



# Accelerating Uplift in Greenland, Iceland and Svalbard

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# Background/Outline

- \*Greenland melting contributed  $\sim 0.2 - 0.4$  mm/yr of sea level rise for period 1990-2000, may increase in future
- \*Greenland vs Antarctica: Greenland is not at pole, impacted by Gulf Stream (may melt faster)
- \*Satellite monitoring: GRACE, Lidar, SAR/mass balance
- \*In principle, could also use isostasy (GPS)
- \*Problem: the past haunts us (visco-elastic effects: peripheral bulge from LGM; LIA)

# Sea Level Rise

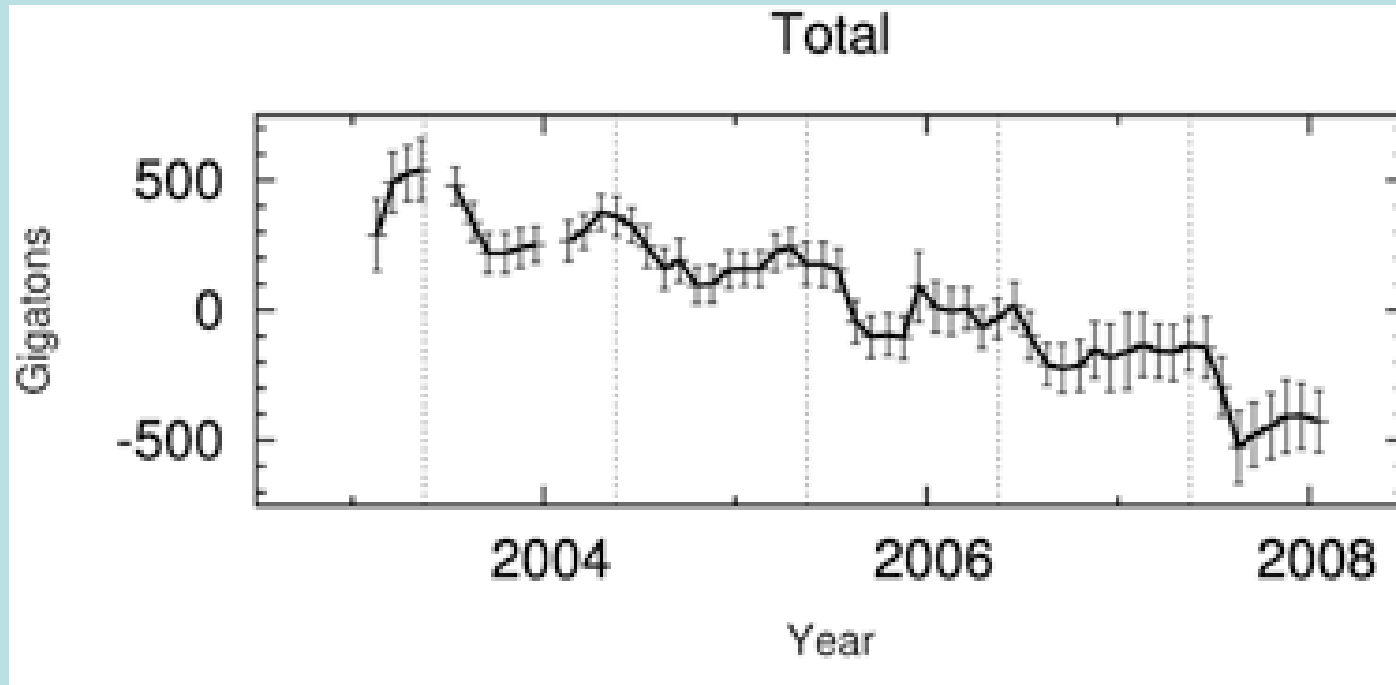
- Global average ~1.8 mm/yr from 1900-2000
- Composed of ~ 0.3- 0.5 mm/yr from mountain ice, ~0.70 - 1.0 mm/yr from thermal expansion
- Relatively small contribution from Greenland (<0.5 mm/yr)
- Current rate:
  - Roughly double?
  - Difficult to measure directly (large decadal fluctuations)
  - Direct measurement of melt contribution from Greenland, Antarctica is important

# Direct Melting Measurements

- Altimetry
- Gravity
- Mass accumulation/loss

# GRACE Data

- 2003-2008 average loss  $\sim 180$  GT/yr



Wouters et al., 2008

# Importance of Glacial Isostatic Adjustment (GIA)

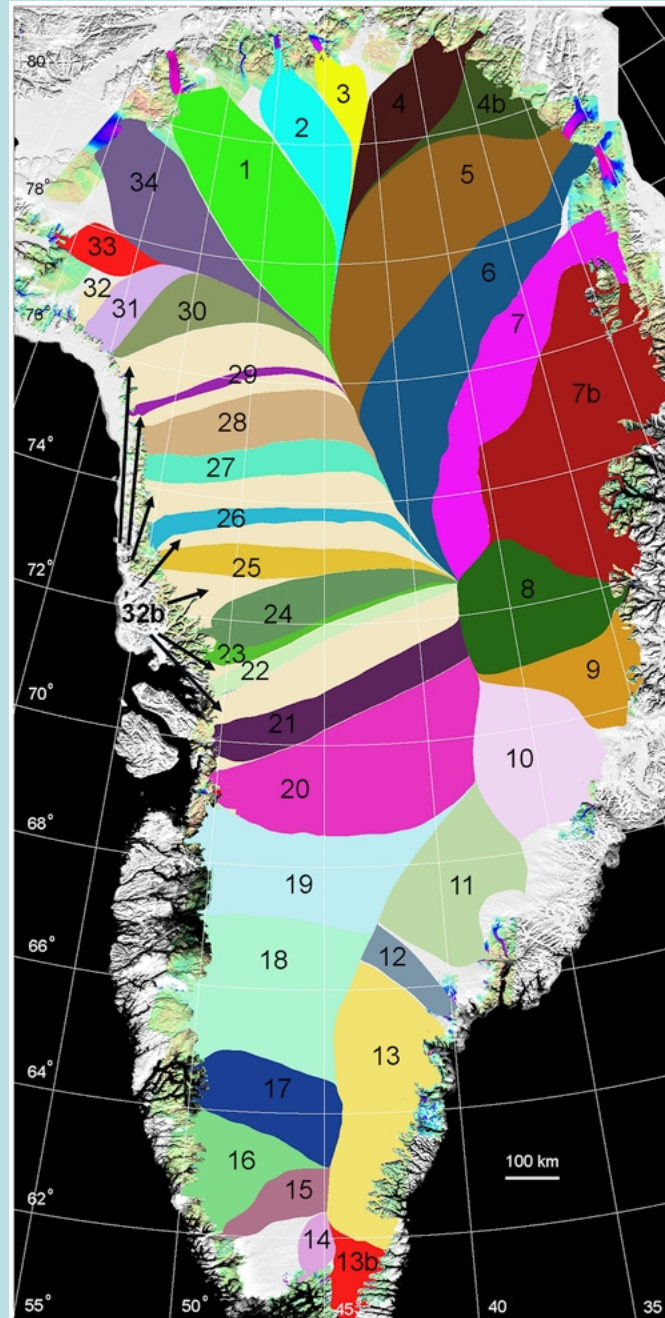
- Both GRACE and Altimetry depend on a model for GIA
- GIA models depend on:
  - Mantle viscosity structure (poorly known)
  - Ice melting history (very poorly known)

