Fault edge detection for analyzing surface deformations with ground movement models

2nd JISDM, Nottingham, UK

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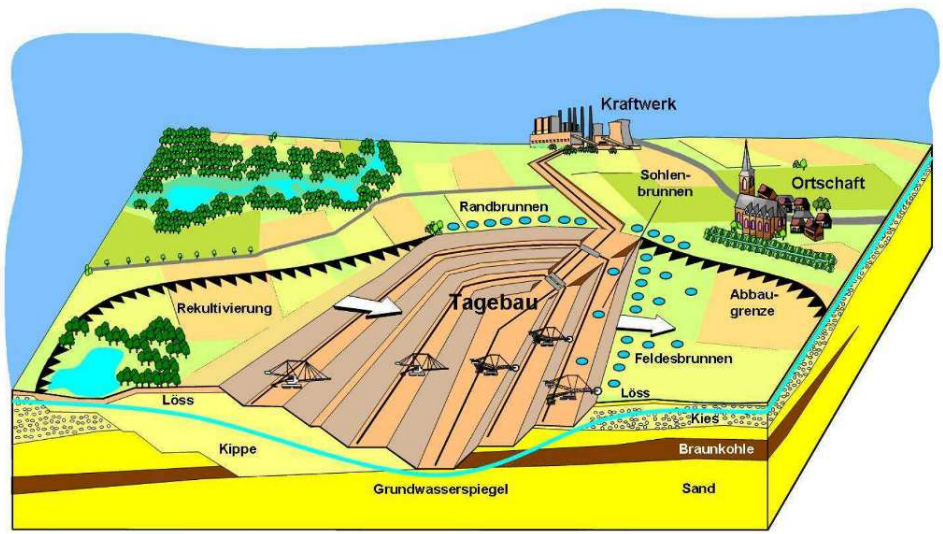
Motivation

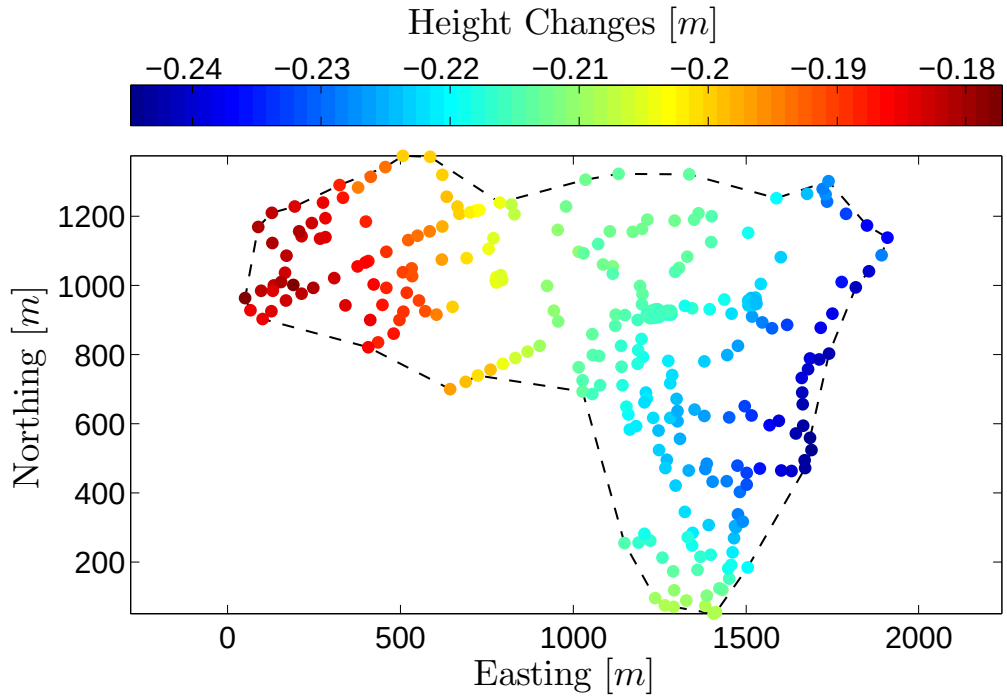
- extensive dewatering for the mining of lignite
- consequence is extensive subsidence of ground
- monitoring of towns with high precision leveling



RWE Power AG

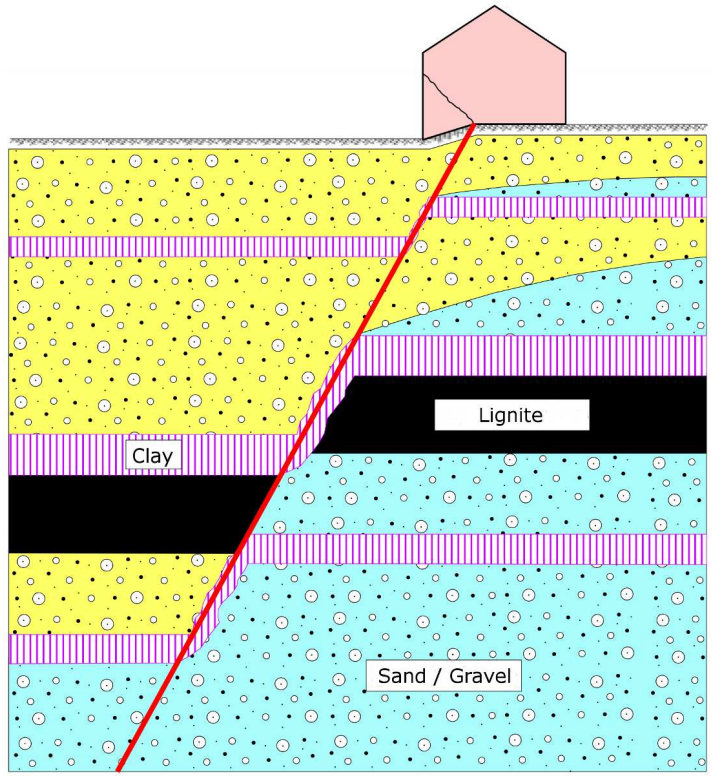
Motivation

- extensive dewatering for the mining of lignite
- consequence is extensive subsidence of ground
- monitoring of towns with high precision leveling
- position of measured height changes due to infrastructure
- **target**: parametrization and estimation of height changes



