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Semi-automatic detection of burial mounds in forested areas

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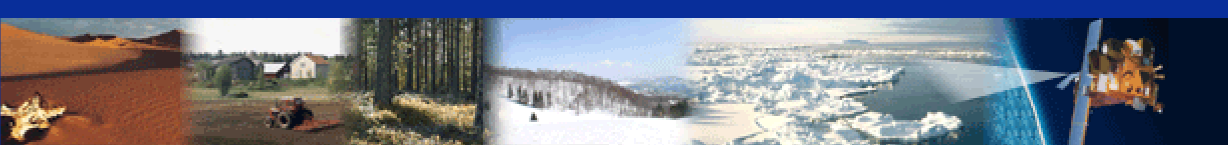
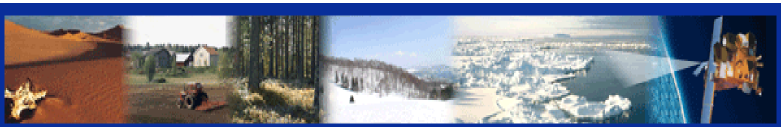


Grave mounds

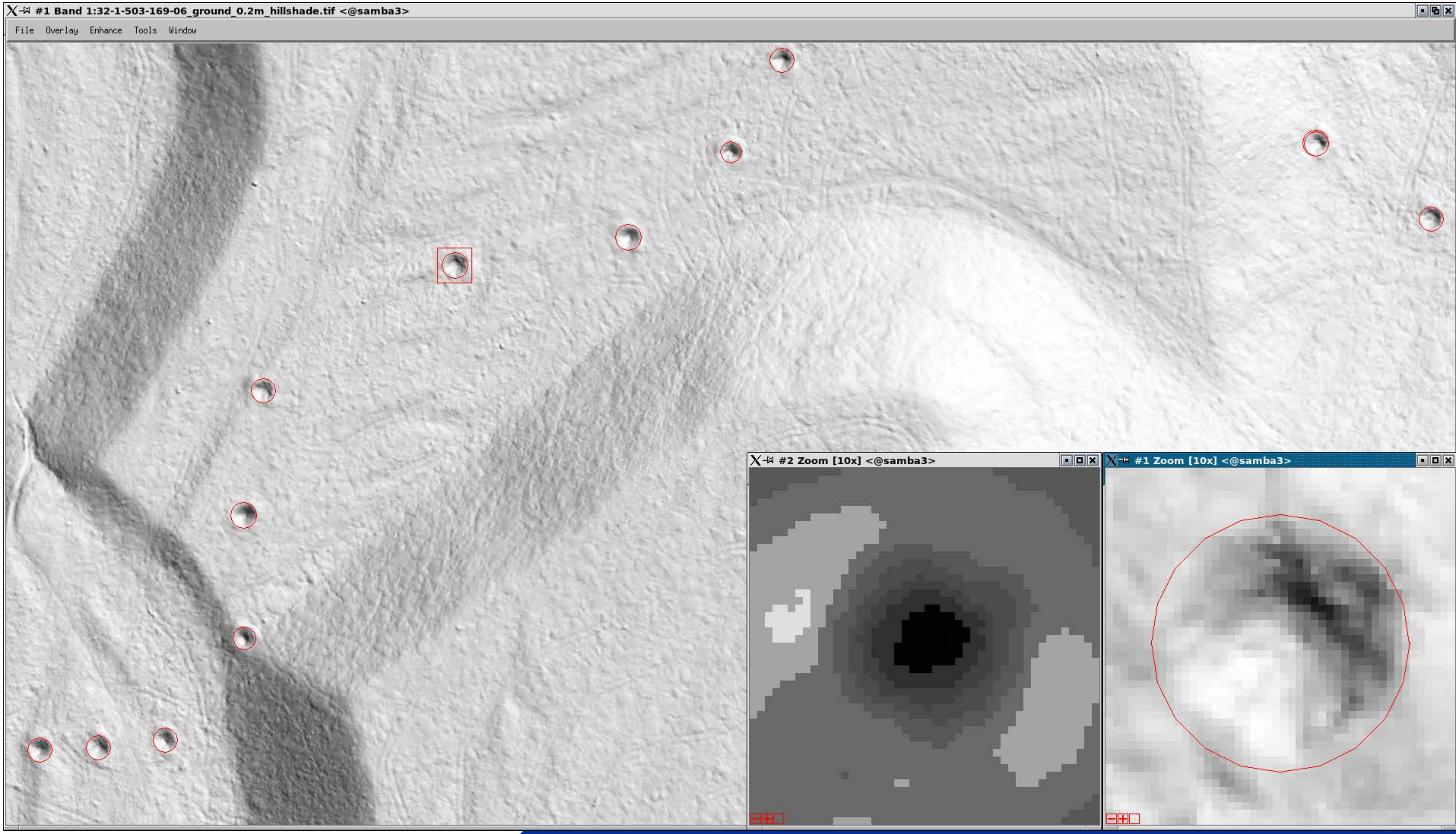
Grave mounds

Semi-automatic detection of archaeology in Norway

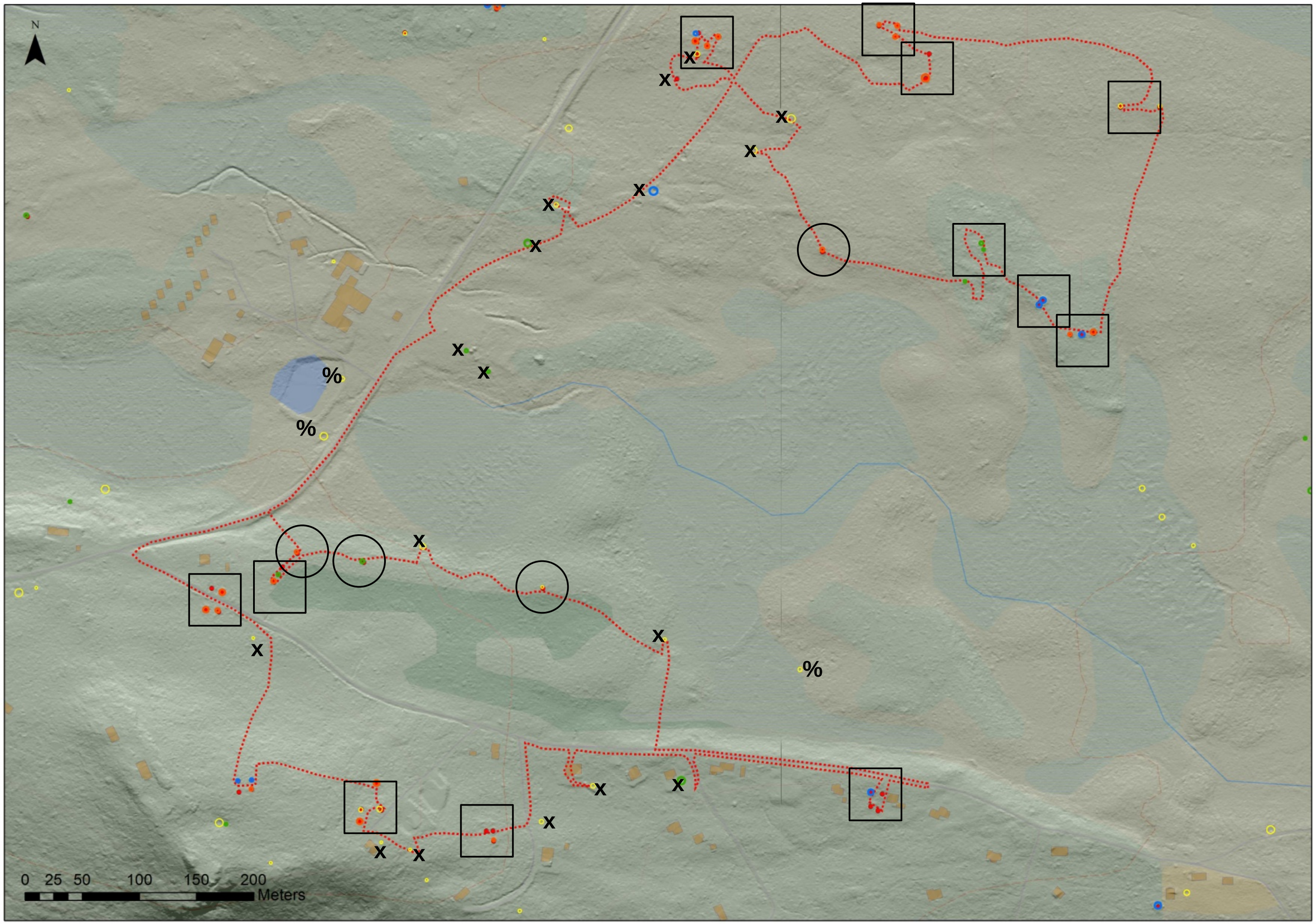
- Traditional mapping of cultural heritage in Norway is inaccurate and incomplete
- Large amounts of very high resolution remote sensing data are being collected
  - **Lidar**
  - Aerial photographs
  - Satellite imagery, e.g., Worldview-2, Quickbird
- Could semi-automatic methods be used on these datasets to map archaeology more accurate and complete?
- Project with Riksantikvaren (Norwegian Directorate for Cultural Heritage) since 2002



Success: mapping pitfall traps in lidar data: Olstappen, Nord-Fron municipality, Norway



