MAP PRODUCTION IN VENEZUELA USING AIRBORNE INSAR

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ABSTRACT

This paper is a final report of a project to map a cloudy tropical region of 266,616 km^2 in southern Venezuela using single pass airborne interferometric synthetic aperture radar (InSAR). The paper summarizes the main activities involved, the practical experiences and the final conclusions. It does not attempt to describe the radar processing in depth: only the detail needed to make it understandable is given. The report demonstrates that airborne radar interferometry is an operational tool for mapping projects in cloudy areas.

1 INTRODUCTION

The Servicio Autónomo de Geografía y Cartografía Nacional de Venezuela (the National Mapping Agency of Venezuela) has undertaken the mapping of the vast region between the Orinoco River and the Brazilian border. 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. 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 orthoimage maps at 1:50,000 scale, with 40 meter contours derived from a digital elevation model over a region of 266,616 km^2. The total number of map sheets covering the area is 536.

The Institut Cartogràfic de Catalunya (Cartographic Institute of Catalonia) submitted a technical proposal based on interferometric SAR technology to ensure that products would be obtained and 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 satellite radar, and therefore the AeS-1 single pass airborne interferometric radar from AeroSensing Radarsysteme, GmbH (Wessling, Germany) was proposed and selected for the project.

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 radar data set has been processed and all the maps have been produced.

2 THE AES-1 RADAR

The AeS-1 interferometric SAR of AeroSensing Radarsysteme (Moreira, 1996) is an advanced radar operating in the X-band that is capable of delivering radar images with pixel sizes ranging from 0.5 to 5.0 m. and elevation data with nominal accuracy of 5 to 50 cm. The radar emits and receives the signals using two antennas that are rigidly mounted on one side of the airplane and 0.59 meters apart, so as to form the baseline of the interferometric geometry. The radar illuminates the terrain laterally at an angle ranging from 20° (near range) to 67° (far range). Due to the separation of the antennas, the range to a point is slightly different as measured by each antenna; this range difference corresponds to a phase difference from which the elevation is determined.

The motion of the airplane affects the phase of a point, so this motion has to be recorded and compensated. The current configuration uses GPS and INS data from an Applanix system to determine the effects induced by the motion of the aircraft and to obtain the orientation of the sensor. In addition, the aircraft had to follow the flight lines with almost no deviations (less than 20 m). Therefore, the flight navigation system makes use of DGPS data transmitted from a reference station. The transmitter's maximum range is 300 km and its location was carefully chosen so as to always have visibility to the aircraft. This was achieved by computing a DTM from the contour lines of existing 1:500,000 scale maps and by performing a visibility analysis. GPS data at the reference stations was recorded for post-processing.

3 MISSION PREPARATION

The project area was divided into strips 130 km. long and 14 km. wide, and flown at 26,000 feet. Depending on the terrain type - flat, hilly or mountainous - the side overlap was 50%, 67% and 75%, in order to guarantee that enough images would avoid the shadowing and layover effects. Consecutive tracks were flown in opposite directions.

The airfields were selected from the few available in the area. The selection criterion was suitability for flight operations: availability of supplies, accessibility and minimization of ferries. The selected airfields were Puerto Ayacucho, La Esmeralda and Santa Elena de Uairén. Fuel and food were carried by river and by air.

The AeS-1 system relies on GPS and INS data for georeferencing, so ground control is used for checking purposes only. The checkpoints can be made visible on the radar image by installing radar reflectors (corner reflectors) at known positions. Therefore, a survey campaign was performed together with the Geodetic Department of the National Mapping Agency of Venezuela to measure 31 positions where the corner reflector would be installed. None was installed at that time, due to the risk of being displaced, destroyed or even covered by the vegetation.

4 FLIGHT CAMPAIGN

Before starting the mission, AeroSensing flew a calibration flight, in order to ensure the absence of any systematic error and to measure different parameters: for example, the corner reflector shape and width in the image, a precise measurement of the baseline, radiometric parameters for compensating the different radiometry in the far and near range parts of the swath, and the effective number of *looks* required to maintain a low enough noise level. For this project the number of *looks* was set to 7.

4.1 DATA CAPTURE

As mentioned earlier, the installation of the corner reflectors was performed simultaneously with the flight. Two reflectors were installed with two different orientations, so that they could be imaged on two opposite tracks. Some had to be installed on top of the "tepuys" and required the use of a helicopter to transport the people, the reflectors and the GPS equipment.

The flight campaign lasted from October 28, 1998 to February 3, 1999, including repairs, mandatory revision of the airplane, re-flights, change of airfields, etc. There were 67 effective flying days, with around 10 tracks per day. While cloud cover does not affect the radar images, dense clouds with high water content and turbulence do prevent operations, since they directly affect the quality of the image.

