Improvement of fault model estimations
by using
multiple datasets and full data covariances:

An application to the Kleifarvatn earthquake, Iceland.

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Kleifarvatn event:
- dynamically triggered on June 17 2000 by a 6.5 Earthquake
- ruptured a previously unknown fault; $M > 5.5$
- noticed by InSAR
Introduction

Model 1: Pagli et al., 2003 ⇒ descending InSAR only
Model 2: Árnadóttir et al., 2004 ⇒ desc. InSAR & GPS
Model 3: Sudhaus & Jónsson ⇒ desc. & asc. InSAR + GPS

Purpose of this case study:
⇒ to give evidence for a fault model improvement
⇒ investigate the impact of data weighting based on the full data covariances

CAT-1 project #3639 - ERS-2 SAR images kindly provided by ESA
I) Available data sets: InSAR + GPS

Forward model assumptions
uniform slip on a rectangular, planar fault
in a homogenous elastic half-space (after Okada, 1992)

model cost evaluation with weight vector
\[ \| e \| = \sqrt{ (R(d_{\text{obs}} - d_{\text{pred}}))^T (R(d_{\text{obs}} - d_{\text{pred}})) } \]

Data covariance matrix
\[ \Sigma^{-1} = R^2 \]
I) Measuring covariances of InSAR data
Forward model assumptions
uniform slip on a rectangular, planar fault
in a homogenous elastic half-space (after Okada, 1992)

model cost evaluation
with weight vector

\[ \| e \| = \sqrt{ (R(d_{\text{obs}} - d_{\text{pred}})^T (R(d_{\text{obs}} - d_{\text{pred}})) ) } \]

Data covariance matrix \( \star \) \[ \Sigma^{-1} = R^2 \]

\( \star \)
- Model 1: equal weights (\( \Sigma \) diagonal)
- Model 2: variance based weights (\( \Sigma \) diagonal)

interferogram forming with \textit{GAMMA} software
unwrapping using \textit{snaphu} (Chen, 2000)
quadtreesubsampling after Jónsson et al. (2002)
GPS after Arnadóttir et al. (2004)
Nonlinear optimization: \textit{Simulated Annealing} +
Least Square Fit after Cervelli et al. (2001)
I) Fault optimization: model and predicted data

Kleifarvatn Earthquake source model parameters:

<table>
<thead>
<tr>
<th>dimensions [m]</th>
<th>orientation [deg]</th>
<th>displacement [m]</th>
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<tr>
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<tr>
<td>dextral</td>
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</table>

Propagating data errors to model uncertainties: “Monte Carlo” approach

\[ ||e|| = \sqrt{(R(d_{obs} - d_{pred}))^T (R(d_{obs} - d_{pred}))} \]

synthetic noise realizations:
I) Fault model uncertainties

Enable comparison through the simulation of the older setups:
- reducing of the data sets
- apply weighting based on the variance only (estimates from our analysis)

Assumptions:
- influences of data processing, InSAR subsampling, small changes in the relative weights of the data
- small changes the setup of the optimization algorithm are negligible.
II) Simulation: number of data sets
(data covariances are not considered)

Model 1

Data variances
asc. InSAR \(4.6 \cdot 10^{-4} \text{ m}^2\)
desc. InSAR \(2.4 \cdot 10^{-4} \text{ m}^2\)
GPS, horizontal components: \(1 \cdot 10^{-4} \text{ m}^2\)
GPS, vertical components: \(2.5 \cdot 10^{-5} \text{ m}^2\)
II) Simulation: number of data sets
(data covariances are not considered)

Model 1
Model 2

Data variances
asc. InSAR 4.6 \cdot 10^{-4} m^2
desc. InSAR 2.4 \cdot 10^{-4} m^2
GPS, horizontal components: 1 \cdot 10^{-4} m^2
GPS, vertical components: 2.5 \cdot 10^{-5} m^2
II) Simulation: number of data sets

(Model 1)
(Model 2)
(Model 3)

- earlier optimization results are reproducible!
- different final models due to parameter trade-offs
- reduction of model uncertainty / suppression of parameter trade-offs with the use of data from a different LOS

**Data variances**

- asc. InSAR: $4.6 \times 10^{-4} \text{ m}^2$
- desc. InSAR: $2.4 \times 10^{-4} \text{ m}^2$
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II) Simulation: data weighting – diagonal versus full covariance matrix

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- GPS, vertical components: $2.5 \times 10^{-5} \text{ m}^2$
II) Simulation: data weighting – diagonal versus full covariance matrix

Weighting is controlled by:

- quadtree box size: large boxes have high weights
- correlation: distance and number of neighboring boxes

\[ \Sigma^{-1} = R^2 \]
II) Simulation: data weighting – diagonal versus full covariance matrix

Model 1

⇒ reduction of model uncertainty when implementing full data covariances
II) Simulation: data weighting – diagonal versus full covariance matrix

⇒ reduction of model uncertainty when implementing full data covariances
Conclusions

- additional use of asc. InSAR *improved* the fault model estimation for the Kleifarvatn earthquake

- including data errors statistics increases the accuracy of model results

distributed slip on the Kleifarvatn fault