Global Flood Mapper v2: Open-Access Flood Mapping and Exposure Assessment with Sentinel-1 SAR

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Abstract

We present Global Flood Mapper v2 (GFM v2), which adds flood depth estimation, on-demand GeoTIFF export, cloud-based impact assessment against high-resolution land cover and five global population datasets to quantify exposure uncertainty, and parameter-encoded URLs for reproducibility and sharing. Its predecessor, GFM v1, was already an open-access, globally operational web portal for rapid, analysis-ready flood mapping that runs entirely in the browser without coding, downloads, or data preprocessing; GFM v2 builds on this foundation without sacrificing that ease of use. Unlike fully-automatic monitoring services, which publish precomputed output from fixed, provider-set detection parameters and do not process every Sentinel-1 acquisition, GFM v2 gives users direct control over which acquisitions are processed and how: users can compare pre- and during-flood imagery, adjust detection thresholds and terrain masks to local conditions, and select any area and date, ensuring small-scale or localized events can always be mapped, regardless of whether an automated monitoring service happened to cover them. By lowering technical barriers without sacrificing user control, GFM v2 supports timely, evidence-based flood response and management.

Keywords: Flood Risk, Disaster, Remote Sensing, Historical Floods, Flood Database

1 Introduction

Floods are among the most widespread and damaging natural hazards, affecting 1.6 billion people between 2000 and 2019 (United Nations Office for Disaster Risk Reduction (UNDRR), 2020). Their frequency, severity, and duration are increasing, with damages projected to rise twentyfold by the end of the century (Visser, Petersen, & Ligtvoet, 2014; Winsemius, Van Beek, Jongman, Ward, & Bouwman, 2016). Timely, high-resolution flood mapping is essential for effective response, yet producing such maps during a disaster remains difficult in many contexts.

Microwave remote sensing is particularly effective for flood mapping because it transmits its own radar pulses and records their return from the Earth's surface, enabling imaging both day and night and through cloud cover. This capability is especially important during rain-induced floods, when optical imagery is often obscured. A pivotal advance came in 2014 with the launch of the European Space Agency's Sentinel-1 satellites, which provide free, 10 m resolution synthetic aperture radar (SAR) data at frequent intervals. Coupled with cloud-based platforms such as Google Earth Engine (Gorelick et al., 2017), these data have made large-scale, near-real-time flood mapping possible. However, most work to date has focused on refining detection algorithms rather than delivering maps in formats that are both rapid and directly usable for decision-makers.

Numerous studies have demonstrated the value of Sentinel-1–based flood mapping for past events (Lal, Prakash, & Kumar, 2020; Lal, Prakash, Kumar, Srivastava, et al., 2020; Rathore, Kumari, Tripathy, Mahto, & Lal, 2025; Tripathi, Pandey, Parida, & Kumar, 2020), using methods that range from simple thresholding algorithms such as Otsu to advanced deep learning models including vision transformers (Sharma & Saharia, 2025). Even so, applying these methods can demand considerable technical expertise, which many responders do not have. In some cases, the methods are not packaged in a ready-to-use form, limiting their practical impact (Tripathy & Malladi, 2022). As a result, essential tasks such as identifying flood extent, affected land cover, or impacted population may go unmet during emergencies. The same gap exists within the scientific community, where flood extents published in journal articles are often unavailable for reuse, leading to duplicated effort and limited reproducibility (Rautela, 2016).

1.1 Existing cloud-based flood portals

Interest in delivering Sentinel-1–derived flood maps through cloud platforms has grown in recent years, yet most tools still fall short of offering an end-to-end solution for both mapping and impact assessment. Many operate only within specific countries or regions and lack global coverage (see Supplementary Table S1). Only a few operate globally, and fewer still let users control which Sentinel-1 acquisitions are processed, rather than simply querying or downloading a subset of an already-computed global product (Li & Demir, 2024; Tripathy & Malladi, 2022). This distinction matters for two reasons. First, it ensures that small-scale or localized flood events are not missed simply because a provider's own automated pipeline did not process, or failed to detect, the specific acquisition needed (see Section 1.2). Second, it lets users with local geographic knowledge tune detection thresholds and masks to the specific terrain and land cover of their area of interest, rather than relying on a single, generically-tuned global default. However, most global portals stop at mapping flood extent without integrating tools to assess impacts on land cover or population. Users must manually intersect flood layers with these datasets, a process that requires GIS expertise, slows response, and increases the risk of error. These limitations are especially consequential for practitioners and humanitarian actors who need rapid, flexible, and actionable insights. Supplementary Table S1 lists publicly available cloud platforms for flood monitoring or mapping, along with their key limitations.

