ENVISAT ASAR Product Calibration and Product Quality Status

B. Rosich[1], P.J. Meadows[2], A. Monti-Guarnieri[3]

[1] *European Space Agency, Directorate of Application Programmes*
ESA-ESRIN, Via Galileo Galilei, 00044 Frascati , Italy
Email: brosich@esa.int

[2] *BAE SYSTEMS Advanced Technology Centre, West Hanningfield Road,*
Great Baddow, Chelmsford, Essex, CM2 8HN, United Kingdom.
Email: peter.meadows@baesystems.com

[3] *Politecnico di Milano, Dipartimento di Elettronica e Informazione*
Piazza Leonardo da Vinci 32, 20133 Milano, Italy
Email: monti@elet.polimi.it

ABSTRACT

ENVISAT ASAR products are operationally distributed to the user community since December 2002 (since January 2004 for Global Monitoring Mode). Calibration activities, based on the ASAR internal calibration modes and on acquisitions over transponders, corner reflectors and the Amazon Rain forest, are routinely performed to ensure the accurate calibration of ASAR products.

In addition, some changes have been introduced in PF-ASAR (ASAR Processing Facility) to further improve the quality of the products and a new product, the Wide Swath Mode Single Look Complex (WSS) product, is being implemented in the processor.

This paper presents the different calibration activities, the calibration results and an updated quality status for the different ASAR products. It introduces also the new WSS product, which will be available to the users before the end of 2004.

INTRODUCTION

The ENVISAT Advanced Synthetic Aperture Radar (ASAR), one of the 10 instruments on board of ENVISAT, is equipped with an active phased array antenna of 320 transmit/Receive modules, organised in 32 rows to produce a versatile position of the image swath by beam steering in elevation. In addition, the instrument is designed to provide a large degree of operational flexibility, acquiring science data in 5 different modes. The *Image Mode* (IM) generates high spatial resolution data, in HH (H Transmit and H receive) or VV (H Transmit and H receive) polarization, over one of seven available swaths located over a range of incidence angles spanning 15 ° to 45 °. The *Wave Mode* (WV) generates vignettes of 10 km by 10 km spaced 100 km along-track, in HH or VV polarisation. The position of the vignette can be selected to alternate between the centre of any two of the seven swaths. The *Wide Swath Mode* (WSM) and *Global Monitoring Mode* (GMM) are based on the ScanSAR technique using five sub-swaths (across track coverage of 400 Km) either in HH or in VV polarisation. The first one is a high resolution mode, for which typical products of 150 m geometric resolution are generated, while the second one is a low rate mode, which allows for a whole orbit operation at the cost of reducing the resolution to ~1Km. The *Alternating Polarisation* (AP) *Mode* provides two simultaneous images from the same area in HH and VV polarizations, HH and HV or VV and VH, using the ScanSAR technique, with the same imaging geometry as Image Mode and similarly high spatial resolution. [1]

Monitoring the instrument performance and product quality is a major task is to be performed during the instrument lifetime in order to ensure the maximum data quality throughout the full mission. This paper provides an overview of the ASAR product quality based on dedicated calibration sites, describes recent improvements in the product quality and introduces a new product type, the Wide Swath Complex, which is being implemented in the operational ASAR processor and which will be available to the users before the end of 2004.

ASAR OPERATIONS: GLOBAL MONITORING

ASAR science data is acquired operationally in Image, Alternating Polarisation, Wave and Wide Swath mode since mid 2002. Some anomalies at instrument level were observed while operating in Global Monitoring mode. These included the corruption of source data packets and an abnormal mode termination. Operations in GM were suspended during the investigation, until a corrective solution was available. A solution to both problems was identified and implemented in November 2003. Test operations started in December 2003 and nominal operations, through an upgraded Background Regional Mission (BRM) Plan were resumed in February 2004. Quality of GM data is nominal since then and products are being distributed in near real time (NRT) to users since March 2004. Some examples of GM products are provided in Fig.1

The BRM establishes the default acquisition plan in absence of user requests. Different levels of priority are defined, being the low rate data (Wave and Global Monitoring modes) the modes with lower priority. Availability of data around the orbit is crucial to perform the around-orbit performance monitoring and to identify possible anomalies as early as possible. Until February 2004, the low rate BRM was based only on wave mode. In other words, wave mode data was acquired over any type of area (ocean, land, ice, sea-ice…) when no high rate data was required. Since February 2004, wave mode data is acquired only over the oceans while global monitoring data is acquired both over land and over ice and sea-ice areas.

