CryoSat-2 for hydrological Purposes Data Processing, Visualization and Analysis

VOLKER MAYER[1], NICO SNEEUW[2] & MOHAMMAD J. TOURIAN[3]

Abstract: CryoSat-2, a remote sensing satellite of ESA, which is originally designed for monitoring sea and land ice surfaces, provides global radar altimetry data, which can also be used for other areas of application. This thesis will analyze its capability for hydrological studies of rivers, more precisely of their water level, extent and slope.
For this purpose a GUI based on MATLAB, called CryoTrack, has been developed. It allows the operator to comprehend the tracks of the CryoSat-2 satellite on a global grid and to access their measurements for selected area and date. This data was used to determine water extent and slope of rivers, by combining the information of several radar altimetry quantities.
Analyzing several intersections between the satellite tracks and the Niger River, algorithms for the designation of river width and slope were derived and tested for their capabilities and limitations. The transitions between water and land surfaces can be detected for wide rivers and their distance allows estimation the river width. The moderate accuracy of this water extent calculation stands in contrast to the very good results of the slope computation between two or more intersections in the second part of the analysis.

1 Introduction

CryoSat-2, launched on 8 April 2010, is the replacement mission for the original CryoSat satellite, which has been lost in a launch failure in 2005. The Mission is part of ESA's Earth Explorers series, which is focusing on the science and research elements of their Living Planet program. With GOCE, ESA's gravity mission launched in March 2009, and SMOS, a water mission from November 2009, there are two other Earth Explorers operating. The focus of the CryoSat-2 mission lies on monitoring of Earth's land and sea ice surfaces. Changes in their thickness and extent help to understand how those areas are affected by climate change. The radar altimetry mission was planned for duration of at least three years and is still operating.
Rivers, especially the amount of their discharge, act a crucial part in the hydrological cycle. Major changes in their water level can cause flooding or droughts and influence civilization in the long-term. Different approaches are pursued to monitor the essential quantities like river width and slope necessary to estimate river discharge. Traditional methods using in situ measurements are often officially restricted by countries and their coverage is expensive and declining. An alternative is space born remote sensing, which is independent from spatial limitations but temporally fixed to the orbit of the respective satellite SMITH. Different satellites and sensor types are exploited for this purpose, like Landsat (space based imagery), MODIS (Spectroradiometry) and Radarsat (SAR imagery) ALSDORF. The focus of most of these missions however, lies on the monitoring of different properties like ice or oceans. Especially a SAR mission focusing on rivers is a long time coming FEKETE.

1) Volker Mayer, Bachelor thesis, Geodäsie und Geoinformatik, University of Stuttgart
2) Prof. Dr.-Ing Nico Sneeuw, Institute of Geodesy, University of Stuttgart
3) Dr.-Ing Mohammad J. Tourian, Institute of Geodesy, University Stuttgart

CryoSat-2 is originally designed to monitor ice surfaces, but the data is already freely available and its capability for hydrological analysis can be tested. Characteristics of this mission might be also useful for the design of a possible specific sensor and mission. ESA provides an application called “CryoSat User Tool” (CUT), which allows selection and visualization of CryoSat-2 user products on a 3D world map. However, this software did not satisfy us. Therefore, suitable software called CryoTrack, together with a respective dataset processing method, was developed to allow hydrological analysis. It allows the operator to visualize the tracks and to quickly find and select the measurement user products of the satellite. For selected area and time, these quantities can be called from the dataset and used for analysis.
The software is used to test the capability of CryoSat-2 for hydrological analysis, by trying to determine important hydrological properties of rivers, like water level, river width and slope.

2 CryoTrack: CryoSat-2 Data Visualization GUI

CryoSat-2 produces a massive amount of data, available via ESA’s FTP server. To perform analyses they need to preprocessed and visualized in a suitable manner. To allow quick access to the desired data, index files have to be prepared within the preprocessing. The MATLAB function CryoSeqRefMat.m has been developed for this purpose and can provide reference arrays on a monthly basis.

