Main evolutions and expected quality improvements in SAR/SARin BaselineC Level1b products

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SUMMARY

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1 Document overview

1.1 Purpose and scope

This document presents the main evolutions and quality improvements expected in the SAR/SARin BaselineC Level1b products from a user point of view. The main objective of this technical note is thus to briefly present and clarify the effects of the IPF1 evolutions on the SAR/SARin Level1b products from BaselineB to BaselineC. The Baseline-C changes concern both the Level 1b products, principally the waveforms, as well as the Level 2 products, principally the retrieved surface elevations. In this respect, a complementary document dealing with the Level 2 product evolutions is also made available to the user [RD-01].

1.2 Acronyms

Aresys	Advanced Remote Sensing Systems
CFI	Customer Furnished Item
ENL	Equivalent Number of Looks
FFT	Fast Fourier Transform
IPF1	Instrument Processing Facility
IPFDB	Instrument Processing Facility DataBase
PDGS	Payload Data Ground Segment
PRF	Pulse Repetition Frequency
SAR	Synthetic Aperture Radar
SARin	Synthetic Aperture Radar Interferometric
SCNR	Signal to Clutter and Noise Ratio
SPR	Software Problem Report
SW	Software

1.3 Applicable documents

AD-01 Products Specification Format - Instrument Processing Facility L1b, C2-RS-ACS-GS-5106 issue 5.0, 2nd August 2013

1.4 Reference documents

RD-01 Main evolutions and expected quality improvements in Baseline C L2 products, issue 1.0, 2nd October 2014

RD-02 Aresys, Technical Note on Release VL1.0, C2-TN-ARS-GS-5137, issue 1.0, 30th October 2013

RD-03 Aresys, Technical Note on Release VM1.0, C2-TN-ARS-GS-5151, issue 1.0, 4th July 2014

RD-04 Aresys, Known biases in CryoSat Level1b products, C2-TN-ARS-GS-5135, issue 1.2, 23th September 2013

RD-05 Aresys, Intraburst and interburst alignment for IPF1 SAR&SIN 20Hz and 1Hz waveforms, C2-TN-ARS-GS-5125, issue 1.3, 25th November 2013

RD-06 Wingham, D. J., Phalippou, L., Mavrocordatos, C., & Wallis, D. (2004). The mean echo and echo cross product from a beamforming interferometric altimeter and their application to elevation measurement. *Geoscience and Remote Sensing, IEEE Transactions on*, *42*(10), 2305-2323.

RD-07 ESA ESRIN, Guidelines for reverting waveform power to sigma nought for Cryosat-2 in SAR mode, issue 1, revision 7, 21th November 2013

RD-08 Aresys, Power scaling in IPF1 SAR/SARin, C2-TN-ARS-GS-5139, issue 1.2, 2nd December 2013

RD-09 Aresys, Proposed implementation for azimuth window normalization, C2-TN-ARS-GS-5128, issue 1.1, 13th June 2013

RD-10 Aresys, IPF1 SAR, SARin and CCAL processors status – Open points towards BaselineC, C2-TN-ARS-GS-5146, issue 1.0

RD-11 K. Giles, D. J. Wingham, N. Galin, R. Cullen, and W. Smith, “Precise estimates of ocean surface parameters from CryoSat”, OST Science Team meeting, Venice, 27 - 28 Sept 2012.

RD-12 ESA, Aresys, Implementation proposal for CRYO-IDE-185, C2-TN-ARS-5130, issue 1.0

RD-13 ESA, Aresys, Leading edge missing in contributing beams due to cutting in Slant Range Correction, C2-TN-ARS-5133, issue 1.0

2 Context

BaselineB Level1b products have been started to be produced and distributed to users the 1st of February 2012. The main information related to the Baseline B are listed in the table below.

01/02/2012	IPF1 Vk1.0	SW version issued following the first year of the CryoSat-2 Operations Phase. This SW is used to process all products marked by the new baseline B and includes the following: • The fix of several ARs from the previous IPF1 Vj1.1; • Updated configuration settings in the PCONF, IPFDB and IPF Task Tables; • Integration of Earth Explorer 3.7.4.1 CFI libraries.

Tab.1 BaselineB main information.

IPF-1 VK 1.0 has been delivered and has worked on the operational platform for around two years. During this period some issues have been identified and the scientific community suggested a series of evolutions that have been taken into consideration in order to update of the IPF processor, aiming at improving the quality of the Level1b products.

The aim of this document is to clarify and illustrate the evolutions on the SAR/SARin Level1b products for BaselineC with respect to the BaselineB, as a consequence the changes applied in IPF1 VM 1.0 will be considered.

Throughout the document, the changes having a direct impact on the quality of the SAR/SARin Level1b waveforms will be highlighted and the waveforms for BaselineB will be compared with those for BaselineC, aiming at highlighting the quality improvement from the user point of view.

3 Baseline configuration

In the table below the main configuration parameters for BaselineB and BaselineC are listed in order to summarize the parameters that have been changed in the BaselineC as well as those that have not been changed.

IPF1 Item description	Baseline B	Baseline C	Comment
Range SAR/SARIn zero-padding	LRM: Not applicable (range bin sample ~.47 m) SAR: 2 (range bin sample ~.23 m) SARin: 2 (range bin sample ~.23 m)	LRM: Not applicable (range bin sample ~.47 m) SAR: 2 (range bin sample ~.23 m) SARin: 2 (range bin sample ~.23 m)	
Range window size	LRM: 128 samples (~60 m) SAR: 128 samples (~30 m) SARin: 512 samples (~120 m)	LRM: 256 samples (~60 m) SAR: 256 samples (~60 m) SARin: 1024 samples (~240 m)	See section 4.3.
Window delay reference sample (range bin starting from 0)	LRM: 64 SAR: 64 SARin: 256	LRM: 64 SAR: 128 SARin: 512	The reference bin has been kept in the middle of the waveform.
Azimuth window	LRM: Not applicable SAR: Hamming SARin: Hamming	LRM: Not applicable SAR: Hamming SARin: Hamming	

Attitude bias compensation (all modes)	YAW= 0 deg PITCH= 0 deg ROLL= 0 deg (only the SARin phase difference was compensated for 0.1054 deg roll bias)	YAW= 0 deg PITCH= 0.0550 deg ROLL= 0.1062 deg	See section 4.2.
STR selection (all modes)	According to availability following a fixed Star Tracker Priority list: 1) STR1ATT 2) STR2ATT 3) STR3ATT	The STR in use on board by AOCS is selected on ground for IPF1 processing.	See section 4.2.
Attitude angles smoothing (all modes)	No	Moving average on the attitude angles (moving average filter length 5 s)	See section4.2.
STR ID and attitude angle in Level1b products (all modes)	STR ID: No Attitude angles: derived from baseline vector and beam vector	STR ID: field #14 Attitude angles: roll field #15, pitch field #16, yaw field #17 of Level1b products	See section 6.
Surface Sample Stack weighting	LRM: Not applicable SAR: No SARin: No	LRM: Not applicable SAR: look angle interval [-0.6, 0.6] deg SARin: look angle interval [-0.7, 0.7] deg	See section 4.4.
Beam Behaviour Parameters (SAR and SARin)	▪ Standard Deviation of Gaussian fit ▪ Stack Centre Gaussian fit. ▪ Stack Scaled amplitude. ▪ Stack Skewness ▪ Stack Kurtosis ▪ Standard deviation as a function of boresight angle ▪ Stack Centre angle as a function of boresight angle	▪ Standard Deviation of Gaussian fit ▪ Stack Centre Gaussian fit ▪ Stack Scaled amplitude ▪ Stack Skewness ▪ Stack Kurtosis ▪ Standard deviation as a function of boresight angle ▪ Stack Centre angle as a function of boresight angle ▪ Doppler Angle Start ▪ Doppler Angle Stop ▪ Look Angle Start ▪ Look Angle Stop Number of contributing beams in the stack after weighting ▪ Number of contributing beams in the stack before weighting	See section 4.4. See section 6.
Power scaling	SAR: ▪ Azimuth window normalization: No ▪ Power Multiplier: 1/128 SARin: ▪ Azimuth window normalization: No ▪ Power Multiplier: 1/512	SAR: ▪ Azimuth window normalization: Yes ▪ Power Multiplier: 2/(64*128) SARin: ▪ Azimuth window normalization: Yes ▪ Power Multiplier: 2/(64*512)	See section 4.6
Datation bias	LRM: 4.7 ms SAR: -0.5195 ms SARin: -0.5195 ms	LRM: 0 ms SAR: 0 ms SARin: 0 ms	See section 4.7.
Range bias	LRM: 0.2046 m SAR: 0.6730 m SARin: 0.6730 m	LRM: 0 m SAR: 0 m SARin: 0 m	See section 4.7.
External phase correction	LRM: Not applicable SAR: Not applicable SARin: 0.612 rad	LRM: Not applicable SAR: Not applicable SARin: 0.0 rad	

Tab.2 Baseline configuration: BaselineB and BaselineC.

4 Resolved anomalies and expected improvement in BaselineC

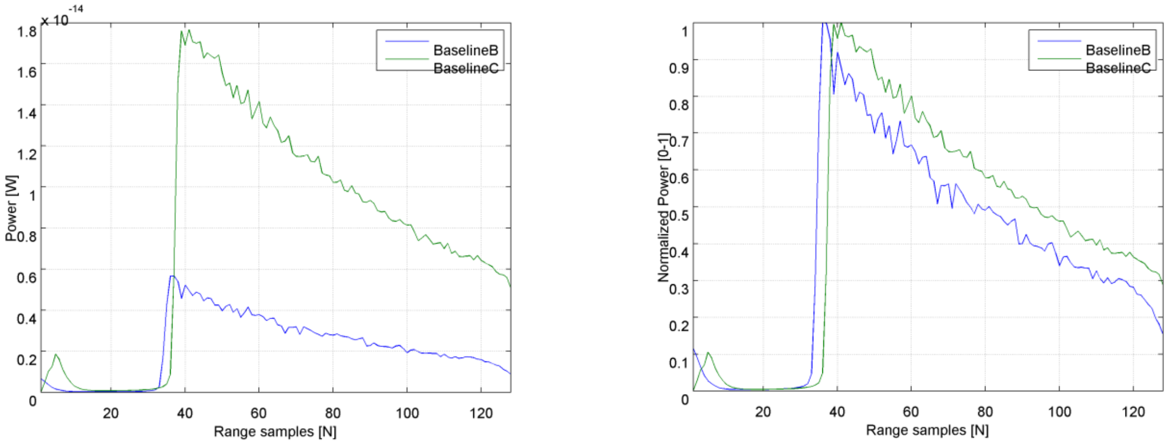
Throughout this section, the quality improvements having a direct impact on the quality of the SAR/SARin Level1b BaselineC products will be described.

4.1 1Hz waveforms

The Baseline C processing chain for the 1Hz waveforms has been improved in order to solve the 3 following anomalies:

- 1Hz waveform *resolved anomaly 1*: The bursts contributing to a single SAR 1Hz waveforms did not really cover 1 second of acquisition in BaselineB .
- 1 Hz waveform *resolved anomaly 2*: The FFT in range compression was not correctly normalized.
- 1Hz waveform *resolved anomaly 3*: The 1Hz waveforms over open ocean resulted to be blurred in case of high altitude rate. In BaselineB the alignment of waveforms to be averaged in the 1Hz waveforms is performed by means of the LAI, which is a measure of the relative distance between the SIRAL and the Earth surface. Aligning the waveforms with respect to the minimum LAI means that the altitude of the satellite is assumed to be constant and in case that the altitude of the satellite is varying among the bursts to be averaged a blurring of the waveform is noticed. In BaselineC, the alignment of waveforms to be averaged in the 1Hz waveforms is performed taking into account both the altitude of the satellite and the LAI. For more details refer to [RD-05].

In the following figure the SAR 1Hz waveforms for BaselineB and BaselineC are compared. From Fig.1(a), where the 1Hz waveforms are compared in power, it can be noticed that the Baseline C waveforms results higher due to the changes solving the 2 first anomalies. Moreover, the different shape of the two waveforms can be noticed in Fig.1(b), where the waveforms have been normalized with respect to their peak power, as it was expected since in BaselineC the correct number of bursts covering 1 second of acquisition is used to compute the 1Hz waveform.



(a) (b)

Fig.1 Comparison of BaselineB and BaselineC SAR 1Hz waveforms over ocean: Power (a) and Normalized Power (b).

The differences in terms of 1Hz waveform shape is evident in the following exemple, where SARin 1Hz waveforms over ocean -in case of high altitude rate - have been compared for BaselineB and BaselineC. As first, from inspection of Fig.2(a) the higher power of the BaselineC waveform can be noticed also in case of SARin. From Fig.2(b), where the waveforms have been normalized with respect to their peak power, it can be noticed that the BaselineC 1Hz waveform has now the expected shape in case of acquisition over ocean, with the leading edge clearly visible, while the BaselineB 1Hz waveform results totally blurred.

