LARGE AREA DEM GENERATION WITH ERS TANDEM DATA

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ABSTRACT

The main subject of this paper is an assessment of the potential to generate large scale digital elevation models by means of interferometric processing of ERS SAR data. A DEM of the entire Czech Republic has been produced using Tandem data preferably from the winter period 1995/96. The corresponding processing steps, including data selection, phase unwrapping, height derivation, and mosaicking are presented. The results are compared to reference elevation information and show a typical vertical accuracy in the order of 10 m, indicating the potential of the methodology to generate large area DEMs on principle. However, fundamental limitations have to be kept in mind particularly regarding the technique's sensibility to temporal changes of the illuminated surface as well as to atmospheric distortions.

Keywords: SAR, interferometry, digital elevation models

1. INTRODUCTION

In recent years interferometric processing of SAR data has become a widely-used tool for the generation of digital elevation models of the earth's surface. Apart from mainly one processing step, i.e. the unwrapping of the interferometric phase, the theoretical background of the methodology has been established in detail and numerous applications have shown the applicability of the technique in principle. However, most of the applications have concentrated on small up to medium size areas with typical scene extensions ranging from 50×50 km^2 up to 100×100 km^2 (ERS quater and full frames, respectively). Main objective of the study presented in this paper was to assess the potential of the methodology for large scale DEM generation using satelliteborne ERS SAR data from the Tandem period.

As testsite the area of the Czech Republic with an estimated extension of 80.000 km^2 was selected. This test area reveals all grades of terrain slopes, ranging from totally flat areas in the mid-western part to almost alpine regions at the border to Slovakia. In addition, the vegetation coverage is highly variable, changing from heavily industrialized areas to agricultural regions and extended forests.

In the following the main steps and principal features of the project are presented, including the data selection procedure, interferometric processor design, and mosaicking of the single DEMs. A validation of the InSAR-derived height maps against external elevation information is performed, finally followed by a discussion of the potential of the methodology for large area DEM derivation.

2. DATA SELECTION

A total of about 220 Tandem scene pairs of the Czech Republic was available, of which 80% have been aquired in descending node modus. Fig. 1 illustrates the location of the image footprints projected onto a map. A small gap of about 5 km between neighbouring 100 km-strips required the processing of alltogether 10 strips which are partly overlapping each other by nearly 50 km.

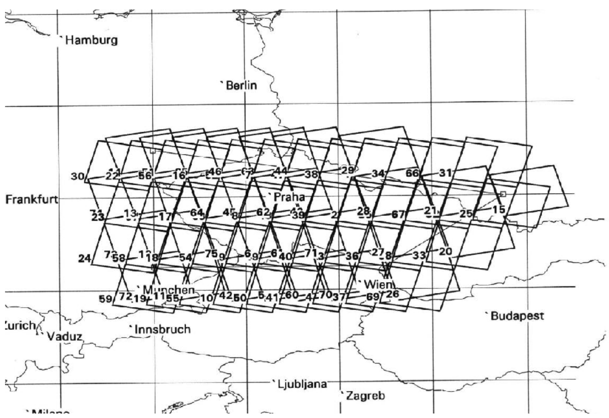

Fig 1: ERS-1/2 full frame footprints of ascending and descending passes (© ESA DESC Software)

The data which were used to generate the elevation mosaic were selected according to the following criteria (in ascending order of importance):

- only ERS-1/2 Tandem phase data were taken into consideration in order to guarantee the maximum possible scene coherence and to ensure up-to-date information at the same time;
- the data were preferably selected from wintertime to reduce loss of coherence due to vegetation cover and motion;
- the interferometric baseline was chosen to lie in the range of 50 up to 300 m, in general prefering the higher values over the lower ones in order to gain height resolution and accuracy; only in cases of mountainous scenes with steep slopes a smaller baseline was favoured;
- adjacent frames of the same ERS track were selected from the same orbit (hence acquisition time), if possible.

The criteria could be met only sparsely with the Tandem data: only 18% of the pairs dated from the winter period, less than 30% had a baseline larger than 100 m, and entire ascending strips appeared only in single cases so that the selection was based on descending scenes, using the ascending passes only to fill gaps and resolve ambiguities in case of erroneous data. All of the requirements at the same time could be satisfied by only 2% of the data.

