LiDAR – latest applications for forestry and biodiversity

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Laboratory of Forest Resources Management and Geo-Information Science
http://blogs.helsinki.fi/4d-gis/
http://blogs.helsinki.fi/marv-gis-en/

Centre of excellence in laser scanning research
http://laserscanning.fi/

Centre of Excellence
in Laser Scanning Research

Centre of Excellence in Laser Scanning Research: "Together what is otherwise impossible"

Hardware-driven approach

Pulsed time-of-flight laser radar

Juha Kostamovaara
Univ. Oulu

Mobile and ubiquitous Laser Scanning

Juha Hyyppä
FGI

Laser scanning for precision forestry

Markus Holopainen
Univ. Helsinki

Laser scanning for built environment

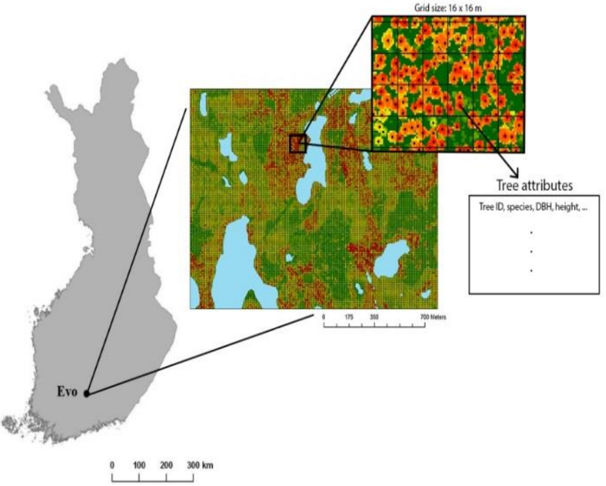
Hannu Hyyppä
Aalto Univ.

International benchmarking studies

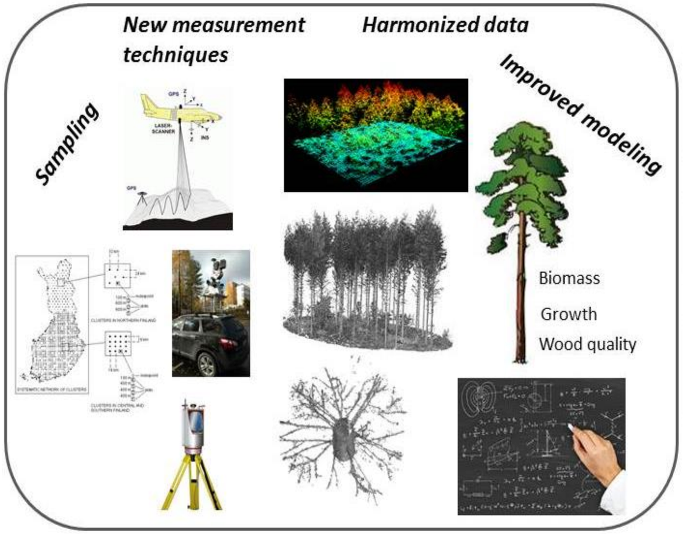
CoELaSR/ University of Helsinki

Research directions

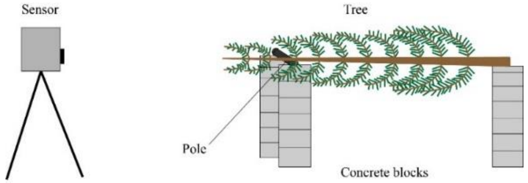
3D/4D Precision forestry

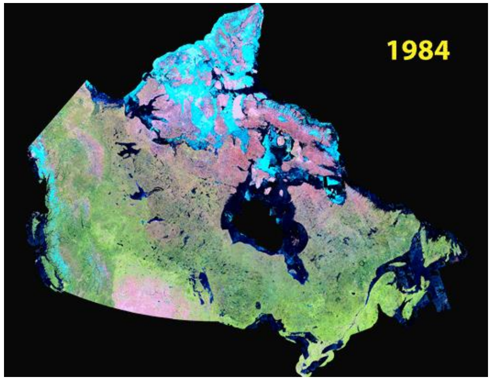


Towards comprehensive tree attribute modelling using 3D point clouds



Forest health, above ground biomass and biodiversity assessment by improved mapping and monitoring





Operational applications in forestry

Centre of Excellence in Laser Scanning Research

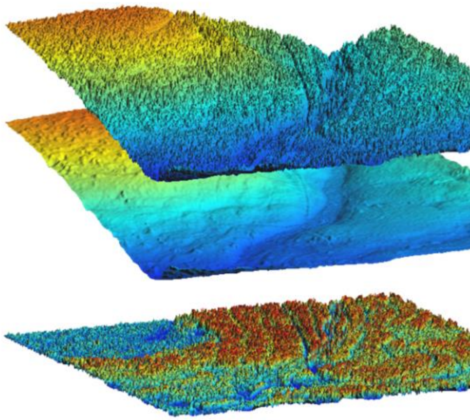
Status of 3D/4D remote sensing based precision forestry in Finland

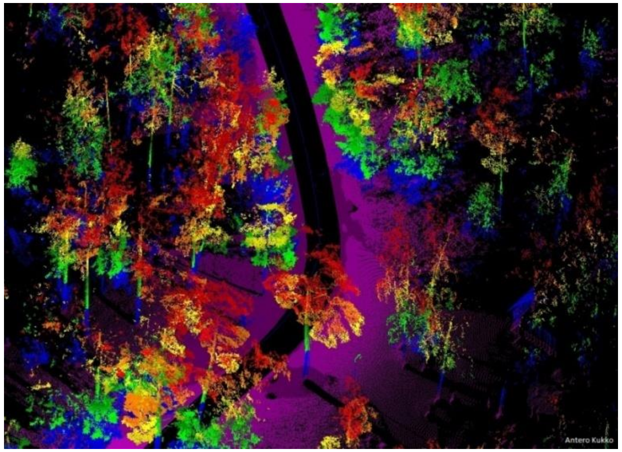
In Operational use

- 3D-remote sensing (ALS-ABA)
- **Added value** using ALS ABA:
  - cost efficient forest resource mapping
  - Stem distributions and timber assortments by means of theoretical models
  - Predicting stand-thinning maturity
  - Forest biomass and energy wood mapping
  - GIS analyses that are based on accurate DTM or CHM

Still mainly in research stage

- ALS Individual tree approach (ITA)
- 4D-remote sensing – monitoring changes by means of accurate 3D remote sensing
- Terrestrial / mobile laser scanning
- Main Challenges
  - **species-specific stem distribution and wood quality**
  - **Tree level above ground biomass components**
  - **Seedling stands**
  - **Added value of the information**





Aboveground biomass components

Kankare, V., Holopainen, M., Vastaranta, M., Puttonen, E., Yu, X., Hyyppä, J., Vaaja, M., Hyyppä, H. & Alho,
Individual tree biomass estimation using terrestrial laser scanning. ISPRS Journal of Photogrammetry and
Remote Sensing, 75(2013):64-75.

