CryoSat Level 1b Processing Algorithms and Simulation Results

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***Abstract* - The CryoSat synthetic interferometric altimeter (SIRAL) has been designed to extend the coverage of conventional pulse-limited altimeters to allow the measurement of sea ice thickness and the elevation of the marginal regions of ice sheets. The science data acquired by the instrument is of a more complex nature than the conventional radar altimeter and is in one of three forms each of which are described in the paper.**

Examination of simulated echoes from each of these 3 modes provides a useful insight into how the CryoSat mission will tackle its primary objectives, and how an improvement in elevation measurement will be made over its conventional satellite borne counterpart.

I. INTRODUCTION

The CryoSat mission is the first of the European Space agency's (ESA) Earth Opportunity Programme and is due to be launched in mid 2004 for a nominal lifetime of 3 years. The primary scientific objectives for the mission, see [1], are to improve the accuracy of measurements of ice sheet elevation and sea-ice thickness and thus enhance understanding of cryospheric dynamics. Over sea-ice this is to be achieved by the use of a radar altimeter with synthetic aperture forming capability to improve the along track resolution allowing improvement in resolving 'leads' within sea-ice floes required for sea-ice thickness measurements. In addition, over ice-sheet margins the direction (along and across track) of the leading edge of an echo is required to improve these poorly modelled regions. This is achieved through the use of a second receiving antenna recording chain allowing interferometric capability.

The instrument concept is not a new one. Methods of improving along-track echo resolution or determining the across-track echoing point go back some years . In the recent past, the D2P described in [2], has been built and tested on board a low altitude aircraft. However, such an instrument has not been a part of a satellite payload.

In order to realise the required scientific goals described in [1] the platform has a range of on-board instrumentation, see [3] for a detailed description. For completeness, the on-board instruments are the SIRAL, see [4], being the main payload on CryoSat that telemeters the time stamped radar waveforms for the 3 science and 3 calibration modes. DORIS provides the orbital state vectors used for satellite localisation. The star tracker generates attitude vectors that are necessary in the determination of satellite orientation. Finally, the laser retro-reflector acquired data is used in the orbital refinement procedure.

This paper describes in section II how telemetered level 0 science data acquired from these instruments are processed to convert parameters to engineering units, apply instrument corrections and process multi-looked echoes to obtain level 1b data. Simulation results are described in section III.

II. SCIENCE DATA PROCESSING

The SIRAL generates pulse limited data similar to that produced by the EnviSat and ERS altimeters. However, the SIRAL data are generated and formatted depending on sub-satellite surface type provided by a geophysical mode mask. There are 3 generalised surface types that require variations in the generation of the level 0 data. For ice sheet interior and ocean this is catered for by traditional accumulated pulse limited power echoes. Over sea ice surfaces, requiring an improvement in along-track resolution, the data required are coherent echoes that can be Doppler processed. Ice sheet margins require both an improvement in along track resolution and capability to resolve across-track echoing point achieved by the use of an additional antenna and recording chain. The antennae are placed in such a way that when the Doppler processed echoes are interferred the across track angle may be resolved.

Fig. 1 shows the general processing scheme for each of the science modes. The initial processing performs the unpacking of level 0 instrument source packets (ISPs), time/position localisation and satellite attitide determination. Instrument corrections are also applied to the data and optional full bit rate (FBR), also known as level 1, products can be generated after this stage.

Internal processing differs depending on the mode extracted from the level 0 data. In the case of the new high resolution science measurement modes (SAR and SARIn), a specialised set of algorithms have been developed to tackle Doppler processing from space using a satellite borne radar altimeter. Final processing generates geophysical corrections and performs the formatting of the level 1b data.

The 3 science modes are now described.

A. Low resolution mode (LRM)

The LRM mode data is equivalent to that obtained from traditional altimeter instruments such as those on-board ERS and Jason. The LRM source packet contains a single power waveform accumulated on-board from 91 square law detected power echoes. Internal processing consists of a single algorithm to compute the Doppler range correction.

