[Catégorie]

Assessment of Orbit Quality through the Sea Surface Height calculation - Yearly report 2016 - SALP activities

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1. Introduction

This document presents the synthesis report concerning analysis and development activities of Orbit validation using altimetry during year 2016. It is part of SALP contract n° 160182 (lot 1.6.2) supported by CNES at the CLS Space Oceanography Division.

2. Overview

For a long time, orbit has been the major error in **altimetry**. This is not anymore the case since the deployment of DORIS and GPS positioning system and several modelling improvements. Still, the errors associated to orbital errors remain particular because they still dominate for the **very large** temporal and geographical **scale (***Figure 1***)**. Typically, errors were shown to have a non-negligible impact on **climate scales studies** (*Ollivier et al. 2012, Couhert et al. 2014*). Thanks to the reduction of other errors and to the increasing capacity of validations diagnosis, orbit errors are also shown to contribute to **mesoscale** and basin scale.

In the frame of SALP contract, the quality of orbits used for altimetry missions is regularly analyzed on POD side, (using intrinsic diagnosis such as tracking metrics, post fit residuals, laser performances…), but also through the assessment of orbit quality on the sea surface height estimation.

These studies have a double objective:

- For all nadir altimetry missions, the **quality of the orbit ephemerides** is crucial for the computation of the Sea Surface Height (SSH). Impacting mostly large scales, spatially and temporally, the errors attributed to the orbit are worse being quantified and analyzed precisely.
- Conversely, to assess evolutions of the orbit computation, having an accurate knowledge of the impact on the SSH quality efficiently completes the intrinsic orbit based diagnosis. Indeed, it provides an **external reference** (the SSH) to **benchmark different orbit solutions** and to detect remaining weakness with a very fine precision.

To address different aspect of the quality (precision, long term stability…), the analyses rely on a **large panel of calval tools and skills**, these studies use **mono-mission** and **multi-missions** diagnosis as well as **in situ** database comparisons.

Past relevant studies already shown their usefulness:

- To **validate standards solutions**, in addition to intrinsic orbit based diagnosis
  - ➔ For instance, currently GDR-E standards validation vs GDR-D previous version
- To better **understand the orbit model** solutions
  - ➔ For instance, they enabled to detect (and solve) imprecision in the gravity field modeling in the orbit computation with an impact of 10 to 20% of the Mean Sea Level trend estimation depending on the missions
- To identify **weaknesses of some products**
  - ➔ For instance, they enabled to compare short time critical (STC 3 days)/no time critical (NTC, 1month) product quality.

These activities are performed since many years in collaboration with CLS and CNES and enable to contribute to international meetings and discussions (participations to the OSTST, ESA missions POD QWG, S3VT PI teams…).

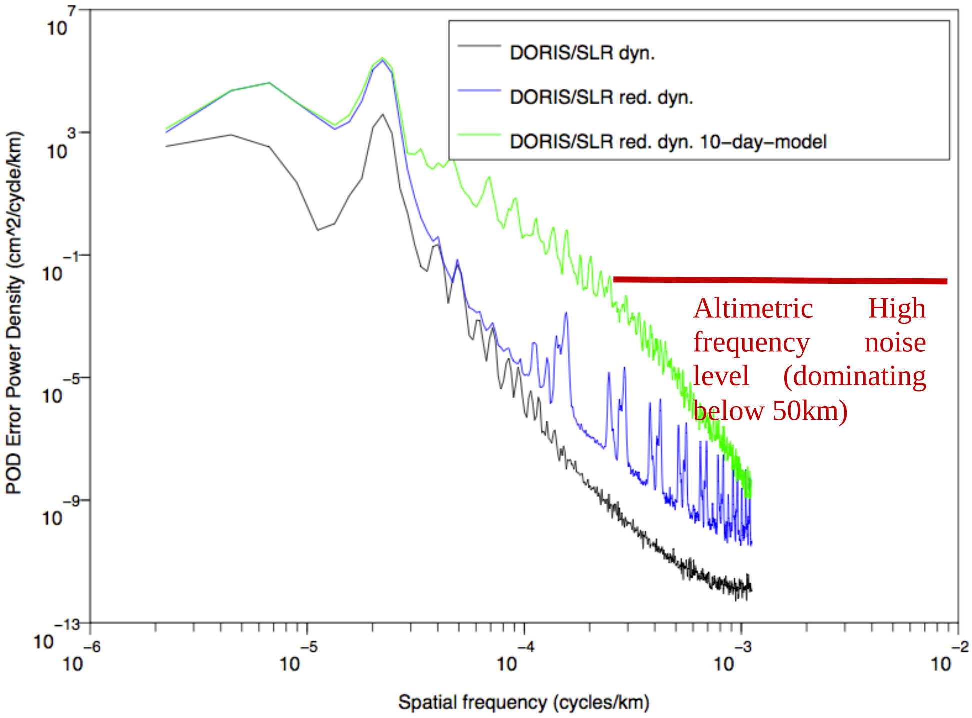


Figure 1 Spectral analysis of the radial differences between a degraded and a reference orbit solution (courtesy of CNES). The degraded orbit corresponds to ENVISAT DORIS-only orbit computed with the EIGEN-GL04S-Annual gravity field with the drift terms removed. The reference orbit is the DORIS/SLR reduced dynamic orbit with the most up-to-date gravity field model (10-day Grace solution). The radial difference between the degraded orbit and the reference orbit gives insight into the radial error.

The frame of these activities covers all the altimetric missions. It mainly focuses on CNES POD production but also integrates studies concerning other POD centres. *Table 1* sums up the official POD used for the SALP DUACS products (MOE = Medium/POD = Precise Orbit Ephemeris respectively for Near/Delayed Time production) as well as the techniques used for the POD definition. Since GDR-E standards, laser information is not anymore part of the solutions for it is used for validation purposes only on POD side.

Mission	***GFO***	***TP***	***E1***	***E2***	***EN***	***C2***	***AL***	***J1***	***J2***	***J3***	***S3***
Duacs production center	*GSFC*		*REAPER (GFZ)*		*CNES*						*GMV/ CNES*
MOE CNES Technique	-	-	-	-	-	*DORIS*	*DORIS*				*DORIS*
POE CNES Technique	-	*DORIS(+SLR)*	-	-	*DORIS*	*DORIS*	*DORIS (AL)* *DORIS+GPS (J1, J2, J3)*				*DORIS +GPS*

Table 1 Altimetric missions considered in this frame and current orbit chosen in the DUACS Aviso products

For each mission, the studies rely on the performance of Sea Surface Height estimation, defined as the sum of several corrections whose standards are described below.

	ERS-1	ERS-2	EN	T/P	J1	J2	GFO	C2	AL	H2
Orbit	Reaper	Reaper	GDR-D	GFSC STD12/15	GDR-E	GDR-E	GSFC	GDR-E	POE-E	GDR-?
Major Instrumental correction			PTR FPAC							Correction Doppler
Sea State Bias	BM3 (Gaspar, Ogor, 1994)	Non parametric Mertz et al., 2005	Tran 2015 (compatible new MWR et new SWH)	Non parametric SSB [N. Tran and al. 2010]	SSB GDR-E	Tran 2012	Non parametric SSB [N. Tran and S. Labroue]	Non parametric SSB de J1 (des GDR-C) avec sig0 débiaisé	SSB Peachi (2D)	Non parametric SSB [N. Tran] (Vent Labroue)
Ionosphere	NIC 09	NIC09(cycle 1-36), GIM from cycle 37	Iono filtre SLOOP / GIM (GDR2.1)	Iono filtre SLOOP	Iono filtre SLOOP	Iono filtre SLOOP recalculé après update SSB band C	GIM	GIM	GIM	GIM
Wet troposphere	GPD+	GPD+	MWR reproc v3	TMR (Scharoo et al, 2004)	MWR replacement product + algo composite	correction NN à 3 entrée (3tB) à partir de simulation ET par classes de vent/tropo	From GFO radiometer	From ECMWF model	correction NN à 5 entrées (2TB+sig0+SST Reynolds+Gamma climato)	From ECMWF model
Dry troposphere	Era Interim based		ECMWF Gaussian grids based	Era Interim based	ECMWF rectangular grids based	ECMWF Gaussian grids based	ECMWF rectangular grids based	ECMWF Gaussian grids based	ECMWF Gaussian grids based	ECMWF Gaussian grids based
Combined atmospheric correction	Era Interim based		MOG2D High Resolution forced with ECMWF pressure and wing fields + IB	Era Interim based	MOG2D High Resolution forced with ECMWF pressure and wing fields + IB			MOG2D High Resolution forced with ECMWF pressure and wing fields + IB from rectangular grids	MOG2D High Resolution forced with ECMWF pressure and wing fields + IB	MOG2D High Resolution forced with ECMWF pressure and wing fields + IB
Ocean tide	FES2014									
Solid Earth tide	Elastic response to tidal potential [Cartwright and Tayler, 1971], [Cartwright and Edden, 1973]									
Pole tide	[DESAI, 2015]									
MSS	CNES-CLS-2015									

Table 2 Standards used for the SSH definition for each mission

This document sums up the different studies performed in this frame for year 2016.

3. Quality of the current CNES POE orbits

To address the orbit quality, the main diagnoses used are of two kinds:

- Absolute diagnosis based on a direct estimation error of Sea Surface Height
- Relative diagnosis based on the comparison of two orbit standards, relatively to the estimation of two Sea Surface Height for which the orbital term is the only difference.

One of the most relevant absolute diagnoses is the map of average difference of Sea Surface Height (SSH) at cross over points. It highlights the systematic discrepancies between coincident ascending and descending tracks separated by less than 10 days (insuring a good stability of ocean variability) and thus a potential error on the SSH estimation.

These diagnosis reveal cumulated errors on the SSH estimate but the very large scale ones are often relevant of orbital signatures. They rely on a statistical computation on points plotted on *Figure 2* where the time difference between ascending tracks is plotted and shown to be very different from a mission to another.

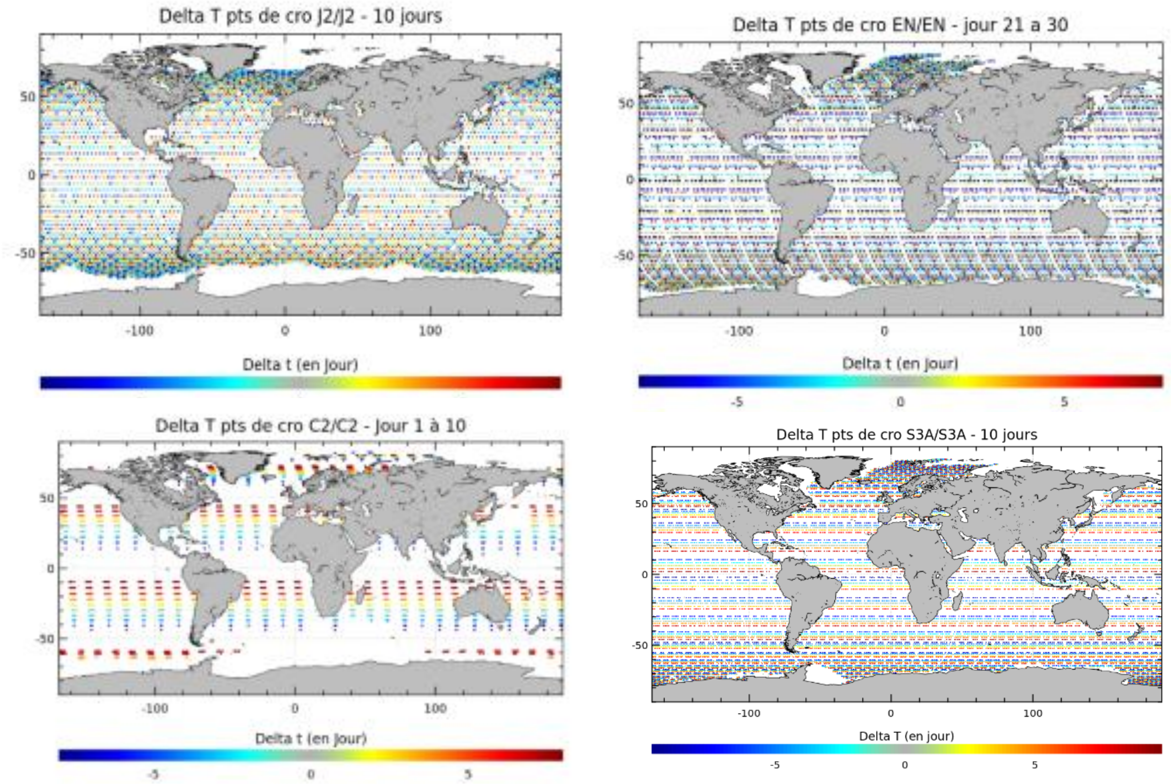


Figure 2 Delta time Asc-Dsc at Crossover point for J2 (or J1)/ C2/EN(or AL) and S3 , with 10days selection (current selection to limit the oceanic variability effect)

Erreur ! Source du renvoi introuvable.

Figure 3 map the average difference of SSH at crossovers for all missions and enables to observe different structures:

For Jason-1, a slight pattern is visible near South America. This pattern, not visible on Jason-2 is due to the remaining South Atlantic Anomaly impact on DORIS instrument, cumulated to the lack of GPS in the solution at the end of the mission.