4.2 ON-SITE QUALITY CONTROL

After landing, the on-board disks were removed and the contents copied to DLT 7000 tapes. On-site quality control followed, in order to detect any anomaly:

- Radar checking: analysis of parameters such as raw signal variations, power variations, etc., in order to ensure that the radar had operated correctly during data acquisition
- Movements of the aircraft: attitude variations of less than 3° in roll, 1° in pitch and 2° in heading, and variations of less than 30 m. in height and 100 m. in position
- Image quality: a 0.8 x 14 km. segment of each track was fully processed and checked

If the control was passed, a copy of the DLT was sent to the ICC (Barcelona). The quality control detected some bad tracks, which were re-flown immediately. The amount of data collected was around 16 Tb.

5 PRODUCT GENERATION

The AeS-1 software runs on a network of standard PCs. The software is predominantly written in IDL and runs on Linux Operative System.

5.1 SAR PROCESSING

The hardware configuration at the ICC consists of 5 processing lines, each with two DLT drives and 13 slave PCs connected to the Ethernet.

At each string the DLT containing a 130 km. long track is read, divided into segments of 0,5 GB with 25% longitudinal overlap and distributed among the slave PCs. Each segment takes up to 6.5 hours to process on a standard Pentium II 450 MHz microprocessor with 256Mb RAM and 9 Gb disk. On average, a track is processed every 32.5 hours. The combined throughput of the 5 strings is a track every 6.5 hours. A central PC with a FoxPro DB dispatches jobs to every processing line and takes care of the archival and data management.

The first step in processing consists of the reconstruction of the two complex images (intensity and phase) from the raw data signal of the two antennas. The aircraft motion is corrected at this stage. The two complex images are then co-registered for computing the interferogram on a pixel-to-pixel basis. The interferogram is then obtained by multiplying the first image with the complex conjugate of the second. The interferogram represents the phase difference due to the elevation of the terrain and is expressed ("wrapped") modulo 2π. The "phase unwrapping" process computes the absolute phase difference by adding 2π if discontinuities of 2π are detected in the interferogram. The AeroSensing method for phase unwrapping is a hybrid least squares combined with region growing algorithm.

All these processes are automatic and involve long computations in the Fourier space. The output is an image coded in slant range and an unwrapped phase interferogram.

5.2 GEOCODING

The phase unwrapping process can fail for several reasons. That is to say, there are discontinuities that are not well resolved, as in the case of the layovers and shadows, and terrain returning low signal (i.e. rivers). These errors must be removed by editing the phase manually.

The elevations are then computed from the absolute phase after phase calibration. Two methods can be used: the first takes the elevation of a corner reflector and assigns it to the corresponding phase at this point (the phase becomes "calibrated"). The second method is iterative and is based on the interferograms of the contiguous tracks covering the same area from opposite sides. The process iterates until a solution that minimizes the differences in elevation is found. This method is very time-consuming but it does not require any ground control or operator interaction.

Once the elevations are known, tracks are geocorrected and assembled together in a mosaicking process. As mentioned earlier, the SAR processing part runs in batch and can be managed by one operator. However, the geocoding requires manual intervention. A group of 12 operators with two supervisors and a project leader operate the configuration at the ICC.

5.3 RADIOMETRIC CORRECTIONS

Because the side looking geometry, the radar images are brighter at the nearest side and darker at the far range. A similar effect occurs with the relief: slopes oriented to the radar beam are brighter. Since a map sheet is formed by mosaicking consecutive opposite tracks, a radiometric compensation process is applied to equalize the radiometry (Fig.1).

