Quantitative structure tree models from terrestrial laser scanner data

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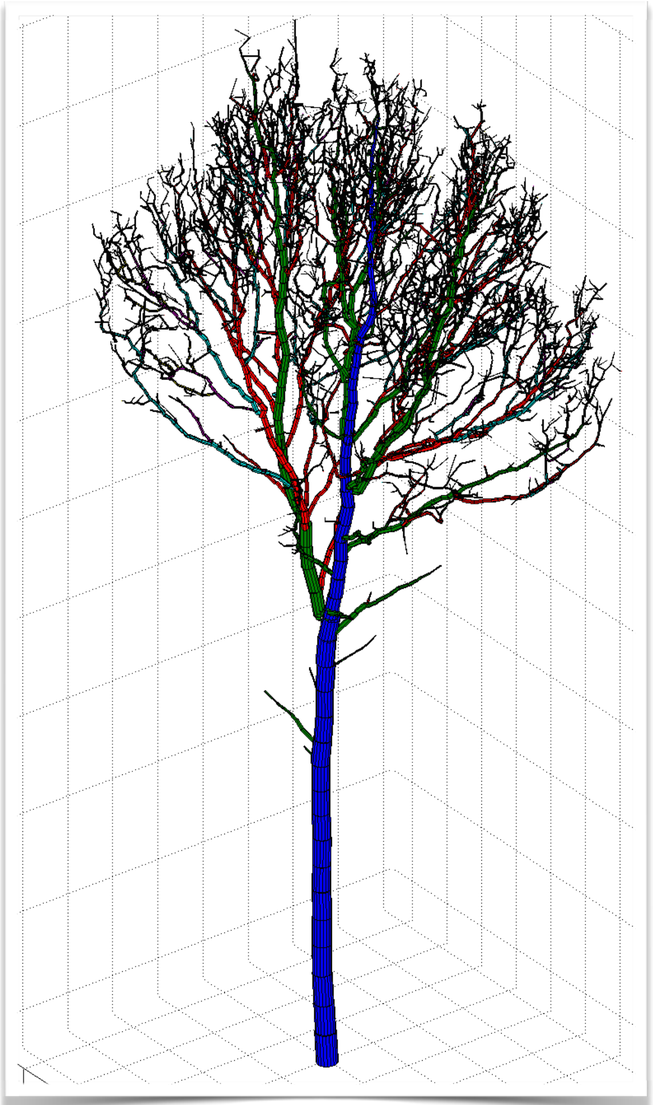
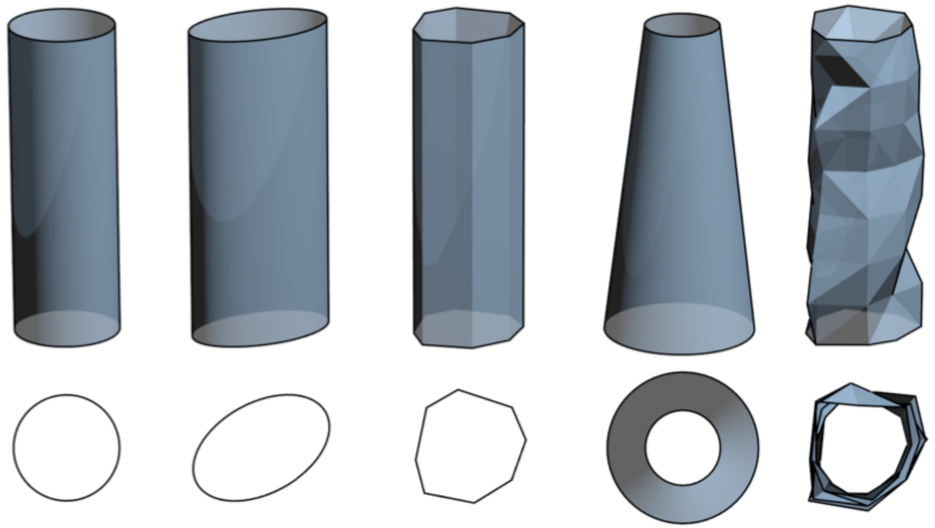
Tree modelling

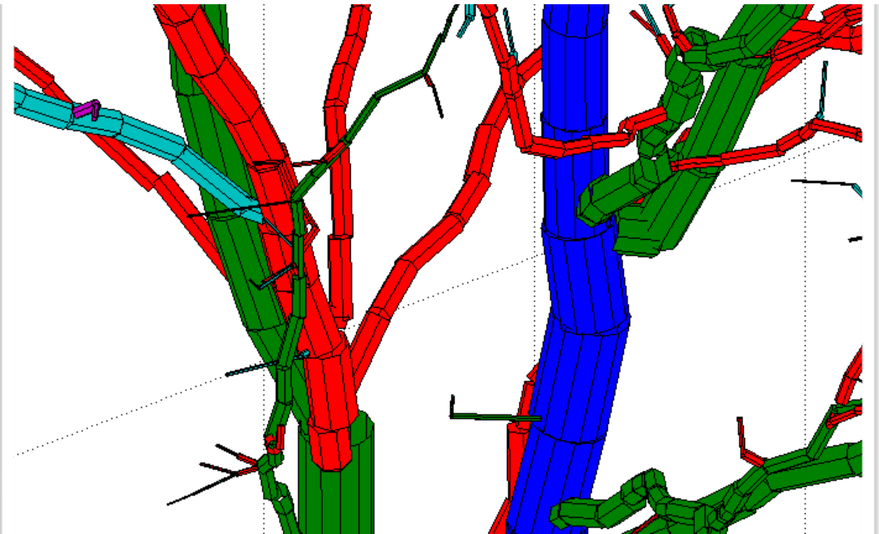
- How to use TLS data for tree modelling and data mining of tree information?
- No standard or obvious way to model trees
  - No useful functional series or parametrisable surface presentations
  - Easy extraction of information from the model
  - Compact size
- “Building block” or “geometric primitive” approach
  - Tree modelled as a hierarchical collection of cylinders which are fitted to local details
- QSM - Quantitative Structure Models
  - Volumes, lengths, taper, branches, topological branching structure, etc.



