School of Systems Engineering
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Airborne Small-Footprint Full-Waveform LiDAR for Discontinuous Vegetation Canopy Characterisation

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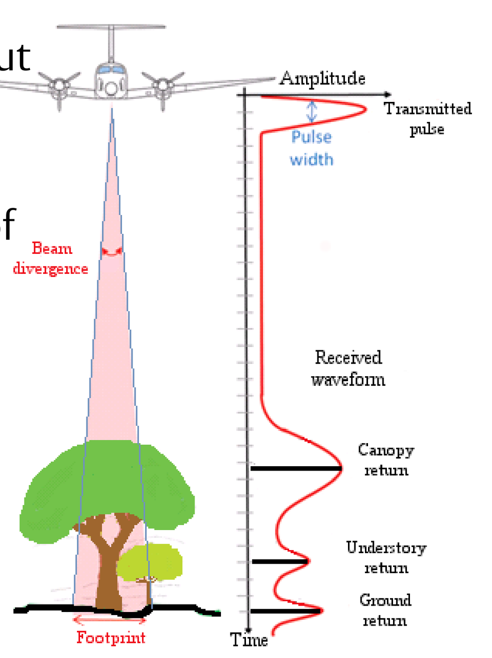
Introduction

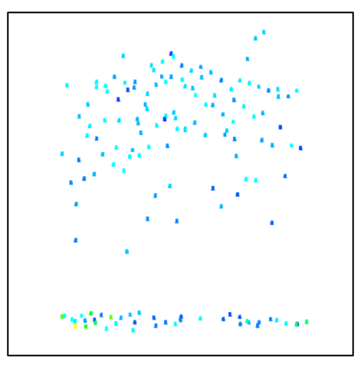
This research focuses on analysis of airborne small-footprint full-waveform LiDAR (Light Detection and Ranging) data for vegetation characterisation. Several experiments have been undertaken aiming to find the best and the most appropriate way of vegetation canopy description especially in a discontinuous canopy environment. Waveform as opposed to conventional discrete LiDAR data were found to provide better estimates of effective leaf area index (LAIe), which correlated well with fish-eye photography values. Raw-waveform vertical vegetation profiles (CHP) were found to highly correlate with field measured profiles. Incidence angle was found to influence vertical profiles and LAIe, however, this influence was found to be outweighed by vegetation heterogeneity.

Waveform vs. discrete

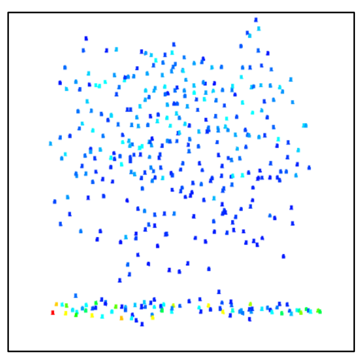
- Additional information about the structure and physical properties of targets
- More control in the hands of end-users - flexibility in designing processing procedure
- Increase in pulse detection reliability, accuracy and resolution
- Increase in point number



Eucalyptus tree (photo SMAPEx-3 2011)



