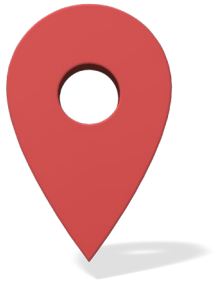


NYA GEODETISKA FORSKNINGSRESULTAT OM LANDHÖJNING OCH KLIMATFÖRÄNDRING

HOLGER STEFFEN

MED STORT TACK TILL ABBAS KHAN, VALENTINA BARLETTA (DTU SPACE, DENMARK), REBEKKA STEFFEN (LM) OCH TERRY WILSON (OSU, USA)

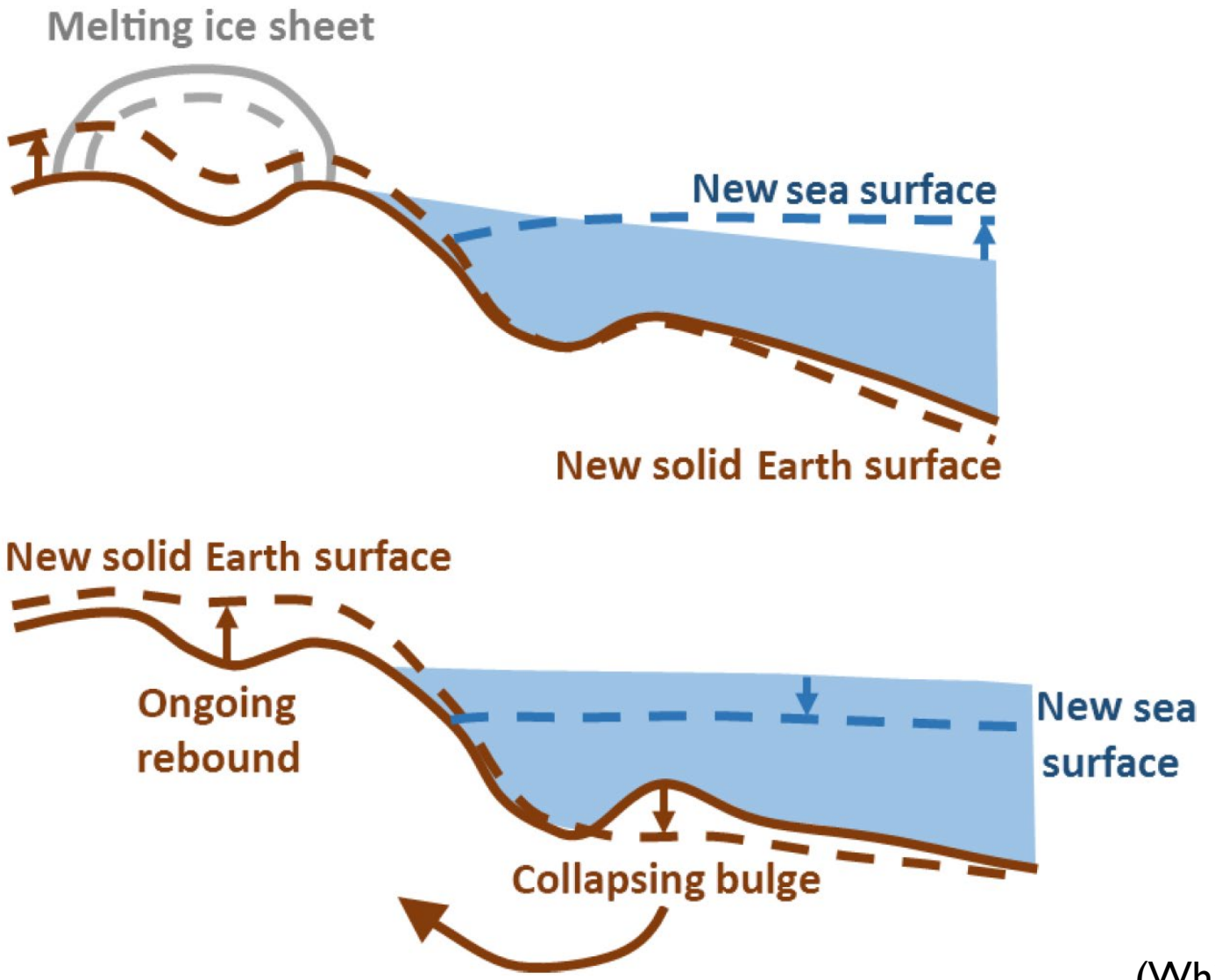
LANTMÄTERIET

GEODESY RESEARCH AT LANTMÄTERIET

- According to Lantmäteriet's instruction, research in the field of geodesy shall be conducted
- Grounds on maintenance, usage and sustainability over time of the reference systems as well as techniques and methods for positioning
- Analyze technical, instrumental and environmental effects on reference systems and our geodetic observations
- Examples:
    - Water vapor in the atmosphere
    - Gravity measurement techniques
    - **Land uplift and corresponding sea level change**
- National and international cooperation

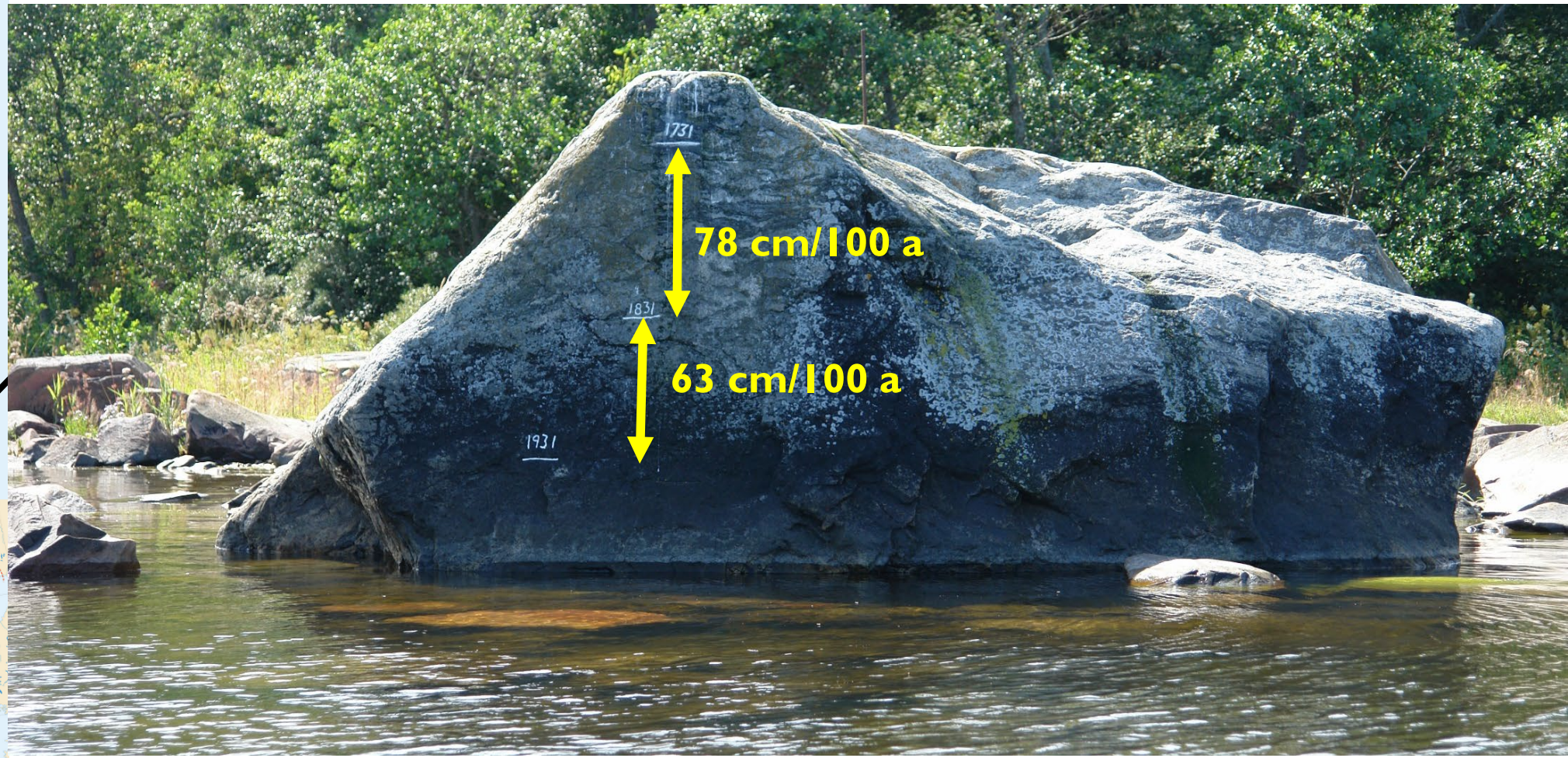
GLACIAL ISOSTATIC ADJUSTMENT

Solid earth,
simplest form



(Whitehouse, 2018)

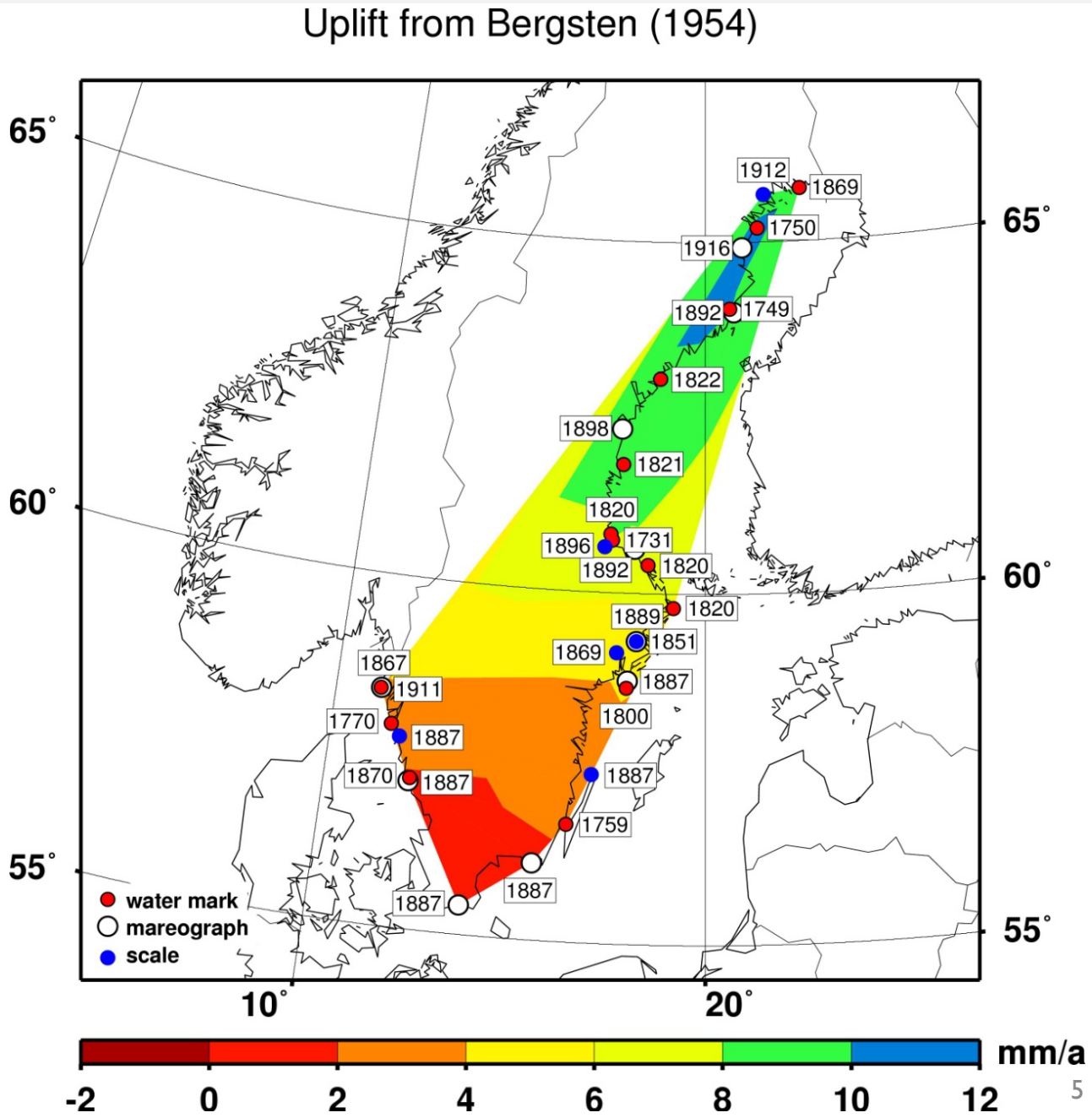
CELSIUS ROCK ON LÖVGRUND



(Source: https://upload.wikimedia.org/wikipedia/de/0/03/Karte_Gävlefischer.png)

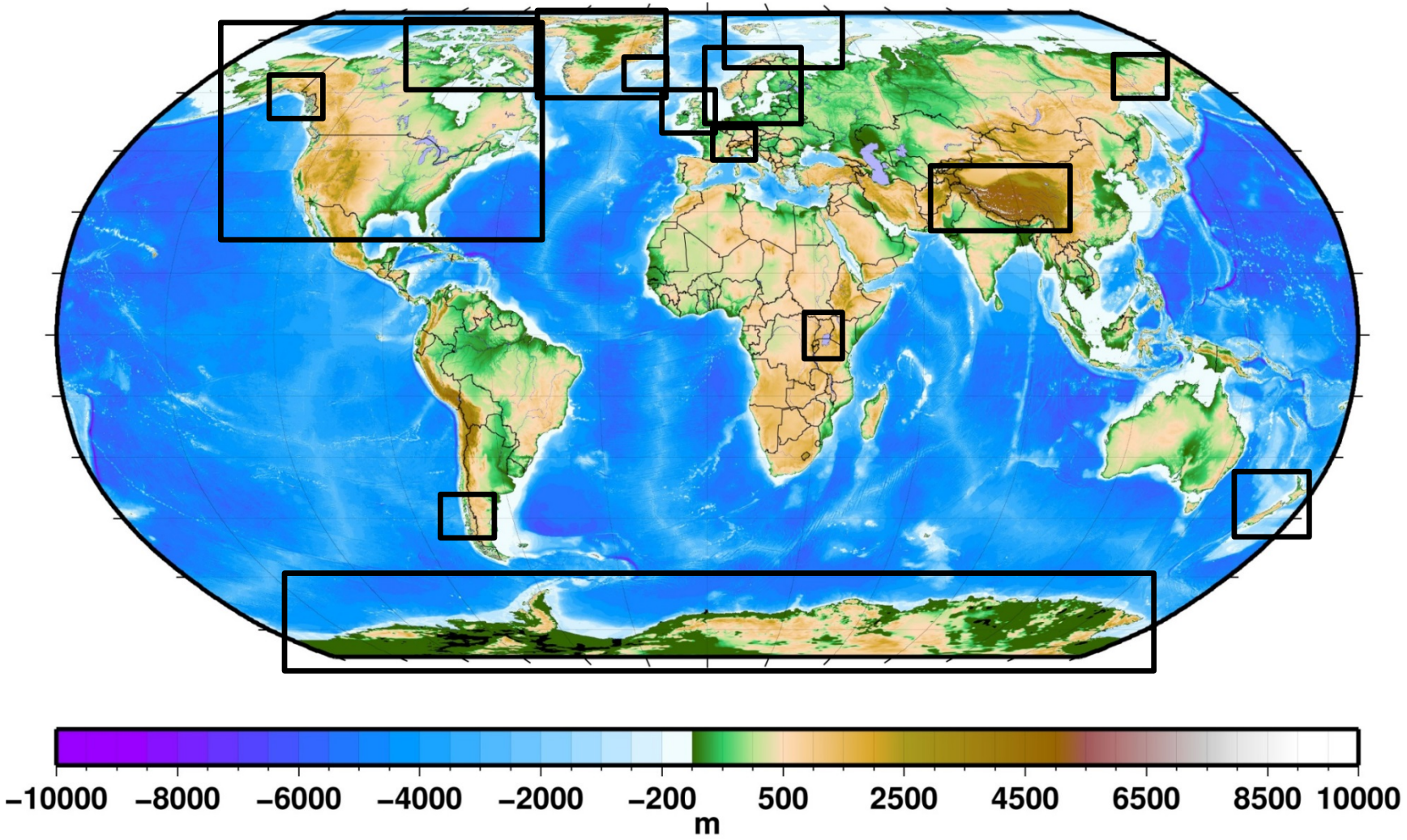
UPLIFT RATE FROM WATER MARKS IN FENNOSCANDIA

Uplift! Not sea-level fall!



