Dynamics of forest biomass pools estimated from spaceborne SAR data

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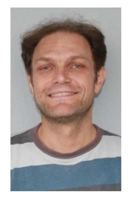

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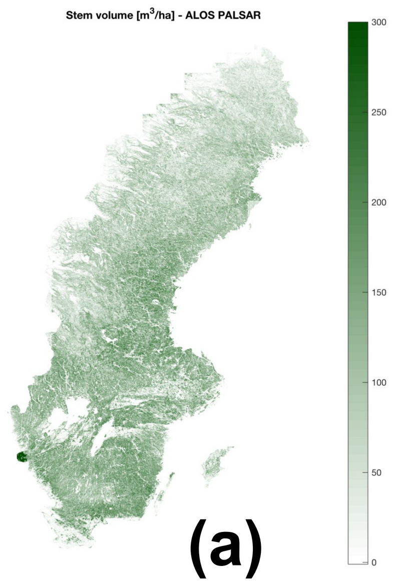
Background

The comprehensive view of land surfaces offered by spaceborne remote sensing make such observations the primary candidate for quantifying dynamics of biomass at large scale. Yet, there is controversy in the results obtained with Earth Observation data from space when compared with results obtained using forest inventory (Pan et al., 2011; Liu et al. 2015). To overcome limitations due to the fact that biomass is not directly sensed and imaging conditions (cloud cover, moisture etc.) can distort the estimates of biomass estimated from remote sensing data, approaches that maximize the information content on biomass embedded in the remote sensing observations should be used. In addition, multiple observations from the same sensor are needed to overcome effects of imaging conditions. Here, we present two examples of ongoing work having the objective of capturing the trajectories of aboveground biomass, i.e. a major predictor of carbon in forests, with records of spaceborne synthetic aperture radar data (SAR) backscattered intensity.

Dynamics of forest biomass in Sweden between 2010 and 2015

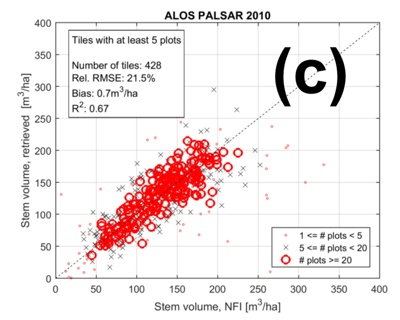
Woody biomass stored in Swedish forest has been increasing during the last 40 years. Forest field inventory achieves high estimation accuracy but bears significant costs and is completed every five years. Optical remote sensing achieve quinquennial maps of biomass since 2000 at the expenses of significant efforts to plan acquisitions. Six years of laser scanning were recently used to obtain a wall-to-wall dataset of biomass. Since 2007, L-band observations of the SAR backscatter by JAXA (ALOS PALSAR-1/2) are repeatedly obtained over Sweden. Here, we investigate the capability of L-band SAR observations to estimate stem volume, and thereof woody biomass and total carbon, for 2010 and 2015.

