On the Suitability of TerraSAR-X Split Antenna Mode for Current Measurements by Along-Track Interferometry

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Abstract – **Latest concepts for the TerraSAR-X hardware design include the availability of a split antenna mode, in which the fore and aft halves of the SAR antenna array with a total length of 4.8 m can act as separate receiving antennas for along-track interferometry (ATI). The effective ATI time lag will be 0.17 ms. We discuss in this paper whether the split antenna mode is suitable for ocean current measurements. Typical (tidal) currents in coastal areas are on the order of 1 to 2 m/s. To measure them, the ATI time lag should ideally be 20 times longer than the time lag of TerraSAR-X. Furthermore, the backscattered power from the ocean at low wind speeds can be below the noise floor of the instrument. However, the high resolution of TerraSAR-X permits averaging over many pixels to reduce noise. Simulated data products suggest that TerraSAR-X will be capable of measuring currents with satisfactory accuracy at a spatial resolution of about 1 km, which will be sufficient for many applications.**

I. INTRODUCTION

Figure 1 shows an artist's view of the German satellite TerraSAR-X, which is scheduled for launch in 2005. The phased array antenna of the X band (9.65 GHz) SAR consists of 384 elements, which can be grouped into two segments of 2.4 m length to obtain separate receiving antennas for along-track interferometry (ATI) [1]. Due to the bistatic configuration (one transmitting antenna, two receiving antennas), the effective ATI baseline is half antenna separation, i.e. 1.2 m, which corresponds to a time lag of 0.17 ms. Ideal ATI time lags for oceanic current measurements at X band should be on the order of a few milliseconds, i.e. about 20 times longer than this [2]; thus the sensitivity of TerraSAR-X to small current variations will be quite low. Furthermore, the normalized radar backscattering cross section (NRCS) of the ocean surface at low wind speeds can be below the instrument noise level at about –19 dB. However, TerraSAR-X will have a relatively high single-look resolution of 3 m × 3 m in stripmap mode (swath width: 30 km), which permits averaging over many pixels to reduce noise at reasonable spatial resolutions. In the following we discuss the current measuring capabilities on the basis of simulated data products.

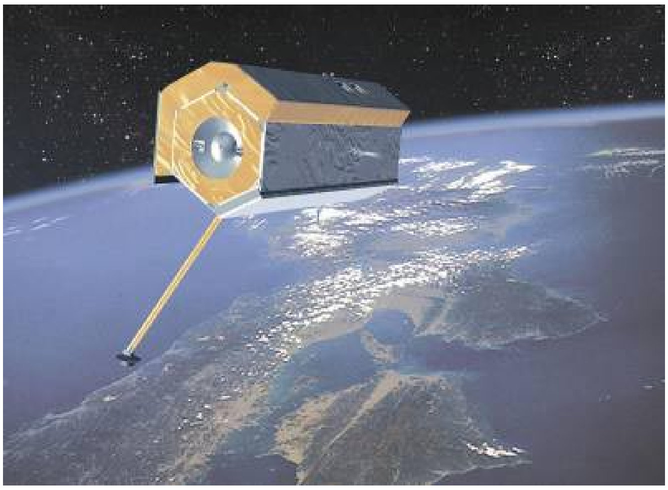

Figure 1. Artist's view of TerraSAR-X in space (www.astrium-space.com). The SAR antenna is the light gray panel facing downward; it is 4.8 m long.

II. SIMULATION OF SPACEBORNE INSAR DATA PRODUCTS

The conventional and interferometric synthetic aperture radar (SAR and InSAR) imaging of ocean scenes can be simulated by the numerical model suite M4S of the University of Hamburg [3]. Starting from an input current field and mean wind vector, M4S computes the spatially varying surface wave spectrum in the test area, converts the mean current and wave spectrum at each grid point into a Doppler spectrum, and maps the contributions to the backscattered signal with different Doppler shifts to the appropriate pixels in the SAR / InSAR intensity and phase images, simulating known artifacts of SAR processing such as an azimuthal offset of targets with a nonzero radial velocity and azimuthal smearing. Also the characteristic amplitude and phase noise statistics for a given instrument noise level and number of independent looks per pixel and for the computed NRCS of the ocean and coherence of the backscattered signal can be simulated in order to obtain realistic realizations of intensity and phase images, as they would be obtained from a real SAR.

