Improvements in precise orbit determination of altimetry satellites

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Altimeter Satellite Orbit Modelling and Determination

- Detailed tests on using reprocessed GFZ Atmosphere and Ocean De-Aliasing (AOD1B) REL05 product for precise orbit determination of ERS-1 (1991-1996), ERS-2 (1995-2006), TOPEX/Poseidon (1992-2005), Envisat (2002-2012) and Jason-1 (2002-2012), as compared to using AOD1B REL04 product and no AOD data was performed. A paper submitted to a peer-reviewed journal.
- Jason-1 orbit was derived using SLR and DORIS data corrected for the South Atlantic Anomaly (SAA) also for years 2012-2013.
- A station file used for altimetry satellite POD was updated with the information on 27 DORIS and 12 SLR stations: new occupations, antenna change, corrections of some errors. This brought more DORIS and SLR data used for POD.
- Jason-2, its macro-model and other satellite-related information was included in the GFZ's EPOS-OC software, eleven orbit versions (CCI00-CCI10) were computed from July 5, 2008 till April 6, 2015 using various models.
- Envisat, TOPEX, Jason-1 and Jason-2 macro-models were updated and improved.
- Based on the results of numerous tests (next slide) new GFZ VER11 orbits of Jason-1 (2002-2013), Jason-2 (2008-2015), TOPEX/Poseidon (1992-2005), Envisat (2002-2012), ERS-1 (1991-1996) and ERS-2 (1995-2006) were derived using best models from the tests performed.

Tests on new models for precise orbit determination

- Improved macro-models reduced SLR RMS fits by 2.6% for TOPEX/Poseidon, 14% for Jason-1 and 7% for Jason-2. Radial arc overlaps have also improved.
- Estimation of the global scaling factor of the solar radiation model for Jason-1 and Jason-2 reduced SLR RMS fits additionally by about 17-18%. It was already estimated in the previous versions of TOPEX/Poseidon orbits.
- Using true attitude in the quaternion form instead of models brought an improvement of SLR RMS fits by 10% for Jason-1 and 1% for Jason-2. Especially notable improvement is observed for Jason-1 for the last year of the mission.
- Using EIGEN-GRGS.RL03-v2.MEAN-FIELD geopotential model versus EIGEN-6S2.extended.v2 geopotential model: increase of SLR RMS by 0.2-0.3% for ERS-2, Envisat, TOPEX/Poseidon, Jason-1, Jason-2, decrease by 0.3% for ERS-1
- Use of the updated version of the atmospheric loading ERA-INTERIM files used for station coordinates for all six satellites.
- Use of the updated version of the ocean loading files for station coordinates for all six satellites.
- Using EOT11a ocean tide model instead of EOT10a for ERS-1, ERS-2, Envisat, TOPEX/Poseidon and Jason-1 POD over the whole duration of each mission => minor impact on the residuals: ERS-1 (+0.04%), ERS-2 (+0.19%), TOPEX/Poseidon (0%), Envisat (-0.14%), Jason-1 (-0.04%).

The main models used for precise orbit determination

Parameter	UHR-GravDat and SLCCI Phase 2 and projects (VER11 orbits, 2015)	SLCCI Phase 1 project (VER06 orbits, 2013)
Terrestrial Reference Frame	ITRF2008	ITRF2008
Polar motion and UT1	IERS EOP 08 C04 (IAU2000A)	IERS EOP 08 C04 (IAU2000A)
Precession and nutation model	IERS Conventions 2010	IERS Conventions 2010
Gravity field model	EIGEN-GRGS.RL03-v2.MEAN-FIELD	EIGEN-6S2
Tropospheric correction for DORIS observations	Vienna Mapping Function 1	Hopfield model
Solid Earth and pole tide	IERS Conventions 2010	IERS Conventions 2010
Ocean tides	EOT11A	EOT10A
Atmospheric tides	Biancale and Bode (2006)	Biancale and Bode (2006)
Atmospheric gravity	GFZ AOD1B RL05 based on ECMWF 6-hourly fields up to degree and order 100	GFZ AOD1B RL04 based on ECMWF 6-hourly fields up to degree and order 50
Third bodies	Sun, Moon, all 8 major planets (DE-421)	Sun, Moon, all 8 major planets (DE-421)

The main differences of VER11 orbits w.r.t. VER06 orbits for ERS-1, ERS-2, Envisat, TOPEX and Jason-1 and VER01 orbit for Jason-2

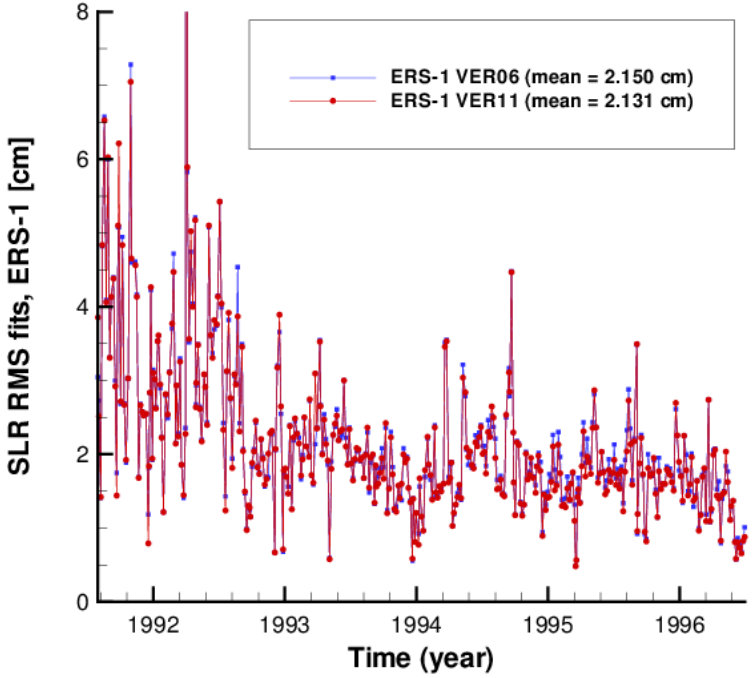
The differences / Satellites	ERS-1	ERS-2	Envisat	TOPEX	Jason-1	Jason-2
AOD1B RL04 → RL05 reprocessed	Yes	Yes	Yes	Yes	Yes	Yes
AOD1B truncation level: 50 → 100	Yes	Yes	Yes	Yes	Yes	Yes
Improvement of parametrization at some orbital arcs	Yes	Yes	Yes	Yes	Yes	Yes
Use of VMF1 instead of Hopfield model for DORIS troposp. correction	–	–	Yes	Yes	Yes	Yes
EIGEN-GRGS.RL03_v2. MEAN_FIELD geopotential model (nstead of EIGEN-6S2 model)	Yes	Yes	Yes	Yes	Yes	Yes
Use additionally DORIS data at some time spans (Envisat, Apr.-Jun. 2002)	–	–	Yes	–	–	–
Correction of DORIS data for the South Atlantic Anomaly (2002-2013)	–	–	–	–	Yes	–
Ocean Tide Model: EOT11a (instead of EOT10a)	Yes	Yes	Yes	Yes	Yes	Yes

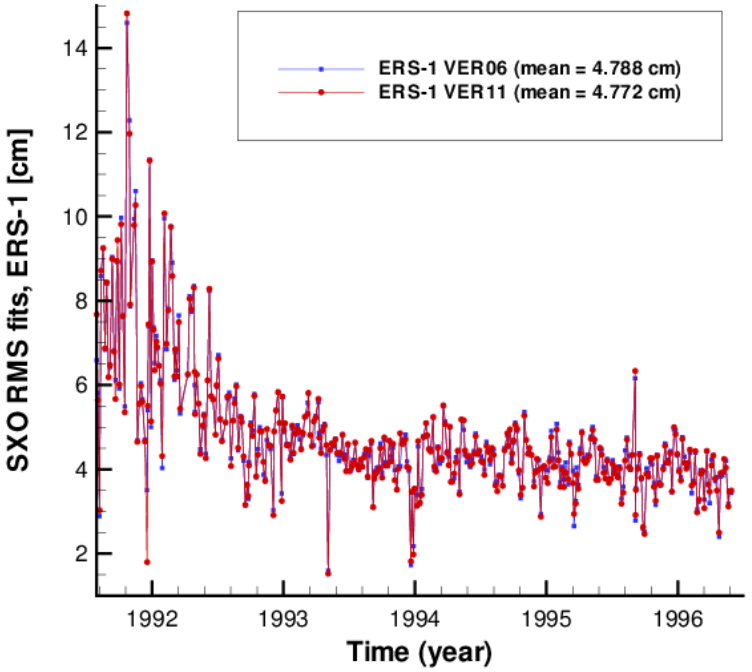
The main differences of VER11 orbits w.r.t. VER06 orbits for ERS-1, ERS-2, Envisat, TOPEX, Jason-1 and VER01 orbit for Jason-2 (cont.)