Motivation

- **but...**
- due to dewatering, tectonic activity can be activated
- discontinuities can result in damage of houses
- separation of smooth ground movement from fault edges essential for reliable estimation

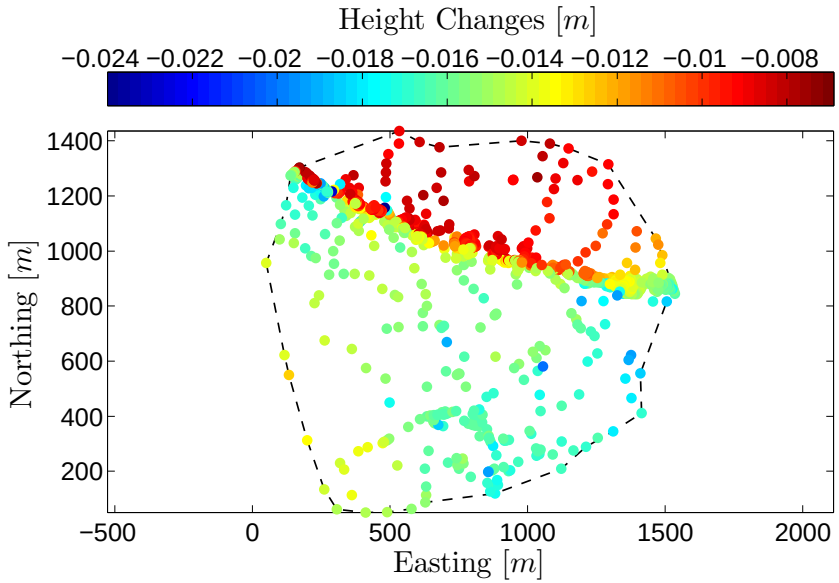


Preuße & Schulte (2012), altered

- **two necessary consecutive steps ...**

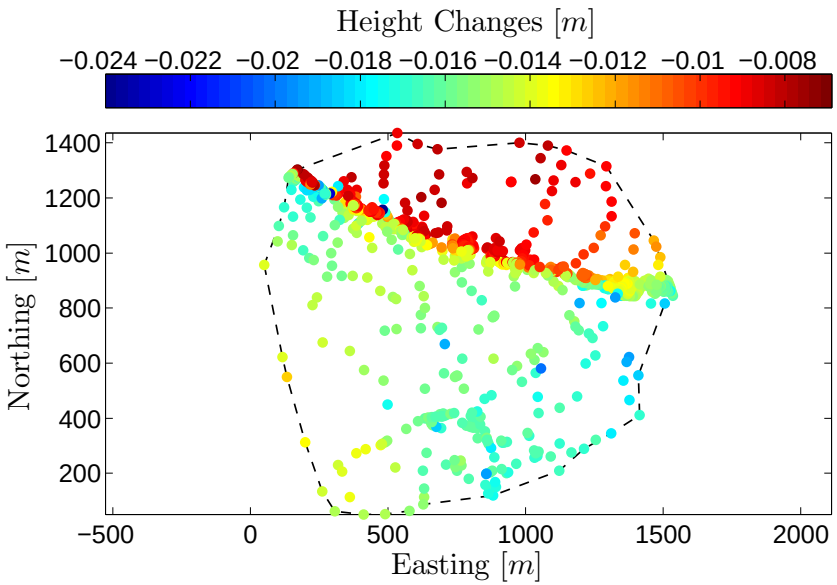
1. **detect** fault edges, if existent
2. **preclude** fault edges, if not existent

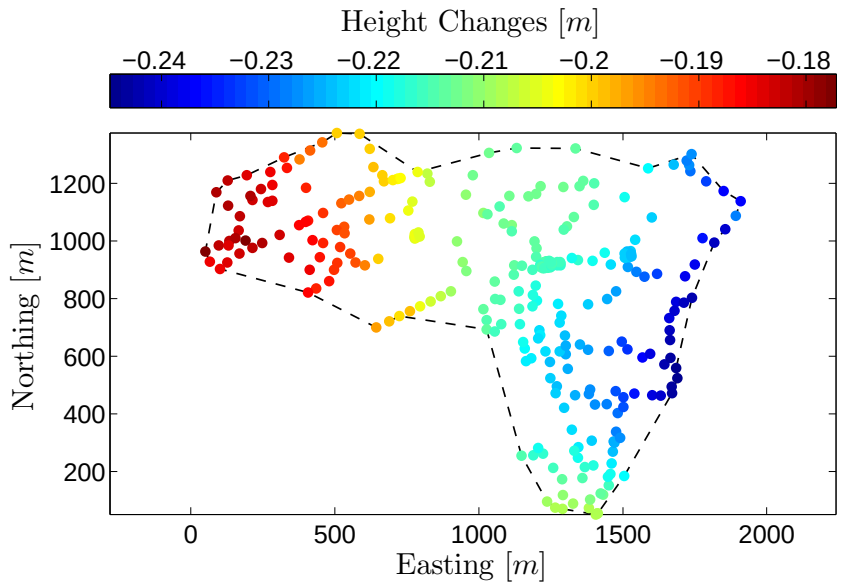
Motivation



- **fault edge existing!**

Motivation





- **fault edge existing!**

- **fault edge existing?**

Approximation of height changes

Fault edge detection
- Detection of most probable fault edge
- Analysis of most probable fault edge

