Geosci. Model Dev., 19, 10887–10896, 2026
https://doi.org/10.5194/gmd-19-10887-2026
© Author(s) 2026. This work is distributed under
the Creative Commons Attribution 4.0 License.

Geoscientific Model Development
Open Access
EGU

SWORD-CTRIP mapping (SCM v1.0): a confidence-aware framework for mapping satellite-derived river reaches to gridded routing networks

Kaushlendra Verma and Simon Munier

CNRM, Université de Toulouse, Meteo-France, CNRS, Toulouse, France

Correspondence: Kaushlendra Verma (er.kaushlendrav@gmail.com) and Simon Munier (simon.munier@meteo.fr)

Received: 28 January 2026 – Discussion started: 5 February 2026
Revised: 18 October 2026 – Accepted: 3 November 2026 – Published: 16 November 2026

Abstract. The Surface Water and Ocean Topography (SWOT) mission provides reach-scale river observations referenced to the vector-based SWORD database. Linking these observations to gridded routing models such as CTRIP requires reconciling differences in river network representation. We present SCM v1.0, a global mapping framework that combines spatial intersection and MERIT Hydro-derived River information with a geometric scoring procedure based on proximity, reach length, and flow-direction alignment. Upstream-area mismatch is retained as a diagnostic and is not included in the weighted composite score. Single-reach cases are assigned directly, while multi-reach cases are resolved through minimum-score selection and classified using nominal High, Medium, and Low score thresholds. The archived classification convention is inconsistent with the score-minimization criterion; therefore, these labels should not be interpreted as calibrated assignment reliability. At $1/12°$ resolution, the final classified population comprises 123 998 CTRIP pixels, including 99 174 single-reach and 24 824 scored assignments. A MERIT-derived basin-hash diagnostic provides a qualitative check of basin-scale spatial organization but does not independently validate network connectivity. The resulting mapping products offer a reproducible basis for linking SWOT observations to CTRIP, while evaluation of network-level consistency and data-assimilation performance remains future work.

1 Introduction

The Surface Water and Ocean Topography (SWOT) mission delivers global, reach-scale observations of water surface elevation (WSE), facilitating the estimation of river discharge when combined with additional constraints such as water surface slope, channel geometry, and hydrological context (e.g., Biancamaria et al., 2016; Durand et al., 2016). These retrievals are spatially contextualized within the SWOT River Database (SWORD), which structures the global river network as a vector-based representation comprising reaches and nodes, each endowed with geometric, topological, and hydrological attributes (Altenau et al., 2021). These representations are specifically optimized for SWOT data retrieval and capture river morphology at sub-reach scales. In contrast, prevalent large-scale hydrological and river routing models such as CTRIP (Munier and Decharme, 2022a), CaMa-Flood (Yamazaki et al., 2011), LISFLOOD (Van Der Knijff et al., 2010), VIC (Lohmann et al., 1998), and mizuRoute (Mizukami et al., 2016), utilize gridded river networks, where river channels are implicitly represented by flow directions between discrete grid cells (O'Callaghan and Mark, 1984). Within these frameworks, water routing is typically performed through pixels guided by flow direction schemes derived from digital elevation models (Yamazaki et al., 2017). This fundamental divergence in structural representation between object-based observational datasets like SWORD and pixel-based modeling frameworks poses a significant challenge for the assimilation of SWOT-derived variables into river routing models. These representational discrepancies extend beyond mere spatial resolution differences, encompassing inconsis-

tencies in reach orientation, upstream drainage area attribution, stream order classification, and flow path topology. As demonstrated by recent studies (Godet et al., 2024; Wade et al., 2025), simplistic allocation strategies such as nearest-neighbor pixel assignment or direct upstream area matching can yield hydrologically implausible linkages, particularly within complex fluvial environments like confluences, braided river systems, or endorheic basins. Such misallocations can degrade the performance of data assimilation schemes, misrepresent underlying routing dynamics, and introduce biases in model-observation comparisons. Prior studies have explored diverse methodologies for linking observational features to model pixels, including Euclidean proximity, catchment overlap, and flowline-based matching (Döll and Lehner, 2002; Fekete et al., 2002; Munier and Decharme, 2022a). While effective within regional contexts, these approaches frequently lack robust generalization capabilities for global-scale applications and typically do not incorporate a quantitative assessment of match confidence or hydrological consistency. Moreover, existing solutions infrequently provide modular, open-source implementations conducive to large-scale deployment and enhanced reproducibility. Recent developments have also explored hybrid raster-vector representations and their application to large-scale hydrological and hydrodynamic modelling (Berkaoui et al., 2026; Shrestha et al., 2025). These studies further emphasize that preserving drainage consistency and network topology is essential when linking observations with numerical models, particularly within emerging modelling frameworks that couple hydrological and hydraulic processes, including differential approaches. This technical note introduces a novel, confidence-aware, global-scale framework for the unambiguous assignment of SWORD river reaches to CTRIP routing pixels, in order to prepare the assimilation of SWOT observations into the CTRIP-HyDAS (Hydrological Data Assimilation System) framework (Verma et al., 2026). The proposed methodology combines spatial intersection and MERIT-derived river-identity constraints with a geometric score based on reach–pixel distance, reach length, and flow-direction alignment. Upstream-area mismatch is retained as a diagnostic rather than included in the weighted score. Assignments are classified according to their selection pathway (single or scored), with multi-reach cases further subdivided into nominal High, Medium, and Low categories. These categories follow the archived score thresholds and are not calibrated measures of assignment reliability. The workflow is designed to operate independently within each Pfafstetter hydrological zone defined using the MERIT Hydro database (Yamazaki et al., 2019), thereby supporting regional reproducibility and generating standardized outputs amenable to both SWOT data assimilation and model benchmarking. Although demonstrated here for CTRIP routing network, the methodology is designed around generic geometry and hydrological consistency criteria and is therefore applicable to other gridded river routing models.