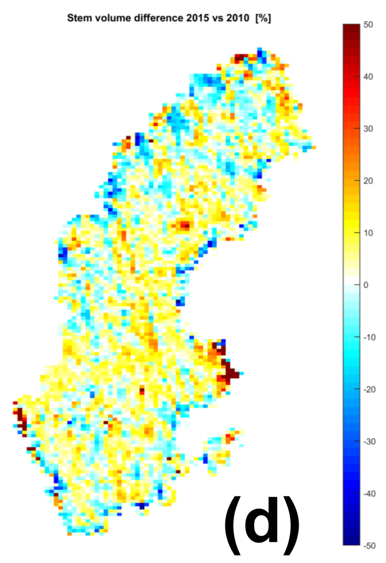


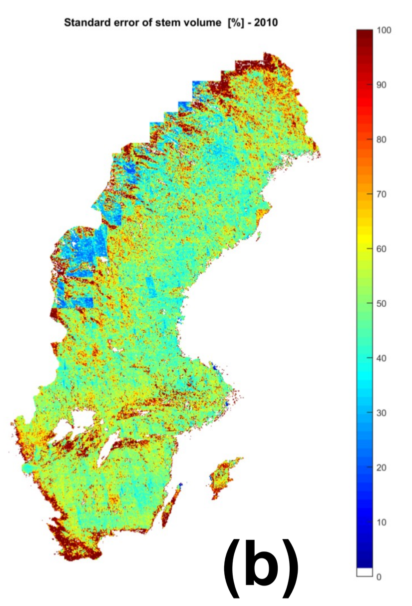
	L-band	NFI (*)	FAO (**)
Tot. stem volume (10^6 m^3)			
2010	*3,033*	*3,002*	*2,948*
2015	*3,104*	*3,150*	*2,988*
Area (km^2)			
2010	*254,595*	*223,790*	*280,730*
2015	*254,683*	*226,560*	*280,730*
Stem volume (m^3/ha)			
2010	*119*	*134*	*105*
2015	*122*	*139*	*106*

(f)

(*) Skogsdata 2013 (inventory 2008-2012) and Skogsdata 2018 (inventory 2013-2017). Productive forest land.
(**) FAO FRA 2010 and 2015, country report for Sweden. Forest land.



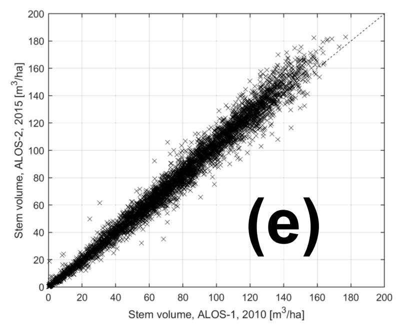




	L-band	FAO (*)
Tot. carbon (10^6 MgC)		
2010	*1,069*	*1,102*
2015	*1,098*	*1,114*
Area (km^2)		
2010	*254,595*	*280,730*
2015	*254,683*	*280,730*
Tot. carbon density (MgC /ha)		
2010	*42*	*39*
2015	*43*	*40*

(g)

(*) FAO FRA 2010 and 2015, country report for Sweden. Forest land.



Maps of stem volume and corresponding standard error were obtained for 2010 (see a and b) and 2015 with a pixel size of 25 m. The spatial distribution reproduces the north-to-south and west-to-east biomass gradient of biomass increase (a). Standard error of 40-50% at pixel level (b) becomes negligible when generating county and national averages. Stem volume estimates are overall unbiased (c). The stem volume difference between 2015 and 2010 mostly indicates increase (d, e). Results are consistent with numbers published by the Swedish NFI and FAO for stem volume (f) and carbon (g). L-band observations of SAR backscatter from space qualify as reliable candidate to provide extended series of biomass estimates in the future.

Methods

SAR data processing

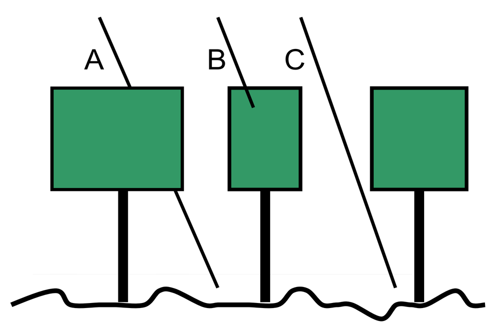
(Santoro et al., 2011)

- Import of SAR data
- Terrain geocoding
- Tiling and filtering

Biomass retrieval approach

(Santoro et al., 2011; 2015)

- Forest backscatter = f(B), Water Cloud Model with gaps



$$\sigma^0_{for} = \sigma^0_{gr} e^{-cB} + \sigma^0_{veg}(1 - e^{-cB})$$

- Model training using self-calibration (BIOMASAR)
- Inversion of model: forest backscatter → growing stock volume or stem volume (m^3/ha)
- For multiple observations of the SAR backscatter: Weighted averaging of the individual volume estimates

