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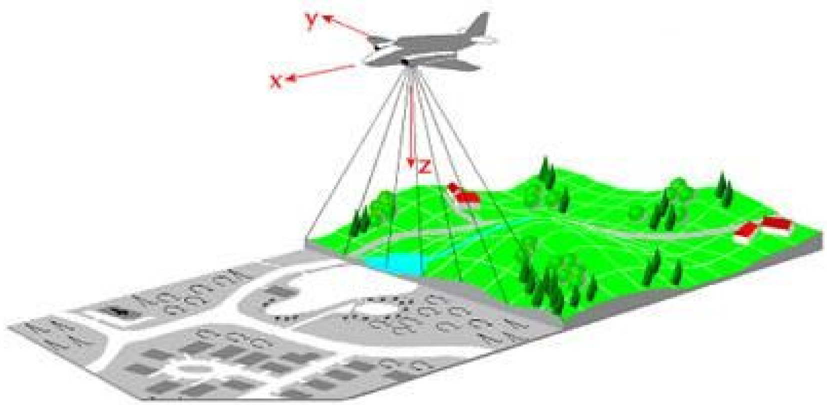
LiDAR application with satellite imagery for forest inventory

Dr. Tuomo Kauranne
President, Arbonaut

What is LiDAR?

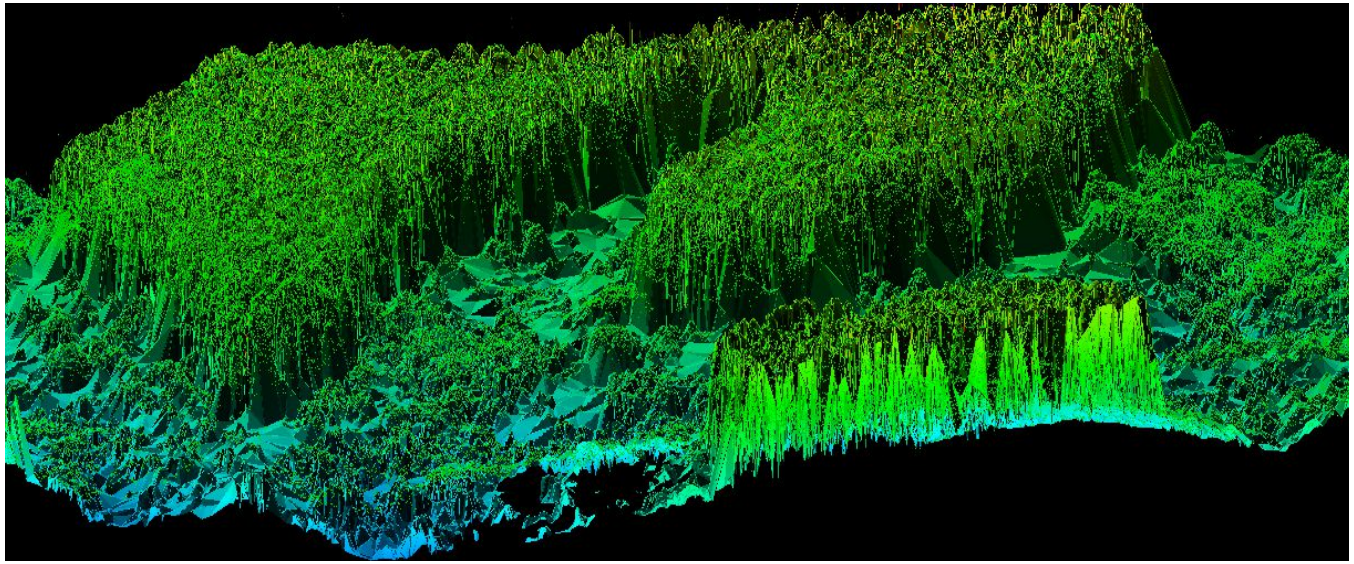
What is Airborne Laser Scanning?