153 echoes detected by RiANALYZE



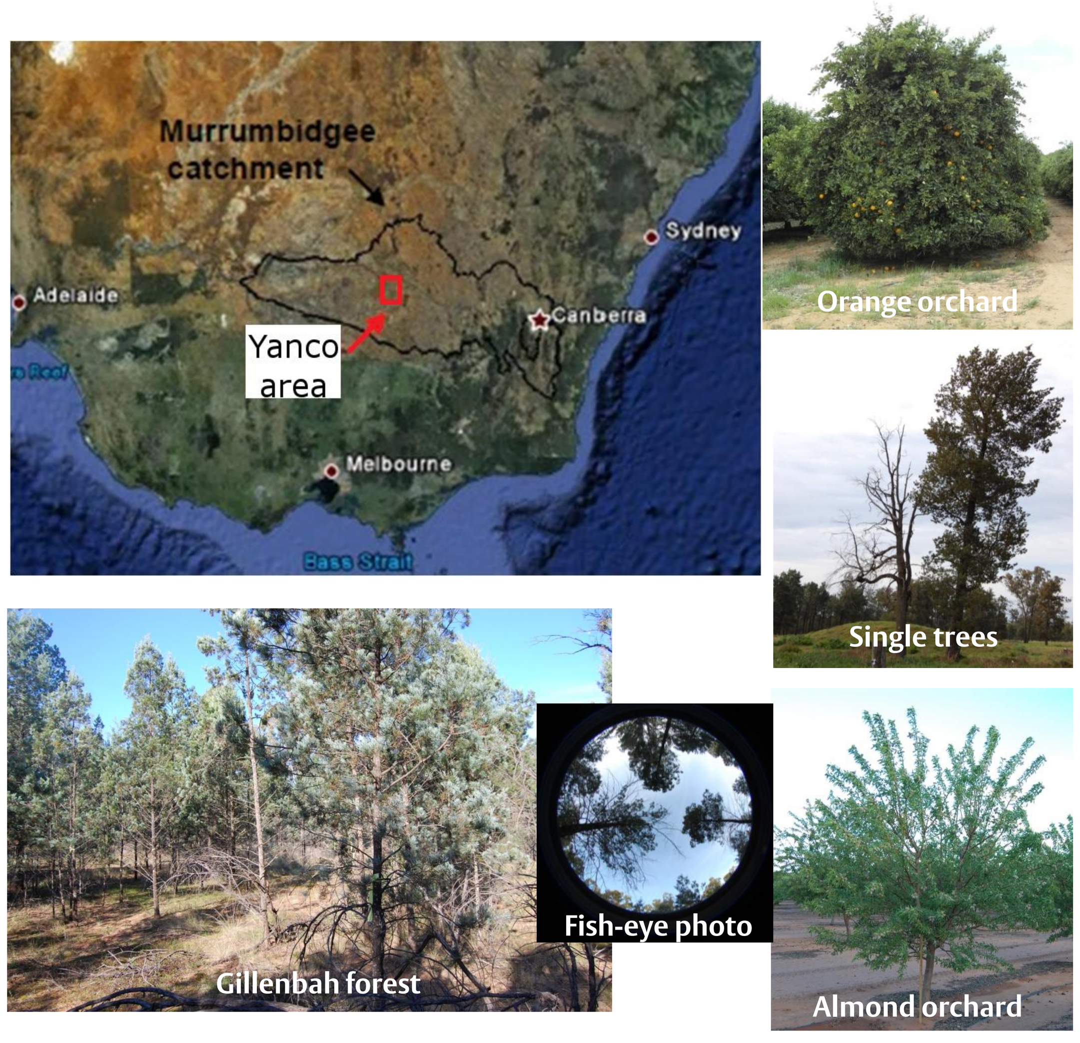
419 echoes detected by custom decomposition

Study Area and Data

Test site

Yanco, New South Wales, Australia:

- Single trees (NAFE'06, SMAPEx-3)
- Orange (NAFE'06) and Almond orchard (SMAPEx-3)
- Gillenbah Forest (SMAPEx-3 2011)



