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Hydrology and Earth System Sciences Discussions

Interactive comment on "Deriving a global river network map at flexible resolutions from a fine-resolution flow direction map with explicit representation of topographical characteristics in sub-grid scale" *by* D. Yamazaki et al.

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We are very glad that anonymous referee #1 acknowledged our new method as innovative and interesting. We greatly appreciate his constructive comments on our HESSD manuscript. We revised our manuscript according to his suggestions. The followings are replies to his detailed comments.

RC: Reviewer's comment

AC: Authors' comment

Note that bold **Fig.** is used for figures in the original manuscript, while italic *Fig.* used for figures in this response.

<Replies to General comments>

RC1: The use of English should be improved by using a professional editor.

AC1: We revised the use of English by native check.

RC2: Discuss the broad literature on methods at smaller scales where algorithm different from D8 algorithms have already been proposed and applied.

AC2: It is added to the last paragraph of section 5. (See **AC9** to Specific comments)

RC3: The authors should reference and discuss the global river network data sets of HydroSHEDS (http://hydrosheds.cr.usgs.gov/, http://www.worldwildlife.org/hydrosheds), as also here, a fine-resolution flow direction map (SRTM 3 arc-seconds) was automatically upscaled to a coarse-resolution flow direction map/river network at 5 min resolution. It would be good to compare maps that you produce with your algorithm to the 5 min HydroSHEDS map (the 5 min HydroSHEDS data can be obtained from Bernhard Lehner, McGill University).

AC3: We referred HydroSHEDS datasets in the revised manuscript. The FLOW method can also be applied to the flow direction map and elevation map of HydroSHEDS. We also added discussion about this point to Section 2.1 as follows:

"The FLOW method can also be applied to other flow direction maps and elevation maps, such as HydroSHEDS which provide 90 m resolution datasets in global scale (Lehner et al, 2008). Using finer-resolution input datasets requires heavier computation for upscaling procedures, but helps to construct a river network map with more precise sub-grid topographic information. However, this paper is focusing on the upscaling method itself rather than input datasets. Therefore, the GDBD flow direction map and the SRTM30 DEM, which requires less computational load, are chosen as input datasets."

We compared river network maps of FLOW and HydroSHEDS at 5 min resolution. The 5 min HydroSHEDS dataset is provided by Dr. Lehner as the reviewer suggested. It is found that there is no significant difference between river network structures of FLOW and HydroSHEDS (e.g. *Fig.1*). It can be said that both FLOW and HydroSHEDS show good representation of actual river networks. We acknowledged the upscaling method used in HydroSHEDS, which utilize both fine-resolution flow direction map and elevation map, is quite sophisticated. However, upscaling method used in HydroSHEDS may cause errors when it is applied to lower resolution, because they are based on D8 method. Unfortunately, the automatic upscaling method used in HydroSHEDS is not opened to public yet (Lehner, personal communication), so it is difficult to discuss about this point further.

RC4: The claim that the resolution of 15 min is the highest available has to be rewritten.

AC4: We modified that part. (See **AC9** to Specific comments)

<Replies to Specific Comments>

RC1: I suggest changing the title, as it is difficult to understand (the "explicit representation" is supposed to refer to the derivation of the global river network map but might appear to be a characteristic of the flow direction map; "in sub-grid scale" is not correct).

AC1: The title is changed to "Deriving a global river network map and its sub-grid topographic characteristics from a fine-resolution flow direction map". We think this title is simple enough to understand.

RC2: Last sentence of abstract: It is not clear to me how inundated area extent could be modeled better with your approach. Please explain in the text or delete.

AC2: Certainly, we deleted this phrase from the abstract.

RC3: p. 5025 line 2: reference for HYDRO1k missing (Lehner, Verdin, Jarvis: "New Global Hydrography Derived from Spaceborne Elevation Data". In: EOS, Vol 89, No. 10, 4 March 2008)

AC3: We appreciate the reviewer's indication. This reference is added to the revised manuscript.

