FIRST RESULTS OF TANDEM-X ALONG-TRACK INTERFEROMETRY

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ABSTRACT

The interferometric imaging modes of the TanDEM-X (TerraSAR-X add-on for Digital Elevation Measurements) satellite formation offer improved along-track interferometric capabilities e.g. through longer and multiple baselines. While the first provide high sensitivities to ground motions, the latter enable to resolve ambiguities. The extraction of motion information from TanDEM-X data by means of ATI is challenging due to the hybrid nature of the interferometric baseline. This is generally composed of an across-track (XTI) and an along-track interferometric (ATI) component B_{ATI} and requires a separation of the respective interferometric phase contributions.

Index Terms— TanDEM-X, Along-track Interferometry, traffic measurement, surface current estimation

1. INTRODUCTION

SAR along-track interferometry permits the detection and measurement of motions of ground objects for large areas and independent of weather conditions [1]. It has a variety of land as well as marine applications. Satellite SAR ATI has been demonstrated initially with the Shuttle Radar Topography Mission (SRTM) [2]-[4]. The first long-term operating SAR ATI system in space became available with the German TerraSAR-X satellite in 2007 [5]. It realizes multiple along-track phase centres by aperture switching (AS) or by splitting the SAR antenna in two halves (dual-receive antenna or DRA mode) on receiving [6]. TerraSAR-X ATI was successfully shown for traffic measurement, surface current estimation and ship detection [7][8].

ATI with single-satellite SAR has several drawbacks, which limit its performance in some applications. As the SAR antenna has a relatively small size, the achievable separation of the receive phase centers, i.e. the effective ATI baseline is very short (1 m for the TerraSAR-X AS mode). The resulting low sensitivity of the ATI phase to ground motion makes it difficult to detect slowly moving objects or to extract surface current estimates at high spatial resolution (since the low motion-induced ATI phase requires averaging). Furthermore, the TerraSAR-X aperture switching mode reduces the effective PRF of the receiving channels. A high PRF is desirable for ground moving target indication (GMTI) as it increases the clutter-free region in the received Doppler spectra. On the other hand, the more advanced DRA mode is only available during short experimental campaigns.

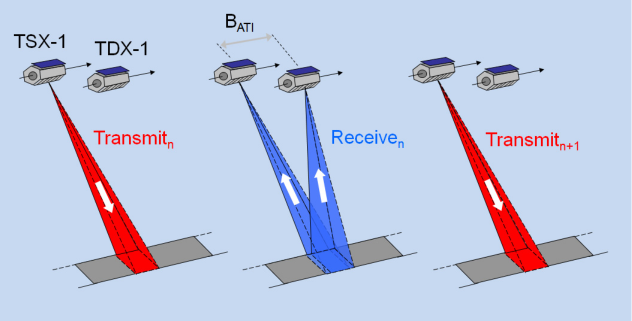

Fig. 1: Bi-static data acquisition with TanDEM-X. While the active satellite (Red) is illuminating the scene, both SAR sensors are recording the echoes (Blue).

With the start of the TanDEM-X mission in 2010, TerraSAR-X was provided an almost equally built sister satellite in order to fly in a close formation [9]. Its primary goal is the acquisition of a high-precision digital elevation model (DEM) by means of across-track interferometry. The two satellites of the formation, TSX-1 and TDX-1, are flown on a helix orbit which allows for safe and flexible adjustment of the XTI/ATI baselines. This way, sensitivities to elevation changes as well as to ground motions can be chosen in a wide range.

In this work we are interested in the extraction of motion information from TanDEM-X data in different contexts of application. We have analyzed data acquired in the bi-static interferometric mode (Fig. 1) for that purpose. In general, XTI and ATI baselines, both varying over time, are present during data acquisition. Consequently, the bi-static interferogram contains topography- and motion-induced phase parts. The XTI phase must be compensated in order to enable motion detection and estimation.

2. METHODOLOGY

Few approaches have been proposed so far for separation of the XTI/ATI phase of SAR sensors with a hybrid baseline.