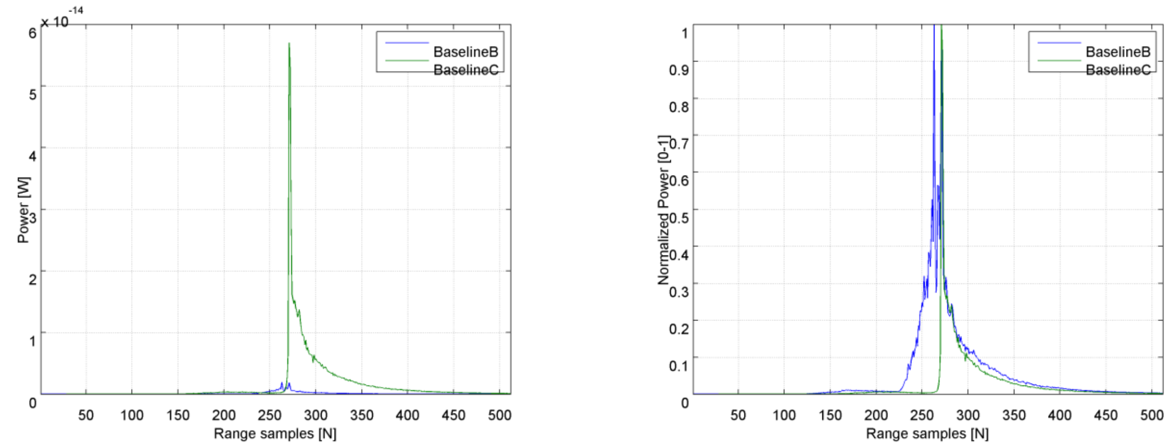


Fig.2 Comparison of BaselineB and BaselineC SARin 1Hz waveforms over ocean: Power (a) and Normalized Power (b).

4.2 Attitude information

Starting from various anomalies on BaselineB products related to the attitude information necessary in IPF1 for processing SAR/SARin data, major modifications have been implemented towards BaselineC. Below are summarized the main changes appearing in the Level1b products:

- Attitude information *change 1:* The attitude information has been annotated in additional fields in Level1b products, as highlighted in Section 6. In particular, at 20 Hz the yaw, pitch, roll values are provided together with the indication of the source of that information (i.e., nominal pointing, Star Tracker Level0 or STR_ATTREF file from Star Tracker Processor).
- Attitude information *change 2:* The roll and pitch mispointing angles that are provided by on ground processing of the Star Tracker data are affected by known biases [RD-04] that will be compensated in BaselineC products. A pitch bias of 0.520 deg and a roll bias of 0.1054 deg will be compensated [RD-04]. It is worth recalling here that in BaselineB products, only the SARin phase difference was corrected for the roll bias. For more details please refer to [RD-04].
- Attitude information *change 3:* The IPF1 uses the attitude information coming from the same Star Tracker that is selected on board as the best available at a given time stamp. It is worth recalling here that for BaselineB the IPF1 used as auxiliary data a Level0 Star Tracker file selected according to a fixed priority order (i.e., 1-2-3) so that very often the IPF did not use the best Star Tracker because this priority order does not always correspond to the one used on board the spacecraft.

Referring to the last point, it has been decided to add to the PDGS a new processor, namely the Star Tracker Processor, that is in charge to provide to the LRM IPF1 and SAR/SARin IPF1 the attitude information coming from the best available Star Tracker according to the rule used on-board. An high level block scheme of the Star Tracker Processor is shown in the following figure. There it can be noticed that the Star Tracker Processor takes as input the all the available Level0 Star Tracker files from the three Star Trackers (STR*ATT) and an auxiliary file provided by ESOC-FOS containing the information from the Housekeeping Telemetry on the Star Tracker selected on-board (HK TLM). As auxiliary input also the Istrument Processing Facility DataBase (IPFDB) is needed. At any given timestamp, the Star Tracker Processor verifies -from the HK TLM auxiliary file - the Star Tracker used on board and processes the corresponding Level0 Star Tracker file to obtain the attitude information. This way, a single sequence of attitude angles as function of time is obtained that is no more related to a single Star Tracker but following the best Star Tracker according to the on-board rule. Before writing the attitude information on the output file, the values of each mispointing angle (i.e. yaw, pitch, roll) are subjected to a moving average in order to reduce the noise. Finally, the STR_ATTREF file is produced, that is then given as auxiliary input to the IPF1s.

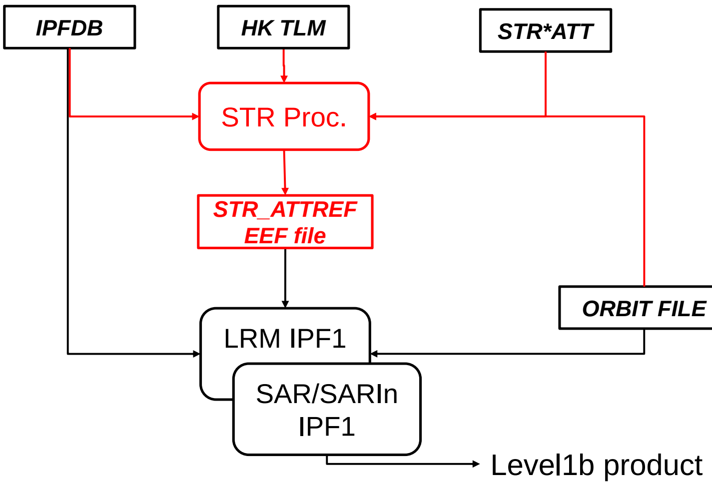


Fig.3 Block scheme of the Star Tracker Processor.

The following figure show an example of the attitude angles produced by the Star Tracker Processor for a time interval of 3 hours the 3rd of February 2011 starting from on-board Star Tracker in the HK TLM. At the beginning, the Star Tracker used on board is the Star Tracker 2, then there is switch on the Star Tracker 1 and finally the Star Tracker 2 again has been selected. By inspection of the attitude information it can be noticed that there is a coherent continuity of the three mispointing angles when there is a switch on the Star Tracker. It can however be observed that the yaw from Star Tracker 1 is noisier than the yaw from the Star Tracker 2, highlighting the switch on the Level0 Star Tracker file used in processing.

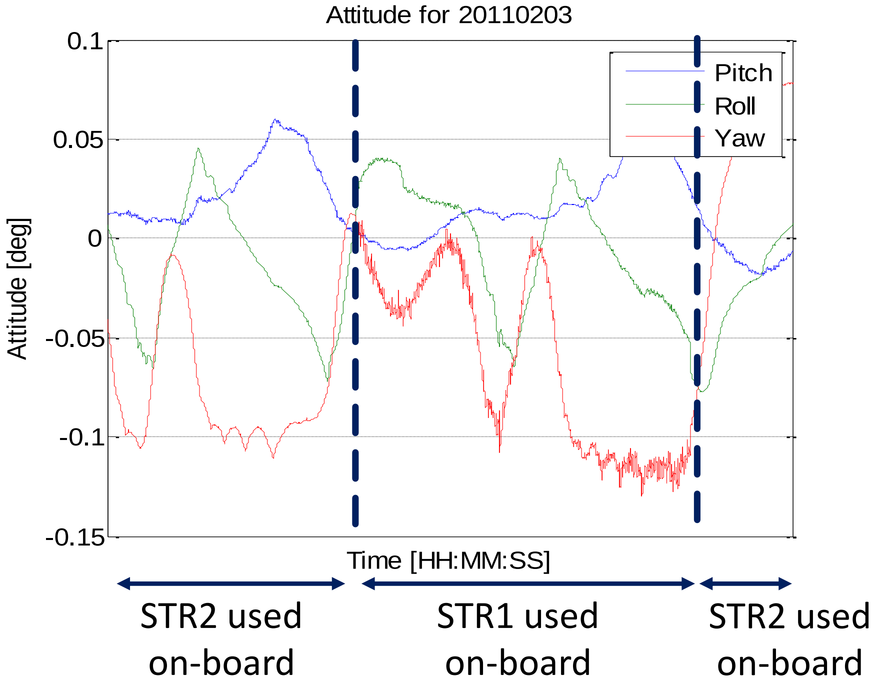


Fig.4 Example of attitude information produced by Star Tracker Processor.

In Fig.5 it is shown a close-up view of the pitch angle when Star Tracker switch from Star Tracker 2 to Star Tracker 1. By inspection of Fig.5 the continuity of the pitch values can be noticed as well as the effects of the moving average (window length equal to 5 seconds) that makes the pitch values less affected by not relevant small scale signals.

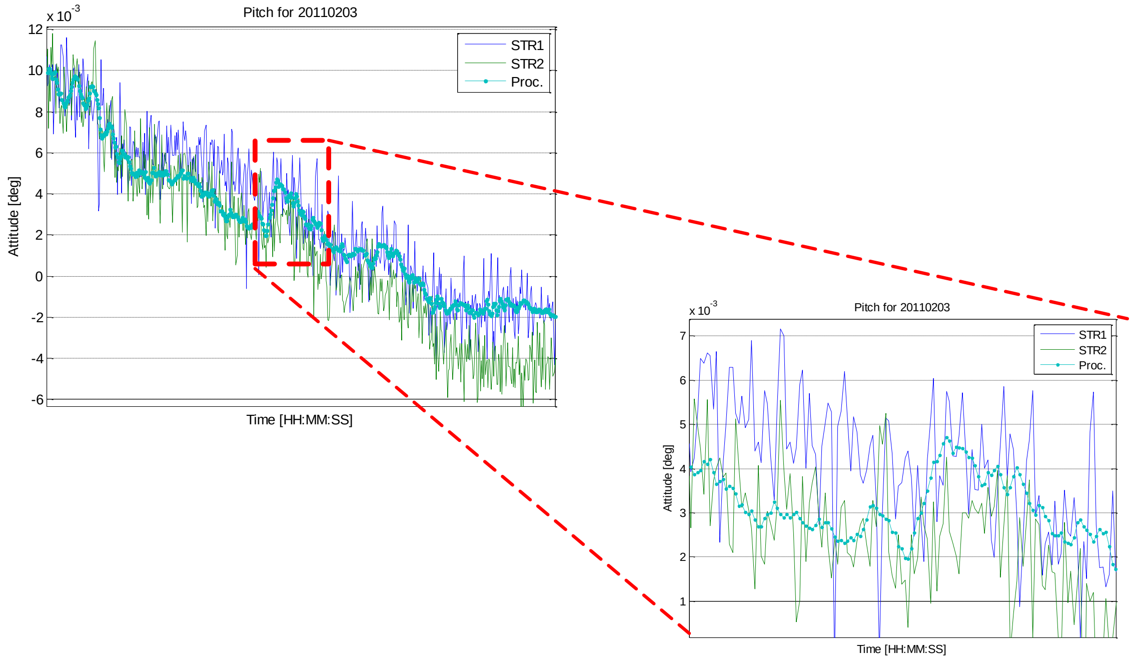


Fig.5 Example of mispointing angle in correspondence of a Star Tracker switch.

4.3 Range window size of 20Hz Level1b waveforms

Recalling that in BaselineB, an oversampling by a factor 2 of the 20Hz waveforms has been introduced, in order to fit the oversampled waveforms in the Level1b product that supported 128 samples for SAR and 512 for SARin, it was decided to cut the waveforms using the leading edge as a reference point. However, this causes the tail of the trailing edge of the waveform to be cut so that part of the information acquired by the instrument is unavoidably lost. Moreover, the loss of the tail of the waveforms can make more difficult the retracking at Level2.

To solve this issue, the Level1b product format has been updated as described in Section 6, so that in BaselineC the 20Hz waveforms will be sized according to the following table. It is worth noticing that for SARin it has been doubled also the phase difference and the coherence for each 20Hz waveform.

Baseline	SAR	SARIn
BaselineB	128 samples (range window of ~30 m)	512 samples (range window of ~120 m)
BaselineC	256 samples (range window of ~60 m)	1024 samples (range window of ~240 m)

Tab.3 20Hz waveforms: number of samples and corresponding range window.

In the following figure, the same SAR 20Hz Level1b waveform from BaselineB and BaselineC is shown. Apart from the different position of the waveform in the range window (the annotated window delay in the Level1b product is changed accordingly), it can be noticed the cut of the SAR waveform for BaselineB at sample 128 while the waveform for BaselineC has a longer trailing edge. The shape of the two waveforms is very similar.

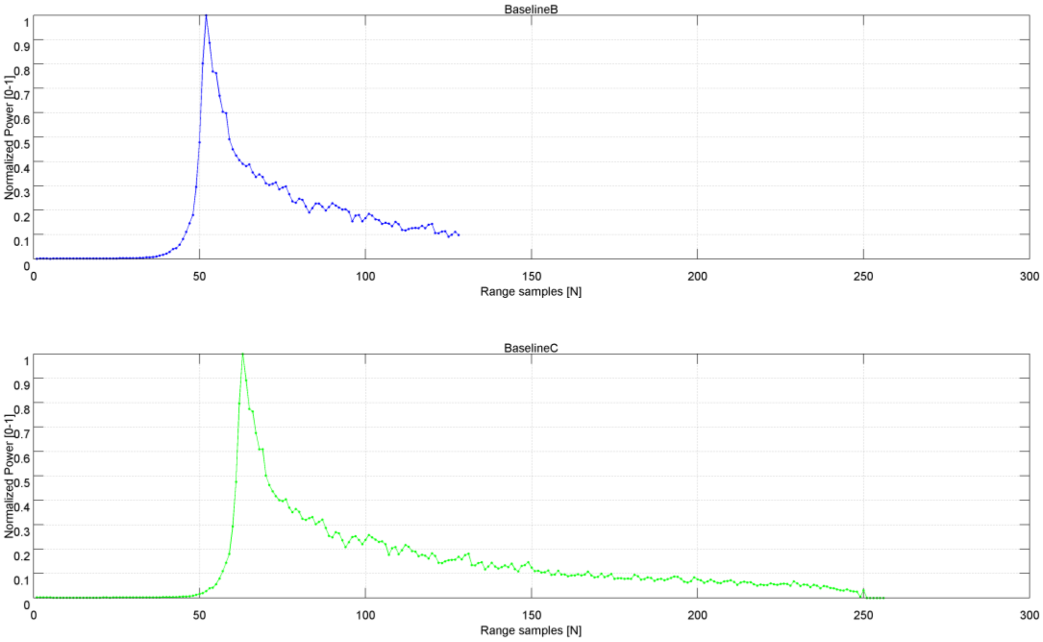


Fig.6 Examples of BaselineB SAR 20Hz waveform (128 samples) and doubled length of BaselineC SAR 20Hz waveform (256 samples).

