UNIVERSITY OF SCIENCE AND TECHNOLOGY OF HANOI

DEPARTMENT OF SPACE AND APPLICATIONS

MONITORING NATURAL DISASTER BY USING SATELLITE DATA

LECTURER: DR. PHAM DUC BINH

Classwork and Final Exam Report

Nguyen Quang Huy
22BI13197

Duong Thu Phuong
22BI13362

March 31, 2025

Contents

List of Figures

1 Tropical cyclones

1.1 GDACS

Before we want to investigate further a tropical cyclone, first we have to know basic information of it, what categories it is, when did it form, etc...

Link to the page: Global Disaster Alert and Coordinate System

To select a particular disaster, we go to alert section, selection which disaster we want to observe, the time period, the level, severity and country of its impact

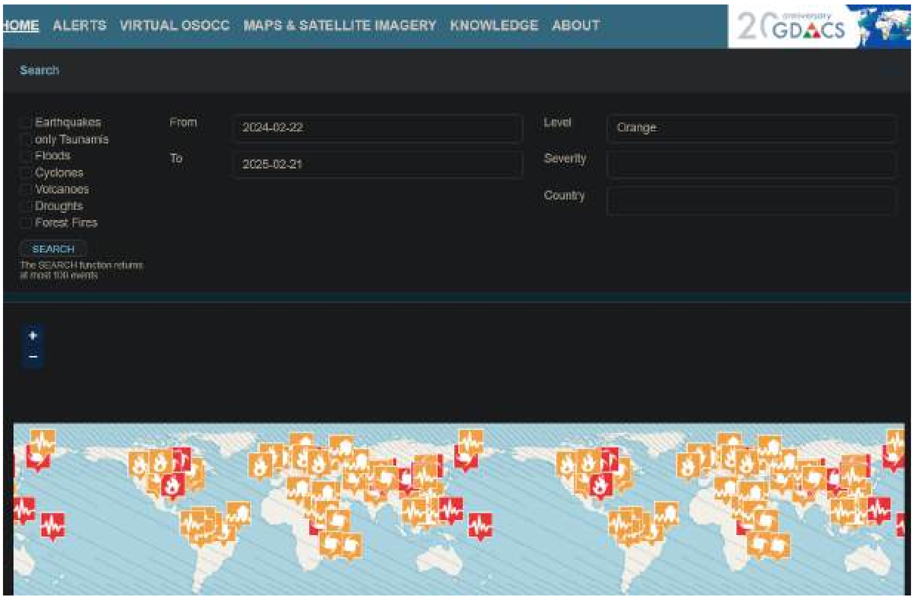

Figure 1: GDACS disaster finding

In this excercise, we chose Yinxing-24 as our cyclone to observe: Yinxing-24 report

1.2 NASA worldview

After selecting the storm we want to observe, in this example we use Yinxing-24, we will use data from satellites to reanimate the formation and the path of the cyclone

Link to the page: NASA worldview

This is a free website for everyone to extract data from satellites. One key feature from this website is NASA's Integrated Multi-satellitE Retrievals for GPM (IMERG) which is useful for observing the whole world due to the combination of many satellites at different part of the globe to one constellation to estimate precipitation over the majority of the Earth's surface. So that we can collect data anywhere anytime we want.

For this example, we use some layers:

1 MODIS to show the true color of the Earth from the satellite

2 GPM to show the precipitation rate

3 IMERG to merge pictures of different satellites to get one whole picture

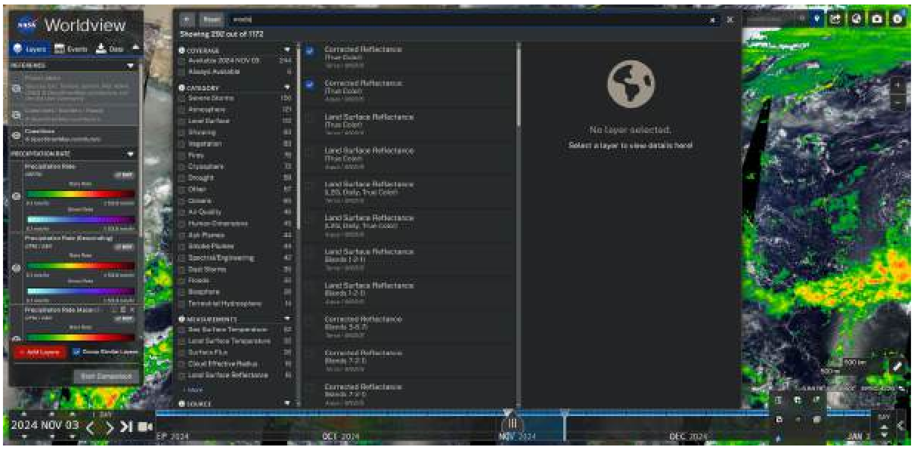

Figure 2: Moderate Resolution Imaging Spectroradiometer

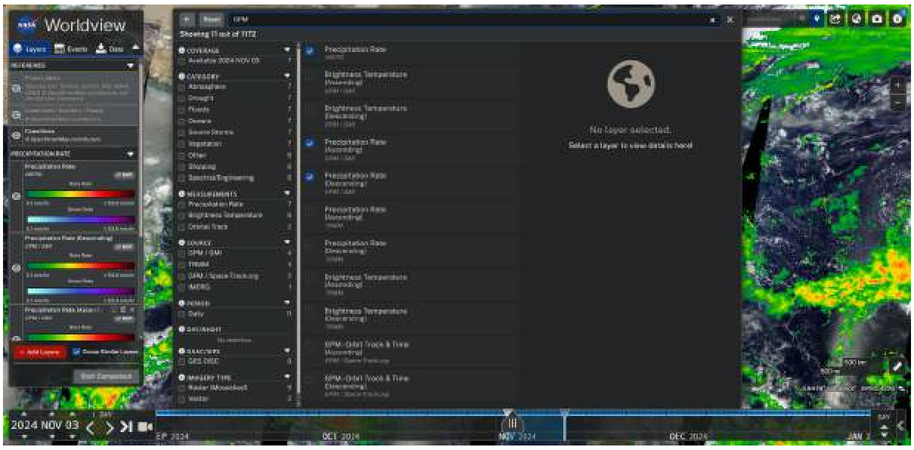

Figure 3: Global Precipitation Measurement

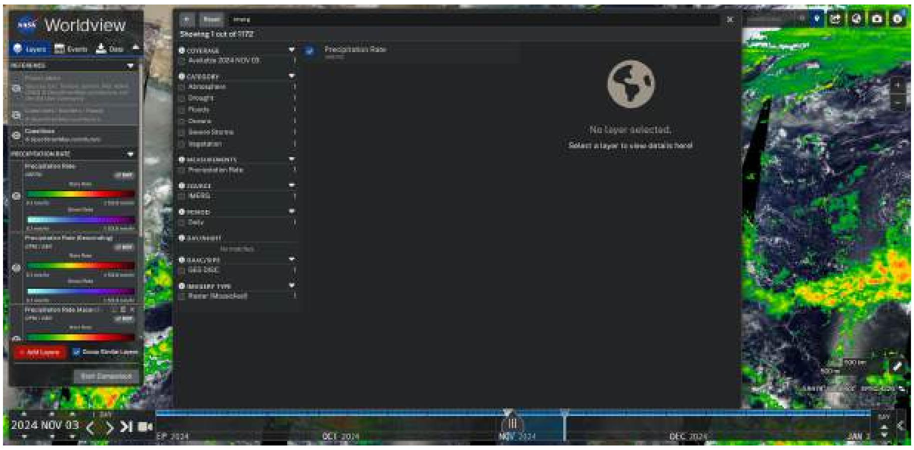

Figure 4: Integrated Multi-satellitE Retrievals for GPM

Yinxing-24 animation link

1.3 Giovani

Beside animation, we can get images from other sources such as Giovani

The difference between Giovani and NASA worldview is Giovani leans to real-time alerts and humanitarian responses through integrated data analysis whereas NASA focuses on detailed satellite observations to enhance scientific understanding of cyclone dynamics.

Yinxing-24 animation link

1.4 Discussion

All the websites above are free and resourceful, all we need is just an account to download the data we need.

2 Mapping a flood using Optical Sentinel-2 Imagery

2.1 Steps

Resampling

The images we imported have all 13 bands with different spatial resolutions from 10m, 20m to 60m.

We need to resample them into the same resolution for further calculations.

In this example, we use band 3 and band 11 for NDVI, and band 3 has a spatial resolution of 10 m. So we resample to 10 m.

Mosaic

We have here are 3 region images of 1 same place. We need to commbine them together to make a whole image

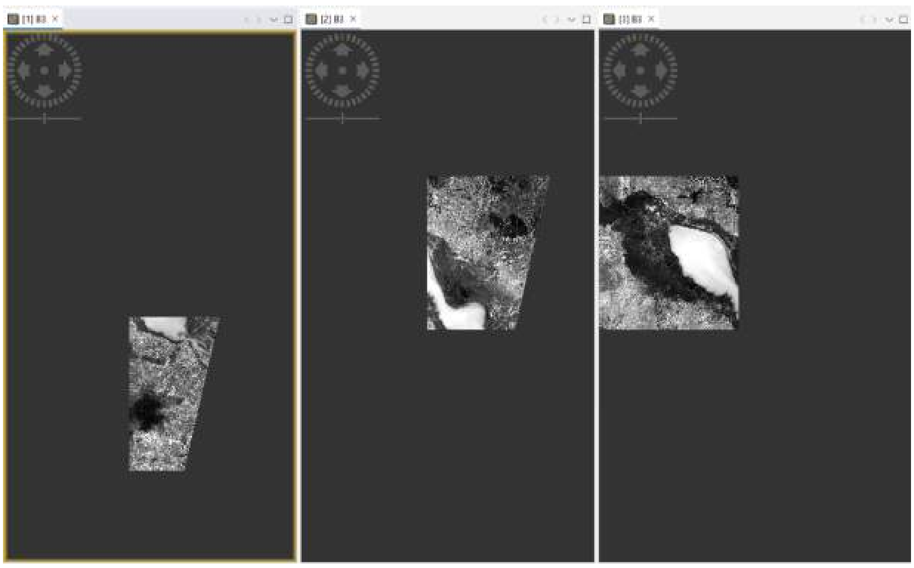

Figure 5: Images of different region of Tonle Sap Lake

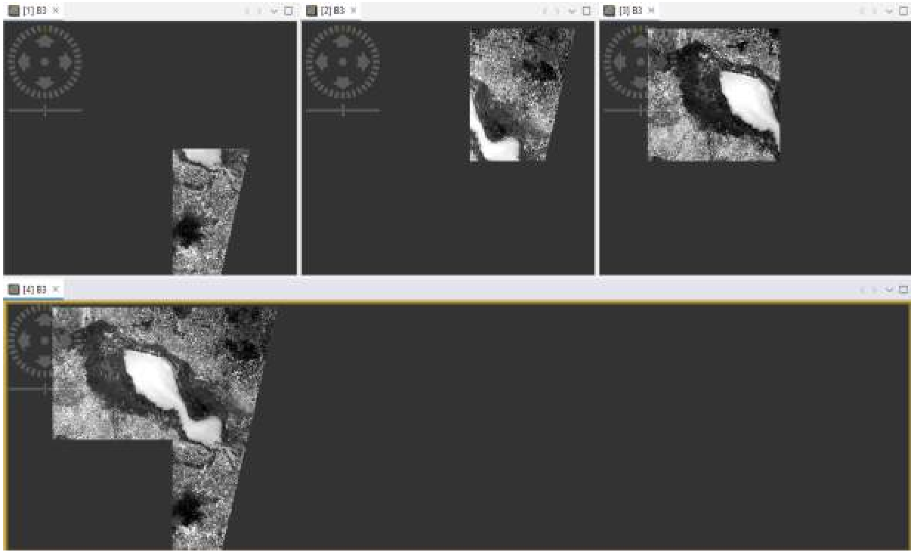

Figure 6: A mosaic picture of Tonle Sap Lake

Then we add MNDWI, an index to indicate the water. This index's is using 2 different band with the highest constrast so we can make the object we want brighter than the background. In this case, we use the Green band and SWIR band.

