Machine-Learning Fusion of PolSAR and LiDAR Data for Tropical Forest Canopy Height Estimation

Maryam Pourshamsi (1), Mariano Garcia (2), Marco Lavalle (3), Eric Pottier (4) and Heiko Balzter (1)

(1) Centre for Landscape and Climate Research, University of Leicester, Leicester, UK
(2) Department of Geology, Geography and Environment, University of Alcala, Madrid, Spain
(3) NASA Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, USA
(4) Insitut d'Electronique et de Télécommunication des Rennes, University de Rennes 1, Rennes Cedex, France

ABSTRACT

This paper investigates the benefits of integrating polarimetric radar variables with LiDAR measurements using Support Vector Machine (SVM) in order to measure the mean forest canopy height. Multiple polarimetric variables are required as an input in order to ensure consistent height retrieval performance across a broad range of forest heights. We train the SVM with LiDAR samples and different polarimetric variables based on 5000 samples (less than 1% of the full subset) collected across the images using a stratified random sampling approach. The trained SVM was applied to the rest of the image using the same variables but excluding the LiDAR samples. The estimated height using our approach was validated versus LiDAR-derived height yielding good accuracy overall (r^2=0.86, RMSE = 6.8 m).

INTRODUCTION

Forest height
- Forest height is one the key forest biophysical parameters
- biomass & first-order canopy structure

LiDAR
- LiDAR provides direct measurements of the forest canopy height
- But, it's limited by the cost of acquisitions, continuous image coverage and persistent cloud coverage especially over tropics

PolInSAR
- PolInSAR has been proposed as an alternative measurement technique for forest height mapping
- But, It's limited by temporal signal decorrelation and modelling of volumetric coherence, and limited availability of spaceborne data

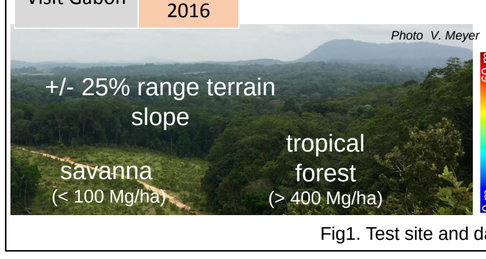
PolSAR
- Instead, polarimetric radar data (particularly dual-pol) are easier to obtain from spacerborne SAR compared to long-baseline PolInSAR data.
- PolSAR, provides useful and important details about the physics inside one pixel and on Its own, does not provide any information about forest height

PolSAR + LiDAR?
- Can an integration between PolSAR components and LiDAR samples help to estimate forest canopy height?

OBJECTIVE
We aim to investigate the synergetic use of LiDAR samples and PolSAR parameters using a Support Vector Machine (SVM) to explore how vertical measurements of LiDAR together with PolSAR parameters can cooperate for estimation of accurate forest canopy height.

DATA & TEST SITE

	UAVSAR	GSFC LVIS
Looking	Left	Nadir
Altitude	12.5 km	7.3 km
Swath	22 km	0.9 km
Inc. angle	25°-65°	0-6°
Frequency	L	1064 nm
Bandwidth	80 MHz	10 nm
Resolution	1.6x0.6 m	18x25 m
Visit Gabon	Feb 2016	Feb 2016



