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Toward a general tropical forest biomass prediction model from very high resolution optical satellite images

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ABSTRACT

Very high spatial resolution (VHSR) optical satellite imagery has shown good potential to provide non-saturating proxies of tropical forest aboveground biomass (AGB) from the analysis of canopy texture, for instance through the Fourier Transform Textural Ordination method. Empirical case studies however showed that the relationship between Fourier texture features and forest AGB varies across forest types and regions of the world, limiting model transferability. A better understanding of the biophysical mechanisms on which canopy texture – forest AGB relation relies is a prerequisite to move toward broad scale applications. Here we simulated VHSR optical canopy scenes in identical sun-sensor geometry for 279 1-ha tropical forest inventory plots distributed across the tropics. Our aim was to assess the respective merits and complementarity of two types of texture analysis techniques (i.e. Fourier and lacunarity) on a set of forests with contrasted structure and geographical origin, and develop a general texture-based approach for tropical forest AGB mapping. Across forests, Fourier texture captured a gradient of stands mean crown size reflecting well the progressive changes in stand structure throughout forest aggradation phase (e.g. Pearson's $r = -0.42$ with basal area) while lacunarity texture captured a gradient of canopy openness (, i.e. Pearson's $r = -0.57$ with stand gap fraction). Both types of texture indices were highly complementary for predicting forest AGB at the global level (so-called FL-model). The residual error of the FL-model was structured across sites and could be partially captured with a bioclimatic proxy, further improving the performance of the global model (so-called FLE-model) and reducing site-level biases. The FLE model was tested on a set of real Pleiades images covering a mosaic of high-biomass forests in the Congo basin (mean AGB over 49 field plots: 359 ± 98 Mg ha^{-1}), leading to a significant relationship ($R^2 = 0.47$ on validation data) with reasonable error levels (< 25% rRMSE). The increasing availability of VHSR optical sensors (such as from constellations of small satellite platforms) raises the possibility of routine repeated imaging

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of the world's tropical forests and suggests that texture-based analyses could become an essential tool in international efforts to monitor carbon emissions from deforestation and forest degradations (REDD +).

1. Introduction

Concerns about the effects of increasing atmospheric carbon dioxide on climate have led to an international initiative aiming at reducing forest-related emissions (Reducing Emissions from Deforestation and forest Degradation, REDD +), notably in the tropics where the bulk of global deforestation occurs (Pan et al., 2011). REDD + implementation fundamentally relies on our capacity to monitor forest carbon stock and dynamics at multiple spatial scales, from entire countries down to scales at which deforestation and degradation processes occur. In this context, remote sensing naturally becomes an essential tool (Baccini et al., 2012; DeFries et al., 2007; Saatchi et al., 2011). However, remote sensing of forest carbon stocks (often through forest aboveground biomass, hereafter denoted AGB) is challenging in the tropics because most satellite sensors are not sensitive to AGB variation above c. 150 Mg ha^{-1}, while AGB often exceeds 400 Mg ha^{-1} in tropical forests (Slik et al., 2013). This saturation is well documented for passive optical sensors of coarse to intermediate spatial resolution such as the Moderate Resolution Imaging Spectroradiometer (MODIS) or Landsat Thematic Mapper (e.g. Lu, 2006; Lu et al., 2012; Zhao et al., 2016) but also for radar signals (notably L-band SAR, Mermoz et al., 2015), and thus constitutes a strong limit for those data types. In the past years, aircraft-based light detection and ranging systems have become popular for tropical forest AGB mapping, as their data appear to be free of saturation. Small-footprint airborne LiDAR data provide a detailed description of forest three-dimensional (3D) structure from which forest AGB can be estimated with good confidence (e.g. 14% relative error on 1-ha plots in Réjou-Méchain et al., 2015). Unfortunately this information comes at a cost rendering the wall-to-wall and regular coverage of large territories uneconomical (Erdody and Moskal, 2010; Messinger et al., 2016) or is even impossible to collect in some countries because of flight restrictions. An interesting alternative to airborne LiDAR may be found in very high spatial resolution (VHSR) optical images, as they are routinely captured by a variety of satellite platforms and therefore represent

