Recommended Practice for Flood Mapping with Sentinel-1 Interferometric Coherence

UN-SPIDER Knowledge Portal

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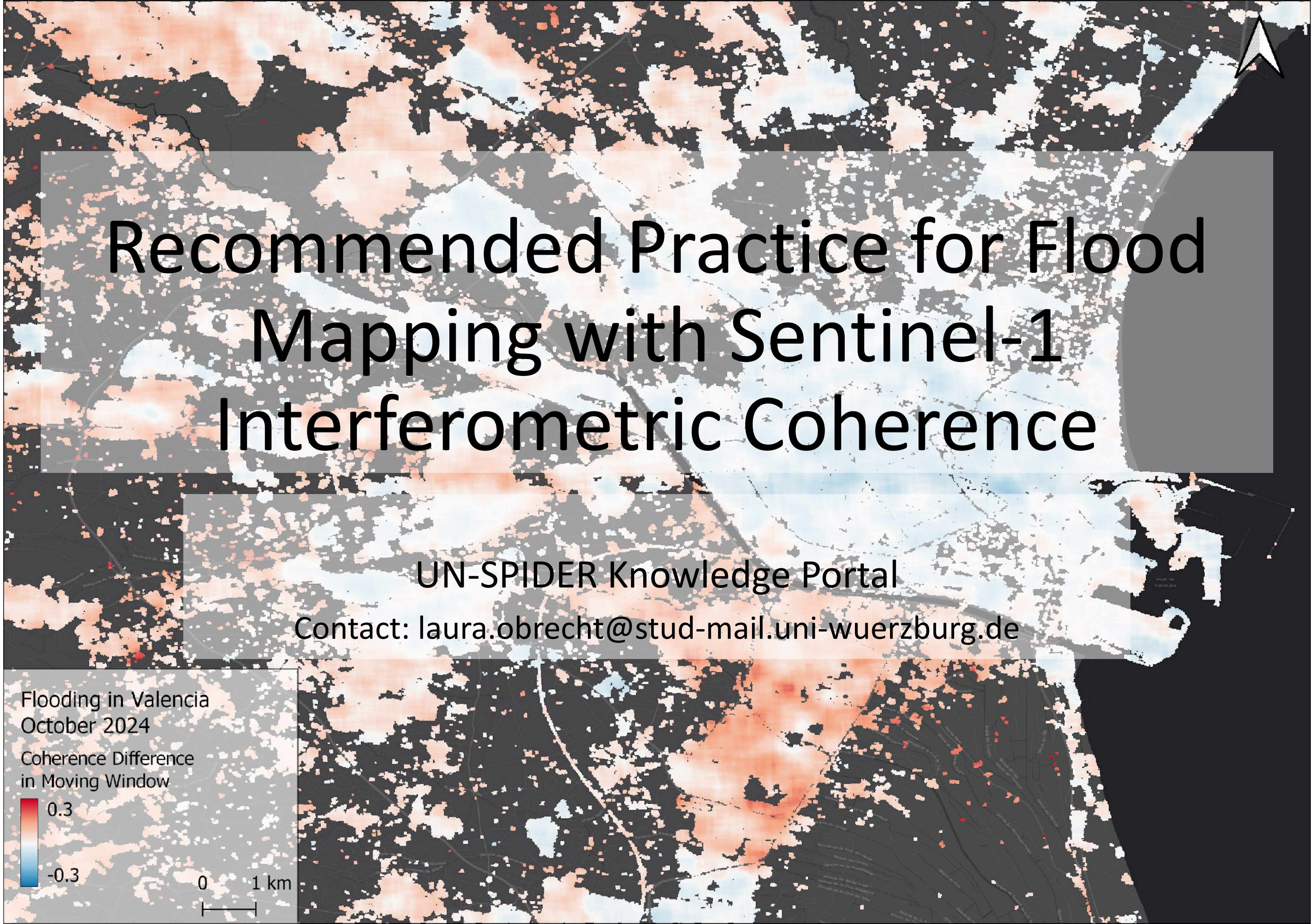


Background

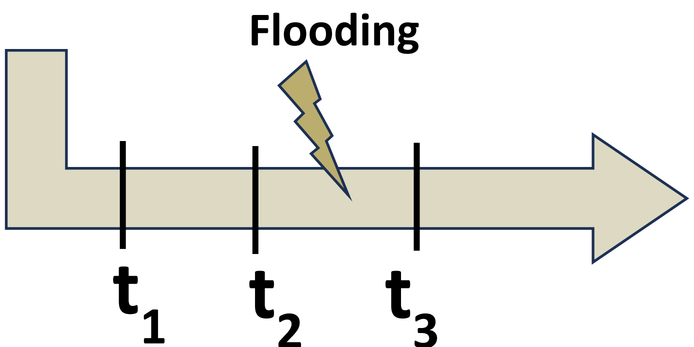
Due to the geometric characteristics of urban fabric, conventional methods of detecting floods with SAR backscatter in urban areas have major limitations. This is predominantly because of high vertical structures in urban environments, which results in high-intensity signals received at the SAR sensor.

SAR interferometry considers not only the intensity (i.e. the amplitude) of the SAR signal, but also the phase information. Interferometric coherence is defined as the correlation between the phase information of two SAR images: the correlation is calculated for each pixel and is a measure of the change between the two images. InSAR coherence ranges from 0 to 1 with 1 being a high correlation between the phases of the two images and 0 meaning no correlation.

Background

Urban areas do not change much in small temporal time scales, for example between two Sentinel-1 acquisitions. This is why surface changes attributed to disasters, like floods, flash floods or storms, can be mapped by calculating InSAR coherence changes. Therefore, three SAR images are needed: two before the disaster (t1 and t2), acting as reference image and one image shortly after the disaster (t3). The coherence is calculated between the two pre-event scenes (t1-t2) and between the 2nd pre-event scene and the post-event scene (t2-t3).

Important to note is, that outside of urban areas, especially in vegetated areas, coherence decorrelates although significant changes might not have happened. This has to do with the uncertainty connected to SAR signals from vegetation. This is why, interpretation of Coherence images will be considered in this practice, as well.



Objective

This Recommended Practice aims to map flooded and destroyed areas in urban environments. This practice can be used by users at any experience level, but in depth interpretation of InSAR coherence images requires a certain level of understanding on how SAR images are acquired. Also drawing reliable conclusions from this analysis might require consulting a specialist in remote sensing. The main part of the analysis is executed in SNAP. The damage assessment is conducted with a Google Earth Engine Script. Additionally, the SNAP output can also serve as a base for more experienced remote sensing analysts to create better flood delineations and damage assessments than the one provided with the Google Earth Engine Script.

