Status of SLR and DORIS data processing of Jason satellites at DGFI-TUM

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Outline

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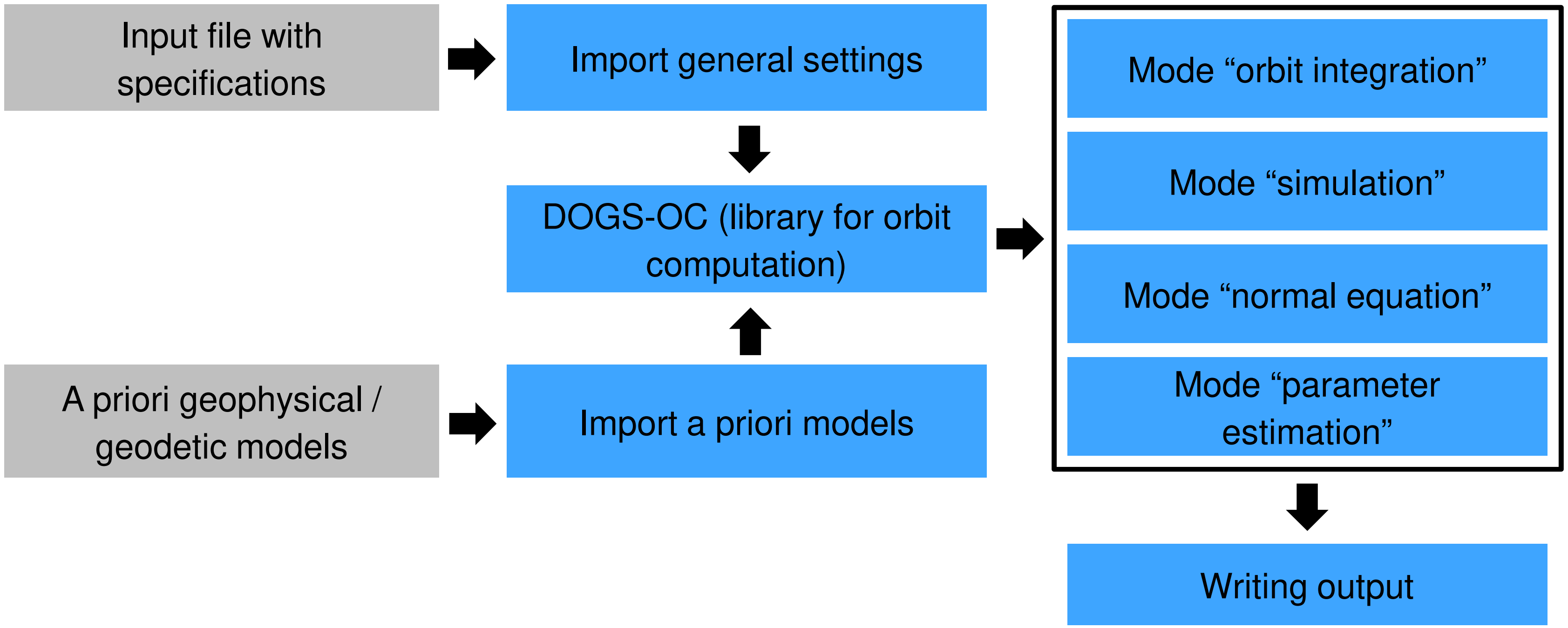
DGFI Orbit and Geodetic parameter estimation Software (DOGS)

The DGFI-TUM software for the analysis and combination of space geodetic techniques comprises three main software libraries:

- ⇨ **DOGS-CS**: combination and solution of equation systems
- ⇨ **DOGS-RI**: analysis of radio interferometry data (VLBI)
- ⇨ **DOGS-OC**: precise orbit determination, parameter estimation, etc. for the satellite techniques SLR and DORIS

