Evaluation of new precise orbits of Envisat, ERS-1 and ERS-2 using altimetry

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Motivation

Precise orbits of altimetry satellites are a prerequisite for a range of altimetry applications, such as sea level anomalies computations, global and regional sea level change studies and others. New precise orbits of altimetry satellites Envisat, ERS-1 and ERS-2 were recently computed within the ESA funded Sea Level Project of the ESA Climate Change Initiative (SLCCI). The first version of these orbits computed with the EIGEN-GL04S geopotential model is evaluated using a dedicated cross-calibration between all altimeter missions operating contemporaneously.

GFZ SLCCI Orbits

New precise orbits of altimetry satellites ERS-1, ERS-2, and Envisat were derived at GFZ within the Sea Level project of the European Space Agency (ESA) Climate Change Initiative (SLCCI).

The orbits were computed in the same (ITRF2008) terrestrial reference frame for all satellites using common, most precise models and standards as listed in Tab. 1.
The ERS-1 orbit is computed using SLR and altimeter crossover data, while the ERS-2 orbit is derived using additionally PRARE measurements. The Envisat orbit is based on DORIS and SLR observations.

The orbit files are available via ftp at ftp://slcci:slcci@ftp.esa-sealevel-cci.org/Data/WP2200

Tab. 1: List of the main models used to compute the GFZ SLCCI orbits.

Terrestrial Reference Frame	ITRF2008 SLRF2008 and DPOD2008 are used for stations missing in ITRF2008
Polar motion and UT1	IERS EOP 08 C04 (IAU2000A) series with IERS daily and sub-daily corrections
Precession and Nutation model	IERS Conventions (2010)
Gravity field (static)	EIGEN-GL04S-ANNUAL
Gravity field (time varying)	Annual and semi-annual variation up to degree and order 50 from EIGEN-GL04S-ANNUAL gravity field model
Solid Earth tides	IERS Conventions (2010)
Pole tide	IERS Conventions (2010)
Ocean tides	EOT10a, all constituents up to degree and order 50
Atmospheric tides	Biancale and Bode (2006)
Atmospheric gravity	ECMWF 6-hourly fields up to degree and order 50
Third bodies	Sun, Moon, Mercury, Venus, Mars, Jupiter, Saturn, Uranus, Neptune and Pluto (DE-421)

Multi-Mission Crossover Analysis (MMXO)

Method:

- Computation of single and dual-satellite crossover sea surface height differences Δx_{jk} in all combinations between passes j and k (max. time interval = 2 days)
- Minimizing both, Δx_{jk} and $\delta x_i = x_{i+1} - x_i$, i.e. consecutive differences of radial errors for time step i for each mission; allows to estimate the radial errors x_i at all crossovers

Output: Time series of relative radial errors for each mission (w.r.t. a reference mission, generally TOPEX or Jason-1), which are used to derive

- Empirical auto-covariance functions (EACF) of the radial errors
- Geographically correlated errors (GCE)
- Mean range bias Δr (per 10 day cycles and per mission lifetime)
- Mean differences in the center-of-origin realization Δx, Δy, Δz (10 day sampling)

Stochastic properties of Radial Errors

Fig. 1 shows the empirical auto-covariance functions (EACF) of the radial errors. They provide useful information on possible systematics within the radial errors. All EACF have relative maxima after the orbital revolution, i.e. correlations between measurements on neighboring ground tracks – an early indication of GCE. ERS-1 also shows longer periods (> some days).