Success: Mapping of arhcaeological pits in lidar data: Øystre Slidre



GPS track

Visual detection

Automatic detection, with confidence:

5 – high

4 – medium high

3 – medium

2 – low

From field survey:

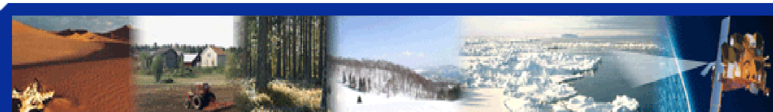
Iron production

Single coal pit

x Not cultural heritage

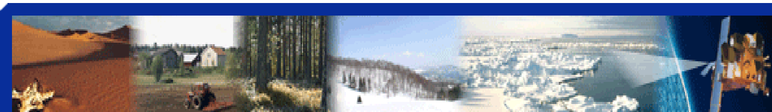
Not inspected in the field:

% Not cultural heritage



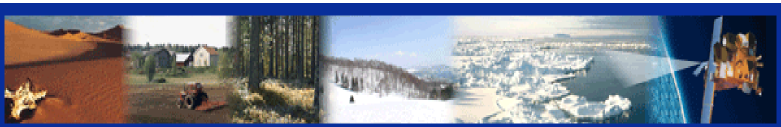
Benefits of semi-automatic detection

- Fast processing of huge amounts of data
- Accurate measurements of position and size
- Provides an initial mapping for subsequent field survey
- Hunting systems and iron extraction sites in Oppland County:
  - The combined use of automatic detection and visual inspection of lidar data, prior to field survey, makes the field survey at least 10 times faster than the traditional method.