Similarly, in the following figure, the same SARin 20Hz Level1b waveform from BaselineB and BaselineC is shown. Apart from the different position of the waveform in the range window, it can be noticed the cut of the SARin waveform for BaselineB at sample 512 while the waveform for BaselineC has a long trailing edge.

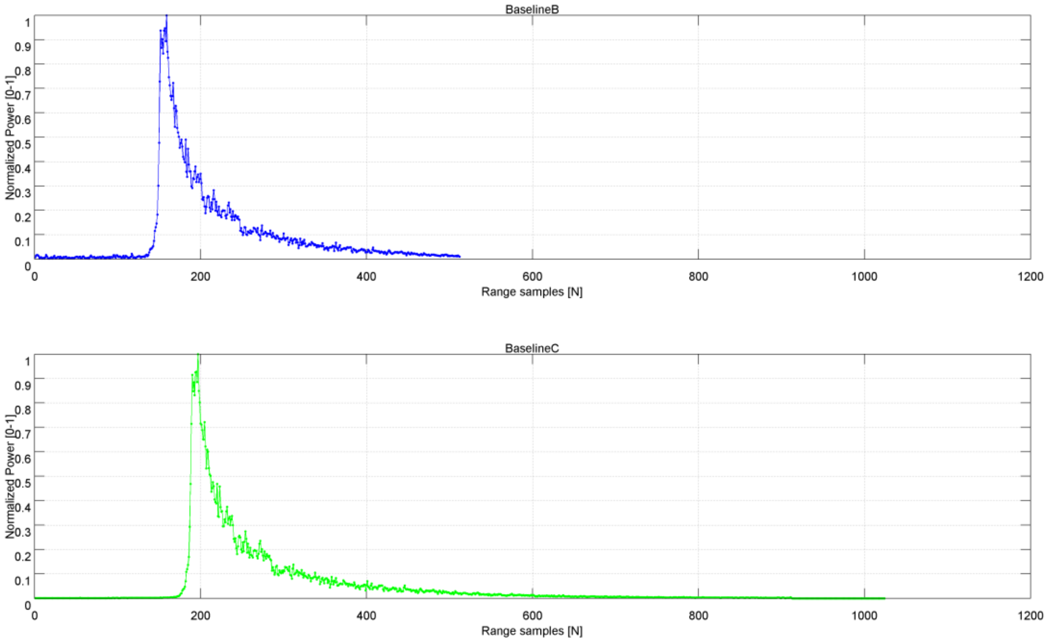


Fig.7 Examples of BaselineB SARin 20Hz waveform (512 samples) and doubled length of BaselineC SARin 20Hz waveform (1024 samples).

In the previous example of Fig.7, the shape of the two normalized waveforms appears to be very similar whereas it is not the case when these waveforms are reported in dB (Fig.8). There, it is possible to notice that the trailing edge of the BaselineC waveform decreases with a constant trend up to sample 1024. Moreover, by inspection of Fig.8, it is possible to notice major differences prior to the waveform leading edges: the noise floor results to be 10 dB higher in case of BaselineB waveform associated to a significant and non physical variability. This improvement in terms of Signal-to-Clutter-Noise-Ratio (SCNR) is related to changes described in the Sections 4.4 and 4.5.

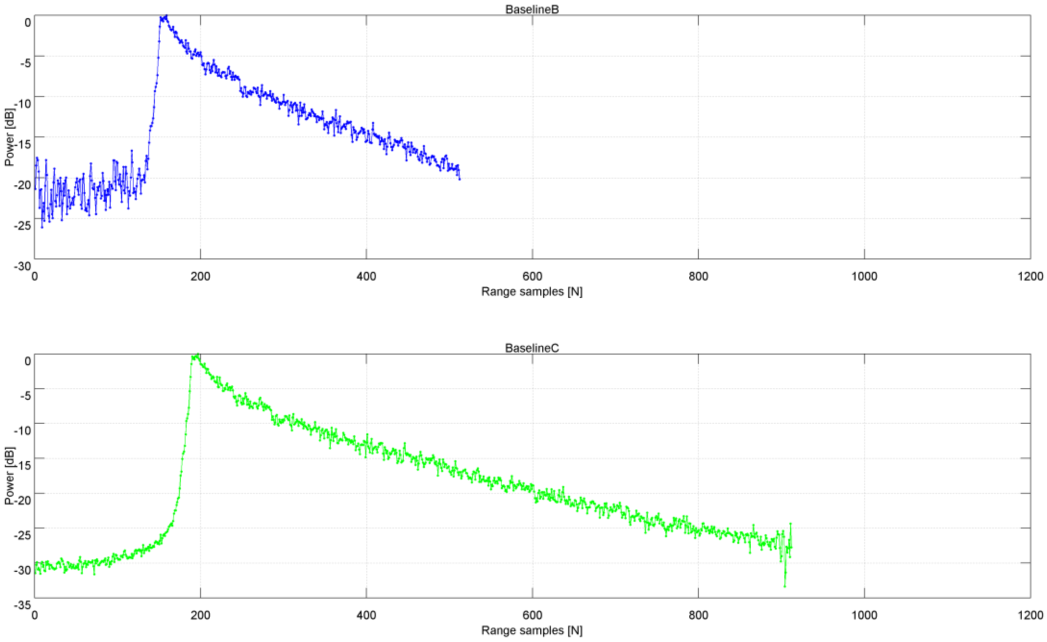


Fig.8 BaselineB and BaselineC SARin 20Hz waveforms in dB.

4.4 Surface Sample Stack Weighting

The Surface Sample Stack Weighting has been introduced to improve the Signal-to-Clutter-Noise-Ratio (SCNR) of the 20Hz Level1b waveforms by filtering out during the multilook operation the single look echoes originated by the furthest acquired bursts with respect to the surface sample.

It is worth recalling here that the 20Hz waveforms are generated in correspondence of an approximately equally spaced (~ 330 m) set of ground locations on the Earth surface, i.e. surface samples, and that a surface sample gathers a stack of single look echoes coming from the processed bursts during the time of visibility.

Then, for a given surface sample the Surface Sample Stack (SSS) is the collection of all the single looks echoes that are referred to the current surface sample, where each single look echo is assumed to be originated from the surface illuminated by an along-track beam. As show in Fig.9, as the altimeter moves along the orbit, the surface sample is seen by the instrument at a different the look angle, that is defined as the angle at which the surfaces sample is seen with respect to the nadir direction of the altimeter. According to [RD-06], the normalized slant range corrected echo power from a spherical surface depends on the look angle ϑ_{look} so that increasing the look angle corresponds to a smaller maximum. When the look angle is null, the surface sample is seen at the nadir and the corresponding echo has the impulse response with the steepest leading edge.

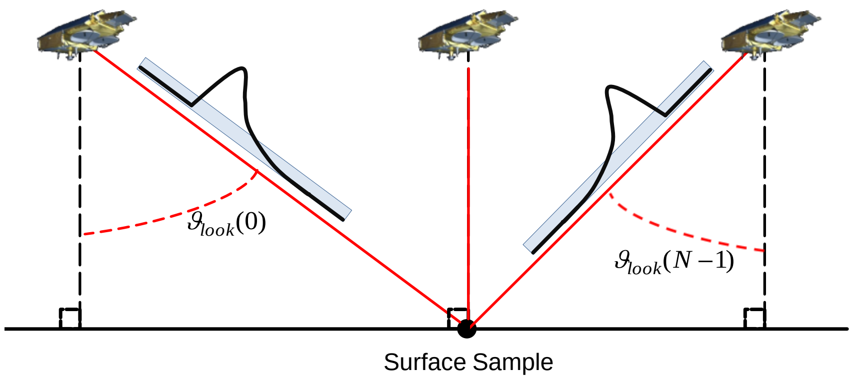


Fig.9 Single looks gathering for a Surface Sample as function of the look angle.

Thus a stack weighting with respect the look angle has been applied to the Surface Sample Stacks in BaselineC: a rectangular window in the range $[-D_w, +D_w]$ is applied, where D_w is the maximum look angle for which the rectangular window has value equal to one. The effects of the Surface Sample Stack Weighting on the SSS are briefly sketched in the following figure. It is worth underlining here that the looks in the Surface Sample Stack can be subjected to weighting with more complex windows, taking care that different windows can be optimal in a different sense. In the framework of the BaselineC evolutions it has been decided to apply a simple rectangular window to the Surface Sample Stacks in order to filter out the farthest beams but without changing the weights among looks in a stack. At this moment, the investigation on optimal windows to be applied to Surface Sample Stacks to improve the data quality in some sense is an open research field.

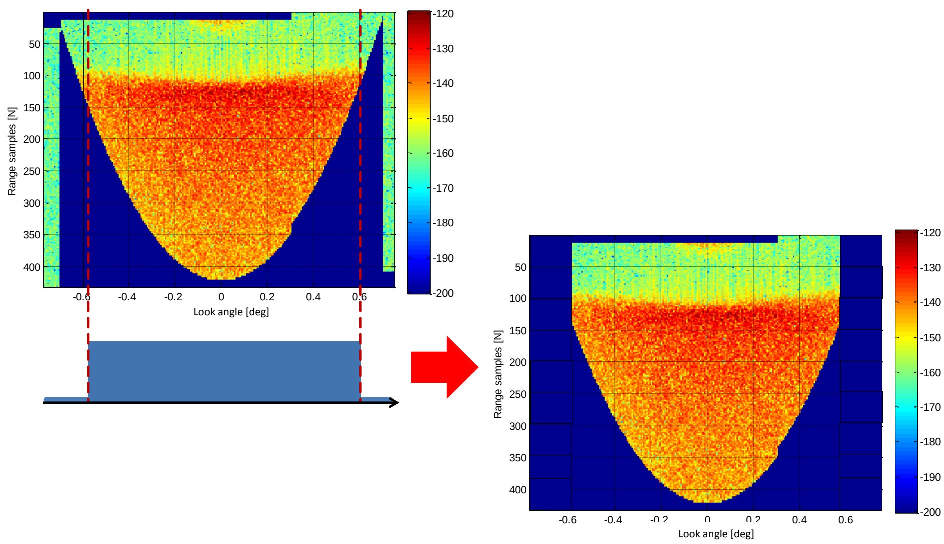


Fig.10 Surface Sample Stack Weighting, the colorbar is in dB.

As it can be observed in Fig.10 the SSS weighting cancels out the beams in the SSS that have been obtained for higher look angles (in absolute value). The width of the weighting window, equal to $2D_w$, has been identified as a trade-off with the number of looks of the multilooked waveform. In fact, as the width of the weighting window is reduced, an higher number of beams is canceled out and in turns less looks are averaged to obtain the multilooked waveform. As a result of a trade-off analysis aimed at comparing the increase of SCNR with respect to the decrease of Equivalent Number of Looks (ENL) as D_w decreases, for BaselineC the value D_w has been fixed to 0.6 deg for SAR and to 0.7 deg for SARin. As an example of the trade-off analysis, in the following figure it can be observed as the SCNR increases as D_w decreases.

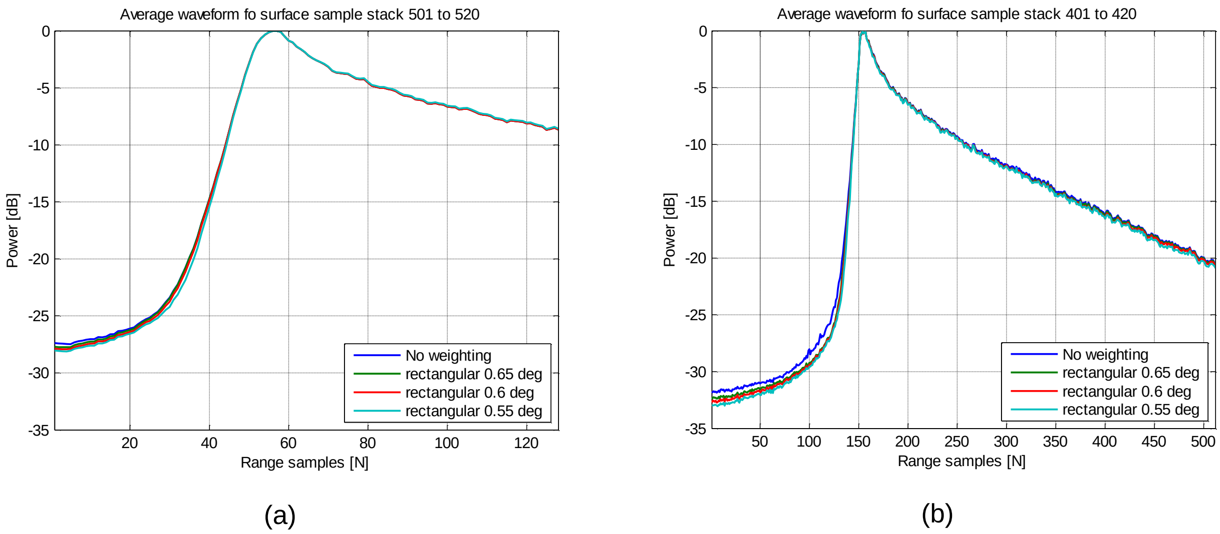
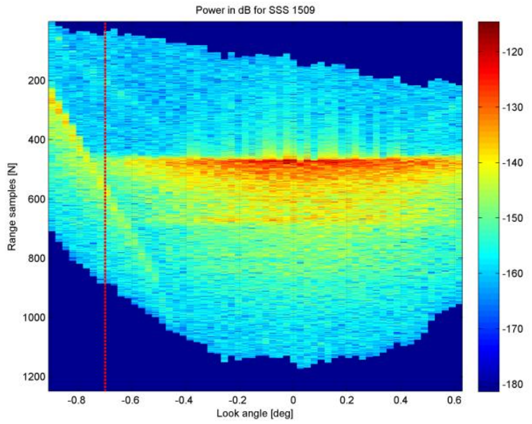


Fig.11 Averaged 20Hz Level1b waveforms for different values of D_w: SAR (a) and SARin (b).

