A COMPARISON OF TERRASAR-X AND SENTINEL-1 FOR URBAN SMALL SCALE FLOOD INUNDATION MAPPING USING A CHANGE DETECTION AND THRESHOLDING METHODOLOGY: A CASE STUDY OF PARIS, FRANCE, JANUARY, 2018

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Abstract

With Open-Source Sentinel missions making more of an impact on the Remote Sensing world, it is worth comparing them up against the higher resolution, commercial, Satellites, such as the TerraSAR-X mission. Especially in the high risk (monetary) urban city areas. Adapting previous studies, a change detection and supervised classification thresholding methodology was applied to Archive and Crisis images of the previously mentioned products. This was to determine the flood extent in urban Paris, Northern France, following heavy rainfall on the 22nd of January, 2018. The results were validated against the Copernicus Emergency Management Service (EMSR265: Floods in Northern France). The TerraSAR-X provided very similar results to the EMS, and as an addition, was able to differentiate flooded areas from vehicles using pixel based backscatter supervised classification. However, to improve on accuracy, it would be useful to have knowledge of the topography, hydrology and land use, prior to flood mapping.

From the Sentinel-1 results, it is assumed that the VV polarisation was affected by rough winds, which is why permanent bodies of water have been detected as flooded water. Further investigation would be needed to be done in order to validate this.

The next step of this study is to understand how the use of further datasets, such as DEMs, LiDAR, hydrological data etc, combined with a time series of events could provide more accurate, and potentially automated results. Furthermore, enabling the forecasting of future events and ensuring mitigation of future disasters.

Introduction

Satellite imagery has become an increasingly useful tool for large-scale hazard mapping, which can provide data quicker and safer than in-situ data sources, where the information can have limited spatial and temporal resolution (Clement, et al., 2017). The Sentinels provide an open-source of high spatial and temporal resolution imagery, that have allowed the development of near real-time large-scale flood mapping, because of the availability (Twele, et al., 2016).

The two main types of satellite imagery for surface water monitoring are Optical and SAR. Optical sensors, such as SPOT or DMC, collect data across a variety of spectral bands, and the various bands display data imagery differently for different land types (Clement., et al, 2017) Optical imagery is also passive, which means they are unable to penetrate cloud, and so are weather dependant. SAR systems, such as TerraSAR-X and Sentinel-1, are active, which means they emit the radar pulse and record the land surface return (Clement, et al., 2017). The advantages of SAR is its ability to penetrate through cloud, making it weather independent; making it ideal for immediate response flood mapping, even if the area is covered in cloud.

Most of the literature is focussed on large scale, rural flood mapping, in areas such as India and Nepal, following major storm events.However, because of the increased cost risk involved with urban hazards, it would seem necessary for the monitoring of these as well, to a greater accuracy (Guistarini. et al., 2013).

The method of change detection, comparing backscatter of an archive and crisis image is quite widely used, and useful, due to its ability to separate permanent water, such as ponds and lakes, to isolate the flooded area (Brown, et al., 2016).

Objective

The objective of this preliminary research is to determine whether pixel based change detection and Supervised Classification (Thresholding) is an accurate method for small scale Flood Inundation Mapping within an urban area. There is also a focus on the ability to use this method to differentiate the backscatter produced by the flooded area and vehicles (i.e. cars and boats). The results of this study will determine the next steps. I.e. Will the use of multiple datasets improve the accuracy, or are the pixel thresholds accurate enough to write an algorithm to create a semi-autonomous approach?

The study area is Paris, in Northern France, following heavy rainfall on the 22nd of January, 2018.

Methodology

Processing in Snap

Read → Calibration → Speckle-Filter → Terrain-Correction → Write

Calibration – To provide imagery in which the pixel values can be directly related to the radar backscatter of the scene. The output scaling applied by the processor must be undone, and the desired scaling must be reintroduced. This will be displayed as Sigma0. Enables comparisons of the two images.

