European Commission

Copernicus Emergency Management Service

Global Flood Monitoring (GFM)

Product User Manual

Prepared by the EXPERT FLOOD MONITORING ALLIANCE

Joint Research Centre

This publication is a Technical Report on the Global Flood Monitoring (GFM) product of the Copernicus Emergency Management Service, which is operated by an international consortium led by the Earth Observation Data Centre for Water Resources Monitoring GmbH (EODC), under a Framework Contract with the Joint Research Centre (JRC), the European Commission's science and knowledge service. The purpose of this report is to serve as a Product User Manual (PUM) for the GFM product, and provide a comprehensive overview of the available data and services.

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1 Introduction

As part of the Copernicus Emergency Management Service (CEMS)[1], the Global Flood Monitoring (GFM) product provides a continuous monitoring of worldwide flood events, by immediately processing and analysing in near real-time (NRT) all incoming Sentinel-1 Synthetic Aperture Radar (SAR) satellite imagery. The GFM product uses three independent, state-of-the-art algorithms - developed by three leading research teams (DLR, LIST, TU Wien) who are members of the GFM consortium - for systematic, automated delineation of flooded areas and water bodies based on all-weather, day-and-night Sentinel-1 SAR images.

The GFM product is designed to deliver, in NRT, critical information on ongoing floods events to users worldwide, including national authorities, emergency units, research centres, decision-makers and other stakeholders. The GFM product is specifically designed to address three major user requirements, namely:

- Providing a continuous global, systematic monitoring of flood events.
- Significantly enhancing the timeliness of flood maps for emergency response.
- Improving the effectiveness of activation requests of the CEMS Rapid Mapping component, through a better identification of the areas of interest.

The GFM product also provides a long-term archive of global flood monitoring data, making it an ideal source of information for planning mitigation and preparedness measures for future flood events, e.g. designing flood protection systems or calibrating hydrological models. Finally, combining data from the GFM product with data from other Copernicus services (e.g. the Copernicus Climate Change Service) can deliver useful information for addressing the challenges in the area of climate change response management.

This Product User Manual (PUM) is the reference document for all end-users and stakeholders of the GFM product of CEMS[2]. It provides all basic information for proper and effective use of the GFM product and its data output layers and describes the functions and capabilities of the GFM product, its applications and alternative modes of operation, and step-by-step guidance on accessing and using the GFM product. In order to enable users to become quickly familiar with the GFM product, a synthesized version of this PUM is provided online, as a Quick Start Guide[3]. Full scientific and technical details of the GFM product are provided on-line, in the GFM Product Definition Document (PDD)[4].

The quality of the GFM product is reported on a quarterly basis using Key Performance Indicators that monitor service availability, product timeliness, thematic quality, unique visitors, total visitors, and total downloads (European Commission, 2020). The results of the GFM product and service quality assessment are published online as Annual Reports[5].

[1] https://emergency.copernicus.eu/
[2] https://extwiki.eodc.eu/GFM/PUM
[3] https://extwiki.eodc.eu/GFM/
[4] https://extwiki.eodc.eu/GFM/PDD
[5] https://extwiki.eodc.eu/GFM/GFM_QA_Reports

The GFM product has been developed and implemented under a Framework Contract with the European Commission's Joint Research Centre (European Commission, 2020), by an international consortium (the "Expert Flood Monitoring Alliance") consisting of six partners:

▪ ***EODC*** *(Earth Observation Data Centre for Water Resources Monitoring GmbH).*	▪ ***LIST*** *(Luxembourg Institute for Science and Technology).*
▪ ***GeoVille*** *(GeoVille Information Systems and Data Processing GmbH).*	▪ ***DLR*** *(German Aerospace Centre / Deutsches Zentrum für Luft- und Raumfahrt e.V.).*
▪ ***TU Wien*** *(Technische Universität Wien).*	▪ ***CIMA*** *Foundation (International Research Centre in Environmental Monitoring).*

The GFM partnership represents Europe's leading group of scientific experts in satellite-based flood monitoring systems, with a wide-ranging and unique experience in global flood mapping services, and extensive links with the main information services of Copernicus (the EU's Earth observation programme), including CEMS and the Copernicus Land Monitoring Service (CLMS). From the earliest days of satellite-based flood mapping and monitoring, the individual members of the GFM consortium have built up unprecedented, complementary capabilities for flood mapping, monitoring, and related disaster risk services, and have accumulated a long history of implementing high-quality, successful applications and projects, and developing the related systems for global data processing and access.

2 Technical overview of the GFM product

The GFM product is an automated, global flood monitoring system that complements the existing components of CEMS for flood early warning and on-demand mapping, by providing continuous (i.e. all-weather, day-and-night), systematic monitoring of all major global flood events, in near real-time, based on the latest Sentinel-1 SAR satellite images.

Key features of the GFM product are the use of a historical time-series or "data cube" of SAR backscatter data, enabling high product timeliness, and implementation of an ensemble method comprising the GFM's three state-of-the-art SAR-based water and flood mapping algorithms, in order to improve the robustness and accuracy of the flood and water extent maps and to build a high degree of redundancy into the service (Wagner et al., 2026; Wagner et al., 2020; Salamon et al., 2021; Matgen et al., 2020).

For each newly acquired Sentinel-1 SAR satellite image, the GFM product provides 10 output layers of worldwide flood-related information, which are listed in Table 1.

Table 1: The ten GFM output layers of global flood-related information, generated in near real-time based on Sentinel-1 SAR satellite imagery.

#	*OUTPUT LAYER*	*DESCRIPTION*
1	**Observed Flood Extent**	▪ Flooded areas mapped by applying the GFM ensemble flood mapping algorithm to the latest Sentinel-1 images of SAR backscatter intensity.
2	**Observed Water Extent**	▪ Open and calm water mapped as the union of the Observed Flood Extent and the Reference Water Mask.
3	**Reference Water Mask**	▪ Normal (i.e. permanent and seasonal) water mapped by applying the GFM ensemble water mapping algorithm to the most recent historical time-series (or "data cube") of Sentinel-1 SAR backscatter images, for a five-year reference period (i.e. 2017-2021).
4	**Exclusion Mask**	▪ Areas where SAR-based water mapping is not technically feasible, due to no sensitivity (e.g. urban areas, dense vegetation), low backscatter (e.g. flat impervious areas, sandy surfaces), topographic distortions, radar shadows, or low coverage of Sentinel-1.
5	**Likelihood Values**	▪ Likelihood (0-100%) of correct flood classification for all pixels outside Exclusion Mask.
6	**Advisory Flags**	▪ Flags indicating potential reduced quality of flood mapping, due to prevailing environmental conditions (e.g. wind, ice, snow, dry soil), or degraded input data quality due to signal interference from other SAR missions;
7	**Sentinel-1 Footprint and Metadata**	▪ Image boundaries of the Sentinel-1 data used, and in addition information on the "metadata", i.e. the acquisition parameters of the Sentinel-1 data used.
8	**Sentinel-1 Schedule**	▪ Next scheduled Sentinel-1 data acquisition.
9	**Affected Population**	▪ Number of people in flooded areas, mapped by a spatial overlay of Observed Flood Extent and gridded population, from the Copernicus GHSL project.
10	**Affected Landcover**	▪ Land cover / use (e.g. artificial surfaces, agricultural areas) in flooded areas, mapped by a spatial overlay of Observed Flood Extent and the Copernicus GLS land cover.

The operational implementation the GFM product includes the following key elements:

▪ Downloading of worldwide Sentinel-1 SAR Level-1 Ground Range Detected (GRD) satellite imagery from ESA.
▪ Pre-processing the downloaded Sentinel-1 data, and storing the resulting georeferenced image stacks as a spatio-temporal SAR "data cube" (or time-series) of backscatter data
▪ Operational application in near real-time and at a global scale, of the GFM's three state-of-the-art, fully automated flood mapping algorithms, in an "ensemble" approach in order to ensure an optimal accuracy of the derived flood and water extent maps, and to build a high degree of redundancy into the production service.
▪ Generation of Sentinel-1-based GFM output layers, including Observed Flood Extent, Observed Water Extent, Reference Water Mask, Exclusion Mask, and Likelihood Values.
▪ Web service-based product access and dissemination of the GFM output layers, including an appropriate user support service.
▪ Regular GFM product and service quality assessments, including assessment of product timeliness and thematic accuracy, and service reliability and accessibility.
▪ As stated in the Technical Specifications (European Commission, 2020), as well as the 10 output layers of flood information, the GFM product is used to generate an archive of worldwide observed floods and water bodies, from 1 January 2015 until recently.

Central to the GFM product are three state-of-the-art algorithms for the SAR-based detection and delineation of flooded areas, which were developed by members of the GFM consortium (LIST, DLR, TU Wien). In order to ensure optimal accuracy of the derived flood (and water) extent maps, and to build a high degree of redundancy into the production service, the GFM product deploys the three state-of-the-art flood mapping algorithms in an "ensemble" approach, whereby an area (i.e. grid-cell) is considered to be flooded if:

- It is classified as flooded by at least two of the three algorithms, in the normal case when all three algorithms produce a result.
- It is classified as flooded by two algorithms, in the exceptional case when only two of the three algorithms produce a result.

The GFM's three flood mapping algorithms are briefly described and compared in Table 2. Full technical descriptions of the three GFM flood mapping algorithms, and the Ensemble algorithm, are provided in the GFM Product Definition Document (PDD)[4].

Table 2: Overview of the three state-of-the-art GFM algorithms (LIST, DLR, TU Wien) for SAR-based flood (and water) mapping.

GFM FLOOD MAPPING ALGORITHM	*MAIN TECHNICAL FEATURES*	*SCIENTIFIC REFERENCE*
Algorithm 1 (LIST)	▪ Hierarchical split-based approach enabling re-calibration of parameters in NRT based on the most recent S-1 image pair. ▪ Uses a highly innovative sequence of hierarchical image splitting, statistical modelling and region-growing to delineate and classify areas with changed flood-related backscatter between two image acquisitions from the same orbits.	Chini et al. (2017)
Algorithm 2 (DLR)	▪ Fuzzy logic-based approach enabling a post-classification and region-growing, taking advantage of topography-derived indices in addition to SAR backscatter.	Martinis et al. (2015)
Algorithm 3 (TUW)	▪ Fully automatic, pixel-based flood extent mapping, which exploits each pixel's full Sentinel-1 signal history in a data cube (time-series) of backscatter measurements. ▪ Enables a very fast, scalable production of flood extent maps through pre-computed global parameters at high quality.	Bauer-Marschallinger et al. (2022)

In order to optimize further the quality of the results of the GFM product, an Exclusion Mask is used to exclude those areas where SAR-based water (and flood) detection is not technically feasible. The GFM Exclusion Mask is created by combining global information layers delineating the following ground surface characteristics:

- No sensitivity areas (e.g. urban areas, dense vegetation), where Sentinel-1 SAR is not sensitive to flooding (or any other type of change) of the ground surface.
- Water look-alikes (e.g. flat impervious areas, sand surfaces), which are indistinguishable from flooded areas due to a low backscatter signature.
- Areas with strong topography (and low probability of flood occurrence), where the Sentinel-1 signals are affected by topographic distortions.
- Radar shadows of mountains, high vegetation canopies or man-made structures.
- Areas with low coverage (revisit frequency) of Sentinel-1 observations, where there is an inadequate historical time-series of SAR data available.

Regarding the Key Performance Indicators that are used as part of the GFM product and service quality assessment to monitor **service availability**, **product timeliness**, **thematic quality**, **unique visitors**, **total visitors**, and **total downloads**:

- The guaranteed 99% service availability of the GFM product is facilitated through EODC's expertise in Sentinel-1 processing operations (begun in 2014), which are regularly assessed by the ESA mission reports. These *lessons learned* are used to implement a completely independent IT infrastructure for GFM operations, which are also organized through redundant 24/7 production coordinator staff availabilities.

- The experience of the entire GFM consortium is used to ensure a product timeliness of 8 hours or less for generating the GFM output layers of worldwide flood information, for all Sentinel-1 GRD scenes available on ESA data hubs within 5 hours of acquisition. Some of the practical measures that ensure product timeliness are listed in Table 3.
- As stipulated in the Technical Specifications (European Commission, 2020), the thematic accuracy of the GFM Observed Flood Extent and Reference Water Mask, should reach a Critical Success Index target of at least 70%. Based on multiple test-cases, for both GFM output layers the thematic accuracy is generally satisfactory[5].

Table 3: Main practical measures to ensure the product timeliness of the GFM product.

#	DESCRIPTION OF MEASURE
1	▪ A redundant Sentinel data access via multi-access point data downloads and parallelization of downloads for an optimised bandwidth utilisation via the hubwatcher software.
2	▪ Automatic retrieval of Sentinel-1 GRD data with the hubwatcher in 96.3 minutes (on average) following ESA publication for general availability.
3	▪ Pre-processing of Sentinel-1 GRD data products and inclusion into the data cube format within 10-20 minutes per scene.
4	▪ Fast data access to the data cube with IO speeds of 15 gibibytes (gib) or 120 gigabytes (GB) per second.
5	▪ Generation of the “ensemble” GFM product using the three parallel flood mapping algorithms consumes up to 30 minutes, with the final flood extent maps and uncertainty values being calculated within a matter of seconds.
6	▪ Total lead-time of the GFM product is 60 minutes, to complete the entire operational NRT workflow from image acquisition to delivery.

3 Description of the ten GFM output layers of worldwide flood-related information

The ten GFM output layers of flood-related information (see Table 1) are briefly described and illustrated in the following sub-sections. Full technical details of the GFM output layers are provided in the GFM Product Definition Document (PDD)[4]. The data formats of the ten GFM output layers are summarized in Table 4.

Table 4: Summary of the data formats of the 10 GFM output layers.

#	GFM OUTPUT LAYER	DATA FORMAT	#	GFM OUTPUT LAYER	DATA FORMAT
1	***Observed Flood Extent*** *(and Maximum Flood Extent)*	*OCG / geojson*	6	***Advisory Flags***	*OCG*
2	***Observed Water Extent***	*OCG*	7	***S-1 Metadata & Footprint***	*Json / geojson*
3	***Reference Water Mask***	*OCG*	8	***S-1 Schedule***	*Geojson*
4	***Exclusion Mask***	*OCG*	9	***Affected Population***	*OCG*
5	***Likelihood Values***	*OCG*	10	***Affected Land Cover***	*OCG*

3.1 GFM output layer: Observed Flood Extent

The GFM output layer Observed Flood Extent identifies the pixels covered by floodwater, mapped using Sentinel-1 SAR backscatter intensity. An example of this output layer is shown in Figure 1. Pixels that are normally under water (identified using the monthly Reference Water Mask) are not part of this output layer. Observed Flood Extent is derived using the GFM ensemble flood mapping algorithm, as described in Section 2 above.

To map flood extent pixels for a certain date, the algorithm uses as input the Sentinel-1 data overpass plus offline-generated Sentinel-1 SAR parameters and auxiliary thematic datasets such as Exclusion Mask and topography (e.g., DEMs and HAND index). The relative orbit path information, to select the corresponding offline-generated Sentinel-1 SAR parameters, is extracted from the Sentinel-1 Metadata. During the near real-time operation of the GFM product, the acquisition month of the Sentinel-1 scene is retrieved from the Sentinel-1 Metadata and the corresponding monthly Reference Water Mask is cropped to the extent of the processed Sentinel-1 scene. All the processing is done at the 20 metres spatial resolution of the Sentinel-1 pre-processed data cube.

Flood pixels values in the Observed Flood Extent output layer are then adjusted based on values of the Exclusion Mask and Reference Water Mask, as follows:

Flood pixel value:	*Exclusion Mask or Reference Water Mask values:*	*Adjusted flood pixel value:*
1 (i.e. Flood)	*1 (i.e. TRUE)*	*0 (i.e. No flood)*

Note that pixel values in the Observed Flood Extent output layer will be No data (i.e. 255) if all three individual algorithms used to compute the flood ensemble return no data (i.e. for locations not covered by the Sentinel-1 satellite).

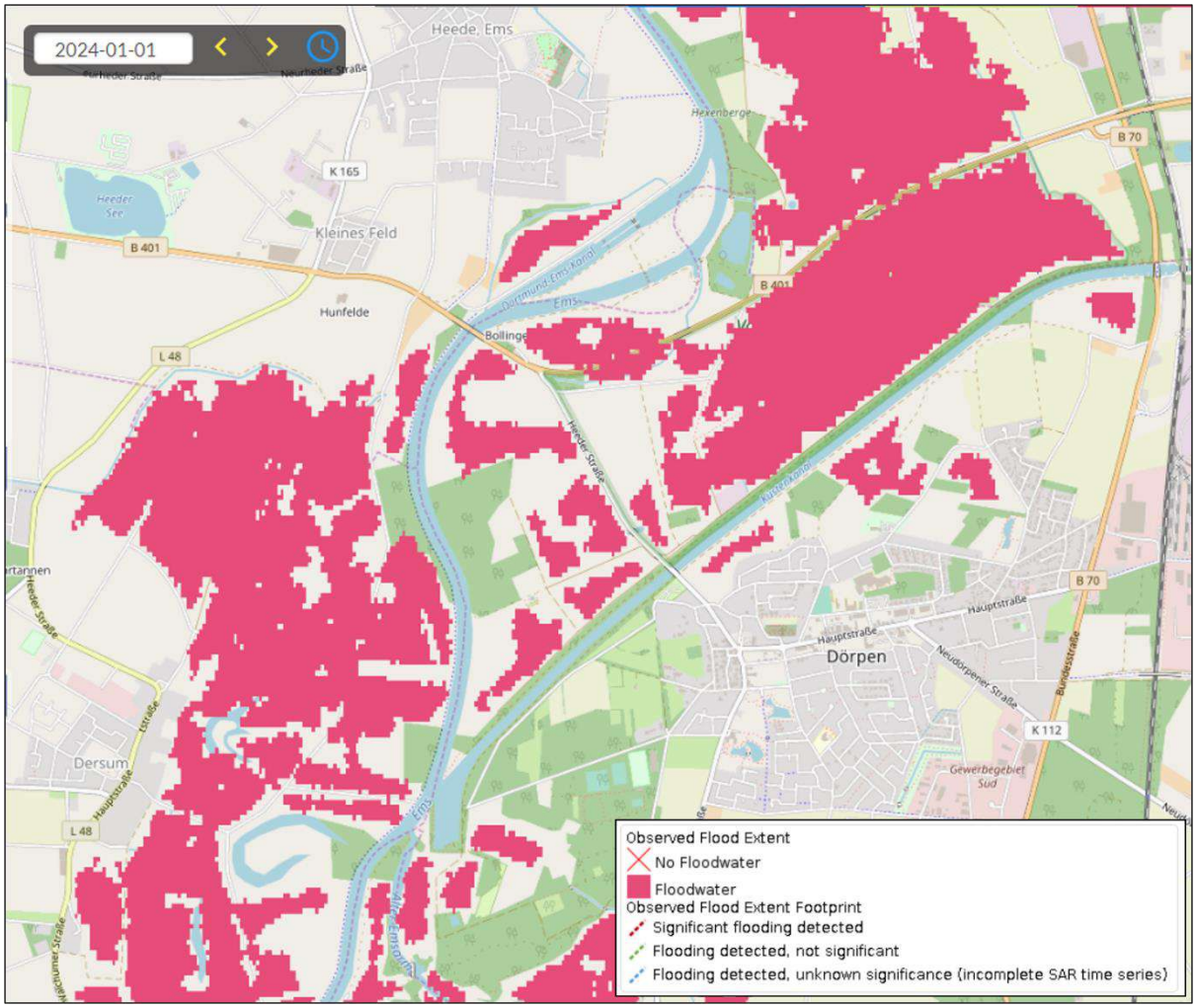


Figure 1: Example of the GFM output layer "Observed Flood Extent".

3.1.1 Maximum Flood Extent

This second-level output layer allows users to download an automatically generated composite showing the maximum flood extent of the available GFM Observed Flood Extent, within a specific time-frame (the limit is two months) for any area of interest. Note that the query can be submitted via both the GFM Web Portal and the REST-APIs, giving users the options to retrieve data as vector (geojson), raster (OCG), or both formats. Further guidance on the proper use of this function is available in the GFM Quick Start Guide[3].

3.2 GFM output layer: Observed Water Extent

The GFM output layer Observed Water Extent shows pixels classified as open and calm water based on Sentinel-1 SAR backscatter intensity and is derived using the GFM ensemble flood and water mapping algorithms. An example of this output layer is shown in Figure 2.

To map water extent pixels for a certain date, the algorithm uses as input the Sentinel-1 data overpass plus offline-generated Sentinel-1 SAR parameters and auxiliary thematic datasets such as Exclusion Mask and topography (e.g. DEM and HAND index).

The relative orbit path information, to select the corresponding Sentinel-1 SAR parameters, is extracted from the GFM output layer Sentinel-1 Footprint and Metadata. All processing is done at the 20 metres spatial resolution of the pre-processed Sentinel-1 data cube.

The GFM output layer Observed Water Extent is created as a union of the GFM Observed Flood Extent (from the GFM ensemble flood mapping algorithm) and Reference Water Mask (from the GFM ensemble flood mapping algorithm), which represents the extent of open water bodies under normal conditions. Reference masks of permanent water extent are often used in practice for this purpose (Wieland and Martinis, 2019).

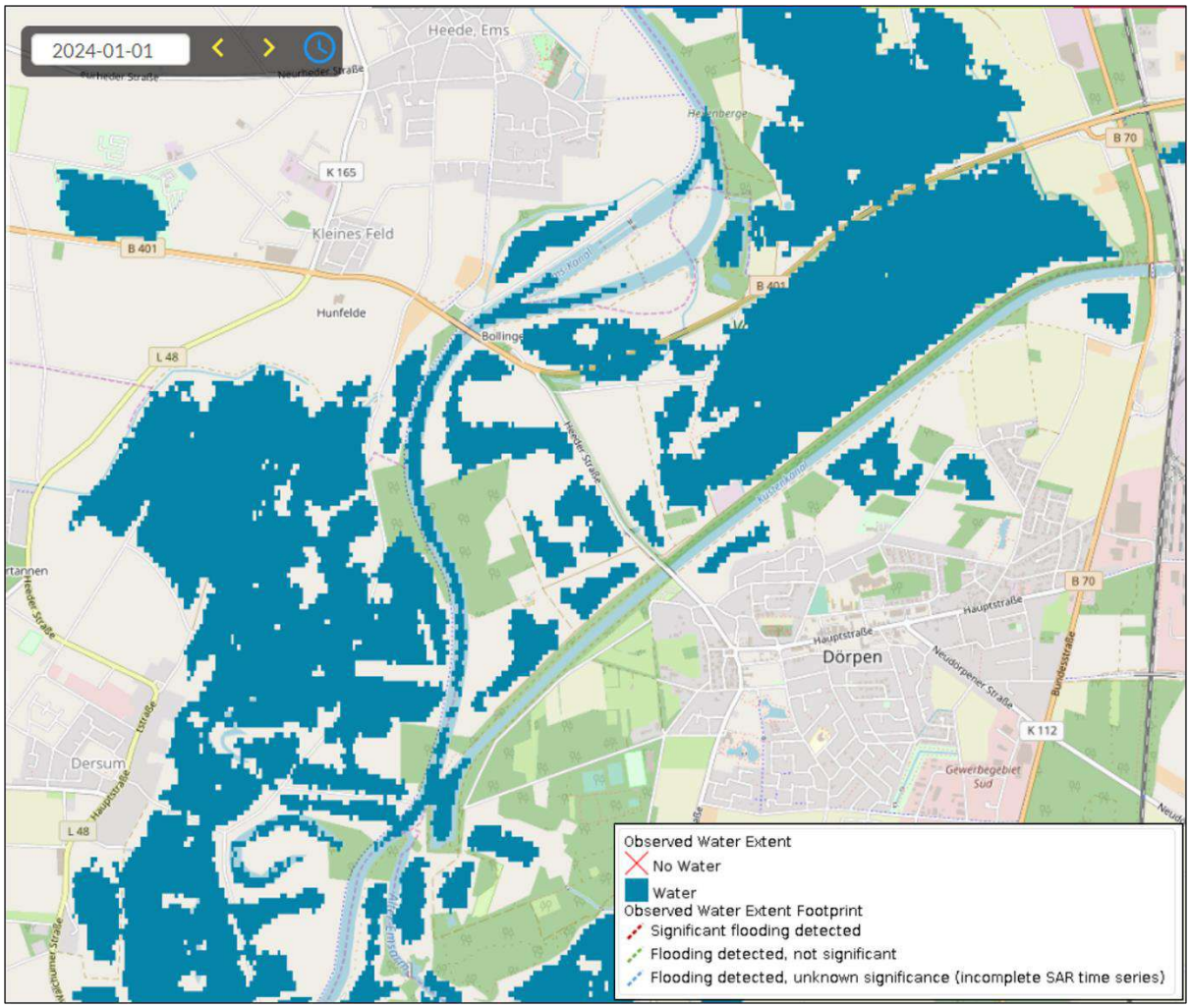


Figure 2: Example of the GFM output layer "Observed water extent".

3.3 GFM output layer: Reference Water Mask

The GFM Reference Water Mask shows open and calm water (permanent and seasonal), mapped by applying the GFM ensemble water mapping algorithm to a five-year "data cube" (time-series) of Sentinel-1 SAR backscatter intensity. An example is shown in Figure 3. Whereas mapping permanent water uses as input the median backscatter of all Sentinel-1 data from a five-year period (2018-2022), the mapping of seasonal water uses the median backscatter of all Sentinel-1 data from a given month over the same five-year period.

