# The influence of decadal- to millennial-scale ice mass changes on present-day vertical land motion in Greenland: Implications for the interpretation of GPS observations

**NKG September 2010**

**Matthew J.R. Simpson[1,†], Glenn A. Milne[1], Leanne Wake[2] and Philippe Huybrechts[3]**

**[1] Department of Earth Sciences, University of Ottawa, K1N 6N5, Canada**
([†] Now at Geodetic Institute, Norwegian Mapping Authority, Hønefoss, Norway)
[2]Department of Geography, University of Calgary, T2N 1N4, Canada
[3]Earth System Sciences & Departement Geografie, Vrije Universiteit Brussel, B-1050 Brussels, Belgium

# Motivation

(i) The accurate interpretation of GPS data from Greenland requires the elastic and viscous components of the motion to be isolated.

(ii) As part of the Greenland GPS Network project (GNET), 51 continuous GPS stations have recently been installed around the periphery of the ice sheet.

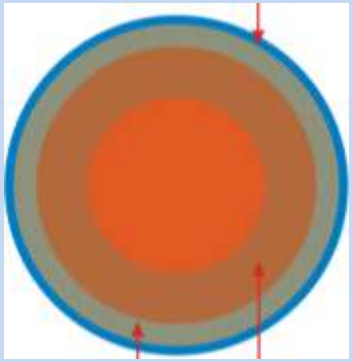
(iii) The secondary aim of this analysis is to examine the possible influence of ice mass variability over the last century (or so) on present-day vertical land motion.

# Methodology

## GIA model

- sea-level model (Mitrovica and Milne, 2003)
- Ice model (ICE-5G non-Greenland
  + Huybrechts, 2002)
- Earth model


