The GOCE Reprocessing Campaign

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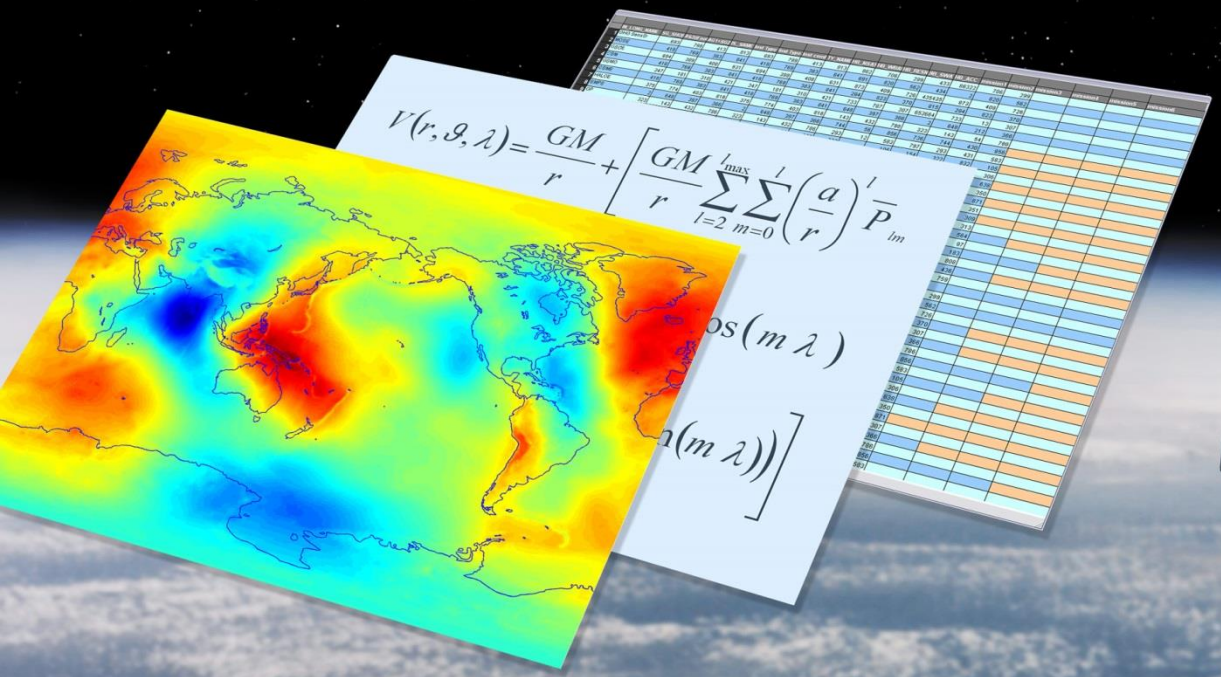

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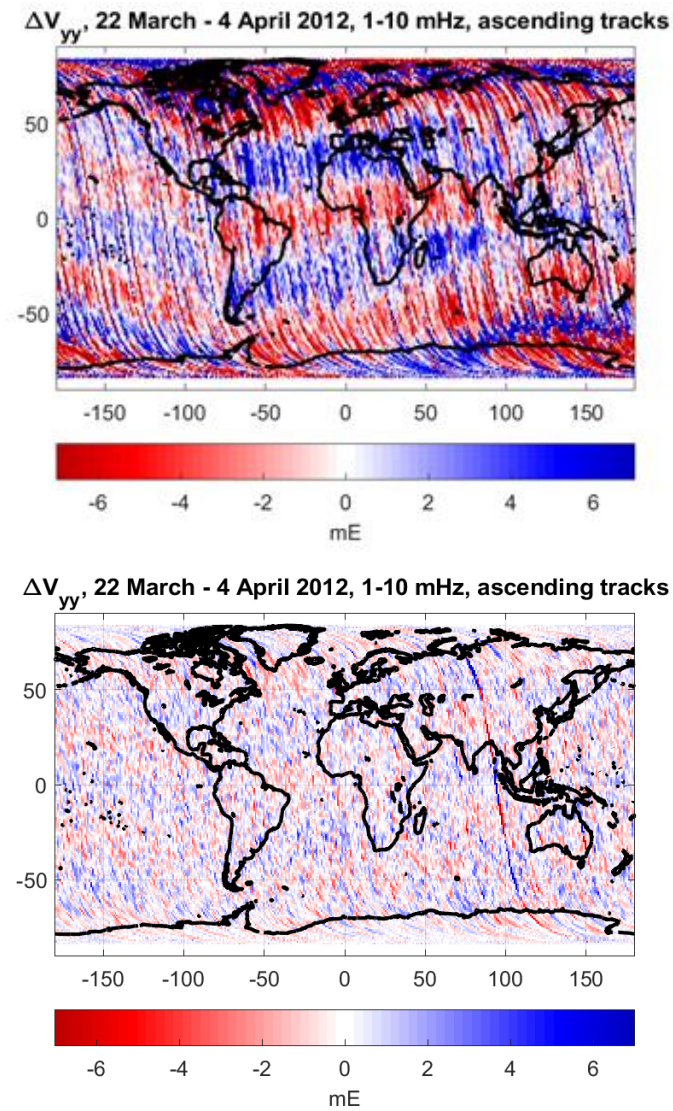
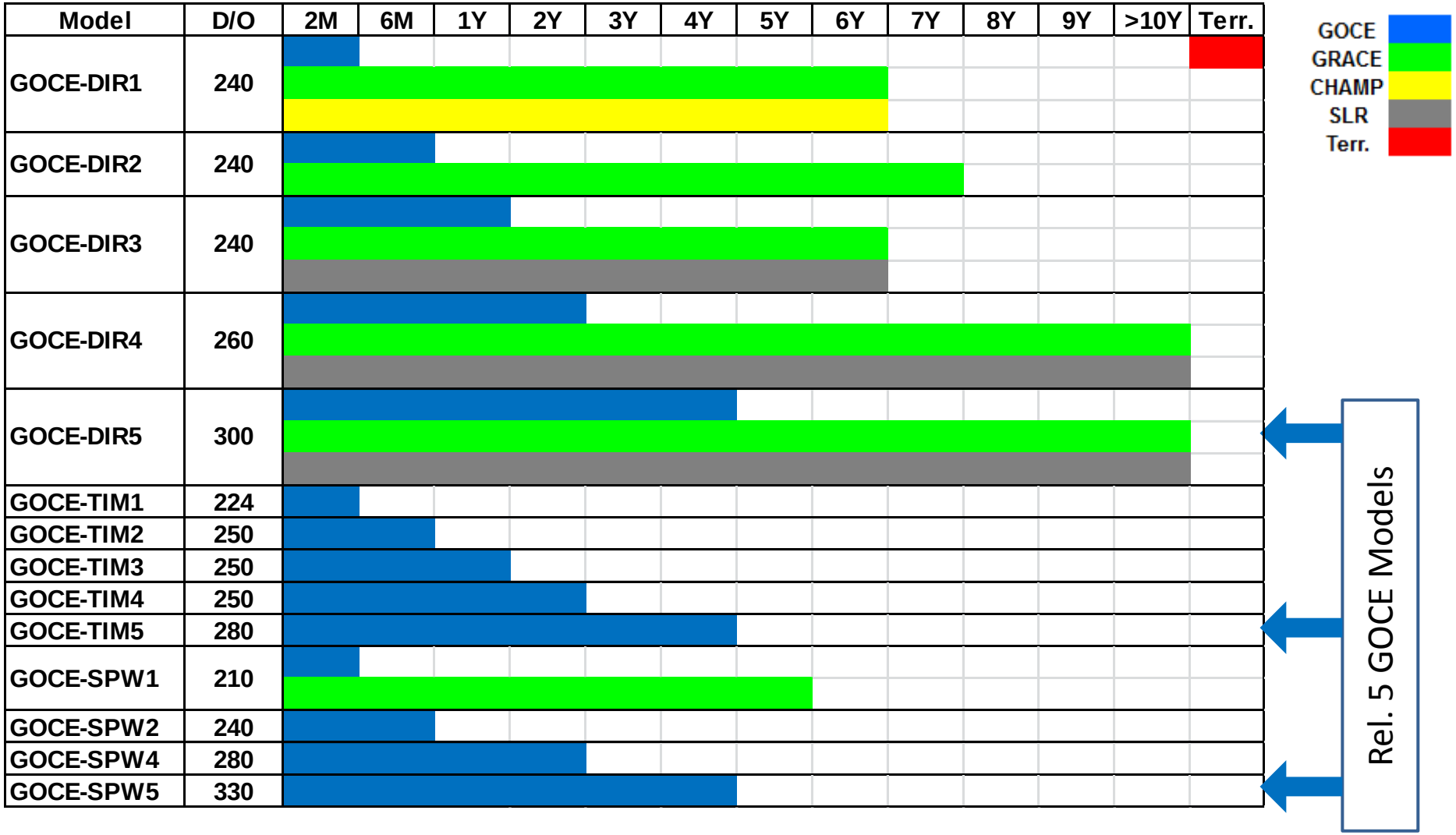


