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Accuracy assessment of a digital height model derived from airborne synthetic aperture radar measurements

ALFRED KLEUSBERG and HANS-GEORG KLAEDTKE, Stuttgart

ABSTRACT

A digital height model (DHM) derived from airborne interferometric synthetic aperture Radar (InSAR) covering about 140 km^2 was compared to the elevations of Trigonometric Points, the DHM of the state of Baden-Württemberg (DHM Ba-Wü), and GPS derived elevations.
The comparisons showed that the DHM derived from InSAR is about 1-2 m below the reference values, on average. The accuracy of the DHM Ba-Wü does not allow any further conclusions regarding the accuracy of the InSAR DHM. The comparison with the elevations of 79 Trigonometric Points (in open terrain) showed a standard deviation of ±1,3 m about the average difference. The comparison with 44 GPS derived elevations (in open terrain) showed a standard deviation of ±0,9 m about the average difference.
The InSAR derived DHM represents the surface reflecting the Radar signal. Therefore the deviation between InSAR DHM and the reference values is much larger in built-up areas and in areas with significant vegetation (e.g. forest).

1. INTRODUCTION

Interferometric Synthetic Aperture Radar (InSAR) measurements from airborne and spaceborne platforms are an efficient means for deriving Digital Height Models (DHM) as an approximation of the earth's topography (Hartl et al., 1998; Schwäbisch, 1997). Typically, such DHMs derived from airborne sensors will be of higher resolution and accuracy compared to results obtained with satellite InSAR.
Several American and European institutions have developed airborne InSAR systems. One of these is the *Star*-3i system operated by Intermap Technologies Ltd of Nepean, Ontario. This system can provide DHMs at various accuracies and resolutions depending on flight altitude and data processing complexity. The system operates in the X-band with a wavelength of about 3 cm; such microwaves do not penetrate vegetation or buildings. Therefore the resulting DHM is a model for the „surface of first return" of the Radar signal, the envelop of the vegetation and/or man made structures over some averaging region. In addition to the DHM, the *Star-3i* system also provides a Radar reflection intensity image.
A strip of *Star-3i* InSAR data was acquired in the state of Baden-Württemberg in June 1997 from a Lear-Jet 36 at an altitude of about 6,800 m. At this flight altitude, the InSAR covers a strip width of about 7 km. The length of the strip is about 20 km, and the data acquisition took about 3 minutes. Together with precise aircraft navigation data, the InSAR data was processed by Intermap into a DHM and a Radar return intensity image with a resolution of 2.5 m by 2.5 m pixel size each. The two data sets were georeferenced in Transverse Mercator (Gauß-Krüger) coordinates with respect to the Bessel Ellipsoid. The DHM heights were referenced to Normal Null (NN).
The Radar return intensity image is depicted in Fig. 1. Flight direction was towards north-east; the Radar was looking to the right of the aircraft. The built-up area visible in the lower part of the image is the City of Freiburg, in the right hand part of the image the hills of the Black Forest can be seen. Black pixels indicate areas with no Radar return. These are mainly Radar shadow areas on the eastern slopes of the Black Forest and areas of water surfaces, e.g. some lakes in the north of the city of Freiburg. The total area without Radar return is about 4 % of the strip.

