GENERATING FLOOD PROBABILITY MAP BASED ON COMBINED USE OF SYNTHETIC APERTURE RADAR AND OPTICAL IMAGERY

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ABSTRACT

Despite a lot of efforts to respond flood hazards with remote sensing data, it is still difficult to generate an accurate flood map using solely optical or radar imagery. While optical data is relatively high-resolution and does not suffer from speckle noise compared to radar data, it is very likely to be impacted by cloud and shadow. On the other hand, radar imagery can be used in all weather conditions due to its capability of penetrating clouds. Although a significant improvement of flood monitoring capability is achieved by using radar data, it is still challenging to map urban floods because of strong backscattering by man-made structures. Therefore, complementary use of optical and radar imagery in flood response is required, particularly in urban areas. In this study, we have adopted the Bayesian Joint Probability function to combine two different flood products generated from SAR and optical imagery. Flood detection with SAR data relies on the difference of backscatter signals between standing water and rougher land surface, while a Normalized Difference Water Index (NDWI) approach is used for optical data. Specifically, Planet Dove data with its 3m spatial resolution is used with higher weight values to detect flood extent in urban areas.

Index Terms— *Floods, Urban Flood map, Joint-probability function, Normalized Difference Water Index*

1. INTRODUCTION

Floods are most common disasters which can be triggered by hydro-meteorological hazards. According to the International Disaster Charter activations since 2000, floods are the most frequent type of disasters around the world [1]. This means that floods are one of the most important disasters that we have to monitor.

Optical satellites have been used a lot to make flood maps, but frequently they don't work well in certain weather conditions such as heavy clouds. Synthetic aperture radar (SAR) imagery, meanwhile, has strong advantage in terms of weather conditions, therefore, radar data is used to complement the products from optical imagery.

However, flood mapping with radar imagery is still challenging for urban areas due to the interference of man-made structures. On the other hands, very high resolution optical imagery such as DigitalGlobe's or PlanetScope data can produce an acceptable level of flood products over urban areas. In order to use the both complementary characteristics of optical and SAR imagery, many studies have been focusing on fusion of the different sensors [2]-[4].

Here, we propose a simple way of producing flood maps by the combined use of SAR and very high resolution optical imagery. The joint probability function approach has been adopted to combine two independent flood products. The proposed method will be able to provide more accurate flood maps, specifically in urban areas.

2. METHOD

2.1 Generating Flood Extent Map

Flood extent detection with SAR imagery relies on the differences in physical interaction between smooth standing water and the rough land surface. Due to the specular reflection over standing water the returned signal strength to the side-looking antenna is minimal in all polarizations as long as the water surface is still. On the other hand, the rougher land surface has a larger signal return to the radar. Based on this, we generate maps of the water extent due to

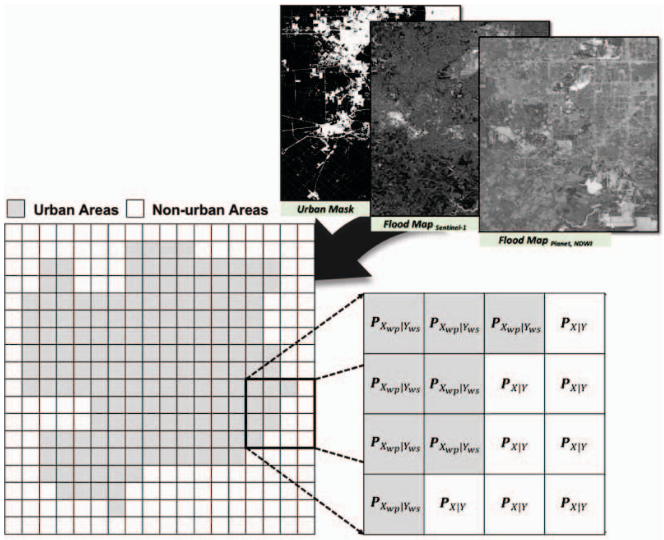

Fig 1. Diagram showing combining two different flood products generated from optical and SAR imagery. Weighted joint-probability functions were applied for urban areas classified based on the USGS land use map.

significant decrease ($\delta\sigma° \leq 3dB$) of backscattered radar signal over flood area.

To generate flood extent map in optical imagery, spectral ratios are used, as this removes the common error sources such as radiometric calibration or atmosphere impacting both bands. Normalized difference water index (NDWI) is a spectral ratio indicating presence of liquid water. We use green and NIR bands of PlanetScope imagery to calculate NDWI, defined by [5]:

$$NDWI = \frac{(X_{green} - X_{nir})}{(X_{green} + X_{nir})} \quad (1)$$

2.2 Weighted Joint-probability Function

The Bayesian Joint Probability function has been adopted to combine two independent probability maps as:

$$\boldsymbol{P}_{X|Y}(X,\, Y) = \frac{\boldsymbol{P}(X)\cdot\boldsymbol{P}(Y)}{\boldsymbol{P}(X)\cdot\boldsymbol{P}(Y)+[1-\boldsymbol{P}(X)]\cdot[1-\boldsymbol{P}(Y)]} \quad (2)$$

$$\text{with} \begin{cases} \boldsymbol{P}(X)_{planet,\ NDWI} & = 0 < f(x) < 1 \\ \boldsymbol{P}(Y)_{Sentinel,\ \sigma°} & = 0 < f(y) < 1 \end{cases}$$

$$\boldsymbol{P}\,(X,\, Y) = \begin{cases} \boldsymbol{P}_{X|Y}(X,\, Y), & Urban\ Mask = 0 \\ \boldsymbol{P}_{X|Y}(X_{wp},\, Y_{ws}), & Urban\ Mask = 1 \end{cases} \quad (3)$$