1.2 Gaps in globally operational Sentinel-1 flood portals

Existing global services for Sentinel-1-based flood mapping fall into two categories: fully-automatic monitors that publish precomputed output, and interactive mappers that let users choose the detection parameters themselves. NASA's OPERA Dynamic Surface Water Extent (DSWx-S1) product (Jung et al., 2026; OPERA, 2024) and the Copernicus Emergency Management Service's Global Flood Monitoring product (hereafter CEMS) (Wagner et al., 2026) are, by their own developers' description, fully-automatic monitoring services, and both share two structural limitations for on-demand, localized use. First, neither provides full Sentinel-1 coverage: a substantial share of acquisitions is not processed into a usable product (Figure 1), consistent with the roughly 20% event non-detection rate the CEMS developers report for their own service (Wagner et al., 2026), and resolving a specific gap requires a support inquiry rather than direct user action. Second, neither exposes the underlying detection parameters, such as adjustable thresholds, to the user. Furthermore, CEMS estimates exposure from only a single gridded population dataset, and because flood exposure estimates vary substantially with the population dataset chosen (Smith, Bates, Wing, et al., 2019), relying on one leaves that uncertainty hidden. CEMS performs well for large floods, but its fixed, provider-set parameters mean users cannot adapt detection to the smaller, more localized events that make up much of global flood risk.

MultiRS Mapper (Li & Demir, 2024), by contrast, is an interactive mapper: it lets users define their own area and date of interest, but it does not support any form of impact analysis, cannot generate downloadable flood maps at large scales, and struggles to reliably distinguish floodwater from other low-backscatter surfaces (see Supplementary S2).

Global Flood Mapper (GFM v1) (Tripathy & Malladi, 2022) is also a user-driven mapper, giving users the most control over the mapping itself: users can directly compare pre- and during-flood Sentinel-1 imagery, adjust the detection threshold to best capture the flood signal for a specific event and geography, define their area and date of interest, combine ascending and descending Sentinel-1 passes to better capture peak flooding, and apply slope and elevation masks to reduce false positives in hilly terrain. These capabilities do not depend on any automated third-party pipeline.Its z-score-based anomaly detection approach, adapted from DeVries et al. (2020), shows strong agreement with high-resolution imagery and field photographs (Tripathy & Malladi, 2022), and independent studies report that it outperforms traditional thresholding baselines (Afifi & Magdy, 2024). GFM v1, however, stops at mapping flood extent. It does not estimate flood depth, export analysis-ready GeoTIFFs on demand, assess impacts on land cover and population, or encode results in shareable links for exact reproducibility.

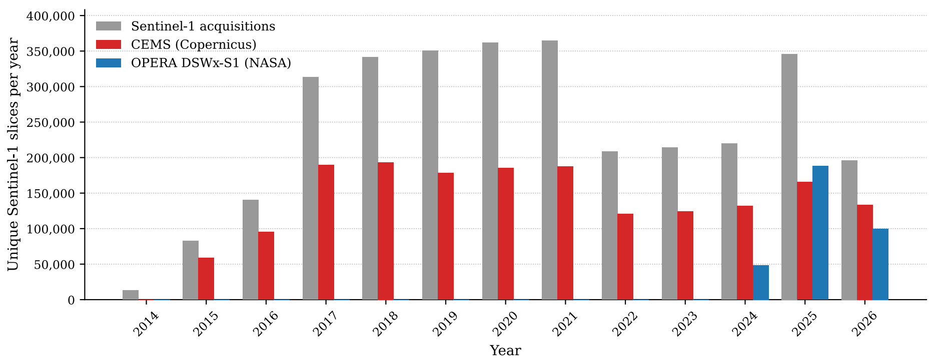

Fig. 1 Unique Sentinel-1 slices acquired globally per year (grey), and the subset processed by CEMS (red) and OPERA DSWx-S1 (blue). Retrieved 23 April–11 July 2026; 2026 reflects year-to-date acquisitions only. The Python script used to reproduce this figure is shared as supplementary material with this article.

