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# Representation of Topography and its Role in Uncertainty:

## A Case Study in Ice Sheet Modelling

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# Overview

- ❑ Introduction
- ❑ Ice sheet modelling
- ❑ Work in progress
  - ❑ Generalisation
  - ❑ Monte Carlo Simulations
  - ❑ Artificial Topographies
- ❑ Results and initial conclusions
- ❑ Next steps



# Introduction

## Topography in modelling

Error and variation can originate from

- Data collection
- Generalisation**
- Representation**  
(data model, attribute retrieval, resolution, ...)
- Reprojection
- Transformation



# Introduction

## Aims of this work

- ❑ Assess the variation that stems from various aspects of representation of topography
- ❑ Quantify this variation and assess its origin
- ❑ Analyse its impact on behaviour and uncertainty of large scale models



# Introduction

## Case study: Ice sheet model (ISM)

Model to simulate past and recent ice sheets under changing climatic conditions.

Typically run on continental or global scale at resolutions of 1-25km.



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# Introduction

## Glacier



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# Introduction

## Ice sheet

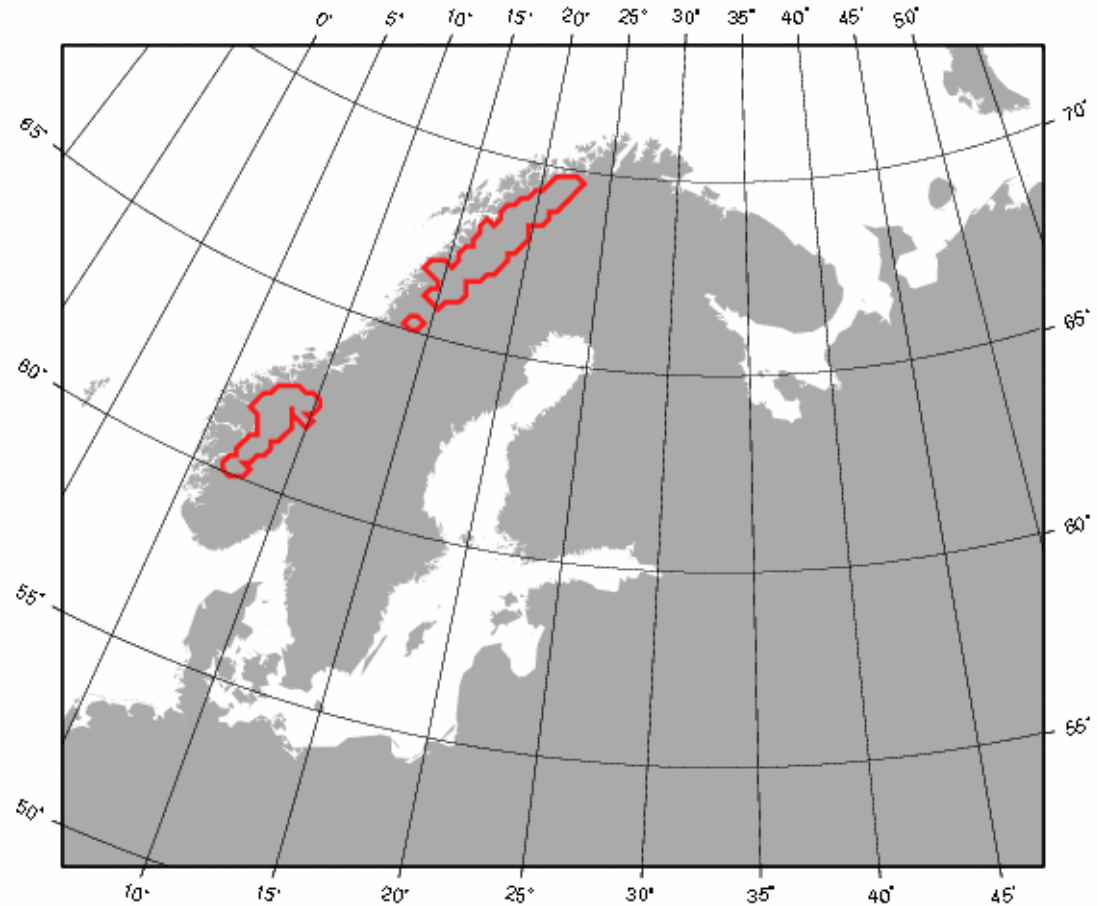


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# Ice sheet model

Modelled extent of Fennoscandian ice sheet over time from 120ka to 80ka BP.

Climate forcing using GRIP s-10 core proxy records.



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# Ice sheet model

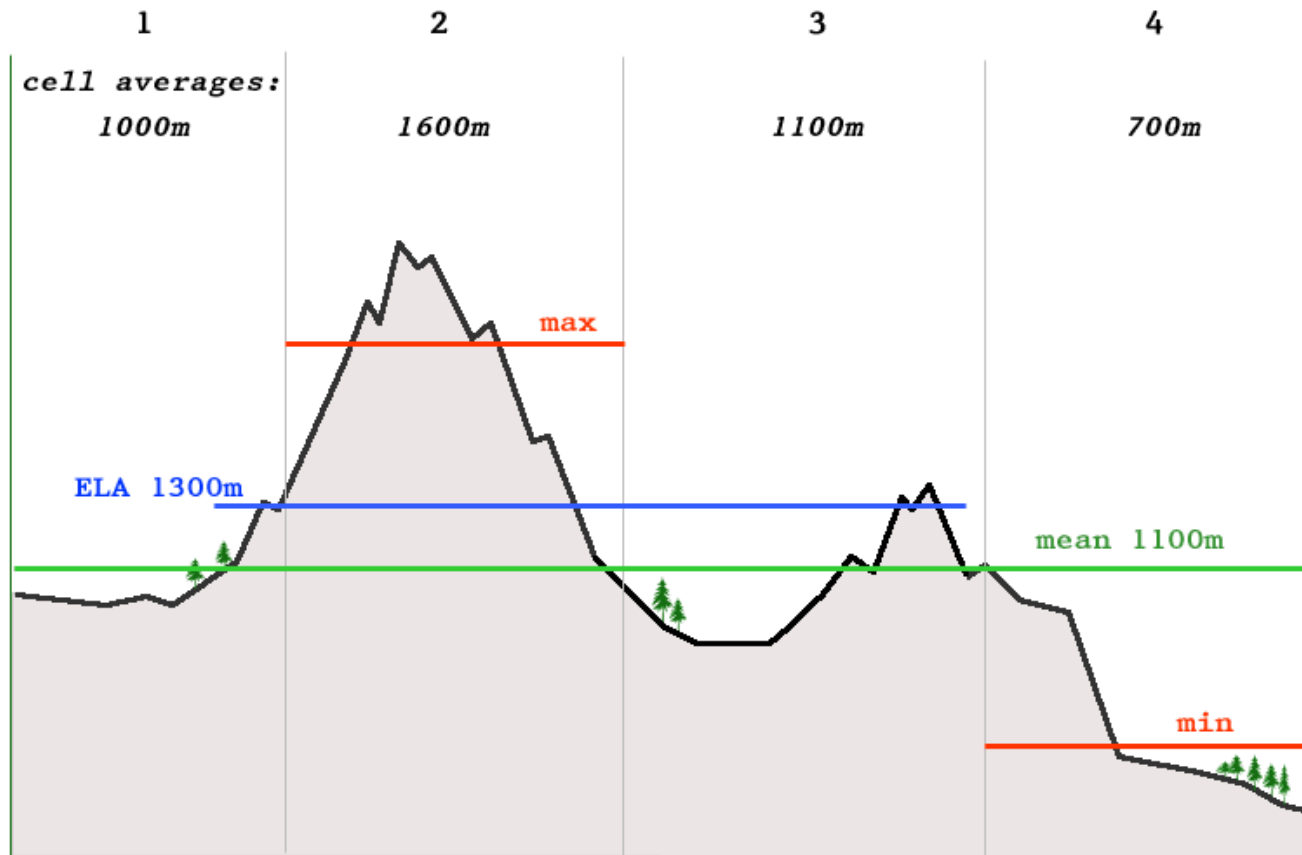
## Why ISM?

- ❑ Environmental relevance
  - ❑ Climate change / sea level rise
- ❑ Suitability for research questions:
  - ❑ Use of low resolution topographies
  - ❑ Depending on topographic features (peaks, valleys, altitude, roughness, ...)



