Synthetic Aperture Radar for tropical savanna inventory and vegetation height retrieval

I.D. Cameron*, K.M. Viergever, E.D. Wallington, I.H. Woodhouse, D. Moss & N. Stuart

*Email: i.d.cameron@sms.ed.ac.uk

Edinburgh Earth Observatory, School of GeoSciences, The University of Edinburgh, Drummond Street, Edinburgh, EH8 9XP, Scotland, UK

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ABSTRACT: This paper investigates the potential use of Synthetic Aperture Radar (SAR) for savanna inventory and biomass estimation at a test site located within the Hillbank savanna of the Rio Bravo Conservation Management Area (RBCMA), the second largest protected area in Belize. Airborne SAR provides a key opportunity for studying savannas, potentially providing information upon vegetation structure and canopy heights at high spatial resolutions. Two commercially available airborne X-band SAR products were utilised: an ortho rectified image (ORRI) of radar response intensity (backscatter) and a first return Interferometric SAR (InSAR) derived digital surface model (DSM) of the vegetation.

Landcover interpretation from aerial photography is a widely used tool by land managers. In this study visual interpretation of the ORRI and DSM proved capable of delimiting the extent of pine woodland areas within the savanna using characteristic canopy height and backscatter intensity signatures for the assemblage. Upon comparison against reference data the interpretation successfully identified 80% of woodland plots from surrounding assemblages.

Studies have shown SAR interferometry (InSAR) to have the potential for estimating forest height and biomass (e.g. Askne et al, 1997), it has yet to be widely applied to savanna formations. Here tree height estimation for an area of savanna woodland was investigated. Woodland heights were estimated from the difference between canopy heights (DSM) and the underlying topography. In the absence of a suitable ground surface model, one was created using traditional ground survey techniques. Retrieved woodland heights showed little relationship when compared to test plots ($R^2 = 0.061$). These poor results were somewhat expected, and may be a result of low tree density, SAR geometry and subsequent edge effects, leading to substantial reductions in the scattering phase centre height.

1 INTRODUCTION

The Kyoto Protocol which came into effect on February 16, 2005 commits industrialised countries to individual targets to limit their greenhouse gas emissions or to remove carbon from the atmosphere (UNFCCC). This provides possibilities for carbon credit trading with developing countries and underlines the importance of estimating and monitoring terrestrial carbon stores nationally or regionally (Rosenqvist, 2003). Land cover mapping provides possibilities for deriving terrestrial carbon stocks but is also an essential management tool for land managers. Effective monitoring of land cover change is possible when accurate land cover mapping can be achieved reliably and repeatedly.

Most mapping and carbon estimation have been carried out in tropical forests (Brown 1997; Araújo, Higuchi et al. 1999; Houghton, Lawrence et al. 2001; Cummings, Kauffman et al. 2002),...
followed by temperate forests (Brown 2002; Tateno, Hishi et al. 2004). Although tropical savannas cover approximately 40% of the tropics (Solbrig 1991) and form the third largest portion of the living terrestrial carbon pool (Brown and Lugo 1982), they have been largely neglected to date. Tropical savannas form highly productive ecosystems, second only to tropical forests (Saugier, Roy et al. 2001) and therefore have enormous potential for carbon sequestration. They are dominated by grasses and sedges and may contain woody species that do not form a continuous canopy cover (Sarmiento, 1984). Undisturbed savannas are found to contain a rich biological diversity (Furley, 1999). Because of easier accessibility than tropical forests, population pressure is higher and land use changes occur more rapidly. In savannas regular burning, cultivation and herbivory lead to degradation. Therefore it is essential to map and monitor these areas to increase understanding of the dynamic nature of tropical land cover and its carbon stocks.