3. INTERFEROMETRIC PROCESSING

3.1 Input Data Quality

Interferometric processing was based on the use of SAR SLC products. Unfortunately, the project time schedule coincided with the beginning of the operational delivery of SLC full frame products which exhibited a series of bugs caused by introducing a new software version to the VMP processor. In detail, 4 principal problems appeared:

- about one third of the ordered frames had been processed too short, leading to non-overlapping scenes within a track. Caused by improper Doppler frequency estimation during processing, this effect could be escaped from only by reordering the data as "shifted frames";
- one third of the interferograms (namely the ones with frame number 2583) suffered from an incoherent horizontal stripe in the upper part of the image. This effect was caused by the processor' s problem of handling sampling window start time changes within a frame. Flawless scenes could not be delivered until the end of the project (August 1997). Therefore, the affected scenes were reordered as raw data and subsequently processed with DFD´s[§] BSAR processor (Ref. 1);
- about half of all ordered scenes were delivered with the I and Q values flipped. Even if both scenes to form the interferogram underwent that exchange (hence resulting in a perfectly coherent interferogram) the effect had to be removed in order to restore the correct phase behaviour for the phase to height conversion process;
- two image pairs were delivered with a f_{DC} value of 3 kHz and a variation of more than one PRF band from near to far range, resulting in the interferogram in a sharp phase jump at a specific far range position. The effect was removed manually by shifting one part of the interferogram by the corresponding fraction of phase cycles.

  The specified problems delayed the termination of the project by roughly two months.

3.2 Algorithmical Aspects

Interferometric processing was performed with common methodology reported in recent publications (Refs. 2, 3). Two further improvements have been applied concerning the phase unwrapping and the height derivation and are illustrated in the following.

For phase unwrapping an improved region growing technique was used which combines advantages from both the global and local approaches (Ref. 4). In a first step a common iterative least-squares algorithm gives a coarse approximation of the absolute phase. After subtraction from the original interferogram the remaining phase pattern (with only few fringes left) is unwrapped applying a rather simple region-growing technique. This method appeared to be robust and flawless even over low coherent areas. Only in extreme layover or temporarily decorrelated regions 2π-errors occured, still not propagating into the higher coherent areas due to the region-growing nature of the technique.

For height derivation a fast and efficient backward solution was applied which reduced the processing time of one full frame interferogram to 15 min. The technique exploits the monotonous and continuous behaviour of the interferometric phase along range in an undisturbed interferogram, which can be utilized to convert the height derivation into a root finding problem. Details of the method are not subject of this paper but will be outlined in a further publication.

For each full frame DEM product about 20 up to 30 ground control points were selected from topographic maps in order to refine the accurate radar imaging geometry (hence the interferometric baseline). The final image products (DEM, coherence map, magnitude mosaic) were resampled onto a grid spacing of 25 m and delivered in the Czech cartographic system (S 42).

§ German Remote Sensing Data Centre

3.3 Hardware Aspects

The entire interferometric processing was executed on two Pentium Pro 200 MHz PCs with 512 MB RAM and a single CPU each. Due to this inevitable memory limitation the software had to be adapted to block processing since each SLC full frame already allocates more than 500 MB. Time consumption for a 100 × 100 km^2 frame approaches 15 h, where 80 % is spent for the phase unwrapping.

3.4 Processor Operationality

The interferometric processor was designed to perfom the entire DEM generation fully operationally except one manual interaction which is the necessary selection of at least one ground control point. This interruption has to take place before the final height derivation step, but following the magnitude and coherence image formation in order to enable the visual identification of homologeous points in both the topographic map and the SAR data.

4. MOSAICKING

Mosaicking of ERS SAR images and InSAR-derived DEMs has to be realized in two dimensions:

- mosaicking of frames within a track, exhibiting similar image parameters already in slant range geometry,
- mosaicking of adjacent strips, which has to be performed after image geocoding since the overlapping parts reveal totally different slant range geometries, resulting from illumination with different incidence angles.

4.1 Mosaicking of single frames

Three frames each were used to form one contiguous strip of 300 km length. The data were taken from a single ERS orbit, hence originating from a coherent stream of raw data. Due to the phase preserving processing of the SLC scenes with ESA' s VMP processor a 300 km interferogram whithout phase distortions could be formed already in the slant range geometry by simply concatenating the range lines at the correct azimuth timing position. The phase differences in the overlapping parts remained below 10 degrees rms.

4.2 Mosaicking of strips

After geocoding of the single strips the 300 km-scenes in rectified map projection have been composed by simply resampling them to a common coordinate grid. In order to reduce possible discontinuities at the transition areas a fading technique was applied. A 50 pixel distance (≅ 12.5 km) corresponding to the master image edges was specified along which the image boundaries are blended using a linear ramp for pixel averaging. Fig. 2 illustrates this edge fading technique.

