TerraSAR-X TOPS, ScanSAR and WideScanSAR interferometric processing

Nestor Yague-Martinez, TU München, Chair of Remote Sensing Technology, Munich, Germany
Fernando Rodriguez-Gonzalez, DLR, Remote Sensing Technology Institute, Weßling, Germany
Ulrich Balss, DLR, Remote Sensing Technology Institute, Weßling, Germany
Helko Breit, DLR, Remote Sensing Technology Institute, Weßling, Germany
Thomas Fritz, DLR, Remote Sensing Technology Institute, Weßling, Germany

Abstract

The German TerraSAR-X and TanDEM-X satellites are able to acquire images operationally in ScanSAR and WideScanSAR modes and experimentally in TOPS mode. This paper gives an overview of the interferometric processing steps of burst-mode acquisitions, emphasizing the importance of the co-registration stage. A co-registration approach based on incoherent cross-correlation is presented. Interferometric results, including differential interferogram, of TerraSAR-X repeat-pass images are provided.

1 Introduction

SAR images acquired in ScanSAR and TOPS mode are of great interest due to their wide-swath coverage. This is achieved by switching cyclically the antenna elevation beam to different range subswaths. The TOPS (Terrain Observation by Progressive Scans) imaging mode, introduced by De Zan and Monti Guarnieri [1], performs additionally an azimuth scanning per subswath, in this way the scalloping effect, present in ScanSAR images, is reduced.

The German TerraSAR-X and TanDEM-X satellites are able to acquire images operationally in ScanSAR mode providing a range extension of 100 km (4 beams). The new operational WideScanSAR mode, introduced in August 2013, increases the range extension (between 194 and 266 km) by using 6 beams. The TOPS acquisition mode was first demonstrated experimentally by Meta et al. [2] with the TerraSAR-X satellite exploiting its electronically steered antenna in azimuth.

Prats-Iraola et al. [3] have addressed the problematic of the interferometric processing of TOPS data and have stressed the high accuracy requirement for the coregistration.

The aim of this paper is to present the current status about interferometric processing of ScanSAR and TOPS data in preparation for future algorithm development towards Persistent Scatterer Interferometry (PSI) for wide area [4]. TerraSAR-X repeat-pass images acquired in ScanSAR and TOPS mode have been processed using the operational Integrated TanDEM-X Processor (ITP) [8]. The SAR processing algorithms of ITP are based on the TerraSAR-X Multi-mode SAR Processor (TMSP) [5]. TMSP supports the processing of ScanSAR data and has been extended to support TOPS data. The interferometric chain of ITP has also been extended to support TOPS and ScanSAR data. The paper shows results of WideScanSAR and TOPS interferograms.

2 TOPS and ScanSAR data spectral properties

The spectral properties of TOPS and ScanSAR focused bursts are similar. Both modes present a linear Doppler frequency variation over azimuth. The only difference from the interferometric processing point of view is that the Doppler frequency variation of TOPS is much higher than that of ScanSAR, imposing more demanding coregistration accuracies for TOPS than for ScanSAR.

3 Methodology

As it has been mentioned in the previous section, the interferometric processing chain for all three modes shares common algorithms. Figure 1 depicts the block diagram that describes the processing of every burst. The raw bursts are processed by TMSP and the focussed bursts are generated. The master and slave bursts are firstly filtered to common spectra in range and azimuth. High co-registration accuracy in azimuth is needed to avoid interferometric phase bias, as pointed out in [7] and [3]. The proposed coregistration approach consists on a geometric prediction of the shifts using precise orbit information and an external DEM from e.g. the Shuttle Radar Topography Mission (SRTM). Our proposal to obtain high accuracy is to apply correlation techniques in order to correct residual deviations of the geometric co-registration estimates. These deviations are due to orbital error and/or shifts induced by geodynamic ef-

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fects. Depending on the particular deformation scenario, a simple offset correction may suffice or a more sophisticated method can be necessary (depicted in Figure 1 by the block co-registration correction model).

After the slave burst has been resampled the burst interferogram can be computed and the burst coherence estimated. In order to generate the interferogram and coherence of every subswath, a mosaicking of the bursts interferograms and bursts coherences is done. The interferogram and coherence of the whole scene is afterwards obtained by mosaicking the corresponding subswaths. The differential phase is obtained by subtracting the SRTM simulated phase from the scene interferogram (not depicted in Figure).