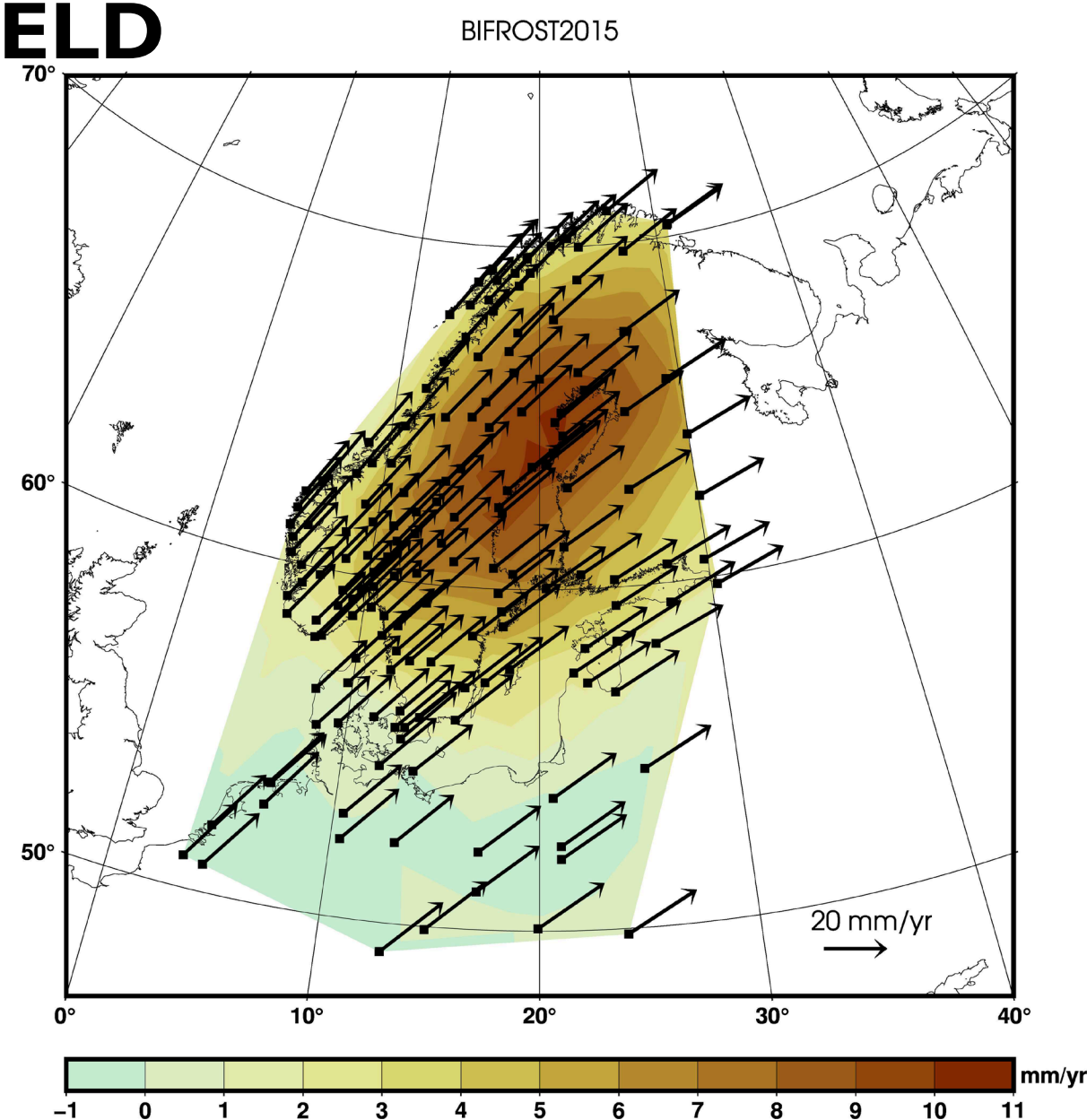
(Steffen and Wu 2011)

GIA AROUND THE WORLD



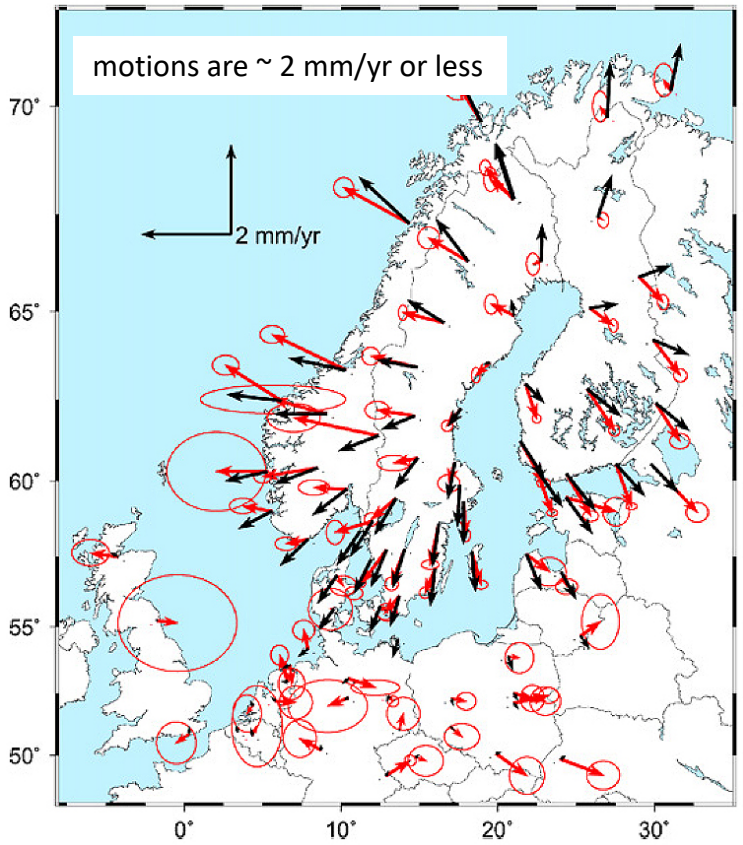
BIFROST2015 VELOCITY FIELD

- Uplift >1cm/a in the centre (somewhere between the cities of Umeå and Skellefteå), forebulge with 1-2 mm/a subsidence in northern Germany and Poland
- Horizontal motion generally 2-3 cm/a northeastward



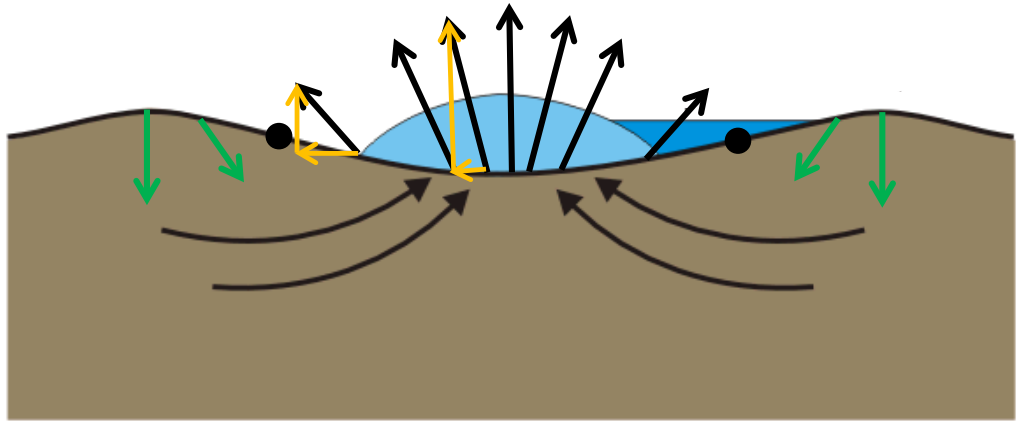
(Kierulf et al., submitted)

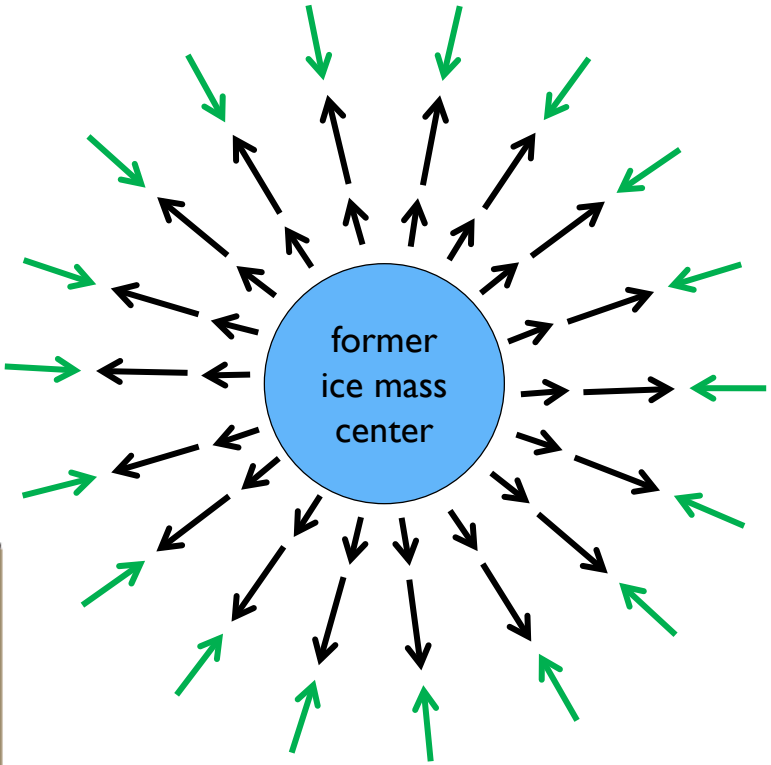
HORIZONTAL DEFORMATION DUE TO GIA



(Lidberg et al. 2010)

During deglaciation, crustal horizontal motions are radially away from the former ice mass center, and increase in magnitude away from the load.
In the forebulge region, motions are towards the former ice mass center.

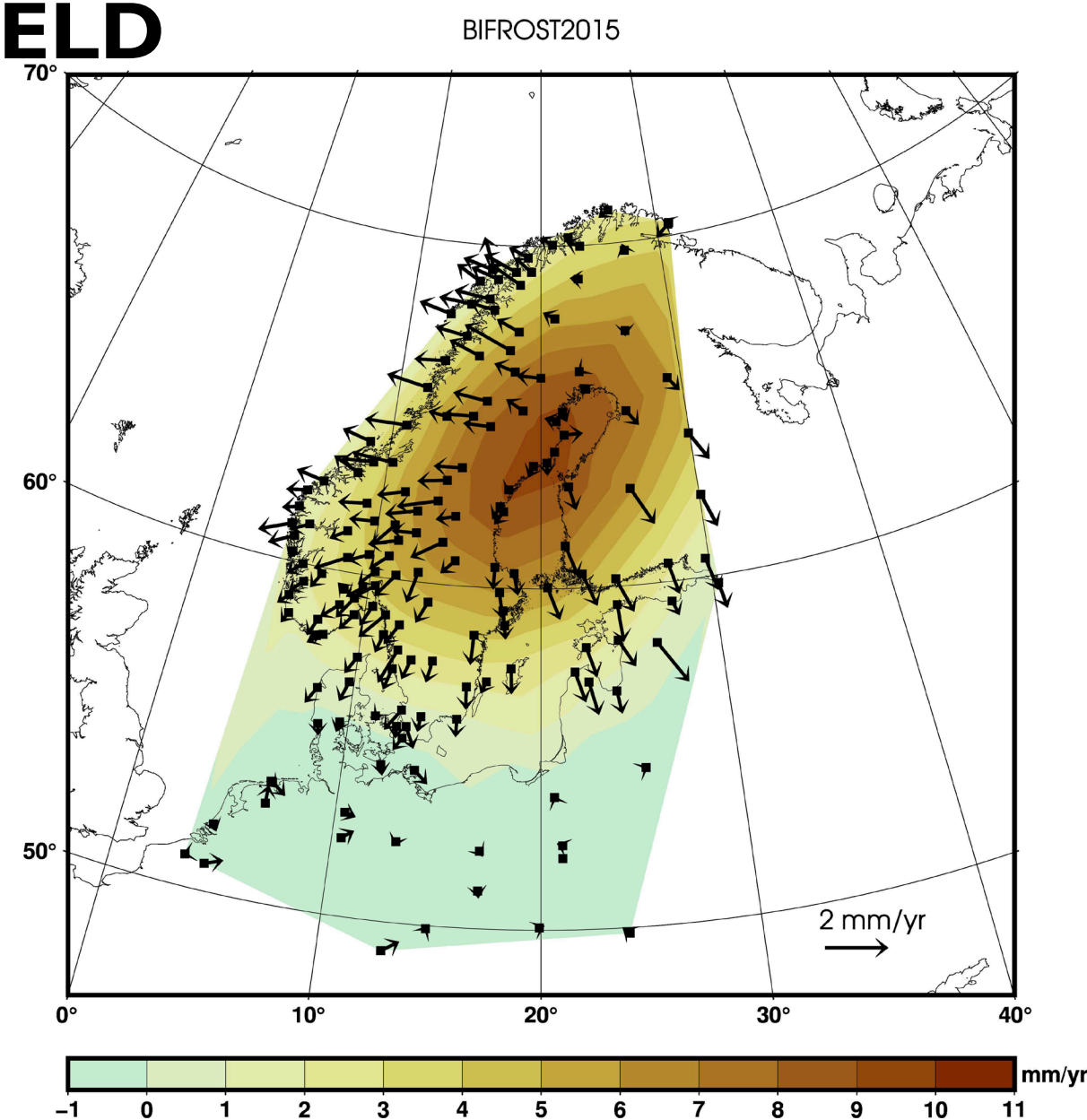




(Slide courtesy of Pippa Whitehouse and Stephanie Konfal)

BIFROST2015 VELOCITY FIELD

- Uplift >1cm/a in the centre (somewhere between the cities of Umeå and Skellefteå), forebulge with 1-2 mm/a subsidence in northern Germany and Poland
- Horizontal motion on the European Plate removed



(Kierulf et al., submitted)

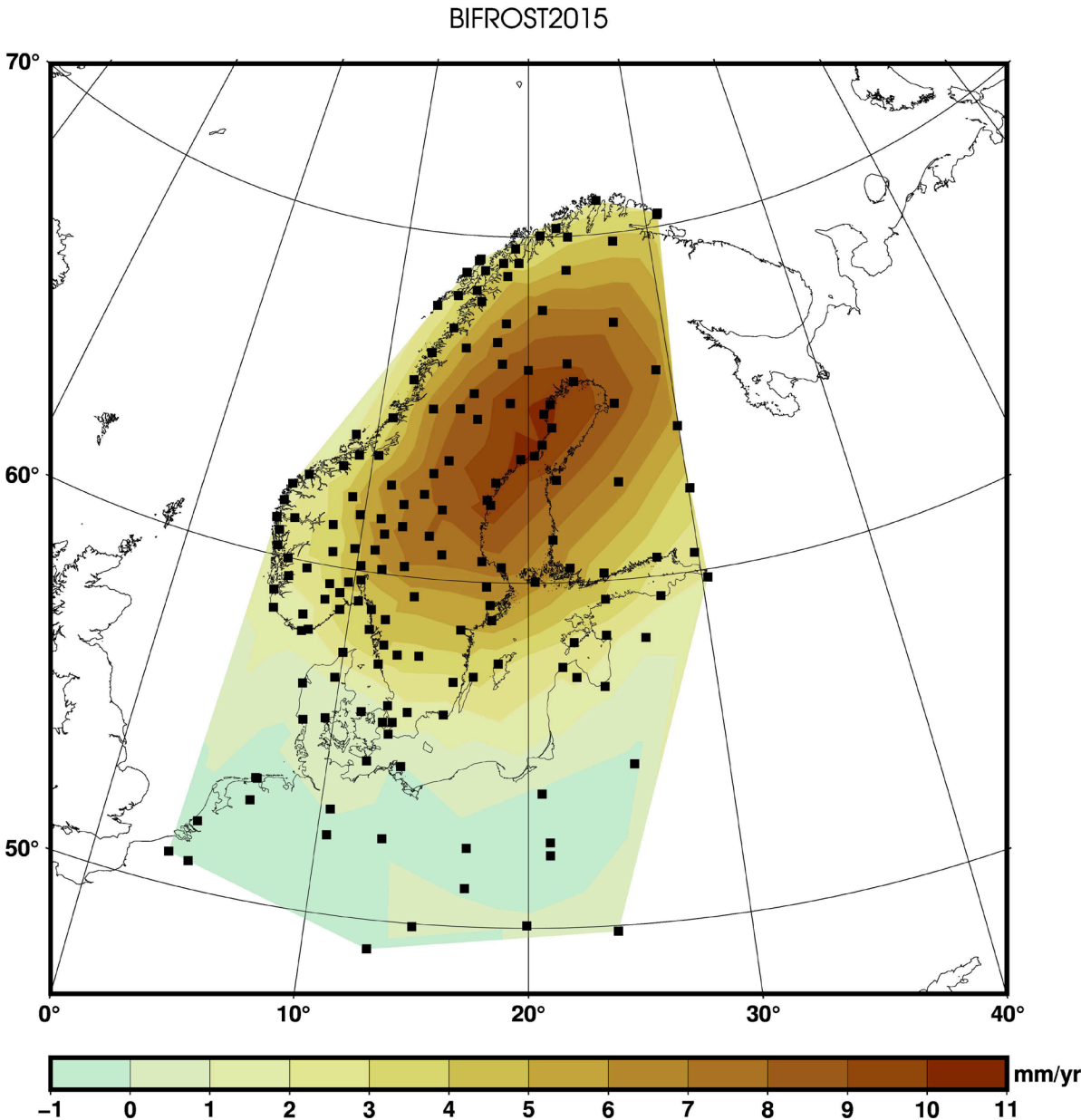
BIFROST2015 UPLIFT

- Uplift >1cm/a in the centre (somewhere between the cities of Umeå and Skellefteå), forebulge with 1-2 mm/a subsidence in northern Germany and Poland
- In an ideal world, uplift pattern consists of:

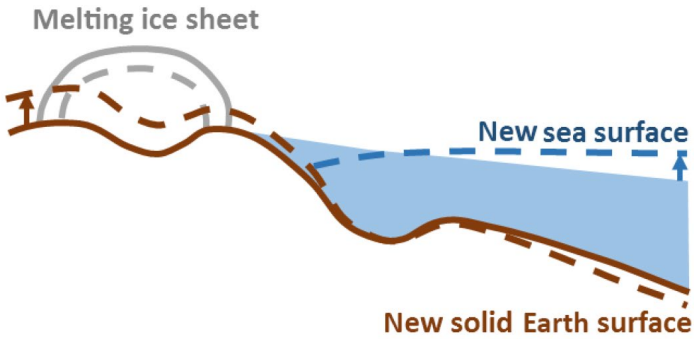
$$\dot{h}_{total} = \dot{h}_{GIA} + \dot{h}_{unmodelled\ errors}$$

$$\dot{h}_{total} = \dot{h}_{GIA} + \dot{h}_{ice\ melt} + \dot{h}_{hydrology} + \dot{h}_{geology} + \dot{h}_{unmodelled\ errors}$$

(Kierulf et al., submitted)



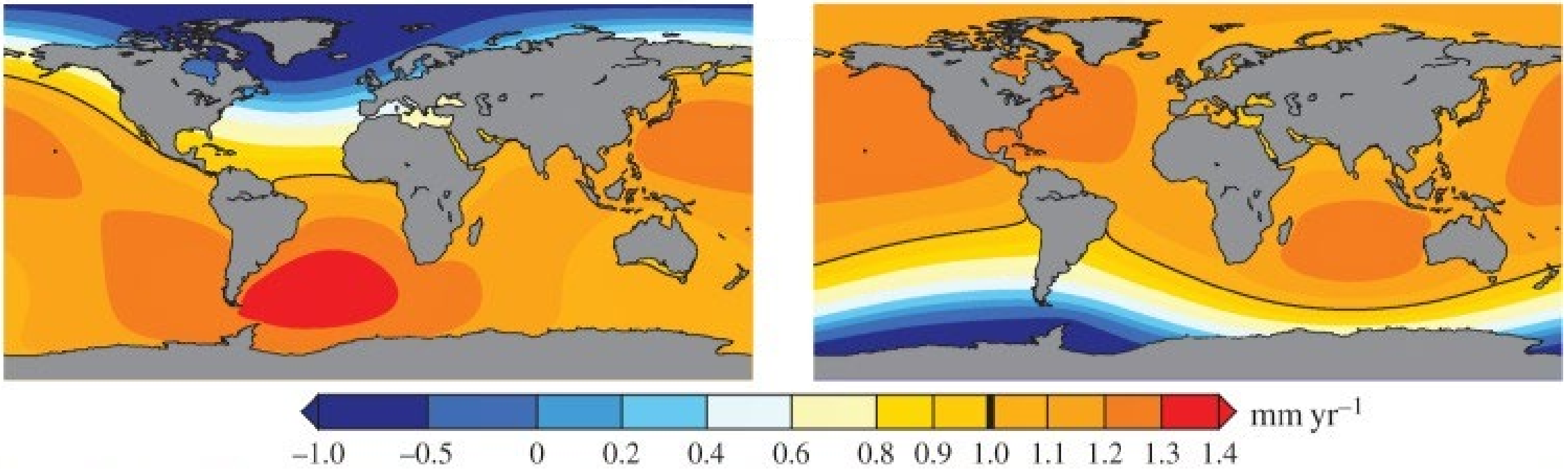
SEA-LEVEL FINGERPRINT



(Whitehouse 2018)

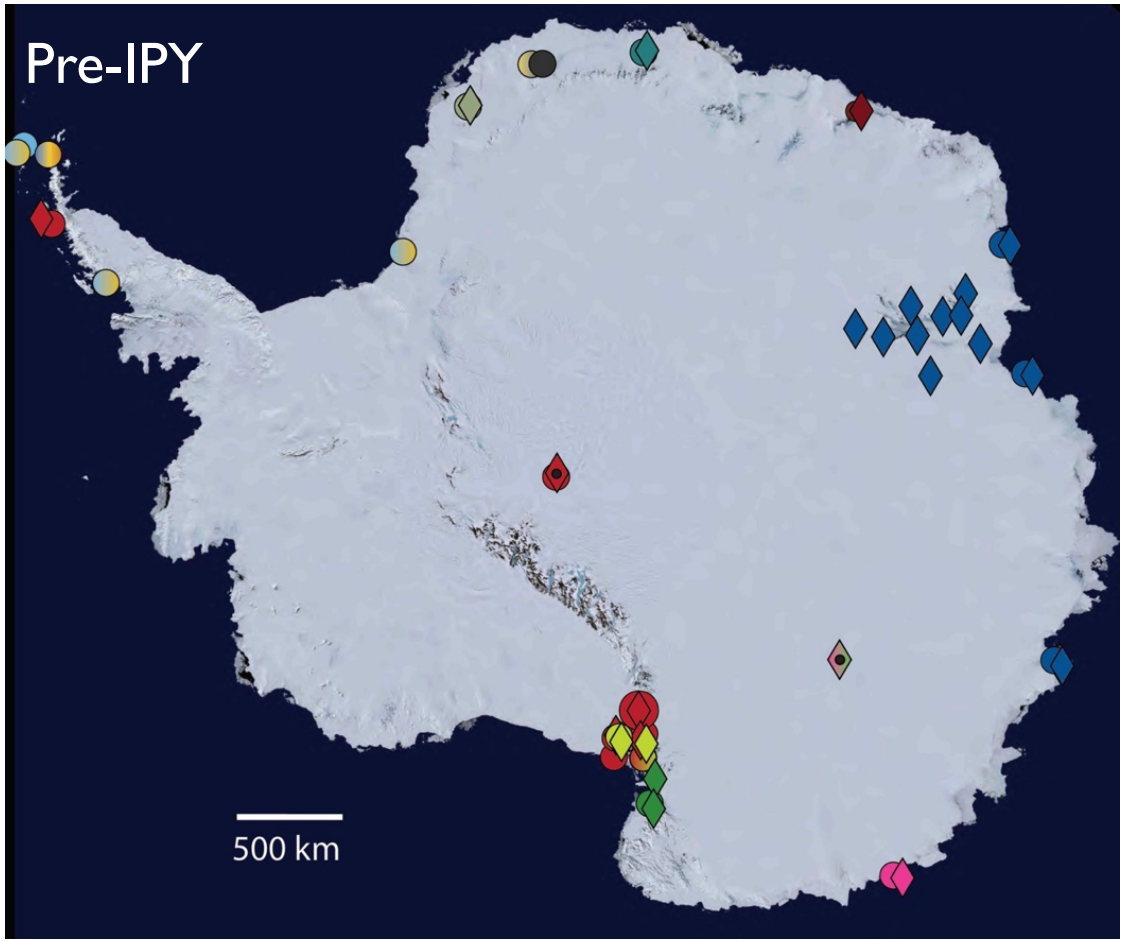
Greenland

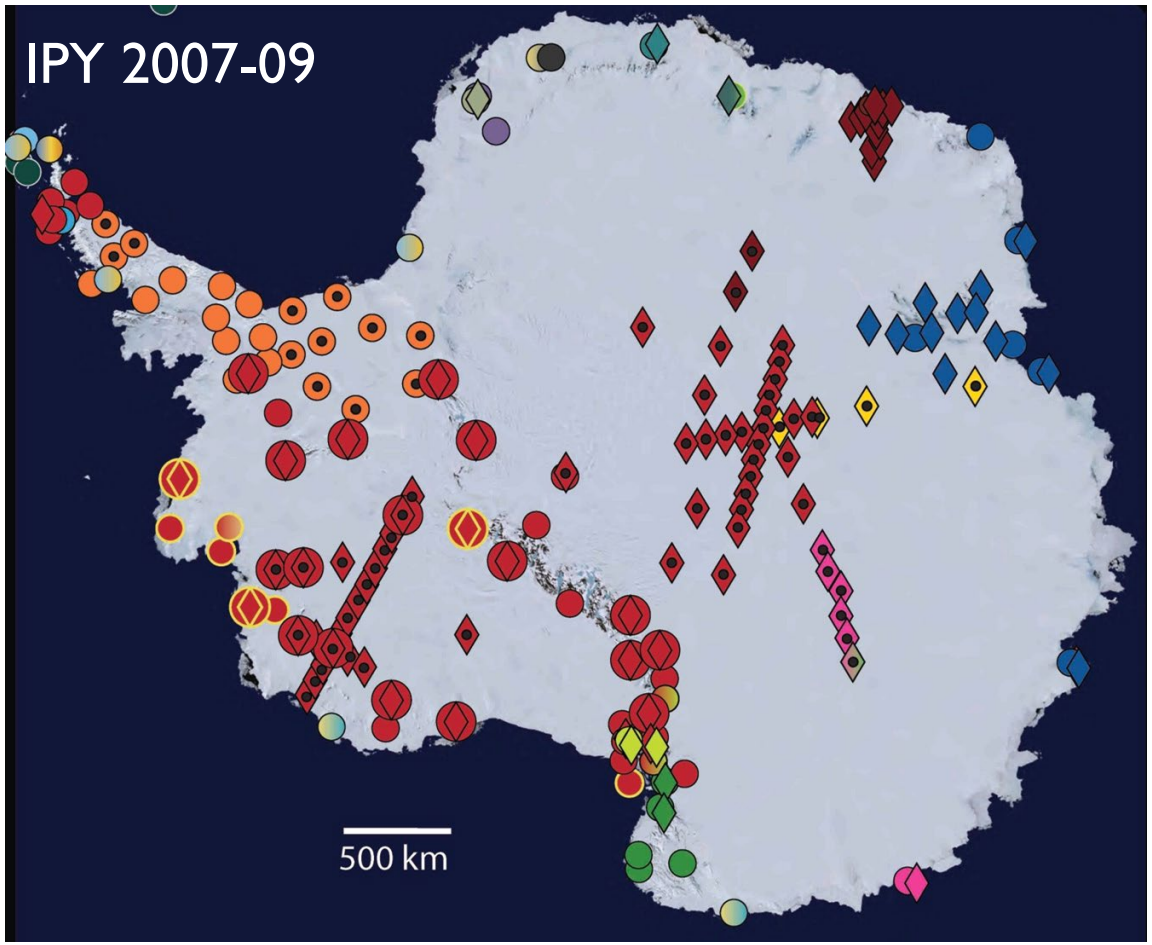
Antarctica



(Tamisiea et al. 2014)

GNSS OBSERVATIONS IN ANTARCTICA



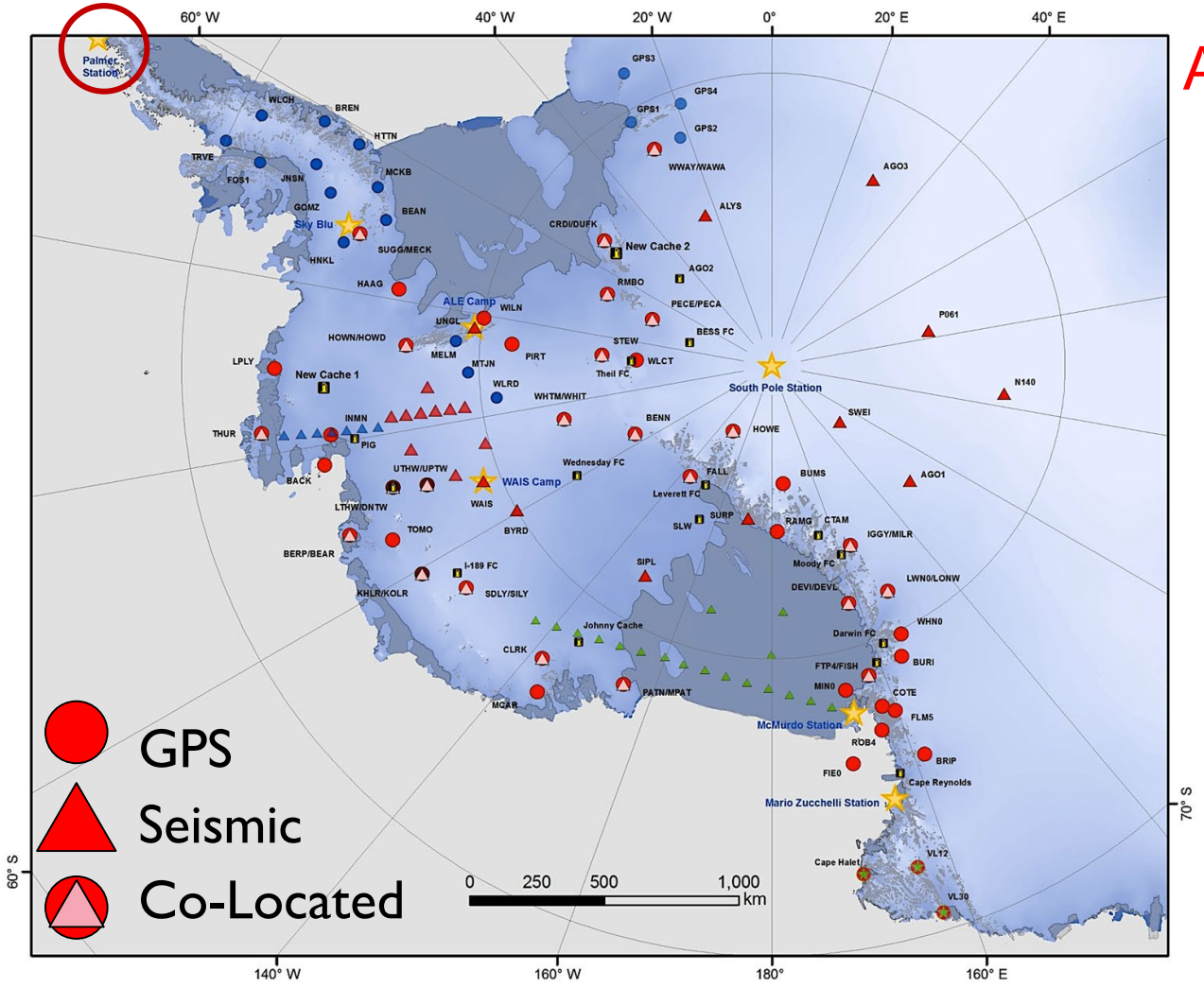


stations – continuous observations

GPS Seismic

(from Wilson 2019)

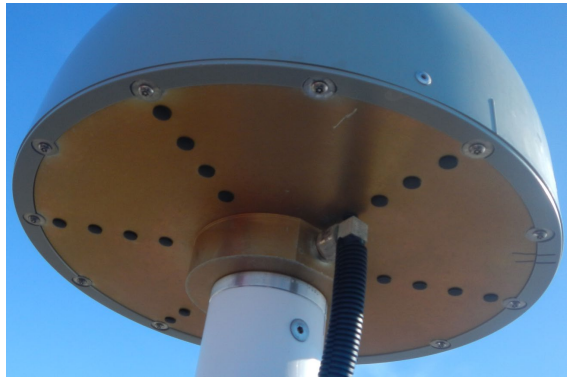
GNSS OBSERVATIONS IN WEST ANTARCTICA



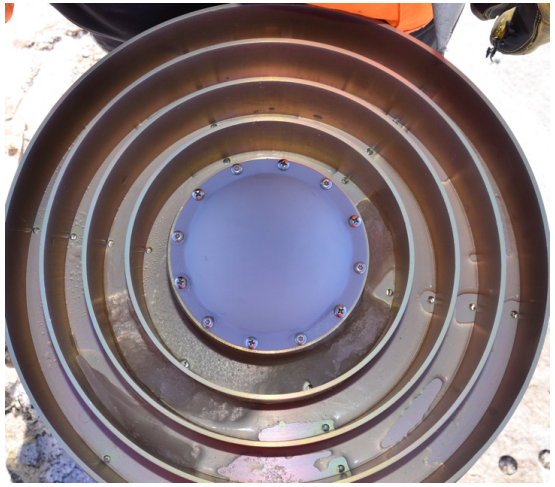
(from Wilson 2019)