Kankare, V., Räty, M., Yu, X., Holopainen, M., Vastaranta, M., Kantola, T., Hyyppä, J., Hyyppä, H., Alho, P. &
R. Single tree biomass modelling using airborne laser scanning. ISPRS Journal of Photogrammetry and R
Sensing 2013c, 85: 66-73.

Motivation:

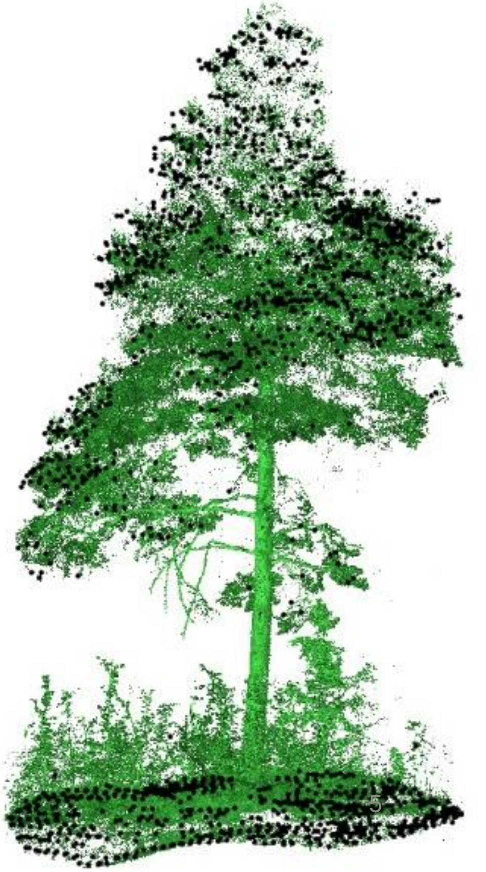
- The methods utilizing TLS and ALS derived metrics in biomass component estimation have not been developed and evaluated before at component level
  - especially with destructively sampled reference data

Highlights of the results:

- Total AGB was estimated with RMSE of:
  - 12.9% / 22.1kg (Scots pine) and 11.9% / 26.0kg (Norway spruce)
- Branch AGB was estimated with RMSE of:
  - 23.4% / 3.8kg (Scots pine) and 38.1% / 14.0kg (Norway spruce)
- **TLS-derived metrics improved especially the estimation accuracy of canopy related AGB components compared to state-of-the-art allometric models.**
  - Existing model accuracy on branch biomass: 62.1% / 10.2kg (Scots pine) and 101.1% / 37.25kg (Norway spruce)

Impact:

"TLS data could provide the means to collect the required reference data for biomass modelling non-destructively"



Timber assortments and stem curve

Kankare, V., Vauhkonen, J., Tanhuanpää, T., Holopainen, M., Vastaranta, M., Joensuu, M., Krooks, A., Hyyppä, J., Hyyppä, H., Alho, P. & Viitala, R. 2014. Accuracy in estimation of timber assortments and stem distribution – A comparison of airborne and terrestrial laser scanning techniques. ISPRS Journal of Photogrammetry and Remote Sensing, 97:89-97.

Motivation:

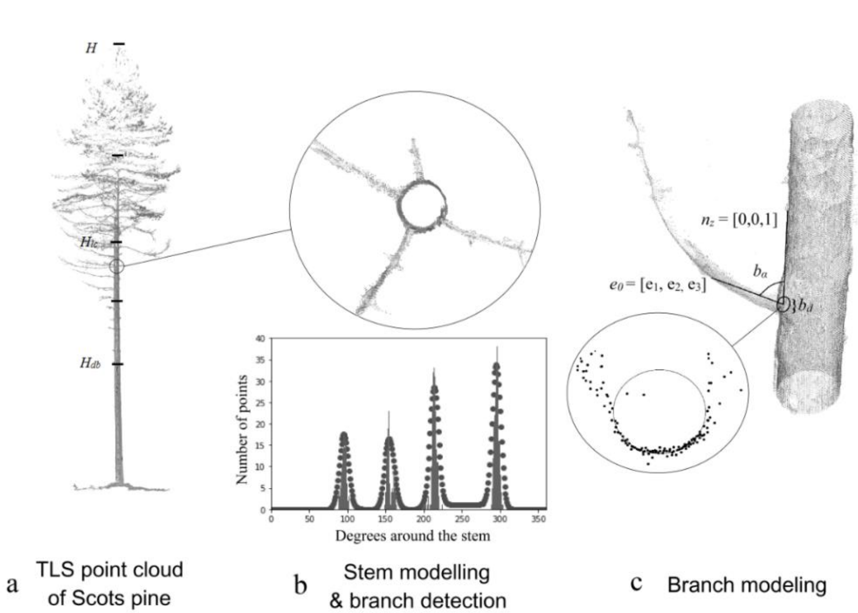
- Methods for TLS and ALS data derived metrics and multisource approach, to estimate timber assortments have not been developed and evaluated at single tree-level before
  - Unique harvester data and NFI guided tree quality measurements as a reference
- Automation of the data processing is mandatory if TLS data is to be used operationally
  - Development of new automatic stem curve algorithms

Highlights of the results and impact:

