INVESTIGATIONS ON TOPS INTERFEROMETRY WITH TERRASAR-X

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1. INTRODUCTION

This paper presents results on SAR interferometry with the so-called TOPS mode. The rationale in order to retrieve accurate interferometric products with such a mode is expounded, emphasizing the critical step of co-registering the pairs. Due to the particularities of the TOPS mode, a high Doppler-centroid is present at burst edges, demanding of very fine co-registration approaches. A co-registration accuracy of one tenth of a pixel, as it is usually recommended with interferometric applications, will result in a large undesired azimuth phase ramp in the TOPS mode, above all at X-band. This paper presents an approach to estimate this offset with the required accuracy. Experimental results with repeat-pass TerraSAR-X data are shown to validate the proposed approach.

2. THE TOPS MODE

TOPS (Terrain Observation by Progressive Scans) has been proposed as a new wide-swath imaging mode [1]. It overcomes the problems of scalloping and azimuth-varying signal-to-ambiguity ratio of the conventional ScanSAR mode by means of steering the antenna in the along-track direction. To achieve the same swath coverage and avoid the undesired effects of ScanSAR, the antenna is rotated throughout the acquisition from backward to forward at a constant rotation rate, opposite to the spotlight case. The fast steering leads to a reduction of the observation time, and consequently a worsening of the azimuth resolution. However, now all targets are observed by the complete azimuth antenna pattern, and therefore the scalloping effect disappears and azimuth ambiguities and signal-to-noise ratio become constant in azimuth. At the end of the burst, the antenna look angle is changed to illuminate a second subswath, pointing again backwards. When the last subswath is imaged, the antenna points back to the first subswath, so that no gaps are left between bursts of the same subswath.

Fig. 1(a) shows the time-frequency diagram (TFD) of one TOPS burst. The total azimuth bandwidth spans several PRF intervals, as in the spotlight case. Note also, that the rotation center is located behind the sensor, and as it happens in the ScanSAR mode, the focused burst is much larger than the raw data burst, requiring special care when performing the azimuth focusing. Note in Fig. 1(a) the dependence of the Doppler centroid with the azimuth position of the target within a burst, which can reach several PRF intervals (the PRF is the gray area for a given time instant).

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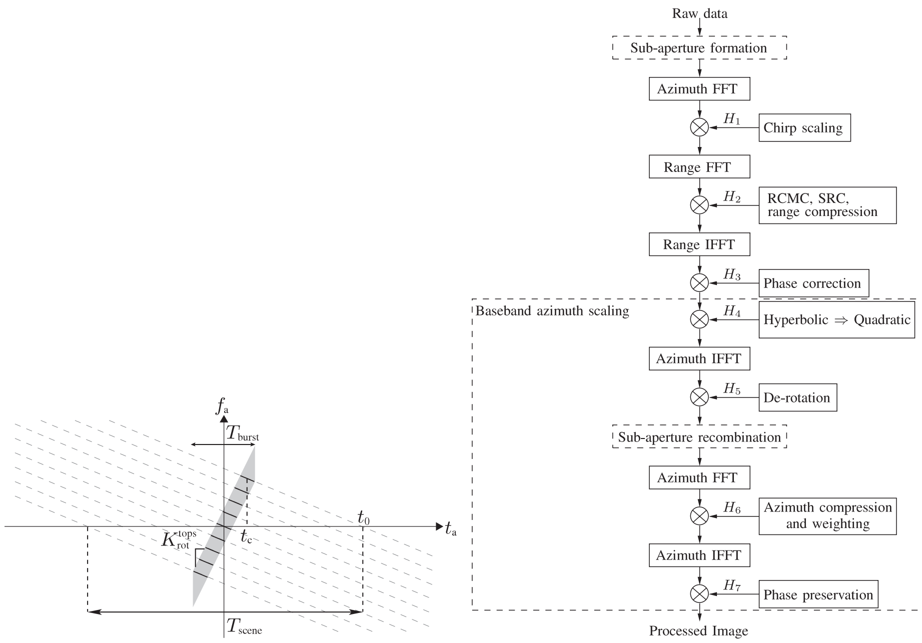

(a) (b)

Fig. 1. (a) Time frequency diagram in the TOPS mode. (b) Block diagram of the TOPS processor with ECS and BAS.

3. TOPS PROCESSING

In order to retrieve accurate interferometric products, a phase-preserving processor is necessary. Baseband azimuth scaling (BAS) has been proposed as an efficient phase-preserving processor for the TOPS imaging mode, as well as being suitable for sliding-spotlight and ScanSAR [2]. Fig. 1(b) shows its block diagram, where the so-called extended chirp scaling (ECS) [3] is used for the range-variant processing, while BAS is used for the efficient focusing of the azimuth signal. In order to accommodate for the signal azimuth bandwidth, which in the TOPS mode is larger than the system PRF, a sub-aperture processing is performed, so that the sub-aperture bandwidth fits within the PRF. Afterwards, BAS is used to perform the azimuth focusing in an efficient way, as note that the signal bandwith still spans several over the PRF interval. Furthermore, the scene extension is larger than the raw data burst. BAS consists in a modified azimuth scaling approach, which solves these two problems simultaneously in an efficient way.

Fig. 2 shows a TOPS data take over Flevoland processed with the proposed processor with a commanded resolution of 16m. Note the absence of scalloping.

