The ERS SAR Products, Systems and Performances

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Abstract

The paper attempts to describe the history of the ERS SAR products. The description spans the full range of ESA activities with the ERS SAR products including the products generation with several SAR processors, the products quality and their calibration.

The lessons learned during the ERS mission in terms of products generation is discussed, particularly in view of the forthcoming Envisat mission. The quality of the ESA SAR products is described and methods to derive the backscattering coefficient with the ESA products is given. The development of new SAR products or new SAR services for the ERS mission is also discussed.

1. Introduction

After six years of operations, the ERS-1 and ERS-2 SAR missions have fully lived up to expectations by successfully demonstrating the ability of imaging radars to provide valuable long-term earth-observation data to several categories of users, ranging from the real time operators involved in sea ice or oceanographic applications, to research-project groups working off-line on environmental issues.

The engineering activities associated to the generation of the SAR products are an essential element of the success of the ERS missions. These activities not only include the SAR products generation but they also cover the verification of their quality, their calibration as well as the monitoring of the performances of the SAR instruments. These engineering activities would not be complete without a continuous effort for improving the current products or for developing new services related to the SAR data in order for the ERS ground segment to better adapt to the user demand.

2. ERS SAR Products Generation

2.1 The generation of ERS SAR products at ESA

The European Space Agency, via its Remote Sensing Exploitation Department located at ESRIN, is operating the ERS Payload Data Ground Segment composed of the following major elements:

- the ESA ERS Central Facility at ESRIN
- the ESA Ground Stations network
- the ESA Processing and Archiving Facilities (PAF's)
- the National and Foreign Stations

The generation of the ESA products takes place in any of the first three elements. The ESA SAR products usually come in two ``flavours'': on-line or off-line.

2.1.1 ESA on-line products

The ESA ground stations network generates the on-line products such as the products derived from the Wave Mode data and then transmit them to users by network. This allows the wave data to reach the world's weather offices within three hours of observation.

The same approach was followed for high resolution SAR images (product UI16), but the size of the product (64 MBytes), the limited coverage of the products (only 3 scenes of 100 x 100 km per orbit) and the difficulties related to the products dissemination (dedicated satellite link, limited number of reception centres) seriously discouraged the potential users.

Products covering a larger area together with a lower pixel size would have been more appropriate. This is discussed in Paragraph 2.2.

2.1.2 ESA off-line products

Most raw data is however sent on magnetic tape from the acquisition stations to one of ESA's ERS Processing and Archiving Facilities (PAF). At those facilities SAR raw data is catalogued, archived and then converted into a series of SAR products.The four PAFs, managed under ESA contract, are located in Germany (D-PAF), in Italy (I-PAF), in the United Kingdom (UK-PAF) and in France (F-PAF). The latter one generates only SAR products derived from the Wave mode.

The SAR products generated at the PAFs are described in [Ref. 1]. For image mode, the ESA products are:

RAW: Raw and auxiliary data for further processing,
SLC (Single Look Complex):
Single-look complex data in slant range,
PRI (PRecision Image):
Multi-look, ground range, calibrated image,
GEC (Geocoded Ellipsoid Corrected):
Multi-look, ground range, calibrated image, precisely located and rectified on a map projection
GTC (Geocoded Terrain Corrected):
Multi-look, ground range, calibrated image, precisely located and rectified on a map projection, corrected for terrain distortion by use of a digital elevation model.

The PAF concept was derived from proposals by some ESA member states to implement facilities dedicated to specific scientific and application domains, based on the existence of groups in their countries already active in these fields. The PAF developed their own SAR processor based on different software and hardware configurations. This however had an important drawback for the ERS SAR users: each PAF was certainly able to generate products according to ESA specifications, but not necessarily identical to the SAR products generated by the other PAFs. This problem was particularly evident for the SLC products and resulted in many complaints from the users involved with SAR interferometry.

The SAR products annotations were another source of problems for the ERS users. Originally each PAF was requested to provide ESA SAR products according to the 1989 CEOS SAR product format document [Ref. 2]. However this document is not a strict specification document but rather a format guideline aiming to ensure compatibility between products from different spaceborne and airborne SAR sensors. Consequently each PAF had his own interpretation of the document and this resulted in many annotations differences amongst the ESA products, specially during the first two years of the ERS-1 mission. The situation was partially improved in 1994 when the Agency issued an ESA CEOS format specification for the ERS SAR products [Ref. 3].

