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# Sea surface height determination in the Arctic using Cryosat-2 SAR data from primary peak empirical retrackers

Maulik Jain *, Ole Baltazar Andersen, Jørgen Dall, Lars Stenseng

*National Space Institute/DTU Space, Elektrovej 327, DK-2800, Denmark*

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**Abstract**

SAR waveforms from Cryosat-2 are processed using primary peak empirical retrackers to determine the sea surface height in the Arctic. The empirical retrackers investigated are based on the combination of the traditional OCOG (Offset Center of Gravity) and threshold methods with primary peak extraction. The primary peak retrackers involve the application of retracking algorithms on just the primary peak of the waveform instead of the complete reflected waveform. These primary peak empirical retrackers are developed for Cryosat-2 SAR data. This is the first time SAR data in the Arctic are processed using such primary peak retrackers. The sea surface heights determined are compared with the sea surface heights generated by the ESA Retracker as available in the Cryosat-2 Level-2 dataset from 2012. Performance of the primary peak retrackers is also compared with the traditional OCOG, threshold and five parameter beta retrackers. In the case of SAR-lead data, it is concluded that the proposed primary peak retrackers work better as compared with the traditional retrackers (OCOG, threshold, five parameter beta) as well as the ESA Retracker.


*Keywords:* SAR altimetry; Cryosat-2; Empirical retracking; Sea ice

## 1. Introduction

Altimetry derived sea surface height is used in climate prediction, monitoring ocean circulation, weather forecasting and determination of the gravity field. ESA's (European Space Agency) Cryosat-2 has the first ever SAR (Synthetic Aperture Radar) altimeter on board a satellite. The objective of this work is to retrieve sea surface heights in the Arctic using this Cryosat-2 SAR data. The retrieval of sea surface heights is done using two primary peak empirical retrackers. These retrackers which have been used for LRM (Low Resolution Mode) data before are implemented here for Cryosat-2 SAR data by selecting and defining the primary peak over which they are applied. The presence of sea ice and coasts makes waveform retracking in the Arctic considerably more difficult compared with the open ocean. The primary peak empirical retrackers are developed focusing on these problematic areas where traditional empirical retrackers provide noisy results.

### 1.1. SAR/LRM altimetric data

Cryosat-2 measures in SAR mode wherever LRM (Low Resolution Mode) data are deemed to give inaccurate results (Cryosat Product Handbook, 2012). The choice whether the data measured are LRM or SAR is made by using SAR/LRM masks(Cryosat Product Handbook, 2012). The SAR data are particularly important in the Arctic Region as they are robust for sea surface height determination and offer smaller along-track footprint size as compared with LRM altimetry. The along-track footprint size of LRM altimetry varies from 2 km to

* Corresponding author.
*E-mail address:* jain@space.dtu.dk (M. Jain).

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10 km while the along-track footprint size of SAR altimetry varies from 250 m to 400 m (Cryosat Product Handbook, 2012). LRM echoes are uncorrelated and pulse limited while SAR altimetry is composed of correlated and coherently transmitted echoes. The LRM mode is used over oceans and ice sheets while SAR mode is preferred over sea ice, land ice sheets, polar ocean and coastal ocean. Detailed descriptions are presented in literature for LRM altimetry (Chelton et al., 1989) and for SAR altimetry (Raney, 1998).

### 1.2. Sea surface height determination using retracking techniques

The procedure of sea surface height determination using retracking techniques is shown in Eqs. (1) and (2) (Andersen and Scharroo, 2011).

$$H_{ss} = H_{alt} - H_{range} - Epoch - H_{geo} \quad (1)$$

$$Epoch = (C_{ntp} - C_{rtrk}) * B_{spc} \quad (2)$$

Here $H_{ss}$ is the retracked sea surface height, $H_{alt}$ is the altitude of the satellite above the reference ellipsoid and $H_{range}$ is the on board tracker range and is the measured distance between the satellite and the sea surface referred to a nominal tracking position in the waveform window. The waveform window contains the power of the signal reflected from the sea surface.

