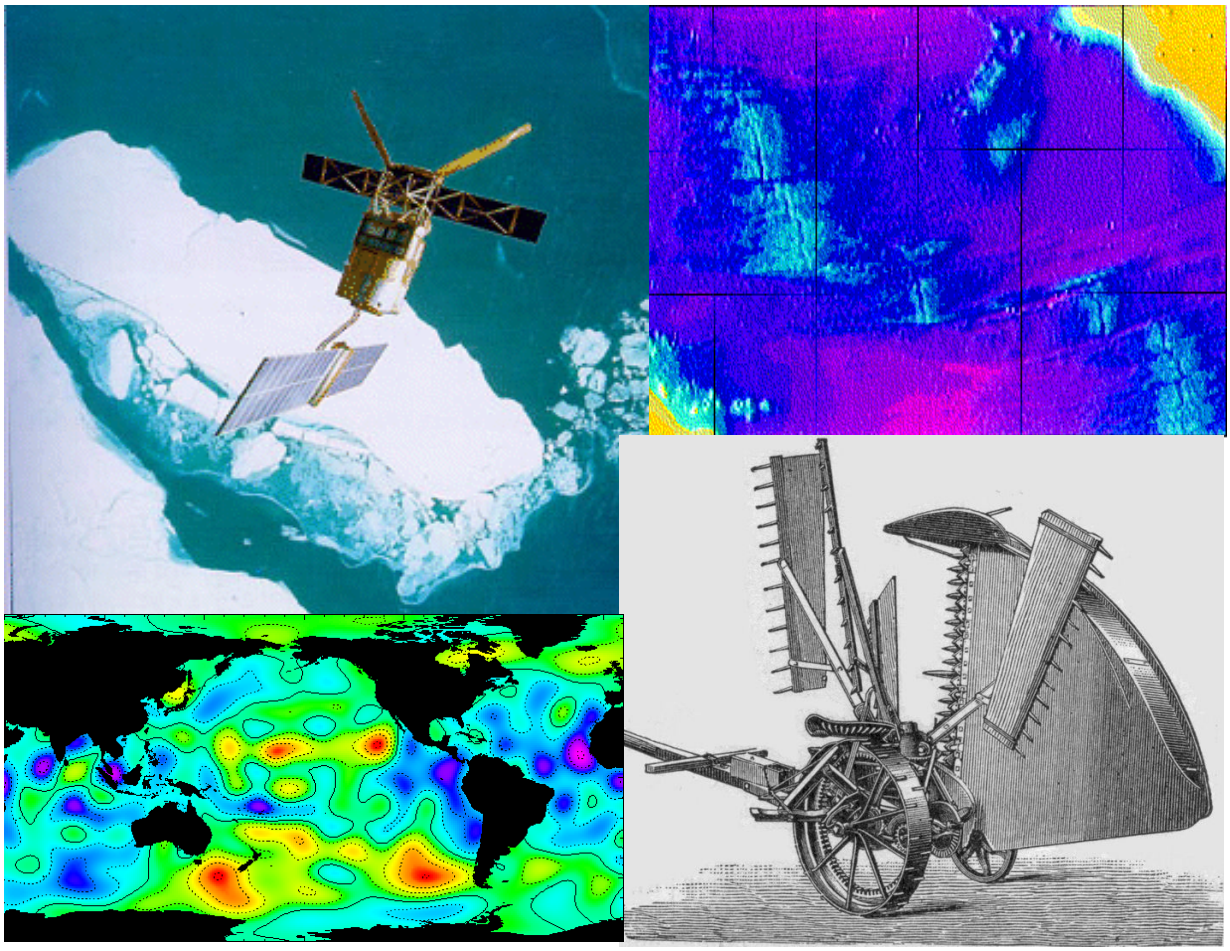
**Reprocessing of Altimeter Products for ERS**

***REAPER***



# Cal/Val evaluation of REAPER ERS altimeter data

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esa

CLS COLLECTE LOCALISATION SATELLITES

MSSL UCL Mullard Space Science Laboratory

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# Contents

# 1 Introduction

## 1.1 Purpose and Scope

The aim of this document is to present the results of the mission performance analysis performed at CLS on REAPER products. The final goal of this activity is to validate the REAPER processing scheme before performing a full reprocessing of altimeter data for the ERS-1 and ERS-2 missions.
After the investigations performed on one cycle of ERS-1 COM3 REAPER data, the present Cal/Val report is updated with results obtained from the analysis the REAPER COM6 dataset over a muche larger period (10 cycles of ERS-1 and 20 cycles of ERS-2)

## 1.2 Document Overview

First the data used and the validation strategy are described. From this data, we present the results of the data quality analysis performed on different geophysical fields of the REAPER products. This evaluation is performed on one cycle of ERS-1 REAPER COM3 radar altimeter dataset, where no outstanding problems were identified, we did not update the analysis with COM6 data.
Eventually classical mission performance indicators are presented like crossovers analysis and global SLA monitoring. These indicators were re-estimated from COM6 dataset over 30 cycles of data.

## 1.3 Applicable And Reference Documents

AD1 REAPER Proposal [MSSL-PRO-08-SB3] v3.0 dated 16 Oct 08
AD2 IODD **REA-IS-IODD-MSL-6002 Issue: 1.0 Date: 28 Jan 2010**
AD3 REAPER CCN proposal

## 1.4 Acronyms And Abbreviations

| | |
|---|---|
| ADD | Architectural Design Document |
| ADF | Auxiliary Data File |
| AESL | Altimetry ESL (Used in Reaper to collectively represent MSSL, CLS and IsardSAT) |
| AltiLLC | Abbreviation of 'Altimetrics LLC' |
| CIL | Configuration Items List |
| CLS | Collecte Loclisation Satellites (AESL) |
| CPG | Climate Physics Group (at MSSL/UCL) |
| CPOM | Centre for Polar Observation and Monitoring (at UCL) |
| DDF | Design Definition File (from ECSS) |
| DEOS | Delft institute of Earth Observation and Space systems |
| DJF | Design Justification File (from ECSS) |
| DPM | Detailed Processing Model (an Algorithm Specification Doc) |
| ESL | Expert Support Laboratory |
| ECSS | European Cooperation for Space Standardization |
| FAT | Factory Acceptance Tests |
| GAMME | GMES hArmonisation in a Multi-Mission Environment |
| GFZ | Helmholtz -Zentrum Potsdam (Deutsches GeoForschungsZentrum) |
| GUI | Graphical User Interface |

| | |
|---|---|
| ICD | Interface Control Document |
| IDL | Interactive Data Language (Research Systems Inc.) |
| IODD | Input / Output Definition Document |
| IPF | Instrument Processing Facility |
| I-Sat | IsardSAT (L1 AESL) |
| ISP | Instrument Source Packet |
| KO | Kick Off (of this project) |
| L1 /L1b /L2 | Processing Levels 1 / 1b/ 2 |
| LIP | Level 2 Ice Processor (AESL reference processor for RA-2 Ice algorithms) |
| LOP | Level 2 Ice Processor (ESL reference processor for RA-2 Ocean algorithms) |
| L1 /L1b /L2 | Processing Levels 1 / 1b/ 2 |
| LIP | Level 2 Ice Processor (ESL reference processor for RA-2 Ice algorithms) |
| MMFI | Multi Mission Facility Infrastructure |
| MSSL | Mullard Space Science Laboratory (Part of UCL) |
| MWR | Microwave Radiometer (on ERS) |
| NetCDF | Network Common Data Form |
| pdf | Portable Document Format (TM of Adobe inc) |
| PDS | Payload Data Segment |
| PM | Project Manager |
| PMP | Project Management Plan (this doc) |
| QWG | instrument Quality Working Group (on ENVISAT) |
| RA | Radar Altimeter (e.g. RA on ERS, RA2 on ENVISAT) |
| RADS | Radar Altimeter Database System |
| REAPER | **Re**processing **A**ltimeter **P**roducts for **ER**S |
| RMS | Root Mean Square |
| SAT | Site Acceptance Tests (at ESRIN) |
| SDD | System Design Document |
| SPH | Specific Product Header |
| SSB | Sea State Bias (correction to RA range measurement) |
| TBC | To Be Confirmed |
| TBD | To Be Decided |
| UCL | University College London |
| URD | User Requirements Document |
| WCRP | World Climate Research Programme |
| WP | Work Package |
| XML | eXtensible Markup Language |

# 2 Data Description

In a previous analysis, we investigated three cycles of ERS-1 and ERS-2 REAPER data. This analysis lead to the identification of an error in the range compression algorithm leading to a wrong datation of 1Hz data, thus making them useless to oceanographic applications.
This issue was corrected and a new set of data was generated. One ERS-1 cycle from this new version of the dataset was then analysed in the previous version of the present report (v2.1). When results only refer to the COM3 dataset, they are highlighted in blue.
In this report (v2.2), we analyse both ERS-1 and ERS-2 1Hz altimeter data from the REAPER COM6 dataset.The analysis is performed on a much longer time period including ten cycles during the verification phase between ERS-1 and ERS-2, and ten cycles during the verification phase between ERS-2 and Envisat.

## 2.1 REAPER data

In order to perform the present analysis, we downloaded and acquired into CLS's database system:

More than ten cycles of ERS-1 REAPER COM6 dataset, corresponding to 4930 product files whose names range from `E1_TEST_ERS_ALT_2__19950514T010346_19950514T024220_COM6.NC` to `E1_TEST_ERS_ALT_2__19960428T225348_19960429T002310_COM6.NC`

1. More than ten cycles of ERS-2 REAPER COM6 dataset, matching the period covered by the previously mentioned ERS-1 files. These filenames range from `E2_TEST_ERS_ALT_2__19950515T094300_19950515T112234_COM6.NC` to `E2_TEST_ERS_ALT_2__19960429T225357_19960430T002308_COM6.NC`.
2. Ten cycles of ERS-2 REAPER during the verification phase with Envisat, these filenames range from `E2_TEST_ERS_ALT_2__20010212T010138_20010212T024229_COM6.NC` to `E2_TEST_ERS_ALT_2__20030602T225223_20030603T002130_COM6.NC`.

These files were uploaded into CLS's database system to allow the use of CLS tools dedicated to mission performance analysis. Table 1 gives the list of the product fields that were uploaded in CLS databases, in order to perform the mission performance analysis.
I would like to emphasize that the using these files is not straightforward. In particular only a `units` attribute is associated to each variable in the netCDF files. We recommend that at least a `_FillValue` is associated to each variable. This will make REAPER data much more user friendly.
For certain variables of the REAPER NetCDF files we encountered unusual numeric values. In some cases we assumed that these corresponded to default values (usually given by the `_FillValue` attribute of a NetCDF variable) and converted them accordingly in CLS database. When this is done, the assumed default value is mentioned in Table 1.

| Product field | default_value |
|---|---|
| latitude_1hz | |
| longitude_1hz | |
| altitude_1hz | 0 |
| altitude_rate_1hz | |
| wf_attitude_1hz | |
| ocean_range_1hz | 0 |
| ocean_stdev_1hz | |

| | |
|---|---|
| ocean_valid_num_1hz | |
| ocean_wind_1hz | |
| ocean_sig0_1hz | |
| ocean_sig0_stdev_1hz | |
| ocean_sig0_valid_num_1hz | |
| swh_1hz | |
| swh_stdev_1hz | |
| swh_valid_num_1hz | |
| em_bias_1hz | |
| f_sea_ice_flag_1hz | |
| tb_23_8_1hz | |
| tb_36_5_1hz | |
| f_mwr_srf_type_1hz | |
| dry_c_1hz | |
| mog2d_c_1hz | |
| wet_c_mod_1hz | |
| wet_c_mwr_1hz | |
| water_vapor_content_1hz | |
| liquid_water_content_1hz | |
| u_wind_1hz | |
| v_wind_1hz | |
| iono_c_mod_1hz | |
| h_mss_cls01_1hz | |
| h_mss_ucl04_1hz | |
| h_geo_1hz | |
| h_ot_1hz | |
| h_ot2_1hz | |
| h_olt_1hz | |
| h_olt2_1hz | |
| h_lpt_1hz | |
| h_lptne_1hz | |
| h_set_1hz | |
| h_pol_1hz | |
| sig0_attn_c_1hz | |

*Table 1: fields of the REAPER NetCDF product acquired for the presetn study and the corresponding assumed default_value when possible*

In previous versions of the commissioning dataset, the altimeter range in the product was corrected for all geophysical corrections and we uncorrected the range when performing the acquisition. This is no longer needed in COM6 as the product range is not corrected for geophysical effects.

## 2.2 Reference data

In this report, the REAPER data are often compared to either matching ERS data or other missions (TOPEX/Poseidon and Envisat). For ERS-1 and ERS-2, comparisons are drawn from the historical OPR, or from our current best for ERS data (called “updated OPR” in this document). A description of what our current best estimate is can be found in the SSALTO/Duacs User Handbook (available at

http://www.aviso.altimetry.fr/fileadmin/documents/data/tools/hdbk_duacs.pdf) under section 3.3.1. for all missions.

# 3 Missing Measurements

The percentage of missing measurements is an important parameter as it monitors the data availability. Here we focus on ocean only and check for missing measurements in the product, this is performed by comparing the product to a theoretical ERS ground track.
Figure 1 displays the temporal evolution of the percentage of missing measurements over the oceanic domain. It shows that REAPER data has an improved coverage compared to OPR data over ocean. During the verification phase between ERS-1 and ERS-2, the percentage of missing measurements for ERS-1 is about two times lower for REAPER data than for the OPR data, and about three times for ERS-2.

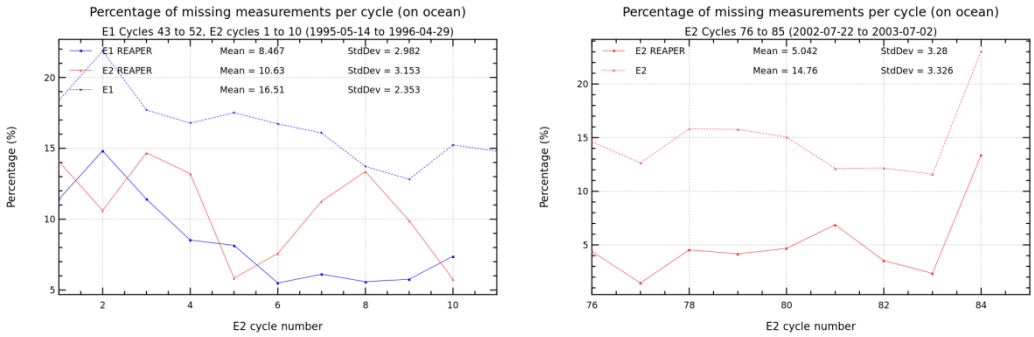



*Figure 1: evolution of the percentage of missing measurements over ocean for REAPER (solid line) and OPR data (dashed line)*

This is a first positive indicator of the quality of the REAPER COM6 data.

However, there is a number of measurements which present excursions in time and space as displayed on Figure 2. These measurements likely result from clock errors which lead to a wrong interpolation along the orbit. For the purpose of this report, we do not consider these measurements in our analysis.

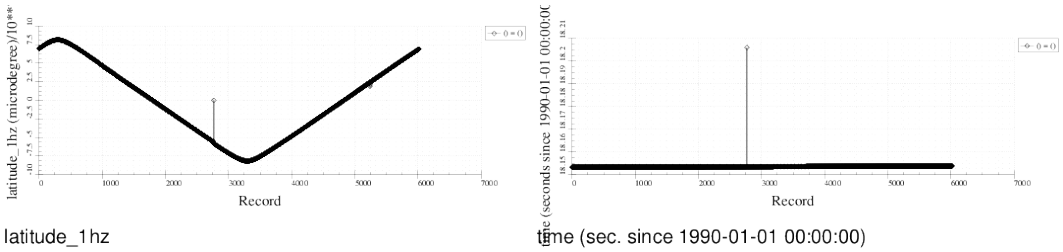



*Figure 2: evolution of the latitude (left) and time (right) of the measurements in one REAPER ERS-1 product file*

# 4 Editing strategy

The editing procedure intends to discriminate, among available measurements, between valid and invalid measurements. This is of course a trade-off between data quality and availablilty. To perform a consistent comparison to historical OPR products, we applied to REAPER data the editing criteria that were used for historical Cal/Val of ERS OPR data.
The editing is mainly based on a set of thresholds which are summarized in the following table.

| parameter | product field | min threshold | max threshold |
|---|---|---|---|
| ionospheric correction | `iono_c_mod_1hz` | -0.4 | 0.04 |
| dry tropospheric correction | `dry_c_1hz` | -2.5 | -1.9 |
| wet tropospheric correction | `wet_c_mwr_1hz` | -0.5 | -0.001 |
| ocean tide + load tide + long period equilibrium tide | `h_ot_1hz + h_olt_1hz + h_lpt_1hz` | -5.0 | 5.0 |
| solid earth tide | `h_set_1hz` | -1.0 | 1.0 |
| pole tide | `h_pol_1hz` | -5.0 | 5.0 |
| sea state bias | `em_bias_1hz` | -0.5 | 0.0 |
| dynamic atmospheric correction | `mog2d_c_1hz` | -2.0 | 2.0 |
| backscatter | `ocean_sig0_1hz` | 6.0 | 30.0 |
| significant wave height | `swh_1hz` | 0 | 11 |
| wind speed | `ocean_wind_1hz` | 0.0 | 30.0 |
| squared mispointing | `wf_attitude_1hz` | -0.16 | 0.16 |
| number of elementary range measurements | `ocean_valid_num_1hz` | 10 | None |
| standard deviation of elementary range measurements | `ocean_stdev_1hz` | 0.0 | 0.45 |
| uncorrected SSH | `altitude_1hz - ocean_range_1hz` | -130.0 | 130.0 |
| SLA | see section 7 for the SLA expression | -2.0 | 2.0 |

*Table 2: thresholds used for the edting of REAPER radar altimeter data*

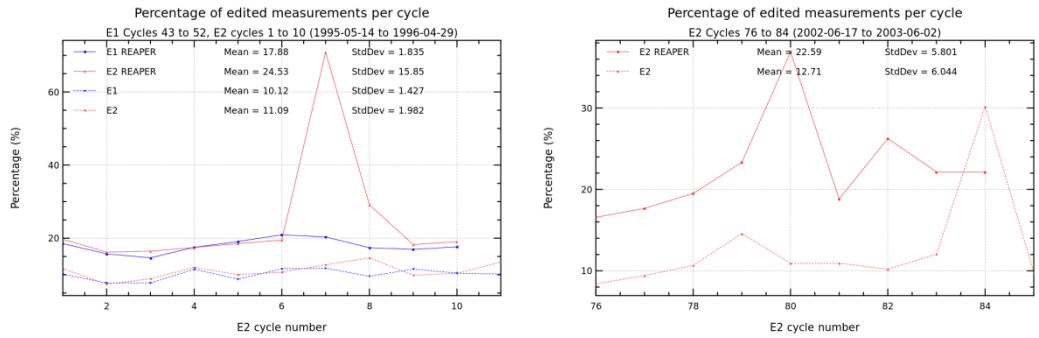



*Figure 3: evolution of the percentage of edited measurements over time for ERS-1 and ERS-2 for REAPER and OPR data*

Figure 3 displays the temporal evolution of the percentage of edited measurements.
The first obvious change with REAPER data is that more REAPER measurements are edited than for the OPR, both for ERS-1 and ERS-2. This does not indicate lower quality of REAPER data but is related to the lower number of REAPER missing measurements highlighted in the previous section of this report; many of these measurements are situated at high latitudes in sea-ice covered regions and are therefore edited.
For ERS-1, the percentage of edited data is stable over time, while it is much more variable for ERS-2. For example cycles 7, 8 and 80 exhibit a very high percentage of edited data which is due to large periods when the radiometer wet tropospheric correction is set to zero in the product and therefore edited by our thresholds criteria.

An example of the spatial distribution of edited measurements for one cycle of ERS-1 and ERS-2 (over ERS-2 cycle 5) is displayed on Figure 4. Over this time period, several tracks of ERS-1 are edited mainly due to lack of radiometer data. Otherwise the pattern of edited data is consistent with what is observed on other missions: data are mainly edited in the tropical band, at the coast and at high latitudes.

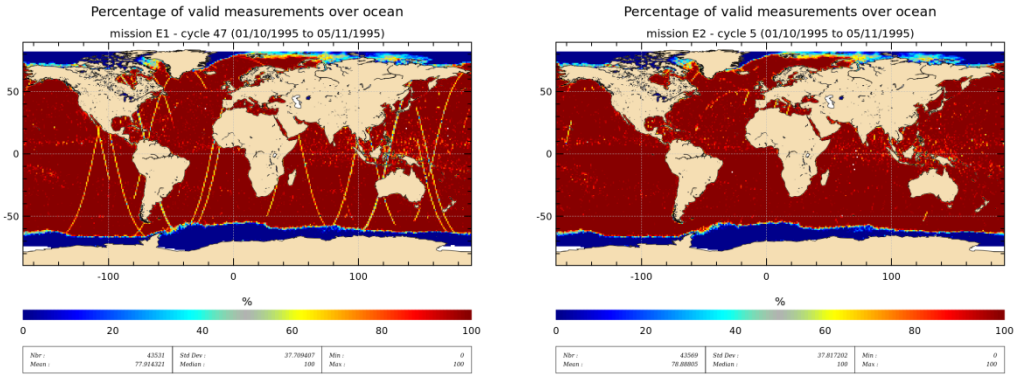



*Figure 4: map of the percentage of valid measurements for ERS-1 (left) and ERS-2 (right) estimated over ERS-2 cycle 5 from REAPER COM6 data*

Apart from the missing radiometer data events, no unusual behavior of REAPER COM6 data was noticed regarding edited data.

# 5 Field-wise comparison

Field-wise verification of the product was performed on one cycle of COM3 data as part of issue 2.1 of the present report. When no errors were identified, we did not update the analysis using COM6 data. The blue bars in the left margin indicate that the corresponding analysis was performed on the COM3 dataset.

In this section we present a parameter wise comparison between OPR data and REAPER data. It should be noted that depending on the parameter and due to different time tags between REAPER and the original OPR data, we cannot ensure that the comparisons are performed over the same sample of the data. This can explain some of the small differences between the two datasets. However, we performed an editing procedure on REAPER data similar to what was performed on OPR data, and comparisons are drawn on valid data only.
When possible (for modeled parameters mainly), we reinterpolated the field at the time and position of REAPER data, in order to perform comparisons strictly on the same data sample.

## 5.1 Orbit

**Product field:** `altitude_1hz`

In REAPER data, the orbit comes from the combined orbit solution which was generated within this project. In order to check the validity of the orbit distributed within ther REAPER products, we used the original SP3 files from the combined orbit solution and interpolate them at the time and position of REAPER 1 Hz measurements using in-house interpolation schemes.

