Preprocessing Sentinel-1 GRD Data in ESA SNAP

October 4, 2025

Introduction

The Sentinel-1 provides Synthetic Aperture Radar (SAR) data, that transmit microwave pulses and records backscatter from the Earth's surface. Due to this, SAR can acquire data in all conditions such as cloud cover, making it an important way for flood monitoring and land analysis.

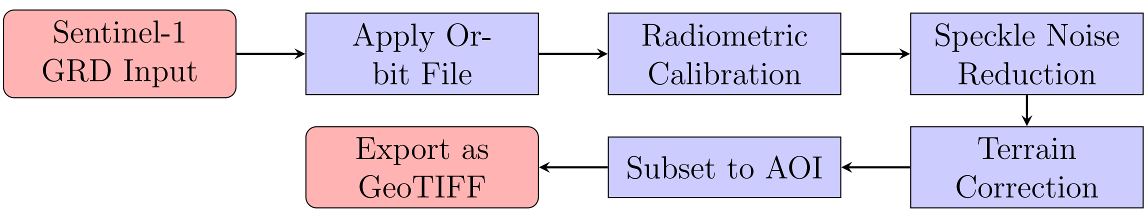
However, raw Ground Range Detected (GRD) data often contain distortions caused by radar geometry, inaccuracies, and noise. Hence, preprocessing is necessary before using the data for scientific studies or machine learning analysis.

The preprocessing pipeline aims to:

- Correct satellite orbit inaccuracies,
- Calibrate pixel values into physically meaningful backscatter coefficients (σ^0),
- Reduce speckle noise,
- Correct for terrain-induced geometric distortions,
- Subset the scene to the desired Area of Interest (AOI),
- Export the result as a GeoTIFF for further processing.

All operations were carried out using the Sentinel Application Platform (SNAP) developed by ESA.

The Workflow



Steps Taken

1. Apply Orbit File

We use this to update the position and velocity of the satellite using Precise Orbit Ephemerides (POE) files provided by the ESA to ensure accurate geolocation.

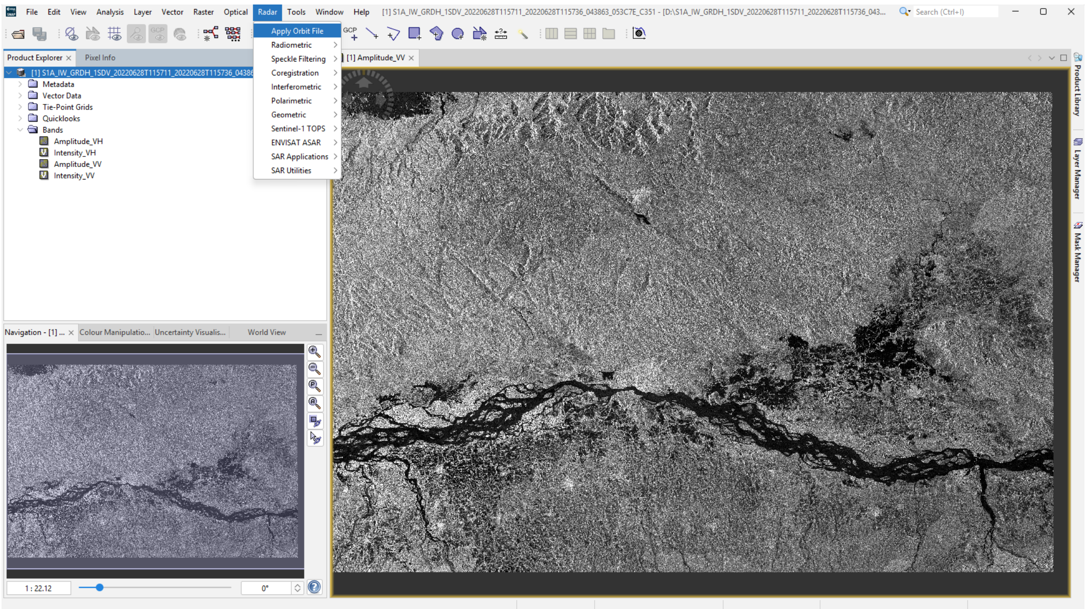


Figure 1: Applying Orbit File

SAR geolocation depends on knowing the exact position and velocity of the satellite at the time it recorded the data. The fundamental equations here are:

$$R = \frac{c\Delta t}{2}, \quad f_D = \frac{2\vec{v} \cdot \vec{R}}{\lambda|\vec{R}|}$$

where R is the slant range, c is the speed of light, Δt is the signal travel time, f_D is the Doppler frequency shift, $\vec{v}$ is the satellite velocity vector, and λ is the radar wavelength.