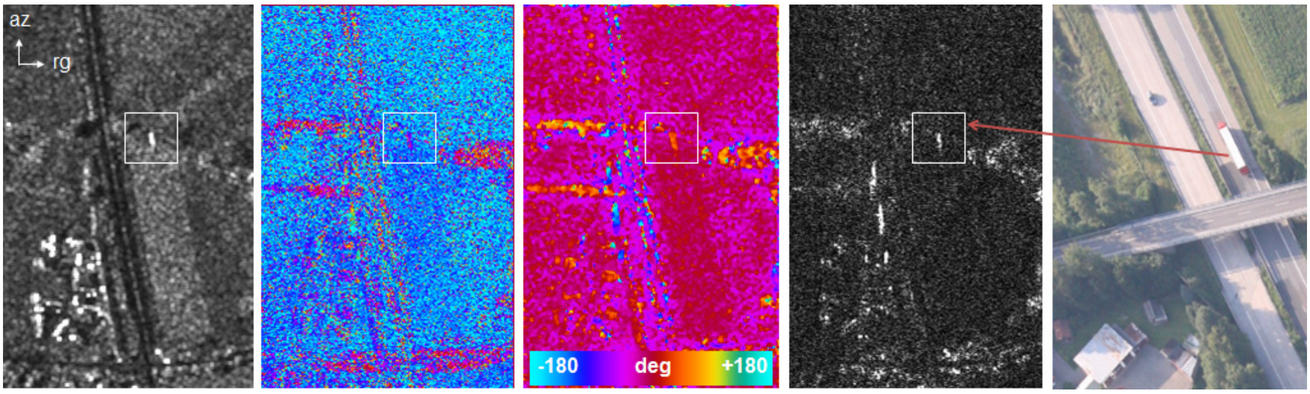

Fig. 2: A truck moving on a motorway is shown in the SAR amplitude, the hybrid interferometric phase, the extracted motion phase, the DPCA image and in an air borne optical reference image (left to right).

A straight forward solution seems to be the simulation of an XTI phase from a sufficiently precise digital elevation model (DEM) and to subtract it from the interferogram phase [10]. This required the DEM to represent the fine topographic details that the TanDEM-X interferogram exhibits or the data to be acquired with a sufficiently small XTI baseline. The approach of [11], which utilizes several interferometric acquisitions within a short time interval, is only feasible for airborne sensors and objects that change their motion characteristic very slowly.

We favour an approach in which, after removal of the flat earth phase contribution, phase alterations through moving objects are detected in the interferogram itself. The basic method was described first in [4] for SRTM data, later refined in [12]. It uses the fact that small moving objects cause spatially limited, often point-like phase alterations in the interferogram. For flat terrain, the XTI phase can be assumed to vary only very little on the other hand.

A phase map that deviates from zero where a moving object is present but vanishes at other locations can be obtained by a sliding window operation. It is carried out, by estimating the average window interferogram phase $\hat{\phi}_{XTI}$ and subtracting it from the window center point, which is excluded from estimation (since it is considered as a potential moving target pixel). The window size must be large compared to the dimensions of the moving objects, otherwise their motion phase is compensated. The estimated phase component $\hat{\phi}_{motion}$ does not represent an ATI phase yet. As a moving target appears azimuthally displaced by $\Delta az = -R \cdot v_{LOS}/v_s$ after focussing (R, v_{LOS} and v_s being the slant range, the line-of-sight target velocity and the sensor velocity), the influence of its ATI phase and of the XTI phase of the respective clutter pixel are determined by the signal-to-clutter ratio (SCR). However, the extracted motion phase can be used already for moving target detection. Moreover, the estimated phase $\hat{\phi}_{XTI}$, which does not contain alterations through moving objects, can be used to treat the single-look complex (SLC) data such that clutter suppression via DPCA becomes possible. This is done by compensating the phase of the master SLC $\underline{S}_1$ for both the flat earth phase and $\hat{\phi}_{XTI}$ before subtracting the slave SLC $\underline{S}_2$ from it. As DPCA is very susceptible to noise, the quality of the clutter suppression depends on the coherence. Severe decorrelation can e.g. occur over forest and water areas.

A different approach must be used to extract the motion information for large, distributed scatterers. Ocean surfaces can be regarded as flat to a first approximation after removal of the flat earth phase. Provided that the XTI baseline is small and that elevation changes through waves are negligible, the phase offset measured at the coastlines can be used to compensate for the XTI phase.

3. RESULTS

A limited amount of data was available for analysis so far. The first data take for which we tested the phase separation approach in a road traffic scenario was acquired on July 6, 2011 over the motorway A93, South of Germany. Reference images of vehicles on the road were simultaneously taken by an air borne camera system. The TanDEM-X data take was part of the global DEM acquisition, thus parameters were not optimized for ATI. The effective XTI and ATI baseline are 144 m and 138 m, resulting in a height and a velocity of ambiguity of 46 m and 3 km/h respectively. The four left panels in Figure 2 show a sub-area of the SAR amplitude, the hybrid interferometric phase and of the extracted motion phase and DPCA images. The signature of a truck, which is shown in the optical image on the right, is marked with a square in the radar data. Due to a small across-track velocity, it appears azimuthally displaced and with a significant motion phase. Signatures of further vehicles driving in the opposite direction and appearing only weakly in the amplitude can clearly be seen left to the road in the DPCA image.