The remainder of this technical note is structured as follows: Section 2 outlines the input datasets and the overall framework architecture; Sect. 3 elaborates on the assignment logic, scoring metrics, and confidence classification schema; Sect. 4 presents global results and diagnostic analyses; Sect. 5 discusses the implications for SWOT data assimilation and outlines potential future extensions.

2 Datasets and Pipeline Overview

The SWORD-CTRIP mapping pipeline establishes a reconciliation between vector-based river observations and gridded routing models via a modular, zone-wise processing workflow. The mapping is performed on CTRIP routing grid at a spatial resolution of $1/12^\circ$ (approximately 10 km at equator). This spatial resolution directly influences the frequency of ambiguous reach-pixel configurations. Coarser routing grids generally increase the occurrence of multiple candidate reaches per pixel, whereas finer grids reduce ambiguity and support direct one-to-one assignments. The mapping integrates three primary geospatial datasets: SWORD v17b, representing reach geometry; CTRIP, serving as the gridded routing model framework; and MERIT Hydro, providing foundational drainage topology and spatial masks. A schematic overview of the pipeline architecture is presented in Fig. 1.

2.1 Input Datasets

The SWORD (Surface Water and Ocean Topography River Database, version 17b) product defines a global river network as a series of interconnected reaches and nodes, assembled by combining multiple global hydrography and satellite-related datasets into a coherent reach–node topology specifically designed for SWOT river observations (Altenau et al., 2021). Each reach is represented as a polyline and annotated with critical attributes including length, slope, stream order, width, and metadata pertaining to SWOT observability. For this study, only valid river reaches are retained, identified using SWORD attribute filters: type $= 1$ selects river reaches (excluding non-river features), lakeflag $= 0$ excludes lake-associated geometries, and stream_order $\neq -9999$ removes ghost or topologically unresolved reaches. This filtering ensures that only physically meaningful river centerlines are considered in the mapping. CTRIP is a global river routing model that operates on a structured grid (Decharme et al., 2019; Munier and Decharme, 2022a). At the $1/12^\circ$ resolution, each grid cell (pixel) is characterized by a centroid location, its upstream drainage area (denoted as dr_area), stream order, and a flow direction vector, typically employing a D8 scheme (e.g., O'Callaghan and Mark, 1984). CTRIP serves as the target domain for the mapping process; consequently, each routing pixel may intersect with zero, one, or multiple SWORD reaches, contingent upon network geom-

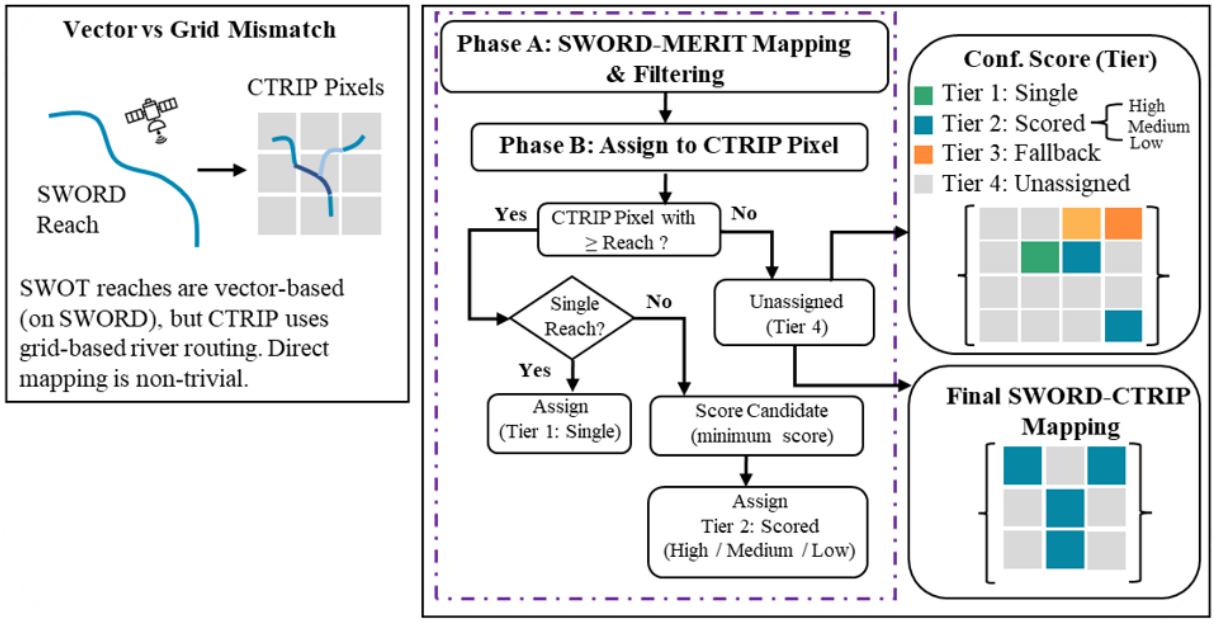


Figure 1. Conceptual overview of the SWORD–CTRIP mapping pipeline. (Left) SWORD represents river reaches as vector objects, whereas CTRIP uses a gridded river-routing network. (Centre) The workflow filters SWORD reaches using MERIT Hydro information and identifies candidate reach–pixel correspondences. Pixels with a single eligible reach are directly assigned (Tier 1), while multi-reach cases are resolved by minimum-score selection (Tier 2) and subdivided into nominal High, Medium, and Low categories. Pixels without an eligible assignment remain unassigned (Tier 4); the conceptual fallback category (Tier 3) is not used in the reported classified population. (Right) The resulting assignments are aggregated into global mapping products for subsequent analysis and potential hydrological data-assimilation applications.

etry and spatial data density. The primary objective of the pipeline is to identify the single most hydrologically consistent SWORD reach for each valid CTRIP pixel.