The differences / Satellites	ERS-1	ERS-2	Envisat	TOPEX	Jason-1	Jason-2
An updated station file (more SLR and DORIS stations)	Yes	Yes	Yes	Yes	Yes	Yes
ERA-INTERIM atmospheric loading for station coordinates (instead of ECMWF fields)	Yes	Yes	Yes	Yes	Yes	Yes
An updated file for ocean loading for station coordinates	Yes	Yes	Yes	Yes	Yes	Yes
EOPC04_08 Earth Orientation Parameters file (as of 4 May 2015)	Yes	Yes	Yes	Yes	Yes	Yes
An improved satellite macro-model	–	–	Yes	Yes	Yes	Yes
Estimation of the global scaling factor of the solar radiation pressure model	–	–	–	–	Yes	Yes
Using true satellite attitude in the quaternion form instead of a model	–	–	–	–	Yes	Yes

The results of precise orbit determination for six altimetry satellites

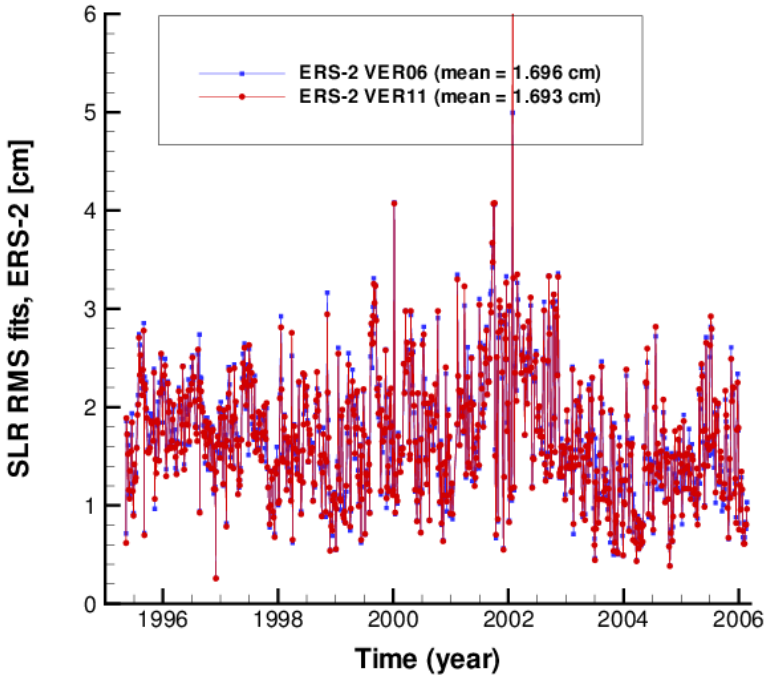
Improvement of RMS fits of observations for ERS-1 (August 1991 – July 1996): VER11 orbit versus VER06 orbit

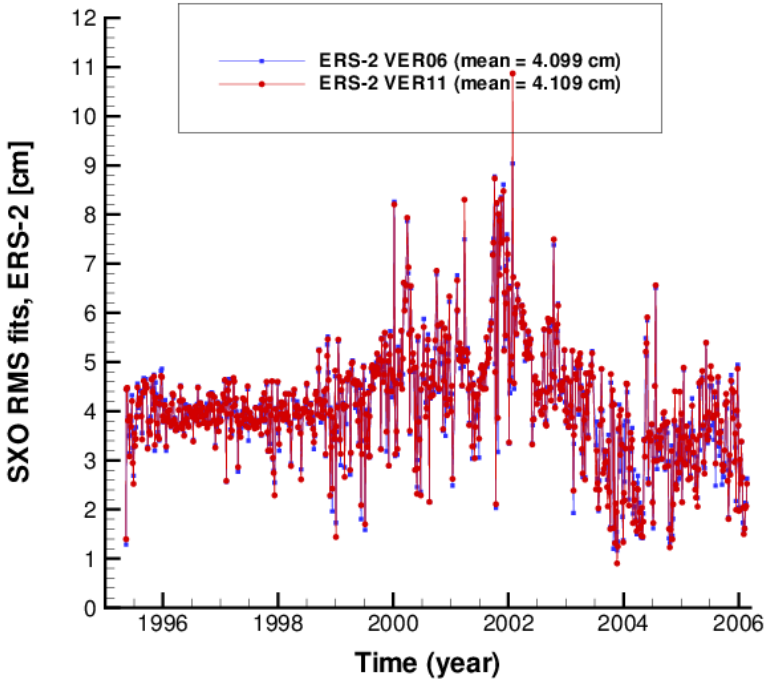




- The mean value of the SLR RMS fits reduced from 2.150 to 2.131 cm, i.e. by 0.019 cm (about 0.9%) for VER11 orbit, as compared to VER06 orbit, a few outliers disapeared;
- The mean value of the SXO RMS fits reduced from 4.788 to 4.772 cm, i.e. by 0.016 cm (about 0.3%) for VER11 orbit, as compared to VER06 orbit.

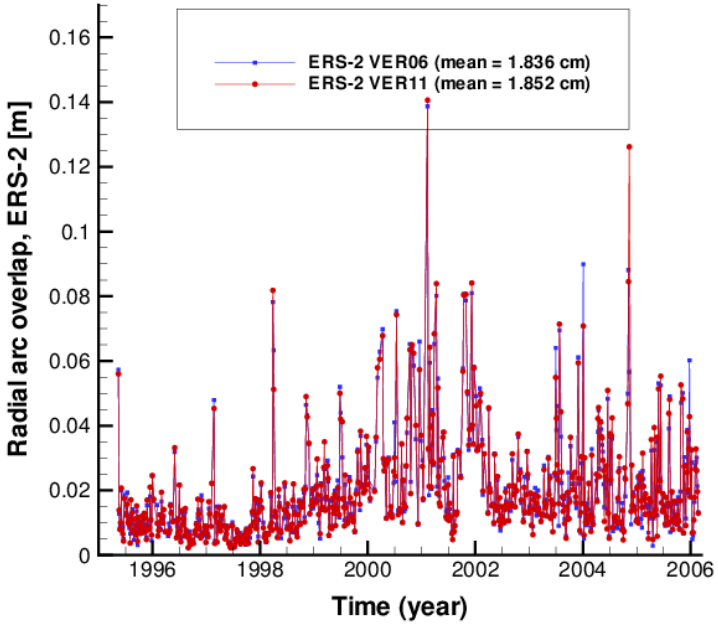
Improvement of RMS fits of observations for ERS-2 (May 1995 – February 2006): VER11 orbit versus VER06 orbit

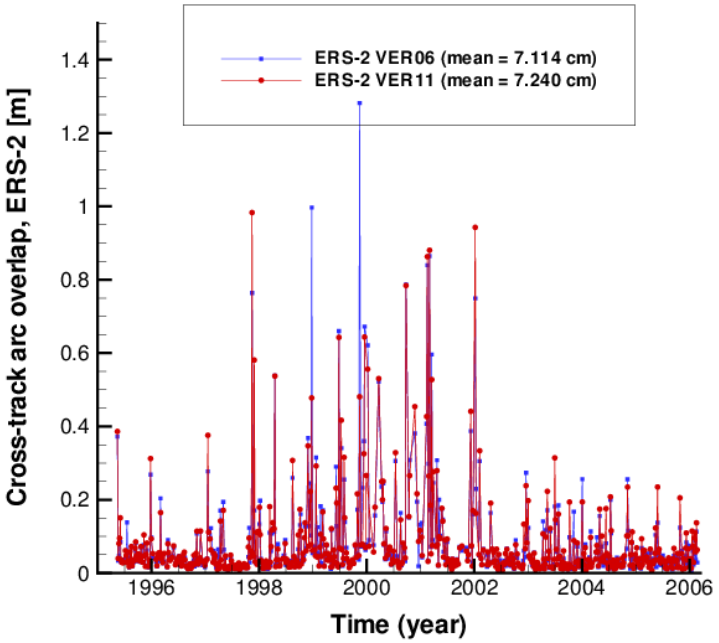


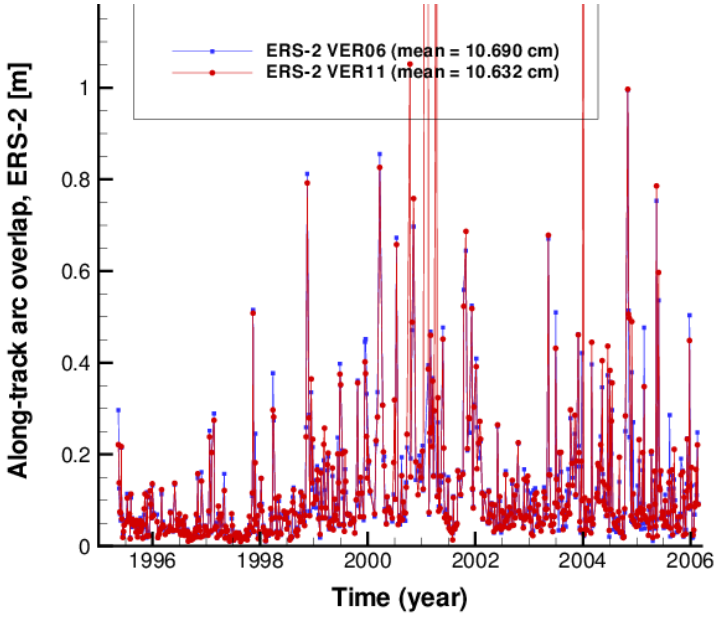


- The mean value of the SLR RMS fits reduced from 1.696 to 1.693 cm, i.e. by 0.003 cm (about 0.2%) for VER11 orbit, as compared to VER06 orbit;
- The mean value of the SXO RMS fits increased from 4.099 to 4.109 cm, i.e. by 0.010 cm (about 0.2%) for VER11 orbit, as compared to VER06 orbit.