RC4: p. 5026 lines 24, 25: "B5", not "B4"

AC4: This is our simple mistake. We corrected it.

RC5: Fig8: Explain in the text the reasons for the different patterns: 1) in general, 2) it seems as if in 8b and 8c, very small drainage areas of 1 km pixels are not represented.

AC5: We are very sorry that data used for **Fig.8b** was mistaken. The corrected plots are shown in *Fig.2*.

Explanation for the different patterns in general is added to the manuscript as follows:

"Patterns of plotting in **Fig.8** indicate the accuracy of upscaling procedures. If the original river network structures are preserved in the upscaled map, the plots are clustered near the 1:1 line. On the other hand, errors in upscaling procedures cause over and under estimations of upstream area, which can be recognized as spreading from the 1:1 line."

Explanation for the characteristics of each plot requires detailed description of each upscaling method. This is out of our manuscript's framework, so we will not discuss further in the manuscript. Yet, detailed explanations are as follows.

The upscaling method by Döll and Lehner (2002) constructs medium resolution river network map using the upscaling method of Fekete et al. (2001) (see *Fig.3a*). However, drainage directions estimated by the method of Fekete et al. tend to accumulate into the cell with large river stream (See *Fig.3b*). Over-estimated drainage area seen in *Fig.2* is caused by this error.

The Double Maximum Method (Olivera et al. 2002) does not include criteria for choosing outlet pixels such as Step.1 of the FLOW method. Therefore, Double Maximum Method tends to choose outlet pixels with large drainage area (See cell A2 in *Fig.3c*). This feature explains why very small drainage areas of 1 km pixels are not represented in *Fig.2c*.

RC6: p. 5030, line 10: it would be good to clarify that the drainage direction map of Döll and Lehner included manual corrections. Would it be possible to include a comparison to their 0.5 degree map with manual corrections in **Fig.8**?

AC6: The clarification about manual corrections is added to the manuscript. Including their 0.5 degree map with manual correction in **Fig.8** seems difficult, because it requires the by-product data only available in their upscaling procedures. Instead, the figure similar to their paper is created using the result of the FLOW method (See *Fig.4*). Manual correction breaks the link between original fine-resolution dataset and coarse-resolution river network map. This is the cause of spread from the 1:1 line in *Fig.4b*.

RC7: Fig.5: I suggest exchanging the left and right boxes such that like in **Fig.1 and 3**, the fine-resolution presentation is at the right-hand side, and show the fine-res. presentation as a zoom-in of the coarse-resolution presentation. Besides, in the fine-resolution presentation please indicate the coarse-grid boundaries, like in **Fig.1 and 3**.

AC7: Fig.5 is modified according to this suggestion.

RC8: p. 5030, line 20, p. 5033 line 21: It is not correct to say that the resolution of global river network maps is limited to 30 min, and the resolution of 15 min is the highest among currently available river network maps for the use in global hydrological models. You yourself used Hydro1K and its modification GDBD, which is a global river network map at 1 km, and there is HydroSHEDS, which provides global river networks at 3 arc-sec, 15 arc-sec and 5 min. They all could be used by global hydrological models, and a resolution of 5 min is currently quite feasible at the global scale.

AC8: Reviewer's comment is true. We decided it is better to emphasize that FLOW can produce river network maps at "variable resolution", rather than "higher resolution". The first paragraph of section 5 is modified accordingly as follows:

"The Flexible Location Of Waterways method (FLOW method) makes it possible to automatically construct coarse-resolution river network maps without tedious manual correction. Because manual correction has been recognized as the largest obstacles for deriving macro-scale river network maps, number of feasible river network maps with adequate manual correction for use in global river routings is limited (e.g. Oki and Sud, 1999; Vörösmarty et al., 2000; Döll and Lenner, 2000). Owing to the advantage on manual correction, the FLOW method can provide river network maps at various resolutions. For example, **Fig.9** illustrates upscaled river network maps describing a part of the Mississippi River basin at the resolution of 30 minutes (**Fig.9a**) and 15 minutes (**Fig.9b**). The FLOW method is also possible to produce river network maps with grid coordinates other than these longitude-latitude-based ones, such as wave-number-based grid coordinates used in General Circulation Models."

