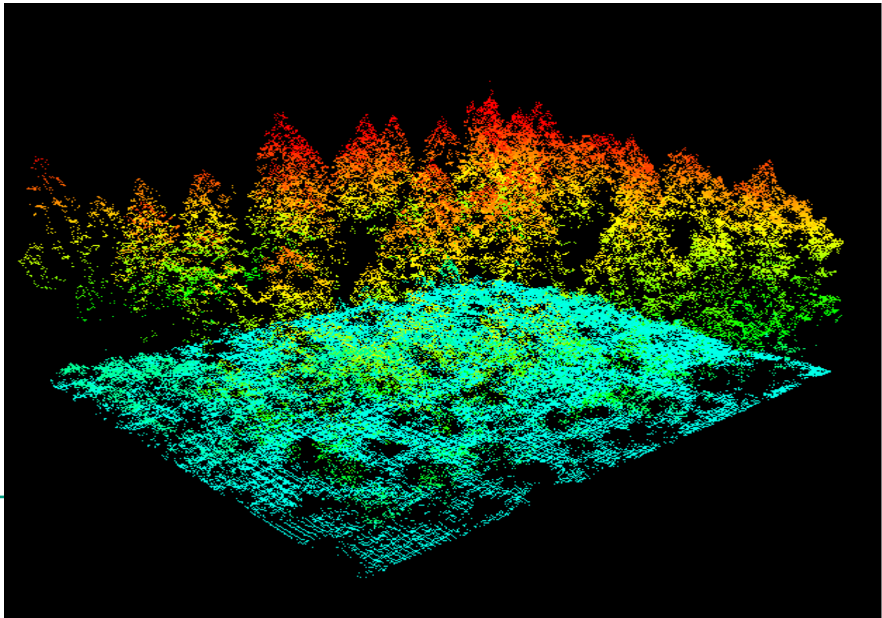
The starting point

2006:

- 21 years of experience in estimating and monitoring forests with 3D data from airborne laser scanning
- 19 years since the first experiment with digital photogrammetry to acquire 3D data about forests
- Use of 3D data operational in forest inventory on full scale

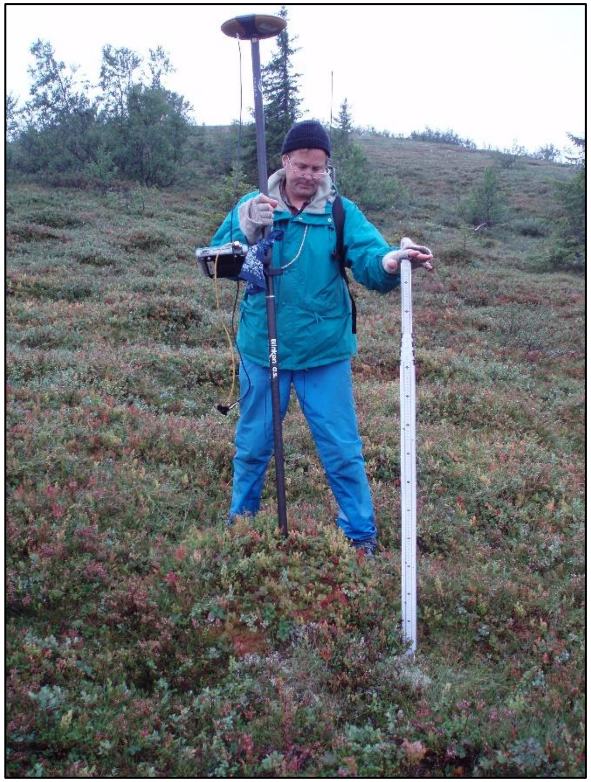


Question – can the technology and approaches be transferred to estimation of small trees in other environments, e.g. boreal-alpine transitions?

