UNITED NATIONS
Office for Outer Space Affairs

SPACE4SDGS

UN-SPIDER Recommended Practices for Exposure Mapping, Flood Hazard Mapping and Flood Mapping

Ingrid Wong, Victor Hertel, Radu Botez
UN-SPIDER Bonn Office

National Virtual Expert Meeting
“Space-based Solutions for Disaster Risk Management and Emergency Response in Nigeria”

13-15 April 2021

Outline

1. **UN-SPIDER Recommended Practices overview**
2. **Floods Hazard Mapping**
3. **Radar-based Flood Mapping with Sentinel-1 SAR data**
   1. **SAR remote sensing basics**
   2. **Rapid flood mapping with Python in the cloud**
   3. **Rapid flood mapping with Google Earth Engine**

Sentinel-2 image of floods along the Niger river in Nigeria in September 2020. Image: Modified Copernicus Sentinel data 2020/Sentinel Hub.

UN-SPIDER Recommended Practices

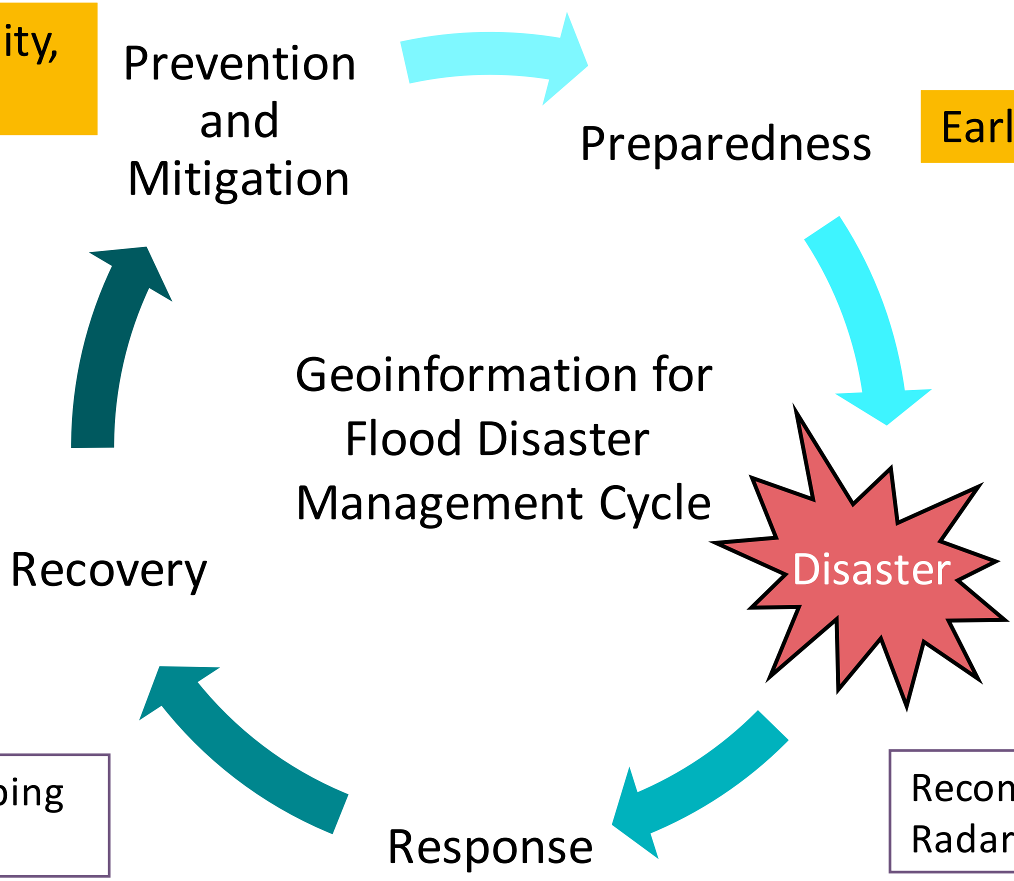
UNITED NATIONS
Office for Outer Space Affairs

SPACE4SDGS

Hazard, exposure, vulnerability, and risk assessments

Recommended Practice: Flood Hazard Mapping and Assessment

Recommended Practice: Exposure Mapping



Early warning systems

Pilot project using GloFAS

Post disaster needs, damage and loss assessments

Recommended Practice: Flood Mapping and Damage Assessment

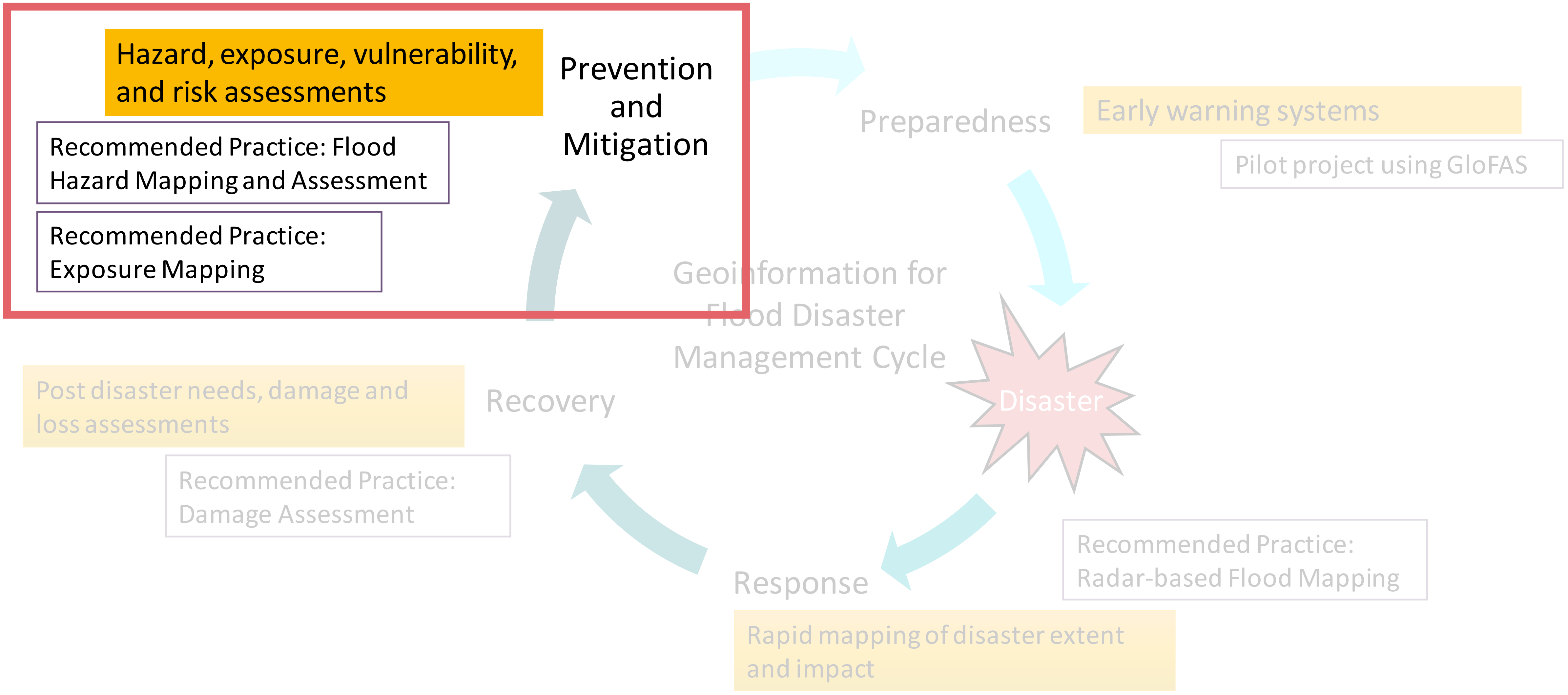
Recommended Practice: Radar-based Flood Mapping

Rapid mapping of disaster extent and impact

UN-SPIDER Recommended Practices

UNITED NATIONS
Office for Outer Space Affairs

SPACE4SDGS



SPACE4SDGS

Flood hazard mapping suggested workflow

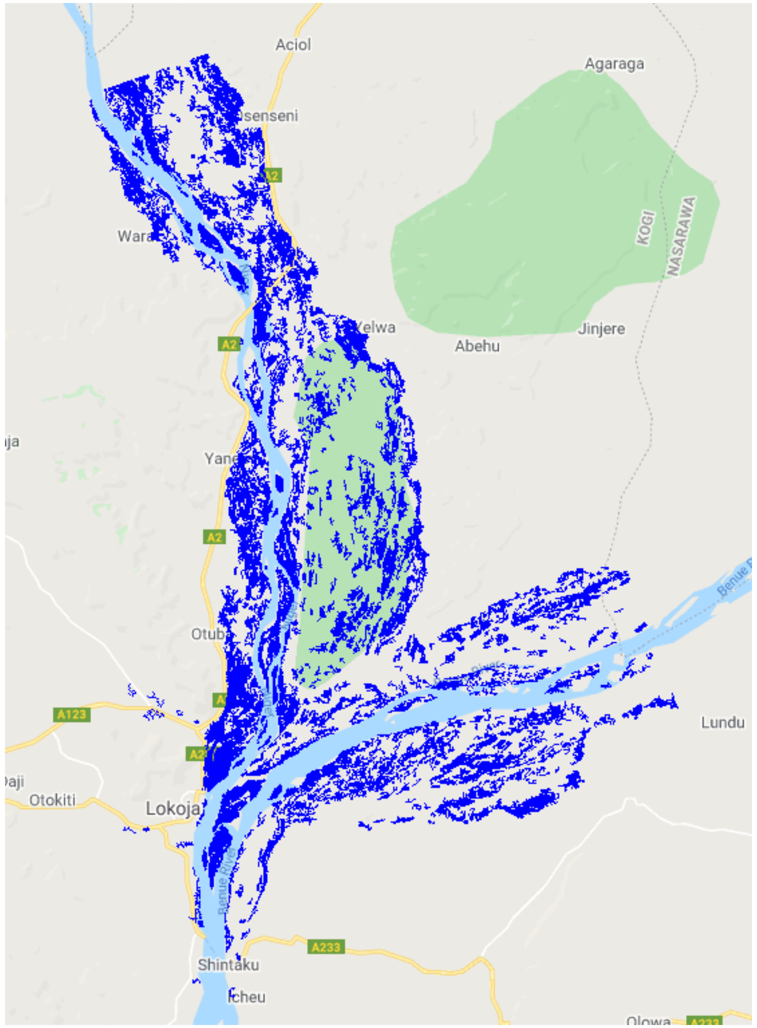
1) **Flood hazard extent generation or retrieving**
   - Based on space-data of past event: Sentinel-1
   - Based on hydrological modelling
   - Archived data
2) **Exposure analysis in GIS using auxiliary data**
   - Population
   - Land cover
   - Infrastructures (buildings, roads)
   - Points of interest
3) **Map creation**
   - Hazard map
   - Exposure map
   - Risk map

Flood hazard extent

- **Shows the extent of a historical flood or potential flood (flood mask layer)**

- **Can be generated through**
  - Space-data of past event
  - Hydrological modelling
  - **Archive the generated flood masks into database for future use**

- **Can be retrieved through**
  - Database of past flood events
  - Database of modelled events
  - Calculated flood return periods



UN-SPIDER Flood hazard extent Recommended Practices

Workflows using Sentinel-1 SAR data	Workflows using modelling
❑ Flood Mapping and Damage Assessment using Sentinel-1 SAR data in Google Earth Engine ❑ Radar-based Flood Mapping	❑ Flood Hazard Assessment ❑ Flood Hazard Mapping
Output: vector (.shp/.kml/.kmz/.geojson) or raster (.tiff/.geotiff) hazard extent layer	**Output: vector (.shp) or raster (.tiff/.geotiff) hazard extent layer**

- **Build up database of flood hazard extents from past events and modelling for future use**

Exposure analysis

UNITED NATIONS
Office for Outer Space Affairs

SPACE4SDGS

- Overlay flood mask layer with exposed elements to estimate the impact

- Exposed elements (auxiliary data)
  - Population
  - Land cover
  - Infrastructures (buildings, roads)
  - Critical infrastructures
  - Points of interest

