DEVELOP-MENT OF RADAR ALTIMETRY DATA PROCESSING IN THE OCEANIC COASTAL ZONE

ESA/ESRIN Contract No. 21201/08/I-LG (CCN 3)

Deliverable on

GPD output for CGDR for European coasts

Version 1.1

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SUMMARY OF MODIFICATIONS

Ed.	Date	Chapter	Modification	Author/s
1.1	08-02-2011	Introduction	Explanation that the present version of this report includes the results for CGDR products version 2.0. Updates the structure of the report	J. Fernandes
1.1	08-02-2011	Section 1	Titles of section 1 and subsection 1.2.2 have been updated; Small language corrections and updates (pages 8, 9 and 11)	J. Fernandes
1.1	08-02-2011	Section 2	This whole section is new. It presents the results for CGDRs version 2.0	J. Fernandes C. Lázaro
1.1	08-02-2011	Sections 2 and 3	These sections have been renumbered being now sections 3 and 4 respectively	J. Fernandes
1.1	08-02-2011	Section 3	Notes about the h18_GPD_interp_flag and about the dry related fields have been added	J. Fernandes
1.1	08-02-2011	Section 4	Some conclusions have been rewritten in face of the new results presented in section 2 for the CGDR products version 2.0	J. Fernandes

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Reference Documents

[RD1] **COASTALT Technical proposal for extended work (Phase 2)**, DRAFT V. 1.0 November 1, 2009, Document Code COASTALT2-TP-10

[RD2] **Wet Tropospheric Corrections in Coastal Areas**, COASTALT CCN2 Deliverable D2.1b v 1.2., 30/06/2009. Document code COASTALT-D21b-12

[RD3] **Global assessment of GNSS-derived tropospheric corrections**, COASTALT CCN3 Deliverable D2.1a v1.1., 16/07/2010

Acronyms

CGDR - Coastal Geophysical Data Records
ECMWF - European Centre for Medium-range Weather Forecasts
EPN - EUREF Permanent Network
ESA – European Space Agency
GNSS - Global Navigation Satellite System
GPD - GNSS-derived Path Delay
IGS - International GNSS Service
MJD – Modified Julian Date
MWR - MicroWave Radiometer
RADS - Radar Altimeter Database System
RD1 – Reference Document 1
RD2 – Reference Document 2
UPorto - University of Porto
ZHD - Zenith Hydrostatic Delay
ZTD - Zenith Total Delay
ZWD – Zenith Wet Delay

Introduction

This document presents the Deliverable D2.1b for the COASTALT project, CCN 3, CONTRACT N. 20698/07/I-LG and is delivered for fulfilment of milestone M11.

The present report describes the work that has been done at University of Porto (UPorto) concerning the computation of the GNSS-derived Path Delay (GPD) correction for the Coastal Geophysical Data Records (CGDR) versions 1.1 and 2.0.

The document is divided in 4 sections. Section 1 presents a brief description of the methodology used in the computations and the results obtained for CGDR Version1.1, Session 2, updates the results for CGDR Version 2.0. Section 3 describes the data format and section 4 presents a summary of the main conclusions and achievements.

1 GPD computation for the CGDR products version 1.1

1.1 Introduction

This section describes the computation of the GPD correction for the COASTALT CGDR products in the European Coasts. The products used are COASTALT CGDR version 1.1., as downloaded from the COASTALT ftp site on August 2010.

These data comprise a set of seven Envisat passes for three different test regions as shown on Figure 1:

- West Britain – passes 0160, 0704
- West Iberia – passes 0001, 0160
- West Mediterranean – passes 0130, 0257, 0887

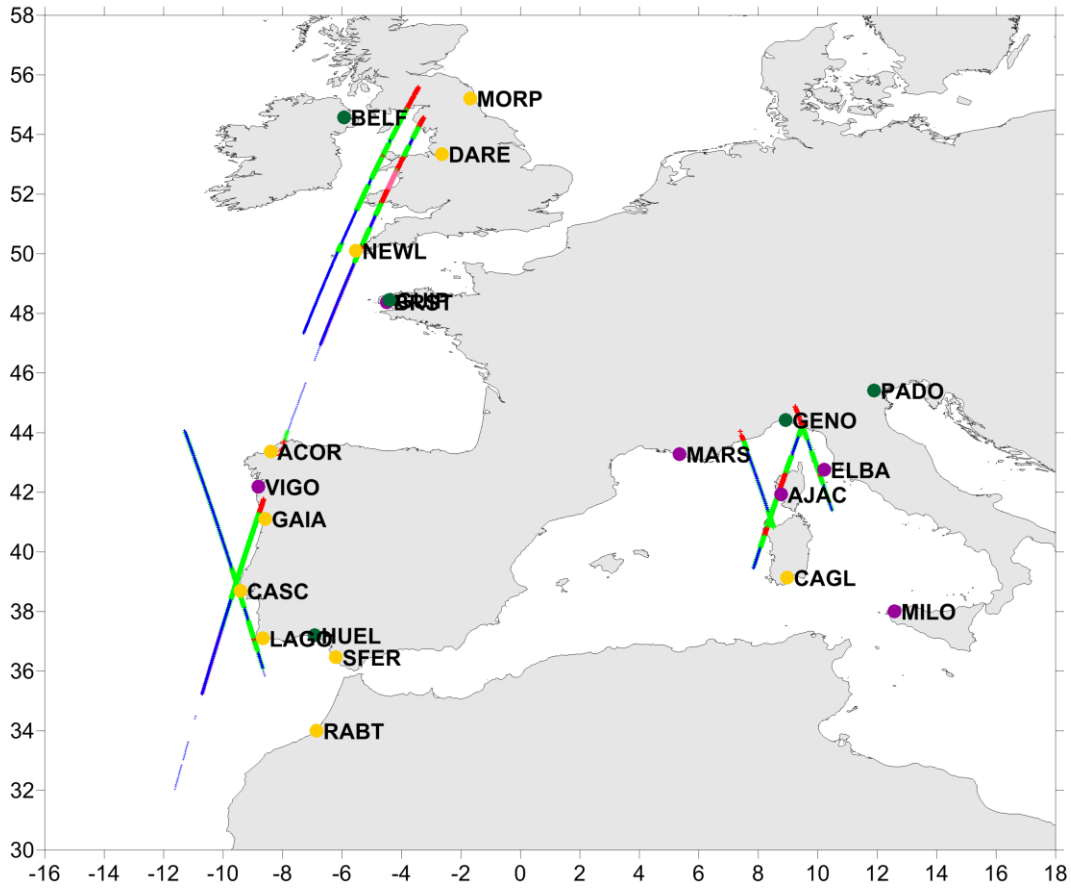

Fig.1 – Location of all 1Hz points present on COASTALT CGDR v1.1 and the 21 coastal GNSS stations in the vicinity of these points. For the altimeter points the colour code represents the 1Hz_GPD_flag: blue (0) – ocean points for which the MWR correction is valid; light green (1)- points for which the GPD algorithm provided a valid output; light pink (2) – points for which there were no data points to compute the GPD correction; red (3) – land points. Colour code for the GNSS stations: yellow - ZWD from Gamit UPorto solutions; dark green - ZWD from IGS/EPN online solutions; Magenta – mixed ZWD solution (see text for details).

