Modelling DEM data uncertainty

Impact assessment on an ice sheet model using Monte Carlo Simulations

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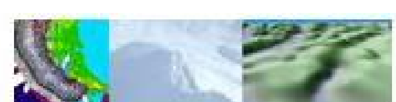

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Outline

- **Introduction & Motivation**
  - Ice sheet modelling
  - DEM uncertainty
- **Methods**
  - Deriving error surfaces
  - Building an uncertainty model
  - Monte Carlo Simulation
- **Results**
  - Uncertainty model
  - MCS on ISM
- **Discussion**
- **Outlook**

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Ice Sheet Modelling (ISM)

ISMs simulate **dynamics** of large ice masses under past, recent or future **climate** conditions

Application:

Predicting response of Antarctic or Greenland ice sheet to climate change → **sea level change**

(Gregory & Oerlemans, Nature 1998)

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Ice Sheet Modelling

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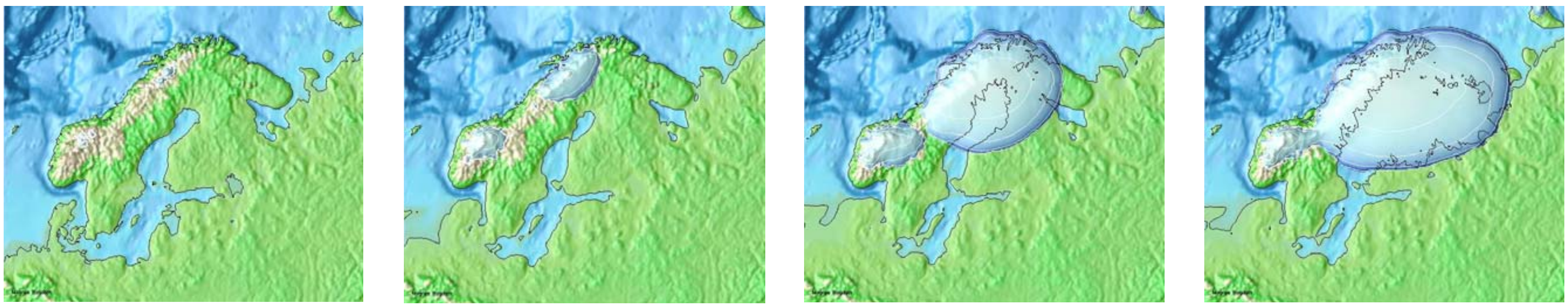
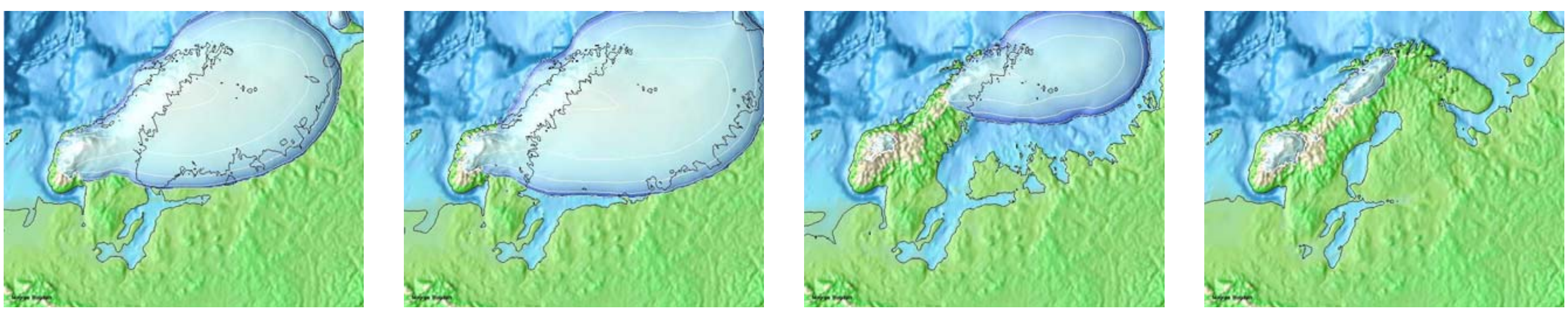
Reconstruction of the Fennoscandian ice sheet through the Last Glacial Maximum



Time



Time

Source: Hagdorn 2003

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Motivation

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Aim:

Compare the impact of **DEM uncertainty** on ice sheet model (ISM) of **Fennoscandia** with that of **climate** factors.

Problem:

- Model runs on GLOBE DEM
  → no uncertainty information
- No reference data available (e.g. SRTM)

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Definition

<u>Error:</u>

Deviation of a measure from its true value

→*elevation error can only be assessed where higher accuracy reference data is available*

(Fisher and Tate, 2006)

<u>Uncertainty:</u>

vague definitions → e.g. “differences due to data gathered at contrasting resolutions should [...] be regarded as an aspect of uncertainty.”

(Fisher and Tate, 2006)

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Modelling DEM uncertainty

DEM metadata on uncertainty:

Amount:

- Global accuracy measures (RMSE / Std.Dev.)

Spatial Distribution:

- None
- accuracy dependency on
  source data / production method

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Modelling uncertainty

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Components of uncertainty:

Amount (mean, max, sum)

Distribution (normal, uniform,…)

Spatial distribution (uncorrelated, correlated)

Correlation (range, variation,…)

No meta-data, no assessment possible

→ assumption based

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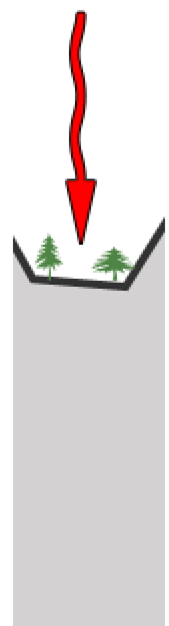
Error, Accuracy, Uncertainty



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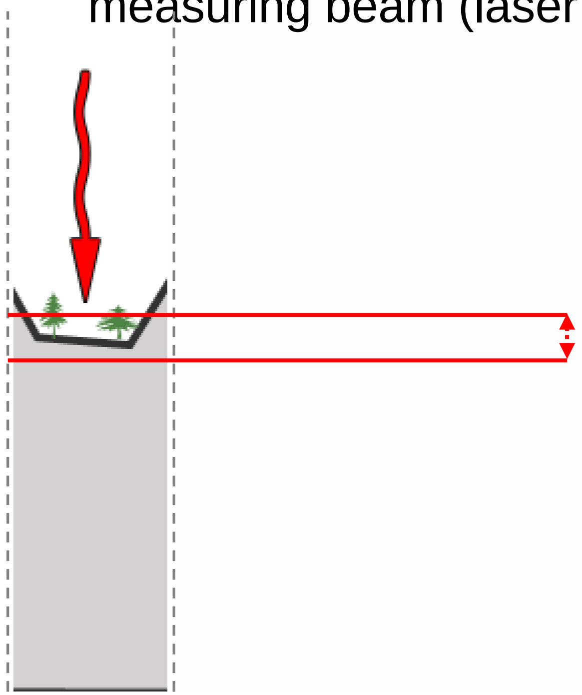

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Error, Accuracy, Uncertainty

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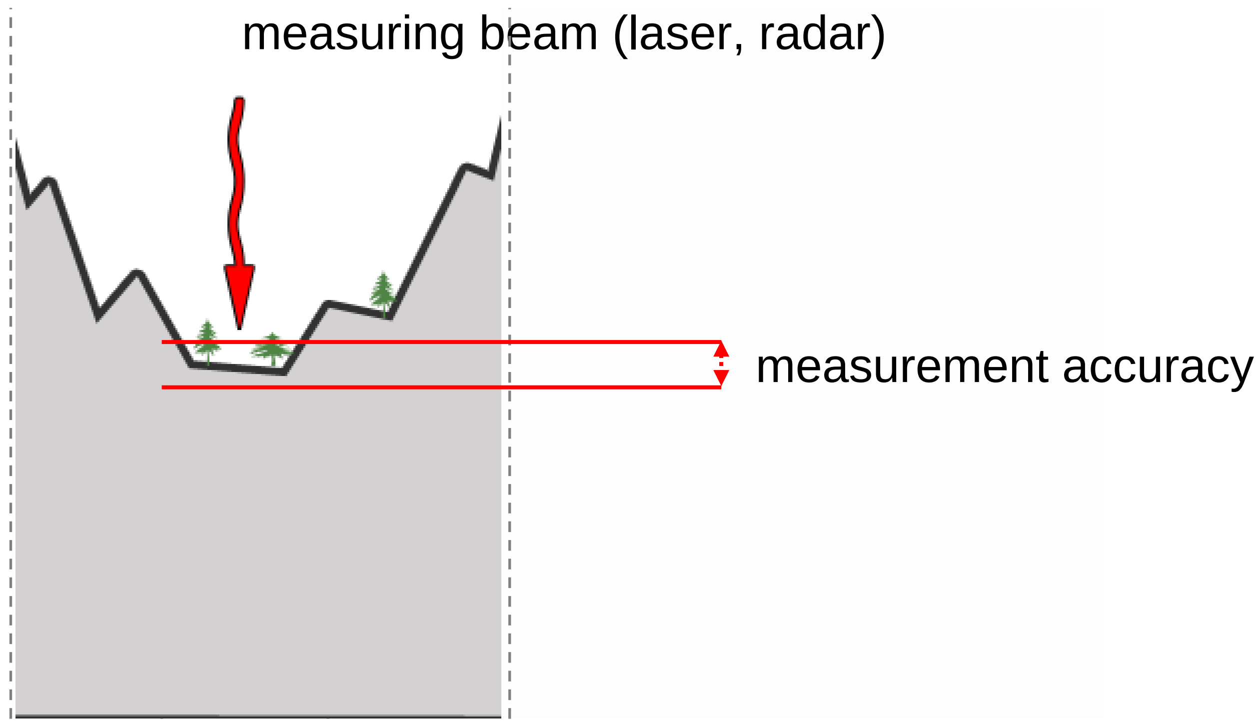

