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FIRST RESULTS OF RECOVERY OF SHORT WAVELENGTH GRAVITY FIELD SIGNALS FROM CRYOSAT-2 DATA

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ABSTRACT

A number of geophysical phenomena in the open ocean are still unresolved by conventional 1 Hz altimetry, but could be observed through the potential improvements offered by SAR, or Delay-Doppler (DD), altimetry. The DD altimeter offers the following benefits with respect to conventional satellite altimetry: Factor of 20 improvements in along track resolution, along-track footprint length that does not vary with wave height (sea state), and improved precision in sea surface height measurements/sea surface slope measurements.

These improvements are studied with respect to retrieval of short wavelength geophysical signal related to mainly bathymetric features. The combination of upward continuation from the sea bottom and smoothing the altimeter observations resulted in the best recovery of geophysical signal for simulated 5-Hz DD observations. The first validation of these theoretical modelling results with respect to resolution and noise are presented using various CryoSat-2 data and evaluation against conventional Radar altimeter data from older GM missions onboard ERS-1 is presented.

A comparison of L2 products for LRM data are carried out with retracked L1b data for the same data types.

Key words: CryoSat-2, Retracking, Gravity field, Ocean.

1. INTRODUCTION

Three months of CryoSat-2 commissioning phase data has been investigated to asses the performances with respect to recovering geophysical signals. A number of different retrackers are applied on LRM and SAR data and the performance is evaluated and compared with LRM L2 data.

The derived datasets are filtered and geophysical signals are extracted and compared with earlier altimeter derived geophysical signals.
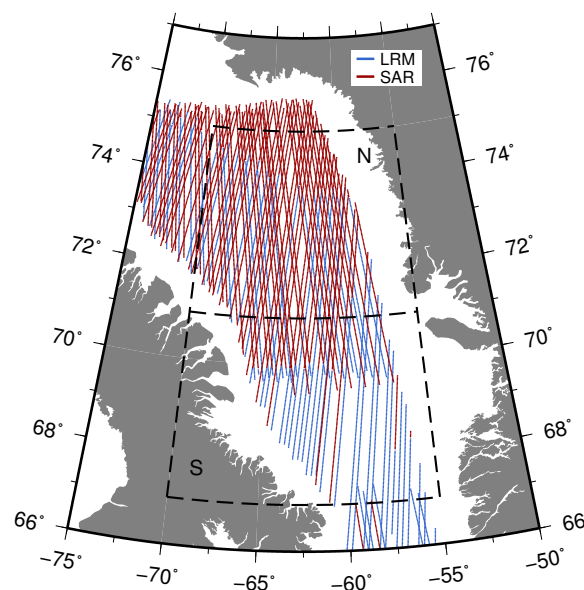

Figure 1. SAR (red) and LRM (blue) data from September to November in the Baffin Bay.

2. AREA AND DATA

Two test areas (S and N) has been chosen in the Baffin Bay (Figure 1) between Greenland and Canada and all available data in the period from September to November 2010 has been investigated. Figure 1 show the available LRM (blue) and SAR (red) data in the three month period.

It is expected that sea-ice can occur in the two test areas in November and thus affect the results negatively.

3. DATA PROCESSING

The provided range and geophysical correction were applied to the 20 Hz Cryosat-2 data. These include correction for the wet and dry tropospheric path delay as well as ionospheric path delay. Similar tide correction (ocean, load, pole and earth) and dynamic atmosphere correction was also applied. No correction for sea state bias were
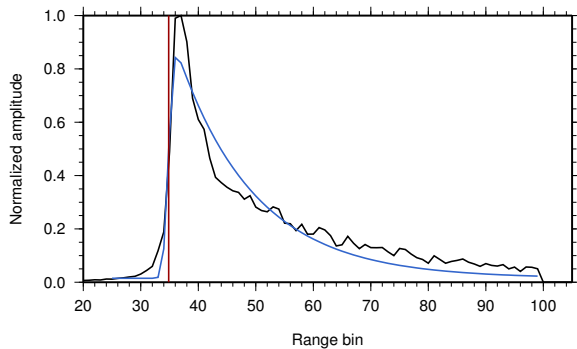
Figure 2. SAR waveform (black) with fitted five parameter Beta retracker with exponential tail (blue) and surface estimate (red).
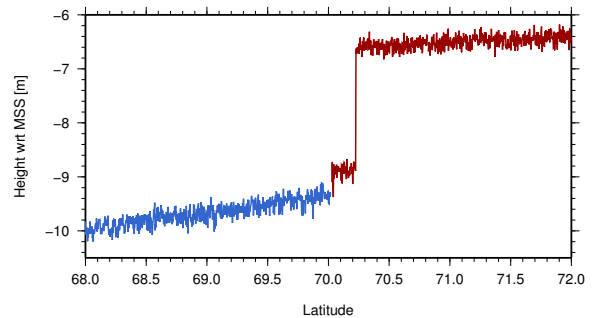

Figure 3. Elevation, obtained with the five parameter Beta retracker, relative to the DTU10MSS from a profile during a shift from SAR (red) to LRM (blue) mode.

provided or attempted and no information on the applied corrections could be retrieved from the data provided.