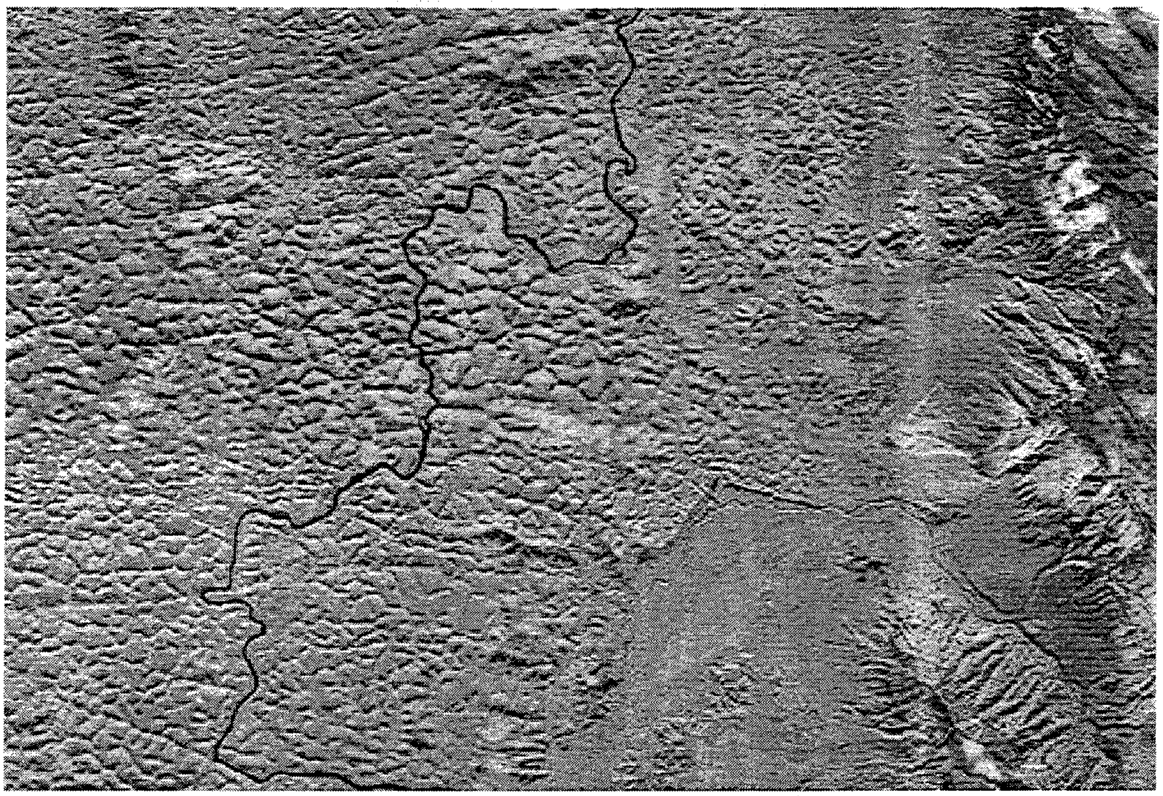

Figure 1. Geocoded image after radiometric correction

5.4 DIGITAL TERRAIN MODEL

Interferometric techniques provide a very dense grid of elevations. It should be noted that since each pixel has a phase associated, each pixel has a height. Thus one finally gains a very dense 5 x 5 m. elevation grid covering the 266,616 km^2. Each elevation is a single precision floating point value of the top of the features; in other words, the result of the interferometric process is a very dense digital surface model (DSM).

The DSM is first filtered in conflict areas, such as the zones near the rivers, and in areas that are void due to specular reflections and shadowing effects.

An almost cloud-free Landsat coverage is used for estimating the height of the trees and converting the DSM into the Digital Terrain Model (DTM). After co-registering with the radar images, the Landsat scenes are classified using unsupervised clustering techniques. Height differences between adjacent classes are obtained by drawing profiles across them and then extracting the heights from the DSM. The output is a table with the average differences in height for each type of transition between classes. The bare soil class is used as a reference, and then the heights are subtracted from the DSM to obtain the DTM. The classes are derived from the texture of the radar images in places where the Landsat scenes are covered by clouds. Interpolating from the neighbouring heights eliminates local minima and maxima.

Contour lines are then computed automatically; and very small closed contours are deleted.

5.5 MAP FINISHING AND EDITING

Geographical names have been extracted from existing maps and placed on the map. Finally, frames, legends and marginalia are placed on the map, plotted on film and printed.

6 QUALITY CONTROL

The radiometric control of the digital images consists of a both qualitative and a quantitative evaluation (Lira, 1999). The qualitative evaluation relies on a visual inspection and checks for defocusing, global contrasts, noise, existing artefacts and visual discrimination of small textures. The quantitative tests check for the real number of *looks*, the radiometric resolution, spatial resolution, contents of the *speckle* associated with the radar images, etc.

The geometric control of the digital products is made using the ground control point measurements done during the field campaign. The points have been observed on the images and a comparison with the ground measurements has been done. Due to the poor image coherence near the water bodies a few points has been rejected but final result shows a very good geometric confidence. The planimetric test using 24 points shows a circular RMS error of 8.8 m. The altimetric test using 31 points shows a RMS error of 5.7 m.

7 CONCLUSIONS

The most important conclusion is that single pass airborne interferometry is a reliable and operational tool for mapping missions in areas with severe cloud cover. Having become accustomed to the long stand-by of photographic missions in this type of area, the performance of the radar flights is a very pleasant surprise, even though some days can be lost due to excessively dense cloud cover or turbulence.

On the other hand, a long period of time is required to process the radar data. This is due not only to the considerable computations, but also to the trial-and-error type of process mentioned earlier. Comparatively, the amount of hardware needed and time spent are several times greater than for an equivalent optical mission. Fortunately, the intensive computer-bound processes run in batch on a configuration that is easily scalable.

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