Ground based savanna inventory involving mapping and destructive sampling is vital for recording baseline carbon stock data, however given their extent and general inaccessibility such techniques are ineffective for coverage of large areas. Remote sensing is seen as a solution which offers repeated coverage over large areas. Although optical remote sensing techniques have proven difficult to implement operationally in the tropics due to frequent cloud cover, radar techniques have been widely used in tropical forest areas (for example Hoekman and Quiñones, 2000) but few studies have concentrated on tropical savannas as of yet (e.g. Santos, 2002).

This paper presents the first results of a study investigating the use of commercially available SAR data for savanna inventory and vegetation height retrieval.

2 STUDY AREA

Pine savannas are recognised as an important component of the Belizean landscape and are a characteristic element of savannas in eastern Central America. They cover a substantial area of the country and are recognised for their unusual and internationally significant mix of South American and North American flora (Bridgewater et al, 2002; Lenthal et al, 1999). The Rio Bravo Conservation and Management Area (RBCMA) in the NE of Belize (see Figure 1) was established by the
Programme for Belize (PFB) in 1989 and is the second largest protected area in Belize. It contains, in addition to savanna tracts, a variety of natural habitats, including upland forest and wetlands.

The RBCMA contains two substantial savanna tracts: Booths River and Rancho Dolores. It is recognised that pine/oak woodlands provide the major woody component of these savannas, with a management plan established in 2000 aiming to increase woody biomass in some areas by a fire suspension and carbon sequestration pilot project. These woodlands cut through the more open grasslands and are thought to be associated with sandy, well drained gentle ridges where pine can survive the wet season (Bridgewater et al. 2002). The exact study area was located in the Rancho Dolores savanna of the RBCMA, located south of the Hillbank research station (NAD27 319617, 1946797) and the New River Lagoon.

Of the various vegetation classifications undertaken on the RBCMA savannas, that of Bridgewater et al (2002) is adopted here. The following vegetation assemblages encountered in the study area and shown in Figure 2:

**Savanna orchard:** seen in transitional areas from wetland to savanna. Often seasonally inundated, pines and oak are completely absent (Fig. 2a).

**Pine-palmetto savanna:** an open assemblage with a ground layer dominated by grasses. Scattered pines (*Pinus caribea*) and palmetto (*Acoelorrapha wrightii*) are also present (Fig. 2b).

**Palmetto thicket:** consisting of clumps or corridors of palmetto often associated with poorly drained areas (Fig. 2c).

**Woodland or pine ridge:** pine dominated areas which forms a broken canopy. In patches oak (*Quercus oleoides*) can dominate (Fig. 2d).

![Figure 2. Savanna vegetation assemblages.](image)

### 3 RADAR DATA

Commercially available X-band Synthetic Aperture Radar (SAR) data collected by Intermap Technologies STAR-3i airborne platform was acquired for sections of the RBCMA including much of the Rancho-Dolores Savanna. This consisted of two products: an orthorectified radar image (ORRI) showing backscatter intensity and a digital surface model (DSM) acquired using SAR interferometry (InSAR). Product characteristics are summarised in Table 1.

The ORRI is derived from a single backscatter image and provides a measurement of the strength of the returned signal normalised as a digital number ranging from 0 – 255. The horizontal posting of the ORRI is 2.5 m.
The DSM provides the height of the radar first returns above the EGM96 ellipsoid, created by combining two SAR backscatter images that were recorded simultaneously by the STAR-3i platform. As the X-band radar has a penetration of between 20 to 60 cm in closely planted coniferous trees (Mougin, \textit{et al.}, 1987), it is often argued that returned signals should be from the near-top of a vegetation canopy. The quoted accuracy of the DSM for moderately sloped, unobstructed terrain is 3 m vertical RMSE and 2 m horizontal RMSE. Although the DSM posting is 5 m the radar integration footprint, or resolution cell, for posted values is roughly $7.5 \times 7.5$ m square (Intermap Technologies, 2003), thus each sample will contain the averaged response from all scattering objects within this area. Both products were geo-referenced to WGS84 UTM-16 coordinates prior to delivery.