2 Introducing GFM-v2: An end-to-end solution for global flood mapping

Building on the open-source foundation of GFM v1, the second version addresses earlier limitations and introduces four key capabilities:

1. **Flood depth estimation** – Incorporates the Floodwater Depth Estimation Tool for GEE (FwDET-GEE) (Peter et al., 2020) with the Copernicus GLO-30 DEM, applied exactly as in the original study. These depth values are indicative and should be treated as guidance rather than absolute measures.

2. **GeoTIFF export** – Enables direct download of flood extents as GeoTIFF rasters without login. Export size limits are approximately 98,000 km^2 at 350 m, 22,500 km^2 at 100 m, or 207 km^2 at 10 m resolution, per GEE constraints. Larger high-resolution exports (10 m) are available for logged-in GEE users.
3. **Impact assessment** – Intersects flood extent with ESA WorldCover (10 m) and five global population datasets (GHS-POP, HRSL, WorldPop, GPW, LandScan) entirely in the cloud to estimate affected land cover and population.
4. **Interactive sharing** – Generates parameter-encoded URLs capturing all user inputs (extent, date, thresholds, selected layers) for exact reproducibility and easy sharing.

Figure 2 illustrates the underlying processing pipeline: the z-score anomaly detection between dry-season and during-flood Sentinel-1 imagery used in GFM v1, followed by thresholding and slope/elevation masking to classify each pixel as high- or low-confidence flood, permanent water, or non-water; and, new in GFM v2, the depth, land cover, and population layers that run on this same flood map.

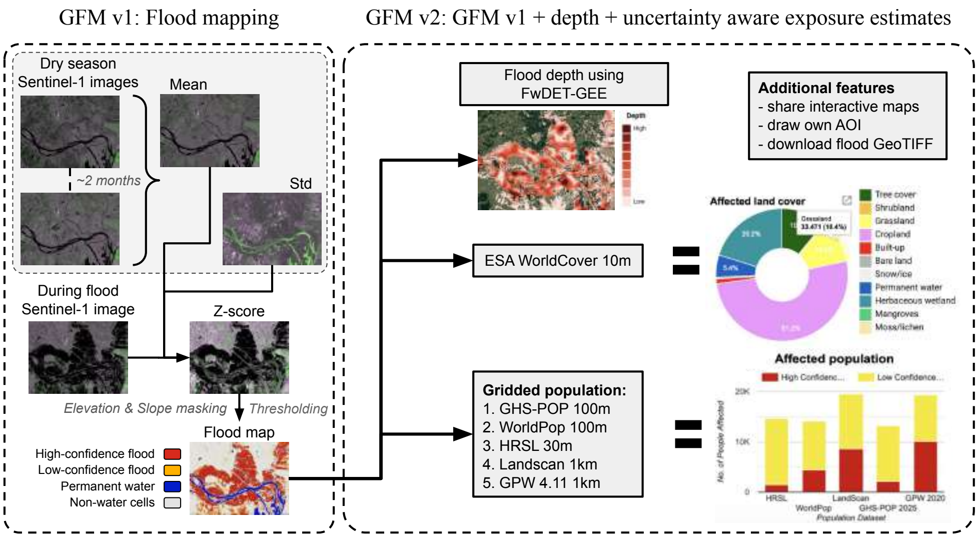

Fig. 2 Processing pipeline for GFM v1 (left), which focused on flood extent mapping, and the capabilities added in GFM v2 (right): flood depth estimation, land cover and population impact assessment, interactive sharing, and GeoTIFF export.