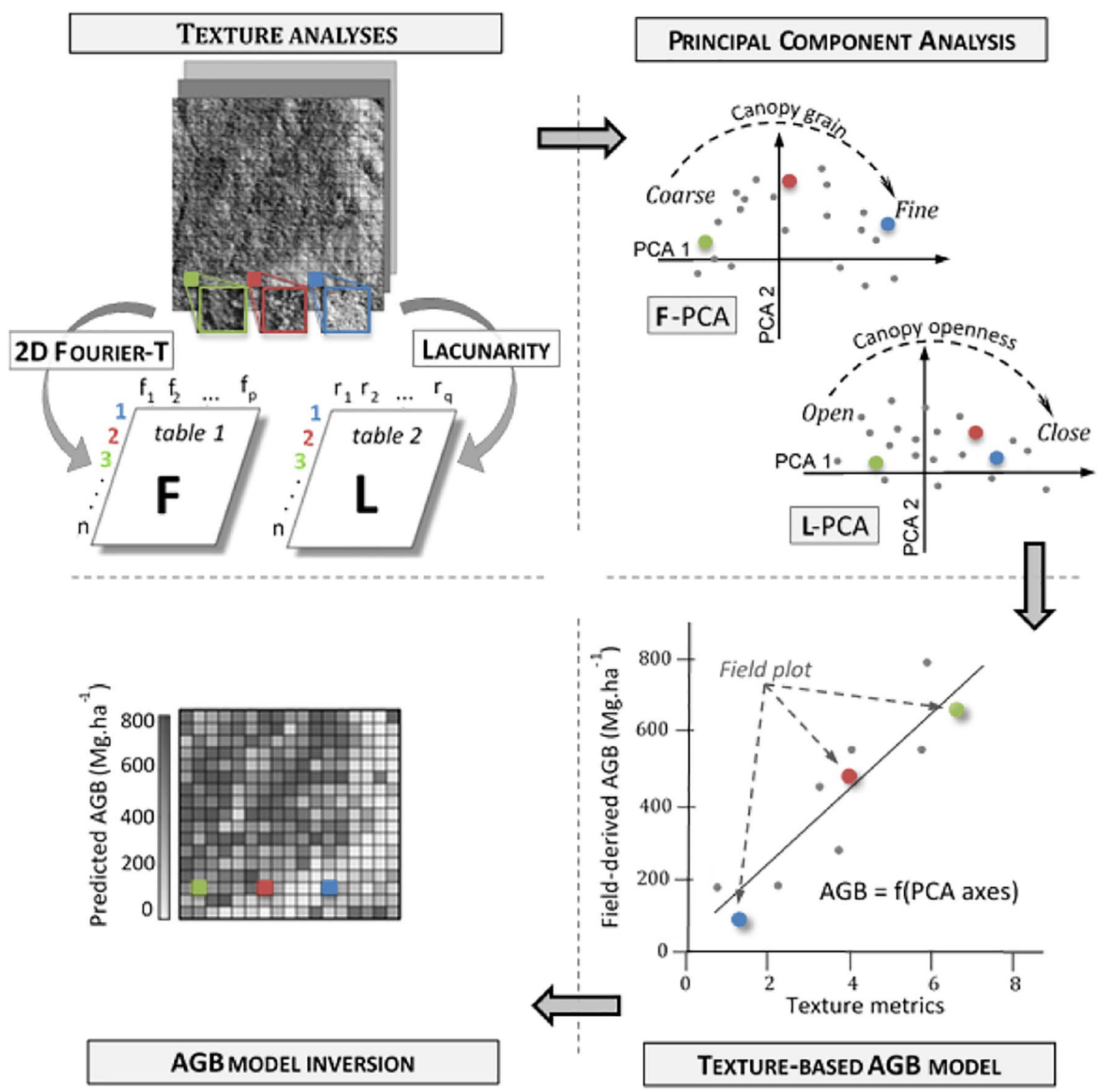

Fig. 1. Typical workflow of texture-based AGB mapping method.