Project MC-IEF FOTOFor2 : Final publishable summary report

The upper mantle, or canopy (fig. 1), of tropical forests is the habitat of most of these forest's tremendous biodiversity and the siege of crucial processes, such as the exchanges of gas, vapor and energy with the atmosphere. Such exchanges not only condition forest growth, they also drive the climate at regional (rainfall cycle) and global (Carbon cycle) scales. Moreover, most of the carbon in a forest is stocked in the trunks of large trees, which appear in the canopy. Yet, as these trees often reach heights of 50 meters or more, directly measuring canopy characteristics from the ground even over an area the size of a football field is more than tedious. Indeed, canopy structure obviously depends on the size, abundance, form and species of its component trees, but also on how they intermingle in tri-dimensional space. Canopy structure is therefore mostly disregarded in usual forest inventory method, where forest structure is approached via the distribution of trunk diameters at breast height (DBH, fig. 1). Even so, obtaining such information over representative extents within a remote ecosystem covering tens of millions of square kilometers is near impossible.

During the past few decades, satellite-borne sensors have been routinely used to map forest extents and deforestation rates, but not really to characterize forest properties, because of limitations in image spatial resolution and corruption by permanent haze and cloud cover over 'rainforests'. As the time and space resolutions of available images improve, new opportunities are offered for the large scale characterization of canopy and forest structural properties (fig. 1). This comes at a time when societal needs are strong, as reducing carbon emissions from forest degradation and deforestation that total up to 20% of current human induced emissions, has been identified as a less costly way to curb climate change than efforts in other sectors.

The main objective of this Marie Curie project was to validate the large scale applicability of a method, called FOTO, allowing to quantify canopy structure from satellite imagery of metric resolution (fig. 1). The FOTO method automates what the human eye does routinely, which is deciphering texture variations in images, to distinguish canopies with a coarse grain, caused by the presence of large crowns or treefall gaps, against those that are finer-grained, such as young stands (fig. 2). Local tests with field data in South America and India showed very good agreements between these texture measures and ground data (DBH distributions).

A pair of important issues needs to be dealt with before using the method over regional to continental scales. The first issue is the existence of **forest types presenting peculiar canopy textures**, such as open canopy forests, or stands dominated by a single species with a peculiar morphology such as raphia palm groves (fig. 3). The second issue is that the **perceived canopy texture depends of the angle between the sun and the sensor** at the time of the acquisition (Fig. 4). Indeed if tree shadows are concealed to the observer (sun behind the sensor), the texture will appear with a finer grain, even if the forest is identical.

Two main approaches were taken in this project: a large scale empirical study and a theoretical study. **In the empirical study**, the idea was simply to measure forest structure (DBH distribution) on the ground in a large number of sites in Central Africa and to match these geo-localized ground data with the texture measured in a collection of satellite images. Through a collaboration with a forest management consulting office (FRM, Montpellier), we disposed of a very large collection of such field plots (150 000 ha inventoried!) previously censused for management purposes. We acquired about 50 satellite images (about 100 km² each) and undertook matching the two collections. Unfortunately, results came up to be very disappointing, mainly because the geo-location of field data was too poor relatively to the important local variations of forest structure. Thanks to a renewed investment of IRD in central Africa through its regional program (PPR FTH AC), and along with several partner institutions and scientists, we undertook a long term effort to acquire more adapted field data in the form of a network of 1-ha, well localized, permanent forest plots. These efforts yielded their first results as we were able to predict forest biomass over a 400 km² area in the Democratic Republic of Congo, more precisely than any other available satellite method (15% error) up to very high biomass levels. To reach this goal we were able to combine images acquired in opposite configurations and to deal with a full range of forest types. This step is a very promising one the road towards a fully operational tool.

