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Discrete global grid flow direction model

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Abstract:

Low spatial resolution GIS representations of entities and phenomena are essential for modeling global processes such as the hydrological cycle and climate change. A critical component of any Earth system model is the flow direction model, which is typically computed on a regular grid of squares. For high-resolution spatial data a metric grid in a projected coordinate system is often utilized with digital elevation models (DEMs) serving as the input data. In this context, water mass is directed from one grid node to an adjacent node, following the path of the steepest slope.

Low-resolution flow direction models are derived by generalizing large-scale models (Eilander et al. (2021), Yamazaki et al. (2019)). Several algorithms exist for obtaining coarse-resolution flow directions from relatively fine-resolution raster flow direction models. Generally, existing methods are limited to structured rectangular meshes which are typically processed in a geographical coordinate system. This approach can lead to distortions due to the variability in cell geometry.

Discrete global grid systems (DGGS) appear to be an effective solution to face these limitations. DGGS are spatial reference systems that use a hierarchy of equal-area tessellations to partition the surface of the spherical Earth into grid cells (ISO (2021)). DGGS grids can consist of various shapes, including triangles, squares, diamonds, or hexagons (Sahr et. al. (2003)). Hexagonal mesh grids are increasingly employed in hydrological simulations, primarily due to their uniform adjacency (de Sousa et al. (2006), Wright et al. (2014), Liao et al. (2020)).

Previous studies on hexagonal mesh grids have focused on the extraction of valley lines (Wang (2020)) and the adaptation of the basic methods of hydrological parameters computation developed for square grids. These parameters encompass flow direction, catchment area, watershed delineation, stream order, stream network, particularly with respect to topological accuracy (Liao et al. (2022, 2023)). Significant research has been carried out to transfer these techniques to one type of hexagonal DGGS and generate flow routing datasets (Li et al. (2022), Liao et al. (2024)).

An important advantage of DGGS is its hierarchical structure, which enables tools for spatial data generalization. A pyramid framework formed by hexagonal and triangular mesh grids was introduced by J. Wright (2017). The study presents a hierarchical model to perform hydrological geomorphometry analysis, specifically including generalization functions for flow directions based on the averaging of directions within coarse-level cells.

However, there is no previous research utilizing the hierarchical structure of DGGS to obtain low resolution global flow direction models. This study addresses this gap. We examined techniques for deriving coarse-resolution flow directions used for square grids and adopted three these methods for the aperture 7 hexagonal Discrete Global Grid System H3 (https://h3geo.org/). The H3 library was extended in the research by the implementation of the COTAT (Reed (2003)), NSA (Fekete et al. (2001)), and VVRFRA (Lucas-Picher et al. (2003)) algorithms. We used the flow direction dataset previously gained on the territory of Africa continent as input data (Shurygina et al. (2024)). It was derived from the ETOPO Global Relief Model 2022 terrain data with a 60 arc-second resolution quantized to 8th H3 level. Accordingly, we received in total 12 generalized flow directions datasets by three methods on 7 – 4 H3 levels.

Additionally, the method for assessing the accuracy of regular grids flow direction models is presented, which allows characterizing the quality of main flow direction reproduction after generalization of higher resolution D8 (D6) models. The method is based on the merging of the input cells into streams of different order with subsequent tracing over a grid of lower resolution. For each traversed cell the flow direction is considered correct if the flow from it reaches any of the cells traversed by the stream. The accuracy of the whole flow direction model is calculated as the ratio of cells with correct direction to all cells. This indicator can be calculated for streams of a given order and higher. In contrast to previously proposed approaches (Reed et al. (2003), Davies et al. (2009), Eilander et al. (2021)), this metric allows us to assess the accuracy of reproduction of the main flow directions within the whole territory, which facilitates clearer geographical interpretation of the results of their generalization.

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The present study confirms, that DGGS as spatial data structure provides a framework which allows spatial data models to be created, in particular flow direction models. The spatial data base was obtained, containing multiscale flow direction model on one continent and may be scaled to global coverage. According to our evaluation technique, all generalization methods reproduce high-order flows better, which generally corresponds to the purpose of generalization methods to identify the main flow directions. It is also seen that the COTAT method gives systematically more accurate results, especially on the coarsest levels. Nevertheless, future research should examine the impact of adjacent levels cells rotation on the accuracy of low-resolution flow direction models, as well as define recommendations for obtaining a correct global dataset as discrete global grid model.

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