RC9: p. 5032, line 26: Please rephrase, the term pilot study does not seem to be correct. I understand that the FLOW approach somehow stands between the normal D8 grid cell approach and the catchment approach. Please explain how flow is related to the catchment approach.

AC9: We modified the first sentence of the paragraph as follows:

"The FLOW method can link the drainage-area-based approach with global river routing models by aggregating 1 km pixels into coarse-resolution drainage area elements whose size is almost similar to the grid size."

Note that the term "catchment" is replaced with "drainage area" according to the reviewer's comment by Dr. Orlandini.

Another paragraph about the discussion on drainage-area-based approach is added to the end of the section 5 as follows:

"A Drainage-area-based approach requires disaggregation of forcing data (e.g. runoff, precipitation, and evaporation) in order to dissolve the mismatch between rectangular gridded forcing and irregular drainage area elements (Koster et al., 2000). This disaggregation technique is somewhat computational, but it brings realistic representation of flux exchanges into hydrological modeling. When this technique is adopted, coarse-resolution grids are no more essential elements upon which river network maps are based. Since drainage area elements can be defined independently of the coarse-resolution grids as done in smaller-scale hydrological models (e.g. Moore and Grayson, 1991; Goleti et al, 2008; Moretti and Orlandini, 2008), the grid-based river network map, which underlies the FLOW method, is not the absolute way for the description of global river network maps. Therefore, upscaling method for macro-scale river network maps may have a potential to be father improved."

RC10: Please write a few sentences to answer the following question: What changes in river routing models would be required to use river network maps derived with the FLOW approach?

AC10: We added a following paragraph into the end of section 3.1:

"In most macro-scale river routing models (e.g. Miller et al., 1996; Arora and Boer, 2002; Oki et al., 2003; Hunger and Döll, 2008), output discharge from each grid is inputted to its downstream grid described by a river network map. Within this model framework, traditional D8 form is actually a sufficient-but-not-necessary condition for describing the river network map. Thus, the river network map derived with the FLOW method can be applied to existing river routing models with some changes on their way of reading a river network map and indicating downstream grids. However, in order to fully utilize the sub-grid topographic features derived by the FLOW method, development of new river routing models is essential."

<References>

Döll, P. and Lehner, B.: Validation of a new global 30-min drainage direction map, J. Hydrol., 258, 214-231, 2002.

Fekete, B. M., Vörösmarty, C. J. and Lammers, R. B.: Scaling gridded river networks for macroscale hydrology: Development, analysis, and control of error, Water Resour. Res., 37, 1955-1967, 2001.

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Olivera, F., Lear, M. S., Famigletti, J. S. and Asante, K.: Extracting low-resolution river networks from high resolution digital elevation models, Water Resour. Res., 38(11), 1231, doi:10.1029/2001WR000726, 2002.

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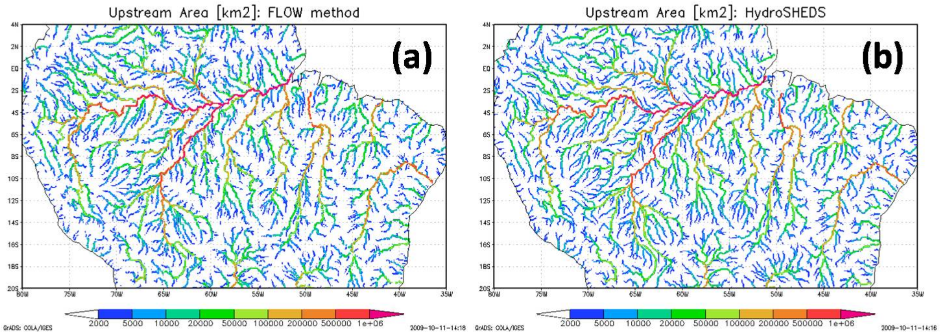

Fig. 1. Upstream area of river network maps of (a) the FLOW method and (b) HydroSHEDS at 5 min resolution.

