Representation of Topography and its Role in Uncertainty: A Case Study in Ice Sheet Modelling

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As elevation and its derivatives are essential inputs for a wide range of process models, topography and its representation in environmental modelling is undoubtedly of key importance and as such has long been recognised in GIScience (e.g. HUTCHINSON & GALLANT, 1999; 2000). Research areas include the variation in derived parameters with resolution, scale, and algorithms (ZHANG *et al.*, 1999; HUTCHINSON & GALLANT, 2000), appropriate models of terrain representation (WOOD, 1998; SCHNEIDER, 2001), generalisation of topographic data (WEIBEL & HELLER, 1991), and others. However, in the main this work has concentrated on so-called primary and composed topography indices (BEVEN & MOORE, 1992), e.g. catchment areas (HURTREZ *et al.*, 1999) or feature extraction at variable scales (FISHER *et al.*, 2004). Sensitivity tests examining the influence of resolution are relatively common in process modelling, but generally do not explore issues of representation, with some notable exception (TUCKER *et al.*, 2001).

In this paper the sensitivity of a large scale dynamic process model to topography and its representation is explored. Model intercomparisons are performed as a first step towards developing a set of experiments to explore the uncertainty introduced into a dynamic process model as a result of variations in representation of terrain. The topographies used as model inputs, the experiments chosen to identify the importance of terrain representation, and the model used are described as well as some initial results from these experiments.

A primary step in this work is to test model sensitivity to different aspects of terrain representation: resolution, DEM quality, generalisation and smoothing effects, and slope algorithms. As a case study, an ice sheet model (BOULTON & PAYNE, 1992; PURVES & HULTON, 2000) is run using a range of natural and artificial DEMs. Ice sheet modelling, in common with most numerical modelling, aims to improve our understanding of the real world through abstractions of reality. In this work we seek to investigate the importance of different abstractions of terrain properties on such models. In ice sheet modelling two key processes – nucleation (the initiation of an ice sheet through the forming of perennial ice) and ablation (the removal of mass from the ice sheet system, usually as melting or calving) – are highly susceptible to aspects of terrain representation. Ice sheet models (ISMs) therefore present an excellent example for sensitivity testing. Also, current ISMs run on resolutions of 5 to 20km, allowing the use of a range of possible higher resolution DEM data sets for the testing of the influence of different methods of terrain generalisation effects.

Suitable elevation data is selected and DEMs from a total of three data sources are tested:

- DEM of Scandinavia created from GTOPO30 (USGS) and ETOPO2 (NGDC) data. This DEM has already been used together with a climate model (based on proxy records) for the simulation of the Fennoscandian ice sheet through the last glacial maximum by Hagdorn (2003)
- DEM generalized from high resolution data (SRTM90 data of Switzerland and southern South America)
- artificial topography of various resolution and amplitude

To test sensitivity of ISM to DEM quality, from each of the original DEM data sources, 150 topographies varying by error values derived from metadata are created to perform Monte Carlo Simulations. The ISM is run on every one of these topographies and ice volume and ice extent are compared between model runs at different timesteps.

To test the effect generalization of topography has on the model, different algorithms and methods are used to downscale the DEM sources to the resolution needed by the model (10 and 20km). As an example, the performance of simple linear interpolation is tested against more complex and demanding feature preserving methods, such as splining in conjunction with hydrological networks or generalising with surface networks (Hutchinson, 1993). Similarly, the impact of smoothing algorithms on DEMs is tested: numerical problems are often faced by models where slope is too steep in DEMs. These are countered by smoothing topography to prevent model crashes (Takeda *et al.*, 2002).

Finally, slope calculation plays a central role not only in ice sheet inception, but also in flow calculations. A number of papers have been written addressing the effects different algorithms have on the calculation of terrain derivatives (e.g. Jones, 1998; Schmidt *et al.* 2004). Furthermore, the effect of scaling on slope estimates is well known (Zhang *et al.*, 1999). In this paper, the effect of different slope calculation algorithms on the ISM will be tested by running the model using different algorithms (e.g. simple 'four nearest neighbours' method, Horn's method, Constrained Quadratic Surface Method, etc.). Alternatively, the residual errors determined for these methods in existing works like Jones (1998), can be calculated and applied to topographies the model is then run on.

Preliminary results show the nucleation process to be significantly affected by random errors of 30, 100, and 300 m standard deviation superimposed on Scandinavian topographies. For subsequent model timesteps, the standard deviations of modelled ice extent and volume over the set of model runs decrease, due to the smoothing effect the growing ice sheets have on the underlying topography. Because superimposing uncorrelated error fields on DEMs produces noisy topographies, effects of sudden changes in altitude and slope on the ISM tend to lead to model instabilities. Thus, above a certain threshold (approx. 200 m STDV of error), these datasets are not well suited to simulate effects of generalisation or measuring errors. However, analysis of

SRTM90 data, generalised to resolutions of 5 and 10km using bilinear interpolation, suggests the usage of error fields with standard deviations of more than 200m for the ISM simulations: the standard deviations of the high resolution (90m) grid cells contributing to one generalised, low resolution (5km) cell range from 100 to more than 500m for altitudes above 800m. Therefore, spatially correlated error fields, that prevent the introduction of extreme noise to the original topography, will be introduced for Monte Carlo Simulations using standard deviations of 100m and above.

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