INTERFEROMETRIC CROSSING ORBIT EXPERIMENT USING TERRASAR-X AND TANDEM-X

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ABSTRACT

The paper discusses quasi repeat-pass SAR interferometry exploiting crossing orbits in order to obtain short revisit times of 1, 5 and 6 days with the TerraSAR-X or TanDEM-X satellite. A special acquisition geometry is necessary for interferometry under crossing orbits to preserve common ground spectra and coherence. This in turn implies limitations for possible acquisition areas. The spectral requirements, the acquisition geometry as well as the geographic limitations are presented. In order to demonstrate the feasibility an experimental acquisition of a test site on the Ronne ice shelf in Antarctica is described and the results are shown. Furthermore, first results w.r.t. glacier surface velocity and topography measurements are presented.

Key words: Crossing Orbits; SAR; Interferometry; Ronne ice-shelf; TerraSAR-X; TanDEM-X.

1. INTRODUCTION

Typical space-borne repeat-pass as well as across-track SAR interferometry considers almost parallel orbit tracks in order to obtain coherence. This requires the whole repeat-pass orbit cycle time for acquiring an interferometric pair of images, i.e. 11 days in case of TerraSAR-X (TSX) and its twin satellite TanDEM-X (TDX) [1]. Taking the Earth rotation and a sun-synchronous orbit into account the orbits are crossing each other several times within one cycle. For a small number of orbits, this implies relatively close orbit tracks as well as ground-tracks after an integer number of days, i.e. less than the usual revisit cycle time. Therefore baselines not exceeding the critical baseline are possible and common range as well as azimuth spectra can be achieved. Short revisit times are of interest for a range of applications due to less contribution of temporal decorrelation.

The flexible commanding capabilities of TSX and TDX, including their azimuth steering capability, turns them into ideal platforms for experiments with this type of non-parallel acquisitions. During the Commissioning Phase of TDX in July 2011 a crossing orbit experiment was already performed over the October Revolution Island, in the Russian Arctic [2]. A not nominal flight formation, with almost identical tracks but a 380 km (48 s) along track separation, offered a possibility of performing an interferogram with both satellites. The Earth rotation caused a small ground track crossing angle of 0.14°. The experiment described in this paper exhibits much larger crossing angles, i.e. up to 4.2°, which are caused by larger time lags in the order of magnitude of days. Fig. 1 shows the corresponding orbit tracks.

Section 2 presents the experimental set-up, its spectral requirements, the acquisition geometry and the resulting restrictions. In section 3 all three areas under investigation are presented. Additionally, a timeline of these currently acquired and planned acquisitions is shown. Section 4 shows the interferometric results of the experimental Ronne ice shelf acquisitions. Section 5 presents some first results of surface velocity and ice topography measurements. Finally, in section 6 the conclusion and an outlook is given.

2. EXPERIMENT DESCRIPTION

2.1. Theory

The basic requirement for the experiment is that the range and the azimuth ground spectrum of both acquisitions must have a preferably large overlap [3], in order to perform a coherent interferogram. A large cross-track baseline and non-parallel orbit tracks imply a spectral shift in range and azimuth, respectively. The limitations are the critical baseline and the maximum squint angle of the system.

In range, the spectral overlap can only be increased by using a larger transmit bandwidth. In order to minimize the impact of different orbit tracks, far range acquisitions are desired due to a smaller incidence angle difference between the two acquisitions. Due to the angle between the orbit tracks, the same parts of the azimuth spectra also do not map to common azimuth ground spectral components. Since this implies a Doppler offset, which is