The time span of these data is from 30 September 2002 to 21 April 2008, corresponding to Envisat cycles 10 – 67.

The procedure adopted in the computations is as described in Fernandes et al. (2010) with some updates resulting from the studies presented in [RD3], which will be reminded here.

For these computations the following region has been selected in order to include all three test areas:

Region A: 32° N $\leq \varphi \leq$ 56° N; 14° W $\leq \lambda \leq$ 16° E

Since the GPD method uses data around the point of computation up to a distance specified by the spatial correlation scale (100 km), the actual region used on the computations, for which all data sets had to be prepared, is region B, obtained by adding 2 degrees to the limits of region A.

Region B: 30° N $\leq \varphi \leq$ 58° N; 12° W $\leq \lambda \leq$ 18° E

1.2 Description of the computations

1.2.1 Computation of the signal variance

As described in [RD2], the GPD algorithm requires the knowledge of the "a priori" signal variance of the Zenith Wet Delay (ZWD) field for the computation region (region B). The signal variance has been computed using all available data for this region and for the year 2007. This comprises the following data sets:

- European Centre for Medium-range Weather Forecasts (ECMWF) derived ZWD (0.25° x 0-25°, 6 hours interval), using only data over ocean
- Envisat Microwave Radiometer (MWR) wet tropospheric correction (only points for which the correction is valid) for cycles 54 to 64. These data have been extracted from the Radar Altimeter Database System (RADS).
- Global Navigation Satellite System (GNSS) derived ZWDs for a set of 49 stations: 20 from UPorto Gamit solutions (shown in yellow in Figure 2) and 29 from online IGS/EPN Zenith Total Delay (ZTD) solution (shown in dark green in Figure 2).

The UPorto Gamit ZWD values referred above are from the set computed for the period [2002 - 2007], referred in [RD2], using a time sampling of 1 hour and were interpolated to 15 minutes

In the computation of the ZWD fields from GNSS data, the initial ZTD derived both from the Gamit and IGS/EPN solutions have been converted in to ZWD by using the Zenith Hydrostatic Delay (ZHD) derived from ECMWF, as described in [RD3].

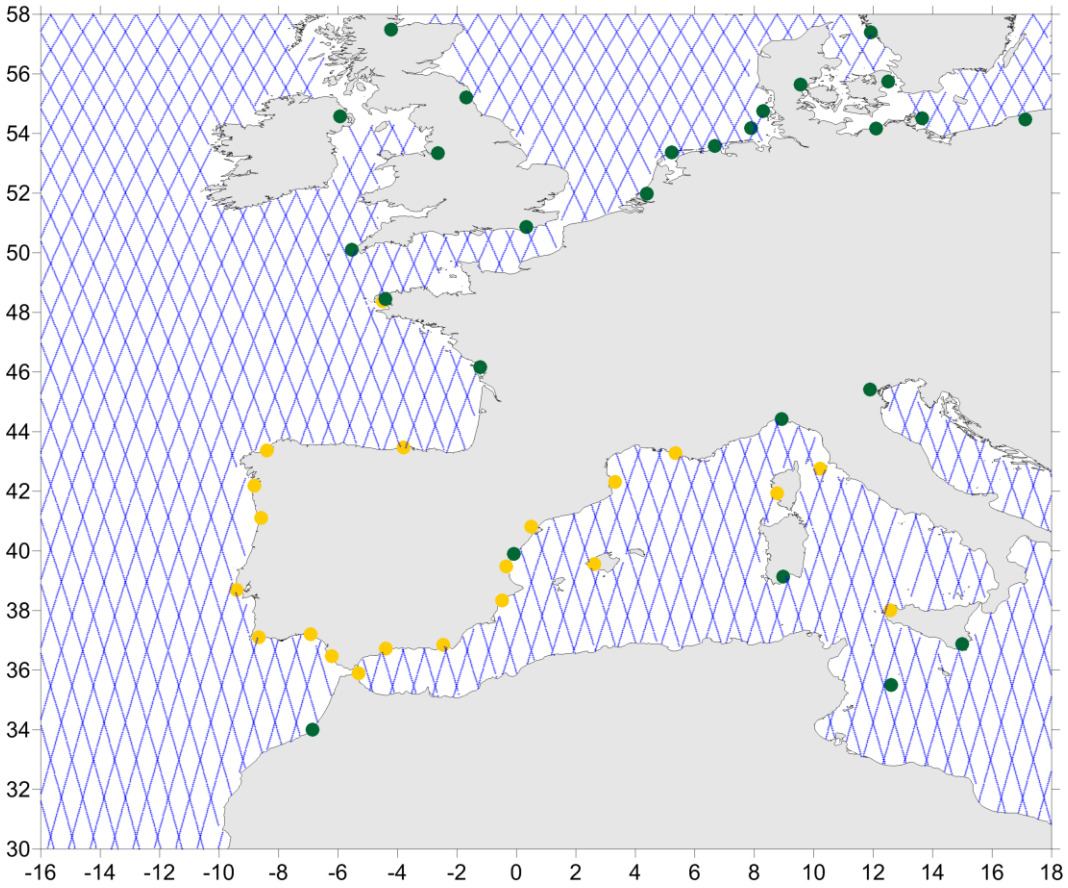

Fig.2 – Location of Envisat MWR points (blue) and the set of all GNSS stations (49) used in the computation of the signal variance for region B. Yellow - ZWD from UPorto Gamit solutions; dark green - ZWD from IGS/EPN online solutions.

The signal variance is obtained as follows:

1) the GPD algorithm is run using the above described data set to update the ZWD value at each grid node of the ECMWF grids.
2) The signal variance of the ZWD field at each grid node has been defined as the variance of this set of ZWD estimates. This way, a signal variance grid is obtained which will be used to generate the signal variance at each computation point by bilinear spatial interpolation.

