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Technical note: Comparing three different methods for allocating river points to coarse-resolution hydrological modelling grid cells

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Abstract. The allocation of points in a river network to pixels of a coarse-resolution hydrological modelling grid is a well-known issue, especially for hydrologists who use measurements at gauging stations to calibrate and validate distributed hydrological models. To address this issue, the traditional approach involves examining grid cells surrounding the considered river point and selecting the best candidate, based on distance and upstream drainage area as decision criteria. However, recent studies have suggested that focusing on basin boundaries rather than basin areas could prevent many allocation errors, even though the performance gain is rarely assessed. This paper compares different allocation methods and examines their relative performance. Three methods representing various families of methods have been designed: area-based, topology-based and contour-based methods. These methods are implemented to allocate 2580 river points to a 1km hydrological modelling grid. These points are distributed along the entire hydrographic network of the French southeastern Mediterranean region, covering upstream drainage areas ranging from $5km^2$ to $3000km^2$. The results indicate that the differences between the methods can be significant, especially for small upstream catchments areas.

1 Introduction

In hydrology, rainfall-runoff models' outputs are often compared to observed discharge series at gauging stations for calibration or evaluation purposes. However, when using gridded models, it is necessary to allocate each gauging station to a specific cell in the model grid. In the literature, terms such as "co-registering" (Fekete et al., 2002), "co-referencing" (Döll and Lehner, 2002), and "matching" (Wang et al., 2018) are also used to describe this process. The allocation of specific river points to a coarse-resolution cell can also be necessary when connecting the output of a hydrological distributed model (providing hydrographs or peak discharges on a grid) to a hydraulic model for inundation modelling. As an example, Dottori et al. (2017) developed a European-wide flood risk assessment system, based on the European Flood Awareness System (EFAS, see Thielen et al. 2009; Bartholmes et al. 2009). The discharge output of EFAS is provided on a grid of spatial resolution of $5km$, which needed to be downscaled to a resolution of $100m$ in order to derive flood hazard maps at the pan-European scale. Dottori et al. (2015) opted for a basic method consisting in allocating the $100m$ river pixel to the $5km$ river cell containing this pixel. This approach has limitations, particularly when the two river networks defined at the $100m$ and $5km$ scales do not overlap.

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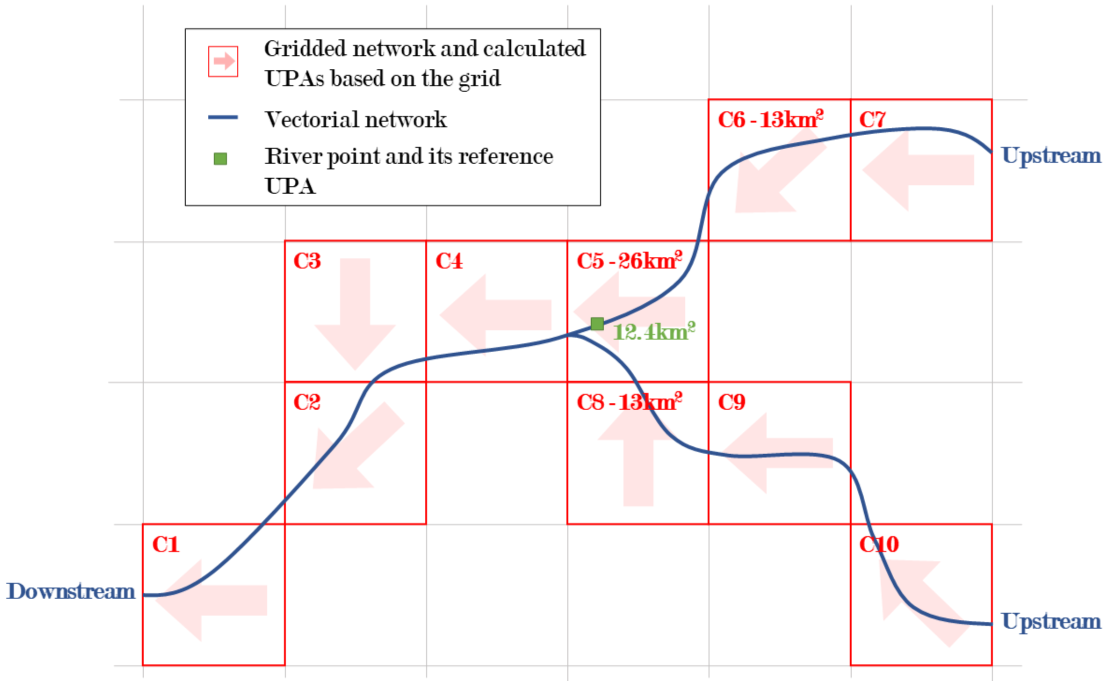

Figure 1. Example of allocation process failure when based on distance and UPA error criteria: green river point is allocated to grid cell C8 instead of grid cell C5

Generally, the allocation of river points to a coarse-resolution grid for hydrological modelling relies on distance and upstream drainage area (UPA) error criteria (Döll and Lehner, 2002; Fekete et al., 2002; Lehner, 2012; Zhao et al., 2017; Sutanudjaja et al., 2018; Wang et al., 2018; Burek et al., 2020; Polcher et al., 2022). However, this process is also prone to errors, especially near confluences, where points of different branches of the river network may have similar UPAs. As a result, their allocation on the coarse-resolution grid can lead to assigning a point to the wrong hydrological grid cell and corresponding upstream watershed, based on a slightly better UPA fit or a slightly shorter distance (see figure 1 for an example).

Considering this possible limitation, efforts have been made to propose more effective protocols for allocating river points to hydrological grid cells. For instance, the methods proposed by Burek and Smilovic (2022); Munier and Decharme (2022) combine distance and UPA error criteria with a comparison between the gauging station's basin boundaries, delineated on the basis of a fine-resolution Digital Elevation Model (DEM), and the basin boundaries of the allocated cell based on the coarse-resolution hydrological grid. In both studies, the similarity between the watershed limits is characterized by the Intersection Over Union index (Rezatofighi et al., 2019).

The idea of comparing basin boundaries had been previously considered, although in a slightly different context, namely the evaluation of hydrological grids obtained from an upscaling algorithm (i.e., transforming a fine-resolution grid into a coarser-resolution grid). Initially, upscaling algorithms were also guided by a comparison between the UPA values of "small pixels"

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and the corresponding upscaled "large cells" (Reed, 2003; Paz et al., 2006; Yamazaki et al., 2008; Eilander et al., 2021). Visual inspections were performed to identify obvious inconsistencies between small scale and upscaled grids and corresponding river networks. To reduce these inconsistencies automatically, additional criteria have been proposed to complement the UPA criterion for the optimisation of uspcaling algorithms such as the mean distance between river networks and the percentage within a buffer (Davies and Bell, 2009), the correctness index and the figure of merit (Li and Wong, 2010), and the watershed delineation percentages of consistency (Sousa and Paz, 2017).

