Very high resolution satellite images for parameterization of tree-scale forest process-based model

Guerric Le Maire, Yann Nouvellon, Olivier Roupsard, Mathias Christina, Fabien Charbonnier, Jia Zhou, Flavio Ponzoni, Jose-Luiz Stape, Jean Dauzat, Pierre Couteron, et al.

VERY HIGH RESOLUTION SATELLITE IMAGES FOR PARAMETERIZATION OF TREE-SCALE FOREST PROCESS-BASED MODEL

Guerric le MAIRE[1], Yann NOUVELLON[1], Olivier ROUPSARD[1], Mathias CHRISTINA[1], Fabien CHARBONNIER[1], Jia ZHOU[2], Flavio PONZONI[3], Jose-Luiz STAPE[4], Jean DAUZAT[2], Pierre COUTERON[2], Christophe PROISY[2]

1: CIRAD, UMR Eco&Sols, Montpellier
2: CIRAD-IRD-UM2, UMR AMAP, Montpellier
3: INPE, São José dos Campos, SP, Brazil
4: North Carolina State University, Raleigh, United States

Very high spatial resolution (VHSR) satellite images provide interesting information for parameterizing tree-scale forest process-based models, and in particular their light absorption submodels, which is at the basis of photosynthesis calculation. Such tree-scale models require a large amount of field measurements to describe the forest ecosystems, i.e. all tree positions, their sizes and shapes, their leaf areas, etc. These data are generally measured directly in the field [1], which can be tedious for large areas like a forest stand. In this study, we explore the possibility to parameterize such tree-scale models directly or indirectly from panchromatic and multispectral very high resolution images.

Tree-scale forest process-based models are numerous. We selected a well-established model, MAESTRA [2], to test the methodology. MAESTRA requires, for its light interception submodule several informations:
- tree positions, i.e. the (x,y) coordinates of their center
- tree sizes, i.e. their height, height and radius of the crown, and shape of the crown
- total leaf surface of each tree
- leaf and soil reflectance, leaf transmittance in the PAR domain
- leaf angle distribution, leaf density distribution

Two study sites were tested. The first was a *Eucalyptus* plantation in Brazil at early growth stages [3], where the canopy was not closed, and where the inter-tree variability of crown sizes and leaf area were high. In such planted ecosystem, the tridimensional dimensions of each tree, and possible absence of tree, were important for light absorption estimations. The second site was a more complex coffee agroforestry system in Costa-Rica. In that system, isolated shade trees are distributed above a raw-planted coffee plantation. These shade trees influence the quantity of radiation that reaches the coffee layer, which can be estimated with the MAESTRA model. For each site, a VHSR image was acquired. For Eucalyptus plantation, the image was a Worldview 2 image with panchromatic (0.5 m resolution) and multispectral (2 m resolution) channels, when the plantation was 6 and 9 month old [4]. For the coffee Agroforestry system, the image was from Quickbird (panchromatic 0.6 m and multispectral 2.4 m) [5]. All images were orthorectified.

A tree crown detection algorithm, based on the marked point processes [6], was used. This mathematical algorithm showed advantages with respect to several individual tree detection algorithms for plantations [7]. It was applied to the panchromatic images of Eucalyptus [4], resulting in the estimation of each tree center and radius. While the presence/absence of trees were adequately determined (more than 90% accurate detections), the precision radius of each tree suffer from high uncertainty due to the image resolution (0.5 m in panchromatic band) compared to the average diameter of Eualypt trees (around 2 meters at the age of measurements). The precision for crown diameter was therefore close to 1 meter. These parameters were directly integrated in the MAESTRA model. From the radius of the crowns, it was then possible to estimate tree and crown heights via allometric relationships [1]. Precise allometric relationships were calibrated at the same date than image acquisition (Figure 1).

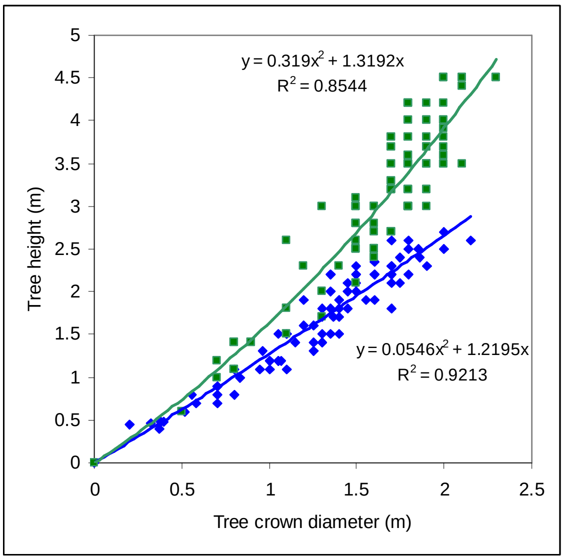

Figure 1. Tree height in function of tree crown diameter in a young plantation of Eucalyptus grandis in Brazil. Measurements were done at age 6 month (blue) and at age 9 month (green)