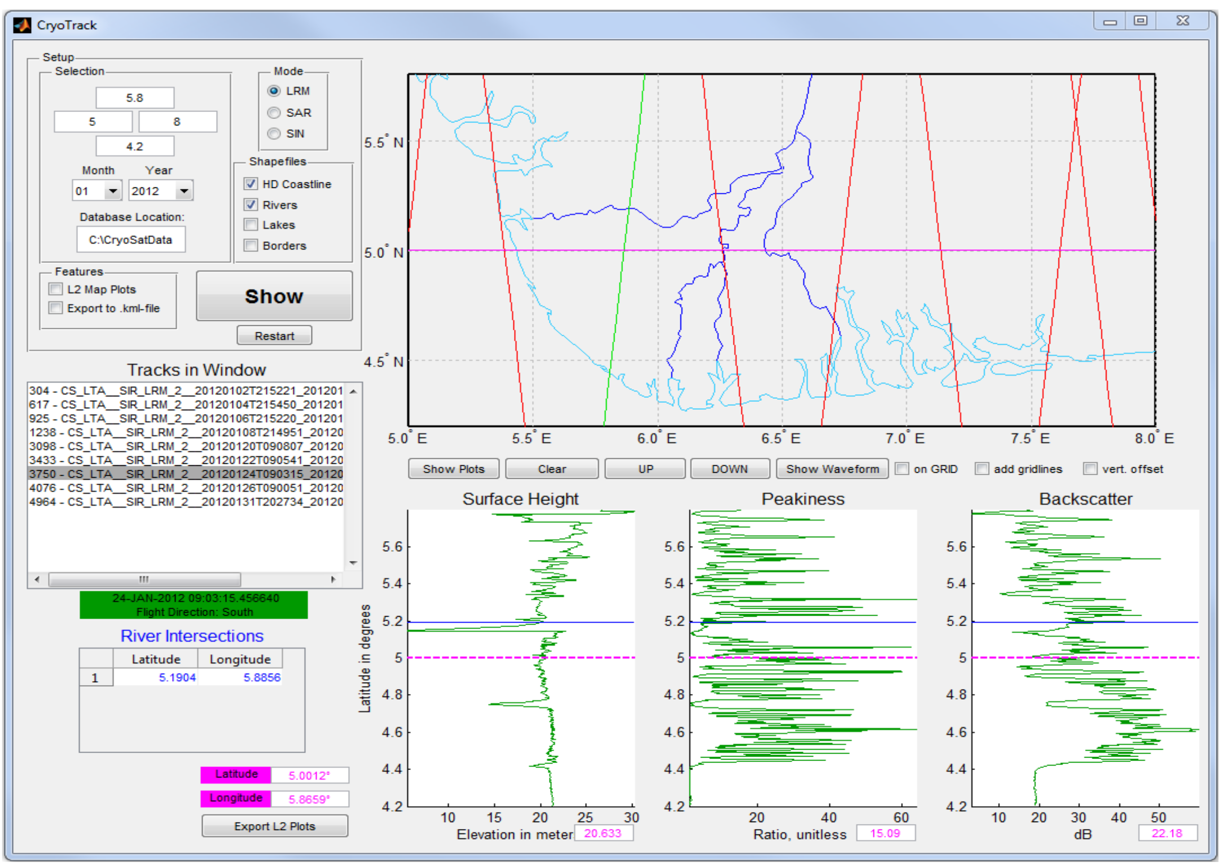


Figure 1: CryoTrack: Graphical user interface based on MATLAB

These Index files play a crucial role in the performance of the CryoTrack GUI. All satellite tracks in the area and month and interest can be visualized and the operator can select every single one and access its information. Out of the various radar altimetry quantities, following have been chosen as most relevant for hydrological analyses:

Surface Height The measured altitude determined by the radar altimeter, corrected to the WGS84 Ellipsoid, which CryoSat-2 is referenced to.

Peakiness Computed measure of how sharply peaked an echo is. Surfaces returning a high specular waveform, in our case water bodies, generate a high peakiness value. Therefore a high value does indicate the presence of a river or at least some kind of water body.

Backscatter The backscatter value σ_0, also known as radar cross section, is a coefficient, which is providing information about the nature of the surface too. It is a function of the radar frequency, polarization, incidence angle, target surface roughness, geometric shape and dielectric properties. For low wind speeds and waves the surface of a water body is very flat and does return a high backscatter value, respectively a peak for the cross section of a river.