1.2.2 Computation of the GPD correction for CGDRs version1.1

To keep the structure of the data as they are provided in the COASTALT ftp site and to facilitate the addition of the GPD fields to the points of the CGDR files, the computation has been performed according to the following steps:

1) From each CGDR netcdf file the following 1Hz parameters, required by the GPD algorithm, have been extracted (the original CGDR names have been kept):
   - cycle
   - pass
   - mdsr_time
   - H1z_MJD (computed from mdsr_time)
   - lat
   - lon
   - mod_dry_tropo_corr
   - mod_wet_tropo_corr
   - mwr_wet_tropo_corr
   - altim_landocean_flag
   - radio_landocean_flag
   - mwr_qua_interp_flag

2) The GPD algorithm was run for this data set using the method described in Fernandes et al (2010) with some modifications introduced after the studies mentioned in [RD3]. In these computations, the above described signal variance and the data set described below have been used. The output fields will be described in section 3.

3) The computed GPD fields at 1Hz were interpolated into 18Hz using linear interpolation.

As in the previous section, in the computation of the ZWD fields from all GNSS data, the initial ZTD have been converted into ZWD using the ZHD derived from ECMWF, as described in [RD3].

For each 1Hz point present on the CGDR, the GPD algorithm was run using the following data sets, for region A and the period 30 September 2002 - 21 April 2008 (Envisat cycles 10 to 67):

- ECMWF - derived ZWD (0.25° x 0.25°, 6 hours interval) using only points over ocean;
- Envisat MWR wet tropospheric correction (only for points for which the correction is valid);
- GNSS - derived ZWDs for a set of 21 coastal stations in the vicinity of the computation points.

Three different sets of GNSS-derived ZWD have been used (see Figures 1, and 3 to 5):

1) 10 stations from the most recent UPorto Gamit solutions described in [RD3]. These have been computed for the period [2002-2009] using a

temporal sampling of 30 minutes and were interpolated to 15 minutes. These are shown in yellow in Figures 1 and 3 to 5;

2) 5 stations from the IGS/EPN online solutions. As described in [RD3] the EPN solutions are available at 1 hour interval while the IGS-derived ZWD are available at 5 minutes interval but were sub-sampled to 15 minutes interval. These are shown in dark green in Figures 1 and 3 to 5;
3) 6 stations with mixed solutions as follows: for the period [2002 - 2007] the values were extracted from the first set of UPorto Gamit solutions (computed for the period [2002 - 2007] using a temporal sampling of 1 hour and interpolated to 15 minutes). For the remaining period (2008), the values from the IGS/EPN online solutions were added to these stations. These stations are shown in magenta in Figures 1 and 3 to 5.

Figures 3 to 5 show, for each of the three COASTALT test regions, for one Envisat cycle, the position of the interpolated 18Hz points. The colours represent the 18Hz GPD interpolation flag (h18_GPD_interp_flag) using the following code:

- blue (GPD_flag=0) – ocean points for which the MWR correction is valid
- light green (GPD_flag=1)- points for which the GPD algorithm provided a valid output
- light pink (GPD_flag=2) – points for which there were no data points to compute the GPD correction
- red (GPD_flag=3) – land points
- pink (GPD_flag=9): points for which the 18Hz interpolation is not available.

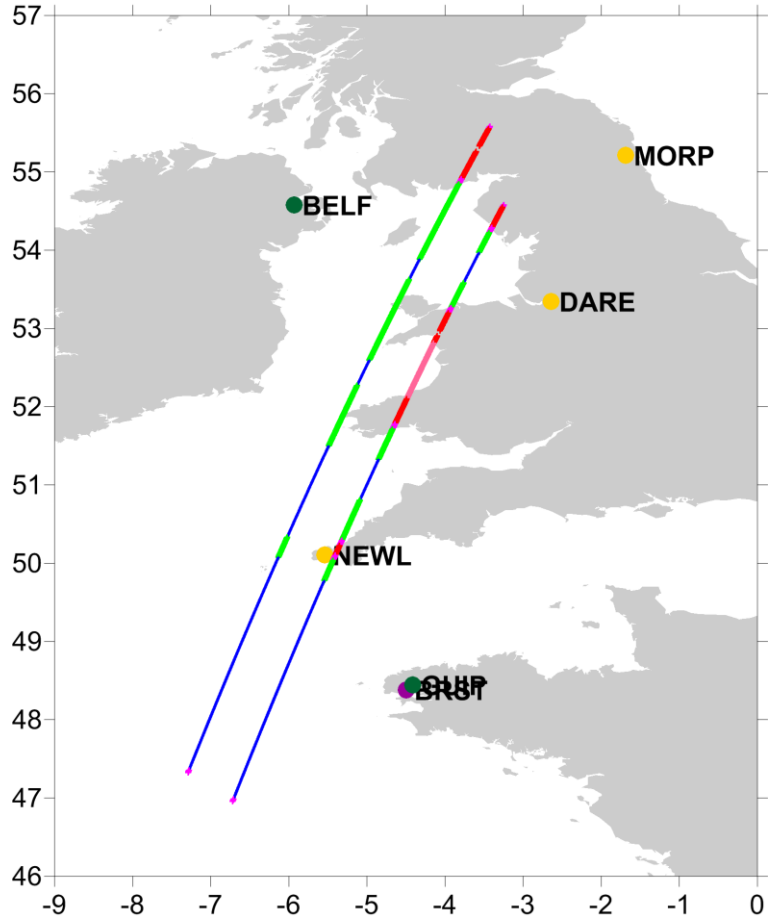

Fig.3 – Location of 18Hz points present on one Envisat CGDR v1.1 and the GNSS stations in the vicinity of these points, on the West Britain region. For the altimeter points, the colour code represents the h18_GPD_interp_flag: blue (0) – ocean points for which the MWR correction is valid; light green (1) - points for which the GPD algorithm provided a valid output; light pink (2) – points for which there were no data points to compute the GPD correction; red (3) – land points; pink (9) - points for which the 18Hz interpolation is not available. Colour code for the GNSS stations: yellow - ZWD from Gamit UPorto solutions; dark green - ZWD from IGS/EPN online solutions; Magenta – mixed ZWD solution (see text for details).

