Radar data processing, quality analysis and level-1b product generation for

AGRISAR and EAGLE campaigns

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INTRODUCTION

For the assessment of specific programmatic needs of the Sentinel program and for the understanding and quantification of bio-geophysical parameters of different vegetated surfaces ESA has initiated and partially funded two airborne campaigns in 2006, AGRISAR and EAGLE [1,2]. In both campaigns the airborne SAR system of DLR, E-SAR was employed to acquire multi-frequency and multi-polarisation data over the different test sites. For a detailed description of the E-SAR system, please refer to [3,4].
For the AGRISAR campaign 16 E-SAR flights have been conducted over Görmin test-site in the period from April-August 2006 to acquire representative data sets which cover the complete agricultural vegetation period of different crops [1]. For the EAGLE project two test-sites have been flown, Cabauw for specific investigations on agricultural areas and Speulderbos for forest parameter assessment [2].
The present paper describes the adopted methodology for processing the acquired E-SAR data and some of the results. First the SAR data sets acquired during AGRISAR and EAGLE campaigns are summarised. Then the standard E-SAR processing approach which leads to RGI (radar geometry images) and GTC (geocoded terrain corrected) products is described. Further discussion is included with respect to the mosaicked DEM which was generated for the AGRISAR test site from E-SAR single-pass SAR interferometry as well as to the obtained radiometric accuracy.
The generation of synthetic QUAD-POL products in C-band (performed for both AGRISAR and EAGLE projects) is described in a dedicated section. Another section is devoted to the generation of Sentinel-1 like data quality products from high resolution C-band data as is requested by the specific programmatic needs of ESA. The paper concludes with further remarks on data quality.

E-SAR DATA ACQUISITION AND PROCESSING METHODOLOGY

AGRISAR data acquisition

In total 16 radar flights have been executed in the period 18.04 to 02.08.2006 over the Görmin test site in northern Germany as indicated in the Fig. 1 below. Mission M01 was dedicated to DEM generation and is not listed.

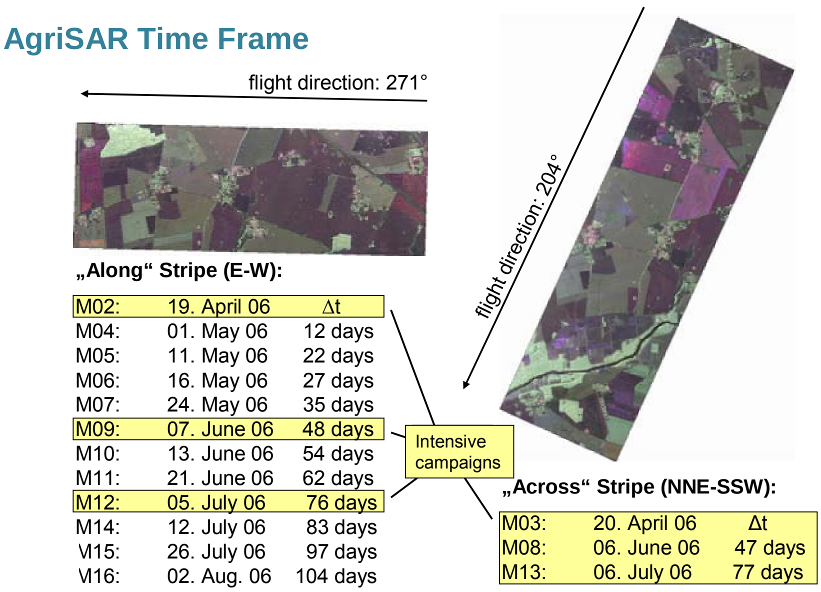

Fig 1: AGRISAR data acquisitions

The following modes (polarisation, no of passes) have been collected for the AGRISAR campaign:

Table 1: AGRISAR data acquisition

Frequency	Polarisation	Passes	Remarks
X-band DEM	VV	6 parallel + 1 tilted	1.7m (single pass baseline)
X-band	HH / VV	15 * 2	Coregistered
C-band	Dual/Quad	15 * 2	Coregistered
L-band	Quad	15	Coregistered