Tree modelling

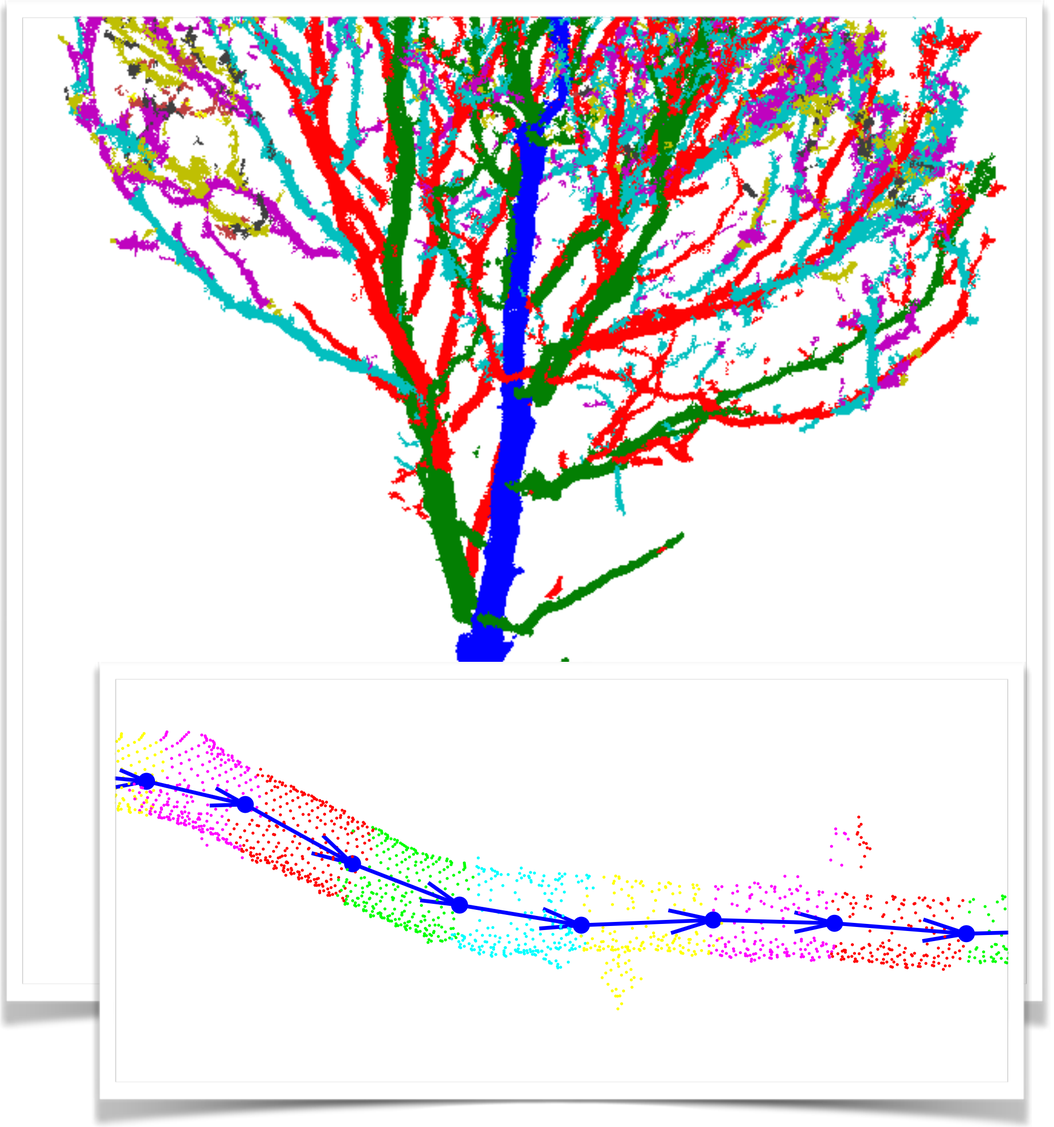
- Other primitives or blocks possible
  - Elliptic and polygonal cylinders, cones
  - Special triangulations
- Circular cylinder the most robust choice
  - Åkerblom et al. 2015: “Analysis of Geometric Primitives in Quantitative Structure Models of Tree Stems”. Remote Sensing
- Dis-continuous surface is not a problem
  - Continuity adds no useful quantitative structure information but makes the modelling harder and less stable





How to produce QSMs from point clouds

- **Automatic reconstruction from a given point cloud in few minutes**
  - **General approach, no species or size dependent assumptions**
  - **Assumes only woody parts**
  - **Raumonen et al. (2013). Fast Automatic Precision Tree Models from Terrestrial Laser Scanner Data. Remote Sensing**
  - **Calders et al. (2015). Non-destructive estimates of above-ground biomass using terrestrial laser scanning. Methods in Ecology and Evolution**
- **Two main steps**
  - **Topological tree structure from hierarchical segmentation of the point cloud**
  - **Geometry from geometric primitives fitted to the segments**



Surface patches

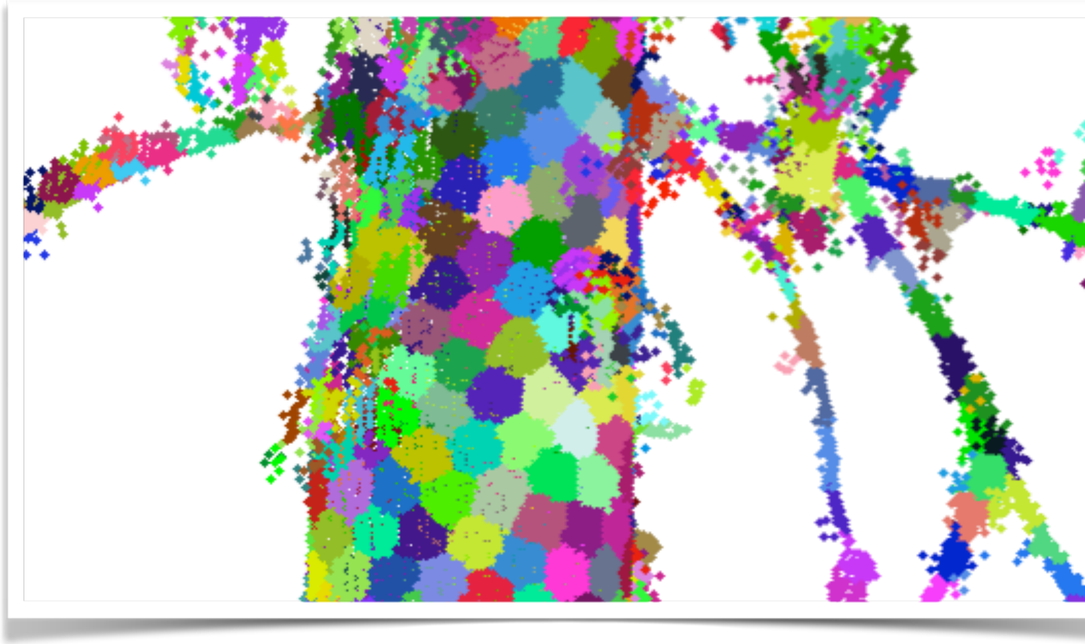
Surface patches

- How to determine individual segments from big point clouds fast and reliably?

