Traceability of essential climate variables through forest stand reconstruction with terrestrial laser scanning

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Highlights: We develop a processing chain that uses terrestrial LiDAR scans as input data to assess the SI-traceability of various in-situ LAI and fAPAR products via radiative transfer modelling. LiDAR data and tree reconstruction is used to represent the explicit 3D forest structure in radiative transfer models.

Key words: *Terrestrial LiDAR; traceability; LAI; fAPAR; forest stand reconstruction*

Introduction

Climate warming will cause more variable weather, an increased amount of major storms and more extreme weather events. Furthermore, ecological responses to climate change are already visible. The date of leaf emergence in spring is a UK climate indicator and spring activities (e.g. shooting and flowering of vegetation) have occurred progressively earlier since the 1960s [1]. Forest ecosystems cover approximately 4 billion hectares or about 31% of the world's land surface and remote sensing from space is essential to collect global data to underpin climate change research efficiently. Biophysical essential climate variables (ECVs), such as leaf area index (LAI), fraction of absorbed photosynthetically active radiation (fAPAR) or albedo need to be monitored to detect small fluctuations over time.

The validation of spaceborne ECV products is generally based on a direct comparison either with products from different earth observation missions or with in-situ estimates. End-to-end traceability of in-situ measurements and satellite-derived ECVs are difficult. Most in-situ methods do not measure the biophysical quantity directly, but estimate this from indirect measurements using a variety of hypotheses and assumptions. One way to deliver SI-traceable reference measurements for in-situ fAPAR and LAI products is to use radiative transfer modelling and simulations. This allows us to control all aspects of the environment and sensor properties, which would not be possible using measured data. Subsequently, biases resulting from differing assumptions can be quantified.

Radiative transfer models require the forest structure to be quantified. This can either be a simple 2D representation of the forest structure or a full 3D explicit description of the forest stand. Manually recording detailed structural information is laborious and time consuming. A more practical and common method is to use mathematical models to generate virtual trees. This technique was for example used by [2] and based on measurements of relatively few plants, growth rules are defined and conditions are adjusted to match the local environment. Recently, the introduction of terrestrial laser scanning (TLS), also referred to as terrestrial LiDAR, has enabled the possibility of generating plant models based on 3D scans [3-5].

This work will develop a processing chain to use terrestrial LiDAR scans as input data to quantify the SI-traceability of various in-situ LAI and fAPAR sensors via radiative transfer modelling. In this paper we will present the first results from explicitly characterising and reconstructing a deciduous forest stand.

Materials and method

Study area and data collection

A six-hectare study site (200 m x 300 m) is established in Wytham Woods, UK. The forest is dominated by *Acer pseudoplatanus, Fraxinus excelsior* and *Corylus avellana.* TLS and LAI data was collected in June and July 2015, with a leaf-off campaign planned for the winter of 2015. The PAR sensor network will be installed in the summer of 2015 for the duration of the project.

Structural 3D data is collected with a RIEGL VZ-400 terrestrial laser scanner, which records multiple return LiDAR data as well as additional waveform data. The wavelength of the instrument is 1550 nm and the beam divergence is nominally 0.35 mrad. The angular sampling for both zenith and azimuth angle is 0.04°, azimuth range is 0° – 360° and zenith range is 0° - 130°. The complete 6 ha is scanned from 176 scan locations, laid out in a 20 m x 20 m grid (see figure 1).

LAI data is collected through digital hemispherical photography (DHP), Li-Cor LAI-2000 and LAI-2200 and TRAC2 (Tracing Radiation and Architecture of Canopies). We employed the VALERI sampling design for the DHP, LAI-2000 and LAI-2200 measurements (1800 measurements in total) and 100 m transects for TRAC measurements similar to [6].

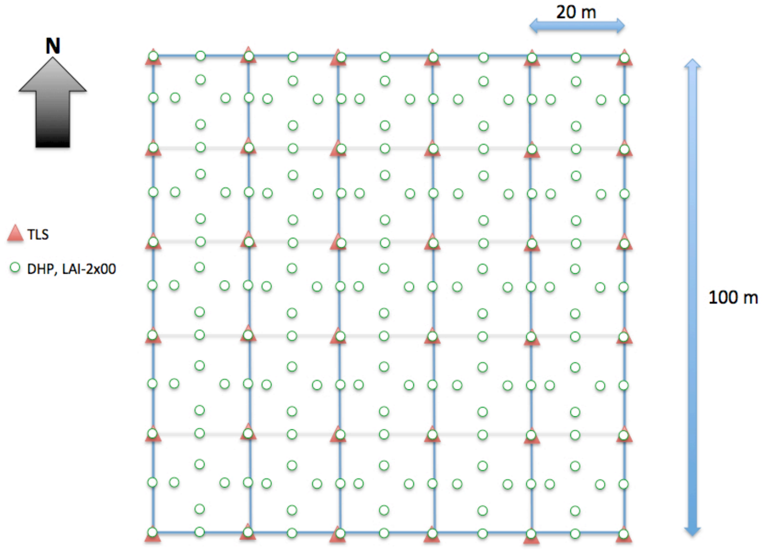

Figure 1: Sampling design for 1 ha

Forest stand reconstruction and radiative transfer modelling

We will use a Monte Carlo ray tracing (MCRT) approach to simulate DHPs, LAI-2000 and LAI-2200, TRAC and PAR measurements. In this study the *librat* MCRT model is used. This model is based on the ararat/drat MCRT model [7] and has been tested in previous studies against observations as well as against other radiative transfer models. This model requires a 3D explicit description of the forest structure, and spectral information about the canopy constituents used to represent the forest structure. We will use TLS data to reconstruct tree models using the quantitative structure model (QSM) approach in [3-4]. These previous studies focused on reconstructing branching structure only, and we will extend this work by adding leaves to the 3D models. Addition of the leaves will be based on the derived light availability, similar to [5]. The TLS point clouds will be filtered using a clustered region growing approach alongside form pruning to exploit the fuzzy appearance of leaf returns due to leaf arrangement, incidence and clumping. This will broadly allow the delineation of wood and leaf returns. We will use the QSM approach to model the tree skeleton and reconstruct the leaves based on the information extracted from the foliage point cloud.

Expected outcomes

This work will give us insight into the SI-traceability of various in-situ LAI and fAPAR products via radiative transfer modelling, stand reconstruction from TLS data and comparison of field measurements with simulations. The actual canopies that are currently being used in projects such as RAMI (radiation transfer model intercomparison) are based on detailed forest inventory measurements. To our knowledge, this study will be the first to reconstruct a large study site directly from TLS data that can be used in a radiative transfer model. Using 3D tree modelling and radiative transfer allows us to control all aspects of the canopy structure and sensor characteristics. Furthermore, the intensive sampling design (figure 1) will allow us to address issues of spatial variance and quantify the effect of different sampling strategies on the inferred ECVs.

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