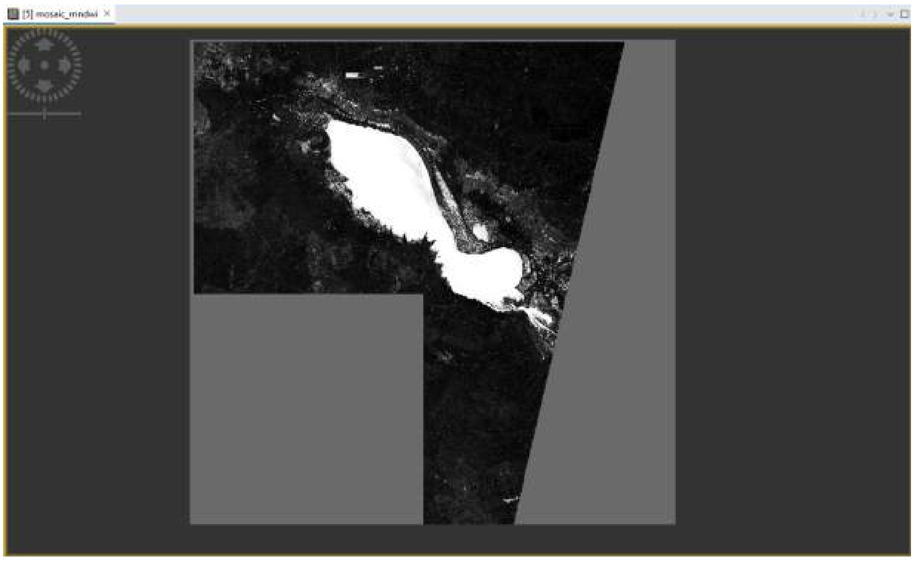

Figure 7: MNDWI

After that, we add expression to only show the pixels that contain MNDWI value and project it on Google Earth Pro.

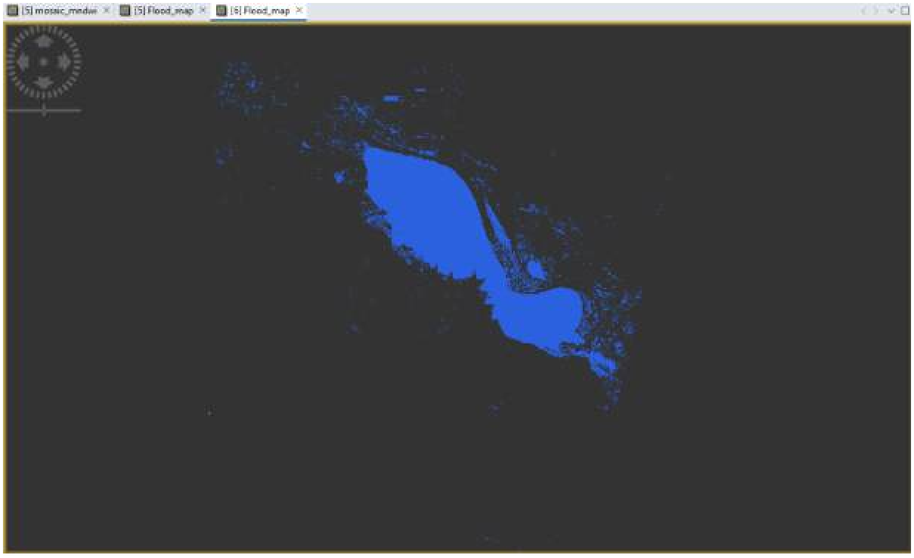

Figure 8: Highlight MNDWI

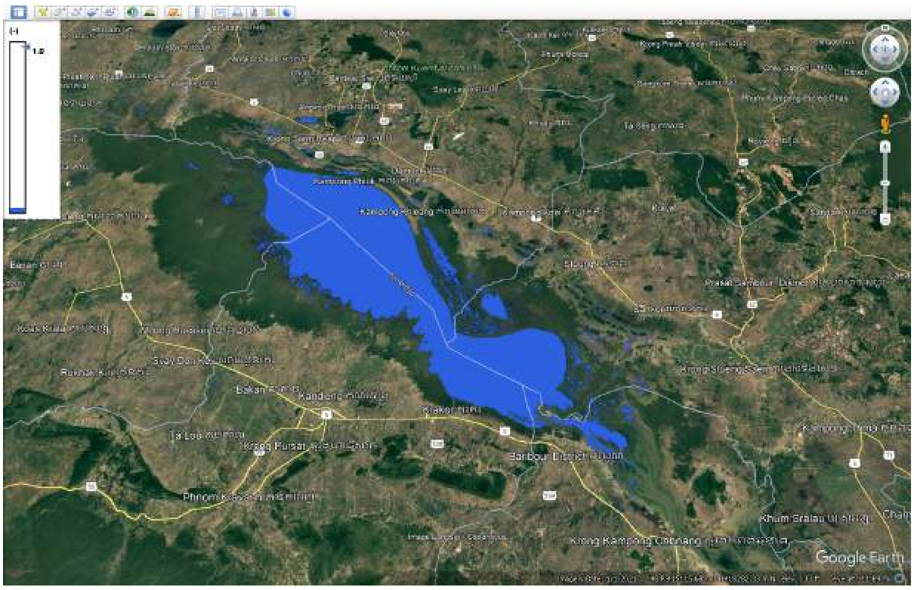

Figure 9: Google Earth Pro view

2.2 Discussion

This method is only useful for cloud-free data. And only available during the day.

Optical remote sensing has been used for dynamic flood monitoring based on the low reflectance of water in the infrared bands and high reflectance in the blue/green bands.

3 Mapping a flood using SAR Sentinel-1 Imagery

3.1 Steps

To use SAR Imagery, we usually compared two images before and after the event to see the differences. But for this excercise, we only use 1 image.

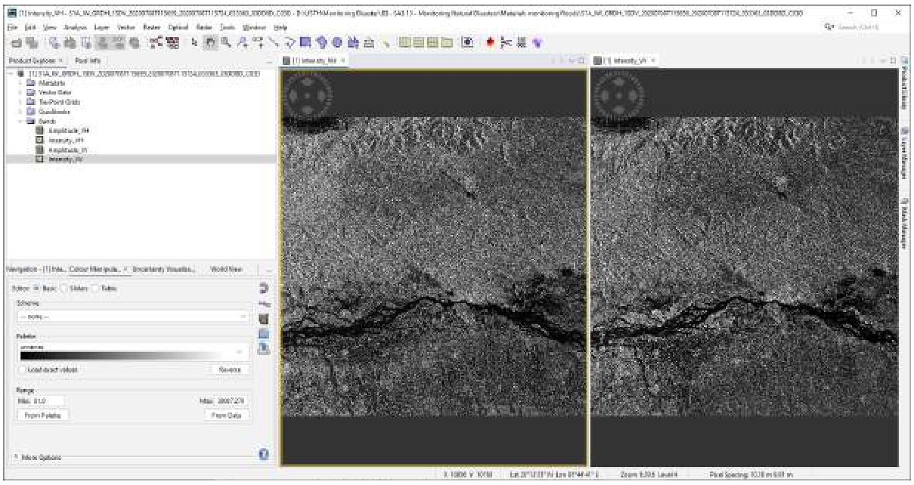

Figure 10: VH and VV polarizations

Then we chose a threshold to represent flood, in this case, we chose -20dB.

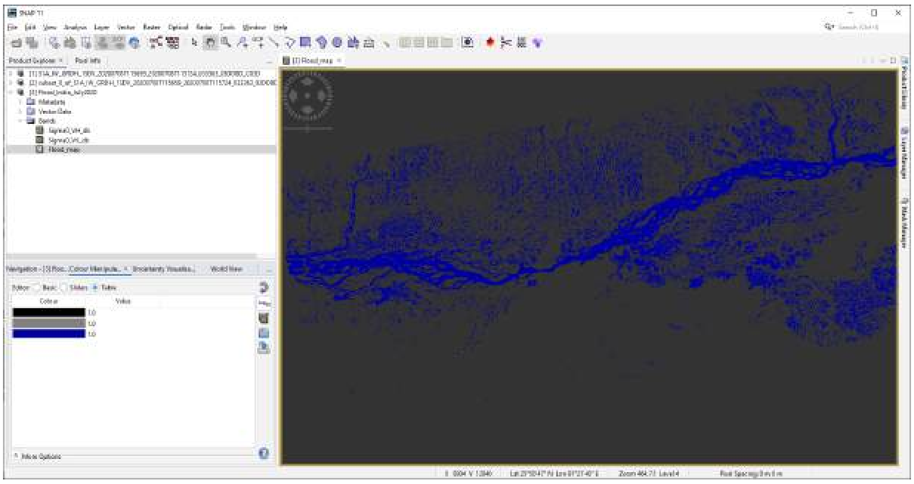

Figure 11: Flood map with threshold ¿ -20dB

And this is the view from Google Earth Pro.

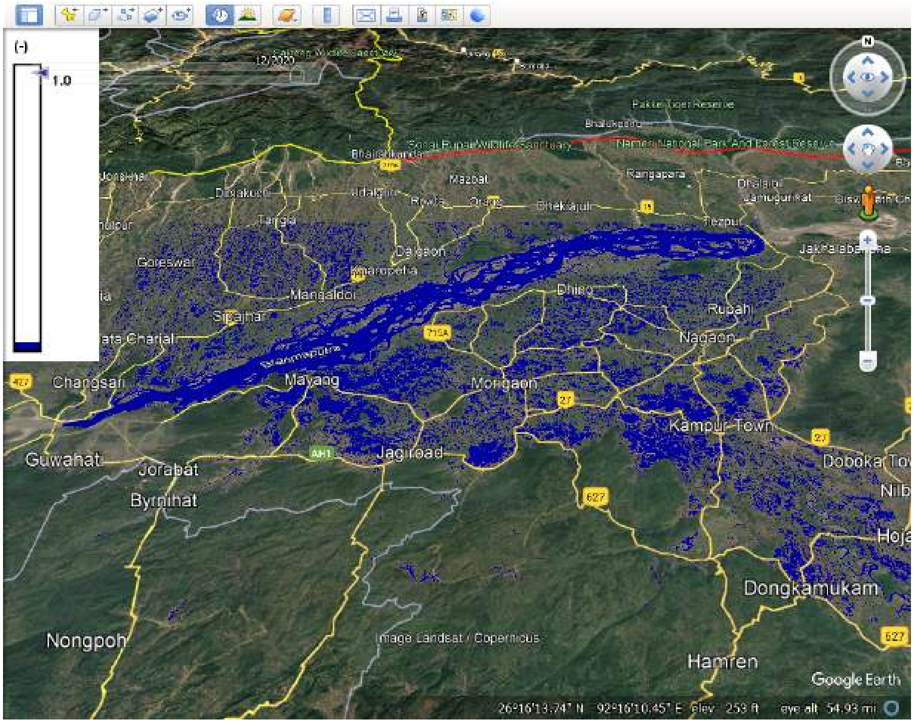

Figure 12: Flood map Google Earth Pro view

3.2 Discussion

The threshold for water can be adjusted for better representation of flood. There is a big difference between flood in the urban and rural area. We have to consider each scenario for the best suitable threshold.