- Random partition into subsets that correspond to small connected surface patches in the tree surface

  - Subsets are more efficient surface “units” than points

  - Much less subsets and more uniformly covered



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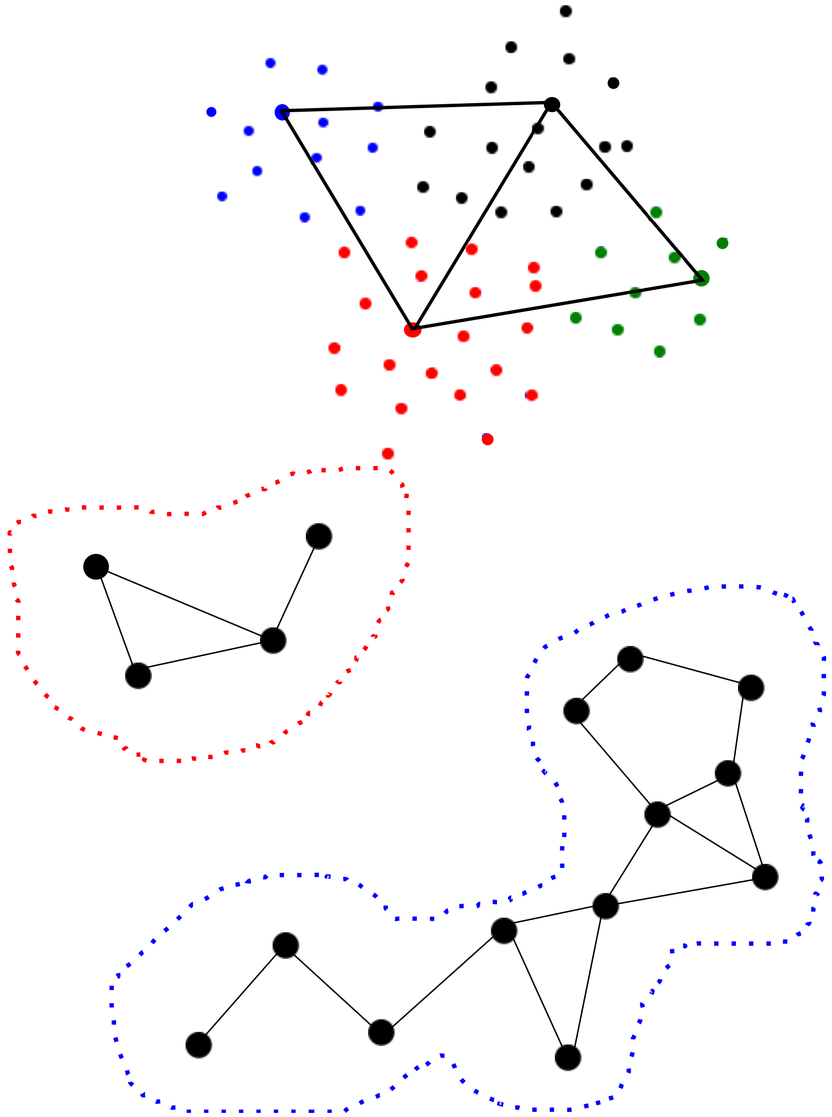

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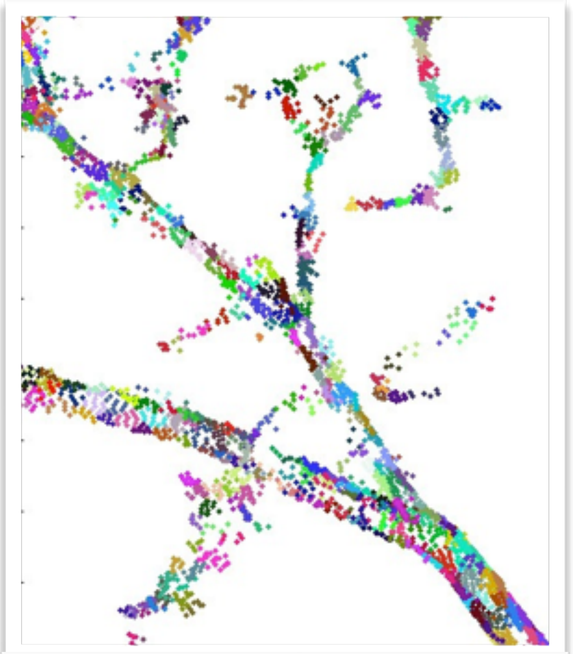
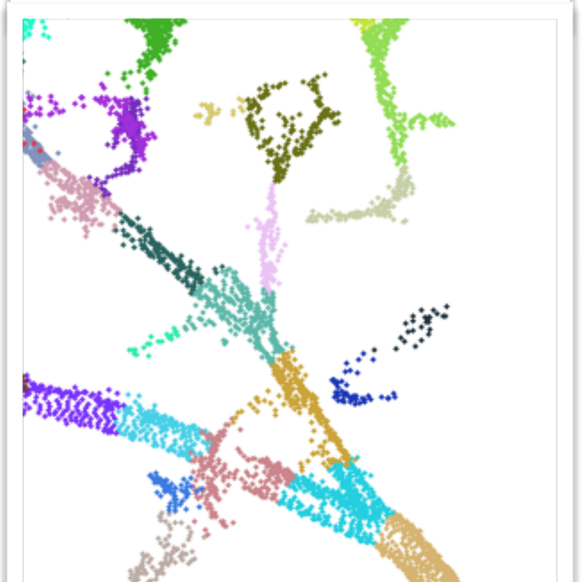
  - Size (and location) affects the segmentation