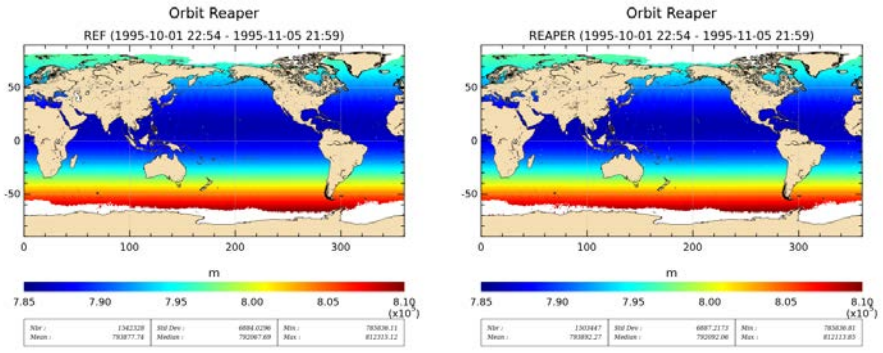



*Figure 5: orbit values for ERS-1 cycle 150 from REAPER data (what is in the product, right) and re-interpolated from the original SP3 files (left)*

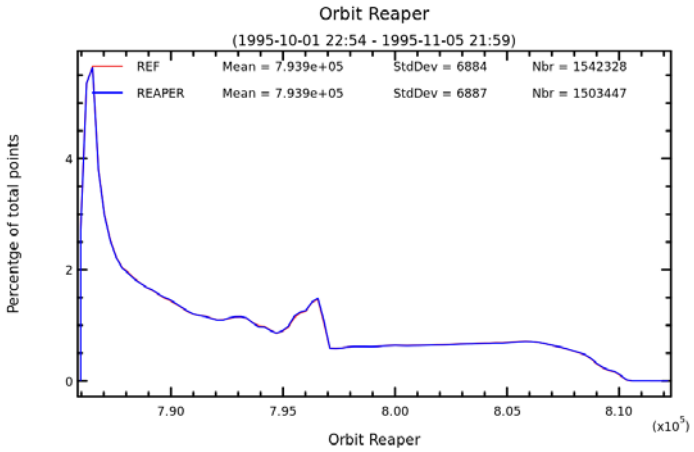



*Figure 6: histogram of orbit altitude values for REAPER data (blue) and the re-interpolated orbits (red)*

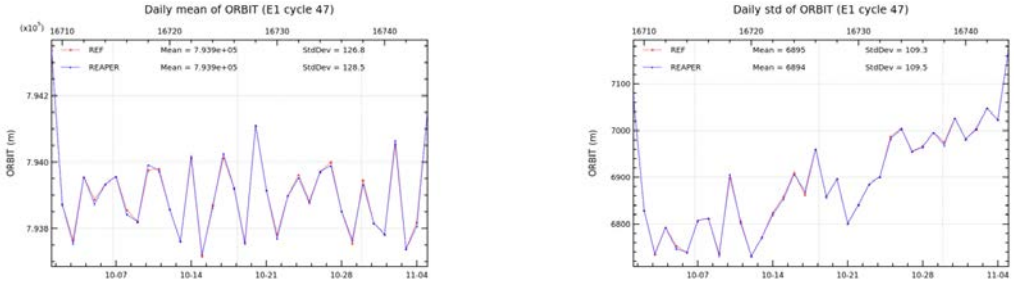



*Figure 7: Daily statistics (mean on left and standard deviation on right) for ERS-1 cycle 150 from REAPER orbit data and re-interpolated orbit from the original SP3 files*

Global statistics seem to show a good agreement between the two orbits, thus suggesting that the orbit is correct in the REAPER products. However, computing the along-track differences between the product and the re-interpolated orbits shows several pass sections with important orbit differences. These passes are clearly visible on Figure 8**Erreur ! Source du renvoi introuvable.**.

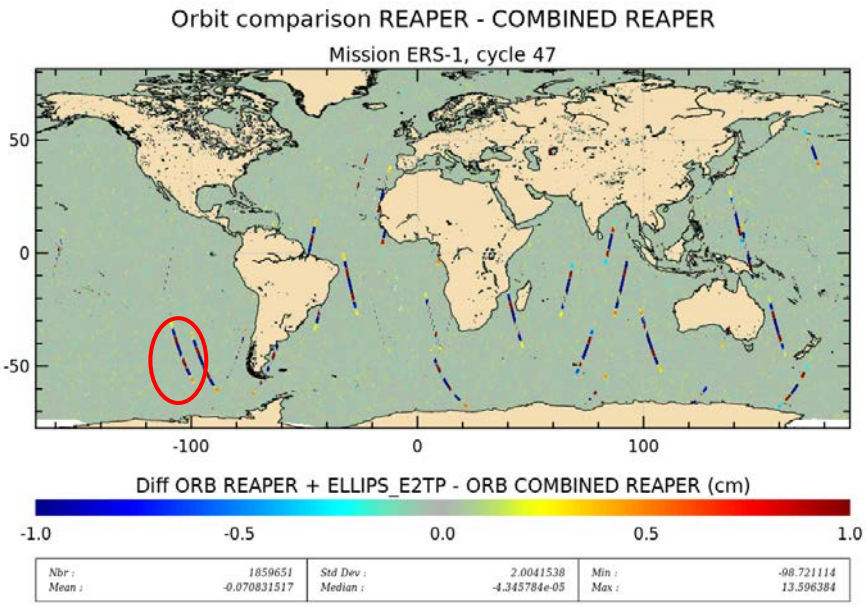



*Figure 8: map of along-track differences between the product orbit and the re-interpolated orbit*

As further illustration of this phenomenon, time series of the orbit differences along pass 983 is displayed below (this pass is circled in red on the map above). Differences larger than 60 cm can be found between the orbit altitudes in the product and the re-interpolates ones.

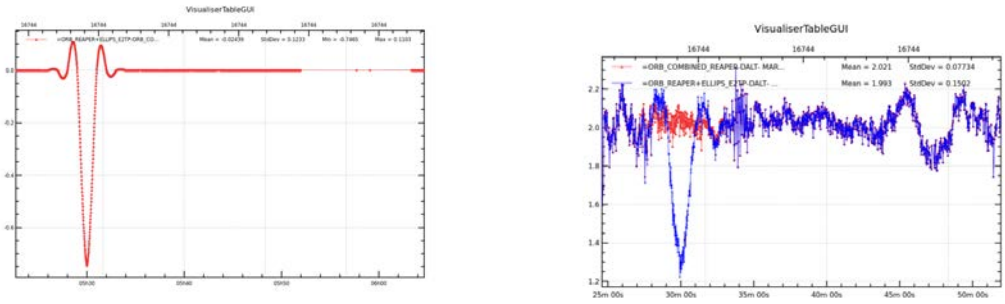



*Figure 9: left: Time series of orbits difference (REAPER - re-interpolated) for ERS-1 cycle 150 pass 983, right: time series of SLA for ERS-1 cycle 150 pass 983 calculated with REAPER orbit (blue) and re-interpolated orbit (red)*

Regarding the time series of the Sea Level Anomalies for this specific pass, an irregular fluctuation is observed for the SLA calculated with the orbit from REAPER products, indicating an issue in REAPER processing.

Orbit differences larger than 10cm are found at least 16 times over the whole ERS-1 cycle. These differences do not appear to be located at the passage between one SP file to another and their origin should be investigated.

The issue on the orbit files has been corrected in REAPER COM6 radar altimeter data and the orbit excursions identified above are no longer present.

## 5.2 Altimeter parameters

For these parameters, we cannot ensure that the same data sample from REAPER and original OPR data is used. However, we perform these comparisons on valid ocean data only, after performing an editing of the data.

### 5.2.1 Altimeter Range

**Product field:** `ocean_range_1hz`

Comparing the range between OPR and REAPER products is difficult due to the datation change between the two datasets, especially on a quantity that varies very quickly along track such as the range. Here we only perform very broad comparisons on a global scale. The quality of the range estimation is further assessed through mission performance indicators based on the sea level anomaly or sea surface height.

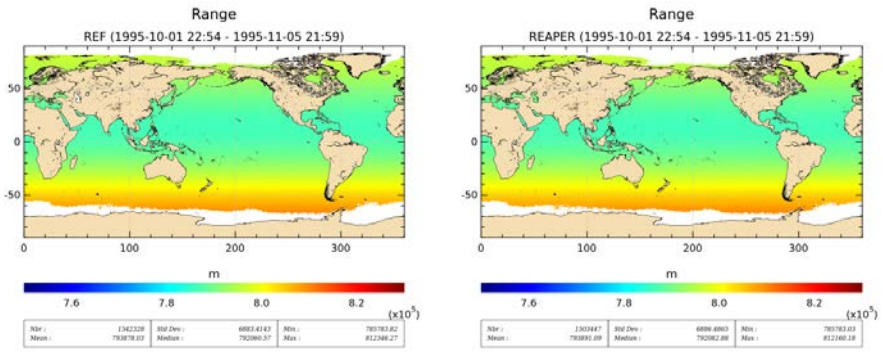



*Figure 10: range values for ERS-1 cycle 150 from REAPER data (right) and OPR data (left)*

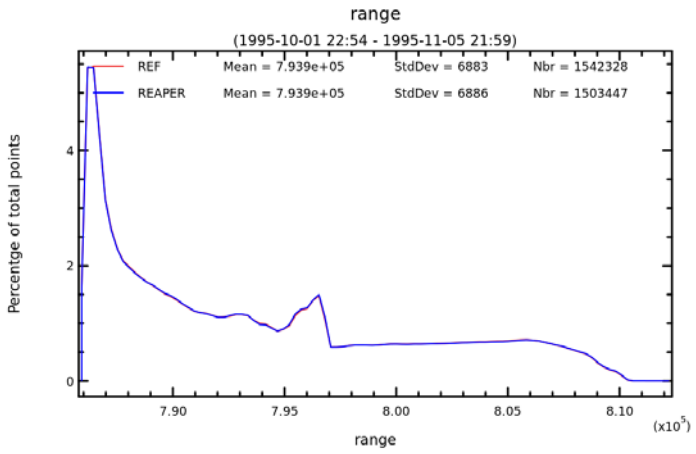



*Figure 11: histogram of range values for REAPER data (blue) and OPR data (red)*

### 5.2.2 Altimeter Range standard deviation

**Product field:** `ocean_stdev_1hz`

This field represents the standard deviation of 20Hz range values used in the compression to estimate the 1Hz range value. This can be more easily compared between OPR and REAPER than the range itself. The comparison

between REAPER and OPR products shows that on average, the standard deviation of the 20 Hz range values used in the estimation of 1Hz range values is lower for REAPER data than for OPR data. This suggests that there is less noise in 20Hz REAPER data than in the OPR data and thus suggests a better performance of REAPER products.
The two maps below show that the reduction pattern of the range standard deviation is spatially homogeneous. Such reduction is confirmed by the histogram of Figure 13 which shows that the average range standard deviation is reduced from 16 cm for OPR data to 14 cm for REAPER data.

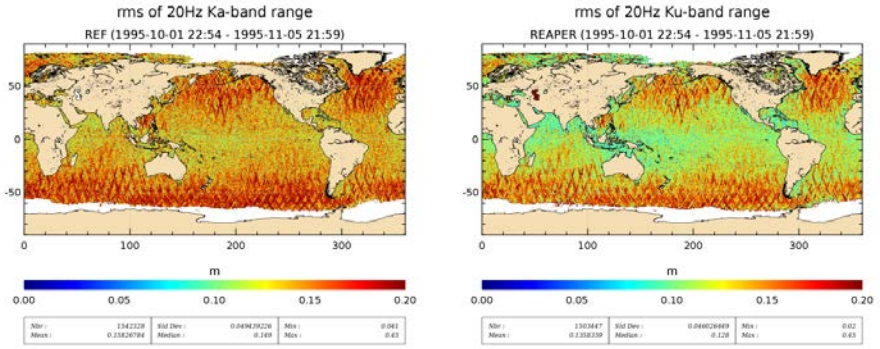



*Figure 12: maps of the standard deviation of 20Hz range measurements (evaluated through the 1hz field of the product) for OPR (left) and REAPER (right) data*

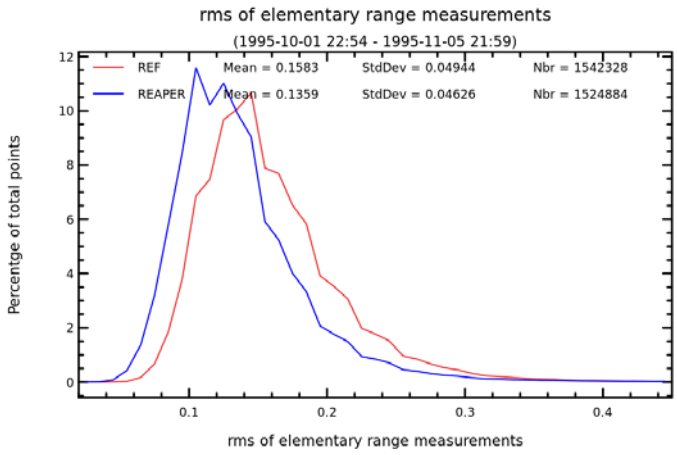



*Figure 13: histogram of the range standard deviation for REAPER (blue) and OPR (red) products.*

### 5.2.3 Altimeter Range number of elementary measurements

**Product field:** `ocean_valid_num_1hz`

This variable of the product indicates the number of 20Hz range measurements used in the compression algorithm to estimate one 1Hz range measurement. It is therefore strongly related to the standard deviation of the 20Hz range described in the previous paragraph. Comparison between OPR and REAPER products shows that the reprocessing performs very well with an average of 19.86 20Hz measurements used in a 1Hz estimation, to be compared to an average of 19.9 for OPR data.

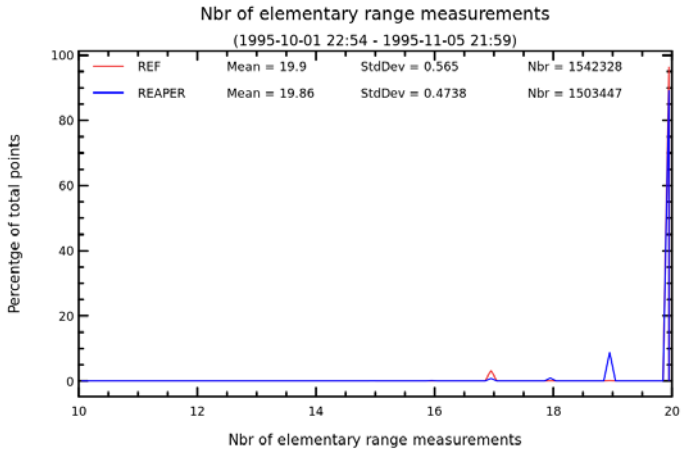



*Figure 14: histogram of the range number of elementary measurementsfor REAPER (blue) and OPR (red) products.*

It should be noted here that our editing removes all measurements where the number of elementary measurements is below 10.

### 5.2.4 Backscatter coefficient

**Product field:** `ocean_sig0_1hz`

Considering the backscatter coefficient, the two maps displayed on Figure 15 estimated from OPR and REAPER products display a very similar pattern. One can notice differences along the ice edges in the southern ocean that may come from a different configuration of the ice flag in the two products.

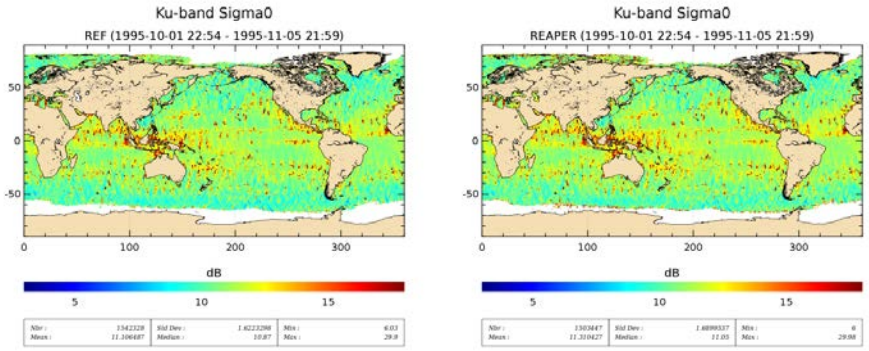



*Figure 15: maps of the 1Hz backscatter coefficient from OPR (left) and REAPER (right) products*

The histogram of the backscatter coefficient shows again a consistent behaviour between REAPER and original OPR products. However, REAPER backscatter appears to be shifted by 0.2dB with respect to OPR data, REAPER data being higher.

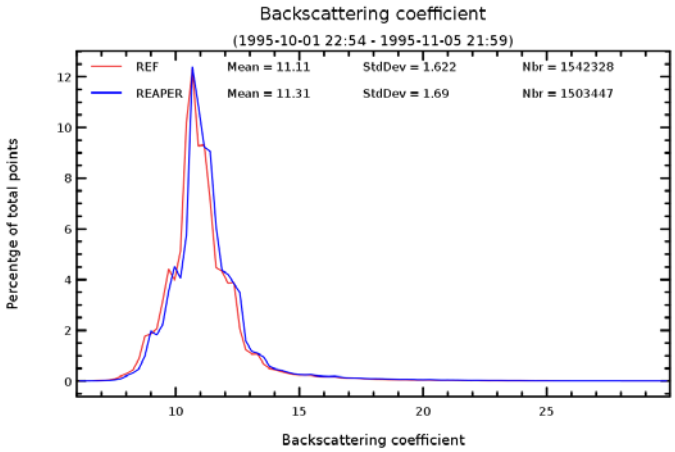



*Figure 16: histogram of the backscatter coefficient for OPR (red) and REAPER (blue) data*

Figure 17 shows that this difference is spatially homogeneously distributed over the globe. The larger differences observed at high latitudes probably originate from the different data samples used in this comparison between REAPER and OPR data.

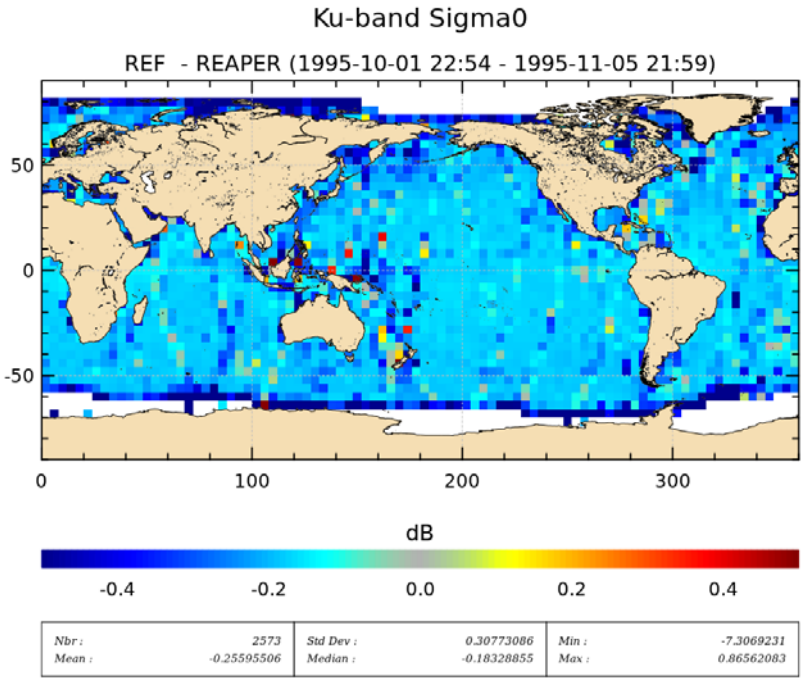



*Figure 17: map of box-average differences between OPR and REAPER backscatter coefficient values*

### 5.2.5 Backscatter coefficient standard deviation

**Product field:** `ocean_sig0_stdev_1hz`

The backscatter coefficient standard deviation appears to be similar in REAPER and OPR products despite a small shift in the histogram (0.20 dB versus 0.21 dB as shown on the histogram of Figure 18 below).

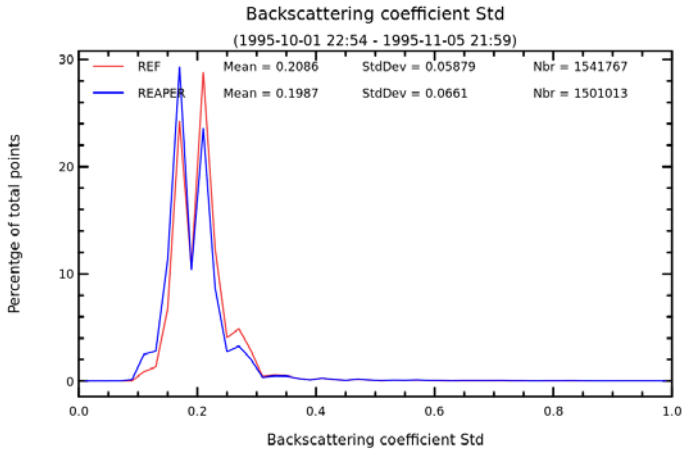



*Figure 18: histogram of the backscatter coefficient standard deviation for OPR (red) and REAPER (blue) data*

Plotting the regional distribution of the backscatter coefficient standard deviation differences between OPR and REAPER data (Figure 19) shows that the largest differences are located in the northern Atlantic and Arctic Ocean where REAPER data show a higher backscatter coefficient standard deviation than OPR data. Almost everywhere else, REAPER's backscatter coefficient standard deviation is slightly lower that the OPR one.

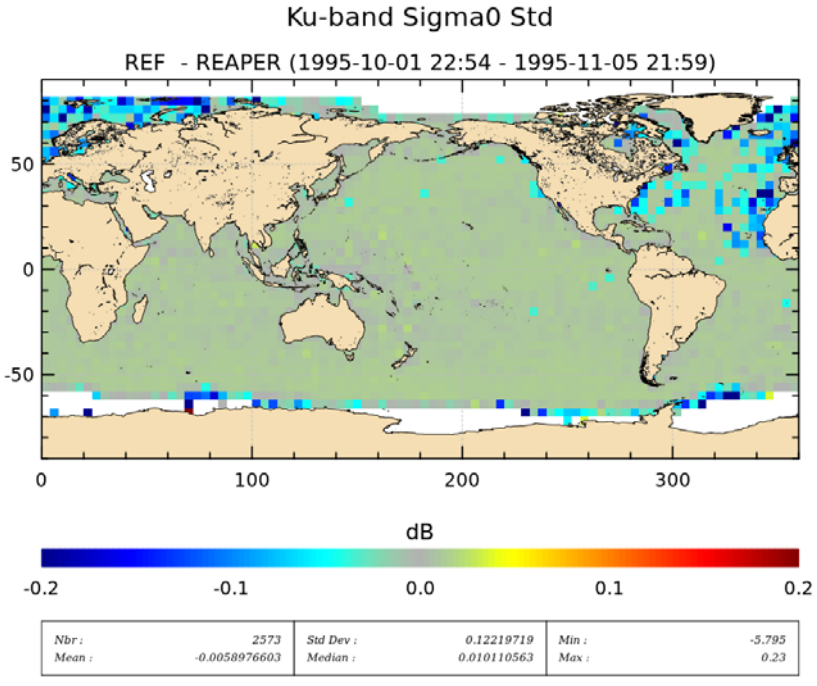



*Figure 19: map of box-average differences between OPR OPR and REAPER backscatter coefficient standard deviation values*

### 5.2.6 Significant wave height

**Product field:** `swh_1hz`

On average, significant wave height is higher in REAPER products than in the OPR products. Over this cycle of ERS-1 data, REAPER waves are 30cm higher than the OPR waves. This increase in the mean goes along an increase in the wave height standard deviation (see monitoring of daily statistics on Figure 22). It should be noted that REAPER SWH is closer to TOPEX/Poseidon than the original OPR product.