Waveform The recorded waveform of the reflected signal. The specularity of an individual curve allows conclusions about the nature of the reflecting surface.

All of these quantities can be visualized in different ways, like graphs or color coded plots, to simplify comparison. The tool does also provide functions to export the selected data and plots to e.g. MATLABs workspace or Google Earth.

3 Hydrological Analysis using CryoSat-2

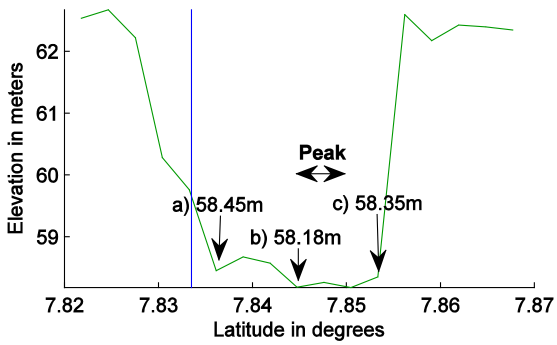
The researches of this thesis does focus on two specific physical characteristics of a river, as there are width, respectively the cross-section water extent, and slope. The basic idea is to compare the measured quantities to find the transitions between water and land surfaces.
Water has a much higher specular surface than solid ground. This property is reflected as peaks in the waveform, as well as in the peakiness and the backscatter value. The idea behind the surface height is, that water bodies are naturally very flat; therefore a shift in surface height would indicate a transition between water and land. According to these approaches, two algorithms were derived and tested.

3.1 River Width

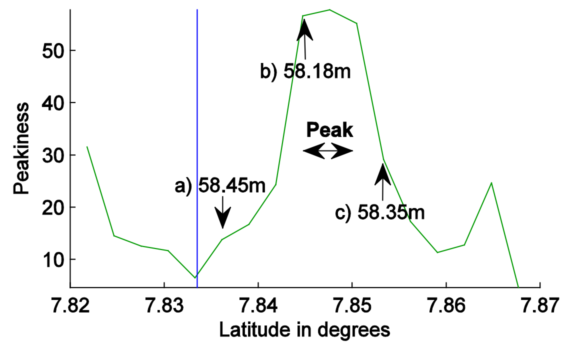
Crucial steps of the river width algorithm are:

- Look for peaks in the peakiness and backscatter graphs.
- Focus on a band of constant surface height around the latitude of the peaks.
- Look at peakiness, backscatter and waveform of the measurements of this band and estimate the latitude of the transitions by comparing all of the quantities.
- Compute distance between the transitions and adjust it for the intersection angle between satellite track and river lane.

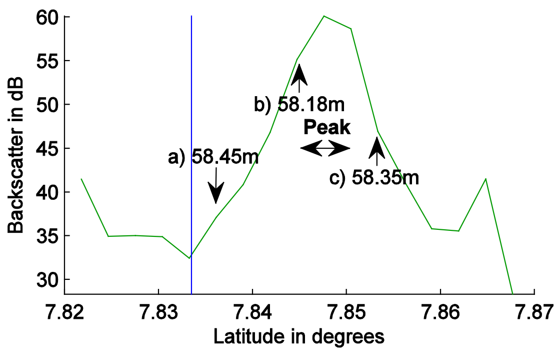
The used testing area used in this thesis is Niger River. It is a very wide river and also part of other research at the Institute of Geodesy in Stuttgart



