Recommended Practice for Flood Mapping with Sentinel-1 and Sentinel-2 Imagery and Digital Terrain Models

UN-SPIDER Knowledge Portal

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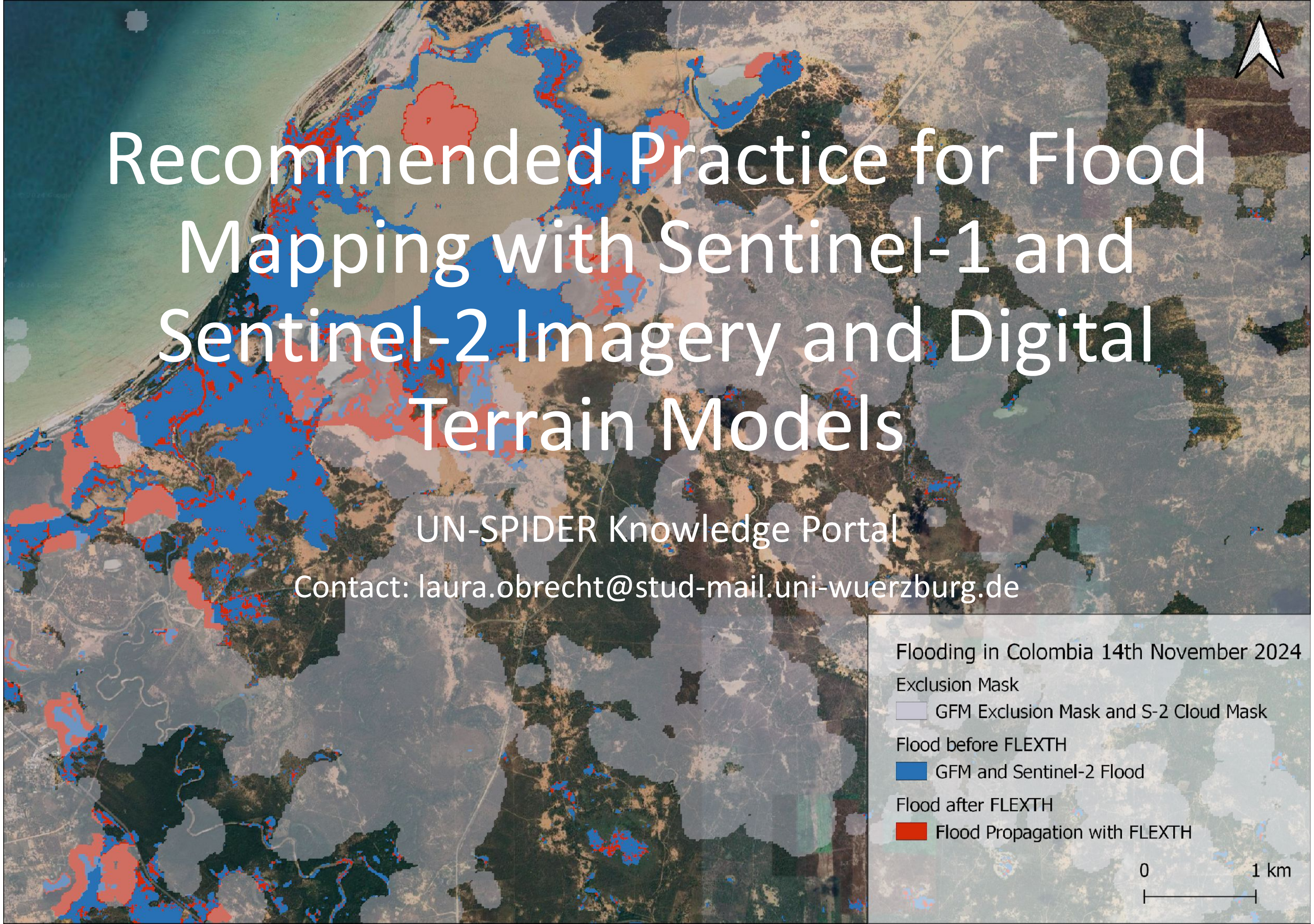


Objective

The objective of this practice is to improve flood maps with Digital Terrain Models. This is necessary, as SAR sensors are not sensible to flood water on every land surface / land use class equally, and optical sensors are limited by clouds.

During this practice, flood delineations from GFM are used and improved. Furthermore, water depths are calculated for the flooded areas, which is valuable information for rapid response teams as well as for estimating economic loss. Water depth cannot be estimated by satellite-based flood mapping (Betterle and Salamon 2024).

Context

Sri Lanka

In October 2024, many provinces of Sri Lanka have been experiencing heavy rainfall and strong winds, causing floods and severe weather-related incidents that resulted in casualties and damage (Sri Lanka: Floods - Oct 2024 | ReliefWeb, accessed: 22.11.2024).

Nepal, Sri Lanka and Bangladesh experience an increased flood risk and extend of the monsoon season from June to October, with heavier rainfall potentially disrupting agricultural activities and affecting infrastructure (OCHA, 19.11.2024).

Applicability

This practice can be applied to flooding events globally. It requires little to no knowledge of GIS and Remote Sensing. A basic understanding of Python code and virtual environments in Python is helpful to the analysis, but is no requirement.