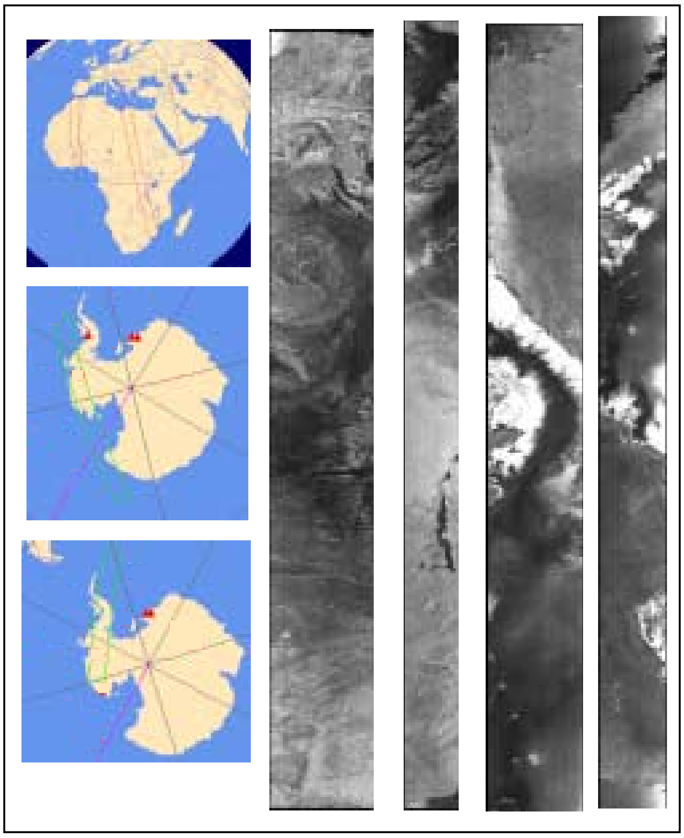


Fig. 1. Examples of Global Monitoring Mode products acquired in May 2004.

ASAR CALIBRATION SITES

Calibration of ASAR products and monitoring of ASAR product quality is performed based on data acquired over various calibration sites, namely:

- the 4 ASAR precision transponders, currently deployed in The Netherlands
- the 4 RADARSAT transponders, deployed in Canada and used for ASAR performance monitoring under agreement with the Canadian Space Agency (CSA)
- ASAR receiving ground stations
- the Amazon Rain Forest area
- corner reflectors deployed for specific calibration campaigns

Data acquired over the transponders (both the ASAR and RADARSAT ones) is used for product quality monitoring and radiometric calibration. Data acquired over the Amazon rain forest is used mostly for elevation antenna pattern monitoring and data acquired over the corner reflectors has been used till now for geometric product calibration.

Details of the above calibration sites are provided in the table below:

SITE NAME	LATITUDE	LONGITUDE
	decimal deg	decimal deg
NL - ASAR Transponders		
Edam	52.524552	5.049332
Zwolle	52.551796	6.006086
Aalsmeer	52.199801	4.818415
Swifterbant	52.55497	5.668955
RADARSAT Transponders		
Ottawa	45.294665	-75.757550
Resolute	74.746398	-95.001370
Fredericton	45.870278	-66.539444
Saskatchewan	53.216470	-105.679290
Ground Stations		
Kiruna	67.854752	20.963405
Neustrelitz	53.328787	13.069388
Amazon Rain Forest		
Amazon Rain Forest	-11 to -4	-71 to -65

Table 1. ASAR calibration sites.

ASAR PRODUCT QUALITY SUMMARY

Product quality is nominal in all modes since GM operations have been resumed. As mentioned in the previous section, product quality analysis is mainly based on data acquired over the ASAR and Radarsat transponders.

The IRF parameters measured for all IM and AP product types are provided in table 2.