# Ice sheet model

Equilibrium line altitude (**ELA**) threshold and the 'altitude generalisation dilemma'



# The Model

- ❑ **Model:** finite differences numerical model, coupled climate model (*Boulton & Payne 1992*)
- ❑ **Data:**
  - ❑ Scandinavian DEM created from GTOPO30 and ETOPO2 data used w/ GRIP s-10 core proxy climate data.
  - ❑ SRTM90 data (South America, Switzerland)
  - ❑ Artificial topographies of various resolution and amplitude



# Work in progress

- Generalisation
- Monte Carlo Simulations
- Artificial topographies



# Generalisation

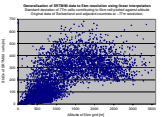
## DEM metadata

Standard deviation ranges from 18m (DTED) to 300m+ (GLOBE Antarctic data)

## Generalisation of SRTM90 data

Bilinear interpolation to 5km resolution:

Standard deviations (STDV) of generalised cells of 500m+ for altitudes >1000m.



# Monte Carlo Simulation

## Monte Carlo Simulation (MCS):

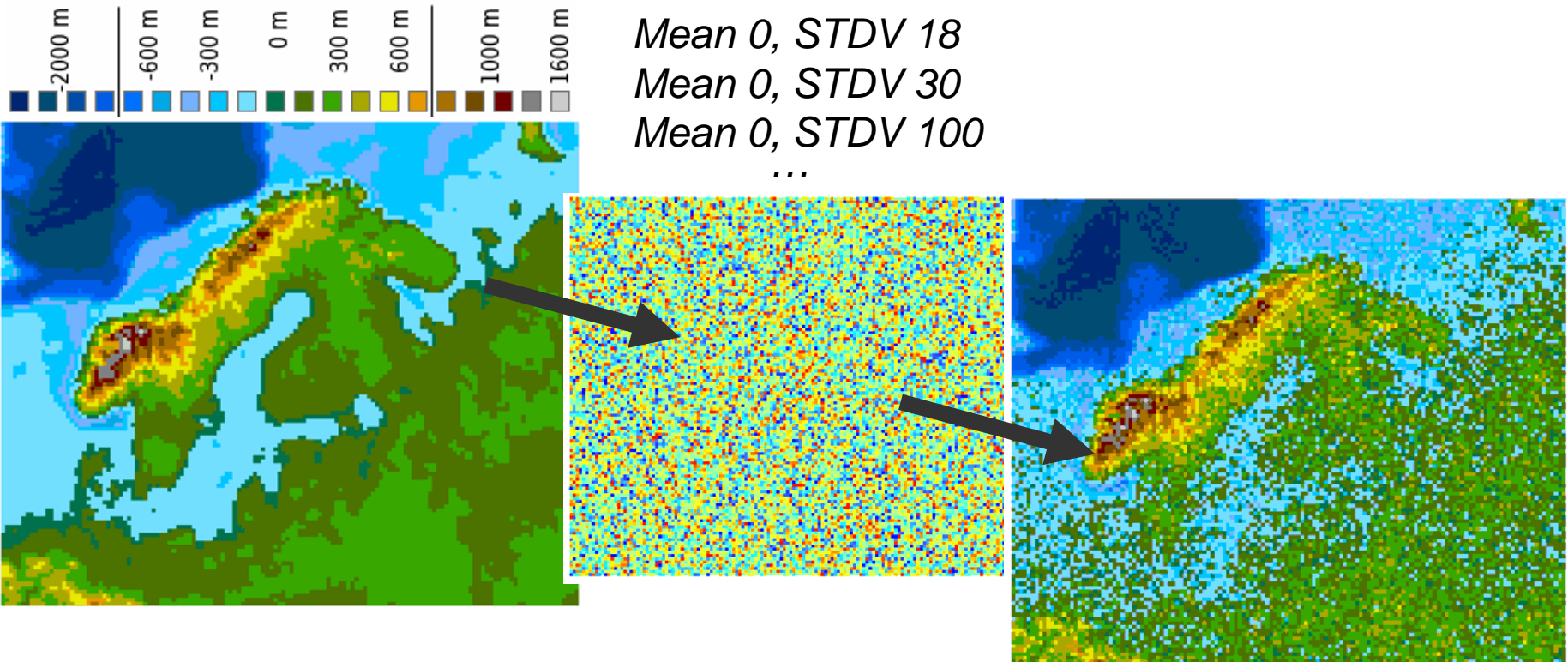
Uncorrelated normal distributed error (mean 0, STDV 18, 30, 100, 300m) superimposed on Scandinavian topography (20km resolution).

150 model runs for each STDV  
14,000 years runtime each



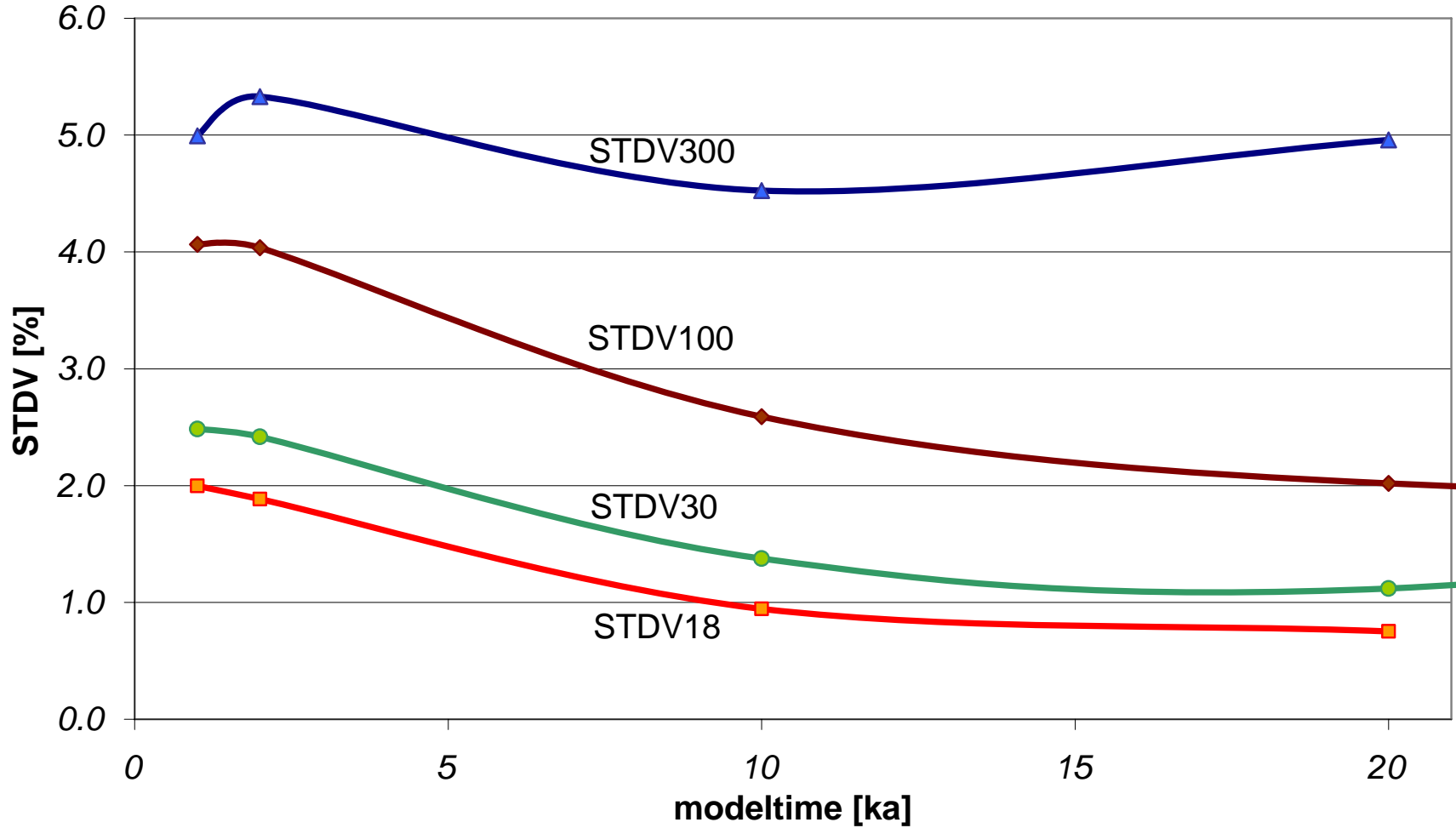
# Monte Carlo Simulation

Adding random, normal distributed error to DEM to produce a set of 150 different topographies.



