VERIFICATION OF THE RA2/MWR LEVEL 2 GEOPHYSICAL REFERENCE PROCESSORS

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ABSTRACT

The RA2/MWR Level 2 processing includes some algorithms designed specifically to extract geophysical measurements over different types of surfaces (ocean, sea-ice, continental ice, etc.). In order to do this, four specialised retrackers have been developed and are continuously run in parallel (over all surfaces):
__ ocean retracker: optimised for ocean surfaces (operating on Ku and S bands), and based on a fit of the waveforms with the Hayne model
__ ice1 retracker: optimised for general continental ice sheets. It employs an Offset Center-of-Gravity parametrisation of the Ku/S band echoes to calculate tracker offsets. This was used for ERS and will ensure measurement continuity.
__ ice 2 retracker: optimised for ocean-like (Ku and S) echoes from continental ice-sheet interior, and based on the Brown model,
__ sea-ice retracker: optimised to estimate a tracker offset for narrow peaked (sea-ice) echoes. It operates only on Ku band
These algorithms were prototyped within CLS, LEGOS and MSSL (referred to as ESLs, or Expert Support Laboratories), and once verified, became reference processors, that were used to validate the Near Real Time and Off-Line ground operational processors (referred to as IPF and F-PAC).
The aim of this paper is to summarise the main activities performed, since launch, by the different ESLs, and supported by ESA, in order to fully verify the Level 2 algorithms, and to validate the Level 2 products that are delivered to the end-users.

1 OCEAN RETRACKER VERIFICATION

The RA2/MWR Level 2 processing includes some algorithms designed specifically to extract geophysical measurements over ocean surfaces. The validation of the ocean retracking of the RA2 waveforms over ocean surfaces, and the optimisation of the ocean retracking performance will be dealt within this section.
In the frame of these activities, the outputs of the ocean retracking have been analysed and compared with other parameters such as level 1b parameters or outputs of the ice2 retracking algorithm. A tuning of the ocean retracking algorithm has been then performed to optimise its performance as far as accuracy and CPU time are concerned

The results of the internal verification activities, that will be shown in the first next three subsections, were obtained analysing the ocean retracking outputs (epoch, composite sigma and amplitude) for a single real orbit (orbit no. 1815) that contained 24 minutes of consecutive measurements over the Pacific ocean, with waveheights between 1 and 4 meters. The ocean/ice2 reference processor (referred to as LOP) was then further validated by using a complete cycle of Level 2 off-line data coming from the F-PAC. This will be explained in the last subsection.

1.1 Epoch

The epoch is the position of the reference point of the waveform (the "half-amplitude" of the leading edge) with respect to the reference sample of the analysis window, i.e. to the reference point for tracking. It is combined with the tracker range to derive the ocean altimeter range.

For Ku and S bands, the epoch estimates were initially analysed accounting for the shape of the waveforms, and compared with the corresponding ice2 estimates. Their behaviour looked correct, except for some S-band measurements that presented high negative values, as shown in Fig.1.1.

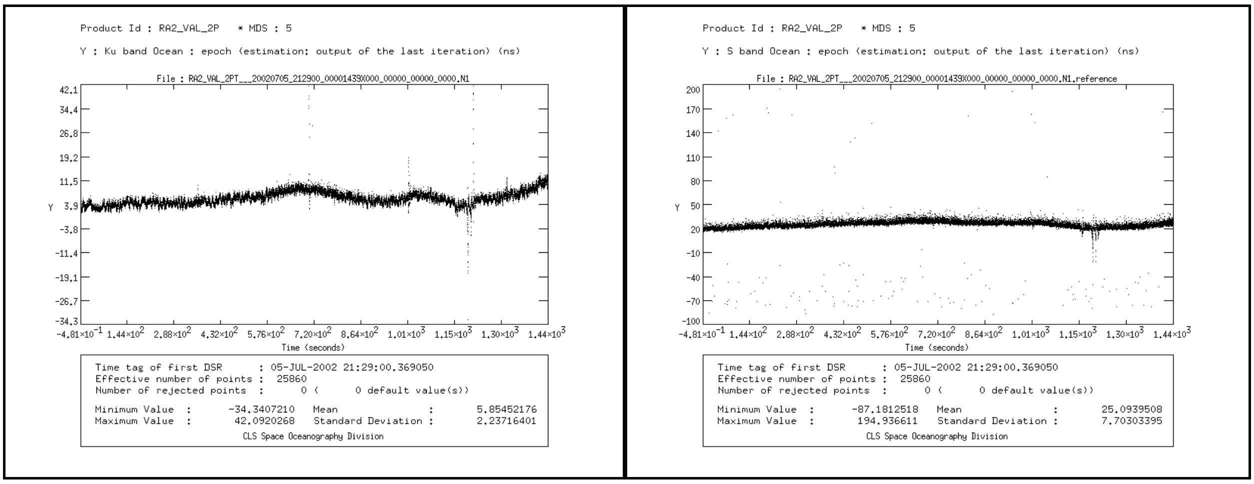

Fig.1.1. Ku-band and S-band epoch before tuning

After the tuning of some processing parameters and a small modification of the ocean retracking convergence criterium (i.e. only based now on the stability of the Mean Quadratic Error between the waveform and the model built from the epoch, composite sigma and amplitude estimates, and not on the adaptative gain), it was noticed, from the high values of the S-band differences before and after the tuning (see first plot in fig.1.2) that the population of bad S estimates with high negative values observed in fig.1.1 had disappeared. The second plot in fig. 1.2 shows the correct epoch estimates for S-band after the tuning.

