Strategy to minimize the impact of the South Atlantic Anomaly effect on the DORIS station position estimation

Hugues Capdeville (1), Guilhem Moreaux (1), Jean-Michel Lemoine (2).

(1) CLS, Collecte Localisation Satellites, 8-10 rue Hermès, 31520 Ramonville Saint Agne, France
(2) CNES Centre National d'Etudes Spatiales, 18 av Edouard Belin, 31400 Toulouse, France

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Introduction

All the Ultra Stable Oscillators (USO) of DORIS satellites are more or less sensitive to the South Atlantic Anomaly (SAA) effect. For Jason-1 and SPOT-5 satellites, a corrective model has been developed and used for the realization of the ITRF2014. However, Jason-2 is also impacted, not at the same level as Jason-1 but strong enough to worsen the multi-satellite solution provided for ITRF2014 for the SAA stations. The last DORIS satellites are also impacted by the SAA effect, in particular Jason-3.

Thanks to the extremely precise time-tagging of the T2L2 experiment on-board Jason-2, A. Belli and the GEOAZUR team managed to draw up a model that accurately represents the variations of Jason-2 USO's frequency. This model will be evaluated by analyzing its impact on the position estimation of the SAA stations. While awaiting a DORIS data corrective model for the others satellites Jason-3 and Sentinel-3A, we propose here different strategies to minimize the SAA effect on the orbit and also and in particular on the station position estimation.

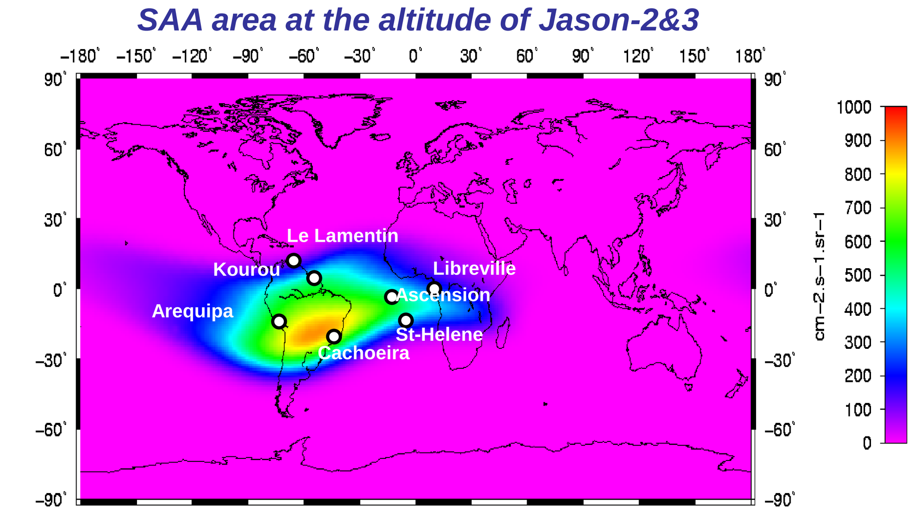
Processing context

Software	GINS/DYNAMO
DORIS data	DOPPLER data (DORIS2.2 format) or phase measurement converted to DOPPLER (RINEX 3.0 format)
Station Coordinates	ITRF2014 (DPOD2014)
Gravity Field	EIGEN-GRGS.RL03-v2.MEAN-FIELD with mean slope extrapolation
DORIS Troposphere	VMF1 + one gradient per station in North & East directions
Attitude Model	Nominal law
Surfaces Forces & Estimated Parameters	Box-wing model for solar radiation, drag, Albedo and IR Macromodel available at : *ftp://ftp.ids-doris.org/pub/ids/satellites/DORISSatelliteModels.pdf* Radiation pressure scale coefficient :1 per day but strongly constrained 1/rev empirical: 2 sets in along-track and cross-track direction (sin/cos)) Drag coefficients adjusted: for all satellites 1 per 4 hours except for Jason-2&3: 1 per half day
Arc cut	3.5 days
Elevation angle cut-off	12 degrees