The X-band DEM has been acquired only once at the beginning of the campaign, covering an area of 10 by 14 km. X, C- and L-band data were recorded at intervals of 1-2 weeks for a east-west strip and three times also for a tilted strip. In X- and C-band two passes were foreseen during each E-SAR flight to acquire all possible polarimetric combinations.
In order to secure high quality E-SAR data, recording of good quality kinematic phase differential GPS measurements was necessary. Therefore a GPS monitoring station has been installed at the airport. Static DGPS surveying using data of a permanent GPS station at a range of less than 50 km has been performed to determine its geographical position with a relative accuracy of less than 5 cm. Six corner reflectors have been set up in the test site for digital terrain elevation generation over the whole Görmin site. From the six, four have been kept fixed on the test site during the whole data acquisition period.

EAGLE data acquisition

The data acquisition for the EAGLE campaign was performed only once on 15-th of June, 2006 for both test sites Cabauw and Speulderbos. Compared to Table 1, X-band acquisition was restricted to VV polarization for the generation of DEMs for geocoding purposes. Also here precision GPS measurements were ensured by a GPS monitoring station installed at the airport. For geometric and radiometric reference purposes a trihedral reflector was deployed within each test-site by a team from ITC. For better data handling purposes, the data of Speulderbos test site were segmented into two parts and processed separately, as the scene length was longer than 15 km.

E-SAR processing methodology

The adopted processing procedure for the E-SAR data is displayed in Fig. 2. Accordingly, the SAR raw signals are recorded on tape during the acquisition flight. At DLR facilities the tape is transcribed on a hard disk and first image surveys are produced. The data are then processed to high resolution radar geometry images (RGI), where as an input navigation data are used for motion compensation. Tiepoints (corner reflectors) are used to evaluate the radiometric performance. The RGI outputs are radar data in slant range and ground range geometry. In addition also system and processing related information files are generated that are useful for further information extraction. The RGI are stored in a DLR archive (Data Information and Management System - DIMS). For geocoded and terrain corrected data (GTC) an elevation model is introduced in a further processing step. The digital elevation model is derived from the single pass X-band data acquisition. The GTC products are also stored in DIMS and are available through a web-interface for all AGRISAR partners. All 16+1 flights of AGRISAR and EAGLE campaigns were stored in DIMS with a total amount of around 30 GByte of RGI and 15 GByte of GTC data. Via the EOWEB interface, registered users can access the data via ordering and subsequent ftp pickup [5].

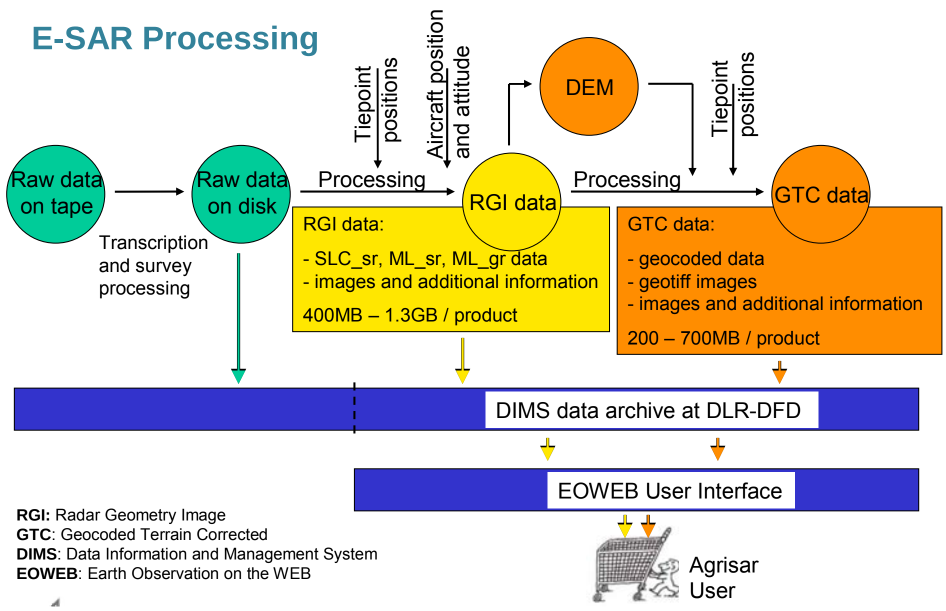

Fig 2: E-SAR processing chain

The E-SAR data specification for the RGI products is summarized in Table 2 for the different frequencies. Accordingly, the X-, C- and L-band frequencies have a slant range resolution of 2 m for the single look complex data (SLC) and for the multilook data. The azimuth resolution is 0.9-1 m for the SLC data and up to 4.5 m for the multilook data. Geocoding has been performed onto a 2x2 m grid in WGS-84 UTM projection, zone 33. The values for the EAGLE data are put in parenthesis.

