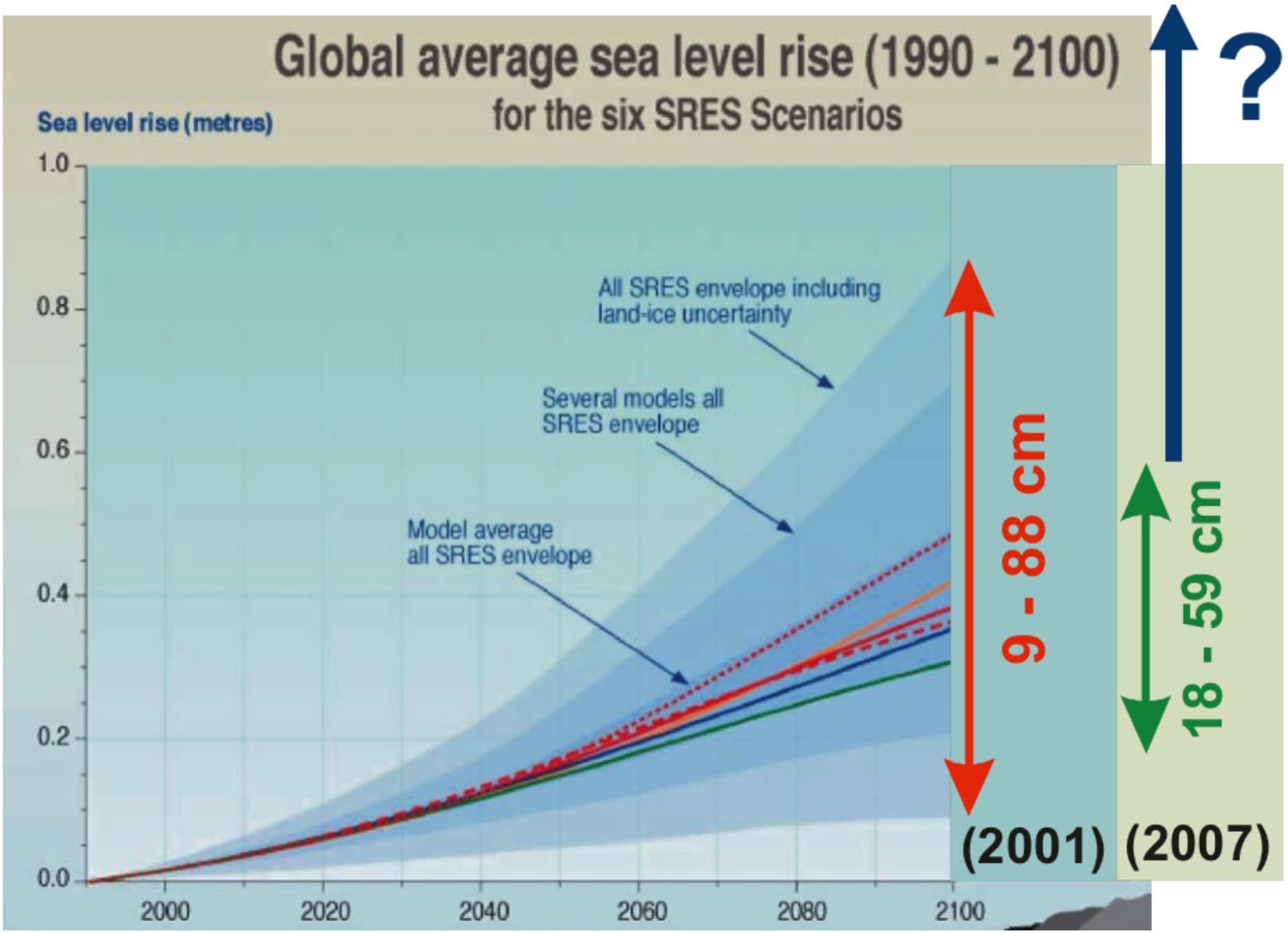


Has the situation changed?
Emphasis on rapid changes

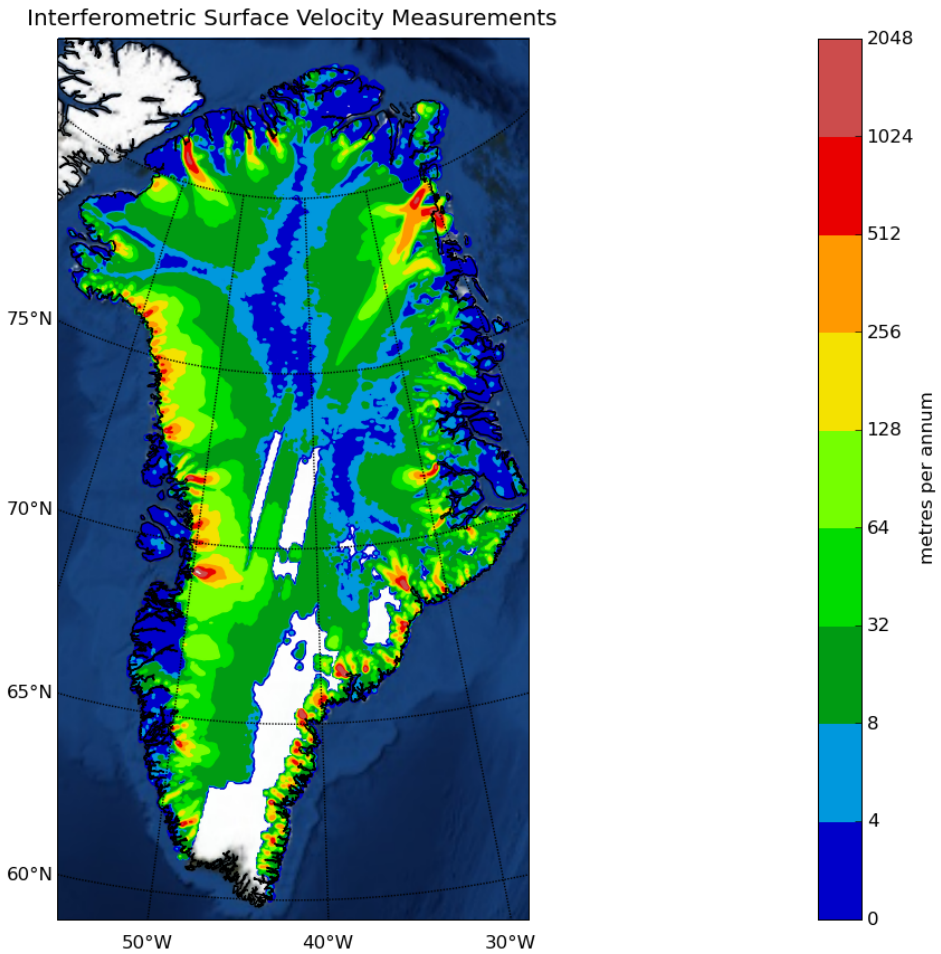


Joughin et al. Large fluctuations in speed