Modelling uncertainty in watershed divides from SRTM and GDEM

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Abstract— **Watersheds are considered important units in many environmental decision-making processes. The delineation of watersheds using digital elevation models (DEMs) is common and presents many advantages. However it is very sensitive to the uncertainty of the elevation datasets used. The main aim of this work is to use a probabilistic approach to extract watersheds divides on two widely available datasets in order to estimate the uncertainty. Hundred simulations of each of the input dataset were generated using a Monte Carlo probabilistic approach. The watershed divides were delineated from each iteration. The different iterations were combined to produce a cumulative probability surface representing how many times a cell was part of a watershed divide. The preliminary results showed a high uncertainty in most of the test area. The highest uncertainty was related to small sub-watershed of low Strahler order streams. For both the considered datasets, the modelling of the elevation errors improved the delineation process, providing important additional information.**

Keywords: digital elevation models, simulations, Strahler orders, probabilistic.

I. Introduction

Watersheds are considered important units in many environmental decision-making processes. A drainage divide or watershed can be defined as the boundary separating drainage basins (Wilson and Gallant, 2000). Watersheds and stream delineation are the first step in hydrological modelling. The delineation of watersheds using digital elevation models (DEMs) is common and presents many advantages. The obtained drainage divides are consistent with elevation data. The delineation process is more objective and consistent, as computers are not subject to mistakes possible with manual delineation (Oksanen and Sarjakoski, 2005; Wilson and Gallant, 2000). Nevertheless, the results obtained may differ substantially according to [i)] 1. data source, 2. data resolution, 3. scale considered and 4. algorithms used (Seyler et al., 2009). In particular the results are sensitive to the uncertainty of the elevation datasets used (Oksanen and Sarjakoski, 2005; Poggio and Soille, 2008).

The aims of this work are i) to use a probabilistic approach to extract watersheds divides on two widely available datasets in order to estimate the uncertainty in the process, and ii) to assess the effects of the introduction of the modelling of elevation errors on the delineation process.

II. Test areas and datasets used

The test area is located in the Rhine basin with an approximate size of 120 km, with well defined morphology and drainage directions (Fig.1).

The datasets used were:

1. GDEM: Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) Global Digital Elevation Model (GDEM) dataset version 1.0 (ERSDAC, 2009) with an average of 9 scenes used on the test area;
2. SRTM: the SRTM original digital elevation data produced by NASA were further processed to fill in no-data voids (Jarvis et al., 2006).

The dataset were mosaicked for the available scenes, and projected to ETRS89-LAEA projection for the first test area (Annoni et al., 2003). The EuroDEM (2008) was used as reference elevation dataset for the error modelling step. It was mosaicked from different sources in order to get the most precise data available in the regions covered (EuroGeographics, 2008; Hovenbitzer, 2008).

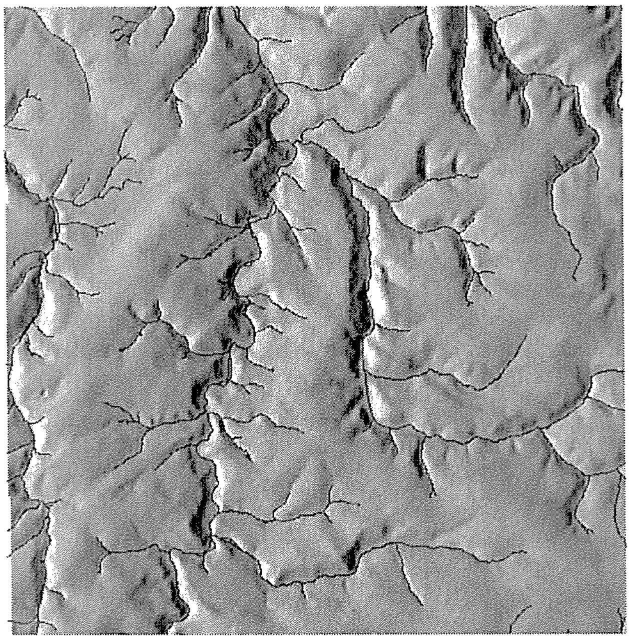

Figure 1. Test area and its morphology

III. DEM PROCESSING

The selected datasets were processed in order to obtain the watershed probability maps. Hundred simulations of each of the input dataset were generated using a Monte Carlo probabilistic approach (Temme et al., 2008). The elevation errors of the considered datasets were obtained as:

$$elev.\ err. = ref.\ dataset - DEM \qquad (1)$$

The elevation errors were interpolated using derived variogram parameters within a Gaussian simulations approach, as implemented in the GSTAT package (Pebesma, 2004) of the R software (http://www.r-project.org/). Finally the simulated DEM were obtained as:

$$Simul.\ DEM = DEM + Interpolated\ \ elev.\ err. \qquad (2)$$

In order to assess the effect of error modelling on the extraction of watershed divides, the following divides net were extracted: [i)] 1. from the original datasets without simulations (no_sim in the following text); and 2. the average of all the 100 simulated DEMs obtained with the model iterations (simul in the following text).

IV. WATERSHED DIVIDE NETS PROBABILITY: PRELIMINARY RESULTS

Fig.2 shows the results for the computation of overall probabilities for the watershed divide nets with values normalised by the number of watershed pixels. The probability values obtained are rather low (maximum = 51%) and when plotting the nets (3, SO 1-6), the spatial distribution is not very consistent.

