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Monitoring the World's Savanna Biomass by Earth Observation

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ABSTRACT *Savannas constitute approximately 40% of the tropics and occur primarily in developing countries. Their net primary productivity rates are third only to tropical and temperate forests. Due to their high carbon sequestration potential savannas are likely to become important areas under Kyoto Protocol initiatives for removing* CO_2 *from the atmosphere. They are, however, prone to human pressure. It is therefore important that accurate methods for the estimation of savanna biomass are developed which can be repeated for monitoring purposes. The paper examines research conducted to evaluate the use of Synthetic Aperture Radar (SAR) for estimating the biomass of the woody vegetation within a savanna in Belize, Central America. Results show that established SAR methods for estimating biomass for closed canopy forest are not directly transferable to the non-continuous cover woodlands that frequently occur in savanna areas. This has important implications for Earth observation satellites launched for the purpose of global biomass estimation.*

KEY WORDS: Remote sensing, environmental studies, biomass estimation, Synthetic Aperture Radar (SAR), savanna

Introduction

Research has shown that the gradual rise in average temperature of the Earth's surface is linked to human-induced increasing atmospheric concentrations of greenhouse gases (Baede *et al*., 2001), of which carbon dioxide (CO_2) has the greatest warming potential. Although it occurs in a relatively low concentration (0.035% of the troposphere), the increase in atmospheric CO_2 since pre-industrial times has caused a radiative forcing of $+1.66 \pm 0.17$ W/m^2, a much larger contribution than any other radiative forcing agent considered in the 2007 IPCC report (Solomon *et al*., 2007). Climate change is expected to have a profound effect on the living environment with repercussions for natural ecosystems and cultural issues such as food security and environmental hazards.

The Kyoto Protocol, which originated from the United Nations Framework Convention on Climate Change (UNFCCC), sets legally binding targets for

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industrialised countries to reduce greenhouse gas emissions or to remove them from the atmosphere. The Protocol was adopted in 1997 and finally came into force in February 2005. It aims to reduce the overall greenhouse gas emissions by at least 5% below existing 1990 levels in the commitment period 2008 to 2012. To achieve this target, industrialised member countries have set different binding targets for themselves ranging from -8% to $+10\%$ of 1990 emissions. The EU has set a 'bubble' target of -8% by 2010 and -20% by 2020, which was redistributed based on EU agreement (UNFCCC, 2007). The UK's reduction target was set at -20% of 1990 levels by 2010, while further legally binding reduction targets have been set at 26–32% below 1990 levels for 2020 (DEFRA, 2007). In the face of mounting concern that national CO_2 emission reduction targets cannot be met solely by emission reduction strategies, industrialised countries are keen to find alternative ways to lower atmospheric CO_2 concentrations.

Carbon Sequestration

A significant mechanism for removing CO_2 from the atmosphere is through carbon sequestration in growing vegetation. The Clean Development Mechanism (CDM) initiative under the Kyoto Protocol provides for, amongst others, forestry projects for carbon sequestration. This allows industrialised countries to offset their atmospheric carbon emissions by funding such projects in developing countries. The viability of carbon sequestration programmes relies, however, on both a scientific understanding of how CO_2 is captured and stored as vegetative biomass and the development of operational techniques for measuring standing biomass globally.

The notion of CDMs in the form of forestry projects has been the subject of debate. Proponents see forests and woodlands as important potential carbon sinks that should be monitored at a global scale. Opponents believe, however, that carbon is only temporarily stored in vegetation and can be released at any time through natural and social processes such as natural decay, fire and deforestation, thus making forests non-permanent carbon sinks. Recent findings (Gibbard *et al.*, 2005) that boreal and mid-latitude afforestation of grassland can have a warming effect due to a reduction in surface albedo have strengthened the latter argument. These studies, however, show an opposite effect in the tropics. Tropical deforestation releases large amounts of CO_2 into the atmosphere which can potentially exceed the effect of carbon sequestration through afforestation and reforestation activities (Gibbard *et al.*, 2005; Grace *et al.*, 2006).

The largest impact on the global carbon cycle is caused by human activities through the burning of biomass and fossil fuels and the removal of vegetation cover, especially forests (Bolin & Sukumar, 2000). It is estimated that approximately 75% of CO_2 emissions to the atmosphere are caused by burning, while the rest is contributed by land use change (Prentice *et al.*, 2001), through removal of carbon sinks. It is therefore regrettable that CDM currently excludes tropical forest conservation projects. Ongoing debate has culminated, at the UN Climate Change Conference in Bali (COP 13, December 2007), in a call for future inclusion of Reduced Emissions from Deforestation in Developing Countries (REDD) (UNFCCC, 2008), now generally referred to as Reduced Emissions from

Deforestation and Degradation. Thus, apart from estimating global forest biomass, there is a need for forest monitoring by quantifying deforestation and other potential sources of atmospheric CO_2 emissions such as fire damage from forest areas. Earth observation techniques are ideal for such mapping and monitoring activities as they offer the capability to repeat data capture frequently and to cover large areas which may be difficult to reach for field measurements.