Table 2: E-SAR processing parameters

Resolution	**SLC image**		**Multilook image**		
	slant range	azimuth	No. of looks	slant range	azimuth
X-band	2m	0.89m (0.59m)	8 (16)	2m	4m (5m)
C-band	2m	0.89m (1.2m)	8 (4)	2m	4m (3m)
L-band	2m	1.0m (1.2m)	8 (4)	2m	4.5m (3m)
Posting	2m x 2m				
UTM zone	33 (31)				

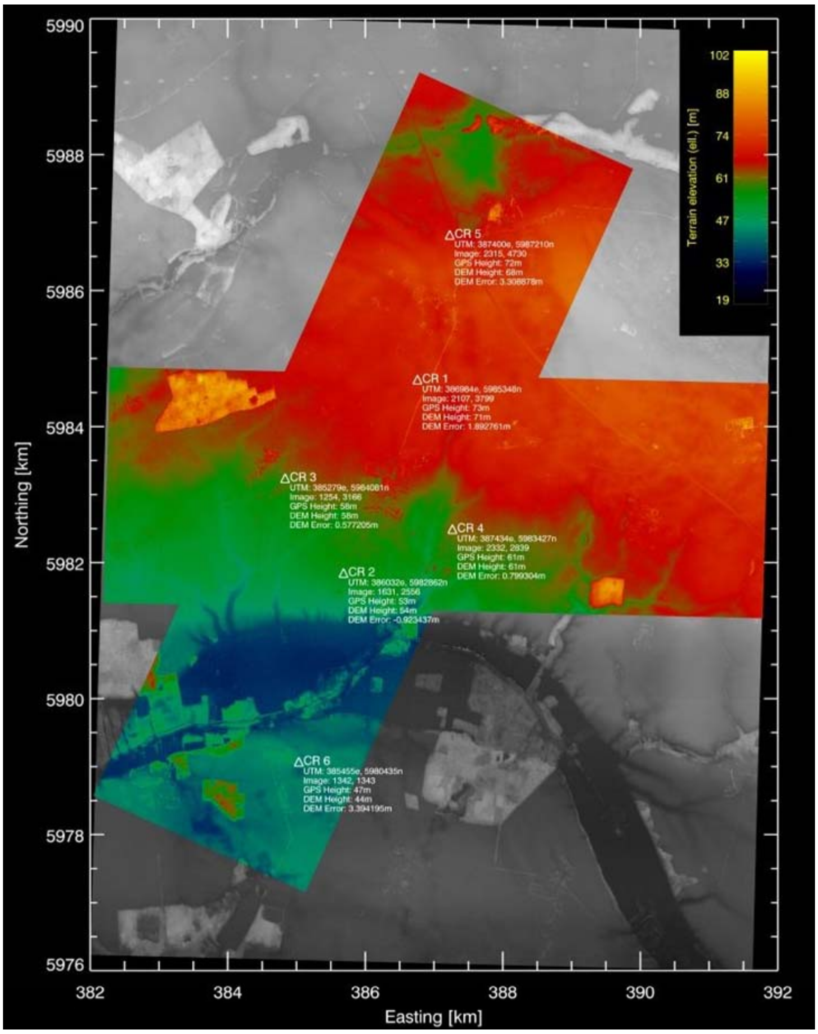

Fig. 3: Digital elevation model from X-band single pass SAR interferometry for the AGRISAR test site (mosaic of the 7 passes in gray levels; test site areas for multi-temporal acquisition in colours).