# Monte Carlo Simulation

MCS: Standard deviation of modelled ice extent over time  
Topography random error STDV of 18, 30, 100, 300m shown



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# Monte Carlo Simulation

## Random Error:

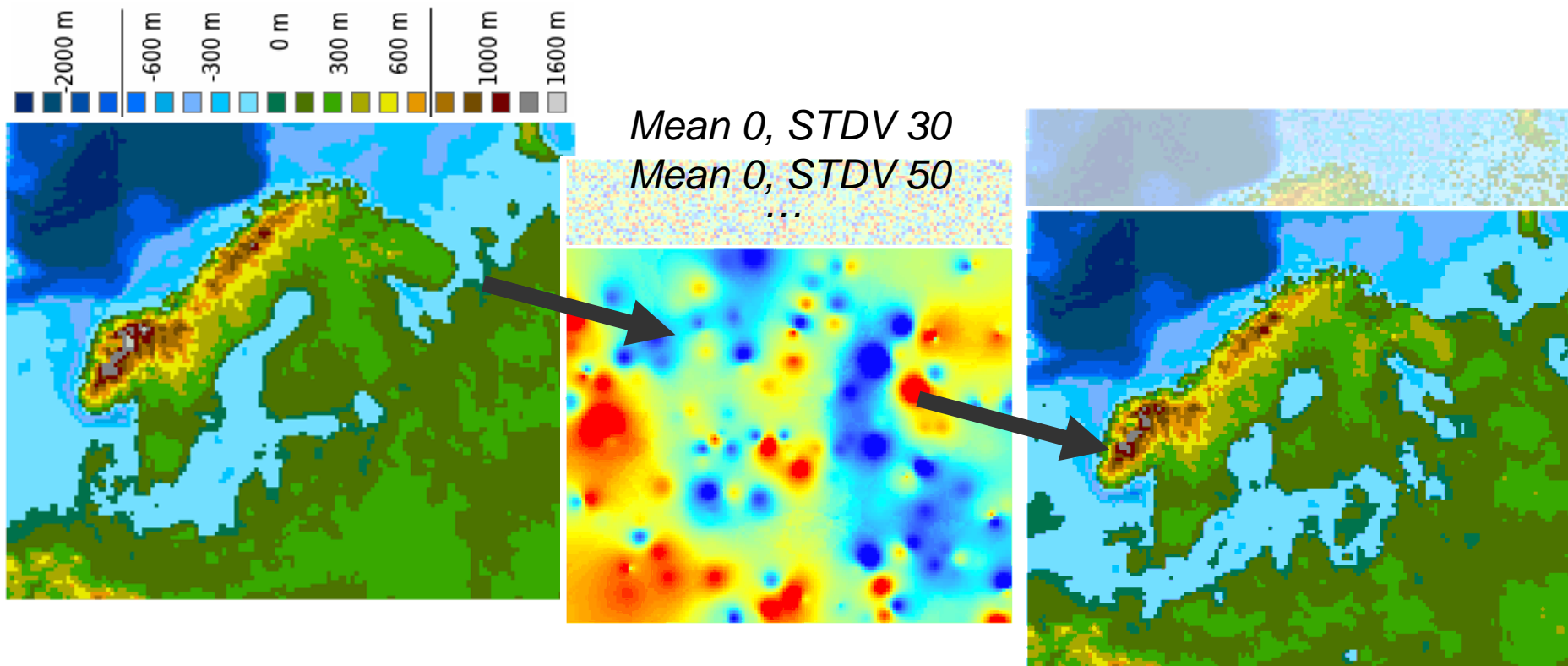
'Noisy' topographies with random errors of STDV 100m+ tend to lead to model instabilities.

For errors of 300m STDV, most model runs crash after 30-40ka and results are not comparable with other runs.



# Monte Carlo Simulation

Adding spatially correlated error to DEM to produce a set of 150 different topographies.



# Monte Carlo Simulation

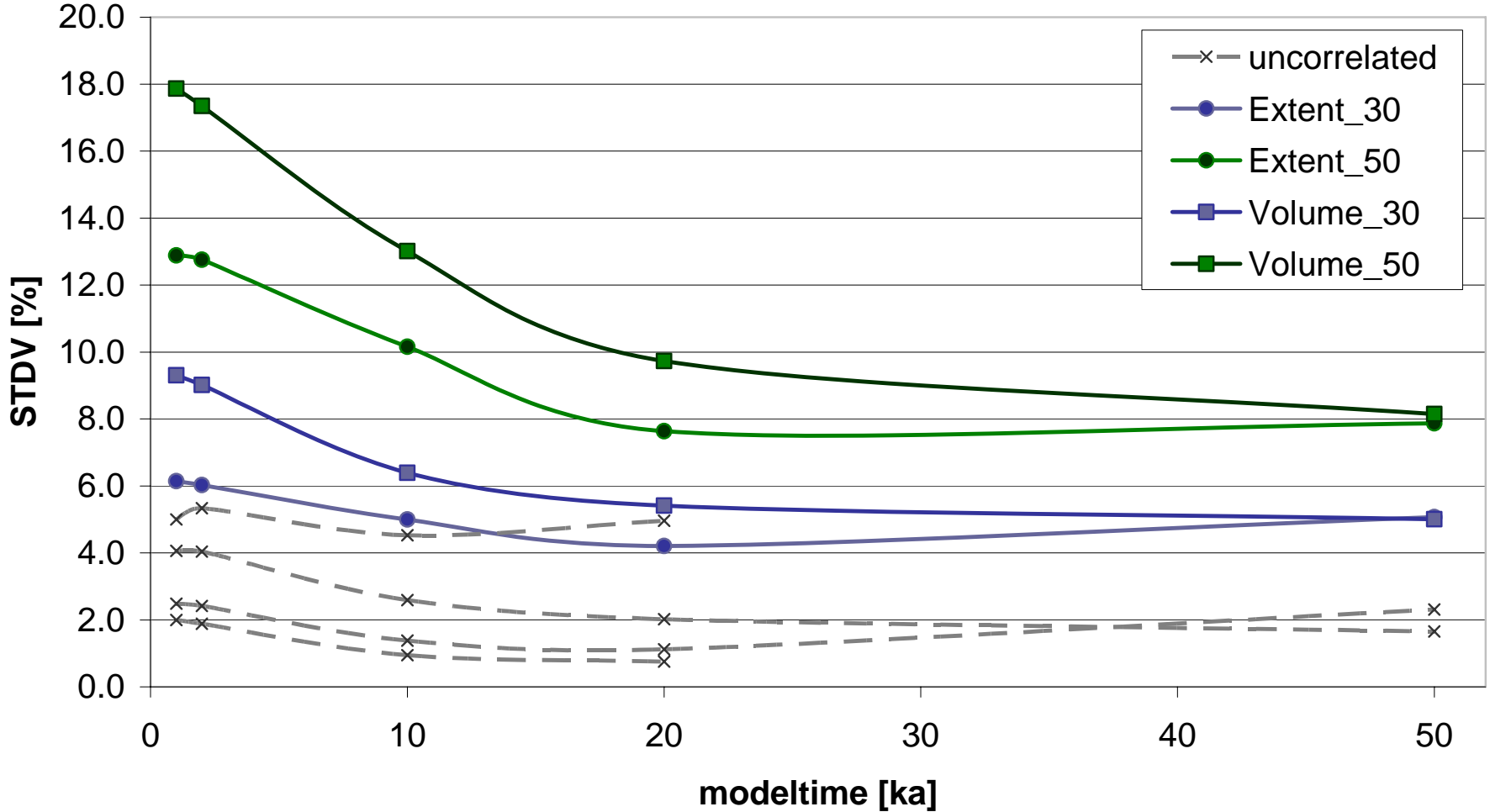
## Spatially correlated random error

Spatially correlated error surfaces are used.  
150 random points with normally distributed  $z$  values (mean 0, STDV of 50 & 100m) interpolated using inverse distance weighting (IDW).  
→ error surfaces of mean 0, STDV 30m & 50m