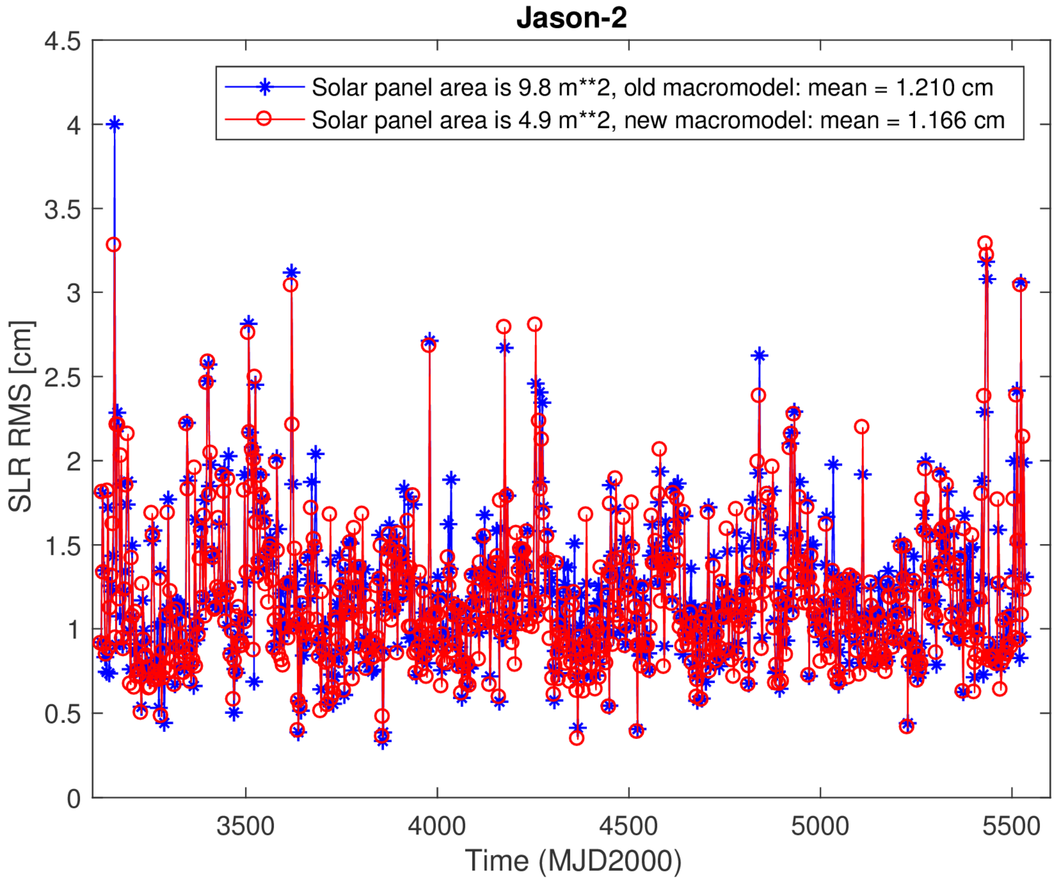


Recent improvements in Jason satellite modelling at DGFI-TUM

An update in Jason-2 satellite macromodel in DOGS-OC

A **new Jason-2 macromodel** implemented according to ftp://ftp.ids-doris.org/pub/ids/satellites/DORISSatelliteModels.pdf (box areas and the reflectance coefficients changed)

- As a result, the mean value of SLR RMS fits over 704 orbital arcs (July 20, 2008 till February 25, 2015) reduced from 1.21 to 1.17 cm (**by 3.6%**).



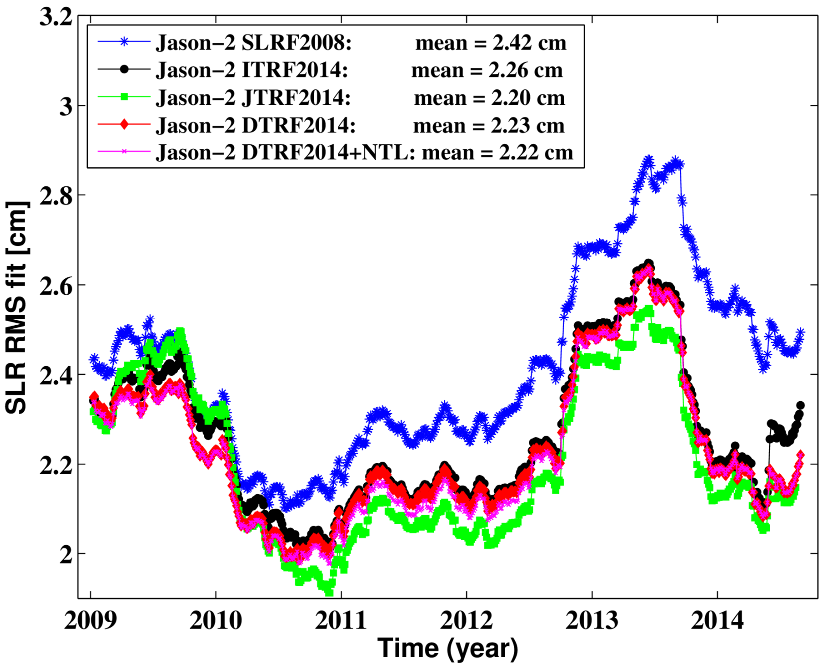
Impact of ITRS2014 realizations on Jason-2 orbit