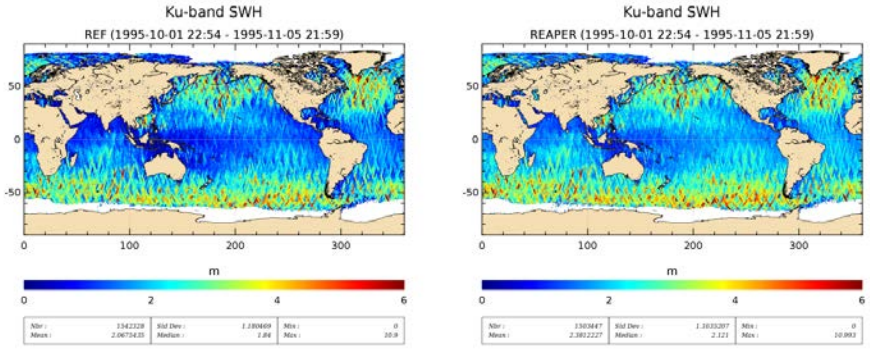



*Figure 20: maps of the significant wave height from OPR (left) and REAPER (right) data*

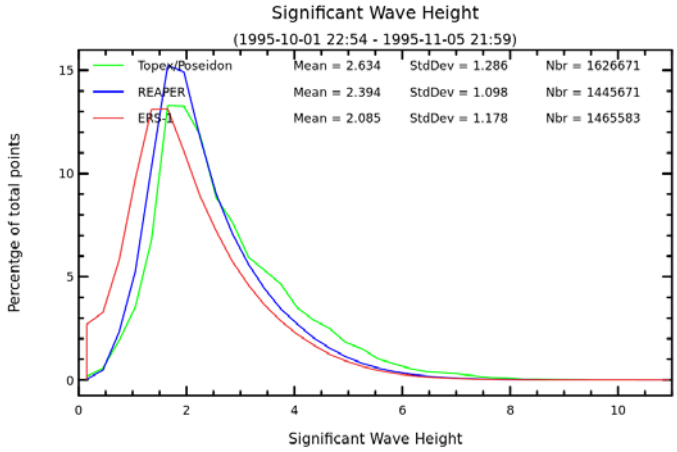



*Figure 21: histogram of the significant wave height for OPR (red), REAPER (blue) and Topex/Poseidon (green) data for latitudes between -66° and 66°*

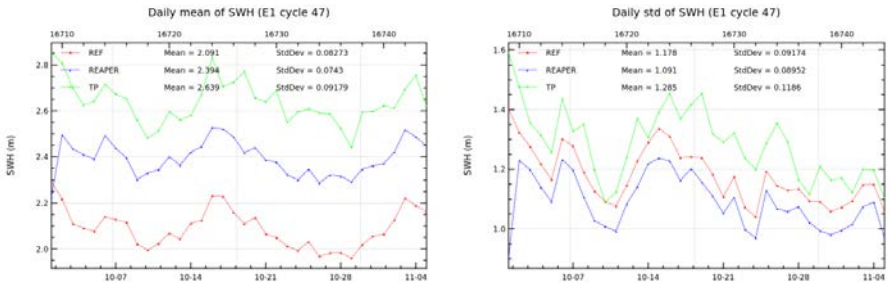



*Figure 22: Daily statistics (mean on left and standard deviation on right) for ERS-1 cycle 150 from OPR (red),REAPER (blue) and Topex/Poseidon (green) significant wave height data for latitudes between -66° and 66°*

Figure 23 displays the box-average of along-track differences between the OPR and REAPER signifcant wave heights. The largest differences are found in a wide tropical band where waves are significantly increased by the reprocessing.

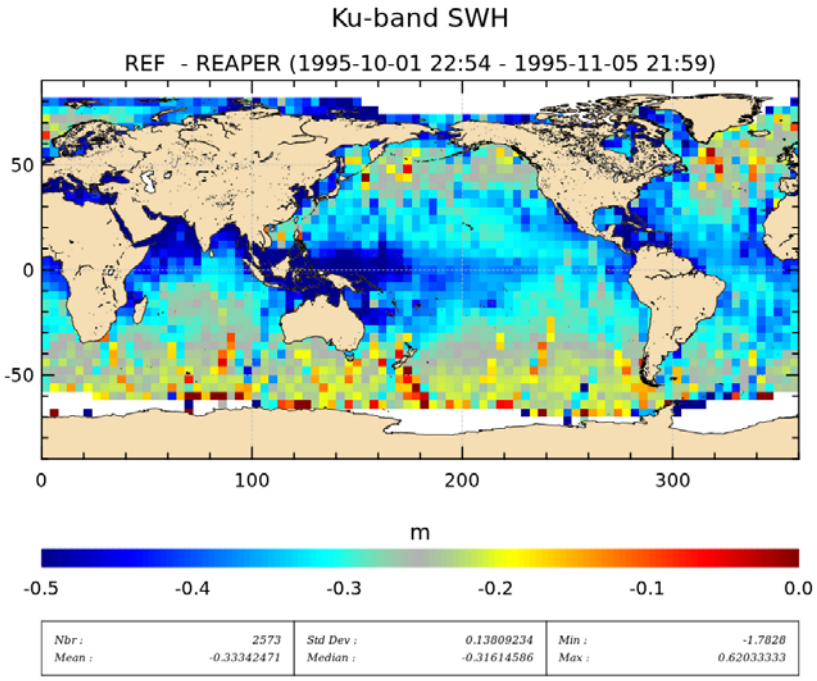



*Figure 23: map of box-average differences between OPR and REAPER significant wave height values*

### 5.2.7 Significant wave height standard deviation

**Product field:** `swh_stdev_1hz`

The increase in the significant 1 Hz wave height values is associated with a decrease in the significant wave height standard deviation in REAPER products with respect to OPR data (from 0.96 m to 0.75 m). The largest reductions in significant wave height standard deviation acorrespond to the largest increase in wave height (see Figure 26).

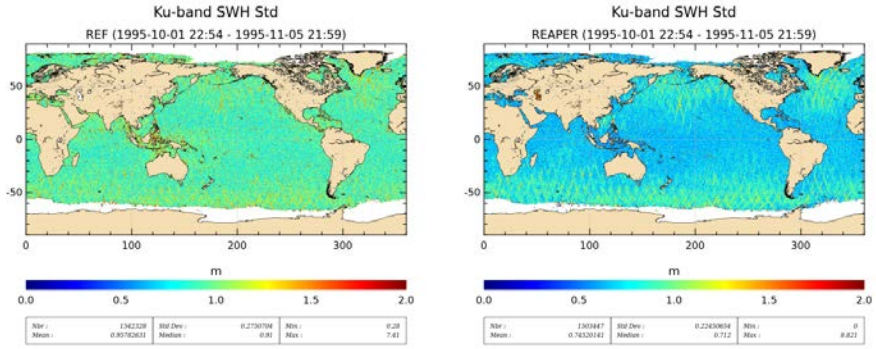



*Figure 24: maps of the significant wave height from OPR (left) and REAPER (right) data*

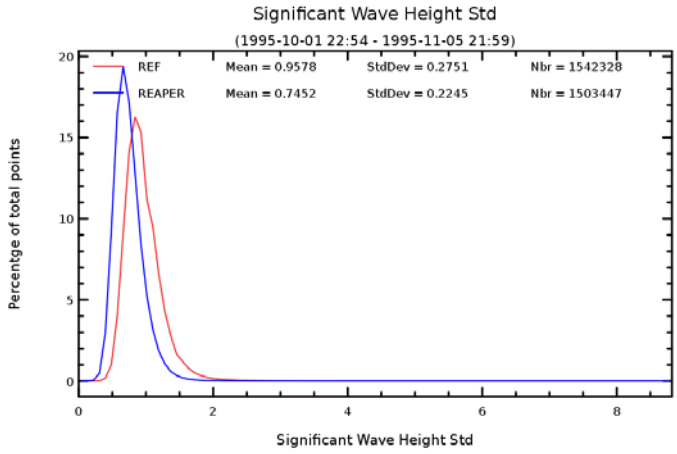



*Figure 25: histogram of the significant wave height standard deviation for OPR (red) and REAPER (blue) data*

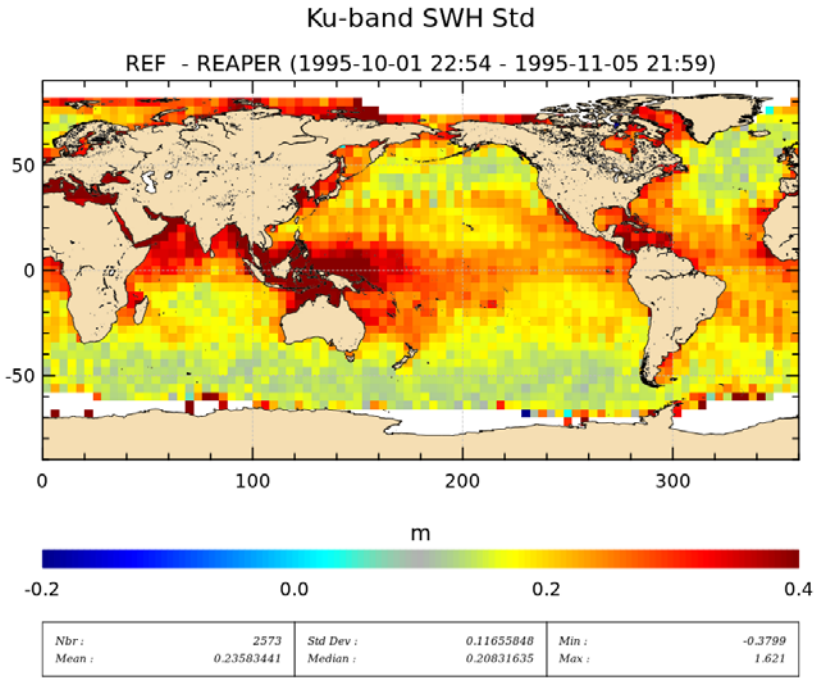



*Figure 26: map of box-average differences between OPR and REAPER significant wave height standard deviation values*

### 5.2.8 Altimeter wind speed

**Product field:** `ocean_wind_1hz`

Regarding wind speed values, the two maps of Figure 27 displaying along-track 1 Hz altimeter wind speed values look similar. However, plotting the histogram (Figure 28) shows that there are no wind speed values lower than 1 $m.s^{-1}$ in REAPER products; as the Envisat table was used in this processing, this is not unexpected.
Figure 29 shows that the reprocessing tends to decrease the wind speed at high latitudes and to increase the wind speed at lower latitudes.

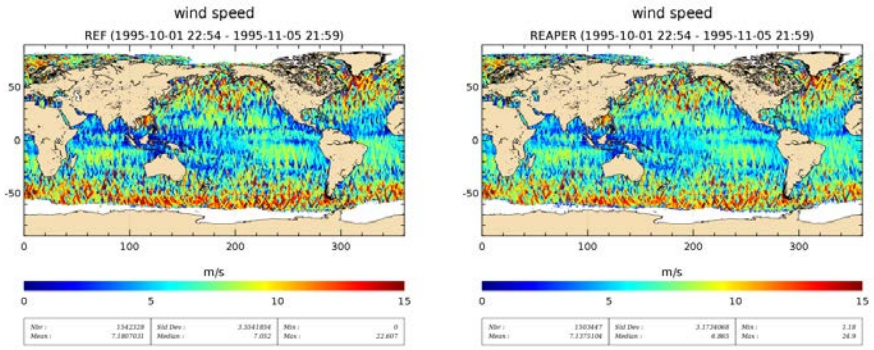



*Figure 27: maps of the altimeter wind speed from OPR (left) and REAPER (right) data*

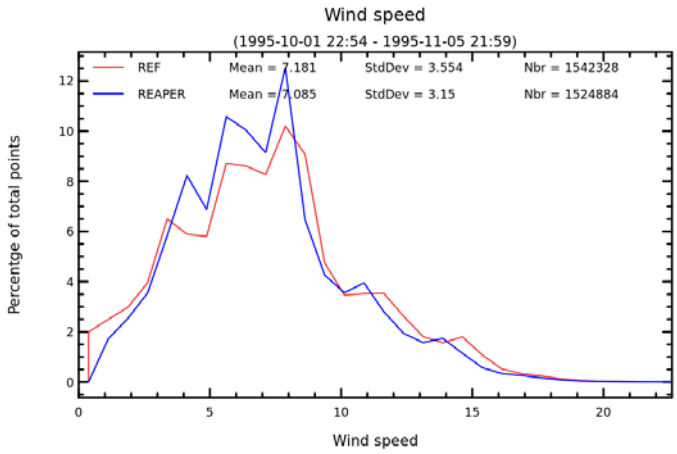



*Figure 28: histogram of the altimeter wind speed for OPR (red) and REAPER (blue) data*

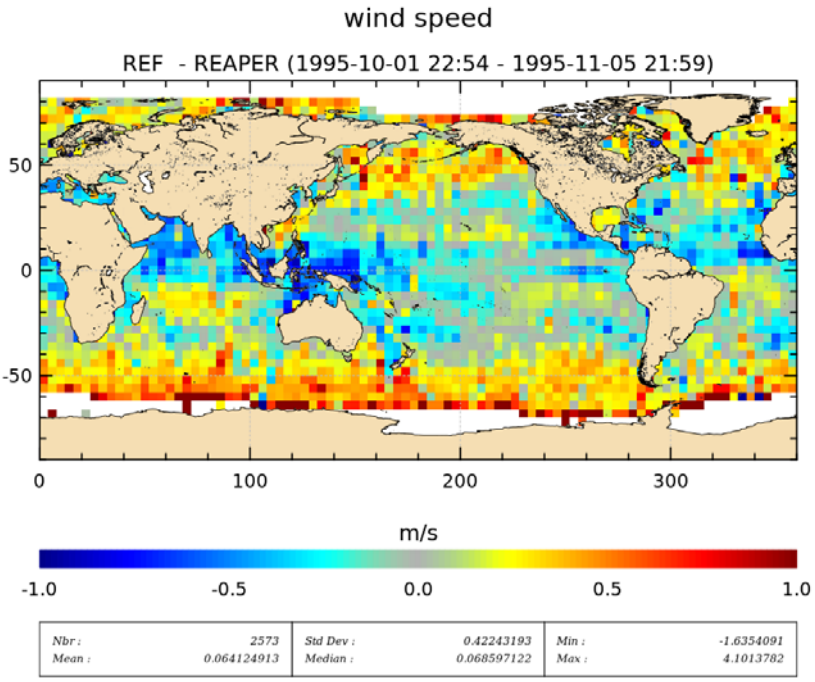



*Figure 29: map of box-average differences between OPR and REAPER altimeter wind speed values*

### 5.2.9 Sea state bias

**Product field:** `em_bias_1hz`

The sea state bias in REAPER product is significantly different from the OPR product. If the mean values are close, the SSB standard deviation has been reduced in REAPER data from 7.7 to 5.5 cm.

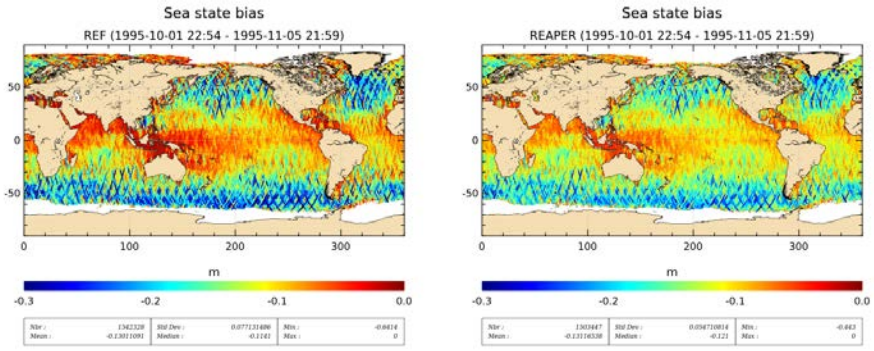



*Figure 30: maps of the sea state bias from BM3 OPR (left) and REAPER (right) data*

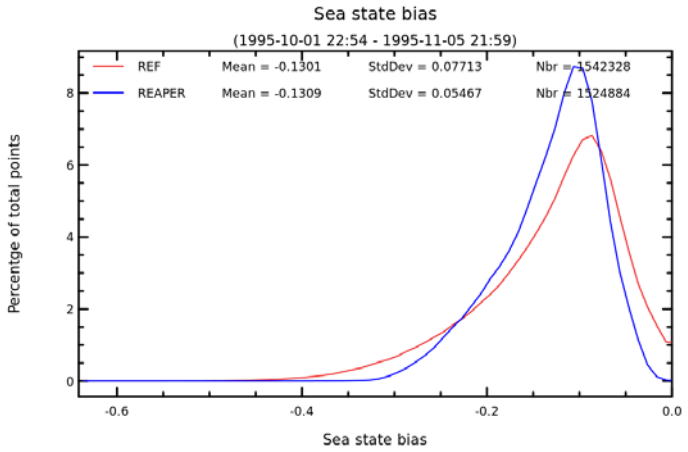



*Figure 31: histogram of the sea state bias from OPR (red) and REAPER (blue) data*

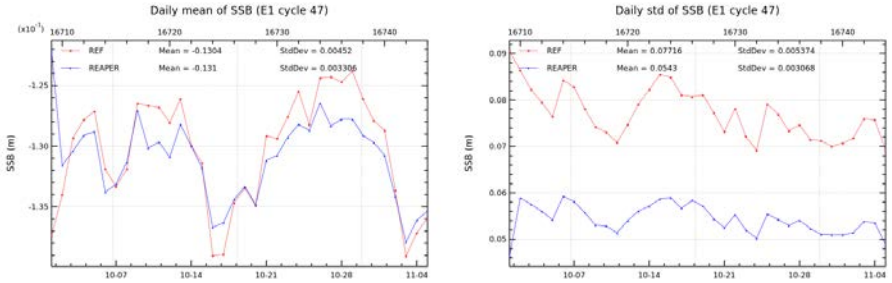



*Figure 32: Daily statistics (mean on left and standard deviation on right) for ERS-1 cycle 150 from OPR (red) and REAPER (blue) sea state bias data*

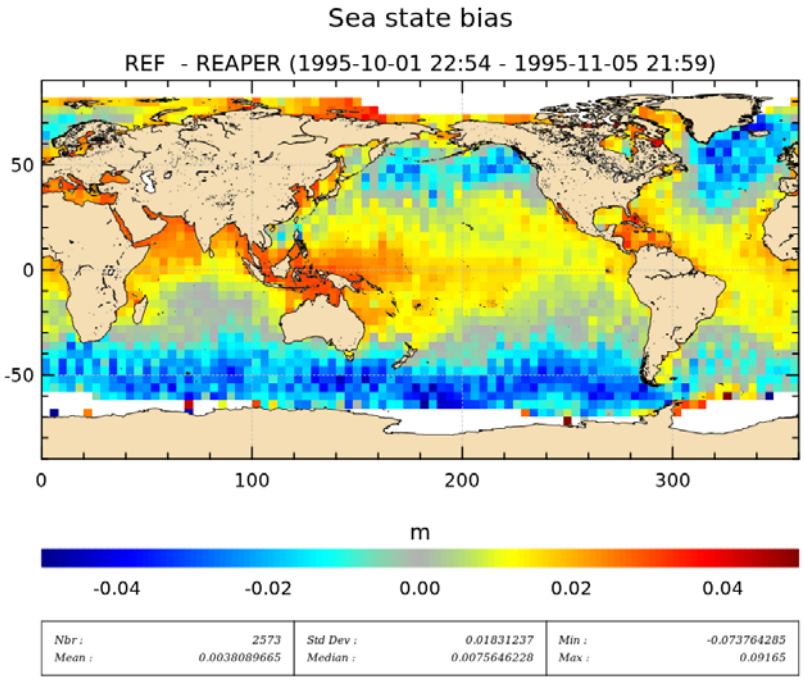



*Figure 33: map of box-average differences between OPR and REAPER sea state bias values*

## 5.3 Radiometer Parameters

### 5.3.1 Brightness temperatures

An evaluation of the brightness temperature and their stability was performed as part of previous REAPER activities and therefore the brightness temperatures will not be addressed in this document, we will rather focus on physical quantities derived from the radiometer measurements. As a general remark, these parameters are significantly modified by REAPER reprocessing.

### 5.3.2 Radiometer wet tropospheric correction

**Product field:** `wet_c_mwr_1hz`

The radiometer wet tropospheric correction is slightly higher for REAPER products (around 3cm). In fact the whole distribution of wet tropospheric corrections is shifted towards longer delays (see histrogram on Figure 35). The spatial distribution of the differences is homogeneously positive all over the globe, with slightly larger values in the tropical band.

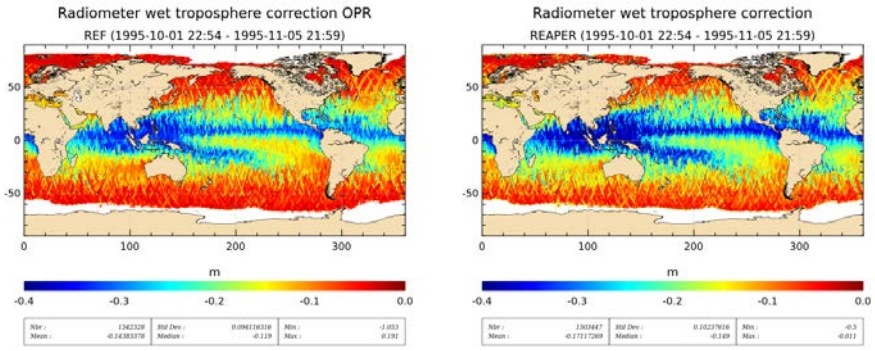



*Figure 34: maps of the radiometer wet tropospheric correction from OPR (left) and REAPER (right) data*

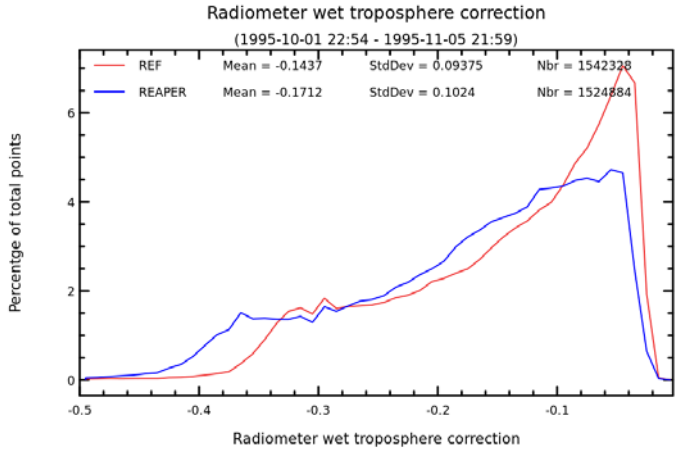



*Figure 35: histogram of the radiometer wet tropospheric correction from OPR (red) and REAPER (blue) data*

A comparison with other satellite altimetry missions and to model-derived wet tropospheric correction, seems to indicate that regarding the radiometer-derived wet tropospheric correction, REAPER brings an improvement over original OPR data.