Product	Az. Res (m)	Rg. Res (m)	ISLR (dB)	PSLR (dB)
IMP	22.07±0.43	range dependent	-13.28±1.37	-16.66±0.87
IMG	22.12±0.45	22.7 - 35.4	-13.33±0.75	-16.87±1.05
IMS	4.76±0.02	9.45±0.07	-14.39±0.27	-19.45±0.67
IMM	146.6±3.7	range dependent	-5.86±3.43	-16.00±2.16
APP	27.65±0.86	range dependent	-12.17±1.68	-19.00±0.86
APG	27.76±0.48	23.2 - 30.3	-13.04±0.44	-19.31±0.85
APS	4.83±1.76	8.42±0.13	3.27±2.38	-2.36±1.39
APM	143.6±3.8	range dependent	-6.05±6.15	-16.54±1.90

Table 2. Spatial resolution, Integrated Side Lobe ratio (ISLR), Peak Side Lobe Ratio (PSLR) and Spurious Side Lobe Ratio (SSLR) for IM and AP products.

For ground range detected products, the range resolution varies with the incidence angle. Figure 3 shows the measured range resolution for IM and AP high resolution, multi-look detected products (IMP and APP). An excellent agreement is observed, with results well below the requirement of 30 m at mid range. Figure 4 provides the measured range resolution for IM and AP medium resolution, multi-look detected products (IMM and APM), together with the theoretical value (solid line). The range resolution requirement for these products is 150 m.

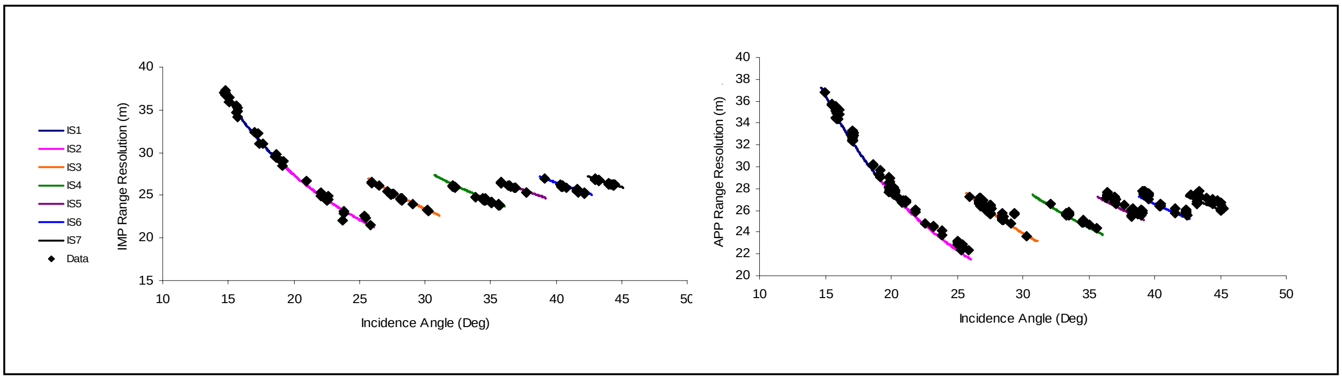


Fig.3. Measured range resolution for IM and AP high resolution, multi-look detected products (IMP and APP).

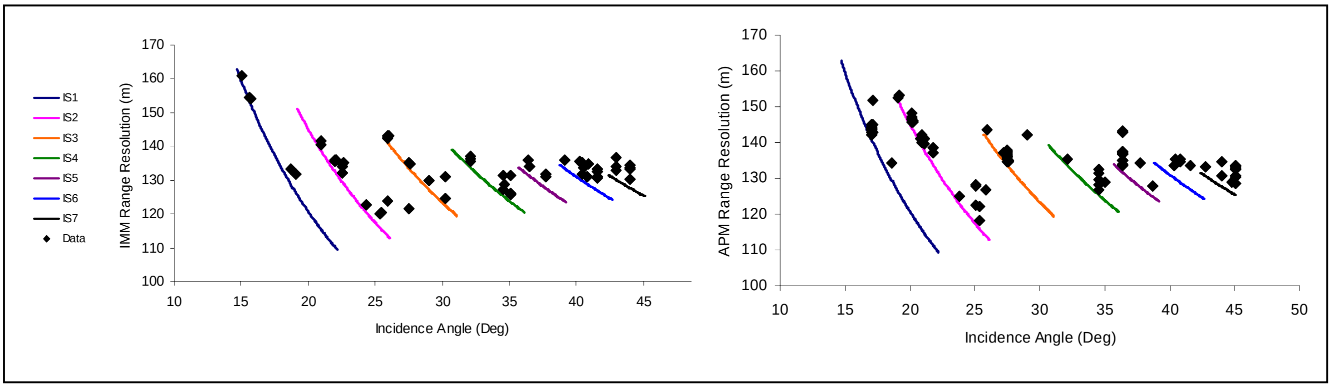


Fig. 4. Measured range resolution for IM (left) and AP (right) medium resolution, multi-look detected products (IMM and APM).