The first calculates the distance (R) from the time it takes the signal to travel to the target and back. The second finds the exact frequency shift f_D caused by the satellite's velocity, which is used to create a sharp, focused image.

Even small errors in orbit data can shift ground positions by tens of meters. Applying the precise orbit file corrects these errors and improves the geolocation accuracy.

2. Radiometric Calibration

This converts the image's raw digital numbers (DN) into physically meaningful radar backscatter coefficients (σ^0), which ensures that the pixel values represent the actual radar reflectivity of the ground, .

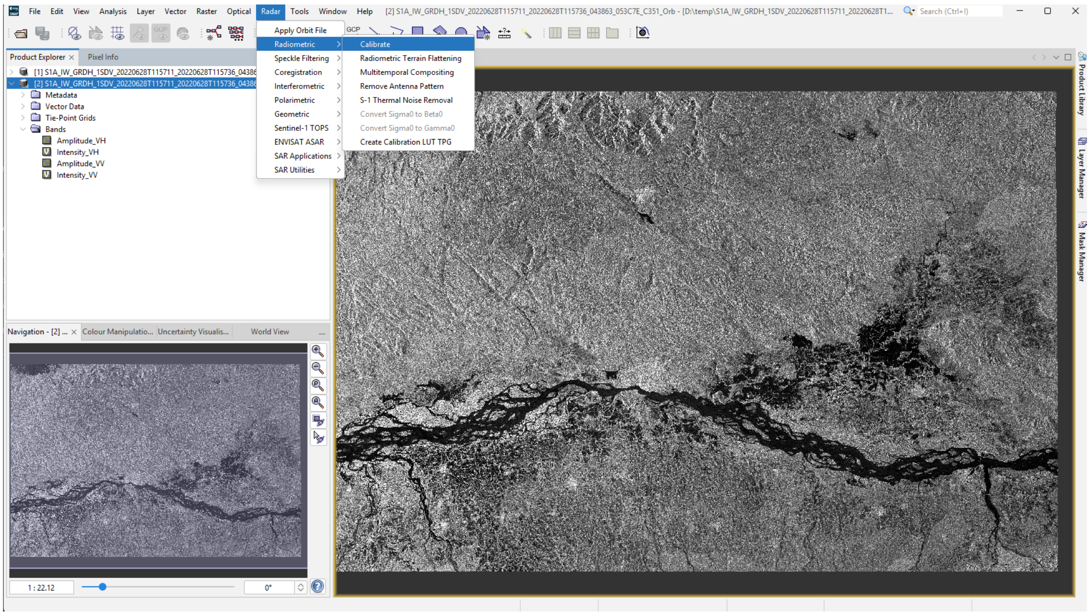


Figure 2: Radiometric Calibrate

The radar equation describes the relationship between received power and target backscatter:

$$P_r = \frac{P_t G^2 \lambda^2 \sigma}{(4\pi)^3 R^4 L}$$

where P_t is transmitted power, G is antenna gain, λ is the radar wavelength, R is the range, and L represents system losses.

Radiometric calibration removes these system and geometric dependencies to produce σ^0:

$$\sigma^0 = \frac{\mathrm{DN}^2}{CF}$$

where CF is a calibration factor which is CF is a lookup value from the product's metadata.

This process ensures that backscatter values are comparable across dates, sensors, and incidence angles.

3. Speckle Noise Reduction

Reduces granular speckle noise that results from the coherent nature of radar imaging, which can degrade image quality and hinder interpretation.Speckle is modeled as multiplicative noise:

$$I = \sigma^0 \cdot n$$

where I is the observed intensity, σ^0 is the true noise-free) backscatter, and n is a random noise factor.