For Jason-2, the map is very homogeneous and clean. In average, all the differences are below +/-1cm.

For Envisat, the map is more inhomogeneous than the Jason's with patterns around +/-2cm. This effect is partly explained by several aspects: Envisat is sun-synchronous so the physical content of ascending and descending passes may present systematic differences (typically the impact of solar radiation pressure…). The blue color indicates that Ascending tracks are systematically below the Descending tracks.

For AltiKa, the map is also more inhomogeneous than the Jason's with patterns around +/-2cm. This effect is partly explained by several aspects: like Envisat, AltiKa is sun-synchronous so the physical content of ascending and descending passes may presents systematic differences to be investigated. The blue color indicates that Ascending tracks are systematically below the Descending tracks. This could be further investigated, potentially for other corrections than the orbit. Furthermore, the time series is shorter than for Jason1 and 2 so the effects are less averaged. The integrated effect should then tend to decrease as time goes.

For Cryosat-2, the striking effect is the double blind band situated around the equator and +/-[50]°Lat. This effect is due to the geometry of the orbit that avoids crossover points below 10 days in this area. Elsewhere, the map presents much larger patches than the Jason's series. Because the time series is smaller than the Jason-2's but also because of the geometry of the orbit introduces latitudinal dependency of the time discrepancy.

For Sentinel 3, the map is the most inhomogeneous with patterns around +/-3cm. This effect is partly explained by several aspects: the time series is shorter than for all the other missions so the effects are less averaged. But when plotted over the same period, the errors are still higher than AltiKa's. The youth of the mission and the potential remaining errors on range does not enable to conclude directly that the discrepancies are due to the orbit only. Still, this could be further investigated.

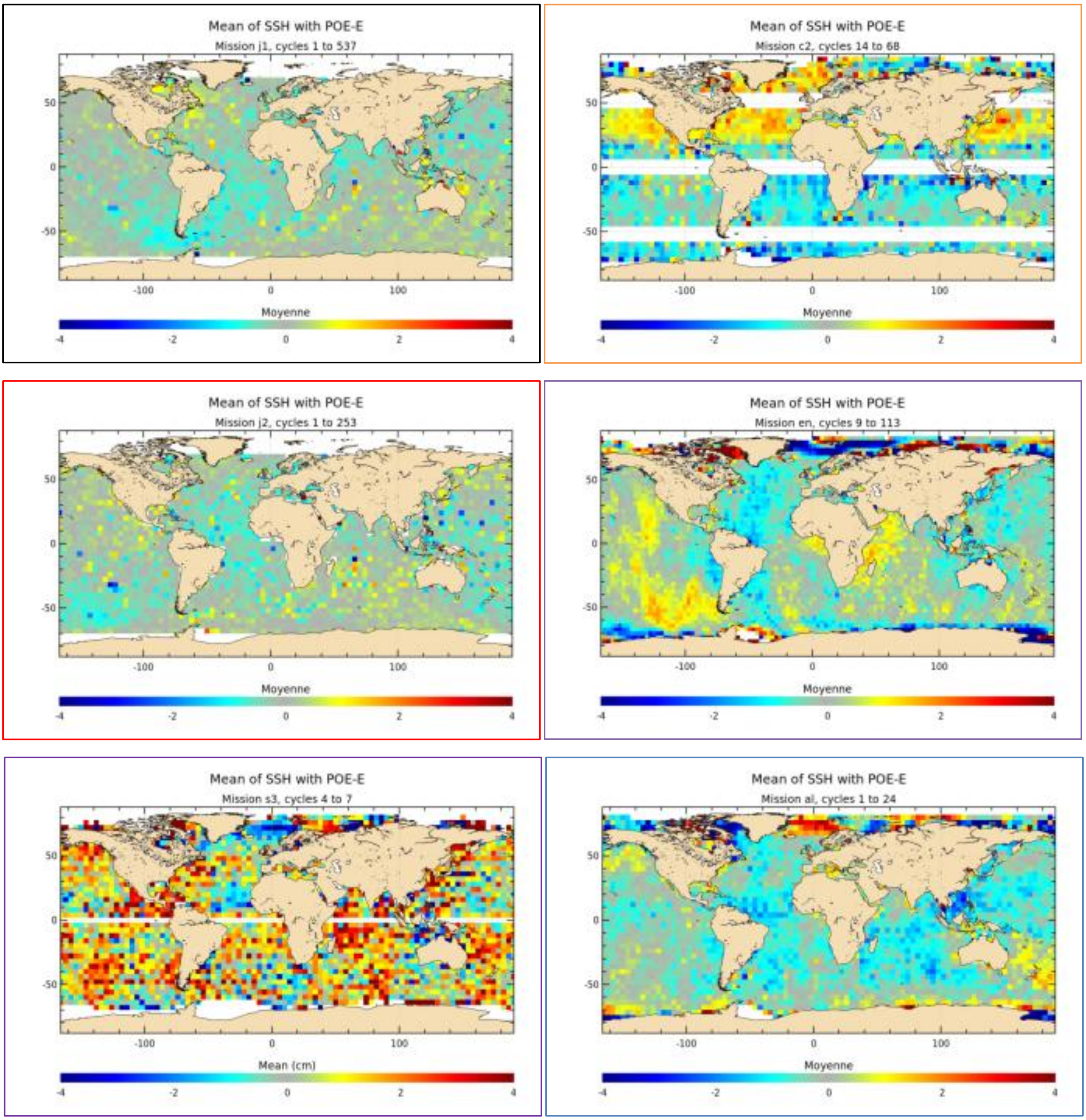


Figure 3 Map of the mean difference of Sea Surface Height at crossovers for all missions using CNES GDR-E standards (Jason1-Jason2-AltiKa-Cryosat2-Envisat-Sentinel3)

The stability of such ascending/descending discrepancies can be monitored thanks to **Erreur ! Référence non valide pour un signet.***Figure 4* which highlights:

- For Jason-1 and Envisat, a slight inter-annual signal not directly explained up to now.

- For all the missions, a periodic signal, equal to the draconitic (beta prime period ie period for which the sun and the orbital plan gets in the same configuration) period (different depending on the mission) under investigation and probably linked to the beta angle of the mission (angle between the orbital plane and the solar rays).
    - For Jason-1 and Jason-2: 118 days
    - For the sun-synchronous Envisat and AltiKa: one year
    - For Cryosat-2: not exactly periodic but close to 1.5year

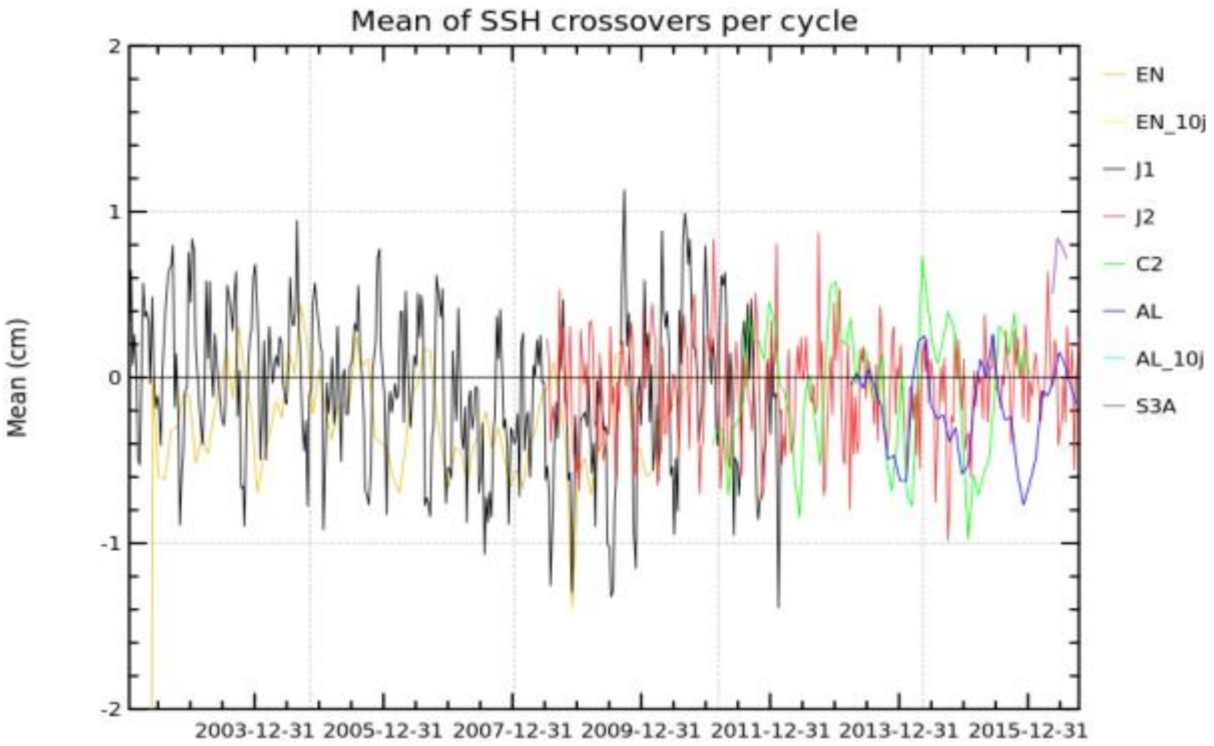


Figure 4 Monitoring of mean difference of Sea Surface Height at crossovers for all missions using CNES GDR-E standards

4. Quality of the CNES MOE orbits compared to the POE

Concerning the relative diagnosis based on the comparison of two orbit standards, comparisons can be performed between multiple solutions. For instance, MOE – POE comparison over ocean where diagnosis of SSH at crossover diagnosis are available, or over land, for which the diagnosis are more basic.

4.1. Multimission comparison of MOE versus POE differences over ocean

As presented in the EUMETSAT meeting in Toulouse in September 2016, a comparison was performed to estimate the relative quality of MOE (3days delay product) compared to POE solution (1month delay product).

One of the most relevant absolute diagnosis is the map of average difference of Sea Surface Height (SSH). It highlights the systematic discrepancies between coincident ascending and descending tracks separated by less than 10 days (insuring a good stability of ocean variability) and thus a potential error on the SSH estimation.

These diagnosis reveal cumulated errors on the SSH estimate but the very large scale ones are often relevant of orbital signatures.

Here, *Figure 5* shows that (for J2 example) the MOE presents a negative systematism between ascending and descending tracks (-1.5cm) and a +/-2cm 120day signal, much reduced at the transition between GDR-C and GDR-D orbits (mainly thanks to the better gravity field modelling) With the POE the quality is globally better, with no clear systematism (mainly thanks to the GPS addition in the solution).

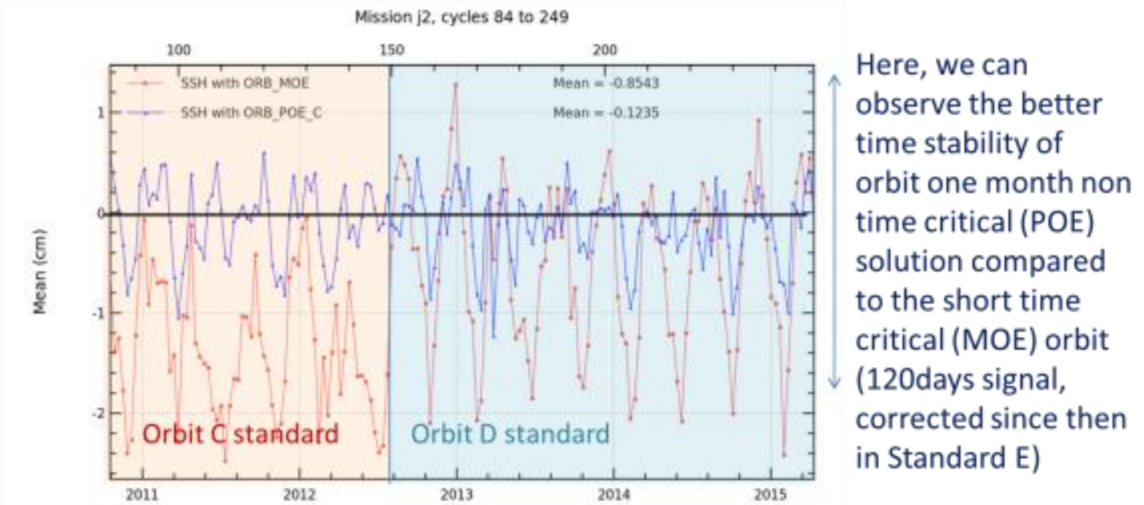


Figure 5 Monitoring of mean difference of Sea Surface Height at crossovers for all missions using CNES GDR-C and D standards for MOE compared to GDR-D POE standards

The variance gain at crossovers also indicates (*Figure 6*) that the MOE is slightly degraded compared to the POE but in a much lower way with GDR-D standards than with GDR-C.