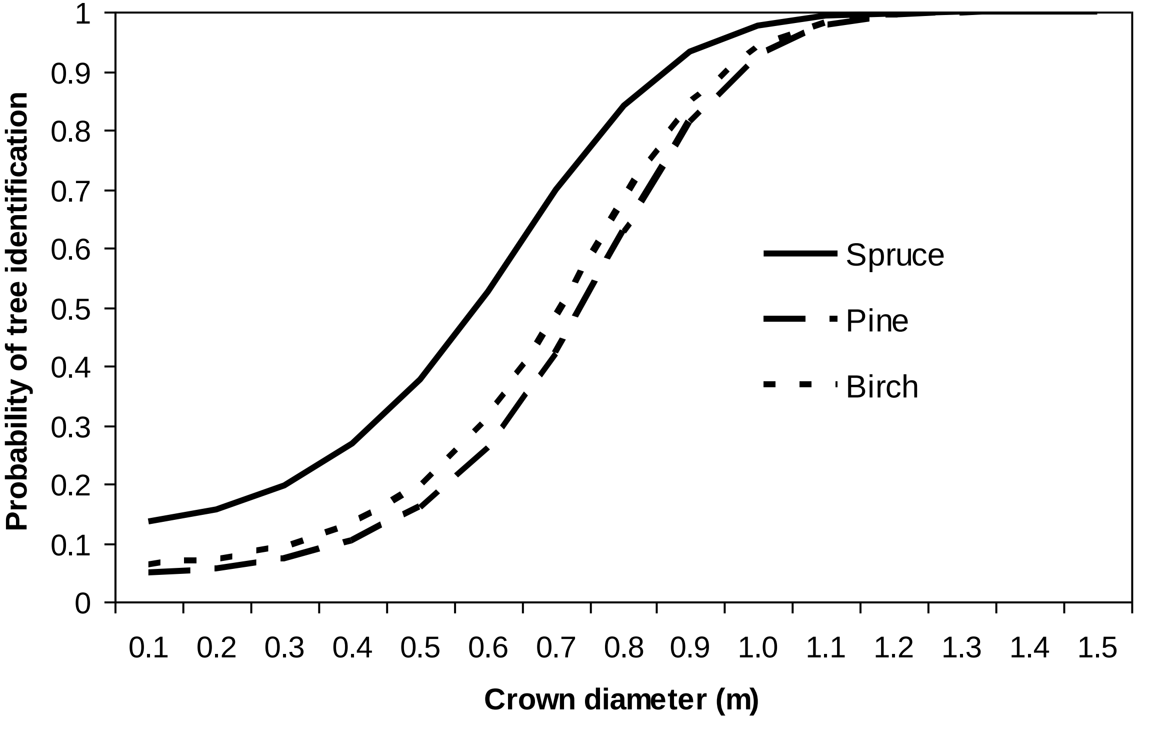
- How sensitive are the data to small trees (the penetration problem)?
- How sensitive are the data to sensor and flight configurations?
- How small trees can we «see» given uncertainty in the elevation of the terrain surface?
- How can we differentiate between trees and other non-tree objects?
- How can we estimate tree sizes over larger areas?
- How can we estimate change over time?
- Can 3D data from images replace ALS?
- …
- …

Many of these questions answered in a NORKLIMA project 2008-2015

Differentiating objects



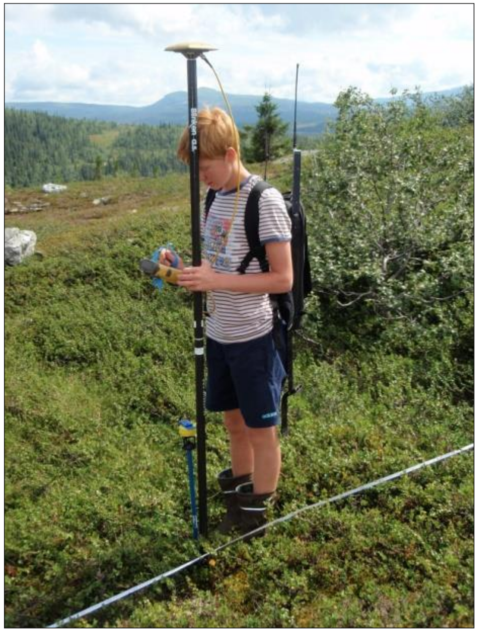
Sensitivity of trees



Accuracy of terrain surface: all data are normalized to the terrain

Systematic errors and precision:

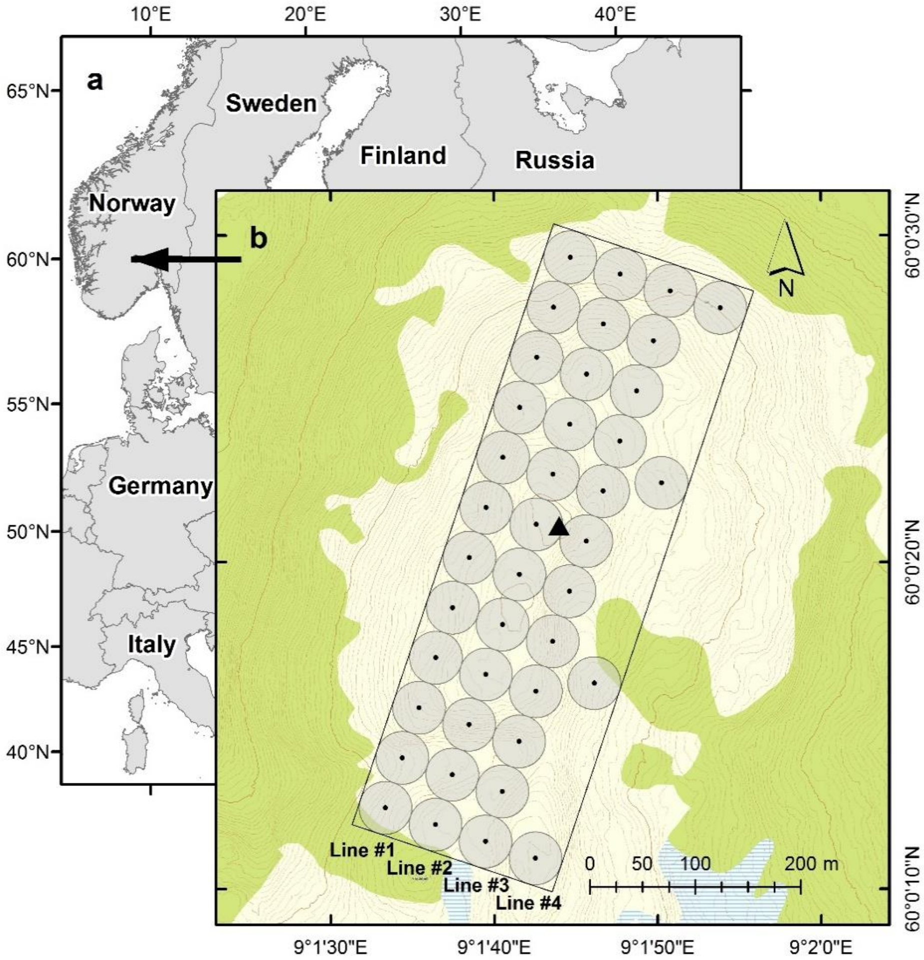
- For different surface materials
- Vegetation height
- Form: concave vs. convex (on a meter-scale)
- ……



Monitoring of subtle changes in vegetation height

Objectives:

- Estimate change in tree height
- Estimate change in height of all vegtation
- Develop and demonstrate a method for change monitoring adopting the estimation techniques



Monitoring of subtle changes in vegetation height

2006-2012

252 trees measured twice (h=1.52 m)

159 non-trees (rocks, tussocks, hummocks)

Coincident ALS data

Monitoring of subtle changes in vegetation height

Simple model for height change:

$$\Delta h = \beta_0 + \beta_1 h_{\text{max2006}} + \beta_2 h_{\text{max2012}} + \varepsilon$$

Simple model for TREE:

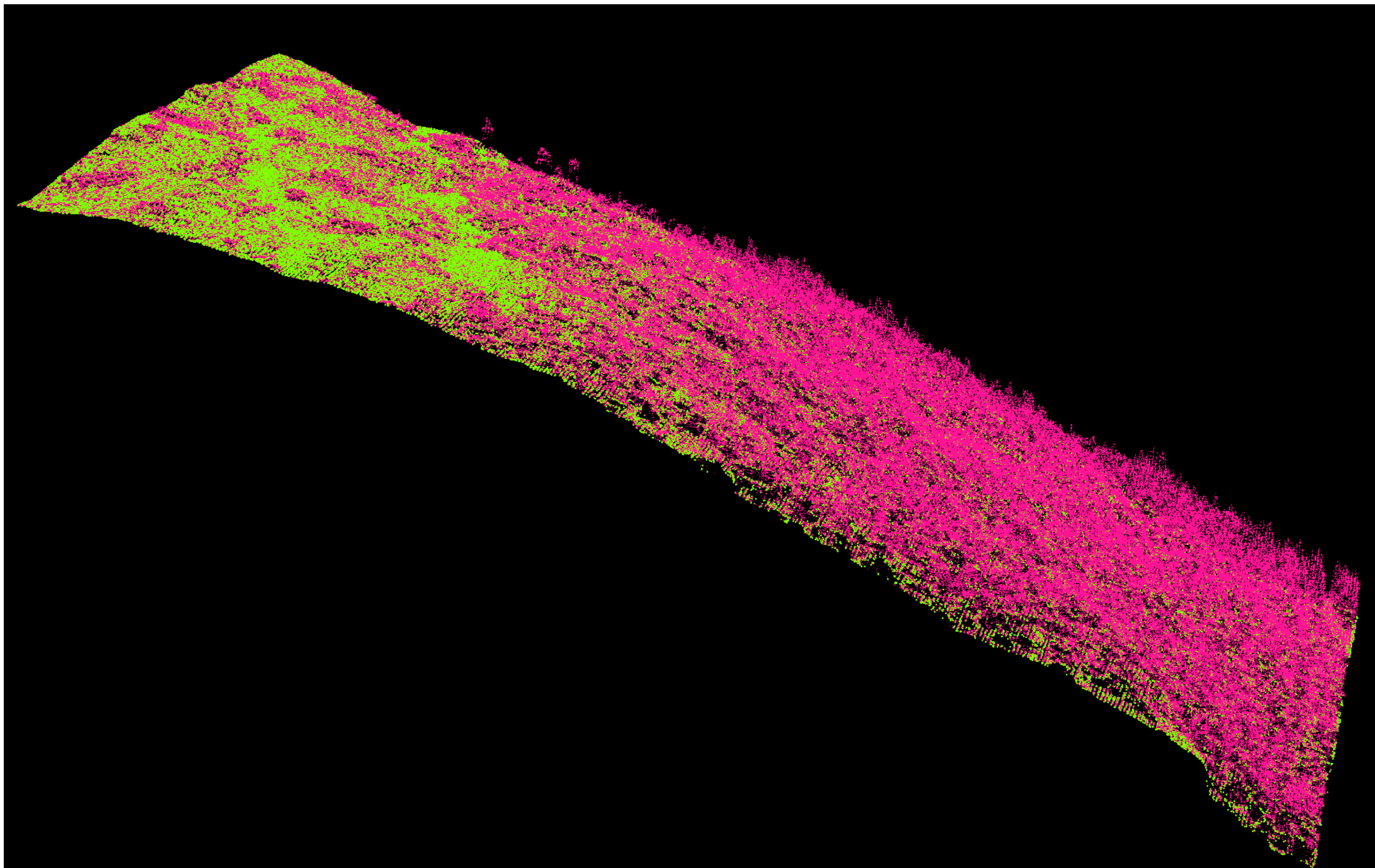
$$\log\left(\frac{\pi_{\text{TREE}}}{1 - \pi_{\text{TREE}}}\right) = \beta_1 + \beta_2 h_{\text{max2006}} + \beta_3 h_{\text{max2012}} + \varepsilon$$

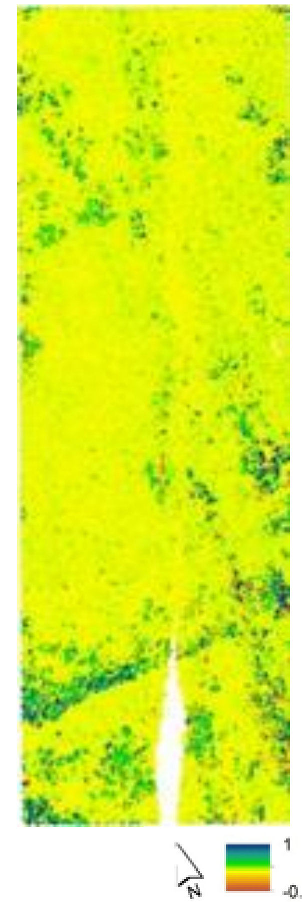
Monitoring of subtle changes in vegetation height

How to express predicted change:

Monitoring of subtle changes in vegetation height

How to express predicted change:





Monitoring of subtle changes in vegetation height

Variance estimation – model-based inference:

$$\widehat{\mathrm{Var}}(\hat{\mu}) = \frac{1}{N^2}\left[\sum_{i=1}^{N}\sum_{j=1}^{N}\widehat{\mathrm{Cov}}_{\mathrm{sam}}\left(\hat{\mu}_i, \hat{\mu}_j\right) + \sum_{i=1}^{N}\sum_{j=1}^{N}\widehat{\mathrm{Cov}}_{\mathrm{res}}\left(\hat{\varepsilon}_i, \hat{\varepsilon}_j\right)\right]$$

We have two models used in a sequence:

- Use bootstrapping with an integrated resampling loop for first component
- Quantify residual variance and covariance with empirical data

Monitoring of subtle changes in vegetation height

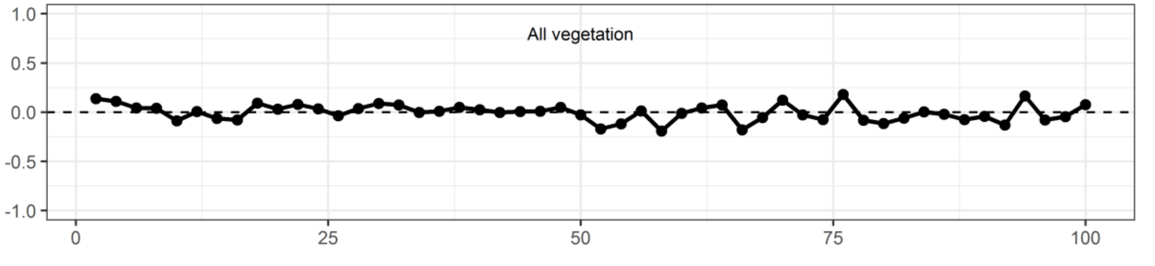
Variance estimation – results

$$\widehat{\mathrm{Var}}(\hat{\mu}) = \frac{1}{N^2}\left[\sum_{i=1}^{N}\sum_{j=1}^{N}\widehat{\mathrm{Cov}}_{sam}\left(\hat{\mu}_i, \hat{\mu}_j\right) + \sum_{i=1}^{N}\sum_{j=1}^{N}\widehat{\mathrm{Cov}}_{res}\left(\hat{\varepsilon}_i, \hat{\varepsilon}_j\right)\right]$$

