ISAR DEM Data Processing for Contours Generation

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Abstract

This contribution presents the different processes applied to a wide area DEM (Digital Elevations Model) in a region in the South of Venezuela, that was obtained by means of single-pass airborne SAR interferometry. Taking into account the well-known SAR technology limitations, the applied SAR interferometric processing as well as the flight mission constraints, different filtering and mosaic techniques have been applied to compute the DEM contour maps.

Keywords: DEM, SAR interferometry, altimetry, mapping, contour**.**

Introduction

The Institut Cartogràfic de Catalunya under contract with the Servicio Autónomo de Geografía y Cartografía Nacional de Venezuela has performed the mapping of a vast region between the Orinoco River and the Brazilian border. The project covered a region of 266616 square km in the South of Venezuela. This remote region of Venezuela has a warm and humid climate, with almost permanent cloud cover. The topography is hilly, with few flat areas and very abrupt elevations emerging from the plain ("tepuis"). The land is mostly covered by rainforest, with trees reaching 40 meters in height. The project consisted in producing 5 meter pixel digital orthoimages and DEM, and orthoimage maps at 1:50,000 scale with 40 meter contours derived from a ground DEM. The whole project involved 536 map sheets.

SAR mapping was selected to perform the project because this technology provides at the same time the image data and the altimetric data required for producing the orthoimages. Moreover, the data can be obtained and the final product delivered in a predictable period of time, regardless of the weather conditions and abundant cloud cover.

The accuracy and pixel size specifications excluded the use of SAR satellite systems. Therefore, the AeS-1 single-pass airborne cross-track interferometric SAR from AeroSensing Radarsysteme GmbH. (Moreira, 1996) was proposed and selected for the project. It operates in X-band with an interferometric baseline of 0.59 m and a viewing angle ranging from 20º to 67º. It was flown at 26,000 feet. The orientation and positional data required to process the SAR data was acquired by means of differential GPS and an on-board INS (Applanix).

After a preliminary ground survey campaign and the preparation of the logistics, the flight mission begun on October 20, 1998 and it ended successfully on February 5, 1999. During the whole year 1999 the SAR interferometric data was processed and a first version of all the maps was produced, but a new edition of the DEM and the revision took more than expected. A shaded representation of the final DEM is shown in image 1. More details about the logistic of the mission and the processing of the radar data can be found in Arbiol and González, 2000.