Heap detection challenges

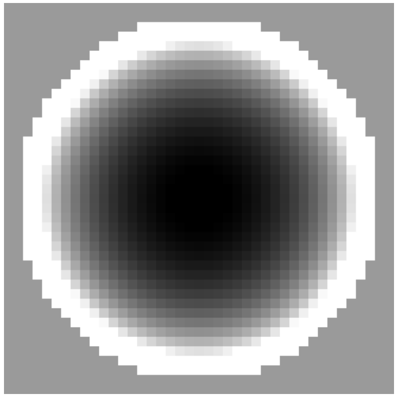
- Grave mounds may be less distinct in the lidar data
- Discriminate between archaeological heaps, modern man-made heaps, and natural terrain features
- **Relevant object properties**
- Classifier
- **Lidar point density on the ground**
  - Acquisition time (leaves on/off)
  - Emitted pulses per m^2
  - Vegetation density, low vegetation



Pattern recognition method

Assumes that objects to be detected may be described using some sort of pattern

1. Identify heap candidates (template matching)
2. **Measure properties of heap candidates**
3. **Classify heap candidates**
    1. **Heap vs non-heap**
    2. **Confidence of heap being achaeology**
4. Visual inspection
5. Field survey



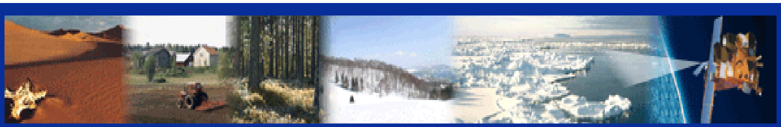
Properties of objects

In use:

- correlation
- radius
- correlation / radius
- minimum height
- average height
- minimum height / radius
- average height / radius
- standard deviation on ring edge
- root mean square (RMS) difference from U-shape
- RMS diff from V-shape
- 50% segment offset
- 50% segment major axis
- 50% segment elongation
- 25% segment offset
- 25%-segment major axis
- 25%-segment elongation

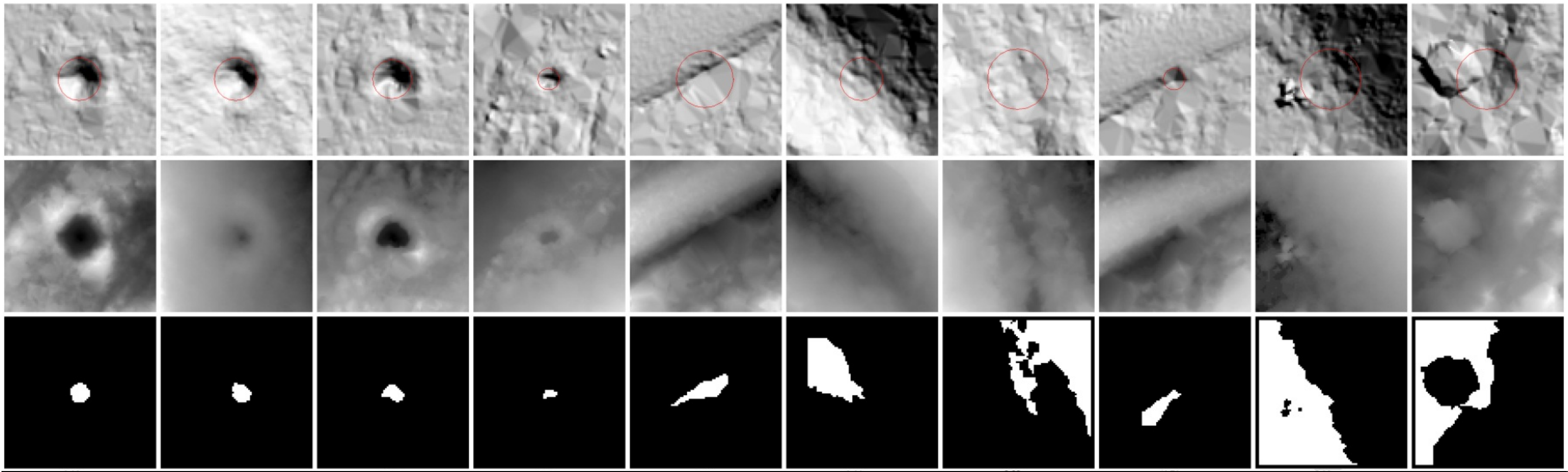
Will investigate:

- Average point density
- Average intensity
- Average gradient
- Squared gradient
- Gradient entropy
- Combinations



What is the 25%-segment? Example with pits

- ► **Threshold = limit for the 25% darkest pixels inside pit (of radius r)**
- ► **Threshold 6r x 6r subimage centered on pit**



	pitfall trap	pitfall trap	pitfall trap	pitfall trap	road edge	valley	valleys meet	road edge	foothill	rock in slope
major axis	11,04	12,00	12,68	8,52	32,91	40,87	61,51	28,19	88,95	94,15
radius	12,00	12,00	11,00	6,00	16,00	12,00	17,00	6,00	17,00	17,00
elongation	0,92	1,00	1,15	1,42	2,06	3,41	3,62	4,70	5,23	5,54