Context

Valencia, Spain

On the 30th of October 2024, the city Valencia in Spain was hit by strong rainfalls, triggering flash floods. More than 200 people were killed during the event and more than 4,000 were evacuated. Satellite technology has played a key role in assessing the damage of the affected areas.

Valuable maps, utilizing different satellite data, were collected by the European Space Agency:

https://www.esa.int/Applications/Observing_the_Earth/Devastating_floods_in_Spain_witnessed_by_satellites

Applicability

This practice can be used to provide an assessment on the damage of a specific urban area. The output can be regarded as a heat map, providing hotspots of damage attributable to flooding or similar disasters. In addition, the Google Earth Engine code provides information on the settlement density in the affected areas. This information is provided by the Joint Research Centre of the European Commission.

Abstract

Flood detection in urban areas is a major limitation of flood detection approaches using SAR backscatter. This is problematic for the disaster response community, as urban areas are also where most damage happens and the most people are exposed to the disaster, considering that the majority population lives nowadays in cities rather than rural areas, the trend increasing.

Definition of Coherence:

Requirements
Applications

Input Data:

- Sentinel-1 SLC data
  Download recommended via the Alaska Satellite Facility

Sofware:

- SNAP
- Google Earth Engine

The proposed practice can be well applied in dense urban areas, like cities but also in areas with little to no vegetation cover. In these areas, mudflows, landslides and flow paths of flash floods can be mapped, although this is not the objective of this practice.

Strengths and Limitations

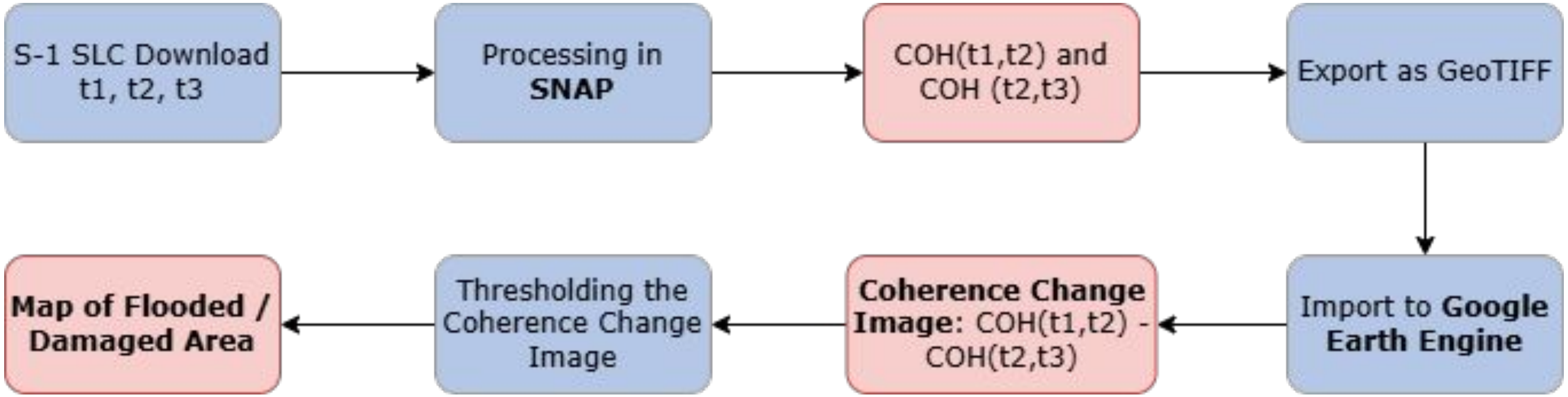
Strengths:

- Independant of clouds
- Detection of changes at sub-pixel level, which is a major advantage in dense urban settlements
- Detection of floods, infrastructure damage and other surface changes

Limitations:

- The practice is limited in detecting floods in vegetated areas like forests and agricultural areas
- Short time span between the SAR image acquisitions essential
- No cloud computing options available, selection of ROI needed, no large-scale computations on

Workflow


S-1 SLC Download t1, t2, t3
Processing in **SNAP**
COH(t1,t2) and COH (t2,t3)
Export as GeoTIFF
Import to **Google Earth Engine**
Coherence Change Image: COH(t1,t2) - COH(t2,t3)
Thresholding the Coherence Change Image
Map of Flooded / Damaged Area

Step by Step

1. Downloading the Scenes from the Alaska Satellite Facility
2. Processing the Scenes with a pre-defined workflow in SNAP
3. Exporting the Coherence GeoTiff
4. Importing the Coherence raster into Google Earth Engine
5. Change Detection in Urban Areas
6. Map of flooded/damaged areas

Downloading the Scenes from the Alaska Satellite Facility

The Alaska Satellite Facility (ASF) downlinks, processes, archives, and distributes remote-sensing data to scientific users worldwide. It is a convenient platform to download Sentinel-1 SLC data:

[ASF Data Search]

Each scene has approximately 4 to 5 GB. On the basis of your AOI, one orbit should be selected, in which all scenes are located. Three S-1 Scenes are necessary: two pre-event scenes and one post-event scene. The scenes need to be of file type L1 Single Look Complex (SLC).