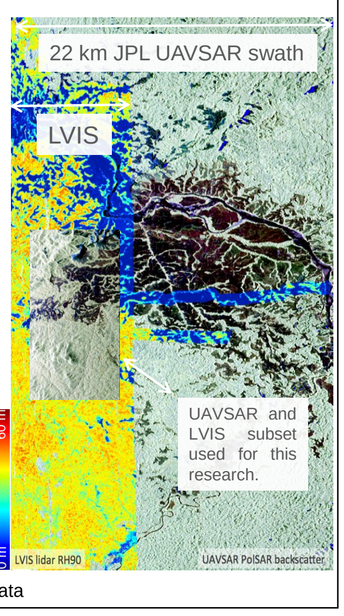


Fig1. Test site and data

METHOD

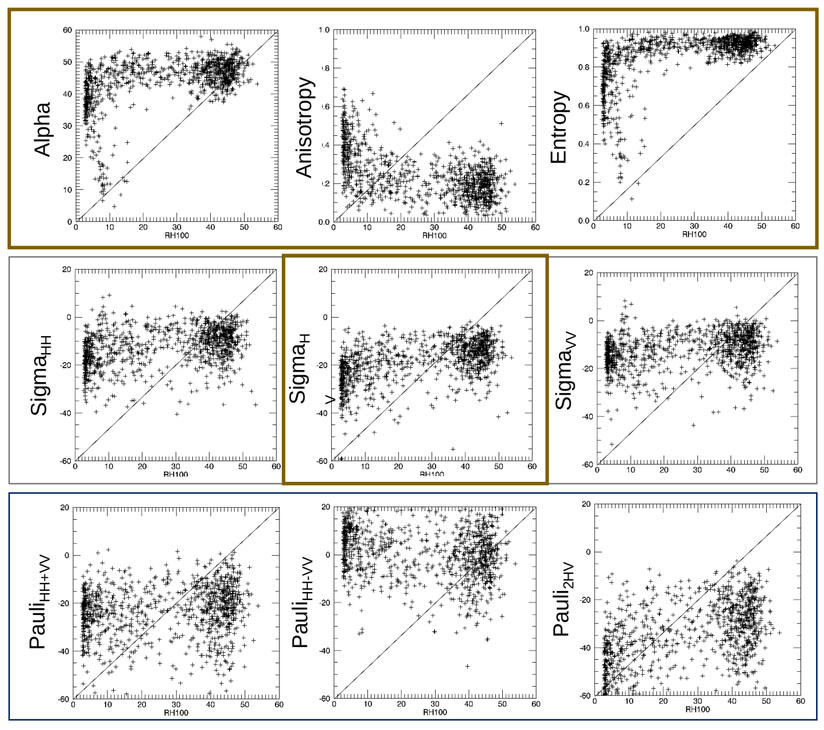
1. Polarimetric SAR processing and generating polarimetric SAR parameters
2. Correlation analysis between individual polarimetric SAR parameters and LiDAR
3. Train the SVM using a small portion of samples from selected polarimetric SAR parameters and LiDAR
4. Apply the trained SVM to the larger subset exclude of LiDAR
5. Height estimation

1 Polarimetric SAR processing and generating polarimetric SAR parameters

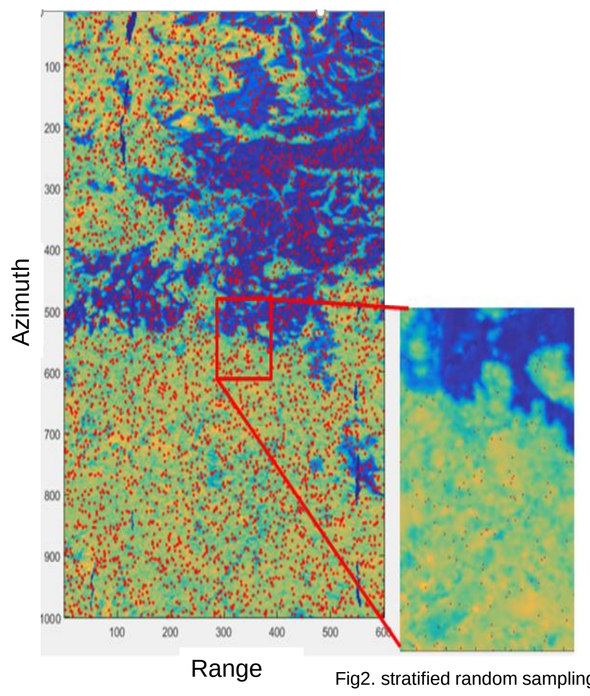
H/A/alpha [3]	Pauli	Backscatter
Alpha	HH+VV	$Sigma_{HH}$
Entropy	HH-VV	$Sigma_{HV}$
Anisotropy	2HV	$Sigma_{VV}$

