Deutsches Geodätisches Forschungsinstitut (DGFI-TUM)
Technische Universität München

Precise orbit determination of altimetry satellites using DORIS and SLR observations in different reference frame realisations

Julian Zeitlhöfler, Mathis Bloßfeld, Sergei Rudenko

Deutsches Geodätisches Forschungsinstitut, Technische Universität München (DGFI-TUM)

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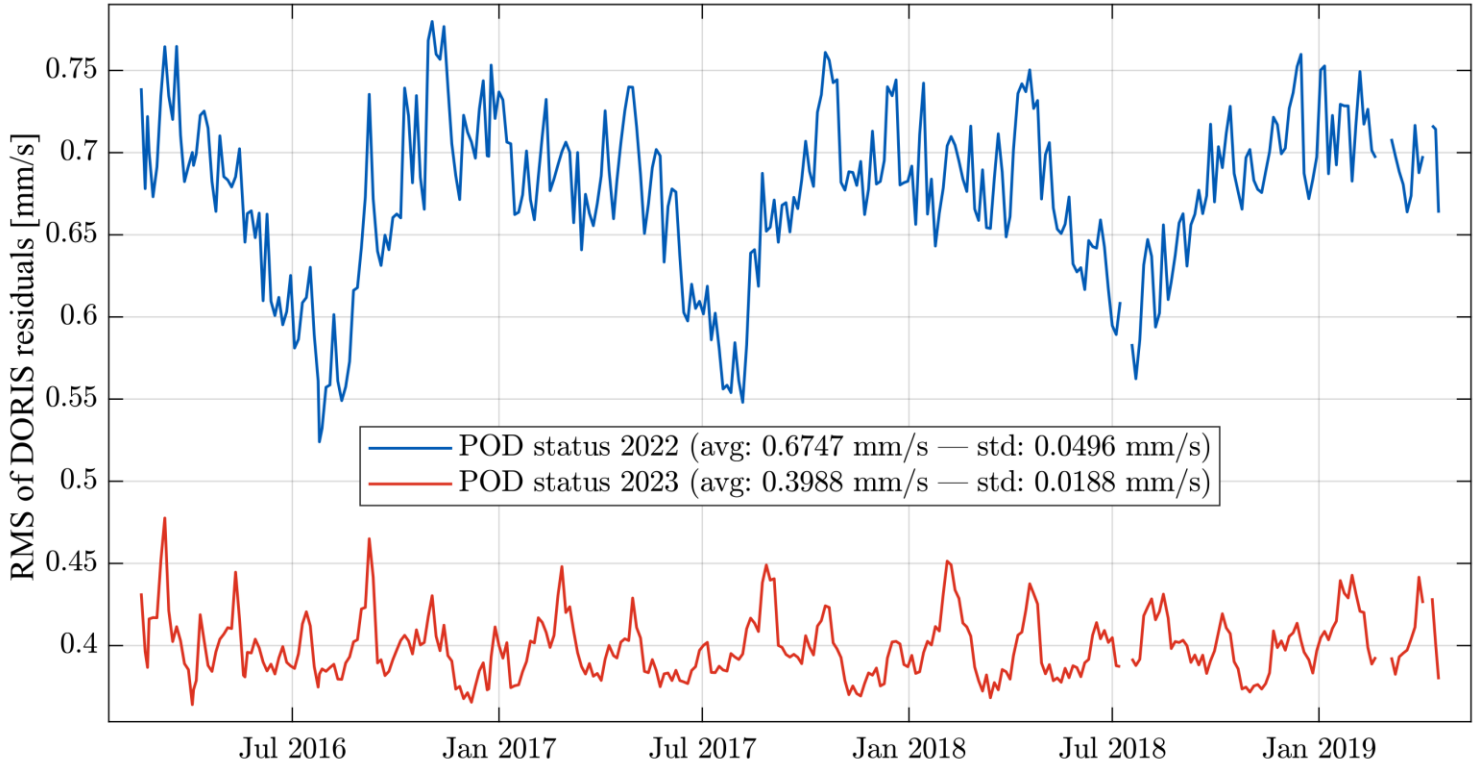
Status of DORIS POD at DGFI-TUM (2023)

Improvements related to the DGFI-TUM POD software DOGS-OC and DORIS data in 2023:

- Enhanced bias handling
- Integration of DORIS RINEX format
- Implementation of the observation weighting

Results of the Jason-3 DORIS POD in 2023:

