On the current accuracy of altimetry satellite orbits





Sergei Rudenko, Denise Dettmering, Mathis Bloßfeld, Julian Zeitlhöfler, and Riva Alkahal

Deutsches Geodätisches Forschungsinstitut (DGFI-TUM)
Technische Universität München

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Context

- Importance of precise orbits of altimetry satellites and scope of this study
- Orbit solutions used
- Altimetry satellite position differences in the radial direction
- Multi-mission crossover analysis as a tool to derive geographically correlated and radial errors
- Geographically correlated errors
- Radial errors
- Conclusions
- Outlook
- References

Importance of altimetry satellite precise orbits and scope of this study

- Precise orbits of altimetry satellites are a prerequisite for the investigation of global, regional, and coastal sea levels together with their changes, since accurate orbit information is required for the reliable determination of the water surface height.

- Orbits of altimetry satellites are nowadays usually computed using DORIS (Doppler Orbitography and Radiopositioning Integrated by Satellite), SLR (Satellite Laser Ranging), and, of some satellites, GPS (Global Positioning System) observations of a global network of tracking stations.

- Significant progress in the improvement of altimetry satellite orbit quality has been achieved in the last 30 years. However, sea level (and trend) estimates computed using different up-to-date orbit solutions, types of observations and up-to-date models still exceed the requirements of the Global Climate Observing System (GCOS) for the regional sea level (< 1 cm) and its trend (< 1 mm/year). For reliable sea level products, the geodetic datum of the altimetry satellite orbits should meet the requirements of the Global Geodetic Observing System (< 1mm for positions, < 0.1 mm/year for trends) in addition to those of GCOS.

- In this study, we evaluate the current accuracy of orbits of altimetry satellites derived by various institutions in the state-of-the-art reference frames using up-to-date background models for precise orbit determination by using various observation types. We present some results of our analysis of satellite orbit differences in the radial direction, geographically correlated errors and radial errors for various orbit solutions.

Factors that impact quality of altimetry satellite orbits

- Type of observations used (SLR-only, DORIS-only, GPS-only, DORIS+SLR, DORIS+GPS)
- Observation quality (time biases, range biases, frequency biases, frequency drifts etc.) and distribution of observations in time and space
- Proper corrections of measurements (tropospheric refraction, center-of-mass, ionospheric refraction, satellite phase center corrections etc.)
- Proper modelling of satellite shape, size, optical properties of its surfaces (macro-model) and its orientation in space
- Accurate modelling of gravitational and non-gravitational forces acting on a satellite
- Accurate terrestrial and celestial reference frame realizations and transformation between them
- Proper modelling of geophysically caused displacements of tracking stations
- A proper parameter adjustment algorithm, observation weighting
- Other factors

Orbit solutions used

Orbit solution	Reference frame used	Observation types used	Reference
CNES GDR-E	ITRF2008	DORIS, GPS	Couhert et al. (2015)
CNES POE-F	ITRF2014	DORIS, GPS	Couhert et al. (2017)
CPOD	ITRF2014	DORIS, GPS	Peter et al. (2018)
GFZ VER11	ITRF2008	DORIS, SLR	Rudenko et al. (2017)
GFZ VER13	ITRF2014	DORIS, SLR	Rudenko et al. (2019)
GRGS ITRF2008	ITRF2008	DORIS, SLR	Soudarin et al. (2016)
GSFC std1504_14	ITRF2014	DORIS, SLR	Lemoine et al. (2015)

Orbit solutions available in ITRF2008 and ITRF2014 are used in this study.

How do the orbits of altimetry satellites derived by various institutions agree with each other in the radial direction?

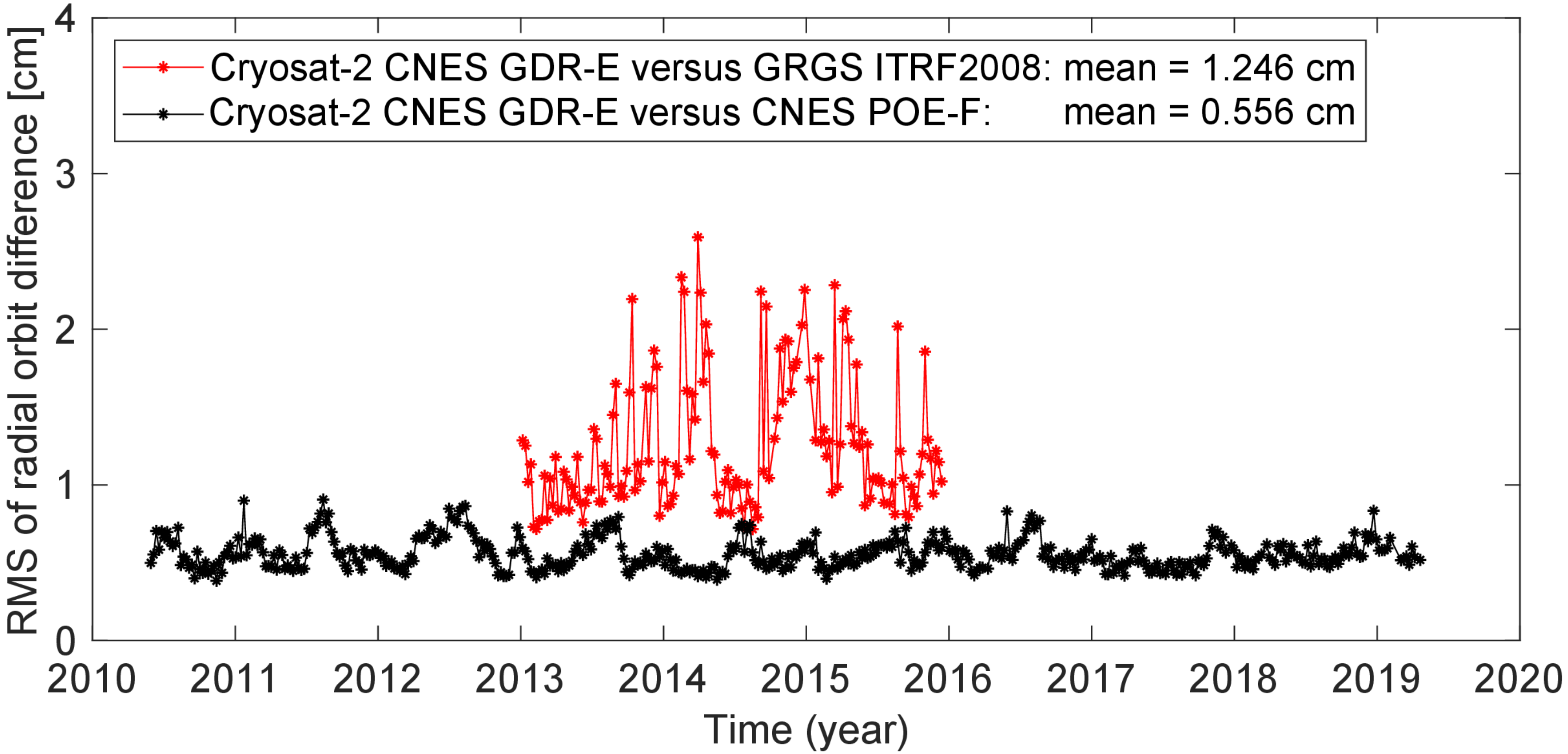
Orbits of altimetry satellites are being derived by various institutions using various observation types for various satellites. Usually up-to-date models and reference frame realizations are used for precise orbit determination. Thus, some sets of orbit solutions derived in the previous Terrestrial Reference Frame realizations (ITRF2005, ITRF2008 and ITRF2014) using related background models are available at the NASA Crustal Dynamics Data Information System (CDDIS, https://cddis.nasa.gov/index.html) and other repositories.

Since no true satellite orbit is known, the differences of satellite positions in the radial direction provided by various orbit solutions can give an indication of consistency (agreement) of these orbits in this direction being important for altimetry applications.

For this study, orbits publicly available in the SP3c format, except the GSFC std1504_14 orbit solution for TOPEX/Poseidon, are used. The following slides show 7- and 10-day mean values (depending on satellites) of the RMS values of satellite position differences in the radial direction for seven satellites: Cryosat-2, Jason-1, Jason-2, Jason-3, SARAL, Sentinel-3A and TOPEX/Poseidon. We show the results for two latest standards for precise orbit determination (GDR-E and POE-F) and related ITRF realizations (ITRF2008 and ITRF2014). The orbit differences were computed at the time intervals at which two respective orbit solutions are available.

