Experiences with the South African VHF Synthetic Aperture Radar

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1. Introduction

In the early 1990s, the SANDF commissioned studies into *Synthetic Aperture Radar* (SAR) at the University of Cape Town Radar Remote Sensing Group, which was already active in the area of satellite borne SAR. A proposal to develop a fully polarimetric, multi-frequency airborne SAR system was supported, to be executed by a consortium consisting of UCT, CSIR and Reunert Radar Systems. The system was originally planned to be airborne during 1995 [3]. However, due to a combination of late delivery of commercial hardware and flight clearance requirements for the large VHF antenna structure, the first radiating flights occurred early in 1999. Although designed for installation on a Boeing 707 aircraft, the system is now fitted to a turboprop variant of the DC3 (C47TP Dakota) aircraft of the *South African Air Force* (SAAF). The antenna elements are mounted directly to the skin of the aircraft.
The implemented SASAR system operated in the VHF-band at 141 MHz with a bandwidth of 12 MHz, fully polarimetric. Budget cuts had forced economies, and UCT had strongly pushed that only the VHF sensor be developed, since it had a wider range of new applications, compared to existing, overseas systems operating in the C and X bands. Funding for the system development has been provided by the *South African National Defence Force* (SANDF) *Defence Research and Development Board* (DRDB), and the system was managed by the CSIR Defencetek. All the signal processing is performed at UCT, using a fully motion-compensated SAR processor based on the range-Doppler algorithm. Unfortunately the aircraft has been sold and the system mothballed. Future plans for the system are not clear.

2. Data Acquisition

The data shown in this paper were acquired from three passes over the Hermanus coastline (specifically the Botrivier lagoon and mountains to the west) of South Africa (approximate latitude 34.5°, longitude 19.25°). The aircraft and equipment were leased from the CSIR and SAAF on behalf of De Beers Consolidated Mines, under the management of UCT RRSG. The time separation between passes was approximately 25 minutes. The vertical baselines were 105m, 206m and 311m. The swath extends from nadir out to approximately 28 km, covering a wide range of look angles from vertical to about 82°. The SAR imaging geometry is depicted (to scale) in Fig. 1. A summary of the system parameters is given in Table I. An example of a processed image covering about half of the usable swath is shown in Figure 2.

Table I: *Typical SASAR system parameters.*

Flight height	3000–4000 m
Flight speed	80–90 m/s
Observation angle (at h = 4000m)	From 0 to ~85 deg
Range (near–far)	24 km
Range Bandwidth	12 MHz
Range Resolution	12 m
Processed Azimuth Beamwidth	6 deg
Corresponding Azimuth Resolution	12 m
Carrier Frequency	141 MHz