Gravity gradient residuals V_{yy}; top: original calibration scheme; bottom revised calibration scheme; Courtesy: C. Siemes

Overview of ESA GOCE Models



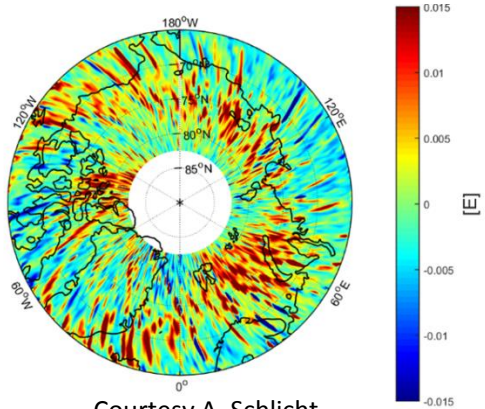
Performance of Rel. 5 Models: 1-2 cm geoid, < 1 mgal gravity anomaly accuracy at d/o 200

Overview of GOCE Models

Nr	Model	Year	Degree	Data	References
165	IGGT_R1	2017	240	G(GOCE)	Lu, B. et al, 2017
164	IfE_GOCE05s	2017	250	S(GOCE)	Wu, H. et al, 2017
163	GO_CONS_GCF_2_SPW_R5	2017	330	S(GOCE)	Gatti, A. et al, 2016
162	GAO2012	2012	360	A, G, S(GOCE), S(GRACE)	Demianov, G. et al, 2012
161	XGM2016	2017	719	A, G, S(GOCO05s)	Pail, R. et al, 2017
160	Tongji-Grace02s	2017	180	S(Grace)	Chen, Q. et al, 2016
159	NULP-02s	2017	250	S(Goce)	A.N. Marchenko et al, 2016
158	HUST-Grace2016s	2016	160	S(Grace)	Zhou, H. et al, 2016
157	ITU_GRACE16	2016	180	S(Grace)	Akyilmaz, O. et al, 2016
156	ITU_GGC16	2016	280	S(Goce), S(Grace)	Akyilmaz, O. et al, 2016
155	EIGEN-6S4 (v2)	2016	300	S(Goce), S(Grace), S(Lageos)	Förste, C. and Bruinsma, S.L., 2016
154	GOCO05c	2016	720	(see model), A, G, S	Fecher, T. et al, 2016
153	GGM05C	2015	360	A, G, S(Goce), S(Grace)	Ries, J. et al, 2016
152	GECO	2015	2190	EGM2008, S(Goce)	Gilardoni, M. et al, 2016
151	GGM05G	2015	240	S(Goce), S(Grace)	Bettadpur, S. et al, 2015
150	GOCO05s	2015	280	(see model), S	Mayer-Gürr, T. et al, 2015
149	GO_CONS_GCF_2_SPW_R4	2014	280	S(Goce)	Gatti, A. et al, 2014
148	EIGEN-6C4	2014	2190	A, G, S(Goce), S(Grace), S(Lageos)	Förste, Christoph et al, 2014
147	ITSG-Grace2014s	2014	200	S(Grace)	Mayer-Gürr, T. et al, 2014
146	ITSG-Grace2014k	2014	200	S(Grace)	Mayer-Gürr, T. et al, 2014
145	GO_CONS_GCF_2_TIM_R5	2014	280	S(Goce)	Brockmann, J. M. et al, 2014
144	GO_CONS_GCF_2_DIR_R5	2014	300	S(Goce), S(Grace), S(Lageos)	Bruinsma, S. L. et al, 2013