Transfer to sample regions

Conclusion

Approximation of height changes

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Approximation of height changes

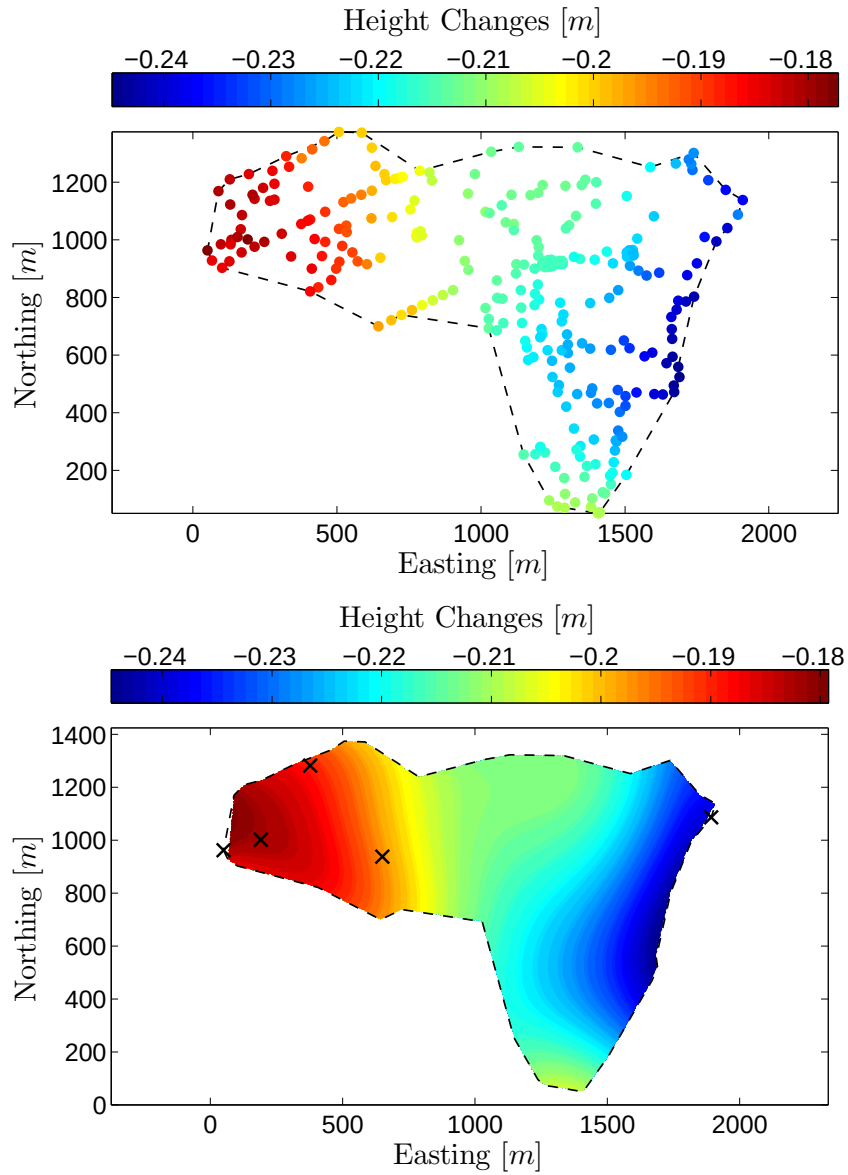
- model of bivariate polynomial

$$l_i = P(x_i, y_i) = \sum_{k=0}^{m_x} \sum_{a=0}^{m_y - k} p_{k,a} \cdot x_i^k \cdot y_i^a$$

- functional model: $\mathbf{l} + \mathbf{v} = \mathbf{A}\mathbf{p}$
- stochastic model: $\mathbf{\Sigma}_{ll} = \sigma^2 \mathbf{I}$, with $\sigma = 1mm$

$$\hat{\mathbf{p}} = \left(\mathbf{A}^T \mathbf{\Sigma}_{ll}^{-1} \mathbf{A}\right)^{-1} \mathbf{A}^T \mathbf{\Sigma}_{ll}^{-1} \mathbf{l}$$

- m_x and $m_y \propto$ complexity of height changes
- elimination of non-significant parameters $p_{k,a}$
- detection of outliers
- checking of adjustment's quality by global test