### 5.3.3 Liquid water content

**Product field:** `liquid_water_content_1hz`

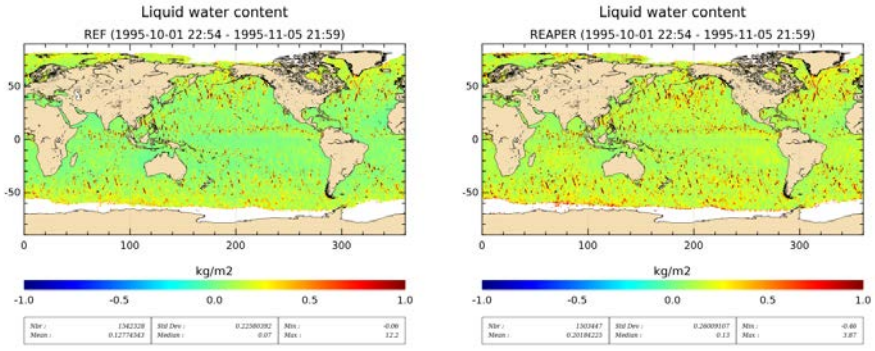



*Figure 36: maps of liquid water content from OPR (left) and REAPER (right) data*

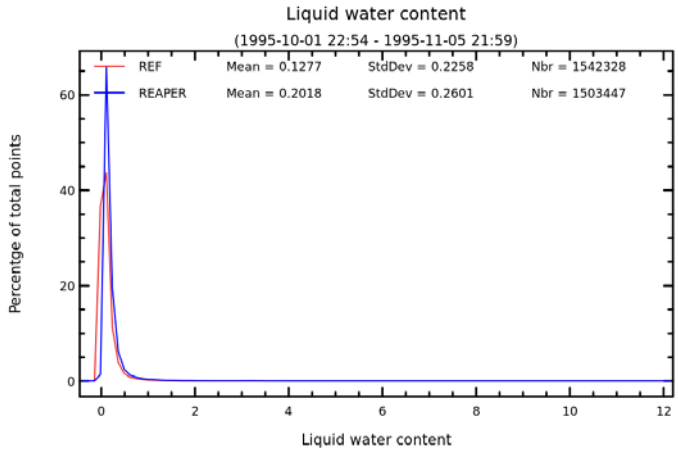



*Figure 37: histogram of liquid water content from OPR (red) and REAPER (blue) data*

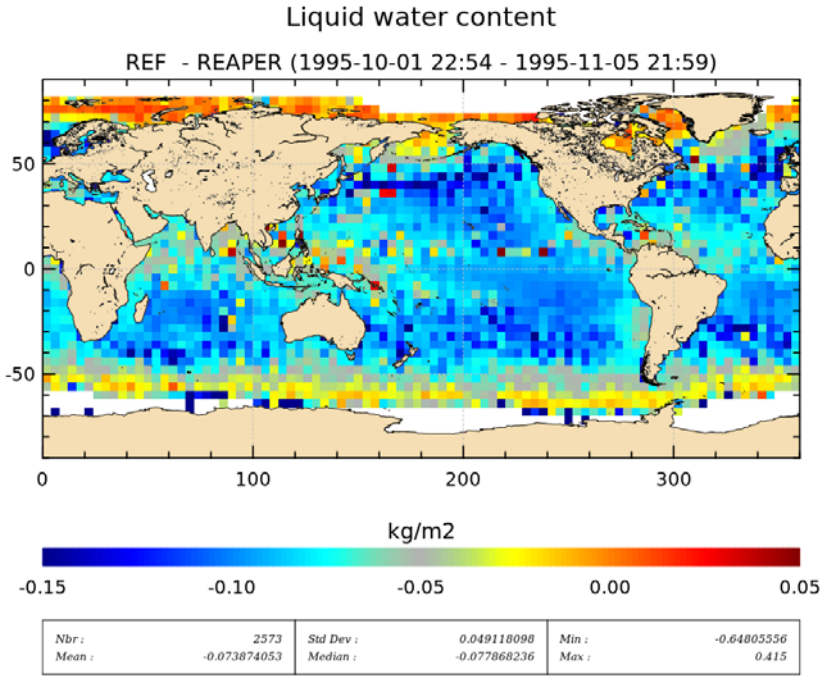



*Figure 38: map of box-average differences between OPR and REAPER liquid water content values*

A comparison with other satellite altimetry missions seems to indicate that regarding the liquid water content, REAPER brings an improvement over original OPR data.

### 5.3.4 Water vapor content

**Product field:** `water_vapor_content_1hz`

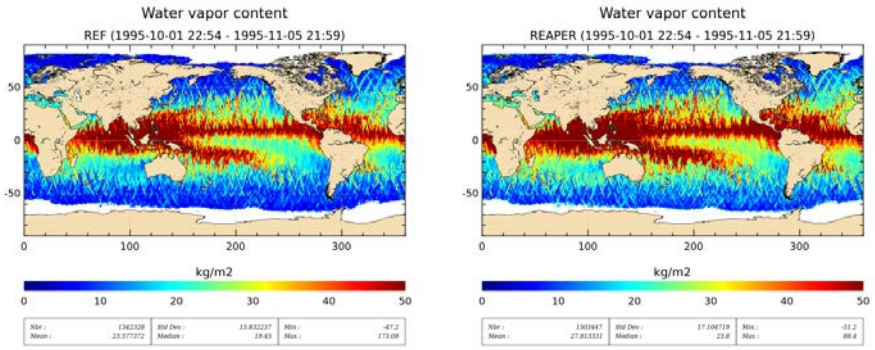



*Figure 39: maps of water vapor content from OPR (left) and REAPER (right) data*

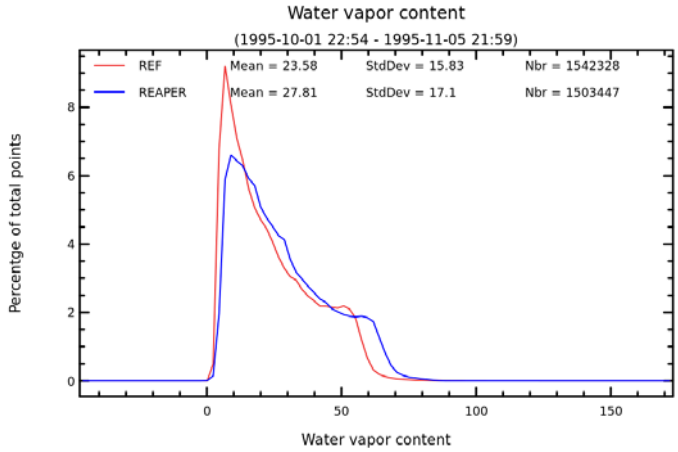



*Figure 40: histogram of water vapor content from OPR (red) and REAPER (blue) data*

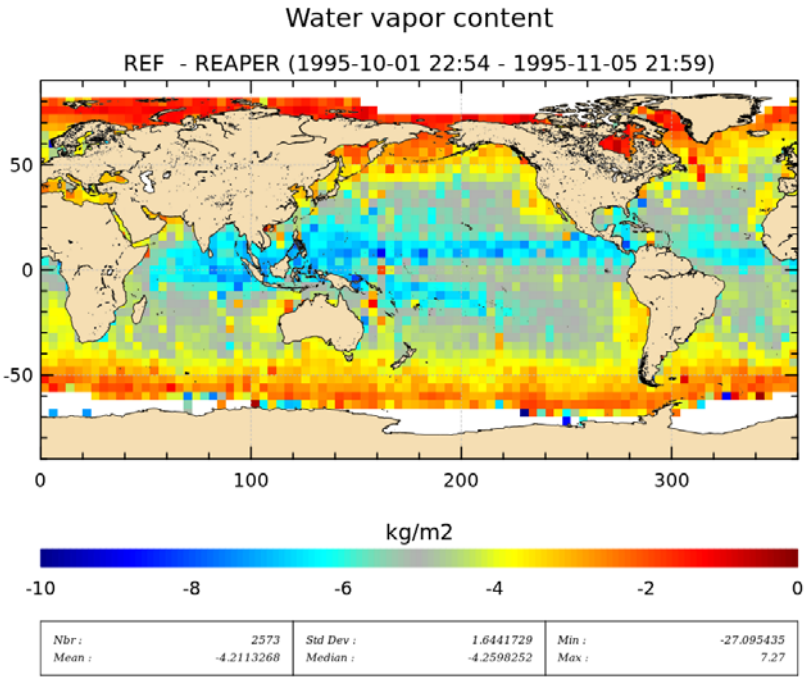



*Figure 41: map of box-average differences between OPR and REAPER water vapor content values*

A comparison with other satellite altimetry missions seems to indicate that regarding the water vapor content, REAPER brings an improvement over original OPR data.

### 5.3.5 Atmospheric attenuation of backscatter coefficient

**Product field:** `sig0_attn_c_1hz`

The atmospheric attenuation of the backscatter coefficient is significantly changed by the reprocessing, by almost 0.1dB, which explains around half of the shift observed on the backscatter coefficient itself. The geographic pattern appears to be physically consistent with higher attenuations observed in known rain areas.

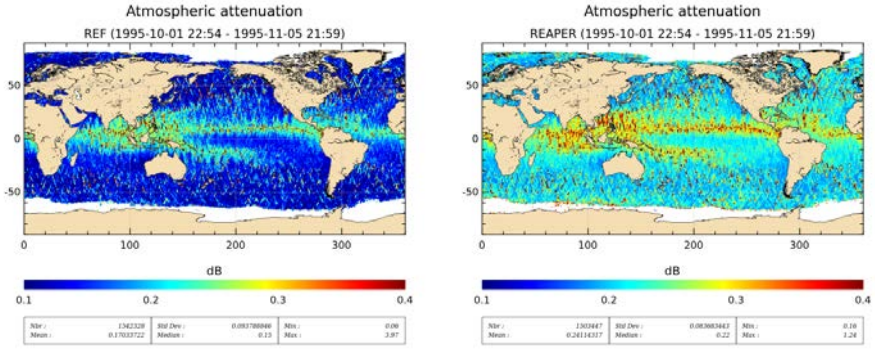



*Figure 42: maps of backscatter coefficient atmospheric attenuation from OPR (left) and REAPER (right) data*

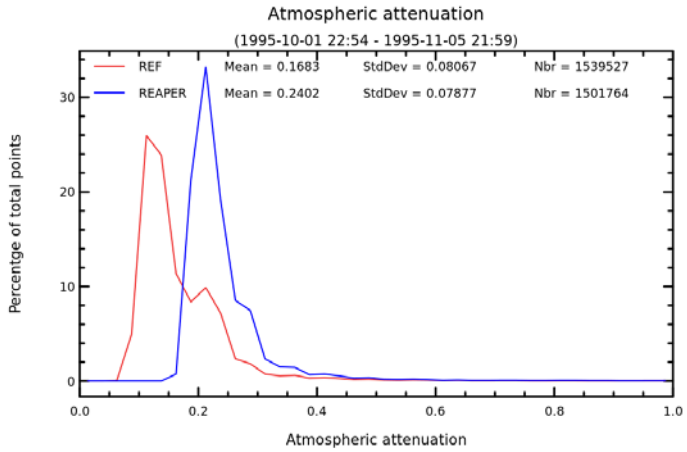



*Figure 43: histogram of backscatter coefficient atmospheric attenuation from OPR (red) and REAPER (blue) data*

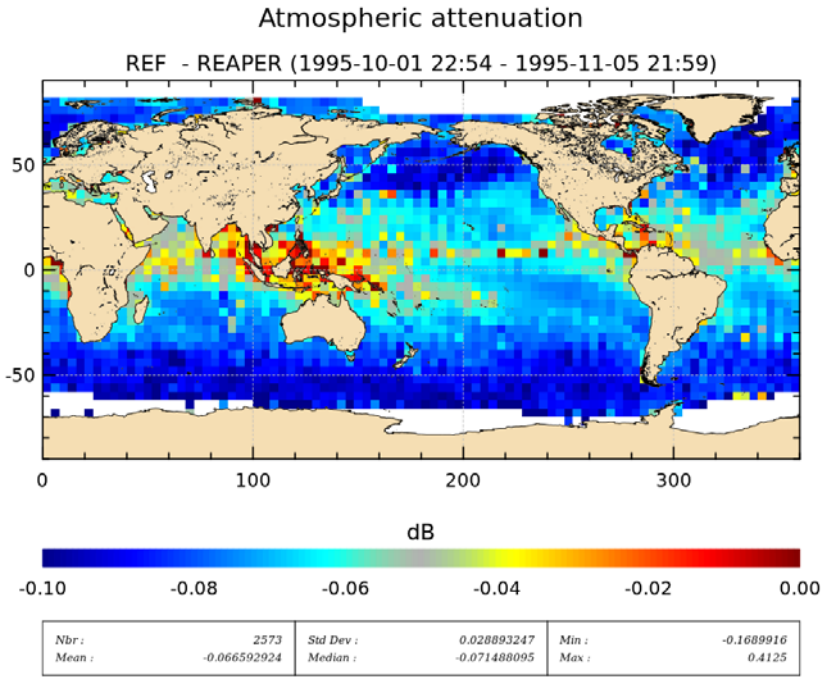



*Figure 44: map of box-average differences between OPR and REAPER sigma0 atmosp. att. Values*

A comparison with other satellite altimetry missions seems to indicate that regarding the atmospheric attenuation, REAPER brings an improvement over original OPR data.

## 5.4 Modeled parameters

For these comparisons between modelled parameters, we interpolated the model outputs to the time and position of REAPER measurements, so the comparisons are performed over the same data sample. In general, all the maps of along-track differences between REAPER product and CLS algorithms show some small scale "noise" due to the fact that REAPER fields are delivered at a 1 mm precision while we use a .1 mm precision in our algorithms.

### 5.4.1 Dry tropospheric correction

**Product field:** `dry_c_1hz`

Differences between the REAPER product modelled dry tropospheric correction and the one we re-interpolated are generally small over ocean. However the two histograms are similar, however the maps show that differences can be greater than 1 meter, but located in lakes or enclosed seas. These differences can be explained by processing differences: REAPER wet tropospheric correction does not account for the effect of S1 and S2 waves over lakes and enclosed seas, while our standard routines do. Our recommendation is to account for S1 and S2 waves over lakes and enclosed seas as well as over ocean.

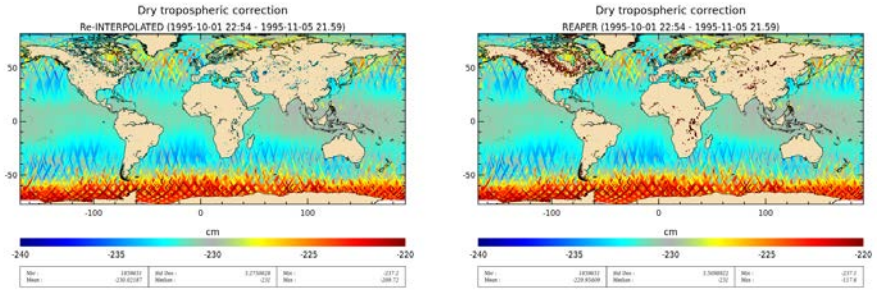



*Figure 45:maps of dry tropospheric correction from re-interpolated (left) and REAPER (right) data*

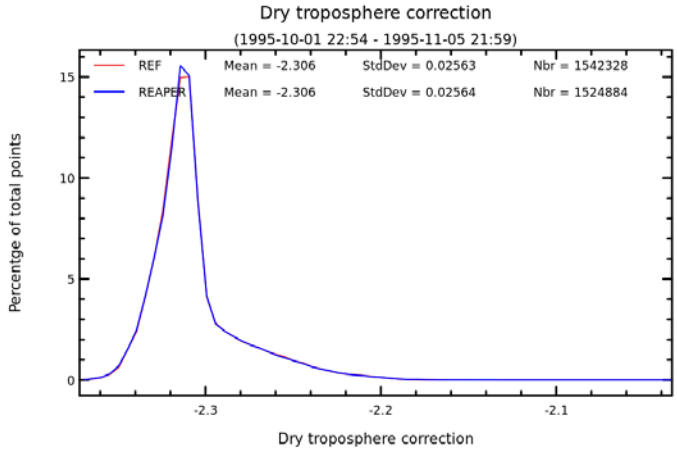



*Figure 46: histogram of dry tropospheric correction from re-interpolated (red) and REAPER (blue) data*

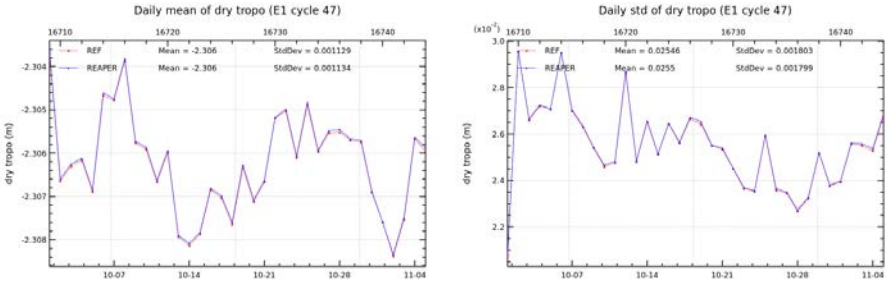



*Figure 47: Daily statistics (mean on left and standard deviation on right) for ERS-1 cycle 150 from re-interpolated (red) and REAPER (blue) dry tropospheric correction data*

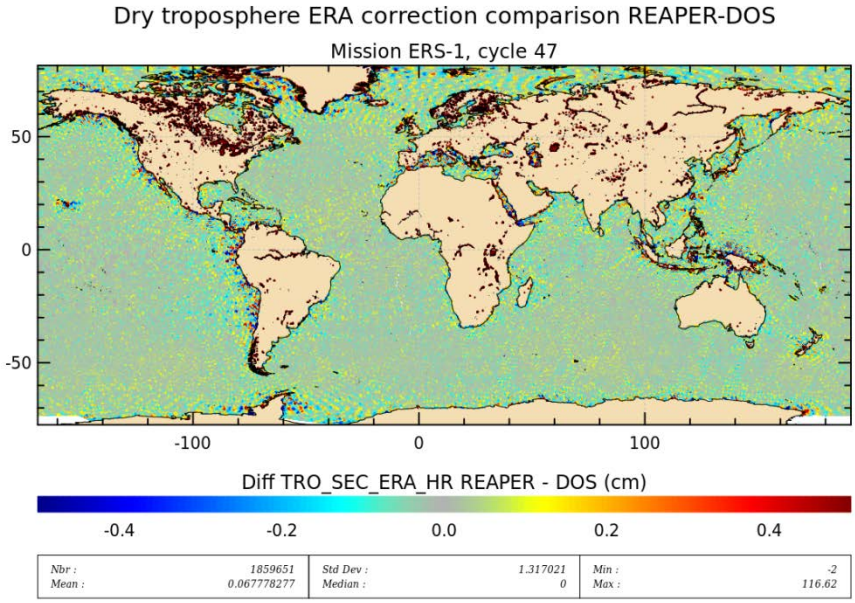



*Figure 48: map of along track differences between re-interpolated and REAPER dry tropospheric correction values*

## 5.4.2 Wet tropospheric correction

**Product field:** `wet_c_mod_1hz`
Differences between the REAPER product modelled wet tropospheric correction and the one we re-interpolated are not significant.

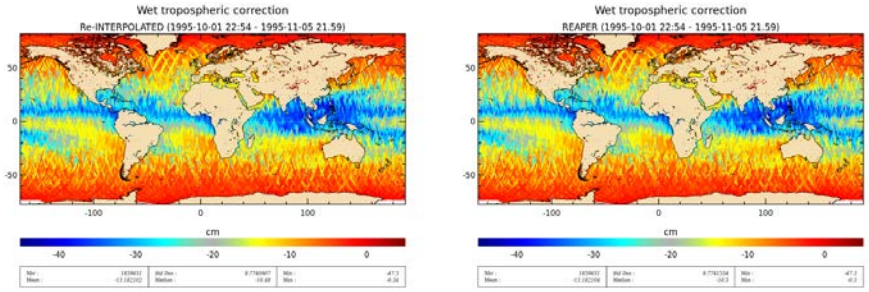



*Figure 49: maps of wet tropospheric correction from re-interpolated (left) and REAPER (right) data*

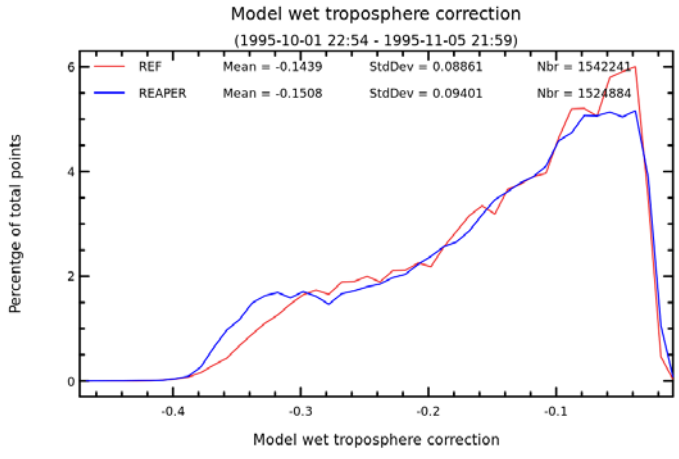


*Figure 50: histogram of wet tropospheric correction from re-interpolated (red) and REAPER (blue) data*

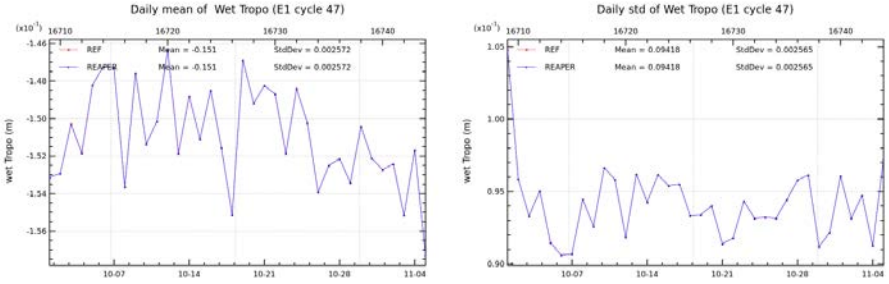



*Figure 51: Daily statistics (mean on left and standard deviation on right) for ERS-1 cycle 150 from re-interpolated (red) and REAPER (blue) wet tropospheric correction data*

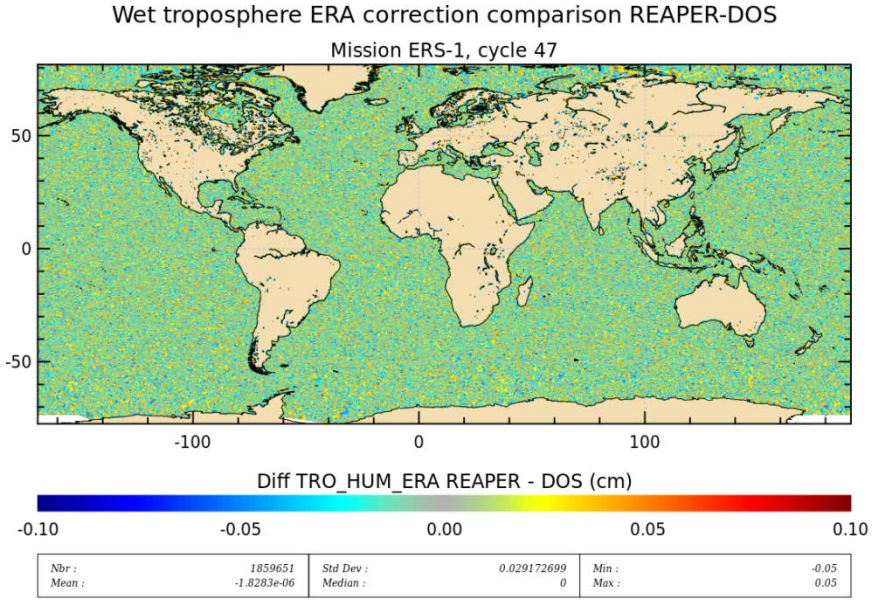



*Figure 52: map of along track differences between re-interpolated and REAPER wet tropospheric correction values*

### 5.4.3 Dynamic atmospheric correction

**Product field:** `mog2d_c_1hz`

Differences between the REAPER product dynamic atmospheric correction and the one we re-interpolated are not significant.