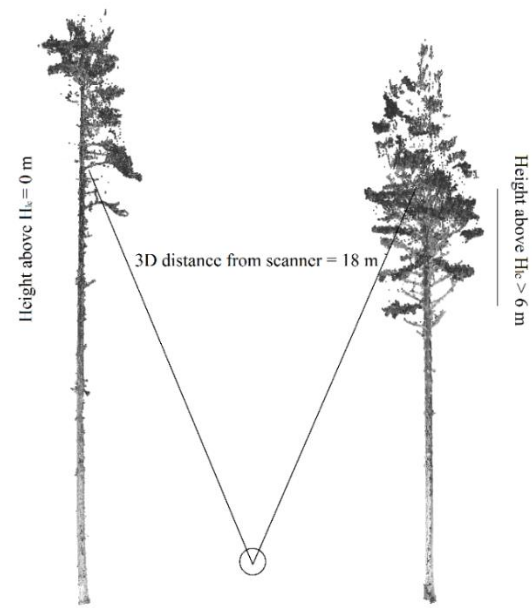
- Timber assortments were estimated the most accurately with **novel multisource approach**, which combines the best features of ALS and TLS
  - Saw log volume 16.8% (0.12m^3)
- **Automatic processing of TLS data was demonstrated to be effective and accurate and could be utilized to make future TLS measurements more efficient**.
  - Overall stem volume accuracy was 9.5% with overall stem curve accuracy of ~1 cm

Measuring wood quality indicators in standing timber using terrestrial laser scanning: a quantitative method for branch detection & modelling

Pyörälä, J., Liang, X., Vastaranta, M., Saarinen, N., Kankare, V., Wang, Y. et al. 2018. Quantitative assessment of Scots pine (Pinus sylvestris L.) whorl structure in a forest environment using terrestrial laser scanning. Ieee Journal of Selected Topics in Applied Earth Observations and Remote Sensing, 11 (9), 1-10. DOI: 10.1109/JSTARS.2018.2819598.



The outline of the method

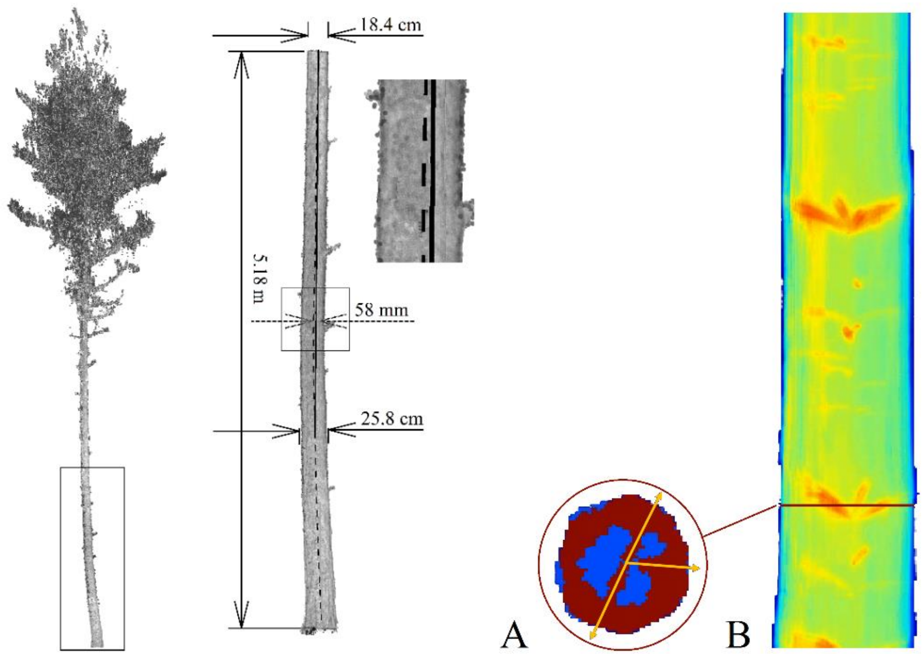


The factors affecting the method performance: scanner distance & occlusion

Measuring wood quality indicators in standing timber using terrestrial laser scanning: a comparison to X-ray scanning data

Pyörälä, J., Kankare, V., Vastaranta, M., Rikala, J., Holopainen, M., Sipi, M., Hyyppä, J. & Uusitalo, J. 2017. Comparison of Terrestrial Laser Scanning and X-ray Scanning in Measuring Scots Pine (*Pinus sylvestris* L.) Branch Structure. Scandinavian Journal of Forest Research. 33:3.

Pyörälä J., et al. Standing timber stem geometry measured by means of terrestrial laser scanning with implications to wood quality. Manuscript.



Selected results:

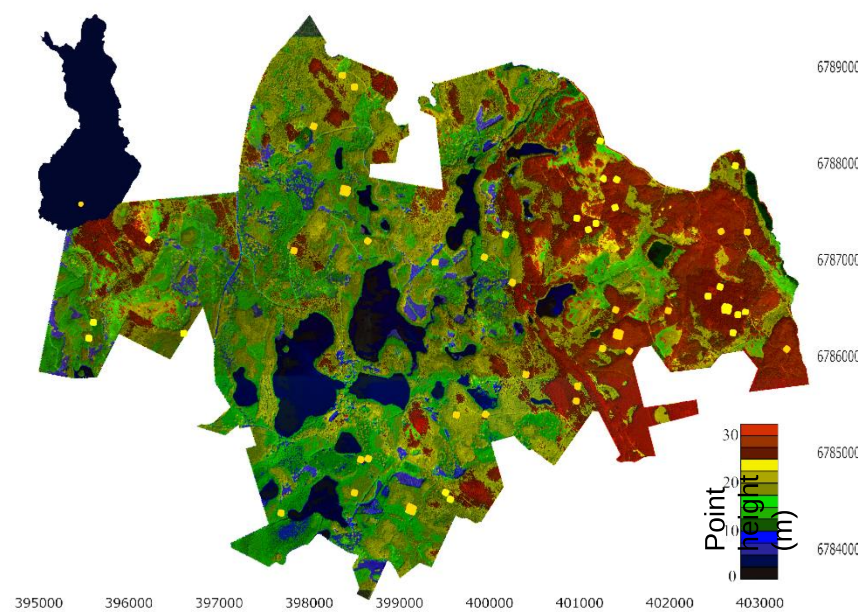
- 55% of whorl structure detected in the log-sections
- Largest knot within the log-section estimated without bias
- Log size and taper accurately estimated
- Sweep estimation still problematic

