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

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13-15 April 2021
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

UN-SPIDER Recommended Practices

- Hazard, exposure, vulnerability, and risk assessments
  - Recommended Practice: Flood Hazard Mapping and Assessment
  - Recommended Practice: Exposure Mapping

- Post disaster needs, damage and loss assessments
  - Recommended Practice: Flood Mapping and Damage Assessment

- Prevention and Mitigation

- Preparedness

- Early warning systems
  - Pilot project using GloFAS

- Geoinformation for Flood Disaster Management Cycle

- Recovery
  - Recommended Practice: Flood Mapping and Damage Assessment

- Response
  - Rapid mapping of disaster extent and impact
  - Recommended Practice: Radar-based Flood Mapping

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UN-SPIDER Recommended Practices

Hazard, exposure, vulnerability, and risk assessments

- Recommended Practice: Flood Hazard Mapping and Assessment
- Recommended Practice: Exposure Mapping

Prevention and Mitigation

- Rapid mapping of disaster extent and impact

Post disaster needs, damage and loss assessments

- Recommended Practice: Damage Assessment

Early warning systems

- Pilot project using GloFAS

Preparedness

Geoinformation for Flood Disaster Management Cycle

Response

Disaster

Recovery

Recommended Practice: Radar-based Flood Mapping

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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
Workflows using Sentinel-1 SAR data

- Flood Mapping and Damage Assessment using Sentinel-1 SAR data in Google Earth Engine
- Radar-based Flood Mapping

Output: vector (.shp/.kml/.kmz/.geojson) or raster (.tiff/.geotiff) hazard extent layer

Workflows using modelling

- Flood Hazard Assessment
- Flood Hazard Mapping

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

- 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
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
Example: Exposure maps

Flood along the Niger River near Lokoja, Nigeria

This map shows the extent of floods along the Niger River near Lokoja, Nigeria on 11 October 2020 overlying on a gridted population map.

- Based on population data, the estimated total affected people within the flooded exntent is 42,957 spreading across four LGAs:
  - 20,773 in Kotonkara
  - 9,422 in Lokoja
  - 1,602 in Oj Cuban
  - 490 in Toto

Legend

- Flooded area
- LGA boundary
- Population per hectare in 2020
- Gridted population count
  - 1,001-1,500
  - 501-1,000
  - 51-500
  - 0-50
  - No data

Data Sources

- Flooded areas: Based on Synthetic Aperture Radar (SAR) satellite imagery (Sentinel-1 GRD) from 11 October 2020.
- Please note that flood extent may in some cases not be accurate due to misclassification of the radars image.
- Gridted population data:
  - WorldPop
- Administrative Boundary data:
  - OCHA NAS
- Map produced on 03 April 2021 by UNOSAT/UN-SPIDER Bonn.

Flood along the Niger River near Lokoja, Nigeria

This map shows the extent of floods, affected cropland and affected built up areas along the Niger River near Lokoja, Nigeria on 11 October 2020.

- Based on the land cover data, below are the total affected areas based on types:
  - Cropland: 32,965 ha
  - Built up areas: 0.22 ha

Legend

- Flooded areas
- Affected land cover
  - Type
  - Cropland
  - Built-up areas

Data Sources

- Flooded areas: Based on Synthetic Aperture Radar (SAR) satellite imagery (Sentinel-1 GRD) from 11 October 2020.
- Please note that flood extent may in some cases not be accurate due to misclassification of the radars image.
- Land cover data: ESA CCI S2 prototype Land Cover 2016 map of Africa 2016.
- Basemap: Google.
- Map produced on 13 April 2021 by UNOSAT/UN-SPIDER Bonn.
Example: Local-scale exposure map
UN-SPIDER Recommended Practices

Hazard, exposure, vulnerability, and risk assessments

Prevention and Mitigation

Preparedness

Early warning systems

Pilot project using GloFAS

Geoinformation for Flood Disaster Management Cycle

Post disaster needs, damage and loss assessments

Recommended Practice: Flood Hazard Mapping and Assessment

Recommended Practice: Exposure Mapping

Recommended Practice: Flood Mapping and Damage Assessment

Rapid mapping of disaster extent and impact

Recommended Practice: Radar-based Flood Mapping

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Satellite Remote Sensing Sensors

- **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

- **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](https://www.copernicus.eu/access)
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
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
### Flood mapping with SAR data in GEE

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

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Backup: QGIS
Backup: Jupyter Notebook

Step by step: Radar-based flood mapping with Python

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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 files. 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 areas 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 app. Click here for further information. Furthermore, the Jupyter Notebook Extensions (God持股, ExecuteFile and Table of Contents) are used for the most convienent performance.
Please specify in the code cell below i) the polarisations 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.

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

# download image from Copernicus Open Access Hub
download = {  
    'polarization': [True, False],  
    'period_start': [2020, 11, 12],  
    'period_end': [2020, 11, 13],  
    'username': 'username',  
    'password': 'password'  
}

# show intermediate results if set to 'True'
plotIntermediate = True
```

Initialization

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

```python
# Click to run
```
If more than one Sentinel-1 image exists in the 'input' subfolder, the user can select which one 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 SAA calibration is to provide imagery in which the pixel values can be directly related to the radar backscatter of the scene. Though uncalibrated SAA imagery is sufficient for qualitative use, calibrated SAA images are essential to the quantitative use of SAA data.

4. **Speckle Filtering**: SAA 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 SAA images. Data which is not directly directed towards the sensor’s Nadir location will have some distortions. 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 SAA 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 skew-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.
Backup: Jupyter Notebook

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.

Files successfully stored under /home/user/Desktop/Recommended Practices/output.