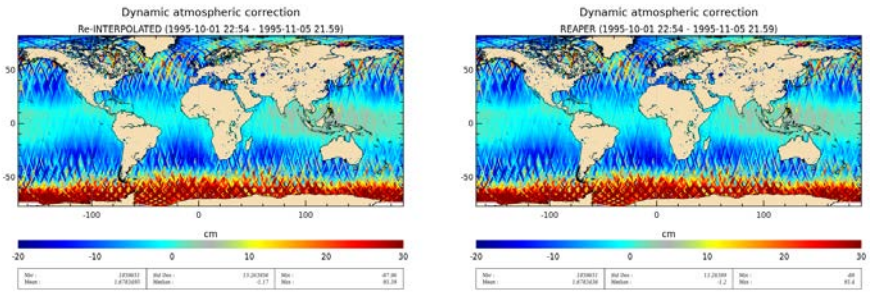


*Figure 53: maps of dynamic atmospheric correction from re-interpolated (left) and REAPER (right) data*

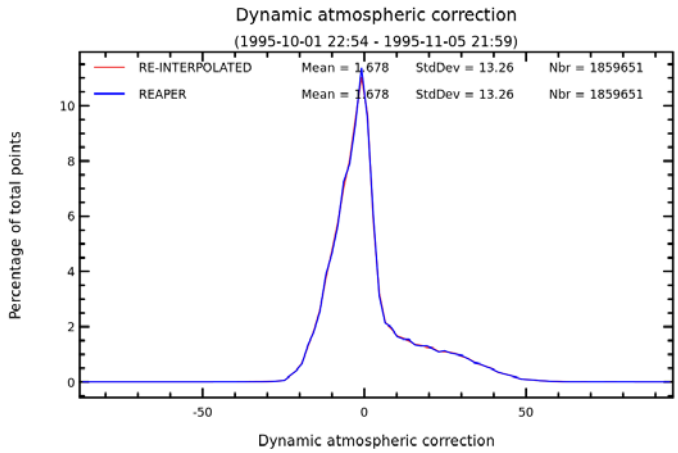



*Figure 54: histogram of dynamic atmospheric correction from re-interpolated (red) and REAPER (blue) data*

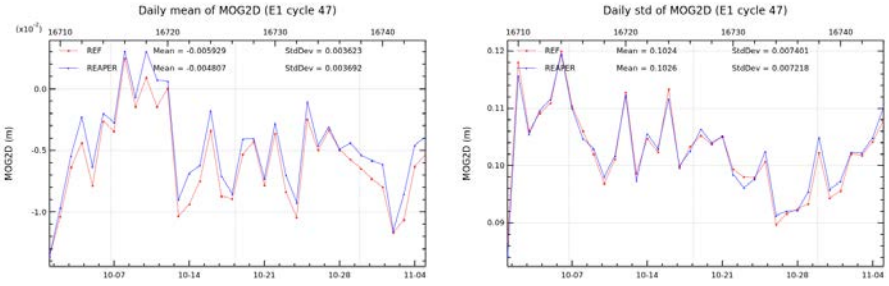



*Figure 55: Daily statistics (mean on left and standard deviation on right) for ERS-1 cycle 150 from re-interpolated (red) and REAPER (blue) dynamic atmospheric correction data*

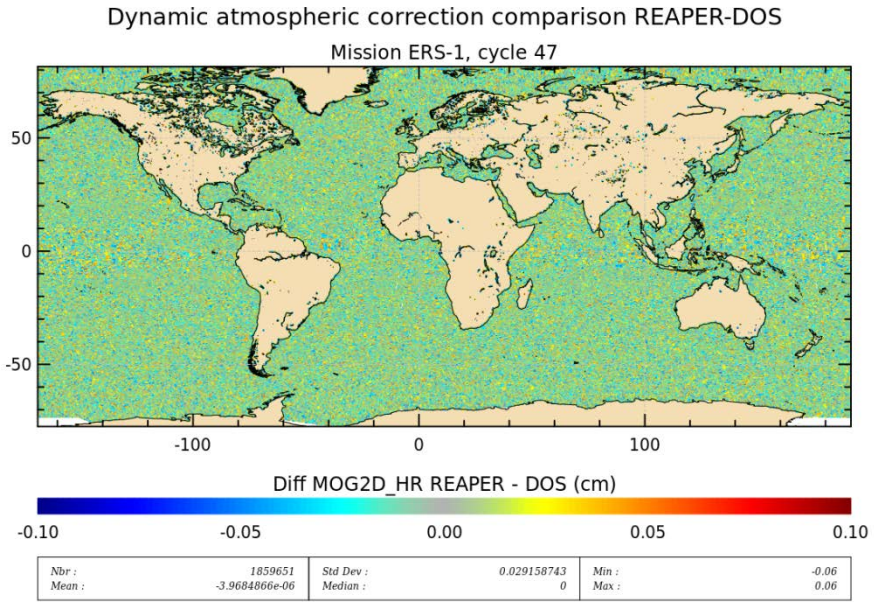



*Figure 56: map of along track differences between re-interpolated and REAPER dynamic atmospheric correction values*

### 5.4.4 Model wind speed

**Product field:** `u_wind_1hz` and `v_wind_1hz`

Differences between the REAPER product model wind speed and the one we re-interpolated are not significant.

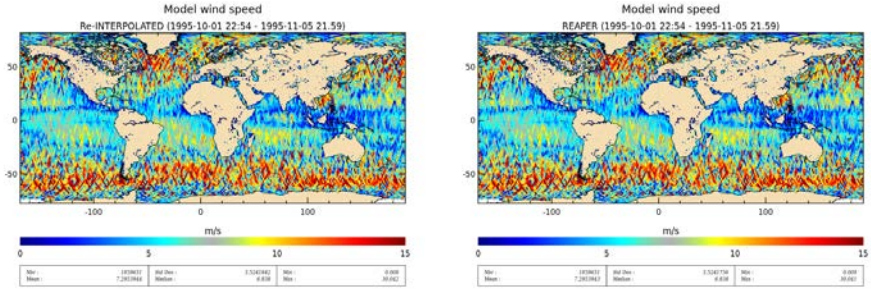



*Figure 57: maps of model wind speed from re-interpolated (left) and REAPER (right) data*

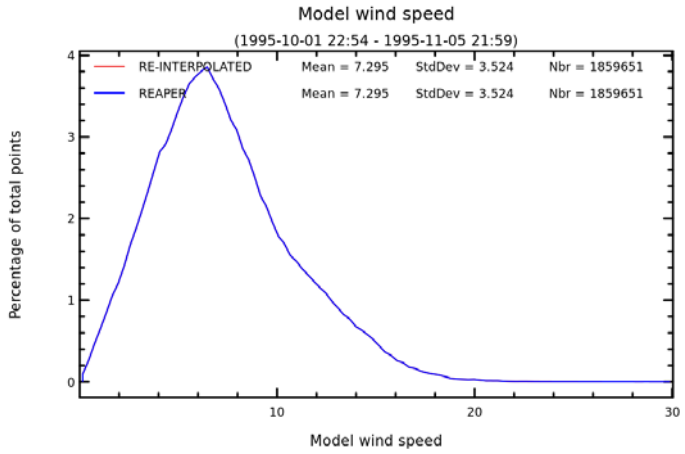



*Figure 58: histogram of model wind speed from re-interpolated (red) and REAPER (blue) data*

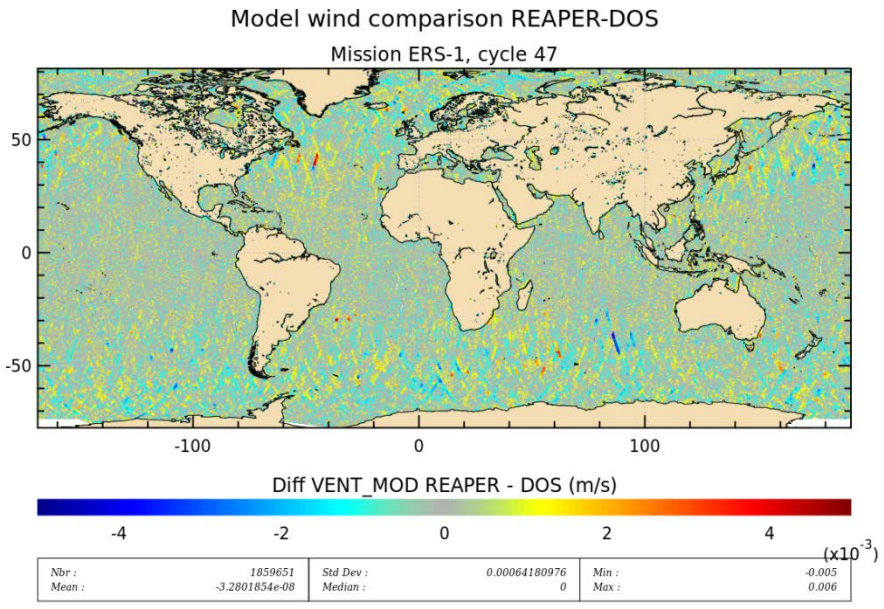



*Figure 59: map of along track differences between re-interpolated and REAPER model wind speed values*

### 5.4.5 Modeled ionospheric correction

**Product field:** `iono_c_gps_1hz`

The GIM ionospheric correction is not available for this cycle of ERS-1 data. However, the product field `iono_c_gps_1hz` is set to 0. It would be better to set the attribute `_FillValue` to this variable and set the values accordingly.

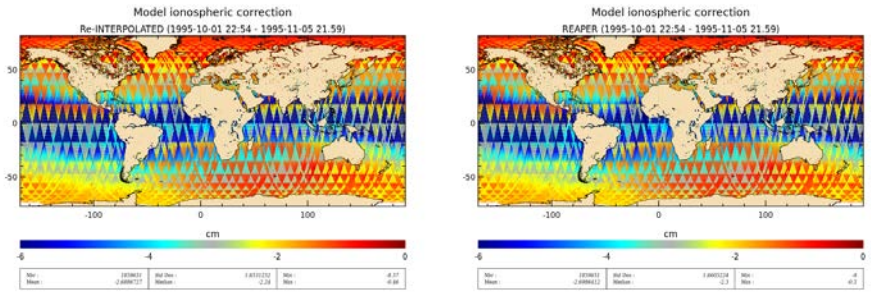



*Figure 60: maps of model ionospheric correction from re-interpolated (left) and REAPER (right) data*

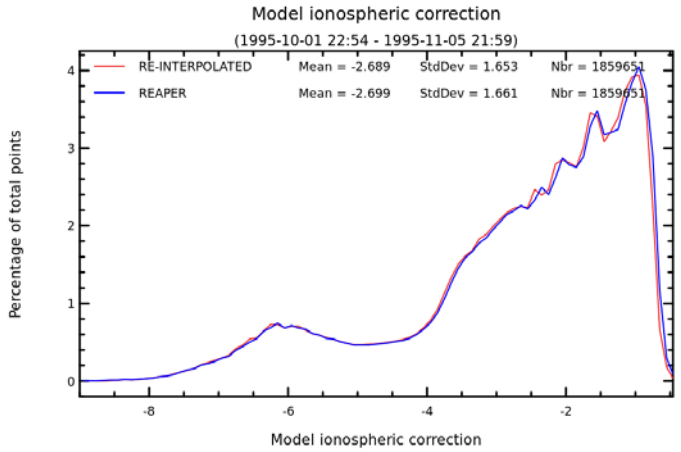



*Figure 61: histogram of model ionospheric correction from re-interpolated (red) and REAPER (blue) data*

Despite similar maps and histograms (see Figure 60 and Figure 61) the map of the differences between the product's ionospheric correction and the one estimated from the NIC09 model shows several tracks and track sections where differences are important (up to 8 mm, see Figure 62). Extracting one of these tracks (numbered 978 crossing the western Pacific Ocean) shows to effects (Figure 63): a quantification effect due to the millimetric precision used in REAPER products, and different shapes of the the ionospheric correction. It is unclear from the product specification document which model was used to estimate the ionospheric correction so we cannot guarantee that NIC09 is the best reference to compare with.

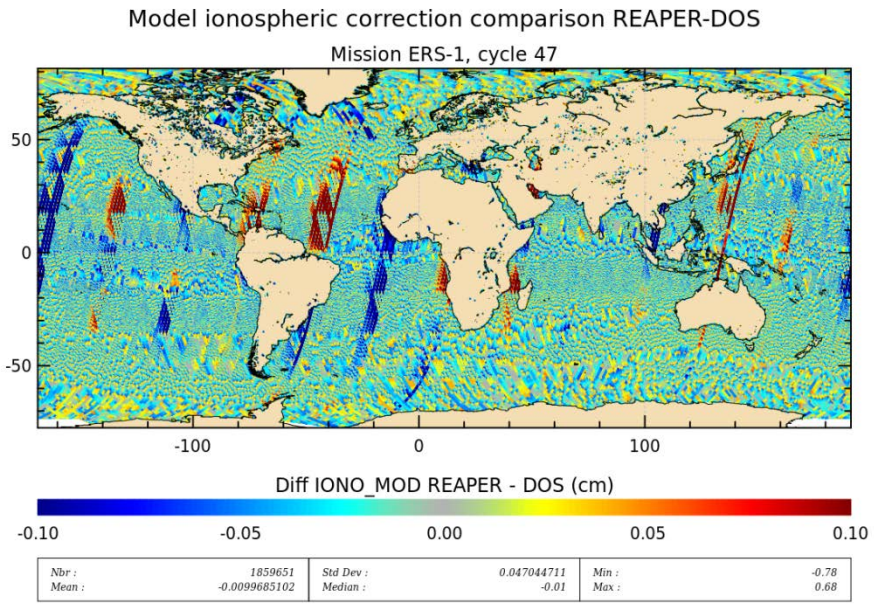



*Figure 62: map of along track differences between re-interpolated and REAPER modeled ionospheric correction values*

Focus on the pass 978 (red pass crossing Australia and east of Japan):

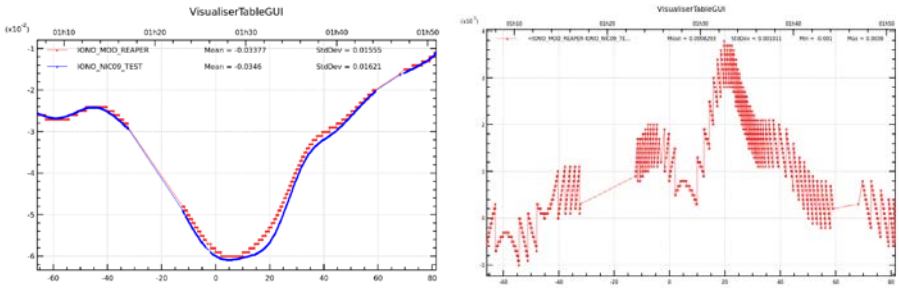



*Figure 63: Times series of re-interpolated and REAPER modeled ionospheric correction (left) and difference of both ionospheric correction (right) for ERS-1 cycle 150 pass 978 along latitude*

## 5.4.6 Mean sea surface

**Product field:** `h_mss_cls01_1hz`

The REAPER products are delivered with the MSS CLS01 mean sea surface model, as long as newer (and improved) mean sea surfaces are available, I would suggest to deliver the product with a more up-to-date mean sea surface model, to match other missions standards. The daily statistics show no important differences between the product MSS and the one we re-interpolated at the position of REAPER data (Figure 66), However, the map of the differences (Figure 67) displays iso-latitude bands where differences amount to 1.5 mm. These differences remain small and come from different the resolution of the data used (REAPER uses a millimetric precision while our algorithms use .1 millimeter precision).

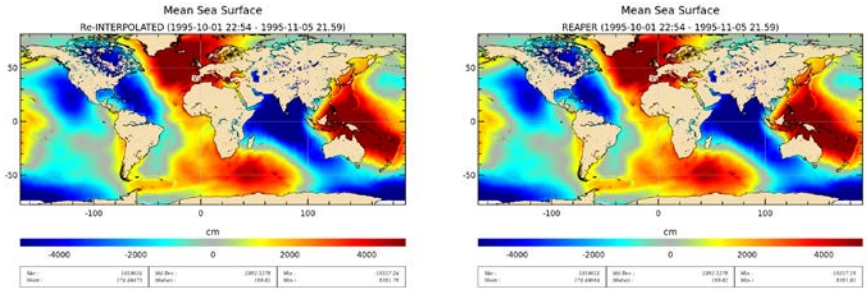



*Figure 64: maps of mean sea surface from re-interpolated (left) and REAPER (right) data*

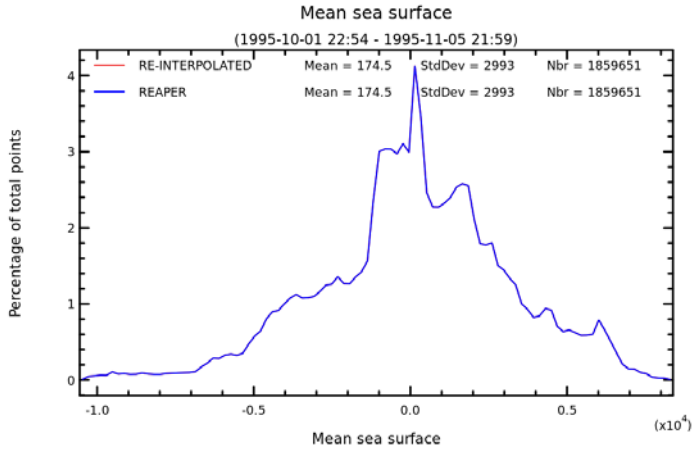



*Figure 65: histogram of mean sea surface from re-interpolated (red) and REAPER (blue) data*

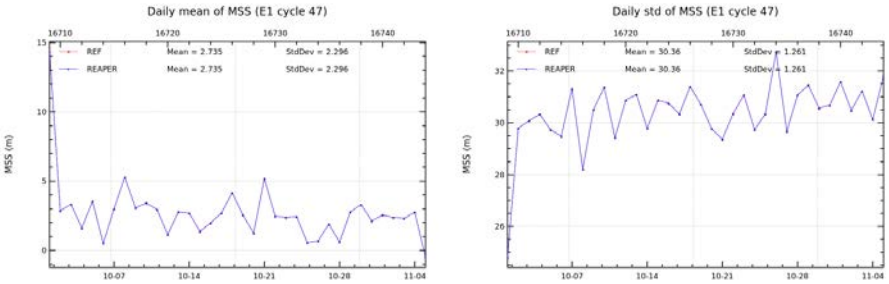



*Figure 66: Daily statistics (mean on left and standard deviation on right) for ERS-1 cycle 150 from re-interpolated (red) and REAPER (blue) mean sea surface data*

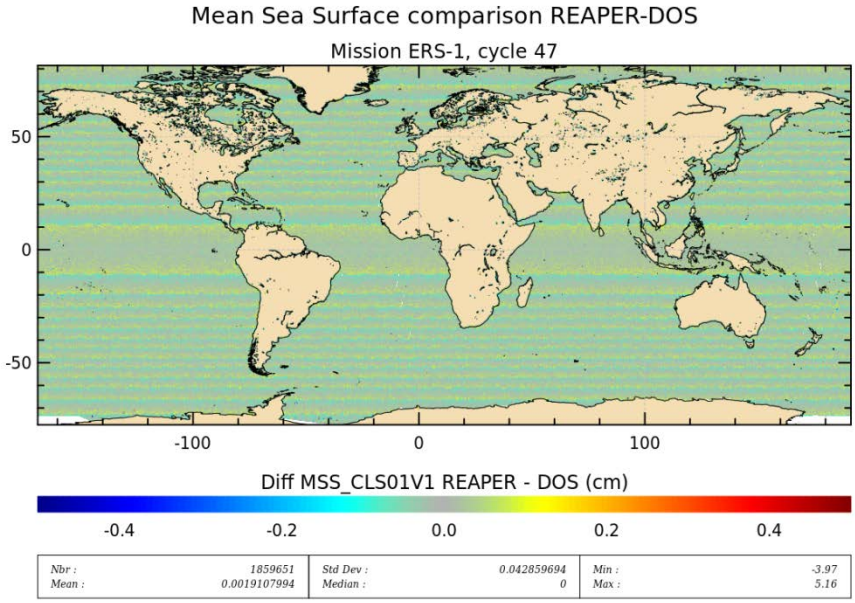



*Figure 67: map of along track differences between re-interpolated and REAPER mean sea surface values*

### 5.4.7 Ocean tide GOT4V7

**Product field:** `h_ot_1hz`

The product specification document defines this as the component of the total ocean tide to be added to the range to remove the effect of local tide. The same document further states that the "OT+OLT" tidal corrections should be used over ocean surfaces. These two indications suggest that the `h_ot_1hz` field of the product contains only the ocean tide, without any loading tide. The comparisons performed here suggest that the the field h_ot_1hz contains the sum of ocean and load tides, therefore only this field should be used to correct the range from tidal effects.
REAPER code produces and ocean tide estimate which is the sum of the ocean tide, the load tide and the long period equilibrium tide.
This is not a contradiction with the recipe used to estimate the SLA on p. 44 of the product specification document but rather a mistake when translating this formula into REAPER product fields. The recipe used in the code should at least be corrected, and this should be clarified in the product specification document. However our recommendation is to deliver to end-users a range corrected for instrumental effects but not for geophysical effects.