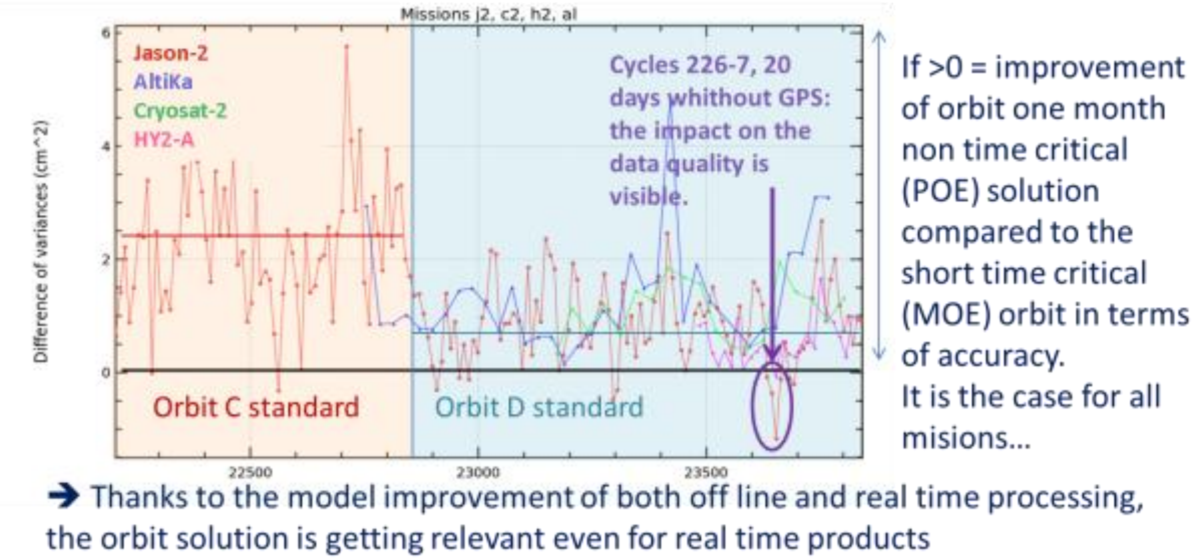


Figure 6 Monitoring of variance difference of Sea Surface Height at crossovers for all missions using CNES GDR-C and D standards for MOE compared to GDR-D POE standards

These diagnosis of MOE/POE comparisons can regularly be updated and contribute to the discussion of potential faster products delivery in the OSTST community.

4.2. Difference of MOE versus POE on lands Cryosat-2 case

Motivation of this study was to determine (in the perspective of SWOT mission which will only provide one daily product) what would be the loss of using a Short Time Critical orbit (MOE) instead of Delayed time one (POE) in terms of performance over ocean AND land?

The aim was therefore to quantify errors at cross-overs over oceans and lands using MOE instead of POE, through the example on Cryosat-2. For this, we analyzed direct orbits and also an empirical correction called EO (Empirical Orbit Fit), based on a fit that minimizes the difference at crossovers over ocean. Such correction is currently applied in Duacs system (Le Traon and Ogor, 1998).

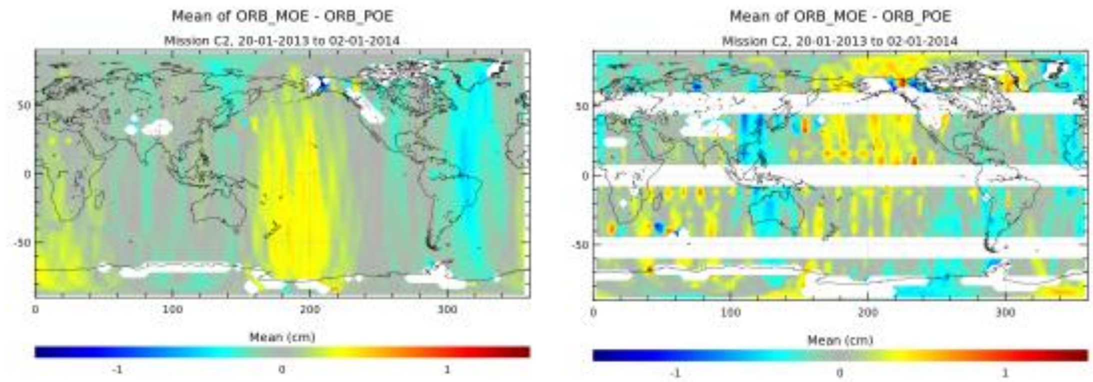


Figure 7 Average difference between MOE and POE orbits using direct difference (left) and at crossovers (right) for Cryosat-2

In average over one year, over the globe, the discrepancies are centimetric (*Figure 7*). The impact of using the statistics at crossovers (*Figure 7* right) is visible on the coverage (blind latitudes and boxes effect).

In average over one cycle (*Figure 8*), the effect is larger but with similar features. For this period, we corrected data from the EO (Empirical Orbit Fit). As seen on the right hand plots of *Figure 8*, and by construction, this reduces the differences between MOE and POE at crossovers over ocean in terms of mean and standard deviation. We also notice that it largely increases the variance at high latitudes which, for this cycle is covered by ice and does not provide sufficient ocean data to fit during the EO estimation step.

Contrarily, for a northern summer period when high latitudes are in open ocean, the variance increase is not noticed anymore (*Figure 9*).

In this study, the variance of orbit difference is used. Provided an hypothesis of decorrelation of orbit errors with the SSH difference at crossovers, this value is equal to a variance gain at cross-overs. Its reduction is a sign of error reduction.

Using the notations:

E: mathematical Esperance

SSH_MOE_A (resp SSH_MOE_D): SSH value using MOE orbit on ascending (resp descending) track

SSH_POE_A (resp SSH_MOE_D): SSH value using POE orbit on ascending (resp descending) track

MOE_A (resp SSH_MOE_D): MOE orbit value on ascending (resp descending) track

POE_A (resp SSH_MOE_D): POE orbit value on ascending (resp descending) track

We have:

$X = E^2(SSH\_MOE\_A - SSH\_MOE\_D) - E^2(SSH\_POE\_A - SSH\_POE\_D) - E^2(MOE\_A - MOE\_D - POE\_A + POE\_D)$

$= E^2(SSH\_MOE\_A - SSH\_MOE\_D) - E^2(SSH\_MOE\_A + MOE\_A - POE\_A - SSH\_MOE\_D - MOE\_D + POE\_D) - E^2(MOE\_A - POE\_A - MOE\_D + POE\_D)$

$= E^2(SSH\_MOE\_A - SSH\_MOE\_D) - E^2(SSH\_MOE\_A - SSH\_MOE\_D + MOE\_A - POE\_A - MOE\_D + POE\_D) - E^2(MOE\_A - POE\_A - MOE\_D + POE\_D)$

$= E^2(SSH\_MOE\_A - SSH\_MOE\_D) - E^2(SSH\_MOE\_A - SSH\_MOE\_D) - E^2(MOE\_A - POE\_A - MOE\_D + POE\_D) + 2E(SSH\_MOE\_A - SSH\_MOE\_D, (MOE\_A - POE\_A - MOE\_D + POE\_D) - E^2(MOE\_A - POE\_A - MOE\_D + POE\_D)$

$= 2E(SSH\_MOE\_A - SSH\_MOE\_D, (MOE\_A - POE\_A - MOE\_D + POE\_D)$

In conclusion, and provided a tuning of the EO estimation to be less sensitive to the absence of data at high latitudes when they are covered with ice, the errors of using MOE instead of POE are very weak over ocean and centimetric over land in average.

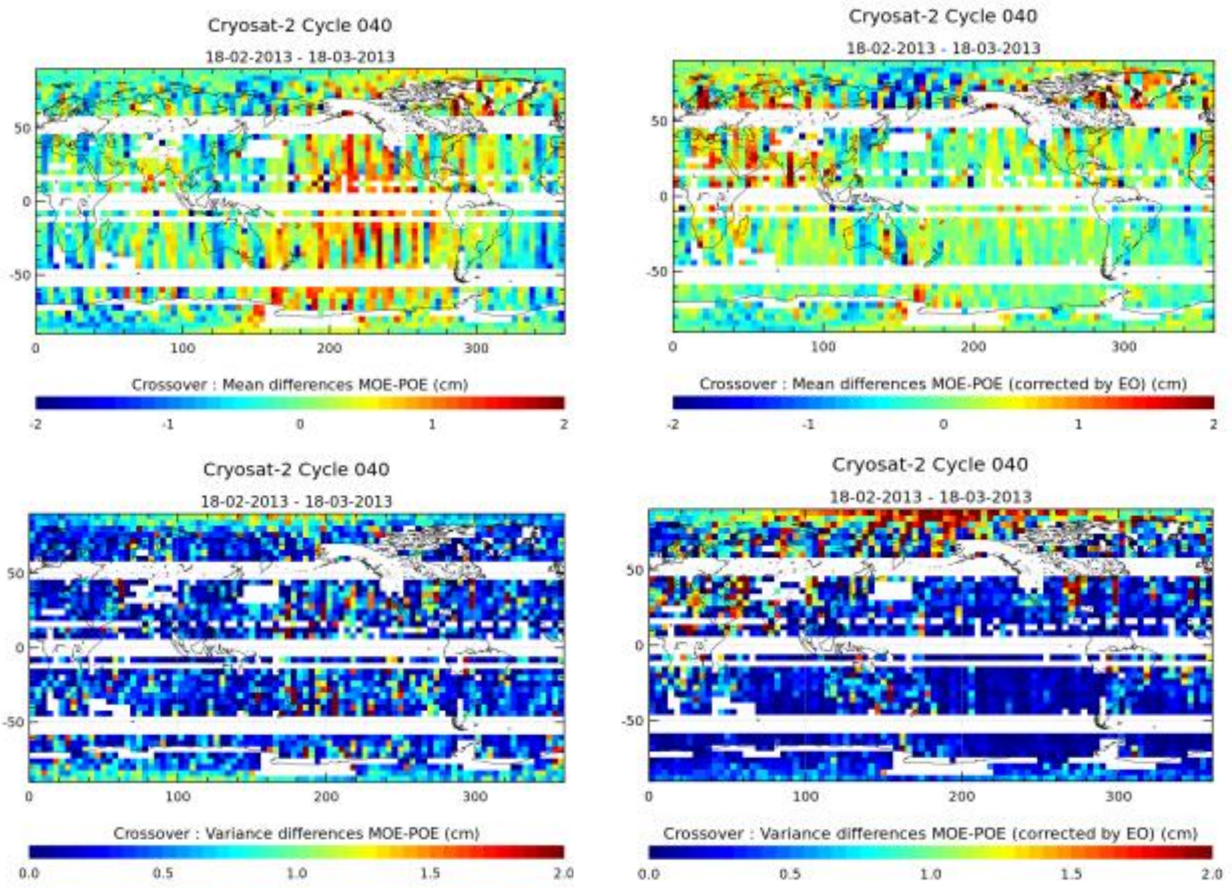


Figure 8 Average difference between MOE and POE orbits using direct difference (left) and at crossovers (right) for Cryosat-2 . North winter time with ice remaining at high latitudes

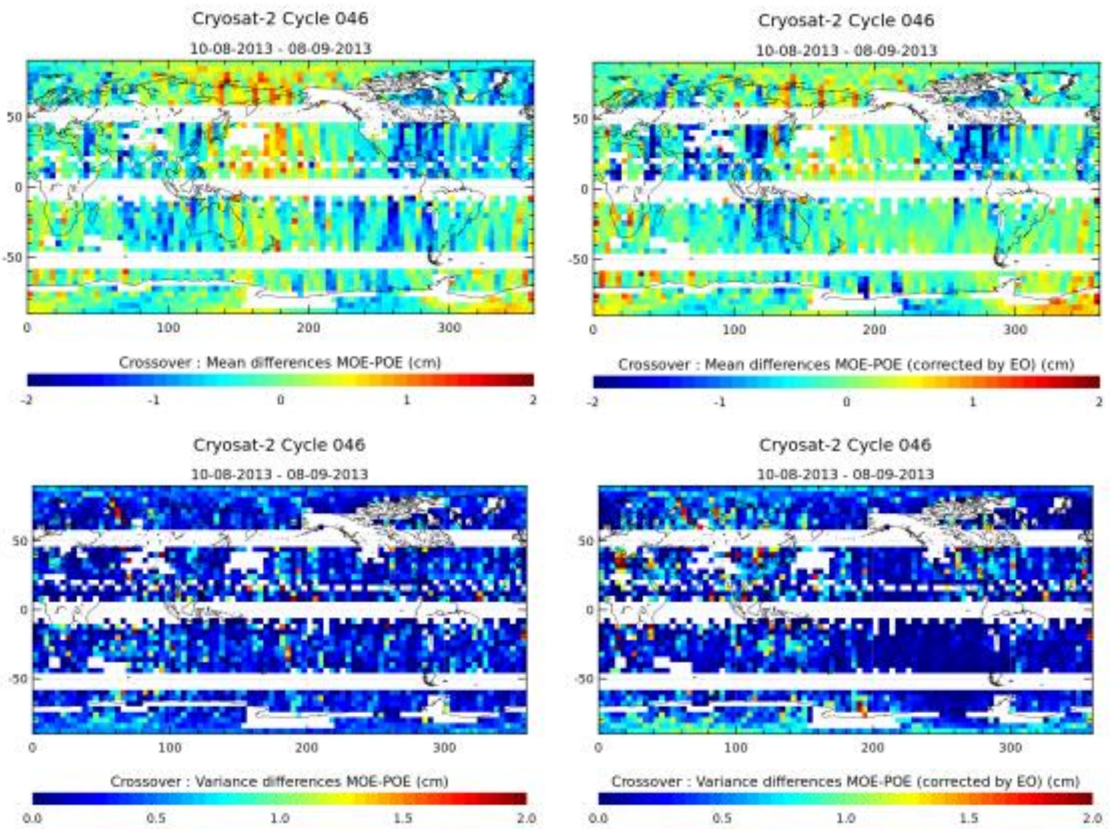


Figure 9 Average difference between MOE and POE orbits using direct difference (left) and at crossovers (right) for Cryosat-2 . North summer time with open ocean at high latitudes