SAA Impact on the precise orbit and on the station position estimation

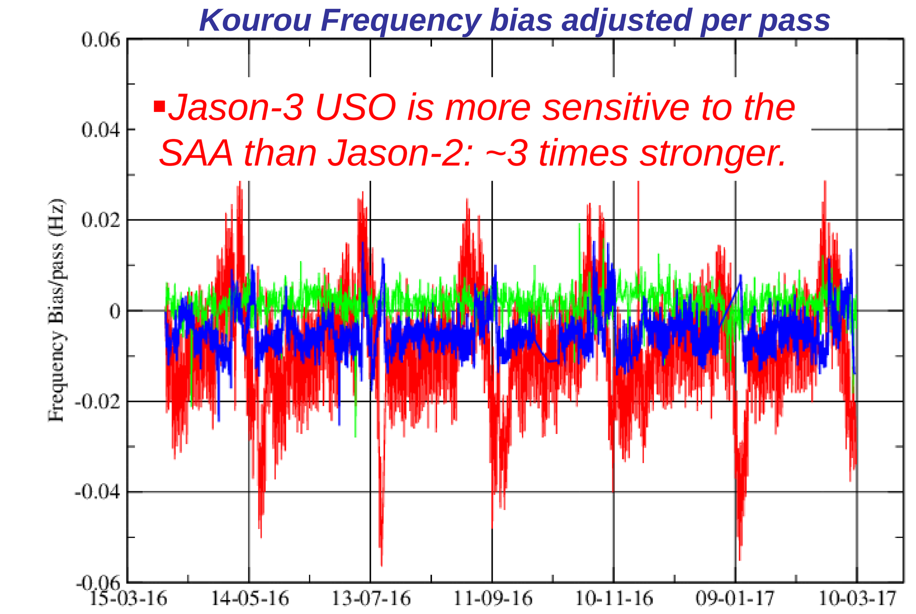
❑ SAA impact on the orbit

SAA area at the altitude of Jason-2&3



▪SAA map from Jason-2 CARMEN data and the SAA stations (>87 MeV integrated proton flux map (2009-2011 average)).
▪Stations in the heart of the SAA area:
Arequipa, Ascension, Cachoeira, Kourou, Libreville, Sainte-Helene.

Kourou Frequency bias adjusted per pass



▪The Frequency bias of Kourou (master beacon) for Jason-3 is larger than those obtained for Jason-2 and Sentinel-3A.
▪The DORIS residuals for Jason-3 (0.36 mm/s) are also larger than those obtained for Jason-2 (0.33 mm/s) certainly due to the SAA effect.

❑ SAA impact on the station position estimation

Single satellite Solution compared to DPOD2014 (computed by CATREF).
As the Cryosat-2 USO is not affected by SAA, we use the Cryosat-2 single satellite solution as a reference.
Differences between the Jason-2/Jason-3/Sentinel-3A and Cryosat-2 solutions in NEU
Mean of 72 weeks (from April 2016 to August 2017)
▪Jason-3 USO is more sensitive to the SAA than Jason-2.
▪The Jason-3 solution gives a bias in at least one of the NEU components for the SAA stations.
▪The sensitivity of the Sentinel-3A USO is not strong enough to affect the station position estimation.

Differences between the Jason-2/Jason-3/Sentinel-3A and Cryosat-2 solutions in NEU

Station	Jason-2 (in cm) North	Jason-2 East	Jason-2 Up	Jason-3 (in cm) North	Jason-3 East	Jason-3 Up	Sentinel-3A (in cm) North	Sentinel-3A East	Sentinel-3A Up
Cachoeira	4.4	4.5	**8.9**	**6.8**	2.6	**20.0**	0.3	-0.6	0.1
Arequipa	-1.6	4.2	**8.8**	-1.7	**10.8**	**20.1**	0.4	-0.7	1.9
Kourou	-2.0	-1.1	0.8	**-6.0**	1.3	3.5	0.8	1.3	0.4
Ascension	1.4	-3.9	**6.1**	2.1	-0.2	**14.8**	1.5	-0.5	-0.2
Saint Helene	**5.0**	-1.6	2.4	**9.5**	-3.2	**9.3**	0.3	-0.7	-1.5
Le Lamentin	-0.6	-0.2	-3.6	-1.8	-2.1	**-5.6**	1.2	0.4	-0.8
Libreville	-3.9	-0.4	2.9	**-6.1**	1.1	**8.3**	1.1	0.3	0.4
Yarragadee	*-1.1*	*-0.1*	*0.2*	*-0.2*	*0.9*	*-0.4*	*0.8*	*0.2*	*0.5*
Thule	*0.2*	*-0.6*	*-0.4*	*1.2*	*-0.7*	*-1.1*	*-0.4*	*0.9*	*-1.6*