4 Monitoring wildfire with satellite observation

4.1 Steps

First, we open 2 pictures of the event, one before and one after.

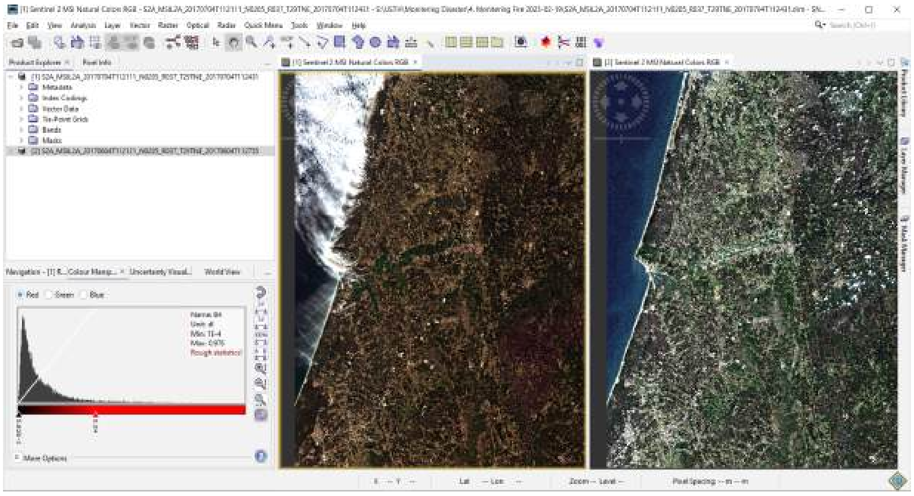

Figure 13: After and Before a wildfire in true color

We are using true color bands, the image of the after event is quite hard to see, so we switch to another combination of bands (B12 for Red, B11 for Green, B8A for Blue).

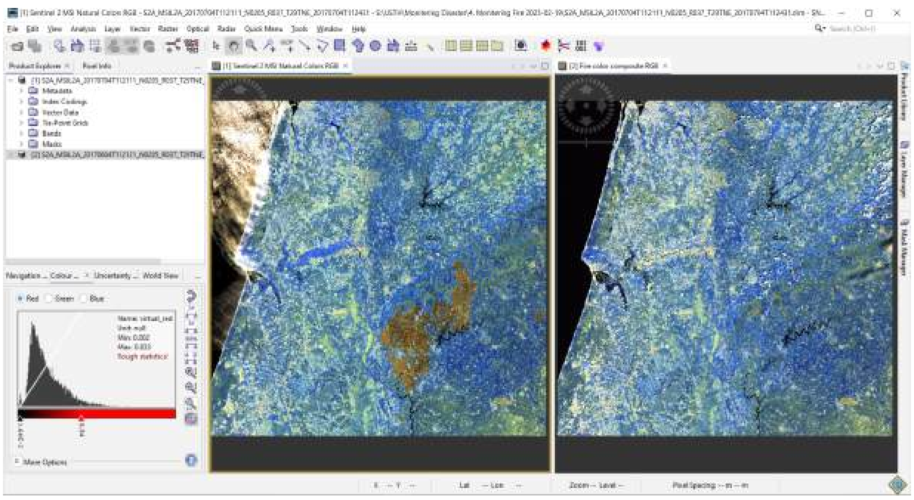

Figure 14: New combination of bands

With this combination, we can see exactly where the fire was. Then we create a cloud mask to hide out the cloud in both images.

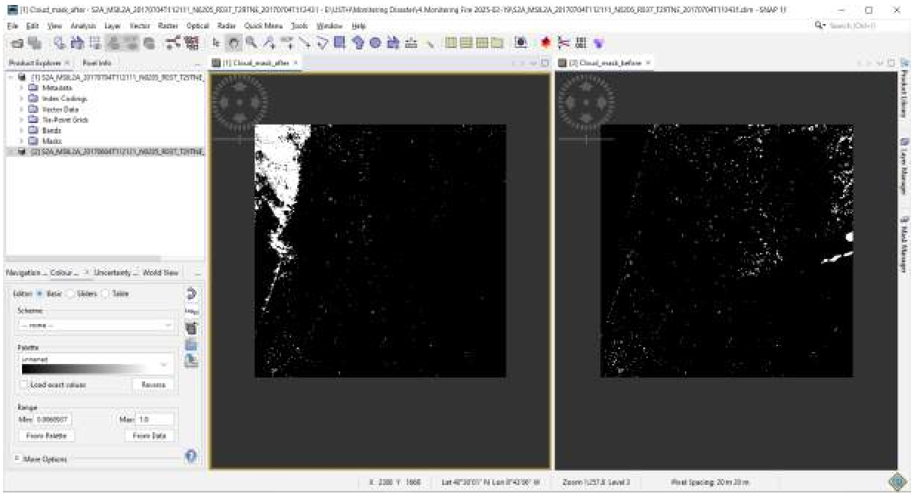

Figure 15: Cloud mask

After that, we use a sequence of processing steps to enhance our images.

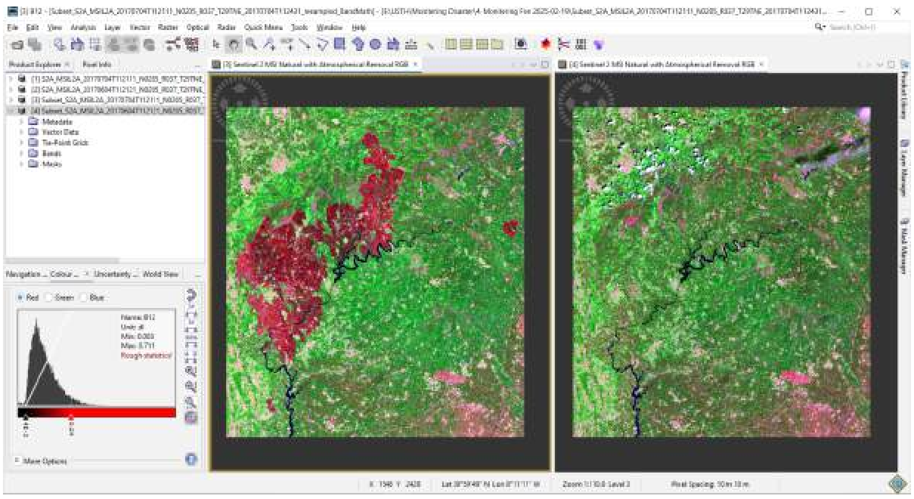

Figure 16: Asmostpherical removal images After and Before

Then we use an index called Normalized Burn Ratio to show the burned area with the best contrast.

$$NBR = \frac{NIR - SWIR}{NIR + SWIR} \tag{1}$$

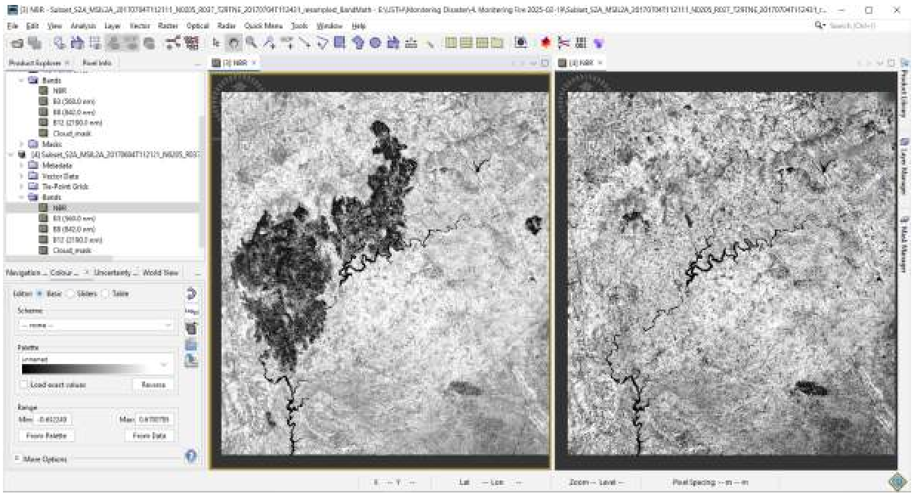

Figure 17: Normalized Burn Ratio

In some cases, the burned area has water body near it, and some burned vegetations fall into it, so we use Normalized Difference Water Index to exclude them.

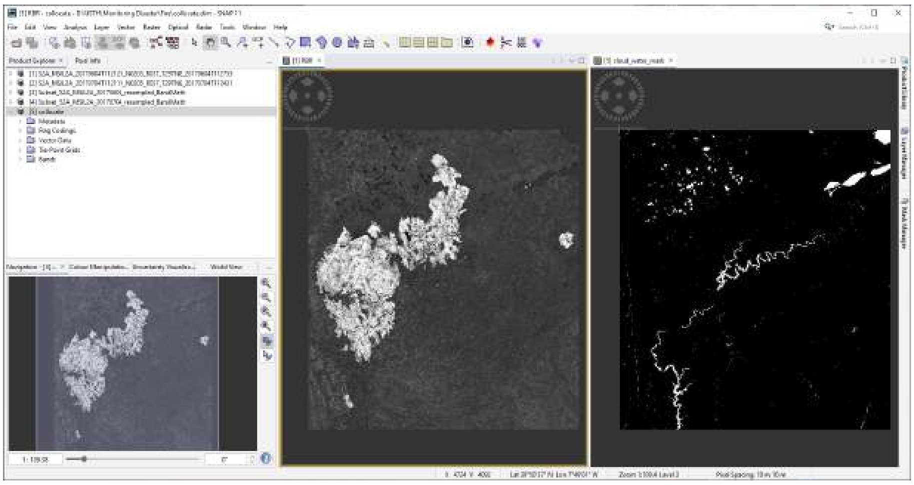

Figure 18: RBR and cloud mask

Finally, we put a threshold for Relativized Burn Ratio to get the burned area (0.27 in this case).

