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SWOT Explorer: A browser extension for searching, previewing, clipping and quality-controlling SWOT satellite hydrology data

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Abstract

The Surface Water and Ocean Topography (SWOT) satellite measures the elevation and extent of rivers, lakes and reservoirs worldwide. Its river and lake products are distributed as one continent-wide file per satellite pass, so studying a single water body means downloading, unzipping and clipping many files with scripts or GIS software. SWOT Explorer is an open-source extension for Chrome and Edge that does this work in the browser, with no server. It finds the passes that really observe a user-drawn study area, previews the measured features on a map, clips and merges files, and builds quality-controlled time series of water level, area and storage change. It grades the reliability of each series and compares SWOT with gauge records and independent altimetry. An example on Blue Nile reservoirs shows the tool separating a consistent series from one that should not be trusted.

Keywords: SWOT; satellite altimetry; surface water; reservoirs; quality control; browser extension

Metadata

Table 1. Code metadata.

Nr.	Code metadata description	Metadata
C1	Current code version	v0.1.0
C2	Permanent link to code/repository used for this code version	https://github.com/Osman-Geomatics93/swot-explorer (archived at https://doi.org/10.5281/zenodo.24144883)
C3	Permanent link to reproducible capsule	None
C4	Legal code license	MIT
C5	Code versioning system used	git
C6	Software code languages, tools and services used	TypeScript, React, WXT (Manifest V3), MapLibre GL JS, Turf.js, Apache ECharts, Dexie (IndexedDB), Zod, Vitest; Python for auxiliary scripts. Services: NASA Common Metadata Repository, Hydrocron, Earthdata Login and the PO.DAAC archive; DAHITI and Hydroweb.
C7	Compilation requirements, operating environments and dependencies	Node.js (developed with version 24) and pnpm to build. Runs in Google Chrome or Microsoft Edge. A free NASA Earthdata Login account is needed to download files.
C8	Link to developer documentation/manual	https://github.com/Osman-Geomatics93/swot-explorer#readme and docs/api-notes.md in the repository
C9	Support email for questions	osmangeomatics93@gmail.com

1. Motivation and significance

The Surface Water and Ocean Topography (SWOT) mission, launched in December 2022 by NASA and CNES, carries a wide-swath radar interferometer that measures water surface elevation and extent over two swaths instead of along a single track [1]. Since July 2023 it has flown a 21-day repeat orbit and observes rivers wider than about 100 m and lakes larger than about 250 m by 250 m across most of the globe [2]. For basins where in-situ records are sparse or not shared between countries, this is a new and independent source of water level information.

Getting an answer from the data is harder than the mission's open-data policy suggests. The lake and river vector products [3,4] are distributed by NASA's Physical Oceanography Distributed Active Archive Center (PO.DAAC) as one zipped shapefile per satellite pass and continent. Three practical problems follow.

1. **Search returns passes that never see the study area.** The catalogue footprint of a continental file is a continent-wide box, so a spatial query matches every pass over the continent. In a test over the Grand Ethiopian Renaissance Dam (GERD) reservoir for October 2025, the catalogue returned 27 lake granules; only 5 came from passes that observe the reservoir, and 4 more were reprocessed duplicates.
2. **Each file must be downloaded, unzipped and clipped.** High-rate products have no server-side subsetting service, so the user keeps a continental file to use a few features from it. Building a time series for one reservoir repeats this for dozens of passes.
3. **Quality information is easy to miss.** Unobserved features carry fill values, the same pass can appear twice after reprocessing, and quality flags and uncertainties must be applied before a value is used. Section 3 shows a reservoir where even flagged-good values disagree by several metres.

Existing access routes address parts of this. NASA Earthdata Search [5] finds and downloads whole granules through a web interface. The PO.DAAC data subscriber [6] and the `earthaccess` library [7] automate downloads from the command line or Python. Hydrocron [8] returns time series for a river reach, node or lake without any file download, but the user must already know the feature identifier and must handle fill values, duplicate rows and quality flags. All of these either deliver whole files or assume programming skills, and none of them tells the user whether a resulting series is trustworthy.

