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Web-based rapid mapping with earth observation and geospatial data supports flood response in Southern Germany in 2024

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Abstract

With the progression of climate change, Central Europe faces an increasing risk of extreme weather events, particularly floods and wildfires. One of the latest events took place in June 2024, when continuous rainfall in southern Germany caused water levels to rise. This paper presents the German Aerospace Center's (DLR) operational response to the flood incident, focusing on the integration of Earth observation data and the dissemination of information via a web-based platform. DLR combined high-resolution aerial imagery, very high-resolution radar and optical satellite imagery, and utilized flood extent masks derived from Copernicus Sentinel-1 and -2 data to support the flood response. The collected datasets were refined with ancillary geospatial layers such as building footprints and infrastructure data, before being integrated into a web-based viewer. The viewer allowed a dynamic visualization and data exploration by public authorities and disaster response organizations, facilitating efficient coordination and decision-making. The first information layers were published within hours of acquisition, and the web-based viewer was accessed more than 800 times during the first week. User feedback from emergency stakeholders highlighted the platform's usability, relevance, and value in crisis coordination. While certain limitations were identified such as the reliance on internet access and challenges in urban radar interpretation, the workflow proved highly effective. This case study demonstrates how a national EO agency can leverage integrated geospatial data, automation, and dissemination tools to support rapid flood response. The approach presented in this paper provides a framework that can potentially be replicated in other countries and disaster scenarios.

Keywords Flood response, Crisis management, Remote sensing, Geoinformation

1 Introduction

Europe experiences the effects of global warming at an increasing pace, resulting in milder winters, more frequent heavy rainfall, and prolonged summer droughts [1]. Central European countries must prepare for increasingly extreme weather conditions, especially a rise in flooding occurrences. Across Europe, the year 2023 recorded the highest



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river discharges in winter. Continuing trends in global warming are expected to further intensify the severity of these extremes [2].

In 2024, following the year of hydrological extremes in Central Europe, several devastating floods occurred. In May of that year, rising water levels affected regions in western Germany (Saarland), while in September, extensive flooding affected many areas of Poland and the Czech Republic. That following October, the Valencian region of Spain was also severely impacted by flooding. The most significant flood in Germany that year occurred in southern Germany, where numerous states and districts declared a state of emergency. The disaster resulted in several fatalities and caused extensive material damage.

In such large-scale events, first-aid responders often do not have a proper oversight of the situation which is needed to coordinate their relief efforts effectively. The principal tasks of first-aid responders and humanitarian coordination during floods also include logistical operations (e.g. coordination of organizational units or transportation of materials) [3]. The utilization of very high-resolution data, acquired either via airborne or satellite platforms, facilitates the execution of these tasks by offering a comprehensive before and after perspective, thereby showing damage, e.g. to roads/bridges or critical infrastructure [4, 5].

The provision of such information is one of the main tasks of the Center for Satellite Based Crisis Information (ZKI) at the German Aerospace Center (DLR). The DLR-ZKI has extensive experience in processing complex information during crisis events for end users. The DLR-ZKI's function is the rapid acquisition, processing, and analysis of satellite data, including the provision of satellite-based information products for rapid mapping, disaster response, and humanitarian relief efforts. In addition, the DLR-ZKI also provides consultancy services, facilitates technology transfer, and conducts training exercises. The strong integration of research, development, and provided services is a key strength of the DLR.

During the floods in southern Germany in June 2024, the DLR-ZKI coordinated flight campaigns for the acquisition of aerial images, acquired very high-resolution optical and radar satellite imagery, and derived flood masks from freely available Sentinel-1 and -2 data. The data were made available in a password-protected web-based viewer to all persons and organizations with a demonstrated need. The information provided during the flooding was used by aid agencies, governments, and technical institutions. Access was subsequently granted to institutions utilizing the data for purposes such as hydrological modelling, hazard-map improvement, and water-management planning. Compared to previous DLR rapid mapping activations, this operation uniquely combined in-house aerial imagery, automated satellite processing, and a fully customized web-based viewer tailored for national and local stakeholders.

In many disaster scenarios, crisis centers such as the DLR-ZKI often rely on freely available satellite data such as the data provided by the Copernicus missions. Although such data offers a valuable overview of the situation, additional sources such as airborne imagery and very high-resolution (VHR) radar data, can provide further details. The rapid acquisition and integration of heterogeneous datasets from multiple airborne and satellite sensors, complemented by ancillary information, into a harmonized web-based visualization platform provides a state-of-the-art methodological approach. This approach demonstrates the potential of modern satellite technologies and advanced

image processing to enhance first-response efforts and overall disaster management. The purpose of this paper is to present the steps that led to the rapid provision of crisis data and to serve as a guide for future crisis responses. The opportunities and future capabilities offered by such implementations are discussed, along with their limitations. As more severe weather and natural hazards are expected in the future, including in Central Europe, a state-of-the-art approach to geospatial data collection and dissemination is essential.

