Deutsches Geodätisches Forschungsinstitut (DGFI-TUM)
Technische Universität München

Assessment of ITRF2014 for precise orbit determination of altimetry satellites

Sergei Rudenko[1], Saskia Esselborn[2], Tilo Schöne[2], Denise Dettmering[1], Karl-Hans Neumayer[2]

[1] Deutsches Geodätisches Forschungsinstitut, Technische Universität München (DGFI-TUM)
[2] Helmholtz Centre Potsdam GFZ German Research Centre for Geosciences, Potsdam, Germany

Symposium "New era of altimetry, new challenges",
International Doris Service (IDS) Workshop,
La Rochelle, France, 31 October - 1 November, 2016

Outline

- A terrestrial reference frame (TRF) is a basis for precise orbit determination of Earth orbiting satellites.

- Three new TRF realizations became recently available:
  - ITRF2014 (Altamimi et al., 2016),
  - DTRF2014 (Seitz et al., 2016) and
  - JTRF2014 (Abbondanza et al., 2016)

- We assess one of them, namely, ITRF2014 for precise orbit determination of altimetry satellites ERS-1 (1991–1996), ERS-2 (1995–2003), TOPEX/Poseidon (1992–2005), Envisat (2002–2012), Jason-1 (2002–2013) and Jason-2 (2008–2015) at the time intervals given, as compared to the previous (ITRF2008) realization.

- We have computed GFZ VER13 orbits of these satellites using the ITRF2014 reference frame and analyse them, as compared to the GFZ VER11 orbits (Rudenko et al., 2016) of the same satellites derived using the ITRF2008 reference frame (Altamimi et al., 2011) by keeping the same all other background models for precise orbit determination and estimated parameters.

Outline (continue)

⇨ Orbit computations were performed using “Earth Parameter and Orbit System - Orbit Computation (EPOS-OC)” software developed at GFZ

⇨ Observation data used:
- ERS-1: Satellite laser ranging (SLR) and single-satellite altimetry crossover data (SXO),
- ERS-2: SLR, SXO and PRARE (Precise Range and Range-Rate Equipment) data,
- TOPEX/Poseidon, Envisat, Jason-1 and Jason-2: SLR and DORIS (Doppler Orbitography Integrated by Satellite)

⇨ Orbital arc length used:
⇨ ERS-1, ERS-2, Envisat – 7 days with 2-day overlaps,
⇨ TOPEX/Poseidon, Jason-1, Jason-2 – 12 days with 2-day overlaps.

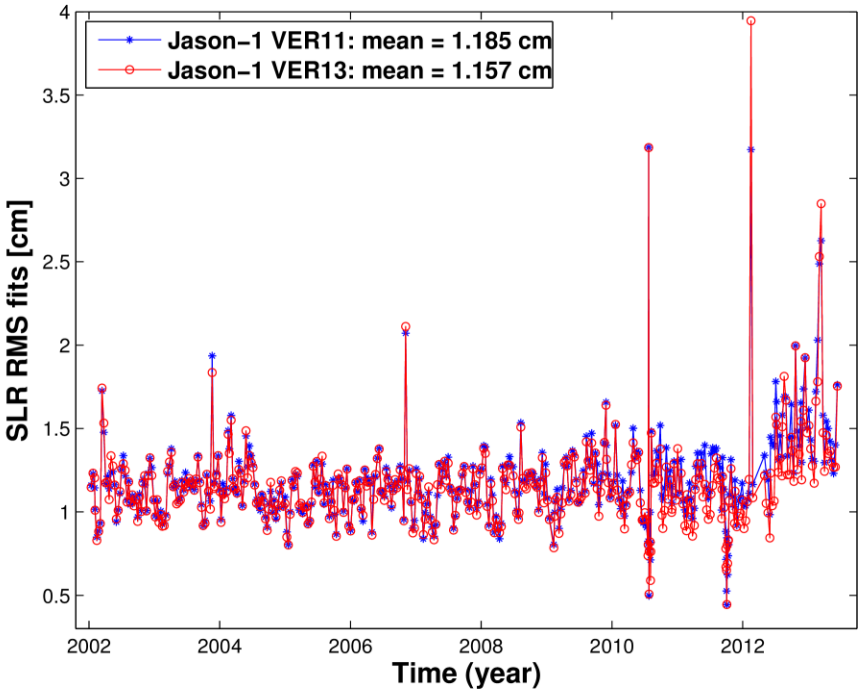
⇨ We compare
- residuals of observations used for orbit determination,
- two-day arc overlaps in radial direction,
- investigate the impact of the ITRF realizations on the geographically correlated and radial errors and on the global and regional mean sea level trends.

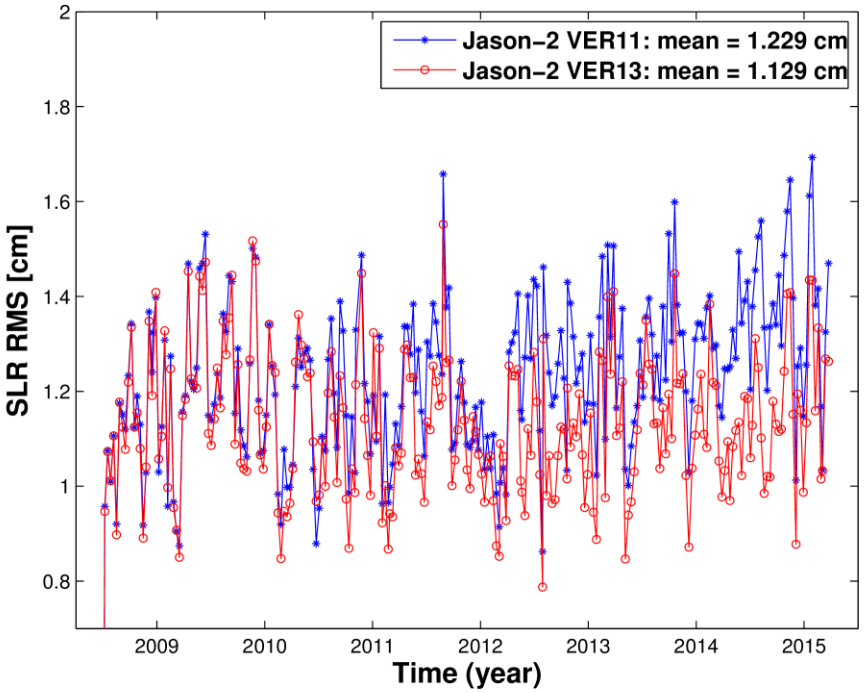
The main models used for orbit determination

Item	The model used
Earth gravity field model	EIGEN-6S4 (up to n=m=90)
Solid Earth and pole tides	IERS Conventions (2010)
Ocean tide model	EOT11a
Atmospheric tides	Biancale and Bode (2006)
Non-tidal atmospheric and oceanic gravity	GFZ AOD1B RL05
Third bodies (Sun, Moon and 7 major planets)	DE-421 ephemerides
Radiation pressure model	GFZ EPOS-OC and CNES/IDS box/wing models
Earth radiation	Knocke model
Atmospheric density model	MSIS-86
Polar motion and UT1	IERS EOP 08 C04 (IAU2000A) with IERS daily and sub-daily corrections
Precession and nutation	IERS Convention (2010)
Tropospheric correction for DORIS data	Vienna Mapping Function 1

Impact of the TRF realizations on SLR RMS fits

SLR RMS fits of Jason-1 (January 2002 – July 2013, left) and Jason-2 (July 2008 – April 2015, right): VER13 (ITRF2014) orbit (red) versus VER11 (ITRF2008) orbit (blue):