MERIT Hydro (Yamazaki et al., 2019) serves as the underlying topographic and hydrological reference dataset used by CTRIP. In this study, MERIT-derived upstream area (upa), flow-direction information, and basin identifiers (cl_ids) support reach filtering, river-identity constraints, and spatial consistency checks during assignment. These constraints help organize the mapping within the drainage network but do not explicitly enforce global downstream connectivity or mass conservation.

2.2 Pipeline Architecture

All mapping operations are conducted independently for each Pfafstetter hydrological zone, facilitating parallel processing and reproducibility. Although direct SWOT observations are not used in the assignment logic, the resulting mapping products establish spatial correspondences between SWORD reaches and CTRIP routing pixels. The procedure combines geometric criteria with MERIT-derived river information to provide a potential interface for integrating SWOT-derived observations into hydrological applications such as CTRIP-HyDAS (Verma et al., 2026). Network-level consistency and data-assimilation performance remain to be evaluated. The overall pipeline is structured into distinct, modular phases, with each phase operating on zone-specific inputs and yielding standardized outputs:

- Phase A – SWORD-MERIT filtering: Initial preprocessing step in which SWORD reaches are filtered to retain only valid river geometries consistent with the target hydrological domain. This phase removes non-river features, lake-associated reaches, topologically undefined or invalid reaches, and SWORD reaches that fall outside the MERIT Hydro basin masks used by CTRIP, ensuring that only physically meaningful and domain-consistent reaches enter the subsequent assignment stages.
- Phase B – Reach assignment and scoring: Assignment of SWORD reaches to CTRIP pixels based on intersection criteria and multi-metric scoring, coupled with the application of confidence tiers.
- Phase C – Fallback category (reserved): A conceptual category for assignments requiring relaxed selection criteria. No such fallback assignments are reported in the archived classified mapping results, and the reviewed selection procedure does not implement the previously described relaxed fallback logic.
- Phase Z – Global aggregation: Consolidation of zonal results into unified global outputs in CSV, NetCDF, and visualization formats.

All input and output data are managed using open, standard formats (e.g., shapefiles, CSV, NetCDF), and the entire pipeline is architected for reproducibility and amenability to extension for use with other grid or vector products or models.

3 Assignment Methodology

The assignment logic delineates the process for identifying the SWORD reach most consistent with each CTRIP routing pixel. This process is a critical prerequisite for accurately mapping SWOT-derived observations to hydrological model states. The methodology is structured around three primary steps: candidate identification via spatial intersection, multi-metric scoring for ambiguous cases, and confidence tier classification. Each CTRIP pixel is represented by a fixed-area grid cell. The initial step identifies all SWORD reaches whose polyline geometries intersect this cell using spatial overlay operations. This leads to three distinct scenarios:

i. Single Intersecting Reach: If exactly one SWORD reach intersects the CTRIP pixel, it is assigned directly. This represents the most unambiguous case and is classified as Tier 1.

ii. Multiple Intersecting Reaches: If two or more reaches intersect the CTRIP pixel, a geometric scoring procedure ranks the candidates and selects the minimum-score reach. These assignments are classified as Tier 2 and subdivided into nominal High, Medium, and Low categories.

iii. No Intersecting Reach: If no eligible SWORD reach is identified for a CTRIP pixel, it remains unassigned (Tier 4). No additional reach is selected through the relaxed fallback procedure previously described in Tier 3.

For CTRIP pixels intersected by multiple SWORD reaches, candidate selection is based on three geometric metrics: angular difference, reach length, and distance to pixel centre. Upstream-area mismatch is additionally calculated as a diagnostic but is not included in the composite score (Table 1).

The upstream-area consistency metric A is computed by comparing MERIT Hydro upstream area and CTRIP pixel drainage area at the candidate reach location. Specifically, $\mathrm{UPA_{MERIT}}$ is obtained by sampling the MERIT upstream area field (upa) in a local window centered on the SWORD reach coordinate, while $\mathrm{dr_area_{CTRIP}}$ is obtained by sampling the CTRIP drainage-area field (dr_area converted from $\mathrm{m^2}$ to $\mathrm{km^2}$) at the same location. The mismatch is defined as $A = \mid \mathrm{UPA_{MERIT}} - \mathrm{dr_area_{CTRIP}} \mid / \mathrm{dr_area_{CTRIP}}$, and A is set to NaN when $\mathrm{dr_area_{CTRIP}} \leq 0$ to avoid numerical instability in near-zero headwater pixels. River identifiers (MERIT_river_id) are used to restrict candidate CTRIP pixels during the assignment step, but are not used in the computation of A. This metric is retained for diagnostic assessment of upstream-area agreement and does not contribute to the weighted composite score or impose an additional area-mismatch rejection threshold in the reviewed scoring stage.

For pixels intersected by multiple SWORD reaches, candidate reaches are ranked using a weighted geometric score. Let Θ_i denote the angular difference between the SWORD reach orientation and CTRIP flow direction, L_i the reach length, and d_i the distance from the reach to the CTRIP pixel centre. The three components are calculated as follows:

$$\Theta_{\mathrm{norm},i} = 1 - \cos(\Theta_i)$$
$$L_{\mathrm{norm},i} = 1 - \mathrm{Norm}(L_i)$$
$$D_{\mathrm{norm},i} = 1 - \mathrm{Norm}\left(\frac{1}{d_i + 0.01}\right).$$

Here Θ_i is expressed in radians when evaluated by the cosine function, and d_i is expressed in kilometres. The normalized function Norm clips values at the 1st and 99th percentiles and then applies min–max scaling. In the archived code, this normalization is performed over the scored candidate records within each processed Pfafstetter zone, rather than separately for each pixel. The composite score S_i is computed for each candidate i and used to rank the candidates as follows:

$$S_i = \omega_\Theta \Theta_{\mathrm{norm},i} + \omega_\mathrm{L} L_{\mathrm{norm},i} + \omega_\mathrm{D} D_{\mathrm{norm},i}$$

where $\omega_\Theta + \omega_\mathrm{L} + \omega_\mathrm{D} = 1$, and $\omega_\Theta, \omega_\mathrm{L}, \omega_\mathrm{D} \geq 0$. The three weights are non-negative and sum to unity. For each pixel, the candidate with the lowest score is selected. Lower scores therefore indicate a better geometric match according to the implemented ranking criterion. Upstream-area mismatch is not included in this weighted score.