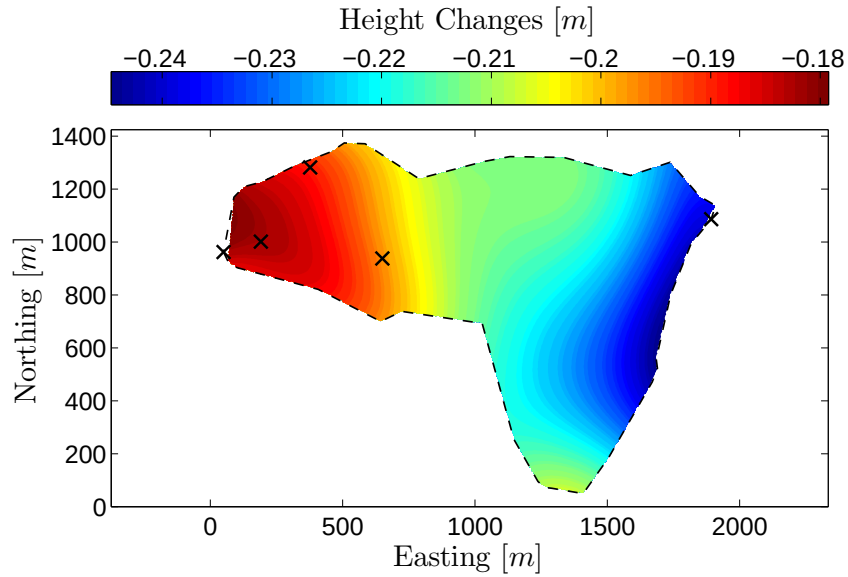


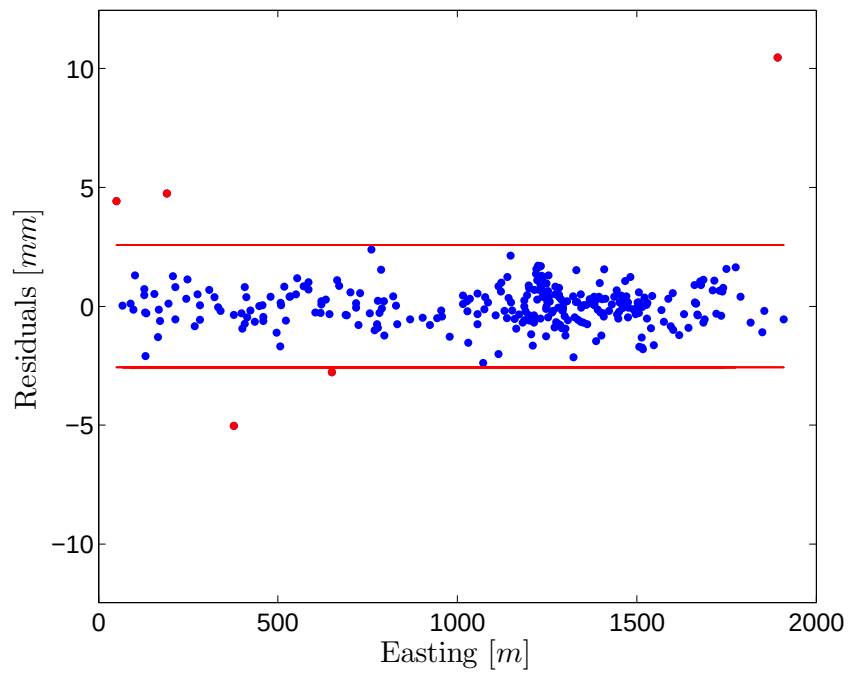
Approximation of height changes

- how to verify the approximation?

1. **the number of outliers should be small regarding the number of observations**
2. the number of parameters and the polynomial order should be small regarding the number of observations
3. **the spatial distribution of outliers should be random**
4. the estimated residuals should underly a normal distribution
5. the global test should be accepted

- **approximation successful!**





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- **approximation successful!**

- no signs of possible fault edge visible
- **however ...**
- can a fault edge be precluded based on these results?

- investigation of methods for fault edge detection

Approximation of height changes

Fault edge detection
- Detection of most probable fault edge
- Analysis of most probable fault edge

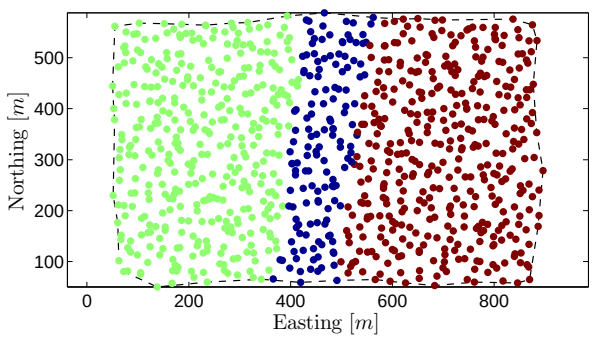
Transfer to sample regions

Conclusion

Procedure

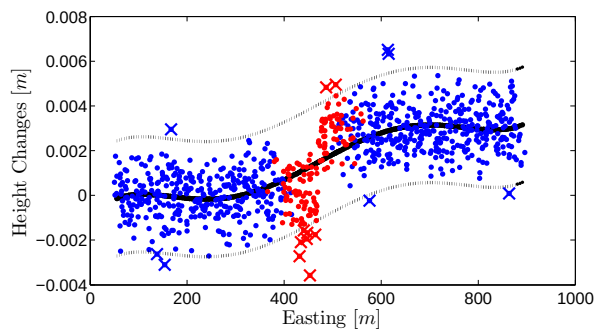
1. Detection
of most probable fault edge

- methods based on digital image processing
- find subregion containing **most probable** fault edge
- „if any fault edge is included, then it is the detected one“



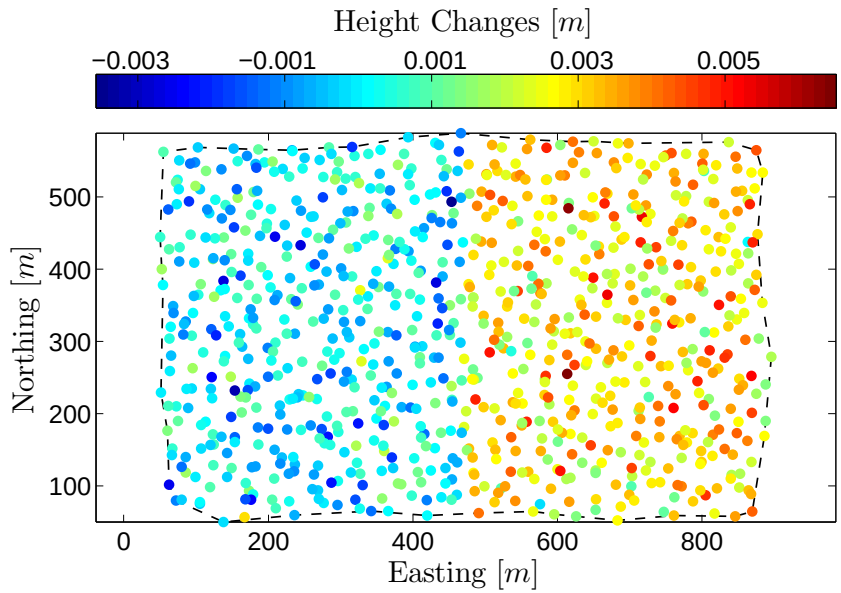
2. Analysis
of most probable fault edge

- methods based on parameter estimation
- approximate only subregions containing smooth ground movement
- analyze residuals regarding systematics