DEM generation for AGRISAR

The digital elevation model for AGRISAR test sites was derived from X-band single pass SAR interferometry of the data acquired during mission 01 on the 18-th of April, 2006. In total 5 overlapping East-West flight strips and 1 NE-SW strip were flown for the complete coverage. In Fig. 3 the elevation model is displayed with area coverage of 10 km by 14 km. The positions, size and orientation of the main AGRISAR strips, which were successively mapped by the different sensors are indicated in color. The acquired across track strip has a high squint (> 10 degree) and strong track variation (+/- 10 m), but nevertheless could be used for referencing the other 6 parallel strips. The terrain height is ranging from 19 m to 102 m. For the position of the different corner reflectors the height error has been measured. Corner reflectors 1 to 4 are used for processing (tiepointing) and 5 to 6 just for control. The height errors of the first four corner reflectors are less than 1 m with the exception of corner 1 which shows a deviation of 1.9 m. The corners 5 and 6 have higher height errors in the order of 3m (possibly induced by the highly disturbed across-track strip). Some uncertainty in the evaluation is also attributed to the fact, that the position of the CR phase center for CR1-4 is located about 1.0m-1.2m above the ground, which means that the DEM value at these positions could be biased.

DEMs were computed also for the two test sites of the EAGLE campaign, however no quality assessment could be performed. Each site was equipped with only one CR, which was used as tiepoint. Note that the resolution and number of looks trade-off for EAGLE X-band data was adjusted to DEM generation rather than keeping it comparable to C- and L-band (see Table 2).

Radiometric Performance Assessment

One important criterion for data quality is the measure of radiometric accuracy by the investigation of the radar cross section (RCS) of the deployed corner reflectors. In Fig. 4 the RCS values are shown for all X-, C-, and L-band data takes exemplarily for the VV polarisation. Except for L-band is the accuracy in all cases within the +/-2dB margin, in C-band even better. In L-band some of the CR signatures are outside the +/-< 2dB margin. We have evaluated these cases in more detail and found the following explanations:

- We attribute the cases of CR RCS higher than the theoretical limit + 2dB margin (red circle) to areas of strong background scattering (near range CR). At the time when the CR were deployed the fields were bare, but during the growing season the crops evolved leading to higher backscatter. After harvesting the estimation of RCS was again reliable.
- For the cases of RCS lower than the theoretical limit -2dB we found significant squint angles for the particular data takes. This means that there is a mis-orientation of the CR with respect to the radar line of sight, which leads to lower estimates for the RCS.

Therefore, although the RCS of the CR in L-band does not seem reliable in some cases, we have a certain confidence that the data themselves are not biased.

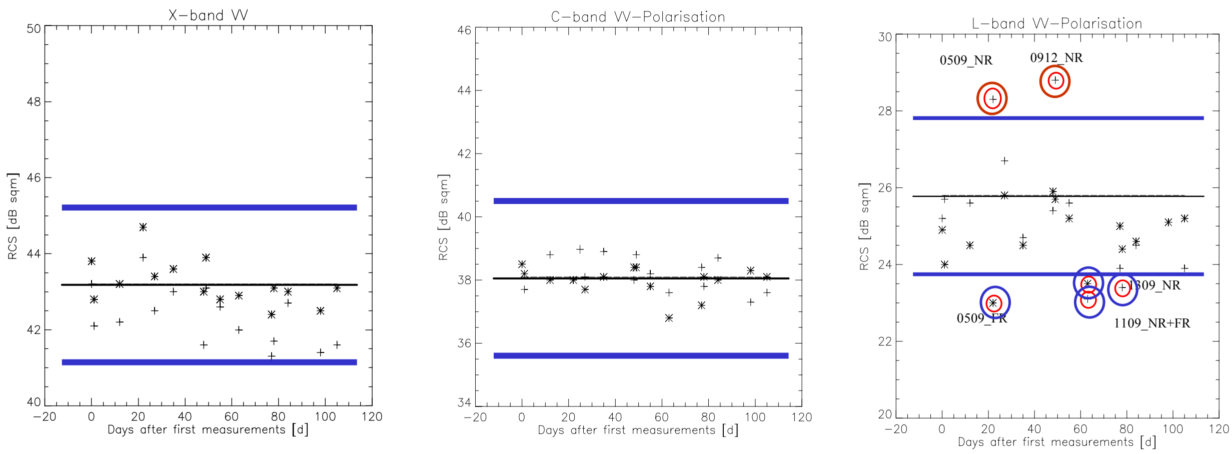

Fig. 4: Radar Cross Section (RCS) of corner reflectors during AGRISAR campaign.