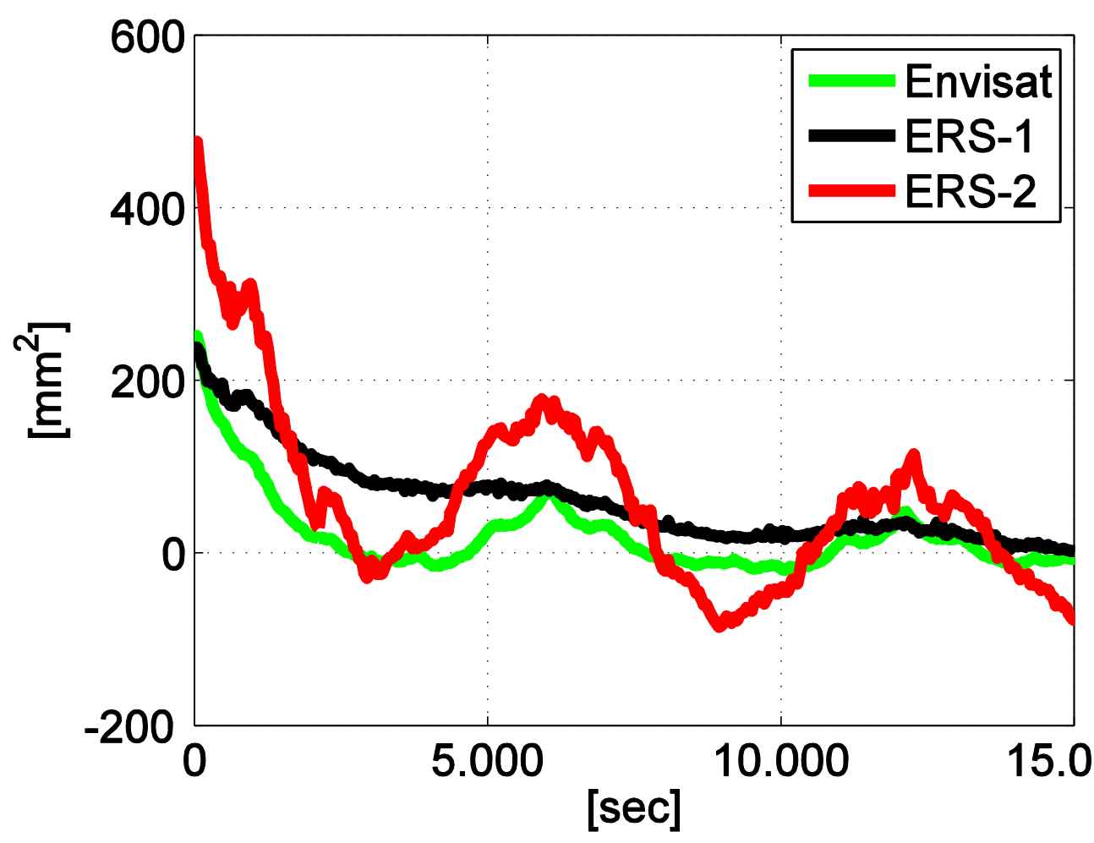

Fig. 1: Empirical Auto-Covariance functions of the radial errors for Envisat (green), ERS-1 (black), and ERS-2 (red)

The orbital period is more distinct in SLCCI orbits than in REAPER (see Fig. 2). The differences in orbital height between SLCCI and REAPER/GDR-C orbits clearly show a 6036 sec period with amplitudes of about 2 cm (for all three missions, without Fig.).

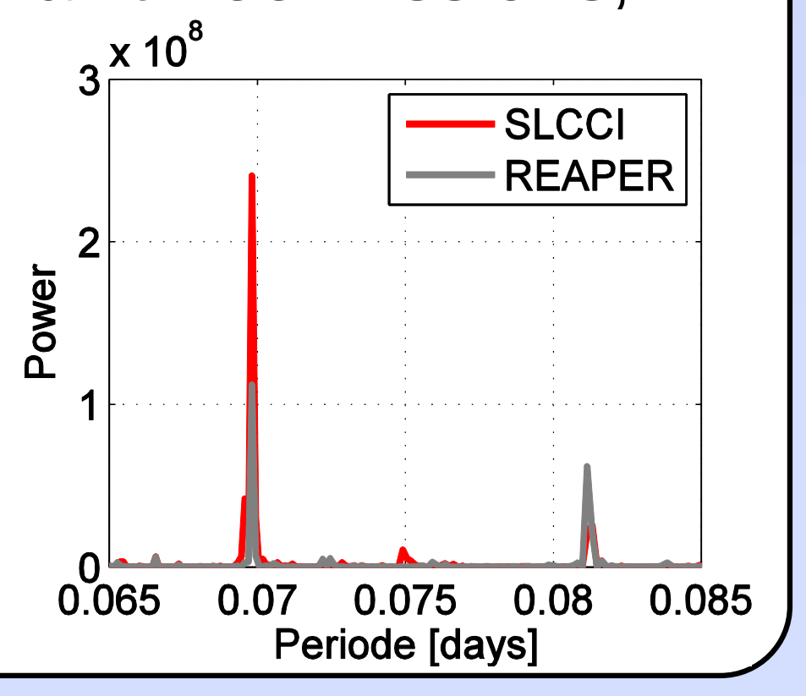

Fig. 2: Power spectrum of ERS-1 radial errors (Cyc. 91) for SLCCI- (red) and REAPER-orbits (grey).

