Tree height measurements and tree growth estimation in a mire environment using digital surface models

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Introduction, motivation, aims

- Project within Swiss Federal Mire Conservation Program
- Monitoring of mires and their vegetation over space and time
- **Why?** Federal Decree on Protection of Mires of National Importance (Federal Constitution Art.78 §5)
- **Who?** WSL in partnership with the Swiss Federal Office for the Environment, Forest and Landscape
- **How?** 103 mire biotopes of national importance were selected with a stratified sampling method for monitoring
- Interdisciplinary cooperation between Geomatics and Landscape / Forest Inventories, also between "sister" institutions

Introduction, motivation, aims

- Within above program (but not only), determination of important parameters

  - vegetation (mainly tree) height

  - vegetation growth -> change over time (here mainly of height)

  - more broadly, determination of a 3D canopy model and of its changes, and possibly of other derived parameters

- For the above, currently only airborne sensors can be employed for cost-efficient, accurate-enough, large-sample studies. Main airborne sensors: cameras (digital or digitised film, ALS)

Introduction, motivation, aims

- Comparison of manual and automated image measurements and ALS for determination of above parameters, with special focus on automated image processing and DSM generation.

  - wide availability of images

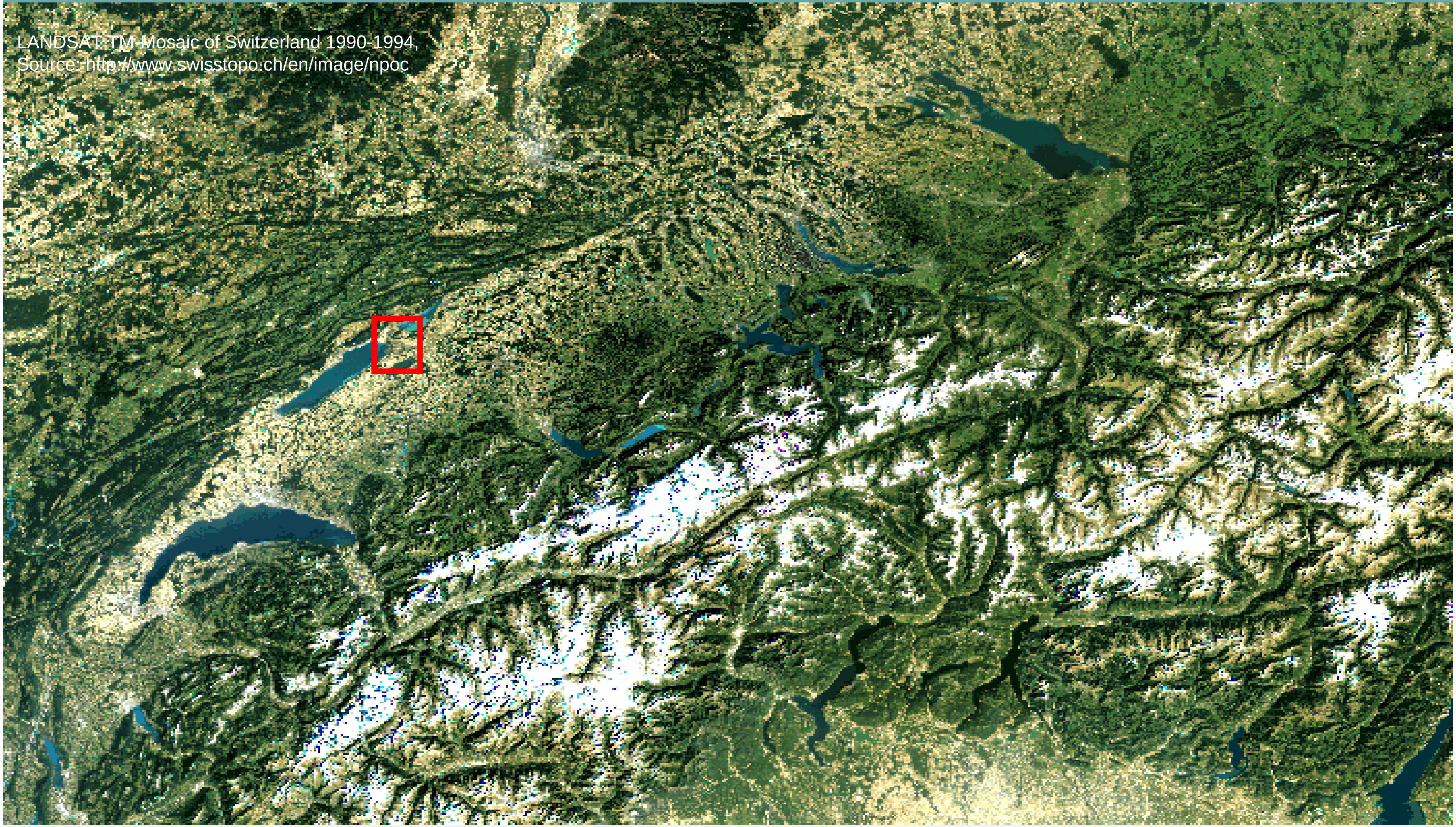
  - determination of other parameters from images

- Aims:

  - automation (time and cost reduction), accuracy, completeness

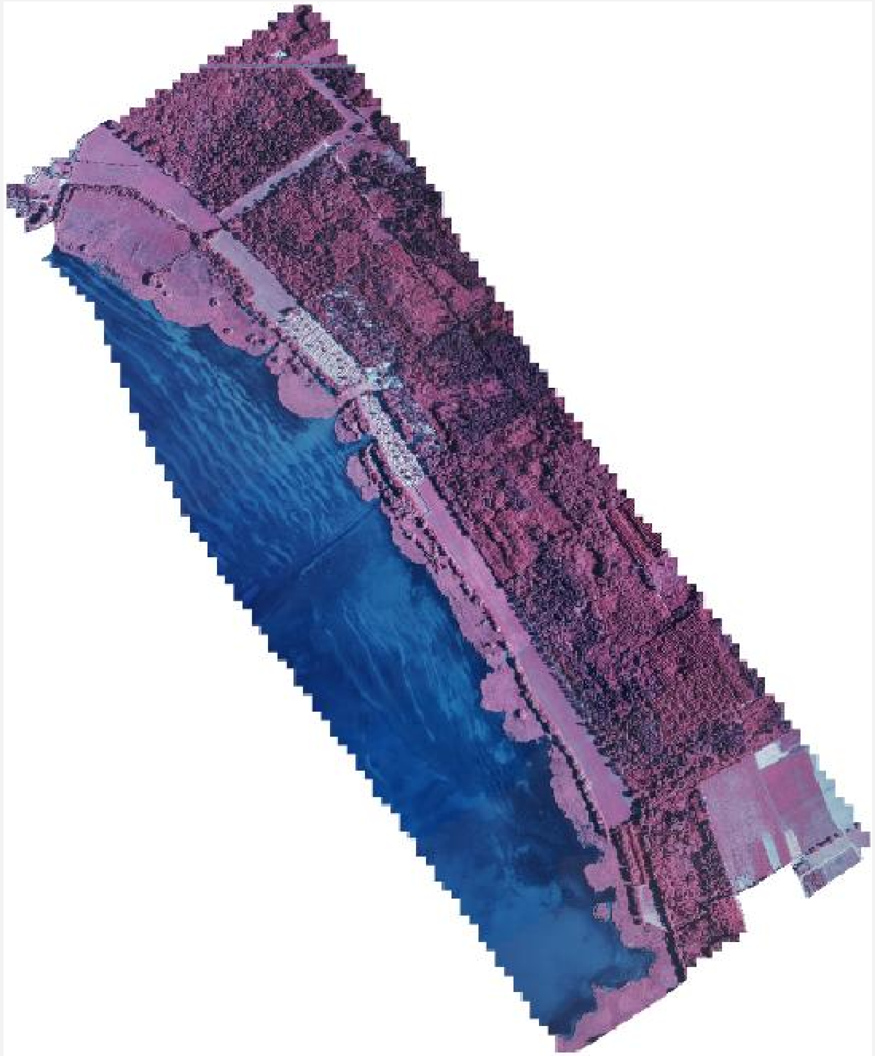
  - test of good quality methods and software developed at ETHZ for DSM generation

