Mass change in Greenland and Antarctica derived from SLR and GRACE

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Introduction

The dominating force acting on a satellite is due to Earth gravity and therefore the satellite's orbit is sensitive to mass distribution and transport in the Earth system. At the Astronomical Institute of the University of Bern (AIUB) the Earth's gravity field and its variations are co-estimated in the frame of an extended orbit determination process. The spatial and temporal resolution of the resulting gravity field depend on the orbital height and ground track pattern of the particular satellite. Most suited for gravity field determination are the geodetic satellite laser ranging (SLR) satellites with a low area to mass ratio, or low Earth orbiters (LEOs) with onboard accelerometers to separate gravitational from surface forces acting on the satellite, like the dedicated gravity field missions CHAMP, GOCE and GRACE.

Satellite Laser Ranging

Most prominent examples are the Laser Geodynamics Satellites (LAGEOS 1 and 2, Fig. 1). LAGEOS 1 was launched in 1976 to an orbit altitude of almost 6000 km with the goal to determine the geoid and continental drift rates. There also exists a fleet of SLR satellites at lower orbits that are exploited at AIUB for the determination of large scale temporal gravity field variations: Starlette, Ajisai, Stella, Larets, Lares, and a number of Earth observation satellites that carry laser retro-reflectores (e.g. Beacon-C).

Fig. 1: LAGEOS 2 (diameter 60 cm) carries 426 corner cube reflectors and weights 405 kg.

Tab. 1: Orbit parametrization of SLR satellites.

Parameter	LAGEOS-1/2	Low SLR
Station coordinates	30-days	30-days
Earth rotation parameters	PWL daily	PWL daily
Geocenter coordinates	30-days	30-days
Gravity field up to d/o	10/10	10/10
Range biases	Selected sites	All sites
Satellite orbits		
Osculating elements	10-days	1-day
Constant along-track S_0	10-days	–
Air drag scaling factor	–	1-day
Once-per-rev in S	10-days	1-day
Once-per-rev in W	–	1-day
Pseudo-stochastic pulses	–	OPR in S

S along-track, *W* out-of-plane, *R* radial orbital direction, *OPR* once-per-revolution, *PWL* piecewise-linear parameterization, *d/o* degree/order

GRACE

The Gravity Recovery And Climate Experiment (GRACE) mission (2002-17) and its successor GRACE-FO (started in May 2018) sense temporal gravity variations related to mass transport processes. Each of the missions consist of two identical satellites that follow each other at a short distance of only 220 km. Main observable is the inter-satellite range that is measured with μm accuracy. Due to their low orbit altitude of initially 480 km and the specific orbit design (near polar, near-repeat cycles of 4-7 days), monthly gravity fields with a spatial resolution of 200 - 400 km can be determined.