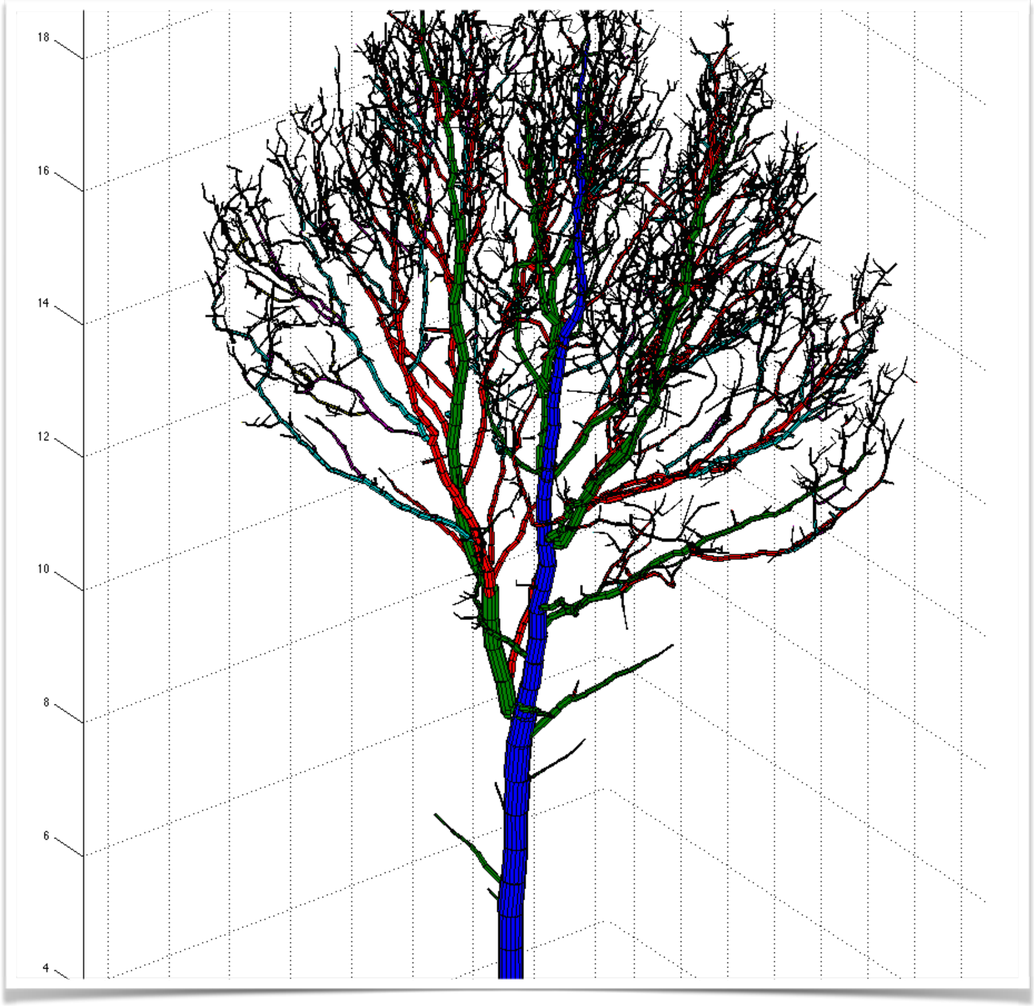


Sensitivities of the resulting QSMs

- Visibility
  - Scan resolution, number of scans, height and structure of the trees
- Main approximation sizes
  - Diameter of the patches, relative length of the cylinders
- Partitions are random
  - Resulting segmentation and QSM always little different
  - Make about 5 models with same inputs to estimate variability
- Cylinder is the most robust building block

Many applications of QSMs

- **Compact model containing most of the topological and geometrical tree information**
- **Not a model specifically build for a few particular attributes**
- **Biomass estimation, change detection, species recognition, etc.**



Above-ground biomass

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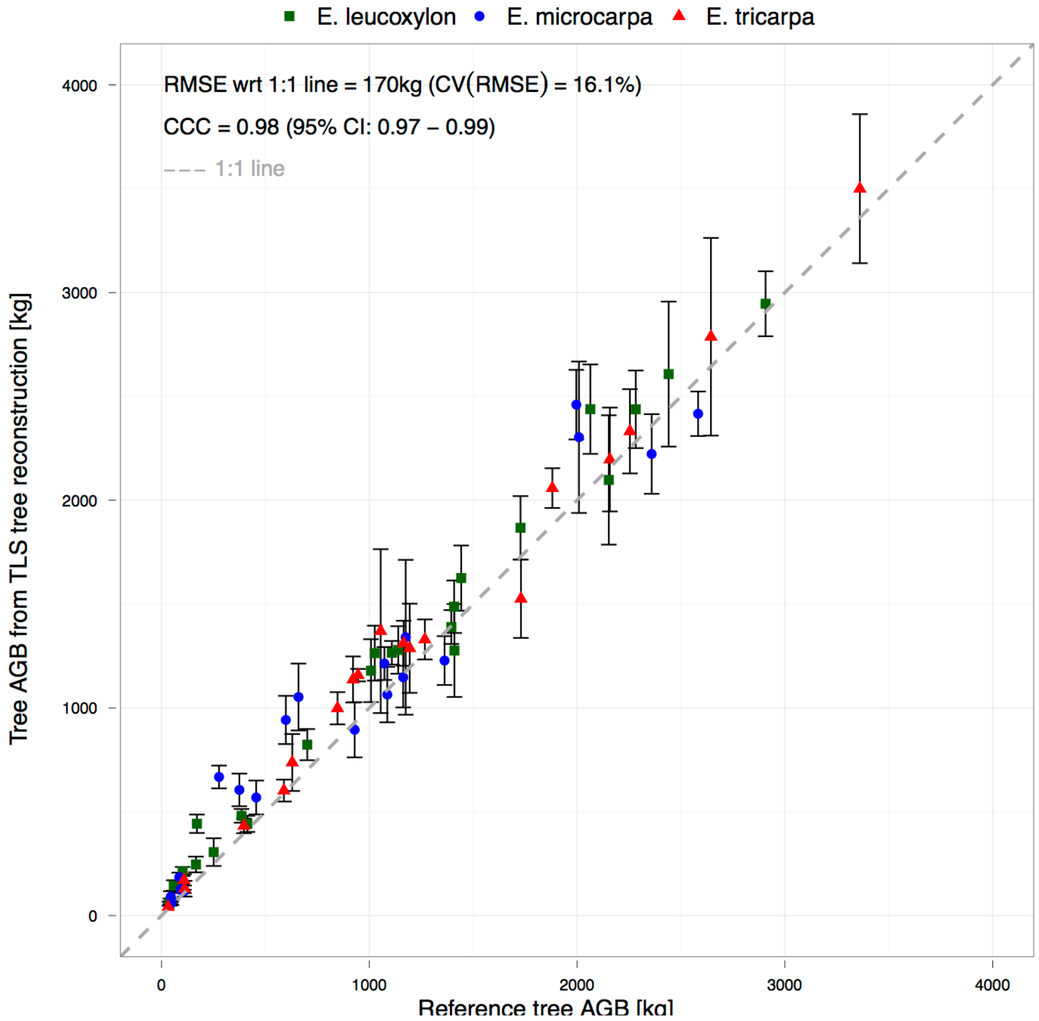
- **TLS+QSM gives volume + wood density = biomass**
  - **Calders et al. (2015). Non-destructive estimates of above-ground biomass using terrestrial laser scanning. Methods in Ecology and Evolution**
  - **Hackenberg et al. (2015). SimpleTree - an efficient open source tool to build tree models from TLS clouds. Forests**
- **Generally under 10% error in biomass**