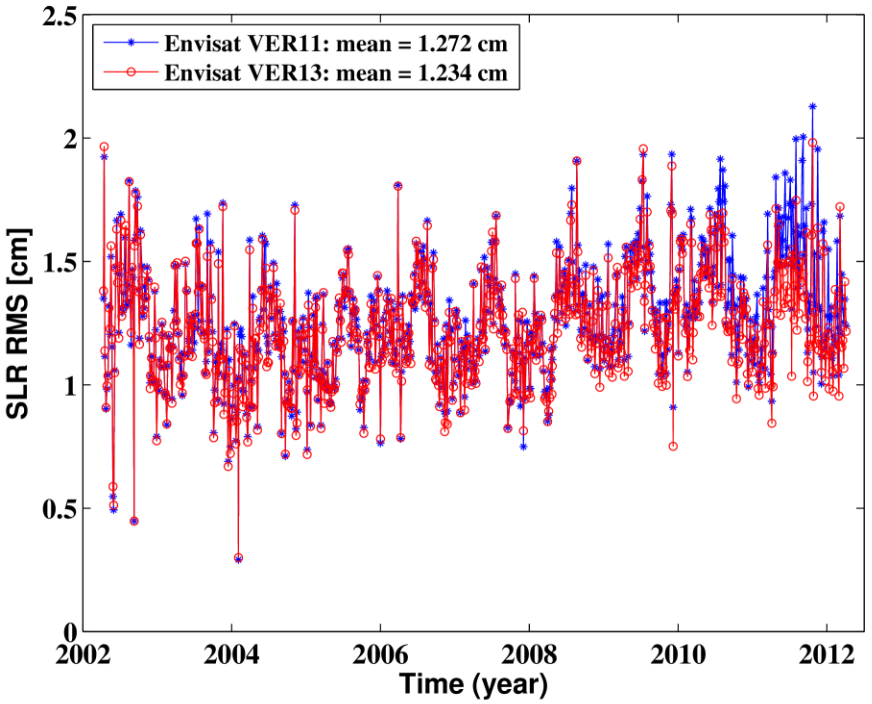


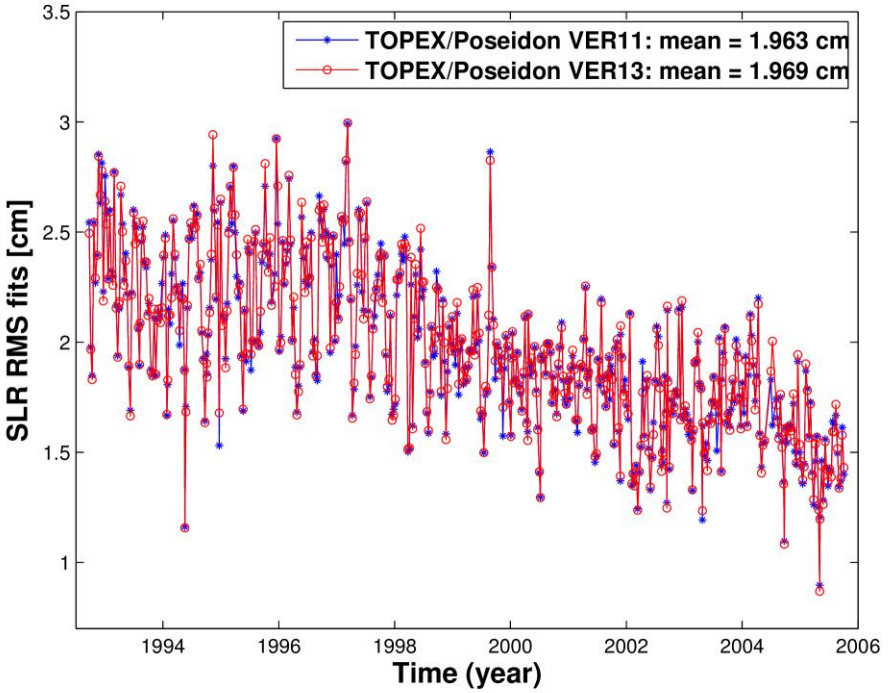
⇨ The mean values of SLR RMS fits reduced (improved) from 1.185 to 1.157 cm, i.e. by about 2.4%, for Jason-1 and from 1.229 to 1.129 cm, i.e. by 8.1%, for Jason-2, when using ITRF2014 instead of ITRF2008.

⇨ The major reduction of the SLR RMS fits is obtained in 2010-2015.

Impact of the TRF realizations on SLR RMS fits

SLR RMS fits of Envisat (April 2002 – April 2012, left) and TOPEX/Poseidon (August 1992 – October 2005, right): VER13 (ITRF2014) orbit (red) versus VER11 (ITRF2008) orbit (blue):

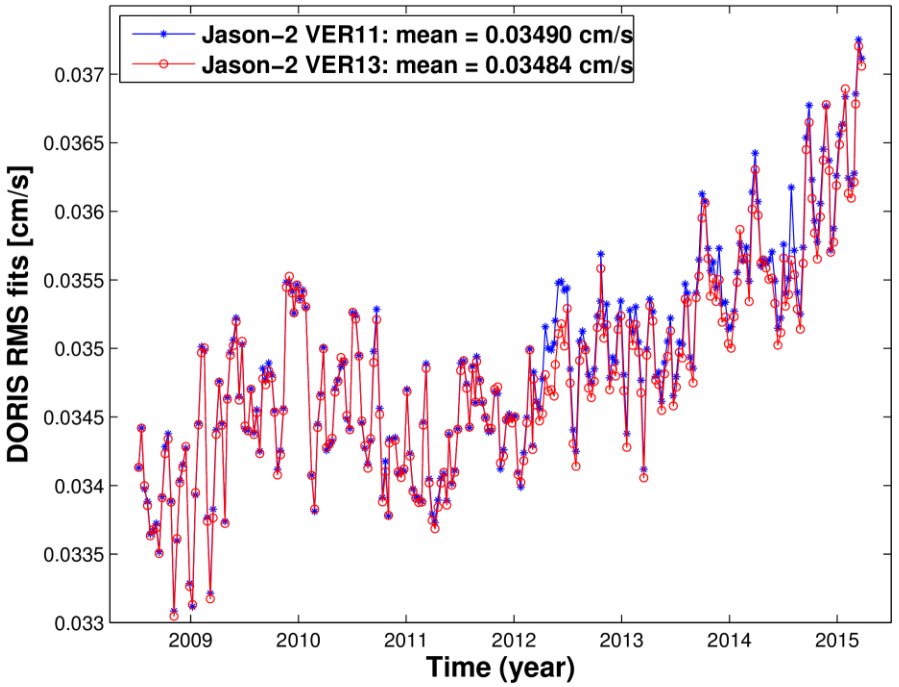


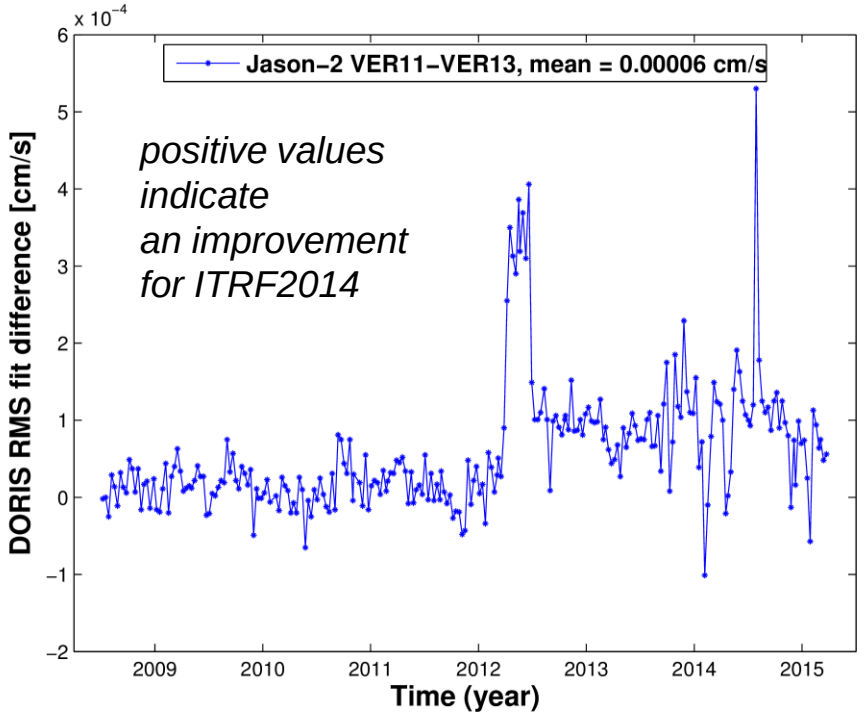


- ⇨ The mean values of SLR RMS fits reduced (improved) from 1.272 to 1.234 cm, i.e. by about 3.0%, for Envisat and increased from 1.963 to 1.969 cm, i.e. by 0.3%, for TOPEX, when using ITRF2014 instead of ITRF2008.
- ⇨ The major reduction of the SLR RMS fits is obtained in 2010–2012 (case Envisat).

