Evaluation of Radargrammetry DEMs based on TerraSAR-X Staring SpotLight Imagery

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Zusammenfassung: Seit einigen Jahren wird Radargrammetrie mit hochaufgelösten Synthetic Aperture Radar (SAR) Daten im wissenschaftlichen und kommerziellen Bereich für Digitale Höhenmodellierung (DHM) angewendet. Im Vergleich zur Interferometrie mit Eingangsdaten aus unterschiedlichen Zeitpunkten ist die Radargrammetrie eine robuste Technik der Höhenmodellgenerierung in allen Bereichen der Erde, da hier nicht die Phaseninformationen des Signals genutzt werden. Gerade in Gebieten mit hoher Wolkenbedeckung stellen Radardaten eine zuverlässige Quelle für Fernerkundungsdaten dar. Mit den derzeit kommerziell verfügbaren SAR Satelliten sind Eingangsdaten für die Höhenmodellgenerierung mit wenigen Metern Auflösung verfügbar, im Falle des TerraSAR-X Elevation10 Produktes sind es beispielsweise 3 m Daten aus StripMap Aufnahmen. Mit der Verfügbarkeit des neuen Submeter Aufnahmemodus Staring SpotLight für die TerraSAR-X und TanDEM-X Satelliten ist eine neue Dimension an Eingangsdaten für die radargrammetrische Prozessierung verfügbar. Dieser Artikel wird die Ergebnisse der radargrammetrischen Prozessierung mit Submeter SAR-Daten vom TerraSAR-X Staring SpotLight Aufnahmemodus untersuchen und präsentieren.

Abstract: For several years the technique of radargrammetry with high resolution Synthetic Aperture Radar (SAR) data has been used in scientific and commercial environment for Digital Elevation Modelling (DEM). Compared to repeat pass interferometry, radargrammetry is a robust DEM generation technique for almost all areas on the globe due to phase independent matching algorithms. Particularly in areas with high cloud coverage, SAR systems are the main source to acquire reliable remote sensing data. With the current available SAR satellites, the data typically has a ground resolution in the range of a few meters, e.g. 3 m StripMap data from TerraSAR-X used for the Elevation10 DEM product. With the availability of the new sub-meter Staring SpotLight mode for the TerraSAR-X and TanDEM-X satellites, a new dimension of resolution is available as input for radargrammetric processing. This paper will discuss the results of radargrammetric processing using sub-meter SAR images from TerraSAR-X Staring SpotLight mode.

1 Introduction

Since the launch of the TerraSAR-X satellite in 2007 high resolution Synthetic Aperture Radar (SAR) data have been used as input for Digital Elevation Modelling. The two main techniques for SAR based Digital Elevation Modelling are interferometry and radargrammetry. Both techniques have advantages as well as disadvantages, depending on the characteristics of the Area of Interest and envisaged application. For the majority of areas on Earth, radargrammetry is the more robust

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technique as repeat pass interferometry has to cope with changes on surface, for example in vegetated areas (TOUTIN, 2000).
Since end of 2013 TerraSAR-X and TanDEM-X have been operated with a new sub-meter imaging mode, the Staring SpotLight mode. In contrast to the sliding SpotLight used by all commercial SAR sensors, the center of rotation of the azimuth antenna steering in the Staring SpotLight acquisition is located within the acquired area. For the operation of this acquisition mode, the antenna steering angle has been increased to ±2.2° (MITTERMAYER et al., 2012) compared to ±0.75° with the sliding SpotLight mode.
This new dimension of commercially available very high resolution SAR data opens up new possibilities in high resolution Digital Elevation Model (DEM) generation using spaceborne data. The potential of radargrammetric processing with TerraSAR-X Staring SpotLight data will be discussed in this paper.

2 Radargrammetry using TerraSAR-X Staring SpotLight Images

Data from TerraSAR-X and TanDEM-X satellites is delivered together with highly accurate orbit information within the range of centimeters. Such highly accurate information is a pre-requisite for a precise three dimensional point calculation, as applied in the course of radargrammetric Digital Elevation Modelling.

