Impact of nominal and measured satellite attitude on SLR- and DORIS-derived orbits of Jason satellites and altimetry results

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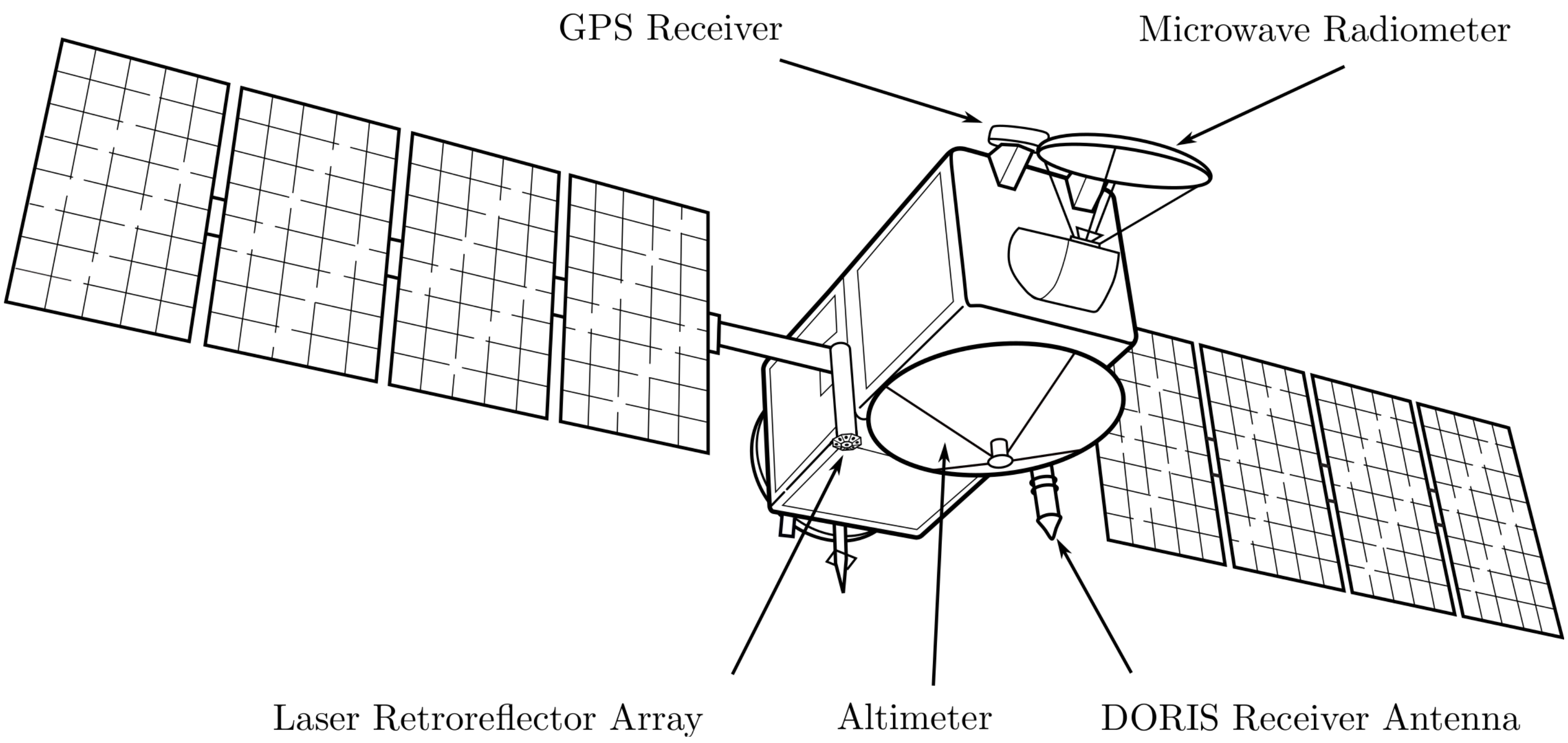
Outline

