1. ABSTRACT
The paper aims to provide an overview and the current status of the Sea Level project of the ESA Climate Change Initiative (CCI) that has started in July 2010. The main objective of this project is to produce and validate the Sea Level Essential Climate Variable (ECV) product. Two years after the project kick-off, the 20 years of progress in radar altimetry symposium was the opportunity to unveil this 18 years climate time series based altimeter measurements. The paper also describes the different activities which were necessary to deliver the ECV products: collect and refine the user requirements, develop, test and select the best algorithms for climate applications. The production system and a brief description of the main product characteristics are provided as well as preliminary results of the product validation.

2. OVERVIEW
Sea level is a very sensitive index of climate change and variability. As the ocean warms in response to global warming, sea waters expand and, as a result, sea level rises. When mountain glaciers melt in response to increasing air temperature, sea level rises because more freshwater glacial runoff discharges into the oceans. Similarly, ice mass loss from the ice sheets causes sea-level rise. Therefore, understanding the sea level variability and changes implies in addition to the understanding of the ocean variability and the exchanges between ocean, land, cryosphere, and atmosphere, an accurate monitoring of the sea level variable at climate scales. That is why Sea Level is one of the variables selected in the frame of the ESA Climate Change Initiative (CCI) program initiated by ESA in July 2010. In overall, this program aims to provide an adequate, comprehensive, and timely response to the extremely challenging set of requirements for highly stable, long-term satellite-based products for climate, that have been addressed to Space Agencies via the Global Climate Observing System (GCOS) and the Committee on Earth Observation Satellites (CEOS). In order to achieve this global objective, the specific objectives of the sea level CCI project are: to involve the climate research community to collect their needs and feedbacks on product quality, to develop, test and select the best algorithms and standards to generate a climate time series (so called SL ECV products), and to provide a complete specification of the production system. After two of projects the first two objectives have been completed. Main achievements are described in the following.

3. USER REQUIREMENTS
The User Requirements related to the Sea Level ECV have been refined through three approaches. The first one has consisted to do a literature review and analysis of the documents coming from various communities, as Global Climate Observing System (GCOS) [1], World Meteorological Organisation (WMO) [2], World Climate Research Program (WCRP). Another source of literature comes from the Ocean Surface Topography community that has provided a synthesis providing a list of high level requirements placed upon the altimetry satellite constellation for the next 15 years [3]. The second approach has consisted to lead a user survey to 20 university departments, scientific research institutes, operational centre and agencies, both in Europe and intercontinental. Lastly, User Requirements has been discussed during discussion sessions within the project between the Earth Observations team and the engaged Climate modeling group. The User Requirements refined within the project are gathered in table 1. Specific spatial and temporal scales have been defined. Firstly, spatial climate scales has been divided into two categories: the Global Mean Sea Level (GMSL) that corresponds to the global mean level averaging on a 10 days period and the Regional Mean Sea level (RMSL) that corresponds to an averaging on 2° by 2° boxes on the 10 days period. Then, three categories of temporal scales are associated for each spatial scales. The long term evolution corresponding to periods greater than 10 years and expressed as a trend. The interannual signals for period shorter to 5 years and periodic signals (Annual signal or 60 days,…).
The User Requirements not defined for specific spatial and temporal scales (i.e., periodic signals of GMSL and RMSL, and inter-annual signals for RMSL) is due to the lack of feedbacks from users and/or from the lack of information in the literature. Conversely, the numbers allocated in tabxx clearly correspond to user needs. For instance, the GMSL trends requirements (0.3 mm/y) corresponds to the threshold to distinguish the different sources playing a role in the variation of mass (glaciers, ice sheet) ,and volume in sea level closure budget.