In summary, numerous methods are available to achieve the objective of allocating a river point to a coarse-resolution grid cell. However, these methods have been developed in different contexts and have rarely been compared. This study aims at comparing the results obtained from three different types of methods for allocating a large number (2580) of river points to a coarse-resolution hydrological grid ($1km \times 1km$). The first method belongs to the category of area-based methods and employs distance and UPA error criteria. The third method is a contour-based approach. The second method is a topological method based on proximity along the river network. Another unique aspect of this work is that it deals with a detailed river network that includes river points with small drainage areas (minimum of $5km^2$), whereas most previous studies have been limited to the main river networks (catchments larger than $500km^2$ in Dottori et al. (2017) for instance).

The paper is structured as follows: Section 2 presents the three tested allocation methods as well as the validation metrics. Section 3 provides an overview of the case-study. Finally, Section 4 compares and discusses the results obtained with the three tested allocation methods.

2 Allocation methods and validation metrics

In this section, we describe three methods that allow for the allocation of a river point to a coarse-resolution grid cell. To implement and evaluate these methods, it is necessary to have reference catchment boundaries for each river point, which can be obtained from a fine-resolution Digital Elevation Model (DEM).

2.1 Method 1: area-based method

Area-based methods can be traced back to Döll and Lehner (2002), who proposed allocating river points to the coarse-resolution grid cells containing the points, provided that the relative difference between coarse and reference resolution UPAs did not exceed 5%. This criterion led, in their case, to a manual re-allocation of 35% of the points. In order to automate the allocation procedure, Lehner (2012) proposed to select the grid cell within a 5km radius search area around each river point (see Figure 2) with the lowest value of a discrepancy criterion $D = RA + 2R$, where RA stands for the relative difference between UPAs that should not exceed 50% and R for the distance between the point and the centre of the grid cell. In most other works (Zhao et al., 2017; Sutanudjaja et al., 2018; Wang et al., 2018; Burek et al., 2020), RA is the only selection criterion, the radius of the search area (1-25km, depending on the spatial resolution) and the maximum acceptable RA value for a successful allocation (10-30%) varying between studies. To maximise the proportion of allocated river points and to optimise the computation time, the approach proposed herein, proceeds in three possible successive steps. At step 1, the closest grid cell verifying $RA < 10\%$

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and $R < 3$ cells is selected, if it exists. If it does not, the maximum RA values is increased to 20% at step 2 and 30% at step 3. It can be noted that the proposed approach combines area and distance criteria.

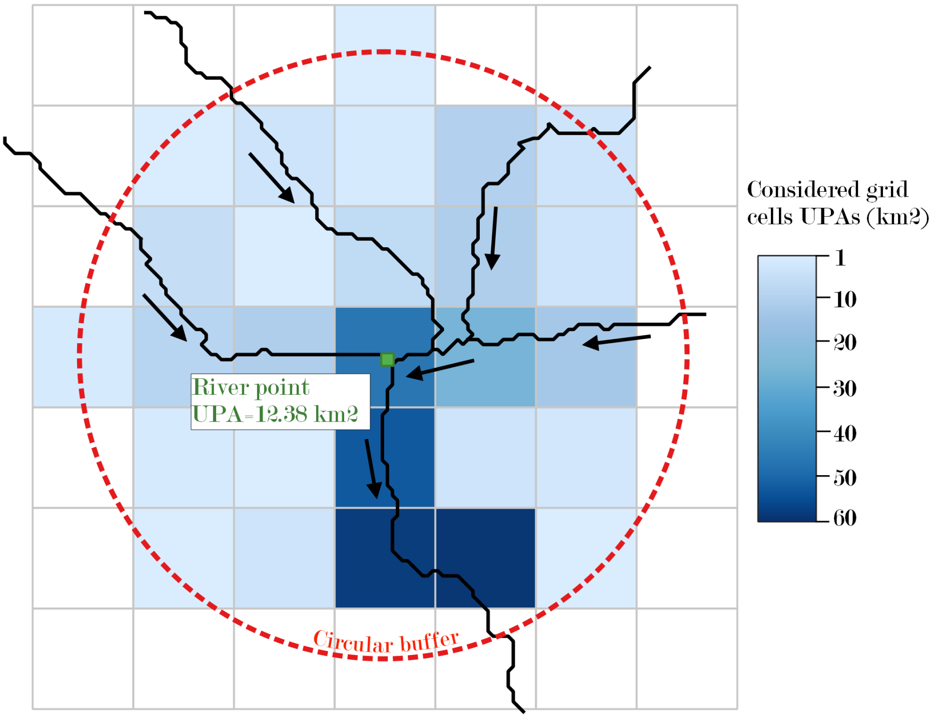

Figure 2. Illustration of Method 1: grid cells candidates for a specific river point

2.2 Method 2: topology-based method

This second method requires a vector-based river network and the definition of coarse grid cells' *outlet points*. The cells' outlet points are located and selected according to the IHU upscaling method (Eilander et al., 2021), used to generate the coarse-resolution hydrological modelling grid (see section 3.2). Each river point can then be connected to the closest upstream or downstream grid cell outlet point and hence allocated to the corresponding grid cell, provided that both points belong to the same river reach, i.e. are not separated by a network confluence (case of point P3 in Figure 3). With this method, river points located between two confluences within the same grid cell cannot be allocated.

2.3 Method 3: contour-based method

Several previous works have stressed the importance of considering the consistency of watershed contours for the evaluation or optimisation of upscaling or allocation methods (Davies and Bell, 2009; Li and Wong, 2010; Sousa and Paz, 2017). Method 3 is similar to method 1, except that it is not only based on the comparison between upstream watershed surfaces, but also between

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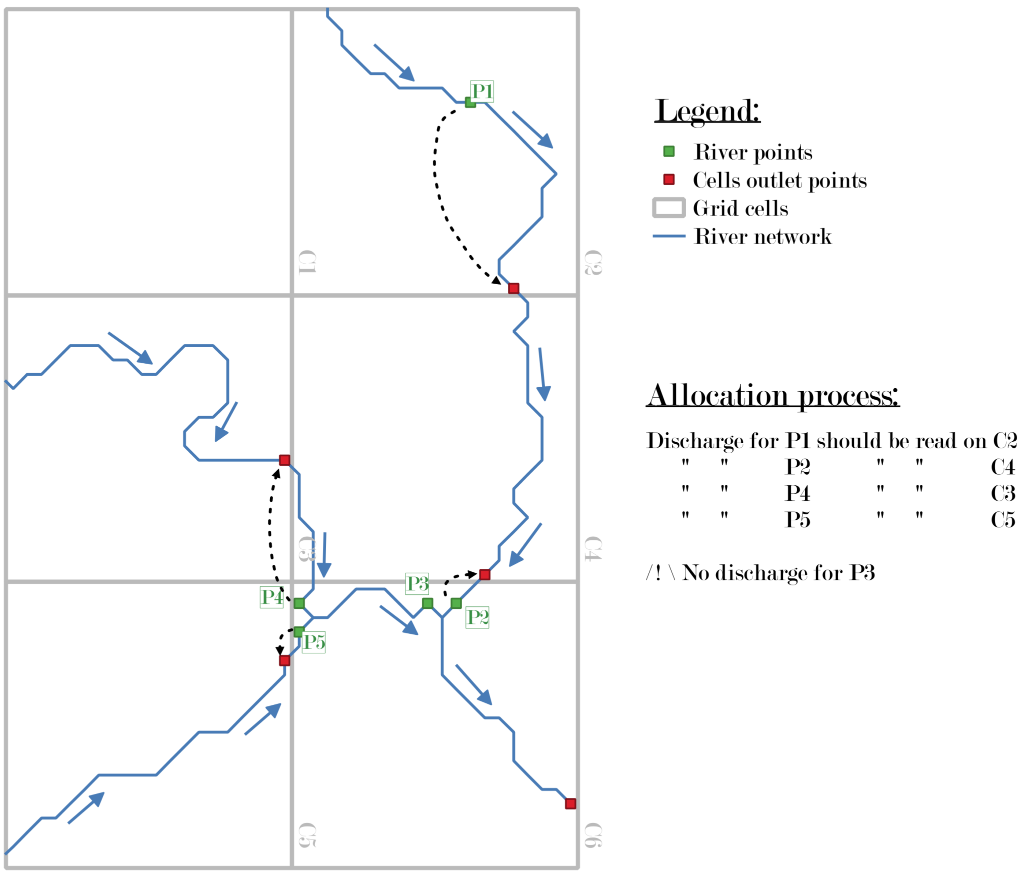