2 Correlation analysis between individual polarimetric SAR parameters and LiDAR

POLARIMETRIC COMPONENTS	RANK CORRELATION COEFFICIENT
H/A/alpha (Alpha)	0.55
H/A/alpha (Anisotropy)	0.55
H/A/alpha (Entropy)	0.65
$Sigma_{HH}$	0.39
$Sigma_{HV}$	0.52
$Sigma_{VV}$	0.35
Pauli (HH+VV)	0.29
Pauli (HH-VV)	0.37
Pauli (2HV)	0.42



3 4 5



Sampled height ranges using 5m bins based on RH100
0-5
5-10
10-15
15-20
20-25
25-30
30-35
35-40
40-45
45-50
50-55
55-60

Fig2. stratified random sampling

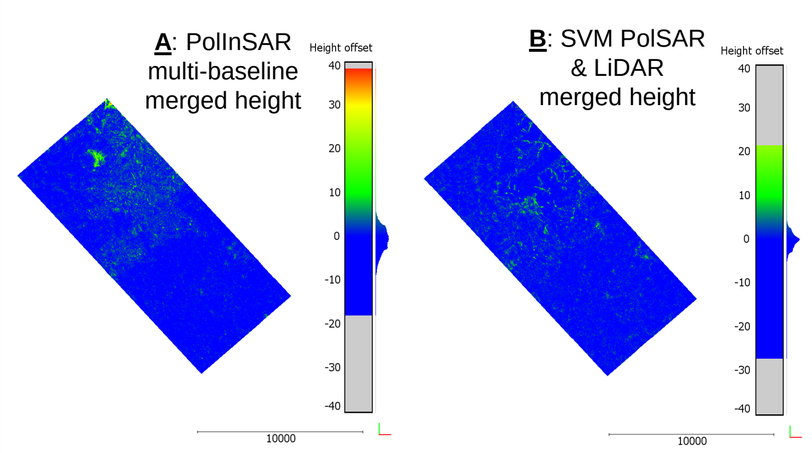


Fig5. 2D visualisation of height differences with LiDAR. A: PolInSAR multi-baseline merged height, B: SVM PolSAR & LiDAR merged height

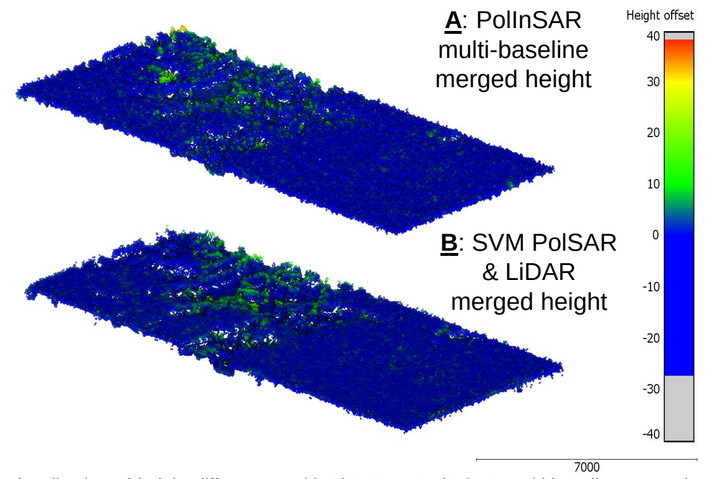
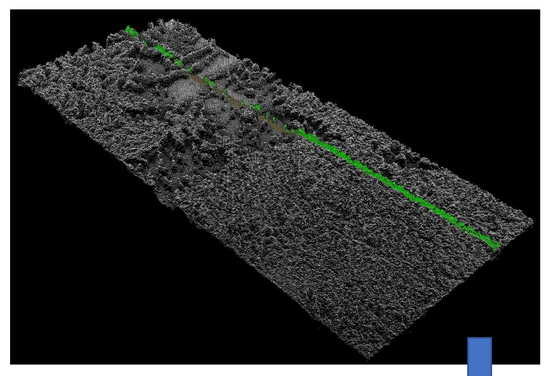
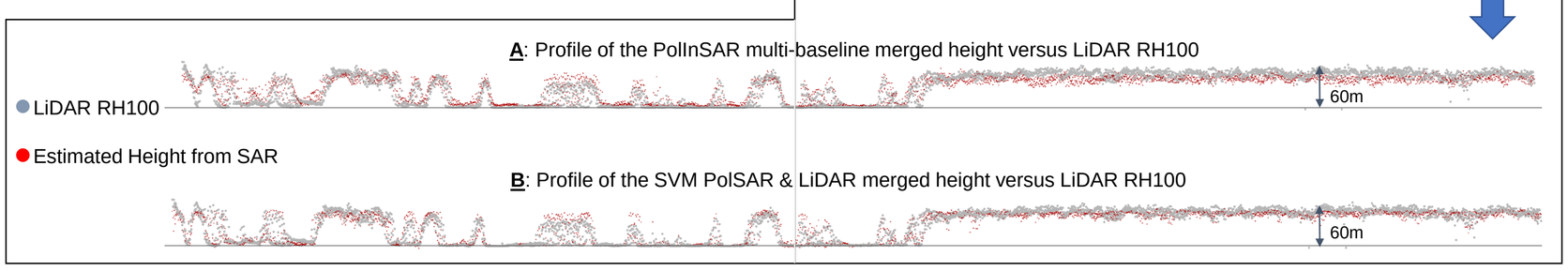