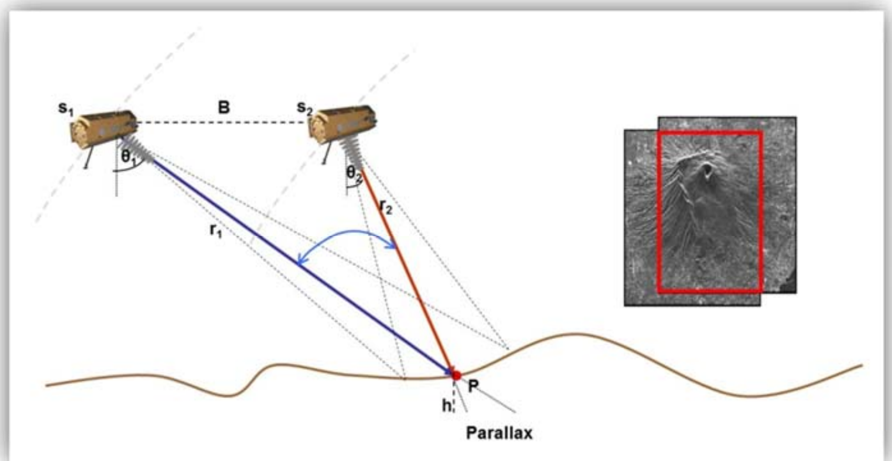

Figure 1: Principle of radargrammetric acquisition scenario

Repeat pass interferometry based on a single satellite does not yield sufficient results in many regions due to decorrelation over vegetated areas. For the TerraSAR-X and TanDEM-X satellites, the repetition frequency is 11 days in monostatic acquisition mode. Any changes on the ground result in a low or no coherence, the basis for interferometric processing. Only images over areas with almost no changes between two coverages, for example rocky deserts, can be taken as input for a highly accurate DEM processing with complete coverage. In all other cases, stereo radargrammetry is a more robust technique for DEM generation. Radargrammetry is based on correlation of (at least) two images (Figure 1). The known orbit positions (S_1 and S_2) as well as the distances to the measured point (r_1 and r_2) are used for the determination of the 3D position, based upon utilization of SAR range and Doppler equations. During the automatic processing, the same features and reflectors will be identified via image matching and used as input for the 3D point calculation (SCHUBERT et al., 2004; RAGGAM et al., 2010b).

2.1 Input Data

Until the end of 2013 TerraSAR-X and TanDEM-X acquired images with a resolution between 1 m and 18.5 m, depending on the acquisition mode. As a trade-off between resolution, vertical accuracy and coverage, typically StripMap images with 3 m resolution were used as input for radargrammetric processing, as applied for the Elevation10 DEM product provided by Airbus Defence and Space.
The very high resolution of the Staring SpotLight mode provides a large potential to generate high resolution DEMs based on radargrammetric processing. For this study, images over the Area of Interest (AoI) Burgau, Austria were collected (see Table 1).

Table 1: Input Images for test site Burgau including central ground resolution is azimuth and range.

Acquisition Mode	Date	Pass Direction	Incidence Angle [°]	Test Site	Azimuth [m]	Range [m]
Staring SpotLight	25.07.2014	Descending	36	Burgau	0.24	0.99
Staring SpotLight	02.08.2014	Ascending	37	Burgau	0.24	0.97
Staring SpotLight	26.07.2014	Descending	56	Burgau	0.24	0.70
Staring SpotLight	01.08.2014	Ascending	56	Burgau	0.24	0.70

The AoI in Burgau (Figure 2) is covered by forest and agricultural land in predominantly flat terrain. The test site has been selected because of the availability of high-quality reference data to be used for the evaluation of the processing results and the challenges inherent to image matching over forest and agricultural land coverage.

