TERRAHIDRO – A DISTRIBUTED HYDROLOGICAL SYSTEM TO DELIMIT LARGE BASINS

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ABSTRACT

This paper describes TerraHidro that is a distributed hydrologic modeling platform. TerraHidro is general purpose water resources system that presents a new concept to represent water flows based on graph structure, in the geographic information system (GIS) context. The drainage extractions and Amazonian basin delimitations using TerraHidro have been compared with ArcGis Hydro Tools regarding to drainage extractions and to show the TerraHidro availability the drainage of Amazonian sub basins, called Xingu, Purus and Tapajos are presented.

Index Terms**—** Local flow, water flow, large basin, drainage network

1. INTRODUCTION

The local flow distribution in a water basin is the most important item to develop distributed hydrologic modeling oriented to hydrological resources. The underlying premise is that terrain is the main landscape contributor in settling these local flows [9], [11]. The basis for terrain representation in GIS is to partition the entire region. A *Cell* is the unit of this partition set and the *local flow* is the water flow for each cell according to its neighboring cells status following a particular neighborhood rule.
The most common data structures found in GIS libraries and systems for terrain representation dedicated to hydrologic modeling are the Digital Elevation Models- DEM [1] with regular grids, Irregular Triangular Networks – TIN [3], representation based on Contour Lines [5] and Irregular Polygons Tessellations [10]. The selected representation carries its own functions for flow extraction and its own local flow data structure attached to it. The local flow representation depends on the data structure that has been used to represent the terrain topography. For instance, the extraction of local flow from DEM uses the 8-neighbor idea, creating a local flow representation, called *Local Drain Direction* - LDD [1].
This condition leads the hydrologic modeling concept to have a strong coupling between the quality of the local flow representation and the parameters for the terrain data structure used, particularly regarding to its spatial resolution with direct implication on the modeling outcomes [6]. This paper presents TerraHydro, a Distributed Hydrological System created to develop hydrographic basin water flow GIS applications used to extract drainage network from large basin. Amazoina basins were used to show the TreaHidro results.

2. PREVIOUS WORKS

Several methods have been applied, by different authors to extract local water flow from the surface representation structures using DEM, TIN and Contour Lines. Those methods were developed to DEM structure, as the D8 unidirectional algorithm where the flow froma a grid cell follows to the steepest descent path among the 8-neighbour [11]. The Rho8 is a stochastic version algorithm of the D8 algorithm [12]. The FD8 and FRho8 are the changes of the previous algorithms and they allow dispersion flowing [15], [16]. Some improvement has been proposed with methods that remove false pits and plane areas [9], [15].
Several hydrological models using these methods of local flow extraction have been embedded in GIS systems as a computer adds for GIS hydrological modelling. The ArcGis Hydro Module [17], The Grass GIS [18], the Topographic Parameterization (TOPAZ) [19], the Topography based on Hydrological Model (TopModel), the MIKE SHE [20] and the PCRaster [21] are examples of systems that make use of DEM terrain representation based on a regular grid data structure for hydrologic modelling. The Watershed Modelling System (WMS) [16] uses DEM and TIN data structures. TIN-based Real-Time Integrated Basin Simulator (tRIBS) uses TIN data structure and the TOPOG [5] e SASHI [8] that use Contour Lines based on those representations.
Most of the toolkits use the DEM data structure because it demands simple algorithms and it has been adopted by several data producers institutions [22], [23]. Some authors have presented that each surface representation structure has its own advantages and disadvantages [24], [6].

3. DRAINAGE EXTRACTION AND BASIN DELIMITATION

Drainage has been used by several applications involving water resources. To extract the drainage, first of all, the local flow and the accumulation area must be determined. Local flow is a flow between two neighbor cells considering the steepest downstream path from the cell X and the eight neighbor cells. Figure 1 shows this concept.

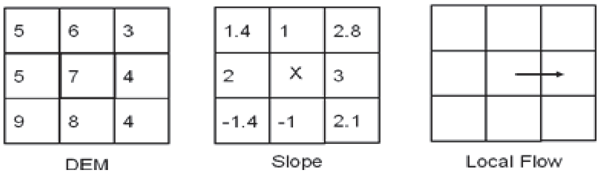

Fig. 1: Local flow extraction to X cell.

