ABSTRACT

The RA-2 in its nominal operation provides averaged waveforms at the rate of 18 Hz (one averaged waveform over 100 individual echoes, every 0.0557 seconds). It has also the capability to provide limited bursts of individual, unaveraged echo sample data in phase (I) and quadrature (Q), at the full PRF rate. In this concept the full-rate data are stored, for a short burst, into an internal buffer memory, in parallel to the normal averaging and other functions of the instrument. The buffered data are subsequently read out at a much lower rate and appended to the normal science data. These Individual Echoes (IE) are, therefore, not processed on-board in the same way that the nominal RA-2 waveforms are.

Recent studies have demonstrated that through the full rate data it is possible to discover some behaviour than cannot be seen with the averaged data. Moreover, it is the first time in altimetry that we have echoes that contain the information of the phase. This is a great potential for new science studies.

This paper describes the algorithm applied on-ground to the IE of the RA-2 Burst Waveforms to reproduce the same process done by the instrument on-board (except for the averaging). Once this algorithm is applied to the IE they will be in the same condition than the normal RA-2 telemetred average waveform, but at 100 time higher surface sampling and with the phase information. The final objective of this work is the use of the IE fully processed and instrument calibrated for calibration, validation and science exploitation purposes. We will present results of studies carried out using these IE.

The blurring on the averaged waveforms depends on the total movement of the range window [1], which in turn depends on slope of the terrain, the orbit slope and ultimately, how well the on-board tracker tracks that particular waveform shape. In early studies using ERS data, the blurring on the averaged waveforms has been estimated by simulating the ERS range window movement during tracking [2]. Using individual echoes there is no longer the need to do so, we can directly use these echoes. The IE will be averaged in the correct way and compared to the averaged waveform provided in the nominal RA-2 product. Changes on the retracted epoch and slope of the leading edge can be assessed for different type of waveforms over different surfaces. In particular we will present results of the analysis of the behaviour of IE over the “Salar D’Uyuni” in Bolivia, to better understand biases in retracking of specular echoes. The results can be used to improve the current understanding of retracted elevations over sea ice and help to improve tuning of current sea ice retracking schemes for the EnviSat RA-2 instrument.

ESA has run a study on this topic to seed the use of individual echoes by scientists. This study is completed and reconstructed echoes will be made available for the first time to the scientific community. Final results from the technical and scientific application of individual echoes and S band data are described in [3].

1. INTRODUCTION

The RA-2 has the capability to provide limited bursts of individual, unaveraged echo sample data at the full PRF rate for research purposes. In this concept the full-rate data are stored, for a short burst, into an internal buffer memory, in parallel to the normal averaging and other functions of the instrument. The buffered data are subsequently read out at a much lower rate and appended to the normal science data. They are available as a dedicated-data product.

In the following subsection we give all the information required in order to understand the processing of the individual echoes, from their collection on-board and transmission to ground, to the way the waveform processing on-board the altimeter works.

2. INDIVIDUAL ECHOES COLLECTION AND TRANSMISSION

During nominal operation RA-2 always transmits pulses 20 microseconds long at Ku-Band (13.575 GHz) with a Pulse Repetition Frequency (PRF) of 1795.332 Hz (at S-Band, 3.2 GHz, it becomes 448.833 Hz). Under nominal operation (during tracking) RA-2 collects therefore 1795 echoes per second, but it transmits to ground only averages over groups of 100 echoes. The averages are transmitted to ground in
Source Packets (SP) which contain 20 averaged echoes (Data Blocks) relevant to the transmission of 2000 pulses.

In order to allow the analysis on single (not averaged by 100) echoes (e.g. collected during tracking) it is possible to collect on-board the individual echoes and transmit them to ground (see Figure 1). This is possible in addition to and without interfering with the normal operations (e.g. Tracking, Preset Tracking). These echoes are only collected in Ku-Band, and not in S-Band. As can be seen in Figure 1, the Individual Echoes (IE) are taken from on-board before the Fourier Transform, and so they are still in the Time domain, and not in the Frequency domain as the normal RA-2 averaged waveforms.

