Measuring canopy leaf moisture content from dual-wavelength terrestrial laser scanning.

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1. Why monitor canopy moisture content?

Leaf moisture content is an important indicator of **drought stress, tree diseases and wildfire risk**. Vegetation moisture status can be accurately determined through physiological approaches at the leaf level; however, it is difficult and time consuming to measure **spatial and temporal variation**. Existing remote sensing techniques, such as estimation from satellite imagery, allow monitoring over large areas, but can be influenced by understorey conditions and may be hard to validate. Accurate, canopy-scale measurements are needed to bridge this gap. **Dual-wavelength Terrestrial Laser Scanning (TLS)** has the potential to provide 3-dimensional measurements of leaf biochemistry in forest canopies, alongside detailed **structural information**.

2. The Salford Advanced Laser Canopy Analyser (SALCA)

The SALCA instrument is a TLS designed specifically for measurement of forest canopies. The scanner measures the distance to objects within the laser beam and records full-waveform return information. A hemispherical scan is produced of the forest canopy, providing information on both **structure and reflectance properties** (return intensity). Unlike commercial instruments, SALCA measures the forest canopy at **two separate wavelengths** in the near and shortwave infrared (1063 and 1545 nm). The wavelengths were selected to allow **separation of returns from foliage and woody material** for improved leaf area index estimation.

Instrument specification:

- **Dual-wavelength terrestrial scanner:** 1063 and 1545 nm.
- **Full-waveform:** 15 cm range resolution.
- **Beam divergence:** 0.56 mrad (2.4 and 3.6 mm initial beam width).
- **Angular sampling step:** 1.05 mrad, 9.6 million waveforms per scan.
- **Maximum range:** 105 m

Shortwave infrared reflectance from leaves is largely determined by the presence of moisture. A **normalised ratio** of the SALCA 1063 and 1545 nm laser return intensities should therefore be sensitive to leaf moisture content (**Equivalent Water Thickness** (EWT), the weight of water per unit area of leaf), allowing estimation at canopy scales. Such a ratio will:

- be insensitive to the amount of material within the laser beam and the beam incidence angle,
- be free from **shadowing** and largely independent of **illumination conditions**,
- allow separation of signals from the canopy and the understorey or soil, by providing **range-resolved measurements**, giving **3D reflectance estimates** at canopy scales.

This study tests the ability of SALCA for measuring leaf EWT at individual leaf and canopy scales, through controlled laboratory and field experiments.

3. Estimating EWT at a single leaf scale: laboratory scans of drying leaves

Figure 1: Change in SALCA-derived reflectance of leaf samples with EWT (g cm^{-2}).