➢ Further improvement required



Research stay at CNES in Toulouse

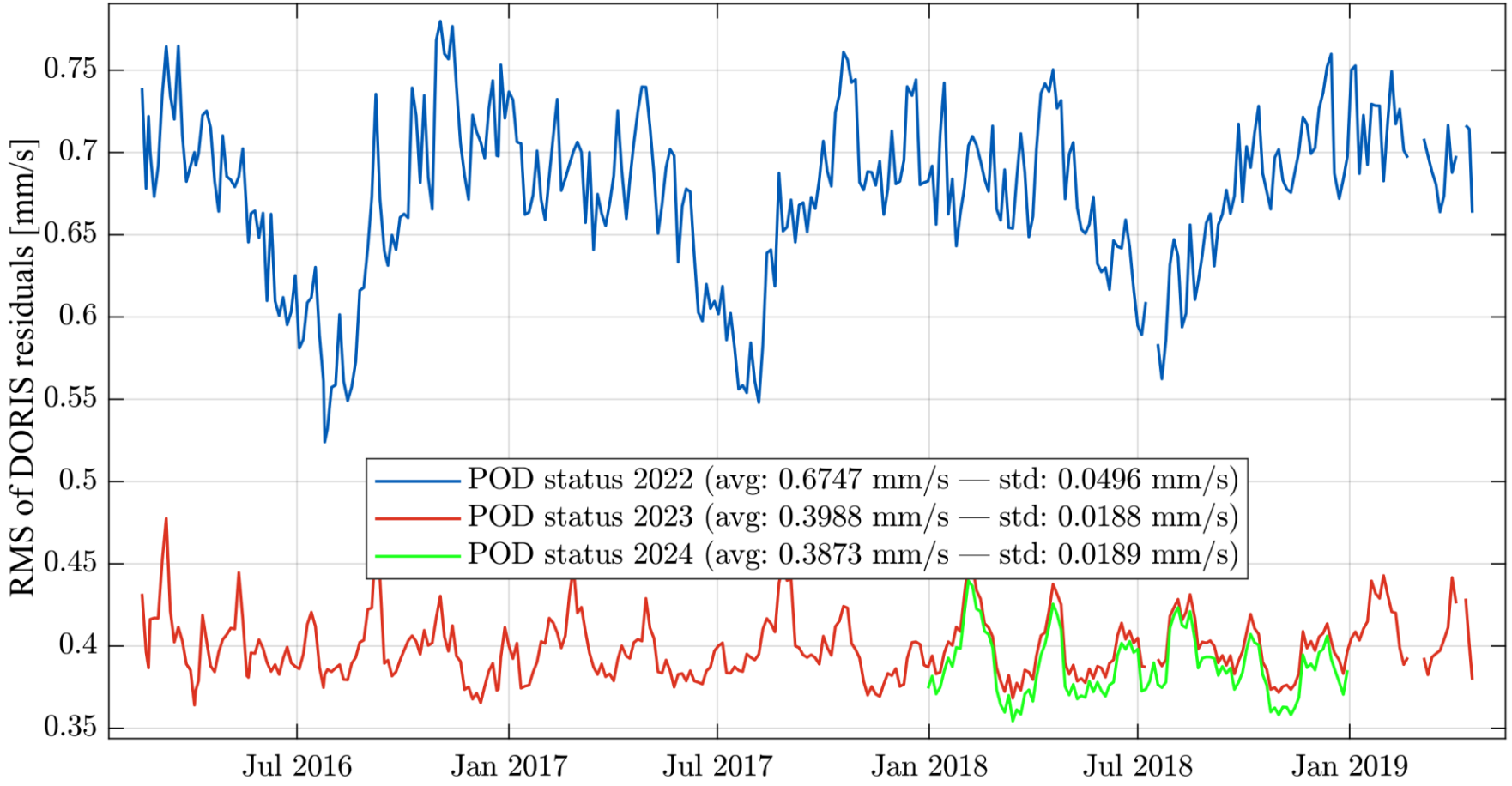
- Supervisors: Jean-Michel Lemoine (CNES), Hugues Capdeville (CLS)
- When: in May and June 2024
- Where: at CNES in Toulouse, France

Benefits of the research stay:

- Further development of the DGFI-TUM POD software DOGS-OC
  - Check of observation processing in- and outside the POD software
  - Processing of RINEX observations refined
  - Consideration of beacons with shifted frequency
  - Consideration of ionosphere-free phase centre (at beacon and on-board)
  - Application of the DORIS phase wind-up effect
  - Weighting of DORIS observations (suggestion by CNES)
- Improving the POD quality at the Associate Analysis Center (AAC) DGFI-TUM
- Enhancement of the DORIS documentation at the IDS website

Research stay at CNES in Toulouse

DORIS RMS before and after the implementations in Toulouse



Current DORIS POD setup

Observations:
- Use of DORIS observations in the IDS2.2 and DORIS RINEX formats
- Conversion of DORIS RINEX data into the GINS format

Parameter estimation:
- Frequency bias (per pass) / frequency drift (per arc)
- Past troposphere implementation: zenith delay (Collins, 1999), mapping functions (dry, wet by Niell), scale factor of tropospheric refraction (per pass)
- Current troposphere implementation: hydrostatic zenith delay (Saastamoinen), wet zenith delay (estimated*), zenith mapping functions (VMF3), hydrostatic and wet gradients (estimated*), gradient mapping functions (VMF3)

  *possible parametrisations: pass-wise, constant, piece-wise constant, continuous piece-wise linear (polygon), discontinuous piece-wise linear (offset+drift)
- Solar radiation pressure (per arc), Earth's radiation pressure (per arc), atmospheric drag (12h res.), empirical accelerations (periodic per arc sine+cosine in tranverse and normal, polygon 12h res. in normal)

DORIS-related effects/models:
- Frequency shift at selected beacons, DORIS phase wind-up effect, weighting of DORIS observations

Station coordinates:
- DPOD2014 versions, DPOD2020 versions 1.x, DPOD2020 versions 2.x (including additional files)

ITRS 2020 realisations

- Three different ITRS 2020 realisations: ITRF2020 (IGN), DTRF2020 (DGFI-TUM), JTRF (JPL)
- The ITRS realisations are based on identical input data but on different combination strategies. This results in a different array of products