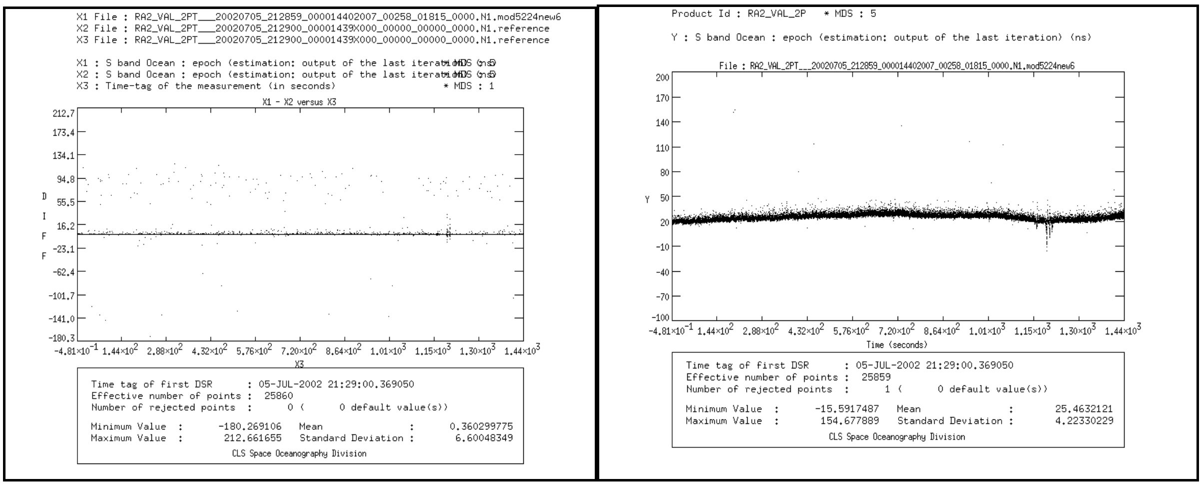

Fig. 1.2 : Difference of the S-band epoch estimates before and after the tuning, and tuned S-band epoch estimates

1.2 Composite Sigma

The composite Sigma (the so-called SigmaC) represents the slope - or the width, of the leading edge of the waveform. It is called "composite" because it represents a combined measurement of the significant waveheight and the width of the Point Target Response of the altimeter.

Fig.1.3 represents the composite Sigma estimates versus time for Ku and S bands for the same orbit no. 1815. It was observed that the minimum value of the estimates corresponded to the half width of the Point Target Response. This was due to a bad management of the limitation of the composite Sigma value performed within the ocean retracking algorithm such that the echo model and its partial derivatives had a physical meaning. As a consequence, the 18-Hz significant waveheights derived from these estimates were then never smaller than 0, which was statistically incorrect for waveheights close to 0, due to the speckle affecting the waveforms. The same strategy was applied to high waveheights, which were limited to 20 m. It appeared thus that the way to estimate the significant waveheight had to be modified.

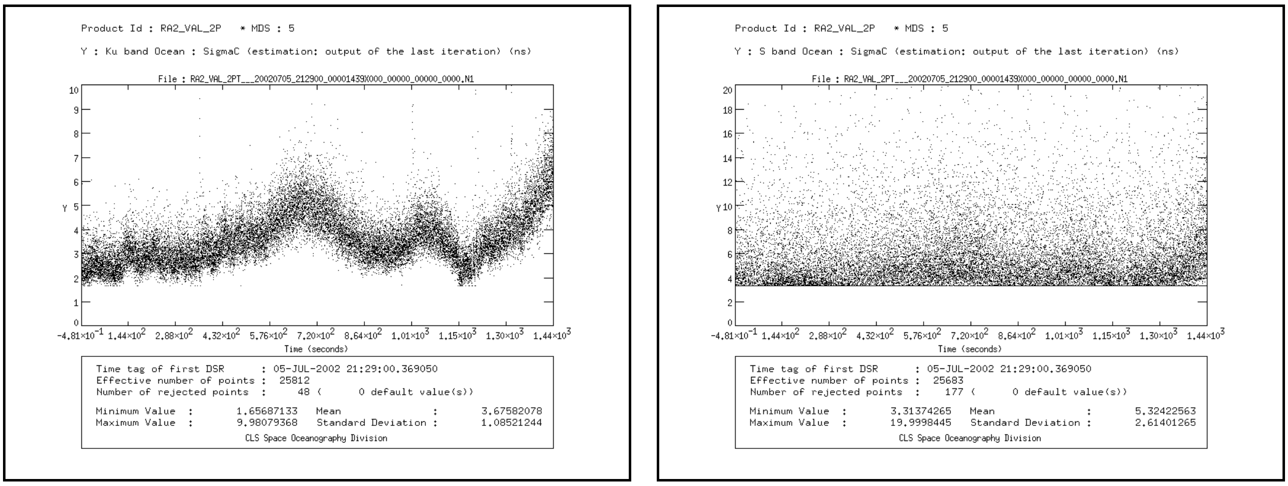

Fig.1.3. Ku-band and S-band composite Sigma before tuning

After the tuning process, outlined in the previous paragraph, no significant improvement of the sigma_c estimates was obtained.

Instead, to solve the problem of the inaccuracy of the estimation of low waveheights, some modifications have been performed to allow estimates of the Sigmac to be smaller (or greater) than the lowest (highest) value set in the computation of the echo model and its partial derivatives.

The improvement of the estimation of the composite Sigma after the algorithm modification is illustrated in Fig.1.4 (to be compared to Fig.1.3).

