'Photogrammetric Week 01' D. Fritsch & R. Spiller, Eds. Wichmann Verlag, Heidelberg 2001.

Surface and Ground Topography Determination in Tropical Rainforest Areas Using Airborne Interferometric SAR

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ABSTRACT

For the generation of topographic maps generally the ground elevation rather than the surface elevation is required, which can be realized, if at all, only with large wavelengths that penetrate the vegetation foliage. This paper reports about a project in the Brazilian Amazon region where Aerosensing's P-band airborne interferometric SAR has been used to map a part of the rainforest. The P-band sensor has been operated in fully polarimetric and interferometric (repeat-pass) mode with a range resolution of 2 m. A digital ground elevation model has been generated with a horizontal spacing of 2.5 m and a rms height accuracy of 2 m. Additionally, a high precision model of the surface elevation, with a rms height accuracy of 0.5 m, has been derived using the single-pass X-band data. A description of the system, obtained results, and validation of the results is given.

1. INTRODUCTION

In the last decade interferometric SAR (InSAR) has reached a wide acceptance as being a suitable tool to generate high-precision digital elevation models. Especially in tropical areas with nearly permanent cloud coverage InSAR provides a cost-efficient means for mapping large areas in short time periods. However, the interaction of microwaves with vegetation is strongly dependent on their frequency, demanding a careful interpretation of the extracted information. Short waves like X-band are mainly scattered back from the top of the canopy, whereas P-band penetrates the foliage and gets reflected from trunk and soil, thus carrying the phase information (and therefore the height information as well) from bald earth. For the generation of topographic maps generally the ground elevation rather than the surface elevation is required, whereas the surface and ground elevation together enable the estimation of additional physical parameters like vegetation height, density, or biomass.

In September 2000 an area of approx. 1,300 km² within the tropical rainforest of Brazil was mapped using the airborne interferometric synthetic aperture radar AeS-1 of Aerosensing Radarsysteme GmbH. The project was carried out within a collaboration between the Brazilian Army (DSG), the Brazilian Institute of Geography and Statistics (IBGE), the Brazilian National Institute for Space Research (INPE), the Applied Electromagnetics (UK), the Italian Research Council (CNR-IRECE) in Naples, Italy and Aero-Sensing Radarsysteme GmbH, Germany. The goals of the project covered various interests of each partner, which where mainly driven by the strong need of information about and underneath dense vegetation. For that purpose, both the X- and P-band subsystems of AeS-1 were operated in order to gather information from the top of the canopy (exploiting X-band data) as well as the bald earth (exploiting P-band data).

The present paper reports about realisation and results of this project. First, a brief overview over the AeS-1 system is given, followed by a detailed presentation of the obtained results. Conclusions and outlook close the paper.

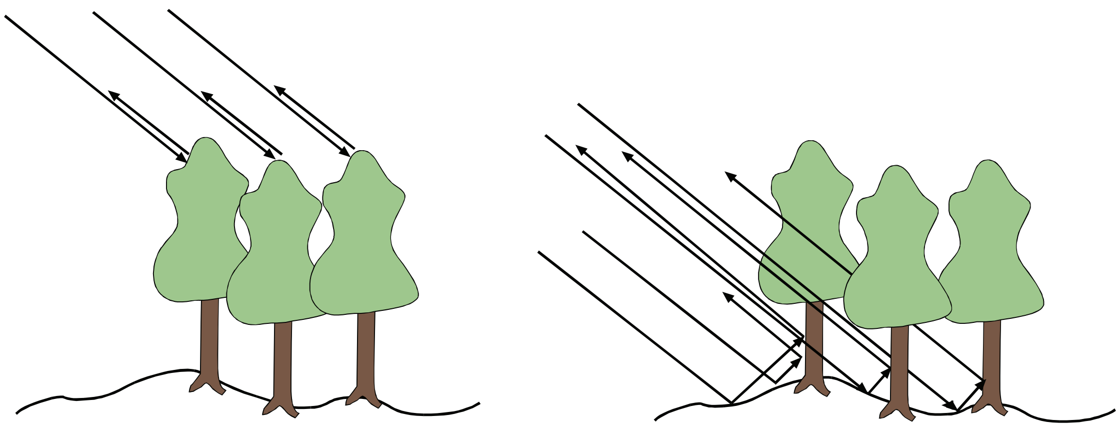

Figure 1: Penetration dependency on radar frequency. Black arrows indicate transmitted and reflected X-band and P-band waves on top of the trees and on the forest floor.