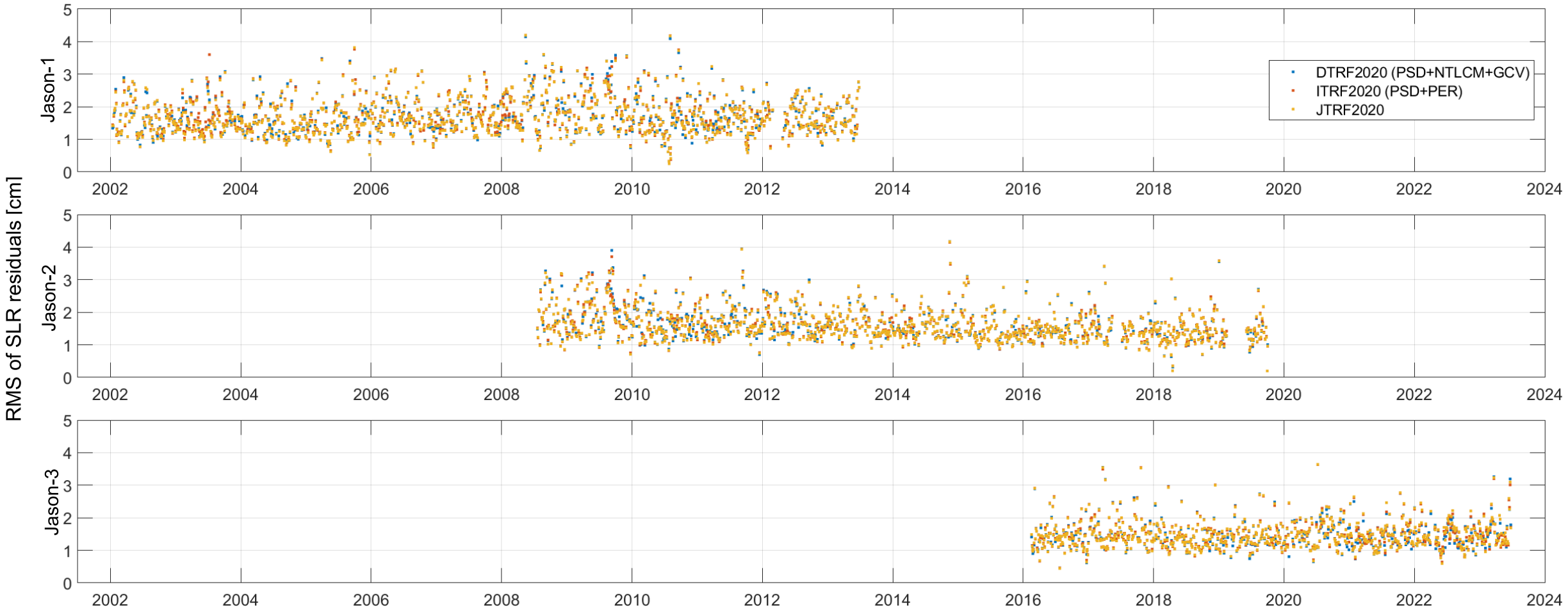
Session 12.2 (Sep. 4): Seitz et al.: DTRF2020 update

	ITRF2020 (Altamimi et al., 2023)	DTRF2020 (Seitz et al., 2023)	JTRF2020 (Gross et al., 2023)
combination level	solution	normal equation	solution
station coordinates	positions and velocities at reference epoch 2015.0	positions and velocities at reference epoch 2010.0	daily positions
post-seismic deformation (PSD)	coefficients of PSD function	discrete PSD correction time series	-
periodic corrections	(semi-)annual + GNSS draconitic periods (and harmonics)	-	-
non-tidal loading (NTL) corrections	-	time series of atmospheric, oceanic and hydrological NTL corrections	-
SLR network translations	1)	translation time series between 1983.0 and 2020.0	-
Helmert transformation residuals	1)	residual time series between 1979.0 and 2020.0	-
history	ITRF1994, ITRF1996, ITRF1997, ITRF2000, ITRF2005, ITRF2008, ITRF2014	DTRF2008, DTRF2014	JTRF2014

1) available at https://itrf.ign.fr/en/solutions/ITRF2020#itrf2020-based-time-series-of-origins-and-scales