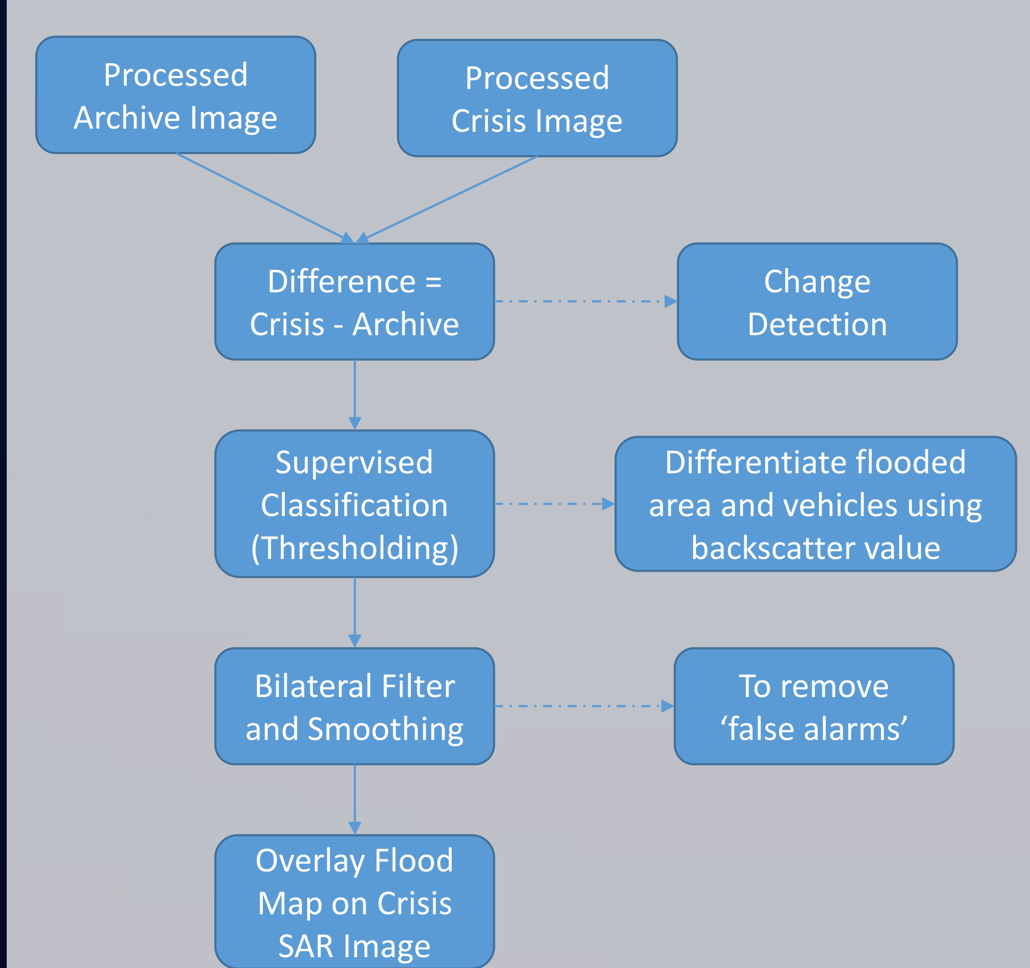
Speckle Filter – Speckle arises because of the reciprocal position of the scatters in each resolution cell. It can be considered a high frequency noise – Multilooking can also be used to reduce this. Reducing speckle improves the resolution. Gamma (5x5)

Terrain Correction – Removes distortion and projects image onto a map system – In this case, UTM.

Conversion of bands to Logarithmic scale (dB) – Makes it easiest to manipulate the image pixel values, using a histogram