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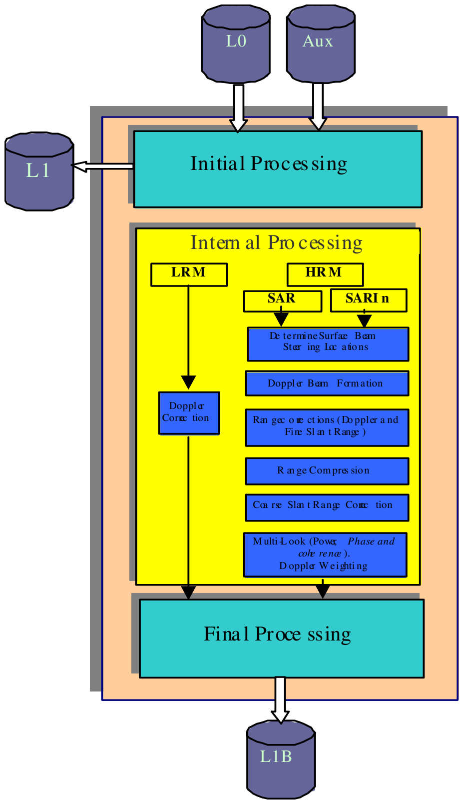

Fig. 1. Processing scheme depicting level 0 and auxiliary file ingestion. Level 1 output follows initial processing with internal and final processing prior to level 1b output.

This range shift occurs to the echo measurement due to Doppler shift. The correction can be computed with knowledge of the average echo location, satellite location and satellite velocity. The resultant ground track spacing of LRM averaged measurements is ~300 metres.

B. *Synthetic Aperture (HRM SAR)*

For the SAR mode the SIRAL generates bursts of 64 complex I and Q time domain echoes every 11.7 mS. The echoes are coherent with a pulse repetition interval ~56µS and can thus be Doppler processed.

In principle Doppler beams can be processed via a 2-D fast Fourier transform (FFT) of the burst of echoes. Here, an FFT across the burst forms the Doppler beams and an FFT across the time domain echoes range compresses them. This procedure produces 64 Doppler beams equally spaced in angle through a plane defined by the satellite velocity and antenna boresite vector.

The Doppler echoes, however, require accumulation to improve the signal-to-noise ratio (SNR). This poses a problem for altimetric Doppler processing since Doppler echo footprints gathered about a common location do not, in general, illuminate the same location.

As a result the processing scheme is, at least geometrically, a complex one. The procedure employs steering of the Doppler beams to point to surface locations (termed surface samples) that are located in advance of the current sub-satellite location such that all Doppler beams formed from a burst can be steered to one of the sample locations.

Each ISP is processed in turn following asynchronous determination of a set of beam directing surface samples. The beams are formed, stored and tagged to their respective surface sample. A Doppler range correction is computed and applied to each beam echo via a phase shift. Additionally, a slant range correction is computed for each Doppler beam to align them with their respective surface samples. Here, fine and coarse corrections are computed and applied before and after range compression respectively.

Range migration effects due the deviation of the antenna phase centres from a straight line orbit throughout the period of a burst (46.7 mS) is a negligible amplitude modulation.

A stack is complete when the Doppler beams from source packets no longer contribute to a surface sample, this can be determined by computing an angle between the satellite velocity and surface sample to satellite direction vector. If this angle exceeds a threshold angle a multi-look of that surface sample stack is triggered. The stack is multi-looked by accumulating each Doppler echo for each range bin generating a single echo. Here a Gaussian weighting function is also applied to the stack to reduce the influence of low power echoes in the stacking procedure. Over highly variable terrain a further waveform alignment is required and performed by aligning all beams with a time delay of a reference beam with the minimum range window time delay. The resultant level 1b waveforms are 128 samples in length giving a 54 m range window for a 350 MHz signal bandwidth.

C. *Interferometric Synthetic Aperture(HRM SARIn)*

There are a number of differences regarding the input level 0 and the processed level 1b data between the SAR and SARIn modes.

Here the SIRAL acquires echo data from a second antenna. The two antenna are placed such that they are orthogonal to the satellite velocity and the interferometric baseline, that is, the vector between each of the antenna phase centres, has a known fixed distance. Provided the difference in phase can be measured between the two antenna, the across track angle of an incoming ray can be inferred by interfering the two signals and the quality of the computed angle can be determined by also computing the coherence between the 2 processed Doppler echoes.

Due to tracking requirements at a lower bandwidth the number of bursts of telemetered data is 1/4 that for the SAR mode. This also results in ~1/4 of the number of Doppler beams compared with the SAR mode data. For example, a stack for SAR mode may contain, say, 240 contributing Doppler beams. The equivalent SARin stack will contain ~60 beams. Since this measurement mode is triggered over ice sheet margins, the range of measured elevations is also larger with a processed range window being ~220 m.

III. RESULTS

The CryoSat mission performance simulator (CRYMPS) simulates the platform orbit, characterizes a surface in order to generate field echoes and simulates the operation of the SIRAL over the series of echoes for all 3 science modes and also has the functionality to simulate all calibration modes.