Test Site


LANDSAT TM-Mosaic of Switzerland 1990-1994,
Source: http://www.swisstopo.ch/en/image/npoc

Test site 'Le Fanel'

47°00' N / 7°03' E



CIR orthoimage 2003

Test site 'Le Fanel'



• Flat terrain (12 m height range) in an environmentally sensitive area along the lakeshore of Lake Neuchatel.

• Mire surrounded by forested area, with an extent of approx. 3 km^2, and mostly characterized by dense deciduous forest (80%) & coniferous forest (20%) with few storm losses and some new reforestations.

• Broad-leaved woodland with meadows and pastures are typical for the site.

Input data

- CIR aerial images (G, R, NIR), 1:5,000 scale, scanned with 14 microns (7 cm GSD), 75% forward overlap, acquired on Aug. 10th 1998 and Aug. 15th 2003
- Processing of one strip, with 4 images
- Image orientation using 12 GCPs, measured with DGPS. Different orientation procedures for 1998 and 2003 images, remaining y-parallax in some of the 2003 images.
- Airborne Lidar data (Swisstopo), first and last pulse recorded, average point density 1 / 2 m^2, accuracy (1 sigma), 0.5 m in open spaces, 1.5 m in vegetation, acquired October 2002 (leaves on). ALS DSM edited.
- ALS data processed at WSL
  -> DTM and DSM with 1 m average point distance, interpolated to 1m regular grid by ETHZ
- Manual stereoscopic measurement of 181 tree tops in 1998 and 2003 images, different tree types, but not small ones among tall ones. Estimated height accuracy 0.4-0.5 m.

Methods

- Tree height

  - measurement of highest visible tree point

  - measurement of ground.

    - In most cases impossible.

    - Measurement (manual) of ground points nearby, if terrain flat. - Reduction of DSM from matching to DTM using programs as for ALS, e.g. TerraScan, SCOP++ Lidar (but more difficult)

    - Here, use of ALS DTM for both 1998 and 2003 images. Ground can change height due to tree undergrowth. Here, assumption that there is no ground deformation.

- Tree growth

  Multitemporal comparison of tree heights. Difficulty in identifying the same point. Is it better to use a small neighbourhood of tree top?

Methods

- Automatic DSM generation from images

  a) using commecial package SocetSet (BAE Systems)

    - ATE method, use of cross-correlation
    - adaptation of matching strategy to mires (no elimination of small objects like bushes)
    - 0.5 m regular grid

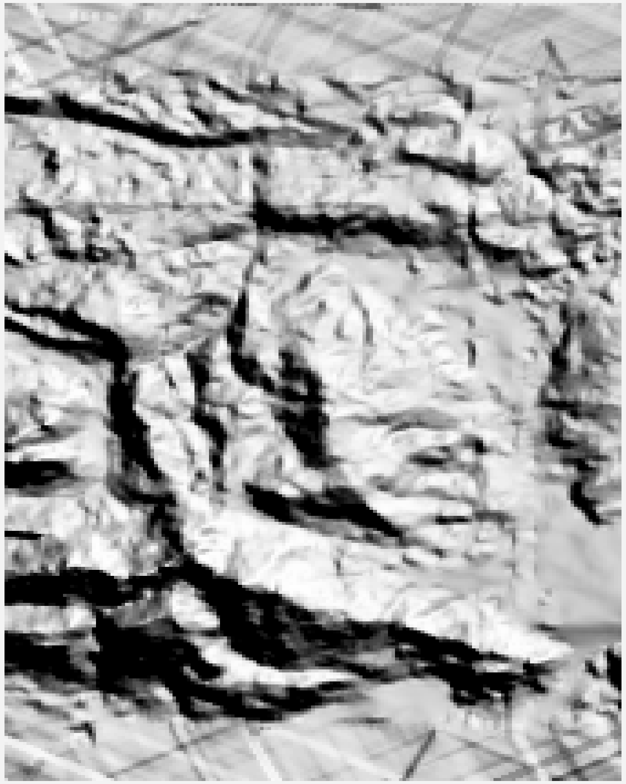
  b) using ETHZ method, software Sat-PP

    - operational, quasi-full photogrammetric processing package
    - satellite and aerial sensors, frame and linear array geometry (ADS40 in preparation)
      - 0.5 m regular grid interpolated from point cloud of similar density
    - adaptive 7^2-15^2 pixel patch size
    - no least-squares matching used
    - total processing time incl. grid interpolation ca. 5 h

- In all cases, DSM from matching was not manually edited

Automatic DSM generation with commercial systems

- Matching results, espec. with commercial systems, can vary a lot depending on the selection of the matching parameters (which have sometimes an unclear definition or at least effect).
- Below 3 automatically generated DSMs with DPW770, SocetSet. Left and right ATE, middle Adaptive ATE (effect of different matching strategies and matching parameters is clear).