LiDAR Data

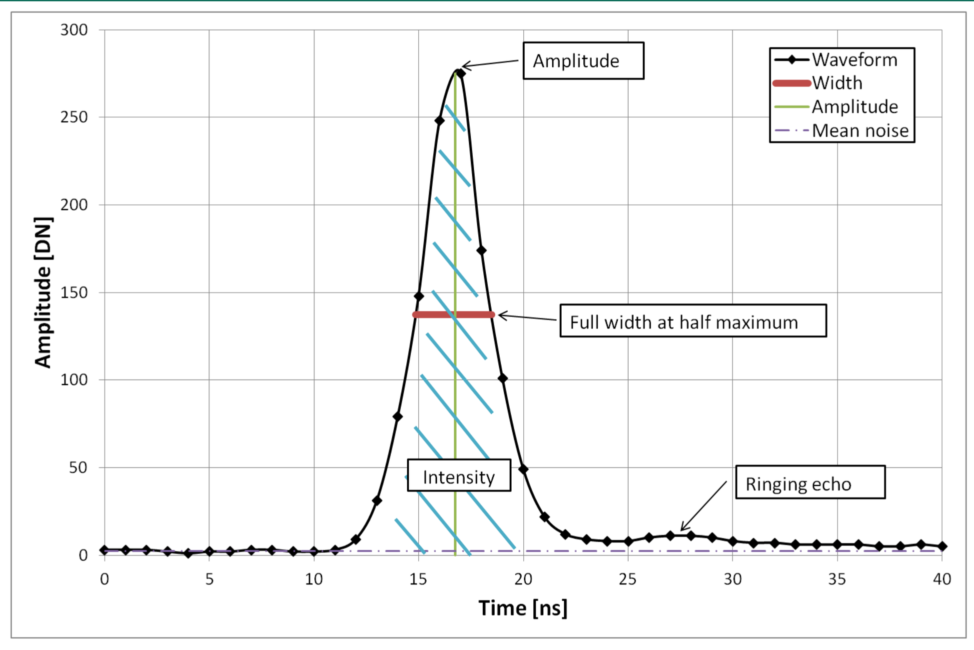
- Acquired with RIEGL LMS-Q560 with waveform digitising of returning pulses (1ns sampling, about 20cm footprint)
- Collected in November 2006 as part of National Airborne Field Experiment (NAFE)
- Collected in September 2011 as part of The Third Soil Moisture Active Passive Experiment (SMAPEx-3)