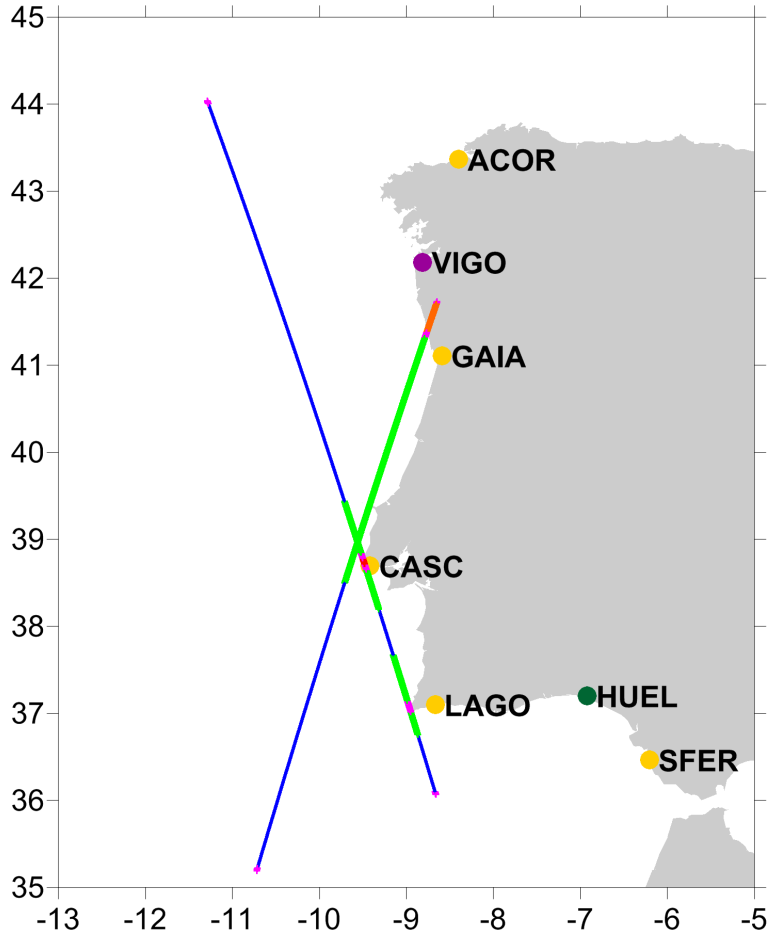

Fig.4 – Same as Figure 3 for the West Iberia region.

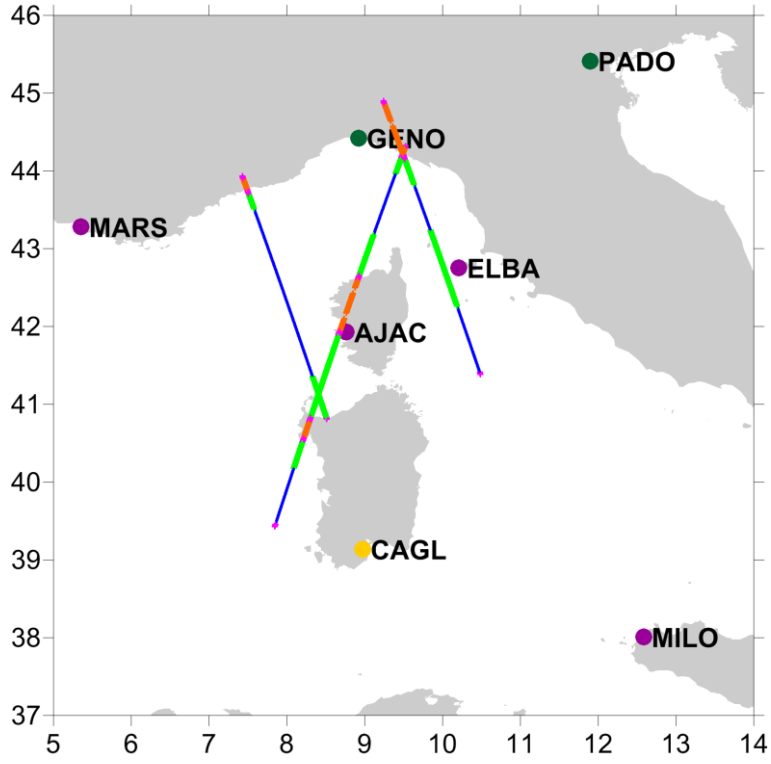

Fig.5 – Same as Figure 3 for the West Mediterranean region.

2 GPD computation for the CGDR products version 2.0

2.1 Introduction

This section updates the results described on the previous section, for the CGDR products Version 2.0 as downloaded from the COASTALT website on 22 December 2010.

The time span of these data is from 26 August 2002 to 26 May 2008, corresponding to Envisat cycles 9 – 68. Figure 6 illustrates the position of all 1Hz points used in these computations.

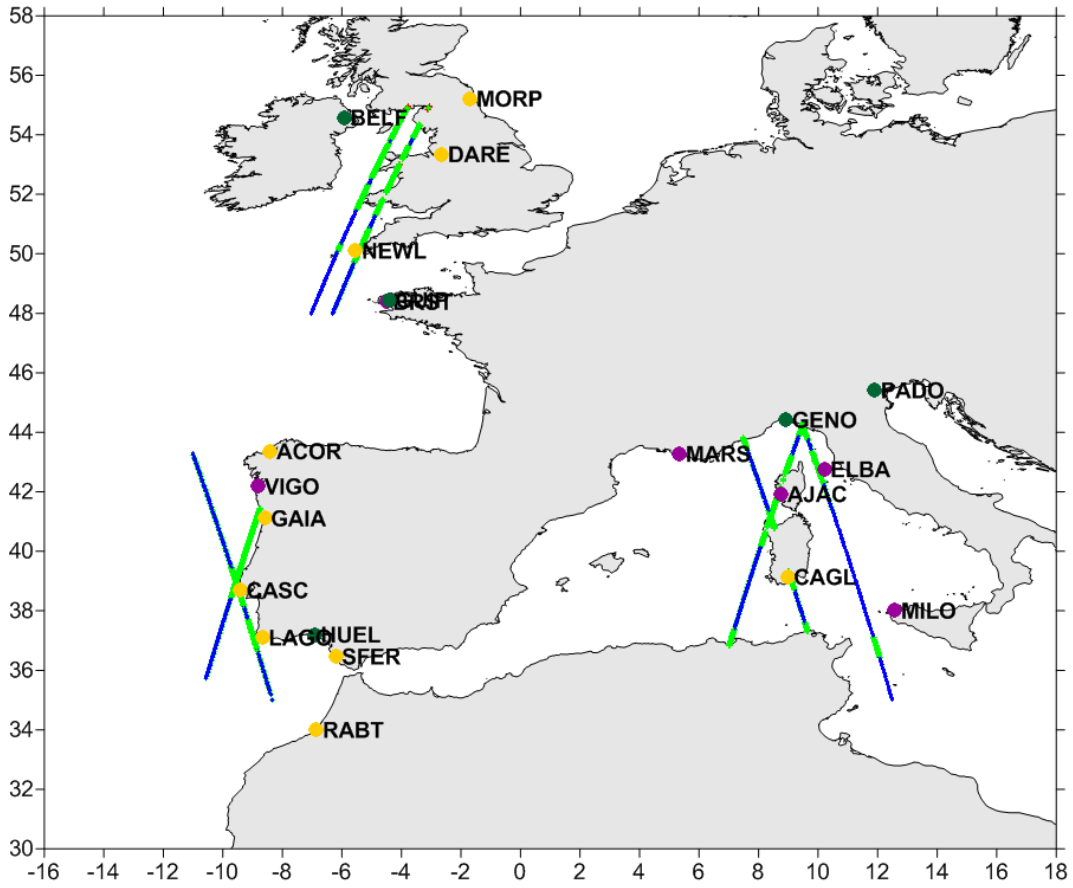

Fig.6 – Location of all 1Hz points present on COASTALT CGDR v2.0 and the 21 coastal GNSS stations in the vicinity of these points. For the altimeter points the colour code represents the 1Hz_GPD_flag: blue (0) – ocean points for which the MWR correction is valid; light green (1)- points for which the GPD algorithm provided a valid output; red (3) – land points. Colour code for the GNSS stations: yellow - ZWD from Gamit UPorto solutions; dark green - ZWD from IGS/EPN online solutions; Magenta – mixed ZWD solution (see text on section 1 for details).