SWOT Explorer fills this gap for hydrologists, water managers and students who work with maps rather than code. It runs entirely in the browser as an extension, needs no server and no GIS software, and takes the user from a polygon drawn on a map to a clipped dataset or a quality-controlled time series. Its distinctive contribution is that it reports when a number should not be trusted, instead of presenting every satellite value as a measurement.

2. Software description

2.1 Software architecture

SWOT Explorer is a Manifest V3 browser extension written in TypeScript and built with the WXT framework [10]. It has no backend: every request goes directly from the user's browser to the data

provider, and credentials, study areas and results stay on the user's machine. The interface is written in React and is available as a narrow side panel next to any web page or as a full-page application; maps are drawn with MapLibre GL JS [11] and geometry operations use Turf.js [12]. Table 2 lists the layers of the code.

Table 2. Layers and modules of SWOT Explorer.

Layer	Modules	Role
Data access	api, auth	Clients for the NASA Common Metadata Repository (CMR), Hydrocron, the PO.DAAC archive, DAHITI and Hydroweb; Earthdata Login
Search and preview	search, preview	Pass-aware granule search; one pass shown on the map before download
Processing	clip, qc, robust, timeseries, gauge, independent	Clipping, quality control, robust reservoir level, storage change, validation
Background	downloads, monitor	Download queue and new-pass alerts, run in the extension service worker
Storage	storage, state	Saved searches, history and cached observations in IndexedDB
Interface	features, map, components	React panels, map view, charts and figure export

Two design decisions shape the code. First, all numerical logic is written as pure functions that are separate from the interface, so it can be tested without a browser: the repository has 130 unit tests in 22 files, which run offline against API responses recorded from the live services. Second, the browser may stop an extension's service worker at any time, so the download queue keeps no state in memory. Every change is read, modified and written back to local storage under a lock, and the worker is woken by download events, messages from the page and a watchdog alarm.

The user signs in with an Earthdata Login username and password or pastes a token. The password is used for a single request to NASA's token endpoint and is never stored; only the token is kept, in the browser's local extension storage. Generated download scripts read the token from an environment variable and never embed it.

2.2 Software functionalities

Pass-aware search. The user draws a rectangle or polygon or uploads a shapefile, then picks a product and a period. Fifteen Version D collections are supported: river reaches, nodes and cycle averages; prior, observed and unassigned lakes and lake cycle averages; pixel cloud and raster water masks; and low-rate sea surface height. For continental products the extension first queries the pixel cloud collection [9], whose tiles of about 64 km have accurate footprints, to learn which cycle and pass pairs really cross the study area. It keeps only granules from those passes and drops older reprocessed versions of the same granule.

Preview before download. For any pass in the result, the lake polygons, river reaches and river nodes measured inside the study area are drawn on the map. River features follow the SWOT River Database [13]. Clicking a feature shows its water level, uncertainty, area or width, quality flag and observation time.

Clip and merge. Zipped shapefiles are fetched with the user's token and parsed in the page. Features are cut to the study area (lines are split at the boundary, polygons are intersected, points outside are dropped), tagged with granule, cycle and pass, passed through quality control and merged into one GeoJSON file, with CSV export. Products that cannot be clipped in the browser are selected by tile or scene and sent to the background download queue, or exported as a URL list or a Bash or PowerShell script.

Quality control. One rule is applied to every time series and every clipped file. By default an observation is kept when its quality flag is 0 or 1 and its water surface elevation uncertainty is at most 0.10 m; fill values are always rejected. The rule can filter rows, keep them with a pass/fail column, or be switched off, and each export states the rule that was used and the number of rows rejected for each reason.

Time series. Clicking a lake, reach or node fetches its full history from Hydrocron, with no file download. Duplicate rows are removed. Water level, area, width and, for reaches, discharge can be plotted and exported with the data citation of the collection.

