GIA Requirements for Future Gravity Satellite Missions:

Implications After More Than 7 Years of GRACE Data

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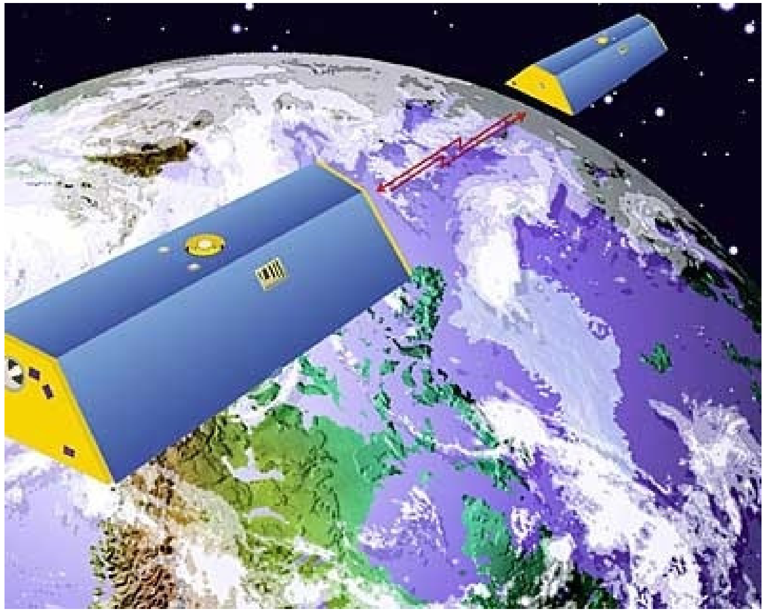
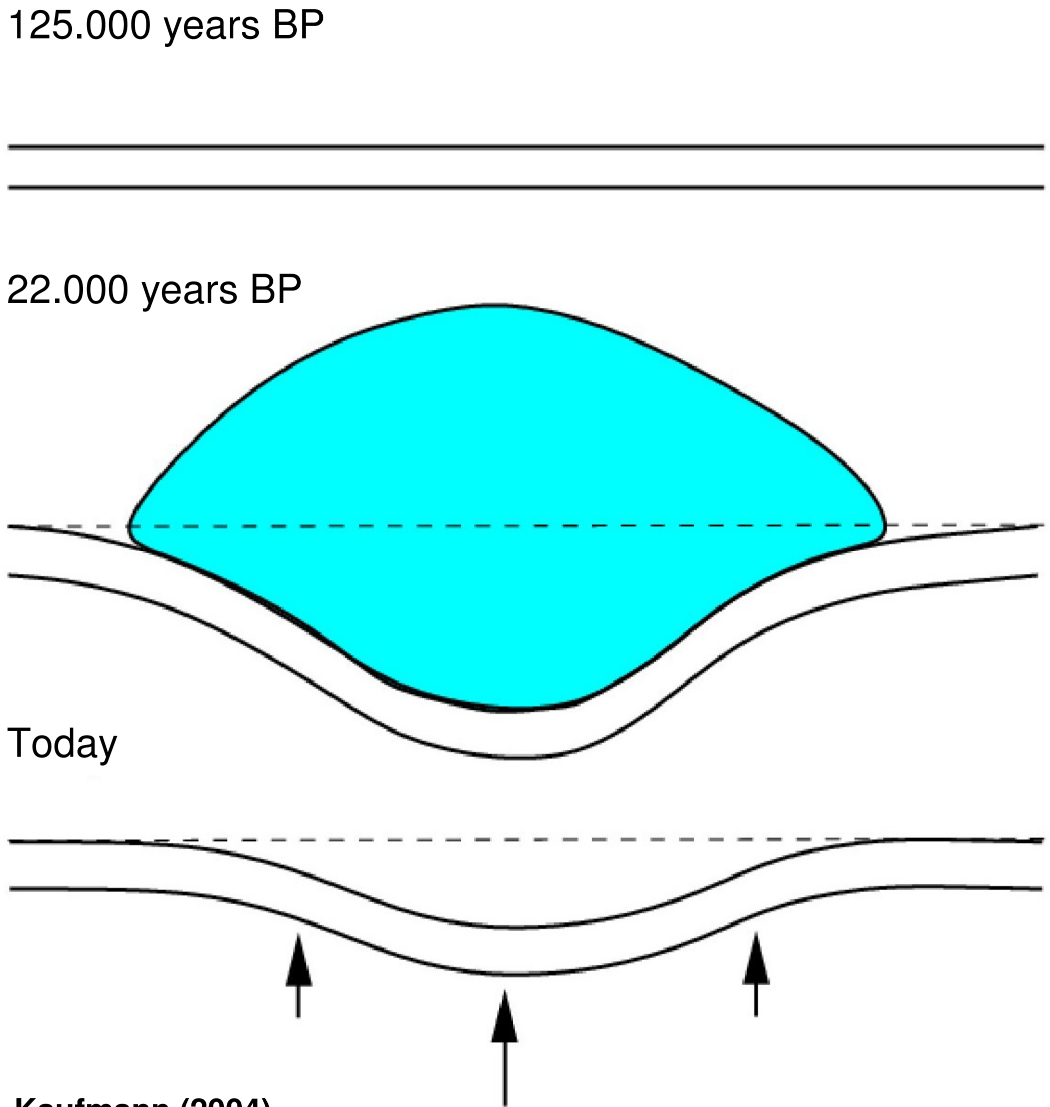


IAG-GGOS Workshop on
Future Gravity Missions
Graz, Austria
31/09 – 02/10/2009

Outline

- Introduction
  - What is GIA?
  - What do we know so far?
  - Trend analysis
- Sources of uncertainty:
  - Measurement errors
  - Filtering
  - Different processing centers
  - Time span
  - Hydrology
- Antarctica: GIA and ongoing ice mass change
- Summary
- Research contributions of GRACE
- Research contributions of future satellite gravity missions
- Recommendations for future satellite gravity missions

Introduction

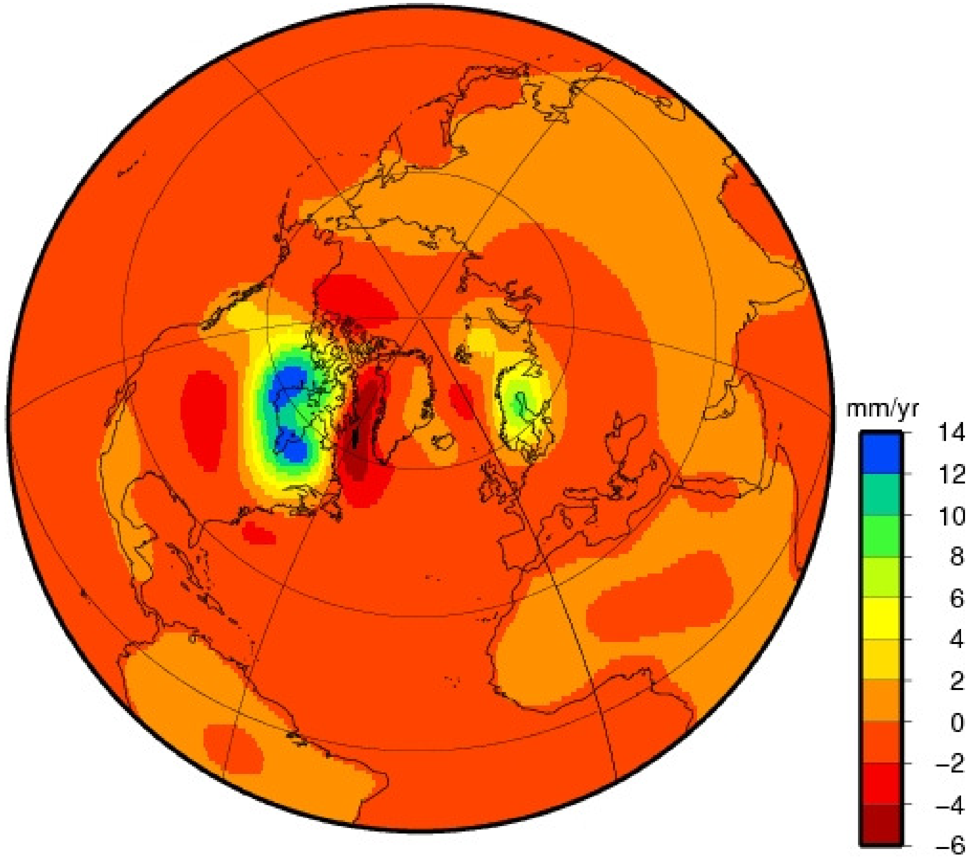


Kaufmann (2004)

Introduction

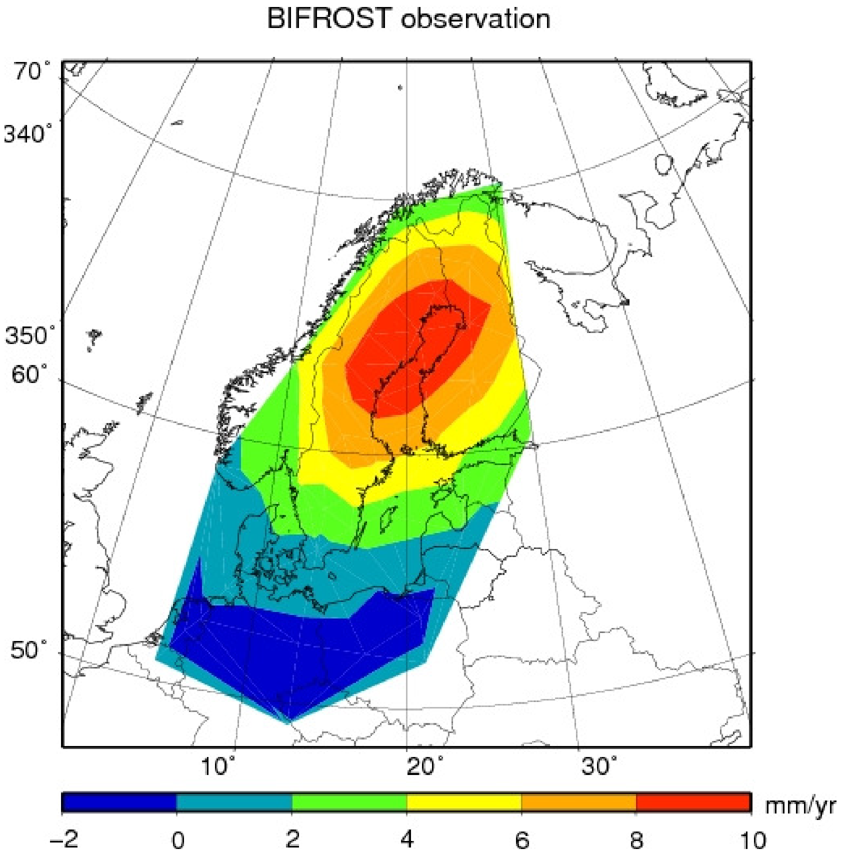
Main regions of interest:
- North America and Fennoscandia
- Greenland and Antarctica
- Other, smaller affected regions in mountain ranges

Available datasets:
- Relative sea level
- Absolute and relative gravimetry
- GPS
- Tide gauges
- GRACE



GIA in Fennoscandia

BIFROST GPS network



Max. measured uplift rate:
10.06 mm/year (at Umeå)
(Lidberg et al. 2007, J. Geod.)

Absolute gravity network

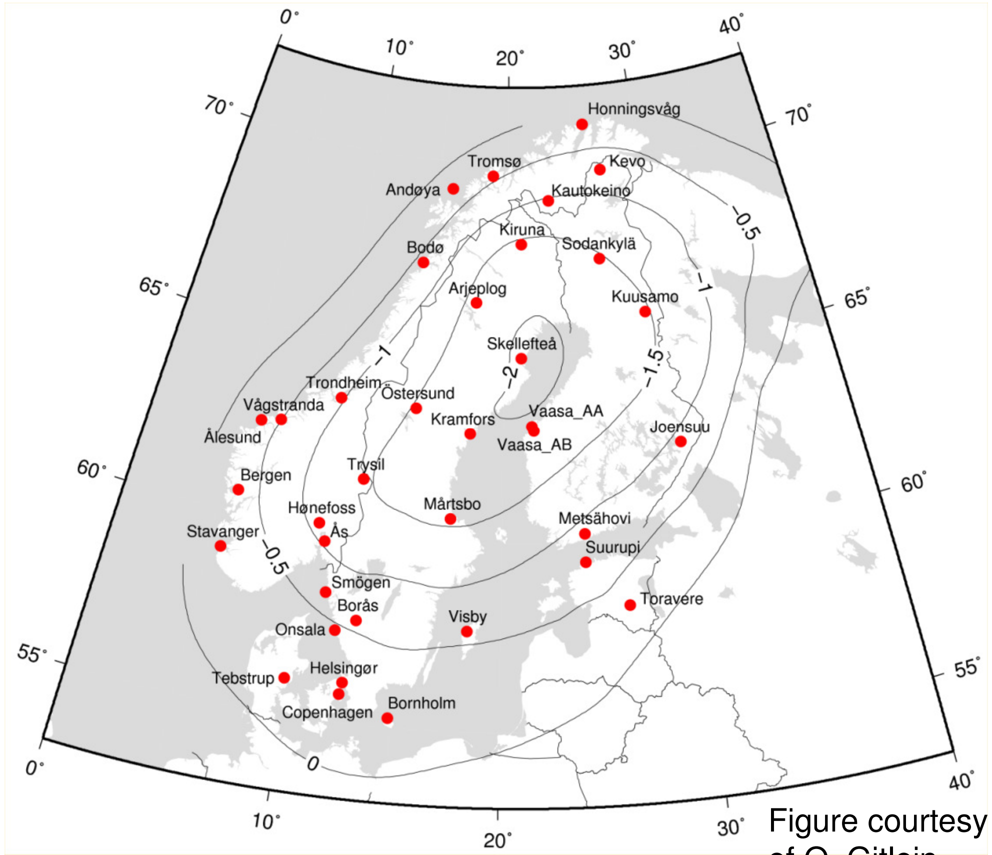
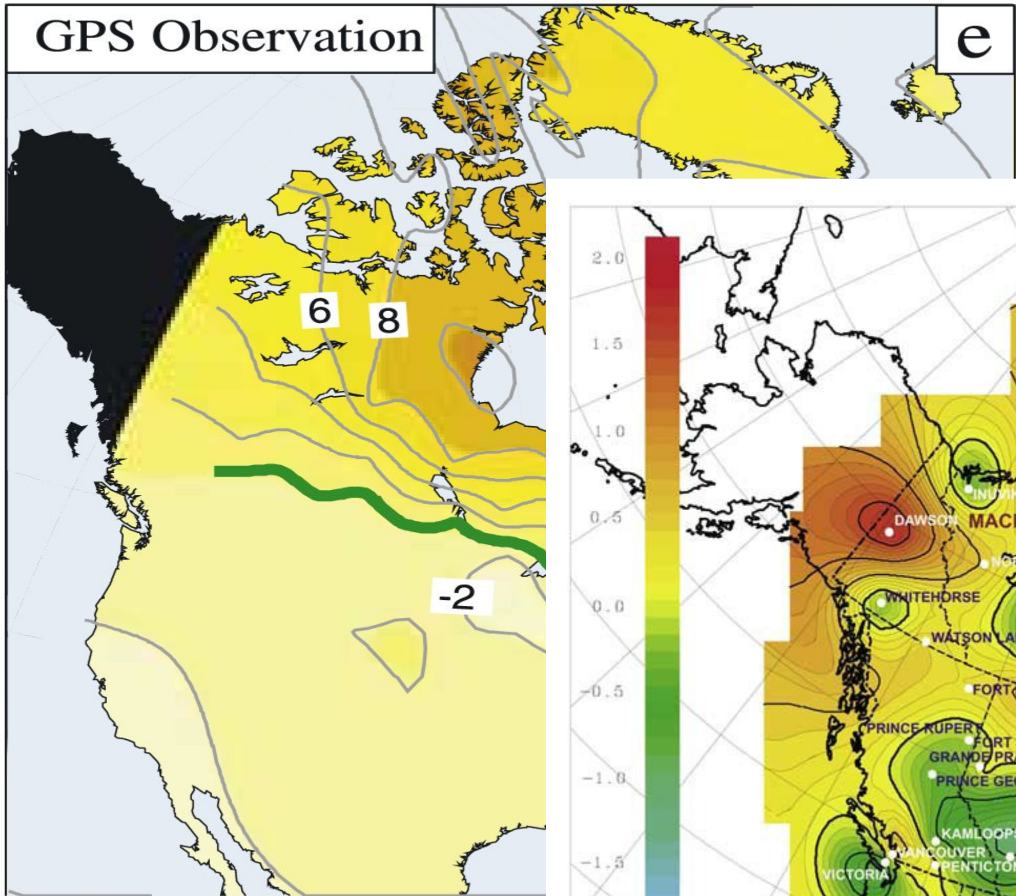