Figure 3. Illustration and limits of Method 2: connection of river points and cells outlet points (black dotted arrows) with an impossibility for point P3, located between two confluences in the same grid cell.

upstream watershed contours. While Munier and Decharme (2022); Burek and Smilovic (2022) did propose an allocation criterion based on a combination of an area-based and a contour-based criterion, it is proposed herein to base the selection of the appropriate grid cell for each river point based on a single criterion, namely the critical success index, CSI (see eq. 1). The CSI is a standard score to compare surfaces, often used to compare flood inundation models for instance (Fleischmann et al., 2019; Hocini et al., 2021).

$$CSI = \frac{a}{a+b+c} \tag{1}$$

Where a (HIT, see figure 4) is the overlapping area between the reference upstream watershed of the considered river point and the upstream watershed of the candidate grid cell, defined on the coarse-resolution grid using the TAUDEM library (Tarboton, 1997). "b" is the area of the reference watershed not overlapping with the coarse grid watershed (MISS) and conversely, "c" is the area of the coarse grid watershed, not overlapping with the reference watershed (FALSE ALARMS). CSI is equal

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to 1 in case of a perfect overlap and 0 when there is no overlap at all. It can be noted that $CSI = IoU = FM$, where IoU is the intersection over union criterion used in some previous studies (Munier and Decharme, 2022; Burek and Smilovic, 2022), and FM is the Figure of Merit used by Li and Wong (2010).

Like for method 2, the allocation procedure proceeds in two possible steps. The grid cell maximising the CSI value is selected among the 9 cells closest to the considered river point. If a minimum CSI value is not reached (i.e. 0.4 for watershed areas under 10 km^2 and 0.6 otherwise), the search area is extended to the 49 closest grid cells.

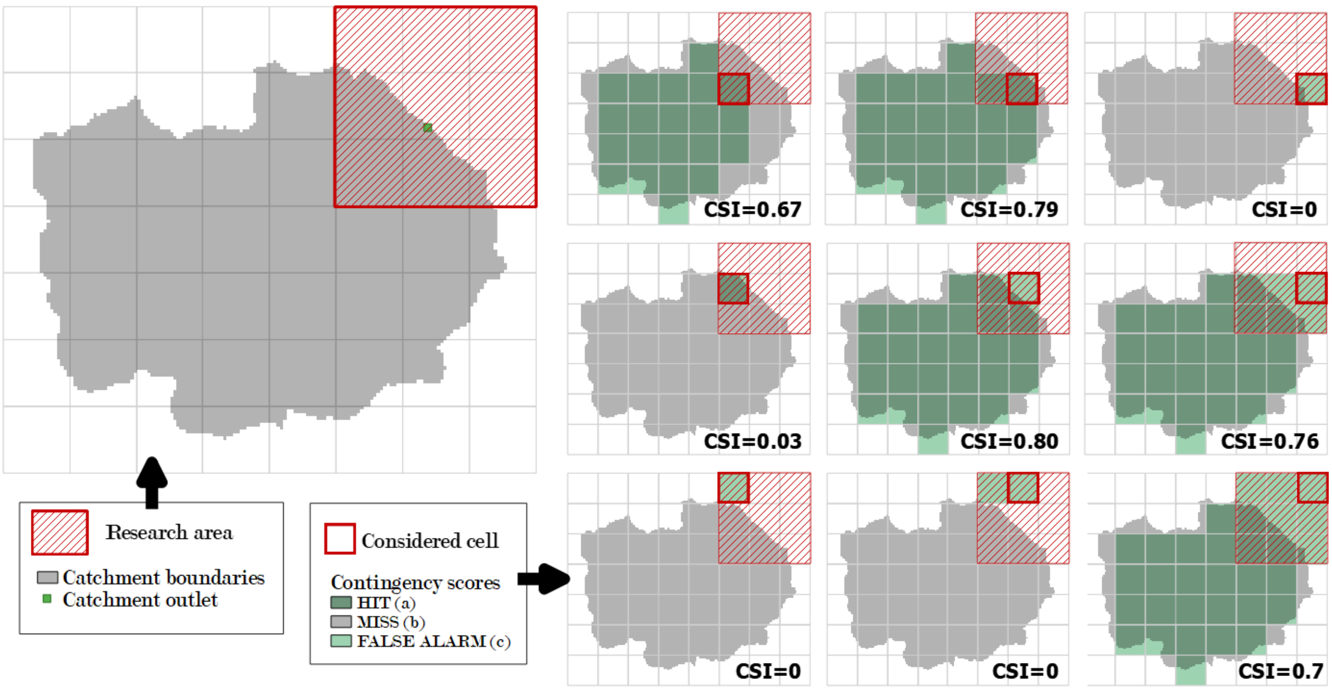

Figure 4. Illustration of Method 3: CSI calculations for the nine candidate cells

2.4 Evaluation metrics

The allocation procedures aims at relating points of the river network, often corresponding to a gauging station, to coarse grid cells of a distributed hydrological model, with the upstream watershed closest to the actual watershed, or at least closest to the watershed delineated based on the finest available geographical data. Therefore, the CSI appears as the best suited score for the efficiency evaluation of allocation methods and will be used hereafter. By construction, method 3 should then lead to the best performances, but at the cost of a higher implementation complexity and significantly larger computation times, as will be illustrated herein. Hence, the main question will be : "how well do methods 1 and 2 compare to method 3 ?"

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3 Case study and data

The test area covers three departments in the Eastern Mediterranean region of France, with a total surface area exceeding 15,000 km^2 (figure 5). Two geographical datasets have been used to implement and compare the allocation methods: the river points to be allocated and their reference catchments boundaries, and the coarse-resolution grid specifically designed for the purpuse of the study.