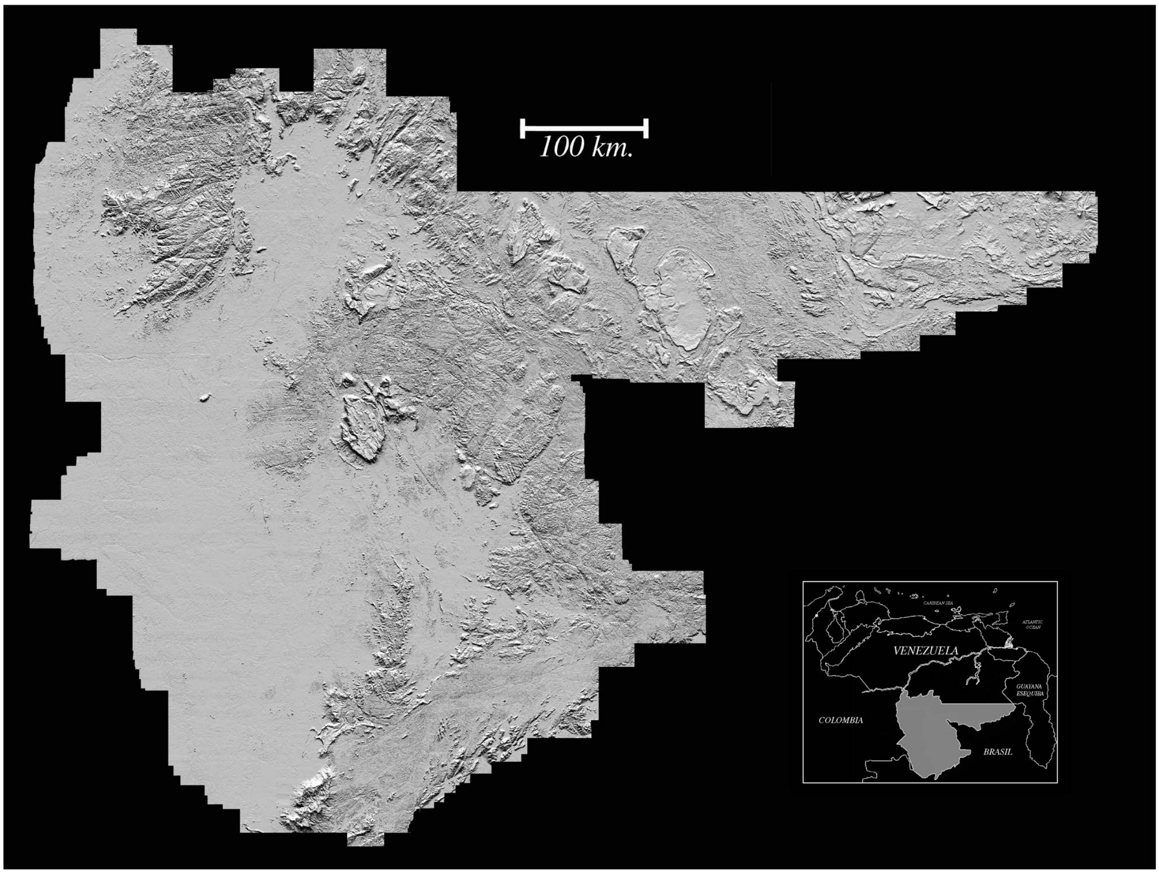

Image 1: DEM produced by the ICC interferometric SAR mission covering 266616 square km in the South of Venezuela.

SAR technology constraints

Several well-known SAR technology limitations exist for the operational use of SAR data. Mainly, they are related to the performance of the SAR in tropical rainforest areas.

The first limitation is the microwave wavelength. The used wavelength (X-Band) can not penetrate the canopy. It is a critical problem when the interest is focussed on the ground altimetry. However, it is not an inconvenient for orthoimage generation.

Another important constraint is that all of the SAR systems, as range sensors, present the following characteristic geometric effects of foreshortening, layover and shadowing. All these effects cause information loss or degradation (low coherence), mainly in high relief areas. Their impact can be reduced by flying in different directions to illuminate the slopes from different angles. Thus, the flights were performed from west to east and vice versa. Note that as in any range sensor, the resolution at near distance is different from far distance. A fifty per cent overlapping between parallel tracks guarantees good resolution data for all the interest area.

Also severe atmospheric phenomena (heavy storms, etc) can degrade the signal leading to very low coherence. Using overlapping tracks this problem can be mostly reduced or avoided.

More than fifty per cent of the map sheets show calm water river networks. Calm water areas have a very low backscattering and, as a consequence, they present very low coherence. It is especially problematic during the SAR interferometric processing, because in the phase reconstruction these calm water areas produce “islands” (isolated zones) where the coherence is high but can not be reconstructed. A more sophisticated phase reconstruction, sometimes requiring user interaction, must be used to fix this problem.

SAR data processing constraints

The complete SAR processing workflow consist of three separated steps: SAR focussing, interferometric processing and cartographic processing.

The raw data recorded on-board must be processed into an imaging product suitable for SAR interferometry. This is done by means of the SAR focussing. This process uses the navigation and attitude data derived from the differential GPS and the INS. The main characteristic of a SAR processor is its ability to process accurately the phase that must be preserved during the processing because it has a direct impact on the quality of the output DEM. This is only guaranteed when the flight squint angle is small so this constraint must be taken into account during the data acquisition. Also problems with the accurate determination of flight position and attitude can critically affect the SAR processor performance due to communication problems with the differential GPS reference station.

The second step is the interferometric processing of the data that ends in the generation of the DEM. Due to the constraints associated to the low coherence areas, phase unwrapping can be difficult, especially when isolated areas exist. In this case, the solution consists of a manual reconstruction or editing of the phase. After the reconstruction of the phase, the unwrapped relative phases must be transformed to absolute values in order to generate a geocoded DEM. The absolute phase offsets were calculated by adjusting its values between different pairs of tracks. The offset adjustment between pairs of tracks can propagate RMS error from track to track. In our opinion, it would have been better to use a block type of adjustment. In order to avoid such problems, some of the tracks had to be reprocessed until a consistent set of absolute offsets was found.