The results for Image and Alternating Polarisation medium resolution (MR) products (IMM and APM) appear to be slightly worst than specifications, which is indeed an effect of the product under-sampling. Image and Alternating polarisation MR products are sampled at 75 m in range and azimuth. However, the range resolution at mid swath is about 130 m, significantly lower than 150 m. Wide Swath Mode products are also under-sampled, as pixel spacing is 75 m but azimuth resolution is about 110 m and range resolution at mid swath is about 120 m. Since the under-sampling factor in WSM is higher than for IMM and APM products, IRF analysis of WSM products is performed on products specially processed at 40 m pixel spacing to avoid aliasing. WSM IRF results obtained on standard 75 m pixel spacing products and on 40 m pixel spacing products are shown in fig.5 for comparison purposes.

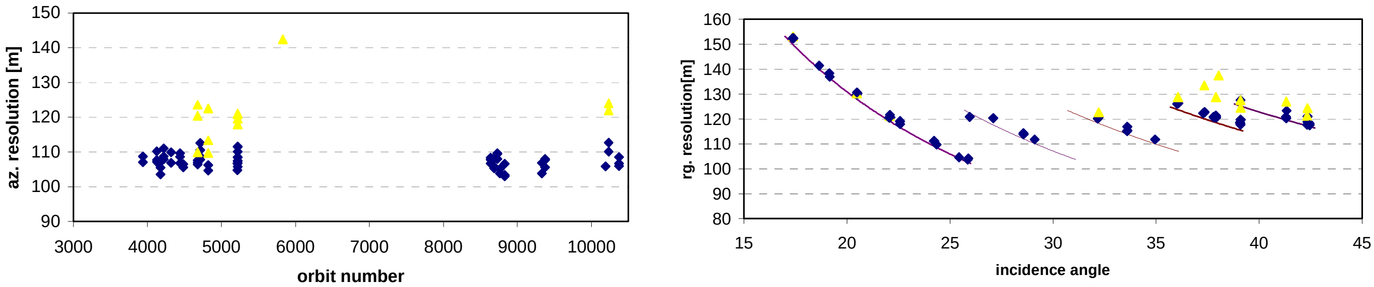


Fig.5. Measured azimuth (left) and range (right) resolution for WSM products. Results for standard products (75 m pixel spacing) are in yellow and results for products with no under-sampling (40 m pixel spacing) are in blue.

Summary of WSM products quality is provided in Table 3.

Product	Az.Resolution	Rg. Resolution	PSLR Az.	PSLR Rg.
WSM	108.13 ±3.5	120.39 ±8.7	-19.46 ±1.17	-20.04 ±1.35

Table 3. Spatial resolution and PSLR for WSM products.

Results for AP single look complex (APS) products are very different from the IM single look complex products (IMS). This is discussed in the next section.

Radiometric calibration results are summarised in table 4. A large standard deviation in the relative Radar Cross Section (RCS) measurements over the RADARSAT transponders is observed as well as a large bias for some of the RADARSAT transponders, particularly over the Resolute transponder. Statistics in table 4 are shown for all transponders, for ASAR transponders only and for RADARSAT transponders only. Investigation on the possible causes of this behaviour over the RADARSAT transponders is on-going.

Product	Transponders used	All Swaths
IMP	All	0.62±0.94
	ASAR	**0.26±0.41**
	Radarsat	1.01±1.18
IMS	All	-0.04±0.74
IMM	All	0.80±0.94
APP	All	0.63±0.89
	ASAR	**-0.28±0.49**
	Radarsat	0.81±0.84
APS	All	-0.08±0.95
APM	All	0.36±0.90
WSM	**ASAR**	**0.33±0.63**

Table 4. Relative Radar Cross Section for IM, AP and WSM products.

ALTERNATING POLARISATION SINGLE LOOK COMPLEX (APS) PRODUCT QUALITY

The Doppler spectrum of the AP mode data is discontinuous due to its bursty nature, having between two and three complete burst per aperture and per polarisation depending on the target position. The discontinuity of the spectrum makes difficult to meet the highest focusing quality and simultaneously ensure the highest overlap in azimuth between data acquired on different passes by keeping as much of the Doppler spectrum as possible.