2.2 Computation of the GPD correction for CGDRs version2.0

In the generation of the GPD correction for version 2.0 of the CGDR products, a code change was made to ensure that all altimeter ocean 18 Hz points would have a valid correction. For this purpose, the GPD correction was again computed in three steps:

1) The required fields were extracted from the netcdf files.
2) The GPD correction was computed for all 1Hz altimeter ocean points plus the two land points closest to the coast. The data used in the computations were the same as previously (GNSS-derived, valid MWR-derived and ECMWF-derived wet tropospheric corrections). As before, only ECMWF data over ocean were used.
3) The correction was interpolated into the 18Hz times using linear interpolation. For this purpose, a new data segment is considered when the time difference between two consecutive 1Hz points is greater than 6 seconds. In practice, a new segment is considered whenever a data gap of at least five 1Hz points occurs. This means that the linear interpolation is not performed whenever the 18Hz time is between two 1Hz points belonging to different segments (separated in time by more than 6 seconds).

Figures 7 to 9 show, for each of the three COASTALT test regions, for one Envisat cycle (cycle 10), the position of the interpolated 18Hz points. The colours represent the 18Hz GPD interpolation flag (h18_GPD_interp_flag) using the same code as on section 1:

- blue (GPD_flag=0) – ocean points for which the MWR correction is valid;
- light green (GPD_flag=1) – points for which the GPD algorithm provided a valid output;
- red (GPD_flag=3) – land points;
- pink (GPD_flag=9) – points for which the 18Hz interpolation is not available.

Note that now, when comparing the results for version 2.0 (Figures 7 – 9) to the corresponding results for version 1.1 (Figures 5-7) the following improvements can be examined:

- There are no points with GPD_flag=2, that is points for which there were no data information to compute the GPD correction. It has been found that this case was due to a bug in the use of the ECMWF land/sea mask, which has been corrected.
- The number of points with GPD_flag=9 (18Hz points for which the interpolated GPD correction is not available) is reduced to the first 10 and last 10 samples of each pass or the first and last 10 samples of each data segment.
- Using the above criteria, it was found that the GPD correction is available for all 18Hz ocean altimeter points. All points with invalid GPD correction are land points.

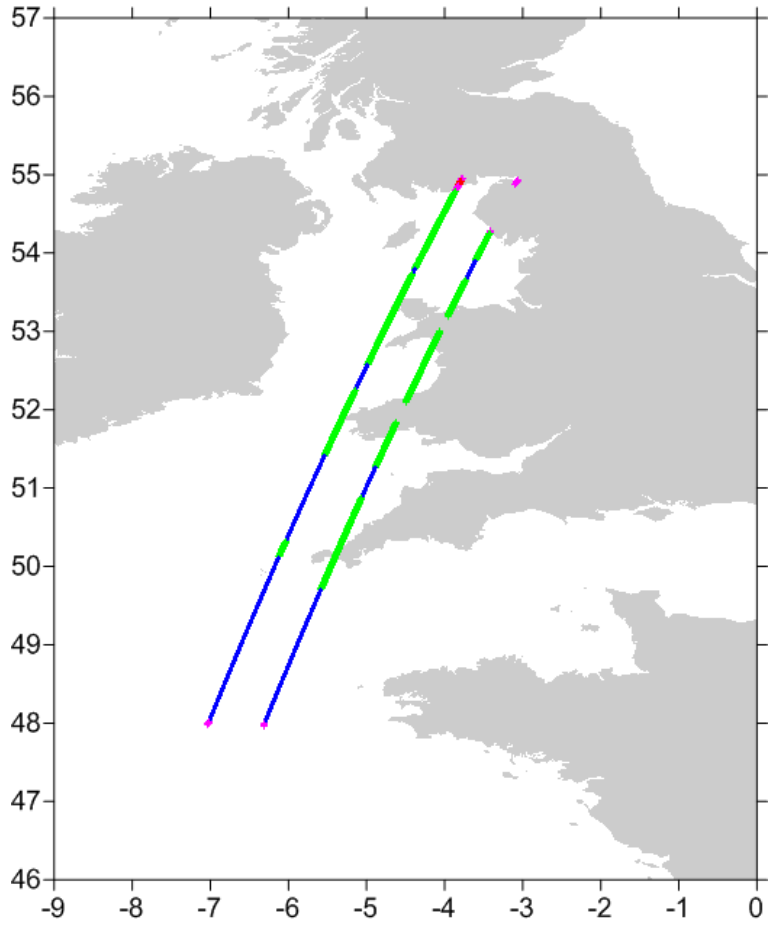

Fig.7 – Location of 18Hz points present on one Envisat CGDR v2.2 (cycle 10) and the GNSS stations in the vicinity of these points, on the West Britain region. For the altimeter points the colour code represents the h18_GPD_interp_flag: blue (0) – ocean points for which the MWR correction is valid; light green (1) - points for which the GPD algorithm provided a valid output; red (3) – land points; pink (9) - points for which the 18Hz interpolation is not available. Colour code for the GNSS stations: yellow - ZWD from Gamit UPorto solutions; dark green - ZWD from IGS/EPN online solutions; Magenta – mixed ZWD solution (see text for details).

Figures 10 to 14 illustrate examples of the GPD correction for various passes of the three test regions. Figure 15 illustrates the formal error and the number of points used in the computation of each 1Hz GPD estimate for the same pass and cycle shown on Figure 14.

From the analysis of these plots the following main conclusions can be drawn:

- The GPD correction is continuous with respect to the MWR correction used in the open ocean.
- On some plots, the influence of the closest GNSS station is evident. Examples of this can be observed in Figure 10 at about latitude 39˚ (station CASC), Figure 12 at about latitude 50.2˚ (station NEWL) and Figure 14 at about latitudes 42˚ (station AJAC) and 44.5˚ (station GENO).
- All altimeter 18Hz ocean points have now a valid GPD correction.