5. Quality of the current CNES POE GDR-E orbits compared to the previous standards GDR-D

Since end 2015 and during 2016, all orbit standards were upgraded from a GDR-D to GDR-E (including Jason-3 and Sentinel-3 also using GDR-E standards from the beginning of the mission), following the calendar below concerning the GDR products shifts:

Cryosat 2 : 2avril 2015 (MOE on April 1st 2015)
4 avril 2015 (POE)

Jason-2 : 26 mai 2015 (MOE on May 25th 2015)
24 juillet 2015 (POE) – cycle 254

SARAL : 1 juillet 2015 (MOE du June 30th 2015)
4 août 2015 (POE) – arc 1 cycle 25

Hy-2A : planned for February 2017

	POE-D (Reference)	POE-E
Gravity model	EIGEN+GRGS.RL02bis_MEAN-FIELD	EIGEN+GRGS.RL03-v2.MEAN-FIELD
Non tidal TVG	one annual, one semi-annual, one drift terms for each year up to deg/ord 50	one annual, one semi-annual, one bias and one drift terms for each year up to deg/ord 80
Surface forces	Radiation pressure model: thermo-optical coefficient from pre-launch box and wing model, with smoothed Earth shadow model	Radiation pressure model: calibrated semi-empirical solar radiation pressure model
DORIS	DORIS weight is reduced by a factor 10 before DORIS instrument change	SAA DORIS beacons weight is divided by 10 before DORIS instrument change
Orbit solution	Doris/Laser/GPS till cycle 169 Doris/Laser after cycle 169	Doris/GPS till cycle 169 Doris after cycle 169

Table 3 Standards used for the POD definition for each standard D and E (only for J1 concerning the DORIS beacons underweighting)

In the frame of these activities, the relative quality of both standards was analyzed and summed up in a poster (Ollivier et al. OSTST 2016).

5.1. Multimission analysis of GDR-E impact on Sea Surface Height error with respect to GDR-D

The impact of POE-E on performance at crossovers is the following:

- For Jason-2 and Cryosat-2: the sea surface height differences are reduced at crossovers (in variance and average) using new POE-E orbit in comparison with the POE-D=> resulting in a good improvement of scales below 10days
- For Jason-1: the monitoring metrics (*Figure 10*) are equivalent but geographically (*Figure 11*), a centimetric improvement is noticed near the South Atlantic Anomaly (impact on south Atlantic and Pacific).
- For Saral/AltiKa: the evolutions have a negative impact on data on this point of view. The increase of variance of SSH difference with POE-E is probably due to ergol instability in the tanks (under investigation). Still, and to be consistent with the modeling of other missions, this configuration was validated. Furthermore, an additional solution (using reduced dynamics light blue curve) was tested but not selected as it only presented a non-significant improvement compared to the mixte (more stable) solution.

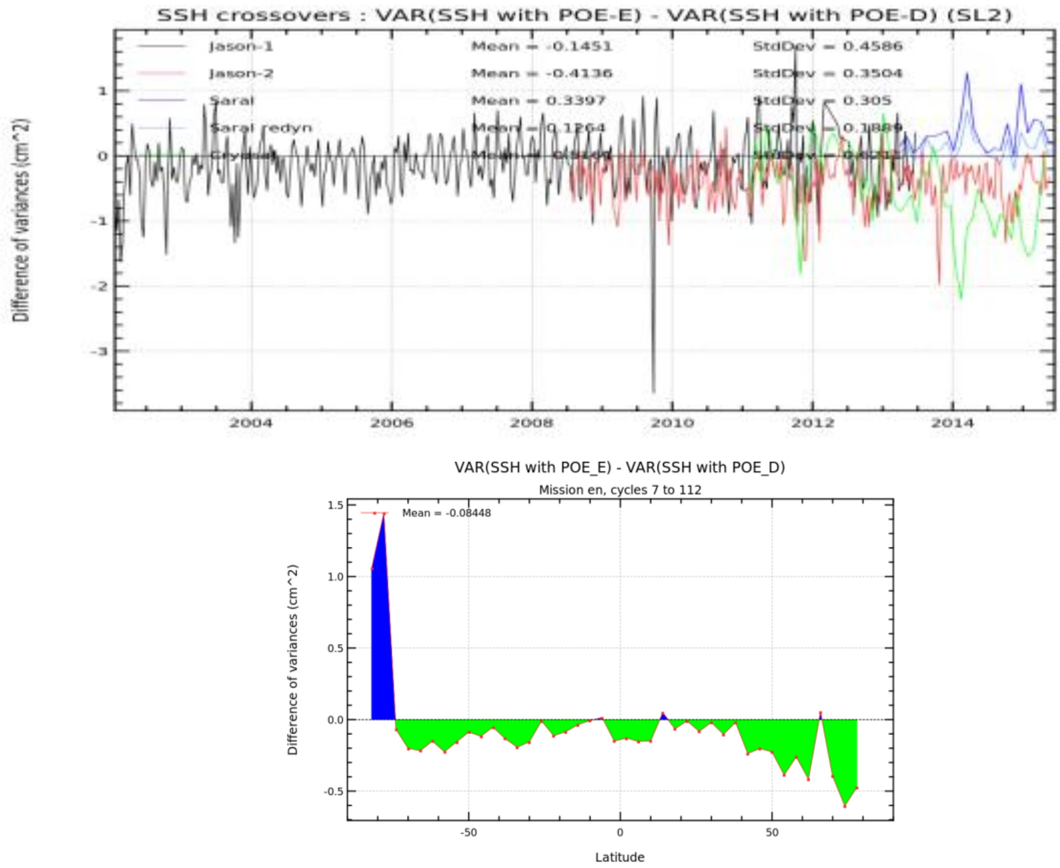


Figure 10 Impact of orbit discrepancy on the Sea Surface Height variance at crossovers for all missions except Envisat (top) using CNES GDR-D POE standards compared to the GDR-E POE. Along track monitoring. Envisat (bottom)

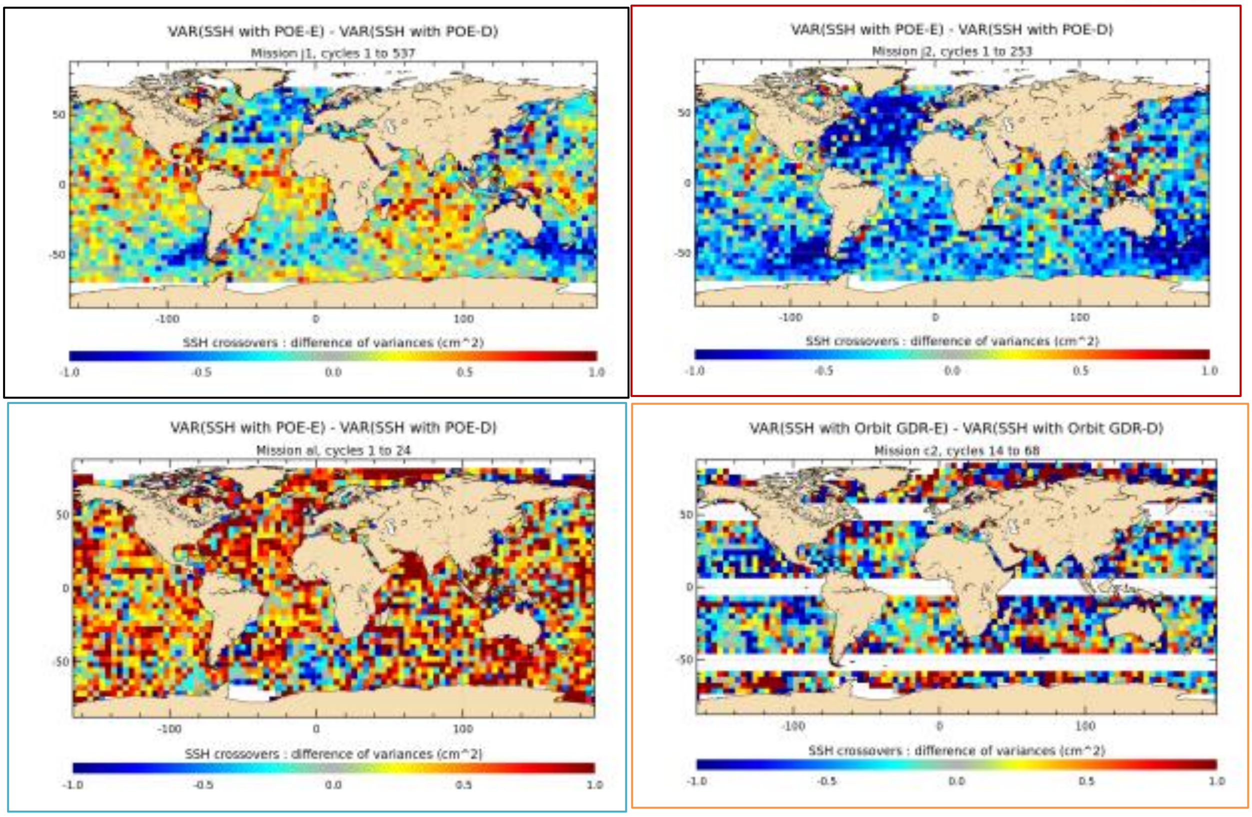


Figure 11 Impact of orbit discrepancy on the Sea Surface Height variance at crossovers for all missions using CNES GDR-D POE standards compared to the GDR-E POE. Map integrated over the whole periods.

5.2. Multimission analysis of GDR-E impact on Mean Sea Level trends with respect to GDR-D

The analysis of stability of the POE GDR-E compared to GDR-D concludes (*Figure 12* and *Figure 13*) that the impact on Global Mean Sea Level (GMSL) trend is negligible or very small depending on the mission:

- Jason-2 : no impact
- Jason-1 : very small impact (0.06 mm/yr)
- Saral/AltiKa : period too short for GMSL trend
- Envisat: very small impact 0.02mm/yr with a parabolic shape (see *Figure 13*)

The impact on the regional Mean Sea Level (RMSL) trend and yearly variability is also studied and estimated (depending on the mission, see *Figure 14*).

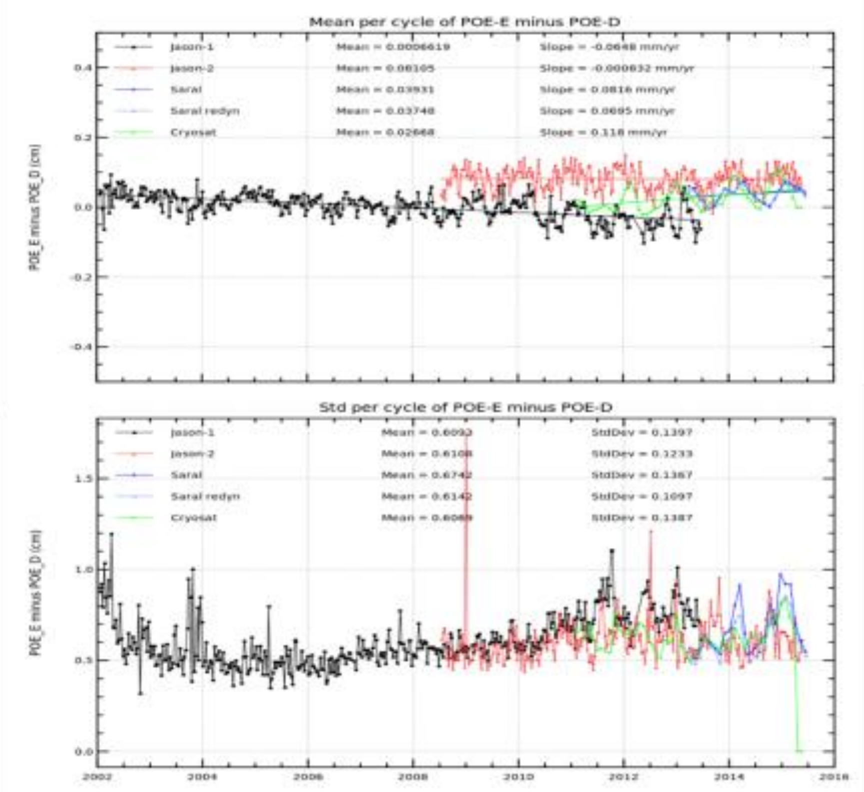


Figure 12 Impact of orbit discrepancy on the Mean Sea Level Trend (top) and on the standard SLA cyclic variability (bottom) for all missions using CNES GDR-D POE standards compared to the GDR-E POE