Robust reservoir level. SWOT may observe one reservoir as several separate water bodies in a pass, each with its own height. For such cases the extension reads the observation-level lake product and, for each pass, applies five steps: (1) keep only the newest reprocessing; (2) apply the quality rule and drop pieces smaller than 1 km²; (3) take the area-weighted median height; (4) drop pieces further than three robust standard deviations from it, where the standard deviation is 1.4826 times the median absolute deviation with a floor of 0.25 m; (5) take the area-weighted median of the rest. A Hampel filter [14] with three passes on each side then flags isolated spikes in the resulting series.

Reliability grade. Aggregation cannot repair a series whose inputs are wrong, so every level series is graded from the absolute change between consecutive passes. A series is graded *good* when the median change is at most 0.5 m and the 90th percentile is at most 2 m, *questionable* when the median is at most 2 m, and *unreliable* otherwise; fewer than five observations are reported as insufficient. The grade is shown beside every chart and in the reservoir comparison.

Area and storage change. For lakes, a Theil-Sen line [15] is fitted to area against level, using only passes that saw the whole lake and only when at least eight such passes exist. With area $A(h) = a + b\,h$, the storage change above the lowest observed level h_0 is

$$\Delta V(h) = \int A(z)\,dz = a\,(h - h_0) + (b / 2)\,(h^2 - h_0^2), \quad \text{with the integral taken from } h_0 \text{ to } h \qquad (1)$$

with A in km² and h in m, so that the result is in million m³. The fit is shown with a caution when its coefficient of determination is below 0.3 or its slope is not positive.

Validation. The user can paste or upload gauge readings (text or Excel). The gauge series is interpolated linearly to each SWOT pass time, but only between readings that are close together, by default within 1.5 times the usual spacing. The extension reports the median bias, the root-mean-square error with and without the bias, the mean absolute error, the share of passes within 10 cm and 25 cm, and the correlation; differences beyond three robust standard deviations are listed as outliers. SWOT can also be compared with independent altimetry from DAHITI [16] and Hydroweb [17]: stations within 60 km whose records overlap the SWOT period are offered, nearest first, and observations are paired within three days.

Cascade comparison and monitoring. Connected reservoirs can be plotted on one time axis, as levels or as change from each reservoir's median; ten Nile-basin reservoirs, from Lake Victoria to Lake Nasser, are built in. A saved search can be monitored: the service worker re-runs it every six hours and raises a browser notification when new passes appear.

3. Illustrative example

The example asks one question of two neighbouring reservoirs on the Blue Nile: how has the water level changed since SWOT began? GERD in Ethiopia and Roseires in Sudan, about 100 km downstream, are observed by the same passes. The data were recorded from the live services in early November 2026 and are stored in `tests/fixtures`, so every value below can be reproduced from the repository.

Search. The user draws a polygon around the GERD reservoir and searches one month of data. Table 3 shows what the catalogue returns and what the extension keeps for each product family.

Table 3. Granules returned by the catalogue and kept by the extension over GERD, October 2025.

Product family	Returned	Kept	Reason for removal
River and lake single-pass	27	5	Passes that do not cross the area; 4 reprocessed duplicates
River and lake cycle averages	4	4	None
Pixel cloud	17	17	None (footprints are accurate)
Raster 100 m and 250 m	25	4	20 distant scenes with a whole-world footprint; 1 other
Low-rate sea surface height	8	7	1 reprocessed duplicate