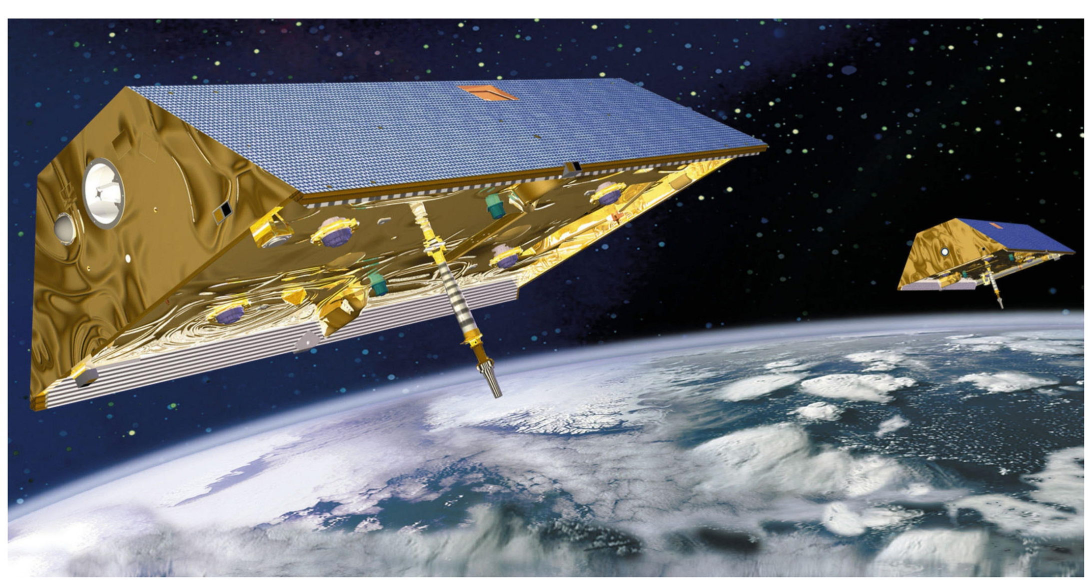

Fig. 2: The twin GRACE satellites (by courtesy of NASA).

Spectral/Spatial Resolution and Signal Leakage

The Earth gravity field is commonly represented by a spherical harmonic expansion. The max. degree and order determine the spatial scale of the representable signal, i.e., the cell size of a corresponding global grid. Monthly gravity fields are available to degree/order 90 (460 km at equator). Truncation of the spherical harmonic expansion causes signal leakage, as demonstrated by Fig. 3. With good a priori knowledge of the mass distribution leakage effects can be corrected. Nevertheless leakage (in and out) remains one of the major limitations to the quantification of mass transport.