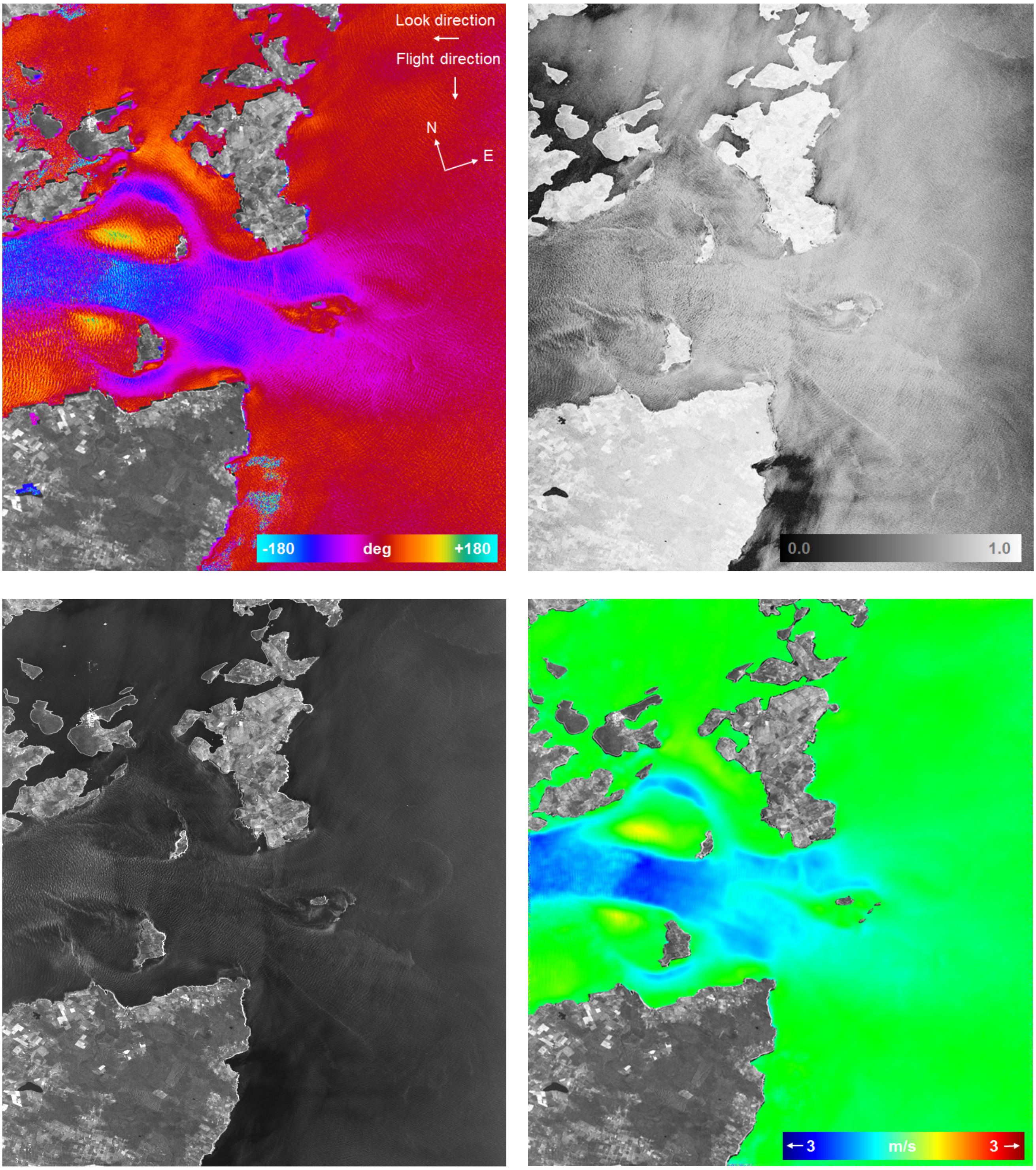

Fig. 3: Ocean surface currents mapped with TanDEM-X at the Orkney Islands. From top-left, the images show clock-wise the offset corrected interferometric phase, the coherence, the ground-range velocity and the SAR amplitude. Land areas have been masked with the latter in the phase and velocity image.

Fig. 3 shows a first result of ocean surface current mapping with TanDEM-X. The data take was acquired over the Orkney Islands on February 26, 2012, 6:41 UTC. The acquisition parameters were optimized for this specific data take and application. The effective ATI baseline was adjusted to 25 m, which provides a high phase-to-velocity sensitivity and avoids severe de-correlation over water at the same time. Furthermore, VV polarization was used to enhance the SNR over water. The upper left image shows the interferometric phase after compensation of the average phase offset along the coast lines. Land areas have been masked with the SAR amplitude. The strong phase variations in the left and center parts of the image are caused by a tidal current directed away from the sensor as well as by wave motions. The coherence image in the upper right exhibits very good interferogram quality for most parts of the water surface. The lower right image depicts the ground-range velocity obtained from the ATI phase. Please note that wave motion has not yet been corrected for. However, this image clearly demonstrates the great potential of TanDEM-X for mapping water surface currents. Such measurements have applications in the field of renewable energy and climate research.

4. CONCLUSIONS

Due to the long, adjustable ATI baselines and corresponding high phase-to-velocity sensitivities, the TanDEM-X formation enables to detect moving objects with low line-of-sight velocities and to map ocean currents with high spatial and velocity resolution. Although the results are preliminary yet, they look very promising and open completely different applications apart from the DEM generation. To take full advantage of the inherent TanDEM-X along-track interferometric data acquisition, the ATI phase needs to be recovered as accurately as possible. We plan to investigate this in our future work.

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