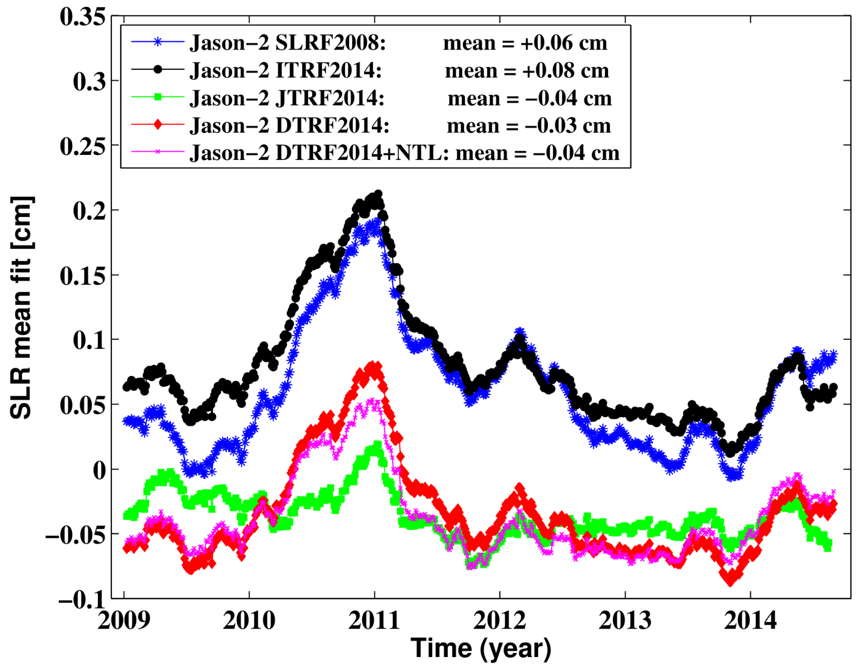
The main characteristics of the ITRF2014, DTRF2014 and JTRF2014

Solution	ITRF2014	DTRF2014	JTRF2014
Institute	IGN (Paris, France)	DGFI-TUM (Munich, Germany)	JPL (Pasadena, USA)
Software	CATREF	DOGS-CS	CATREF + KALMAN
Combination approach	Solution (parameter) level	Normal equation level	Solution (parameter) level
Station position	Position $\boldsymbol{X}_{\boldsymbol{ITRF}}(t_0)$ + velocity $\dot{\boldsymbol{X}}_{\boldsymbol{ITRF}}(t_0)$	Position $\boldsymbol{X}_{\boldsymbol{DTRF}}(t_0)$ + velocity $\dot{\boldsymbol{X}}_{\boldsymbol{DTRF}}(t_0)$	Weekly positions $\tilde{\boldsymbol{X}}_{\boldsymbol{JTRF}}(t_i)$
	+ PSD model (for selected stations) + annual signals (on request)	+ non-tidal loading (NTL) models + SLR origin (Ori) + residual station motions (Res)	

official ITRF solutions **additional add-ons**

Impact of ITRF2014, DTRF2014, JTRF2014 realizations on 50-week running averages of Jason-2 SLR RMS and mean fits (SLR-only orbits)



