Recent Developments and Applications of Multi-Pass Airborne Interferometric SAR using the E-SAR System

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Abstract

Airborne SAR systems are traditionally considered to be a suitable testbed for the demonstration of new Earth observation data acquisition techniques and for the development of new applications based on the acquired multi parameter data sets. Spaceborne SAR system concepts and mission design is based on the experience gathered from these airborne SAR experiments and from dedicated campaigns. DLR's E-SAR system is supporting these activities since the late 1980-ties by providing high resolution multi-frequency and multi-polarisation data sets to a large user community. Triggered by the scientific needs and also by the recent advancements in motion compensation techniques several new operating modes are now available for the E-SAR system on a quasi-operational basis. This paper gives an overview of these techniques and presents novel application examples.

1 Introduction

During the last decade airborne repeat-pass SAR interferometry has become the most demanded technique for the development of new application products (e.g. model based forest heights derived from polarimetric SAR interferometry). Other techniques like differential SAR interferometry and SAR tomography are also based on multi-pass SAR acquisitions providing direct measurements of the quantities of interest, i.e. surface displacement or forest structure. With the improvement of motion compensation, especially by taking into account the topography and estimation of residual motion errors, the generation of data products from repeat-pass airborne interferometry is now quasi-operational. The paper first provides an overview of the E-SAR system, which was used for extensive campaigns during the past 10 years. Then the most important achievements in motion compensation are reviewed and the present processing approach for repeat-pass interferometry is described. Finally, several application specific approaches to the evaluation of airborne multi-pass data are presented.

2 DLR's E-SAR system

Since it acquired the first images in 1988, the E-SAR system has been continously improved and extended towards a multi-frequency (X-, C-, L- and P-band) and multi-polarimetric and interferometric SAR system. Detailed parameters can be found in [1].

The navigation system is a key element of the airborne SAR system. The last upgrade consists in the integration of a real-time D-GPS/INS system (IGI CCN24/Aerocontrol IId) combined with a FUGRO OmniStar 3000L D-GPS receiver, allowing most precise navigation and positioning. E-SAR is hence able to perform repeat-pass SAR interferometry at baselines of less than 10m, allowing the realization of advanced and innovative techniques like Pol-InSAR (see section 4.1), SAR tomography (see section 4.2) and differential SAR interferometry (DInSAR) (see section 4.3).

A new P-band subsystem was built, including antenna, IF converter and front-end sections. The center frequency was shifted to 350MHz to avoid excessive radio frequency interference. It was primarily used within the INDREX-II and BIOSAR campaigns in support for the BIOMASS mission presently under consideration as one of the six Earth Explorer Core Missions being investigated by ESA. In support of the Sentinel-1 C-band programm, important campaigns were carried out serving for agricultural parameter retrieval (AGRISAR, 2006) and for ice studies (ICESAR, 2007).

3 Multi-pass interferometric processing

The processing of airborne interferometric SAR data is a key issue to generate products with accurate phase information, especially for the purpose of combining data acquired on multiple passes. In recent years several algorithms have been developed. These activities were focused on the needs imposed by the Pol-InSAR and tomographic imaging modes, as well as by differential airborne SAR interferometry. In the following sections some of the most important developments are described.

3.1 Topography consideration for motion compensation

The consideration of the topography for motion compensation is mandatory for multi-pass interferometric SAR processing, in which case the deviations from the reference track are uncorrelated for the individual acquisitions. Several efficient approaches based on short FFT's were developed during recent years and a comparison is presented in [2]. For E-SAR processing the Subaperture-Topography-Adaptive (SATA) and the Precise-Topography and Aperture dependent (PTA) approaches are used and integrated into the SAR processing.

3.2 Residual motion errors

The multi-squint approach has proven to be a reliable method for the estimation residual motion errors in case of low scene decorrelation. An example of relative residual errors is shown in Fig. 1. Details on the approach are in [2]. Residual motion errors can also be estimated independently for each data set using the recently proposed Weighted Phase Curvature Autofocus algorithm (WPCA) [3]. This approach estimates residual errors independently for each image, which is advantageous for highly decorrelated interferometric pairs.

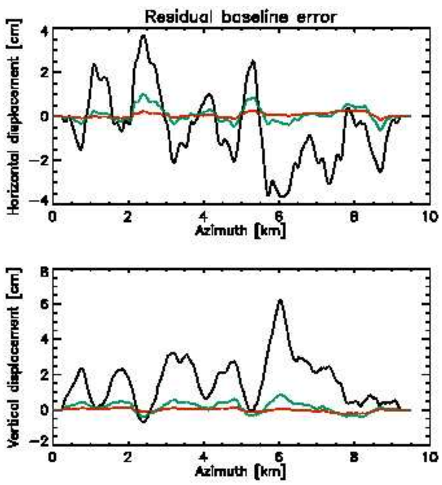

Figure 1: Relative residual platform motion estimated by the multi-squint approach.