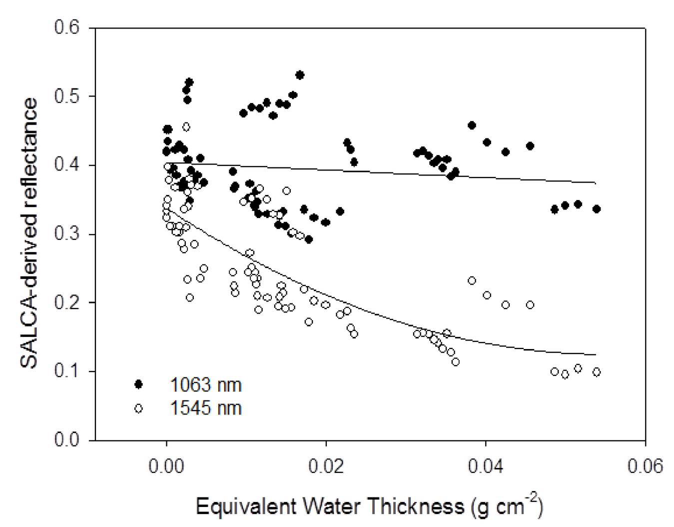
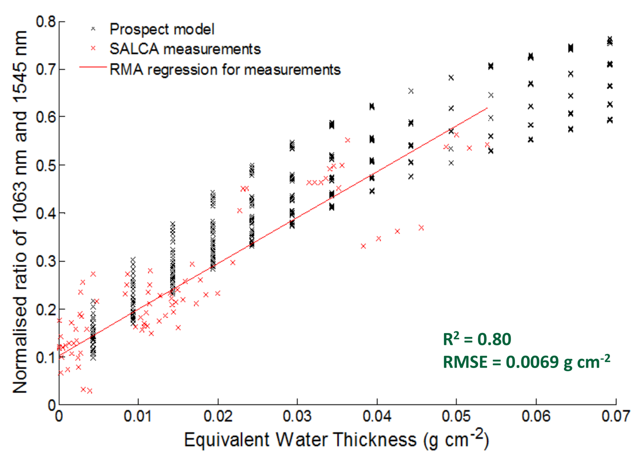
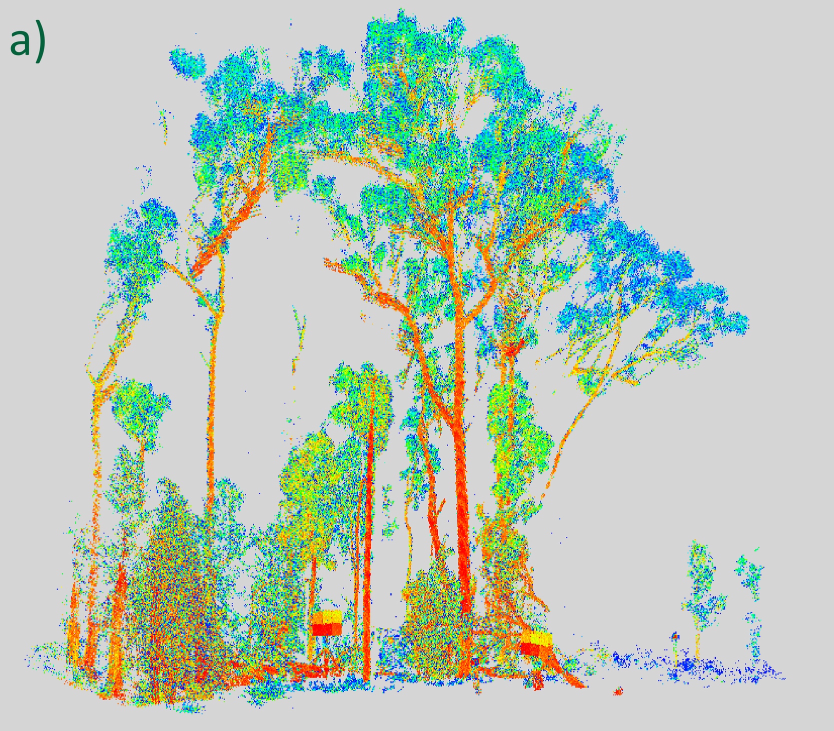


Figure 2: Comparison of SALCA-derived relationship and that predicted by the PROSPECT-5 leaf reflectance model. Variability in modelled results primarily reflects the influence of leaf structure.



From: Gaulton *et al.* 2013. *Remote Sensing of Environment*, 132, 32-39.

a)



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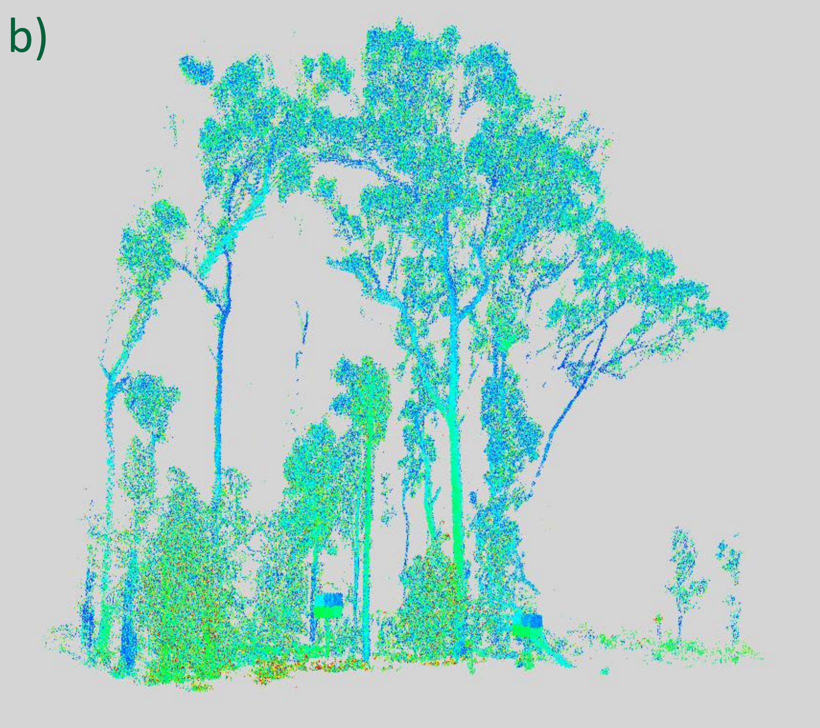

