EVALUATION OF CRYOSAT-2 MEASUREMENTS FOR THE MONITORING OF LARGE RIVER WATER LEVELS

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ABSTRACT

In this study, and maybe for the first time, we explore the ability of CryoSat-2 satellite to monitor the water level of large rivers. We focus on a section of 500 km of the Madeira river (Amazon basin), around the town of Manicoré, cf. Fig.1.

Due to the drifting orbit of the mission, the usual concept of "virtual station" vanishes and data are to be extracted within polygons that delineate the riverbeds. This results in spatio-temporal time series of the river water level, expressed as a function of both space (distance to the ocean) and time.

We use Cryosat-2 low resolution mode (LRM) data processed with an Ice2 retracker, i.e., the content of the upcoming IOP/GOP ocean product from ESA [1]. For this study, we use demonstration samples (year 2011 on our validation area), processed by the so-called Cryosat Processing Prototype developed by CNES in the framework of the Sentinel-3 Project from ESA [5] [4]. At the time of this study, the product came with no corrections ("solid earth tide", atmosphere, etc.), .

Validation is performed on (1) river water level pseudo time series and (2) river pseudo profile. An overview of the spatio-temporal time series is also given in 2D and 3D plots. Despite the lack of geophysical corrections, results are really promising (Std 0.51 m) and are challenging those obtained by Envisat (Std 0.43 m) and Jason-2 (Std 0.47 m) on nearby virtual stations.

We also demonstrate the potential of the CryoSat-2 and the appropriateness of its drifting orbit to map rivers topography and derive water levels "at anytime and anywhere" , a major topic of interest regarding hydrological propagation models and the preparation of the SWOT mission.

Key words: satellite altimetry, river water level, quality, Amazon basin.

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1. STUDY AREA & DATA EXTRACTION

1.1. Area

This study focuses on the Madeira river (Amazon basin) around Manicoré, between Humait (upstream) to Fazenda Vista Alegre (downstream), cf. Fig. 2.

1.2. Drifting orbit

CryoSat-2 operates from a drifting orbit that has a very long repeat period (369 days) and a high number of crossover points (inter-track distance at equator is 7 km). Because of such a long repeat period, the usual concept of "virtual stations" vanishes. This calls to rethink the way data is extracted, edited, filtered and even used!

1.3. River contours

We use the SWBD (SRTM Water Body Data) to delineate the river contours and a point in polygon algorithm to determine whether measurement were taken over the river or not (land, islands, etc.).

1.4. Data preprocessing

Once CryoSat-2 data have been extracted and edited, a temporal filter is applied after reducing spatial variability of the data (that is to remove the river topography derived from in situ data). The final spatio-temporal series are built by selecting the most representative measurement from each river crossing. Since we don't have apply any correction, we won't discuss the systematic bias of altimetry measurements.

2. VALIDATION OF RIVER LEVEL PSEUDO TIME SERIES

CryoSat-2 pseudo water level time series (cf. Fig. 3) are artificially built by removing the spatial component variability of the altimetry data (that is the river water level profile, cf. Fig. 5 and 4).

Three different time series are built by progressively restricting the length L, the longitudinal section of the river, where CryoSat-2 data are to be extracted (cf. Fig.2):

(1) L=464 km (all available data),

(2) L=236 km to simulate the orbit periods of Jason-2 (10 days),

(3) L=67 km to simulate the orbit periods of Envisat (35 days).

Time series are compared to in situ gauging data from Manicoré : best results have a standard deviation of 0.51 m despite the lack of corrections. It seems clear that CryoSat-2 is able to deliver high quality river water levels, in the range of Envisat (0.43 m) and Jason-2 (0.47 m) accuracy (data from UEA, [2]).

3. THE BENEFITS OF A DRIFTING ORBIT

3.1. River pseudo profile (high stage)

The river profile of the Madeira river (high water stage) is estimated using CryoSat-2 data and in situ time series from Manicoré gauging station. This pseudo river profile is artificially built by removing the temporal variability component of the altimetry data (that is the in situ river water level signal).