2 DLR crisis response mechanism

The ZKI is a unit of the DLR that provides rapid mapping products for natural as well as man-made disasters throughout the entire disaster cycle. It primarily uses satellite and/or geospatial data to derive user-oriented products. The DLR-ZKI can be described as a link between DLR research and users, and is ISO certified for its standardized services [3]. Considering the latest research findings, the DLR-ZKI generates up-to-date situation information prior to, during, and following a disaster situation or major event. The aim is to always transfer the results of scientific research into state-of-the-art information products and applications for end users. For this reason and in order to be better prepared for the future disaster operations, the ZKI is also involved in several research projects and innovation developments [3]. The main users of the DLR-ZKI include national and international policy makers, aid organizations, situation centers, and research institutions. Examples of DLR-ZKI activities, research projects, and disaster response can be found at <https://www.dlr.de/en/zki>.

The DLR-ZKI disseminates information through a variety of channels in order to facilitate rapid and effective access for users. Printable maps are available for download directly from the department's homepage (<https://activations.zki.dlr.de/en/activations/>). Furthermore, the DLR-ZKI publishes specialized geospatial layers, such as flood masks, available for download to support detailed analysis and planning (<https://activations.zki.dlr.de/en/activations/?type=flood>). Additionally, web-based map viewers are implemented for interactive data visualization, enabling users to explore and customize layers according to their needs. Depending on the sensitivity of the data, access to these web-based map viewers can be restricted via password protection. The technical implementation and specific features of the web-based map viewer was developed for the June 2024 flood and are described in more detail in Sects. 3.3, 3.4.

3 Earth observation-based information during the June 2024 flooding in Germany

The following subchapters describe the onset and development of the flooding as well as the planning and implementation of operational activities, and the different data acquired. The data processing workflow is then outlined, along with the integration of all datasets into a web-based visualization platform.

3.1 Event onset and hydrological context

At the beginning of June 2024, southern Germany experienced a period of prolonged, heavy rainfall, leading to a rapid rise in water levels, particularly in the border state of Baden-Wuerttemberg and in the state of Bavaria. The resultant floods were extensive, particularly in Swabia and the Danube region, requiring numerous emergency measures.

The onset of the event could be traced back to the 29th of May, when a warning of prolonged and continuous heavy rainfall was issued for southern Germany. This was attributed to the so called Vb weather pattern, where warm, moist air from the Mediterranean region moves over Central Europe, leading to heavy rainfall when encountering cold air masses from the north [6]. The upper soil layers had already been saturated by heavy rainfall in the previous weeks, making it difficult for the soil to absorb and store water [6]. Together with the weather conditions and the water-saturated soil, it was especially the predicted long duration of precipitation that significantly increased the risk of rising water levels [6, 7].

On the 31st of May, heavy rain began to fall in Germany, moving from southern Bavaria and Lake Constance to the eastern half of Bavaria by the morning of June 1st. The precipitation continued until the low-pressure system moved eastwards towards Poland, until finally ceasing on the 3rd of June in most affected areas [8]. In certain regions, the precipitation levels reached twice the average monthly rainfall for May [6]. Record discharges were measured at 57 different water gauges [7]. In the main region of the foothills of the Alps, the hundred-year flood was exceeded by a factor of 1.7, making this event particularly severe and leading to extreme flooding [8].

This particular flood occurrence caused the fatalities of six people, multiple evacuations, and the declaration of a state of emergency in 15 districts and cities (Fig. 1). The masses of rainfall caused dams to break which resulted in a limited supply of electricity, drinking water and mobile communication [8]. According to the German Insurance Association, the estimated economic losses amounted to approximately 2 billion euros, not including the impact on crop yields and the transportation sector due to the disruption of rail, road, and waterway traffic.

