COMPARISON OF CURRENT FIELDS FROM TerraSAR-X AND TanDEM-X ALONG-TRACK INTERFEROMETRY AND DOPPLER CENTROID ANALYSIS

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A little more than 25 years ago, Goldstein & Zebker of JPL described the concept of ocean surface current measurements by SAR along-track interferometry (ATI) and presented a first example result [1]. Since then, the feasibility of current measurements by this technique has been demonstrated in a number of experiments, using ATI systems on aircraft (e.g. [2]), on a space shuttle [3], and on the first ATI-capable satellite, the German TerraSAR-X [4]. Furthermore, a number of theoretical studies have been performed to understand the ATI imaging mechanism of current and wave fields and to find out how the ATI data quality depends on radar frequency, incidence angle, along-track baseline, etc., and what parameter combinations are most promising for accurate high-resolution current measurements (e.g. [5]). According to these studies, the ideal along-track baseline (defining the time lag between the two SAR images that form an interferogram) at X band should be on the order of 20 to 30 m.

Unfortunately, the Shuttle Radar Topography Mission setup and the split-antenna modes of TerraSAR-X offer baselines of only 3.5 m and approx. 1 m, respectively, resulting in a clearly suboptimal sensitivity to target velocities and a requirement to average the interferograms over many full-resolution pixels to reduce phase noise. In contrast to this, the along-track baselines between the TerraSAR-X satellite and its companion TanDEM-X are too large over most ocean regions of interest: With the standard helical orbit pattern, the two satellites have an along-track distance between 0 at the northern- and southernmost points of the orbit and about 550 m over the equator, limiting the region of useful along-track baselines for inter-satellite interferometry to narrow latitude bands far in the north and south. In regions of longer along-track baselines, the data quality should suffer from temporal decorrelation of the backscattered signal and phase wrapping (i.e. the range of line-of-sight target velocities within relatively small areas of an image may be mapped into a phase interval of more than 2π in the interferogram).

However, the TanDEM-X formation geometry gets modified from time to time to optimize the cross-track InSAR performance in certain regions or for certain applications, and a setup used from January 12 through March 29, 2012, shifted the region of useful along-track baselines to a latitude band that included the Orkney Islands off the northern coast of Scotland. The Orkney Islands are a very good test area for current measurements, since the tidal currents in some areas can get as large as 5 m/s, and several teams of scientists and engineers have looked into possibilities to install underwater turbines for electricity generation in such areas. Because of this, the flow field is relatively well known, and it is relatively easy to obtain reference data from in-situ measurements and numerical circulation models for comparison with ATI results. Furthermore, we already acquired a few along-track InSAR images of the area in the Aperture Switching (AS) and Dual Receive Antenna (DRA) modes of TerraSAR-X in 2009 and 2010, such that an aquisition of additional TanDEM-X images would allow us to compare results from different ATI modes of TerraSAR-X and TanDEM-X for the same test area.

We were able to acquire two TerraSAR-X / TanDEM-X image pairs of the Orkney Islands test area on February 26 and March 19, 2012, with effective along-track baselines of 24 m and 40 m, respectively. The data acquisitions were programmed within the framework of an internal science project of the German Aerospace Center (DLR) in Oberpfaffenhofen, including some specific fine-tuning of the satellite orbits to optimize the along-track baseline. All SAR processing and interferogram generation was performed at DLR as well, using the dedicated software described in [6]. Fig. 1 shows the interferometric phase information obtained from the March 19 image, averaged over grid cells of 25 m × 25 m and converted into horizontal Doppler velocity. The data quality is so good that the orbital motions of individual long waves are resolved. At the same resolution, the phase signatures in a DRA mode image from April 26, 2010, are very noisy, not even revealing clear signatures of the current field (a corresponding figure will be shown at the conference). This is a tremendous data quality improvement.