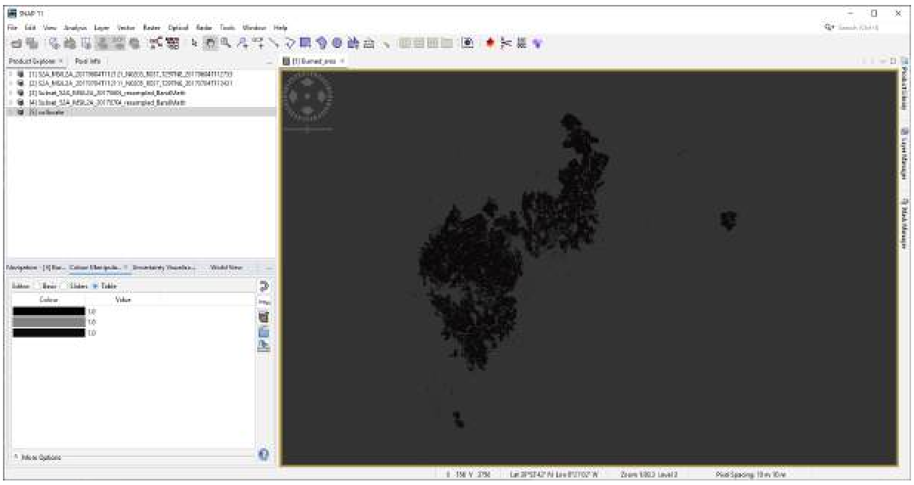

Figure 19: Burned area

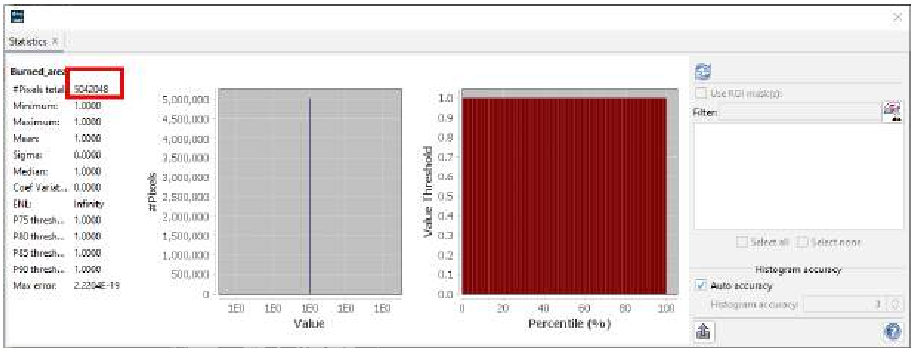

Figure 21: Burned area statistic

And on Google Earth Pro view:

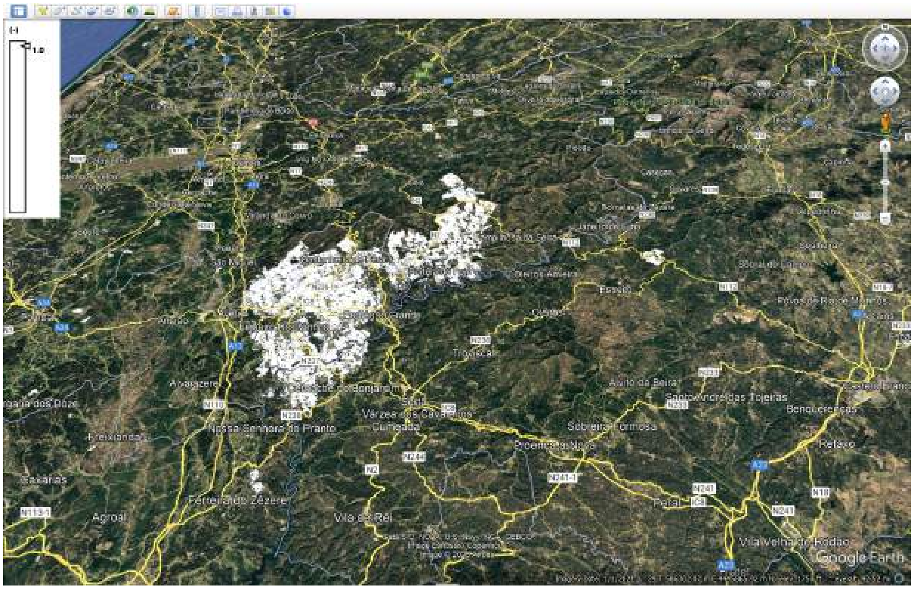

Figure 20: Burned area view from Google Earth Pro

The area of wildfire with the RBR equals to 0.27 is:

$$5,042,048 \times 10m \times 10m = 504,204,800\ m^2 \approx 504.20\ km^2 \tag{2}$$

4.2 Discussion

Depend on the threshold we put at RBR, we can get the area of the burned area. So we have to take into account the acceptable threshold.

5 Oil spills

5.1 Steps

To observe oil spill using SAR Imagery, we have to use VV polarization because it gives us the best contrast of oil and sea on the image.

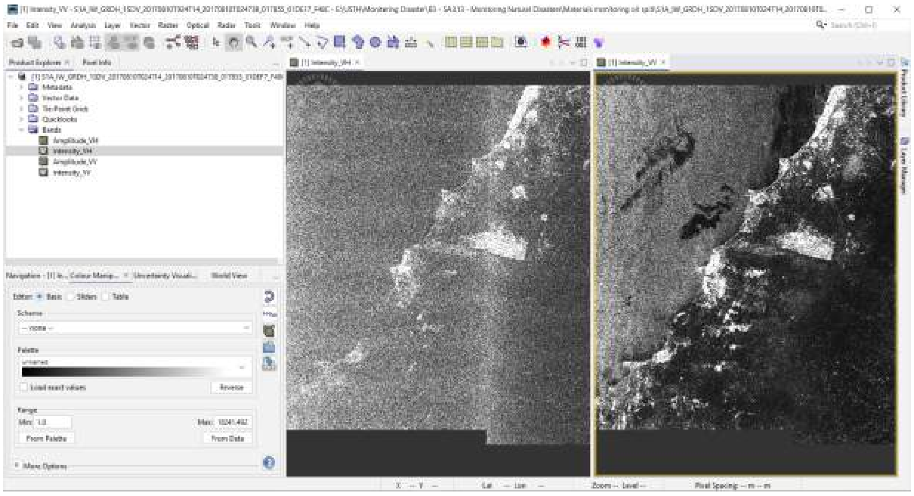

Figure 22: VH and VV polarization

After we have determined the area we going to observe, we will create a subset to reduce the data we have to process and enlarge the area we need.

For the scope of this example, we only focus on the middle area. And only choose the VV in band subset to reduce have the time to process.

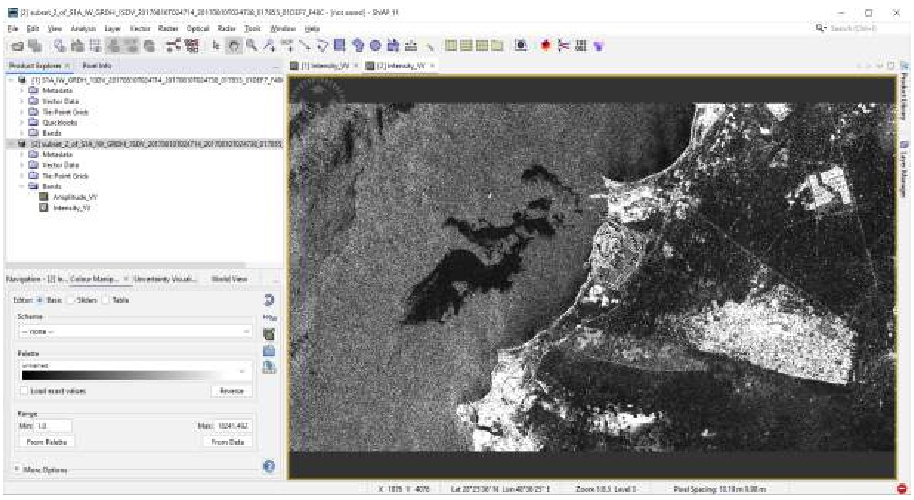

Figure 23: Subset of the area

Next, we use a speckle filter to reduce the noise and smooth the image.

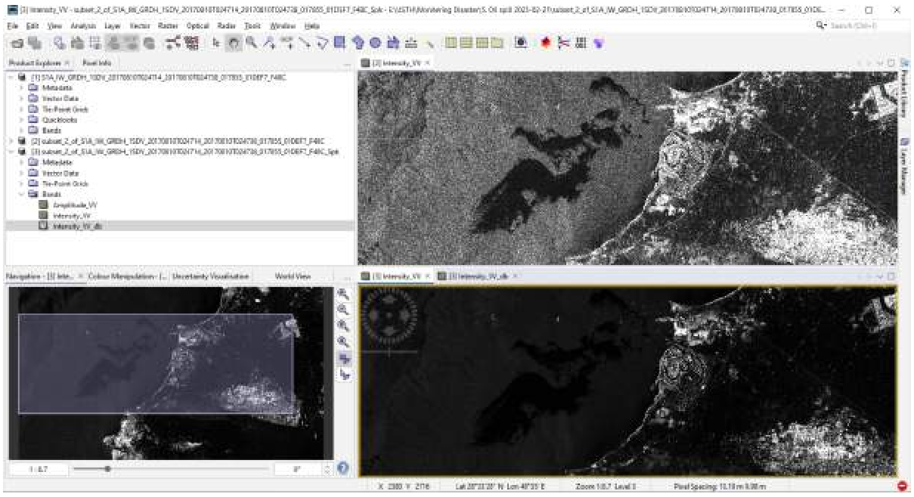

Figure 24: Before and after speckle filtering

For the image to be better highlighted, we have to make the oil to be more contrast than the sea, by changing intensity into dB.

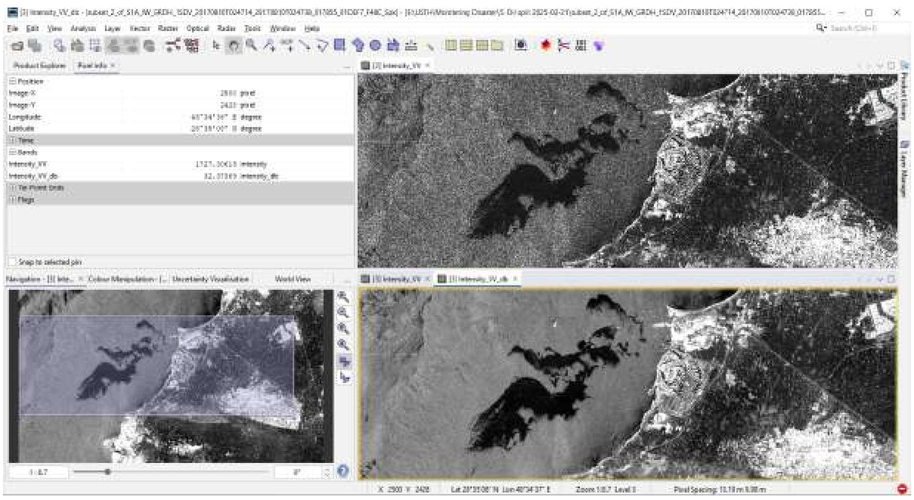

Figure 25: Linear to dB

Before we detect the oil spill, first we have to define the threshold for the image to be separate between the sea and the oil.