In the theoretical study, we simulated canopy textures (fig. 5) using 3D models of forests and a physical light transfer model (DART from UMR CESBIO, Toulouse). At tree level, the 3D model was rather crude, as tree crowns were represented as simple geometrical shapes filled with turbid medium mimicking foliage. However at forest stand level, field information on trees dimensions and positions allowed obtaining very satisfying canopy images (fig. 4). These images proved sufficiently reliable to test the response of FOTO texture to variations in sun-view angle (fig. 5) or forest structure in a more systematic way than was possible with real data. Such theoretical approaches are essential to test possible correction methods of for sensitivity studies.

In parallel to the study on canopy texture, we invested in a complimentary approach in which the daily time resolution of some existing space-borne sensors (e.g. MODIS) allows assessing **seasonal changes in the canopy**, such as leaf shedding. However as pixel size is in this case at best of 250 m, scientists fail to agree on what is actually captured by such data. We therefore made use of our collection of higher resolution images to literally count individual leafless crowns and match these numbers with the MODIS data. The good results obtained allowed to produce the first regional quantitative map of the proportion of deciduous (leaf shedding) trees in a region saddling three central African countries.

In terms of its impacts, this project has therefore been pivotal in shaping a long term research agenda (the grantee has been recruited for a permanent position in IRD) aimed towards improving our capacity to understand and monitor tropical rainforests, an ecosystem of fundamental importance for the social, economical and environmental services it delivers at global scale. Given Europe's commitment as a party in climate change conventions, as well as in multilateral and bilateral cooperation with developing countries, this is an agenda that is clearly worth supporting. **The main deliverables** of this project include disseminations through **three world-class scientific conferences**, **six scientific publications** in international peer reviewed journals, **two book chapters** and the production of a regional map of forest types and deciduousness.

Figure 1. Different viewpoints on a tropical forest. Lower panel: trunk diameters are the usual entry to forest structure. Middle panel: Many relevant processes occur in the canopy. Upper panel: A forest canopy viewed by a high resolution satellite (GeoEye©, false colors, pinkish crowns are leafless).