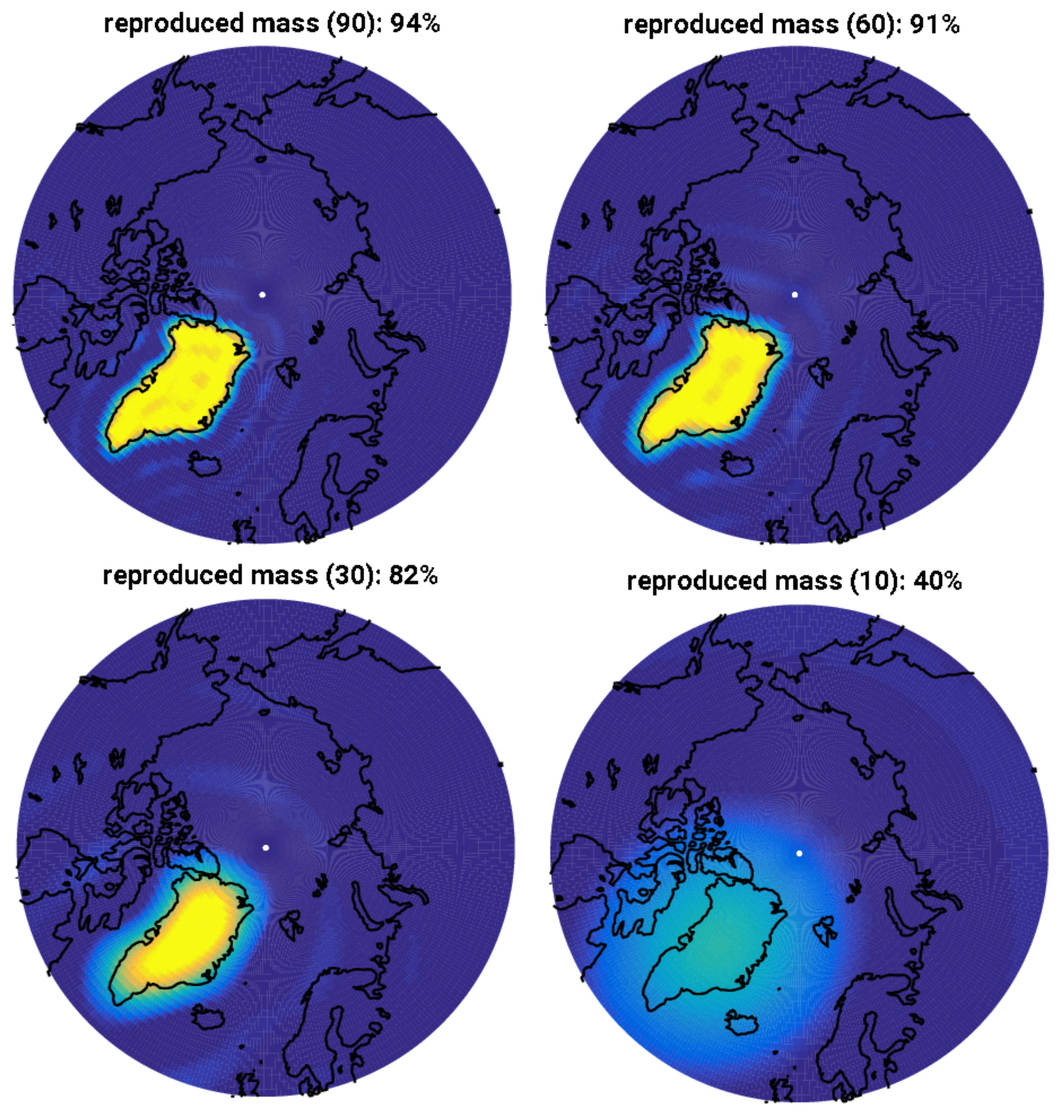

Fig. 3: Simulation of leakage effects over Greenland. The numbers refer to the percentage of the original mass recovered within the borders of Greenland after spherical harmonic expansion to a certain max. degree/order.

Satellite derived mass trends

Mean annual mass trends 2003-14 derived from GRACE observations are shown in Fig. 4. Clearly visible is ice melt at the coast of Greenland, the Bay of Alaska, the Patagonian ice fields and in Western Antarctica. Mass gain near Hudson Bay and Fennoscandia is related to glacial isostatic adjustment (GIA).

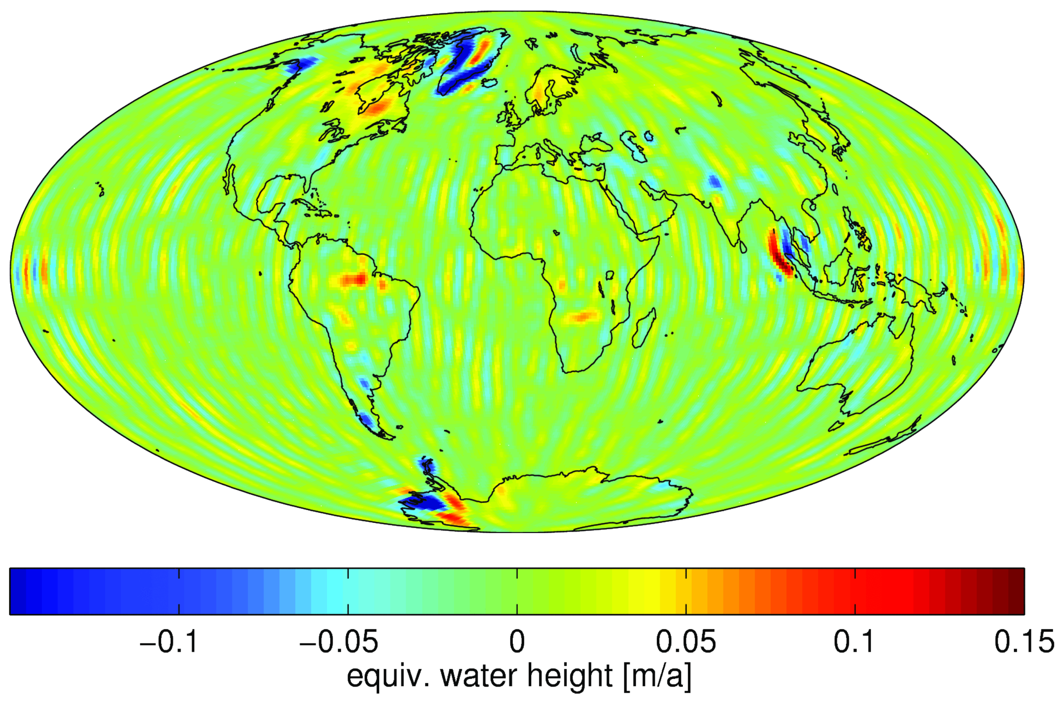

Fig. 4: GRACE mean annual mass trends (unfiltered, note the noisy striping related to the ground track pattern).