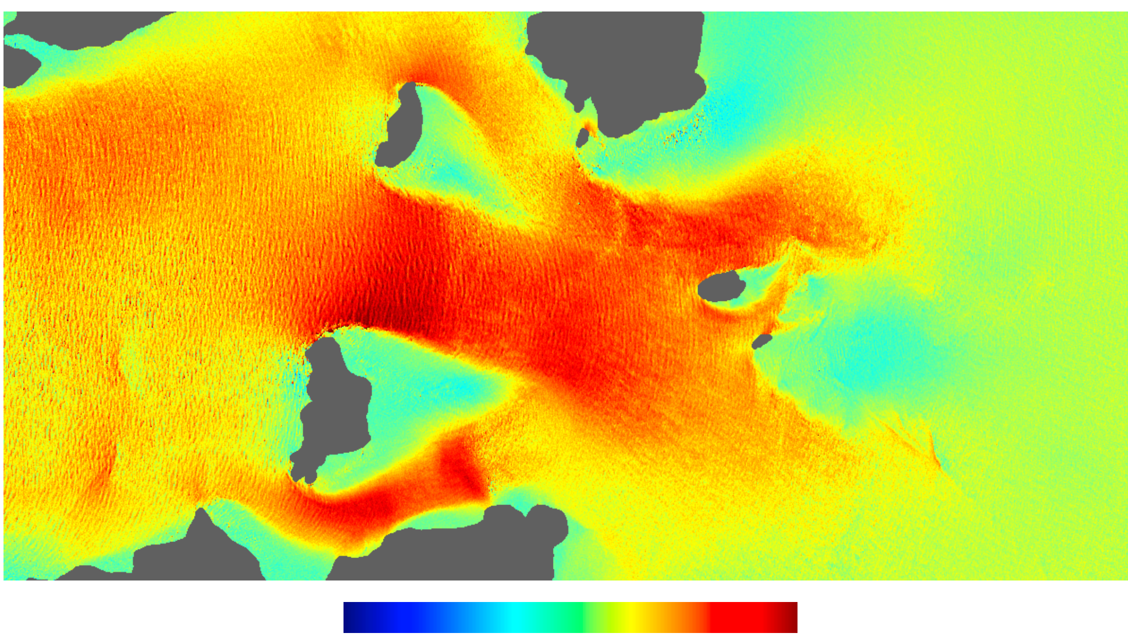

Fig. 1: Doppler velocity image obtained from a TanDEM-X interferogram with an along-track baseline of 40 m, acquired March 19, 2012, 06:41 UTC; grid resolution is 25 m × 25 m, scene size is approx. 30 km × 15 km.

The visible wave patterns in both TanDEM-X interferograms enable us to apply directional filtering in such a way that the small-scale velocity variations are smoothed out while a higher spatial resolution is preserved in the direction parallel to the wave crests. Furthermore, we can apply spatially varying wave motion corrections to the Doppler velocities to obtain the best possible estimates of actual line-of-sight surface currents, based on the visible wave patterns and larger-scale image intensity variations and the theoretical Doppler / ATI model of [7]. For comparison, we apply a similar phase noise filter and similar corrections to the lower-quality TerraSAR-X DRA mode data. Finally, for comparison with another promising current retrieval technique, we perform a Doppler centroid analysis for single-channel data of the two TanDEM-X image pairs, using the procedure described in [8]. The Doppler centroid analysis cannot be expected to deliver as accurate results as along-track interferometry with optimal system parameters, but it has the unique advantage that it can be applied to the raw data of any newly acquired or archived single-antenna SAR image without any special preparations [9].

All TerraSAR-X / TanDEM-X based results are compared with surface current fields from the tidal computation package POLPRED of the National Oceanography Centre (NOC) in Liverpool, UK. POLPRED uses 26 harmonics derived from a 2D numerical circulation model [10] to estimate current fields at any tidal phase of interest. We find good agreement between all three ATI-derived line-of-sight current fields and their POLPRED counterparts, with small mean and rms differences and correlation coefficients between 0.85 and 0.90. Of course, the TanDEM-X inter-satellite ATI results have a higher spatial resolution than the TerraSAR-X DRA-mode result, but this does not lead to much better agreement with the available model current fields because of POLPRED's own limited resolution (1 km grid). Regarding the Doppler centroid results, they are less accurate than the ATI results, but still good enough to resolve all major features that are visible in the model current fields and the smoothed ATI current fields. This is a quite impressive and somewhat surprising finding.

So far, our ATI results are consistent with the theoretical expectation that an increased along-track baseline permits more accurate current measurements at higher spatial resolutions. They also enable us to quantify the effective accuracy and spatial resolution improvements at baselines of 25 and 40 m. But is it true that effective baselines on the order of 30 m are the best choice for ATI current measurements at X band? To answer this question, we analyze a series of seven interferograms from TanDEM-X that were acquired over the open ocean between Antarctica and the southern tip of South America while the effective along-track baseline increased from approx. 14 to 42 m. This dataset permits the first satellite-based measurement of the signal autocorrelation (or coherence) as function of time, covering time lags from approx. 1.8 to 5.5 ms, and a comparison with the theoretical predictions on which all of our baseline recommendations have been based so far. A first look suggests relatively good agreement between measured and theoretically expected coherences, but when this abstract was submitted in January 2013, a detailed analysis of this dataset was still pending. However, final results of this analysis will be ready to be presented at IGARSS in July 2013.

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