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3-D uncertainty-based topographic change detection with structure-from-motion photogrammetry and precision maps

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Structure-from-motion (SfM) software greatly facilitates the generation of 3-D surface models from photographs, but doesn't provide the detailed error metrics that are characteristic of rigorous photogrammetry. Here, we present a novel approach to generate maps of 3-D survey precision which describe the spatial variability in 3-D photogrammetric and georeferencing precision across surveys. Such maps then enable confidence-bounded quantification of 3-D topographic change that, for the first time, specifically account for the precision characteristics of photo-based surveys.

Precision maps for surveys georeferenced either directly using camera positions or by ground control, illustrate the spatial variability in precision that is associated with the relative influences of photogrammetric (e.g. image network geometry, tie point quality) and georeferencing considerations. For common SfM-based software (which does not provide precision estimates directly), precision maps can be generated using a Monte Carlo procedure. Confidence-bounded full 3-D change detection between repeat surveys with associated precision maps, is then derived through adapting a state-of-the-art point-cloud comparison (M3C2; Lague*, et al.*, 2013).

We demonstrate the approach using annual aerial SfM surveys of an eroding badland, benchmarked against TLS data for validation. 3-D precision maps enable more probable erosion patterns to be identified than existing analyses. If precision is limited by weak georeferencing (e.g. using direct georeferencing with camera positions of multi-metre precision, such as from a consumer UAV), then overall survey precision scales as $n^{-1/2}$ of the control precision (n = number of images). However, direct georeferencing results from SfM software (PhotoScan) were not consistent with those from rigorous photogrammetric analysis.

Our method not only enables confidence-bounded 3-D change detection and uncertainty-based DEM processing, but also provides covariance information for all parameters. Thus, we now open the door for SfM practitioners to use the comprehensive analyses that have underpinned rigorous photogrammetric approaches over the last half-century.