3.1 The river points to be allocated

The BNBV (Base Nationale des Bassins Versants) is a French reference GIS layer describing the network of rivers with an upstream catchment area larger than $5km^2$, over the whole territory of France. It was produced by Organde et al. (2013), based on the processing of a hydrologically-validated 50m-resolution flow direction grid. It includes a vector description of the river reaches and identifies approximately 15,000 points of interest along the river network across mainland France. These points correspond to locations of gauging stations, urban areas, confluences, river mouths. Intermediate outlets were also added to ensure comprehensive coverage of the whole river network. The upstream watershed limits and areas are associated to each BNBV point.

Figure 5 displays the BNBV outlets and river reaches in the Eastern Mediterranean region. BNBV outlets located in the étang de Berre area were excluded from our study due to the lack of meaningful flow direction in a lagoon. The region contains 2580 BNBV outlets that will be allocated to a coarse-resolution grid. The vector representation of the upstream catchment limits serves as the reference for the evaluation and for the implementation of Method 3, while the vector description of river reaches is essential for Method 2.

3.2 The coarse-resolution hydrological modelling grid

Regional gridded hydrological models are often implemented on 1km resolution grids, aligning with the typical resolution of operational radar-based quantitative precipitation estimates. In this context, the $1km \times 1km$ hydrological modelling grid was herein generated by upscaling the 50m flow direction grid from the BNBV database using the IHU method (Eilander et al., 2021), see figure 6 to visualize the upscaling results. The IHU method incorporates principles from previous upscaling methods (Döll and Lehner, 2002; Fekete et al., 2001; Olivera et al., 2002; Paz et al., 2006; Wu et al., 2011) and has demonstrated superior performance compared to the benchmarks methods, e.g. DMM method (Olivera et al., 2002) and EAM method (Yamazaki et al., 2008). Moreover, the IHU method is the only fully automated and open-source flow direction grid upscaling method known to the authors. After implementing the IHU method, we made minimal manual corrections to the flow direction grid. Only a small number of cells, approximately a dozen out of around 14,000 cells, required adjustments. These manual corrections were primarily made along the zone's borders, particularly near the coastline.

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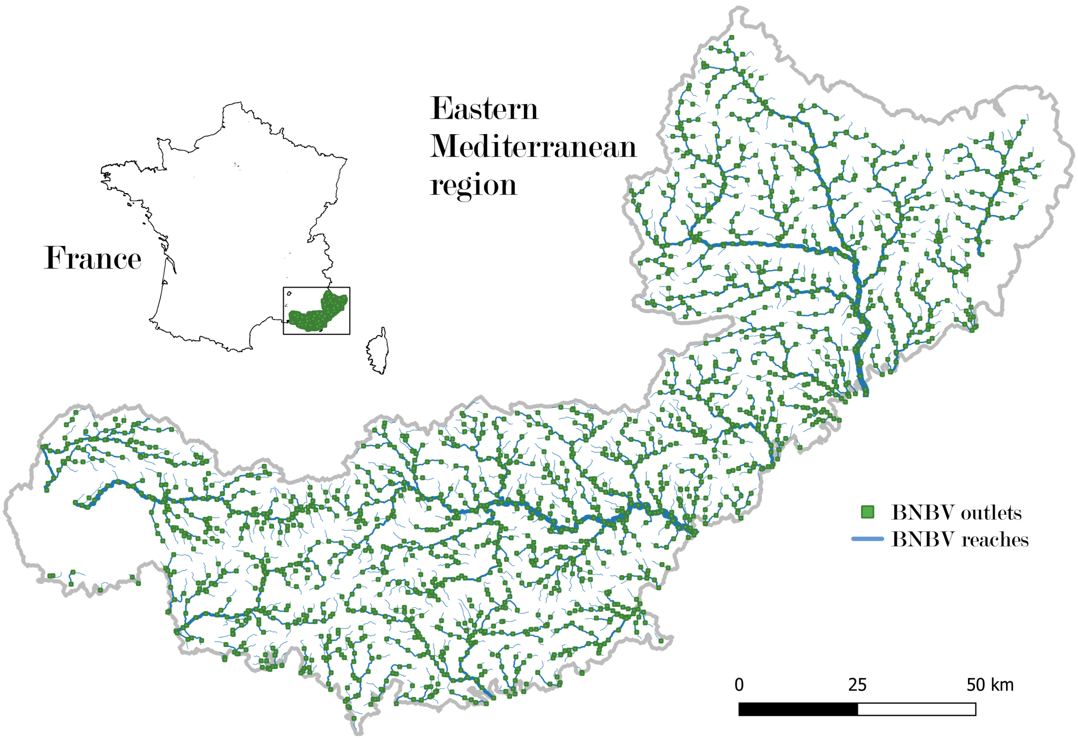

Figure 5. The 2580 BNBV outlets on the French Eastern Mediterranean region

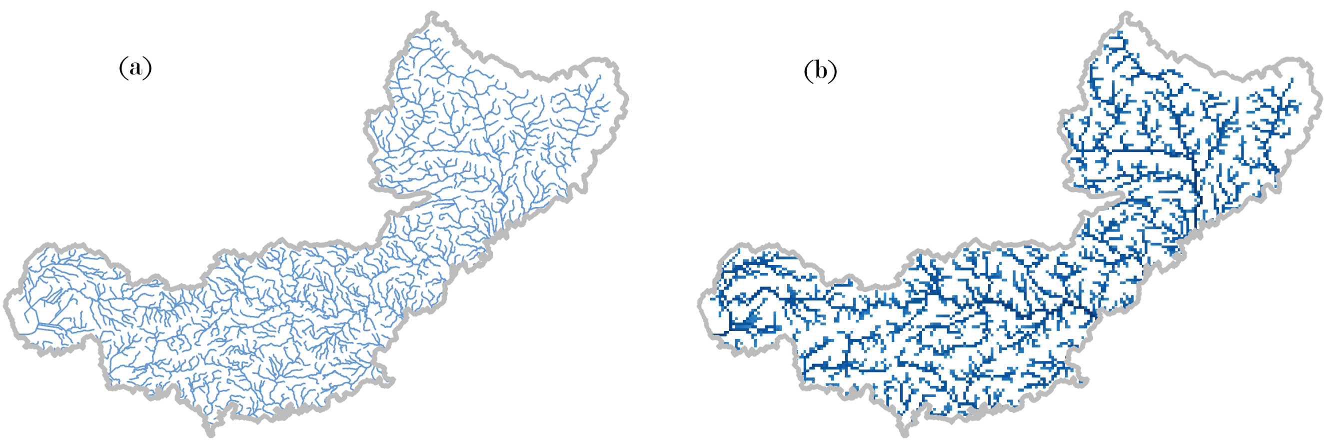

Figure 6. Initial $50m$ river network vectorized for $S > 5km^2$ (a) and $1km$ upscaled surface accumulation ($S > 5km^2$) grid (b)

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4 Results and discussion

4.1 Advantages and disadvantages of each method

Table 1 provides an overview of the general advantages and disadvantages of each method. Computation time is an important consideration, and Method 1 demonstrates superior performance in this regard compared to the other two methods. However, method replicability is another crucial factor to consider. Method 2 is limited in its compatibility as it relies on the IHU upscaling. On the other hand, Method 3 requires reference catchment boundaries. Furthermore, the confidence level varies between the methods. Method 1 relies solely on basin area information, which means that near confluences, it may allocate a river point to a neighboring grid cell with a similar basin area but belonging to a different catchment. Method 2 ensures that the river points and chosen grid cell belong to the same river reach, while Method 3 selects the cell with the most similar upstream catchment in terms of basin contour and location. Lastly, Method 3 guarantees the allocation of all river points, covering 100% of the dataset, whereas the other two methods may not achieve complete allocation.

