Arctic and Antarctic changes from from satellite and airborne surveys

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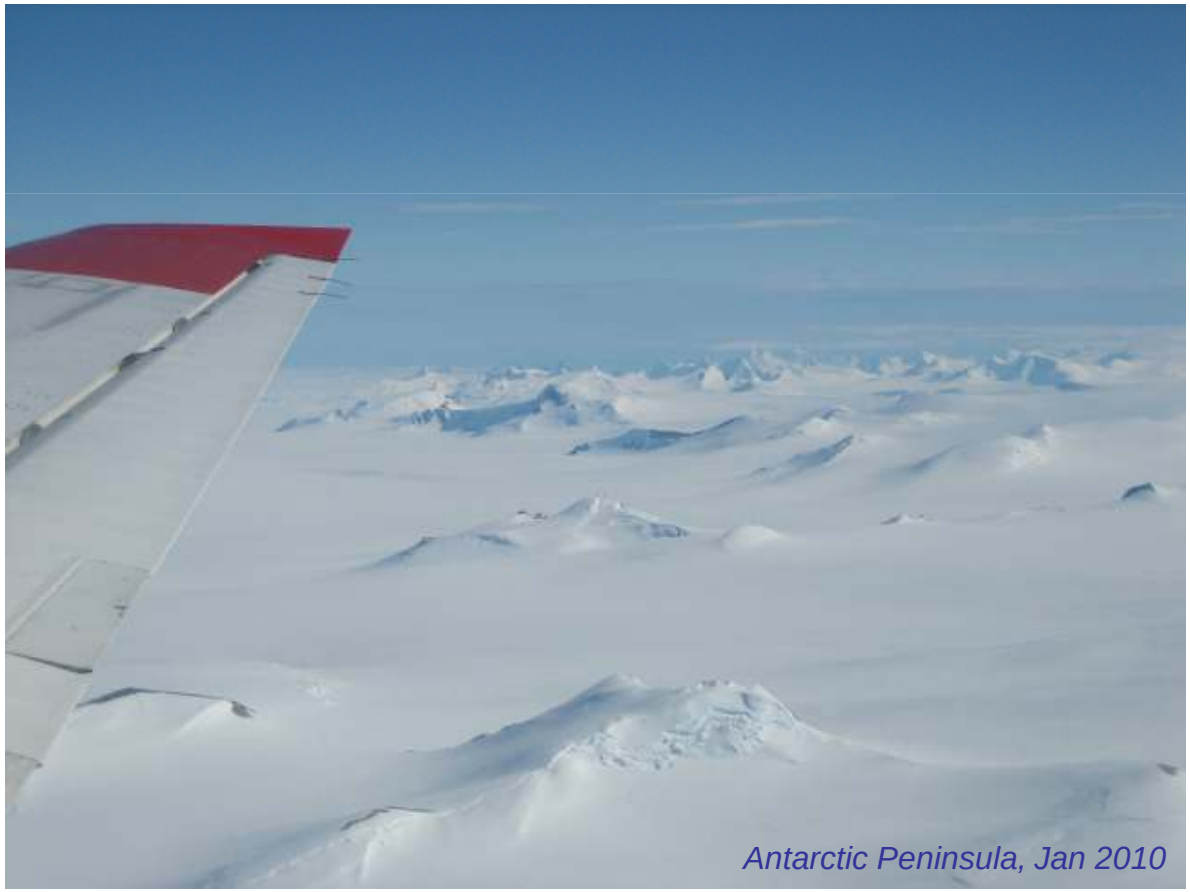


Antarctic Peninsula, Jan 2010

Temporal changes

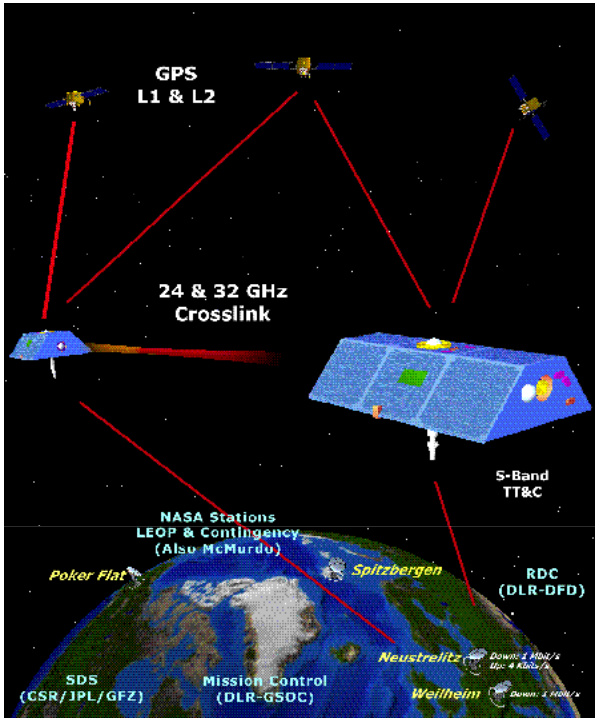
Monitoring melt of the ice caps by satellite mass changes (GRACE, ICESat ..)
... *important role for geodesy in climate change and sea level studies*

Spatial changes

Airborne gravity surveys to fill-in polar voids in gravity field coverage
(new data for GOCE and global models ..)

⇒ ***This talk main focus: GRACE mass loss of Greenland and Antarctica***
⇒ ***Secondary focus: Polar airborne gravity surveys .. Norway++ cooperation***

Analysis of GRACE ice sheet data 2002-09



Data: Monthly spherical harmonic solutions (Release 4):
CSR [Center for Space Research, University of Texas], 89
GFZ [Geoforschungszentrum, Germany], 86
JPL [NASA-JPL, GRACE validation solutions], 82
C20-term substituted with SLR values

Processing:

- Expansion to harmonic degree N = 30 or 60
  Degree 60 corresponds to 3° resolution

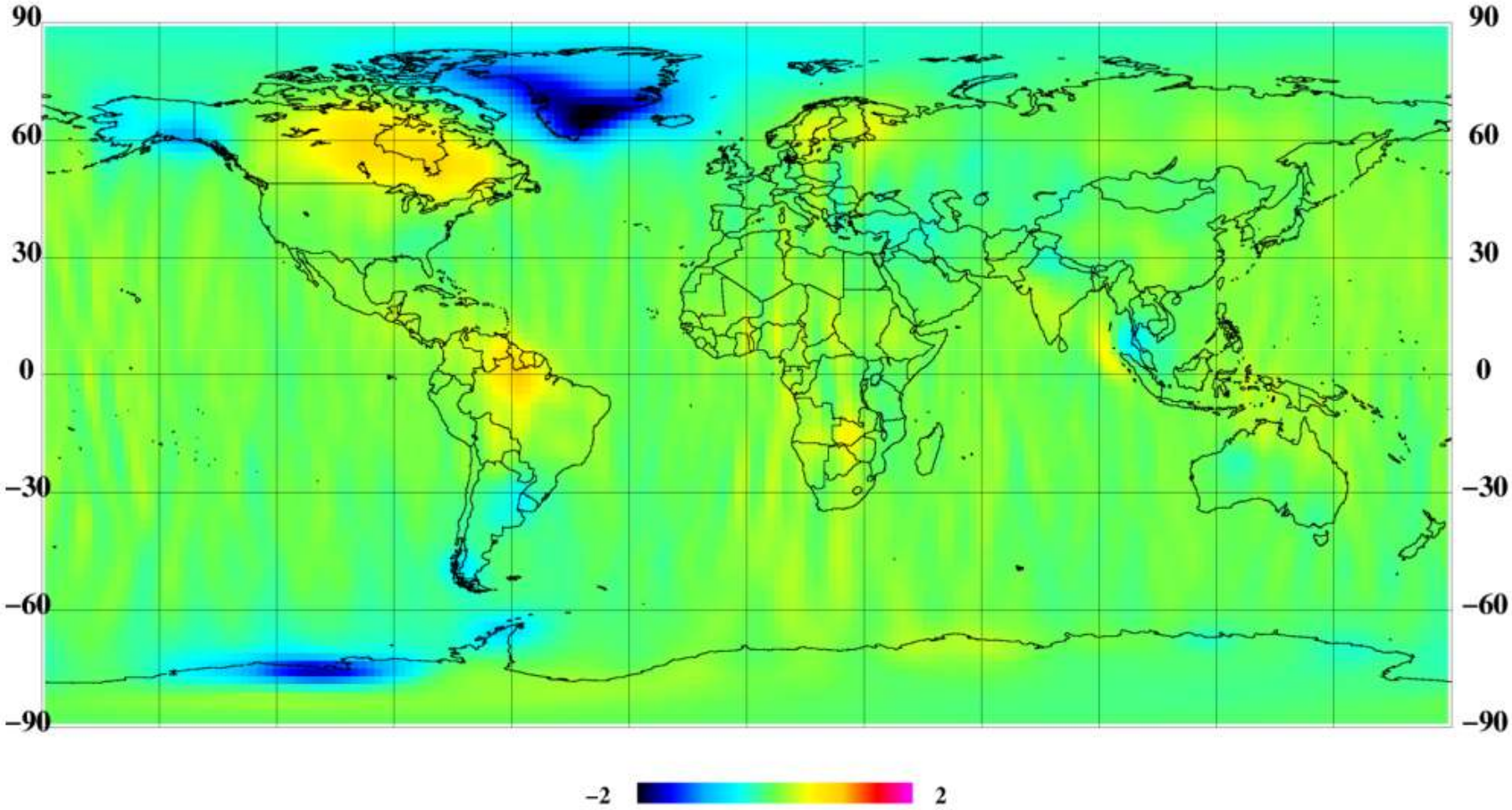
$$T(r,\varphi,\lambda) = \frac{GM}{R}\sum_{n=2}^{N}\sum_{m=0}^{n}\left[\overline{C}_{nm}\cos m\lambda + \overline{D}_{nm}\sin m\lambda\right]\overline{\mathrm{P}}_{nm}(\sin\varphi)$$

- Potential fields: geoid *N* or gravity disturbance δg equivalent, function of potential T (units: mm or μgal = 10^{-8} m/s^2)

$$N = \frac{T}{\gamma} \qquad \delta g = \frac{\partial T}{\partial r}$$

- 4-parameter trend and seasonal analysis: $dg(t) = a + b\,t + c\cos(\omega t) + d\sin(\omega t)$

Global analysis – yearly trend (CSR RL4 dg at 480 km, deg 60)



Units: 10^{-9}g (µgal)