Abstract

Flood mapping in urban areas poses significant challenges for Synthetic Aperture Radar (SAR) sensors due to limitations in detecting water in regions characterized by dense vegetation, urban infrastructure, or complex surface conditions. These limitations include reduced sensitivity in vegetated or built-up areas and water-like backscatter effects on smooth, dry, or snow-covered surfaces. The Global Flood Monitoring (GFM) platform employs Sentinel-1 SAR backscatter data for automated flood delineation but recognizes the constraints posed by such conditions. To address these challenges, the GFM has integrated an exclusion mask that highlights regions prone to SAR-based misclassification.

This recommended practice introduces a novel algorithm developed by the Joint Research Centre of the European Commission that combines SAR-derived flood layers with digital terrain models, the GFM exclusion mask and incomplete Sentinel-2 flood maps. By leveraging DTMs, water depth calculations and hydrodynamic propagation models are applied to infer flood conditions within exclusion mask areas, enhancing the reliability of flood extent delineations.

Requirements

Input Data:

- GFM outputs for a flooded Area of Interest:
  - Flooded Area
  - Permanent and Seasonal Water Bodies
  - Excluision Mask
- Digital Terrain Model
- Sentinel-2 flood map and cloud mask (calculated in GEE during this practice)

Sofware:

- Global Flood Monitoring Database

Applications

This practice can be used for any area with major flooding. The practice is especially relevant for large floodings, that extend into cities and vegetated areas, like forests and agricultural fields.

The contribution through the incomplete Sentinel-2 flood mask is especially important, if GFM underestimates the flooded area. In this context, the practice utilizes two incomplete and not perfect flood maps and combines them to get the best result possible.

Strengths and Limitations

Strengths:

- The approach is based on physics and the actual topography of the area. That means it overcomes many limitations associated with satellite imagery.
- Utilizing two data sources strengthens the practice and makes it robust to several application

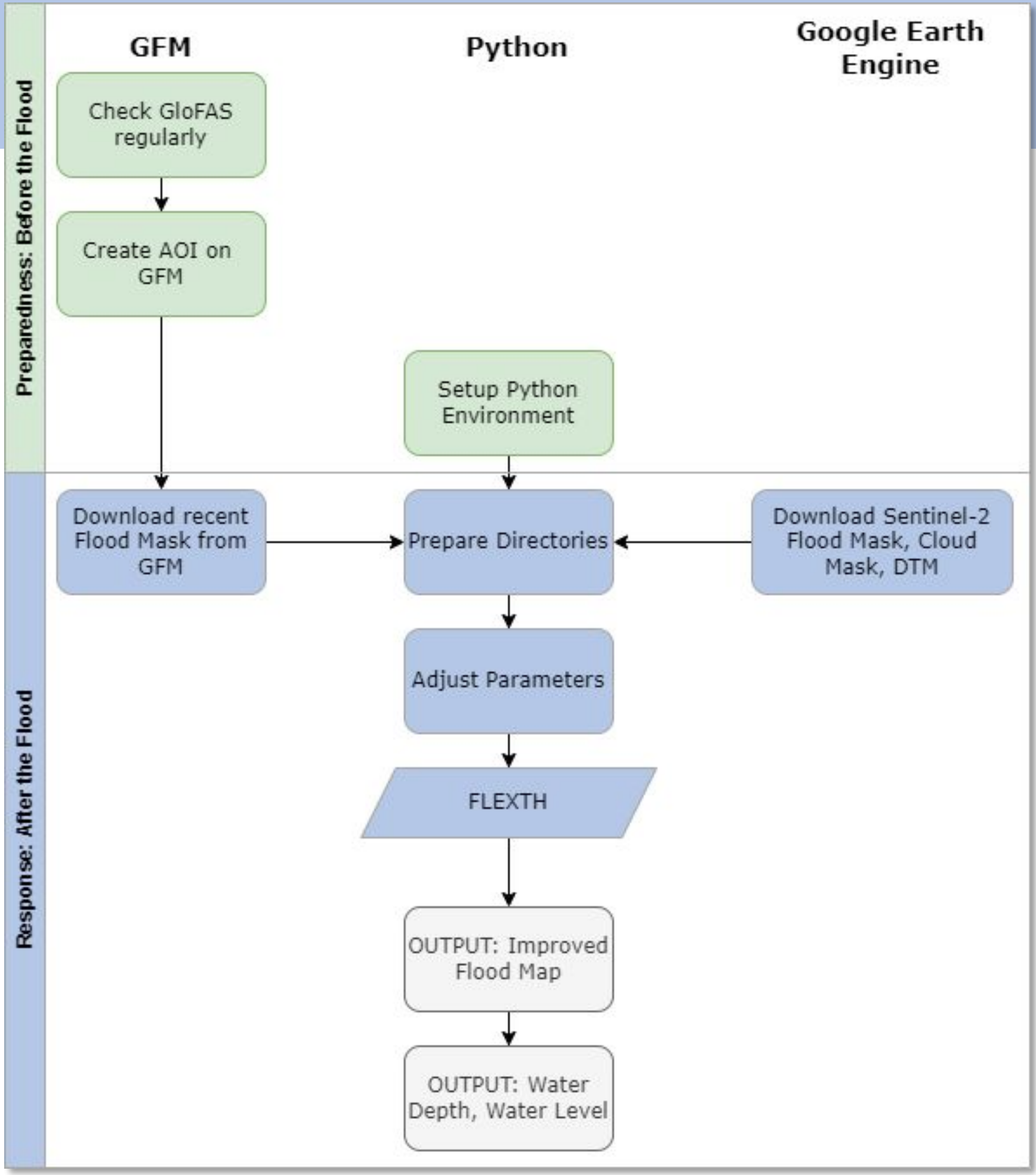
Limitations:

- The greatest limitations of the practice come from the spatial resolution and accuracy of the input flood delineation and of the Digital Terrain Model.
- The quality of the output is dependent on the number of flooded pixels, provided with the input flood delineation.

