A new least impact approach for hydrological conditioning of DEMs

Markus Metz
Department of Molecular Biology
Fondazione Edmund Mach (FEM)
San Micheleall'Adige, Italy
markus.metz@fmach.it

Abstract—**Digital elevation models (DEMs) are the primary source for 2D hydrological modelling. Most approaches require a sink-free DEM, because standard flow tracing methods stops at the bottom of sinks. Sinks are commonly removed by sink filling, raising elevation values in the sink to the spill point. This is equivalent to filling a sink with water until the water overflows. The modifications introduced to the DEM by sink filling can be substantial. Sink filling assumes that elevation values are too low, and raises elevation values until the DEM is completely drained. DEMs obtained with remote sensing (radar, LiDAR, stereo imagery) have systematically too high and not too low values. Thus selected elevation values should be lowered rather than raised in order to drain a DEM completely. This method is known as carving, where a channel is carved into the DEM. The minimum impact approach investigates each sink and determines the impact of filling and carving. Each sink is then removed with the method causing less modifications. Here we present a new minimum impact approach that further reduces the amount of modifications. Each sink is removed by a combination of filling and carving. The best combination for a given sink is the combination of filling the sink up to a certain level and carving out a channel from that level that causes the least modifications to the DEM. Flow directions for carving are determined with a least cost path search. We compare the amount of modifications introduced by different methods and the resultant surface flow accumulations. The new method is implemented in the GRASS GIS module r.hydrodem. The hydrologically conditioned DEM can be used with any hydrological modelling software.**

I. INTRODUCTION

2D hydrological modelling provides the base for commonly used terrain parameters such as flow direction, basin delineation, surface flow accumulation, and stream network extraction. These parameters are in turn used for Hortonian analysis of drainage networks [1]. 2D hydrological modelling typically uses a Digital Elevation Model (DEM) with optional additional data to fine-tune the modelling. Most DEMs used nowadays are derived from remote sensing data (radar, LiDAR, stereo imagery). DEMs are not a true representation of the terrain, but a simplified model based on spatial samples. Due to the characteristics of data acquisition, any errors in these data result in systematically too high elevation values. For example, the bottom of narrow valleys can not be detected with viewing angles that are not exactly vertical (which is not possible for stereo DEMs), and none of the methods can penetrate vegetation (LiDAR can penetrate leaves but not wood). For 2D hydrological modelling, an important consequence of these simplified models containing a certain amount of errors is that artificial sinks are introduced. 2D Hydrological modelling commonly assumes that surface waterflow stops at the bottom of sinks, therefore these sinks need to be removed if the study area should be completely drained.

The first and still most commonly used method to remove sinks is known as sink filling [2], where each sink is filled up to the level of the spill point. Sink filling is thus raising elevation values. An alternative is carving [3, 4], where a channel is carved out from the bottom of the sink through the obstacle. Depending on the size of the sink and the size of the obstacle, either sink filling or carving might cause less modifications. The minimum impact approach of [5] investigates each sink and determines the impact of filling and carving. The method causing less modifications is then used to remove the sink.

II. LEAST IMPACT SINK REMOVAL

A. Theory

Here we present a new method that further reduces the impact of sink removal on the DEM. Each sink is removed with a combination of carving and filling. The best combination for a given sink is determined as the combination of filling the sink up

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to a certain level and carving out a channel from that level that causes the least modifications to the DEM. The drainage directions from the bottom of a sink to its spill point are determined with a least cost path search [6], as implemented in the GRASS GIS [7] modules *r.watershed* and *r.stream.extract*. Using a least cost path search algorithm, a DEM can be full drained without prior hydrological conditioning of the DEM. Since most other hydrological modelling software does not use least cost path search to determine drainage directions, the new tool *r.hydrodem* is provided to improve the result of hydrological modelling [6]. The new tool is implemented such that also very large datasets can be processed without causing out-of-memory errors. A limit on how much memory should be used can be set as an option for the tool.

B. Examples

The new least impact approach was tested on a LiDAR DEM with 1 meter resolution and a total of 525,000 grid cells (Fig. 1). Sink filling required modification of 6,299 cells, whereas the least impact approach modified only 331 cells (5% of the sink filling method).

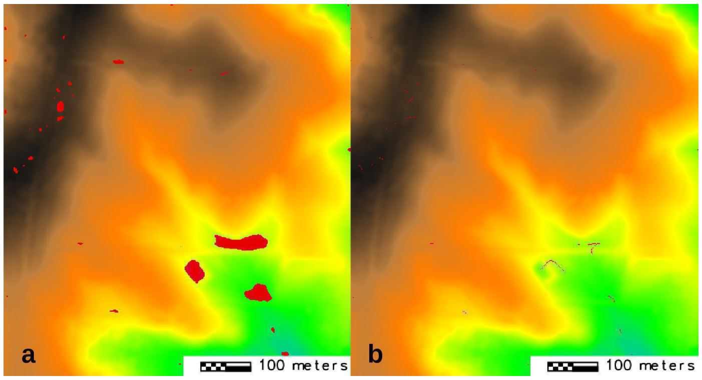

Figure 1. Amount of modifications (red)on a LiDAR-based Digital Elevation Model with a) sink filling and b) least impact approach.

Another test was performed on a radar-based DEM with 30 meter resolution and a total of 225,000 grid cells (Fig 2). Sink filling required modification of 12,066 cells, whereas the least impact approach modified only 5,218 cells (43% of the sink filling method).

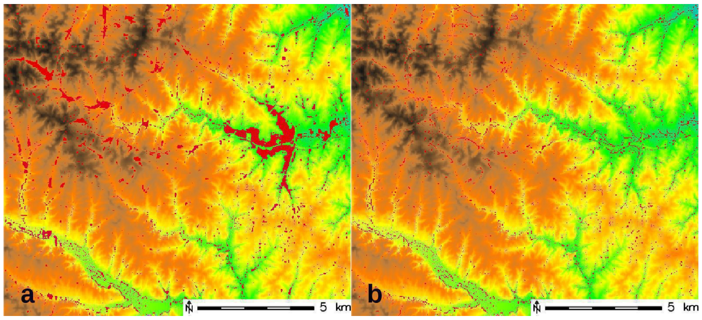

Figure 2. Amount of modifications (red) on a radar-based Digital Elevation Model with a) sink filling and b) least impact approach.

III. CONCLUSIONS

The new least impact approach to remove sinks requires much less modifications than traditional sink filling. As shown by [6], the least cost path search results in more realistic stream network extraction than sink filling. Differences in stream networks to the minimum impact approach of [5] were marginal. Automated hydrological conditioning of a DEM serves two purposes: 1) make them DEM more similar to the (unknown) ground truth, 2) enable 2D hydrological modelling to drain the study area completely unless the existence and location of real sinks is known. Therefore a method that minimizes modifications to the DEM is preferable.

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