Rather than prescribing a single global set of weights, the relative contributions of distance, reach length, and angular alignment are determined empirically for each Pfafstetter zone. The archived procedure evaluates 66 combinations of three non-negative weights, incremented by 0.1 and summing to unity. For each combination, candidate records are classified using the raw composite-score thresholds $S \geq 0.8$ (High), $0.5 \leq S < 0.8$ (Medium), and $S < 0.5$ (Low). The weight combination maximizing the number of nominal High candidate records is selected. The resulting zone-specific weights are reported in Table S1 in the Supplement.

The selected weights vary across Pfafstetter zones, reflecting differences in the candidate-score distributions. Zero weights indicate that the corresponding metrics were not selected by the zone-specific optimization, rather than their exclusion from the overall framework. Since the optimization is based on internal score thresholds rather than independently verified reach-pixel correspondences, it does not establish assignment accuracy or robustness to alternative weighting configurations.

Table 1. Metrics used to assess candidate SWORD reaches for multi-reach CTRIP pixels. Distance, reach length, and angular difference contribute to the weighted geometric mismatch score, whereas upstream-area mismatch is retained as a diagnostic.

Metric	Description	Role in candidate assessment
D	Great-circle distance (km) between the CTRIP pixel centre and the SWORD reach centroid.	Scoring component; smaller distances favour reaches closer to the pixel centre.
L	SWORD reach length (km, where available from the source geometry)	Scoring component; longer reaches are favoured through the normalized length penalty.
A	Fractional absolute difference between MERIT Hydro upstream area and CTRIP drainage area.	Diagnostic of upstream-area agreement; not included in the weighted composite score.
Θ	Absolute angular difference (degrees) between SWORD reach orientation and CTRIP D8 flow direction.	Scoring component; smaller angular differences favour better directional agreement.

Table 2. Assignment-tier classification scheme for SWORD-CTRIP mapping.

Tier	Label	Assignment Logic
1	Single	Exactly one candidate reach; directly assigned
2	Scored	Multiple candidate reaches; minimum-score candidate selected and assigned a nominal High, Medium, or Low category
3	Fallback	Reserved fallback category; no assignment reported in the final classified population
4	Unassigned	No classified reach assignment

After weight optimization, the candidate with the minimum composite score is selected for each multi-reach pixel. The final High, Medium, and Low categories are assigned using the same raw-score threshold applied during optimization: $S \geq 0.8$ (High), $0.5 \leq S < 0.8$ (Medium), and $S < 0.5$ (Low). Single-reach assignments are classified separately. Although inverse-score confidence variables are also calculated in the archived code, they are not used to determine the final categories. Consequently, lower scores are preferred during candidate selection, whereas higher raw scores receive higher nominal category labels. The inconsistency is retained to preserve reproducibility of the archived SCM v1.0 product. The reported categories should therefore be interpreted as nominal algorithm-defined classes, not calibrated measures of assignment reliability.

The assignment outcomes are organized into four tiers according to the selection procedure (Table 2). Multi-reach assignments are additionally subdivided into nominal High, Medium, and Low score categories.

The archived implementation applies a spatial co-ordinate tolerance of $0.9 \times (1/12°) = 0.075°$ when identifying candidate CTRIP pixels associated with the mapped MERIT river identifier. For single-reach cases, a minimum stored reach-length value of 1 is applied, although its physical interpretation depends on the source representation. For multi-reach cases, candidates with missing required geometric metrics are excluded before scoring. Angular differences greater than 90° are flagged diagnostically, but no separate maximum angular-difference or upstream-area-mismatch thresholds are imposed in the reviewed scoring stage. The minimum-score candidate is selected for each scored multi-reach pixel. Although a fallback tier is included in the conceptual classification scheme, the reviewed selection procedure does not implement the previously described relaxed selection based on reach length or SWOT observability. Accordingly, no Tier 3 assignments are reported in the final classified population. Assignment categories are stored with the selected reach identifiers to support subsequent analysis, but their interpretation as quantitative reliability measures requires independent validation.

The pipeline generates a suite of standardized outputs designed for direct use in downstream applications. These include: (i) CSV files detailing per-pixel assignments, all scoring metrics, and final confidence tier labels; (ii) NetCDF grids containing the assigned reach identifiers and confidence tiers for efficient spatial analysis; and (iii) a series of diagnostic plots summarizing metric distributions and overall mapping performance. These outputs support mapping diagnostics, visualization, and potential integration into hydrological data-assimilation systems such as CTRIP-HyDAS, subject to further evaluation of assignment uncertainty.