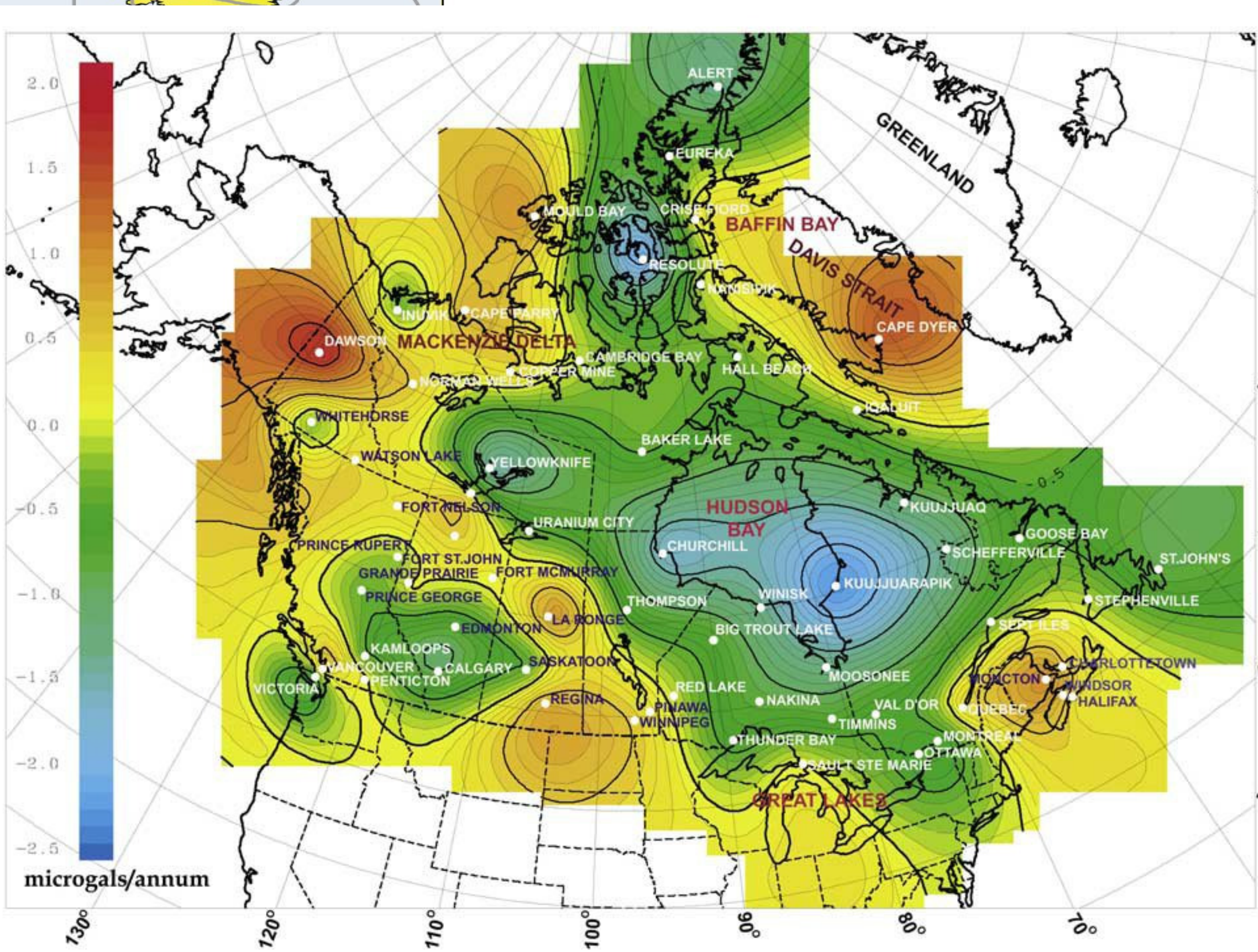
Figure courtesy of O. Gitlein

Max. gravity change:
~-2 µGal/year (Bothnian Bay)
(Ekman and Mäkinen 1996, GJI)

GIA in North America



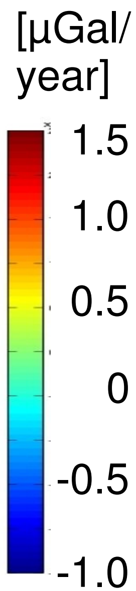
Max. gravity change:
-2.35 μGal/year (at Kuujjuarapik)
(Pagiatakis and Salib 2003, JGR)

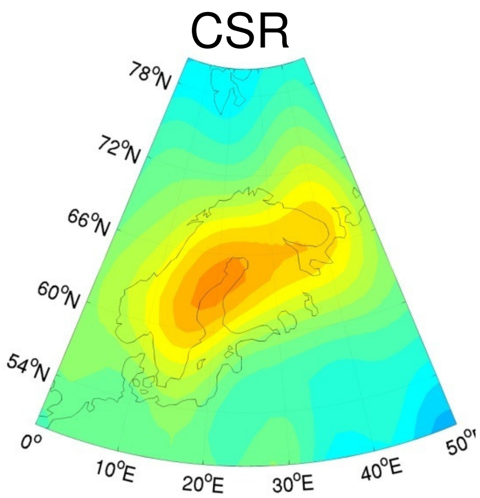


Max. uplift rate:
~10 mm/year (near Huds
(Sella et al. 2005, GRL)

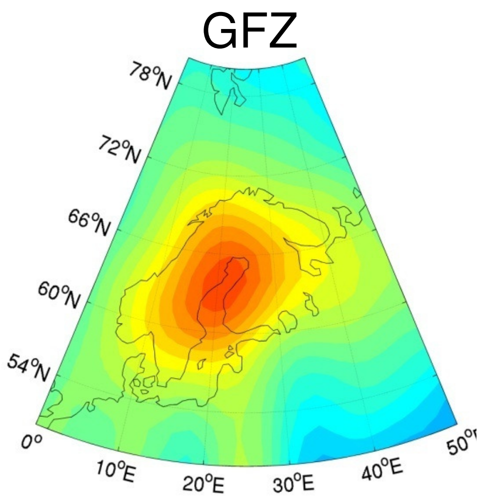
Measurement errors are small

Secular trend of monthly solutions

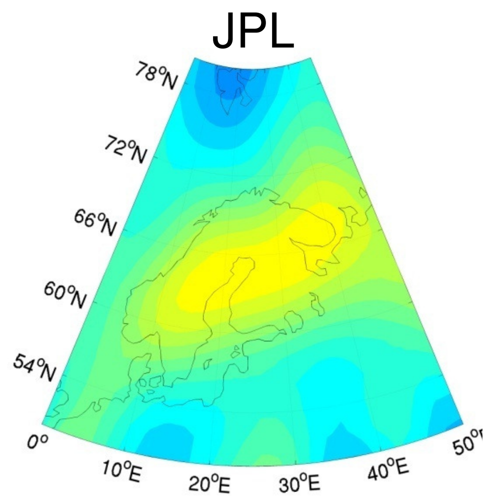




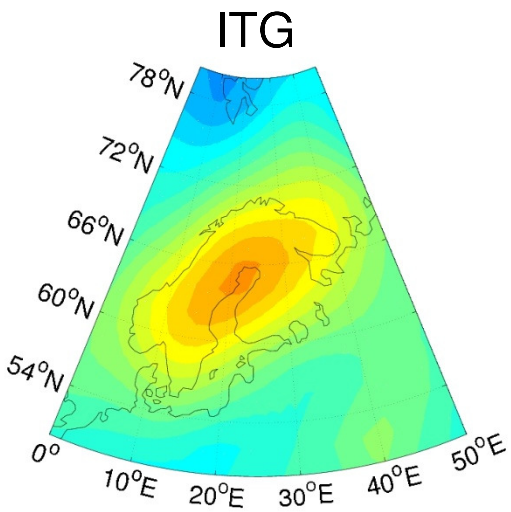
07/2003 – 03/2009



07/2003 – 03/2009



07/2003 – 03/2009



02/2003 – 02/2008

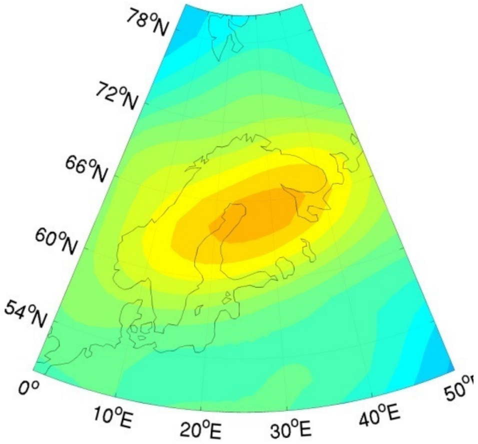
Correlations:

CSR	JPL	ITG	
0.90	0.79	0.81	GFZ
-	0.93	0.88	CSR
-	-	0.90	JPL

Fennoscandia, Gauss filter: 400 km

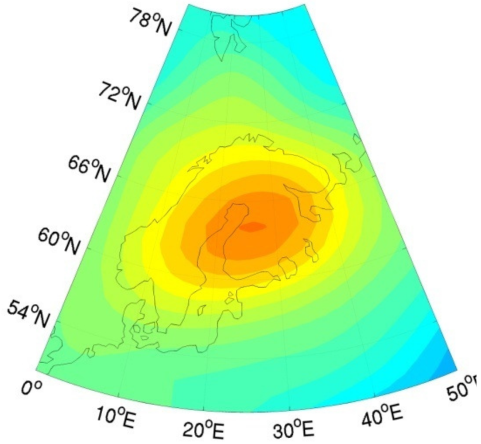
Secular trend of monthly solutions

CSR



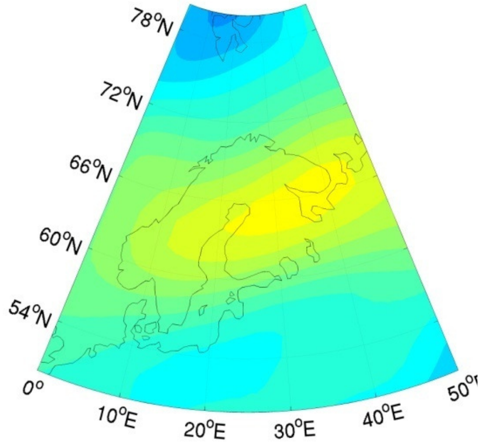
07/2003 – 03/2009

GFZ



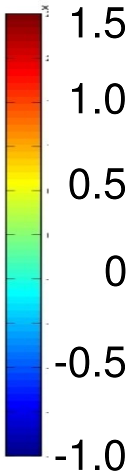
07/2003 – 03/2009

JPL

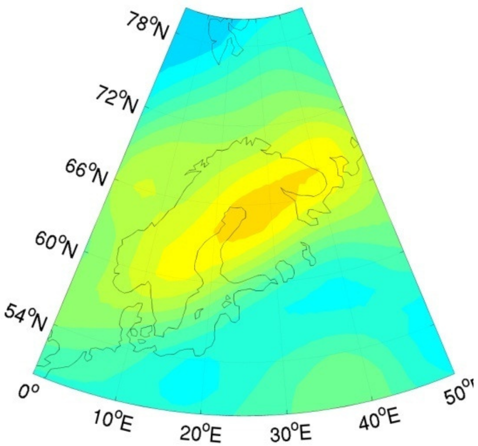


07/2003 – 03/2009

[µGal/
year]



ITG



02/2003 – 02/2008

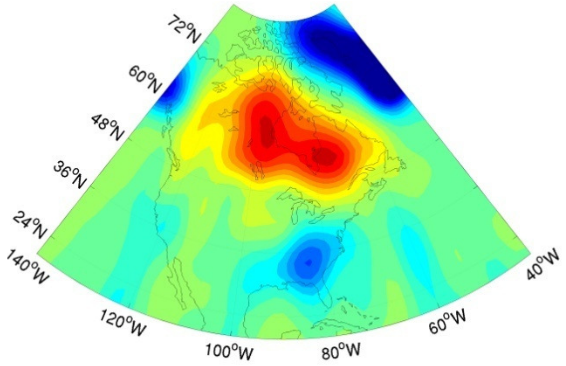
Correlations:

CSR	JPL	ITG	
0.94	0.83	0.91	GFZ
-	0.94	0.94	CSR
-	-	0.93	JPL

Fennoscandia, Destriping + Gauss filter: 400 km

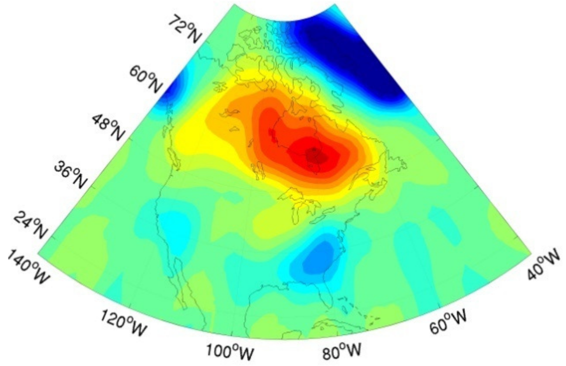
Secular trend of monthly solutions

CSR



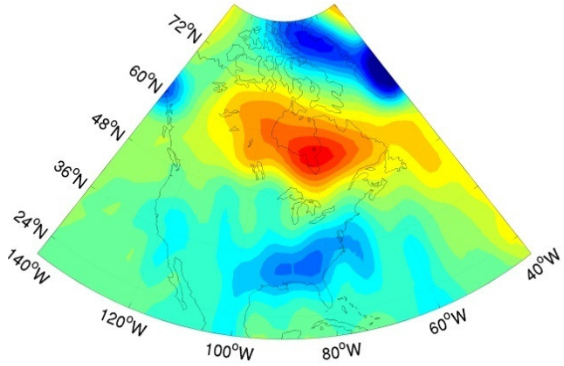
07/2003 – 03/2009

GFZ



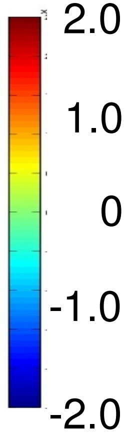
07/2003 – 03/2009

JPL

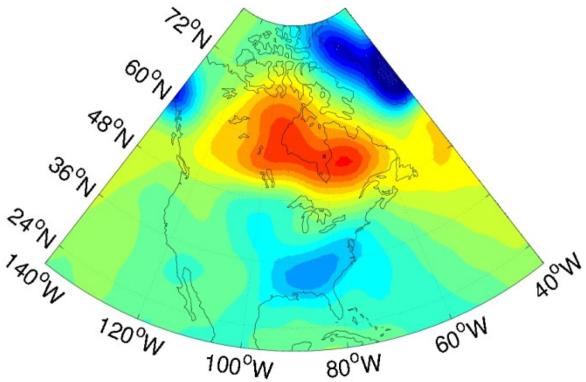


07/2003 – 03/2009

[µGal/ year]



ITG



01/2003 – 02/2008

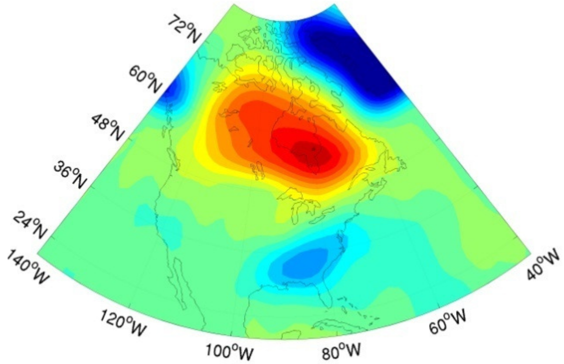
Correlations:

CSR	JPL	ITG	
0.98	0.86	0.96	GFZ
-	0.86	0.94	CSR
-	-	0.93	JPL

North America, Gauss filter: 400 km

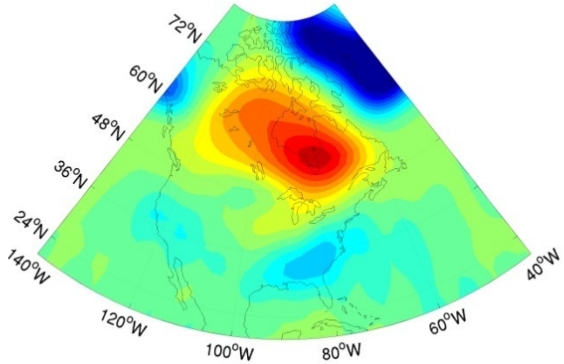
Secular trend of monthly solutions

CSR



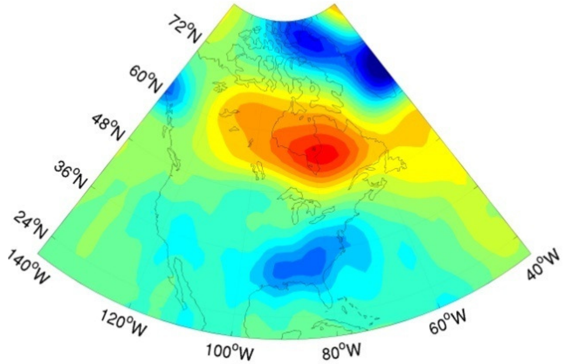
07/2003 – 03/2009

GFZ

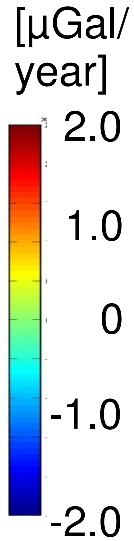


07/2003 – 03/2009

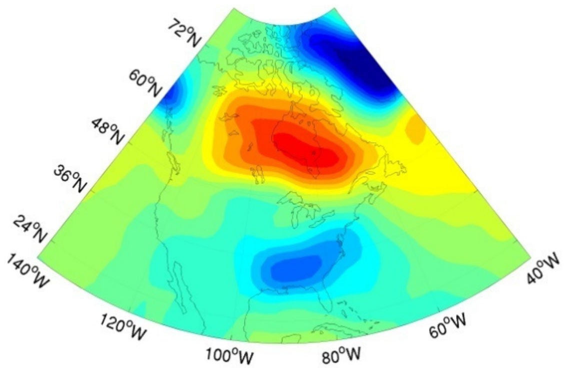
JPL



07/2003 – 03/2009



ITG



01/2003 – 02/2008

Correlations:

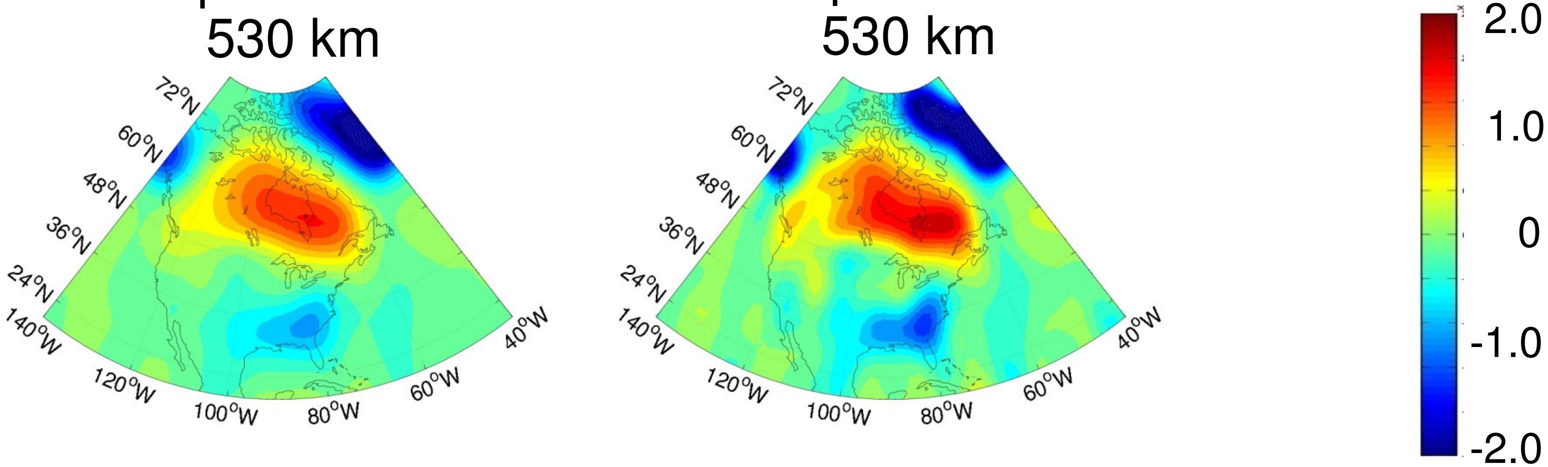
CSR	JPL	ITG	
0.99	0.87	0.97	GFZ
-	0.88	0.97	CSR
-	-	0.94	JPL

North America, Destriping + Gauss filter: 400 km

Comparison of filter techniques

isotropic Gaussian
530 km

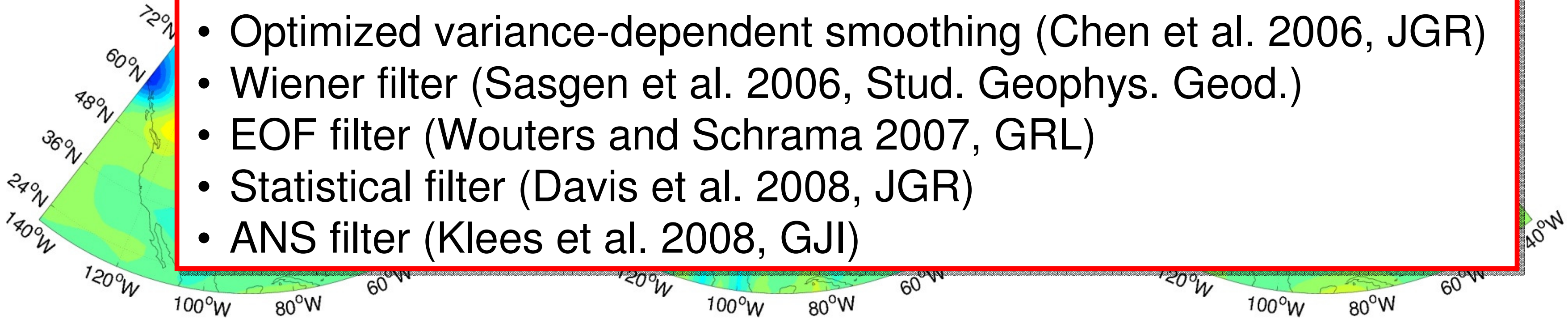
isotropic Pellinen
530 km



non-isotropic Gaussian
340/680 km, m1=15
(Han

correlated
error filter

non-isotropic decorrelation
filter DDK1
)

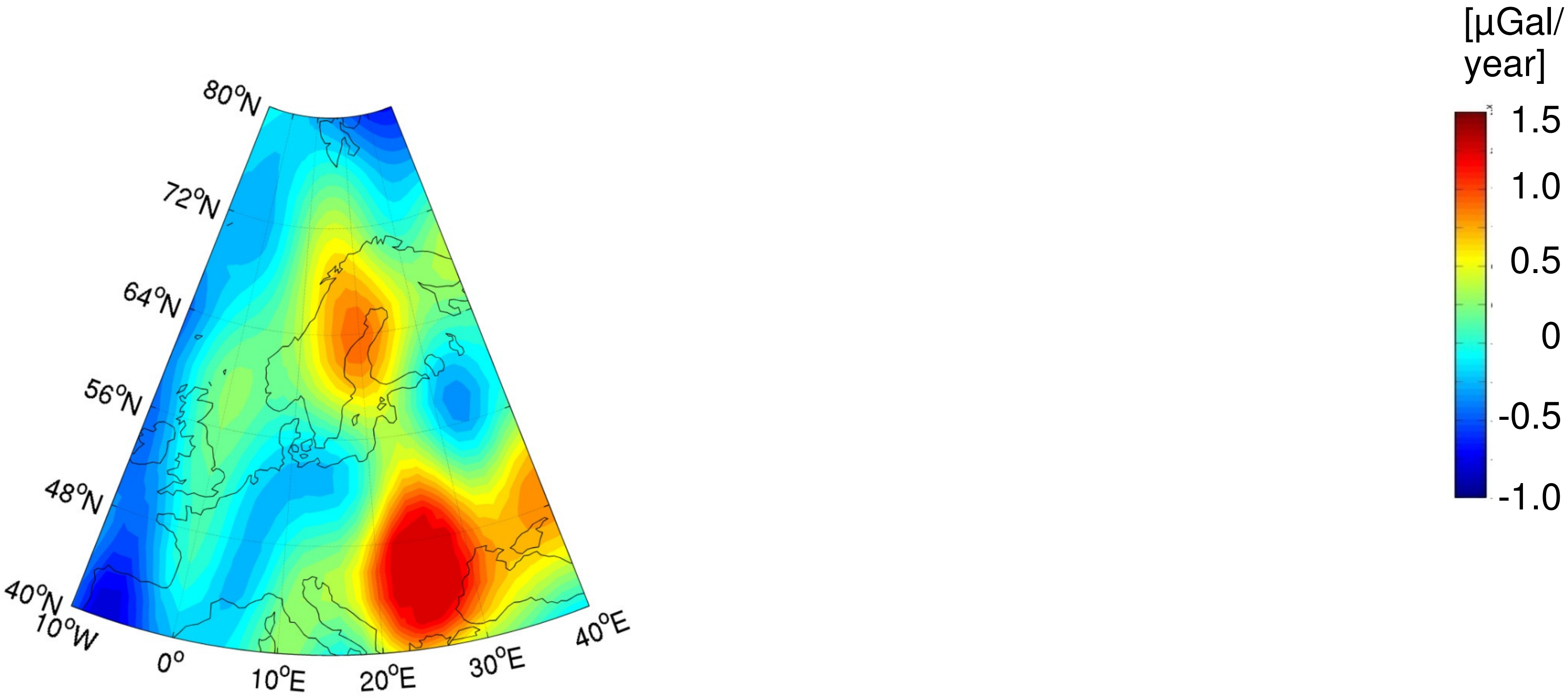


Other filters:

- Optimized variance-dependent smoothing (Chen et al. 2006, JGR)
- Wiener filter (Sasgen et al. 2006, Stud. Geophys. Geod.)
- EOF filter (Wouters and Schrama 2007, GRL)
- Statistical filter (Davis et al. 2008, JGR)
- ANS filter (Klees et al. 2008, GJI)

GFZ solution (02/2003 - 05/2008)