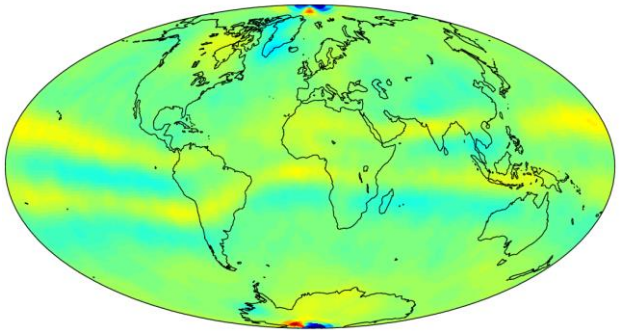
GOCE Reprocessing – Why?

Increased residuals for cross-track gradients (V_{yy}) and others around geomagnetic poles



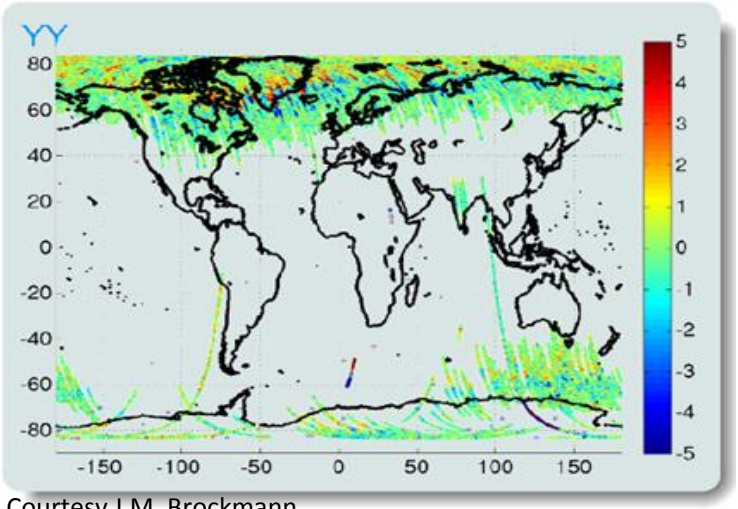
Courtesy A. Schlicht

Kinematic orbits show systematic effects around the geomagnetic equator because of degraded GPS data – impact on gravity field



Geoid height differences (-5 cm …5 cm) wrt. TIM Rel. 4 model; Courtesy A. Jäggi

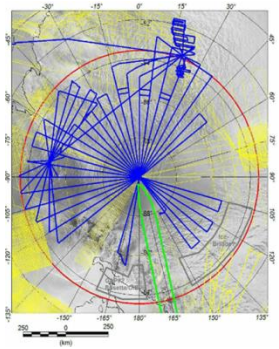
Reduced performance for the gravity field in these areas because of outlier rejection i.e. less data for gravity field computation