Conclusions

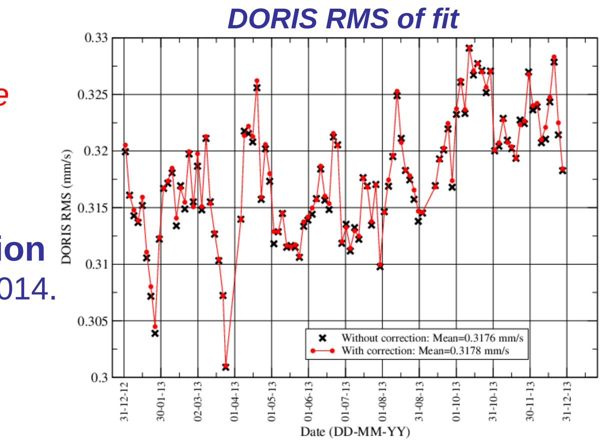
Impact of the SAA effect: Jason-2 and Jason-3 exhibit higher DORIS RMS for the DORIS stations in the SAA region. Compared to Jason-2, the Jason-3 USO is more sensitive to the SAA. Without any correction, Jason-3 and Jason-2 induce coordinate differences larger than 10 cm. A data corrective model for Jason-3 could be useful for the station positioning.
Strategy to minimize the SAA impact on the positioning: the strategy brings an improvement in the station position estimation for the SAA stations. With the strategy the solutions affected by the SAA (Jason2&3) can be add to the multi-satellite solution without damage.
Correction of the DORIS scale jump in 2012:
When we used the new position of the CoM given by the Chinese Project the HY2A scale is significantly reduced. When we did our own pre-processing when using doris2.2 data the scale jump is removed. The DORIS scale jump in 2012 is fully corrected.

Strategy to minimize the SAA effect

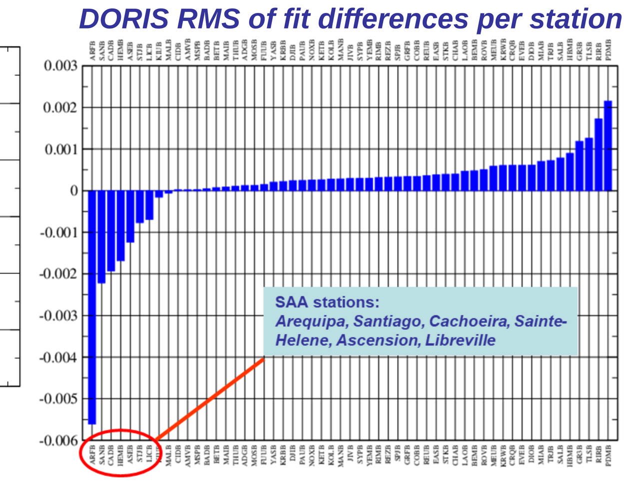
❑ Test of the SAA corrective model for Jason-2 DORIS data developed by A. Belli and P. Exertier

Impact on the precise orbit
Time span processing: year 2013.
doris2.2 data no and corrected by the model.
- *DORIS residuals reduced by the use of the model for SAA stations.*
- *No orbit differences significantly.*

DORIS RMS of fit



DORIS RMS of fit differences per station



Impact on the station position estimation
Single satellite Solution compared to DPOD2014.
Cryosat-2 solution used as a reference.
Differences between the Jason-2/Jason-2 corrected and Cryosat-2 solutions in NEU.
- *The use of the corrective model improves slightly the single satellite station position estimation.*

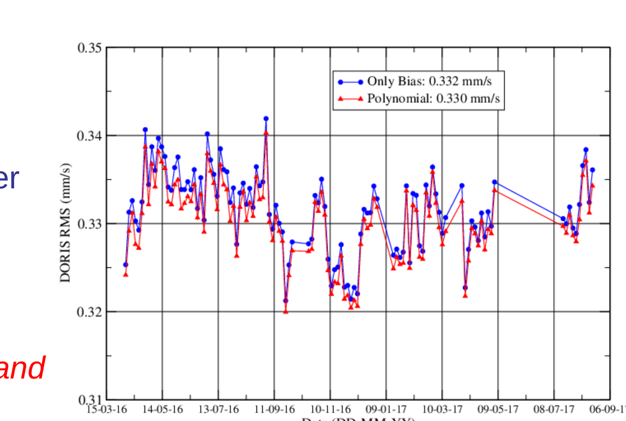
Differences between the Jason-2/Jason-2 corrected and Cryosat-2 solutions in NEU