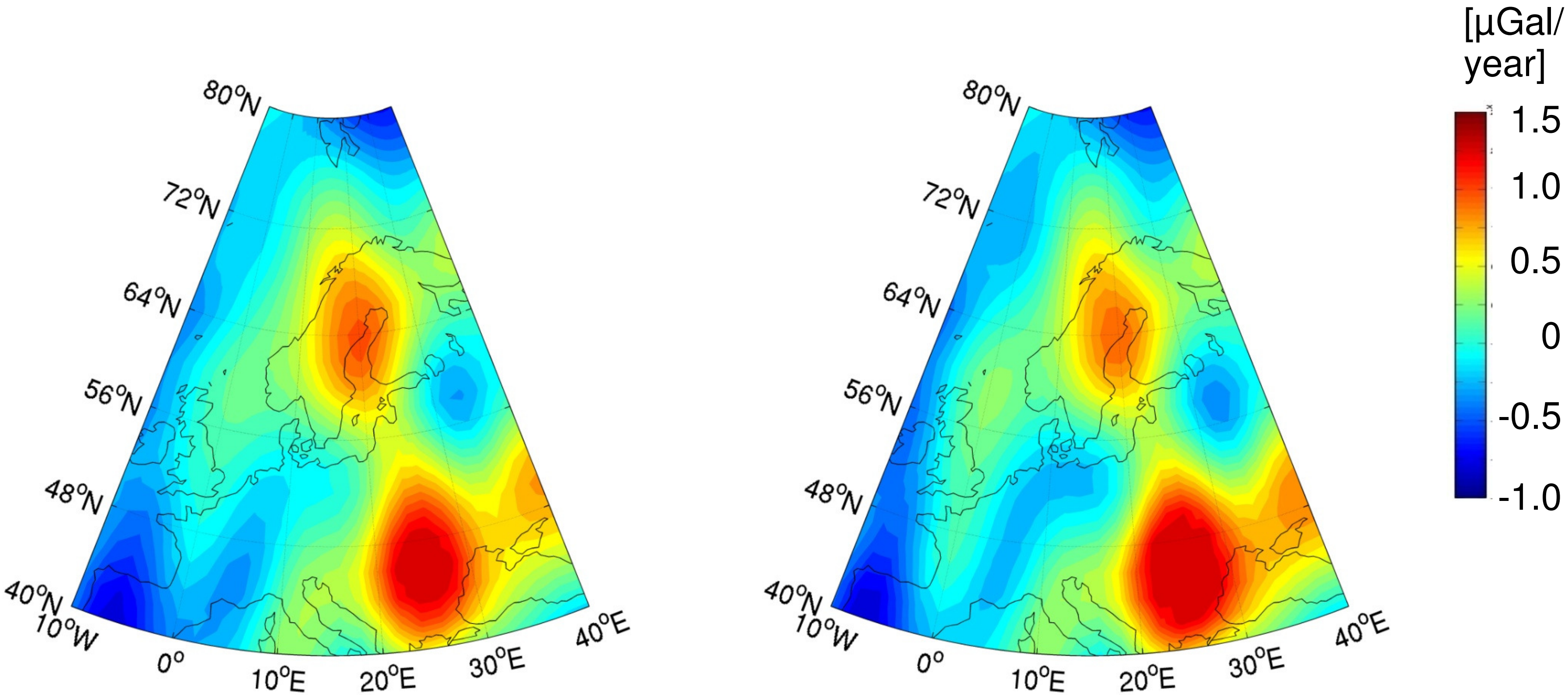
Effect of different time spans



07/2003 – 12/2006

GFZ solution, Gauss filter: 400 km

Effect of different time spans

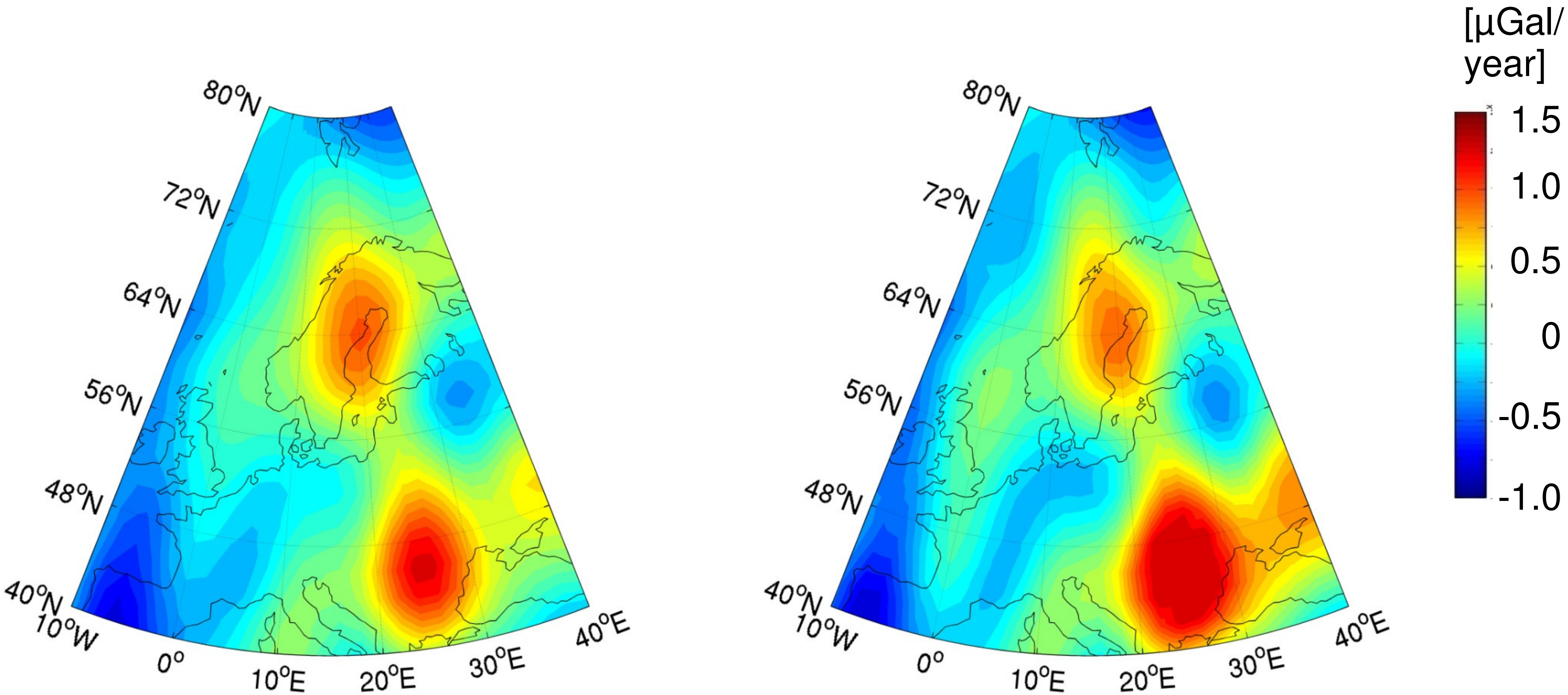


07/2003 – 03/2007

07/2003 – 12/2006

GFZ solution, Gauss filter: 400 km

Effect of different time spans

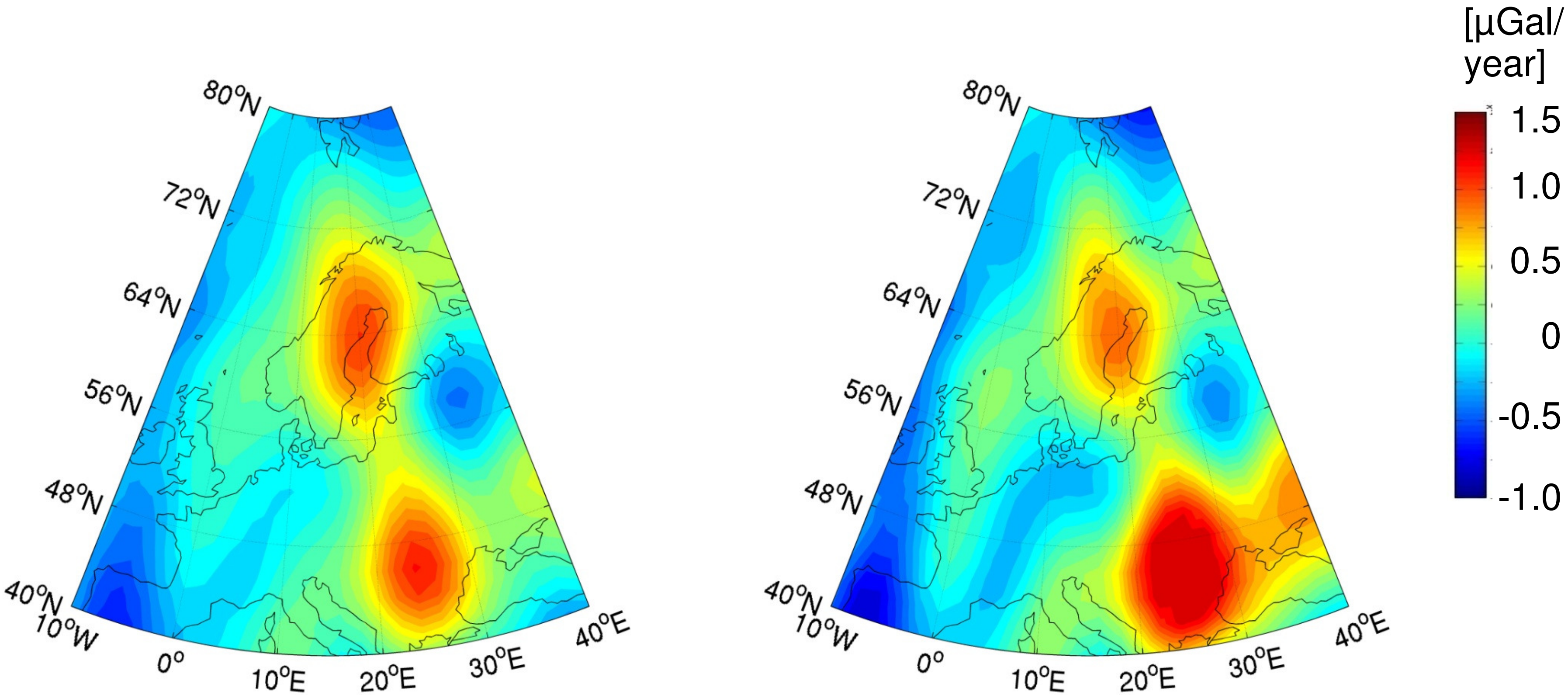


07/2003 – 06/2007

07/2003 – 12/2006

GFZ solution, Gauss filter: 400 km

Effect of different time spans

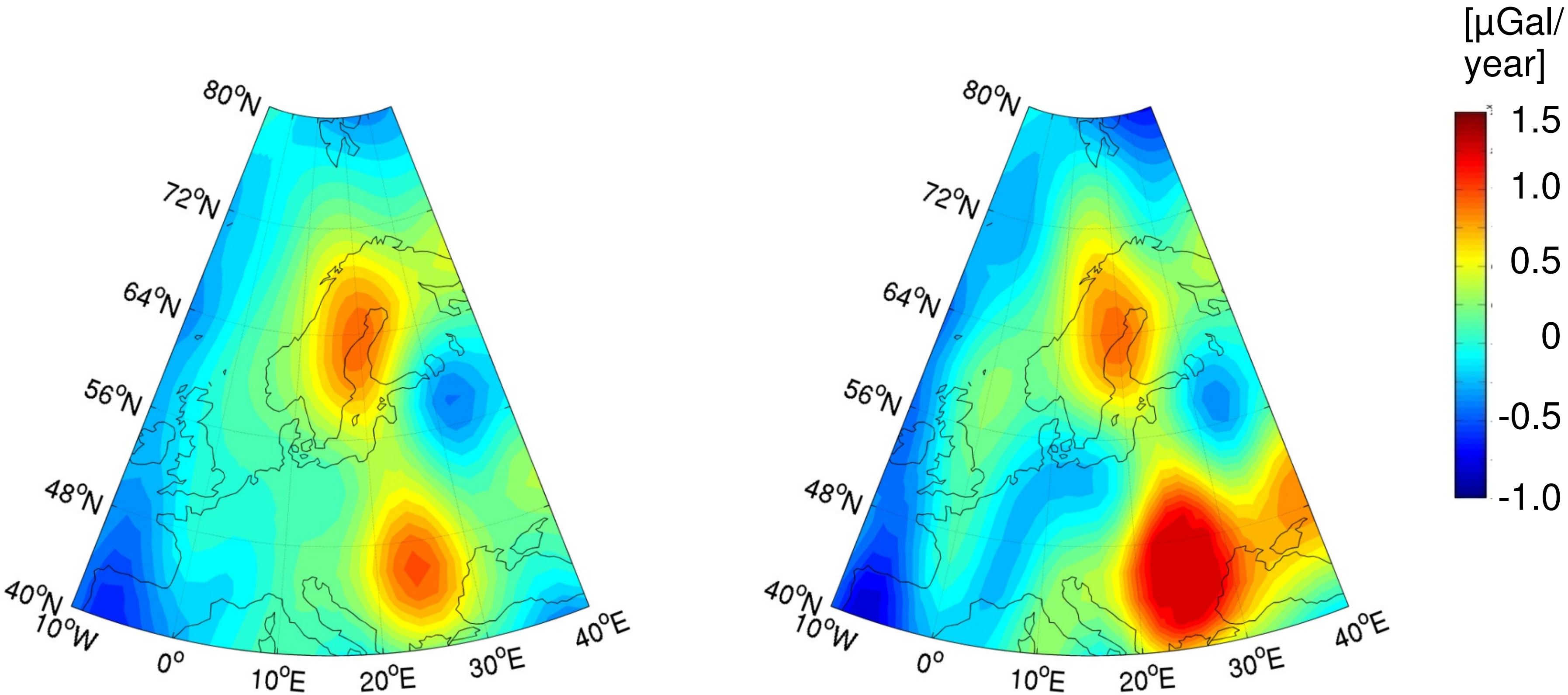


07/2003 – 09/2007

07/2003 – 12/2006

GFZ solution, Gauss filter: 400 km

Effect of different time spans

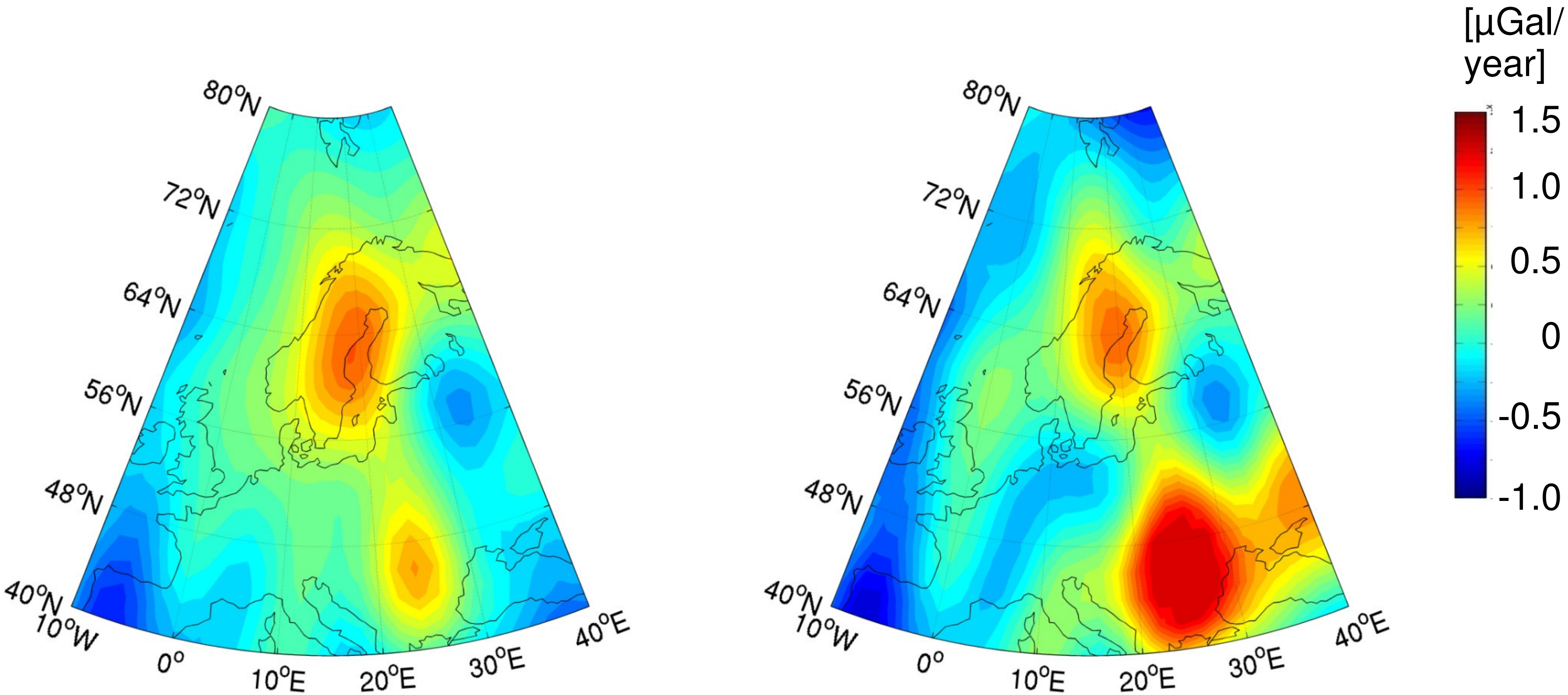