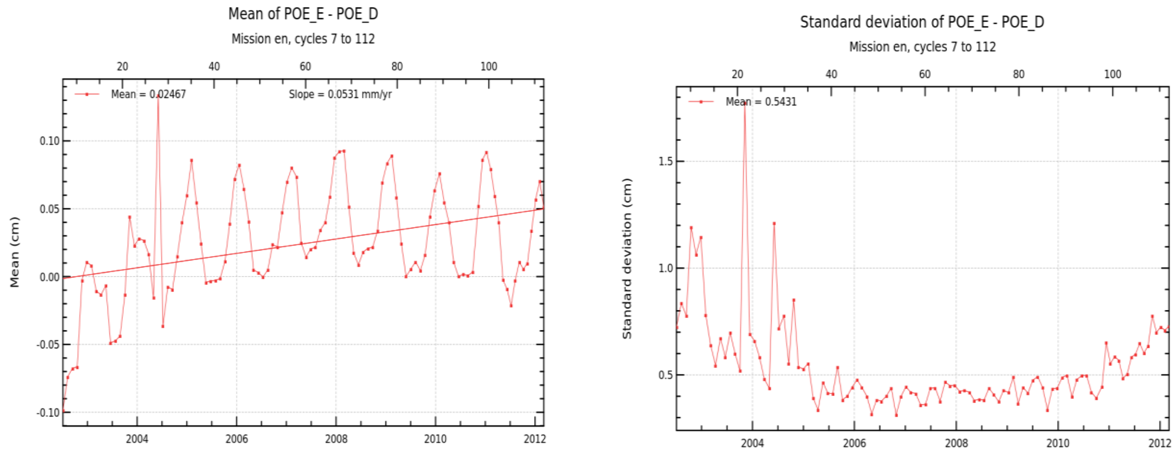


Figure 13 Impact of orbit discrepancy on the Mean Sea Level Trend (left) and on the standard SLA cyclic variability (right) for Envisat mission using CNES GDR-D POE standards compared to the GDR-E POE

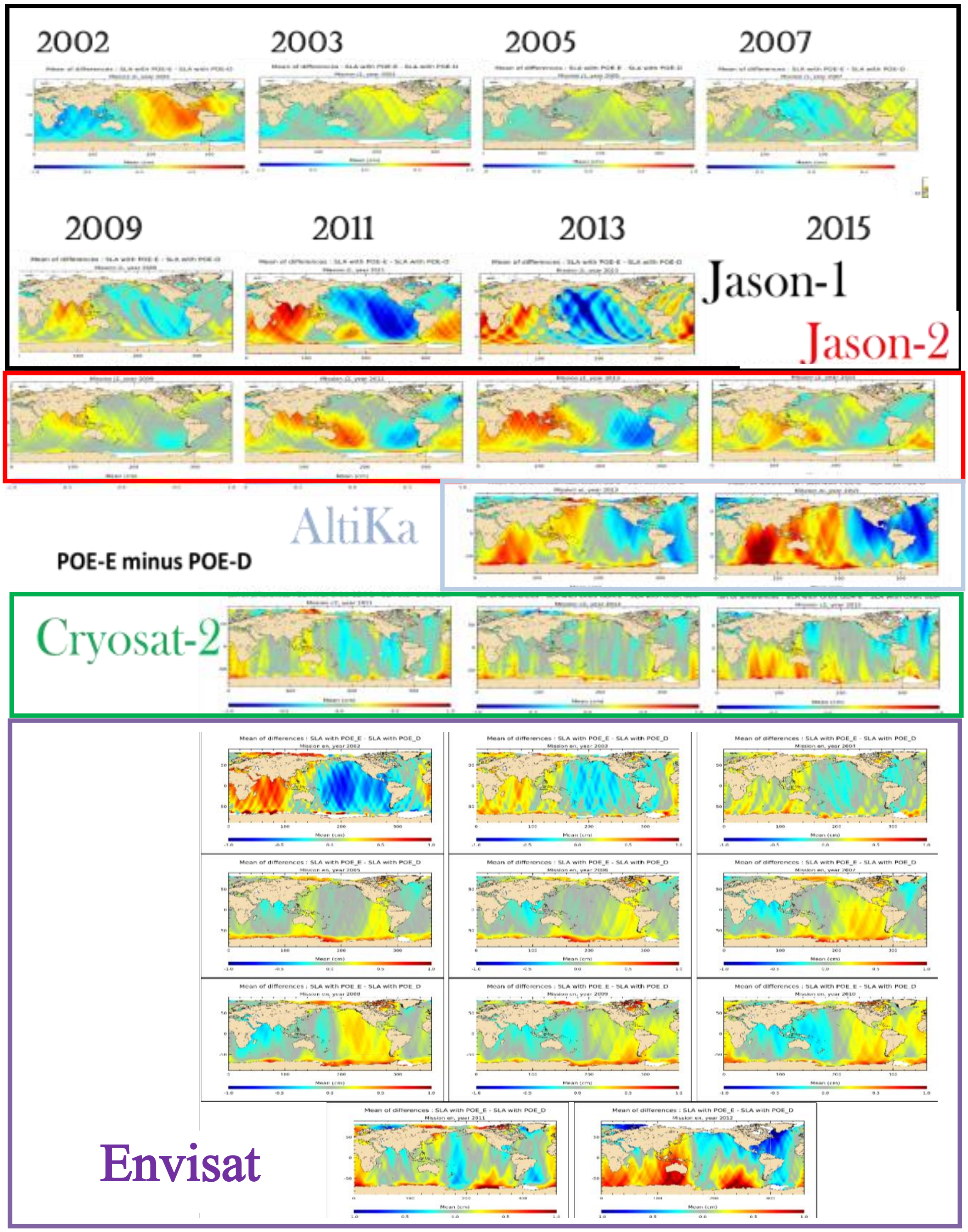


Figure 14 Impact of orbit discrepancy on the Regional Mean Sea Level yearly variability for all missions using CNES GDR-D POE standards compared to the GDR-E POE

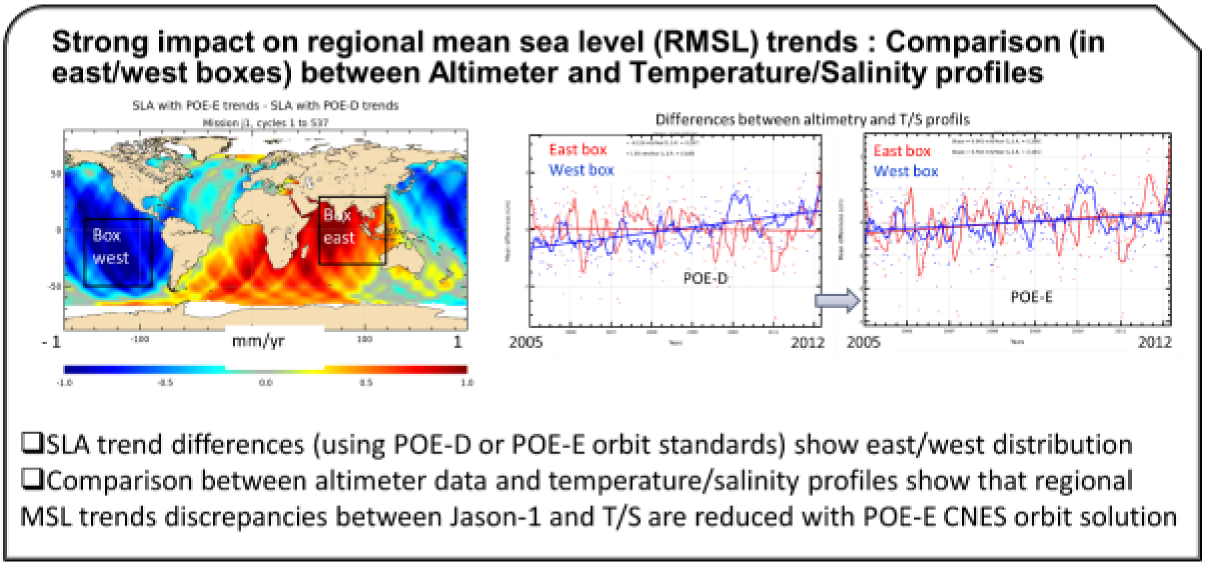


Figure 15 Impact of orbit discrepancy on the Regional Mean Sea Level with respect to in situ measurement for Jason-1 using CNES GDR-D POE standards compared to the GDR-E POE

Furthermore, thanks to comparisons to Argos temperature Salinity in situ data set, this change was shown to be an improvement for Jason-1 (*Figure 15*). The method used to demonstrate it was already published for the previous standards step (GDR-C to GDR-D) in Valladeau et al. 2012 and Ollivier et al. 2012. Indeed, the discrepancies between altimetry and in situ data set are more consistent in terms of trends in Eastern and Western basins defined in the black boxes plotted on *Figure 15*. For more details see also the Yearly report on "in situ" studies on Aviso web page http://www.aviso.altimetry.fr/en/data/calval.html .

5.3. Residual analysis of GDR-E impact on Jason-1 / Jason-2 consistency during tandem phase

Jason-1 and Jason-2 have the same altimetric system. During the tandem phase (cycles 1 to 20 of Jason-2), they are only separated by few seconds and their content is therefore totally comparable. On the *Figure 21*, the difference of Sea Surface Height is plotted along track and highlight centimetric discrepancies. These small differences are due to the orbit. Indeed, they are signatures of 2 factors:

- Jason-1 had lost its GPS payload for this period.
- The DORIS only orbit is affected by the DORIS onboard Ultra Stable Oscillator (USO) sensitivity to the radiation occurring in South Atlantic Anomaly region. Therefore, some of the DORIS beacons in the area were under-weighted in the orbit solution (Capdeville et al. 2006) to reduce the sensitivity to radiation effects.

In the GDR-E solution, this under-weighting was updated, in order to reduce the bias between both missions and to minimize a transition error on the Regional Mean Sea Level.

The resulting difference between both missions is very slightly modified, featuring a clearer N/S bias.

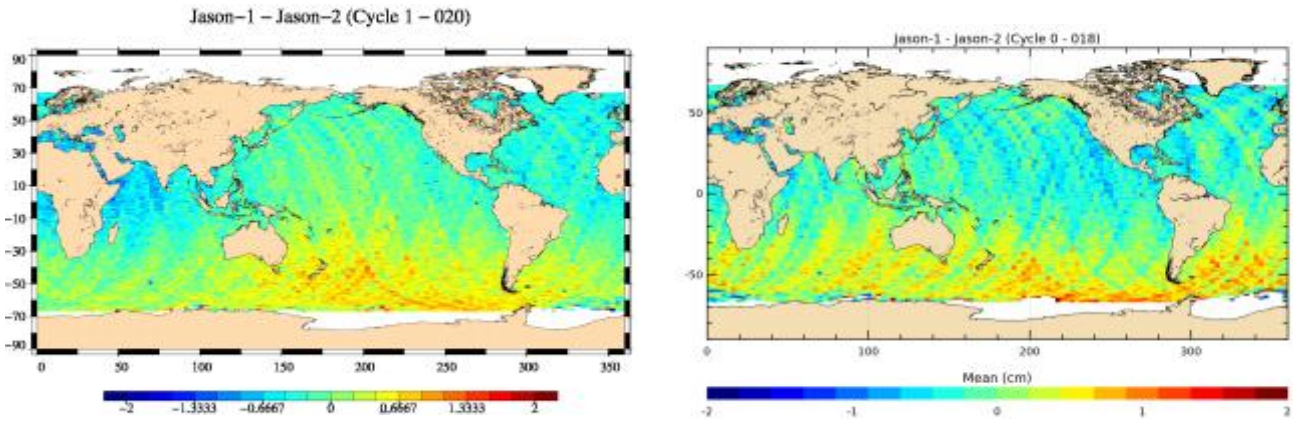


Figure 16 Impact of orbit discrepancy on the Sea Level on the difference Jason-1-Jason-2 during tandem phase using CNES GDR-D POE standards (left) and the GDR-E POE (right)

5.4. Focus on polar zones for Cryosat-2 GDR-D – GDR-E POD evolution and impact on Sea Surface Height

For Cryosat-2, the yearly impact of orbit on sea surface height was focused on a polar point of view. Indeed, the orders of magnitude (between +/-1cm) are higher on polar zones than elsewhere (see *Figure 17*).