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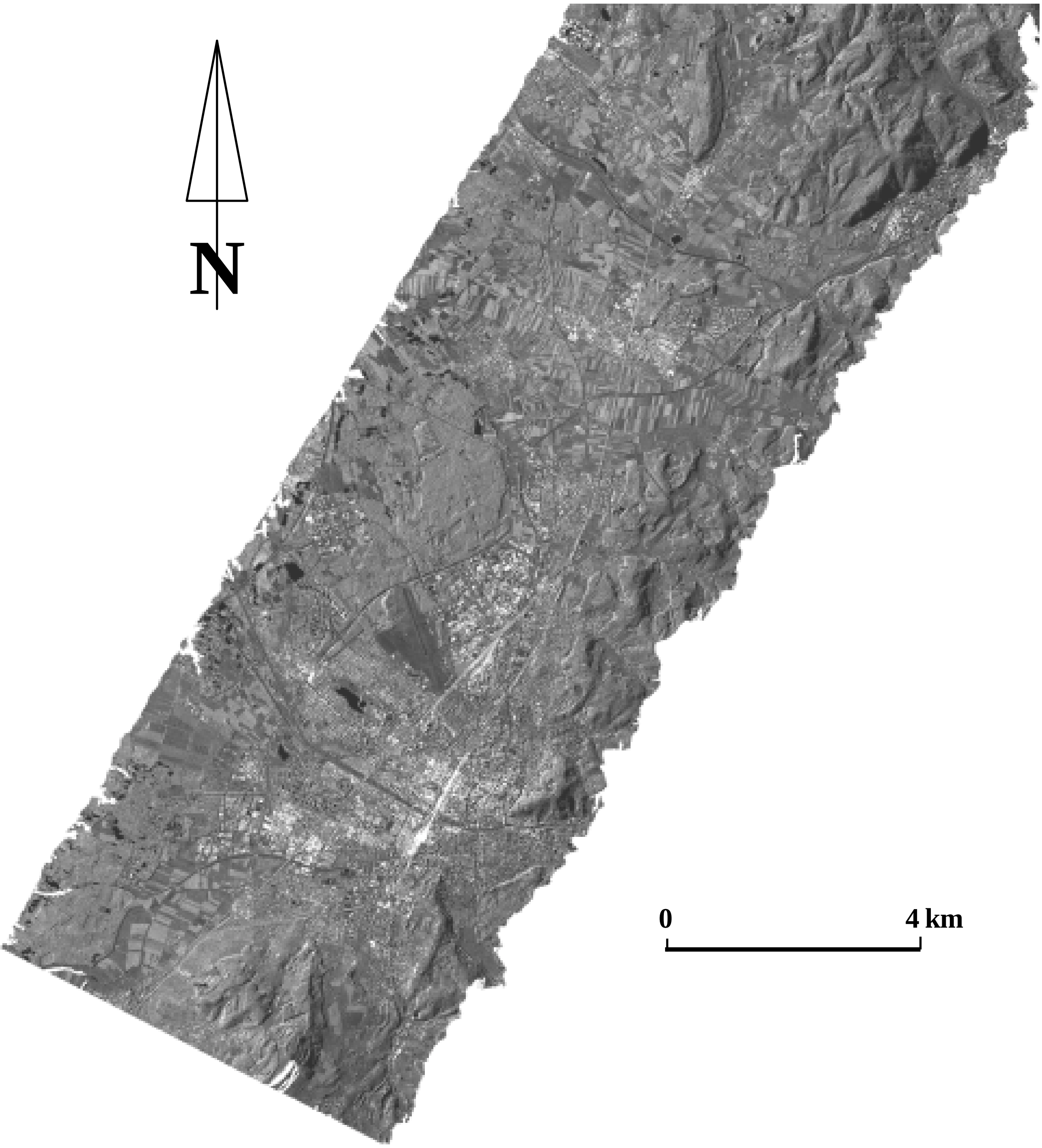

Figure 1: *Star-3i* Radar return intensity image.

The InSAR derived DHM and the corresponding Radar return intensity image were provided by Intermap Technologies Ltd. to the Institute of Navigation of Stuttgart University for the evaluation of the accuracy of the DHM. This evaluation was done through comparison with data maintained by

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the Landesvermessungsamt Baden-Württemberg, and by comparing DHM values to heights determined from Global Positioning System (GPS) measurements in various parts of the test area. Below we present a few aspects of this comparison; the complete evaluation can be found in (Kleusberg and Klaedtke, 1998).

2. COMPARISON TO HEIGHTS OF TRIGONOMETRIC POINTS (TP)

A total of 269 Trigonometric Points (TP) were located in the test area; 11 of these were found to be in areas of Radar shadow. The horizontal coordinates and the heights of the TP were provided by the Landesvermessungsamt Baden-Württemberg. The horizontal coordinates and the heights of the trigonometric points are supposed to be accurate to better than 0.1 m.
Using the horizontal coordinates of the TP, the corresponding pixels in the *Star-3i* DHM data set were located, and the height differences in the sense *Star-3i* DHM minus height of the TP were calculated. These differences are shown in Fig. 2. The points of comparison are sequentially numbered, beginning in the western part of the test area and increasing towards east.