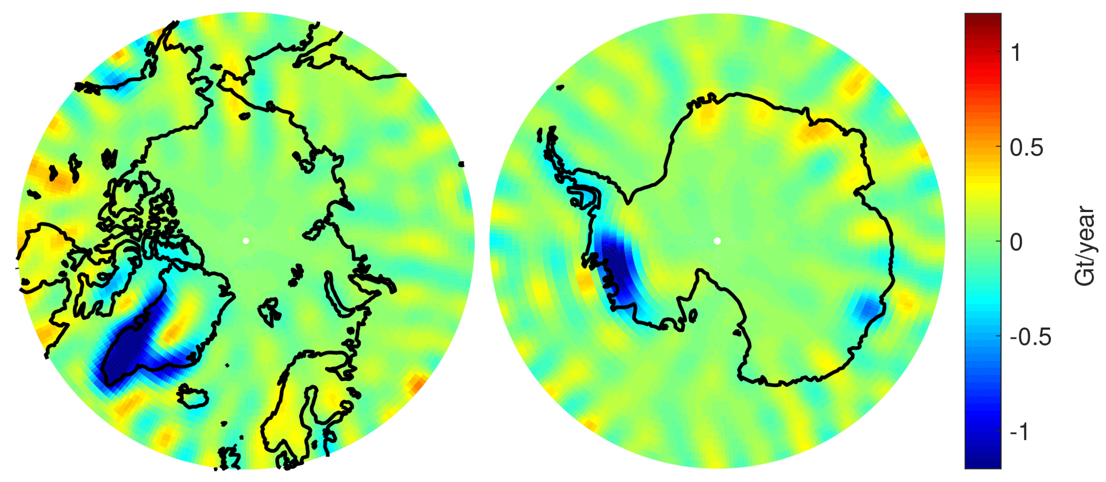

Fig. 6: GRACE mass trends 2010-14 (degree/order 60, unfiltered).

Satellite derived mass trends (cont.)

While GRACE covers the period 2002-17, earlier observations of mass change have to be based on geodetic SLR satellites. A common evaluation of LAGEOS and low SLR satellites reveals a good agreement with GRACE (truncated at degree/order 10) and a start of major ice melt in Greenland around 2003 (Fig. 7). Due to leakage effects at this very low max. degree/order, absolute mass loss is drastically underestimated (see Figs. 5, 6 and 8 for a comparison of GRACE and SLR derived mass trends at different spherical harmonic resolutions).