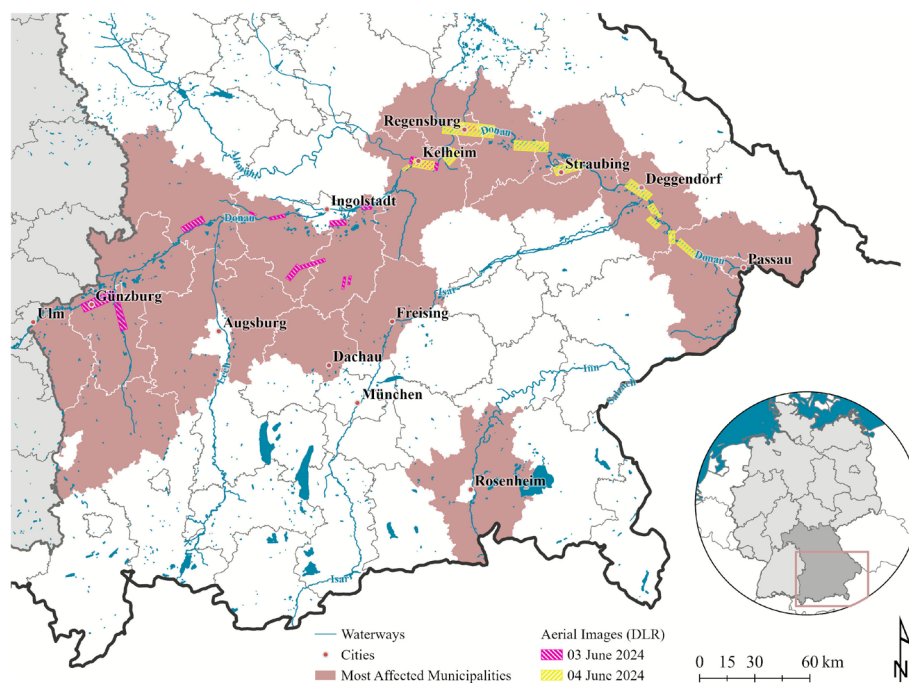


Fig. 1 Overview of the most affected municipalities and DLR flight areas during the flooding in June 2024. Map created by the authors using ArcGIS Pro 3.5 [9]

3.2 Operational planning and data acquisition

The DLR-ZKI was informed of a possible flood situation on the 29th of May through the meteorological warning services and user contacts (e.g. Bavarian Red Cross, BRK). A rapid-mapping activation was then initiated. Due to persistent cloud coverage, very high-resolution optical satellites could not be tasked. Therefore, the DLR-ZKI scheduled two aerial survey flights along the Bavarian Danube on the 3rd and 4th of June. Additionally, the DLR-ZKI tasked 30 cm Umbra SAR data. The flood extent was derived from medium-resolution Sentinel-1 and Sentinel-2 data. The timeline in Fig. 2 provides an overview of the data used and generated, and forms the basis for the detailed data descriptions in the following subsections.

3.2.1 Aerial imagery

Following the immediate aftermath of the flood occurrence, the DLR provided the first professional aerial images of the affected areas with a 10 cm ground resolution. These images were taken on the 3rd and 4th of June 2024 using the 3K camera system consisting of three non-metric Canon cameras (EOS 1Ds Mark III) equipped with 50 mm ZEISS lenses from the Institute of Remote Sensing Technology [10]. The systems were mounted on the DLR research aircraft DO228-212 (D-CFFU) and could be deployed spontaneously in the affected areas along the Danube in cooperation with the flight crew of the department of Flight Experiments. Due to the challenges provided by poor weather conditions and sometimes very low cloud cover, the flight planning was adjusted several times during the flights and had to be closely coordinated with the respective air traffic control authorities. The average flight altitude was between 400 and 800 m above ground. Immediately after landing, digital orthophotos and mosaics for the respective areas of interest (AOI) were calculated from the images with position and location data from aircraft. Data corrections were carried out by the Satellite Positioning Service of the German National Survey Department (SAPOS) alongside the Copernicus Digital Elevation Model. The aerial images were available for use early the next day. The AOIs were defined in close cooperation with the BRK and by observing the flood progression. A total of 24 AOIs were encompassed by the flights—13 AOIs on June 3rd and 11 AOIs on June 4th. The size of the AOIs varied between 4 and 73 km² (Fig. 1). In total, more than 453 km² were covered by the aerial flights within approximately nine flight hours. No further flights were required as the cloud cover cleared in the following days and the water levels receded back to safe levels.