	Method 1	**Method 2**	**Method 3**
Computation times	$\simeq$ Second	$\simeq$ Minute	$\simeq$ Hour
Replicability	Replicable	Requires the definition of *cells outlet points*	Replicable
Additional data	None	River network vector and cell outlet points	Reference basin limits
Confidence level	Variable	High	High
% of allocated outlets	Potentially < 100	Potentially < 100	100

Table 1. Advantages and disadvantages of each method

4.2 Comparison of allocation performances

In order to compare the quality of allocation among the three methods, we initially examined the CSI statistics. However, it should be noted that while Method 1 and Method 3 successfully allocated all 2580 considered river points (BNBV outlets in the Eastern Mediterranean zone), Method 2 only allocated 2532 points (98%). To ensure a fair comparison, these 48 points were excluded from the analysis. Figure 7 displays the histograms of CSI values for each method, along with the corresponding mean and median values. The results indicate that Method 1 has significantly lower performances compared to Methods 2 and 3. This discrepancy is primarily attributed to a high percentage of river points with very low CSI scores (less than 0.05) in Method 1. These low scores occur when a river point is allocated to a cell solely based on similar basin area, disregarding substantial differences in the shape and location of the upstream catchments (e.g. figure 1).

Despite the similarity in results between the three methods, there are important considerations to be made. While Method 2 may appear more appealing due to faster computation times, it is crucial to note that 48 BNBV outlets had to be excluded from the analysis when using Method 2. This exclusion encompassed outlets with varying basin areas, and not particularly small ones (mean=$172 km^2$). Method 3 was able to allocate these outlets successfully, with a mean CSI of 0.7. Additionally, Figure 7

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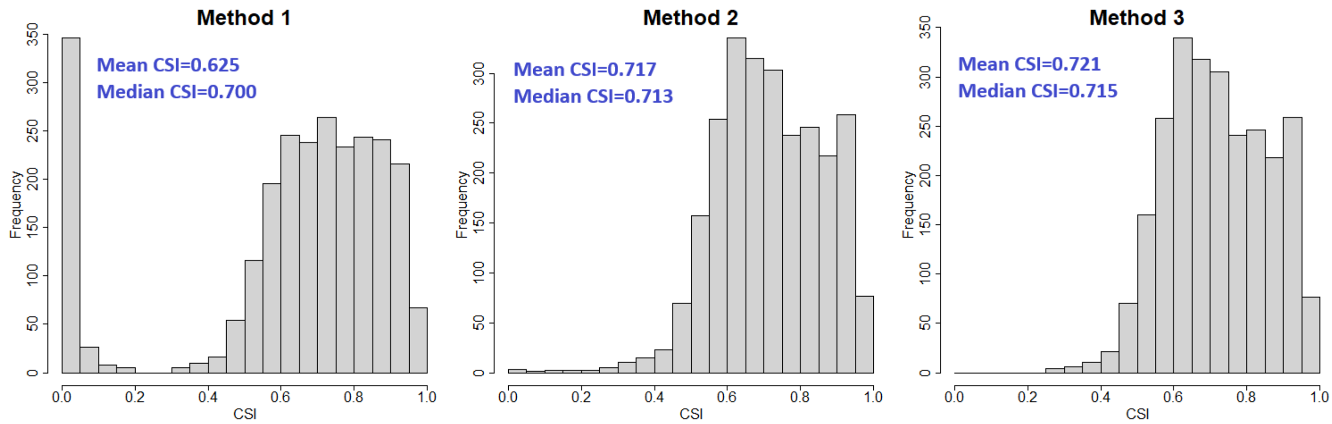

Figure 7. Histograms of CSI values for the three allocation methods

highlights that Method 3 consistently yields a minimum CSI of around 0.25, whereas Method 2 falls below 0.05 (with 12 river points having CSI < 0.25). These findings emphasize the superiority of Method 3 in terms of allocation quality, even when considering the challenging cases of the excluded outlets.

Figure 8 provides a more detailed comparison of CSI scores between Method 2 and Method 3. It clearly demonstrates the consistent superiority of Method 3 over Method 2. While the CSI differentials are generally small, the green circle in the figure highlights cases where the differential can be significant. These are characterised by river points with small upstream basin areas (less than $12km^2$) located far from the nearest cell outlet point, resulting in notable differences in UPAs (see Figure 9 for an illustrative example). Furthermore, Figure 8 reveals that Method 3 effectively corrects the allocation errors made by Method 1 (indicated by orange circles in the figure). However, it also indicates that there are surprisingly cases where Method 1 yields slightly better CSI scores than Method 3 (nine cases circled in blue). This suggests that the minimum CSI values defined in section 2.3 for the two possible steps of Method 3 may not be optimal, a topic that will be further discussed in Section 4.4.

4.3 The influence of the upstream basin area

The analysis reveals that basin area plays a significant role in explaining the largest allocation errors. Specifically, among all the river points allocated using Method 1 and having a CSI lower than 0.05, 80% have a basin area smaller than $9km^2$. Similarly, with Method 3, among all the river points with CSI scores lower than 0.6, 100% have a basin area lower than $25km^2$, and 92% have a basin area lower than $10km^2$.

The histogram comparison in Figure 10 highlights two important observations. Firstly, Method 3 effectively prevents the largest allocation errors generated by Method 1, that are shown by the blue bars on the left of the histograms. Secondly, these allocation errors predominantly occur for small catchment areas. For catchments larger than $100km^2$, CSI scores exceed 0.75 for both methods. Consequently, Method 1 can be considered a reliable method when applied to the main river network, which explains its widespread usage in previous studies : i.e. for almost all the studied watersheds, the minimum catchment size in