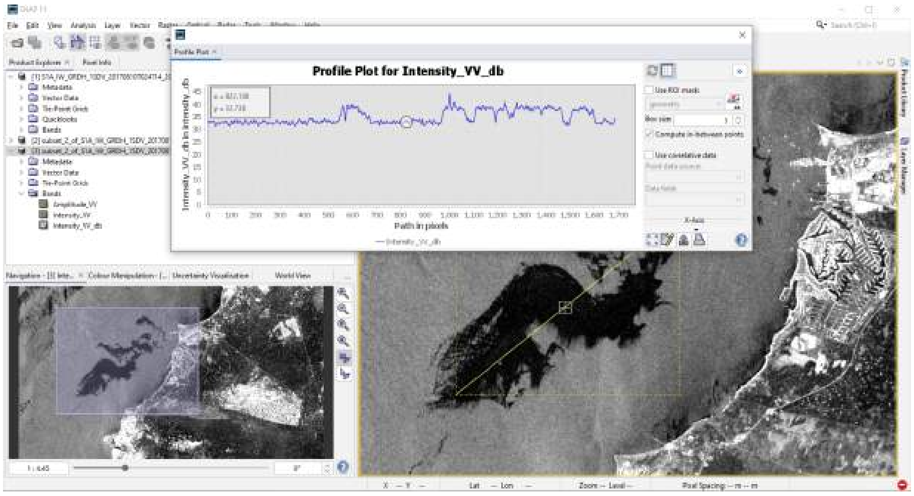

Figure 26: The oil threshold is approximately at 33 dB

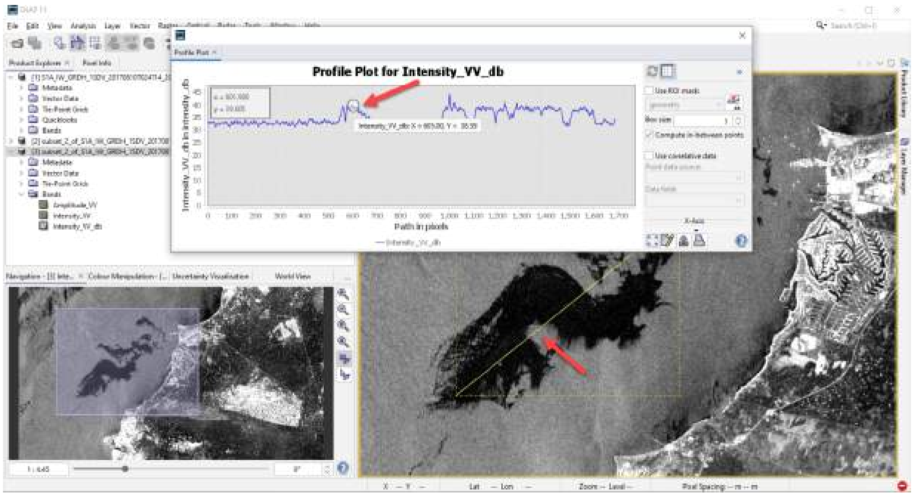

Figure 27: The seawater threshold is at 37 dB

After using the tool in SNAP and running for an extended time, we got this layer of oil.

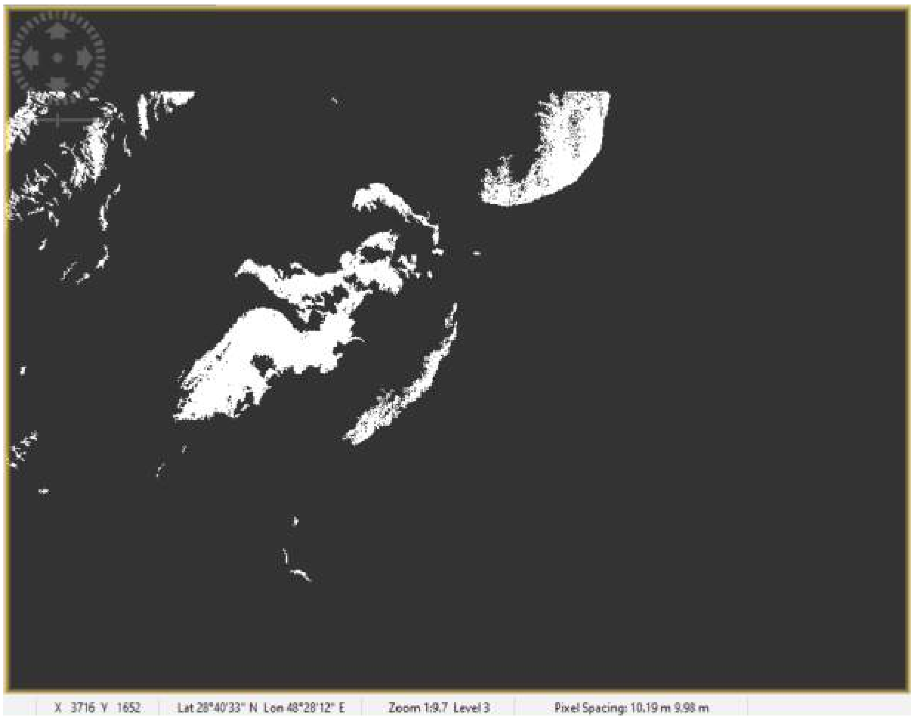

Figure 28: Oil mask

In this mask, we can't distinguish false oil mask from the right one without any other information.

Combining with other data sources, field trip observation, etc... to conclude the area we observe.

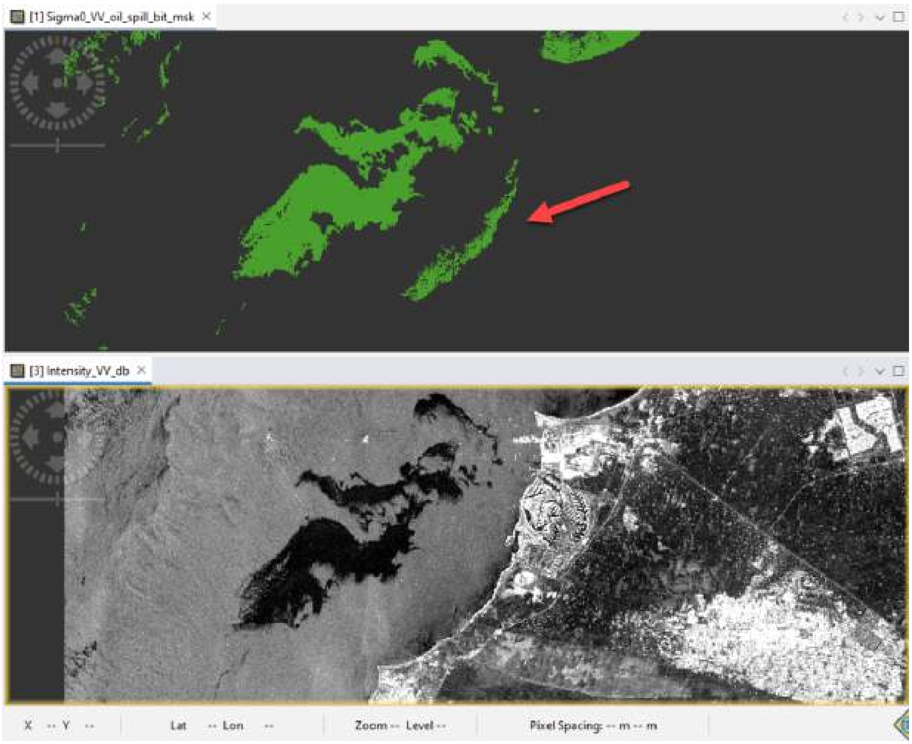

Figure 29: Oil mask

From this we can consider only the middle part is the oil.

Apply a mask and band math with the oil to get the main area.

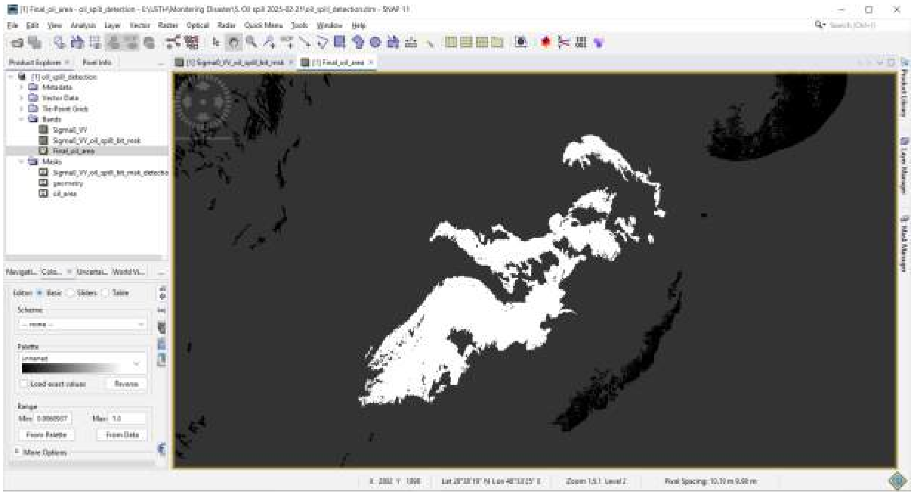

Figure 30: Final oil area

Consider the statistic of the area:

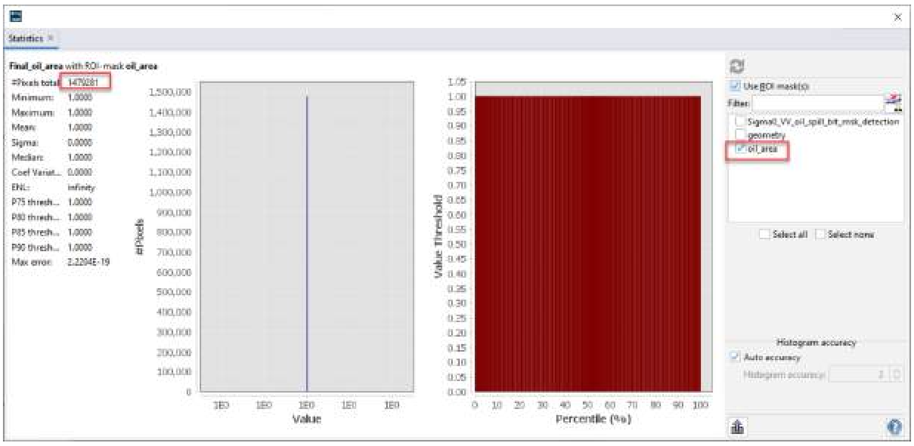

Figure 31: Oil area in pixels

The total area through this method is:

$$1,479,281 \times 10.19m \times 9.98m = 150,437,256.4\ m^2 \approx 150.44\ km^2 \tag{3}$$

Apply Geolocation grid to for correction and export to Google Earth file, we get this:

Figure 32: Before

Figure 33: After

Another way to observe an oil spill is to have 2 images before and after the event.

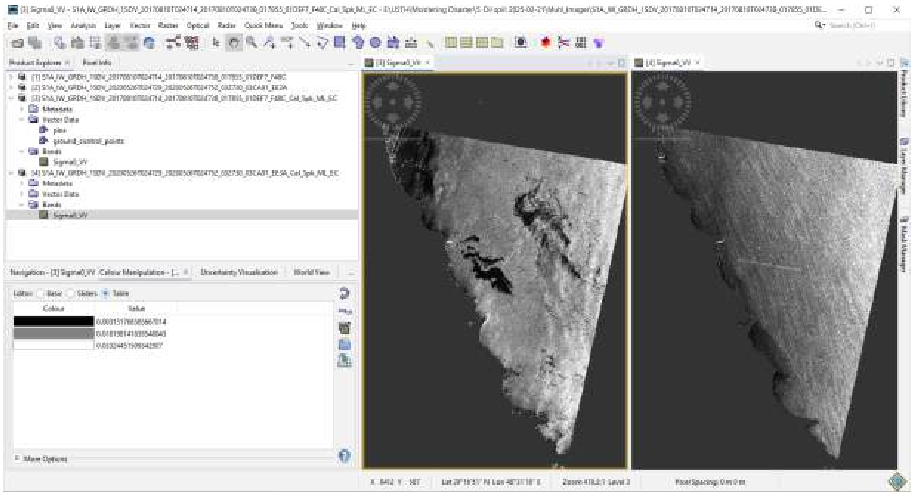

Figure 34: Before and After oil spill

Then we created stacks of 2 layers of the images on top each other to create 1 single product; after that, we converted it into dB.