Impact of the TRF realizations on DORIS RMS fits

DORIS RMS fits of Jason-2 (July 2008 – April 2015, left) VER13 (ITRF2014) (red) and VER11 (ITRF2008) orbits (blue) and their differences (right, positive values mean an improvement)

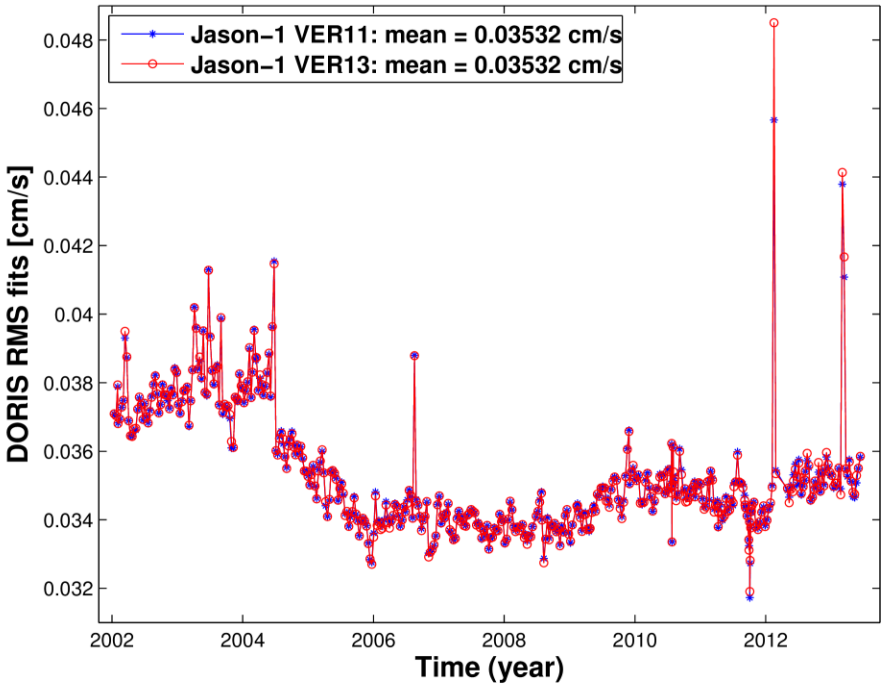


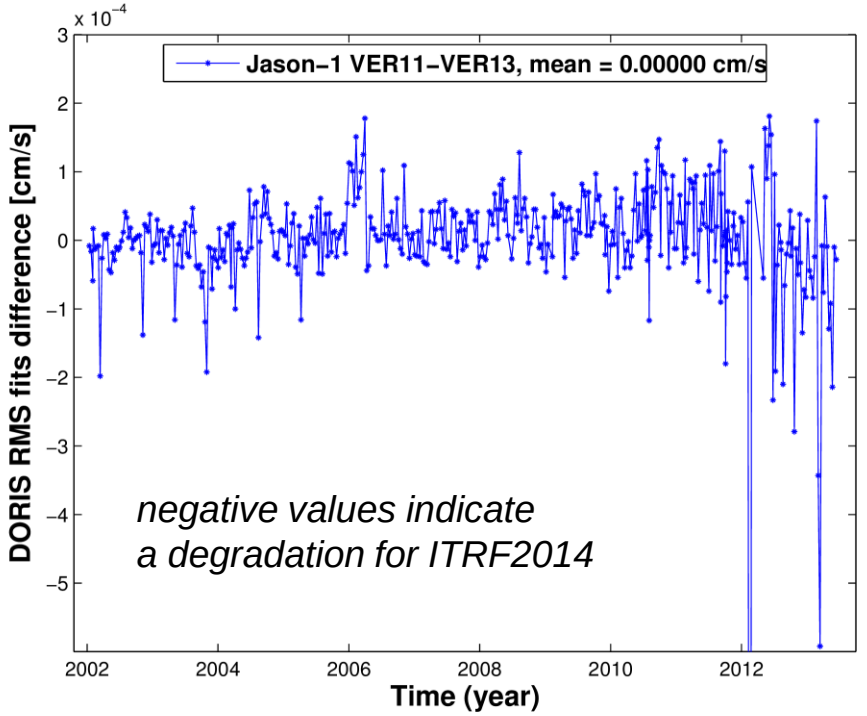


- ⇨ The mean values of DORIS RMS fits reduced (improved) from 0.3490 to 0.3484 mm/s, i.e. by about 0.2%, when using ITRF2014 instead of ITRF2008. An improvement of 0.3–1% is observed in 2012–2015.
- ⇨ However, using ITRF2014 instead of ITRF2008 does not completely reduces the trend in DORIS RMS fits observed for Jason-2 since 2011.

Impact of the TRF realizations on DORIS RMS fits

DORIS RMS fits of Jason-1 (2002 – 2013, left) VER13 (ITRF2014) (red) and VER11 (ITRF2008) orbits (blue) and their differences (right, positive values mean an improvement)