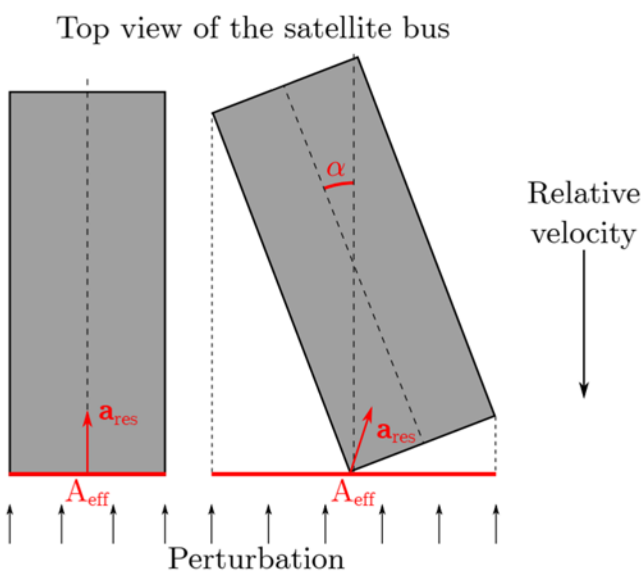
- ⇨ Importance of the knowledge on satellite attitude
- ⇨ Attitude representation and its processing at DGFI-TUM
- ⇨ Jason-1/-2/-3 satellite POD using nominal and measured satellite attitude
- ⇨ Impact of using measured attitude instead of nominal attitude on:
  - RMS fits of SLR and DORIS residuals,
  - standard deviation of single-satellite crossover differences,
  - orbit differences
- ⇨ Conclusions and outlook

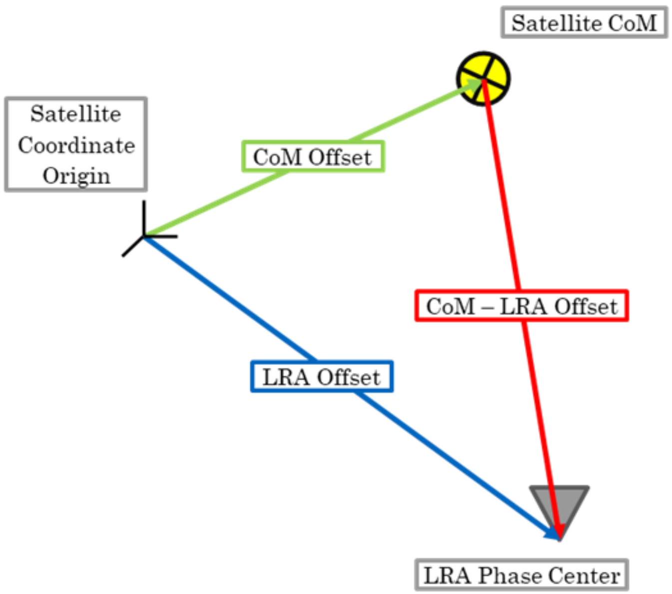
Geodetic payload of Jason satellites



- Non-spherical satellites
- Precise information on satellite shape, size, surface optical properties, maneuvers and mass variations is required
- An information of satellite orientation (attitude) in space is required

Importance of precise knowledge on satellite attitude for precise orbit determination

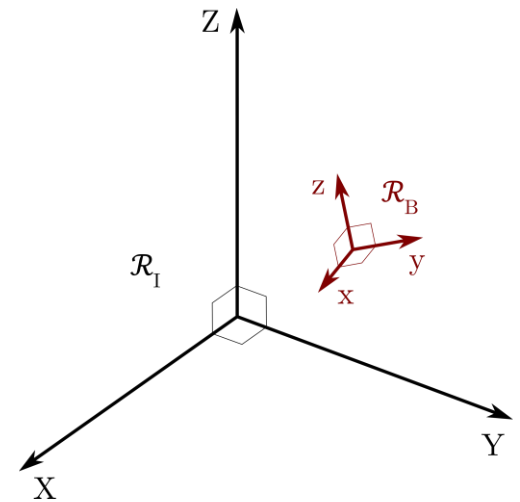




Effective satellite surface area A_{eff} of the surface forces depends on the orientation of non-spherical satellite w.r.t. perturbing force direction

Positions of the LRA and DORIS phase centers in the inertial reference frame depend on the satellite orientation in space

Attitude representations



Different ways of attitude representation

Determination of the orientation of the satellite body reference system $\mathcal{R}_B$ with respect to the inertial reference system $\mathcal{R}_I$

- Euler angle and axis
- Direction cosine matrix
- Euler angles
- Quaternions

Quaternions

Composed of four elements q_s, q_x, q_y, q_z (the first one is scalar, the later three provide the orientation).