Classifier

- Initial screening: Remove obvious non-heaps based on fixed thresholds
- Confidence assignment:
  - Very low
  - Low
  - Medium
  - Medium high
  - High
  - Very high
- Manually set thresholds vs. statistical classifier

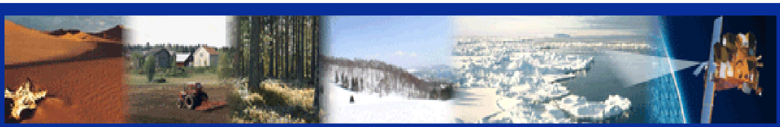
Confidence values

- Tight or loose thresholds?
  - Number of missed heaps vs. number of false detections

- A confidence value on each detection reflects this

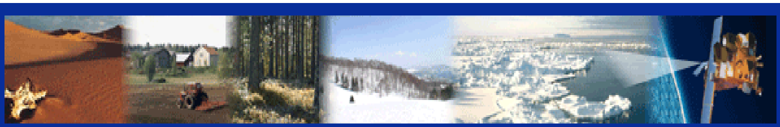
- Example thresholds and rules:

example thresholds	confidence					
measurements	very low	low	medium	med. high	high	very high*
normalized correlation	≥1	≥2	≥2.5	≥3.0	≥3.5	
minimum height	≥0.05	≥0.1	≥0.15	≥0.25	≥0.4	≥1
average height	≥0.25	≥0.4	≥0.45	≥0.5	≥0.55	
RMS U-shape	≤0.2	≤0.1	≤0.09	≤0.08	≤0.07	≤0.02
RMS V-shape	≤0.2	≤0.1	≤0.08	≤0.07	≤0.05	≤0.015
25% segment offset	≤20	≤10	≤8	≤6	≤4	
25% segment elongation	≤4	≤2	≤1.75	≤1.5	≤1.25	
assigned tag	1	2	3	4	5	6



Classifier and attributes selection

- Six different classifiers are evaluated:
  - Decision tree (CART algorithm)
  - Nearest neighbour
  - Naïve Bayes (assuming independent attributes)
  - Mahalanobis distance
  - Linear discriminant analysis
  - Quadratic discriminant analysis
- For each classifier, find the best subset of attributes



Evaluation of statistical classifiers

Classifier	1	2	3	4	5	6	7	8	9	10	11	12	13	14	Accuracy [%]
Trees	7	5	8	9	4	13	2	15	1	3	10	11	14	6	84.5
1NN	8	5	11	7	4	3	14	10	13	2	6	12	1	9	81.1
NaiveBayes	13	14	3	9	1	15	10	7	12	5	2	11	4	8	83.2
Mahalanobis	7	1	14	12	6	10	9	8	3	5	13	11	2	4	85.4
LDA	7	13	6	14	1	3	5	11	4	12	8	9	10	2	84.6
QDA	13	14	10	9	12	1	11	3	7	8	2	4	5	6	83.3

Attributes of heaps:

1 = correlation
2 = minimum height
3 = average height
4 = normalized minimum height
5 = normalized average height
6 = standard deviation on ring edge
7 = root mean square (RMS) difference from U-shape
8 = RMS diff from V-shape
9 = 50% segment offset
10 = 50% segment major axis
11 = 50% segment elongation
12 = 25% segment offset
13 = 25%-segment major axis
14 = 25%-segment elongation