on Greenland s Jakobshavn Isbr glacier. Nature (2004) vol. 432 pp. 608-610

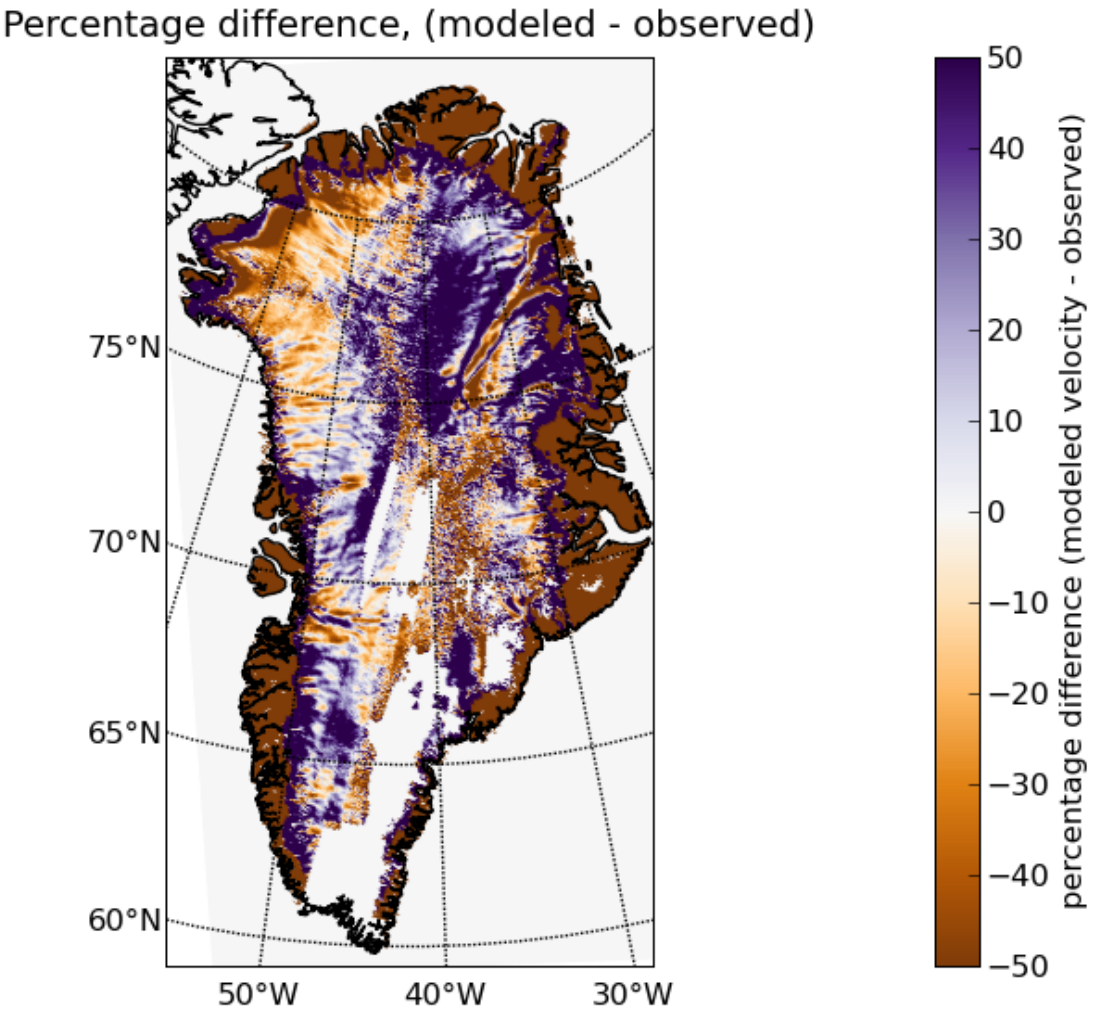
Has the situation changed?
Emphasis on short term sea level rise