07/2003 – 12/2007

07/2003 – 12/2006

GFZ solution, Gauss filter: 400 km

Effect of different time spans

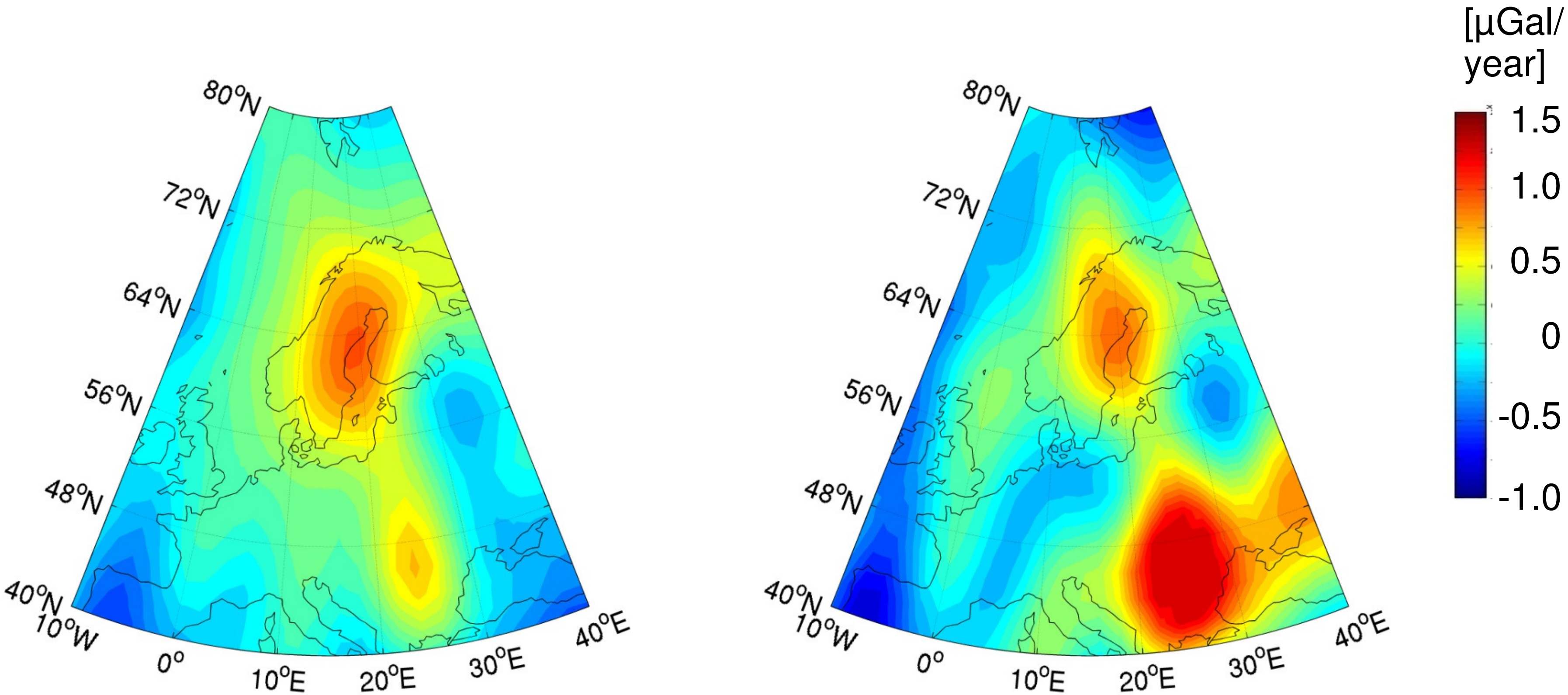


07/2003 – 03/2008

07/2003 – 12/2006

GFZ solution, Gauss filter: 400 km

Effect of different time spans

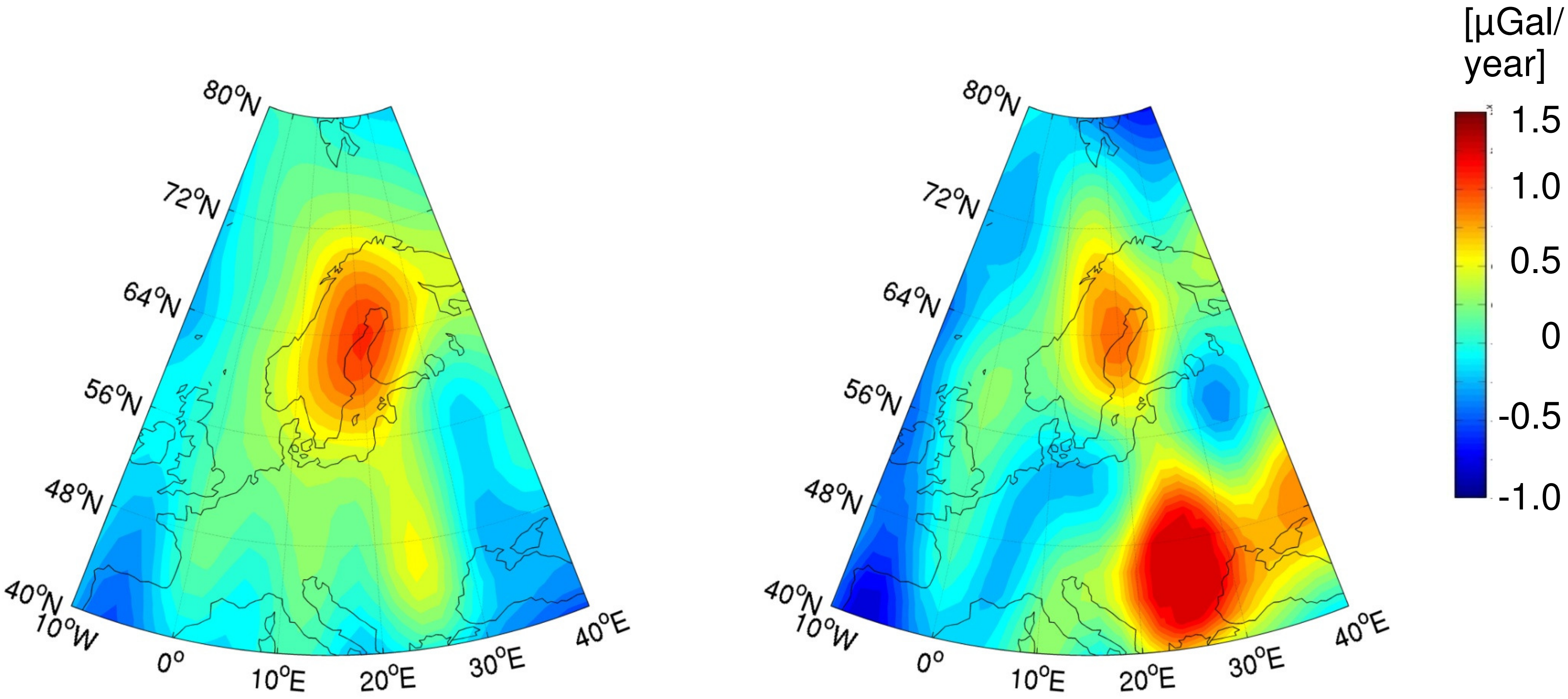


07/2003 – 06/2008

07/2003 – 12/2006

GFZ solution, Gauss filter: 400 km

Effect of different time spans

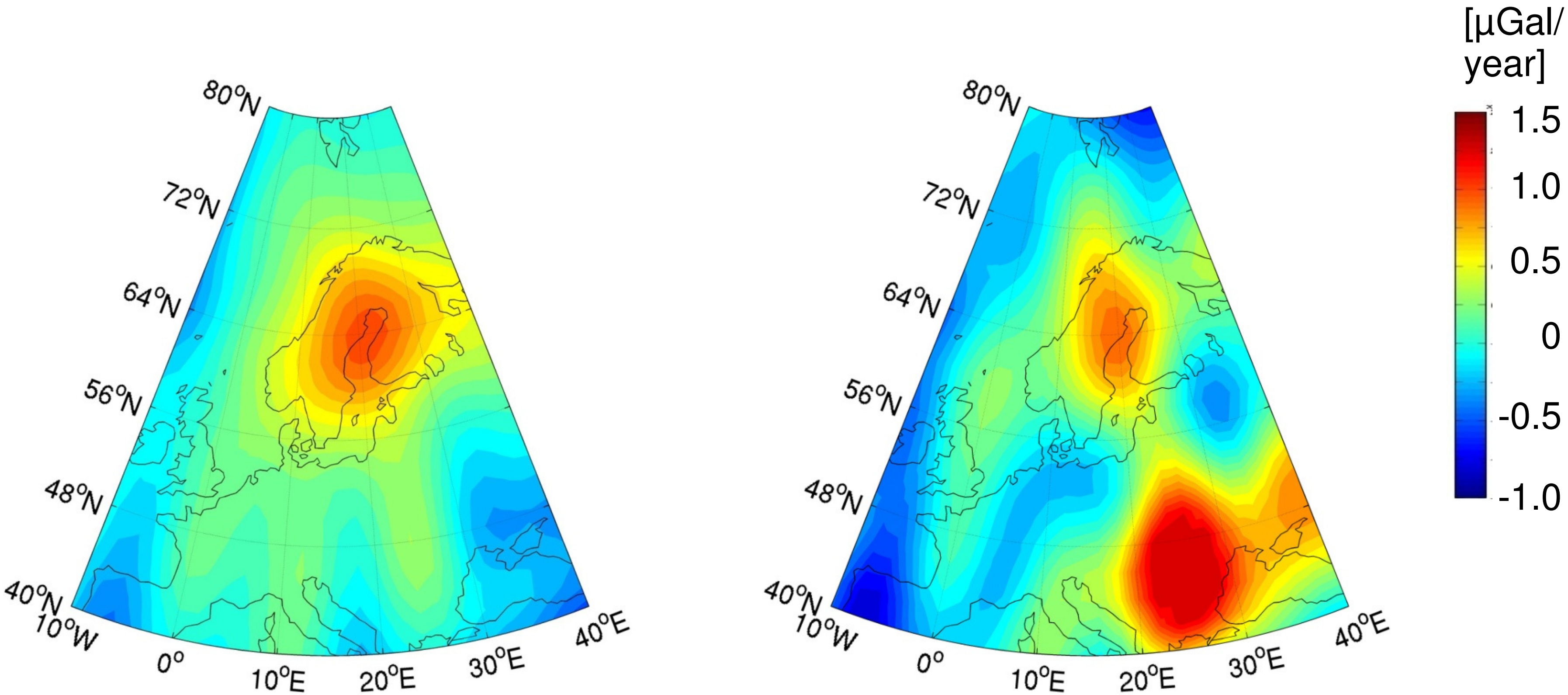


07/2003 – 09/2008

07/2003 – 12/2006

GFZ solution, Gauss filter: 400 km

Effect of different time spans

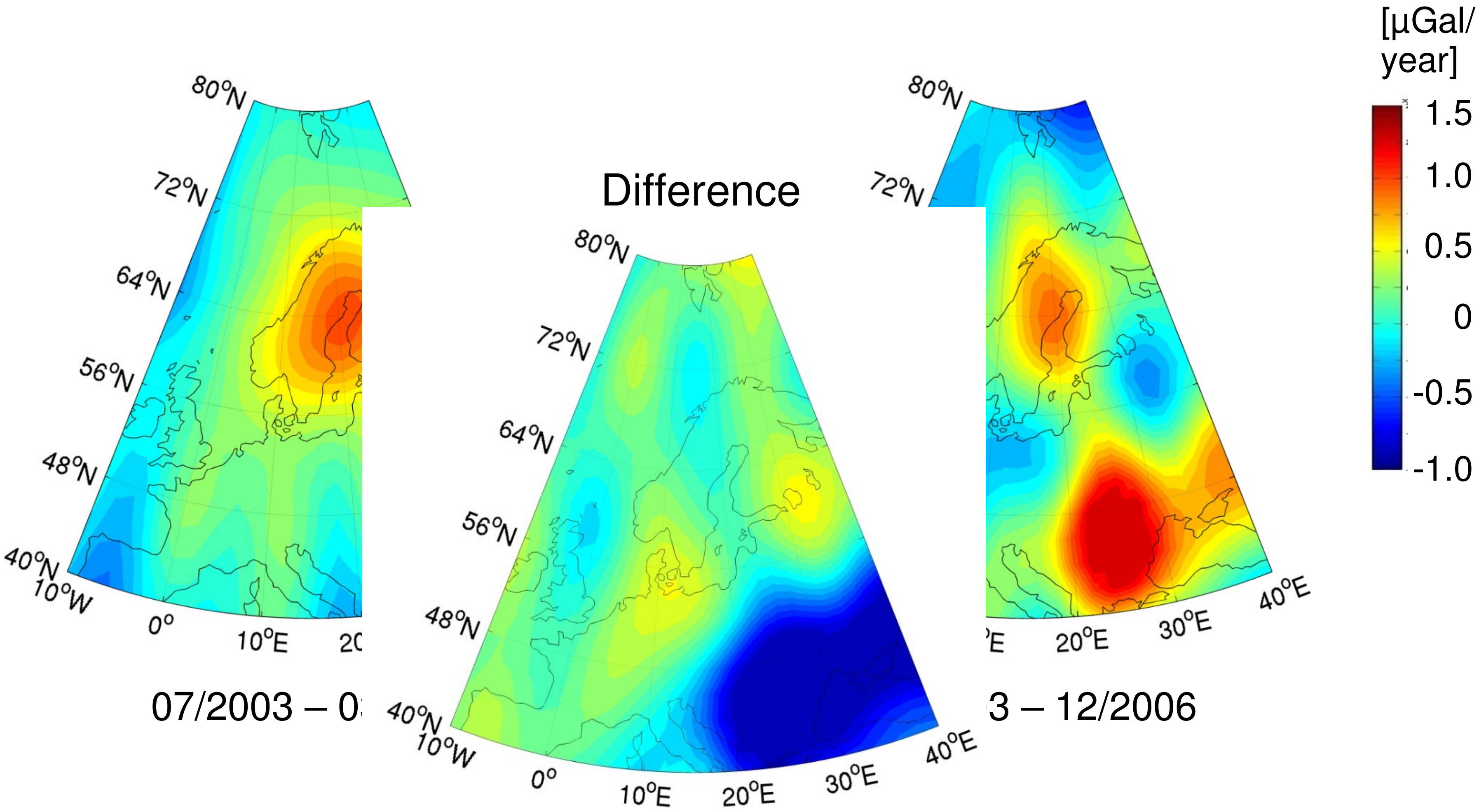


07/2003 – 12/2008