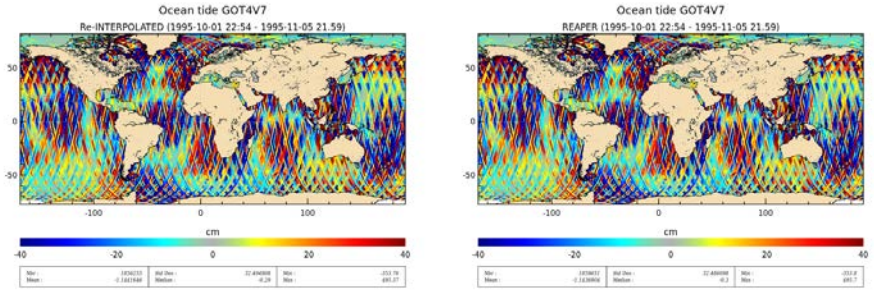


*Figure 68: maps of ocean tide GOT4V7 from re-interpolated (left) and REAPER (right) data*

We re-interpolated GOT4.7 tide solution using in-house algorithms (Figure 68, left) at REAPER data time and position. This algorithm computes not only the ocean tide but the sum of ocean and load tides. The two maps of Figure 68 are very similar, which is confirmed by the histogram comparing the two corrections (Figure 69) and the map of the differences (Figure 71) between them. This validates the GOT4.7 sum of ocean and load tide distributed in REAPER products.
Again, some quantification effects are present due to the millimetric precision used for this field in the REAPER product.

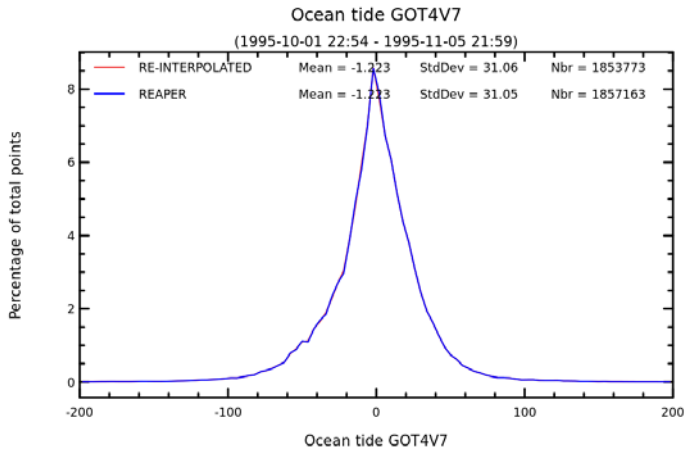



*Figure 69: histogram of ocean tide GOT4V7 from re-interpolated (red) and REAPER (blue) data*

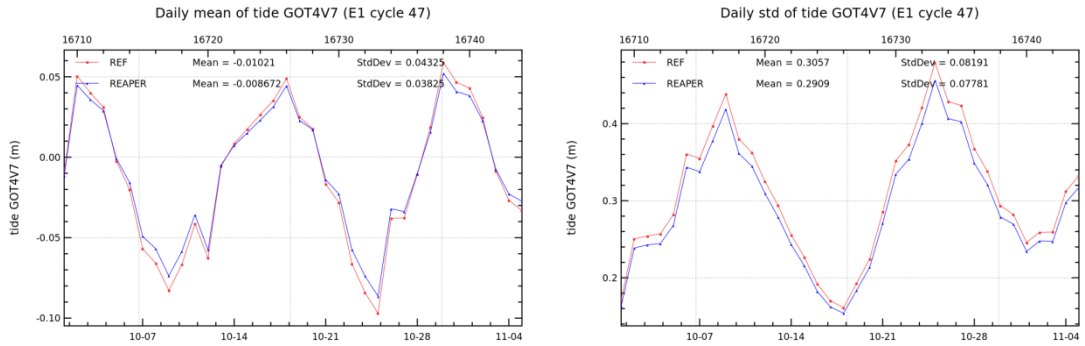



*Figure 70: Daily statistics (mean on left and standard deviation on right) for ERS-1 cycle 150 from re-interpolated (red) and REAPER (blue) tide GOT4V7 data*

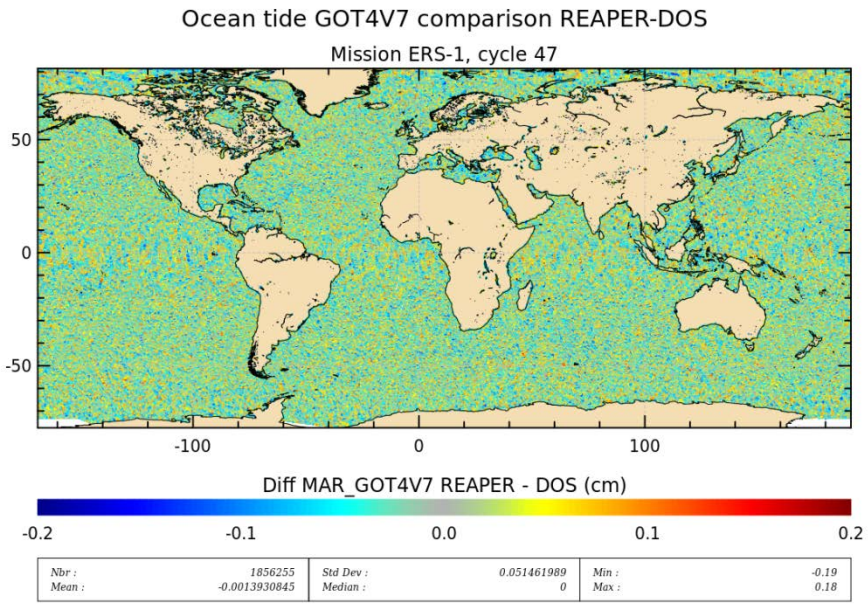



*Figure 71: map of along track differences between re-interpolated and REAPER ocean tide GOT4V7 values*

## 5.4.8 Load tide GOT4V7

**Product field:** `h_olt_1hz`

Here we investigate the load tide independently from the ocean tide. The comparison with between GOT4.7 load tide distributed in the product and the load tide estimated from the same model using in-house algorithms shows no significant differences.

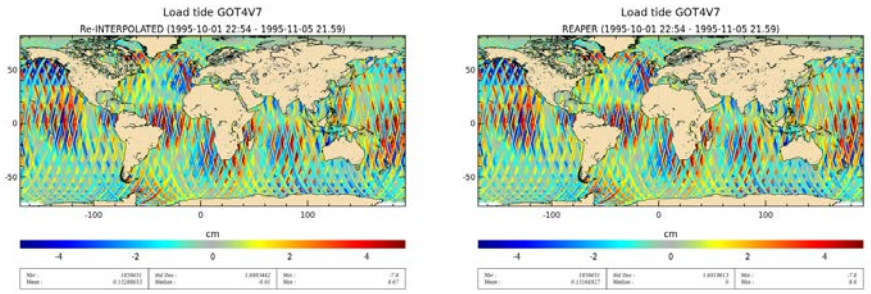



*Figure 72: maps of load tide GOT4V7 from re-interpolated (left) and REAPER (right) data*

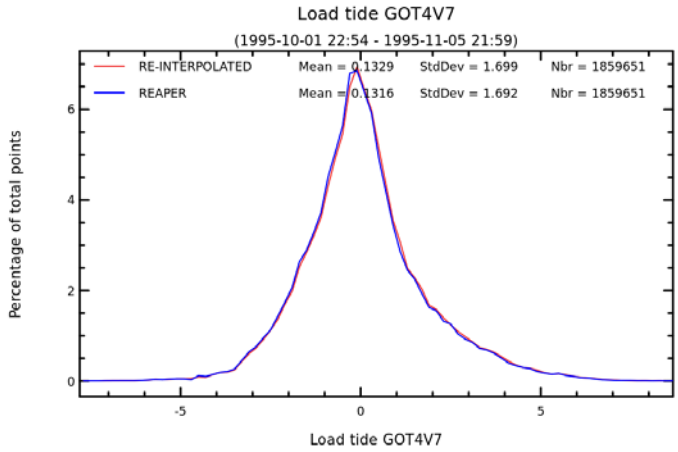



*Figure 73: histogram of load tide GOT4V7 from re-interpolated (red) and REAPER (blue) data*

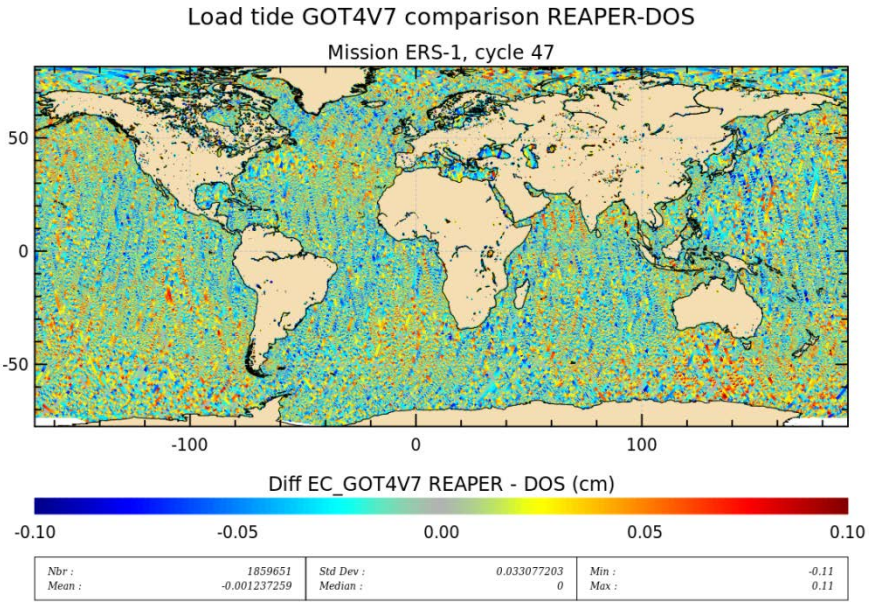



*Figure 74: map of along track differences between re-interpolated and REAPER load tide GOT4V7 values*

### 5.4.9 Ocean tide FES04

**Product field:** `h_ot2_1hz`

We perform the same comparison with the second tide model distributed in the REAPER product (FES04). In fact the product specification document states that this field contains the FES2008 model, while the L2 DPM document states that FES2004 is used, here we assumed this field contains FES2004 model results.
The same conclusions than with the GOT4.7 model can be drawn: this product field seems to contain the sum of ocean and load tides rather than the ocean tide alone.
Differences between the sum of FES04 ocean and load tide distributed in REAPER products and the one we estimated from the same model using in-house algorithms are

larger than when considering GOT4.7 model. They can reach up to 3 cm especially in the Arctic Ocean.

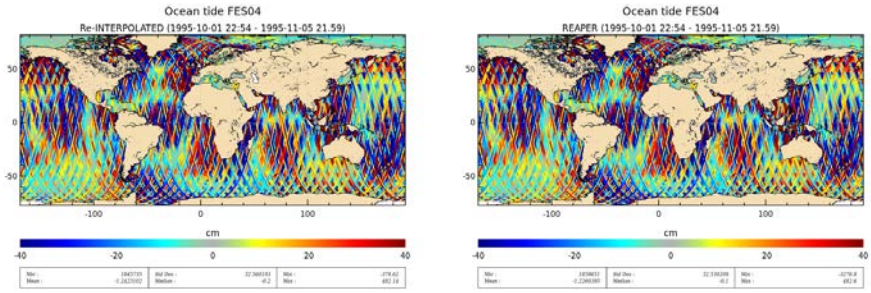



*Figure 75: maps of ocean tide FES04 from re-interpolated (left) and REAPER (right) data*

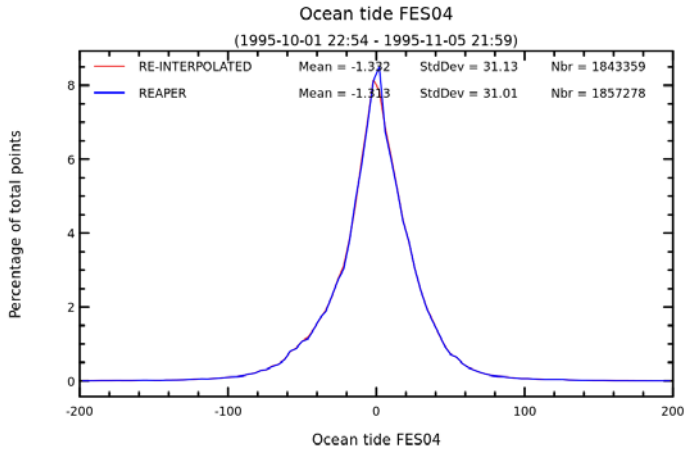



*Figure 76: histogram of ocean tide FES04 from re-interpolated (red) and REAPER (blue) data*

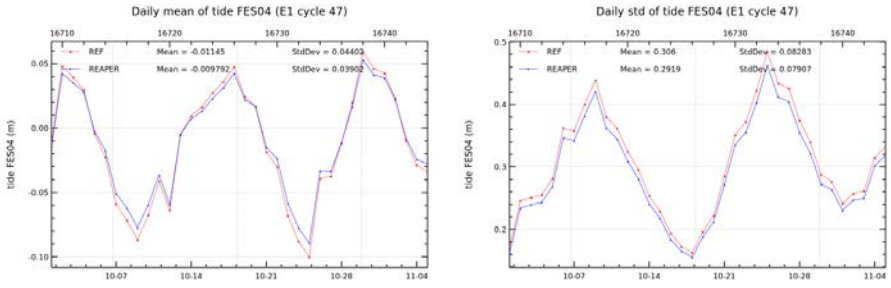



*Figure 77: Daily statistics (mean on left and standard deviation on right) for ERS-1 cycle 150 from re-interpolated (red) and REAPER (blue) tide FES04 data*

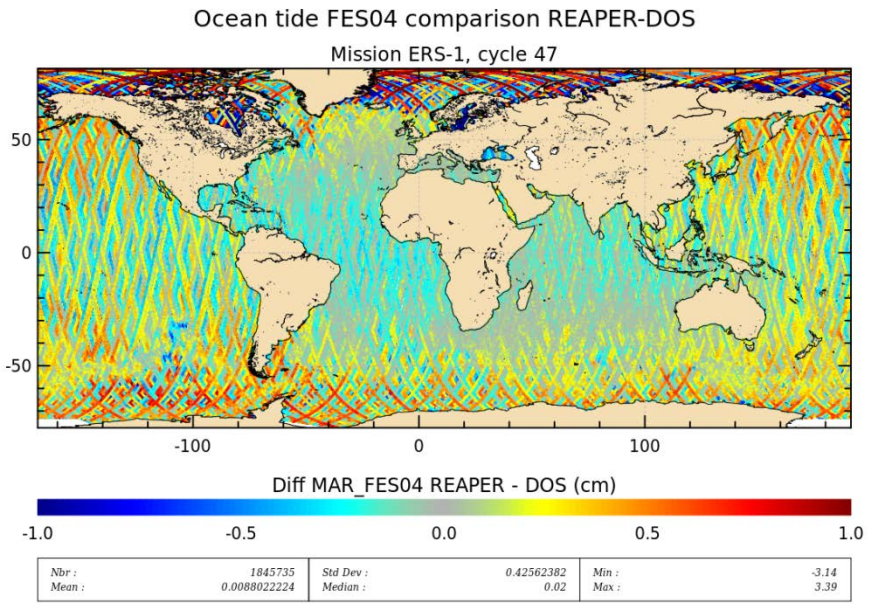



*Figure 78: map of along track differences between re-interpolated and REAPER ocean tide FES04 values*

## 5.4.10 Load tide FES04

**Product field:** `h_olt2_1hz`

Here we investigate the load tide independently from the ocean tide. The comparison with between FES04 load tide distributed in the product and the load tide estimated from the same model using in-house algorithms shows no significant differences.

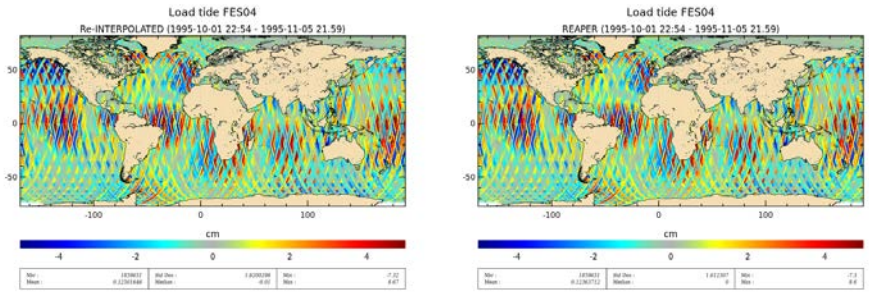



*Figure 79: maps of load tide FES04 from re-interpolated (left) and REAPER (right) data*

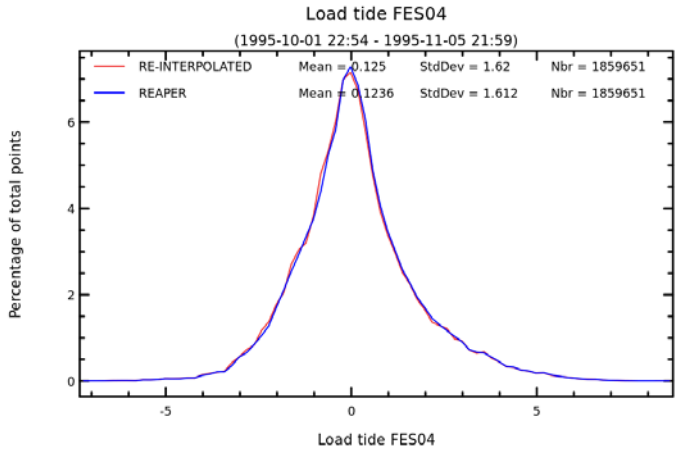



*Figure 80: histogram of load tide FES04 from re-interpolated (red) and REAPER (blue) data*

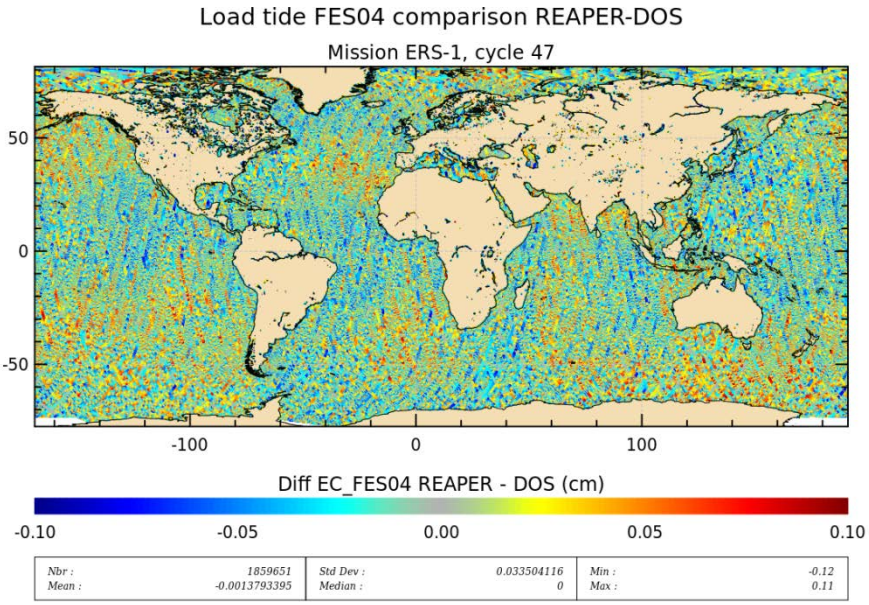



*Figure 81: map of along track differences between re-interpolated and REAPER load tide FES04 values*

### 5.4.11 Earth tide

**Product field:** `h_set_1hz`

Regarding the solid earth tide, there are no significant differences between the product earth tide and the one calculated by our algorithms.

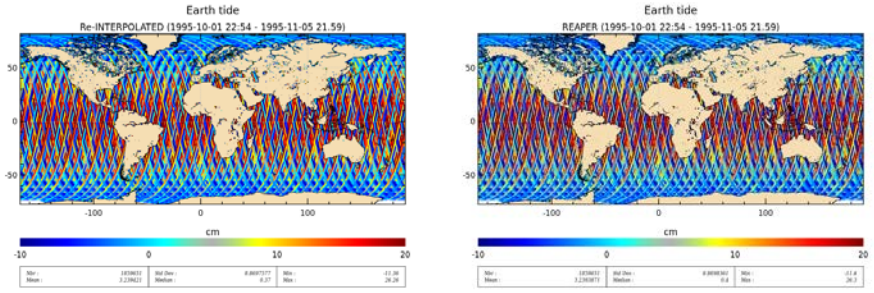



*Figure 82: maps of earth tide from re-interpolated (left) and REAPER (right) data*

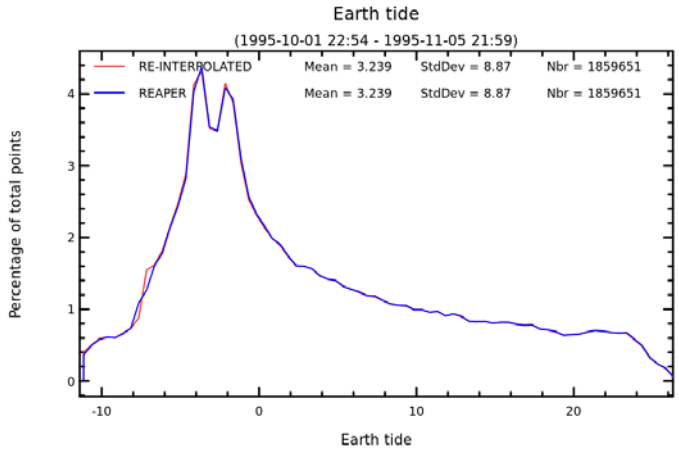



*Figure 83: histogram of earth tide from re-interpolated (red) and REAPER (blue) data*

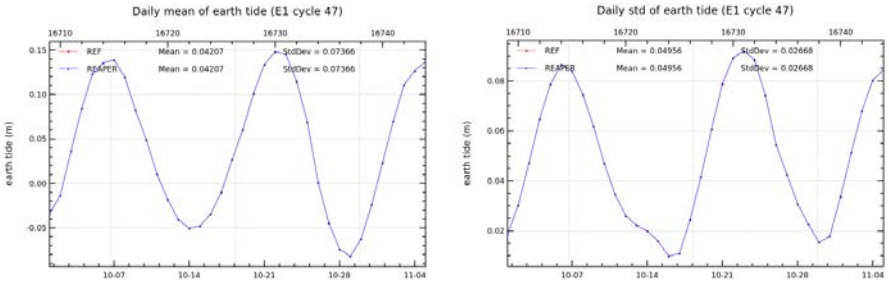



*Figure 84: Daily statistics (mean on left and standard deviation on right) for ERS-1 cycle 150 from re-interpolated (red) and REAPER (blue) earth tide data*

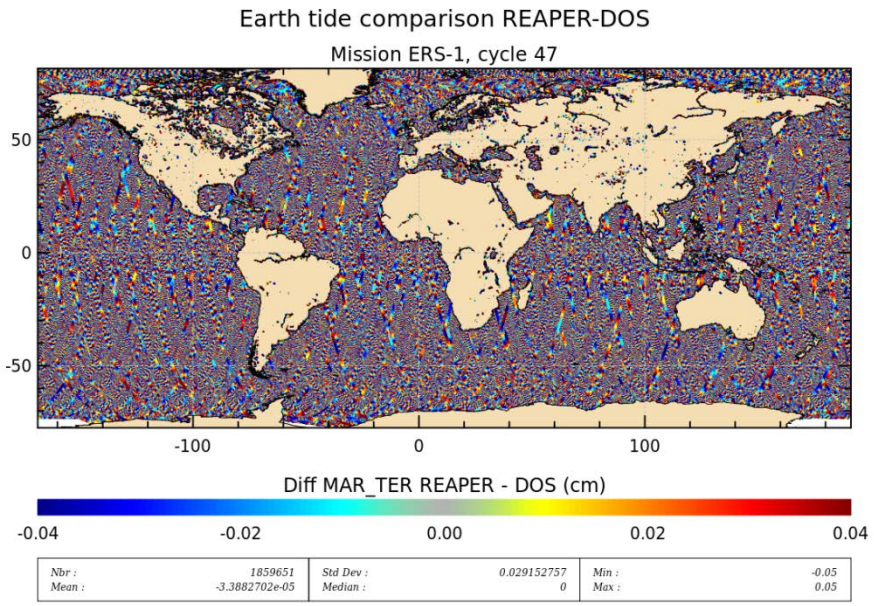



*Figure 85: map of along track differences between re-interpolated and REAPER earth tide values*

## 5.4.12 Pole tide

**Product field:** `h_pol_1hz`

Regarding the pole tide, there are no significant differences between the product pole tide and the one calculated by our algorithms.