3.1. Retracking

A number of retrackers has been implemented to analyse the CryoSat-2 data. First the Offset Center Of Gravity (OCOG) retracker [1] is applied on all waveforms. This has been done even though the OCOG is expected to give erroneous results for SAR waveforms. Next a threshold retracker [2] is applied, using a 50% threshold for LRM data and a 80% threshold for SAR data, to obtain estimates of the range to the surface. In addition a five parameter Beta retracker with exponential tail [3] is implemented using a Levenberg-Marquardt nonlinear least squares algorithm to fit the model to the waveform. The Beta retracker is initialize with the output from the threshold and OCOG retracker.

Figure 2 shows an example of a SAR waveform and the fitted five parameter Beta model. It is clearly seen that the sharp peak characteristic of SAR waveforms is not captured by the Beta retracker.

Finally of a new retracker based on a simplification [4] of the CryoSat waveform [5] has been implemented. This retracker, including the characteristic SAR peak, is however still work in progress and therefore not included in this work.

The OCOG, threshold and Beta retrackers has been applied on all three months of LRM and SAR data from the Baffin Bay and used for the further analysis.

Figure 3 shows a descending segment of the data acquired on October 5 during a shift from SAR to LRM mode. A distinct offset of around 2 m is seen near the end of the SAR profile (red), this is believed to be caused by an error in the applied tropospheric correction. The bias and tilt with respect to the DTU10 Mean Sea Surface is also clearly seen.

3.2. Data editing and retrieval of geophysical signals

An initial screening and outlier detection of the data were performed by comparing the 20 Hz observations with the DTU10 Mean Sea Surface and removing data if they differ by more than 3 times the local standard deviation from this model. To reduce the effects of residual orbit errors and sea surface variability tracks were fitted individually to the EGM2008 geoid model by estimating bias and tilt terms to each track, thus removing all signals with a wavelength longer than the size of the region (typically about $3° - 4°$).

Subsequently, a crossover adjustment of the tracks was carried out, also using bias and tilt terms. The processing and interpolation and gravity field prediction follows the method used by Andersen et al. [6] except from the fact that only ERS-1 geodetic mission data have been used along with Cryosat-2 data for the gravity field determination.

4. RESULTS

As seen in Table 1 the standard deviation of the observations are reduced dramatically. For the Threshold retracked data and the beta retracked data this reduces the standard deviation from around 1 meter to around 10 cm. For the OCOG retracker the reduction is from around 1 meter to roughly 25 cm.

The importance of upgrading from 1 Hz to 5 Hz sea surface height data for gravity field determination was demonstrated by the ESA SAMOSA project [7]. Subsequently a 5 Hz averaging were performed by analysing sections of 6 data points and removing the two data points that departed the largest with the mean value. Then the remaining four data points were used to compute the 5 hz average. The section were then moved 4 points along the track and the process were repeated. This furthermore reduces the standard deviation of the sea surface height to between 5 to 20 cm dependent on the data types.

The similar values for the 1 Hz ERS-1 geodetic mission

	LRM (area S)				SAR (area N)		
	OCOG	Threshold	Beta	L2	OCOG	Threshold	Beta
Points (Before editing)	28444	28444	28139	18182	72925	72925	68824
Points (removed gross error)	28060	28127	27941	18180	68664	71653	68176
Std. dev.	1.008 m	0.998 m	1.027 m	0.760 m	1.231 m	1.237 m	1.279 m
Std. dev. (removed tilt and bias)	0.250 m	0.085 m	0.110 m	0.076 m	0.349 m	0.254 m	0.363 m
Points (resampled 5 Hz)	6921	6958	6921	4421	16974	17786	16585
Mean (obs-ref)	0.003 m	0.000 m	0.003 m	0.000 m	0.000 m	0.000 m	0.000 m
Std. dev. (obs-ref)	0.130 m	0.051 m	0.066 m	0.044 m	0.232 m	0.171 m	0.187 m
ERS-1 GM std. dev.	0.09 m				0.141 m		

Table 1. Effect of the data editing and choice of the retrackers in comparison with ERS-1 geodetic mission.

data are around 9 cm, so the 5 Hz (1.1 km along-track) Cryosat-2 data reduces the standard deviation by a factor of two compared with the 1 Hz (6.7 km along-track) older geodetic mission data. This number is very promising for future use of Cryosat-2 data for short wavelength gravity field recovery and represent a significant improvement with the older geodetic mission data.