Allometric relationships between tree height and tree leaf area are also precise for such plantations (r^2>0.9). Such allometric relationship can be used to give an estimation of leaf area of each tree, since tree eight is estimated on the image (from tree diameter). However, since the uncertainty on crown diameter is high, we explored the use of the radiometry of the multi-spectral images. For that purpose, the crown positions and delineation obtained before were used, and average values of NDVI were calculated for each tree. A simple vegetation index was calibrated with leaf area field measurements of several trees. Due to the size of some of the trees, this step was enhanced by the linear unmixing approach that was described in [8]. The results showed that it was possible to estimate the leaf area of each tree with an accuracy of 30 % and no bias. Use of high resolution forest reflectance model [9, 10].
Other necessary information for MAESTRA parameterization was not derived from satellite measurements. These parameters could be considered to be constant between trees, and therefore were estimated during the field campaign. The procedure that was developed for *Eucalyptus* plantations was tested on the more complex agroforestry system. For detection of shade tree positions and size, the VHSR images appeared to be useful, but automatic detection of shade trees were more difficult because of background heterogeneity, giving an accuracy of 70%. The lack of precise measurements of tree leaf area brings additional error for the shade tree parameterization [11]. However, the use of VHSR images were encouraging for mapping leaf area of the coffee strata [5].

In conclusion, this study showed that it was possible to parameterize a tree-scale model like MAESTRA from a VHSR image. This method is however limited to simple forest structures where canopy is not closed, where each individual tree could be delimited, and where allometric relationships could be calibrated. While other methods like airborne lidar or aerial photographs at even higher resolution may provide more precise information [12], this method based on VHSR images may be a good alternative for larger scale applications. With future hyperspectral VHSR images, the parameterization of such models could also includes informations on photosynthetic capacities through pigment and/or physiological reflectance indices.

[1] G. le Maire, Y. Nouvellon, M. Christina *et al.*, “Tree and stand light use efficiencies over a full rotation of single- and mixed-species Eucalyptus grandis and Acacia mangium plantations,” *Forest Ecology and Management*, vol. http://dx.doi.org/10.1016/j.foreco.2012.03.005, 2012.
[2] B. E. Medlyn, "A MAESTRO Retrospective," *Forests at the Land-Atmosphere Interface*, Mencuccini M., Moncrieff J., McNaughton K. *et al.*, eds., pp. 105-122, Wallingford, UK: CABI Publishing, 2004.
[3] Y. Nouvellon, J. L. Stape, G. Le Maire *et al.*, "Factors controlling carbon and water balances on fast growing Eucalyptus plantations.." pp. 43-46, Proceedings IUFRO Improvement and Culture of Eucalypts, Porto-Seguro, Brazil.
[4] J. Zhou, C. Proisy, X. Descombes *et al.*, "Tree crown detection in high resolution optical images during the early growth stages of eucalyptus plantations in Brazil," ACPR 2011, Beijing, 2011.
[5] S. Taugourdeau, O. Roupsard, J. Avelino *et al.*, “Leaf area index at the crossroad of environmental services in a coffee agroforestry system ”, in prep.
[6] X. Descombes, R. Minlos, and E. Zhizhina, “Object Extraction Using a Stochastic Birth-and-Death Dynamics in Continuum,” *Journal of Mathematical Imaging and Vision*, vol. 33, no. 3, pp. 347-359, 2009.
[7] M. Larsen, M. Eriksson, X. Descombes *et al.*, “Comparison of six individual tree crown detection algorithms evaluated under varying forest conditions,” *International Journal of Remote Sensing*, vol. 32, no. 20, pp. 5827-5852, 2012/01/12, 2011.
[8] G. le Maire, C. Marsden, Y. Nouvellon *et al.*, “MODIS NDVI time-series allow the monitoring of Eucalyptus plantation biomass,” *Remote Sensing of Environment*, vol. 115, pp. 2613–2625, 2011.
[9] J. P. Gastellu-Etchegorry, V. Demarez, V. Pinel *et al.*, “Modeling radiative transfer in heterogeneous 3-d vegetation canopies,” *Remote Sensing of Environment*, vol. 76, pp. 1-15, 1996.
[10] J. P. Gastellu-Etchegorry, E. Martin, and F. Gascon, “DART: a 3D model for simulating satellite images and studying surface radiation budget,” *International Journal of Remote Sensing*, vol. 25, no. 1, pp. 73-96, Jan, 2004.
[11] F. Charbonnier, O. Roupsard, E. Dreyer *et al.*, "Verifying MAESTRA from plant to plot in a heterogeneous agroforestry system of Costa Rica," 30th AMS Conference on Agricultural and Forest Meteorology, Boston, MA, 2012.
[12] M. Erikson, *Segmentation and Classification of Individual Tree Crowns in High Spatial Resolution Aerial Images*, PhD thesis, Swedish University of Agricultural Sciences, 2004.