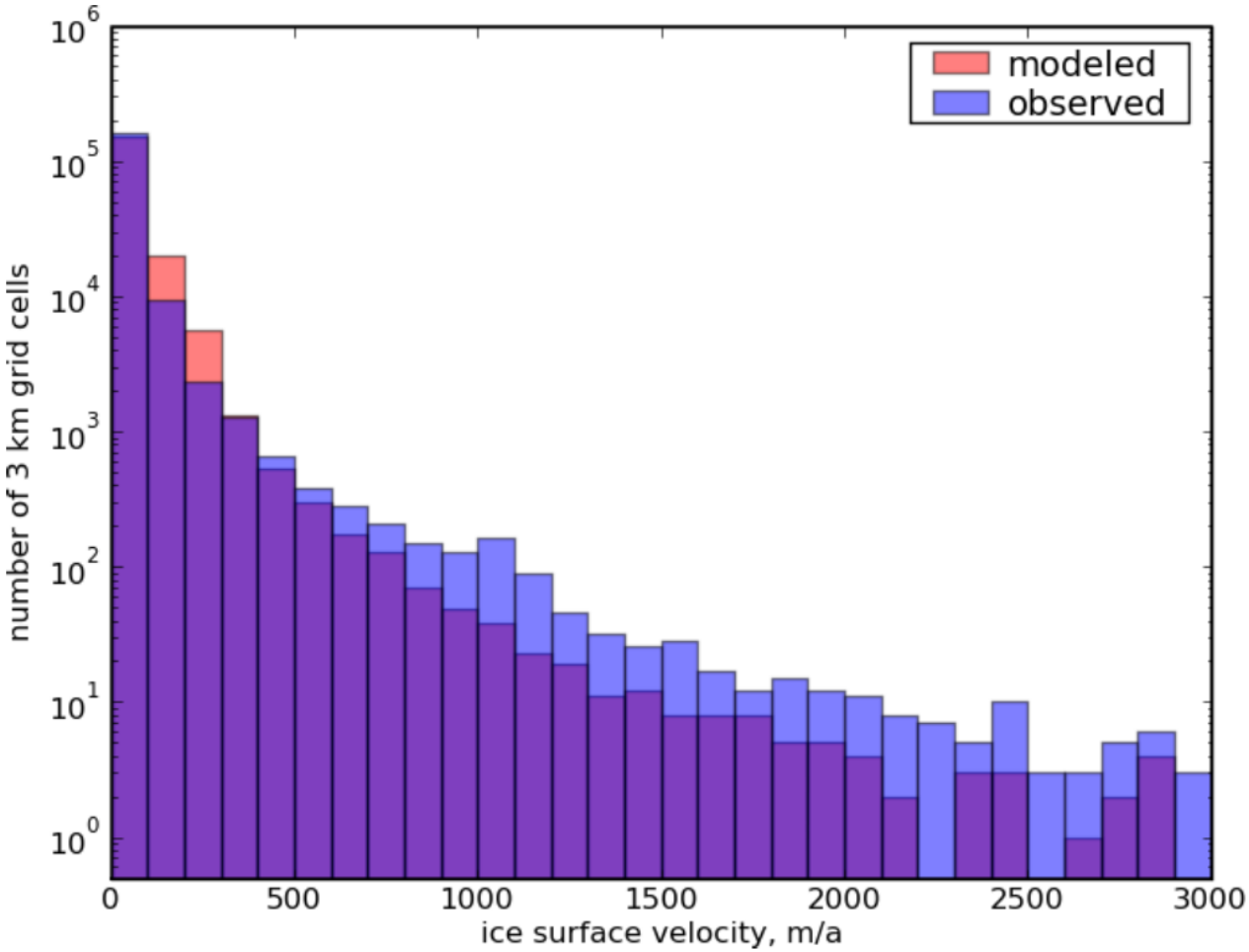
Can data be aggregated in meaningful ways?
Velocity



Can data be aggregated in meaningful ways?
Velocity Differences



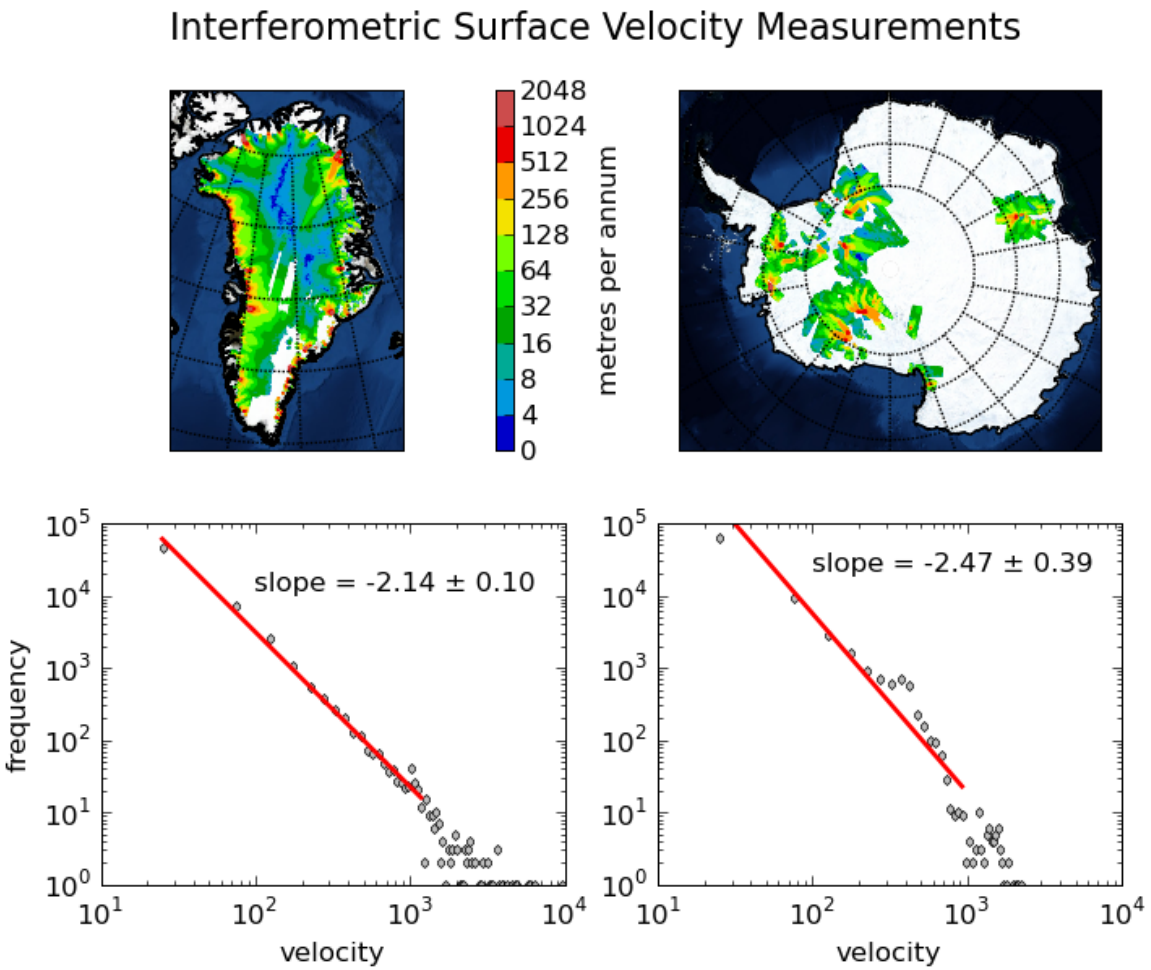
Can data be aggregated in meaningful ways?
Distribution, Bueler