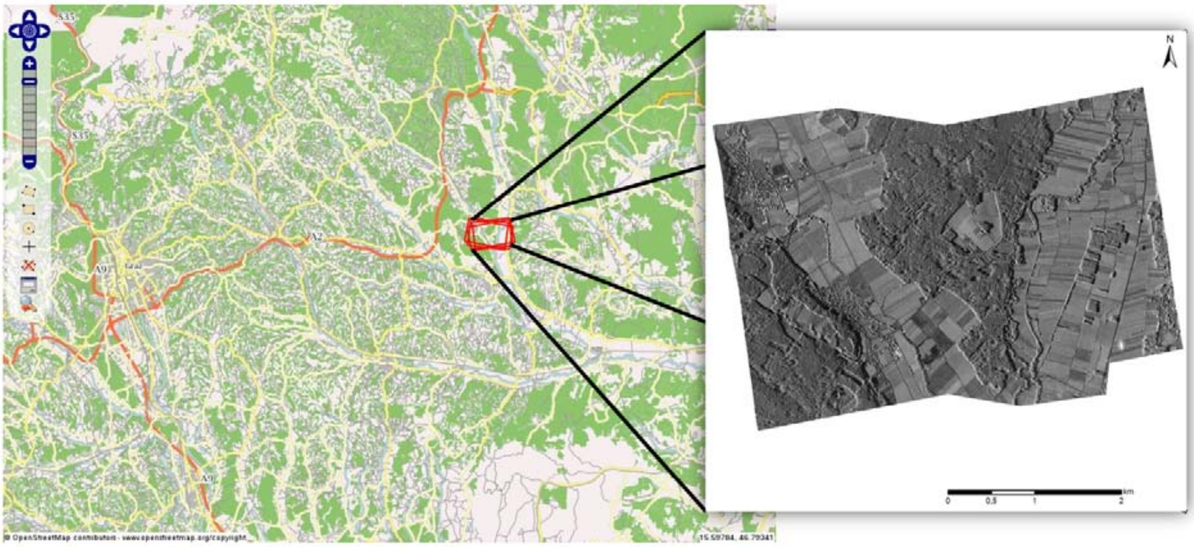

Figure 2: Test site overview for TerraSAR-X acquisitions and radargrammetric processing of Burgau in Austria

2.2 Radargrammetric Processing

The input for radargrammetric processing comprises at least two images acquired with different incidence angles but from the same orbit direction. The choice of the stereo angle as the difference of both incidence angles depends on the available incidence angles and the terrain relief of the AoI. In evaluation results from KIEFL et al., 2010, RAGGAM et al., 2010a, HENNIG et al., 2010, a stereo angle of 15-25° provides the best results for most areas.

As none of the COTS tools for stereoscopic DEM generation are applicable to very high resolution spaceborne SAR data, the SAR stereo processor developed by Joanneum Research and embedded in its Remote Sensing Software Package Graz (RSG) was used for the study. A publication referring to radargrammetric processing of TerraSAR-X SpotLight images with 1 m resolution is available in GUTJAHR et al., 2014.

Within a joint research project (Vision+: Integrated visual Information with independent knowledge; a funding project by FFG – Austrian Research Promotion Agency), an adaptation of this processor is currently under development, aiming at robust, large area, automatic DEM retrieval from sub-meter SAR data such as TerraSAR-X Staring SpotLight images. The main topics will include: (1) Assurance of high (relative) geo-location accuracy which is a prerequisite for epipolar rectification. This accuracy should be below 1 pixel to assure precise stereo disparity estimation (GUTJAHR et al., 2014); (2) Appropriate exploitation of the high azimuth resolution, e.g. by applying a multi-looking to minimize the speckle information; (3) Customization of the stereo matching cost-function with respect to Staring Spotlight data.

First results of the processing are taken as input for the evaluation results.

3 Evaluation Results

For the evaluation and validation of DEMs, a process has been set up within the Elevation10 (http://www.geo-airbusds.com/en/66-geo-elevation-and-dem) product development, the radargrammetric DEM product by Airbus Defence and Space with a 10 m posting. The process includes a visual and a statistical analysis (HENNIG et al., 2010). Additionally to the standard evaluation the radargrammetric processing will be analyzed within this study, as the goal is an improved processing for high resolution SAR imagery.