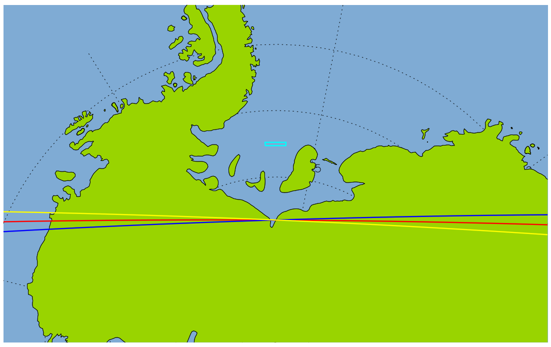

Figure 1. Earth fixed crossing orbit tracks and geographic location of test site on Ronne ice shelf, Antarctica (78°S, 56.5°W). (red: orbit 1, blue: orbit 5, yellow: orbit 6, cyan: test site)

much larger than the azimuth beam width, a physical application of a relative squint between the acquisitions is required in order to compensate the crossing angles. A derivation of the physical parameters w.r.t. the common spectra can be found in [2]. For comparison, the smaller crossing orbit angles in [4] allowed to keep a reduced common azimuth band for interferogram generation.

The crossing points of a sun-synchroneous orbit are always located in the polar regions, i.e. at ±82° latitude in the case of TSX/TDX. The resulting restrictions of these orbit positions and methodoloy due to baseline, incidence angle, bandwidth and system squint angle, imply limited potential acquisition areas at very high latitudes in combination with a very narrow range of latitudes. Only areas between 84.5°and 88°latitude on the northern hemispere and between -75°and -80°latitude in the southern hemispere can be adressed. In addition, as a result of the partially very large baseline, i.e small height of ambiguity, it is very challenging to monitor terrain containing some topography. In the case of the Ronne ice shelf interferograms the minimal height of ambiguity was 2.2 m and 5.8 m for the 1 day and the 5(6) day interferogram, respectively.

2.2. Acquisition Geometry and Configuration

Since TSX and TDX are currently in their nominal formation flight, i.e. the bistatic configuration, the quasi repeat-pass acquisitions can be executed by only TSX or TDX, respectively, depending on the exclusion zones in the polar regions [5]. In order to achieve spectral overlap only orbits with a temporal separation of 1, 5 or 6 days are possible. The closest (symmetric) pair of tracks corresponds to a temporal lag of 5 or 6 days and the second closest pair to a 1 day lag with crossing angles of 2.1°and 4.2°, respectively [6].

The required acquisiton geometry of the experiment for this orbit geometry is shown in Fig. 2. In order to obtain two crossing orbit interferograms a triple data take acquisition is performed. That means only three data takes are acquired, where the first and the second exhibit a 5 day lag and the second and third a 1 day lag. The orbits of the fifth and sixth day are symmetric w.r.t. the first one. This offers additionally the possibility to obtain even three interferograms from these three acquisitions.

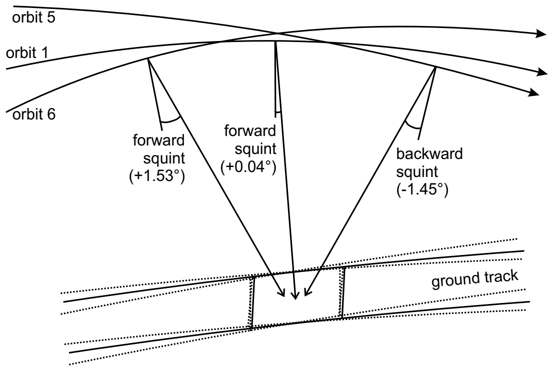

Figure 2. Crossing orbit acquisition geometry of a triple data take acquisition.

In order to satisfy the requirement of a common azimuth ground spectrum the relative squint angles have to be adjusted. The second acquisition squint has to fit into the required relative squint angle of the 5 day interferogram (1st and 2nd acquisition) as well as of the 1 day interferogram (2nd and 3rd acquisition). For the acquisition over the Ronne ice shelf, described in section 4, the angles were determined to 0.04°, -1.45° and 1.53°, resulting in relative squints of -1.49°and 2.98°. Again, due to the symmetry also the azimuth spectral shift of the third possible interferogram between the first and the last acquisition (6 day lag) is eliminated in this configuration.