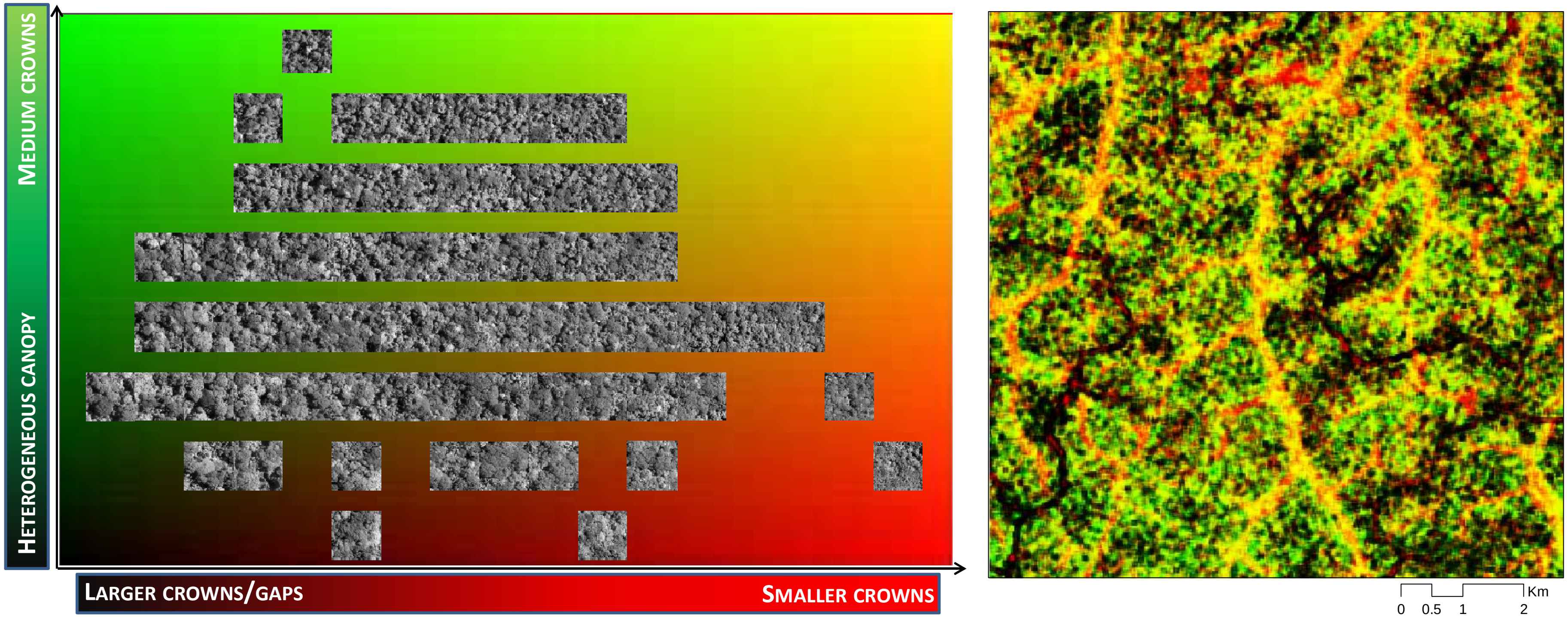

Figure 2. Canopy texture sorting produced by the FOTO method. Left panel: forest canopies are sorted in function of the mean crown size and canopy heterogeneity. Right panel: Canopy texture can then be mapped, highlighting impacts of logging and road tracks on hill crests (black), and finer textured canopies in lowlands (yellow and red).