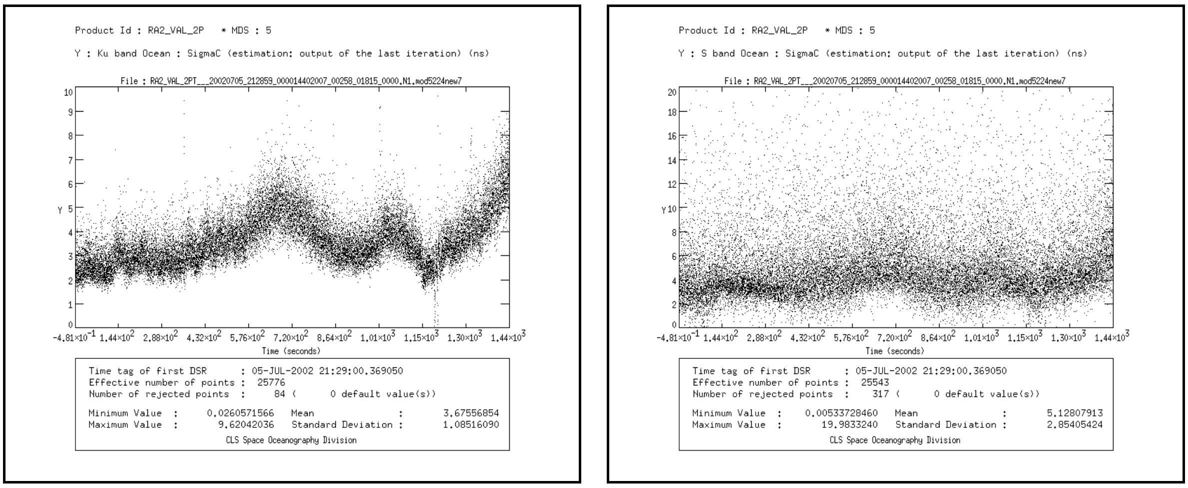

Fig.1.4 . Ku-band and S-band composite Sigma after tuning

Furthermore, the way to derive the 1-Hz estimate of the significant waveheight from the 18-Hz composite Sigma has been changed. Before, the 1-Hz significant waveheight was derived from an arithmetic averaging of the valid estimates of the 18-Hz significant waveheights which in turn were derived from the 18-Hz composite Sigma. The drawback of this method was that the 18-Hz significant waveheights were set to 0 if the corresponding composite Sigma was smaller than their lowest theoretical value, i.e. the width of the Point Target Response. The modification consisted in computing first the averaged value of the composite Sigma and then in deriving the corresponding 1 Hz significant waveheight.

The impact of this second modification on the accuracy of the significant waveheight estimation for low waves has been assessed from the statistical analysis results obtained by CLS on a cycle of data. For what concerns the limitation of waveheights in the range (0, 20 m), we can see from the scatter plots between the Ku-band and the S-band estimates before and after the modifications (see fig. 1.5), that the estimates issued from the updated algorithms are no more limited within that range.

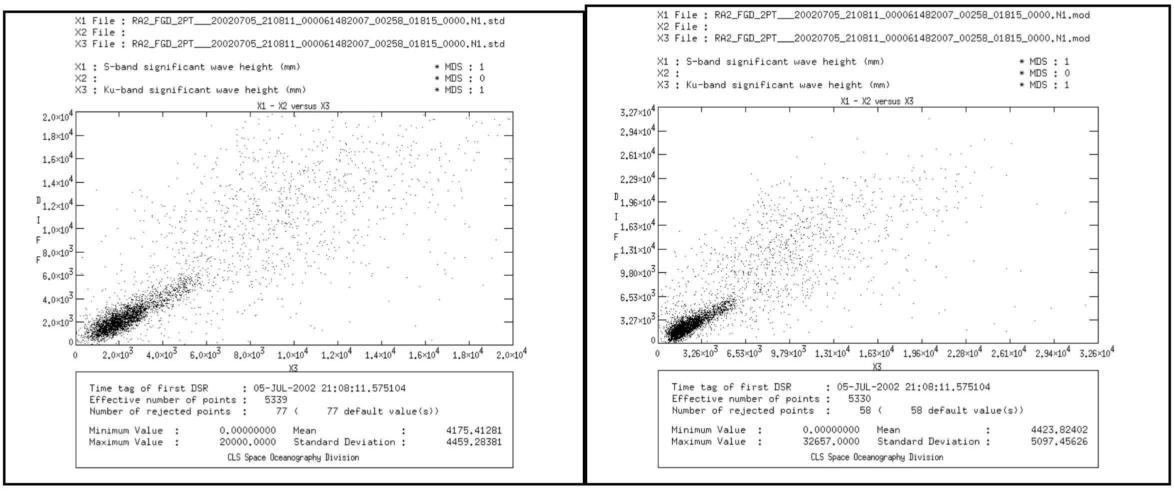

Fig.1.5: Scatter plot of the Ku/S bands sigmaC before (left) and after (right) tuning.

1.3 Amplitude

The amplitude is the level of the useful signal of the waveform (thermal noise excluded). It is combined with the so-called Level 1b "sigma0 scaling factor" which accounts for the tracker AGC and the radar equation, to derive the ocean backscatter coefficient.

As for the previous parameters, the amplitude estimates were initially analysed and compared with the corresponding ice2 estimates, showing a general good behaviour apart from some S-band values that presented very low values (see fig. 1.6).

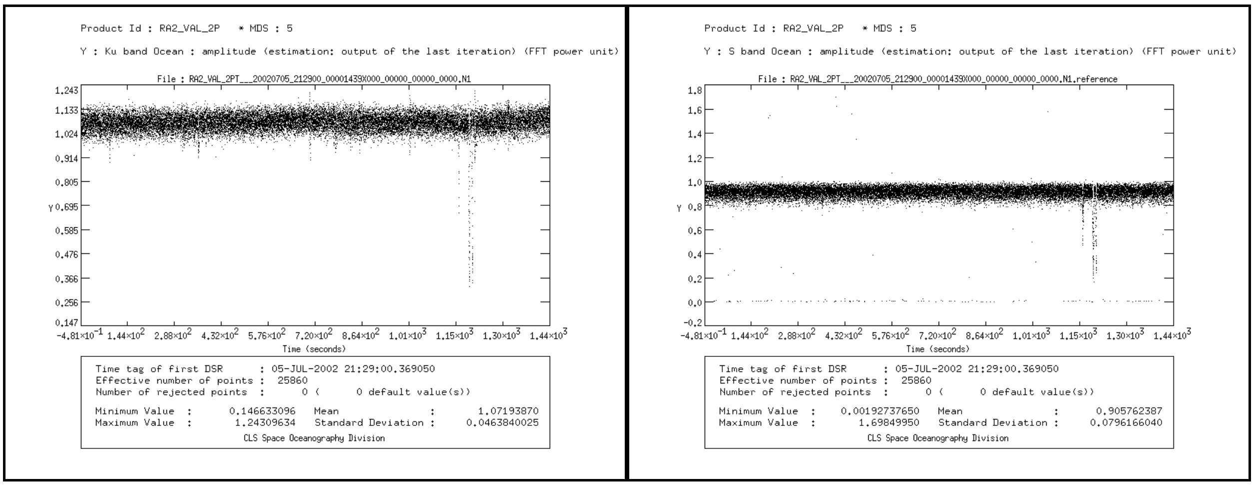

Fig. 1.6 : Ku/S band amplitude estimates before tuning

After the modification in the processing parameters and in the convergence criterium, it was shown, by plotting the difference of S-band amplitude estimates before and after the tuning (see first plot in fig. 1.7), that the population of bad estimates with very low values observed in fig. 1.6 had disappeared. The second plot in fig. 1.7 shows the amplitude estimates after the tuning process.