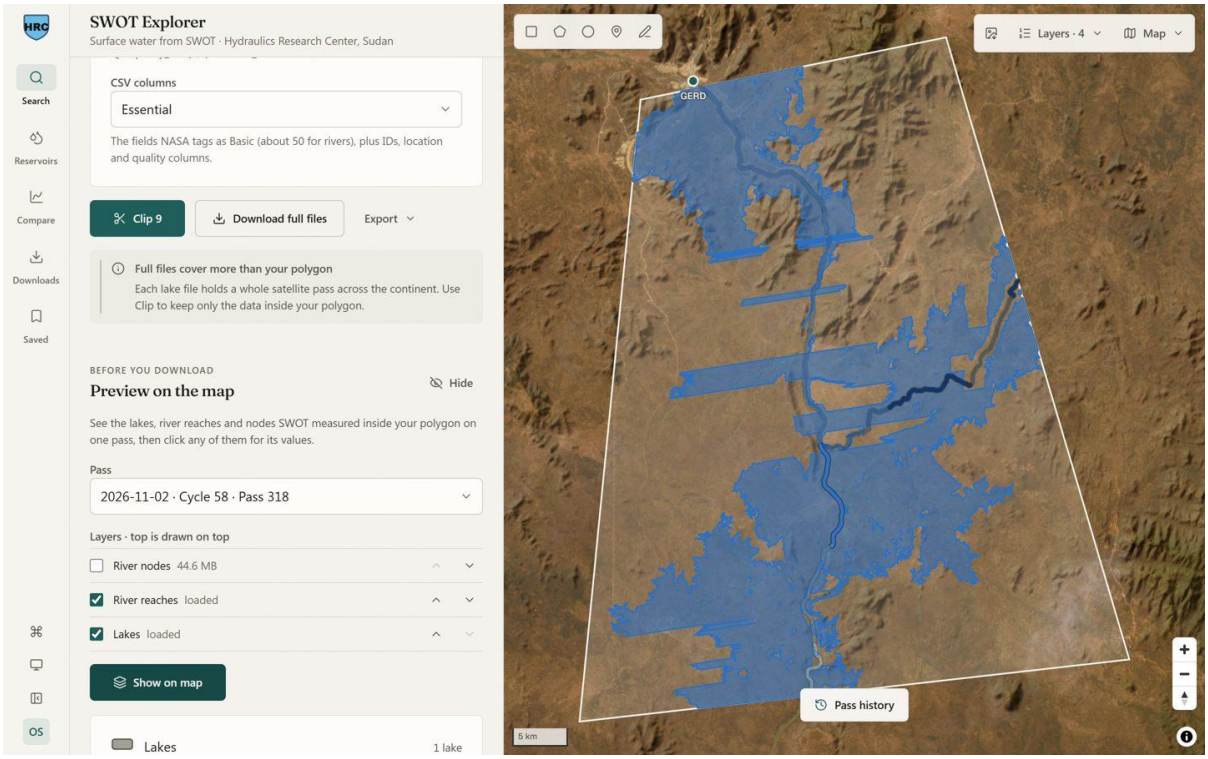


Fig. 1. Water bodies and river reaches measured by SWOT inside the study area on the pass of 2 November 2026, previewed before download.

Preview and time series. Showing the latest pass on the map (Fig. 1) and clicking the GERD lake polygon returns a water level of 606.75 m with an uncertainty of 0.04 m and a water area of 863.52 km² on 2 November 2026. Taken alone, this looks like a precise measurement. Opening the lake's history (Fig. 2) changes the picture, as Table 4 shows.

Table 4. SWOT prior-lake water level series from Hydrocron, July 2023 to 2 November 2026, as processed by SWOT Explorer.

	GERD	Roseires
Observations	113	169
Passing quality control	76	158
Rejected: uncertainty above 0.10 m	32	5
Rejected: quality flag 2 or 3	5	5
Rejected: not observed (fill value)	0	1
Range of accepted levels (m)	567.85 to 617.35	482.41 to 492.82
Median change between consecutive passes (m)	6.74	0.26
90th percentile of change (m)	18.30	0.75
Reliability grade	Unreliable	Good