The impact of the range spectral shift was minimized in the interferograms by exploiting high incidence angles of around 47.2°. Additionally, the 300 MHz pulse bandwidth of TSX/TDX was used, yielding a reduced scene size of 15 km in range. The size in azimuth is approximately 80 km. The resolution is 0.9 x 2.6 m^2.

3. ACQUISITION AREAS AND TIMELINE

A reasonably flat test site located on the Ronne ice shelf in Antarctica (see Fig. 1), was chosen due to the high latitude in the southern hemisphere (78°S, 56.5°W) and the expected lower temporal decorrelation by surface melt processes in the current local winter time. Furthermore, the ice shelf is known to inherit ice surface motion and is therefore even more interesting w.r.t. short-term monitoring. The first two acquisition triplets were executed with a 300 MHz pulse bandwidth (see Fig. 3, *"Glacier300"*). The configuration of these acquisitions were described in section 2 and the results of the triple acquisition on the 1st, 5th and 6th May, 2011 are shown in section 4. The same test site was also acquired with a 150 MHz bandwidth in order to increase the swath width to 30 km (*"Glacier150"*). In principle, good results are possible as well, but two of the first interferograms with the smaller bandwidth suffered most probably from bad weather conditions, i.e. no coherence could be observed within the 5 and 6 day interferograms. The data sets acquired since August, 2011 are not fully processed yet. Furthermore, a

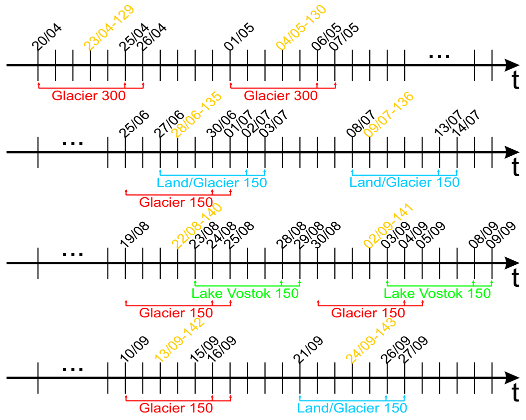

Figure 3. Current status of acquisition timeline with all triple acquisitions over three test sites.

second test site was chosen on the Ronne ice shelf close to the first one, but including a grounding line, i.e. a transition area of land and glacier (*"Land/Glacier150"*). Due to relatively strong topography and the lack of a DEM the interferometric processing will be a challenge. TSX/TDX bistatic acquisitions are planned in order to support the interferogram generation with high resolution DEM data.

A third test site over Lake Vostok in Antarctica was chosen as well. The relatively flat area, the possible ground control points at Vostok station and the expected low temporal decorrelation promise good results. Over all test sites the triple acquisition was at least once acquired again after 11 days, i.e. after one repeat-pass cycle. This offers the possibility to perform regular repeat-pass interferograms for comparison. From a time series of one acquisition triplet each month, investigations of seasonable changes could be obtained. Fig. 3 shows the timeline of all current acquisitions.

4. FIRST INTERFEROMETRIC RESULTS

In this section the results of the 300 MHz Ronne ice shelf triple acquisition are presented and discussed. An intensity image of the scene is shown in Fig. 4. On the left side of the image some little topographic structure is visible.

Fig. 6 shows from top to bottom the phase and coherence of the 1 day lag, the 5 day lag, the 6 day lag and the 11 day lag (repeat-pass) acquisition. Despite the mostly low coherence, fringes are perfectly visible in all interferograms. The fringes presumably originate from geophysical features, due to the 11 day repeat-pass interferogram containing the same fringes. The almost total loss of coherence in the 11 day interferogram is because of tempo-

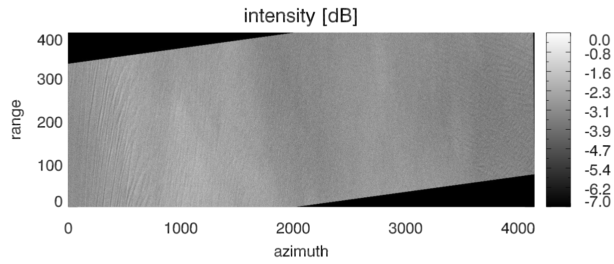

Figure 4. Intensity image, Ronne ice shelf, May 7th, 2011.

ral decorrelation, since the baseline is short and constant in this configuration.