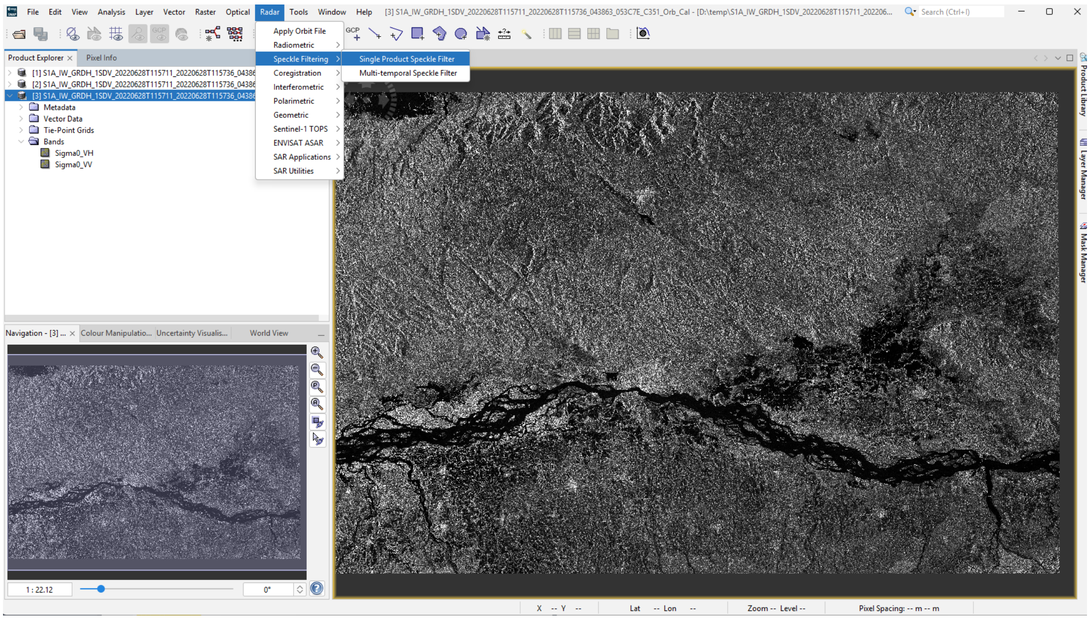


Figure 3: Speckle Filtering

Filters such as Lee, Refined Lee, and Frost are commonly used to suppress this noise. They use local statistics to smooth flat areas while preserving sharp features like edges. As an example, the Refined Lee filter modifies each pixel as:

$$I_{\text{filtered}} = \bar{I} + W(I - \bar{I})$$

where W is a weight determined by local mean and variance.

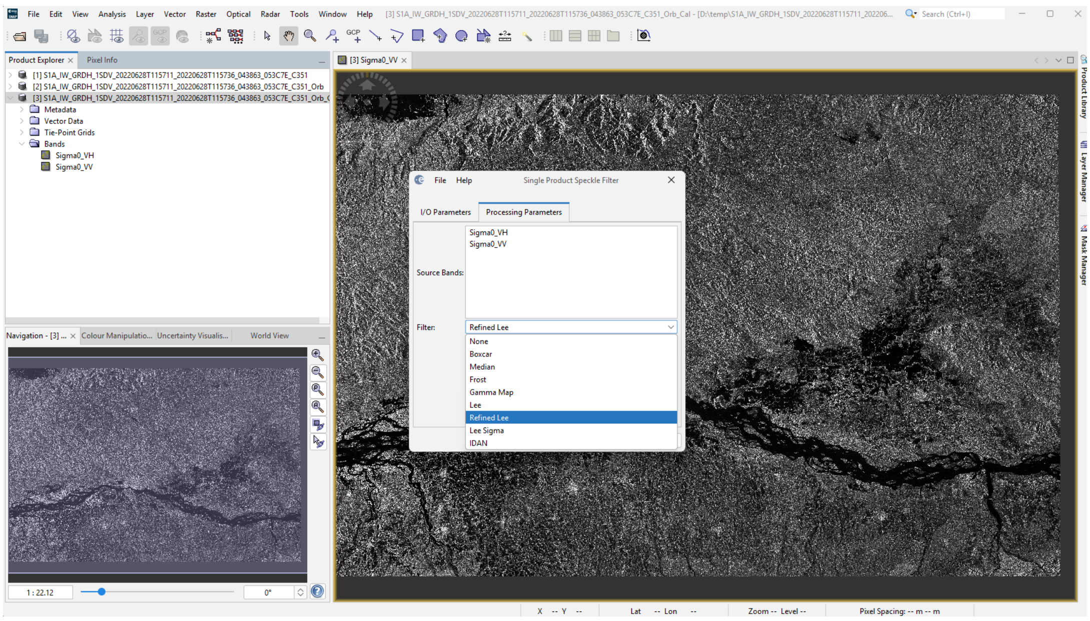


Figure 4: Filters Available on SNAP

In this work, the Refined Lee filter was applied to reduce speckle noise.

