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

Hebeler, F. & Purves, R.S.

GIS Division, Department of Geography, University of Zurich, Switzerland

Today, Geographical Information Systems (GIS) are an essential tool for assessing and anticipating the impact of global climate change, either through direct GIS-based modelling or through their functions for manipulating, analysing and visualising model in- and output.

In this paper, a GIS is used to assess the impact of uncertainty introduced to a large scale environmental model by different aspects of topography representation, namely the accuracy of the used Digital Elevation Model (DEM) and the resampling process necessary to produce topographies suitable as model input. Ice sheet models make an excellent case study for this purpose, as they are an important source of estimates on the reaction of the earth's ice masses to climate change and its impact on global or regional sea level change or freshwater availability. Such models have multiple sources of uncertainty including inputs describing climate forcing, the topography on which this climate acts, and the modelled responses of ice sheets to such forcing.

Up until recently, most ice sheet models at continental or regional scales have relied on a limited number of sources of elevation data, such as those provided at resolutions of the order of kilometers by the USGS (GTOPO30) and the NGDC (GLOBE). Previous experiments (Hebeler & Purves 2004) demonstrated that quoted accuracies in such DEMs of between 18m and 150m have significant impacts on modelled ice sheet extent and volume for a set of Monte Carlo simulations run on Scandinavian topography at a resolution of 20km.

The availability of high resolution elevation data at a near global scale provided by the Shuttle Radar Topography Mission (SRTM) provides an excellent opportunity to further explore such uncertainties. In this paper we explore the sensitivity of ice sheet model runs in southern South America to topographic uncertainty, by treating SRTM data as a ground truth for comparison with GLOBE (compare Jarvis et al. 2004).

A comparison of STRM with GLOBE data reveals that along the Andean ridge, from the Pacific coast to the Amazon basin, elevation values are highly biased with various sources of supposed error (for example, data sources of different quality, measurement, interpolation, and systematic errors, Figure 1). Importantly, while the average differences of GLOBE altitudes from corresponding SRTM means are around 35m over the whole area, large patches in the Andean Highlands, where ice sheet inception and growth is likely, show spatially auto-correlated differences of 80-300m.

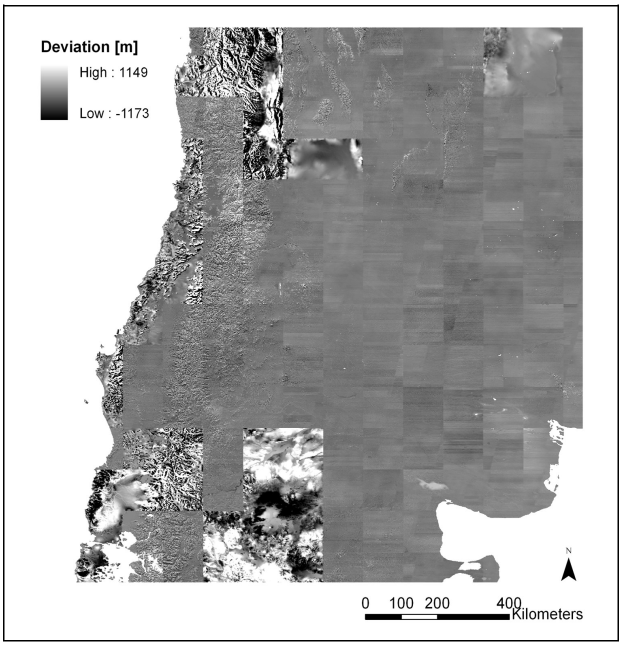

Figure 1. Deviation of the GLOBE DEM from mean SRTM90 altitude data. Tiles of assembled GLOBE data in the centre and eastern area are clearly visible with longitudinal stripes indicating errors introduced by measuring and assembling. In the central western area, random error is visible as fine grained speckles. In the northern and southern part, large systematic errors in the range of 80 to 300m and above are visible as larger tiles. (Area: 29-43deg S, 74-61deg W)

In order to examine the impact these inaccuracies have on ice sheet models, a suite of topographies was produced from the original GLOBE data by adding a random, spatially correlated error surface simulating the observed uncertainties. These modified topographies were then resampled to a resolution of 10km suitable for ice sheet modelling using a bilinear interpolator. This resampling process is a further source of uncertainty in elevation values. To estimate the influence of this resampling in comparison to uncertainties present in elevation data, SRTM data was generalized to 10km resolution using a range of methods implemented in commercial GIS (ESRI ArcGIS 9) software, producing a second set of topographies.

The two suites of generalized DEMs can then either directly serve as input for Monte Carlo Simulations (MCS), or, alternatively, observed dependencies of deviations in the suites of DEMs can be used to create random variation in topography that serve as input to an ice sheet model. In this case study, a MCS of the Patagonian ice sheet during the first 20k of the Last Glacial Maximum using the GLIMMER ice sheet model is run. Previous experiments have shown that the observed relative variation of modelled ice extent and volume depends on the absolute size of the ice mass and, in Patagonia, it is expected to be of the order of 10%. The induced uncertainties can also be compared with the system's sensitivity to variation in mass balance through climate forcing, in order to assess the relative influence of these different terms on uncertainty. Finally, the variations caused by topographic uncertainty can be expressed as water equivalent, enabling the calculation of the influence on local or regional processes such as seasonal discharge, overall freshwater availability or relative sea level rise.

REFERENCES

GLIMMER, the GENIE Land Ice Model with Multiply Enabled Regions. Available under the GNU GPL at http://glimmer.forge.nesc.ac.uk/

Hebeler, F. & Purves, R.S., 2004: Representation of topography and its role in uncertainty: a case study in ice sheet modelling. Proceedings of the GIScience 2004 conference, College Park, Maryland, Oct 19-24 2004, p.118-121

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. Cali, International Centre for Tropical Agriculture (CIAT): 32, Working Document no. 198