The fringes in azimuth can result from a reference height error, as no DEM was available. Only the WGS84 ellipsoid was used for the flat earth removal. A height offset together with the strong varying baseline results in a linear phase ramp, which should be equal for the 5 and 6 day interferogram but different for the 1 day one. The fringes in range arise presumably from a gradient in the surface velocity of the glacier. Due to the lack of ground control points only a relative radial velocity of 0.1 m/day was obtained, see section 5. Fig. 5 shows the absolute velocity of around 1.8 m/day, which is estimated by using the range and azimuth coregistration offsets. This value is in the same order of magnitude as the measurements presented in [7].

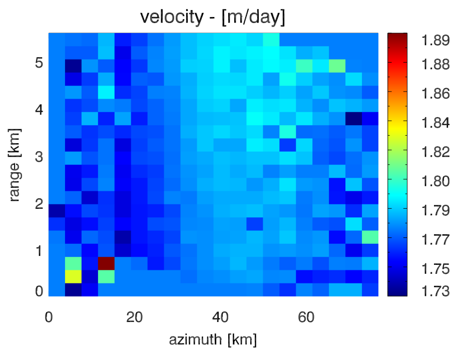

Figure 5. Absolute glacier surface velocity of the Ronne ice shelf.

The azimuth coherence trend for each interferogram matches perfectly with the baseline characteristic in Fig. 7. Approaching the zero baseline the coherence is relatively good, i.e. 0.8 (see Fig. 8). The increasing baselines result in a loss of coherence, which follows from volume decorrelation due to the increasing incidence angle difference. Geometric decorrelation was eliminated by azimuth adaptive spectral range filtering.

5. SURFACE VELOCITY AND TOPOGRAPHY

Fig. 9 and Fig. 10 show the low and high pass filtered total unwrapped phase of the 1 and 5 day interferograms.