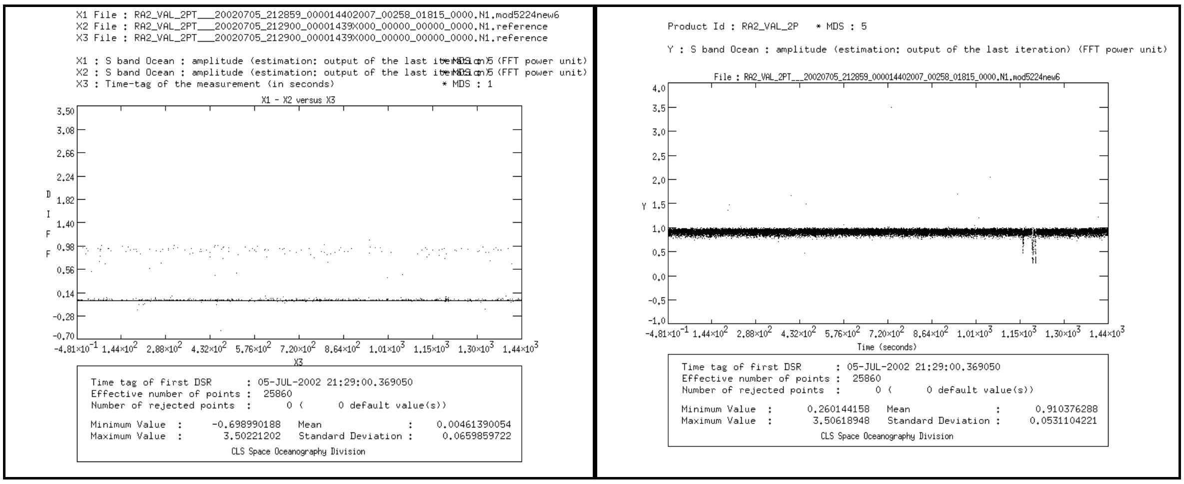

Fig. 1.7 : Difference of the S-band amplitudes estimates before and after tuning (left) and amplitude tuned estimates (right)

1.4 Verification of LOP with large sets of data – Statistical analysis

For what concerns the verification process of the altimetric parameters as coming from the ocean/ice2 retrackers, a three steps method consisting of data editing (i.e. editing of measurements against thresholds), altimeter data analysis (i.e. estimation of min/max values, average and standard deviation of the main parameters, as well as the Sea Level Anomaly) and crossovers and residual data analysis (i.e. estimation of sea surface height variability at crossover locations and estimation of the BM1 and the pseudo-orbit error from along-track data) has been applied on two sub-cycles of data.

The main results coming out of this process (se table 1.1) can be summarised as follows:

- The standard deviation of the range in Ku band is about 8.1 cm, which corresponds, at 1Hz, to 1.81cm. This result is comparable to the ones obtained for the TOPEX or JASON missions.
- The standard deviation of the range in S band is about 30 cm, which corresponds at 1Hz to 6.71cm. This result is coherent with the one obtained for Ku band, since the standard deviation value in S band is impacted by the fact that the S bandwidth is half the Ku bandwidth and by the fact that there is four times less elementary measurements.
- The significant wave height is about 2.4m which is close to the climatological value.
- The backscatter coefficient in Ku and S band are very close. Their mean value is about 8.7 dB, which is smaller than the expected one, of about 2 dB. This is due to a wrong value in an external auxiliary file and has been already corrected.
- The mean value of the waveform square off-nadir angle is about 0.025 deg2, which corresponds to 0.16 deg. This is a rather high value. The IF mask used at Level 1b to correct the waveform samples is currently under investigation for this reason.
- The mean value of the Sea Level Anomaly is about 34 cm. The SLA, is estimated using corrections present in the product as the radiometer wet correction and the altimetric ionospheric correction. The MSS model used is the OSU95, that is to be updated in a near future to GSFC00.1 in the off-line Level 2 products.

Table 1.1. Parameters editing for first subcycle (10 - 17 Oct 2002) / second subcycle (18 - 25 Oct 2002)

Parameter (unit SI)	Std range (Ku)	Std range (S)	SWH (Ku)	SWH (S)	Sigma0 (Ku)	Sigma0 (S)	Wf-Off Nadir angle	SLA
Min	0.026 / 0.023	0.073 / 0.004	0.13 / 0.0	0.0 / 0.0	6.00 / 6.00	5.71 / 5.83	- 0.16 / -0.16	-2.27 / -0.52
max	0.45 / 0.49	2.69 / 5.97	9.89 / 8.50	10.3 / 13.7	25.33 / 27.49	23.55 / 45.31	0.16 / 0.16	1.29 / 1.32
mean	0.081 / 0.081	0.30 / 0.31	2.51 / 2.47	2.36 / 2.35	8.81 / 8.97	8.28 / 8.63	0.025 / 0.026	0.34 / 0.33
Std	0.028 / 0.029	0.082 / 0.17	1.05 / 1.13	1.07 / 1.13	1.64 / 1.82	1.79 / 2.62	0.033 / 0.025	0.13 / 0.13

Finally, some crossovers and residual data analysis has been also performed on the same data showing a standard deviation at the crossovers of about 8cm, which is quite similar to the JASON result. The time tag bias is pretty good with a small estimated value (see table 1.2).

Table 1.2. Results of the crossovers and residual data analysis

	sub-Cycle 10 Oct - 17 Oct	**sub-Cycle 18 Oct - 25 Oct**
Number of crossovers	129	224
Std of crossover sea surface height differences (m)	0.082	0.075
Time tag bias value (s)	0.00014	0.00012
BM1 Sea State Bias	6.23%SWH	4.65%SWH

2 ICE2 RETRACKER AND ALGORITHMS VERIFICATION

The RA2/MWR Level 2 processing includes some algorithms designed specifically to extract geophysical parameters over ice-sheet interior and land surfaces, by fitting a Brown-like model to the altimeter waveform. The main outputs of the ice2 processing (ice2 range and backscatter coefficient, leading edge amplitude, leading edge width and trailing edge slope) were investigated, and as a result, two main problems were detected and solved.

