Potential Of Sentinel-1 SAR Observations To Monitor Floods In The North Vietnam

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Abstract: As one of the countries affected the most by global warming and climate change, the frequency and intensity of extreme weather events occurring recently in Vietnam are increasing. Floods, among others, are one of the most damage disasters in Vietnam. In this paper, we illustrate how satellite data (especially free SAR data from the Sentinel-1 satellite) can be used to monitor floods, at 30 m spatial resolution, in the North Vietnam where the cloud cover is very high. Although there is no reference inundated map at the same spatial and temporal resolutions for comparison, SAR-derived permanent surface water map is in good agreement with free-cloud Landsat-derived surface water map. This study shows strong potential of SAR satellite observations for monitoring and forecasting applications over highly cloud-covered environments like the tropical regions.

Keywords: SAR, Sentinel-1, Landat-8, Flood detection, North Vietnam.

1. INTRODUCTION

Floods are one of the most devastating, common, and costly natural disasters, affecting on average ~96.9 million people worldwide, and causing ~$13.7 billion in damage each year [1]. During a 20-year period (1995-2015), floods accounted for 43% of all weather-related disasters (Figure 1a), and for 25% of global economic damage (Figure 1b). At the same time, floods affected 2.3 billion and killed 157,000 people worldwide, accounting for 55% (top 1) and 25% (top 3) of number of people affected and killed by weather-related disasters (Figure 1c,d). In recent years, the frequency of extreme weather events occurring globally, including droughts, hurricanes, tropical storms, and especially floods, has increased due to combined effects of global warming and climate change [2]. As a consequence, flood monitoring and early warning are in need to reduce damages to the affected regions. Hydrological model forecasting systems are considered the most effective tools for monitoring floods, but almost all existing flood forecasting systems are developed at local and regional scales, and usually for developed countries [3]. The fact is that these forecasting systems are not available for many remote and ungauged regions (especially in Asia or Africa where the flood frequency is higher than in other continents) [4].

In this study, SAR Sentinel-1 satellite observations are used to test the capability to detect floods in the north and north center Vietnam. With the presence of the Red River Delta, the north Vietnam is one of the most populated regions within the country (see Figure 2). Free cloud optical Landsat-8 observations acquired in normal conditions before the floods are used for evaluation of the inundated areas. Several serious floods occurred in the north Vietnam in 2017, but the 9-14 October 2017 flood is chosen because it was one of the most damaging disasters affecting the country in 2017 [4]. Floods occurred mainly due to a tropical depression leading to unusual heavy precipitation over the region. According to official reports from the General Statistics Office of Vietnam [5], there were 109 dead or missing, and 49 injured; 3,000 houses were collapsed; 73,000 houses were flooded; 99,000 hectares of rice and 53,000 hectares of crops were flooded or damaged. The total value of damages caused by the disasters is estimated at ~VND6.1 trillion (~$270 million).
shows regions affected by the disasters, as well as the number of people dead or missing in each province.

Table 1: List of 4 SAR Sentinel-1 and 1 Landsat-8 observations cover the north Vietnam, used in this study.

<table>
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<tr>
<th>SAR Sentinel-1</th>
<th>Landsat-8</th>
</tr>
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<td>S1A_IW_GRDH_1SDV_20171007T225043_20171007T225108_018713_01F930_8110</td>
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<td>S1A_IW_GRDH_1SDV_20171010T110602_20171010T110627_018750_01FA53_652A</td>
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SAR SENTINEL-1 AND LANDSAT-8 SATELLITE OBSERVATIONS

Four Level-1 Ground Range Detected (GRD) Sentinel-1 images from the Interferometric WideSwath mode (IW, spatial resolution of 20 m, and pixel spacing of 10 m) that cover the northeast and north center regions of Vietnam are downloaded. Two images were acquired before the flood, on 7 October 2017, and two images were acquire after the flood, on 10 October 2017. Details of the four images are presented in Table 1. The Sentinel-1 images are processed using the ESA Sentinel Application Platform (SNAP) software following pre-processing steps described in [6]. Only backscatter coefficient images at VH polarization are used for flood detection as VH polarization images are more sensitive to the presence of surface water than VV polarization images [7]. With the presence of mountains in the north Vietnam, mountain shadows and water bodies have similar reflectance signatures with the backscatter coefficient VH polarization (both surface types have low backscatter coefficient when looking off nadir). Incidence angle information are used to distinguish the two surface types since the incidence angle of mountain shadow pixels are out of the valid range of Sentinel-1 incidence angle (29°– 46°). At the end of the pre-processing steps, SAR Sentinel-1 VH polarized images at 30 m spatial resolution (similar to that of the Landsat-8 image) are ready to be used for flood detection. Sentinel-1 data are downloaded from the Copernicus Open Access Hub (https://scihub.copernicus.eu/dhus/#/home).

Due to the cloud contamination over the north Vietnam during the flood event, the surface is totally opaque from optical satellite sensors. Figure 4 shows the mean annual cloud cover in the region (top), derived from 15 years of MODIS observations, and the average cloud cover in 12 months (bottom). At any moment, more than 60% area is covered by clouds, and it can reach to 80-85% during rainy seasons. Vegetation canopy is another factor that limits the use of optical satellite data here since optical sensors cannot detect water under vegetation canopy. It is clear in Figure 5 that this region is largely cover by forests, except for the Red River Delta, and along the coast line.

Free-cloud Landsat-8 images (see details in Table 1), acquired 2 months before the flood event (on 7 August 2017), are used for validation of the surface water map derived from Sentinel-1 images. Original Landsat-8 images are converted from digital number (DN) to Top-of-atmosphere (TOA) surface reflectance.
before being used to calculate the Normalized Difference Water Index (NDWI). Landsat-8 data are downloaded from the Libra development SEED project (https://libra.developmentseed.org/).