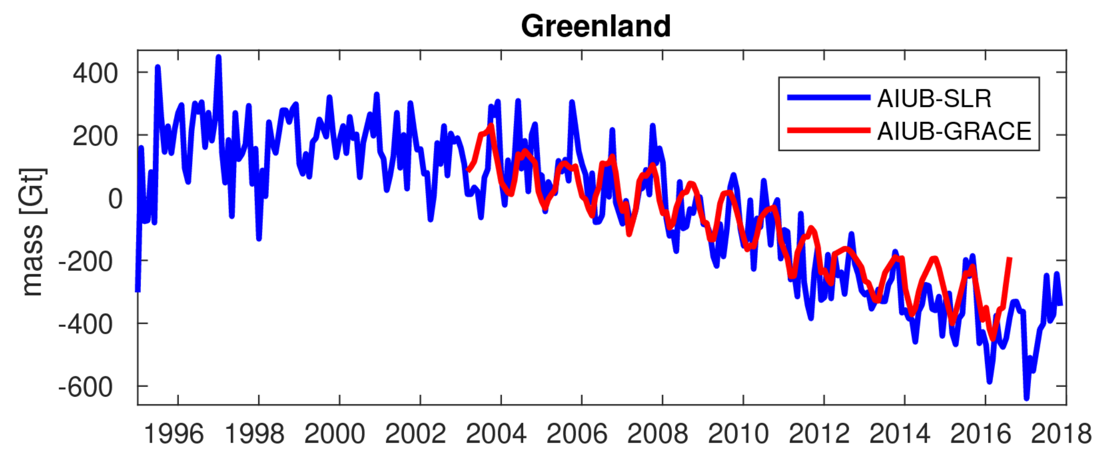

Fig. 7: Monthly mass variation within Greenland as derived from SLR or GRACE (truncated at degree 10).

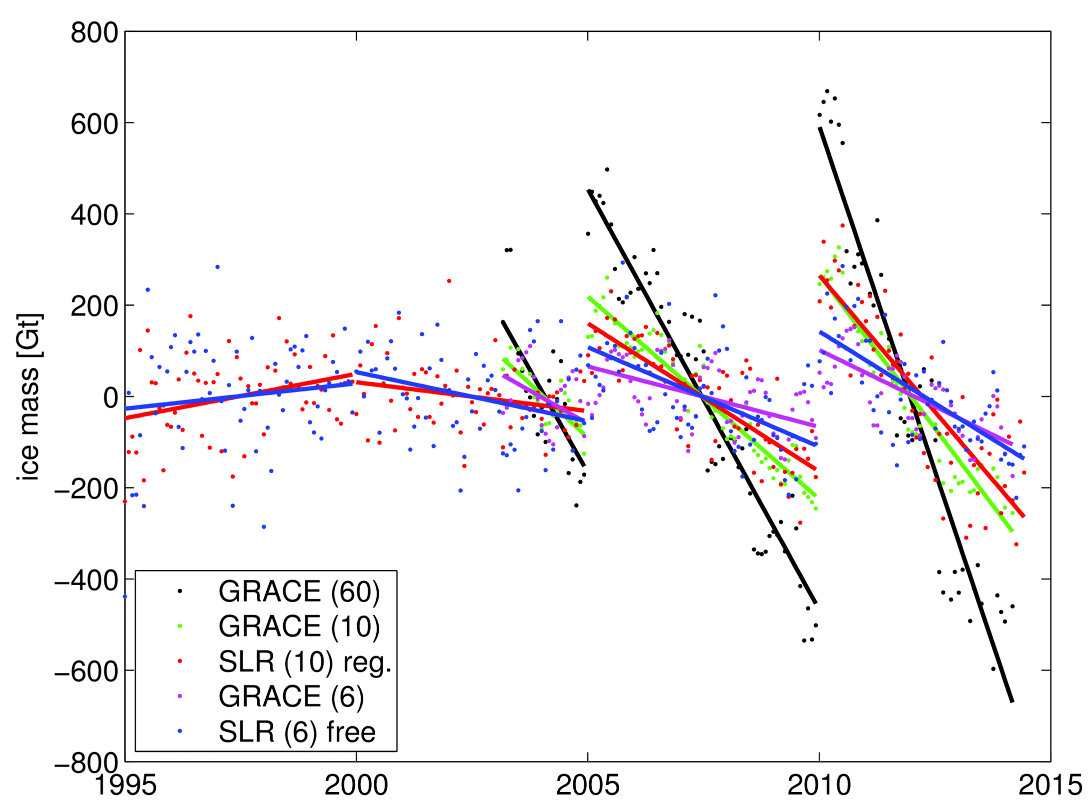

Fig. 8: Monthly mass estimates and best fitting trends per 5 year period as derived from GRACE or SLR at different resolutions.

Combination Service for Time-variable Gravity fields

At AIUB, it is our goal to unify the releases of GRACE monthly gravity fields from different analysis centers in a statistically correct way on normal equation level and to combine them with SLR to strengthen the very low degree coefficients of the gravity field. The combination will be performed in the frame of COST-G, a new technique center of the International Association of Geodesy (IAG).