The resulting profile is compared to in situ river profile interpolated from the three gauging stations (cf. Fig. 2). Overall results are quite consistent (Std=0.13 m, $R^2 = 0.977$).

3.2. Spatio-temporal series

Spatio-temporal series are the natural form of CryoSat-2 measurements of river water levels. The drifting orbit allows an unprecedented coverage with its unique sampling of the river in both space and time. Such orbit seems really promising, notably to better constraint river propagation models.

Figures 6 and 7 illustrate this space and time sampling and gives an estimation (interpolated surface) of the river water level “anywhere and at any time” : $Z(x, t)$.

4. CONCLUSION

The good validation results (Std 0.51 m) and the wide range of new applications of CryoSat-2 data in hydrology arise like **a little revolution**.

The drifting orbit allows to map river water surface topography, derive river profiles and build pseudo time series. Such orbit, with high spatial density coverage, might be more suited than repetitive orbits to answer the needs of water level and discharge propagation models, and moreover, fully argue the great potential of the forthcoming SWOT mission.

Once again, this is a call to work hard toward massively merged altimetry products for hydrology as well as to develop powerful tools to handle such databases. CryoSat-2 will be a precious source of data to glue past, present and future data from repetitive-orbit altimetry missions such as Envisat, Jason-2, AltiKa, Sentinel-3 and Jason-CS. . . an opportunity to fulfill, for the next ten years, the water level database on which SWOT data must grow (“GoogleWater”?).

5. PERSPECTIVES

Perspectives of this study include applying the same steps to the official L2 ESA products (should be available in march 2013) and evaluating the SIRAL-2 SAR and SARin modes in the perspective of SWOT and Sentinel-3. Work has already been initiated to apply CryoSat-2 data coupled to in situ and multi-mission altimetry into discharge and water level models of the Amazon basin and Niger rivers.

The estimation of $Z(x, t)$ from multi-mission and in situ data will be **a topic of major interest**.

ACKNOWLEDGMENTS

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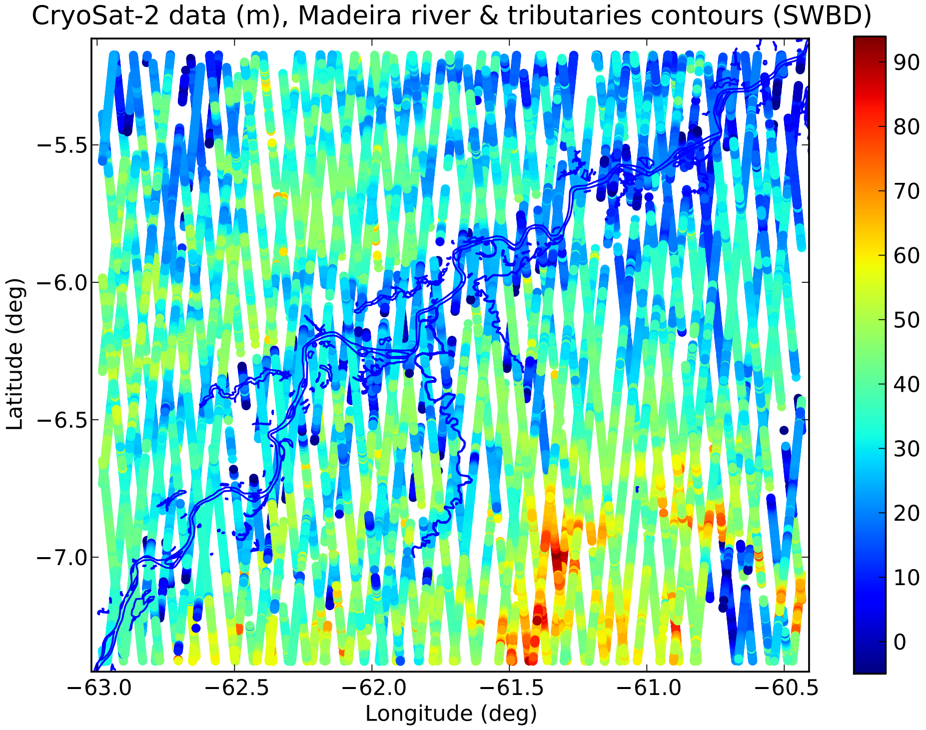

