Opportunities for Orbit Improvement Using the Jason Series of Satellites : Salient Results from the 2017-2020 OSTSTs

A. Couhert[1,*], P. Bonnefond[2], S. Bruinsma[1], P. Exertier[3], S. Houry[1], J.-M. Lemoine[1], F. Mercier[1], J. Moyard[1], F. Reinquin[1], H. Roinard[4]

[1] Centre National d'Etudes Spatiales, Toulouse, France
[2] Observatoire de Paris–SYRTE, Paris, France
[3] Observatoire Midi-Pyrénées–GET, Toulouse, France
[4] Collecte Localisation Satellites, Toulouse, France

*Mail : alexandre.couhert@cnes.fr

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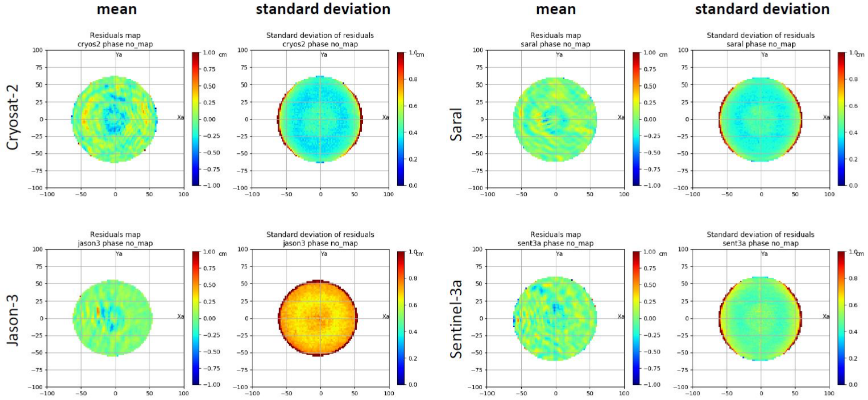
INTRODUCTION

1. TRACKING TECHNIQUES PROCESSING

Preparation of future DORIS formulations

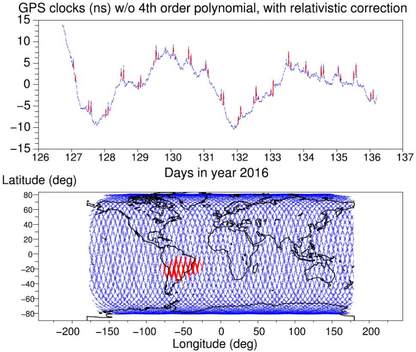
- Further steps were achieved towards a *direct phase processing*.
  - The preprocessing of DORIS phase data for low-elevation measurements was improved.
  - Satellite DORIS antenna phase maps were identified for the first time.



Residual DORIS phase maps (mean/standard deviation) for CryoSat-2, Jason-3, Saral/AltiKa, and Sentinel-3A.

Preparation of future DORIS formulations

- Strategies for the mitigation of the *South Atlantic Anomaly (SAA)* effect were developed.
  - Additional frequency drifts were adjusted per pass for the DORIS beacons located in the vicinity of the SAA (above South America) for the Jason-2/3 satellites.
  - The common clocks of Sentinel-3A observed with the GPS on-board instrument was used to estimate the behavior of the DORIS Ultra Stable Oscillator (USO).

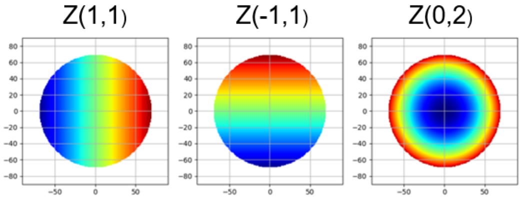


GPS clock and corresponding Sentinel-3A ground tracks (in red for the DORIS USO frequency drifts).

New in-flight identification of DORIS/GPS receiver Phase Center Offsets (PCO)

- A modeling using an expansion in *Zernike polynomials* was succefully introduced.

(in cm)		Cryosat-2		Jason-3 **(a)**		Saral		Sentinel-3A	
		doppler	phase	doppler	phase	doppler	phase	doppler	phase
Phase center offset	Z(1,1) Xa **(b)**			- 1.12 - 1.83	- 1.43 - 2.34				
	Z(-1,1) Ya **(b)**	- 0.19 - 0.29	- 0.68 - 1.02	0.35 0.57	0.39 0.64	0.75 1.13	0.65 0.98	0.15 0.23	0.05 0.08
	Z(0,2) = Za	0.33	0.36	- 0.39	- 0.34	- 0.02	0.30	0.19	0.53
Phase map coefficients	Z(0,4)	- 0.16	- 0.13	- 0.40	- 0.35	- 0.08	0.07	- 0.06	0.12
	Z(0,6)	0.05	0.09	- 0.05	0.00	0.04	0.11	0.05	0.15
Center of mass						R = +1 cm			