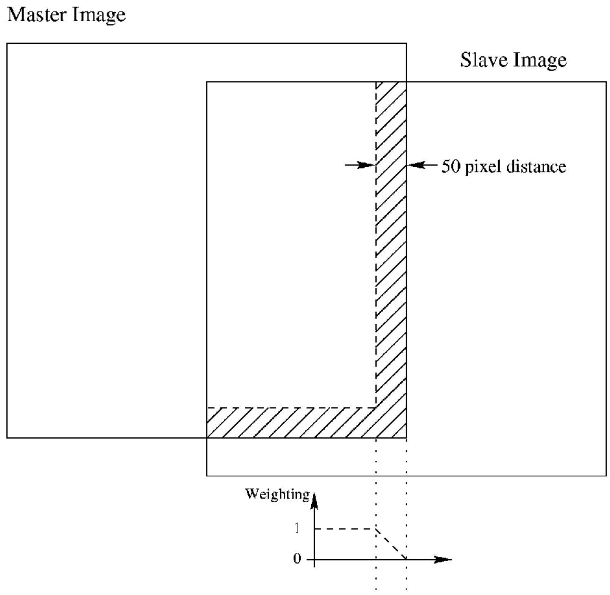

Fig. 2: Edge fading technique applied to the transition areas between adjacent scenes

In Fig. 3 (next page) the resulting mosaicked elevation map of the entire area is shown. Fig. 4 displays the composed coherence map (descending strips). Varying degrees of coherence can be observed especially at the strip boundaries, caused by different acquisition times.

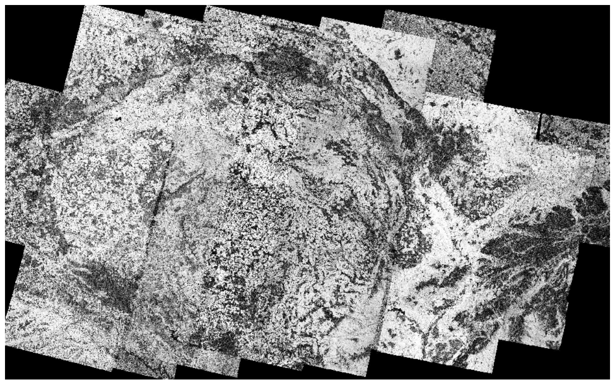

Fig. 4: Composed coherence map of the Czech Republic The scene coherence of the strips varies according to the acquisition time

5. DEM VALIDATION

For a portion in the western part of the investigated area a reference DEM has been available for validation purposes. This reference elevation data originated from digitization of topographic maps and held a horizontal resolution of 100 × 100 m^2 with a vertical accuracy in the order of 10 m.

Fig. 5 shows the difference of the reference DEM and an InSAR-derived elevation map. Only small height variations, mostly below 10 m, are present in this example which can serve as a representative for the achievable height accuracy. Corresponding mean value