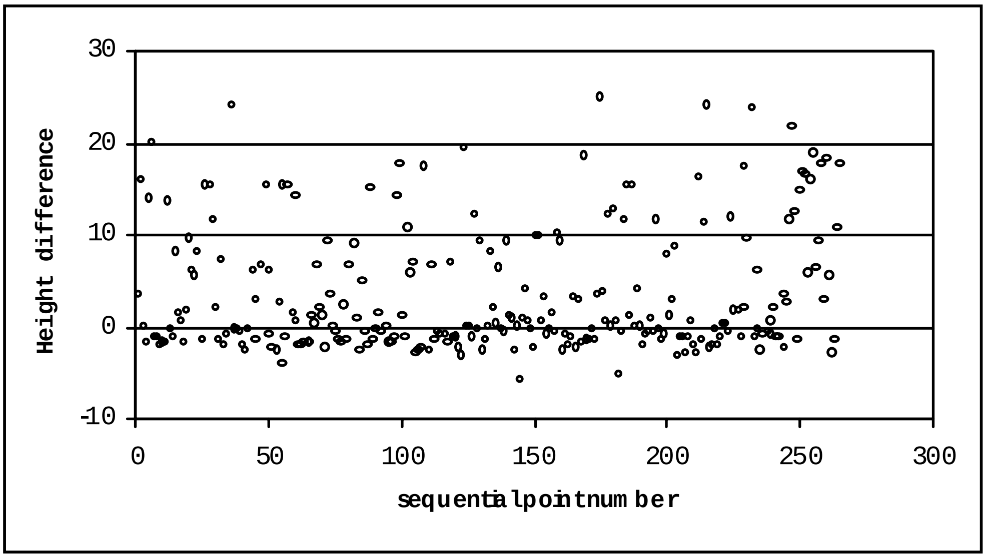

Figure 2: Height differences for 257 Trigonometric Points.

It is obvious, that the majority of the height differences are within a ±5 m band, with a number of larger positive values up to about 25 m (a single negative outlier amounting to –39 m resulting from a data transfer mistake has been removed from the figure). The large positive differences indicate areas where the InSAR DHM is above the published height of the TP by up to 25 m. To check if this is due to forest vegetation and/or man made structures in the vicinity of the TP, a separate evaluation was carried out for those 79 TPs that were, without doubt, in open terrain.
This result is shown in Fig. 3. It is obvious that the large positive height differences have disappeared, and the majority of the values are between –2 m and zero; their mean value is 0.9 m, with a standard deviation of ±1.3 m.

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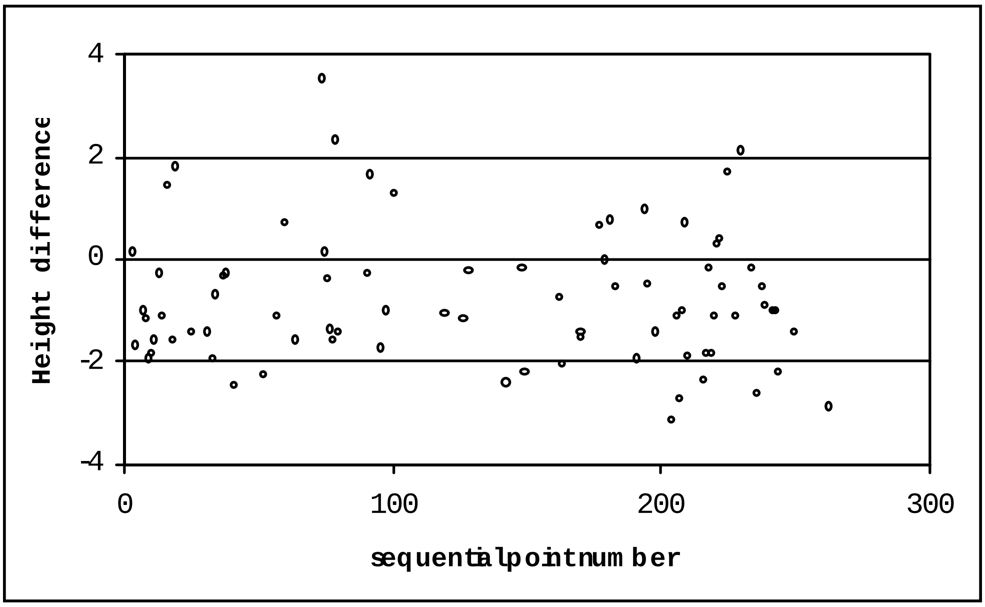

Figure 3: Height differences for 79 Trigonometric Points in open terrain.

3. COMPARISON TO GPS DETERMINED HEIGHTS

For a total of 10 locations within the test area GPS surveys were conducted to determine reference points for the assessment of the accuracy of the *Star-3i* DHM. These locations were selected to be in open terrain, distributed over the test area, representative for flat and sloped terrain, and easily accessible. For each of the 10 locations, at least four points were determined with Differential GPS. These points were typically separated by about 50 m and were arranged in a rectangle in flat areas, and along the line of steepest descent in sloped areas.
GPS data were collected April 7 to 8, 1998 with geodetic type GPS receivers; the data were processed using network adjustment capable software. The resulting ellipsoidal coordinates with respect to the World Geodetic System 1984 (WGS84) were transformed to Gauß-Krüger coordinates and heights above NN. The accuracy of the GPS points is estimated to be better than 0.1 m in the horizontal coordinates, and better than 0.2 m in the height component.