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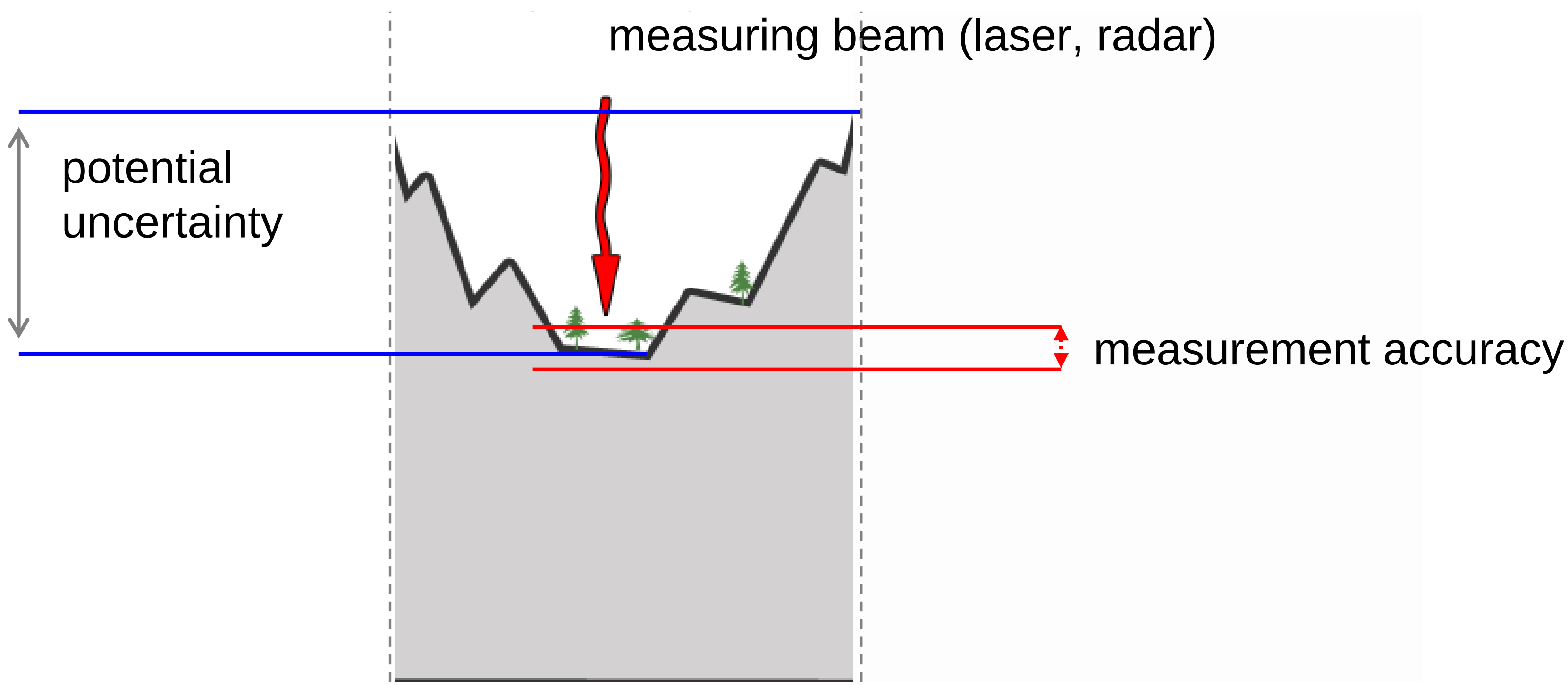

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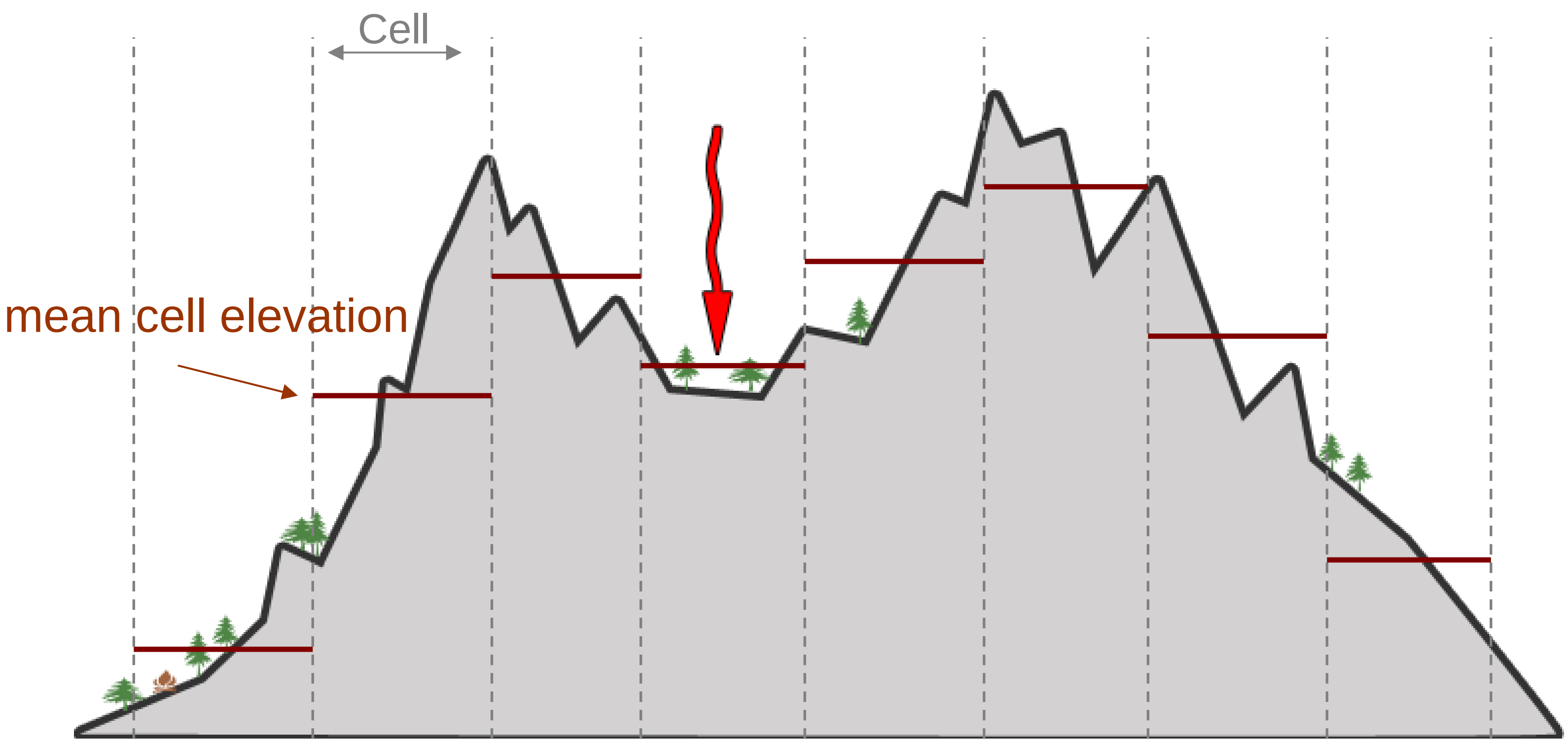