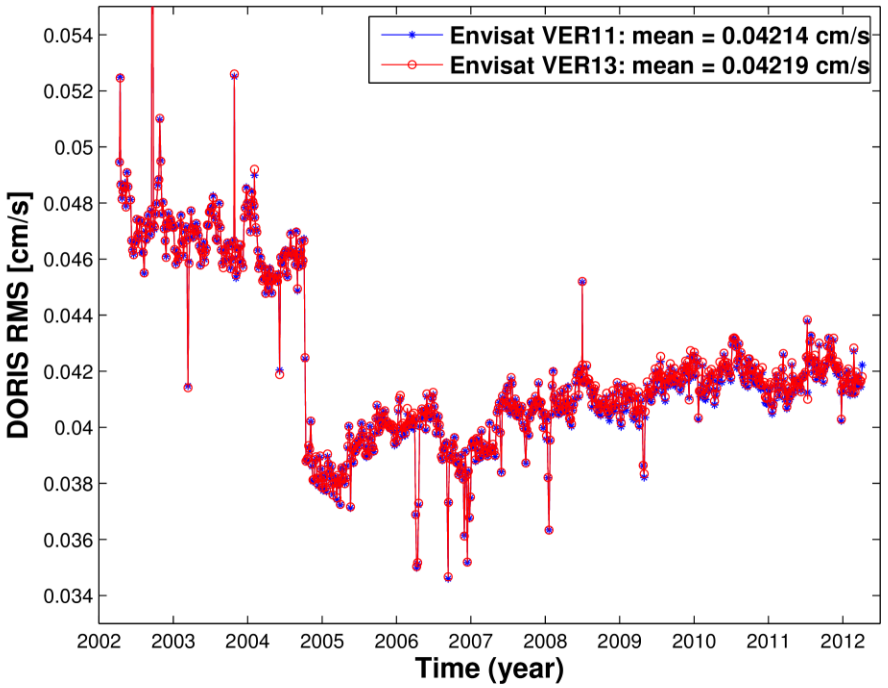


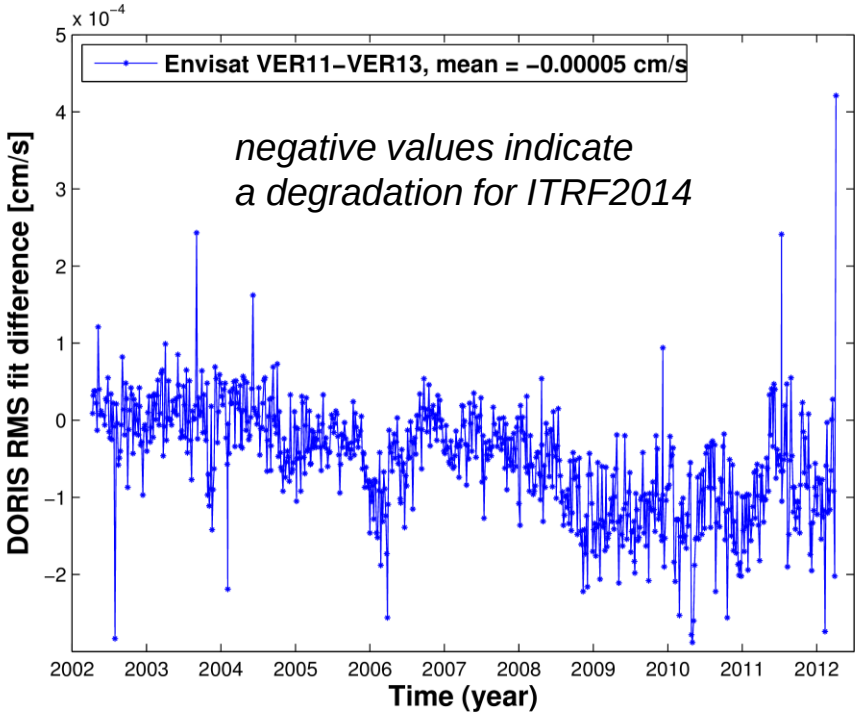


⇨ Generally, rather small impact on DORIS RMS fits of Jason-1 is found. A small improvement (about 0.2%) of DORIS RMS fits is observed in 2010–2011 and a small degradation (about 0.3%) of DORIS RMS fits is observed in 2012–2013.

Impact of the TRF realizations on DORIS RMS fits

DORIS RMS fits of Envisat (2002 – 2012, left) VER13 (ITRF2014) (red) and VER11 (ITRF2008) orbits (blue) and their differences (right, positive values mean an improvement)

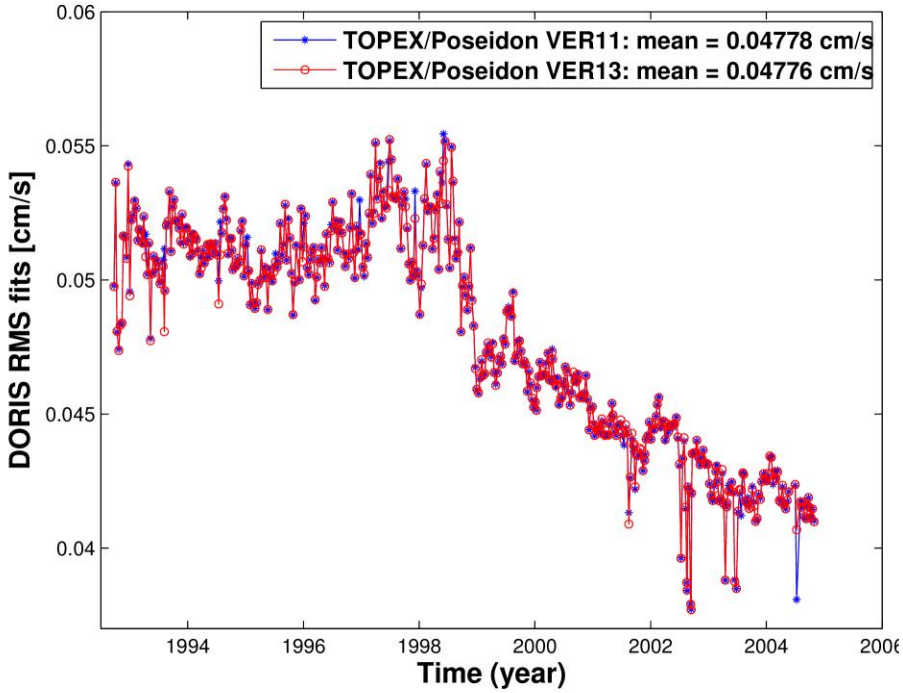


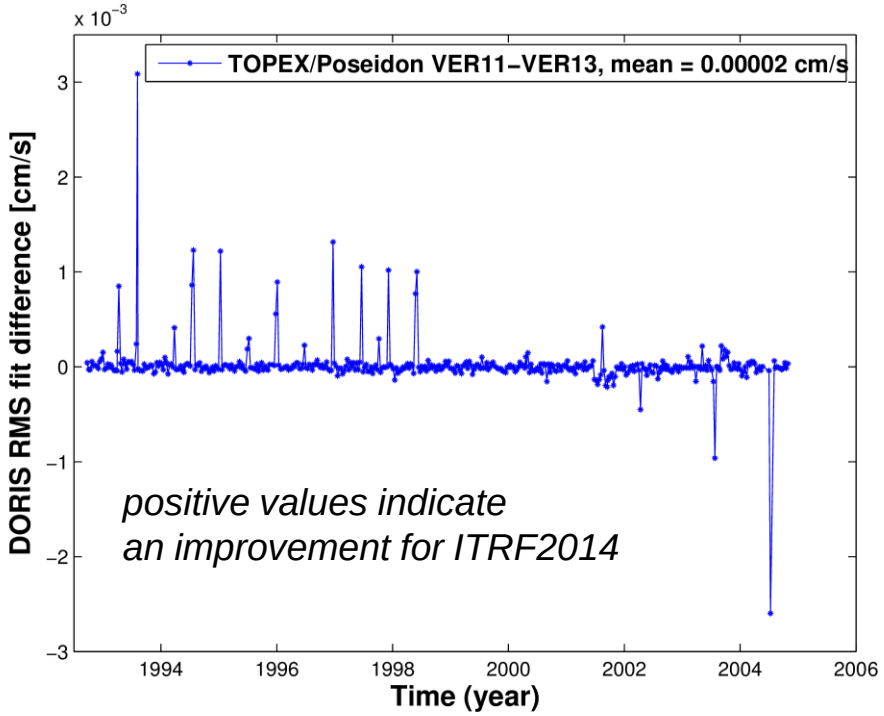


- The mean values of DORIS RMS fits increased from 0.4214 to 0.4219 mm/s, i.e. by about 0.1% over the whole time interval, when using ITRF2014 instead of ITRF2008.
- A detailed investigation (the right plot) shows an increase of DORIS RMS fits by about 0.3% in 2004–2006 and 2008–2012.

Impact of the TRF realizations on DORIS RMS fits

DORIS RMS fits of TOPEX/Poseidon (1992 – 2005, left) VER13 (ITRF2014) (red) and VER11 (ITRF2008) orbits (blue) and their differences (right, positive values mean an improvement)