Difficulties in image matching of forests

- Difficulties when matching one image dataset
  - occlusions
  - repetitive patterns
  - shadows
  - perspective differences
  - semi-transparent surfaces
  - rough surfaces, surface discontuities, mixed surfaces

Above problems worse:

  - when no leaves
  - when using feature-based image matching (points, edges)

- Possible improvements
  - use of more than 2 images (large forward and side overlap)
  - use of geometric constraints
  - sophisticated matching methods, automatic blunder detection
  - match densely, use small GSD to reduce surface smoothing

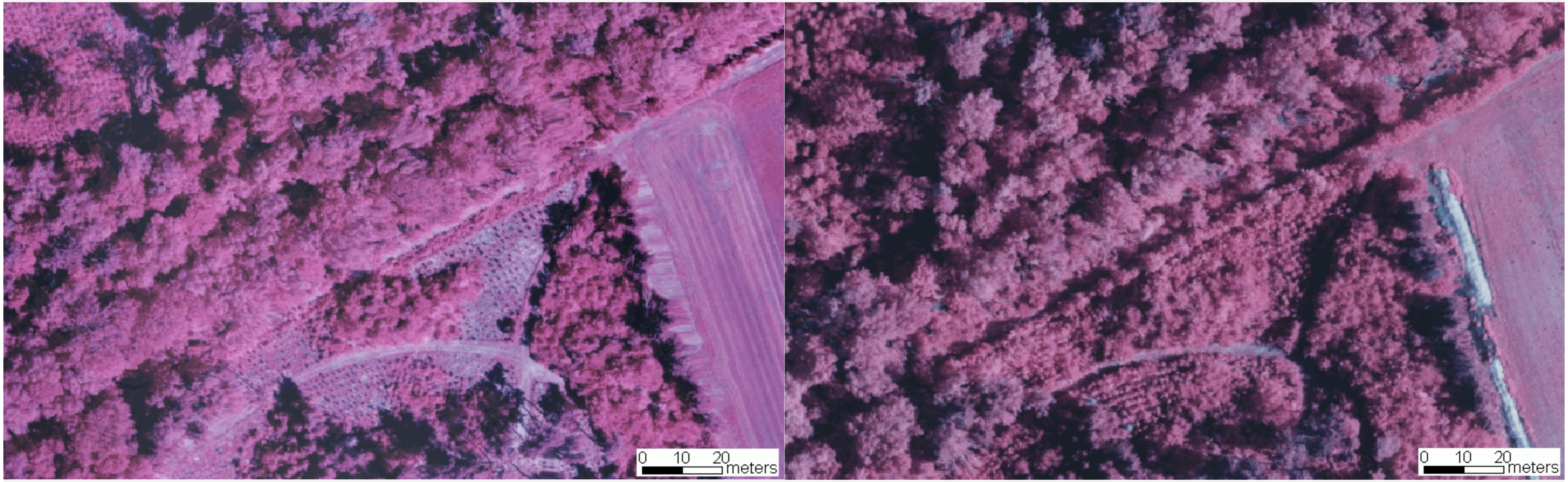
Difficulties in image matching of forests

- Difficulties when comparing multitemporal image datasets
  - different image scales
  - different image quality
  - different growth state
  - different illumination and atmospheric conditions
  - different viewpoints
  - different image orientation
- Possible improvements
  - fly almost on the same date
  - good and similar illumination and atmospheric conditions
  - high sun elevation
  - leaves on
  - similar image acquisition parameters, using modern capabilities for precise navigation and pin-point photography

Manual measurement of reference data

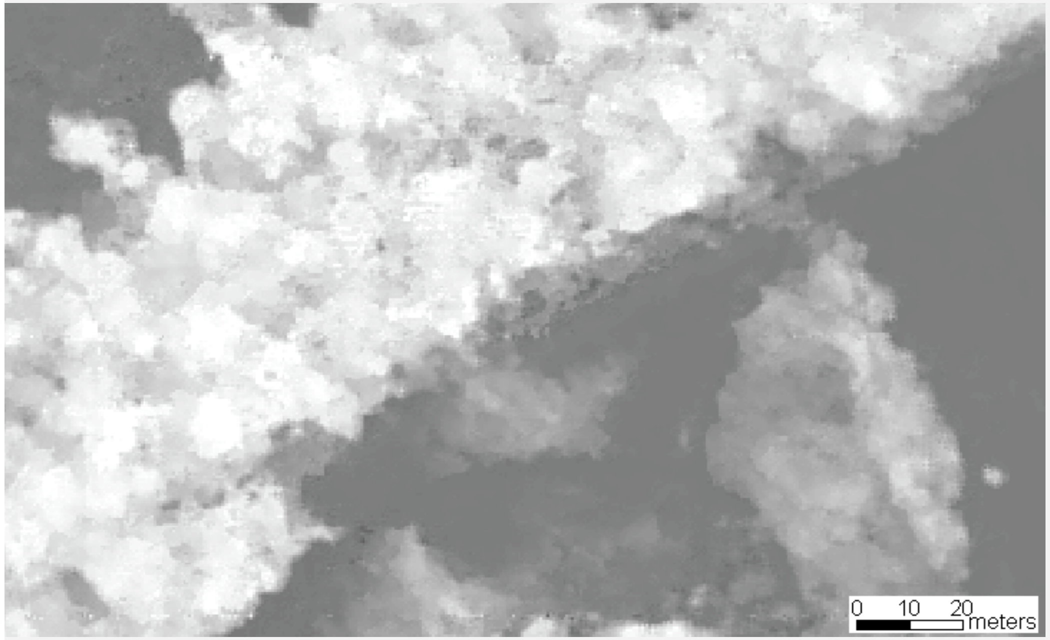
- Difficulty in identifying the same point
- Possible planimetric differences between DSMs due to orientation differences (not checked in this case)
- Possible change of planimetric position of tree highest point
- Here,
  - reference points removed if planimetric difference between 1998 and 2003 tree top > 2 m
  - remaining points had in most cases planimetric difference less than 1 m
  - average planimetric position of 1998 and 2003 measurements used to interpolate height in DSMs from matching and ALS and compared to manual measurements. Average planimetry used to smooth image orientation differences and reduce uncertainty of point identification.
- ALS interpolated heights were corrected by 1 / 5 (2003-1998) of average tree growth and compared to 2003 manual measurements

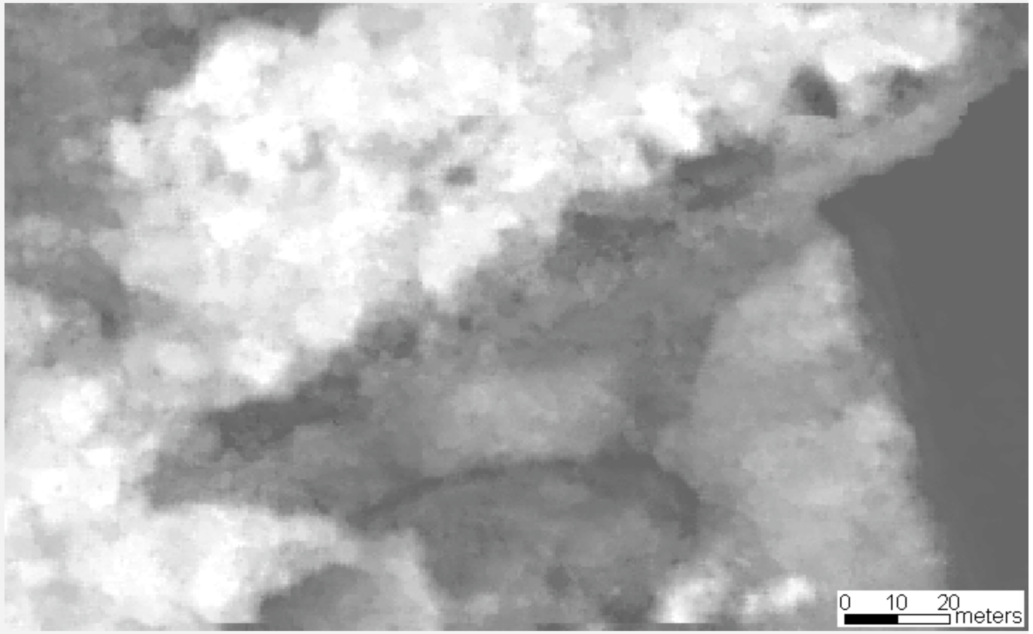
Results



1998 and 2003 CIR images. Significant differences in color, texture, shadows etc. Slightly poorer image quality in 1998 dataset.