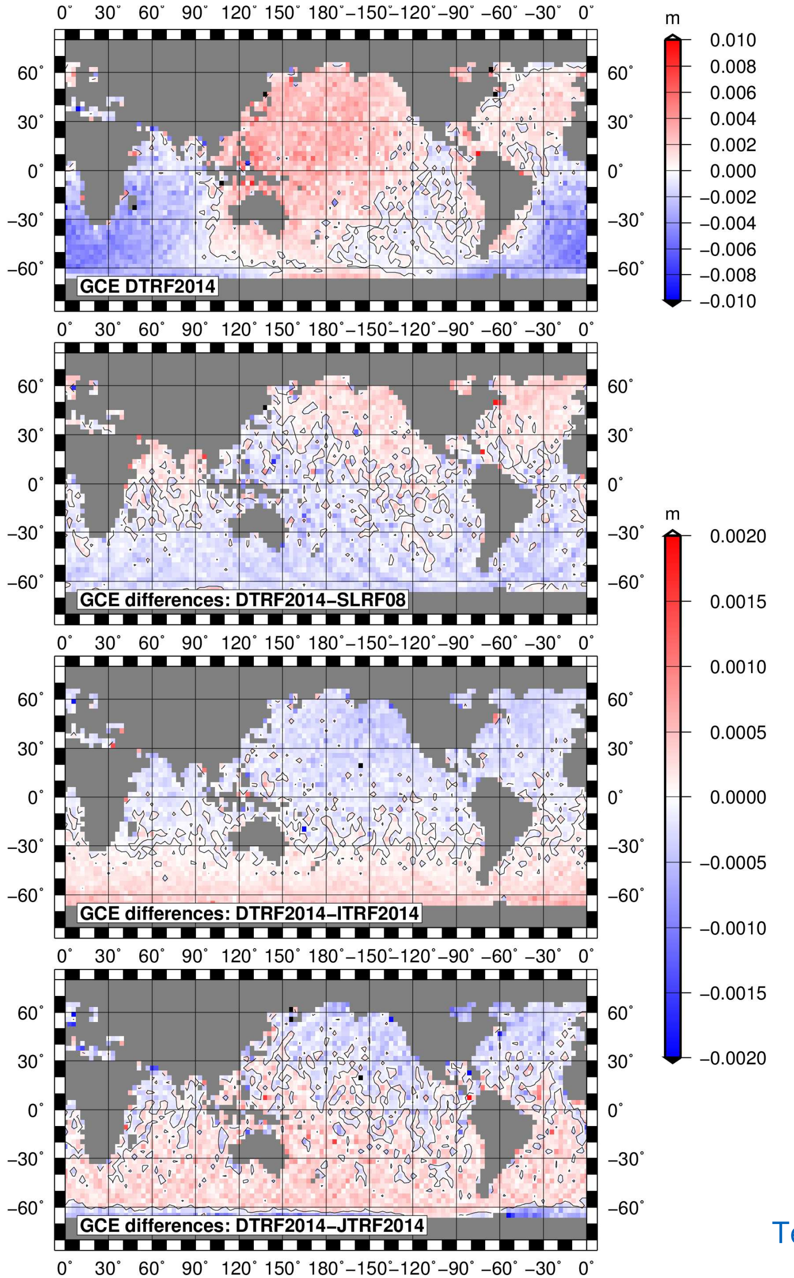


⇒ The smallest RMS fits are obtained using JTRF2014 followed by DTRF2014+NTL.

⇒ The smallest absolute mean fits are obtained using DTRF2014.

⇒ ITRF2014 provides larger absolute mean fits of observations (comparable with SLRF2008) than other realizations. (Rudenko et al., 2018)

Jason-2 geographically correlated mean SSH errors



10-day single satellite SSH crossover differences (SXO) for Jason-2 orbits based on various ITRS realizations (SLR-only orbits):

ITRS realization	SXO mean [mm]	SXO std [mm]	Difference w.r.t. SLRF2008 mean [mm]	Difference w.r.t. SLRF2008 std [mm]
SLRF2008	**1.00**	**59.52**	**---**	**---**
ITRF2014	**0.80**	**59.46**	**–0.2**	**–0.1**
DTRF2014	**0.68**	**59.40**	**–0.3**	**–0.1**
DTRF2014 +NTL	**0.64**	**59.38**	**–0.4**	**–0.1**
JTRF2014	**0.62**	**59.16**	**–0.4**	**–0.4**

⇒ JTRF2014 provides the largest improvement of the SXO standard deviation.

