ID: 77551

5th International GOCE User Workshop
25-28 November 2014, Paris, France

Gravity Field Recovery from GOCE Precise Science Orbit Positions

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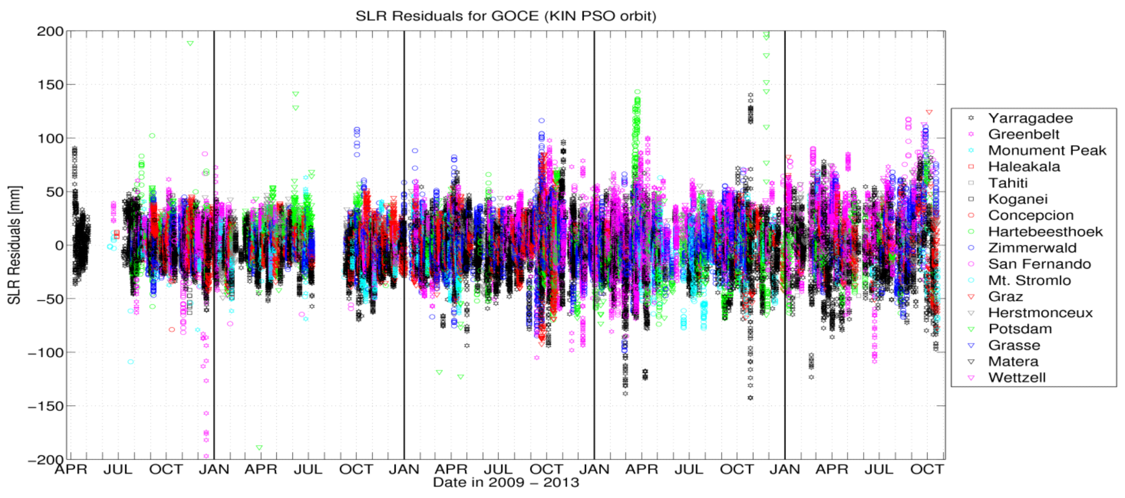
Introduction

The Gravity field and steady-state Ocean Circulation Explorer (GOCE), ESA's first Earth Explorer Core Mission, was launched on March 17, 2009 into a sun-synchronous dusk-dawn orbit and re-entered into the Earth's atmosphere on November 11, 2013. It was equipped with a three-axis gravity gradiometer for high-resolution recovery of the Earth's gravity field, as well as with a 12-channel, dual-frequency Global Positioning System (GPS) receiver for precise orbit determination (POD), instrument time-tagging, and the determination of the long wavelength part of the Earth's gravity field. A precise science orbit (PSO) product was provided by the GOCE High-level Processing Facility (HPF) from the GPS high-low Satellite-to-Satellite Tracking (hl-SST) data from the beginning until the very last days' of the mission.

We use the 1-sec kinematic positions of the GOCE PSO product for gravity field determination and present GPS-only solutions covering the entire mission period. The generated gravity field solutions reveal severe systematic errors centered along the geomagnetic equator, which may be traced back to the GPS carrier phase observations used for the kinematic orbit determination. The nature of the systematic errors is investigated and reprocessed orbits free of systematic errors along the geomagnetic equator are derived. Eventually, the potential of recovering time variable signals from GOCE kinematic positions is assessed and the contribution of GOCE in view of a multi-satellite combination of low Earth satellites tracked by GPS hl-SST is studied.