E. Bueler, C. Khroulev, A. Aschwanden, and I. Joughin, Modeled and observed fast flow in the Greenland ice sheet, Presentation at IGS International Symposium on Glaciology in the International Polar Year, Newcastle, UK, July 2009

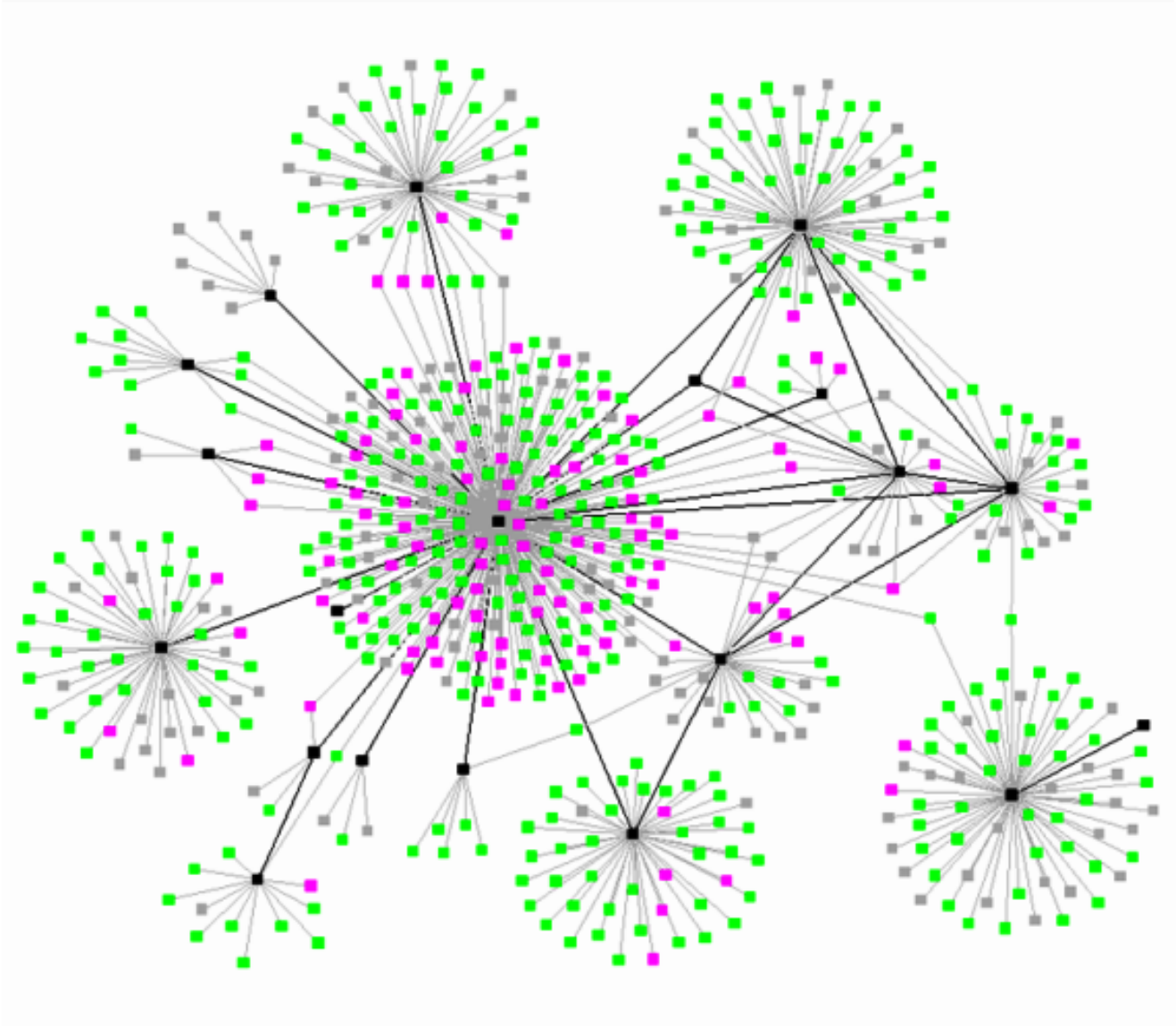
Power-law behavior
Simple method

$$N \propto V^{-\alpha}$$



Power-law behavior

Meaning???



Power-law behavior
Meaning???

Power-law behavior

Meaning???