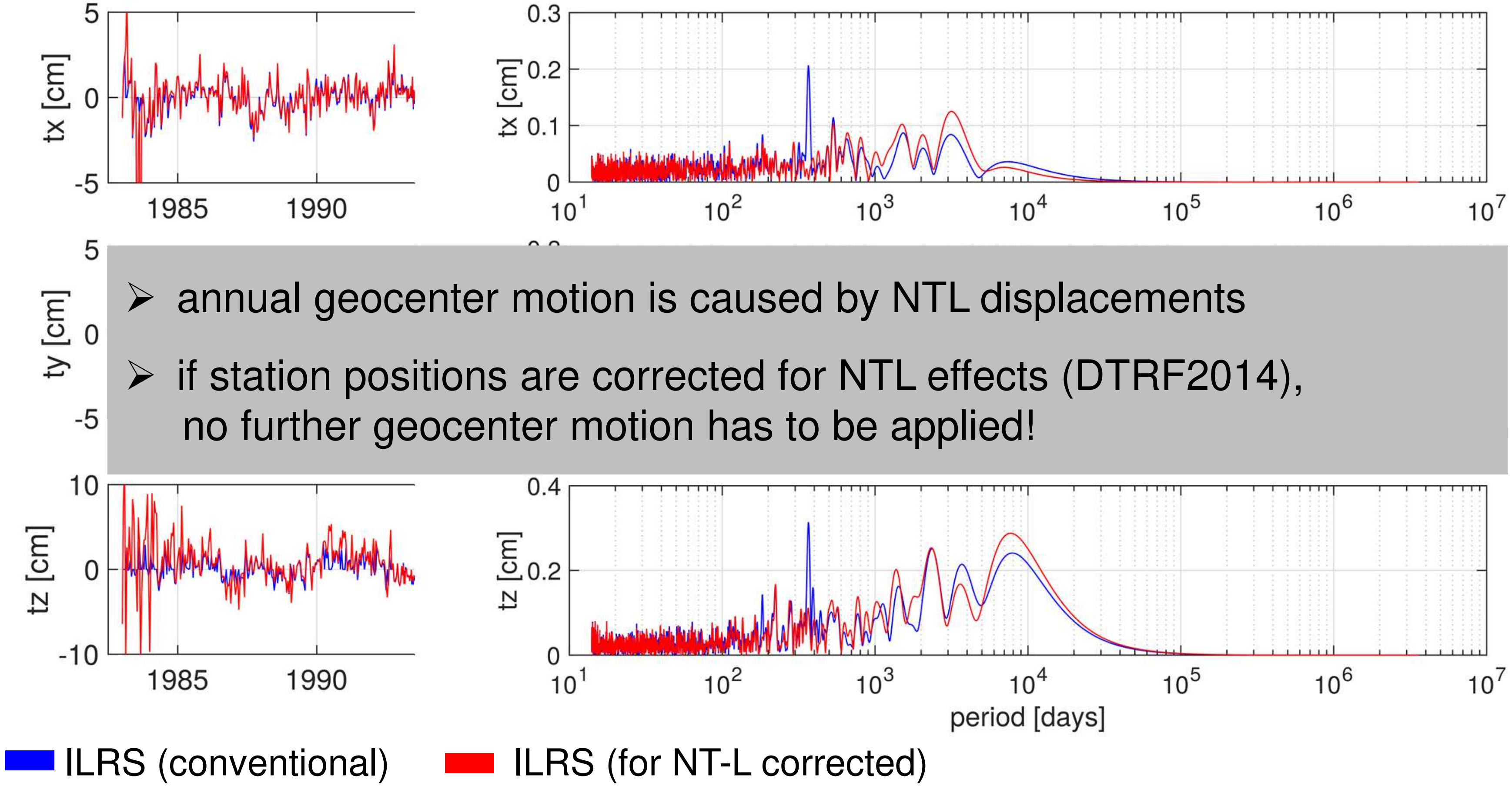
⇒ JTRF2014 and DTRF2014+NTL give the smallest (best) SXO mean among the ITRS realizations tested. (Rudenko et al., 2018)

Non-tidal loading and geocenter motion

Non-tidal loading (NTL) and geocenter motion

In the DTRF2014, the geocenter is realized by SLR-only

- At NEQ-level, station coordinates are corrected for NTL displacements
- weekly transformations of ILRS solutions on combined DTRF2014 **(origin)**