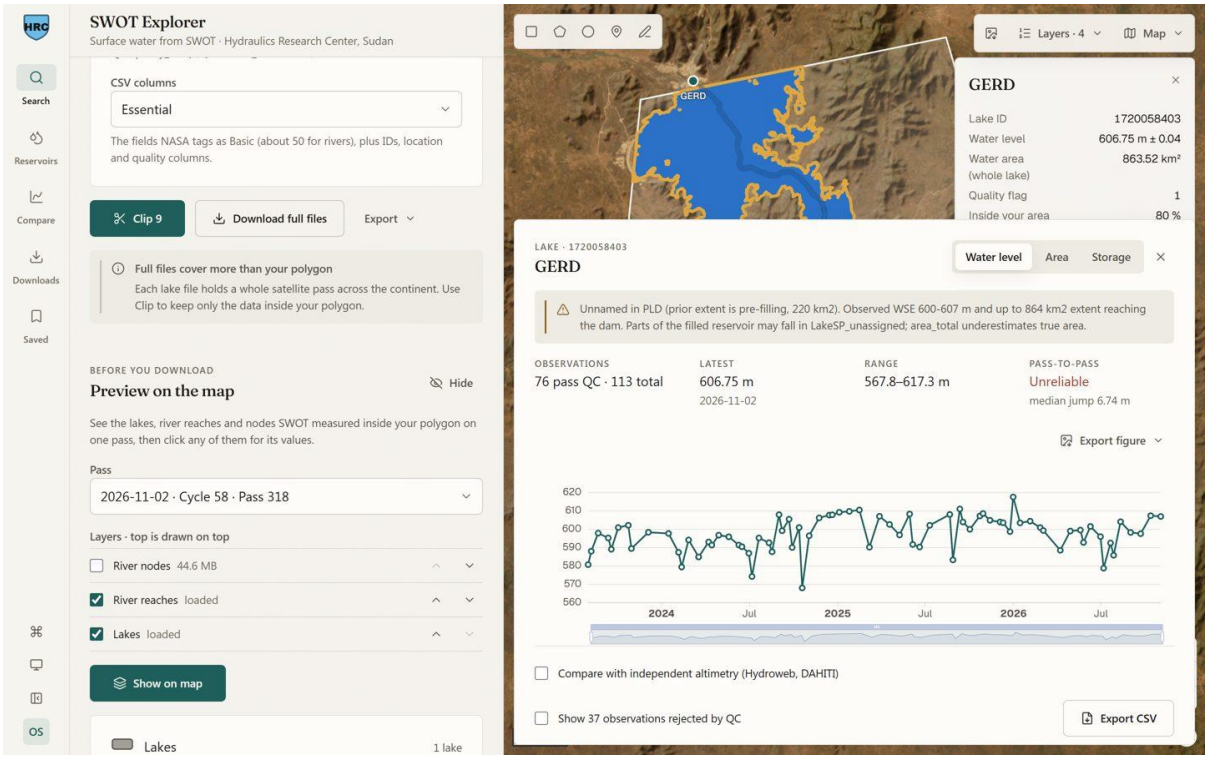


Fig. 2. Water level history of the GERD prior lake with its reliability grade.

At Roseires the accepted levels move by a median of 0.26 m between passes and trace the reservoir's annual cycle of about 10 m. At GERD the accepted levels jump by a median of 6.74 m from one pass to the next, which is not physically plausible for a reservoir of this size. The quality rule alone does not catch this: a third of the observations are rejected, but those that remain still disagree.

Robust mode. The observation-level product explains why. On the pass of 2 November 2026 the reservoir was recorded as separate water bodies with different heights: 690 km² at 605.7 m, 174 km² near the dam at 611.6 m, and 2.4 km² at 538.2 m. All three carry quality flag 1 and an uncertainty below 0.05 m. The prior lake polygon used by the product predates the filling of the reservoir (220.5 km², against up to 864 km² observed), which is a likely cause. Table 5 gives the result of the robust procedure of Section 2.2 for both reservoirs.

Table 5. Robust level from observation-level lake granules, July 2023 to November 2026.