4. Terrain Correction

Corrects geometric distortions caused by the side-looking view of the sensor and topographic relief, and projects the image into a standard map coordinate system (e.g., UTM, WGS84).

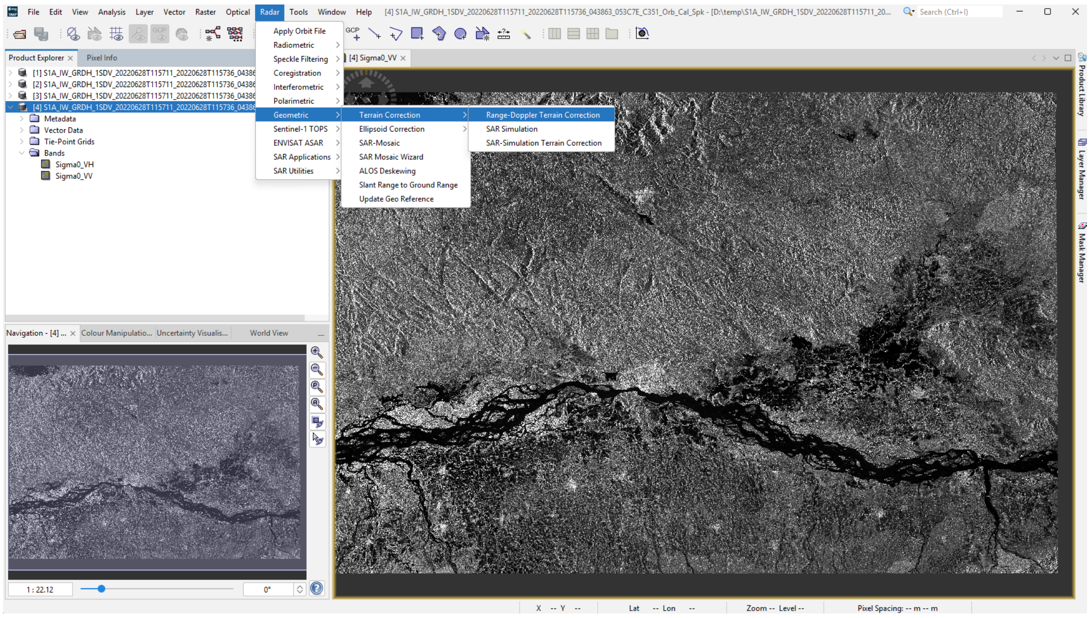


Figure 5: Rabnge-Doppler Terrain Correction

While Ground Range Detected (GRD) products are oriented to ground range, they are not yet accurately geocoded and still contain significant errors due to terrain Terrain correction uses a Digital Elevation Model (DEM) to map each pixel to its correct geographic location. The Range-Doppler Terrain Correction algorithm reprojects the data, compensating for topographic effects such as foreshortening, layover, and shadow.