Power-law behavior
Problems with method

The trouble with binning data:

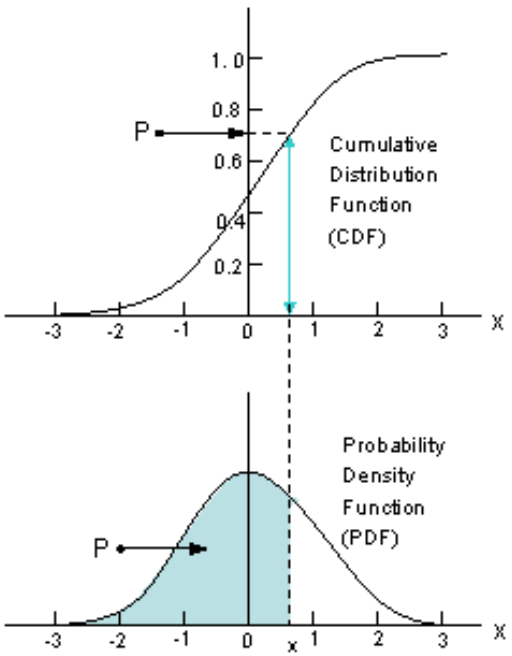
Method	Value	Error
LS + PDF, Constant width	1.39	$\pm$.05
LS + CDF, Constant width	2.48	$\pm$.04
LS + PDF, Log. width	1.19	$\pm$.02

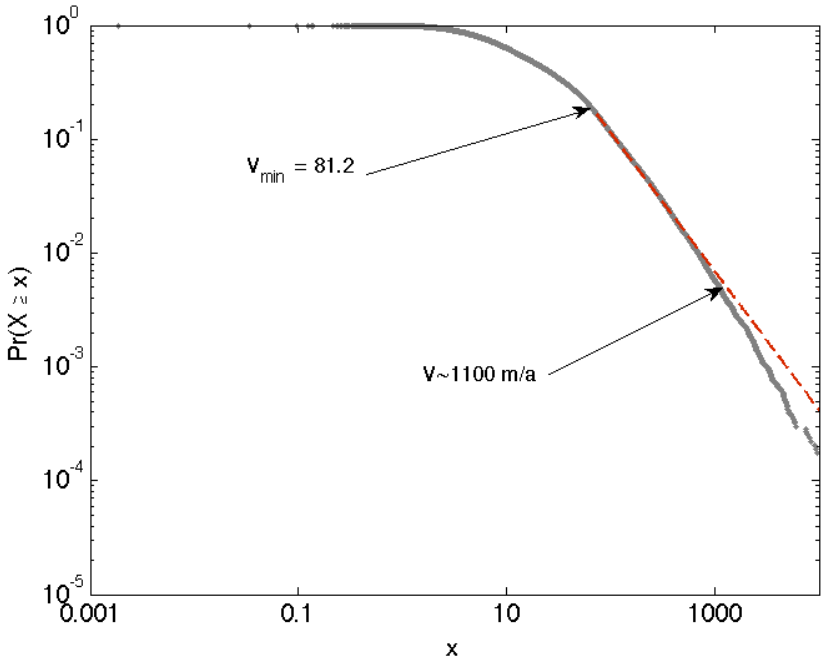
from: Clauset, A., Shalizi, C. R. and Newman, M. E. J. (2007). Power-law distributions in empirical data

Power law behavior
Improved method

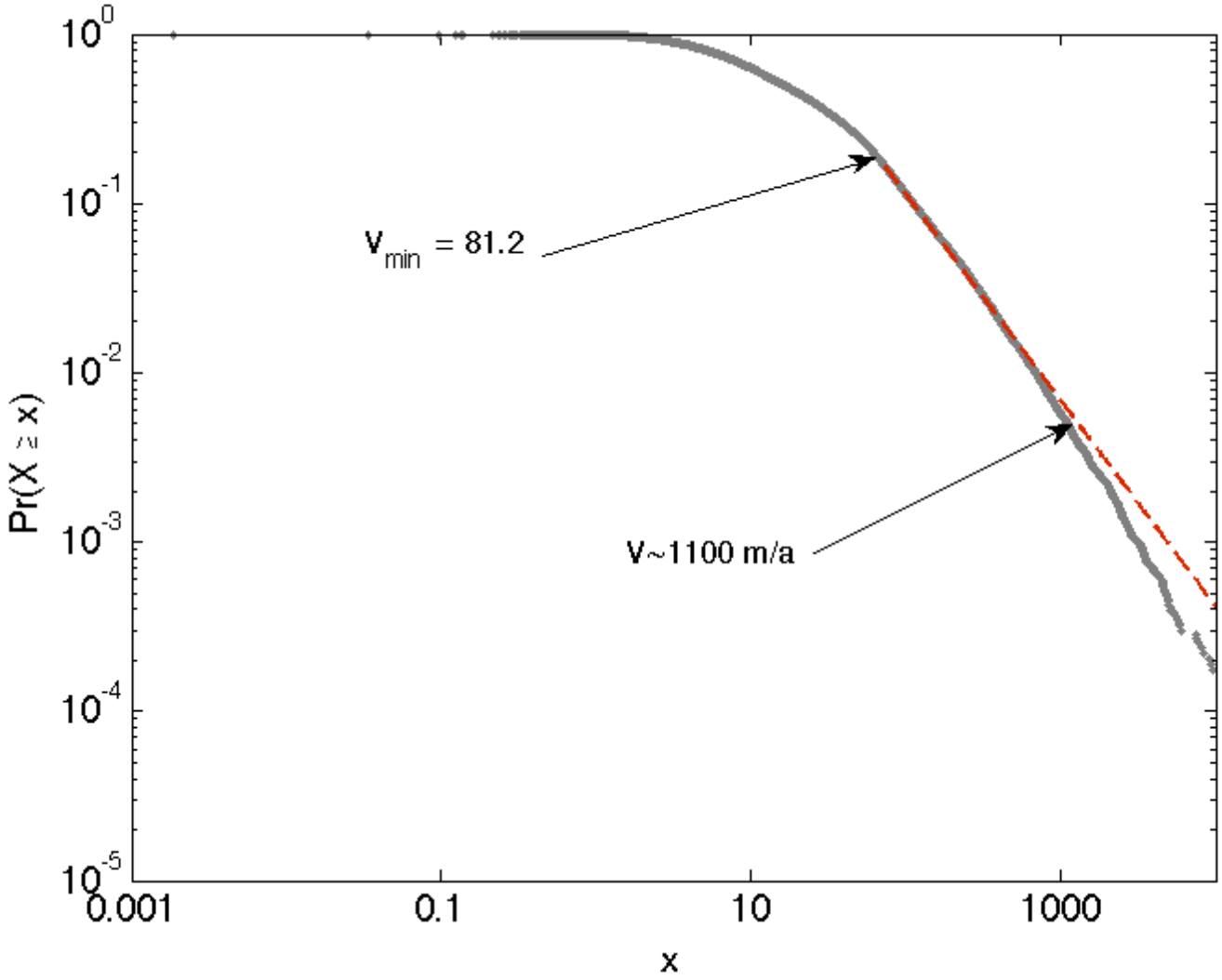
Consider the cumulative distribution function (CDF):