Two-day arc overlaps for ERS-2: VER11 orbit versus VER06 orbit



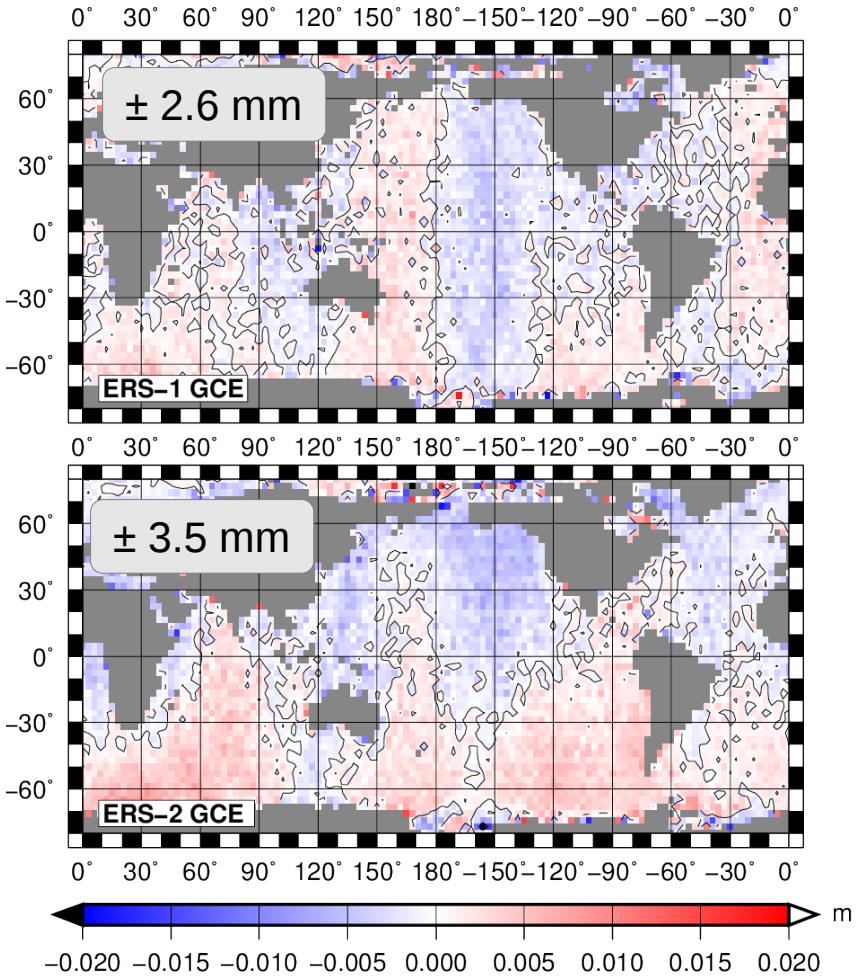




Change of the mean values
of the arc overlap of VER11 orbit,
as compared to VER06 orbit:
Radial – from 1.836 to 1.852 cm,
i.e. by +0.016 cm (about +0.9%),
Cross-track – from 7.114 to 7.240 cm,
i.e. by +0.126 cm (about 1.8%),
Along-track – from 10.690 to 10.632
cm, i.e. by -0.058 cm (about -0.5%)

Geographically correlated errors for ERS-1 and ERS-2 orbits

GFZ VER11



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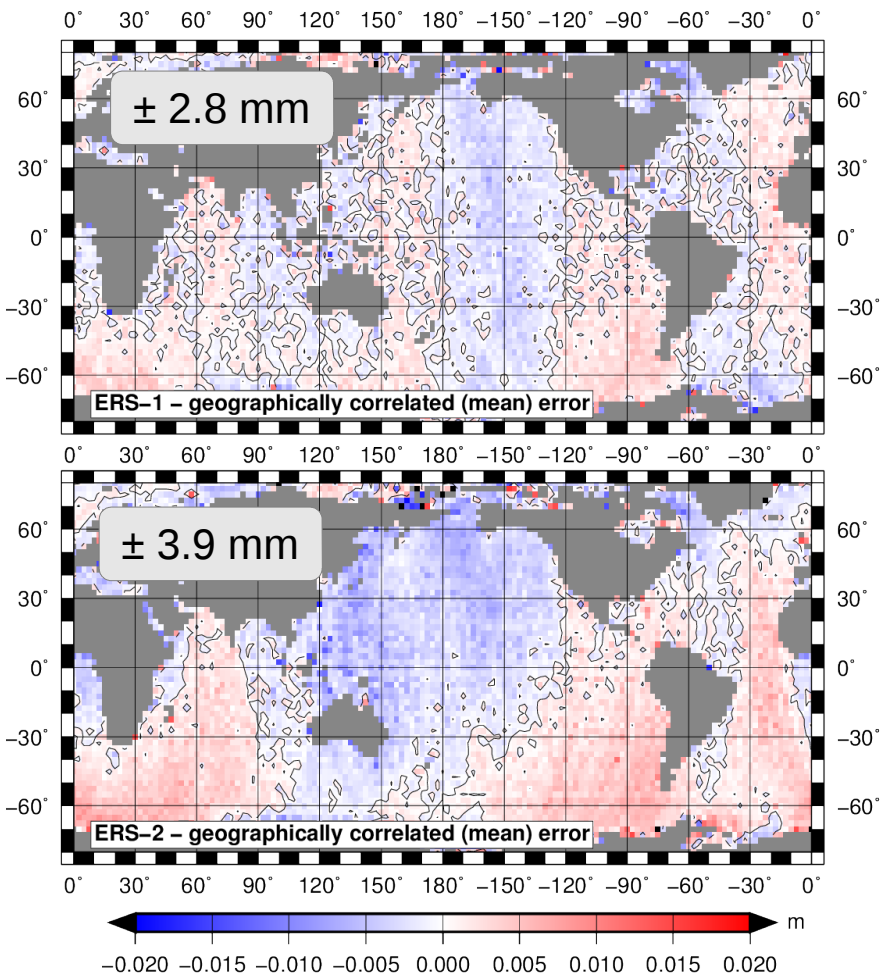
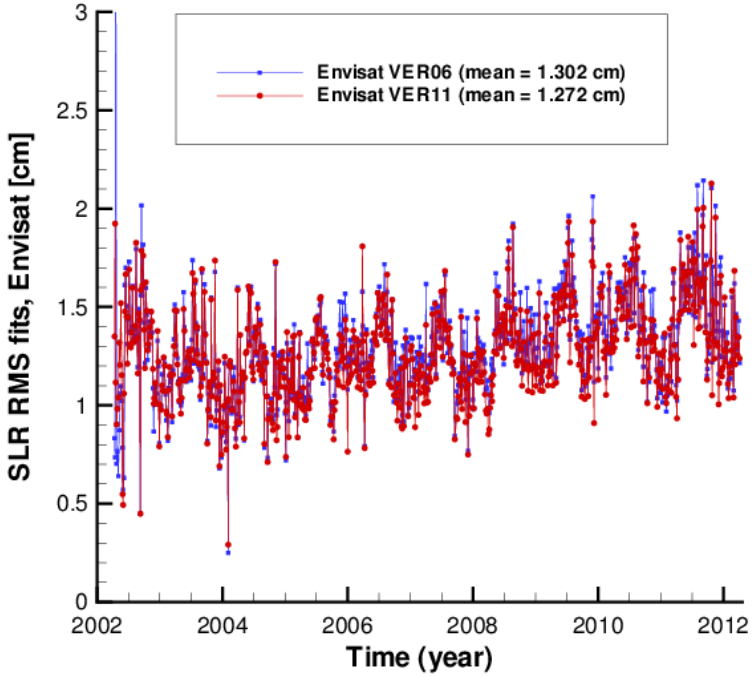
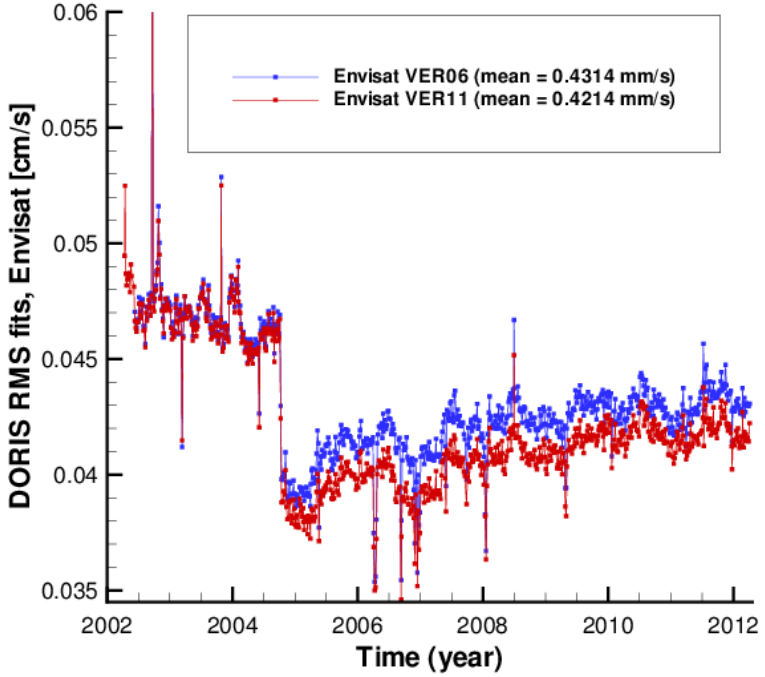


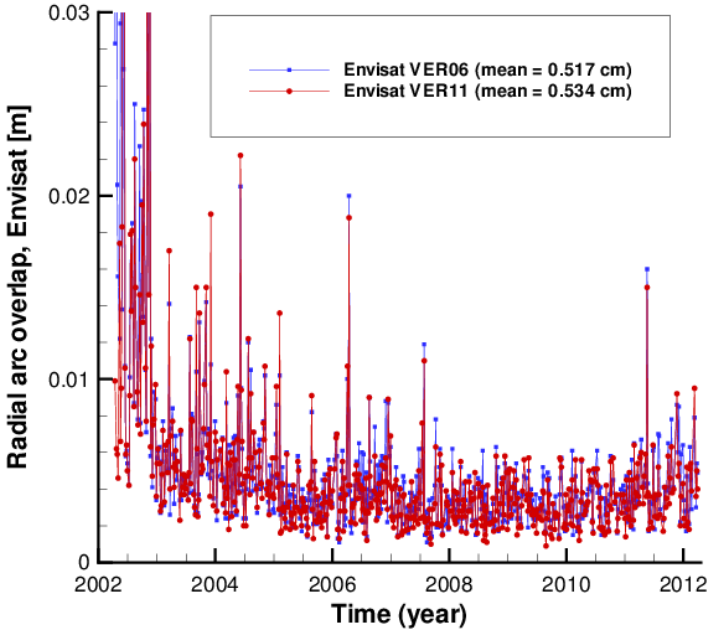
Improvement of RMS fits of observations for Envisat (April 2002 – April 2012): VER11 orbit versus VER06 orbit