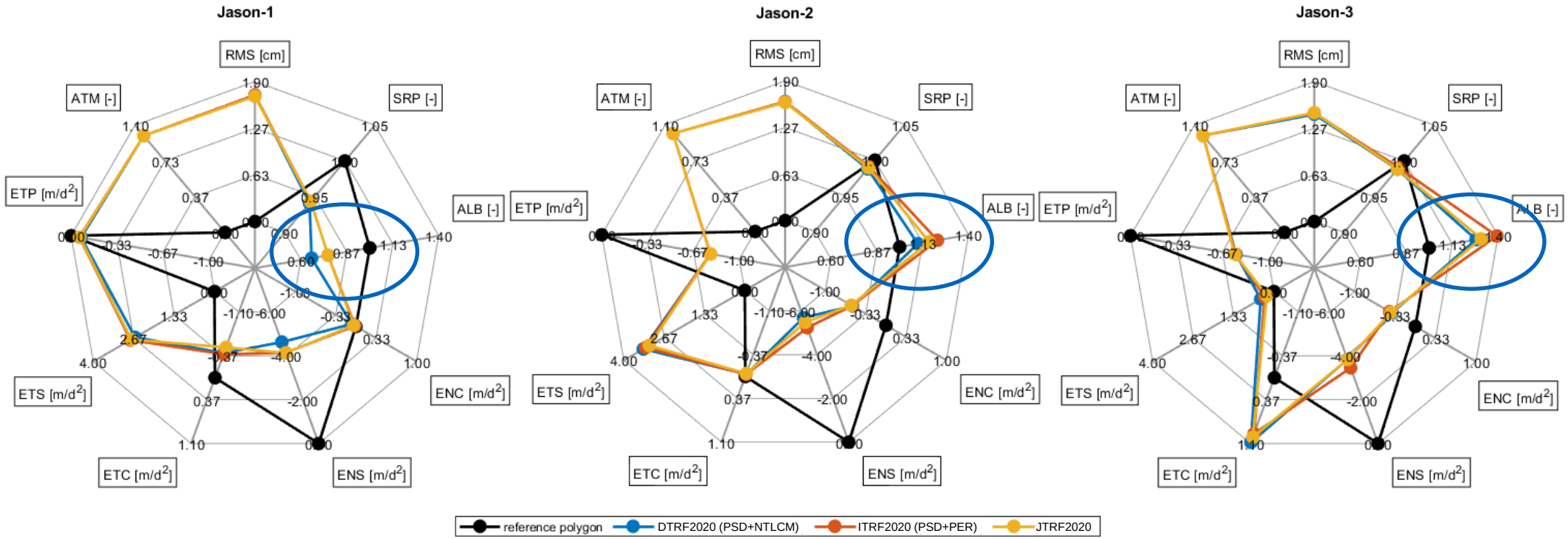
xTRF2020: RMS values of SLR residuals

- **No obvious differences** between the RMS values of the SLR observation residuals found for all xTRF2020 solutions (**most recent ILRS DHF used; cf. LAGEOS-1 RBs for Jason-1/2/3**)



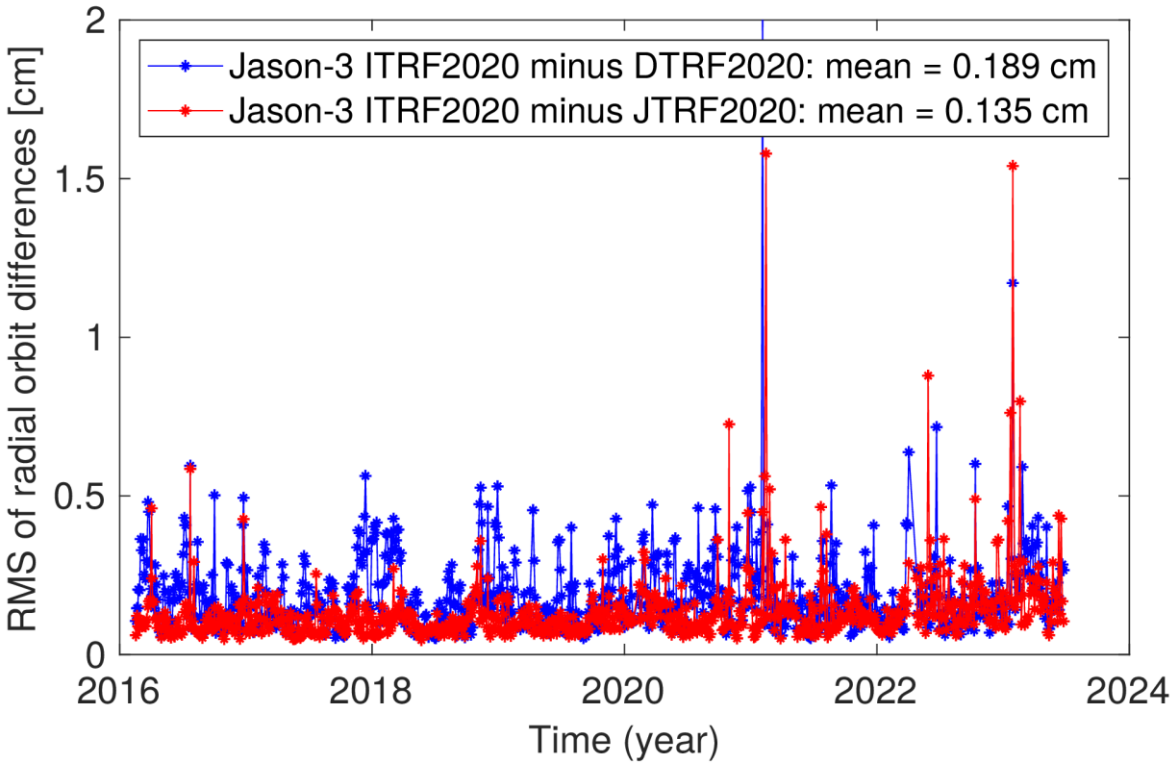
xTRF2020: impact on estimated POD parameters