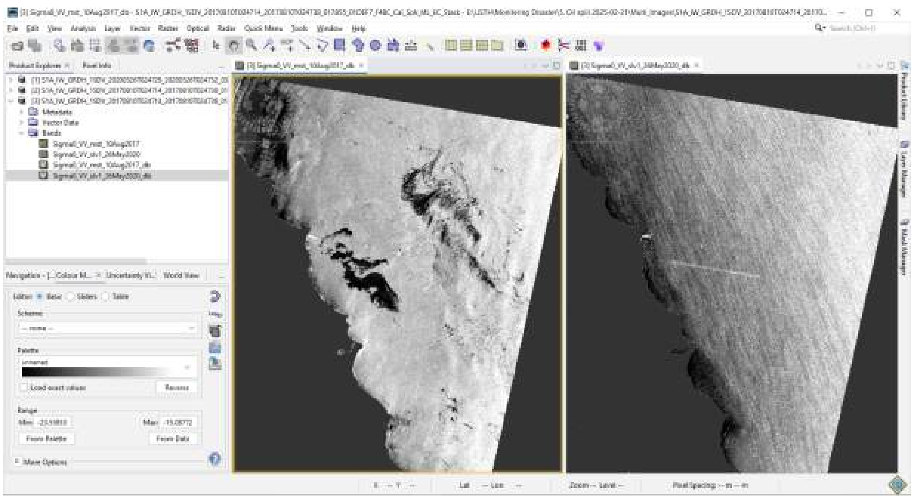

Figure 35: Images in dB

We averaged out the slave band (2020) to reduce noise then created a band math to calculate the oil mask; in this case, we chose -7dB.

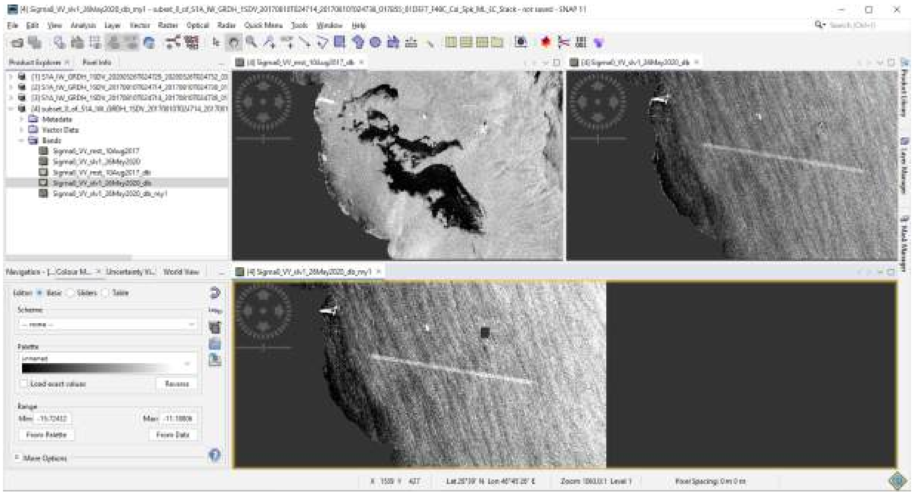

Figure 36: Filter noise

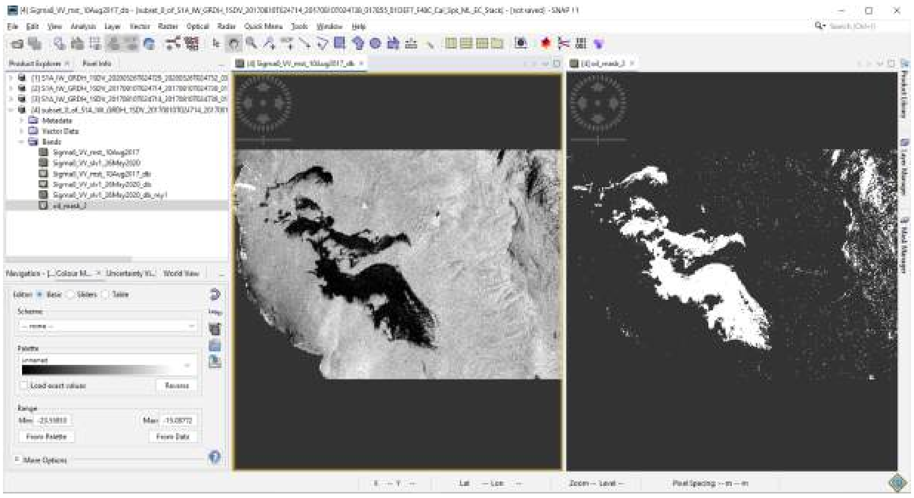

Figure 37: Oil mask

Finally, we got this area of oil.

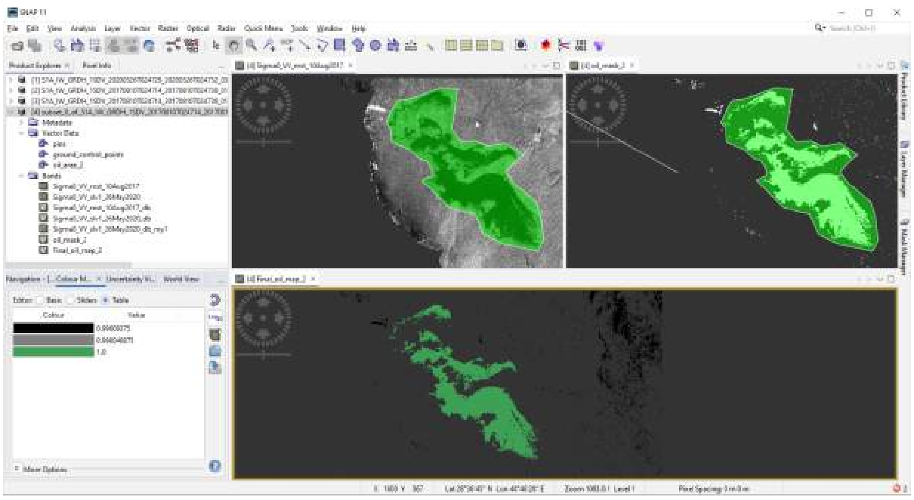

Figure 38: Final oil map 2

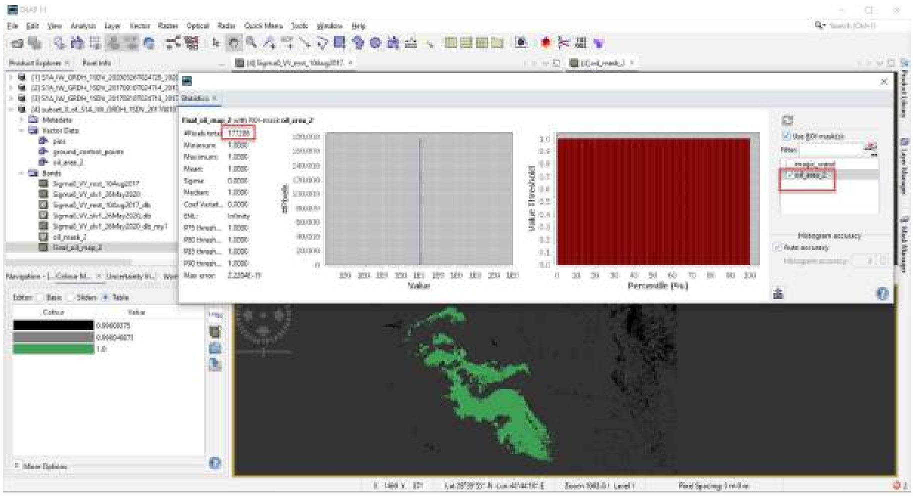

Figure 39: Statistic

The oil area with this method is:

$$177,286 \times 30m \times 30m = 159,557,400\ m^2 \approx 160\ km^2 \tag{4}$$

Stack 2 images of oil area on top of each other, we got this.

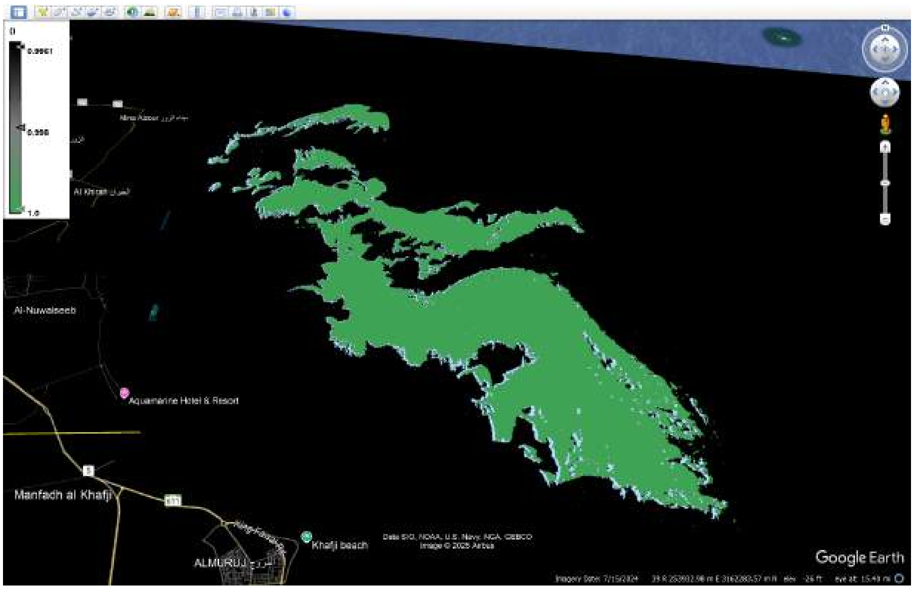

Figure 40: 2 oil areas

5.2 Discussion

The differences are due to the tools that we used in SNAP to process and the threshold that we chose. We should use another source to confirm our results. But these 2 independent methods showing similar results can tell us that the accuracy of those are high and reliable.

6 Earthquake

6.1 Steps

To observe an earthquake, we need 2 images of the event with the closest period as possible, 1 before and 1 after.

The data we get from satellite to observe earthquake are different then previous disater. They have a different mode to scan and collect data, in this case is stripmap SAR, which produces 3 Integrated Waveform, from there we also have to choose burst (horizontal strip) of the area.

For this exercise, we chose IW3, VV polarization, burst 5-8 for the before image and 4-7 for the after image.

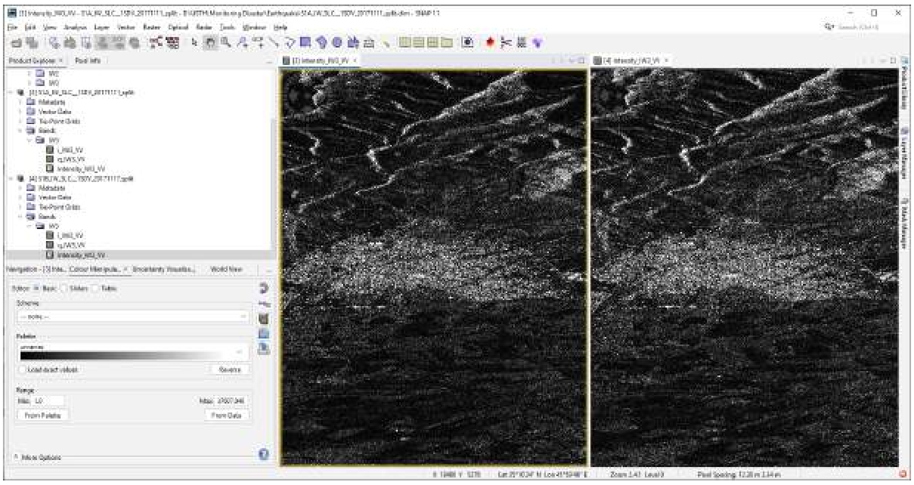

Figure 41: Radar image

We apply orbit file to correct all errors related to the orbit file. Then for coregistration, to creat interferogram, it requires two or more images to be coregistered, one master image and others are slaves.