- Scanning LiDAR from airborne vehicle



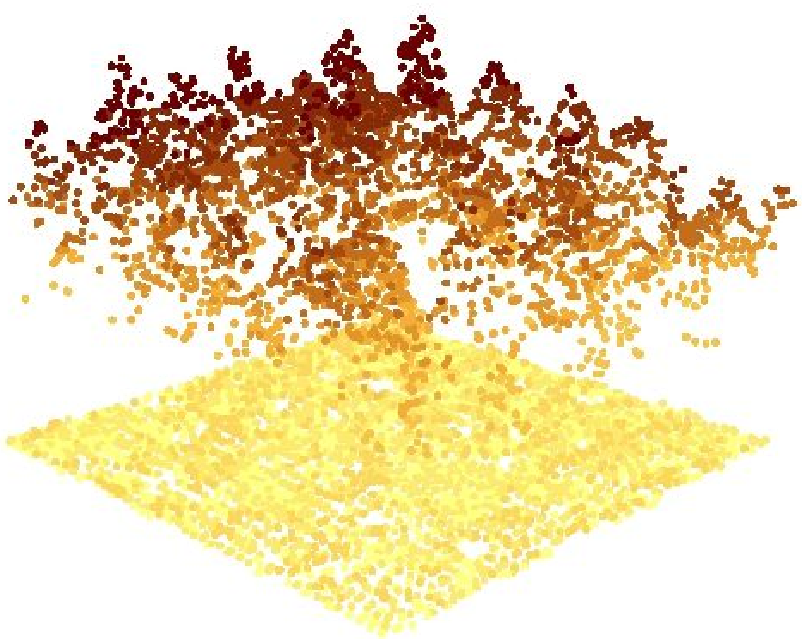
What is LiDAR?

LiDAR scanning produces 3D description from the object



LiDAR applications in forest inventory

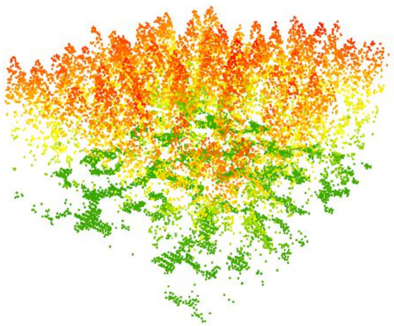
- LiDAR based vegetation mapping methods rely on accurate 3D description of the vegetation and terrain surface

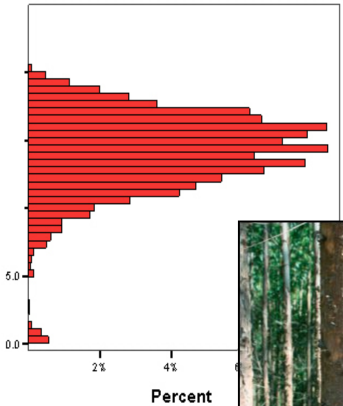


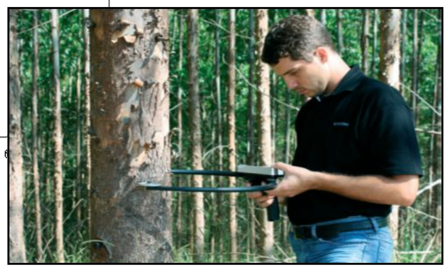
LiDAR applications in forest inventory

Modeling

- Field calibration plots are used for estimating model parameters for prediction models







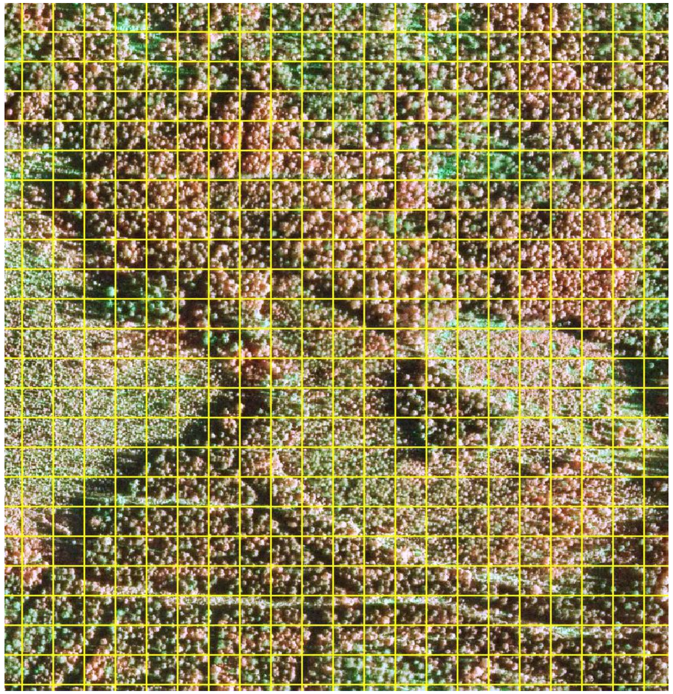
$H_{est} = x_1 * hperc80$

$AGB_{est} = x_1 * hperc70 + x_2 * vegetation\ density$

LiDAR applications in forest inventory

Result calculation

- Results are calculated for a grid cell as mean values (for example, volume/ha) or
- Stand level results are aggregated from basic inventory unit (cell/tree)
- Full census data