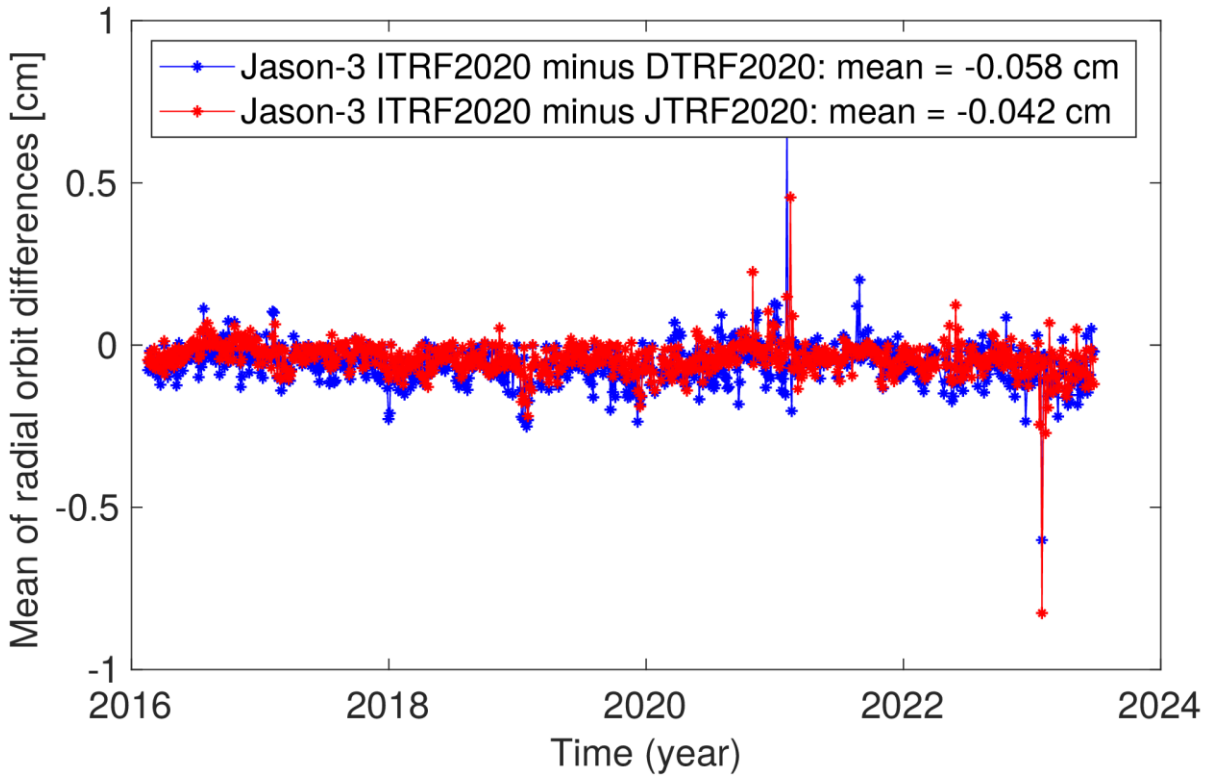
- Nearly all orbit parameters are very similar using different TRF solutions
- Estimated **Earth's albedo and infrared radiation scale factors differ**. Is it due to different realisation of xTRF2020 scales?



RMS – root mean square	ENC/S – empirical cosine/sine coefficient (normal to orbit)
SRP – solar radiation pressure scale factor	ETC/S – empirical cosine/sine coefficient (tangential to orbit)
ALB – Earth Albedo scale factor	ETP – empirical piece-wise linear polygon (tangential to orbit, 12h resolution)
ATM – Atmospheric drag scale factor polygon (12h resolution)	

xTRF2020: RMS & mean of radial orbit differences (Jason-3)



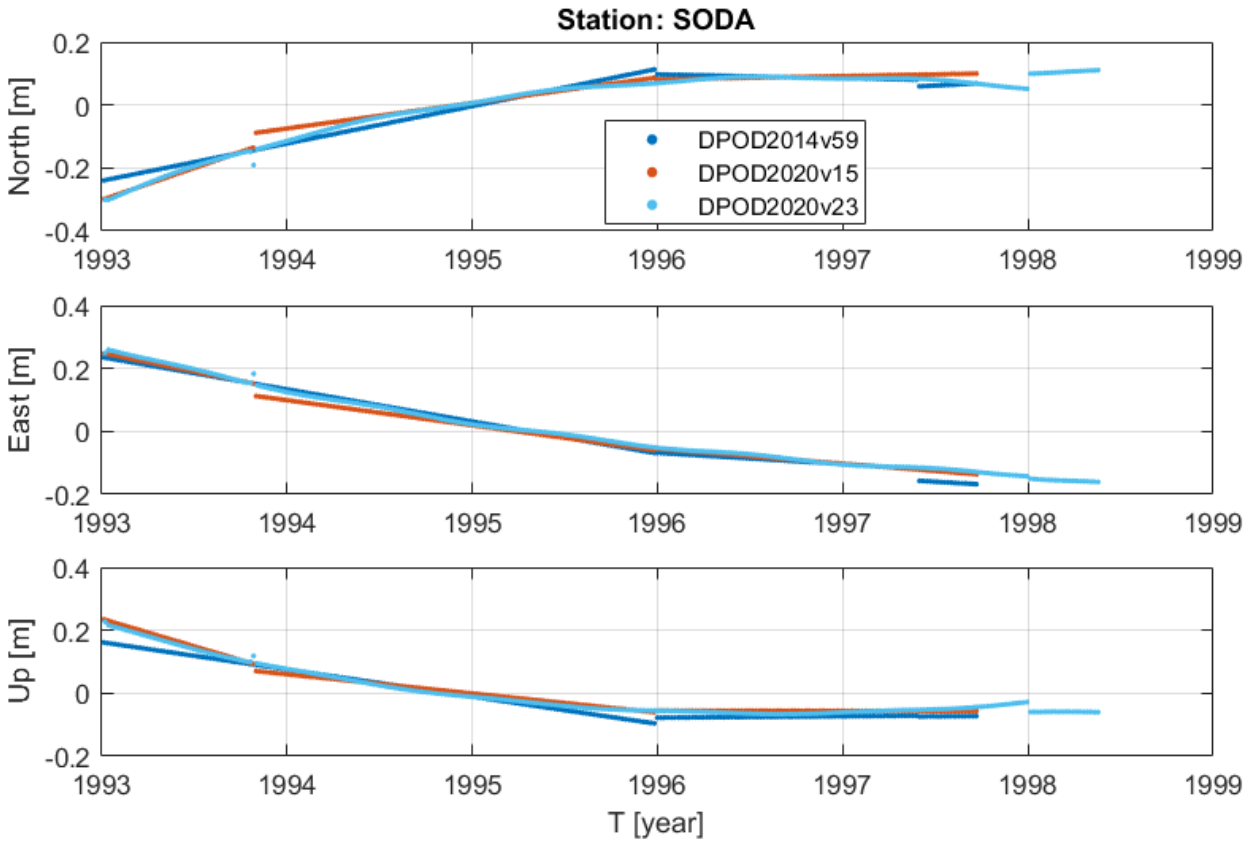


- Larger agreement between ITRF2020 & JTRF2020 compared to ITRF2020 & DTRF2020 based orbits
- The RMS and mean values of the orbit differences in the radial direction for xTRF2020-based orbits of Jason-3 are 0.14-0.19 cm and –(0.04-0.06) cm, respectively.