The nominal tracking point is located in the nominal tracking position which is the bin on the mid-point of the bin-axis in the waveform window. The correct tracking point is the mid-point on the waveform's leading edge that corresponds to the retracking position, which in turn corresponds to the total range from the satellite trajectory to the nadir point on the sea surface. $C_{ntp}$ and $C_{rtrk}$ are the distances in units of bin numbers from the first bin of the waveform window to the nominal tracking position and the retracking position, respectively.

The *Epoch* is the difference in meters from the nominal tracking position to the retracking position. This is computed as shown in Eq. (2). In Cryosat-2 SAR data, the reflected waveform is formed by incoherent summing of a stack of looks which are co-registered with the look at the center of the stack. At the stack center, the range from the altimeter to the nadir point is correctly obtained from the retracking position. Fig. 1 shows the retracking position in the reflected waveform.

$B_{spc}$ is the bin spacing in meters in the waveform window, and is the equivalent distance between two bins in the waveform. This equivalent distance for Cryosat-2 SAR Baseline B data processed here is 23.42 cm (Cryosat Product Handbook, 2012). $H_{geo}$ is the sum of range and geophysical corrections needed to correct the range, including tropospheric, ionospheric, tidal and barometric corrections. Range correction is required and is important in order to take into account the effect of the troposphere, ionosphere and tides on sea surface height determination. These factors effect the range measurement and hence must be considered for correct range estimation. The values of $H_{alt}$, $H_{range}$ and $H_{geo}$ are available in the Cryosat-2 dataset.

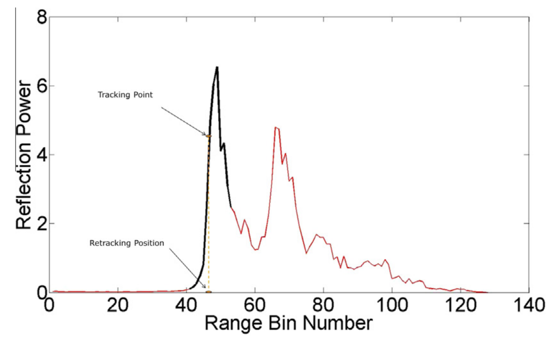

Fig. 1. Illustration of retracking position for a Cryosat-2 SAR waveform (in red). The retracking position is the location of the tracking point in terms of bin numbers. The black color shows the extracted primary peak described in Section 1.3. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

The range is retracked by finding $C_{rtrk}$ in the waveform window. The technique of calculating $C_{rtrk}$ by using various algorithms on the reflected waveform is called retracking. Range retracking is necessary to find the correct tracking point in the waveform window. Once the retracking position in decimal bin numbers is obtained, it is used in Eqs. (1) and (2) to compute the sea surface height. The sea surface height anomaly can subsequently be obtained by subtracting the geoid or the mean sea surface (depending on application) from the sea surface height (Andersen and Scharroo, 2011).

### 1.3. Novelty in this work

This article deals with the novelty of using primary peak empirical retrackers on Cryosat-2 SAR data in the Arctic. The primary peak is the part of the return waveform that is reflected from the sea surface at nadir. The primary peak is the high peak at the end of the leading edge in the waveform window. Small peaks caused by the elevated sea ice above the sea surface near nadir might occur before the primary peak. They are followed by the higher primary peak caused by the specular reflection from the lead near nadir and subsequent peaks caused by the sea ice from off-nadir angles. Primary peak empirical retrackers have been used on LRM data before. Improved threshold retrackers based on extraction of primary peaks have been developed for GEOSAT LRM data for coastal ocean (Hwang et al., 2006). The improved threshold retrackers have also been used for ENVISAT LRM data for coastal ocean (Fenoglio et al., 2008). But this paper presents the first results of application of primary peak retrackers on SAR data in the Arctic. The results have been compared with the ESA derived sea surface heights as available in the Cryosat-2 Level-2 data as well as the retracked sea surface