As a result, 12 masks are available, one per month, which includes information on the permanent and seasonal water extent. This parameter database is updated once a year. For example, the NRT system running in 2022 relied on the Reference Water Mask extracted from the Sentinel-1 pre-processed data cube from 2020 and 2021.

Radar shadow and low sensitivity exclusion layers, and the HAND index, are applied to the reference water mask (and associated uncertainty layer) to correct pixels that were possibly misclassified. Finally, the Copernicus Global Surface Water Maximum Water Extent layer (Pekel et al., 2016) is used to remove possible false positive classifications, while the Copernicus Water Body Mask is used to correct false negatives (e.g. large lakes with roughened surface falsely classified as land) and to enforce a consistent land-sea border.

A truly permanent water area would mean that there was observed water coverage in every single observation of the considered time-period, i.e., the Water Occurrence (WO), which is the ratio between the number of water detections during a certain time-period and the number of valid observations of the same period, would be 100%. To consider uncertainties in the single water segmentations and the occurrence of hydrological extreme events the WO threshold is usually relaxed to a value of 85-90 % (e.g. Pekel et al., 2016).

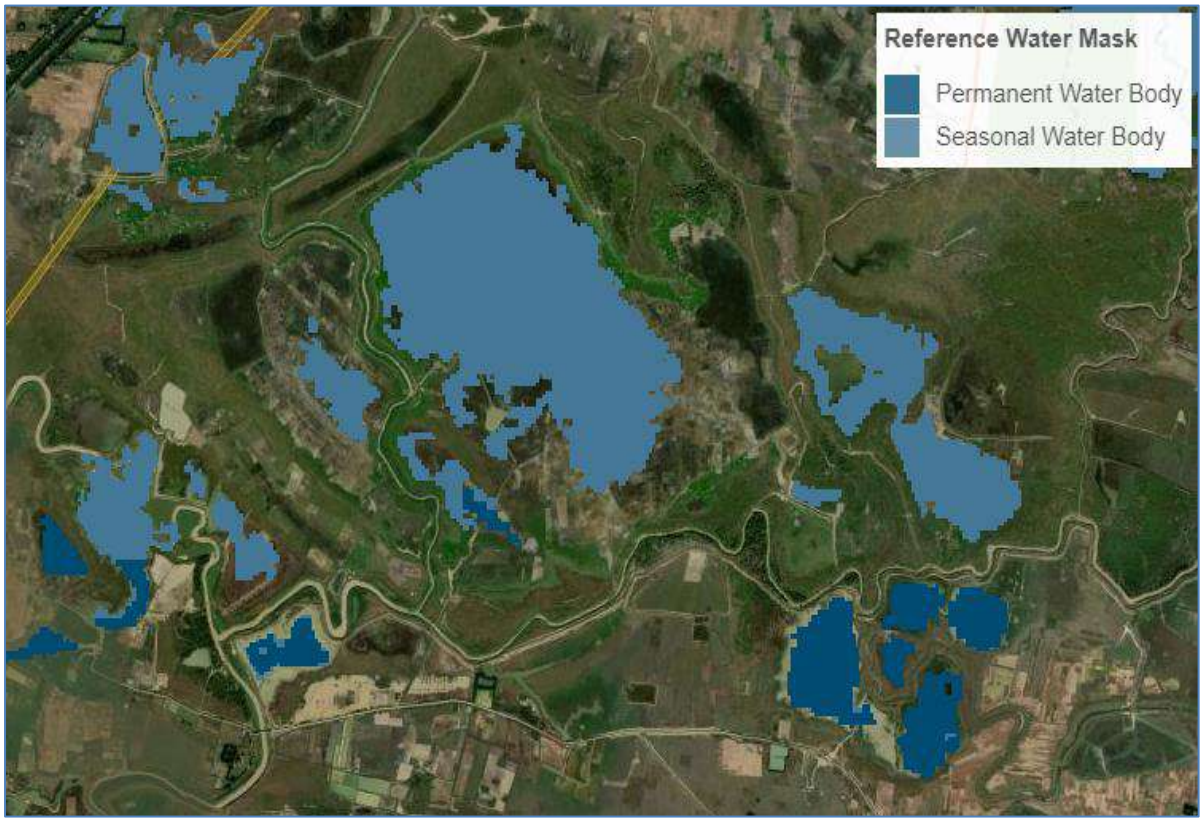


Figure 3: Example of the GFM output layer "Reference water mask".

3.4 GFM output layer: Exclusion Mask

The GFM output layer Exclusion Mask indicates those locations (pixels) where the SAR data does not contain the necessary information for a robust flood delineation, due to the combined deleterious effects of the following main “static” factors:

- No sensitivity to flood mapping, where Sentinel-1 does not receive sufficiently strong signals from the ground surface to distinguish a flooded from a non-flooded surface.
- Water look-alikes, where Sentinel-1 SAR backscatter from non-flooded ground surface is so low as to be indistinguishable from the backscatter from smooth open water.
- Strong topography, when Sentinel-1 signals are heavily distorted by terrain effects, effectively enhancing the noise and signal disturbances to such a degree to that it becomes larger than the change in backscatter due to potential flooding.
- Radar shadows, when Sentinel-1 receives no signals from certain regions of the land surface because of mountains, high vegetation canopies or anthropogenic structures.

To generate the GFM Exclusion Mask, various methods are used to address the problems of SAR-based flood mapping. The parameter database stores for all locations (pixels), the areas excluded by the four groups of factors, with the radar shadow layer per local Sentinel-1 orbit configuration (up to six per location). During NRT operation, relative orbit is derived from the S-1 metadata, and the respective Exclusion Mask layers are subset to the extent of the processed Sentinel-1 scene, forming a single binary mask for exclusion areas.

As no-sensitivity is a problem leading more often to under-estimation than over-estimation of flooding (e.g. in urban areas), the no-sensitivity -masking is only applied to pixels classified as non-flooded. Pixels classified as flooded are kept unmasked. Any no-data areas from the flood mapping algorithm are forwarded to this layer and added as no-data values.

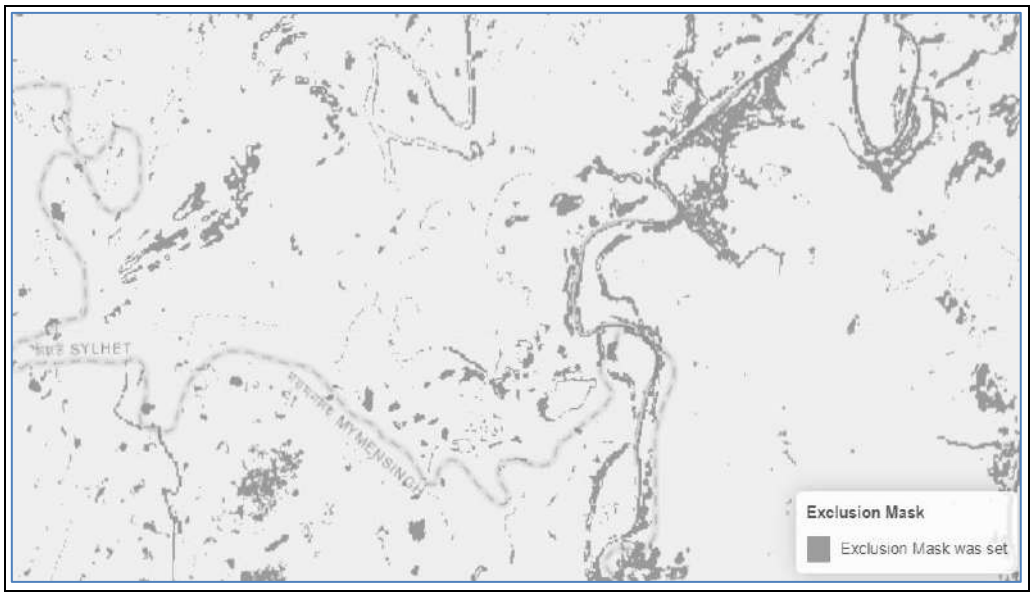


Figure 4: Example of the GFM output layer “Exclusion mask”

3.5 GFM output layer: Likelihood Values

Along with the binary map product (i.e. Observed Flood Extent), aggregated "likelihood" values are generated, as a simplified "appraisal of trust" in the **ensemble flood mapping** method. An example of this output layer is shown in Figure 5

The methods used by the three GFM flood mapping algorithms to compute the Likelihood Values for a Sentinel-1 grid-cell, and that used by the GFM Ensemble algorithm to combine these values into a final Likelihood Value for each grid-cell, are described in the GFM Product Definition Document (PDD). Likelihood values lie in the interval 0 to 100%, where:

- Likelihood values near 0 represent lower confidence of flood classification accuracy.
- Likelihood values near 100 represent higher confidence of flood classification accuracy.
- A likelihood value of 50 separates both classes (Unflooded and Flooded).
- Unflooded pixels necessarily show likelihood values in the interval [0, 49].
- Flooded pixels show likelihood values in the interval [50, 100].
- Unflooded likelihoods propagate towards 0, as Unflooded confidence increases.
- Flooded likelihoods propagate towards 100 as Flooded confidence increases.

Like the GFM Observed Flood Extent output layer, the computed Likelihood Values are adjusted based on values of the Exclusion Mask, as follows.

Flood pixel value:	*Exclusion Mask value:*	*Adjusted flood pixel value:*	*Adjusted Likelihood Value:*
1 (i.e. Flood)	*1 (i.e. TRUE)*	*0 (i.e. No flood)*	*49 (i.e. lowest for No flood)*

Figure 5: Example of the GFM output layer "Likelihood values".

3.6 GFM output layer: Advisory Flags

The GFM Advisory Flags indicate pixels that may suffer from decreased contrast between water and non-water surfaces due to meteorological factors as wet snow, frost and dry soil or wind-roughened water. Pixels marked by the Advisory Flags are not excluded by the Exclusion Mask, but users are advised to use with caution the GFM flood and water extent results over these areas. An example of this output layer is shown in Figure 6. For each incoming Sentinel-1 scene processed by the flood mapping algorithm, advisory flag information is generated in near-real time. The decreased contrast between water and non-water surfaces is indicated by two distinct flags and their overlapping regions:

1. The **low regional backscatter** flag identifies low backscatter areas on a regional scale, which may be due to conditions such as dry soil, frost, or snow cover. To do this, regional backscatter for that month is compared to the incoming scene at 20 km scale. If low backscatter is detected in the incoming scene at this scale, a 14 km buffer zone is applied around affected pixels, flagging them as areas of regional low backscatter.
2. The **rough water surface** flag highlights areas surrounding known water bodies that are likely affected by wind, indicating potential disturbances in the water surface. Therefore, the backscatter from known water bodies, as identified by the reference water mask, is compared to the calm water signature derived from backscatter time-series data. If a significant increase in backscatter is detected, a 5 km buffer zone around the affected water surface is flagged for potential wind impact.
3. The regions where **advisory flags 1 and 2 overlap** are highlighted separately.

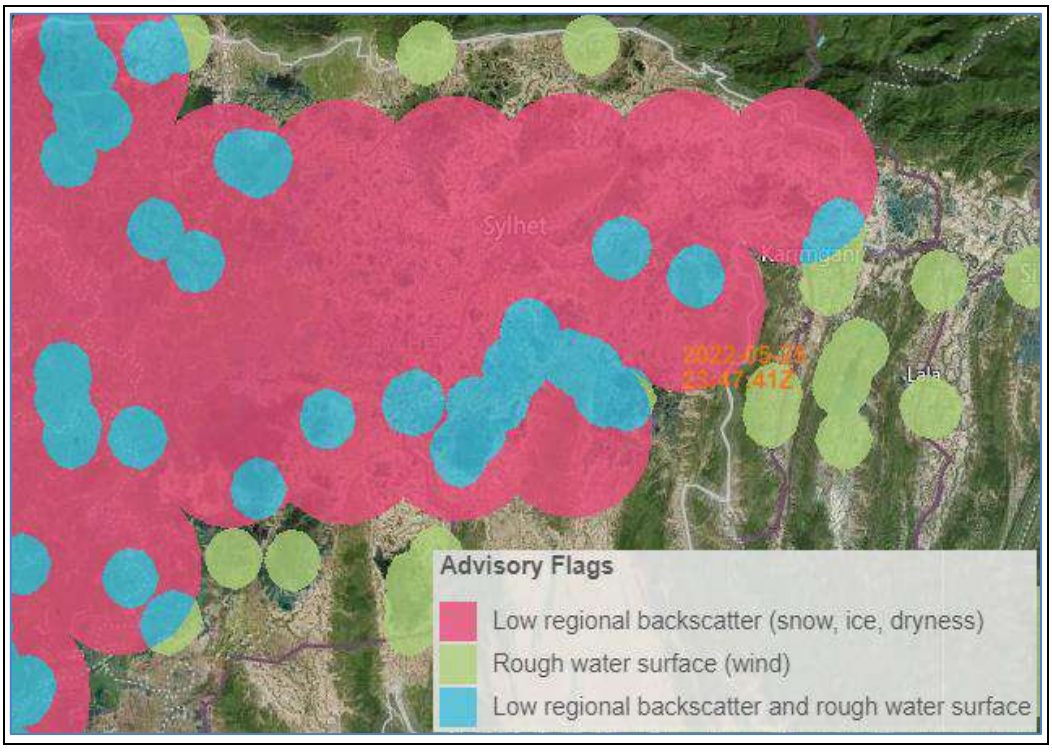


Figure 6: Example of the GFM output layer "Advisory flags".

3.7 GFM output layer: Sentinel-1 Footprint and Metadata

The GFM output layer “Sentinel-1 Footprint and Metadata” shows all metadata attributes provided with each Sentinel-1 GRD data product used to generate the main GFM ain output layers. Metadata of each Sentinel-1 GRD scene are provided in the distributed Sentinel “Standard Archive Format for Europe (SAFE)” format, an XML file containing the mandatory product metadata. Examples of this output layer are shown in Figure 7 and Figure 8.

The four categories of attributes in the manifest file are: (a) **Summary**; (b) **Product**; (c) **Platform**; (d) **Instrument**. Platform- and instrument-related attributes are “static” for the different Sentinel-1 satellites. There are 29 attributes in the manifest file, e.g. information on absolute orbit number, pass direction, polarisation, sensing start and end date and product timeliness category. An example of the included attributes is given below:

- After successful retrieval of a Sentinel-1 GRD product at EODC the manifest file is parsed and inserted into the operated metadata-base. Access to this actively maintained database is via the well-defined OGC CSW standard referred to as metadata catalogue. The database itself builds on PostgreSQL following a relational database system.
- The requested Sentinel-1 metadata are provided via PostGIS representing a spatial database extender of the PostgreSQL database. The PostGIS layer allows on-demand querying of geographic objects of OGC mapping standards such as WMS-T, WCS or WFS.
- The footprint of a Sentinel-1 GRD scene as provided in each data product is included in the mentioned manifest file. The footprint is represented as human readable Java Topology Suite (JTS) object named “JTS footprint”.
- The JTS footprint is converted to Well-known Text (WKT) and Well-known Binary (WKB) in the process of parsing and ingesting the acquired manifest files into the metadata database. WKT and WKB are originally defined by OGC to describe simple features.
- Hence, the Sentinel-1 footprint will be available as PostGIS layer accessible via all supported OGC mapping standards. On-the-fly conversion to standalone data formats can be supported via standard GIS tools based on user request.

Sentinel 1 Metadata	
Mode	IW
Title	S1A_IW_GRDH_1SDV_20220129T143052_20220129T143118_041677_04F566_617D
Format	SAFE
Abstract	-
Mdsource	REMOTE
Platform	SENTINEL-1
Time end	2022-01-29T14:31:18.024000
Publisher	ESA
Identifier	S1A_IW_GRDH_1SDV_20220129T143052_20220129T143118_041677_04F5
Instrument	SAR-C
Time begin	2022-01-29T14:30:52.811000
Insert date	2022-01-29T16:03:13.784000
Total slice	0
Polarisation	VV+VH
Product type	GRD
Slice number	20
Number of lines	0
Orbit direction	ASCENDING
Platform number	A
Processing date	1970-01-01T00:00:00
Processing site	AIRBUS DEFENCE AND SPACE-TOULOUSE
Abs orbit number	41677
Processing level	1
Rel orbit number	130
Resolution class	HIGH
Number of samples	0
Processing country	-
Progessing facility	COPERNICUS S1 CORE GROUND SEGMENT - TLS
Processing software	-
Processing organization	ESA
Polarisation combination	DV
Processing software version	-
Product timeliness category	FAST-24H

Figure 7: Example of the GFM output layer "Sentinel-1 Footprint and Metadata", showing the ancillary information for a specific Sentinel-1 overpass.

Figure 8: Example of the GFM output layer "Sentinel-1 Footprint and Metadata", showing incoming Sentinel-1 overpasses.

3.8 GFM output layer: Sentinel-1 Schedule

Sentinel-1 observations follow a strict acquisition planning often referred to as acquisition segments. Information on the planned future acquisition is provided by ESA in form of Keyhole Markup Language (KML) files. A single file usually covers an acquisition period of about 12 days, with the start and stop time of the future planned acquisitions already given in the file name. The GFM output layer "Sentinel-1 schedule" shows planned Sentinel-1 acquisitions for the next three days. An example of this output layer is shown in Figure 9.

KML files are published regularly by ESA, well before activation, with potential last-minute changes due to requests from the Copernicus Emergency Management Service. Information provided in the KML files is organised based on the planned data takes. Parameters listed in Table 5 are included in the KML. The KML files are regularly checked and downloaded at EODC and ingested into the described metadata database for further analysis. All parameters are exposed as PostGIS layer to extract the requested schedule information indicating the next planned Sentinel-1 GRD acquisition for a given location.

Figure 9: Example of the GFM output layer "Sentinel-1 schedule".

Table 5: Information provided with the next planned Sentinel-1 GRD acquisition.

PARAMETER	*DESCRIPTION*
Datatake ID:	▪ Unique product identifier (hexadecimal).
Mode:	▪ Instrument acquisition mode.
Observation (duration):	▪ Duration of the planned data take (in seconds).
Observation (start):	▪ UTC start date and time of the planned data take.
Observation (end):	▪ UTC end date and time of the planned data take.
Orbit (absolute):	▪ Absolute orbit number at the start time of the data take.
Orbit (relative):	▪ Relative orbit number at the start time of the data take.
Polarisation:	▪ Instrument polarisation for the acquired data take.
Satellite ID:	▪ Satellite identifier.
Swath:	▪ Instrument swath (from 1 to 6 for SM, not applicable for IW and EW).

3.9 GFM output layer: Affected Population

The GFM output layer Affected Population is derived from the CEMS Global Human Settlement (GHS) layer and, in particular, from the GHS-POP dataset. This data contains a raster representation of the population's distribution and density as the number of people living within each grid cell. The information is available at various spatial resolutions and for different epochs. An example of this output layer is shown in Figure 10.

For the GFM processing, the dataset at the highest possible resolution (100m) and for the latest available timestep (2020) is used. Combining this re-projected and re-sampled raster dataset and flood extent provides the number of affected people for each specific pixel detected as flooded. Note that the updated dataset replaces the former GHSL population dataset at 250m resolution with the reference year 2015, which was available at the start of GFM operations and was used for production during October 2021 – March 2023.

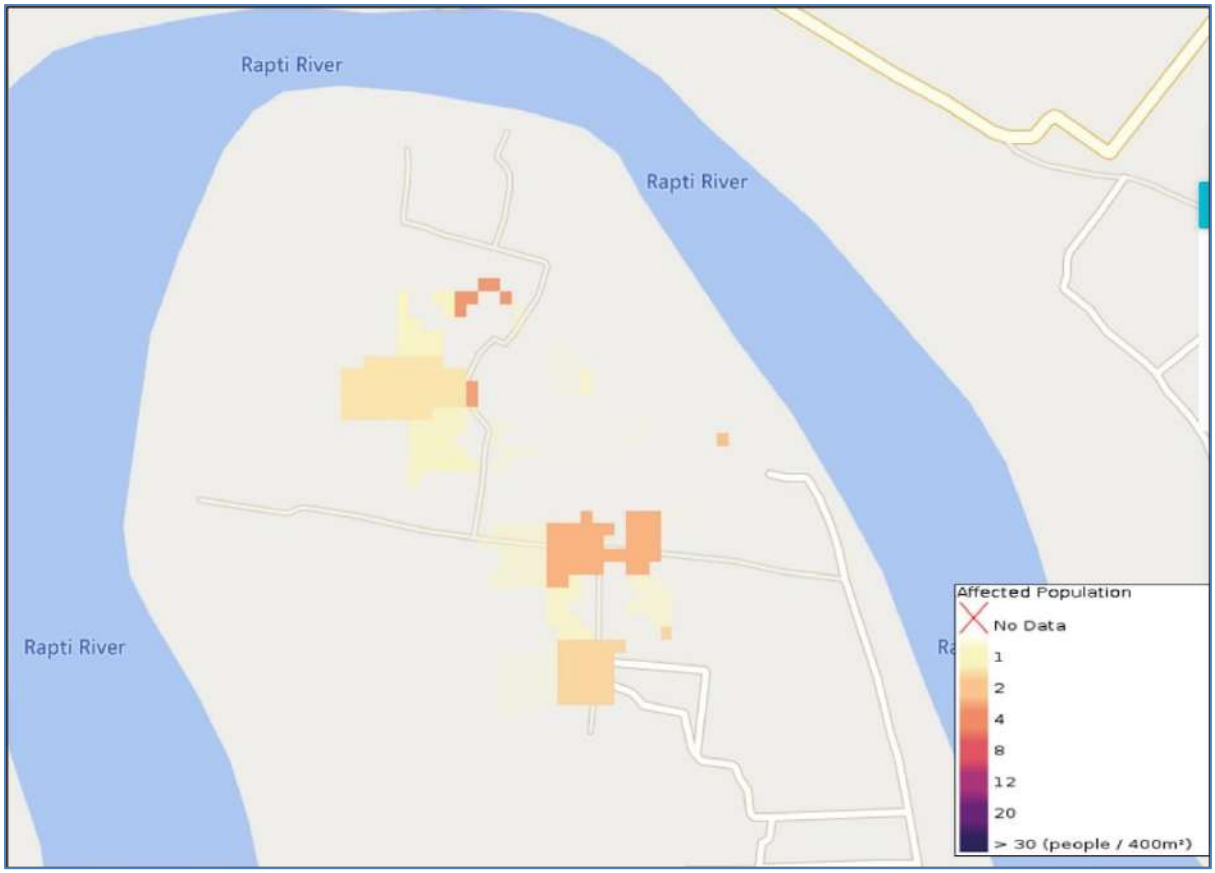


Figure 10: Example of the GFM output layer "Affected population".

3.10 GFM output layer: Affected Landcover

The GFM product also provides, in addition to affected population, an output layer showing the Affected landcover for a particular flood case. This information can provide a first assessment of affected land cover or land use types, for example how much agricultural area is affected by the flood extent. An example of this output layer is shown in Figure 11.

Based on the GFM consortium's production heritage and experience in land cover mapping, this output layer is derived from the 100m-resolution database of the Copernicus Global Land Cover Service enriched with information from the Copernicus Pan-European High-Resolution Layers (Imperviousness, Forests, Grassland, Water and Wetness) over Europe.

The Global Land Service includes 23 classes and provides annual updates, with an overall accuracy of 80%. The Copernicus Pan-European High-Resolution Layers have an overall accuracy of 85%+ and are available at 20 m (the 2018 version at 10 m) spatial resolution. In addition to both datasets, GFM also includes the most relevant classes from OpenStreetMap (roads, railways, etc.) to allow a first assessment of affected areas and infrastructure.