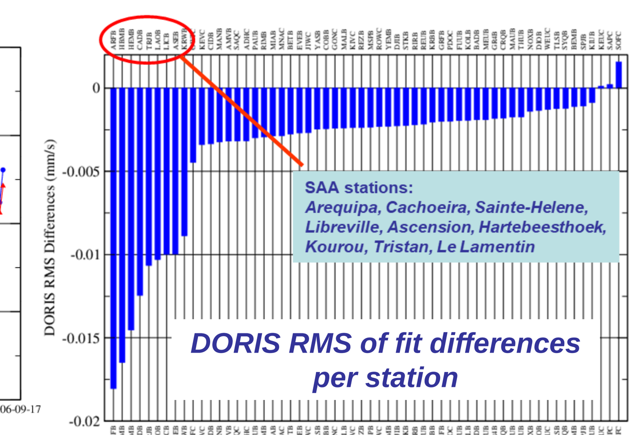
Station	Jason-2 (in cm) North	Jason-2 East	Jason-2 Up	Jason-2 corrected (in cm) North	Jason-2 corrected East	Jason-2 corrected Up
Cachoeira	4.3	2.2	**7.4**	2.8	3.3	4.1
Arequipa	-2.0	2.4	**8.8**	-1.6	1.9	3.4
Santiago	**8.2**	-0.3	1.8	**6.1**	0.2	-0.7
Ascension	0.7	-1.7	**5.3**	-0.1	-0.4	3.2
Saint Helene	**5.2**	0.3	2.9	3.9	0.5	1.2
Libreville	-2.7	-1.0	2.9	-2.1	-0.6	1.4
Kourou	-2.2	-0.4	1.9	-1.4	-0.7	0.9
Yarragadee	*0.3*	*-0.8*	*0.5*	*0.1*	*-0.8*	*0.6*
Thule	*-0.3*	*-0.9*	*-2.0*	*-0.4*	*-1.1*	*-1.8*

Mean of 52 weeks (from Jan. to Dec. 2013).

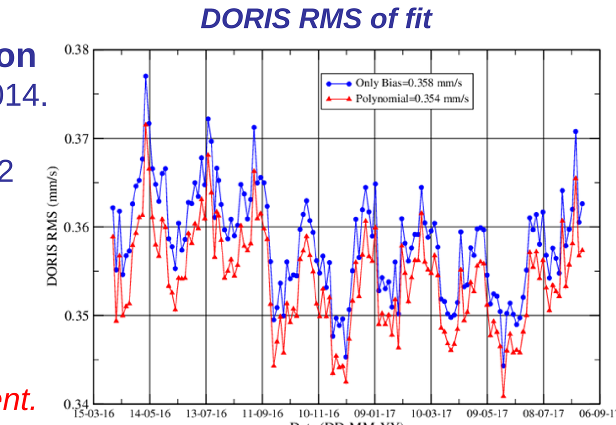
❑ Strategy description of Estimation of the beacon frequency Polynomial on SAA station per pass

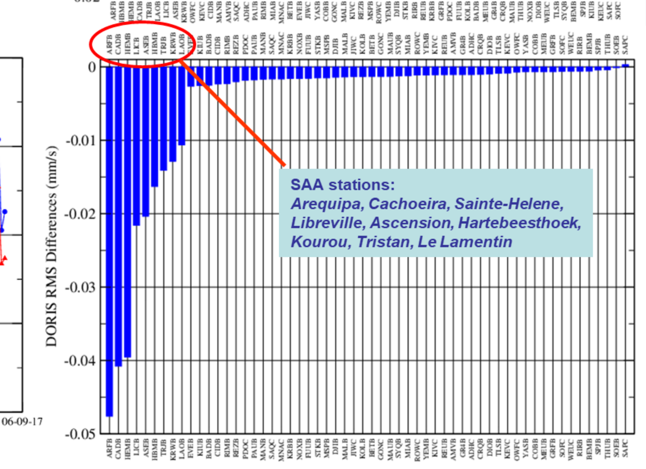
Impact on the precise orbit
Classical processing:
one Frequency Bias adjusted per pass.
With strategy:
Frequency Polynomial (degree 4) adjusted per pass.
- *The DORIS residuals are lower when we apply the strategy of polynomial adjusting frequency per pass for SAA stations.*
- *The impact is significant for SAA stations and the number of measurements is higher.*