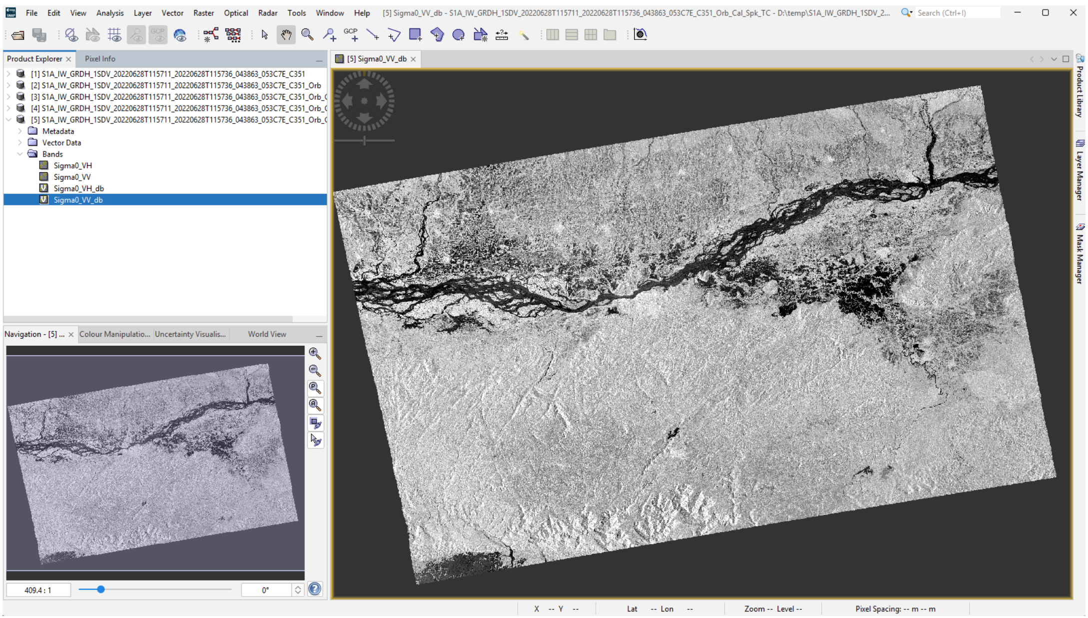


Figure 6: Terrain Corrected

We converted the obtained Bands into dB scale using:

$$\sigma^0_{\text{dB}} = 10 \cdot \log_{10}(\sigma^0)$$

This logarithmic scaling helps in visualizing and interpreting backscatter values more easily.

5. Subset to Area of Interest (AOI)

Extracts only the relevant study area to reduce the size of the data and focus the analysis.