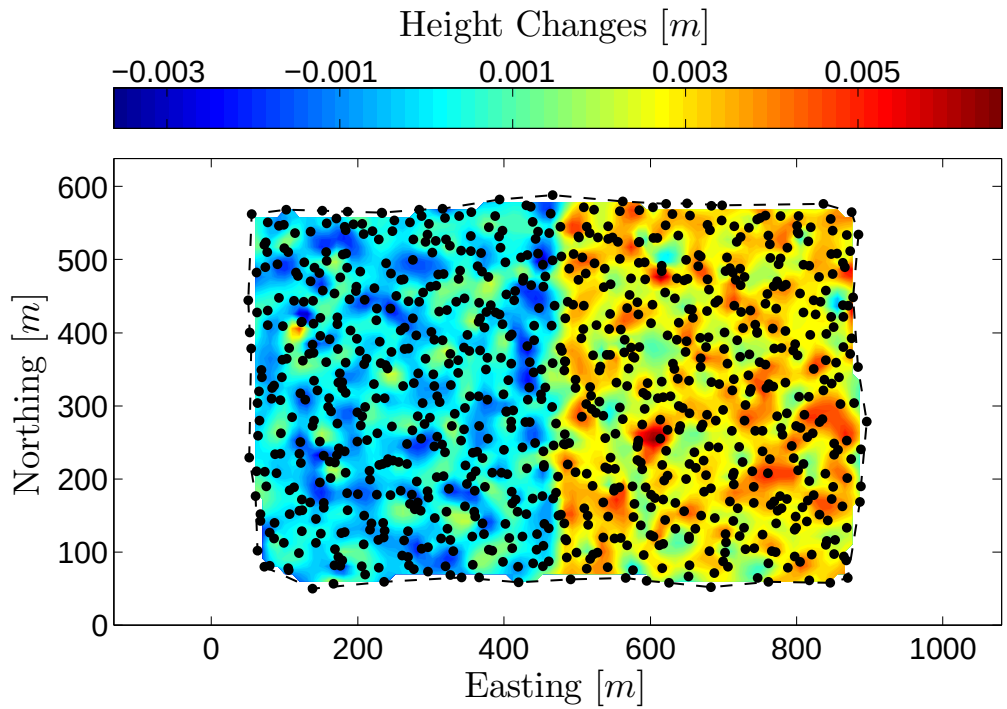
Simulated height changes

- 900 sampling points
- constant height changes with $\sigma = 1mm$
- fault edge of $3mm$