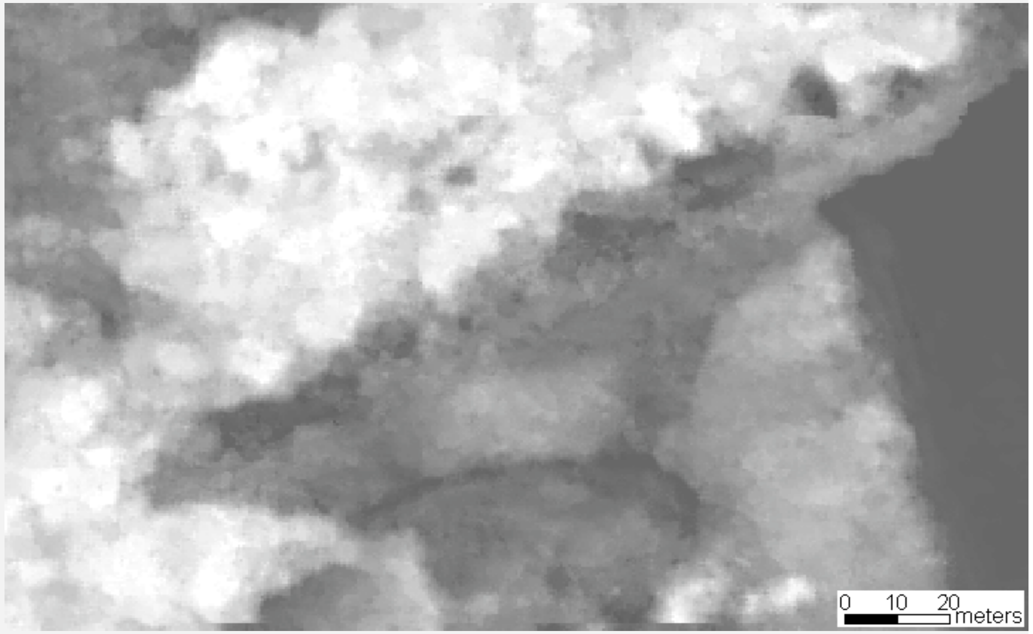
Results





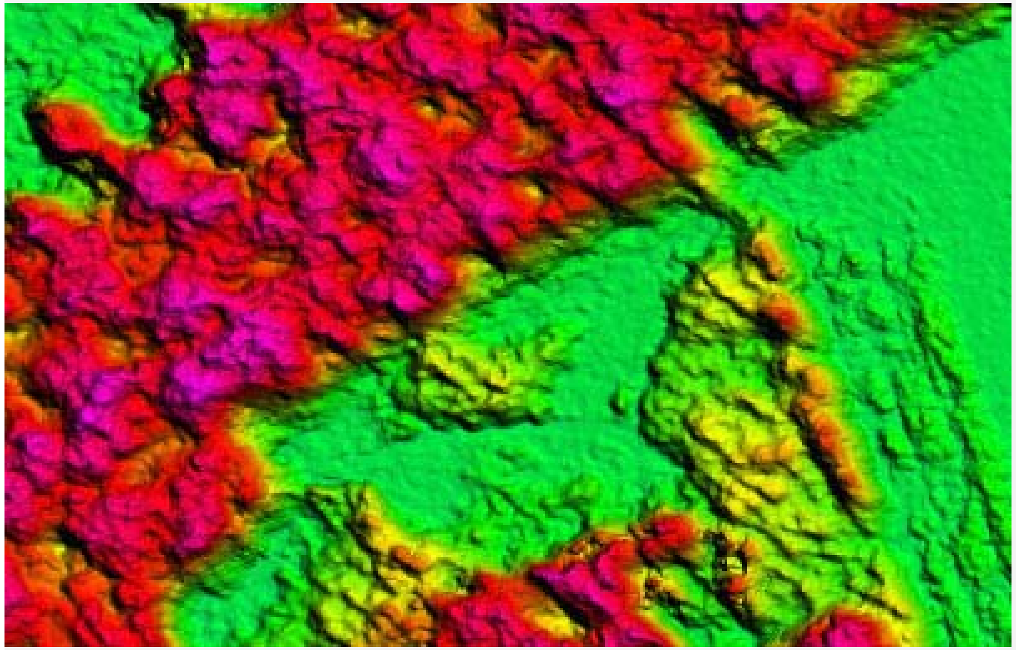
Grey level coded DSM using SocetSet from 1998 and 2003 CIR images.