In the cartographic processing, the DEMs and the corresponding orthorectified SAR images are mosaicked to generate the final data for each map sheet. Tracks flown in parallel and opposite directions covering the same area are mosaicked selecting the best coherence data to fill the low coherence gaps. In case of high coherence data but different resolution, the best resolution data is chosen. Where the resolution is similar, a mean value was computed in the overlapping areas. Despite of this procedure, DEM gaps remain. For example, in high slope regions, when one track is affected by shadowing, the track flown in opposite direction might be affected by layover. In these cases the mosaicking process generates a gap.

Flight mission constraints

Before starting operations, the SAR system basic configuration parameters were accurately calibrated using corner reflectors as ground control points. This calibration was performed twice more during the mission. However, an accuracy degradation of the system during the flight campaign was observed when the data was processed. Different tracks showed orientation problems that affected the final DEM accuracy. A re-calibration was performed after flight campaign to compensate for the observed drifts.

Another problem associated to the acquisition of the data was the difficulty to follow the flight plan. The flight must be extremely precise to facilitate as much as possible the focussing and the interferometric processing of the data. The flown trajectory must be very close to the planned trajectory in order to assure the required overlapping. Unfortunately, despite the efforts of the flight crew, some tracks presented high squint angles and some data gaps appeared.

ISAR DEM

The ISAR DEMs resulting from the above described processing workflow have a pixel of 5 by 5 meters and are very smooth. They were processed into sheets according to the geodetic tiling of the country. Due to the constraints mentioned before, the DEMs have different unavoidable artefacts. The most important identified artefacts are gaps, stripping, mosaic problems and granulation.

Gaps. The DEM is obtained mosaicking tracks flown in opposite directions. Even so some gaps remain in regions of high slope or due to the presence of water. In water covered regions the backscattering is very low because water is calm and we have mirror reflection of the radar signal. Close to the gaps the signal coherence is low and the noise is higher. In this project the coherence threshold for accepting the data has ranged between 0.3 and 0.5. The lower the threshold is, the smaller the gaps without information are but, in return, the noisier this information is. This threshold has been chosen because we gave more priority to the image. Image quality is less sensitive to the coherence than the DEM. Close to the water gaps the z values of the DEM take random values that in some places range some hundreds of meters. The DEM generated by the AeroSensing software is smooth due to the applied filtering, so removing the noise is even more difficult. (image 2).