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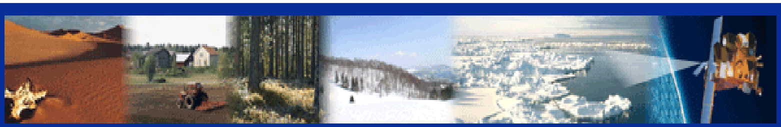
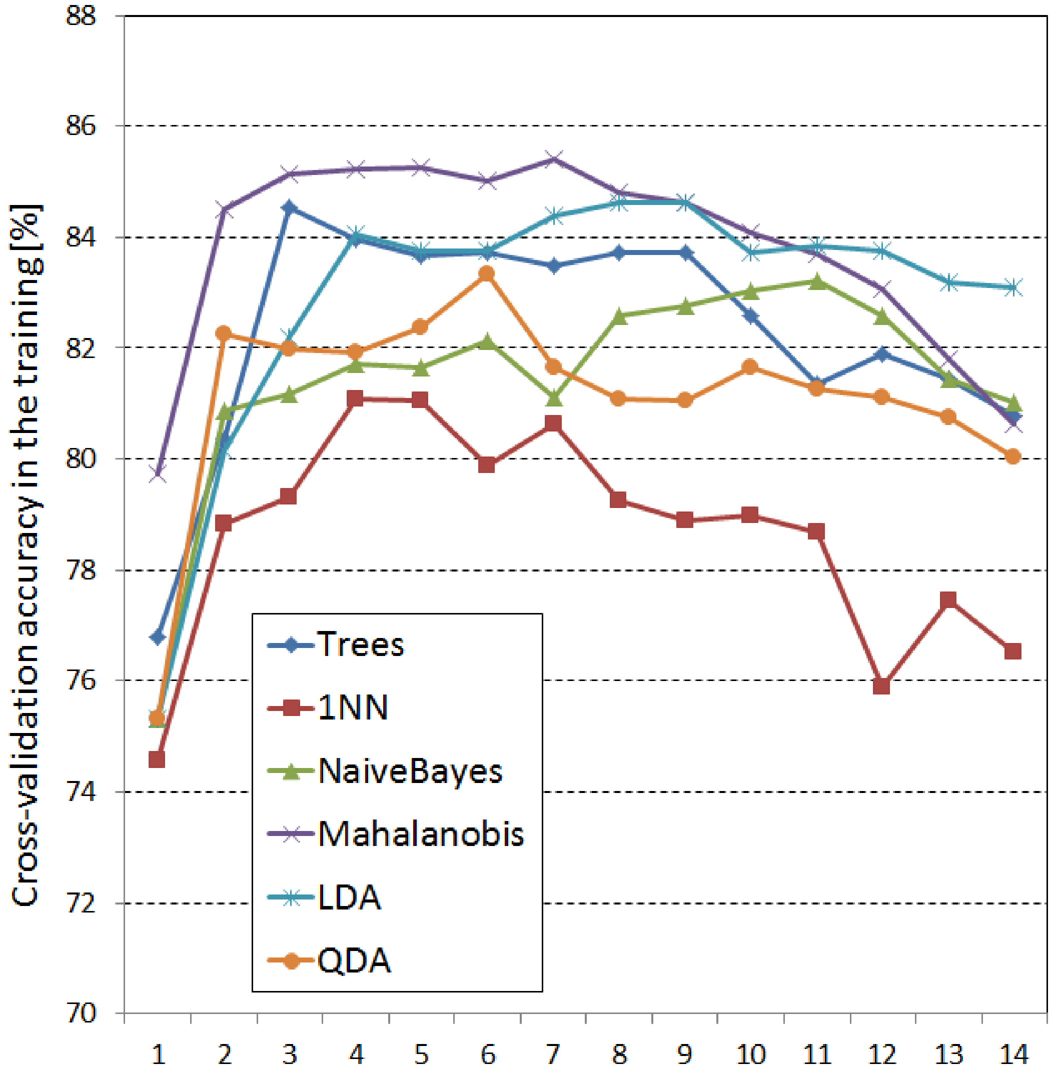


Evaluation of statistical classifiers



Confidence estimation with statistical classifier

- **Statistical classifier: the probability that an object is a grave mound**
- **A confidence level may be obtained by thresholding this probability**
- **Initial thresholds**

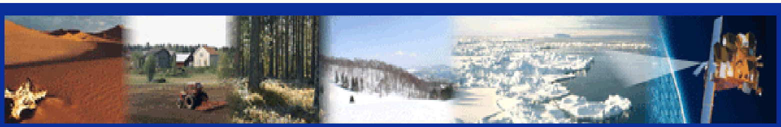
1	2	3	4	5
0.1	0.25	0.5	0.75	0.90

- **Penalty weights for misclassifications**

score value	1	2	3	4	5	6
confidence	very low	low	medium	medium high	high	very high
pit	1024	256	64	16	4	1
non-pit	1	4	16	64	256	1024

- **Optimize thresholds to minimize accumulated penalty on training data**
- **Final thresholds**

1	2	3	4	5
0.05072984	0.05121662	0.47666119	0.67167690	0.76737689

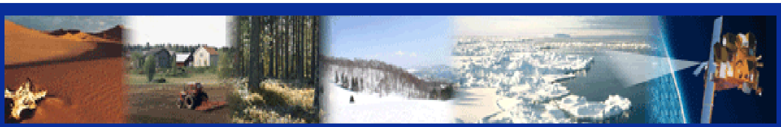


Performance on heaps (Larvik)

Mahalanobis

confidence	very low	low	medium	medium high	high	very high	sum
grave mound			14	39	25	18	96
not grave mound	4		647	144	13	1	809
sum	4	0	661	183	38	19	905

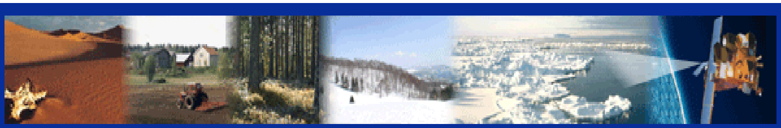
- Statistical method not able to discriminate between very low, low and medium confidence
- Could combine manual thresholds for very low – medium confidence with statistical classifier for medium high – very high confidence
- Alternatives:
  - manually adjust thresholds on posterior probability from statistical classifier
  - Lower punishment weights for true grave mounds which receive medium or low confidence



Combined classifier

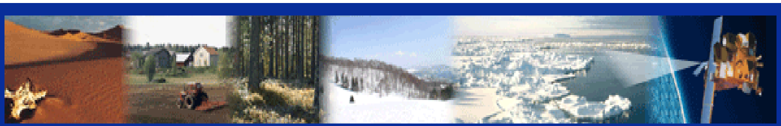
- Use statistical classifier first
- If confidence <= medium, then reassign confidence using manually set thresholds

confidence	very low	low	medium	medium high	high	very high	sum
grave mound	1	5	8	39	25	18	96
not grave mound	145	351	155	144	13	1	809
sum	146	356	163	183	38	19	905