# Monte Carlo Simulation

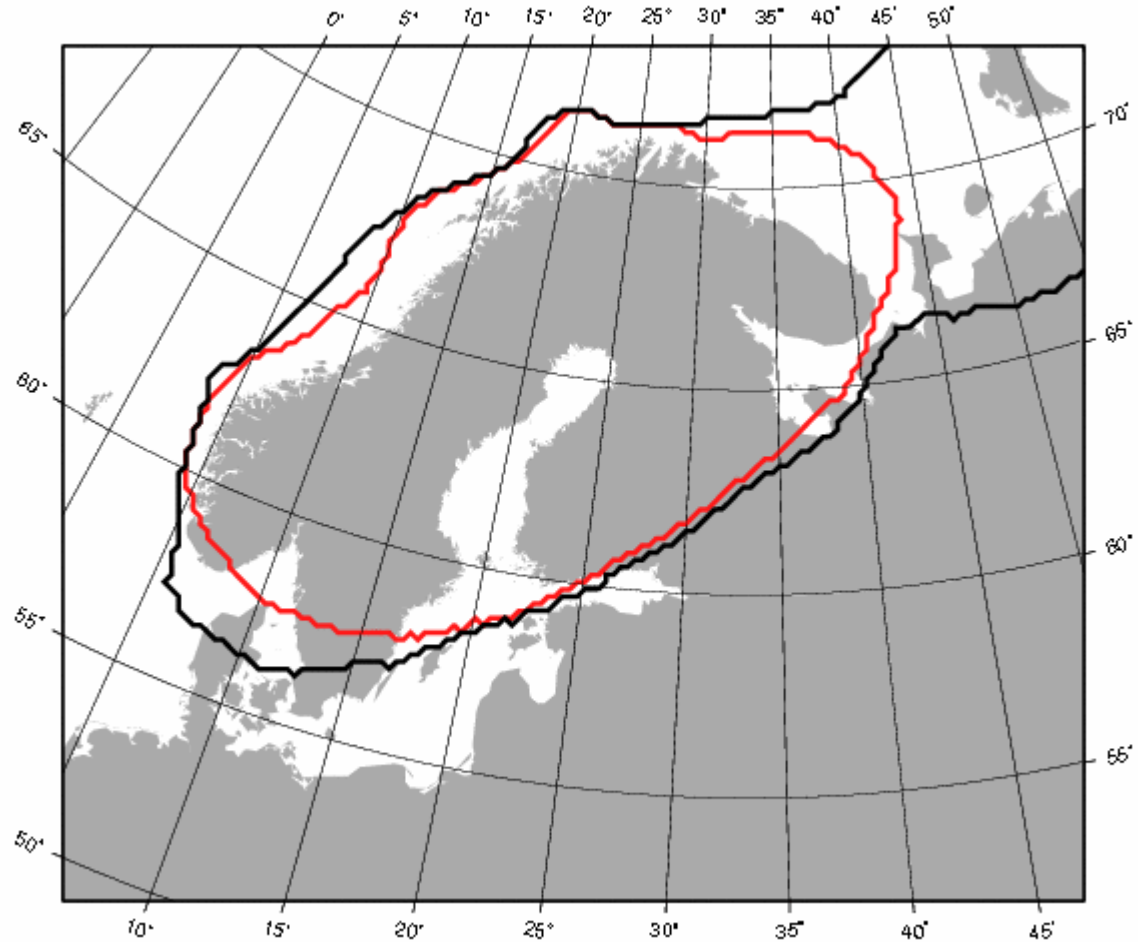
MCS: Standard deviation of modelled ice extent and volume over time  
STDV of correlated error surfaces 30m and 50m



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# Monte Carlo Simulation

MCS using correlated error of  $\sim 50\text{m}$  STDV. Ice extents of minimum and maximum runs plotted on Scandinavian topography in steps of 10ka.



**Ice extent** — *minimum*  
— *maximum*



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# MCS Summary

Use of correlated error surfaces give good results (little absolute deviation of mean from standard experiment and uncorrelated error MCS)

Relatively large sensitivity of ISM to (correlated) variations in altitude.

→ 8-18% STDV of model results for superimposed error fields of less than 50m STDV

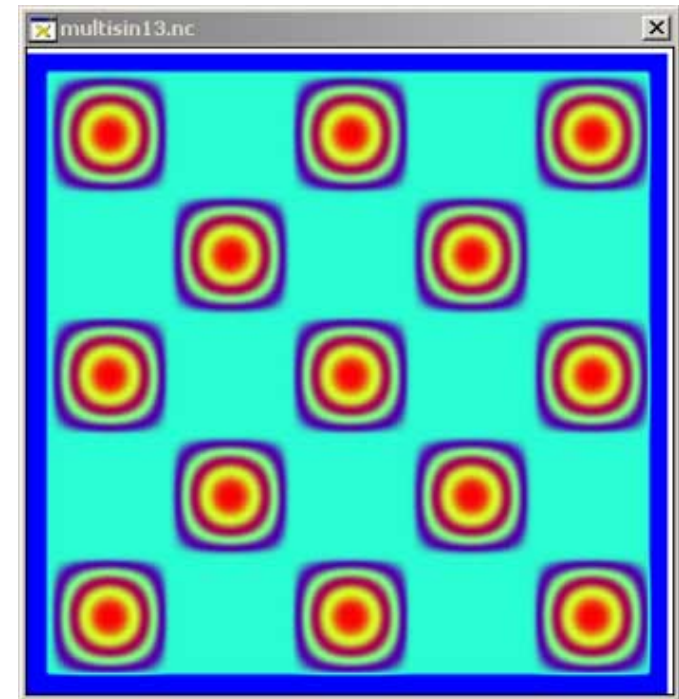


# Artificial topographies

Goal: test and quantify influence of isolated landscape features.

Topographies with specific landscape features can be created and modified.

Example: Plain topography with peaks of varying altitude, extent, number, distance, etc...



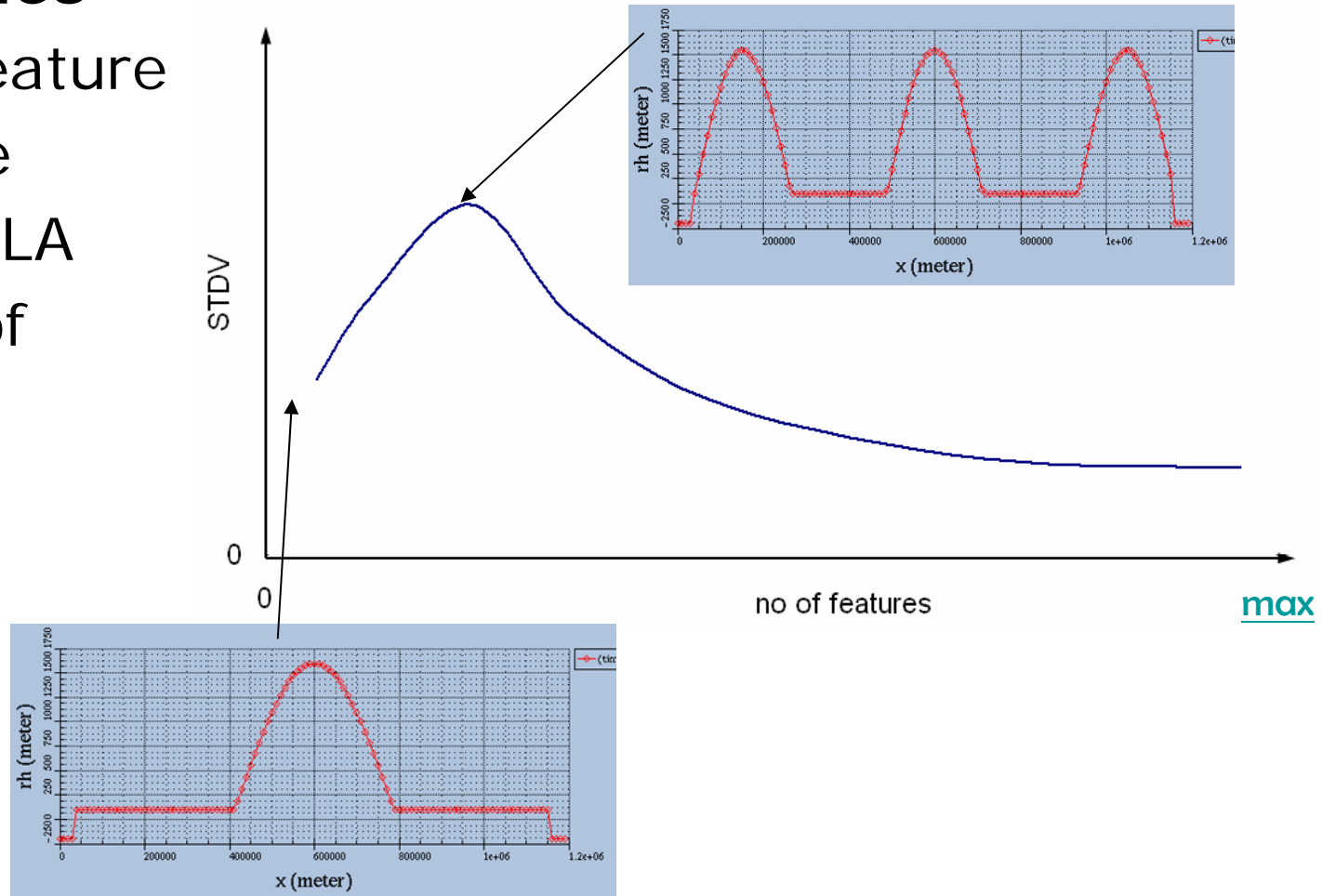
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# Artificial topographies