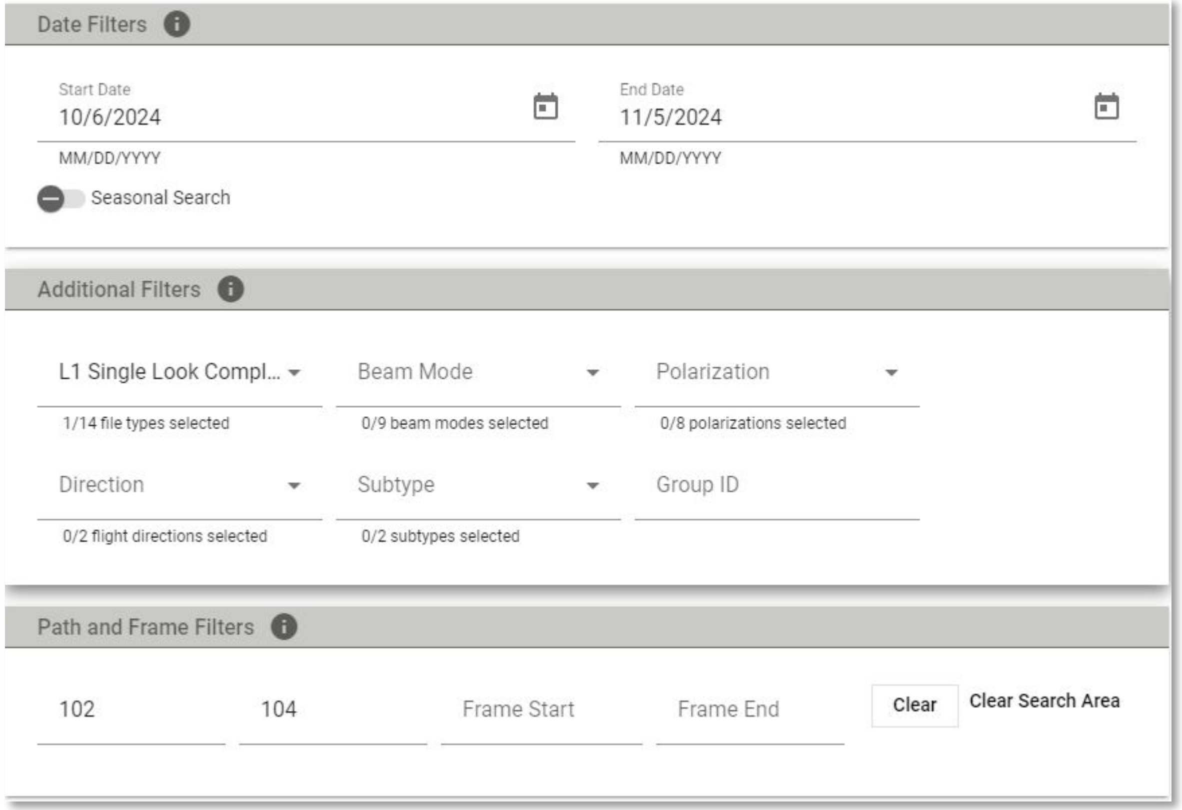
Drawing the AOI:

After loading the page, you can directly start drawing your AOI. Then use the “Filters” option to select the date range. Under “Additional Filters” select “L1 Single Look Complex (SLC)” as file type. If you know already the path, specify it in the section “Path and Frame Filters”.

Downloading the Scenes from the Alaska Satellite Facility

How to use the Filters:

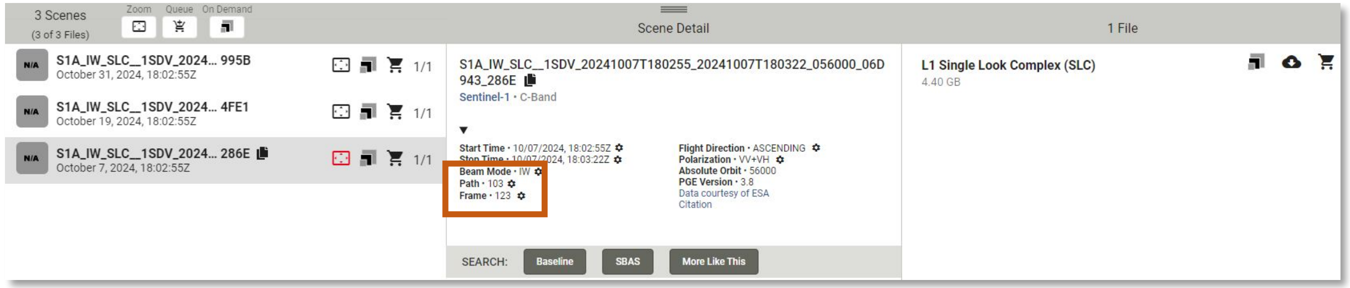
- **Select Start Date and End Date:** they should be appart by at least one month, end date should be shortly after the disaster happend.
- **File Type:** select L1 Single Look Complex
- **Path and Frame** filters can be specified later
- Click „Apply“

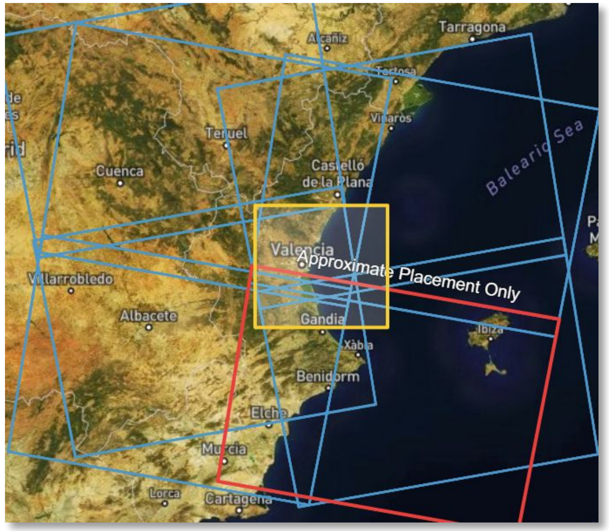


Downloading the Scenes from the Alaska Satellite Facility

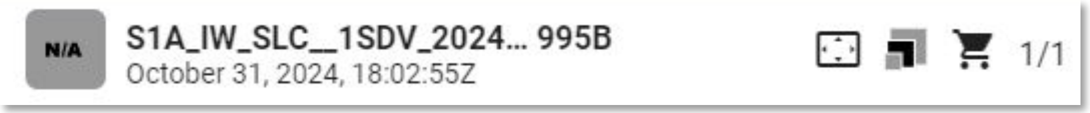
After clicking on apply, you will see the scenes (in blue) covering your AOI (yellow/orange). By hovering above the unique rectangles, you will see to what extent they cover your AOI (red). Decide for one rectangle and click on it. In the scene list, you will see it highlighted. You will also see the Path and Frame of the Scene. Use these numbers to go again into “Filters” and add them to path start/end and frame start/end. After clicking again on SEARCH, you will only see one rectangle left on the map.

All the three scenes need to be in the same rectangle, i.e. they need to have the same path and frame!