elastic lithosphere

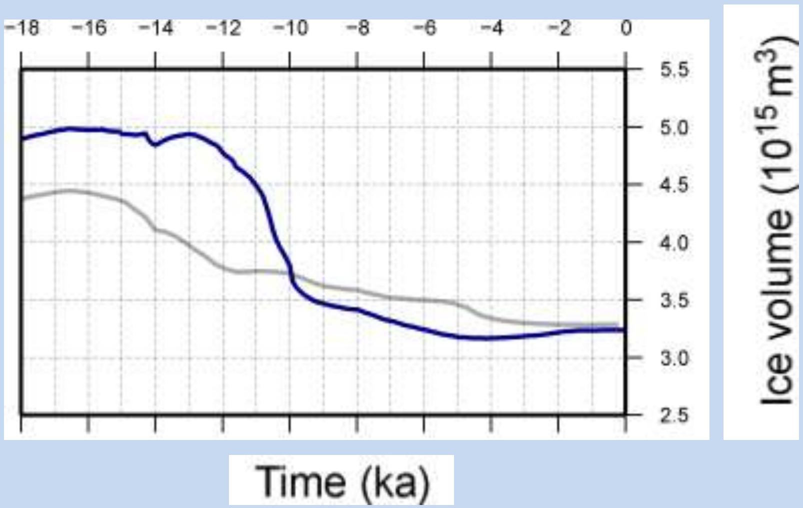


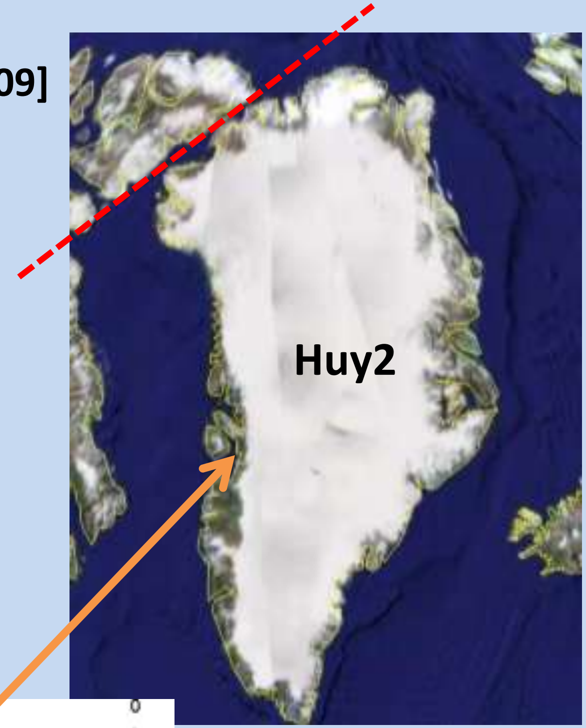
upper mantle

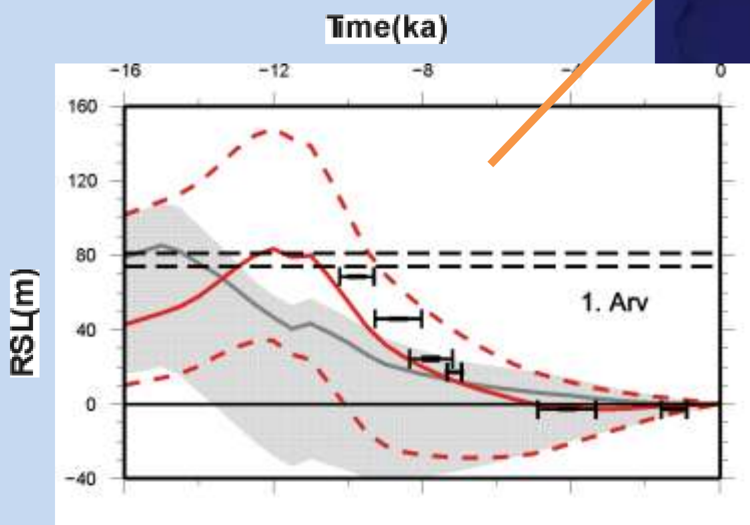
lower mantle

# Methodology

## Huy2 Ice history for Greenland [*Simpson et al.*, 2009]



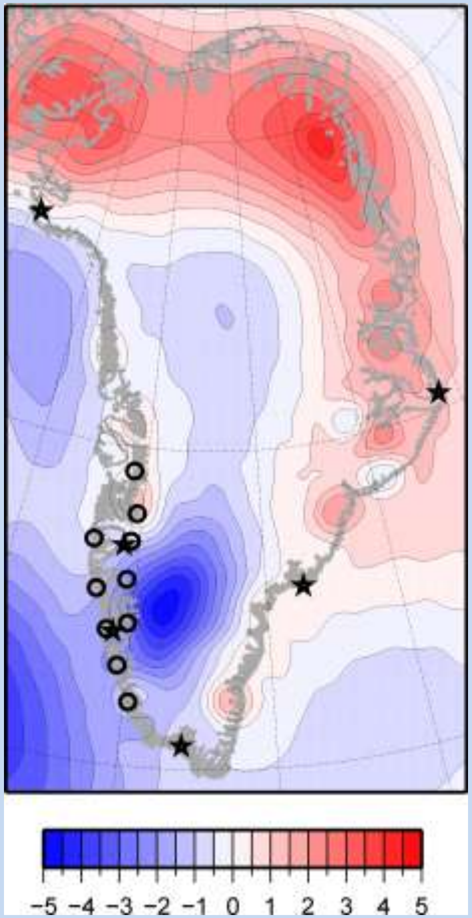

**Lithosphere - 120 km**
**Upper mantle - 5 x $10^{20}$ Pa s**
