Estimating Tropical-Forest Density Profiles from Multibaseline Interferometric SAR

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Abstract

Vertical profiles of forest density are potentially robust indicators of forest biomass, fire susceptibility and ecosystem function. Tropical forests, which are among the most dense and complicated targets for remote sensing, contain about 45% of the world's biomass. Remote sensing of tropical forest structure is therefore an important component to global biomass and carbon monitoring. This paper shows preliminary results of a multibasline interfereomtric SAR (InSAR) experiment over primary, secondary, and selectively logged forests at La Selva Biological Station in Costa Rica. The profile shown results from inverse Fourier transforming 8 of the 18 baselines acquired. A profile is shown compared to lidar and field measurements. Results are highly preliminary and for qualitative assessment only. Parameter estimation will eventually replace Fourier inversion as the means to producing profiles.

1 Tropical Forest Profiles

The structure of forests in the lateral 2 dimensions has been accessible to remote sensing for several decades. With the recent development of interferometric SAR (InSAR) [1] and lidar [2] came the possibility of remotely sensing the vertical direction of forests. Profiles of vertical vegetation density show potential of being among the most robust indicators of ecosystem state (e.g. fire susceptibility) and biomass [3], [4]. Measuring vertical properties of the forest requires more than single-baseline, single-polarization measurements [5]. Multipolarization [6] and multifrequency [7] InSAR have had some success in estimating tree height, but multibaseline InSAR, in analogy with multibaseline Very Long Baseline Interferometry used in astronomy [8], is probably required for robust density profile measurement. Because tropical forests represent about 45% of the Earth's forested biomass, this paper describes preliminary results activity on an experiment at La Selva Biological Station in Costa Rica, http://www.ots.ac.cr/en/laselva/.

2 The La Selva Experiment

We flew AirSAR over La Selva in March 2004 at 9 altitudes to realize 18 baselines, as suggested by Figure 1. There are 2 baselines per aircraft altitude, and because interferometric sensitivity is proportional to baseline/radar altitude, many baselines can be effectively created by flying many altitudes. An incidence angle of 35 degrees was maintained

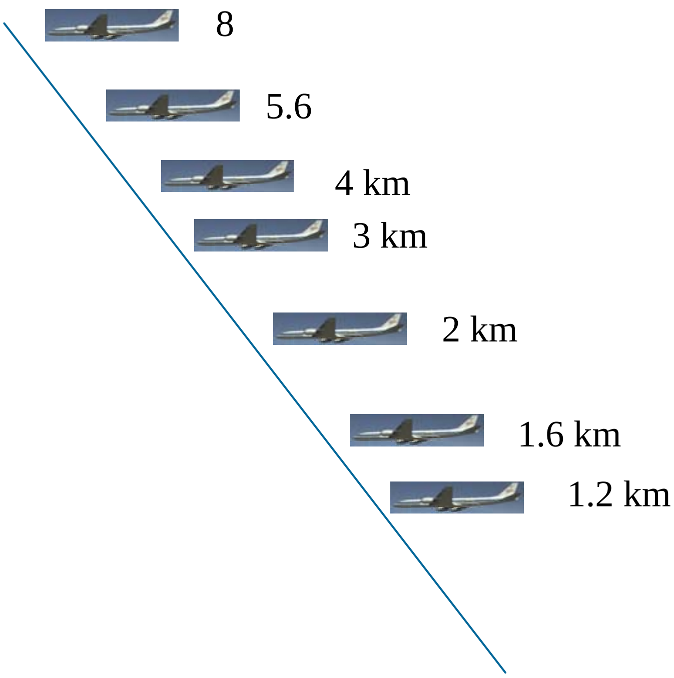

Figure 1 Seven of the 9 altitudes flown over La Selva. The incidence angle was 35 degrees over selected test targets. C and L band data were acquired.

over primary, secondary, and selectively logged test sites. This was done to be (perhaps overly) careful that the scattering mechanisms from altitude to altitude do not change. Data were acquired at both C- and L-band, but only C-band results will be discussed in this paper.

3 Modelling InSAR

The InSAR complex cross correlation is schematically modelled at each altitude as [5]

$$InSAR \propto \int_0^{h_v} \rho(z) \left\langle f_b^2(z) \right\rangle e^{-\frac{2\rho(z)\left\langle \mathrm{Im}\, f_f(z) \right\rangle (h_v - z)}{\cos\vartheta}} e^{i\frac{kB\cos^2\theta}{h\sin\theta} z} \, dz$$

Where h_v is the altitude of the top of the forest, $\rho(z)$ is the vegetation scatterer number density (the profile we want to estimate), B is the baseline length, $\left\langle f_b^2(z) \right\rangle$ is the average brightness of a backscatter, $\mathrm{Im}\, f_f(z)$ is the imaginary part of the forward scattering amplitude (proportional to absorption/attenuation), ϑ is the incidence angle, k is the wave number, and h is the aircraft altitude. Eventually, we will estimate parameters which describe $\rho(z)$ starting with the above physical model from the multiple altitude/baseline data. More qualitative results presently available will be shown below.

4 Field Measurements

In order to be able to compare InSAR-derived profiles to ground-based measurements, as well as to estimate the biomass of test stands, field measurements were conducted in February 2006 (**Figure 2**).

Figure 2: Field measurements, showing the tape defining the transect line, and team members measuring the perpendicular distance of each tree to that line. Field work was performed 11-23 February 2006.