ANET-POLENET ~2007-2017

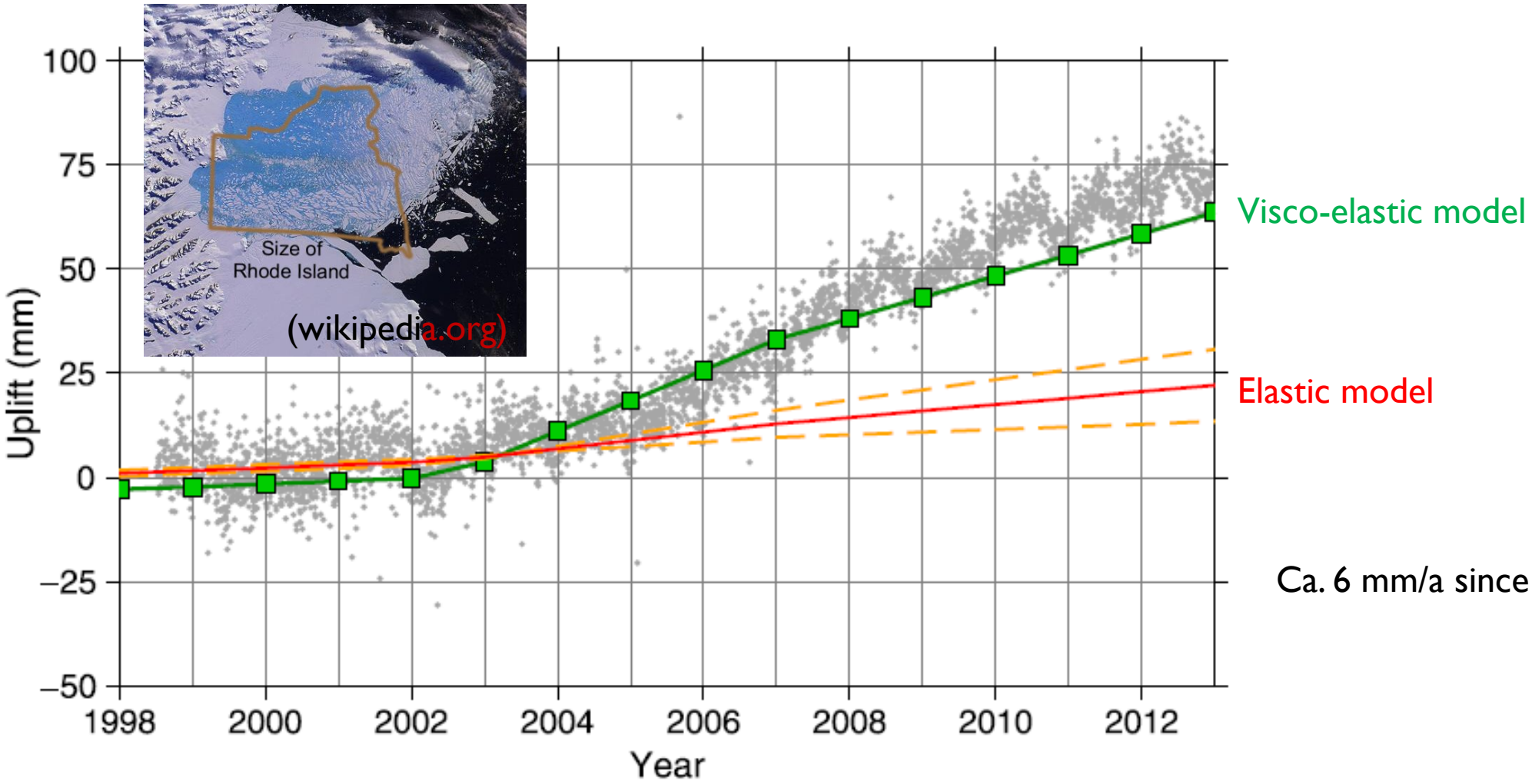
Pre-Tape



Post-Tape, -Plug



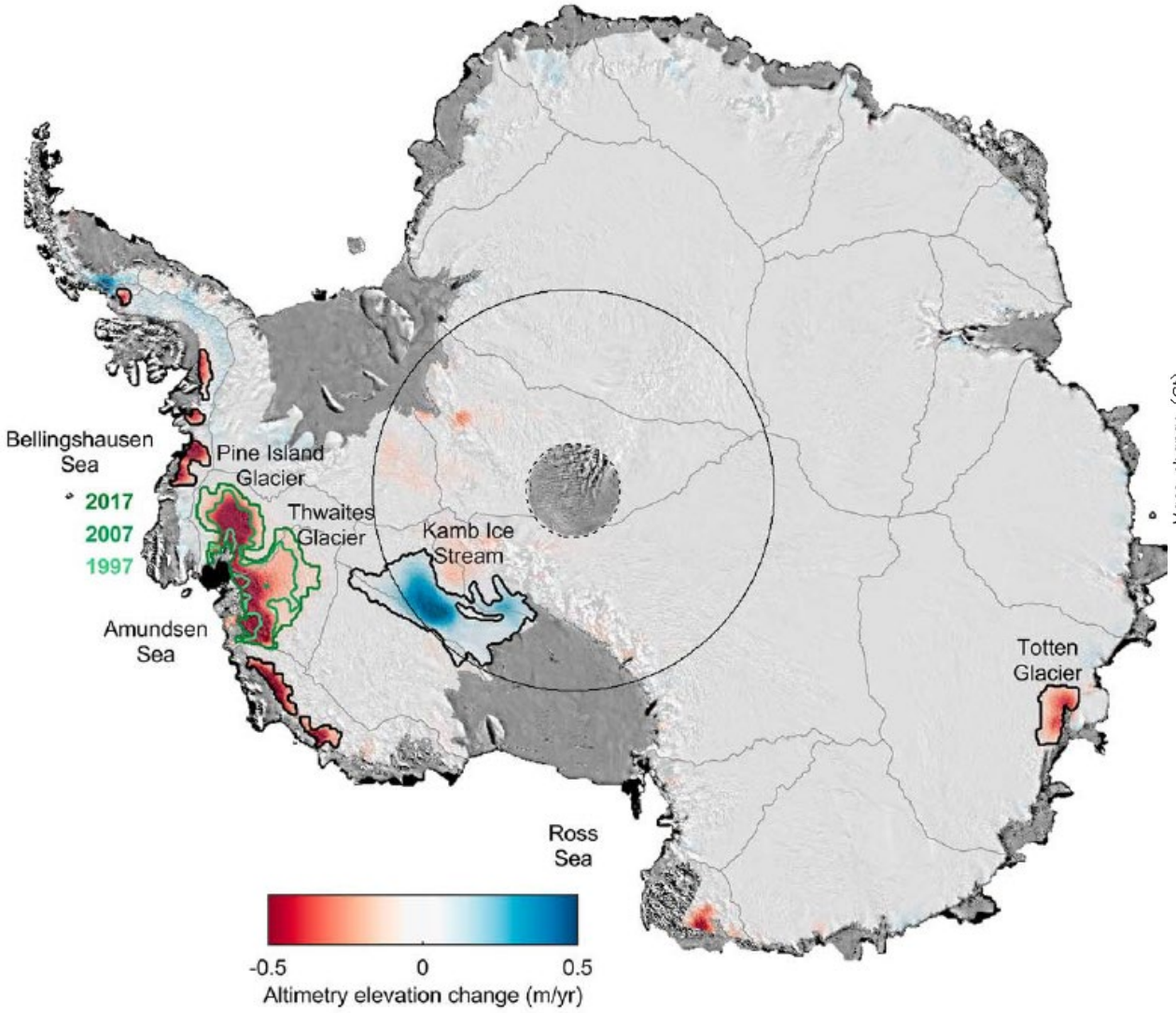
LAND UPLIFT AT PALMER STATION, ANTARCTICA

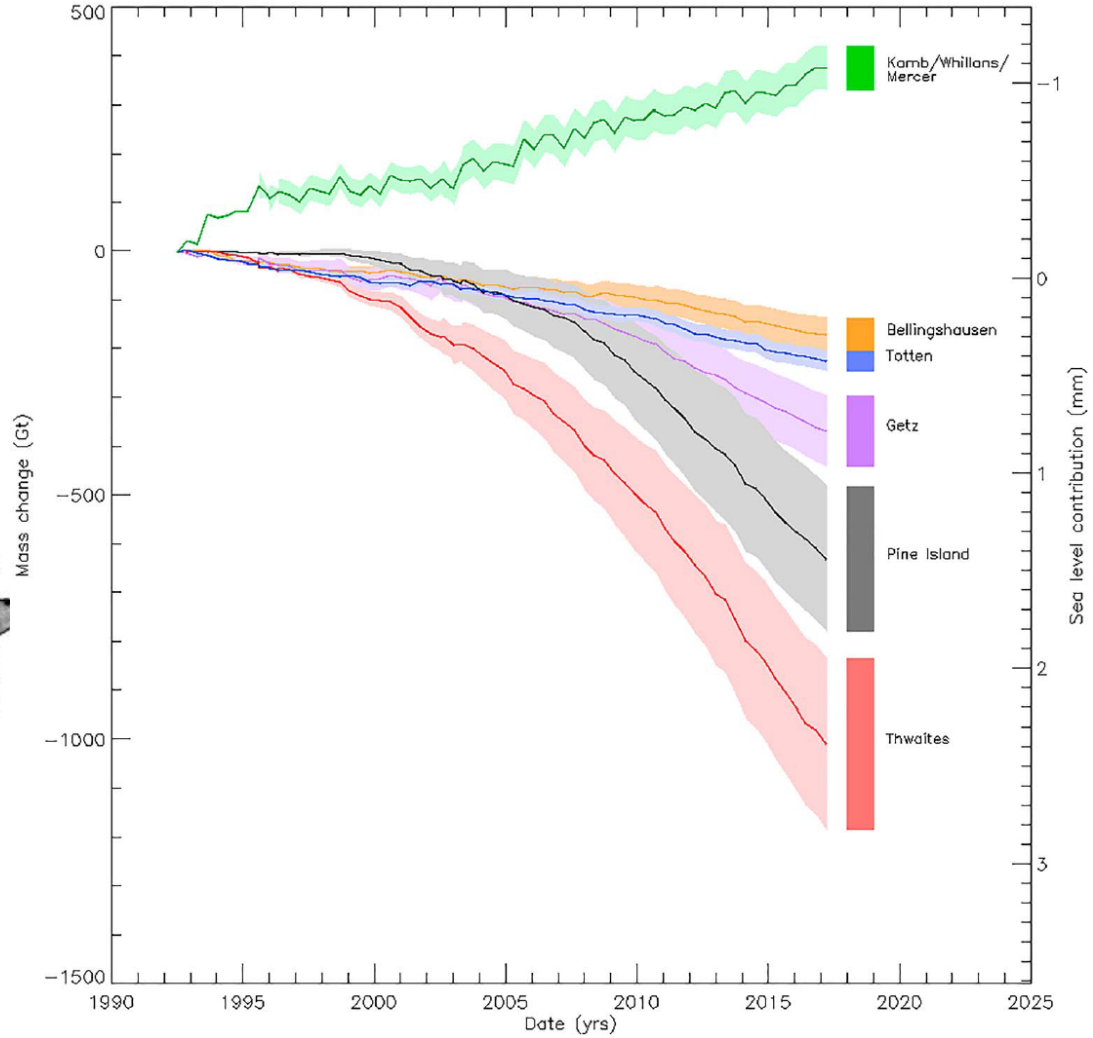


Ca. 6 mm/a since 2003!

(Nield et al. 2014)

RECENT ICE MELT IN ANTARCTICA

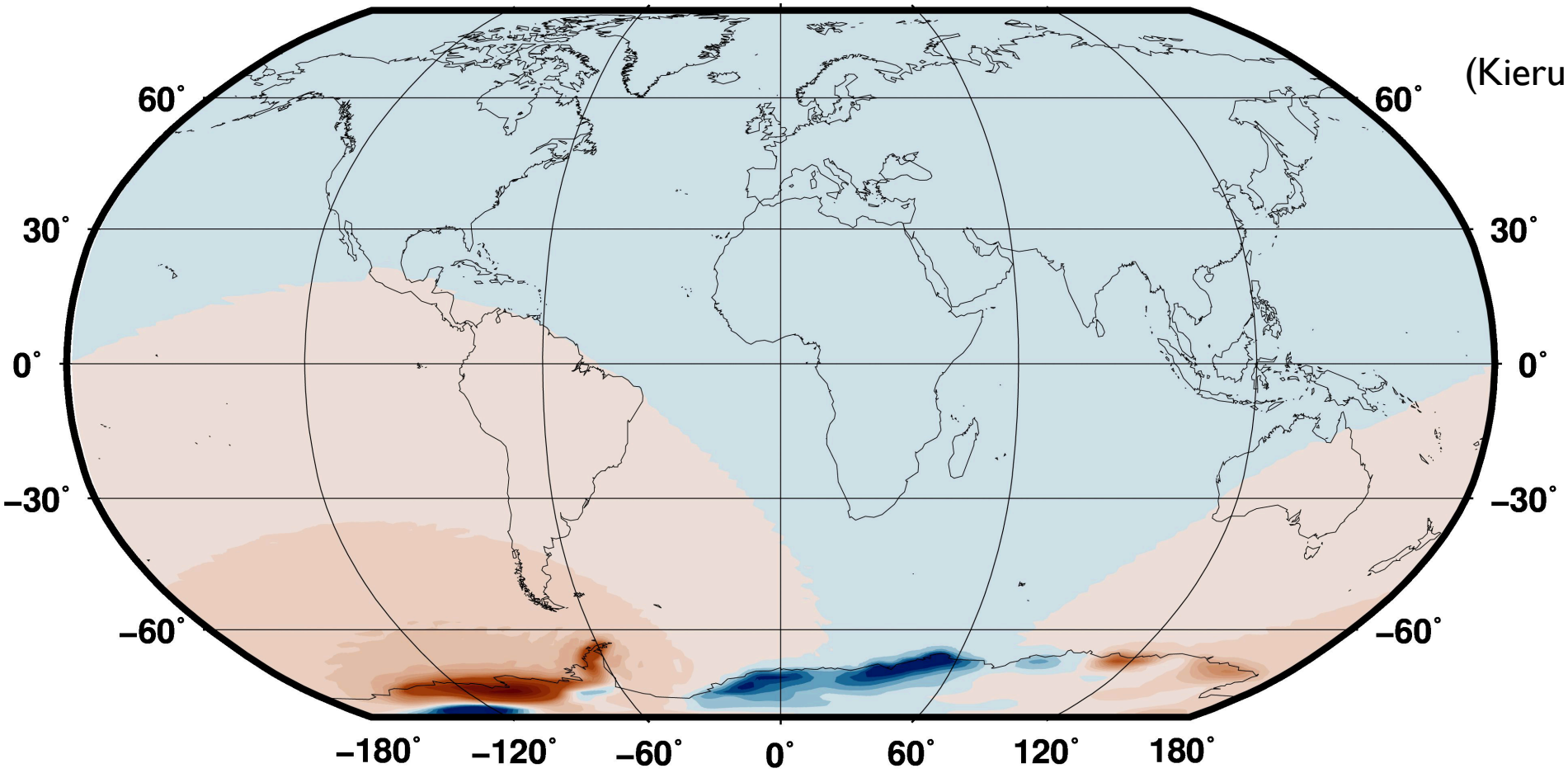




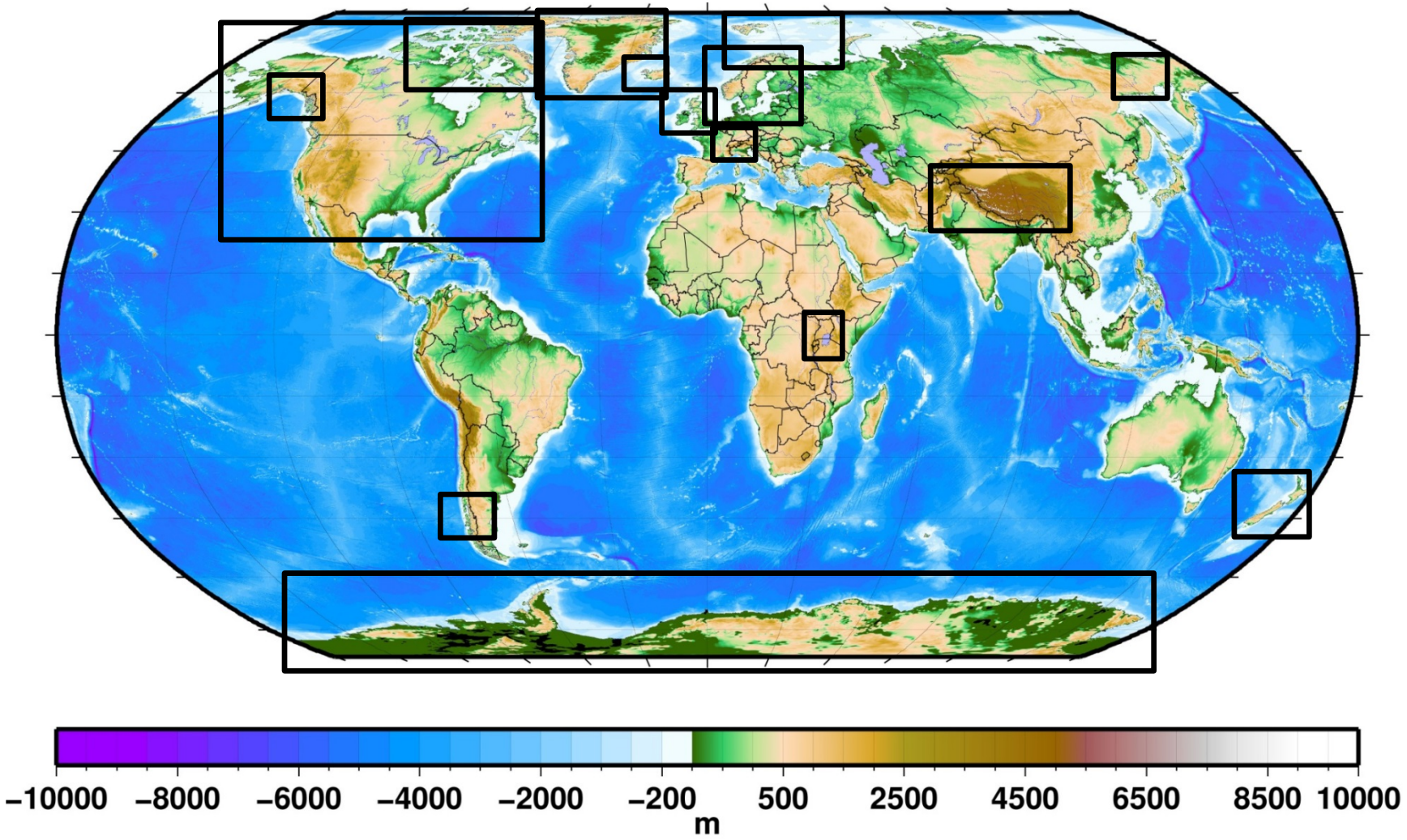
(Shepherd et al. 2018)