4 Results and Evaluation

This section presents the global SWORD-CTRIP mapping results, focusing on the spatial distribution of assignments, nominal score categories, and basin-scale consistency diagnostics. Figure 2 summarizes the global SWORD-CTRIP assignment results. The CTRIP land/river-routing domain com-

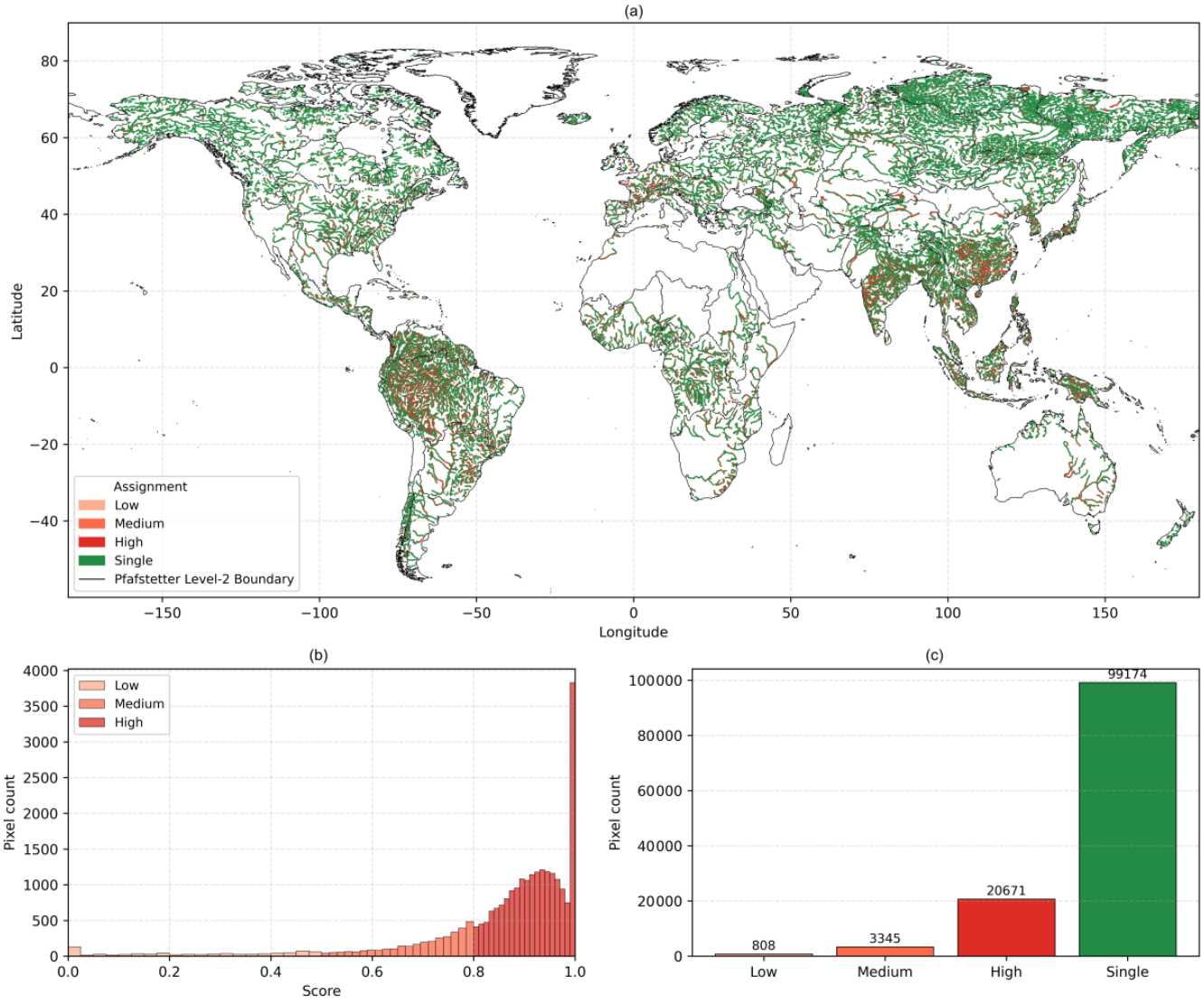


Figure 2. Global distribution of SWORD-CTRIP assignment categories and composite scores. **(a)** Spatial distribution of Single, nominal High, Medium, and Low assignments. **(b)** Composite-score distribution for multi-reach assignments. **(c)** Number of classified CTRIP pixels in each assignment category (total: 123 998). The nominal score categories are defined by the archived classification thresholds and do not represent independently calibrated assignment reliability. SWORD data courtesy of SWORD. CTRIP data courtesy of CTRIP. MERIT Hydro data courtesy of MERIT Hydro.

prises 2 213 485 pixels at 1/12° spatial resolution, of which 123 998 (5.60 %) belong to the final classified-assignment population. The remaining 2 089 487 pixels are outside the population and should not be interpreted solely as unsuccessful matches, since not all CTRIP routing pixels necessarily have a corresponding SWORD reach. Figure 2a shows the spatial distribution of assignment categories. Single-reach assignments dominate, accounting for 79.98 % of classified pixels, while the remaining 20.02 % are resolved through multi-reach scoring. These cases are particularly relevant in complex river environments, including braided channels and deltas, where several SWORD reaches may intersect the same CTRIP pixel. Figure 2b presents the composite-score distribution for scored assignments. As discussed in Sect. 3, the High, Medium, and Low labels represent nominal categories defined by the archived scoring implementation and should not be interpreted as calibrated assignment reliability. Figure 2c reports the corresponding pixel counts, summarized in Table 3. Representative pixel-scale examples are provided in Fig. S1 in the Supplement. These examples illustrate how the scoring framework resolves ambiguity in multi-reach pixels and how assignments behave in structurally complex regions such as braided or deltaic systems.

Although the methodology is not tied to a specific grid resolution, its behavior depends on the relative scale of the routing grid and the underlying river network. At coarser res-

Table 3. Global distribution of classified SWORD–CTRIP pixel assignments by assignment tier and nominal score category. Percentages are calculated relative to the 123 998 classified pixels reported in Fig. 2c; CTRIP pixels outside this population are excluded.