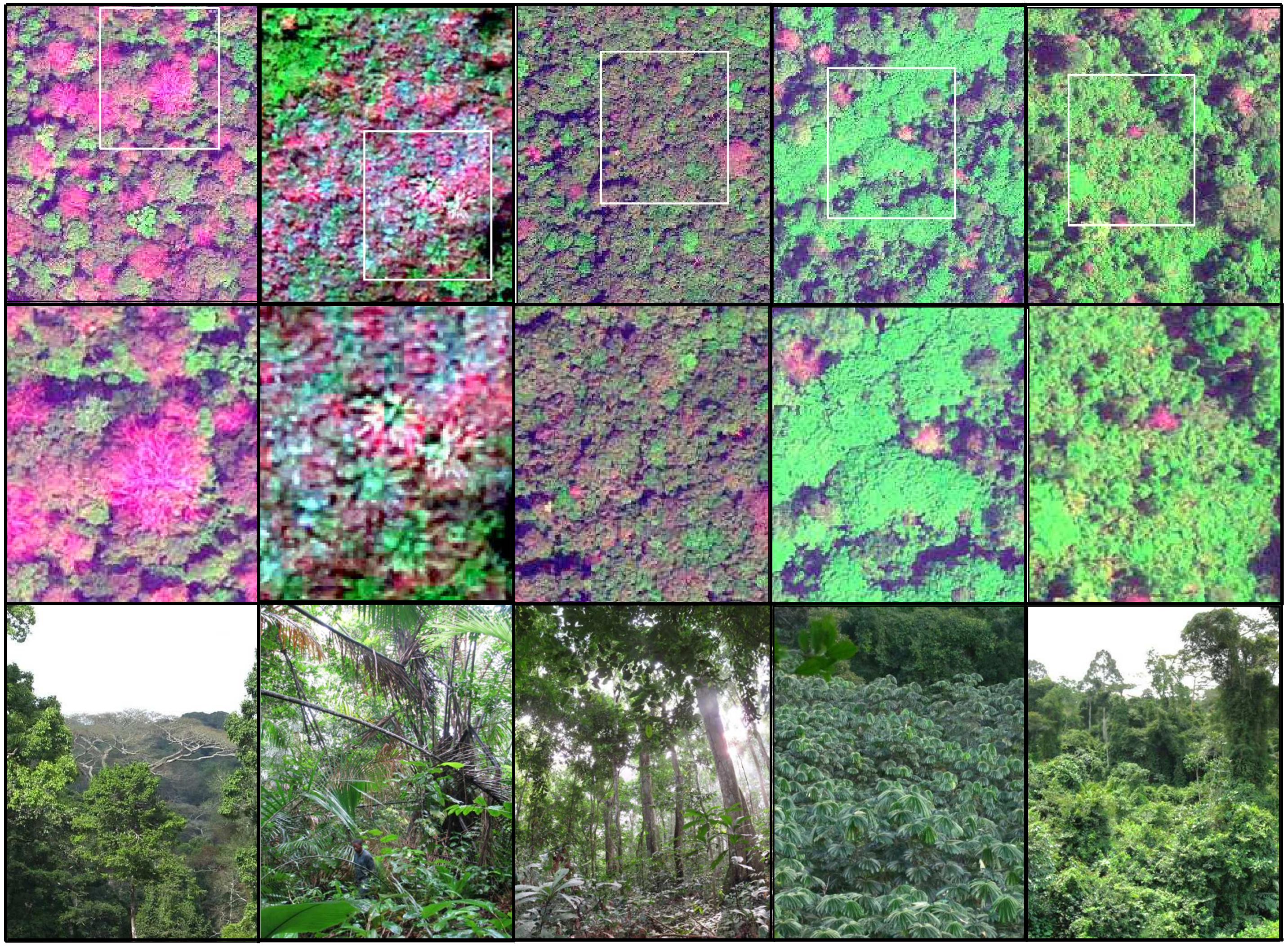

Figure 3. Forest with peculiar canopy textures. Upper and middle panels: close-ups of the canopy viewed on metric resolution images (GeoEye©, false colors, pinkish crowns are leafless). Lower panel: Ground level or canopy level views.