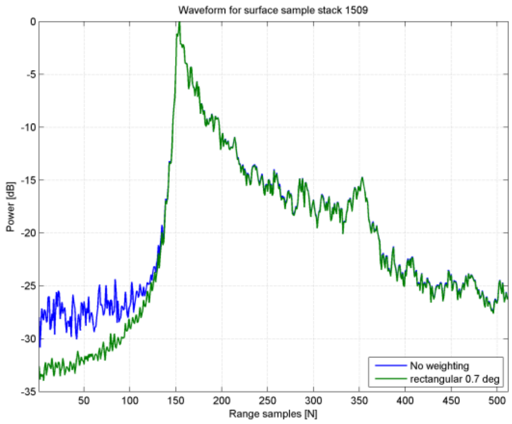
It is worth recalling that the Product Format has been updated in order to provide additional information to the users about the Surface Stack before and after the weighting. In fact, according to Tab.8, for each 20Hz waveform, the following fields are provided:

- Look Angle Start: the look angle of the first contributing beam (after the Surface Sample Stack weighting).
- Look Angle Stop: the look angle of the last contributing beam (after the Surface Sample Stack weighting).
- Number of contributing beams in the stack after weighting.
- Number of contributing beams in the stack before weighting.

The main quality improvement given by the Surface Sample Stack weighting has been verified in case of SARin acquisitions that are affected by ambiguous target in the stack. In fact, being in case of SARin the Doppler Bandwidth smaller than the PRF, the aliasing effect unavoidably creates some ambiguous targets in the stack, as it is shown in the following figure. In Fig.12 (a) a SARin stack is shown and the ambiguity is visible at lower look angles. In Fig.12 (b) the waveform corresponding to no weighting (i.e., BaselineB) and to rectangular weighting with D_w =0.7 deg (i.e., BaselineC) are compared. In case that the weighting is applied, so that the single look echoes most affected by the ambiguity are filtered out, the improved SCNR can be noticed.



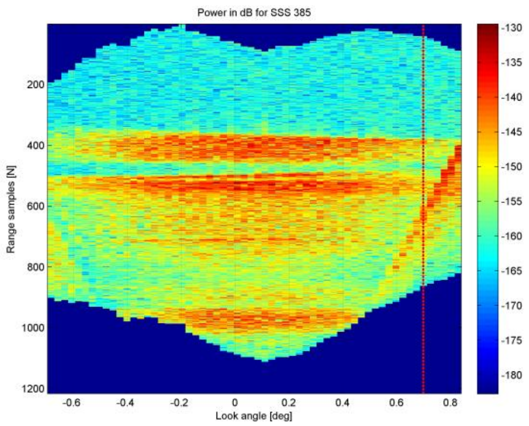
(a)



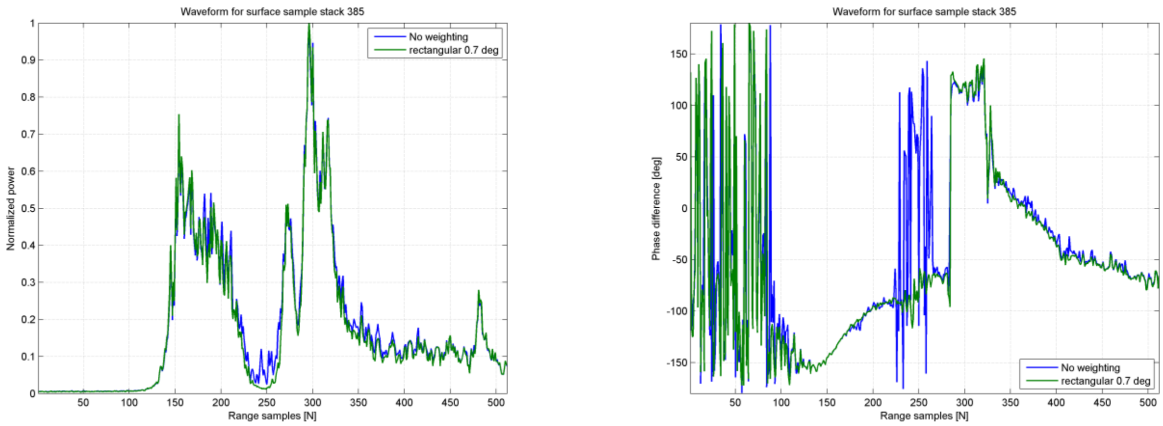
(b)

Fig.12 SCNR improvement on SARin waveform by filtering out the ambiguity. In Fig.12(a) the dotted red line indicates the boundary of the applied rectangular weighting window.

By reducing the effect of the ambiguities through the Surface Sample Stack weighting, also the SARin waveforms in case of complex returns from the Earth surface are improved. As it is shown in the following figure, by filtering out the ambiguity from the stack as in Fig.13 (a), the SARin 20Hz waveform is less noisy around sample 250 in both power and phase difference.



(a)



(b) (c)

Fig.13 SARin waveform by filtering out the ambiguity in case of complex return from the ground. In Fig.13(a), the dotted red line indicates the boundary of the applied rectangular weighting window.

4.5 Slant range correction

By analysis of SAR acquisition over ocean in case of high altitude rate, i.e. higher than 20 m/s, it was noticed that the Surface Sample Stacks obtained from BaselineB processing have some of the single look echoes where the leading edge is missed [RD-13]. As an example of this behavior, single look echoes where the leading edge is missed have been highlighted in the following figure, where a Surface Sample Stack is shown.

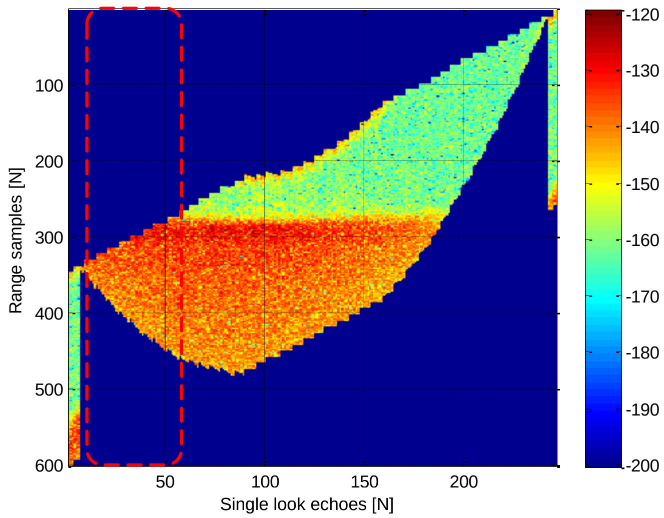


Fig.14 Surface Sample Stack with missed leading edge in some single look echoes.

The problem has been identified in the coarse slant range correction that was applied at Burst level after azimuth and range focusing in BaselineB. In fact, in order to compensate the slant range differences among echoes within the same burst, the echoes are shifted with respect to the central echo. But, being the memory allocated for the burst limited, shifting the echoes will in turn cause the loss of data since all the samples that are moved out of the buffers are unavoidably lost. While this approach for low altitude rate is not an issue, since the sample that are lost are not carrying information about the Earth surface, in case of severe altitude rate the sample lost can be those corresponding to the leading edge of the waveform. To avoid this issue, in BaselineC the coarse slant correction is applied directly on the stack in conjunction with the window delay alignment. Using the processing for BaselineC, the same stack shown in Fig.14, is correctly aligned and all the single look echoes contain the leading edge, as it is shown in Fig.15

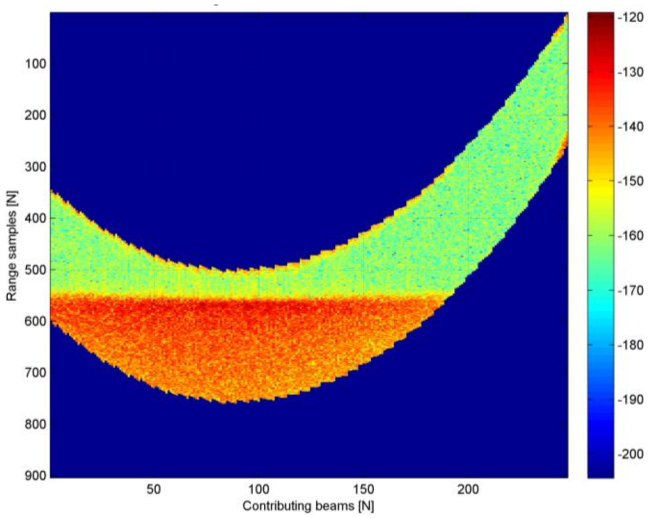
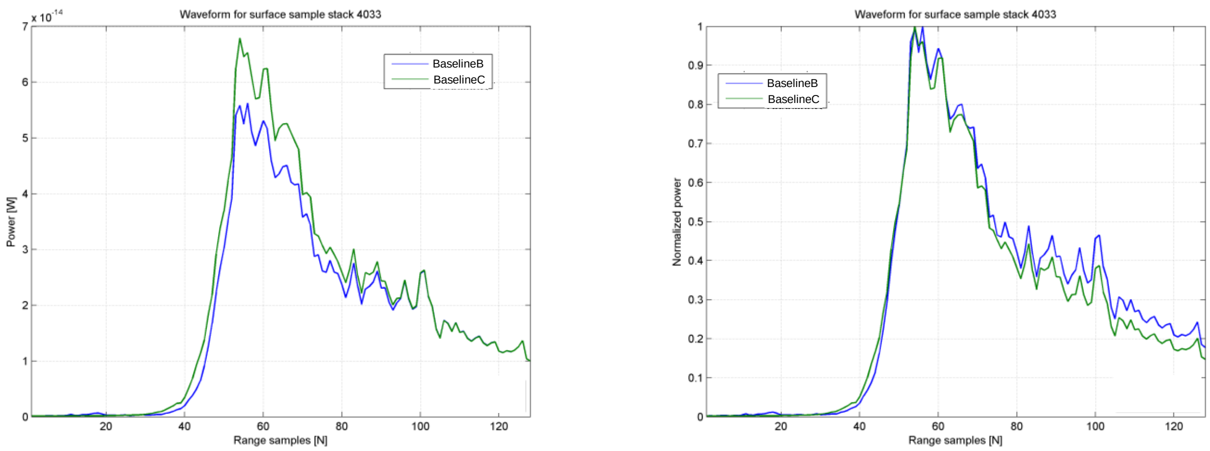


Fig.15 Surface Sample Stack with leading edge in all the single look echoes.

The 20Hz Level1b waveforms obtained by multilooking the stacks shown in Fig.14 and Fig.15, for BaselineB and BaselineC respectively, are compared in the figure below. In Fig.16(a) the power waveforms are compared and it is possible to notice that

- the BaselineC is higher in power up to about sample 100 as it was expected since in that range of samples more non-zero single look echoes are averaged together
- after sample 100 the two waveforms are perfectly identical since the same single look echoes are averaged

Moreover from Fig.16 (b), where the power waveforms normalized w.r.t. to the peak are compared, it is possible to notice that the shape of the two waveforms is different in the trailing edge, so that it is expected that BaselineC leads to different geophysical parameters from Level2 analysis.



(a) (b)

Fig.16 Comparison of 20Hz level1b waveforms for BaselineB and BaselineC using the two different approaches for coarse slant range correction.

4.6 Power normalization

Starting from the analysis in [RD-07] and [RD-08], it has been verified that the peak power of the 20Hz Level1b waveforms for SAR and SARin was too high in BaselineB with respect to the expected value according to the sigma0 of the sea surface. This issue has been solved by correcting the power scaling of the processed data in two points:

- The azimuth window, that is applied to burst data before beam forming to lower the sidelobes of the azimuth impulse response function, has been normalized in power [RD-09]
- The power scaling due to correctly normalize the FFTs used for beam forming and range compression has been updated [RD-07]

In the following figure are shown the tracks for the two sample products (one SAR and one SARin) that will be used throughout this section to verify the effectiveness of the change on power scaling.

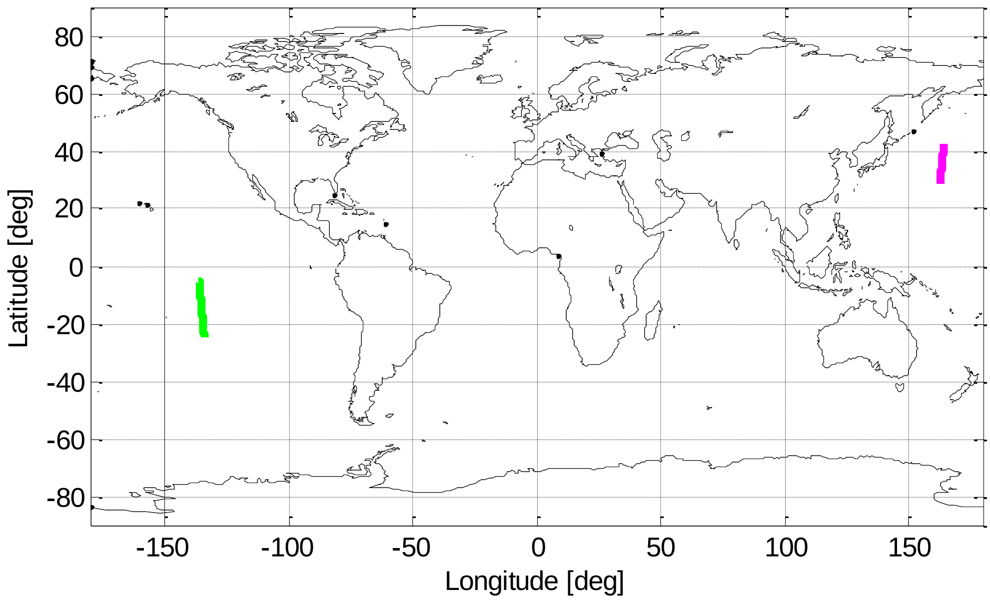


Fig.17 Tracks for the SAR (in green) and SARin (in purple) acquisitions that have been used as sample products throughout this section.