Workflow

The workflow can be divided into two sections: **1) Preparedness before the flood** and **2) Response after the flood**.

Its implementation is done in GFM (Global Flood Monitoring Database), Python, and in the Google Earth Engine.



Before the Flood

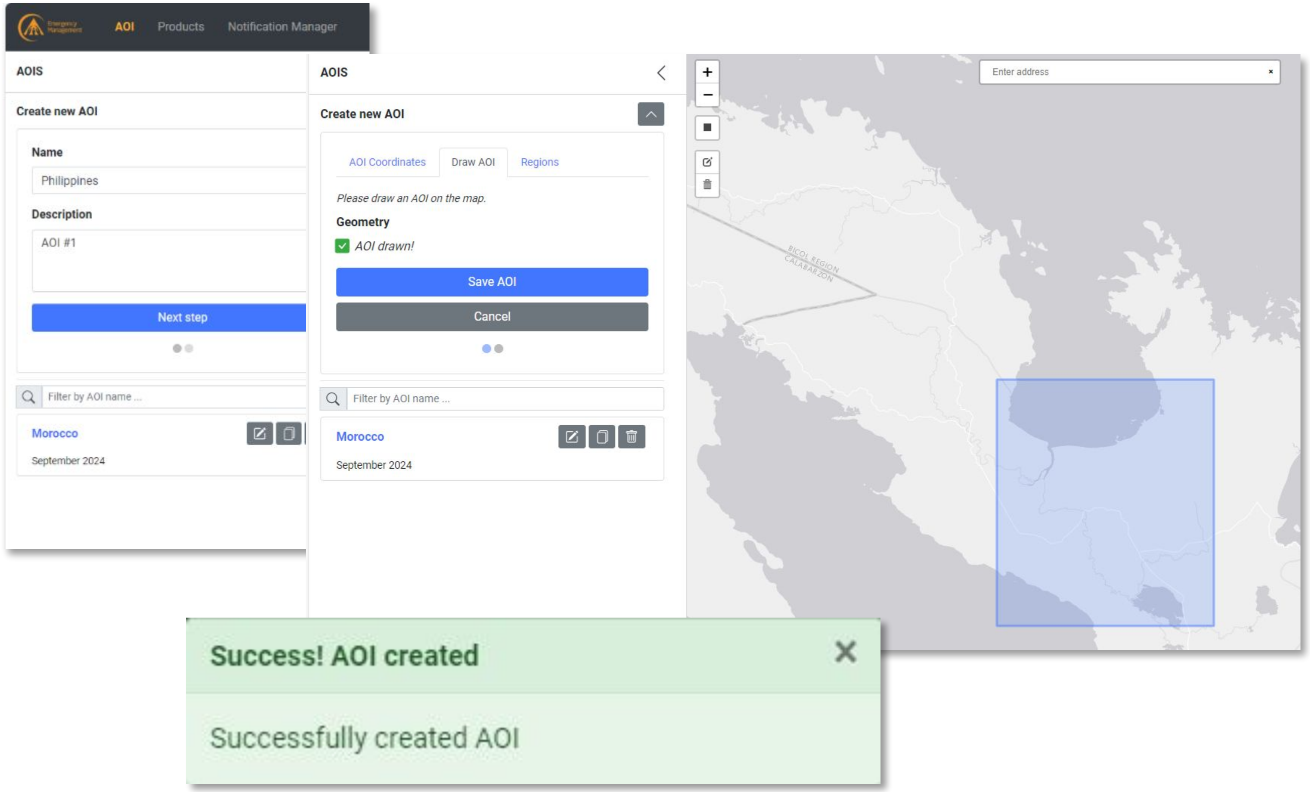
There are multiple steps in this practice, you can already perform before a flood hits your Area of Interest (AOI). This will help you to safe crucial time during the disaster, to ensure a rapid response.

Before the Flood: Create your AOI on GFM

First, make a user account on GFM: Global Flood Monitoring.

To access the data, you need to create an AOI, which will be stored in your GFM account. You need to assign a name and a description to your AOI. Then click on "Next step".

In the next step, you can choose between giving the Coordinates to your AOI, drawing the AOI or selecting a region. Most of the time, drawing the AOI is the best idea. Therefore, select the square to the right of the panel, draw the AOI and select Save AOI.



Check GloFAS regularly

To know when floods are likely to hit your region, check GloFAS regularly. Check if there are any unusually high precipitations forecasted.