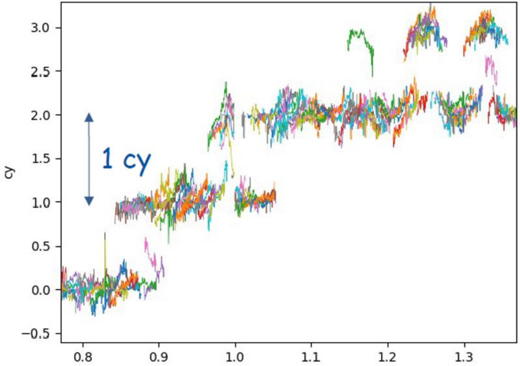


DORIS phase center corrections for CryoSat-2, Jason-3, Saral, Sentinel-3A, and first Zernike modes corresponding to the PCO.

❖ Operational fixed GPS orbit solutions

➢ An efficient and robust *ambiguity fixing process* was built up.

- Use of the CNES/CLS IGS Analysis Center GPS orbit/clock solutions.
- Now implemented for Jason-3, Sentinel-3A/B and HY-2B.

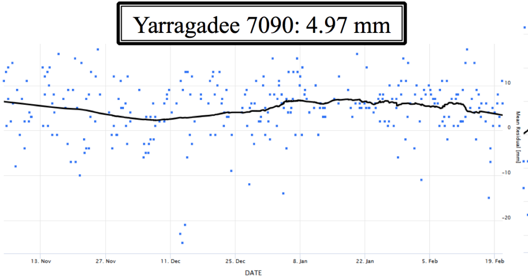


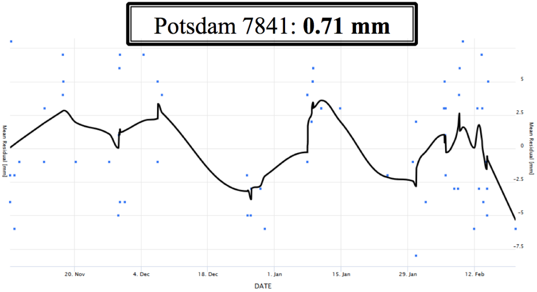
Rounded floating ambiguity residuals showing that they are clumped around integer values.

1. Tracking Techniques Processing

Improved knowledge of the Satellite Laser Ranging (SLR) measurements

- *Ground stations* : monitoring of range biases which can no longer be ignored.
  - OSTM/Jason-2 GPS+DORIS precise orbits were used to independently estimate SLR ranging biases.
  - CNES released official reports of these SLR residuals to the ILRS Quality Control Board for station bias investigations (available at `ftp://cddis.gsfc.nasa.gov/pub/reports/slrcnes/jason2`).
  - The solved for biases can now be explored and visualized through a web-based interactive portal written by E.C. Pavlis (Station Performance Tool available from `geodesy.jcet.umbc.edu/QC`).





Biases estimated for Yarragadee (left) and Potsdam (right) using Jason-2 GPS+DORIS orbits.

1. TRACKING TECHNIQUES PROCESSING

Improved knowledge of the Satellite Laser Ranging (SLR) measurements

- *Ground stations* : accurate millimeter determinations of yearly range biases.
  - A study was performed with H. Peter (PosiTim) and D. Arnold (AIUB) to mitigate the sources of range bias correlations for the validation of altimeter satellite precise orbits.
  - SLR station bias estimations were made more robust (less prone to geographically correlated orbit errors) by using multiple altimeter and gravity satellites independently tracked by DORIS and GPS.

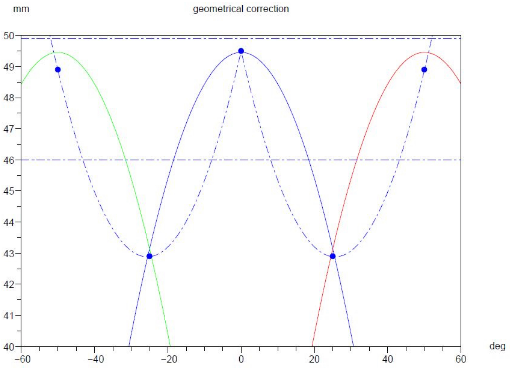
Differences between CNES & AIUB

Δ<= 2mm	2>Δ<= 5mm
1873	1874
1888	1884
1891	7105
7090	7124
7110	7403
7119	7501
7249	7821
7810	7838
7811	7941
7824	
7825	
7827	
7839	
7840	
7841	
8834	

Set of stations having negligible differences in their bias estimates.