DORIS RMS of fit





Impact on the station position estimation
Single satellite Solution compared to DPOD2014.
Cryosat-2 solution used as a reference.
Differences between the Jasons and Cryosat-2 solutions in NEU.
Solution with strategy:
Frequency Polynomial adjusted per pass.
- *The strategy brings an improvement in the station position estimation for the SAA stations,especially for the vertical component.*

Differences between the Jason w and wo strategy and Cryosat-2 solutions in NEU

Station	Jason-2 (in cm) North	Jason-2 East	Jason-2 Up	Jason-2 with strategy (in cm) North	Jason-2 with strategy East	Jason-2 with strategy Up
Cachoeira	4.4	4.5	**8.9**	**2.7**	**4.8**	**3.3**
Arequipa	-1.6	4.2	**8.8**	-0.3	1.3	1.6
Kourou	-2.0	-1.1	0.8	-1.3	-1.5	0.5
Ascension	1.4	-3.9	**6.1**	0,2	-3.1	**2.9**
Saint Helene	**5.0**	-1.6	2.4	**2.2**	-1.9	-0.5
Le Lamentin	-0.6	-0.2	-3.6	-0.7	0.3	0.7
Libreville	-3.9	-0.4	2.9	**-1.9**	0.1	2.3
Yarragadee	*-1.1*	*-0.1*	*0.2*	*-0.9*	*-0.1*	*0.6*
Thule	*0.2*	*-0.6*	*-0.4*	*0.8*	*-0.3*	*-0.8*

Station	Jason-3 (in cm) North	Jason-3 East	Jason-3 Up	Jason-3 with strategy (in cm) North	Jason-3 with strategy East	Jason-3 with strategy Up
Cachoeira	**6.8**	2.6	**20.0**	**4.9**	**6.2**	**5.2**
Arequipa	-1.7	**10.8**	**20.1**	-0.2	4.6	3.5
Kourou	**-6.0**	1.3	3.5	-3.5	0.4	0.8
Ascension	2.1	-0.2	**14.8**	-1.0	1.1	**5.2**
Saint Helene	**9.5**	-3.2	**9.3**	**4.9**	-3.3	1.7
Le Lamentin	-1.8	-2.1	**-5.6**	-0.6	-1.1	-0.6
Libreville	**-6.1**	1.1	**8.3**	**-3.1**	1.7	2.3
Yarragadee	*-0.2*	*0.9*	*-0.4*	*-1.1*	*0.1*	*0.1*
Thule	*1.2*	*-0.7*	*-1.1*	*0.9*	*-0.2*	*-1.8*

Mean of 72 weeks (from April 2016 to August 2017)

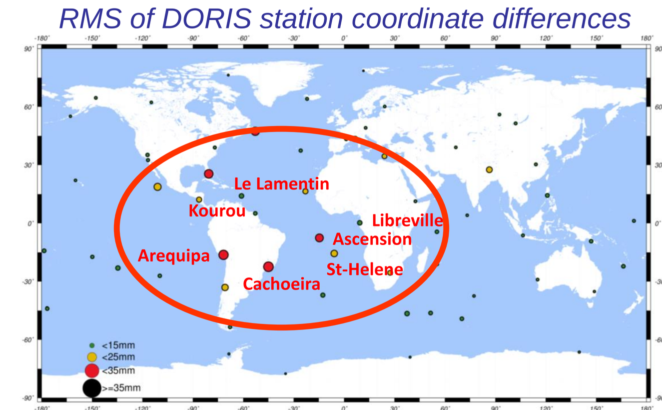
❑Strategy to add single satellite solution affected by the SAA in the multi-satellite solution