2. AES-1 INTERFEROMETRIC SAR

Since 1998 Aero-Sensing's AeS-1 radar is equipped with an X- and a P-band subsystem which are operated using the same backend. The main system parameters are summarized in Table 1. Under

	X-BAND	P-BAND
Frequency	9.55 GHz	415 MHz
Bandwidth	400 MHz	70 MHz
Polarization	HH	HH, VV, HV, VH
PRF	up to 16 kHz	up to 7 kHz
Peak Power	2.5 kW	up to 1.5 kW
Antenna Beamwidth (azimuth)	8°	50°
Antenna Depression Angle	45°	50°
Flight Altitude	500...11.000 m	500...11.000 m
Resolution (rg × az)	0.5 m × 0.2 m	2.5 m × 0.7 m
Height resolution	up to 0.05 m	up to 1 m

Table 1: AeS-1 system parameters

typical flight conditions, data are gathered at 3 km height, 45° antenna depression angle, 100 m/s aircraft velocity, and a (repeat-pass) interferometric baseline of 25 m for P-band. The aircraft

position is recorded precisely by D-GPS together with an INS and can be estimated to an absolute accuracy of up to 3 cm. A detailed system description can be found in (Wimmer et al., 2000).
In the discussed flight campaign, AeS-1 was operated in the following system configuration:

- *X-band:* 400 MHz bandwidth, 2 km swath width, HH polarization, single-pass interferometric mode with 2.4 m baseline.
- *P-band:* 70 MHz bandwidth, 2 km swath width, multi-polarization (HH, VV, HV, VH), repeat-pass interferometric mode with 25 m baseline. Parts of the area have been mapped in additional operating modes like repeat-pass tomographic mode (up to 10 different baselines over the same area), or wide swath mode (4 km, 7 km, and 14 km swath width).

Interferometric SAR data processing was carried out fully operational. Processing procedures are reported in detail in (Wimmer et al., 2000) and (Schwäbisch et al., 1999).

3. RESULTS

In the following results from one of the testsites near to the Tapajos river in the state of Amazonia are presented. Various ground truth surveys were undertaken during the two weeks lasting project simultaneously to the aerial survey, including control, verification, experimental and maintenance measurements:

- Corner reflectors have been deployed for calibration as well as for verification.
- Other man-made objects were placed in hidden positions below the dense forest canopy to check their visibility in the P-band imagery.
- A forest parameter inventory including biomass, tree type and age, and stem diameter
- estimation has been carried out.
- A large amount of D-GPS bald earth height measurements were undertaken for validation purposes by INPE.

Figs. 2 and 3 show parts of the DSM derived from the X-band and the DGM derived from the P-band data. The area extends over 2×2 km^2 and was processed with a grid spacing of 2.5×2.5 m^2, as requested by the customer. Forested areas and clear cuts can be clearly distinguished in the DSM. On the other hand, a contiguous image of the water drainage system is visible only in the DGM, water bodies underneath the canopy disappear in the DSM.
Height validation carried out by INPE showed a standard deviation of 1.83 m (1 sigma) and an RMSE of 1.92 m, measured by evaluating elevation profiles in different areas.

