ON THE PERFORMANCE OF CRYOSAT-2 SAR MODE OVER WATER SURFACES

Christine Gommenginger(1), Cristina Martin-Puig(2), Salvatore Dinardo(3), R. Keith Raney(4)
Paolo Cipollini(1), David Cotton(5), Jérôme Benveniste(3)

(1) National Oceanography Centre, Southampton, UNITED KINGDOM, cg1@noc.ac.uk
(2) Starlab, SPAIN, (3) ESA-ESRIN, ITALY
(4) Johns Hopkins University, Applied Physics Laboratory, UNITED STATES
(5) Satellite Oceanographic Consultants Ltd, UNITED KINGDOM

ABSTRACT

This paper presents analyses of L1B waveforms in SAR mode and Low-Rate Mode (LRM) over water surfaces from numerical simulations from the CryoSat Mission Performance Simulator (CRYMPS) and from CryoSat-2 satellite measurements. This work was performed as part of the ESA project "Development of SAR Altimetry Studies and Applications over Ocean, Coastal zones and Inland waters (SAMOSA)". The project aims to determine the performance of SAR altimeters over the ocean and the coastal zone, compared to those of conventional pulse-limited altimeters. The performance for range and wave height retrieval in SAR mode is assessed with the help of the SAMOSA1 theoretical waveform retracker developed in the SAMOSA contract to retrack peaky SAR mode waveforms (Gommenginger et al., 2010). The SAMOSA1 SAR ocean retracker has been delivered to the Sentinel-3 team to form the basis of the operational SAR ocean retracker for the Sentinel-3 Surface Topography Mission. In this paper, we present an analysis of range retrieval accuracy as a function of significant wave height from CRYMPS L1B LRM and SAR waveforms, and for pseudo-LRM waveforms obtained from the SAR mode data. First results of the SAMOSA1 SAR ocean retracker applied to CryoSat-2 waveforms over ocean are presented.

1. MOTIVATION & CONTEXT

The CryoSat-2 SIRAL altimeter operates in three modes: a) Low-Rate Mode (LRM) over the open ocean, similar to conventional pulse-limited altimetry; b) SAR Interferometric mode (SARIN) over continental ice; and c) SAR mode (SAR) over sea ice. The CryoSat-2 instrument is also switched in SAR mode over some ocean test sites as a precursor for the SRAL altimeter on the GMES Sentinel-3 Surface Topography Mission (STM), which will also feature SAR capability. At present, it is expected that S3-STM will operate in SAR mode in ocean regions of high mesoscale variability and in the coastal zone.

The work presented in this paper was performed in the context of the ESA project SAMOSA for the "Development of SAR Altimetry Studies and Applications over Ocean, Coastal zones and Inland waters". Key aims of the project included a) to develop a theoretical retracker for SAR altimeter ocean waveforms; b) to compare range retrieval accuracy in LRM and SAR mode as a function of significant wave height (SWH); c) to investigate how to reduce SAR mode data to pseudo-LRM to establish their statistical equivalence with LRM. Here, we first focus on a) and b), before presenting first results of retracking CryoSat-2 L1B SAR waveforms over the ocean.

2. THE SAMOSA1 SARALT OCEAN RETRACKER

SAR Altimeter waveforms are much peakier than conventional Brown-type waveforms and therefore need a different approach to extract geophysical information. Within SAMOSA, a new theoretical model was developed (Martin-Puig et al., 2009) to fit SAR altimeter waveforms over water surfaces. The model gives analytical and numerical solutions to compute the Delay-Doppler Map for a single SAR burst. The model depends on the following geophysical parameters: range, significant wave height, along-track mispointing and Sigma0. Fig. 1 shows the typical peaky shape of SAR waveforms at zero Doppler in single-look DDM, and the broadening of the echo with increasing SWH.

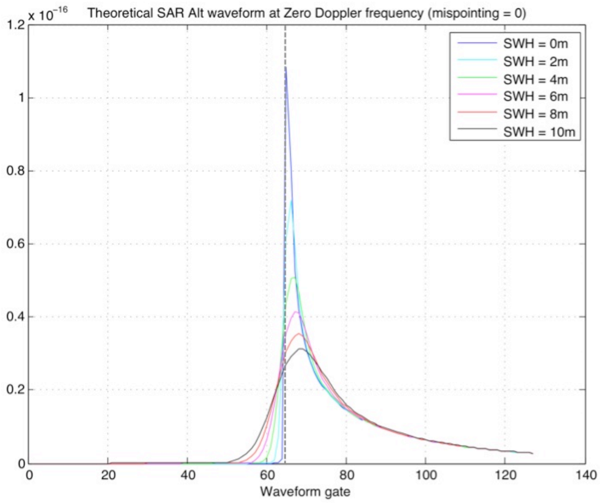

Figure 1. SAMOSA1 modelled SAR Altimeter waveforms for different values of significant wave height. The waveforms correspond to zero Doppler frequency in the single-look delay-Doppler maps.