By comparison of the peak power for the 20Hz Level1b power waveforms for a SAR acquisition over open ocean in case of BaselineB and BaselineC, a difference in power between -9 dB and -8 dB has been measured, as it is shown in the following figure. According to Fig.19, from the BaselineB product a sigma0 between 16 dB and 17 dB was obtained so that from the BaselineC product a sigma0 between 7.5 dB and 8.5 dB can be foreseen, that is more in line with the expected values.

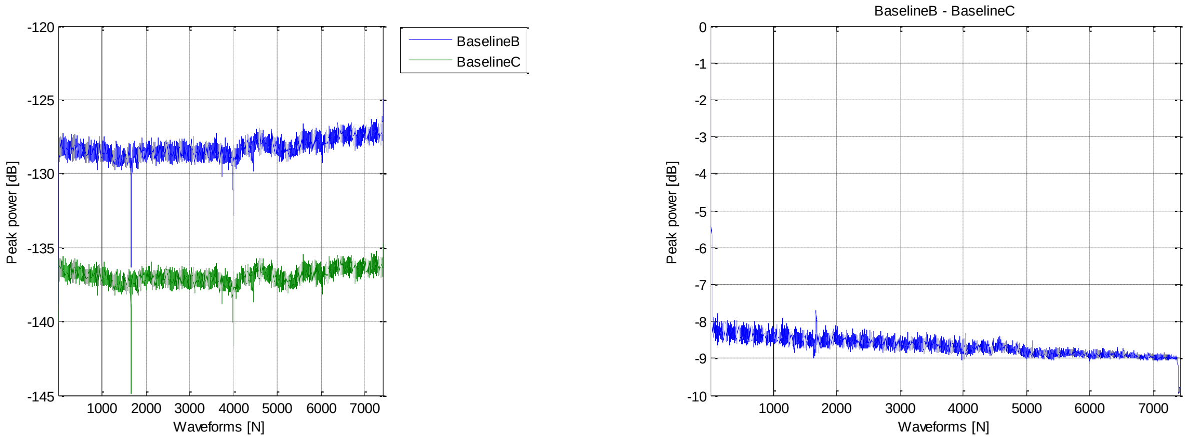


Fig.18 20Hz Level1b SAR waveforms: peak power difference.

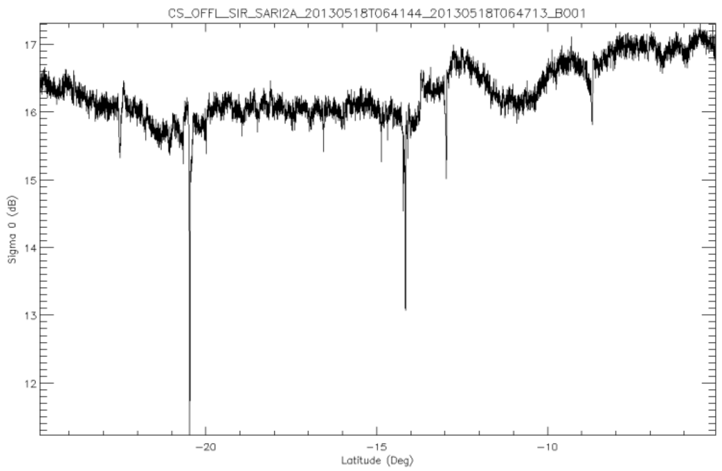


Fig.19 Sigma0 in dB obtained from SAR BaselineB product.

By comparison of the peak power for the 20Hz Level1b power waveforms for a SARin acquisition over open ocean in case of BaselineB and BaselineC, a difference in power equal to about -10 dB has been measured, as it is shown in the following figure. According to Fig.21, from the BaselineB product a sigma0 between 15 dB and 17 dB was obtained so that from the BaselineC product a sigma0 between 5 dB and 7 dB can be foreseen, that is more in line with the expected values.

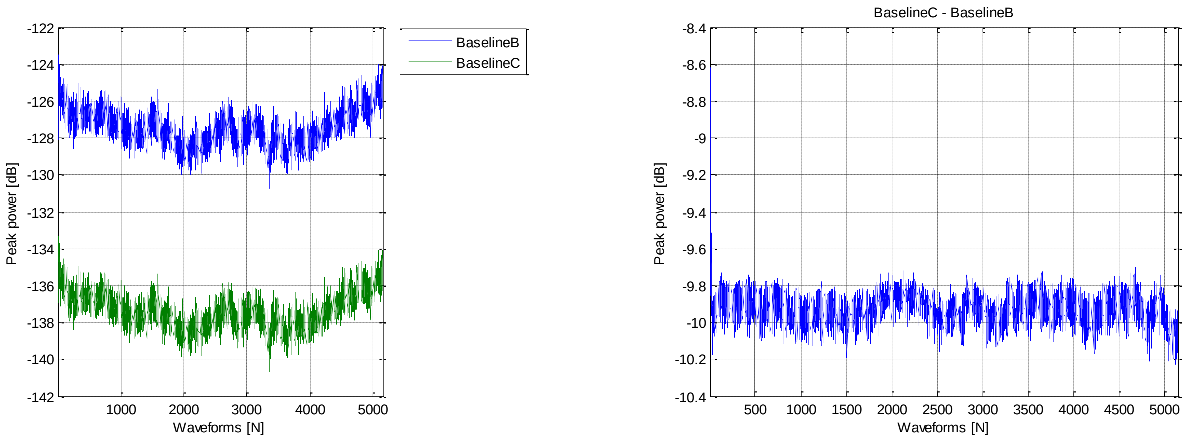


Fig.20 20Hz Level1b SARin waveforms: peak power difference.

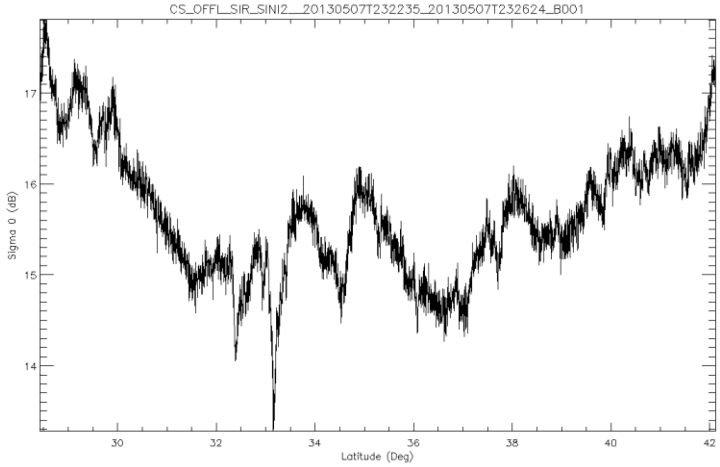


Fig.21 Sigma0 in dB obtained from SARin BaselineB product.

4.7 Datation and range biases

According to [RD-04], the following biases related to the datation and the range measurement were observed on the SAR/SARin BaselineB Level1b products. The SAR/SARin BaselineB Level1b products will be corrected for those biases.

Bias	SAR	SARIn
Range bias	0.6730 m	0.6730 m
Datation bias	-0.5195 ms	-0.5195 ms

Tab.4 Range and datation biases.

It is worth noticing the change to compensate the range and datation biases is not tracked in Section 6 since they have been applied in the IPF1 Preprocessor instead of the Specialized IPF1.

5 Analysis of sample products

Throughout this section some sample products for BaselineC have been analysed in comparison with the corresponding BaselineB products aiming at verifying the quality of the BaselineC products not only at single waveform level as it has been done in Section 4.

Throughout this section, Level 1b power waveforms at 20Hz are plotted as a z-scope plot, where the x-axis is the Level1b waveform number and the y-axis is termed as “Elevation over ellipsoid” for sake of simplicity. What the y-axis really means is each L1b waveform is simply shifted with respect to the orbit height and window delay to derive an estimated elevation for the centre of the echo window. All other samples are plotted with respect to the echo window centre and thus energy that appears as a lower elevation than the leading edge of the waveform is simply further in range. It has to be underlined that no geo-corrections have been applied.

5.1 SAR sample products

As first the BaselineB product CS_LTA__SIR_SAR_1B_20110822T110625_20110822T110726_B001.DBL has been compared with the corresponding product for BaselineC. The track for this product is shown in the following figure.

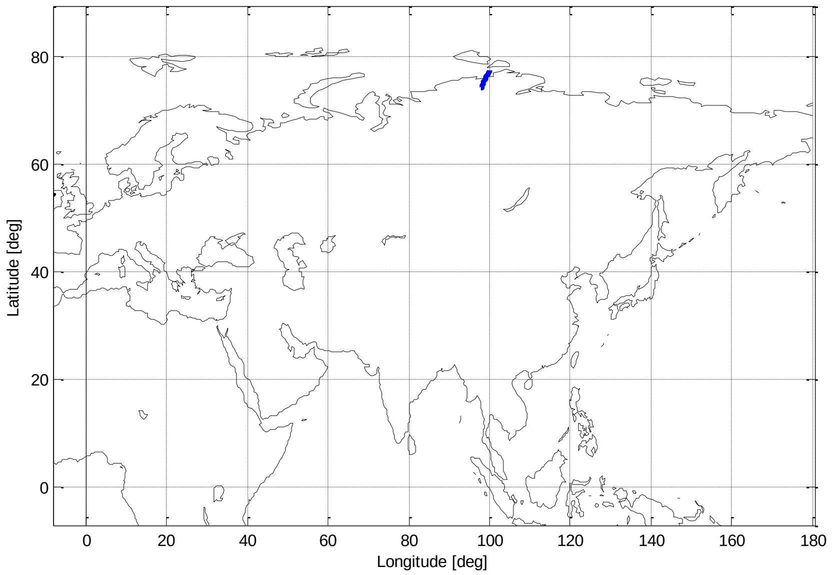


Fig.22 Track for BaselineB product CS_LTA__SIR_SAR_1B_20110822T110625_20110822T110726_B001.DBL.

As first, it has been verified that the attitude angles annotated in the Level1b product. It is worth noticing that in the following figure we compare the attitude angles annotated in BaselineC product with the attitude angles derived from the baseline vector and the beam vector annotated in BaselineB product. By inspection of Fig.23 it can be noticed that the average difference for each attitude angle between BaselineB and

BaselineC is approximately equal to the bias corrected in BaselineC according to Tab.2, i.e. 0 deg for yaw, 0.055 deg for pitch and 0.1062 deg for roll.