Diameter at breast height, tree height, height-to-base-of-crown, x-y position, and x-y canopy extent were measured for each tree within a 10 m x 100 m transect, for 30 transects. From these measurements, we will estimate vegetation (leaf) density as a function of height. In the next section, preliminary estimates of density are shown, which crudely clump the entire volume of each tree at the center of the canopy, rather than distributing the vegetation properly.

5 Preliminary Results

It is very important to stress that the results presented here are qualitative and may bear little resemblance to the final results. They are presented to show the reader that InSAR profiles are beginning to emerge from this analysis, and that they seem qualitatively reasonable, given lidar and field measurements at La Selva.

In order to arrive at the InSAR profiles of Figure 3, the equation above was considered as simply a Fourier transform of a vertical function of z, that is all terms in front of the complex exponential were lumped into a “radar brightness” term, not vegetation density. The radar brightness was inferred by inverse Fourier transforming 8 terms (for 8 baselines) like the one equation above, with no regard to the sparse Fourier spacing, or the presence of the ground and finite ceiling, both of which will introduce high spatial frequencies neither measured nor taken into account by straight inverse Fourier transforming.

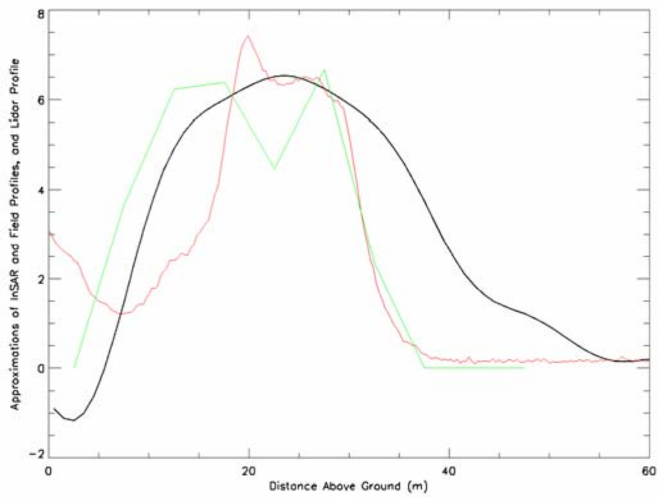

Figure 3: Qualitative, preliminary InSAR C-band power (black) and field (green) density profiles for a primary forest shown along with an LVIS lidar power profile (red) [9]. Remote sensing averaged over 100 x 100 m. Field measurements over 10 x 100 m.

The InSAR profile and field measurements are extremely preliminary. We know, for example, from simulation that the large altitudes on the right side of the InSAR profile are artefacts, and the distribution is probably too wide. The InSAR and lidar profiles are both of signal power, while the field profile is closer to vegetation density. We expect the InSAR and lidar profiles to show attenuated signals near the bottom of the forest relative to the field profile. These results show the beginning of our analysis, that all 3 methods see similar distributions, but are in no way an indication of the ultimate performance. Future InSAR analyses will model the density based on the above equation. We will probably use 1 or 2 Gaussians for the vegetation plus a ground return [10]. We will do biomass regression to the parameters describing the vegetation profiles.

6 Acknowledgment

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References

[1] Treuhaft R.N., Law B.E., Asner G.P. 2004. Forest attributes from radar interferometric structure and its fusion with optical remote sensing. BioScience 54(6): 561-571.

[2] Lefsky, M.A., W.B. Cohen, G.G. Parker, and D.J. Harding. 2002. Lidar remote sensing for ecosystem studies. Bioscience 52(1):19-30.

[3] Treuhaft R.N., Asner G.P., Law B.E. 2003. Structure-based forest biomass from fusion of radar and hyperspectral observations. Geophysical Research Letters 30: 1472–1475.

[4] Drake, J.B., R.O. Dubayah, D.B. Clark, R.G. Knox, J.B. Blair, M.A. Hofton, R.L. Chazdon, J.F. Weishampel, S.D. Prince. 2002. Estimation of tropical forest structural characteristics using large-footprint lidar. Remote Sensing of Environment. 79:305-319.

[5] Treuhaft R.N., Madsen S.N., Moghaddam M., Van Zyl J.J. 1996. Vegetation characteristics and surface topography from interferometric radar. Radio Science 31: 1449–1485.

[6] Papathanassiou K.P., Cloude S.R. 2001. Single-baseline polarimetric SAR interferometry. IEEE Transactions on Geoscience and Remote Sensing 39: 2352–2363

[7] Neeff, T. Dutra, L. V., Santos, J.R., Freitas, C., Araujo, L. 2005. Tropical forest biomass measurement by interferometric height modelling and P-band radar backscatter. Forest Science 51 (6): 585-594.

[8] Thompson AR, Moran JM, Swenson Jr. GW. 1986. Interferometry and Synthesis in Radio Astronomy. New York: John Wiley & Sons.

[9] Processing of NASA LVIS elevation and canopy (LGE, LCE and LGW) data products, version 1.0. J. B. Blair, M. A. Hofton, and D. L. Rabine. http://lvis.gsfc.nasa.gov, 2004.

[10] Treuhaft RN, Siqueira PR. 2000. Vertical structure of vegetated land surfaces from interferometric and polarimetric radar. Radio Science 35: 141-177.