>95%

Var_{res}<5%

Residual autocorrelation

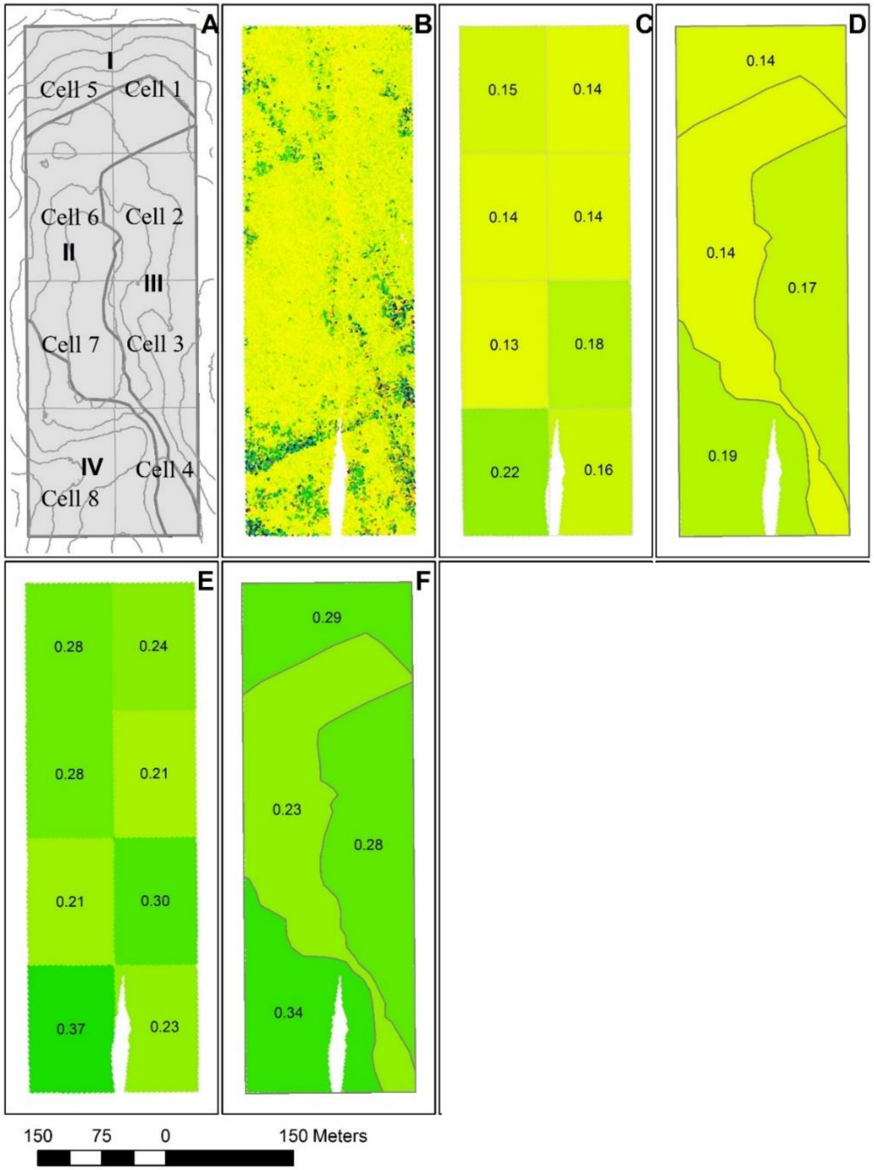


Monitoring of subtle changes in vegetation height

Resulting estimates per 1.5 ha unit and for polygons

A=area
B=Vegetation height change
C=Vegetation height change
D=Vegetation height change
E=Mean tree height change
F=Mean tree height change

CI entire area vegetation change:
0.12-0.20 cm
CI entire area tree height change:
0.24-0.34 cm



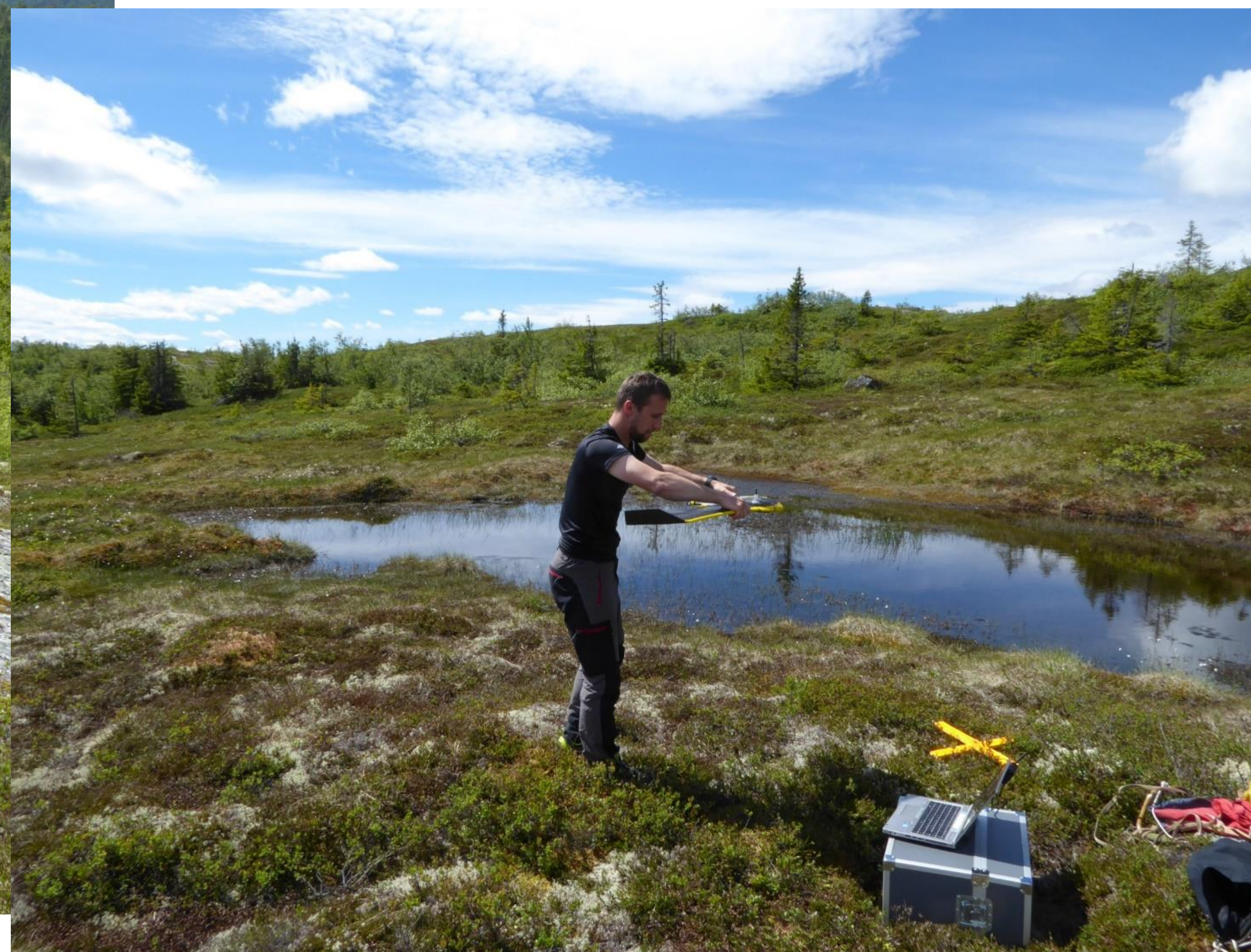
Next problem: can 3D from image matching replace 3D data from lasers?