Data processing

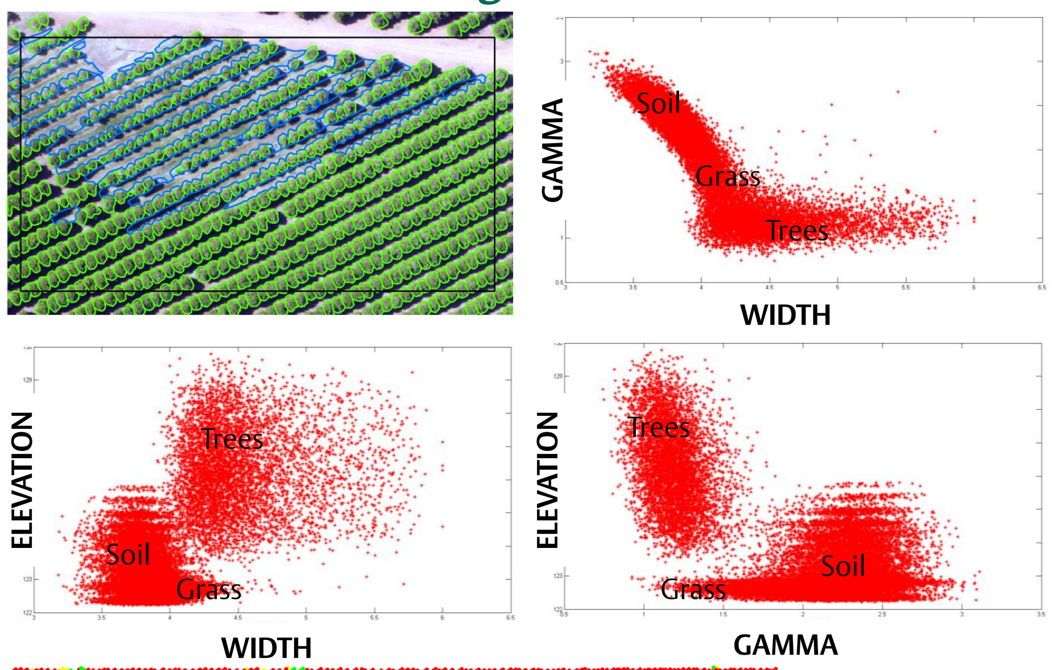
Gaussian decomposition and calibration

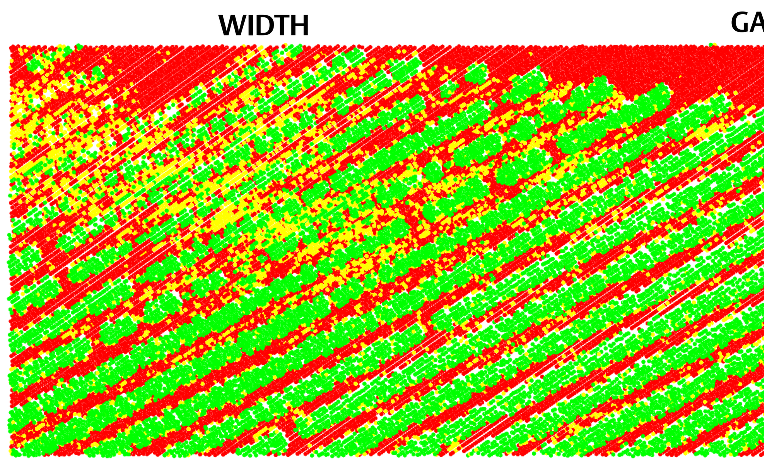
1. Calibration - calibration constant calculated based on known reflectance of the target surface (road) and LiDAR samples of that road, separately for each acquisition
2. Initialisation – simple peak detection (location, amplitude, width)
   - Local amplitude maximum detection
   - Removal of ringing echoes based on amplitude ratio
   - Full width at half amplitude maximum calculation
3. Optimisation using trust-region-reflective algorithm
   - Gaussian function used to fit into waveform curves
   - Further removal of ringing echoes
4. Calibration constant used to calculate backscattering coefficient (gamma)