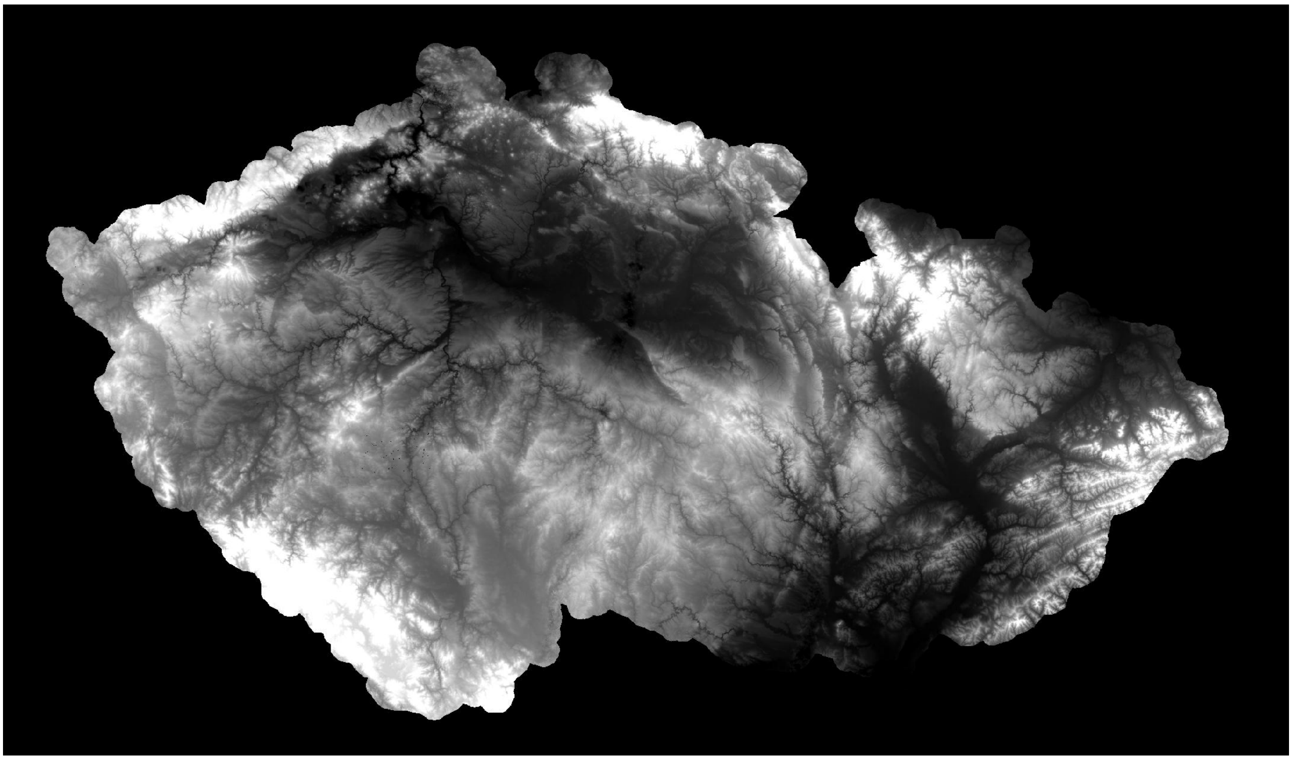

Fig. 3: Mosaicked elevation map of the Czech Republic

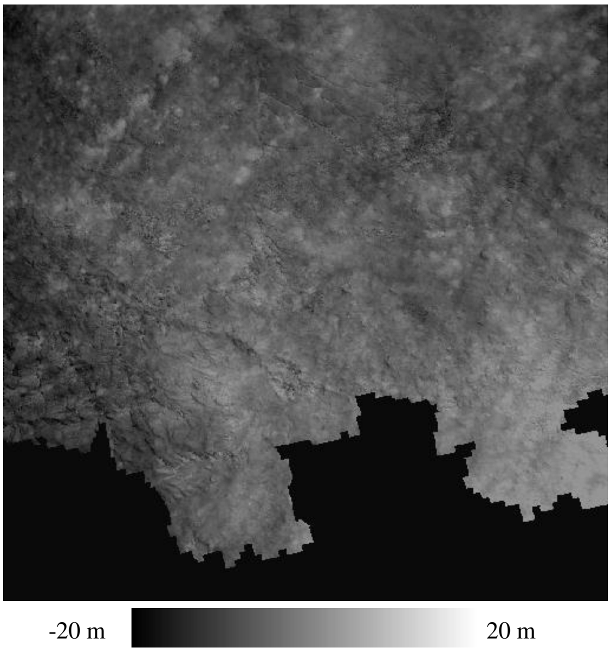

Fig. 5: Height difference between InSAR DEM and reference DEM

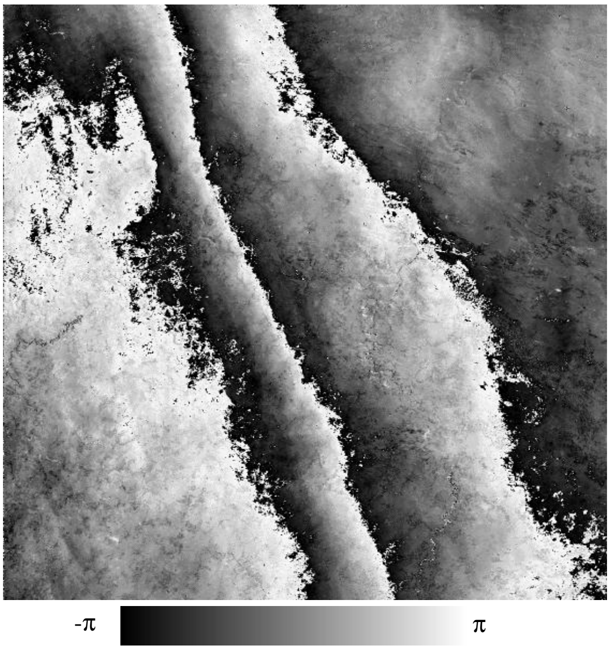

Fig. 6: Phase difference between interferogram and reference DEM (transformed into synthetic interferogram)

and standard deviation are -4.7 m and 7.8 m, respectively. The overall coherence is degraded particularly by decorrelated forested areas and mountaineous regions with steep slopes, causing undersampled interferograms.