3.1 Processing Results

For the first phase of the study, the existing radargrammetric processor was used for the processing. The goal of this step is the identification of changes within the results introduced by the very high resolution of the input data.

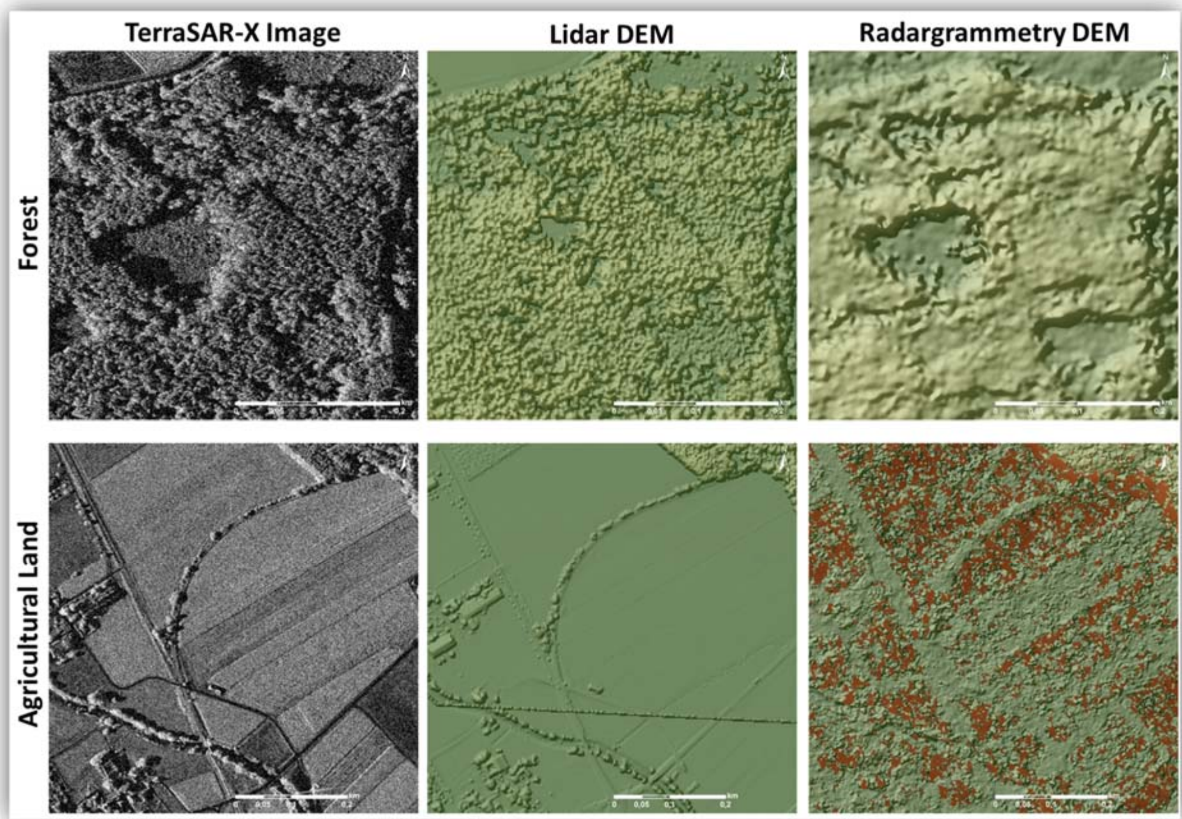

Figure 3: Processing Result over forest and agricultural land (red indicates voids).

The results of the processing show that the principle approach is working. Some challenges have been identified, especially in homogenous areas such as agricultural land, where the matching of the same pixels is extremely difficult due to missing features. Some results of the processing over agricultural areas and forest are shown in Figure 3. The SAR image shows the homogenous backscatter in the fields and the calculated DEM shows large gaps in these areas.

The matching in forest areas works reasonably well, as the high resolution facilitates the identification of crown structures and single trees. The comparison of the data with Lidar DEM data from 2006 and 2007 shows the potential of change detection due to clear-cut and / or storm loss (Figure 4).