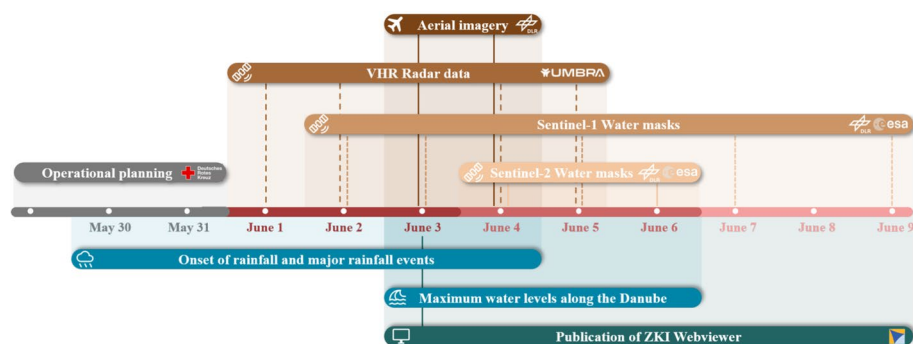


Fig. 2 Timeline of the rapid mapping activation from the onset of the event to the publication of the web viewer showing all airborne and satellite data acquired during the flood

3.2.2 Satellite imagery

The DLR maintains a processor for automated surface water monitoring from Copernicus Sentinel-1 (SAR) and Sentinel-2 (multi-spectral) satellite images. The processing chain uses sensor-specific convolutional neural networks (CNN) trained on a globally distributed, multi-modal reference dataset [11] to automatically extract the extent of open water bodies. The processor is continuously improved and adapted to new scenarios. More information on the methodology can be found in [12, 13].

In order to rapidly distinguish inundated areas from non-flooded surface water extents, the DLR hosts a precomputed seasonal reference water mask. The reference water mask product consists of aggregated surface water information over an observation period of two years and is primarily based on the analysis of Sentinel-2 data, complemented by Sentinel-1 based information in regions where optical acquisition availability is scarce [14]. This flood mapping workflow has been extensively tested and is regularly applied in the context of scientific studies and DLR-ZKI disaster/ rapid mapping activations. The latest use-cases include flood disaster activations in Pakistan 2022, Chad 2022, and Germany 2021. Global continuous monitoring of surface water bodies is currently being implemented and data collections will be made publicly available. The flood processor was able to provide information for most of the affected regions in Bavaria and Baden-Wuerttemberg during the floods in southern Germany between the 2nd and 10th of June 2024. The majority of the information was derived from Sentinel-1 data, as the two possible Sentinel-2 acquisitions (June 4th and 6th) were too cloudy for consistent analysis. In addition to flood masks, very high-resolution satellite data were also integrated into the DLR-ZKI's products. This included an optical GeoEye image of Deggendorf provided by European Space Imaging (EUSI), with a resolution of 50 cm. Further optical imagery was however not possible due to high cloud cover. Nevertheless, (high) cloud coverage does not pose a challenge for radar imagery. Consequently, EUSI was able to cover a total of seven regions between the 1st and 5th of using very high-resolution Umbra radar data. The Umbra images—with a spatial resolution of 30 cm—currently require expert-based evaluation due to the absence of automated processing to reveal flood areas.

3.2.3 Ancillary data

To enhance the value of the satellite data and its derived products, additional geospatial data were integrated into the DLR-ZKI's informational products to provide essential context for more targeted planning of rescue operations. All data were obtained from the Bavarian Surveying Administration and constitute official information [15]. Building footprints and the general extents of residential areas were combined in the web-based viewer, to indicate the locations of settlements potentially affected by the extent of the flood. This information enabled the rapid identification of areas with the highest concentration of residential buildings at risk. To assess the accessibility of the affected regions and to plan relief measures based on road and rail network conditions, official data on transportation infrastructure were also included. These geospatial layers can be overlaid with flood masks to visualize the impact on accessibility.

3.3 Integration and dissemination

In addition to printable maps [16], the DLR-ZKI has set up a password-protected web-based map viewer containing various data sets visualizing and analyzing the extent of the flooding. The web-based viewer is based on Esri's ArcGIS Experience Builder, which provides a robust and flexible platform for customizing geospatial applications [17] (see Figs. 3 and 4). Esri technology is widely recognized for its advanced mapping and data visualization capabilities, which have made it a popular choice for disaster response and management [18–21].

The decision to use ArcGIS Experience Builder was based on several advantages. The software allows rapid deployment of customized applications through a low-code environment, supports seamless integration with the broader Esri ecosystem (including ArcGIS Online and Living Atlas), and offers a wide range of ready-to-use widgets. Furthermore, its user-friendly interface reduces onboarding time, a key factor during time-sensitive disaster scenarios. Another important consideration was interoperability. Many public protection and disaster relief organizations in Germany, including the Federal Agency for Technical Relief (THW), also use Esri-based environments, ensuring smooth data exchange and familiarity for end users.