Range Biases and Center-of-Origin Realization

For each mission relative range bias w.r.t. TOPEX (M-GDR with GSFC std0809 orbit) are computed as well as center-of-origin shifts. This post-processing is performed per 10-day cycle by means of a least squares adjustment based on the following model:

$$x_i + v_{x_i} = \Delta r + \Delta x \cos\varphi_i \cos\lambda_i + \Delta y \cos\varphi_i \sin\lambda_i + \Delta z \sin\varphi_i$$

Whereas the range biases Δr are mainly due to instrumental effects, the origin shifts (Δx, Δy, Δz) are mainly caused by the orbit realization.

	Δr	Δx	Δy	Δz
ERS-1	442.0 ± 7.6	0.9 ± 3.2	0.7 ± 2.7	-2.3 ± 5.1
ERS-2	71.1 ± 6.7	0.0 ± 6.4	1.4 ± 5.0	-3.4 ± 7.4
Envisat	449.8 ± 6.8	-0.2 ± 3.5	**-4.2 ± 5.2**	0.1 ± 5.3

Tab. 2: Global mean range bias (Δr) and center-of-origin shifts relative to TOPEX (GSFC std0809 orbit) based on GFZ SLCCI EIGEN-GL04S orbits; in [mm]

Table 2 shows the mean values for each mission. None of the shifts is mathematically significant.

However, the Δy component of Envisat shows a clear systematic trend with time (see Fig. 4), which might be caused by long-term variations of the gravity field which were not taken into account in the EIGEN-GL04S version of GFZ SLCCI orbits (in contrast to GDR-D ones).