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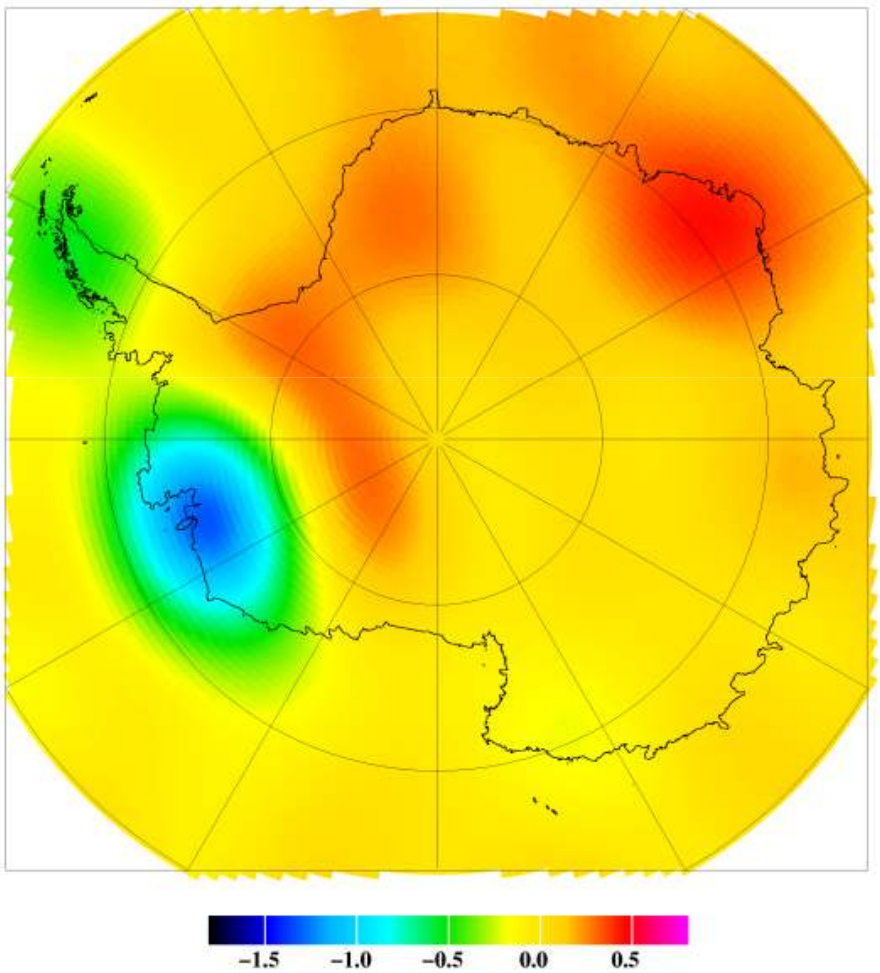
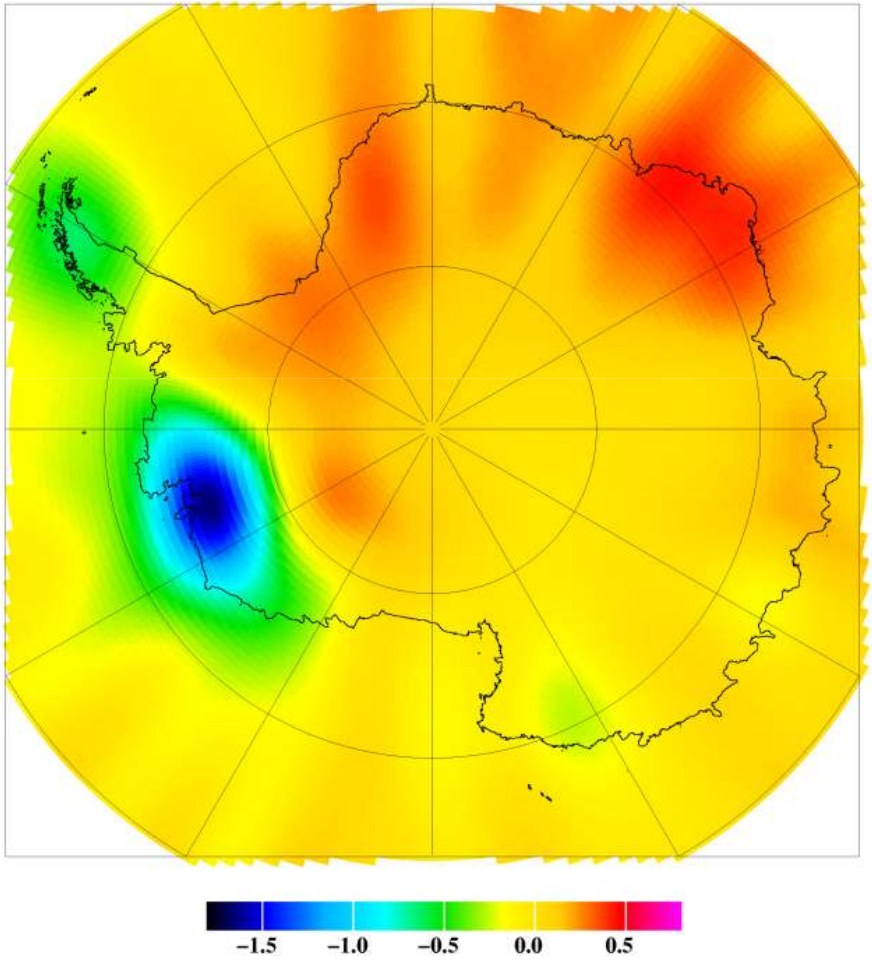
Antarctica – trend analysis of 8 year period sharpen change areas

Trends (μgal/yr ≈ 10^{-9}g/yr)



CSR deg 30



CSR deg 60

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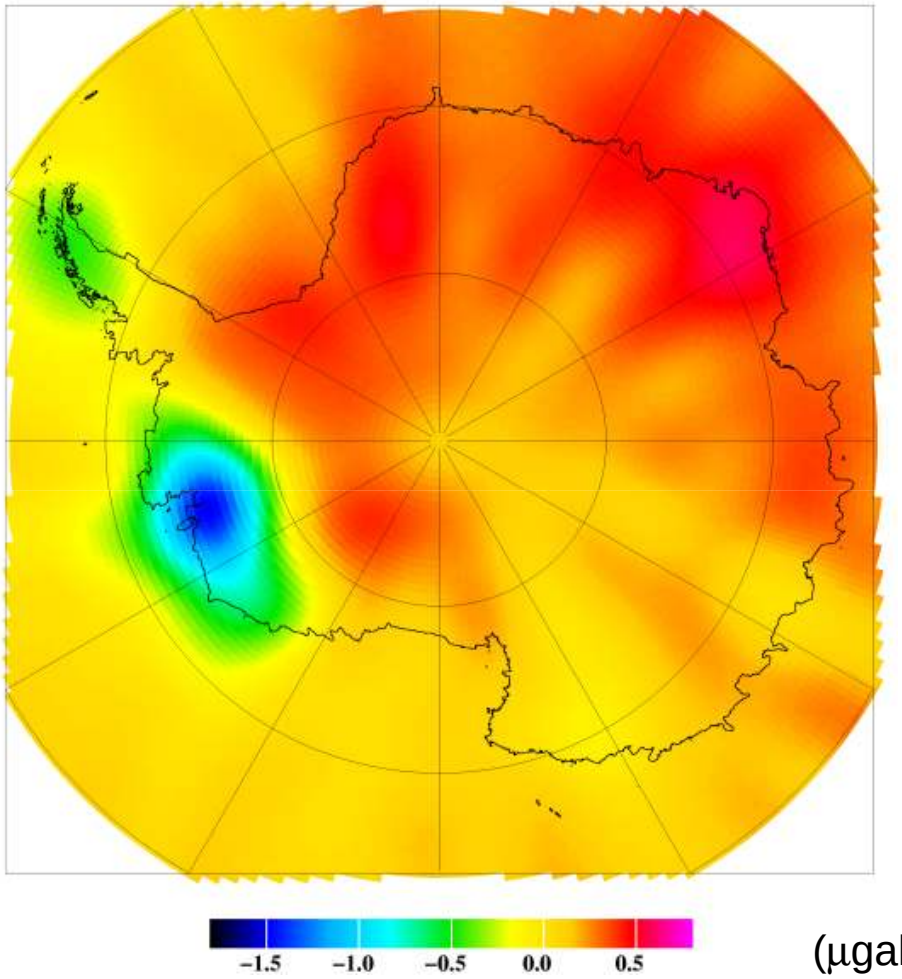
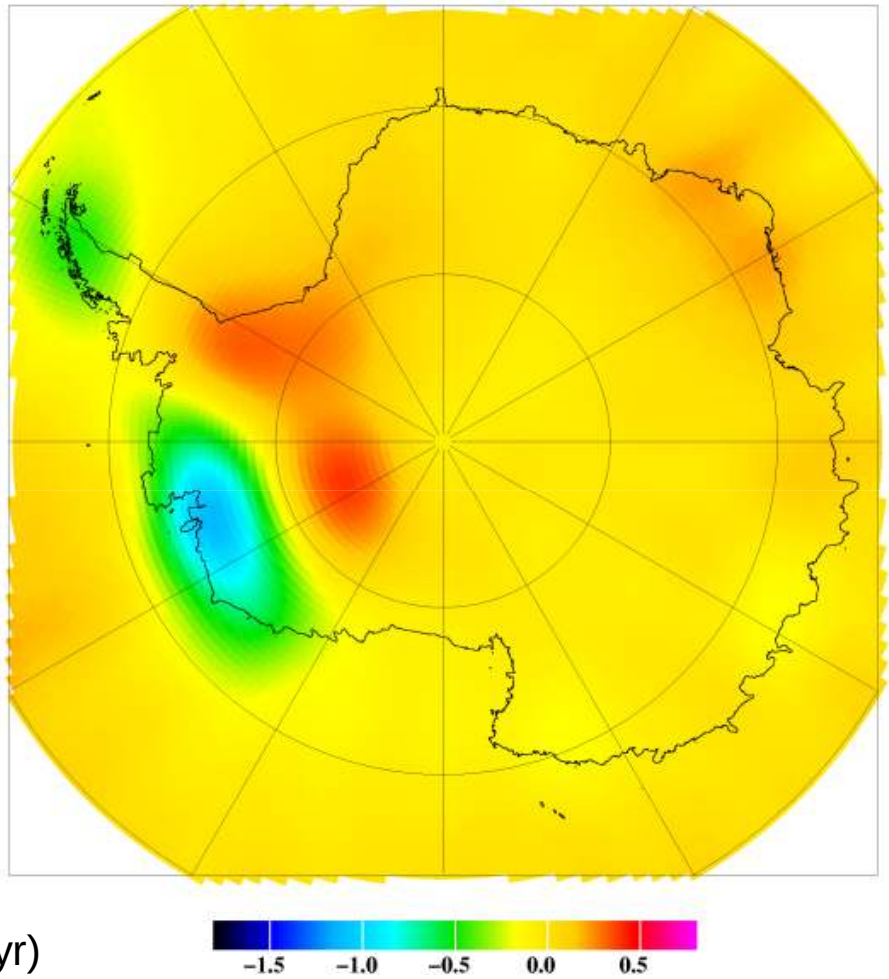
Comparison between different GRACE processing centers



(µgal/yr)