Quality of kinematic PSO



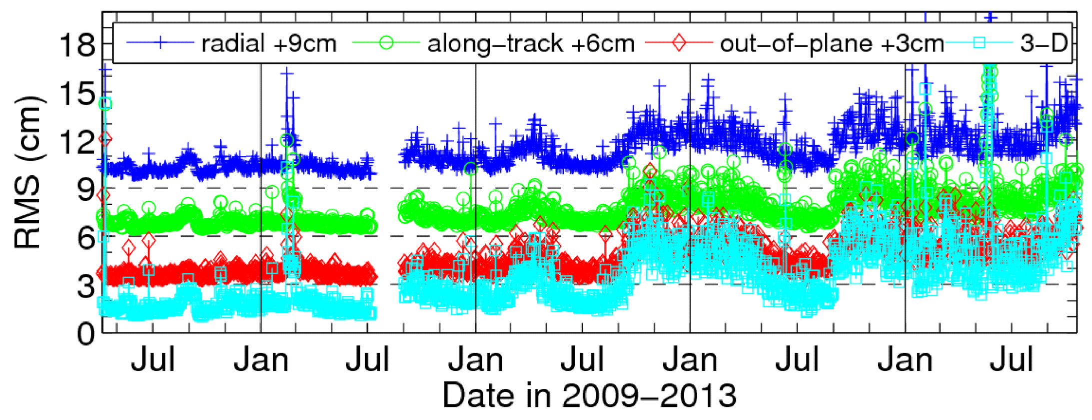
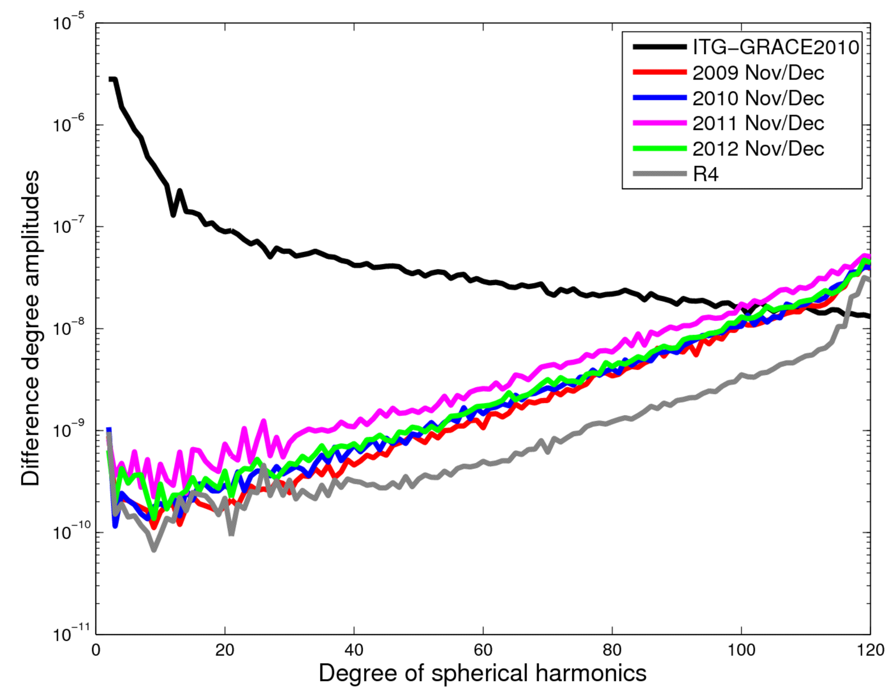


Figure (top): SLR residuals from April 10, 2009 - October 20, 2013 for the kinematic GOCE PSO solutions. An overall RMS of 2.42 cm is achieved.
Figure (bottom): RMS of differences between kinematic and reduced-dynamic PSO. The quality of the kinematic positions is significantly changing over the mission period.

