High-resolution stream network delineation using digital elevation models: assessing spatial accuracy

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Abstract—**We used the hydrologically corrected Multi-Error-Removed Improved-Terrain Digital Elevation Model at a 3 arc-second (90 m) spatial resolution to derive a seamless, standardized stream network by using GRASS-GIS hydrological modules. We compared the spatial accuracy of the derived stream network with the NHDPlusV2 dataset across the conterminous Unites States. The results demonstrate that spatial accuracy is in the order of 1 pixel displacement compared to the NHDPlusV2 locations, indicating a high level of accuracy. The implemented methodology will be extended to a global scale hydrography in an upcoming project.**

I. INTRODUCTION

Streams and rivers govern important processes in the natural ecosystem. Understanding their patterns and features across the landscape and large spatial extents is fundamental to the efficient management of natural resources, such as the reduction of flood risk and the quantification hydropower generation capacity and drinking water supply. These hydrological characteristics are studied from various viewpoints across research disciplines such as hydrology, environmental chemistry, geomorphology, engineering, geography and ecology.

Remotely-sensed digital elevation models (DEMs) at different spatial resolutions allow the identification of stream, river and other water body locations using a variety of different flow-routing algorithms. Such algorithms are based on the natural phenomena that water follows the steepest and shortest route along a relief, and accumulates in valleys, lowlands, flat areas and depressions [1,2,3,4].

Two types of algorithms are common use to compute the flow direction: single flow direction and multiple flow direction. Beside these, other algorithms analyze the DEM with mathematical morphological operator [5]. Hence, the DEMs are well-suited for deriving river channels with spatial accuracy, which is a function of the grid cell size of any given DEM. For DEM resolutions of 30m, the average distance between predicted and mapped stream channels is 140 m. However, this distance exponentially increases at resolutions greater than 180 m [6].

In this study, we used the hydrologically corrected Multi-Error-Removed Improved-Terrain Digital Elevation Model (MERIT-DEM) 3 arc-seconds [7] to derive a seamless, fully-standardized stream network across the conterminous United States. We selected this territory due its variability in landscapes, geomorphology and climatic conditions. Moreover, the readily available high-resolution NHDplus hydrography [8] provides an excellent opportunity to validate the spatial accuracy of newly-derived stream networks. The final aim is to scale up the analyses from a regional to global level at a later stage. The underlying methods encompass a workflow within the Geographic Resources Analysis Support System (GRASS) open source software using a suite of hydrological modules.

II. DATA AND METHOD

A. Source layers

The quality of DEMs influences the derived stream network, and even minor elevational inaccuracies have the potential to alter the calculated geographic location of the stream [9]. This phenomenon is more evident in naturally flat surfaces where elevational inaccuracies are larger than actual relief variations.

For this study, we used the MERIT-DEM [6] as baseline topography data to delineate flow directions. The MERIT-DEM was developed by removing multiple error components from the

SRTM3 and AW3D DEMs, and is considered to be the best-effort DEM which is currently available on a global scale [10]. Nevertheless, it is worth noting that flow direction is still difficult to calculate using the MERIT-DEM alone, due to remaining errors and its limited spatial/vertical resolution. One way to address this limitation related to vertical errors is to use the “stream burning” (or carving) approach [11]. This approach, introduced by Hutchinson (1989)[12], proposes the use of ancillary information such as pre-existing stream network data, to “carve” the DEM and force the flow to pass through those cells that correspond to the actual stream network. For this purpose, we used additional data sources of water bodies, such as G3WBM [13], GSWO [14] and water layers from OpenStreetMap to carve the elevation of water pixels in the MERIT-DEM. Subsequent to drawing on the hydrologically corrected MERIT-DEM, we developed and applied an in-house Fortran90 code able to first, smooth the sinks that the carving produces and second, to calculate flow direction and flow accumulation. These hydrographies were useful for extracting stream networks using GRASS-GIS software.

To assess the spatial accuracy of the newly-derived stream network (MERIT-DEM-derived) we compared it with NHDPlus Version 2 (NHDPlusV2). The NHDPlusV2 is a geo-spatial database of surface water features, built by the US EPA Office of Water and by the US Geological Survey [9]. This dataset was derived from the US National Elevation Dataset (NED) in a 1 arc-second (approximately 30 meters) spatial resolution, and has about 3 million rivers at a 1:100,000-scale or higher [8], which has made it suitable to spatially validate the location of streams that are derived from lower-resolution DEMs. Note that the NHDPlus was used only to assess stream network’s spatial accuracy and not to carve the MERIT-DEM.

B. *Stream network extraction methodology*

A fully standardized stream network extraction was performed using a work-flow of hydrological modules within GRASS [15]. The hydrologically corrected MERIT-DEM [6], along with the associated MERIT-accumulation and the MERIT-depression datasets, served as the base layers for all calculations. With these aforementioned rasters as inputs, the GRASS *r.stream.extract* function was used to extract stream networks for the given study area. In order to define the channel initiation, the flow accumulation threshold was an additional parameter used for the *r.stream.extract* function. In our case, we set a minimum flow accumulation value of 0.2 km^2 constant across all regions. The 0.2 km^2 contributing area threshold value produced a very dense stream network that, at a later stage, will be pruned and corrected for the actual presence of water, as modeled by geomorphological and environmental factors. However, our immediate intention was to identify the maximum length of all stream channels, so as to derive later the hydrographical features that regulate water presence.