By way of contrast Fig. 6 reveals much more significant deviations. In this image the phase difference between the original interferogram and the synthetic phase pattern of the reference DEM (transformed into slant range geometry) is displayed, exhibiting almost 3 phase cycles. Due to the nature of the residual phase pattern (locally varying phase gradients) these differences cannot be related to error sources like baseline estimation inaccuracy (typically characterized by homogeneous phase ramps), unwrapping errors or reference DEM incorrectness (both generally marked by local distortions in mountainous regions). The most likely cause is atmospheric heterogeneity at the two acquisition dates, a well-known issue which already has been announced in recent publications (Ref. 5)

Fig. 7 gives another example of atmospheric artefacts, in this case becoming apparent in a kind of ripple structure present in the difference interferogram. Additional similar observations have been made by comparing overlapping areas of neighbouring strips which sometimes expose local discrepancies that could not be addressed to further error sources.

In order to prevent possible errors due to atmospheric heterogeneities a consistency check was introduced by investigating the overlapping areas with respect to height deviations. For certain areas a third or even fourth scene pair of the affected regions had to be used.

6. CONCLUSIONS

As has been demonstrated in the previous sections of this paper ERS SAR data from the Tandem period can be used successfully for the generation of large area digital elevation models. Apart from the reported problems the SLC data quality is sufficiently high, especially regarding the phase stability and geometric accuracy, in order to enable mosaicking of the data without any difficulties. The processing itself can be executed almost entirely operationally, only for ground control point selection manual interaction is necessary.

However, some fundamental limitations have to be noted:

- Rms accuracy of the estimated height maps will not exceed the order of 10 m, which is in agreement with previously reported studies.
- Atmospheric disturbances may have a strong impact on DEM quality. Typically, 3 or 4 data pairs are needed to resolve ambiguities.
- The repeat-pass characteristic of ERS (causing temporal decorrelation) and its small look angle (leading to slope undersampling) degrade the achievable accuracy on principle. Subsequently the phase unwrapping remains to be the most problematic processing step.
- Even with the accurate orbit information of ERS there is a strong demand on a large number of ground control points in order to adjust the baseline accuracy to the needs of interferometric height derivation.
- Despite of the large number of acquired Tandem scene pairs it is not likely to find data of equally high quality to cover an extended area like the Czech Republic.

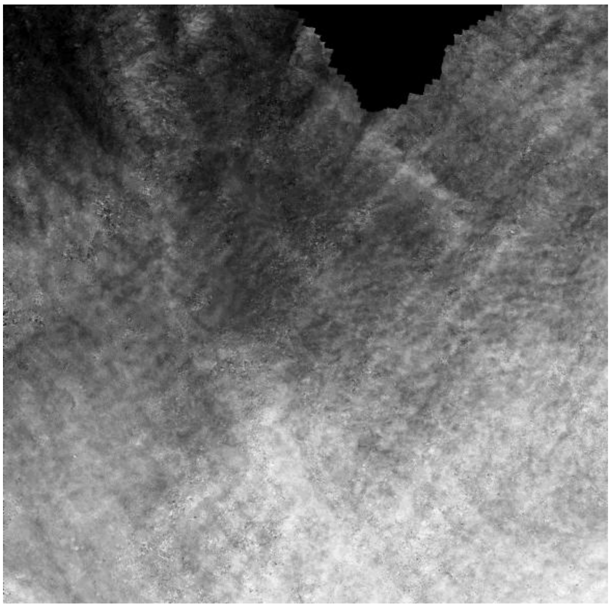

Fig. 7: Phase difference between interferogram and reference DEM (transformed into synthetic interferogram); same key as in Fig. 7;

7. ACKNOWLEDGEMENT

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8. REFERENCES

1. Breit H, Schättler B & Steinbrecher U 1997, A High Precision Workstation-Based Chirp Scaling SAR Processor, *Proc. IGARSS'97*, Singapore, pp. 465-468
2. Schwäbisch M, Matschke M, Knöpfle W & Roth A 1996, Quality Assessment of InSAR-derived DEMs Generated with ERS Tandem Data, *Proc. IGARSS'96,* Lincoln, pp. 802-804
3. Schwäbisch M, Geudtner D 1995, Improvement of Phase and Coherence Map Quality Using Azimuth Prefiltering: Examples of ERS-1 and X-SAR, *Proc. IGARSS '95*, Firenze, pp. 205-207
4. Reigber A & Moreira J 1997, Phase Unwrapping by Fusion of Local and Global Methods, *Proc. IGARSS'97*, Singapore, pp. 869-871
5. Goldstein R 1995, Atmospheric limitations to repeat-track radar interferometry, *Geophysical Research Letters*, Vol. 22, No. 18, pp. 2517-2520