Figure 1. All available data, after editing, from CryoSat-2 (heights as colored dots) and SWBD river contours of the Madeira river and its direct tributaries (blue polygons). Note that this map is not exhaustive regarding the other rivers.

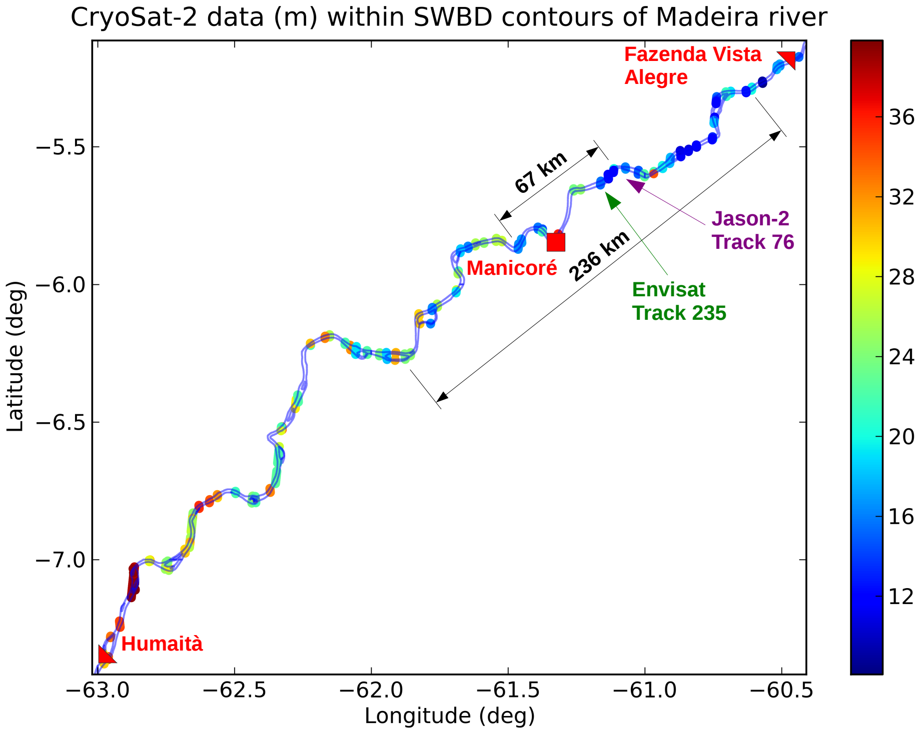

Figure 2. Same area after geolocalized extraction of the CryoSat-2 data (heights as colored dots) within riverbed polygons of the Madeira river only (blue polygons) and Envisat and Jason-2 virtual stations. Later on, data will be filtered to produce a proper alti-hydrological dataset.