07/2003 – 12/2006

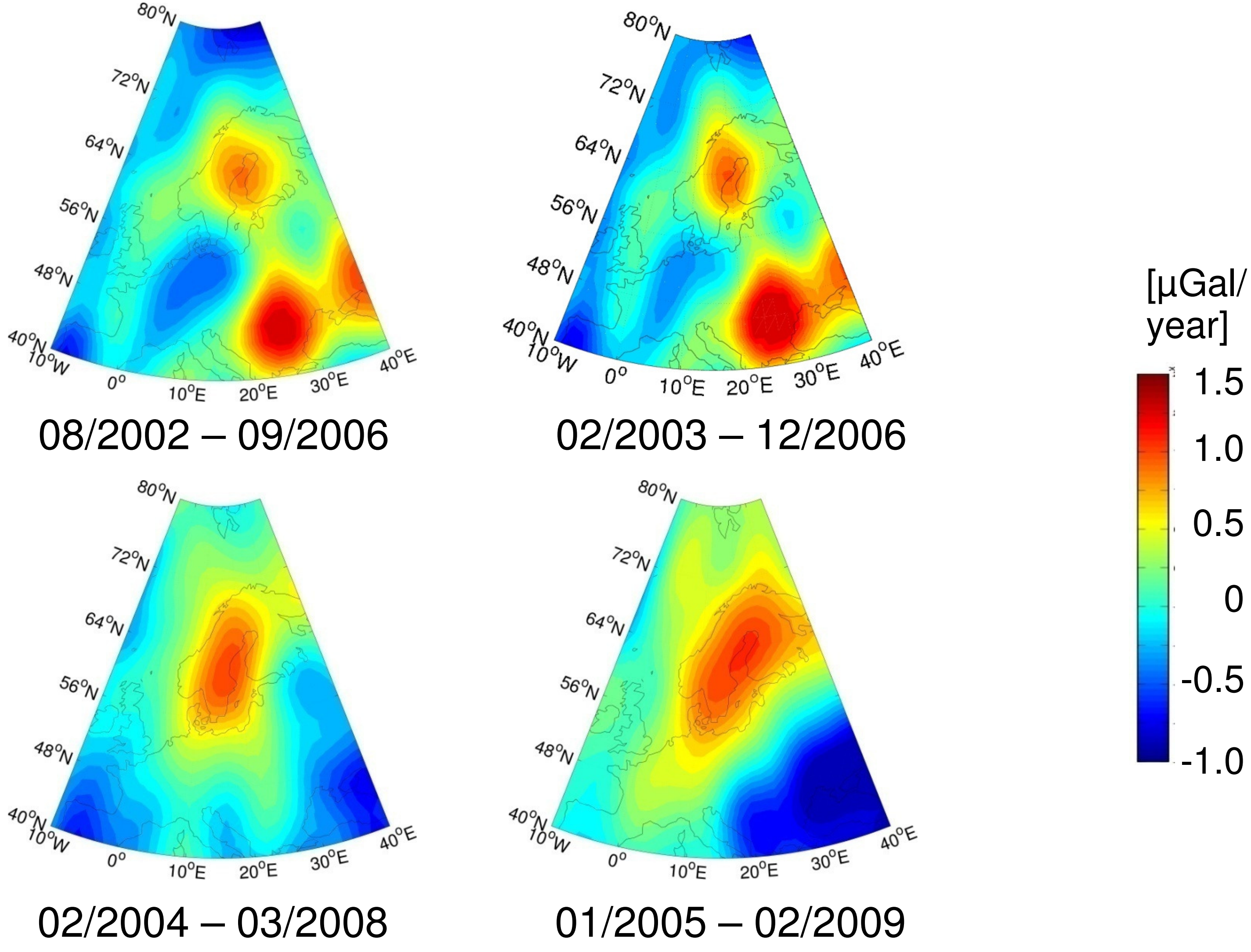
GFZ solution, Gauss filter: 400 km

Effect of different time spans



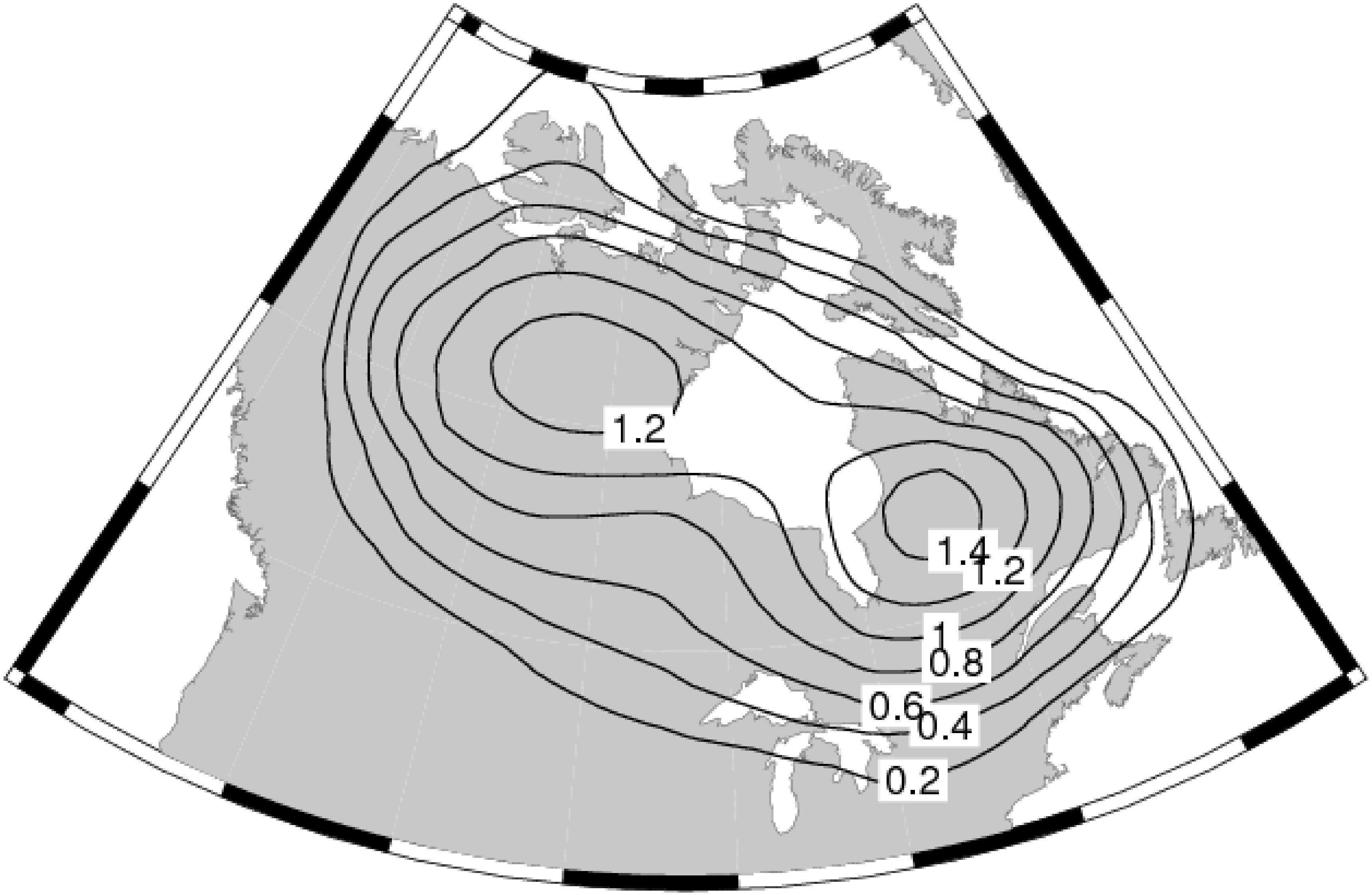
GFZ solution, Gauss filter: 400 km

Effect of different time spans

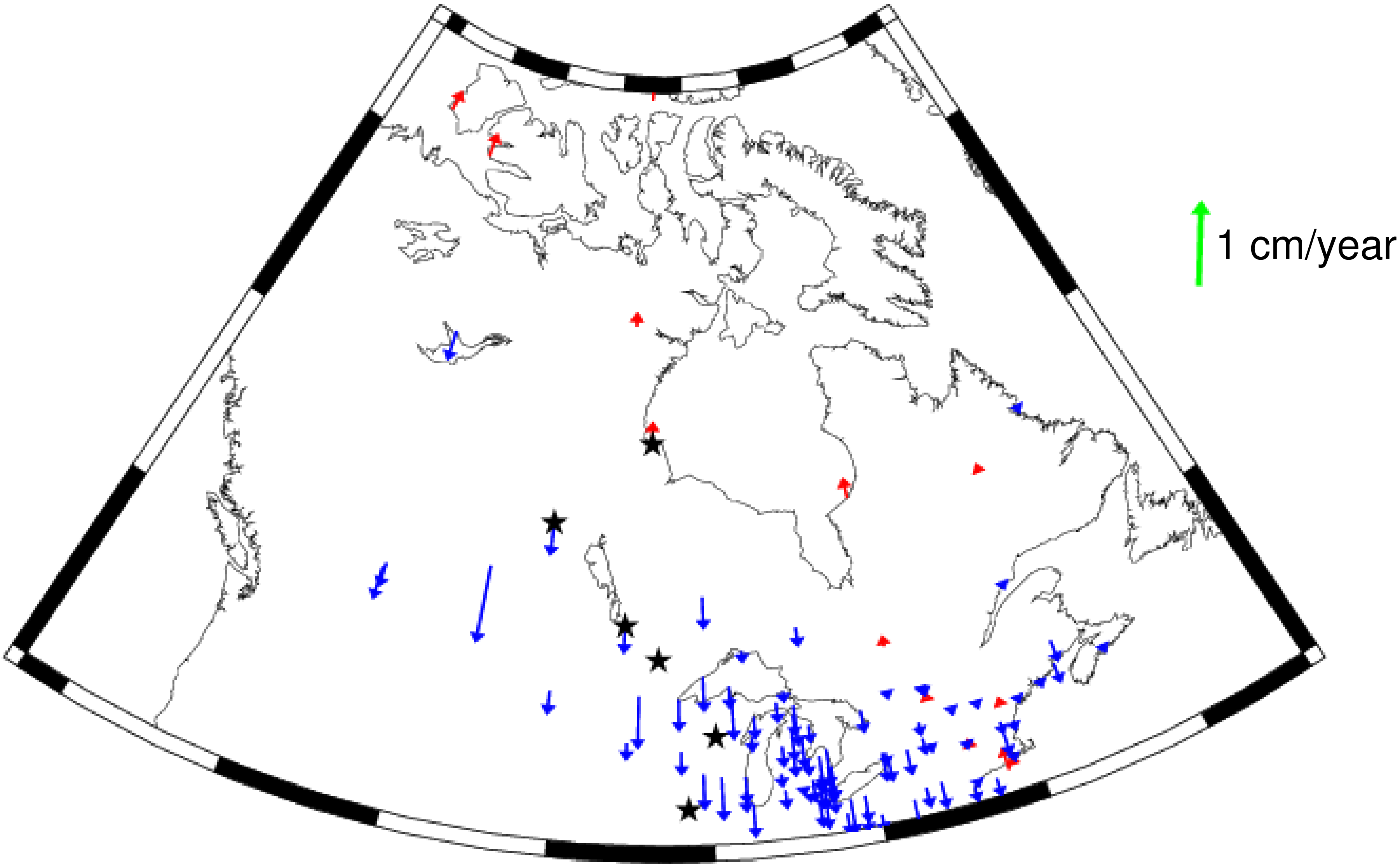


GFZ solution, Gauss filter: 400 km

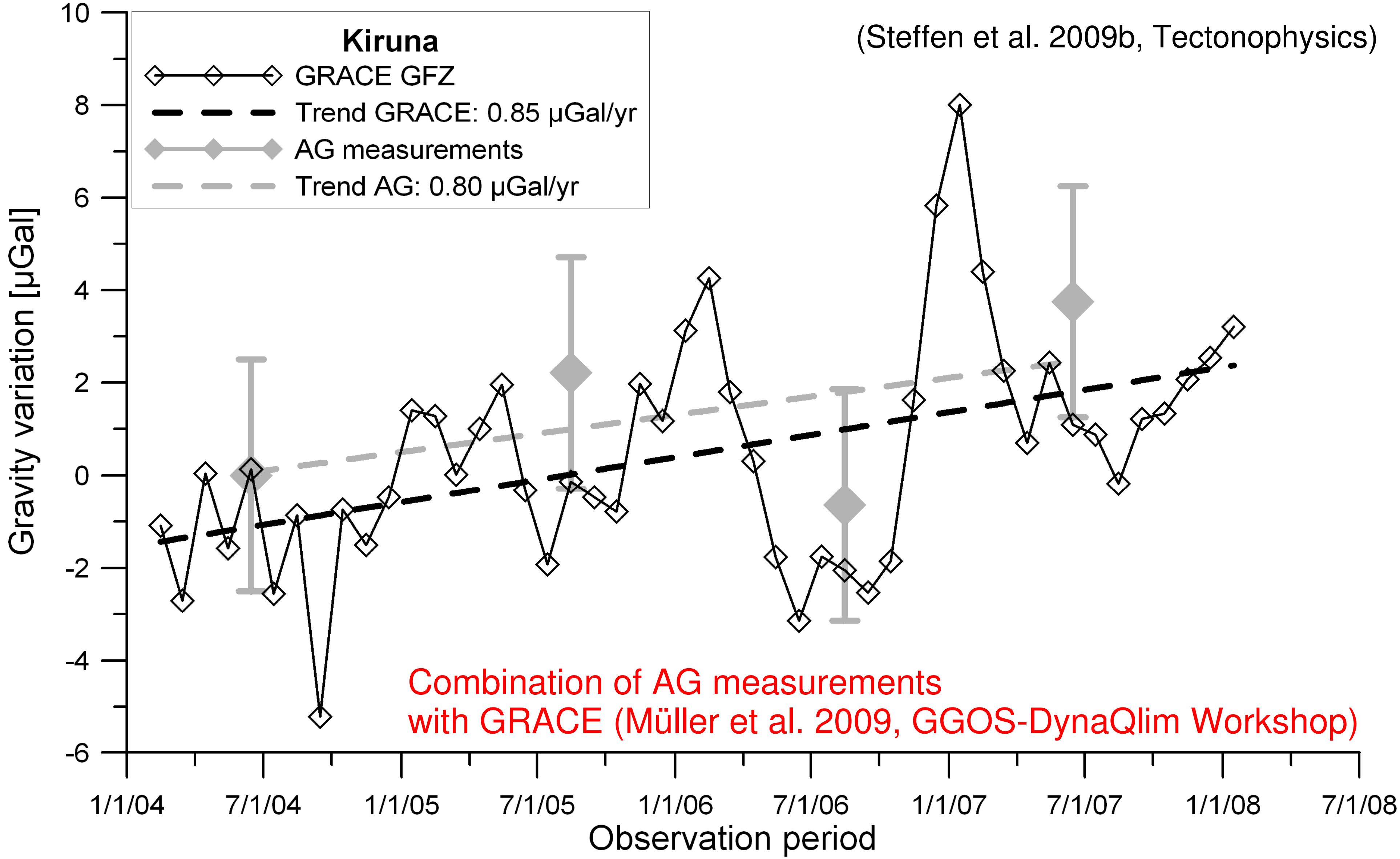
CSR Aug 2002 – April 2009



(GRACE – GLDAS) – GPS

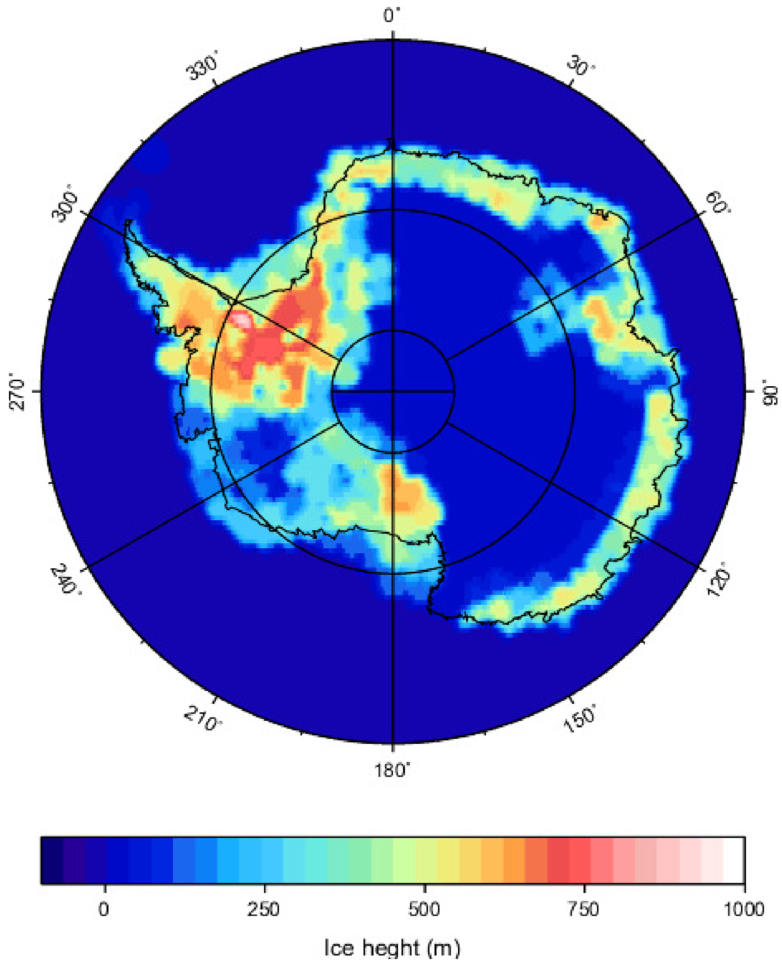


Comparison to absolute gravity

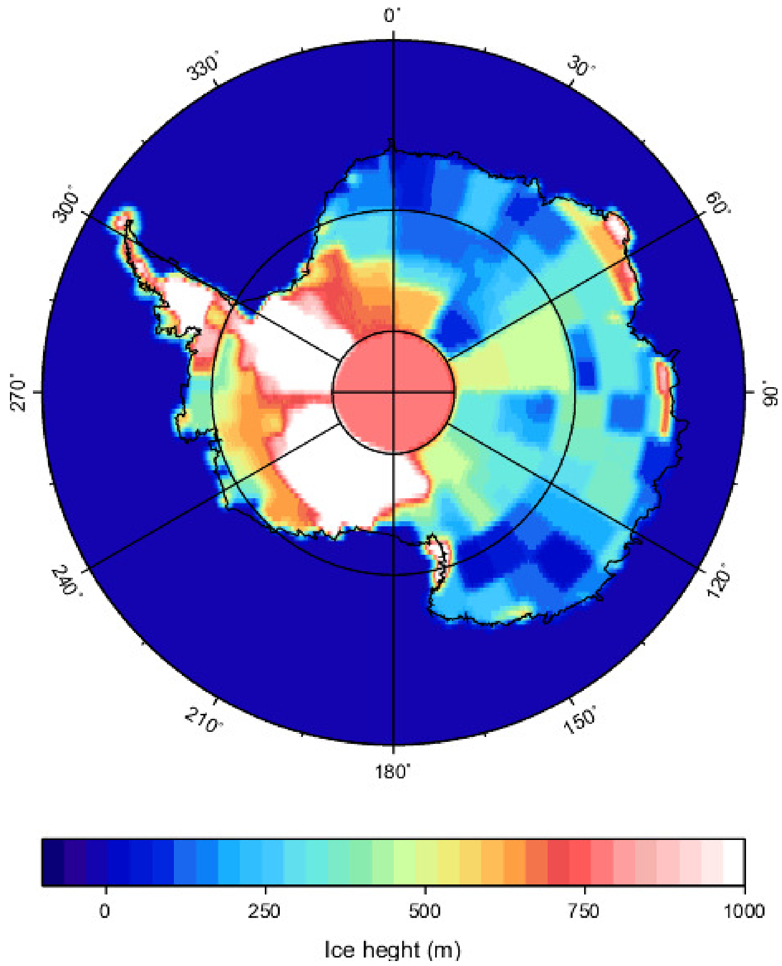


Antarctica: Ice load at LGM

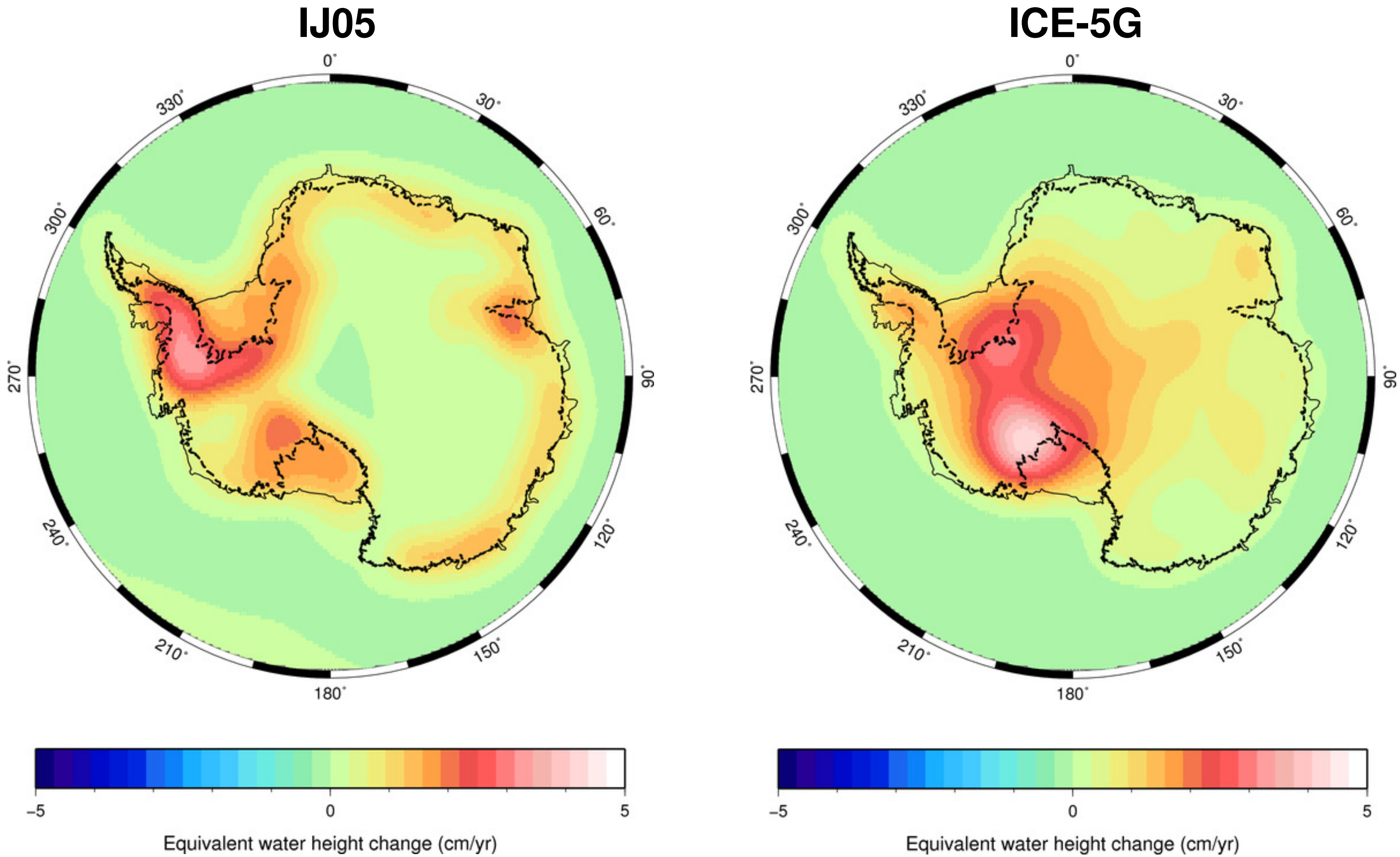
IJ05 (Ivins&James, 2005)