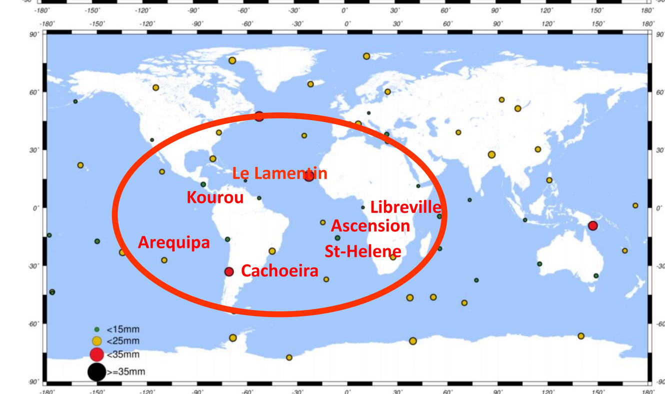
For Jason-1, the method we implemented, tested and adopted for ITRF2014 is: before combining Jason-1 solution to the other single satellite solutions, we rename the SAA stations (and all their adjusted parameters) so these SAA stations from Jason-1 do not contribute to the realization of the combined solution.
Multi-satellite Solution compared to DPOD2014
We computed weekly multi-satellite solutions from 2010 to August 2017 (8,5 years).
We provided 3 solutions:
Solution of reference REF:
Envisat + Spot4 + Spot5 + Cryosat-2 + HY-2A + Saral + Sentinel-3A
Solution 1: REF + Jason-2 + Jason-3
Solution 2: REF + Jason-2 SMS + Jason-3 SMS
With SMS = SAA Mitigation Strategy: Renaming + (Polynomial adjusting)

Differences between the solutions with Jason-2&3 and the solution of reference REF in NEU

Station	Solution 1 (in cm) North	Solution 1 East	Solution 1 Up	Solution 2 (in cm) North	Solution 2 East	Solution 2 Up
Cachoeira	0.9	-0.2	2.2	0.3	0.2	0.7
Arequipa	-0.5	1.1	2.3	0.0	0.3	0.4
Kourou	-0.4	0.1	0.2	-0.2	0.06	0.04
Ascension	0.1	-0.5	2.0	0.1	-0.1	0.5
Saint Helene	1.4	-0.4	1.6	0.5	-0.2	0.4
Le Lamentin	-0.1	-0.3	-1.1	0.0	-0.1	-0.2
Libreville	-1.0	-0.3	1.1	-0.02	-0.06	0.2
Yarragadee	*0.1*	*-0.1*	*0.06*	*0.1*	*-0.1*	*0.07*

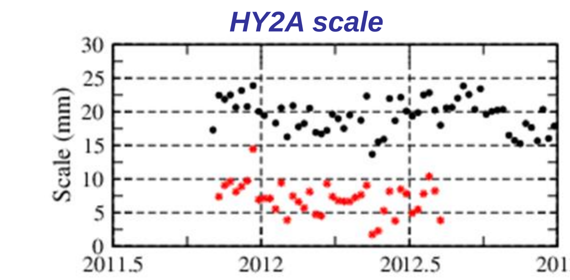
RMS of DORIS station coordinate differences

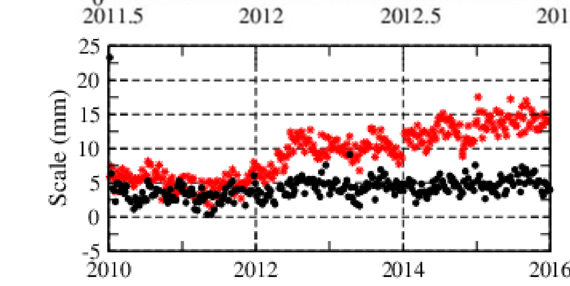




- *The IDS solution provided for the ITRF2014 was worsened by the Jason-2 solution for the SAA stations.*
- *The strategy brings an improvement in the station position estimation for the SAA stations, especially for the vertical component.*

HY2A scale





Multi-satellite scale

❑ Correction of the DORIS scale factor jump in 2012

Correction of the HY-2A high scale
The high scale level of HY-2A increased the scale of the DORIS solution.
- *We used the new position of the CoM given by the Chinese Project and the HY2A scale is significantly reduced.*

Scale variations due to the use of Doris2.2 data
Impact of using only the data considered to be good in CNES pre-processing:
The increase of the scale factor for Jason-2 and Cryosat-2 was fully explained by the change of tropospheric model used by CNES in its POD processing (GDR standards): from CNET (GDR-C) to GPT/GMF (GRD-D).
The larger number of data, especially at low elevation, was the cause of the change we observe in the scale factor.
- *We did our own pre-processing when using doris2.2 data and the scale jump is removed*

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