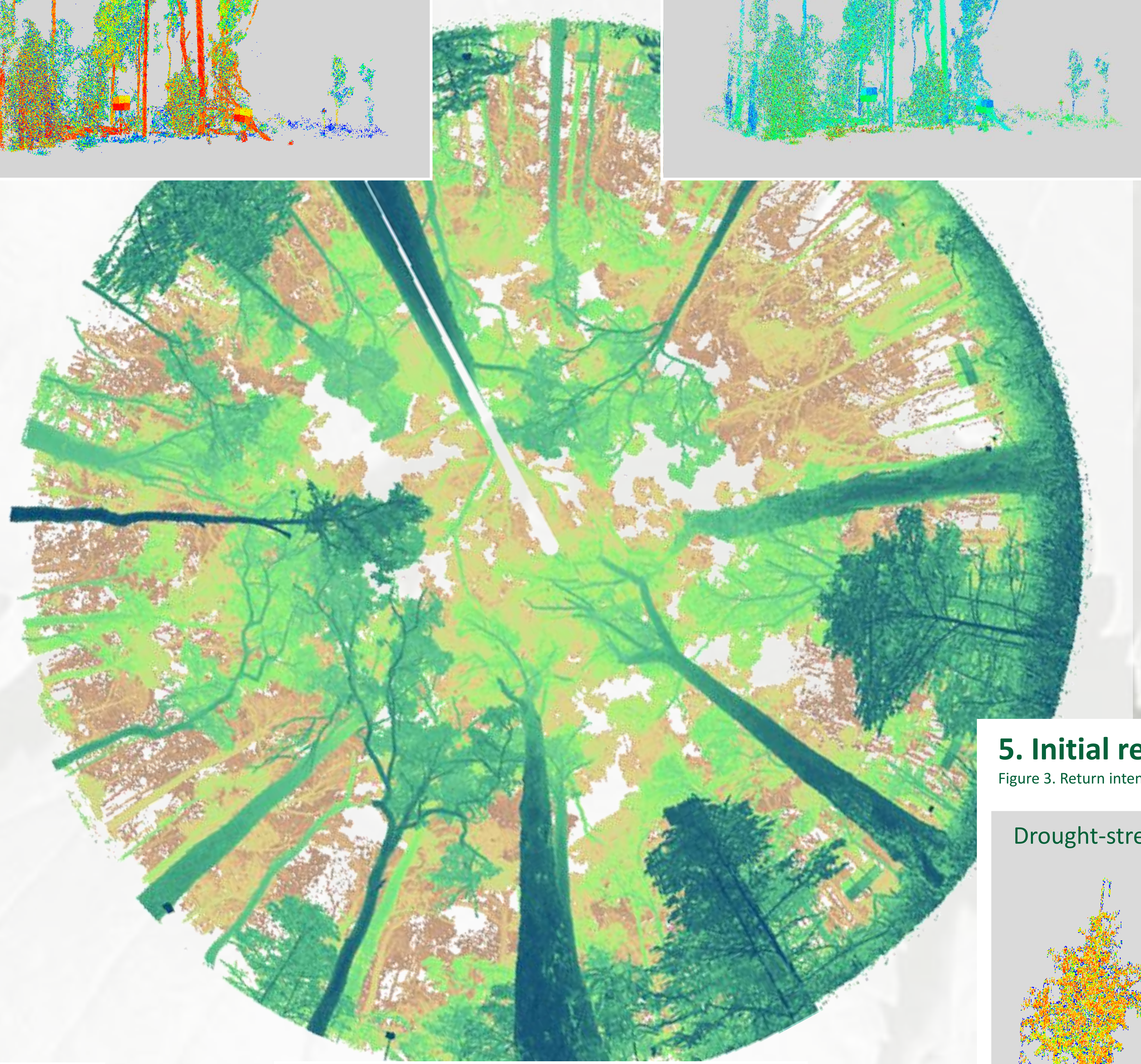

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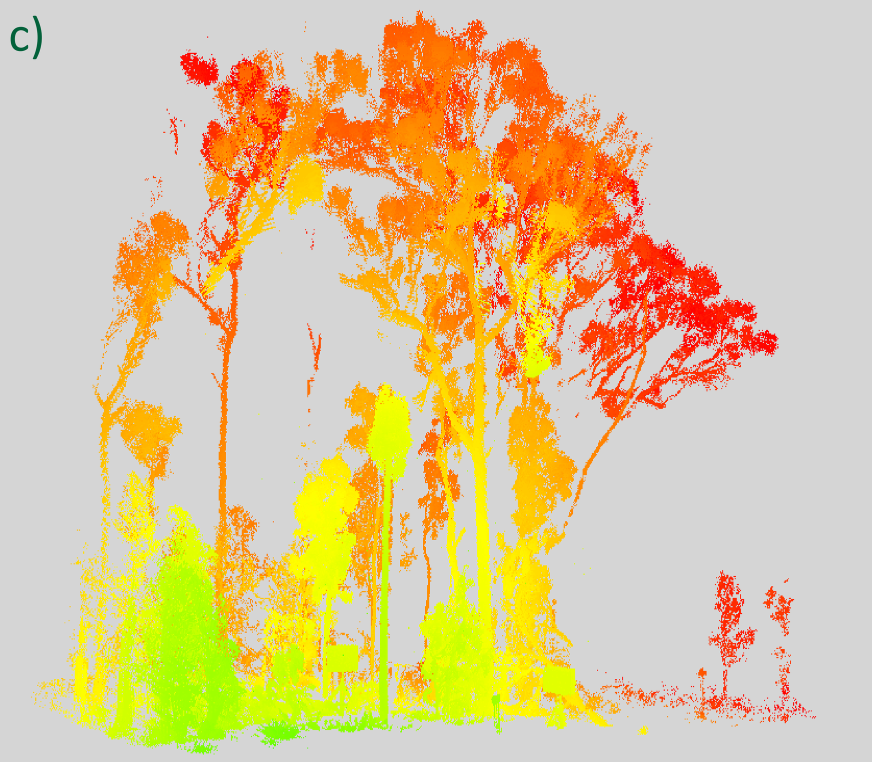


4. Estimating EWT at a canopy scale: field experiments

Applying relationships between foliage EWT and SALCA intensity ratios from the single leaf to a canopy scale requires consideration of the **influence of woody material** on the return signal, the presence of returns from **objects partially occupying the laser beam** and the impact of **changes in canopy structure** (e.g. LAI). Controlled field experiments were carried out in June-July 2013 at Newcastle University's Cockle Park Farm. 22 potted *Tilia cordata* and *Pinus nigra* were subjected to drought stress over a 1 month period and repeatedly scanned with SALCA. Destructive measurements of EWT and non-destructive measurements of leaf physiology and biochemistry were also obtained. Preliminary results are presented below.

