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Operational use of SAR interferometry for DEM generation and land use mapping

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Abstract

This paper describes a system for producing rectified DEMs and interferometric coherence maps from SAR raw data. It has currently been tested on ERS-1 SAR data. The processing is done in four steps: processing of complex images from raw data, generation of interferometric fringes and coherence from the complex images, unwrapping of the fringe phase pattern and rectification to a given coordinate system. The complex images are produced with an in-house developed SAR processor, which is based on the range/doppler algorithm. It produces one-look complex images with a desired azimuth frequency band. Fringe generation uses the two complex images and the satellite orbit parameters. The latter are used for calculating the absolute physical separation bwtween the two trajectories as a function of time. Phase unwrapping is done in two steps: filtering of the fringes and inversion. Lowpass filtering of the fringes is done, and the filtered fringes are inverted by means of a transform based global method, whereby the unwrapped phase for the whole area is rapidly generated. The whole chain has been tested with ERS-1 SAR images from an area in Northern Finland. The area is covered with boreal forest, causing relatively low contrast fringes. The resulting height model has been compared with a high quality model from the National Board of Survey, showing an average deviation of 10-15 m. The coherence map is currently geometrically corrected by means of an existing elevation model. Comparison with a land use map generated from high-resolution optical satellite images shows good correspondence.

Keywords: SAR interferometry, DEM, coherence, land use

Introduction

SAR interferometry has turned out to be a very powerfull technique for several applications, including generation of digital elevation models (DEM) and land use mapping. Particularly the former is a unique application with strong commercial aspects. An overview over the use of SAR interferometry is given in (Genset.al.).

The applications considered here are DEM generation and land use mapping. In Finland digital terrain models for the whole country have been made by the Finnish Board of Survey based on topographic maps generated by conventional methods using optical imagery. Particularly for the northern part of Finland these maps have somewhat lower quality than for the rest of the country. The pixel spacing for this DEM is 25 m. Also land use maps, including forest classification, have been made with the same pixel spacing. This data set is based on segmentation and classification of Landsat imagery, leading to inconsistencies between overlapping images taken at different points in time.

Methods for using SAR interferometry for the above mentioned applications have been developed at VTT during the last few years. A test area in Northern Finland has been used for comparing the INSAR derived DEM with the conventionally generated one and correspondingly for the land use mapping. A project aiming at the generation of an INSAR based DEM for the whole of Northern Finland, ~100000 square kilometers, is currently being planned. The main purpose of this is to be able to do DEM updating by means of SAR interferometry.

Interferogram generation

The interferograms used are generated by means of an in-house developed SAR processor based on the range/doppler-algorithm. Since both images are processed from raw data, the azimuth doppler frequency spectra are used to extract the common azimuth frequency band for both images. The complex images are then generated by using the same doppler centroid and band pass filters for both images. This avoids any azimuth band filtering of the complex images before fringe generation.

The processing chain for generating interferometric fringes and coherence is shown in figure 1.

The image registration is done by means of image correlation, generating a regular grid of tie points for the image resampling. Before the resampling common band filtering in range is performed. The filters used correspond to the frequency shift caused by flat earth at mid-swath.

The fringe pattern corresponding to flat earth is calculated from the orbit parameters. This is done by propagating along both orbits simultaneously and calculating the resulting phase history as a function of range. The phase correction is stored in a file for every 100 pixels in both directions, and values in between are interpolated during fringe and coherence calculation. The coherence is calculated within a window of 2 by 8 pixels in range and azimuth, respectively.

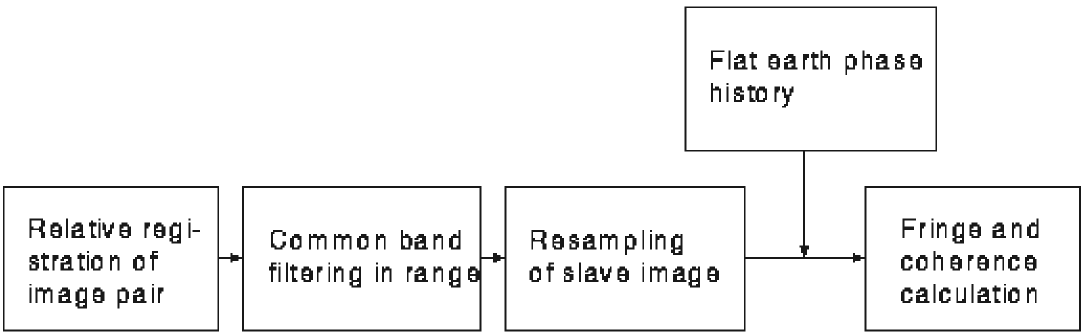

Figure 1: Processing chain for generation of interferometric fringes and coherence