Tier	Subclass	Description	Pixel Count	Percentage
1	Single	Single intersecting reach; directly assigned	99 174	79.98 %
2	Nominal High	Multi-reach assignment; raw score ≥ 0.8	20 671	16.67 %
2	Nominal Medium	Multi-reach assignment; $0.5 \leq$ raw score < 0.8	3345	2.70 %
2	Nominal Low	Multi-reach assignment; raw score < 0.5	808	0.65 %
3	Fallback	Assignment through fallback procedure, none reported	0	0.00 %
Total			123 998	100.00 %

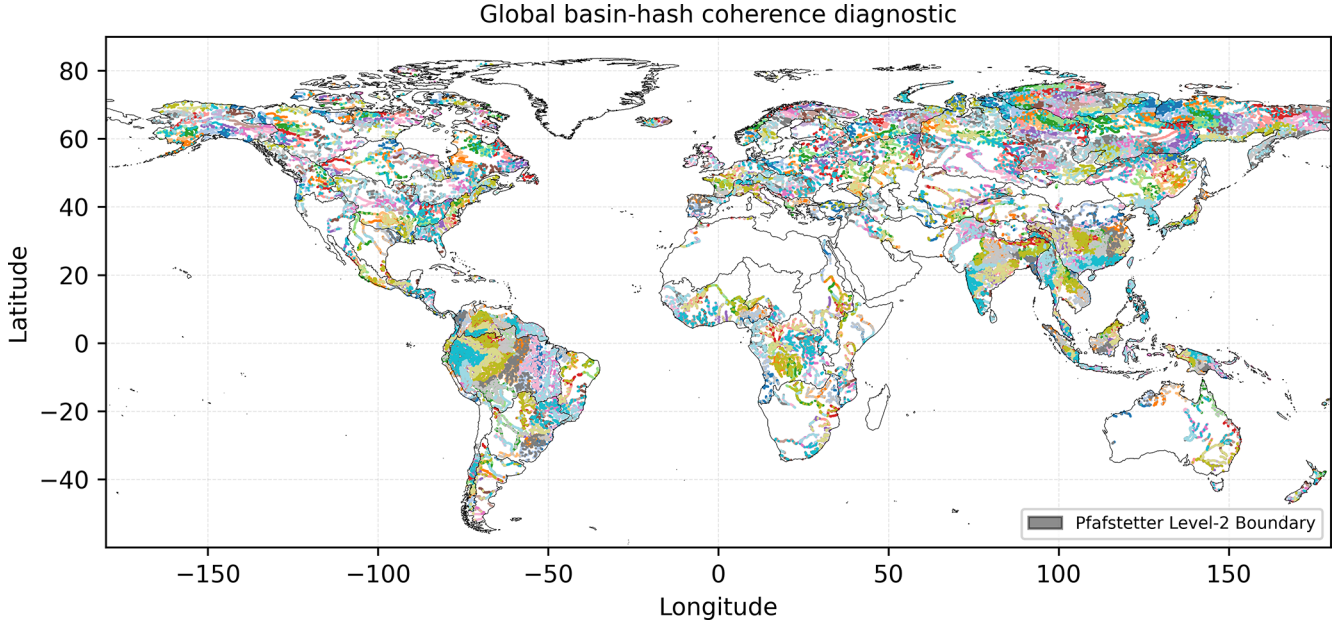


Figure 3. Basin-hash spatial-coherence diagnostic for the SWORD–CTRIP mapping. CTRIP pixels are colored according to the basin hash inherited from their assigned SWORD reach, derived from MERIT Hydro drainage information. Gray lines indicate Pfafstetter Level-2 boundaries. The broad organization of basin-hash patterns across major river basins provides an a posteriori consistency check of basin-scale spatial structure, but does not independently validate individual assignments or demonstrate downstream continuity or mass conservation. SWORD data courtesy of SWORD. CTRIP data courtesy of CTRIP. MERIT Hydro data courtesy of MERIT Hydro.

olutions, multiple SWORD reaches are more likely to intersect a given pixel, increasing the importance of the scoring framework. At finer resolutions, ambiguity is reduced and assignments are more frequently resolved through direct intersection (Tier 1). This scaling behavior reflects the geometric nature of the problem rather than a limitation of the method. Future work could explicitly quantify this sensitivity by comparing assignment statistics across multiple grid resolutions.

To complement the assignment-category and score statistics, Fig. 3 presents an a posteriori diagnostic of basin-scale spatial coherence based on the basin hashes associated with assigned SWORD reaches. The resulting spatial patterns broadly follow major drainage basins and Pfafstetter Level-2 boundaries, including the Amazon, Congo, and Nile basins. However, because the basin hashes are derived from MERIT Hydro, which is also used in the mapping procedure, this analysis is not an independent validation. It provides a qualitative consistency check of basin-scale organization but does not establish the correctness of individual reach–pixel assignments, downstream continuity, or mass conservation. Explicit evaluation of network connectivity remains necessary for these purposes.

The mapping framework establishes a geometric correspondence between SWORD reaches and CTRIP routing pixels but does not impose global network-connectivity, downstream-continuity, or mass-conservation constraints. Flow-direction alignment contributes to the geometric score, while upstream-area mismatch is retained as a diagnostic. Consequently, the mapped reach locations provide a potential interface for hydrological applications, but their network-level consistency and effects on model simulations require further evaluation. An additional audit of the archived per-

zone selected-assignment records was performed to examine repeated reach identifiers. Among 124 009 unique SWORD reach–pixel pairs, no SWORD reach was associated with more than one CTRIP pixel. However, two of the 124 007 distinct pixel locations were associated with two different selected reaches. The finalization procedure stores one reach identifier per pixel location, resolving such pixel-level conflicts in the output structure. These statistics describe the archived selected-assignment records and were not independently verified against the final global NetCDF. Although no repeated reach-to-pixel assignments were identified in this audit, the mapping procedure does not explicitly enforce global reach uniqueness.