One of the principal advantages of utilizing a web-based viewer is its capacity for continuous updates. In contrast to printed maps, which become outdated as soon as conditions change, web-based viewers can be updated in near real-time to reflect the latest developments. This provides users with access to the most up-to-date information,

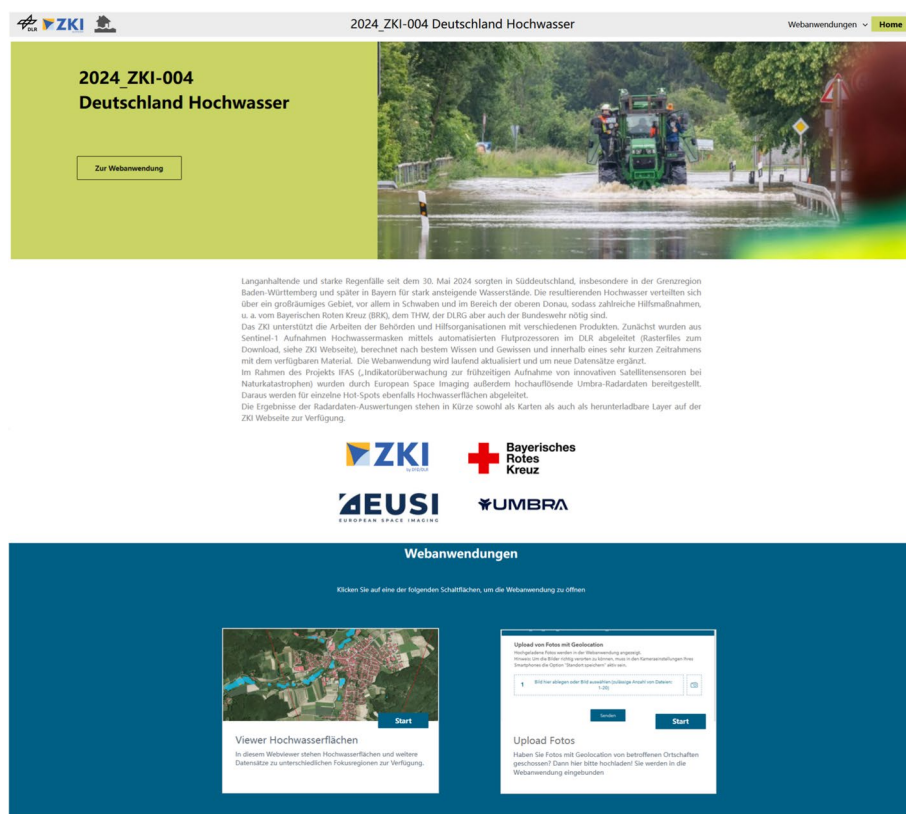


Fig. 3 Landing page of the web-based viewer “Flood Germany 2024”. The landing page offers a short introduction to the event and users have multiple different options to access the data. Additionally, users can upload photos relevant to the disaster. Web-based viewer created by the authors using ArcGIS Experience Builder, version 3.24 [17]



Fig. 4 Flood zones and affected areas in Passau, Germany. Flooded areas are shown in light blue, the reference water mask is shown in dark blue. Additional information (e.g. infrastructure and settlement areas) are shown in pink. Web-based viewer created by the authors using ArcGIS Experience Builder, version 3.24 [17]

facilitating more informed and effective decision-making. This flexibility has made them indispensable not only during flood occurrences, but also in broader crisis scenarios such as disease spread [22] or conflict monitoring [23].

Web-based viewers also generally provide more information than printed maps. Multiple focus areas, such as flood zones, infrastructure, building footprints, and population density, can be combined into one single interactive platform instead of visualized on multiple printed maps. The web-based viewer developed for the June 2024 flood integrated satellite imagery, DLR aerial imagery and flood extent layers (see Sect. 3.2). In addition, external datasets, including governmental geospatial data, such as building footprints, roads and railways, were incorporated to provide a comprehensive overview of the situation (Fig. 4).

The web-based viewer is remotely accessible, which makes it ideal for collaborative work independent of location. It also allows for fast dissemination of information through a single URL. During the June 2024 flooding, it was primarily used by public authorities, including the Federal Agency for Cartography and Geodesy (BKG) and the Federal Office of Civil Protection and Disaster Assistance (BBK), as well as public protection agencies and disaster relief organizations such as the BRK and the THW. During the flood occurrence in 2024 between the 3rd and 10th of June, the web-based viewer was accessed on 817 separate occasions. By the time this paper is published, this number has risen to over 1250.