Figure 2 shows an example of a fringe pattern for an area extending a little over 10 km in both directions. The average coherence is about 0.5. The image pair used is taken at September 5 and 11, 1991. The baseline is 286 m, and the height difference corresponding to one fringe is about 30 m. The image is shown with its original sampling distances.

Figure 2: Example of interferometric fringes with average coherence 0.5.

DEM extraction

The extraction of the DEM from the interferometric fringes requires phase unwrapping, conversion from phase to height and geometric rectification. Two unwrapping methods have been developed, one based on locally fitting a plane to the phase history and the other on instantaneous frequency estimation. The latter method is described in (Engdahl).

The local plane fitting corresponds to a lowpass filtering of the fringes, where the inclination of the plane corresponds to the local fringe frequency in both directions. Fitting the plane to the phase function corresponds to demodulating the fringe pattern to baseband. Because of the wrapped phases, the plane cannot be directly fitted to the phase function. The best fit is sought by doing to separate fits, the first by minimizing the mean square error over the plane, taking into account the modulo operation, and the second by doing the same but first applying a shift of 180 degrees to the phase function. The assumption is that the smaller error value determines the choice between the two fits. The center value of the fitted plane is then taken as the filtered value. The window size used is from 3 to 9 pixels, starting with the smaller window and gradually increasing it. After each filtering step the resulting function is median filtered with the same window size.

The filtering process described above can be shown to introduce a bias in the output values, since it tends to draw the values towards 0 and 180 degrees. By starting with a small window size, this effect is, however, very small, and alternatively it can be compensated for by scaling the output values.

Figure 3 shows the result of filtering the phase function in figure 2. Figure 4 shows the synthetic fringe pattern generated by propagating along the orbit and using the existing terrain model for calculating the fringes. Zero phase difference does not correspond to exactly the same terrain height in both directions.

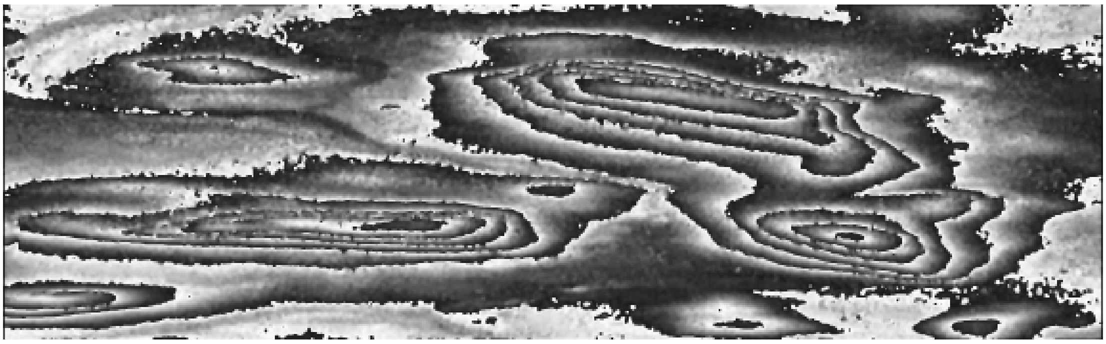

Figure 3: Filtered interferometric fringes.