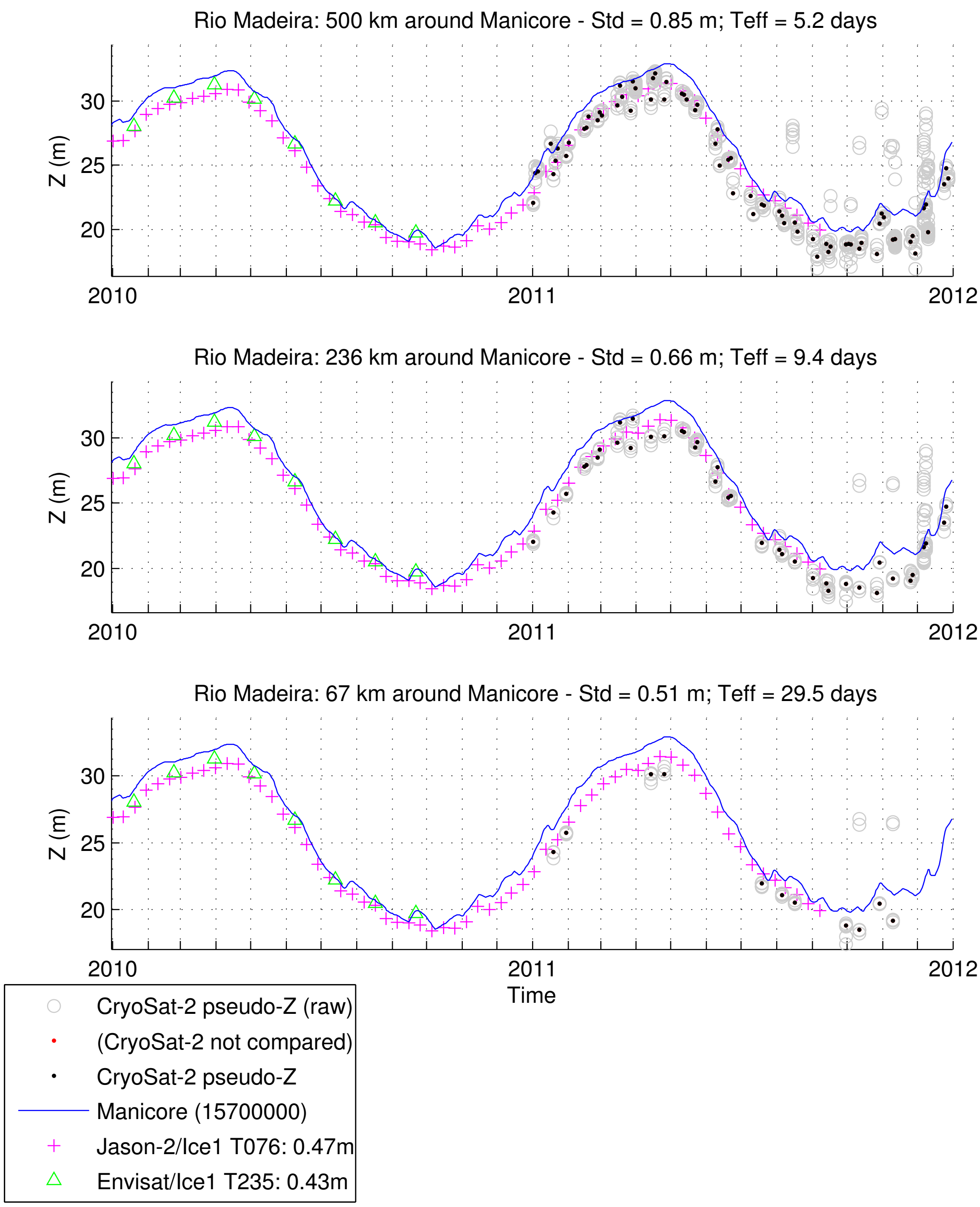

Figure 3. Validation of CryoSat-2 pseudo time series. [top] All available data, [middle] Jason-2-like time series (236 km), [bottom] Envisat-like time series (67 km). Superimposed are the time series of Envisat (Ice1, △) and Jason-2 (Ice1, +) from UEA. Validation of CryoSat-2 data is performed on filtered data (●), while we can actually see all measurements extracted within the riverbed polygons (○).