# Mass Accumulation/Loss Estimates

- Does not depend on GIA
- Requires estimation of interior snow accumulation, peripheral loss by calving and melting
- Done for each drainage basin, then summed

# Major Drainage Basins

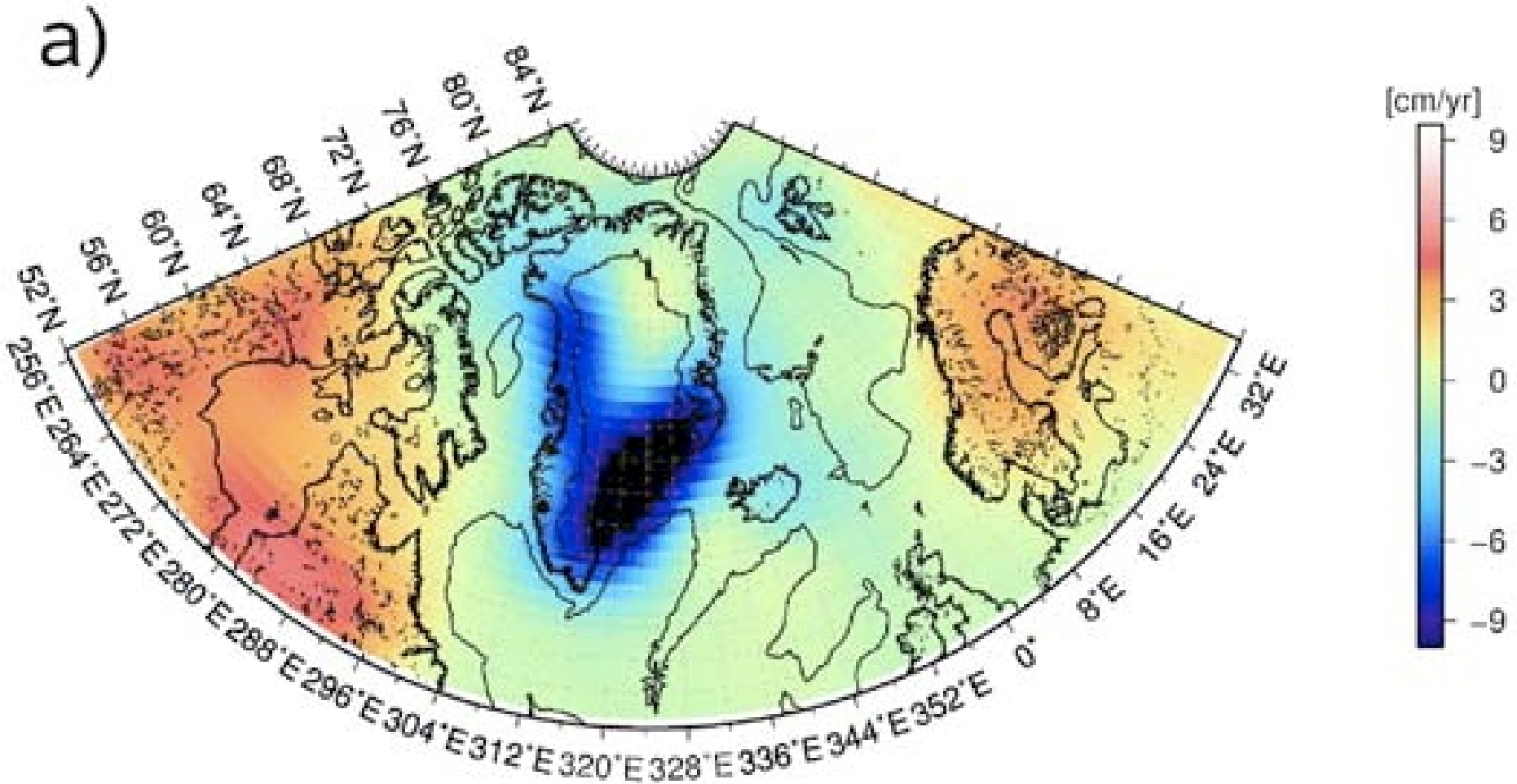
Rignot et al  
2008



# Mass Accumulation/Loss

- Subtract two large numbers, each with uncertainties, to obtain a small number
- Suggests accumulation rate  $\sim$  constant, but increasing loss at margins
- Consistent with GRACE results

# GRACE 2003-2008



Wouters et al (2008)