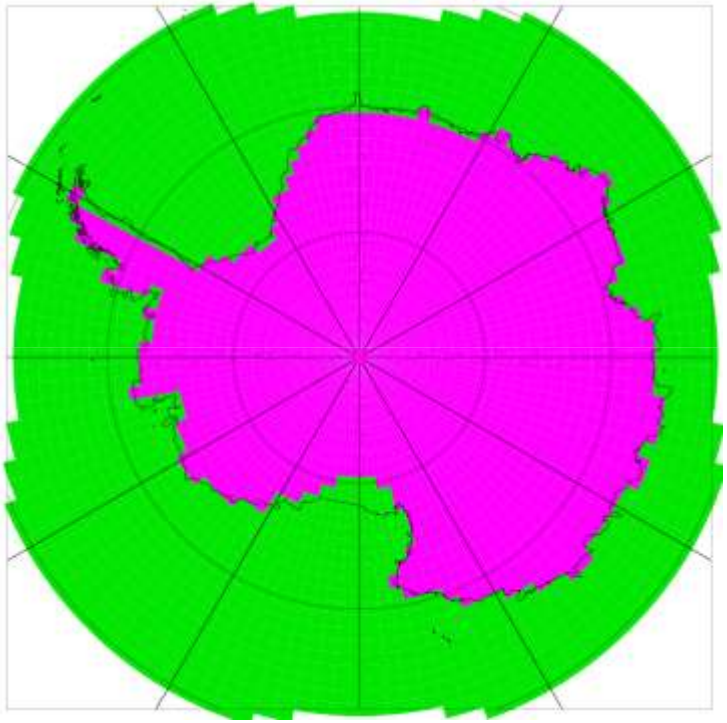


GFZ degree 60

JPL degree 60

.. confirms Thwaites/Pine Island glaciers and peninsula as major loss areas

Converting gravity change to ice mass change by point mass inversion



Ice mask solution domain – 1º x 3º masscons

Obs. $\underline{y} = \{\delta g_i\}$, i = 1, .., n at altitude (grid)

Modelpar. $\underline{x} = \{m_j\}$, j = 1, .., m at surface,

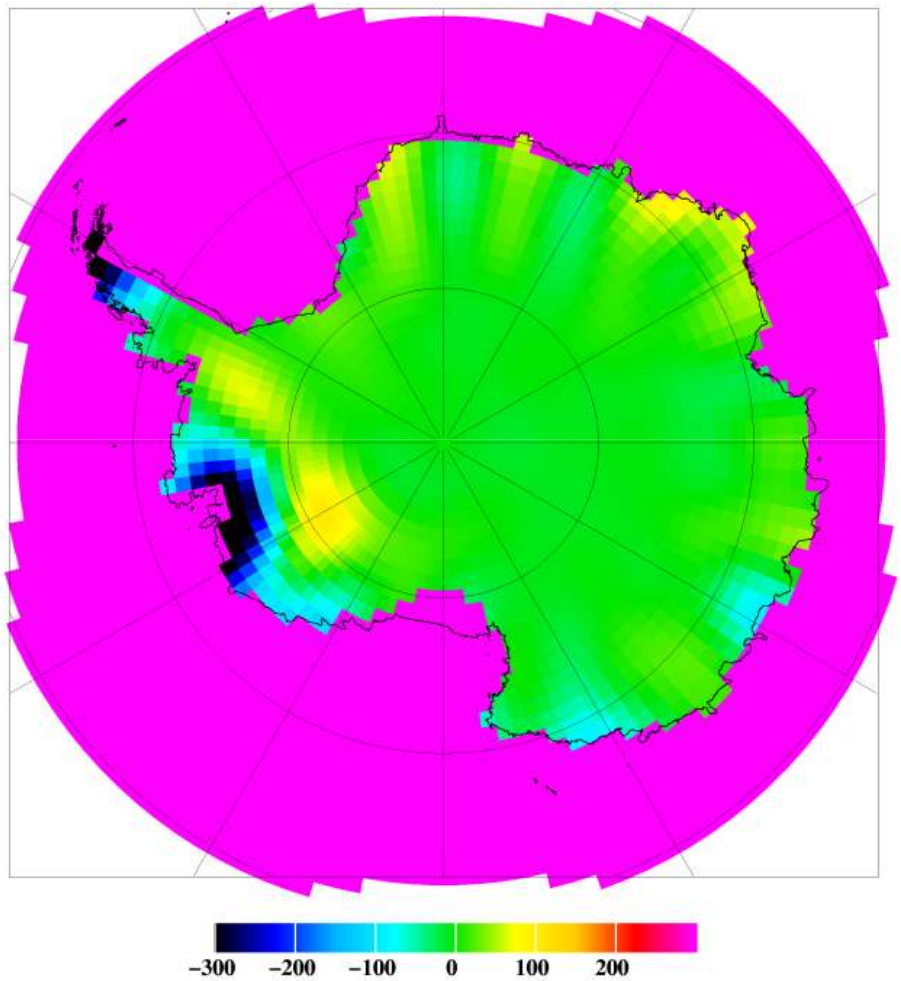
$$\delta g_i = G m_j \frac{R^2 r - R^3 \cos\psi}{[r^2 + R^2 - 2Rr\cos\psi]^{3/2}}$$

Model masscons only in Antarctic area ..
assuming no signal from ocean

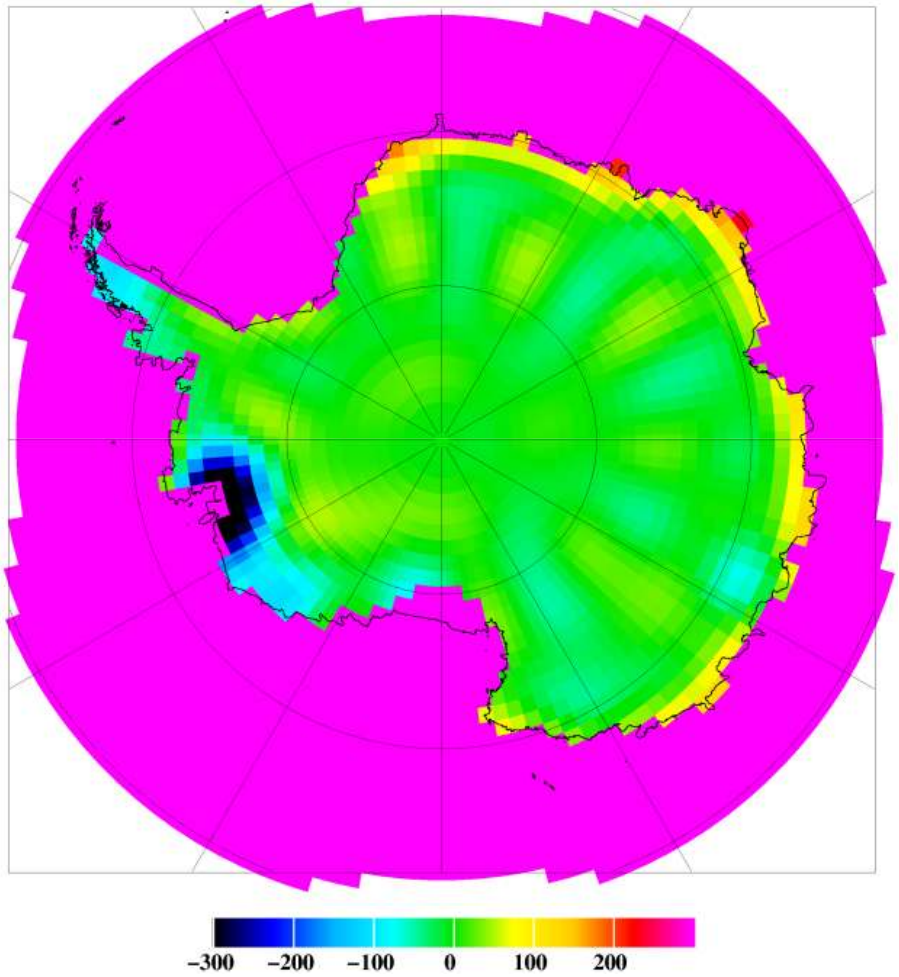
Obs.eq. $\underline{y} = A\underline{x}$ … *need regularization*

Generalized inverse $\underline{x} = [A^T A + \lambda \underline{I}]^{-1} A^T \underline{y}$
-> *dM/dt* (Tychonov regularization)

Examples of mass inversion, shown as mm/year eq. water change



CSR deg 60



GFZ deg 60

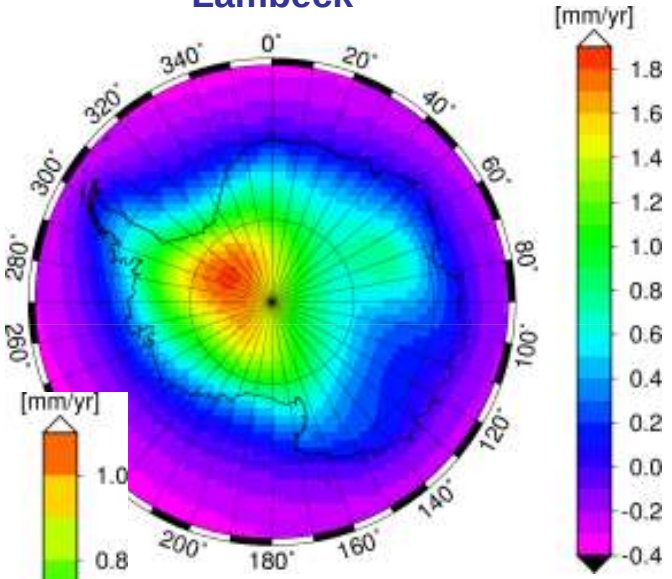
Glacial isostatic adjustment corrections

GIA corrections from finite-element spherical harmonic modelling
[SELEN code, G. Spada/GIA COST action]

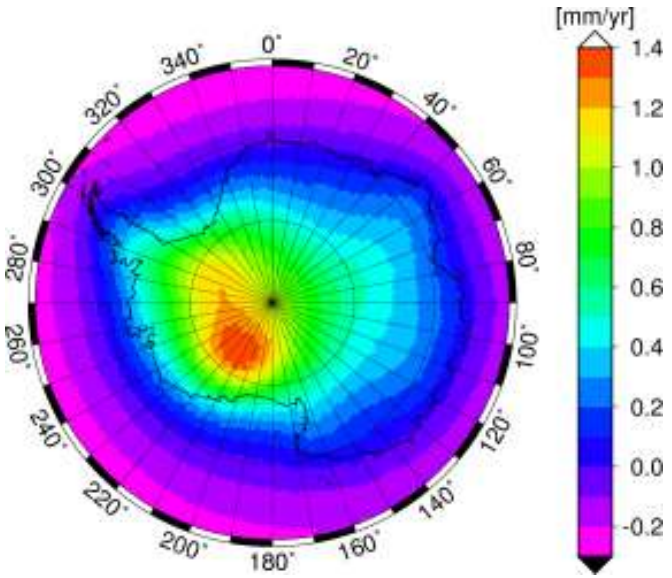
- 3 ice history models:
ICE-5G (Peltier), IJ05 (Ivins), Lambeck
- 3-layer viscosity model, lithosphere thickness 120 km
- Geoid response converted to gravity spherical FFT