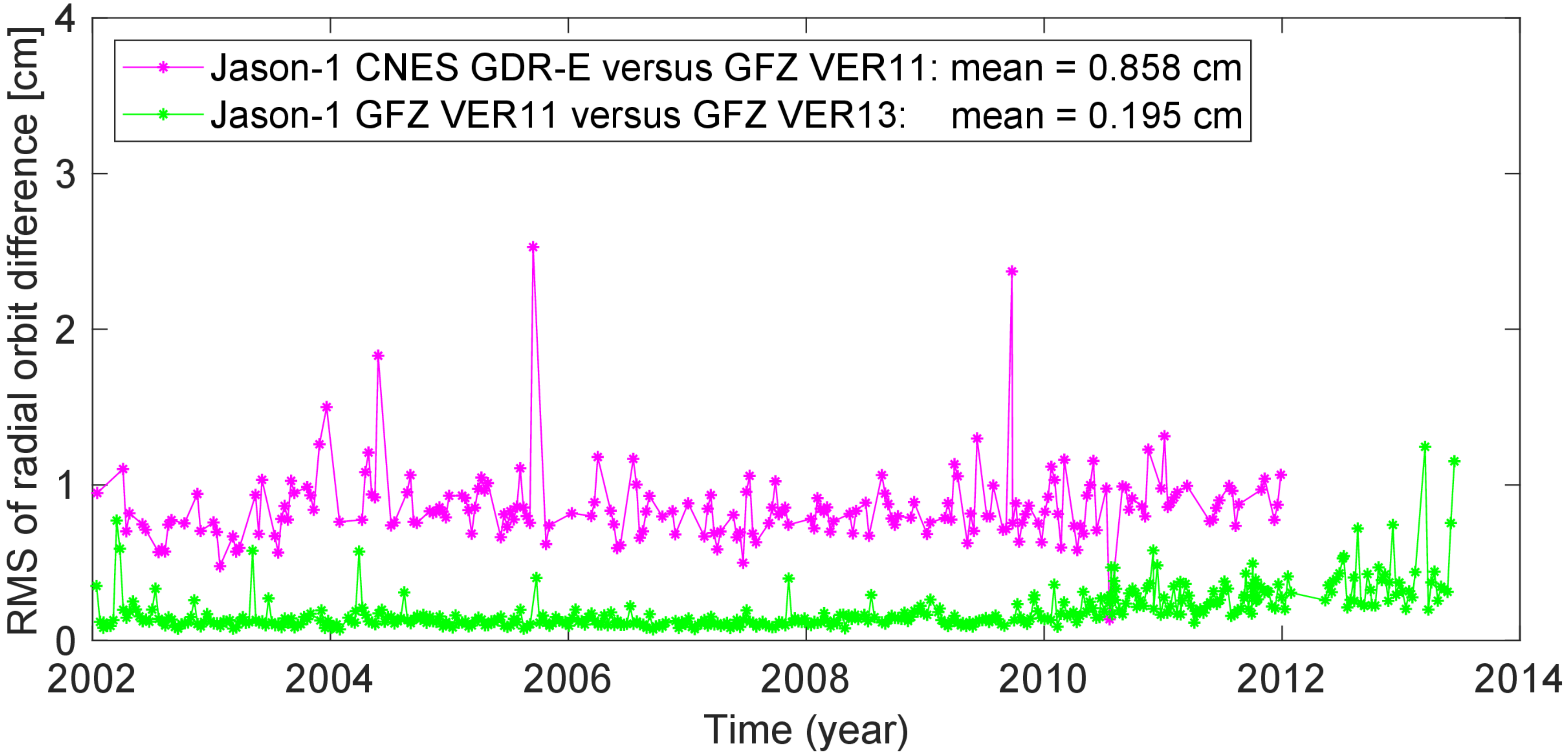
For Jason-2, a typical example of orbit differences at a 10-day time span in radial, along-track and cross-track directions is shown.

7-day mean of the RMS values of radial orbit differences: Cryosat-2



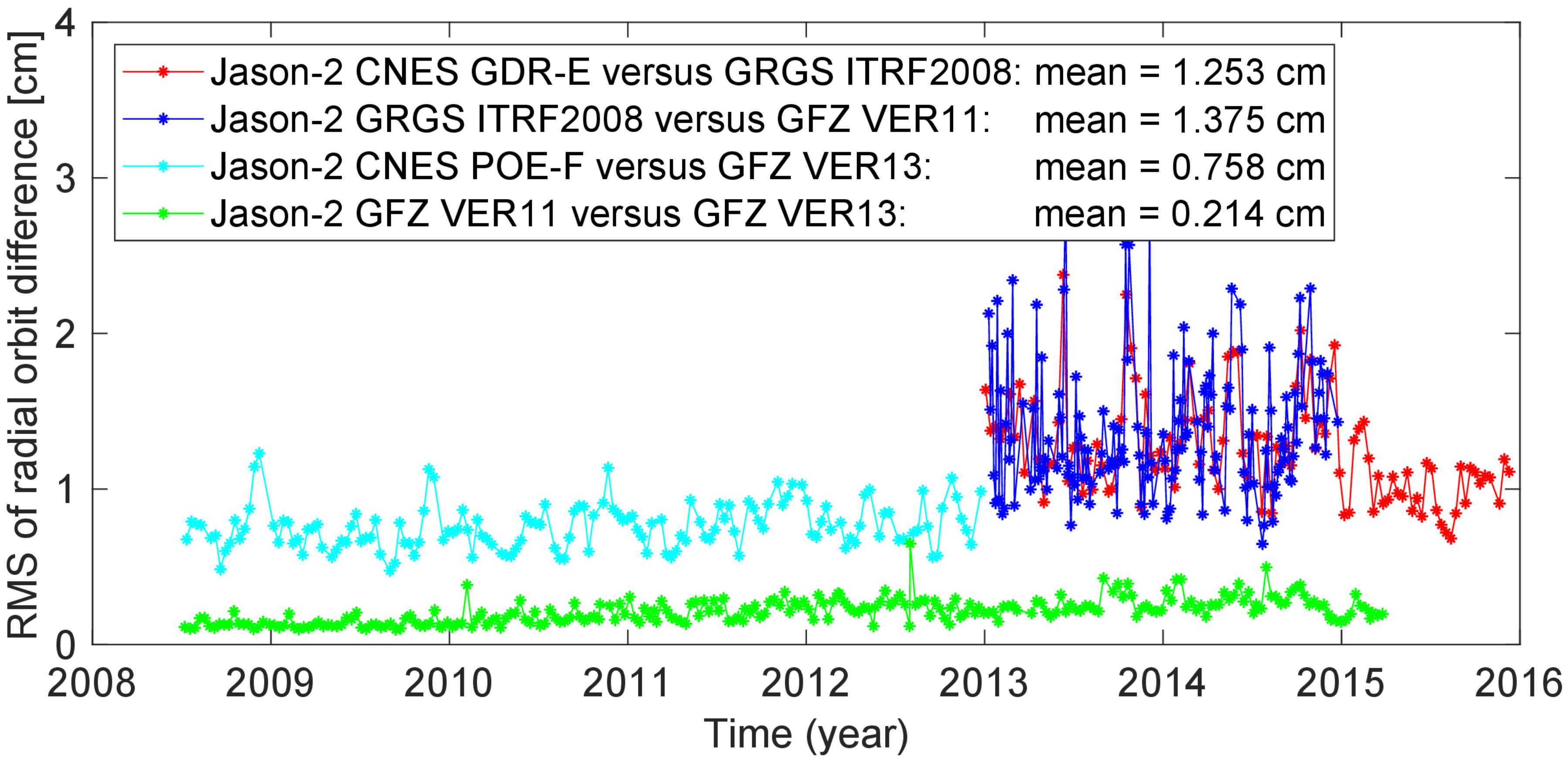
Cryosat-2 orbit solutions derived by various institutions in the ITRF2008 with the GDR-E orbit standards agree in the radial direction within 1.2 cm (RMS), those of CNES derived using GDR-E and POE-F orbit standards agree within 0.6 cm (RMS).

10-day mean of the RMS values of radial orbit differences: Jason-1



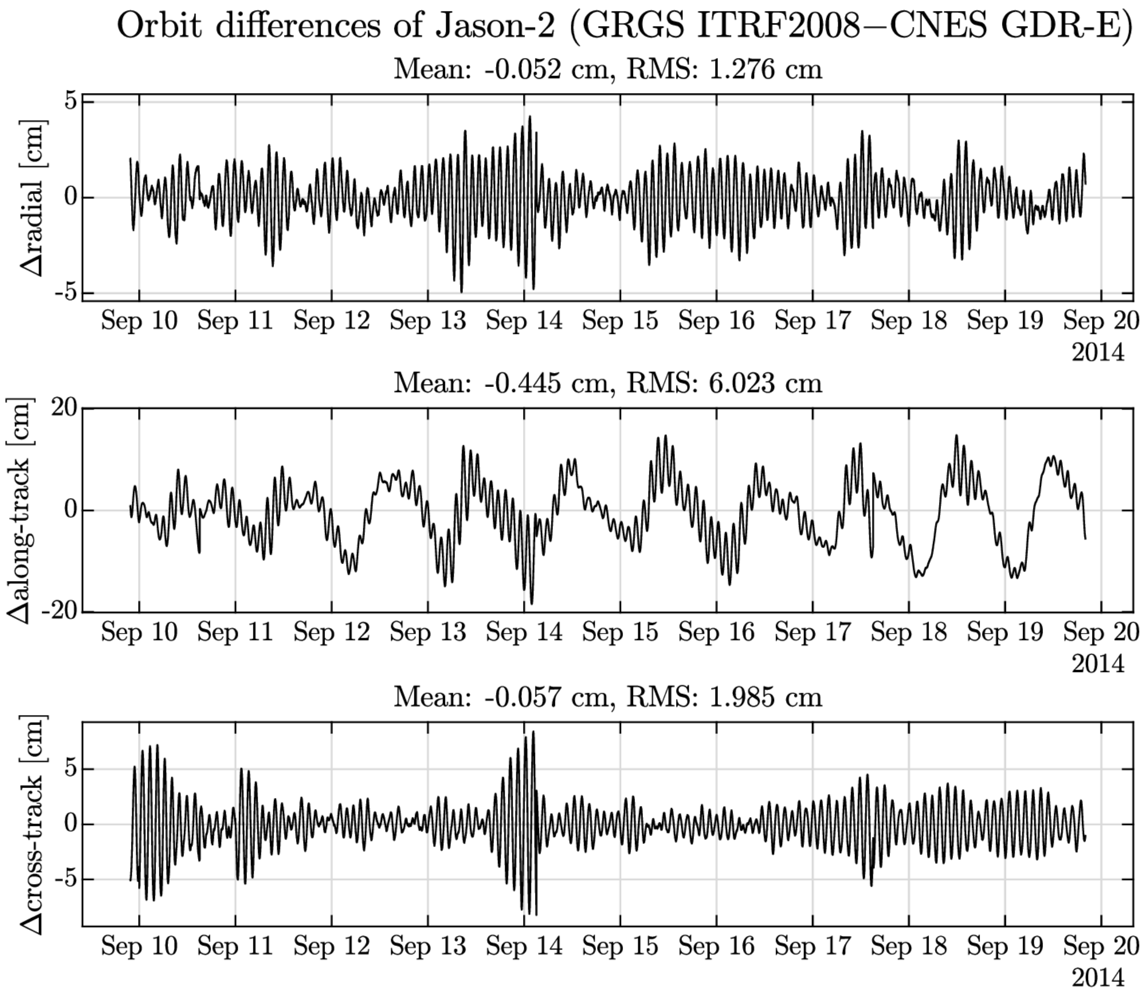
Jason-1 orbit solutions derived by various institutions in the ITRF2008 with the GDR-E orbit standards agree in the radial direction within 0.9 cm (RMS), those of GFZ derived in the ITRF2008 and ITRF2014 agree within 0.2 cm (RMS).