Session 5.2 (Sep. 4): Rudenko et al.: Progress in POD of altimetry satellites

Comparison of different DPOD versions

- DPOD2014v59 (Moreaux, 2020)
  - Contains 218 DORIS stations at 90 sites
- DPOD2020v15 (Moreaux, 2023)
  - Contains 217 DORIS stations at 89 sites
  - Secular DPOD realise mean centre of mass (CM) in POD
- DPOD2020v23 (most recent version; Moreaux, 2024)
  - Contains 221 DORIS stations at 89 sites
  - Includes periodic (annual and semi-annual) for all stations (are the corrections also given in CM frame?)
  - Includes post-seismic deformation corrections for selected stations
  - Refinement of the SINEX content: harmonisation of DATA/REJECT and SITE/ECCENTRICITY time intervals



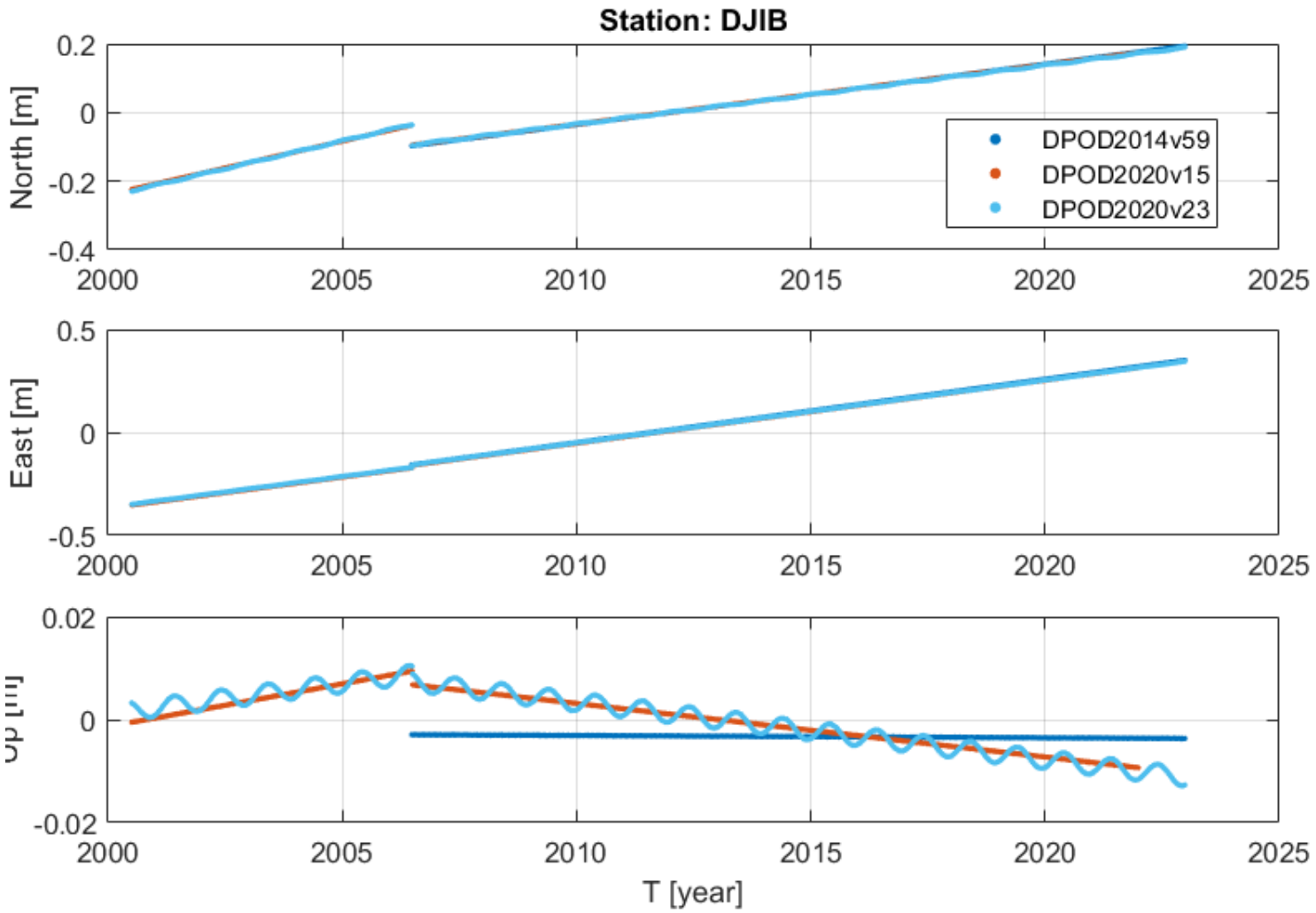
Comparison of different DPOD versions

DORIS station DJIB:
- Djibouti, Djibouti
- DOMES: 39901S002
- Sol. 1: 04.07.00 – 27.06.06
- Sol. 2: 28.06.06 – …

DPOD2014v59 >> DPOD2020v15:
- Partly different station velocity
- Position error at cm-level in case of extrapolation of DPOD2014 up to today

DPOD2020v15 >> DPOD2020v23:
- Periodic signals in DPOD2020v2
- Updated SOLUTION/EPOCHS block

North, East, Up w.r.t. mean position in DPOD2020v23 (WGS84)