Figure 3 shows the GFM v2 interface, with the mapping view at the top and the new impact assessment panel at the bottom. In addition, while GFM v1 already classified flood extent into high- and low-confidence classes, GFM v2 lets users export each class separately (Figure 3), giving users a built-in, spatially explicit indication of detection confidence.

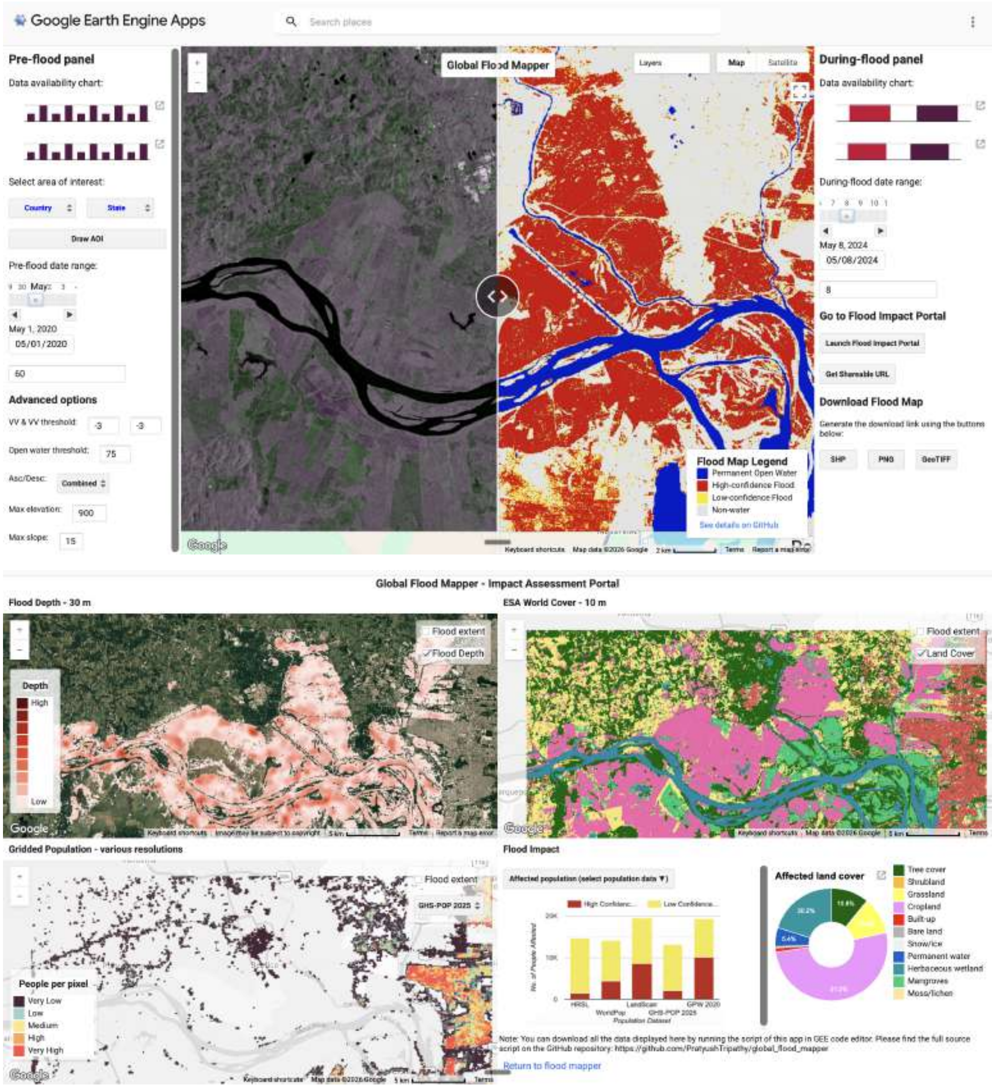

Fig. 3 Screenshot of the GFM v2 interface. (Top) Custom flood mapping portal showing a user-defined area of interest and export options. (Bottom) Impact assessment interface displaying flood extent alongside land cover and multiple population datasets. Area-level exposure is summarized as pie and bar charts.