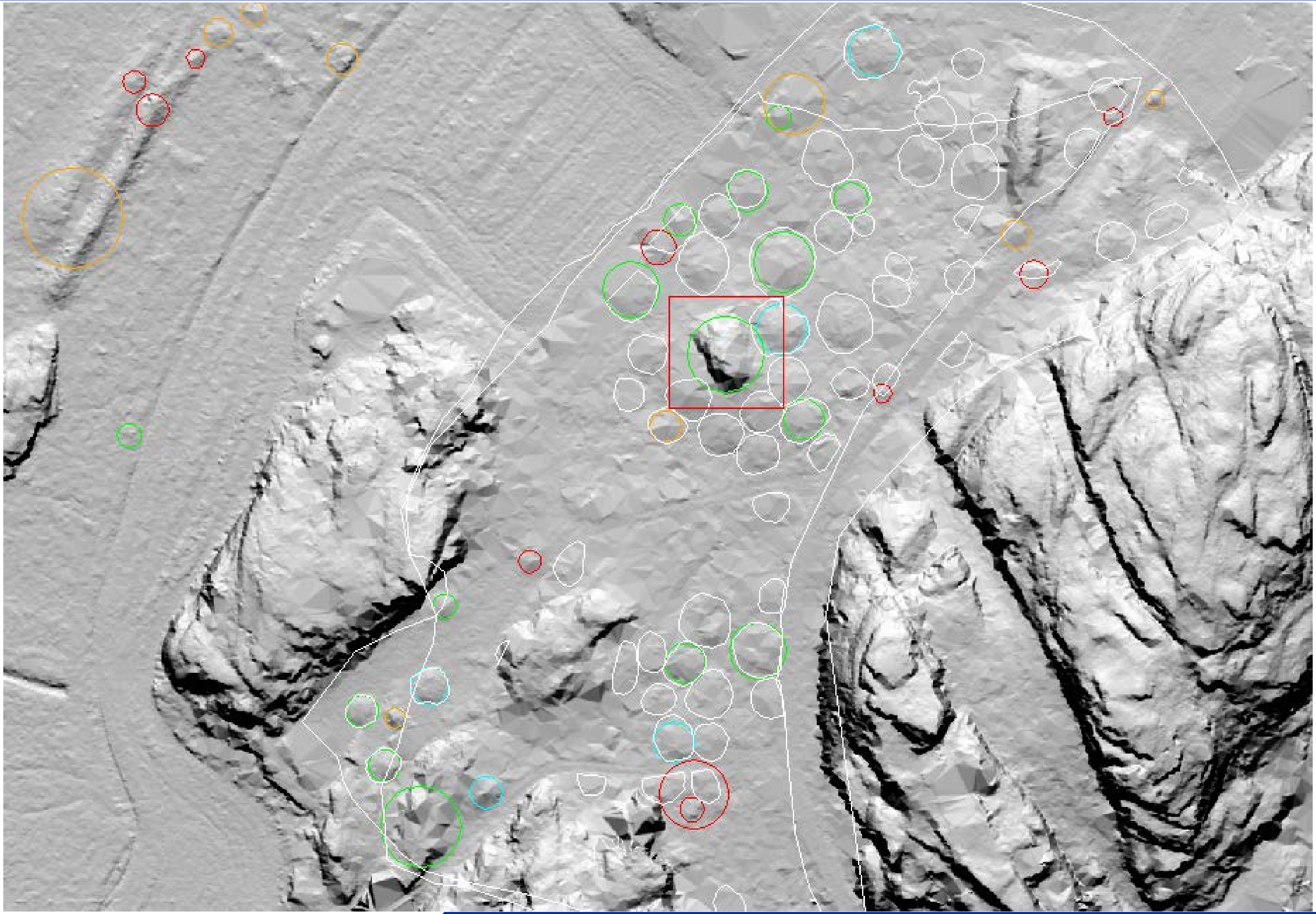


Manual thresholds for heaps

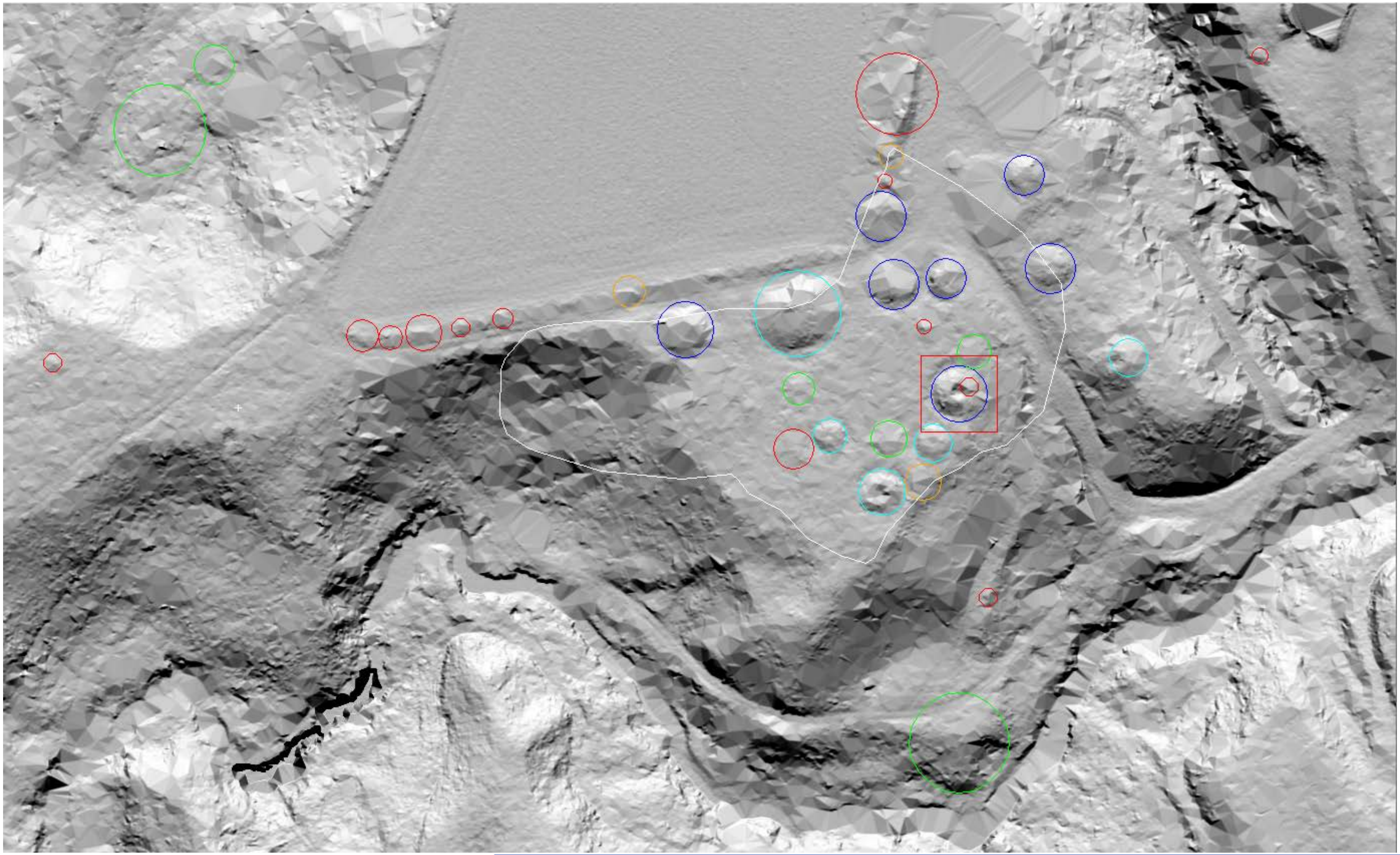
optimised on training set	confidence	
measurements	low	medium
RMS diff from U-shape	≤0.08	≤0.06
radius	≥1.4	≥1.8
correlation	≥1.2	≥2.0
25% segment elongation	≤4	≤1.6
standard deviation on ring edge	≤0.7	≤0.4
25% segment offset	≤25	≤15
normalized avgerage height	≤0.3	≤0.25
normalized avgerage height	≥0.05	≥0.06
normalized correlation	≤8	≤8
normalized correlation	≥1	≥1.5