The initial version of the web-based viewer, comprising basic flood extent information, was published within just a few hours after the event. Additional data, including satellite scenes, aerial imagery and water masks, were added successively. Aerial image processing, orthophoto generation, and upload of the data acquired during the DLR's own flight campaigns to the web-based viewer took around one day (see Sect. 3.2.1). This shows how web-based viewers are essential tools in disaster response, as they offer a flexible and interactive alternative to traditional mapping. The ability to dynamically combine different data sources enables a high level of contextual awareness, making these viewers especially useful during rapidly evolving situations. Beyond this specific rapid mapping

activation, similar DLR-ZKI web applications have proven effective in other emergencies, including during the Türkiye and Syria earthquake in 2023 [24], as well as for humanitarian relief missions and disaster management [25, 26].

3.4 Web viewer: key functions and widgets

The web-based viewer provided a number of standard and DLR-specific key functions and widgets with the objective of enhancing user interaction and improving decision-making during the crisis. These include:

- Users can toggle different geospatial data layers (e.g. flood extent, infrastructure) to change the focus of the displayed relevant information, to improve clarity, and reduce visual clutter.
- Basemap Options: A variety of different map types, including topographic, satellite, Open-StreetMap, and terrain maps, offer different perspectives to support different analytical requirements.
- User Data Upload: Users can upload relevant datasets (e.g. CSV, vector files) or integrate external data via URLs to enhance data comprehensiveness.
- Layer Swipe: This tool allows side-by-side comparisons of datasets, aiding in change and impact analyses. Responders can use the tool to compare pre-flood and during-flood images, allowing the identification of submerged infrastructure in the affected region.
- Drawing Tools: Users can draw lines, points, or polygons on the map to highlight important areas, plan routes, or mark locations requiring immediate attention, which helps in dynamic decision-making.
- Geographic Coordinates Extraction: Users can click on the map to retrieve precise coordinates for tasks like rescue coordination.
- Bookmarks: Predefined hotspots and user-created bookmarks simplify navigation to critical locations without manual searches.
- Printing: Customizable map views can be printed for offline use, with specific layers and markers tailored to field requirements.
- Geotagged Image Uploads: Users can upload geotagged photos from mobile devices. These images are then automatically placed on the map to enhance situational awareness and real-time documentation (see Fig. 5).

The integration of these tools enabled a flexible, interactive and user-centric platform to support disaster response operations. Users could customize their map views, add their own data and easily navigate through key areas. This further demonstrates how the web-based viewer supports efficient and effective decision making in critical situations.

3.5 Web viewer: limitations and usability considerations

While web viewers offer many benefits in a variety of contexts, it is important to recognize their inherent limitations, especially when it comes to high-risk situations like crisis management. One of the most significant drawbacks is their reliance on internet connectivity. In instances where infrastructure is compromised or connectivity is constrained, accessing the web viewer can be challenging or even impossible. Furthermore, handling large geospatial datasets in near real-time can result in performance issues, such as prolonged loading times or unresponsive interfaces, particularly when users



Fig. 5 Image upload via smartphone and automatic integration into the web viewer based on geolocation is shown. Upload interface and web-based viewer created by the authors using ArcGIS Survey 123, version 2.34 [27] and ArcGIS Experience Builder, version 1.15 [17]

operate on less powerful devices. The effective use of web-based geospatial viewers also requires a basic level of digital literacy and, ideally, prior familiarity with the platform. While the DLR-ZKI tries to ensure low-threshold access to their information products, user feedback suggests that under particularly time-critical emergency conditions, the operational complexity of such tools can pose a barrier. Although decision-makers often possess the skills to interact with web viewers, first responders sometimes require additional support or training to integrate these tools into their workflows. As web-based viewer technologies become increasingly more common in emergency management practices, and as such user interfaces are further adapted to operational requirements, these usability challenges are expected to decrease over time.

3.6 Web viewer: user feedback and operational experience

To evaluate the usability and effectiveness of the web viewer, structured feedback was collected from participants across various operational contexts, including real rapid mapping activations, exercises, and projects. The setup and functionalities of the different web-based viewers are highly similar, ensuring that user feedback can be easily transferred to the general DLR-ZKI web-based viewer template. Respondents of the survey included members of public protection agencies and disaster relief organizations such as the above mentioned BRK, the World Food Programme (WFP), firefighting units, and other emergency services. Overall, users evaluated the web-based viewer positively. The 2D visualization was frequently highlighted as clear and easy to use while still providing all necessary information. Users appreciated the simple interface and overview capabilities, reporting high satisfaction with both the built-in tools (average rating: 4 out of 5) and the selection of datasets (average rating: 4.4 out of 5). Satellite, aerial, and drone imagery were considered particularly valuable for situational awareness, with most users expressing a preference for imagery-based basemaps. The importance of real-time data availability, as well as adequate spatial and temporal detail, was consistently emphasized.