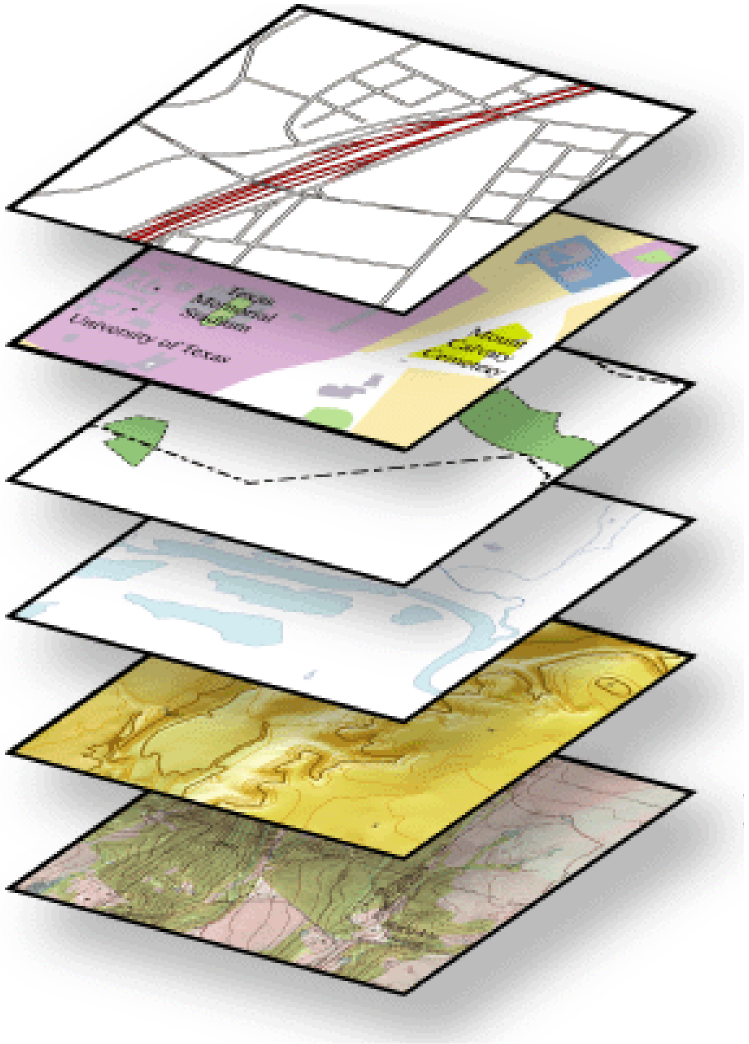


Image: Modified from Esri

SPACE4SDGS

UN-SPIDER Exposure analysis Recommended Practices

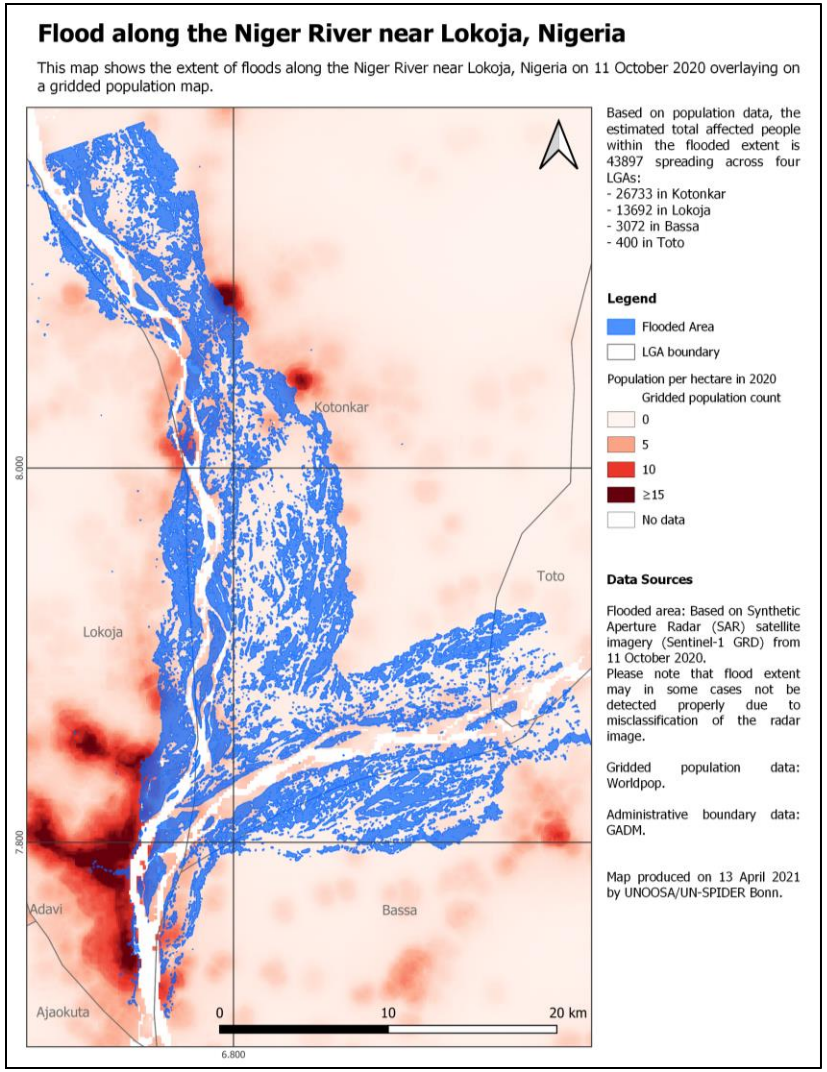
- **Exposure Mapping**
  - QGIS
  - Import exposed elements

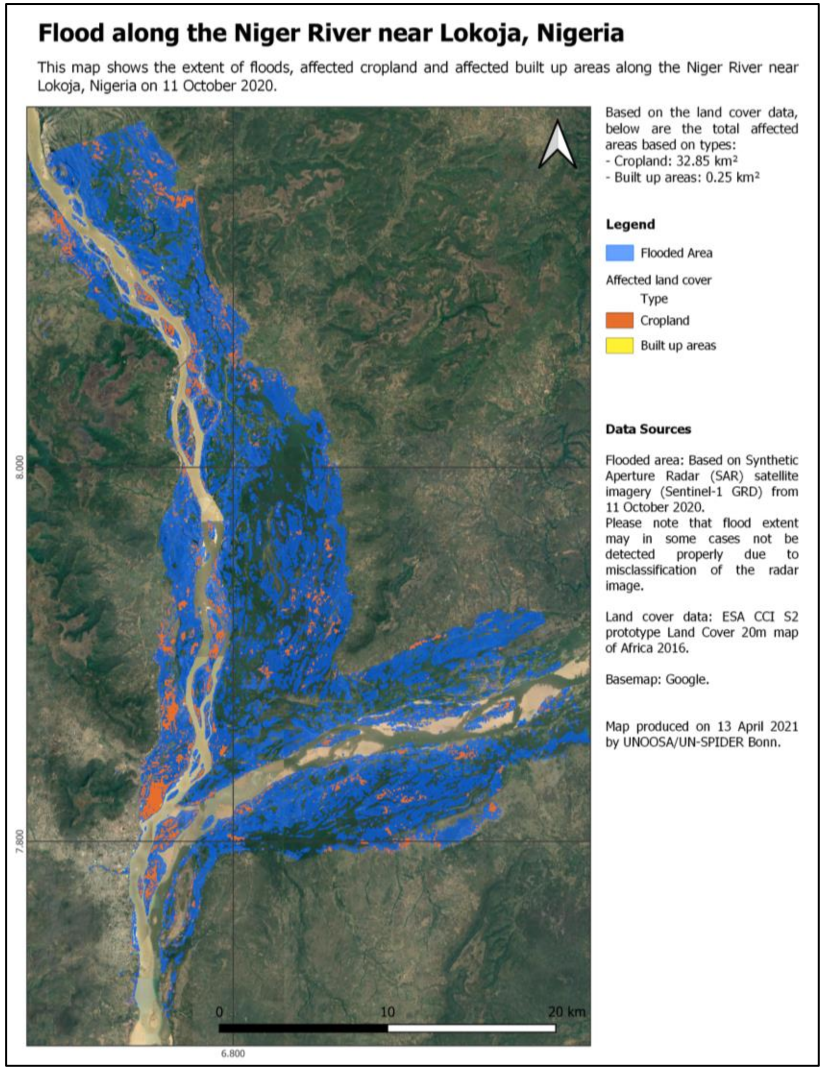
- **Disaster Preparedness Using Free Software Extensions**
  - QGIS (InaSAFE plugin)
  - Import exposed elements

- **Flood Mapping and Damage Assessment using Sentinel-1 SAR data in Google Earth Engine**
  - Google Earth Engine (cloud-based platform)
  - Output: Affected number of population and cropland area