After that, the accumulation areas are calculated from the local flows. Each Y cell receives a value that is the amount of the area of all cells that participate of a path arriving in the Y cell. Next step requires to define the accumulation area subset called drainage network. The user must define a threshold value. All grid cells with value equal or greater than the threshold are drainage cells. At this point, TerraHidro determines the river reaches that define drainage segments, between water springs and junctions, between junctions, or between junctions and mouth of the drainage. The Basin delimitations can be done by selecting one or more points over the drainage. TerraHidro finds the basin for each given point or for each river reach basin. At the end, the basins can be used as grid cell, or in vector forms. Figure 2a, 2b, 2c and 2d presents this concept. Figure 2a shows a geographic region with the corresponding drainage. Figure 2b presents the basin delimitation identified by a red point on the top of the image. All points of this geographic region contribute with water flow by that point. Figure 2c shows the river segments. Each segment is represented by a different color. Figure 2d shows the watershed by each river segment.

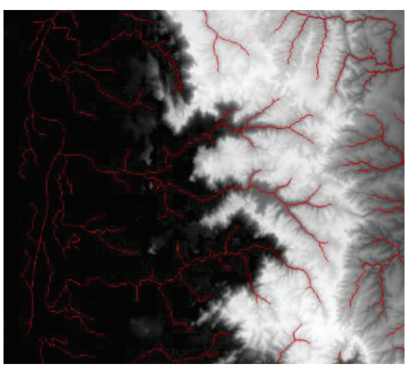

Fig. 2a. Geographic region drainages.

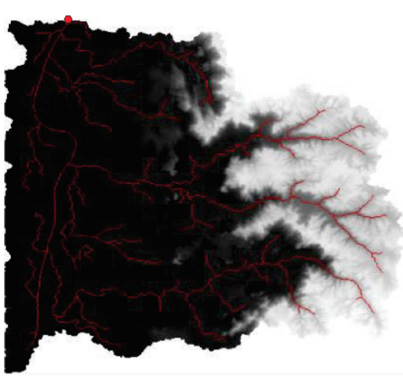

Fig. 2b. Basin delimitation for the red point.

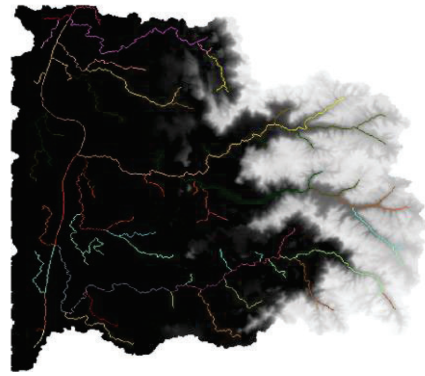

Fig. 2c. River segment definitions.

Fig. 2d: Watersheds delimitations. Each watershed corresponds one river segment.

4. DRAIANGE RESULTS AND COMPARISON

To show the TerraHidro functionalities some results have been extracted from TerraHidro and they are presented regarding to Amazonian sub basins. SRTM surface model, with 90m of resolution, have been used to extract hydrographic information. SRTM has many spurious local depressions that prevent local flow continuity that need to be eliminated allowing, then, the flow continuity. TerraHidro eliminates all local depressions lying in the geographical region, ensuring the drainages are totally linked. The basins used here are Xingu, Purus and Tapajos Rivers that are important Amazonian rivers. Figures 3, 4 and 5 present, respectively for each of these rivers, the drainage extracted, and zooms of the same regions showing the quality of the drainage, regarding to the SRTM data set.

The implementation here uses data stored in TerraLib [2] open source geographical library implemented in C++ language. Terraview, a TerraLib based software, is used to visualize and to manipulate vector and raster data stored in geodatabases to read, write and visualize the grids. The grids used in this application are in TerraLib format and they can't be directly read in Haskell, so a binding in C language called Terra-HS [4] was used to access the TerraLib grids.

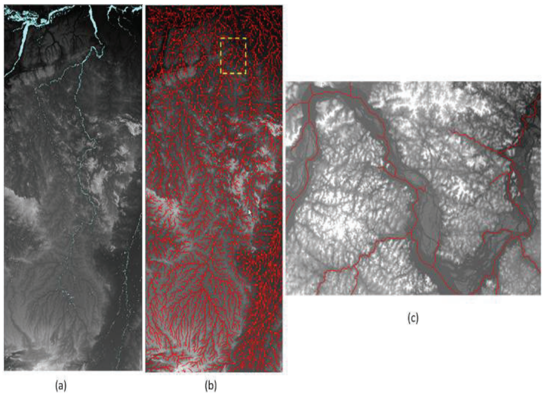

Fig. 3: Xingu River drainages. (a) Geographical region; (b) Drainage in red; (c) Drainage shows a zoom of the yellow rectangle.