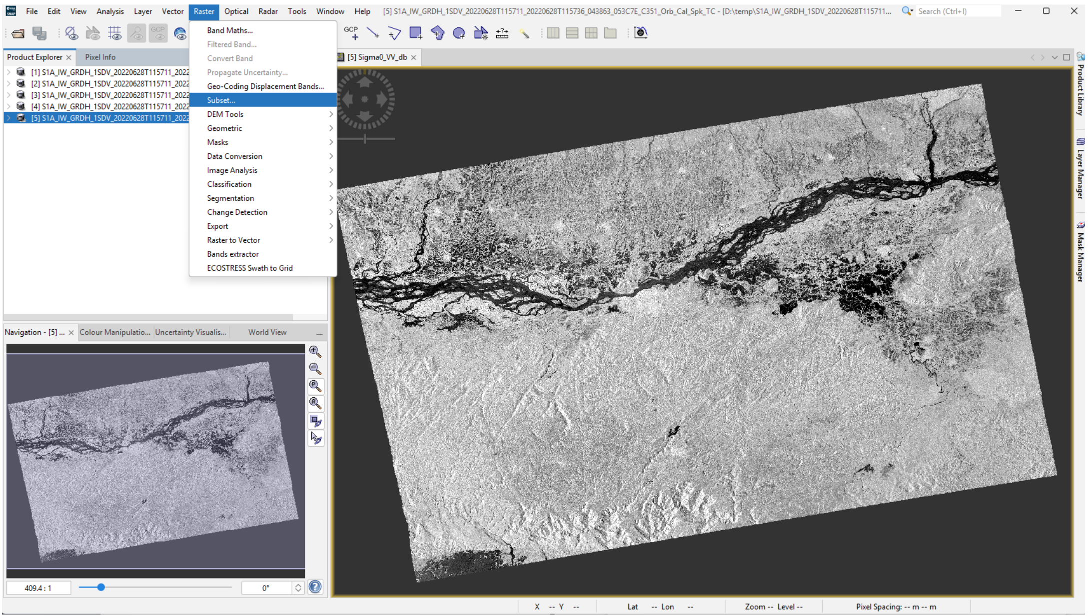


Figure 7: Subsetting to AOI

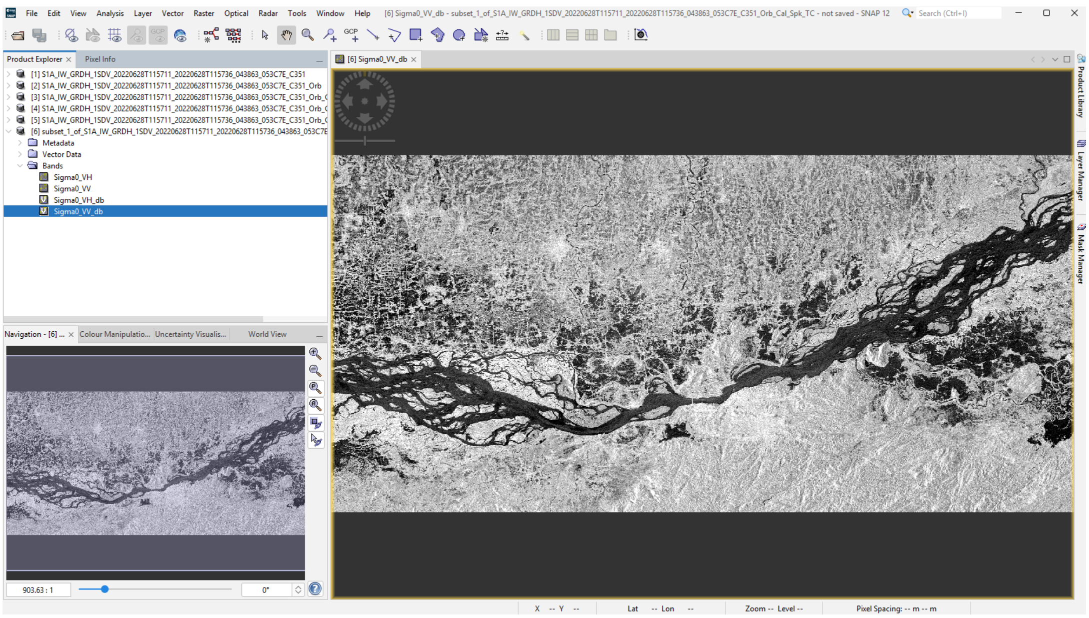


Figure 8: Area of Interest

6. Exporting the Final Product

After preprocessing, the resulting dataset:

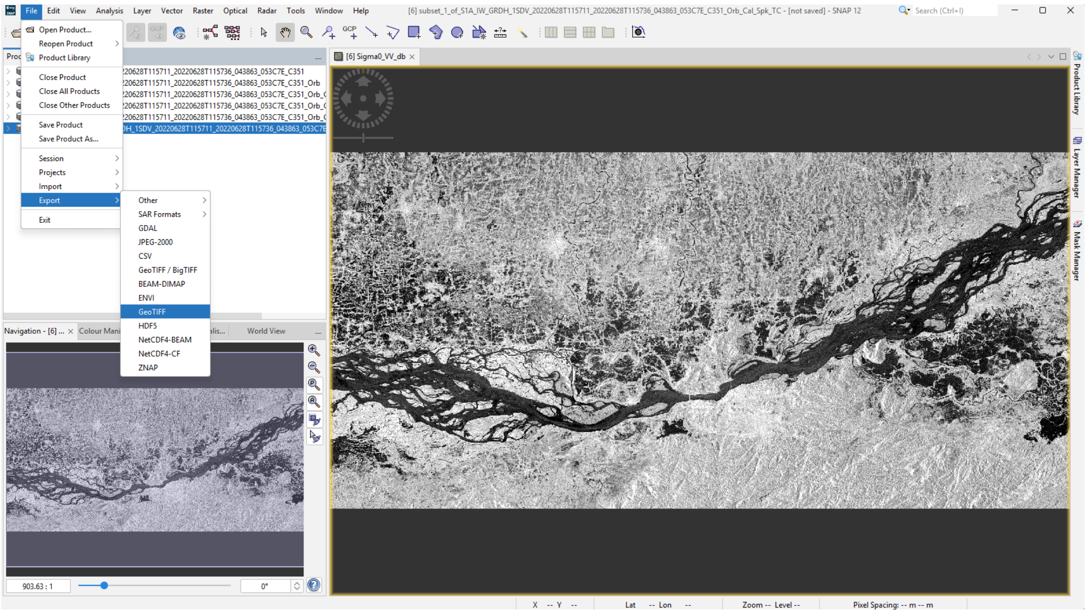


Figure 9: Exporting as GeoTIFF

The final output was exported as a GeoTIFF file using:

This GeoTIFF is used as our input for Convolutional Neural Network (CNN)–based analysis for flood mapping in our Area of Interest.