5 Conclusion

This study introduced the SWORD-CTRIP mapping framework (SCM v1.0) to establish spatial correspondences between vector-based SWORD river reaches and the gridded CTRIP river-routing network. The framework combines spatial intersection and MERIT-derived river information with geometric scoring based on distance, reach length, and flow-direction alignment. At $1/12^\circ$ resolution, the final classified population comprises 123 998 CTRIP pixels, including 99 174 single-reach assignments (79.98 %) and 24 824 multi-reach assignments (20.02 %). The latter are resolved through minimum-score selection and subdivided into nominal High, Medium, and Low categories. Because the archived category thresholds are not consistent with the score-minimization criterion, these labels should not be interpreted as calibrated measures of assignment reliability. The framework provides a reproducible basis for linking SWORD reaches to CTRIP pixels, while independent evaluation of assignment accuracy remains necessary.

The mapping addresses structural correspondence between vector-based observations and gridded routing representations but does not provide a calibrated estimate of assignment uncertainty. Other uncertainty sources, including SWOT measurement errors, discharge retrieval uncertainty, and routing discretization errors, remain outside the scope of this study. The mapping outputs could potentially support observation screening, observation-error inflation, or adaptive localization in hydrological data-assimilation systems such as CTRIP-HyDAS. However, these applications have not been implemented or evaluated here. Quantifying assignment uncertainty and assessing its effects on assimilation performance will require independently verified reach–pixel correspondences and dedicated data-assimilation experiments.

The MERIT-derived basin-hash diagnostic provides an a posteriori consistency check of basin-scale spatial organization, but not an independent validation of hydrological connectivity. The observed spatial patterns do not establish downstream continuity or mass conservation, which require explicit network-level evaluation. Future developments could incorporate stream-order constraints, reach-level observability, and additional hydrological descriptors, alongside independent assessment of reach–pixel correspondence and network consistency. Although demonstrated for CTRIP, the general approach could be adapted to other gridded routing networks or extended to vector-based routing representations. The archived SCM v1.0 products and processing scripts provide a reproducible starting point for these developments.

Code and data availability. The complete SWORD-CTRIP mapping (SCM v1.0) pipeline, encompassing all processing scripts (Phases A–Z), scoring utilities, and diagnostic plotting tools, is openly accessible via Zenodo archive (https://doi.org/10.5281/zenodo.18402332) (Verma and Munier, 2026). This repository contains example input data, structured output files, and a comprehensive quick-start guide specifically designed for reproducing the primary assignments and diagnostics presented in this study. The SWORD v17b reach shapefiles and NetCDF products are accessible through the SWOT data portal (https://www.swordexplorer.com/, last access: 28 May 2025), with a persistent DOI provided as https://doi.org/10.5281/zenodo.15299138 (Altenau et al., 2025). The MERIT Hydro dataset is publicly available, as described by Yamazaki et al. (2019), and can be accessed at https://hydro.iis.u-tokyo.ac.jp/~yamadai/MERIT_Hydro/ (last access: 28 May 2025). The CTRIP model grid and associated river routing data are fully described in Munier and Decharme (2022a) and accessible at https://doi.org/10.5281/zenodo.6482906 (Munier and Decharme, 2022b). The derived assignment products, including final reach–pixel matches, confidence tiers, and diagnostic datasets, are provided via Zenodo archive (https://doi.org/10.5281/zenodo.18402332) (Verma and Munier, 2026) to ensure long-term accessibility and reproducibility.

Supplement. The supplement related to this article is available online at https://doi.org/10.5194/gmd-19-10887-2026-supplement.

Author contributions. KV and SM contributed equally to the conceptualization and design of the study, methodological development, data analysis, interpretation of results, and manuscript preparation. Both authors contributed to the development and evaluation of the mapping framework, reviewed and revised the manuscript, and approved the final version.

Competing interests. The contact author has declared that neither of the authors has any competing interests.

Disclaimer. Publisher's note: Copernicus Publications remains neutral with regard to jurisdictional claims made in the text, published maps, institutional affiliations, or any other geographical representation in this paper. The authors bear the ultimate responsibility for providing appropriate place names. Views expressed in the

text are those of the authors and do not necessarily reflect the views of the publisher.

Acknowledgements. The authors acknowledge the teams responsible for the development and maintenance of the SWOT River Database (SWORD), the MERIT Hydro dataset, and the CTRIP river-routing framework. The authors also acknowledge the institutional research support provided by the Centre National de Recherches Météorologiques (CNRM), Météo-France, and CNRS.

Review statement. This paper was edited by Thomas B. Wild and reviewed by two anonymous referees.

References

Altenau, E. H., Pavelsky, T. M., Durand, M. T., Yang, X., Frasson, R. P. D. M., and Bendezu, L.: The Surface Water and Ocean Topography (SWOT) Mission River Database (SWORD): A Global River Network for Satellite Data Products, Water Resour. Res., 57, e2021WR030054, https://doi.org/10.1029/2021WR030054, 2021.

Altenau, E. H., Pavelsky, T. M., Durand, M. T., Yang, X., Frasson, R. P. D. M., and Bendezu, L.: SWOT River Database (SWORD) (Version v17b) [Dataset], Zenodo [data set], https://doi.org/10.5281/zenodo.15299138, 2025.

Berkaoui, M. A., Saadi, M., Colleoni, F., Huynh, N. N. T., Akhtari, A., Larnier, K., Roux, H., and Garambois, P.-A.: A Raster–Vector Framework for Multi-Scale Hydrological–Hydraulic Modeling Across Large Domains, EGUsphere [preprint], https://doi.org/10.5194/egusphere-2026-1557, 2026.