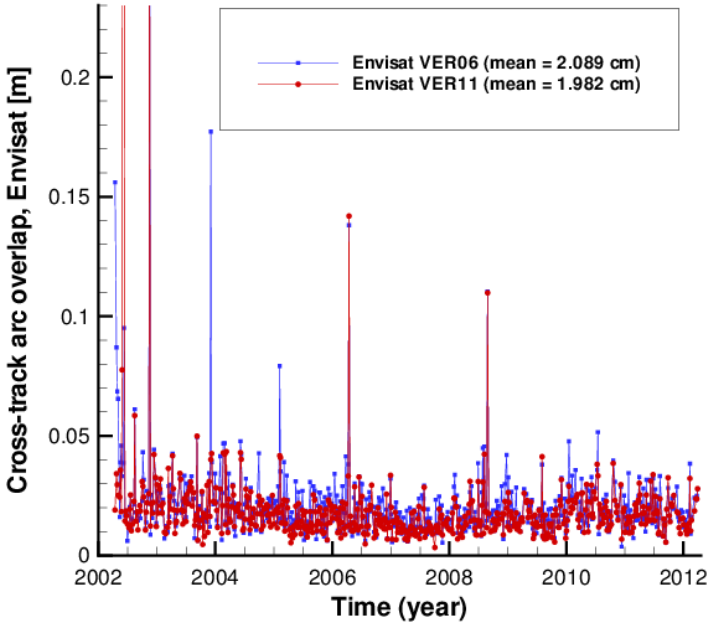


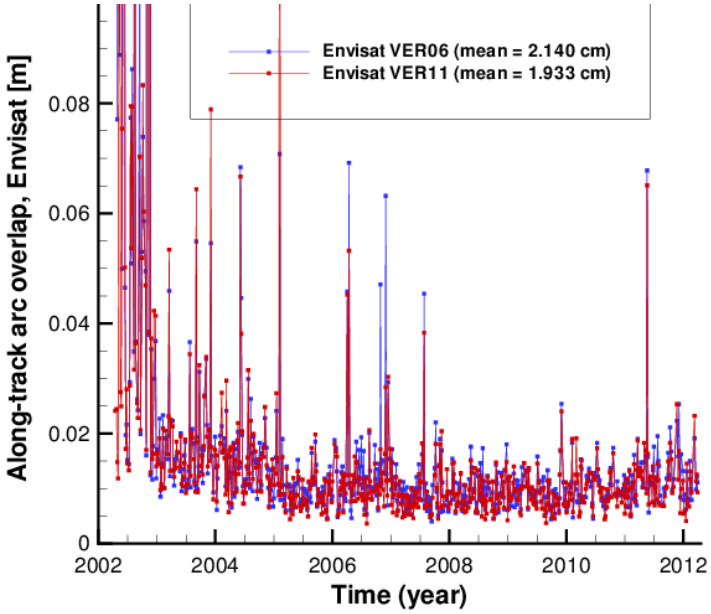


- The mean value of the SLR RMS fits reduced from 1.302 to 1.272 cm, i.e. by 0.03 cm (about 2.3%) for VER11 orbit, as compared to VER06 orbit;
- The mean value of the DORIS RMS fits reduced from 0.4314 mm/s to 0.4214 mm/s, i.e. by 0.0100 mm/s (about 2.3%) for VER11 orbit, as compared to VER06 orbit.

Two-day arc overlaps for Envisat: VER11 orbit versus VER06 orbit



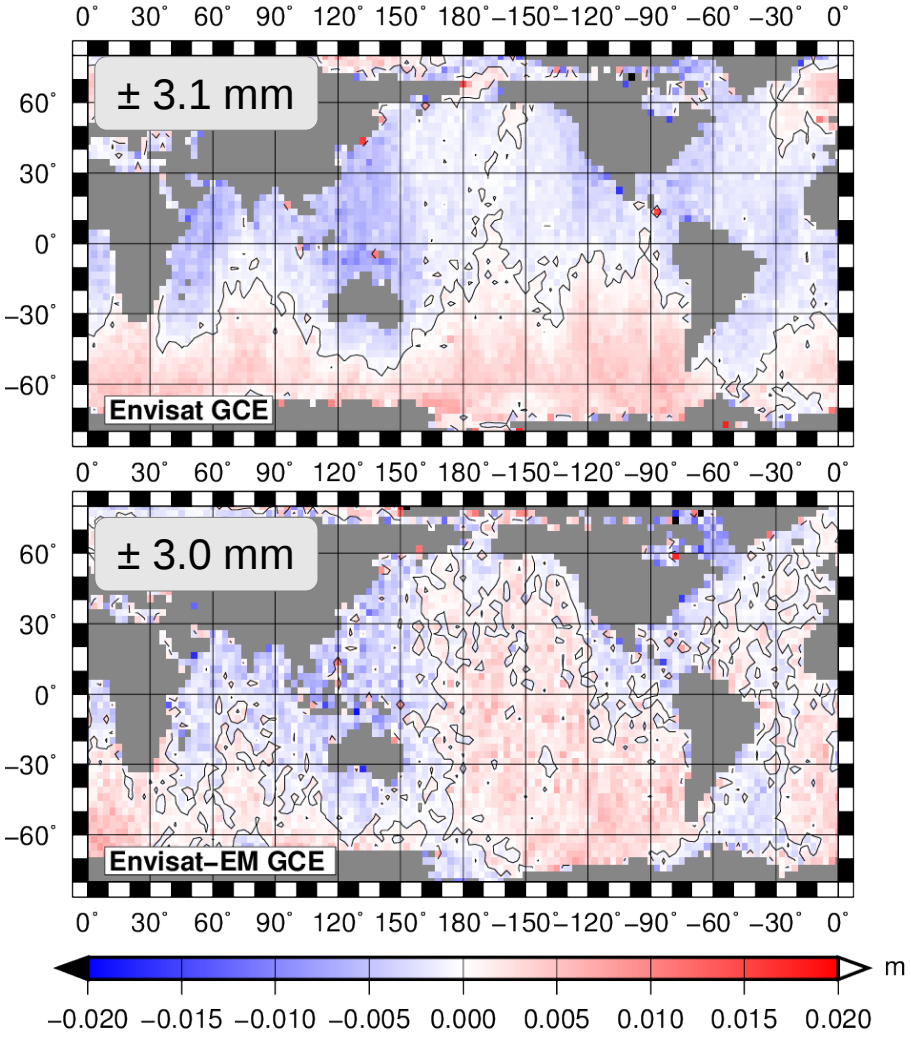




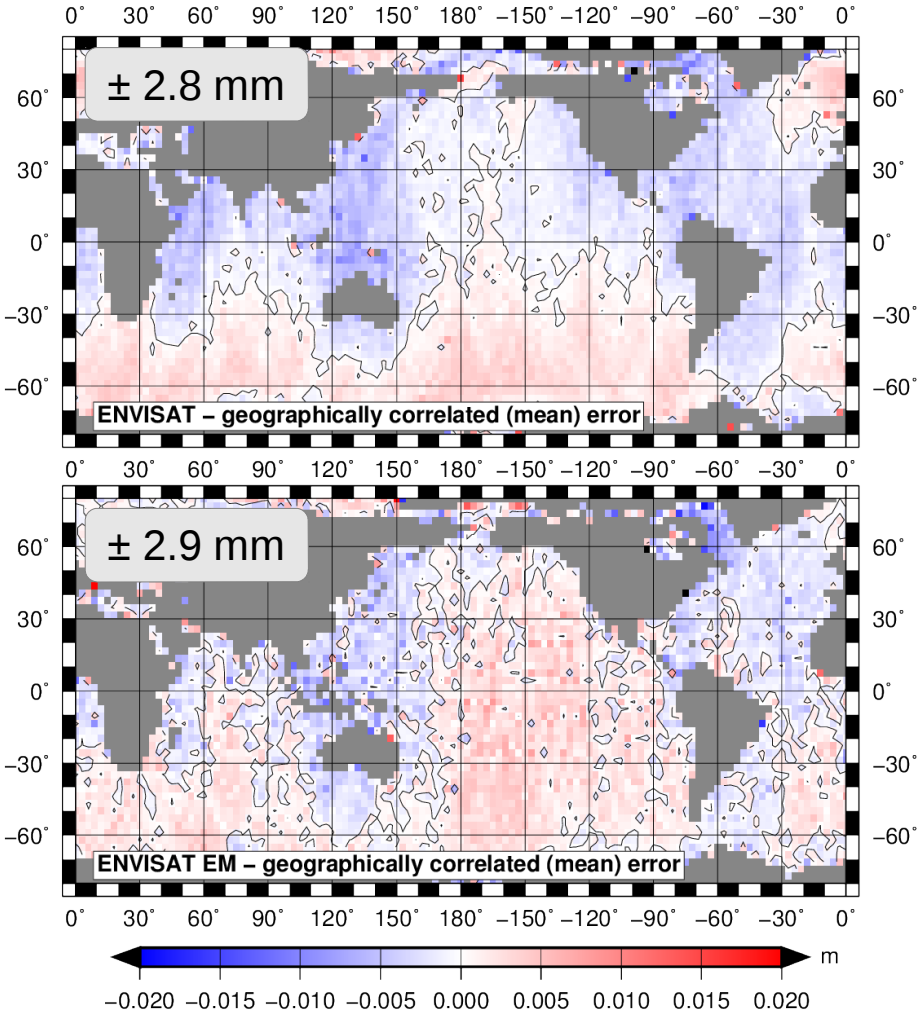
Reduction of the mean values
of the arc overlap of VER11 orbit,
as compared to VER06 orbit:
Radial – from 0.517 to 0.534 cm,
i.e. by -0.017 cm (about -3.2%),
Cross-track – from 2.089 to 1.982 cm,
i.e. by 0.107 cm (about 5.1%),
Along-track – from 2.140 to 1.933 cm,
i.e. by 0.207 cm (about 9.7%)