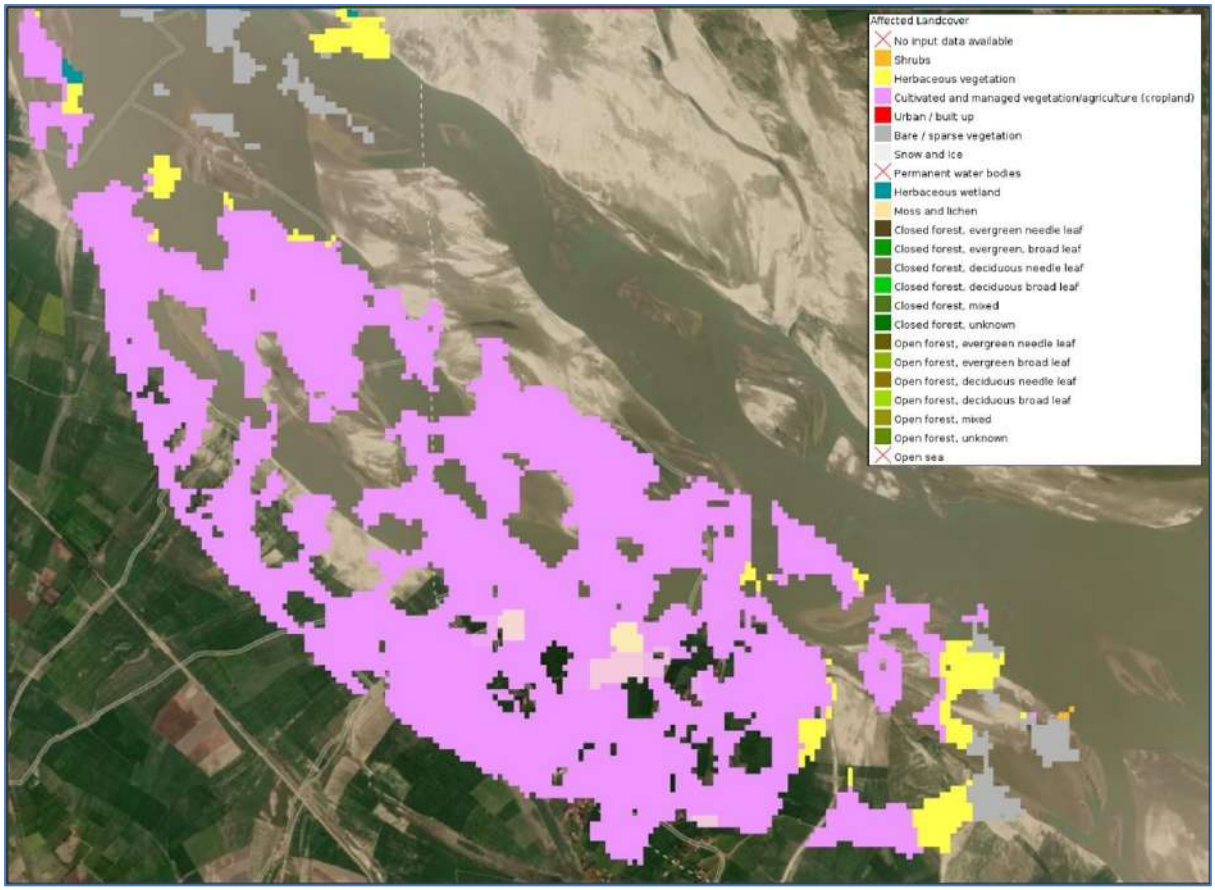


Figure 11: Example of the GFM output layer “Affected land cover”.

4 Recommendations and caveats regarding use of the GFM product

In general, it is possible to distinguish between both over- and under-detection of the Observed Flood extent (i.e. false alarms and missed alarms, respectively), as outlined below.

4.1 False alarms

False alarms unnecessarily draw the attention of users and thus could create frustration and mistrust in the product. The following “water look-alike” surfaces can yield false alarms:

- Very dry or sandy soils.
- Frozen ground.
- Wet snow.
- Flat impervious areas (e.g. smooth tarmac-covered airfields or roads).
- Certain growing conditions and agricultural practices over cropland.

These surfaces and artifacts usually feature very low backscatter signatures and thus appear as water in SAR imagery, rendering the water and flood mapping a difficult task.
Another common effect in SAR remote sensing is **radar shadowing**, which appear over strong terrain (especially at the far-range section of the SAR image) as well as in the vicinity of high objects above the ground, like high buildings and along forest borders.

4.2 Missed alarms

Missed alarms on the other hand would lead to situations where a flood event is not detected and leaves the users without notice, possibly losing time for reaction measures. Floods occurring in **urban areas**, **densely vegetated areas**, or under weather conditions featuring **strong winds** or **heavy rainfall** can lead to missed alarms. In particular, wind and heavy rainfall are hard-to-spot dynamic process as they roughen water surfaces and hence undermine the initial assumption of low backscatter due to specular reflection on smooth water surfaces.

4.3 How to address false and missed alarms with the GFM product

A variety of methods can be used to address the abovementioned issues of SAR-based water mapping which potentially cannot be directly solved by the proposed flood detection algorithms using only NRT-available backscatter information and hence indication need on pixel level for potential misclassification due to reduced sensitivity.

These challenges are classified into **Static effects** (related to ground surface, land cover or topography), and **Dynamic effects** (due to meteorological dynamics). Note that, with respect to the GFM reprocessing cycle, static layers are unchanged during NRT processing but may be updated during reprocessing after evolution activities.

Both the Exclusion Mask and Advisory Flags are delivered with the other GFM output layers and aim at improving the reliability, usefulness and user acceptance of the GFM product. The masking and flagging of dynamic and static effects is implemented as follows:

Static effects:	▪ These are bound to ground surface characteristics such as land cover (e.g. flat impervious areas, urban areas, densely vegetated areas), and shadowing (radar shadowing). ▪ These effects are addressed by the Exclusion Mask. Pixels that cannot be classified by the SAR sensor into flooded, permanent / seasonal water, and non-water areas, are highlighted in this output layer as no-data pixels. ▪ The Exclusion Mask indicates all pixels that cannot be classified by the input Sentinel-1 data, considering statistical parameters from the data cube as well as auxiliary datasets. The pixels addressed by Exclusion Mask thus can be directly discarded as no-data, leaving the interpretation of the produced flood extent and (adjacent) no-data-gaps to the users, who are generally familiar with their area-of-interest.
Dynamic effects:	▪ These are triggered by weather conditions – i.e. meteorological features (strong wind, heavy rainfall), meteorological-induced state of the soil (soil dryness, frozen ground, or wet snow). ▪ They are flagged by the dynamic Advisory Flags. The Advisory Flags indicate locations where the SAR data might be disturbed by such processes during the acquisition but leaves the flood and water extent layers unmasked. ▪ The GFM output layer Advisory Flags highlights where meteorological processes such as wind or frozen conditions may impair flood and water detection. As the Advisory Flags can only be retrieved at a coarser resolution, the information is not fed into the Exclusion Mask. As a separate output layer, it serves to guide users when interpreting the product, allowing additional insight on its local reliability at the time of Sentinel-1 acquisition.

4.4 Other known issues

Land-sea border:	▪ To assure a globally consistent land-sea border for all GFM flood and water output layers, the CopDEM Water Body Mask (WBM) is integrated into the observed water extent and all pixels are set to “water” where the WBM indicates “sea”. While this static land-sea border provides consistency, it does not take into account daily coastline dynamics caused by tides. It may, therefore, occur in rare cases that the land-sea border shows a low-tide case whereas the Sentinel-1 flood mask covers a high-tide. In such a scenario flood pixels may falsely be identified on near-shore sandbanks that are actually inundated during high-tide.

Linear gaps between Sentinel acquisitions:	▪ Sentinel-1 IW C-band SAR products are the main input to the GFM product. After raw satellite data downlink, ESA as the original data provider, slices the data per 25 seconds sensing time (equivalent to about 170 km in track direction) without leaving any overlap / data duplication. ▪ During the SAR geocoding step, computing the correct backscatter values along the slice edges requires the adjacent measurements. If not available, it generates no-data values, locally. As the GFM service ingest the SAR datasets separately in near-real-time (NRT), neighbouring slices are not available, and narrow stripes of no-data are generated at a dataset's start- and end rows, yielding thin linear gaps. Waiting to have all adjacent files mutually available would decrease the timeliness of the pre-processing, and is not done within the GFM service. ▪ As a consequence, GFM layers remain unclassified over the location of the Sentinel-1 no-data pixels, leaving thin linear gaps. Figure 12illustrates the issue for a flood event in Myanmar in June 2022.

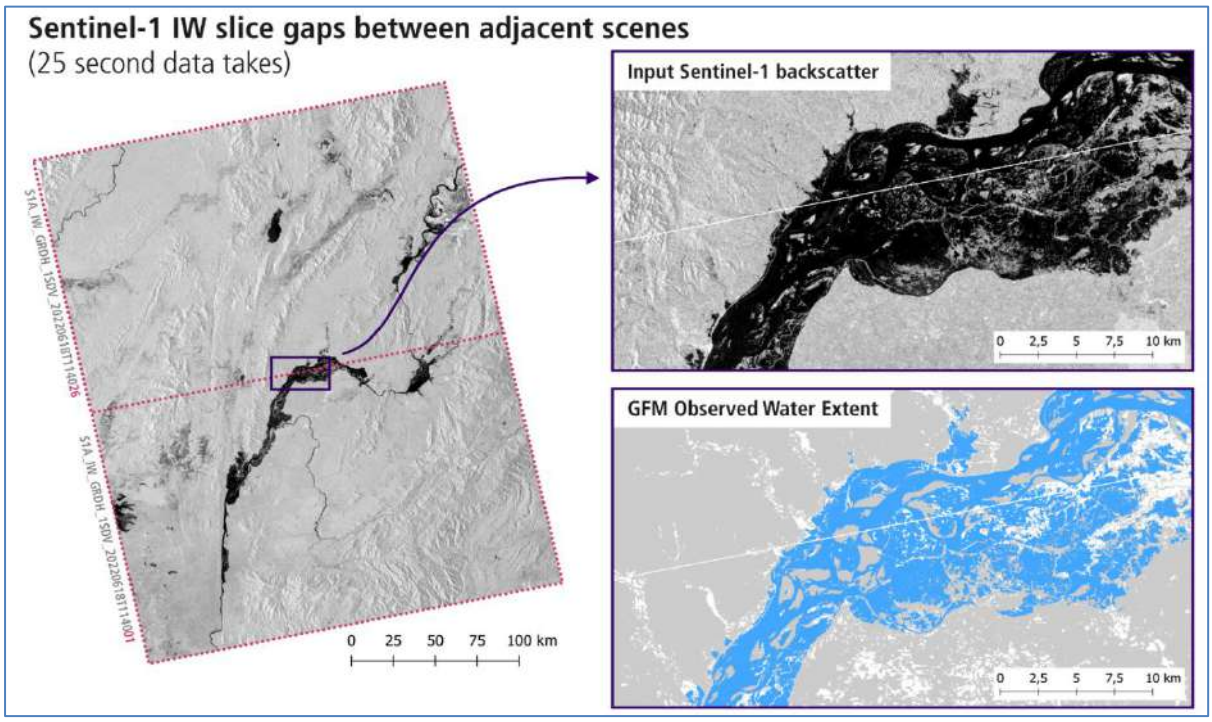


Figure 12: Example of linear gaps between Sentinel-1 acquisitions in GFM product results.

5 Potential user ecosystem for the GFM product and other relevant services

This section provides an overview of the "user ecosystem" of the GFM product - i.e. the broader network of potential users, and their interactions with the different components of the system - which is based on the extensive experience of the GFM consortium and a review of relevant European projects in the field of floods, natural hazards and satellite data. Table 6 summarizes how different types of GFM users might best exploit different components of the GFM product and related services, that are most suited for their needs.

Table 6: Overview of potential user ecosystem for the GFM product and related services.

FIELD	*PURPOSE*	*SUGGESTED APPROACH*	*DATA ACCESS*
CIVIL PROTECTION:	***NRT situational awareness***	▪ Automatic feed on flood mapping for specific area. ▪ Automatic acquisition of flood map data on specific clients.	– **Push Notifications** – **REST-APIs**
OPERATIONAL HYDROLOGICAL FORECASTING:	***NRT verification of impact-wise forecasts***	▪ Automatic acquisition of flood map data on EFAS / GloFAS. ▪ Automatic acquisition of flood map data in other national / regional / global forecast systems (e.g., Tethys, WW Hype, FANFAR).	– **REST-APIs** – **Web Application**
DISASTER RISK REDUCTION PLANNING:	***Retrieval of historical flood-prone areas***	▪ Access to the full archive within a specific client application and draft sets of prescriptions to decrease the current risk level or avoid creating new risk.	– **Web Map Service** – **STAC**
RESEARCH:	***Calibration/validation of hydrological/hydraulic forecast models***	▪ Download the entire archive of the GFM output layers in raster format to calibrate / validate hydrological / hydraulic forecast models.	– **REST-APIs** – **Web application** – **Web Map Service** – **STAC**
	Test flood mapping alternative algorithms	▪ Access and download the Sentinel-1 data used to derive the flood maps over a certain region for specific events and compare them to GFM outcomes.	– *UNDER DEVELOPMENT*
	Flood mapping algorithms calibration	▪ Upload a proprietary algorithm on the Cloud, run it on full GFM archive or a temporal / spatial subset.	– *UNDER DEVELOPMENT*

	Flood models calibration	▪ Access the full GFM archive in raster or vector format, and calibrate model based on historical flood maps.	– **REST-APIs** – **Web application** – **STAC**
INSURANCE:	***NRT disaster loss estimate***	▪ Access in NRT the flood maps in raster or vector format to outline a footprint-based estimate of disaster loss.	– **GloFAS / EFAS** – **Web application**
NON-EXPERT END USERS:	***NRT actionable information***	▪ Receive a ready-to-print map in NRT for a certain event in a selected region. ▪ Receive short feeds depicting in NRT the flood status over a certain region. ▪ Receive notifications on relevant floods in NRT.	– **GloFAS / EFAS** – **Web application**

6 The GFM product access and dissemination system

The GFM output layers of worldwide flood-related information are freely available through the following dissemination channels, each designed to provide flexible and easy data access:

- GloFAS and EFAS.
- A full set of tailored REST-APIs.
- A Web Map Service.
- A Web Push Notification Service.
- A dedicated Web Application.
- The GFM STAC Catalogue.

As is illustrated in Figure 13, all data access methods are routed to a central storage via a central access layer. The storage-access layer is capable to serve products in the desired format by drilling down into the data-cubes, querying databases for meta-data or user management, and receiving data for the WMS-T service.

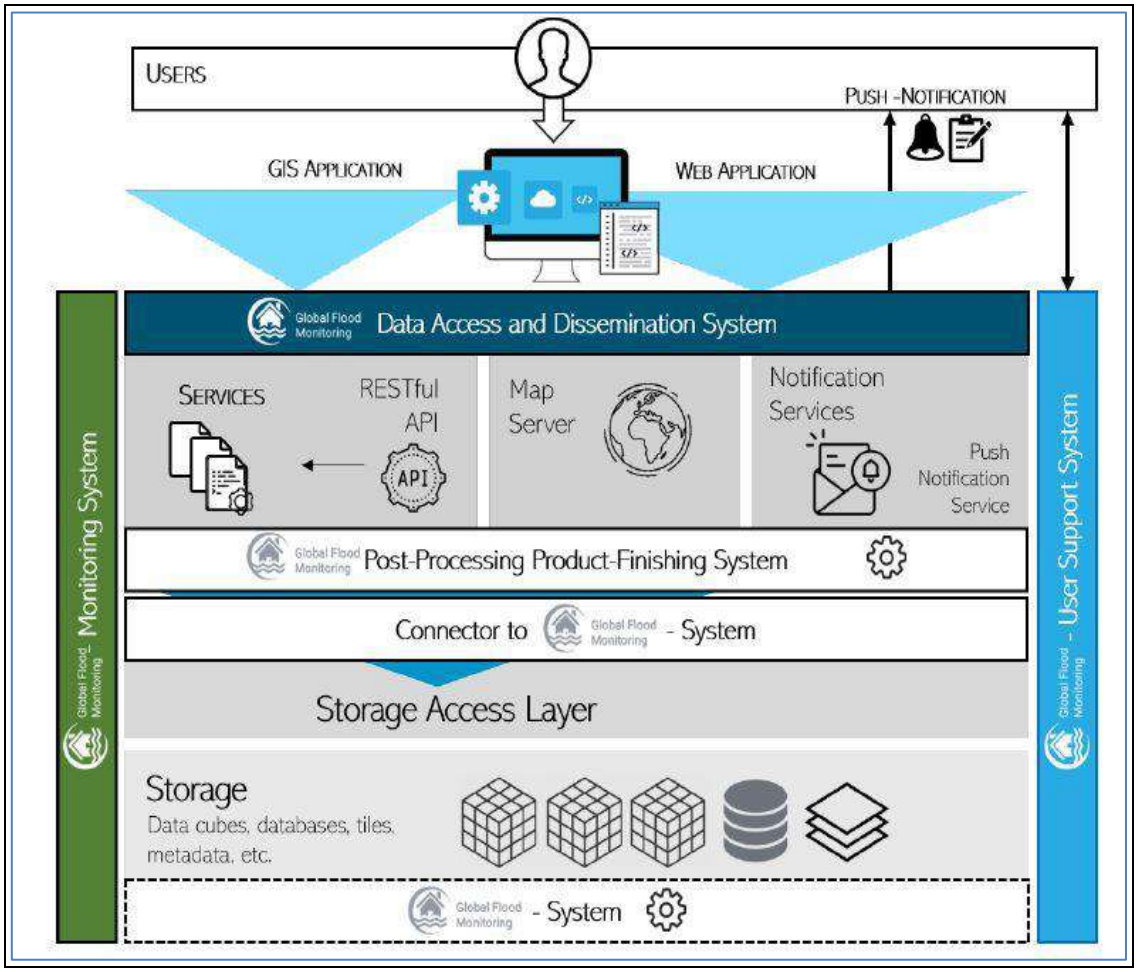
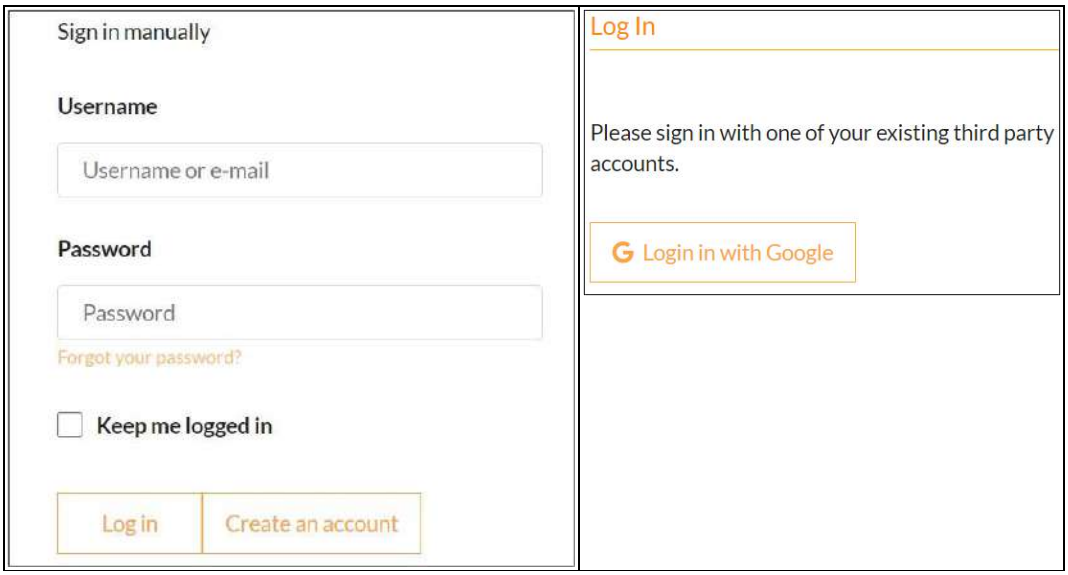


Figure 13: Overview of the GFM product access and dissemination system.

6.1 The Global Flood Awareness System (GloFAS)

The Global Flood Awareness System (GloFAS)[6] is the global flood service of CEMS, an operational system monitoring and forecasting floods across the world. GFM output layers are made available within the GloFAS Map Viewer. In order to access the Map Viewer, users are requested to register to the service (**left graphic below**). Once registered, the Map Viewer can be accessed by typing the account details (**right graphic below**). As can be seen, users can also sign in to the Map Viewer by means of their Google accounts.



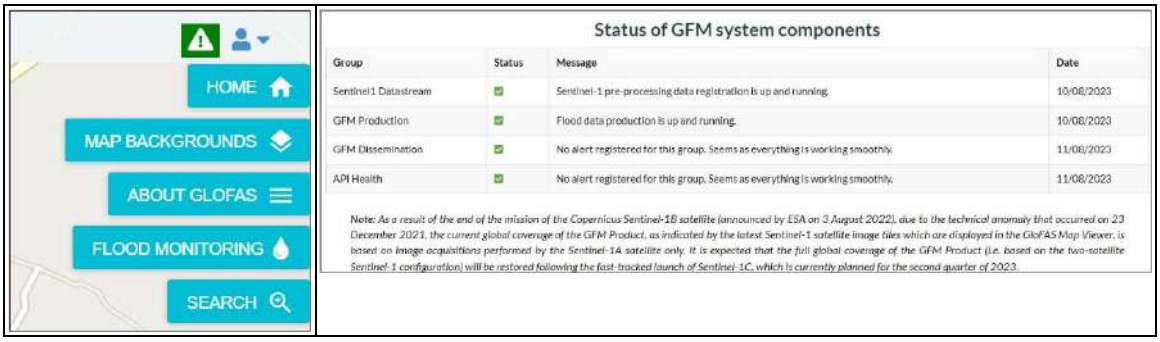
6.1.1 Monitoring the Health Status of the GFM product

Information on the overall health state of the GFM product is presented to the user within GloFAS Map Viewer (**left graphic below**). An alert sign in the top menu (next to the user profile) indicates the health state of the service. The alert sign is colour coded as follows:

***Green**: Service Up and Running*	***Amber**: Service Degraded*	***Red**: Service Not Available*

Detailed information on the health state of the various components of the GFM product are shown by clicking on the alert sign. This opens a pop-up window in the Map Viewer with the latest registered alert notifications (**right graphic below**). The different alert notifications are organised by "***Group***" providing details about the current "***Status***", a "***Message***" describing the alert notification, and a "***Date***" indicating when the alert was raised.

[6] https://global-flood.emergency.copernicus.eu/

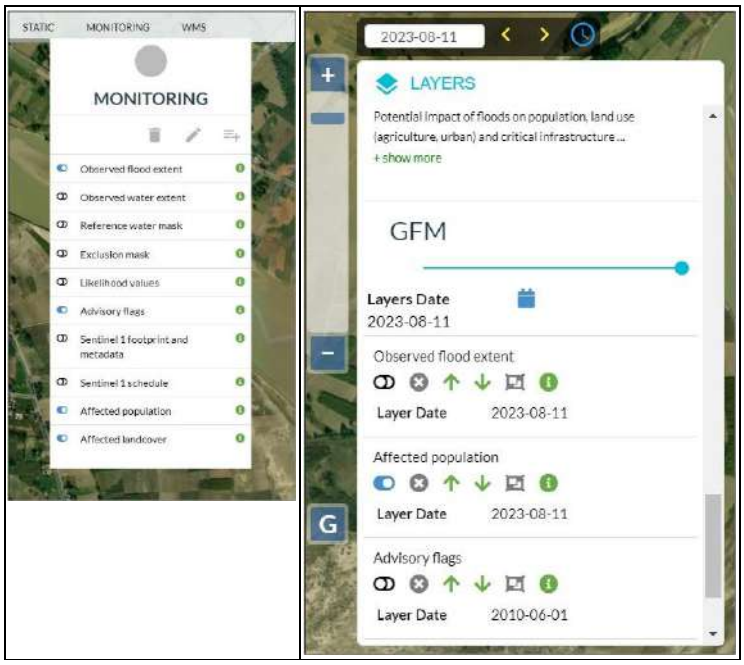


The column “Group” (**right graphic above**) refers to the individual components of the service. Four service components / groups are defined, as outlined below:

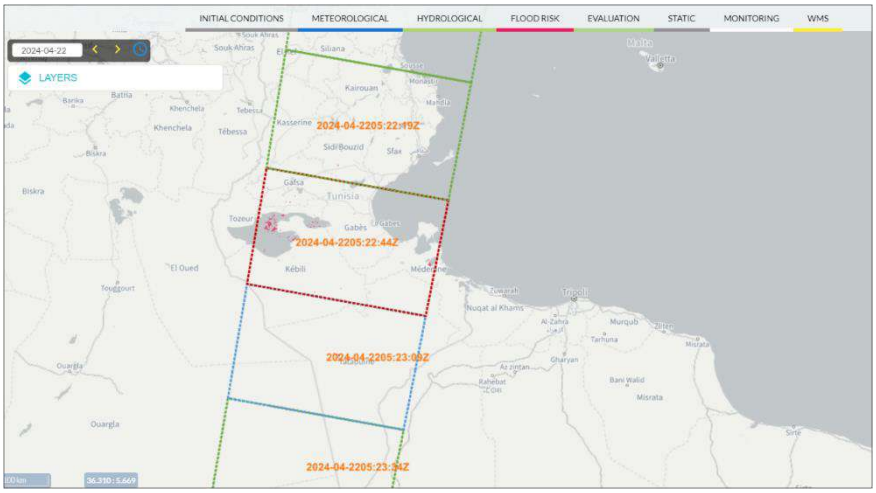
Sentinel1 Datastream:	▪ The group shows alerts related to any required Sentinel-1 data used to deduce the various layers provided by the service. One major alert event in this group is the Copernicus Services Data Hub acting as reference for all the Sentinel-1 input data used in the service. ▪ Downtimes of the Copernicus Services Data Hub as well as issues in receiving the required data are notified within this group. Furthermore, observed issues related to the pre-processing of Sentinel-1 data will be alerted, because the pre-processed data is the main input data stream to deduce flood information.
GFM Production:	▪ This group shows alerts related to production of the individual GFM output layers. Any observed issues within the actual production system of GFM are forwarded within this group. Anomalies detected in the processing workflow of the flood layers as well as non-availabilities of components of the production system are covered in this notification group as well as the monitoring of the interface towards to the GFM dissemination system.
GFM Dissemination:	▪ This group is related to the provision of access to the GFM output layers. End user entry points the GFM layers are provided by a WMS-T server as well as a dedicated Web Application (portal). Degradations or the unavailability of those will be reported within this group.
API Health:	▪ Finally, this group depicts alerts in respect to the developed RESTful APIs. The RESTful APIs are a backend system of high importance connecting the GFM production and dissemination system. In addition, the APIs allow for machine-to-machine communication to enable push notifications via X (formerly Twitter.).