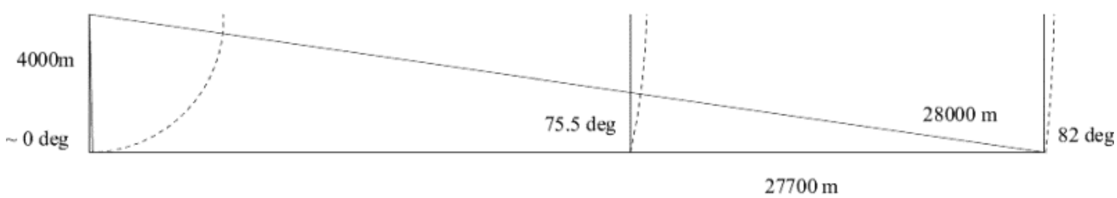

Figure 1: *Typical SASAR imaging geometry – to scale.*

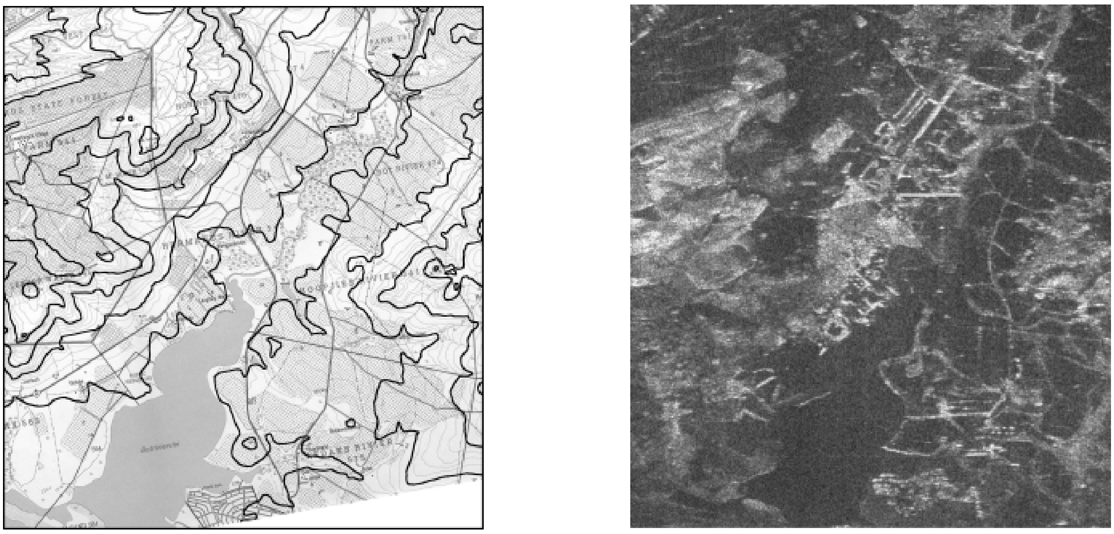

Figure 2: *Map and intensity image of the Hermanus/Botrivier area of South Africa.*

3. VHF SAR Characteristics

The VHF frequency of operation has certain unique characteristics which differ from higher frequency SAR systems:

- Good foliage canopy penetration. This allows for possible applications of “bald earth” topography mapping and the detection of vehicles under bush cover.
- Reasonable ground penetration capabilities are expected in arid regions. The use of the radar for geological- and hydrological mapping applications is under investigation.
- Forest stem volume measurements. Studies performed with the CARABAS system [4] have shown that it is feasible to estimate stem volume using a VHF SAR sensor. The long wavelengths (3–15m) penetrate forest canopies and measure backscattering from the tree trunks. Observations have indicated that the scattering strength is directly related to stem volume. It is also very sensitive to terrain slopes, which must be corrected for when estimating stem volume. The CARABAS system is particularly suited for dense forests, where other remote sensing techniques fail.
- A VHF SAR system is very sensitive to large-scale man-made structures such as buildings, fences and power lines. Investigation is also being made into ship detection for maritime patrol applications.
- As the radar is sensitive to objects of a different (larger) scale than with higher frequency systems, a comparison of the imagery from a VHF radar and a higher frequency radar provides additional information.

4. Semi Desert and Forest Measurements

The polarimetric VHF SASAR system has flown over two different terrain types, namely over a flat semi-desert area near the town of Upington, and also over a mountainous, forested coastal area near the town of Hermanus (see Figure 2). It was found that the flat, unvegetated desert terrain provides almost no backscattered signal for larger incidence angles, but that man-made targets such as fences show up very brightly [2]. For the coastal scene, it was observed that large returns from heavily vegetated areas over the entire range extent were obtained, with many features of interest. The mountainous area revealed that only the steepest mountain slopes provide significant backscatter, which implies that forest biomass measurements in this type of terrain look promising. Another application, which shows promise in heavily vegetated areas, is interferometric mapping of the ground layer (as if the vegetation has been stripped).

5. Interference Suppression

Radio frequency interference (RFI) is a significant problem for SAR systems operating at VHF/UHF-band, because the spectrum is already used extensively by other services such as television, mobile communications, radio and cellular phones. Experience with the SASAR system has shown that even in remote locations the interference power often exceeds receiver noise by many dB, becoming the limiting factor on system sensitivity and severely degrading the image quality. Both the notch filter and the LMS adaptive filter have been applied successfully on RFI contaminated images.

6. Motion Compensation

Longer synthetic apertures are required at VHF frequencies than at higher frequencies to achieve a given azimuth resolution for a given target closest approach range. This, in turn, has implications on the motion compensation requirements of the system. Biases and drifts in the on-board accelerometers result in unacceptable position errors, leading to loss of image focus. To combat this, a differential GPS system is used in conjunction with the inertial measurement unit. The techniques currently employed by the RRSG for flight path reconstruction for the SASAR system are described in [1]. It was found that reconstructing the flight path from a combination of "smooth" accelerometer-derived inertial data and "stepped" differential GPS data provided sufficient accuracy for at least first-order motion compensation. Autofocus techniques have been applied subsequently to fine-tune the motion compensation.