**Lower mantle - $10^{21}$ Pa s**

Matthew Simpson NKG Sept '10

NORWEGIAN MAPPING AUTHORITY

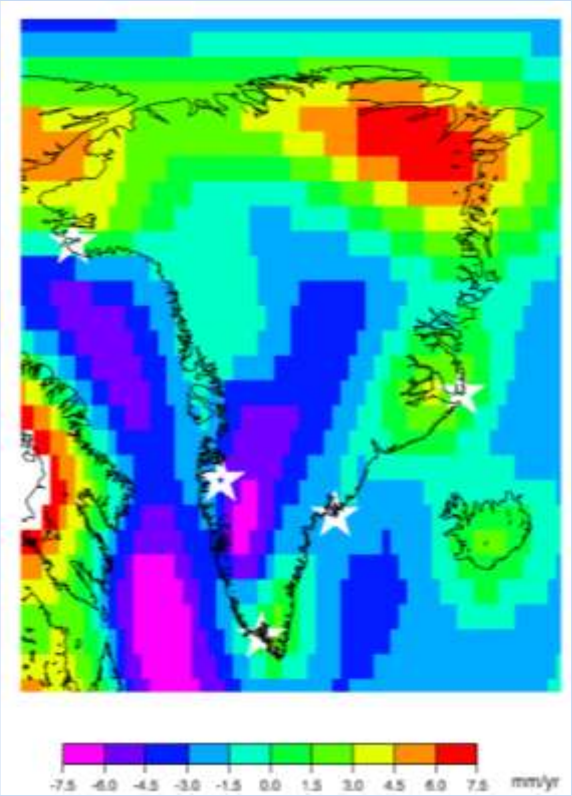
# Results – predicted uplift rates

**Huy2**



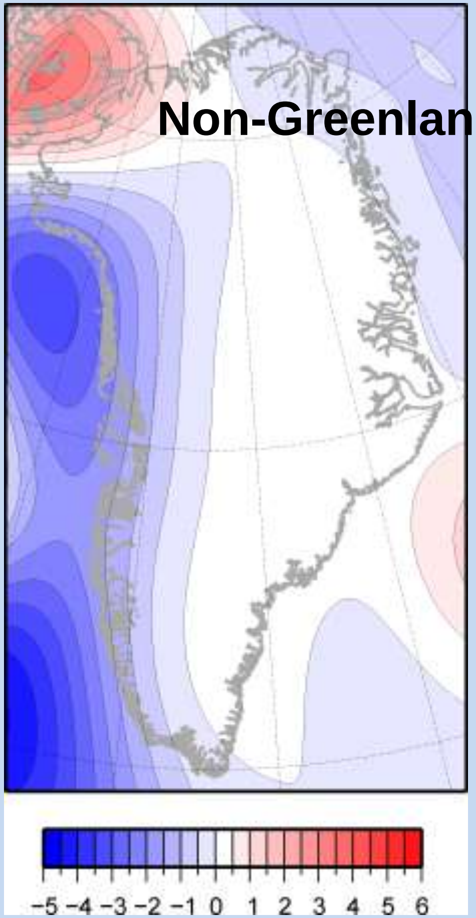

**mm/a**

**ICE-5G(VM2) – Peltier [2004]**



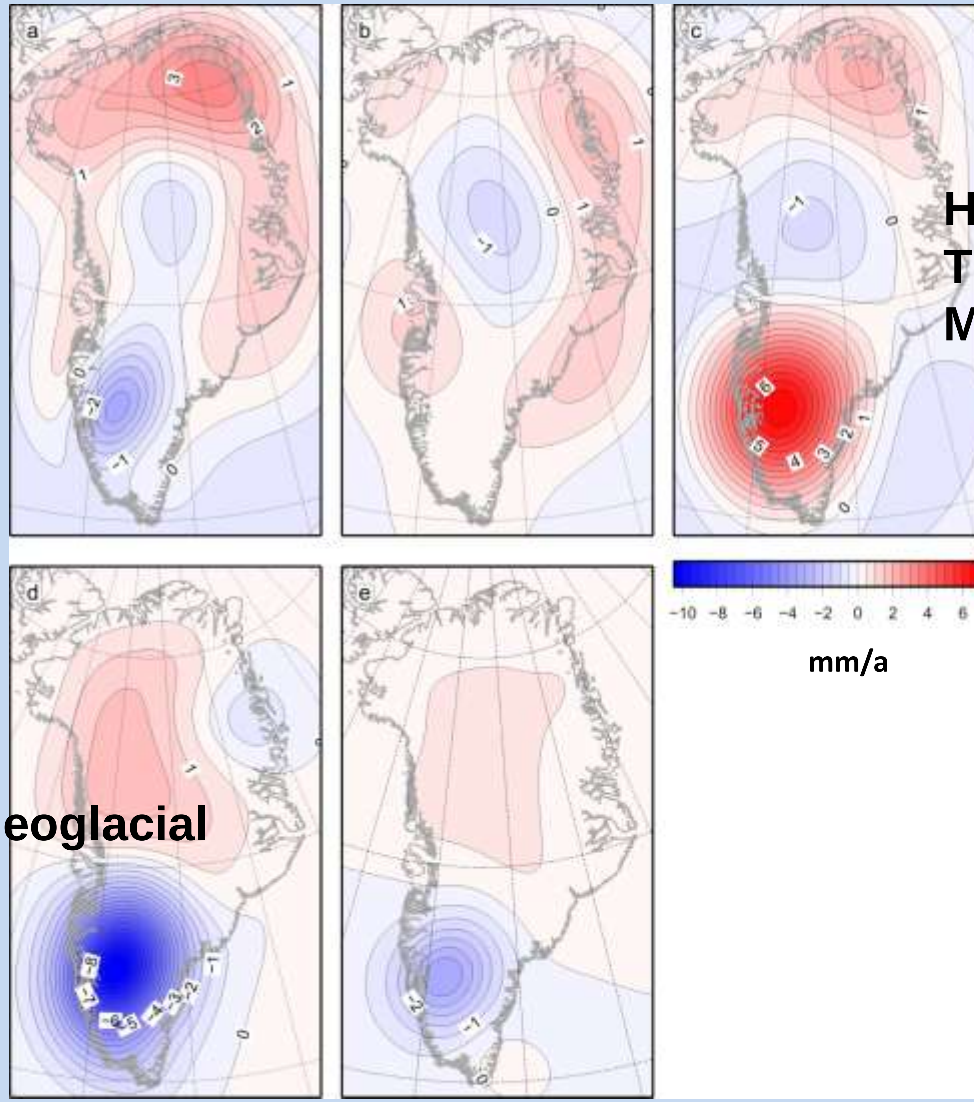

**Khan et al. [2008]**

# Results – stages of evolution




mm/a