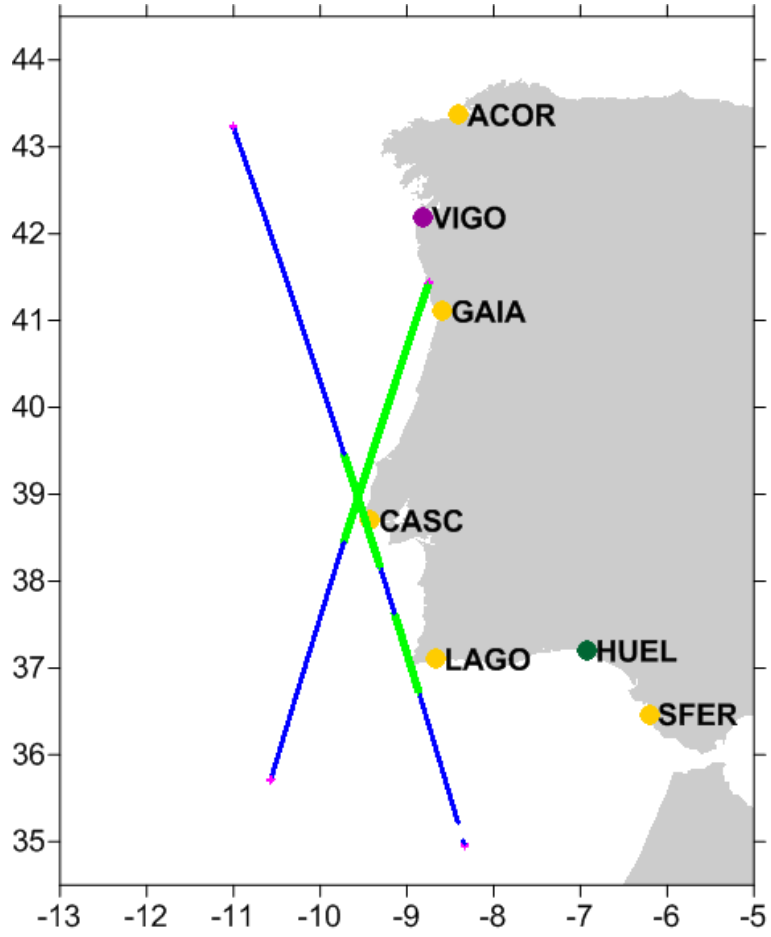

Fig.8 – Same as Figure 7 for the West Iberia region.

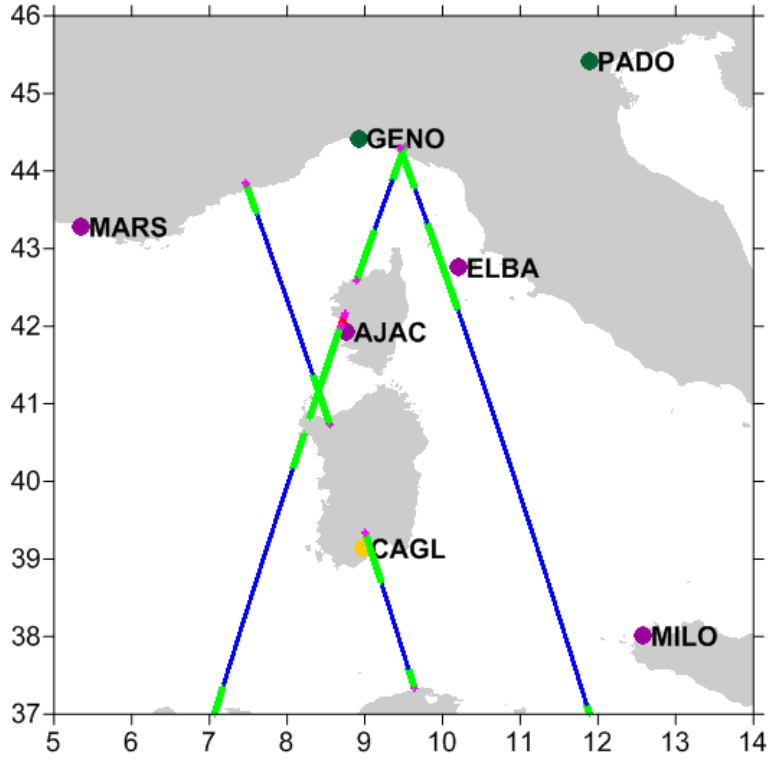

Fig.9 – Same as Figure 7 for the West Mediterranean region.

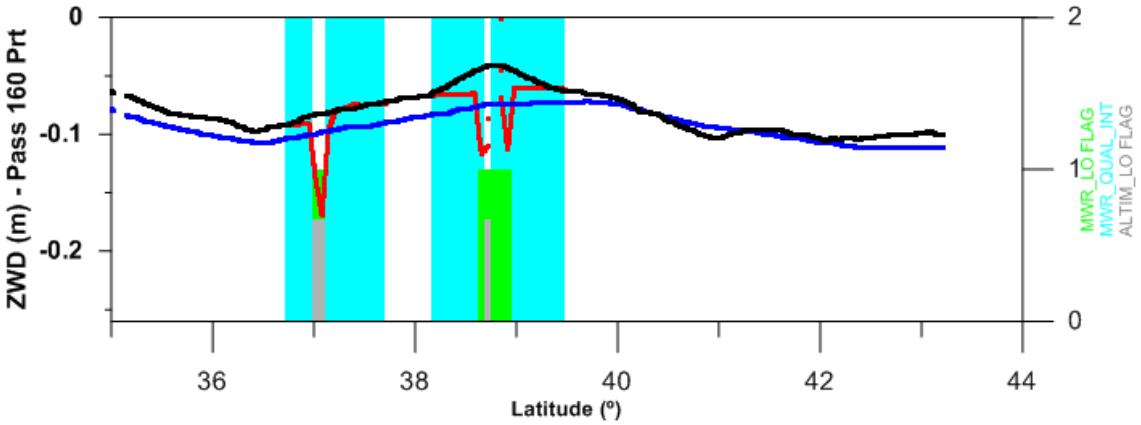

Fig.10 – Results obtained for Envisat pass 001 (West Iberia), cycle 58. The wet tropospheric correction from three data sets is shown (in meters): MWR (red), ECMWF-model from GDR (blue) and GPD output (black). The shaded areas indicate regions where the h18_radio_landocean_flag is 1 (green) or the h18_mwr_qua_interp_flag is > 0 (light blue) or land regions identified by values of the h18_altim_landocean_flag > 0 (grey). Note that the scale for the h18_altim_landocean_flag is not the same as for the other flags (shown in the right Y axis). The h18_altim_landocean_flag can have values 0 (not shown in the plot), 3 or 9, as explained in the text.