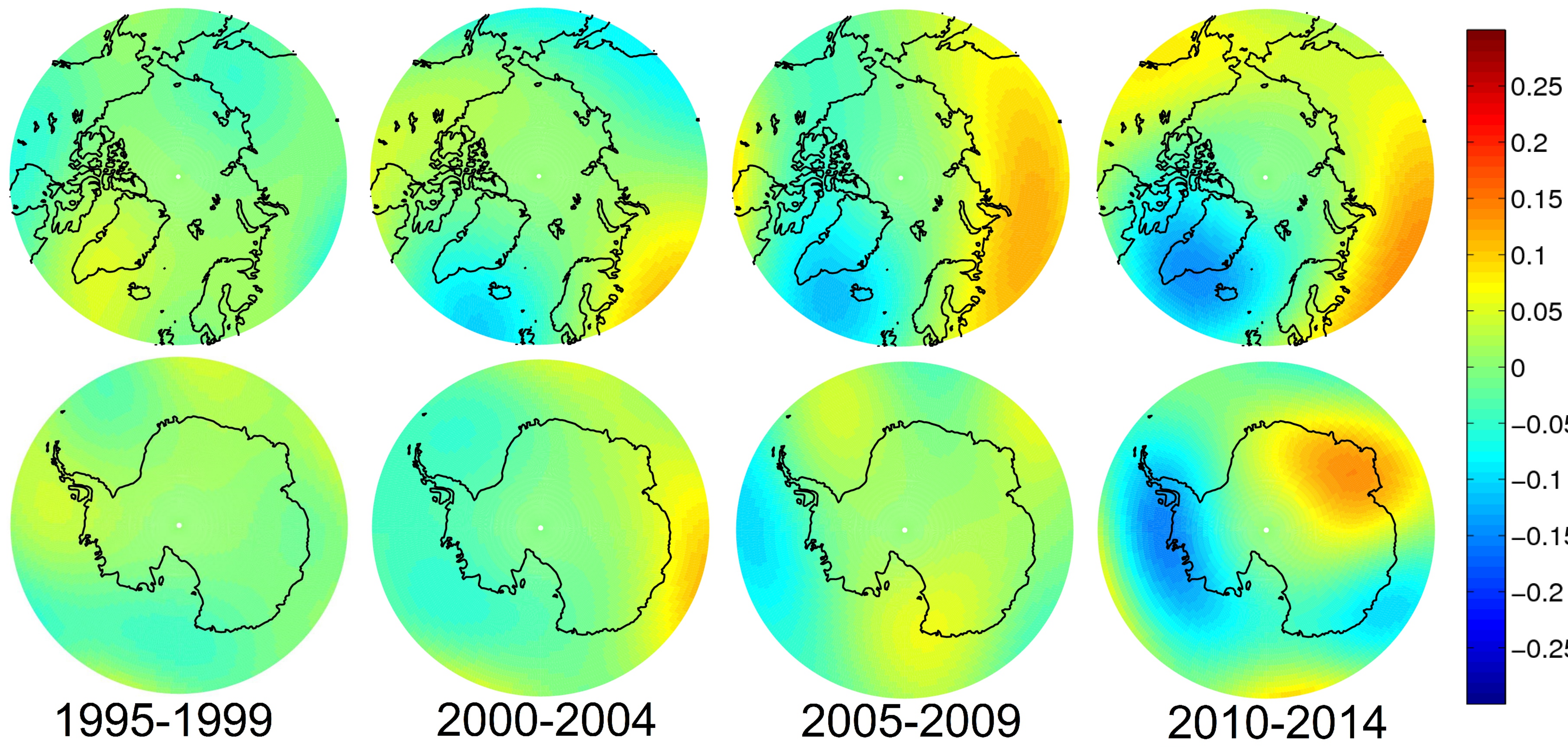

Fig. 5: Polar mass trends as derived from SLR. Even at very limited spatial resolution the mass loss in Greenland and western Antarctica is visible.

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