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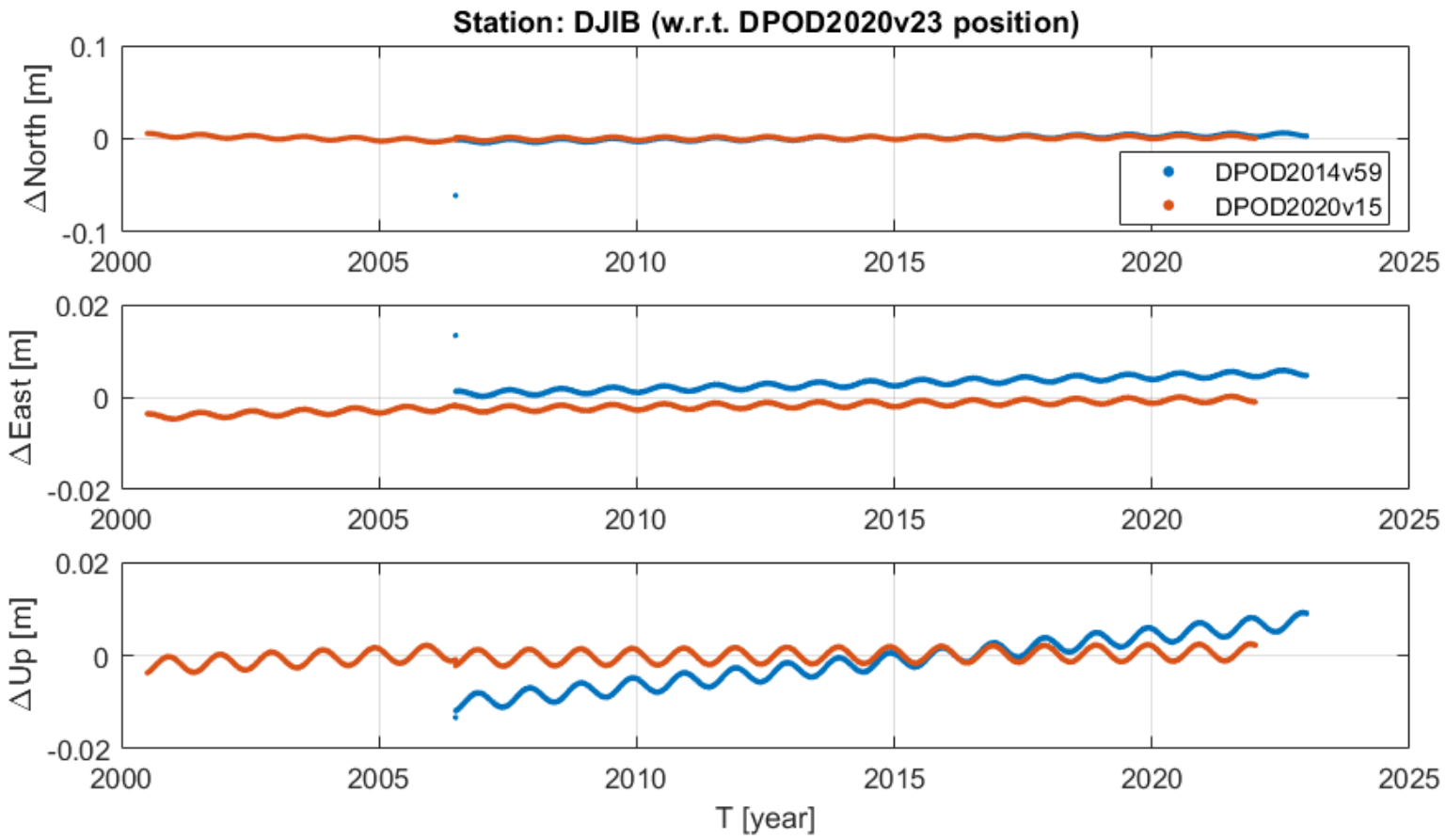
➢ Position differences of most stations at the level of few centimetres.



Orbit interpolation accuracy

- **Orbit comparisons** with internal and external orbit solutions **important for orbit validation and quality assessment**
- **Interpolation required** for orbits provided in different time systems (e.g., UTC, TAI, GPS) and at different time instants
- Orbits mostly exchanged via the **SP3 format** (Hilla, 2016) in the terrestrial reference frame
- **Coordinate transformation required** for the comparison in the orbital system (radial, transverse, normal, RTN)
- Several experiments performed to assess the accuracy of polynomial interpolation methods (Zeitlhöfler et al., 2024)

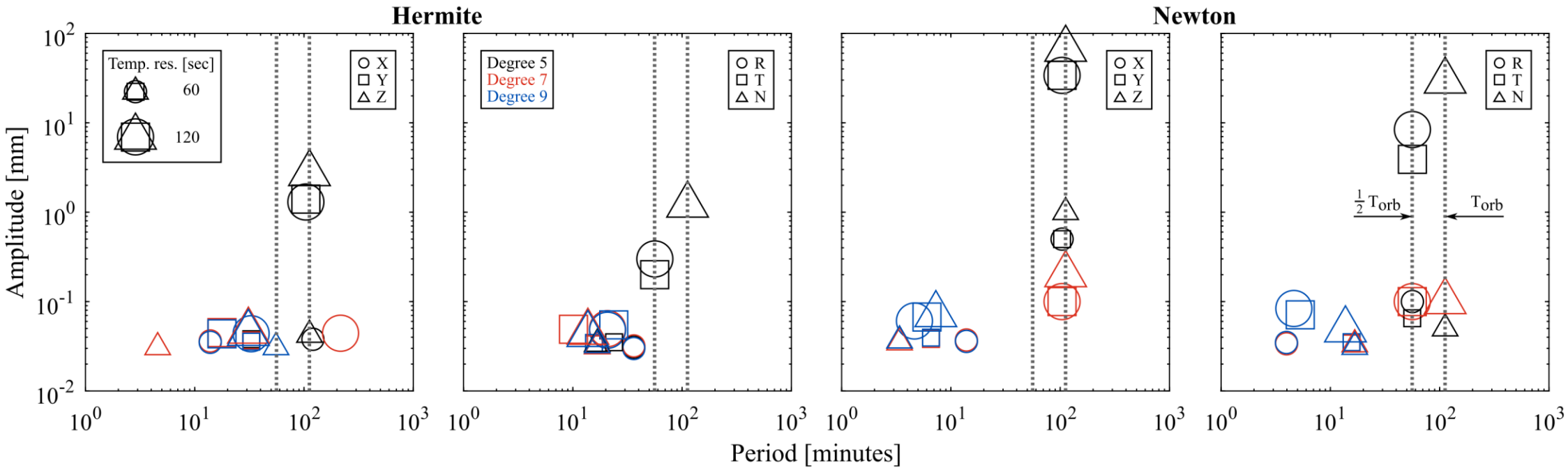
Target: to obtain interpolation accuracy well below one millimetre