# GPS as a Tool for Monitoring Greenland

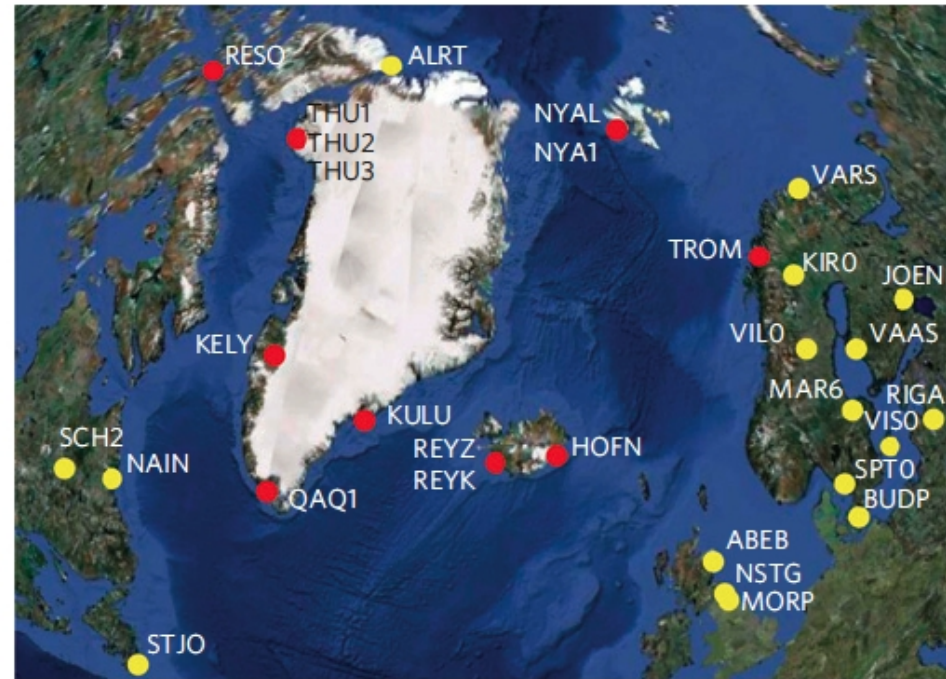
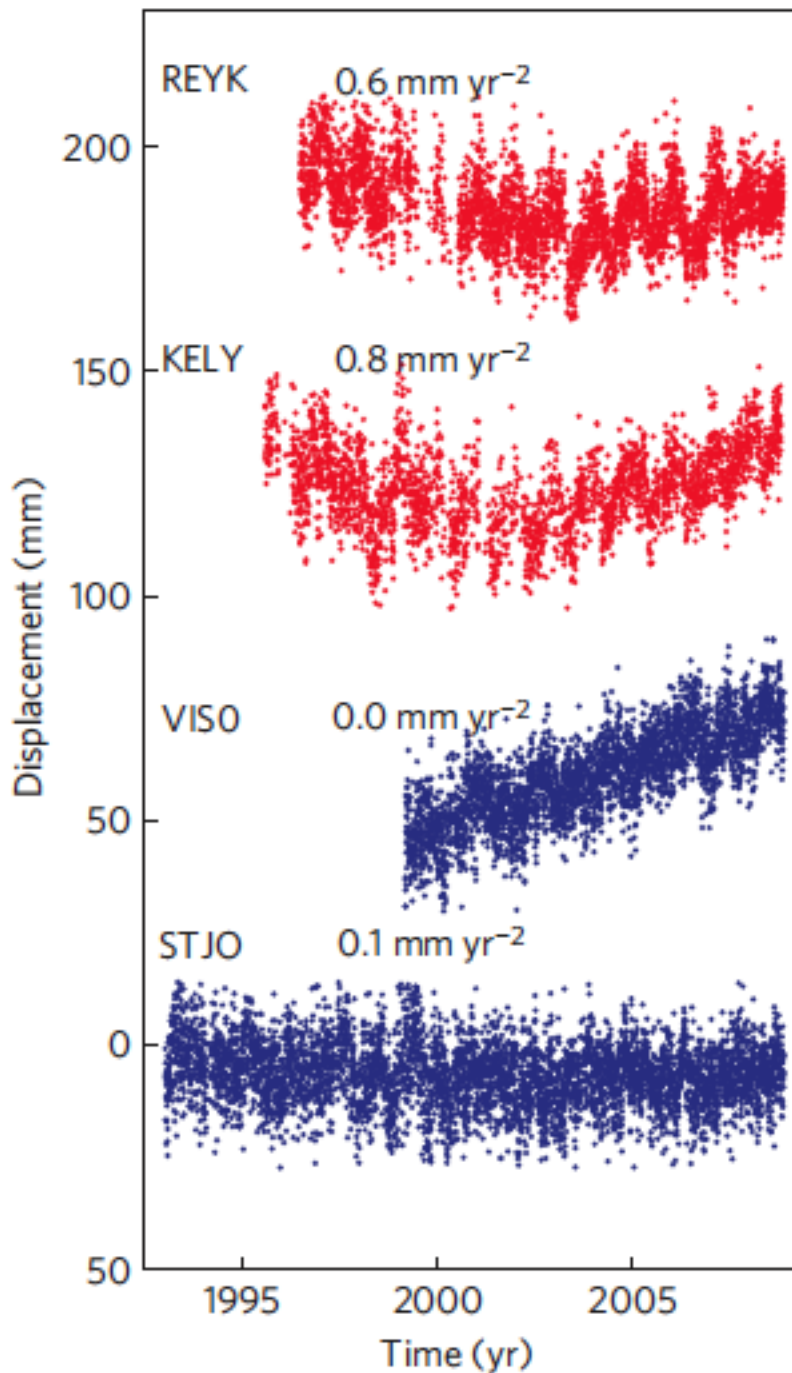
- Restricted to rocky coast (but that is where loss is concentrated)
- MAL studies indicate interior in approximate mass balance (outflow to edges balanced by new snow)
- Need to deal with GIA
- Most GIA models predict that Greenland is subsiding due to peripheral bulge collapse from Laurentide glaciation

# “Correcting” for GIA

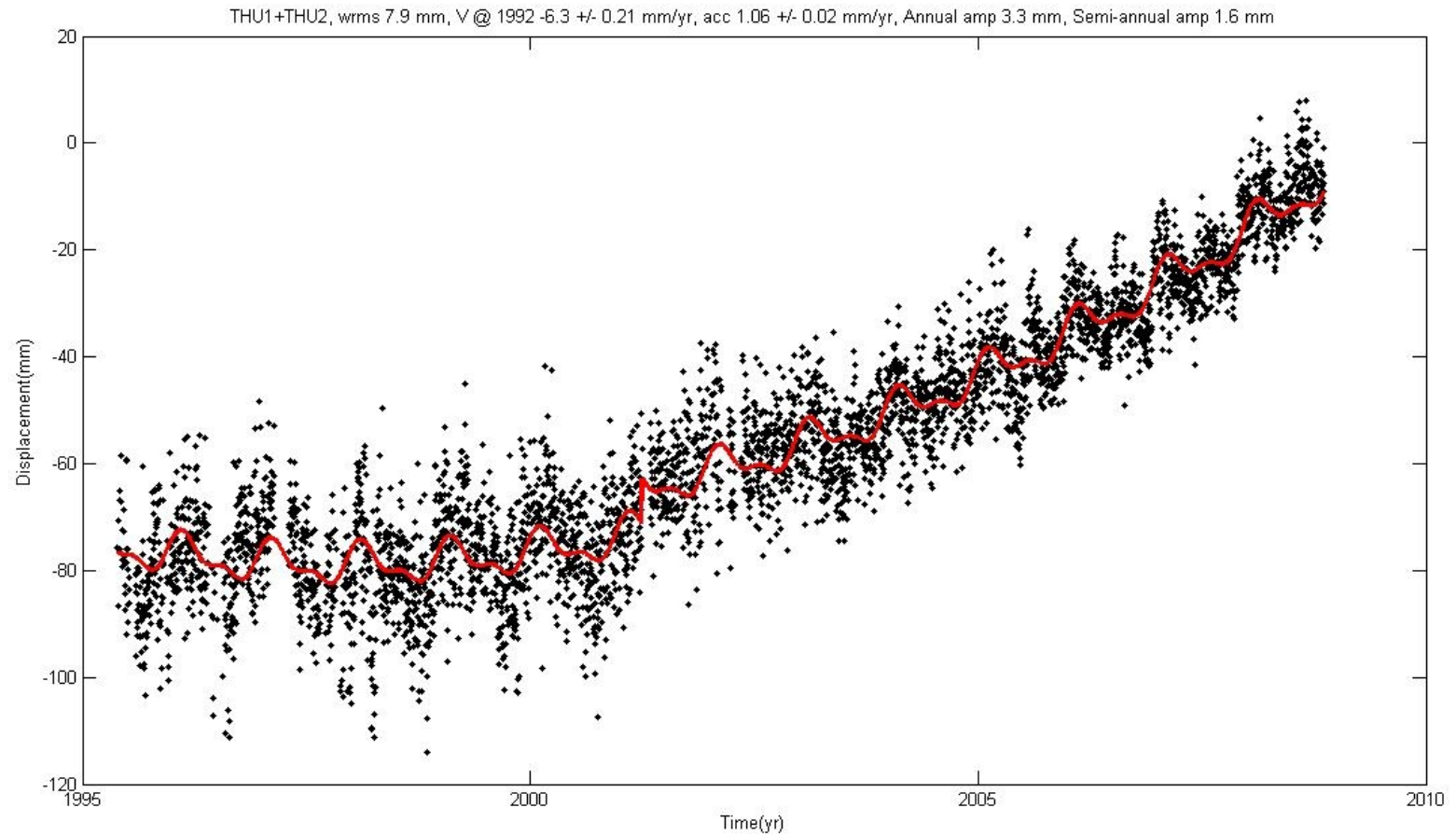
- GIA models are “noise source” if we want to look at present-day melting
- Focus on perturbations to velocity field (accelerations) rather than velocity field itself