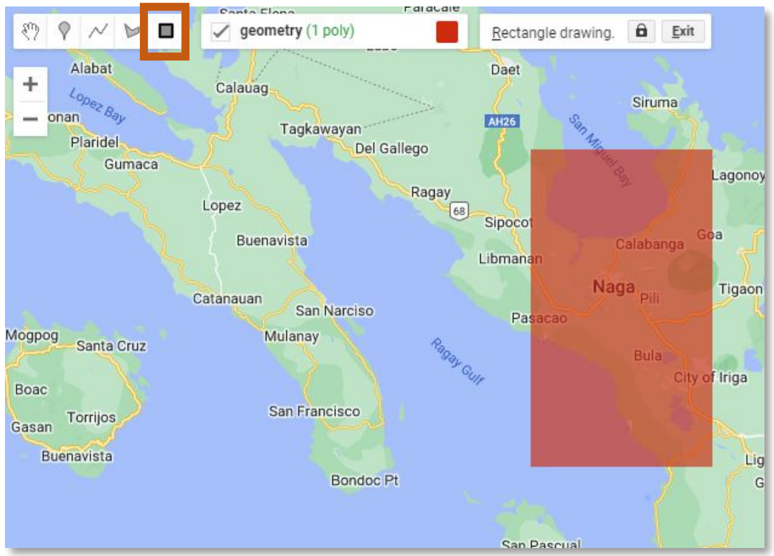
Download the FABDEM of your AOI

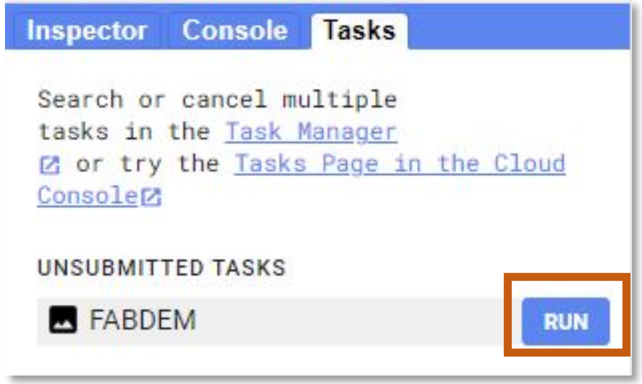
The FABDEM is a 30m open-access Digital Terrain Model. You can find all necessary informations in this *Data Application of the Month* or in this *Scientific Publication:*

https://iopscience.iop.org/article/10.1088/1748-9326/ac4d4f/meta.

Among other options, the FABDEM can be downloaded with Google Earth Engine. With the link below, you can download the FABDEM for your AOI. By clicking on the rectangle tool, you can draw a polygon of your AOI. Then you can click on Run, to run the script. Under tasks, you will see the FABDEM popping up. Click on RUN. When the task is finished, you can download the DTM from your Google Drive.

Using other DTMs, for example a high-resolution national DTM or commercial DTMs is also possible. The spatial resolution and accuracy of the DTM is one of the key points to the success of this practice.





https://code.earthengine.google.com/78b037560aa4567b5d950d228531844f

Setup Python

This is a step by step procedure to setup the Python environment, in which the FLEXTH algorithm will work. If you already have a Python installation on your computer, it still makes sence to follow this guide, to ensure all libraries are installed properly.

We need to install the latest version of Miniforge, which is a light-weight Python distribution. Follow this Link, which leads you to a repository storing the Miniforge3 installers for the different operating sytems (OS). If you are using a Windows 64bit machine click on „latest“ in the respective row. On the next page look for „Miniforge3-Windows-x86_64.exe“. Click on the link to download the executable.

Miniforge3

Latest installers with Python 3.12 (*) in the base environment:

OS	Architecture	Minimum Version	Download
Linux	x86_64 (amd64)	glibc >= 2.17	Miniforge3-Linux-x86_64 @ latest
Linux	aarch64 (arm64) (**)	glibc >= 2.17	Miniforge3-Linux-aarch64 @ latest
Linux	ppc64le (POWER8/9)	glibc >= 2.17	Miniforge3-Linux-ppc64le @ latest
macOS	x86_64	macOS >= 10.13	Miniforge3-MacOSX-x86_64 @ latest
macOS	arm64 (Apple Silicon) (***)	macOS >= 11.0	Miniforge3-MacOSX-arm64 @ latest
Windows	x86_64	Windows >= 7	Miniforge3-Windows-x86_64 @ latest

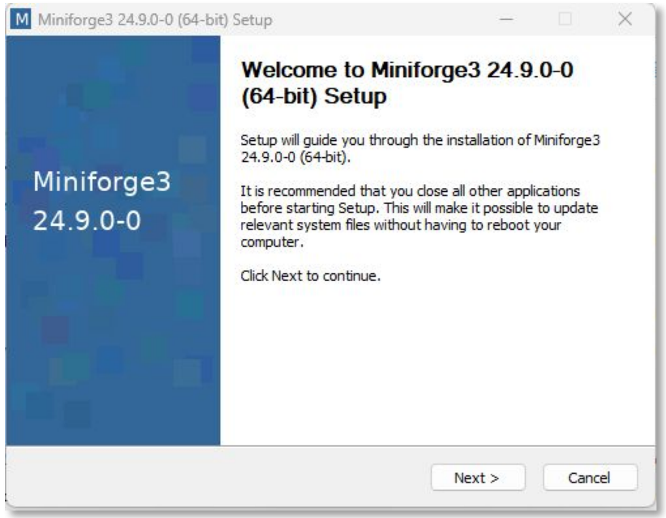
- Miniforge3-Darwin-arm64.sh
- Miniforge3-Darwin-x86_64.sh
- Miniforge3-Linux-aarch64.sh
- Miniforge3-Linux-ppc64le.sh
- Miniforge3-Linux-x86_64.sh
- Miniforge3-MacOSX-arm64.sh
- Miniforge3-MacOSX-x86_64.sh
- Miniforge3-Windows-x86_64.exe

Setup Python

Double click the executable to start the setup. In the setup menu, click on „Next“ , then on „I agree“. Install for „Just Me (recommended)“.