Complete loading history | 21 – 10 ka BP | 10 – 4 ka BP

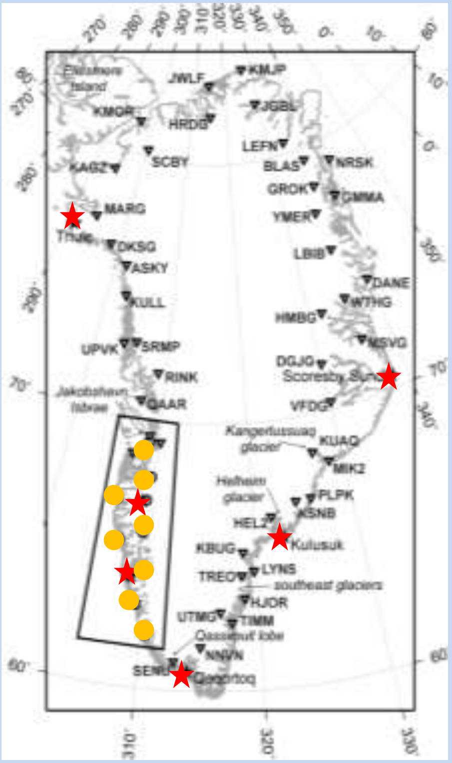



4 – 1 ka BP | 1 - 0 ka BP

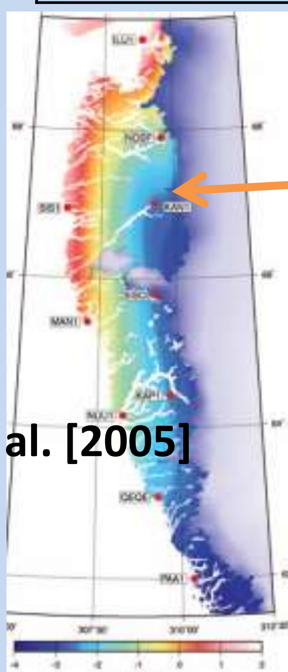
Matthew Simpson NKG Sept '10

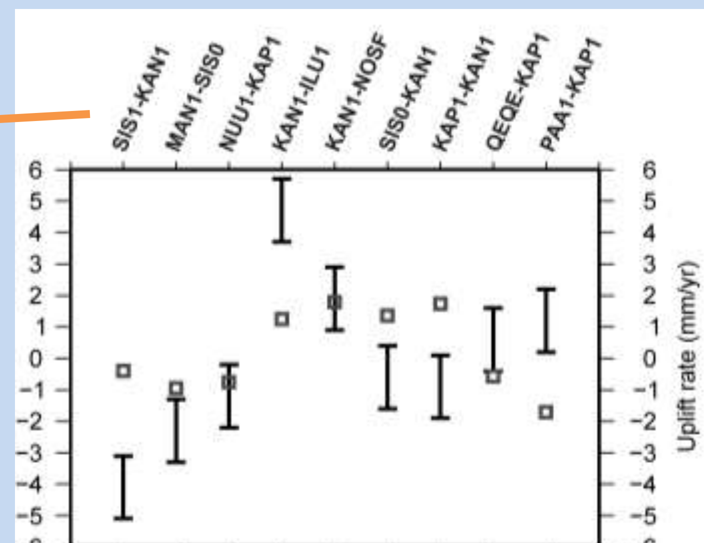
NORWEGIAN MAPPING AUTHORITY

# Results - comparison with GPS observations




| GPS location | Observed uplift rates (mm/a) corrected for elastic term [*Khan et al.*, 2008] | Predicted uplift rates (mm/a) Huy2 (best-fit Earth model) |
|---|---|---|
| Kellyville | -1.2 1.1 | -0.94 |
| Nuuk | -2.2 1.3 | -1.92 |
| Qaqortoq | -0.3 1.1 | -0.66 |
| Kulusuk | -0.4 1.1 | 0.23 |
| Scoresby Sund | 0 1.1 | 1.17 |
| Thule | 3.6 1.1 | 0.02 |






Dietrich et al. [2005]