C-BAND SYNTHETIC QUAD-POL DATA

For the AGRISAR campaign DLR-HR has generated for the first time synthetic quad-pol products in C-band. Two data sets with nominal zero baseline, one VH-VV and one HV-HH, are processed as a repeat-pass interferometric pair, including residual motion compensation (see Fig. 5). The phase of the HV-VH interferogram is used to eliminate the possible presence of an interferometric phase and CR are used to calibrate the co-polar phase between HH and VV.

The reference track data of the slave are adapted to those of the master in order to suggest data acquisition from a common flight. However, the real tracks keep the information of the individual flights, which could be used e.g. to estimate volume decorrelation. Finally the data are geocoded as quad-pol product. Synthetic quad-pol products were generated for the intensive AGRISAR campaign dates (19-th of April, 7-th of June, 5-th of July, 2006) as well as for the EAGLE test sites. A zoom of a synthesized quad-pol image from AGRISAR test site is given in the Fig. 6 below, corresponding to the red rectangle in Fig. 5.

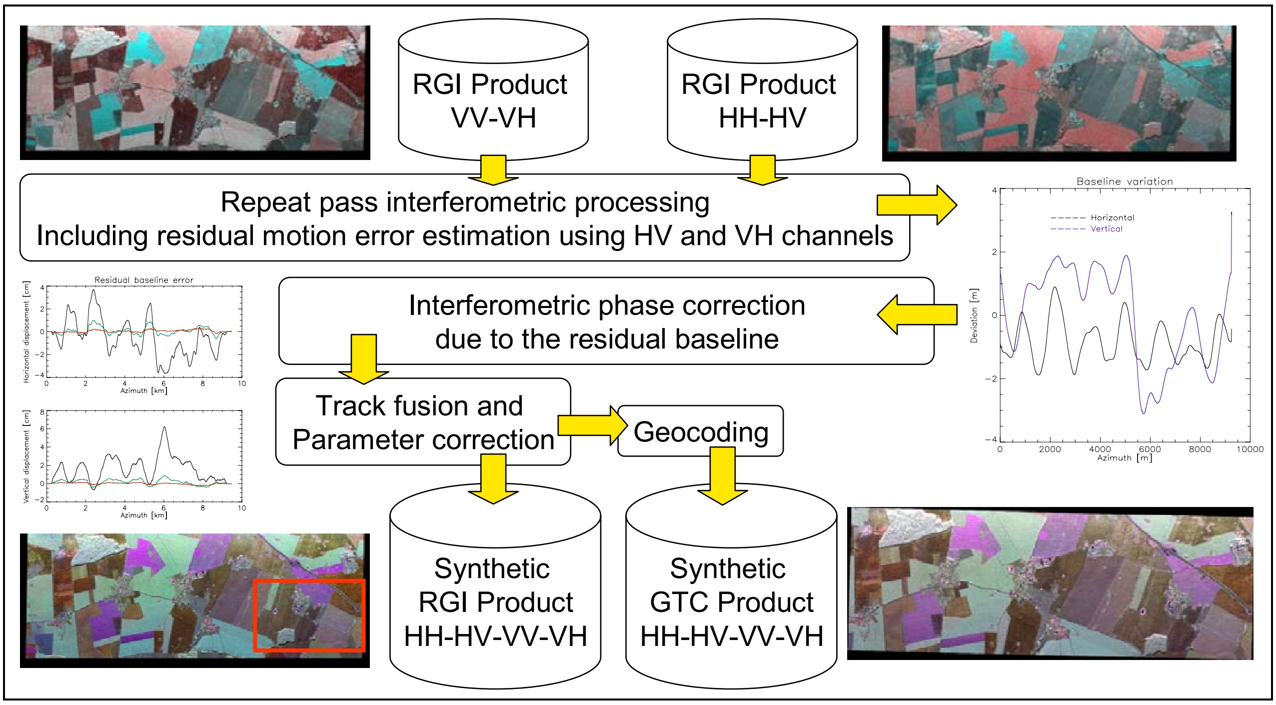

Fig. 5: Generation of synthetic quad-pol products from pairs of C-band dual-pol data sets.