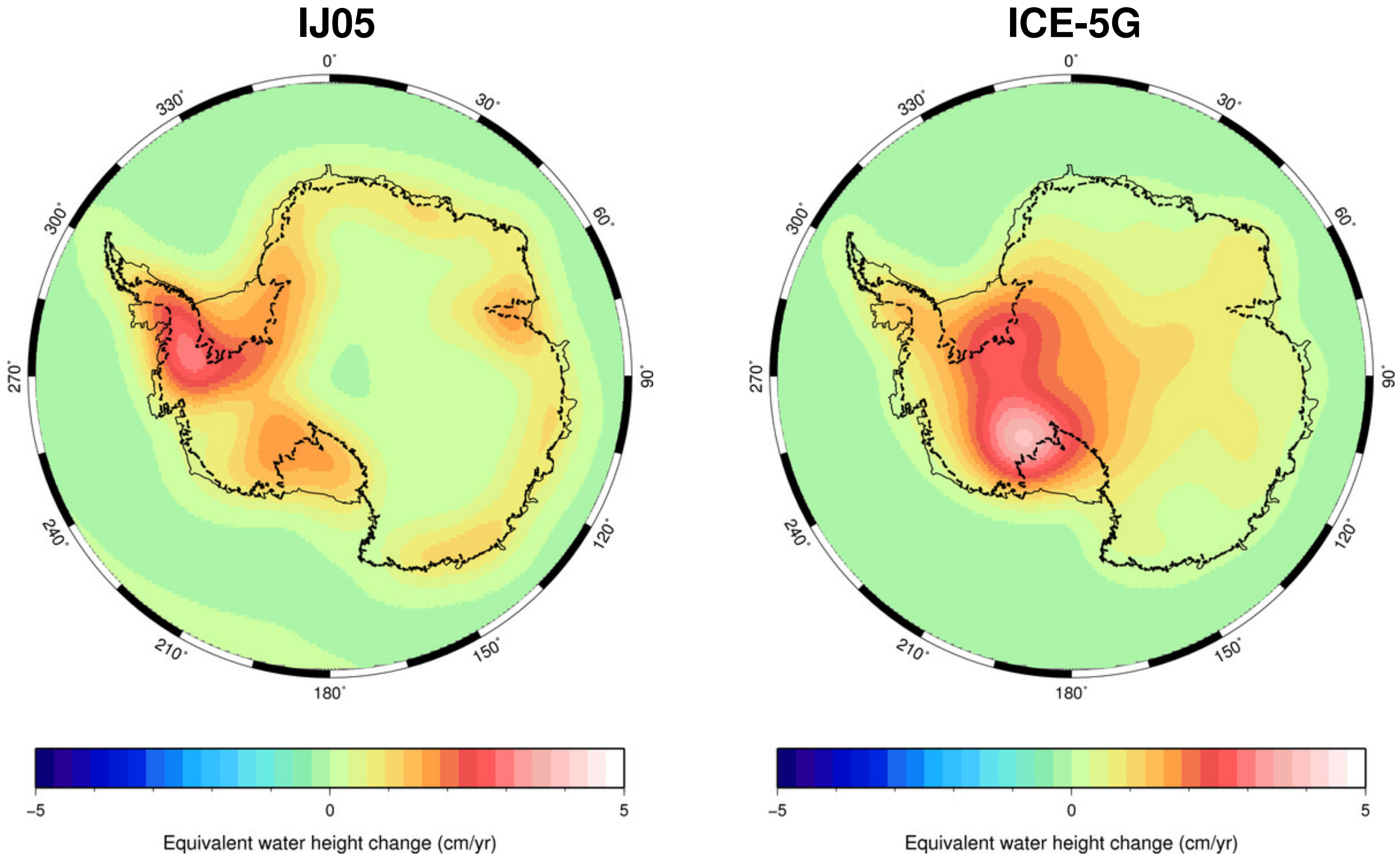
ICE-5G (Peltier, 2004)



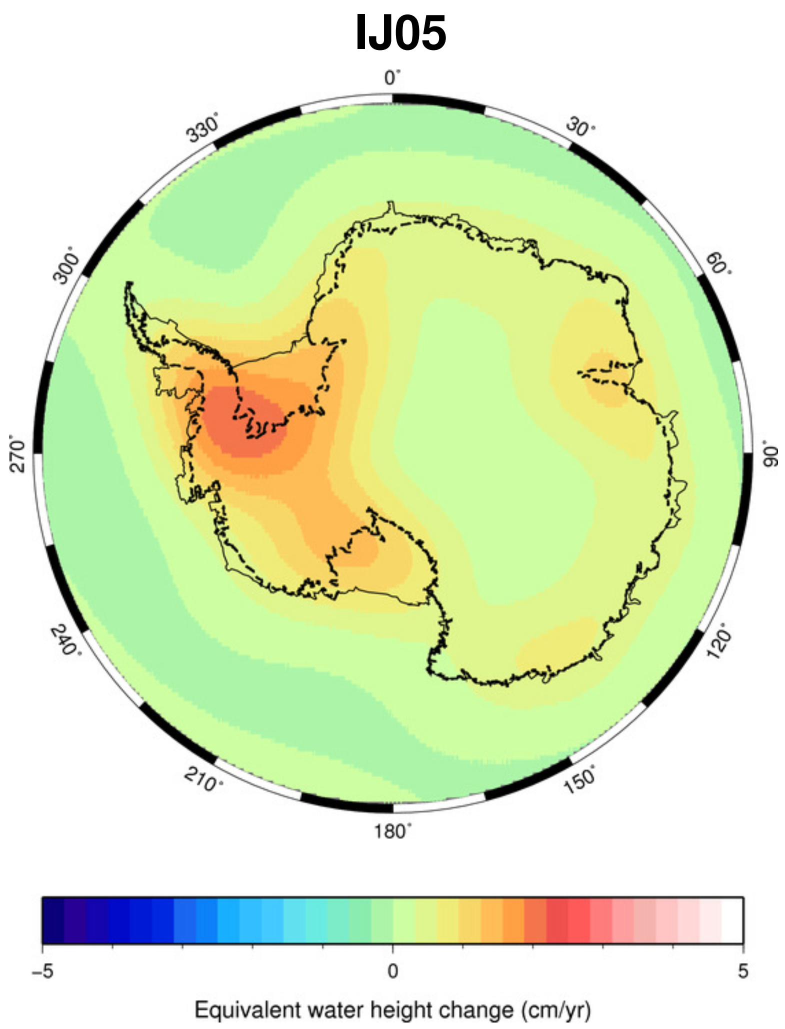
Present-day GIA (100 km resolution)

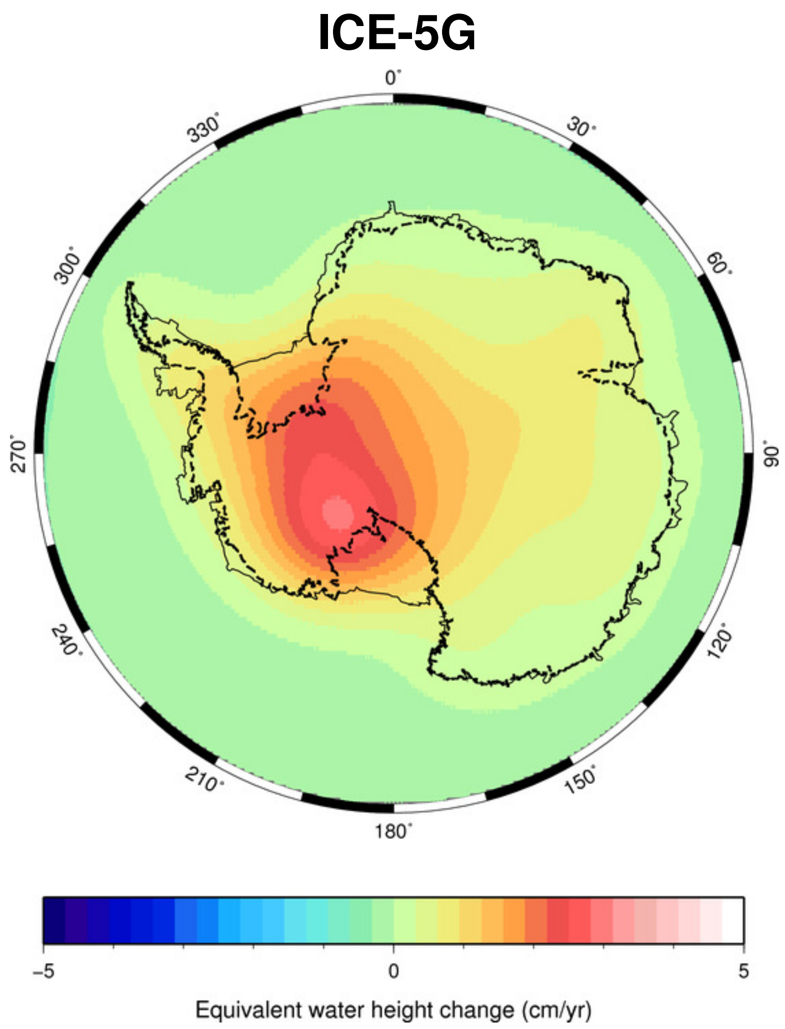


200 km resolution

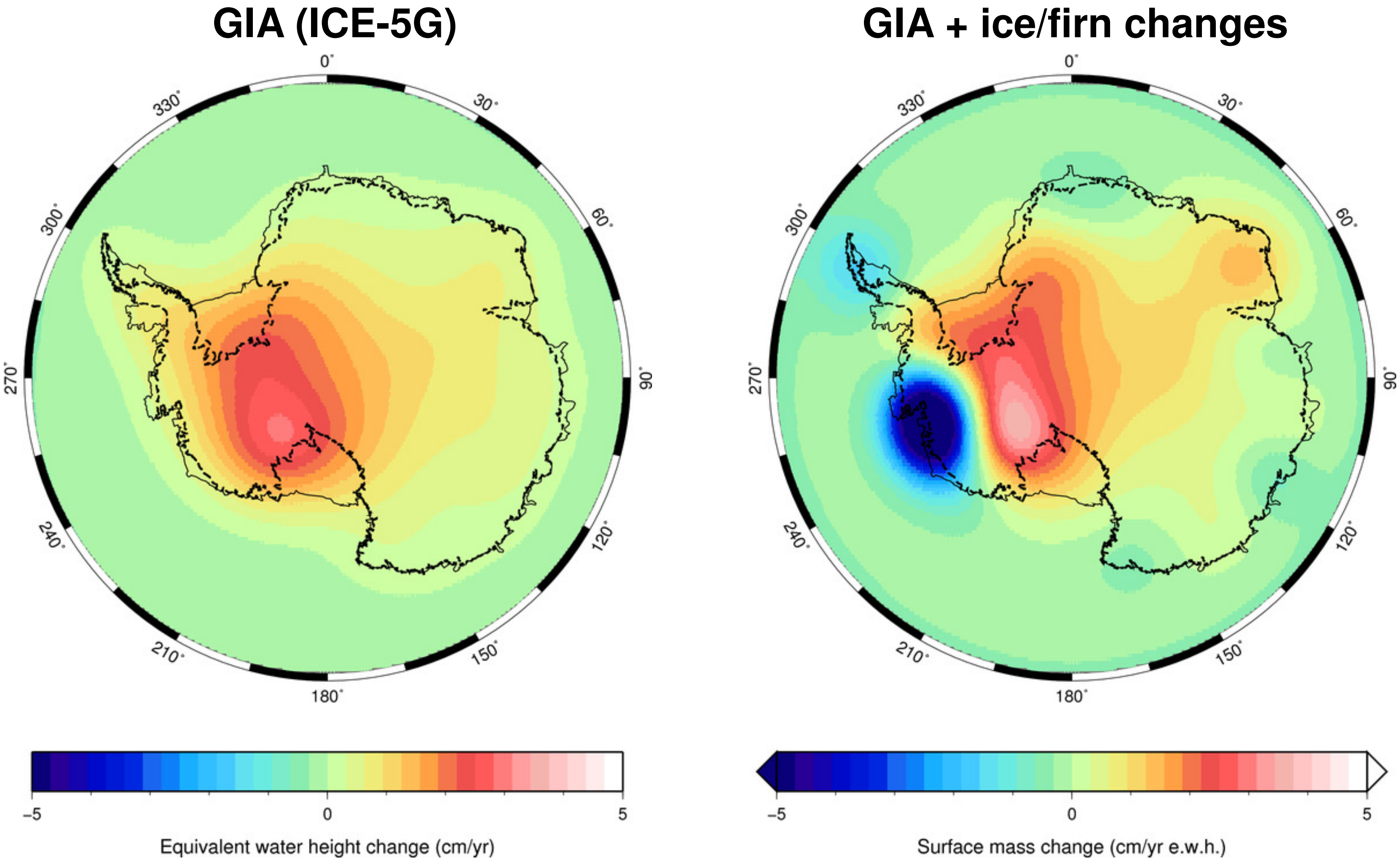


400 km resolution

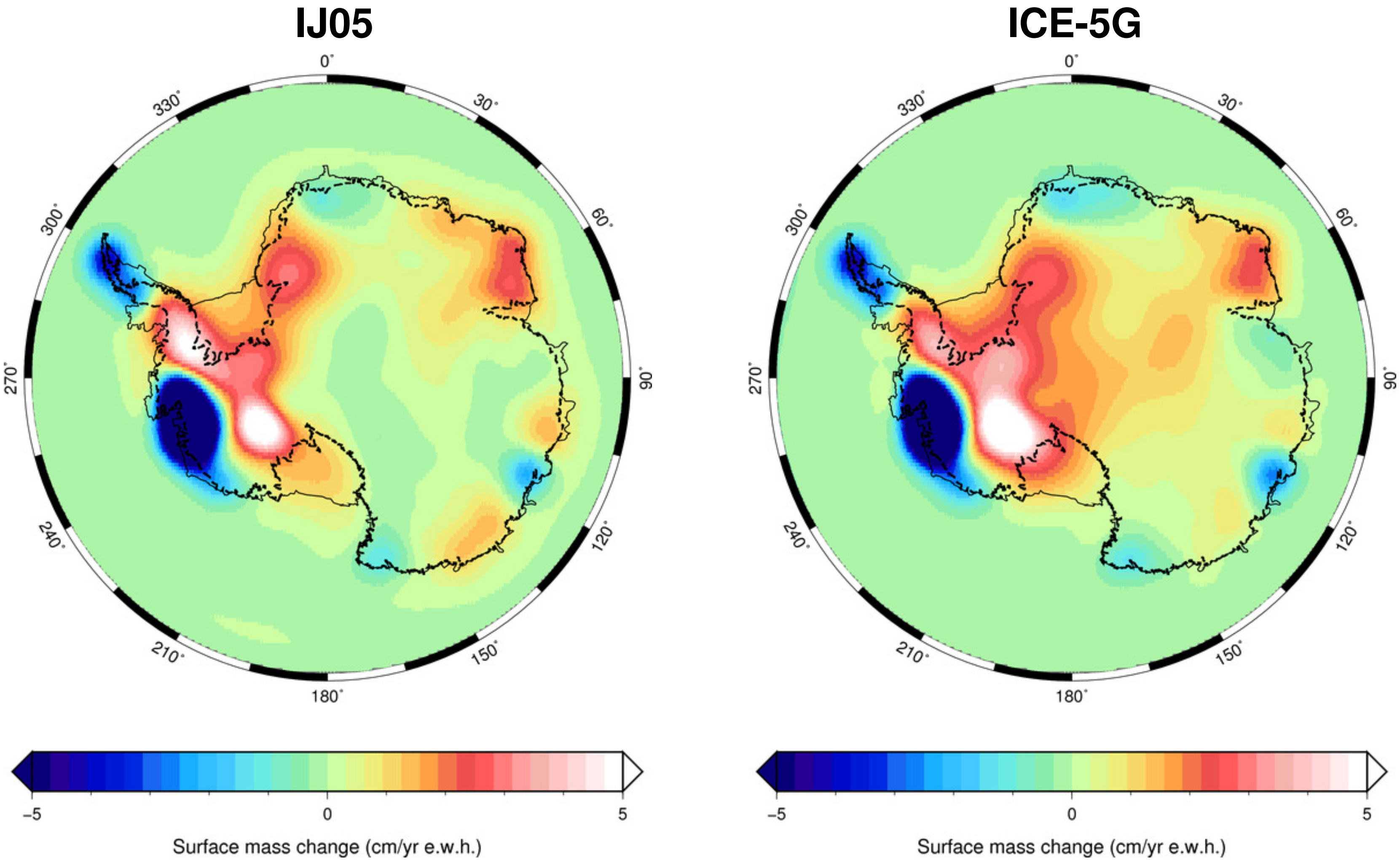




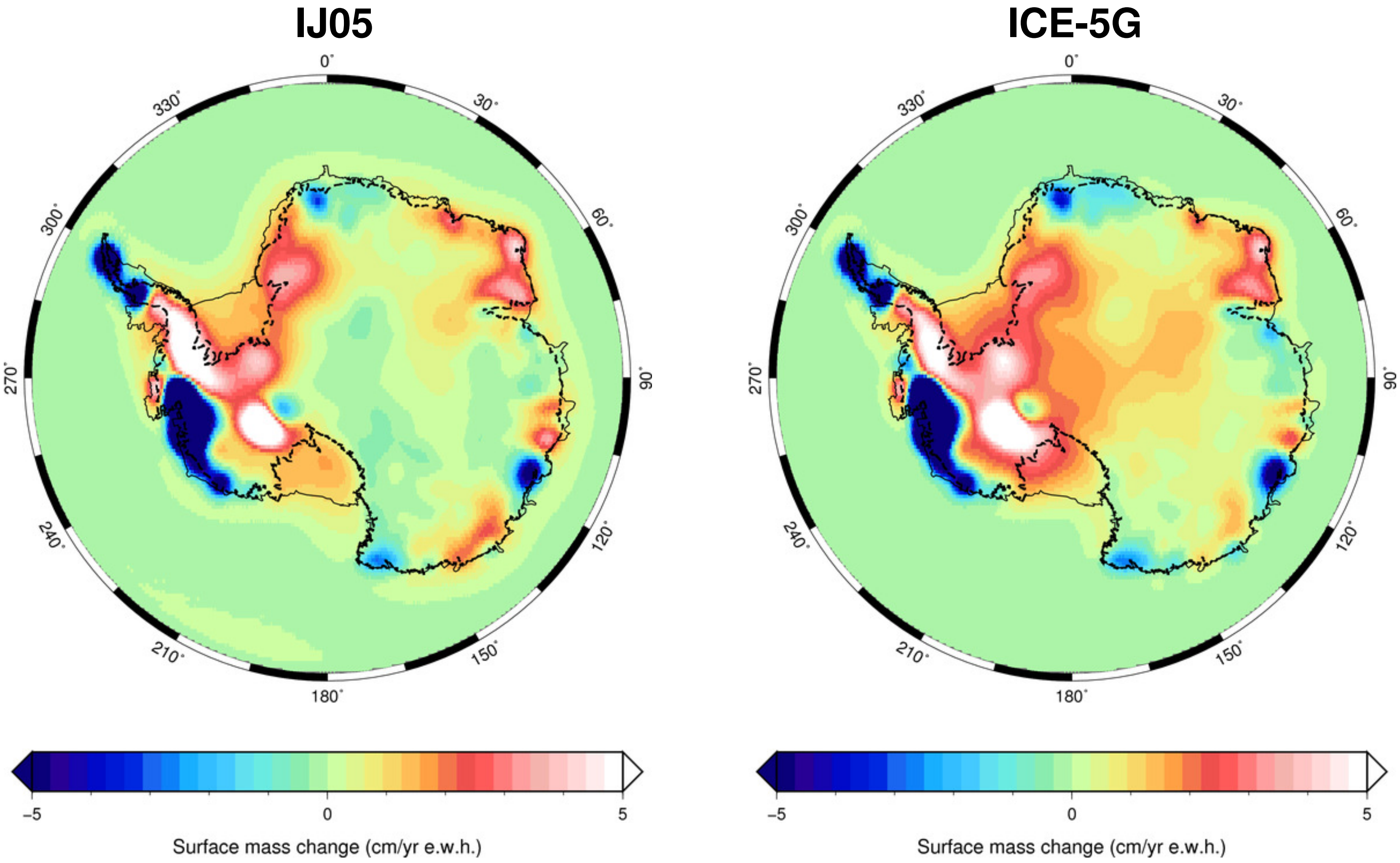
Ice + GIA mass change (400 km resolution)