6.1.2 How to browse GFM products in GloFAS Map Viewer

Once logged in, the GFM output layers are listed in the top bar under the *"**Monitoring**"* menu (**left graphic below**). Each layer can be visualized by moving the toggle to the "on" position. The selected output layer is then added to the dynamic layer list on the left side of the screen (**right graphic below**).



In the example below, the Observed Flood Extent layer is switched on. The GloFAS Map Viewer then displays the Sentinel-1 tiles for which GFM has detected flood-covered areas.



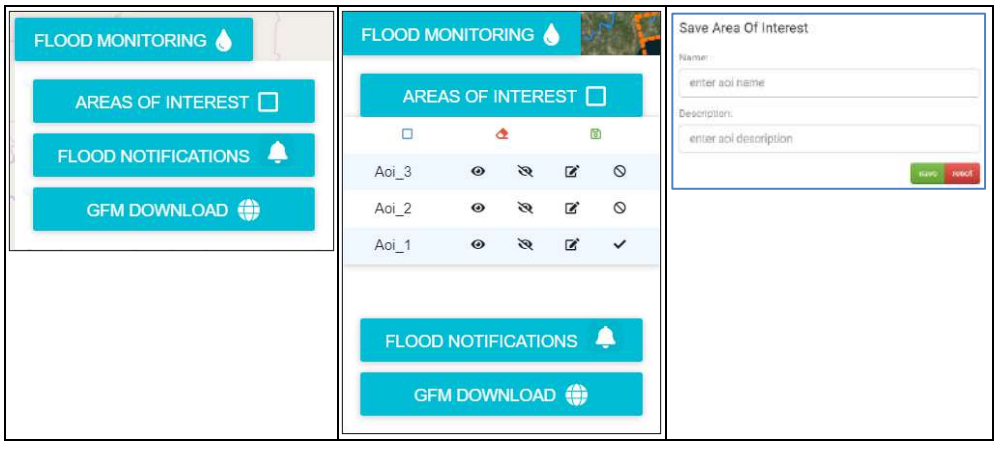
The dashed edge of each S-1 overpass tile is colour-coded according to the size and the pattern of the detected flooded, as shown in the legend below:

COLOUR	CONDITION	CLASS-NAME
RED	Anomaly TRUE AND > 5,000 flood pixels	Flooding detected - unusually high amount and flooded area > 2 km²
GREEN	{ Anomaly FALSE } OR {Anomaly TRUE AND < 5,000 flood pixels}	Flooding detected – not unusually high amount, or flooded area < 2 km²
BLUE	Anomaly NONE	Flooding detected - unknown significance (incomplete SAR time-series)

6.1.3 Areas of interest

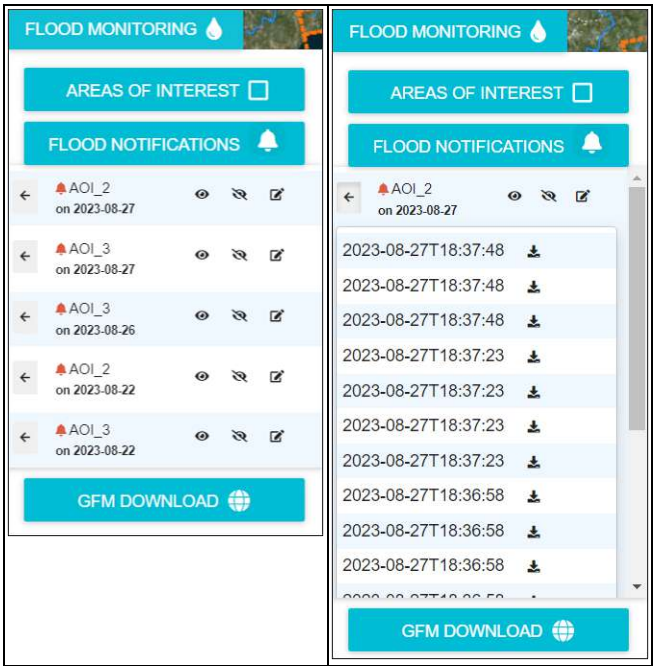
GFM-registered users can also draw their own areas of interest (AOIs), as explained below:

- By clicking on “Flood Monitoring”, the system displays a first sub-menu (**left graphic below**), offering the option of selecting: (a) the list of the designed AOIs, and (b) the list of the notification for the AOIs as set in the GFM Web Portal.
- This menu (**centre graphic below**) allows the users to visualise the list of the user-defined AOIs. As can be seen, to the right of each AOI's name, the user can display the boundaries of the AOI (eye-shaped icon), hide the boundaries of the AOI (barred eye-shaped icon), or modify the boundaries of the AOI (“pencil & sheet”icon, which redirects the user to the GFM webapp).
- As can be seen, above the list of the available AOIs, users have the option to design the AOIs of their choice directly through GloFAS (**Blue square**: Design an AOI; **Red rubber**: Delete the AOI; **Green floppy disc**: Save the AOI).
- When “Save the AOI” is selected, a form is displayed (**right graphic below**) to be filled out to save the AOI and display the available GFM output layers.
- Note that the maximum number of AOIs for each user is limited to **25**. Once the limit is reached, a new AOI can be added only if one of the previous is deleted.



6.1.4 Floods notification

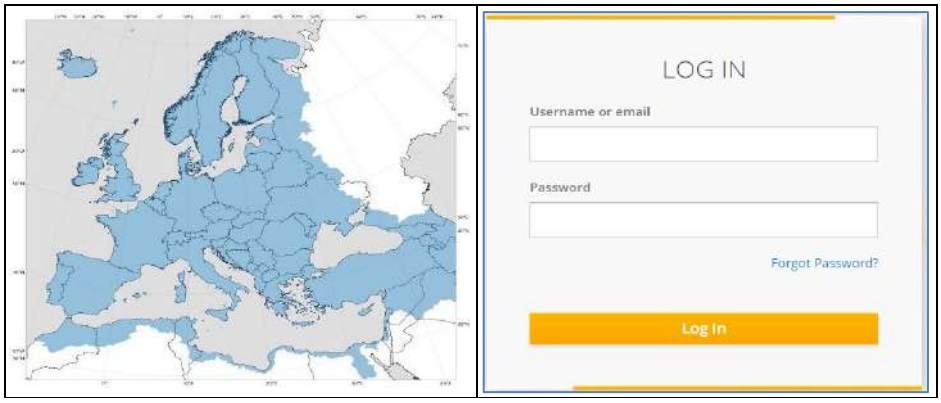
Users have the option to be notified any time a new GFM output layer is available for a specific AOI, on proper configuration of the notification setup through GFM Web Portal. Once done, flood notifications are displayed on GloFAS as well through the menu (**left graphic below**). When users click on a notification, the system will display every newly available output layer. GFM output layers can then be downloaded in a bundle (.zip file) in TIFF format by pressing the down-arrow icon (**right graphic below**). By pressing GFM DOWNLOAD, the user is re-directed to the landing page of the GFM Web Portal.



6.2 The European Flood Awareness System (EFAS)

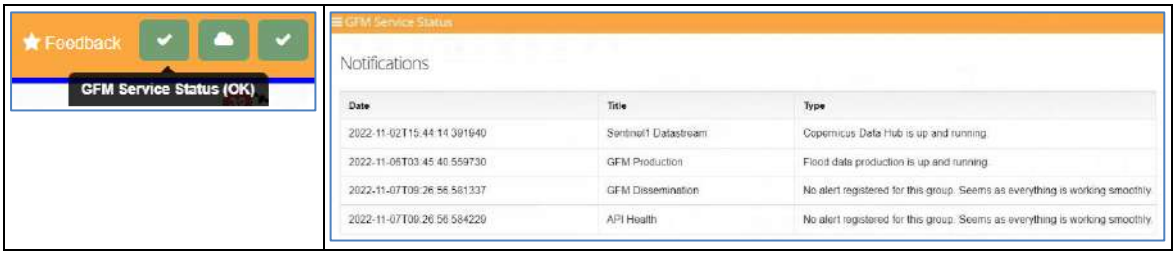
The European Flood Awareness System (EFAS)[7] is the flood service of CEMS and is an operational system for monitoring and forecasting floods across the pan-European domain (**left graphic below**). GFM output layers are available through the EFAS Map Viewer[8]. To access the Map Viewer and visualise the products in real-time, users are asked to become EFAS partners. (See terms and conditions of the association agreement[9]). Once registered, the Map Viewer can be accessed by entering account details (**right graphic below**).

[7] https://european-flood.emergency.copernicus.eu/
[8] https://www.efas.eu/efas_frontend/#/home
[9] https://www.efas.eu/en/become-efas-partner



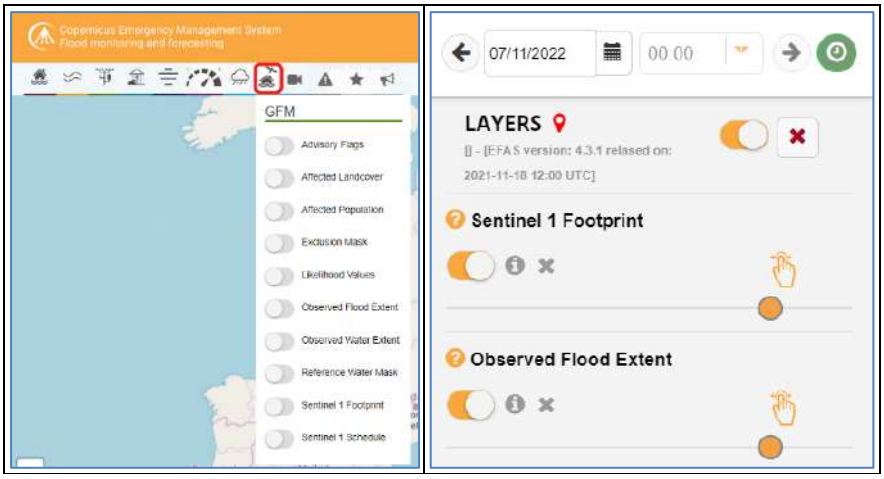
6.2.1 Monitoring the Health Status of the GFM product

Also in the EFAS Map Viewer, information on the overall health state of the GFM service is presented. An “alert sign” in the top menu, on the right, next to the user profile indicates the health state of the service (**left graphic below**). Detailed information on the health state of the various components of the service can be retrieved by clicking on the “alert sign”. This will open a pop-up window onto the map viewer (**right graphic below**) presenting the latest registered alert notifications. The different alert notifications are organised by **Group** providing details about the current **Status**, a **Message** describing the alert notification and a **Date** indicating when the alert was raised. The column **Group** refers to the individual components of the service. The four groups are explained in Section 6.1.1 above.

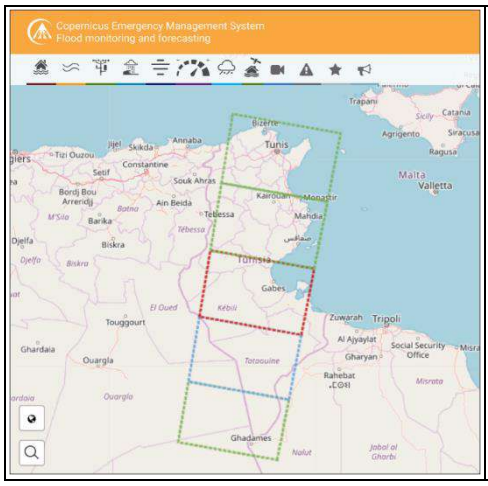


6.2.2 How to browse GFM products in EFAS Map Viewer

Once logged in, GFM output layers are listed in the top bar under the ***“GFM”*** menu (**left graphic below**, red rectangle). Each layer is visualized by toggling to the “on” position. The layer is added to the dynamic layer list on the right on the screen (**right graphic below**).



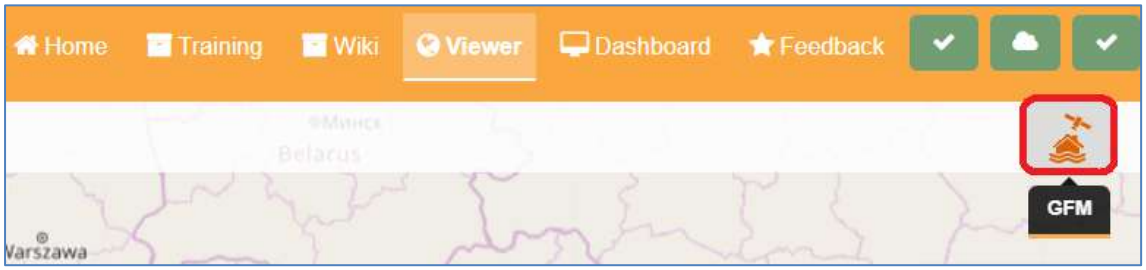
When the Observed Flood Extent output layer is switched on, the EFAS Map Viewer displays the S-1 tiles (**left graphic below**) for which GFM detected flooded areas, with the amount of flooding indicated by colour-coding (**right graphic below**).



COLOUR	CONDITION	CLASS-NAME
RED	Anomaly TRUE AND > 5,000 flood pixels	Flooding detected - unusually high amount and flooded area > 2 km²
GREEN	{ Anomaly FALSE } OR {Anomaly TRUE AND < 5,000 flood pixels}	Flooding detected – not unusually high amount, or flooded area < 2 km²
BLUE	Anomaly NONE	Flooding detected - unknown significance (incomplete SAR time-series)

6.2.3 Areas of interest

On clicking on the “GFM” icon, as shown below, GFM-registered users can draw their own areas of interest (AOIs).



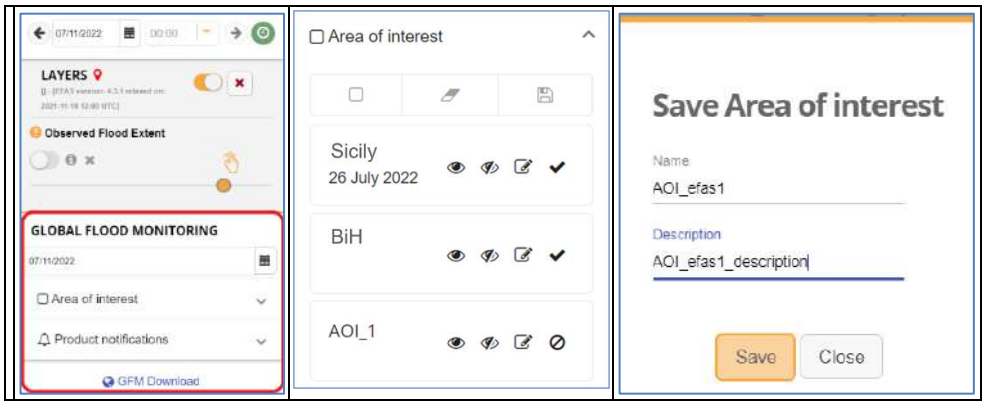
- The system then displays a menu (**left graphic below**) offering the user the possibility of selecting (a) the list of drawn AOIs, and (b) the list of the notification for the AOIs as set in the GFM WebApp.

- The "Area of Interest" menu (**centre graphic below**) allows users to visualize the list of user-defined AOIs. To the right of each AOI's name, users can: display the AOI boundaries (**eye-shaped icon**); hide the AOI boundaries (**barred eye-shaped icon**); modify the AOI boundaries (**"pencil & sheet" icon**, which redirects to the GFM web portal).

- Above the list of the available AOIs (**centre graphic below**), users are offered the chance to design the AOIs of their choice directly through GloFAS:

***Square icon**: Design an AOI.*	***Eraser icon**: Delete the AOI.*	***Floppy disc icon**: Save the AOI.*

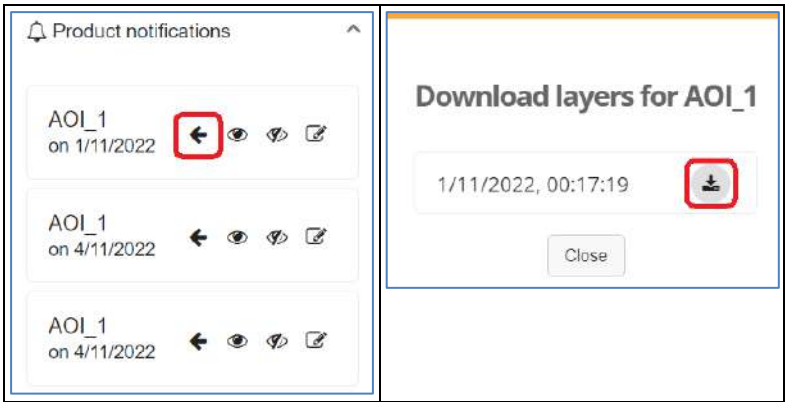
- When "Save the AOI" is selected, a form is displayed for users to fill out, to save the AOI and display the available GFM products output layers (**right graphic below**).



6.2.4 Flood notifications

Users have the option to be notified when a new GFM output layer is available for a specific AOI, on proper configuration of the notification setup through the Web Portal, as follows:

▪ Flood notifications are displayed on EFAS as well through a menu (**left graphic below**).
▪ When users click on a notification, the system will display all newly available GFM output layers. These can then be downloaded in a bundle by pressing the leftward arrow icon (**left graphic below**, red rectangle).
▪ The system will then open a pop-up window allowing the users to download the aggregate .zip file (containing all the output layer, in TIFF format), by pressing the downward arrow (**right graphic below**, red rectangle).



6.3 REST-APIs

RESTful API endpoints are another channel for the GFM data access and dissemination system, regardless of configuration services, product order or product serving services.

All GFM-related RESTful APIs are written in Python with the Flask framework for web applications. Flask is a lightweight Web Server Gateway Interface (WSGI) web application framework written in Python. The API gateway is exposed to the web by NGINX webservers which handle all requests from the internet and route them to WSGI HTTP servers, in our case Gunicorn. Gunicorn translates the requests in WSGI compliant calls and moves the proper request to the pool of workers executing the request. After successful executing the result is converted by Gunicorn to the HTTP request and handed over to NGINX, which takes care of the final delivery. Load-balancing is be handled by NGINX to serve the appropriate amounts of HTTP servers for the GFM data access and dissemination system.

Note that all components for RESTful API access are distributed as open and free licenses.

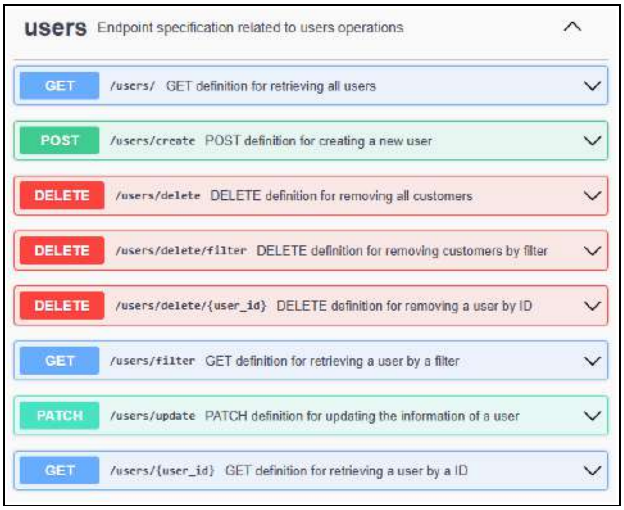
The documentation on how to configure GFM-related RESTful APIs is available through the popular Swagger UI allowing end-users and / or development teams to visualize and interact with the APIs resources without having any of the implementation logic in place. All of the API functions are described in the online guide and tutorial, available via a dedicated GFM URI[10], while the GFM Quick Start Guide[3] provides further information and examples.

All of the GFM-related RESTful APIs are listed in sections 6.3.1 to 6.3.10 below. In order to use the set of APIs, users need to get an access token. Information on how the access token could be retrieved are provided in Section 6.5.6 below (about the GFM Web Portal).

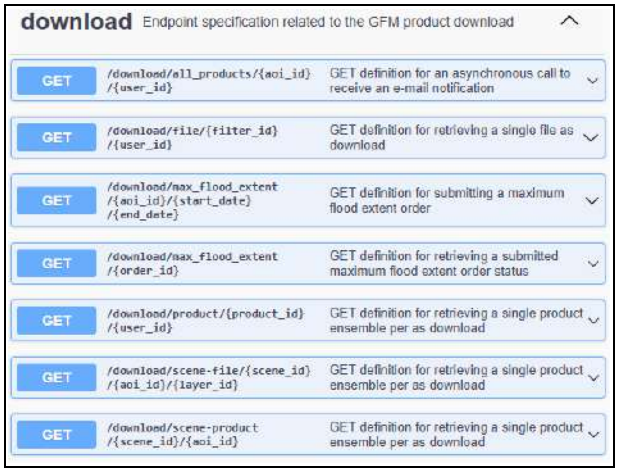
[10] https://api.gfm.eodc.eu/v2/

6.3.1 APIs - Auth (endpoint specification related to authentication operations)

6.3.2 APIs - Users (endpoint specification related to users operations)

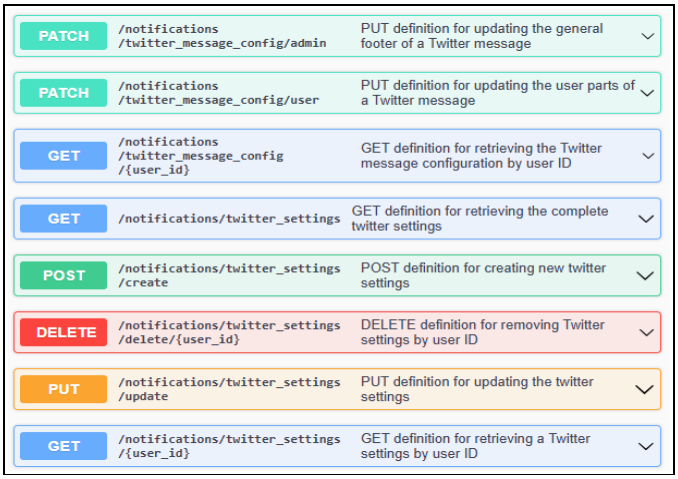


6.3.3 APIs - Download (endpoint specification related to the GFM Product download)

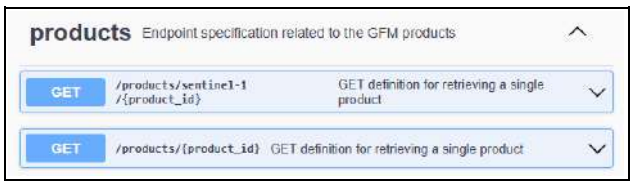


6.3.4 APIs - Legend (endpoint specification related to product legends)

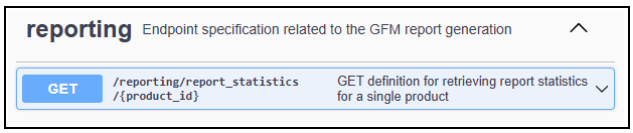
6.3.5 APIs - Notifications (endpoint specification related to the notification service)



6.3.6 APIs - Products (endpoint specification related to the GFM Products)



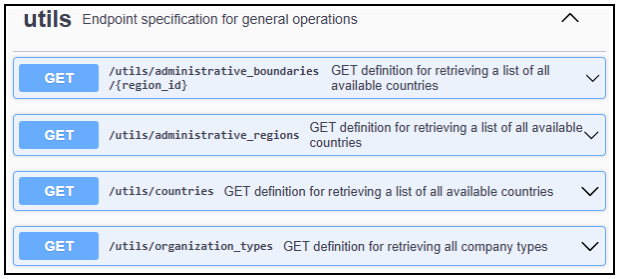
6.3.7 APIs - Reporting (endpoint specification related to the GFM report generation)



6.3.8 APIs - AOI (endpoint specification related to the area of interest)

6.3.9 APIs - Support (endpoint specification related to support requests)

6.3.10 APIs - Utils (endpoint specification for general operations)



6.4 WMS-T

GFM products are fully accessible via a GIS environment or web browser. The WMS layers can be accessed using any WMS client viewer, e.g. Quantum GIS (QGIS) or ESRI ArcMap. GFM offers WMS that supports temporal requests (WMS-T). The WMS-T service for the GFM product is based on GeoServer technology. GeoServer allows users to display the needed spatial information making maps available in a variety of output formats.

OpenLayers, a free mapping library, is integrated in GeoServer, making map generation quick and easy. GeoServer is built on GeoTools, an open source Java GIS toolkit. The GFM WMS-T is freely accessible at a dedicated URL[11]. The service is designed to display a single global layer per day.