Example – Finland

- Background
  - Finnish government noticed a need for a new forest inventory approach
  - The traditional method (field inventory by compartments) had became too expensive and it was not possible to reach the annual inventory goals
  - Goal of the new method: cost savings, more efficient forest policy because of better inventory data
  - Extensive testing of new methods (aerial images, satellite data, and new technology: LiDAR, based on Norwegian examples)

Example – Finland

- Based on research and test results, LiDAR was selected as the best candidate method
  - LiDAR based method was the only one, which fulfilled the accuracy requirements
- LiDAR method was piloted with success and currently ~2 million hectares are inventoried annually using the method

Example – Finland

- Organizations
  - Finnish Forest Centre (governmental organization for collecting and maintaining data from private owned forests)
  - Metsähallitus (state forests)
  - Forest industry (and other big forest owners)
- All the biggest forest owners use currently LiDAR as their default inventory method in Finland

Example – Finland

- Inventory needs, Finnish Forest Center:
  - Inventory period ~ 10 years (every stand inventoried after 10 year period)
  - The inventory requirements are derived from field based inventory by compartments –method (traditional method)
    - Forest inventory data needed for forest management planning (every stand needs to be inventoried)
    - Volume, mean height, mean diameter, basal area, number of stems, age, species proportions
    - Extra variables: silvicultural need, pre-commercial thinning, site type, harvest planning
    - Stand delineation

Example – Finland

- Solution; Finnish Forest Centre:
  - LiDAR data and aerial images collected for forest inventory needs in co-operation with National Land Survey of Finland (national height model production)
  - Field data collected by Finnish Forest Centre (500 – 700 field plots for each project area)
  - Forest stand delineation and inventory calculation by using LiDAR and aerial images (private companies, like Arbonaut, offer services)
  - Between the inventories the stand data is updated using growth models and management reports

Example – Finland

- Solution; Finnish Forest Centre:
  - ~10 projects in year, ~200 000 ha each
  - Time frame of an inventory project
    - Remote sensing and field data collection in summer
    - Data analysis in autumn/winter
    - Delivery of inventory product in spring/winter
    - Quality check and publishing the data in spring/summer/autumn
  - Inventory project from data collection to publishing with quality checks in about a year