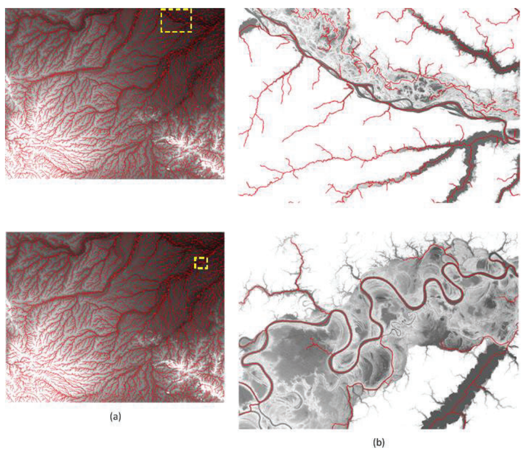

Fig. 4: Purus River Drainages. (a) General drainages; (b) Zooms of two particular regions (yellow rectangles).

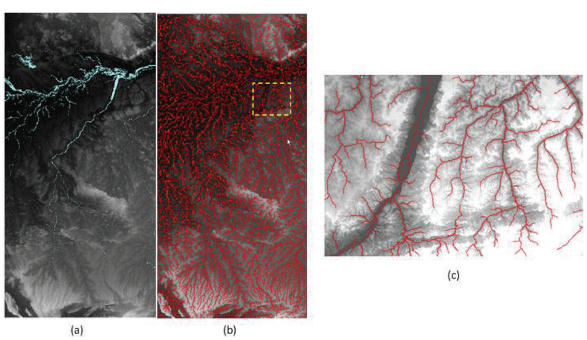

Fig. 5: Tapajos River drainages. (a) Geographical region; (b) Drainage in red; (c) Drainage shows a zoom of the yellow rectangle.

TerraHidro processed these jobs in a personal computer with 3GB of RAM memory. This low amount of memory required improvement of the source code to execute the TerraHidro functions using large data sets. Table I shows same values relating the processing of each river.

TABLE I.

	Xingu	Tapajos	Purus
Rows	15.962	19.201	12.000
Columns	7.202	9.601	15.600
Pits	6.472.113	8.647.984	13.279.394
Processing Time - LDD	3:20:04 h	5:33:38 h	5:40:31 h
Processing Time – Accumulated Area	2:48 min	10:58 min	12:07 min

Table I shows that SRTM produces a large amount of spurious local minima data or polygons. TerraHidro eliminates all local minima and generates the flow completely connected.

Some tests have been performed comparing the drainage extracted from TerraHidro and the ArcGIS Hydro Tools that is the ArcGIS hydrological model. This choice is because of the significant ArcGIS as the most widely used GIS in the world. Figure X presents two cases where TerraHidro shows better results than ArcGis Hydro Tools. Probably, it succeeds because ArcGis Hydro Tools uses a local flow method that eliminates local minima creating flat areas. The algorithm used to extract the local flows generates straight and parallel lines into the flat areas. A version, of the Priority First Search – PFS algorithm [25] doesn't present this problem. The proposed algorithm searches and finds the path between local minima neighbors. TerraHidro ensures a better drainage extraction regarding to topographical aspects.

As drainage is the base for applications in water resources it is important to get realistic drainages, and TerraHidro produces best results relating ArcGIS Hydro Tools as showed at the Figure 5. TerraHidro drainages flows along the rivers while AcGIS Hydro Tools presents straight lines that don't exist in the real world. This happens because ArcGIS creates flat areas to eliminate depressions areas and the drainages extracted in the flat areas products straight lines.

5. CONCLUSIONS

TerraHidro presents a different approach to operate local flows using a graph unifying structured called G-GCS. This approach allows using only one operator set to develop applications involving local flows and earth resources located within a hydrographic basin. An example of application was implemented in Amazonian basin. The comparison between TerraHidro and ArcGis Hydro Tools has showed that TerraHidro results are better than ArcGis Hydro Tools results and the significant of TerraHidro system in adopting a small computational power computer without crash the program. Figure 6 shows these comparisons.

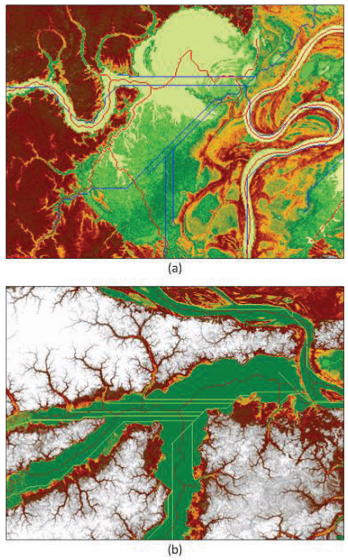

Fig. 6. Comparison between drainage extraction from TerraHidro represented by red lines and ArcGIS Hydro Tools with (a) blue lines and (b) yellow lines.

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