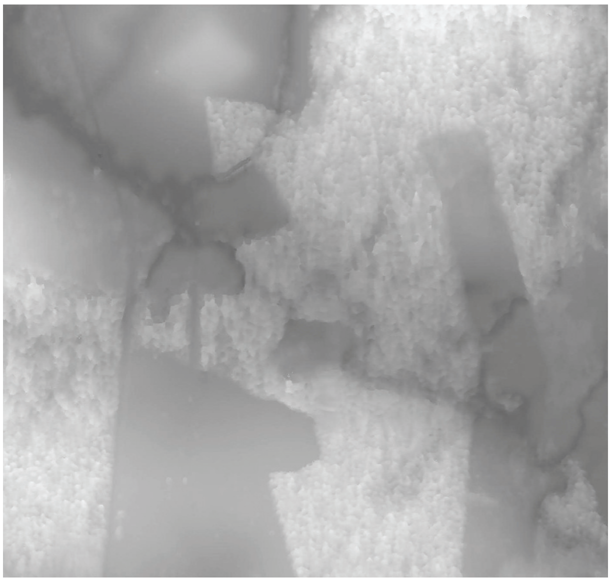

Figure 2: Digital surface model (X-band)

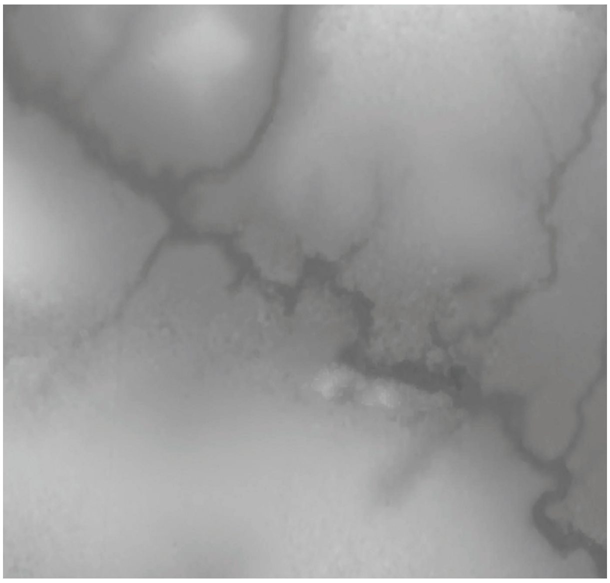

Figure 3: Digital ground model (P-band)