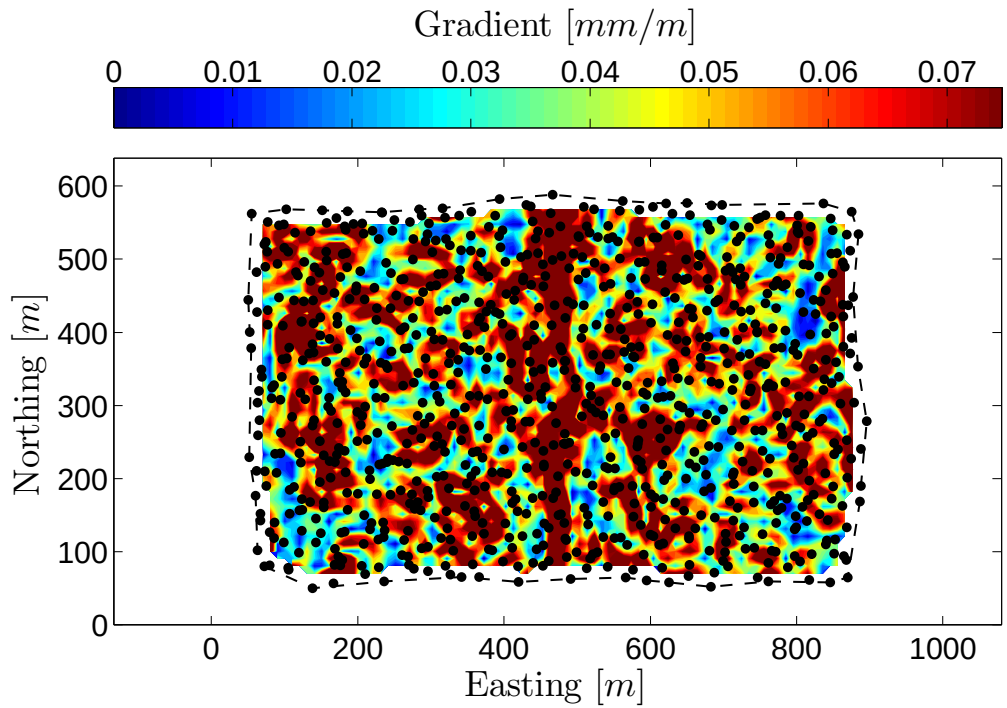
1. Interpolation

- grid of $10m$ point distance
- biharmonic spline interpolation



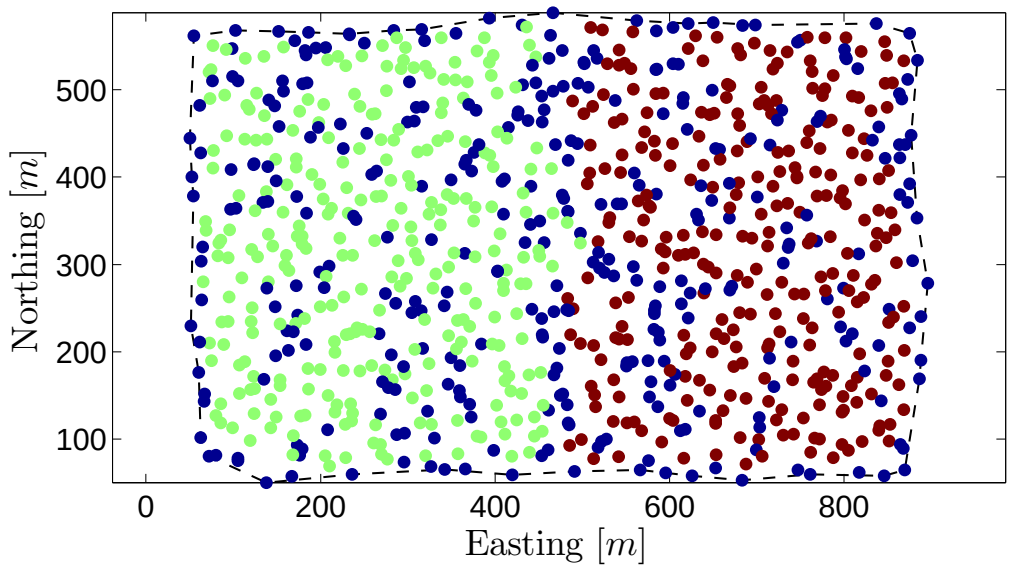
2. Convolution

- building the gradient
- using Prewitt operator
- gradients of mm/m



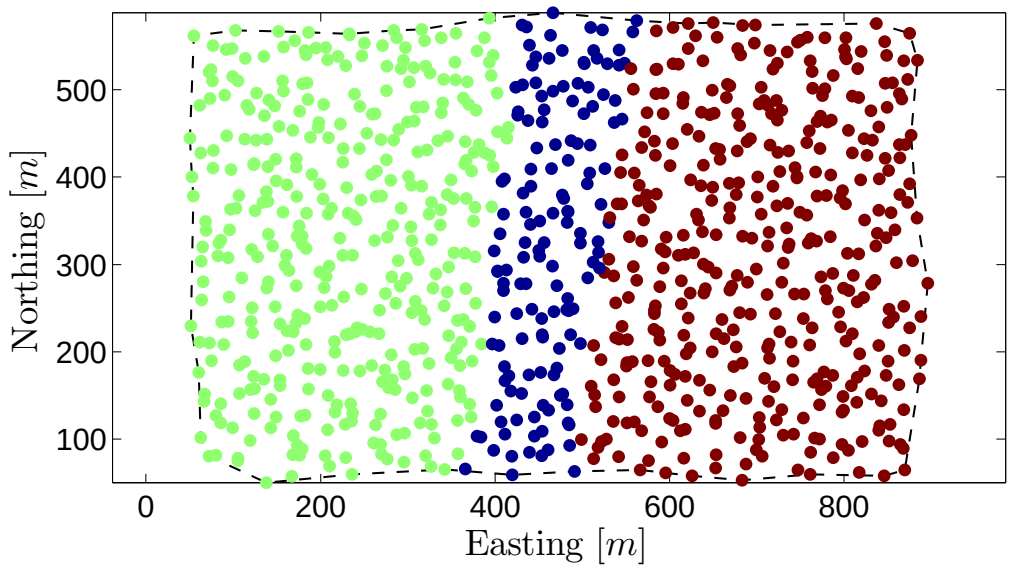
3. Labeling

- iterative identification of gradient threshold that divides region into subregions
- labeling by connected components



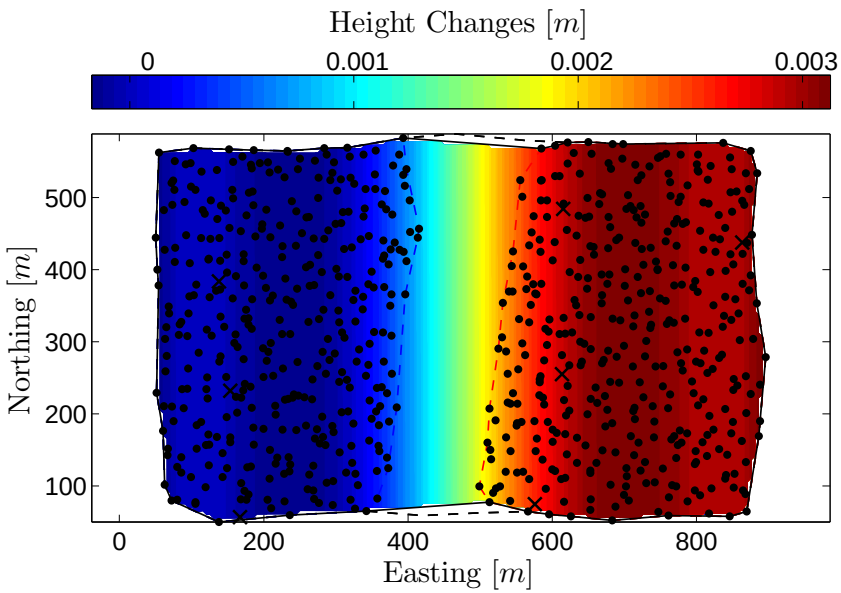
4. Separation

- merging of subregions
- subregions 1 and 2 containing smooth ground movement
- subregion 3 containing most probable fault edge