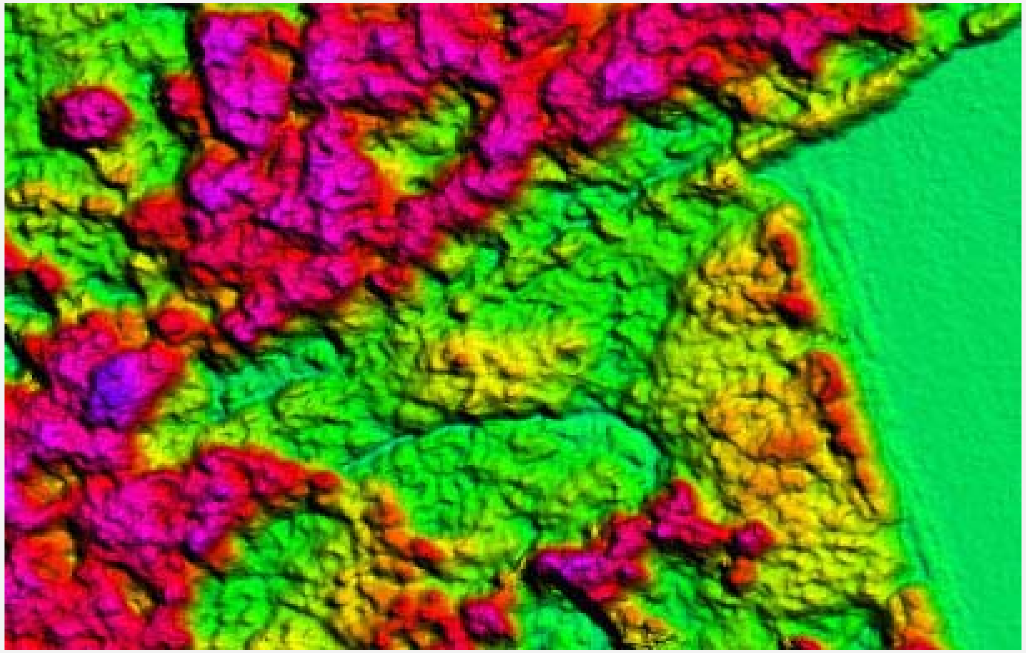
Results



2003 CIR image and DSM from SocetSet.

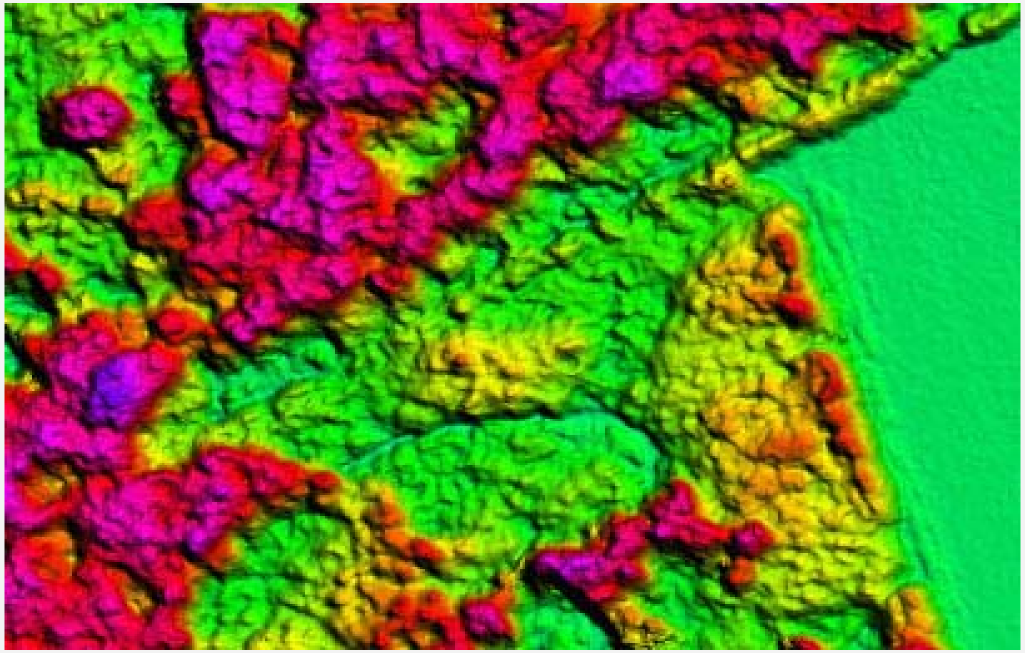
Results





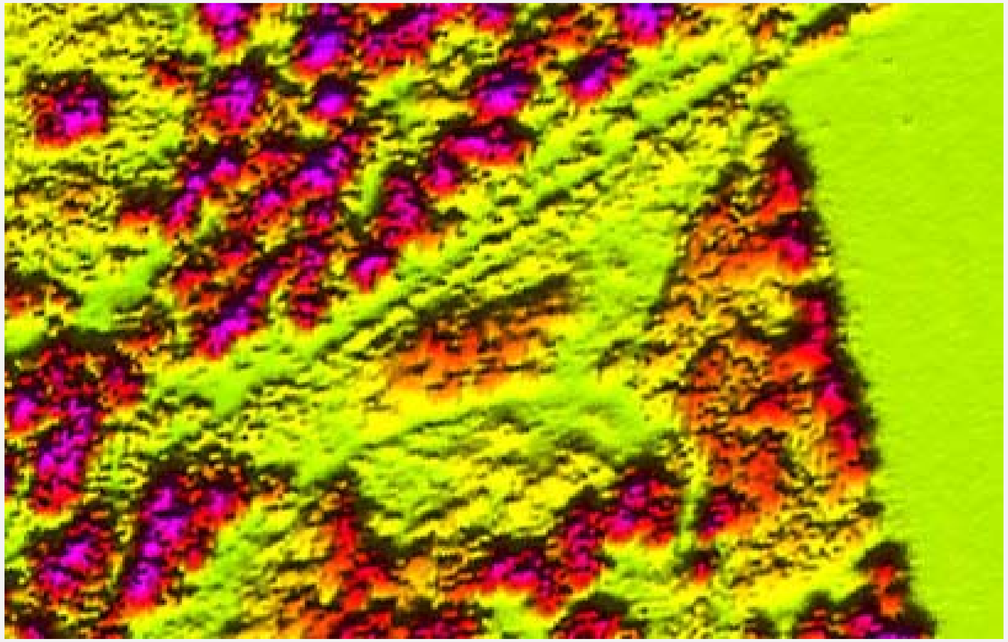
DSM from 1998 and 2003 using ETHZ matching method.

