On the altimetric performance of the Sentinel-3 SAR-mode altimeter over the ocean: a numerical study

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OVERVIEW

We consider the performance of Delay Doppler Altimeters to measure sea level and significant wave height over the open ocean and the coastal regions. This work was performed as part of the ESA-funded SAMOSA project.

Delay Doppler Altimeters (DDA) are a new generation of nadir-looking altimeters with coherent pulse-to-pulse capability (SAR mode). Some benefits of DDA include finer along-track spatial resolution (~ 300m) and a two-fold improvement in range retrieval accuracy compared to conventional Low-Rate-Mode (LRM) pulse-limited altimeters. The altimeter payload for Cryosat-2 and the Sentinel-3 Surface Topography Mission will both feature Delay-Doppler capability (Section 1).

This study aims to quantify the improvement in altimetric range and significant wave height retrieval accuracy using simulated SAR and LRM altimeter waveforms generated by the Cryosat Mission Performance Simulator (CRYMPS) for 3D ocean surfaces with realistic ocean wave fields (Section 2).

In order to retrack the CRYMPS SAR waveforms, a new theoretical retracker for multi-looked SAR ocean waveforms was developed (Section 3). The CRYMPS LRM and SAR waveforms were retracked with appropriate theoretical retrackers and the retrieved SAR and LRM range and significant wave height compared in different sea state conditions (Section 4). Main results and future work are summarised in the Conclusion section.

1 - Delay Doppler Altimetry on Sentinel-3 and Cryosat-2: a quiet revolution in ocean altimetry

The concept of SAR altimetry, also known as Delay Doppler Altimetry, was first proposed by K.R. Raney (1998). Based on the same hardware as conventional altimeters, the SAR-enabled altimeter can operate in two modes (Figure 1):

(a) a conventional low rate mode (LRM) with continuous generation of pulses at a low pulse-repetition frequency (PRF) to ensure independent successive pulses and enable incoherent averaging;

(b) a high PRF SAR mode, characterised by bursts of pulses emitted at high PRF, to ensure pulse-to-pulse coherence and Doppler beam selection capability to increase the number of looks.

The altimeter payload on Cryosat-2 and Sentinel-3 Surface Topography Mission (launch due 2012) both feature Delay Doppler capability. For S3-STM, SAR mode will be used over ocean regions of high spatial variability, such as the Western Boundary Currents and coastal regions.

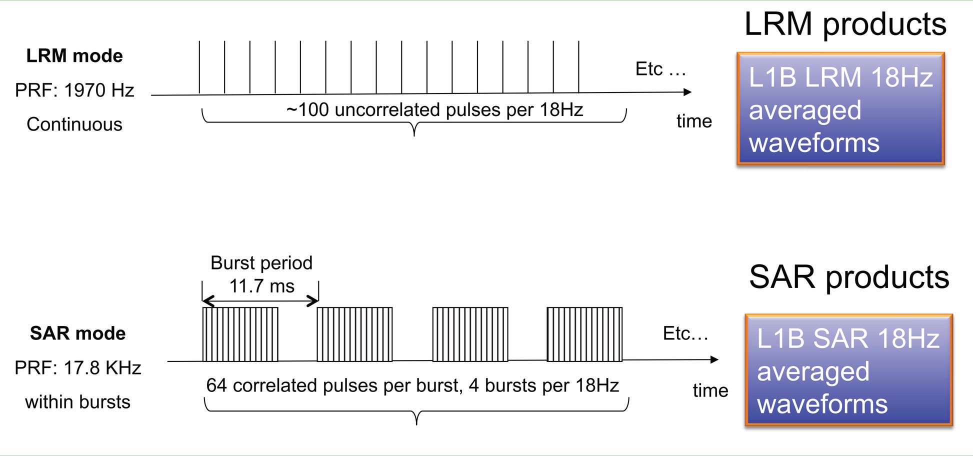

Figure 1 - Data acquisition mode in LRM (top) and SAR (bottom) mode for the Cryosat-2 mission.