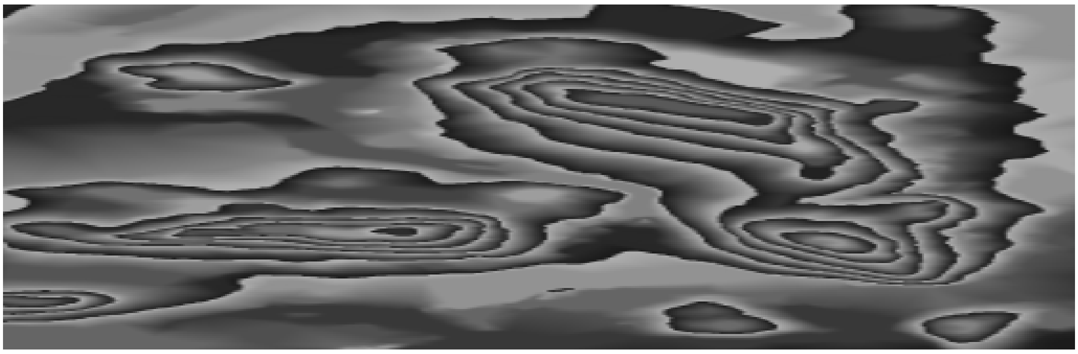

Figure 4: Synthetic interferometric fringes.

After filtering the fringes, the unwrapping is done by means of a two-dimensional transform-based method (Pritt and Shipman). This is a global method based on derivating the wrapped phase function. It is therefore sensitive to noise, and is not able to unwrap the unfiltered fringes. After filtering, however, the unwrapping is possible, and the result is shown in figure 5. This height model has been geometrically rectified by shifting all pixels in range according to terrain height and incidence angle. The orbit parameters are used for this purpose. The DEM has also been transformed to the modified UTM map projection used for the existing height model, with a pixel spacing of 25 m. Figure 6 shows the existing height model. The example shown here was done completely automatically, without any ground control points or reference heights. Although the terrain height agreement is generally better than 20 m, the maximum deviations exceed 40 m. Particularly towards the edge of the image the average deviations may become large, because the global unwrapping method will not get corrections from areas outside the image. When generating the DEM for larger areas by processing overlapping blocks, only the central part of each block should therefore be used.