GIA corrections increase mass loss by about 50%

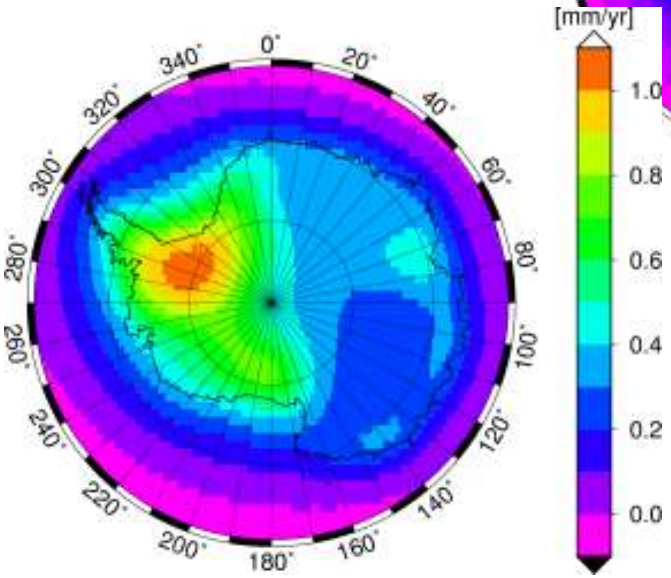
Lambeck



ICE-5G



IJ-2005



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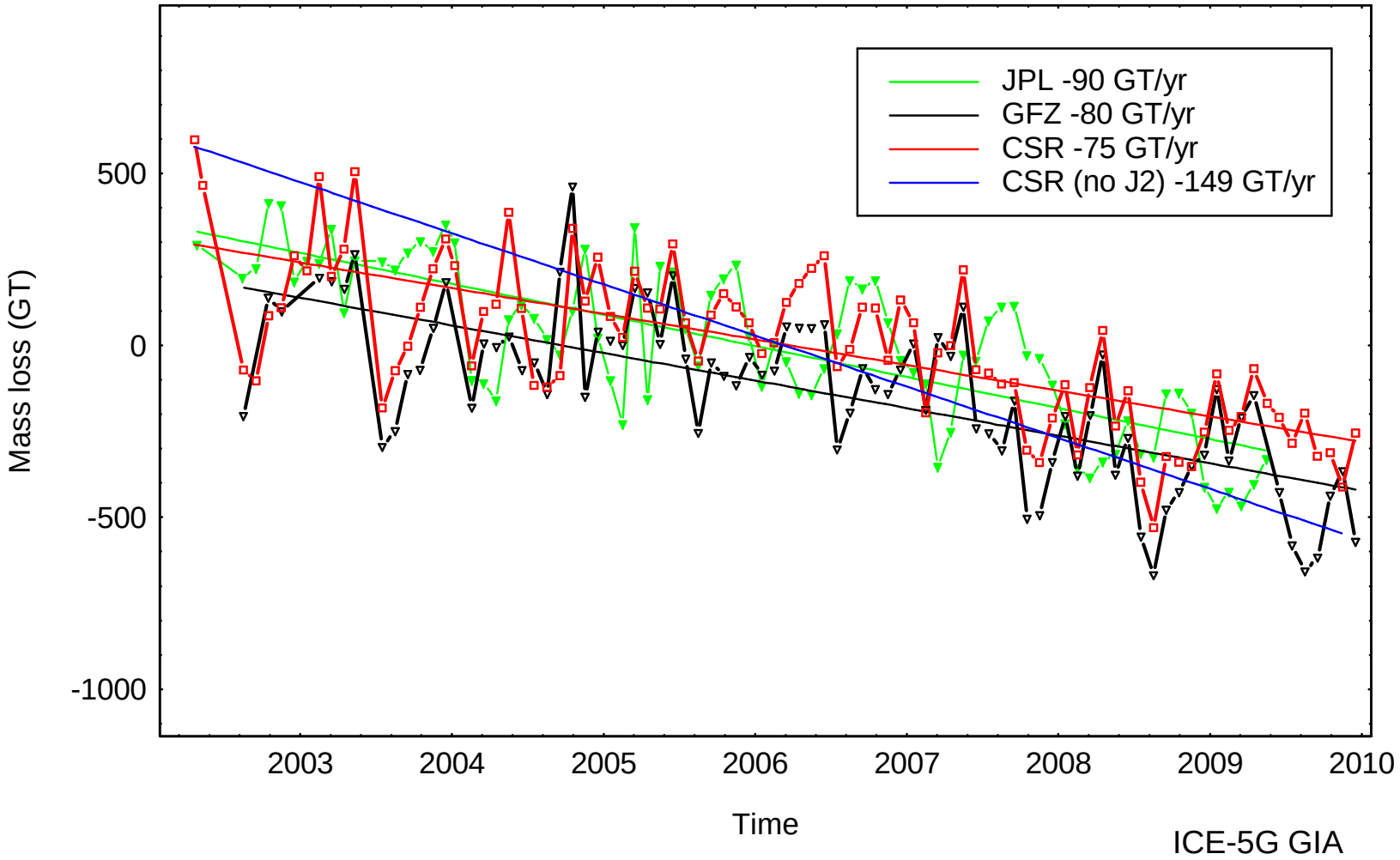
Total mass loss estimates of Antarctica 2002-9

GRACE mass loss - Antarctica



ICE-5G GIA

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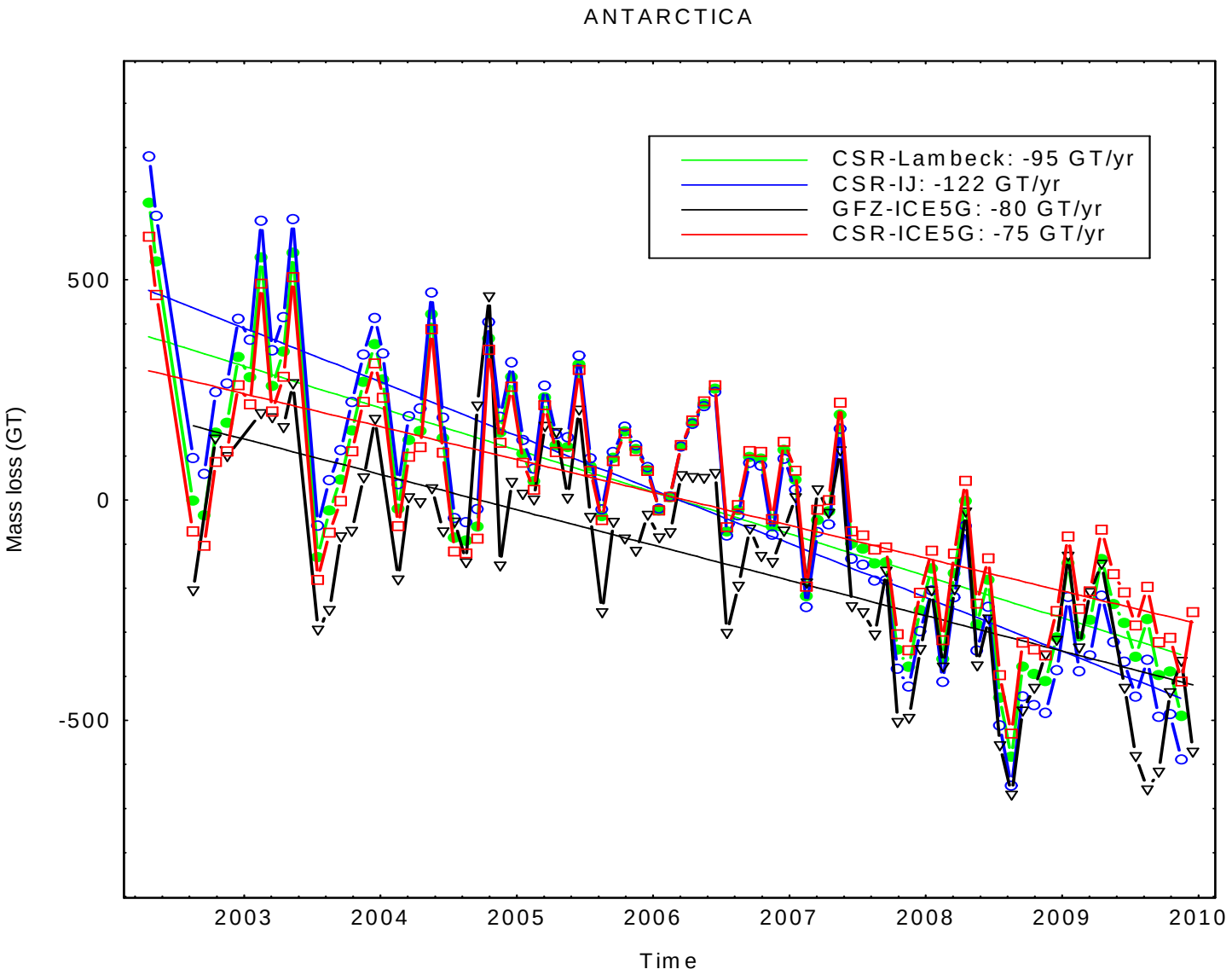
GRACE mass loss estimates 2002-9 – different GIA models