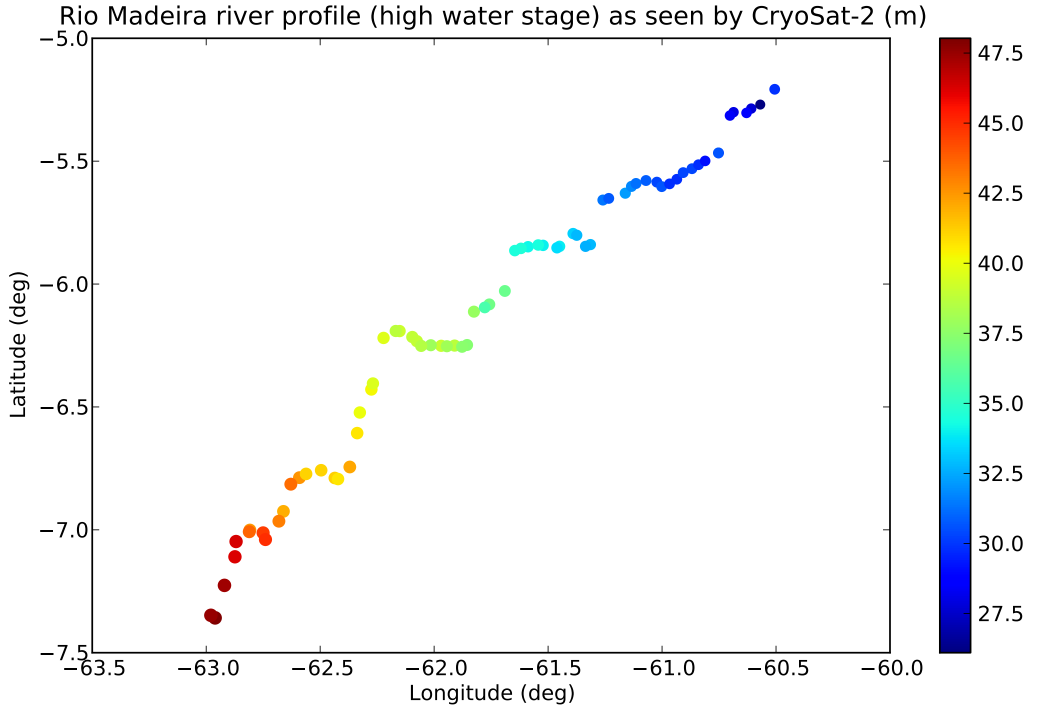

Figure 4. Map of the Madeira river pseudo river profile measured by CryoSat-2 and rectified using in situ gauging data from Manicoré (to remove temporal variations). Map view with colored heights (m).