Downloading the Scenes from the Alaska Satellite Facility



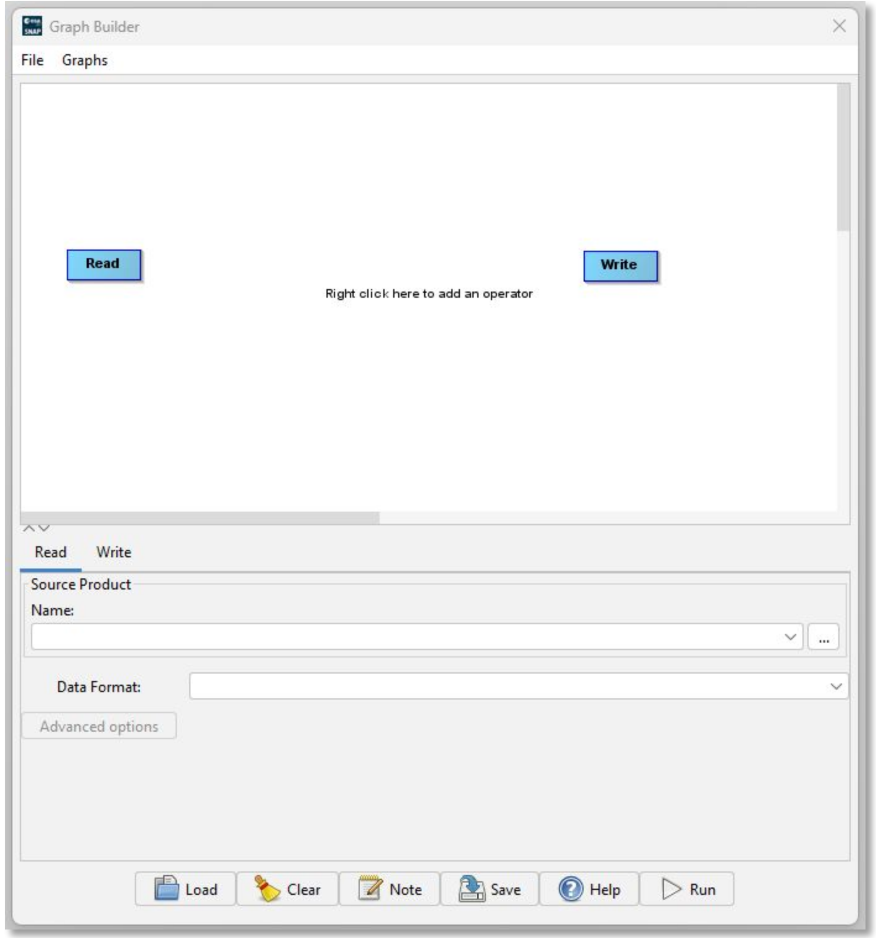
Now, with the shopping cart icon you can add the three scenes to the download section.

In the download tab, you can start the download of the scenes, by clicking on the cloud icon. This will take some time as each scene has between 3 to 5 GB.

So please make also sure that there is enough disk space available on your computer.

2. Processing the scenes in SNAP

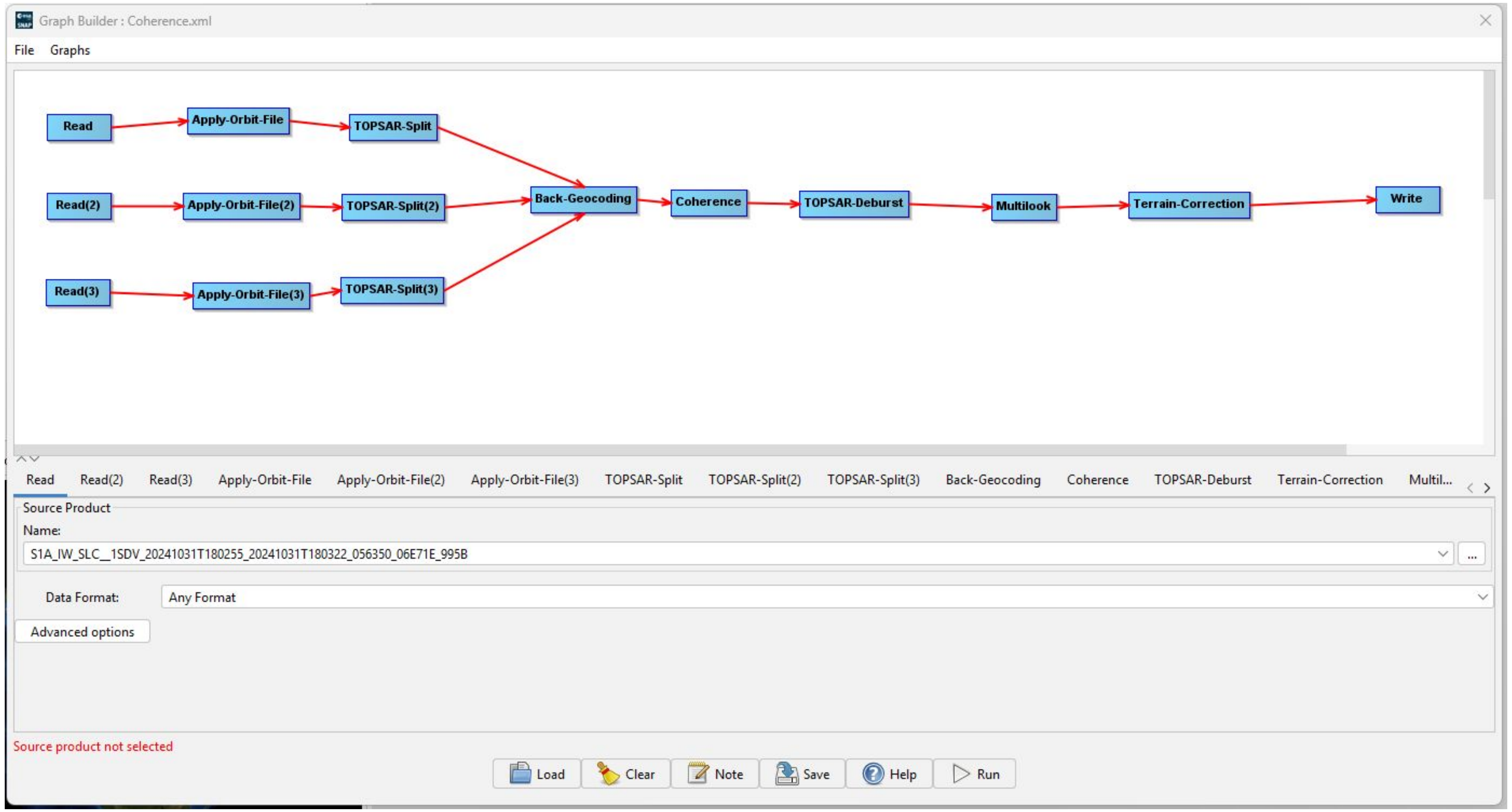
- Drag and Drop the three Scenes (zipped) into the Product Explorer Window in SNAP.
- Click on the Graph Builder tool in the tool bar. On the bottom of the Graph Builder Window, click on „Load“. Browse to the directory, where you stored the Coherence.xml file. Double click to open it.



2. Processing the scenes in SNAP

This is how the loaded Graph should look like. Essentially, this is a **processing pipeline**, for the three input SLC scenes.