Successive bursts are subsequently subjected to Doppler-beam selection to build the Stack, which is incoherently integrated to obtain multi-looked waveforms comparable to the SAR L1B products. The SAMOSA1 SARAlt ocean retracker has now been documented in the form of a Detailed Processing Model (Gommenginger et al., 2010) and delivered to the Sentinel-3 team responsible for the implementation of the operational processor for S3-STM.

3. SIMULATED SAR AND LRM WAVEFORMS FROM CRYMPS OVER WATER

The CryoSat Mission Performance Simulator (CRYMPS) was designed by UCL/MSSL to assess the performance of CryoSat over ice. It provides simulated products in LRM, SAR and SARIN mode for specified surfaces. Within SAMOSA, CRYMPS L1B LRM and SAR products were obtained for ocean surfaces with a number of scenarios with variable significant wave height. Explicit 3D ocean surface Digital Elevation Maps were generated for input into CRYMPS, featuring realistic ocean surface waves generated by inverting wave spectra based on the Elfouhaily et al. (1997) theoretical model for given SWH values.

a)

b)

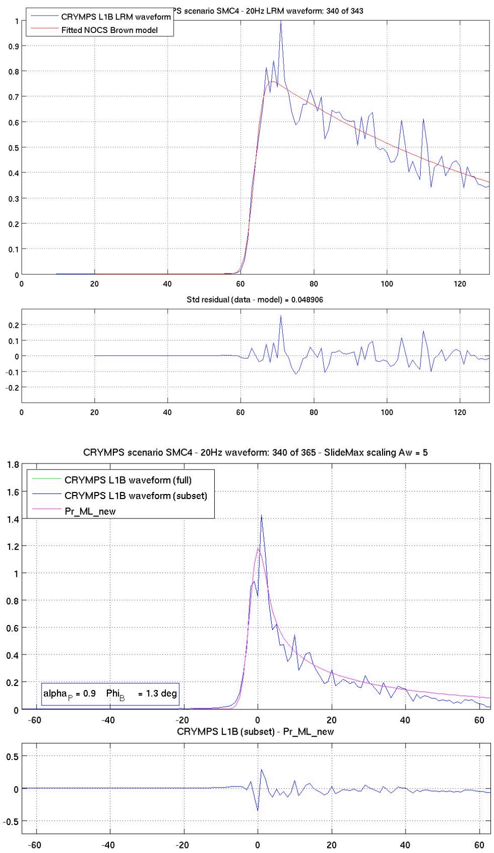

Figure 2. (a) CRYMPS LRM waveform over ocean and fitted Brown model; (b) CRYMPS SAR waveform over ocean and fitted SAMOSA1 SAR model. Significant wave height is around 3 meters in both cases.

Fig. 2 shows two examples of CRYMPS waveforms in LRM (top) and SAR (bottom) mode extracted from one of the ocean scenarios. The waveforms were fitted respectively with the NOC implementation of the Brown ocean model and the SAMOSA1 SARAlt ocean retracker. Based on the Full-Bit-Rate (FBR) products, the SAR mode data were sampled and incoherently averaged to generate pseudo-LRM waveforms, according to an averaging strategy developed by Starlab (Martin-Puig et al., 2011). The pseudo-LRM waveforms are Brown-like and were also retracked with the NOC Brown retracker.

4. RANGE RETRIEVAL ACCURACY AS A FUNCTION OF SWH

CRYMPS L1B LRM and SAR data were obtained for three ocean scenarios, which spanned values of SWH from 0.1 m to 5 m. The top row in Fig. 3 shows the profiles of significant wave height from the DEM of the three ocean scenarios. The subsequent rows in Fig. 3 show the retrieved SWH obtained by retracking the CRYMPS LRM, pseudo-LRM and SAR waveforms with the relevant retrackers. The colours identify those segments of the scenarios that correspond to a fixed value of SWH. A similar figure for the retracked range (not shown) provides the data used to assess the range retrieval accuracy as a function of significant wave height shown in Fig. 4.