6.4.1 QGIS

The steps for loading the GFM WMS-Ts are summarised below:

1	▪ Launch QGIS[12].
2	▪ To avoid timeout errors, set the timeout for network requests to **14,400,000 ms**.
3	▪ In the browser panel right-click on the *WMS / WMTS*[13] icon.
4	▪ In the *Create a New WMS / WMTS Connection* window insert a title for your WMS connection in the *Name* section and paste the GFM WMS URL[11], then click *OK*.
5	▪ At this point in the browser panel under the *WMS / WMTS* icon you should see the title for the WMS connection that you have entered. Click on the arrow near the WMS connection to open it. You should see the **GFM** WMS layers as follow:
6	▪ To view the layers simply drag and drop the layer icon into the Layers panel underneath the *Browser* panel, the layer will be displayed in the *Map Panel.*
7	▪ In the *Layer* panel you can see the legend associated to each layer underneath the name of the layer.
8	▪ Some of the layers are queryable, to retrieve the info for the layer: – Select the layer from the *Layers* tab (the layer name needs to be highlighted). – In the main toolbar locate the *info* button. – Click on any feature of the layer in the *Map Panel* and the *Identify* result window will open with the information for the layer.
9	▪ Further information on how to use QGIS can be found in the QGIS on-line training manual.[14] Specific instructions on the use of GFM data in QGIS are also provided in the GFM Quick Start Guide.**Error! Bookmark not defined.**

[11] https://geoserver.gfm.eodc.eu/geoserver/gfm/wms
[12] https://qgis.org/en/site/
[13] WMS (Web Map Service) / WMTS (Web Map Tile Service).
[14] https://docs.qgis.org/3.16/en/docs/

6.4.2 ArcGIS / ArcMap

Using ESRI ArcGIS / ArcMap, you can load a WMS-T directly into your map, as follows:

1	▪ Launch ArcMap[15].
2	▪ In the *Catalog* panel (right side of the screen) click on the *Add WMS Server* icon.
3	▪ In the *Add WMS Server* window insert the GFM WMS URL[11] in the URL section then click on the *Get Layers* button to retrieve the WMS layers. After the retrieving of the layers click on the OK button to close the window.
4	▪ In the *Catalog* panel you should see all available GFM layers. To view the layers, drag and drop the layer icon into the *Table of Contents* panel on the left of the screen. In the *Table of Contents* you can see the legend associated with each layer by right clicking the name of the layer and then select the legend from the context menu.
5	▪ Some of the layers are queryable. To retrieve the information for the layer: – Select the layer from the *Table of Contents* (the layer name needs to be highlighted). – In the main toolbar locate the *info* button. – Click on *any feature of the layer* in the *Map Panel* and the *Identify* result window will open with the information for the layer.
6	▪ Users can request different forecast time using the time slider button. In the time slider window, move the cursor to call different forecast times for the selected layer: – Open the *Time Slider Window* and a pop-up appears. – Go to *Options* (in the pop-up) and modify the following inputs: display date format = yyyy-MM-dd, display time format = none. – Using the *Time slider*, load the GFM WMS layers specified in the available range.
7	▪ Further documentation on using ESRI ArcGIS / ArcMap is available on-line.[16]

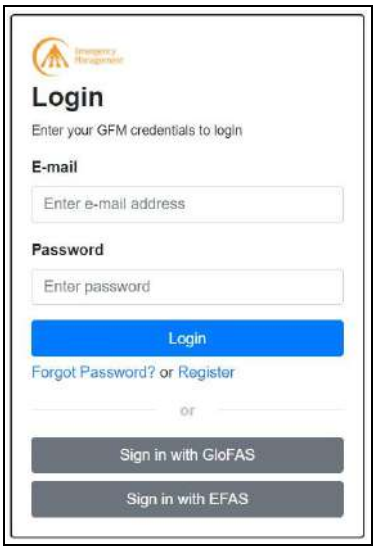
6.5 GFM Web Portal

Users can access this application via GloFAS or EFAS[6,7], or directly via the dedicated URL[17]. With this single-page application the following tasks can be performed, as described below:

▪ *Definition of areas of interest (AOIs)*
▪ *Download of available GFM output layers for AOIs*
▪ *Generation of summary report for AOIs, for selected GFM output layers*
▪ *Activation of notifications for AOIs, via GFM web portal or X (ex-Twitter)*
▪ *Code snippet tool to create inline frame widget for integration in a HTML page*
▪ *Retrieval of tokens to access GFM output layers through a set of REST-APIs*

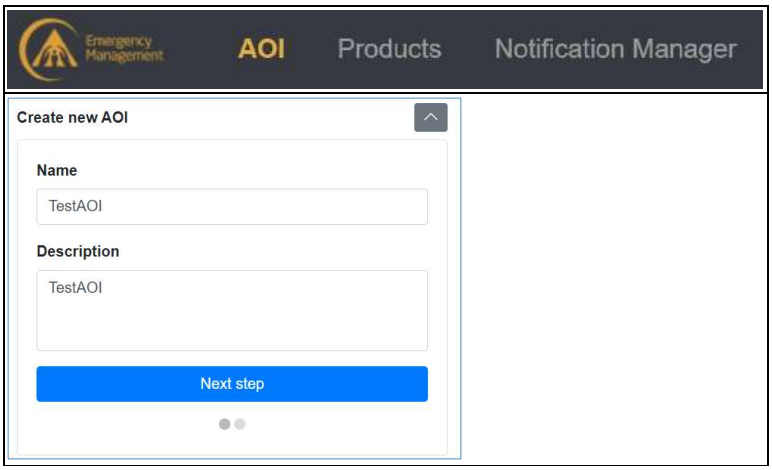
[15] https://desktop.arcgis.com/en/arcmap/
[16] https://doc.arcgis.com/en/
[17] https://portal.gfm.eodc.eu/

Registered users of GloFAS or EFAS can access the system by entering their account details, as shown below. Other users are required to select “Register” and fill in the registration form.



6.5.1 Definition of areas of interest (AOIs)

The AOI dashboard enables users to create and manage their AOIs. To create an AOI, first select “***AOI***” in the main banner (**top graphic below**) and then insert a “***Name*”** and “***Description*”** for the AOI and click “***Next Step***” (**bottom graphic below**).



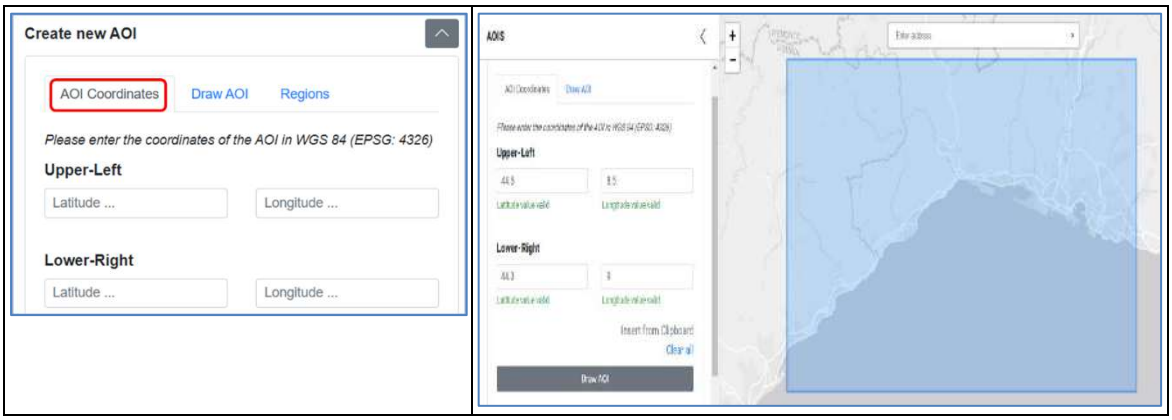
An AOI can be defined in three optional ways, which are explained below:

1. Entering AOI’s upper-left and lower-right latitude and longitude coordinates.
2. Drawing AOI on a map.
3. Selecting a specific administrative region as an AOI.

Note that the maximum number of AOIs for each user is limited to 25. Once the limit is reached, a new AOI can be added only if a previous AOI is deleted.

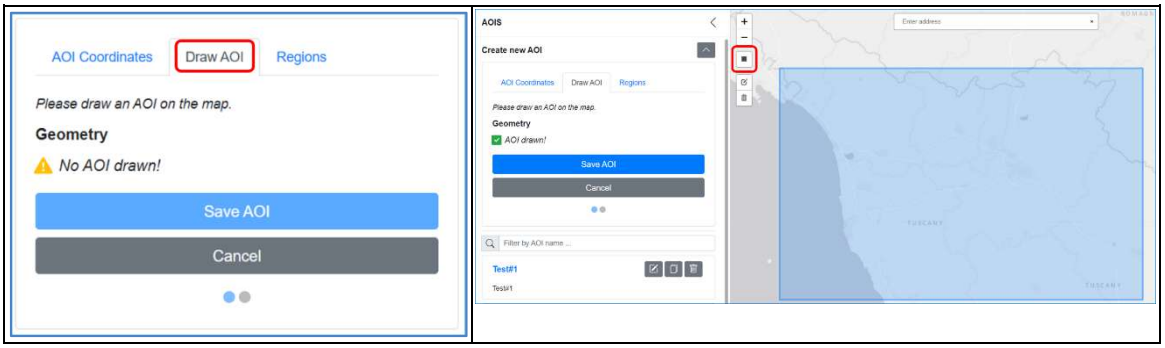
Option 1 - Entering AOI's upper-left and lower-right latitude and longitude coordinates:

Select the "AOI Coordinates" button, enter the upper-left and lower-right latitude and longitude coordinates of the AOI, and click another button, for example "Draw AOI" (**left graphic below**). The system will display the selection on the map (**right graphic below**). Save the AOI (using the "Save AOI" button) to add the AOI to the list of AOIs.



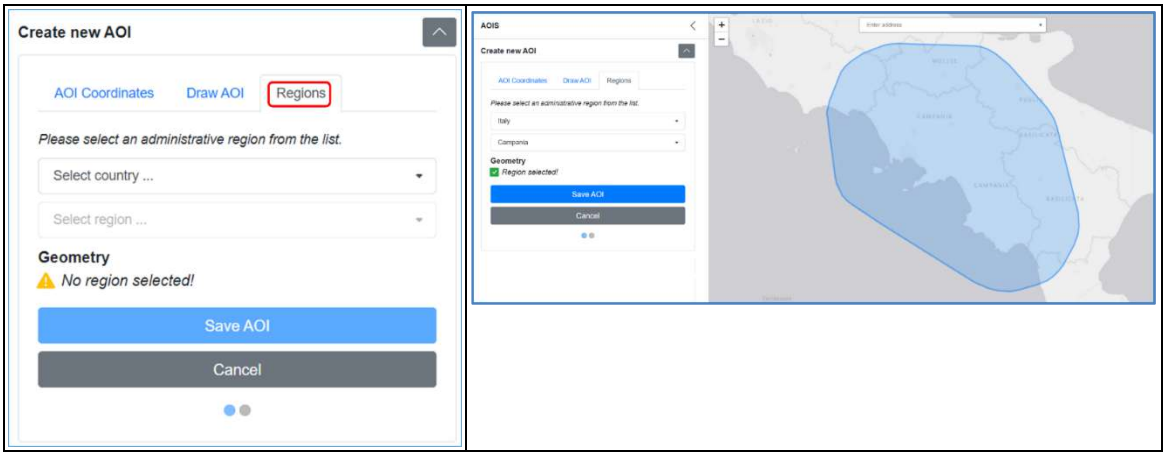
Option 2 - Drawing AOI on a map:

Select the "***Draw AOI"*** button (**left graphic below**). Click on the dark grey square on the map and draw a rectangle over the area for which you wish to retrieve flood information (**right graphic below**). Each AOI in the list can be further edited (using the **pencil icon**) or deleted (**bin icon**). When editing, users may change the rectangle dimensions or drag it rigidly (i.e. not changing its shape) across the map. Once the user is satisfied with the defined area, the button "***Save AOI"*** will add the AOI to the list.



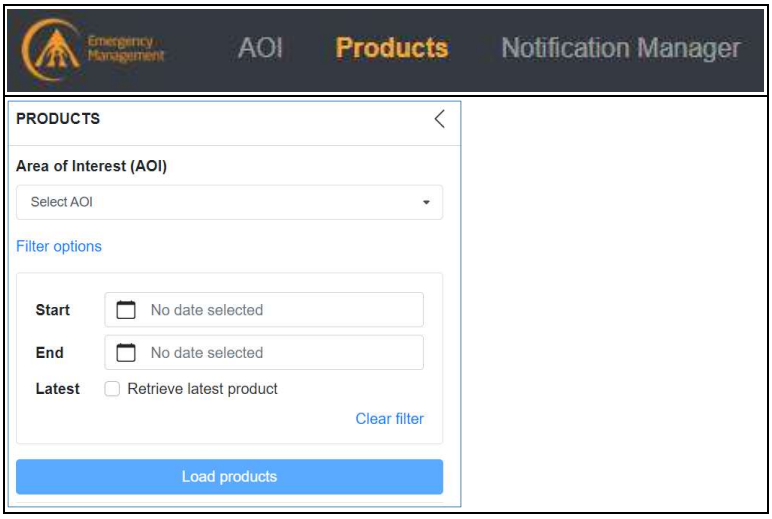
Option 3 - Selecting a specific administrative region as an AOI:

Select the "***Regions***" button (**left graphic below**), and then through the dedicated drop-down menus choose the Country and the Region of interest. In this case the system will automatically draw a polygon fully encompassing the Region of interest (**right graphic below**). If the AOI is satisfactory, the "***Save AOI"*** button will add the AOI to the list.



6.5.2 Download of available GFM output layers for AOIs

To download the GFM output layers, first select "***Products***" in the main banner (**top graphic below**), which brings up the Products form (**bottom graphic below**).



The GFM output layers for a specific AOI are first retrieved as follows:

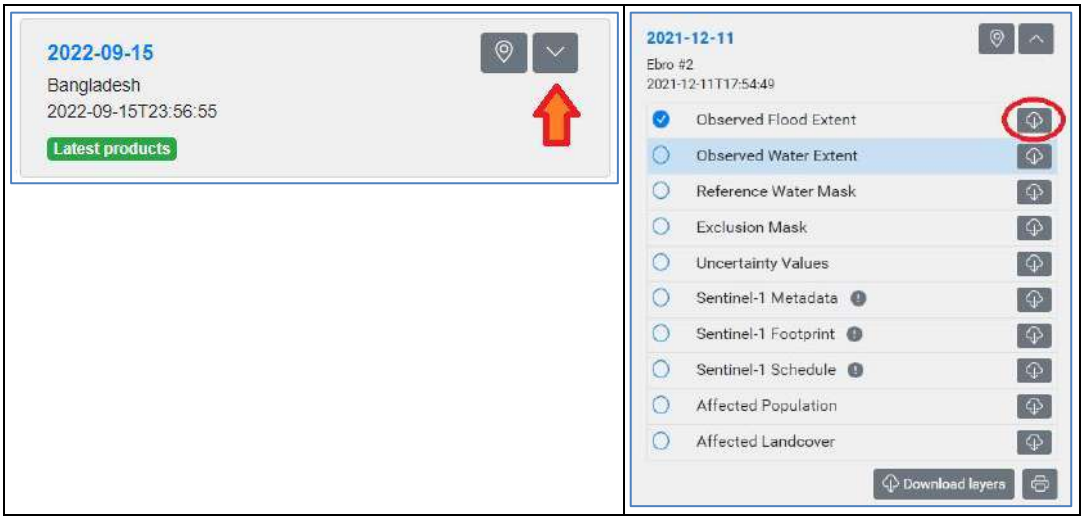
▪ Select an AOI through the drop-down menu "Select AOI".
▪ Choose a reference period, using one of the following options: a) Select its Start and End date through the calendar-shaped icons, or b) Tick the "Latest" box to retrieve the latest GFM output layers.
▪ Click on "Load products".

The GFM output layers for an AOI can be downloaded using five options, described below:

1. Download a single GFM output layer for a specific date
2. Download selected GFM output layers for a defined time-period
3. Download selected GFM output layers for a specific date
4. Download all GFM output layers for multiple dates
5. Download the maximum flood extent

6.5.2.1 Download a single GFM output layer for a specific date

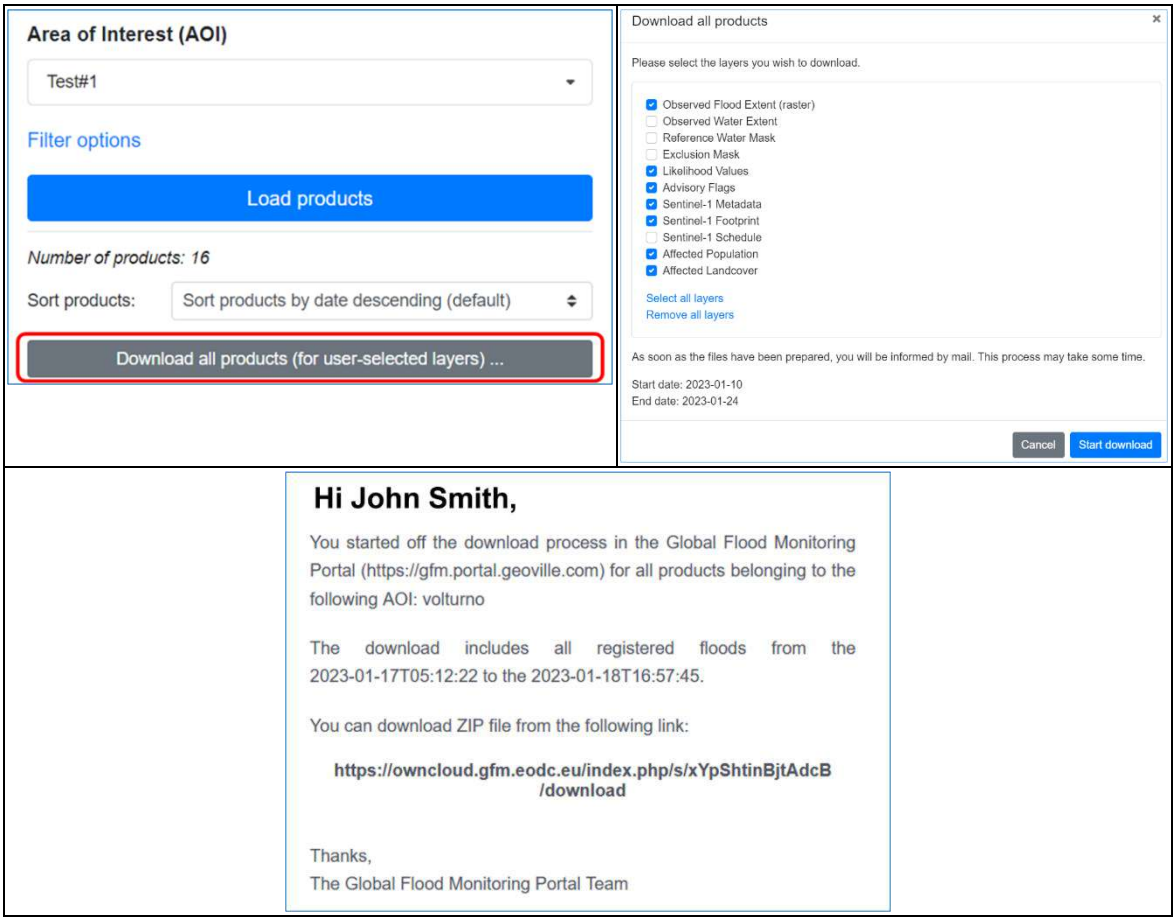
To download a single GFM output layer, users must click on a specific product (**left graphic below**, red arrow), select the output layer (right graphic below), and click Download (**right graphic below**, red circle). Note: (a) the length of the selected time-frame cannot be longer than 6 months; (b) this feature is not available if "Retrieve latest product" filter was ticked.



6.5.2.2 Download selected GFM output layers for a defined time-period

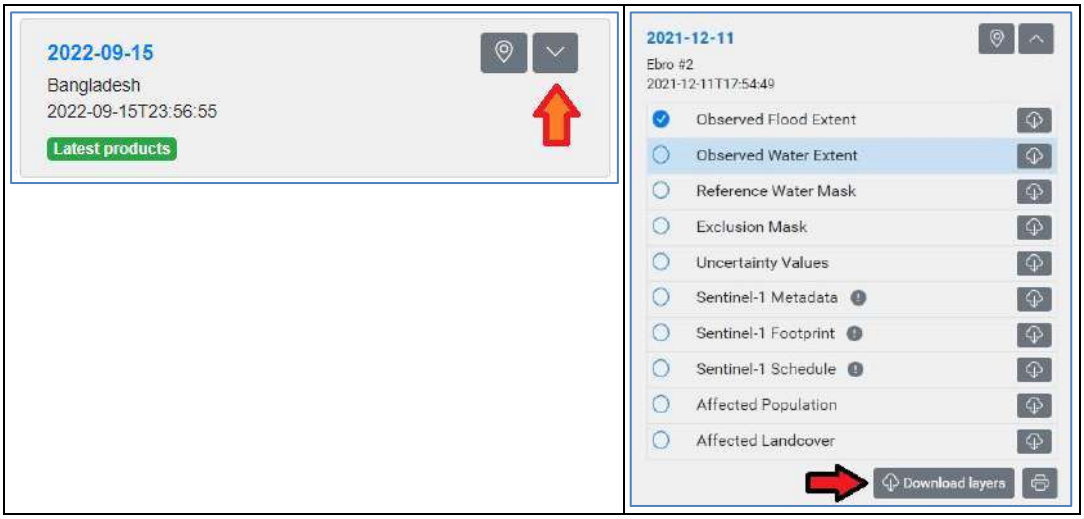
1. Choose the AOI and the reference period (as shown in **Section 6.5.2** above).
2. Select “Download all products (for user-selected layers)” (**top left graphic below**).
3. In the pop-up window (**top right graphic below**): – Check / uncheck the GFM output layers of interest. – Check that the timeframe is correct. – Press “***Start download***”.
4. As soon as the bundle of the requested output layers will is ready, an email including the URL to download the bundle, will be sent out (bottom graphic below).

Note: (a) The length of the selected timeframe cannot be longer than 2 months; (b) This feature is not available if the "Retrieve latest product" filter has been ticked.



6.5.2.3 Download selected GFM output layers for a specific date

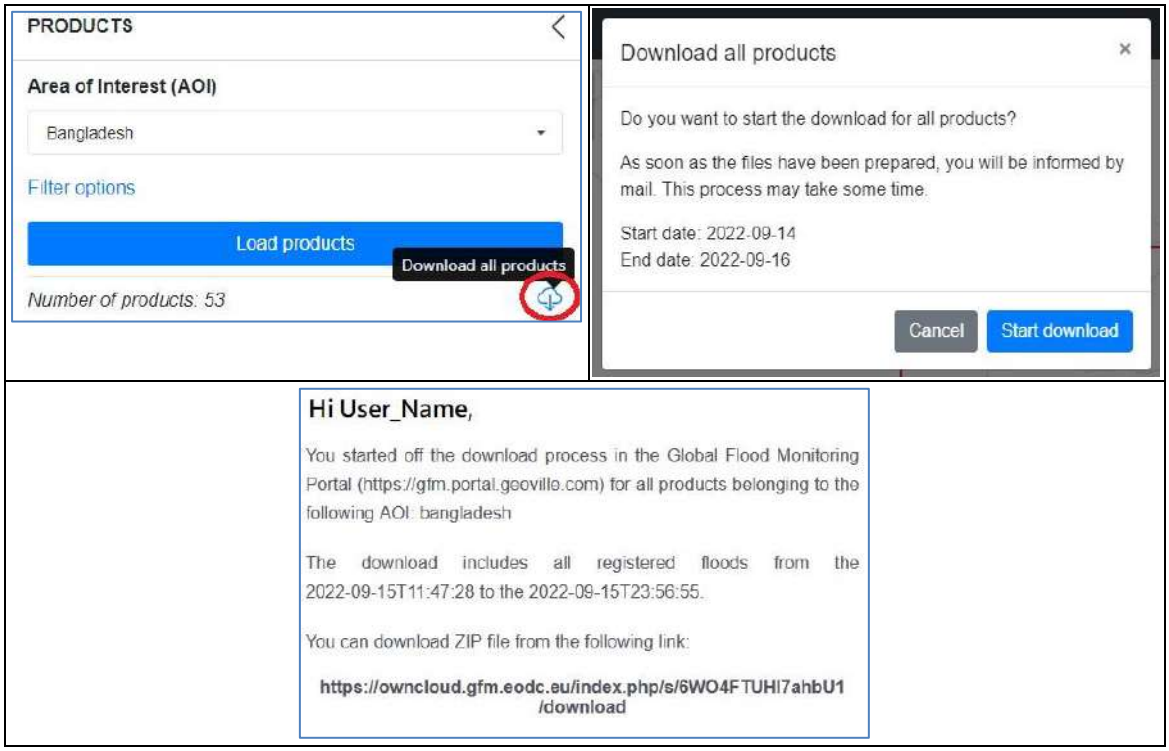
To download selected GFM output layers for a specific date, first select the output layers (**left graphic below**, red arrow), and select “Download layers” (**right graphic below**, red arrow).



6.5.2.4 Download all GFM output layers for multiple dates

1. If multiple dates are available, users can download all GFM output layers for all dates, by clicking on the button “Download all products” (**top left graphic below**, red circle).
2. The system will then display a message asking the user to confirm the submission of the query (**top right graphic below**). The query is confirmed by pressing “Start download”.
3. The system will start assembling the data package. Once completed, an e-mail is sent out providing the link to download the requested dataset (**bottom graphic below**).

