EXPLOITATION OF GOCE AND CRYOSAT-2 DATA – COMBINED APPLICATIONS

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ABSTRACT

The two ESA Earth Explorer Core missions CryoSat-2 and GOCE provide a unique opportunity for exploring a broad variety of scientific applications in the fields of Geodesy, Oceanography and Cryospheric research. Both missions are currently in orbit and acquiring measurement data. Combining the data derived from the two missions allows computing oceanographic products such as Absolute Dynamic Topography (ADT) with a spatial resolution and accuracy higher than current solutions.

To get an idea of possible improvements in spatial resolution and accuracy with respect to the utilization of previous missions' data, a preliminary case study in the Pacific region will demonstrate the ADT quality. The products used within the case study will be GOCE-only and CryoSat-2-only Low Rate Mode level 2 (LRM L2) datasets on one hand and multi-mission altimetry products and non-GOCE derived geoid models on the other hand. Parameters for comparison are, due to the limited availability of CryoSat-2 data, along track differences and correlation coefficients for single passes of CryoSat-2. An example for an ADT map replacing CryoSat-2 data with Envisat data is presented to show the performance of the techniques applied.

1. AVAILABLE CRYOSAT-2 DATA

Due to recent updates within the CryoSat-2 ground segment and the implementation of an updated processor, LRM L2 data available for the analysis carried out in the following sections, ranges only from 28 January 2011 until 13 February 2011. Fig. 1 shows the ground track pattern of the available CryoSat-2 LRM L2 measurements in the North Pacific region for the time span mentioned above. As explained in section 3, the data suffers from some quality problems and inconsistencies. Therefore the data cannot be regarded as a fully validated product. Nevertheless it will be shown that already at this stage, promising results can be obtained.

Because of large distances between regions covered with measurements and regions not covered, it was decided to execute an along track approach, outlined in section 2, in order to perform an analysis of the ADT derived by CryoSat-2 Sea Surface Heights (SSH) and GOCE geoid solutions. A comprehensive description of the CryoSat-2 satellite, its payload and its three measurement modes can be found in [4].

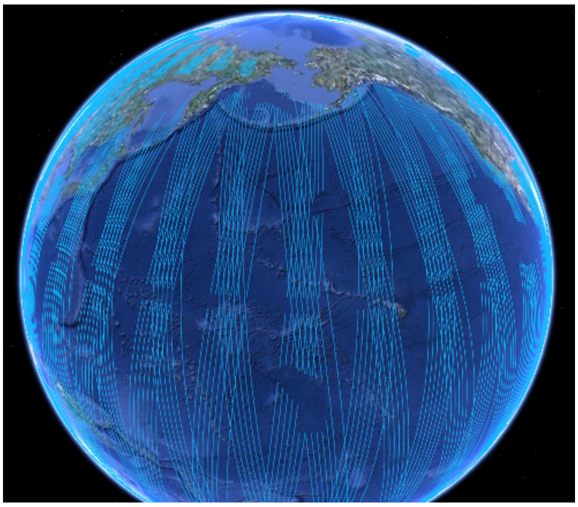

Figure 1 available CryoSat-2 LRM data North Pacific

2. ALONG TRACK APPROACH

As mentioned in section 1, an along track approach was utilised to perform the analysis shown in section 3. The approach is promoted by W. Bosch [2] and sketched in Fig. 2.

The basic equation to determine the ADT is

$$ADT = SSH - N \qquad (1)$$

with the geoid height N. Since spectral consistency of both SSH and N is a basic requirement, filtering is an essential step in order to apply equation 1. Following [2], a Gaussian filter kernel has been chosen for the 1D along track domain as well as for the 2D spectral domain because of its isotropic characteristics and its

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similar behaviour in the 1D and 2D domain. The kernel performs a low pass filtering and its size is the same in all steps. The filtering in the spectral domain was applied by using the workflow filter_shf of the GOCE User Toolbox (GUT) v2.0 [7]. The filter correction (N_{corr}), which is necessary to overcome filter errors in areas with high variability in bathymetry, has been computed evaluating the ultra high resolution geoid EGM2008 [10] developed up to degree/order 2190. An example for the occurrence of the filter error can be a pass of the altimeter along a trench. Applying 1D along track filtering does not change the SSH measurements significantly. But applying 2D filtering so to say lifts the SSH measurements due to the higher surrounding areas. With shrinking size of the filter kernel the amount of the correction decreases.