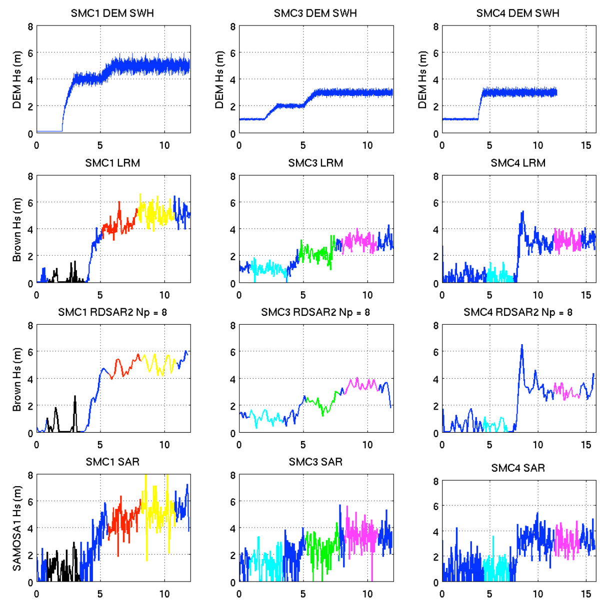

Figure 3. (top) CRYMPS DEM SWH and retracked SWH for (middle-top to bottom) LRM, pseudo-LRM and SAR mode, for three CRYMPS scenarios over ocean. Colours indicate data segments corresponding to 2 seconds of data at a fixed value of SWH.

Fig. 4 shows the retrieval accuracy at 1Hz of the relative range (position of the leading edge in the window) and indicates that a) SAR mode retrieval accuracy is improved by a factor of about 2 with respect to LRM; b) pseudo-LRM shows retrieval performance close to LRM. However, we found that the retrieval of SWH in SAR mode was much noisier than in LRM, and may have been related to the excessive noise observed in the CRYMPS SAR waveforms over ocean.

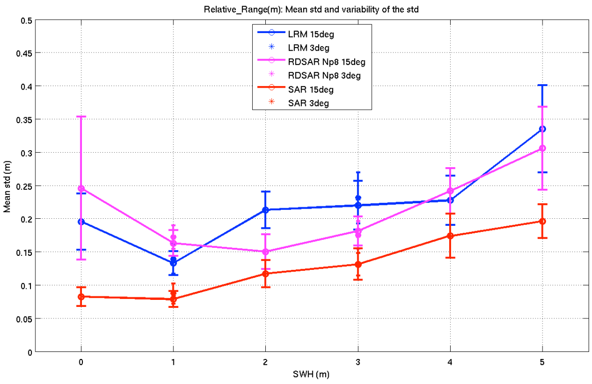

Figure 4. Range retrieval accuracy as a function of significant wave height in LRM (blue), pseudo-LRM (magenta) and SAR (red) mode based on CRYMPS data over ocean.

5. RETRACKING CRYOSAT-2 SAR L1B OVER WATER

The SAMOSA1 SAR retracker was applied to CryoSat-2 L1B SAR waveforms collected over water. Fig. 5 shows a CryoSat-2 L1B SAR waveform taken for a SAR acquisition in the Agulhas region, south-east of South Africa. The measured waveform is fitted with the SAMOSA1 SARAlt ocean model and we note the very good fit of the model to the measured waveform. In this example, there is a complete data drop-off in the second half of the waveform. This loss of data, instrumental in origin, is observed also in other SAR products, to a lesser or greater detrimental effect.

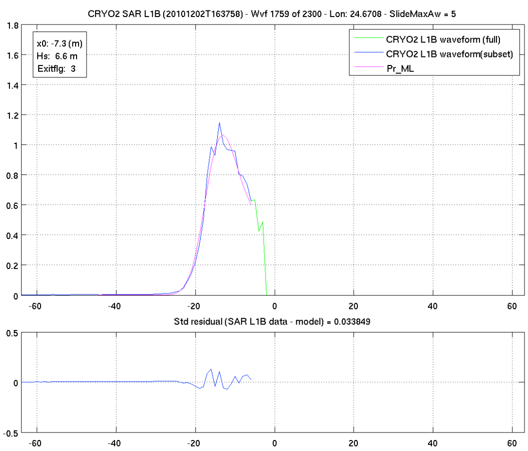

Figure 5. CryoSat-2 SAR waveform in the Agulhas region fitted with SAMOSA1 SARAlt ocean model.

Fig. 6 shows the SARAlt retracked results for the whole of this SAR acquisition in the Agulhas region. This product corresponds to a landward ascending pass, with latitude 35 degree signaling the continental shelf break. The retrieved SAR significant wave height is consistent with measurements from other altimeters on the same day. Both retrieved SWH and "satellite_height minus range" (bottom subplot) presents variability and features consistent with geophysical signals one can expect in this region. Further analyses will be needed to estimate precisely the range accuracy in these datasets.