Background – data acqusitions

	2006	2007	2010	2012	2017	2022
Field data	~400 Trees/non-trees		>400 Ground points Non-trees	~400 trees	~450 trees	>500 trees
RS data	ALS	3X ALS		ALS	ALS Drone image	Drone laser

Can 3D data from image matching replace lasers?

Comparing estimates from ALS and images



Comparing estimates from ALS and images

Objective:

- Compare estimates and precision of heights of trees and other vegetation for ALS and DAP*

*DAP=digital aerial photogrammetry

DATA from 2017:

389 trees (h=1.72 m)

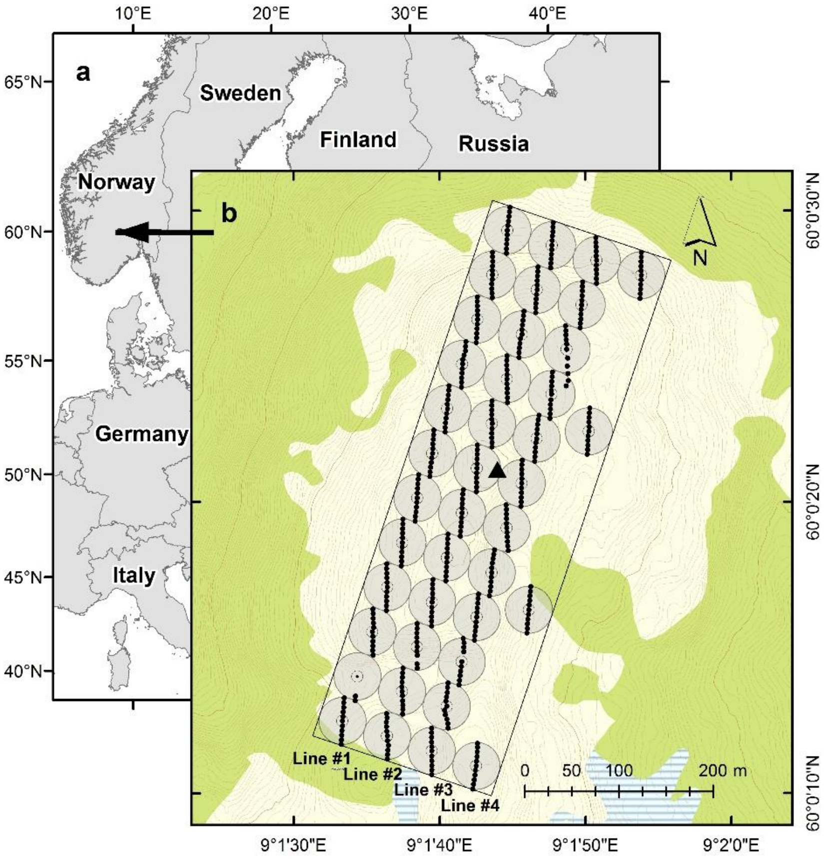
327 none-tree ground points

ALS and image data

Analysis:

Simple linear model for height prediction

Model-based inference

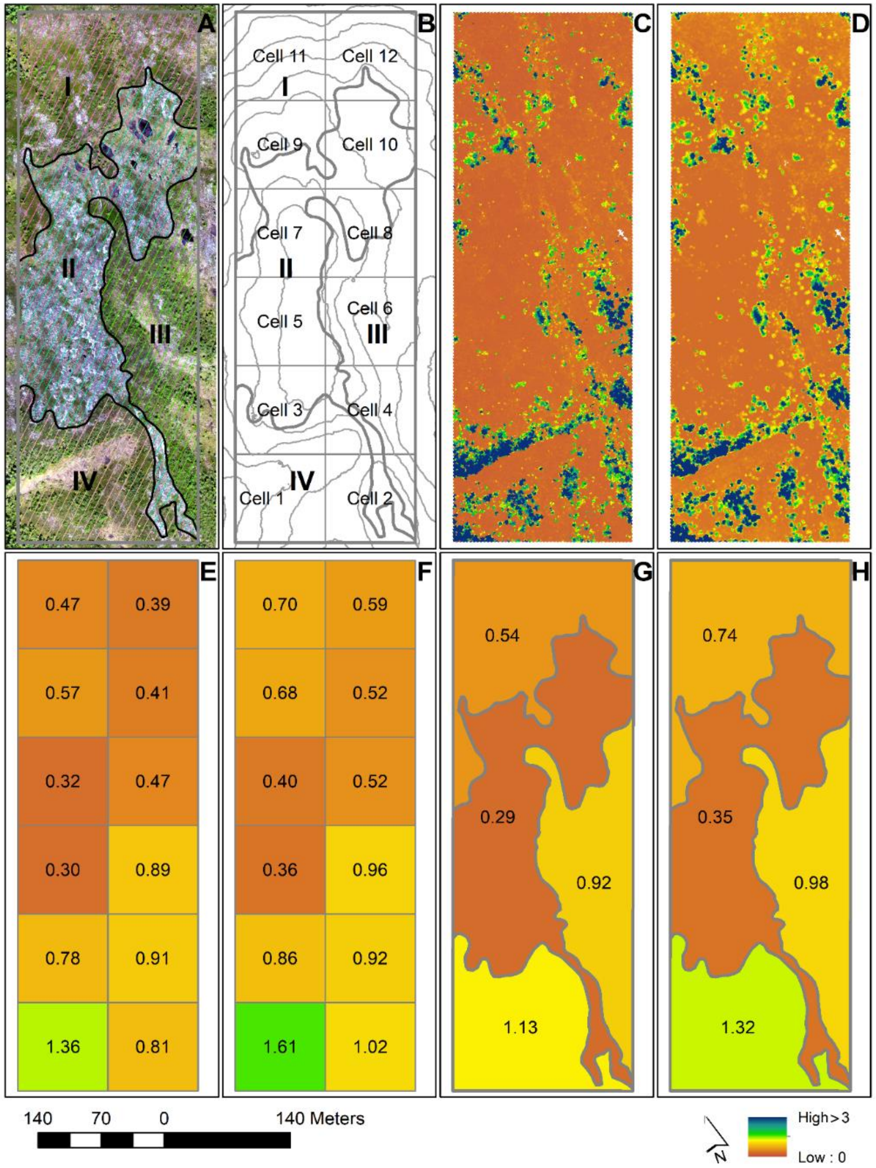


Comparing estimates from ALS and images

Resulting estimates per 1.5 ha unit and for polygons

A/B=area
B=Vegetation height change
C=Vegetation height ALS
D=Vegetation height for DAP
E=Mean vegetation height for ALS
F=Mean vegetation height for DAP
G=Mean vegetation height for ALS
H=Mean vegetation height for

Mean vegetation height entire area ALS:
0.64 m (SE=0.014 m)
Mean vegetation height entire area DAP:
0.76 m (SE=0.018 m)



Conclusions

- ALS data seems to enable precise change estimation of small trees and other vegetation for spatial units of 1.5 ha (or smaller?)
- DAP estimates of vegetation height are precise for 1.5 ha spatial units but less precise than ALS
- There is an unexplained statistically significant difference in height between ALS and DAP despite local model calibration. Further studies with comparison to ground «truth» are required