Interferogram formation, the interferogram is to generate the phase difference map, so both images (master and slave) will be multiplied with their different phases. The interferometric fringes means 2 π cycle of phase change with surface difference, which will be represented in a color cycle, so when frinage is denser, the deformation will be stronger.

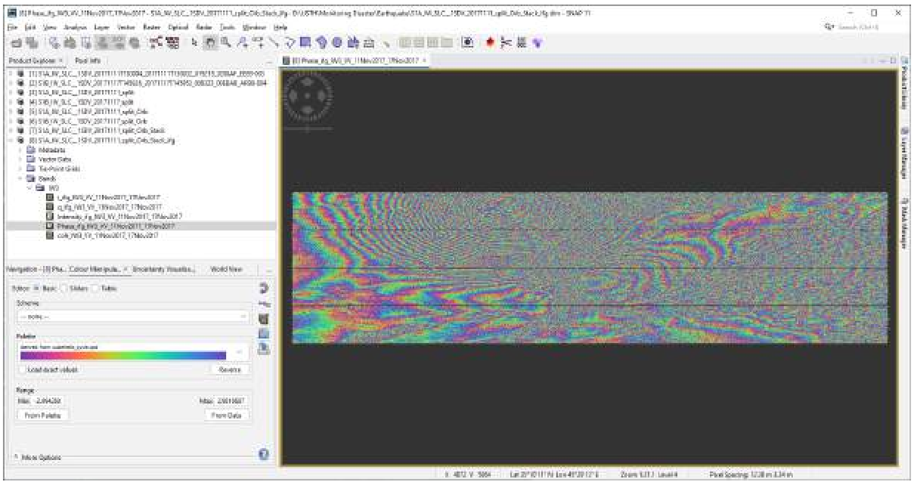

Figure 42: Phase

We deburst them to erase the black lines.

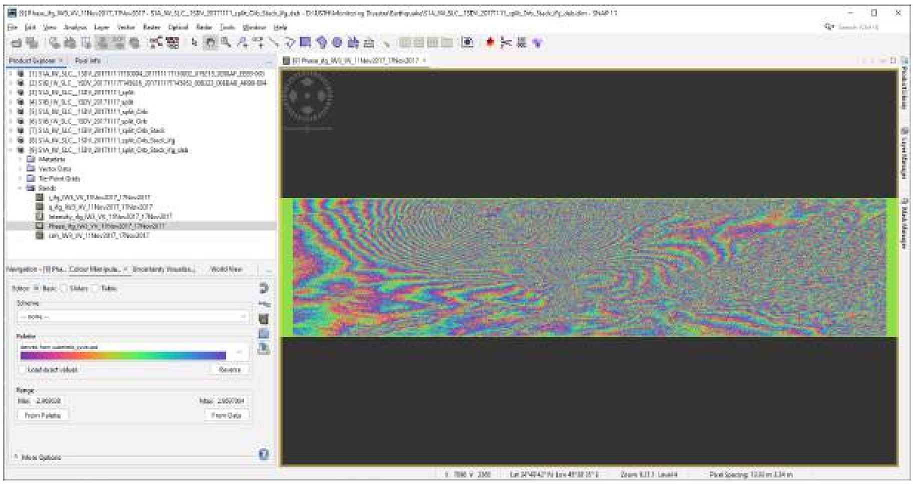

Figure 43: Deburst

Next, we have to remove the interference from topography for mapping phase difference in the interferogram, this step is to remove known DEM when processing data.

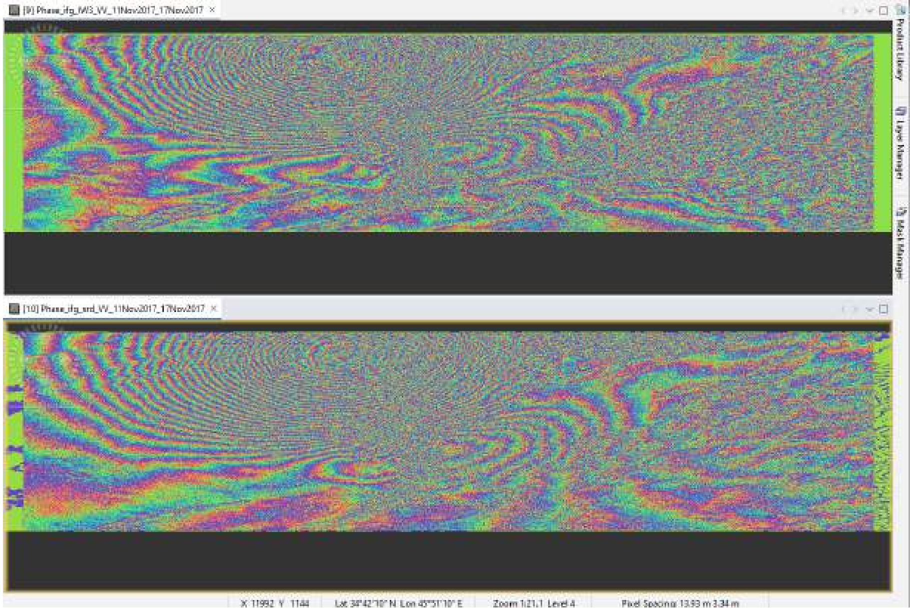

Figure 44: Topographic phase removal

To improve the phase map and reduce noise, we do multilooking. To visually improve the fringe for earthquake deformation, we do phase filtering.

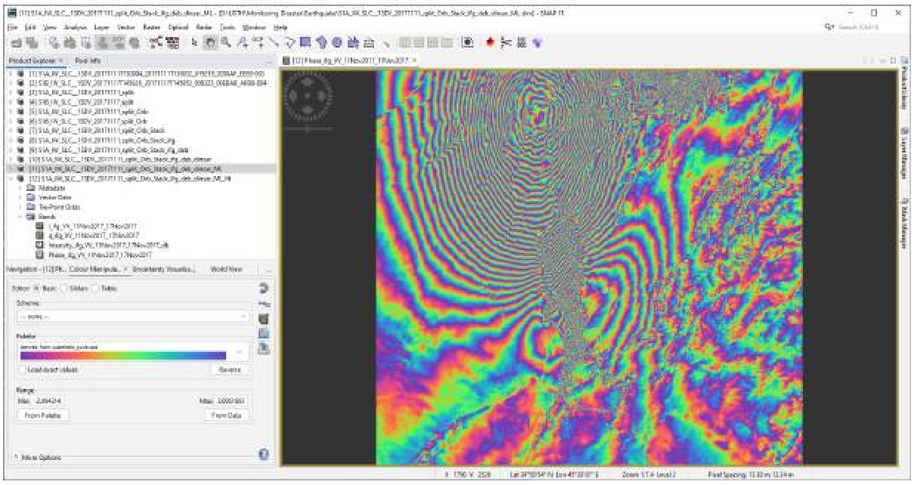

Figure 45: Phase filtering

Lastly, we do a geometric correction to project the interferogram into a geographic coordinate system, so this step can help to export data next step.

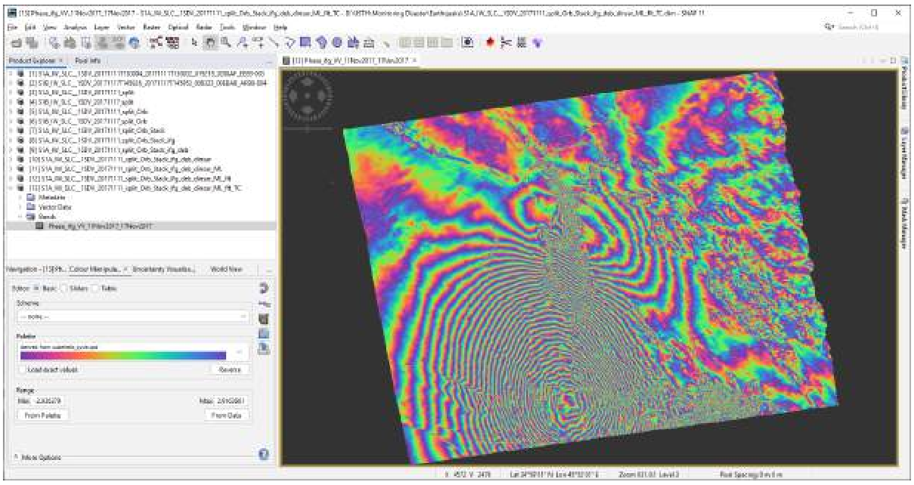

Figure 46: Terrain correction

Finally, we see it in Google Earth Pro.

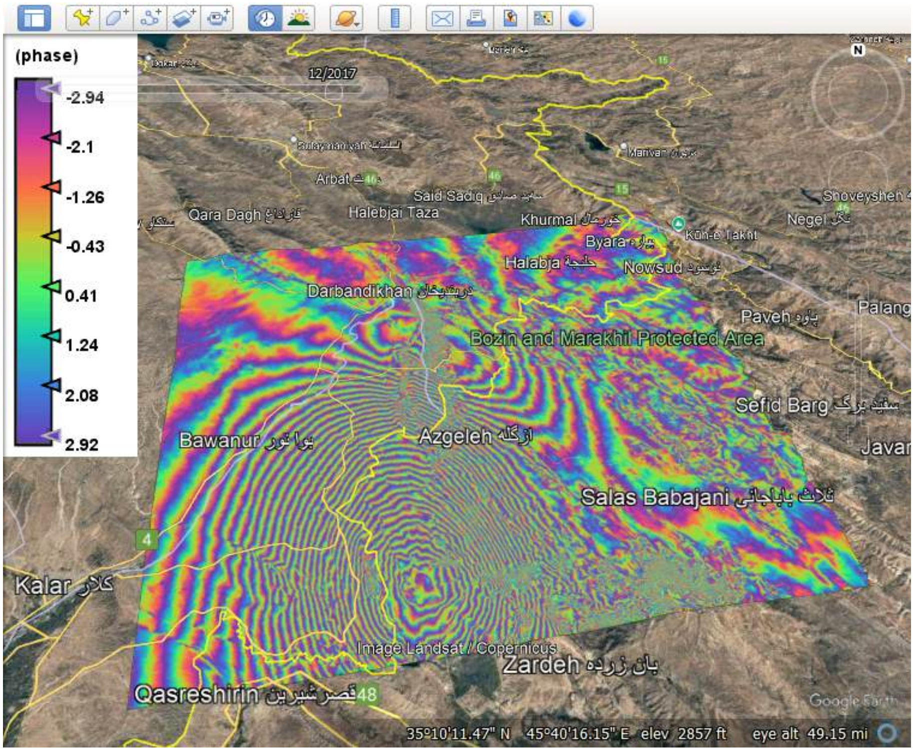

Figure 47: Google Earth Pro view

6.2 Discussion

We can still improve this method by adding SNAPHU unwrapping tool to set a smoother image of the earthquake.

7 Final Exam

7.1 Abstract

This is the final report for Natural Disaster Monitoring using Satellite Data coursein the Space Program of USTH by Dr.Pham Duc Binh. This report is about the use of the Sentinel-1 satellite to observe and monitor volcano activities. As a subject, we want to leam new things,so this study approaches the problem the way isn't in this course.