### 4 SAVANNA INVENTORY

Automated classification of remotely sensed imagery has dual benefits of repeatability and extensibility and is widely used for effective vegetation inventory. Within the RBCMA Stuart \textit{et al} (in press) demonstrated that medium resolution optical data is capable of accurately identifying general features such as the savanna/high forest boundary, however internal savanna assemblages are often poorly discriminated due to resolution limitations. Sporadic availability of cloud-free scenes further limits the potential of optical remote sensing for monitoring changes in savanna conditions.

As synthetic aperture radar images can be acquired day or night under all weather conditions they are ideal for year round monitoring of vegetation in the tropics. Indeed, textural analysis of SAR backscatter intensity images have been successfully used within the tropics for classifying vegetation cover (Simard \textit{et al}, 2002; Okhimamhe, 2003).

Within the developing world, land managers rarely have access to either the computing facilities or technical expertise required to conduct such classifications. Instead land managers such as those employed in the RBCMA often visually interpret optical imagery, particularly aerial photography, to aid vegetation inventory. Indeed visual interpretation of optical data has been shown accurate for vegetation inventory in Belize (King, 1994).

Comparing backscatter texture from the ORRI against previous classifications of optical data (Stuart \textit{et al}, in press) showed that areas clearly identified previously, such as gallery forest and wetland areas can be readily identified within the radar intensity image. It was decided to conduct an exploratory visual classification of the Intermap SAR data to see whether internal savanna formations of interest to land managers, such as pine woodland, could be accurately delimited.

#### 4.1 Classification method

An area of the Rancho Dolores savanna roughly 4 km by 5 km in extent was selected for visual interpretation. In order to utilise both the backscatter texture and vegetation height information in the interpretation a composite of SAR images was created. Greyscale backscatter (ORRI) data was overlaid with semi-transparent height (DSM) data in colour. Three interpreters with field knowledge were set the task of delimiting the extent of pine/oak woodland. Each interpretation was conducted fully independently drawing only upon the imagery provided and their knowledge of the area. The interpretations were combined by selecting extent of areas identified as woodland to be the minimum
area commonly agreed on by all three interpretations (Figure 3). Comparison of the three interpretations showed that, while there was good agreement on the general location of heavily wooded areas, there was often disagreement among interpreters regarding the location of the woodland/non-woodland boundary.

![Backscatter High Low Woodland interpreted from SAR Test plots Woodland interpreted from SAR Woodland identified Woodland not identified Non-woodland identified](image)

Figure 3. **Left** Interpreted woodland extent overlain on the Intermap ORRI; **Right** Woodland extent interpreted from SAR compared against areas identified correctly and incorrectly.

### 4.2 Results

The interpretation was validated using test plots obtained from vegetation surveys conducted between 1997 and 2000, covering the imagery acquisition. Each plot represented an example of a single vegetation assemblage and was as uniform as possible. Plot boundaries had been recorded using differential GPS and could be overlain on the SAR data with negligible geo-location error (Moss, 1997). The vegetation test plots were aggregated into ‘woodland’ and ‘non-woodland’ classes. Non-woodland included pine/palmetto savanna, palmetto thickets and savanna orchard plots. The interpreted woodland area was overlaid with the test plots and areas that were both correctly and incorrectly identified were calculated in m².

The results (Table 2) showed that 81.4% of the known woodland area was correctly identified as such. Equally importantly none of the non-woodland test plots were identified as woodland in the interpretation. It is interesting to note that three major areas of woodland to the north east and south west of the study area were identified by some interpreters but not all three. Given the low density of much of the savanna woodland this variability is not unexpected.