From volume to woody biomass and carbon

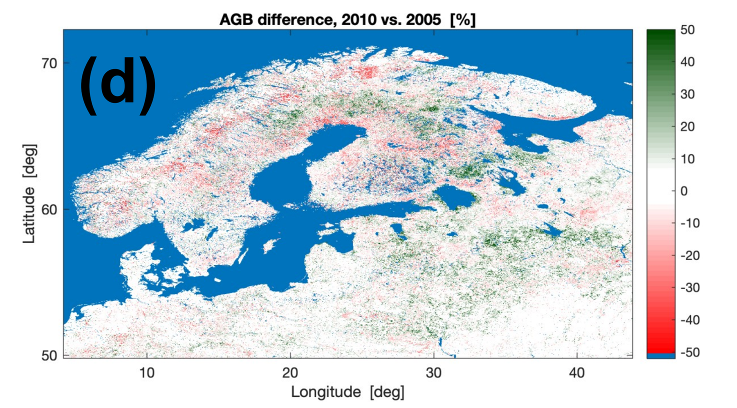
(Thurner et al., 2014; Santoro et al., in prep.)

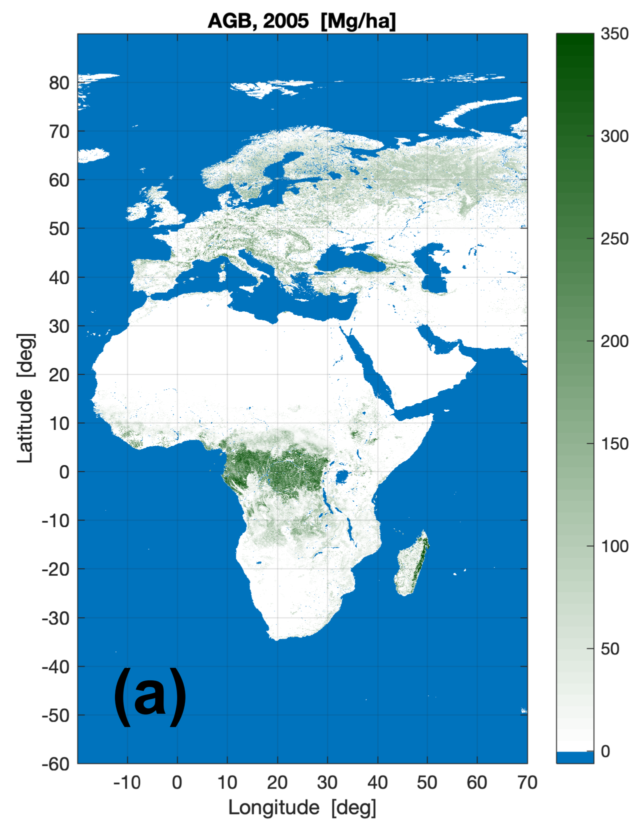
- Stem biomass density (Mg/ha) = (stem volume × wood density)
- AGB (Mg/ha) = stem biomass x stem-to-total biomass expansion

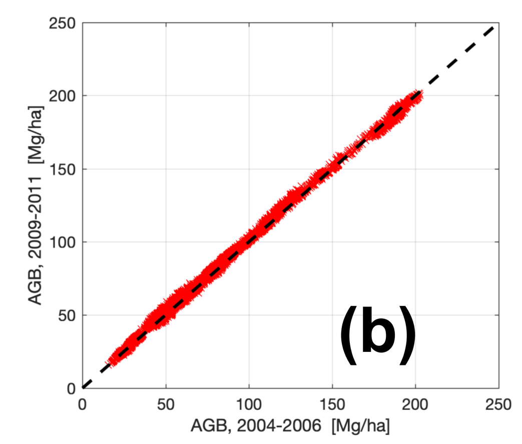
- BGB (Mg/ha) = stem biomass x BG biomass expansion
- Total carbon density (MgC/ha) = 0.5 × total biomass density