The Importance of Savannas

To date, the definition of *forest* for the purposes of carbon sequestration projects is loosely based on the FAO definition (FAO, 2006) which defines *forest* based on minimum canopy cover (10–30%), minimum surface area (500–10 000 m^2) and minimum tree height at maturity (2–5 m) (Schulze *et al.*, 2002). This definition includes most woodlands within savanna areas. Traditionally thought of as mainly grassland, the term *savanna* has evolved to convey a broader meaning. Currently, savannas are defined as ecosystems of the warm (lowland) tropics that commonly experience alternating wet and dry seasons (Furley & Newey, 1983). The vegetation forms a dynamic mosaic of continuous herbaceous cover (grassland) and non-continuous cover woodland, the latter consisting of scattered-to-dense tree, shrub and palm.

Savannas are the most common vegetation type in the tropics and subtropics (Mistry, 2000). Due to the overlap in *forest* and *savanna* definitions, estimates of the global extent of the savanna biome vary between different authors, ranging between ~10 and ~33% of the global land surface (House & Hall, 2001 and others). Despite different estimates of their extent, it is generally agreed that savannas occur primarily in developing countries and support approximately 20% of world population (Mistry, 2000; House & Hall, 2001). Human-induced disturbance such as agricultural land use and fire therefore form major disturbances (Frost *et al.*, 1986), with effects ranging from mild woodland degradation to deforestation.

Figures quoted in the literature for savanna carbon stocks vary widely according to the amount and extent of tree cover, for example from 1.8 tC/ha in the absence of trees to 30 tC/ha for areas with substantial tree cover (Grace *et al.*, 2006). The estimated global average savanna carbon stock is 28.8 tC/ha (House & Hall, 2001). Carbon makes up approximately 50% of vegetative biomass which can be defined as the dry weight of vegetal material expressed in mass units per unit area (Brown, 1997). Carbon is stored in live or dead biomass, which occurs either above-ground (AG) or below-ground (BG). Above-ground live biomass occurs as living vegetation, of which the roots form BG live and dead biomass.

Reported net primary productivity rates vary between 1.4 and 22.8 tC/ha/year, with a mean and 95% CI at 7.2 ± 2.0 tC/ha/year (Grace *et al.*, 2006). This is third only to tropical rainforests (11.2 ± 4.2 tC/ha/year) (Grace *et al.*, 2001) and temperate forests (7.8 tC/ha/year) (Saugier *et al.*, 2001). As their importance in terms of carbon sequestration potential has until recently been largely overlooked, savannas are not routinely censused in the same way as forests (Grace *et al.*, 2006), and it is therefore difficult to assess change in their extent, structure and biomass.