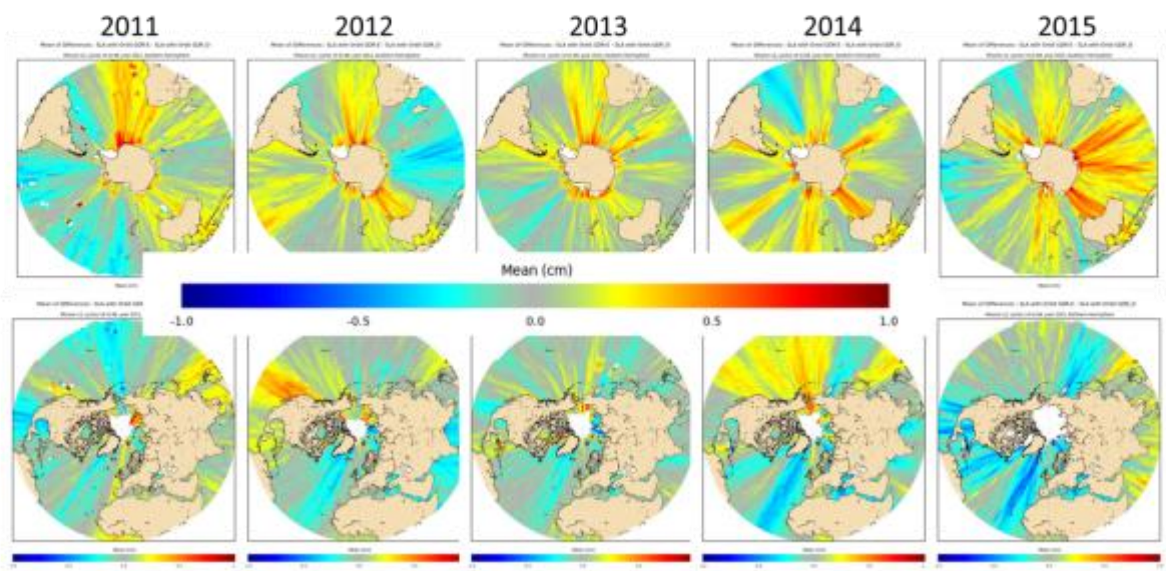


Figure 17 Impact of orbit discrepancy on the Sea Level yearly variability for Cryosat-2 mission using CNES GDR-D POE standards compared to the GDR-E POE. Top: South hemisphere, bottom Northern hemisphere

6. Quality of the CNES POE orbits compared to other production centres

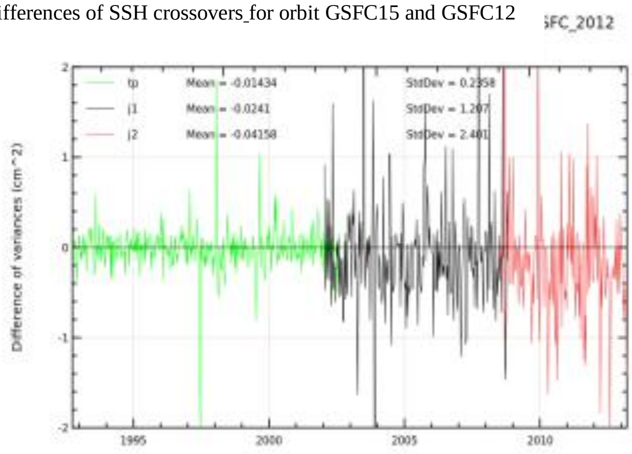
6.1. GSFC-2015 orbit quality for TOPEX-Jason-1 and Jason-2

6.1.1. Comparison to GSFC-12

Further to the presentation during the OSTST (Washington 2015) we downloaded and analyzed the new GSFC orbit standard (GSFC15) compared to the CNES POE E standard(quite similar to GSFC12).

These orbits were compared to standard GSFC12 for Topex/Poseidon, Jason 1 and Jason 2 missions. GSFC is the actual standard in CCI products for TOPEX/Poseidon.

Variance differences of SSH crossovers_for orbit GSFC15 and GSFC12



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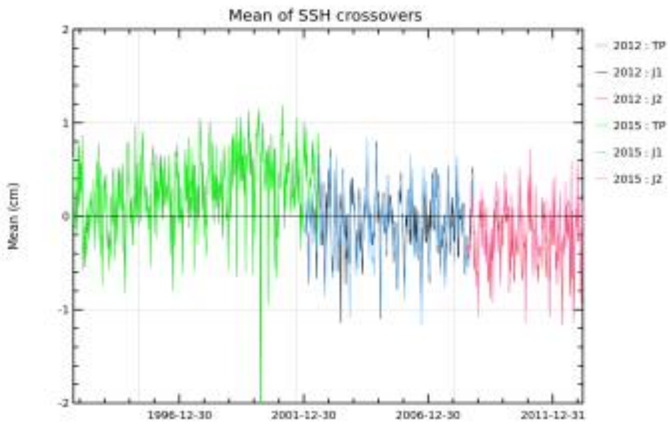


Figure 18: Monitoring of mean difference (left) variance reduction (right) of Sea Surface Height at crossovers for TP, J1 and J2 missions using GSFC_2012 and GSFC_2015 standards

The analysis of monitoring of mean of Sea Surface Height at crossovers shows no small differences between both standards. GSFC15 standard has a low (positive) impact concerning short temporal scale (signals < 2 months): a small variance reduction is obtained on the three missions.

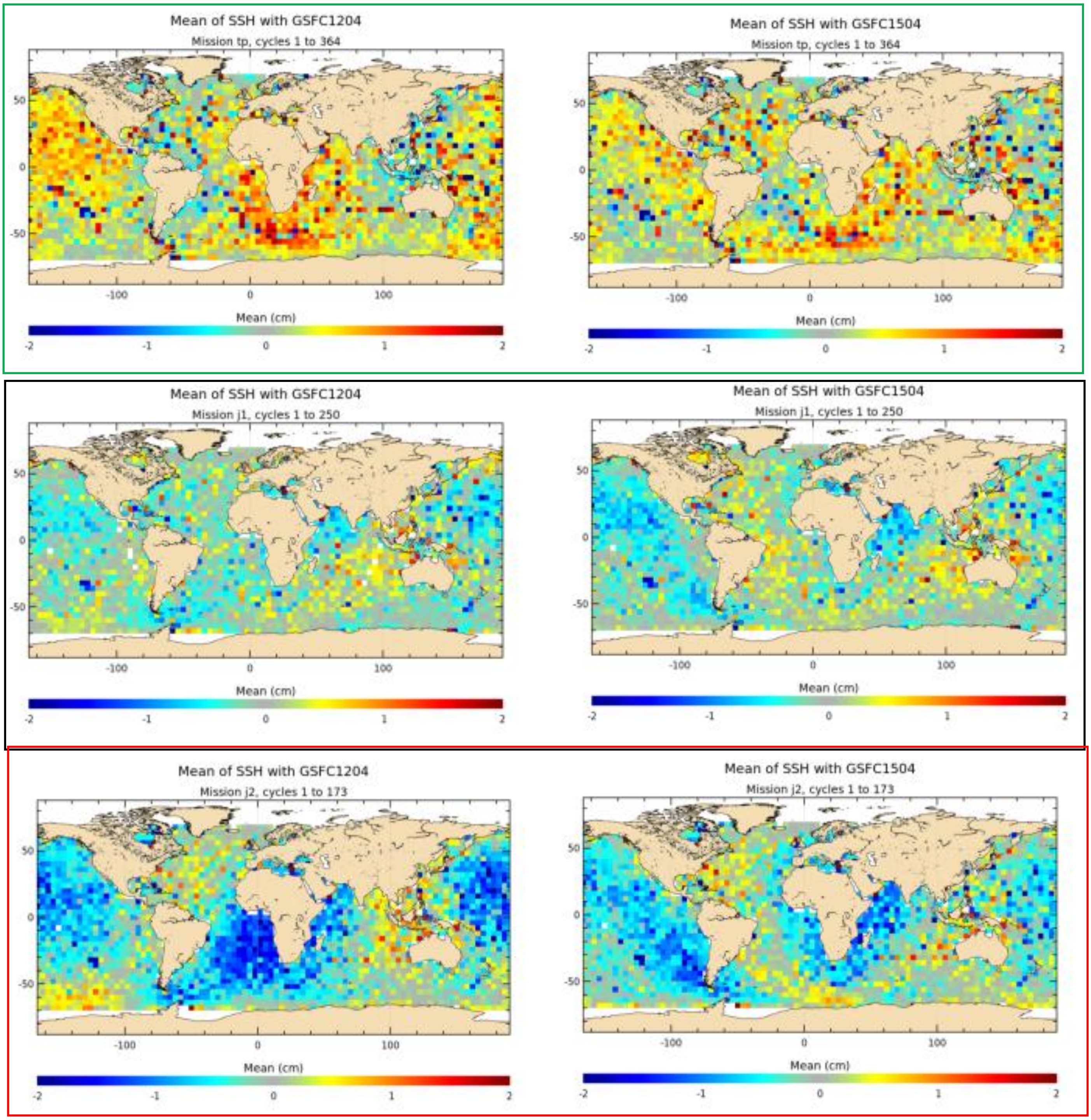


Figure 19 : Maps of the mean difference of Sea Surface Height at crossovers for Topex, Jason 1 and Jason 2 missions using GSFC_2012 and GSFC_2015 standards

GSFC15 standard give more homogenous maps of the mean difference of Sea Surface Height at crossovers for Topex/Poseidon and Jason 2. For Jason 1 patches are similar but weaker.

To conclude, GSFC1504 orbit is close to GSFC1204 orbit in terms of quality. Yet, several advantages were observed concerning the GSFC15. Therefore, this solution was chosen for the new TOPEX/Poseidon standards in CCI products.

Concerning the quality evolution we notice positive impact concerning:

⇒ East/West gradient on geographical trends (South Atlantic+Indian vs Pacific) with a more homogeneous signature for GSFC1504 when compared to T/S profile concerning east/west trend

⇒ Strong impact for the regional MSL trends (+/- 1 mm/yr)

Concerning the quality evolution we notice almost no impact concerning:

⇒ the global MSL : low impact (reduction of 0.07 mm/yr),

⇒ Differences between odd and even passes trend evolutions slightly increased but very weak with GSFC1504

⇒ No clear impact on mesoscale performance at crossover points.

⇒ Comparisons with tide gauges show equivalent results for GSFC1204 and GSFC1504.

6.1.2. Comparison of GSFC and CNES POE E for Jason 1 and Jason 2 missions

In CCI products for Jason 1 and Jason 2 missions the orbit standard is the CNES POE E standard . When we compare the POE E with GSFC15 for Jason 1 and Jason 2, the CNES orbits always give a lower variance so better quality except for Jason 1 when they stop to use degraded GPS data.

In terms of differences of means at SSH crossovers, maps are very similar for Jason 1 mission for both standards. However, for Jason 2 we observed geographical patches with GSFC standard that are not present with CNES standard. This homogeneity at crossovers involves a better quality of orbits with CNES standard.

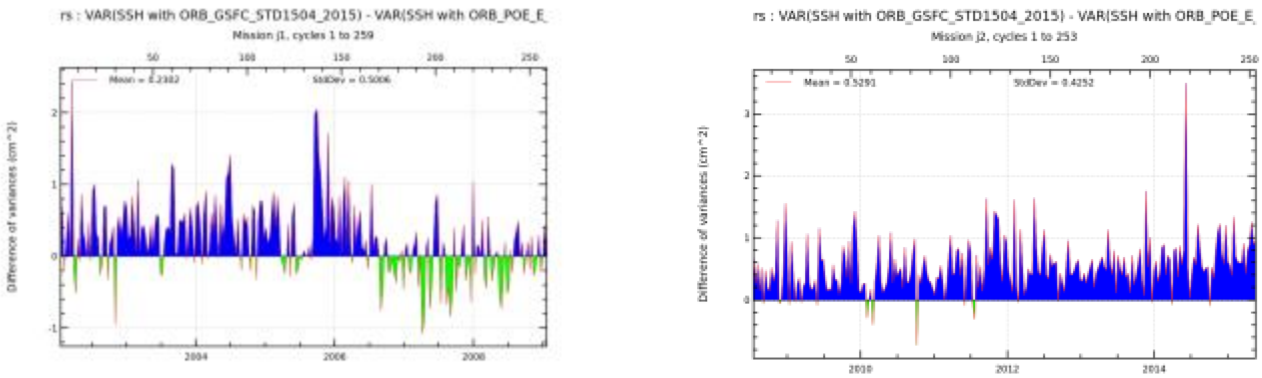


Figure 20 : Difference of variances at crossovers for Jason 1 (left) and Jason-2 (right)

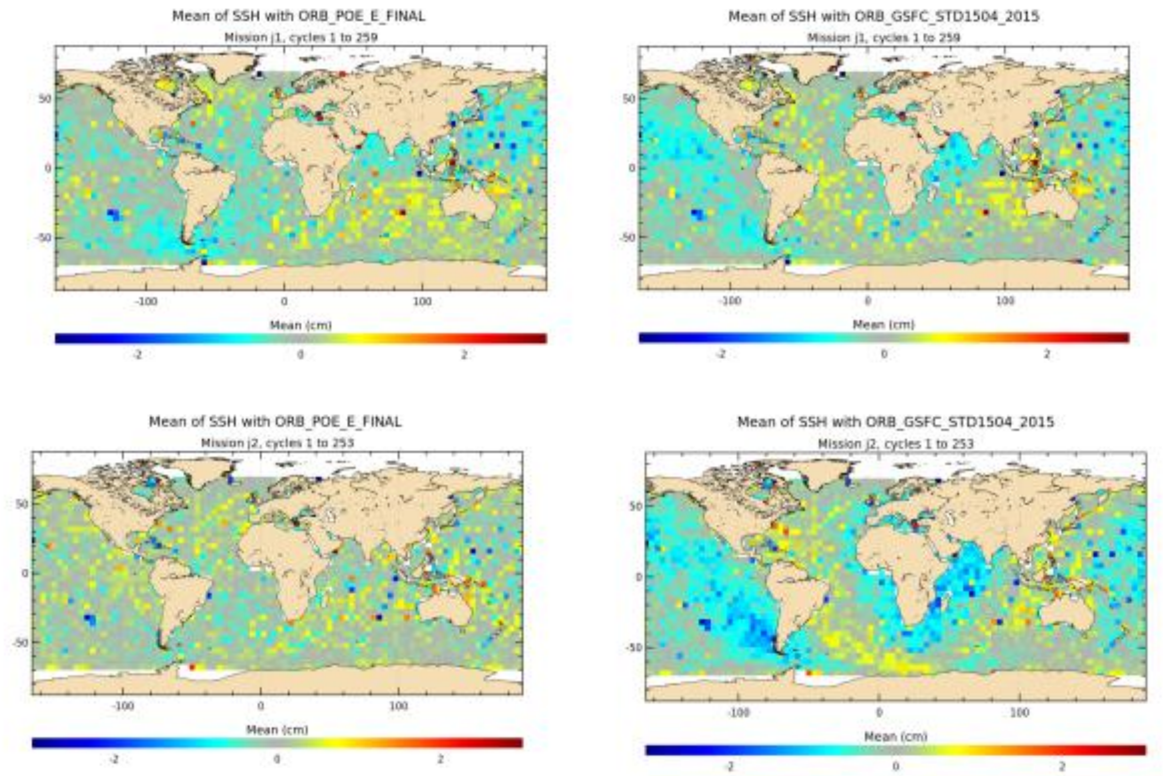


Figure 21: Differences of mean at crossovers for Jason 1 and Jason 2 missions for GSFC and CNES standards

To conclude:

- For J1:
  - Similar performance slightly better for CNES orbits (as with previous standards) for the period when GPS is taken into account. Degraded afterwards (linked to the laser information included for GSFC orbits).
  - Odd effect between long term trends Asc/dsc for CNES orbits ➔ to be understood
- For J2:
  - Better performance of CNES orbits at crossovers (reduced dynamic effect). Very good consistency of long term behavior

6.2. Orbits quality from different POD centers for Sentinel 3

The study was realized over the same very short period (three months). Statistics at crossovers over this period allow concluding that the orbit quality are similar for every center. Because of the low number of cycles statistics have to be considered with precaution.

