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Hydrology and Earth System Sciences Discussions

Interactive comment on "Uncertainties associated with digital elevation models for hydrologic applications: a review" *by* S. Wechsler

S. Wechsler

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I would like to express appreciation to Reviewer #2 for your thoughtful and detailed comments.

Anonymous Referee #2

Comment: There is no clear discussion on what is meant by 'DEM error';, it would be good to distinguish, for between errors such as elevation errors (z-direction), positional errors (x and y directions) and errors due to too coarse resolution (topographic features not correctly represented)....Part 2 (DEM error) is central, but unfortunately just this chapter is quite short and important points are missing. This would be the place to discuss different measurement and computation techniques used to generate DEMs

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and what kind of errors (both source, size and spatial structure) are associated with these techniques. Honestly, this would be the key contribution I would have expected from the title of the paper. Unfortunately nowhere in the paper I could see, for instance, a number on how large errors might be.

Comment Continued: "Knowledge about the spatial structure of error is an important component for gaining an understanding of where errors arise and uncertainty is propagated. Methods should accommodate detailed DEM error information when available, yet provide mechanisms for addressing uncertainty in the absence of this information. "(p. 2348, line 2ff) . . . I agree, this is really a key point. Users of DEMs need to understand the errors and their spatial structure. I agree that information of this kind is difficult to obtain for DEM users, but this is exactly why I would like to see this type of information here.

***Response**: Section 2.0 was restructured to include a more detailed discussion of DEM error and accuracy. Some sources of DEM errors were listed. The discussion of the RMSE as a measure of DEM accuracy was enhanced and an example was provided. Maune (2001) provides details on DEM production methods and associated measures of quality. I therefore touch on these topics here but refer the Reader to Maune (2001) for more details.*

Comment: In part 3 different topographic indices are discussed. The point that there are different algorithms for most such indices is true, but I would say beyond the scope of this paper. This is a large issue on its own and there are more studies than those cited here which have looked on the effect of different algorithms.

***Response**: I respectfully disagree with the Reviewer's comment that the discussion of different algorithms for producing hydrologic variables is beyond the scope of this paper. The inability for current algorithms to adequately represent hydrologic variable is a severe problem, and contributes significantly to the issue of uncertainty as related to hydrologic applications. This paper seeks to call out this problem and as such chal-*

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lenge software vendors and the hydrologic community to develop better and agreed upon methods to represent DEM-derived topographic features that are frequently used in hydrologic analyses.

The section was modified to include an introductory paragraph that explains why this topic is relevant to this review.

Comment: The issue of DEM resolution (part 4) addresses a different type of error, i.e. features which are missed due to a too coarse resolution. It would be important to distinguish between different types of errors.

Response: *In the 2^{nd} paragraph the 3^{rd} sentence was modified to read "...Smaller grid cell sizes allow better representation of complex topography. These high resolution DEMs are better able to refine characteristics of complex topography that are missed in coarser DEMs. ...". This is a simple modification but I hope distinguishes between the errors that the Reviewer is referring to.*

Comment: Part 5 about interpolation should rather be included in part 2 (how the DEM is generated).

Response: *Section 5 was deleted and integrated into Section 2.*

Comment: Also note: in the case of LIDAR data we usually have to do less interpolation but rather aggregation to come from several points per m2 to a DEM with (usually) less resolution (p. 2353, lines 1-2).

Response: A statement to this effect was integrated into the interpolation discussion added to Section 2. The following sentence was added: "...Once elevation data is collected, DEMs are generated using interpolation or aggregation techniques..."

Comment: In part 6 sinks are discussed. Here more reference to the work by Lindsay could be made (see references below), also Rodhe and Seibert suggested an alternative approach to treat sinks.

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Response: *References to these sources were included in the manuscript.*

Comment: Stream burning is only discussed shortly, but would probably deserve more space. Here advantages and problems with the burning should be considered, if there is really no literature about this, the review could at least discuss these issues.

Response: *I added the following statements to the section on stream burning to address this valid comment.*

"...An advantage of this procedure is that it avoids iterative modification of the entire DEM, focusing on just the low lying stream areas. Errors could result from inconsistencies between the data sources, specifically in regard to scale....DEMs are altered to generate surfaces over which flow can be routed to facilitate their use in further hydrologic analyses. The impact of this modification on resulting analyses bears further investigation.

Comment: Obviously errors in the DEM affect distributed hydrological models (part 7). For this article, I guess one should leave it at this statement, getting more into modelling would probably require a review article on its own.

Response*: I agree this is an area that would benefit from an entire review. Therefore I did not elaborate in this manuscript, beyond the information provided in this section.*

Comment: Part 8 is partly difficult to follow. Some figures would certainly help here. Generally it is a bit surprising that there is hardly any figure, I am pretty sure that this is the first paper on DEM-related issues without any map-figure that I have seen. Many of the issues addressed in the paper would be more appealing and easier to understand when there were some figures.

Response*: The reviewer is correct, each section could benefit from its own figure. In the interest of space I added only two figures – one to demonstrate bias in sink filling and one to demonstrate uncertainty in results from a Monte Carlo simulation.*

Comment: In the conclusions I am missing some clear messages on how to move

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forward beyond the obvious “we have to be aware of the errors” . . . What guidelines should be followed? Where is a need for further research?

Response: *In response to Reviewers' comments the conclusion section was restructured and streamlined.*

Comment: The reference list is impressively long, but the text would at several places benefit from focusing on key publications.

Comment: At several points references is made to previous studies but results are not fully reported. As example see p. 2356, line 7f: “As would be expected, the number of depressions found was related to grid cell resolution“, How was the number of depressions linked to resolution? Decreasing or increasing? The reader should not be required to revisit the original paper to get this information.

Response: *This statement was revisited and clarified. The section now reads: . . .* The occurrence of depressions in remotely sensed DEMs representing varying terrain types (flat to mountainous) was evaluated. As would be expected, flat areas experienced more depressions than high-relief landscapes. The number of depressions found was related to grid cell resolution; coarser grids were found to be more vulnerable to depressions (Lindsay, 2005 #48). I recognize that in other areas I make reference to research but do not provide an expanded summary of the works. If I were to recapitulate every finding in this document, the manuscript would become quite unwieldy. This paper identifies many studies related to the areas discussed but cannot possibly provide summaries for each study.

Comment: Relevant references. . .

Lindsay, 2006 'Sensitivity of channel mapping techniques to uncertainty in digital elevation data', International Journal of Geographical Information Science, 20(6): 669-692.

Response: *This reference was integrated into revised DEM Simulation section*

Lindsay, 2006 'Distinguishing between artefact and real depressions in dig-

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ital elevation data', Computers & Geosciences, 32(8): 1192-1204. doi: 10.1016/j.cageo.2005.11.002 (with I F Creed).

Response: *This reference was integrated into the revised Section 5: Surface Modification for Hydrologic Analysis*

Lindsay, 2005 'Removal of Artefact Depressions from Digital Elevation Models: Towards a minimum impact approach', Hydrological Processes, 19(16): 3113-3126 (with I F Creed).

Response: *This reference was integrated into the revised Section 5: Surface Modification for Hydrologic Analysis*

Rodhe, A. and Seibert, J., 1999, Wetland occurrence in relation to topography -a test of topographic indices as moisture indicators, Agricultural and Forest Meteorology 98-99: 325-340

Response: *This reference was integrated into the section on DEM Resolution.*

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