# GPS time series

## Vertical component



**GPS Position Time Series:** account for equipment change, annual variation, and possible rate changes; use 7 parameter model (red line). All Greenland sites show acceleration

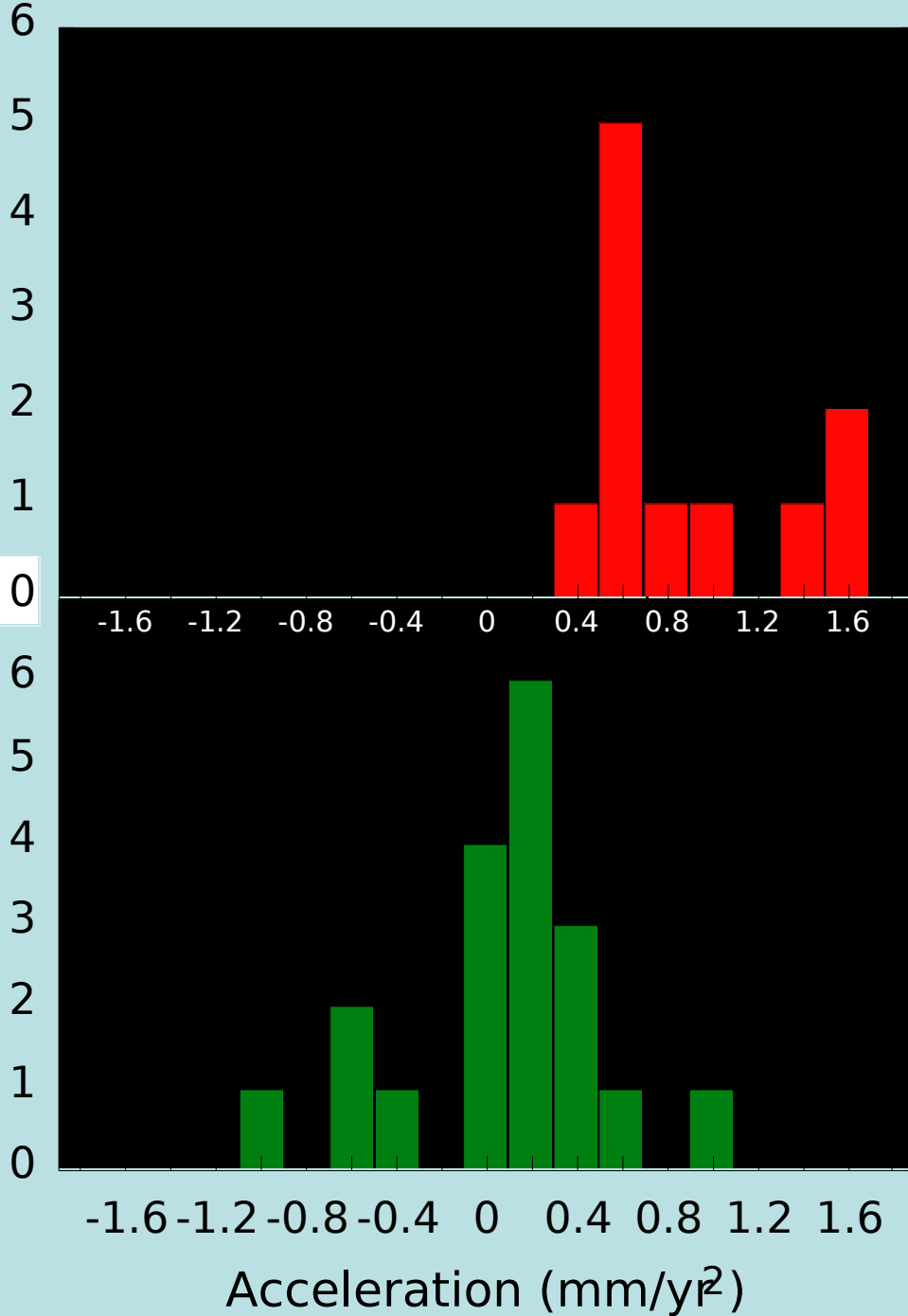


# Reference Frame Effects

- Previous studies have assumed that deviations from linear trend reflect long term drift of GPS reference frame
- Evaluate via regional comparisons (Fennoscandia, Canada)