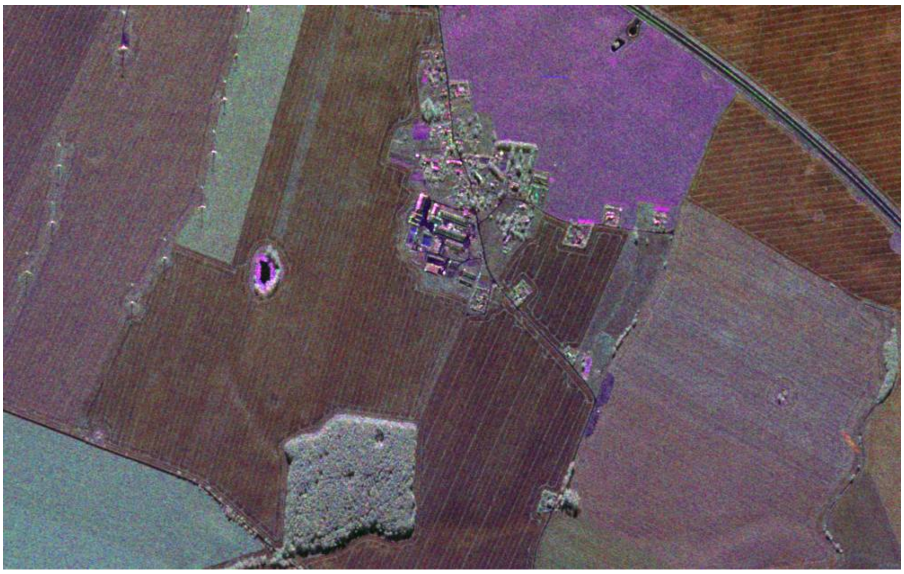

Fig. 6: Synthetic C-band fully polarimetric image from AGRISAR test site (zoom from a red marked rectangle)

Note that the polarimetry information in the synthesized quad-pol C-band data might be affected by temporal decorrelation, as there is usually a time separation of about 15 minutes between the two dual-polarized data sets used as input. A illustrative example is the Cabauw data set from EAGLE campaign, where moving targets (ships) appear either yellow or blue, depending in which of the two data sets they were present (see Fig. 7). Velocity components in line-of-sight are responsible for the displacement from their natural position and defocusing is due to along-track velocity components.