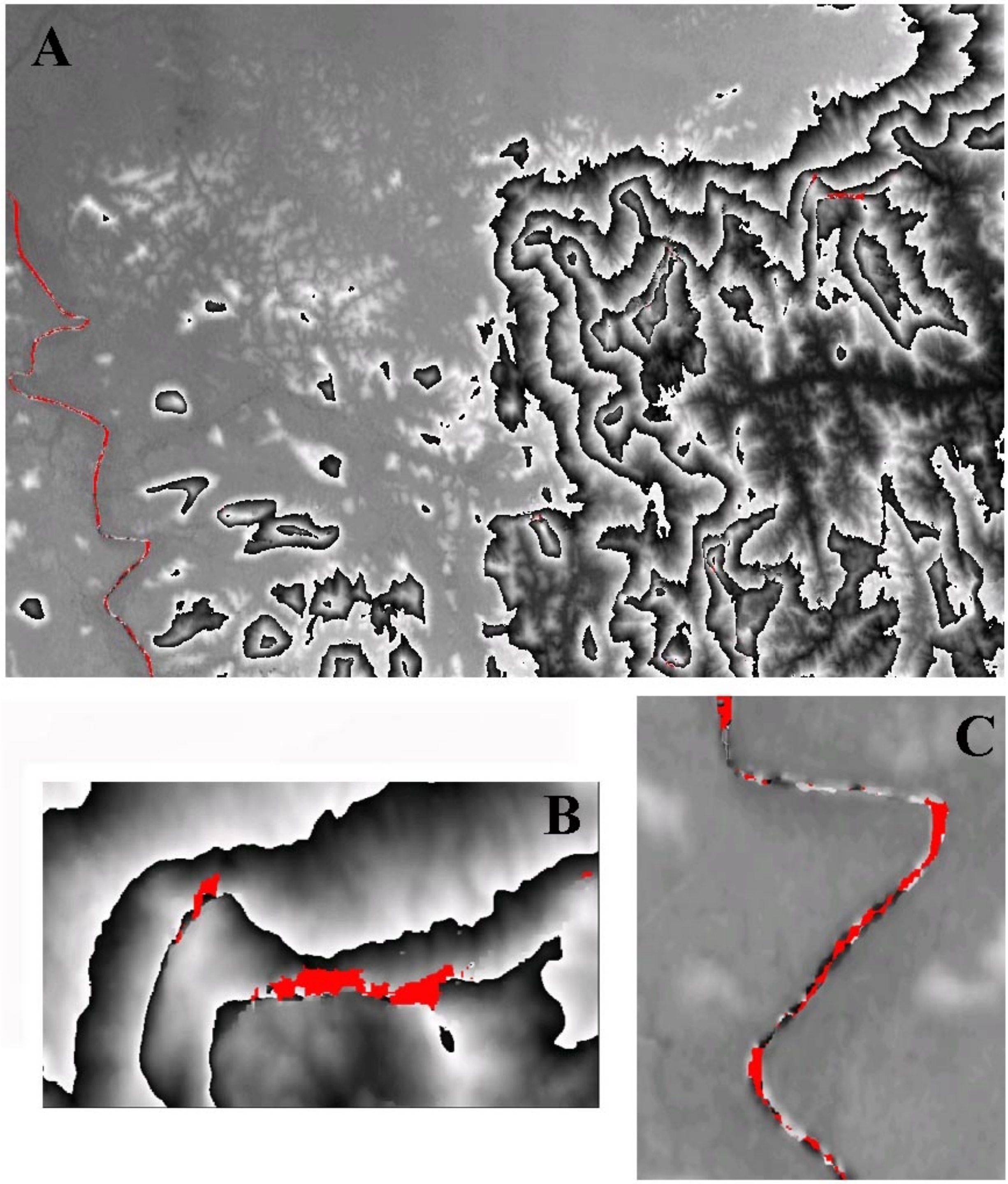

Image 2: Gaps detected in map sheet 7021ii: A: Full map; B: Detail of gaps associated to high slopes; C: Detail of gaps associated to water bodies.