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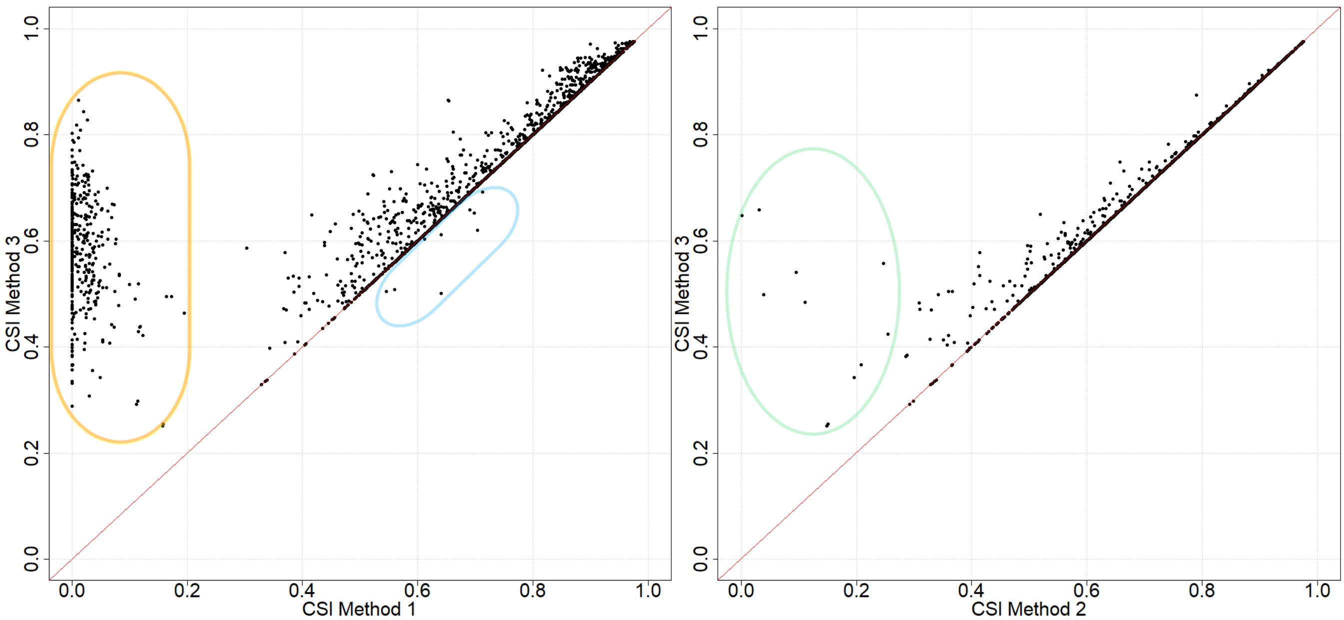

Figure 8. Comparison of CSI scores for each outlet, between Methods 3 and 1, and between Methods 3 and 2

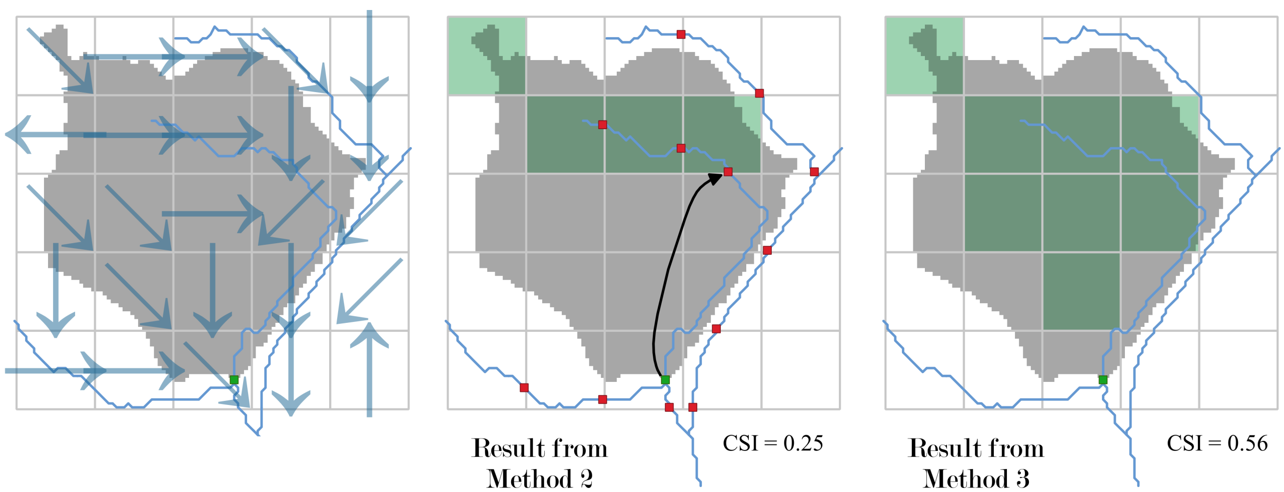

Figure 9. An example of high CSI differential between Methods 2 and 3 (basin area $12km^2$)

various previous research works is between 100 and $10,000$ km^2 (Fekete et al., 2002; Döll and Lehner, 2002; Sutanudjaja et al., 2018; Wang et al., 2018; Zhao et al., 2017; Burek et al., 2020; Polcher et al., 2022).

In addition, Figure 10 also confirms that, with Method 3, the lowest CSI scores are obtained for small catchments - the minimum CSI value is consistently higher than 0.7 for catchment sizes larger than $50km^2$. The low CSI values reflect the

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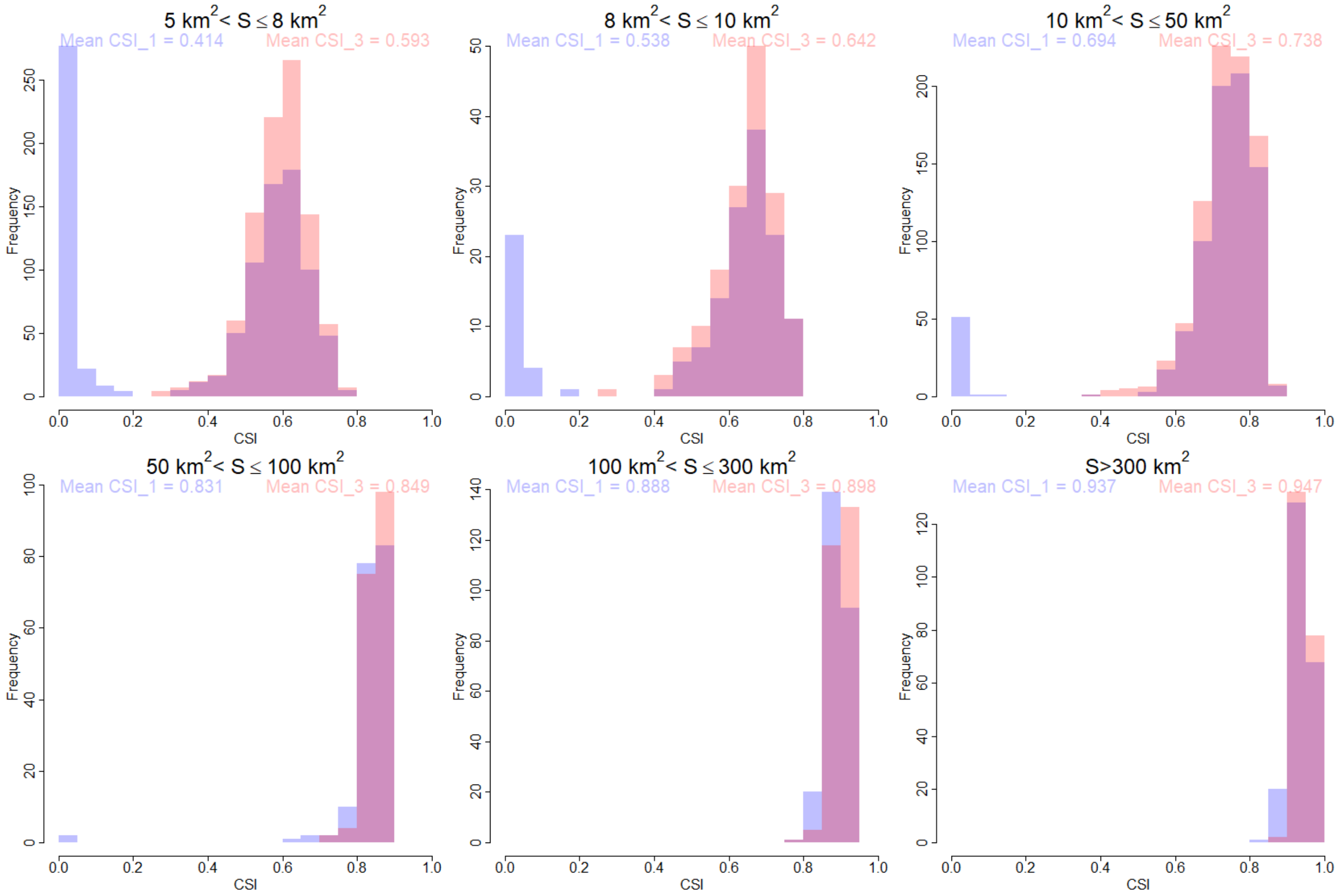