CENTRE OF EXCELLENCE
IN LASER SCANNING RESEARCH

FINNISH GEODETIC INSTITUTE - UNIVERSITY OF HELSINKI - UNIVERSITY OF OULU - AALTO UNIVERSITY

Evo test site for international benchmarking studies: Evo campaign 2014→

- Test site area 4 km x 6 km
- Located in Evo ~100 km north of Helsinki
- 91 forest test plots (32 x 32 m)
- 24 test plots selected for EuroSDR comparison of tree extraction using TLS data
- Field inventory, TLS
- MLS with ATV and PLS using backpack
- Satellite: VHR optical stereo, TSX stereo, TDX INSAR
- Airborne data (NLS): ALS and aerial images with different flying altitudes



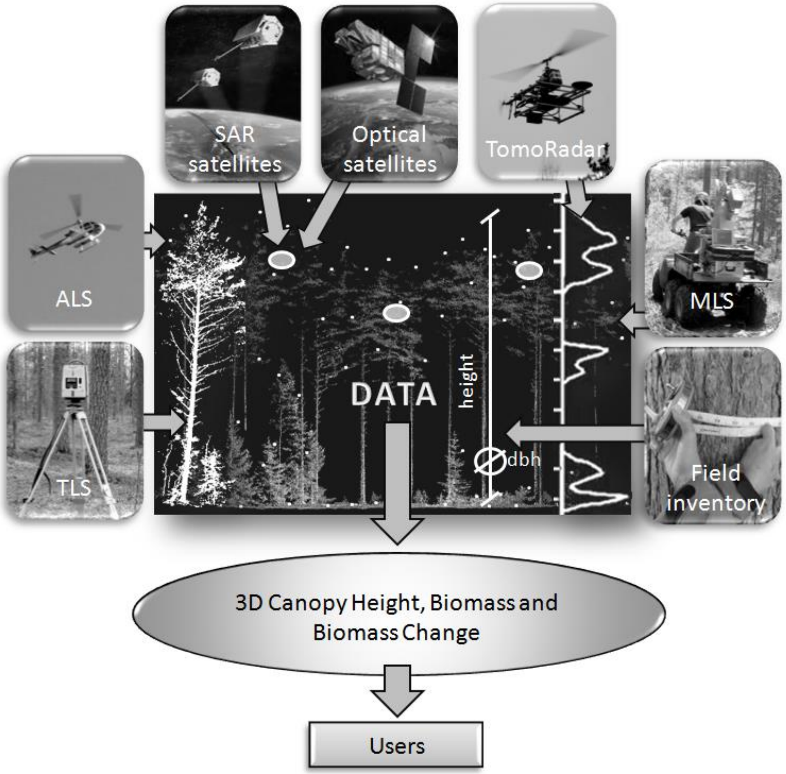
Investigating the capabilities of select 3D remotely sensed data sources to characterize forest structure

M. Vastaranta, T. Yrttimaa, et al. X. Yu, N. Saarinen, M. Karjalainen, K. Nurminen, K. Karila, V. Kankare, V. Luoma, J. Pyörälä, S. Junttila, T. Tanhuanpää, H. Kaartinen, A. Kukko, E. Honkavaara, A. Jaakkola, X. Liang, Y. Wang, M. Vaaja, H. Hyyppä, M. Katoh, M.A. Wulder, M. Holopainen & J. Hyyppä. Manuscript.

Yu, X., Hyyppä, J., Karjalainen, M., Nurminen, K., Karila, K., Vastaranta, M., Kankare, V., Kaartinen, H., Holopainen, M., Honkavaara, E., Kukko, A., Jaakkola, A., Liang, X., Wang, Y., Hyyppä, H., Katoh, M. 2015. Comparison of Laser and Stereo Optical, SAR and InSAR Point Clouds from Air- and Space-Borne Sources in the Retrieval of Forest Inventory Attributes. Remote Sensing 7, 15933-15954.

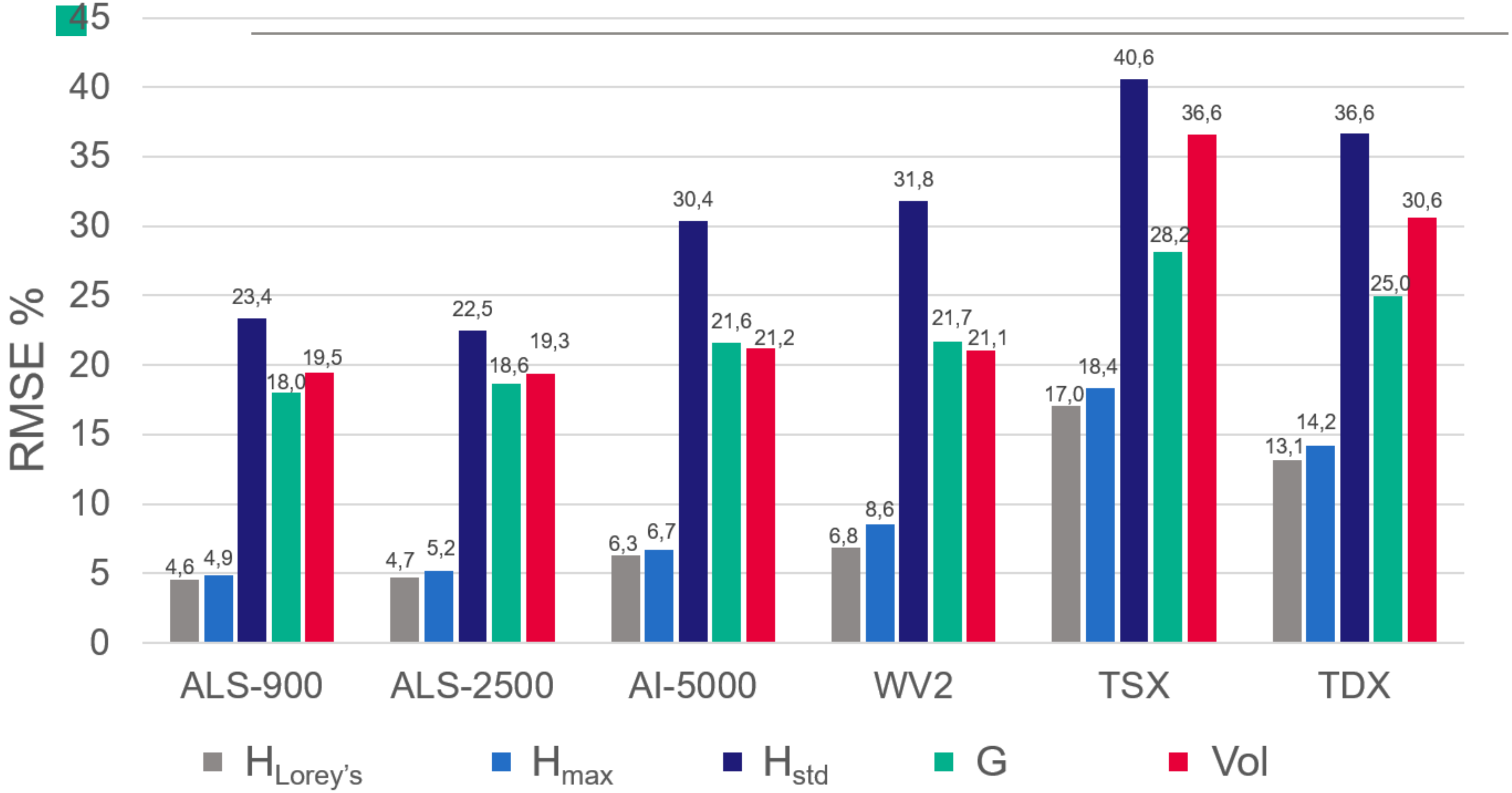
Objectives:

- To better understand the strengths and limitations of various 3D remote sensing data sources for measuring height and capturing variation in forest height and canopy cover density
- Forest inventory attributes predicted using airborne laser scanning (ALS), aerial imagery (AI), WorldView-2 satellite imagery (WV2), Tandem-X interferometry (TDX) and TerraSAR-X radargrammetry (TSX)



Results

Prediction accuracy of forest structural attributes

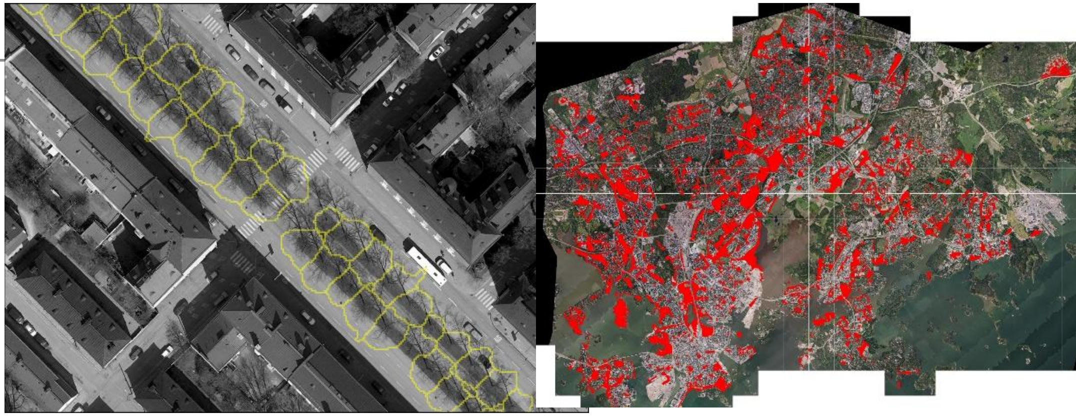


Conclusion – 3D RS comparison

- ALS-based DEM/DTM is needed in all 3D RS methods
- Stand height prediction accuracies of different 3D RS materials are close to each other.
  - In addition to ALS, forest inventory attributes that are correlated with height can be predicted rather well also with AI, WV2, and TDX
- However, only ALS can provide information on variation in tree heights and canopy cover density, i.e. **If it is important to characterize also the canopy cover density and height variation, ALS should be used.**
- It has been suggested in Finland that ALS data could be acquired at regular time periods (i.e., every 3-5 years)

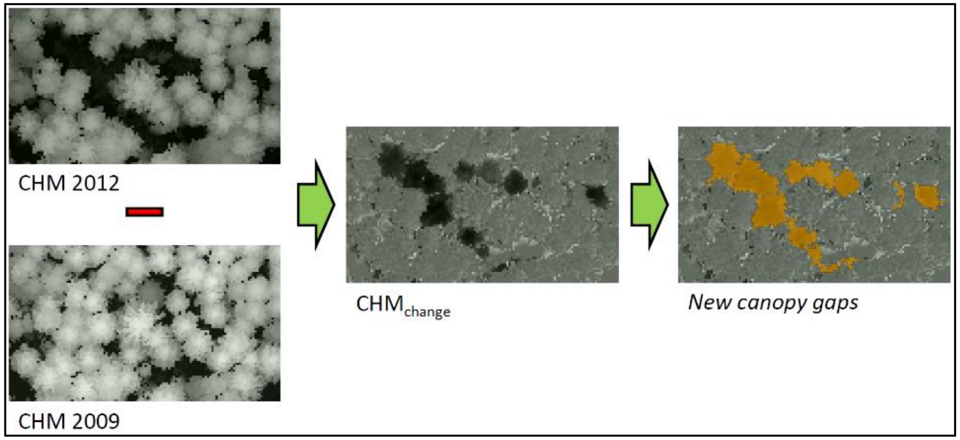
Developing laser scanning applications for mapping and monitoring single tree characteristics for the needs of urban forestry (Topi Tanhuanpää)

- The aim is develop LS-based methods for assessing tree-level information from urban forests and maintaining the tree registers.
  - See, e.g.: Tanhuanpää, T., Vastaranta, M., Kankare, V., Holopainen, M., Hyyppa, J., Hyyppa, H., Alho, P. & Raisio, J. 2014. Mapping of urban roadside trees - A case study in the tree register update process in Helsinki City. Urban Forestry & Urban Greening. 13 (3), 562-570.
  - Tanhuanpää, T., Kankare, V., Vastaranta, M., Saarinen, N., Holopainen, M. (2015). Monitoring downed coarse woody debris through appearance of canopy gaps in urban boreal forests with bitemporal ALS data. Urban Forestry & Urban Greening, 14(4): 835–843.
- The developed methods have already been put into practice in the city of Helsinki and are currently further developed for park trees.