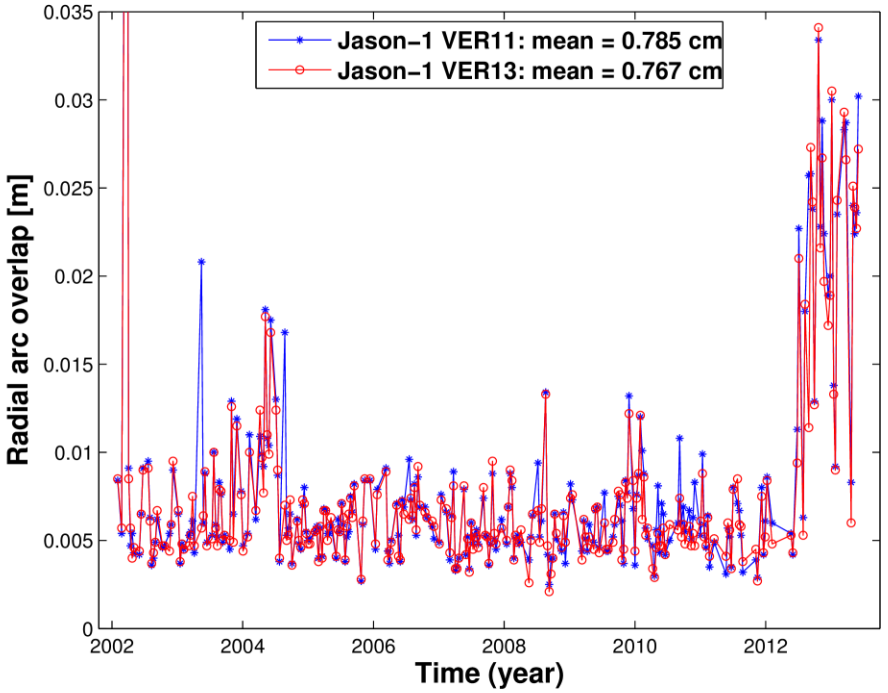


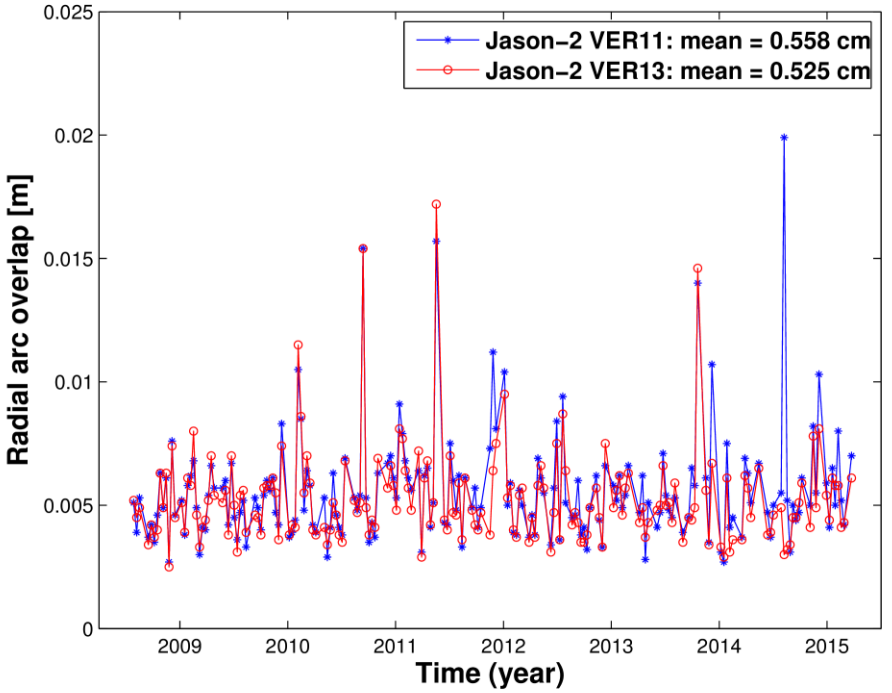


- ⇨ The mean values of DORIS RMS fits almost did not change, when using ITRF2014 instead of ITRF2008.
- ⇨ However, an improvement of DORIS RMS fits of 1–3% is observed at about 20 arcs in 1993–1998, when using ITRF2014 instead of ITRF2008. The number of accepted DORIS observations at these arcs is 1.2–2.5 times larger when using ITRF2014.

Impact of the TRF realizations on radial arc overlaps

Two-day radial arc overlaps of Jason-1 (January 2002 – July 2013, left) and Jason-2 (July 2008 – April 2015, right): VER13 (ITRF2014) orbit (red) versus VER11 (ITRF2008) orbit (blue):

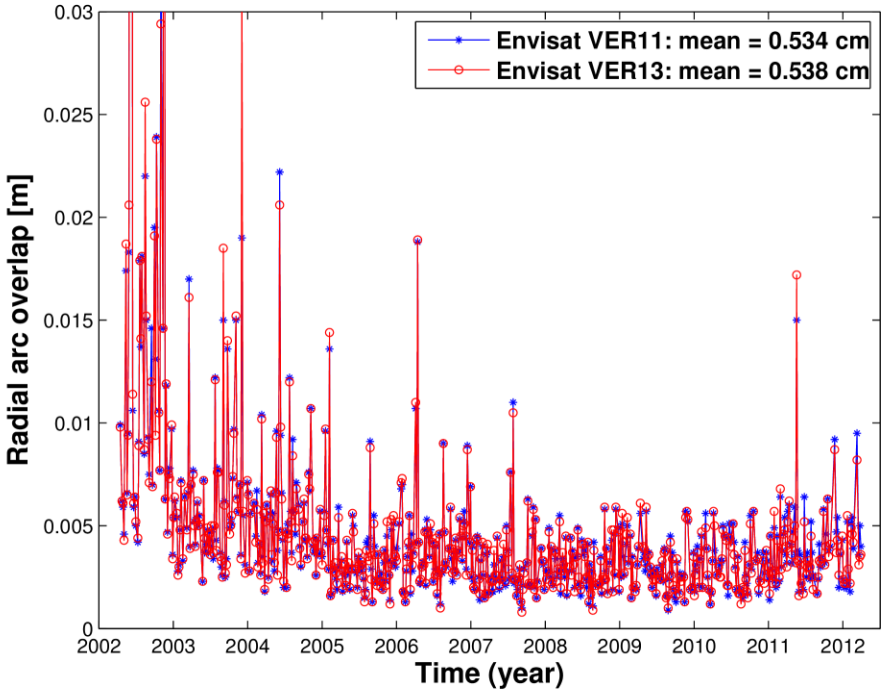


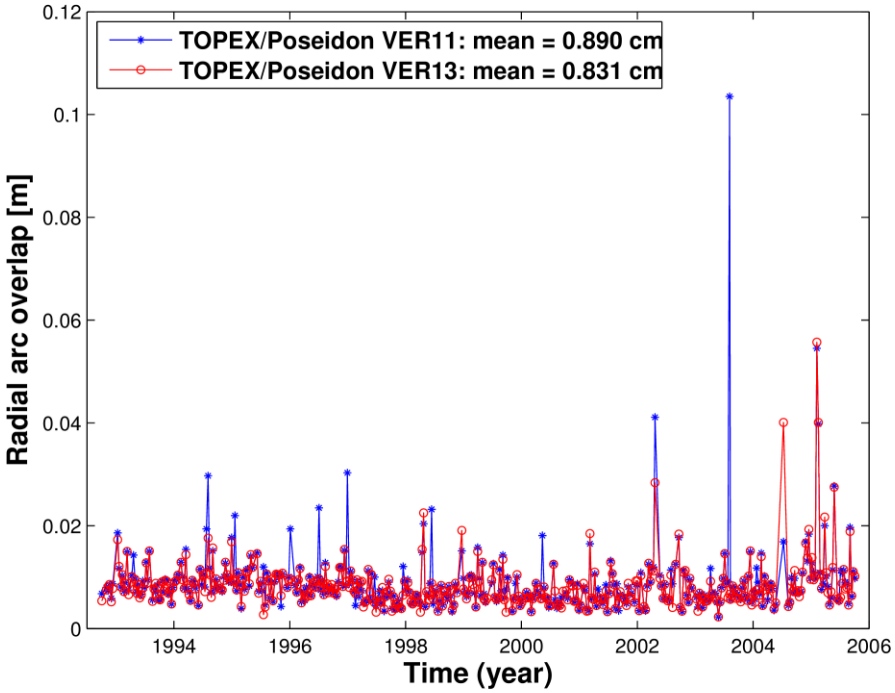


The mean values of the radial arc overlaps reduced (improved) from 0.785 to 0.767 cm, i.e., by about 2.3%, for Jason-1 and from 0.558 to 0.525 cm, i.e., by 5.9%, for Jason-2, when using ITRF2014 instead of ITRF2008.