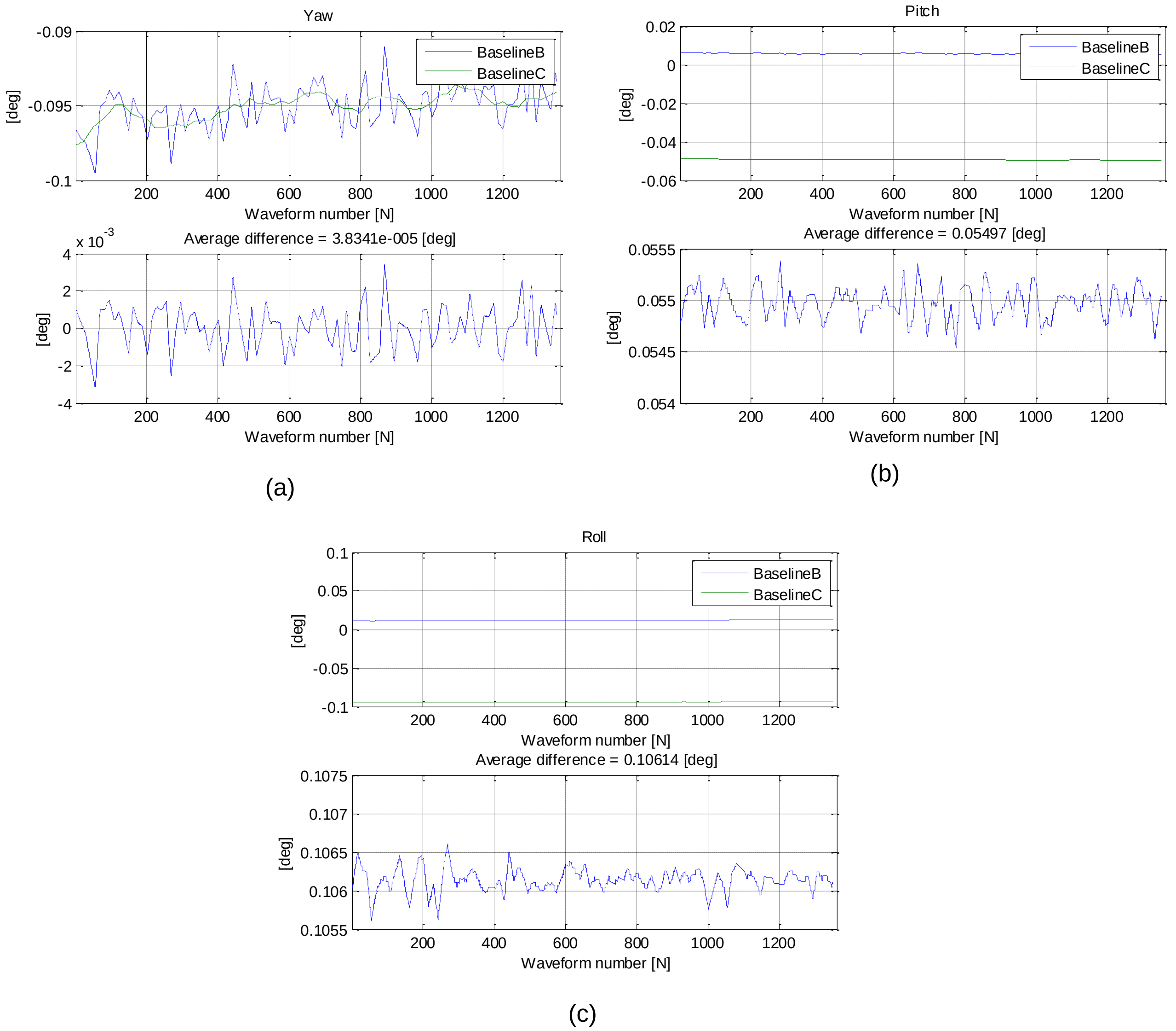
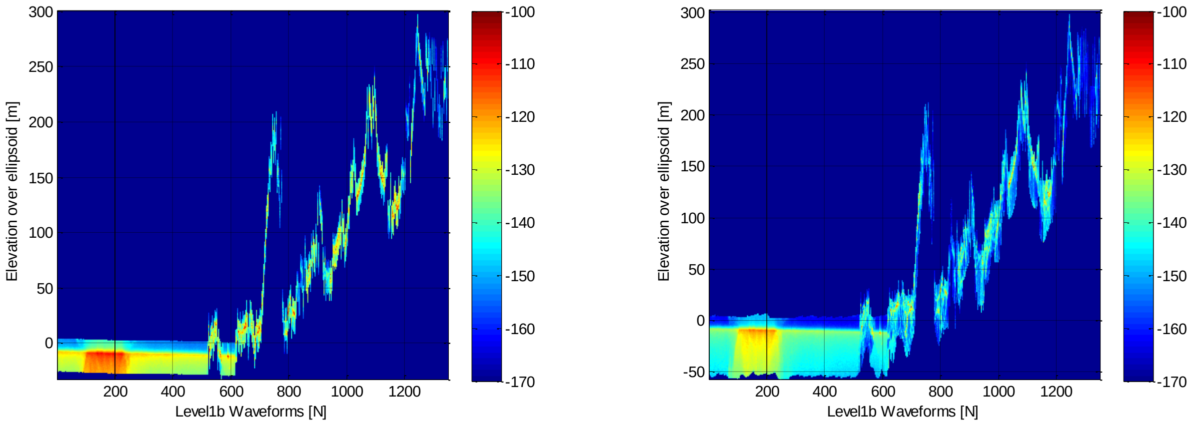


Fig.23 Comparison of attitude angles from BaselineB and BaselineC product: yaw (a), pitch (b) and roll (c).

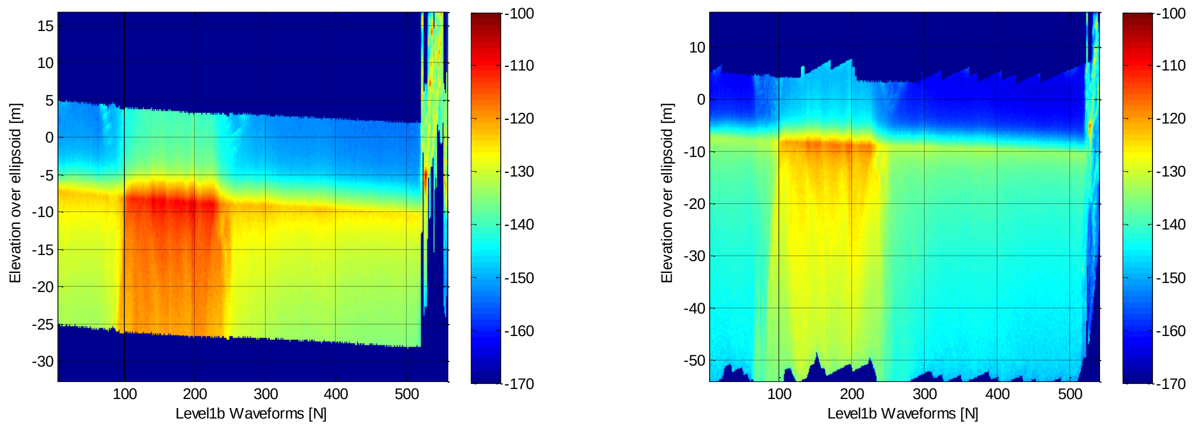
In figure Fig.24, the z-scopes plot of the 20Hz Level 1b power waveforms for BaselineB and BaselineC are compared. The colorbar is the power in dB in order to recognize the peak power of the waveforms. There it is possible to notice that the profile is very similar and that the expected difference in power is noticeable, according to the discussion in Section 4.6.



(a) (b)

Fig.24 Sample SAR product: z-scope for BaselineB (a) and BaselineC (b), colorscale in dB.

The similar shape of the z-scope plot for the two products is visible in Fig.25, where it is possible to notice as first the larger range window for the BaselineC product. Moreover, the surface appears similar in the two products as well the scattering in the Level1b waveforms from 100 to 225 (approximately).



(a) (b)

Fig.25 Close-up view on sample SAR product: z-scope for BaselineB (a) and BaselineC (b), colorscale in dB.

Finally, in Fig.26 the retracking point for the two products has been compared. The retracking point has been evaluated on the waveforms, already shifted with respect to both the orbit height and window delay, by interpolating the waveforms with a factor 2 and then applying an OCOG retracker. It has to be underlined that no geo-corrections have been applied. By inspection of Fig.26, the retracking point for BaselineC is overlapped to the BaselineB retracking point for almost the whole product. Anyway, some waveforms exhibit different retracking points when complex topography over land is on ground track. Those differences on the retracking point can be reasonably addressed to the different shape of the waveforms due to the changes described in Section 4.

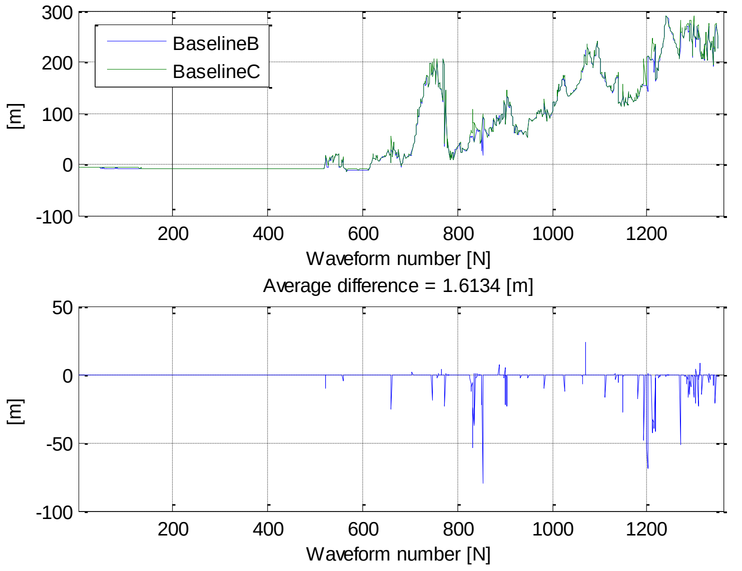


Fig.26 Retracking point for sample SAR product.

On the other hand, looking at the comparison on the retracking point from the BaselineB and the BaselineC products over sea, that is shown in the following figure, it can be noticed that the retracked profile is very similar and that the BaselineC range is shorter of about 0.68 cm, which is approximately equal to the range bias that has been removed with respect to BaselineB according to Tab.4.

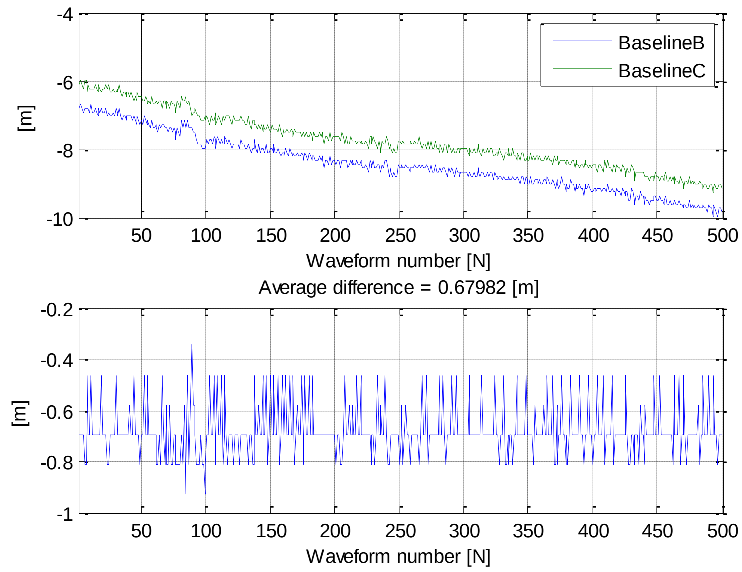


Fig.27 Retracking point for sample SAR product: close up view when sea is overflown.

The same analysis has been carried on another BaselineB SAR product, namely CS_LTA__SIR_SAR_1B_20121028T194426_20121028T194755_B001.DBL, that contains at the beginning a long acquisition over open ocean. The track for this product is shown in the following figure.

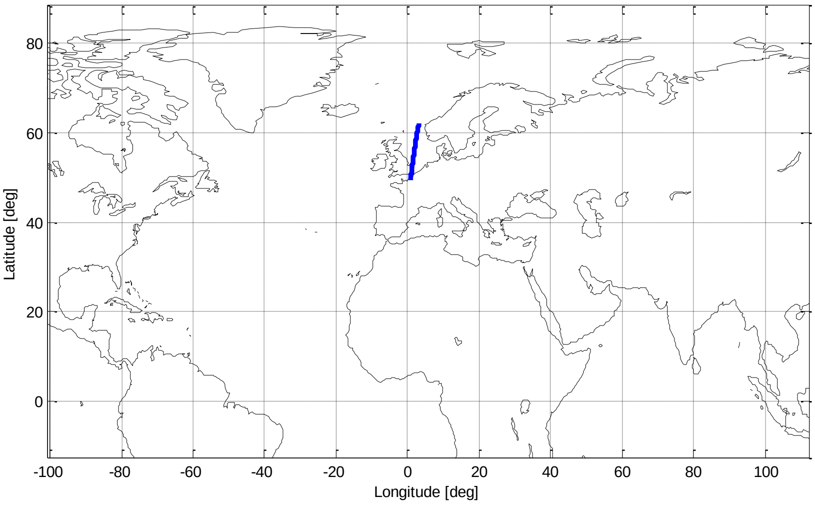


Fig.28 Track for BaselineB product CS_LTA__SIR_SAR_1B_20121028T194426_20121028T194755_B001.DBL.

From inspection of Fig.29, where it is shown the z-scope plot of the 20Hz Level 1b power waveforms for BaselineB and BaselineC, again it can be noticed

- The larger range window for BaelineC
- The lower power of the BaselineC waveforms
- The similar profile obtained by aligning the 20Hz Level1b waveforms

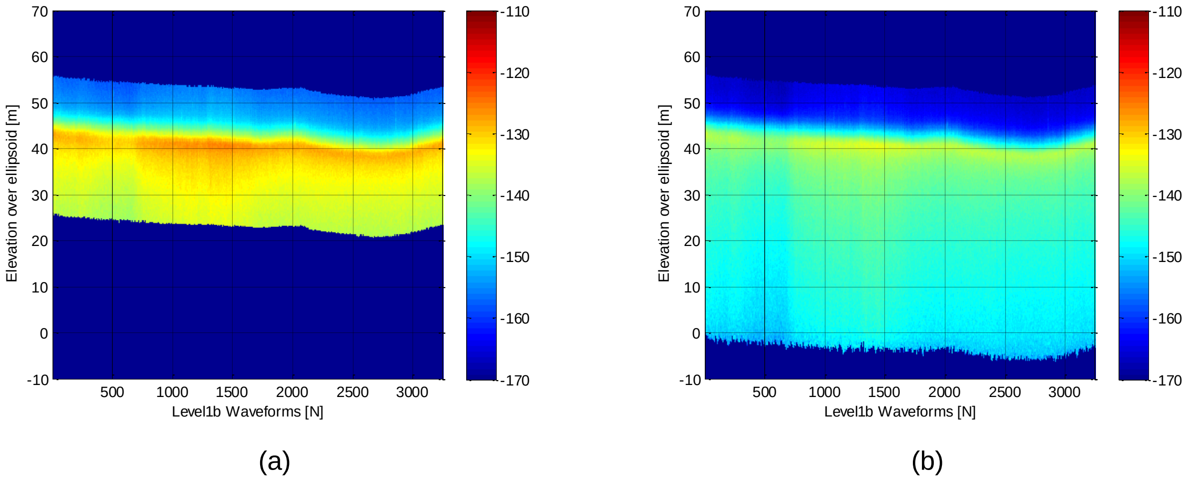


Fig.29 Sample SAR product over open ocean: z-scope for BaselineC (a) and BaselineB (b), colorscale in dB.

5.2 SARin sample products

The BaselineB product CS_LTA__SIR_SIN_1B_20110823T142338_20110823T142456_B001.DBL has been compared with the corresponding product for BaselineC. The track for this product is shown in the following figure.