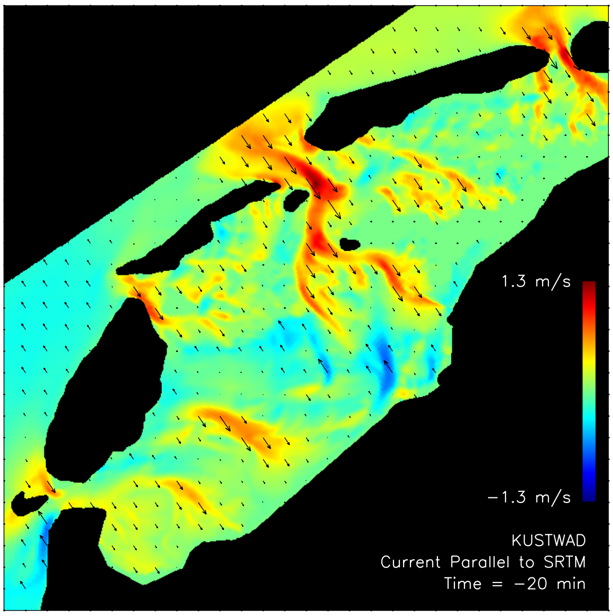

Figure 2. Current field in the Dutch Waddenzee, 70 km × 70 km, as obtained from the circulation model KUSTWAD, and as used for the simulation of SRTM and TerraSAR-X ATI images with the M4S model.

The oceanic scenario selected for our simulations is the one in the Dutch Waddenzee which was imaged by SRTM from a Space Shuttle on 15 February 2000, and which has been presented in another paper in this issue [4]. An input current field for M4S simulations for this scenario is available from the numerical circulation model KUSTWAD. The current component parallel to the look direction of SRTM, i.e., the current component to which the SRTM phase differences are sensitive, is shown in Figure 2. The wind speed at the time of the SRTM overpass was about 5 m/s from west.

III. Model Validation with SRTM Data

One reason for selecting the known Waddenzee scenario for spaceborne InSAR simulations is the fact that the existing SRTM data can be used for model validation. For this purpose, a first simulation was carried out with SRTM parameters (9.6 GHz, VV, incidence angle = 55°, time lag = 0.47 ms, 64 looks per 100 m × 100 m grid cell, noise-equivalent NRCS (NESZ) = –29 dB). The simulated SRTM phase image was processed in the same way as the real one [5] to obtain a simulated SRTM-derived line-of-sight current field. It is shown together with the real SRTM result in Figure 3.

In [4], we have shown plots of correlation and regression coefficients between spatial variations in the KUSTWAD and SRTM-derived current fields on different length scales. The overall correlation is 0.558 with a falloff at length scales below about 2 km, and the regression coefficient is close to 1 at all scales. A comparison of the simluated SRTM-derived currents with the KUSTWAD currents reveals very similar behavior, except for a larger overall correlation of 0.948. We think that this discrepancy can be attributed to systematic differences between the KUSTWAD current field and the actual current field at the time of the SRTM overpass. Otherwise, the simulated and real SRTM data exhibit very similar properties.

IV. TerraSAR-X Simulation Results

For best comparability with SRTM, whose current measuring capabilities have been evaluated in [4], our TerraSAR-X simulations have been performed for the same swath with the same look direction. That is, only the imaging of the given line-of-sight current field by TerraSAR-X, but not the specific orbit and swath parameters have been taken into account.