3.2 Visual and Statistical Analysis

For the visual and statistical analysis the following data was available (Figure 4);

- SRTM DEM with 90 m resolution (for visual analysis only);
- Lidar DEM with 1 m resolution (for visual and statistical analysis);
- DEM from radargrammetric processing with 1 m resolution.

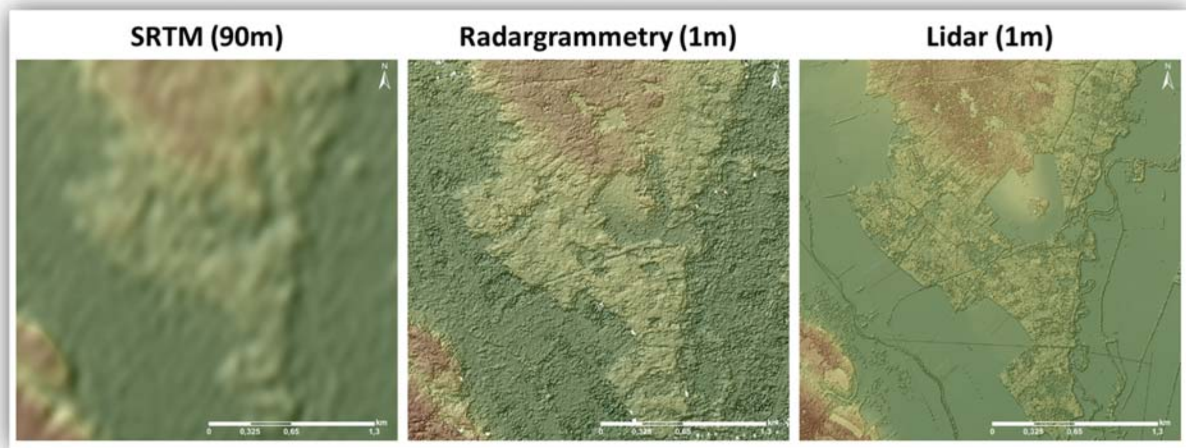

Figure 4: Comparison of SRTM, Radargrammetry DEM and Lidar DEM from test site Burgau

The visual comparison shows significant effect in terms of resolution. SRTM looks much smoother and less detailed than the Radargrammetry and Lidar DEM. As Lidar is based on an airborne system the recognisability of small features is higher than in the spaceborne based Radargrammetry DEM.

The elevation differences between the radargrammetric DEM and Lidar data have been calculated and the results are summarized in Table 2.

Table 2: Statistical Analysis of Radargrammetry DEM in comparison to Lidar DEM

	Lidar vs. Radargrammetry
Minimum [m]	**-38**
Maximum [m]	**52**
Mean [m]	**-1.89**
Standard Deviation [m]	**5.52**

The difference between the highly accurate Lidar DEM and the radargrammetry DEM results in a difference of 5.52 m standard deviation. A major influence on the difference is based on the technological difference of the data acquisition. Using Lidar the return signal could be divided between first- and last pulse. The derived elevation model results in a surface model with almost no penetration of vegetation as the signal is reflected at the top of the vegetation. The Radargrammetry DEM from TerraSAR-X is based on X-band radar data with a wavelength of approximately 3.5 cm. The transmitted signal does penetrate parts of the vegetation and the derived DEM will result in a surface model with an underestimation of vegetation heights. A percentage of the calculated standard deviation between the DEMs is based on the described difference.

Another influence is based on temporal changes between the data acquisitions. The Lidar DEM was acquired in 2006/2007 and the TerraSAR-X data in 2014. Particularly in the forest area some large height differences are noticeable. As visible in a comparison between the Lidar DEM and the SAR image these areas are not covered by forest anymore (Figure 4 and 6). The reasons for the high differences are caused by clear-cuts and / or storm-loss.

The overall differences are mainly in the range of ±4 m which shows the stability of the processing and a high quality of the input data (Figure 5). Outliers and blunders are not removed in the processing results. A DEM editing, which is standard for a commercial product, would improve the overall statistic.

