ESA Sea level CCI

Reference:	CLS-SLCCI-15-0015
Nomenclature:	SLCCI-MM-042
Issue:	1.0
Date:	Dec. 18, 15

Algorithm Selection Meeting Executive Summary - SL_cci Phase II (26-27 November 2015)

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1. Introduction

The Sea Level Climate change Initiative (SL_cci) project aims at providing a homogeneous and accurate sea level Essential Climate Variable (ECV) for climate studies. The Algorithm Selection meeting is an important step in the project since its goal is to provide recommendations for the selection of the algorithms that will be used for the generation of the SL_cci v2.0 reprocessed ECV product.

New altimeter standards developed and tested within the project as well as external contributions have been identified, processed and evaluated by comparison with a reference for different altimeter missions (TOPEX/Poseidon, Jason-1 & 2, ERS-A & 2 and Envisat). All standards have been evaluated for each mission with respect to their equivalent in the current SL_cci product (V1.1), if possible, or to other equivalent contributions. Their potential impact on the future reprocessed V2 SL_cci ECV has been assessed on the spatial scales (Global, Regional, Mesoscale) and the temporal scales (long-term, inter-annual, periodic…). The selection criteria may differ between the "reference" missions (TOPEX/Poseidon, Jason-1, Jason-2) and the "complementary" missions (ERS-1, ERS-2, EnviSat, GeoSat-Follow-On, CryoSat-2, SARAL/AltiKa). Indeed, in the L4 gridded products, the complementary missions are adjusted on the reference missions in terms of trends. Hence, the improvement and consistency of long-term evolutions between the reference missions are particularly important. The improvement and consistency of mesoscale signals is a primary criterion for complementary missions.

All the documents presenting the results of these performance analyses have contributed to the conclusions of the selection meeting. These documents are available on the website of the project (www.esa-sealevel-cci.org). The key messages resulting from the meeting are described below. The list of the altimeter standards selected for the SL_cci reprocessed ECV is given in conclusion.

2. Orbit Selection

New precise VER11 orbits of ERS-1 (1991-1996), ERS-2 (1995-2003), TOPEX/Poseidon (1992-2005), Envisat (2002-2012), Jason-1 (2002-2013) and Jason-2 (2008-2014) were computed at GFZ within the SL_cci Phase 2 project in the same ITRF realization (ITRF2008) using consistent, improved models for precise orbit determination for all six missions.

The analysis of these orbits performed at GFZ shows improved orbit quality of these orbits, as compared to the previous (VER6) GFZ orbits derived within the SL_cci Phase I project. Based on the results of validation performed at CLS and GFZ, we recommend to select GFZ VER11 (2015) orbits for ERS-1, ERS-2 and Envisat, CNES POE-E orbits for Jason-1, Jason-2, Altika and Cryosat, and GSFC std15 orbit for TOPEX/Poseidon for the further use in the SL_cci Phase II project. Further improvement of the orbit quality is expected by using new, improved reference frame realizations, improved modelling of gravitational and non-gravitational forces acting on satellites, further improved satellite-specific models, non-tidal loading corrections and other models.

3. Selection of Atmospheric corrections (DAC & DT)

The Dynamic Atmospheric Correction (DAC) and the Dry Troposphere (DT) correction are computed thanks to the atmospheric forcing provided by a numerical model. The altimeter SLA performances have been evaluated using these corrections forced by different atmospheric models: the operational ECMWF model, the ERA-Interim reanalysis and the Japanese JRA-55 reanalysis. The corrections (DT and DAC) computed with JRA-55 perform a bit better than the operational ECMWF database but remain less efficient compared to the use of ERA-Interim forcing. In particular, mesoscale signals are strongly deteriorated with JRA-55 versus ERA-Interim at southern high latitudes. Over the very recent years (2014), the operational ECMWF model is better than the ERA-Interim reanalysis because of the improved spatial resolution.

The recommendation for the computation of the DT and DAC corrections is to use the ERA-Interim dataset for reference and complementary missions. In addition, it has been concluded that DT-ERA can be used on the entire altimetry period; DAC-ERA can also be used on the entire period, but it is less efficient for mesoscale signals for recent years (Jason-2) as it raises variance in some coastal/shallow water regions; the JRA-55 reanalysis shall not be used for SL_cci ECV but it will be worth testing the next release; New ECMWF reanalysis should be available in 2017 and will be of interest.