2.1 Leading edge detection problem and solution

When the ice2 leading edge backscatter coefficient was first analysed, it was noticed that many outliers (see first plot in fig. 2.1) with extremely low values were present. This was explained by the fact that the detection of the leading edge was performed on the very first (noisy) part of the waveform and not around the effective leading edge position.
In order to solve this problem, some processing parameters, stored in an external auxiliary file, have been optimised (e.g. a higher signal to noise detection level, an improved threshold for the waveform maximum value, etc.) leading to a clear improvement in the values of the leading edge sigma0 (see second plot in fig. 2.1).
Although the tuning of the processing parameters for this purpose is still on-going, the behaviour of the leading edge sigma0 seems to be satisfactory now.

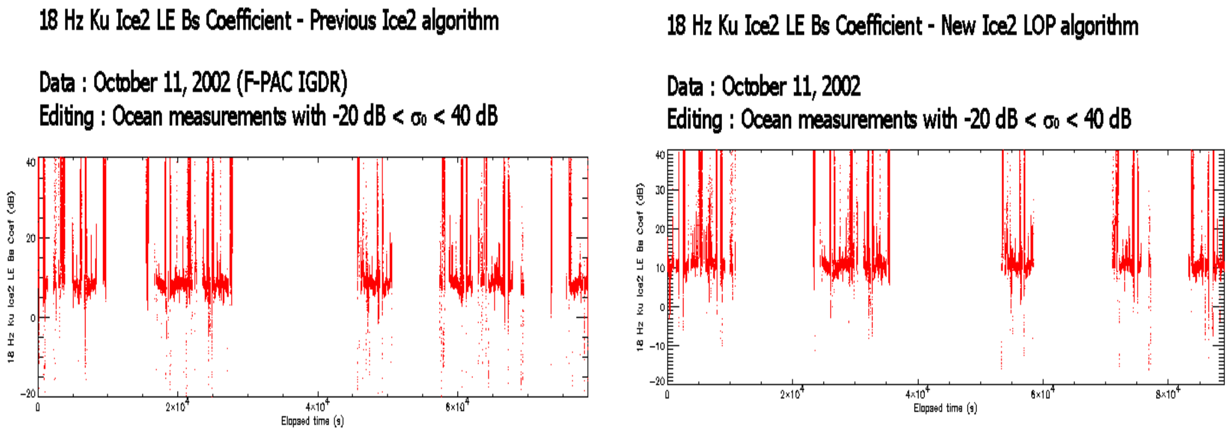

Fig. 2.1 : wrong (plot on the left) and correct (plot on the right) detection of the leading edge for the leading edge backscatter coefficient.

2.2 Wavefront sampling

When analysing the histogram of the leading edge width, it was noticed that some preferential and some forbidden values, corresponding to a non-commensurable sampling of the potential values, were present (see first plot in fig. 2.2). In order to solve this problem, the coarse estimation sampling step was tuned (i.e. becoming an integer factor of the fine step value) and the fine estimation interval was widened, leading to an improvement in the shape of the histogram (see second plot in fig. 2.2).

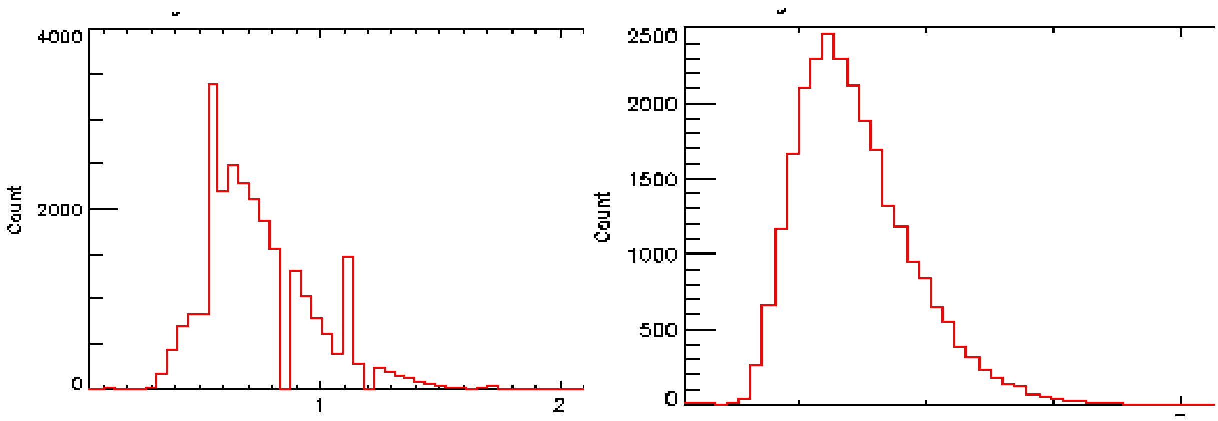

Fig.2.2 Leading edge width histogram with non-regular sampling (left) and with regular sampling (right).

2.3 Check on ice2 outputs over ocean and Antarctica

Using a large set of real data (one cycle of off-line Level 2 products from F-PAC), the main outputs from the ice2 processing (i.e. mean values and standard deviation) have been obtained (see table 2.1), indicating, as expected, higher values for the leading edge ice2 sigma0 when compared with the ice2 sigma0, and a noisier leading edge sigma0 when compared with the ice2 sigma0.

Table 2.1: Average and standard deviation of Ice2 outputs for EnviSat cycle 10 over ocean

Ice2	Param.	Average	St. Dev.
Ku Band	LeBs (dB)	11.1	6.7
	Bs (dB)	8.8	5.0
	LeW (m)	0.9	0.5
	TE (μs^{-1})	-5.7	7.1
	LeBs – Bs (dB)	2.6	2.6

S Band	LeBs (dB)	11.5	7.2
	Bs (dB)	9.9	5.3
	LeW (m)	1.2	1.0
	TE (μs^{-1})	-2.8	7.0
	LeBs – Bs (dB)	1.8	2.6

Comparisons of ice2 and ocean corresponding outputs for the same cycle have been also performed showing a good agreement between the two sets of processing algorithms.