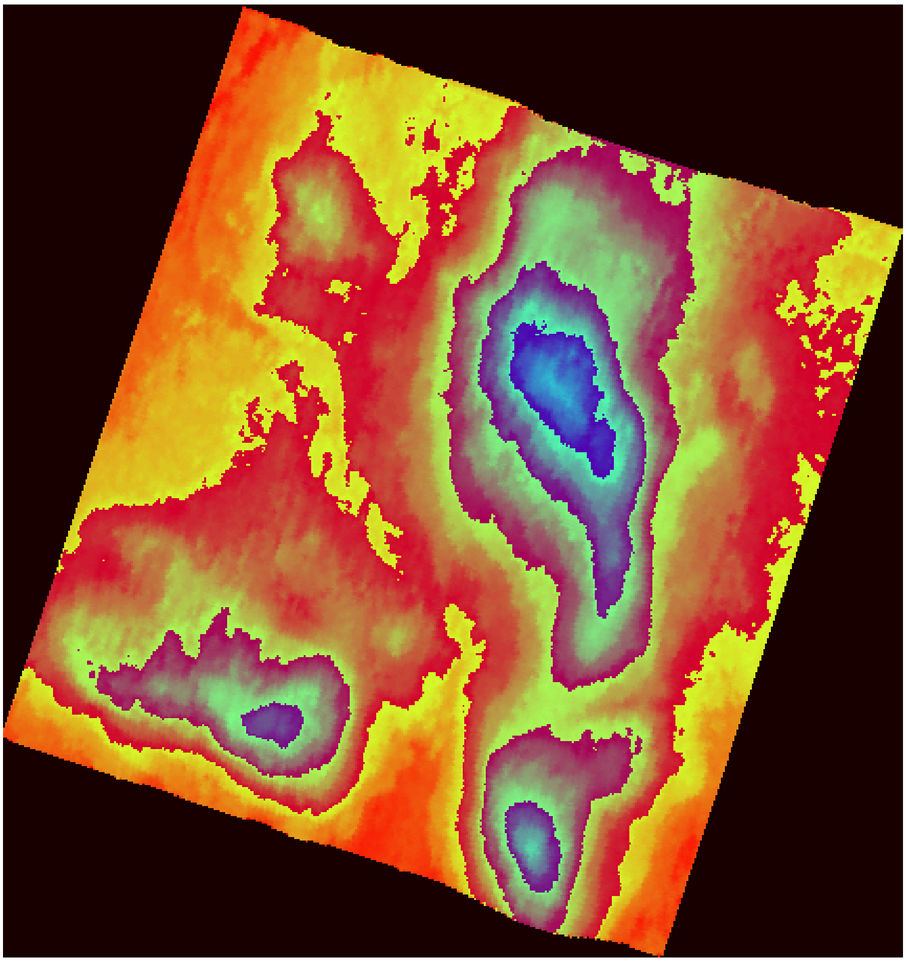

Figure 5: Rectified height model.

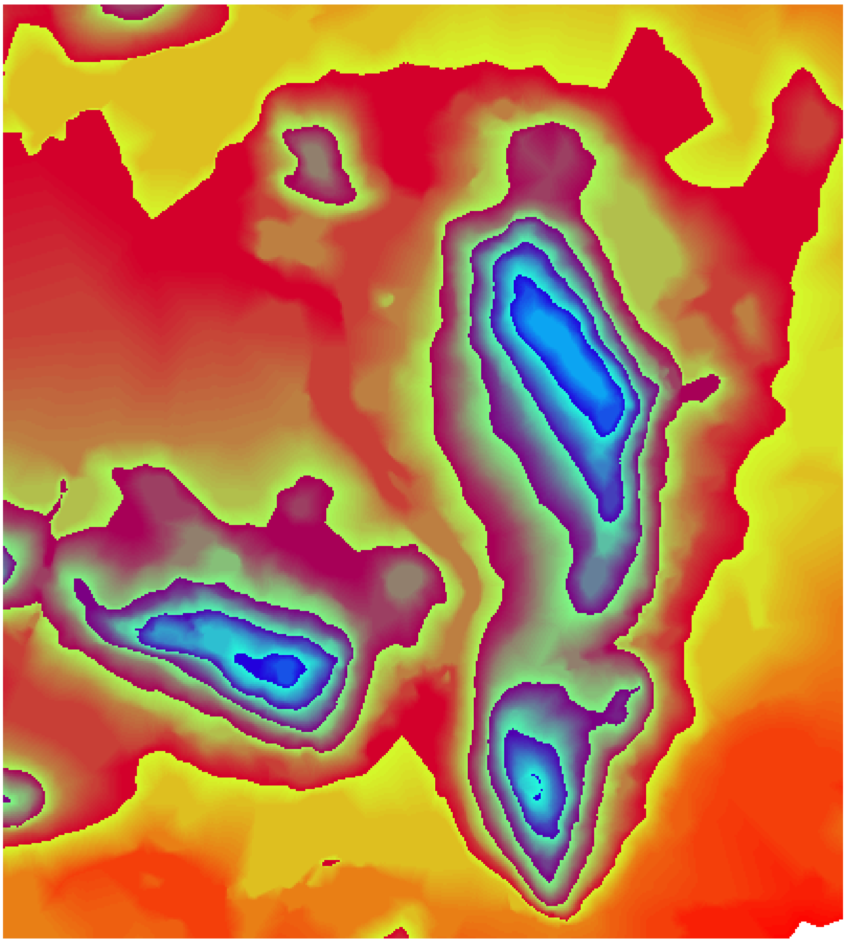

Figure 6: Existing height model.

The method described above is quite fast, but not too precise if used without any human assistance. The method described in (Engdahl) is more accurate, but is much slower.

Land use mapping

Interferometric coherence can be used for land use mapping (Wegmüller et.al), (Herland). Figure 7 shows the coherence for an area in Northern Finland. The land use and forest classification map, based on Landsat images, is shown in Figure 8. The actual interpretation requires a detailed analysis of the target type and corresponding coherence values, but simple visual comparison shows that a large part of the homogeneous areas in the land use map also appear in the coherence map.

