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GIS in ice sheet modelling: assessing the impact of topographic uncertainties

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1. Motivation

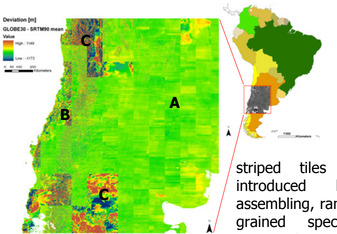
Ice sheet models (ISM) are an important tool in studying the response of the earth's ice masses to climate change and their impact on sea level rise. Running at **low resolutions of 5-20km**, these models have multiple sources of uncertainty including inputs describing climate forcing, the topography on which this climate acts, and the topography on which the ice sheet model itself operates. Two main **topographic sources of uncertainty** are **DEM quality**, with accuracy of the data being influence by data capture and processing methods, and the effect of **generalisation** of topography from higher to lower resolutions that are suitable as model input.

Sources of uncertainties in Digital Elevation Maps (DEM):

I) Data quality

Possible error sources include

- **Data capture:** Low resolution, imprecise, distorted or miscalibrated measurements, digitizing of contours
- **Processing:** Projection of data, merging from different sources, interpolation from contour lines, filling of "NoData holes"



Area: 29-43deg S, 74-61deg W

Fig.1: **Deviation of the GLOBE DEM** (~1km resolution) from mean SRTM90 altitude data (~100m resolution). Errors from different sources are visible: longitudinal striped tiles (A) indicating errors introduced by measuring and assembling, random error visible as fine grained speckle (B), and large systematic errors, possibly due to interpolation (C)

II) Generalisation

Effects of resampling include

- Loss of information
- Smoothing
- Feature removal or rearrangement (i.e. removal of valley, shift of highest peak)
- Strong dependency of results on applied generalisation method

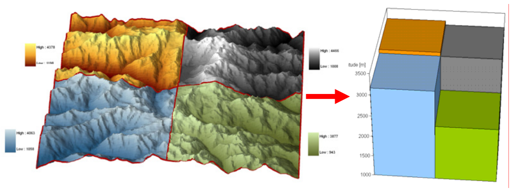


Fig.2: A 40x40km excerpt of the **Zermatt** area, at **100m** resolution (SRTM data, left), with the same area resampled to **20km** resolution (right).

2. Assessing the impact of topographic uncertainties

In order to assess their impact on ISMs, **uncertainties need to be quantified**. For an estimation of uncertainties in GLOBE/GTOPO30 data, which has been widely used as model input topography, available high resolution SRTM90 data has been used as "ground truth". The deviation of GLOBE data from mean SRTM 90 values (Fig.1) is caused by various error sources and is correlated with altitude.

For testing the effect generalisation has on mountainous topography, DEMs (100m resolution) of Switzerland and Patagonia were resampled to 5 and 10km cellsizes with varying origins using a range of common generalisation methods. Comparing the resulting low resolution DEMs, variations in target cells across all DEMs also proved to show distinct **altitude dependencies** (Fig.3).

Using these dependencies, a suite of 150 spatially auto-correlated error surfaces have been created and superimposed on the Fennoscandian DEM (Fig.4). The resulting suite of topographies is used as input for **Monte Carlo Simulations** of the Fennoscandian ice sheet through the last glacial maximum (Hagdorn, 2003), using the **GLIMMER ISM**.

Generating correlated error surfaces for MCS:

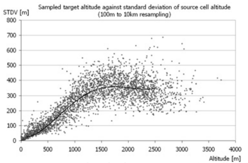


Fig.3: Standard deviation of cells from high resolution DEM (100m) plotted against resampled altitude of target resolution (5km).

- **Random sample altitude** at location x,y on target DEM
- Calculated **STDV σ** for this altitude from derived dependency
- Assign **random Δz** drawn from normal distribution with STDV σ around mean 0
- Interpolate **error surface** from random points using IDW
- Add **error surface** to target DEM

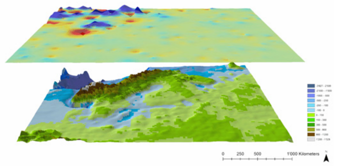


Fig.4: Example spatially correlated error-surface (top) created from random normal distributions with standard deviations depending on input topography altitude (bottom, Fennoscandia, 20km resolution). 150 of these were generated with mean of 0±7.7m and mean STDV of 70±9.4m.

3. Results

For every timestep of the modelled ice sheet, an uncertainty surface can be generated through statistical analysis across all 150 model runs (Fig.5). Variations of modelled ice volume and extent are on **average 5-10%** with maxima of >20% during **inception** (Fig.7). A strong **negative correlation** of variation with absolute ice extent and volume can be observed (Fig.8). These results emphasize that careful consideration of uncertainty should be taken when using low resolution ISMs to ask questions about inception and, potentially, retreat. These experiments illustrate the importance of considering topographic uncertainty in low resolution, *shallow-ice approximation* ice sheet models. Approaches from GIScience, in conjunction with newly available high resolution terrain data, allow us to explore the relationship between elevation uncertainty and ice sheet extent and volume. **Future work** will examine how **key landscape features** may be identified and preserved during the terrain generalisation process.

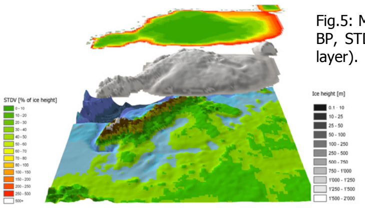


Fig.5: Modelled mean ice height (ih, middle layer) at 96ka BP, STDV [%] of ih (top layer) over topography (lower layer).

Statistical analysis of Monte Carlo Simulation results delivers **uncertainty surface** for ice height, extent and volume.

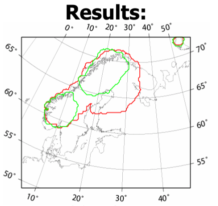


Fig.6 (above): Minimum (green) and maximum (red) modelled ice extent at 108ka BP over Fennoscandian coastlines.

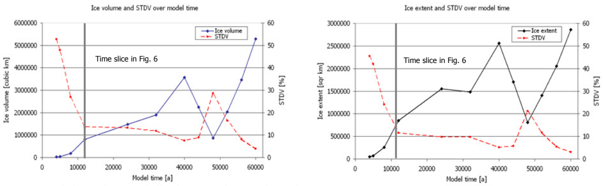


Fig.7 (above): Modelled ice volume (top left, blue) and ice extent (top right, black) with STDV [%] (red) over model time, starting at 120ka BP.

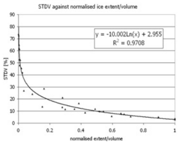


Fig.8 (right): STDV of ice extent and volume exhibits a negative logarithmic correlation (approx. -10ln(x)+3) with normalised extent and volume (R^2=0.97).

References:

Hagdorn MKM, 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: Compari-sons with digital elevation models generated from carto-graphic data. *Cali, International Centre for Tropical Agriculture (CIAT): 32, Working Document no. 198*

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The GLIMMER project:

http://glimmer.forge.nesc.ac.uk/