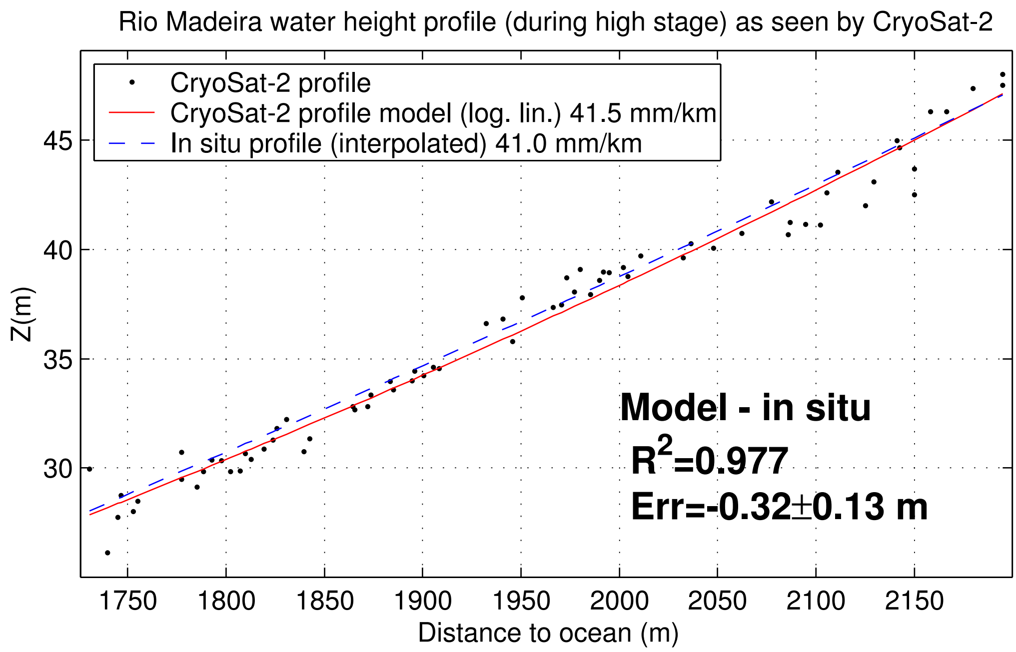

Figure 5. Madeira river longitudinal pseudo river profile measured by CryoSat-2 and rectified using in situ gauging data from Manicoré (to remove temporal variations). The CryoSat-2 measurements (•) are fitted using a log-linear model ($y = a.x^b$, red curve) ; the estimated mean slope (41.5 mm/km) is very consistent with in situ data (dashed blue line) mean slope (41.0 mm/km). Errata : Unit of "Distance to ocean" is (km), not (m).

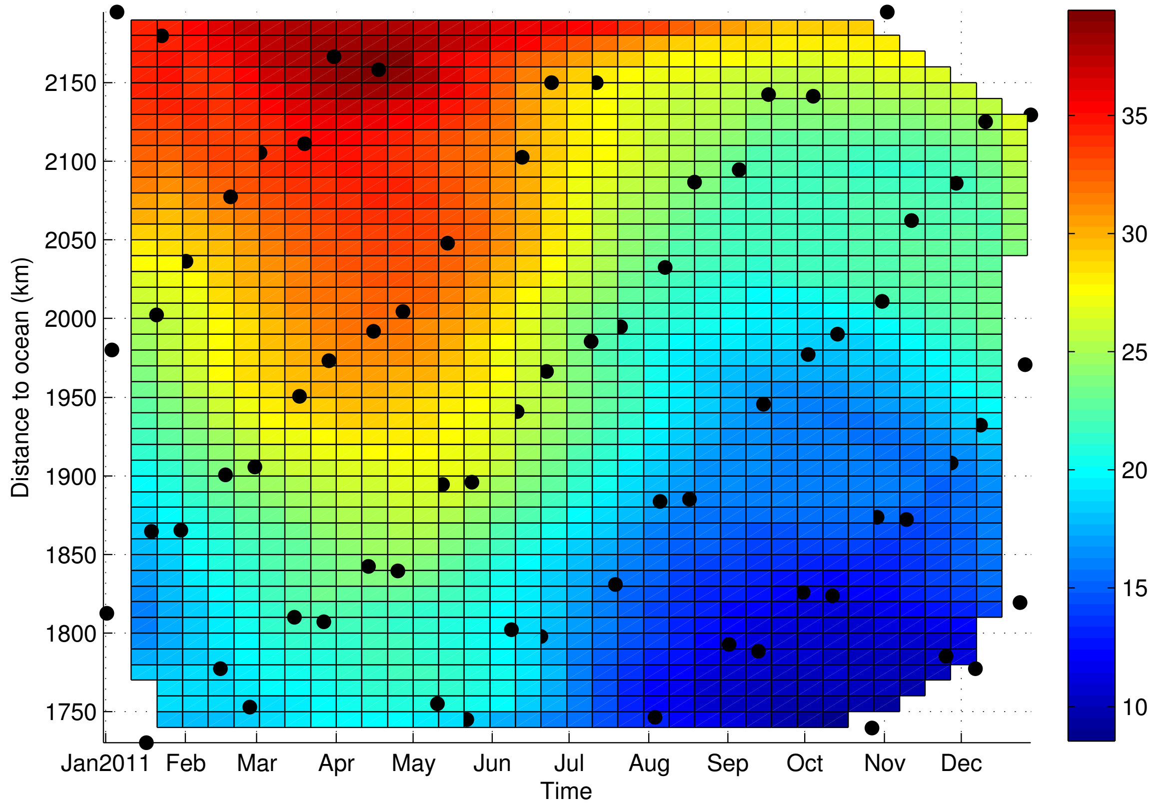

Figure 6. 2D view of the spatio-temporal sampling distribution of CryoSat-2 river water level measurements $Z(x,t)$. CryoSat-2 measurements (•) were interpolated to estimate river water level $Z(x,t)$ "anywhere along the river path and at any time" (colored surface).

