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Comparing methods to determine 3-D gully uncertainty using structure-from-motion (SfM) photogrammetry

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High resolution digital elevation models (DEMs) are being increasingly produced with the structure-from-motion photogrammetry technology. Nevertheless a further study on the SfM survey uncertainties is still needed for the detailed surface changes deprived from successive DEMs. For conventional DEMs of difference (DoDs), vertical standard deviations of two DEMs are used to calculate 'level of detection' ($LoD_{95\%}$), which means the changes smaller than this value can be disregarded. Since only one $LoD_{95\%}$ value is used across the entire DoDs, the spatial variability is not accounted. Moreover, uncertainty estimates for surface change detection in steep topography regions could be inaccurate as the horizontal error is disregarded. For clouds comparing, Multiscale Model to Model Cloud Comparison (M3C2) uses local surface roughness to estimate uncertainty with spatially variable $LoD_{95\%}$ values. However, the purely roughness-based precision estimates are not suitable for photogrammetric point clouds. Precision Map based on M3C2 (M3C2-PM) is a new approach accounting spatially variable precision inherent to SfM survey, and enables confidence-bounded qualification of 3-D topographic change. M3C2-PM uses M3C2 to determine the distances among the clouds, while the precision map estimates regarding SfM process, such as the bundle adjustment. This study investigates the efficiency of the new method M3C2-PM by comparing DoDs, $LoD_{95\%}$, and M3C2.

The research was carried out on a cropland gully (E 126.84°, N 47.34°) in the Mollisol region of the Northeastern China. The productive black soil in this area is facing seriously soil erosion and hence the attention on the erosion process research is increasingly raised. The gully is about 90 m long, with average depth and width of 6.5 and 8.5 m. In the autumn of 2018 we used a DJI 4 Pro drone to collect images. Two manually-controlled flights of 50m (SfM-50) and 100m (SfM-100) of heights were carried out. Ground control was provided through the deployment of ten circular targets on the square boards, with their coordinates measured using RTK. The benchmark terrestrial laser scanner (TLS) data were acquired for comparison using a Focus3D X330. The images were processed in PhotoScan (v.1.2.6). ArcGIS (v.10.2) was used for the DoDs and $LoD_{95\%}$ analysis. CloudCompare (v.2.9.0) and sfm_georef (v.3.0) were used for the M3C2 and M3C2-PM analysis. Three sections of gully morphological difference among SfM-50, SfM-100 and TLS were investigated, which should be zero.

The results show that average gully morphological differences using M3C2-PM (7 mm) is slightly better than that of M3C2 (9 mm). Besides, both are much improved from values of DoDs (25 mm) and $LoD_{95\%}$ (18 mm). For M3C2-PM methods, 42% of gully area is detected as 'change', while for M3C2 and $LoD_{95\%}$, the changed gully area are 55% and 57%. Since lower 3-D variability and less 'change' area are detected, our research shows that M3C2-PM can substantially improve the estimates of gully morphological uncertainty from photo-based surveys.