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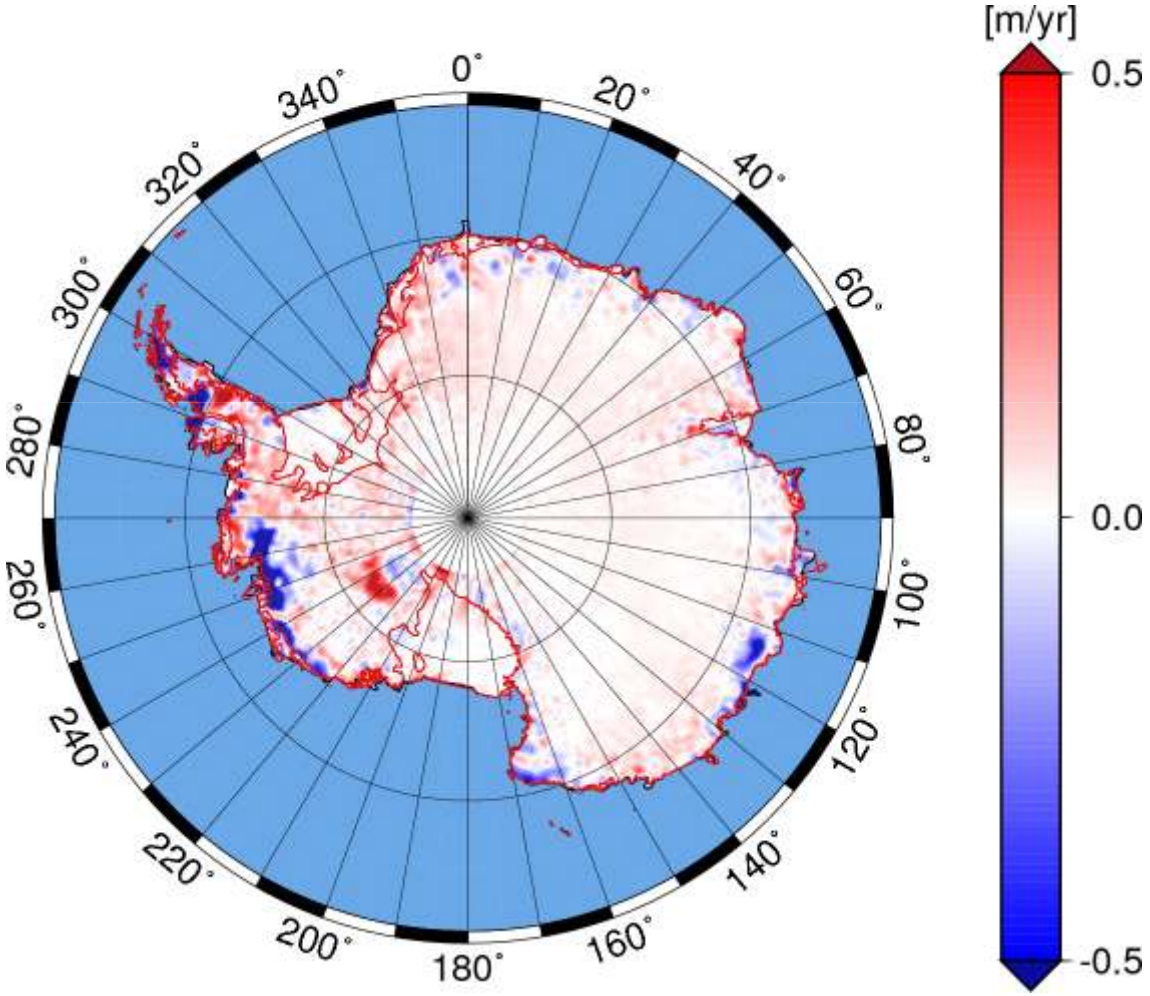
ICESAT height changes 2003-2009

ICESat laser altimetry 2003-9
2-3 month epochs / year

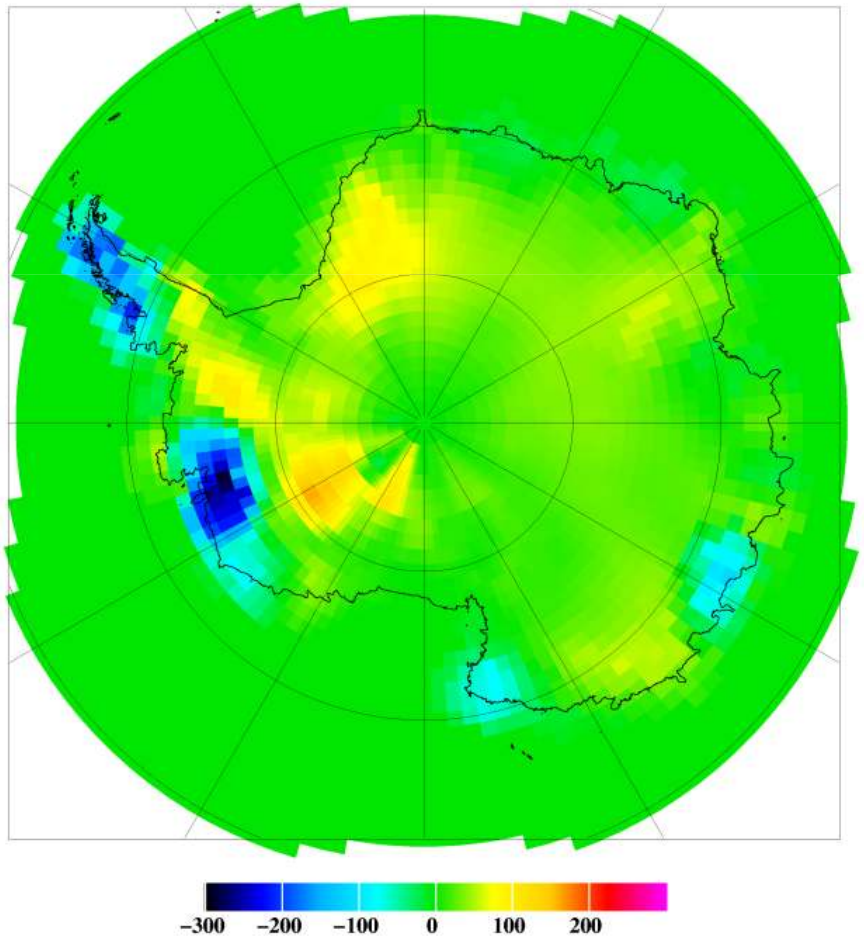
ICESat analysis:

- Repeat-track height changes (relative to reference DEM)
- Interpolation to grid
- Trend analysis

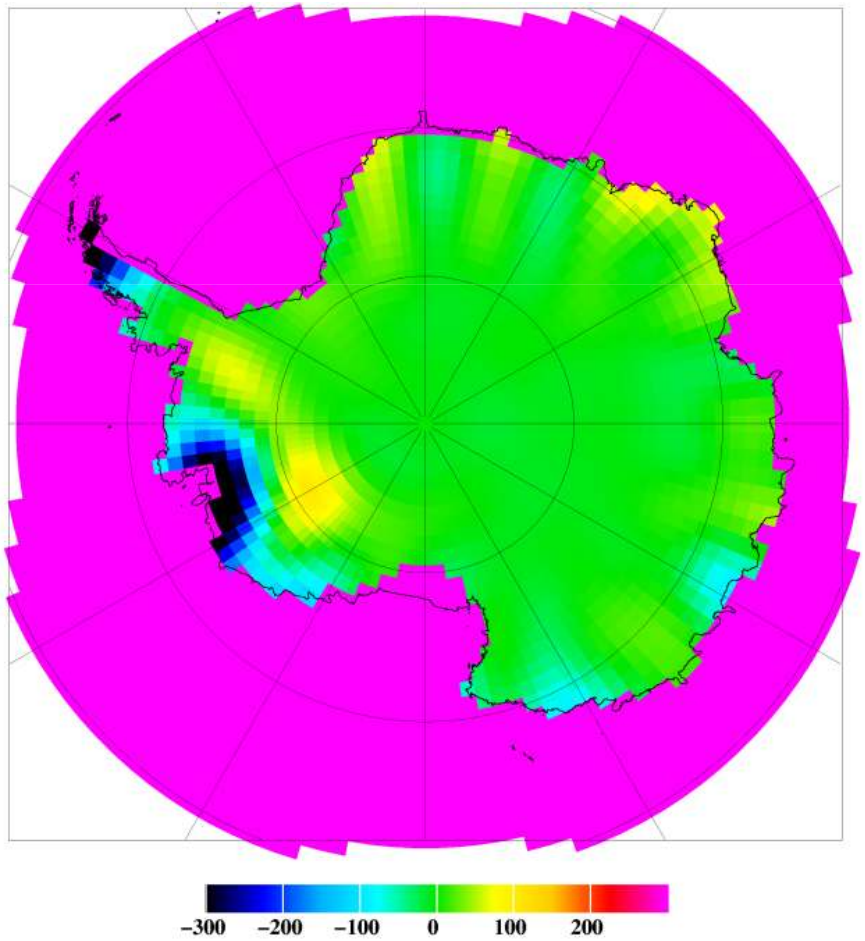


ICESAT height changes compared to GRACE

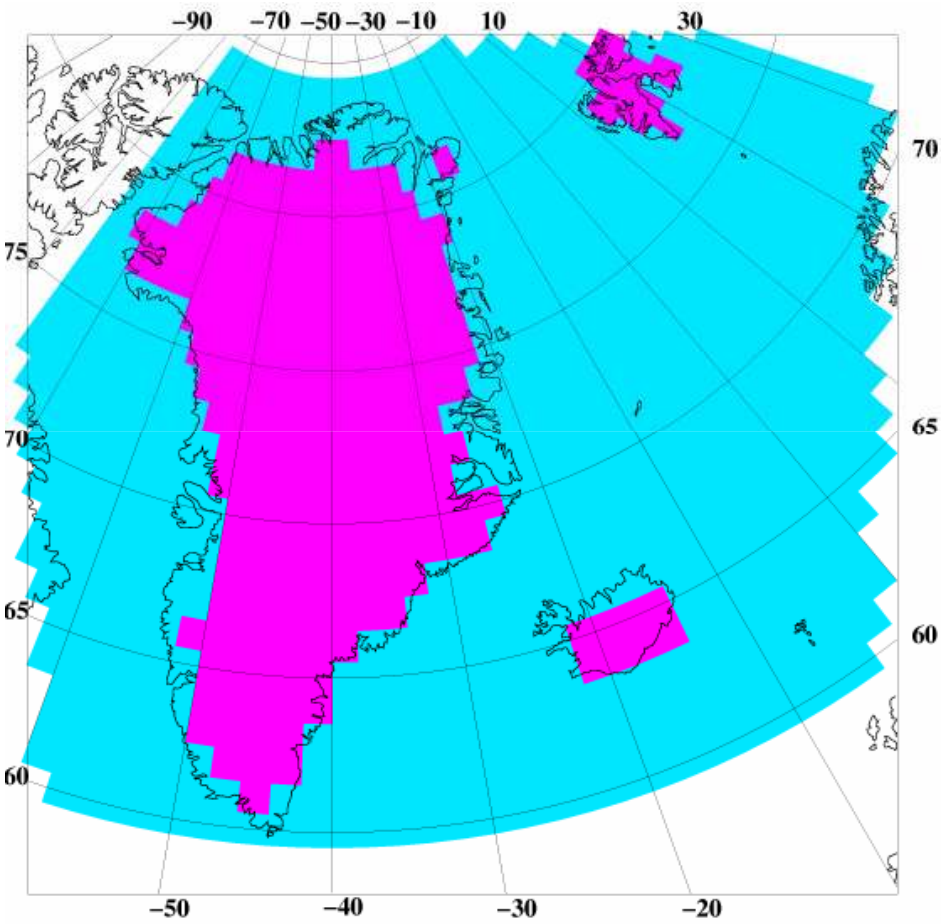
ICESat height changes (mm/yr)
filtered to GRACE resolution