ELASTIC EFFECT OF ANTARCTIC ICE MELT

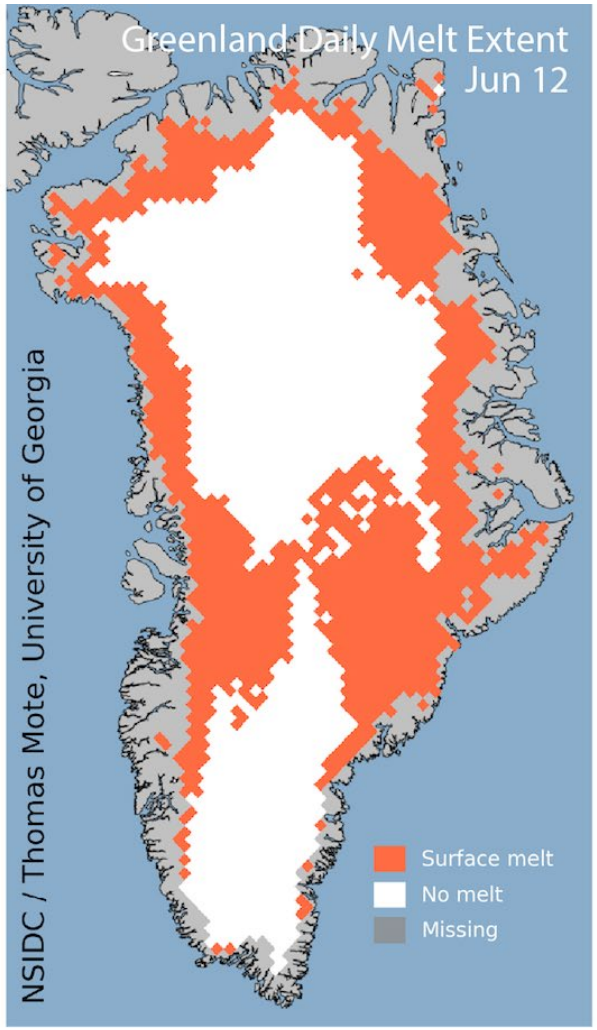
2002-2014
(Kierulf et al. submitted)

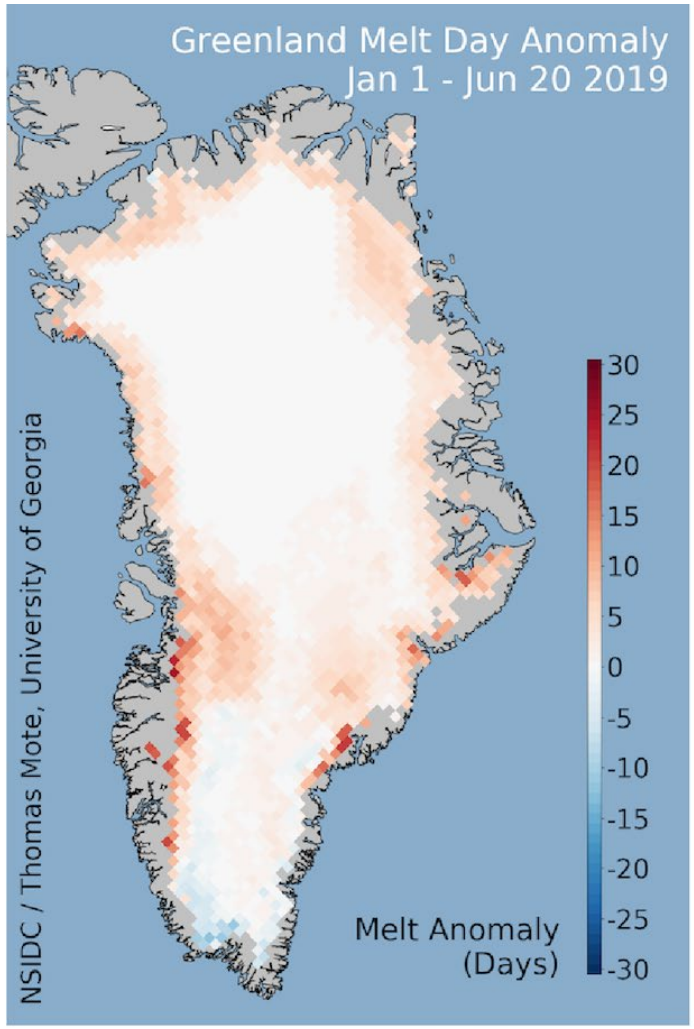


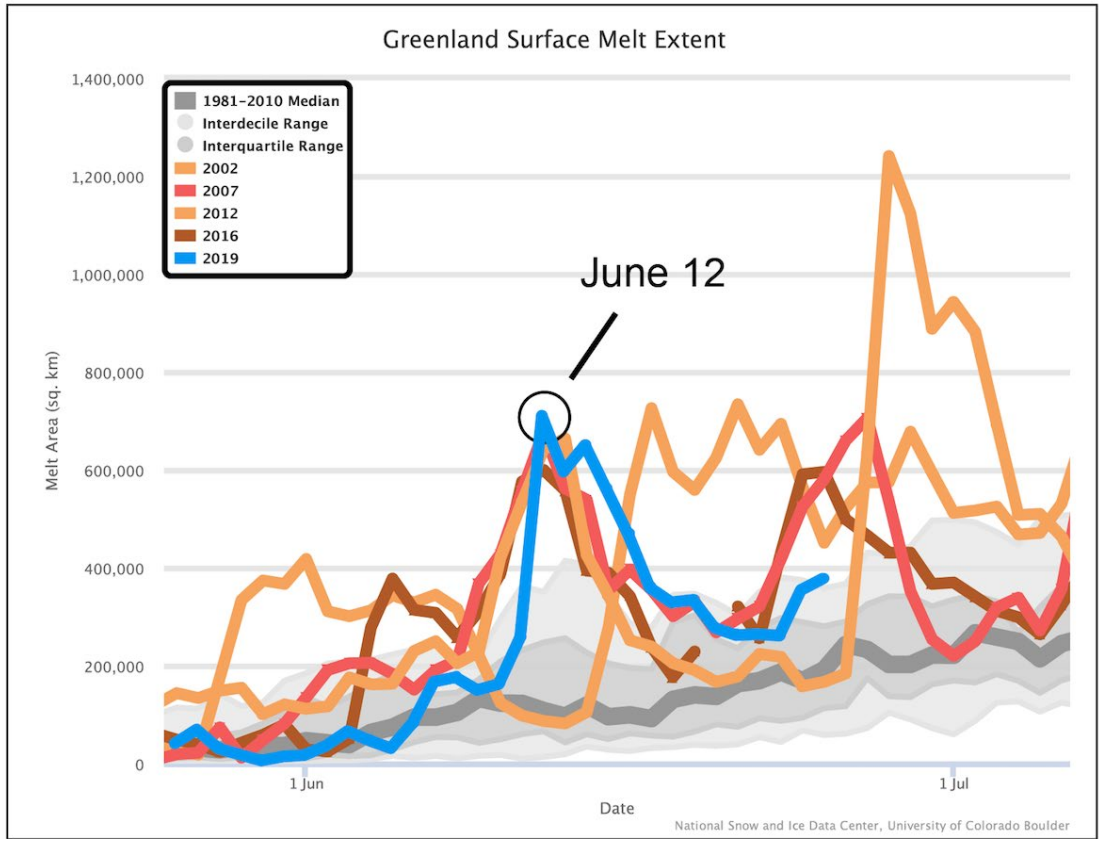
GIA AROUND THE WORLD



RECENT ICE MELT IN GREENLAND

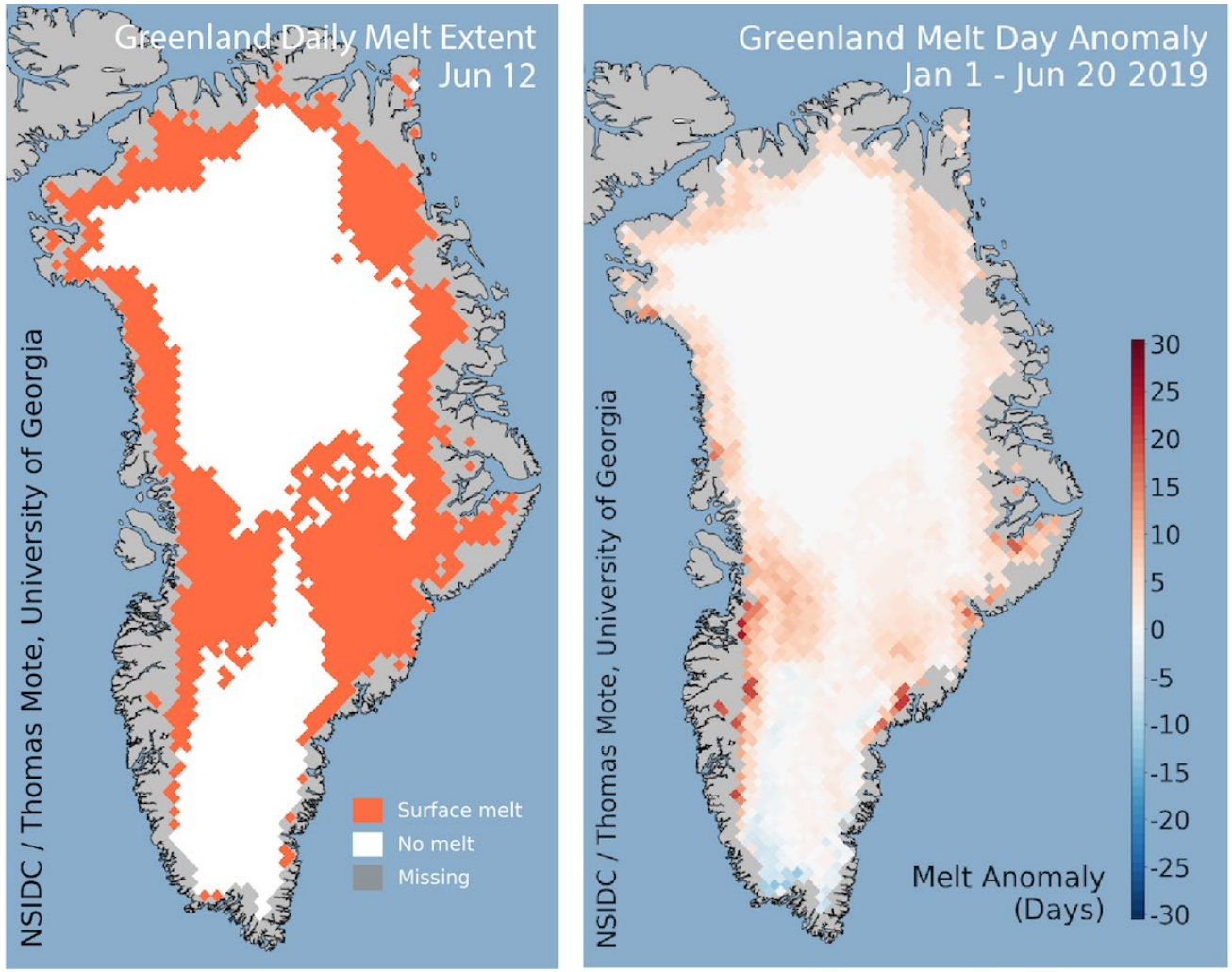




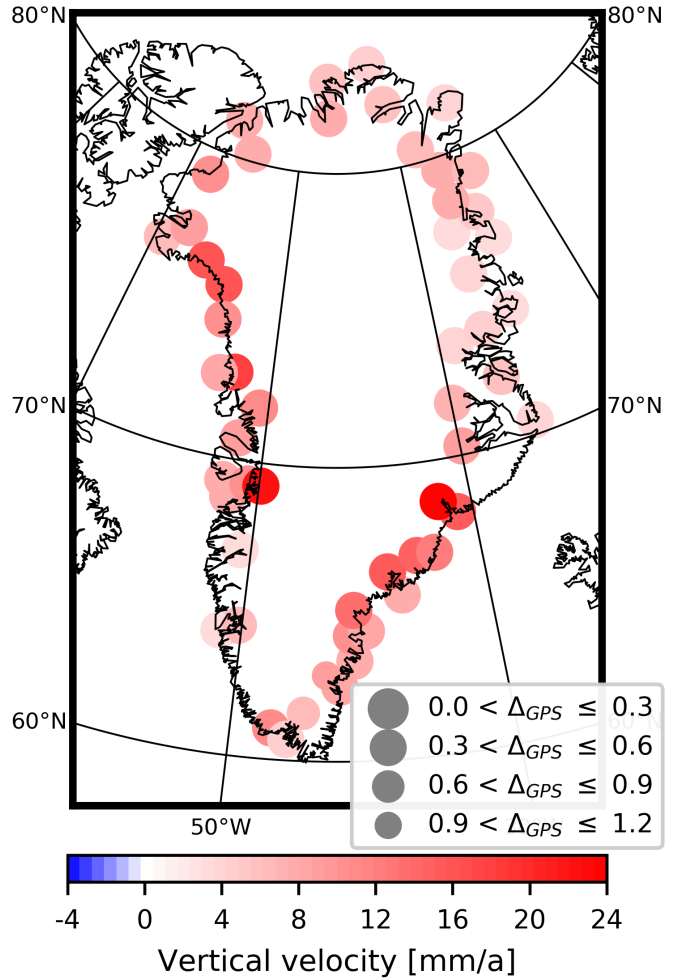


(NSDIC 2019)

RECENT ICE MELT IN GREENLAND



(NSDIC 2019)



(after Khan et al. 2016)

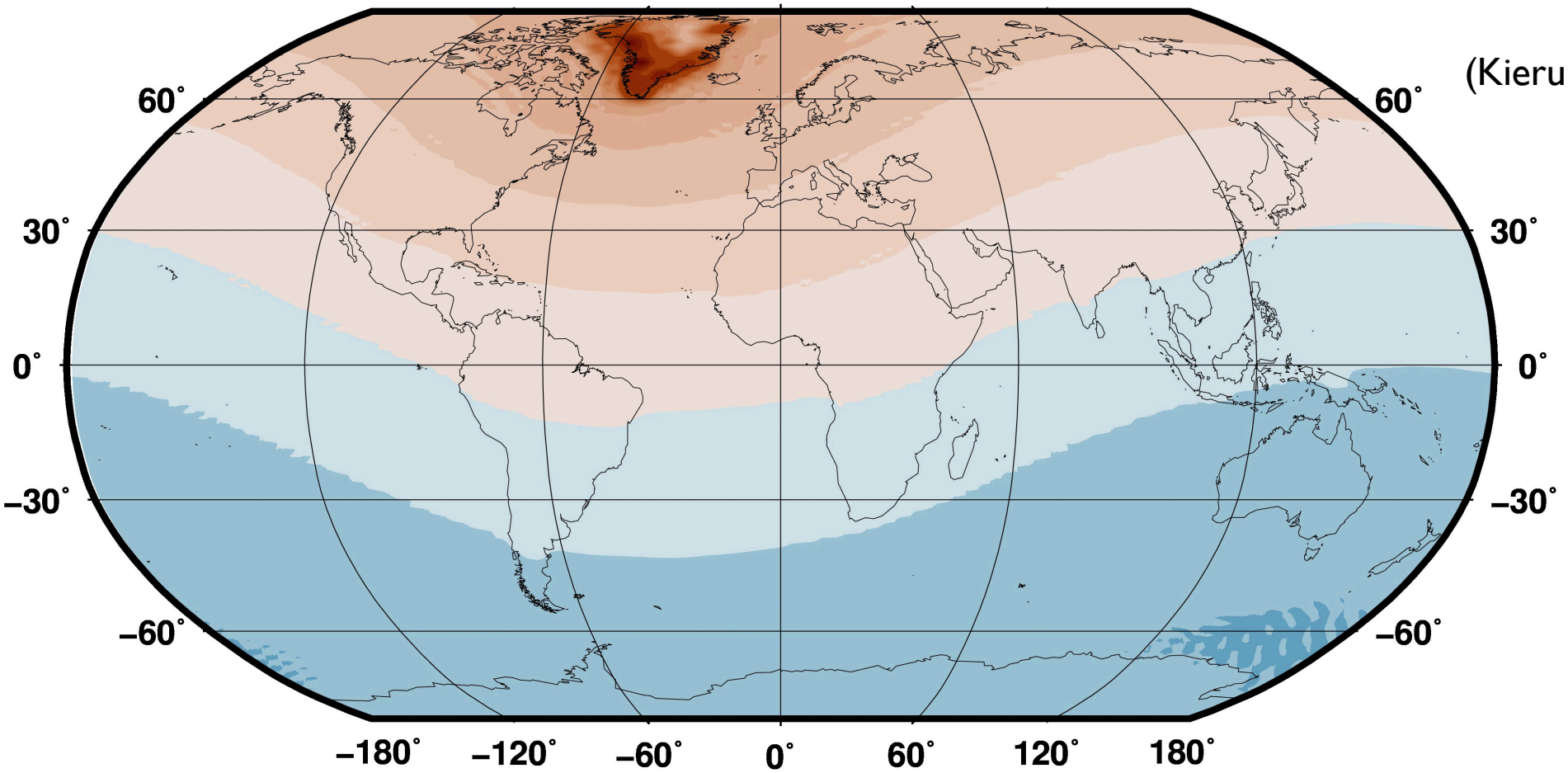
(Photo courtesy of Abbas Khan, DTU Space, Denmark)