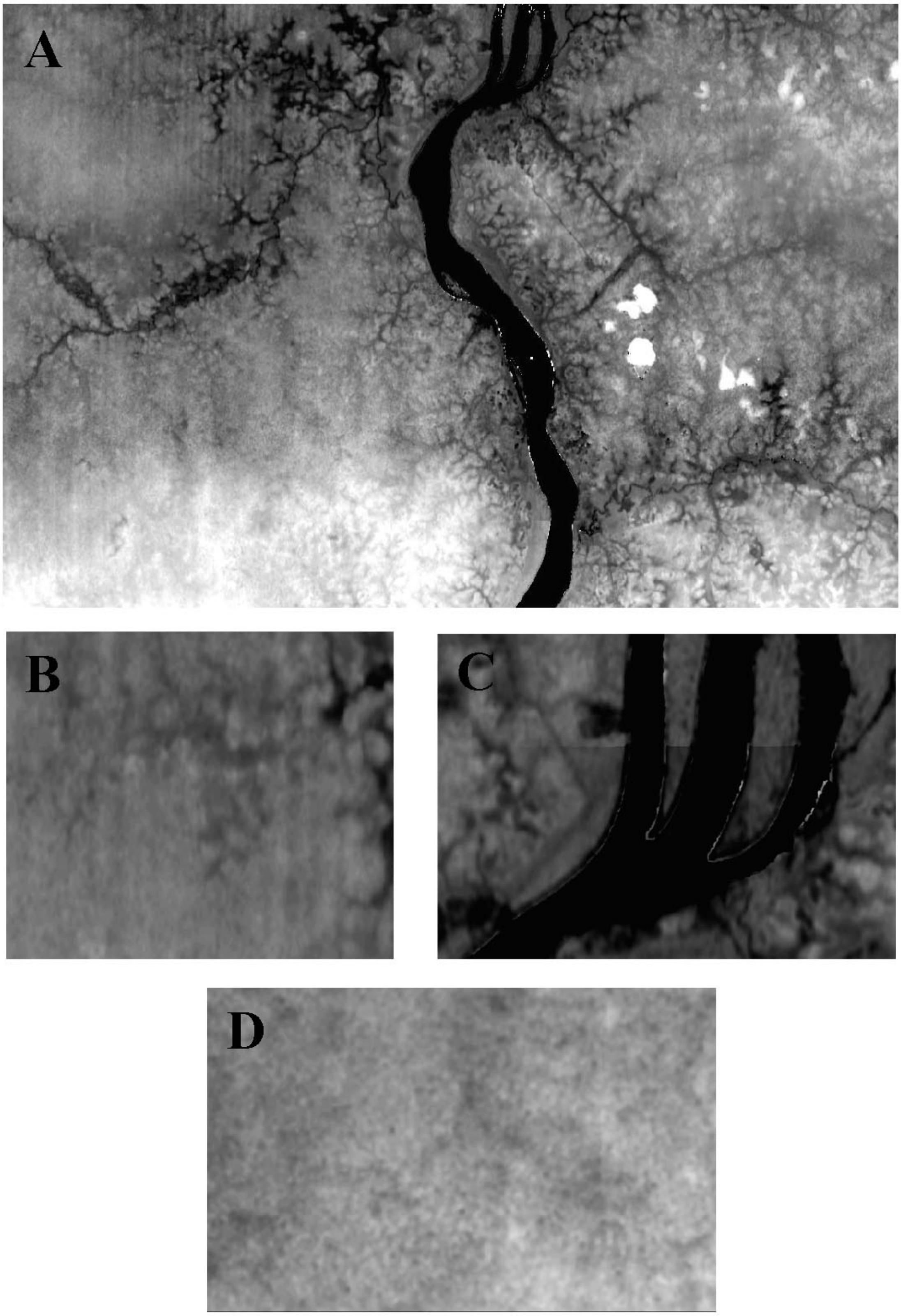

Image 3: Artefacts observed on map sheet 6819iv: A: Full map; B: Stripping artefact detail; C: Mosaic Artefact detail; D: Granulation artefact detail.

Stripping. This artefact appears when flight parameters exceed some specific values. For example, the reconstruction of the signal algorithm performs better if the images are taken at small squint angles. In flat regions the DEM may show this residual stripping that is very apparent in hypsometric representations of the flat terrain due to the low range in elevations. Anyway, the height error is in the range of acceptable tolerances (Image 3-B).

Mosaic problems. Due to the adjustment of the absolute phase offset between pairs of tracks, a residual offset error remains, even if the adjustment is within the range of acceptable tolerances. This residual can generate a very apparent mosaic artefact between tracks in flat areas. This kind of artefact can be fixed by readjusting the offset with its neighbour tracks (Image 3-C).

Granulation. Ground DEM resolution (5 m) is enough to resolve the individual trees in rainforest. The canopy is the main contribution to the DEM in low relief regions (Image 3-D).

DEM Post-processing

In order to remove or reduce as possible the described artefacts different procedures were applied to the ISAR DEMs.

DEM editing

The processing applied fulfilled the following objectives:

- Remove gross errors
- Filter artefacts
- Fill the gaps originating from shadows, occlusions and low coherence areas

It was decided not to interpolate and fill the gaps in water areas with the values of the borders because of the artefacts that could be introduced.

We wanted to remove noise as far as possible but without affecting the model details. To do so a filtered DEM is generated with a grid size of 15 m to which a median filter of size 7x7 is applied. Then the original 5x5 m DEM and the smoothed one are compared. Null values are assigned to the original DEM points where the difference between both models is larger than 40 m. (In order to compare both models the smoothed one is re-sampled to 5 m by bilinear interpolation) (image 4).

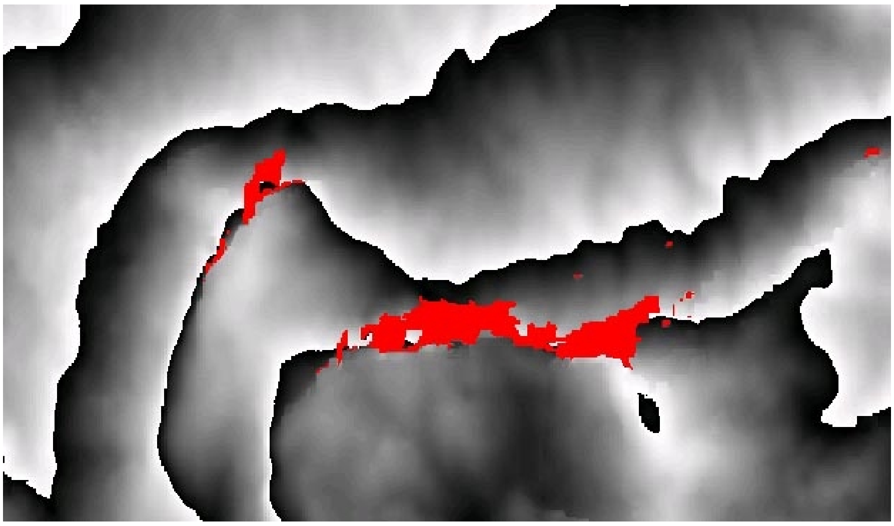

Image 4: Sub-scene of the map sheet 7021ii (Image 2-B) after cleaning of noise.