4. TOPS INTERFEROMETRY

4.1. Co-registration Accuracy Requirements

Similar as with ScanSAR, a precise knowledge of both the pointing accuracy and the along-track position are necessary in order to retrieve an interferometric pair with overlapping spectra [4]. However, one of the most challenging aspects in TOPS interferometry is the fact that the acquired data have large Doppler-centroid variations within a burst. For typical TerraSAR-X TOPS acquisitions, the Doppler centroid can vary by more than 10 kHz within one burst. It is well known that in presence of squint, linear phase ramps are induced in the focused response both in azimuth and range [5, 6]. Thus, constant misregistration can cause the presence of along-track and across-track linear phase ramps, of which the latter is in most cases negligible. However, since each TOPS burst is acquired with a varying Doppler centroid every focused point presents a different linear

Fig. 2. TOPS acquisition over Flevoland. Azimuth is horizontal and range is vertical, with near range on the top.

phase ramp in the azimuth direction. The slope of the ramp depends on the Doppler centroid. The resulting interferometric TOPS phase bias in the presence of azimuth misregistration is similar to the ScanSAR bias and is equal to [6]

$$\phi_{\text{azerr}} = 2\pi f_{\text{DC}} \Delta t, \tag{1}$$

where f_{DC} is the Doppler-centroid and Δt is the co-registration error in seconds. Within a burst, this corresponds to a linear phase term along azimuth, since f_{DC} is a function of the azimuth position within the burst. For a TerraSAR-X acquisition with Doppler variation of 10.35kHz, pixel spacing of 8.69 meter, a misregistration of 0.1 pixel spacing introduces a ramp of approximately 2.5π within the burst. Therefore, an overall azimuth coregistration accuracy of better than 0.001 of the pixel spacing is required for this configuration, in order to achieve an error smaller than $10°$.

4.2. Fine Co-registration with Spectral Diversity

Note that the above requirement applies mainly to a constant coregistration offset for the whole burst, and the achievable relative coregistration accuracy can be much better than this requirement. First, a coregistration can be performed either using orbit's information and an external DEM, amplitude cross-correlation, or coherence maximization, all of which yield accuracies better or around one tenth of a pixel. Then a fine coregistration using spectral diversity [6] would result in the required fine accuracy. Due to the high-demanding requirements in terms of co-registration accuracy, this paper proposes the use of spectral diversity in the overlapping region between two consecutive TOPS bursts. Since the spectral separation between the end of a burst and the beginning of the next one is much larger than the separation that one can achieve within the footprint, a much higher accuracy can be obtained. The accuracy in the estimation of the co-registration error is given by [6]

$$\sigma_{\Delta t} = \frac{\sigma_{\phi_{\text{sd}}}}{2\pi \Delta f}, \tag{2}$$

where ϕ_{sd} is the spectral diversity phase, and Δf is the distance between the two looks. Substituting eq. (2) in (1), and assuming that $\Delta f = 2f_{\text{DC}}$, as it is the case when using two consecutive bursts, gives a final phase error equal to

$$\sigma_{\phi_{\text{azerr}}} = \frac{\sigma_{\phi_{\text{sd}}}}{2}, \tag{3}$$

i.e. the final error in the interferogram is half of that in the spectral diversity phase and *independent of the Doppler centroid*. Hence, the final accuracy is a function of the coherence and the number of looks performed in the spectral diversity phase [6, 7]. Since a previous fine coregistration is assumed and only a constant offset is of interest, a large amount of samples can be averaged, which will yield in most cases the required accuracy.

5. EXPERIMENTAL RESULTS

A time series are being acquired over Flevoland with TerraSAR-X. Different coherence levels can thus be evaluated to demonstrate the performance of the co-registration (phase calibration) approach. **The paper will contain several evaluation results on this data set, paying special attention on the aforementioned considerations.**

6. REFERENCES

[1] Francesco De Zan and Andrea Monti Guarnieri, "TOPSAR: Terrain observation by progressive scans," *IEEE Trans. Geosci. Remote Sensing*, vol. 44, no. 9, pp. 2352–2360, Sept. 2006.

[2] Pau Prats, Rolf Scheiber, Josef Mittermayer, Adriano Meta, and Alberto Moreira, "Processing of sliding spotlight and TOPS SAR data using baseband azimuth scaling," *IEEE Trans. Geosci. Remote Sensing*, Feb. 2010.

[3] A. Moreira, J. Mittermayer, and R. Scheiber, "Extended chirp scaling algorithm for air- and spaceborne SAR data processing in stripmap and ScanSAR imaging modes," *IEEE Trans. Geosci. Remote Sensing*, vol. 34, no. 5, pp. 1123–1136, Sept. 1996.

[4] Adriano Meta, J. Mittermayer, Pau Prats, Rolf Scheiber, and Ulrich Steinbrecher, "TOPS imaging with TerraSAR-X: Mode design and performance analysis," *IEEE Trans. Geosci. Remote Sensing*, Feb. 2010.

[5] M. Bara, R. Scheiber, A. Broquetas, and A. Moreira, "Interferometric SAR signal analysis in the presence of squint," *IEEE Trans. Geosci. Remote Sensing*, vol. 38, no. 5, pp. 2164–2178, Sept. 2000.

[6] R. Scheiber and A. Moreira, "Coregistration of interferometric SAR images using spectral diversity," *IEEE Trans. Geosci. Remote Sensing*, vol. 38, no. 5, pp. 2179–2191, July 2000.

[7] R. Bamler and Michael Eineder, "Accuracy of differential shift estimation by correlation and split-bandwidth interferometry for wideband and Delta-k SAR systems," *IEEE Geosci. Remote Sensing Lett.*, vol. 2, no. 2, pp. 151–155, Apr. 2005.