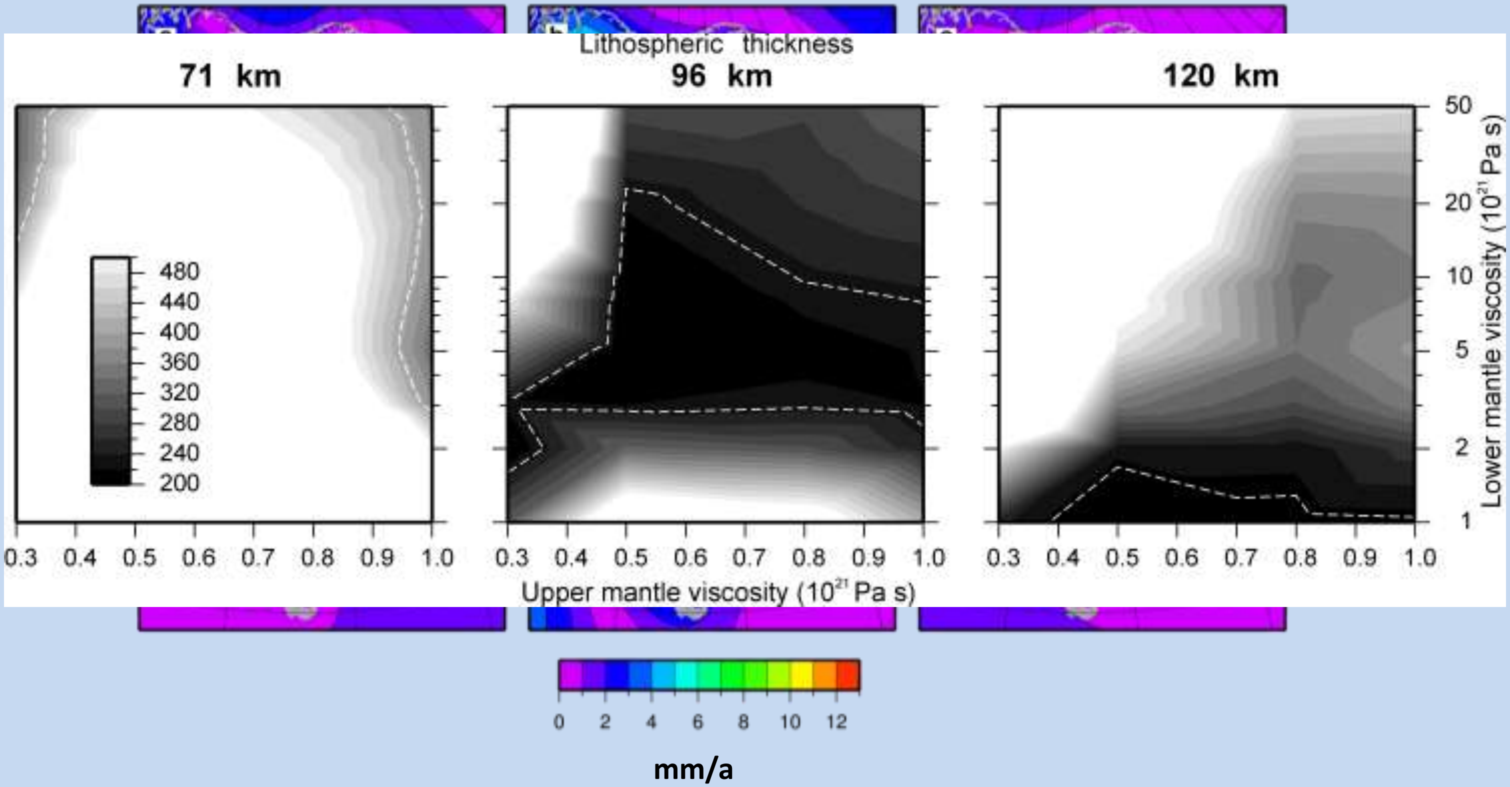
Matthew Simpson NKG Sept '10

# Results - sensitivity to changes in Earth model parameters

**Lithospheric thickness**
**71 to 120 km**

**Upper mantle**
**0.3 x $10^{21}$ to $10^{21}$ Pa s**

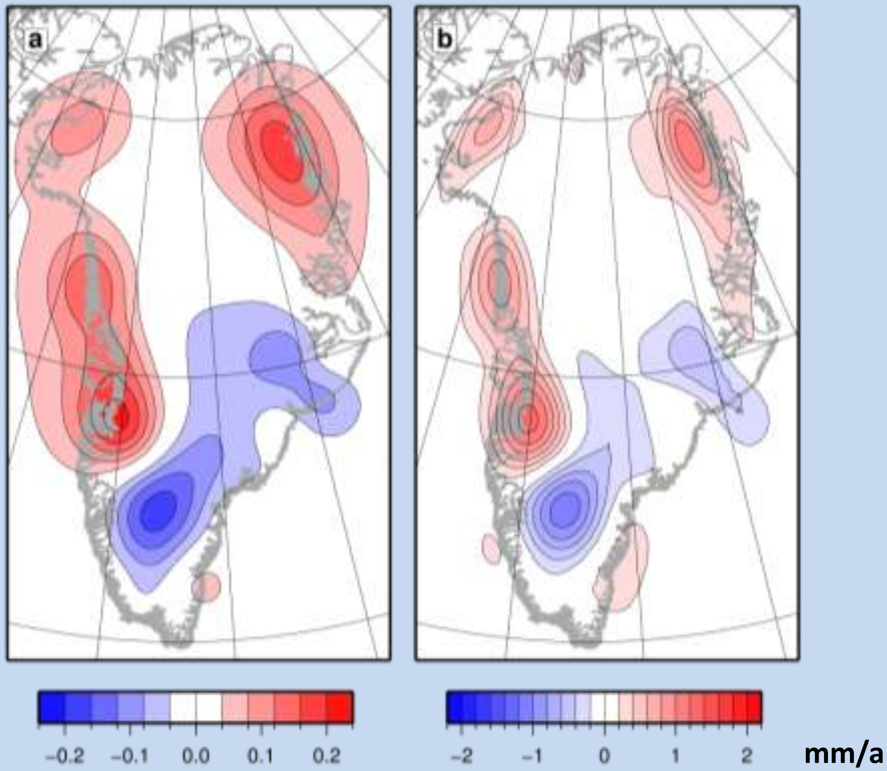
**Lower mantle**
**$10^{21}$ to 50 x $10^{21}$ Pa s**




Matthew Simpson NKG Sept ‘10

# Results – the last 100 years?

## Huy2




Viscous

Elastic

100 year BP ice-ocean loading increment marks the last timestep prior to present-day for this GIA model.