Defined by $\boldsymbol{q} = q_s + iq_x + jq_y + kq_z$ or $\boldsymbol{q} = [q_s \quad q_x \quad q_y \quad q_z]^T = [s \quad \boldsymbol{v}]^T$

Trigonometric functions: $q_s = \cos\frac{\theta}{2}$, $q_x = e_1 \sin\frac{\theta}{2}$, $q_y = e_2 \sin\frac{\theta}{2}$, $q_z = e_3 \sin\frac{\theta}{2}$

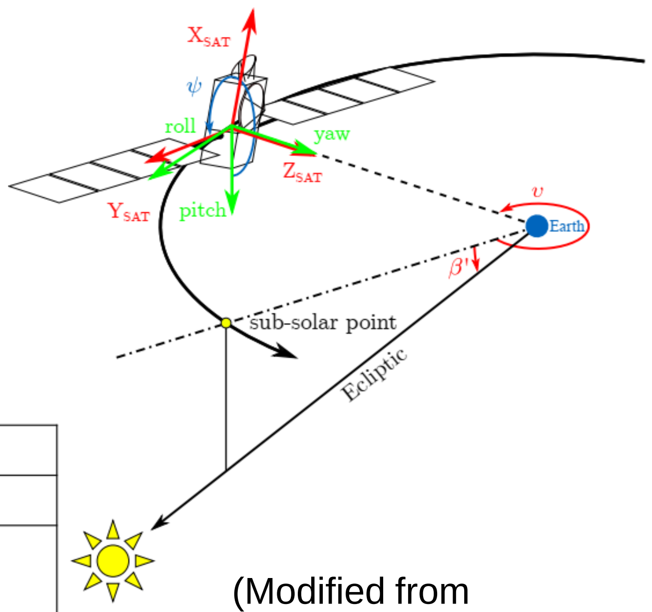
Unit quaternions: $|\boldsymbol{q}| = \sqrt{q_s^2 + q_x^2 + q_y^2 + q_z^2} = 1$

Principle of the nominal yaw steering model for Jason satellites

Fulfillment of two prerequisites:

- Earth/nadir-pointing of the altimeter antenna
- Sun-pointing of the solar arrays