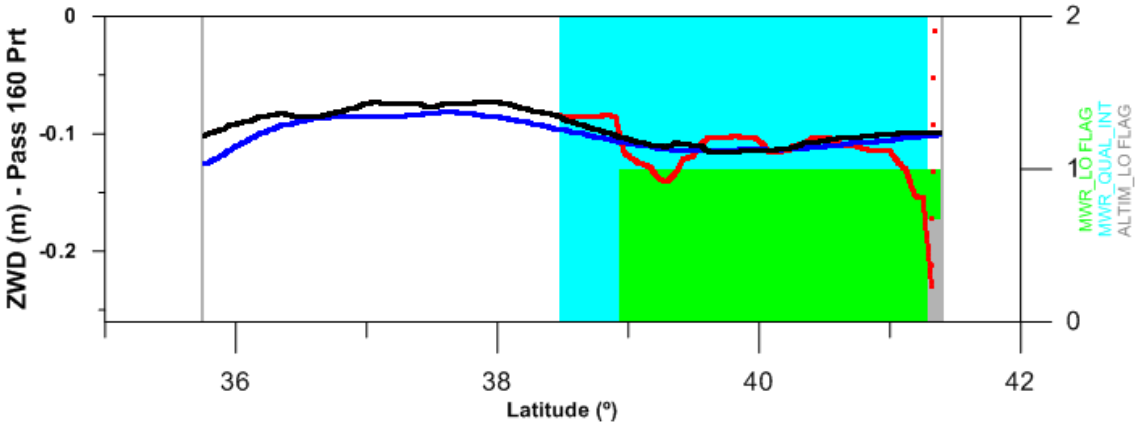

Fig.11 – Same as Figure 10 for Envisat pass 160 (West Iberia), cycle 58.

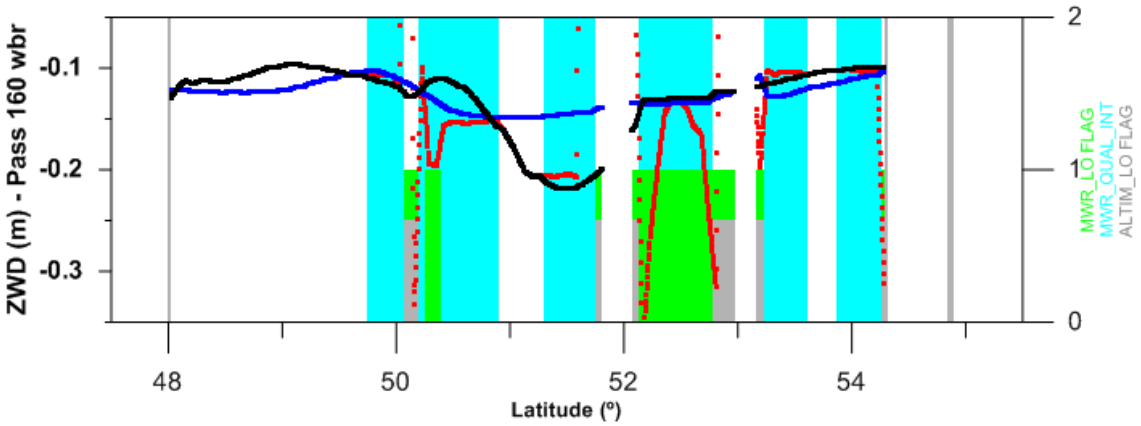

Fig.12 – Same as Figure 10 for Envisat pass 160 (West Britain), cycle 58.

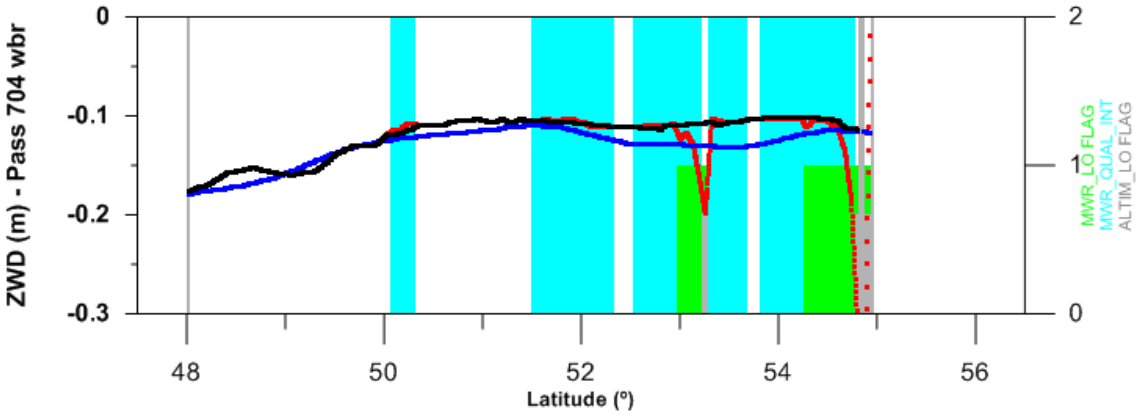

Fig.13 – Same as Figure 10 for Envisat pass 704 (West Britain), cycle 58.

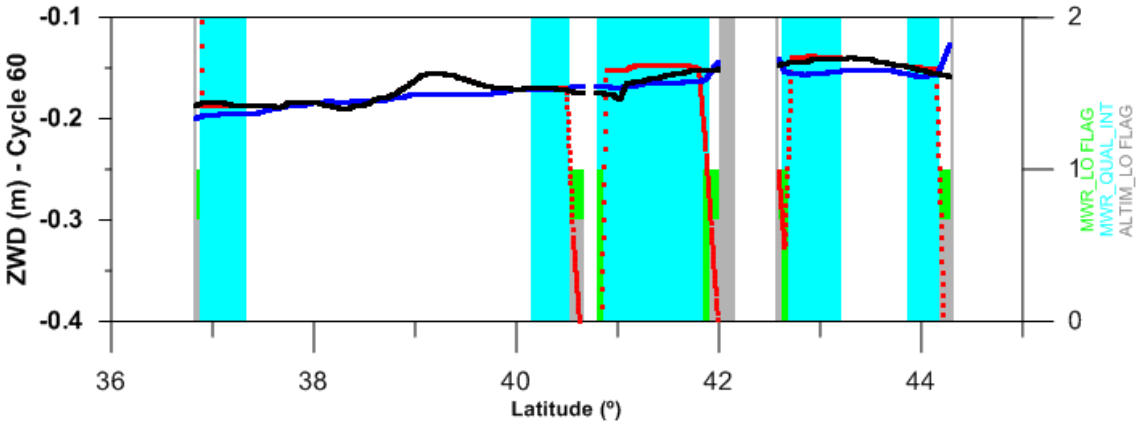

Fig.14.Same as Figure 10 for Envisat pass 130 (West Mediterranean), cycle 60.