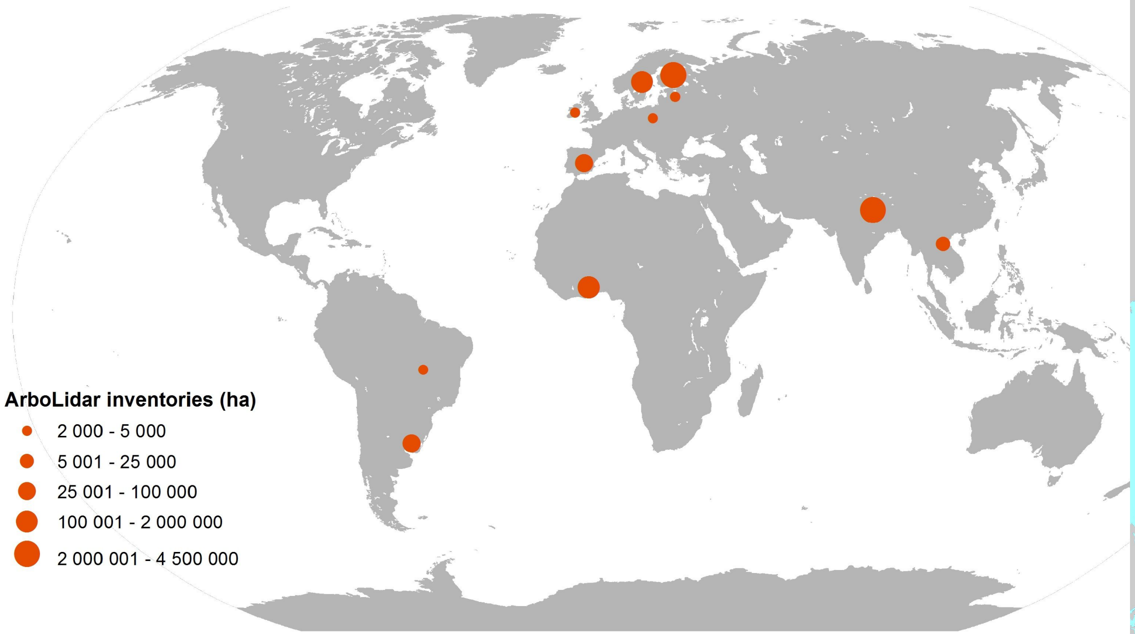
Example – Finland

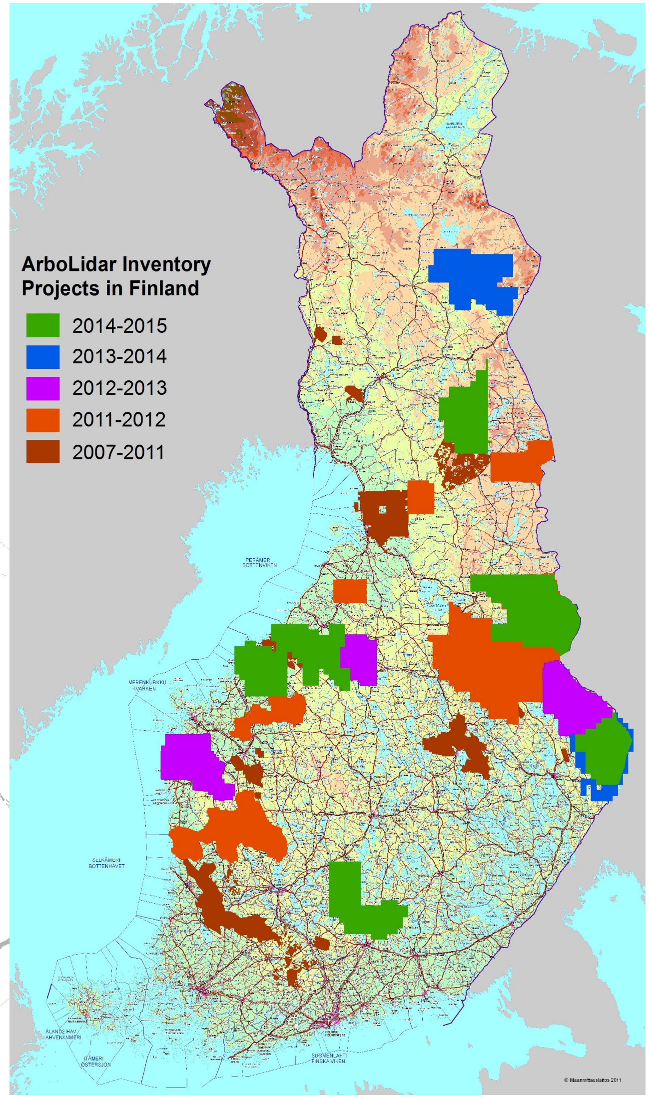
- Solution; Finnish Forest Centre:
  - Inventory results are calculated for every stand
  - Reports can be reported to current legislation format

Example – Finland

- General notifications
  - The product specified by the Finnish Forest Center has became almost a standard
  - State forests and private sector took the new method in use almost at the same time
  - Behind the success: Government’s investments in research and piloting
- New inventory method has pushed forest organizations to renew their forest information systems and the way the inventory information is used

ArboLiDAR inventories





Example – Perm region in Russia

- A comparison was carried out between Perm University and Arbonaut on the applicability of the Finnish LiDAR inventory to Russian forests.
- The study area was in Solikamsk forest district, and covered roughly 10 000 ha.
- Airborne LiDAR data was complemented with SPOT-5 satellite imagery for species recognition.
- From the presentation by Alexey Shurgin, I understand that forest use in Mari El is even more similar to Finnish conditions!

