Investigations to the Calibration of a Numerical Slope Model by Means of Adaptive Kalman-Filtering

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1. Motivation

Mass movement 'Steinlehnen'

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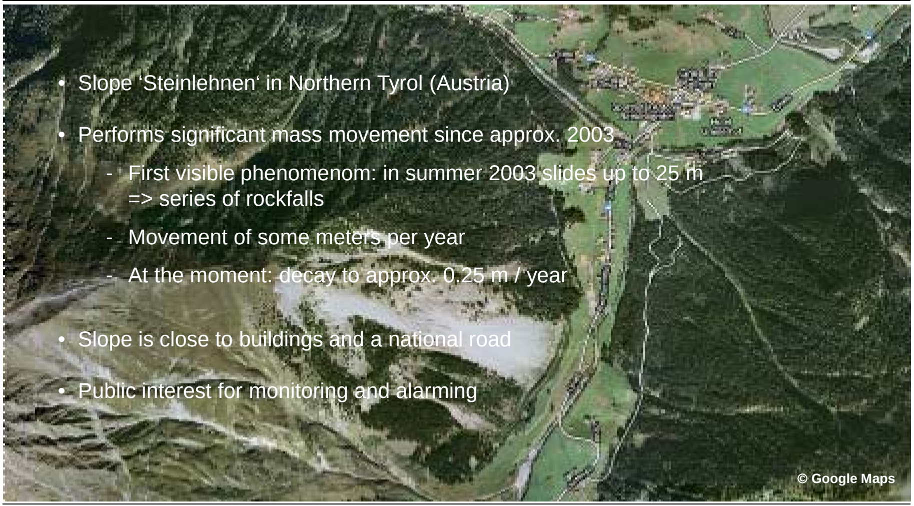

- Slope 'Steinlehnen' in Northern Tyrol (Austria)
- Performs significant mass movement since approx. 2003
  - First visible phenomenom: in summer 2003 slides up to 25 m => series of rockfalls
  - Movement of some meters per year
  - At the moment: decay to approx. 0,25 m / year
- Slope is close to buildings and a national road
- Public interest for monitoring and alarming

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1. Motivation

Mass movement 'Steinlehnen'

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- Project 'KASIP' (funded by Austrian Science Fund)
- Cooperation between four partners from geodesy and geology
- Investigation of a new type of alarm system based on
  - slope monitoring data (classical appoach)
  - simulations with a calibrated numerical slope model

  ⇒ improved prediction of possible failure events

  ⇒ improved explanation and evaluation of the monitoring data
- Monitoring: detection and reaction to short term effects (e.g. accelerations, …)
- Combination with numerical simulations: forecasting long term effects

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1. Motivation

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Mass movement ‘Steinlehnen‘

- Absolute height: between 1200 and 2400 m
- Slope inclination: upper part $i \approx 43°$ lower part $i \approx 31°$
- Geologists: approx. four different sliding masses bounded by scarps

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1. Motivation

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Highly active masses (by geologists)

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2. Monitoring

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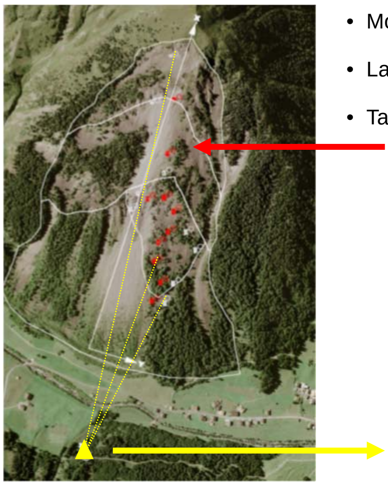
Design of the monitoring system



- Monitoring since summer 2003 by alpS
- Laserscanning (only first months)
- Tacheometer system (from opposite slope)
  - 24 miniprisms in slope
  - mean distance $d \approx 1200$ m, cm-accuracy
  - no permanent monitoring
  - since summer 2009 by TU Darmstadt