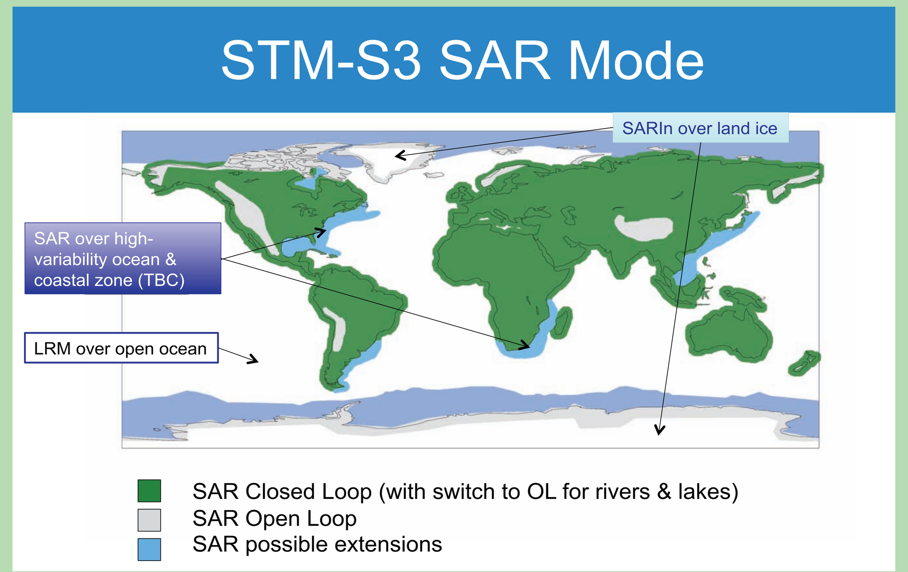

Figure 2 - Provisional mission duty cycle for Sentinel-3 Surface Topography Mission altimeter (Figure courtesy of H. Rehban)

2 - Simulated SAR and LRM altimeter waveforms over ocean from CRYMPS

The Cryosat Mission Performance Simulator (CRYMPS) is an end-to-end software simulator developed and run by University College London. CRYMPS computes the full scattering problem from LEO altitudes for explicit 3D descriptions of the Earth Surface to produce Cryosat L1B and L2 products in LRM, SAR and SARIn mode.

LRM and SAR altimeter waveforms were obtained for simulated 3D ocean surfaces with changing elevation and realistic ocean wave fields. Figure 3 shows one 12 seconds scenario with changing significant wave height conditions along-track. Middle and right panels show the 20Hz and 1Hz averaged waveforms for this scenario in LRM and SAR mode.

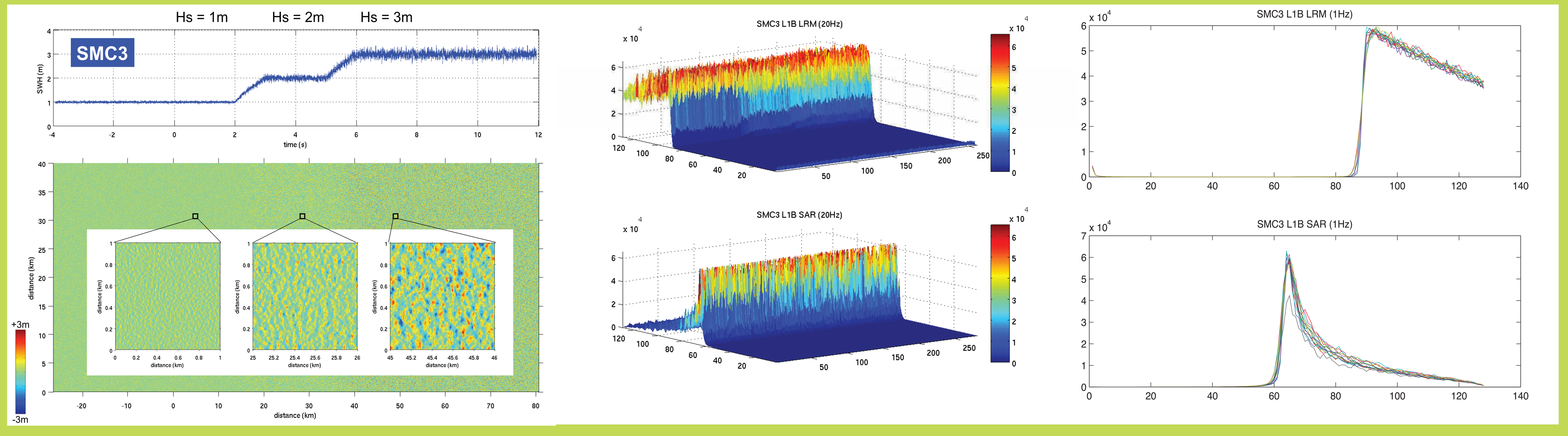

Figure 3 - (left) Ocean scenario SMC3 used as input into CRYMPS, showing (top) the profile of significant wave height and (bottom) top-view of the 3D ocean surface with waves modelled using the Elfouhaily et al., (1997) theoretical spectrum; (middle) 20Hz waveforms for LRM (top) and SAR mode (bottom); (right) same for averages over 1 second.