Usage of yaw steering algorithms based on those of TOPEX/Poseidon

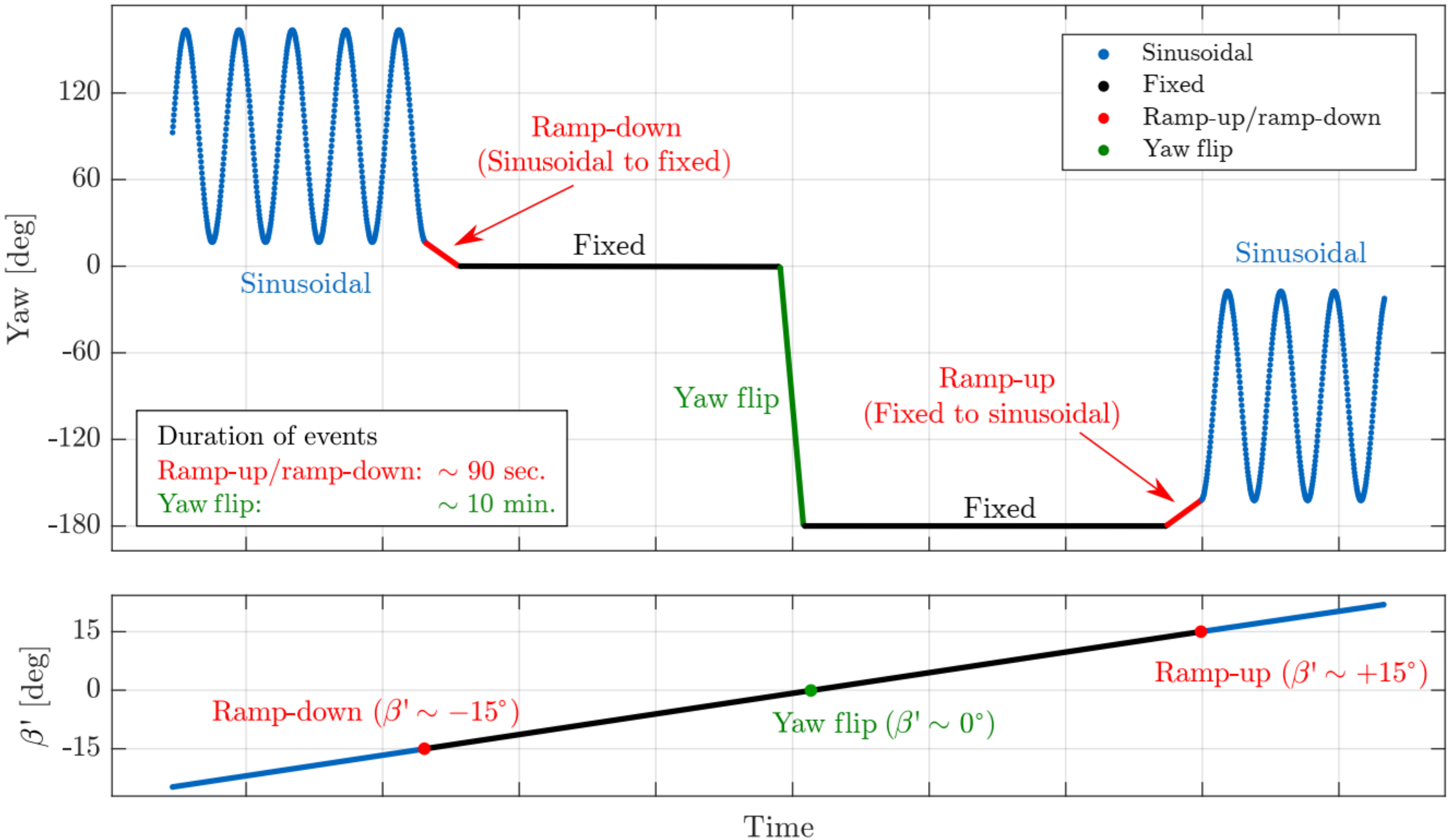


(Modified from Cerry et al., 2010)

Yaw regime	Occurrence	Description
Sinusoidal	$\lvert\beta\rvert > 15°$	Yaw sinusoidal law
Fixed	$\lvert\beta\rvert < 15°$	Yaw = 0° if $\beta > 0°$ Yaw = 180° if $\beta < 0°$
Ramp-up	$\lvert\beta\rvert \geqslant 15°$	Yaw fixed to sinusoidal
Ramp-down	$\lvert\beta\rvert \leqslant 15°$	Yaw sinusoidal to fixed
Yaw flip	$\lvert\beta\rvert \approx 0°$	Yaw = 0° if $\beta > 0°$ Yaw = 180° if $\beta < 0°$

$$yaw_{nominal} = \psi_{nominal} = \begin{cases} 90° - (90° - \beta')\sin\nu & \text{, if } \beta' > 15° \\ -90° + (90° + \beta')\sin\nu & \text{, if } \beta' < -15° \end{cases}$$

Changes of the yaw and β´ angles in the nominal yaw steering model



Attitude processing at DGFI-TUM

Attittude data loading (determination of GPS week relevant files)

Combination of attitude quaternion files and a file containing solar panel orientation angles in a unique attitude file for each GPS week

Appropriate interpolation when varying epochs are given

Data analysis

- Elimination of duplicate epochs
- Removal of invalid data
- Detection and rejection of outliers (defined by the user)
- Removal of quaternions without the norm 1
- Temporal resampling
- Removal of epochs within gaps of the other data set
- Determination of missing epochs in one data set with respect to the other one

Data interpolation

- Quaternions: Spherical linear quaternion interpolation
- Solar panel angles: linear interpolation

Precise orbit determination of Jason satellites using nominal and measured satellite attitude

Satellites and time spans analyzed:

- Jason-1 (January 13, 2002 to June 29, 2013)
- Jason-2 (July 20, 2008 to January 9, 2019)
- Jason-3 (February 17, 2016 to January 9, 2019)

Observations type used:

