Retrieval of 2-D current and ocean wave information using Tandem-X in a squinted split antenna mode configuration

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Abstract

It is well known that along track interferometric SAR systems (ATI) are able to provide information on ocean surface currents. For example interferograms acquired during the Shuttle radar topography mission (SRTM) were used at DLR to measure currents in the river Elbe. The ocean current information is important for many practical applications like, e.g., monitoring of sediment transport in coastal areas, optimal siting of current turbines, or forecast of oil slick drift. It has been shown that the TerraSAR-X split antenna mode can be expected to provide current information comparable to SRTM data, i.e., the ocean current component in the antenna look direction on a kilometre scale. This is already valuable information and complements the traditional in situ current measurements very well. However, there is still demand for two-dimensional (2-D) ocean current vectors to get a more complete picture of the 2-D spatial structure of the current field in particular in areas with strong spatial dynamics of the current direction. The presentation will give an overview of a proposal to carry out an experiment in the framework of the Tandem-X mission with the objective to retrieve additional 2-D information on currents and ocean waves. The idea is to operate both SAR instruments in split antenna mode with large squints of one or both satellites. Using this flight configuration it is expected that it will be possible to gain information on 2-D ocean current vectors. Due to the lack of suitable instruments this technique has never been applied using spaceborne platforms before. First experiments with airborne systems demonstrating the potential of the approach have been conducted. Apart from new current field information the proposed configuration enables the derivation of 2-D information on near surface wind fields applying the standard scatterometer approach. Furthermore it is expected that the approach will provide new information on the so called modulation transfer function (MTF) for ocean waves, which is one of the key factors in SAR ocean wave spectra retrieval schemes. The presentation will give a summary of the main technical issues including simulation studies showing the impact of different key parameters, e.g., the squint angle. The potential as well as limitations of the approach will be discussed.

1 Introduction

Information about ocean surface currents is needed for many applications in particular in coastal areas, e.g.,

- Assessment of sediment transport processes
- Assessment of fresh water outflow from rivers
- Optimal siting and operation of current energy converters
- Investigation of current ocean wave interaction

The last point is of particular importance for the generation of extreme high individual waves, which can be fatal for ships or offshore platforms [3]. The measurement of currents with traditional in situ sensors like acoustic Doppler profilers (ADCPs) is relatively expensive and a broad picture of the 2-D dynamics of the current field is hard to obtain with these point measurements. It has been amply demonstrated that along track interferometric (ATI) synthetic aperture radar systems are capable of providing information on ocean surface currents [6, 4]. The concept has been demonstrated with both airborne and spaceborne radar systems. It has also be shown that the upcoming TerraSAR-X mission will be able to estimate currents with an accuracy level comparable to the Shuttle radar topography mission (SRTM) operating in the so called split antenna mode. Although the current information provided by spaceborne ATI systems is already very useful the approach is limited by the fact that only the current component in the antenna look direction can be measured.

In this paper we propose to use the two TerraSAR-X instruments to be flown in the Tandem-X mission to estimate both current components. In the Tandem-X mission two identical TerraSAR-X platforms will be flown on the same orbit. The core objective of the Tandem-X mission is the generation of a high resolution digital elevation model (DEM) of the solid earth making use of the across track interferometric component between the two platforms. The idea of this study is to operate both instruments in a split antenna mode and to fly one or both of the satellites with a strongly squinted imaging geometry. We propose that such a flight configuration is set up in the framework of an experiment for a limited time after the core mission objectives have been achieved.
Figure 1: Tandem-X with a squinted imaging geometry of the second platform to measure 2-D current vectors.

2 Theoretical background

The idea behind the measurement of ocean surface current with ATI SAR systems is the acquisition of two single look complex (SLC) SAR images with a small time lag. The phase of the two images contains information about the slant range distance to the backscattering facets on a centimeter scale. Denoting the SLC images acquired by the first and second antenna with $c_1$ and $c_2$ the so called interferogram

$$i = (c_1 c_2^*)$$

is formed. The phase of the interferogram then provides an estimate of the slant range component of the surface motion taking place in the time between the two SLC acquisitions.

In the present study this approach is applied to two ATI systems, which fly on the same orbit with distance $A$. We propose that such a flight configuration with the second TerraSAR-X instrument flown with a strongly squinted flight geometry will be realized in the framework of the TAndem-X mission. The propose imaging geometry is sketched in Fig. 1. For TerraSAR-X the along track baseline is given by

$$B_x^{(1)} = 2.4 \text{ m}$$

and the distance $A$ is variable. The only limitation for $A$ in the context of current measurements is that the two interferograms should represent more or less the same current conditions, i.e., a time lag in the order of several minutes seems to be feasible. In this study assume that only the second TerraSAR-X platform to be launched in the near future will be squinted and the first satellite will remain untouched.

It is important to note that due to the squinted geometry the along track component $B_x^{(2)}$ of the second platform will be shortened compared to the along track baseline $B_x^{(1)}$ without squint according to

$$B_x^{(2)} = B_x^{(1)} \cos \Phi$$

The geometry is sketched in Fig. 1.

Another aspect to take into account is that due to the squinted geometry of the second satellite an additional across track component will be introduced in the respective interferogram $i_2$ as indicated in Fig. 2. The across track component is given by

$$B_{\perp}^{(2)} = B_x^{(1)} \sin \Phi \cos \theta$$

where $\Phi$ is the squint angle and $\theta$ is the incidence angle.