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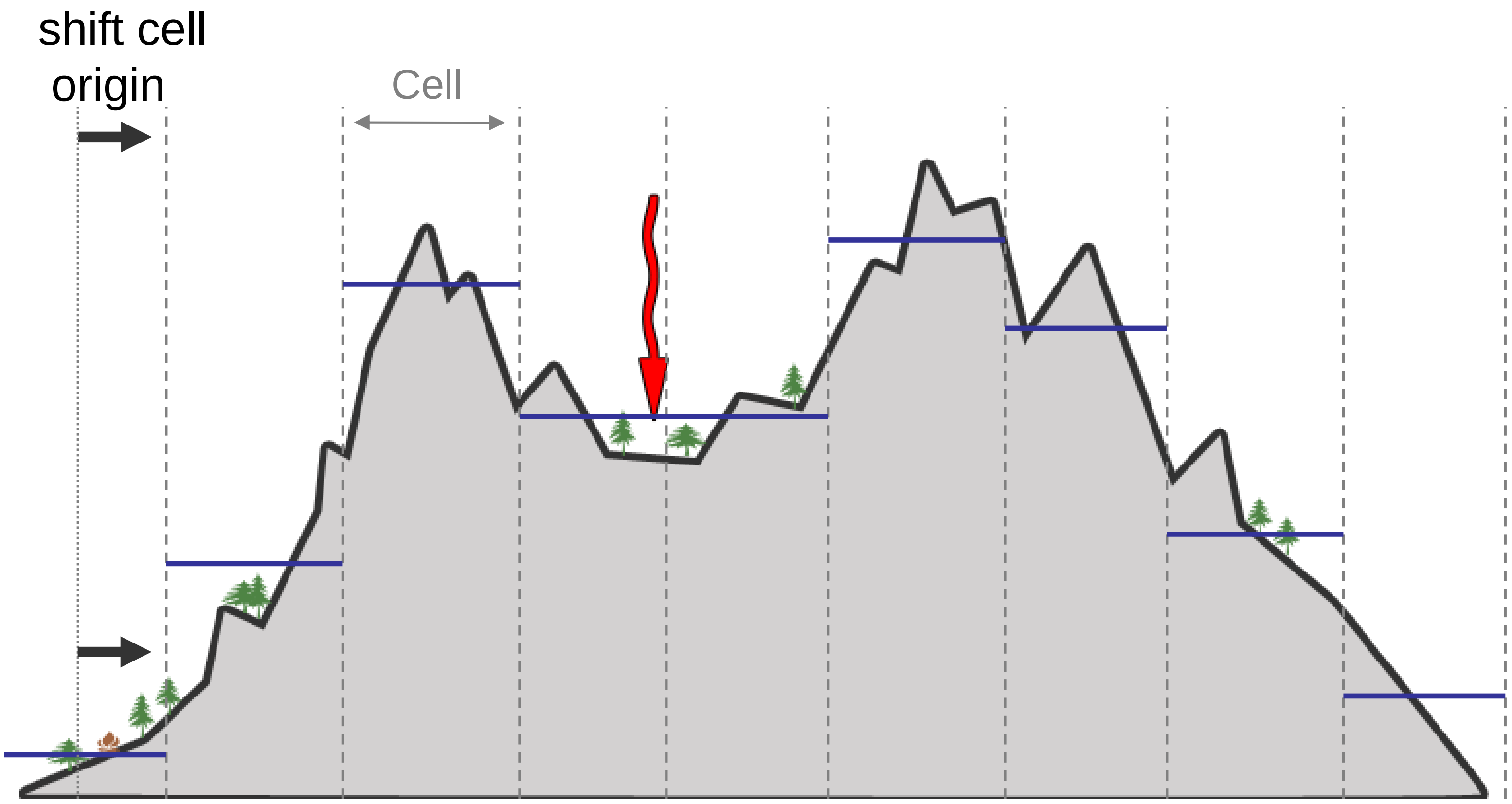

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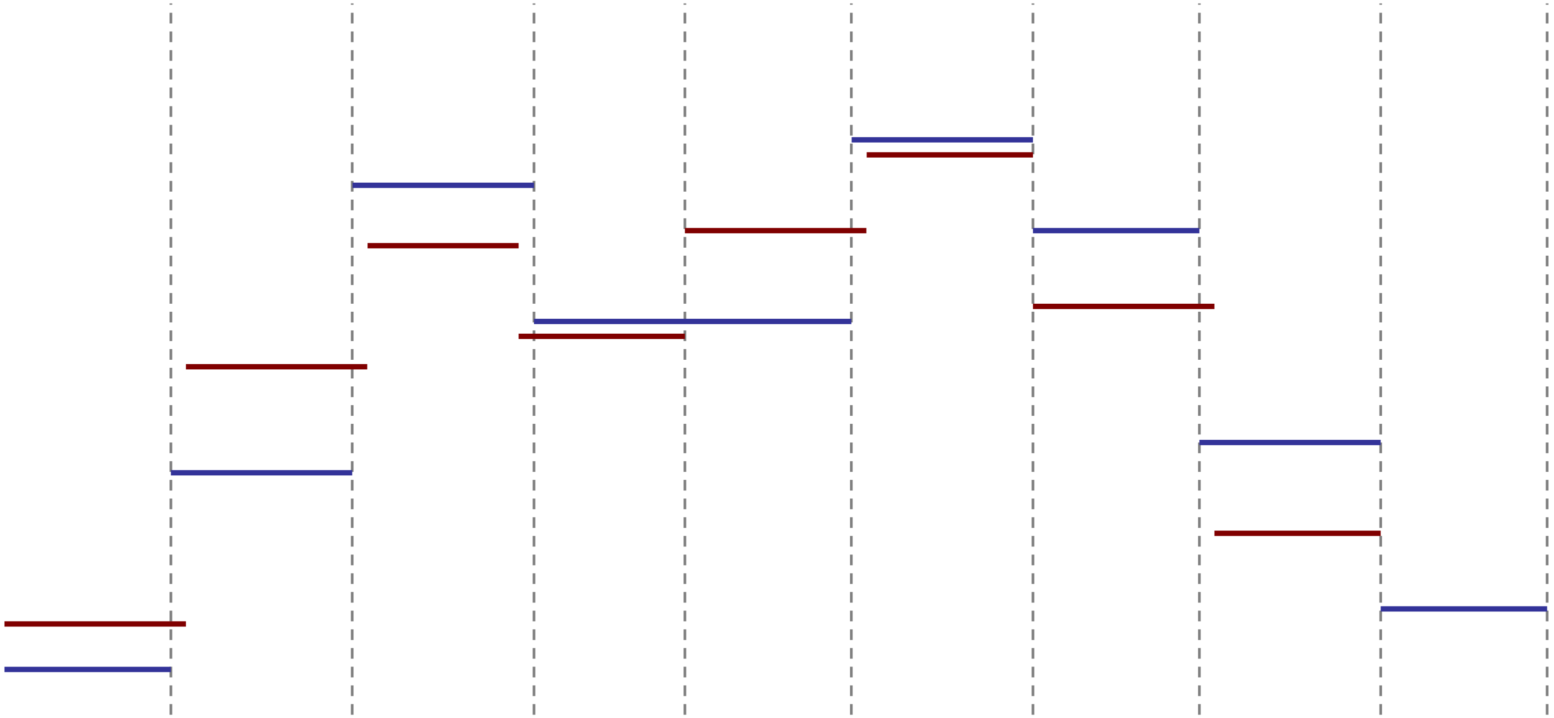