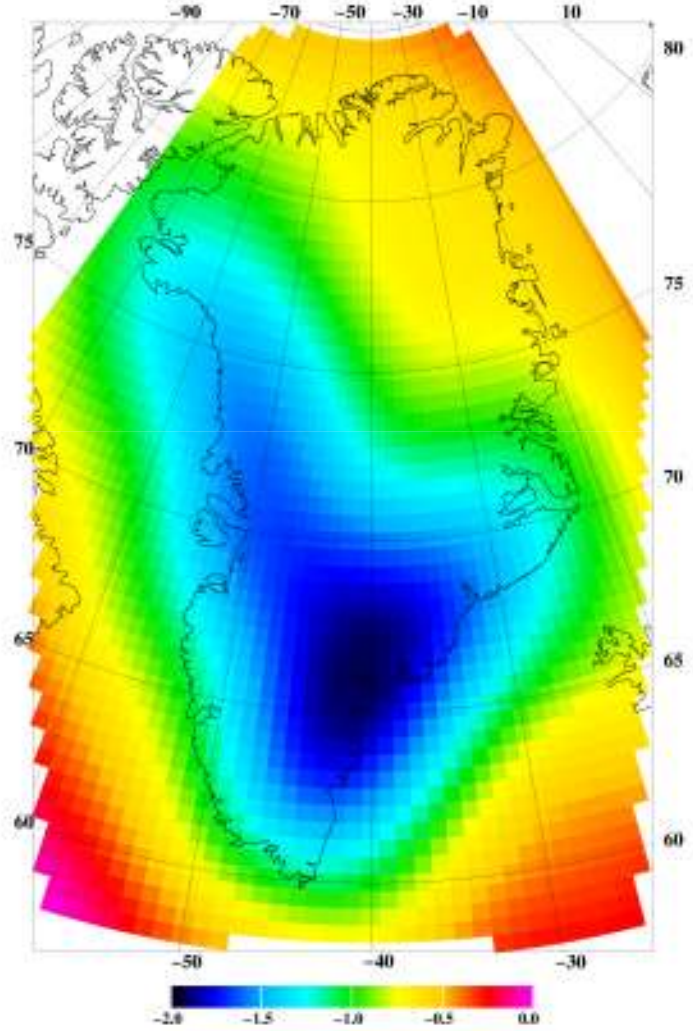
GRACE equivalent water
height changes (CSR deg. 60)



Greenland: Same principle – solve for masscons in ice covered area



Ice mask (including Iceland and Svalbard)



Gravity trend at altitude (CSR degree 60)

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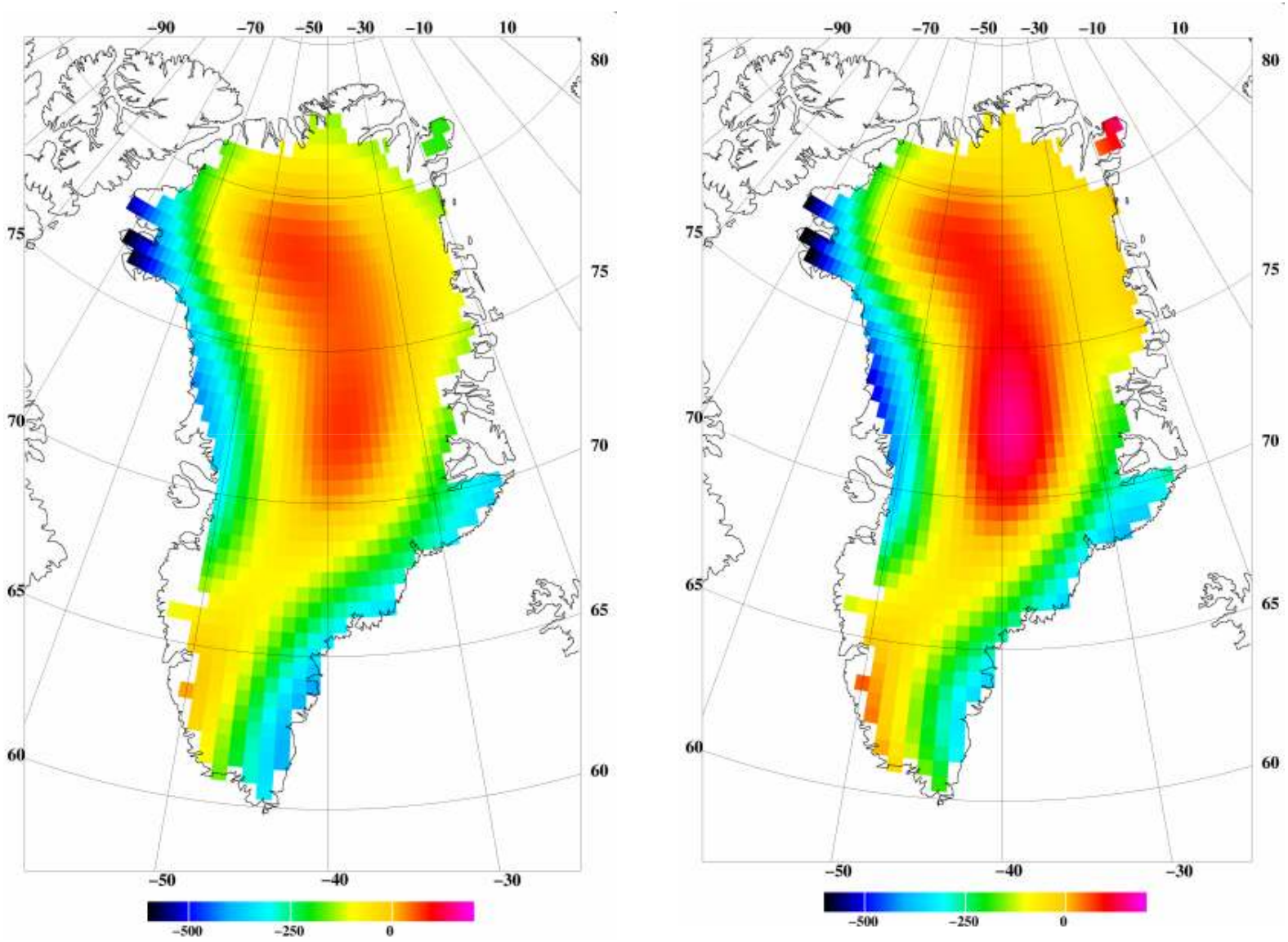
Masscon solutions (mm water-eq./year)



CSR Both degree 60, ICE-5G GIA **GFZ**

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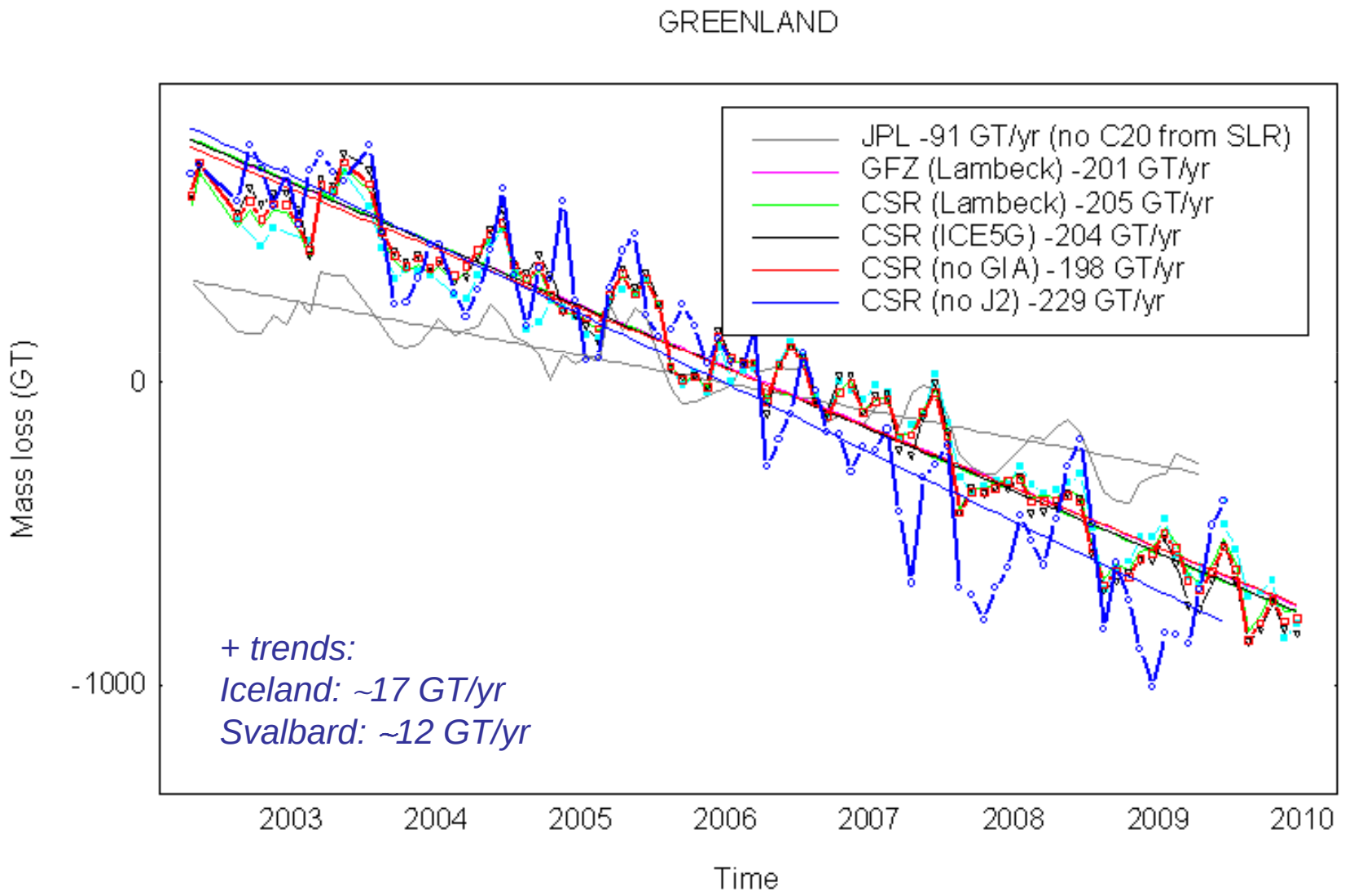
Greenland mass trends 2002-9 (and 2006-9)