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2. Monitoring

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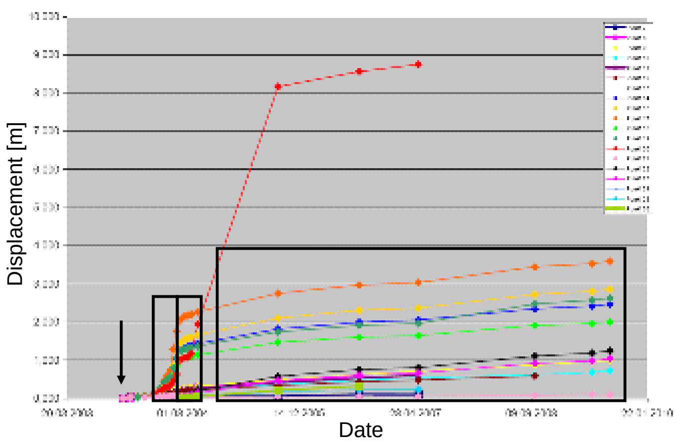
Tacheometer: results from 2003 - 2009

Relative 3D-displacements of discrete slope points (absolute value)



- Start Nov. 2003 after rockfall and first stabilisation phase
- Acceleration approx. April – July 2004
- Deceleration approx. July – October 2004
- Currently approx. constant velocity (2-3 dm / year)
- Homogenous behaviour (to valley)
- **Δt partly not very dense !!!**

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2. Monitoring

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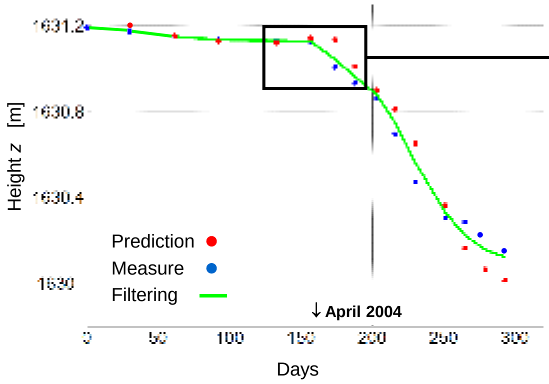
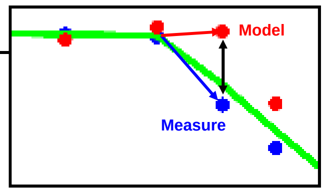
Detection of changes in the kinematic state

- **Example:** absolute movement in *z*-direction (slope point 14)
- Kalman-filter with kinematic motion model



Change of current kinematic state (start acceleration)



vz = - 0,5 cm/month

az = 0,0 cm/month²

***vz* = - 8,0 cm/month**

***az* = - 3,0 cm/month²**

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3. Modelling and calibration

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Why parametric modelling ?

Investigations in kinematic model
- Restriction to monitoring data
- Descriptive
- Limited capability for prediction
- No explanation of slope mechanisms

Parametric modelling (numerical model)
- Based on continuum mechanics
- Causative
- Capability for prediction and simulation
- Explanation of slope mechanisms

Problems
- Model structure itself
- Parameter determination (calibration)

Goal: realistic parametric model of mass movement
- Prediction and simulation
- Improved explanation of monitoring data (e.g. case-based reasoning)

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3. Modelling and calibration

Association of monitoring and numerical data

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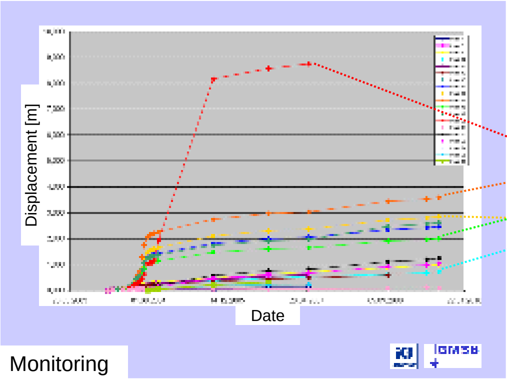
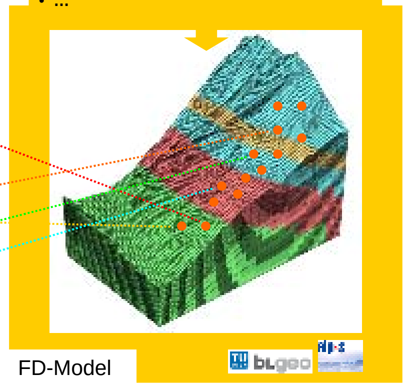
Idea: Coupling monitoring data and numerical model (fini

Input e.g. advance information
- Slope geometry
- Homogenous areas (e.g. strength)
- Possible slide faces
- ...