For what concerns the comparisons of EnviSat ice2 outputs with the corresponding ERS ones, using data on Antarctica plateau over 2500 m, the results have shown the following.
Ku and S band measurements agree well, while S band is systematically lower, due to the deeper S-band penetration in the snowpack. Ku measurements from ERS and ENVISAT show similar variations (0.25 dB RMS difference). S band measurements from ENVISAT show similar variations with larger amplitude, that could come from a geophysical signal that will have to be investigated.
Table 2.2 summarises the results. The values for the backscatter are in italic because the ERS maps are not referenced to the usual ocean backscatter scale. Envisat sees the surface above ERS in average because it is not corrected for slope error. Half of the RMS may come from the large scale slope error pattern. Orbit errors are reduced in the standard deviation by summing up the track by track variance. The overall differences between S and Ku are explained by the deeper penetration in the snow pack. The trailing edge difference may come from some ENVISAT mispointing-like effects that are currently under investigation.

Average (St. Dev.)	Height (m)	Bs (dB)	LeW (m)	TE (μs-1)
Ku Env – Ku Ers	0.6 (0.92)	*-2.72* (0.98)	-0.88 (0.6)	-1.85 (0.98)
S env –Ku ers	-1.04 (1.03)	*-3.31* (1.06)	0.78 (1.01)	4.64 (1.13)
S env –Ku env	-1.65 (0.34)	-0.62 (1.02)	1.65 (0.85)	2.78 (1.05)

Table 2.2. Summary of the comparison results between ENVISAT data from october 2002 over Antarctica and ERS data from the geodetic mission (1994-95) over the same region.

3 ICE1/SEA-ICE RETRACKERS AND ICE ALGORITHMS VERIFICATION

The RA2 L2 processing includes some algorithms designed speci fically to extract geophysical measurements over non-ocean surfaces.These algorithms are referred to collectively as the Level 2 Ice Processing (LIP).
The Level 2 NRT products,produced from the ESA near-real time operational processor were compared against the ESL's own reference processor. This was a first step in the validation of the algorithms and products. Later on, the LIP algorithms were further validated by checking against independently computed results.
We were then able to validate the off-line products from the F-PAC by comparing them against the near real time products. Statistical methods, in the form of Cross-over analyses, were also used to assess the accuracy of surface height derived from combining retracking, instrumental corrections and geophysical corrections.
Detailed Results of these processes are explained in the following subsections.

3.1 LIP Waveform Quality Checks

At the beginning of the LIP processing, a set of checks are made on the echo waveform shape to determine if it is suitable for retracking by the Ice1 and Sea Iceretrackers. Essentially the checks determine if there is a recognisable leading edge to retrack.
This processing checks that the average power is above some multiple of the noise power,and also that the average power in the later part of the window is above a certain multiple of the power in the early part of the waveform.Echoes that fail the checks are flagged in the product by setting the appropriate bits in the Ice1 and SeaIce retracking quality flag words. The current settings for the thresholds, that are stored in an external auxiliary file, has proved useful in discriminating bad echoes. Analysis is underway to investigate if further improvements can be

achieved. The tuning of this algorithm is achieved purely through replacing the auxiliary data file so that the processing code is not touched.

3.2 Peakiness

Peakiness is an echo shape parameter, useful in discriminating surface types. This Level 2 parameter was validated in the NRT and OFL products by independent computation.

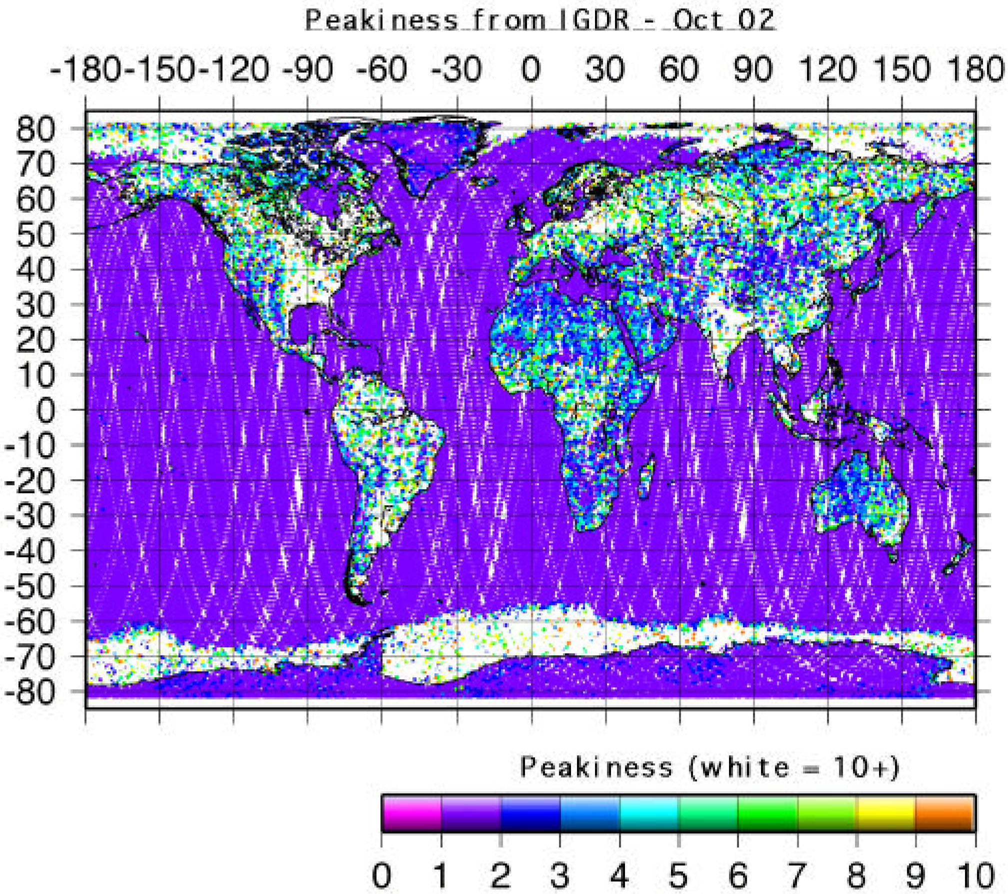

Fig.3.1.Global Plot of Echo Waveform Peakiness

3.3 Ice1 And Sea Ice Retracking

Two retracking algorithms are implemented in the LIP: the Ice1 retracker and the Sea Ice retracker.The Ice1 retracker employs a Offset Centre-of-Gravity parameterisation of the ku and S band echoes to calculate tracker offsets.The Sea Ice retracker operates on the Ku band only and is optimised to estimate a tracker offset for narrow peaked echoes. Retracking offsets between all processors show a good agreement to within 2 mm. The residual difference can be attributed to the different implementation platforms. The result has been validated by independent calculation.
Rarely an echo waveform may be too noisy or badly formed for Ice1 or SeaIce retracking to be reliable. A retracking result close to the range window boundaries (upper bound and lower bound stored in an auxiliary file) is also treated as suspect.
Such cases are flagged and a default "best guess" of range is returned for the LIP retrackers.