Key datasets identified by the respondents as most relevant included flood extents, damaged infrastructure, and affected population. The web-based viewer was generally preferred as the primary source of accessing information, although printed maps were still regarded as useful for fieldwork. Users also highlighted the benefit of being able to overlay different georeferenced datasets and described the platform as a low-barrier, high-impact tool for operational coordination. On the other hand, some users noted that non-experts, such as volunteers, might require an introduction to effectively use the web-based service. This feedback further confirms that the web-based viewer successfully meets the requirements of diverse emergency stakeholders and supports informed decision-making under time-critical conditions.

4 Discussion and outlook

The 2024 flood response in southern Germany provided an opportunity to evaluate and refine rapid mapping methods for disaster management. The rapid mapping activation demonstrated that not only are flexible sources of data and methodological robustness important to the efficiency and utility of crisis information products, but timely dissemination is also a determining factor.

Well-established crisis response mechanisms like the Copernicus Emergency Management Services (CEMS) [28] or the International Charter “Space and Major Disasters” [29] already exist within the context of disaster management. Additionally, international rapid mapping initiatives like the United Nations Satellite Centre UNOSAT [30] provide quick estimates in a web-based viewer of the number of affected people and infrastructure during disasters. These platforms provide robust and reliable geospatial data that support emergency operations.

The DLR-ZKI differs from these services as it focuses on research related to crisis preparedness and response. If suitable, the DLR-ZKI contributes to crisis response by utilizing state-of-the-art methodologies or by providing exclusive data, such as aerial imagery, in addition to already existing mechanisms. The primary objective, however, lies in developing and testing innovative approaches for disaster mitigation and management in close collaboration with end users. The presented paper demonstrated such an integrated approach, in which the DLR contributed both aerial imagery acquired with its own aircraft and camera systems and products derived from its internal flood processing chain.

A key methodological strength of the web-based viewer for the June 2024 flood was the multimodal data strategy, integrating optical, radar, and aerial imagery. This combination ensured both spatial coverage and local detail under varying conditions. The complementary use of Sentinel-1/2 data, high-resolution radar imagery, and aerial photography mitigated limitations associated with individual sensors, such as (high) cloud cover or restricted acquisition capacity. However, differences in resolution, data formats, and acquisition latency introduced challenges in the harmonization of data. These findings highlight the need for standardized preprocessing pipelines, improved co-registration routines, and automated data fusion workflows to enable scalable and repeatable applications. Maintaining these standards is an ongoing effort, managed continuously between crises to ensure that data handling and processing do not cause significant delays during disasters. Even so, with the increase of new satellite sensors and data products, the rapid delivery of crisis information will continue to be a challenge and should

not only be addressed by the organizations responsible for producing enhanced information but also by the data providers.

Interoperability remains a methodological cornerstone for collaborative crisis response. The adoption of OGC-compliant standards (e.g., WMS, WFS) would facilitate seamless data exchange across agencies and platforms, reducing redundancy and improving information flow [31]. Similarly, consistent use of Esri-based or open-source frameworks can improve compatibility and long-term maintainability of geospatial infrastructures.

Building on this, automation plays a pivotal role in accelerating data processing and ensuring the timely delivery of information during a crisis. This holds particularly true for flood detection process chains and classifications which, through automation, substantially reduced overhead, and allowed near-real-time dissemination of results. Despite this, further improvements are possible, especially regarding the automatization of quality control, metadata generation and web publication. These tasks still demand extensive manual expert handling, making them relatively time-consuming.

The use of web-based dissemination platforms proved essential for operational coordination. Web-based viewers enable centralized data access, near real-time updates, and integration of heterogeneous data layers, from flood extents and infrastructure damage to meteorological and hydrological parameters. Their modular design supports low-latency information sharing and user-specific customization. Still, technical dependencies such as internet connectivity and device performance must be addressed through low-bandwidth optimization and mobile-ready interfaces to ensure usability in field conditions. Furthermore, several organizations have reported that some of their volunteers, often with limited experience using digital tools, encounter difficulties navigating web-based platforms. To address this, users have requested comprehensive introductions, simplified access procedures, and, in some cases, workshops to support effective operational use of the web viewer. The DLR-ZKI attempts to address this issue with dedicated user interactions during projects and exercises.