Gravity field from kinematic PSO



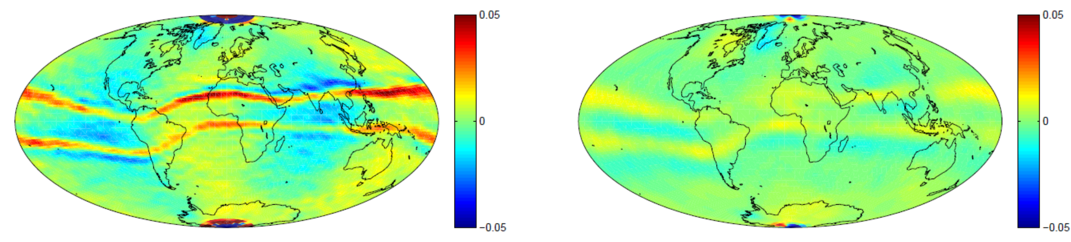
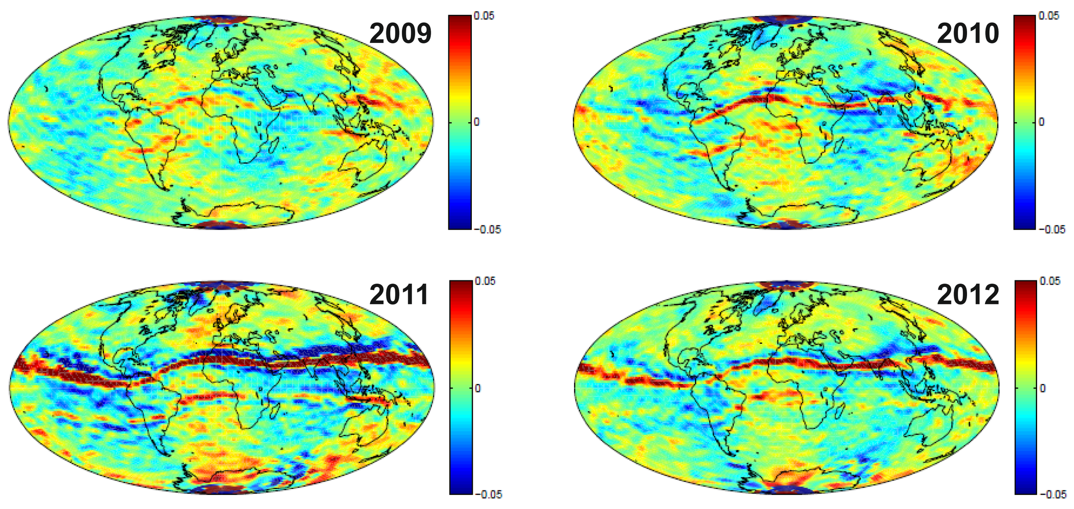
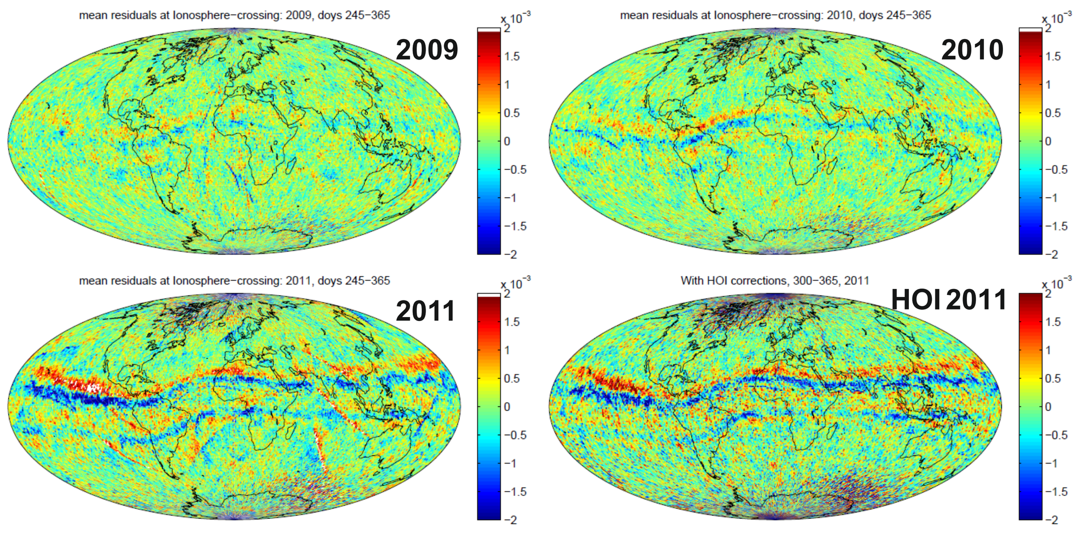


Figure (top): Square-roots of degree difference variances of GPS-only solutions covering different time periods wrt ITG-GRACE2010.
Figure (bottom): 300-km-filtered geoid height differences (m) of the GPS-only R4 solution (2009/11-2012/06, left) and the corresponding timewise solution (right) wrt ITG-GRACE2010.