Where $\boldsymbol{P}(X)$ and $\boldsymbol{P}(Y)$ are probabilities of floods estimated from PlanetScope and Sentinel-1 SAR imagery, respectively. The land cover map provided from USGS was used to create urban mask layer, and the weighed joint probability function has been applied for urban areas. X_{wp} and Y_{ws} are weighted probabilities of PlanetScope and Sentinel products, respectively. If we equally trust both probability maps, then weighting factors $ws = wn = 1$. In case we trust one less, the weighting factor of that observation is lower than 1, and the impact of that observation is less. In order to find the optimal weighting factors of the observations, we have generated the joint probability maps by applying different weighting factors.

3. RESULT

We applied the proposed method for flooded areas near Houston, TX, due to the Hurricane Harvey. The pre- and post- imagery of Sentinel-1 were acquired on August 18 and August 30, 2017, respectively,

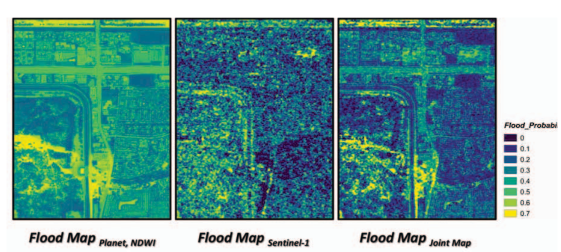

Fig 2. Flood maps in urban area generated from Planet, Sentinel-1, and Joint-probability maps.

from the descending orbit. PlanetScope imagery used in this study was captured on August 31, 2017, which nearly corresponds to the Sentinel-1 acquisition time.

Figure 2 shows the results of flood extent detection in urban area generated from Planet NDWI map, Sentinel-1 amplitude change map, and comprehensive use of both independent maps. As can be seen from the joint probability map, flooded areas are more clearly recognized with less noise compared to SAR-derived product. It is also confirmed that false alarms in Planet-derived product are reduced from the joint map.

Figure 3 shows results over a rural area. Similar to the results over the urban area, more distinct flood extents can be recognized from the product by the joint probability distribution method.

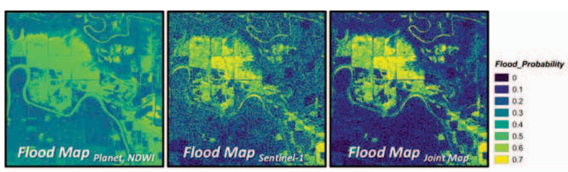

Fig 3. Flood maps in rural area generated from Planet, Sentinel-1, and Joint-probability maps.

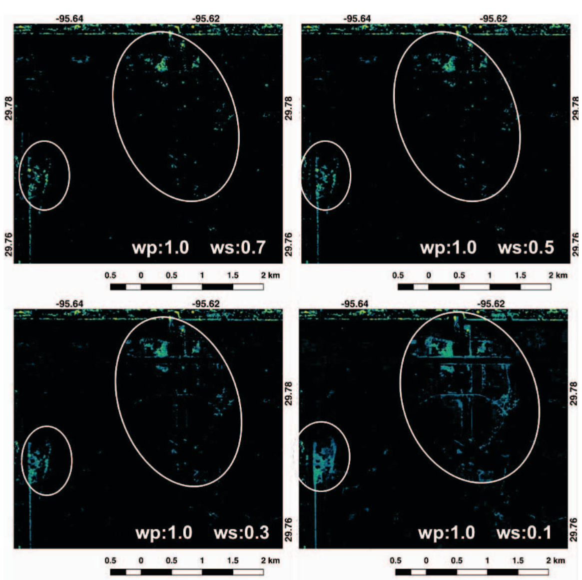

Fig 4. Test results of flood mapping in urban area by weighted joint probability approach. Four di

Flood extent in urban area is hard to detect by using solely SAR-derived product due to the double bounce caused by man-made structures. Considering this lower effectiveness of SAR-derived flood map, different weighting factors have been provided to two independent probability maps. Figure 4 shows the preliminary test results of applying different weighting factors. As can be seen in Fig. 4, applying the lower weighting factor to SAR-derived flood map shows clearer flood extent.

4. DISCUSSIONS AND CONCLUSIONS

We proposed an effective flood mapping method based on the comprehensive use of optical and SAR imagery using the Bayesian Joint Probability function approach. The proposed method results in generation of the enhanced flood extent map by suppressing false alarms in optical imagery and speckle noises in SAR imagery. The weighted joint probability function was also applied for urban area, and it confirmed that the lower weighting values on SAR products worked well for identifying urban flooding.

There may be limited simultaneous observations over the same area from both optical and SAR sensors. For that reason, the proposed method might not be ideal for rapid disaster response. However, it will be helpful over long-lasting flood events or analyzing the restoration process providing more precise and accurate flood maps.

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