Due to the high data rate of the full rate echo data (>4Mbps) the IE are sampled in short bursts into a buffer memory which is read out at a lower rate into following source packets.

This process has however some limitations. First of all the maximum number of IE (128 samples each) that can be stored on-board (selectable in multiples of 100) is limited to 2000 (equivalent to 1 Source Packet) by the capacity of the on-board memory. Then, the time after which a new set of IE’s can be stored is constrained by the time it takes to deplete the on-board memory into the source packets. The latter has available, for this operation, 1600 words (16 bit) only. Furthermore, by macro command (MCMD) we can choose to store IE’s in groups of 100 (equivalent to 55.7 milliseconds) up to 2000 (equivalent to 1.114 seconds) and transmit them to ground. The operation can only be repeated once the whole set of previously collected IE’s is transmitted to ground.

The IE’s are attached to the Level 0 and in the Level 1b product as separated field [4]. The IE’s of the Level 1b product, unlike the averaged waveforms, have not been instrument calibrated but only extracted from the Burst Mode Level 0 field and reported in the Burst Mode Level 1b or Level 2 MDS. These IE’s MDS’s have no information on the IE datation (time when the echo was at the surface, that can be computed using the on-board binary time from the on-board clock). Datation is extremely important in altimetry in order to retrieve the coordinates of where exactly on earth are we measuring [5]

In this particular case of the IE, datation is not only important for this reason but also in order to know from where do we need to extract the parameters used in the IE’s processing. If the datation is not correctly known, the parameters used in the processing would be wrong and so the processing itself, leading to an error in the final retrieved surface characteristic (e.g. elevation).

### 3. DATATION ON IE’S

The IE echoes are collected on-board, after an instrument instruction given by a MCMD, and stored in a buffer. These echoes are later read out and written spread onto various Source Packets. This happens for several cycles, the number of cycles also given in the MCMD. A cycle is defined as 1 on-board collection and a full read-out of the buffer onto the data. The first cycle, cycle 0, is (obviously) the one right after the MCMD, and the rest of cycles are cycle n, n = 0, N-1, being N the total number of cycles. Typically the data collected on-board is of 1 full SP (=20 DB, 1.114s), but it can also be from 1 to 20 data blocks. When the data collected is 1 SP, the read out takes 160 SP (equivalent to about 3 minutes).

We performed a study the purpose of which was to investigate the on-board delay on the Individual Echoes collection onto the buffer, with respect to the individual echoes used to construct the average waveform written into every source packet data block. The first cycle was treated separately from the other n-1 cycles, simply because it was believed not to have the same behaviour. The delay can be from 0 or 1 IE, to few data blocks.

The results of the study [6] is that:

**From the second cycle to the last cycle:**

The IE data collected belong to the 21st DB right after full read-out of the previous cycle. This is the 1st DB of the 2nd SP after full read-out of the previous cycle. This also means that there is an empty SP to which the IE were supposed to be collected, however the data are not collected on this SP but on the following SP.

The first IE data collected in the nth cycle belong to the 1st echo of the 1st average waveform (or DB). Taken into account the previous result, this means that the first IE data collected in the nth cycle belong to the 1st echo of the 1st DB of the 2nd SP after the data from the previous cycle have been fully dumped.

**The first cycle:**

The IE data collected belong to the 1st DB of the 1st SP after the MCMD.

The results of which was the first IE collected, or in other words, to which echo of the average waveform it belonged to, were extremely surprising. We did not find a consistent result. Different test data sets gave us different results,
extremely variable to be able to characterise them. We did not find any correlation between the time delay and the MCMD execution time. Therefore, this lead us to recommend to ESA to advise scientists not to use the first IE cycle of the total length of IE’s set collection.