Improved knowledge of the Satellite Laser Ranging (SLR) measurements

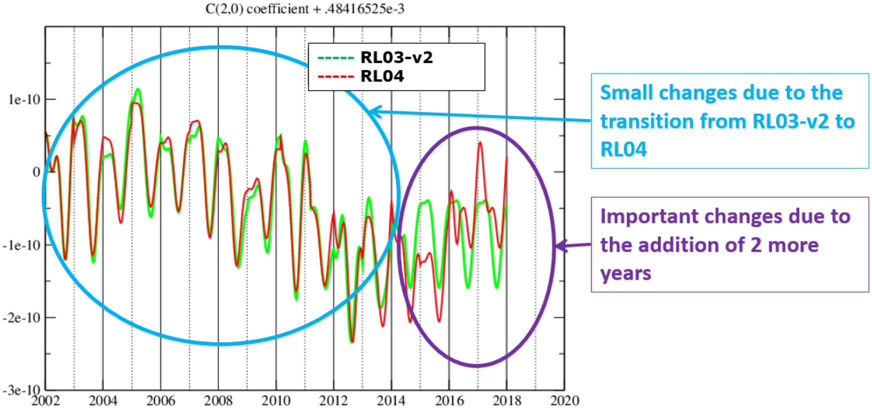
- *Laser Retroreflector Array (LRA)* : construction of sub-millimetric range correction models.
  - The LRA assembly of the different altimeter missions was analyzed to compute the exact optical path length for the corner cubes.



Delays corresponding to the reflexions on the central cube (blue) and two external cubes (green/red) of the Jason LRA assembly as a function of the zenith angle.

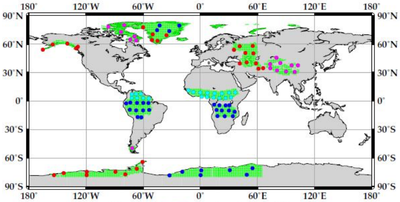
Updated GRACE-based TVG models

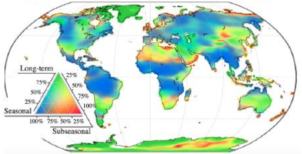
- The release of the new *EIGEN-GRGS.RL04.MEAN-FIELD* updated the previous one over 2 years : mid-2014 to mid-2016.



Example of the C(2,0) spherical harmonic coefficient.

- **Leverage the historical orbiting satellites for pre-GRACE era TVG recovery**
  - ~100 *mascons* defined in 13 regions of high hydrological variability were estimated.
    - *Seasonal :* N/S Amazon basin and Central Africa
    - *Long-term* : High Moutains Asia, NE/SW Greenland, S South America, E/W Antarctica, Golf of Alaska, Arctic Islands, Caspian Sea





Selected mason regions (top ; colored circles) and associated dominant modes as detected by GRACE (bottom ; Humphrey et al., 2016).

Progresses on future realizations of the TRF origin

- Independent assessments of the *ITRF origin stability* were defined.
  - IGS GPS products can be referenced with respect to the Center-of-Mass of the Earth using Jason-3.
  - From non-sun-synchronous satellites, DORIS data can provide solutions for geocenter motion.

Geocenter from Jason-2 (DORIS) & Jason-2 (SLR) (Couhert et al., 2018), LAGEOS1+2 (Ries, 2016), and GPS+GRACE (Haines et al., 2015)

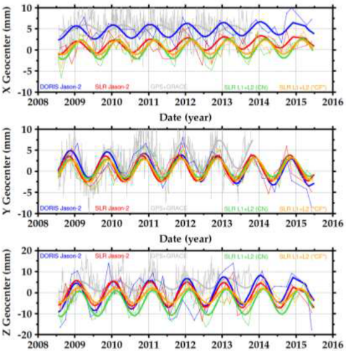


Table 9
Estimates of Geocenter Annual Variations From This Study and Independent Results

	X		Y		Z	
Solution	A (mm)	ϕ (day)	A (mm)	ϕ (day)	A (mm)	ϕ (day)
GPS+GRACE	0.9	105	3.5	334	—	—
SLR L1+L2 (CN)	2.3	61	2.3	317	6.1	41
SLR L1+L2 (CF)	1.7	59	2.7	322	3.6	39
DORIS Jason-2	1.6	13	3.2	322	6.4	18
SLR Jason-2	1.5	21	3.1	302	5.9	21