Maps of mean differences at crossovers show quiet good results (*Figure 22* and *Figure 23*). The quality is comparable for each center.

For standard deviations, differences have a relative signification but have to be interpreted with precaution. Indeed, differences are low and depending on the selection the “best” orbit is not always the same.

The mean of standard deviation differences (*Figure 24*) is not very relevant. This mean does not allow to see possible geographical asymmetries so a low mean is not the proof of a higher quality.

More generally, a global statistic over a few cycles can hide undesirable regional and long-term comportments.

The absence of notable anomalies enables to conclude that the quality of all the orbits is similar and good for this level of analysis.

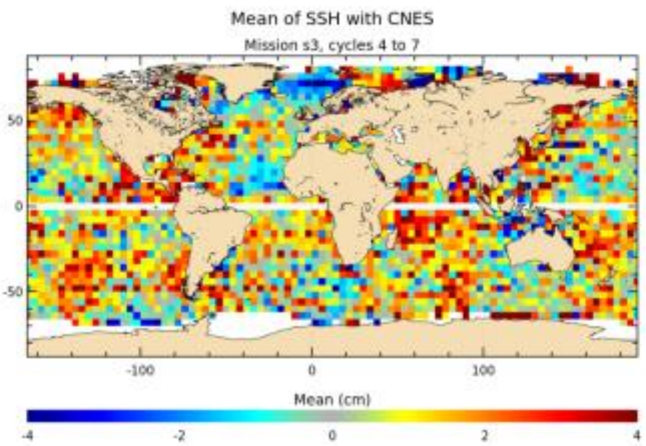


Figure 22: Map of the mean Sea Surface Height for Sentinel 3A mission using CNES standards

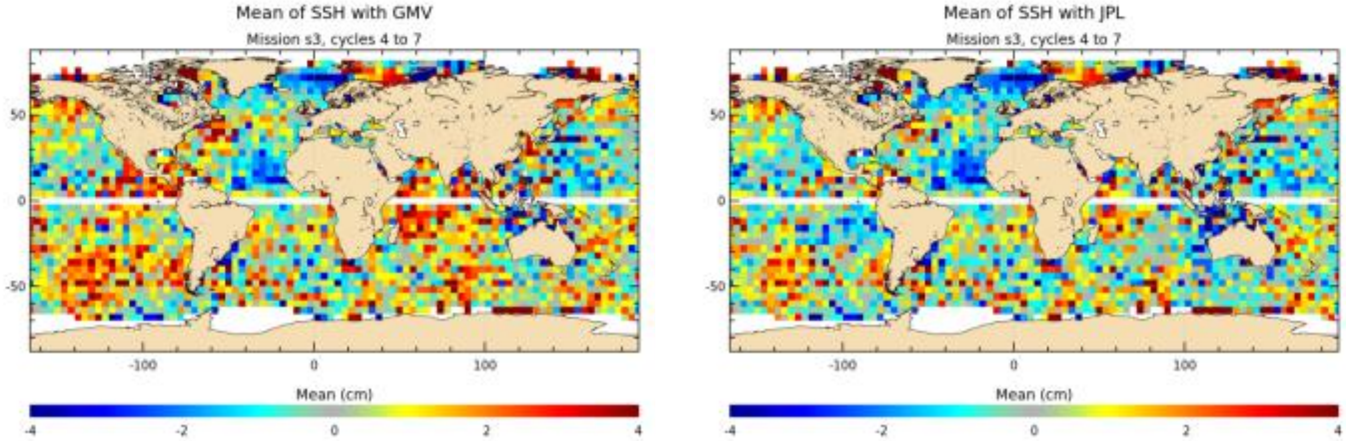


Figure 23 Map of the mean Sea Surface Height for Sentinel 3A mission using GMV (left) and JPL (right) standards

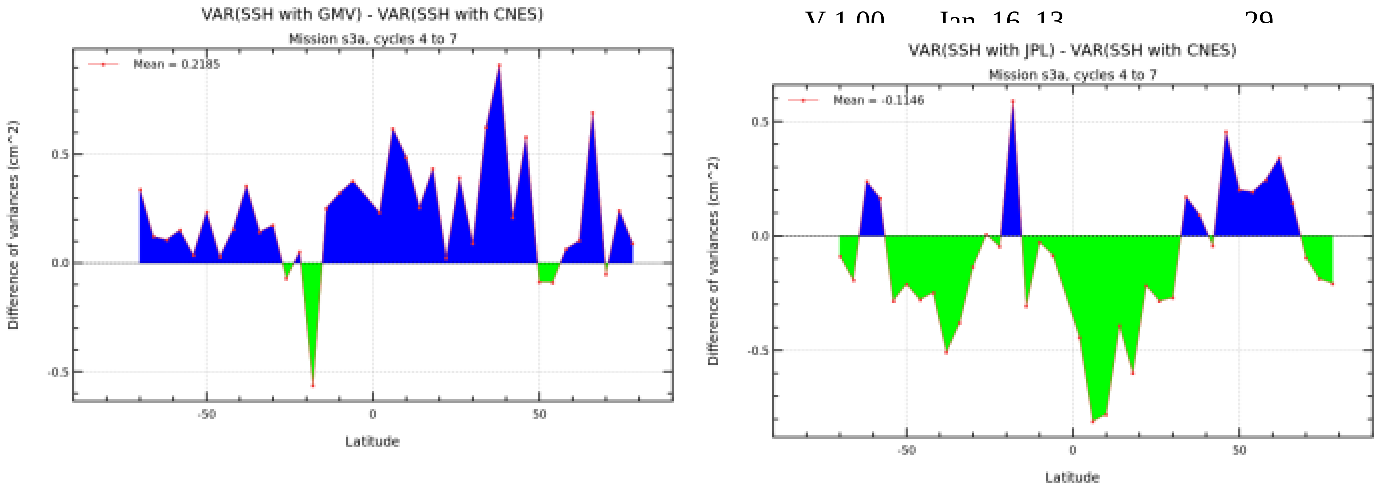


Figure 24: Difference of Variance of Sea Surface Height for Sentinel 3A mission between CNES GDR_E and GWV (left) and JPL(right) standards function of latitude

7. Particular investigations on CNES study orbits

7.1. Impact on orbits of the geocenter position change

New **GDR-E** standards are reaching a very good quality (cf. OSTST 2015 and above). Thanks to GRACE-based models, gravity field errors are now much reduced. Smaller and smaller errors –considered as negligible before- are now observable. This highlighted the fact that **changing the geocenter position can induce millimetric variations on the orbits (order of magnitude of the precision required for climate studies).** A sensitivity study was performed this year to analyze this point.

GPS constellation reference network is aligned to ITRF origin, thus the geocenter position estimation from GPS constellation is not possible in the current solution. Hence, this study is performed on **pure DORIS orbit solutions**. Besides, a **dynamic model** is used in order to focus on the Z impact (unlike reduced dynamic which effect was shown to be mixed in X, Y and Z directions, see A. Couhert's talk available on Aviso web site).

	Geocenter model	Technics	Mission
POE-E standard	Ries model = annual motion (no drift) of the LASER reference geocenter	DORIS + GPS Reduced dynamics model	Jason-2
DORIS Dyn Ries	Ries model = annual motion (no drift) of the LASER reference geocenter	DORIS Dynamic model	Jason-2

Table 4 Discrepancies between the official POE and the tests Standards used for the study

The impact of choosing a bi technique reduced dynamic orbit or a pure DORIS using dynamic modelling is quantified on *Figure 25*. No global trend differences are noticed but large scale effects very variable in time appear (*Figure 26*).

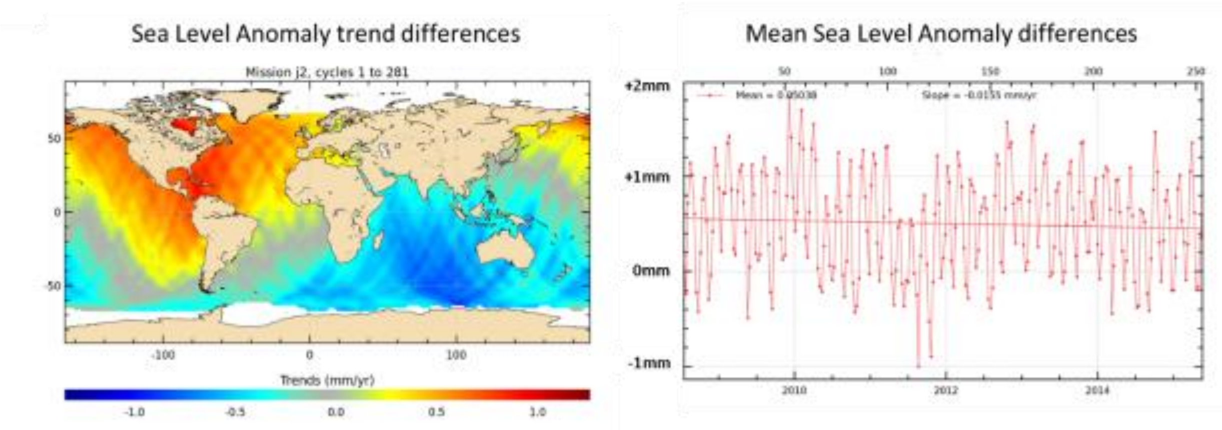


Figure 25: Difference between a pure DORIS dyn Ries (dynamics and using DORIS) and POE_E standards (Reduced dynamics and using DORIS+ GPS). Map of trend (left), Mean Sea Level monitoring (right)

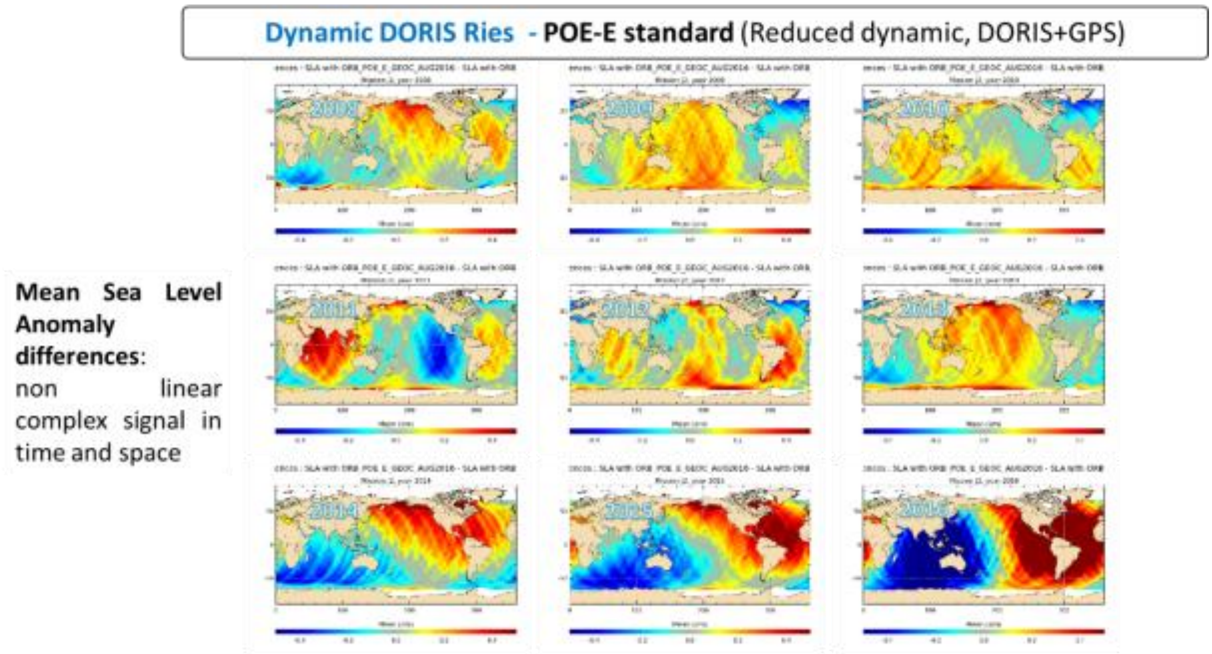


Figure 26: Difference between a pure DORIS dyn Ries (dynamics and using DORIS) and POE_E standards (Reduced dynamics and using DORIS+ GPS)

7.1.1. Impact on orbits of the geocenter position change

The above observations stresses that the assumption to work on pure DORIS data will not be directly transposable to the POE. Yet, the sensitivity study consisted in changing only the Geocenter position, all the other parameters being unchanged. The solutions tested are listed in *Table 5 Standards used for the study*

	Geocenter model	Technics	Mission
DORIS Dyn Ries	Ries model = annual motion (no drift) of the LASER reference geocenter (~GDR-E)	DORIS Dynamic model	Jason-2
DORIS Dyn NoGeoc	No geocenter model (~GDR-D)	DORIS Dynamic model	Jason-2
DORIS Dyn FF	Fiducial free: DORIS geocenter motion estimated with free network (w.r.t ITRF2008/DPOD2008)	DORIS Dynamic model	Jason-2

Table 5 Standards used for the study

The conclusions are the following:

- Using no geocenter in the orbit solution instead of the RIES model one (*Figure 27*) has
  - No global trend difference
  - No large scale effects on regional trend difference
  - clear small annual signal
- Using a fiducial free orbit solution instead of the RIES model one (*Figure 28*) has
  - No global trend difference but 0.8 $mm.yr^{-1}$ N/S regional trend
  - Clear North/South slightly variable in time cf. yearly average(*Figure 29*)

The very weak effect observed on the map illustrate the proximity of both geocenter position in this configuration.