$$P(x > X) = \int_{-\infty}^{x} p(x)dx$$

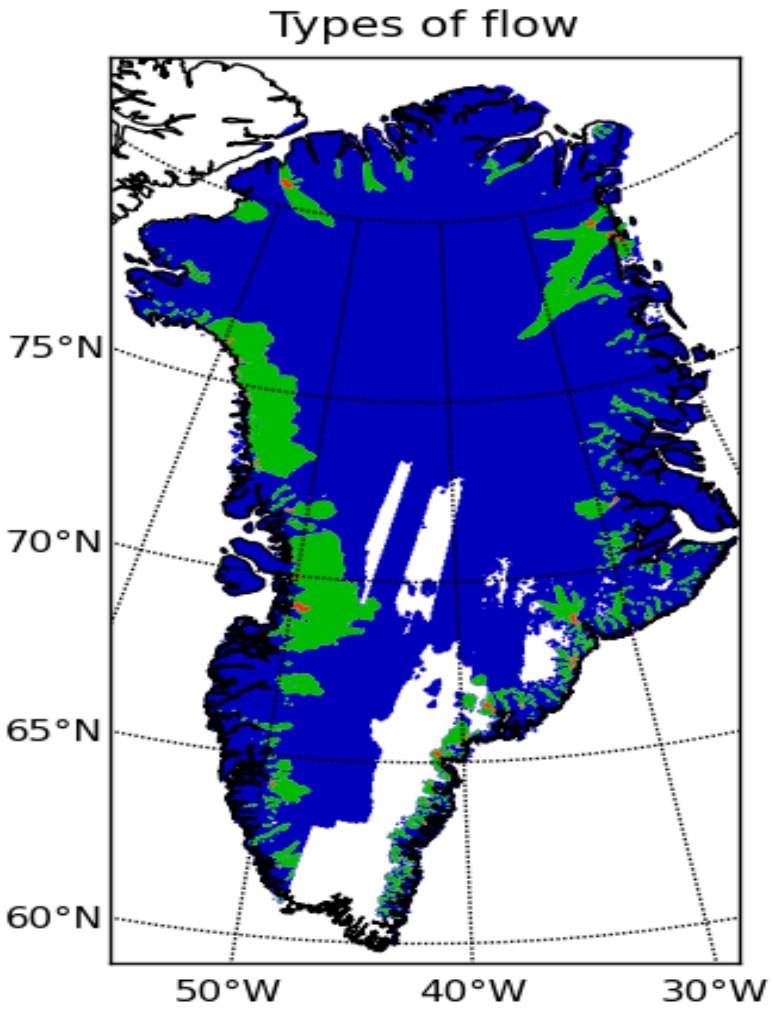


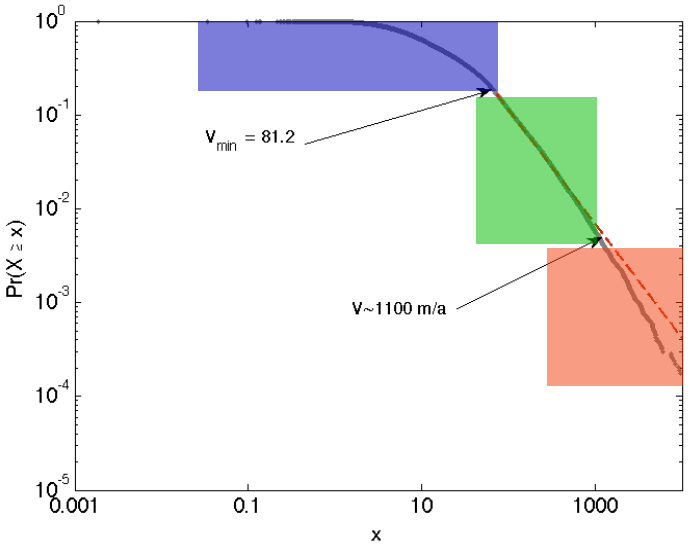


Power law behavior
CDF of ice velocity data



Power law behavior





Comparing the metric to model output

Several models participating is seaRISE

Results from various models

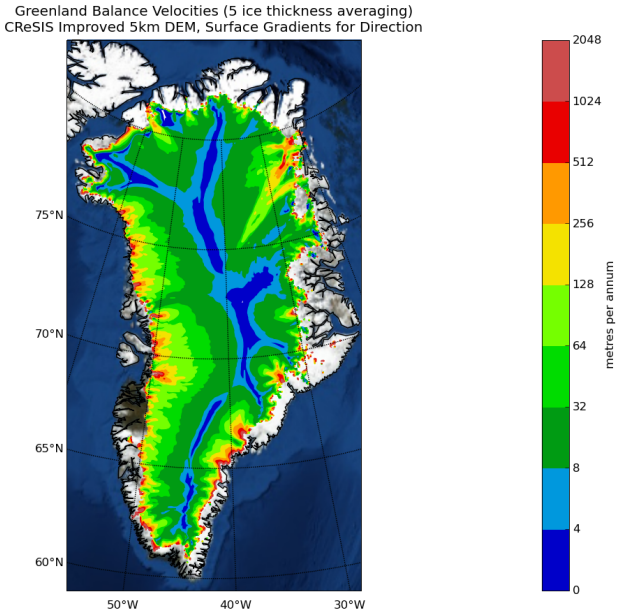
Model	**exponent,** α	$\mathbf{x_{min}}$	**p-value**
INSAR Data	2.41±0.08	81.9 ±17 m/a	.578
Balance Velocity†	2.28 ± 0.06	86.3 ± 18 m/a	.158
PISM	2.70±0.15	62.5 ±18 m/a	.532
CISM (SIA)	2.91±0.12	94.8 m/a ±19 m/a	.926
CISM (HO), isothermal	1.24±0.04	2.09±0.15 m/a	0.0

† these are *vertically averaged* velocities.