Systematic errors in gravity field solutions traced back to the GPS data

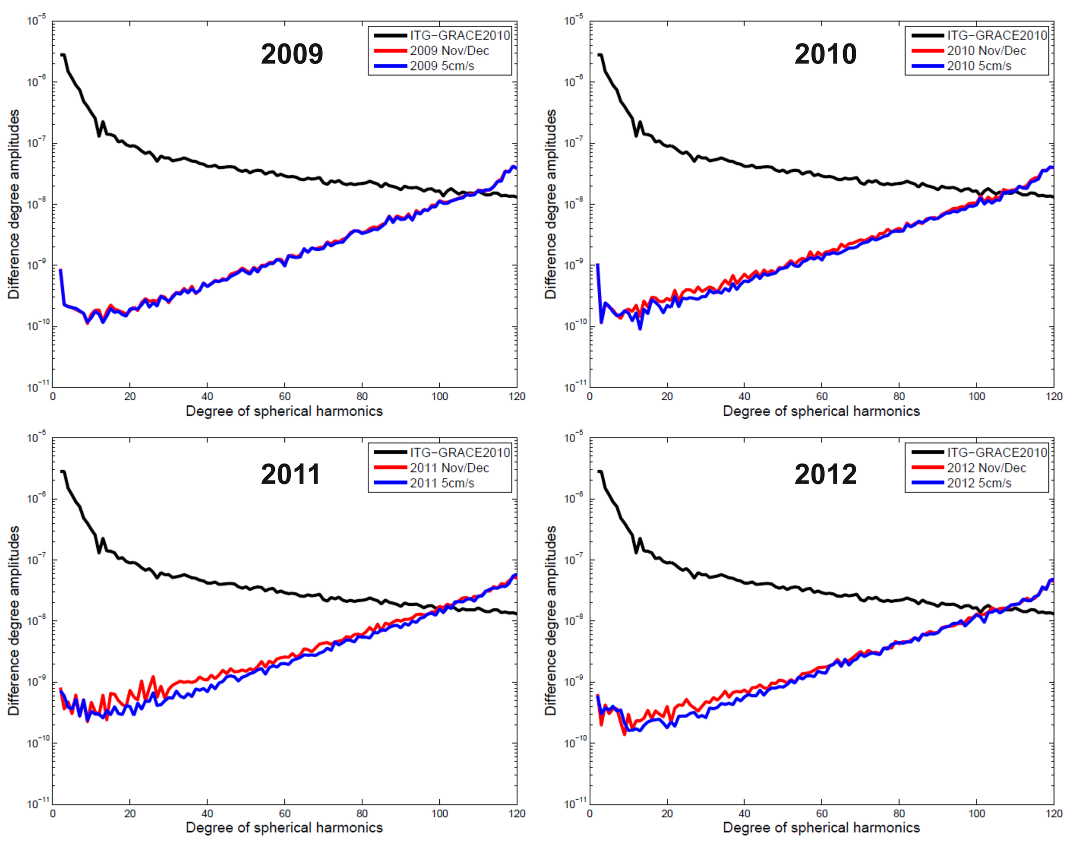




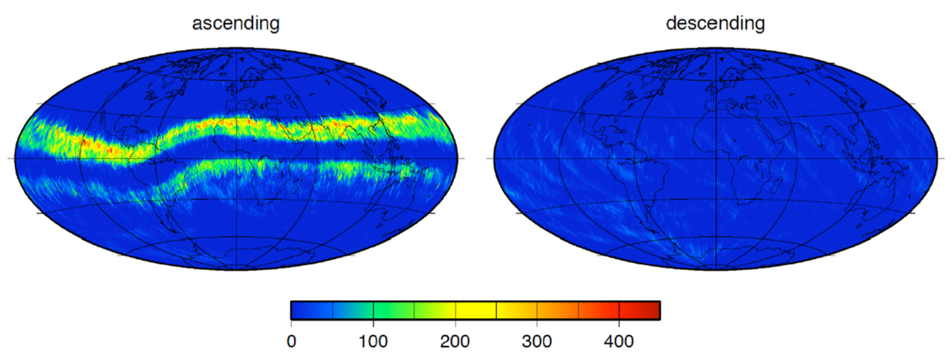
Figures (left): 300-km filtered geoid height differences (m) of bi-monthly GPS-only gravity field solutions for the Nov.-Dec. period of 2009 (top left), 2010 (top right), 2011 (bottom left), 2012 (bottom right). All solutions are prone to severe systematic errors centered along the geomagnetic equator. Barely visible in 2009, the size of the systematic errors is increasing over the years with a maximum impact on the solution from 2011. Due to their systematic nature the errors