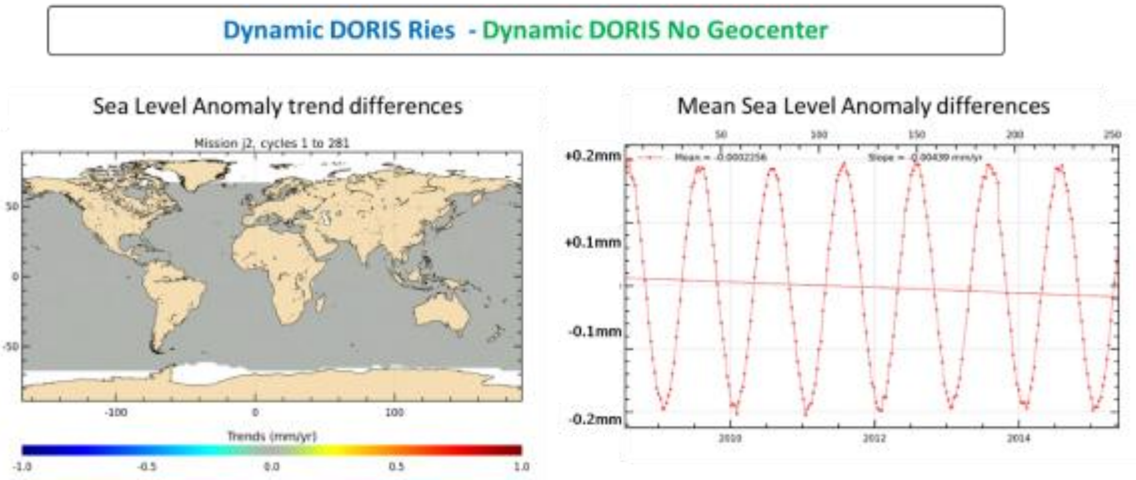


Figure 27: Difference between a pure DORIS dyn with a Ries (dynamics and using DORIS) or no Geocenter model. Map of trend(left), Mean Sea Level monitoring (right)

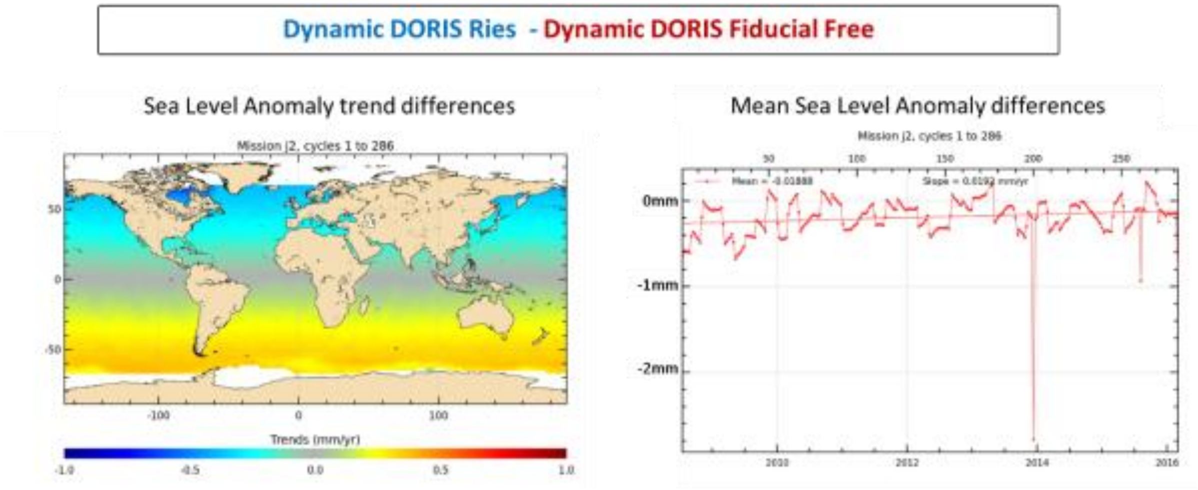


Figure 28: Difference between a pure DORIS dyn with a Ries (dynamics and using DORIS) or a fiducial free geocenter models. Map of trend (left), Mean Sea Level monitoring (right)

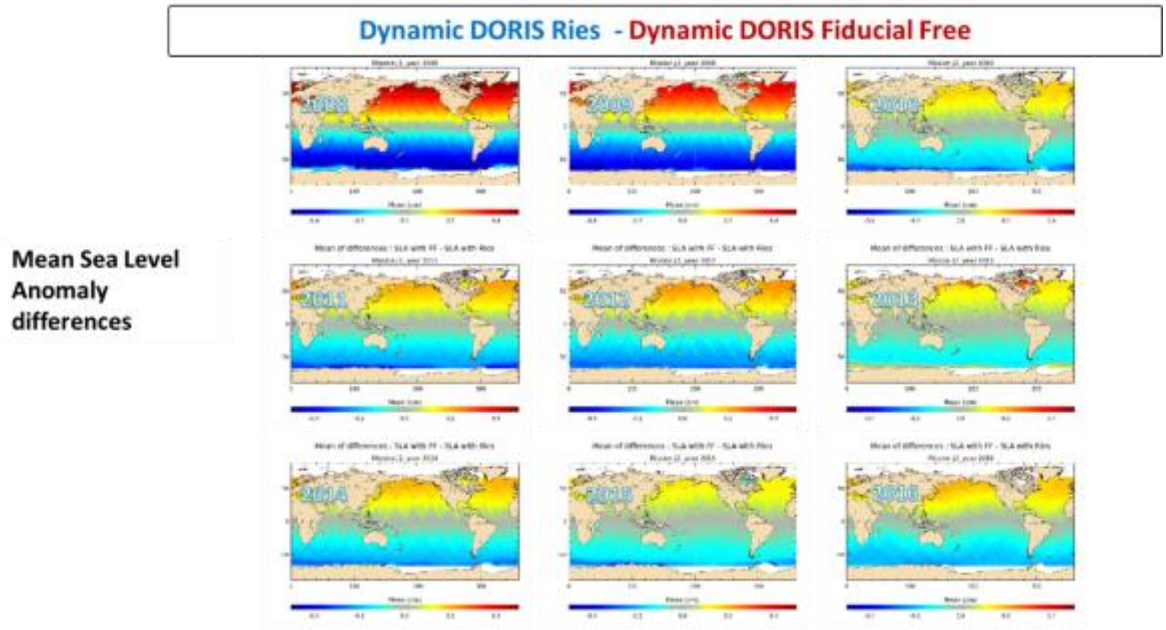
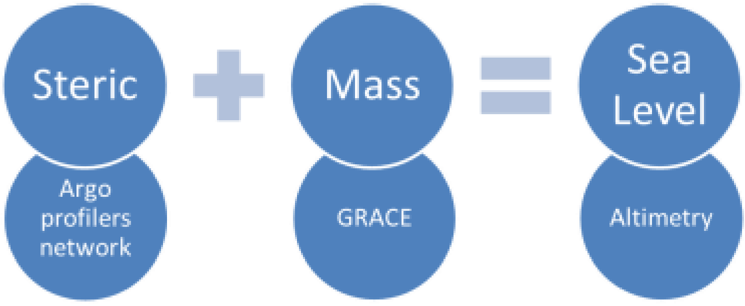


Figure 29: Difference between a pure DORIS dyn with a Ries (dynamics and using DORIS) or a fiducial free geocenter models. Yearly averages.

7.1.1. In situ comparison

To determine which of these solution is the best, we compared the altimetric data (using the different orbits), assuming that



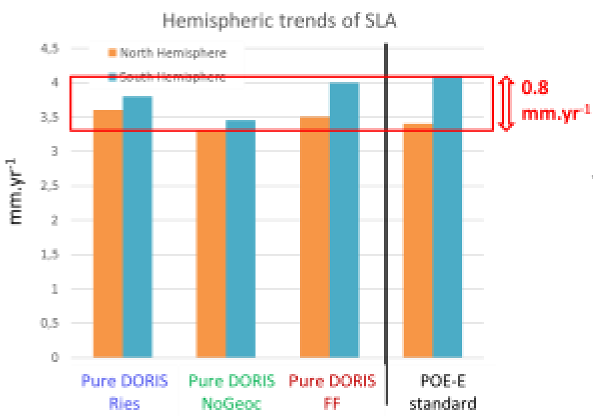
And knowing that usually, residuals SLA - Steric - Mass are a relevant metric to assess orbit quality (Couhert et al., 2015), however, Mass estimations from GRACE also suffer from geocenter motion (Swenson, 2008).

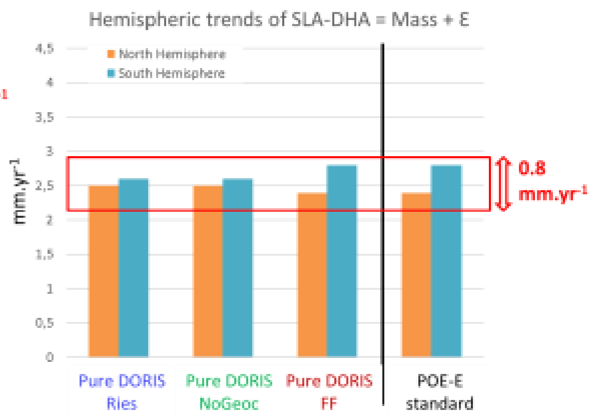
Over a (infinitely) long period, the following approximation can be made:

- The map of mass-height-equivalent trends is theoretically uniform
- The map of Dynamic Height Anomaly (DHA, steric) trends is theoretically uniform
- **The map of Sea Level Anomaly (SLA) trends is theoretically uniform**

In our case:

- The period is short (7 years) → Trend estimates are impacted by interannual variations
- However, a first-order diagnosis is to compare the consistency between regional trends → here: North vs South
- **Large uncertainty with this method: ~0.8mm.yr^{-1}**





The conclusion of this study by now is that:

Changing the geocenter position model has a hemispheric ~1 mm.yr^{-1} impact in orbits (= order of magnitude of the precision required for climate studies). The discrepancies induced by a **change of geocenter** is of a **similar order** of magnitude as changing the **POD estimation method** (impact of GPS and reduced dynamics) that can hardly be totally separated from the geocenter modelling itself. The analysis performed here also showed a non-negligible effect of the **annual signal** which deserves further investigations. Deciding **which solution is the best remains challenging** because it reaches the level of precision of the methods based on SLA or in situ comparisons.

Still, the **rather theoretical** issue addressed here raises interesting perspectives to improve the diagnosis that enable to validate orbital solutions with altimetry.

8. Conclusion

Altimetric missions aim at measuring the same Sea Level anomaly which tends to increase globally by 3mm/yr and which, below 10 days is considered to be low. Relying on these hypotheses, metrics based on the long term stability or consistency of ascending/descending passes enable to identify errors in the measurement that, concerning very large scales can often be allocated to orbital errors.

In this document, we analyze and compare the missions' behaviors from an absolute point of view and compare orbits solutions in order to validate a new standard or to determine the best solution among different solutions.

The first analysis could be performed on the new Sentinel3 mission. It highlights larger discrepancies on the mean SSH difference at crossovers than for others. The effect is similar (slightly worst) for GMV and (slightly better) for JPL orbits. Those metrics must be computed on a larger time series in order to be more relevant

For all missions data orbit quality is very good, sometimes reaching the limits of diagnosis precision. MOE solutions are also improving a lot, almost reaching the same quality level as POE one's.

Appendix A - **List of acronyms**

TBC	To be confirmed
TBD	To be defined
AD	Applicable Document
RD	Reference Document