4. Selection of Wet Troposphere Corrections (WTC)

4.1. The GPD+ WTC

For the wet tropospheric correction (WTC), the GPD+ set of corrections, computed by Uporto, have been selected. Compared to previous versions, the GPD+ WTC data set differs in the following aspects: i) covers now the 8 missions used in the generation of the sea level ECV; ii) in addition to on-board MWR and GNSS, data from scanning imaging radiometers are also used; iii) all radiometers have been inter-calibrated with respect to the SSM/I and SSM/IS sensors on-board the Defense Meteorological Satellite Program series (F10, F11, F13, F14, F16 and F17) as reference, due to their well-known stability and independent calibration.

The new products are shown to reduce sea level anomaly variance, both along-track and at crossovers with respect to previous non-calibrated versions and to other WTC data sets such as AVISO Composite correction and atmospheric models. In comparison with previous GPD versions, the main impacts are on the sea level trends at decadal time scales (0.2 mm/yr) and on regional sea level trends. The impact on mesoscale signals is however very low. However, these impacts on long-term trends remain in the wet troposphere long term evolution uncertainty (+/-0.3 mm/yr) and the comparison with independent tide gauges for instance is not accurate enough to assess this impact.

The recommendation for the computation of the WTC corrections is to use the GPD+ correction for reference and complementary missions, knowing that the impact on the global and regional long-term evolutions will be strong. However, in view to obtain the best WTC for use in the version 2 of the SL_cci ECV, new products will be generated until mid-February 2016, based on recently released on-board MWR WTC for the following 3 missions: Jason-1 (GDR-E), Envisat (Version 3.0) and SARAL.

5. Selection of Instrumental corrections

5.1. Ionosphere correction for the Envisat mission

In Phase I, after an agreement with ESA and industry from a Point Target Response (PTR) expert meeting, the EnviSat Ku-band PTR waveform was reversed, implying a change of the sign of the PTR time delay instrumental correction. The PTR time delay has a direct impact in the range, as an additive term. Therefore, the Ku-band PTR waveform reversion caused a significant impact in the Mean Sea Level (MSL) long term drift, matching much more the other missions series and in-situ measurements.

In Phase II, we repeat the same question for the RA2 secondary band: Has the S-band PTR waveform been reversed? The industry cannot give a final statement about the direction of the S-band PTR waveform. The S-band measurements series is shorter than the Ku-band series, and the knowledge of the S-band SSH retrievals is not as good as the Ku-band (neither as the usual secondary C-band used in other altimetry missions). Hence, the study of the S-band MSL series is not a proper option for taking a decision about reversing or not the S-band PTR waveform.

A solution was adopted, consisting in analysing the impact of the Ku-band ionospheric correction in the Ku-band MSL. The dual-frequency Ku-band ionospheric correction depends only in the Delta-Range between the two bands (i.e. Ku and S). Knowing this dependency, and using the two options of reversing or not the S-band PTR waveform (that impacts the S-band range), we can build two dual-frequency Ku-band ionospheric corrections and analyze its impact in the Ku-band MSL. The complete mission S-band data series, from launch to January 2008, was processed for the two options, applying all the improvements that will be implemented in the 2016 RA2 reprocessing campaign, and adopting the same data rate as in Phase I. One NetCDF file per cycle was produced (60 cycles, from 4 to 63), and delivered to CLS for the Round Robin exercise study. A preliminary analysis of the impact of this change was done at L1b stage, finding a small long term drift (less than 0.5 mm/yr) and small variability in nominal scenario (around 0.2 mm).

This correction is shown to have no significant impact by comparison to the reference ionospheric correction. However, results show it results in the loss of points (1%). Even though the cause for this data loss has not been identified yet, and due because the impact is not significant anyway, the recommendation is to not use it.