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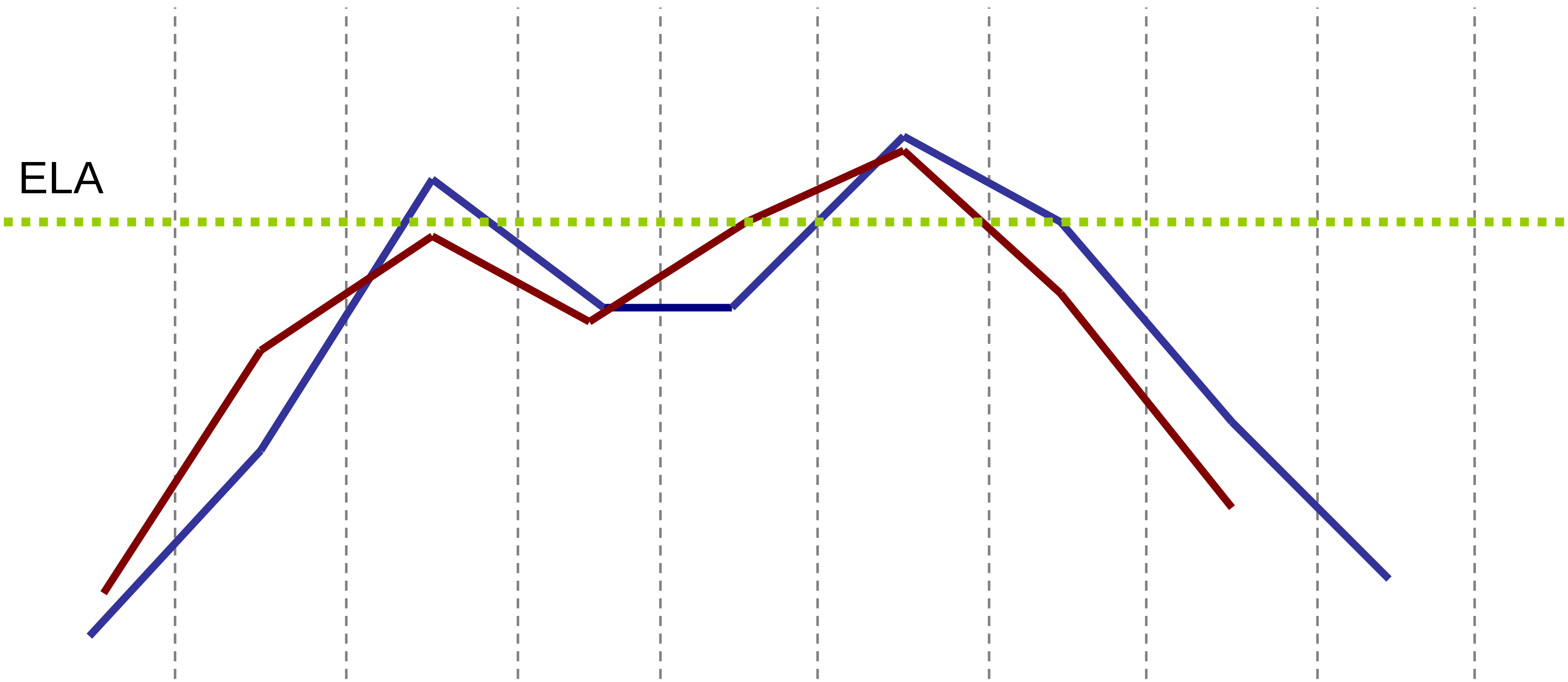
DEM uncertainty in ISM



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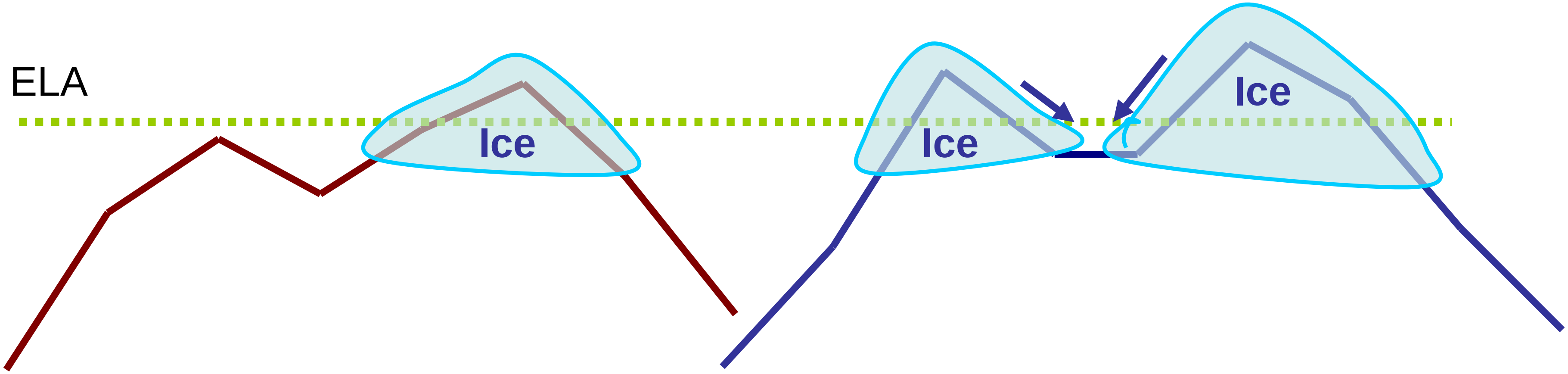

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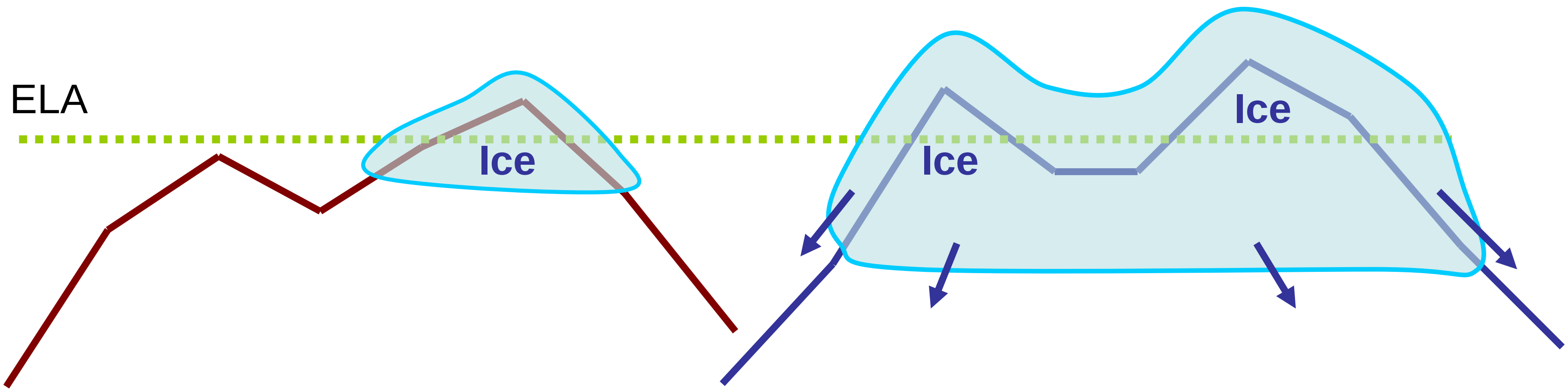

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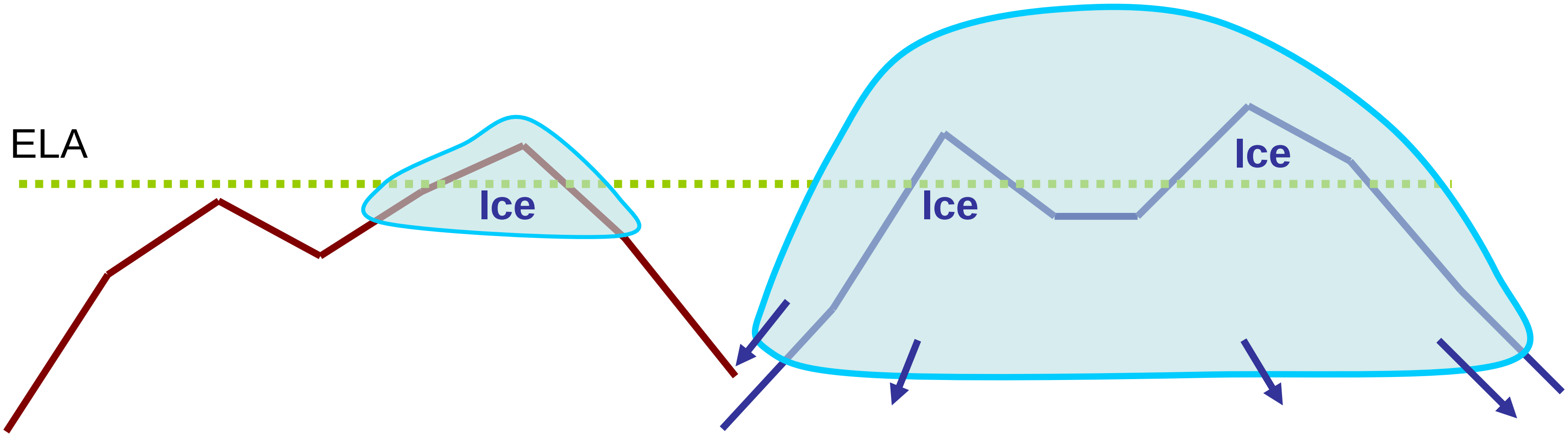
DEM uncertainty in ISM



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GLOBE Uncertainty

SRTM = higher accuracy data for GLOBE
→ derive GLOBE error

Hypothesis:

GLOBE error is function of terrain parameters
→ transferable to Fennoscandia

Aim:

Model GLOBE uncertainty using SRTM as higher accuracy reference data

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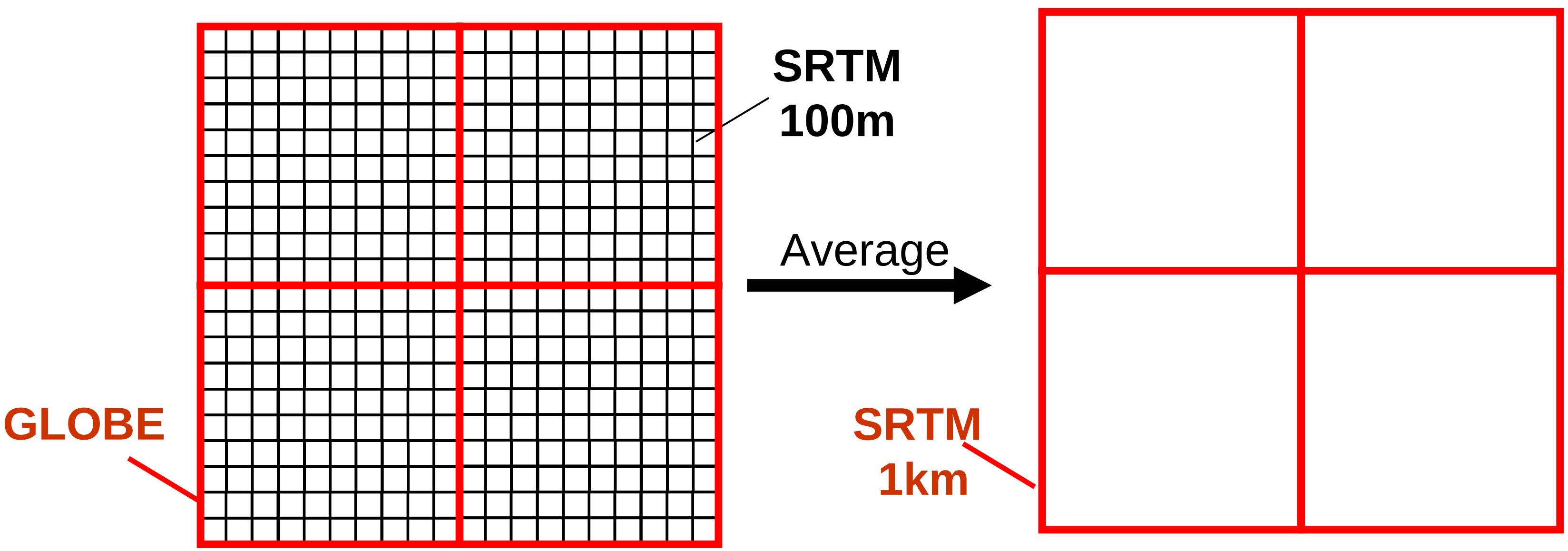
Deriving GLOBE Error

- 3 DEMs used: Alps, Pyrenees, Turkey
- Average SRTM data (~100m) within each GLOBE cell (~1km) (100:1) (Jarvis *et al* 2004)



- Subtract GLOBE from resampled 1km SRTM

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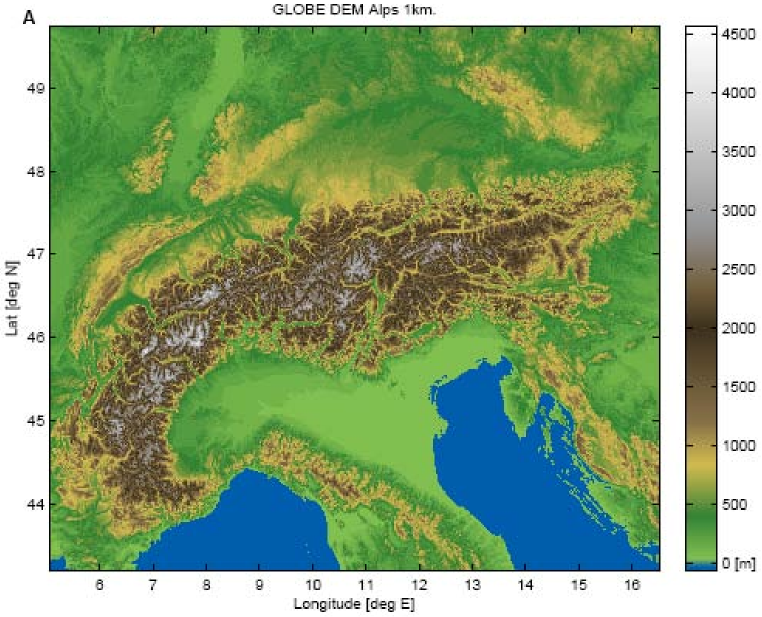
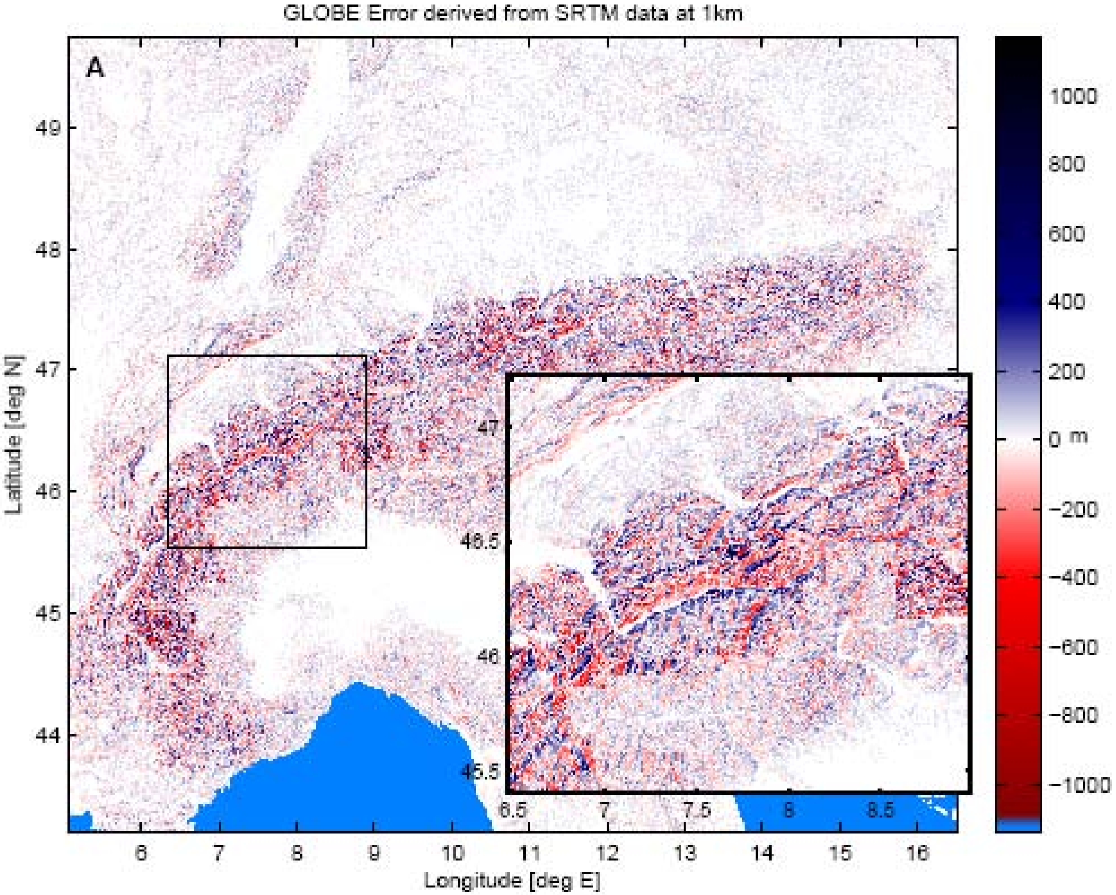
Deriving GLOBE Error





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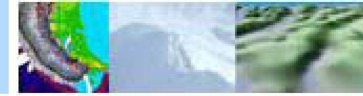