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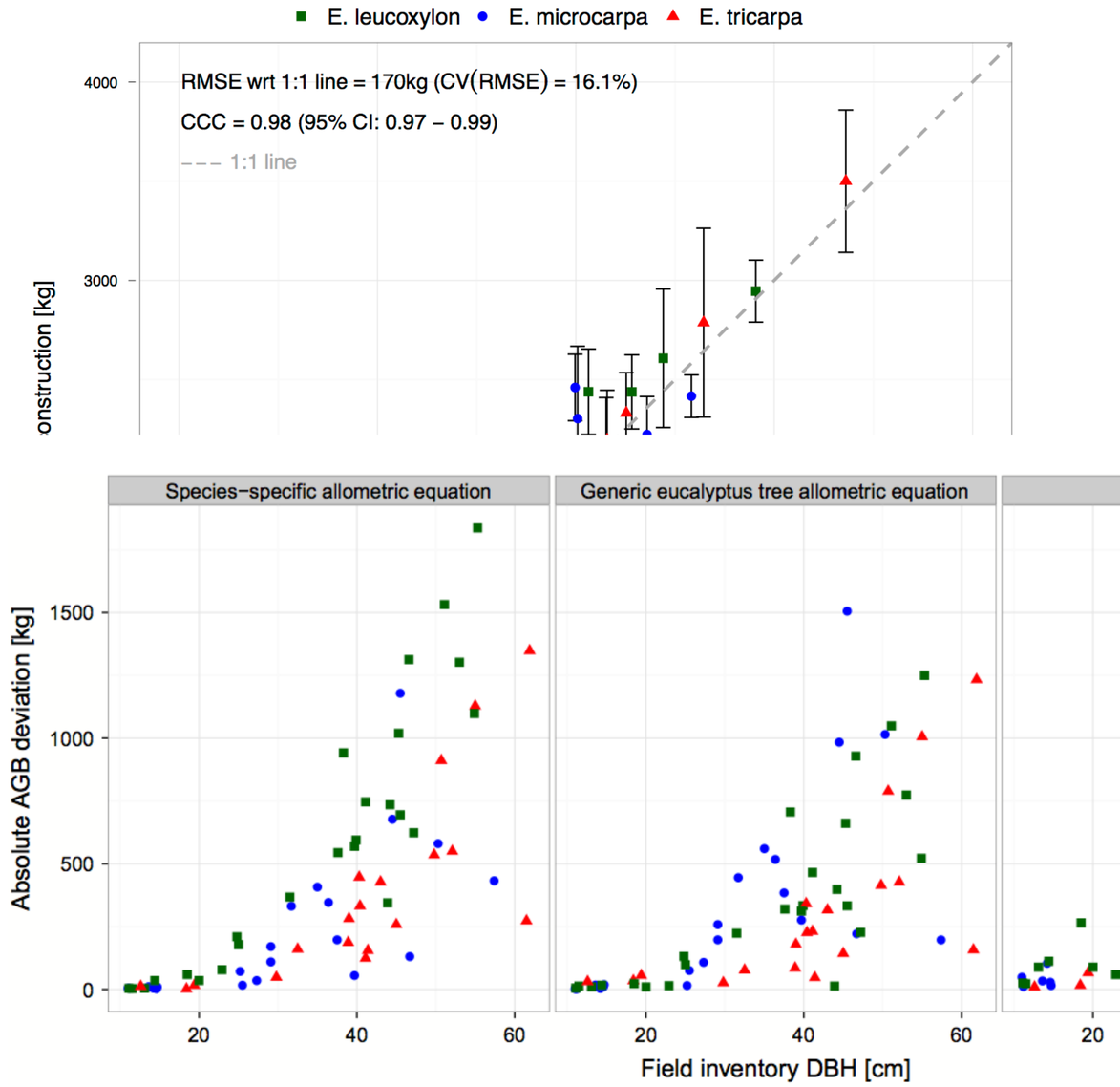
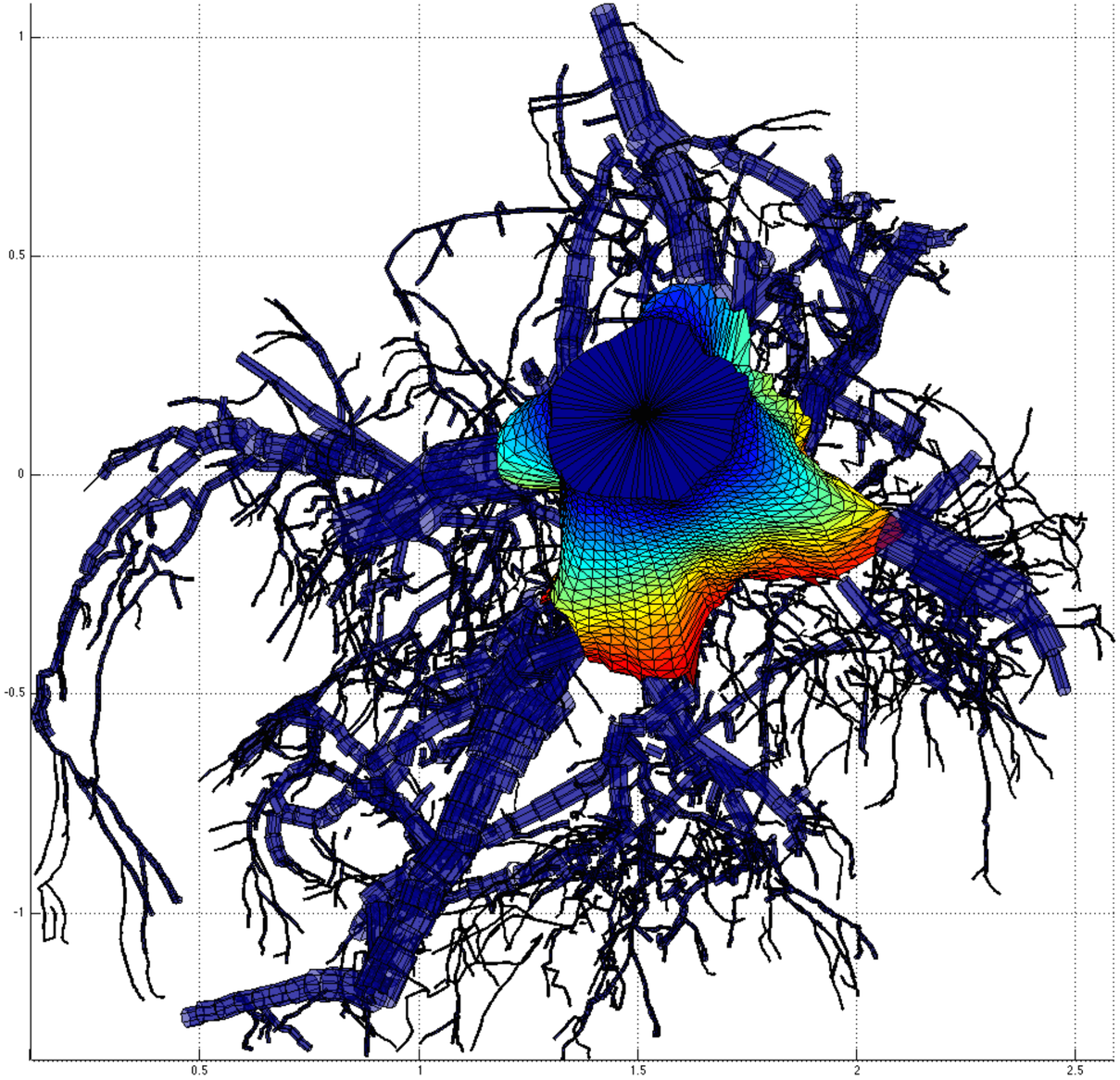
- **Generally under 10% error in biomass**
  - **For big trees allometry can give 30-50% errors**