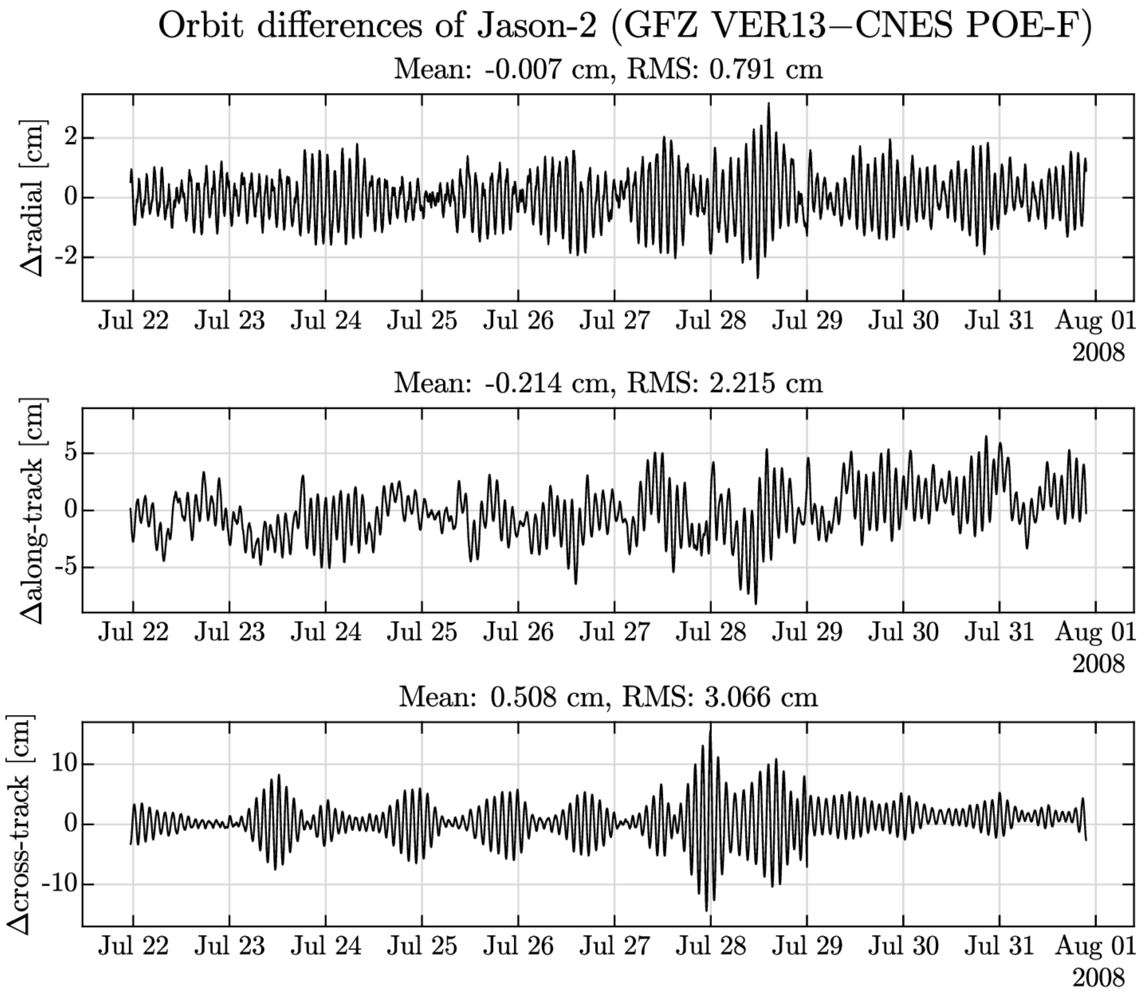
10-day mean of the RMS values of radial orbit differences: Jason-2



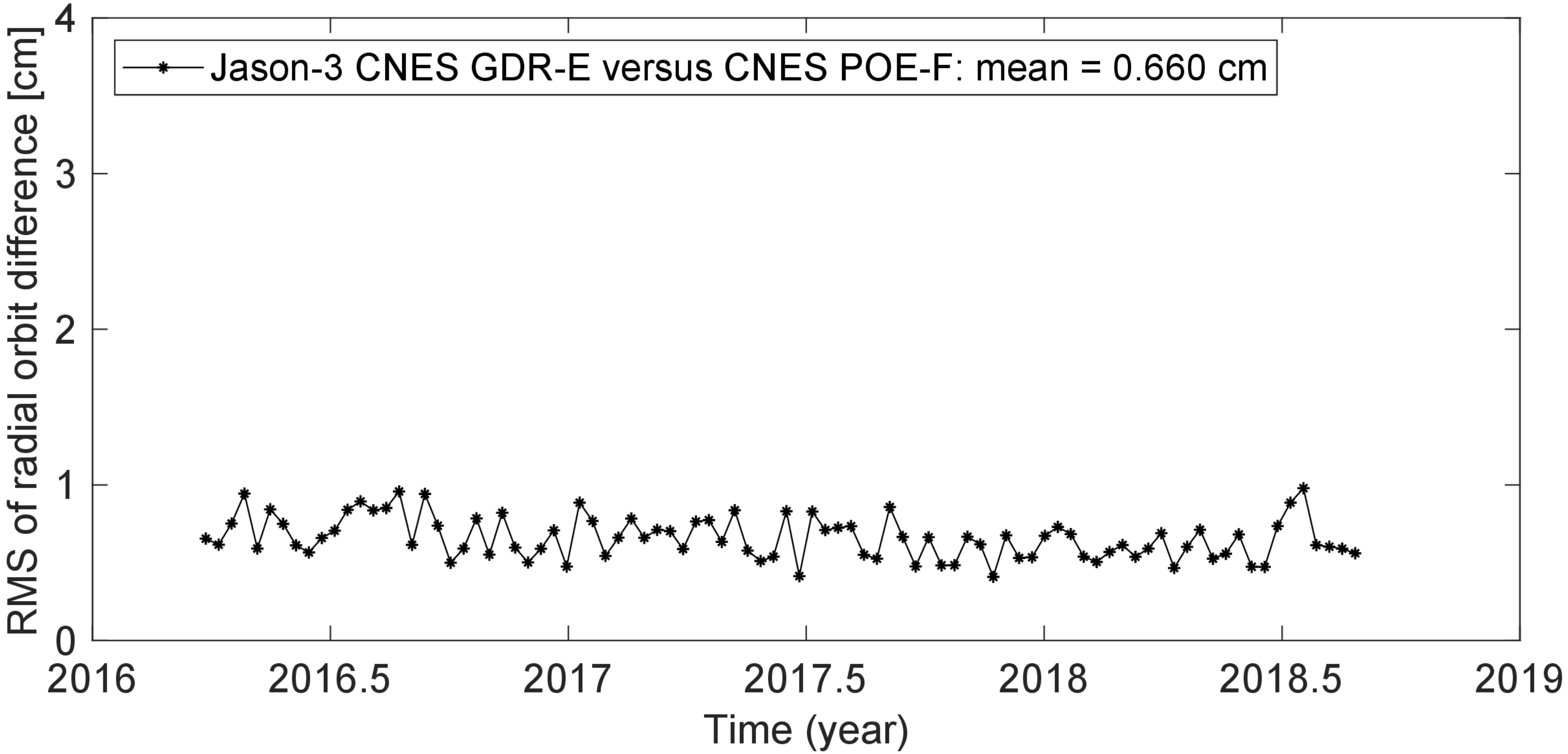
Jason-2 orbit solutions derived in the ITRF2008 with the GDR-E orbit standards agree in the radial direction to 1.3-1.4 cm (RMS), while those derived in the ITRF2014 with POE-F orbit standards – to 0.8 cm (RMS).