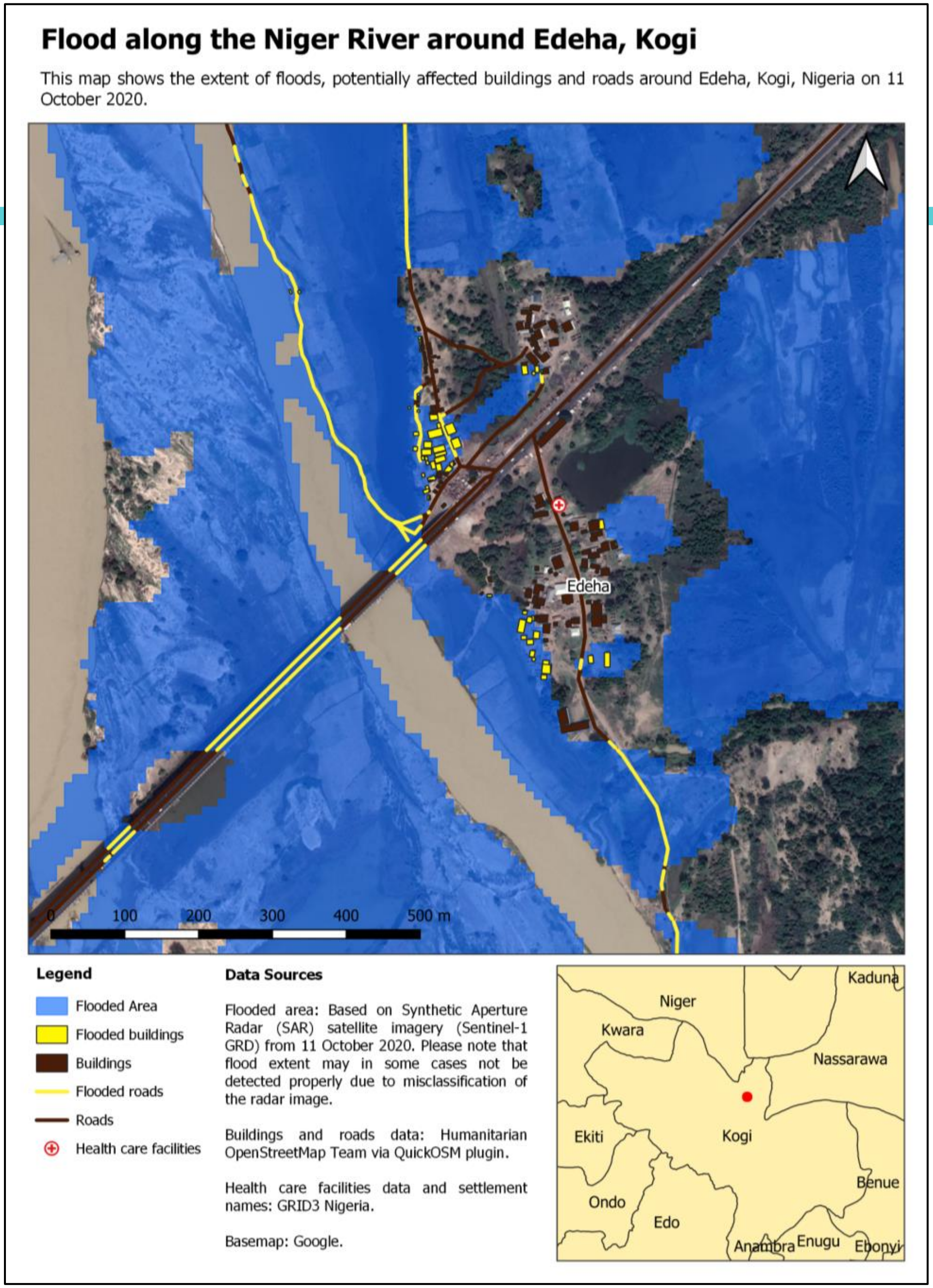
SPACE4SDGS

Example: Exposure maps





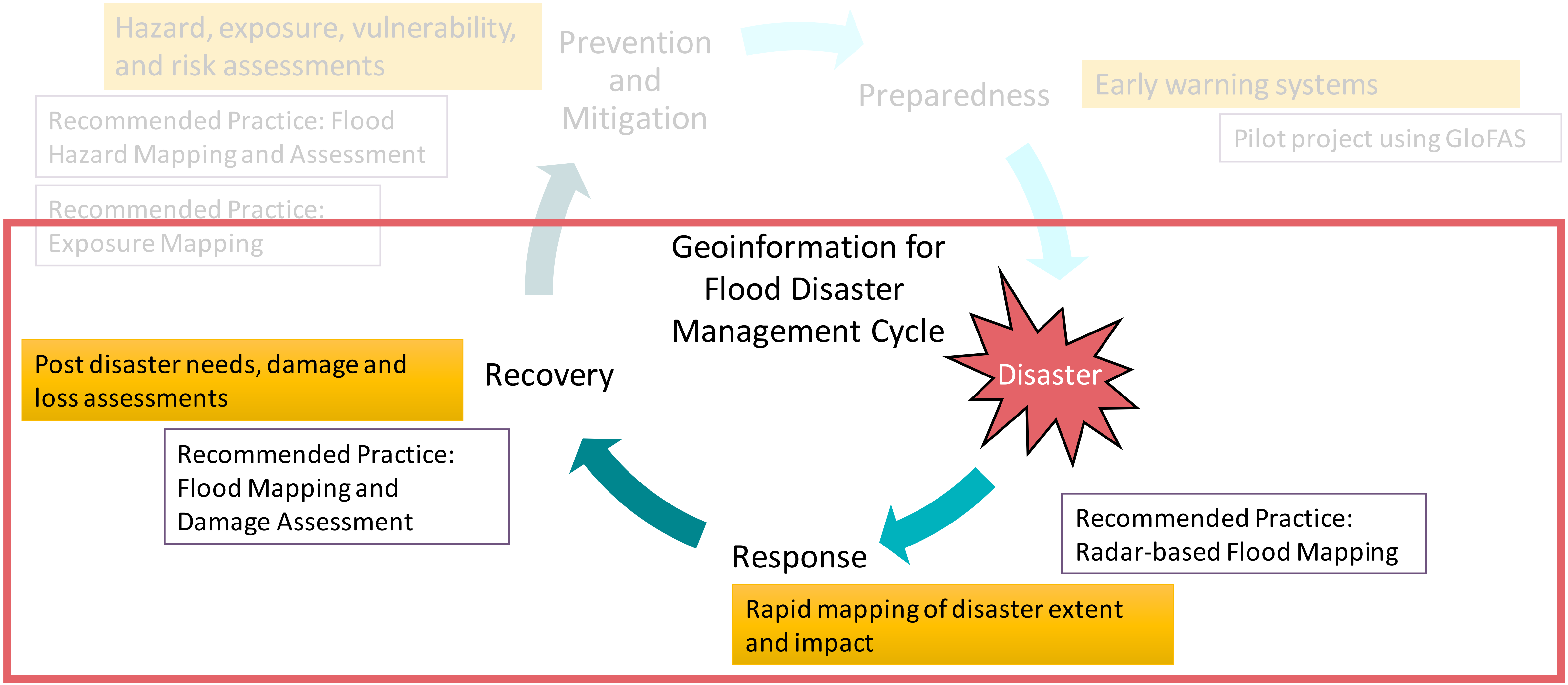
Example: Local-scale exposure map



UN-SPIDER Recommended Practices

UNITED NATIONS
Office for Outer Space Affairs

SPACE4SDGS



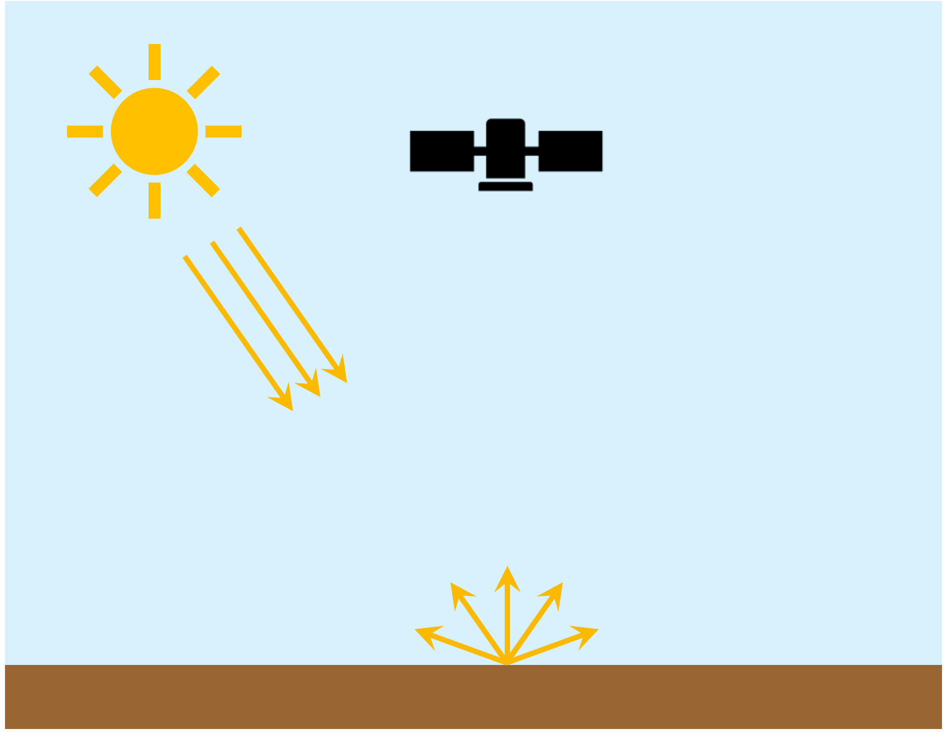
Satellite Remote Sensing Sensors

UNITED NATIONS
Office for Outer Space Affairs

SPACE4SDGS

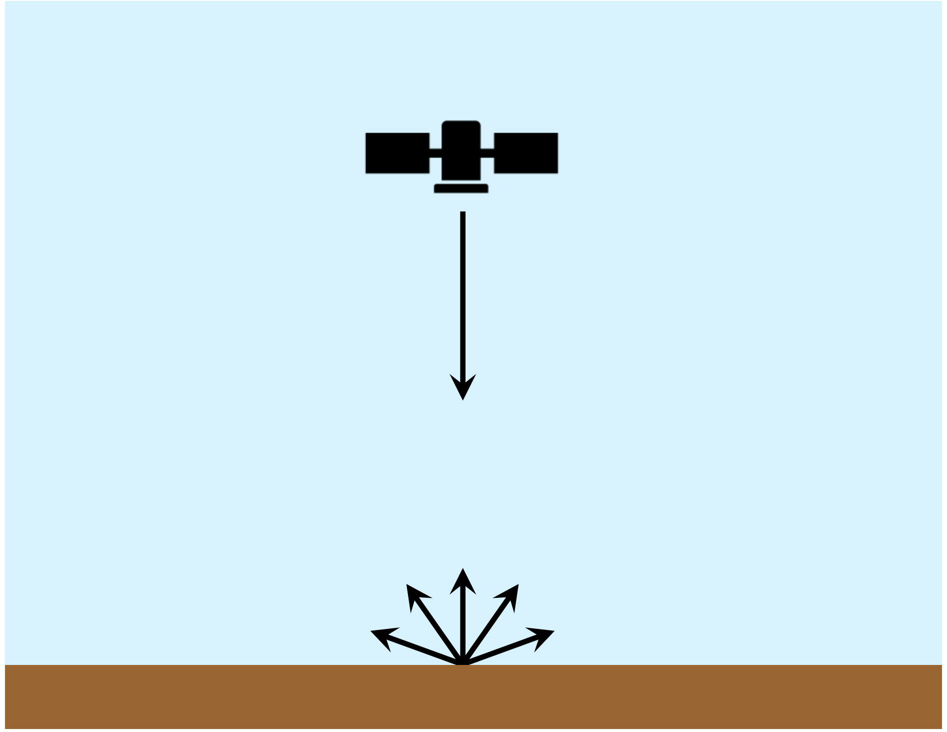
❑ Passive Sensors

+ Easy interpretation (optical sensors)
- Depend on weather and lighting conditions (optical sensors)



❑ Active Sensors (e.g. Synthetic Aperture Radar, SAR)

+ Independent of weather and lighting conditions
- Require pre-processing

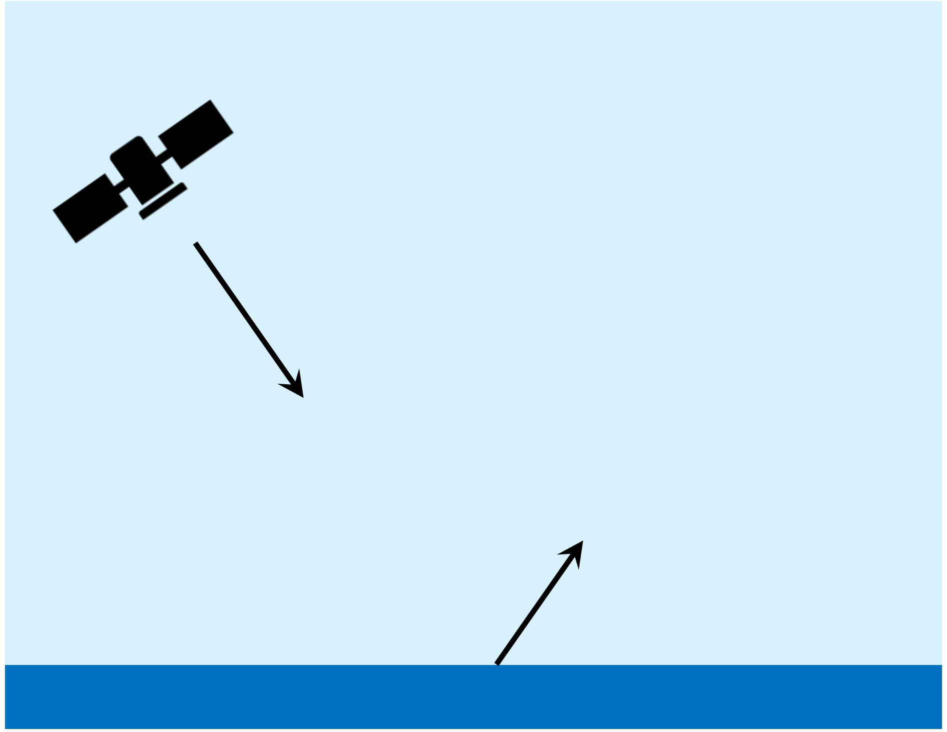


SAR Reflection Types

❑ Specular Reflection

Occurs on smooth surfaces (e.g. water)

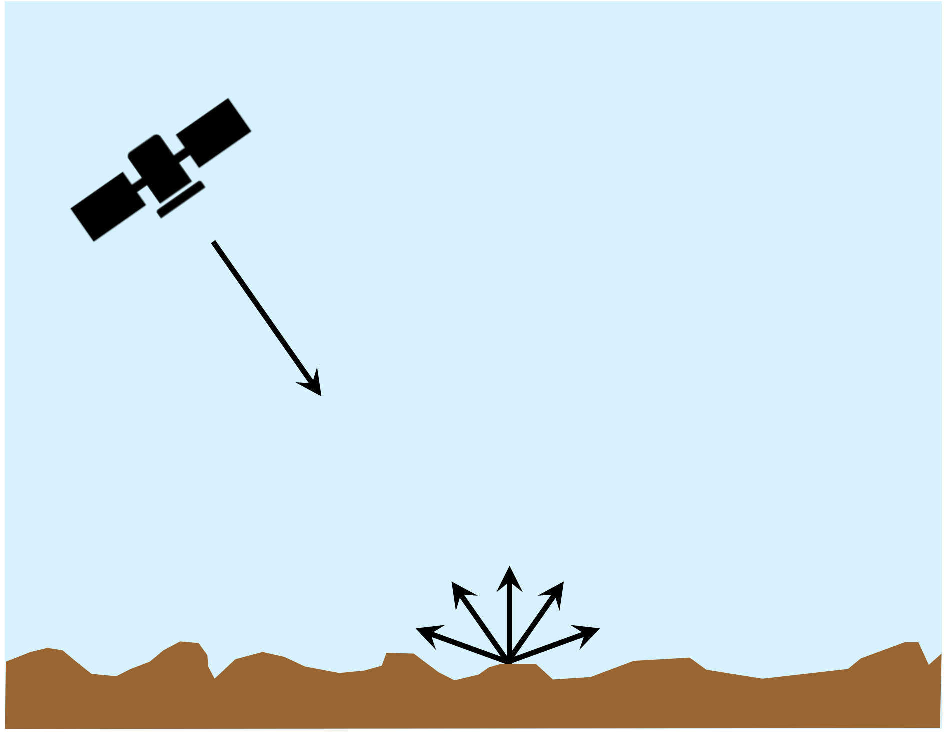
→ Appears **dark** due to low backscatter intensity