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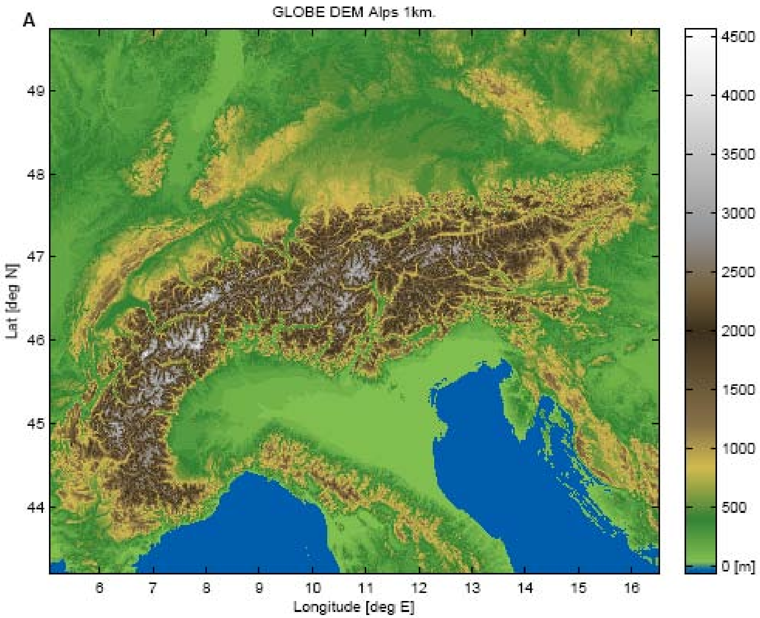
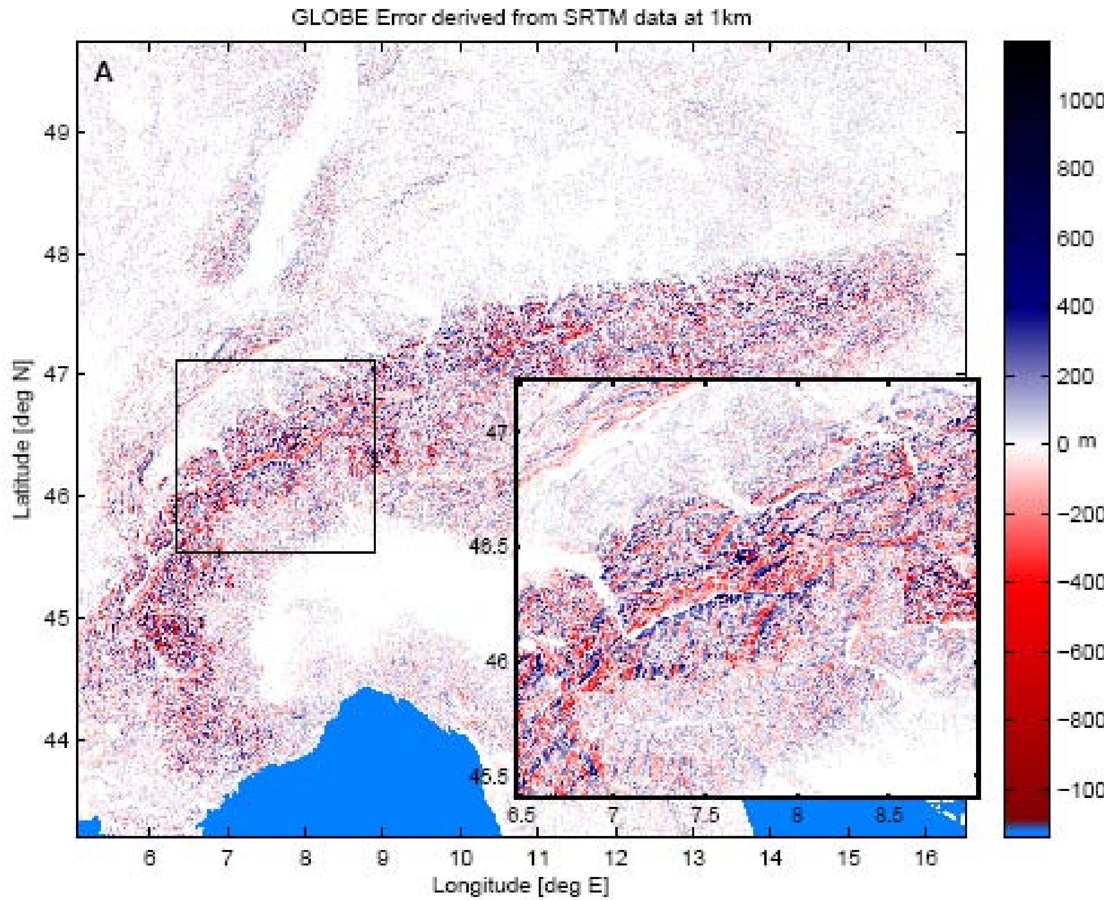
Analysing GLOBE Error



Regression analysis:

Error, Magnitude of error, Sign of error



Tested parameters:

Elevation
Gradient (slope/aspect)
Roughness
Curvature
Moran's I (correlation index)

…

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Correlation of Error

Error magnitude:

$$abs(\varepsilon) = f(\text{roughness, elevation}) \quad (r^2 = 0.44)$$

Sign of error:

$$S = f(\text{aspect, extremity}_{mean})$$

$$\text{with } -1 \leq S \leq 1$$

(~ 60% sign modelled correctly)

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Uncertainty model

Final Uncertainty model:

$$U_{tot} = (abs(\varepsilon) + residuals) * S$$

include stochastic components

→ convolution filter using range from error surface semivariogram

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Modelling GLOBE Uncertainty

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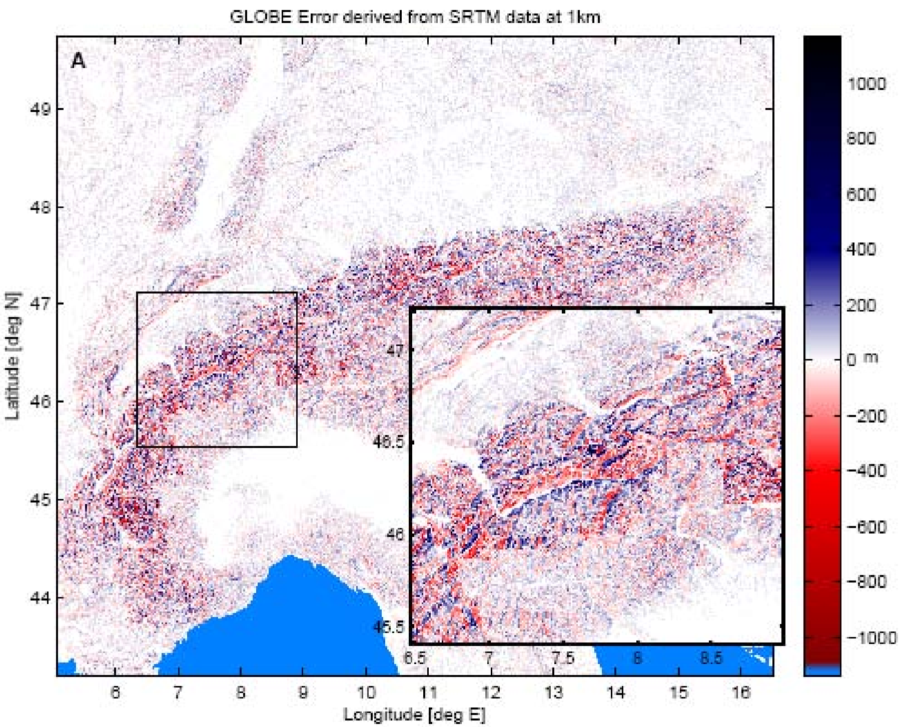
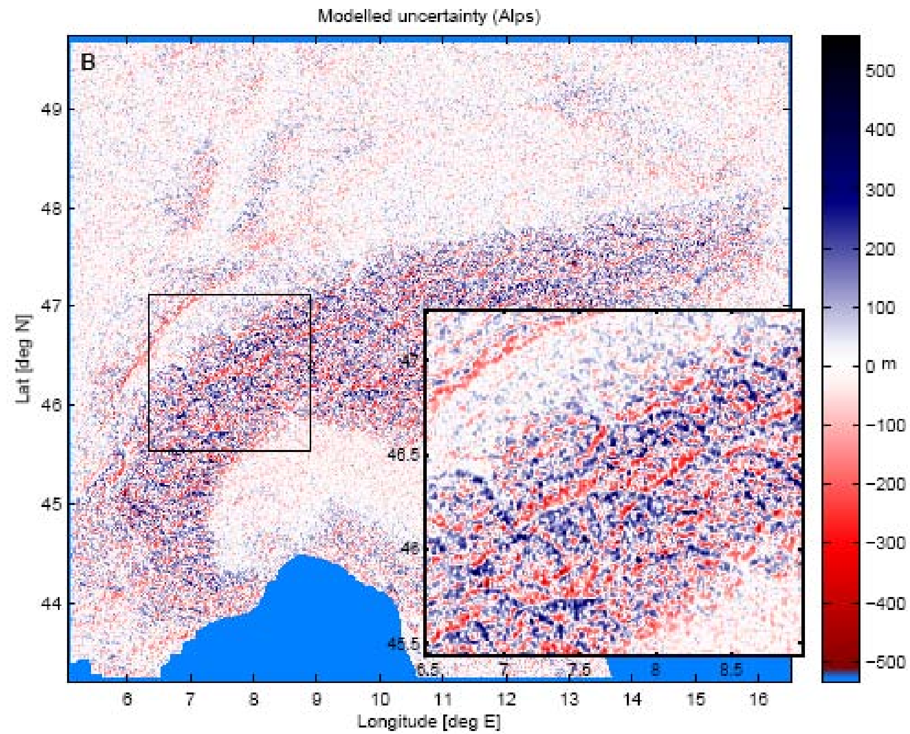
Error