$$\gamma_i = C_{cal}\frac{4R_i^2 a_i s_i}{\pi \beta_t^2 a_{sys,i}}$$



Width vs. Backscattering coefficient

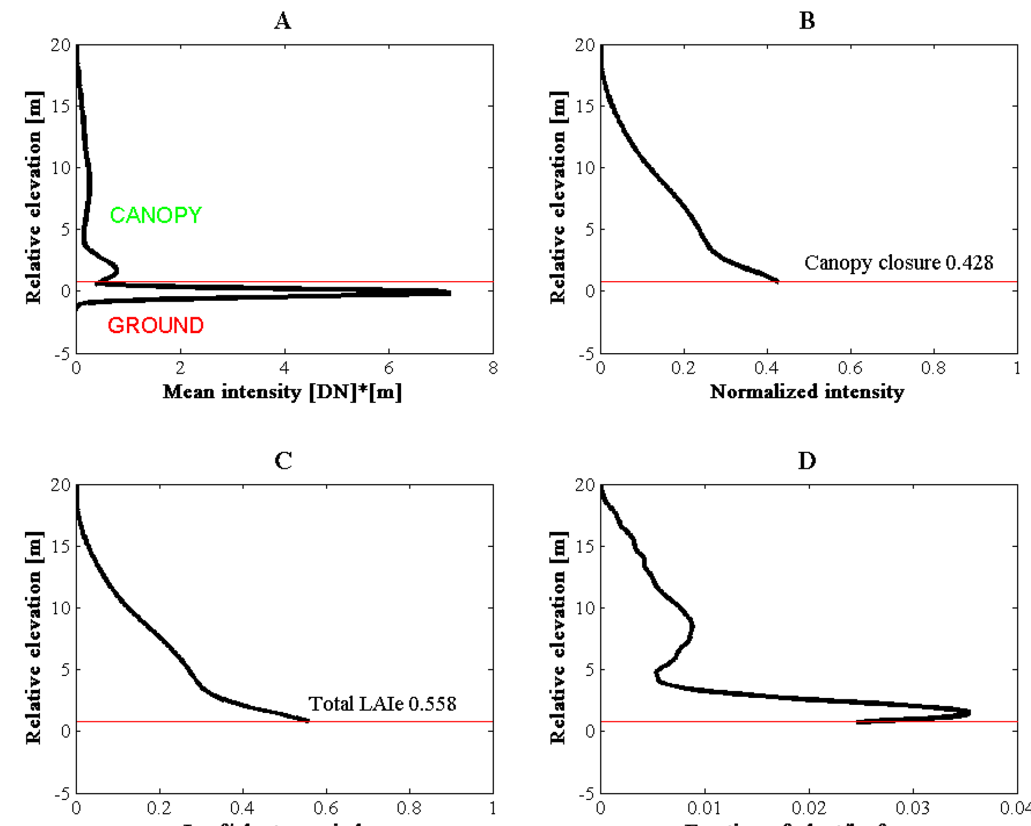




Classification of an orange orchard based on gamma (backscattering coefficient) and width of single and last returns with 91% accuracy against aerial photography interpretation and elevation above ground level

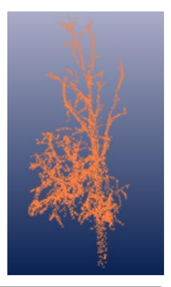
Canopy description from raw-waveform curves

1. Calculation of mean noise and standard deviation of the noise for each waveform
2. Subtraction of the mean noise from the amplitude values
3. Identification of the beginning of vegetation and ending of the ground return
4. Returned energy profile – incremental area under the waveform graph (A)
5. Canopy closure profile- cumulative area underneath the returned energy profile from top of canopy to beginging of ground return, normalized by total cumulative enery (B)
6. Effective Leaf/Plant Area profile : LAIe= -ln(1-closure) (C)
7. Canopy height profile (CHP) - Normalization of leaf/plant area and conversion to incremental distribution (D)

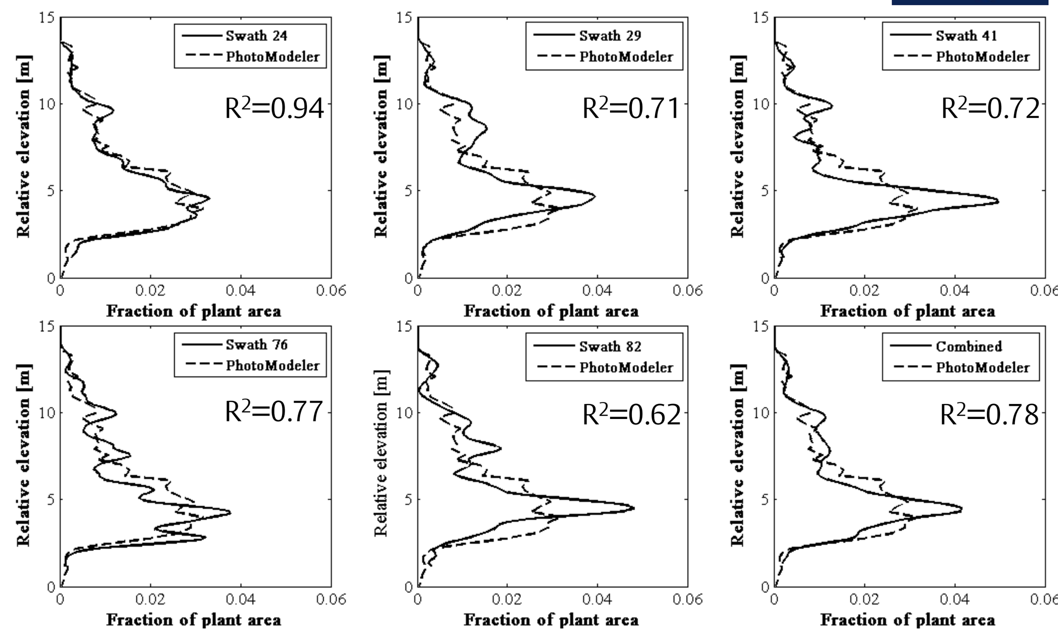


Example of canopy height processing stages for Site 10 in Gillenbah forest (site-aggregated data): A. Returned energy profile; B. Canopy closure profile; C. Cumulative leaf/plant area index profile; D. Canopy height profile. Red line represents the beginning of ground return