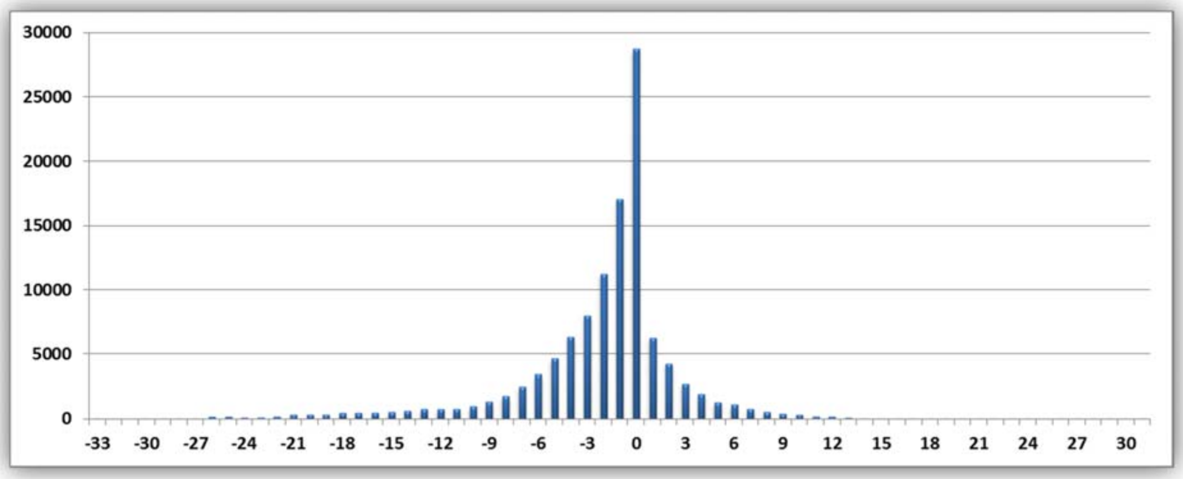

Figure 5: Error distribution of difference image: Lidar DEM - Radargrammetry DEM (error in meters on x-axis and count of pixels on y axis)