- SLR
- DORIS (for Jason-1 and Jason-2 only) in the IDS 2.2 format

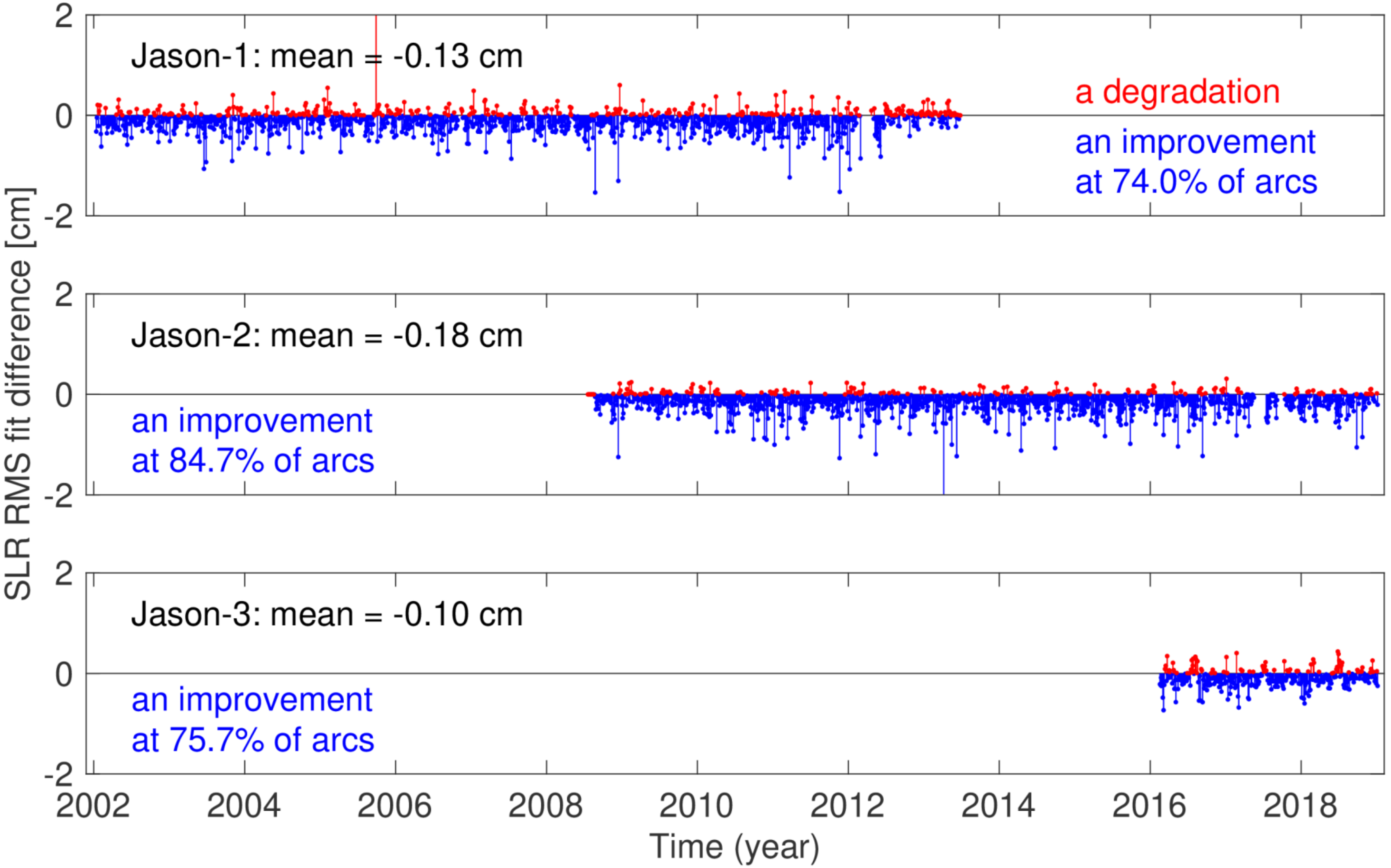
Software used: “DGFI Orbit and Geodetic parameter estimation Software”.

Background models and reference frames used:

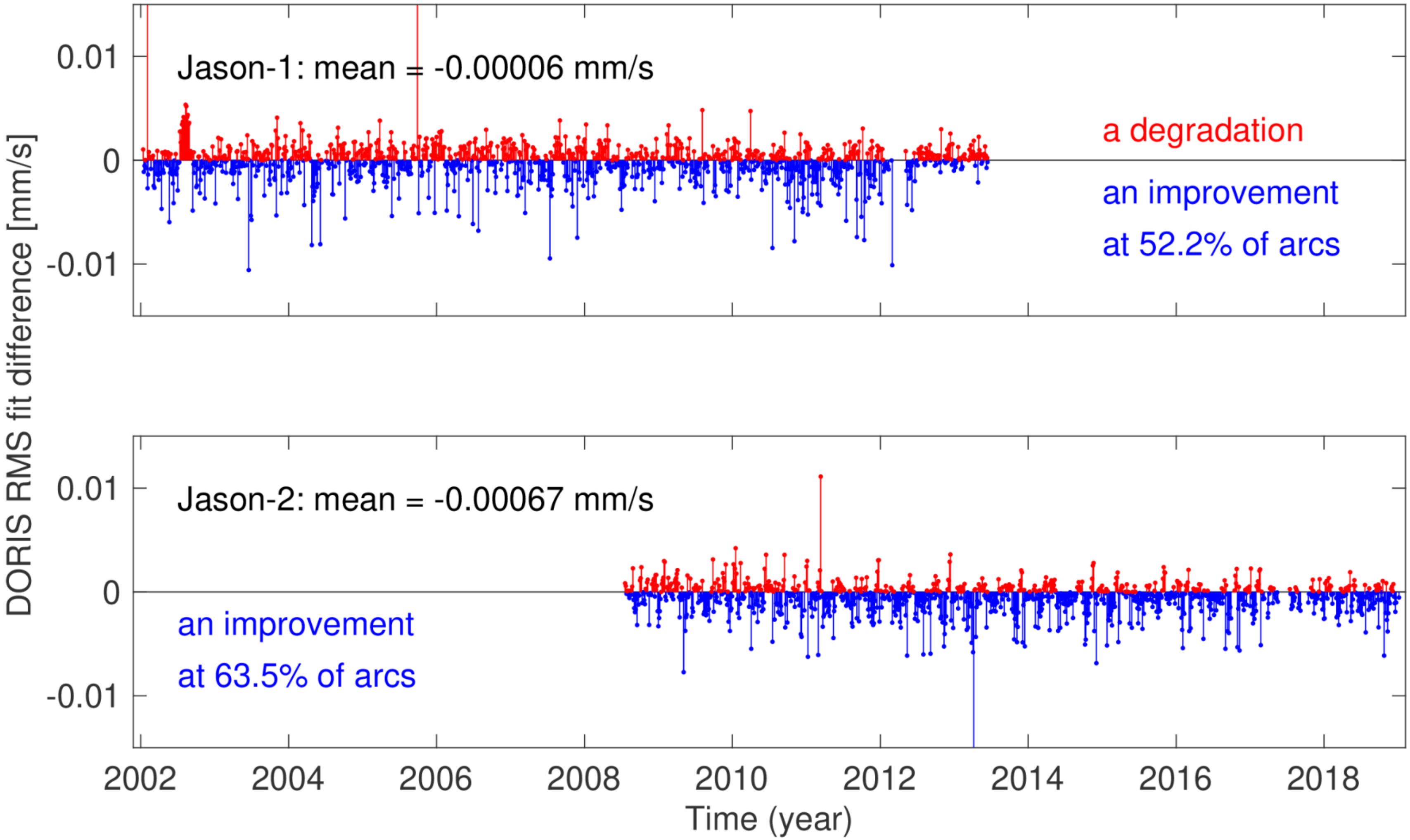
- Up-to-date models consistent with the IERS Conventions (2010)
- SLRF2014 for SLR and DPOD2014 for DORIS stations