## Dependencies

- Type of feature
- Amplitude
- Climate/ELA
- Number of features

STDV of results against absolute number of key features



# Conclusions

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## MCS:

- ❑ Uncorrelated random error has little influence on variation of results
- ❑ Random error causes instabilities
- ❑ Correlated error of relatively small variation has strong influence on ISM



# Conclusions

## **Generalisation (IDW):**

- ❑ Strong impact on topography variation
- ❑ Large influence on model results

## **Artificial topography:**

- ❑ Landscape features influence model
- ❑ Significance of feature is climate dependant



# Next steps

**Identify key topographic features** that control model results such as peaks, troughs, valleys...

Use **“feature depending”** generalisation methods:

Generalise topography depending on landform classes: use maximum altitude at peaks, minimum at valleys, mean on plateaus, ...



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# Next steps

## Assess influence of

- ❑ more sophisticated generalisation methods
- ❑ data model: raster, TIN, ...
- ❑ attribute retrieval: calculation of values, derivatives
- ❑ Resolution
- ❑ Different climates
- ❑ **other ISMs**: finite element model



# Acknowledgements

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**TopIce**

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no input signal  
<waiting>



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# Current work

Model sensitivity test  
with base topography  
altered as follows:

*red*

– 100m added

*orange*

– 30m added

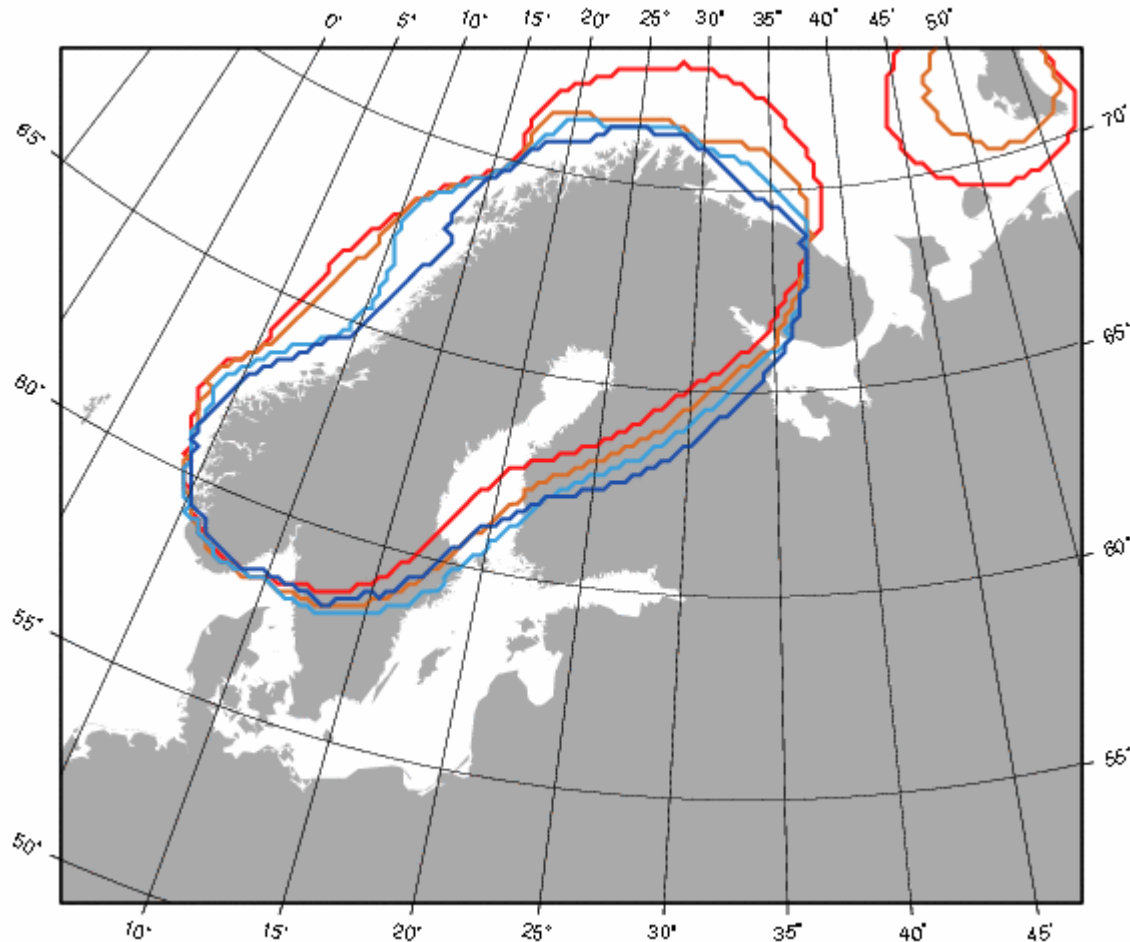
*light blue*

– 30m subtracted

*dark blue*

– 100m subtracted

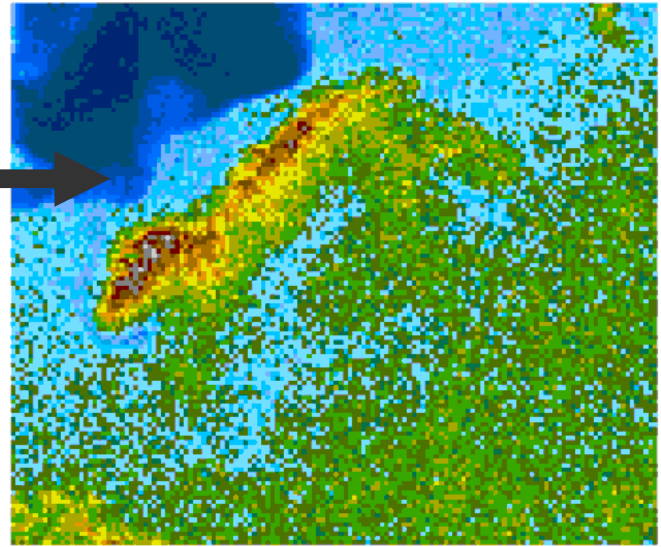
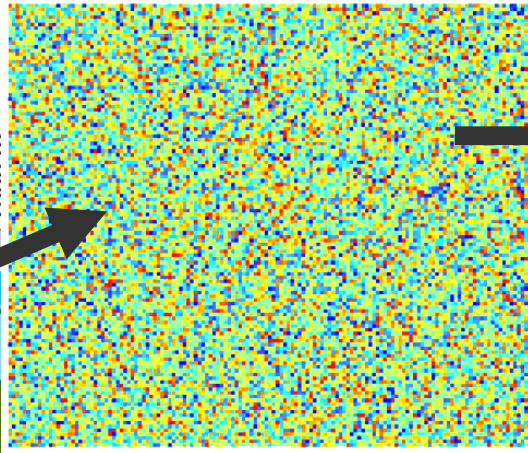
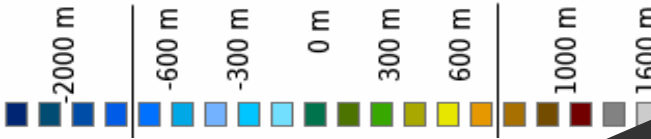
Ice extent compared  
after 4000 years