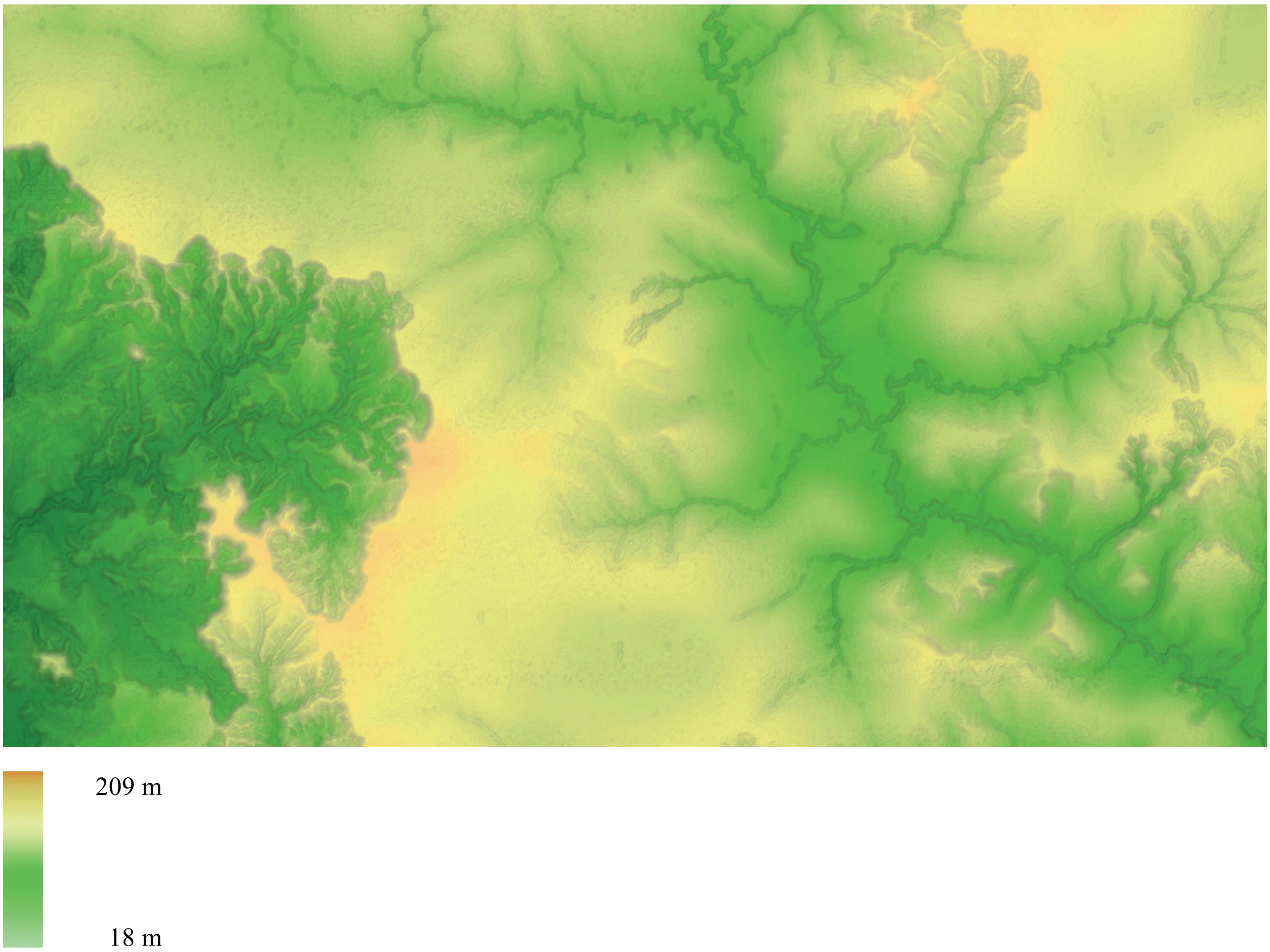

Figure 4: P-band DGM of an area of approx. 280 km² within the Tropical Rain Forest of Brazil.

Figure 4 shows the DGM extending over an entire map sheet (22 × 13 km^2). Grid spacing again is 2.5 × 2.5 m^2 and the height accuracy is 2 m. The image accurately reproduces the topographic fine structure underneath the forest and displays the two different discharge regimes.

In Figure 5 the difference between the DSM and DGM is shown via different colors. Bright green areas indicate the biggest differences of around 30 m, whereas dark green illustrates areas with almost the same height estimates of DSM and DGM. Within the bright green area even individual trees are visible. The image shows significant tree height variations within the forested regions. This underlines the importance of independently measuring the forest floor height for precise DGM generation, instead of estimating the canopy height and subtracting a mean tree height.