However, the number should be interpreted with caution.First only a limited number of tracks have been investigated and the majority of the tracks are much shorter than the $3° - 4°$ and therefore only representative of very short wavelength signals. Secondly the sea state bias correction has not been applied and we have not been able to confirm the accuracy of the other range and geophysical corrections applied.

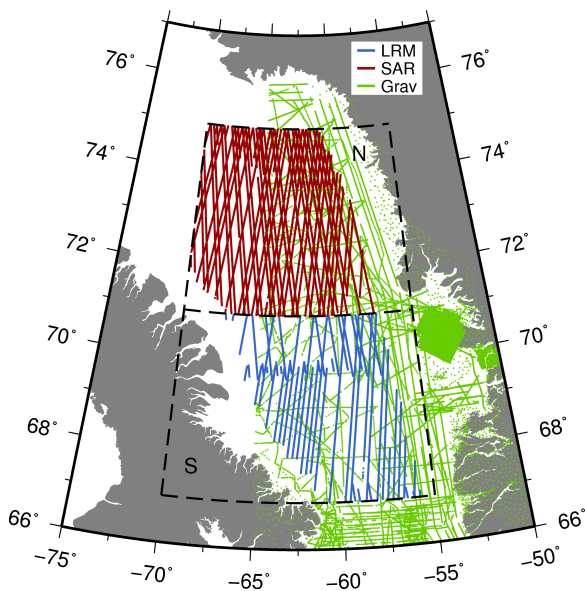### 4.1. Comparison with marine gravity data

Figure 4. SAR (red), LRM (blue), and marine gravity data (green) in the Baffin Bay.

Table 2 present the comparison with marine gravity field data obtained in the Baffin Bay by several agencies and extracted from the Nordic gravity field database. A to-

tal of around 5100 marine gravity field observations were available for interpolation in the northern region and 1900 gravity field observations were available for the southern region. The obtained gravity field determination shown in Table 2 is encouraging. Even though the gravity field determination is generally only improved by 0.2 mGal for LRM and less for SAR this is a promising improvement in light of the fact that this is preliminary results. The reason being firstly that no fine-tuning of the gravity field determination to handle 5 Hz Cryosat-2 were made and the second reason being that only very limited numbers of Cryosat-2 tracks were available for the gravity field determination. A preliminary tuning of the processing toward the higher along-track resolution brings the the standard deviation down to 5.714 mGal for northern area. Thirdly much more finetuning of the processing of the data (i.e., including sea state bias correction) is expected in future versions of the data.

For the northern region a total of 482 ERS-1 Geodetic mission tracks were merged with 74 Cryosat-2 tracks and for the southern region 478 ERS-1 geodetic mission tracks were merged with 41 Cryosat-2 tracks. These CryoSat-2 tracks have a very inhomogenous distribution compared with the eight km equidistant cross track distance of the ERS-1 Geodetic Mission data.

For both the northern section, where SAR data were used, and for the southern section, where LRM data were used, Cryosat-2 data retracked using the tresshold retracker gave slightly favourable result when included in the gravity field determination. For the southern section we were also able to compare with the Level-2 retracked data and find a slight improvement, however L2 data were only available for about 60% of the L1b waveforms.

It might be argued that the comparison with marine grav-

	LRM (area S)	SAR (area N)
ERS-1 GM	6.578 mGal	6.130 mGal
ERS-1 GM + OCOG	7.730 mGal	8.725 mGal
ERS-1 GM + Thres	6.350 mGal	6.106 mGal
ERS-1 GM + Beta	6.535 mGal	6.302 mGal
ERS-1 GM + L2	6.430 mGal	

Table 2. Standard deviation of the difference between marine gravity and gravity estimated from altimetry.

ity field data is not impressive giving standard deviation around 6.5 mGal. This should be compared with many other marine regions with current gravity fields like DTU10GRA which gives numbers around 3 mGal in comparison with marine data. The reason for this is the fact that the gravity field variation in the Baffin Bay is extremely large. The standard deviation of the gravity field anomalies in the Baffin bay is 59 mGal compared with 27 mGal as the global number.

Secondly the marine gravity field observations in this region is generally taken under very rough conditions which directly degrades the accuracy of the observed gravity field observations.

5. CONCLUSION AND OUTLOOK

Three months of CryoSat-2 LRM and SAR data from the Baffin Bay has been investigated using SAR L1b, LRM L1b and LRM L2. The L1b data has been retracked with three different retrackers and compared internally and with an independent dataset. From this first investigation we find very promising results in the comparison with the mean sea surface in both LRM and SAR data. The comparison with the marine gravity field is also promising and preliminary tuning of the processing indicates that significant improvement can be achieved. Furthermore sea-ice debris is expected to be present in the November SAR data and will need to be handled in a future editing scheme to avoid degradation of the derived sea surface and thereby the derived gravity field.

ACKNOWLEDGMENTS

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