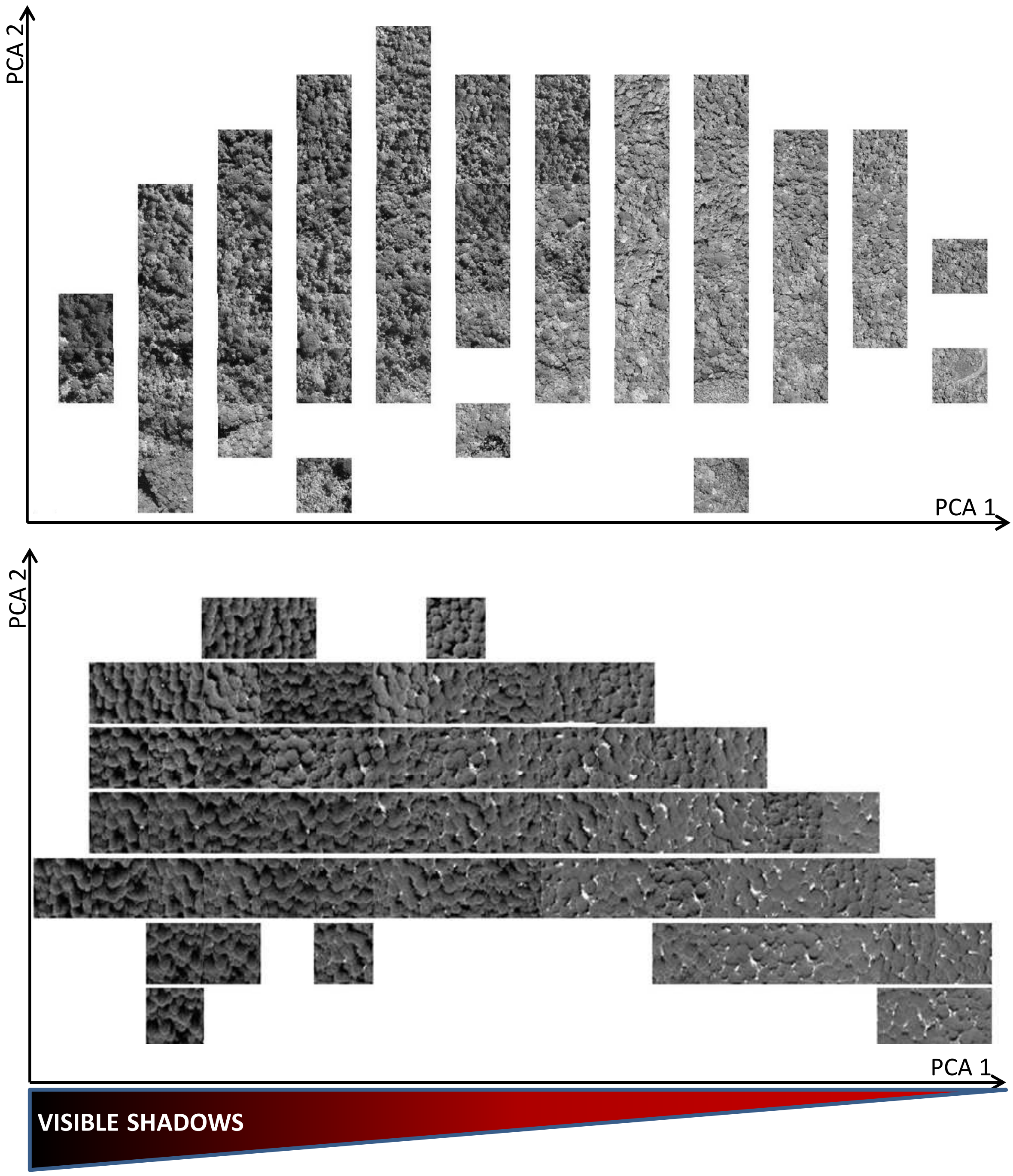

Figure 4. Effect of changing sun-view angle on canopy texture: configurations with more visible shadows are perceived to have a coarser grain. Upper panel: real images (Ikonos ©). Lower panel: simulated examples with constant forest structure.

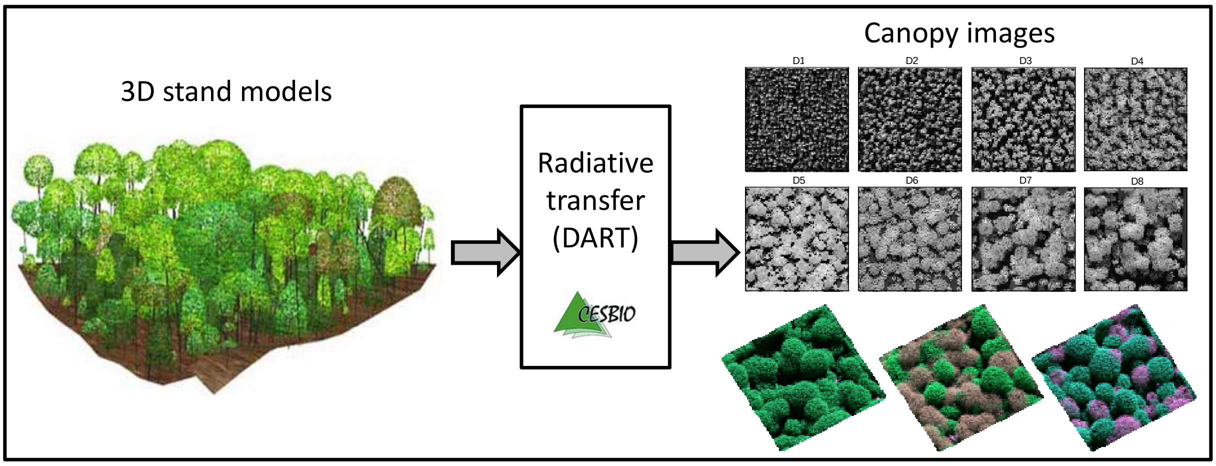

Figure 5. Simulating canopy images from 'lollipop' forest stands and a light transfer model.