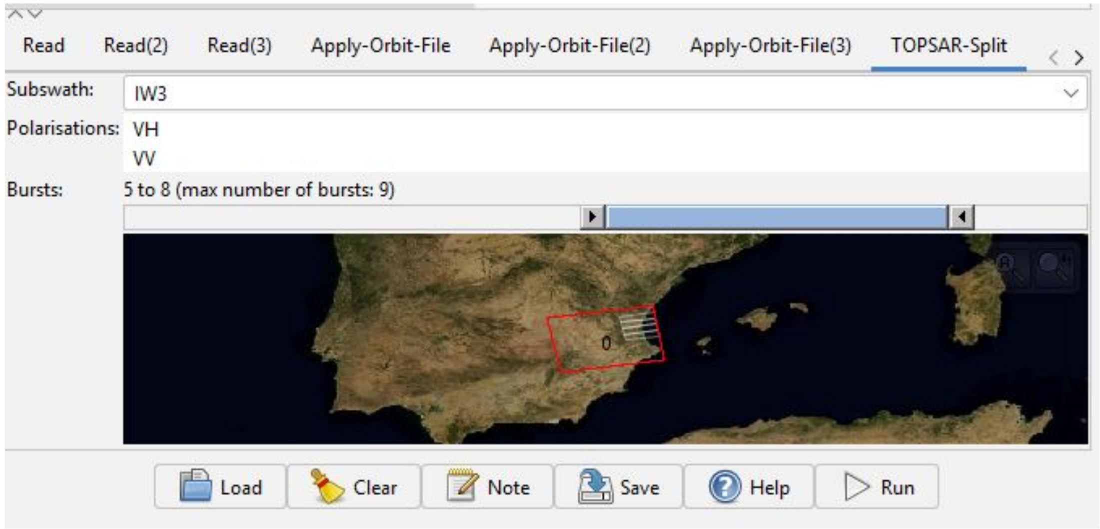
The individual processing steps in the blue boxes can be also found in the normal task bar.



2. Processing the scenes in SNAP

A few things need to be selected manually in the graph window:

1. For the three **Read** tabs, the Sentinel-1 scenes need to be selected. This has to be in the right order:
   - Read = Pre-Event 1
   - Read(2) = Post-Event
   - Read(3) = Pre-Event 2
2. **TOPSAR-Split** Tab, select the Subswath and the bursts. The positioning of the subsets can be seen in the map on the bottom of the window.
   Apply the same selection to all the TOPSAR-Split tabs (2) and (3).



TOPSAR Split (In Detail)

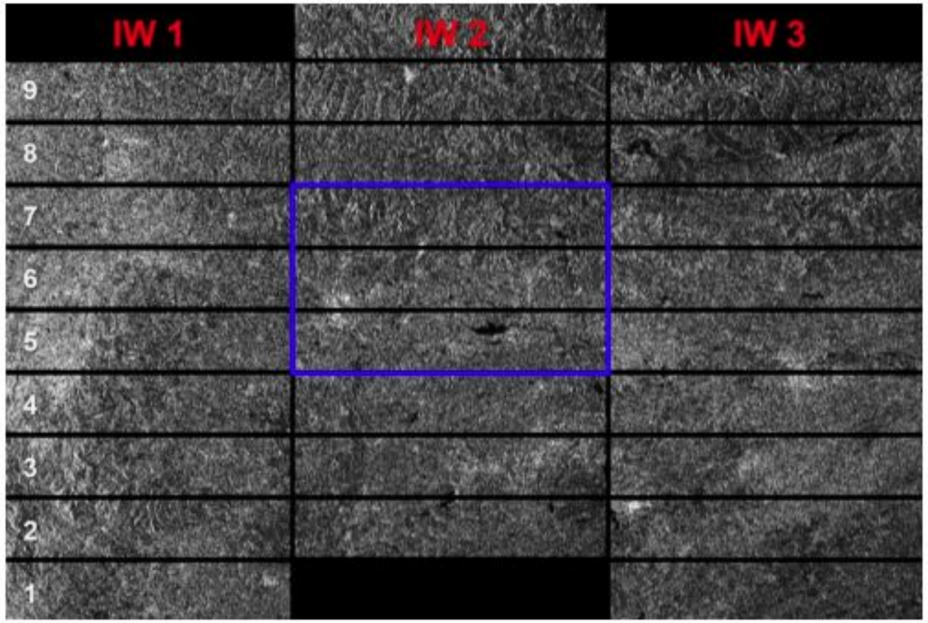


Figure 1: Sub-swaths (red) and bursts (white) of S1 IW products (blue area is used in this tutorial)

https://step.esa.int/docs/tutorials/S1TBX%20TOPSAR%20Interferometry%20with%20Sentinel-1%20Tutorial_v2.pdf

Sentinel-1 scenes, that can be used for interferometry, are captured in three sub-swaths (IW1, IW2, IW3), using Terrain Observation with Progressive Scans SAR (TOPSAR). Each sub-swath image consits of a series of bursts, where each burst is processed as a separate image.

That is why we first split the scene, and later deburst it, i.e. put it back together into one image with the TOPSAR Deburst tool.

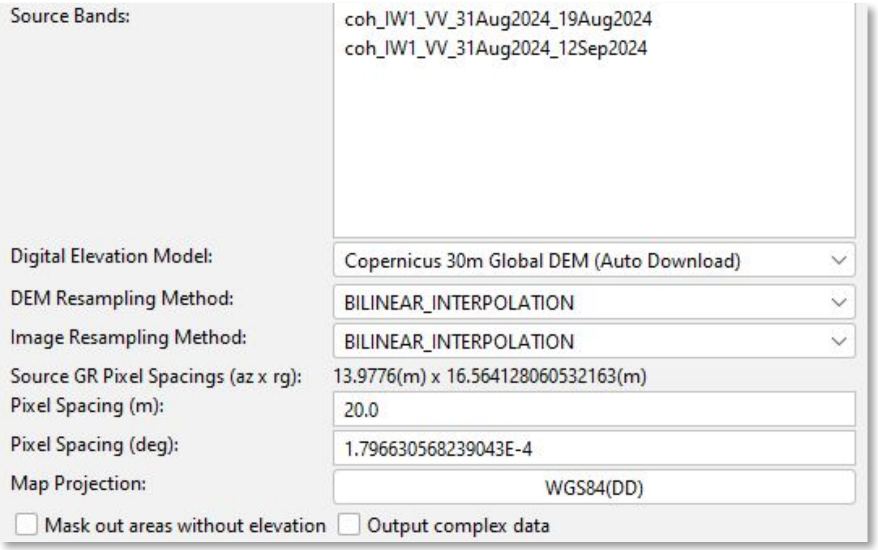
2. Processing the scenes in SNAP

A few things need to be selected manually in the graph window:

3. In the **Terrain-Correction** Tab, you can control the output layers, which should be named:
   - coh_IWx_VV_pre-Event2_pre-Event1
   - coh_IWx_VV_pre-Event2_post-Event

   If you also selected the VH polarization, two more layers will appear with VH instead of VV in their names.