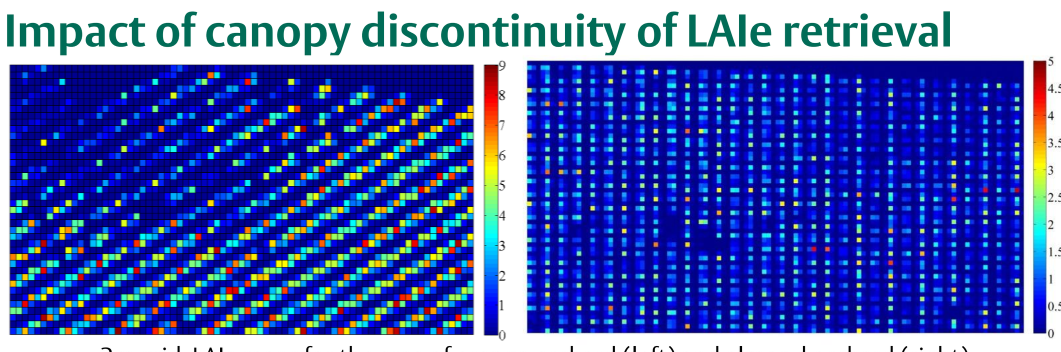
Examples of experiments



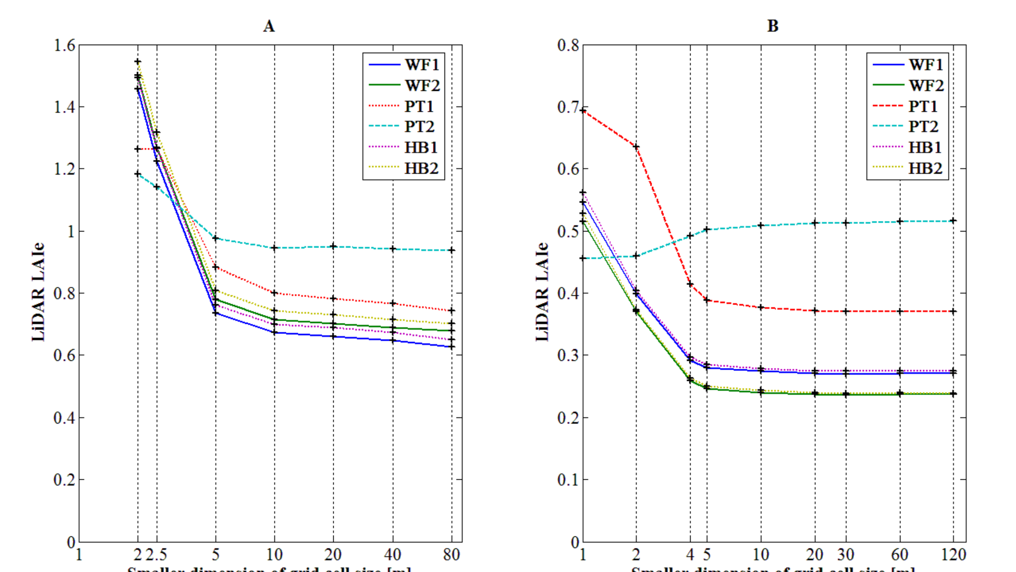
CHP of a single tree from different swaths