However, because of the different software and hardware systems used by the PAFs SAR processors, there were still many user complaints concerning the non-standardization of the ESA SAR products between PAFs. For this reason it was decided in 1996 to have the same SAR processor at all PAFs. The adopted common processor is the Verification Mode Processor, already used by D-PAF for ERS users and by ESRIN for verification purposes. Since early 1997, the PAFs generate identical SAR products with identical annotations. This concerns only the RAW, SLC and PRI products as nothing is changed with the geocoding processing chains (GEC and GTC products).

The opportunity of the SAR products standardization was taken to upgrade the SLC product. This was necessary for two reasons: the SLC was a quarter frame product, and the product specification did not contain specific phase preservation requirements necessary to insure interferometric applications (see paragraph 2.1.3). The upgraded product (acronym: SLC-I) is now a full frame product (100 km x 104 km) and its phase preservation is ensured [Note: the SLC products were already phase preserving at D-PAF and I-PAF].

2.1.3 Phase preserving evaluation

SAR interferometry is based on the phase information in SAR complex products. However traditional quality requirements for SAR processors and products are mainly based on measurements of the module of the impulse response function and do not guarantee phase preservation. The need for specific phase quality requirements leads the Agency to define specific phase requirements for complex products generation [Ref. 4].

The methodology for phase preservation, originally proposed by [Ref. 5], consists in two different tests:

- the interferometric offset test which consists in generating two complex products independently processing the same raw data set twice, but starting at different range and azimuth positions, then in evaluating the statistics of the generated interferogram.
- the point target test based on the phase quality analysis of the impulse response function.

The key points of the methodology are the appropriate conditions under which the complex products used for the tests are generated. As the offset test aims to generate an interferogram where only the processor introduced phase aberrations are present, the processing parameters shall be carefully analysed and the test conditions established in detail.

The results [Ref. 4] of the phase preservation tests show the validity of the methodology and point out the fact that the tested processors are phase preserving if all the processing corrections are applied with the best possible accuracy.

2.1.4 Upgrade of Wave Mode products

Wave mode products are also been improved since beginning of the ERS mission. The fast-delivery UWA product, defined as the power spectrum of an imagette [Ref. 1], is currently upgraded with introduction of a new processing algorithm in order to provide:

- new annotations (land-sea flag, incidence angle, number of samples, ...),
- correction for a calibration constant,
- information at shorter and longer wavelengths,
- azimuthal clutter cut-off wavelength information.

2.2 The development of new SAR products and services

2.2.1 The medium/low resolution SAR products

The original list of ERS SAR products (paragraph 2.1) did not contain medium or low resolution SAR products (i.e. products with pixel spacing between 50 and 500 m). However this family of products would be beneficial to several aspects:

- visibility of the ERS SAR acquisitions, i.e. the possibility to `see' all acquired raw data: it is interesting to note that within the ESA ground segment (Kiruna, Fucino and Maspalomas acquisition stations), only 10% of the ERS-1 raw data acquired have been processed to high resolution products. This is a small value but it corresponds to 38 000 high resolution products. By consequent about 90% of the ERS-1 SAR raw data have never been ``visualized'', i.e. transformed to image products.
- promotion for the use of high resolution data (browse function, i.e. identification of scenes to be processed at high resolution),
- closer monitoring of the SAR instrument performances.
- scientific studies and surveillance applications of large scale phenomena (mainly in oceanography, sea ice and geology),
- small data volume and thereby reduced time of distribution to users.

In order to meet these needs, two groups of products can be foreseen [Ref. 6]:

- browse products, with pixel spacing around 200 m and a low radiometric resolution, mainly used to assist users in the selection of high resolution products.
- medium resolution products, with pixel spacing around 100 m and an high radiometric resolution, used as a a digital product for studies of large scale phenomena.

It is important to note that, in order to be fully successful, both groups of products have to be processed and distributed in near real time (i.e. within 2 hours), and shall cover the totality of a SAR acquisition segment.