Estimated parameters: Keplerian elements, solar radiation pressure scaling coefficient, Earth albedo scaling coefficient, along-track and normal empirical acceleration, atmospheric drag scaling coefficient (every 12 h); station frequency bias (for DORIS data, 1 per path)

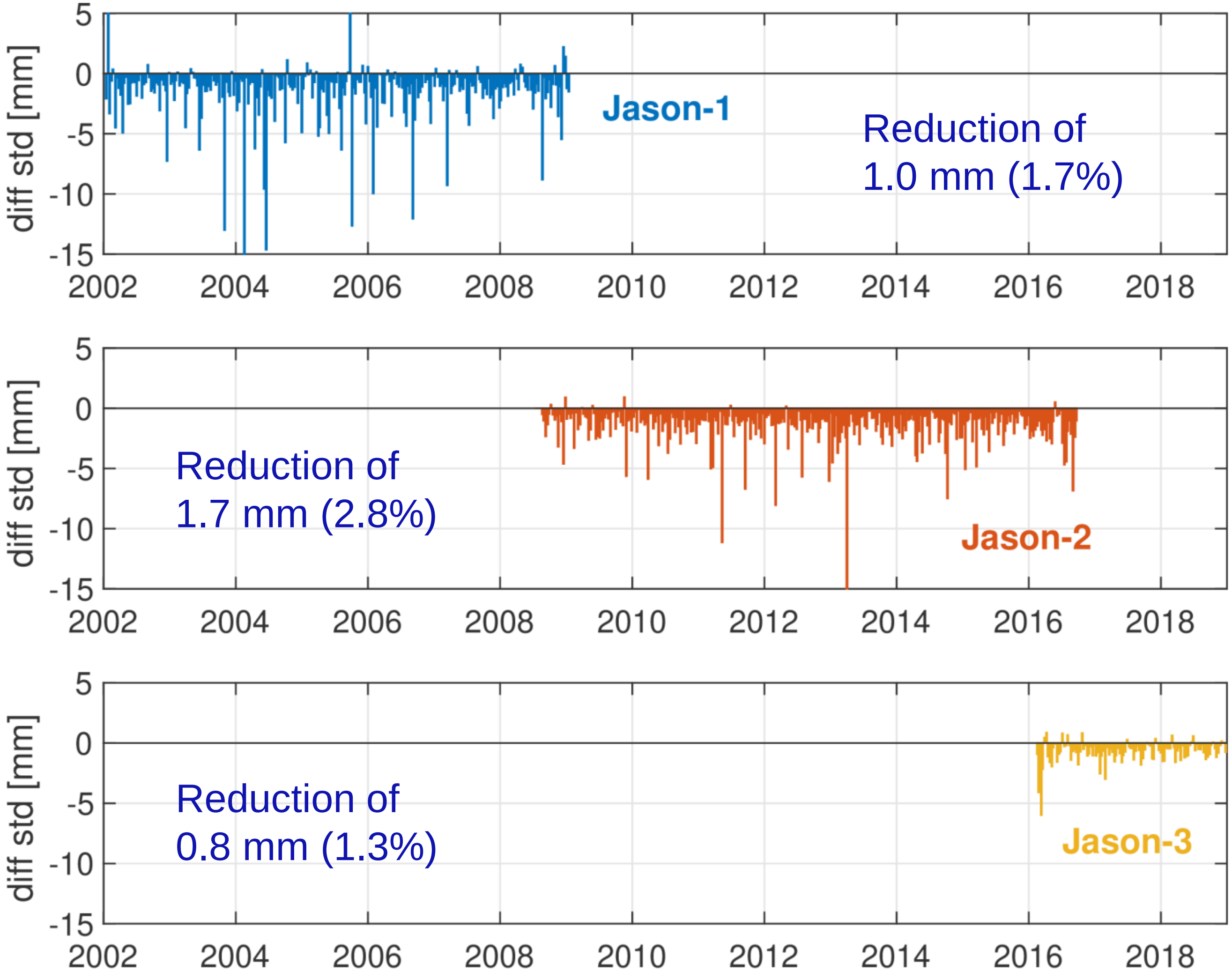
Differences of SLR RMS fits of SLR-only orbits: “measured attitude” versus “nominal attitude”