Reasons:
- Differences between background models are progressively getting smaller
- These small differences map into the orbits and cause small orbit differences (e.g., Rudenko et al., 2023)

Orbit interpolation accuracy

Interpolation accuracy:

- Best results for the **Hermite interpolation** method
- Increasing the interpolation degree benefits the interpolation accuracy
- **Minimum interpolation error of 0.5 mm** in all cases (average value)

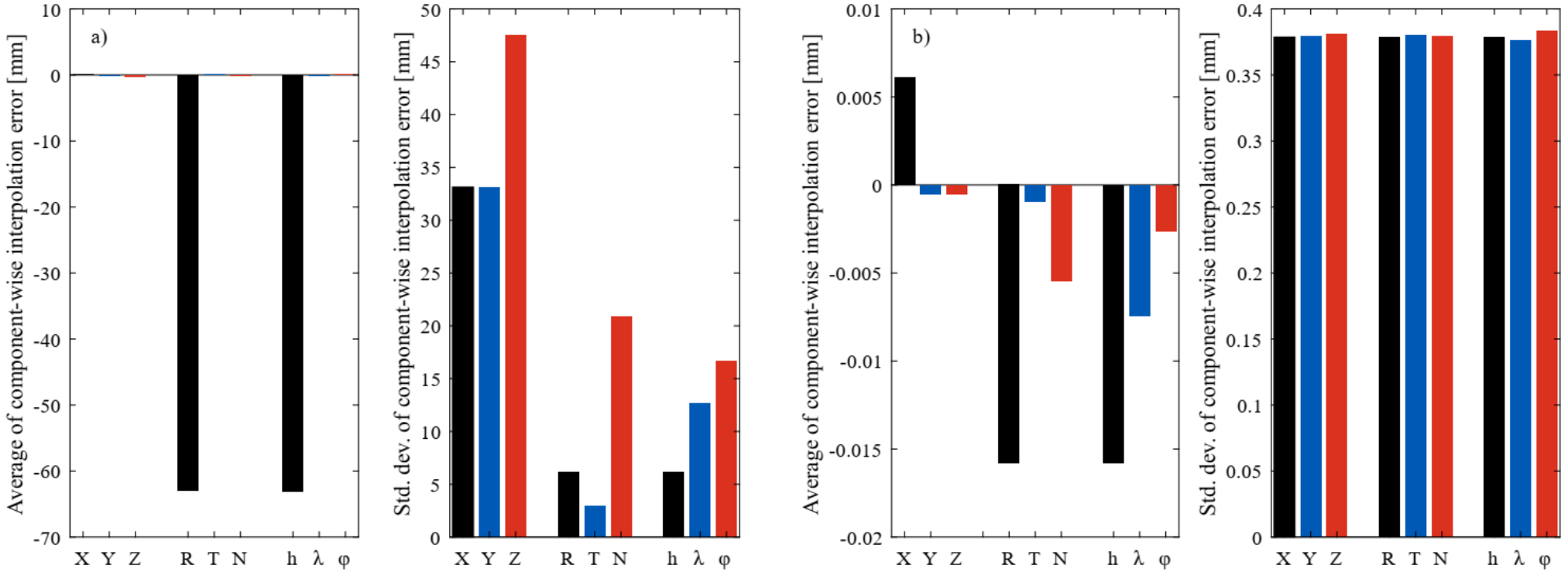


Orbit interpolation accuracy

Transformation effects:

- Redistribution of orbit error into certain components at transformation
- The choice of sufficient interpolation settings prevents this effect

Newton interpolation, degree 5, step size 120 seconds (left) and 30 seconds (right):



Conclusions and outlook

- Very successful stay in Toulouse at CNES earlier this year
- Implementation of several effects into the DGFI-TUM POD software
- ITRF2020, DTRF2020, and JTRF2020 perform **comparable** for SLR-based POD. Notable differences only in the **estimated Earth's albedo and infrared radiation scale factor**. Is the scale the reason?
- The current SP3 format limits the interpolation accuracy to ~0.6 mm => initiating an update of the format by providing additional decimal digits for the satellite position and velocity. Comments?

Next steps:

- Finishing the implementation of VMF3
- Reprocessing of orbits with new implementations
- Correlation analysis of POD parameters
- Refine the parameter setup of DORIS-only and SLR-DORIS combined orbits
- Comparison between Jason-2 IDS2.2- and RINEX-derived orbits
- Continue working on Sentinel satellite platforms

Thank you very much for your attention!

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