The same approach is followed for the Envisat ASAR products (i.e. browse and medium resolution products will be available for all imaging modes).

Browse processor:

Proceeding along this line, ESA has developed an ERS SAR browse processor [Ref. 7] with the following major characteristics:

- it processes one entire acquisition segment (i.e. several ERS SAR frames) within 1h 30 after data acquisition,
- the generated browse product has a size lower than 3 MBytes in order to be quickly transferred through terrestrial networks,
- the browse product is used as basic SAR product to populate browse systems such as earthnet online, the ESA Earth Observation image browser.

The image generated by the ERS SAR browse processor has a pixel spacing of 200 m, is not calibrated and is Jpeg compressed (one scene is about 70 kilobytes).

The ERS SAR browse processor is currently installed at UK-PAF and ESRIN. The generated browse images mainly correspond to the Kiruna acquisition station (Europe + Arctic). An example of browse image is given in Figure 1. The images are freely accessible via the Image browser of "**earthnet** *online*".

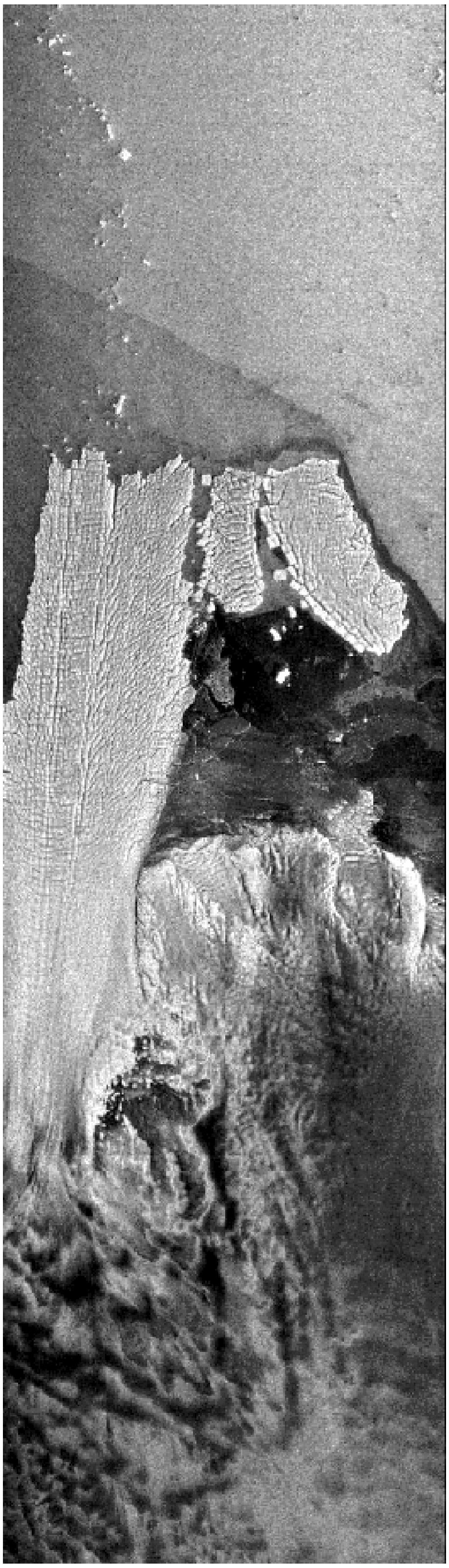

Figure 1: Browse image
Antarctica - Victoria Land
ERS-1 / 10 February 1996

Availability of real time SAR browse data via network would be possible if similar ERS browse processors would be installed directly at acquisition stations. Real time browse images coupled with information extraction such as oil slicks detection would certainly enlarge the use of ERS SAR data.

Medium resolution processor:

ESA is currently developing a prototype SAR processor aiming to generate ERS medium resolution products. These products (100 m pixel spacing) will correspond to a complete acquisition segments and will be suitable for scientific analysis, i.e. calibrated, with an high radiometric resolution (Equivalent Number of Looks around 40) in order to reduce the speckle effect.