Method for updating a roadside tree register and mapping of park trees.

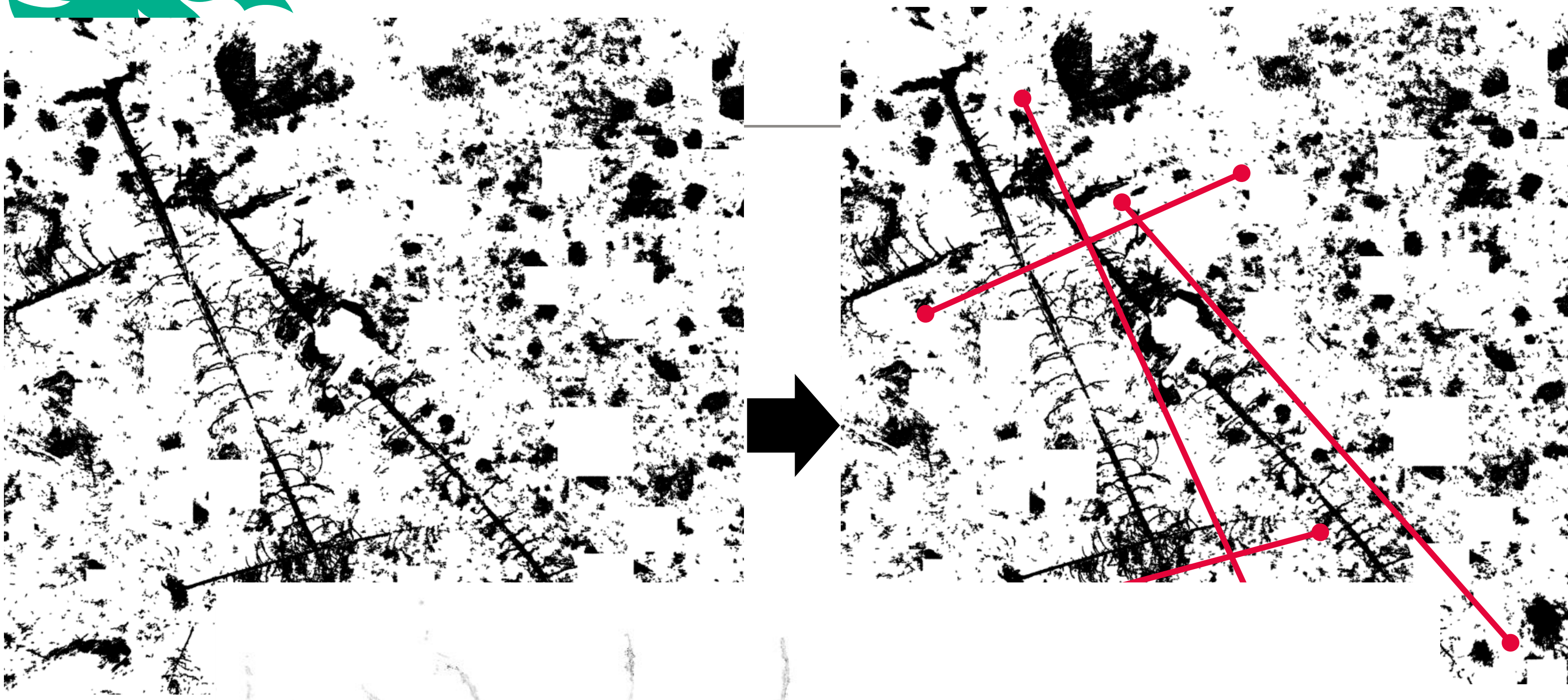
Mapping of park trees

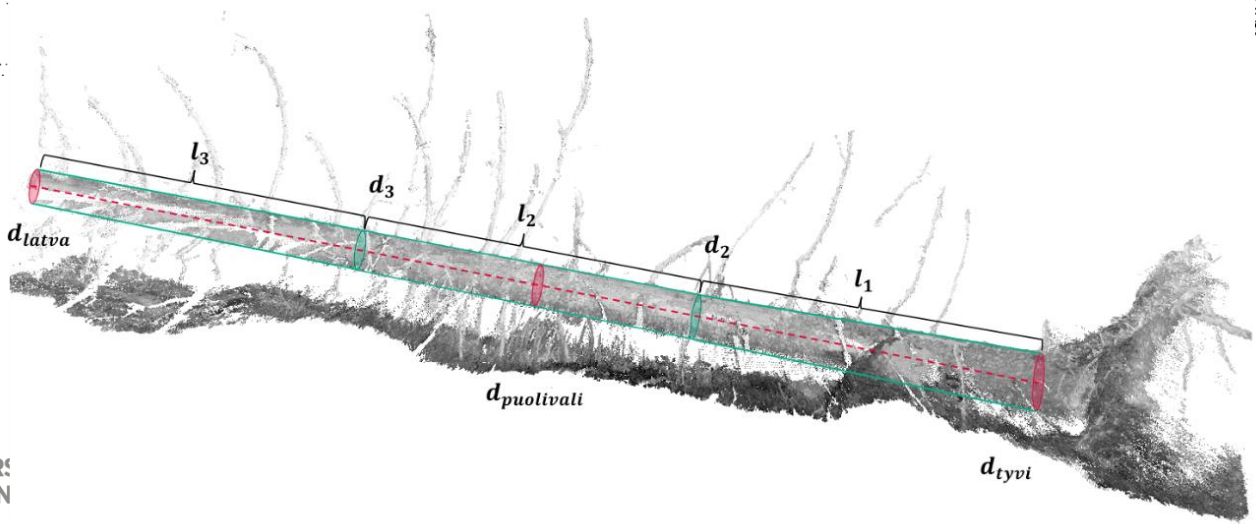


Mapping of fallen trees in urban areas throught changes in canopy height

Tuomas Yrttimaa: Maalahopuun kartoitus maastolaserkeilauksella
(Decaying dead wood mapping by means of terrestrial laser scanning)

Regognition and measurements





Assessing Biodiversity in Boreal Forests with UAV-Based Photogrammetric Point Clouds and Hyperspectral Imaging