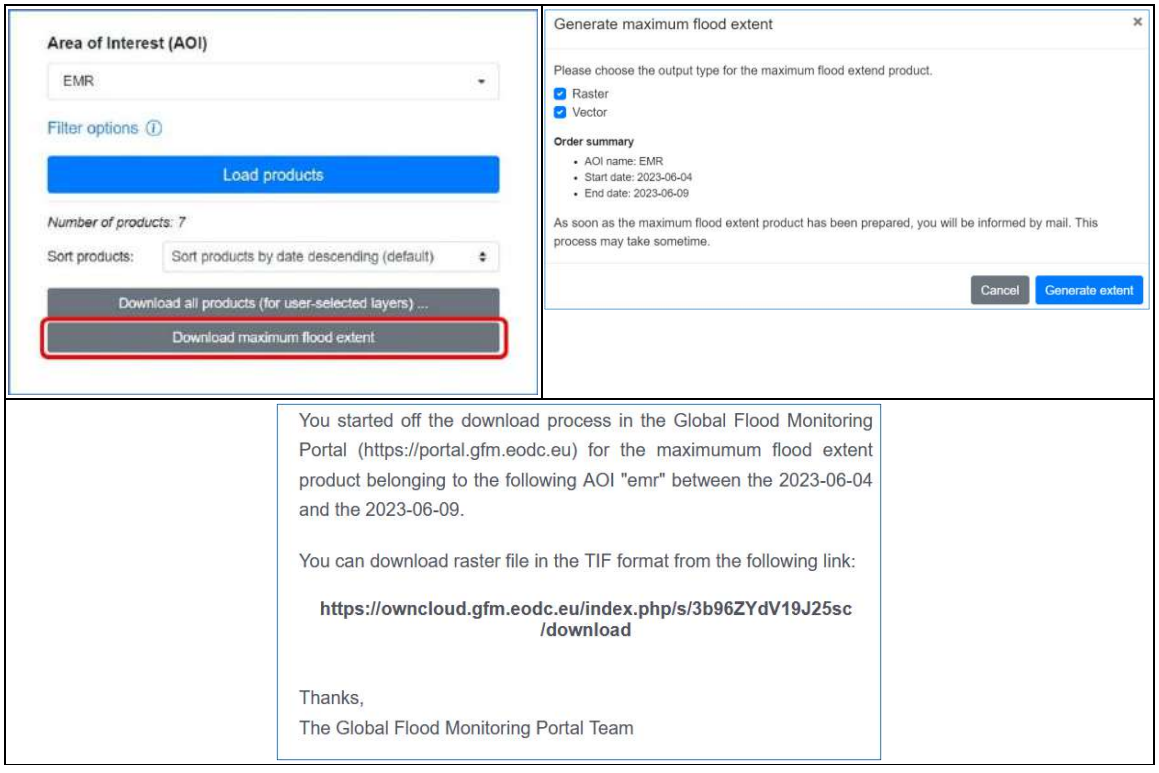
Note: (a) The length of the selected timeframe cannot be longer than 2 months; (b) This feature is not available if the "Retrieve latest products" filter has been ticked.



6.5.2.5 Download the maximum flood extent

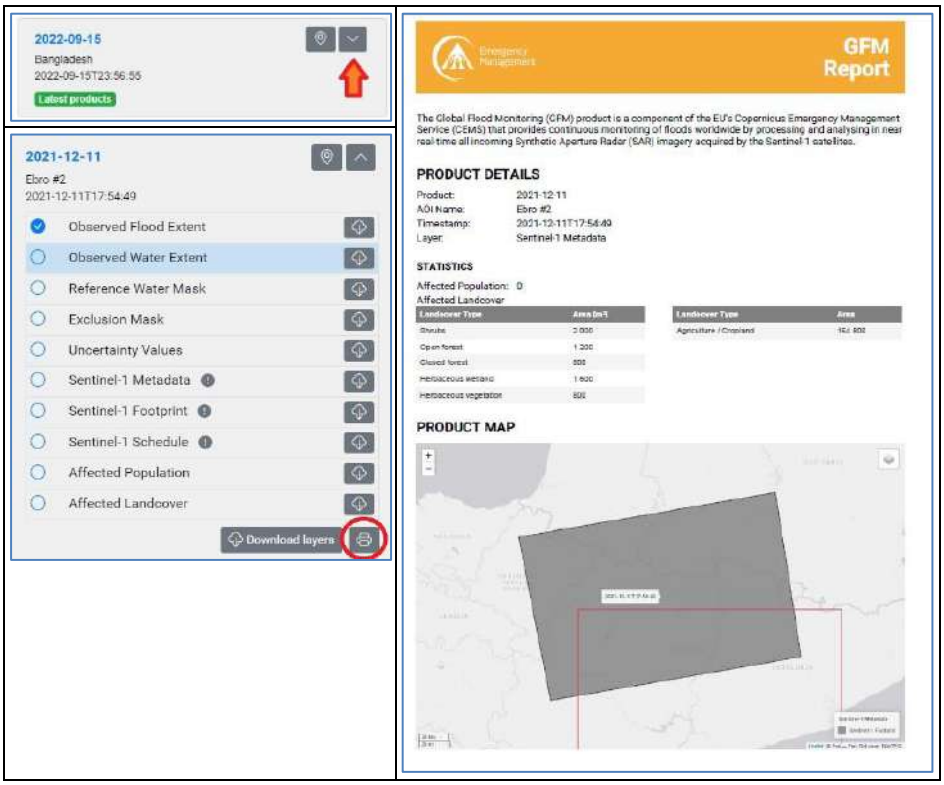
1. The maximum flood extent is the composite of all Observed Flood Extent output layers available for a user-defined period. A request for the maximum flood extent for an AOI is made by selecting "***Download maximum flood extent***" (**top left graphic below**).
2. A pop-up window (**top right graphic below**) will then display: – A checkbox to set the format of the output (raster [tiff], vector [geojson], or both). – The details of the query (AOI name, start date, end date).
3. By clicking on "***Generate extent***", the system will automatically submit the query to the GFM production servers and a confirmation e-mail will be sent to the user.
4. As soon as the computational process will be completed, the system will send a second mail, containing the URL to download the data (**bottom graphic below**).

Note: (a) The length of the selected timeframe cannot be longer than 2 months; (b) This feature is not available if the "Retrieve latest products" filter has been ticked.



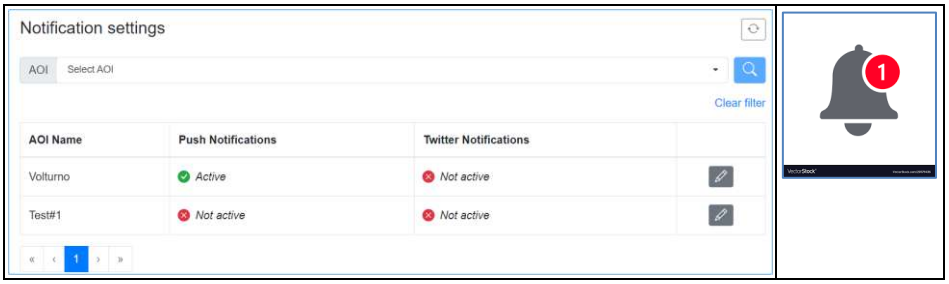
6.5.3 Generation of summary report for AOIs, for selected GFM output layers

1. To generate a short report for a selected GFM output layer, the user opens the list of GFM output layers (**top left graphic below**, red arrow), selects an output layer (**bottom left graphic below**), and clicks “printer” button (**bottom left graphic below**, red circle).
2. A PDF document is automatically downloaded to the local drive with all the basic information on the output layer (**right graphic below**).



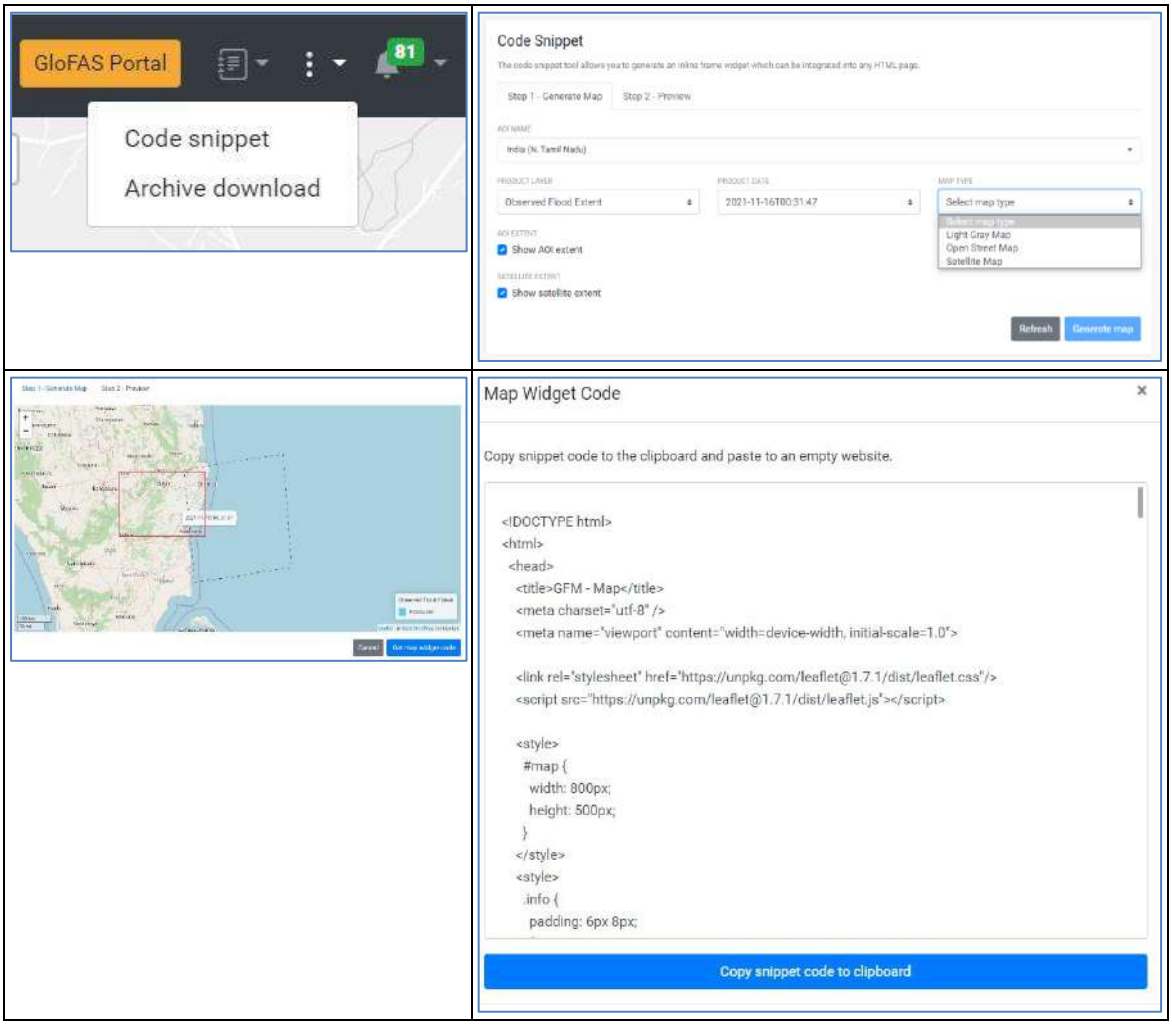
6.5.4 Activation of notifications for AOIs, via GFM web portal or X (ex-Twitter)

1. Click on the AOI / AOIs for which notifications are required.
2. The system opens a dialogue window where users can choose to be notified by email or through their X (formerly, Twitter) account (**left graphic below**).
3. Every time users will access the application, the bell-shaped icon in the top right corner will show the number of new / unread notifications (**right graphic below**).



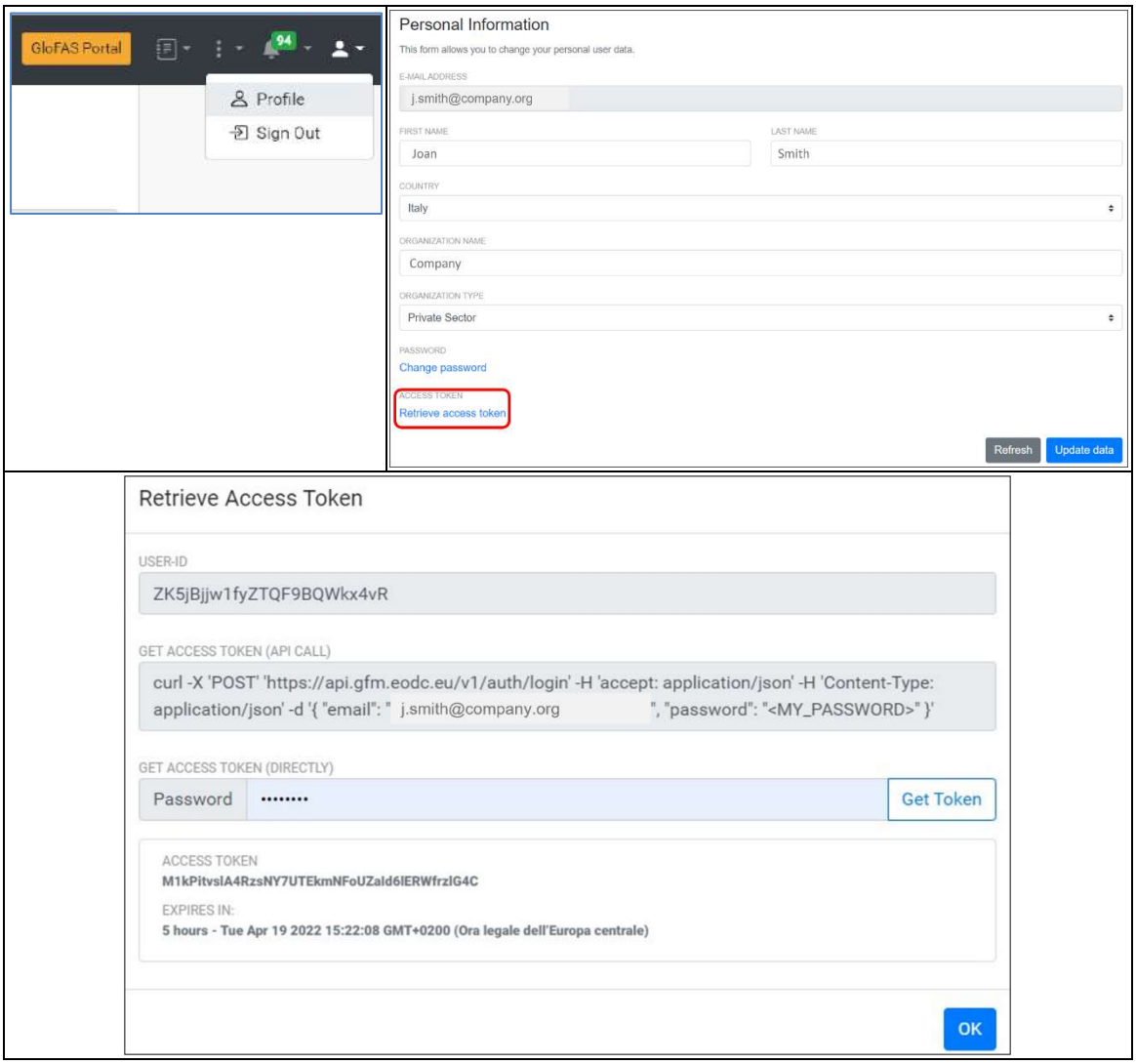
6.5.5 Code snippet tool to create inline frame widget for integration in a HTML page

1. The code snippet tool allows users to generate an inline frame widget that can be integrated into any HTML page. To activate this feature, users must click of the three-point column icon on the top bar and select “Code snippet” (**top left graphic below**).
2. Once done, the system will open a form users shall fill in to request the desired product layer, acquisition time, and background for a specific AOI (**top right graphic below**).
3. After all the needed parameters are entered, users must click on the "Generate map" button: the system will then display a preview of the map according to user's request (**bottom left graphic below**).
4. If the generated map fulfils the requirements, users can ingest it as a widget code by copying it into their HTML code (**bottom right graphic below**).



6.5.6 Retrieval of tokens to access GFM output layers through a set of REST-APIs

1. GFM offers the possibility to access its products through a set of REST-APIs. To use the APIs, users need to get an access token that can be retrieved in their "Profile" section of the GFM Web Portal (**top left graphic below**).
2. The token could be then retrieved by clicking on the button "***Retrieve access token***" (**top right graphic below**).
3. The final step is to type the personal password in the text box at the bottom of the pop-up and to press the “Get Token” button (**bottom graphic below**).
4. The system will then generate a temporary token that will be valid for the next 5 hours.



6.6 GFM STAC catalogues

The GFM output layers of worldwide flood-related information are also available through the GFM **STAC catalogues**[18]. A STAC catalogue is a simple, flexible JSON-format file of links that provides a structure to organize and browse STAC items, where each item is a single geospatial dataset (or "spatio-temporal temporal asset"), represented as a GeoJSON feature plus date and time information, and links[19]. Note that JSON is a text-based data format for storing and exchanging data, which is widely used for transferring data between a server and a web application. GeoJSON is an open standard, text-based format for representing simple geographical features and their non-spatial attributes, based on JSON.

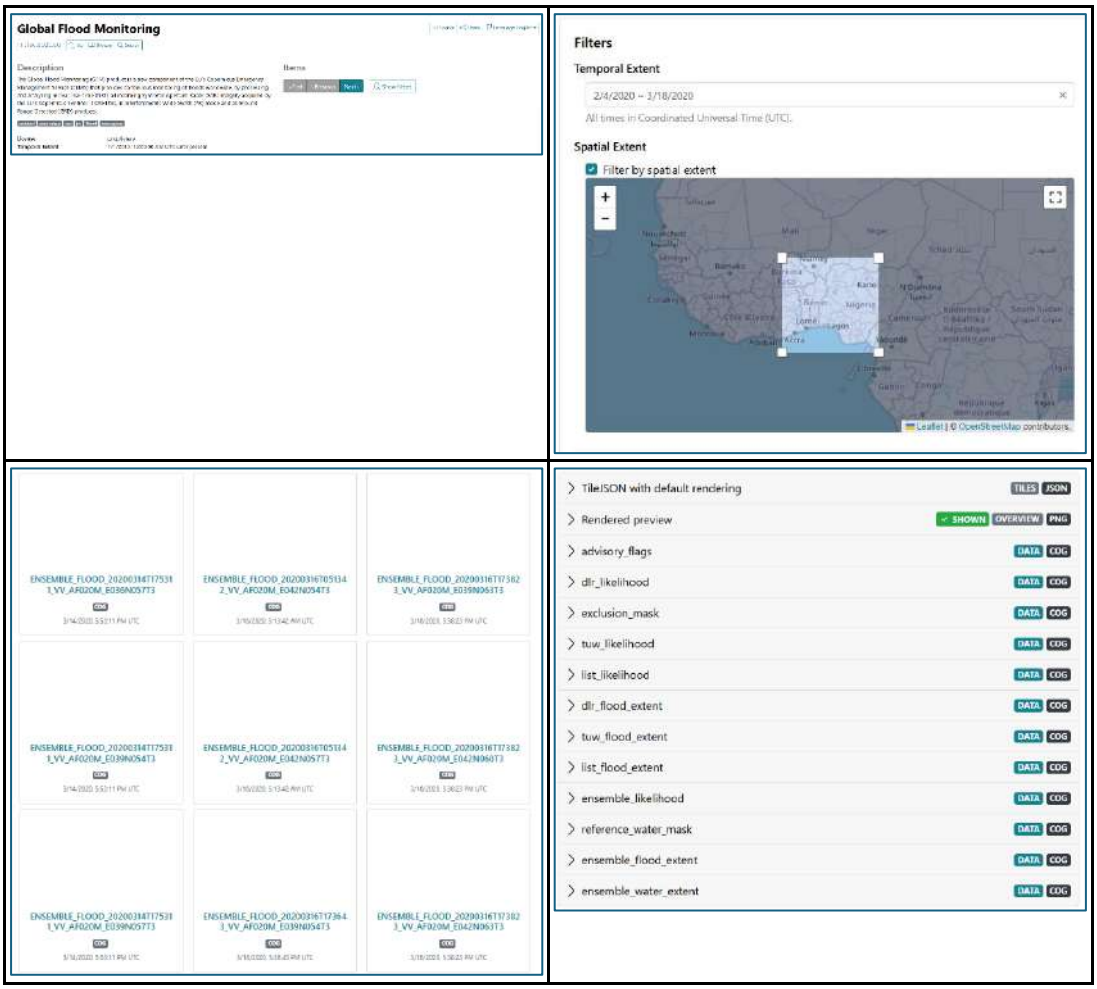
In order to access and explore the GFM STAC catalogues, GFM provides a set of **Jupyter notebooks** (listed below), which are freely available on EODC's GFM GitHub platform[20]. A Jupyter notebook is a JSON-format computational notebook documents combining code (in Python), text descriptions (in Markdown), data, rich visualizations, and interactive controls[21]. (The name Jupyter refers to the programming languages Julia, Python and R).

Download_gfm_python.ipynb	▪ ***GFM data discovery and download**: Query the GFM STAC collection using the Python library pystac_client, and download the data using built-in Python libraries as well as utilizing the command line tool stac-asset.*
gfm_dask_objectstorage.ipynb	▪ ***Save results in cloud object store**: Remotely process data on the EODC cluster using the Python library Dask, and save the result in a cloud object store*
gfm_filter.ipynb	▪ ***Refine STAC query using filters**: Refine the query of the GFM STAC catalogue using the STAC API filter extension.*
gfm_maximum_flood_extent_dask.ipynb	▪ ***EODC Dask Tutorial**: Remotely process the GFM data on the EODC cluster using Dask.*
gfm_maximum_flood_extent_local.ipynb	▪ ***GFM maximum flood extent with STAC**: Find data using STAC, load it into a xarray object, and calculate result.*
gfm_maximum_flood_extent_simple_plot.ipynb	▪ ***Computation of GFM Maximum Flood Extent for area and time of interest**: Use STAC to find GFM Observed Flood Extent and derive maximum flood extent.*
gfm_maximum_flood_extent_stac.ipynb	▪ ***Compute maximum flood extent utilizing STAC**: Use STAC to find GFM Observed Flood Extent and derive maximum flood extent.*
gfm_plot_flood_scene.ipynb	▪ ***Plot GFM flood scene**: Plot part of a flooded GFM scene using an OpenStreetMap basemap as background.*
gfm_rfm_evaluation.ipynb	▪ ***Evaluating Observed Flood Extent from the GFM against Forecast Flood Extent from the EFAS Rapid Flood Mapping layer**[22]: Use STAC to derive maximum flood extent for a flood event, extract the corresponding forecast product from the EFAS rapid flood mapping, and perform a simple evaluation.*

[18] https://services.eodc.eu/browser/#/v1/collections/GFM
[19] https://stacspec.org/
[20] https://github.com/eodcgmbh/eodc-examples/tree/main/demos/GFM
[21] https://docs.jupyter.org/en/latest/what_is_jupyter.html
[22] https://data.jrc.ec.europa.eu/dataset/85470f72-9406-4a91-9f1f-2a0220a5fa86

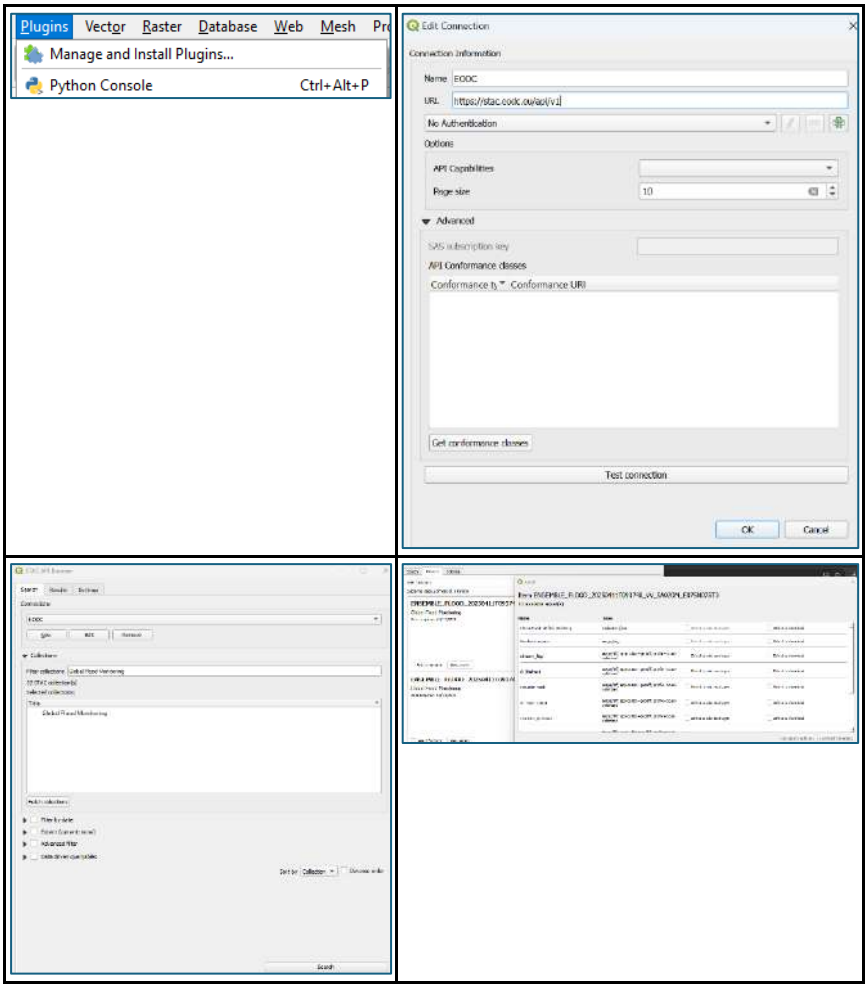
6.6.1 Accessing the GFM STAC catalogues using the EODC STAC Catalogue Browser

1. The EODC Catalogue stores all Sentinel-1 scenes. Request the latest data in the GFM STAC catalogue via the EODC STAC Catalogue browser[18] (**top left graphic below**).
2. By clicking on the "Search" option, specific Sentinel-1 scenes can be selected using the provided "Temporal Extent" filter to select the desired time period, and the "Spatial Extent" filter to select the desired area (**top right graphic below**).
3. Once the desired parameters are defined, the number of results to be displayed on each page can be set (the default is 12). When the query is submitted, the retrieved results are listed (**bottom left graphic below**).
4. By clicking on one of the retrieved scenes, all of the related assets (i.e. geospatial datasets) stored in the GFM STAC catalogue are listed (**bottom right graphic below**), including the intermediate products (e.g. the observed flood extent detected by each individual GFM flood mapping algorithm).
5. By expanding each listed asset, the user will be presented with all the options for that specific asset (i.e. Download, Copy URL, Show on Map), and its relevant metadata.