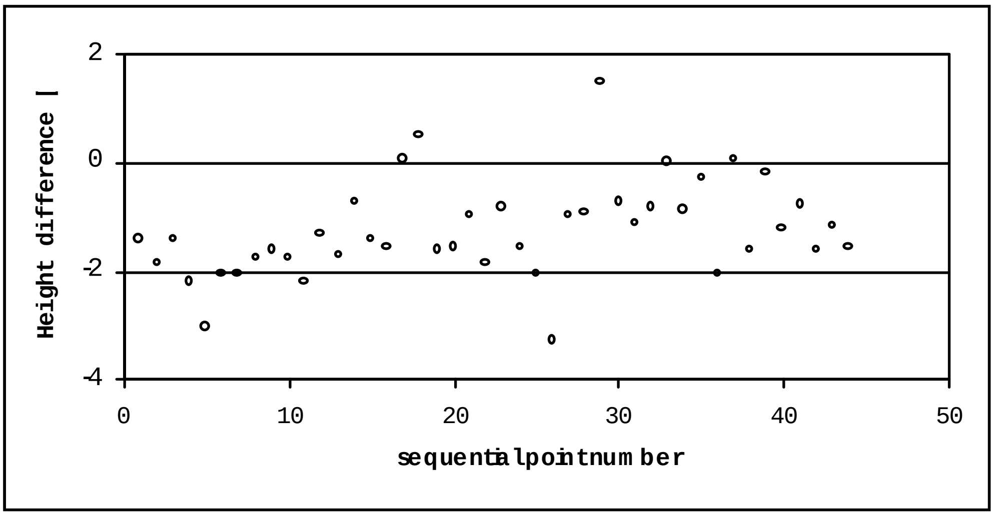

Figure 4: Height differences for 44 reference points determined with GPS.

The heights of the 47 GPS determined ground level points were compared to the co-located pixel of the *Star-3i* DHM. It was found that three of the GPS points fell into areas of Radar shadow in the DHM. These three points were excluded from the following comparison. Fig. 4 shows the differences in height for the remaining 44 GPS determined points of comparison. The differences are in the sense InSAR DHM minus GPS determined height.

The height differences range between -3.3 m and +1.5 m. The mean value is -1.3 m and the standard deviation of the variations about the mean value is 0.9 m. Of the 44 points, 20 points are located in flat terrain. The height differences of these points have a mean value of -1.1 m, and a standard deviation of the variations about the mean of 0.7 m. The remaining 24 points in sloped terrain have a mean value of -1.4m, and a standard deviation of the variations about the mean of 1.0 m.

4. CONCLUSIONS

The comparison of the InSAR DHM with both heights for Trigonometric Points and with GPS determined height values has shown a systematic deviation of about 1m - 1.5m (InSAR DHM *lower* than reference heights); such systematic deviations can easily be corrected with control points. In addition the height differences show a more random variation characterised by a standard deviation of ±1 m. The comparison presented in this article is restricted to points in open terrain (grass land, agricultural land, streets).

In the forest and in built-up areas the InSAR DHM describes the surface of first return of the Radar signal. No reference values were available for this surface, and the accuracy of the InSAR DHM has not been evaluated for such areas.

The InSAR data acquisition is extremely fast, and to a large degree independent of weather conditions. In order to fill the gaps resulting from Radar shadow in mountainous regions, the InSAR must be flown repeatedly with a different viewing angle. For agricultural areas used to grow crops with a significant height, the InSAR data acquisition should be completed before the crops have grown up or after the crop harvest.

5. ACKNOWLEDGEMENTS

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The InSAR DHM data is property of Intermap Technologies Ltd.

6. REFERENCES

Hartl, P., K. H. Thiel, X. Wu, und Y. Xia (1998): SAR-Interferometrie: Grundlagen und Anwendungsbeispiele. Petermanns Geographische Mitteilungen, Ergänzungsheft 287, Justus Perthes Verlag Gotha, pp. 35-52.

Kleusberg, A. and H. G. Klaedtke (1998): Accuracy Assessment of the *Star-3i* Derived DHM in Baden-Württemberg. Contract Report to Intermap Technologies Ltd., Institut für Navigation, Universität Stuttgart.

Schwäbisch, M. (1997): SAR-Interferometrie – Technik, Anwendungen, Perspektiven. Zeitschrift für Photogrammetrie und Fernerkundung, pp. 22-29.