are not reduced by accumulating longer data series but become more pronounced (see figure above).

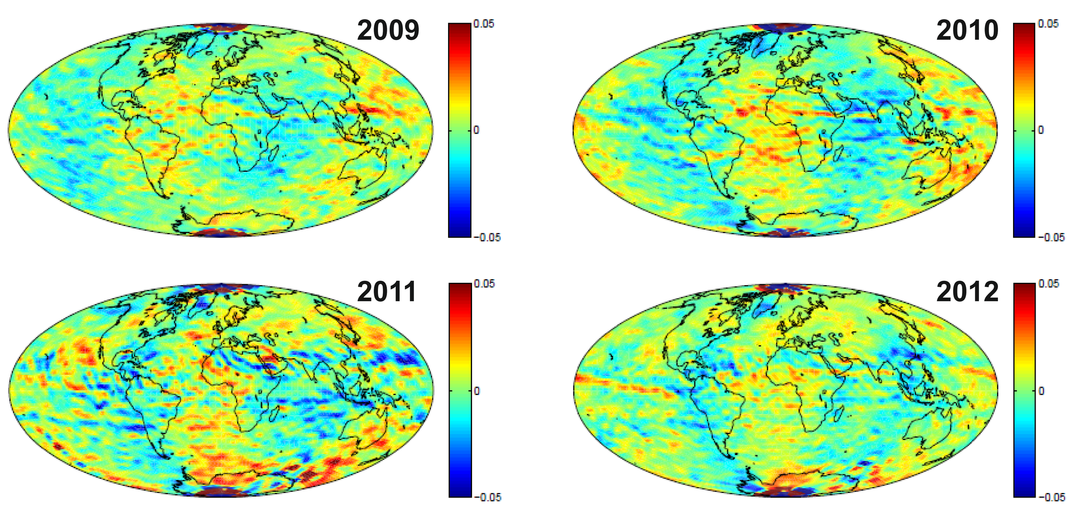
Figures (right): Mean (m) of ionosphere-free GPS carrier phase observation residuals mapped to the ionosphere piercing point for the Sept.-Dec. period of 2009 (top left), 2010 (top right), 2011 (bottom left), 2011 with Higher Order Ionosphere (HOI) corrections applied according to the IERS 2010 conventions (bottom right). The systematic effects cannot be reduced when using the global ionosphere maps from the CODE IGS analysis center to derive the total electron content (TEC) needed to compute