3 - A new theoretical retracker for ocean SAR altimeter waveforms

Given the increased peakiness of SAR altimeter waveforms over ocean surfaces compared to LRM waveforms (see Figure 3), a new theoretical model was developed from first principles (Martin-Puig & Ruffini, 2009).

The theoretical model describes the distribution of received power in Delay and Doppler frequency space for a single look. In its analytical form, the model depends on geophysical parameters such as the delay (epoch), significant wave height, normalised radar cross section at nadir, mispointing angle and a parameter linked to the root mean square slope. Figure 4 (right) shows the dependence on significant wave height of the single-look Delay Doppler Map across zero Doppler.

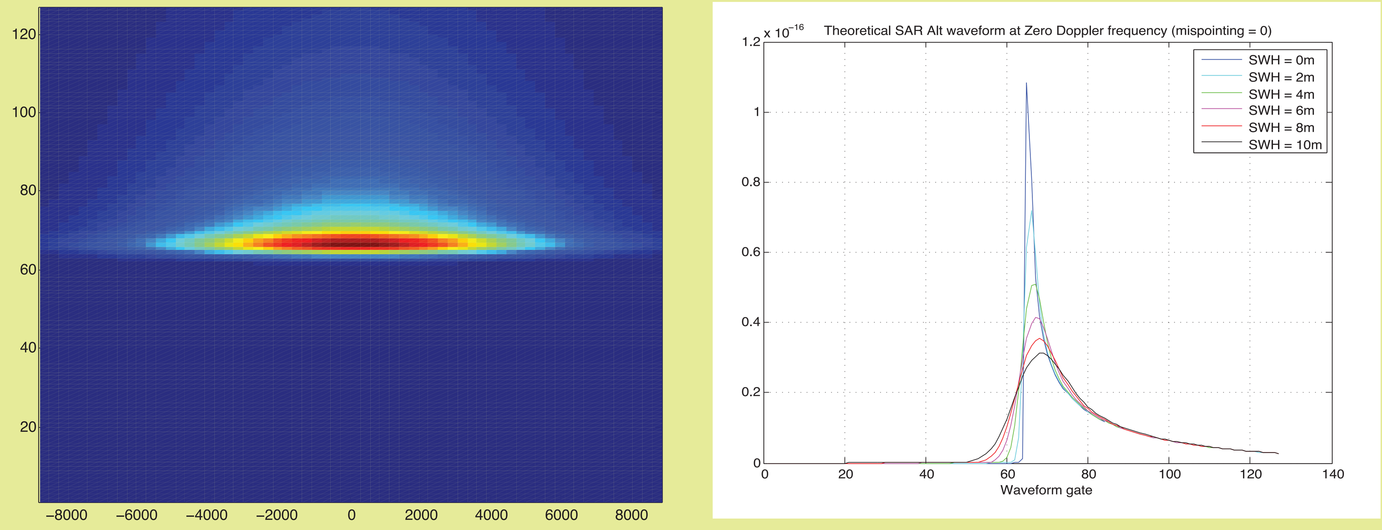

Figure 4 - (left) Theoretical single-look Delay-Doppler Map showing the distribution of received power in Delay (y axis as gate position) and Doppler frequency (x axis in Hz); (right) cross-section from the DDM through zero Doppler frequency for different values of significant wave height.

Multi-looking & Prototype SAR retracker

The single-look signals have to be accumulated over successive pulses to produce multi-looked L1B waveforms with reduced noise. The accumulation is typically done at 20Hz, where "20Hz" refers to the L1B posting rate rather than the accumulation duration.

Figure 5 illustrate the princicple of multi-looking. It consists of selecting from each successive burst the relevant Doppler beam staring at a particular ground cell. This yields a much larger number of looks (of order 200) for a much smaller along-track cell size.

A prototype SAR altimeter retracker was developed to fit the 20Hz L1B waveforms with multi-looked theoretical model waveforms.