Below-ground biomass and structure

- Stump-root systems of big trees were uprooted and cleaned, then scanned
- Hybrid QSM
  - triangulation for the stump
  - cylinders for the roots
- Smith et al. (2014). Root system characterization and volume estimation by terrestrial laser scanning. Forests
  - Underestimated volume by 4.4%
  - Widely applicable and easily adapted to derive other topological and volumetric root variables

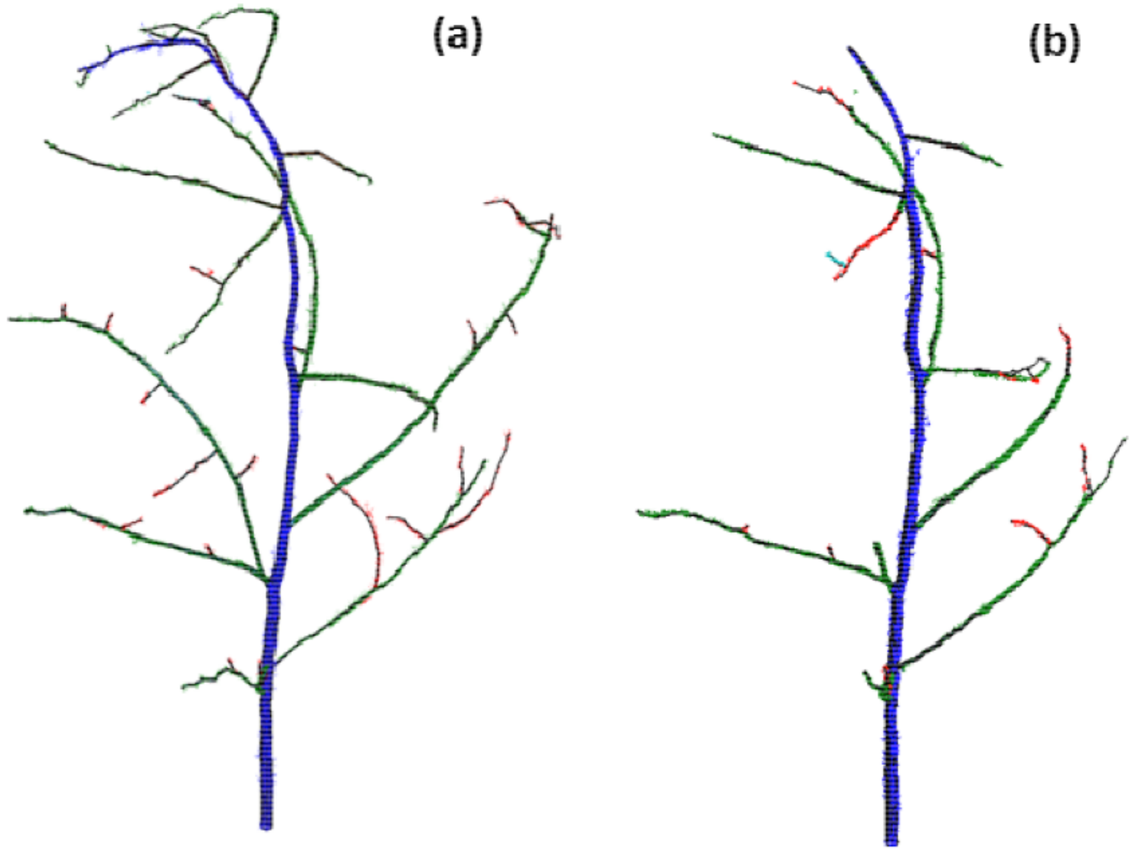


Massive scale tree modelling

- **Huge point clouds from forest plots and regions**
  - **Multi-hectare, thousands of trees, 10^8-10^9 points**
  - **Basic computer is enough**
  - **Raumonen et al. 2015: “Massive-scale tree modelling from TLS data”. *ISPRS Annals*, Volume II-3/W4**
- **The challenge is automatic tree extraction**
  - **Partition the whole point cloud into small subsets**
  - **Locate stems using heuristics**
  - **Segmentation separates the trees**