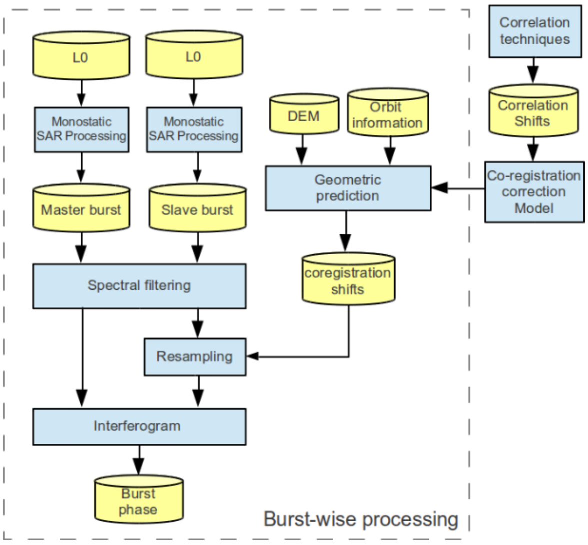

Figure 1. Block diagram of the burst-wise processing

3.1 Necessary Coregistration accuracy

The coregistration requirements for burst mode data are more demanding than for conventional stripmap data due to the significant Doppler frequency variation of the focused bursts. Scheiber and Moreira [7] performed an analysis of the phase bias introduced due to a misregistration error in the case of squinted acquisitions. For the case of a varying Doppler centroid frequency over azimuth, a phase ramp appears, being the excursion:

$$\Delta\phi_{\mathrm{burst}} = 2\pi\Delta f_d \Delta t \approx \frac{4\pi}{\lambda} v_s \Delta\varphi_d \Delta t$$

Where a rectilinear orbit and a flat non-rotating Earth has been assumed, v_s is the platform velocity, Δf_d is the Doppler frequency variation in azimuth within the burst, $\Delta\varphi_d$ the corresponding squint angle variation and Δt is the mis-registration between master and slave bursts, in seconds.

The necessary azimuth co-registration accuracy for TerraSAR-X ScanSAR, WideScanSAR and TOPS modes is summarized in Table 1 (allowing an interferometric phase error variation along the burst of 3°). TMSP applies a 2.2 oversampling factor in azimuth.

	ScanSAR	WideScan-SAR	TOPS
Azimuth resolution	18.5 m	40 m	18.5 m
Azimuth pixel spacing	8.4 m	18. 2 m	8.4 m
Needed Azimuth co-registration accuracy	0.004 pix 0.002 r.e. (3.3 cm)	0.002 pix 0.001 r.e. (4.3 cm)	0.001 pix 0.0005 r.e. (8.8 mm)

Table 1. Required azimuth co-registration accuracy for all three modes (typical values), allowing a maximum interferometric phase error variation along the burst of 3°.

De Zan provides the accuracy of the incoherent cross-correlation in [6]. The theoretical maximal achievable accuracy for ScanSAR, WideScanSAR and TOPS mode with incoherent cross-correlation using all available pixels of the scene is shown in Figure 2 (correction of a rigid offset).

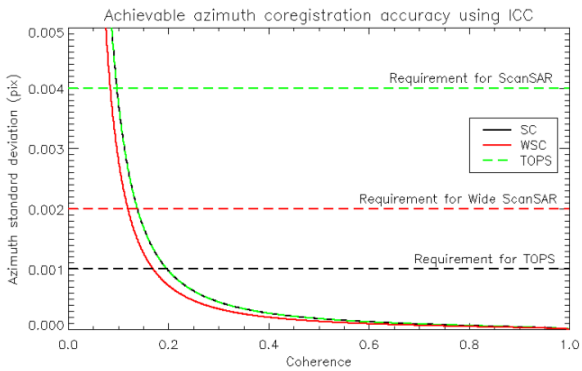

Figure 2: Theoretical maximal achievable azimuth coregistration accuracy using all available pixels of the scene. Assumed acquisition sizes: 100 x 150 km for ScanSAR and TOPS, 230 x 200 km for WideScanSAR.

3.2 Co-registration for Stationary Scenes

If no deformation is expected and the orbits of both acquisitions are parallel, a correction of the geometric estimates with a constant value, as proposed in [3], provides satisfactory results. The offset can be calculated as the median of the differences between the geometrical and the cross-correlation estimates. Section 4.1 provides a validation of this co-registration approach by compar-

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ing the interferometric phase at the inter-burst overlapping regions of a stationary scene with TerraSAR-X TOPS data.