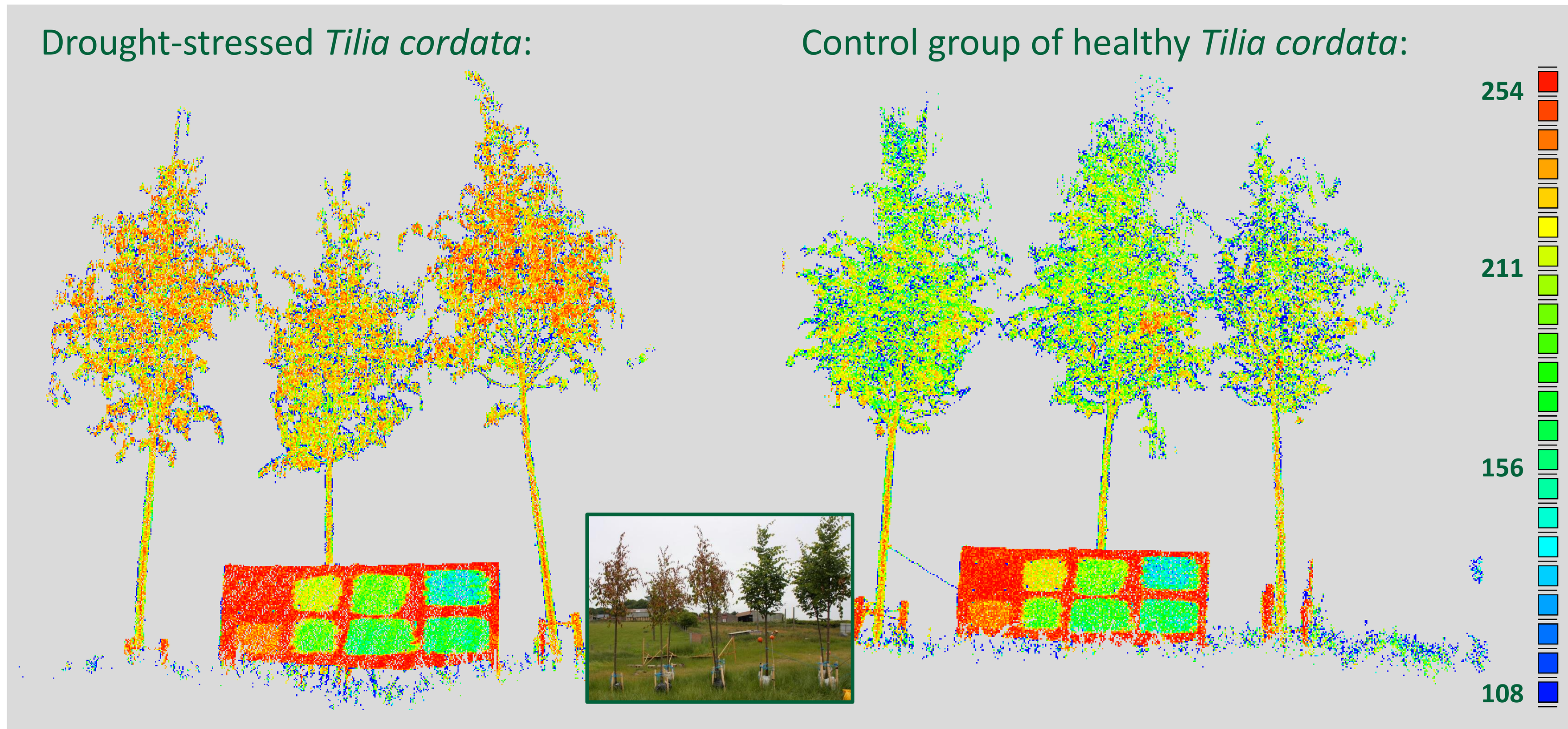
Experimental set-up and measurements:

SALCA data examples

Left: A 'fish-eye' projection of a SALCA scan, coloured by 1063 nm first return intensity (blue = high, brown = low), for a forest plot in Brisbane Forest Park, Australia, showing a full hemisphere of scan data acquired at high angular resolution. **Inset**: colour schemes represent a) 1545 nm return intensity data, b) value of a normalised ratio of 1063 and 1545 nm return intensity for each return and c) range to the return from the scan centre.

5. Initial results: Comparison of tree groups after 1 month of drought.

Figure 3. Return intensity from 1545 nm wavelength. Higher intensities were observed for dry trees, due to reduced absorption by leaf moisture.



Acknowledgements

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More information on the SALCA instrument and on-going research can be found at: **salca-salford.blogspot.co.uk**