### Table 1: Sea Level CCI User Requirements

<table>
<thead>
<tr>
<th>Spatial Scales</th>
<th>Temporal Scales</th>
<th>User Requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Global Mean Sea Level (10-day averaging)</td>
<td>Long-term evolution (&lt; 10 years)</td>
<td>Not defined</td>
</tr>
<tr>
<td></td>
<td>Inter annual signals (&lt; 1 year)</td>
<td>Not defined</td>
</tr>
<tr>
<td></td>
<td>Periodic signals (Annual, 90-days, ...)</td>
<td>Not defined</td>
</tr>
</tbody>
</table>

The algorithms and corrections that has been developed and evaluated within this project cover all the spectra of the altimetry processing starting with instrumental corrections (level1) and geophysical corrections as dynamic atmospheric corrections, wet tropospheric corrections, orbits, etc…and ending with the multi-satellite merging techniques. The algorithms has been developed by SL CCI project partners but are also collected from other external projects and in particular from reprocessing projects (REAPER,…). Nevertheless, all these investigations are focused on climate signal improvement meaning that a particular attention will be paid on the stability, continuity and homogeneity of the time series.

Then, we performed a round-robin exercise which is based on the following principles:
- to use a common set of validation diagnoses for all the algorithms.
- to use the same altimeter data base
- to produce validation reports containing a synthesis of the analysis of the main diagnoses
- to organize a selection process with the involvement of external experts in altimetry processing and climate modeling

The Round Robin consists in comparing and analyzing the impact of the new algorithms with respect to the ones used in the reference products representing the state of the art at the beginning of the project which is the AVISO products (http://www.aviso.oceanobs.com/msl/). The diagnoses has been defined in order to provide statistics for each spatial and temporal scales defined by the User Requirements. They are based on three main kinds of categories. The first one corresponds to the global internal analysis that characterizes the global performance and improvement for a given mission. The second one measures the sea-level consistency improvements between different altimetry missions and lastly the third category uses independent data (mainly in-situ) to assess the impact of the algorithms. These diagnoses could be applied to all level of altimetry product (level 1 to level 4). The algorithms and corrections addressed are the following ones: Orbits; Instrumental corrections; sea state bias; ionospheric corrections; wet&dry tropospheric corrections; atmospheric corrections; ocean, solid earth and pole tides; mean sea surface; merging algorithms.

### 4.5 The Round-Robin results

In practice, 5 new orbit solutions derived from the Reaper and SLCCI projects (for ERS-1 and ERS-2) and from CNES and ESA production centres have been already evaluated. For the wet troposphere correction, the ERA-interim data have been compared to the radiometer and operational ECMWF models. New algorithms concerning the ionosphere correction, the sea state bias correction, the oceanic tides and the atmospheric corrections have been tested as well. All the diagnoses for each algorithms categories have been analyzed and synthesized in validation reports that were analyzed by an external expert team. A specific meeting has been organized between the expert team and the project partners in order to provide the final recommendations for the algorithm selection.

As it is not possible to provide an exhaustive review of the main results the reader is welcome to look at the Product Validation and Assessment report (PVSAR project’s document available at the following address (http://www.esa-sealevel-cci.org/documents#)). It contains a synthesis of the discussion as well as the recommendations proposed by the external expert team.

A summary of the algorithms selected for the Sea Level ECV products generation are gathered in table 2.

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<td>0.3 mm/yr</td>
</tr>
<tr>
<td></td>
<td>Inter annual signals (&lt; 1 year)</td>
<td>0.5 mm over 1 year</td>
</tr>
<tr>
<td></td>
<td>Periodic signals (Annual, 90-days, ...)</td>
<td>Not defined</td>
</tr>
</tbody>
</table>

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5. THE SEA LEVEL ECV PRODUCT

5.4 The production system

The ECV products have been produced by the existing SSALTO/DUACS infrastructure which already processed multiple altimeter missions for AVISO and MyOcean projects. It consists as illustrated in Figure 1 to implement the new CCI algorithms and corrections within the existing processing chain. The interest is that it is cost effective and more efficient in term of development duration and cost. The use of the existing infrastructure enables to produce a long time series of about 18 years covering the 1993 to 2010 period. Seven altimeter missions (T/P, ERS-1/2, ENVISAT, Jason-1/2, GFO) have been reprocessed representing 50+ years of data.

