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Testing Quantification Methods with Synthetic Drumlins in a real DEM

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Poorly understood errors are a key problem for proposed computational methods that aim to extract and quantify the morphology of landforms (e.g. drumlins, craters, seamounts). A novel way of quantitatively investigating such errors is presented, using a case-study to i) determine which parameters are recovered accurately ii) test claims about apparently morphologically distinct sub-populations and iii) compare extraction methods' accuracy in the presence of topographic 'noise' e.g. surface clutter. The approach could be readily adapted to assess a variety of landforms.

Drumlins' attributes, such as height (h) and volume (V), may preserve information about the dynamics of former ice sheets. A computational regional-residual separation method, the 'Cookie-Cutter', has recently been proposed to reproducibly quantify h and V from DEMs. However, error in the 'regional' basal surfaces passing underneath the drumlins is significant and poorly understood. For instance, it is not known if important parameters, e.g. recovered mean volume ($\overline{V_r}$), reflect the actual population at all. A new way to quantitatively investigate errors in such methods is presented. Its use of idealised drumlins located randomly with respect to noise (e.g., trees) and larger features in a real landscape is novel, as is the drumlins' 2D Gaussian shape.

184 drumlins with digitized outlines in western Central Scotland are used as a case study. The normalised and stacked profiles of these drumlins are demonstrably Gaussian. Length (l_{in}), width (w_{in}), h_{in} and V_{in} determined from these outlines and profiles provide an initial description of 178 drumlins with $V_{in} > 0$. An initial estimate of drumlins' 3D form is then removed from within the outlines to leave only height associated with surface clutter and larger features. Finally, idealised 'synthetic' drumlins are inserted with random locations and orientations to create a synthetic DEM. Critically, because the synthetic DEM is almost entirely still the original landscape, usual concerns when generating synthetic landscapes such as replicating the statistical properties of the original are avoided. 10 DEMs were created (1780 drumlins), and then the Cookie-Cutter used to retrieve the drumlins' parameters.

For groups of 178 drumlins, 14.3 $\pm$ 6.4 (2σ) drumlins with negative (i.e., incorrect) volumes suggests that 9 found for the digitized landforms is typical for the Cookie-Cutter, and that the synthetic DEMs are acceptably realistic. Individual volumes are recovered poorly, with 39.2% being within $\times$0.75 - 1.25 of V_{in}. In contrast, mean volume ($\overline{V_{in}}$) of 1.59 $\times$ 10^5 m^3 is recovered well as 1.56 $\pm$ 0.16 $\times$ 10^5 m^3 (2σ), implying that individual errors are randomly distributed. Mean height ($\overline{h_{in}}$) of 6.8 m is recovered poorly at 12.5 $\pm$ 0.6 (2σ) m, demonstrating that consideration of errors is important before stating the value of parameters. Variants on the Cookie-Cutter may also be assessed. For the 1780 individual synthetic drumlins, the tensioned spline used induces about half as much error as an un-tensioned spline, with standard deviations of the ratio $V_{recovered}/V_{in}$ being 1.28 and 2.29 respectively. Finally, by linking input and recovered values for synthetic drumlins, it is possible to deduce that the statistically significant (p = 0.007) difference in recovered mean volumes between Younger Dryas (YD) and Last Glacial Maximum (LGM) age sub-populations observed for the digitized landforms is only 40-45% likely to exist in reality. Testing variants demonstrates that results are insensitive to the exact method used to create the synthetic DEMs