ICESAT: Greenland changes 2003-9

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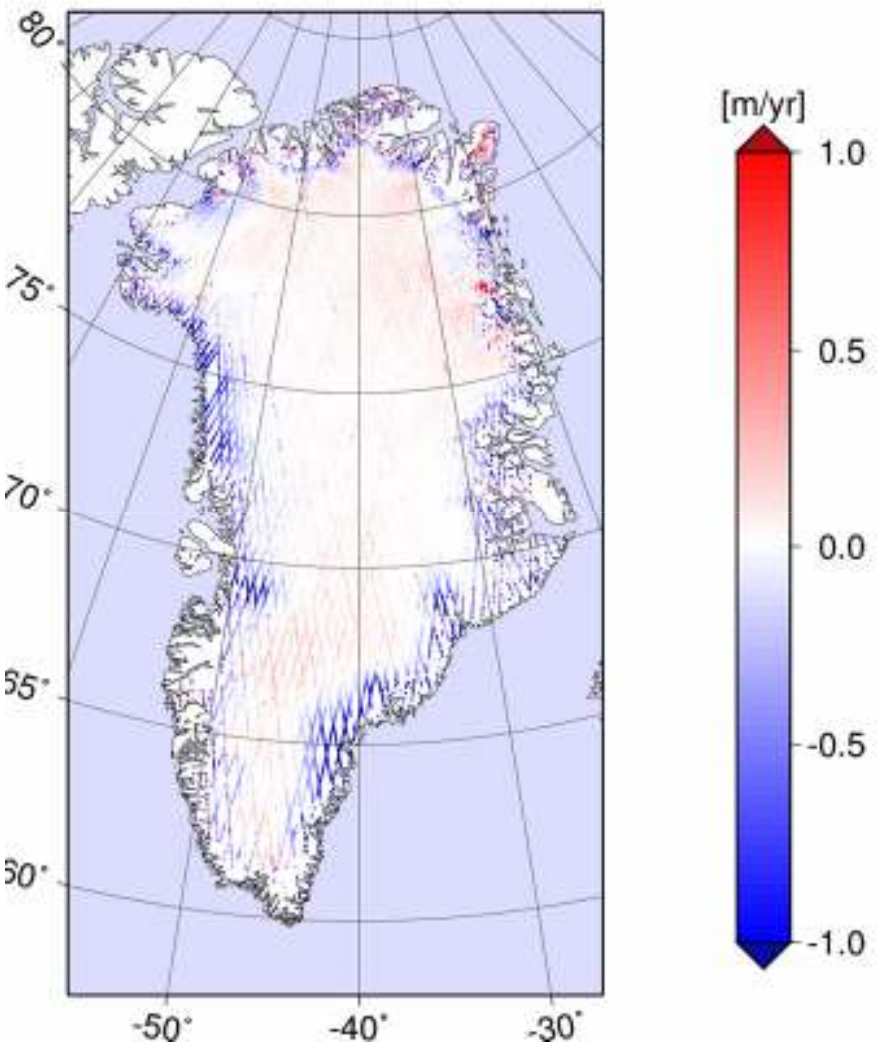
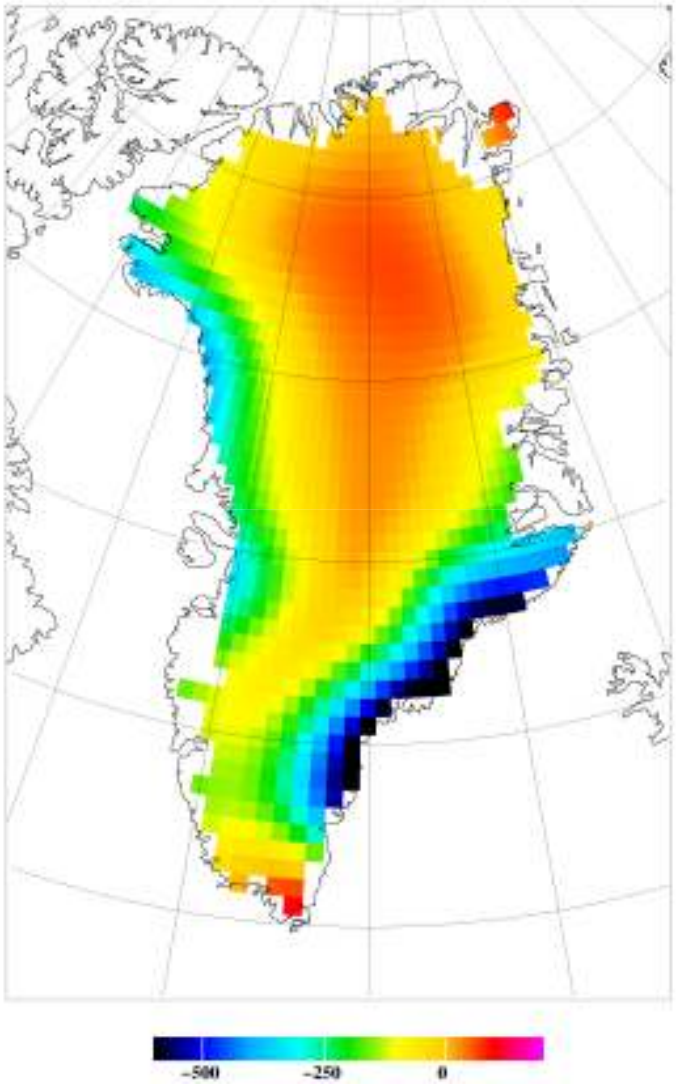
Height changes



Mass changes filtered at GRACE resolution



Total mass loss from ICESat based on firn density model, driven by ECMWF/ HIRHAM regional climate model and GIA: ~210 GT/year (Sørensen et al., 2010, subm.)

GRACE summary

• GRACE shows Antarctica mass loss of ~100 GT/year, Greenland at ~205 GT/year

Difference between processing centers less with C_{20} from SLR

In accordance with Velicogna/Wahr and others ..

but Wu et al, JPL (Nature-Geoscience 2010) get ~ 100 GT/yr from GRACE+GPS analysis

Still need for research to unify estimates

• Differences between different GIA models up to 30%

Polenet IPY permanent GPS networks and absolute gravity to improve GIA models ..

Greenland: GNET 2007-9 (OSU, DTU, U-Lux)

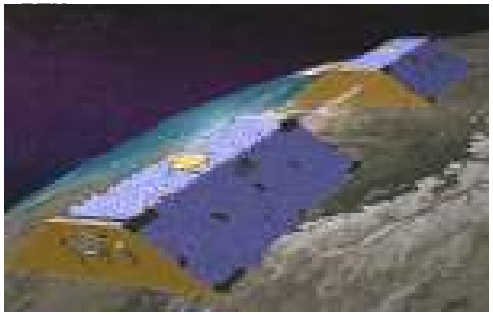
Antarctica: POLENET .. (20+ partner countries)

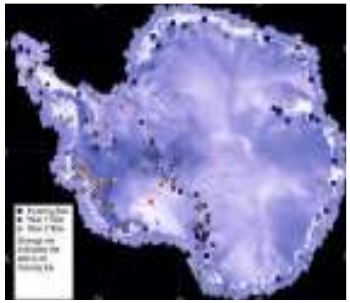
New Danish A10 absolute gravimeter for GNET:

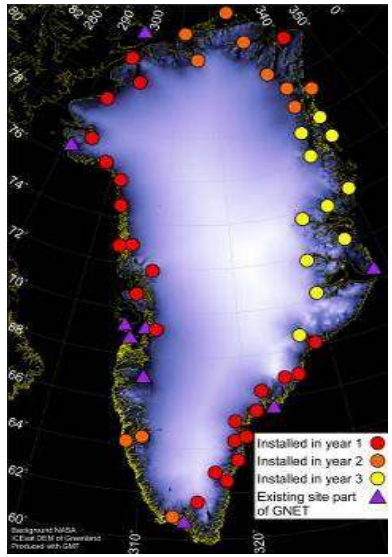
Greenland campaigns 2009-10; Antarctica 2011-12

• GRACE results in excellent agreement with ICESat

Space estimates to improve with release of ESA CryoSat data (October 2010) ..







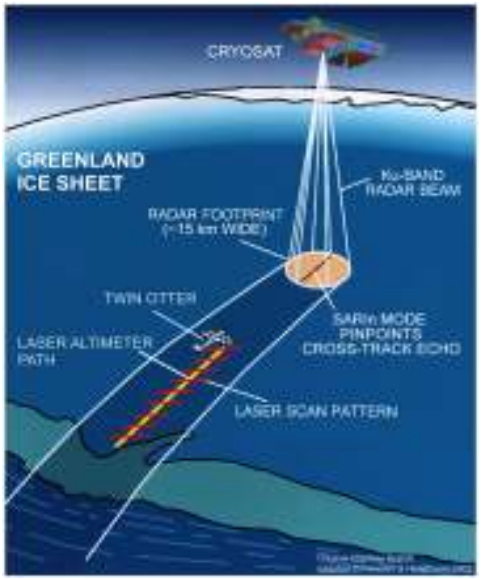
Arctic and Antarctica – ongoing and recent airborne surveys

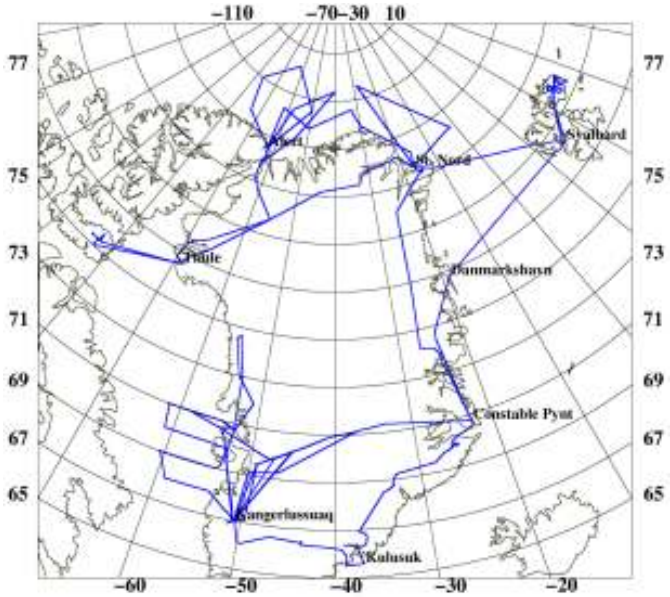
- ESA CryoSat cal-val campaigns ... understanding CryoSat signals
  Svalbard-Greenland-Canada 2006, 2008, 2011-12

- Arctic Ocean: LOMROG-2009 airborne gravity+magnetic survey:
  Danish-Canadian UNCLOS project - DC3 aircraft

- Antarctica 2010-12: Airborne gravity, magnetics, ice radar, laser ..

All with Nordic cooperation to various degrees (but not NKG ..)
New Nordic cooperations: TOP-Forsk Initiative (SVALI for icecaps ..)