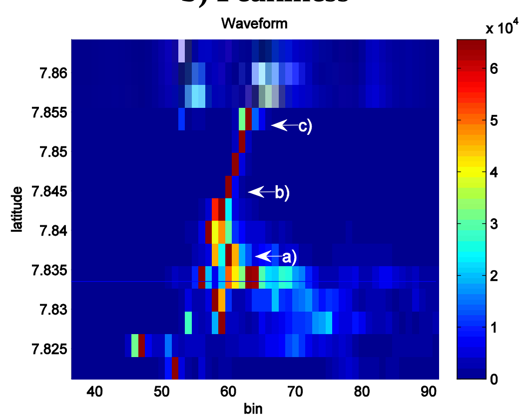
a) Surface Height



b) Peakiness



c) Backscatter



d) Color Coded Waveform Plot

Figure 3: Google Earth

Figure 2: CryoSat-2 crossing Niger River on the 01/04/12, River direction: West, Points: b) 7.8447° N 6.8405° E, c) 7.8533° N 6.8396° E. Niger runs through a valley. Peaks indicate water extent from b) to c) of 1270m. Blue line: Rough estimation of the river lane. Dashed magenta line: marks the selected measurement. Figure 2d) shows the waveform of neighbouring measurements, to allow direct comparison

This example shows various measurements of the CryoSat-2, while flying over Niger River. At this point Niger runs through a little stream valley. The peaks in peakiness and backscatter are obvious but the river bed does not define the river clearly. It seems to be somewhere between point a) and c). However, the amplitudes of backscatter and particular peakiness decrease significantly from point b) on. They also drop at c), but to the right a steep slope is limiting the river. Hence the best estimate is b) to c) with surface height differences of less than 20cm in between. Their distance is about 1270m, varying less than 100m from the reference value taken from Google Earth. The waveform grid plot, see Figure 2d), matches this assumption. Three waveforms are perfectly specular with all their power within one bin and the fourth at c) does also have a sharp peak. This result is very satisfying especially concerning the limited resolution of CryoSat-2 with only one measurement roughly every 300m. Within its bounds CryoSat-2 is actually useful for hydrological measurements like this.

Various parts of the river have been analyzed at different times of the year. The Location of the River was always comprehensible and also islands within the river could be reproduced.

3.2 River Slope

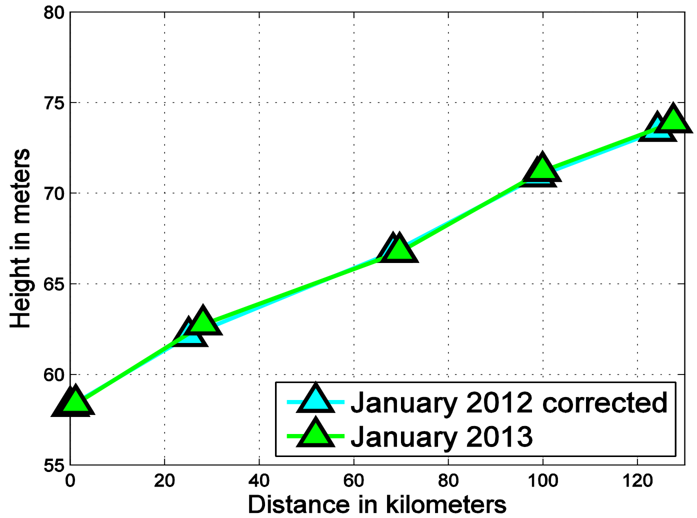


Figure 5: Computed Rivers slope visualized along the course river. Fairly linear and consistent behavior over the distance.