3 Validation

Flood extent mapping in GFM v2 remains unchanged from GFM v1, which improved on the z-score-based anomaly detection approach of DeVries et al. (2020), validated for events in Houston, Texas; Thessaly, Greece; and eastern Madagascar, by adding slope and elevation masks that improved accuracy by about 20 percent over standard Otsu thresholding (Afifi & Magdy, 2024). In this version, GFM focuses on the tool itself, adding the portal capabilities described in Section 2 to make flood mapping more accessible and useful.

Flood depth estimation uses the FwDET-GEE model, which reported a root mean square error of 0.62 m in independent validation (Peter et al., 2020). The model is integrated without modification. Population exposure estimates are generated by intersecting flood extent with multiple global gridded population datasets, enabling users to compare results and evaluate variability between products.

4 Limitations and Future Directions

Current limitations of GFM v2 arise from both sensor characteristics and processing constraints. Sentinel-1 SAR cannot reliably detect inundation in dense urban areas or beneath vegetation because C-band radar does not penetrate buildings or tree canopies, and post-processing methods to address these gaps are not yet scalable at the global level. Flood depth estimates from FwDET-GEE face similar challenges, as their accuracy depends on DEM quality; artefacts such as sinkholes, voids, or vegetation bias can directly affect the results. For this reason, the depth values should be interpreted as indicative rather than definitive. A dedicated uncertainty layer that combines DEM and land-cover information to flag where urban or vegetated cover is likely to degrade detection, distinct from the high-/low-confidence classes already reported, is a natural direction for future work.

Google Earth Engine's compute limits also constrain GFM v2. Processing limits restrict large-area, high-resolution analyses, and the hosted app runs on a single shared Google Earth Engine project subject to Google's monthly compute quota for noncommercial use, so heavy concurrent use across users can degrade performance or intermittently disrupt some features. We have made the complete source code of GFM v2 publicly available on GitHub; running the provided script in a user's own Google account draws on that user's individual quota instead of the shared app's, and also enables export of flood maps at native 10 m resolution.

5 Conclusion

GFM v2 advances global flood mapping by combining flood extent detection, depth estimation, exposure assessment, and instant sharing within a single browser-based interface. Unlike fully-automatic monitoring services that publish precomputed output from fixed, provider-set parameters, GFM v2 exposes the underlying detection parameters to the user, so flood maps can be tuned to local geography rather than constrained by a single, generically-tuned pipeline. Building on the validated detection method from GFM v1, it enables rapid, customizable mapping worldwide without data downloads or specialized software, giving researchers and practitioners the flood information they need for timely decisions during flood events. Future work may expand the input datasets, automate parameter selection, and improve detection in urban and vegetated areas.

Supplementary information. A Supplementary Information document, and the code and data used to generate Figure 1, accompany this submission.

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Declarations

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Author Contributions. A.A. led the software development and contributed to methodology, visualization, and writing of the original draft. P.T. led the conceptualization, methodology, visualization, supervision, and writing of the original draft, and contributed to software development. Both authors reviewed and approved the final manuscript.

Code availability. The source code for Global Flood Mapper Version 2 is publicly available at a GitHub repository, https://github.com/PratyushTripathy/global_flood_mapper.

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Supplementary S1. Existing flood monitoring and mapping portals

Table 1 lists publicly available cloud platforms for flood monitoring or mapping, along with their key limitations.

Table 1: Existing flood mapping and impact assessment cloud platforms.