The most used processing chain for E-SAR data in multi-pass mode is shown in Figure 2. It incorporates the SATA or PTA algorithm for consideration of topography during motion compensation and multi-squint for residual motion errors.

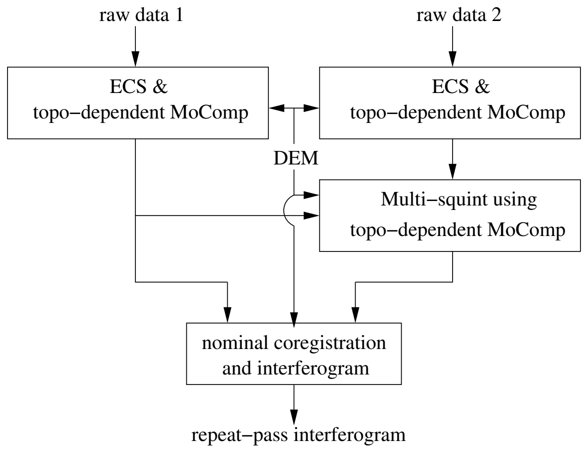

Figure 2: Interferometric processing of E-SAR data.

3.3 C-band quad-pol data synthesis

Due to limitations in antenna design and data rate the C-band E-SAR system can only be operated in dual-polarized mode. However, by means of a repeat-pass acquisition (HV-HH and VH-VV), it is possible to generate fully-polarimetric images. Data processed by the above processing chain are used to estimate and compensate the residual interferometric phase between the HV and VH polarisations, which originates from a non-zero baseline between two acquisitions. Fig. 3 shows a fully polarimetric E-SAR image obtained from such two dual-polarized data takes at C-band. For agricultural applications this approach leads to good results for areas not being affected by the temporal decorrelation between passes (wind, moving targets). Special consideration deserve forest heights of 10-30 m where the phase error due to the small but not negligible baseline between the passes, together with potentially different phase centers, prevents 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.

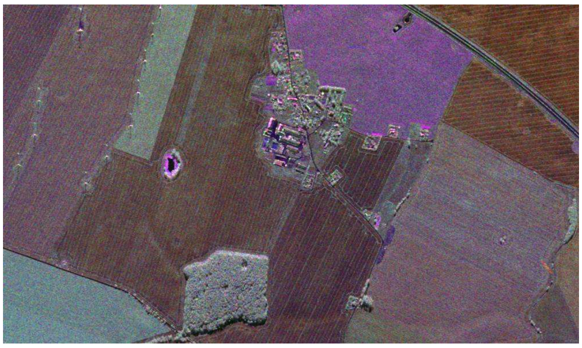

Figure 3: Synthetic quad-pol image in C-band acquired during AGRSAR campaign (RGB=HH-HV-VV).

4 Multi-Pass SAR application examples

4.1 Pol-InSAR

Polarimetric SAR interferometry is an established technique developed at DLR and was successfully demonstrated by the E-SAR system at different frequencies for different applications. Through it ability to separate different scattering mechanisms and locate their position in height it provides sensitivity to the vertical distribution of scattering mechanisms. Hence, it becomes possible to investigate the 3D structure of volume scatterers and to extract information about the underlying scattering processes using only a single frequency polarimetric radar sensor. In the following subsets of examples are given from the different application areas, where airborne campaigns in repeat-pass Pol-InSAR mode were performed.

4.1.1 Forest Heights

Repeat-pass Pol-InSAR in combination with a two layer forest model is the main tool for forest height estimation [4]. Forest height estimation from the Pol-InSAR technique was successfully demonstrated within an accuracy of 10-20%, when compared to Lidar or ground measurements. This result is obtained over various forest types ranging from boreal, temperate, mediterranean and tropical forest and is the most matured Pol-InSAR application for bio-/geophysical parameter estimation.

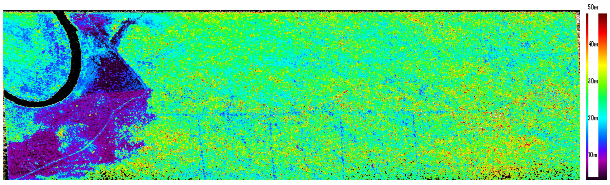

Figure 4: Forest height map derived from L-band E-SAR data acquired durinf INDREX-II. Test site Mawas in Indonesia (2004).