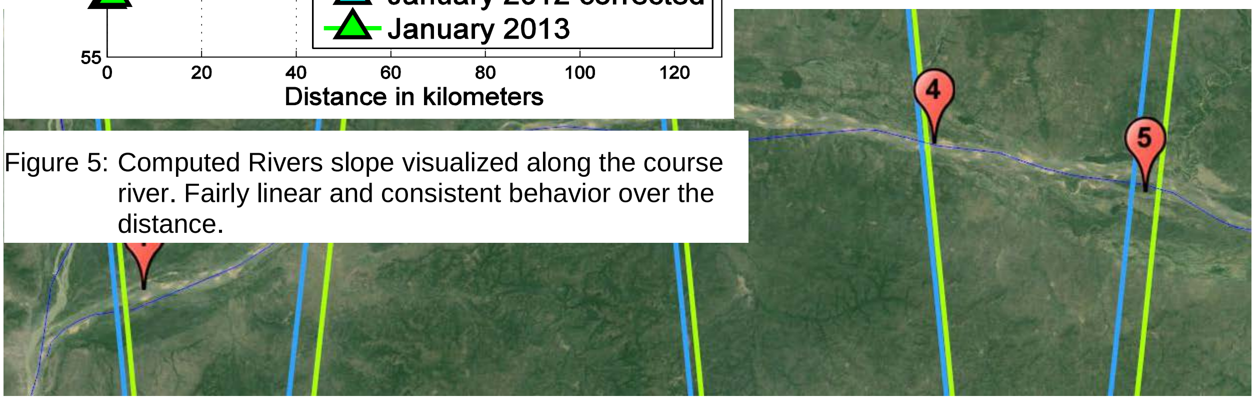


Figure 4: Corresponding satellite tracks Google Earth of CryoSat-2 over Niger in January 2012 and 2013. Offset is caused by minor changes in the satellite orbit.

The second analyzed river property is the along-track slope. Again, an algorithm was developed based on the idea of computing the surface height difference of two neighboring satellite tracks, divided by the distance between the intersections. The detection of the river itself is easier, because only the middle and not the transitions have been estimated. However, temporal offsets between the intersections can cause issues. The center point is determined of the river as the point with the highest specularity within the river using another algorithm. Minor changes in the precision of this method are usually not significant, due to the relatively much greater distance between the satellite tracks. It is important to compute the distance between the intersections along the river; otherwise bends could incorrectly increase the slope. The computed slope matched the expected values and also the differences in the year-to-year comparison stayed within a small cm-per-km range. A special case in which a track crosses a river at least twice was also discussed. Such a particular case is not biased by a temporal offset disappears and provides a very good slope value.

The example shown here, compares the observations of Niger River in January 2012 and 2013. The computed slopes proved constant over the period down to sub-cm range. The numerical values are comprehensible and match the expectations.

4 Conclusions

Combining the measured quantities surface height, peakiness and backscatter the presence of major rivers can easily be distinguished. The biggest limitation for such analysis stays the same as for other space-born radar sensors: The low resolution of only one measurement roughly every 300m. For wide rivers like Niger however, good estimates have been achieved using the developed algorithm. Especially the surface height, which naturally is quite constant above a water surface, is a very good indicator.

Besides the manual way of combining the information of the quantities as shown before, also an automatic algorithm was tested within this thesis. A Quotient computed out of the peakiness and backscatter values divided by the gradient of the surface height, was an attempt to combine the measurement to a single value and to reduce the necessary amount of threshold to only one. The determination of a reliant threshold however, is the biggest challenge in both cases and requires more testing as I was able to perform in the extent of this bachelor thesis. Big intersection angles between track and river are another major limitation for this kind of river analysis. The sharper the angle between river and the satellite track direction is, the less precise the cross-section estimation will become

River slope determination on the other side is less ambiguous, mostly because only one valid measurement per intersection is needed. Solely the determination of the along-track distance of the river and the temporal offset may cause difficulties. However, as the computed slope value is an average value over kilometers, small uncertainties in height and distance are not that significant.

All the performed analyses done so far just used the low resolved data CryoSat-2 provides. Higher resolved measurements like SAR might be even better, but they are only locally available. Amongst other reasons, that’s why CryoSat-2 stays in the focus of the hydrological research of Institute of Geodesy Stuttgart.

5 Bibliography

MAYER, VOLKER: Bachelor thesis: CryoSat-2 for hydrological Purposes Data Processing, Visualization and Analysis, University of Stuttgart, Institute of Geodesy, 2013, http://elib.uni-stuttgart.de/opus/volltexte/2013/8679/

SMITH, L. C. AND PAVELSKY, T. M.: Estimation of river discharge, propagation speed, and hydraulic geometry from space: Lena River, Siberia, Water Resources Research, 44, W03 427, doi: 10.1029/2007WR006133, 2008.

ALSDORF, D. E., RODRÍGUEZ, E., AND LETTENMAIER, D. P.: Measuring surface water from space, Reviews of Geophysics, 45, doi: 10.1029/2006RG000197, 2007.

FEKETE, B. M. AND VÖRÖSMARTY, C. J.: The current status of global river discharge monitoring and potential new technologies complementing traditional discharge measurements, IAHS Publ. 309, 2007.