Reduction of systematic errors in gravity field solutions



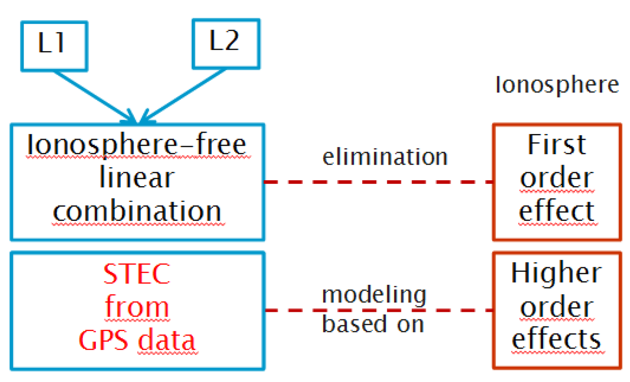
Figures: Square-roots of degree difference variances of GPS-only solutions covering different time periods when including/excluding GPS observations with ionosphere changes larger than 5cm/s.



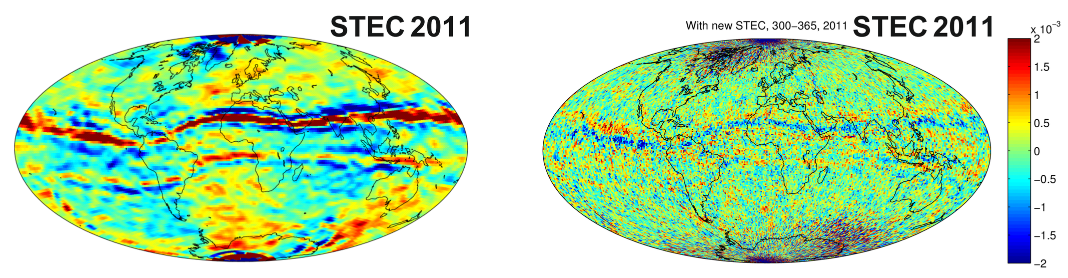


Figures: 300-km filtered geoid height differences (m) of bi-monthly GPS-only gravity field solutions for the Nov.-Dec. period of 2009 (top left), 2010 (top right), 2011 (bottom left), 2012 (bottom right) wrt ITG-GRACE2010 when only using GPS observations with ionosphere change smaller than 5 cm/s.

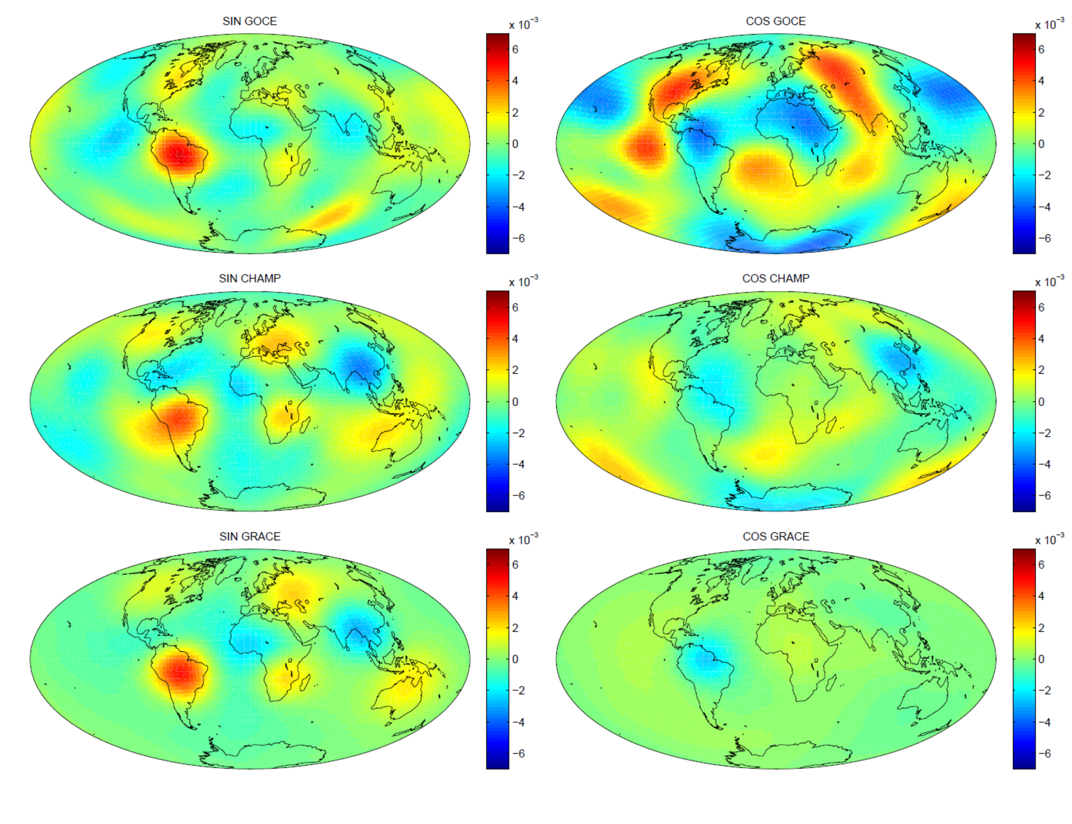
Figures: Number of removed GPS observations when excluding observations with ionospheric changes larger than 5 cm/s. This almost exclusively affects regions along the geomagnetic equator for ascending arcs due to the sun-synchronous dusk-dawn GOCE orbit. The systematic effects may be efficiently removed by such a procedure with only a small loss of kinematic positions (0.1%, 0.2%, 6.2%, and, 3.7%, for the Nov.-Dec. period of 2009, 2010, 2011, and 2012, respectively).