2.2.2 The medium/low resolution InSAR products

The SAR interferometry (InSAR) technique has seen a considerable expansion with the ERS-1 mission and more particularly with the ERS-1/ERS-2 tandem mission. However due to its repeat-pass nature the ERS SAR interferometry suffers some limitations such as the loss of coherence or the atmospheric changes between image acquisitions. For this reason, ESA is developing an InSAR quick-look processor from an original idea described in [Ref. 8]. The InSAR quick-look is mainly intended for data browsing and selecting (e.g. for quick analysis of the coherence of the area or for identification of atmospheric artifacts) prior to performing a full resolution interferometric processing.

The current version (prototype) of the InSAR quick-look processor delivers an InSAR browse image and an InSAR medium resolution product (following the same approach than for the SAR low resolution image, described in the previous paragraph).

The InSAR browse product is a jpeg-compressed colour image with pixel spacing of 200 m (i.e. similar to the SAR browse product) containing three coregistered channels: flattened phase, coherence and intensity. The Agency intends to display the InSAR browse images in its Image Browser server ("**earthnet** *online*").

The InSAR medium resolution product is more appropriate to scientific investigations because of its pixel spacing of about 35 m. It contains three coregistered images: the unflattened phase image, the coherence image and the intensity image.

2.2.3 The SAR toolbox

In order to facilitate the use of ERS SAR data and consequently to contribute to the diffusion of ERS SAR data within a large audience, a SAR toolbox is currently under development. The toolbox shall help the users in handling their ERS SAR products. It will be composed of a set of software modules meant to be used by a very large audience having different computer systems.

It is intended that the SAR Toolbox will be easily usable in conjunction with commercial image processing software packages. However it is out of scope to reimplement modules already available within these commercial image processing software packages.

The Toolbox will contain the following groups of tools:

- Tools for product data extraction directly from the physical medium device.
- Tools to interprete the product annotations,
- Tools for data and format conversion (e.g. to TIFF),
- Tools for image resampling (e.g.in spatial and frequency domain),
- Tools for image coregistration (e.g. generation of coregistered multitemporal images or coherence images),
- Tools for speckle filtering,
- Tools for image calibration including a tool for ADC saturation correction (paragraph 3.2.2) and the generation of an image of the backscattering coefficient.

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3. ERS SAR Products Quality and Calibration

3.1 The quality of the ERS SAR products

The quality of the SAR products has always been of high level since the beginning of the ERS mission, mainly because of the high reliability of the SAR instruments but also because of the high standard of the ERS SAR processors.

Within the ERS ground segment, the product quality activities are performed with the support of a system called the Product Control System (PCS). The Product Control System's operational tasks [Ref. 9] include the monitoring of ERS data product quality and the verification of the compliance of product quality parameters with the product specifications. The PAFs are responsible for the quality control of each SAR product delivered to users

The following table gives some of the current quality parameters of SAR PRI & SLC products.

Quality parameters	PRI	SLC
range resolution	23.5 m at mid-range	9.7 m slant-range
azimuth resolution	21.7 m	5.4 m
range PSLR	-18.5 dB	-21.6 dB
azimuth PSLR	-15 dB	-27.3 dB
ISLR	-9.3 dB	-12.6 dB
radiometric resolution	2 dB	3.1 dB
noise equivalent sigma nought	-24.8 dB	
azimuth ambiguity ratio	-27.1 dB	
localisation accuracy	range 250 m, azimuth 50 m	

Table 1: PRI & SLC quality parameters as measured in the ERS-2 reference scene (Flevoland, 4 August 1995).

3.2 The calibration of the ERS SAR products

Calibration of ERS SAR products is essential in order to take full advantage of the potential information contained in a product. Calibration allows the geophysical interpretation of SAR data by relating the digital number of SAR products to physical measurement such as the backscattering coefficient.