Geographically correlated errors for Envisat orbits

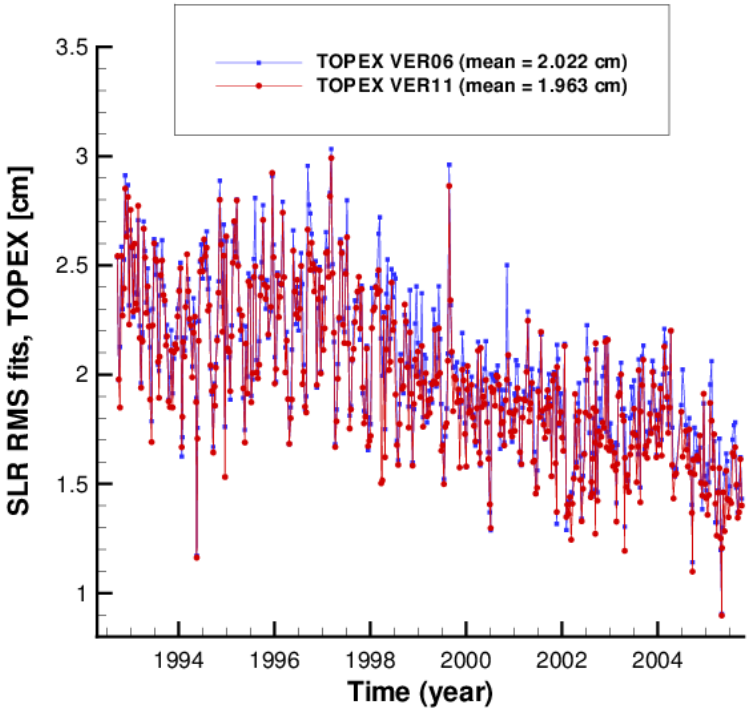
GFZ VER11

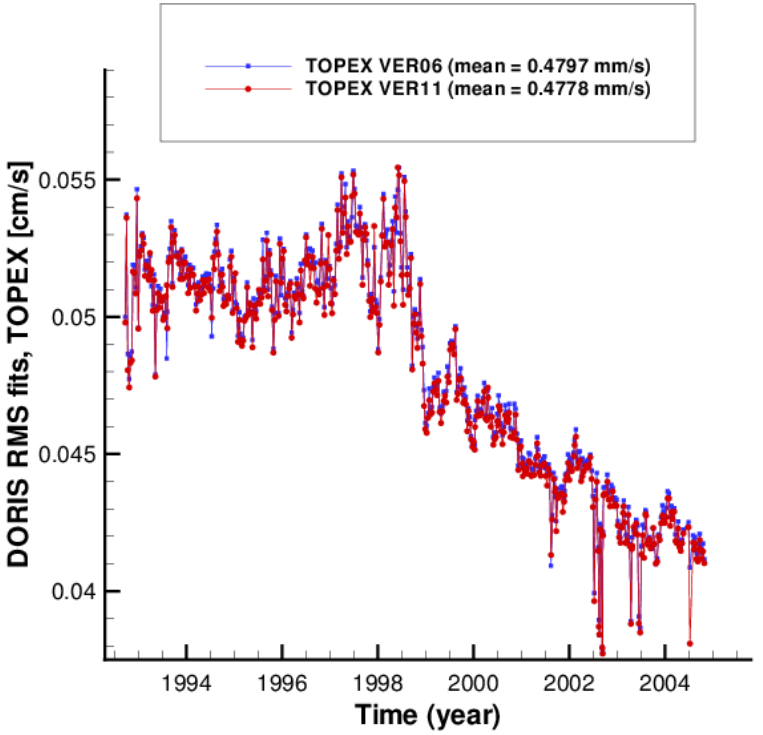


CNES GDR-D



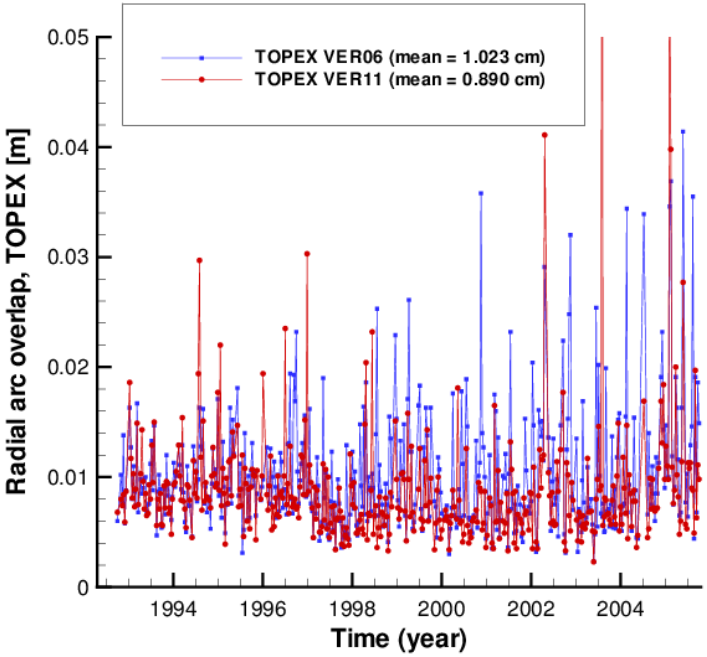
Improvement of RMS fits of observations for TOPEX/Poseidon (September 1992 – October 2005): VER11 orbit versus VER06 orbit

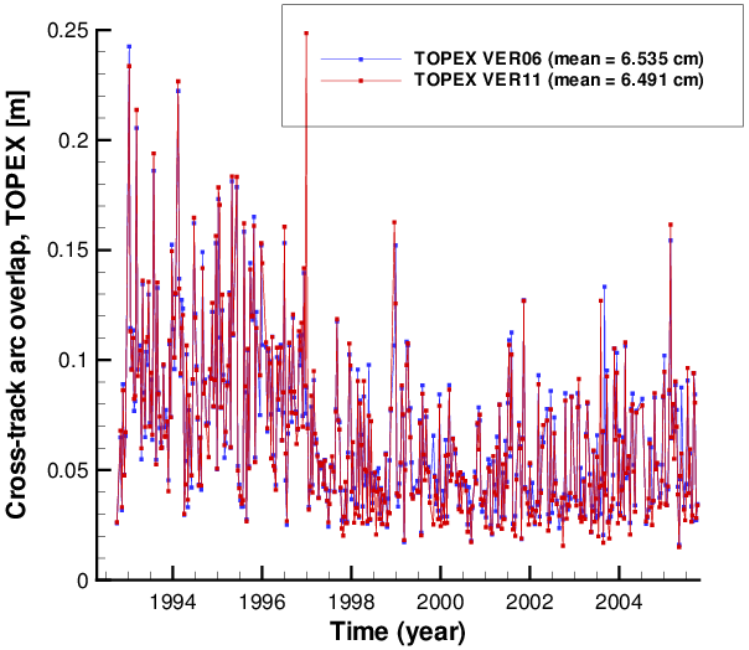


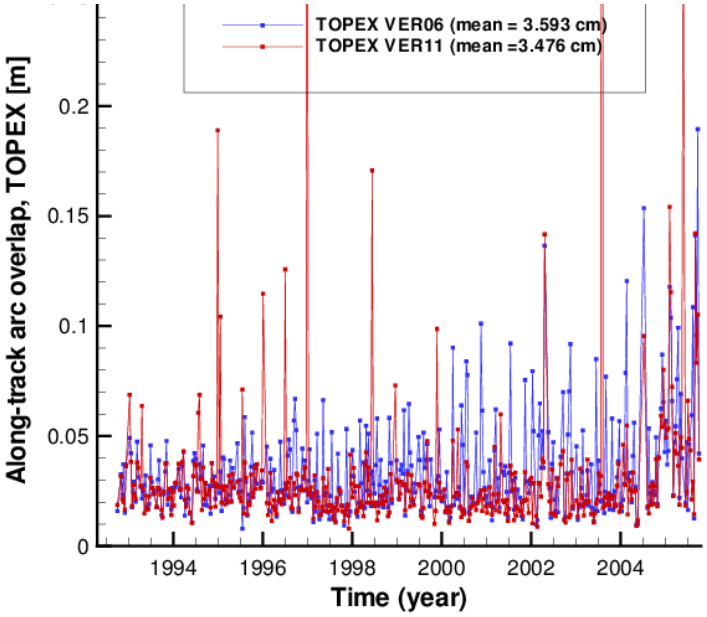


- The mean value of the SLR RMS fits reduced from 2.022 to 2.009 cm, i.e. by 0.059 cm (about 2.9%) for VER11 orbit, as compared to VER06 orbit;
- The mean value of the DORIS RMS fits reduced from 0.4797 mm/s to 0.4780 mm/s, i.e. by 0.0019 mm/s (about 0.4%) for VER11 orbit, as compared to VER06 orbit.

Two-day arc overlaps for TOPEX: VER11 orbit versus VER06 orbit



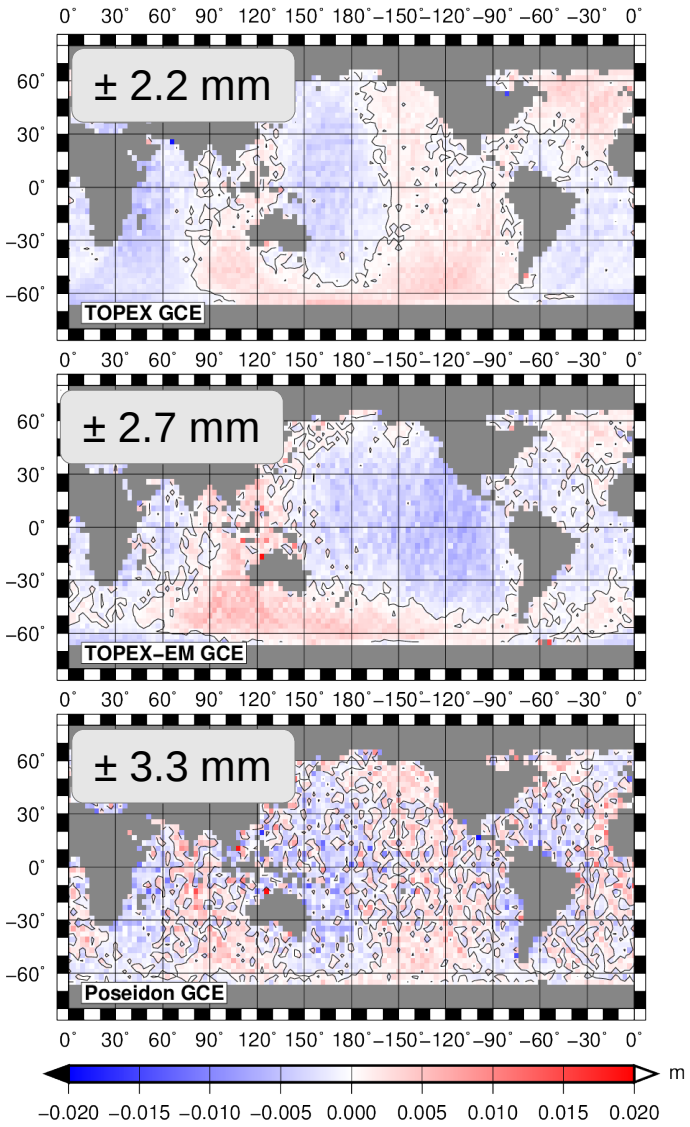




Reduction of the mean values
of the arc overlap of VER11 orbit,
as compared to VER06 orbit:
Radial – from 1.023 to 0.890 cm,
i.e. by 0.133 cm (about 13.0%),
Cross-track – from 6.535 to 6.491 cm,
i.e. by 0.044 cm (about 0.7%),
Along-track – from 3.593 to 3.476 cm,
i.e. by 0.117 cm (about 3.3%)