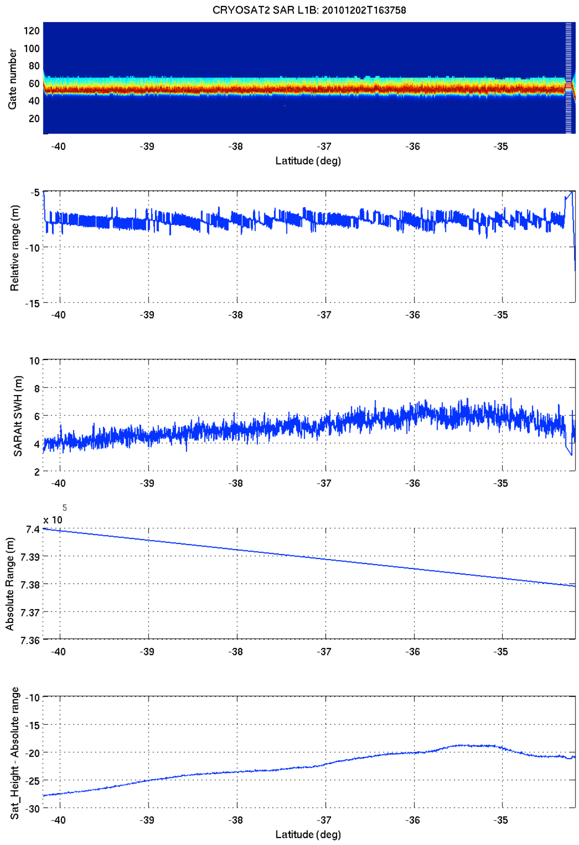

Figure 6. L1B SAR data over Agulhas and retracked results, showing from top to bottom: L1B SAR waveforms; relative range of leading edge within ranging window; retrieved SAR SWH; satellite to surface range; Satellite_height minus range in meters.

6. SUMMARY AND CONCLUSIONS

A new retracker for SAR altimeter waveforms over water was developed based on an analytical closed form model developed in the ESA SAMOSA project. The SAMOSA1 SARAlt ocean retracker is fully documented and has been delivered as a Detailed Processing Model to the Sentinel-3 team.

Simulated LRM and SAR L1B waveforms were obtained over water surfaces from the CRYMPS simulator, driven by explicit 3D ocean surface DEM with realistic ocean waves of different significant wave height. The CRYMPS LRM and SAR L1B waveforms were successfully retracked with a Brown and the SAMOSA1 SAR ocean retracker, respectively. We find that SAR mode gives an almost two-fold improvement in range accuracy compared to LRM, in line with earlier findings by Jensen & Raney (1998). In this study however, the retrieval of SWH was much noisier with SAR than with LRM, possibly as a result of excessive noise in the CRYMPS SAR waveforms over water.

Pseudo-LRM waveforms, obtained by reducing the SAR FBR data according to a methodology developed by Starlab in the SAMOSA project, are found to resemble Brown ocean waveforms, and match the retrieval capabilities of LRM for both range and SWH.

The SAMOSA1 SARAlt ocean retracker was also successfully applied to CryoSat-2 SAR waveforms, showing very good agreement between modelled and measured waveforms. We evidenced some examples of zero-power values affecting the second half of the waveforms range gates. However, the retrieved range and SWH show smooth spatial evolution over ocean topography and on coastal approaches, features that are consistent with expected geophysical signals in the region.

7. REFERENCES

Elfouhaily, T., Chapron, B., Katsaros, K., & Vandemark, D.: A unified directional spectrum for long and short wind-driven waves. J. Geophysical Research-Oceans, 102 (C7), 15781-15796.

Gommenginger , C., Martin-Puig , C., Srokosz, M., Caparrini, M., Dinardo, S., Lucas, B. & J. Benveniste: Detailed Processing Model of the Sentinel-3 SRAL SAR altimeter ocean waveform retracker, Version 1.3.1, 21 June 2010. ESRIN Contract No. 20698/07/I-LG "Development of SAR Altimetry Mode Studies and Applications over Ocean, Coastal Zones and Inland Water" (SAMOSA), 63 pages, 2010.

Jensen, J. R. & R.K. Raney: Delay Doppler radar altimeter: Better measurement precision. Proceedings IEEE Geoscience and Remote Sensing Symposium IGARSS'98. Seattle, WA, IEEE: 2011-2013, 1998

Martin-Puig, C. & G. Ruffini, “SAR Altimeter Mean Return Waveform from Near-normal incidence ocean surface scattering”, SAMOSA WP5 Technical Note, Issue 4, 7th April 2009.

Martin-Puig, C., J. Marquez & R.K.Raney “RDSAR software documentation”, SAMOSA CCN WP2100 Deliverable No.4, Version 1.1, 8th October 2011.