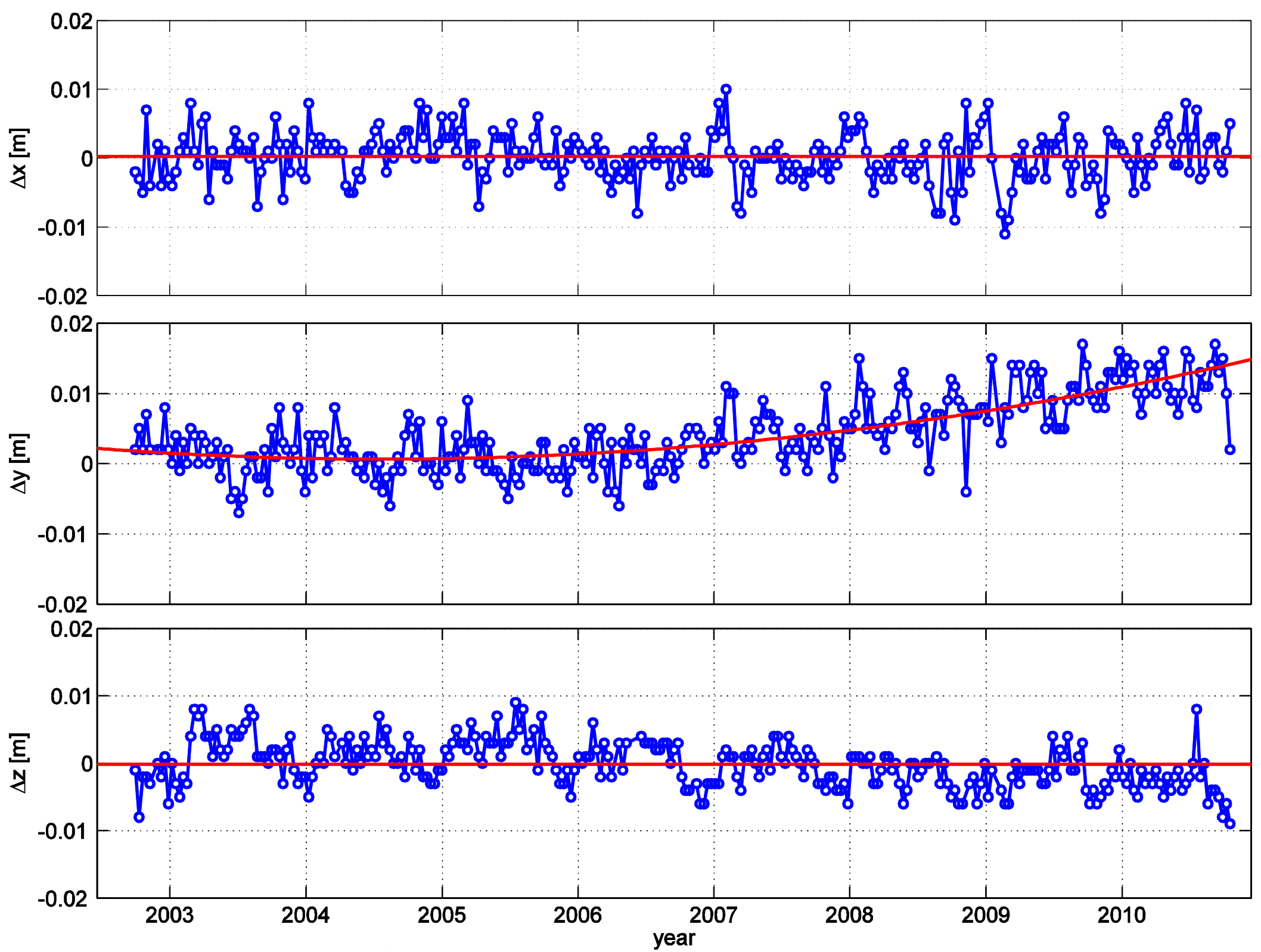

Fig.4: Center-of-origin realization of Envisat GFZ SLCCI EIGEN-GL04S orbit; differences to Jason-1 (GDR-C orbit)

References:
Dettmering D., Bosch W.: Multi-Mission Crossover Analysis: Merging 20 years of data into one consistent long-term data record. Poster OSTST and 20yra, 2012
Rudenko, S. et al: Computation and evaluation of new consistent orbits of Envisat, ERS-1 and ERS-2 in the ITRF2008 reference frame. EGU2012-5894-1, 2012
Rudenko, S. et al: New improved orbit solutions for the ERS-1 and ERS-2 satellites. Advances in Space Research, 49(8), 2012

Scatter of Radial Errors

The standard deviation *sd* of the radial errors serves as an indicator for the data quality. The scatter is highest in times with high solar activity (see Fig. 3).
The mean *sd* for the whole mission life-time reaches 19.8 mm for ERS-1, 25.8 mm for ERS-2, and 18.1 mm for Envisat.
For ERS, the scatter is slightly lower when using REAPER orbits (18.7/23.6 mm). For Envisat GDR-C orbit it reaches 18.5 mm.