Is this metric sensitive to the right thing?
Balance velocity test

Balance Velocity

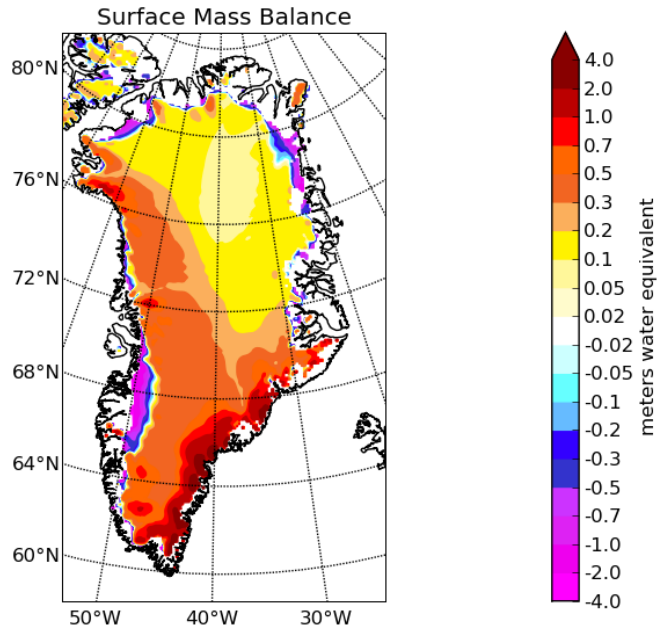
$$\frac{\partial H}{\partial t} = -\nabla \cdot \mathbf{u}H + a$$
$$\frac{\partial H}{\partial t} = 0$$



Is this metric sensitive to the right thing?
Balance velocity test

Accumulation field

$$a = \nabla \cdot \mathbf{u}H$$

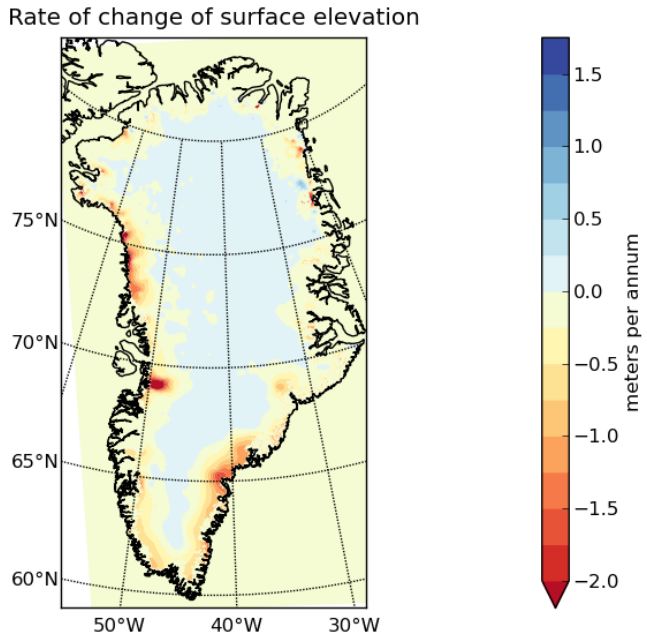


Ettema J., M.R. van den Broeke, E. van Meigaard, W.J. van de Berg, J.L. Bamber, J.E. Box, and R.C. Bales (2009), "Higher surface mass balance of the Greenland ice sheet revealed by high-resolution climate modeling", Geophys. Res. Lett., 36, L12501, doi:10.1029/2009GL038110