   If the dates are switched, go back to the Read Tabs, and control the selection order described in step 4.



2. Processing the scenes in SNAP

A few things need to be selected manually in the graph window:

4. In the **Write** Tab, select the destination directory, to write the output to.
5. Click on **Run**.

The execution and the calculation of the coherence will take some time. Depending on your computation capacity, it can take up to a few hours.

2. Processing the scenes in SNAP

If the graph does not work, you can also execute the steps individually in SNAP. You will need more storage capacity on your machine for that, as interim products need to be stored after each step.

1. Apply Orbit File (10 min)
2. S-1 TOPS Split (select only VV polarization, up to 3 bursts in one IW swath)
3. Coregistration: S-1 Back Geocoding (DEM: COP-30; uncheck “Mask out areas with no elevation”)
4. Coherence Estimation **(square pixel size?)**
5. Deburst
6. Speckle Filtering (**median filter?**)
7. Terrain Correction (DEM: COP-30, Map projection: Auto UTM, include layover shadow mask as output band)

3. Exporting the Coherence Image

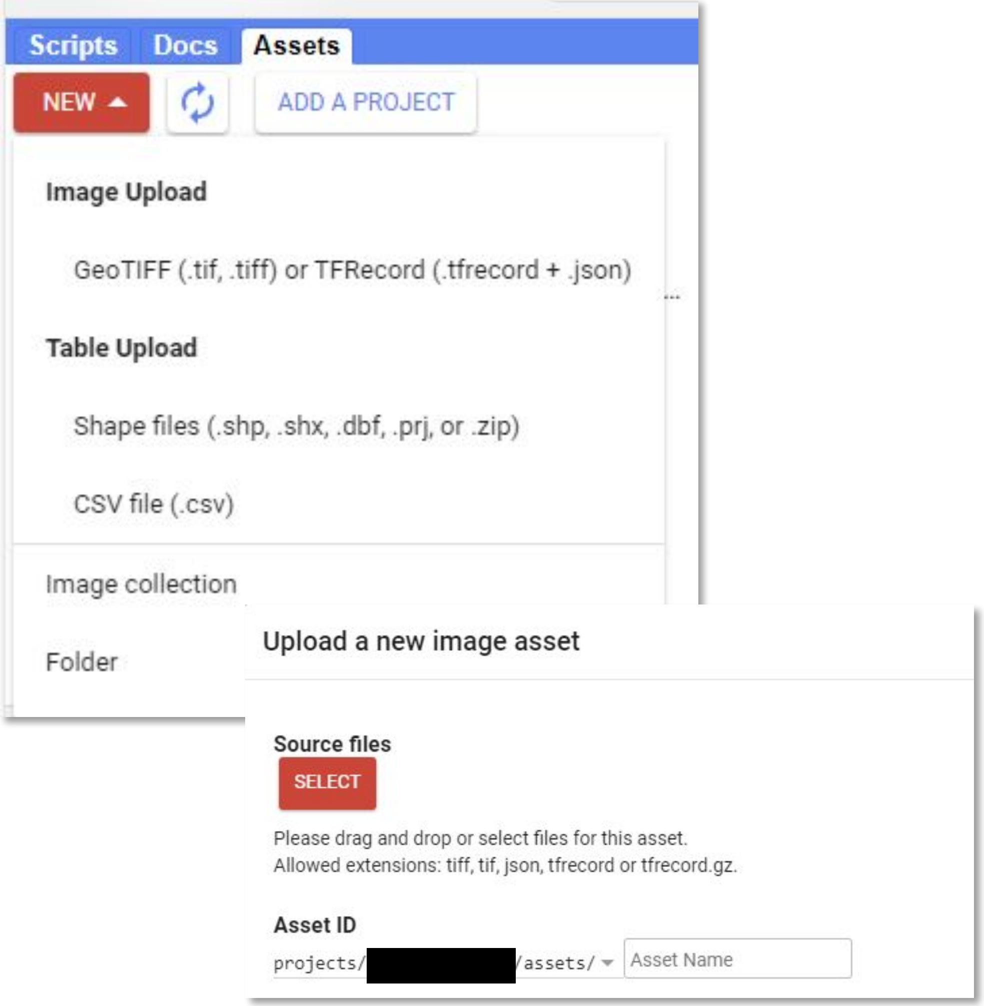
After the processing has finished you can close the graph builder window. In the product explorer window on the left, you will find a new product [4], called

S1A_IW_SLC__1SDV_xxxx_xxxx_xxxx_xxxx_xxxx_Orb_Stack_Coh_Deb_ML_TC

Click on the product, then go to **File** on the Task bar and select **Export**. Select **GeoTIFF**. Choose a directory for your export and click **Export Product**.

4. Import the Coherence Image to Google Earth Engine

- Open the following Google Earth Engine Script:
- In the left panel, go to the Assets Tab, click on the red **NEW** button, under **Image Upload** select “GeoTIFF (.tif,.tiff) or TFRecord (.tfrecord + .json)”.
- Select the exported tif from the previous step, by clicking on SELECT and give a name to the file under **Asset Name**. Click on UPLOAD.
- Under tasks, you will see the upload progressing. Afterwards click on “Run”.



4. Import the Coherence Image to Google Earth Engine

- Under the Assets tab on the left side, you will see your raster under CLOUD ASSETS. If it does not show up, click on the Refresh Icon.
- By hovering above the file, you will see an arrow, by clicking on which, you can import the raster into the script.

5. Change Detection in Urban Areas

In the following, we will discuss the results of the Change Detection performed in the Google Earth Engine at the hand of the example of the flooding in Valencia.