A number of scenarios have been generated for varying complexity of surfaces from which 2 are presented here. For initial level 0/1b simulations, data generated employs a simple Gaussian shaped antenna pattern[1] with the half power at 0.65°. The scatterer echo integration angle, used to accumulate the response of scatterers in the formation of field echoes, is also set to the same angle[2].

The first of the simulations is for an ocean surface, here a stack of power echoes is displayed in Fig. 2 prior to multi-looking. It can be seen that all the echoes across the stack are aligned. The effect of the antenna modulation can be observed across the stack and also with increasing range.

The second scenario makes use of a DEM of the Totten glacier region of Antarctica[3]. Fig. 3 shows processed echoes for the LRM, SAR and SARin modes for the same location. Comparison between the LRM and SAR(In) power echoes reveals the reduced power in the tail end of the latter. This is due to Doppler processing since power within the real antenna pattern but outside the Doppler footprint cannot contribute power and is a feature of the improved resolution. The SARin echo also shows the across-track angle which wraps[4] close to range bin 255. High coherence in the tail-end of the echo gives confidence the echo is incident from the measured across-track angle. This is also the case with the leading edge. Low coherence between range bins 110 – 170 due to echo power arriving from each side of the ground-track gives low confidence in the angle measurement.

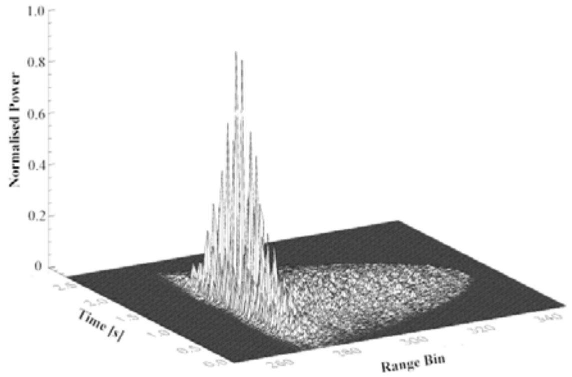

Fig. 2. Simulated Doppler beam stack over ocean surface.

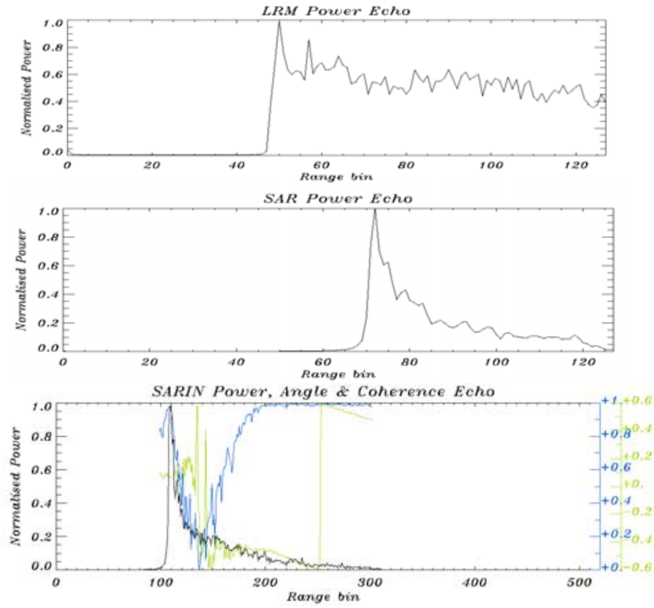

Fig. 3. (Top) Totten glacier LRM echo power, (Middle) SAR mode level 1b normalised echo power and (Bottom) SARIn normalised power, angle in units of degree (green) and coherence (blue).

IV. CONCLUSION

Most uncertainties with the processing of level 0 SIRAL data to level 1b have now been resolved with room for refinement of algorithms prior to the launch of CryoSat. Further, the processing algorithms will undergo improvement having gained experience with the CryoSat dataset at the end of its lifetime.

More scenarios are to be generated over a wider range of surfaces in order to fine tune the processing algorithms prior to launch. For example, one would want to simulate level 1b data over sea-ice models, over surfaces with variable backscatter and polar angles, and for ice-sheet surfaces, add the effect of volume scattering to the field echoes.

ACKNOWLEDGMENT

The authors would like to thank the European Space Agency for supporting the work carried out in this paper under contract number 13849/99/NL/GD.

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1 This provisional actual antenna pattern will be replaced with a model of the actual one when it becomes available.

2 The integration angle will need to be increased so as to allow simulation of echoes incident through the antenna side lobes.

3 This scenario employs a single layer of scatterers; hence, effects of volume scattering are not simulated.

4 Unwrapping is an activity for level 2 processing.