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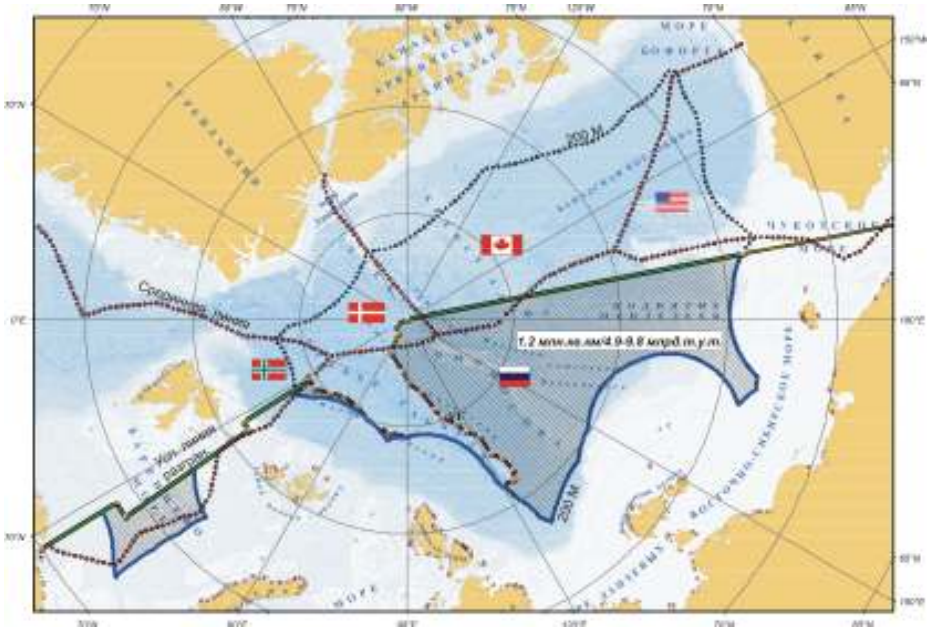
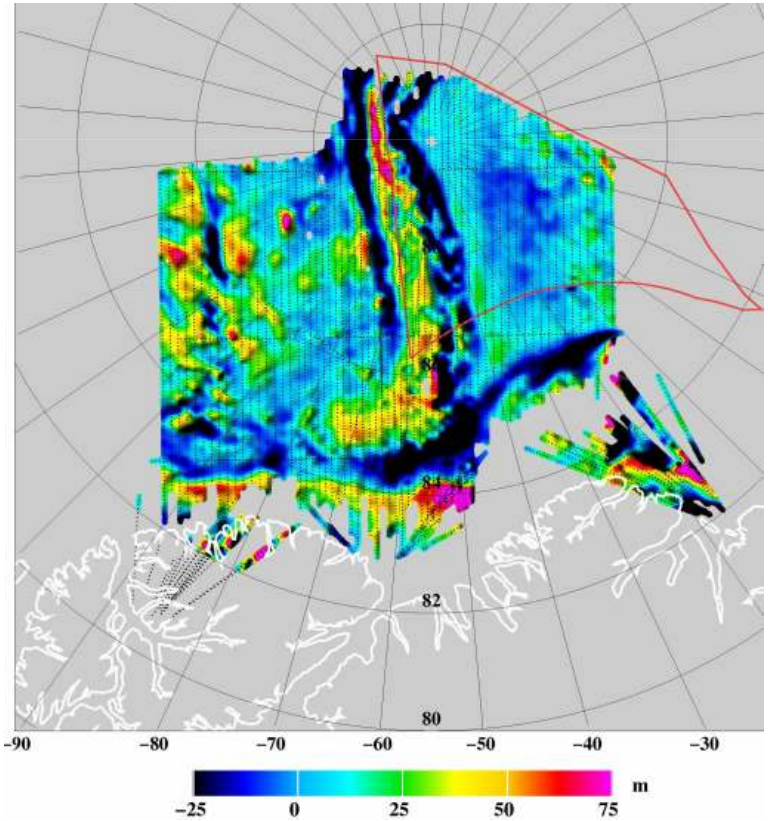
LOMGRAV-2009 .. part of Danish Continental Shelf Project

- Airborne gravity and magnetics north of Greenland and Ellesmere Island
- DC3T used for extended range flights
- Cooperation with National Ressources, Canada, *and Univerisity of Bergen*
- *Supplements icebreaker cruises with Oden – joint with Sweden (seismics)*



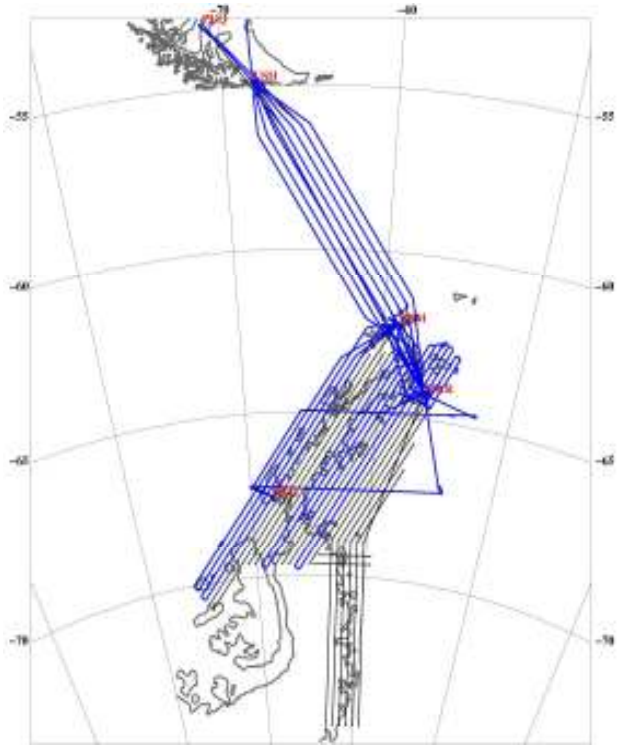


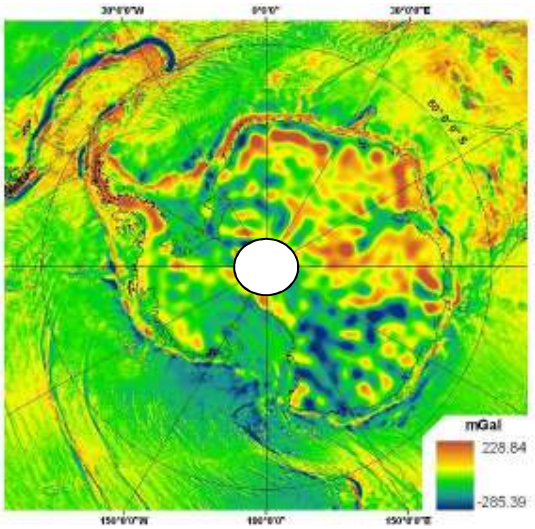
DTU-Space survey of Antarctic Peninsula: ICEGRAV Jan-Feb 2010

- First major Danish-led project in Antarctica (*SCAR member since 2006) - funding from NGA, NASA and DTU*

- Cooperation with University of Texas ICECAP (TUD radar), Instituto Antarctico (Argentina), CECS (Chile), UiB (Norway)

- Overall goals:
  Gravity – support global gravity field modelling (EGM08)
  Geoid – ocean circulation and MDT in Drake Passage
  General geophysics, magnetics, ice altimetry and radar





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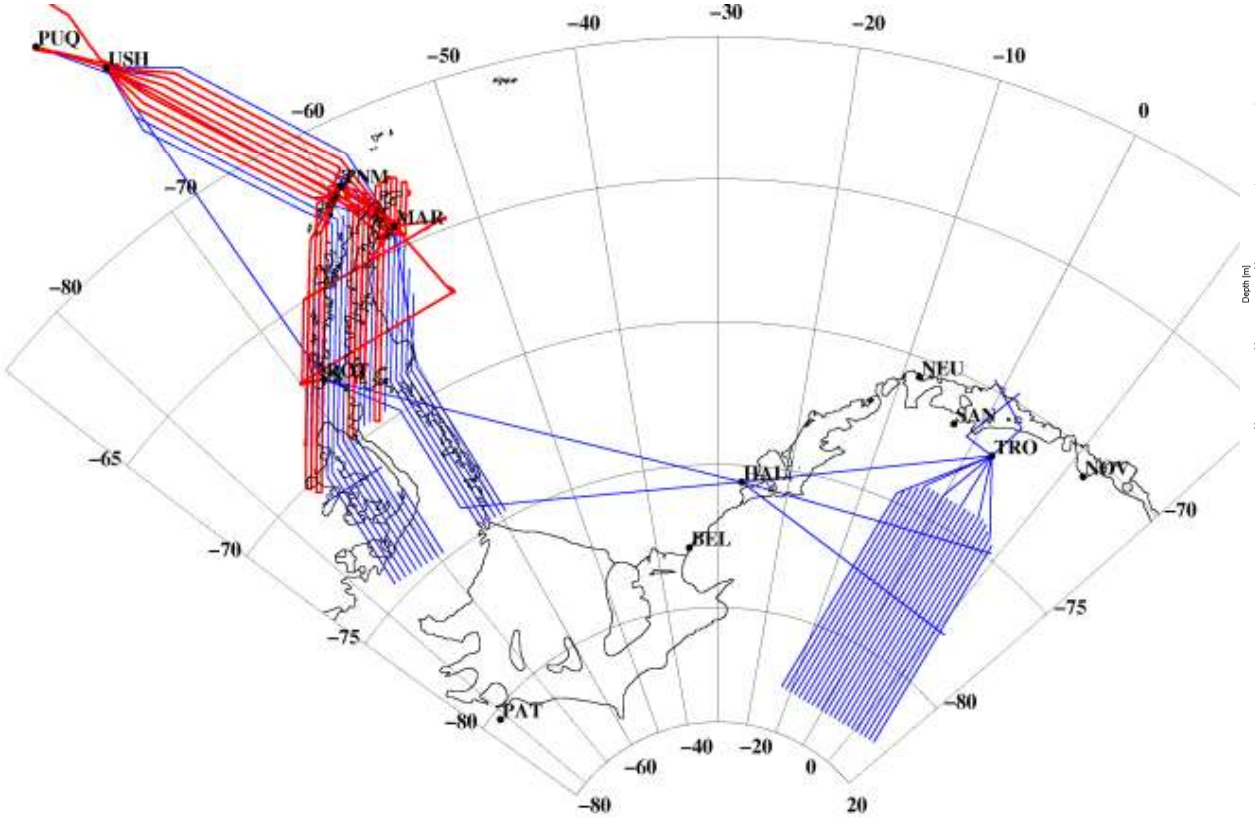
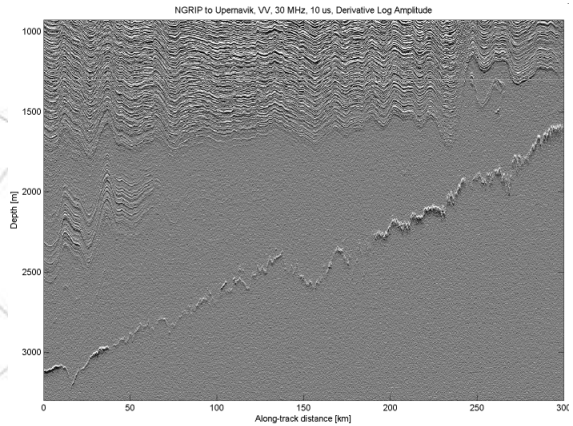
Upcoming: ICEGRAV 2010/11 .. peninsula and Dronning Maud Land

- Cooperation with Norsk Polarinstitut/UiB/SK + Argentina + UK + UTIG
- New radar: P-band sounder .. *ice mapper for Jupiter moons!*

Geodesy takes lead in interdisciplinary polar and climate science .. last major "white spot" on earth to be covered ..






Thanks for your attention
KNS glacier, Nuuk, laser scanning June 2009