(Photos courtesy of Abbas Khan, DTU Space, Denmark)

(Photo courtesy of Abbas Khan, DTU Space, Denmark)

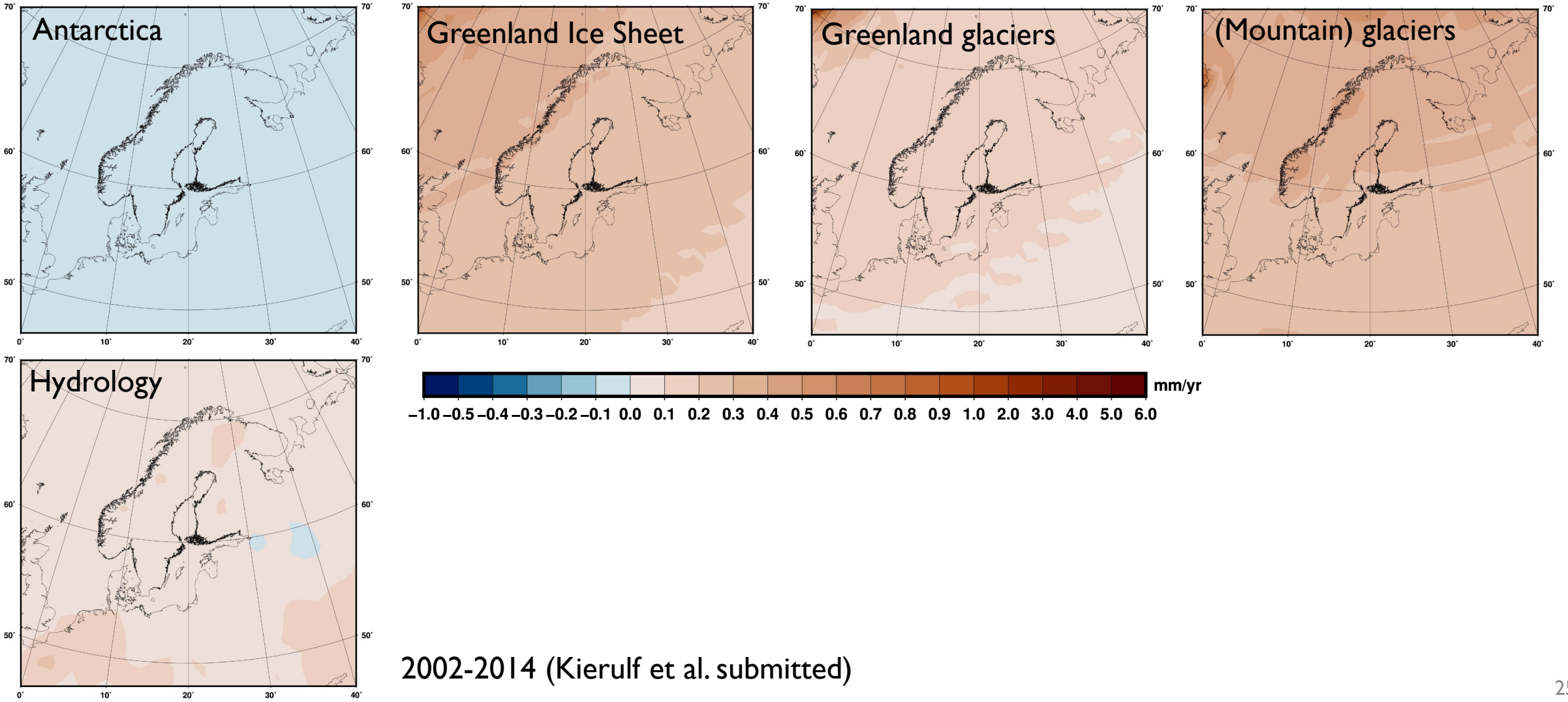
(Photo courtesy of Abbas Khan, DTU Space, Denmark)

ELASTIC EFFECT ON A GLOBAL SCALE



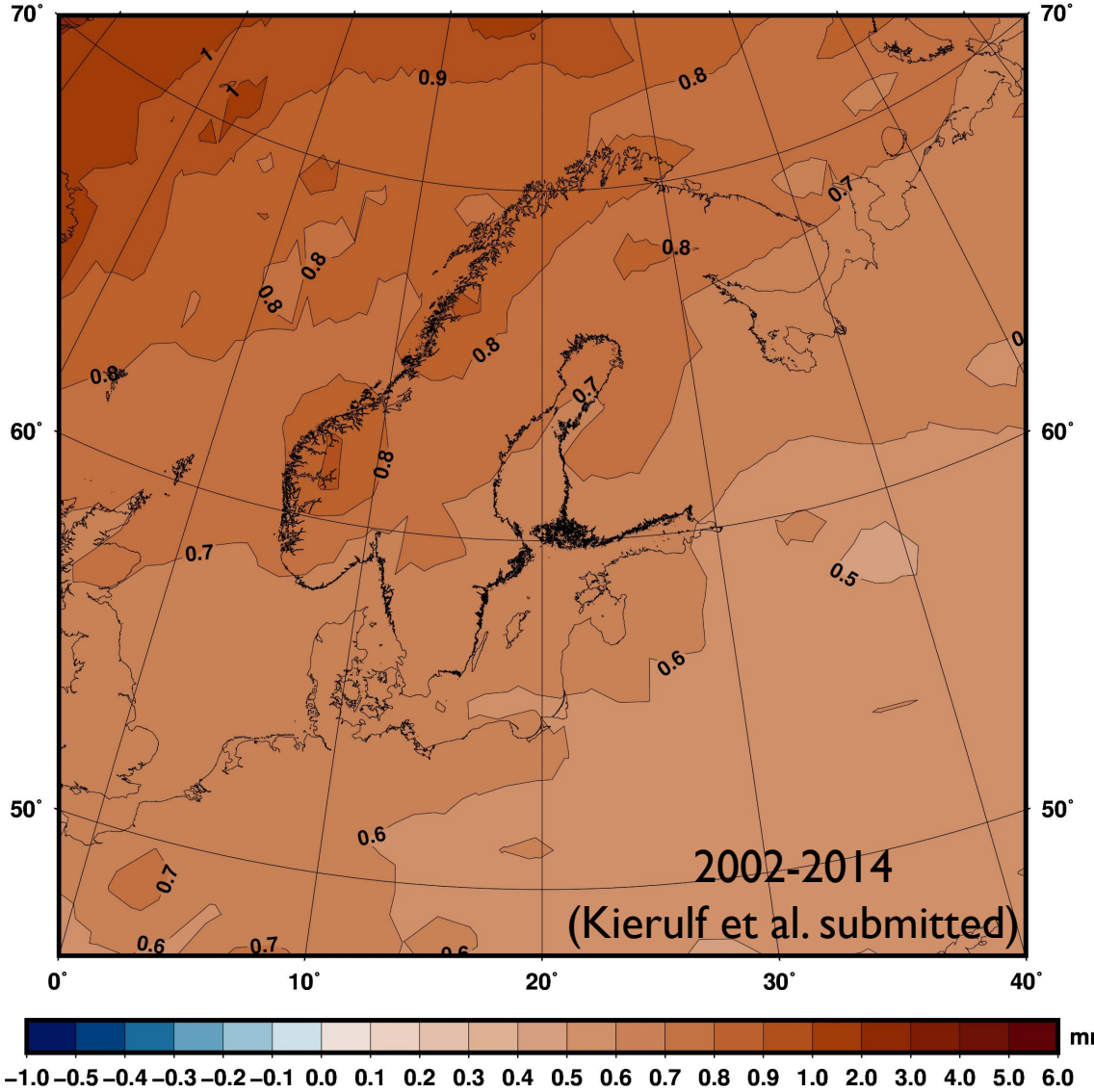
2002-2014
(Kierulf et al. submitted)

ELASTIC EFFECTS IN EUROPE

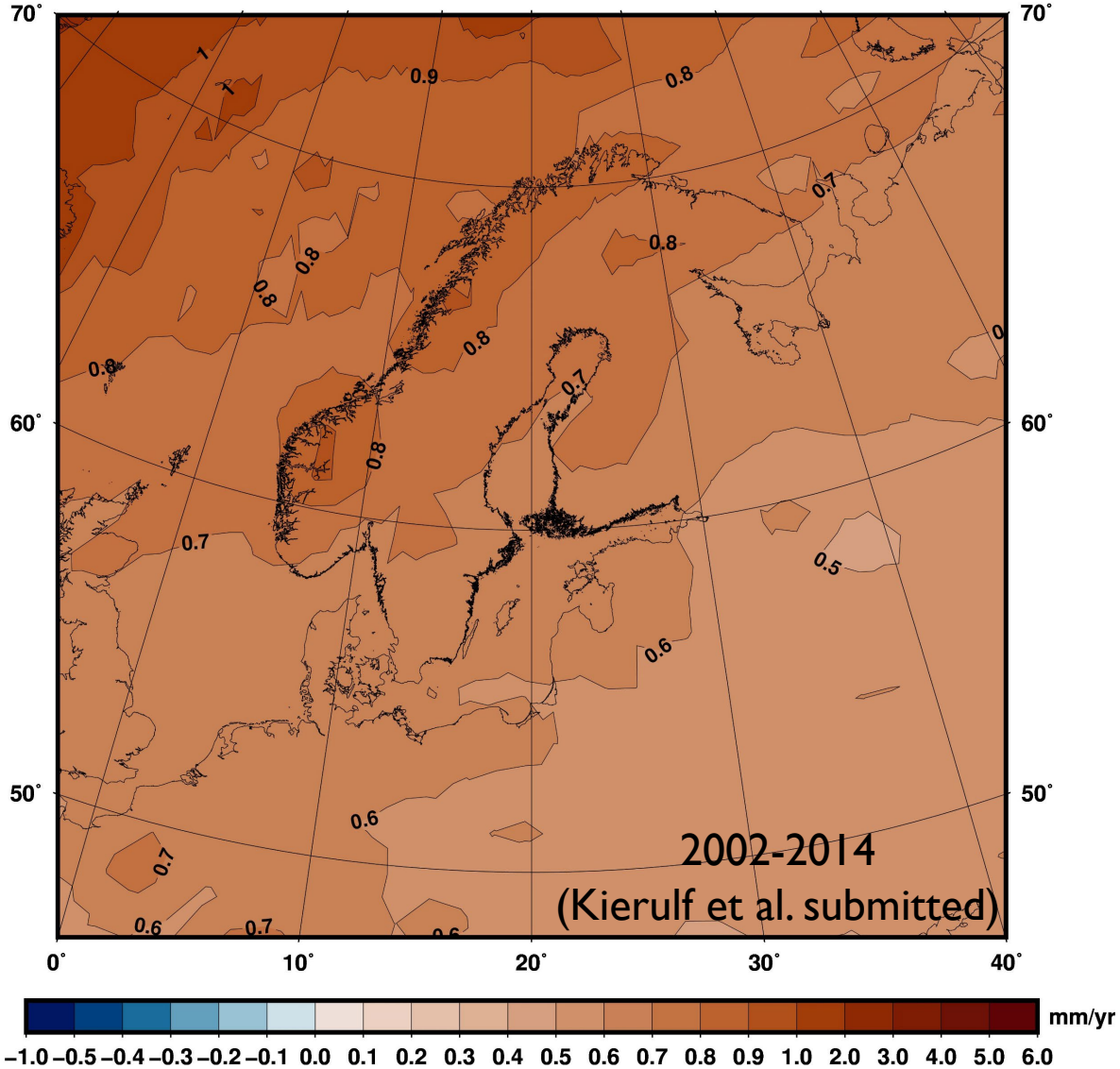


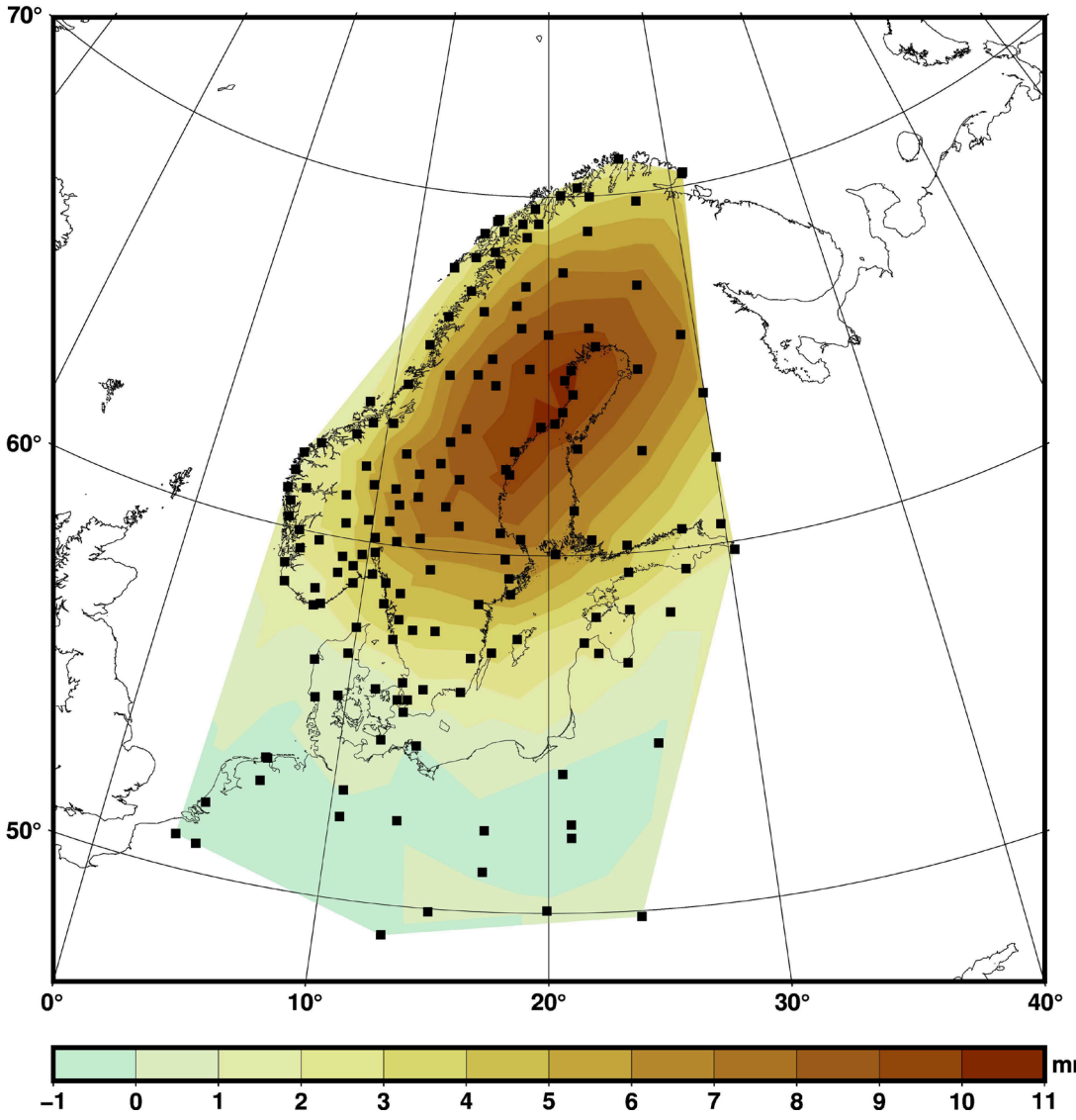
2002-2014 (Kierulf et al. submitted)