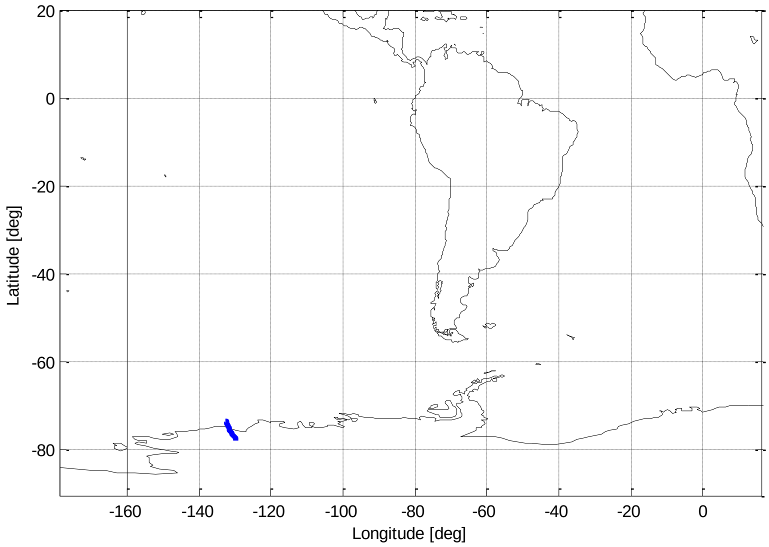


Fig.30 Track for BaselineB product CS_LTA__SIR_SIN_1B_20110823T142338_20110823T142456_B001.DBL.

In Fig.31, the z-scopes plot of the 20Hz Level 1b power waveforms for BaselineB and BaselineC are compared. The colorbar is the power in dB in order to recognize the peak power of the waveforms. There it is possible to notice that the profile is very similar and that the expected difference in power is noticeable, according to the discussion in Section 4.6.

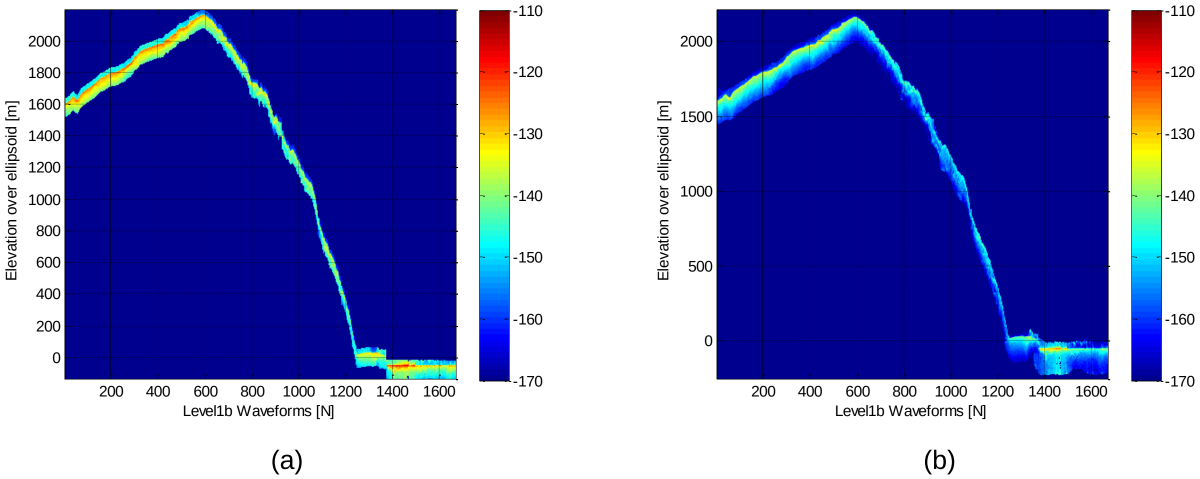
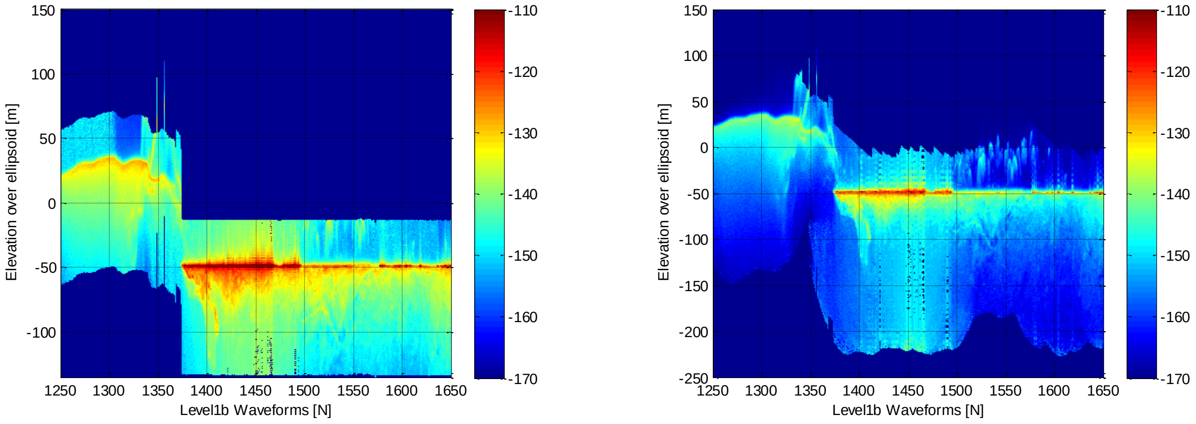


Fig.31 Sample SARin product: z-scope for BaselineB (a) and BaselineC (b), colorscale in dB.

The similar shape of the plot for the two products is visible in Fig.32, where it is possible to notice as first the larger range window for the BaselineC product. Moreover, the surface appears similar in the two products as well the scattering.



(a) (b)

Fig.32 Close-up view on sample SARin product: z-scope for Level1b power for BaselineB (a) and BaselineC (b), colorscale in dB.

Finally, in Fig.33 the retracking point for the two products has been compared. The retracking point has been evaluated on the waveforms, already shifted with respect to both the orbit height and window delay, by interpolating the waveforms with a factor 2 and then applying an OCOG retracker. It has to be underlined that no geo-corrections have been applied. By inspection of Fig.33, the retracking point for BaselineC is overlapped to the BaselineB retracking point for almost the whole product. Anyway, some waveforms exhibit different retracking points when complex topography over land is on ground track. Those differences on the retracking point can be reasonably addressed to the different shape of the waveforms due to the changes described in Section 4.

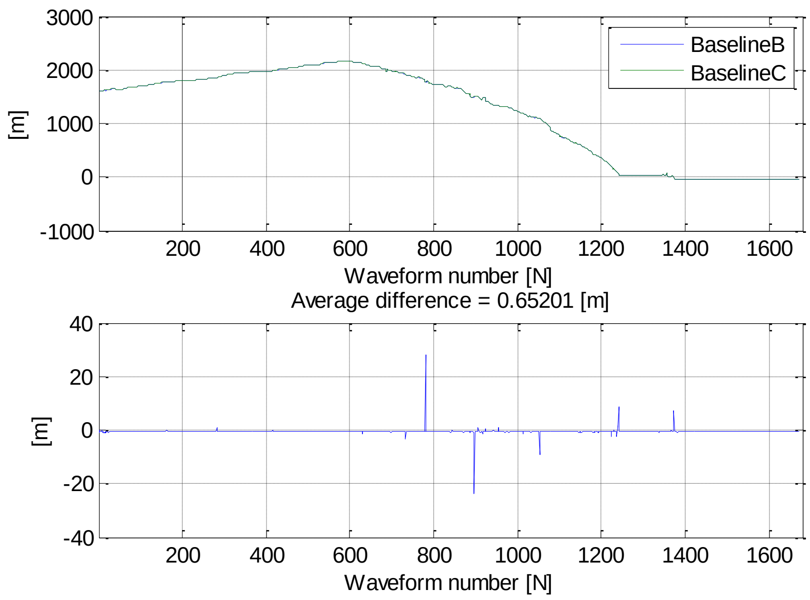


Fig.33 Comparsion of retracking point for sample SARin product for BaselineB and BaselineC.

On the other hand, looking at the comparison on the retracking point from the BaselineB and the BaselineC products over sea, that is shown in the following figure, it can be noticed that the retracked profile is very similar and that the BaselineC range is shorter of about 0.67 cm, which is approximately equal to the range bias that has been removed with respect to BaselineB according to Tab.4.

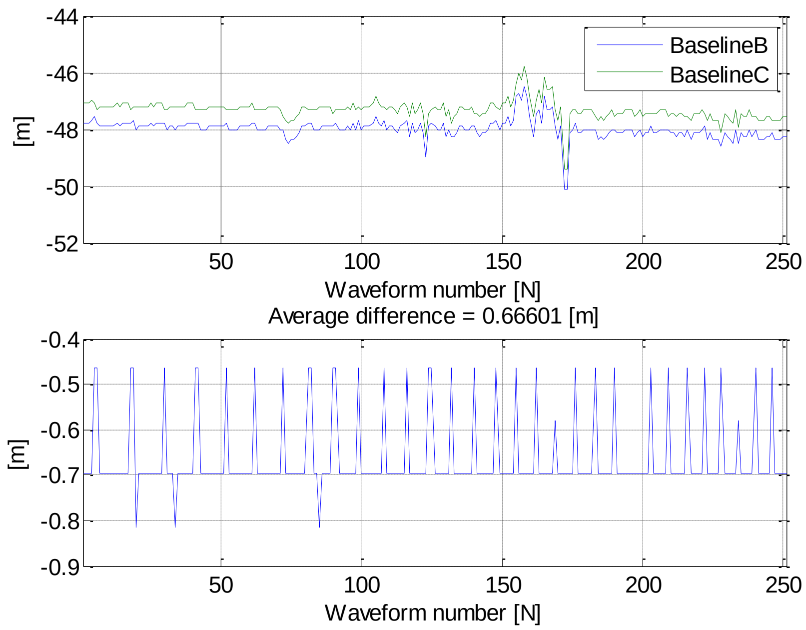


Fig.34 Retracking point for sample SARin product: close up view when sea is overflown.

On the same waveforms acquired over sea, the phase difference at the retracking point from the BaselineB and the BaselineC has been evaluated. By inspection of Fig.35 it can be noticed that the phase difference from the two products has approximately the same shape but there is a difference of about 0.611 rad, that is approximately equal to the external phase correction that has been removed in BaselineC according to Tab.2.

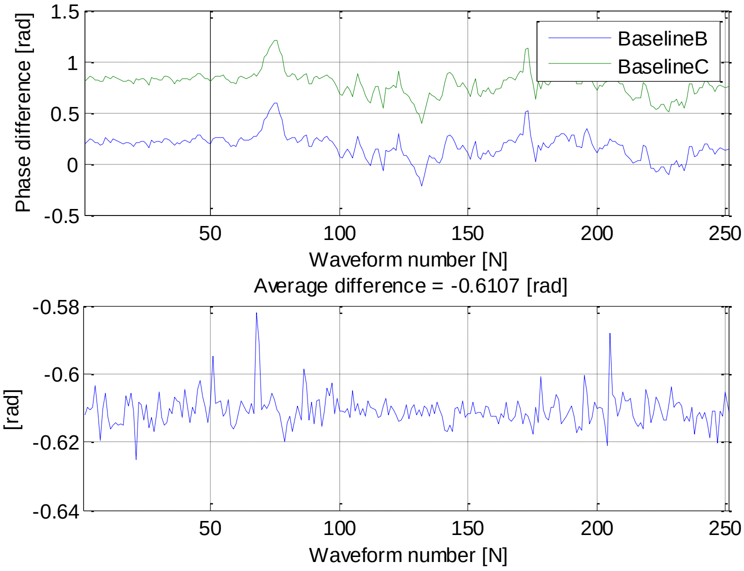


Fig.35 Phase difference at retracking point for sample SARin product: close up view when sea is overflown.

Furthermore, the BaselineB product CS_LTA__SIR_SIN_1B_20110822T101530_20110822T102129_B001.DBL has been compared with the corresponding product for BaselineC. The track for this product is shown in the following figure.

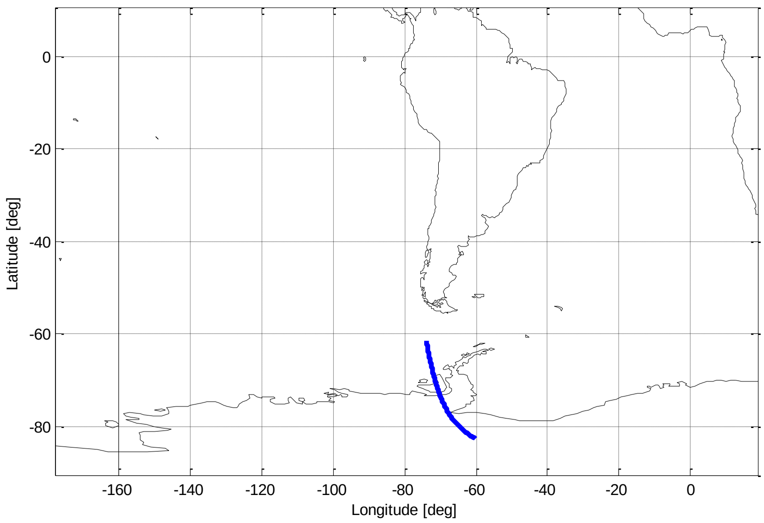


Fig.36 Track for BaselineB product CS_LTA__SIR_SIN_1B_20110822T101530_20110822T102129_B001.DBL.

In Fig.37, the z-scopes plot of the 20Hz Level 1b power waveforms for BaselineB and BaselineC are compared. The colorbar is the power in dB in order to recognize the peak power of the waveforms. There it is possible to notice that the profile is very similar and that the expected difference in power is noticeable, according to the discussion in Section 4.6.