The baseline of the second squinted platform thus has both along and across track components. It has been shown [7] that for such hybrid InSAR system the interferometric phase is to first order be given by the following expression.

$$\Phi^{(2)} = m k E \left( \frac{B_x^{(2)}}{V} u_r + \frac{B_{\perp}}{R_0 \sin \theta} \eta_r \right)$$

$$= m \left( \frac{2 \pi}{u_{amb}^{(2)}} u_r + \frac{2 \pi}{\eta_{amb}^{(2)}} \eta \right)$$

Here $m$ is a system dependent constant, which is $m = 1$ for bistatic interferometric modes such as the TerraSAR-X split antenna mode. The parameters $u_{amb}^{(2)}, \eta_{amb}^{(2)}$ are defined as the ambiguity velocity and ambiguity height respectively and $R_0$ is the slant range distance. With a TerraSAR-X orbit altitude of $H = 514$ km we can estimate $R_0$ as

$$R_0 \approx H \cos \theta$$
Figure 2: Additional across track component of the second TerraSAR-X instrument due to the squinted flight geometry.

The first term in the sum accounts for the along track component [2] and the second term is associated with the across track contribution [5]. Furthermore, \( k_E \) is the electromagnetic wavenumber, \( V \) is the platform velocity, \( B_x^{(2)} \) the along track baseline, \( B_\perp \) the across track component (compare [1]), and \( \theta \) the incidence angle. For TerraSAR-X the radar frequency is 9.65 GHz and the radar wavenumber thus

\[
k_E = \frac{2 \pi}{0.0311 \text{ m}}
\]

The platform ground velocity of TerraSAR-X will be approximately \( V \approx 7000 \text{ m/s} \). The respective expression for the InSAR phase of the first platform \( \Phi^{(1)} \) is analogue to the expression for \( \Phi^{(2)} \) apart from the missing across track term, i.e., \( B_\perp = 0 \).
3 Ambiguity heights and velocities

The ambiguity velocities and elevations appearing in eq. 6 are shown as a function of squint angle in Fig. 4 and Fig. 5. Fig. 4 shows the ground velocity $u_g$ which is related to the slant range velocity $u_s$ by $u_g = u_s \sin \theta$. As one can see the sensitivity of the system with respect to velocities goes down by a factor of two if the system is squinted by about 60 deg. For 45 deg incidence angle a ground velocity of 1 m/s corresponds to 2.8 deg interferometric phase for zero deg squint angle and about 1.44 deg for 60 deg squint angle.

Concerning the across track baseline we see that the ambiguity heights are well above 2 km. For the typical elevations on the ocean $\eta = 1 \text{ m}$ the resulting across track interferometric phase will thus be below 0.2 deg and thus an order of magnitude smaller than the along track component. Furthermore it is important to note that for the estimation of the ATI phase the interferograms have to averaged over spatial scales of at least 1 km to achieve a reasonable phase noise reduction. We assume that the small modulations of the across track phase caused by ocean surface gravity waves which have wavelength below 1 km are in a good approximation averaged out to zero.

4 Estimation of current vectors

For a given ocean surface current vector $\mathbf{u} = (u_x, u_y)$ the respective interferometric phases $\Phi = (\Phi^{(1)}, \Phi^{(2)})$ of the Tandem-X system may be expressed as

$$\Phi = 2\pi \sin \theta \begin{pmatrix} (u^{(1)}_{amb})^{-1} -1 & 0 \\ (u^{(2)}_{amb})^{-1} \cos \Phi & (u^{(2)}_{amb})^{-1} \sin \Phi \end{pmatrix} \mathbf{u}$$

or by inversion the current vector can be computed from the measured ATI phases according to

$$\mathbf{u} = \rho \mathbf{A} \Phi$$

with

$$\mathbf{A} = \begin{pmatrix} (u^{(2)}_{amb})^{-1} \sin \Phi & 0 \\ -(u^{(2)}_{amb})^{-1} \cos \Phi & (u^{(1)}_{amb})^{-1} \end{pmatrix}$$

and

$$\rho = \left(2\pi \sin \theta \left( (u^{(1)}_{amb})^{-1} - (u^{(2)}_{amb})^{-1} \sin \Phi \right) \right)^{-1}$$

As expected the determinant of the matrix in eq. 9 becomes zero for $\Phi \rightarrow 0$ which reflects the fact that the squint of the second platform is the key feature of the system. The linear system eq. 9 has a unique solution for $\Phi \neq 0$ and $\theta \neq 0$. However the question whether this measurement is useful depends on the impact of the phase noise on the resulting solution. Assuming that the phases $\Phi^{(1)}$, $\Phi^{(2)}$ are independent Gaussian distributed with standard deviation $\sigma_{\Phi}$, the respective covariance matrix of the solution vector $\mathbf{u}$ is given by

$$\text{COV}(\mathbf{u}) = \sigma_{\Phi}^2 \rho^2 \mathbf{A}^T \mathbf{A}$$

(13)

These error estimates for both current components can then be used to assess the expected errors in the magnitude and direction of the current vector as well.

5 Conclusions

A study was presented, which is based on the idea to use the upcoming Tandem-X mission for the measurement of two dimensional ocean surface current vectors operating both TerraSAR-X systems in split antenna ATI mode. In the proposed configuration the second TerraSAR-X platform is flown with a large squint angle. The current study investigated the sensitivity of the interferometric phases acquired by the two ATI systems with respect to surface velocities and elevations for different squint angles and incidence angles. Furthermore a simple linear approach to estimate the current vector from the ATI phase was presented. Further studies are currently undertaken to investigate the dependence of the retrieved current vectors on the ATI phase noise.

References