ESA is currently planning the operations such that specific targets are hit with the second cycle of the IE collection.

Figure 2 illustrates the complete sequence of IE on-board collection and reading out into the data source packets.

Only when understanding the IE’s datation we will be able to develop a correct IE’s processor. This is because the data needed for the processing is not packed with the IE’s but with the normal average waveforms (in the Main MDSR). We need to understand datation to know where these data are to be extracted.

4. **IE ON-BOARD PROCESSING**

The collection of the IE data starts when the instrument receives the corresponding command. The execution time of this command is used later to collect and date the IE data.

The ground processing of the IE’s raw data, starts by its collection from the input products. Although the raw data can be found in Level0 and Level1b products (the latest being a copy of the Level0), some parameters needed for the processing are already included in Level1b, thus, using only Level1b seems the simplest approach.

The first step is the determination of the datation of the first IE encountered in the data.

During the collection process, IE’s are grouped in sets of 100 echoes. Each set is assigned the corresponding AE (Average Echo) and some parameters related to the instrument on-board processing.

As stated before, the collected IE’s data have not been processed on-board by the instrument. This processing must be reproduced on-ground. Theoretically, after the emulation of the on-board processing, the average of one set of IE’s should produce a waveform identical to its corresponding AE.

Some of data needed to reproduce the on-board processing of each IE’s are not available, and has to be computed using available data attached to its associated AE record. In particular, the parameters needed are:

- attenuation (AGC coarse and fine)
- time delay (Rx_dist coarse and fine)

Thus, the first task on the reproduction of the instrument processing is the simulation of the Alfa-Beta Tracker to obtain the estimated data for each IE [7].

Once all parameters needed are obtained for each IE of the set, the on-board emulation can go on. Schematically, the process consists on the following operations applied sequentially to each IE [7]:

- apply hamming window: each IE is weighted using the hamming weighing;
- apply the Rx_fine shift: input IE format, which is in-phase and quadrature, is shifted in frequency by applying Rx_fine parameter as a phase rotation in the time domain;
- transform the echoes to the frequency domain: by applying a FFT;
compute the module and phase of each IE in the frequency domain;
• apply the AGC_fine to the IE module.

The result of the above operations is the module of each IE in the frequency domain, as if they had been processed by the on board processor \((P_r(j,k) \text{ with } k = 0,N_F - 1 \text{ is the power of the } j\text{-th IE}),\) plus the phase of each IE \((\psi(j,k))\) \([7]\).

After this step, the data have to be further processed up to Level1b. In order to do so, the following parameters are calculated:

• Orbit and datation: interpolating available AE data to infer the latitude, longitude, height and datation for each IE.
• Window delay: calculated for each IE using Rx fine and coarse.
• AGC: calculated for each IE using AGC fine and coarse components.

Finally IF Mask is applied to IE waveforms, as it is applied to the average waveforms, using this time the right Rx_fine \([8]\).

5. RANGE COMPUTATION USING IE’S

The Salar d’Uyuni on the Altiplano of southwestern Bolivia is a 9,600 km² salt lake, the largest salt flat in the world. Its surface is expansive, flat, smooth, and is a specular reflector, making it an ideal satellite altimeter target \([9]\).

EnviSat flies over this salar on relative orbit numbers 139 (descending) and 146 (ascending), being track 139 the longest one over the salar (see Figure 3). The results presented below have been generated using pass 139 on 10th of October 2002.

The EnviSat ground track with IE’s extends from 67.652307ºW to 67.667355ºW in longitude and from 20.164784ºS to 20.227354ºS in latitude.

The epoch provides an estimation of the propagation time, so it provides the satellite height over the surface, to finally retrieve the surface elevation. In order to retrieve the proper range over this particular surface, we have been looking for suitable retracker for the Uyuni echoes. Three retractors were analysed: a gaussian retracker, a zeropadding retracker and a zeropadding + gaussian fitting retracker.