Impact of canopy discontinuity of LAIe retrieval

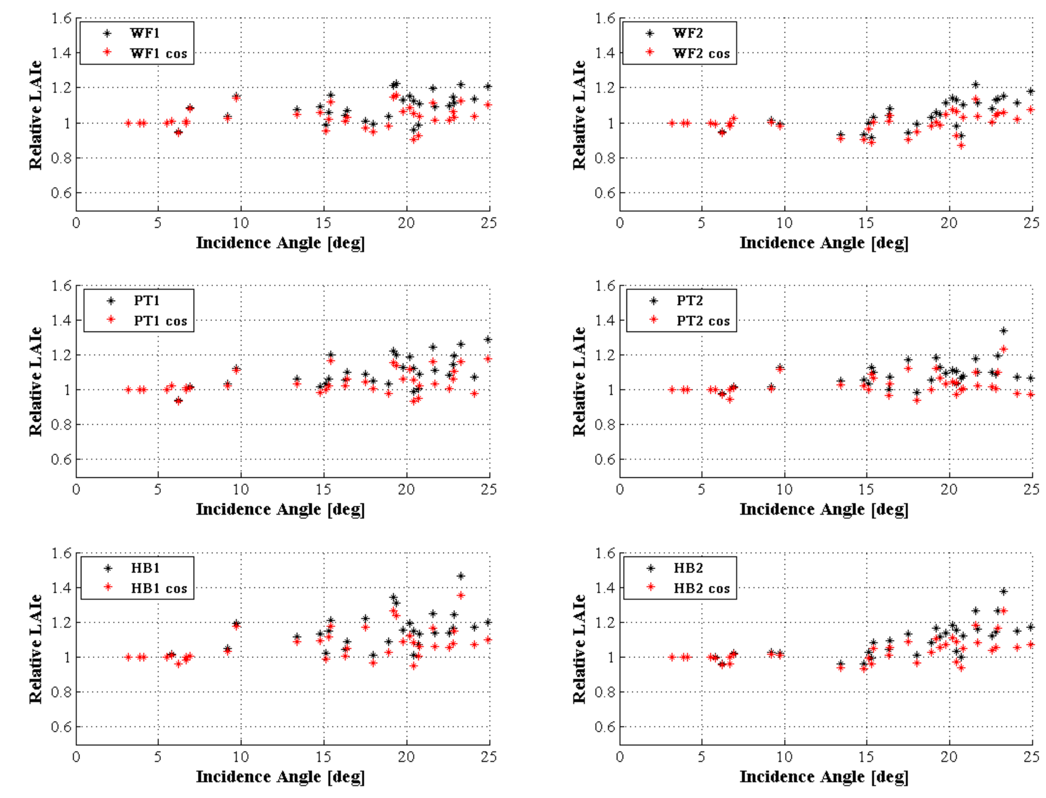


2m grid LAIe maps for the area of orange orchard (left) and almond orchard (right) (at different scales)



Effective leaf area index of Orange orchard (A) and Almond orchard (B) sites depending on the grid cell size used (logarithmic scale). WF1 - raw-waveform method with dataset-adjusted reflectance ratio; WF2 - raw-waveform method with fixed reflectance ratio; PT1 - discrete point method using only single returns; PT2 - discrete point method using all returns; HB1 – hybrid method using dataset-adjusted reflectance ratio; HB2 – hybrid method with fixed reflectance ratio

Incidence angle influence on LAIe



Scatterplots of relative LAIe (normalized by LAIe at near-nadir angle) depending on the method and incidence angle. WF1 - raw-waveform method with dataset-adjusted reflectance ratio; WF2 - raw-waveform method with fixed reflectance ratio; PT1 - discrete point method using only single returns; PT2 - discrete point method using all returns; HB1 - hybrid method using dataset-adjusted reflectance ratio; HB2 - hybrid method with fixed reflectance ratio . 'cos' suffix indicates LAIe corrected for the incidence angle.

Conclusions

- The raw-waveform method was found to be the most suitable to derive LAIe as well as vegetation vertical profiles (CHP) which highly correlated with fish-eye photography estimates and field biomass profiles, respectively
- Discrete point methods of LAIe estimation provided unreliable results in a discontinuous canopy cover environment
- Incidence angle was found to affect LAIe retrieval but its influence was outweighed by vegetation heterogeneity

Acknowledgements

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