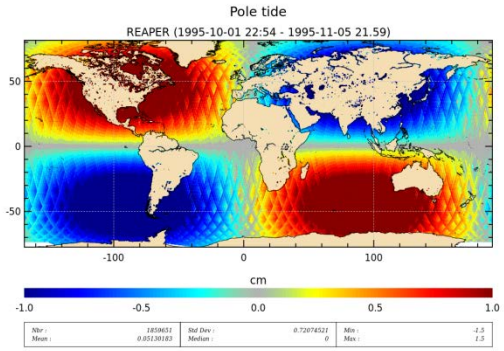



*Figure 86: maps of pole tide from re-interpolated (left) and REAPER (right) data*

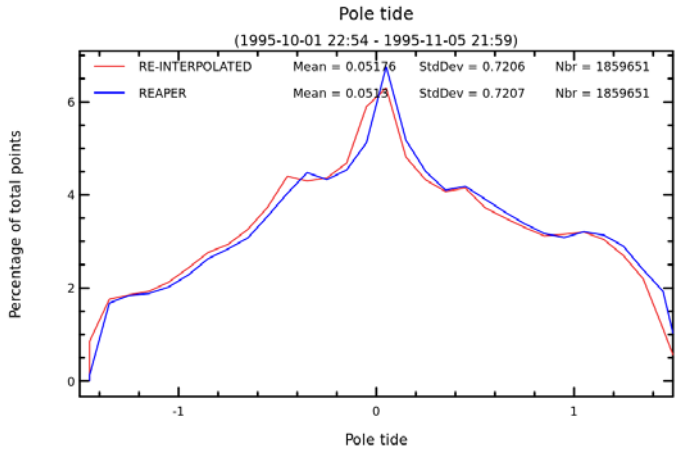



*Figure 87: histogram of pole tide from re-interpolated (red) and REAPER (blue) data*

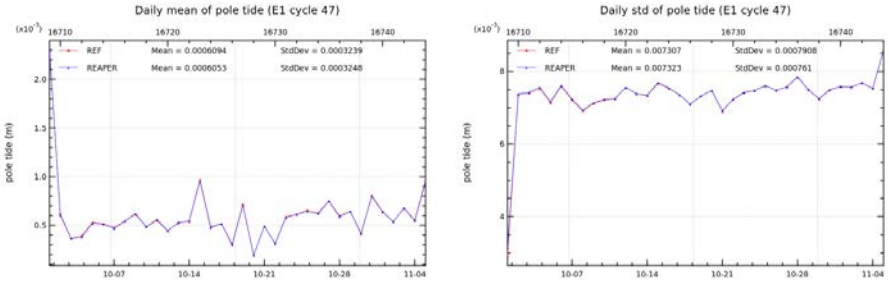



*Figure 88: Daily statistics (mean on left and standard deviation on right) for ERS-1 cycle 150 from re-interpolated (red) and REAPER (blue) pole tide data*

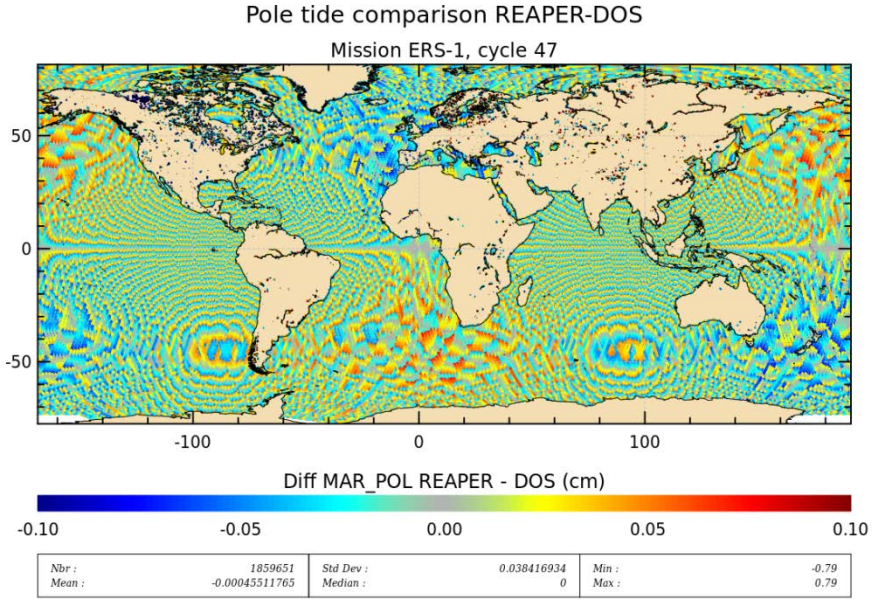



*Figure 89: map of along track differences between re-interpolated and REAPER pole tide values*

# 6 Cross-Over Analysis

Analysis of SSH differences at cross-overs is a useful tool to evaluate the global performance of satellite altimeter data. Only valid data are used to estimate cross-overs and time differences lower than 10 days only are considered. Global statistics are estimated over a sub-sample of the whole cross-overs population, we only select cross-overs where:

- Bathymetry is deeper than -1000 m (2),
- Latitude is less than 50°
- Oceanic variability is low

For this analysis, we estimate the sea surface height as:

*SSH = Orbit – range – earth tide – pole tide – ocean elastic tide – ocean load tide – long period equilibrium tide – dynamic atmospheric correction – dry tropospheric correction – wet tropospheric correction – ionospheric correction – sea state bias*

Where the ocean tide model GOT 4V7 is used. In the COM6 version of the REAPER products, the load and equilibrium tides are not included in the ocean tide GOT 4V7 field. Consequently, the sea surface height for REAPER will be (translated into REAPER product field names):

*SSH_REAPER* = `altitude_1hz - ocean_range_1hz - h_set_1hz - h_pol_1hz - h_ot_1hz – h_olt_1hz – h_lpt_1hz - mog2d_c_1hz - dry_c_1hz - wet_c_mwr_1hz - iono_c_mod_1hz - em_bias_1hz`

It should be noted that, in this section, when REAPER data are compared to the OPR product (especially for standard deviation of SSH differences at crossovers), we use our current best for ERS-1 and ERS-2 as a reference, not the historical OPR performance.

## 6.1 Maps of mean differences

Figure 90 displays the spatial distribution of mean SSH differences at crossovers for ERS-1 and ERS-2 estimated from REAPER COM6 data over the first ten cycles of ERS-2. Both maps show a strong hemispheric pattern which points toward a remaining time-tag bias in the data.

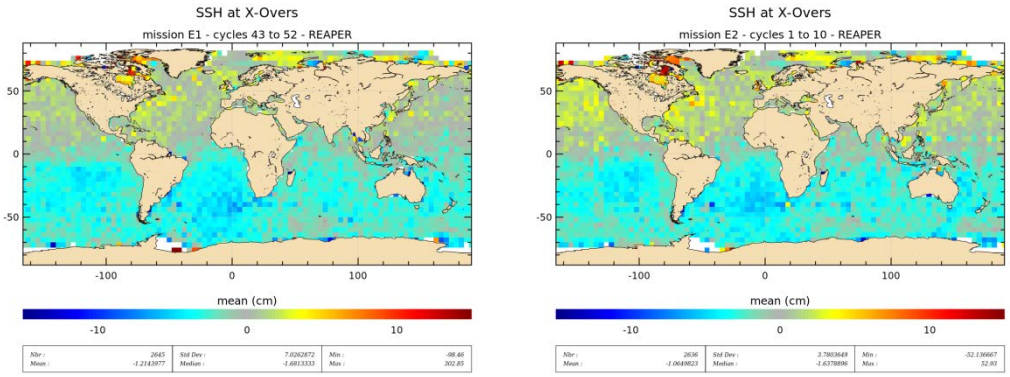



*Figure 90: map of the mean of SSH differences at crossovers for ERS-1 (left) and ERS-2 (right) estimated from REAPER COM6 data over the first 10 cycles of ERS-2*

Correcting for a 0.6 ms pseudo time tag bias in ERS-1 data and for 0.5 ms in ERS-2 data leads to the maps of mean SSH differences displayed on Figure 91. The maps are much more spatially homogeneous and the hemispheric pattern is efficiently corrected. Small differences

remain and the two maps show similar patterns with a negative bias in the southern Atlantic Ocean and the Eastern tropical Pacific Ocean.

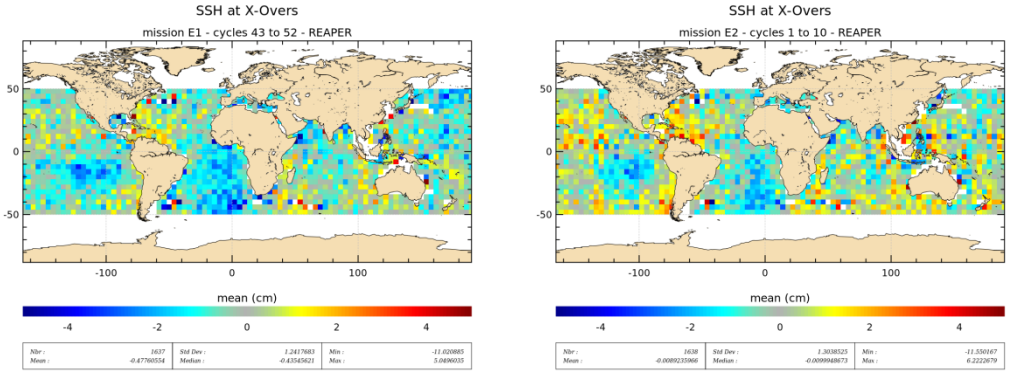



*Figure 91: map of the mean of SSH differences at crossovers for ERS-1 (left) and ERS-2 (right) estimated from REAPER COM6 data over the first 10 cycles of ERS-2 after correcting for the pseudo time tag bias.*

Over the same period we also estimate a map of standard deviation of SSH differences at cross-overs which are displayed on Figure 92. The two maps are very similar and do not show anomalous patterns of high standard deviation.

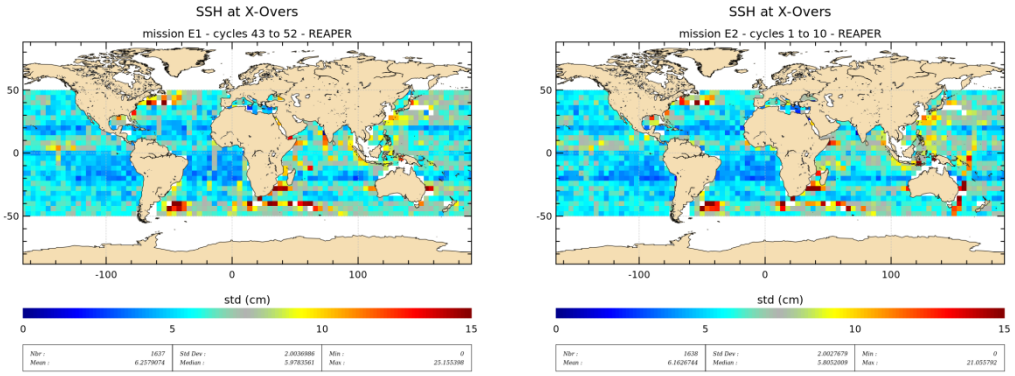



*Figure 92: map of the standard deviation of SSH differences at crossovers for ERS-1 (left) and ERS-2 (right) REAPER COM6 data estimated over the first 10 cycles of ERS-2*

## 6.2 Time series

Monitoring the mean and standard deviation of SSH differences is a way to evaluate the mission performance over time. Figure 93 displays the temporal evolution of the standard deviation of global SSH differences, which is the main indicator for mission performance. For this analysis, we use the same geographical selection as above.

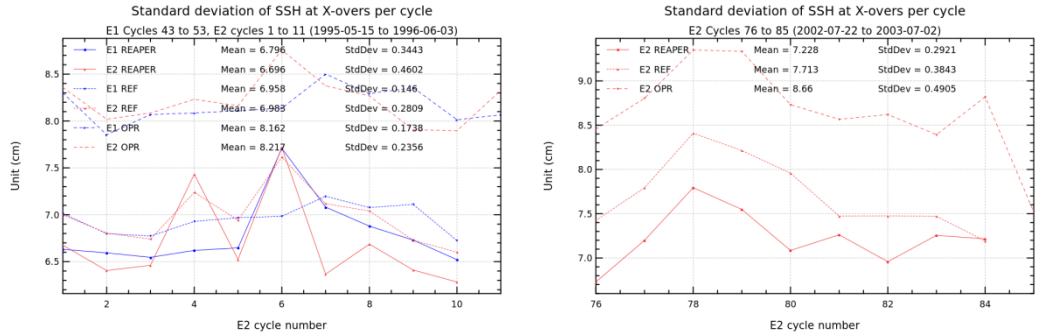



*Figure 93: temporal evolution of the standard deviation of SSH differences at crossovers for latitudes below 50°, bathymetry greater than 1000 m and low oceanic variability areas. The statistic is estimated from historical OPR, our current best estimate (updated OPR) and REAPER data.*

Clearly REAPER data provides a better performance than original OPR data, and a better performance than our current best estimate, except for 2 cycles. Over ten cycles of the verification phase between ERS-1 and ERS-2, the mean standard deviation is around 6.7 cm for REAPER data for both missions, which has to be compared to 8.2 cm for historical OPR data and 7 cm for updated OPR data. For ERS-2 over cycles 76 to 84, the standard deviation at crossovers is a bit higher with 7.2 cm for REAPER data and 8.7 cm for OPR data (7.7 cm for updated OPR data).

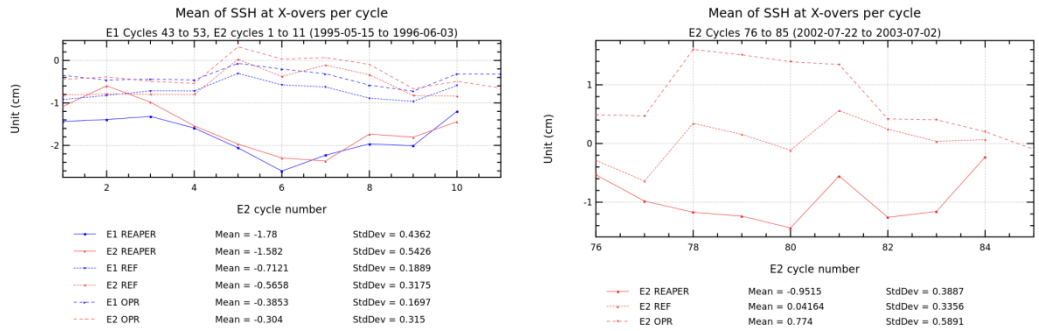
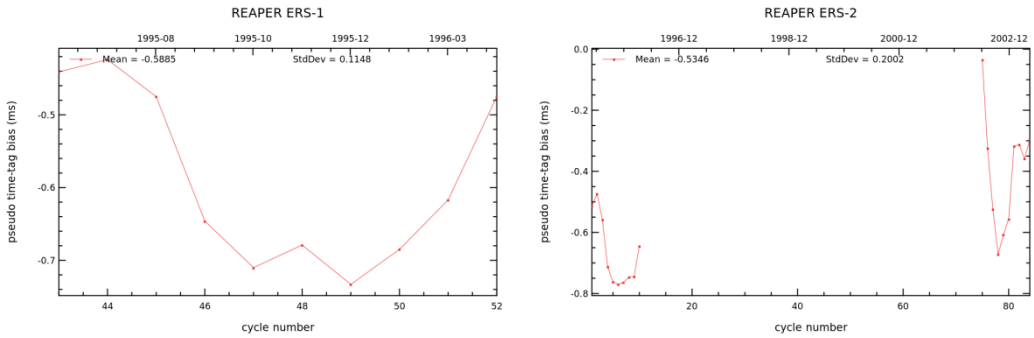



*Figure 94: temporal evolution of the mean of SSH differences at crossovers for latitudes below 50°, bathymetry greater than 1000 m and low oceanic variability areas.*

Figure 94 displays the mean of SSH differences using the same selection as above for ERS-1 and ERS-2. This value is slightly more negative for REAPER data than for original and updated OPR data, and shows a larger variability over the period considered here.

## 6.3 Pseudo time-tag bias

Using crossovers we can estimate the pseudo time tag bias in REAPER data by regressing the SSH differences at crossovers agains the orbital altitude rate. This method will merge true time-tag errors and other errors correlated to the altitude rate, thus the “pseudo”.




The mean pseudo time-tag value is about -5 ms for ERS-1 and ERS-2, with a long-term temporal variability for ERS-2 (the time-tag seems higher at the beginning and lower at the end of the period). Given that the orbital altitude rate can reach 25 m/s, this represents a resulting SSH error of about 1 cm.

# 7 Sea Level Anomaly analysis

In this section we estimate the Sea Level Anomaly (SLA) from REAPER data and compare it to our reference dataset.

## 7.1 Maps

Figure 95 displays two maps of sea level anomaly evaluated over one cycle of ERS-1 from REAPER COM6 data. Important differences can be noticed between those two maps. The same amplitude of differences can be observed for the ERS-2 mission (Figure 96).
To emphasize those differences, we calculate the differences between the reference and REAPER SLA maps for ERS-1 and ERS-2, the results are displayed on Figure 97.

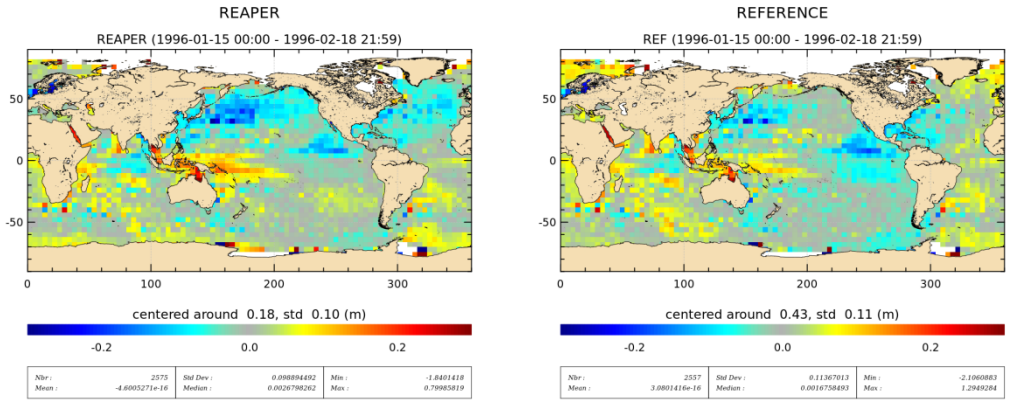



*Figure 95: maps of SLA over one cycle of ERS-1 for REAPER COM6 data (left) and the reference (updated OPR) data.*

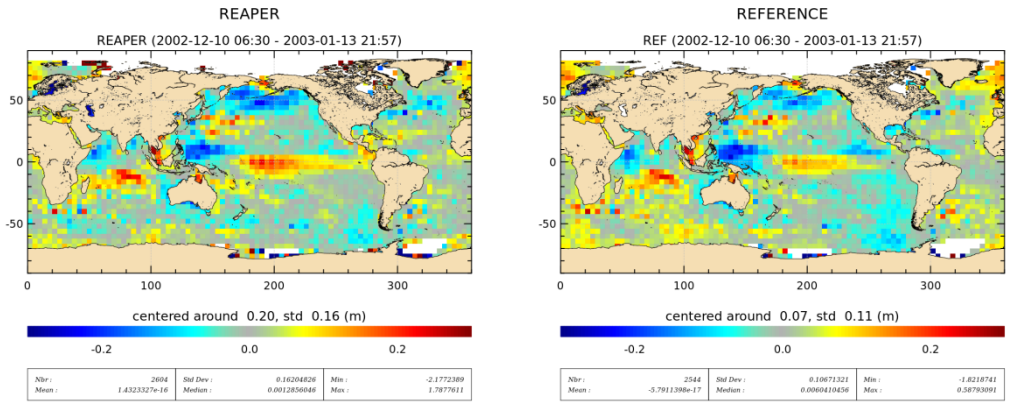



*Figure 96: maps of SLA over one cycle of ERS-2 for REAPER COM6 data (left) and the reference (updated OPR) data.*

The map of the differences exhibits large geographically correlated patterns, which appear to be quite similar for both missions, despite different time periods used: a negative patch in the tropical Pacific Ocean and a positive patch in mid to high latitudes. These differences could be related to different orbits or radiometer retrieval algorithms.