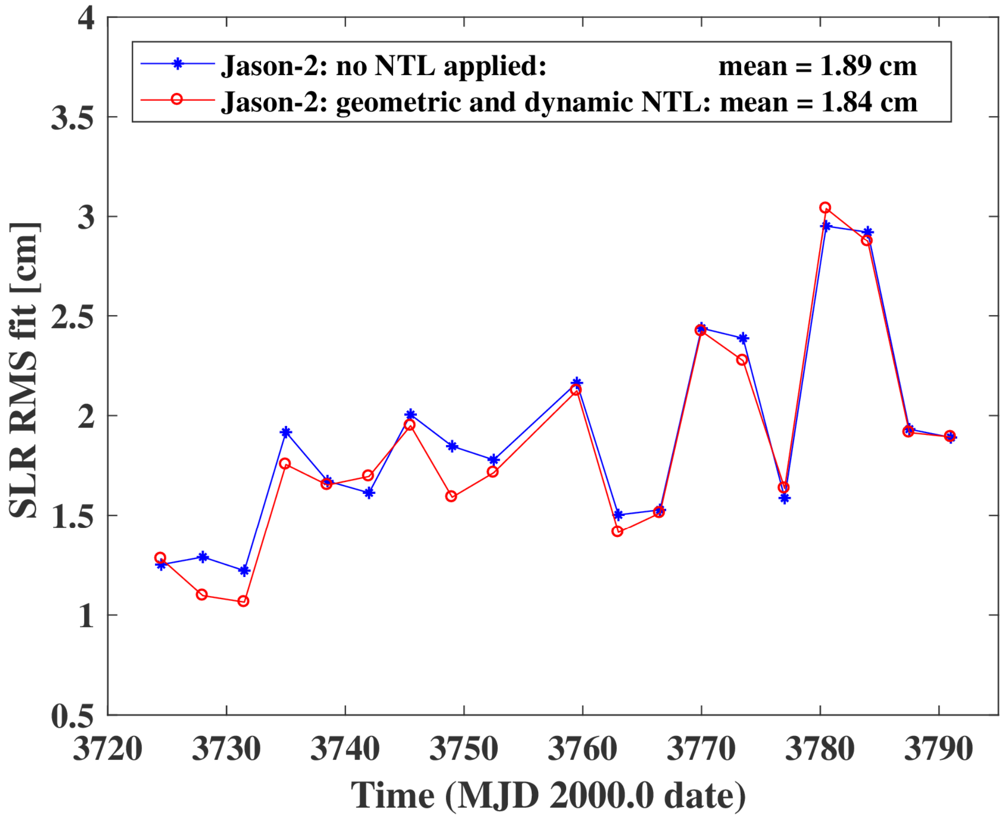


- annual geocenter motion is caused by NTL displacements
- if station positions are corrected for NTL effects (DTRF2014), no further geocenter motion has to be applied!

Impact of non-tidal loading (NTL) on the RMS fits of Jason-2 SLR observations

For a consistent correction of NTL, one has to correct the

- station coordinates for NTL loading displacements (geometric effect)
- satellite velocity by NTL gravitational acceleration (dynamic effect)



Taking into account both geometric and dynamic effect of non-tidal loading reduces RMS fits of SLR observations by about **2.6%**

Impact of using true attitude for Jason satellites instead of nominal attitude

Jason-2 nominal attitude model

- Jason-2 **nominal attitude model** (yaw-steering model) adopted when quaternions and solar panel angles are not available

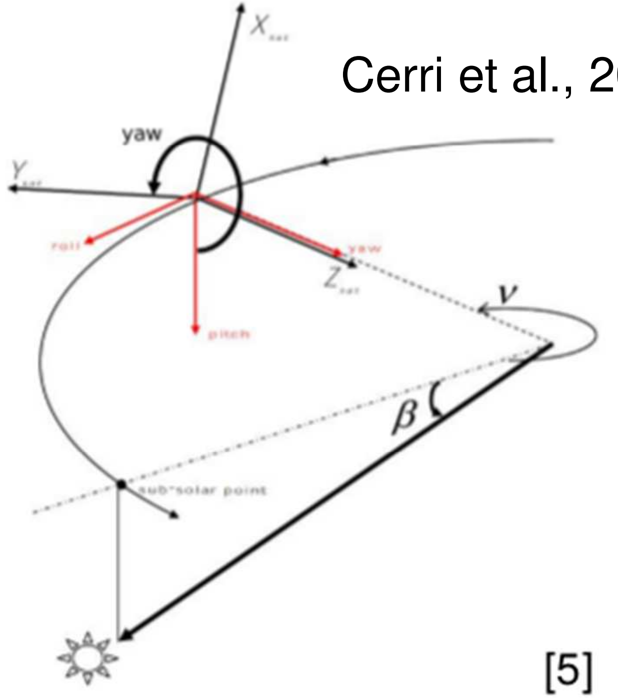
Nominal roll, pitch and yaw angels:

$$r_{nom} = 0°, \;\; p_{nom} = 0°$$

$$y_{nom} = \begin{cases} 90° - (90° - \beta) \sin \nu & if \;\; \beta > 0° \\ -90° + (90° + \beta) \sin \nu & if \;\; \beta < 0° \end{cases}$$