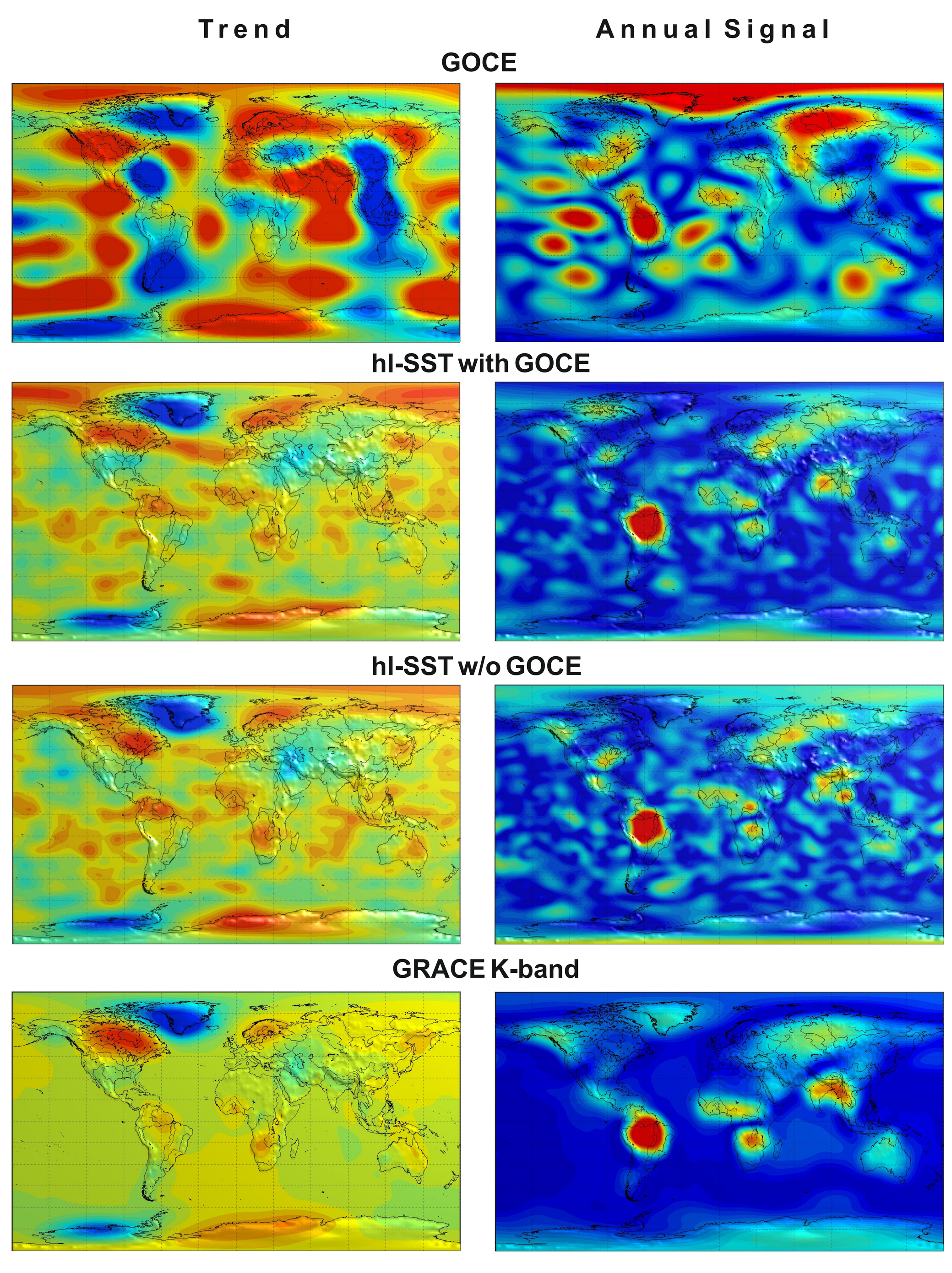
Alternatively a more sophisticated modeling of the TEC values used for the evaluation of the HOI terms may be attempted. Instead of using global ionosphere maps derived from terrestrial data, GOCE GPS data may be used to derive slant TEC (STEC) values along the orbit as seen from GOCE.
The figures below confirm some reduction of the systematic errors, but not a complete elimination.