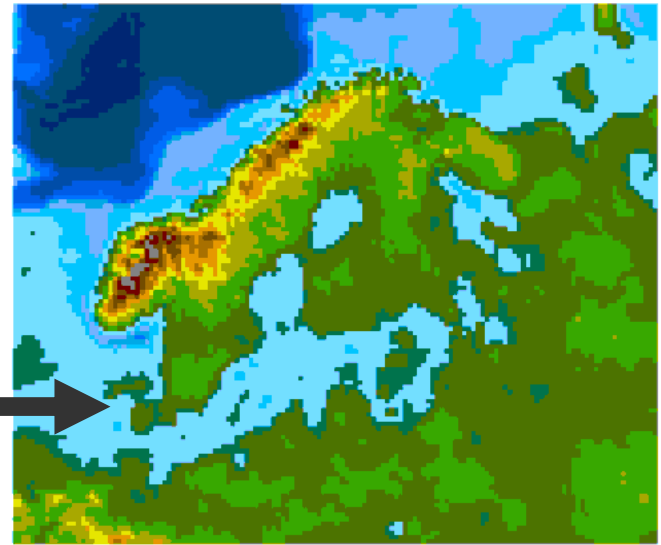
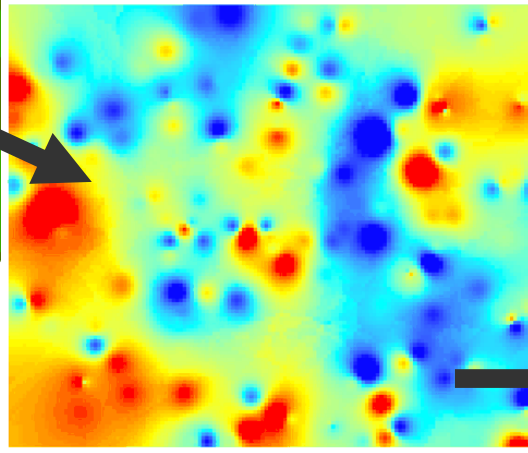
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# Errors

uncorrelated random error



**ADDING ERROR**



spatially correlated error



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# Ice sheet model

## 'Altitude dilemma'

Solution approaches:

- Hypsometric subgrids

*(Marshall & Clark 1999)*

- Feature dependant generalisation

*(Wood, Fisher)*

- Model using higher order physics allowing higher resolution topographies



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# References

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- Zhang, X., Drake, N.A., Wainwright, J. and Mulligan, M. (1999). Comparison of slope estimates from low resolution DEMs: scaling issues and a fractal method for their solution. *Earth Surface Processes and Landforms*, 24, 763-779

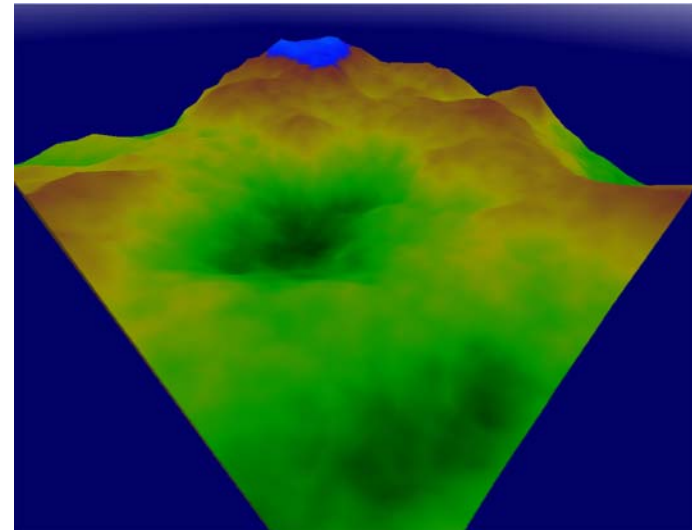
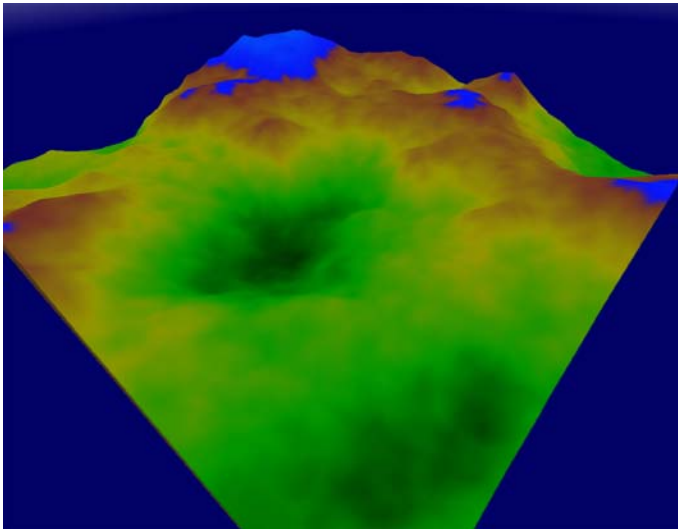


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# Ice sheet model

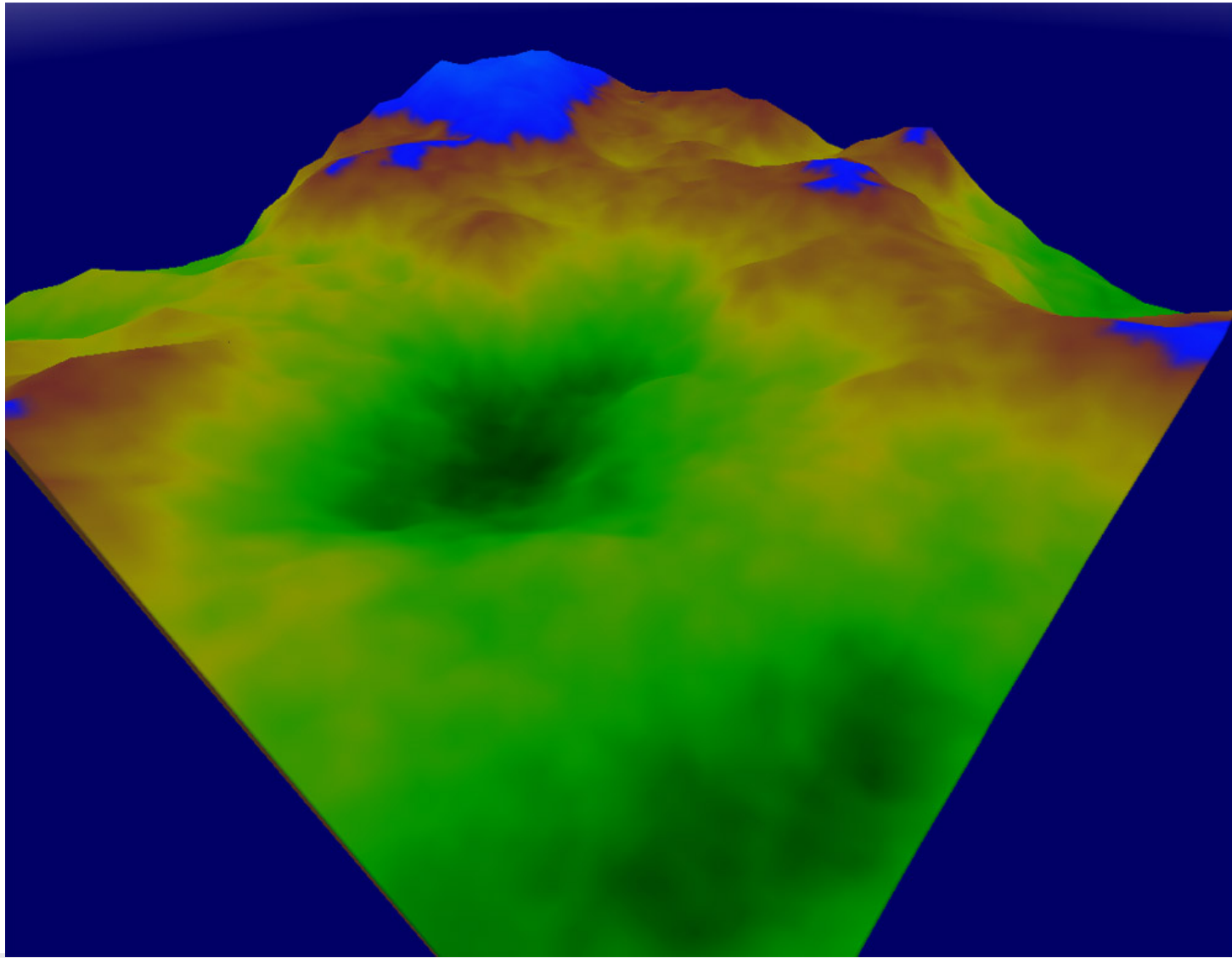
## ISM - specific features:

threshold of equilibrium line altitude (ELA)