The script will generate multiple layers:

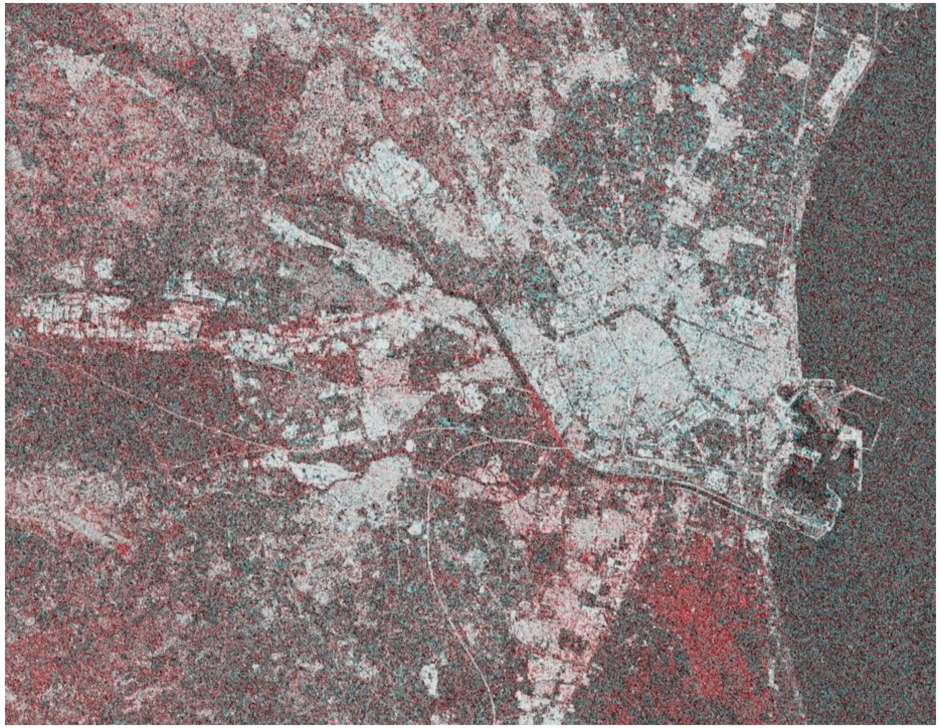
1. RGB visualization of the pre and post coherence image
2. The coherence difference between the pre and post image in a moving window
3. The thresholded coherence difference image, visualizing affected areas in blue and intact areas in white

```
Coherence Difference in Moving window:
Tile error: Reprojection output too large
(13626x13772 pixels).
```

5. Change Detection in Urban Areas

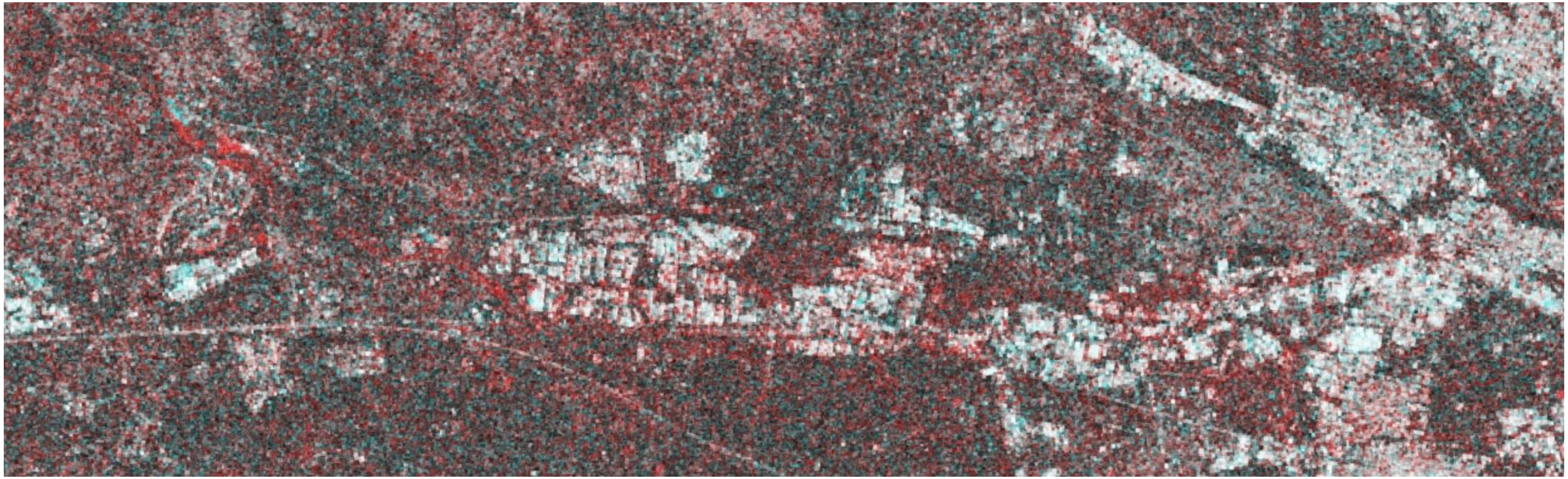
This is an RGB visualization of the pre and post event coherence. With R = Pre-Event and G = B = Post-Event Coherence. That means, that affected areas appear in red, as post-event Coherence < pre-event coherence. Whereas stable areas (i.e. no change) appear in white to bluish.

Besides there is also a lot of space in the image, where red blue and black pixel neighbor each other, i.e. there is a lot of noise and no clear coherence signal. This is the case over vegetated areas like agricultural fields. Nonetheless urban fabric (houses, roads, the harbor) emerge well from the surrounding fabric.