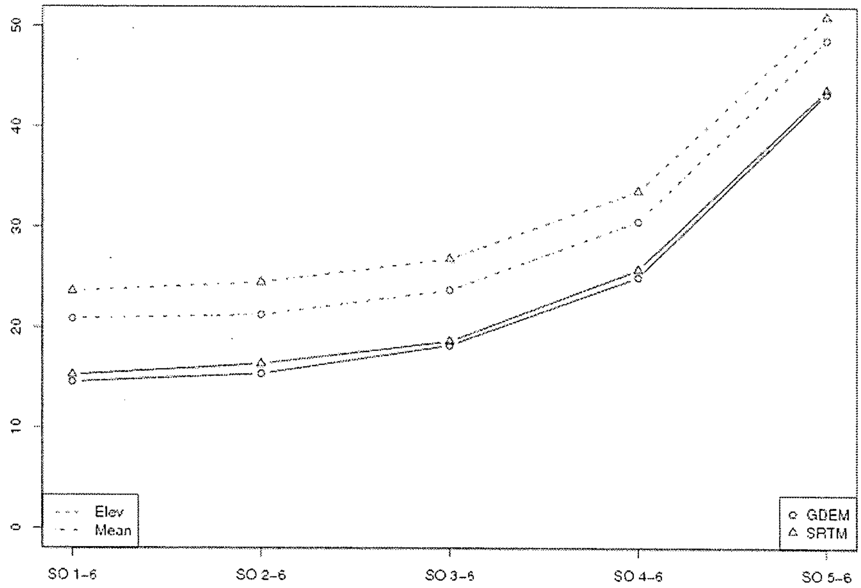

Figure 2. Overall probability (%) of watershed divides for different Strahler orders (SO).

The simulated DEMs were further processed for pits removal with the method described in Soille (2004) in order to obtain a flowing surface while minimising the sum of the elevation differences between the input and the filtered DEMs. The watershed divides were delineated from each simulated DEM using the r.watershed tool within GRASS GIS (GRASS Development Team, 2008). The different iterations were combined to produce a cumulative probability map representing how many times a cell was part of a watershed divide. The cumulative probability map was calculated considering watersheds of increasing Strahler orders (Strahler, 1952):

- prob0 orders 1 to maximum (6 in the case of this study);
- prob1 orders 2 to 6;
- prob2 orders 3 to 6;
- prob3 orders 4 to 6;
- prob4 orders 5 and 6.

In order to reduce the uncertainty due to lower order segments the overall probability was calculated using the cumulative probability maps for watershed divides derived from increasing number of Strahler order (Fig.3).

The analysis of overall probability for the most probable watershed divide net did not provide clear results when all the Strahler orders were considered. The results of the overall probability have a more clear trend when considering segment of increasing Strahler order to generate watersheds. This underlines the influence of high uncertainty in deriving streams of low Strahler orders, such as one or two.

V. CONCLUDING REMARKS

The delineation of watersheds and stream networks is important in many environmental and hydrological applications. DEM error propagation can provide valuable additional information for the reliability of the watershed delineation. In this study an error propagation analysis based on Monte Carlo approach was performed on two different widely available datasets. In both cases, the modelling of the elevation errors improved the results of the delineation process. The most of the uncertainty in the watershed divides could be linked to sub-basins generated around low Strahler order streams. The results are then dependent on the scale considered, with more defined results when considering larger basins. GDEM, despite its higher resolution, provided less defined results, especially after the introduction of the error modelling. Further investigations focus on comparison of obtained results with [i)] 1. ground data, and 2. remote sensing information. In addition, we are testing methods to derive the most probable watershed divides, similarly to the most probable river networks as described in (Poggio and Soille, 2008, In review)

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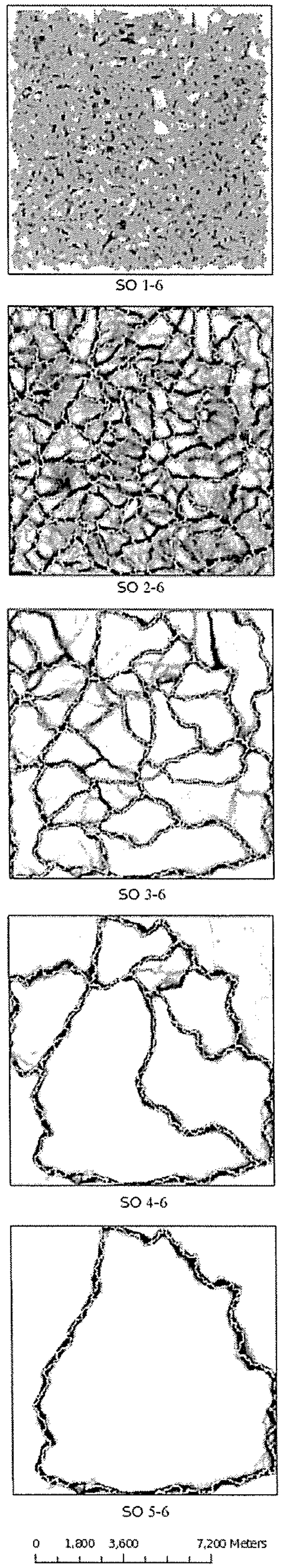

Figure 2. Most probable watershed divide nets for different Strahler orders (SO) considered.