Yaw mode	B' region	description
sinusoidal	B' > |15 °|	Yaw = cos (orbit angle) scaled by B'
fixed low	B' < |15 °|	Yaw =0° +B' Yaw =180° -B'
fixed high	B' > |80 °|	Yaw =+90° +B' Yaw =-90° -B'
ramp up	B' => |15 °| increase	Yaw fixed to sinusoidal transition (90 seconds)
ramp down	B' =< |15 °| decrease	Yaw sinusoidal to fixed transition (90 seconds)
flip	B' crosses 0°	Yaw =0° +B' (10 minutes) Yaw =180° -B' (10 minutes)

Cerri et al., 2010



[5]

➢ YAW axis always pointing towards Earth's center

➢ YAW-steering model describes rotation around YAW axis → satellite's cross-section in flight direction changes → non-gravitational accelerations change!

Jason-2 refined attitude model

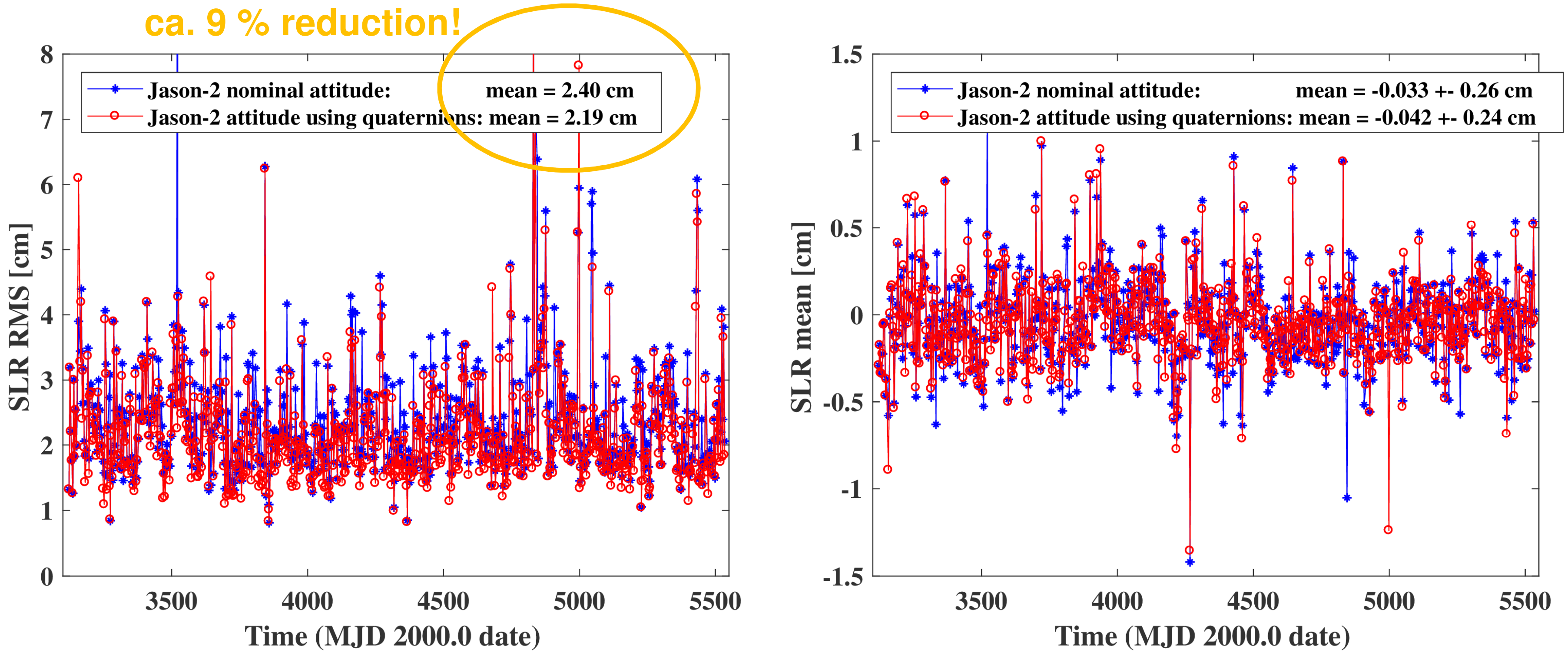
Jason-2 attitude (quaternions and solar panels orientation angles) from
ftp://ftp.ids-doris.org/pub/ids/satellites/ja2att.txt

Pre-processing steps applied on original quaternion files at DGFI-TUM:

- Combination of Jason satellite quaternions and solar panels orientation angles in a unique attitude file for each GPS week
- Checks for data gaps and periods of too high frequency
- Exclusions of periods of problematic data
- Spherical linear quaternion interpolation and linear interpolation of solar panels angles
- Check if quaternion norm equal to 1
- etc.