4.1.2 Agricultural Parameters

The first approximation for agriculture parameter estimation was done in using the two layer forest model and to adapt it to the much shorter crop vegetation, even being aware of the considerable difference in structure compared to forest volumes, which changes from a random to an oriented distribution of particles. The main problem is that the parameter space is increasing. However, the main interest is the estimation of the differential extinction, which is closely related to the water content of the crop and therefore it provides information about the vitality of a plant. Current research is performed with data acquired in the frame of the AGRISAR campaign conducted for ESA in 2006.

4.1.3 Volumetric Ice Modelling

Recently, research was concentrated to ice volumes that can be potentially also described by Pol-InSAR with a strong surface component on top of an infinity volume layer. The main research is focused on the description of the volume structure and their changes. Hence, the extinction into the volume layer is an important parameter that needs to be understood and is changing with depth. Data acquired by the E-SAR sensor during two campaigns on Svalbard in 2005 (SVALEX) and 2007 (ICESAR) serve for this research.

4.1.4 Urban areas

Even though that urban areas are characterised by deterministic scatterers Pol-InSAR provides some insight into the location of the deterministic scatterers. The main research is focused on the detection and identification of coherent scatterers, already successfully demonstrated with airborne (E-SAR) and spaceborne (TerraSAR-X) sensors [5].

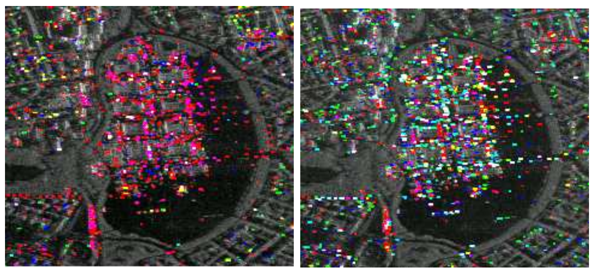

Figure 5: Coherent scatters detected in E-SAR data on Theresienwiese, Munich, at different polarisations (left) and different frequencies (right)

4.2 SAR tomography

SAR tomography uses a second aperture (by means off additional surveys) in perpendicular direction to the along-track synthetic aperture, resolving in this way targets with different heights inside a resolution cell. Recently additional tomographic data takes have been acquired in Germany, Switzerland and Sweden. A tomographic profile of a container hidden inside the forest is shown in Figure 6. It was generated via Capon methods from HH polarised L-band data. Tree crown contributions can easily be distinguished for the forested areas. In contrast the strong trunc-ground dihedral reflection is very weak, as the container is placed on a road parallel to the flight track. More details are available in [6].

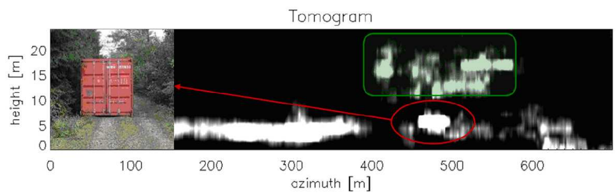

Figure 6: Tomogram computed from 21 L-band tracks (HH polarisation).

4.3 Differential SAR interferometry

First airborne differential SAR interferometric measurements with the E-SAR system have been demonstrated recently for a time series acquired in L-band [7]. Here we show an example for the retrieval of a glacier displacement field. L-band data were acquired over the Aletsch glacier on two successive days in autumn 2003. A modified multi-squint approach was applied to separate glacier movement from residual motion errors. In a next step the along-track displacement were estimeted via a c o-registration approach and the across-track displacement with differential interferometric combination. Fig. 7 depicts the obtained 2D glacier field.

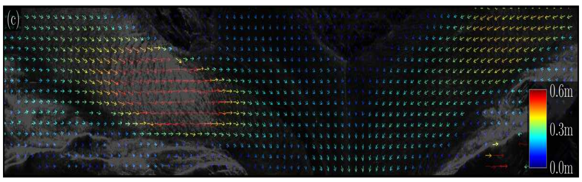

Figure 7: One day displacement field of Aletsch glacier.

Airborne differential SAR interferometry is a promising alternative for small scale applications where requirements do not comply with satellite orbit cycle or orientation.

5 Conclusion

In this paper a summary of the E-SAR system and its data processing and evaluation potential with respect to multi-pass data has been provided. It is essential to conclude that without the most recent advancements in residual and topography dependent motion compensation, new application areas like airborne differential SAR interferometry and SAR tomography will not have evolved. Moreover, these methods will also be applicable to the new airborne SAR system of DLR, F-SAR. Due to its flexibility and its large application space, multi-pass interferometric acquisitions will keep on being highly demanded.

6 Acknowledgment

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