Impact of the TRF realizations on radial arc overlaps

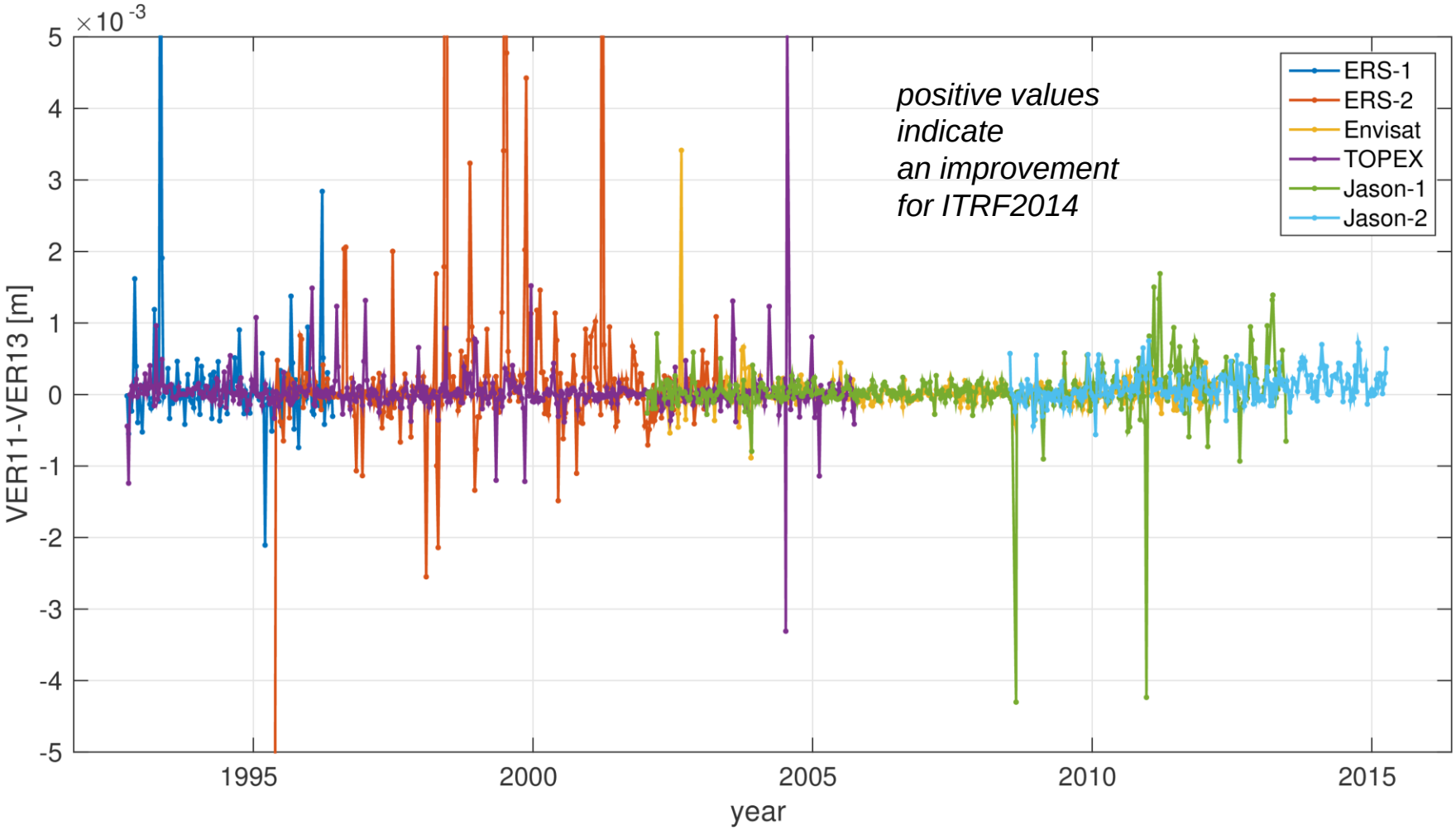
Two-day radial arc overlaps of Envisat (2002–2012, left) and TOPEX/Poseidon (1992–2005, right): VER13 (ITRF2014) orbit (red) versus VER11 (ITRF2008) orbit (blue):





The mean values of the radial arc overlaps increased (degraded) from 0.534 to 0.538 cm, i.e., by about 0.7%, for Envisat and reduced (improved) from 0.890 to 0.831 cm, i.e., by 6.6%, for TOPEX/Poseidon, when using ITRF2014 instead of ITRF2008.

Differences in the standard deviation of single-satellite crossover differences (VER11 minus VER13)



Standard deviation and mean of single-satellite crossover differences computed using VER11 and VER13 orbits of six satellites and their differences

Satellite	VER11 ITRF2008 crossover RMS (cm)	VER13 ITRF2014 crossover RMS (cm)	Difference of VER11-VER13 crossover RMS (%)	VER11 ITRF2008 crossover mean (mm)	VER13 ITRF2014 crossover mean (mm)	Difference of VER11-VER13 crossover mean (%)
ERS-1	5.832	5.820	0.22	1.832	1.672	8.7
ERS-2	6.060	6.036	0.41	−1.679	−1.755	−4.5
Envisat	4.547	4.545	0.04	4.064	4.459	−9.7
TOPEX	4.893	4.889	0.08	−3.504	−3.315	5.5
Jason-1	4.503	4.497	0.12	3.854	3.421	11.2
Jason-2	4.261	4.250	0.26	2.523	1.958	22.4

Green colour indicates an improvement, red indicates a degradation

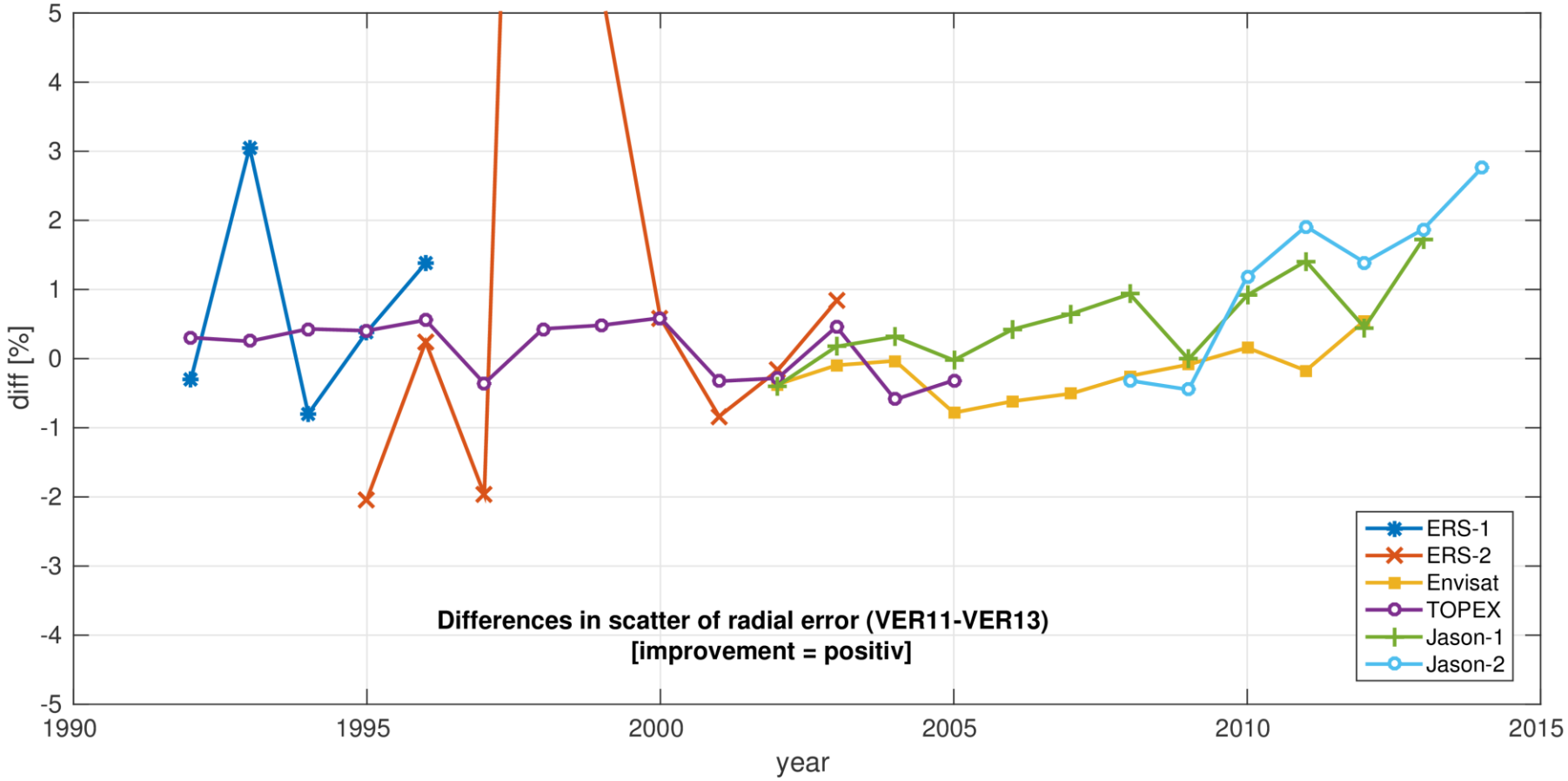
Scatter of radial errors from the multi-mission crossover analysis