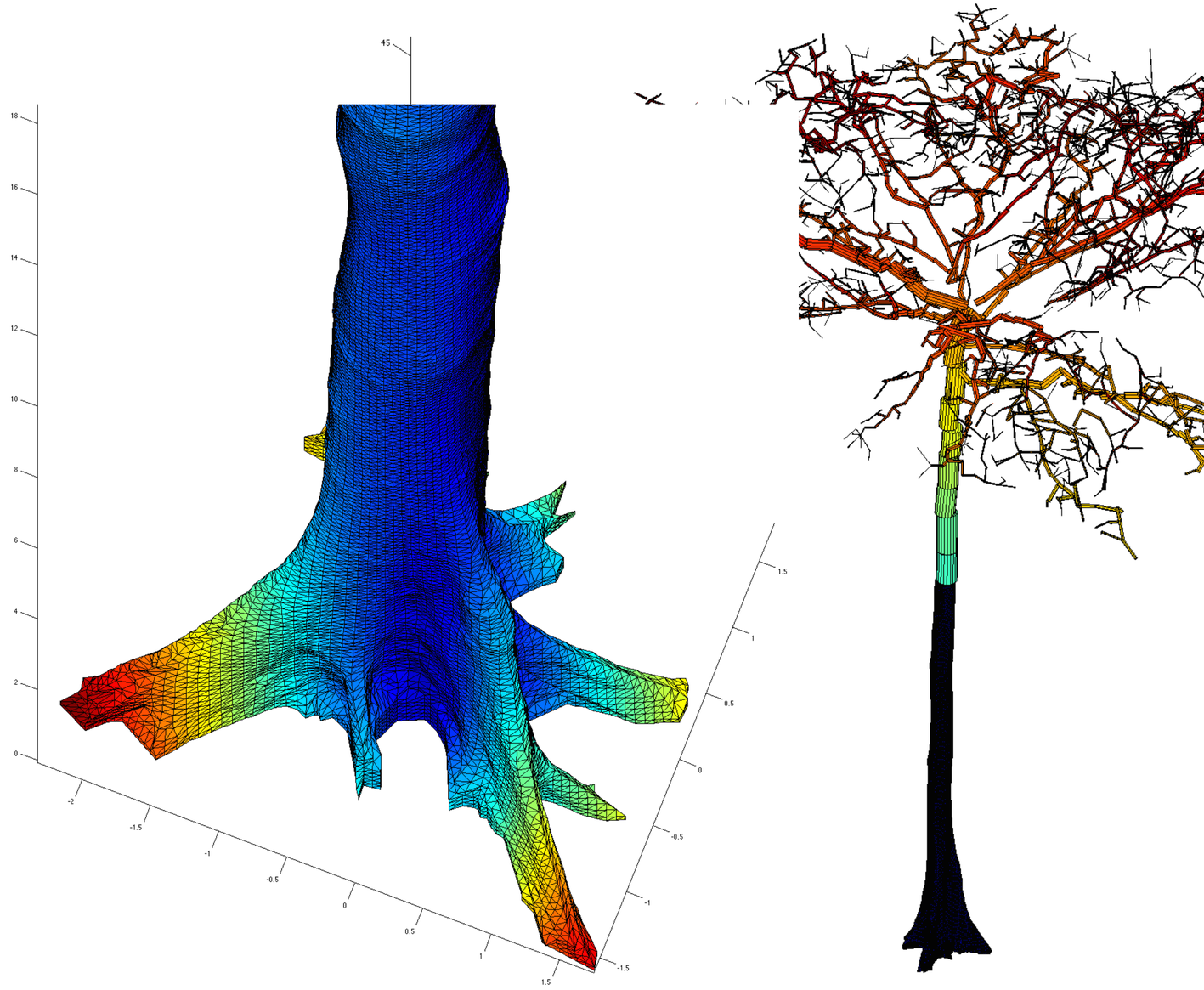
Change detection and quantification

- **Nondestructive TLS measurements can be repeated in time**
- **QSM can detect and quantify the changes**
- **Kaasalainen et al. (2014). Change Detection of Tree Biomass with Terrestrial Laser Scanning and Quantitative Structure Modelling. Remote Sensing, 6, 3906-3922.**



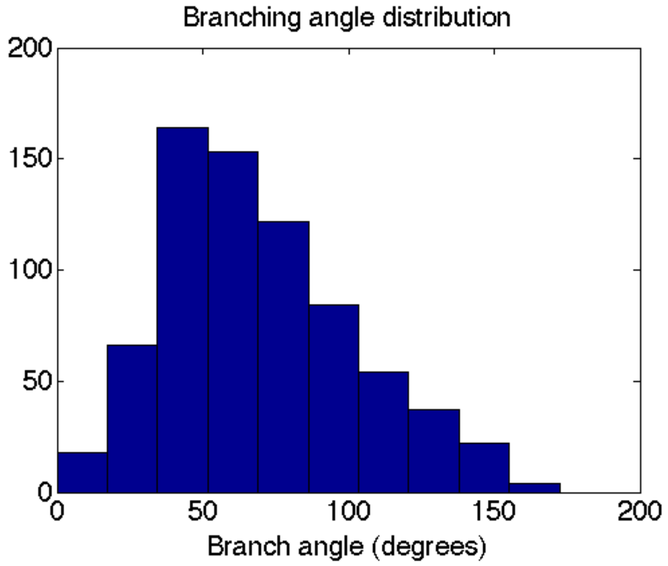
Buttress roots

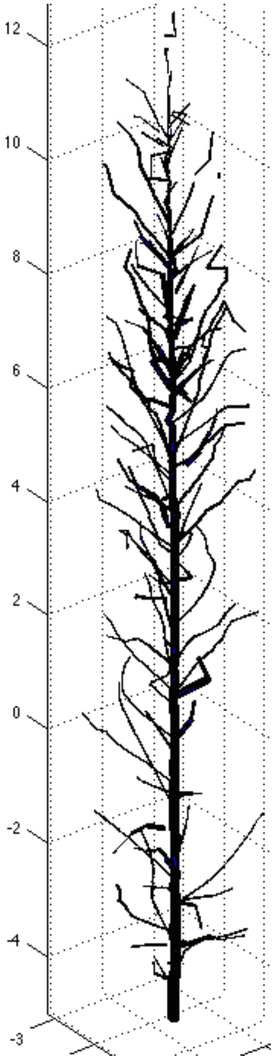
- **Hybrid QSMs for large trees with complicated buttress roots**
- **Triangulation based on cross-section boundary curves**
- **Bauwens et al. Work in progress.**