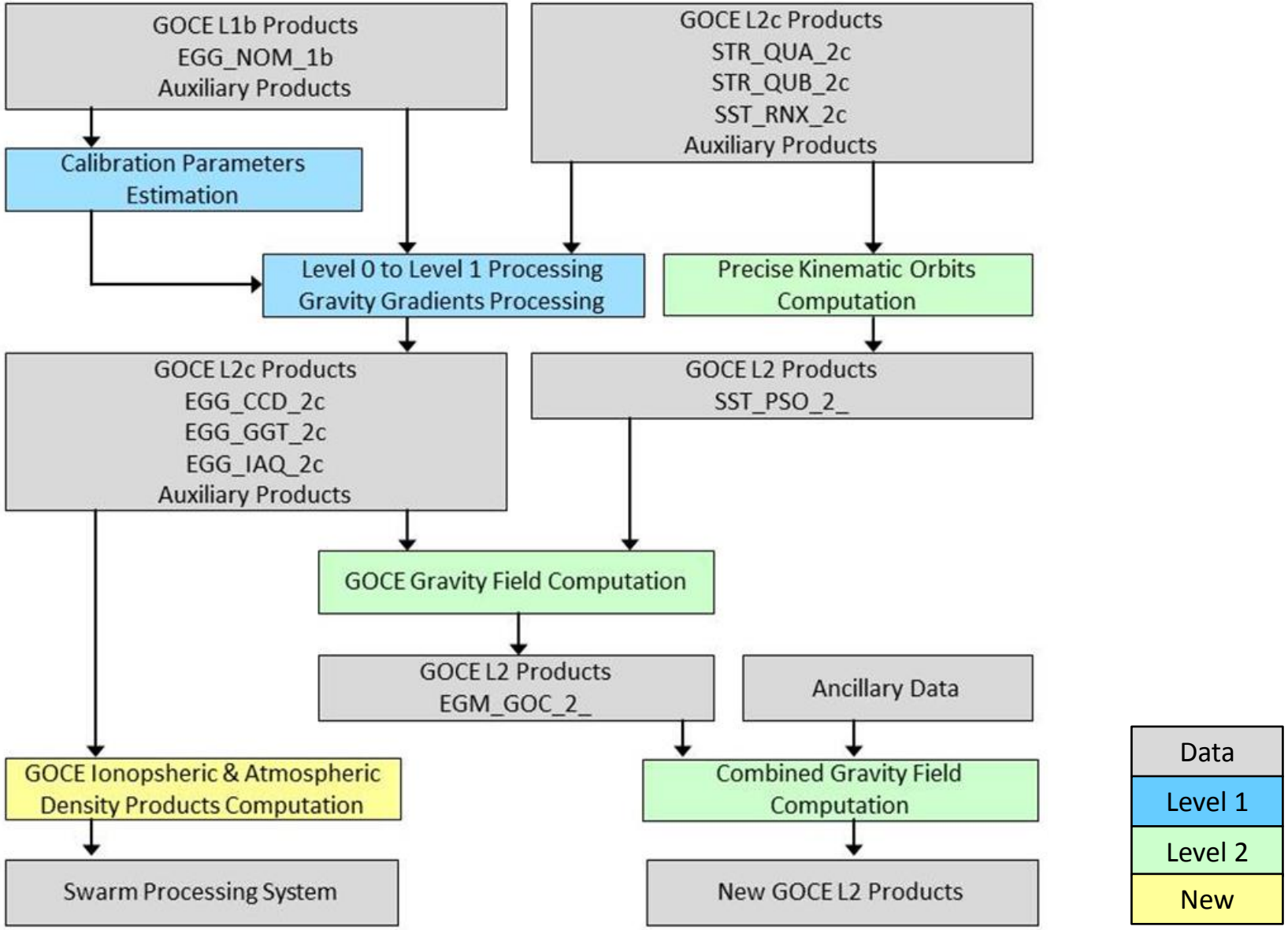
Courtesy J.M. Brockmann

New applications of GOCE data

- Ionospheric and atmospheric density profiles.
- New combined gravity field models using new airborne gravity data acquired on behalf of ESA over large parts of Antarctica.



GOCE Reprocessing – Overview

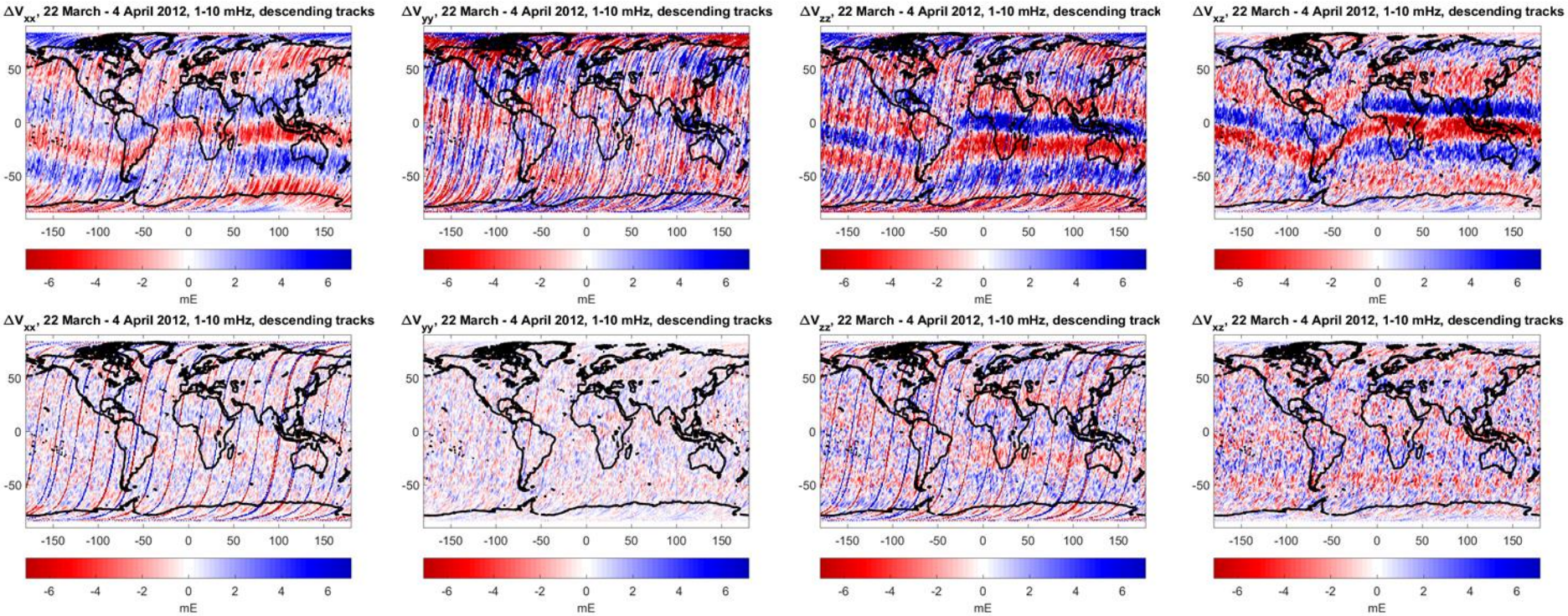


Impact of Reprocessing - Gradients

Calibration Parameters (L1 Processor)

Errors in the gravity gradients are large in areas around the magnetic pole.

As a major cause of these errors leakage of common-mode signal into the gravity gradients via the differential mode accelerations has been identified.