The adopted solution in PF-ASAR consists in keeping two complete bursts for all the samples. This strategy satisfies the requirements for InSAR processing but introduces a modulation in the azimuth IRF due to the segmentation of the Doppler spectrum for each target. The result of this modulation is that the ideal focusing requirements do not apply to the APS products.

The IRF modulation caused by the discontinuity of the Doppler spectrum can be characterized by the coherent addition of two sinc(t) functions with a relative frequency shift of twice the burst bandwidth.

$$s(t) = \cos(2\pi BW_{burst}\, t).e j^{2\pi BW_{burst} t} \sin(\pi BW_{burst}\, t) / \pi BW_{burst}\, t$$

As it can be observed in Fig.6, the envelope corresponds to the response of one burst and therefore to the sinc(t) function.

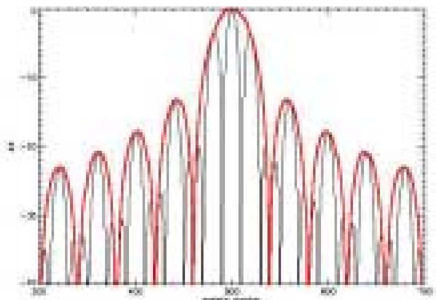


Fig. 6. Theoretical modulated IRF for APS products (2 bursts) and envelope (red).

The theoretical azimuth resolution of this modulated IRF, corresponds to $(0.242/BW_{burst}).V_{sat\_ground}$, and the azimuth Peak Side Lobe Ratio (PSLR) for this response is –3.5 dB.

ELEVATION ANTENNA PATTERN MONITORING

Monitoring of the elevation antenna pattern is mainly based on data acquired over the Amazon rain forest, using mostly Wide Swath, Image precision (IMP) and alternating polarisation procession (APP) products.

The use of Wide Swath mode products is particularly important since it offers the possibility to monitor 5 beams simultaneously (SS1, IS3-SS2, IS4-SS3, IS5-SS4, IS6-SS5). However, since no measurement is performed on the overlapping areas between neighbouring beams, WSM products are combined together with Image and AP products in order to measure the pattern over the maximum possible range extend.

Measurement of IS1, IS2 and IS7 patterns (which are not part of the ScanSAR beams) is performed using only IM and AP products. Alternating Polarisation products are however mainly used to measure the elevation antenna pattern for the cross-polarised beams (HV and VH).

Update of the elevation antenna pattern is performed when the peak-to-peak difference between the measured and the current patterns exceeds 0.3 dB over the centre 80% of the beam.

The table below provides the list of recent updates in the elevation pattern for all beams. The elevation antenna patterns are provided in the ASAR External Calibration auxiliary file (ASA_XCA_AX), which is updated every time a new update is performed. These auxiliary files are provided on line at: http://earth.esa.int/services/auxiliary_data/asar/)

Beam	Pol	RECENT ELEVATION ANTENNA PATTERN UPDATES		
SS1	HH	27/08/2003		06/04/2004
SS1	VV	27/08/2003		06/04/2004
IS1	HH		09/12/2003	
IS1	VV		09/12/2003	06/04/2004
IS1	HV			
IS1	VH		09/12/2003	06/04/2004
IS2	HH			06/04/2004
IS2	VV		09/12/2003	06/04/2004
IS2	HV			06/04/2004
IS2	VH			06/04/2004
IS3_SS2	HH	27/08/2003	09/12/2003	
IS3_SS2	VV	27/08/2003		
IS3_SS2	HV			
IS3_SS2	VH			
IS4_SS3	HH			
IS4_SS3	VV			
IS4_SS3	HV			06/04/2004
IS4_SS3	VH			06/04/2004
IS5_SS4	HH	27/08/2003		06/04/2004
IS5_SS4	VV	27/08/2003		
IS5_SS4	HV			06/04/2004
IS5_SS4	VH			06/04/2004
IS6_SS5	HH			
IS6_SS5	VV			
IS6_SS5	HV			06/04/2004
IS6_SS5	VH			06/04/2004
IS7	HH			
IS7	VV			
IS7	HV			
IS7	VH			

Table 5. Updates of elevation antenna patterns for the different ASAR beams since August 2003.

RECENT PRODUCT QUALITY IMPROVEMENTS

Elevation antenna pattern correction is performed by default on all ASAR ground range detected products. If the local terrain height elevation is not taken into account during processing, the elevation angles derived based on the reference ellipsoid (WGS 84 for ASAR) may differ from the actual ones.