Differences of DORIS RMS fits of DORIS-only orbits: “measured attitude” versus “nominal attitude”



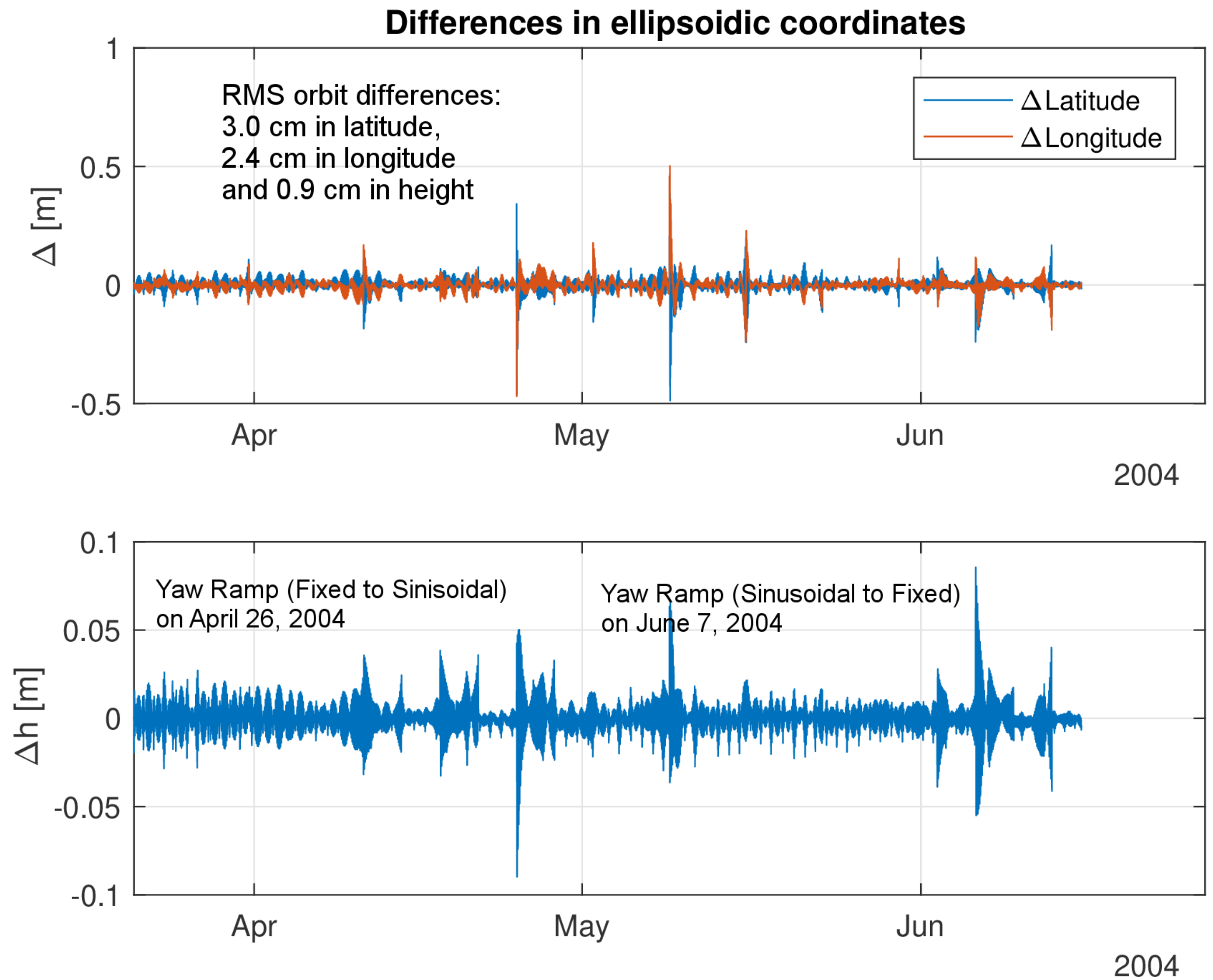
Differences of standard deviation of single-satellite crossover differences