Example of the orbit differences for Jason-2: GRGS ITRF2008 – CNES GDR-E (left) and GFZ VER13 – CNES POE-F (right)



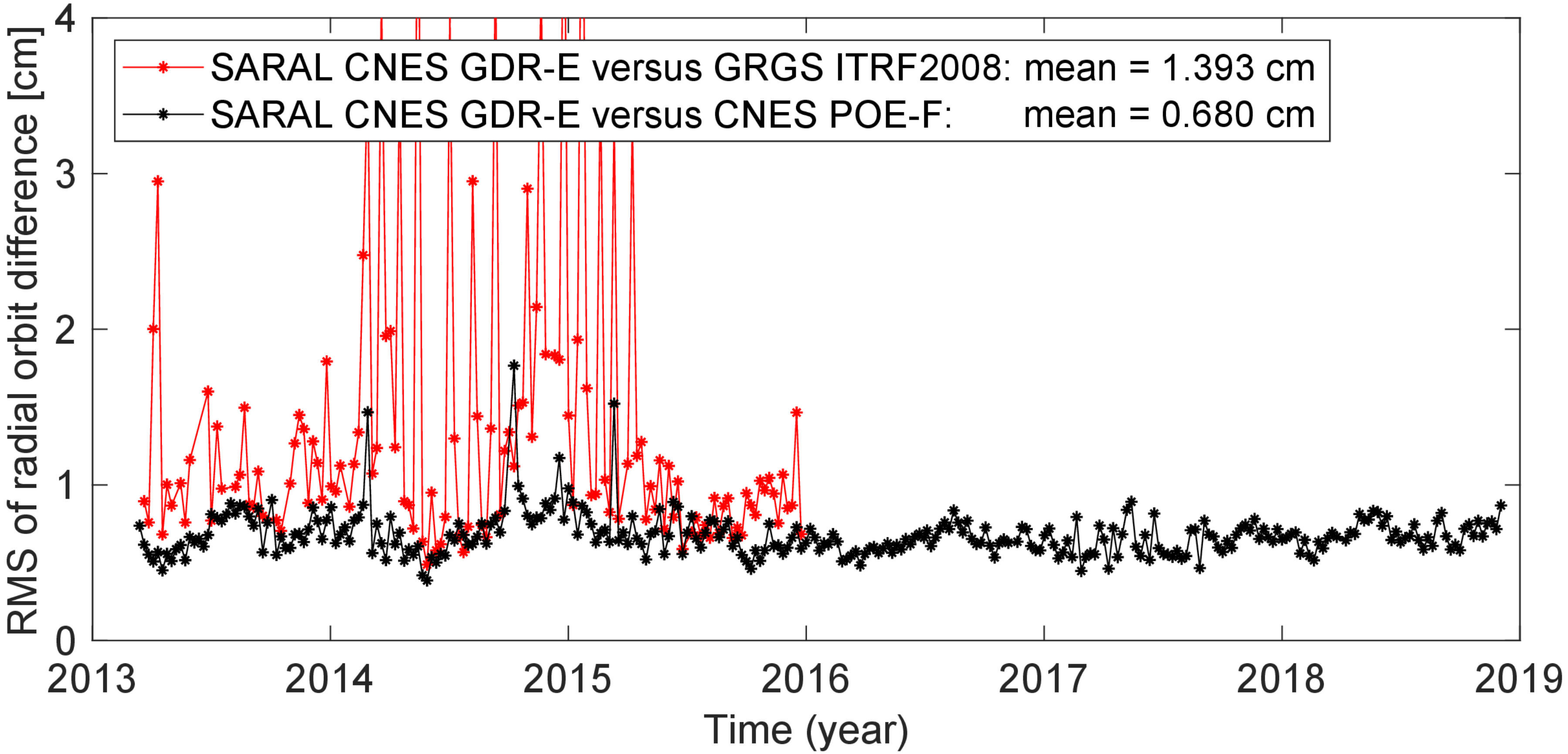


10-day mean of the RMS values of radial orbit differences: Jason-3



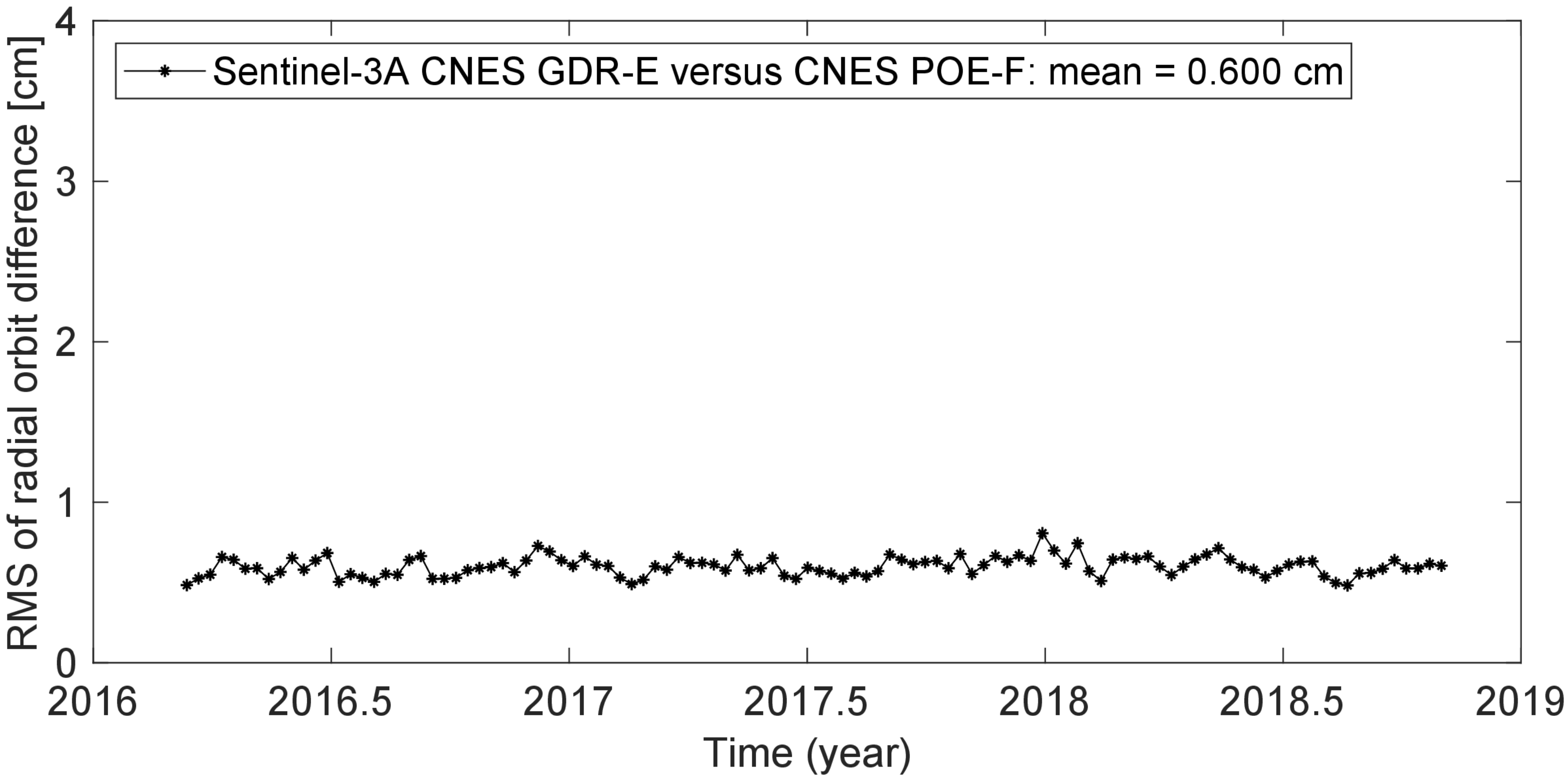
Jason-3 orbit solutions derived by CNES using GDR-E and POE-F orbit standards agree within 0.7 cm (RMS).