average height	≥0.1	≥0.2

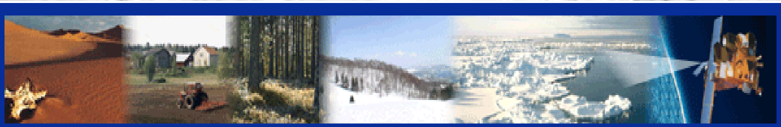


Detection results: Kaupang (Larvik)



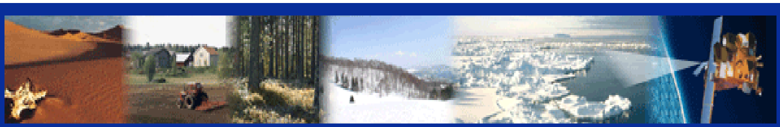
Detection results: Ødelund (Larvik)





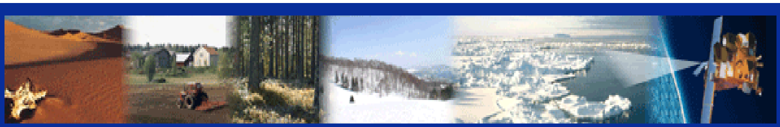
Gradient

- Can high gradient indicate non-archaeological heap?
- Currenlty investigating several gradient measures:
  - Sobel gradient g
  - Gradient squared g^2
  - Gradient entropy $\sqrt{g} \cdot g$



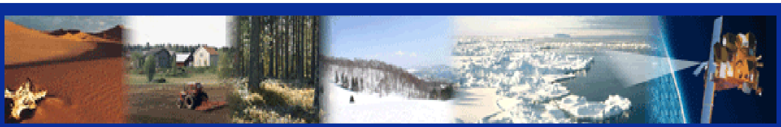
What can go wrong?