Satellite	VER11 ITRF2008 (cm)	VER13 ITRF2014 (cm)	Difference VER11-VER13 (cm)	Difference VER11-VER13 (%)
ERS-1	1.893	1.870	0.023	1.2
ERS-2	2.615	2.567	0.048	1.8
Envisat	1.648	1.651	−0.003	−0.2
TOPEX	1.486	1.485	0.001	0.1
Jason-1	1.567	1.564	0.003	0.2
Jason-2	1.103	1.086	0.017	1.6

Green colour indicates an improvement, red indicates a degradation

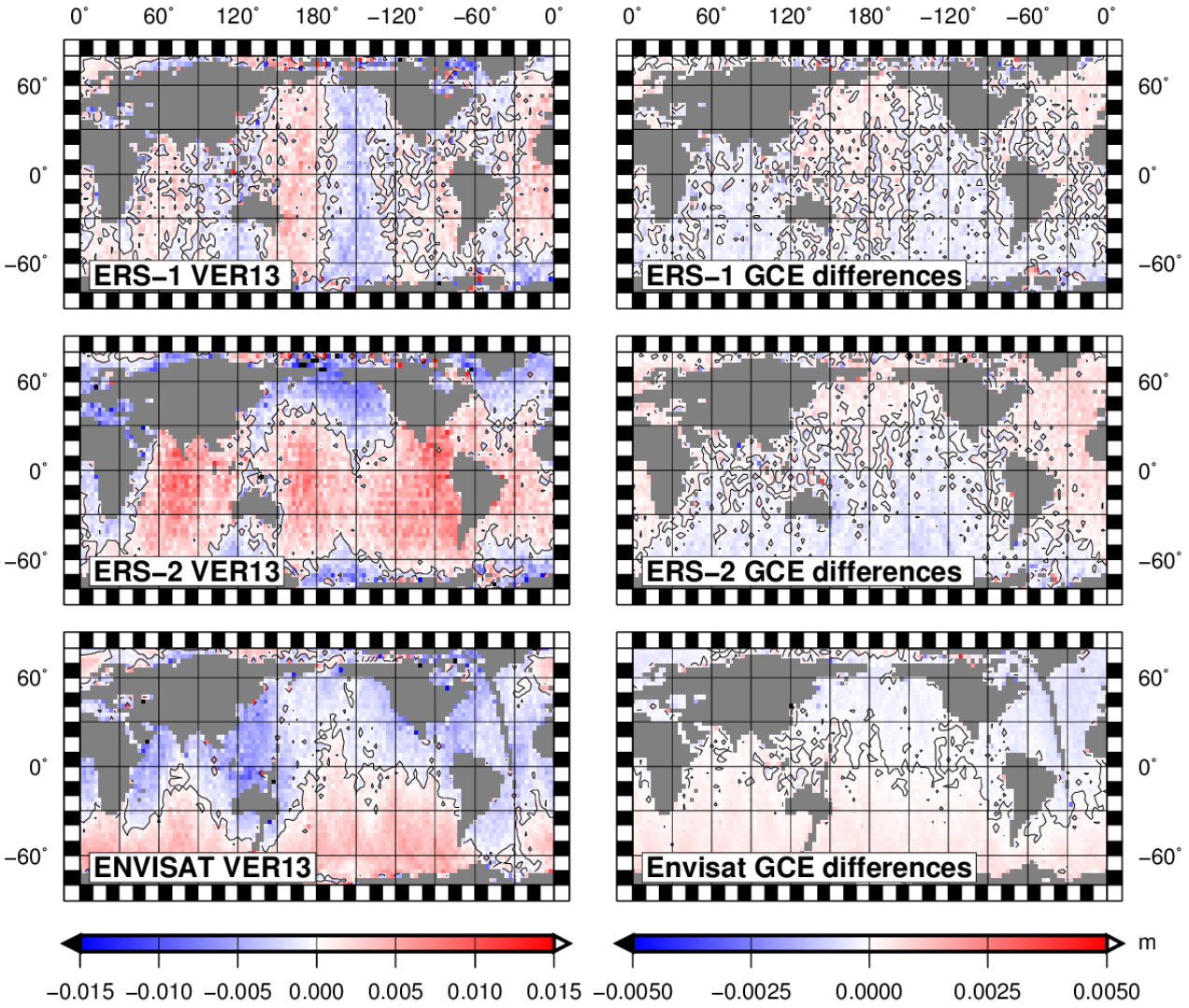
⇨ Using ITRF2014 instead of ITRF2008 brings an improvement of the scatter of radial errors by 0.1–1.8% for five satellites and a small degradation of 0.2% for Envisat

Differences in the scatter of the radial errors (VER11 minus VER13)

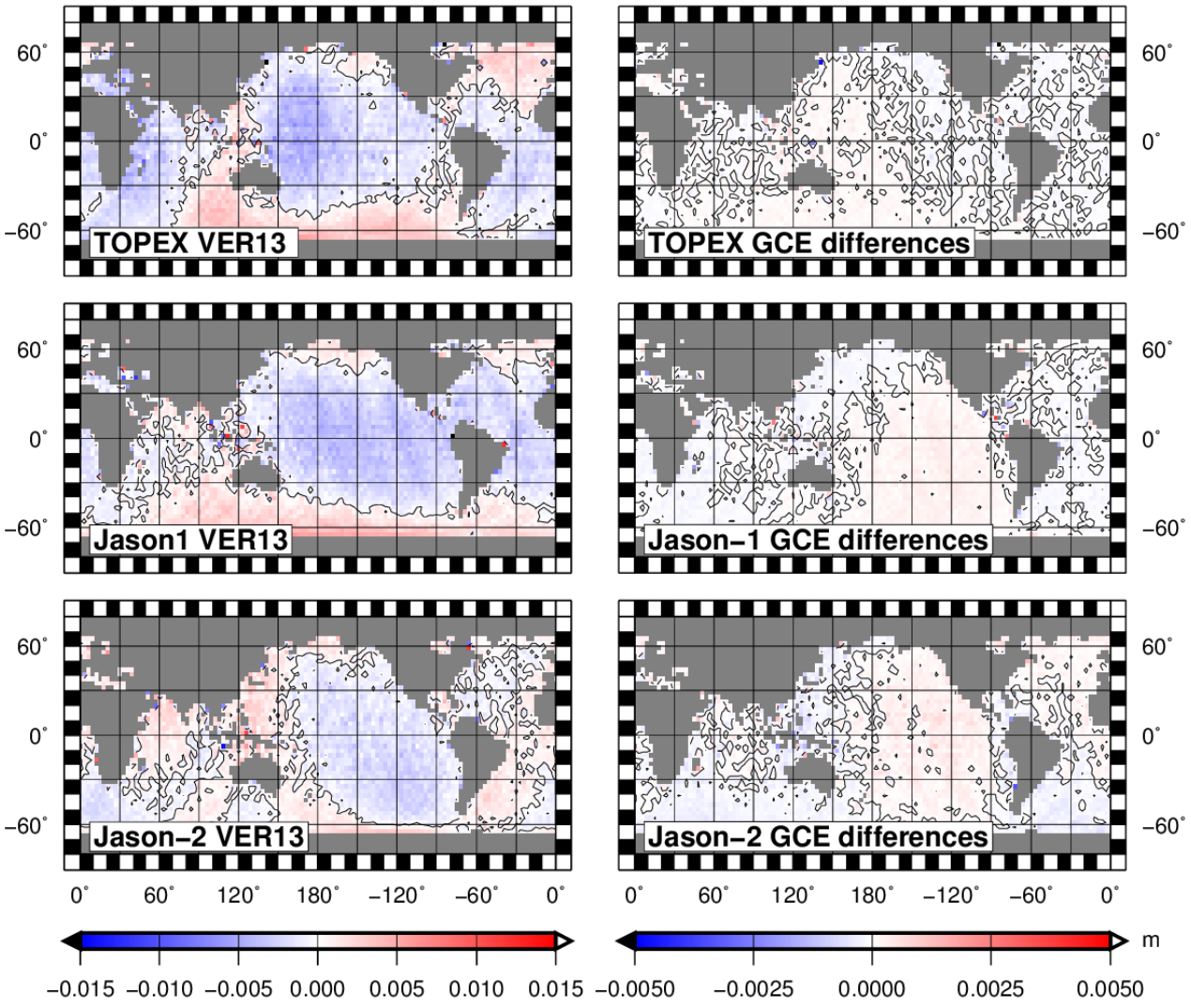


An improvement in the scatter of radial error is observed for ERS-2 in 1998–2000, Jason-1 and Jason-2 totally over 2005–2015.