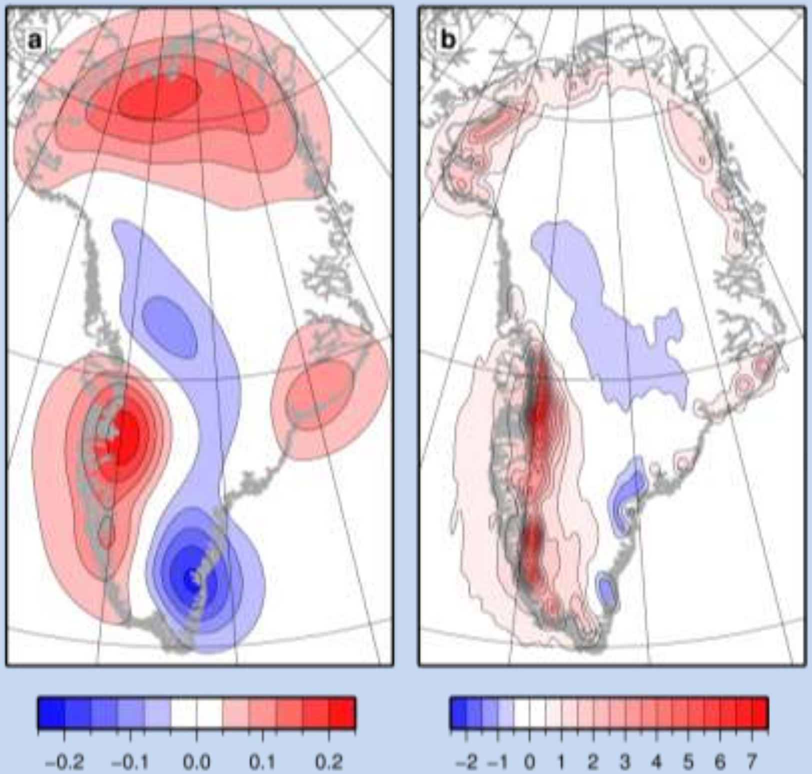
With a relatively weak upper mantle ($10^{20}$ Pa s) the viscous signal is ± 1.2 mm/a.

Recent analyses have considered changes over the last 100 years or so [e.g. *Huybrechts et al.*, 2004; *Hanna et al.*, 2005; *Rignot et al.*, 2008; Ettema et al., 2009; *Wake et al.*, 2009].

NORWEGIAN MAPPING AUTHORITY

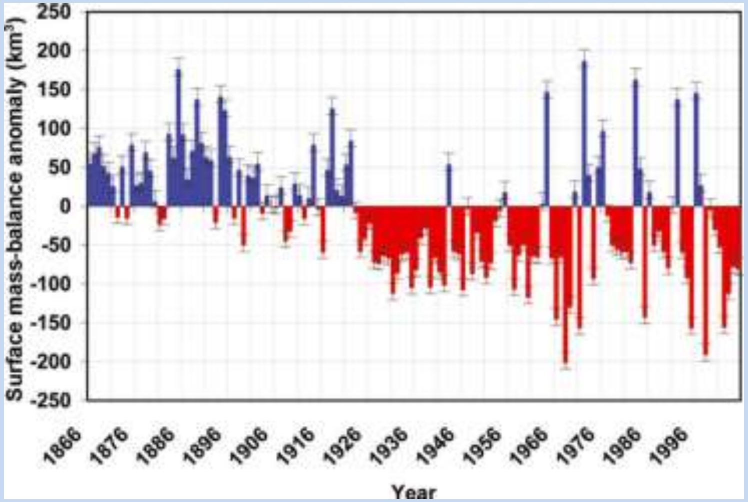
# Results – the last 100 years?