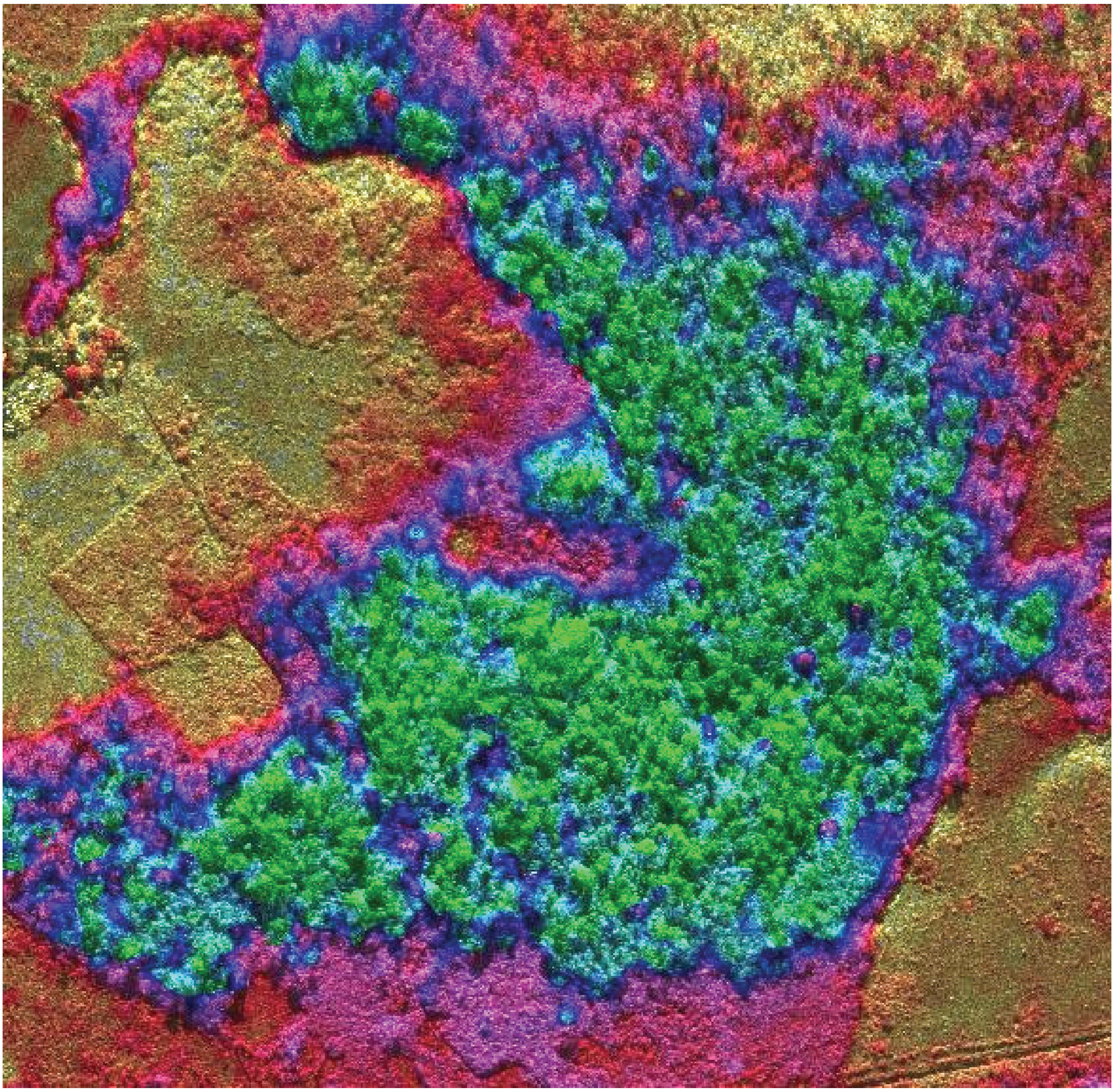

Figure 5: Difference map of DSM and DGM data of an area of approx. 2 × 2 km^2 (bright green = 30 m, dark green = 0 m).

As an example for final image products, Fig. 6 shows a SAR orthoimage map, generated from the X-band amplitude data together with the contour lines of the bald earth model. Map generation was carried out by the Ministério da Defensa, Diretoria de Serviço Geográfico of Brazil.