Geographically correlated errors of VER13 orbits (left) and differences with respect to VER11 orbits (right)



Geographically correlated errors of VER13 orbits (left) and differences with respect to VER11 orbits (right)

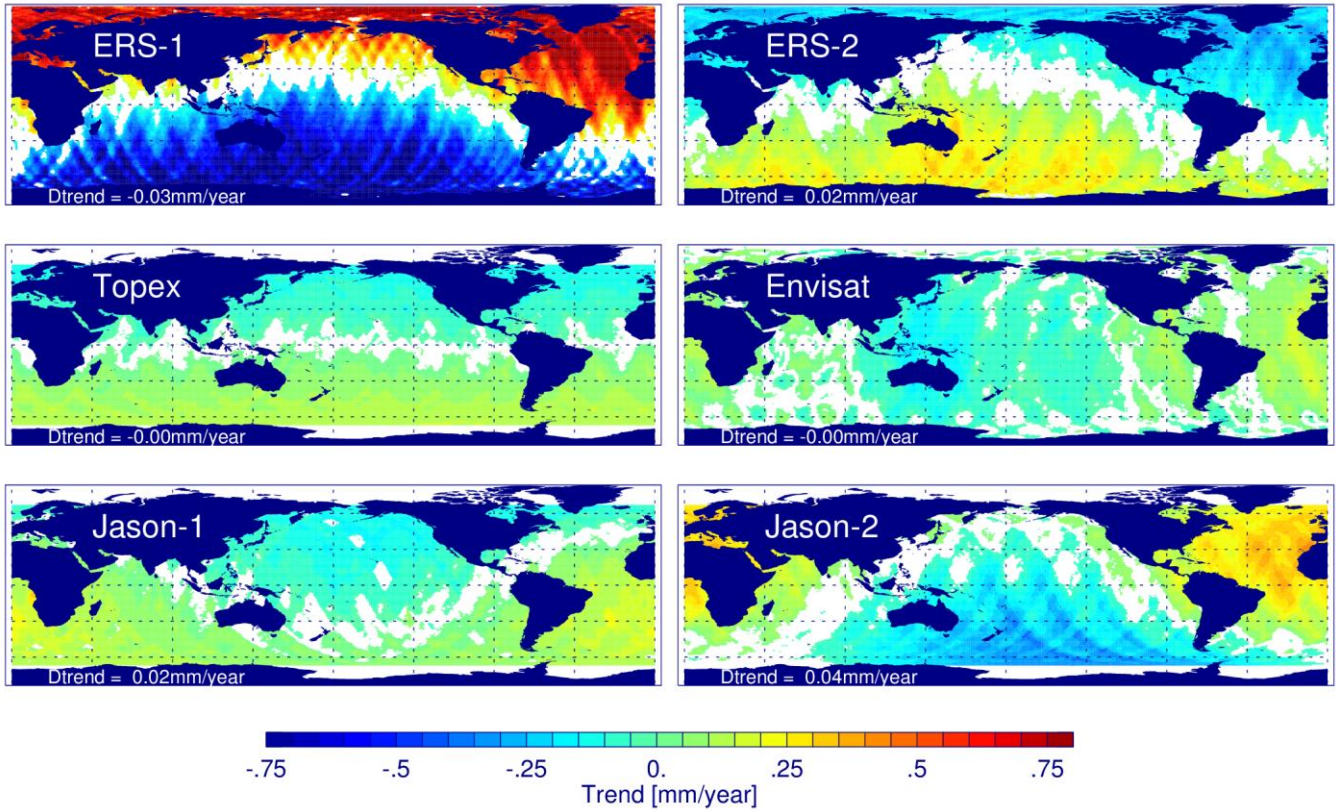


Geographically correlated errors (GCE)

Satellite	VER11 ITRF2008 (mm)	VER13 ITRF2014 (mm)	Difference VER11-VER13 (mm)	Difference VER11-VER13 (%)
ERS-1	2.508	2.515	−0.007	−0.3
ERS-2	4.427	4.310	+0.117	+2.6
Envisat	3.280	3.398	−0.118	−3.6
TOPEX	2.161	2.190	−0.029	−1.3
Jason-1	2.188	2.165	+0.023	+1.1
Jason-2	1.519	1.437	+0.082	+5.4

⇨ The major improvement of the GCE is obtained for Jason-2 (5.4%), followed by ERS-2 (2.6%) and Jason-1 (1.1%) when using ITRF2014 instead of ITRF2008. On the contrary, the GCE degraded for Envisat by 3.6%, TOPEX by 1.3% and ERS-1 by 0.3% using ITRF2014 instead of ITRF2008.

Impact on the global and regional mean sea level trends



- The impact of the replacement of ITRF2008 by ITRF2014 on the global mean sea level trend is less than 0.01 mm/y for Envisat and TOPEX, equals to 0.02 mm/y for ERS-2 and Jason-1, −0.03 mm/y for ERS-1 and 0.04 mm/y for Jason-2.
- The impact on the regional mean sea level trend is −0.2 to 0.3 mm/y for Envisat, TOPEX and Jason-1, −0.5 to 0.4 mm/y for ERS-2 and Jason-2 and −1.2 to 1.4 mm/y for ERS-1.

Conclusions: impact of using ITRF2014 instead of ITRF2008

1. The major improvement of the orbit quality is obtained for years 2010-2015.
2. RMS fits of SLR observations improved by 2--9% for ERS-2, Envisat, Jason-1 and Jason-2 and did not change for ERS-1 and TOPEX/Poseidon.
3. DORIS RMS fits improved by 0.3–1% for Jason-2 in 2012-2015, slightly (by 0.3%) degraded for Envisat in 2008-2012 and minor changed for Jason-1 and TOPEX.
4. Two-day arc overlaps in the radial direction improved by 0.4–7.1% for ERS-2, ERS-1, Jason-1, Jason-2 and TOPEX/Poseidon, but slightly (by 0.7%) degraded for Envisat.
5. The scatter of the radial errors improved by 0.1–1.8% for all satellites, but degraded by 0.2% for Envisat.
6. The standard deviation of crossover differences improved by 0.04–0.41% for all satellites.
7. The mean of crossover differences improved by 5.5–22.4% for TOPEX, ERS-1, Jason-1 and Jason-2, but degraded by 4.5% for ERS-2 and 9.7% for Envisat.
8. A small impact (0.01–0.04 mm/y) on the global mean sea level trend has been found
9. The impact on the regional mean sea level trend is between 0.2 and 0.5 mm/y for most satellites and up to 1.4 mm/y for ERS-1.

Outlook: we are going to test also DTRF2014 and JTRF2014 for precise orbit determination of some of these satellites

References

- Abbondanza et al. (2016) JTRF2014, the 2014 JPL Realization of the ITRS, Geophysical Research Abstracts, vol. 18, EGU2016-10583.
- Altamimi et al. (2011) ITRF2008: an improved solution of the international terrestrial reference frame. J. Geod., 85, 457-473.
- Altamimi et al. (2016) ITRF2014: A new release of the International Terrestrial Reference Frame modeling nonlinear station motions, J. Geophys. Res. Solid Earth, 121, 6109-6131.
- Rudenko et al. (2016) Improvements in precise orbits of altimetry satellites and their impact on mean sea level monitoring, IEEE Transactions on Geoscience and Remote Sensing, submitted.
- Seitz et al. (2016) The new DGFI-TUM realization of the ITRS: DTRF2014 (data). Deutsches Geodätisches Forschungsinstitut, Munich, 10.1594/PANGAEA.864046.

Acknowledgements

This study was partly supported by the ESA within the Sea Level Climate Change Initiative phase 2 project and by the German Research Foundation (DFG) within the project “Consistent dynamic satellite reference frames and terrestrial geodetic datum parameters”