Fig6. 3D visualisation of height differences with LiDAR. A: PolInSAR multi-baseline merged height, B: SVM PolSAR & LiDAR merged height





RESULTS & DISCUSSION

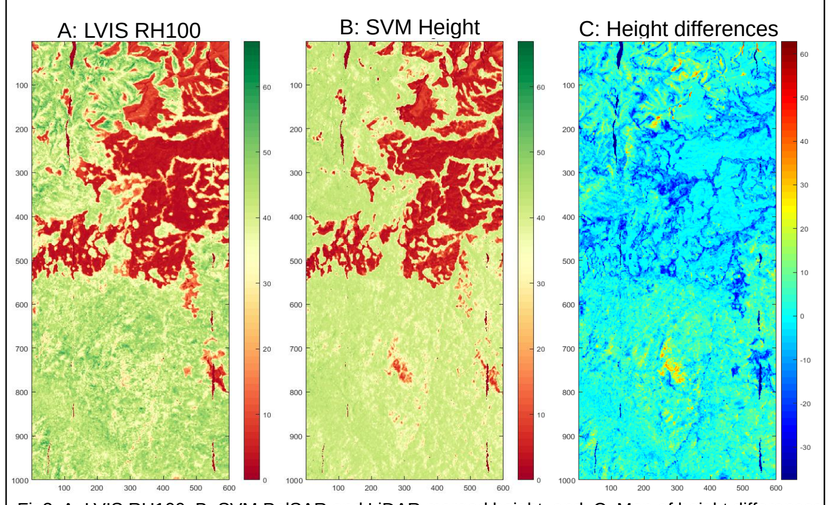


Fig3. A: LVIS RH100, B: SVM PolSAR and LiDAR merged height, and C: Map of height differences

- The study site covers two different forest types, short/sparse savannahs and tall/dense forest.
- Our approach worked reasonably well for the short/sparse vegetation (up to 20 m height)
- The estimated height well captured the height pattern of the study site.