	GERD	**Roseires**
Granules read	117	115
Observed pieces	1,375	2,926
Reprocessed duplicate granules removed	14	16
Passes with a level	95	96
Spikes flagged by the Hampel filter	7	0
Median change between consecutive passes (m)	8.29	0.32
90th percentile of change (m)	22.63	1.10
Reliability grade	Unreliable	Good

The robust procedure leaves Roseires consistent and does not rescue GERD: the pieces themselves are inconsistent, so no aggregation of them gives a usable level. The extension therefore labels the GERD series as unreliable in the chart, in the export and in the cascade comparison (Fig. 3), instead of smoothing it into a plausible-looking curve. Among the other built-in reservoirs, Lake Nasser is graded good (314 of 342 observations accepted, median change 0.17 m) and Tekeze questionable (82 of 112 accepted, median change 1.50 m).

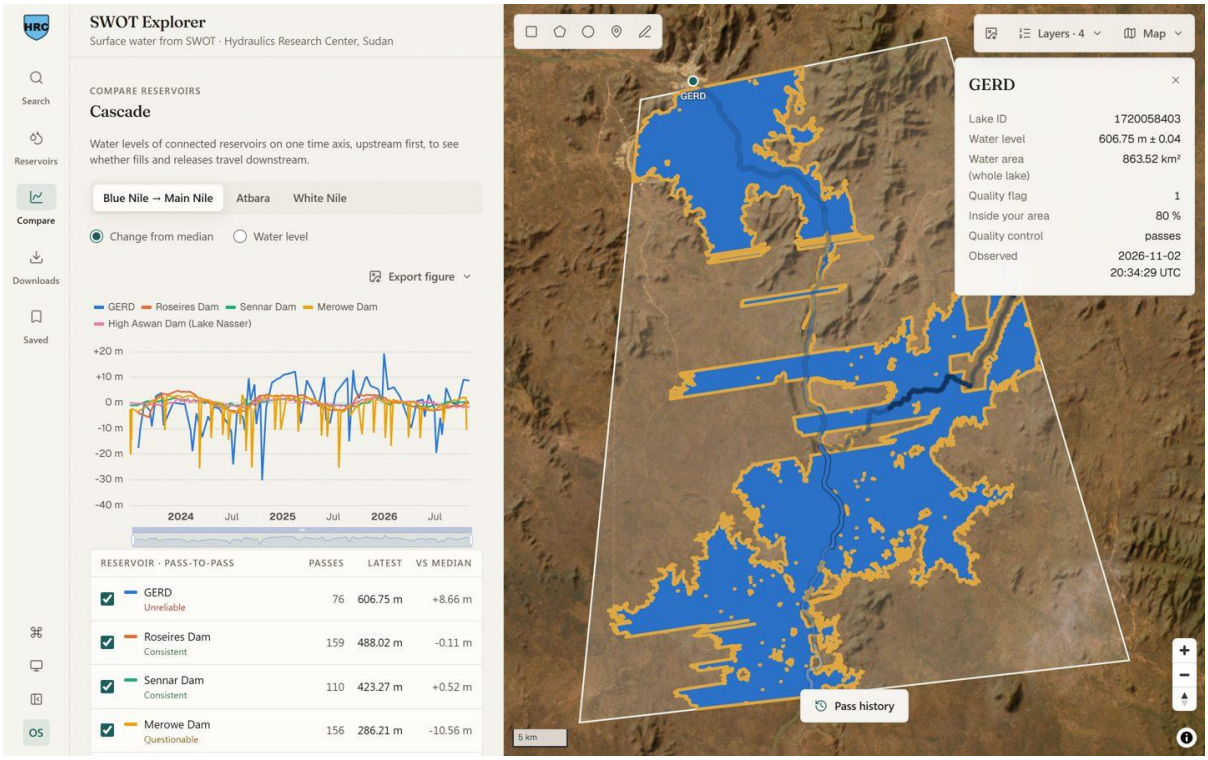


Fig. 3. Cascade comparison of Blue Nile and Main Nile reservoirs as change from each reservoir's median.