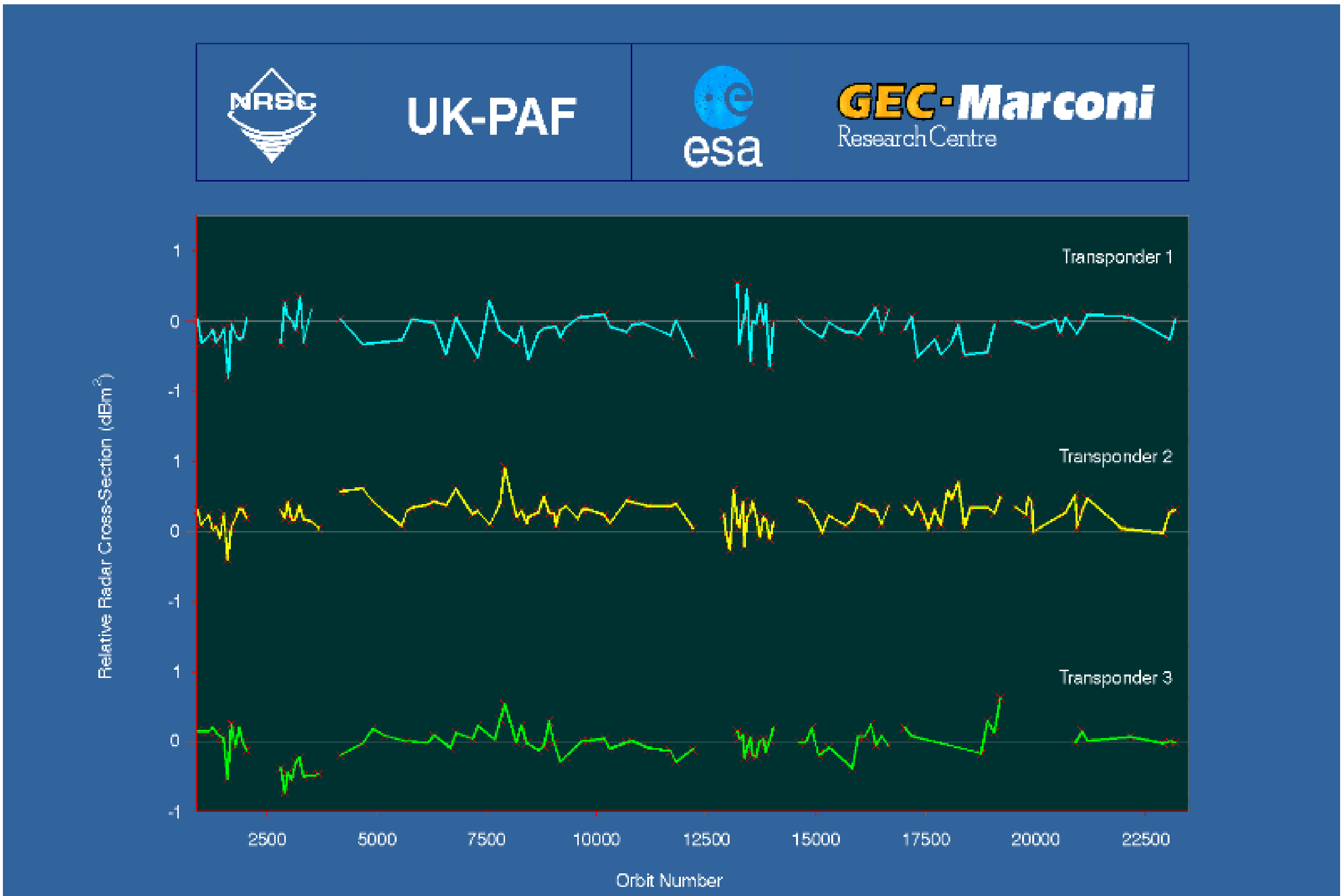
The ESA strategy for the radiometric calibration of the ERS-1 and ERS-2 SAR images is based on the following key elements:

- the overall stability of both instruments monitored by ESA-developed active calibrators and on-board measurements.
- the capability to compensate on-board anomalies by off-line corrections (e.g. replica pulse power correction) or by modifications in the instrument/processor gains.
- the support of the PAFs and European expert institutes for confirmation of ESA results.

