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# Accuracy assessment of interferometrically derived DTMs

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**Abstract**

In this paper results of a quantitative analysis of interferometrically derived digital terrain models (DTMs) and topographic maps digitised DTMs of two different test sites are presented. Two INSAR derived DTMs from ERS-1 phase D SLC data of the area around the city of Dortmund in Germany and an ERS-1/2 tandem phase SLC image pair of the area around the city of Graz in Austria were assessed. For the comparison of the results, difference DTMs were computed from the INSAR derived DTMs and the topographic maps digitised DTMs. Although good rms height error were achieved for the ground control points used in the DTM generation, the standard deviation of the difference DTMs on average was about 18 m for the Dortmund test data and 29 m for the Graz test area. The horizontal accuracy, i.e. residuals of the Easting and Northing of the ground control points, on average was within half a pixel and a pixel in the North and East directions respectively. Obviously, a need for the use of more ground control points and the 100 points state vector orbit restitution has been identified in this work. With the use of these extra data, the vertical and horizontal accuracy of INSAR generated DTM can be significantly improved even in SLC image pairs of relatively smaller baselines.

## 1. Introduction

Before the launch of ERS-2, ERS INSAR data have been acquired by ERS-1 in time intervals of 3 or 35 days - or multiples therefrom - between the image pairs. However, recently a combination of an ERS-1 and an ERS-2 SLC scene being acquired during the ERS Tandem mission. This mission was specifically designed for the acquisition of appropriate SLC image pairs within a period of typically one day, which is the repeat orbit interval between the two satellites.

Although satisfactory results concerning the validation of interferometrically derived digital terrain models have been reported in the literature, a comprehensive analysis of the results especially the reproduction of the results from the same test area with different data sets have not been performed. Therefore, in this paper results of a comprehensive analysis of interferometrically derived DTMs and topographic maps digitised DTMs of two different test sites are presented. The work includes the assessment of two INSAR derived DTMs from ERS-1 phase D SLC data of the area around the city of Dortmund in Germany and an ERS-1/2 tandem phase SLC image pair of the area around the city of Graz in Austria. The reference digital terrain models were resampled to cell sizes of 40m x 40m for matters of comparison with the interferometric products.

## 2. Test Area and SLC Data

In general, experiments made over two different test sites are presented in this paper. These are:

*Test area "Dortmund":*

For an area south-west of the city of Dortmund in Germany, the following ERS-1 SLC image pairs were processed:

Orbits: 12864 & 12907 (Dortmund-1);

13896 & 13939 (Dortmund-2).

Dates: 31-12-1993 & 03-01-1994;

13-03-1994 & 16-03-1994.

Baselines: 63 & -74 meters.

*Test area "Graz":*

This test site covers the city of Graz as well as the south-western areas. An ERS Tandem SLC image pair was used for this area with acquisition dates as follows:

Orbits: 21338 (ERS-1) & 1665 (ERS-2).

Dates: 14-08-1995 & 15-08-1995.

Baseline: 56 meters.

## 3. Data Processing

The above selected data sets were interferometrically processed by an in-house built INSAR software tool. The tool typically consist of all the interferometric chain, i.e. coregistration, spectral filtering, flat terrain phase removal, fringe generation and smoothing, phase unwrapping and the conversion of the unwrapped phase into terrain height information. Here only the last step which is the derivation of the terrain heights will be described. For the description of the other processing steps the reader is referred to references [1] - [6] and [10].

## 4. DTM Generation Procedure

The geometric imaging disposition for interferometric data is shown in figure 1. Various approaches may be used to convert the unwrapped phase values pixel-by-pixel to corresponding ground points. The procedure which has been implemented in our software is briefly described in the following.

First, the slant range difference $\delta_i$ is calculated for each pixel from the individual phase values $\Phi_i$:

$$\delta_i = -\frac{\lambda}{4\pi} \cdot (\Phi_i + \Phi_c)$$

Usually, $\Phi_c$ is a constant phase offset. In our approach, however, linear terms in range and azimuth are additionally considered in order to compensate for converging or diverging orbits and similar effects because of erroneous a-priori information. The terms of this phase offset „function" are determined in advance by using a sufficient number of ground control points with respective reference values for $\delta_i$ and $\Phi_i$.

Besides, the slant range distance $R_1$, which corresponds to the length of vector $\vec{r}_1$, is determined from the SAR range pixel coordinate. Then, the slant range distance $R_2$ and the baselength $B$ can be calculated in a next step as follows:

$$R_2 = |\vec{r}_2| = R_1 + \delta$$

$$B = |\vec{s}_2 - \vec{s}_1|$$

These entities are used to determine the angle $\alpha$ between baseline vector $\vec{B}$ and pointing vector $\vec{r}_1$ in sensor position $\vec{s}_1$ by the equation:

$$\cos\alpha = \frac{R_2^2 + B^2 - R_1^2}{2 \cdot B \cdot R_1}$$

Using $\vec{s}_1$, $\vec{B}$, $\alpha$, $R_1$ as well as 3D vector relations, the pointing vector $\vec{r}_1$ and the ground point $\vec{p}$ are finally calculated.