THE SUM OF ELASTIC EFFECTS IN EUROPE

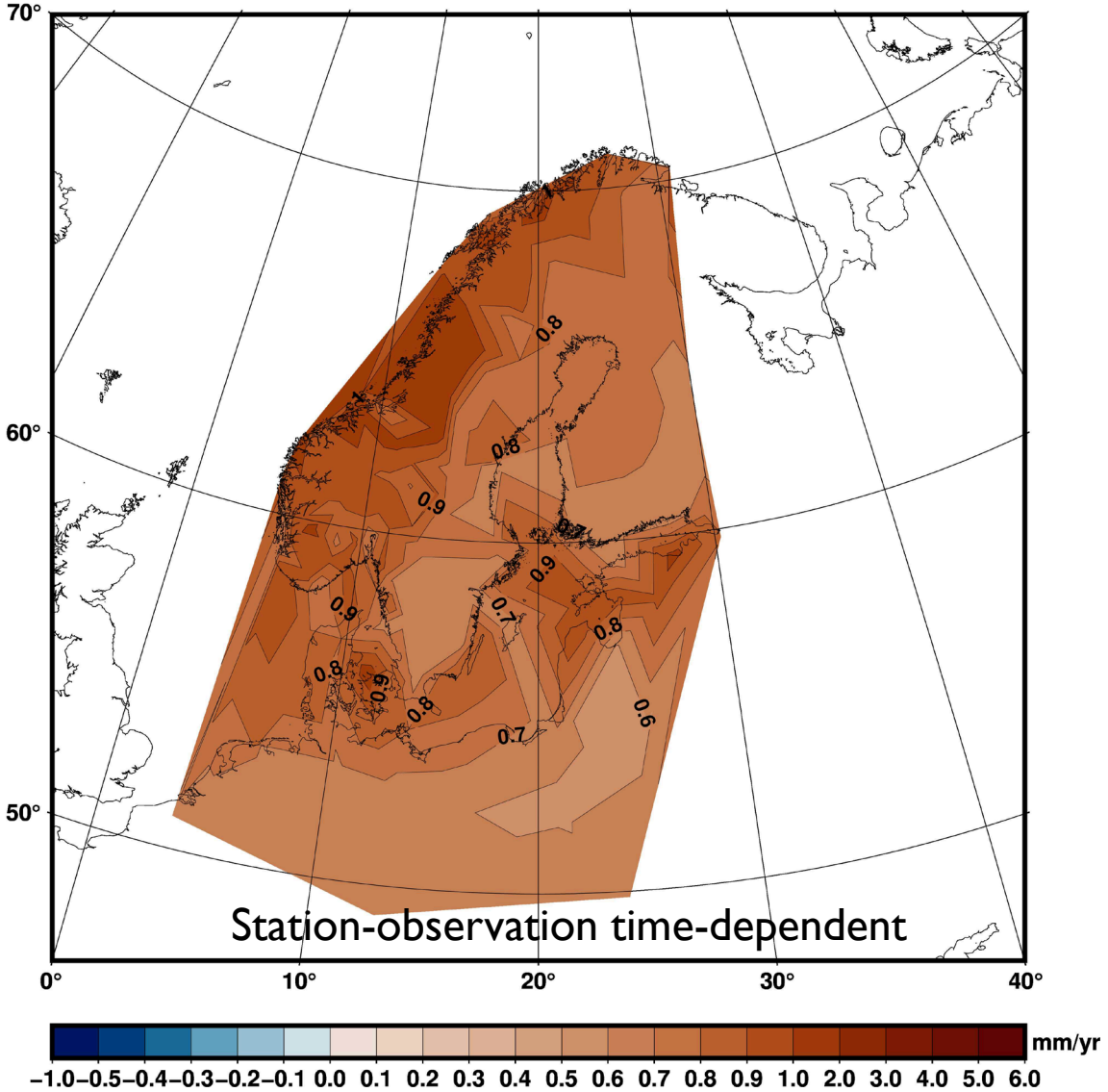


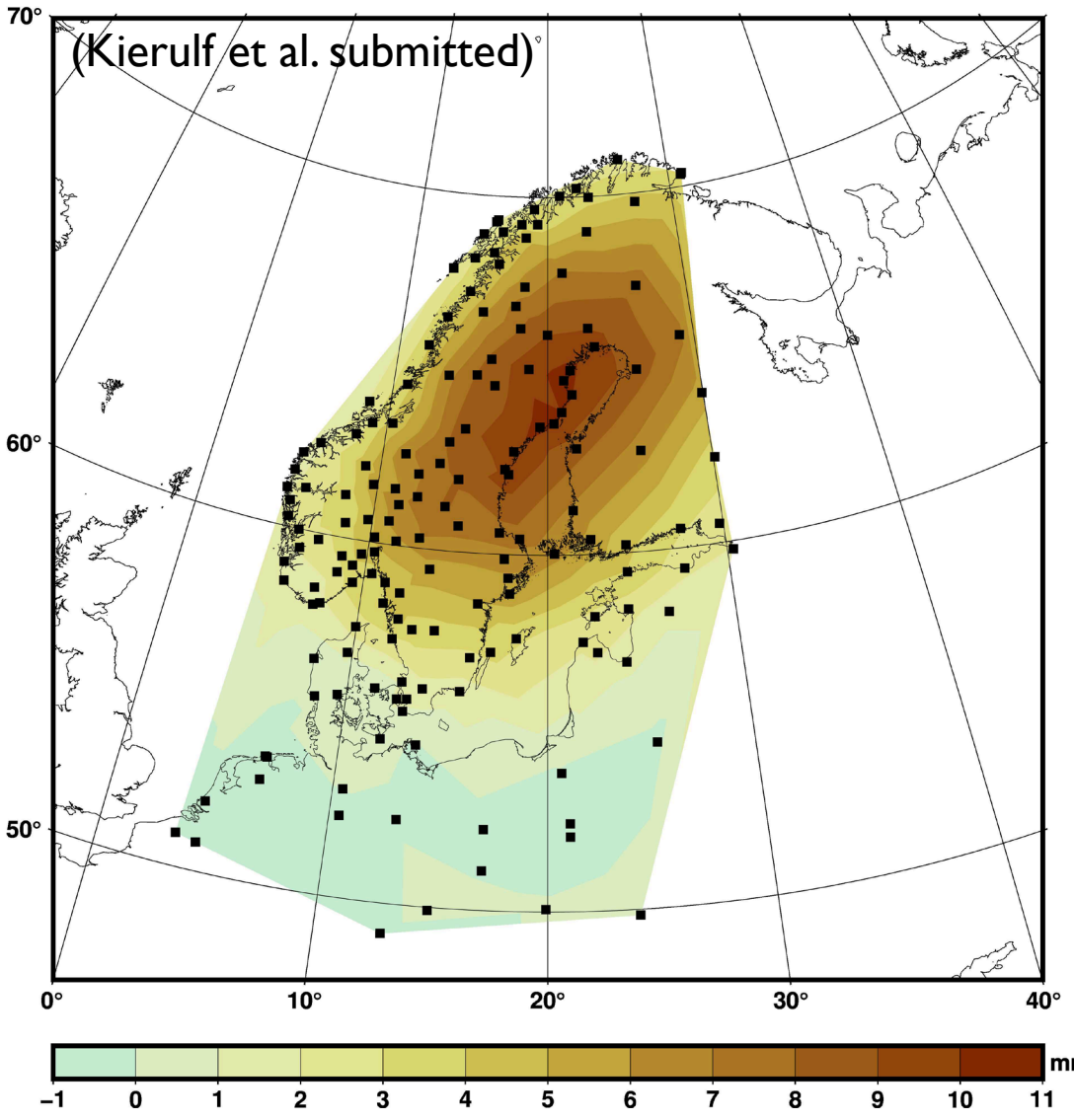
THE SUM OF ELASTIC EFFECTS IN EUROPE



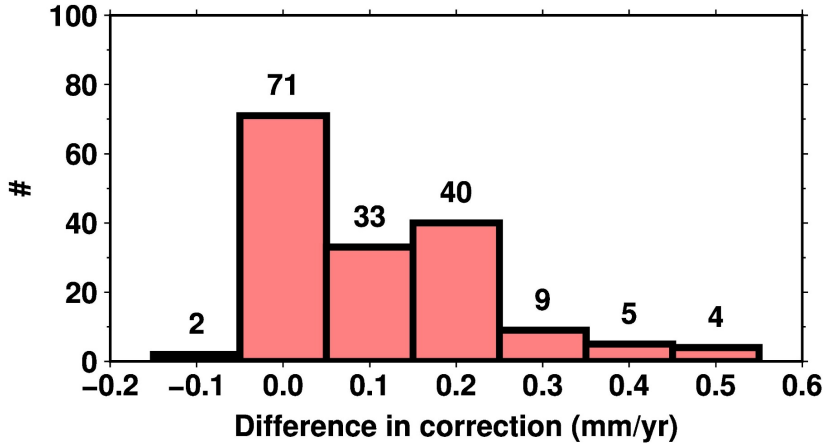


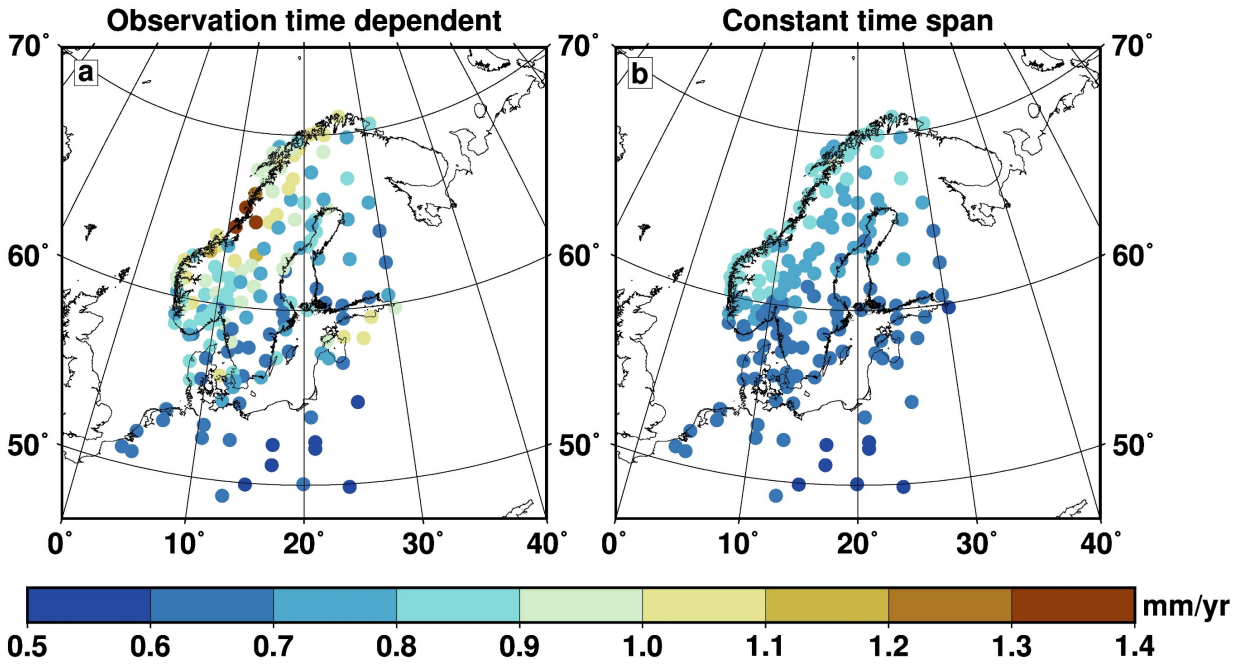
THE SUM OF ELASTIC EFFECTS IN EUROPE





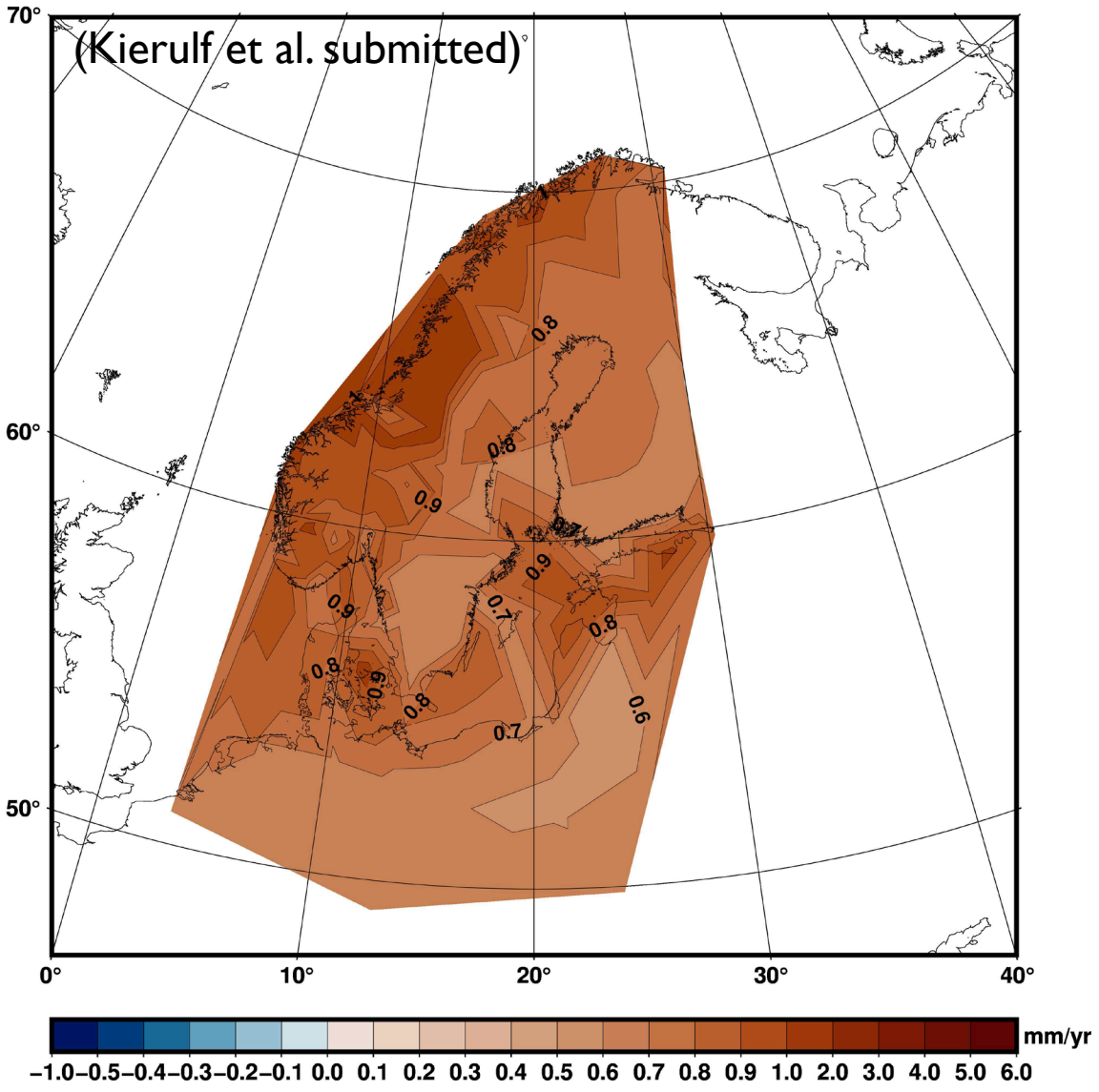
THE SUM OF ELASTIC EFFECTS IN EUROPE

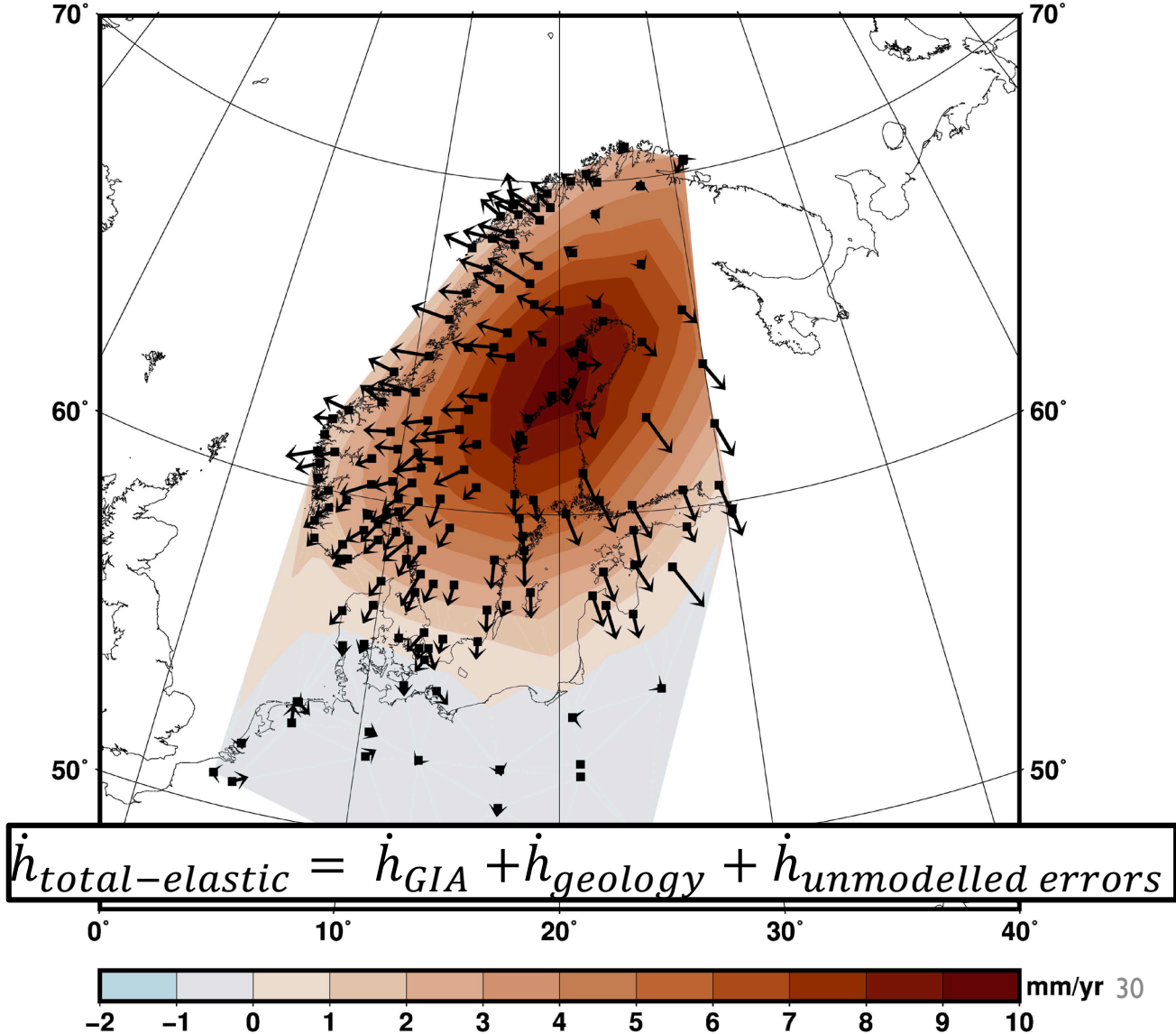




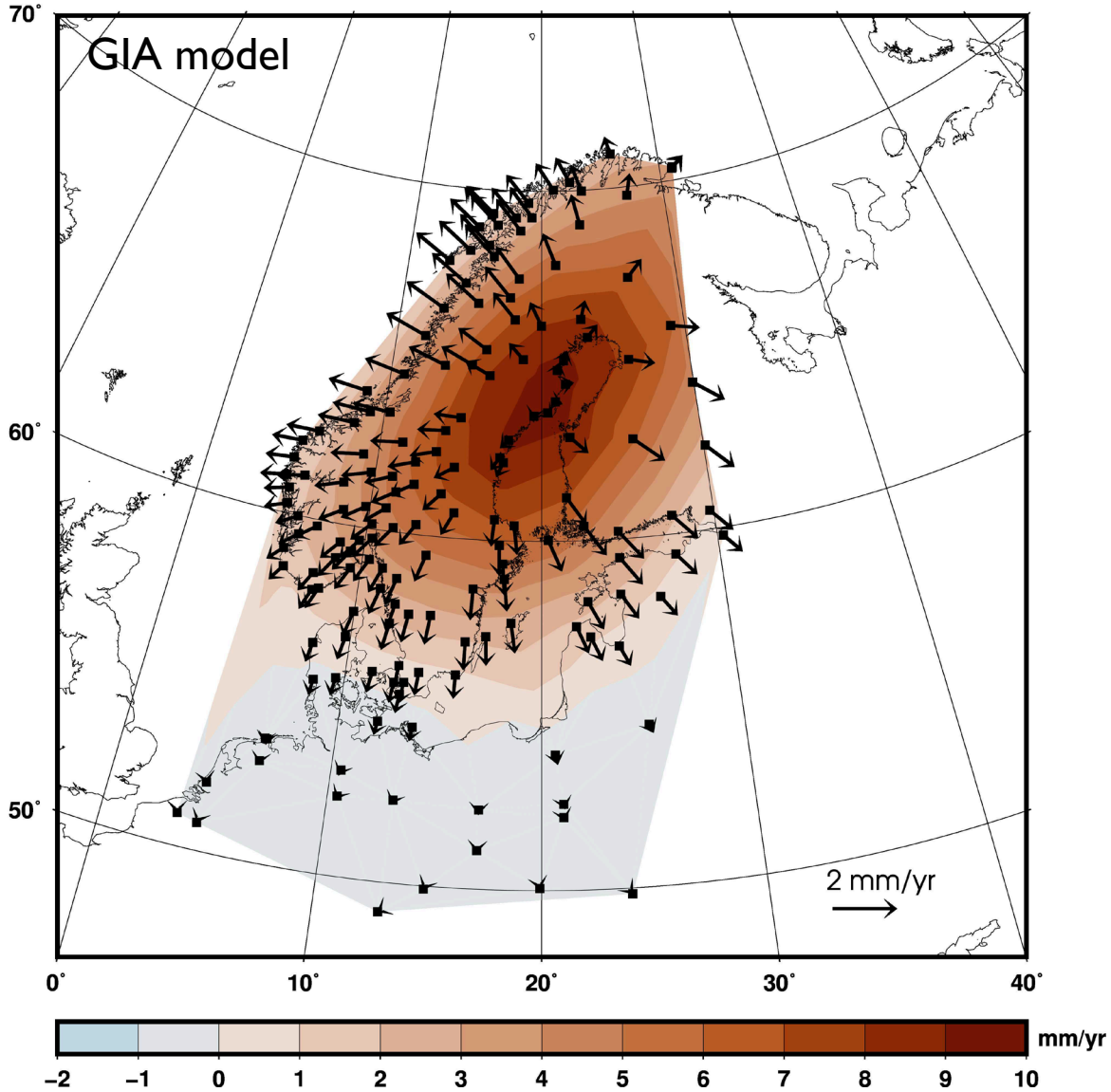
(Kierulf et al. submitted)

LAND UPLIFT ELASTICALLY CORRECTED

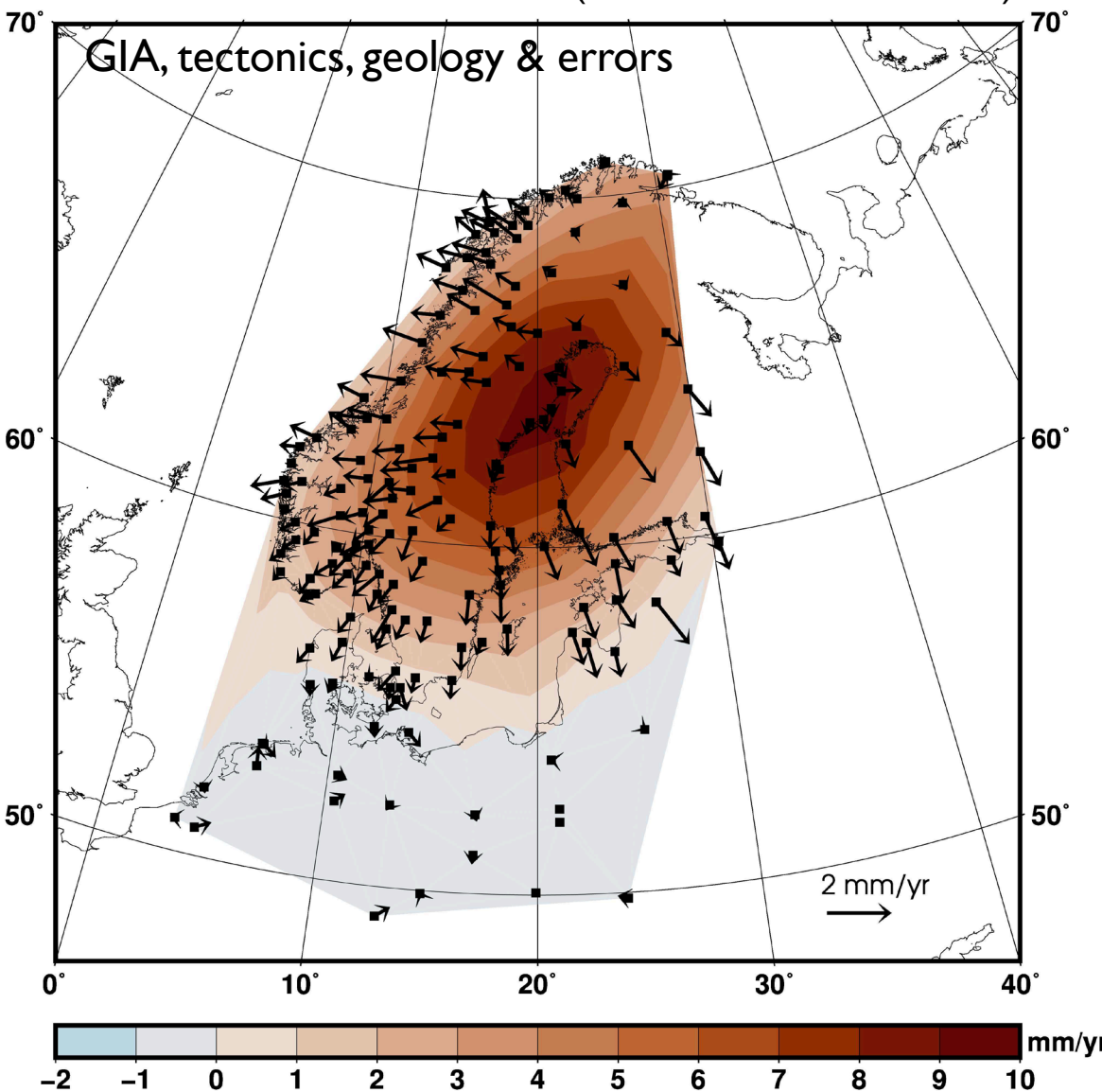




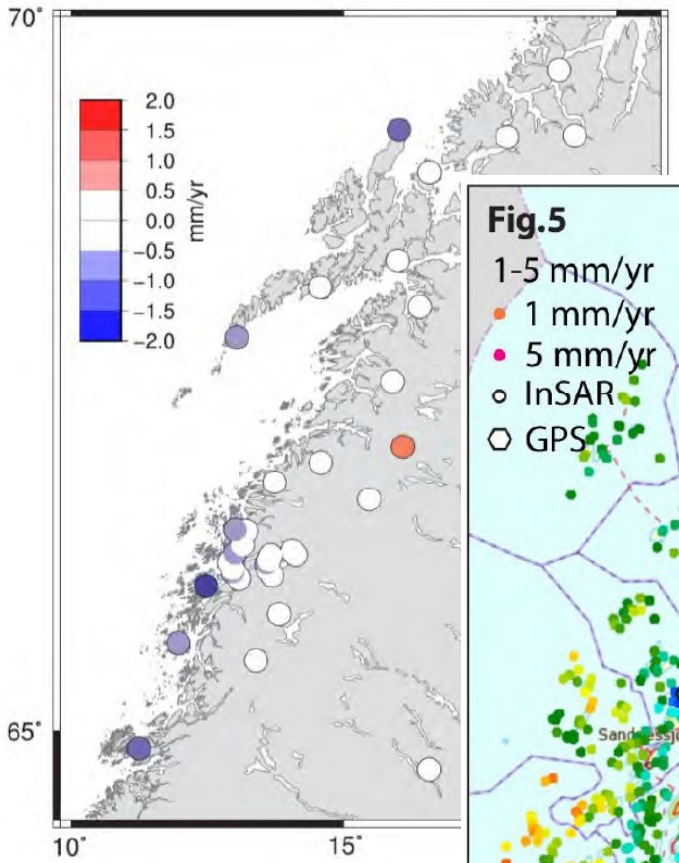
GIA SIGNAL



(Kierulf et al. submitted)