Geographically correlated errors for TOPEX/Poseidon orbits

GFZ VER11



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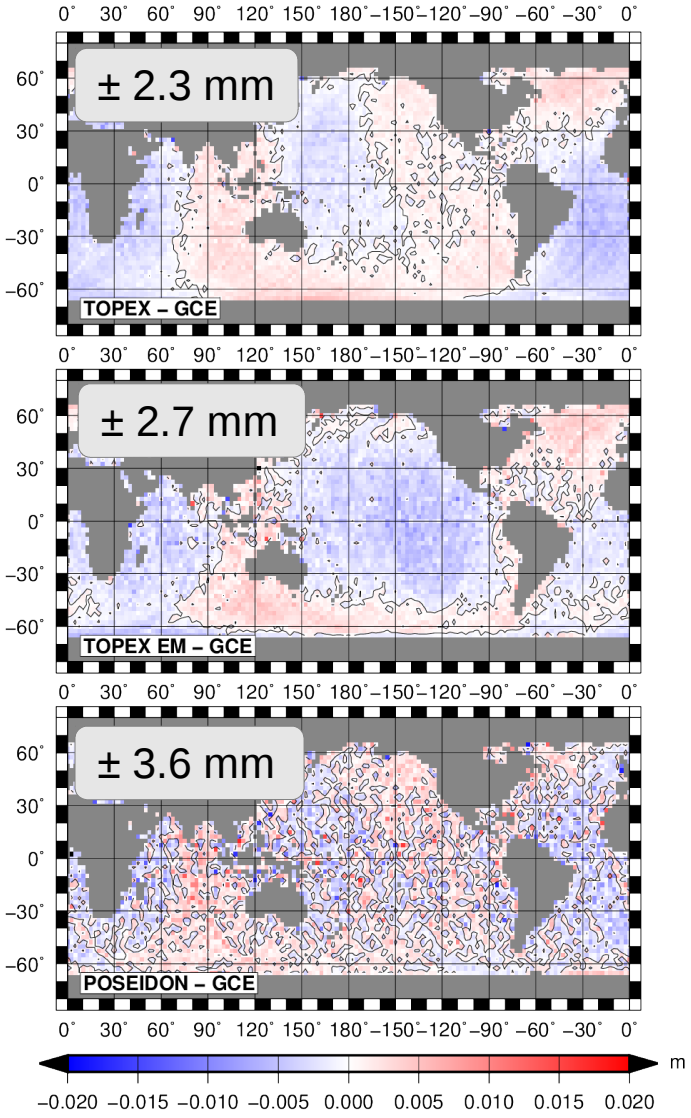
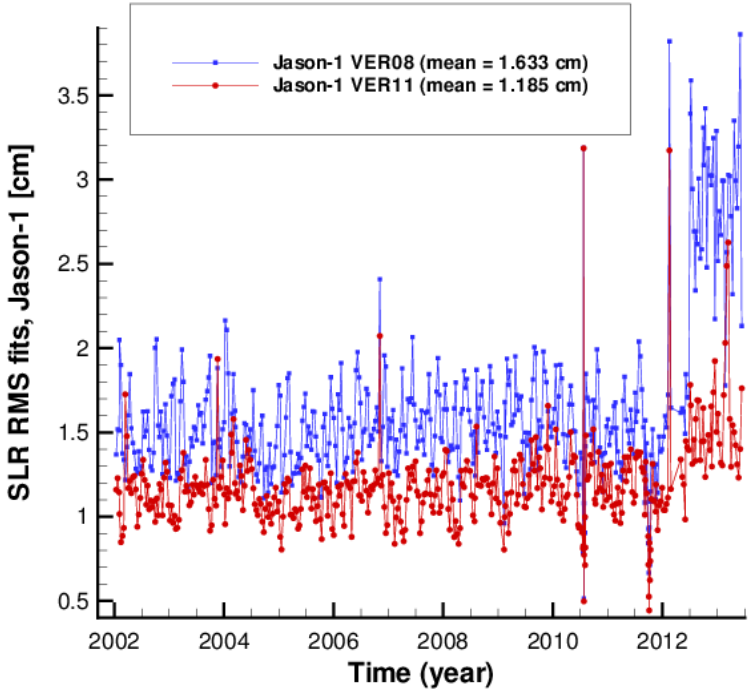
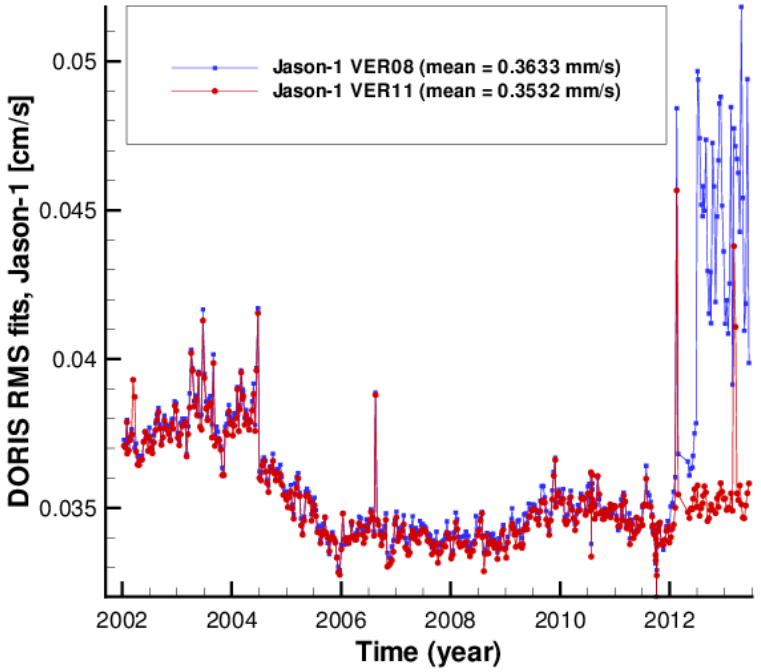


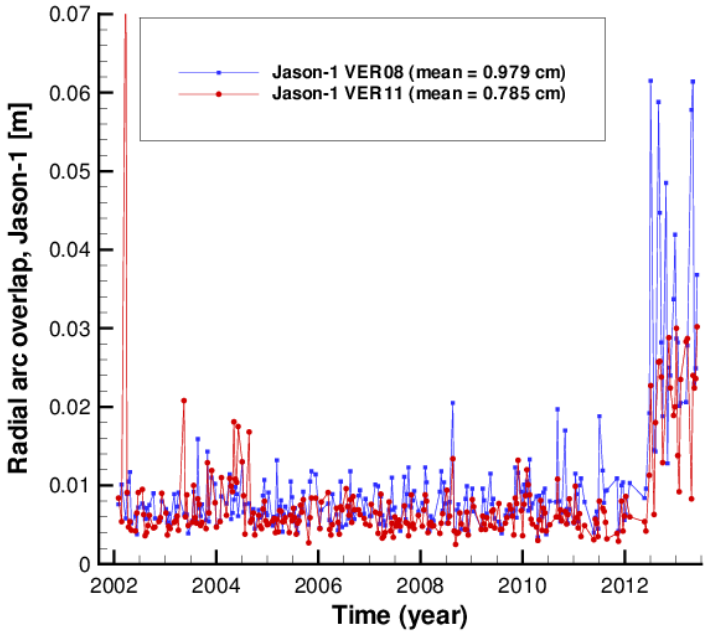
Improvement of RMS fits of observations for Jason-1 (January 2002 – July 2013): VER11 orbit versus VER08 orbit

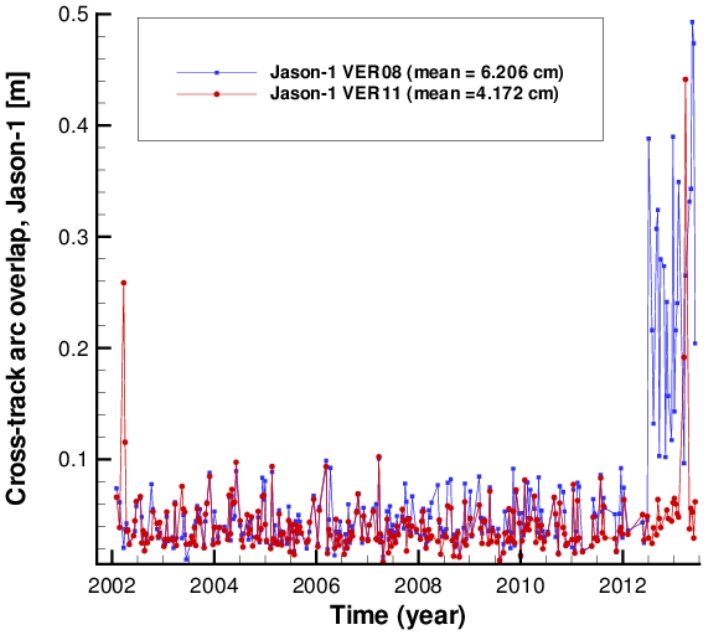


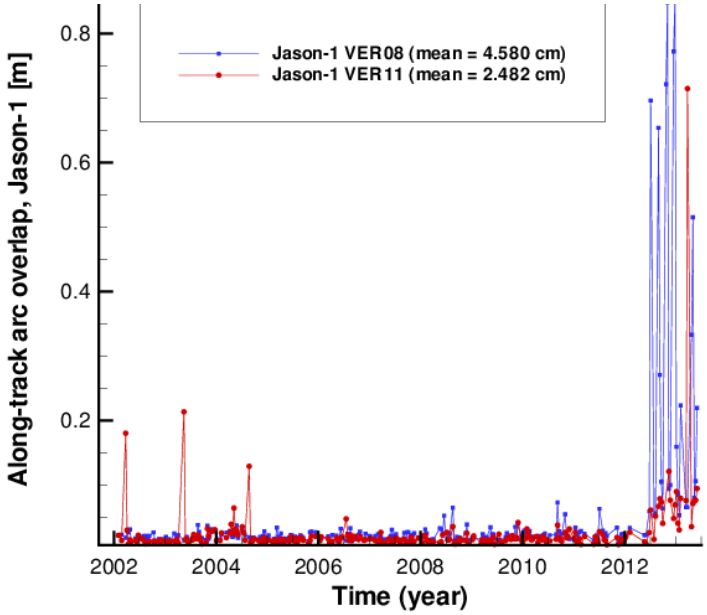


- The mean value of the SLR RMS fits reduced from 1.633 to 1.185 cm, i.e. by 0.448 cm (about 27.4%) for VER11 orbit, as compared to VER08 orbit;
- The mean value of the DORIS RMS fits reduced from 0.3633 mm/s to 0.3532 mm/s, i.e. by 0.0101 mm/s (about 2.8%) for VER11 orbit, as compared to VER08 orbit.