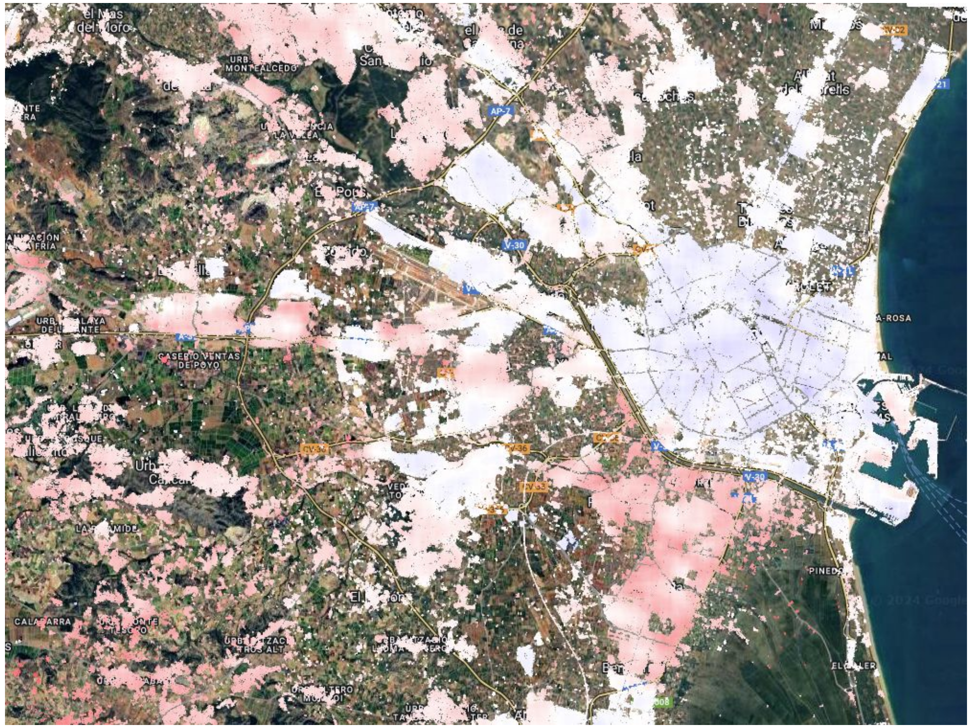
5. Change Detection in Urban Areas

In this part of the Coherence Change image, you can see the urban areas in bright colors. There is also a red line stretching from the upper left part of the image to the lower right part. This is a river, which overflowed during the flood, damaging the areas in the neighborhood.



5. Change Detection in Urban Areas

What is done now in the GEE script, is that all pixels apart from urban settlement are masked out. On the remaining area the **difference between the pre and post coherence** image is calculated. To smooth the image, a moving window is applied to the difference image, which we will now refer to as coherence difference.



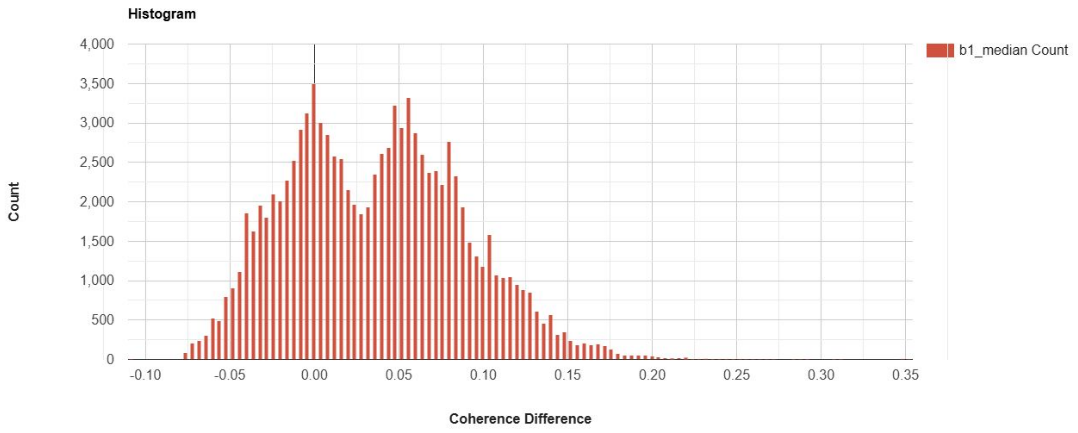
5. Change Detection in Urban Areas

Thresholding the Coherence Change image:

The GEE code will produce a histogram of the observed coherence difference in the console on the right. By clicking on the arrow, you can open it in a new window and analyze the values by hovering above the bars.

In the best case, the distribution should be bimodal, as in the example. We are looking for high positive changes, i.e. hotspots, which are affected the most by flooding.

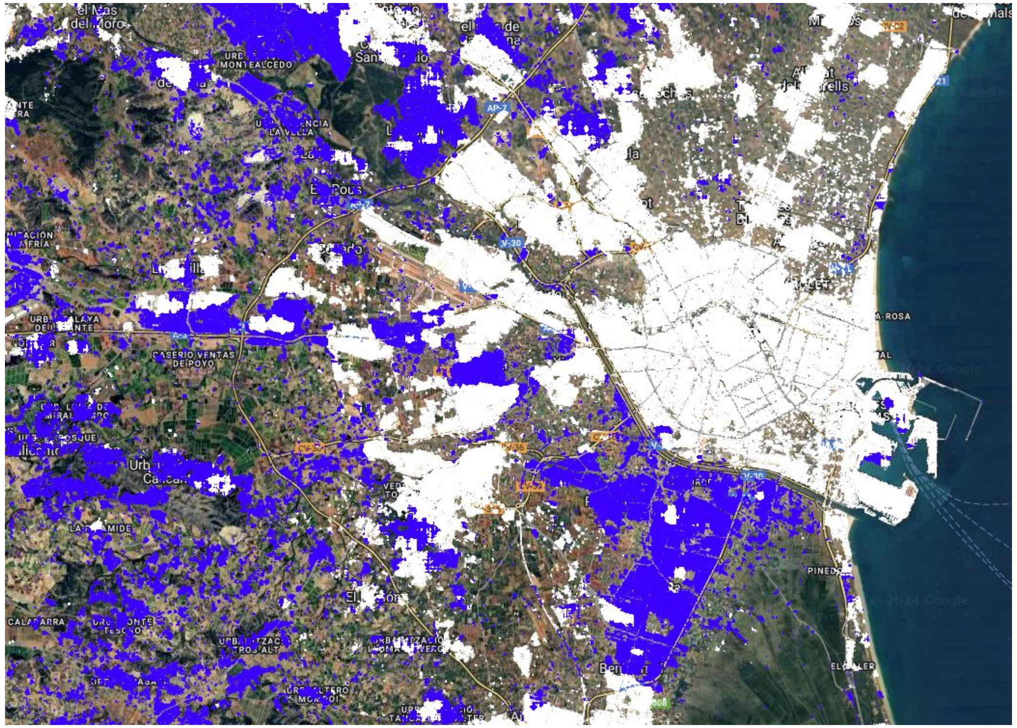
The values around 0 belong to areas, that did not experience significant change. In this example, we would select a threshold of 0.04 to map the high positive changes.



5. Change Detection in Urban Areas

Thresholding the Coherence Change image:

Now, the threshold is applied to the moving window coherence change image. All urban areas with a higher difference than the set threshold will be visualized in blue. These areas are expected to are damaged/flooded.



blue: damaged/flooded urban fabric,

white: not damaged urban fabric

References

Pelich, Ramona; Chini, Marco; Hostache, Renaud; Matgen, Patrick; Pulvirenti, Luca; Pierdicca, Nazzareno (2022): Mapping Floods in Urban Areas From Dual-Polarization InSAR Coherence Data. In *IEEE Geosci. Remote Sensing Lett.* 19, pp. 1–5. DOI: 10.1109/LGRS.2021.3110132.