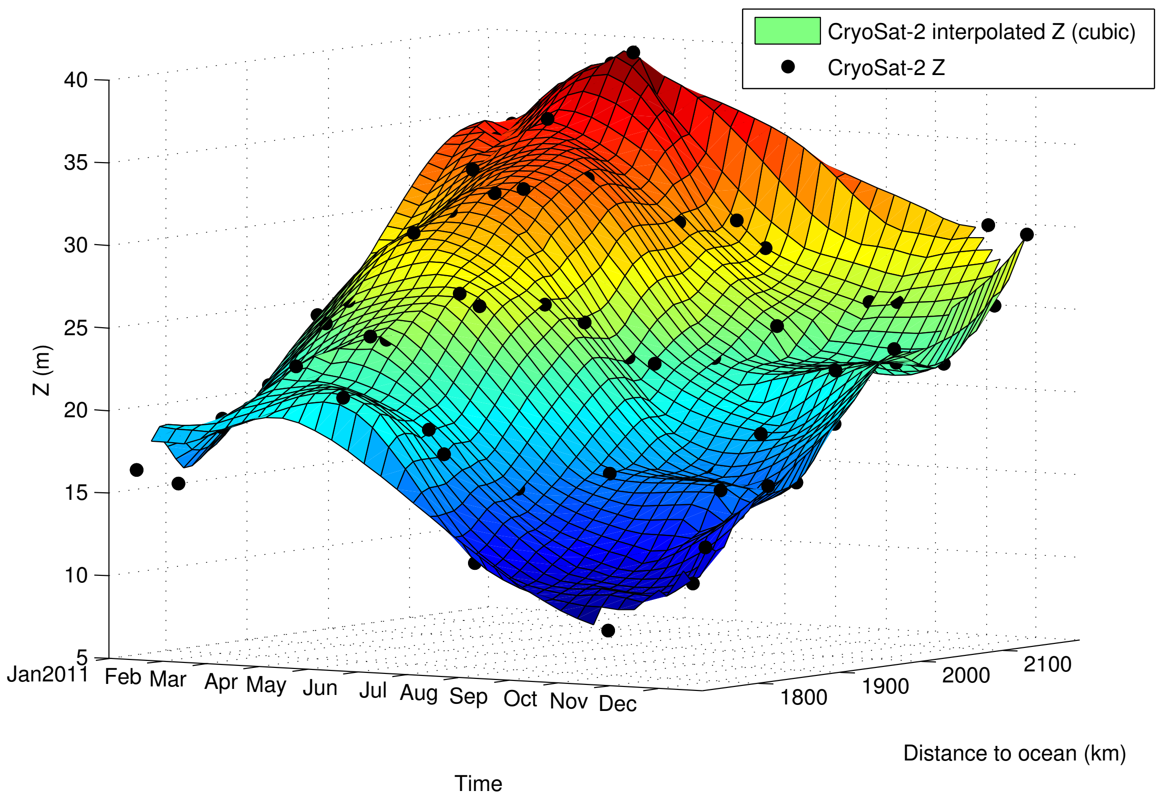

Figure 7. 3D view of the spatio-temporal sampling distribution of CryoSat-2 river water level measurements $Z(x,t)$. CryoSat-2 measurements (•) were interpolated to estimate river water level $Z(x,t)$ "anywhere along the river path and at any time" (colored surface).