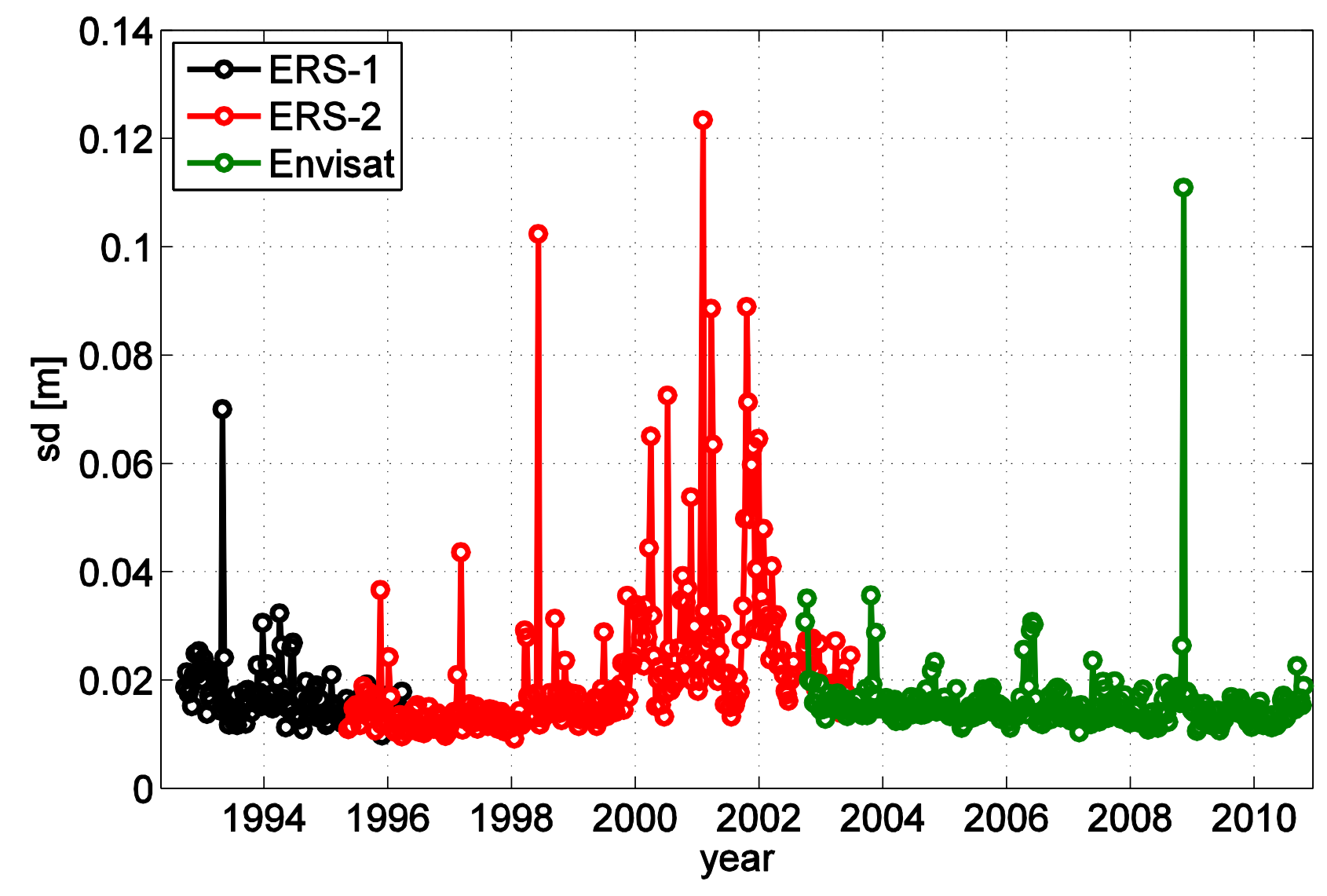

Fig. 3: Standard deviation of radial errors for SLCCI orbits

Geographically Correlated Errors (GCE)

Error components having the same sign for ascending and descending passes are called geographically correlated errors (GCE). The MMXO is able to reveal GCE from the estimated radial errors for each of the involved missions. GCE mainly represent problems in precise orbit determination (POD), e.g. reference frame differences, but also include other geographically correlated effects.

Fig. 5 shows the GCE for ERS-1, ERS-2, and Envisat based on the GFZ SLCCI orbits:

- All SLCCI GCE show large scale pattern with moderate amplitudes.
- The GCE for all three missions do not exceed 1 cm (except for a few outliers).
- The RMS is 3.0 mm for ERS-1, 3.8 mm for ERS-2, and 3.2 mm for Envisat.
- These values are slightly higher than the corresponding GCE for the REAPER combined orbits, reaching 2.8 mm (ERS-1) and 3.7 mm (ERS-2), resp. The pattern is similar to the REAPER GCE. The RMS for Envisat GDR-C orbit is 3.1 mm.
- With respect to early DEOS DGM-E04 orbits (RMS of 7.7 mm for ERS-1 and 9.5 mm for ERS-2), SLCCI solutions show significant improvements.