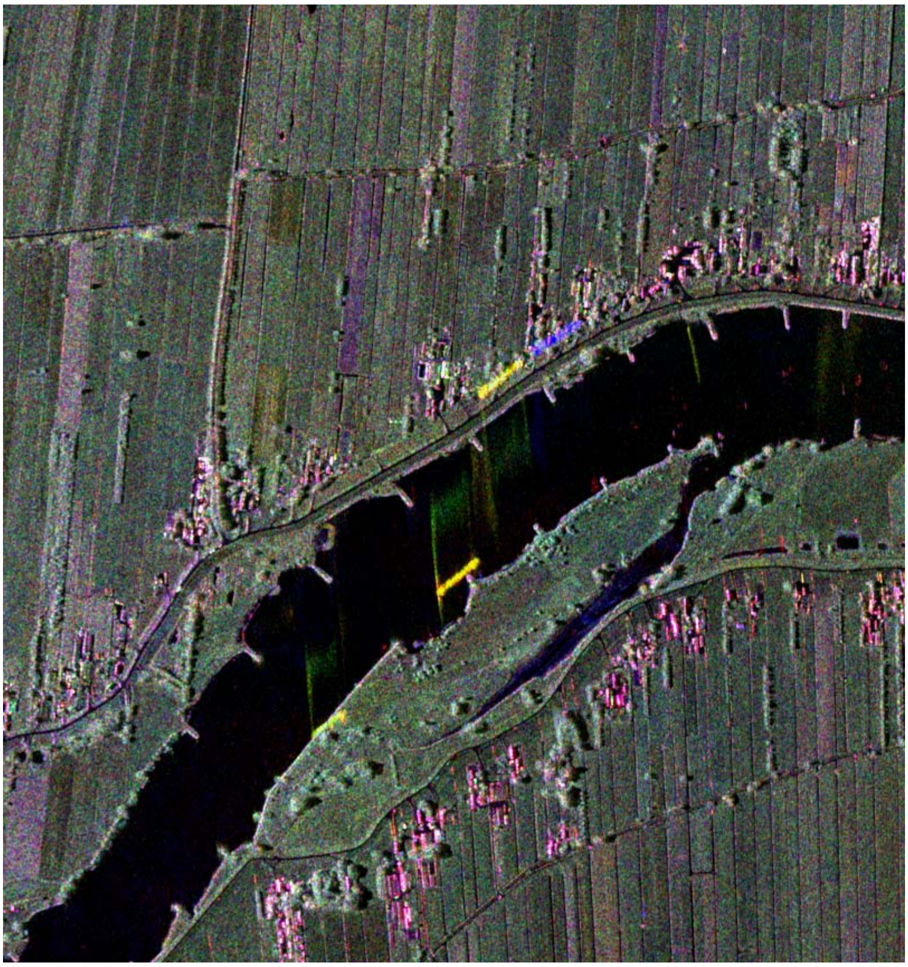

Fig. 7: C-band synthetic quad-pol product; part of Cabauw test site (EAGLE campaign).
Color coding is RGB: HH-HV-VV

Another source of uncertainty is the possible presence of a large baseline. Although the two input data sets were acquired with nominal zero meter baseline, motion errors might induce real baselines of up to several meters. This information can be retrieved from the real track information, which is part of the product. Note that, besides coherence drop (volume decorrelation) also a phase shift between the HH and VV polarizations can occur in the presence of high vegetation. An indication of the expected phase shift can be obtained via the interferometric sensitivity information [6]:

$$\Delta\varphi_{if} = \frac{4\pi B \sin\left(\theta + \xi\right)}{r\lambda \sin\left(\theta\right)} \Delta h_{veg} ,$$

where B is the real baseline, ξ the baseline tilt from horizontal, r the range to the target, λ the wavelength and Δh_{veg} the vegetation height. For a vegetation height of 2m and a real horizontal baseline of 5m between the two input acquisitions and a range of 4500m the uncorrected interferometric phase shift between polarizations will be in between 20 deg (far range) and 80 deg (near range) . This may be acceptable in a worst case, however for a forest height of 20 m the phase error will definitively be too large, preventing reliable polarimetric evaluations.

The HV-VH coherence is able to provide reliability information, as its decrease is an indication of either temporal or volume decorrelation.

SENTINEL-1 SIMULATION

Sentinel-1 is the next generation SAR satellite presently being built under contract of ESA. For the support of product development for these future data, Sentinel-1 simulation has been performed for some of the C-band data sets of the AGRISAR campaign (ID's 0909 and 0910 acquired June 7 2006 and ID's 1207 and 1208 acquired on July 5, 2006) as well as for the Cabauw test site of EAGLE. Different modes of Sentinel-1 have been simulated, the interferometric wide swath mode (IWS) and the stripmap mode. The parameters which were used for the simulation are summarized in Table 3.

Table 3: SAR parameters used for Sentinel-1 simulation.

Sentinel-1 simulation	**Interferometric Wide Swath(**)**		**Stripmap**	
	slant range(*)	Azimuth	slant range(*)	Azimuth
Resolution (SLC)	2.1 m	20 m	1.7 m	5 m
PSLR	25 dB (with spectral weighting function)			
NESZ	-22 dB (insertion of additional noise as function of off-nadir)			
DTAR	-22 dB (modification of presumming filter)			

(*)The selected slant-range resolution corresponds to a ground range resolution of 5m at 25 deg for the IWS mode and 5m at 20 deg for the stripmap mode.

The comparison of high resolution E-SAR and simulated Sentinel-1 data in IWS and stripmap mode is shown in Fig. 7. Note, that the visual appearance of the stripmap simulation is close to the high resolution E-SAR data, whereas for the IWS simulation details of buildup areas cannot be discriminated any more. However, the information on the extended agricultural fields is well maintained.