After performing an ANOVA study \([10]\), we have finally developed and applied a Gaussian retracker \([11]\) in order to extract the epoch, simply because it was the least noisier. The epoch has been defined as the time corresponding to the maximum of the Gaussian (Figure 4).

![Gaussian retracker fitting an Uyuni echo.](image)

The retracker has been used with the 2000 IE’s collected over the Salar (i.e. 100 IE per Data Block, and 20 Data Blocks per Source Packet). It corresponds to 1 second of data. These echoes had been processed as described in the previous sections. The results after retracking the IE’s have been compared with the ones obtained by retracking the averaged waveforms from the Level 1b PDS data product.

Figure 5 shows an example of the retracking of 100 Individual Echoes (pink lines) and the retracking of Level 1b echo from the PDS data products (blue line). In this particular case, the range obtained from the average waveforms data is different from the average of the IE’s ranges approximately by 4 cm. This difference is due to several reasons as:

• the blurring effect associated to the movement of the range window during the on-board tracking of the 100 IE’s that form an average waveform (see Figure 5), and
• the fact that we have compensated each IE by the IF mask, whereas the average waveform is compensated after the average introducing errors in the position and therefore in the power at each sample.

![Two Envisat passes over the Salar d’Uyuni.](image)
In order to better compare the results obtained with the IE’s against the ones obtained from the average waveform in the PDS level 1b data products, the retracked ranges have been converted to elevations.

Figure 6 shows, in dark blue, the elevations calculated for each IE over the salar d’Uyuni in pass 139 on the 10th of October 2002. The horizontal axis corresponds to 2000 IE (equivalent to 20 average waveforms or DB).

When retracking each IE and calculating the mean elevation (red line), we obtain an elevation of about 3697.63 meters and a standard deviation of about 2 centimetres (light blue lines).

Data from 2006 were also analysed. Unfortunately most passes did not fall sufficiently centred in the salar but in the limits of it. Only data from April 2006 (5 records, or approximately 0.2785 seconds) and September 2006 (also about 5 records) were such that the return echoes were sufficiently specular to be able to apply the Gaussian retracker.

Figure 8 and Figure 9 show the differences of about 1 cm between L1b and IEs in April 2006 (Figure 8), and a bit higher in September 2006 (Figure 9).

This elevation can be compared with the one obtained retracking the average waveforms of the Level1b PDS product (green lines). There are differences of approximately 7 mm between these elevations (Figure 7).

So, when retracking the average echo provided by RA-2, there is a loss of information leading to an error in the elevation. This error is about 1 cm over the salar the Uyuni, but it very much depends on the surface characteristics.

1 Some of these elevations do not include the geophysical corrections other than the ionospheric correction (e.g. Figure 8).
6. CONCLUSIONS AND FUTURE WORK

After having developed this IE processor, we have, for the very first time in altimetry, a much higher surface sampling and the phase information of our echoes.

The IE’s have allowed us to demonstrate that the use of un-averaged echoes when possible can provide better surface information (in particular elevation, but this can be extend to other characteristics as Significant Wave Height). The on-board average echo is distorted due to movement of the range window during the tracking process. This distortion can be avoided by using the IE’s that formed that average waveform.

We have analysed 3 cases over the salar d’Uyuni and we have found a discrepancy of about 1 cm between the two retrieved ranges (or surface elevation).

After these first results, our next objective is to study a higher number of passes with IE centred over the salar and also over the ocean, in order to see further advantages of having a 100 time higher surface sampling. And finally, the phase provided by those IE will be especially studied owing to the fact that it is the first time in altimetry that echoes transmitted on-ground contain this phase information.

Finally, a strong recommendation to the altimetry scientific community to discard the first cycle of the IE set collection. The information on which is the first cycle shall be provided by ESA.

7. REFERENCES


8. ACKNOWLEDGEMENTS

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