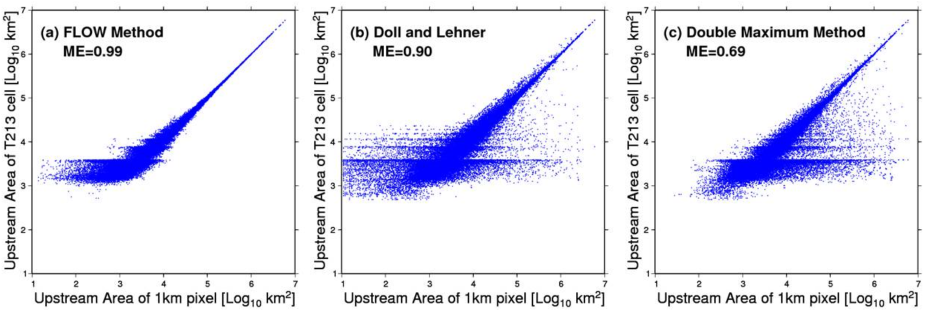

Fig. 2. Comparison between upstream areas obtained from an upscaled river network map and from an original flow direction map (Correction for Fig.8 of the manuscript). Dataset used for Fig.8 was mistaken.

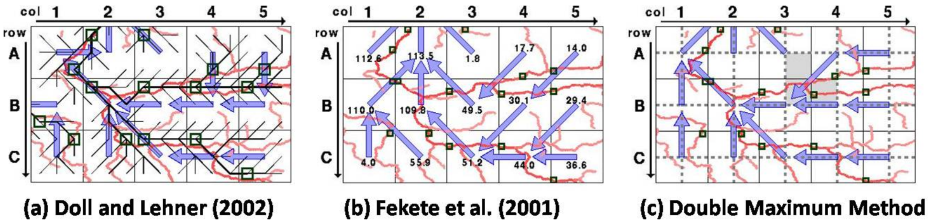

Fig. 3. River network maps constructed by methods of (a) Döll and Lehner, (b) Fekete et al., and (c) Double Maximum Method.

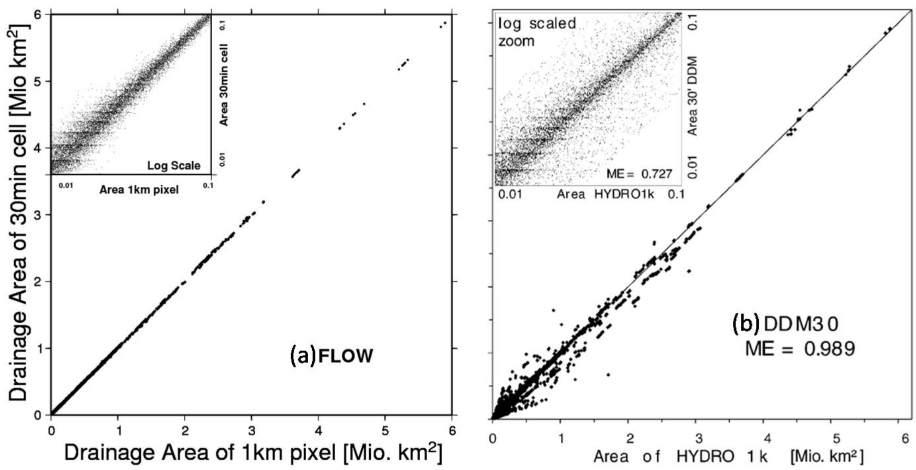

Fig. 4. Comparison between upstream areas obtained from an upscaled river network map and an original flow direction map for (a) FLOW method and (b) Döll and Lehner (2002) with manual correction.