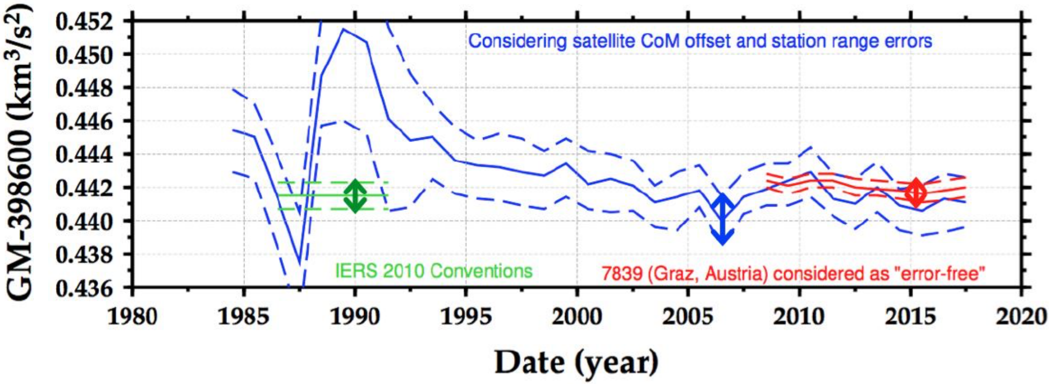
Note. A ratio = Amplitude ratio; $\delta\phi$ = Phase shift; GPS = Global Positioning System; DORIS = Doppler Orbitography and Radiopositioning Integrated by Satellite; SLR = Satellite Laser Ranging; CN = center-of-network; CF = center-of-figure.

The paper explains how the DORIS data can be processed to produce a geocenter time series. This points to the possibility to derive a new IDS product for users using the non-polar orbiting satellites (e.g. Jason-2, Jason-3, HY-2C, SWOT).
The IDS GB is considering to establish a Pilot Project and Working Group to further explore the development of this potential new product.

Possible future product : a DORIS contribution to geocenter.

3. Terrestrial Reference Frame

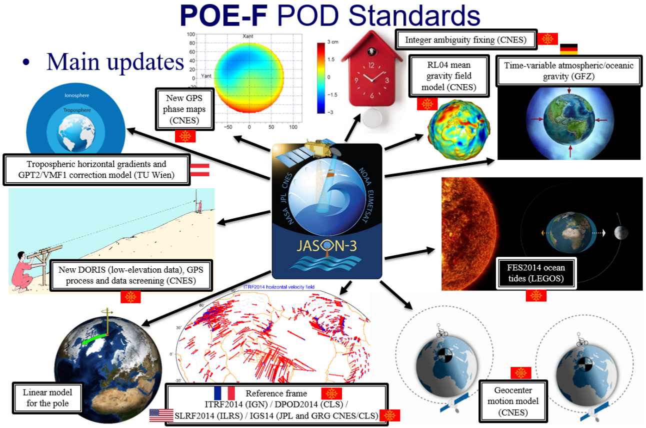
- **Insights into the current uncertainty of the TRF scale**
  - The question of the need to refine the value of GM was raised to help improving the determination of the scale of the TRF.
    - Our reestimated value of GM ($398600.4420 \pm 0.0003\ \mathrm{km^3 s^{-2}}$) would lead to reduce the scale discrepancy between SLR and VLBI solutions.



Annual determinations of GM (Earth scale). The dashed lines correspond to the annual error estimates (3-σ).

Updated POD processing standards

- The CNES *POE-F*[1] standards was endorsed for the constellation of altimeter missions.



Main updates of the last CNES POD processing standards.

1. POE-F stands for the precise orbits supplied for placement on the Geophysical Data Record's Version F.

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Updated POD processing standards

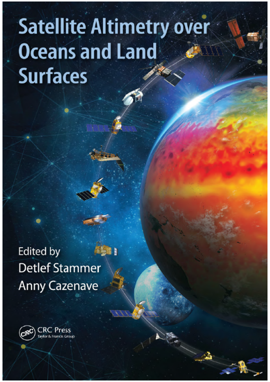
- *DORIS-only orbits* now approach the GPS-based performances for small S/M ratio satellites.
  - The radial performances are about $5\text{-}7\ \mathrm{mm}$.
  - In the case of LEO altimetry (based on DORIS and/or GNSS orbits), SLR is a state-of-the-art technique for the validation of the orbit accuracy.

Mean of RMS over 2017 (in cm)		Cryosat-2	Jason-3		Saral	Sentinel-3a	
		DORIS-only	DORIS-only	GPS-only	DORIS-only	DORIS-only	GPS-only
SLR core network, 3D	POE-E	1.66		1.62	1.77		1.10
	POE-F	1.18	1.59	1.06	1.14	1.25	0.85
SLR core network, radial	POE-E	**0.98**		**0.90**	**0.78**		**0.72**
	POE-F	**0.68**	0.89	**0.70**	**0.66**	0.63	**0.54**
DORIS	POE-F	0.45	0.43		0.39	0.45	

Performances of DORIS-only and GPS-based CNES POE-F reduced-dynamic orbits (SLR RMS over 2017 in cm).

Broader communications

- Contributions to the 2017 and 2019 GGOS Unified Analysis Workshop.
- Redaction of the chapter Precision Orbit Determination in the reference book *Satellite Altimetery over Oceans and Land Surfaces*.



Satellite Altimetry Over Oceans and Land Surfaces book cover.