Saarinen, N., Vastaranta, M., Näsi, R., Rosnell, T., Hakala, T., Honkavaara, E., Wulder, M.A., Luoma, V., Tommaselli, A.M.G., Imai, N.N., Ribeiro, E.A., Guimarães, R.B., Holopainen, M., Hyyppä, J. 2018. Assessing biodiversity in boreal forests with UAV-based photogrammetric point clouds and hyperspectral imaging. Remote sensing 10(2): 338. doi:10.3390/rs10020338

Biodiversity indicators in this study

Biodiversity Indicator	Attribute (unit)	Definition for the Attribute
Species richness	Volume (m^3/ha) and number of trees (N/ha) of each tree species	
Amount of dead wood	Volume (m^3/ha) and number (N/ha) of dead trees	
Structural heterogeneity	Standard deviation in dbh (cm) and tree height (m)	Including both horizontal and vertical variation
Successional stage	Basal-area-weighted mean diameter (cm)	Used in Finnish forest management planning for determining developmental class, i.e., maturity or successional stage
Amount of large deciduous trees	Volume (m^3/ha) and number (N/ha) of deciduous trees with dbh > 25 cm	Large trees were defined as dbh > 25 cm, because it is the minimum dbh limit for regeneration according to Good forest management practices in Finland

3D / 4D remote sensing & biodiversity, furher studies

- Tree species regognition
- TLS/MLS/UAV in detecting & mapping of downed dead wood
- Multiphase sampling with multisource RS: TLS/MLS/UAV combined with airborne 3D point clouds
- Large area dead wood mapping by means of 4D RS
- Forest site type (growth) mapping by means of 4D RS

PhD Thesis, UH, Forest Resource management & Geoinformatics 2014→

- Topi Tanhuanpää (2016). Developing laser scanning applications for mapping and monitoring single tree characteristics for the needs of urban forestry. Dissertationes forestales 230. https://dissertationesforestales.fi/article/2013
- Ninni Saarinen (2016). Predicting vegetation characteristics in a changing environment by means of laser scanning. Dissertationes Forestales 216. https://helda.helsinki.fi/handle/10138/161063
- Ville Kankare (2015). The prediction of single-tree biomass, logging recoveries and quality attributes with laser scanning techniques. Dissertationes Forestales 195. https://helda.helsinki.fi/handle/10138/154644
- Aarne Hovi (2015). Towards an enhanced understanding of airborne LiDAR measurements of forest vegetation. Dissertationes Forestales 200, https://helda.helsinki.fi/handle/10138/156361
- Titta Majasalmi (2015). Estimation of leaf area index and the fraction of absorbed photosynthetically active radiation in a boreal forest. Dissertationes Forestales 187. https://helda.helsinki.fi/handle/10138/153249?show=full
- Svetlana Saarela (2015). Use of remotely sensed auxiliary data for improving samle-based forest inventories. Dissertationes Forestales 201, https://helda.helsinki.fi/handle/10138/156392
- Reija Haapanen (2014) Feature extraction and selection in remote sensing-aided forest inventory. Dissertationes Forestales 201. https://helda.helsinki.fi/handle/10138/13631

Ongoing PhD Thesis, UH, Forest Resource Management & Geoinformatics

- Samuli Junttila: The utilization of new measurement technologies in the mapping of declined trees
- Joanne White: Large-area forest change mapping by means of Lidar and Landsat-TM time series
- Tuula Kantola: Evaluating insect-induced damage in forest landscapes at varying spatial scales
- Jiri Pyörälä: Timber quality estimation by means of terrestrial laser scanning
- Ville Luoma: Improving understanding of forest growth dynamics by using multitemporal characterizations of trees

Selected publications

- Holopainen, M., Vastaranta, M. & Hyyppä, J. 2014. Outlook for the next generation's precision forestry in Finland. Forests 2014, 5(7), 1682-1694; doi:10.3390/f5071682
- Kankare, V., Liang X., Vastaranta, M., Yu, X., Holopainen, M., Hyyppä, J. 2015. Diameter distribution estimation with laser scanning based multisource single tree inventory. ISPRS Journal of Photogrammetry and Remote Sensing 108, 161-171.
- Kankare, V., Vauhkonen, J., Tanhuanpää, T., Holopainen, M., Vastaranta, M., Joensuu, M., Krooks, A., Hyyppä, J., Hyyppä, H., Alho, P. & Viitala, R. 2014. Accuracy in estimation of timber assortments and stem distribution – A comparison of airborne and terrestrial laser scanning techniques. ISPRS Journal of Photogrammetry and Remote Sensing, 97:89-97.
- Kankare, V., Joensuu, M., Vauhkonen, J., Holopainen, M., Tanhuanpää, T., Vastaranta, M., Hyyppä, J. Hyyppä, H., Alho, P., Rikala, J. & Sipi, M. 2014. Estimation of the Timber Quality of Scots Pine with Terrestrial Laser Scanning. Forests 2014, *5*(8), 1879-1895; doi:10.3390/f5081879
- Liang, X., Kankare, V., Hyyppä, J., Wang, Y., Kukko, A., Haggrén, H., Yu, X., Kaartinen, H., Jaakkola, A., Guan, F., Holopainen, M., Vastaranta, M. 2016. Terrestrial laser scanning in forest inventories. ISPRS Journal of Photogrammetry and Remote Sensing, 115:63-77.
- Junttila, S., Kaasalainen, S., Vastaranta, M., Hakala, T., Nevalainen, O., Holopainen, M. Investigating Bi-Temporal Hyperspectral Lidar Measurements from Declined Trees—Experiences from Laboratory Test. Remote Sens. 2015, 7, 13863-13877.
- Junttila, S., Vastaranta, M., Hämäläinen, J., Latva-käyrä,P., Holopainen, M., Clemente, R.H., Hyyppä, H. & Navarro-Cerrillo, R.M. 2017. Effect of forest structure and health on the relative surface temperature captured by airborne thermal imagery – Case study in Norway Spruce-dominated stands in Southern Finland, Scandinavian Journal of Forest Research, 32:2, 154-165, DOI: 10.1080/02827581.2016.1207800
- Junttila, S., Vastaranta, M. Liang,X., Kaartinen, H., Kukko, A., Kaasalainen, S., Holopainen, M., Hyyppä, H. and Hyyppä, J. 2017. Measuring Leaf Water Content with Dual-Wavelength Intensity Data from Terrestrial Laser Scanners. *Remote Sens.* **2017**, *9*(1), 8; doi:10.3390/rs9010008
- Näsi, R., Honkavaara, E., Lyytikäinen-Saarenmaa, P., Blomqvist, M., Litkey, P., Hakala, T., Viljanen, N., Kantola, T., Tanhuanpää, T. & Holopainen, M. 2015. Using UAV-based photogrammetry and hyperspectral imaging for mapping bark beetle damage at tree-level. *Remote Sensing* 2015, *7*(11), 15467-15493;
- Pyörälä, J., Kankare, V., Vastaranta, M., Rikala, J., Holopainen, M., Sipi, M., Hyyppä, J. & Uusitalo, J. 2017. Comparison of terrestrial laser scanning and Xray scanning in measuring Scots pine (Pinus sylvestris L.) branch structure, Scandinavian Journal of Forest Research, DOI: 10.1080/02827581.2017.1355409
- Saarinen, N., Vastaranta, M., Kankare, V., Tanhuanpää, T., Holopainen, M., Hyyppa, J. & Hyyppa, H. 2014. Urban-Tree-Attribute Update Using Multisource Single-Tree Inventory. Forests. 5, 5, 1032-1052.
- Saarinen, N., M. Vastaranta, E. Honkavaara, M.A. Wulder, J.C. White, P. Litkey, M. Holopainen, and J. Hyyppä. 2015. Using multi-source data to map and model the predisposition of forests to wind disturbance. Scandinavian Journal of Forest Research, DOI: 10.1080/02827581.2015.1056751
- Saarinen, N., M. Vastaranta, E. Honkavaara, M.A. Wulder, J.C. White, P. Litkey, M. Holopainen, and J. Hyyppä. 2016. Using multi-source data to map and model the predisposition of forests to wind disturbance. Scandinavian Journal of Forest Research, 31(1):66-79.
- Saarinen, N., Kankare, V., Vastaranta, M., Luoma, V., Pyörälä, J., Tanhuanpää, T., Liang, X., Kaartinen, H., Kukko, A., Jaakkola, A., Yu, X., Holopainen, M. & Hyyppä, J. Feasibility of Terrestrial laser scanning for collecting stem volume information from single trees. ISPRS Journal of Photogrammetry and Remote Sensing 123 (2017) 140–158