# Acceleration

Number of Sites



# Implications of Accelerating Uplift

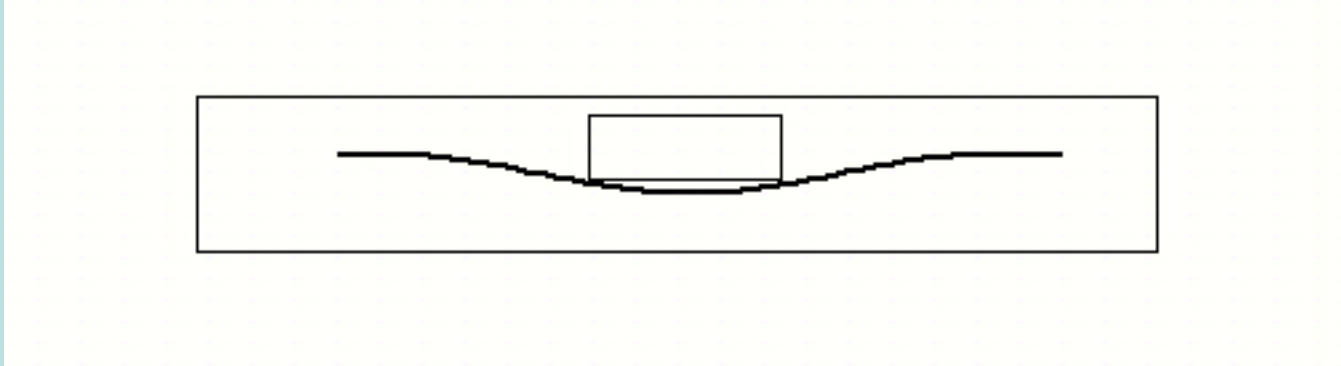
- Accelerating uplift implies accelerating ice loss in regions with multi-year land ice
- Unlikely to be reference frame effect (not observed in Fennoscandia or northern Canada)
- Time scale implies mainly elastic response to mass unloading
- Evidence from phase of annual term supports elastic response



MODIS  
Summer 2006  
Western Greenland

0 100 km

# Modified 2-D Model: Finite Width Line Load



$$U @ \frac{3.3(1 - \nu)}{pG} [N_0]$$

*Jaeger et al., 2007*

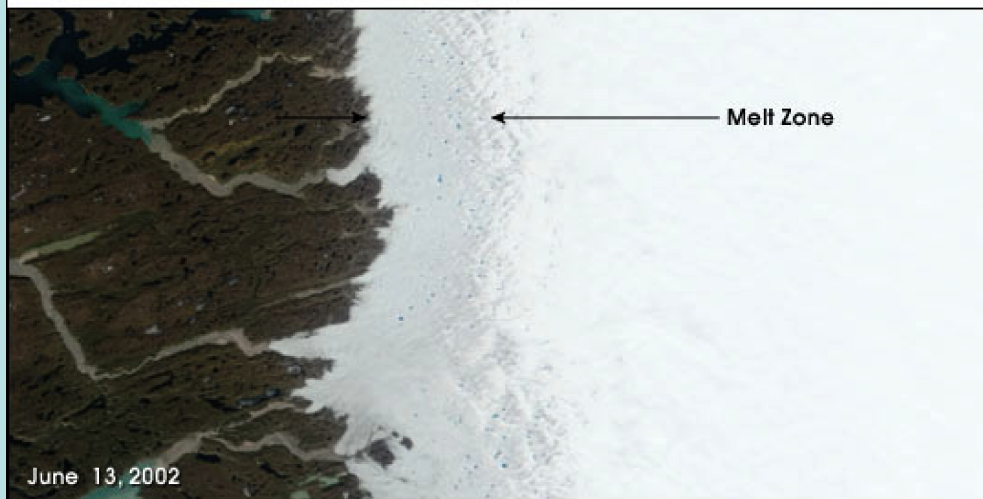
# Model results

- Applicable to western and southeastern Greenland, where melting is focused in narrow coastal band
- 1 mm/yr of increased uplift =>load change of  $\sim 5 \cdot 10^7 \text{ N/m}^2$
- For 1700 km coastal strip in W Greenland, implies acceleration  $\sim 8 \text{ GT/yr}^2$
- Corresponding SE Greenland value  $\sim 12 \text{ GT/yr}^2$
- $\sim$  agreement with GRACE result