For the Install Location, you can just go with the default folder. Click „next“. For the Advanced Installation Options, you can also go with the default selection. Click „install“.

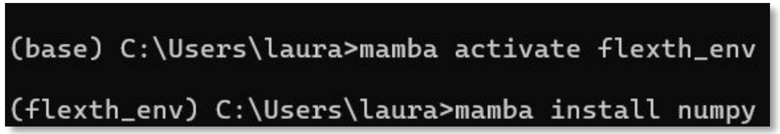
After the installation click „next“ and then „Finish“. Open the Miniforge Prompt. This is a command line interface. First, we create a new virtual environment for the practice called „flexth_env“. Then we install the necessary libraries into the new environment:



Setup Python

```
mamba create –n flexth_env python=3.12
mamba activate flexth_env
mamba install numpy scipy rasterio astropy opencv gdal scikit-image matplotlib geopandas spyder jupyterlab
jupyter lab
```

Press Enter after every line of code. You will be asked to confirm some changes with a „Y“ and pressing Enter. Care, that you don‘t add or miss any spaces in the text.



After activating the environment, you should see the name of the environment in brackets at the beginning of the line. A Python interface called Jupyter Lab will open after the last line of code.

The installation of the libraries will take some time. You will see a progress bar in the terminal window and it will print „done“ once the installation is terminated.

Make yourself familiar with the FLEXTH tool

If everything worked out, you are now able to open Jupyter Lab by writing jupyterlab into the console and executing the command (the last line in the previous code).

The script is divided into 6 sections:

1. Loading necessary libraries.
2. Specifying user-specific input and output directories.
3. Selecting the AOI and DTM sources.
4. Setting further Parameters
5. Mosaicing and Reprojecting GFM outputs.
6. FLEXTH

Make yourself familiar with the FLEXTH tool

In Jupyter Lab, on the left side, you can see your directories. Browse to the directory of the FLEXTH script “**GFM2FLEXTHnb.ipynb**”. Go to the first cell and click on the “Run current Cell” symbol on the task bar.

If the execution of the first cell works without any error messages, you will read “**Libraries are loaded**” in the console.

Now you are prepared to use the tool in the case of a flooding.

During the Flood

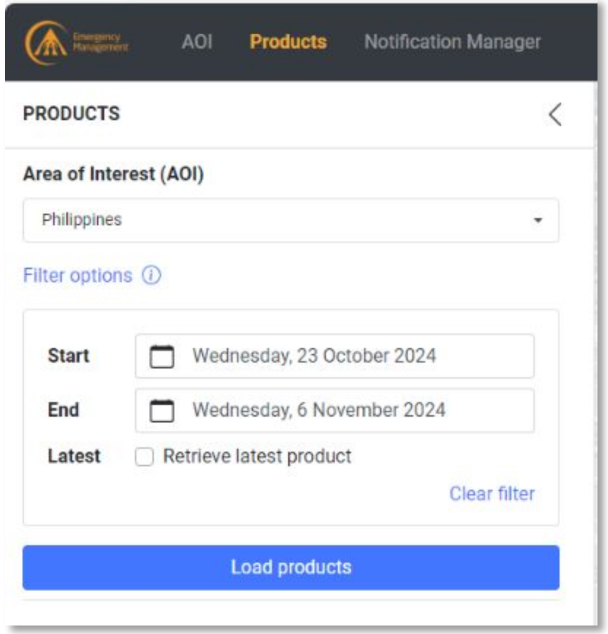
This practice uses the outputs from the Global Food Monitoring Database, as it provides timely and state-of the art flood delineations. Furthermore it also fulfills the requirement of an exclusion mask.

Still, it is also possible and encouraged, to use own flood delineations in this practice. If you want to use your own flood delineation, we ask you, to use the original script developed by Andrea Betterle, accessible via this link:

https://code.europa.eu/floods/floods-river/flexth

The code runs in the same environment. You will still need an exclusion mask, a DTM and if available a mask for the permanent and seasonal waterbodies.