3.4 Slope Correction

The echoes of a pulse limited radar are reflected from the closest point on the surface within the antenna beam. For flat surfaces such as the ocean this corresponds to the Nadir but over sloping surfaces the closest point is offset up-slope fromNadir. To correct the location and height of the echoing point the echo direction is calculated using slope models supplied in auxiliary files. The correction is algorithmically complex and involves co-ordinate system transformations, computation of the attitude and azimuth direction of the echoing point through interpolation of the slope models, computation of the slant range and finally the geodetic location for the echoing point.

Checking the computation of the attitude and azimuth angles was an important part of the LIP validation procedure. Initial investigations showed that the Azimuth angle was computed in the wrong quadrant.
The convention is now correctly handled by ensuring an appropriate sign for the components in the model file.
Fig.3.2 illustrates the correct behaviour of the Slope Correction over northern Greenland while Fig 3.3 shows in detail how the echoing point is located up-hill compared with the Nadir position of the satellite orbit track.

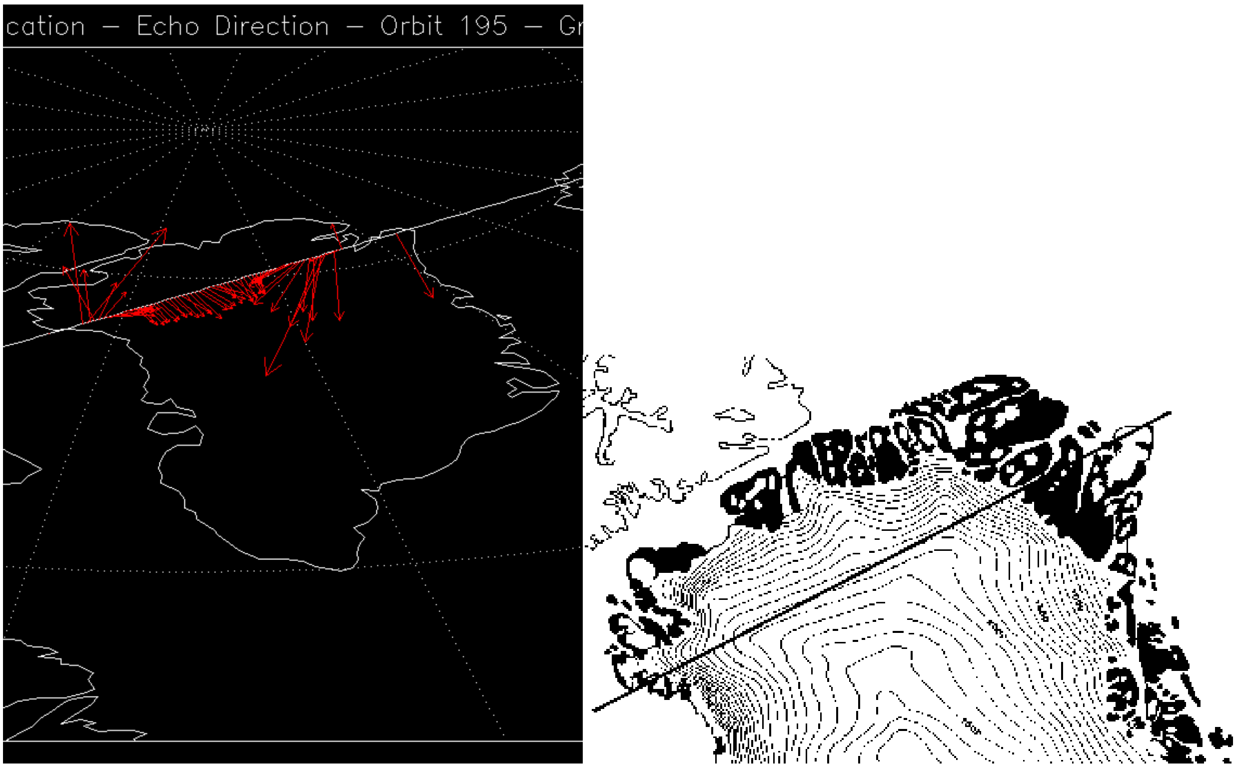

Fig. 3.2 : Slope correction azimuth (arrow direction) and attitude (arrow length)