SLR-only orbits

An improvement when using "measured attitude" instead of "nominal attitude"

Differences of Jason-1 satellite positions of two orbits: “measured attitude” versus “nominal attitude”



SLR-only orbits

The differences up to a few cm in the height direction

Change |β'|<15° to |β'|<30° of the fixed law for Jason-2 and Jason-3 from July 2017.

RMS-differences of Jason-1/-2/-3 satellite positions of SLR-data based orbits: "measured" versus "nominal attitude"

Satellite and β' angle		Latitude (cm)	Longitude (cm)	Height (cm)
Jason-1	|β'|<15°	2.8	2.2	0.8
Jason-2	|β'|<15°	2.4	2.0	0.9
Jason-2	|β'|<30°	1.8	1.4	0.6
Jason-3	|β'|<15°	2.5	2.0	0.9
Jason-3	|β'|<30°	1.6	1.3	0.6

Increase of the maximum beta-prime angle for fixed yaw from 15° to 30° for Jason-2 and Jason-3 in July 2017 reduces the RMS differences between the SLR-data based orbits computed using nominal and measured attitude after that change by 25-36%.

Change |β'|<15° to |β'|<30° of the fixed law for Jason-2 and Jason-3 from July 2017.

RMS-differences of Jason-1 and Jason-2 satellite positions of DORIS-data based orbits: "measured" versus "nominal attitude"

Satellite and β' angle		Latitude (cm)	Longitude (cm)	Height (cm)
Jason-1	|β'|<15°	2.0	1.5	0.65
Jason-2	|β'|<15°	1.8	1.5	0.67
Jason-2	|β'|<30°	1.5	1.1	0.64

Use of the nominal attitude instead of measured attitude causes RMS differences of the DORIS-data based orbits of Jason-1 and Jason-2 of about 6-7 mm.

Increase of the maximum beta-prime angle for fixed yaw from 15° to 30° for Jason-2 in July 2017 reduces the RMS differences between the DORIS-data based orbits computed using nominal and measured attitude after that change by 4, 16 and 23% in the height, latitude and longitude directions, respectively.

Conclusions and outlook

⇨ Precise knowledge on the **Jason satellite attitude** is important for precise orbit determination of these satellites

⇨ Using **measured satellite attitude** (satellite body orientation in the quaternion form and solar panel angles) instead of nominal attitude

- **reduces SLR RMS fit**s at 74-85% of processed arcs by 1.0-1.8 mm (5-8%),
- **slightly reduces DORIS RMS fits** at 52-64% of processed arcs,
- **reduces standard deviation** of single-satellite **crossover differences** by 0.8-1.7 mm (1.3-2.8%)
- causes the **RMS differences** of Jason-1/-2/-3 **satellite coordinates** in the height direction at the level of about 6-9 mm for the SLR data based orbits and of about 6-7 mm for the DORIS data based orbits

⇨ Change of the **maximum β' angle for the fixed law** from 15° to 30° for Jason satellites reduces the RMS differences of satellite coordinates computed using nominal and measured attitude by 25-36% for SLR-data based orbits and by 4-23% for DORIS-data based orbits.

⇨ Preprocessed at DGFI-TUM attitude data of Jason-1, -2 and -3 will be made available (soon!)

Reference

Bloßfeld M., Zeitlhöfler J., Rudenko S., Dettmering D.: Observation-based attitude realization for accurate Jason satellite orbits and its impact on geodetic and altimetry results. Remote Sensing, in preparation.

Zeitlhöfler J.: Nominal and observation-based attitude realization for precise orbit determination of the Jason satellites, Master’s thesis, Technical University of Munich, Department of Civil, Geo and Environmental Engineering, Deutsches Geodätisches Forschungsinstitut (DGFI-TUM), 2019.