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3. Modelling and calibration

Calibration method

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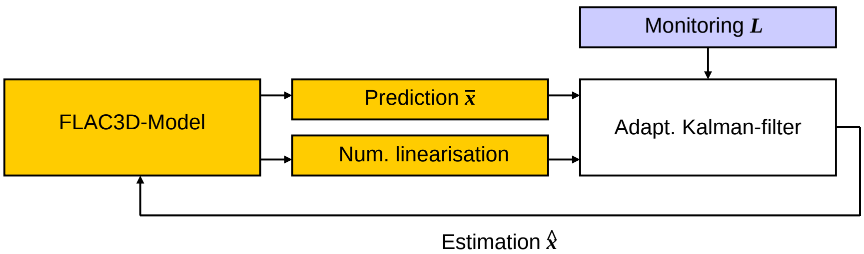
Calibration FD-model with adaptive Kalman-Filtering

State vector ***x*** = (grid points, velocities, accelerations | relevant model parameters)

adaptive part



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3. Modelling and calibration

Example

- FD-model of full slope currently in development (Engineering Geology, TU Vienna)
- Example deals with restricted and simplified scarp
- Restrictions and simplifications:
  - restricted to about 700 grid points
  - homogenous and isotropic material properties
  - Mohr-Coulomb material model
  - simulated motion only triggered by gravity

- Scarp failure mainly dependent from two strength parameters: inner friction φ and cohesion c

=> Enable evaluation of current scarp stability (e.g. Factor of Safety)

=> **Goal of model calibration**: estimation of realistic values

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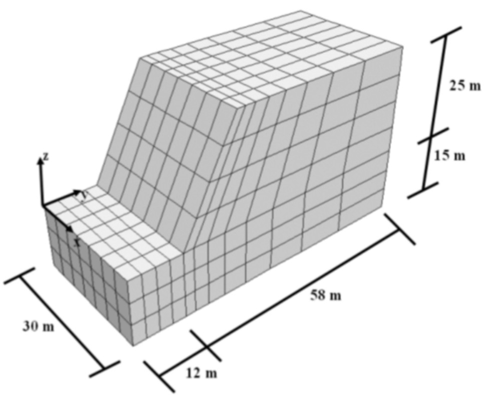
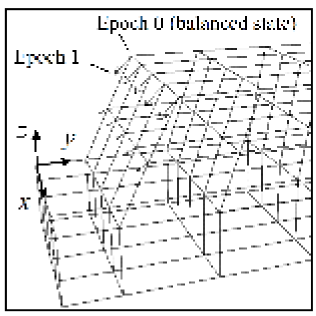
3. Modelling and calibration

Example

Geometrical design



Simulated 'measurements'



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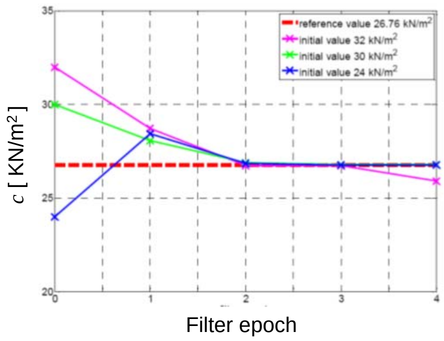
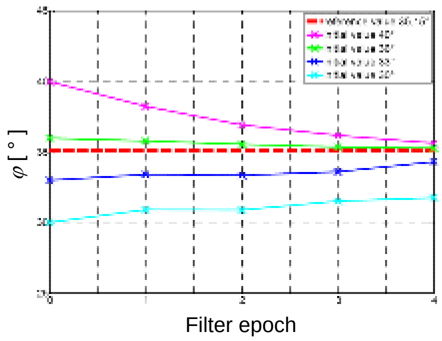
3. Modelling and calibration