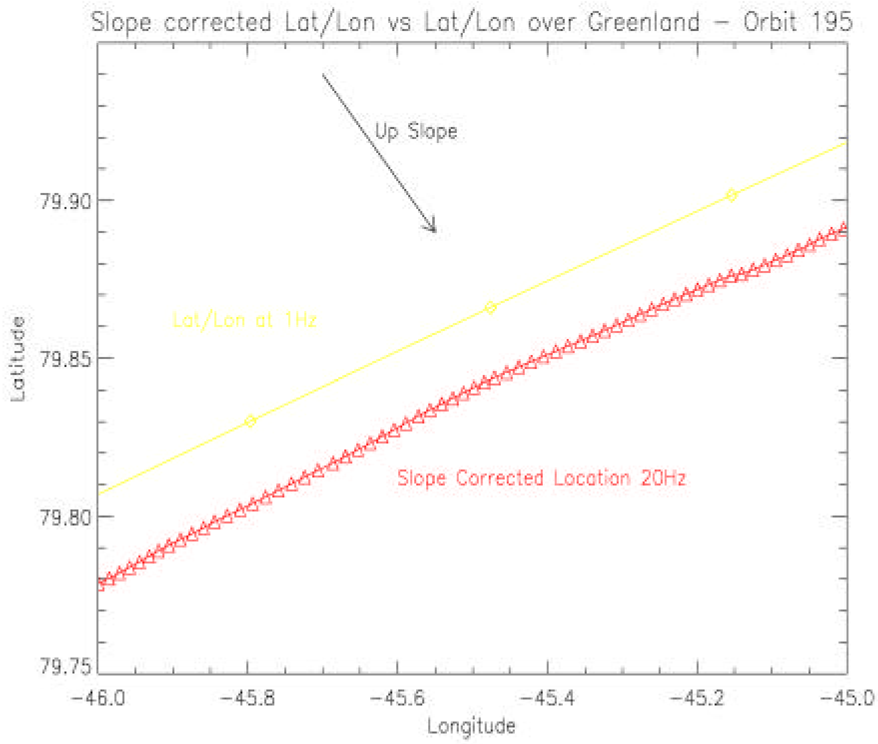

Fig. 3.3 : The effect of slope correction on echo location

3.5 Slope Doppler Correction

When the Radar echo is not returned from Nadir over topographic surfaces then there is a component of the satellite's velocity along the line of sight. This results in a Doppler shift to the Radar frequency which translates into an additional, small range error. LIP processing computes the velocity along the line of sight vector defined by the echo direction attitude and azimuth angles and writes the Delta Doppler Slope Correction to the Level 2 products. The delta is added to the normal Doppler Correction. The delta is zero over flat surfaces and outside the areas covered by the slope model files (i.e. Greenland and Antarctica).
The correction is heavily dependent on the Echo Direction computation described above. Once that function was validated it was easy to verify by independent calculation that the Slope Doppler correction in the Level 2 products was correct. Small differences between the off-line products and the near real time ones need further investigation.

3.6 LIP statistical analysis

Surface Height is obtained from Level 2 products by combining the satellite altitude, retracked range measurement, instrumental range corrections and geophysical range corrections. Crossover analysis is a useful method for assessing the quality of surface height measurement and hence is sensitive to errors in any of the components. This is a statistical technique which can be run on 3 days of data or on a whole 35 day cycle. Results can be masked for different areas of the globe or different surface types. The significance of the result is generally improved by using larger data sets. The method can also be used to detect a time-tag bias in the GDR record datation.
We have applied crossover analysis to sets of data from different Level 2 products and masked for different geographic areas. As the surface height derivation inputs the satellite altitude results from products using a precise orbit will be better than those derived from a Preliminary orbit.
Results are very encouraging showing a generally good quality of the preliminary Level 2 products received so far.
An example result is given here for crossovers from global ocean surfaces for latitudes up to 62 degrees. This is derived from 10500 crossovers from about half a cycle of IGDR data acquired in October 2002.

Residual error in surface height =21 cm RMS.
Time Tag bias estimate =-0.4 ms.

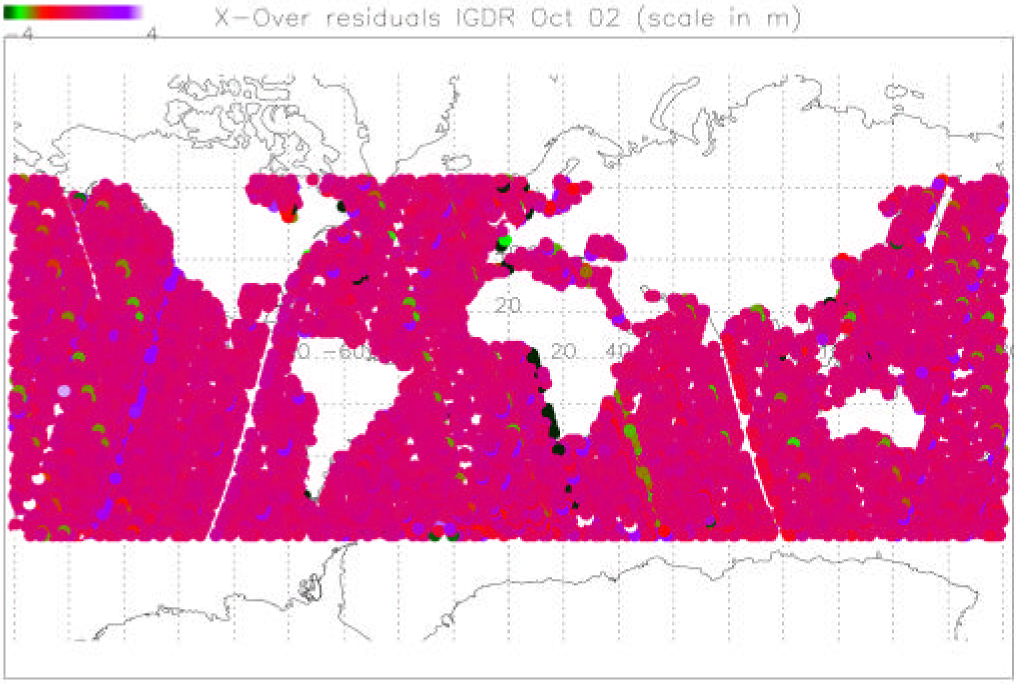

Fig. 3.4 : Residual errors in height at crossovers for half a cycle of IGDR data.

4 CONCLUSIONS

After an exhaustive verification process of all Level 2 reference processors, and consequently of the operational ones (IPF and F-PAC), the main conclusion is that the Level 2 algorithms (with some exceptions as the rain flag or the SSB that will be validated only when more data will be made available to the cal/val users) are fully validated.

For what concerns the ocean retracking, the tuning process led to an improvement in the estimates of some S-band epoch and amplitude values. Some further investigation on the estimation of low waveheights is to be done with larger sets of data so as to fully validate the new algorithm.

Regarding the Mean Quadratic Error between the waveform and the model built from the retracking estimates, used as an edition criterium within the 1 Hz compression process of the ocean physical parameters (altimeter range, SWH and backscatter coefficient), to date, the threshold used in the processing is such that this criterium is unused. Such threshold should be effectively used to remove non-ocean like waveforms from the compression process (e.g. problems of “sigma0 blooms”). This will be addressed in a near future.

The results of the validation of the ice2 retracking algorithms show, in general, a good behaviour and the ice2 outputs are in line with ocean EnviSat values and with ERS land altimetry. A final tuning of some processing parameters is still on its way and will be assessed when more data will be analysed.

Concerning finally LIP retracking and ice algorithms computation, the main result is that these algorithms have been fully validated in the L2 products. Some minor discrepancies in the off-line products (primarily flags) have been identified and will be addressed in the off-line processor. Peakiness, slope Correction and Delta Doppler Correction calculations and outputs have been verified as correct. The preliminary crossover results from the Level 2 products are encouraging and give overall confidence in the quality of the L2 Processing and products. A final tuning of some processing parameters will be performed with larger sets of data.