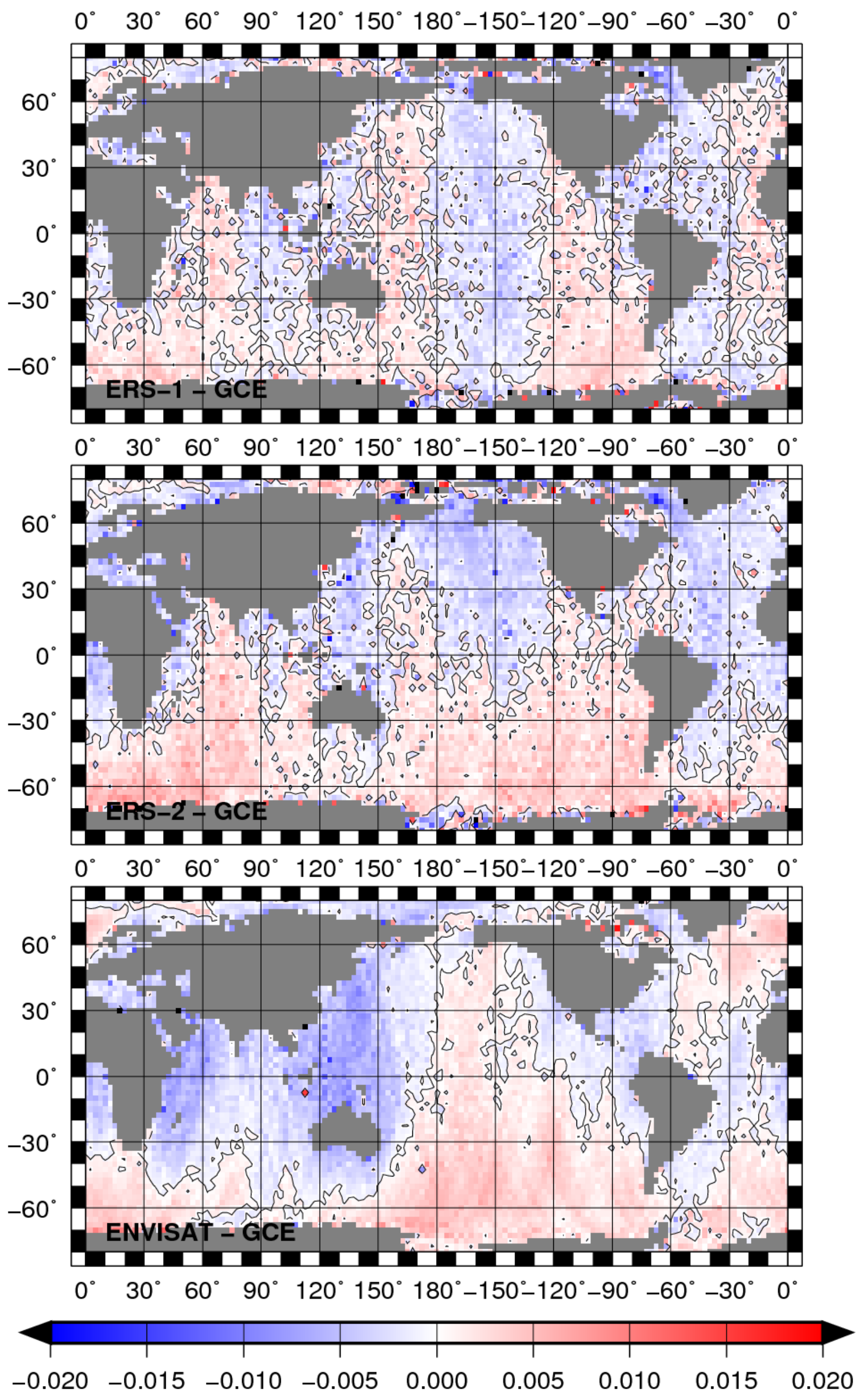

Fig. 5: Geographically correlated error for ERS-1 (top), ERS-2 (middle), and Envisat (bottom) based on GFZ SLCCI EIGEN-GL04S orbits.

Conclusions

GFZ SLCCI orbits for ERS and Envisat show GCE smaller than 1 cm and no significant differences in the center-of-origin realization. However, a systematic trend in the Δy-component between Envisat and Jason is found. That might be caused by the non-consideration of long-term drifts of the gravity field. For ERS, the comparison to REAPER combined orbits reveals small systematics with the orbital period as well as slightly increased scatter of radial errors. In order to exploit the advantages of a combined orbit solution (such as REAPER), a reprocessing of ERS orbits in ITRF2008 (or newer) with the use of latest standards and the participation of a few orbit groups is advisable.

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