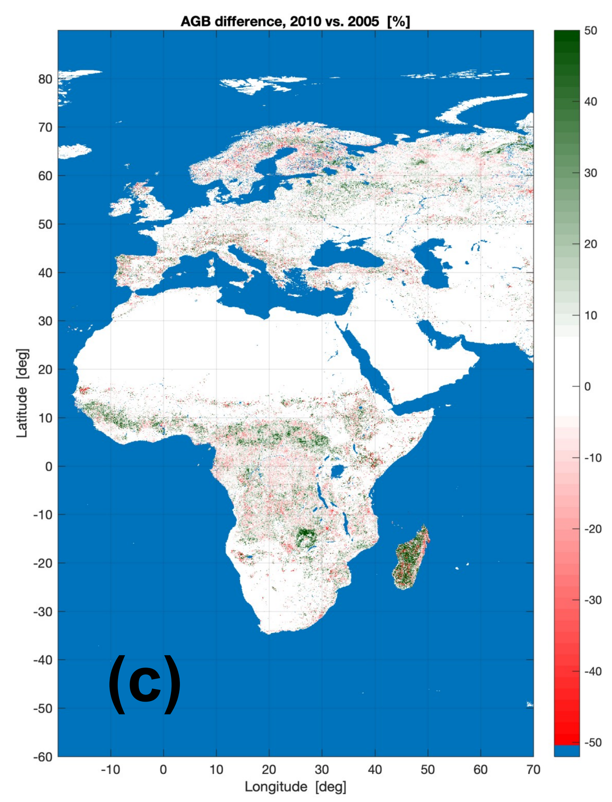
Biomass pools of a Euroafrican transect between 2004 and 2011

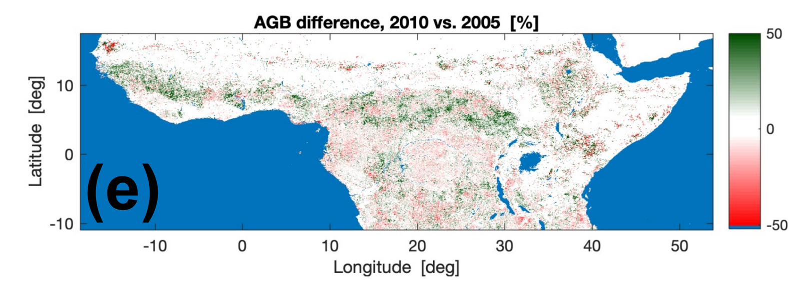
The biomass pool of Europe, including Russia, has been increasing in the last decades, showing signs of saturation (Nabuurs et al., 2013). In contrast, Africa is characterized by loss of AGB (Pan et al., 2011). In this study, we estimated AGB on a yearly basis between 2004 and 2011 from repeated acquisition of Envisat ASAR C-band observations of the SAR backscatter with a pixel size of 1,000 m. This work is part of a larger effort to quantify biomass dynamics over three decades with multiple remote sensing observations. Here, we focus on 3-years averages for the epoch 2005 and 2010.











The spatial distribution of AGB (a) appears to be well captured, with increasing biomass for decreasing latitude in the northern hemisphere and the largest biomass pool in forests of Central Africa. Biomass of southern African savannas is comparable to values estimated for the northernmost latitudes. The yearly biomass maps present very strong inter-annual consistency. Latitudinal averages of AGB for 2005 and 2010 indicate overall similar AGB values (b). The difference map of AGB for the epochs 2005 and 2010 indicates an overall balance of increasing and decreasing biomass (c). Northern regions of Europe show a generally increasing biomass with a few losses, the reason of which is yet unclear (d). At Equatorial latitudes, we estimate an increase of biomass in sub-Sahelian regions and, in contrast, slight loss of biomass in the Congo basin (e). These results are preliminary and need to be benchmarked in the larger context of the remote sensing data pool and *in situ* observations.

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