Flood portal	**Source**	**Global**	**Type**	**Download flood map**	**Impact assessment**	**Remarks**
HANZE	Paprotny et al., 2024	No	Flood database	Yes	No	Database of past flood images that is no longer updated.
FLOWIDER	Roopa & Kelkar, 2024	No	Flood monitor	No	No	Not operational globally. Only tracks the water levels of certain rivers in India.
–	Turner and Sun, 2024	No	Flood monitor	No	No	Only tracks floods in Melbourne.
Flood Inundation Mapper	United States Geological Survey	No	Flood monitor	Yes	No	Has information on older floods (e.g., 2018) but no recent ones.
FEMA Flood Mapper	Federal Emergency Management Agency, USA	No	Flood monitor	No	No	Not operational globally, only in the United States. Maps flood hazard, not extent.
HydroSAR	Meyer et al., 2024	No	Flood mapper	No	No	The option to download flood extent did not return a result during testing.
CEMS	Copernicus EMS	Yes	Flood monitor	Yes	Yes	Users must create an account, and have to go to a separate webpage to download maps. Impact assessment estimates exposure from a single gridded population dataset.
MultiRS Flood Mapper	Li & Demir, 2024	Yes	Flood mapper	Yes	No	Can generate and download flood extent of area and date of choice. Its GitHub repository contains tutorial documentation only, not the application source code; the application was also unreachable at the time of a check on 11 July 2026 (see Supplementary S2).
Global Flood Mapper	Tripathy & Malladi, 2022	Yes	Flood mapper	Yes	No	Can generate and download flood extent of area and date of choice.

Supplementary S2. Limitations of MultiRS Flood Mapper

The MultiRS Flood Mapper offers an intuitive interface for extracting floods from single Sentinel-1 scenes, but its reliance on a simple backscatter threshold from one image can lead to false positives, particularly over smooth, non-water surfaces. For instance, Figure 1 shows the MultiRS output for an area in India on 6 June 2024, where extensive areas are classified as floodwater. However, corresponding Sentinel-2 optical imagery for the same date (Figure 2) shows no water present. This misclassification occurs because surfaces such as bare soil or paved areas can have low radar backscatter that resembles open water in threshold-based detection. Without additional contextual information or multi-date analysis, such outputs risk overestimating flood extent, especially in areas with diverse land cover.

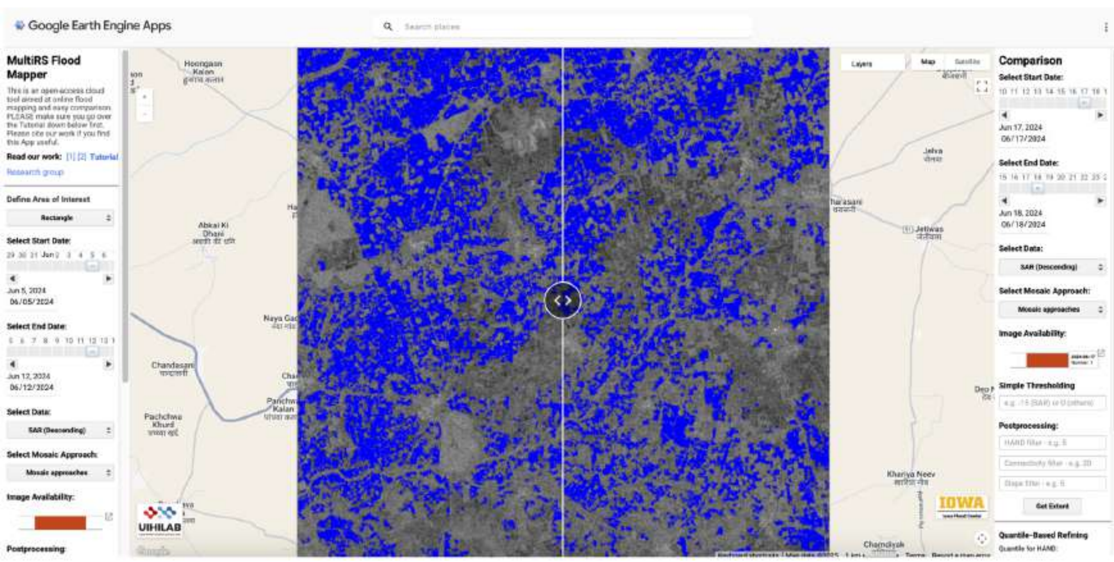

Figure 1: MultiRS Flood Mapper output for 6 June 2024, showing large areas classified as floodwater.