Results



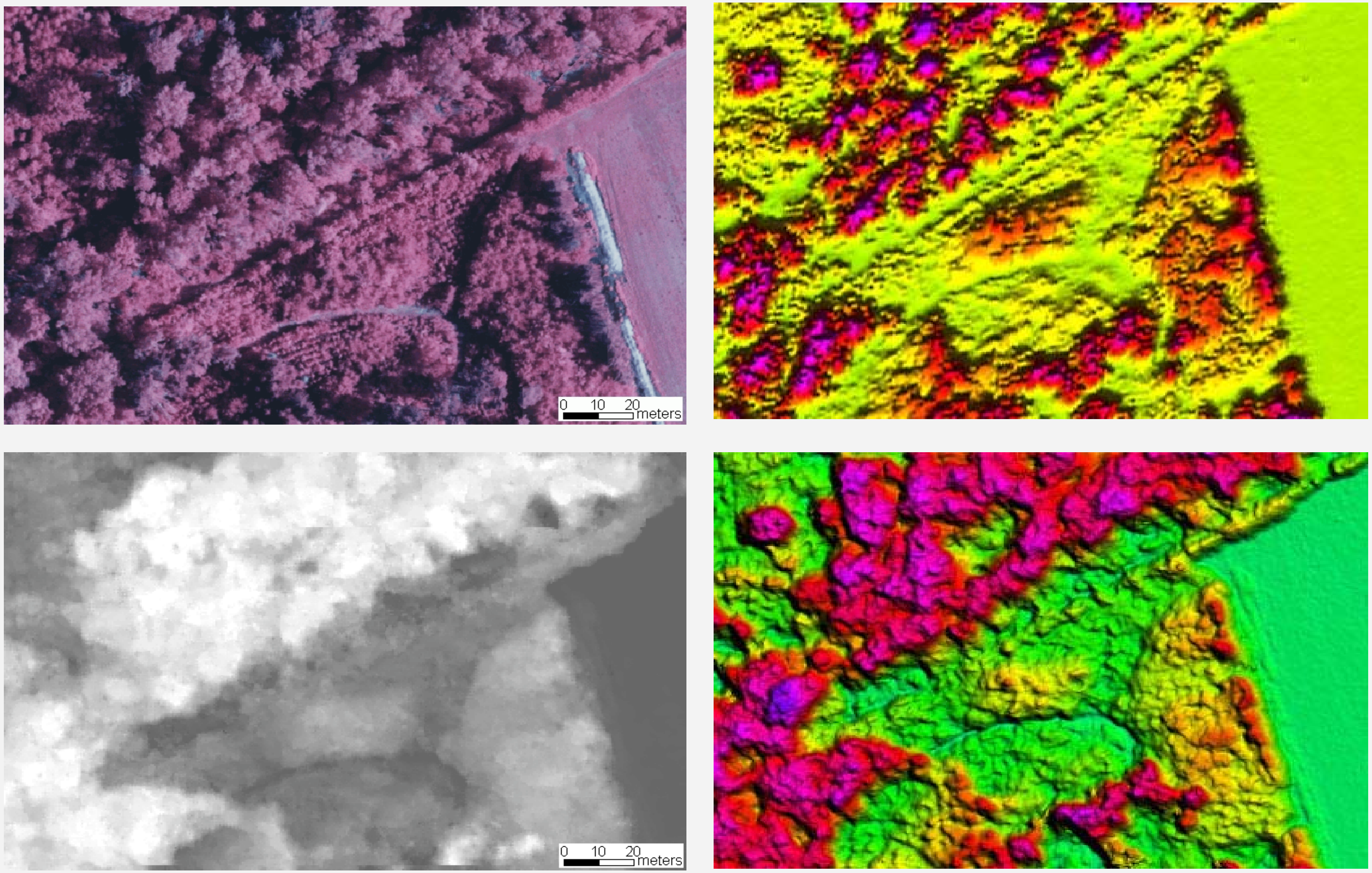
2003 CIR image and DSM using ETHZ matching.

Results



2003 CIR image and 2002 Lidar DSM.

Results



Clockwise: 2003 CIR image, 2002 Lidar DSM, DSM using ETHZ method and SocetSet.

Results – Tree height accuracy

Statistics of DSM differences with reference data (interpolated tree height in DSM – reference height). 181 points (manual tree heights 4 - 33 m), results in (m).

	Average with sign	RMS	Max. / # absolute differences > 1.5 & 5 m
ETHZ DSM, 1998 images	-1.36	2.35	-16.92 / 44 & 6
ETHZ DSM, 2003 images	-0.85	1.68	-18.06 / 31 & 1
ALS DSM, 2002 data, (corrected for 2002 to 2003 difference)	-6.44	7.83	-21.77 / 168 & 100

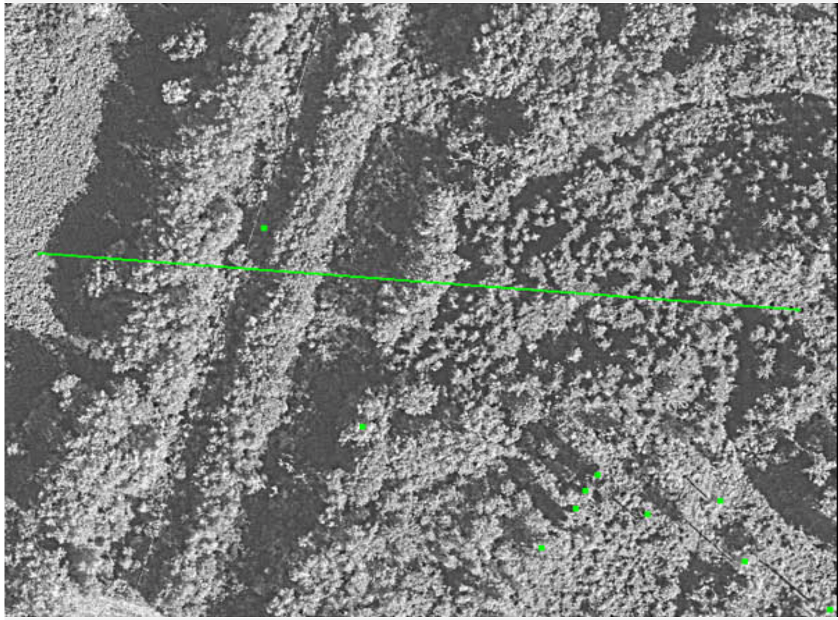
Results – Tree Growth

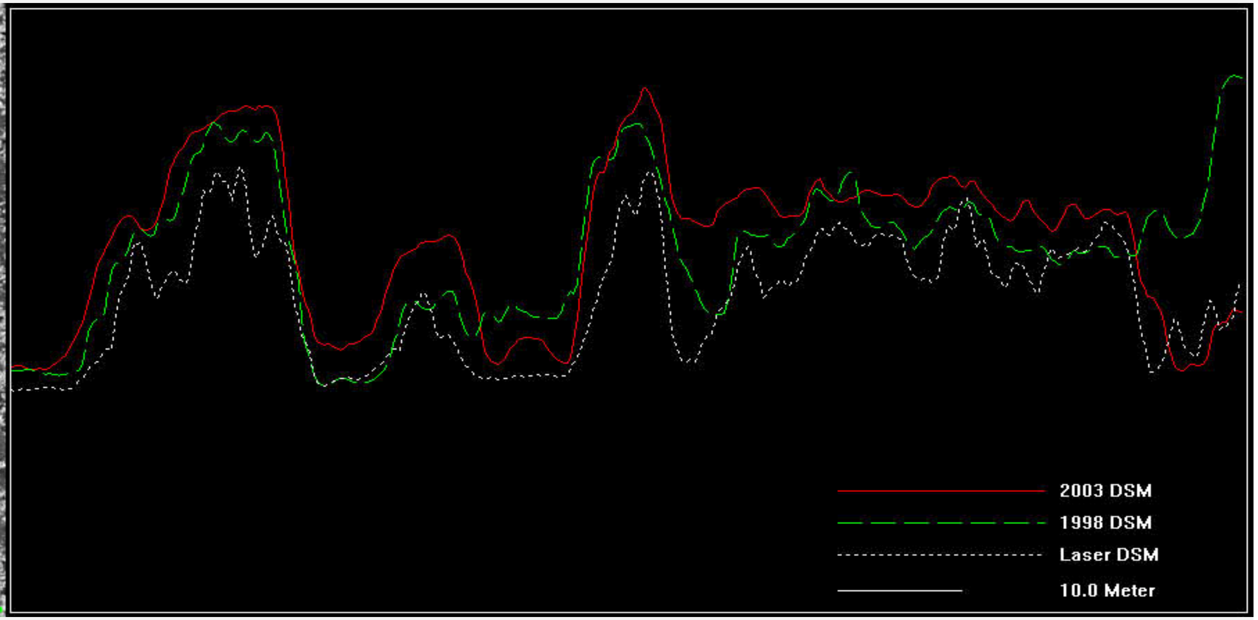
Statistics of tree height differences between 2003 and 1996. 181 points, results in (m).