Download the Input Layers from GFM

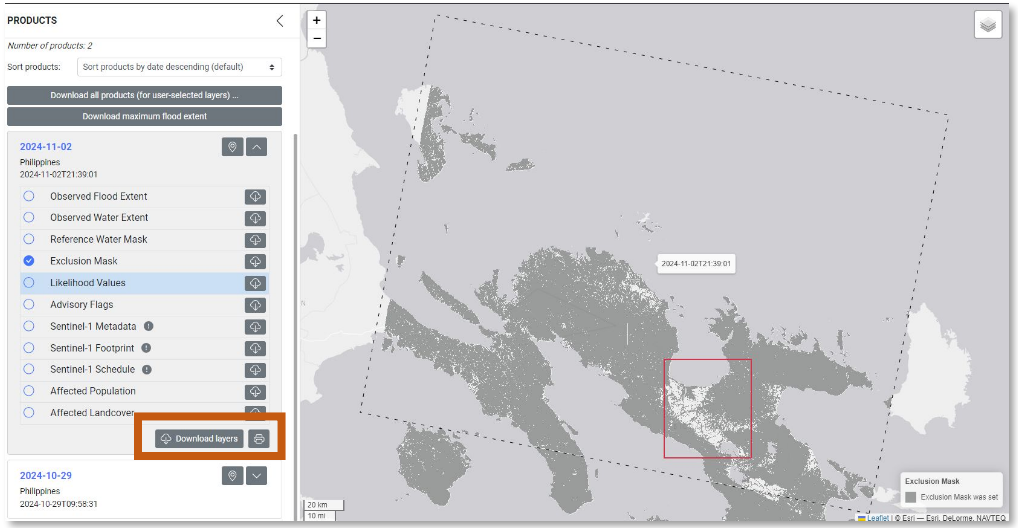


On the task bar, go to Products, select your created AOI and set the Start and End date. If you select „Retrieve latest product", you will get the latest acquisitions overlapping with your AOI.

Select one of the scenes, ideally the scene should be acquired only a few days after the flooding. In the example the scene from 2024-11-02 over the Philippines is selected. The Sentinel-1 footprint will show within a dashed line. Care that the AOI is completely covered by the footprint as in the example.

You can browse through the different layers. In the example, the exclusion mask is visuallized.

Now, click on „Download Layers". The download will start automatically.

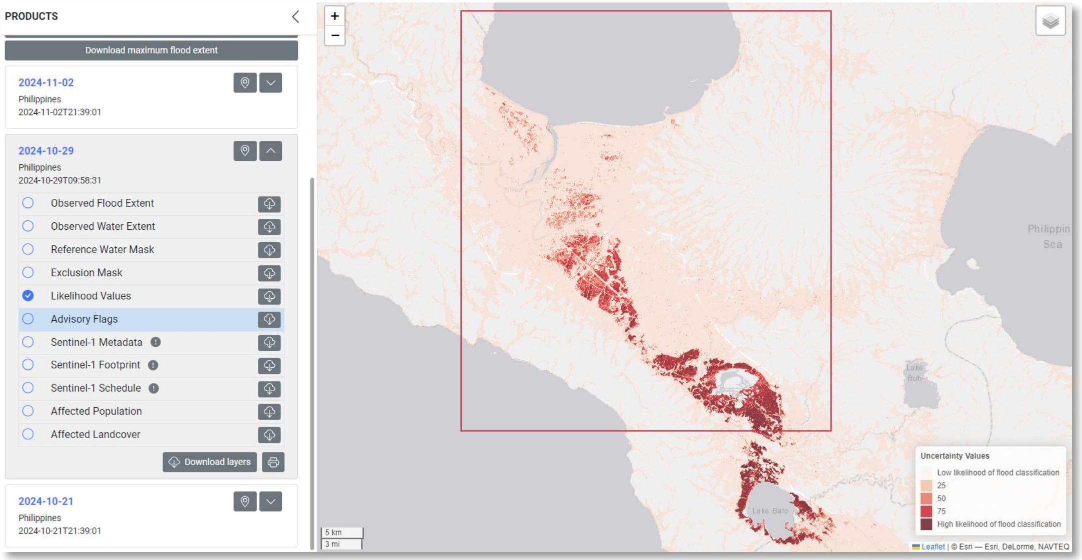


The Likelihood Layer vs. The Flood Extend

GFM also provides a likelihood layer, in which pixels are assigned a likelihood of flooding. Detailed documentation on how these values are calculated is provided here: [GFM Product Output Layers | EODC Public Wiki]()

This is useful in case there are not enough pixels classified as flooded in the Observed Flood Extent Layer. In that case this layer is thresholded with a likelihood threshold, for example pixels with a likelihood > 40% are considered as flooded.

Also, the **Reference Water Mask** is used in the FLEXTH tool. Like that, water bodies will not be detected as flood.



Download Sentinel-2 Water Mask and Cloud Mask

Open the following Google Earth Engine Script:
https://code.earthengine.google.com/d2eb152e6bf075861d5d22af05ed4f27

Draw your AOI, as you have done it before for the FABDEM download. Select a date range before the flood (START_DATE1, END_DATE1). Optimaly, it covers a time span of more than one month, so that an image with less than 10 percent cloud cover (CLOUD_FILTER1) is available.