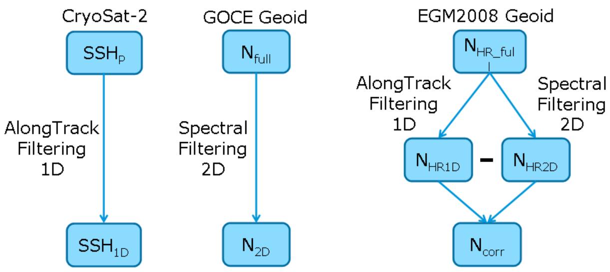

Figure 2 Along track approach

As sketched in Fig. 2, the EGM2008 geoid has been evaluated along the passes of the altimeter on the one side at full resolution with subsequent 1D along track filtering to obtain N_{HR1D} and on the other side after the 2D filtering in the spectral domain to obtain N_{HR2D}. The geoid heights N_{2D} derived from a GOCE geoid were evaluated along the passes of the satellite after applying 2D spectral filtering.

This leads from equation (1) to the full equation

$$ADT = SSH_{1D} - N_{2D} + N_{corr} \qquad (2)$$

with

$$N_{corr} = N_{HR1D} - N_{HR2D} \qquad (3)$$

3. ADT RESULTS

The following section compares results of ADT estimates computed with the along track approach described in section 2 with ADT estimates from an independent source.

3.1. Independent ADT

The independent ADT estimates used for comparison reasons were produced by Ssalto/Duacs and distributed by Aviso, with support from CNES [12]. They are provided on daily basis from a multi mission (Jason-1, Jason-2 and Envisat RA2) altimetry dataset on a ¼ degree global grid. The Aviso results along the CryoSat-2 pass, shown in section 3.2 and 3.3, were interpolated from the grid for the very same day as the pass.

Fig. 3 shows the ADT grid from Aviso for 3 February 2011. The black arrow in the Pacific Ocean marks the location of the CryoSat-2 pass on 3 February 2011 utilised for comparisons described in section 3.3, the blue circle marks the location of the results shown in section 3.2. The scale of the ADT is in meters.

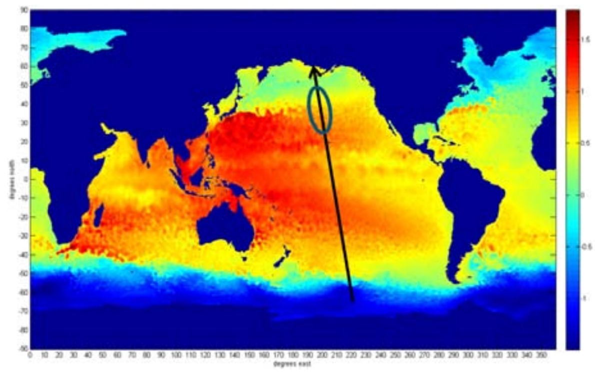

Figure 3 ADT from Aviso and CryoSat-2 pass [m]

3.2. Comparison of different ADT results

Fig. 4 shows the estimate of the ADT using CryoSat-2 LRM L2 measurements and a GOCE derived geoid (time-wise solution 2[nd] release [9] in red and direct solution 2[nd] release [3] in blue) in comparison with the Aviso result (black). An overview of the different GOCE derived geoid models can be found in [8] as well. The resolution is 150km, which implies a half-weight-half-width filter length of 75km.

The very high correlation between the different solutions is clearly visible. The correlation coefficient was computed ranging from 0.97 to 0.98 for the different solutions. It varies only slightly for other resolutions like 120km and 200km.

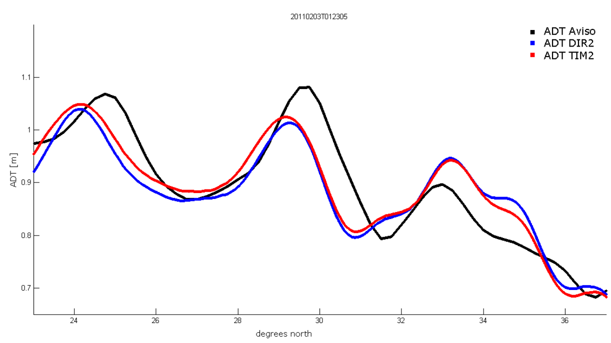

Figure 4 CryoSat-2/GOCE-TIM2 (red), -DIR2 (blue) and Aviso (black) ADTs

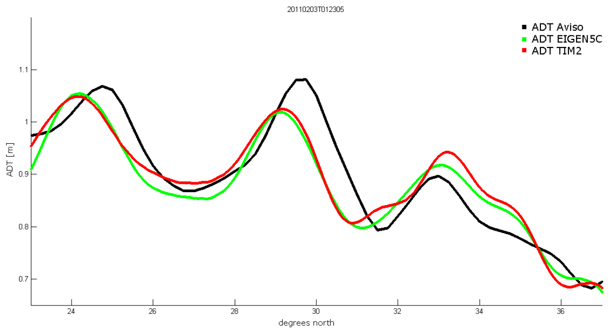

Figure 5 CryoSat-2/GOCE-TIM2 (red), CryoSat-2/Eigen5C (green) and Aviso (black) ADTs