7-day mean of the RMS values of radial orbit differences: SARAL



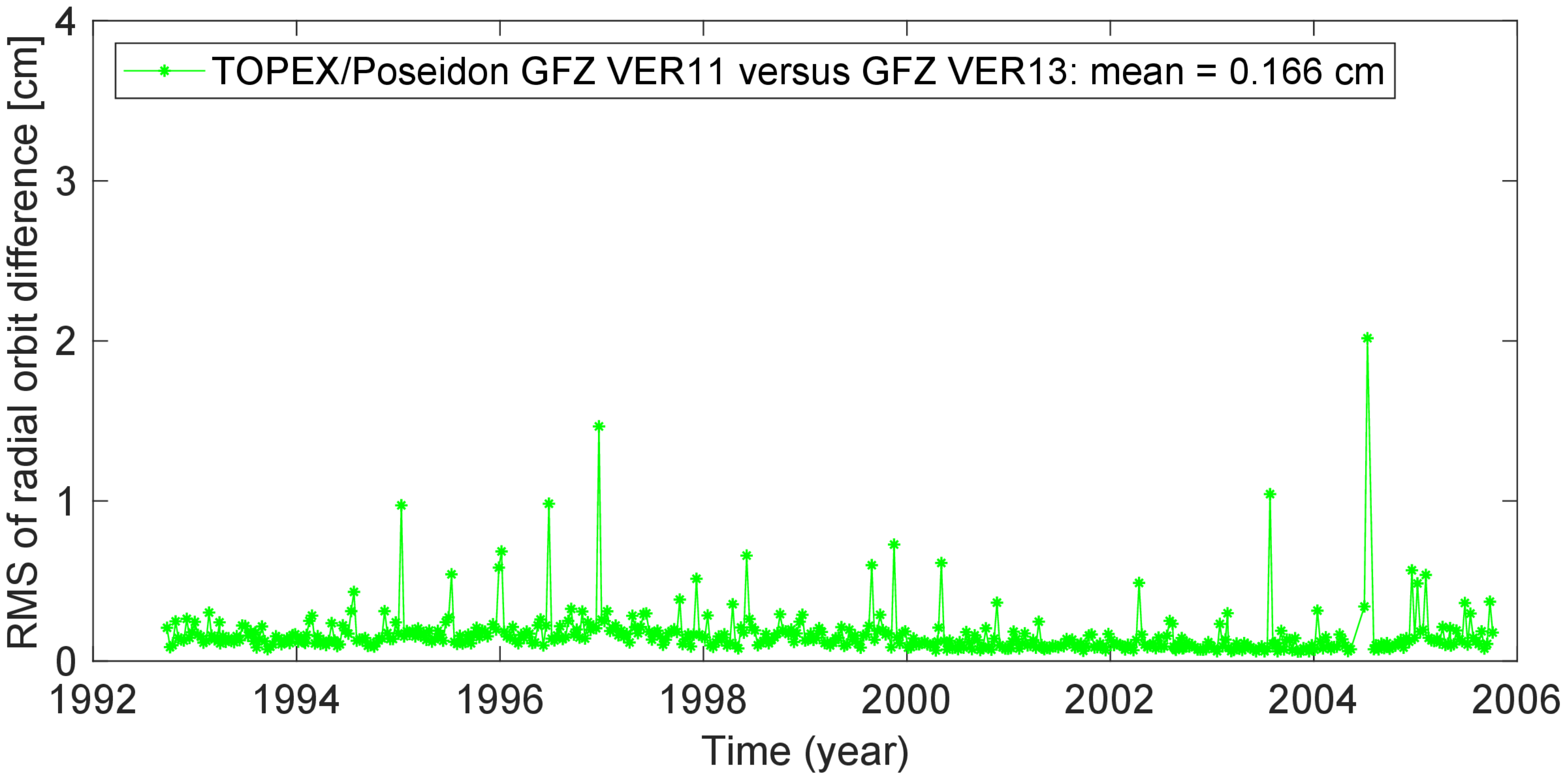
SARAL orbit solutions derived by various institutions in the ITRF2008 with the GDR-E orbit standards agree in the radial direction within 1.4 cm (RMS), those of CNES derived using GDR-E and POE-F orbit standards agree within 0.7 cm (RMS).

10-day mean of the RMS values of radial orbit differences: Sentinel-3A



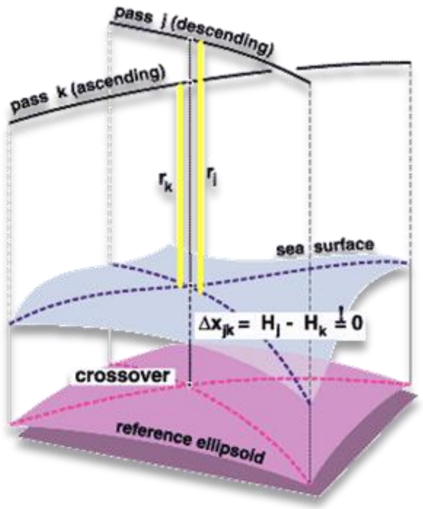
Sentinel-3A orbit solutions derived by CNES using GDR-E and POE-F orbit standards agree within 0.6 cm (RMS).

10-day mean of RMS values of radial orbit differences: TOPEX/Poseidon



TOPEX/Poseidon orbit solutions derived by GFZ in the ITRF2008 and ITRF2014 agree within 0.2 cm (RMS).

Multi-mission crossover analysis (MMXO)

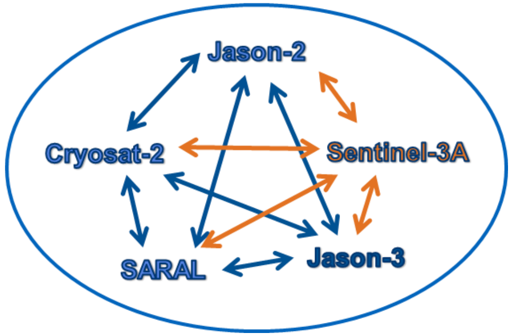


- building **single- and dual satellite sea surface height (SSH) crossover differences** in all combinations (Δt < 2 days)
- minimizing crossover differences and along-track consecutive differences in a least squares adjustment
- **estimation of radial errors at all crossover points**
- automated mission weighting by variance component estimation (VCE)
- TOPEX/Jasons taken as reference mission

Output: **time series of radial errors**

⇒ temporal and spatial characteristics of errors can be analysed

⇒ offsets, scatter, dominant frequencies, geographically correlated errors,…



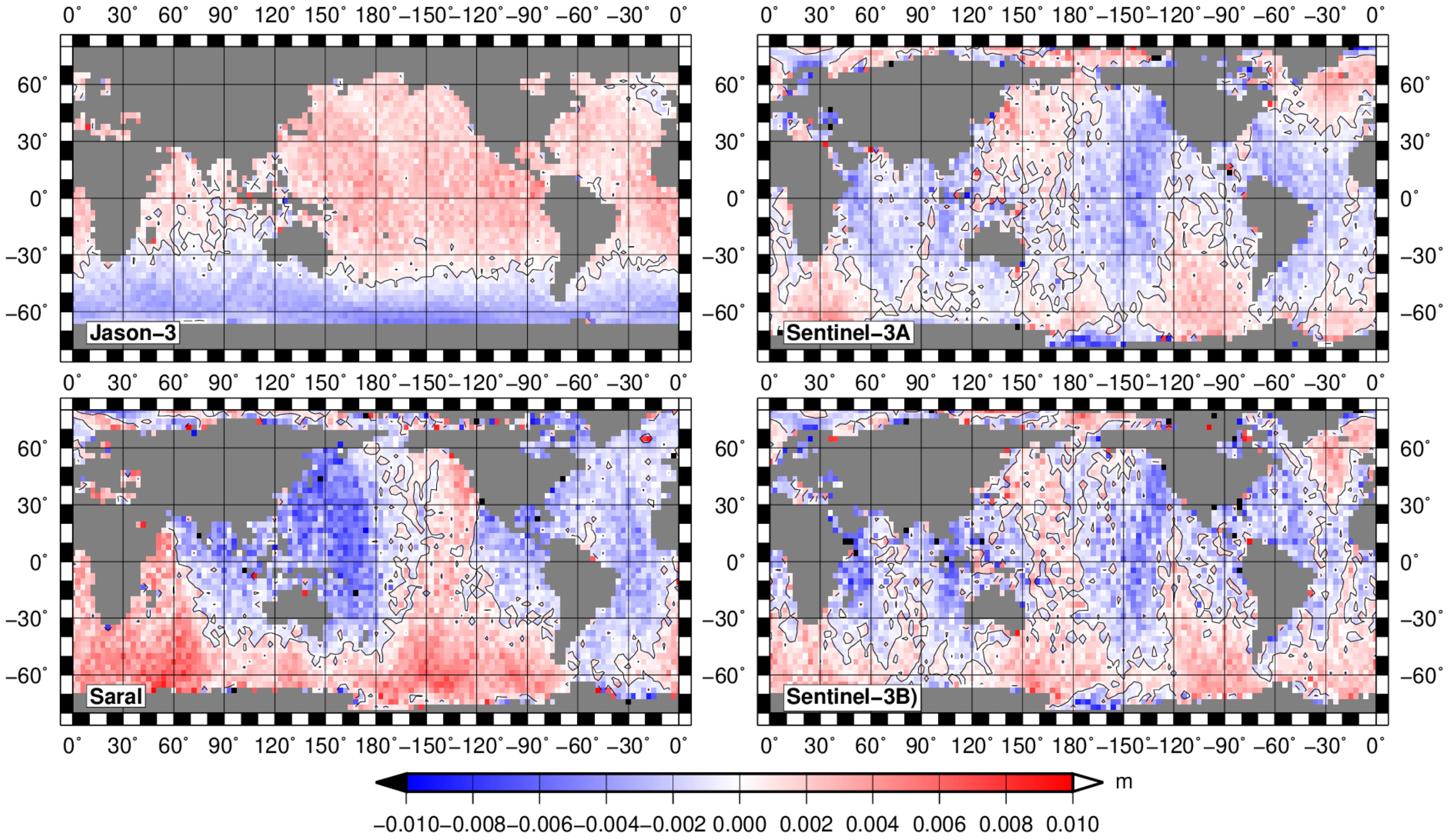
SSH crossover analysis

⇒ Not only orbit errors but also effects from instruments and corrections included