The remaining noise is removed by manual editing with the help of a hypsometric representation of the terrain. Only null values are assigned during these editions. The editing process increases the number and the area of the original gaps.

Automatic filling of gaps

An automatic filling process has been developed and applied to the 15 m DEMs and the resulting values are transferred to the original 5 m DEM after bilinear interpolation.

The filling technique applied is different depending on the size of the gap. Gaps larger than 10 pixels are filled with the help of a triangular irregular network (TIN) model. For gaps smaller than 10 pixels a 3x3 binomial (gaussian) filter is applied iteratively to the values in the boundary until no null values remain. Only null values are modified during these iterations.

The TIN based gap filling procedure works as follows. First, the masks of null value regions are expanded by one pixel and then a TIN is interpolated over the null values from pixels of the border. With this TIN model we obtained a reasonable height for the pixels in the gaps with Akima's quintic interpolation (Akima, 78). This interpolation is very smooth (it is C^1 and visually C^2) (Images 5 and 6).

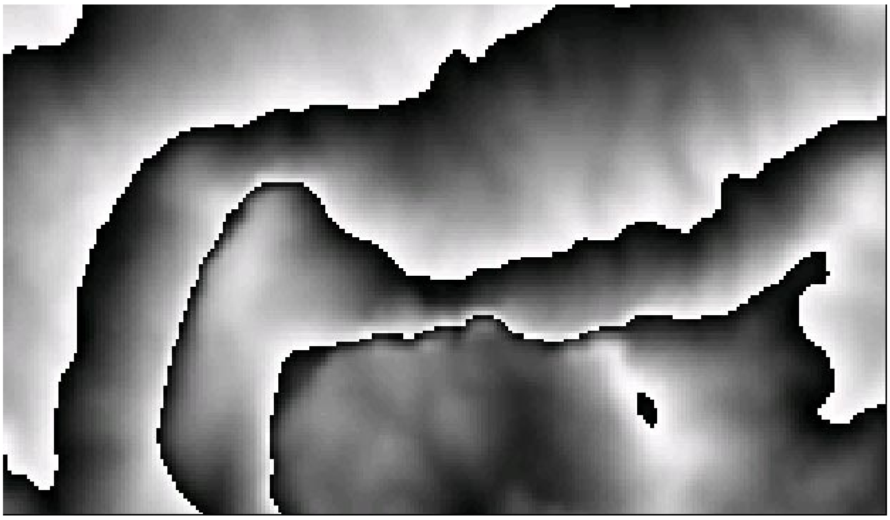

Image 5: Sub-scene of the map sheet 7021ii without holes.

Generation of Contour lines

The contour lines are generated from the filled and filtered DEMs described so far but resampled at 15 m. DEMs are 500 m larger than required by each side (image 6). To ensure the continuity between neighbouring DEMs, up to eight neighbours are mosaicked and averaged with weights computed with the help of Hermite polynomials in the overlapping areas.

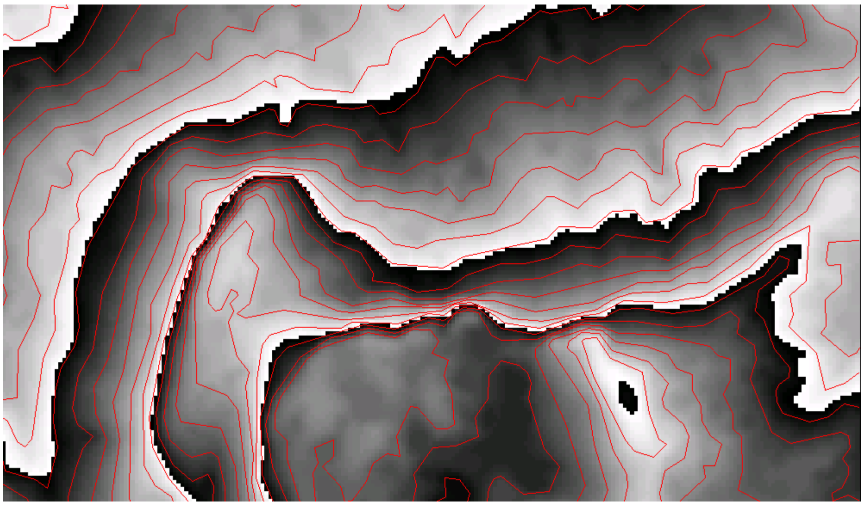

Image 6: Sub-scene of the map sheet 7021ii with the interpolated contours.