Fig. 5 shows the estimate from Aviso (black) and the GOCE time-wise 2nd release solution (red) with respect to the estimate using the EIGEN 5C [6] geoid (green). Again the different results are highly correlated. The differences between the computed solutions are only marginal. It should be taken into account that the Aviso result is based on three altimetry missions Jason-1, Jason-2 and EnviSat. Their ground tracks do not coincide with the CryoSat-2 ground tracks. Since ADT represents the instantaneous state of the ocean at the time of measurement, the results gained from different missions' data vary by up to several cm due to the observation of different spots of the ocean at different time. Because of the orbit configuration of the altimetry missions involved, the closest observation can be up to 30km apart from a CryoSat-2 observation. This is also the reason for the displacement of some peaks of the different ADT results in along track direction.

Fig. 6 shows the full ascending pass of CryoSat-2 in LRM mode with the ADT computed utilizing the GOCE time-wise 2nd release geoid (red). The ADT from Aviso is plotted in black. The part highlighted in blue marks the results shown in Fig. 4 and Fig. 5. The CryoSat-2 LRM L2 internal Mean Sea Surface (MSS) is represented by the yellow line.

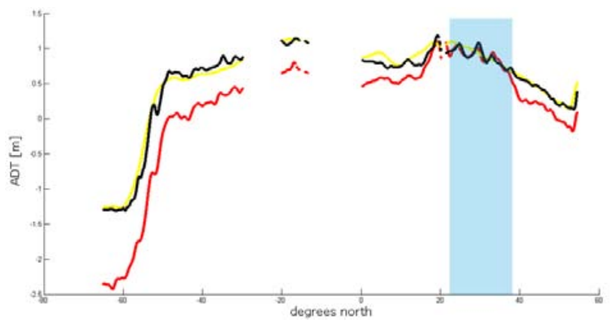

Figure 6 full ascending pass GOCE/CryoSat-2 (red) & Aviso (black) ADTs & CS internal MSS height (yellow)

A prominent feature is the offset in most parts along the pass, although the correlation between the two estimates remains high. This offset has been observed for all data available at the moment of computation (28 January until 12 February 2011). The characteristics of the offset will be shown in more detail in section 3.3 as a contribution to the CryoSat-2 product validation activities.

3.3. Latitude dependent offset

As mentioned in section 3.2 and shown in Fig. 6 an offset between the Aviso and the GOCE/CryoSat-2 derived ADT has been observed. To analyse the offset in more detail, 307 datasets from CryoSat-2 LRM L2 measurements (1 until 3 February 2011) have been examined. These measurements are distributed equally over the globe. For all of these datasets the offset between the ADT from Aviso at the corresponding day and GOCE/CryoSat-2 has been computed.

Fig. 7 shows the mean offset for one degree latitude bins between the two results at 150 km resolution. From this figure a latitude dependency is clearly visible. The minimum offset is observed at about 20 degrees north. At this point an effect due to the incidence of different ellipsoids can be excluded. For an effect due to an ellipsoid error, the minimum or maximum of the offset would be expected to be at the equator. Another indicator for erroneous values within the SSH in the Level 2 LRM product is the offset between the internal MSS (Fig.6 yellow line), which comes with the product but from independent source, and the GOCE/Cryosat-2 ADT. The good matching between the MSS and the Aviso ADT with variations in a range of several decimetres (Sea Level Anomaly SLA) confirms this surmise.