Biancamaria, S., Lettenmaier, D. P., and Pavelsky, T. M.: The SWOT Mission and Its Capabilities for Land Hydrology, Surv. Geophys., 37, 307–337, https://doi.org/10.1007/s10712-015-9346-y, 2016.

Decharme, B., Delire, C., Minvielle, M., Colin, J., Vergnes, J.-P., Alias, A., Saint-Martin, D., Séférian, R., Sénési, S., and Voldoire, A.: Recent changes in the ISBA-CTRIP land surface system for use in the CNRM-CM6 climate model and in global off-line hydrological applications, J. Adv. Model. Earth Syst., 11, 1207–1252, https://doi.org/10.1029/2018MS001545, 2019.

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

Durand, M., Gleason, C. J., Garambois, P. A., Bjerklie, D., Smith, L. C., Roux, H., Rodriguez, E., Bates, P. D., Pavelsky, T. M., Monnier, J., Chen, X., Di Baldassarre, G., Fiset, J.-M., Flipo, N., Frasson, R. P. D. M., Fulton, J., Goutal, N., Hossain, F., Humphries, E., Minear, J. T., Mukolwe, M. M., Neal, J. C., Ricci, S., Sanders, B. F., Schumann, G., Schubert, J. E., and Vilmin, L.: An intercomparison of remote sensing river discharge estimation algorithms from measurements of river height, width, and slope, Water Resour. Res., 52, 4527–4549, https://doi.org/10.1002/2015WR018434, 2016.

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

Godet, J., Gaume, E., Javelle, P., Nicolle, P., and Payrastre, O.: Technical note: Comparing three different methods for allocating river points to coarse-resolution hydrological modelling grid cells, Hydrol. Earth Syst. Sci., 28, 1403–1413, https://doi.org/10.5194/hess-28-1403-2024, 2024.

Lohmann, D., Raschke, E., Nijssen, B., and Lettenmaier, D. P.: Regional scale hydrology: I. Formulation of the VIC-2 L model coupled to a routing model, Hydrolog. Sci. J., 43, 131–141, https://doi.org/10.1080/02626669809492107, 1998.

Mizukami, N., Clark, M. P., Sampson, K., Nijssen, B., Mao, Y., McMillan, H., Viger, R. J., Markstrom, S. L., Hay, L. E., Woods, R., Arnold, J. R., and Brekke, L. D.: mizuRoute version 1: a river network routing tool for a continental domain water resources applications, Geosci. Model Dev., 9, 2223–2238, https://doi.org/10.5194/gmd-9-2223-2016, 2016.

Munier, S. and Decharme, B.: River network and hydrogeomorphological parameters at 1/12°resolution for global hydrological and climate studies, Earth Syst. Sci. Data, 14, 2239–2258, https://doi.org/10.5194/essd-14-2239-2022, 2022a.

Munier, S. and Decharme, B.: River network and hydrogeomorphological parameters at 1/12° resolution for global hydrological and climate studies (Version 1.1.3) [Dataset], Zenodo [data set], https://doi.org/10.5281/zenodo.6482906, 2022b.

O'Callaghan, J. F. and Mark, D. M.: The extraction of drainage networks from digital elevation data, Comput. Vision Graph., 28, 323–344, https://doi.org/10.1016/S0734-189X(84)80011-0, 1984.

Shrestha, P. K., Samaniego, L., Rakovec, O., Kumar, R., and Thober, S.: A Novel Stream Network Upscaling Scheme for Accurate Local Streamflow Simulations in Gridded Global Hydrological Models, Water Resour. Res., 61, e2024WR038183, https://doi.org/10.1029/2024WR038183, 2025.

Van Der Knijff, J. M., Younis, J., and De Roo, A. P. J.: LISFLOOD: a GIS-based distributed model for river basin scale water balance and flood simulation, Int. J. Geogr. Inf. Sci., 24, 189–212, https://doi.org/10.1080/13658810802549154, 2010.

Verma, K. and Munier, S.: SWORD-CTRIP Mapping (SCM v1.0): A Confidence-Aware Framework for Mapping Satellite-Derived River Reaches to Gridded Routing Networks (Version SCM v1.0) [Software], Zenodo [code], https://doi.org/10.5281/zenodo.18402332, 2026.

Verma, K., Munier, S., Boone, A., and Le Moigne, P.: CTRIP-HyDAS: A Global-Scale Data Assimilation Framework for SWOT-Derived Discharge using Synthetic Observations at High Resolution (1/12°), Water Resour. Res., https://doi.org/10.1029/2025WR040888, 2026.

Wade, J., David, C. H., Altenau, E. H., Collins, E. L., Oubanas, H., Coss, S., Cerbelaud, A., Tom, M., Durand, M., and Pavelsky, T. M.: Bidirectional Translations Between Observational and Topography-Based Hydrographic Data Sets: MERIT-Basins and the SWOT River Database (SWORD), Water Resour. Res., 61, e2024WR038633, https://doi.org/10.1029/2024WR038633, 2025.

Yamazaki, D., Kanae, S., Kim, H., and Oki, T.: A physically based description of floodplain inundation dynamics in a global river routing model, Water Resour. Res., 47, https://doi.org/10.1029/2010WR009726, 2011.

Yamazaki, D., Ikeshima, D., Tawatari, R., Yamaguchi, T., O'Loughlin, F., Neal, J. C., Sampson, C. C., Kanae, S., and Bates, P. D.: A high-accuracy map of global terrain elevations, Geophys. Res. Lett., 44, 5844–5853, https://doi.org/10.1002/2017GL072874, 2017.

Yamazaki, D., Ikeshima, D., Sosa, J., Bates, P. D., Allen, G. H., and Pavelsky, T. M.: MERIT Hydro: A High-Resolution Global Hydrography Map Based on Latest Topography Dataset, Water Resour. Res., 55, 5053–5073, https://doi.org/10.1029/2019WR024873, 2019.