- Too few lidar ground points per m^2
  - Wrong acquisition time
  - Dense vegetation or low vegetation
  - Too few emitted pulses per m^2
- Heap is small (height and/or radius)
- Template matching fails to detect all grave mounds
- Heap measurements are not useful in separating grave mounds from natural heaps and modern man-made heaps
- Classifier
  - Initial screening removes some true grave mounds
  - Confidence assignment



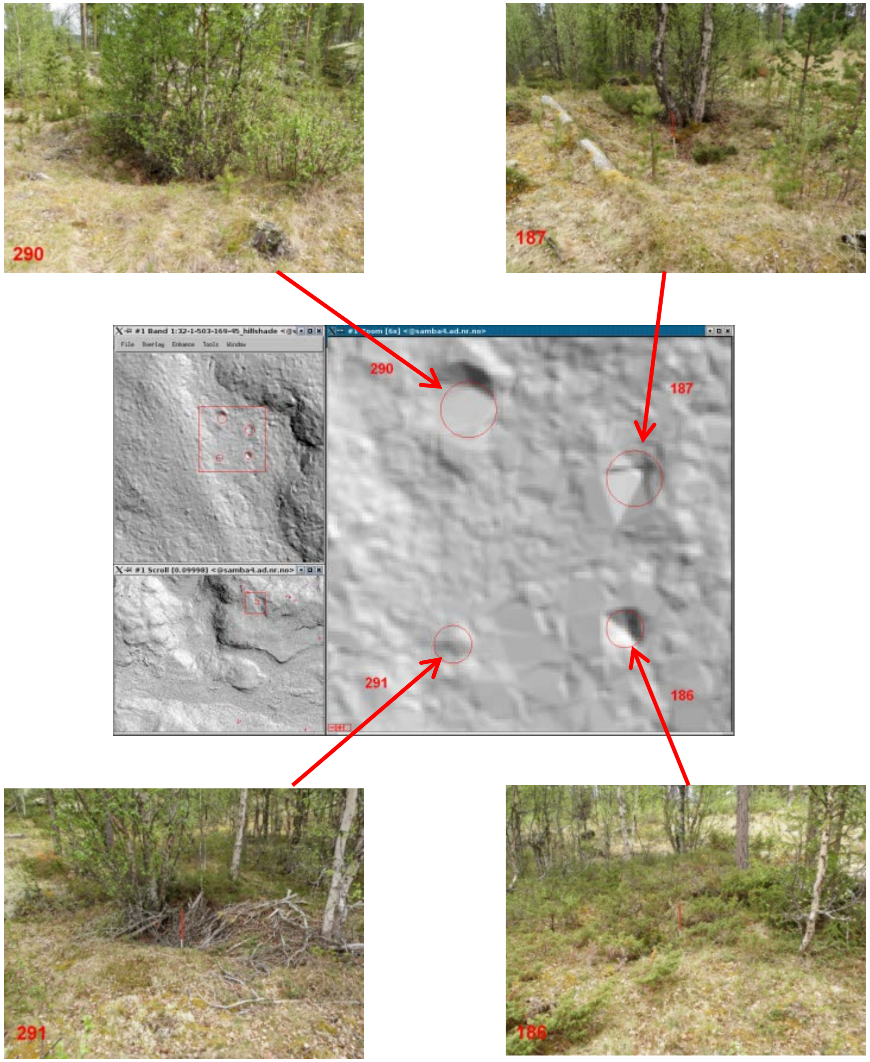
Conclusions

- Automatic detection of pits in lidar data has become an important tool as part of archaeological survey of cultural heritage in Oppland County, Norway
- **Similar methods are needed for the automatic detection of heaps in lidar data for the mapping of grave mounds**
- **The current method is promising but needs further improvement**



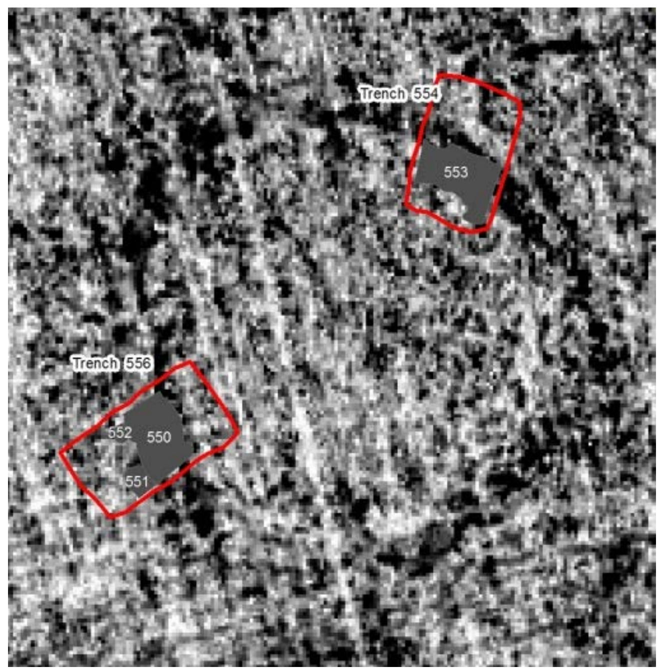
Alternative conclusions

- Bad data => bad results
- Good data => good results



Also in the project: mapping of levelled grave mounds

- ▶ Cropmarks
- ▶ Georadar
- ▶ Digging



Acknowledgements

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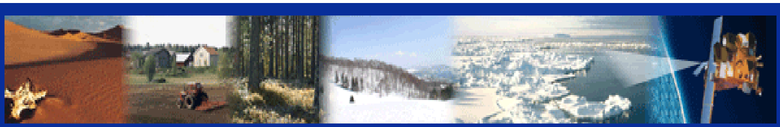
- Fieldwork in the project has been conducted by Oppland County, Vestfold County, The Museum of Cultural History at the University of Oslo, and The Norwegian Institute for Cultural Heritage Research (NIKU)

UiO : Kulturhistorisk museum



Thank you for your attention!