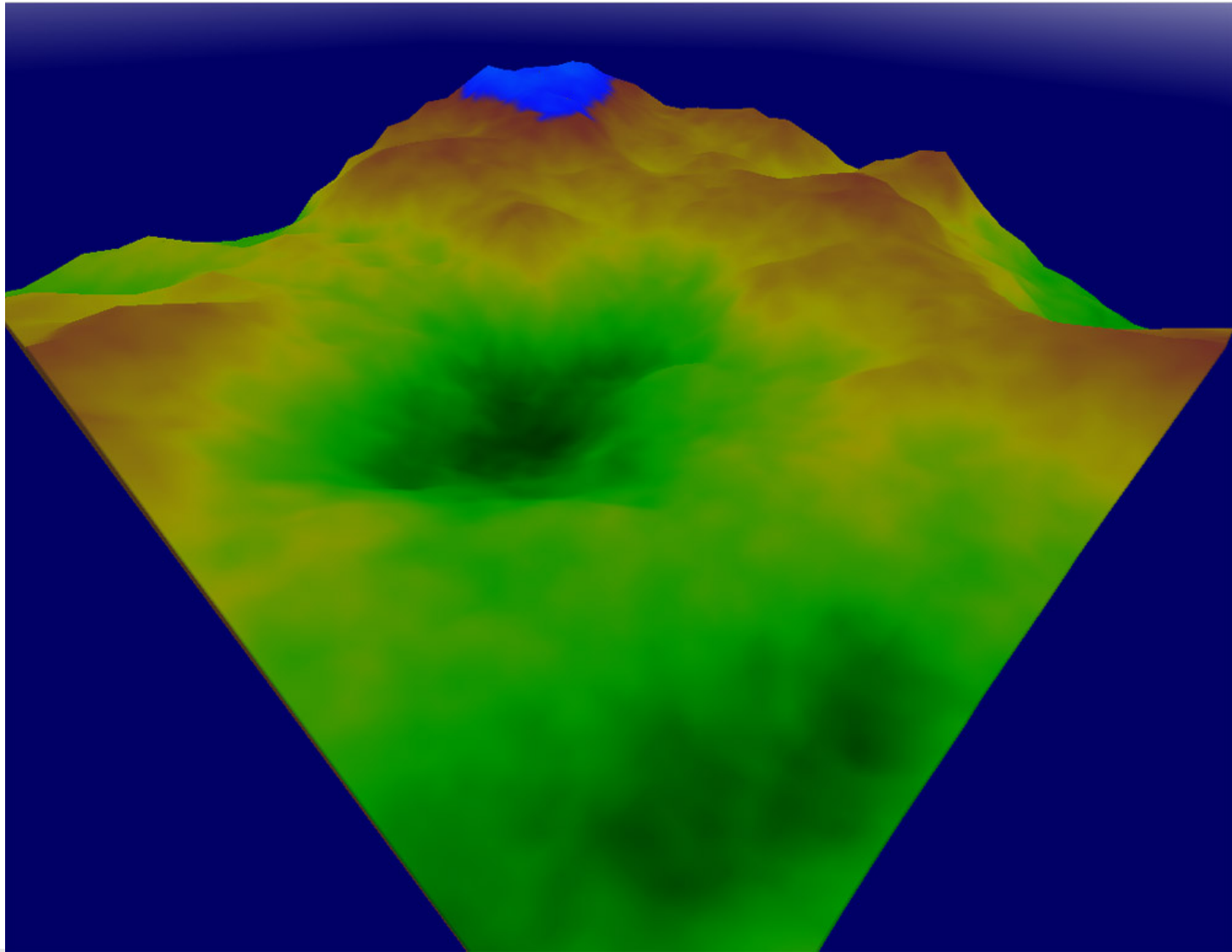
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ELA at 1600m – Areas with positive mass balance in blue.

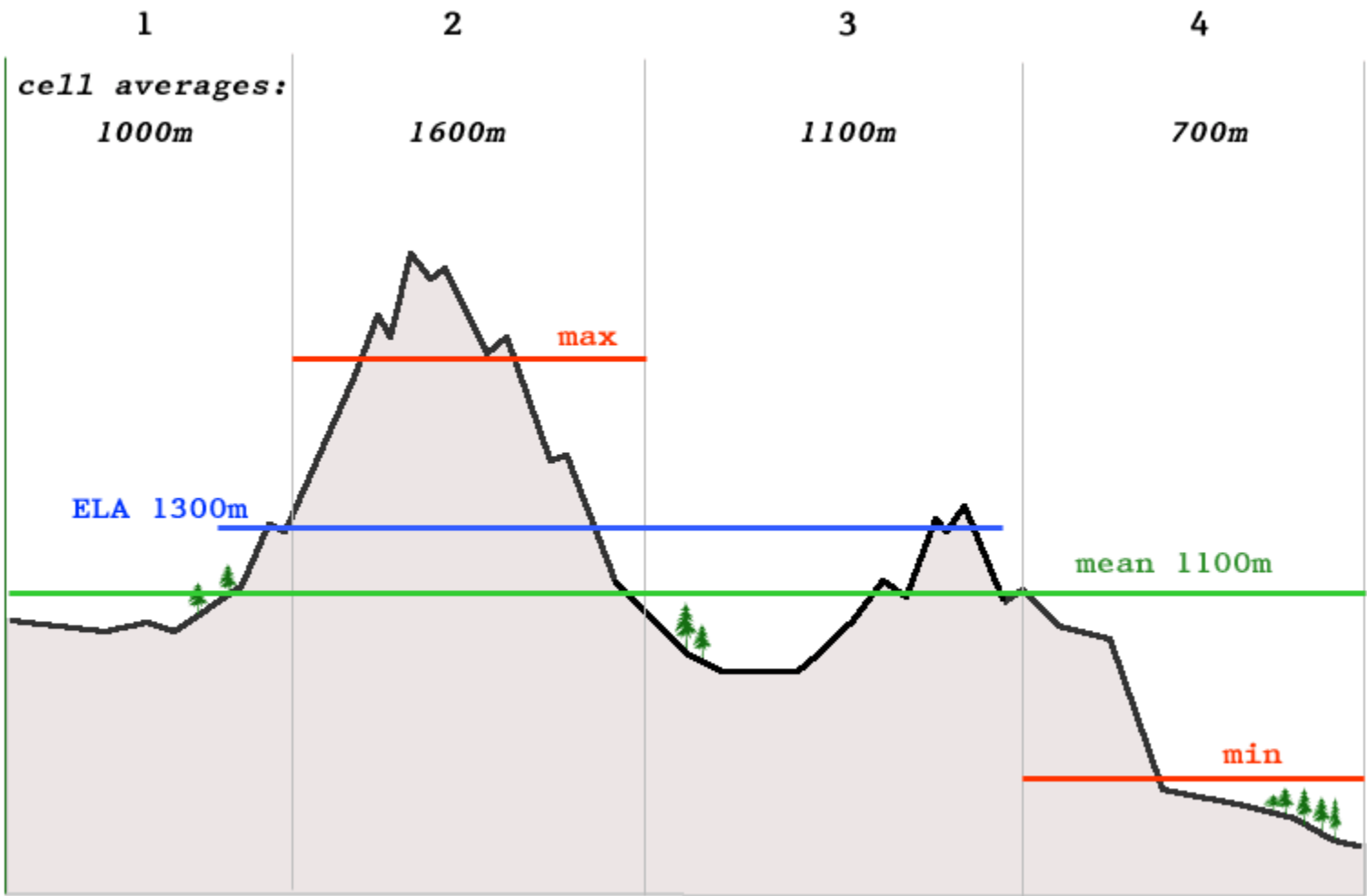


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ELA at 1700m – Areas with positive mass balance in blue.