❑ Diffuse Reflection

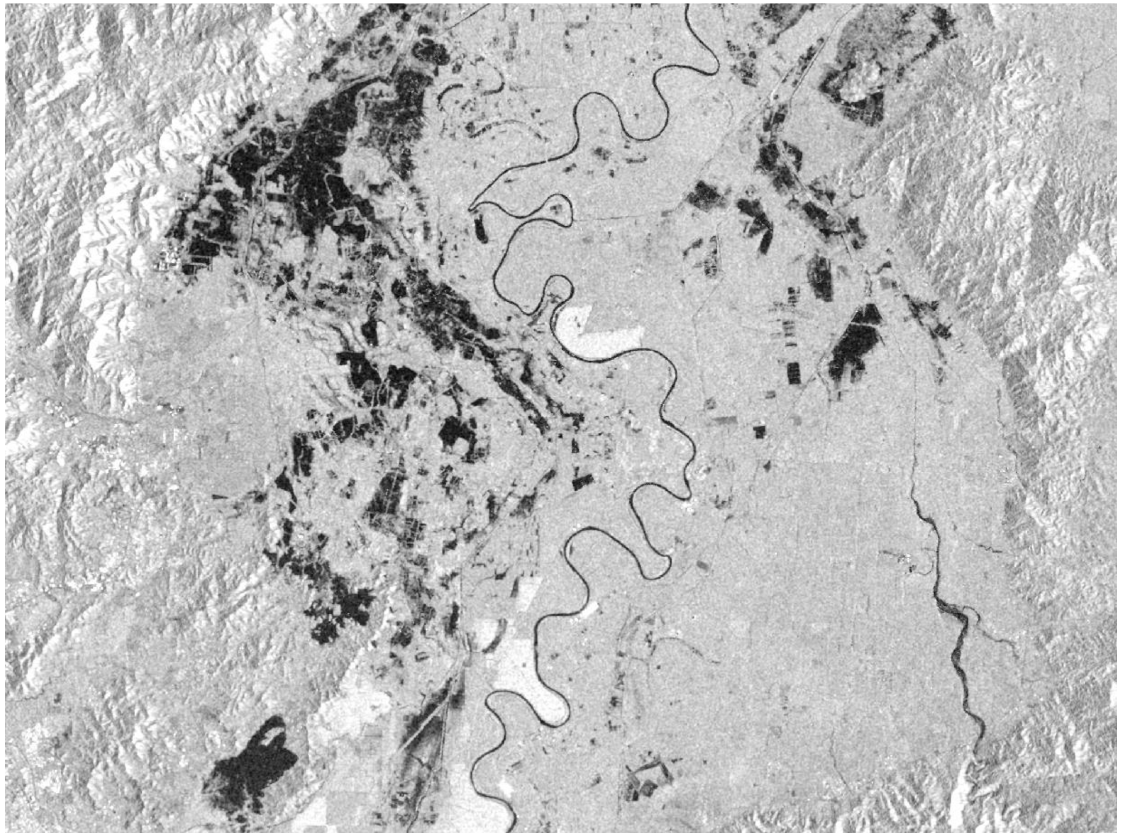
Occurs on rough surfaces (e.g. soil)