⇒ Comparison of results from different orbit solutions to separate the effects

Bosch et al. (2014)
http://doi.org/10.3390/rs6032255

Geographically correlated errors of CNES POE-F orbits



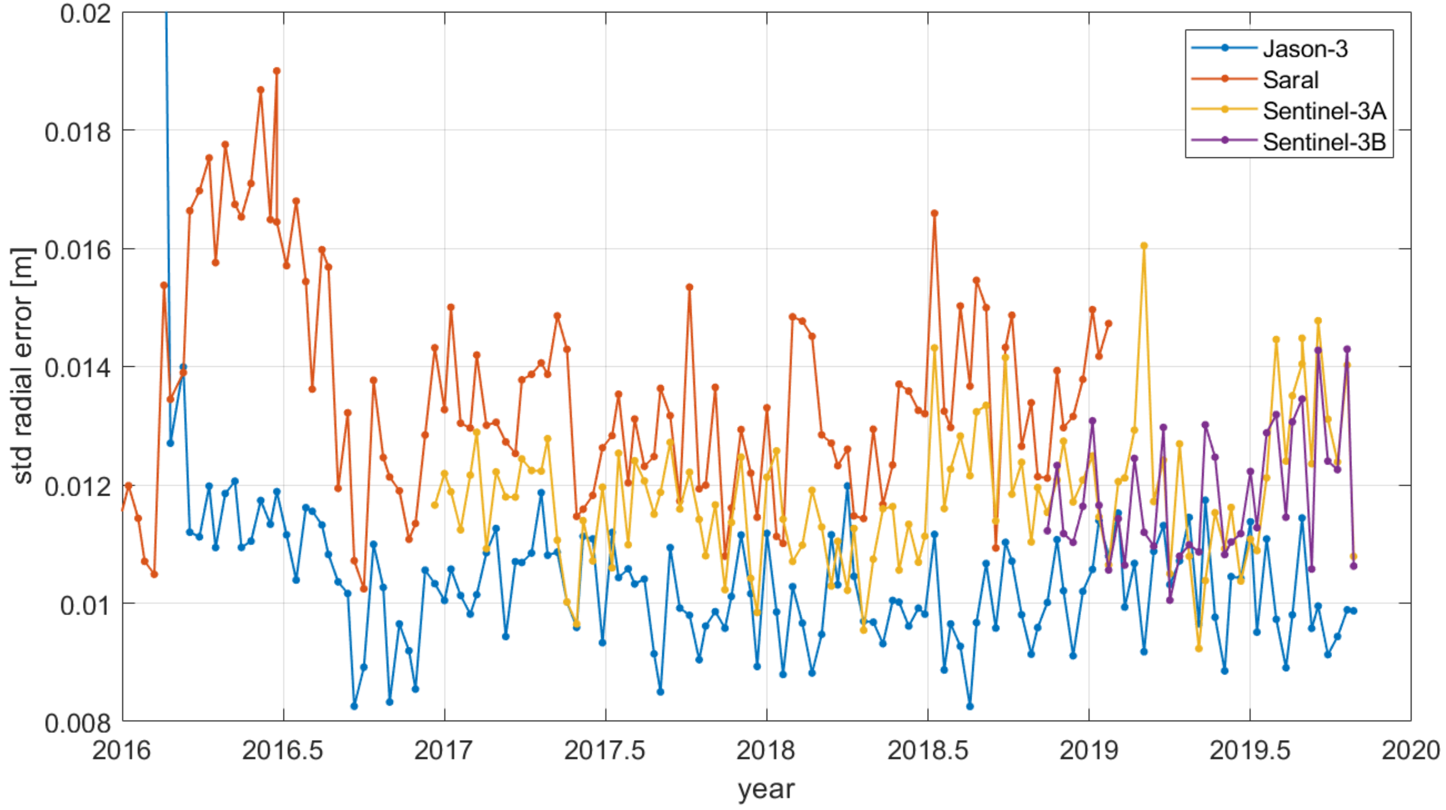
Jason-3:
0.35 ± 2.13 mm

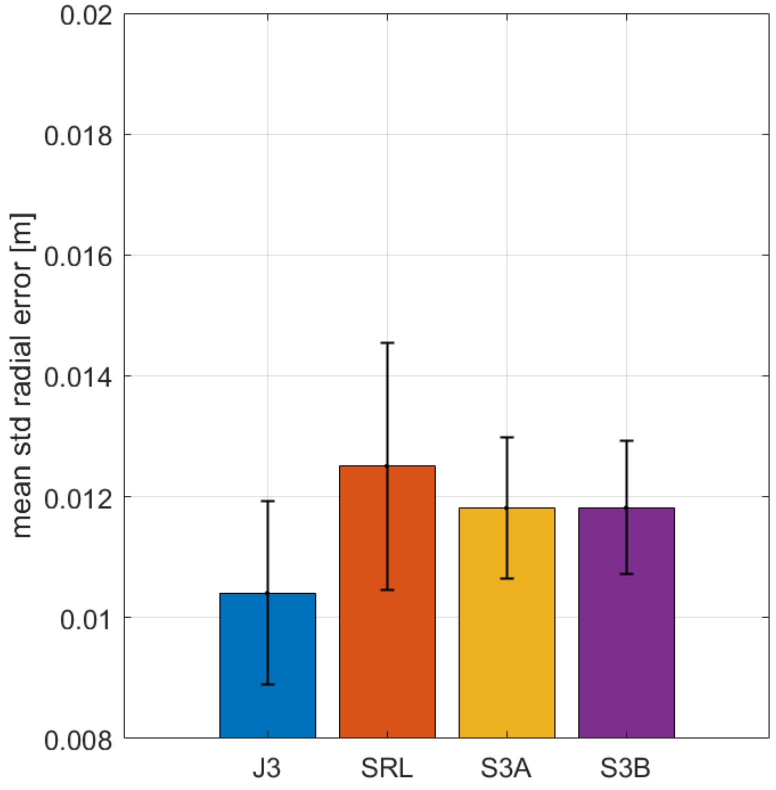
Sentinel-3A:
-0.44 ± 2.16 mm

Saral:
-0.17 ± 3.16 mm

Sentinel-3B:
-0.36 ± 2.72 mm

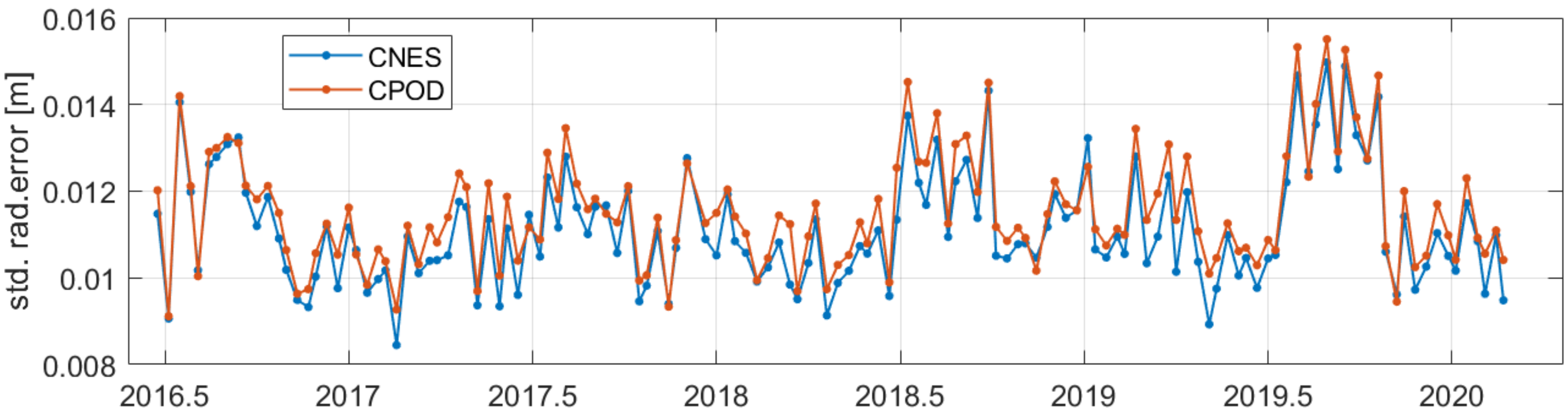
Scatter of radial errors of CNES POE-F orbits





The mean values of standard deviations of radial errors are 1.0-1.3 cm.

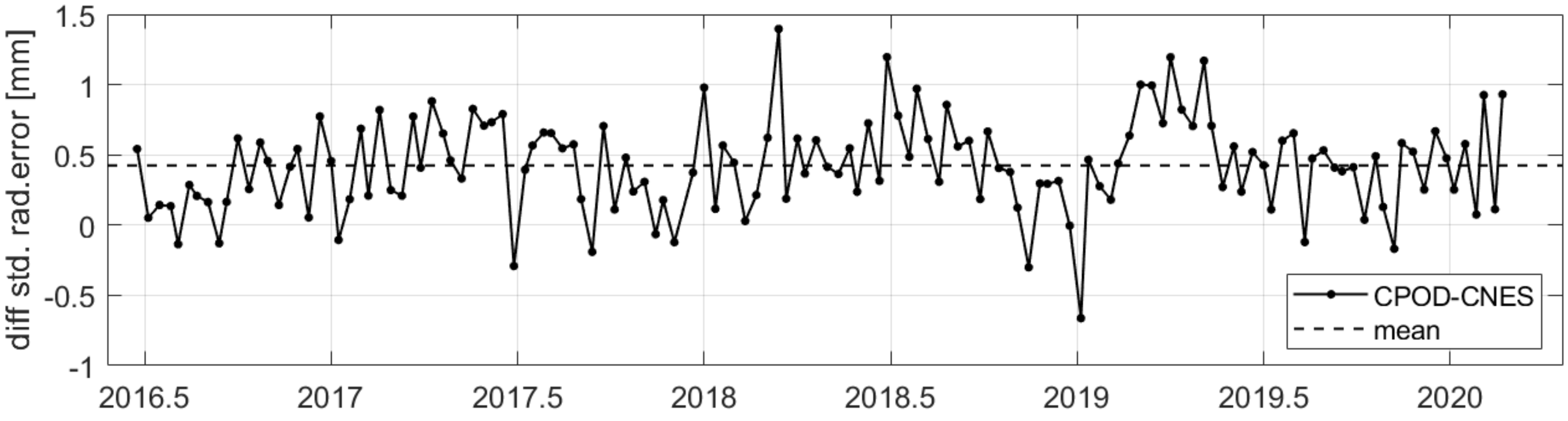
Sentinel-3A: scatter of radial errors of CNES POE-F and CPOD orbits