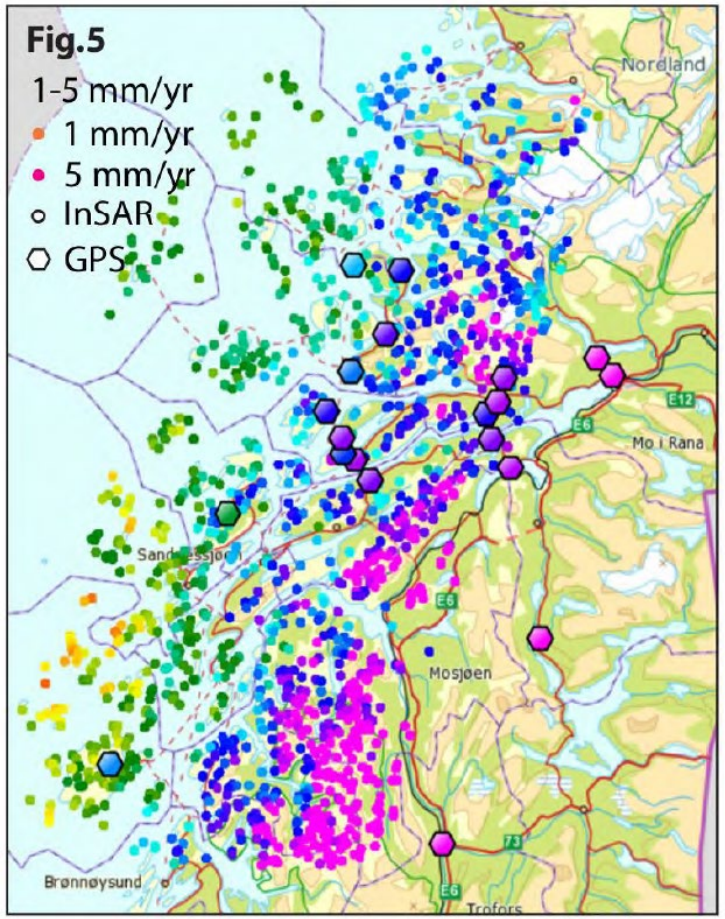


THE REMAINING SIGNAL

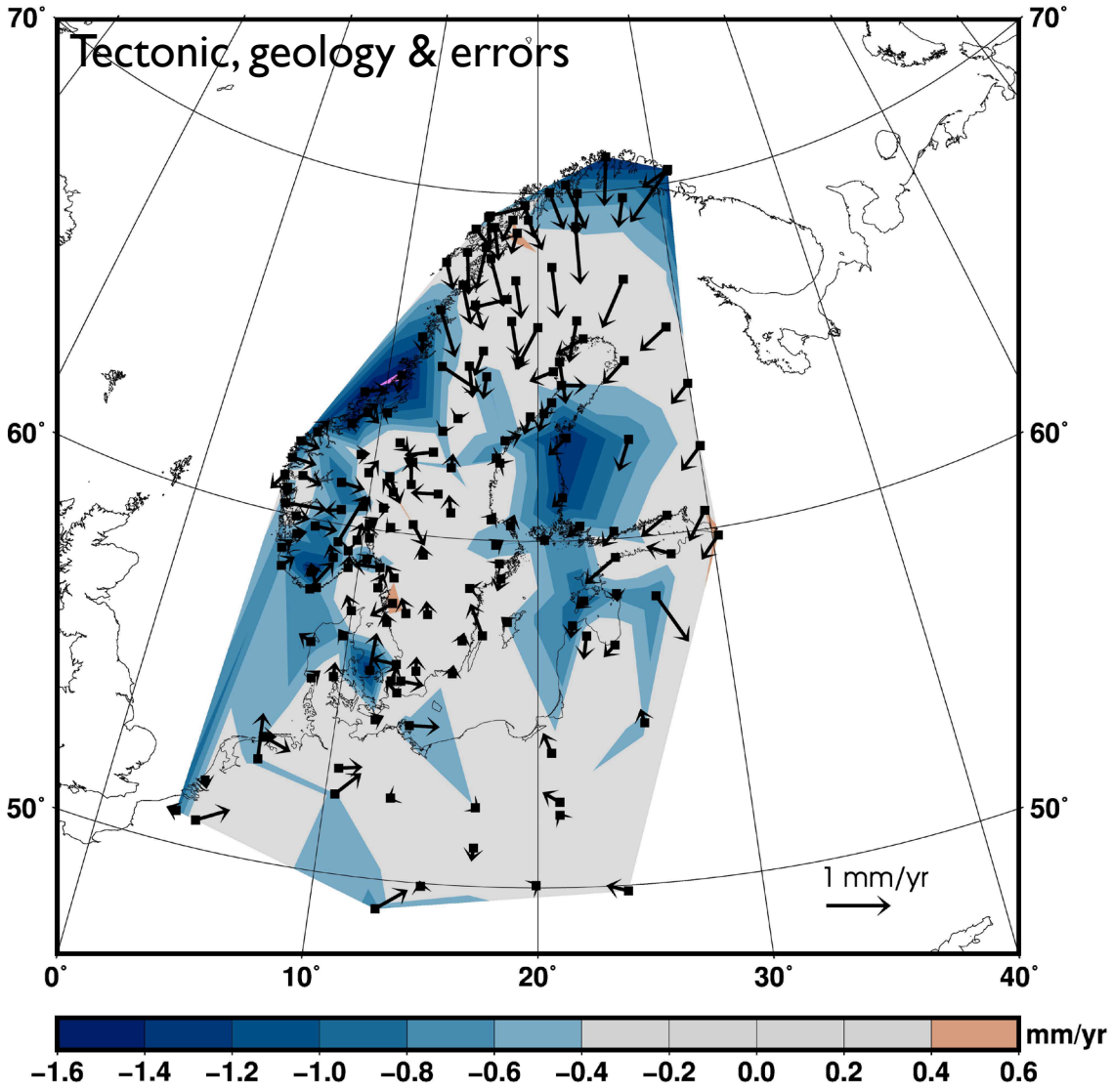


(Kierulf 2017)

(Rouyet et al. 2018)



(Kierulf et al. submitted)



TAKE HOMES

- GNSS observations are an essential technique in investigations on ongoing climatic and geodynamic processes, especially in polar areas
- Glacial isostatic adjustment is clearly visible and in (previously) glaciated areas the dominant signal
- Ongoing ice melt in Greenland and Antarctica is visible in GNSS observations and even affects our GNSS observations in Fennoscandia
- Maximum land uplift in Fennoscandia due to the last glaciation is less than 1 cm/a!