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On the Potential of Long Wavelength Imaging Radars for Mapping Vegetation Types and Woody Biomass in Tropical Rain Forests

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1. STUDY SITE AND BIOMASS ESTIMATES

The Manu National Park, in Peru, is located at the remote western edge of the Amazon basin [1-3]. It contains pristine, tropical rain forest types with a striking diversity of tropical tree species. The generally humid climate is interrupted by a dry season in July-August. Floodplain succession and climax forests occur on nutrient rich alluvial soils along the Rio Manu and mature forests on more dry and leached soils on the adjacent hills. Since a biomass inventory was not available for any forest in this area, a ground team characterized the major forest types and approximate spatial distribution of vegetation along the accessible areas of the lower Manu river in September 1993. Seventeen plots with representative vegetation types were measured for average tree and canopy height, canopy closure, tree density and understory composition. The aboveground biomass for all forest types was estimated by applying allometric equations [4], derived from pristine South-Asian forests [5]. Aboveground dry biomass of early forest succession like mature *Tessaria integrifolia* (Asteraceae) and *Gynerium sagittatum* (Poaceae) (10 m) was estimated to be 4 kg/m^2 and 4.3 kg/m^2 in *Gynerium-Cecropia membranacea* stand (17 m). Aboveground biomass in a permanently inundated Aguajal (max. 22 m height) was estimated to be 13 kg/m^2, in a mainly dry and open Aguajal (26 m) 17 kg/m^2, and 18 kg/m^2 in a typical Aguajal (28 m) with moist soil and a high palm density. Broadleaf forest types along the Rio Manu are evergreen to semi-deciduous with wide variations in canopy structure. In the floodplain, we calculated for a mosaic forest (>27 m) on rich alluvial soil a biomass of 31 kg/m^2. On adjacent hills, forests vary from tall stands with closed canopies to open semi-deciduous stands. We calculated 28 kg/m^2 for a semi-deciduous upland forest (30 m) and 46 kg/m^2 for a tall forest (40 m) with closed overstory. Total aboveground biomass of a tall (>50 m), old growth floodplain forest at Cocha Cashu, Rio Manu, was estimated to be 104 kg/m^2. This value represents probably the highest aboveground biomasss accumulation found in this area due to the large size of individual trees reaching emergent tree heights of 53 m with diameter at breast height (dbh) of 3 m and a closed canopy of dominant trees with dbh between 0.9 and 2.4 m [6]. The estimated biomass values for mature old growth floodplain forest clearly exceed the reported average value of 67 kg/m^2 for high dense tropical forests of the generally poorer soils on Terra Firme in the Brazilian forests [7]. However, in general, even higher forest volumes are possible and have been repeatedly reported for temperate coastal rain forests in higher latitudes [8]. Since the impressive, mature floodplain forests cover relatively small areas, the average aboveground biomass weighed by the area covered by each species is expected to be much lower.

2. MAPPING OF MAJOR VEGETATION FORMATIONS

Using a maximum-a-posteriori Bayesian classifier for polarimetric SAR data, and selecting training areas representative of various types of vegetation along the Rio Manu floodplain, we generated a classification map (AIRSAR Workshop Slide 2b) of the 10-km wide P-band data into the following 9 categories of land cover: 1) tall semi-deciduous forest; 2) palm aguajal; 3) tessaria forest; 4) gynerium forest; 5) cecropia forest; 6) mosaic forest; 7) segdes; 8) bare soil; and 9) water. Classifications obtained using the L- or C-band data did not prove as useful as the one generated using the P-band data. At P-band, HH-polarization is the most useful polarization for separating the different types of vegetation. Comparison of the SAR results with sample plots placed at selected locations along the Manu river indicates that the SAR-derived vegetation map provides a correct representation of the distribution in forest types in that area, and that the P-band radar is able to separate most major vegetation formations in the floodplains. The treatment of forested areas in the uphill section of the Park is complicated by the presence of an undulating 30-50 m topography, for which we do not have a reliable digital elevation model, and which would need to be accounted for to obtain a correct mapping of the vegetation.

3. MAPPING OF MAJOR CLASSES OF BIOMASS

We developed an empirical relationship between forest biomass and radar backscatter for this area to generate a map of forest biomass [9]. At the low biomass levels (< 10 kg/m^2), we used the regression curve which was developed for Alaskan forests and which utilized the P-band HH-, HV-, and VV-polarized data gathered during the dry season [10]. At the higher biomass levels, the regression curve correctly separated the different classes of biomass, but underestimated forest biomass quite significantly. We modified the regression to increase the predicted biomass levels for large radar backscatter values and obtain a better agreement with our ground estimates.

Areas where the forest biomass predicted from the radar exceeds 30 kg/m^2 (dark green) correspond to the mature floodplain forests where woody biomass is indeed expected to be the largest. The forest floor in the imaged broadleaf forests was dry at the time of the AIRSAR overflight (the dry season ends in September), so the enhanced radar signature of these stands at HH-polarization is not caused by wetter ground layers but more likely by tall tree trunks of large diameter. Forest biomass is lower in palm forests (green), which are surrounded by broadleaf forests of higher biomass (dark green). Old meanders, sealed off by freshly deposited sediment and showing as oxbow lakes (Cochas) with open water are mapped as areas of no biomass (black). Low biomass (brown) is estimated along the termini of Cochas, having an early succession of sedges, grasses and shrubs (especially *Annona tessmannii* (Annonaceae)), which are occasionally intercut by a tall stand of *Heliconia episcopalis* (Musaceae) with slightly larger biomass (oxbow at center right of the scene, green). In the expanding meander loop, in the center left of Slide 2b, that points down towards the lower border of the river, the early succession of riparian vegetation is well discriminated in the biomass map. Forest succession starts from the beach with short, even-aged stands of fast-growing *Tessaria* shrubs, followed by *Gynerium* stands (6 m in height) with higher biomass (dark brown). Adjacent are older successional stages of *Tessaria-Gynerium* (10-12 m in height) (light brown), and pure *Gynerium* (yellow). Continuing inland, towards the top of the scene, are deciduous leafless tree species mixed with *Cecropia* (10-26 m) above a 5 m tall understory of *Gynerium*. This forest appears blue-green in AIRSAR Workshop Slide 2a, and corresponds to a higher biomass level. A mosaic of semi-deciduous floodplain forest (30-35 m) with higher predicted biomass follows. This type of clearly zoned and highly productive, riparian forest succession, where each stage reaches a greater absolute height than the previous one, is characteristic of this area and can be identified at many other locations along the river in AIRSAR Workshop Slide 2a.

4. CONCLUSIONS

In the tropical rain forests of Manu, in Peru, where forest biomass ranges from 4 kg/m^2 in young forest succession up to 100 kg/m^2 in old, undisturbed floodplain stands, the P-band polarimetric radar data gathered in June of 1993 by the AIRSAR instrument separate most major vegetation formations and also perform better than expected in estimating woody biomass. The worldwide need for large scale, updated biomass estimates, achieved with a uniformly applied method, as well as reliable maps of land cover, justifies a more in-depth exploration of long wavelength imaging radar applications for tropical forests inventories.

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