→ Appears **bright** due to high backscatter intensity

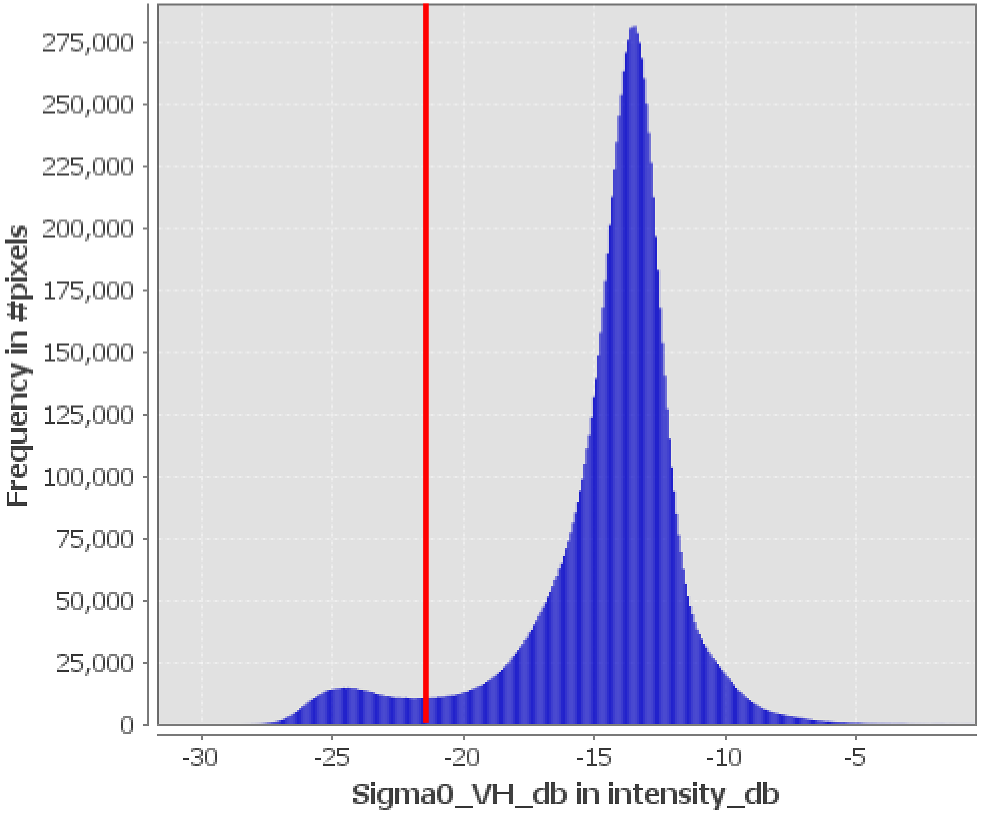


Rule-based Flood Segmentation

❑ SAR image after processing

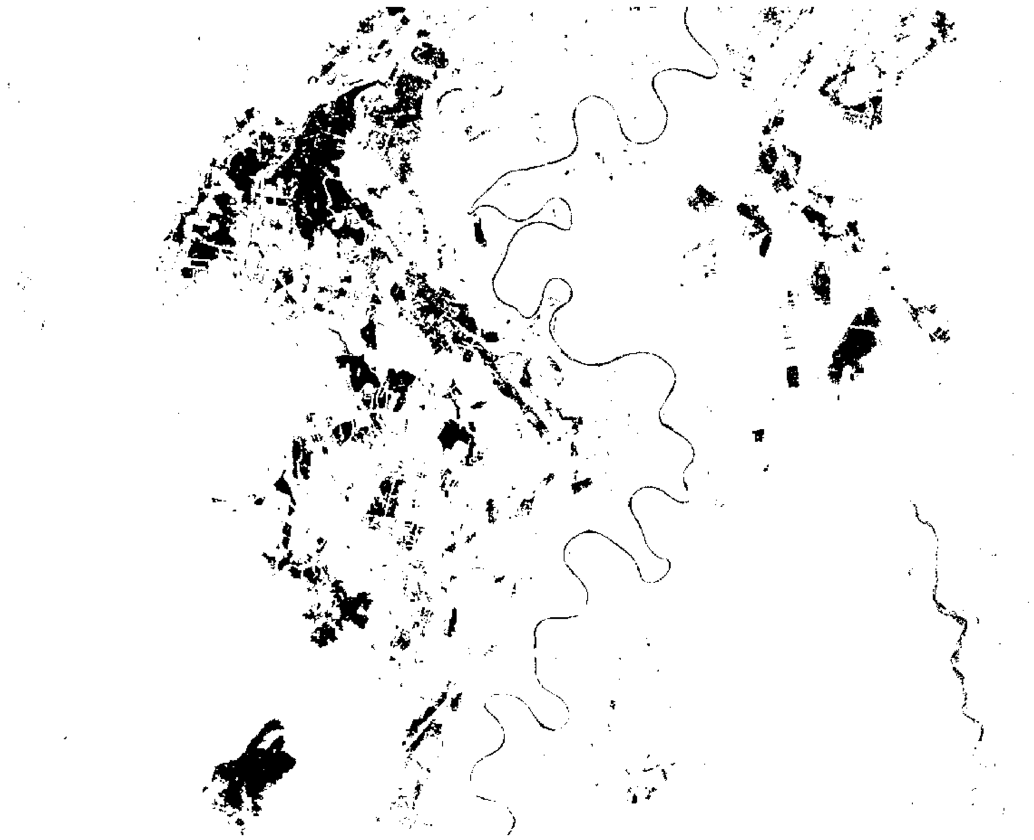


❑ Histogram

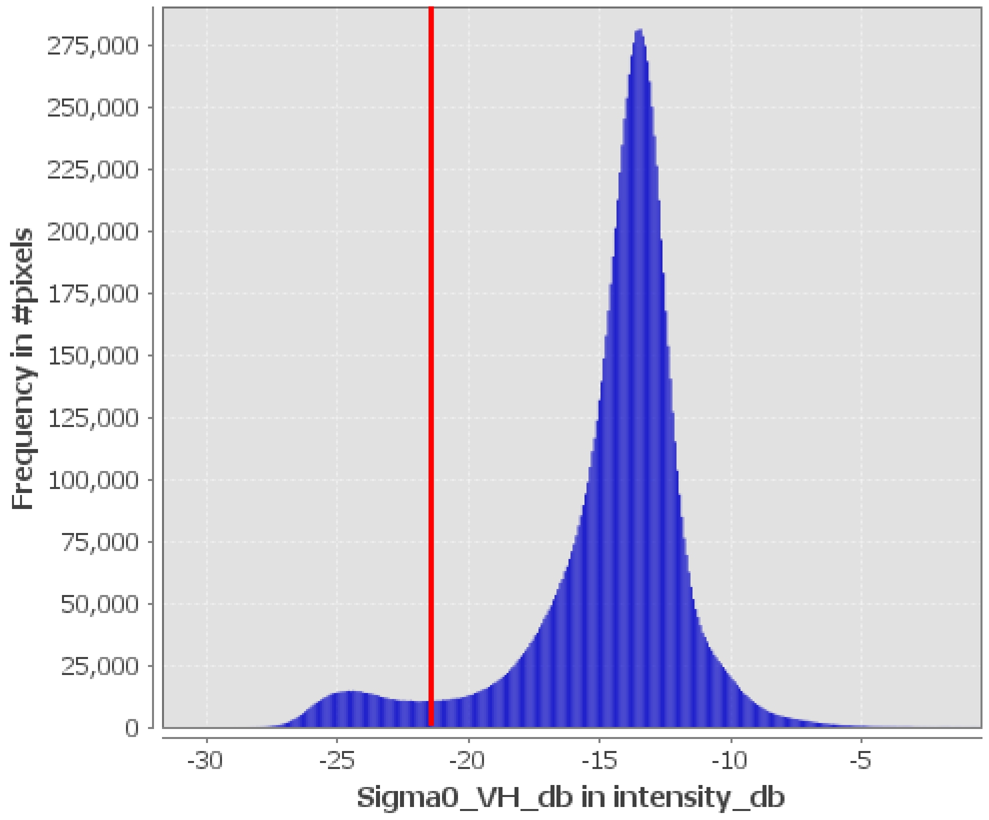


Rule-based Flood Segmentation

- SAR image after processing



- Histogram

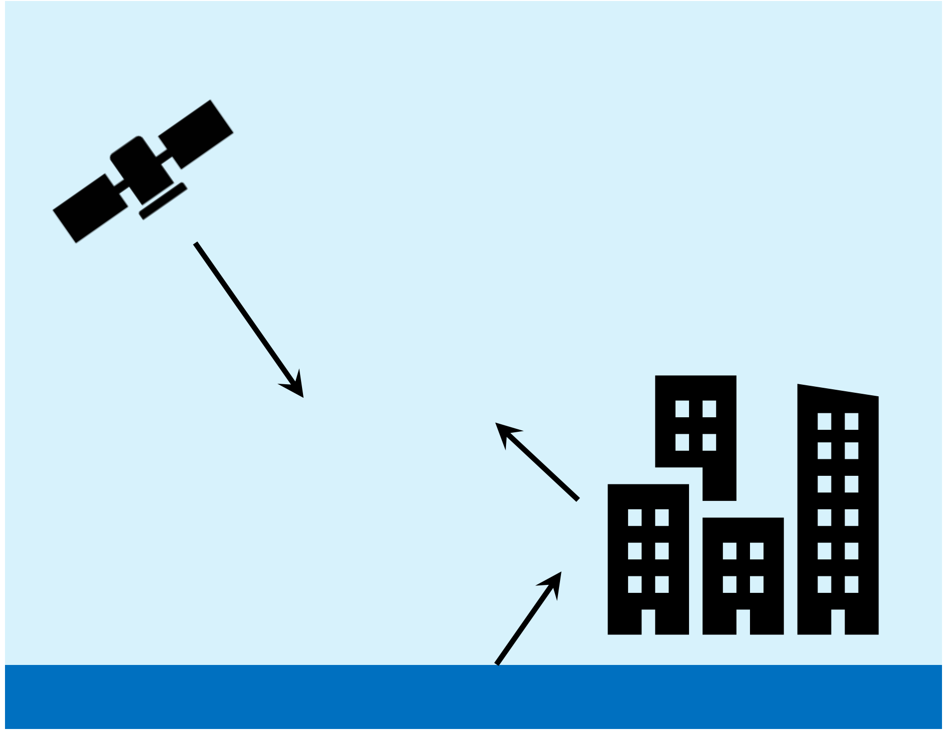


Limitation: Double bounce backscatter

❑ Urban Areas

Multiple reflections at urban geometries

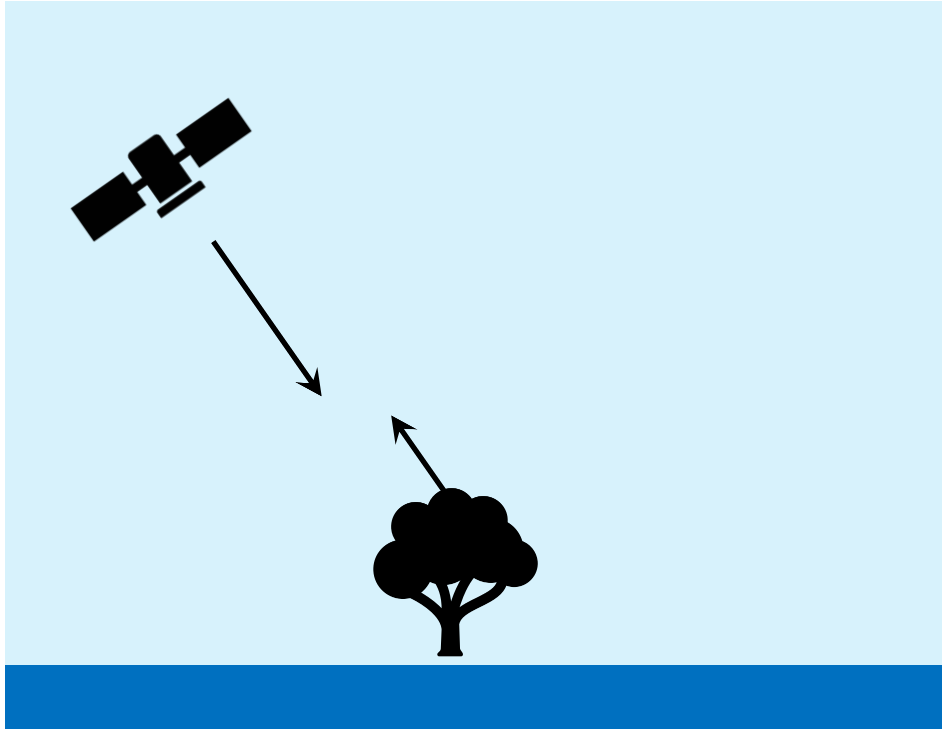
→ Appears **bright** due to high backscatter intensity



❑ Flooded Vegetation

Multiple reflections in vegetation

→ Appears **bright** due to high backscatter intensity



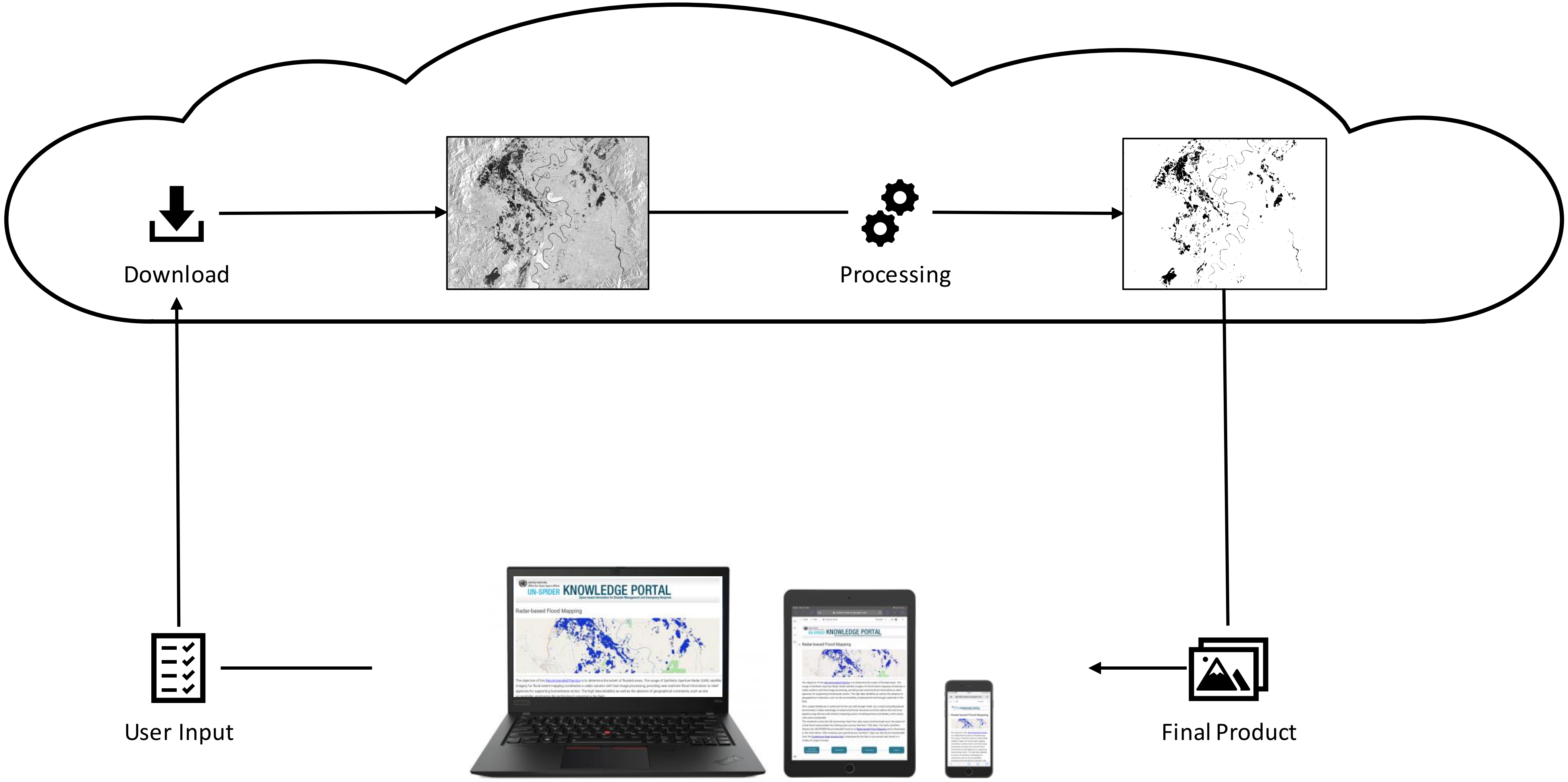
Platform & Data

UNITED NATIONS
Office for Outer Space Affairs
SPACE4SDGS

- **Jupyter Notebook**
  - Open-source and interactive web application
    → Share text, live code, visualizations, etc.
  - Includes full processing chain including data query/download and processing

- **Sentinel-1**
  - Synthetic Aperture Radar (SAR) mission
  - Two identical satellites: Sentinel-1A, Sentinel-1B
  - Repeat cycle (max. 6 days at Equator)
  - Access: [Copernicus Open Access Hub]

Cloud Computing



SAR-based Flood Mapping

❑ Processing workflow

SAR Image

Apply Orbit File

Thermal Noise Removal

Radiometric Calibration

Speckle Filter

Terrain Correction

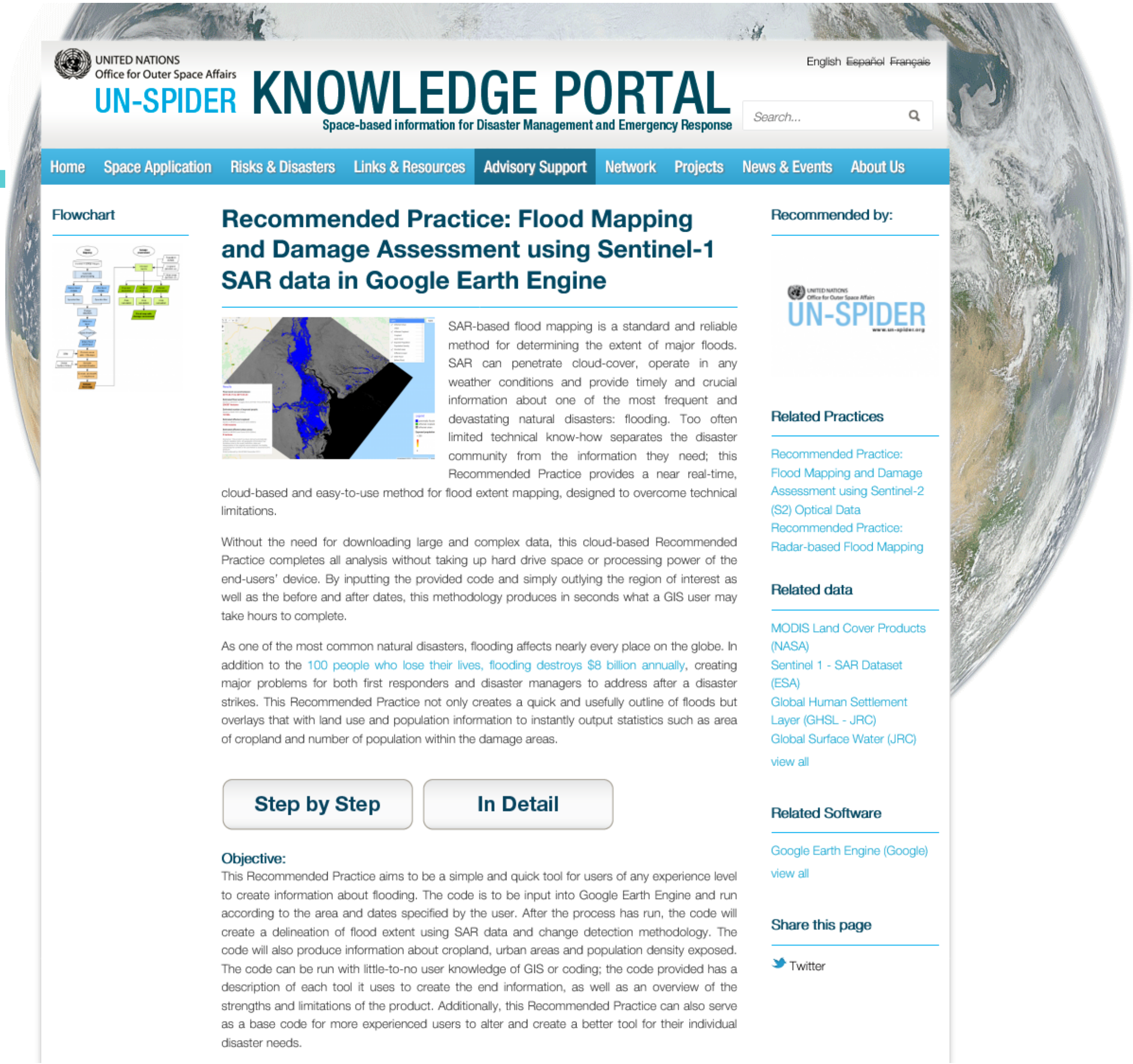
Binarization

Speckle Filtering

Flood Mask

Flood mapping with SAR data in GEE

https://un-spider.org/advisory-support/recommended-practices/recommended-practice-google-earth-engine-flood-mapping



UNITED NATIONS
Office for Outer Space Affairs
UN-SPIDER KNOWLEDGE PORTAL
Space-based information for Disaster Management and Emergency Response

English Español Français

Search...