Selected publications

- Saarela, S., Graström, A., Ståhl, G., Kangas, A., Holopainen, M., Tuominen, S., Nordkvist, K. & Hyyppä, J. 2015. Model-assisted estimation of growing stock volume using different combinations of LiDAR and Landsat data as auxiliary information. Remote Sensing of Environment 158(2015):431-440.
- Tanhuanpää, T., Vastaranta, M., Kankare, V., Holopainen, M., Hyyppa, J., Hyyppa, H., Alho, P. & Raisio, J. 2014. Mapping of urban roadside trees - A case study in the tree register update process in Helsinki City. Urban Forestry & Urban Greening. 13 (3), 562-570.
- Tanhuanpää, T., Kankare, V., Vastaranta, M., Saarinen, N., Holopainen, M. 2015. Monitoring downed coarse woody debris through appearance of canopy gaps in urban boreal forests with bitemporal ALS data. Urban Foresty and Urban Greening 14 (4), 835-843.
- Tanhuanpää T., Kankare V., Setälä H., Yli-Pelkonen V., Vastaranta M., Raisio J., Holopainen M., Niemi M. (2017). Assessing above-ground biomass of opengrown urban trees: a comparison between existing models and a volume-based approach. Urban Forestry & Urban Greening 21, 239-246.
- Vastaranta, M., Wulder, M. A., White, J., Pekkarinen, A., Tuominen, S., Ginzler, C., Kankare, V., Holopainen, M., Hyyppä, J. and Hyyppä, H. 2013. Airborne laser scanning and digital stereo imagery measures of forest structure: Comparative results and implications to forest mapping and inventory update. Canadian Journal of Remote Sensing, 39(5):382-395.
- Vastaranta, M., Holopainen, M., Karjalainen, M., Kankare, V., Hyyppä, J. & Kaasalainen, S. 2014. TerraSAR-X stereo SAR and airborne scanning LiDAR height metrics in imputation of forest above-ground biomass and stem volume. IEEE Transactions on Geoscience and Remote Sensing, 52(2):1197-1204.
- Vastaranta, M., Saarinen, N., Kankare, V., Holopainen, M., Kaartinen, H., Hyyppä, J. & Hyyppä, H. 2014. Multisource single-tree inventory in the prediction of tree quality variables and logging recoveries. Remote Sensing, 2014, 6, 3475-3491; doi:10.3390/rs6043475.
- Vastaranta, M., M. Niemi., M.A. Wulder, J.C. White, K. Nurminen, P. Litkey, E. Honkavaara, M. Holopainen, and J. Hyyppä 2015. Forest stand age classification using time series of photogrammetrically derived digital surface models. Scandinavian Journal of Forest Research, 1-12.
- Vauhkonen J, Holopainen M, Kankare V, Vastaranta M, Viitala R. 2016. Geometrically explicit description of forest canopy based on 3D triangulations of airborne laser scanning data. *Remote Sensing of Environment, 173:248-257*.
- Yu, X, Hyyppä, J., Litkey P., Kaartinen, H., Vastaranta, M. and Holopainen, M. 2017. Single-Sensor Solution to Tree Species Classification Using Multispectral Airborne Laser Scanning. *Remote Sens.* 2017, *9*(2), 108; doi:10.3390/rs9020108
- Yu, X., Hyyppä, J., Karjalainen, M., Nurminen, K., Karila, K., Vastaranta, M., Kankare, V., Kaartinen, H., Holopainen, M., Honkavaara, E., Kukko, A., Jaakkola, A., Liang, X., Wang, Y., Hyyppä, H., Katoh, M. 2015. Comparison of Laser and Stereo Optical, SAR and InSAR Point Clouds from Air- and Space-Borne Sources in the Retrieval of Forest Inventory Attributes. Remote Sensing 7, 15933-15954.

Thank you for your time!