Separately, at the time of a check on 11 July 2026, attempting to load the MultiRS Flood Mapper application (`https://hydroinformatics.uiowa.edu/lab/floodmapper/`) failed with a Google Earth Engine project-verification error (Figure 3); this reflects the application's state at the time of this check and may be resolved by the developers at any point. Its GitHub repository (`https://github.com/uihilab/MultiRS_Flood_Mapper_Tutorial`) contains tutorial and documentation material only; the underlying application source code is not publicly available.

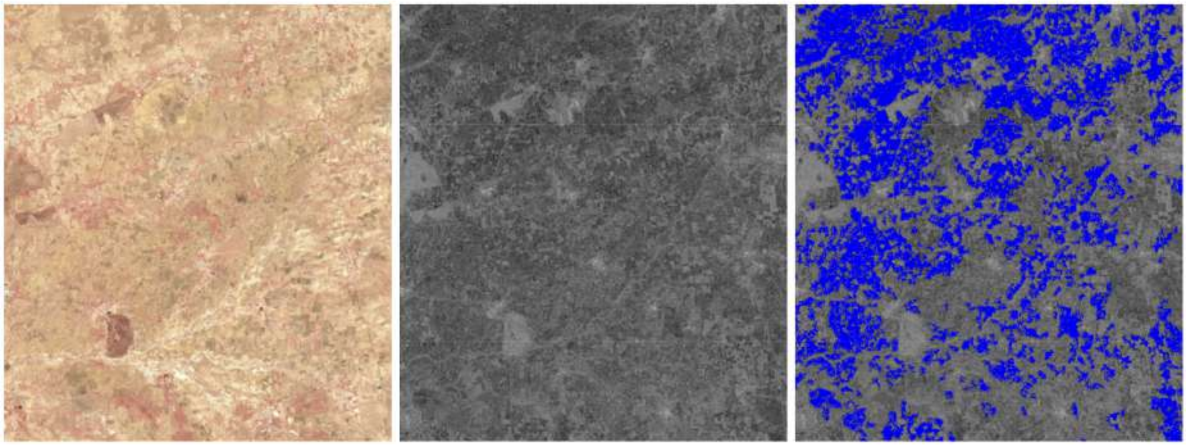

Figure 2: Comparison of Sentinel-2 (left), Sentinel-1 VV band (center), and the MultiRS flood mask (right) for 6 June 2024. The optical imagery confirms that areas flagged as water in the MultiRS mask were dry at the time. The Google Earth Engine script to reproduce this view is available at `https://code.earthengine.google.com/7146b773c8906eb9c1f50e176c89be9e`.

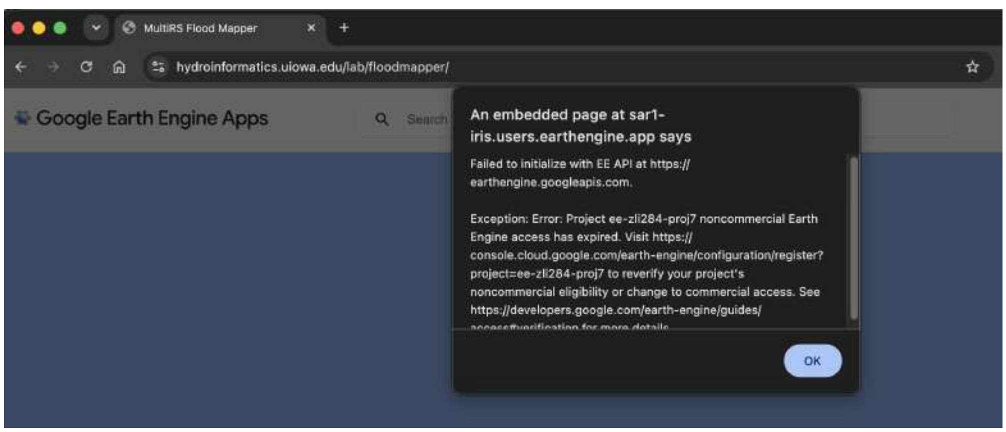

Figure 3: MultiRS Flood Mapper access error observed on 11 July 2026: the application failed to initialize with the Google Earth Engine API, reporting that the developer's non-commercial Earth Engine project registration had expired.