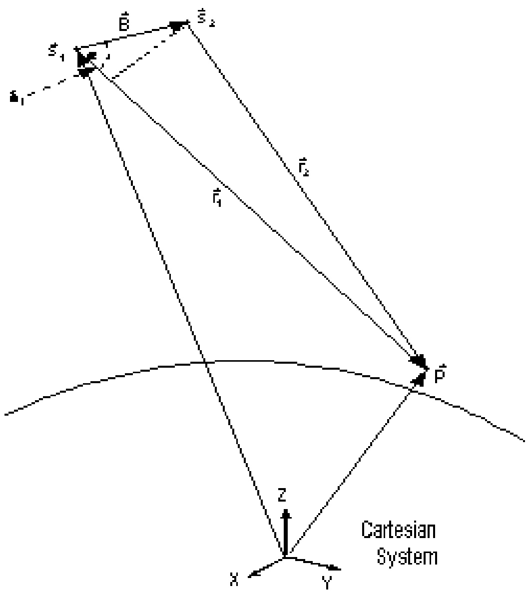


*Figure 1: Geometric INSAR imaging disposition.*

## 5. Analysis of Results

In the following, analysis of the results achieved for the individual test areas with regard to the production of digital terrain models and their comparison to the reference DTMs is given.

*Test area "Dortmund"*

For this test area good quality interferograms could be generated from the ERS SLC data. Practically, all over the quarter scene the achieved coherency was very high, above 0.75, except of the water bodies and some forested areas. Based on ground control points measured in a 1 : 50000 topographic maps, two DTMs were generated from the unwrapped phase data. These DTMs are shown in figures 2 and 3, while in figure 4 the reference DTM is presented, both being illustrated in height colour coding. Only from a comparison of the difference DTMs generated by subtraction of the reference DTM from the INSAR ones, the differences between these DTMs become obvious. Whereas, the pure gray value coded shapes of the terrain correspond almost perfectly, especially at the hilly part of the area.

Cross checking verification activities on a number of points in the image have shown a good height correspondence for most parts of the INSAR generated DTM, with some exceptions in the hilly terrain areas. In general, it can be stated that because of the small baseline the orbits reconstruction during the DTM generation might become unstable and could lead to such local errors. Also other parameters, such as weather information, need to be investigated in order to conclude on some of these variations that have been observed in the INSAR DTM, especially in the flat terrain part of the image (upper left side). The statistical errors achieved for the ground control points and the difference DTMs for this test area are shown in tables 1 and 2 respectively.

*Test area "Graz"*

Relatively good quality interferograms were generated from some parts of this ERS-1/2 tandem data set of this test area, but the coherency in some parts of the quarter scene was very low and on average it was around 0.45. This in particular applies to the forested areas, which by experience are rather critical for the interferometric data processing. Generally, a DTM was successfully generated from the unwrapped phase data which is shown in figure 5, while in figure 6 a reference DTM derived from topographic maps of the test area is presented. It can be noted that the INSAR derived DTM, as shown in figure 5, accurately reflect the shape of the topography of the area. This can simply be deduced from the visual comparison with the map derived reference DTM in figure 6. From the cross checking of some points in the INSAR DTM with the reference one, it was observed that large deviations (about 50 m) could be found especially in the hilly regions. As mentioned before, the small baselines could be of influence in the stability of the orbits reconstruction. A comprehensive analysis, which deals with INSAR DTMs of different baselines could, in our opinion, lead to good qualitative and quantitative analysis of this test area. The statistical errors obtained for this test area are presented in tables 1 and 2, respectively for the GCPs and difference DTMs.

*Table 1: Residuals of GCPs coordinates.*

| Test Area | East | North | Height |
|---|---|---|---|
| Dortmund - 1 | 53 m | 32 m | 14 m |
| Dortmund - 2 | 51 m | 33 m | 15 m |
| Graz | 50 m | 34 m | 12 m |

*Table 2: Residuals of difference DTMs.*

| Test Area | Mean | Std. Deviation |
|---|---|---|
| Dortmund-1 | 12 m | 18 m |
| Dortmund-2 | 14 m | 19 m |
| Graz | 23 m | 29 m |