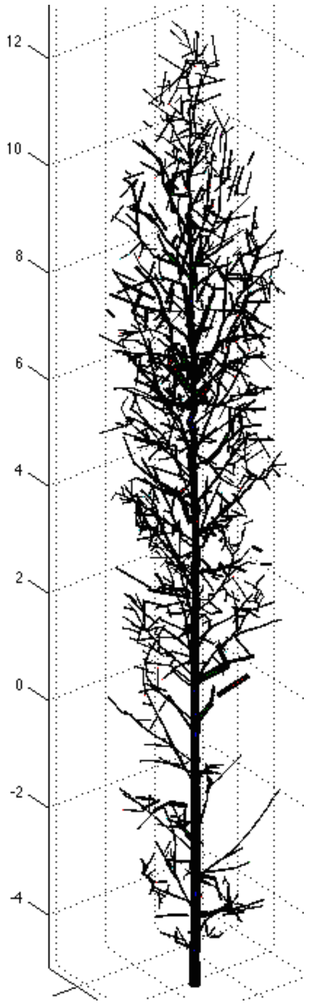


Tree structure metrics and distributions

- **Easy extraction of topological and geometrical structural tree information**
  - **E.g. branching angle**
- **Determination of tree phenotype**
- **Species recognition**

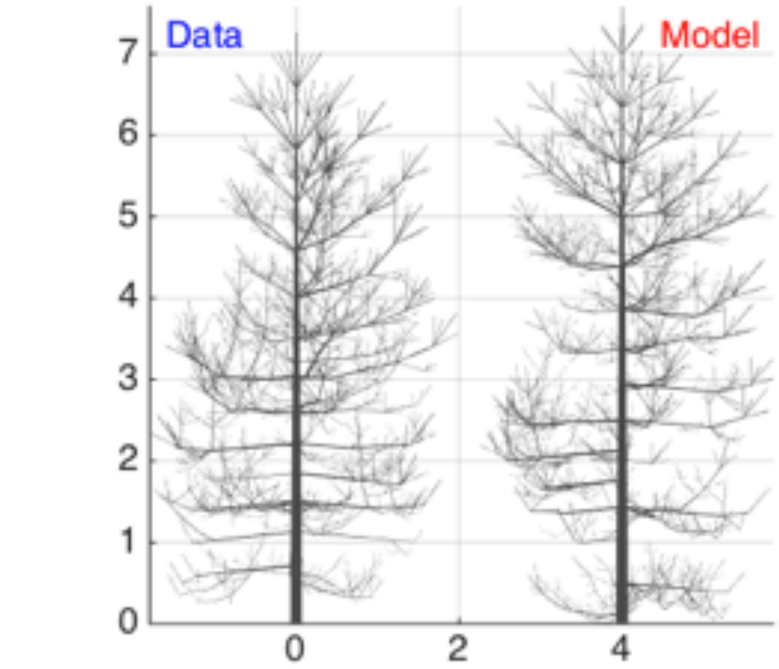




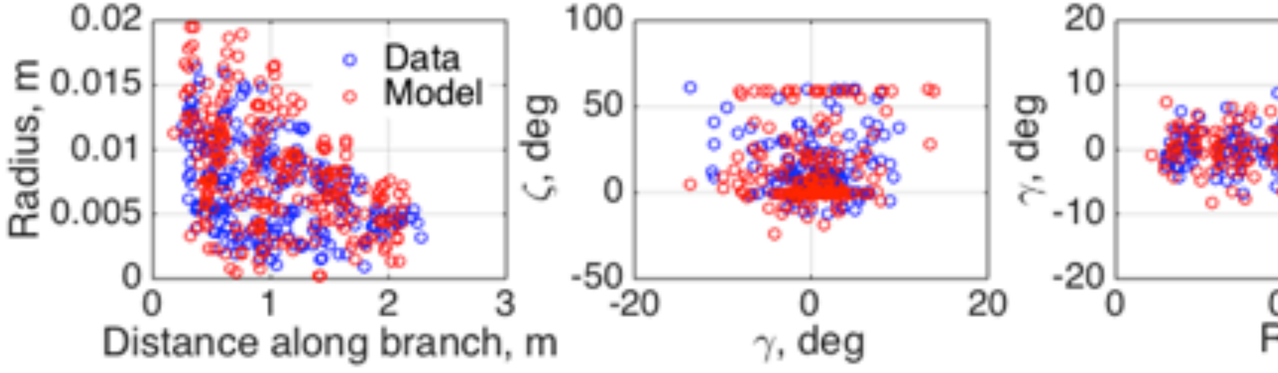


Functional structural tree models

- Stochastic Structure Models (SSM)
- FSTMs with randomness by considering some parameters as distributions
- FSTMs are optimised against statistical structural data from QSMs
  - Optimise model parameters so that structural distributions coincide
- Potapov et al. (2015). Data-based stochastic modelling of tree growth and structure formation. Silva Fennica, under review



Parameter name	Data v
L_R, mean	0.009
L_R, std	0.001
Q, mean	0.2
Q, std	0.03
T	15
$\Delta\beta$	10.0
$\Delta\xi$	5.0
β_{init}	35.0



Other applications

- Mechanical response to wind forcing
- Forest fires and fuel structure modelling
- QSMs as supports for eco-physiological data
  - leaves, chlorophyl, etc
- And surely some more…

Summary

- TLS and QSMs offer a comprehensive way to model and measure trees
- Non-destructive, fast, cheap
- Many applications
- New approach
  - accurate and comprehensive models for each tree
  - instead of traditional statistical approach or models for particular attribute