	Manual measurements	ETHZ matching	Growth differences (ETHZ matching – manual)
Average with sign	1.53	2.04	0.51
RMS	2.01	3.45	2.41

Results – Comparison of DSMs

Profile though two ETHZ and ALS DSMs. Left 2003 image.





Results – Comparison of DSMs

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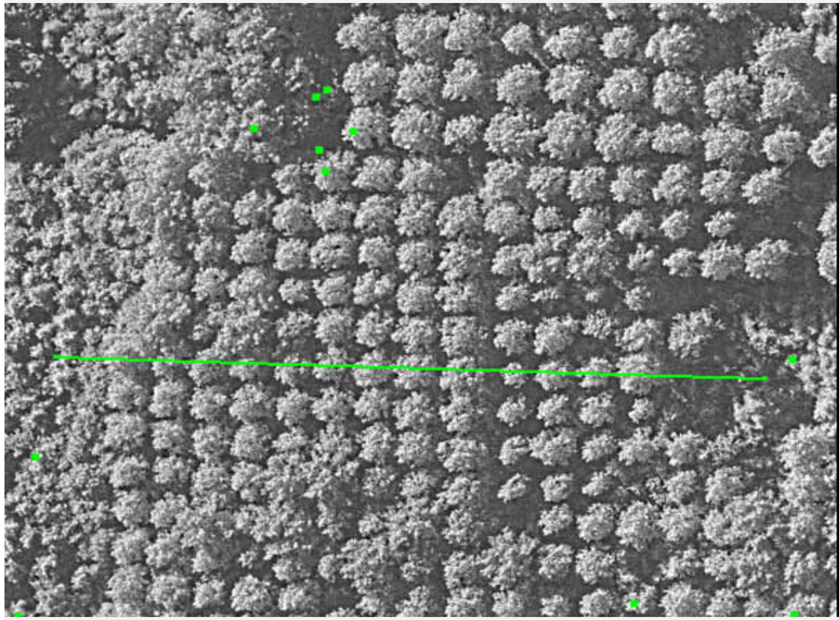
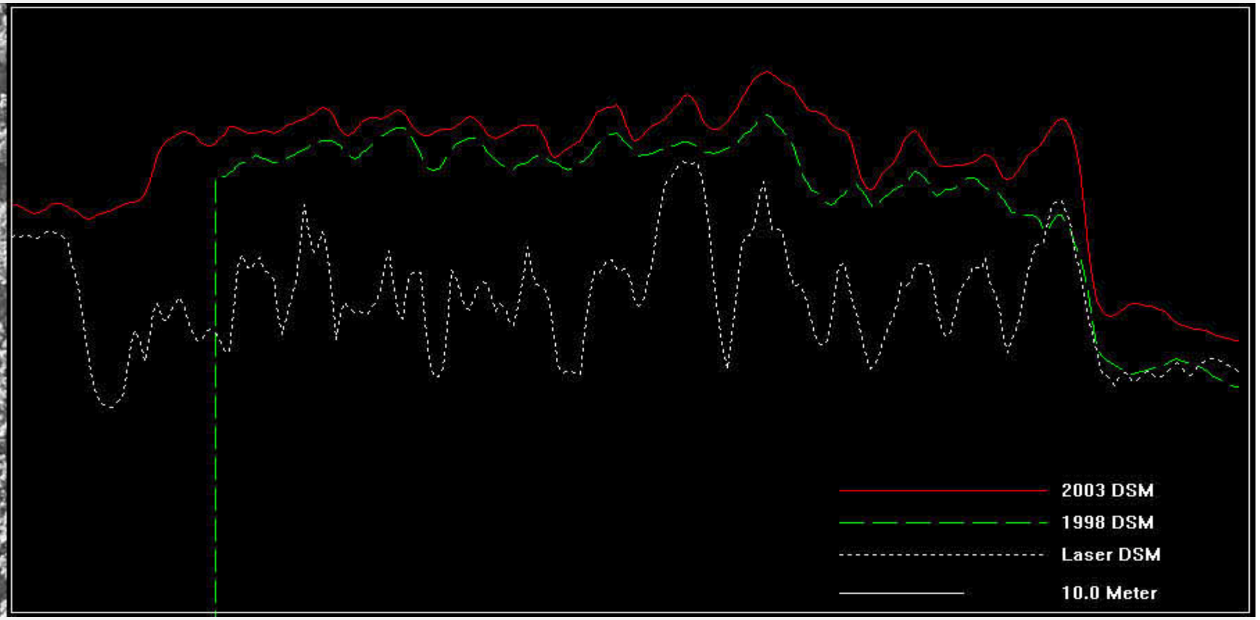




Results – Discussion

- SocetSet results inferior to ETHZ method
- Both matching and ALS DSMs underestimate tree height (will always happen)
- Error statistics influenced by interpolating a regular grid and modelling errors
- ALS DSM

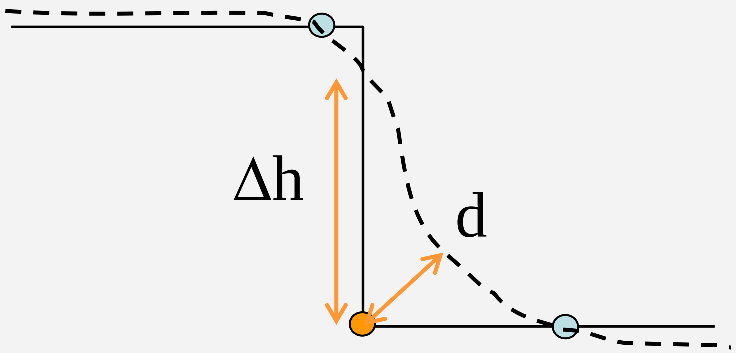
- seems more crisp (less smooth) but looks quite irregular
- quality of ALS DSM in forests questionable (not acquired for forestry applications)
- statistics show poorer accuracy than matching DSM and more blunders
- ALS DSM measures systematically below the canopy

- ETHZ DSM

- very high point density
- very few blunders, however, small errors remain
- 2003 results better than for 1998 due to image quality
- 2003 results close to manual measurement accuracy, espec. for tree growth
- potential to derive 3D canopy model and growth using the whole tree volume.

Modelling errors

- Quantitative comparison of DTM/DSM to reference data
- Two comparisons:
  - **Height differences (2.5D)**: difference between the heights of reference data and the heights interpolated from generated DTM / DSM.
  - **Euclidean distance (3D)**: normal distance between the surfaces (Geomatic Studio v4.1 by Raindrop)
- Limit of (2.5D) terrain height comparison: even if measurement correct, surface modeling error may cause large height differences (example: step egde below)



Further work and suggestions

- Need of more detailed analysis, e.g.