## Wake et al. [2009] SMB reconstruction 1866-2005




mm/a

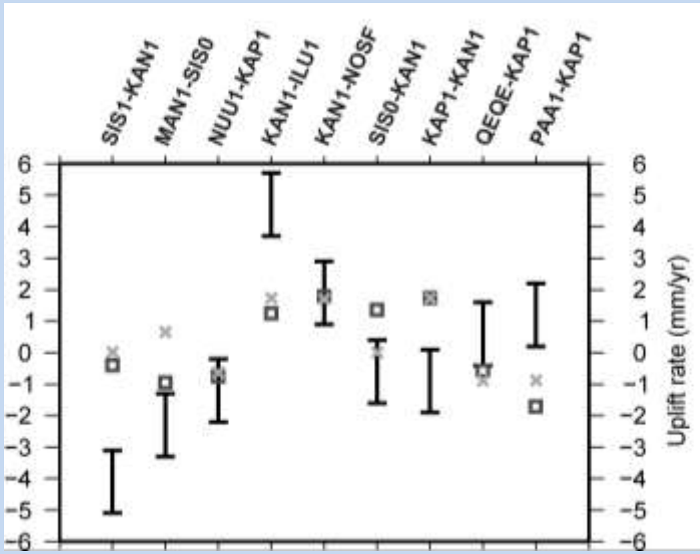
Viscous 1886 – 2005 Elastic 1995 – 2005

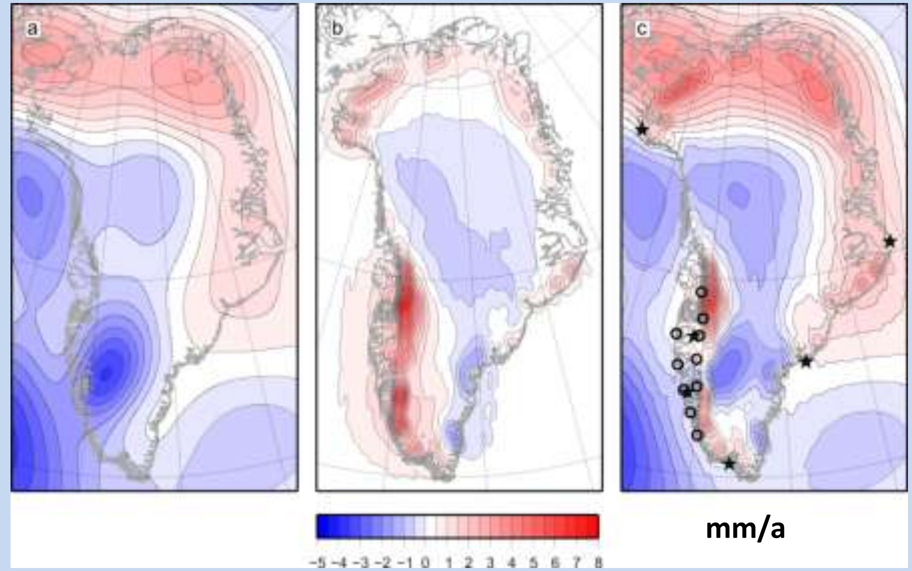



Does not account for non-steady-state ice-dynamic features (i.e. outlet glaciers).

NORWEGIAN MAPPING AUTHORITY

# Results – A hybrid model




**Huy2 + *Wake et al*. [2009] = Total**

| GPS locations | Observed uplift rates (mm/a) uncorrected for elastic term [*Khan et al*., 2008] | Predicted uplift rates (mm/a) | |
|---|---|---|---|
| | | Huy2 (best-fit Earth model) | Huy2-Wake (best-fit Earth model) |
| Kellyville | 0.2 1.1 | -0.94 | 0.42 |
| Nuuk | -1.5 1.3 | -1.92 | -0.71 |
| Qaqortoq | 1.1 1.1 | -0.66 | 0.2 |
| Kulusuk | 5.2 1.1 | 0.23 | 0.48 |
| Scoresby Sund | 0.9 1.1 | 1.17 | 1.5 |
| Thule | 3.9 1.1 | 0.02 | 0.93 |



NORWEGIAN MAPPING AUTHORITY

# Conclusions

**(1) Predicted present-day uplift rates in Greenland are strongly dependent on the adopted Earth model. In particular, predictions in southwest Greenland are *highly* sensitive to changes in upper mantle viscosity.**

**(2) Analysis of post-LGM Greenland loading changes shows how different periods of ice mass variation dominate in particular regions of Greenland.**

**(3) Results from the *Wake et al*. [2009] model indicate that decadal-scale ice mass variability over the past ~140 years plays only a small role in determining the present-day viscous response.**

**(4) Modern surface mass balance changes have a large influence on predicted present-day uplift rates in some regions of Greenland.**



NORWEGIAN MAPPING AUTHORITY