Export to GeoTiff to use in ArcMap

Change Detection and Thresholding Process – ArcMap



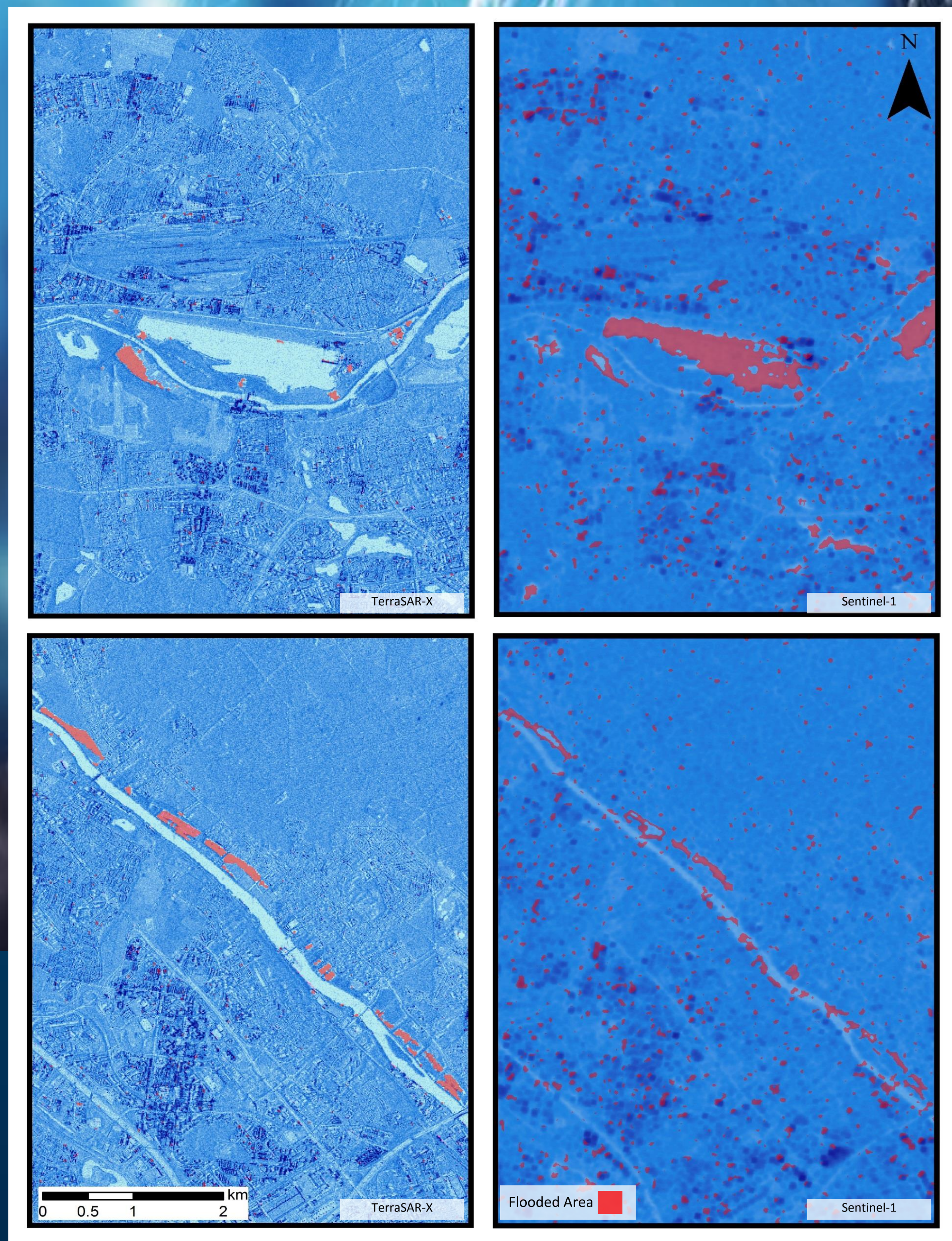


Figure 3 Top and bottom left: Example TerraSAR-X Flood Map

Top and bottom right: Example Sentinel-1 Flood Map

Results

Change Detection

The results from the change detection were quite straight forward, where the image was produced from a subtraction of pixel from the archive image, against the crisis image. This displayed features from the crisis image, that were not present in the archive. I.e. Flooded areas and vehicles.

Flood Classification

Please refer to figure 3 for an example of the results of the flood maps.

The Sentinel-1 data, compared to the TerraSAR-X seems to have a lot of 'false alarms', which appears as spots in the image. The Sentinel-1 data also seem to identify permanent water bodies as change, and therefore have been picked up as flooded areas. The TerraSAR-X, however, appears smoother and to have less flood affected areas. Overall, the main flooded areas are that around permanent bodies of water. There do not appear to be any major flood areas in the centre of the city.

Overall, the Sentinel-1 does identify virtually the same flooded areas as the TS-X, but there are many 'false alarm' looking areas which would affect the accuracy of the imagery. Something that may be resolved if topographic, hydrological and land use data was available.