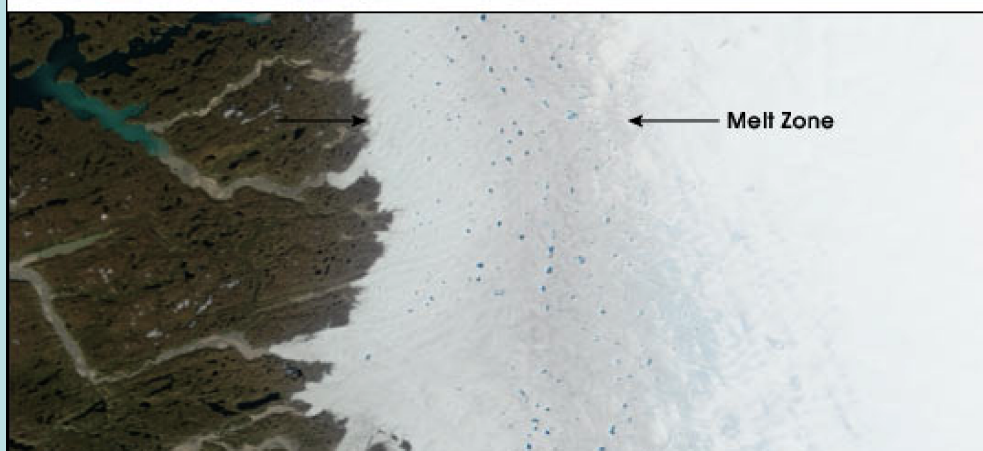
June 2001

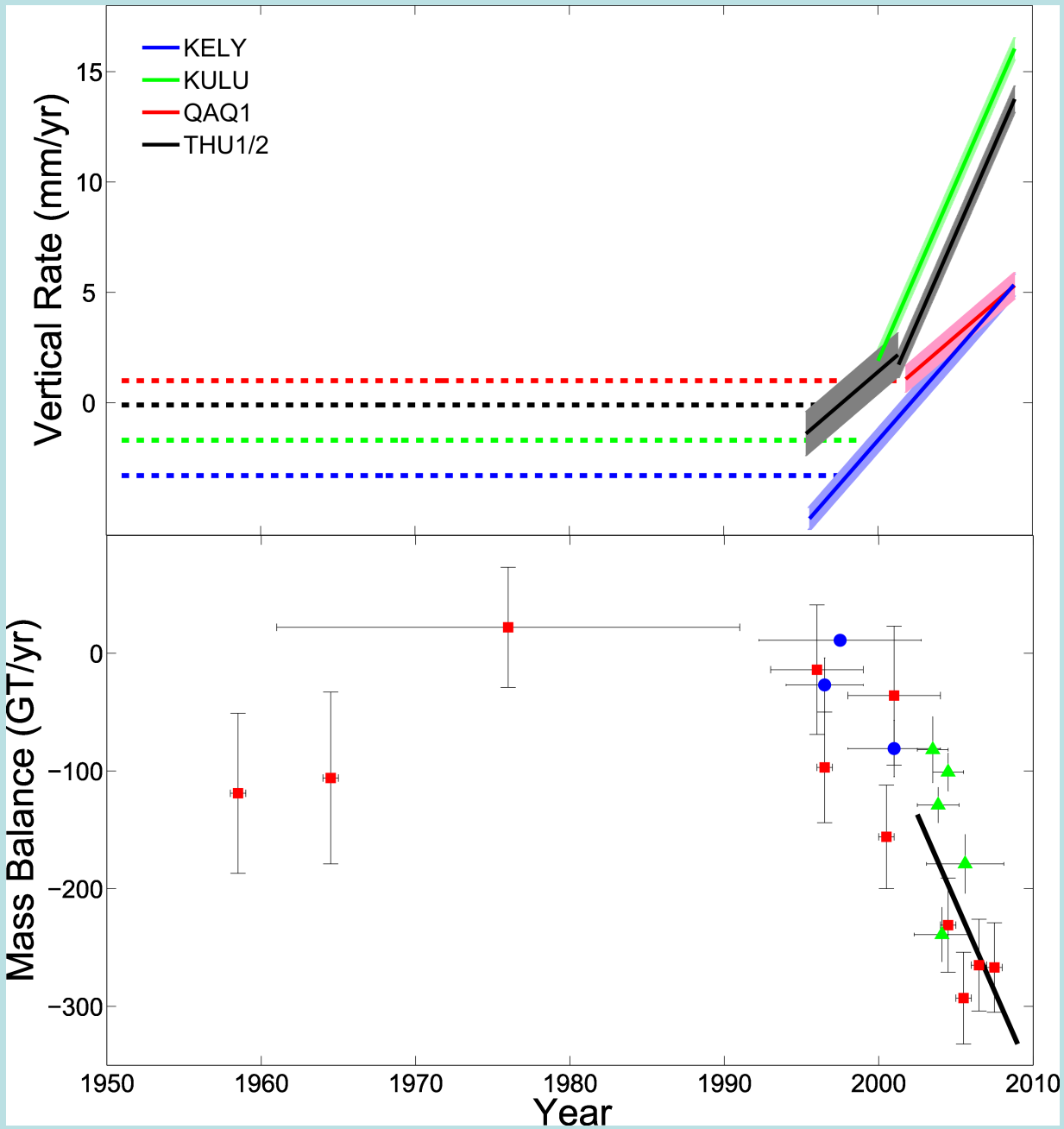


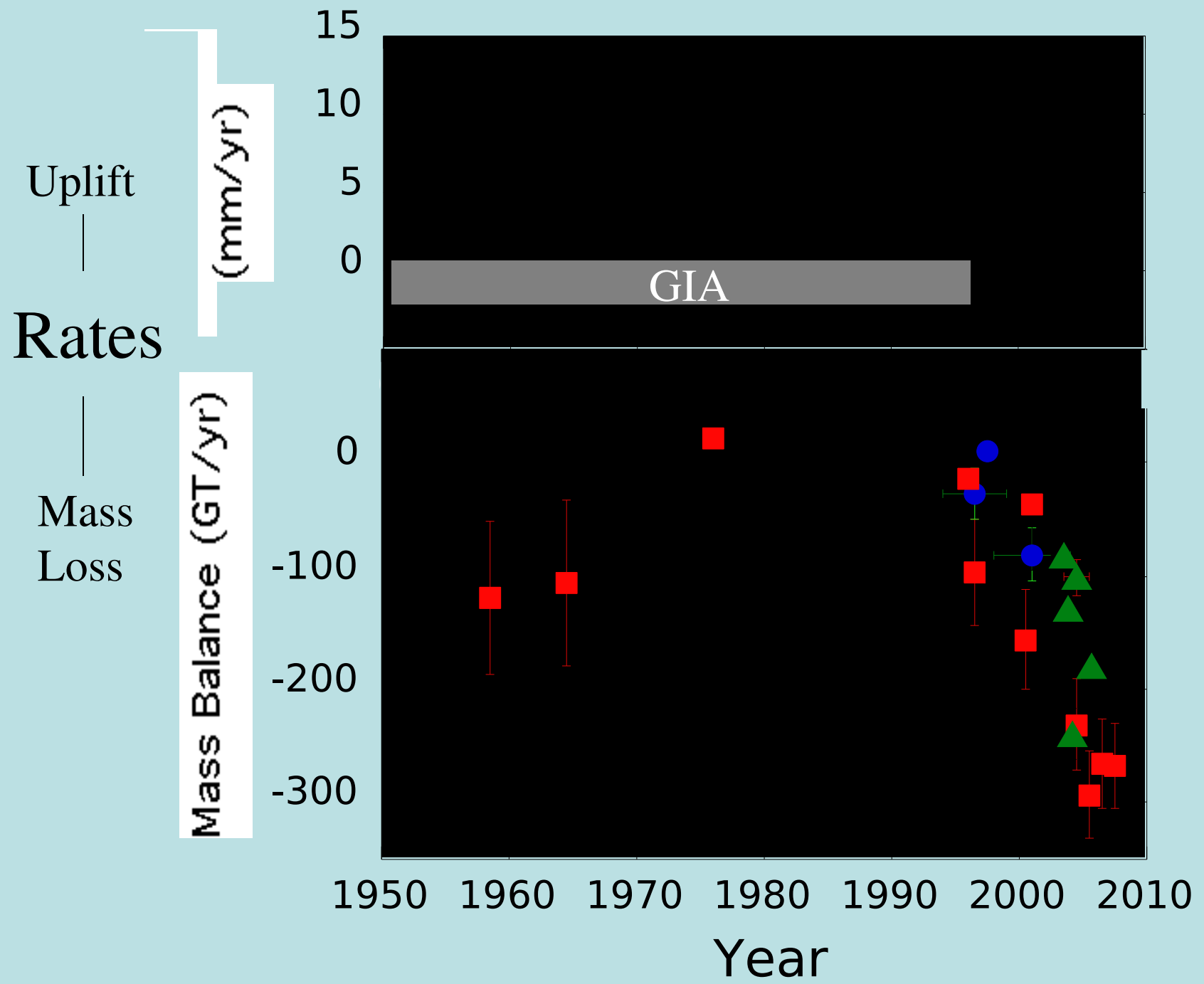
June 2002



June 2003





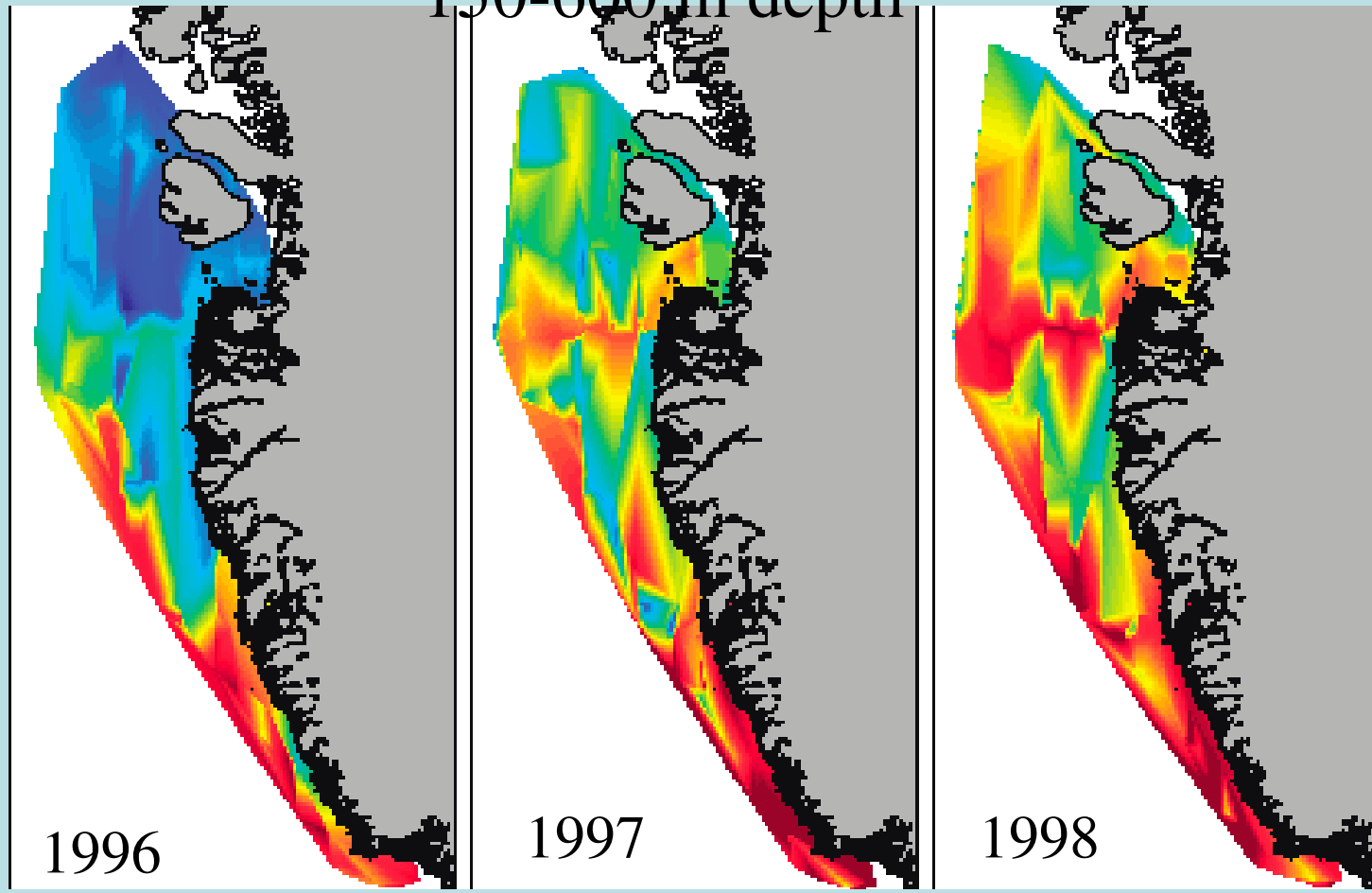


# Constraints on Timing

- Only two GPS stations operating in 1995, both on west coast