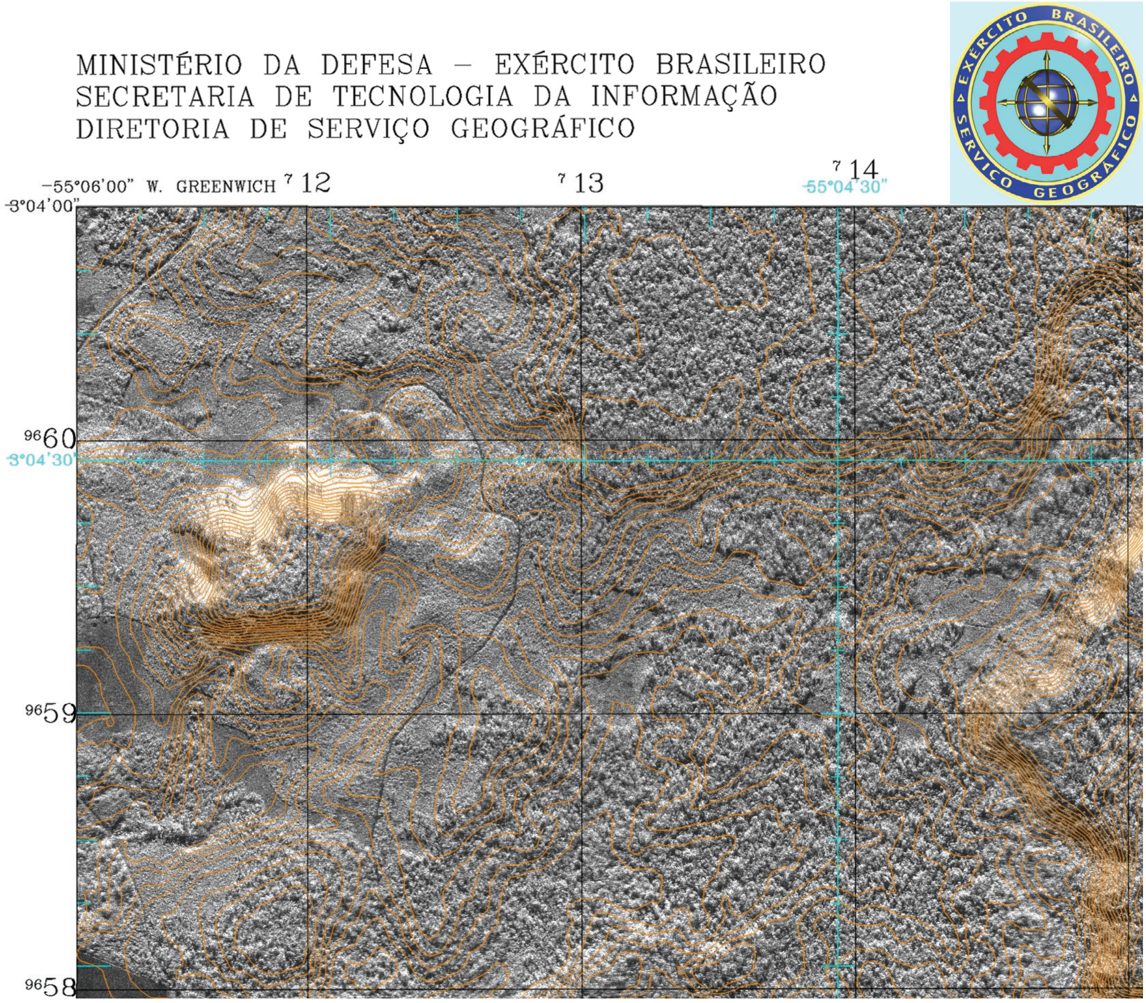

Figure 6: Part of a SAR orthoimage map with DGM contour lines in a scale of 1:25 000 generated from X- and P-band data by DSG, Brazil.

4. CONCLUSIONS

One of the main results of the project is the prove that P-band interferometric SAR observations can be used to accurately estimate the ground topography of densely vegetated areas like the Brazilian rainforest. With the airborne InSAR AeS-1 system, an accuracy of 2 m RMSE has been obtained in hilly terrain with elevation changes up to 200 m and vegetation heights up to 40 m. Additionally, it is important to note that results have been achieved by exploiting only the HH component of P-band and applying conventional interferometry techniques. A further use of polarimetric interferometry may improve ground elevation estimation in even more densely vegetated areas with taller trees, as reported by (Cloude et al., 2000).

5. REFERENCES

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