7. Repeat-Pass Interferometry

The results of the first interferometric experiments of the SASAR system were published in [5] and [6]. Interferometric fringes were obtained, but the coherence exhibited an along-track banded nature, which resulted from difficulties in registering the data owing to local variations in azimuth ground sample spacing.

Furthermore, high coherence fringes were only obtained in areas of natural surfaces covered by significant vegetation, whereas bald earth areas backscatter comparatively little energy, resulting in severe loss of coherence [2]. It is therefore concluded that the poor SNR obtained from unvegetated terrain is a severely limiting factor for interferometry in the VHF band, resulting in patchy interferograms which would be difficult to unwrap.

Significant improvements were obtained regarding the registration of the *single look complex* (SLC) images by applying a warping function which performs localised warping on smaller patches of the entire image. Figure 3 shows some of the results that were obtained from the Hermanus area. The figure shows the intensity image, coherence image, interferogram and flattened interferogram. This interferogram was compared to a simulated interferogram [7] that was obtained from a *digital elevation model* (DEM) of the area. Unfortunately, the real interferograms shown in Figure 3 did not agree well with the simulated interferograms. Possible reasons for this discrepancy are:

- Motion compensation was performed to mid-range. Due to SASAR's large change in look angle from near to far swath, the phase error at the near and far range is significant. This phase error becomes very problematic because the deviation of the aircraft's flight path from a straight line can be as much as 100m from the nominal straight flight path. It is suspected that the position data contains errors in the order of a few wavelengths, due to inaccurate GPS hardware and/or accelerometers on board the aircraft. It is therefore important to invest in the best possible position measuring hardware.
- It is believed that the azimuth data is irregularly spaced. This could be due to "drop-outs" occurring in the data recording system (i.e. missing range lines). However, it could also result from the platform's deviation from the nominal flight path, causing a "bunching up" of range lines as the aircraft moves away from the nominal flight path and a "stretching out" of range lines when it flies on, or parallel to, the nominal flight path.
- Non-parallel flight paths also affect the interferogram, although this problem is not as serious as the previous ones. A stable platform such as a Boeing would help to minimise motion errors.

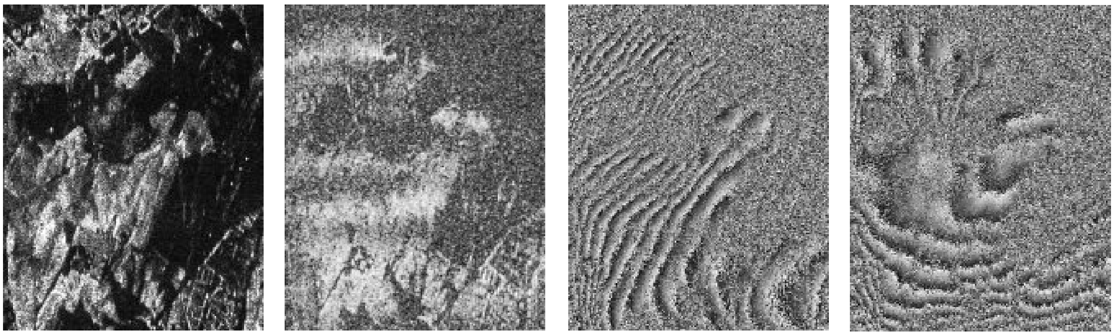

Figure 3: *SASAR interferometric results (from left to right): Hermanus intensity image, coherence image, interferogram and flattened interferogram.*

6. Conclusions

Low-frequency SAR systems operating in the VHF/UHF band offer exciting new application possibilities, mainly due to their foliage penetration and ground penetration capabilities. Our latest attempts at extracting interferometric information from repeat pass data acquired with the SASAR system have shown that high coherence fringes can be obtained using repeat pass interferometry at VHF band. Unfortunately, the obtained interferograms exhibit little correlation with the topography, which means the extraction of reliable height information is not feasible without improving the current system. It is believed that the most significant interferometric errors are caused by inaccurate motion compensation.

The achievements of this prototype system are extremely promising and it is a great pity that at present there does not seem to be funding available to exploit this new technology for geophysical and environmental applications.

7. Acknowledgements

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