Our research aims to anticipate crises and to be better prepared during such events so that informational products and data can be published in a timely manner to benefit the crisis management sector and the general population. Meteorological data, specifically real-time precipitation forecasts and historical precipitation data, could assist in the prediction of future flood risks and the identification of regions most vulnerable to further inundation. River and stream gauge data can provide real-time water level data (e.g. [32]), allowing responders to monitor rising waters and plan evacuations or protective measures more effectively. Topographical and elevation models are also important to the analysis of flood events, as they allow responders to assess the movement of water across different terrains and identify natural barriers or low-lying areas that are at greater risk of being submerged. However, collecting, streamlining and maintaining these data sources is still a challenge that requires further investigation.

Finally, these methods demonstrate a high degree of transferability. The modular DLR-ZKI workflow—combining Earth observation data, automated analysis, and web-based visualization—can be adapted to other regions and hazard types, provided that compatible data sources and digital infrastructures are available. This is also reflected by the widespread use of the workflow and web-based viewer in various rapid mapping activations (<https://activations.zki.dlr.de/en/activations/>).

In summary, the following key findings may provide valuable insights for other space-based crisis response teams:

- Early coordination with stakeholders is essential. Rapid engagement with civil protection agencies ensured that products were targeted to real operational needs.
- Automation accelerates impact. Pre-developed processing chains for flood detection from Sentinel-1/2 significantly reduced delivery times.
- Shared use of Esri-based systems enabled smoother data exchange across public protection agencies and disaster relief organizations.
- User interface matters. Even the best data has limited impact without an intuitive platform. Training and interface design are critical for adoption.
- Having predefined flight plans, processing workflows, and team coordination significantly improved response efficiency.

These lessons underline that technical innovation is mutually dependent on process design and user engagement. With the increase of disaster frequencies and complexity, the ability to rapidly transform raw geospatial data into usable information will be a defining capability for emergency response institutions.

5 Conclusion

The ongoing challenge of creating and implementing practical tools that can be easily used by first responders, humanitarian organizations, and government authorities lies in converting heterogeneous data and research. In general, effectively connecting ongoing research to crisis situations requires careful coordination and input from end users. Due to the amount of data available during a disaster, a solution that is both user-friendly and easily accessible is essential. It is thus important that only relevant research results are included, rather than overwhelming users with unnecessary information. Our work shows that in large-scale events, timely and detailed information is especially valuable. We demonstrated that a multimodal approach that integrates data from different sources (satellite and aerial imagery, derived products, and additional geospatial information) to provide a comprehensive situational overview for emergency responders is required in crisis situations. Since each crisis differs in scale and impact, flexibility in data handling and the ability to access various data sources are crucial. While the DLR-ZKI has established mechanisms for crisis response, the data and the methods information is generated and shared are tailored to the needs of the users. However, the constant factor in all cases is the time component. To save lives and plan operations efficiently, it is essential that information is made available as quickly as possible and in a comprehensible format. This can be achieved through the maintenance of an active user network, web-based viewer template solutions, and ongoing research.

Acknowledgements

The authors would like to thank all DLR colleagues, who contributed to the activation products and who supported the above-mentioned work. This includes colleagues from the German Remote Sensing Data Center and the DLR-ZKI duty team. The authors would also like to thank European Space Imaging for their quick and reliable data acquisition in case of a disaster.

Author contributions

A.S.: Outline of the paper, writing of the manuscript, ZKI activation coordination. M.H.: writing of the manuscript, GIS contributions and set up of web viewer, general Esri technology, S.G.: writing of the manuscript, calculation of flood layers and reference water masks, V.G.: flight operations and aerial image processing, M.G.: head of DLR-ZKI, supervision of activation.

Funding

Open Access funding enabled and organized by Projekt DEAL. Not applicable.

Data Availability

The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request. Access to the web viewer for the flood in June 2024 is available upon request for legitimate users. The water-mask rasters and printable PDF map products are available at <https://activations.zki.dlr.de/en/activations/item/s/ACT163/>

Code availability

Not applicable.

Declarations**Conflict of interest**

The authors declare no conflict of interest.

Ethical approval and accordance

I confirm that all the research meets ethical guidelines and adheres to the legal requirements of the study country.

Consent to participate

Not applicable.

Consent to publish

Not applicable.

Received: 19 August 2025 / Accepted: 14 January 2026

Published online: 27 January 2026

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