C. *Spatial accuracy of the stream network*

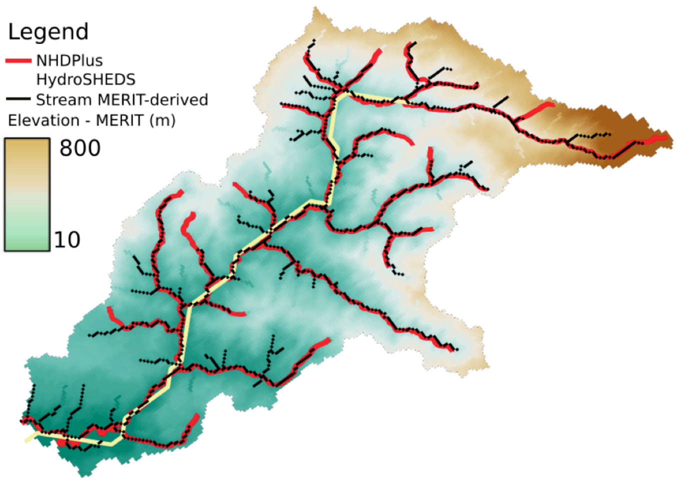

Figure *1*: Gradient color indicates variation in elevation based on the MERIT-DEM. Green represents streams of HydroSHEDS (500 m), which is currently the best available, seamless global hydrography. The black line shows the stream network derived from MERIT-DEM (90 m) and the red line illustrates the observed NHDplusV2 streams (10 m).

We re-projected the MERIT-DEM-derived stream network and the NHDplusV2 using equidistant conic projection, with the barycentric location in the middle of the conterminous United States. This allowed minimal distortion on distance units. To concentrate our attention only on "natural streams", we selected from the NHDplusV2 the streams having a "NHD Feature Type" attribute, labeled as *StreamRiver*, *Connector*, *ArtificialPath*, while excluding *CanalDitch*, *Pipeline*, *Coastline*. By including the *Connector* and *ArtificialPath* labels, we ensured the completeness of hydrographic network. Additionally, we excluded water bodies attributed as CanalDitch and Pipeline, as these belong mainly to agricultural areas, are artificially created and hence do not often follow the terrain relief. Thereafter, we transformed the vectorised NHDplusV2 stream network to grids by matching the MERIT-DEM-derived network resolution (90 m) and extent. This rasterized NHDplusV2 served as a basis for creating a proximity map, which indicated the spatial distance to NHDplusV2 streams. We then overlaid the NHDplusV2-proximity and MERIT-DEM-derived stream networks, and extracted spatial distance values for the MERIT-derived streams. The mean of the selected spatial distance values represented the mean error distance displacement between the two stream networks. The proximity map is a euclidean distance layer. We expanded the proximity map up to a maximum distance of 400 m. This allowed us to focus our attention only on stream segments that fell close to the NHDplusV2. It also helped to target larger rivers and eliminate from the analyses small tributaries (stream order first and second). As already mentioned, small tributaries will be subject to a water presence modeling in a subsequent phase of the project.

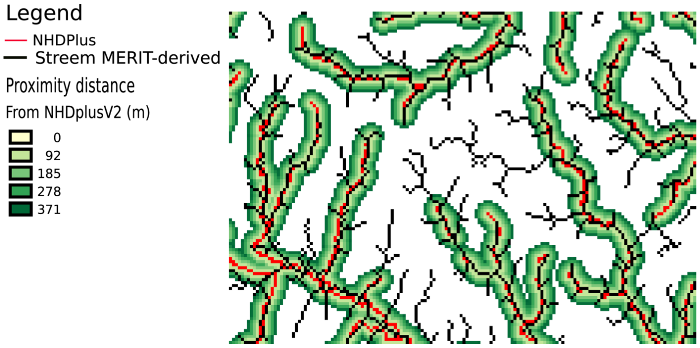

Figure 1. Comparison of the NHDPlusV2 and MERIT-DEM derived stream networks. Gradient colors indicates distance values in meters between the MERIT-DEM-derived and the NHDPlusV2 stream network. The MERIT-DEM derived network matches the location of the NHDPlusV2 by an average offset of 104m.

III. RESULTS

The minimum flow accumulation value of 0.2 km^2 produced a stream network that reached the headwater of the NHDplusV2 (Fig.1). However, it also resulted in small 1st order streams that overestimated the stream network density. This will be corrected in the second phase of research, where such streams will be pruned with the modeled presence of water. To concentrate our results on the main MERIT-derived stream, we excluded from the computation all 1st order streams that fell outside a maximum distance of 400m of the NHDplusV2. This leads to an average distance of 104m between each NHDplusV2 and MERIT-derived stream across the entire conterminous United States. This means that the MERIT-derived streams are displaced by about one grid cell (90 m) when compared to the NHDplusV2. Fig. 2 provides a more detailed visual comparison of the NHDplusV2 network and the MERIT-derived streams, which illustrates very good agreement between both datasets.

IV. CONCLUSION

We demonstrated the use of the hydrologically corrected MERIT-DEM to derive an accurate stream network at high resolution within the conterminous United States. The selected stream initiation threshold of 0.2 km^2 produced a very detailed stream network, which currently overestimates the number of first order streams when compared to the national NHDplusV2 stream network dataset. The quality of the derived stream network was assessed as good, since the average accuracy is about one grid cell (90 m). The overestimation of the first order streams is expected to decline as soon as water availability is included in the computation. From a computational perspective, GRASS provides fast and flexible functions for hydrological modeling with automated scripting workflows, and allows for the processing of very large data sets using efficient computational algorithms and memory management. A global implementation of this procedure is in progress and the obtained product will be available to the public.

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