Modelled Uncertainty



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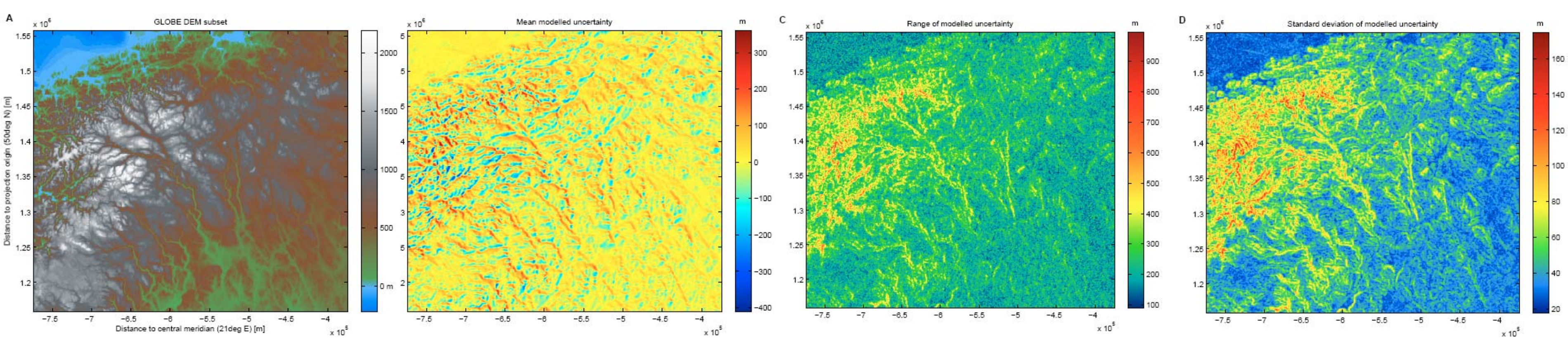
Monte Carlo Simulation

- Calculate **topographic parameters** for GLOBE DEM of Fennoscandia
- Calculate **100 uncertainty surfaces**
- Add uncertainty to Fennoscandia DEM
- Resample to 10km
- Run GLIMMER ice sheet model 100x



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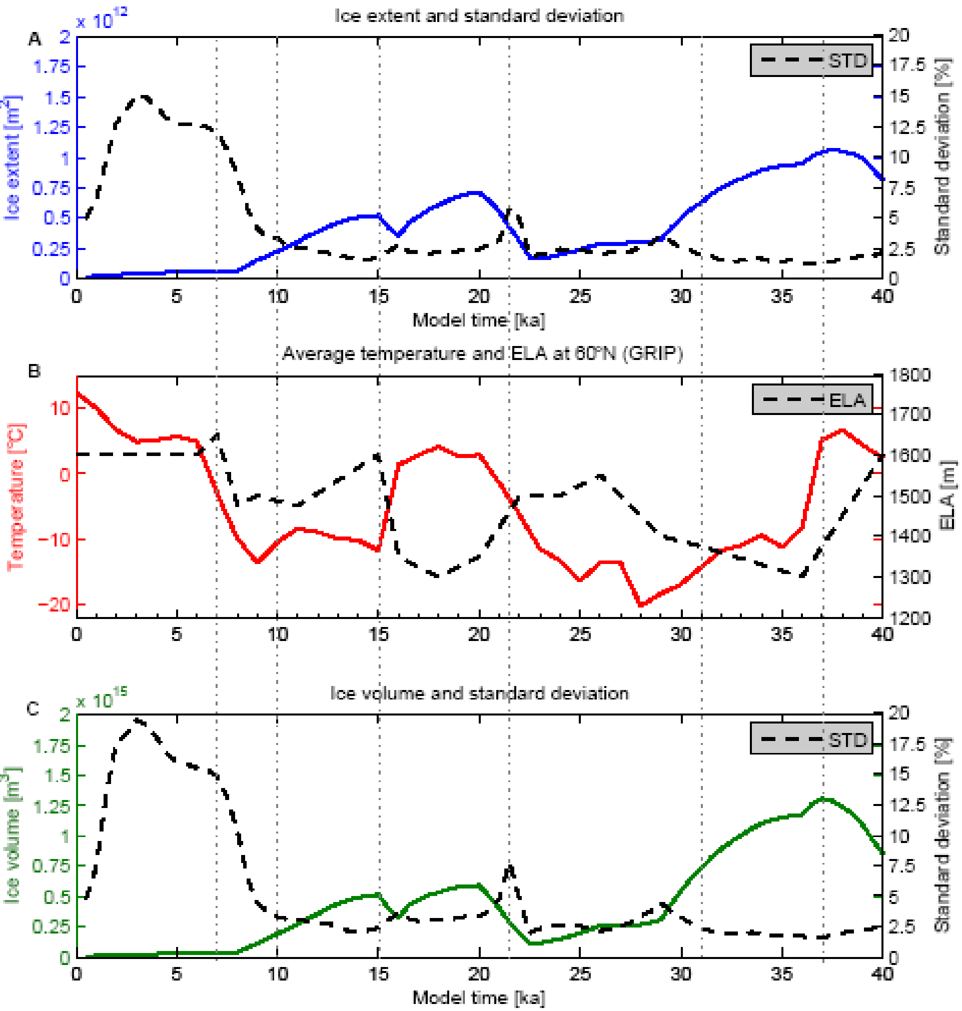
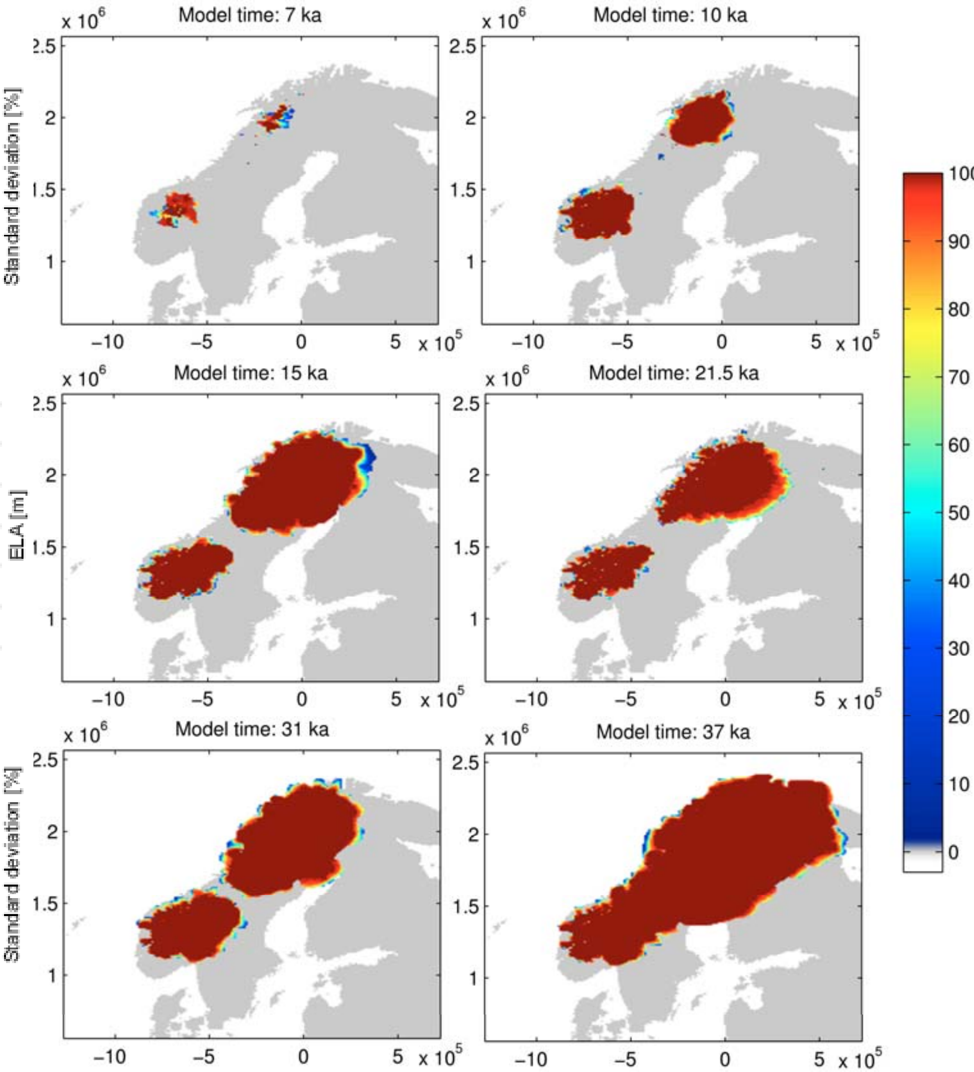
MCS Results