3.3 Co-registration for Deformation Mapping Applications

If the scene under study presents deformation in range direction (i.e vertical and or East-West direction on ground), no considerable phase bias will appear due to a possible range mis-registration. In section 4.2 a TOPS differential interferogram over Mexico City will be shown. However if deformation is expected in the azimuth direction (mainly North-South direction), e.g scenes that cover seismic activity, glaciers, etc, a more complex co-registration correction model may be necessary. This case is out of the scope of this paper and will not be covered.

4 Results

In the following three sub-sections some results with TerraSAR-X and TanDEM-X data are presented.

4.1 TOPS interferogram of a stationary scene: Salar de Uyuni

Two TerraSAR-X acquisitions in TOPS mode acquired on 10.10.2007 and on 21.10.2007 in descending geometry over Salar de Uyuni, Bolivia have been used to generate an interferogram. The effective baseline in the centre of the scene is 57 m. The incidence angle ranges from 36° to 44°. Figure 3 shows the interferometric phase of the whole scene.

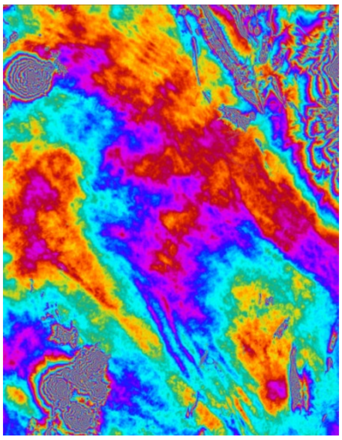

Figure 3. Interferometric phase of the TOPS scene over Salar de Uyuni (4 beams, 13 bursts / beam). Range direction is horizontal. The image covers an extension of 100 km x 130 km.

The approach for the co-registration has been validated in terms of inter-burst phase comparison. The phase differences in the overlapping areas of the first beam provide a median value of 0.88 degree, being the standard deviation 62.6 degrees. Figure 4 shows the histogram of the phase differences. The mean coherence of the beam is 0.79. Figure 5 shows the phase differences in the burst overlapping areas of the first TOPS beam, presenting values of a few degrees, which confirms the validity of the coregistration approach based on incoherent cross-correlation.

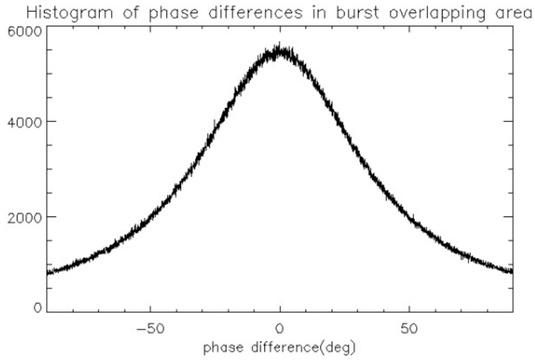

Figure 4. Histogram of the phase differences of all burst overlapping areas of the first TOPS beam.

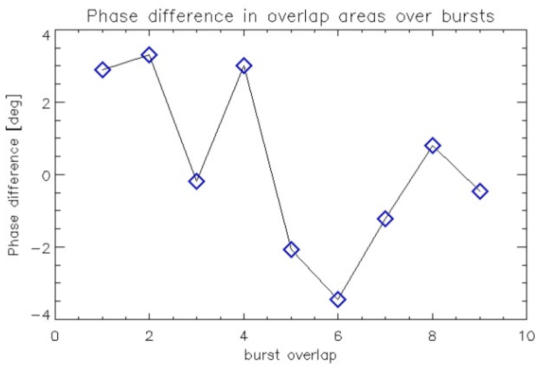

Figure 5. Phase differences in the burst overlapping areas of the first TOPS beam.

4.2 TOPS Interferogram of a scene with deformation

Two TerraSAR-X acquisitions in TOPS mode acquired on 20.09.2009 and on 17.12.2009 in descending geometry over Mexico City have been used to generate an interferogram. The effective baseline in the centre of the scene is 132 m. The incidence angle ranges from 24° to 35°.

Figure 6 shows the differential interferometric phase (SRTM simulated phase compensated) of the whole scene. Observe the fringe pattern over the city due to deformation (reported also in [4]).