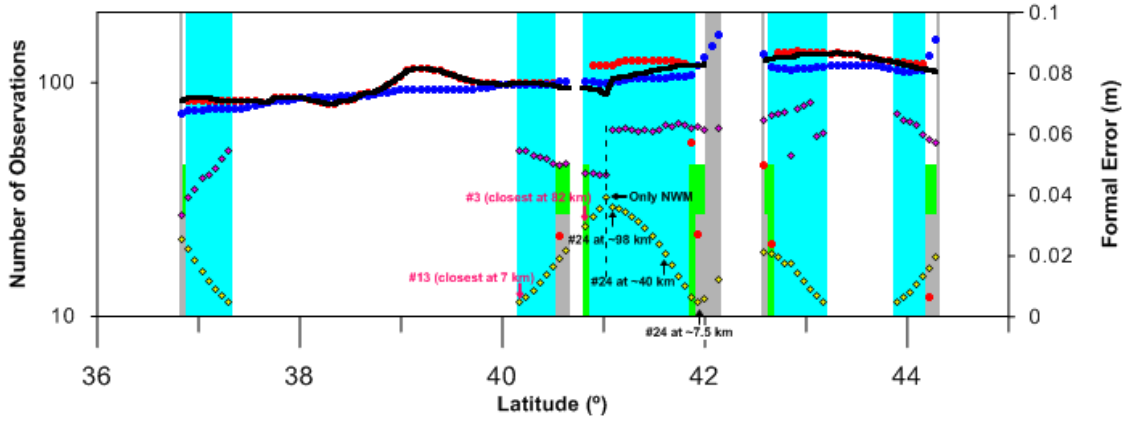

Fig.15.Same as Figure 14, for Envisat pass 130 (West Mediterranean), cycle 60. To facilitate the view, the ECMWF (blue) and MWR (red) corrections are represented at 1Hz. In this figure the formal error and the number of used measurements for each 1Hz computation are also shown. For some points (indicated by the arrows), in particular around the point of maximum formal error (where only NWM observations were available), the number of GNSS and valid MWR observations are shown, respectively in black and magenta, as well as the distance to the closest measurement of the indicated data type.

3 Description of the GPD files content

The data are provided at 18Hz, as ASCII files with the same name as the original CGDR netcdf files, just adding "_GPD" to the file name and replacing the extension ".nc" by ".dat".

Example:

Original COASTALT_V1.1 file on directory: reproc0001_prt:
RA2_MWS_2POF-P20020930_213418_00003017A010_00000_03060_3093.nc

Corresponding GPD file:
RA2_MWS_2POF-P20020930_213418_00003017A010_00000_03060_3093_GPD.dat

Each file contains the following fields:
cycle
pass
h1Hz_MJD
sample
hz18_time
h18Hz_MJD
hz18_lat
hz18_lon
h18_mod_dry_tropo_corr
h18_mod_wet_tropo_corr
h18_mwr_wet_tropo_corr
h18_altim_landocean_flag
h18_radio_landocean_flag
h18_mwr_qua_interp_flag
h18_GPD_wet_tropo_cor
h18_GPD_interp_flag
h18_GPD_formal_error
h18_GPD_num_ponts
h18_GPD_signal _variance

Field description:

All fields are as described in the COASTALT manuals and on the netcdf files. Here only the new fields are described:

h18_GPD_wet_tropo_corr – 18Hz wet tropospheric correction computed as described in sections 1 and 2 (in metres). This correction is valid when the h18_GPD_interp_flag is 0 or 1.

h18_GPD_interp_flag – 18Hz GPD flag set as follows:

- 0 – ocean points for which the MWR correction is valid. In this case the GPD correction is set as equal to the original MWR correction
- 1 – points for which the GPD algorithm provided a valid output
- 2 – points for which there were no data points to compute the GPD correction
- 3 – land points
- 9 – points for which the 18Hz interpolation is not available

For all cases except when the above flag is 1, fields h18_GPD_formal_error and h18_GPD_signal_variance are set to a default value of 9.000 and field h18_GPD_num_points is set to 0.

Note that on version 2.0 of the products there are no points with h18_GPD_interp_flag=2, as explained above.

h18_GPD_formal_error – Formal error in the GPD estimation (in metres)

h18_GPD_num_ponts – Number of data points (of any data type) used in the GPD estimation

h18_GPD_signal _variance – signal variance in m^2.

Note that although the field related with the dry tropospheric correction has been mentioned as an input field of the GPD program and is also provided in the GPD 18Hz files, actually this field is not used in the GPD estimation. It is only provided for completeness, since it is a useful field for various studies.

4 Conclusions

This section summarises the main conclusions presented in this study:

The GPD wet tropospheric correction has been successfully computed for the CGDR 1Hz points and interpolated to 18Hz, both for version 1.1 and version 2.0 of the CGDR products.

For version 1.1 the results from the GPD files have been successfully incorporated in the CGDR by using the addcor module. The same is being performed for version 2.0 of the products.

The decision to perform the computations at 1Hz and not at 18Hz is based on:

- The spatial and temporal scale of the data used by the GPD algorithm
- The temporal and spatial variability of the wet tropospheric correction
- The time required to make the computations (20 times larger for 18Hz when compared to 1Hz)

Some points for which the correction is available at 1Hz cannot be interpolated into 18Hz. For each pass, this happens for the first 10 samples of the first point and for the last 10 samples of the last point. It also happens for the first and last 10 samples of each data segment (a new segment is considered whenever a data gap of at least five1Hz points occurs. This usually corresponds to ocean segments separated by land points.

By adjusting the code to allow the computation of all altimeter 1Hz ocean points plus the two land points closest to the coast, on version 2.0 all altimeter 18Hz ocean points have now a valid GPD correction.

Although various tests were made, it was found that, for the moment, it is safer to use only ECMWF data over ocean. This seems to be the best approach until the authors fully understand how to handle ECMWF over land. For a given point, the GPD estimate is obtained through objective analysis based on all points within a search radius around the point. Therefore, if the ECMWF land data is not handled properly, then the land data will corrupt the coastal ocean estimates. By using only ECMWF data over ocean we ensure that only reliable data are used in the computations.

The files provided with this delivery contain the GPD correction for all CGDR v1.1, except for file: RA2_MWS_2POF-P20020926_201936_00003018A009_00443_03002_2801_hz18.nc

This is the only file for Envisat cycle 9 on the whole data set and, on the performed data analysis before the GPD computations, by mistake, only Envisat cycles 10 to 67 have been identified.

For version 2.0, the correction is provided for all passes with valid fields on the netcdf files.

Although the provided files contain various additional fields that can be used by users wishing to validate the correction and give feed back to authors, the most important fields, that shall be added to the CGDR, are:

- h18_GPD_wet_tropo_cor
- h18_GPD_interp_flag
- h18_GPD_formal_error

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