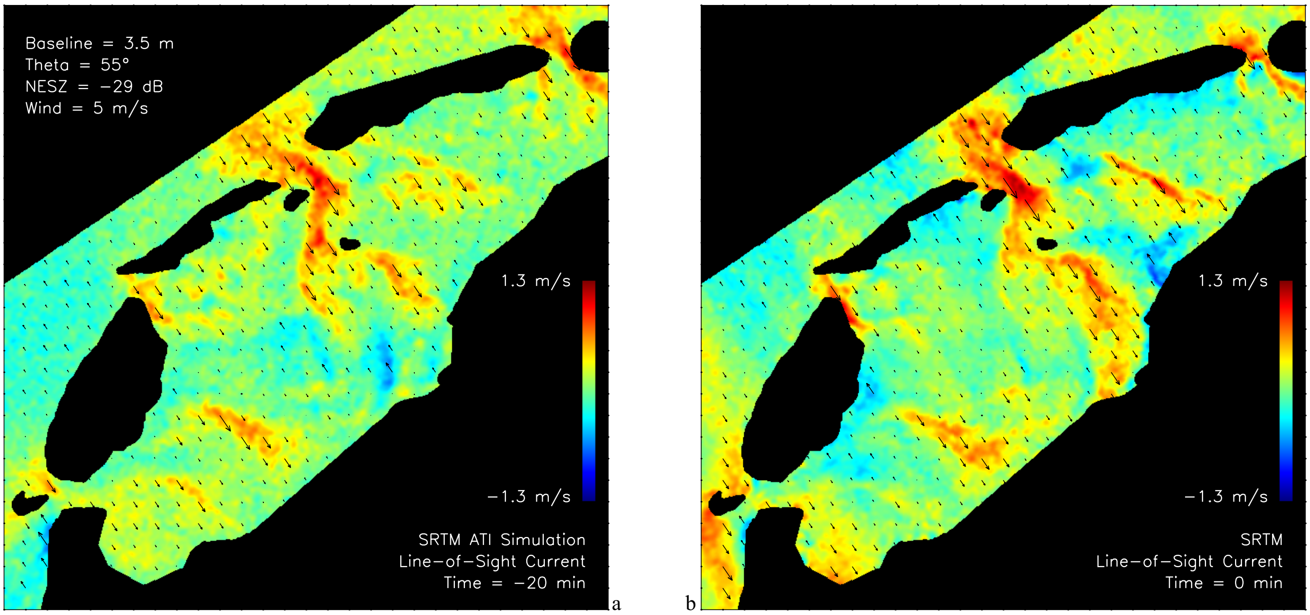

Figure 3. Simulated (a) and actual (b) SRTM-derived line-of-sight current field in the Waddenzee test area on 15 February 2000, 12:34 UTC.

Simulations have been performed for the ScanSAR and stripmap modes of TerraSAR-X (9.65 GHz, VV, incidence angle = 20° to 45°, time lag = 0.17 ms, 39 / 1111 looks per grid cell, NESZ = –19 dB) and for wind speeds of 5 and 10 m/s. The actual swath widths of the two imaging modes would be 100 km and 30 km, respectively.

Consistent with our expectations, the simulated ScanSAR mode data are quite noisy. The current patterns in the Waddenzee become visible at steep incidence angles and high wind speeds only; the data quality is always worse than the quality of the SRTM data of Figure 3b.

However, the simulated stripmap mode data with 1111 independent looks are quite promising: Figure 4 shows the result for a wind speed of 5 m/s (corresponding to the SRTM case) and an incidence angle of 30°. The correlation between this simulated TerraSAR-X data product and the KUSTWAD currents is better than in the SRTM simulation (0.958 vs. 0.948). Due to high instrument noise, the correlation becomes worse at larger incidence angles (0.889 at 40°) and better at higher wind speeds (0.979 at 10 m/s). Given the fact that SRTM has been found to resolve current variations down to scales of 1 to 2 km [4], which is quite satisfactory, we can expect an even better performance from TerraSAR-X.

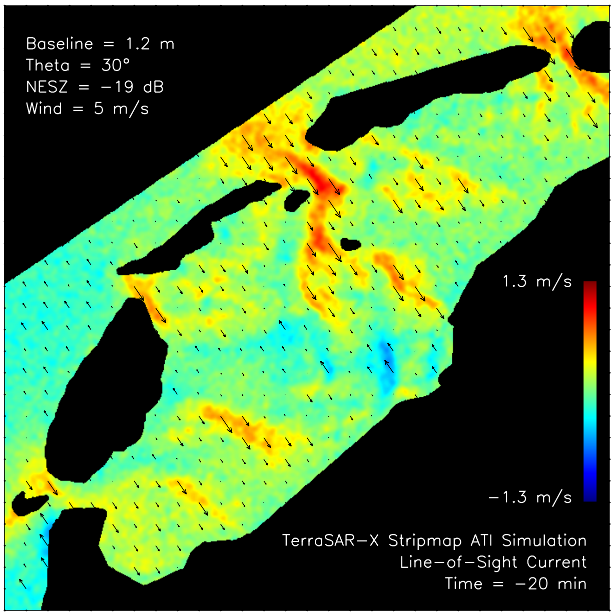

Figure 4. Simulated TerraSAR-X-derived line-of-sight current field for stripmap mode, an incidence angle of 30°, and a wind speed of 5 m/s.