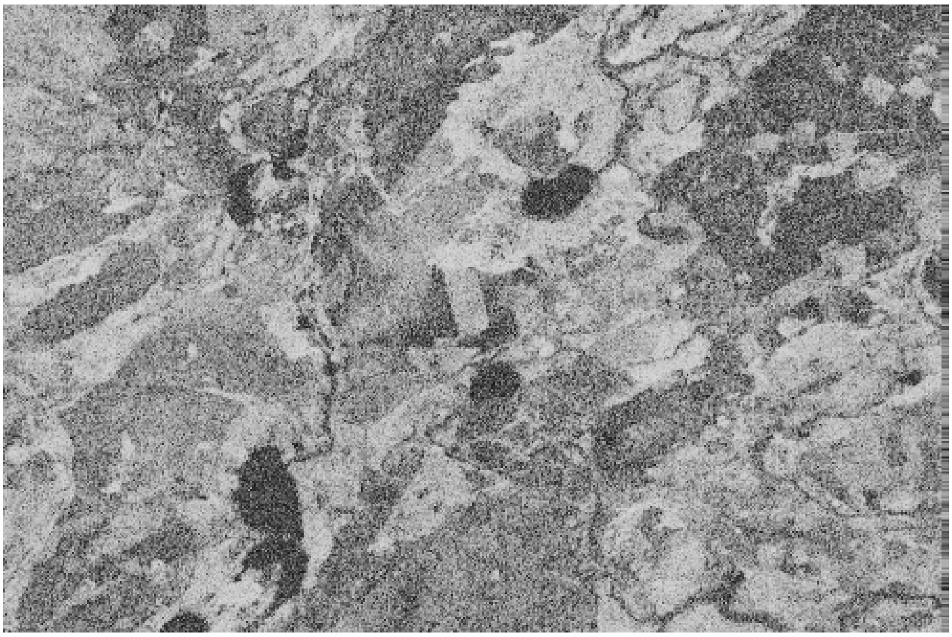

Figure 7: Coherence for a 10 km by 6 km area.

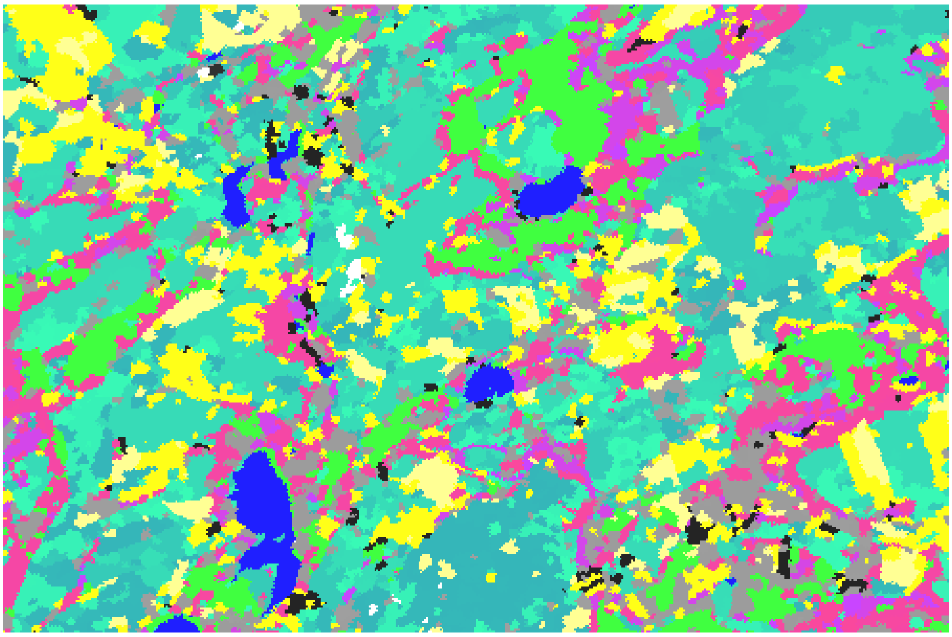

Figure 8: Land use map for the area in figure 7.

Conclusions

Methods have been developed for utilization of SAR interferometry for DEM generation and land use mapping. These include the necessary rectification procedures for using the results together with existing maps. A project is currently being planned where the DEM of Northern Finland will be updated by means of SAR interferometry. This will make it possible to do the same for other areas or generate DEMs for areas where such information is not available.

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