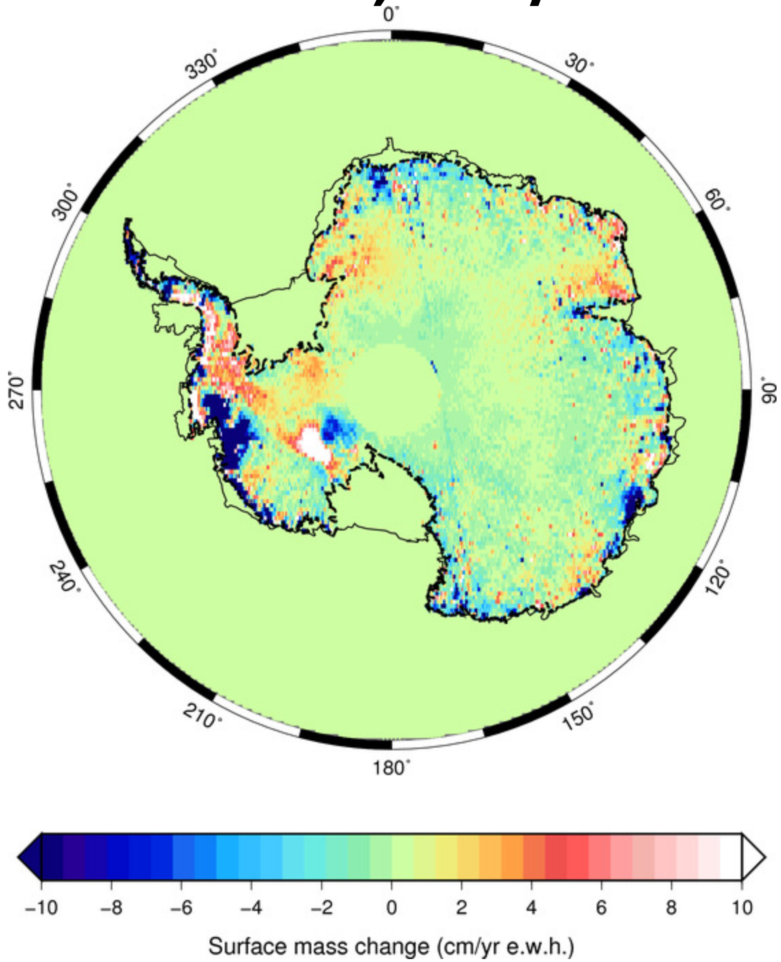
Ice + GIA mass change (200 km resolution)



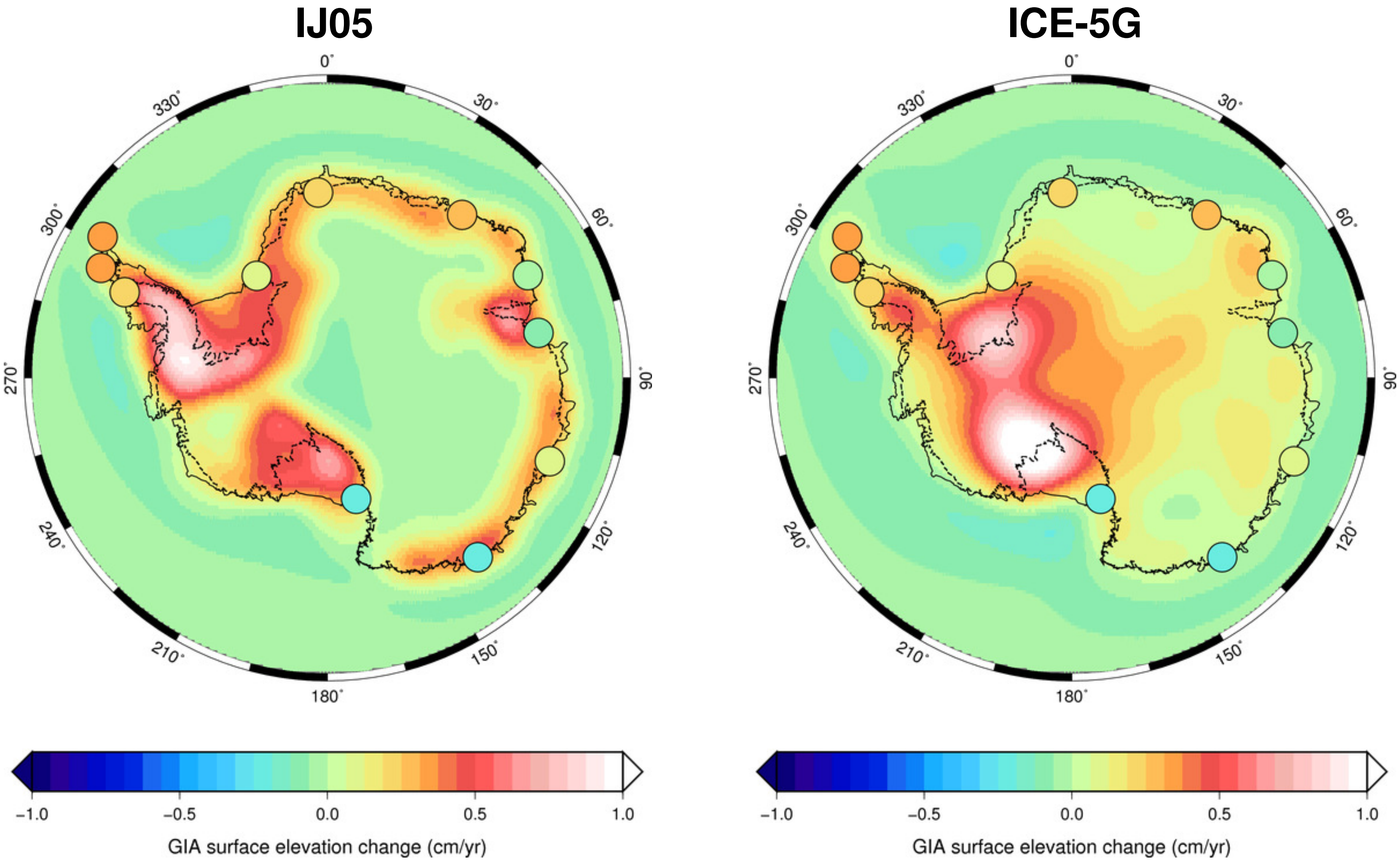
Ice + GIA mass change (100 km resolution)



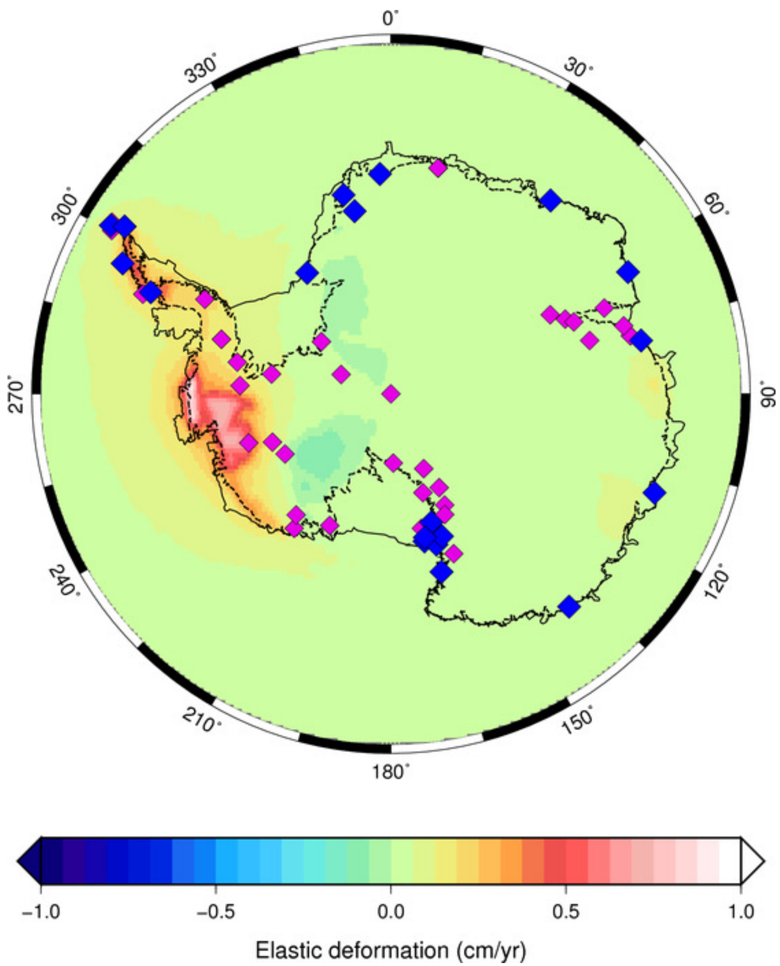
Surface mass change from ICESat (crossovers, 03/03-03/08)



GIA and GPS (Rülke et al., 2009)



Elastic deformation and upcoming GPS



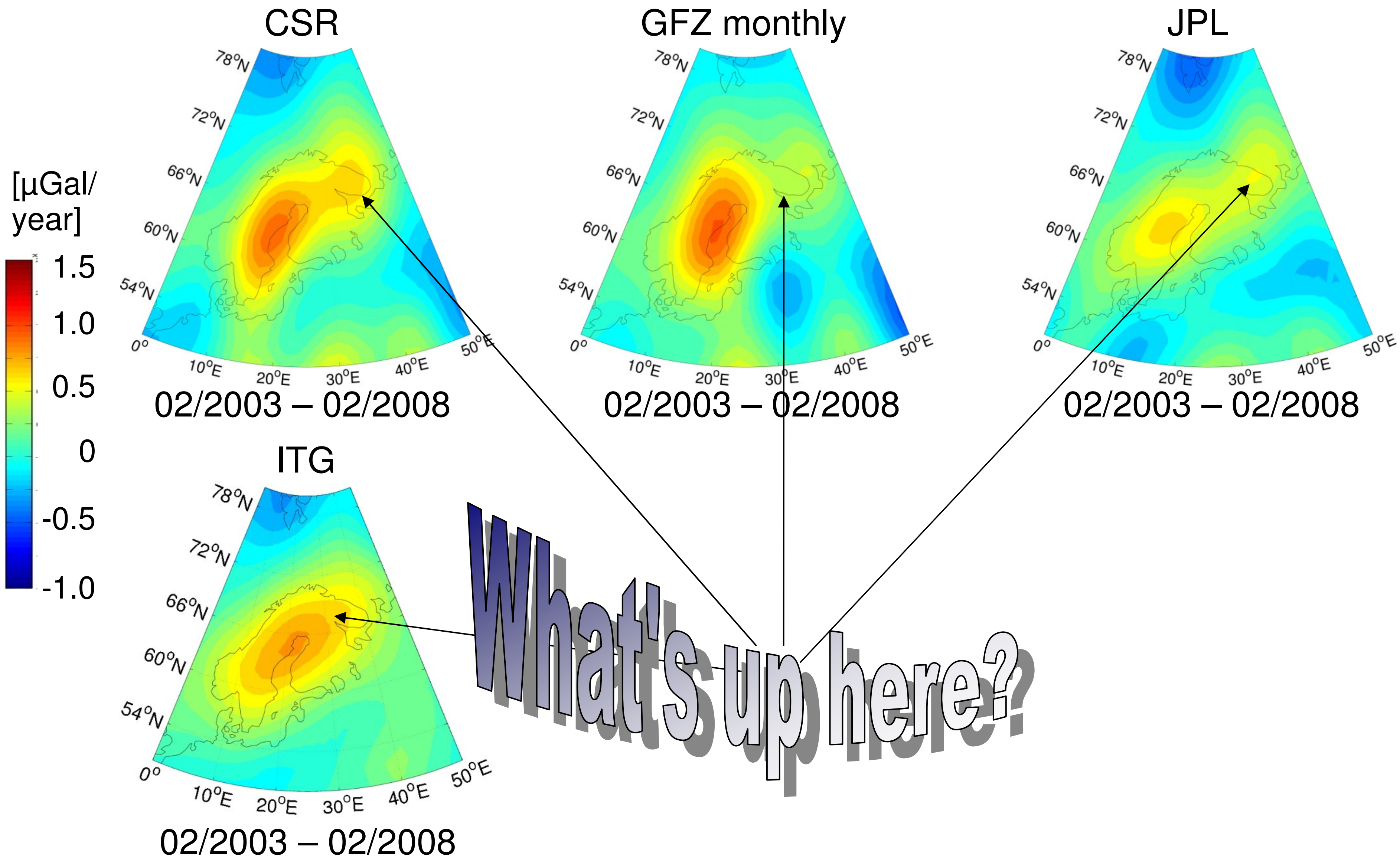
Conclusions

- GIA signature is significant in Fennoscandia and North America, values of up to 2.0 – 2.5 µGal/year
- Fennoscandia: uplift center and shape comparable with terrestrial measurements such as GPS and AG
- Longer time spans sharpen uplift structures
- For hydrology reduction: better hydrology models would be helpful
- In Antarctica, the (expected) gravity change signature of GIA has a magnitude comparable to that of changes in the ice sheet
- High-resolution gravity can help isolate both that part of the signal which is only due to ongoing ice sheet changes and dome structures from the GIA component
- Separation of ongoing ice mass variations from GIA requires combination with additional datasets, such as GPS measurements (point-like, therefore better combined with high-resolution gravity) and altimetry

Possible future GIA-related interests

- Regional signatures, e.g. GIA signature of the Barents Sea area
- Lateral variations: 3D structure of crust, lithosphere and mantle
- Rheology and chemical composition of the Earth's crust and mantle, including low-viscosity crustal and asthenospheric zones
- Clear definition of number and position of domes in North America
- Reduction of hydrology and inland seas, and combination with terrestrial data (AG, GPS) will help improving results
- Investigation of smaller ice sheets

Secular trend of monthly solutions



Fennoscandia, Gauss filter: 400 km

Recommendations

1. **Length of Time Series**: Continuous measurements > 15 years

- reduce hydrology effect;
- reduce tidal aliasing and system noise (if random in nature);
- reduce the amount of filtering.

2. **Spatial resolution**: the higher the better

- See more detail in ice history (Rocky Mountains, Great Lakes area)
- Remove non-GIA processes in and outside North-America

3. **Temporal resolution**: not critical since GIA is secular effect. Groundtrack density could be increased at the expense of time resolution

Acknowledgements

Leibniz-Universität Hannover (Jürgen Müller, Heiner Denker, Olga Gitlein, Ludger Timmen)

GFZ Potsdam (Svetozar Petrovic, Andreas Güntner, Christoph Dahle, Roelof Rietbroek, Roland Schmidt, Susanna Werth, Frank Flechtner, Johann Wünsch, Franz Barthelmes)

IMAU, Utrecht University (Roderik van de Wal, Michiel Helsen, Michiel van den Broeke)

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