3.2.1 The ERS SAR stability performances

One of the main PCS roles is to assess ERS instruments behaviour and the related margins. This information represents vital feedback for future programmes, including the analysis and development of algorithms for validation and calibration activities. This includes the stability of the ERS SAR systems which is one of the key issues to ensure that the scientific community can take fully advantage of ERS SAR data. The PCS also provides the information needed by users to absolute calibrate ERS SAR imagery. Without this calibration it would not be possible to properly compare SAR image ERS data with data acquired by other sensors as well as to extract from the SAR images geophysical information related to the surfaces imaged.

Both ERS-1 and ERS-2 show a very high radiometric stability through the mission. This stability is defined as the standard deviation of the radar cross section measured on the transponders deployed at the ERS calibration site of Flevoland in the Netherlands (Figure 2). The radiometric stability of the ERS-1 SAR system is 0.5 dB during its 5 years of activity. It shall be noted that this value not only includes the instrument stability, but also the transponders and processors stabilities.



ERS-1 SAR Relative Radar Cross-Sections for the ESA Transponders during the period September 1991 to January 1996 (after corrections for ADC Power Loss and Replica Pulse Power Variations).

Figure 2: ERS-1 radiometric stability measurements over 4.5 years using the three ESA transponders located in Flevoland [courtesy of P. Meadows, GEC Marconi Research Centre].

For the ERS-2 SAR system the stability showed by the transponders measurements is similar. Other parameters indicating the good performance of the ERS SAR systems are the noise present in the receiver, the calibration pulse or the replica pulse. This information is accessible in the ESA Earth Observation information service "**earthnet** *online*".

3.2.2 The derivation of the backscattering coefficient in ERS SAR products

The high stability of the ERS SAR instrument insures the relative calibration of the SAR products. The absolute calibration of a SAR product, i.e. the derivation of the radar backscattering coefficient, is possible if these additional key points are verified:

- the calibration constant is available,
- the in-flight elevation antenna pattern is compensated,
- the sources of radiometric errors are identified and corrected.

The calibration constants are available for both ERS missions and for all PAFs. Their value is derived using the ESA active calibrators deployed in Flevoland. The in-flight elevation antenna patterns for both missions are derived from homogeneous images over the Amazonian rainforest [Ref. 10].

Also, during the six years of exploitation of the ERS-1 and ERS-2 SAR instruments, various sources of radiometric accuracy errors have been identified that are related to either the on-board instrument (e.g. ADC non-linearities or replica pulse power variations) or the PAF processors (e.g. inaccuracies in the implementation of the elevation antenna pattern). Correction methods exist for each of these sources of radiometric errors.

An ESA document [Ref. 11] gives the steps whereby users can derive measurements of the backscattering coefficient so from their ERS SAR PRI products. The Precision Image (PRI) product is indeed the ESA standard product for SAR radiometric precision analysis. The steps for the soderivation method include corrections for the implementation of the elevation antenna pattern, for the backscattering coefficient dependence on incidence angle, for any replica pulse power variations and finally for Analogue to Digital Convertor (ADC) non-linearities.

The correction for ADC non-linearities is the most complex correction and requires users to perform image analysis of their products following the method originally proposed in [Ref. 12]. In order to avoid a complex and time-consuming procedure, the user shall make sure that the ADC non-linearities correction method needs to be applied before implementing it. The ERS-1 SAR ADC saturation occurs mainly for *large distributed targets having high backscattering coefficients* [Ref. 13], e.g. the rough sea or large towns. ERS-2 SAR ADC saturation is much reduced compared to the ERS-1 SAR due to a reduction in on-board gains. It is estimated that the ADC power loss can, in general, be estimated to a precision of better than 0.5 dB. Exceptions to this are regions consisting of numerous bright point targets (such as e.g. cities).

4. Conclusions

Since 1991, the ERS missions have revolutionised many areas of the Earth sciences and their practical applications. The high standard of performance of the ERS SAR instrument operations and the reliable provision of well-calibrated data over a long period of time have stimulated the use of SAR data into a much broader range of utilisation than was originally thought.

This has been achieved through close and fruitful cooperation between the European industry involved in the development and the operations of the ERS ground segment, the scientific community, and the ESA teams.

The Agency however continue to look for improvement of SAR products or services to help the SAR scientific and applications community to make the best use of their ERS data.

5. References

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*Most of the above references are available via " **earthnet** online", the new online information service for Earth Observation users provided by ESA.*