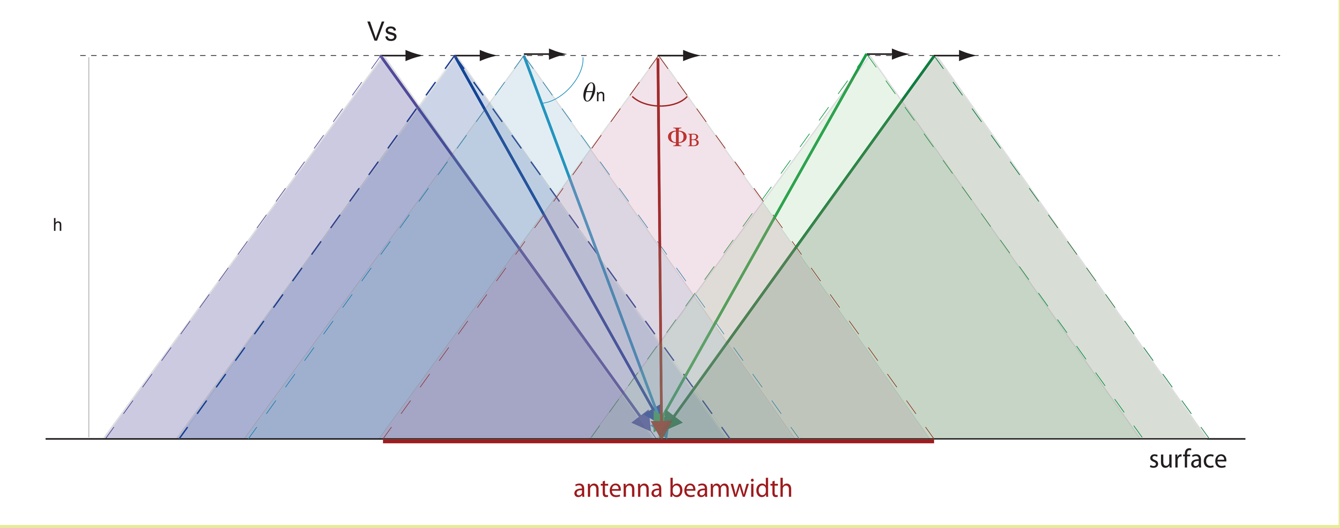

Figure 5 - Principle of multi-looking in SAR mode, leading to larger number of independent looks from successive bursts than LRM, to yield higher S/N and finer along-track spatial resolution.

4 - Epoch and SWH retrieval by retracking LRM and SAR waveforms

The CRYMPS LRM and SAR waveforms for two open ocean scenarios were retracked with a conventional Brown ocean retracker and the new prototype SAR altimeter retracker (see Section 3). Both LRM and SAR waveforms were retracked using ordinary least square fitting of the L1B 20Hz waveforms with the appropriate theoretical waveform model.

Figure 6 shows the results for two open ocean scenarios featuring along-track changes in significant wave height conditions from 0.1 to 4 meters. This permits a direct comparison of the epoch and SWH retrieval capabilities of LRM and SAR as a function of significant wave height.

From Figure 6 we note that:

1) Both LRM and SAR SWH are able to detect the changes in significant wave height seen in the DEM, with SAR overestimating SWH slightly.

2) There are unexplained spikes in retrieved SWH and epoch for both LRM and SAR mode, with some features visible in LRM and SAR at the same position along-track.

3) The variability in the retrieved SWH and epoch is larger in SAR mode than in LRM, and increases with significant wave height in both cases. This is contrary to what was expected from previous studies.