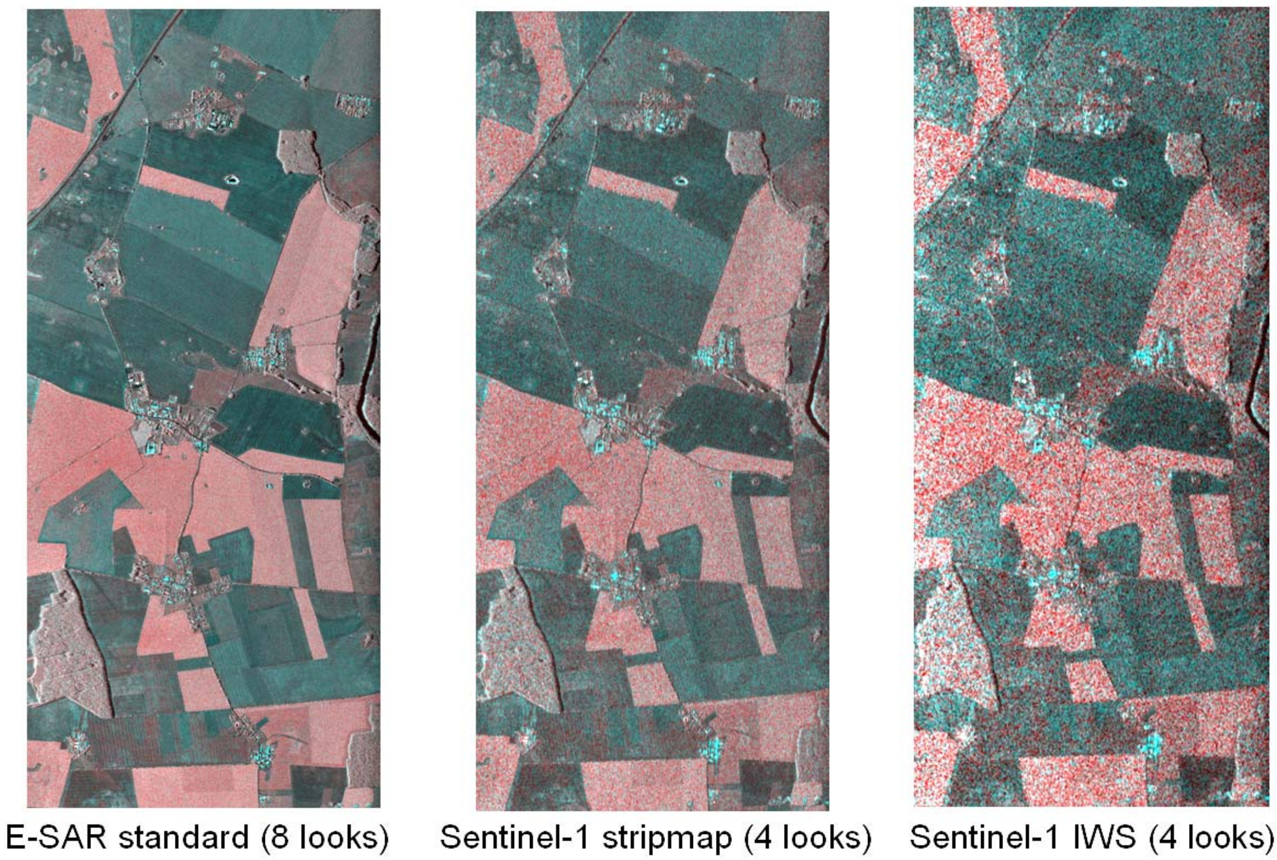

Fig. 8: Comparison of high resolution E-SAR data with Sentinel-1 simulation in stripmap and IWS mode. Color coding is RGB: HV-HH-HH

CONCLUSIONS

In the frame of AGRISAR and EAGLE campaigns a huge amount of high resolution SAR data has been acquired, processed and made available to the individual project teams. The data are generally of high quality. In particular no loss of data has occurred. Also the quality of aircraft navigation and radar system settings was close to optimum, which ensures comparable data sets between the individual flight missions and precise and consistent geometry. Geocoding of all frequency bands onto a common geo-referenced grid allows the integration with ground measurement data and/or data of other sensors deployed during the campaigns. A small drawback is the presence of radio frequency interferences (RFI) in some of the L-band data takes (particularly in the cross-polarized channels), which could not be properly removed due to their wide-band characteristic.
Finally, the generation of quad-pol products in C-band (which maintain to a great extend the phase between polarizations) could be demonstrated for the first time in the frame of these two campaigns and the simulation of Sentinel-1 products is clearly a valuable input for product development for the upcoming generation of space-borne C-band satellites.

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