Rather good agrrement of the scatter of radial errors of two orbit solutions:

1.153 ± 0.131 cm

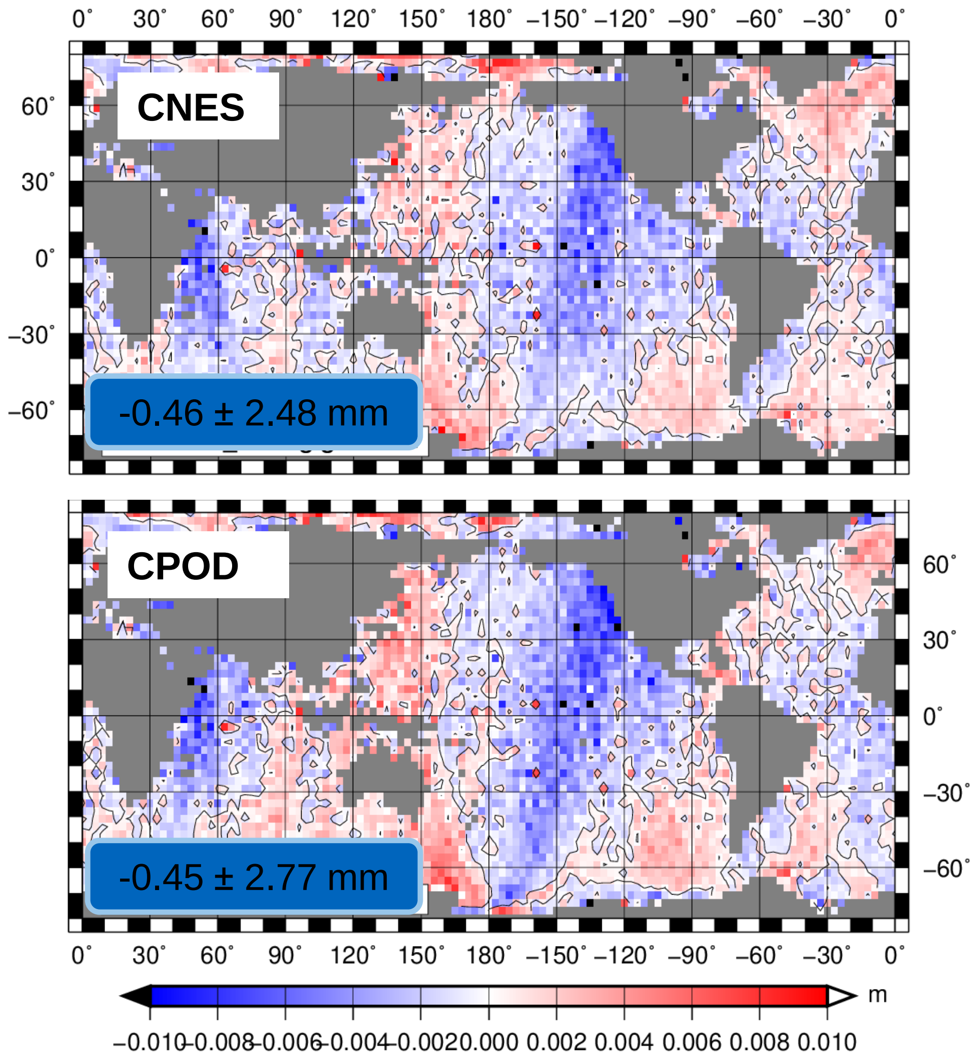
1.110 ± 0.131 cm



0.42 ± 0.33 mm

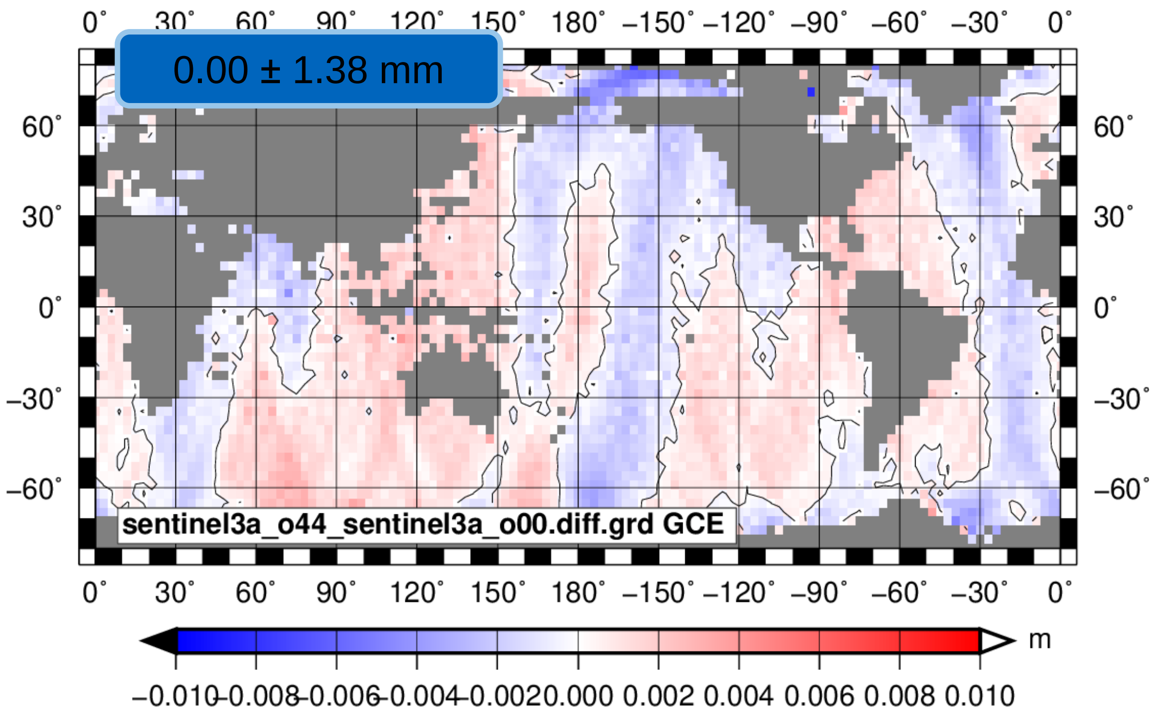
~3.6%

Sentinel-3A: geographically correlated errors of CNES and CPOD orbits

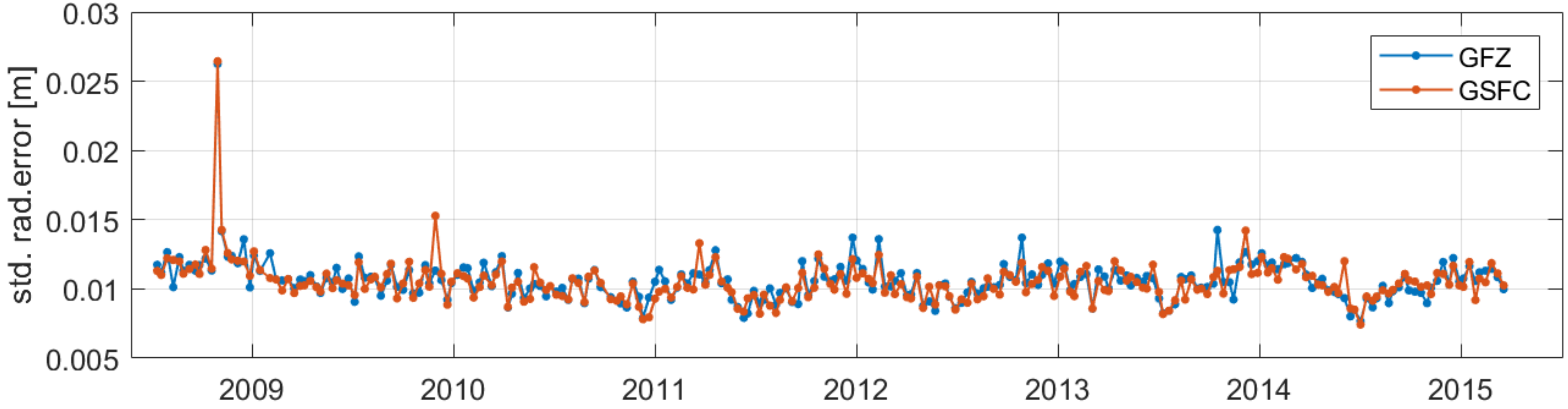


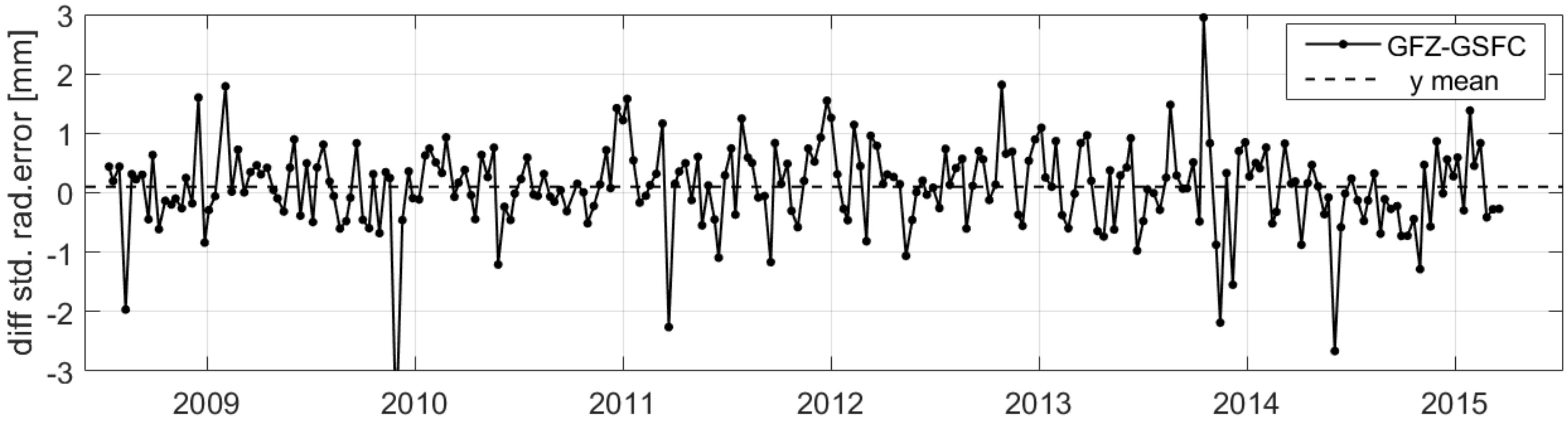
CNES POE-F and CPOD (ITRF2014) orbits
Nov. 2018 – March 2020