- Suggests accelerated uplift and coastal melting began in mid or late-90's (based on departure from GIA model)
- GRACE measurements began in 2002, confirm post-2000 acceleration
- What happened in mid-late 1990's? (air temp ~ constant)

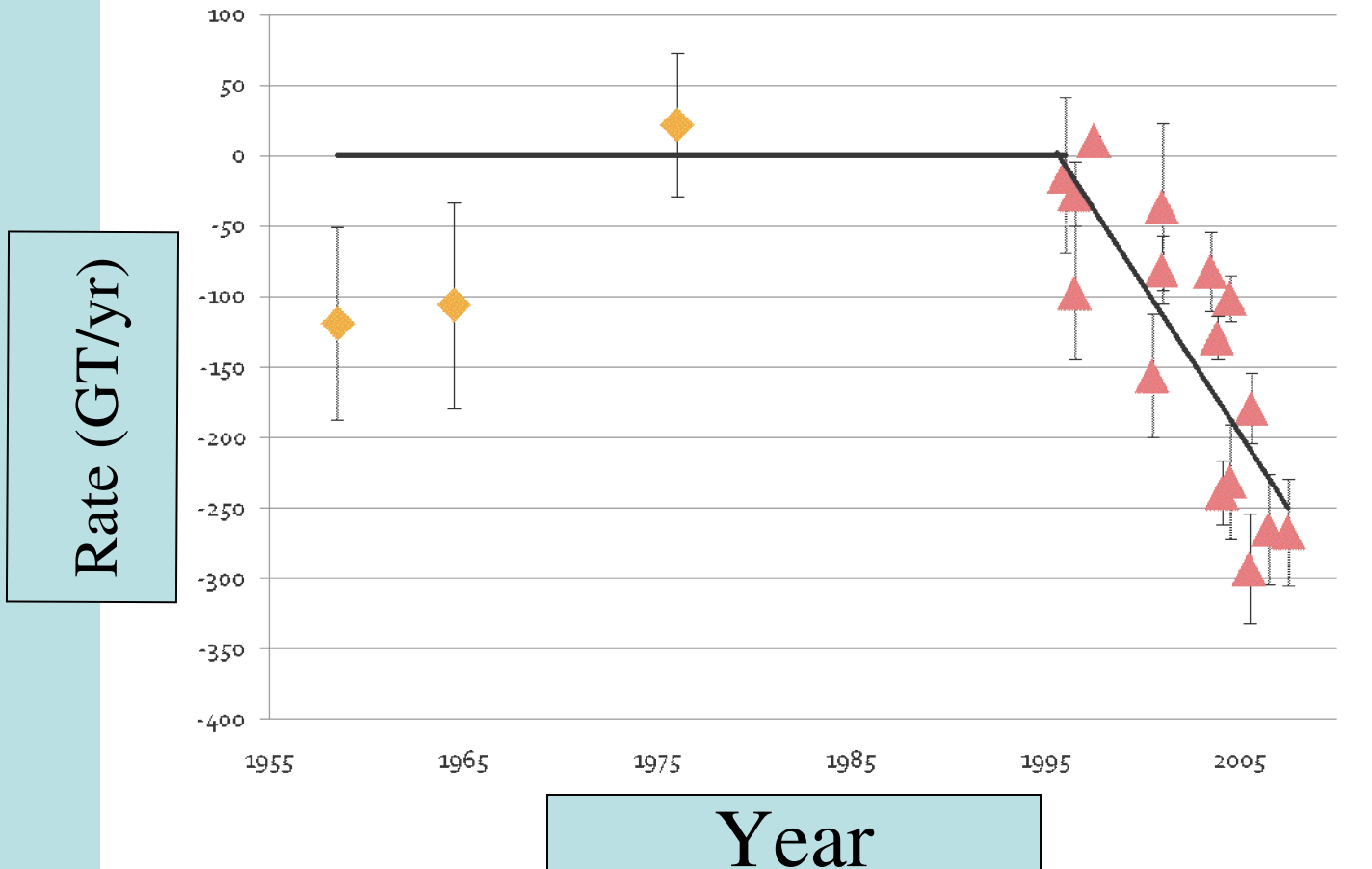
# Sub-Surface Water Temperature, Western Greenland

