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A novel (raster input/output) method of equilibrium line altitude (AAR, AABR) estimation and glacier hypsometry analysis

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Estimation of the equilibrium line altitude (ELA) of paleoglaciers is standard procedure in palaeoclimatic interpretation of glacial landforms. Among several methods of palaeo-ELA estimation, the accumulation area ratio (AAR) and area-altitude balance ratio (AABR) best predict glacier mass balance characteristic and are most commonly applied in palaeoglaciological studies. The AABR elevation index is much more complicated in computation than AAR. Published computer-based calculations of this index using the iterative procedure for searching glacier elevation where net mass balance crosses zero for user-given BR value. We developed python code in ArcGIS which, instead of searching the ELA for the given BR value, iteratively searches for appropriate BR values which satisfy the glacier mass balance equation for each elevation band of the glacier. We use integer (1 m high) elevation bands of glacier DEM. This resolves the problem of possible error associated with the calculation of this index (error < 1 m). Our tool calculates also other indexes (THAR, AAR) and glacier hypsometric parameters (area, cumulative area). As a result, we obtained ELA and hypsometric parameters in entire elevation range (from glacier toe to top) recorded into raster attribute table (DEM raster .dbf file). The advantage of presented method is time-effectiveness. It works from a few to several dozen seconds for medium sized glaciers. One calculation run yields all possible ELA results of given glacier.

Obtained ELA results can be visualised directly on the glacier DEM and analysed in a spreadsheet. As the all glacier hypsometric and ELA parameters are given simultaneously for the entire glacier elevation range, it opens a new possibility of ELA estimation and glacier hypsometry analysis. Parameters like hypsometric indexes and integrals or glacier histogram central tendency measures and skewness can be easily derived. The data allows for examination of the cross-index relations (e.g. THAR 0.4 = AAR 0.6 = BR 2.25) and it could be used to cross-check ELA results computed with different methods. From this, we present that the AABR method can reduce ∼33% of the AAR method uncertainty. Cross-index relations has also shown that using the AAR method with a fixed ratio could often result of unaware overrunning the BR empirical range (∼1.0 - 3.0). This is particularly the case of the standard AAR 0.67 method used in the Alps, which for tested sets of glaciers gives too high cross-calculated BR values (average 3.0-4.0, extremes 5.0-10). This shows that the AAR 0.67 method is prone to give unrealistic ELA results. We suggest that the ELA results for any particular palaeoglacier should be published with an external uncertainty range (e.g. ELA 2000 +41/-46 m) from the standard deviation of empirical average AAR and BR values (e.g. Rea, 2009; QSR). This gives an opportunity for standardisation/calibration of the method. Our tool offers to apply such approach in a simple way.

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