Area and storage. At Roseires SWOT saw the whole reservoir on 51 accepted passes, and the area-level fit has a slope of 22.6 km² per metre with a coefficient of determination of 0.58. At GERD the fit on 23 full passes has a coefficient of determination of 0.06 and is shown with a caution. Lake Nasser is wider than the swath and was seen whole only once, so the extension states that storage needs an area-elevation curve from another source.

Comparison with other sources. The same chart can overlay an independent altimetry series from Hydroweb or DAHITI, or the user's own gauge readings, and reports the statistics described in Section 2.2. The median difference is reported separately from the remaining error because SWOT heights and other records usually refer to different vertical datums, so a constant offset is expected and only the remainder measures disagreement. No numerical comparison is reported here: the search returned no independent series for Roseires at the time of writing, and no gauge records were available for publication. The comparison routines are covered by the unit tests.

4. Impact

SWOT Explorer changes who can use SWOT hydrology data. A question such as "how is this reservoir changing?" previously required a scripting environment or GIS software, knowledge of the product structure and of the catalogue's footprint behaviour, and enough storage for continental files. With the

extension the same question is answered from a polygon drawn on a map, and the result is exported with the quality rule, the rejected observations and the data citation attached.

The tool also supports research questions that are awkward to pursue by hand. Monitoring a cascade of reservoirs across national borders needs the same processing repeated for every reservoir and every new pass; the cascade view and the saved-search alerts make that routine. The gauge and independent-altimetry comparisons give a consistent way to quantify SWOT's agreement with other sources at a site, separating a constant datum offset from real disagreement. The reliability grade gives a simple and reproducible screening step before SWOT levels are used in water balance or operations studies, and the GERD example shows that this step is needed.

For users in regions where in-situ data are limited, the extension lowers the cost of entry: it is free, installs from the Chrome Web Store, needs no server or licence, and runs on an ordinary laptop. Because the code is open under the MIT license and the numerical methods are small, tested functions, other groups can reuse the quality control, robust level and validation routines or add reservoirs of their own basin.

5. Conclusions

SWOT Explorer brings search, preview, clipping, quality control, time series and validation of SWOT hydrology data into a browser extension with no server behind it. Its search keeps only the passes that observe the study area, and its reliability grade tells the user when a series should not be trusted, which the Blue Nile example shows to be necessary even for observations that carry good quality flags.

The current version has limits that users should know:

- It runs in Chrome and Edge only.
- Only vector products are clipped in the browser, and the whole file is still transferred before it is clipped. Pixel cloud, raster and ocean products are selected by tile or scene.
- The reliability thresholds were calibrated on five Nile-basin lakes and reservoirs and may need adjustment elsewhere, in particular for water bodies with fast real variations.
- Storage is a change relative to the lowest observed level and assumes a linear relation between area and level.
- The extension supports Version D products and depends on the stability of the public NASA, DAHITI and Hydroweb interfaces.

Planned work includes built-in reservoir sets for other basins and validation against gauge records at more sites.

CRediT authorship contribution statement

Osman Osama Ahmed Ibrahim: Conceptualization, Methodology, Software, Validation, Visualization, Writing - original draft, Writing - review and editing.

Declaration of competing interest

The author declares no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The source code, the unit tests and the recorded data used in Section 3 are available at https://github.com/Osman-Geomatics93/swot-explorer and archived at https://doi.org/10.5281/zenodo.24144883 [18]. SWOT data are freely available from NASA PO.DAAC [3,4,9].

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work the author used Claude (Anthropic) to draft the manuscript text from the software's source code, tests and documentation. Claude was also used during software development to help plan the implementation and to find and fix errors in the code. After using this tool, the author reviewed and edited the content as needed and takes full responsibility for the content of the publication.

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