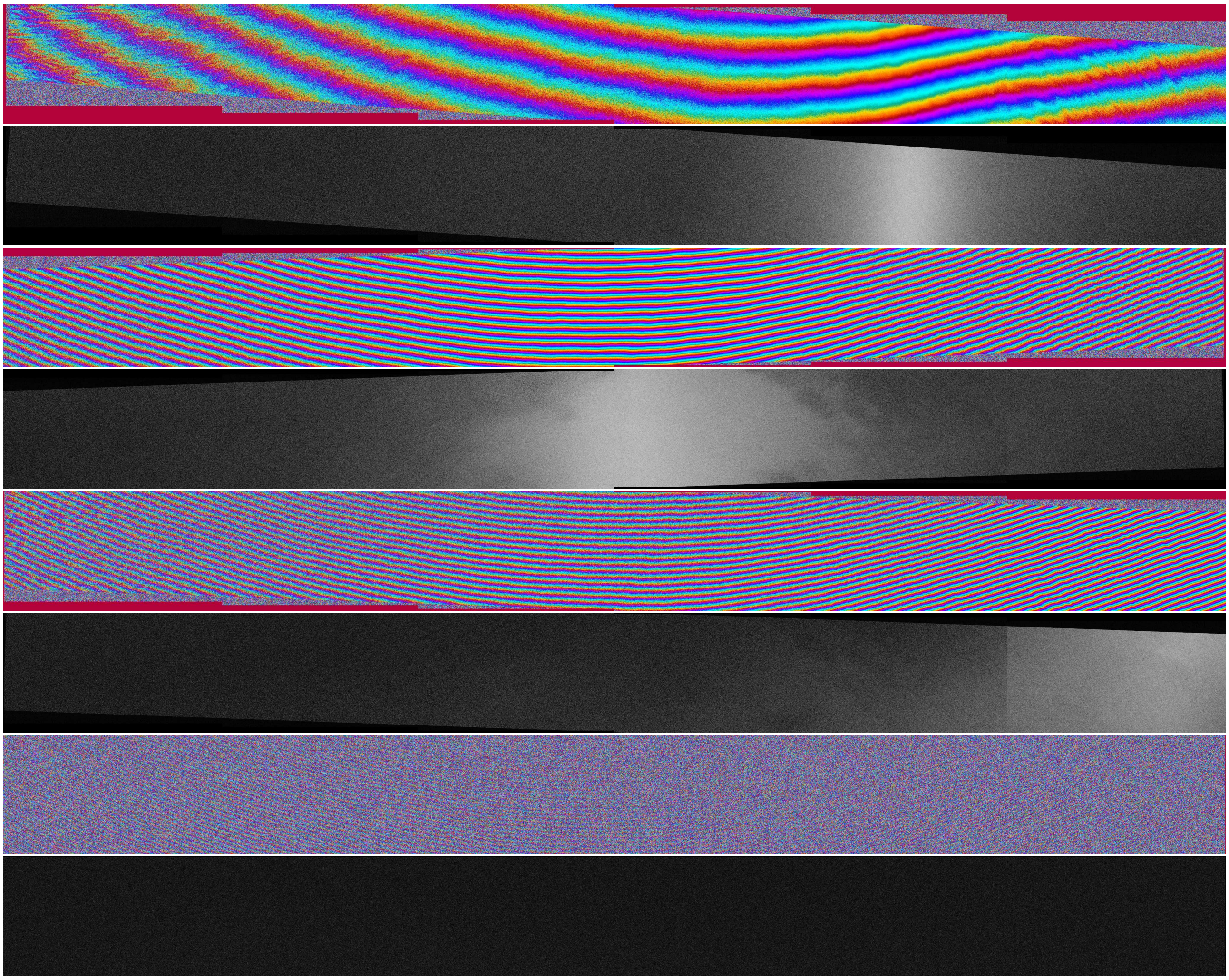

Figure 6. Phase and coherence of crossing orbit interferograms over Ronne ice shelf. From top to bottom: 1, 5, 6, 11 day lag interferogram, each with phase and coherence. The coherence range is from 0 to 0.8. The 11 day lag is the nominal repeat-pass cycle of TSX/TDX. (Range from bottom to top, Azimuth from right to left)

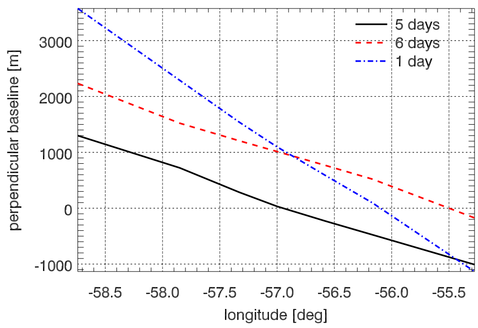

Figure 7. Baselines of crossing orbit interferograms of the triple acquisition over Ronne ice shelf.

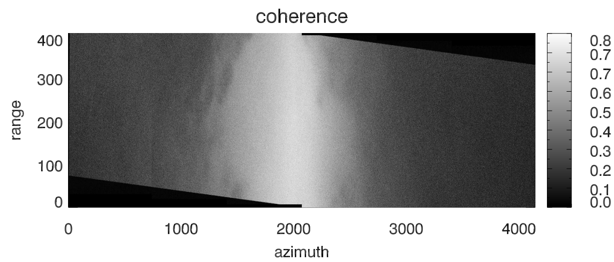

Figure 8. Coherence of 5 day lag interferogram.

Assuming that the impact of the surface velocity gradient is much stronger than of the very little topography, the low-pass filtered phase in Fig. 9a is related to the radial velocity gradient, which is 0.1 m/day, and the high-pass filtered phase in Fig. 9b is partly related to topography, i.e. before and after the zero baseline position. Some topographic details in the left area of the intensity image in Fig. 4 can be noticed as well in the high-pass filtered phase of Fig. 9b.