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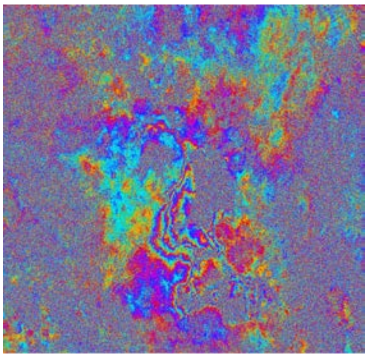
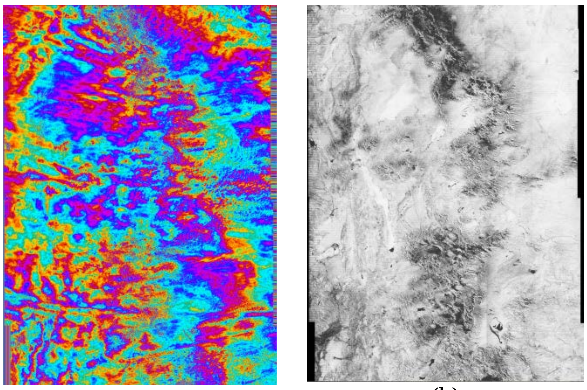


Figure 6: TOPS differential interferometric phase over Mexico City. The temporal Baseline is 88 days. Range direction is horizontal. The image covers an extension of 100 km x 100 km.

4.3 WideScanSAR Interferogram

A WideScanSAR interferometric pair over Salar de Arizaro, in north-western Argentina, has been selected to demonstrate the interferometric potential of the WideScanSAR mode. The images were acquired on 04.09 and 26.09.2013 in descending geometry. The effective baseline in the centre of the scene is 38 m. The incidence angle varies from 26° to 45°. Figure 7 shows the differential phase (w.r.t. SRTM) and the coherence.



(a) (b)

Figure 7. Differential phase (a) and Coherence (b) of the WideScanSAR interferogram over Salar de Arizaro (6 beams, 224 bursts / beam). Range direction is horizontal. The image covers an extension of 230 km x 430 km.

5 Conclusions

In this paper the authors provide results about the processing of TerraSAR-X ScanSAR, WideScanSAR and TOPS data from L0 level till differential interferogram. The validity of ITP for TOPS processing, and especially the co-registration approach based on correlation, has been demonstrated by an inter-burst comparison of the interferometric phase. Examples of a TOPS interferogram for deformation mapping applications (over Mexico City) and a WideScanSAR interferogram has been as well provided.

Acknowledgements

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References

[1] F. de Zan and A. Monti Guarnieri. TOPSAR: Terrain Observation by Progressive Scans, IEEE Transactions on Geoscience and Remote Sensing, Vol. 44, No. 9, September 2006, pp 2352-2360.

[2] A. Meta, J. Mittermayer, P. Prats, R. Scheiber and U. Steinbrecher. TOPS Imaging with TerraSAR-X: Mode Design and Performance Analysis. IEEE Transactions on Geoscience and Remote Sensing, Vol. 48, No. 2, February 2010, pp 759-769.

[3] P. Prats-Iraola, R. Scheiber, L. Marotti, S. Wollstadt and A. Reigber. TOPS Interferometry with TerraSAR-X, IEEE Transactions on Geoscience and Remote Sensing, Vol. 50, No. 8, August 2012, pp 3179-3188.

[4] Adam, N.; Rodriguez Gonzalez, F.; Parizzi, A. and W. Liebhart. Wide area persistent scatterer interferometry, in Proc. IGARSS, 2011, pp. 1481-1484, Vancouver, Canada, 2011.

[5] H. Breit, T. Fritz, U. Balss, M. Lachaise, A. Niedermeier, M. Vonavka. TerraSAR-X SAR Processing and Products. IEEE Transactions on Geoscience and Remote Sensing, Vol. 48, No. 2, February 2010, pp 727-740.

[6] F. de Zan. Accuracy of incoherent Speckle Tracking for circular Gaussian Signals. IEEE Geoscience and Remote Sensing Letters. 2013

[7] R. Scheiber and A. Moreira. Coregistration of Interferometric SAR Images Using Spectral Diversity. IEEE Transactions on Geoscience and Remote Sensing, Vol. 38, No. 5, September 2000, pp 2179-2191.

[8] N. Yague-Martinez, C. Rossi, M. Lachaise, F. Rodriguez-Gonzalez, T. Fritz, H. Breit. Interferometric processing algorithms of TanDEM-X data, in Proc. IGARSS, 2010, pp. 3518 – 3521, Honolulu, 2010.

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