150-600 m depth



# Implications for future sea level rise?

Assume linear behavior after 1995



# Greenland contribution to Sea Level Rise

5

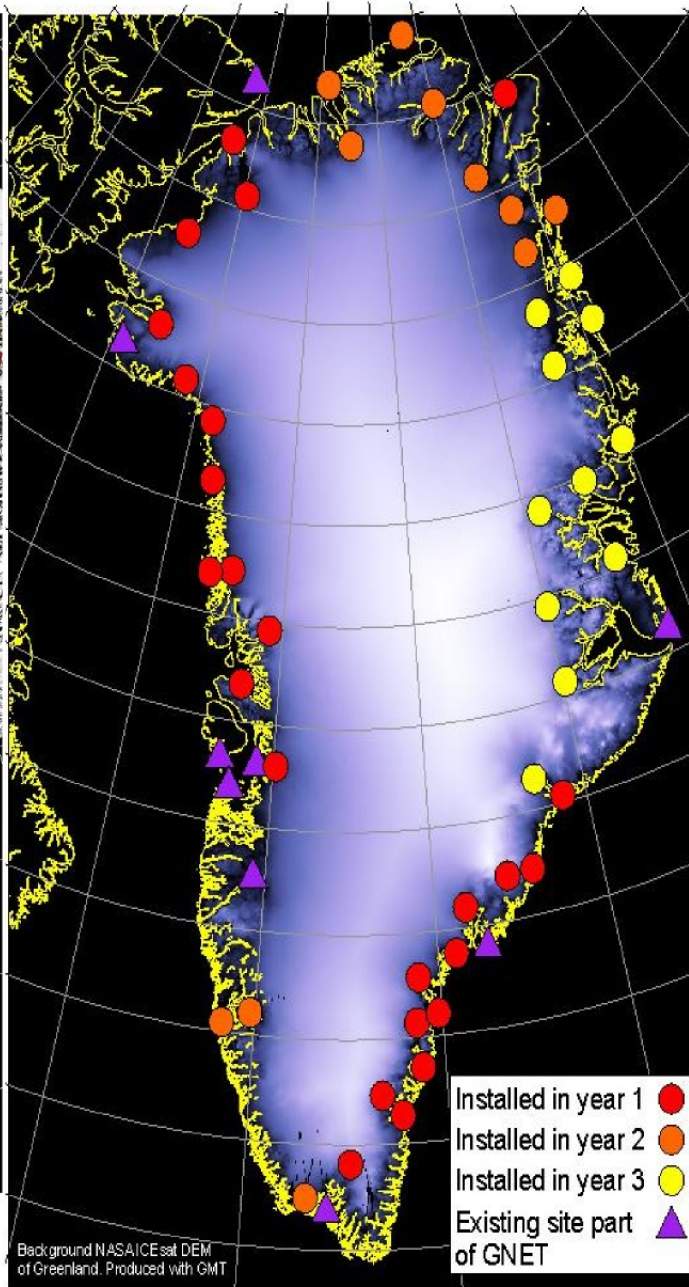
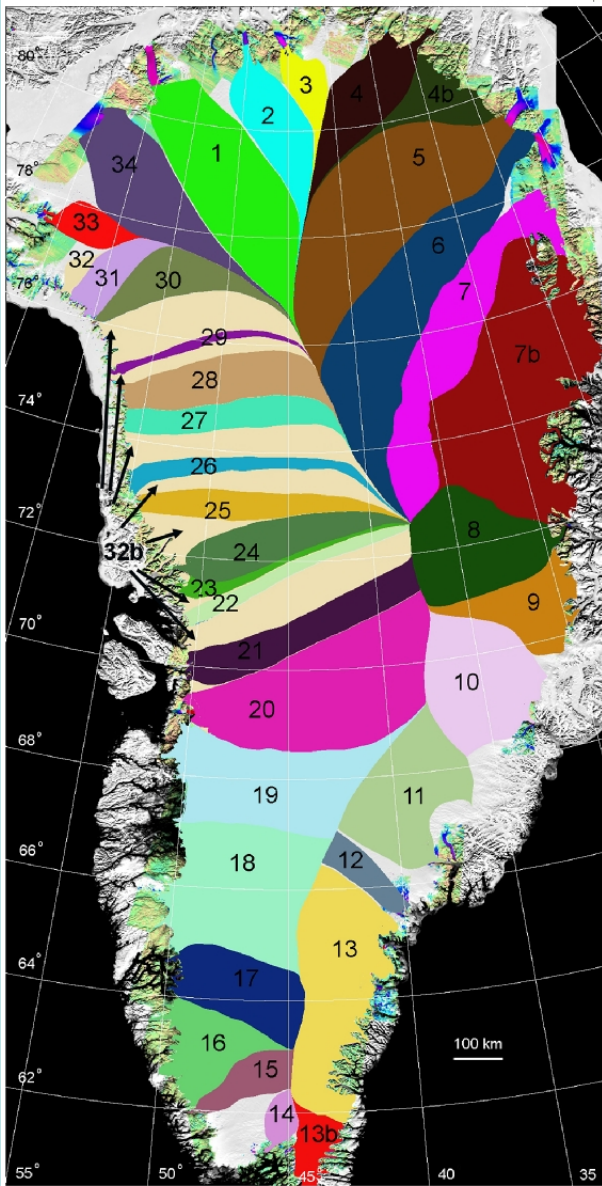
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5

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GNET:  
will provide  
basin-by-  
basin  
view of ice  
health

# Conclusions

- Perturbations to the vertical velocity field measured by GPS are sensitive to recent land ice melting
- Uplift of Greenland, Iceland and Svalbard is accelerating
- A simple elastic model for coastal melting in Greenland gives ice loss is approximate agreement with other techniques