5.5 The ECV products

The ECV products consist in a time series of \(\frac{1}{4}^\circ\) monthly gridded fields combining all the missions available at a given time. In addition to this product, ocean ECV indicators have also been produced: the Global Mean sea level time series and the regional mean sea level trends (Figure 2). Sea level ECV products are available on demand at the following address: [http://www.esa-sealevel-cci.org/node/164](http://www.esa-sealevel-cci.org/node/164).

![Figure 1: Description of the functional architecture of the SSALTO/DUACS system where the specific CCI algorithms and corrections are implemented.](image1)

![Figure 2: Map of regional patterns of observed sea level (in mm/year).](image2)

<table>
<thead>
<tr>
<th>Mission</th>
<th>CCI Algorithm</th>
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<tbody>
<tr>
<td>Orbit</td>
<td></td>
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<tr>
<td>Instrumentation</td>
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<tr>
<td>Correction</td>
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<tr>
<td>Sea State Bias</td>
<td></td>
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<tr>
<td>Ionosphere</td>
<td></td>
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<tr>
<td>Dry Troposphere</td>
<td></td>
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<tr>
<td>Combined atm.</td>
<td></td>
</tr>
<tr>
<td>Ocean Tide</td>
<td>GOT 4.5</td>
</tr>
<tr>
<td>Solid Earth</td>
<td></td>
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<tr>
<td>Pole tide</td>
<td></td>
</tr>
<tr>
<td>MSL</td>
<td></td>
</tr>
<tr>
<td>Merging</td>
<td>New regional biases and monthly OI</td>
</tr>
</tbody>
</table>

Table 2: Summary of the recommendations for the Sea Level ECV production. In green, the new algorithms used for each mission. White corresponds to no change with respect to the reference products (AVISO).
6. **PRODUCTION VALIDATION & USERS ASSESSMENT**

The first step of the validation has been performed and consists in comparing the Sea Level ECV products with the reference products (AVISO). Differences have been characterised for the GMSL where a clear improvement has been done the ERS-1/2 & ENVISAT series (Figure 3). Indeed, thanks to significant improvements (of the order of 2 mm/y) in the Point Target Response (PTR) corrections for ENVISAT, the GMSL trend observed by ERS-1/2&ENVISAT is now of about (2.6 mm/y) which is more consistent with the T/P&Jason-1/2 series (2.98 mm/y). One can also note that the interannual variability is improved, in particular for the old ERS-1/2 missions. Reconciliate ERS-1/2&ENVISAT with T/P-Jason in term of GMSL signals series is a necessary step to improve the RMSL trends at local scales.

![Figure 3](image-url)

**Figure 3:** Global mean sea level for the period 1993-2010 (in cm) from the reference products (top) and from Sea Level CCI product (bottom). In red the T/P-Jason1/2 time series, in blue the ERS-1/2-ENVISAT time series.

Another illustration of the improvement of the RMSL is given (Figure 4) representing the differences with SL CCI products and the reference products (AVISO) on the 1993-2010 period. Large scales patterns of about +/- 2 mm/y appear that represent a significant part of the RMSL trends signal which is comprised of the order of 10 mm/y. It represents a combination of the improvements done using the new orbits (GDR-D for Jason 1/2 & Reaper for ERS-1/2), with other corrections as the dry and combined atmospheric corrections which used ERA Interim fields instead the ECMWF operational analyses.

![Figure 4](image-url)

**Figure 4:** Map of the Regional Mean sea level trends differences between the reference product (AVISO) and the Sea Level CCI products (in mm/y).

7. **SUMMARY & CONCLUSIONS**

After a two years development and production cycle that enables to deliver the so-called ECV products to the user community, the next step of the work will consists to assess the quality of the products by performing a full round robin exercise between the SL ECV products and the reference products (AVISO). This activity has already started and preliminary results are shown in this paper. Although, significant improvements have been made are at inter-annual GMSL scales and at RMSL trends, one can establish that the user requirements are not reached. Still work is needed. The User assessment phase that will be performed in the coming year should allow us to better characterise the product errors and consequently to define new ways of improvements.

8. **REFERENCES**

- Mean Sea Level Aviso www site web site: [http://www.aviso.oceanobs.com/msl](http://www.aviso.oceanobs.com/msl)

http://www.wmo.int/pages/prog/sat/Databases.html