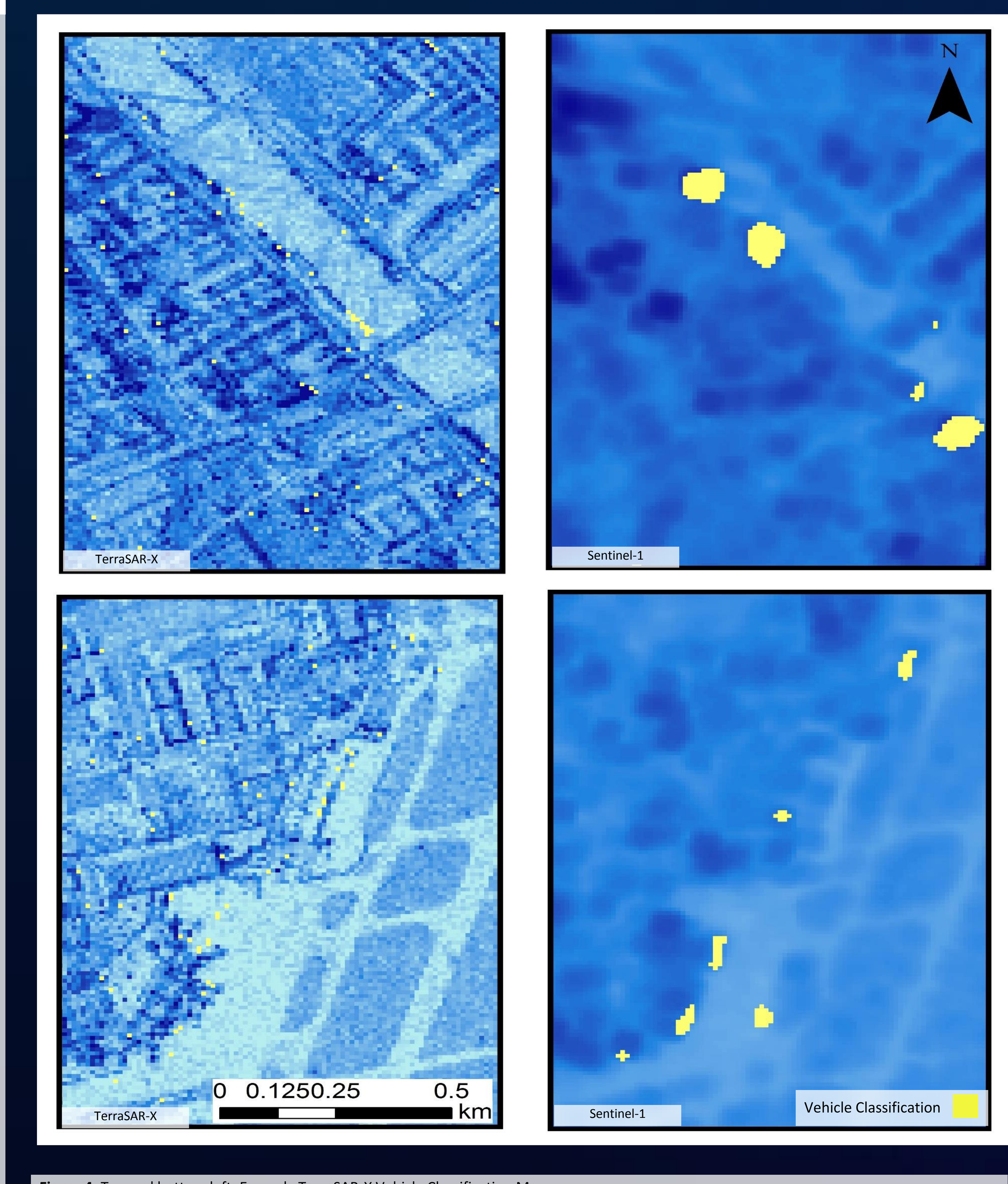


Figure 4: Top and bottom left: Example TerraSAR-X Vehicle Classification Map

Top and bottom right: Example Sentinel-1 Vehicle Classification Map

Results

Vehicle Classification

Please refer to figure 4 for example vehicles classifications.

Using the Supervised classification tool in ArcMap, a sample set of perceived vehicles, likely to be boats and cars, with an abnormally low backscatter (under -25 dB). Both the Sentinel-1 and TerraSAR-X produced results with areas that you would expect an abundance of (larger) vehicles. I.e., the airports and along the river in Figure 4. However, much like the flood classifications, the Sentinel-1 produced quite large shapes, which is likely that it has identified a group of vehicles, as opposed to individual. The TerraSAR-X has produced results, though very difficult to see, which may suggest that these are individual vehicles. I.e. A boat on the river, or an airplane/car on the airport runway.

For validation of this exercise, it would be useful to use same day, high resolution optical data, such as 0.5m Pleaides, providing the weather would allow it.

Discussion

As this is an introductory study, there is a lot of SAR system discussion, review of current literature and ideas for future study.

The advantage of this method, without the Supervised Classification of other features to flood extent, is that it is very quick to produce, providing the data over the AOI is available. The introduction of Supervised Classification does slow down the process, but with SAR advantage of accuracy. It is also a method that could be used for the less qualified analyst, due to its simplicity.