5.2. External corrections: ionosphere correction, SSB

In the framework of the SLOOP project, a new ionospheric correction based on an iterative filtering method has been computed for TOPEX/Poseidon, Jason-1, Jason-2 and Envisat. The Round-robin exercise shows an improvement at mesoscale by comparison to the reference correction, combined with a significant data gain.

The recommendation for the Ionospheric correction is to use the SLOOP filter for the reference missions. For the complementary missions, the recommendations are to use NIC09 model for ERS-1 (reference), the SLOOP filter for Envisat and the GIM model for AltiKa and Cryosat-2.

For the ERS-2 ionospheric correction, Remko Scharroo and Pierre Prandi have proposed to use the NIC09 model instead of the BENT solution. This will be evaluated within the SL_cci validation activities and the impact will be presented during the annual review.

Regarding the Sea State Bias correction, upgraded solutions have been computed for Jason-1, Jason-2 (Tran, 2012) and Envisat (Tran 2015). Round-Robin exercises show improvement on the mesoscale by comparison to the reference solutions.

The recommendations are thus to use the Tran (2010) model for TOPEX and Tran (2012) for Jason-1/2. For the complementary missions, the BM3 model (Gaspar, 1994) is proposed for ERS1, the non parametric Mertz (2005) model for ESR-2, the Tran (2015) model for Envisat, the PEACHI 2D solution for AltiKa and the non parametric SSB from Jason-1 (GDR-C) for Cryosat-2.

For the ERS-1 SSB correction, Remko Scharroo has proposed to use the same solution as the one used for the ERS-2 mission. This will be evaluated within the SL_cci validation activities and the impact will be presented during the annual review.

6. Selection of tide models FES2014, GOT4.10, new polar tide correction

6.1. Ocean tide

The ocean tide models which have been evaluated are the GOT4V8, GOT4V10c and FES2014 models. The recommendation is to use the FES2014 model. There are significant positive impacts for mesoscale signals at high latitudes, including in Arctic Ocean and in coastal areas; moreover when using FES2014 tide model, the amplitude of the 60 day signal remains very low (below 1 mm) for the T/P, Jason-1 and Jason-2 missions, which is remarkable.

6.2. Pole tide

The pole tide altimeter correction is used to correct the response of the solid Earth and Oceans to the polar motion. The Wahr (1985) model has been used for all missions since TOPEX and a new model has been recently available (Desai 2015). The new model has a significant positive impact on the regional mean sea level trends and the comparison with independent in-situ data (Argo profiles) has demonstrated that the use of this model reduces the amplitude of the annual signal of the global mean sea level. Therefore, the recommendation is to use this Desai 2015 pole tide model for all missions. Notice that this new pole tide solution does NOT include the displacement associated with long-term drift in polar motion, and users should use a GIA model to remove this component for example.

7. Selection of Mean Sea Surface

The Mean Sea Surface (MSS) used in the current SL_cci ECV (v1.1) is the DTU10 model. DTU15 MSS (and MDT) are ready for release. DTU15 MSS is based on DTU13 model with the use of Cryosat-2 measurements and updates in coastal zones and at high latitudes. It has been highlighted that the coastal SAR to SAR-in change might be good for Cryosphere, but not for MSS determination.

The new DTU15 MSS model is recommended for the computation of the Sea Level Anomalies in the reprocessed ECV. The reference period of this MSS is 1993-2012. It has been underlined that the inter-annual content of the reprocessed v2.0 SL_cci ECV will change due to the evolution of the MSS reference period (1993-2008 for DTU10 in the current v1.1 ECV and 1993-2012 for DTU15). This will have to be explained to the users since it affects modelers for instance who use Mean Dynamic Topography and perform altimeter data assimilation.

8. Selection of reprocessed Level2 products

The SL_cci FCDR products are derived from altimeter level-2 products. For the release 2.0, we will used the same products as for the release 1.1 for TOPEX/Poseidon (M-GDR), Jason-1 (GDR-C), Jason-2 (GDR-D), ERS-1 (OPR), ERS-2 (OPR), Envisat (GDR-V2.1), GFO. For these missions L2 reprocessing project are planned or on-going but they will not be finished before the start of the next SL_cci reprocessing (March 2016). For SARAL/Altika and Cryosat-2, which were not used in release V1.1, we use respectively the GDR-T patch2 and CNES CPP products.