Two-day arc overlaps for Jason-1: VER11 orbit versus VER08 orbit





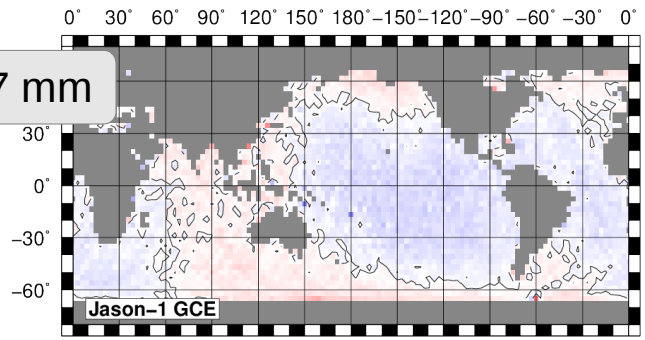


Reduction of the mean values
of the arc overlap of VER11 orbit,
as compared to VER08 orbit:
Radial – from 0.979 to 0.785 cm,
i.e. by 0.194 cm (about 19.8%),
Cross-track – from 6.206 to 4.172 cm,
i.e. by 2.034 cm (about 32.8%),
Along-track – from 4.580 to 2.482 cm,
i.e. by 2.098 cm (about 45.8%)!

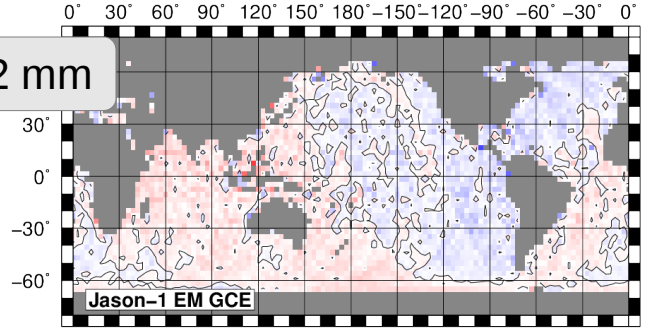
Geographically correlated errors for Jason-1 orbits