CPOD-CNES



Jason-2: scatter of radial errors of GFZ and GSFC orbits





GFZ VER13 and GSFC std1504_14 orbits

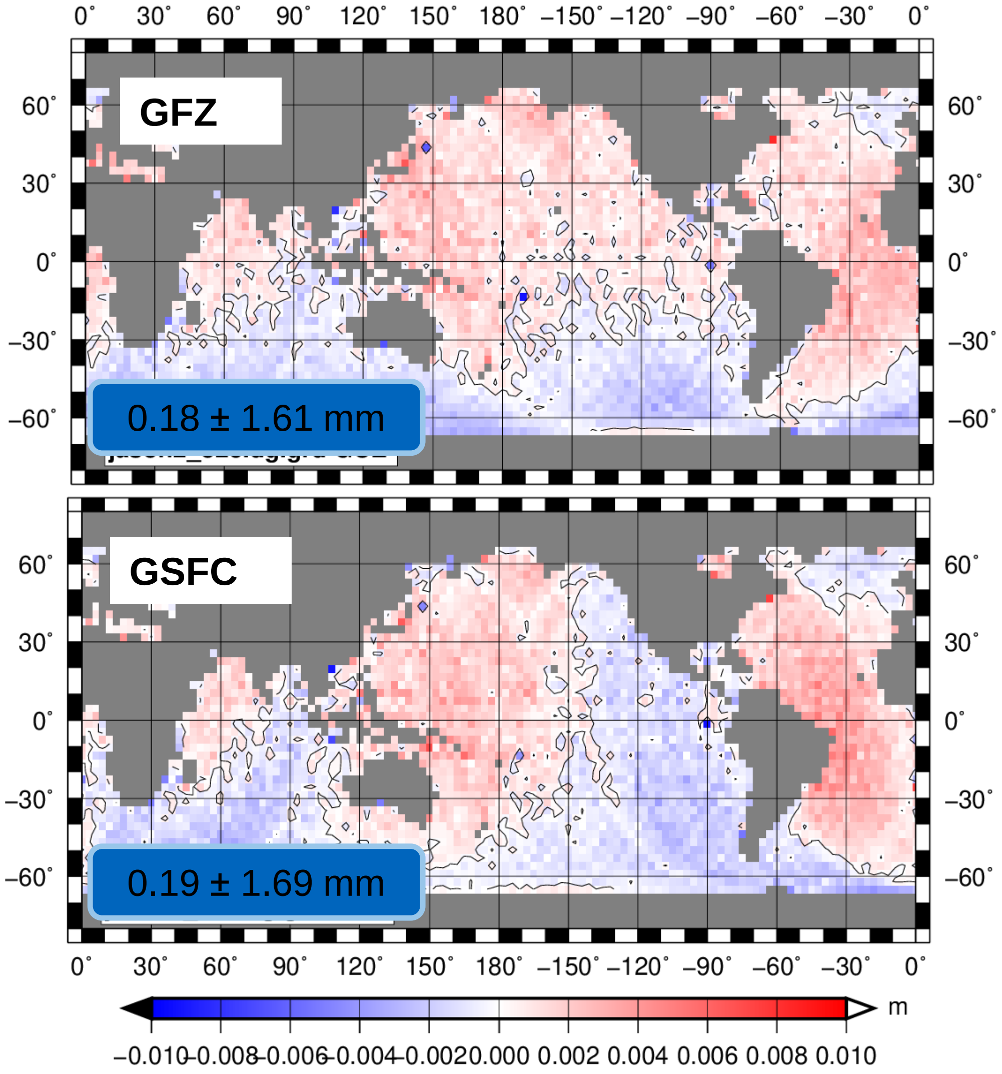
1.051 ± 0.153 cm

1.061 ± 0.154 cm

0.10 ± 0.73 mm

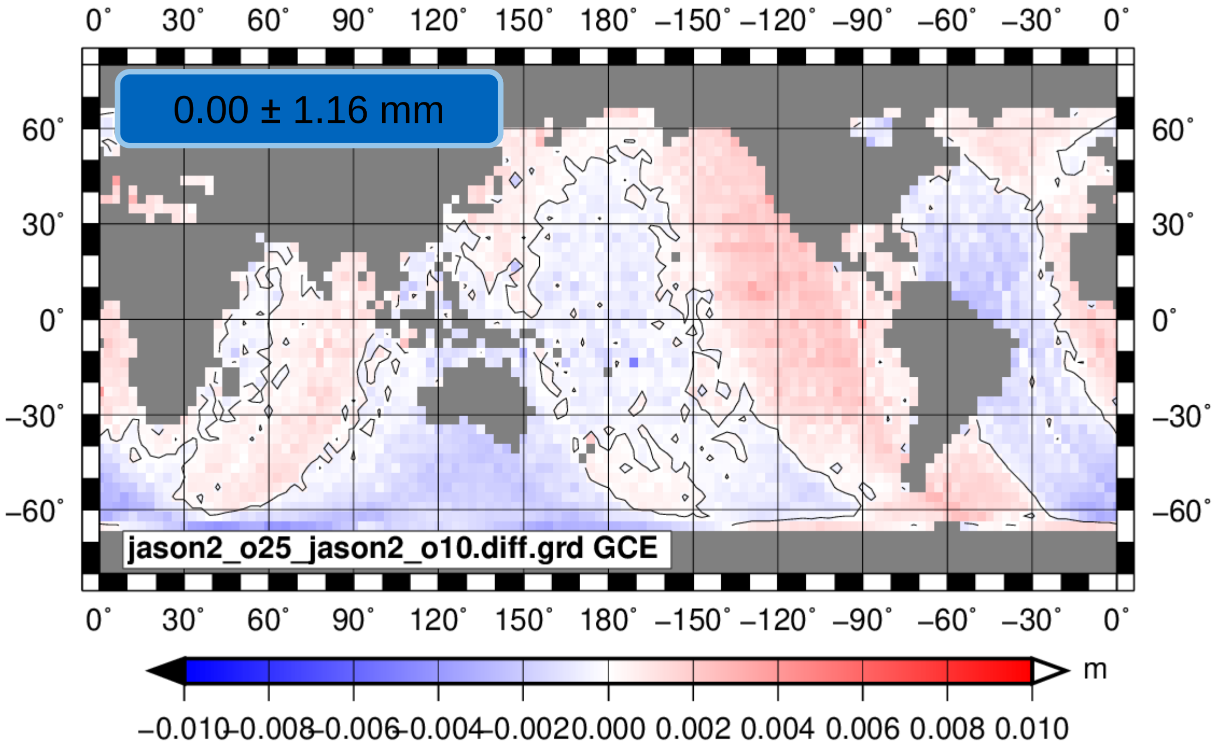
~0.95%

Jason-2: geographically correlated errors of GFZ and GSFC orbits



GFZ VER13 and GSFC std1504 orbits
July. 2008 – March 2015

GFZ-GSFC



Conclusions

The RMS orbit differences in the radial directions are:

0.9 – 1.4 cm for the solutions of different institutions in the GDR-E orbit standards (ITRF2008),
0.8 cm for the solutions of different institutions in the POE-F orbit standards (ITRF2014),
0.6 – 0.7 cm for CNES solutions derived using GDR-E and POE-F orbit standards,
0.2 cm for GFZ orbit solutions derived in the ITRF2008 and ITRF2014.

The standard deviations of the radial errors of the orbits used in this investigation are 1.0 – 1.3 cm.

The mean values of geographically correlated errors (GCE) of these orbits are within ±0.05 cm, the standard deviation of the GCE are 0.16 – 0.32 cm.

The values of the radial errors obtained from the multi-mission crossover analysis fit good to the values of the RMS orbit differences in the radial direction.

The overall conclusion: the accuracy in the radial direction of the up-to-date orbits derived using POE-F orbit standards in the ITRF2014 reference frame used in this study is about 0.8 – 1.0 cm.

Outlook

An availability of additional orbit solutions, in particular, derived using GPS-only, or DORIS+GPS, or DORIS+SLR, or DORIS-only measurements using the latest standards for precise orbit determination would give an insight on the impact of the tracking data and related models on the orbit accuracy.

Further research should help us to investigate the main reasons of the remaining differences of orbit of altimetry satellites.

Use of new, improved models and reference frame realizations for precise orbit determination of altimetry satellites should contribute to the further improvement of the orbit quality for altimetry satellites.

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