As a result, the antenna pattern correction performed during the processing will not completely compensate for the elevation antenna gain modulation and a residual gain will be introduced.

The resulting radiometric error depends on the terrain height and on the antenna radiating pattern shape. Errors higher than 1 dB can be expected for the low incidence angle beams (worst case is SS1) over high elevation areas. An estimate of the residual radiometric error is provided in figure 7 for SS1 and SS5 (IS6) beams, assuming local terrain height is 1000 m (solid line), 2000 m (dotted line) and 3000 m (dash line).

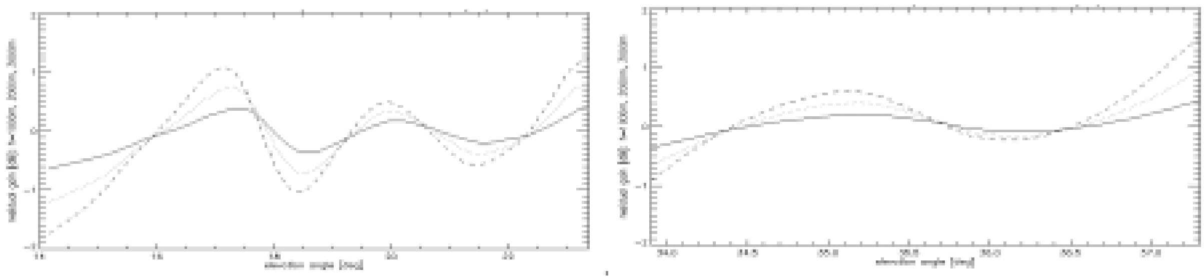
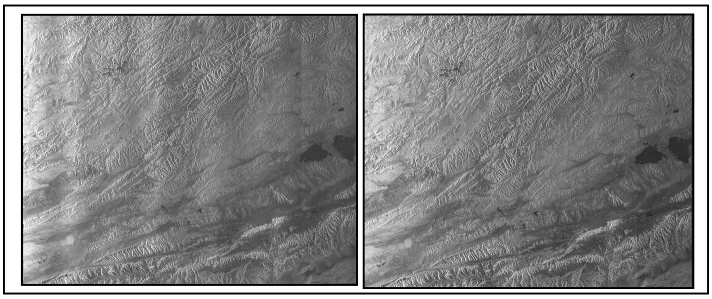


Fig.7. Radiometric error introduced during antenna pattern correction over SS1 (left) and SS5-IS6 (right) if the local terrain height is not accounted for. Three different terrain height values assumed: 1000 m (solid line), 2000 m (dotted line), 3000 m (dashed line).

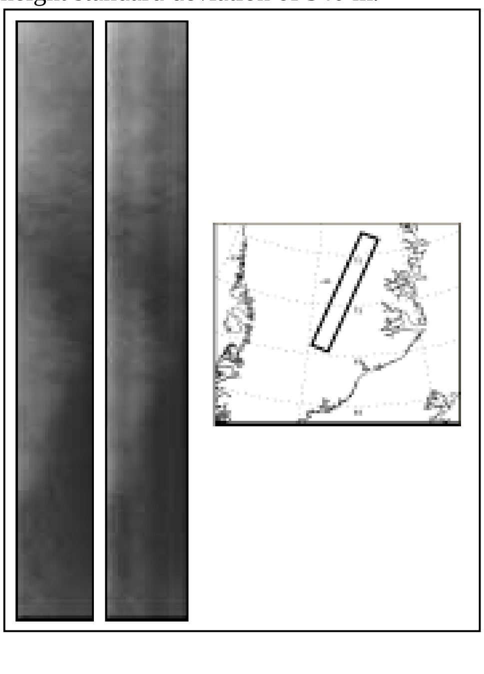
In order to avoid this residual antenna pattern correction, the local terrain height shall be taken into account during processing. The use of the average terrain height over the data segment will solve the problem over scene-type products (typically 16 seconds long) and over plateau areas. However, a residual radiometric modulation may remain over long products (up to 6000 Km in case of GM mode) and over areas with varying topography. As a first correction step, the use of a single average terrain height has been implemented in the ASAR processor (version 3.8, in operations since April 2004). The extension of this strategy to a complete solution, which will take into account the variation of topography along and across the data segment, is foreseen in the near future.