Home | Space Application | Risks & Disasters | Links & Resources | Advisory Support | Network | Projects | News & Events | About Us

Flowchart

Recommended Practice: Flood Mapping and Damage Assessment using Sentinel-1 SAR data in Google Earth Engine

SAR-based flood mapping is a standard and reliable method for determining the extent of major floods. SAR can penetrate cloud-cover, operate in any weather conditions and provide timely and crucial information about one of the most frequent and devastating natural disasters: flooding. Too often limited technical know-how separates the disaster community from the information they need; this Recommended Practice provides a near real-time, cloud-based and easy-to-use method for flood extent mapping, designed to overcome technical limitations.

Without the need for downloading large and complex data, this cloud-based Recommended Practice completes all analysis without taking up hard drive space or processing power of the end-users' device. By inputting the provided code and simply outlying the region of interest as well as the before and after dates, this methodology produces in seconds what a GIS user may take hours to complete.

As one of the most common natural disasters, flooding affects nearly every place on the globe. In addition to the 100 people who lose their lives, flooding destroys $8 billion annually, creating major problems for both first responders and disaster managers to address after a disaster strikes. This Recommended Practice not only creates a quick and usefully outline of floods but overlays that with land use and population information to instantly output statistics such as area of cropland and number of population within the damage areas.

Step by Step | In Detail

Objective:
This Recommended Practice aims to be a simple and quick tool for users of any experience level to create information about flooding. The code is to be input into Google Earth Engine and run according to the area and dates specified by the user. After the process has run, the code will create a delineation of flood extent using SAR data and change detection methodology. The code will also produce information about cropland, urban areas and population density exposed. The code can be run with little-to-no user knowledge of GIS or coding; the code provided has a description of each tool it uses to create the end information, as well as an overview of the strengths and limitations of the product. Additionally, this Recommended Practice can also serve as a base code for more experienced users to alter and create a better tool for their individual disaster needs.

Recommended by:

UN-SPIDER

Related Practices

Recommended Practice: Flood Mapping and Damage Assessment using Sentinel-2 (S2) Optical Data
Recommended Practice: Radar-based Flood Mapping

Related data

MODIS Land Cover Products (NASA)
Sentinel 1 - SAR Dataset (ESA)
Global Human Settlement Layer (GHSL - JRC)
Global Surface Water (JRC)
view all

Related Software

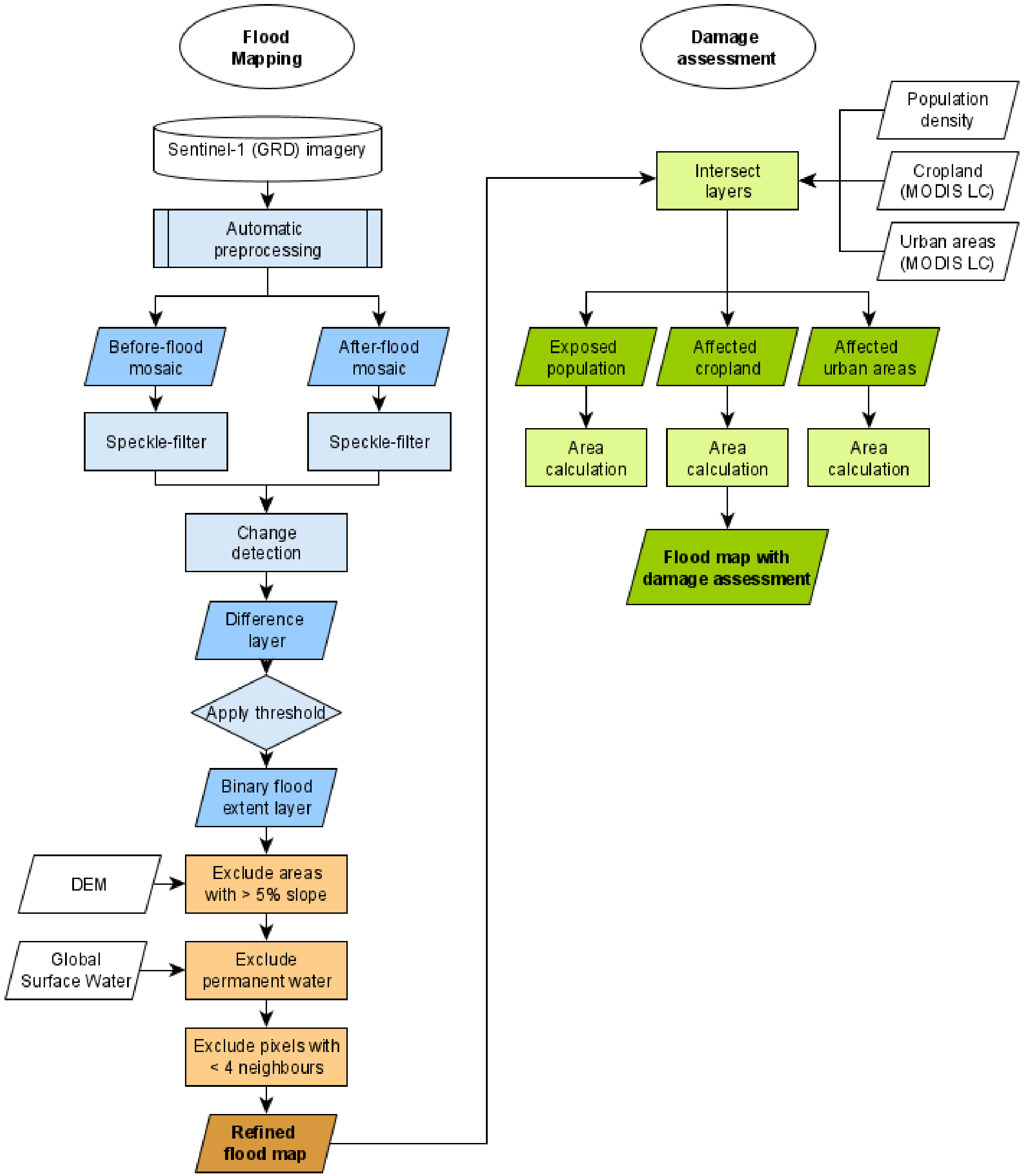
Google Earth Engine (Google)
view all

Share this page

Twitter

Flood mapping with SAR data in GEE

Data sources used:
- Sentinel-1 SAR data
- DEM
- Global Surface Water Explorer dataset (JRC)
- Global Human Settlement Layer (JRC)
- HydroSHEDS (based on SRTM)
- MODIS Land Cover data



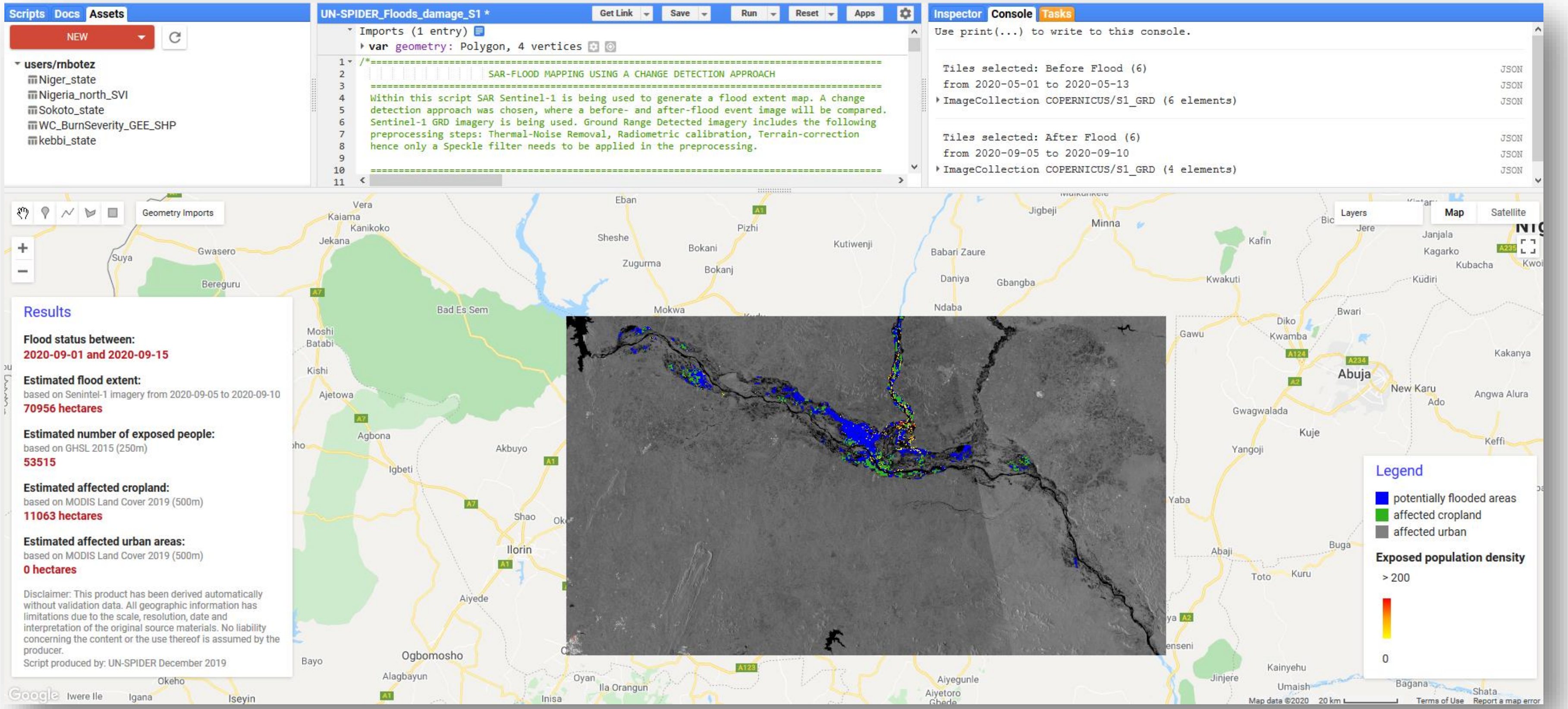
SPACE4SDGS

Flood mapping with SAR data in GEE

Advantages	Limitations
Weather/daytime independent	False positives from changes on land surfaces not caused by flooding
Workflow can be applied to different areas	Difficulties on detecting floods in urban or densely vegetated areas (double-bounce effect etc.)
Fully automated after specifying AOI and time periods	No capturing of flood peak due to the acquisition frequency of Sentinel-1
Quick cloud processing	Delay in availability of Sentinel-1 data in GEE (couple of days)
Easy access to additional dataset to delineate the flood extent (e.g. slope) and damage (population data, land cover data)	Resolution of additional datasets causes uncertainties for damage assessment

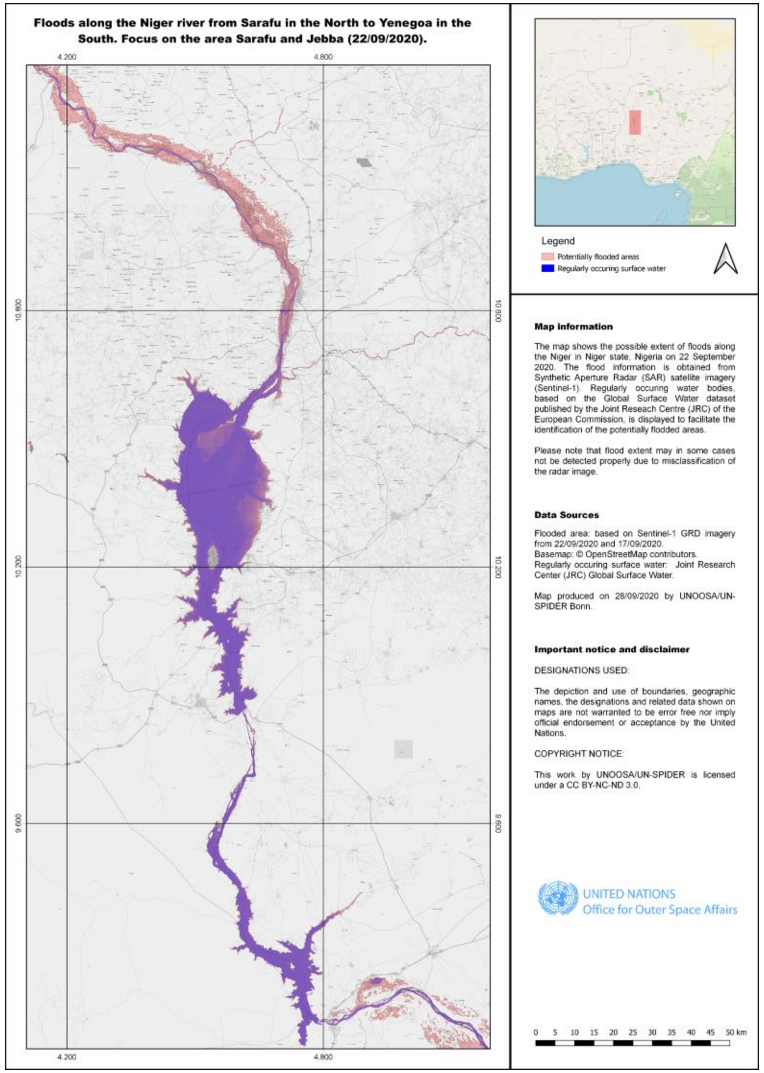
SPACE4SDGS

Flood mapping with SAR data in GEE



Mapping results in GIS software

- Export flood mask from Jupyter notebook / Google Earth Engine as vector file
- Import into ArcGIS/QGIS
- Combine with other data sources
- Create map