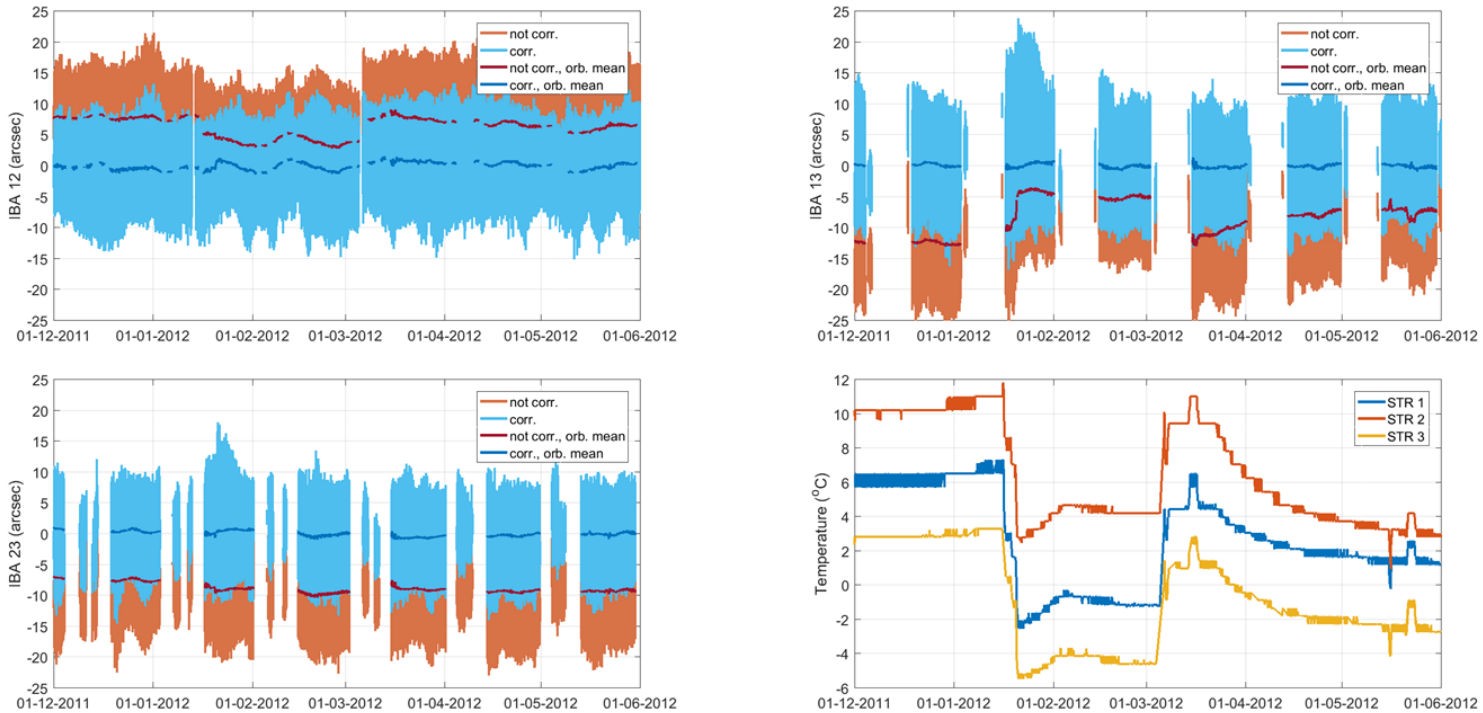
Gravity gradient residuals; top: original calibration scheme; bottom revised calibration scheme; Courtesy: C. Siemes

Leakage of common mode accelerations can be drastically reduced by estimating an additional quadratic factor for the differential mode accelerations in the calibration step (refer to next presentation by Ch. Siemes).

Impact of Reprocessing - Gradients

Star Tracker Attitude Bias – Angular Rates (L1 Processor)

- Bias in the star tracker observations depend on the temperature of the CCD sensor.
- So far constant rotation matrices between the star tracker and GRF are assumed.
- For estimating constant and temperature dependent biases a parameter model was defined, which estimates these parameters per measurement epoch.
- Bias changes need to be considered when the gradiometer angular accelerations are combined with the star tracker attitude angles.

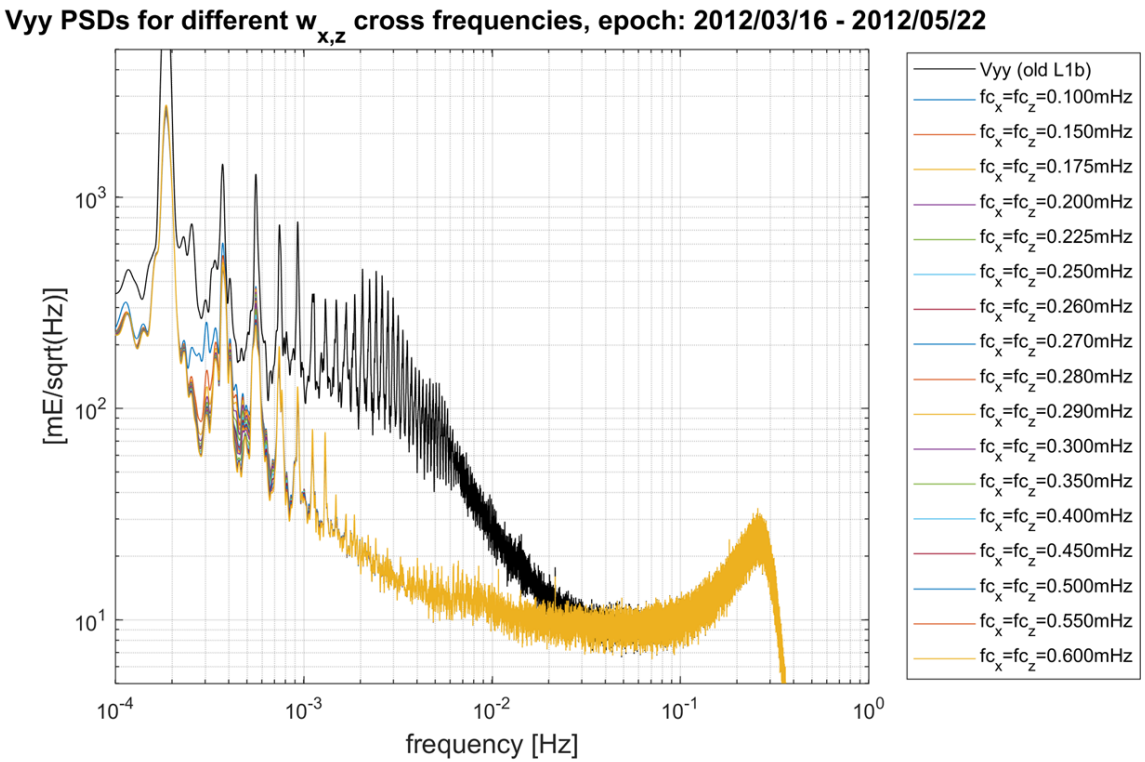


Star tracker observations of the three GOCE star trackers before and after correcting them for constant and temperature dependent biases for 6 months of GOCE data compared to CCD temperatures; Courtesy: C. Siemes

Impact of Reprocessing - Gradients

Angular Rate Reconstruction (L1 Processor)