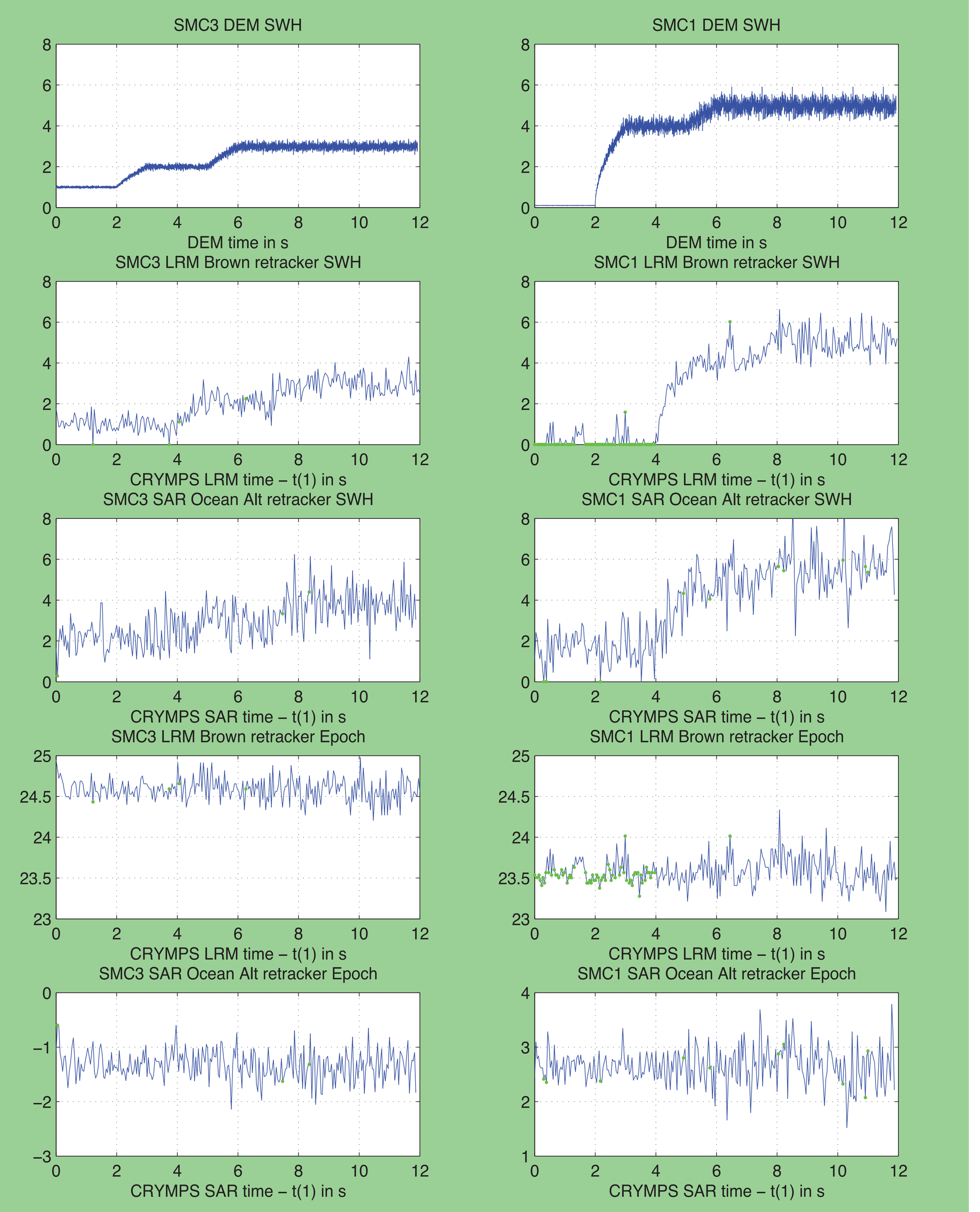

Figure 6 - Retracker output for two CRYMPS scenarios over open ocean (left) SMC3 (see Section 2) and (right) SMC4 (DEM not shown). The subplots show, from top to bottom (a) true significant wave height in surface DEM (b) retrieved SWH in LRM mode (c) retrieved SWH in SAR mode (d) retrieved epoch in LRM mode (e) retrieved epoch in SAR mode.

Conclusions & Future Work

The Cryosat Mission Performance Simulator (CRYMPS) was used to generate simulated altimeter waveforms over rough ocean surfaces with realistic ocean wave fields. L1B 20Hz waveforms were obtained in both pulse-limited low-rate mode (LRM) and SAR altimeter mode.

The CRYMPS LRM and SAR ocean waveforms were retracked to retrieve epoch and significant wave height using, respectively, a Brown ocean model and a new prototype SAR altimeter retracker based on a new analytical model for SAR Delay Doppler Maps.

The new SAR ocean retracker was found to perform well, providing excellent fit to the CRYMPS multi-looked SAR waveforms. Some unexplained spikes and artefacts showed up however in the retrieved geophysical values in both LRM and SAR mode. The variability in the retrieved parameters was also larger in SAR mode than in LRM mode - a result in conflict with the expectation of lower S/N in SAR mode thanks to multi-looking.

Future work will include the analyses of new CRYMPS scenarios over ocean surfaces to investigate, in particular, the sensitivity of the CRYMPS waveform noise to the scattering polar angle used in the simulator.

References

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