6.6.2 Accessing the GFM STAC catalogues using QGIS

1. After installing QGIS[23], the STAC API Browser needs to be installed. In QGIS open the overview of all plugins, via “Plugins - Manage and Install Plugins” (**top left graphic below**). Once found, select “Install Plugin”, and close the window.
2. In QGIS, create a new connection via the “New Connection” / “Edit Connection” (**top right graphic below**). Select a name and enter the URL[24]. Use “Test Connection” to check that the connection works, then click on OK to create the connection.
3. To display the GFM STAC catalogues, enter “Global Flood Monitoring” under “Filter Collections”, click on “Fetch collections” and “Search” (**bottom left graphic below**).
4. The available assets corresponding with the query are listed (**bottom right graphic below**). Click on “View assets” to display the data or download the item. Use “Select footprint” and “Add the selected footprint” to visualise the data on the dashboard.



[23] https://www.qgis.org/en/site/forusers/download.html
[24] https://stac.eodc.eu/api/v1

6.6.3 Further sources of information on using STAC catalogues and Jupyter Notebooks

STAC (SpatioTemporal Catalog) specification:	▪ https://stacspec.org/en
Reading Data from STAC API by Microsoft Planetary Computer (with useful material to understand STAC):	▪ https://planetarycomputer.microsoft.com/docs/quickstarts/reading-stac/
Radiant Earth STAC browser, where any STAC API URL can be added (e.g. CDSE, Google Earth Engine), and the respective STAC cataloguess / items visualized:	▪ https://radiantearth.github.io/stac-browser/
EODC STAC API:	▪ https://stac.eodc.eu/api/v1
EODC's STAC Browser:	▪ https://services.eodc.eu/browser/#/v1/
EODC knowledgebase, on how to access and work with EODC services and data:	▪ https://docs.eodc.eu/
EODC Portal (new entrypoint for EODC services), including the "Explorer", which is another way for visualizing STAC catalogues / items:	▪ https://portal.services.eodc.eu/
Jupyter Notebook documentation:	▪ https://jupyter-notebook.readthedocs.io/ ▪ https://docs.jupyter.org/en/latest/what_is_jupyter.html

7 Frequently Asked Questions (FAQs)

7.1 General Queries

7.1.1 What is the GFM product?

The GFM product is a component of the Copernicus Emergency Management Service (CEMS) that is specifically designed to provide users around the world with timely, up-to-date, and reliable global flood mapping information based on Sentinel-1 satellite imagery.

GFM is implemented and operated by a consortium comprising the following organizations: EODC; GeoVille; TU Wien; LIST; DLR; CIMA. All data produced by GFM are freely available through GloFAS and the GFM WebApp (for example), as described in Section 6 of this PUM.

7.1.2 How can I contact the GFM Users Support service?

The **GFM Users Support** service is coordinated by CIMA Foundation and will be guaranteed through e-mail, during working hours (8:00-17:00), 5-days-a-week in English. Duty officer's contact: gfm-user-support@cimafoundation.com

Users can also use (a) **GloFAS Contact Us** form[6], or (b) **EFAS user support**[7]. Remember to file requests by selecting **Floods Monitoring** in the *Subject* drop-down menu, as shown below.

7.1.3 How do I get GFM training and / or access educational material?

Most of the information that users need for proper use of the GFM product is in the PUM and PDD[3]. Other material is constantly updated on GloFAS and EFAS web-page (see below).

7.1.4 How to credit GFM as data source in publications

GFM is part of the CEMS ecosystem, as are all the products provided and made available through GloFAS and EFAS. Therefore, the same rules apply to GFM when credits are to be given. Please check the Terms and Conditions sections on the aforementioned web portals[1].

7.1.5 Where do I find GFM's technical documentation?

Comprehensive technical documentation on the GFM product is provided on-line on the GFM Wiki page[3], both in wiki format and also as printable PDF versions, in the form of:

- The GFM Product User Manual (PUM).
- The GFM Product Definition Document (PDD).

7.1.6 What other information sources could I consult before taking a decision?

GFM aims to guarantee a high degree of accuracy for all its products, yet users must be aware that a certain degree of uncertainty has to be taken into account.

Therefore, before taking a decision, it is highly recommended to crosscheck GFM's information with other, independent sources such as VIIRS, MODIS, UNITAR, International Disaster Charter, Dartmouth Flood Observatory and others.

National hydro-meteorological services are another valuable and authoritative way to check current danger levels. Please check the full list of the World Meteorological organization (WMO)[25] to find the national body corresponding with your region or area of interest.

[25] https://wmo.int/

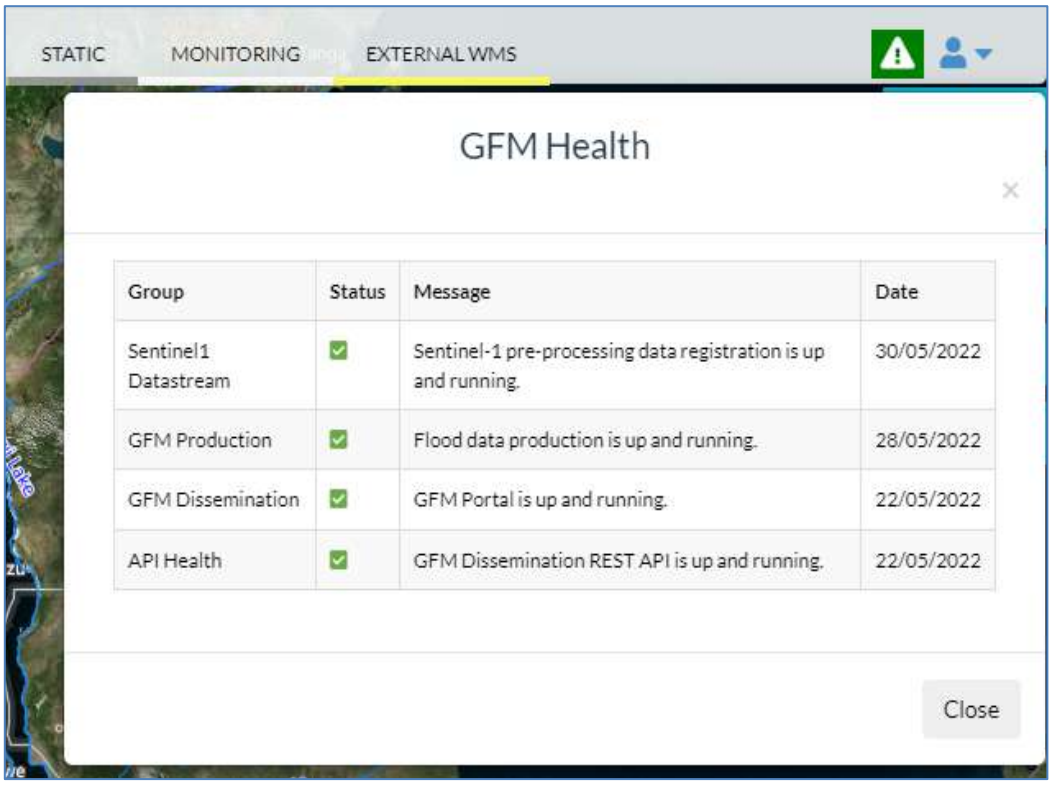
7.1.7 Are there any restrictions on using GFM's imagery downloaded from GloFAS?

GFM is part of CEMS ecosystem, as are all the products provided and made available through GloFAS and EFAS. Therefore, the same rules apply to GFM Please check the Terms and Conditions sections on the aforementioned web portals[1].

7.1.8 How can I know whether the system is fully operational or not?

As the GFM products are made available through GloFAS and EFAS, these systems will inform users on any malfunction affecting this component.

For instance, in GloFAS any failure in the generation of each daily dataset as well as any limitation of the service are shown in the upper right corner with a banner:



In case of a malfunction, the banner turns red: by clicking on it, a pop-up window will open, listing all the missing or delayed outputs of the system.

7.1.9 Is the information I provide to GFM Login really safe?

GFM is part of CEMS ecosystem, as are all the products provided and made available through GloFAS and EFAS. Therefore, the same rules apply to GFM regarding security matters. Please check the privacy sections on the aforementioned web portals[1].

Regarding external applications, such as the GFM Web Portal: the GFM team guarantees to secure all access by standard encryption, as per the project's Terms of Reference.

7.2 Data Access

7.2.1 How can I request a specific GFM product output layer?

GFM is part of CEMS ecosystem, as are all the products provided and made available through GloFAS and EFAS. Regardless of which portal (GloFAS or EFAS) will be accessed, all GFM products will be then available on both.

If a user wishes to download a specific product or a bundle of products related to a specific AOI or time span, GFM has a Web Portal through which a query (or more) can be refined according to user requirements. All the information on how to do this, which formats data are provided in, and so on, are addressed in the dedicated Section 6 of the PUM.

7.2.2 Which web services are available?

GFM offers many ways of access the data of its products, and specifically a full set of web-based tools have been designed to meet users' expectations. In particular, users may use the services listed below, as described in the dedicated Section 6 of the PUM:

- A full set of tailored REST - APIs.
- A Web Map Service.
- A dedicated Web Portal.
- The STAC catalogue

7.2.3 Can you download GFM product output layers for individual countries?

Users interested in downloading products for a specific country shall address in the first place the GFM Web Portal[10], which enables you to configure the system to receive notifications on your e-mail or X (formerly, Twitter) account, on any update regarding floods detected, site-specific.

Moreover, the Web Portal also offers the capability of downloading the required dataset in bundle or for separate products for a specific region.

7.2.4 How do I subscribe to upcoming products?

Users interested in products for a specific country shall address in the first place the GFM Web Portal[10], which enables you to configure the system to receive notifications on your e-mail or X (formerly, Twitter) account, on any update regarding floods detected, site-specific.

Moreover, the Web Portal also offers the capability of downloading the required dataset in bundle or for separate products.

7.3 Products / Processing

7.3.1 How frequently are GFM data updated?

GFM output layers rely on Sentinel-1 data, therefore their availability is determined by this. One of the GFM output layers is the Sentinel-1 (S-1) schedule, with which users can retrieve information on the next data update. Specifically, updated and authoritative information on the revisit time are available on S-1 webpage (see Figure below, © ESA).

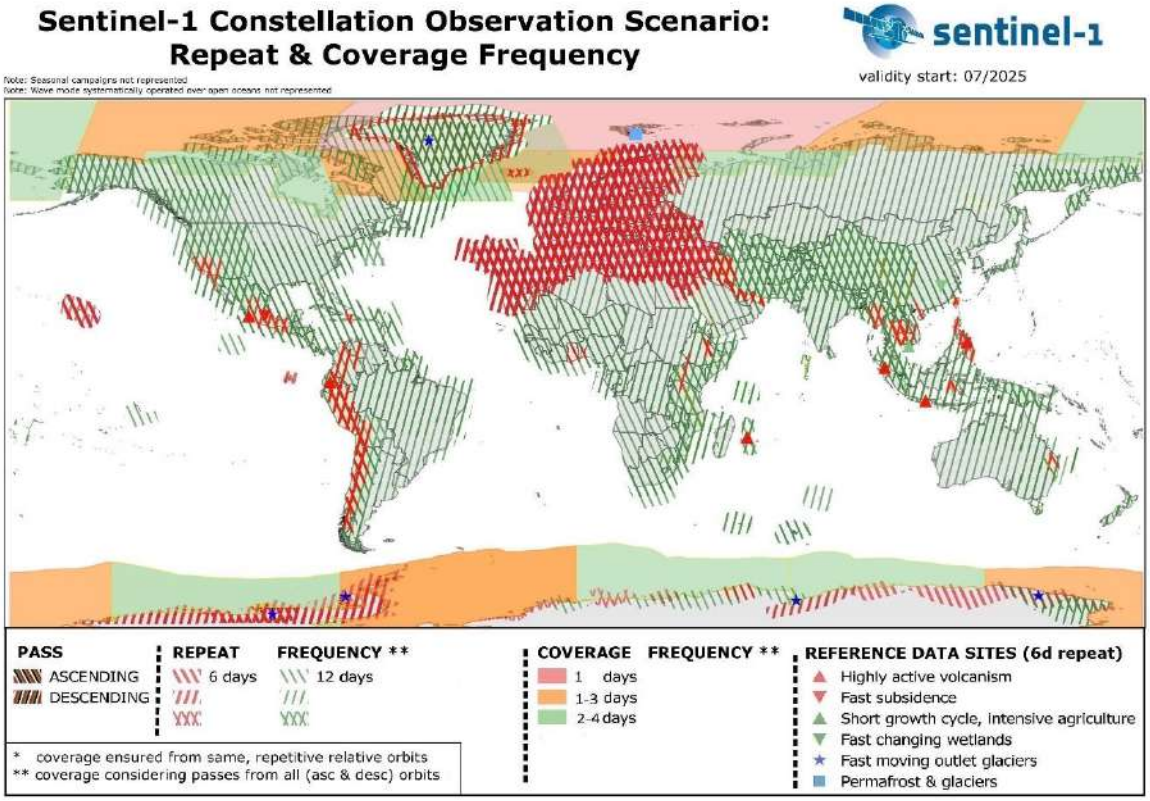


Figure 14. Illustration of the Sentinel-1 satellites revisit and coverage frequency.

7.3.2 What time does the satellite pass over my area?

Information on the next available S-1 pass over a specific area is provided as one of the GFM output layers, i.e. the S-1's schedule, available on GloFAS and EFAS. The time of the planned future acquisition is also provided by ESA in form of Keyhole Markup Language (KML):

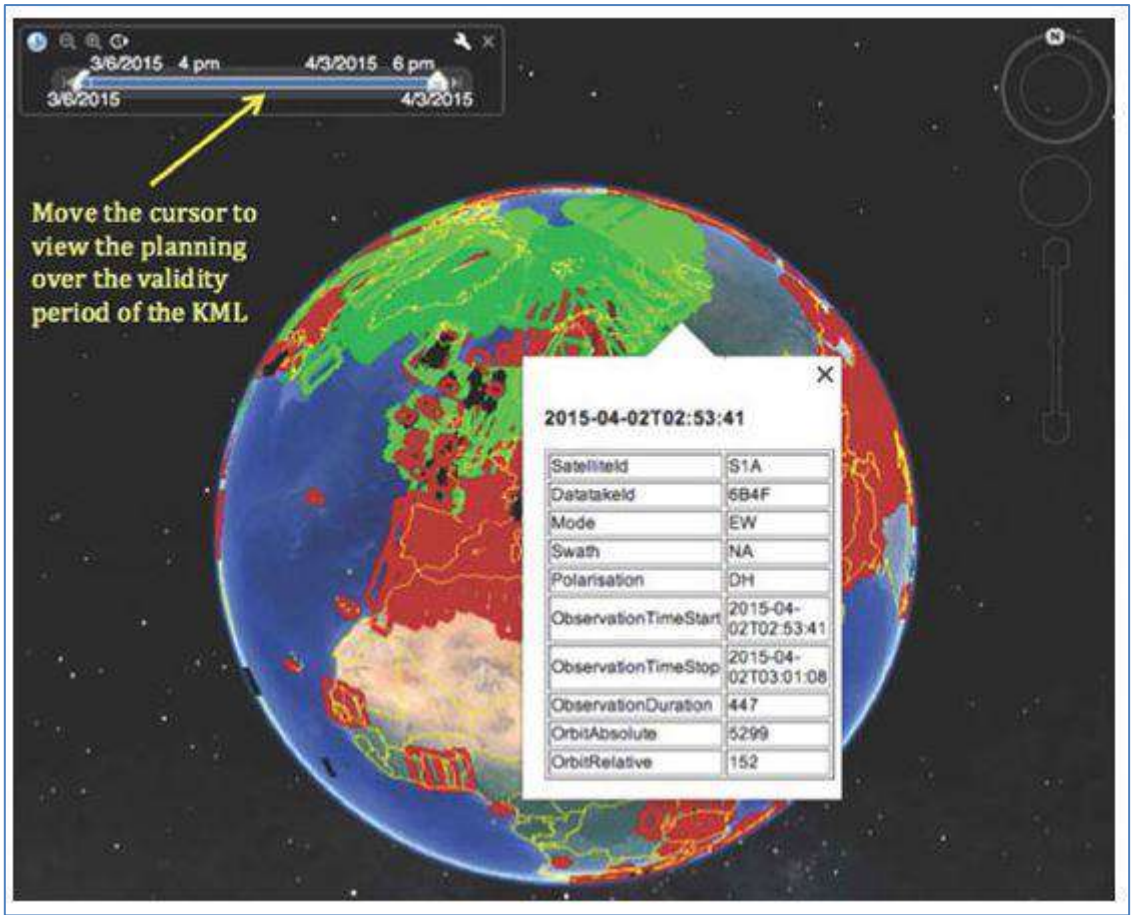


Figure 15. Illustration of the Sentinel-1 satellites schedule.

7.3.3 In which format are the GFM output layers available?

GFM makes available in near real-time a full set of output layers of worldwide flood information, which are listed in Table 1 of this PUM. Further details, including the format of the GFM output layers, are provided in Table 4 and in Section 3 of this PUM.

7.3.4 Which projection is used for the output layers?

The projection used for all the GFM product output layers, in vector / raster format, is WGS84 - EPSG:4326. More specific details on EPSG can be found at https://epsg.org/

7.3.5 How to interpret the GFM Likelihood Values output layer

GFM's flood detection estimate is provided through an ensemble algorithm. Based on a "consensus-maps" and an expert-designed threshold of classification, uncertainty is a non-negligible factor to be taken into account prior to any decision-making process.
For this very reason, the likelihood output layer is produced and associated to every computed flood detection extent, offering the end user a clear and immediate information on the confidence of the estimate in terms of percentage.

This has a value in the range of [0, 100], where values towards 100 indicate high confidence in the ensemble flood extent detection approach.

Consequently, uncertainty information provided along with the map product communicates how much confidence is associated with the S-1 classification. End users can then use highly certain flood map products to identify resource requirements over areas of flood exposure to make timely emergency response decisions.

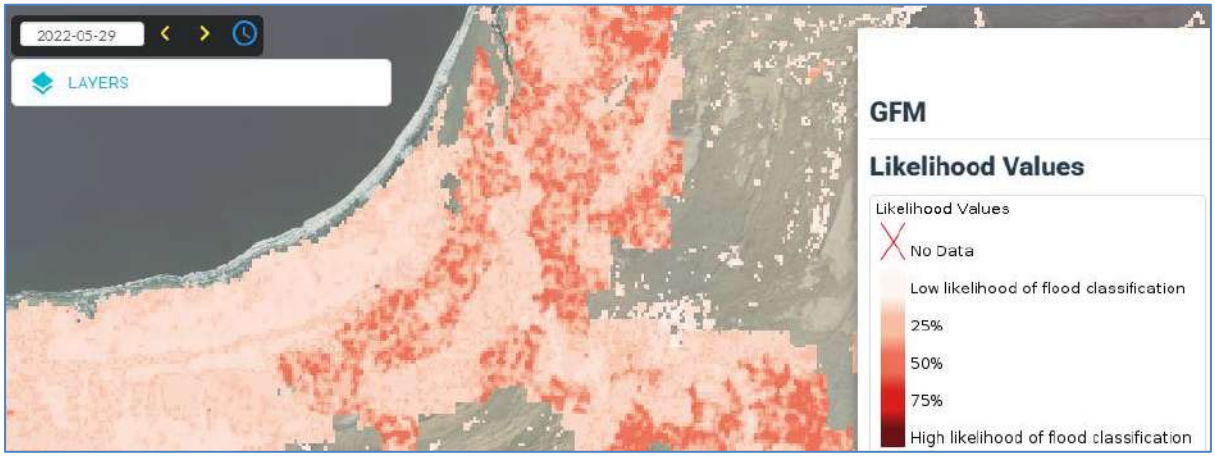


Figure 16. Example of the GFM output layer "Uncertainty values".

More specifics are also available on the dedicated sections of the GFM PDD[3].

7.3.6 I found a mistake in a GFM output layer. How can I report it?

Ideally, QA/QC process are operational within GFM's project framework to ensure the highest quality standard together with a minimization of potential systemic errors and mistakes. Nevertheless, users are encouraged to report any inconsistencies they could come across to the GFM User Support, as described below.

The **GFM Users Support** service is coordinated by CIMA Foundation and will be guaranteed through e-mail, during working hours (8:00-17:00), 5-days-a-week in English. Duty officer's contact: gfm-user-support@cimafoundation.com

Users can also use (a) **GloFAS Contact Us** form[6], or (b) **EFAS user support**[7]. Remember to file requests by selecting **Floods Monitoring** in the *Subject* drop-down menu, as shown below.

7.3.7 How does GFM estimate the impact of an event?

A preliminary assessment of sector-specific impacts of observed flood events, is provided using the GFM output layers “Affected Population” and “Affected Landcover”, as described in the dedicated Sections 3.9 and 3.10 of this PUM.

7.3.8 What is the spatial resolution of the data?

The spatial accuracy of the GFM product conforms to the optimal geometric quality of standard products derived from Sentinel-1 20-metre resolution GRD data. A thorough description of the steps leading to the final 20-metre resolution of the GFM is available[26].

7.3.9 How to ingest GFM'S WMS-Ts in a desktop GIS application

GFM can be displayed through state-of-the art GIS software. Users can find all the information on how this is done in the dedicated Section 6.4 of this PUM.

7.4 Data Quality of the GFM product

7.4.1 How are GFM data validated?

Implementing and operating the GFM product requires a set of procedures to ensure the best possible scientific and technical quality of the GFM output layers (including observed flood extent, reference water mask, exclusion mask, etc.) and of the generating service. The GFM product and service quality assessment (QA) procedures include both systematic automated and planned offline quality checks considering all aspects of the production.

The quality of the GFM product is reported on a quarterly basis using Key Performance Indicators that monitor service availability, product timeliness, thematic quality, unique visitors, total visitors, and total downloads (European Commission, 2020). The results of the GFM product and service quality assessment are published online as Annual Reports[5].

[26] https://extwiki.eodc.eu/gfm_assets/s1.pdf

7.4.2 Are there known GFM products quality issues?

The overall thematic accuracy shows good results and meets the target values of the assessed quality criteria. The quality assessment was performed based on several defined flood events since the near real-time production is in place and the assessment will continue on a regular basis in the future. The results of the GFM product and service quality assessment are published online as Annual Reports[5].

7.4.3 Where can I find the latest report(s) on GFM products quality / reliability?

The quality of the GFM product is reported on a quarterly basis using Key Performance Indicators that monitor service availability, product timeliness, thematic quality, unique visitors, total visitors, and total downloads (European Commission, 2020). The results of the GFM product and service quality assessment are published online as Annual Reports[5].

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9 Annex 1: Professional profile of the Expert Flood Monitoring Alliance

The Global Flood Monitoring (GFM) product of the European Commission's Copernicus Emergency Management Service (CEMS) is run by an international consortium, called the Expert Flood Monitoring Alliance (described in detail below), consisting of:

- 2 companies: the EODC (Group Leader) and GeoVille
- 3 research institutions: TU Wien, LIST and CIMA Foundation
- The German Aerospace Centre (DLR)

The consortium comprises a highly experienced group of leading experts in Europe for satellite-based flood monitoring systems with a unique CLMS, CEMS and global flood mapping service heritage. From the early days of satellite-based flood mapping and monitoring applications, the individual members of this group have built unprecedented, yet thematically complementary flood mapping, monitoring and related disaster risk service capacities as well as an accumulated a long track record of high-quality implementations and successful projects, related processing and data access systems with applications globally.

9.1 EODC [*https://eodc.eu/*]

The Earth Observation Data Centre for Water Resources Monitoring GmbH (or EODC) was established in May 2014 as a visionary concept outlined by Prof. Wolfgang Wagner and a group of public and private actors in the field of Earth Observation. The setup of the EODC was a direct response to the advent of Copernicus (the EU's Earth observation programme), and the resulting unprecedented amounts of data that would be acquired by Copernicus over the coming decades.

The Sentinel-1 satellites' projected data volumes and related data transfer requirements, in combination with data-hungry algorithms (e.g., machine learning, time-series analysis), far exceed local storage and bandwidth capacity. The algorithms themselves also demand increased computational power. Therefore, the focus and mission of EODC is to connect in an efficient manner the required storage (data) and computing power (software), thus eliminating data transfer issues. This is achieved through close c-operation with EODC's partner network, consisting of leaders in Earth observation science (i.e., academic and research institutions), business (SMEs), governmental and inter-governmental institutions, and non-profit organizations (NGOs and foundations).

The EODC serves as a platform where customers and long-term partners of EODC can access state-of-the-art cloud-computing, data, and products from a vast long-term repository of EO missions. Moreover, EODC offers exclusive access to the Vienna Scientific Cluster (VSC) super-computing infrastructure (VSC-3 and VSC-4, ranked 82 in the top 500 in June 2019).