9. Selection of Arctic sea level products

Two independent altimetric SL datasets have been created and cross-validated (DTU and CLS/PML).

The two candidate climatologies came at different spatial and temporal resolution, CLS/PML is weekly on 2°x2° grid, whilst DTU is monthly on a 0.5° grid. The maps of SSH in the DTU climatology however look smoother because of the interpolation used. The DTU dataset also provided greater spatial and temporal coverage. As we had no credible ground truth to hand, PML's analysis concentrated on the time variability of each, and whether such behaviour looked physically reasonable. For their common 78-month period, the mean difference (DTU-CLS/PML) was ~3cm higher for the Alaskan/Russian sector than for the North Atlantic. This is because the CLS/PML dataset has incorporated a new retracker to better recover sea level in leads, which is essential for the region of permanent ice cover. In terms of temporal variations, the CLS/PML dataset showed much greater consistency between successive months. Both showed a clear annual cycle with a September maximum for the sea level in the permanently open sector of the Atlantic, whilst DTU also a clear February peak for the Russian sector. Both agreed very well on the sea level trend with an increase of ~20 mm/year in the Beaufort Gyre (associated with wind spin-up) but a reduction elsewhere.

10. Selection of new algorithms in coastal areas

The quality of the SL_cci data in the coastal zone has been assessed by comparison with carefully quality-controlled tide gauge data over North East Europe and South East Australia. SL_cci gridded products and tide gauges agree well in terms of annual amplitude (differences <1.6 cm) and phase, with statistically significant correlations at all stations. Altimetry-derived and tide gauge-derived trends are not statistically different at any station, given the uncertainty in the estimates. The same uncertainty is still too large for an accurate computation of vertical land motion rates from tide gauge and altimetry data, as it appears from comparisons with GPS-derived land movement rates. Ongoing work points at some significant impacts of the choices for the altimetric corrections in the coastal zone. These impacts and the effect of specialised retrackers need to be investigated further.

PML have successfully coded a routine to retrack multiple waveforms at once (2-D retracker), taking advantage of the expected continuity in range, wave height and amplitude between successive records. This has been demonstrated to work well in the open ocean, delivering smoothly varying profiles of these three parameters, but the key interest in implementation and location for validation is the coastal zone. Removing tides from the time series at both tide gauge and altimeter locations showed the 2D technique to be an improvement for some gauges; however, there remain issues with GDR corrections and occasional waveform artefacts that still need to be resolved.

11. Conclusion of selection meeting

Following these considerations, the SL_cci consortium together with external experts selected a new set of altimeter standards that will be used for the production of the V2 reprocessed sea level ECV. These can be seen in the table below. A significant improvement is expected by comparison to the current V1.1, with the main impacts on the long-term evolutions, at global and regional scales, and for mesoscale signals. Detailed analyses of the impact of these standards on the altimeter MSL estimation will be performed in the following months.

	Reference missions			Complementary missions					
	TOPEX	Jason-1	Jason-2	ERS-1	ERS-2	Envisat	GFO	Altika	Cryosat
Orbit solutions	GSFC STD15	POE-E		GFZ15			Ref	POE-E	POE-E
Wet troposphere	GPD+	GPD+ from GDR-E	GPD+	GPD+	GPD+	GPD+ from RadV3.0	Ref	GPD+ from RAD-Patch3	GPD+
Sea State Bias	Tran 2010	Tran 2012	Tran 2012	BM3 Gaspar,1994	Non param. Mertz, 2005	Tran 2015	Ref	PEACHI 2D	Non param. (J1 GDR-C)
Ionosphere	SLOOP			NIC09	BENT+GIM	SLOOP	Ref	GIM	GIM
Dry troposphere	ERA-interim							ERA-interim	ERA-interim
Comb. Atm. cor.	ERA-interim							ERA-interim	ERA-interim
Ocean tides	FES2014								
Solid Earth tide	Ref								
Pole tide	Desai, 2015								
Mean Sea Surface	MSS DTU 15								
L2 products	M-GDR	GDR-C	GDR-D	OPR	OPR	GDR V2.1		GDR-T patch2	CPP CNES