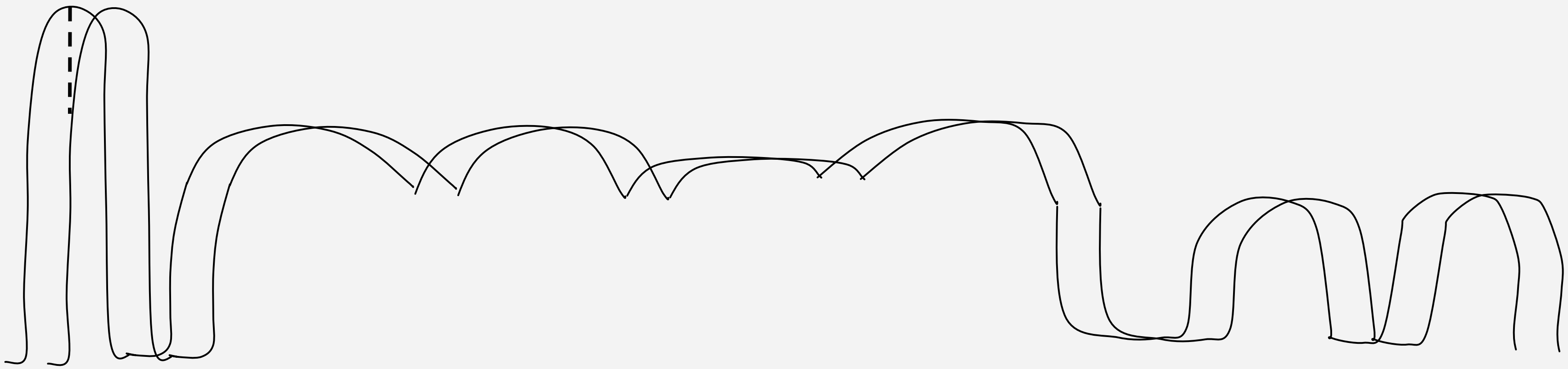
  - reasons for matching errors

  - relation of tree growth to tree type and tree height

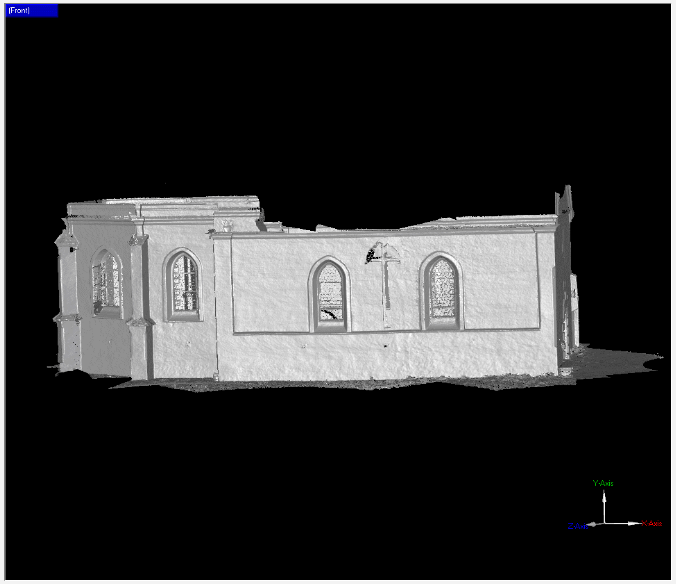
- More tests with better image data (better quality, digital sensors, at least 60% sidelap and 6-wise image coverage of the scene, more similar imaging conditions and orientation). Use of ADS40 data of Swisstopo.
- Need of more extensive and better reference data, including various tree types and sizes and small possibly occluded trees
- Improve co-registration of DSMs for growth analysis
- DTM from manual measurements or good quality existing DTM. Use one DTM for growth analysis
- Derive tree height from local average around the highest point? Could also lead to blunder detection.
- Automate tree area detection and tree height measurement. Combination with information from digital sensors (RGB, NIR, texture). Alternatively, work semi-automatically.

Misregistration of DSMs

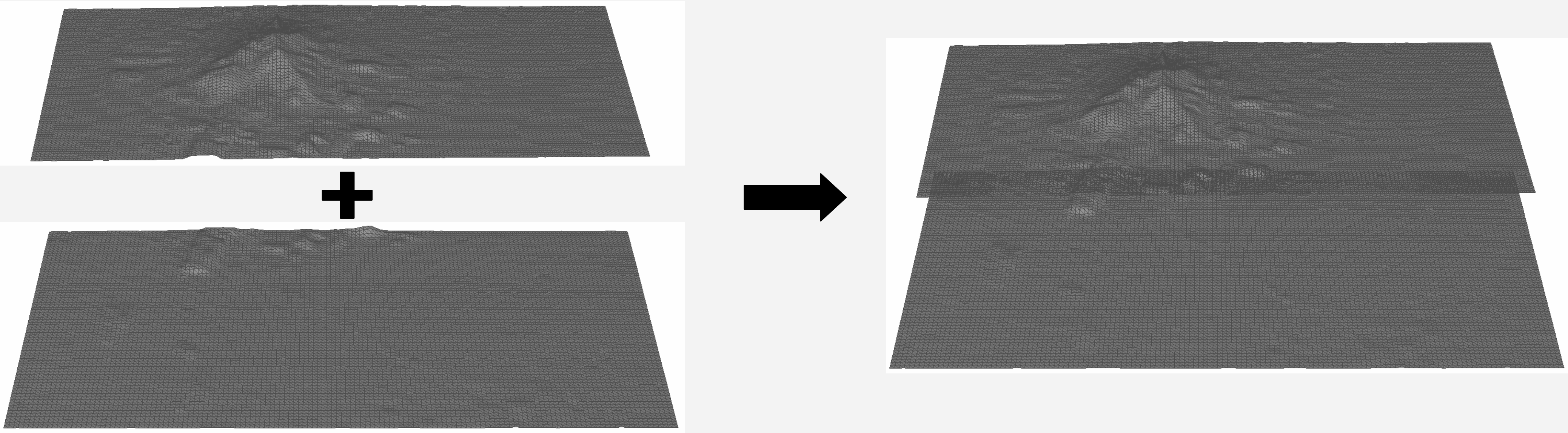
Correct misregistration before performing multitemporal comparisons or with reference data



Co-registration of point clouds using LS3D matching



Co-registration of point clouds using LS3D matching



Further work and suggestions

- Dense automated measurements could lead in spite of errors to correct more global estimates

  - of tree height and other parameters, if number of trees high

  - of tree growth by not taking outliers into account, e.g. for a certain tree type and size, leave out largest and lowest growth values.

- For frequent observation of small areas, possibility to use other platforms, e.g. UAVs, and medium format digital sensors.
- All in all, promising results but need of further tests and increase of automation for tree height and growth estimation