Twele. et al., (2016) and Clement. et al., (2017) stated that the VV polarisation (Sentinel-1 polarisation is this case) indicated that under calm wind conditions, a slightly higher thematic accuracy. However, it is argued that the lack of backscatter consistency in Sentinel-1 (VV Polarisation) can also be blamed on rough wind, which roughens the water. As the floods were caused by a heavy storm, it is likely that there was rough wind during the acquisition period, and therefore has created a difference in the archive and crisis Sentinel-1 images. This would explain why change was detected in the permanent water bodies in the Sentinel-1 flood maps. And potentially for the abundance of 'false alarms'. An interesting further study would be the combination of both Sentinel-1 polarisations (VV and VH) vs the HH TerraSAR-X. This may alleviate the issues of rough wind artefacts. It is also argued that the use of C-Band (Sentinel-1) is more challenging for mapping water surfaces due to the long wavelength, and therefore lower classification accuracies can be expected (Brisco, et al., 2008). It is also widely accepted that the HH-Polarisation is more superior than other Polarisations (I.e. the VV/VH Polarisation of Sentinel-1) for flood mapping (Brisco, et al., 2008; Twele, et al, 2016). The short wavelength X-Band of TerraSAR-X is argued to enable a more accurate identification of waterbodies. Although, its disadvantage lies with the reduced ability of being able to penetrate through dense vegetation. However, when it comes to small shrubs and vegetation, the signal return is high (Martinis & Twele., 2010).

A study was conducted by Panchagnula, et al. (2012), which aimed to optimise the threshold ranges, in order to speed up the process of flood mapping, and aim toward an automated process. And though their backscatter values for each polarisation was quite similar to what was used in this study, there was no mention of anomalous backscatter being generated by anything other than water. When a Radar pulse hits a smooth surface, it produces very low backscatter and creates a dark appearance in the image. This is known as specular reflection and tends to occur on bodies of water, as well as other smooth surfaces, such as vehicles, solar panels etc. So even if the threshold value range is more or less correct, there may be other features that produce a similar backscatter value that isn't water. Therefore, the use of an analyst may help produce more accurate results than an autonomous method. Although, it is also correct that an analysts solution would generally take longer than if the process was autonomous, using pre-programmed threshold values. In the situation of Panchagnula, et al. (2012), where they used this method for large flood extents in India, it would be ideal, due to the speed, covering a huge area and water volume. However, for the smaller scale urban floods of Paris, the end user wouldn't want to mistake flooded areas with other features. higher resolution of the TerraSAR-X, it was far easier to identify areas of high backscatter, purely down to the fact that the individual pixels covering a smaller area. However, due to the built up area of Paris, there are still issues of needing to understand topographic and land use, which would bare an impact on the results (Giustarini. et al., 2013) Having knowledge of this

Another step toward consistent monitoring and rapid response of flood hazards is the fusion of datasets (Giustarini. et al., 2013) . This can be achieved using various approaches. The fusion can occur at pixel level, feature and decision making levels (Sgahaier. et al., 2018), although it is argued that pixel based fusion is the most intuitive way to combine information (Sgahaier. et al., 2018). This method enables data acquisition to be a little more flexible, which allows for an improved speed in which analysis of flooded areas can occur. Again, this notion can also coincide with the above, of introducing datasets such as DEMs, LiDAR, hydrological datasets etc for improved accuracy.

A disadvantage of SAR is its side looking nature. This produces radar layover and shadow, mainly caused by vegetation and man-made features; buildings. Although, it has been argued that it is possible to detect flooding in urban areas, using high resolution SAR using double scattering between building walls and the surface of the flooded area. (Mason. et al., 2014) Certainly something to consider for future study.

Conclusion and Future Studies

The TerraSAR-X flood map does display a clear difference between the flooded area and permanent water body which does coincide with the EMS charter image. The TerraSAR-X also produced a classification of vehicles. The Sentinel-1, instead, managed to identify the areas of very low backscatter, but due to the resolution, seemed to group the areas of change, as opposed to individual vehicles.

To conclude, I believe that the method of thresholding and supervised classification is a useful technique for small scale flood mapping, using high resolution data. The TerraSAR-X produced results that appeared more accurate than the Sentinel-1. And the method is relatively easy to use, even for the less experienced analyst.

As a future study, and a comparison up against the paper of Brown, et al (2016), it could be worth using the WorldDEM Digital Elevation Model, instead of LiDAR to accurately produce flood surface elevation data. This way, the volume of water could be calculated, and flooded areas could be categorised by how badly they have been affected. The combination of having surface data, alongside a time series of events could help produce models for future events and , and set mitigation strategies out to prevent disasters in the future.

References and Acknowledgments

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A special thanks to Airbus Defence and Space DE and DLR for granting me the TerraSAR-X and TanDEM-X data for these research purposes.

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