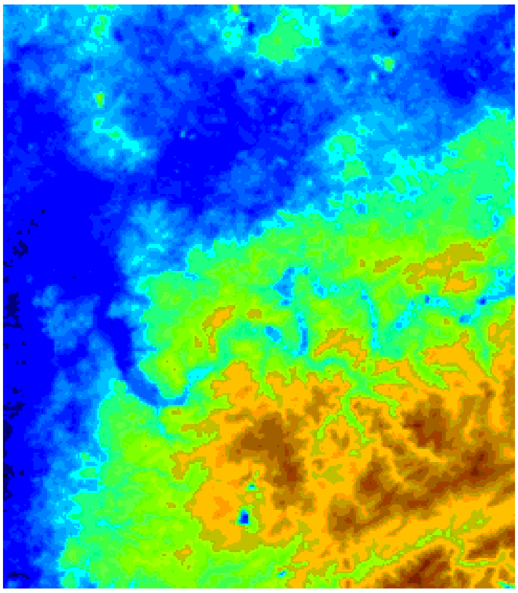

*Figure 2: INSAR derived DTM from "Dortmund-1" test data.*

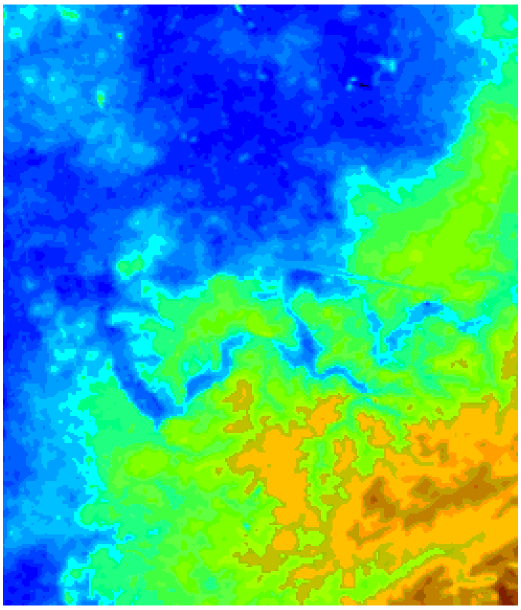

*Figure 3: INSAR DTM derived from "Dortmund-2" test data.*

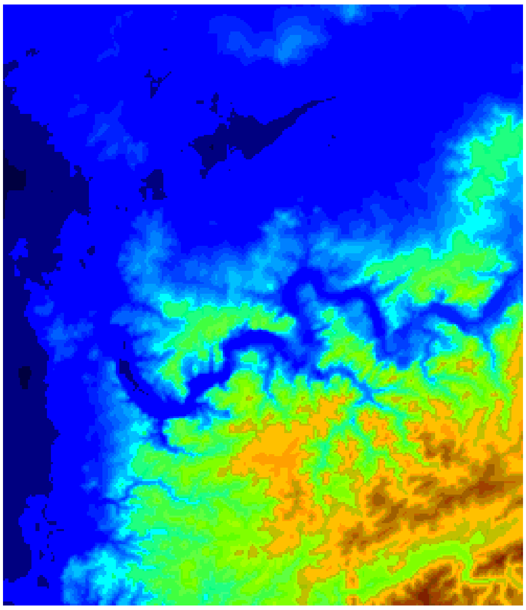

*Figure 4: Reference DTM for "Dortmund" test area.*

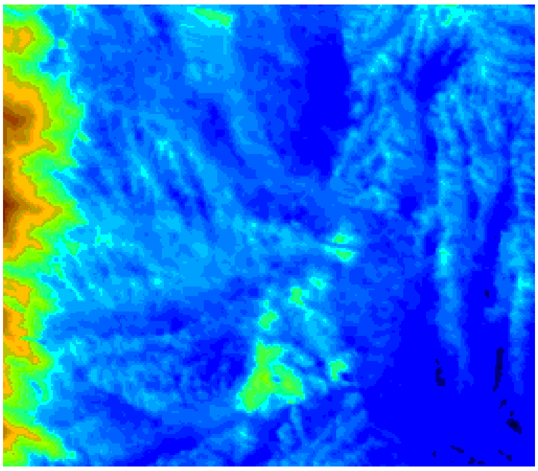

*Figure 5: INSAR derived DTM from the "Graz" test data.*

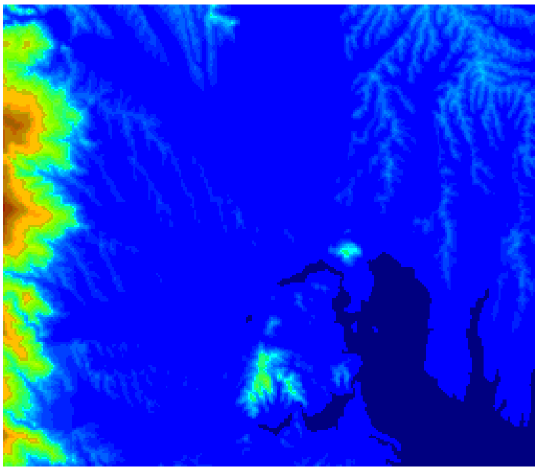

*Figure 6: Reference DTM for "Graz" test area.*

## 6. Conclusions

Generally, it can be concluded that even at relatively small baselines INSAR derived DTMs give height information with acceptable errors. The rms errors for the Dortmund test area were quite good, whereas those for the Graz test site were poor. However, enough care must be exercised due to the fact that atmospheric turbulence can introduce errors of large magnitude in the INSAR height measurements. But to come to qualitative and quantitative conclusions on the INSAR derived DTMs, further work still needs to be performed for the validation of INSAR derived DTMs. These could typically consist of SLC data sets of different baselines and from various terrain topography, use of the precision orbit information, and adequate selection of control points for the DTM generation process.


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