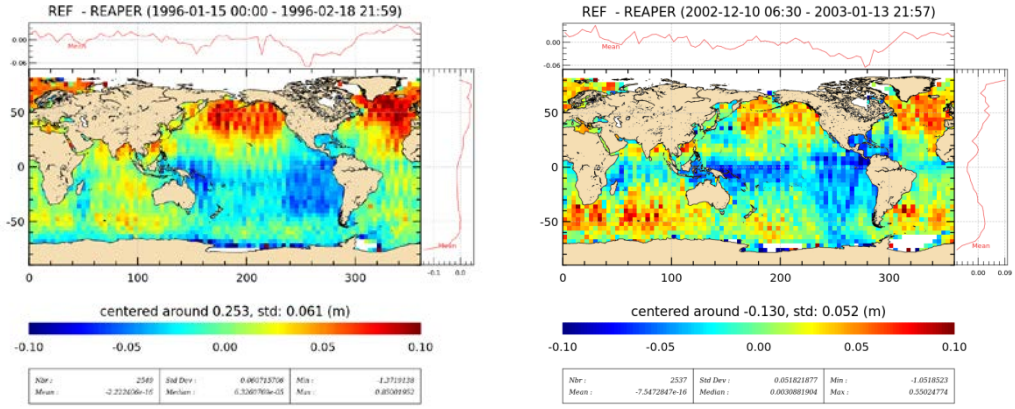
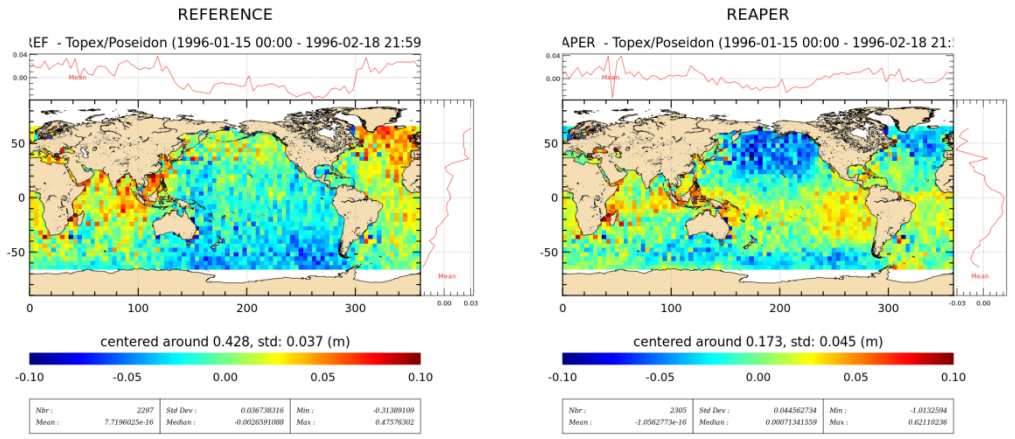



*Figure 97: difference between reference and REAPER SLA maps for ERS-1 (left) and ERS-2 (right) data, the differences are estimated from the maps of Figure 95 and Figure 96.*

In order to investigate if the SLA changes brought by the REAPER products are actually an improvement over the updated OPR dataset, we compare the SLA maps presented above to TOPEX/Poseidon data over the same period. Results are displayed on Figure 98 and show a very different behavior of REAPER data with respect to TOPEX/Poseidon compared to the reference dataset: the differences to TOPEX/Poseidon which followed a longitude dependent pattern are now more latitude-dependent. In particular, REAPER differences to TOPEX show a positive patch in the tropics for both ERS-1 and ERS-2 missions. These latitude dependent patterns are attenuated, but not completely removed when using the modeled wet tropopheric correction (see Figure 99)



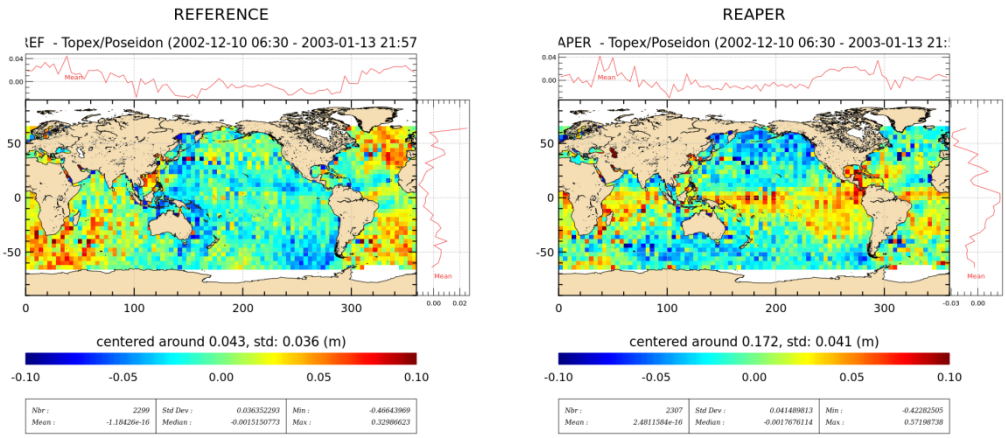



*Figure 98: maps of SLA differences between ERS-1 (top) or ERS-2 (bottom) and TOPEX/Poseidon using the updated OPR (left) and REAPER (right) data, the differences are estimated over one cycle.*

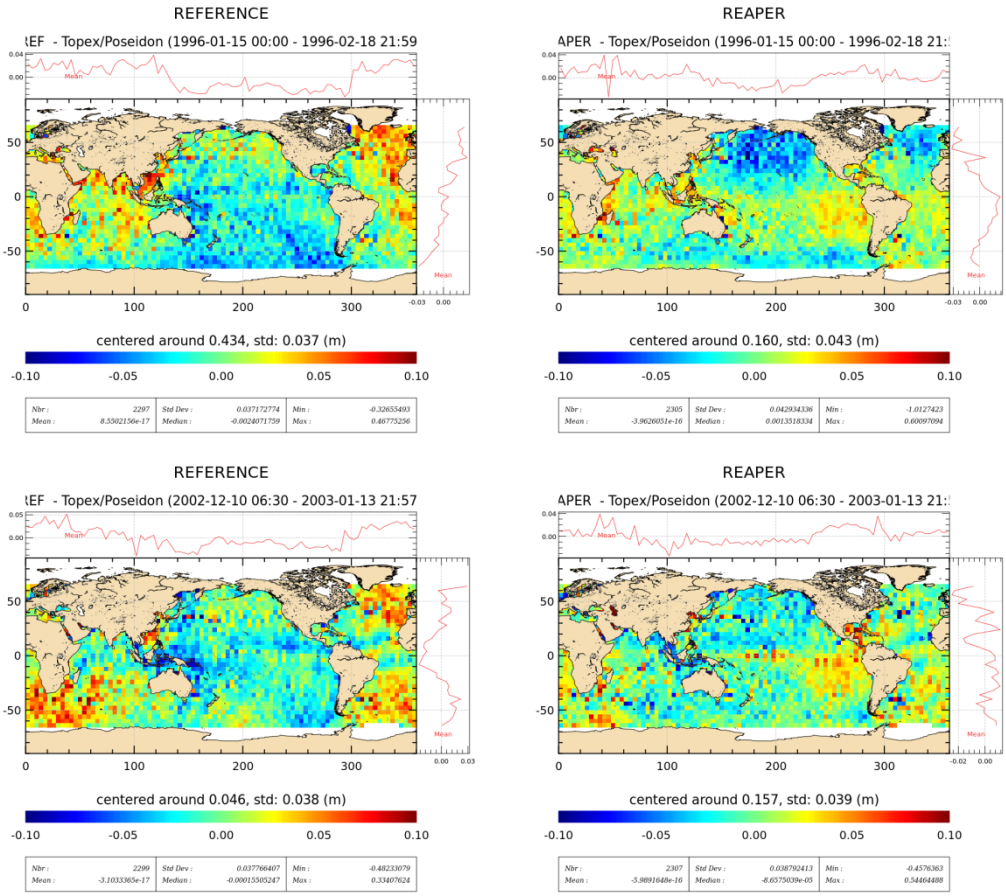



*Figure 99: same as Figure 98 using the modeled wet tropospheric correction on all missions*

## 7.2 Time series

Monitoring global average sea level anomaly also provides information about the mission performance. Figure 100 displays the temporal evolution of cycle-per-cycle standard deviation of global SLA, it shows a consistent behavior between REAPER and original OPR

(updated) data. For the ERS-2/Envisat verification phase, the metric from Envisat is plotted, and shows a lower level of global SLA standard deviation.

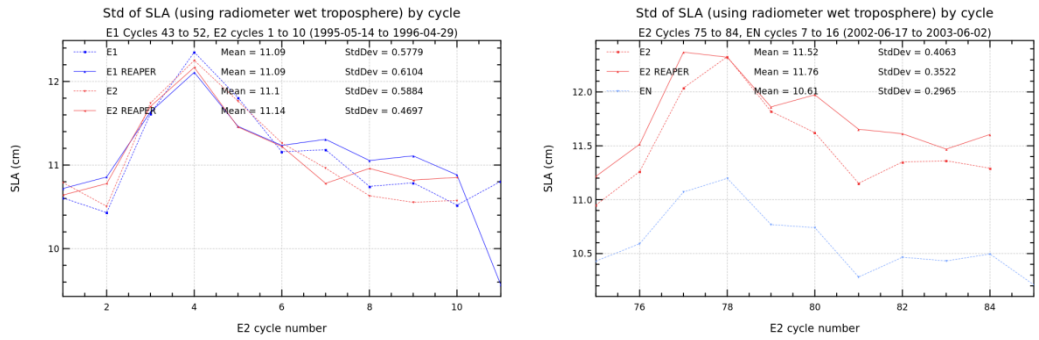



*Figure 100: temporal evolution of the standard deviation of global average sea level anomaly per cycle using the radiometer wet tropospheric correction*

Regarding the temporal evolution of global mean SLA, Figure 101 displays the evolution of global mean SLA estimated from REAPER and OPR data, over the two periods processed in COM6. The reprocessing induces cycle–averaged changes sometimes greater than 1 cm. In order to find a reference, we compare the ERS data to Topex/Poseidon data in Figure 103.

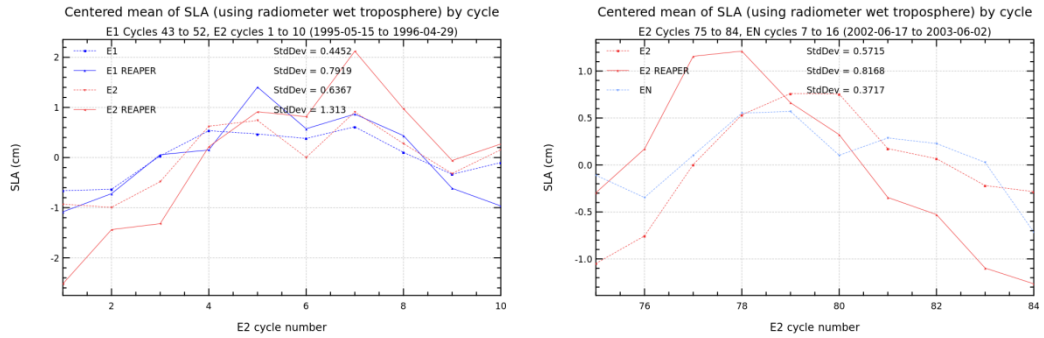



*Figure 101: temporal evolution of the global mean sea level anomaly for REAPER and OPR data over two different periods*

This figure shows inconsistencies between REAPER ERS data and TOPEX/Poseidon measurements as large as 1 cm, especially for ERS-2 data. Over the verification phase between ERS-1 and ERS-2, ERS-2 REAPER data shows a large drift which is not seen in neither ERS-1 data or on ERS-2 updated OPR data (see Figure 101), this is unchanged by switching to the modeled wet tropospheric correction (see Figure 102). Regarding these global SLA comparisons, the updated OPR data seems to perform better than REAPER data.

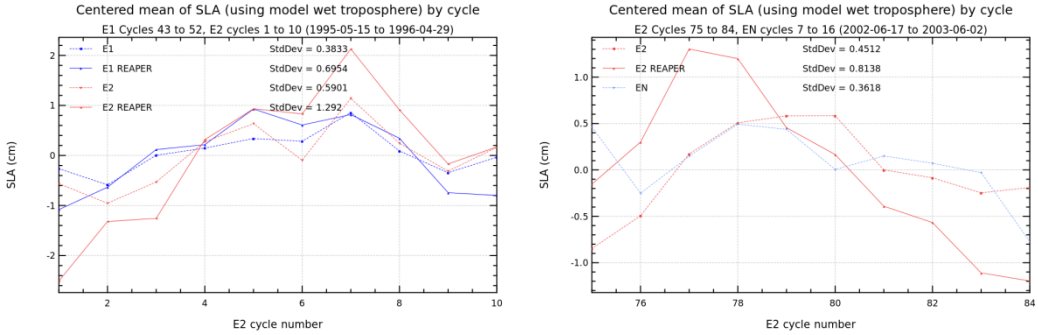



*Figure 102: same as Figure 101 but using the modeled wet tropospheric correction for all missions*

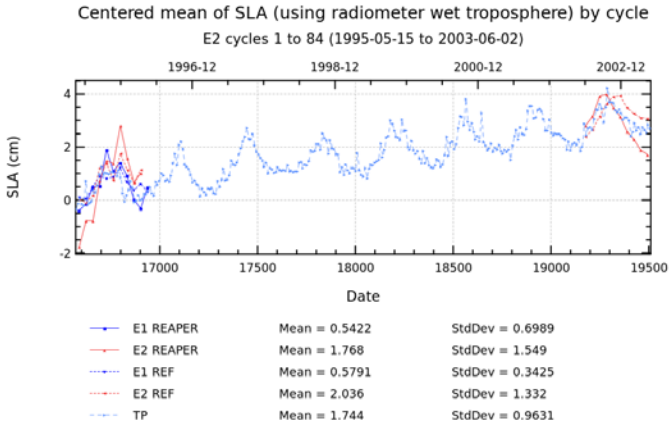



*Figure 103: temporal evolution of the global mean SLA for all latitudes below 66° from REAPER and updated OPR ERS-1 & 2 data, Topex/Poseidon data is overlaid to provide a reference*

# 8 Biases

From the analysis previously described, we can derive biases between ERS-1 and ERS-2 for different parameters.

## 8.1 SSH bias

Plotting the daily global SSH differences between ERS-1 and ERS-2 estimated from REAPER COM6 data (see Figure 104, where days with large data gaps have been removed) indicates a global SSH bias between ERS-1 and ERS-2 of -0.5 ± 0.15 cm (ERS-1 being lower than ERS-2).
The same analisys performed on ERS-2 and Envisat during the verification period indicates a bias between the two missions of 28.3 ± 0.16 cm.

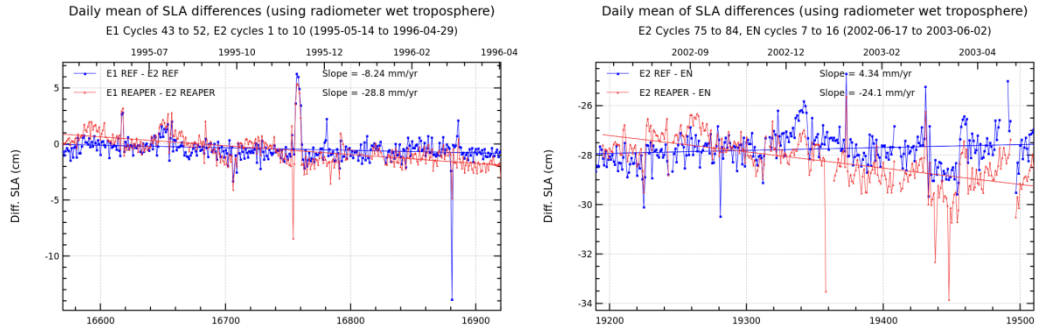



*Figure 104: daily mean SLA differences between ERS-1 and ERS-2 (left) and between ERS-2 and Envisat (right)*

Figure 104 also displays an important drift between ERS-1 and ERS-2 and between ERS-2 and Envisat over the verification phases. Regarding this, the reference (updated OPR) dataset shows a much lower drift between missions than REAPER does.
Mapping the SSH differences over the verification phases (Figure 105) gives us an insight on the regional distribution of the inter-mission biases. Between ERS-1 and ERS-2, a small latitudinal dependency of the bias is observed. Between ERS-2 and Envisat however, the bias is much more variable, with geographically correlated patterns which may come from the ionospheric correction. Using GIM ionospheric and the modeled wet tropospheric correction significantly reduces the amplitude of these signals, as shown on Figure 106.

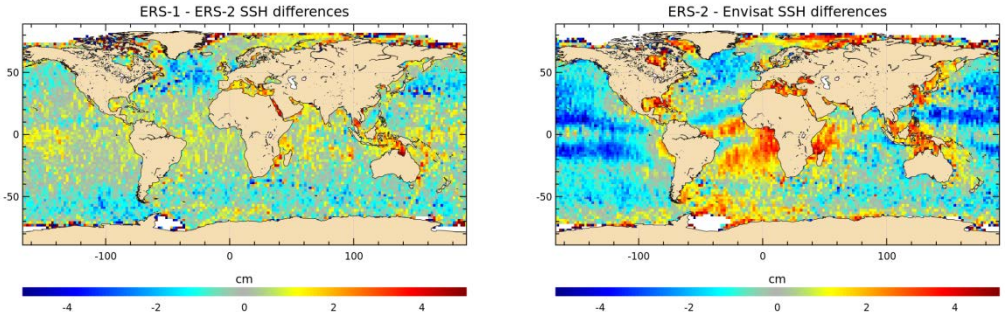



*Figure 105: maps of mean SSH differences between ERS-1 and ERS-2 (left) and between ERS-2 and Envisat over the two verification phases.*

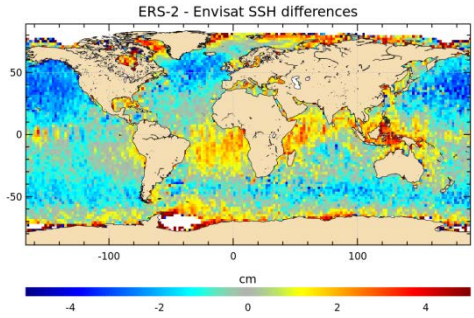



*Figure 106: map if the SSH differences between ERS-2 and Envisat over the verification pahse, using the GIM model and the modeled wet tropo on both missions*

Another question is wether these geographical differences are larger than the ones observed over the verification phases for our reference (updated OPR) dataset. Figure 107 displays the same maps as Figure 105, but using the reference (updated OPR) data. The consistency between ERS-1 and ERS-2 seems better with REAPER data than with the reference dataset. The same result is observed between Envisat and ERS-2.

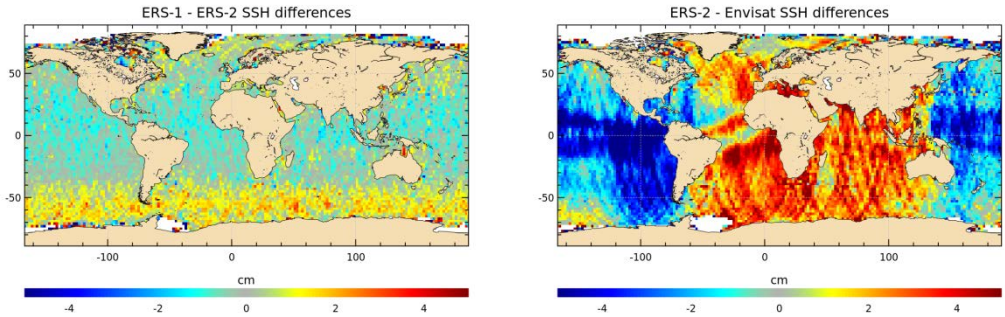



*Figure 107: maps of the SSH differences between ERS-1 and ERS-2 (left) and between ERS-2 and Envisat (right) using the updated OPR dataset.*

## 8.2 Wave, wind and backscatter biases

A similar approach is used to estimate biases for backscatter and significant wave height. Between REAPER ERS-1 and ERS-2 the estimated (ERS-2 minus ERS-1) biases are:

- 26 cm for SWH,
- 0.1 dB for backscatter,
- -0.2 m/s for wind speed.

Concerning the biases between REAPER ERS-2 and Envisat data, the estimated (Envisat minus ERS-2) biases are:

- -26 cm for SWH,
- -0.2 dB for backscatter,
- 0.5 m/s for wind speed

The temporal evolution of the mean SWH and backscatter are displayed on Figure 108 (where Envisat data is also plotted). The differences already noticed in sections 5.2.4 and 5.2.6 between REAPER and OPR data appear to be consistent over a longer time period. REAPER ERS-2 backscatter seems to show a drift over time (global mean backscatter is higher during the verification phase with ERS-1 than during the verification phase with Envisat), a behavior that should be monitored when the full period is reprocessed.

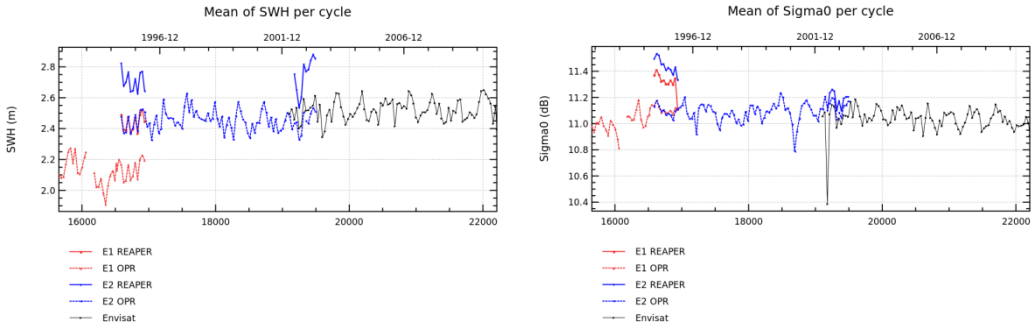



*Figure 108: temporal evolution of the mean of SWH (left) and backscatter coefficient (right)*

# 9 Conclusions

In this report we analyzed the system performance of REAPER ERS-1 and ERS-2 satellite altimetry data, using 1 Hz data over the oceanic domain. This work is based on about thirty ERS cycles of COM6 commissionning dataset generated withn the framework of the REAPER project. Several apects of the mission performance are investigated: data availability and validity, validity of geophysical corrections, crossovers and global SLA statistics. The essential points of the mission performance analysis are summarized below.

***Data Availability***

Less data are missing in the REAPER products than in the OPR, however these new data are located at high latitudes and the editing leads to rejecting them. The number of valid measurements in therefore not significantly changed.

***Product Fields and Corrections***

The problems related to orbit interpolation identified in previous versions of the dataset are now corrected. We identified no errors in the geophysical corrections. However, changes to the wet tropospheric correction are large.

***Crossovers analysis***

The main mission performance indicator comes from estimating SSH differences at crossovers. On the short period studied is this report, the analysis shows that REAPER satellite altimetry data shows a better performance level than our current best for both ERS-1 and ERS-2 missions, based on the standard deviation of SSH differences at crossovers. Regarding the mean, the data are still impacted by a ≈0.6 ms time-tag bias, variable in time.

***Global SLA analysis***

The analysis of global SLA variability displays positive results as REAPER data seems to improve the consistency between missions, either comparing ERS-1 to ERS-2, ERS-2 to Envisat or ERS to TOPEX/Poseidon. We do raise a concern about the temporal evolution of ERS-2, especially at the beginning of the period where an important drift with respect to TOPEX/Poseidon is suggested; however the time period is too short to draw a firm conclusion.

Given the results presented in this report, we see no outstanding issue that would prevent a reprocessing of the full ERS period.