Is this metric sensitive to the right thing?
Balance velocity test

$\frac{\partial H}{\partial t}$ field

$$a - \frac{\partial H}{\partial t} = \nabla \cdot \mathbf{u}H$$



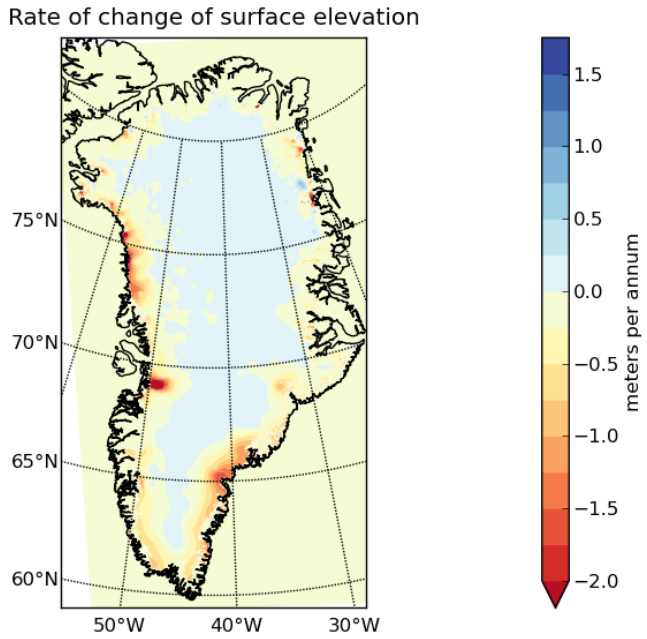
Csatho 2009, personal communication

Is this metric sensitive to the right thing?
Balance velocity test

Utilizing the $\frac{\partial H}{\partial t}$ field

$$a - \frac{\partial H}{\partial t} = \nabla \cdot \mathbf{u}H$$

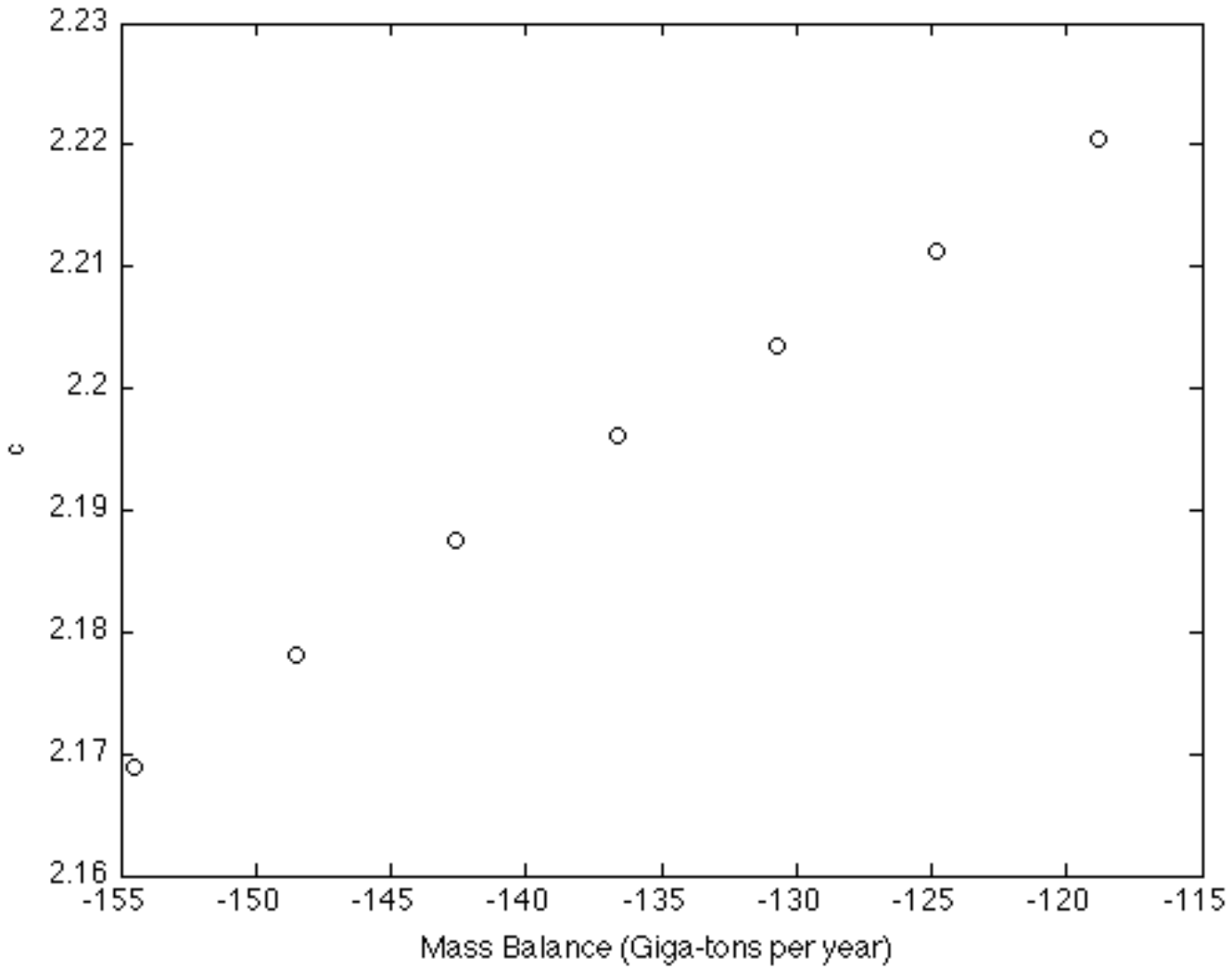
$$a - \gamma \left(\frac{\partial H}{\partial t}\right)_{\text{Dyn}} - (1-\gamma)\left(\frac{\partial H}{\partial t}\right)_{\text{SMB}} = \nabla \cdot \mathbf{u}H$$



Csatho 2009, personal communication

Sensitivity of α to mass balance

Using balance velocity calculation



Summary
The point of this talk

Distributions of observation and model output may provide a useful metric for evaluating ISM output because:

- They provide a simple aggregation of a large amount of data
- Power law distributions have mature statistical tools for evaluation of data
- These metrics appear to be sensitive to changes in mass balance

Extra Slide
Benford's Law