In order to account for the height of the canopy, classified cloud free Landsat images with a pixel of 25 m are generated. For some regions without Landsat coverage, texture synthetic bands derived from the radar images are used in image classification (Otazu and Arbiol, 2000). The height profiles are analysed on class boundaries and a least squares estimation of height differences between classes is performed. A procedure has been designed in order to assign a height to each multispectral class using non-vegetated areas as reference values (image 7).

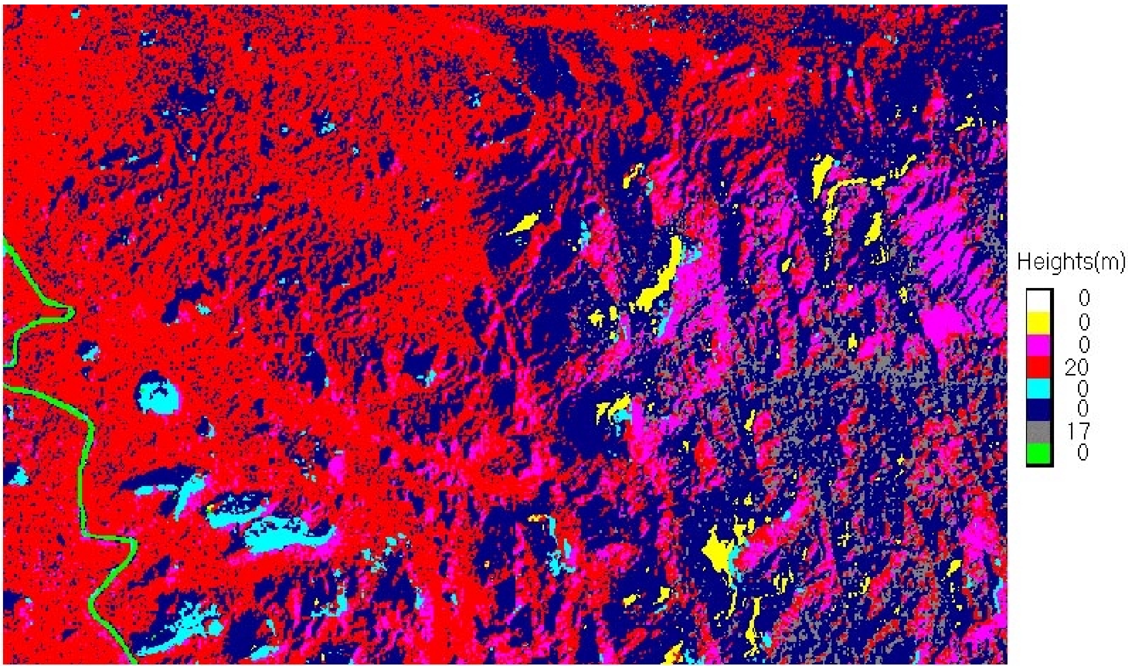

Image 7: Landsat image classification of map sheet 7021ii.

Some mismatches between Landsat and radar images have been observed due to different epoch acquisition and registration errors. The effect on the DEM is the creation of spurious local minima and maxima in the border of vegetation areas. They are reduced by filtering with a binomial filter of 5x5 pixel size. Then local minima are filled and local maxima with height smaller than 40 m are removed. The filling of local minima is justified because depressions are very rare in natural landscapes. The removal of small local maxima helps to eliminate the small contours originated by the vegetation residuals.

In areas with slope larger than 160% only the master contours (200 m) are drawn in the map. The selection is automatic. After mask generation for the steep regions, small sized masks are removed and the remaining are simplified. These masks are used to reclassify the inner contours and to remove the inner contour labels.