Impact of the refined satellite attitude handling on Jason-2 RMS and mean fits of SLR observations

RMS (left) and mean (right) fits of Jason-2 SLR observations computed using nominal versus interpolated, cleaned and preprocessed attitude data



The mean value of SLR RMS fits reduced by 0.21 cm (**8.8%**) from 2.40 to 2.19 cm. The absolute mean fits slightly increased by 0.009 cm from 0.033 to 0.042 cm. The scatter of the mean fits reduced by 0.02 cm from 0.26 to 0.24 cm.

DORIS-related models implemented in DOGS-OC

- ⇨ Treatment of DORIS data in GINS and IDS 2.2 format
- ⇨ Jason-1/2/3 and TOPEX/Poseidon macromodels according to IDS
- ⇨ Estimation of the correction to the wet part of the tropospheric zenith delay
- ⇨ Estimation of the pass-wise frequency bias
- ⇨ Station-dependent phase center offsets in the measurement direction

- ⇨ Corrections to DORIS measurements:
  - ➢ center of Mass correction of the instrument at the satellite,
  - ➢ phase center correction of the emitter (beacon),
  - ➢ tropospheric refraction (different models available),
  - ➢ relativistic contraction (according to model of Moyer),
  - ➢ frequency bias and frequency-drift,
  - ➢ IDS phase law applied.

- ⇨ Computation of the partial derivatives of the theoretical observation w.r.t. the included free parameter, i.e. dynamic parameter, Center of Mass correction, pole coordinates, time parameter (UT1, LOD), and the station parameter together with biases.

DORIS-related models implemented in DOGS-OC (continue)

- Computation of the partial derivatives of the theoretical observation w.r.t. the included free parameter, i.e.
  - dynamic parameter (e.g. initial state vector, gravity field coefficients, empirical accelerations),
  - center of Mass correction,
  - pole coordinates,
  - time parameter (UT1, LOD),
  - the station parameter (coordinates),
  - station frequency biases, tropospheric (wet) scaling factors.

- Troposphere distance correction models implemented:
  - refined model of Hopfield using the algorithm of Yionoulis,
  - simplified model of Hopfield,
  - simplified model of Saastamoinen,
  - model of Davis,
  - tropospheric delay: Collins (1999), mapping functions (dry, wet) by Neill.

DORIS-related models to be implemented in DOGS-OC

- ⇨ Treatment of DORIS data in RINEX format
- ⇨ Corrective models for DORIS observations due to South Atlantic Anomaly (Jason-1 and Jason-2) or use of corrected observations
- ⇨ Estimation of station frequency drift
- ⇨ Implementation of nominal beacon frequency shifts for selected stations
- ⇨ Troposphere correction models based on GPT3 and VMF3
- ⇨ Other IDS macromodels

Conclusions and outlook

⇨ The update of the Jason-2 macromodel in DOGS-OC reduces SLR RMS fits by **3.6%**.

⇨ DTRF2014 with non-tidal loading and JTRF2014 show better performance than ITRF2014 and SLRF2008.

⇨ If non-tidal loading displacement corrections are applied, no geocenter model is necessary any longer!

⇨ Modelling of non-tidal loading in station positions and gravity field changes reduces SLR RMS fits of Jason-2 by about **2.6%**.

⇨ Refined attitude modeling reduces SLR RMS fits of Jason-2 by **8.8%**, as compared to using nominal attitude model.

⇨ Processing of DORIS data has been implemented in DOGS-OC. The work is in progress to reduce RMS fits of DORIS observations.

References

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⇨ Rudenko S., Bloßfeld M., Müller H., Dettmering D., Angermann D., Seitz M. (2018): Evaluation of DTRF2014, ITRF2014 and JTRF2014 by Precise Orbit Determination of SLR Satellites. IEEE Transactions on Geoscience and Remote Sensing, pp. 3148-3158, DOI: 10.1109/TGRS.2018.2793358.

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