Methodologies to create surface water maps using SAR Sentinel-1 and optical Landsat-8 images are described in the next section.

Surface water detection with optical Landsat8 observations is based on the application of a water index (NDWI [13]). The NDWI is calculated as the ratio between the green and the near-infrared (NIR) wavelengths (see Equation 1) As seen in Figure 7, the reflectance of water is higher in the visible wavelengths than in the NIR ones that makes water pixels have positive NDWI values, and non-water pixels have negative NDWI values.

\[
NDWI = \frac{GREEN - NIR}{GREEN + NIRD} \quad (1)
\]

SAR SENTINEL-1 AND LANDSAT-8 SATELLITE OBSERVATIONS

The detection of surface water pixels with SAR Sentinel-1 VH polarization images is often based, at least partly, on application of a threshold on the VH polarized backscatter coefficient [10] [11] [12]. Flat surface waters act like mirrors when interact with microwave beams coming at incidence angles, therefore, incoming energy is mostly reflected in the specular direction. As a consequence, water bodies are associated with the low VH polarized backscatter coefficient, and they appear very dark in the images. Figure 6 shows the histograms of Sentinel-1 VH polarized backscatter coefficient in one region located in the north Vietnam before (blue) and after (red) the flood event. From the small figure, the best threshold to separate water and non-water pixels is around the values \( T = -21.5 \) dB. Therefore, the threshold \( T = -21.5 \) dB is chosen to apply directly to the VH polarized backscatter coefficient images to produce surface water maps before and after the flood event. Permanent water bodies (lakes or rivers) are pixels being inundated in both the two images, while flood areas are pixels not being inundated before but being inundated after the event.

![Figure 4: Top: Mean annual cloud cover (in percentage) over the North Vietnam derived from 15 years of twice-daily MODIS satellite observations [8]. Bottom: Mean annual cloud cover for the region in 12 months.](image1)

![Figure 5: Vegetation cover (in percentage) over the North Vietnam [9].](image2)

![Figure 6: Histogram of Sentinel-1 VH polarized backscatter coefficient in one region located in the North Vietnam before (blue) and after (red) the flood event. The small figure zooms to the threshold (T = -21.5 dB) to separate water and non-water pixels.](image3)
RESULTS
This section focuses on analyzing inundated areas in Thanh Hoa province because it was the region damaged the most by the flood event from 9-14 October 2017 [5]. In Thanh Hoa, there were 21 dead or missing; ~15,000 hectares of rice, crops and ~11,000 hectares of aquaculture were flooded or damaged. At the same time, there were ~17,300 pigs and more than 600,000 dead poultry. Figure 8-left shows an inundated map of the region derived from SAR Sentinel-1 observations at 30 m spatial resolution. Yellow color presents flood inundation areas, while blue color presents surface waters existing on both 7 and 10 October 2017. Total inundated area is ~360 km², corresponds to ~10% of the area. Flooded areas are mostly located along the coast line, and near rivers and lakes. However, the inundated map is produced based on the simple threshold method applied to the SAR Sentinel-1 VH polarized images, inundation results are very sensitive to the change of the threshold. The total inundated area increases (or decreases) by 14%-16% when the threshold is increased (or decreased) by 0.5 dB. For validation, a surface water map of the region derived from a free-cloud Landsat-8 NDWI image is used as a reference map (Figure 8-right). As already mentioned, Landsat-8 observations were acquired 2 months before the flood event because of the cloud contamination constraint. SAR-derived permanent surface water extent (blue) is very similar to that derived from Landsat-8 images. Main river branches and lakes are correctly detected. However, the SAR-derived methodology has difficulties detecting small river branches (top right of the region) although they are clearly detected with Landsat-8 images. It could be a consequence after Sentinel-1 images are re-gridded from its original spatial resolution to 30 m to match with Landsat-8 images. Sizes of the bottom left lakes are bigger in the SAR-derived map than in the Landsat-derived one. It is because of the time difference when Sentinel-1 and Landsat-8 observations were acquired. The same techniques are applied to detect flooded areas in two other provinces (Ninh Binh and Nghe An). Results are shown in Figure 9, but free-cloud Landsat-8 images are not available for comparison in these two locations. It is clear that flooded areas are less extended in these two regions, compared to what happened in Thanh Hoa.

CONCLUSIONS AND PERSPECTIVES
This paper highlights a direct application of the SAR Sentinel-1 observation in detecting open water bodies, and especially in mapping flooded areas over tropical areas (like in the North Vietnam). It also indicates clear advantages of SAR satellite observations in flood detection, compared to optical satellite observations due to its cloud penetration ability. The flood from 9-14 October 2017 in the North Vietnam is chosen to study as it was one of the most damaging disasters in the region in 2017. Pre- and post-event surface water maps derived from SAR Sentinel-1 VH polarized images, are analyzed and compared to identify permanent surface water bodies, as well as flood inundation areas. SAR-derived surface water maps are in good agreement compared to results derived from free-cloud Landsat8 data, although their acquiring time was 2 months apart. This study shows strong potential of the Sentinel-1 mission in detecting open water bodies, especially over tropical regions. Results from this study are useful for managers, decision-makes or insurance companies to identify effected areas, as well as to quantify damages after the flood events occurred. Future works will focus on improvement of the algorithm to optimize the classification methodology by finding the best threshold to classify water and non-water pixels in different types of environment. SAR satellite data can also be used to monitor soil moisture regularly, and warnings can be sent to the community if the soil moisture is observed to be saturated because it is likely that floods can occur if there is precipitation in near future.
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REFERENCES