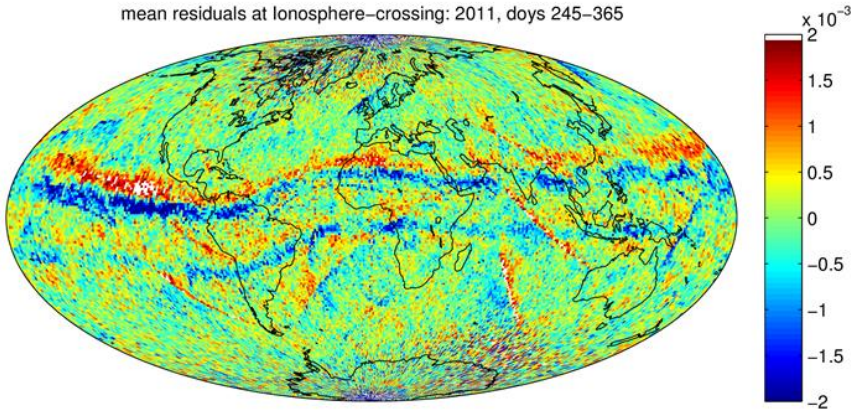
- Angular rate reconstruction so far applies an optimal fixed filter frequency (0.27 mHz), determined from the star tracker and gradiometer derived angular rate noise.
- Combination needs to be implemented more flexible and should be adapted to the real data situation.
- A “moving” estimation using a certain data window is proposed. Angular rate reconstruction and gradients benefit from this approach.



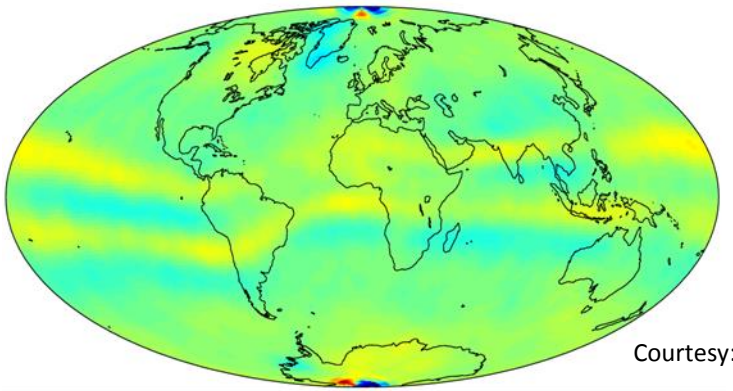
PSD of V_{yy} gravity gradient residuals with old and new calibration scheme and variable filter frequencies; Courtesy: M. Rexer

Impact of Reprocessing - Orbits

- PSO's show excellent quality, e.g. 1.84 cm SLR rms (RD) 2.42 cm SLR rms (KIN).
- But, a clear correlation of the kinematic orbit quality and the gravity field with solar activity was found.



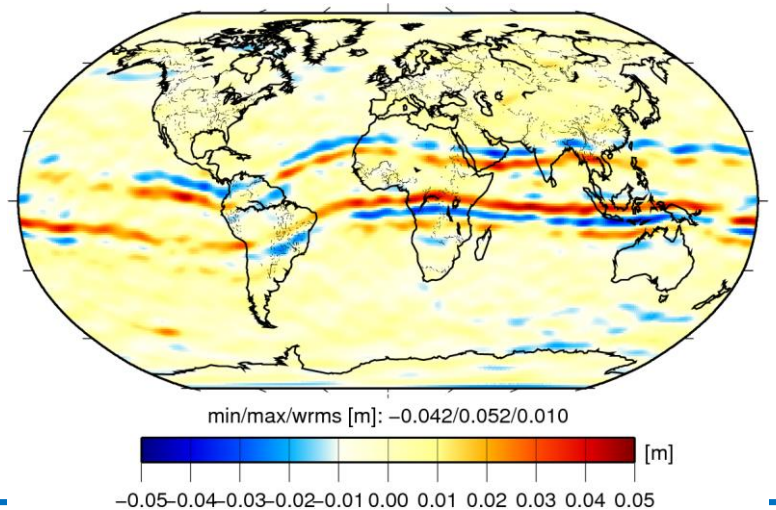
Phase observation residuals (- 2 mm … +2 mm) mapped to the ionosphere piercing point

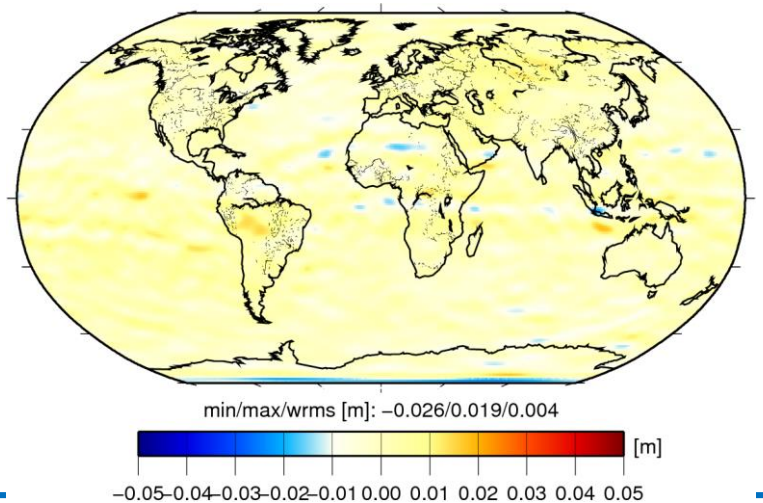


Courtesy: A. Jäggi

Geoid height differences (-5 cm …5 cm) wrt. TIM Rel. 4 model

- Improved screening of raw RINEX GPS data files (lessons learned from Swarm).