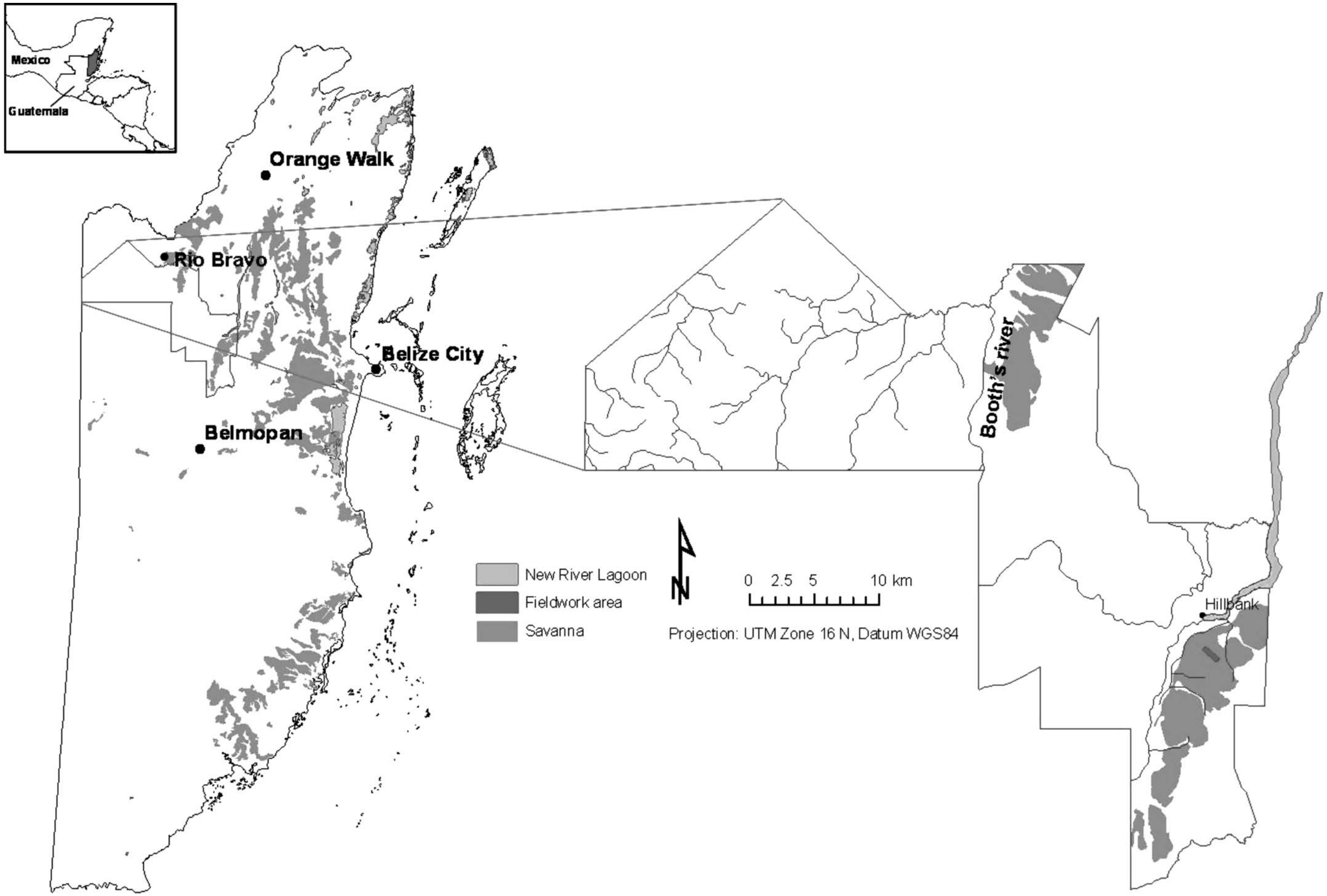

Figure 1. Map showing the location of the study area in a tract of savanna that falls within the Rio Bravo Conservation and Management Ara (RBCMA) in Belize, a protected area of approximately 100,000 ha. The RBCMA savannas are representative of Central American savannas. The remainder of the RBCMA land cover consists mainly of tropical forest.

Biomass Estimation Techniques

With the increasing importance of forestry-based carbon sequestration initiatives and global forest monitoring, there is a need for accurate information, at regional and national scales, on the spatial extent, condition, biomass and growth potential of forests and woodlands with a canopy cover as low as 10%. Earth observation (EO) techniques are better suited to these information needs than traditional *in situ* methods for biomass estimation. The latter involve laborious fieldwork, often based on destructive sampling (Overman *et al.*, 1994). Whilst regional biomass estimates based on *in situ* methods are unlikely to portray accurately the heterogeneity of the landscape, those based on EO data produce updatable biomass estimates which more accurately represent the spatial heterogeneity of the landscape. Depending on the spatial and temporal resolution, EO can detect differences in the spatial distribution of biomass density such as the occurrence of forest gaps and land cover changes, offers systematic observations at scales ranging from local to global and improves the monitoring of inaccessible areas (Rosenqvist *et al.*, 2003).

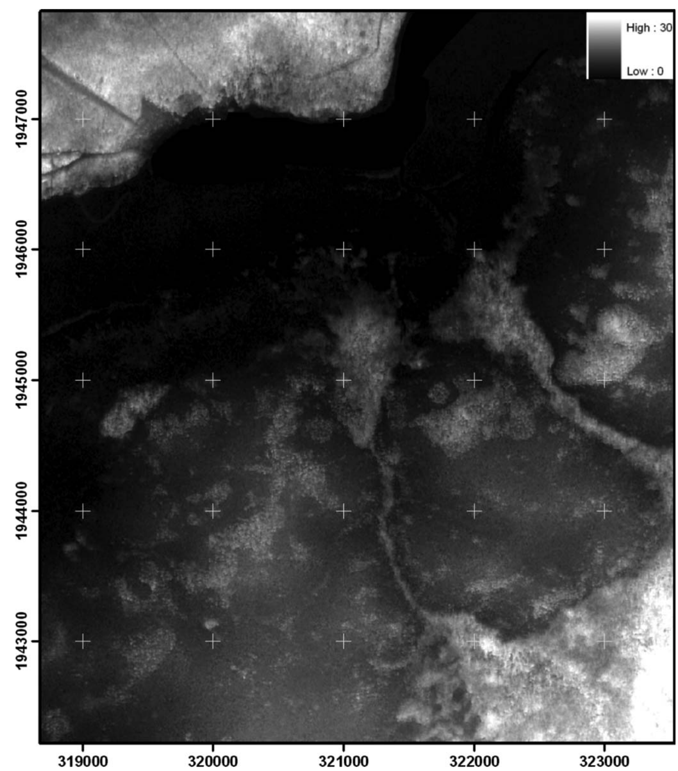

Figure 2a. An example of InSAR data of a savanna in Belize. Shortwave InSAR data (C-band) represents vegetation heights and therefore also indicates the spatial distribution of forest biomass. Lighter shades represent taller vegetation such as tropical forest and savanna woodland while darker shades correspond to relatively low vegetation such as open grassland and wetland (compare with Figure 2b)