Figure 10. Histograms of CSI scores obtained from Method 1 (blue) and 3 (red) divided into classes of surfaces. The overlaying of both histograms gives pink.

uncertainties affecting the boundaries of small basins defined on a 1km resolution grid, particularly pronounced for narrow watersheds. However, it is important to note that the impact of low CSI scores on the representation of rainfall is relatively minor for small catchments compared to larger ones, because of the limited variability of rainfall at scales of the order of a square kilometre.

4.4 Discussions on the criterion conditioning Method 3 iteration

While Method 3 appears, without surprise, to be the most reliable, it has also some shortcomings. One is the limited search zone on the coarse-resolution hydrological grid. The current implementation first considers only the nine surrounding pixels and then extends the search area to forty-nine surrounding pixels under certain conditions. This approach was chosen to reduce the computation time, which is significantly longer for Method 3 compared to the other two methods. The criterion used for

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the second iteration depends on the catchment size, based on the assumption that the upstream drainage area (UPA) would influence the allocation results.

The second iteration of Method 3, is only activated for 70 outlets out of 2580. Extending the research area in the second iteration improved the allocation for only 10 out of these 70 outlets. However, the increase in CSI for these improved allocations was quite significant, with a median increase of 133%. Moreover, it is obvious on figure 8 that Method 3 does not lead to the optimal allocation in some rare cases : see the 9 cases the circled in blue. A visual analysis indicates that the search area composed of the 49 surrounding grid cells would have solved the problem, if the second iteration of Method 3 would have been activated. Increasing the threshold values for this activation to 0.55 (resp. 0.65) for catchment areas lower (resp. higher) than 10 km^2, would solve the problem encountered for these 9 points in the present case study, but at the cost of higher computing times : 353 points processed in the second iteration of method 3, instead of 70 for the initial theshold values.

5 Conclusions

This comparative study of methods allocating river points to coarse grid cells was driven by the shift in approach from area-based methods to contour-based methods. In this work, we compared these two method families and introduced a new method based on topological proximity.

The study results revealed that contour-based methods were more relevant and satisfying from a hydrological point of view, although costly in terms of computing time. The introduced topology-based method is a good compromise because it leads to similar quality than the contour-based method, however it has important disadvantages: it requires the definition of "cells outlet points" as well as the vector-based description of the river network, and it cannot allocate all the points. It was observed that the area-based method generated numerous allocation errors, which the contour-based method was able to address for a significant portion of them. However, upon closer examination, it was observed that the performance gap between both methods was more pronounced for small catchments, while being less significant for larger catchments (with $S > 100km^2$). The area based methods thus lead to satisfying results if we only consider river points with large UPAs compared to the grid cell resolution. Based on the results obtained, we would recommand a minimum factor of 100 between a river point's UPA and the resolution of the hydrological modelling grid for the application of an area-based method.

Low CSI scores will nevertheless remain with contour-based methods, due to the inherent difficulty of representing the boundaries of small basins at a 1km resolution. However, it is important to note that low CSI scores on small catchments are generally less problematic than low CSI scores on larger catchments, because of the more limited variability of rainfall at smaller spatial scales. An alternative approach that could circumvent the challenges faced is to use hydrological models structured based on vectorial objects instead of regular grids. These models preserve the topology of river networks and allow seamless integration of observational data. However, vector-based modeling also introduces its own challenges related to data and computational requirements and the need for accurate input data.

Code and data availability. All data and codes used for the production of the results were published on the french platform *recherche.data.gouv.fr*, DOI will be provided when the dataset is verified.

Author contributions. JG performed the computational work, helped by PN, and did most of the writing. PN, OP, EG and PJ supervised this work and reviewed the paper.

Competing interests. The authors declare that they have no conflict of interest.

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References

Bartholmes, J. C., Thielen, J., Ramos, M. H., and Gentilini, S.: The european flood alert system EFAS – Part 2: Statistical skill assessment of probabilistic and deterministic operational forecasts, Hydrology and Earth System Sciences, 13, 141–153, https://doi.org/10.5194/hess-13-141-2009, publisher: Copernicus GmbH, 2009.

Burek, P. and Smilovic, M.: The use of GRDC gauging stations for calibrating large-scale hydrological models, Earth System Science Data Discussions, pp. 1–18, https://doi.org/10.5194/essd-2022-231, publisher: Copernicus GmbH, 2022.

Burek, P., Satoh, Y., Kahil, T., Tang, T., Greve, P., Smilovic, M., Guillaumot, L., Zhao, F., and Wada, Y.: Development of the Community Water Model (CWatM v1.04) – a high-resolution hydrological model for global and regional assessment of integrated water resources management, Geoscientific Model Development, 13, 3267–3298, https://doi.org/10.5194/gmd-13-3267-2020, publisher: Copernicus GmbH, 2020.

Davies, H. and Bell, V.: Assessment of methods for extracting low-resolution river networks from high-resolution digital data, Hydrological Sciences Journal, 54, 17–28, https://doi.org/10.1623/hysj.54.1.17, 2009.

Dottori, F., Kalas, M., Salamon, P., Bianchi, A., Thielen Del Pozo, J., and Feyen, L.: A near real-time procedure for flood hazard mapping and risk assessment in Europe, http://89.31.100.18/~iahrpapers/85343.pdf, 2015.

Dottori, F., Kalas, M., Salamon, P., Bianchi, A., Alfieri, L., and Feyen, L.: An operational procedure for rapid flood risk assessment in Europe, Natural Hazards and Earth System Sciences, 17, 1111–1126, https://doi.org/10.5194/nhess-17-1111-2017, publisher: Copernicus GmbH, 2017.