In terms of related expertise, the EODC has been working on an IT infrastructure concept that fully supports storage, processing, and re-distribution of various types of EO data, using most up-to-date ICT solutions. Following changes in technology over time and requirements arising through different types of EO data, this concept is being constantly adapted. Lessons learned and knowledge gained through this process form a solid basis for understanding of the needs and requirements associated with high performance storage and retrieval of large data streams, value-added product generation, as well as timely delivery in different manners (e.g., download, web-mapping, and processing services, etc.) and to interdisciplinary interested parties.

The EODC's three broad spheres of service provision include cloud and high-performance computing, data and product provision, and the development of bespoke EO software and services.

Regarding related experience, the EODC is active in a number of national and international projects. After the successful implementation and completion of phase 1 and phase 2 of ESA's CCI Essential Climate Variable (ECV) soil moisture project, EODC leads the R&D evolution of the soil moisture ECV. Furthermore, EODC provides an operational framework for the production, and scientific advancement, for the soil moisture climate data record derived from passive and active space borne EO data sets. The EODC successfully led the Copernicus Climate Change Service (C3S) Soil Moisture Service and currently leads the C3S Land Hydrology and Cryosphere (LHC) Services with an operational Climate Data Production System (CPS) in place, it provides Soil Moisture Climate Data Records (CDR) and coordinates the provision of Lakes, Glaciers, and Ice Sheets and Ice Shelf ECV CDR's to ECMWF and C3S.

Moreover, EODC coordinates its partners in the provision of near real-time soil water index (SWI) products, provides a mirrored processing chain, and offers reprocessing service in the C-GLOPS project, which is the first fully operational phase of the Copernicus Global Land segment. Furthermore, EODC and its partners are active in projects dealing with the development of scientific algorithms and automatic processing chains for the monitoring of different local, regional, and global parameters from Sentinel 1, Sentinel 2 and other EO data sources. More information is provided on the EODC official website.

9.2 GeoVille [https://www.geoville.com/]

Also based in Austria, GeoVille is an internationally operating company that provides consultancy, services and products related to Earth observation (EO), geo-information and geographic information systems (GIS). Enabling the geographic inventorying of human and natural dynamics through the eye of satellite sensors, while adding the spatial dimension to information-gathering, analysis and monitoring for policy support and informed decision-making, constitutes GeoVille's core mission, together with providing turnkey geospatial intelligence solutions for efficient data access, client operations and management.

In terms of related expertise, since its foundation (in 1998) GeoVille has fed the continuous demand for the delivery of satellite-based flood mapping and monitoring services. Hence, very early on, GeoVille invested in research and development activities in order to build up the know-how and capacities to delineate floods from normal water extent, in both optical and microwave (radar) satellite data. This started in the 1990s with manual mapping procedures, and over the years has evolved from semi-manual processing procedures to fully automatic identification and mapping services. Integral to this evolution were the build-up of associated satellite data access and processing facilities, the product quality assurance procedures and extension of the various product delivery mechanisms.

GeoVille was the first European service provider with RADARSAT (2000) and TerraSAR-X (2008) distribution agreements for the sole purpose to be able provide to provide flood monitoring services. Later in 2014, GeoVille invested in a strategic private-public-partnership to found the EODC, which was a blueprint for the Copernicus DIAS, to be able to store and process Sentinel-1 data on a global level, partly to enable fully automatic flood monitoring services and related data access mechanisms.

Today, GeoVille operates the first fully automatic Sentinel1- and Sentinel2-based land monitoring system within its LandMonitoring.earth platform, which provides RESTful Web service based 24/7 access to its customers around the globe. GeoVille has further significant expertise in operations, quality assurance and data access via cloud-based service solutions within the Copernicus Data and Information Access Services (DIAS) and the Copernicus Land Monitoring Service (CLMS). GeoVille currently operates the CLMS processing systems for the “Imperviousnes” and “Water and wetness” products of the Copernicus High Resolution Layers (HRL), and the CLC+ Sentinel-1 and -2 -derived products.

Regarding related experience, some R&D milestones include the Austrian Space Application programme projects NeosQuick (2003), Aid4Floods(2004), NatHaz (2005) and SAR-X(2007), which all contributed to the service application development of SAR-based flood mapping capacities.

The FP-7 project FLOODIS (2010) and InCreo (2011) were a game-changer for the data access as they provided for the first system development with multiple mechanisms to automatic flood monitoring capacities via web pull / push and mobile app technologies, which were further improved in the H2020 projects I-REACT (2015). The latter achieved

true fully integrated data approaches providing a fully automatic risk assessment capacity to the end-users at global level.

Regarding product accuracy assessment, GeoVille has developed the open-source, on-line based validation platform LACOVAL / LACO-Wiki for standardizing the validation of land cover and land cover changes by map users and producers alike. GeoVille has ample hands-on validation experience and commits itself to respect best-practice (ISO certified) along established standards (e.g., CEOS Cal/Val, LPV, EARSC, JRC) of the EO sector.

GeoVille has wide-ranging, hands-on validation experience, and commits itself to respect best-practice (ISO certified) along established standards (e.g., CEOS Cal/Val, LPV, EARSC, JRC) of the EO sector. GeoVille is currently the product and service quality assurance service provider of the JRC S2 Global Mosaic Service.

Regarding flood monitoring applications, GeoVille was first to provide operational TerraSAR-X flood monitoring services to water and disaster risk centres in Europe. On a global level, GeoVille provided its flood mapping expertise as service provider to the JRC EMS Risk & Recovery Mapping (2015-2017), the ESA projects (TIGER-NET, GlobWetland, EO4SD Climate Resilience and ESA WorldWater) and the development sector via many International Financial Institutions, such WB, with focal regions in Africa, Central and South Americas and South-East Asia.

Within TIGER-NET GeoVille processed the first documented S1-flood delineation (in Namibia), which triggered related monitoring services in many other African countries (e.g., Nile Basin, Zambezi Basin, etc.). Since then, hybrid optical (HR and VHR) and SAR based flood mitigation, assessment and monitoring services are provided through an operational system. Today, GeoVille operates with its expert IT department a state-of-the-art multi cloud-based operation, monitoring, and data access system with application programme interfaces (APIs) to feed the entire range of internet-based access mechanisms for its customers worldwide. Please refer to the administrative section of the Cover Letter, for a full company description with related evidence of expertise and experience documentation.

More information is provided on the GeoVille official website.

9.3 TU Wien [*https://www.tuwien.at*]

TU Wien (Technische Universität Wien) was founded in 1815 (as “k.k. Polytechnisches Institut”), making it the first university of technology in today’s German-speaking world.

TU Wien’s microwave remote sensing (MRS) research group, which contributes to the GFM consortium, is part of the Department for Geodesy and Geoinformation (GEO), which conducts research and teaching in observing, modelling, and communicating geo-scientific states and processes, and has about 100 staff. The MRS focuses on the physical modelling of radar backscatter and the retrieval of soil moisture, water bodies, vegetation, and other geophysical variables from scatterometer and Synthetic Aperture Radar (SAR) data.
Their scientific work has paved the ground for several operational soil moisture data services for ASCAT and Sentinel-1 in cooperation with national (e.g. ZAMG, EODC) and international (e.g. EUMETSAT, ECMWF) partners. These data services have been developed and operated within the framework of EUMETSAT’s Satellite Application Facility in Support to Operational Hydrology and Water Management (HSAF), the Copernicus Global Land and Climate Change Services (CGLS and C3S), and the ESA Climate Change Initiative (CCI).

In addition to the scientific output in numerous peer-reviewed research articles and conference contributions, most scientific algorithms and satellite data management software developed by the MRS team for scatterometer and SAR data analysis are implemented in various Python libraries, several of which are available as open source on https://github.com/TUW-GEO. The software libraries for ASCAT and Sentinel-1 are designed to allow global and operational processing, and have been deployed on desktop computers, operational systems, cloud platforms and high-performance computing environments. The MRS group has led and participated in international research projects funded by ESA and the European Commission.

TU Wien has been one of the initiators and co-founders of the EODC. In addition to being able to use EODC’s Petabyte-scale storage with its stored Sentinel EO data (Sentinel-1: globally all available GRD data; Sentinel-2: globally all available L1C data), its cloud platform, and TU Wien’s super-computing facilities (Vienna Scientific Cluster), the TU Wien MRS group has powerful in-house processing capabilities: they operate an 800 TB Fileserver with a 1 PB robotic tape library, 12 top end working stations, several terminal servers, approximately 80 workstations and a back-up server. The internal network is based upon a Windows Active Directory Domain.

Owing to an intense collaboration with the IT-departments of EODC and TU Wien, the remote sensing research group is experienced in handling large earth observation data volumes and developing software packages for automatic processing.

In terms of related expertise, the experts of TU Wien contribute to the consortium an in-depth knowledge of SAR data processing, building upon a long-standing experience with the European Envisat and Sentinel-1 missions.

With its SAR team focusing on Level-1 data ingestion, processing, aggregation, and the retrieval of geophysical variables feeding into Level-2 products, a strong scientific and technical competence on Sentinel-1 IW and EW mode data has been gained. The pre-processing engine of the SAR Geophysical Retrieval Toolbox (SGRT) – which dates to 2007 and has been constantly enhanced and adapted – features a near-real-time-capable (NRT) workflow especially tailored for Sentinel-1 input. It integrates the state-of-the-art geocoding and calibration functionalities of ESA'S SNAP Toolbox, as well as an in-house-developed border-noise-removal algorithm and several automated routines for quality-control, resampling and gridding. With the perspective of Big Data entering remote sensing, the spatiotemporal data-cube for raster data based on the Equi7Grid was created in 2014 and is hosted now by EODC, allowing a geometric accurate and efficient handling and storage of massive satellite data volumes.

In addition to the two other thematic key variables soil moisture and vegetation, the mapping and monitoring of water bodies has been the central topic of several research and operation projects of TU Wien. Thanks to the possibility of directly accessing the Sentinel-1 data-cube and analysing the full time series of SAR backscatter at pixel level, the delineation of permanent and seasonal water body extent can be achieved on a global scale.

Most recent research has been conducted on the analysis of temporal and spatial signatures of water bodies to estimate flood frequencies and to detect flood events.

Regarding related experience, the MRS research group of TU Wien has been part of several operational and thematic-related projects:

Copernicus Global Land Service (GIO-GL, C-GLOPS1, C-GLOPS2; 2013-ongoing): NRT provision of a portfolio of bio-geophysical products on the status and evolution of land surface at global scale, using the most suitable satellite sensors including the Sentinel fleet. As project partner, TU Wien is responsible for the soil moisture product and processing chain development, data-cube design, and the continuous scientific quality evaluation.

HSAF (CDOP 1-3; 2007-ongoing): NRT and CDR (climate data record) provision of operational data on hydrological variables (precipitation, soil moisture, snow parameters) from EUMETSAT satellites. As project partner, TU Wien is responsible for the soil moisture product and processing chain development, and the continuous scientific quality evaluation

EC H2020 I-REACT (2016-19): Project to increase the resilience of European citizens and assets to natural disaster by integrating existing local and European services into a platform that supports the entire emergency management cycle. TU Wien's role as project partner was to develop and demonstrate an on-demand NRT Sentinel-1 flood mapping service.

ESA Globwetland (2015-17): A large Earth Observation application project to develop and demonstrate an open-source software toolbox for the end-to-end processing of a large

portfolio of EO products and the subsequent derivation of spatial and temporal indicators on wetland status and trends, from local to basin scales. TU Wien was a sub-contractor to GeoVille, producing Sentinel-1 water body maps for about 20 % of the African land surface area based on Sentinel-1 time service.

CLMS HRL Water & Wetness (2017-22): This service provided high-resolution water and wetland layers based on multiple input data for Europe. TU Wien was a sub-contractor to GeoVille, producing water body maps for Europe based on Sentinel-1 time series.

ESA Sentinel-1 Global Backscatter Model (2018-19): The development and production of a global 10 m Sentinel-1 backscatter model. This involved pre-processing the entire global Sentinel-1 data record for the years 2016 and 2017, applying strict quality control procedures and the selection of suitable backscatter models.

FFG Austrian Data Cube (2018-20): This project delivered a data cube system for Austria with the goal to remove technological barriers for the use of Copernicus data in Austria. TU Wien was responsible for the definition and production of the Sentinel-1 data cube to the Acube.

9.4 LIST [https://www.list.lu/]

The Luxembourg Institute of Science and Technology (LIST) is a Research and Technology Organization (RTO) active in the fields of materials, environment, and IT, under the trusteeship of the country's Ministry of Higher Education and Research.

It works across the entire innovation chain: fundamental and applied research, incubation, transfer of technologies. By transforming scientific knowledge into technologies, smart data and tools, LIST empowers citizens in their choices, public authorities in their decisions and businesses in their strategies.

LIST's research unit Environmental Sensing and Modelling, which is engaged with this proposal, carries out impact-driven research, geared towards monitoring, forecasting and predicting environmental systems in a changing world. Its research and development activities are centred on the combination and exploitation of remote sensing information obtained by multiple and complementary sensors installed on spaceborne and airborne platforms.

The assimilation of remote sensing data with numerical prediction models enables the generation of higher-level information ranging from local or regional to global scales, with unprecedented accuracy and spatio-temporal resolution. This strategy is used to develop innovative applications in precision agriculture, natural resources management, disaster risk reduction and maritime surveillance.

The development of scientific algorithms enabling the systematic, automated, and rapid production of flood extent maps from various satellite Earth Observation data sets counts among the unit's primary research objectives. Moreover, the scientists at LIST are renowned for their research leading towards a more efficient assimilation of various EO-derived data sets into hydrologic and hydraulic models, as well as a more comprehensive assessment of flood hazard and risk at large scale through a combination of numerical modelling and remote sensing. Its EO relevant expertise in both fields is demonstrated by a track record of scientific publications and research projects.

Over the last decade the unit's collective knowhow and its technological assets have been applied to develop new products and services supporting flooding-related disaster risk reduction at large scale.

Some examples of such applications are provided in the following:

ESHAPE (EuroGEO Showcases: Applications Powered by Europe), 2019-2023, European Commission – H2020: LIST is leading the project's flood pilot (as part of the water resources showcase) and is generating a Sentinel-1 and ENVISAT-based record of floods over Europe for the time period 2002 – 2019.

EDRIFT (Satellite EO based solutions to support disaster risk financing in Southeast Asia), 2018-2020, European Space Agency: The project aims to setup and maintain a fully automated Sentinel-1 based flood mapping processor to systematically monitor water bodies in 3 countries of SE Asia during every year's Monsoon season.

SEADRIF (Southeast Asia Disaster Risk Insurance Facility), 2018-2020, World Bank: The project aims to automatically generate flood extent maps and to estimate the number of persons affected by flood events to support the parametric insurance models of the disaster risk financing industry.

LANDCOVER CCI (Global land cover map development for climate modelling applications), 2013-2015, European Space Agency: The LIST oversaw the quality control and large-scale validation of the permanent water bodies layer derived from the collection of ENVISAT ASAR recordings.

HTEP (Hydrology Thematic Exploitation Platform), 2013-2015, European Space Agency: Implementation of an 'on demand' Sentinel-1 based flood mapping application on the HTEP platform and development of a water extent monitoring system for large lakes in Africa.

Other relevant projects in recent years include HYDRAS+ (Improving drought management by assimilating multi source satellite data into hydrologic models), HASARD (Implementation of new methods for remote sensing-based flood hazard mapping on the ESA's Grid Processing on Demand environment, and WATCHFUL (Water Cycle Feasibility: characterizing the water cycle at global and basin scales using EO data).

9.5 CIMA Research Foundation [https://www.cimafoundation.org/]

CIMA Research Foundation (hereafter called CIMA Foundation) is a scientific organization under the Italian Legal Regulations governed by public law, which is recognized as a centre of excellence for civil protection by the national Italian regulation.

CIMA Foundation's mission is to develop scientific and engineering technologies for application in environmental-related fields with focus on disaster risk reduction, civil protection and preservation of terrestrial and water-related ecosystems, always connecting research, operations, capacity development and assistance to the end users. CIMA Foundation's researchers have a long record in defining procedures and models to assess flood risk. This expertise grew taking advantage of the direct contact with institutions operating on the topic and has been always characterized using the state-of-the-art technologies to improve the detail of flood hazard mapping as well as of flood vulnerability assessment.

Specific GIS and WEB-GIS tools developed by CIMA represent the best of the available information on the territory and provide an added value in all the projects developed in this research area and are taken as current global reference for flood monitoring by international bodies such as WMO.

In terms of related expertise, CIMA Foundation has a diversified expertise that is based on the knowledge expressed by more than 100 researchers, post-docs Ph.D. candidates and collaborators. The core expertise of CIMA Foundation aligns along three axes:

Early warning system for floods and fires, including links and preparation of related emergency plans.

Multi hazard, Multi risk National and Local Disaster Risk Profiles definition and connection with national and local strategies, including specific cost benefit analysis for mitigation measure prioritization.

Use of Satellite products in support of the two above mentioned axes

Satellite information is heavily used in support of CIMA Foundation modelling approach. CIMA Foundation is official validator of rainfall and soil moisture products for the H-SAF. It has been also contributing to the Copernicus Risk & Recovery service where modelling and satellite observations are properly merged to produce more reliable and cost-effective risk maps.

CIMA Foundation distinctive expertise is in the constant contact with the end users of such scientific products. This contributed to its capacity in producing actionable research that impacts in the everyday life of users and eventually citizens in line with its mandate. In particular, the Risk Assessment and Loss Data Department is specialized in modelling risk and impacts linked to natural hazards, with a special focus on floods. Statistical approaches

are used to combine hazard information with data describing exposure characteristics (i.e., population, built-up, service and productive systems or the environment), as well as vulnerability, the predisposition of exposed elements to be adversely affected by hazards. Common products for such activities are probabilistic risk profiles or impact assessment studies.

Special effort is dedicated to the integration of global (satellites or non-satellite) information with local data to obtain the best representation of exposure and vulnerability fitting to the purposes of the specific study. To this end, specific tools have been developed for use at the national or international level. CIMA Foundation has a specialised ICT unit that has developed many applications for Disaster Risk Reduction and specifically in developing space technology application for DRR.

Thanks to a more than a decade's experience in developing applications for ASI, ESA and Italian Civil Protection department, CIMA Foundation can contribute a strong expertise in front-end and back-end design and realisation with specific attention to service delivery through APIs and dedicated web-services. CIMA Foundation has an ISO 9001:2008 Quality Assurance Certificate provided by AENOR International. This quality assurance certifies CIMA Foundation quality process in conducting scientific research and technological transfer which includes standard procedures and practices assuring the quality of services.

Regarding related experience, since 2010, under a framework agreement, CIMA Foundation provides technical, scientific assistance and technological innovation to the Italian Civil Protection department and the Italian Civil Protection system (including regions) for developing tools and new governance system for the management of climate risk with focus on floods, hydro-meteorological extreme, landslide and forest fires.

CIMA Foundation has assisted the Italian Civil Protection department in international cooperation activities for capacity developing on Disaster Risk Reduction with focus on Climate risks. Recently, CIMA Foundation is working closely with the World Bank DRFI and ESA (SEADRIF & eDrift projects) on a series of project in support of Risk Financing in Southeast Asia, that merges the early warning system, the impact evaluation and the use of satellite data for parametric insurance activation in Cambodia, Laos PDR and Myanmar. This has resulted in an operational service that will commence by this monsoon season in Myanmar and Laos.

Under the umbrella of the WMO, CIMA Foundation implements the Dewetra platform, a system for real time monitoring, prediction and prevention of flood and wildland fire risks. So far, the Dewetra platform has been operationally implemented in: Albania, Italy, Serbia, Croatia, Lebanon, Bolivia, Ecuador, Philippines, Tunisia, Ecuador among others. CIMA Foundation assists the end-users of the platform with a 24/7 user support.

CIMA Foundation is in the steering committee of the Global Flood Partnership and of the Risk Nexus Initiative. CIMA Foundation participated in the Project PREVIEW, Prevention Global Flood Partnership Information and Early Warning (FP6) and led the project RASOR –

Rapid Analysis and Spatialisation of Risk (www.rasor-project.eu): A Copernicus downstream project funded under the FP7 that developed an advanced web-based platform for multi hazard and multi-risk assessment assisted by EO Data (www.rasor.eu).

CIMA Foundation is part of the IMPREX - IMproving PRedictions and management of hydrological EXtremes H2020 project (www.imprex.eu) dealing with real-time impact assessment and its application in EWS and implementing a Pan-European Hydro-meteorological forecasting chain that will be complementing the existing EFAS Copernicus service.

CIMA Foundation is also partner in GEO-CRADLE, Coordinating and integRating state-of-the-art Earth Observation Activities in the regions of North Africa, Middle East, and Balkans and Developing Links with GEO related initiatives towards GEOSS. CIMA Foundation strongly involved in the Heimdall H2020 project led by DLR aiming at developing a platform that exploits modelling and EO data for the management of Emergencies.

CIMA Foundation has been in the lead of the Global Flood Hazard Model contributing at the UNISDR Global Assessment Report (https://www.preventionweb.net). CIMA coordinates the Global Flood Record within the Global Flood Partnership (https://portal.gdacs.org), with the aim of combining satellite, model data, and observation to Loss Data to better analyse and predict Flood Impact. CIMA is also Implementer of the DesInventar Loss Data base in many Countries (i.e., Albania, Kosovo, Serbia, Belarus, Caribbean Countries) in collaboration with UNDRR and UNDP.

9.6 DLR [https://www.dlr.de/en]

As the German Aerospace Research Centre and the national space agency DLR is organised as a chartered non-profit organization and has approximately 9,100 employees at 27 locations in Germany. DLR's work on the GFM product is conducted by the Georisks and Civil Security department of the German Remote Sensing Data Center (DFD).

Its main focus is to support the entire disaster-management cycle with satellite-based geoinformation products in cases of environmental and natural threats, humanitarian crisis situations and civil security emergencies. The department has strong expertise and longstanding experience in satellite-based flood mapping and monitoring. Its scientific and technical work includes developing new analytical methodologies for working with remote sensing data, using and further developing geoinformation technologies, developing thematic remote sensing processors and monitoring systems, vulnerability and risk modelling, and designing and establishing crisis information and early warning systems.

The department also operates the Centre for Satellite Based Crisis Information (ZKI), whose function is the rapid acquisition, processing and analysis of satellite data and the provision of timely satellite-based information products for rapid decision support in case of disasters and humanitarian crisis and civil security emergencies.

In terms of related expertise, the core expertise of DLR is on research and development as well as the establishment of operational services in the fields of satellite-based emergency mapping (e.g., ZKI, CEMS), flood mapping and monitoring (e.g., InsuResilience flood monitoring India) and early warning systems (e.g., German Indonesian Tsunami Early Warning System).

With its national and international receiving stations DLR offers direct access to data from Earth Observation missions, derives information products from the raw data, disseminates these products to users, and safeguards all data in the National Remote Sensing Data Library for long term use. This includes amongst others the Sentinel-1 and 3 (OLCI) Processing and Archiving Centres (PACs). In this context, DLR develops, operates and continuously improves fully automated processing chains for flood monitoring from SAR (Sentinel-1 and TerraSAR-X) and optical (Sentinel-2 and Landsat) satellite data.

Software tools and algorithms are based on sound scientific studies, published in peer-reviewed journal articles and are being extensively tested in numerous national and international projects and services with world-wide coverage.

Regarding related experience, DLR has longstanding experience in satellite-based emergency mapping with particular focus on flood mapping and monitoring services throughout numerous projects and services. The most relevant ones are listed below:

The International Charter "Space and Major Disasters", 2010-present: Association of space agencies and satellite operators to provide a unified system for the rapid acquisition and

delivery of satellite data in case of disasters. DLR entered the Charter in October 2010 and provides data for the TerraSAR-X satellite mission. In this context also flood products derived fully automatically by DLR's Sentinel-1 and TerraSAR-X Flood Services are provided to users.

ZKI-DE, 2013-present, service contract with Federal Ministry of the Interior – Germany: DLR developed the ZKI-DE Service for enabling federal authorities to obtain and analyse current remote sensing data and geoinformation at short notice to support civil and public security.

Copernicus Emergency Management Service (CEMS – Mapping component), 2015-2018, EU: Copernicus service for satellite-based emergency mapping in case of disasters or humanitarian crisis worldwide. DLR was mainly involved in service enhancement and evolution as well as in emergency mapping.

SAFER (Services and Applications for Emergency Response), 2009-2012, EU FP7: Develop the existing satellite-based emergency response service into an operational service (ERS - Emergency Response Service) with focus on meteorological-driven (e.g. fires, floods) and geophysical hazards (e.g. earthquakes, landslides)

Other relevant projects include DAREnet (Danube river region resilience exchange network), InsuResilience (Flood monitoring for the insurance sector in India), ASAPTERRA (Advancing SAR and optical methods for rapid mapping), CODE-DE (Copernicus data and exploitation platform Deutschland), HEIMDALL (Multi-hazard cooperative management tool for data exchange, response planning and scenario building), DRIVER+ (Driving innovation in crisis management for European resilience), RIESGOS (Multi-risk analysis and information system components for the Andes region) and GITEWS

Together with LIST and TU Wien, DLR was part of the core Expert Group that was set up by the European Commission’s Joint Research Centre (JRC) to assess the feasibility of an automated, global, satellite-based flood monitoring product, to complement and enhance the capabilities of the CEMS for mapping and monitoring floods (Matgen et al., 2020).