The phase of the 5 day interferogram in Fig. 10 is normalized to 1 day. It shows the same results w.r.t. relative velocity and topography like Fig. 9. The phase related

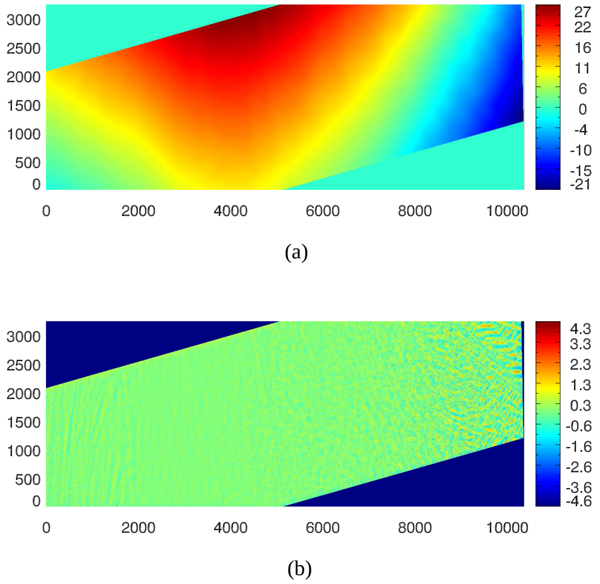

Figure 9. (a) Low-pass filtered and (b) high-pass filtered total unwrapped phase of 1 day interferogram (in radians).

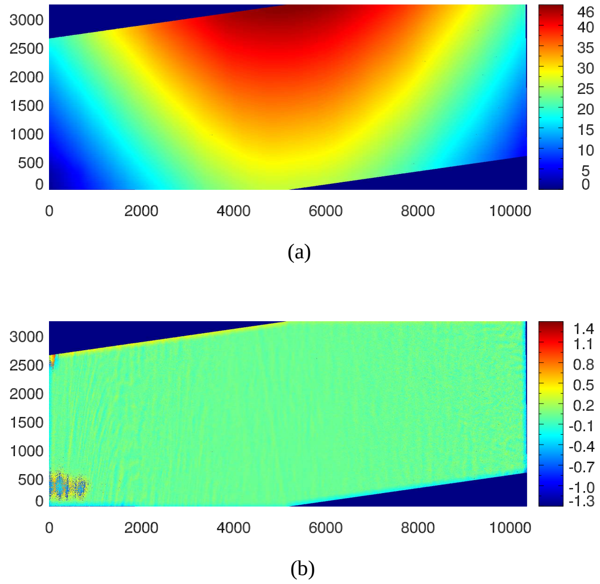

Figure 10. (a) Low-pass filtered and (b) high-pass filtered total unwrapped phase of 5 day interferogram normalized to 1 day (in radians).

to the topography is not as detailed, since the baseline is more slowly increasing as in the 1 day case (cp. Fig. 7). Due to the polar region the atmospheric influence is expected to be comparably low.

6. CONCLUSION AND OUTLOOK

Quasi repeat-pass SAR interferometry with short revisit times under crossing orbits was demonstrated by the shown results. The proposed experiment is feasible for 1, 5 and 6 day lags in case of TSX and TDX. The spectral requirements as well as the configuration of a special triple acquisition geometry were introduced. It is composed of three data takes executed in three different orbits, which are not parallel to each other. This offers the possibility to generate three quasi repeat-pass interferograms within one repeat cycle for a given target area additionally to the regular repeat-pass interferogram. But although the accessible geographic areas are very limited to a range of latitudes in the polar regions, promising applications in glacier and ice shelf monitoring, like short-term surface velocity measurements or high resolution DEMs, could be performed in these areas with a repeat-pass SAR system.

In the future, further investigations are planned including other test sites and 150 MHz acquisitions in order to increase the swath width. The current timeline was presented in section 3. Furthermore, TSX/TDX bistatic DEM acquisitions over these areas are planned in order to support the studies w.r.t. topography. From a time series even more geophysical information, e.g. about seasonal changes, could be retrieved.

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