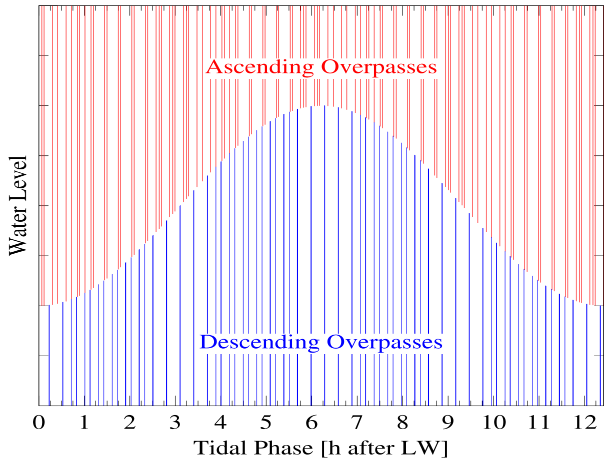

Figure 5. Coverage of the tidal cycle in the Waddenzee by ascending and descending TerraSAR-X overpasses within a period of one year.

V. Two-Dimensional Current Field Retrieval

The restriction to one-dimensional current measurements in the line-of-sight direction can be a serious shortcoming of ATI, since many applications require the knowledge of fully two-dimensional surface current fields. In areas such as the Waddenzee one can try to derive the missing current component from the measured one and the known bottom topography, using a high-resolution model like KUSTWAD. In the general case this will not always be possible.

In principle, spaceborne ATI systems can measure two different current components during ascending and descending overpasses of a test area, which can then be combined to obtain, for example, mean two-dimensional current fields for different tidal phases. For example, there will be three ascending and three descending overpasses of the Waddenzee within one 11-day repeat cycle of TerraSAR-X. Figure 5 shows the corresponding sampling of the tidal cycle which can be obtained within a period of one year. The coverage of the tidal cycle is quite dense and uniform. Also the seasonal coverage has been found to be quite uniform, i.e., aliasing of seasonal current variations into the tidal cycle should not be a serious problem.

VI. Discussion

Our results indicate that TerraSAR-X in split antenna stripmap mode will be capable of measuring surface currents with a spatial resolution of about 1 to 2 km. Technically, the data would be suited, for example, for the generation of current atlases for coastal areas of interest, showing high-resolution two-dimensional current fields for different tidal phases.

References

[1] J. Mittermayer, V. Alberga, S. Buckreuß, and S. Riegger, "TerraSAR-X: Predicted performance", in *Proc. SPIE 9th Int. Symp. Rem. Sensing*, 12 pp., Int. Soc. Optical Eng., Bellingham, WA. USA, 2002.

[2] R. Romeiser et al., *Study on Concepts for Radar Interferometry from Satellites for Ocean (and Land) Applications (KoRIOLiS)*, 110 pp., http://www.ifm.uni-hamburg.de/~romeiser/koriolis.htm, 2002.

[3] R. Romeiser and D.R. Thompson, "Numerical study on the along-track interferometric radar imaging mechanism of oceanic surface currents", *IEEE Trans. Geosci. and Rem. Sensing*, vol. 38-II, pp. 446-458, 2000.

[4] R. Romeiser et al., "Validation of SRTM-derived surface currents off the Dutch coast by numerical circulation model results", elsewhere in this issue, 3 pp., 2003.

[5] R. Romeiser, H. Breit, M. Eineder, and H. Runge, "Demonstration of current measurements from space by along-track SAR interferometry with SRTM data", in *Proc. IGARSS 2002*, 3 pp., Inst. of Elec. and Electron. Eng., Piscataway, N.J., USA, 2002.