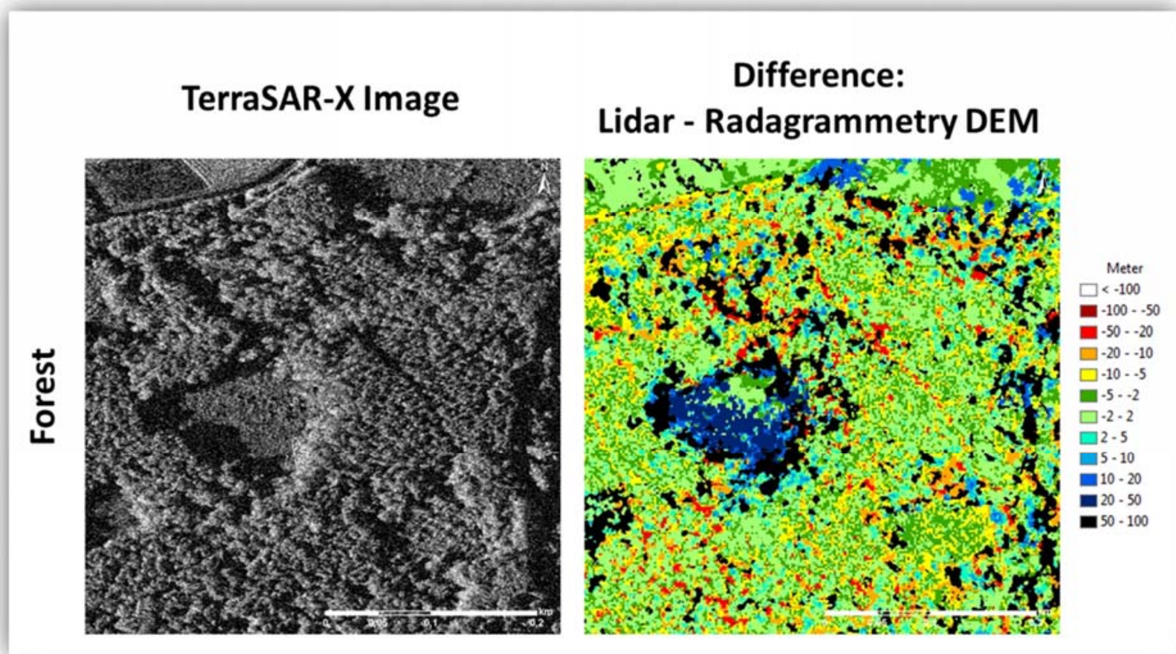

Figure 6: Difference between Lidar and Radargrammetry in forest areas

4 Conclusions and Outlook

The study shows the potential of radargrammetric processing using very high resolution SAR imagery. With the current processing an accuracy of 5.52 m compared to the reference Lidar DEM could be achieved. The accuracy includes acquisition related differences and larger errors caused by height changes in forest areas; the real accuracy is even higher.
The processing indicates room for improvements of the algorithm particularly for homogenous areas. The calculated DEM results in non area-wide coverage and interpolation is required for a complete coverage. In a next step, the algorithm will be adapted to sub-meter resolution SAR image inputs. A higher accuracy of the derived height values and less void areas are expected within the continuation of the development.

5 Literature

KIEFL, N.; HENNIG, S. & KOPPE, W., 2010: TerraSAR-X Stereo Digital elevation models for complex terrain conditions in alpine regions and its suitability for orthorectification purposes of optical and SAR imagery. ISPRS TC VII Symposium – 100 Years ISPRS, Advancing Remote Sensing Science, Wagner, W. & Székely, B. (eds.), Vienna, Austria, July 5–7, 2010, ISPRS Archives **38** (7B), p. 333-336.

GUTJAHR, K.; PERKO, R.; RAGGAM, H. & SCHARDT, M., 2014: The Epipolarity Constraint in Stereo-Radargrammetric DEM Generation. IEEE Transactions on Geoscience and Remote Sensing, **52** (8), p. 5014-5022.

HENNIG, S.D. & DÜRING, R., 2010: Digital Elevation Modeling using TerraSAR-X Radargrammetry. XXIV FIG Congress, Sydney, Australia, 11-16 April 2010.

HENNIG, S.D.; KOPPE, W.; KIEFL, N. & JANOTH, J. 2010: Validation of Radargrammetric Digital Elevation Models (DEMs) Generated with TerraSAR-X Data. 8th European Conference on Synthetic Aperture Radar EUSAR 2010, 8th European Conference on Synthetic Aperture Radar, Aachen, 07-10 June 2010.

MITTERMAYER, J.; WOLLSTADT, S.; PRATS, P.; SCHEIBER, R. & KOPPE, W., 2012: Staring Spotlight imaging with TerraSAR-X. 2012 IEEE International Geoscience & Remote Sensing Symposium, p. 1606-1609.

RAGGAM, H.; PERKO, R.; GUTJAHR, K-H.; KOPPE, W.; KIEFL, N. & HENNIG, S., 2010a: Accuracy Assessment of 3D Point Retrieval from TerraSAR-X Data Sets. EUSAR 2010, 8th European Conference on Synthetic Aperture Radar, Aachen, 07-10 June 2010.

RAGGAM, H.; GUTJAHR, K.; PERKO, R. & SCHARDT, M., 2010b: Assessment of the stereo-radargrammetric mapping potential of TerraSAR-X multibeam spotlight data. IEEE Transactions on Geoscience and Remote Sensing, **48**, p. 971-977.

SCHUBERT, A.; SMALL, D.; MEIER, E. & NÜESCH, D., 2004: Extraction of Surface Topography from SAR Images Using Combined Interferometry and Stereogrammetry. Proceedings of European Conference on Synthetic Aperture Radar, Ulm, Germany, 25–27 May 2004; p. 775-778.

TOUTIN, T., 2000: Evaluation of radargrammetric DEM from RADARSAT images in high relief areas. IEEE Transactions on Geoscience and Remote Sensing, **38**, p. 782-789.