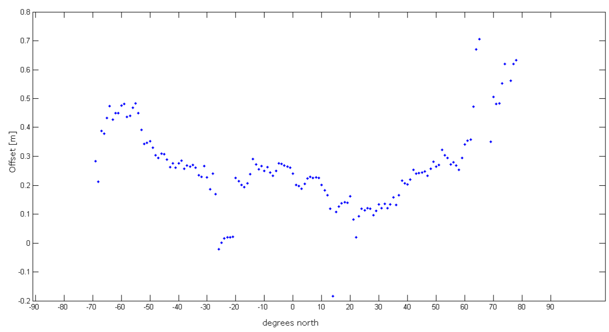

Figure 7 latitude dependent offset

The comparison of the internal MSS height with the DTU10 MSS [1] shows very good agreement. This indicates that the geolocation of the CryoSat-2 measurements is good and the offset between the two ADT results is more likely due to a wrong determination of the range. To identify the root of the problem further investigations are currently ongoing.

It was shown at the CryoSat Validation workshop from 1 – 3 February 2011 in Frascati (Italy) [5], that several issues regarding the overall accuracy and consistency of the LRM L2 product are pending. This includes a time tag bias, incomplete product files, missing correction terms and physically incorrect values for crucial product parameters like SSH, Significant Wave Height (SWH)

and Sea State Bias (SSB). The update of the processing as implemented from 28 January 2011 resolved some problems, but nevertheless significant problems are still present in the current datasets.
It was also shown at the workshop [5] that the problems mentioned in the previous paragraph are not due to issues within the satellite and the on-board hardware itself. The acquisition of measurement data and the transfer to the ground station works fine. The problems are due to errors in the processing chain of the ground segment for the LRM L2 product. Since validation activities are currently on-going it is expected to overcome these difficulties in the near future. A reprocessing of all data acquired so far is foreseen as soon as all problems have been solved.

3.4. ADT from EnviSat SSH and GOCE geoid

To give a first idea of possible results combining altimetry and GOCE data for ADT maps, Fig. 8 shows an estimate in the North Atlantic region. The resolution is again 150km. The EnviSat-RA2 data used for the computation is the GDR from cycle 096 (27 October until 26 November 2010). As already explained above, the use of CryoSat data was not possible due the unavailability of enough data and its insufficient quality. The geoid model applied is the time-wise 2nd release solution.
The extrapolation performed to fill the gaps between the tracks of the EnviSat passes is a local regression using weighted linear least squares and a second degree polynomial model (LOESS). This algorithm is implemented in the Basic Radar Altimetry Toolbox (BRAT) [11] which was called for this task.

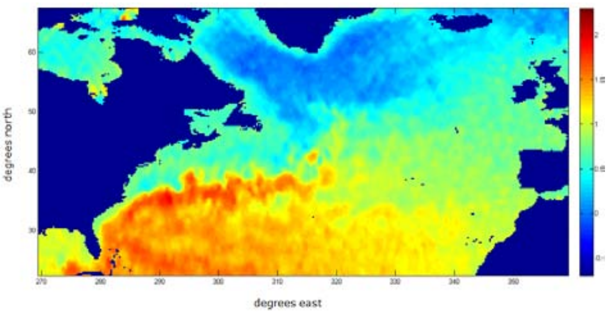

Figure 8 ADT from EnviSat and GOCE tim2 geoid

The estimate shows quite reasonable results for a resolution of 150km and proofs that the methods applied to the altimetry and GOCE data work in a good manner. Depending on the quality of future CryoSat products, the methods can be executed with CryoSat-2 and GOCE data as well. The scale of the ADT is in meters.

4. CONCLUSION AND OUTLOOK

The preliminary results presented in sections 3.2 and 3.4 give a first idea of the capabilities and the potential of the combination of GOCE and Cryosat-2 derived products. It is shown that the estimate of an ADT is of comparable quality to a multi-mission estimate from independent sources, although the CryoSat-2 mission is at an early stage and validation of the ocean products is still ongoing. With impending updates on CryoSat-2 ground segment processing in the near future, an improvement of data quality can be expected.
With more data from CryoSat-2, more comprehensive approaches to access and to characterise the potential of the data can be expected as well.
More comprehensive approaches include the production of not only single tracks of ADT estimates but also maps of ADT including error characteristics and the combination of not only LRM mode but also SAR mode measurements to increase the global coverage. Especially the utilisation of SAR mode measurements opens the gate to higher accuracy SSH and ADT estimates.
A characterisation of the CryoSat-2 mission in relation to other altimetry missions by analysing for example cross over differences provides not only a contribution to CryoSat-2 product validation but also an evaluation of the mission with respect to the general implementation of CryoSat-2 to standard ocean products computation due to the upcoming aging of other missions like Envisat and Jason-1.
Albeit all deficits still present in CryoSat-2 LRM L2 data, it can be concluded that the reconstruction of the ADT shows promising results.

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