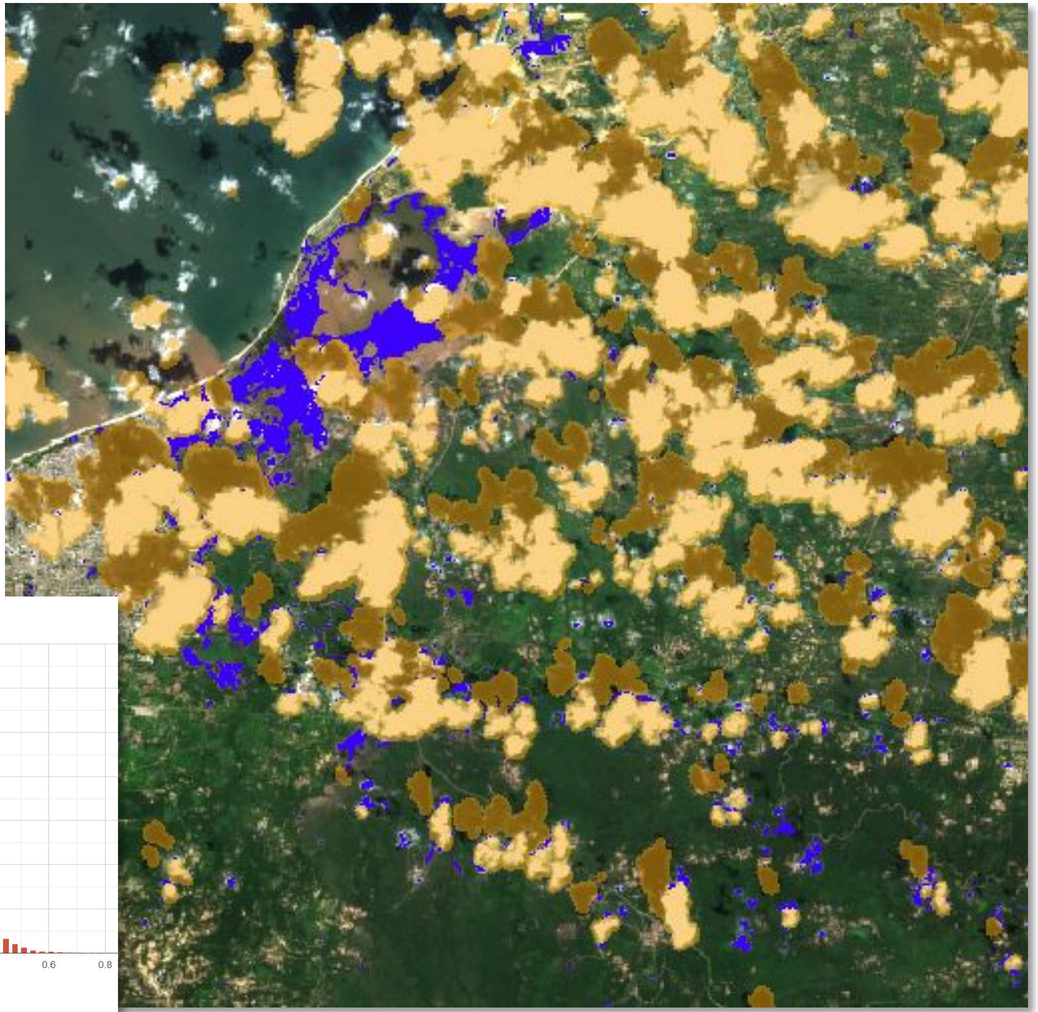
Select also a date range after the flood (START_DATE2, END_DATE2). It should start a day before the flood. CLOUD_FILTER2 manages the maximum cloud cover. Eventually you need to increase the number.

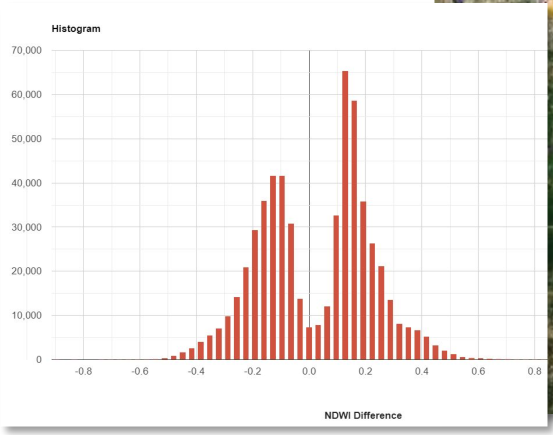
If not all clouds are masked completely, these cloud parts are likely to be wrongly classified as water. In that case, decrease the CLD_PRB_TRESH. Testing showed that 20 is a good threshold.

Download Sentinel-2 Water Mask and Cloud Mask

After clicking on run, a similar map will load. Clouds and cloud shadows will appear in orange, flooded areas in blue. The code will also provide you with a histogramm to refine the NDWI change threshold.

In this example, we would use a threshold of 0.03, as it is exactly in between the two peaks. You can change the threshold
according to your AOI.

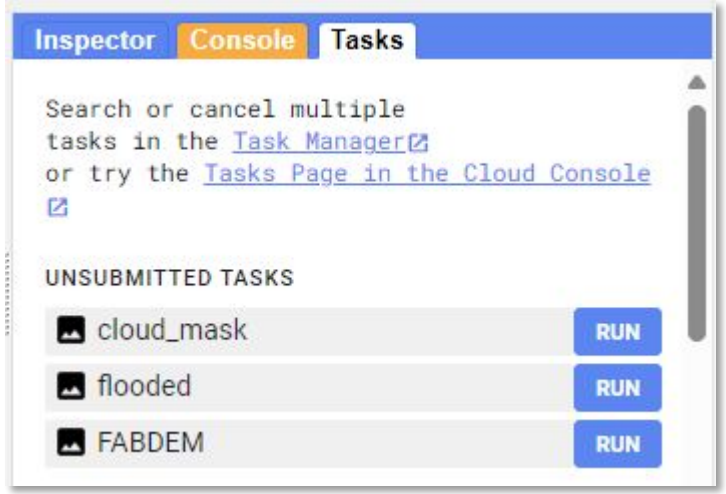




Download Sentinel-2 Water Mask and Cloud Mask

On the right side under the Tasks tab,
you will see the following layers, ready for download:

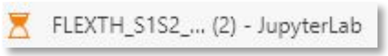
- Cloud_mask
- Flooded
- FABDEM



Click on RUN for each of the layers. You will then find them in a folder called S2_floods in your Google Drive. Download the entire folder, if no older flood products are stored in there.