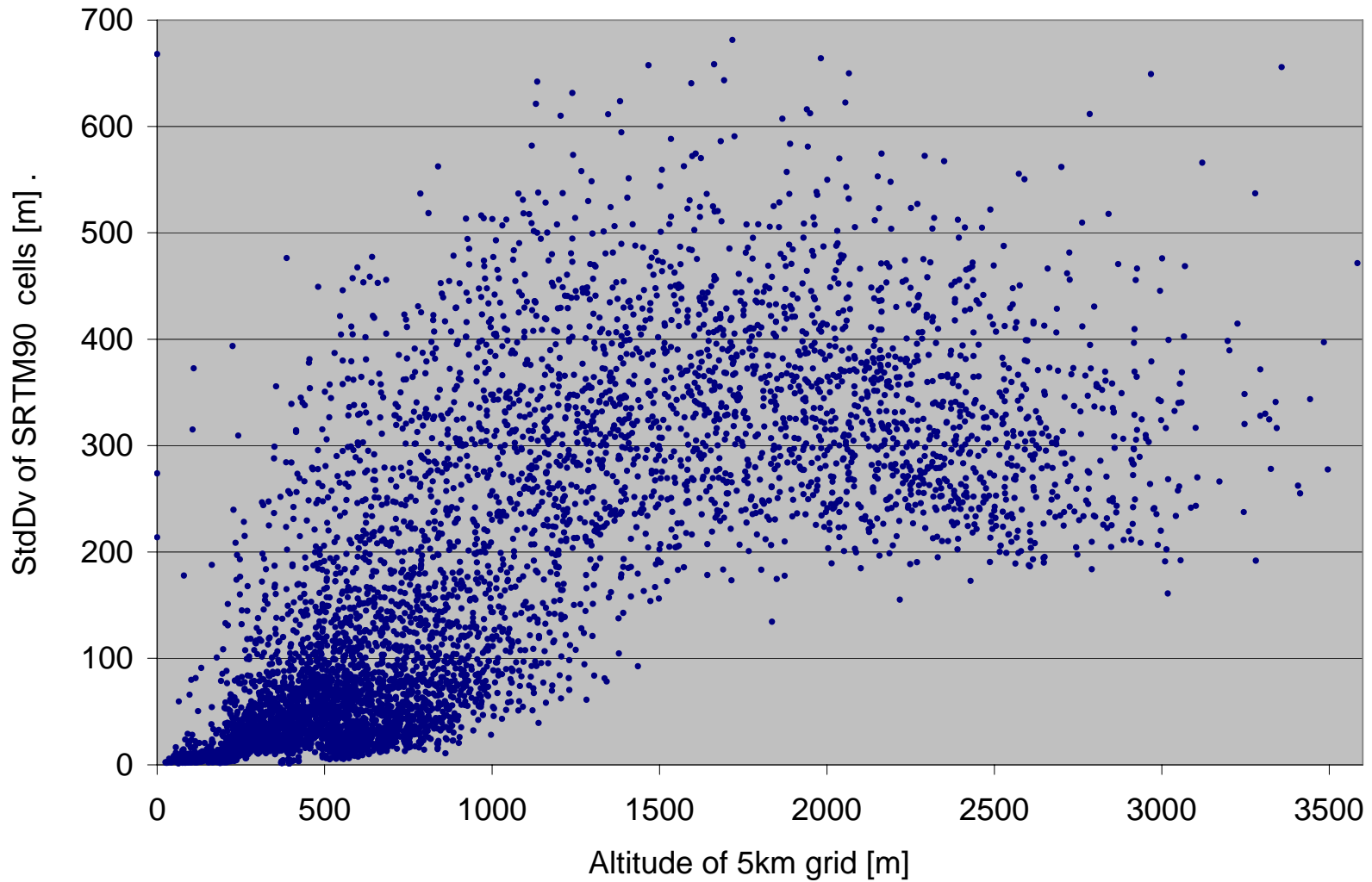


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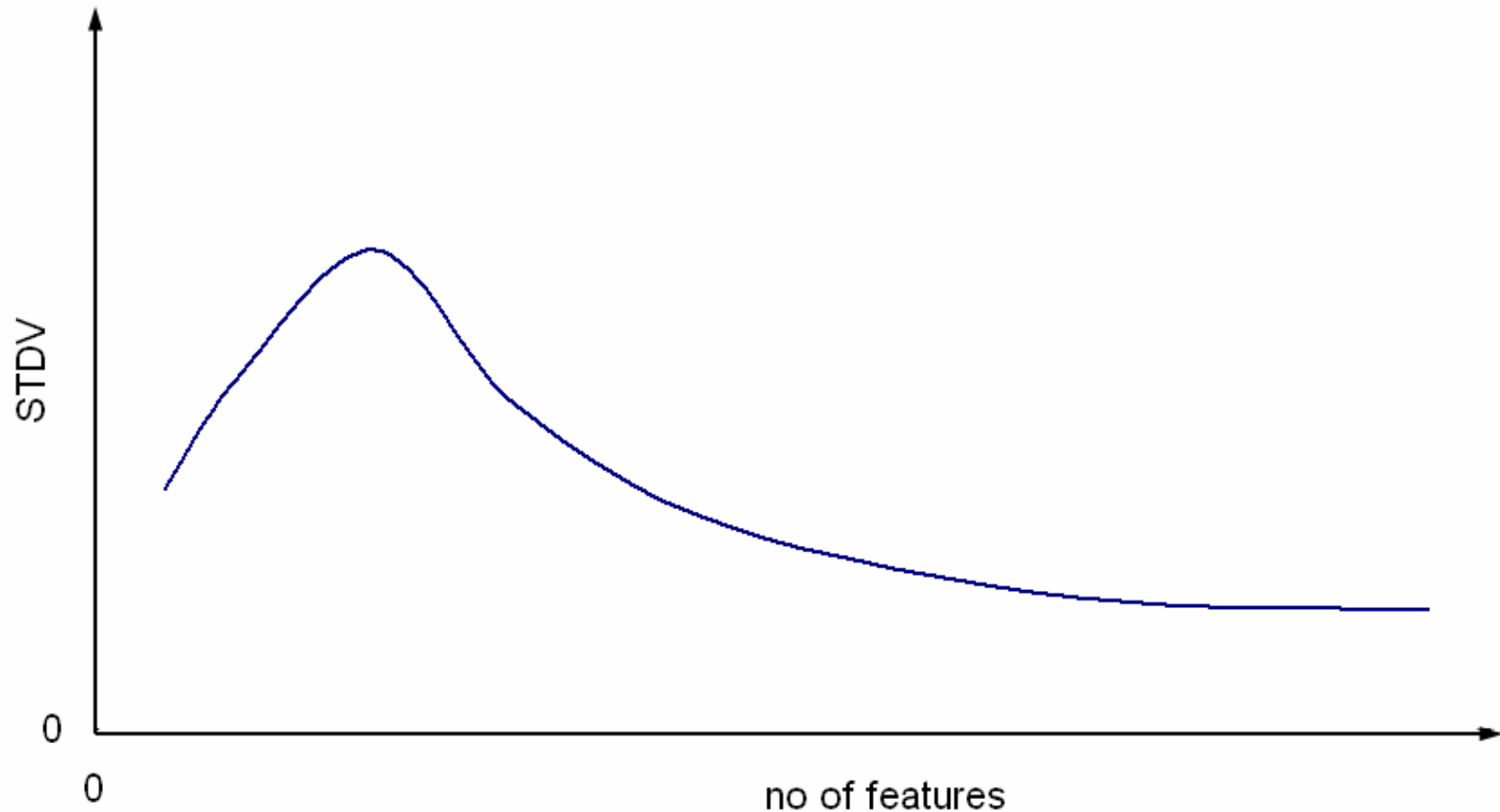
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**Generalisation of SRTM90 data to 5km resolution using linear interpolation**  
Standard deviation of 77m cells contributing to 5km cell plotted against altitude  
Original data of Switzerland and adjoined countries at ~77m resolution.



# Model dependency on key features

STDV of results against absolute number of key features



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