<table>
<thead>
<tr>
<th></th>
<th>Correctly Identified</th>
<th>Incorrectly Identified</th>
</tr>
</thead>
<tbody>
<tr>
<td>Woodland</td>
<td>81.4%</td>
<td>18.6%</td>
</tr>
<tr>
<td>Non-Woodland</td>
<td>100%</td>
<td>0%</td>
</tr>
</tbody>
</table>

Table 2. Interpretation accuracy for woodland and non-woodland classes
Discussion
This study has shown that it is possible to interpret high spatial resolution X-band SAR data of some tropical savanna areas in a manner similar to the interpretation of aerial photography. The interpretation provided a conservative estimate of woodland extents within savanna areas to a greater degree of accuracy than has proved possible using medium resolution optical remote sensing. The ease with which this data could be interpreted, and the accuracy of the final classification, suggests that high resolution SAR may offer distinct benefits to land managers for monitoring savanna woodlands. Initial exploration with AirSAR high resolution C, L and P band data, based upon an extensive 2005 fieldwork campaign, has shown further potential for classification of a wider range of savanna vegetation formations. The scheduled launch of next-generation satellite SAR platforms, such as TerraSAR-X and ALOS PALSAR, may make it feasible to use such high resolution data for year-round monitoring of savanna assemblages.

5 VEGETATION HEIGHT RETRIEVAL
Assessing biomass is central to calculating the carbon sequestration potential of a woodland or forest. Since remote sensing is incapable of directly measuring biomass it is common to take a regression approach whereby parameters that can be measured, such as tree height or backscatter, are related to biomass. Since short wavelength X and C band signals tend to be returned from the upper portion of a canopy interferometry at these wavelengths has been shown to provide a reliable estimate of vegetation height for dense forest stands when used in combination with an accurate model of the underlying ground surface (Askne, 1997). Ground surface elevations can be estimated through polarimetric interferometry (Papathanassiou & Cloude, 2001) or using pre-existing digital elevation models (DEM’s) (Askne, 1997; Wallington et al., 2004).

5.1 Survey methodology
As the study area in Belize has no available mapping or elevation models at a level of accuracy or detail suitable for this investigation it was decided to undertake a local topographic survey using traditional survey techniques from which a DEM could be produced for the study site.

5.1.1 Establishment of control network
GPS base stations were established in the savanna using dual frequency GPS. Each station was continuously observed for 5-6 hours as recommended (AUSPOS, 2005) and observations were submitted to two online GPS processing services; AUSLIG AUSPOS and JPL AutoGIPSY. These services use International GPS Service (IGS) products to compute precise ITRF coordinates which were later projected into WGS84/UTM plane coordinates. The achievable accuracy was assessed by re-observing an existing geodetic station located within the RBCMA. Both online processing services yielded acceptable solutions with horizontal solutions within 160 mm of published coordinates; however the vertical solution from AUSPOS was considerably poorer being within 200 mm of the published coordinate while GIPSY was within 4 mm. For the topographic survey stations GIPSY was used to provide coordinates for stations used in the topographic survey.

A point of detail (POD) radiation survey was conducted from four stations using an EDM to sample the topographic variation across the study area. 560 ground points were surveyed, located to characterise key features of interest within the terrain such as ditches and breaks of slope and to provide an even sampling distribution across the study area, subject to constraints of visibility. A variety of interpolation methods were investigated, of which ordinary kriging was found to produce marginally more accurate results. The final DEM was produced using this interpolation method, with results re-sampled into a 5 m raster using a nearest neighbour method of assignment to match the DSM posting.

Upon comparison between the survey DEM and Intermap DSM it became apparent that there was a significant difference in elevation values between the two products. Examining areas of low or bare vegetation, where the DSM and DEM should be coincident, showed the DSM to be, on
average, 1.19 m below the DEM. This error lies well within the quoted vertical 3 m RMSE of the Intermap DSM. As result it was decided to calibrate the DSM to the DEM, effectively raising DSM heights by 1.19 m.