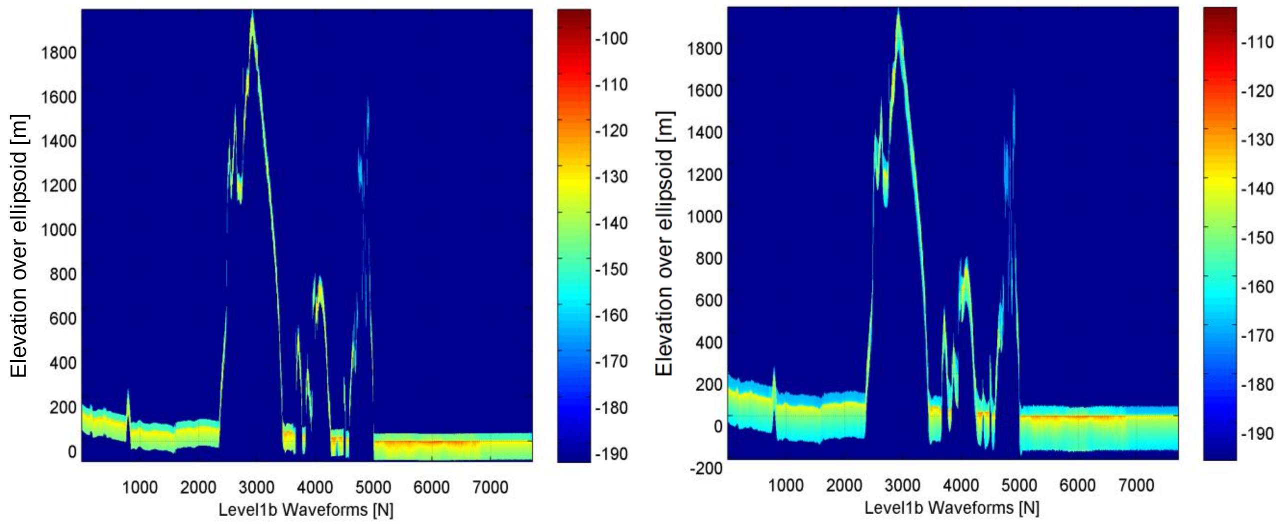


Fig.37 Sample SARin product: z-scope for BaselineB (a) and BaselineC (b), colorscale in dB.

The last waveforms of the SARin products, that have been acquired over ocean, have been analyzed to compare the phase difference from the BaselineB and the BaselineC products. Thus, the phase difference at the retracking point from the BaselineB and the BaselineC has been evaluated. By inspection of Fig.38 it can be noticed that the phase difference from the two products has approximately the same shape but there is a difference of about 0.612 rad, that is approximately equal to the external phase correction that has been removed in BaselineC according to Tab.2.

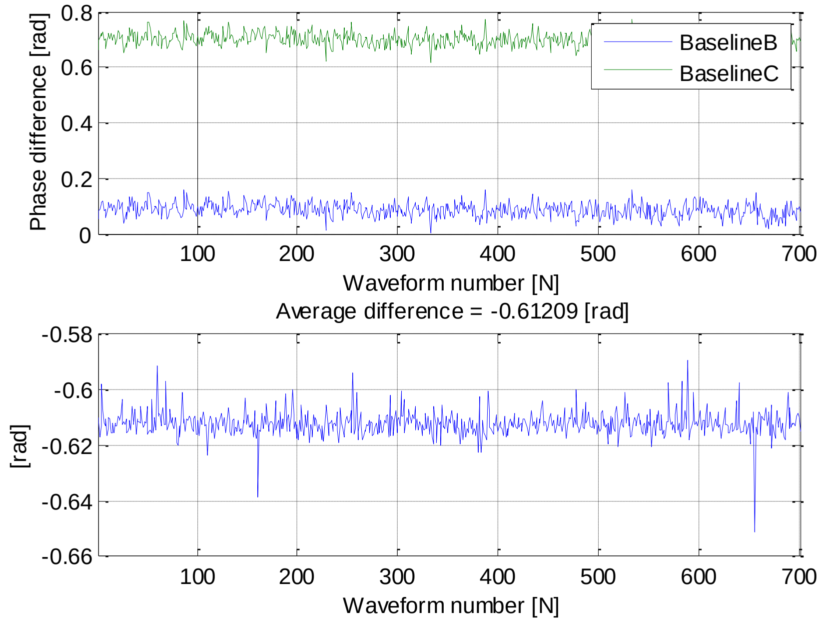


Fig.38 Phase difference at retracking point for sample SARin product: close up view when sea is overflown.

The, starting from the phase difference at retracking point, the angle of arrival has been computed and compared with the roll angle annotated in product (or derived from baseline vector in case of BaselineB product). By inspection of Fig.39 it can be verified that from both the Baselines the difference between the roll angle and the angle of arrival is about zero over ocean. The roll from the two Baselines are different due to the roll bias compensation (see Tab.2) but the angle of arrival from the sea surface is still near to the roll due to the external phase correction that has been removed in BaselineC (see Tab.2).

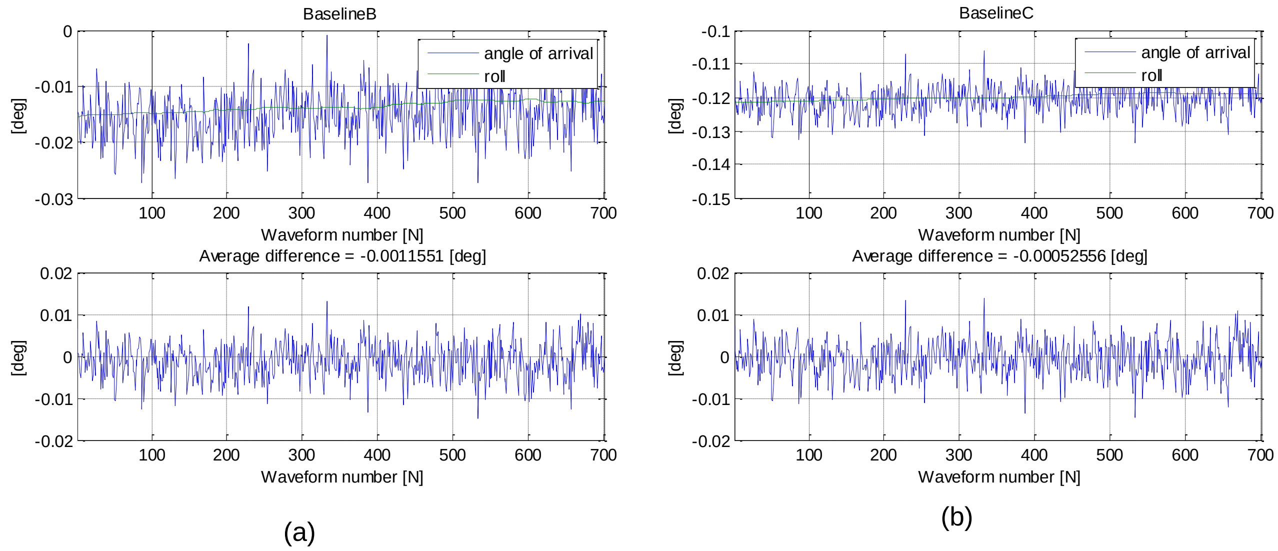


Fig.39 Comparison of roll angle and angle of arrival derived from the phase difference: BaselineB (a) and BaselineC (b).

6 Appendix A: Changes in the L1b Product Format

In the Tables below the changes in the Product Format for the SAR/SARin BaselineC Level1b product with respect to the BaselineB Level1b product have been highlighted.

By inspection of Tab.5 (where only the new fields have been shown), it can be noticed that the following fields have been added (see Section 4.2):

- Star Tracker ID: The following values are valid Star Tracker Identifications:

  0 : No Star Tracker data used for product generation and attitude initialization done by using default values from the IPFDB

  4 : STR_ATTREF file from Star Tracker Processor used in Level1 processing for product generation
- Antenna Bench Roll Angle corresponding to the Time Stamp
- Antenna Bench Pitch Angle corresponding to the Time Stamp
- Antenna Bench Yaw Angle corresponding to the Time Stamp

Field	Description	Units	Bytes	Format
Time and Orbit Group (structure repeated 20 times per record)				
14	Star Tracker Identification	–	2	us
15	Antenna Bench Roll Angle	10^{-1} µdeg	4	sl (see note 4)
16	Antenna Bench Pitch Angle	10^{-1} µdeg	4	sl (see note 4)
17	Antenna Bench Yaw Angle	10^{-1} µdeg	4	sl (see note 4)
Measurements Group (structure repeated 20 times per record)				
Corrections Group (once per record)				
		Sub-Total Size	3784 bytes	

Tab.5 SAR/SARin BaselineC Level1b product format: Time and Orbit Group.

By inspection of Tab.6 and Tab.7, it can be noticed that the length of the 20Hz Level1b waveforms is equal to 256 samples for SAR and to 1024 samples for SARin, resulting in a double length with respect to BaselineB waveforms.

Field	**Descriptor**	**Unit**	**Bytes**	**Format**
Waveform group: SAR (structure repeated 20 times per record)				
81	Averaged Power Echo Waveform [256]	Scaled	256*2	us
82	Echo Scale Factor (to scale echo to watts)	-	4	sl
83	Echo Scale Power (a power of 2)		4	sl
84	Number of echoes averaged	-	2	us
85	Flags	-	2	us
86	Beam behaviour parameter	-	100	(see table 2.3.4-5)
		Sub-Total Size	12480 bytes	
		Total Record Size	**16564 bytes**	

Tab.6 SAR/SARin BaselineC Level1b product format: SAR Waveform Group.

Field	Descriptor	Unit	Bytes	Format
Waveform group (SARin) (Structure repeated 20 times per record)				
87	Averaged Power Echo Waveform [1024]	Scaled	1024*2	us
88	Echo Scale Factor (to scale echo to watts)	-	4	sl

89	Echo Scale Power (a power of 2)		4	sl
90	Number of echoes averaged	-	2	us
91	Flags	-	2	us
92	Beam behaviour parameter		100	(see table 2.3.4-5)
93	Coherence [1024]	1/1000	1024*2	us
94	Phase difference [1024]	Microrad	1024*4	sl
		Sub-Total Size	166080 bytes	
		Total Record Size	**170932 bytes**	

Tab.7 SAR/SARin BaselineC Level1b product format: SARin Waveform Group.

By inspection of Tab.8, it can be noticed that according to [RD-12] the following fields have been added in the Beam Behavior parameters associated to each 20Hz waveform:

- Doppler Angle Start: the value of the Doppler angle for the first contributing beam to a surface sample. The Doppler angle is the angle at which the surface sample is seen with respect to the normal to the velocity vector.
- Doppler Angle Stop: the value of the Doppler angle for the last contributing beam to a surface sample. The Doppler angle is the angle at which the surface sample is seen with respect to the normal to the velocity vector.
- Look Angle Start: the value of Look Angle for the first contributing beam to a surface sample. The Look angle is the angle at which the surface sample is seen with respect to the nadir direction of the altimeter.
- Look Angle Stop: the value of Look Angle for the last contributing beam to a surface sample. The Look angle is the angle at which the surface sample is seen with respect to the nadir direction of the altimeter.
- Number of contributing beams in the stack after weighting (see Section 4.4). This field is the same as “Number of echoes averaged” present in the waveform group for SAR (field 84 of L1B) and SARin (field 90 of L1B).
- Number of contributing beams in the stack before weighting annotated for monitoring purposes (see Section 4.4).

Beam Behaviour ID	Byte Index	Definition	Type	Setting
1	[0-1]	Standard Deviation	us	Unitless Stack beam/100
2	[2-3]	Stack Centre (Beam in stack at maximum of the fitted gaussian)	us	Unitless Stack beam/100
3	[4-5]	Stack Scaled Amplitude	ss	<dB/100>
4	[6-7]	Stack Skewness	ss	Unitless Value/100 or -99900 if cannot be computed
5	[8-9]	Stack Kurtosis	ss	Unitless Value/100 or -99900 if cannot be computed
6	[10-11]	Standard deviation (as a function of boresight angle)	us	<microradians> Range 0 to 0.065525 radians (0 – 3.755º)
7	[12-13]	Stack Centre angle (as a function of	ss	<microradians>

		boresight angle)		Range -0.032767 to 0.032768 radians (-1.87741º – 1.87741º)
8	[14-17]	Doppler Angle Start	sl	<10^{-1} microradians>
9	[18-21]	Doppler Angle Stop	sl	<10^{-1} microradians>
10	[22-25]	Look Angle Start	sl	<10^{-1} microradians>
11	[26-29]	Look Angle Stop	sl	<10^{-1} microradians>
12	[30-31]	Number of contributing beams in the stack after weighting	us	Unitless
13	[32-33]	Number of contributing beams in the stack before weighting	us	Unitless
14	[34-99]	reserved		Set to zero

Tab.8 SAR/SARin BaselineC Level1b product format: Beam Behaviour Parameters.

It is worth noticing that the new fields added in the Beam Behaviour Parameters allow the user to reconstruct, at least in first approximation, the look angle and the Doppler angle associated to each contributing beam in the Surface Sample Stack that has been multilooked to obtain the current 20Hz Level1b waveform. In fact, the user now has knowledge of the first sample of the angle vector, the last sample of the angle vector and the number samples in the vector, i.e. the number of contributing beams the in the stack. In case of SAR, the user can generally assume regular angular steps between beams. In case of SARin, the user can generally assume regular angular steps between beams with the exception of one double step every one second due to the interleaved CAL4 bursts.