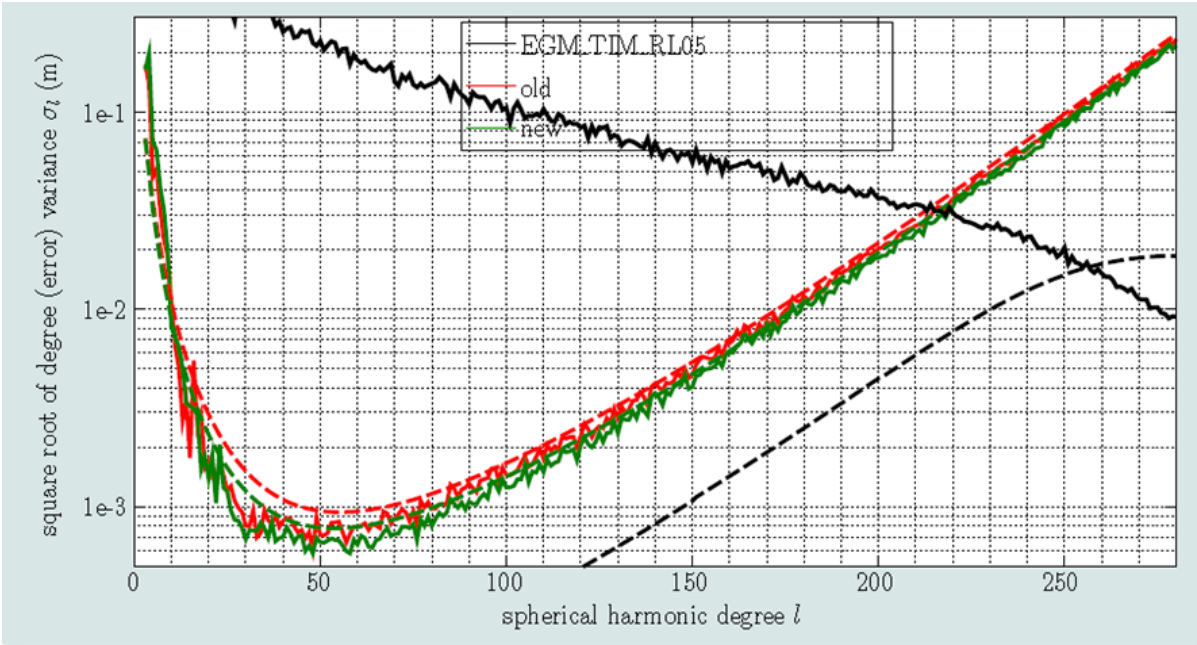
Differences of Swarm gravity field models computed from 13 months kinematic orbits to GOCO05S. Left: based on original GPS data; Right: based on screened GPS data

Impact of Reprocessing – Gravity Field

Rel. 6 TIM, DIR and SPW models will be processed with reprocessed gradients and orbits.

TIM6

- Improved time-variable modelling of the stochastic characteristics of gravity gradients by estimating de-correllation filters will be applied (see talk J.M. Brockmann).
- The cumulative formal errors between degree 30 and 200 reduces by roughly 12% while the cumulative errors (based on the signal differences) reduces by roughly 10%.



SGG only gravity field solution for a data segment combining xx,yy,zz and xz gravity gradients applying the original and the improved filter process in terms of degree variances compared to the Rel. 5 TIM model. red: old solution; green: new solution; black: Rel. 5 TIM signal and errors; solid : differences to TIM5; dashed: formal errors.

Courtesy: J.M. Brockmann

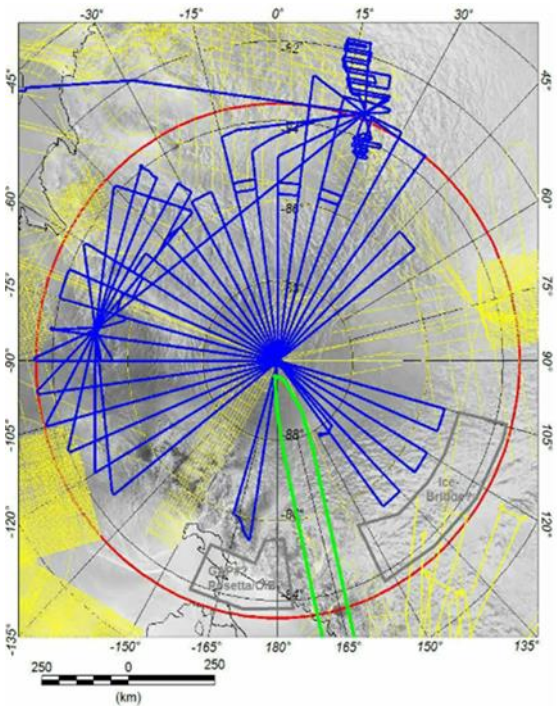
DIR6, SPW6

- Improved outlier detection and lessons learned from Rel. 5 processing.