7.2 Introduction

The monitoring of active volcanoes is a critical component of disaster risk reduction efforts worldwide. With approximately six hundred known active volcanoes on Earth, developing effective monitoring techniques is essential for mitigating the risks and hazards associated with potential eruptions. Among the most significant technological advancements in this field is the application of Synthetic Aperture Radar (SAR) data from satellite platforms, particularly the Copernicus Sentinel-1 mission, which has revolutionized our ability to monitor volcanic activity remotely [1]

One of the most powerful applications of Sentinel-1 data for volcanologists is Differential SAR Interferometry (DInSAR). This technique allows scientists to detect even the slightest signs of crustal deformation that might indicate an impending eruption. [1] By comparing radar signals from different time periods, researchers can generate surface displacement maps—called interferograms—that reveal how the volcano's surface has moved over time. [2] These measurements can detect inflation (upward movement) when magma is accumulating beneath the surface or deflation (downward movement) after eruptions or when magma withdraws.

The devastating eruption of Anak Krakatau on December 22, 2018, offers a compelling case study for the application of SAR monitoring. Located in the Krakatau Complex in Indonesia's Sunda Strait, this volcano experienced a major flank collapse during eruption that triggered a tsunami, killing 437 people and causing widespread destruction along the shores of Java and Sumatra. What makes this event particularly significant is that the tsunami struck without warning, highlighting the critical need for improved monitoring systems [3]

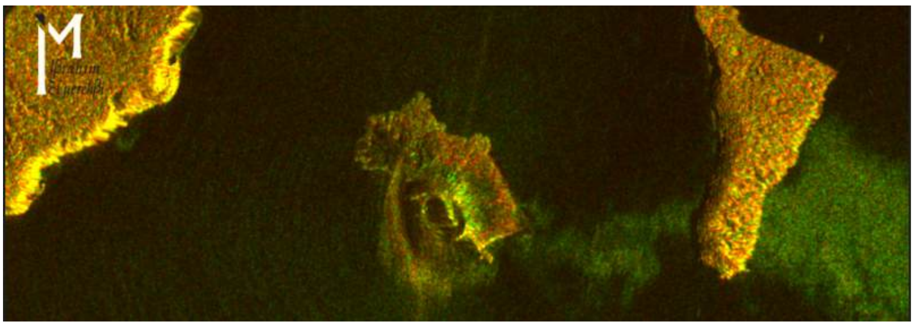

Figure 48: Anak Krakatau Volcano Explosion as seen in SAR by Ibrahim El Merehbi

7.3 Research Methodology

7.3.1 Case study

The volcano eruption we want to observe is Anak Krakatau (Anak Krakatoa) 2018 to find out why and how it erupted, how it impacted the civilians around. The area is 120 km^2 with 3 islands surrounding 1 volcano in the middle in Indonesia

The initial goal is to use images from Sentinel-2 to observe the volcano at the time it erupted and the past. But due to the cloud, we couldn't make use of any photos from Sentinel-2. So we have to use Sentinel-1 data to observe surface displacement maps (interferograms) that allow observation of deformation over time.

7.3.2 Methodology

This methodology is based on instruction from RUS Webinar: Volcano Monitoring with Sentinel-1 - HAZA10

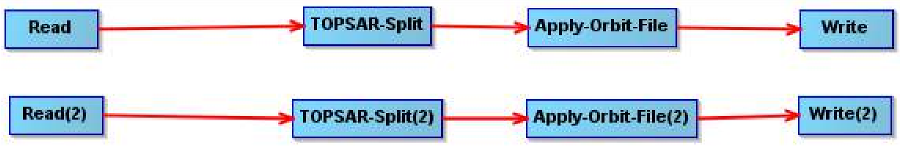

Figure 49: Methodology

- **TOPSAR-Split** to chose the burst in which the area is in
- **Apply orbit file** to calculate precise orbit data takes time

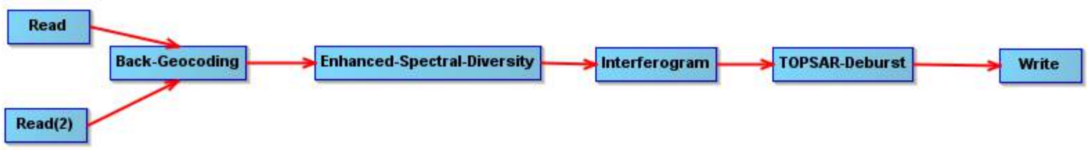

Figure 50: Methodology

- **Back-Geocoding** to precise co-registration of SAR images acquired at different times or from different orbits
- **Enhanced-Spectral-Diversity** to improve the accuracy of image co-registration by exploiting the spectral diversity in the azimuth direction

- **Interferogram** uses two SAR images of the same area acquired at different times to measure changes in land surface altitude over time
- **TOPSAR-Deburst** to join different bursts into one image

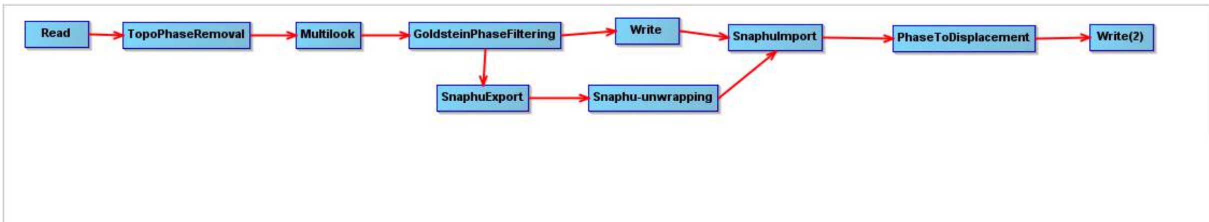

Figure 51: Methodology

- **TopoPhaseRemoval** eliminates phase contributions caused by terrain elevation
- **Multilook** averaging multiple independent looks of the same scene
- **GoldsteinPhaseFiltering** to reduce noise in the interferometric phase
- **Snaphu** These three steps involve the Statistical-Cost, Network-Flow Algorithm for Phase Unwrapping (SNAPHU) software, which resolves the 2π phase ambiguity in wrapped interferograms
- **PhaseToDisplacement** uses the radar wavelength to transform phase differences into ground movement measurements

7.3.3 Material

From Copernicus browser data space of ESA, we extracted 6 months data from Sentinel-1, from June to December, with level 1-SLC, orbit track 47, decending satellite track, strip map IW mode, polarization VV, IW3, burst 2-3. The day of eruption is December 22 2018. The area is 150 km^2.

Area of research

SNAP ESA to process data

SNAPHU to unwrap

7.4 Result and Discusstion

7.4.1 Result

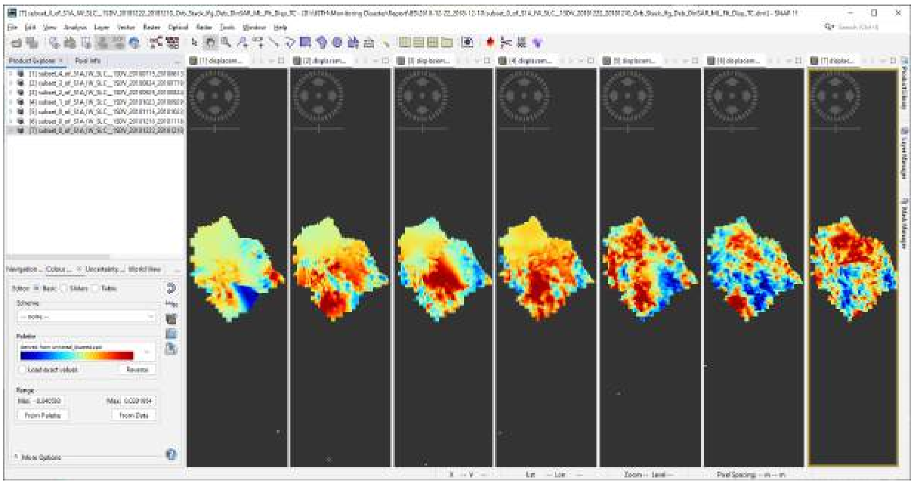

Figure 52: Displacement of Anak Krakatoa over time

In the results showing the conditions every 28-day consequently, we can see that the whole island is periodically deflating and inflating.

Anak Krakatoa is one of the most monitored volcanoes in the world with a great surveillance system and many scientists have worked all these years on its activity.

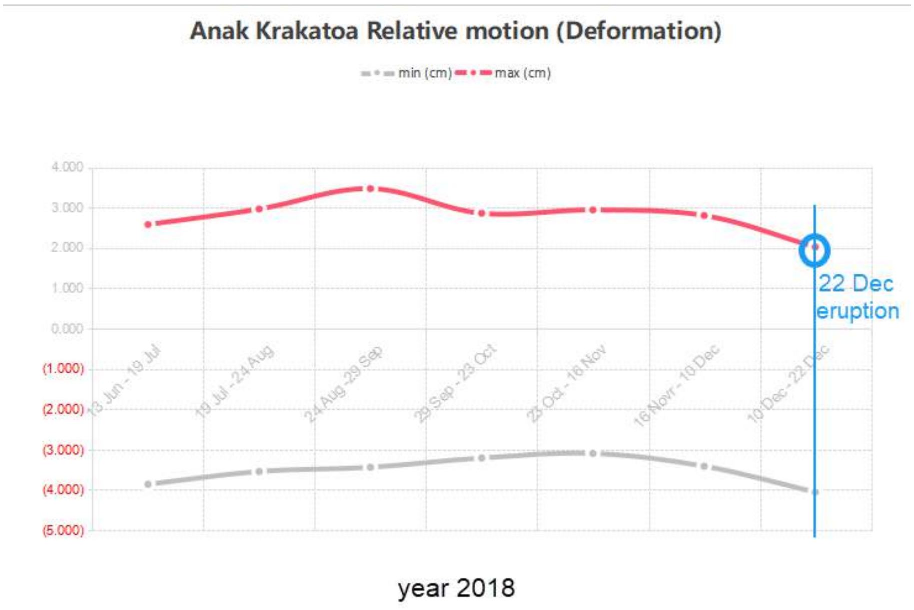

Figure 53: Anak Krakatoa relative motion

As confirmed by F.Di Traglia et al., 2014, inflation and deflation were recorded immediately before andafter each new effusive event,like in our case.Anyvent opening can cause sliding and high displacementrate is recorded.

Also,the displacement rate increases during the upwelling because the magma is less dense, while the displacement rate decreases when the degassed magma column is pushed out from the pipe.

7.4.2 Discussion

Sentinel-1 SAR imagery has proven to be an invaluable tool for monitoring Anak Krakatau volcano, providing critical information about volcanic processes that would be difficult or impossible to obtain through other means. The application of advanced processing techniques such as SBAS and data fusion approaches enhances the utility of SAR data for comprehensive volcano monitoring, allowing for detailed analysis of deformation patterns, morphological changes, and lava flow dynamics.

The case of Anak Krakatau demonstrates both the current capabilities and future potential of SAR-based volcano monitoring. While current systems already provide valuable information for volcanic hazard assessment, ongoing advancements in satellite technology, data processing algorithms, and integrated monitoring systems promise to further enhance the role of SAR in volcanic disaster mitigation.

The fusion method of optical Sentinel-2 and Sentinel-1 SAR data offers a particularly effective approach for continuous monitoring of volcanic activity in both cloudy and clear weather conditions, addressing one of the fundamental challenges in operational volcano monitoring. This integrated approach represents a significant advancement in the global effort to monitor volcanic activity more effectively and mitigate its potential impacts on vulnerable communities.

References

[1] Thu. Copernicus. 2022.

[2] Sentinel Online. Sentinel online. 2025.

[3] Ibrahim El Merehbi. Anak krakatau volcano explosion as seen in sar. 2019. Accessed on 2025-03-31.