Too small contours (perimeter < 700 m) are removed and when the contour corresponded to a peak, it is substituted by a spot height. We consider that the spot height corresponds to a peak when it is closed by a contour and there is nothing else in the area delimited by this contour.

Some spot heights are generated randomly in flat regions with a homogeneous distribution. To perform this step, a grid of 6 by 6 sq. km cell size is analysed. Taking into account the maximum and minimum height in each cell we check if there is a contour in the cell. If there isn't any, a spot height is generated by interpolation in the DEM.

Contours are snapped to neighbouring map sheets and snap mistakes are detected. Due to the simplification of the contour lines it is possible that intersections between contours occur in steep regions. These contour problems are automatically detected and corrected by hand.

Other corrections performed by hand are the edition of the contours in water covered regions and in steep regions, and the improvement of the contour label placement. In mountainous regions only master contours are labelled. After all these editing procedures, the final map sheet contours are generated (image 8).

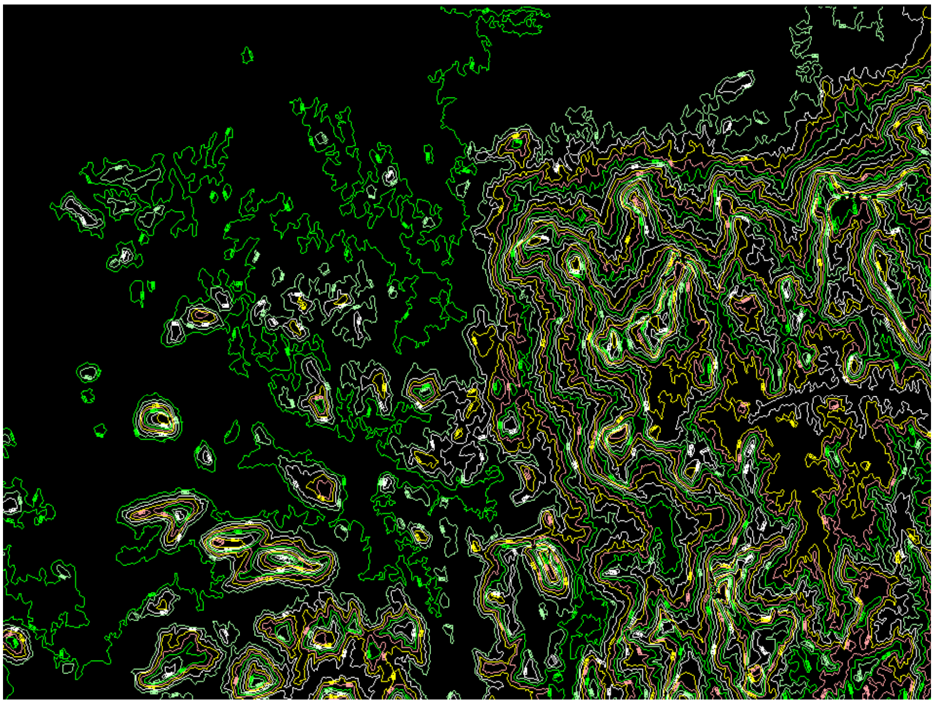

Image 8: Final Map sheet 7021ii contours.

Programming

The SAR focussing and the ISAR processing were done by using the AeroSensing software. Additional image processing was performed by means of the ICC software coded in Fortran and running on Compaq Open VMS. Almost all of the DEM post-processing and the contour generation programming was done in AML, the programming language of Arc/Info.

Conclusions

In this contribution, an operational application of airborne SAR interferometry has been shown. The obtained results indicate that this technique is able to generate high density and high precision DEMs in large areas at low cost and with very satisfactory performances. However, the limitations of the SAR technology, the present state-of-art of the SAR data processing, together with the difficulties associated to the flight mission, impact directly on the quality of the data. Usually, data acquired in extreme conditions, such high relief areas, low coherence areas, non-precise flight performances, etc., are highly degraded. Only a low percentage of the covered area present degradation but these areas are particularly problematic. To mitigate as possible its effects, the standard procedures required to generate map products must be modified. In this contribution, the methods developed to generate contour lines in presence of low quality data, have been shown and discussed. The obtained contour maps are within the range of acceptable tolerances. This is very encouraging because the implemented procedures overcome very well some of the described system constraints. Nevertheless, an improvement of the limiting elements, related to the system, the processing or the mission, seem to be essential to carry out projects with more demanding requirements and performances.

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