Thank you

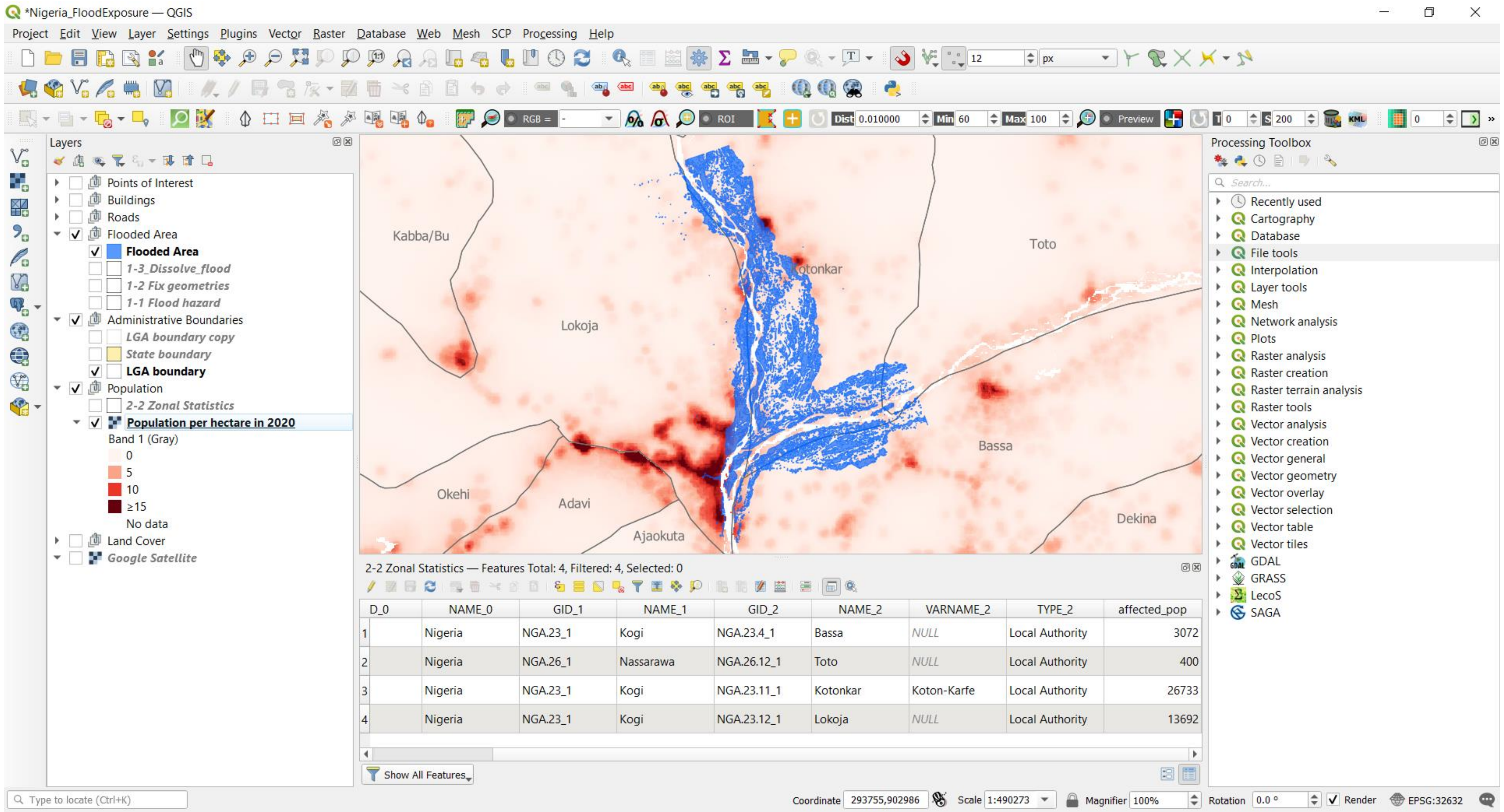
www.un-spider.org

@un_spider
facebook.com/unspider

Backup: QGIS

UNITED NATIONS
Office for Outer Space Affairs

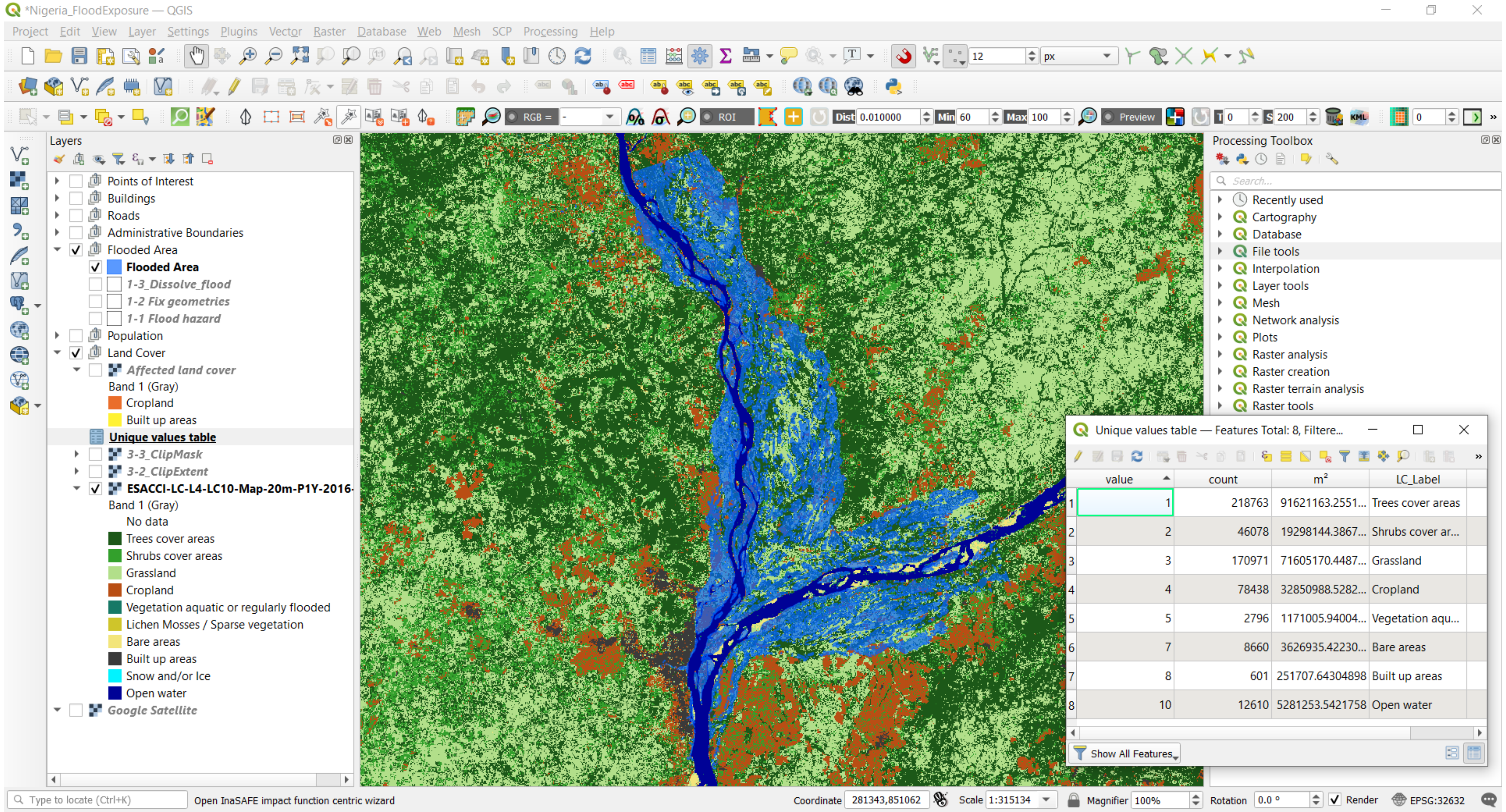
SPACE4SDGS



Backup: QGIS

UNITED NATIONS
Office for Outer Space Affairs

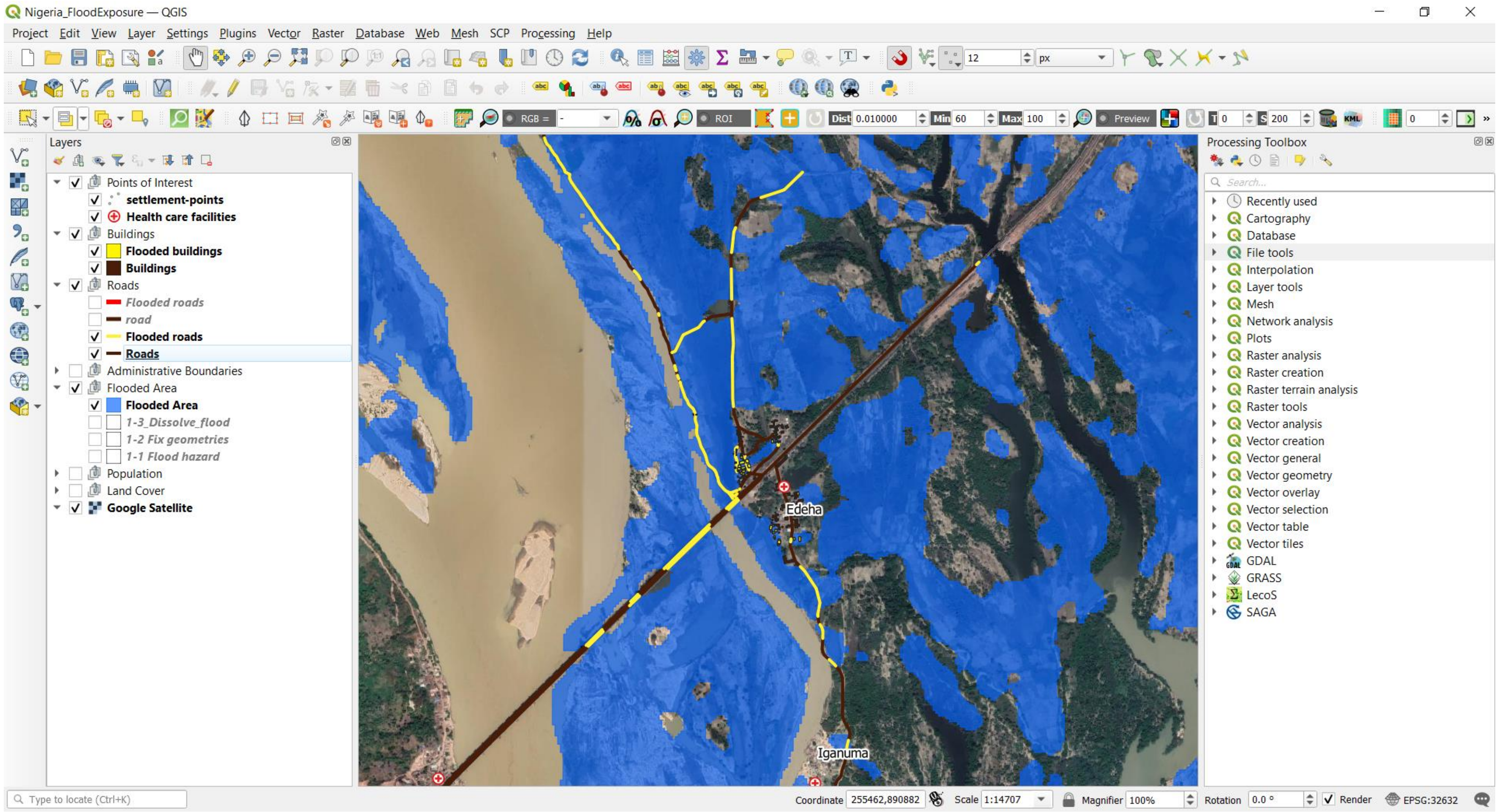
SPACE4SDGS



Backup: QGIS

UNITED NATIONS
Office for Outer Space Affairs

SPACE4SDGS



Backup: Jupyter Notebook

Step by step: Radar-based flood mapping with Python

Share this page
Share 312
Twitter
Share

Back to overview | In Detail

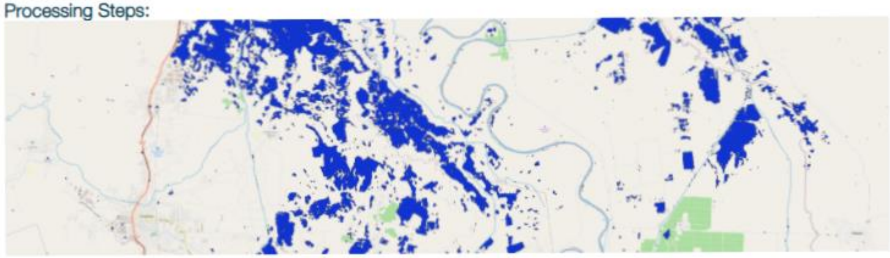
Data Access:
A static Jupyter Notebook for automatic radar-based flood extent mapping is shown below. The notebook can be accessed on GitHub or directly executed in Binder or Google Colab. Please find below the links to the respective platforms:

Open in GitHub 12

launch binder

Open in Colab

Processing Steps:



The objective of this Recommended Practice is to determine the extent of flooded areas. The usage of Synthetic Aperture Radar (SAR) satellite imagery for flood extent mapping constitutes a viable solution with fast image processing, providing near real-time flood information to relief agencies for supporting humanitarian action. The high data reliability as well as the absence of geographical constraints, such as site accessibility, emphasize the technology's potential in the field.