The height of vegetation across the study area was estimated by subtracting the surveyed DEM from the calibrated Intermap DSM on a cell by cell basis. Within the area interpreted as pine woodland this surface was considered to represent the average height of the woodland canopy. The vegetation heights in the woodland areas were compared against 25 plots gathered during the 2004 field season. Plots were selected to be representative examples of the woodland. Each measured 10 m$^2$ with the location recorded by GPS. For each plot the height of every tree was recorded with the heights averaged for each plot.

5.2 Results

Figure 4 presents a transect running NS across the DSM, DEM and retrieved vegetation heights for the study area. The average retrieved heights within the interpreted woodland area tend to be between 4 m and 8 m. This represents a significant underestimation of vegetation height when compared against the test plots where tree heights were observed to range from 6 m to 25 m, with an average height of 11.8 m.
Some underestimation of vegetation height would be expected as the SAR signal will penetrate through the canopy to varying depths dependant on canopy density. Other studies using Intermap InSAR in homogeneous woodland have demonstrated strong linear relationships between retrieved vegetation height and test plot heights despite such underestimation (Wallington et al., 2004). However, in this case, there is virtually no relationship between retrieved vegetation height (DSM-DEM) and test plots as the scatter diagram in Figure 5 shows ($R^2 = 0.061$).

Figure 5. Comparison of retrieved vegetation heights against observed plot heights.

5.3 Discussion

The results demonstrate that in this instance the accuracy of woodland height estimation is poor, with a weak correlation between field observations and retrieved heights. Although it has been demonstrated elsewhere that Intermap InSAR is capable of accurately estimating vegetation heights (Wallington et al., 2004; Wallington & Woodhouse, 2003), these studies were in homogeneous temperate forest stands. Savanna woodland, however, is particularly open and heterogeneous. Under heterogeneous conditions InSAR derived heights have been shown to be heavily attenuated by contributions from ground and lower canopy scattering (Mette et al., 2005). Such edge effects may also introduce a displacement of the phase scattering centre in the slant-range towards the sensor. Returned heights may therefore be displaced horizontally and, as a result, there may be subsequent errors in matching retrieved heights to their associated field observations. Based on these results, further fieldwork has been adapted to account for these effects.

This pilot study used a detailed ground survey to obtain accurate estimation of ground surface elevations. It is recognised, however, that the success of this technique operationally will depend upon accurate ground surface measurements being available across far wider areas. Longer wavelength InSAR data, such as may be provided by the planned ALOS PALSAR sensor, is capable of penetrating through vegetation and may allow for accurate ground surface estimation, creating DEM’s for potentially the whole globe.

6 FUTURE WORK

An additional high resolution NASA-JPL AirSAR dataset has been acquired for the study area: C-band single-pass InSAR and L- and P-band polarimetric SAR. An extensive fieldwork campaign was carried out in April and May 2005, acquiring x-y-z position, tree height, crown depth, crown width and diameter at breast height measurements for every tree in a 1000 m $\times$ 20 m transect crossing a wide variety of savanna formations. The transect was oriented in the radar range direction to investigate whether the problems experienced in this study are due to radar signal displacement. Based on these data, future research will (1) investigate the use of AirSAR for classification of the different savanna formations, (2) evaluate the capability of high resolution InSAR data in combination...
with adapted field data collection for improving heterogeneous canopy height estimations, and (3) investigate the capability of high resolution polarimetric SAR for estimating above-ground woody biomass of savanna woodlands.

7 CONCLUSION

This study presented the initial findings of an investigation into the use of commercially available X-band SAR data for savanna mapping and monitoring. Visual interpretation of SAR images allowed for accurate delimitation of woodland extents. Such data may be of significant interest to land managers in the developing world. The location and extent of pine/oak woodlands showed anticipated associations with convex elevation ridges. Vegetation heights retrieved by subtracting a surveyed DEM from the InSAR DSM were shown to have a poor correlation with field observations. This poor estimation may be linked to the heterogeneity of savanna woodlands introducing edge effects and associated attenuation of retrieved heights. A new campaign of study will further investigate the use of AirSAR data for savanna inventory.

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