1. Approximation

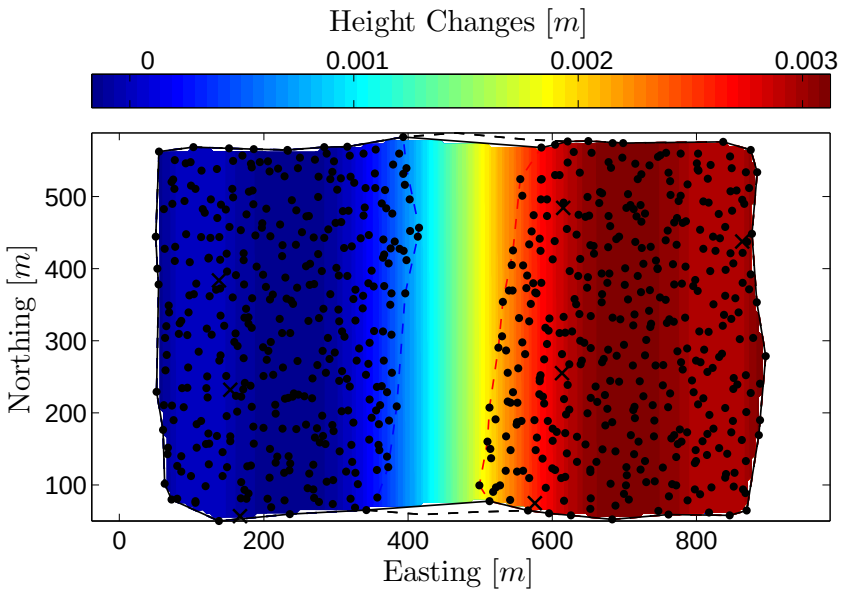
- approximating only subregions containing smooth ground movement
- model of bivariate polynomial



2. Analysis of fault edge

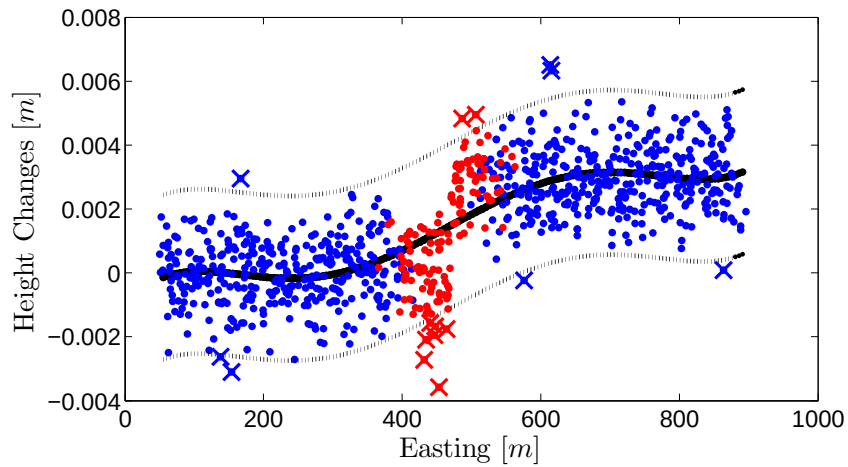
1. Approximation

- approximating only subregions containing smooth ground movement
- model of bivariate polynomial



2. Analysis

- building residuals to models
- analyzing residuals of fault edge subregion



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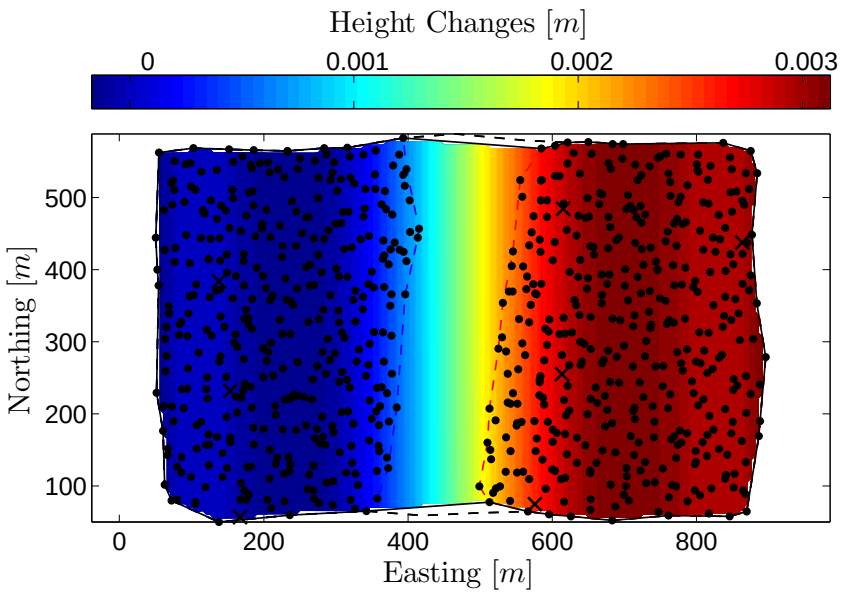