Accurate land cover mapping from EO data in conjunction with known biomass estimates for each land cover class is a relatively straightforward use of EO for biomass estimation. Radar EO methods such as Synthetic Aperture Radar (SAR) interferometry (InSAR), used for canopy height retrieval in closed-canopy forests, can be used in conjunction with allometric equations to estimate AG biomass (Askne *et al.*, 1997). Additionally, SAR backscatter has been statistically correlated with forest biomass up to a certain level, depending on the radar wavelength (Le Toan *et al.*, 1992; Imhoff, 1995).

Evaluating the Use of SAR for Biomass Estimation in a Belizean Savanna

Neither the use of (i) InSAR for canopy height retrieval nor (ii) SAR backscatter-biomass correlations have been sufficiently tested in non-continuous cover forests at the lower end of the biomass scale. Research has therefore been conducted to evaluate the use of these methods for estimating biomass in a Belizean savanna (see Figure 1). Single-pass shortwave InSAR data from AIRSAR and Intermap

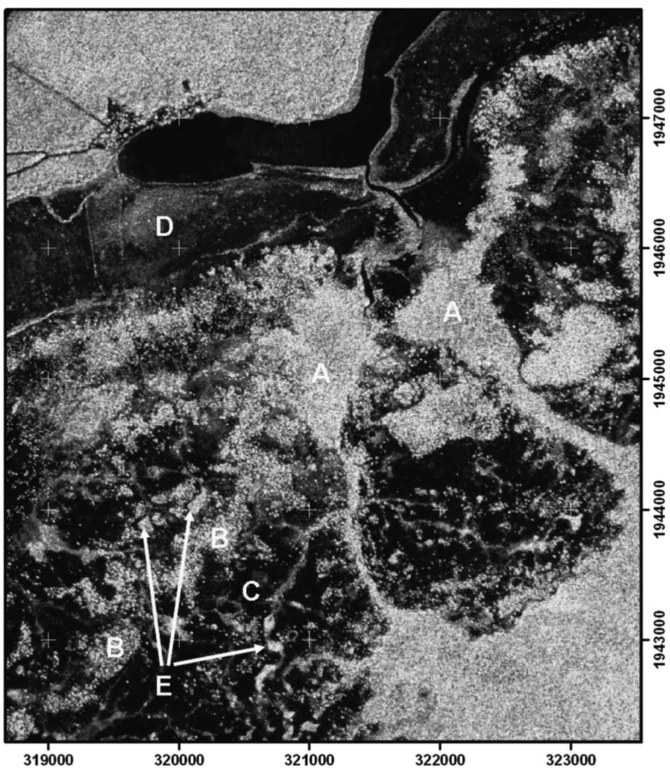

Figure 2b. An example of SAR data of a savanna in Belize. Longwave SAR backscatter (P-band) shows different land cover such as dense tropical forest (A), non-continuous cover woodland (B), grassland (C), wetland (D) and palmetto (E). Note that areas of high backscatter (lighter shades) correspond to land cover with high biomass (A and B) as well as areas of relatively low biomass (E)

Technologies were used and longer wavelength fully polarimetric SAR backscatter data from AIRSAR were also employed. The results (see Viergever *et al.* (2007, 2008) for more detail) suggest that neither method established for biomass estimation in closed canopy forests can be directly applied to savanna areas containing non-continuous cover woodlands:

(i) Although the shortwave InSAR data show clear trends in spatial distribution of savanna woodlands (see Figure 2a), they inconsistently underestimate vegetation heights by more than 50% in some instances.
(ii) High values of long-wavelength SAR backscatter are observed for areas containing high biomass vegetation, but also for relatively low biomass palmetto vegetation (see Figure 2b).

The use of InSAR for woodland height retrieval is therefore likely to underestimate woodland biomass while the use of SAR backscatter-biomass correlations is likely to result in overestimation of biomass for savanna areas containing low-biomass palm-like vegetation. These results have important implications for newly-launched and planned EO satellites for the purpose of global biomass estimation and are expected to have an impact on carbon accounting under Kyoto Protocol and forest monitoring under REDD. Further research is needed to find an optimal way to combine different EO methods, such as InSAR and SAR backscatter, for accurate biomass estimation of the non-continuous woodlands occurring in savanna areas.

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