Time variable gravity field recovery from GOCE kinematic positions



Figures (top): Annual amplitude (in m geoid heights) of the sine (left column) and cosine (right column) term recovered from GOCE GPS data (top row), CHAMP GPS data (middle row) and GRACE K-Band data (bottom row).
Figures (right): Trend and annual signals (in cm/y or cm equivalent water heights) based on a Kalman filter approach using GOCE-only solutions (top), combined hl-SST solutions including GOCE, GRACE A+B, CHAMP, Metop A+B, TanDEM, TerraSAR-X, Swarm A+B+C (second row), combined hl-SST solutions excluding GOCE (third row) from 2009-2013. GRACE K-Band solutions from GFZ are shown for comparison (bottom). All hl-SST solutions are 750 km Gauss filtered, C20 and degree 1 terms are replaced.
Although GOCE-only solutions are of limited value for recovering time variable signals due to the presence of the polar gap and the rather short time series of only 4 years, the contribution to a combined hl-SST solution can be clearly seen (compare the two middle rows in the right figure).



Conclusions

Gravity field solutions from GOCE kinematic PSO positions are affected by systematic errors centered along the geomagnetic equator. The errors may be traced back to the ionosphere-free GPS carrier phase observations and may be eliminated empirically by discarding measurements with large ionospheric changes in the kinematic orbit determination. Alternatively, a more refined modeling of HOI correction terms in the orbit determination might be promising, but will require further effort and investigations.
Gravity field solutions based on GOCE kinematic positions show only a limited sensitivity to the annual gravity signal caused by land hydrology. The comparison with results from CHAMP and GRACE indicates that more refined analysis techniques are needed to further exploit time variable signals from GOCE kinematic positions. In combination with other low Earth satellites tracked by GPS hl-SST, however, the contribution of GOCE to the recovery of time variable signals can be clearly seen.

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Poster compiled by A. Jäggi, November 2014
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