GFZ VER11

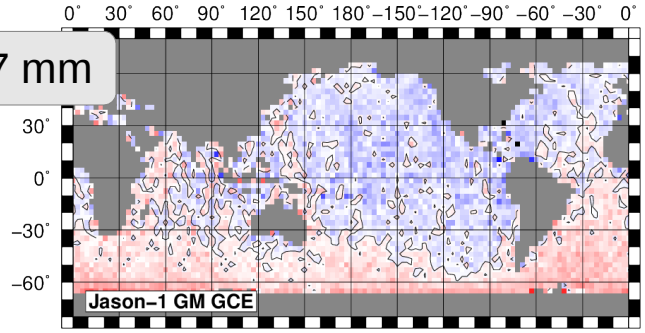
± 1.7 mm

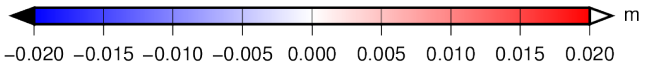


± 2.2 mm



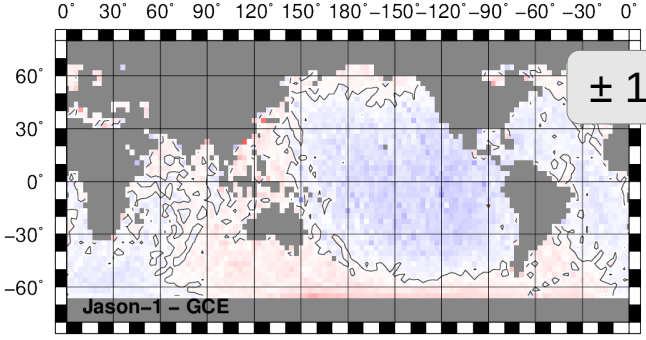
± 3.7 mm



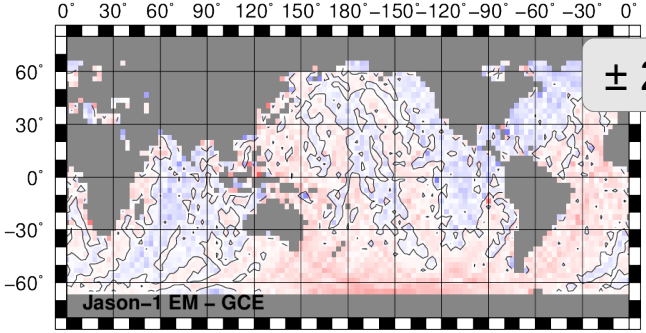


CNES GDR-D

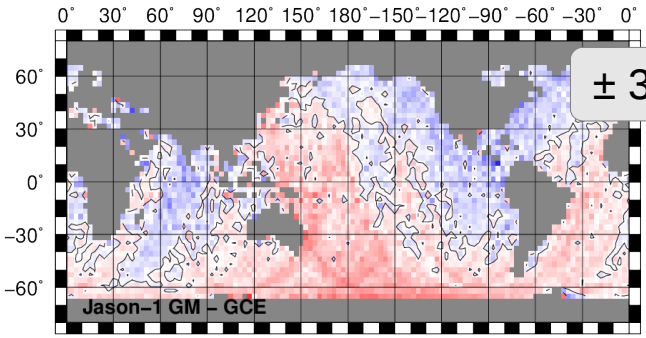
± 1.7 mm

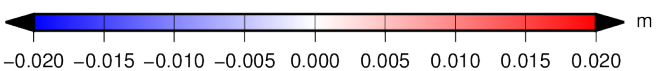


± 2.3 mm

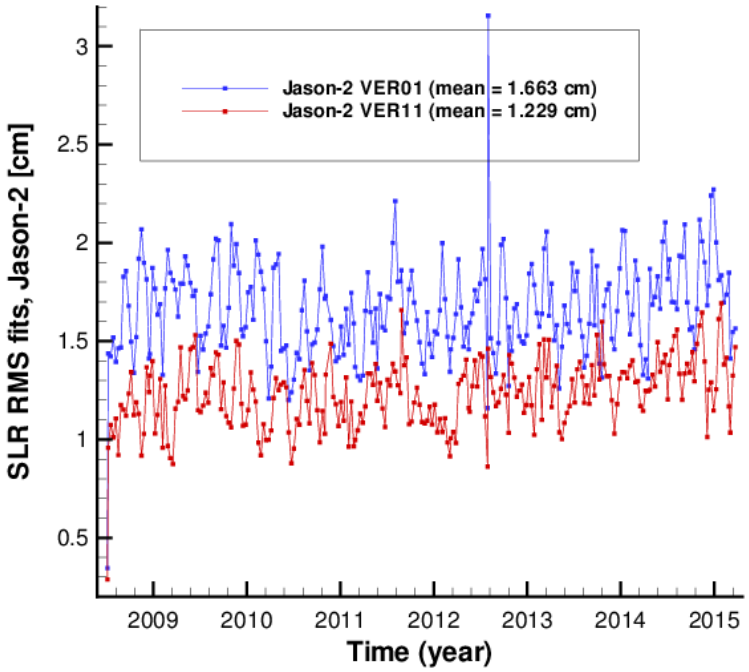


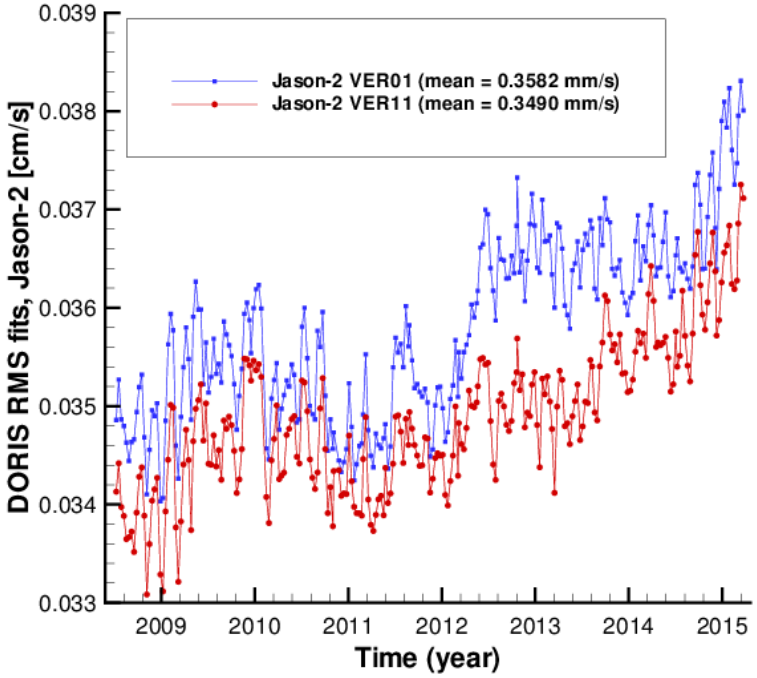
± 3.9 mm





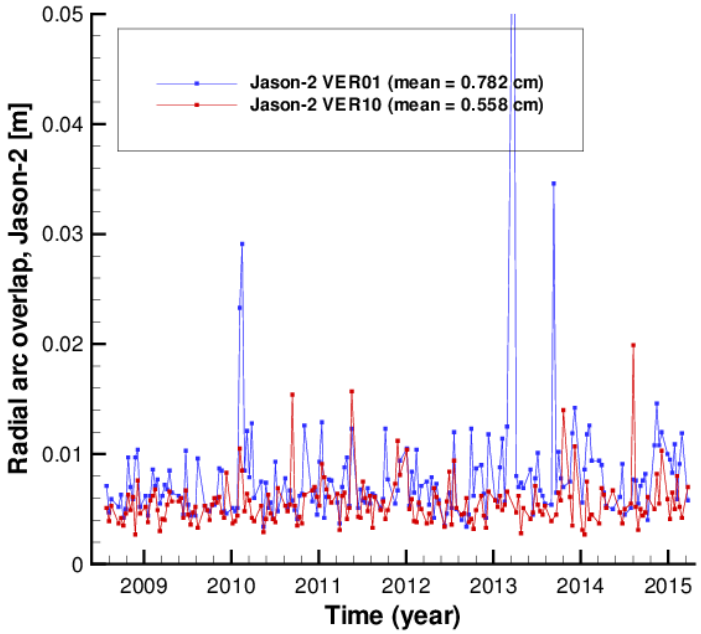
Improvement of RMS fits of observations for Jason-2 (5 July 2008 – 5 April 2015): VER11 orbit versus VER01 orbit

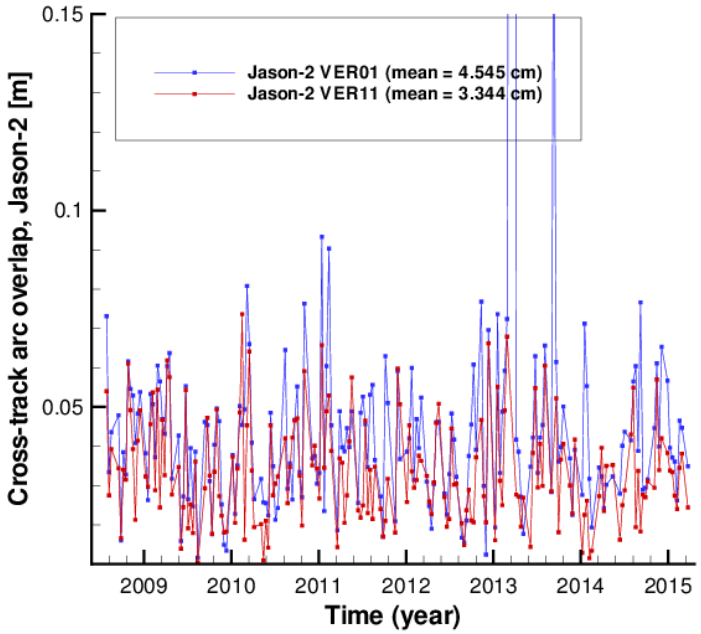


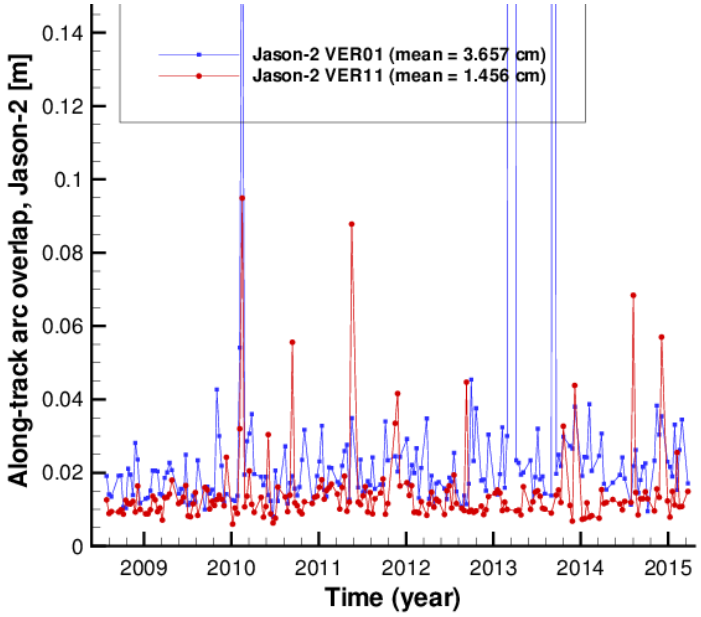


- The mean value of the SLR RMS fits reduced from 1.663 to 1.229 cm, i.e. by 0.434 cm (about 26.1%) for VER11 orbit, as compared to VER01 orbit;
- The mean value of the DORIS RMS fits reduced from 0.3582 mm/s to 0.3490 mm/s, i.e. by 0.0092 mm/s (about 2.6%) for VER11 orbit, as compared to VER01 orbit.

Two-day arc overlaps for Jason-2 (2008-2015): VER11 versus VER01



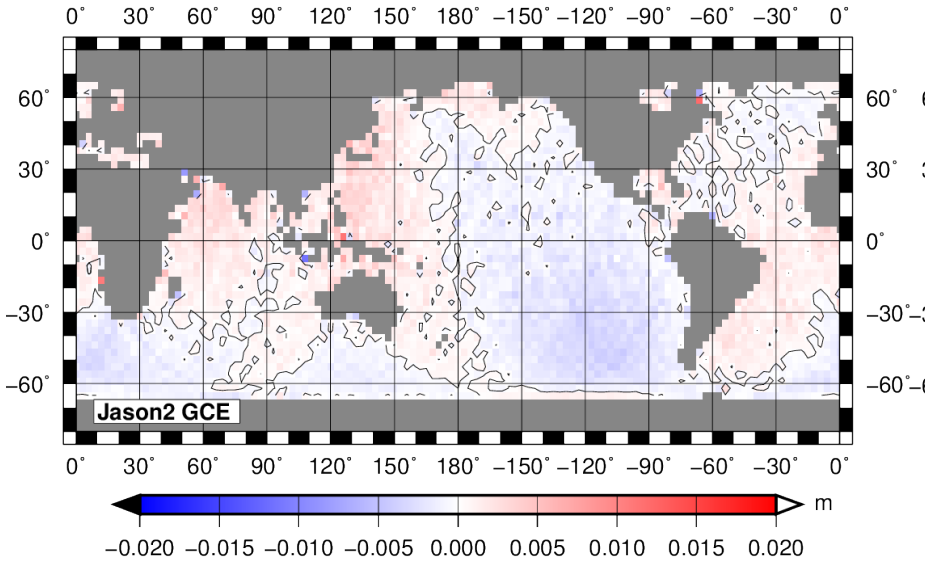




Reduction of the mean values
of the arc overlap of VER11 orbit,
as compared to VER01 orbit:
Radial – from 0.782 to 0.558 cm,
i.e. by 0.224 cm (about 28.6%),
Cross-track – from 4.545 to 3.344 cm,
i.e. by 1.201 cm (about 26.4%),
Along-track – from 3.657 to 1.456 cm,
i.e. by 2.201 cm (about 60.2%)

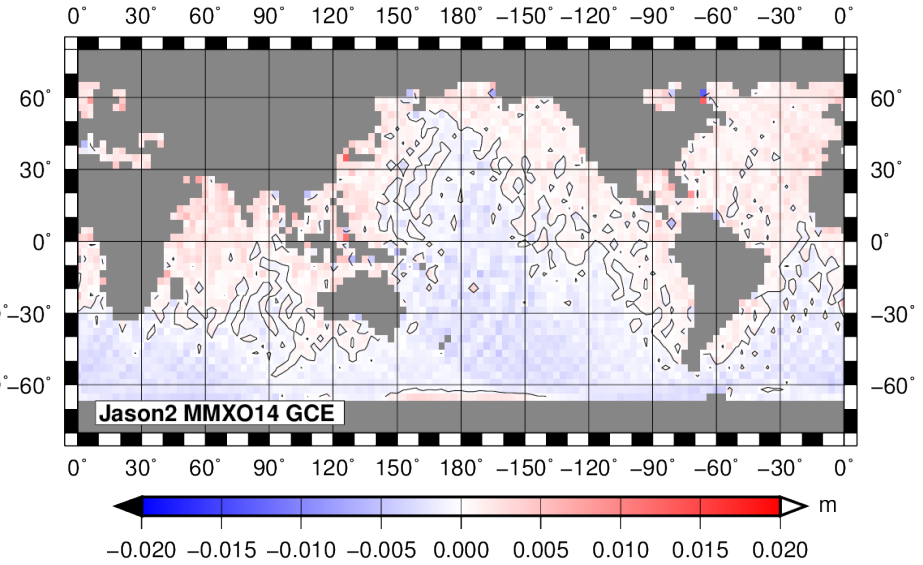
Geographically correlated errors for Jason-2 orbits

GFZ VER11



± 1.6 mm

CNES GDR-D



± 1.7 mm

Conclusions and outlook

- New precise orbits of ERS-1 (1991-1996), ERS-2 (1995-2006), TOPEX/Poseidon (1992-2005), Envisat (2002-2012), Jason-1 (2002-2013) and Jason-2 (2008-2015) were computed at GFZ in the same ITRF realization (ITRF2008) using consistent, improved models for precise orbit determination for all six missions.
- The analysis of these orbits performed at GFZ shows improved orbit quality of the new (VER11) orbits computed within the UHR-GravDat project and the phase 2 of the ESA Sea Level project of the Climate Change Initiative (SLCCI), as compared to the previous (VER06) orbits derived within the phase 1 of the SLCCI project
- The major improvement of the orbit quality was obtained for Jason-1, Jason-2, TOPEX/Poseidon and Envisat.
- Further improvement of the orbit quality is expected by using new, improved reference frame realizations, improved modeling of gravitational and non-gravitational forces acting on the satellites, using new improved DORIS models

Acknowledgements

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Thank you for your attention!