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Discussion - ISM

- Uncertainty model delivered topographies suitable for ISM
- Despite resampling to 10km, relative small (mean 40m Std.Dev.) uncertainty considerably impacts ISM results
- Inception and retreat phases in ISM are affected most
- Quantified impact of DEM uncertainty

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Discussion – Uncertainty model

Method for modelling DEM uncertainty

- including **spatial correlation**
- **robust** across different GLOBE regions
- despite **lack of metadata**
- **realistic** topographies
- suitable for Monte Carlo Simulations
- allows **sensitivity testing**
- **portable** to other data sets (SRTM/LIDAR)

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Improvements / Outlook

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- Testing of more parameters
- **Selection** & **preprocessing** of GLOBE data: data sources, processing, misregistration, …
- **Spatial correlation**: directional variograms, stochastic simulation
- Separation of error and uncertainty
- Different approaches: neural networks (ANN)

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Summary

- Derivation of GLOBE DEM error using SRTM as reference data

- Correlation of GLOBE error with terrain parameter
- Stochastic modelling of residuals (and error sign)

  →Uncertainty model for GLOBE DEM

- Transfer & application of uncertainty model for Monte Carlo Simulation of ISM

- Assessment of ISM sensitivity to DEM uncertainty

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References

- **Fisher**, P. and **Tate,** N. 2006: Causes and consequences of error in digital elevation models. *Progress in Physical Geography* 30 (4), 467-489
- **Gregory**, J. & **Oerlemans**, J. 1998: Simulated future sea-level rise due to glacier melt based on regionally and seasonally resolved temperature changes. *Nature* 391, 474-477
- **Hagdorn**, M.K.M. 2003: Reconstruction of the Past and Forecast of the Future European and British Ice Sheets and Associated Sea-Level Change. *unpublished PhD thesis, University of Edinburgh*
- **Jarvis**, A., **Rubiano**, J., **Nelson**, A., **Farrow**, A. & **Mulligan**, M. 2004: Practical use of SRTM data in the tropics: Comparisons with digital elevation models generated from cartographic data. *Working Document No. 198. International Centre for Tropical Agriculture (CIAT), Cali, Columbia*

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Discussion slides

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Analysing GLOBE Error

Regression analysis of GLOBE error

- error
- magnitude of error
- sign of error

with **topographic parameters**, e.g.

- Elevation
- Slope
- Aspect
- Roughness (elevation, slope)
- Curvature
- Extremity (Mean, Max, Min)
- Moran's I (correlation index)

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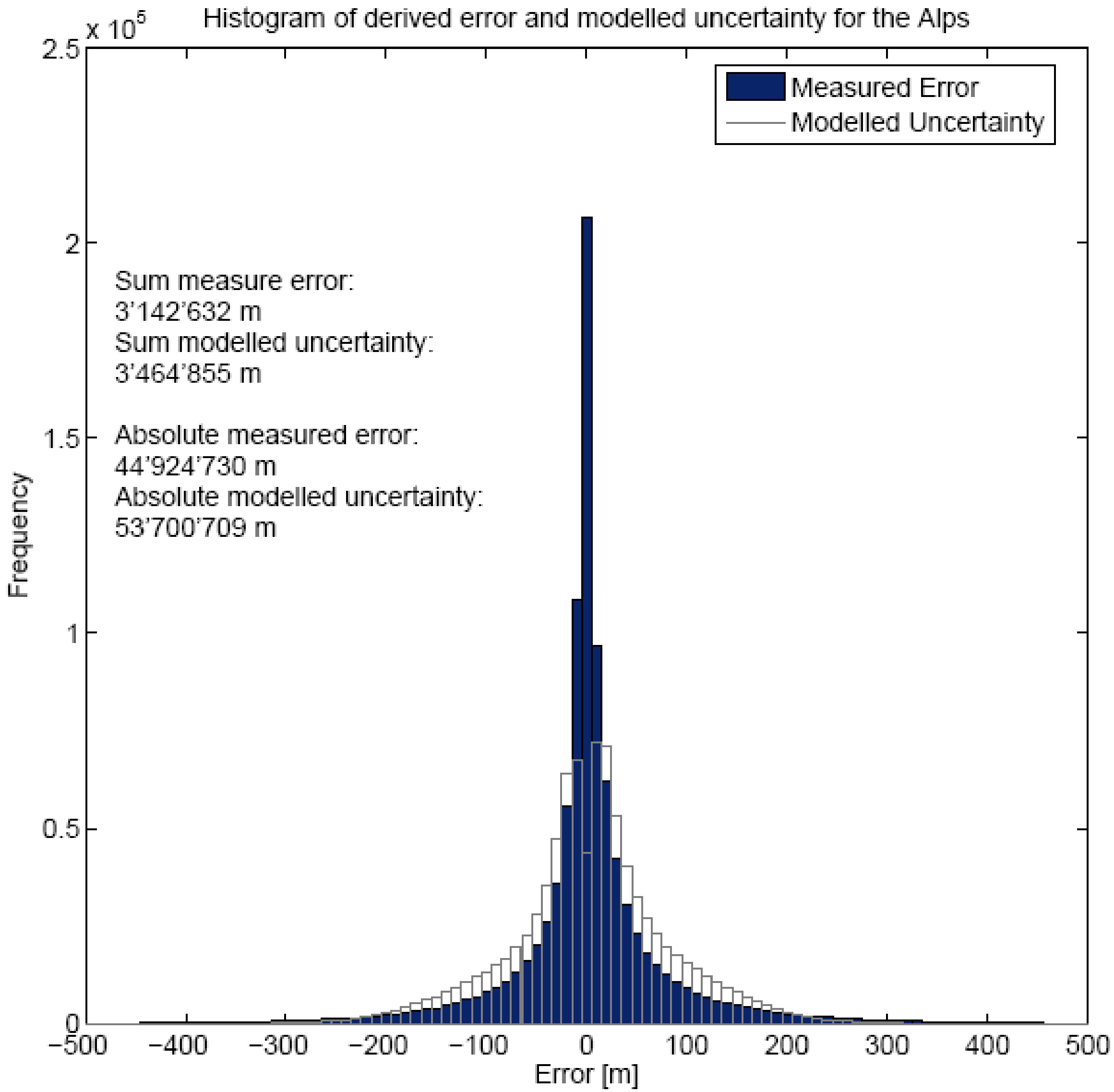
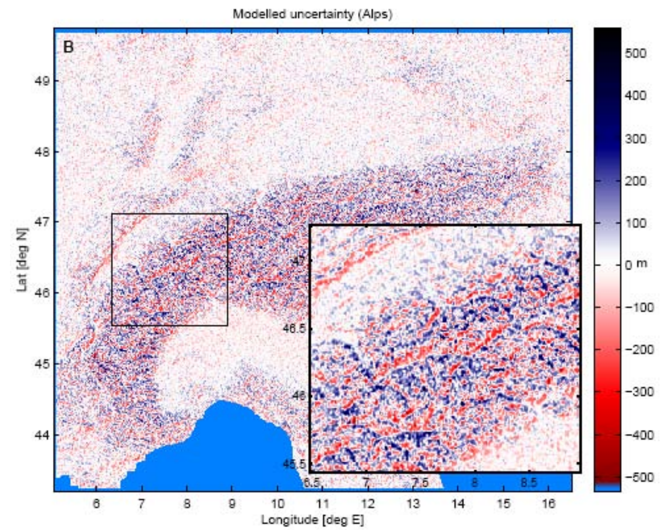
Modelling GLOBE Uncertainty





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Correlation coefficients:

Magnitude of error:

- Roughness (0.66)
- Slope (0.62)
- Extremity_{min} (0.58)
- Elevation (0.53)

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Uncertainty model

2 Stochastic components:

Regression residuals (magnitude of error):

Modified **normal distribution** N[0,45] randomly added to abs(ε) → 1st **stochastic component**

Sign of error:

S = f(extremity$_{mean}$, aspect) with $-1 \leq S \leq 1$

r=randn(-1..1)

abs(r) > abs(S) → S = S * -1

Discussion – Uncertainty model

- Correlations & regression robust across different GLOBE DEM regions
- Magnitude of error correlates well
- Spatial configuration of error well captured
- Uncertainty model results suitable for MCS (2 stochastic elements)

→ **Hybrid Error/Uncertainty Model**

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