Example – Perm region in Russia

Table 1. Field sample data statistics, mean values and (standard deviations). *n* = 281. V = total volume, G = basal area, N = stem number, H = tree height, D = breast height diameter

	Pine	Spruce	Deciduous	Total
V, m^3/ha	151.1 (159.6)	142.7 (141.1)	68.0 (113.0)	361.7 (163.3)
G, m^2/ha	14.4 (14.6)	15.0 (13.1)	6.9 (10.6)	36.3 (14.0)
N, n/ha	317.0 (409.7)	618.5 (428.7)	244.1 (380.7)	1180.0 (533.0)
H, m	21.7 (4.3)	16.6 (5.6)	18.4 (5.2)	20.4 (3.6)
D, cm	28.9 (8.2)	21.2 (8.8)	21.5 (8.8)	26.2 (6.1)

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	Perm	Matalansalo 2007	Kuortane 2009	Kuhmo 2012
Size of the study area, ha	10,000	2000 [1]	22,000	50,403
ALSdata, nominal sampling density, scan year	~4/ m^2 , 2013	0.7 m^2, 2004	0.64 m^2, 2006	~1/m^2, 2008
Aerial imagery, , year	2.5 m, 2014 [2]	0.5 m, 2004 [3]	0.5 m, 2006	N/A, 2004
Modeling plots, number of plots, acquisition year [4]	281, 2015–2016	463, 2004	335, 2006	471, 2008–2009
Inventory method	Sparse Bayesian regression	k-MSN	k-MSN	Sparse Bayesian regression
Number of validation stands Mean validation stand size	18 independent, 271–164 artificial, 0.1–1.0 ha[5]	67, 1758 m^2	69, 1.0 ha	60, 0.74 ha
Mean volume, m^3/ha	457.9 (independent) 361.7 (artificial) [5]	203.4	149.1	104.3
SD of volume, m^3/ha	111.2, (independent) 151.7–83.3, (artificial) [5]	90.55	NA	NA
Tree species distribution in % (pine, spruce, deciduous)	42, 39, 19 (artificial) [5]	49, 41,11	76, 16, 8	63, 21, 16

Table 3. Plot level RMSE values relative to the mean in the Perm and Finnish studies.

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	Perm	Matalansalo 2007	Kuortane 2009	Kuhmo 2012
Pine				
V	0.67	0.52	0.48	0.49
G	0.64	0.47	0.39	0.46
N	0.73	0.61	0.45	0.51
D	0.25	0.23	0.21	0.14
H	0.18	0.16	0.15	0.09
Spruce				
V	0.64	0.56	1.25	1.04
G	0.56	0.51	1.14	0.94
N	0.54	0.64	1.11	0.78
D	0.37	0.33	0.55	0.24
H	0.29	0.30	0.51	0.16
Deciduous				
V	0.84	1.03	1.47	1.48
G	0.82	0.88	1.23	1.34
N	1.01	0.90	1.24	0.99
D	0.51	0.46	0.62	0.34
H	0.44	0.32	0.43	0.19
Total				
V	0.28	0.20	0.25	0.25
G	0.27	0.17	0.21	0.23
N	0.36	0.30	0.33	0.28
D	0.16	NA	NA	0.12
H	0.07	NA	NA	0.08

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Table 5. Stand level RMSE values relative to the mean in the Perm and Finnish studies. In Perm, the results are presented for four different levels of aggregation.