	r^2 [%]	RMSE [m]	RRMSE [%]
SVM estimated height	0.86	6.08	18.9

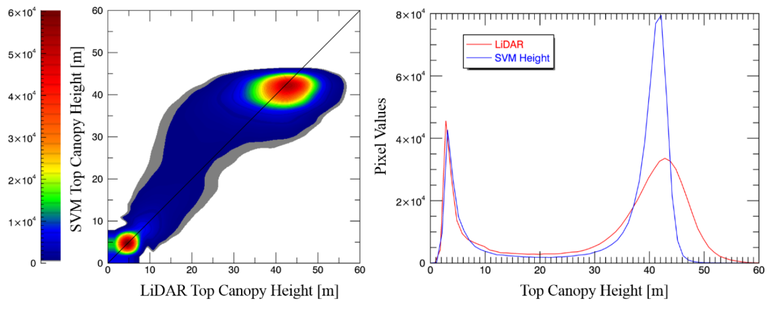


Fig4. validation of the PolSAR and LiDAR merged height versus LiDAR RH100

- There are two scenarios for the taller vegetation: overestimation for the height ranges between 20-40m, and underestimation for 40-60 m.
- Effect of topography and terrain slope in the SAR images.
- For the taller trees, the underestimation is also related to penetration depth at L band which can penetrate the canopy only up to a certain depth.

CONCLUSION

- We used fully polarimetric airborne L Band SAR and a small portion of airborne LiDAR samples, to build a machine learning for forest height estimation.
- The experiment indicates that, it is possible to estimate forest canopy height using polarimetric parameters and a small portion of LiDAR measured height to estimate forest canopy height over a larger scene where LiDAR is not available.
- Individual polarimetric parameters are contributing to the model by providing different physical information inside scatterers, while LiDAR is giving information on vertical distribution of them.
- The robustness of this approach needs to be assessed over the other test sites and also using different datasets (e.g. satellite SAR, different SAR wavelength)
- Using different polarimetric parameters are recommended.
- This method is useful for upcoming GEDI LiDAR mission, which provides a large number of samples at global scale.
- The method can be configured in absence of LiDAR measurements if ground data is available, where the SVM can be trained using the ground measured height.

ACKNOWLEDGMENT

- We would like to thank European Space Agency (ESA) and NASA for their joint effort in conducting the AfriSAR campaign and providing us with the data.
- UAVSAR data pre-processing was carried out at the NASA Jet Propulsion Laboratory, California Institute of Technology. LiDAR data sets were provided by the Laser Vegetation and Ice Sensor team at the Laser Remote Sensing Branch of the NASA's Goddard Space Flight Center.
- PolSARPro software was used for some post-processing of the SAR data, including generation of the H/A/alpha decomposition components.

REFERENCES

[1] M. Lavalle and S. Hensley, "Extraction of structural and dynamic properties of forests from polarimetric-interferometric SAR data affected by temporal decorrelation," IEEE Transactions on Geoscience and Remote Sensing, vol. 53, pp. 4752-4767, 2015.
[2] J. B. Blair, D. L. Rabine, and M. A. Hofton, "The Laser Vegetation Imaging Sensor: a medium-altitude, digitisation-only, airborne laser altimeter for mapping vegetation and topography," ISPRS Journal of Photogrammetry and Remote Sensing, vol. 54, pp. 115-122, 1999.
[3] J.-S. Lee and E. Pottier, Polarimetric radar imaging: from basics to applications: CRC press, 2009.
[4] E. Krogager, "New decomposition of the radar target scattering matrix," Electronics Letters, vol. 26, pp. 1525-1527, 1990.
[5] P. Hyde, R. Nelson, D. Kimes, and E. Levine, "Exploring LiDAR–RaDAR synergy—predicting aboveground biomass in a southwestern ponderosa pine forest using LiDAR, SAR and InSAR," Remote Sensing of Environment, vol. 106, pp. 28-38, 2007.
[6] H. A. Zebker and J. Villasenor, "Decorrelation in interferometric radar echoes," IEEE Transactions on geoscience and remote sensing, vol. 30, pp. 950-959, 1992.

CORRESPONDING AUTHOR CONTACT DETAILS

Maryam Pourshamsi
PhD Student, University of Leicester
Email: mp389@le.ac.uk
Twitter: @Marpourshamsi