Open Python

Now we will go again into our Python environment. Therefore execute the code bellow as you did it before during the Python setup.

If Jupyter Lab is busy, you will see an hour glass on the browser tab: 


```
mamba activate flexth_env
jupyter lab
```

Prepare Input and Output directories

Unzip the downloaded folder from GFM and Google Drive and move them to your directory. In the same directory, create a folder called „output“. The directory should look something like this:

Name	Date modified	Type
colombia_2024-11-17T22_59_38_2024_11_25T10_39_19_564885	28/11/2024 11:39	File folder
output	28/11/2024 11:39	File folder
S2_floods	28/11/2024 11:39	File folder

Copy the folder paths to the script, gee_dir being S2_floods folder, gfm_dir being the unzipped download folder from GFM, and output_dir being the newly created output folder.

Prepare Input and Output directories

Under „Setting further Parameters“, you can specify a few more things:

- If you want to use the likelihood layer instead of the flood layer, specify **likelihood = True**. Per default 40% is used as a threshold. You can change it of course in **likelihood_threshold**.
- All outputs will transformed into EPSG 3857 per default. If you want to use a national or regional coordinate system, please provide the epsg code in **dst_crs** in the format EPSG:XXXX.

AOI
DTM

In order not to process the entire Sentinel-1 scene, it is possible to specify an AOI, which should be either a geopackage (.gpkg) or a shapefile (.shp).

Specify the path to your AOI in **roi_path**.
If you do not wish to select an AOI, just write None.

Specify the path to your dtm in the variable **dtm_path**. It should be a tif, for example the FABDEM, which we downloaded with the Google Earth Engine during the first steps of this practice.

Hydrological Parameters

Parameter	Description	Value	Units
Param_threshold_slope (S_max)	Border pixels steeper than tis (D_z/D_x) are not used to estimate water level.	0.1 = 10%	
Param_size_gaps_close (A_g)	Up to this size, gaps in the flood map will be closed.	0.01	km2
Param_border_percentile (P)	Assign Water level based on the percentile P of the elevation of border cells (valid if Method B is selected).	0.5	
param_max_number_neighbors (N_max)	Number of border pixels used to compute water level at a single location	100	
param_min_flood_size (N_min)	If the number of valid pixels along the border is less than this, WL is estimated based on the distribution of the elevation of the pixels inside the flooded area	10	
param_inner_quantile (P*)	for flooded areas that don't meet the criteria above, uses this percentile of the elevation of the pixels inside the flooded area to estimate water levels	0.98	
param_inverse_dist_exp (alpha)	inverse distance weighting exponent used to interpolate WL inside flooded areas	1	
param_max_propagation_distance (D_max)	maximum propagation distance in km	10	km
param_distance_range	flooded areas of this size reach half of the maximum propagation distance	10	km2
param_WD_star	dummy water depth in cm assigned if estimated WL<DTM in initially delineated flooded areas	10	cm

Hydrological Parameters

Testing showed, that the default values are effective and robust in a wide range of settings. Nonetheless, parameters can be tweaked to match specific needs and/or use cases.

Parameters may require adjustments for resolutions much larger/smaller than 10m.

If the flood does not propagate far enough into urban and vegetated areas, the parameter A1/2 (param_distance_range) is the most responsive one. The parameter can be interpreted like: if you have an area of 10 km2 flooded, then the water will propagate 5 km into areas of the exclusion mask. If you lower the size of the area or increase the maximum propagation distance, the flooded area will increase.

Troubleshooting

- If you don‘t have enough RAM on your machine, you will get the error message: …unable to allocate … for an array with size. Consider tiling your input data, and if you did already, consider reducing the tile size
- The code does not overwrite the rasters automatically. You have to delete the mosaics and reprojected rasters before reprocessing the inputs (cell …). Or you move them to another directory.

Visualize and interpret the Output

By executing the last cell 7. Quick Output Summary, the area flooded before FLEXTH and the area flooded after FLEXTH will be outputted.

References

Hawker, Laurence; Uhe, Peter; Paulo, Luntadila; Sosa, Jeison; Savage, James; Sampson, Christopher; Neal, Jeffrey (2022): A 30 m global map of elevation with forests and buildings removed. In *Environ. Res. Lett.* 17 (2), p. 24016. DOI: 10.1088/1748-9326/ac4d4f.

Betterle, Andrea; Salamon, Peter (2024): Water depth estimate and flood extent enhancement for satellite-based inundation maps. In *Nat. Hazards Earth Syst. Sci.* 24 (8), pp. 2817–2836. DOI: 10.5194/nhess-24-2817-2024.

Expert Flood Monitoring Alliance, McCormick, N., Salamon, P., Global Flood Monitoring (GFM) – Product User Manual. European Commission. 2023.