With the current implementation, in order to avoid the introduction of radiometric errors using a single terrain height value over a long data segment or over an area with dramatic terrain elevation changes, the standard deviation of the terrain height within the data segment is used as indicator of the height variations. The estimated average height is not accounted for in case the standard deviation exceeds a certain threshold, which is different for different product types. This strategy makes possible to ensure that the average terrain height will be used only when it prevents any residual radiometric error.

Figure 8 shows two examples of products processed with and without the use of the average terrain height. The first one is an Image Mode medium resolution (IMM) product over Greenland (800 Km x100 Km), for which the average terrain height is 2900 m and the height standard deviation is 240 m. The second one is an example of a Wide Swath mode (WSM) product (300 km x 400 km) over the Himalaya Mountains with average terrain height of 4700 m and the height standard deviation of 540 m.



Fig,8. Examples of ASAR products over high elevation areas, with and without using the average terrain height during the processing. Left: WSM products over the Himalaya Mountains. Right: IM medium resolution product over Greenland.



Another recent improvement ASAR products quality is the removal of a range location bias. A detailed analysis of the products absolute location error (ALE) evidenced a systematic range bias in all ASAR products of about 28 m (when processing with DORIS precise orbits). The range gate bias, available in the ASAR Instrument auxiliary file (ASA_INS_AX, available at:
http://earth.esa.int/services/auxiliary_data/asar/) was updated in December 2003 to compensate the observed range miss-location. ASAR products are operationally processed with the updated range gate bias since 13 December 2003 and the measured ALE in range is now less than one sample. More details on the ALE analysis and results can be found in [2].

NEW PRODUCT: THE WIDE SWATH COMPLEX

The unique ASAR Wide Swath mode level 1 products originally foreseen were ground range multi-look detected products. However, the possibility to perform interferometry between Image and Wide Swath mode and the interest in Wide Swath complex products for ocean applications motivated the implementation of a new wide swath single look complex (WSS) product in the ASAR processor. A prototype WSS processor was developed for ESA by Politecnico di Milano and Politecnico di Bari and prototype WSS products have been successfully used to demonstrate not only the potential of IM-WS interferometry but also the possibility to perform WS-WS interferometry. The adopted approach is the same as the prototype processor [3] and consists in processing each burst and beam individually and to provide them separately within the product. Data will be sampled in a common grid both in range and in azimuth and a Doppler Grid annotated data set will be included, which will provide information on the local fine Doppler Centroid estimates across the product

The new ESA WSS phase preserving product will be available to users before the end of 2004.

Although ASAR Wide Swath mode was not designed to keep burst synchronisation between different acquisitions, preliminary analysis shows that there might be a high percentage of cooperative WSM interferometric pairs (with partial/full burst synchronisation). Some of these pairs have been identified and processed. An example of a WS-WS interferogram is provided in figure 9 (Courtesy Politecnico di Milano).

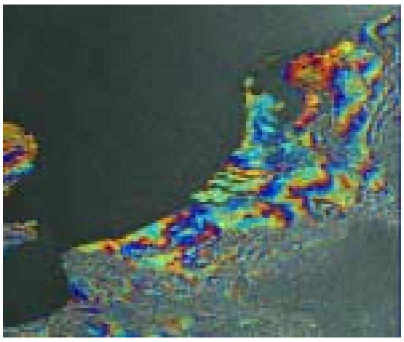


Fig. 9. WSM (01/12/2002)-WSM (05/01/2003) interferogram over The Netherlands (Normal baseline:400 m)

CONCLUSIONS

All ASAR modes are fully operational since late 2003 and results provided hereconfirm that product quality is well within the requirements. Radiometric errors over high terrain elevation areas have been partially corrected and the range location bias has been removed. A new WS complex product, which is expected to open the door to new applications, is being implemented and shall be available to users in few months time.

REFERENCES

[1] B. Rosich, M. Zink , R. Torres, J. Closa , C.Buck, “ASAR instrument performance and product status”, IGARSS’03 (Toulouse, France), 21-25 July 2003.
[2] D. Small, B. Rosich E. Meier, D. Nüesch, “Geometric Calibration and Validation of ASAR Imagery”, These proceedings.
[3] P. Guccione, “Phase preserving processing for ENVISAT Wide-Swath”, EUSAR 2004 (Ulm, Germany), May 25-27, 2004, pp 107-110.