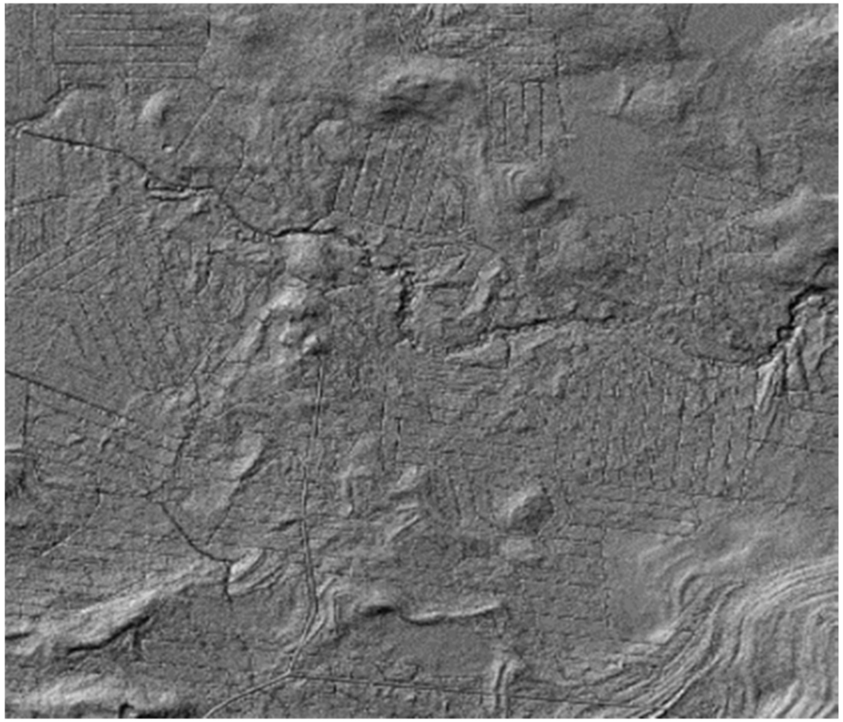
	Perm, 0.1 ha	Perm, 0.25 ha	Perm, 0.5 ha	Perm, 1.0 ha	Matalansalo 2007	Kuortane 2009	Kuhmo 2012 [1]
Pine							
V	0.50	0.42	0.38	0.34	0.28	0.31	0.33 (0.27)
G	0.47	0.40	0.37	0.33	0.27	0.24	0.31 (0.24)
N	0.45	0.36	0.33	0.10	0.41	0.27	0.37 (0.30)
D	0.23	0.17	0.15	0.15	0.17	0.09	0.16 (0.14)
H	0.17	0.12	0.10	0.09	0.08	0.16	0.11 (0.09)
Spruce							
V	0.50	0.45	0.43	0.40	0.33	1.28	0.63 (0.47)
G	0.41	0.36	0.34	0.31	0.31	1.21	0.68 (0.57)
N	0.30	0.22	0.18	0.14	0.38	1.20	0.83 (0.77)
D	0.24	0.20	0.18	0.16	0.20	0.40	0.40 (0.39)
H	0.18	0.15	0.13	0.12	0.18	0.39	0.37 (0.37)

Table 5. Stand level RMSE values relative to the mean in the Perm and Finnish studies. In Perm, the results are presented for four different levels of aggregation.

	Perm, 0.1 ha	Perm, 0.25 ha	Perm, 0.5 ha	Perm, 1.0 ha	Matalansalo 2007	Kuortane 2009	Kuhmo 2012 [1]
Deciduous							
V	0.58	0.45	0.40	0.42	0.62	1.08	0.69 (0.60)
G	0.51	0.37	0.34	0.33	0.52	0.90	0.74 (0.67)
N	0.47	0.33	0.30	0.34	0.48	0.97	0.96 (0.91)
D	0.48	0.42	0.39	0.38	0.25	0.37	0.39 (0.38)
H	0.44	0.39	0.37	0.35	0.18	0.27	0.35 (0.34)
Total							
V	**0.21**	**0.18**	**0.15**	**0.12**	**0.10**	**0.19**	**0.15 (0.07)**
G	**0.19**	**0.16**	**0.14**	**0.11**	**0.09**	**0.14**	**0.16 (0.10)**
N	**0.20**	**0.15**	**0.13**	**0.10**	**0.16**	**0.22**	**0.34 (0.31)**
D	**0.09**	**0.6**	**0.4**	**0.02**	**NA**	**NA**	**0.10 (0.08)**
H	**0.05**	**0.03**	**0.02**	**0.01**	**NA**	**NA**	**0.10 (0.09)**

Additional LiDAR products

- Digital terrain model
- Road construction
- Forest fire risk assessment
- Forest management planning
  - Clear cuts, thinnings
  - Intensive forestry
- Flood risk assesment



Conclusions

- LiDAR can be used for various forest inventory problems
- LiDAR can improve the efficiency of the inventory by providing accurate results without extensive field campaign
  - Time savings
  - Cost savings
- In Finland, the key to success has been collaboration between government, research and private sector

Benefits of LiDAR based forest inventory

- Government
  - Real and up-to-date situation of the forest data
  - Improves the forest leasing process
  - Data management in digital format
    - Better monitoring and control of forest use
- Forest industry
  - More efficient use of forest resources
  - Better reporting to government
  - Decrease investment risks
- Other beneficiaries
  - Science, infrastructure engineering, ecology

Thank You!

tuomo.kauranne@arbonaut.com