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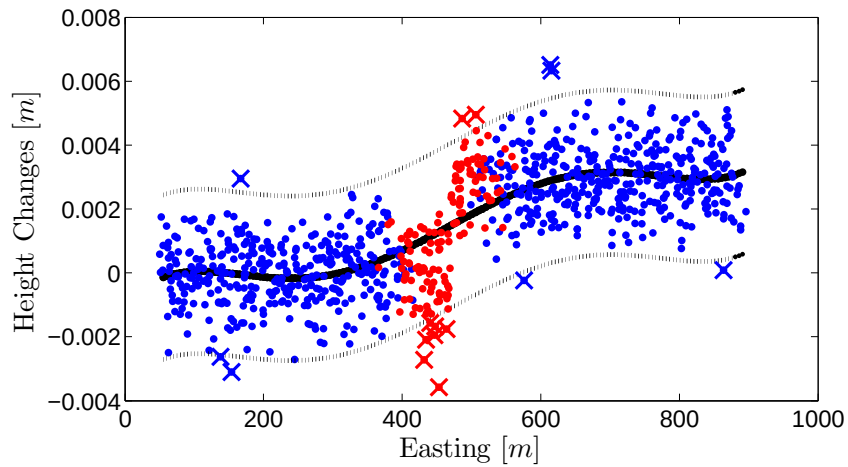

- **fault edge detected!**

Approximation of height changes

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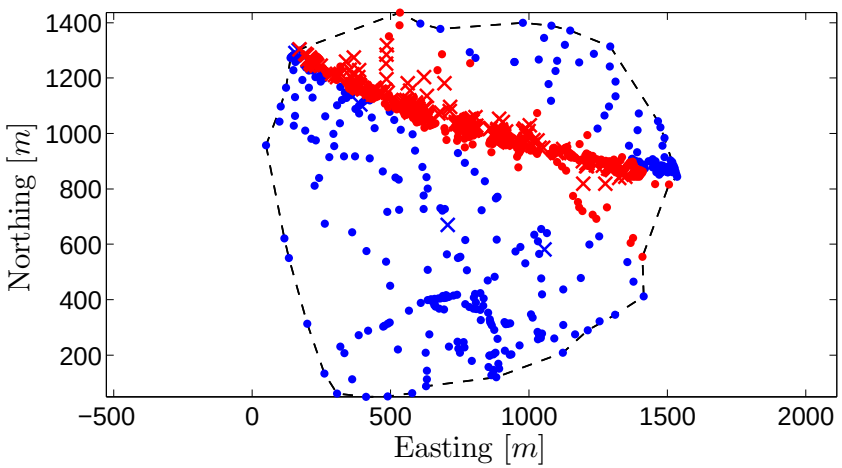
Transfer to sample regions

Conclusion

Transfer to sample regions

- many outliers in fault edge subregion
- systematic spatial distribution



- **fault edge detected!**

Transfer to sample regions

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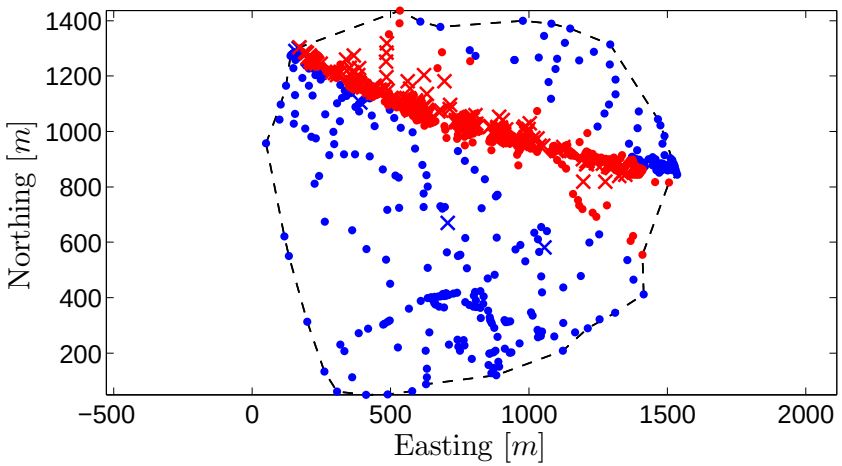
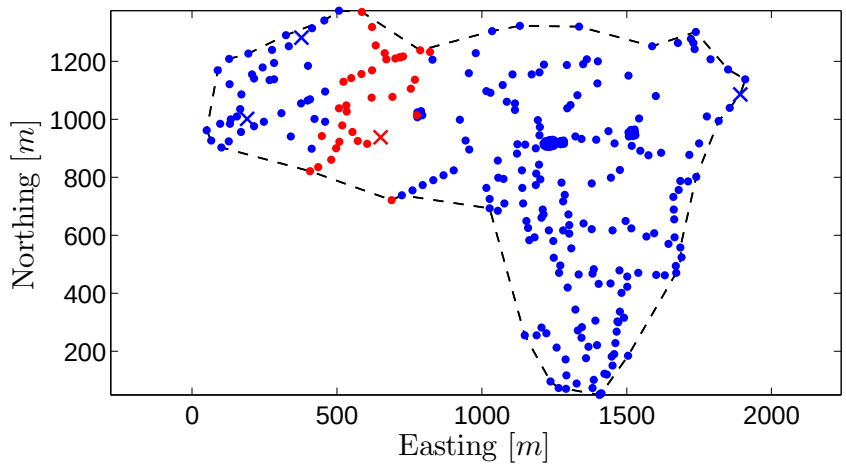


- **fault edge detected!**

- detected outliers not systematic
- outliers have been revealed before



- **fault edge unlikely!**

Approximation of height changes

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Transfer to sample regions

Conclusion

Conclusion

Detection of most probable fault edge

- based on digital image processing
- reliable identification of subregion that contains most probable fault edge
- identification by gradient

Analysis of most probable fault edge

- based on parameter estimation
- revealing significant fault edge by conspicious outliers
- judging fault edge as **existent** or **unlikely**

- **however ...**
- fault edge **preclusion** needs further analysis
- ... statistical significance test
- ... damage relevance

! Thanks for your attention !

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