Example

Results model calibration: strength parameters c and φ

- Randomly initialisation
- Deviations r after 4 epochs: $r \approx 0.8$ ‰ (c) and $r \approx 0.4$ - 3 % (φ)



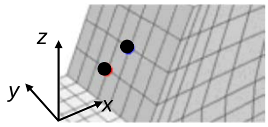


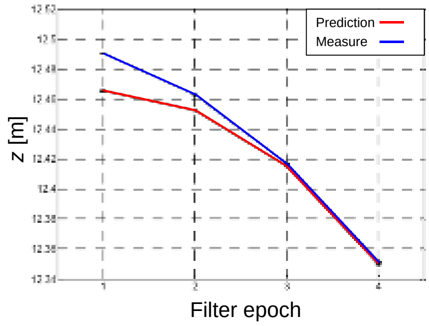
3. Modelling and calibration

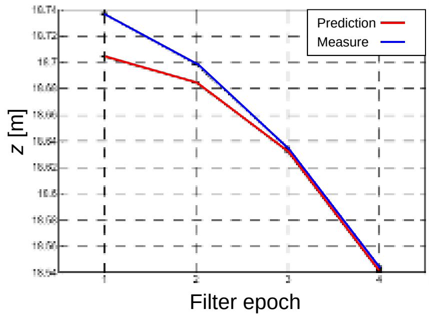
Example

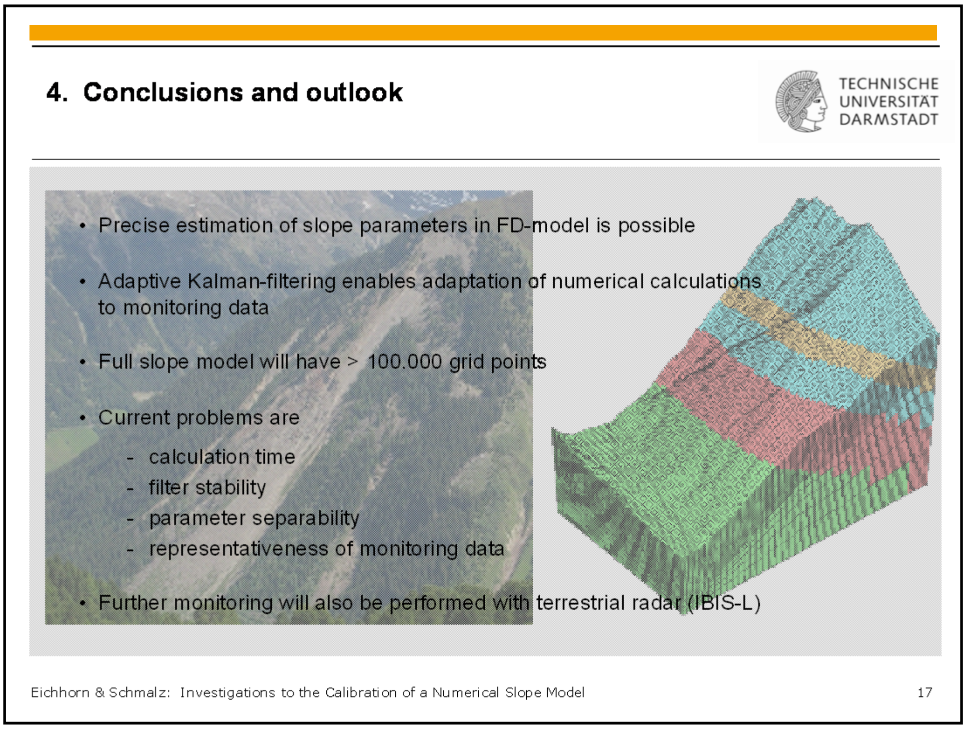
Adaptation of predicted to 'measured' displacements

- Exemplarily for two scarp points (z-component)
- Deviations after 4 epochs < 1 mm








4. Conclusions and outlook
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• Precise estimation of slope parameters in FD-model is possible
• Adaptive Kalman-filtering enables adaptation of numerical calculations to monitoring data
• Full slope model will have > 100.000 grid points
• Current problems are
- calculation time
- filter stability
- parameter separability
- representativeness of monitoring data
• Further monitoring will also be performed with terrestrial radar (IBIS-L)
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