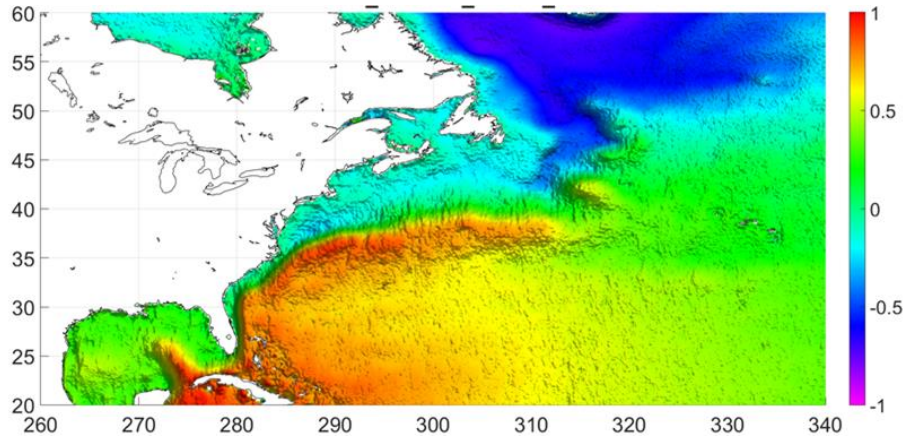
Impact of Reprocessing – New Products

Combined Gravity Fields

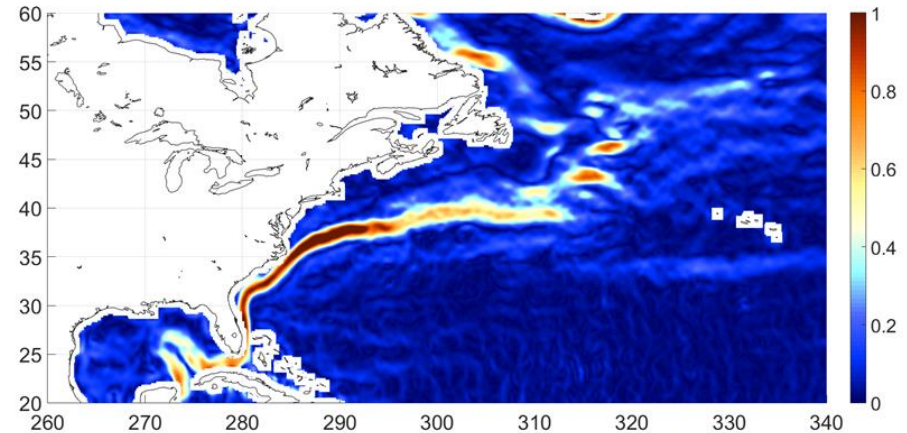
- PolarGap data over Antarctica – Fill the polar gap of GOCE and ideally to make any regularization obsolete.
- Optimized high resolution ocean geoid – Combination of reprocessed GOCE model and up-to-date altimetric gravity data – Computation of geodetic MDT (OGMOC project).



Airborne gravity observations taken by the PolarGAP project (10-2015 to 04-2017)



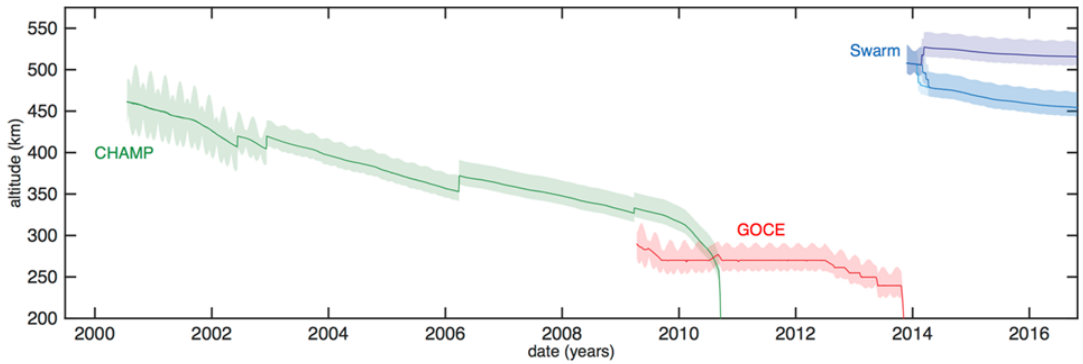
MDT from DTU15MSS and extended XGM2016 [m] and derived Geostrophic current velocities [m/s].



Impact of Reprocessing – New Products

Ionosphere & Thermosphere

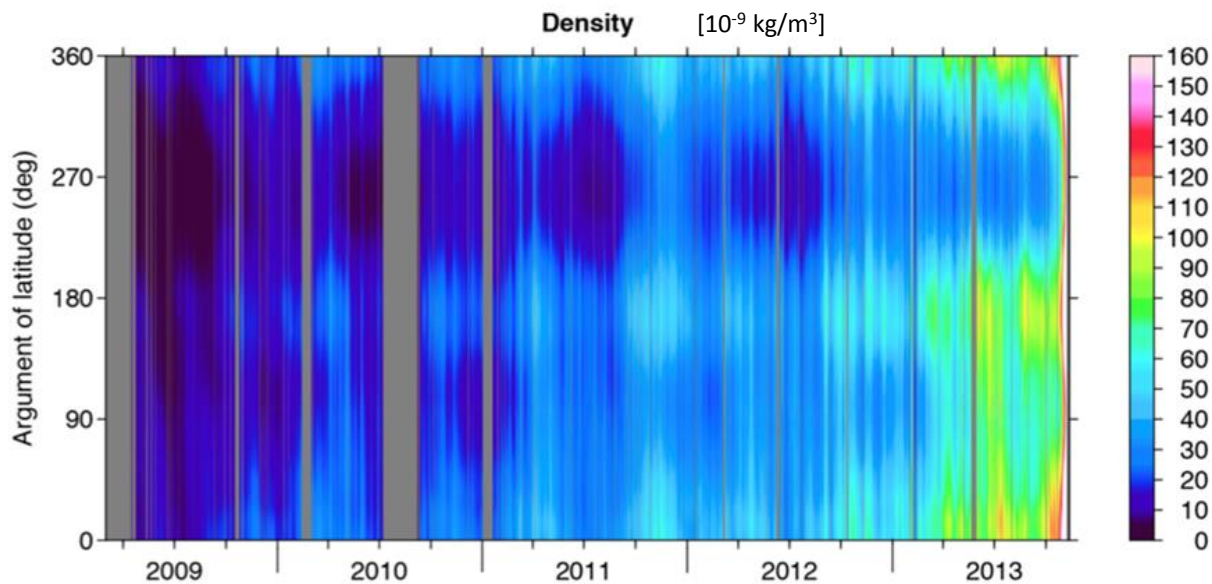
- Slant Total Electron Content (TEC) & Rate of TEC index (ROTI) from the GOCE GPS (low near polar orbit & post-sunset local time for high latitude and equatorial irregularities).



Evolution of the orbits of CHAMP, GOCE and Swarm; Courtesy van den Ijssel

- For 2009 to 2013 GOCE gradiometry based thermosphere density and wind data sets were produced. Improvements with reprocessed data and from lessons learned are expected.

Density estimates from GOCE for the complete mission duration; Courtesy Doornbos



Summary & Schedule

Summary

- Rel. 5 GOCE gravity field models meet mission requirements.
- Higher noise in gradients and GPS observations identified, which is correlated to the magnetic field (magnetic poles and geomagnetic equator).
- Reprocessing of L1B gravity gradients by improved calibration scheme, star tracker combination and angular rate reconstruction. Improved screening of GPS data.
- Expected improvements: Gravity gradients between 10% and 20%; Elimination of correlations to geomagnetic equator in kinematic positions.
- Improvements in GOCE gravity field models expected at the same level.
- New HPF products resulting from GOCE+ and SWARM+ studies now on a systematic basis.

Schedule

- Complete set of new gradient products in February 2019.
- Reprocessed precise science orbits in August 2018.
- Rel. 6 GOCE and combined gravity field models in May 2019.
- Ionosphere products in August 2018.
- Thermosphere products in May 2019