Döll, P. and Lehner, B.: Validation of a new global 30-min drainage direction map, Journal of Hydrology, 258, 214–231, https://doi.org/10.1016/S0022-1694(01)00565-0, 2002.

Eilander, D., van Verseveld, W., Yamazaki, D., Weerts, A., Winsemius, H. C., and Ward, P. J.: A hydrography upscaling method for scale-invariant parametrization of distributed hydrological models, Hydrology and Earth System Sciences, 25, 5287–5313, https://doi.org/10.5194/hess-25-5287-2021, publisher: Copernicus GmbH, 2021.

Fekete, B. M., Vörösmarty, C. J., and Lammers, R. B.: Scaling gridded river networks for macroscale hydrology: Development, analysis, and control of error, Water Resources Research, 37, 1955–1967, https://doi.org/10.1029/2001WR900024, 2001.

Fekete, B. M., Vörösmarty, C. J., and Grabs, W.: High-resolution fields of global runoff combining observed river discharge and simulated water balances, Global Biogeochemical Cycles, 16, 15–1–15–10, https://doi.org/10.1029/1999GB001254, 2002.

Fleischmann, A., Paiva, R., and Collischonn, W.: Can regional to continental river hydrodynamic models be locally relevant? A cross-scale comparison, Journal of Hydrology X, 3, 100 027, https://doi.org/10.1016/j.hydroa.2019.100027, 2019.

Hocini, N., Payrastre, O., Bourgin, F., Gaume, E., Davy, P., Lague, D., Poinsignon, L., and Pons, F.: Performance of automated methods for flash flood inundation mapping: a comparison of a digital terrain model (DTM) filling and two hydrodynamic methods, Hydrology and Earth System Sciences, 25, 2979–2995, https://doi.org/10.5194/hess-25-2979-2021, publisher: Copernicus GmbH, 2021.

Lehner, B.: Derivation of watershed boundaries for GRDC gauging stations based on the HydroSHEDS drainage network - Technical Report prepared for the GRDC, Global Runoff Data Centre, Tech. rep., Koblenz, Germany, 2012.

Li, J. and Wong, D. W. S.: Effects of DEM sources on hydrologic applications, Computers, Environment and Urban Systems, 34, 251–261, https://doi.org/10.1016/j.compenvurbsys.2009.11.002, 2010.

Munier, S. and Decharme, B.: River network and hydro-geomorphological parameters at 1/12 resolution for global hydrological and climate studies, Earth System Science Data, 14, 2239–2258, https://doi.org/10.5194/essd-14-2239-2022, publisher: Copernicus GmbH, 2022.

https://doi.org/10.5194/hess-2023-165
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Olivera, F., Lear, M. S., Famiglietti, J. S., and Asante, K.: Extracting low-resolution river networks from high-resolution digital elevation models, Water Resources Research, 38, 13–1–13–8, https://doi.org/10.1029/2001WR000726, 2002.

Organde, D., Javelle, P., Ardilouze, C., and Lamblin, R.: Base nationale des bassins versants du SCHAPI, Tech. rep., 2013.

Paz, A. R., Collischonn, W., and Lopes da Silveira, A. L.: Improvements in large-scale drainage networks derived from digital elevation models, Water Resources Research, 42, https://doi.org/10.1029/2005WR004544, 2006.

Polcher, J., Schrapffer, A., Dupont, E., Rinchiuso, L., Zhou, X., Boucher, O., Mouche, E., Ottlé, C., and Servonnat, J.: Hydrological modelling on atmospheric grids; using graphs of sub-grid elements to transport energy and water, EGUsphere, pp. 1–34, https://doi.org/10.5194/egusphere-2022-690, publisher: Copernicus GmbH, 2022.

Reed, S. M.: Deriving flow directions for coarse-resolution (1–4 km) gridded hydrologic modeling, Water Resources Research, 39, https://doi.org/10.1029/2003WR001989, 2003.

Rezatofighi, H., Tsoi, N., Gwak, J., Sadeghian, A., Reid, I., and Savarese, S.: Generalized Intersection Over Union: A Metric and a Loss for Bounding Box Regression, in: 2019 IEEE/CVF Conference on Computer Vision and Pattern Recognition (CVPR), pp. 658–666, https://doi.org/10.1109/CVPR.2019.00075, iSSN: 2575-7075, 2019.

Sousa, T. M. I. and Paz, A. R.: How to evaluate the quality of coarse-resolution DEM-derived drainage networks, Hydrological Processes, 31, 3379–3395, https://doi.org/10.1002/hyp.11262, 2017.

Sutanudjaja, E. H., van Beek, R., Wanders, N., Wada, Y., Bosmans, J. H. C., Drost, N., van der Ent, R. J., de Graaf, I. E. M., Hoch, J. M., de Jong, K., Karssenberg, D., López López, P., Peßenteiner, S., Schmitz, O., Straatsma, M. W., Vannametee, E., Wisser, D., and Bierkens, M. F. P.: PCR-GLOBWB 2: a 5 arcmin global hydrological and water resources model, Geoscientific Model Development, 11, 2429–2453, https://doi.org/10.5194/gmd-11-2429-2018, publisher: Copernicus GmbH, 2018.

Tarboton, D. G.: A new method for the determination of flow directions and upslope areas in grid digital elevation models, Water Resources Research, 33, 309–319, https://doi.org/10.1029/96WR03137, 1997.

Thielen, J., Bartholmes, J., Ramos, M.-H., and de Roo, A.: The European Flood Alert System – Part 1: Concept and development, Hydrology and Earth System Sciences, 13, 125–140, https://doi.org/10.5194/hess-13-125-2009, publisher: Copernicus GmbH, 2009.

Wang, F., Polcher, J., Peylin, P., and Bastrikov, V.: Assimilation of river discharge in a land surface model to improve estimates of the continental water cycles, Hydrology and Earth System Sciences, 22, 3863–3882, https://doi.org/10.5194/hess-22-3863-2018, publisher: Copernicus GmbH, 2018.

Wu, H., Kimball, J. S., Mantua, N., and Stanford, J.: Automated upscaling of river networks for macroscale hydrological modeling, Water Resources Research, 47, https://doi.org/10.1029/2009WR008871, 2011.

Yamazaki, D., MASUTOMI, Y., OKI, T., and KANAE, S.: An Improved Upscaling Method to Construct a Global River Map, Beijing, 2008.

Zhao, F., Veldkamp, T. I. E., Frieler, K., Schewe, J., Ostberg, S., Willner, S., Schauberger, B., Gosling, S. N., Schmied, H. M., Portmann, F. T., Leng, G., Huang, M., Liu, X., Tang, Q., Hanasaki, N., Biemans, H., Gerten, D., Satoh, Y., Pokhrel, Y., Stacke, T., Ciais, P., Chang, J., Ducharne, A., Guimberteau, M., Wada, Y., Kim, H., and Yamazaki, D.: The critical role of the routing scheme in simulating peak river discharge in global hydrological models, Environmental Research Letters, 12, 075 003, https://doi.org/10.1088/1748-9326/aa7250, publisher: IOP Publishing, 2017.