This Jupyter Notebook covers the full processing chain from data query and download up to the export of a final flood mask product by utilizing open access Sentinel-1 SAR data. The tool's workflow follows the UN-SPIDER Recommended Practice on Radar-based Flood Mapping and is illustrated in the chart below. After entering user specifications, Sentinel-1 data can directly be downloaded from the Copernicus Open Access Hub. Subsequently, the data is processed and stored in a variety of output formats.

File Structure
The Jupyter Notebook file constitutes the directory of origin. Additional data is contained in subfolders. Sentinel-1 images need to be stored in a subfolder called *'input'*. If no image is provided, the subfolder will automatically be created when accessing and downloading data from the Copernicus Open Access Hub through this tool. If an area of interest (AOI) file is available (supported formats: GeoJSON, SHP, KML, KMZ), it needs to be placed in a subfolder called *'AOI'*. If none are available, an interactive map will allow to manually draw the area of interest. For reasons of automatic file selection, it is recommended to place only one AOI file in the respective folder. However, if multiple files exist, GeoJSON files are prioritized followed by SHP, KML, and KMZ. The processed data is stored in a subfolder called *'output'*.
In order to run the tool with no user interaction, all inputs must be clearly defined. This means that the *'input'* subfolder must include one single Sentinel-1 image and the *'AOI'* subfolder one single AOI file. All other scenarios do require manual interaction such as downloading data or defining an AOI.

Limitations
Difficulties in detecting flooded vegetation and floods in urban areas due to double bounce backscatter. If water and non-water are very unequally distributed in the image, the histogram might not have a clear local minimum, leading to incorrect results in the automatic binarization process.

Important The Jupyter Notebook takes advantage of the ESA SNAP API Engine and requires installation of the SNAP-Python interface *snappy*. Click here for further information. Furthermore, the Jupyter Notebook Extensions *Codefolding*, *ExecuteTime* and *Table of Contents (2)* are used for the most convene performance.

Backup: Jupyter Notebook

UNITED NATIONS
Office for Outer Space Affairs

SPACE4SDGS

User Input

User Input → Download → Processing → Export

- Polarisation
- Download Image
- Plot Results

Please specify in the code cell below i) the polarisation to be processed, ii) whether data shall be downloaded from the Copernicus Open Access Hub with respective sensing period and login details, and iii) whether intermediate results should be plotted during the process.

```
# polarisations to be processed
polarisations = 'VH'                              # 'VH', 'VV', 'both'

# download image from Copernicus Open Access Hub
download = {
    'imageDownload'     : True,                   # 'True', 'False'
    'period_start'      : [2020, 11, 5],          # format: [Year, Month, Day]
    'period_stop'       : [2020, 11, 13],         # format: [Year, Month, Day]
    'username'          : 'username',             # username for login
    'password'          : 'password'              # password for login
}

# show intermediate results if set to 'True'
plotResolut s = True                               # 'True', 'False'
```

Initialization

This section loads relevant Python modules for the following analysis and initializes basic functionalities.

```
# Click to run
```

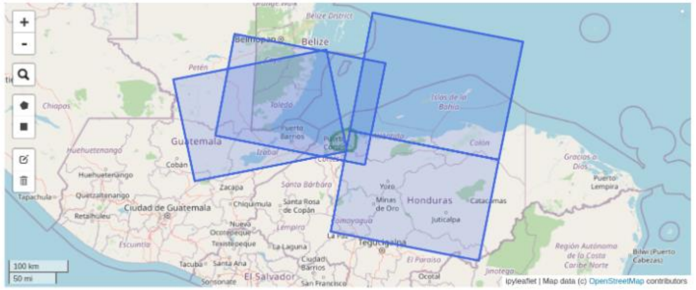
Download Image

User Input → Download → Processing → Export

- Username
- Password
- Sensing Period

This section allows interactive data access and download from the Copernicus Open Access Hub. If an AOI file is given in the *'AOI'* subfolder, the tool searches and displays available Sentinel-1 images accordingly. If no AOI file is provided, the search bar on the left side of the interactive map can be used to find the desired region. The AOI can be then be selected and manipulated manually by using the drawing tool. Clicking the Search button below the map will load available images. If multiple AOIs are drawn, only the last one is considered. When hovering over a Sentinel-1 image, the tile index and ingestion date are shown. The table below summarizes information on all available tiles and allows the download. The data is stored in the automatically created *'input'* subfolder. The Open Access Hub maintains an online archive of at least the latest year of products for immediate download. Access to previous products that are no longer available online will automatically trigger the retrieval from the long term archives. The actual download can be initiated by the user once the data are restored (within 24 hours).

```
# Click to run
```



Search

```
Loading...
Successfully connected to Copernicus Open Access Hub.
```

Index	Ingestion Date	Polarisation	Size	
Tile 1	2020-11-11 18:41:37.561000	VV VH	1.57 GB	Download
Tile 2	2020-11-07 12:39:05.077000	VV VH	1.6 GB	Download
Tile 3	2020-11-07 03:19:32.917000	VV VH	1.83 GB	Download
Tile 4	2020-11-07 03:19:22.950000	VV VH	1.57 GB	Download

```
Product 9d5fefa0-7d53-461c-804a-61fb01ce64b5 is online. Starting download.

Downloading: 100%|██████████| 991M/991M [00:44<00:00, 22.3MB/s]
MD5 checksumming: 100%|██████████| 991M/991M [00:02<00:00, 391MB/s]
```

Backup: Jupyter Notebook

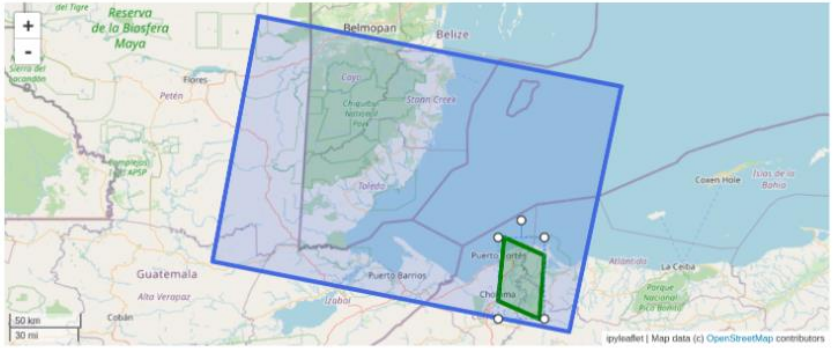
Processing

If more than one Sentinel-1 image exists in the *'input'* subfolder, the user can select which one is to be used for the processing. The subset is generated according to the AOI file in the *'AOI'* subfolder. If no AOI file is provided, an interactive map allows drawing the area of interest. Subsequently, the following processing steps are performed:

1. ***Apply Orbit File***: The orbit file provides accurate satellite position and velocity information. Based on this information, the orbit state vectors in the abstract metadata of the product are updated. The precise orbit files are available days-to-weeks after the generation of the product. Since this is an optional processing step, the tool will continue the workflow in case the orbit file is not yet available to allow rapid mapping applications.
2. ***Thermal Noise Removal***: Thermal noise correction is applied to Sentinel-1 Level-1 GRD products which have not already been corrected.
3. ***Radiometric Calibration***: The objective of SAR calibration is to provide imagery in which the pixel values can be directly related to the radar backscatter of the scene. Though uncalibrated SAR imagery is sufficient for qualitative use, calibrated SAR images are essential to the quantitative use of SAR data.
4. ***Speckle Filtering***: SAR images have inherent texturing called speckles which degrade the quality of the image and make interpretation of features more difficult. Speckles are caused by random constructive and destructive interference of the de-phased but coherent return waves scattered by the elementary scatter within each resolution cell. Speckle noise reduction can be applied either by spatial filtering or multilook processing. A Lee filter with an X, Y size of 5, 5 is used in this step.
5. ***Terrain Correction***: Due to topographical variations of a scene and the tilt of the satellite sensor, distances can be distorted in the SAR images. Data which is not directly directed towards the sensor's Nadir location will have some distortion. Therefore, terrain corrections are intended to compensate for these distortions to allow a realistic geometric representation in the image.
6. ***Binarization***: In order to obtain a binary flood mask, the histogram is analyzed to separate water from non-water pixels. Due to the side-looking geometry of SAR sensors and the comparably smooth surface of water, only a very small proportion of backscatter is reflected back to the sensor leading to comparably low pixel values in the histogram. The threshold used for separation is automatically calculated using scikit-image implementations and a combined use of the minimum method and Otsu's method. The GlobCover layer of the European Space Agency is used to mask out permanent water bodies.
7. ***Speckle Filtering***: A Median filter with an X, Y size of 7, 7 is used in this step.

```
# Click to run
```

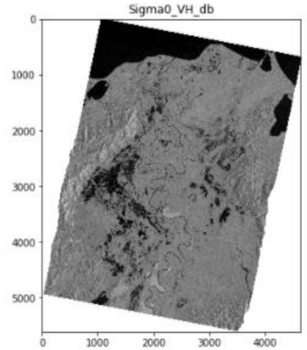
```
Selected:  S1A_IW_GRDH_1SDV_20201111T114548_20201111T114613_035200_041C27_0A8E.zip
```

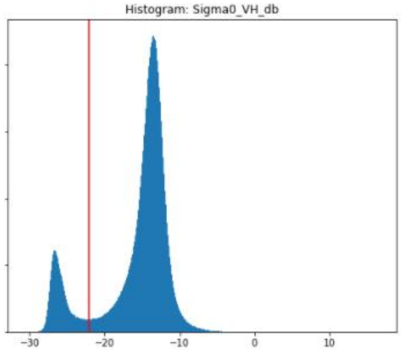


Start Processing

```
Subset successfully generated.

1. Apply Orbit File:             ---  0.02 seconds ---
2. Thermal Noise Removal:        ---  0.01 seconds ---
3. Radiometric Calibration:      ---  0.03 seconds ---
4. Speckle Filtering:            ---  0.01 seconds ---
5. Terrain Correction:           ---  0.05 seconds ---
6. Binarization:                 --- 14.39 seconds ---
7. Speckle Filtering:            ---  0.01 seconds ---
8. Plot:                         --- 55.75 seconds ---
```





Backup: Jupyter Notebook

UNITED NATIONS
Office for Outer Space Affairs

SPACE4SDGS

Data Export

The processed flood mask is exported as GeoTIFF, SHP, KML, and GeoJSON and stored in the *'output'* subfolder. An interactive map shows the flood mask.

```
# Click to run
```

```
Exporting...

1. GeoTIFF:                  --- 31.88 seconds ---
2. SHP:                      --- 23.53 seconds ---
3. KML:                      ---  0.55 seconds ---
4. GeoJSON:                  ---  1.68 seconds ---

Files successfuly stored under /home/eouser/Desktop/Recommended Practices/output.
```