OPERATIONAL AGRICULTURAL FLOOD MONITORING WITH SENTINEL-1 SYNTHETIC APERTURE RADAR

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ABSTRACT

Agricultural flood monitoring is important for food security and economic stability. Synthetic Aperture Radar (SAR) has the advantage over optical data by operating at wavelengths not impeded by cloud cover or a lack of illumination. This characteristic makes SAR a potential alternative to optical sensors for agricultural flood monitoring during disasters. The purpose of this study is to assess the effectiveness of using freely available Copernicus Sentinel-1 SAR data for operational agricultural flood monitoring in the United States (U.S.). The operational detection of flood inundation was tested during Hurricane Harvey in 2017, which resulted in significant flooding over Texas and Louisiana, U.S. This paper presents 1) the agricultural flood monitoring method that utilizes Sentinel-1 SAR, the NASS 2016 Cultivated Layer, and the NASS 2016 and 2017 Cropland Data Layers; 2) flood detection validation results and 3) inundated cropland and pasture acreage estimates. The study shows that Sentinel-1 SAR is an effective and valuable data source for operational disaster assessment of agriculture.

Index Terms— *Sentinel-1, Synthetic Aperture Radar, Agriculture Flood Monitoring, Flood Detection, Hurricane Harvey*

1. INTRODUCTION

Agricultural flood monitoring is important for food security and economic stability and is of significant interest to the United States Department of Agriculture (USDA) National Agricultural Statistics Service (NASS). In agricultural remote sensing applications, optical sensor data are traditionally used for acreage, yield and crop condition assessments. However, optical data are affected by cloud cover and cannot acquire useful data during the night. Cloud-free optical imagery is difficult to obtain during the flood event period. This limits the capability to assess the flood disaster event in a timely manner. Synthetic Aperture Radar (SAR), however, can penetrate cloud cover and acquire imagery day or night, which makes it particularly useful for flood disaster monitoring. A variety of SAR techniques have been used successfully since the 1990s to map flooding extent including visual interpretation [1-3], image thresholding [1, 4, 5], automated classification [6, 7], texture algorithms [5], change detection methods [8, 9] and principle components analysis [10]. The application of SAR data to map flooding extent has grown over the past decade which coincides with the launch of fine spatial resolution SAR sensors including Terra SAR-X, COSMO-Sky Med, RadarSat 2 and Sentinel-1 A and B.

The objective of this study is to assess the effectiveness of using Copernicus C-band Sentinel-1 SAR data for operational agricultural flood monitoring in the United States (U.S.) by developing and implementing an operational flood detection procedure. Freely available Sentinel-1 SAR data offers a unique opportunity for affordable operational flood detection of agricultural areas in near real-time.

The Hurricane Harvey disaster event was selected as a case study for this assessment. Hurricane Harvey struck areas of Texas (TX) and Louisiana (LA), U.S. from August 25 – August 31, 2017. Flooding was extensive with 132 cm of rain recorded in Cedar Bayou, TX and 120 cm in Beaumont, TX [11]. NASS was interested in quantifying the extent of flooding over cropland and pasture in near real-time. Consequently, a recently developed agricultural flood monitoring procedure based on Sentinel-1 SAR data was implemented in response to the flood event.

This paper describes a procedure for agricultural flood monitoring based on Sentinel-1 SAR data. The NASS 2016 Cultivated Layer is used to define cropland and the NASS 2017 Cropland Data Layer (CDL) is used to identify the specific crops planted in 2017. A region within TX and LA, which is approximately 8433 km^2 (Fig. 1), is selected as the study area for this assessment because this is the region most heavily impacted by the storm. Predominant crops in the area include corn, cotton, rice and sorghum. The inundated cropland, pasture hay and individual crop types are detected and the acreages are then estimated. The flood mapping results are validated with the manually derived reference data.

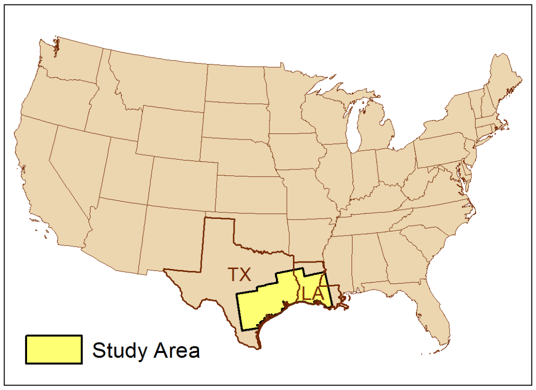

Fig. 1. Texas (TX) and Louisiana (LA) U.S. – Region impacted by Hurricane Harvey flooding and study area (bright yellow) for agricultural flood monitoring assessment.

2. DATA AND SCOPE

2.1. Sentinel-1 Synthetic Aperture Radar

The Sentinel-1 constellation includes two polar-orbiting C-band SAR satellites (Sentinel-1A and Sentinel-1B). Sentinel-1A data, used in this study, are interferometric wide swath (250 km); Level-1 ground range detected products which have been multi-looked and projected to ground range; 5x20 m spatial resolution and dual polarization (VV and HH). Pre-flood imagery acquired on July 31, August 5, August 19 and August 22, 2017 and post-flood imagery acquired on August 29, August 31, September 3 and September 5, 2017 were used to identify changes in inundation over agricultural land. Sentinel 1 data have a short latency with all data available for download within 24 hours of acquisition.

2.2. NASS Cropland Data Layers and Cultivated Layer

The Cropland Data Layer is an annual georeferenced, crop-specific land cover classification covering the continental U.S. at a 30 m resolution [12]. The Cultivated Layer is created using five years of historic CDLs [13-14]. The CDLs are created using the decision tree classifier Rulequest See5.0 software, and ERDAS Imagine software, which was also used in the pre- and post-processing of all raster data. Environmental Systems Research Institute (ESRI) ArcGIS software was used to prepare the vector-based training and validation data. Agricultural training and validation data were derived from the Farm Service Agency Common Land Unit Program. The United States Geological Survey National Land Cover Database (NLCD) was used as non-agricultural training and validation data.

2.3. Ground Reference Validation data

Flood inundation detection results were validated from manually-derived ground reference data which were defined using Sentinel-1 SAR, Landsat 7 ETM+ Level 1, Landsat 8 TIRS Level 1 and Sentinel-2 imagery. Pre-flood imagery used in defining the ground reference data was acquired between July 1, 2017 and August 15, 2017. Post-flood imagery was acquired between August 27, 2017 and September 11, 2017 (Fig. 2). All imagery has between 0 – 15% cloud cover.

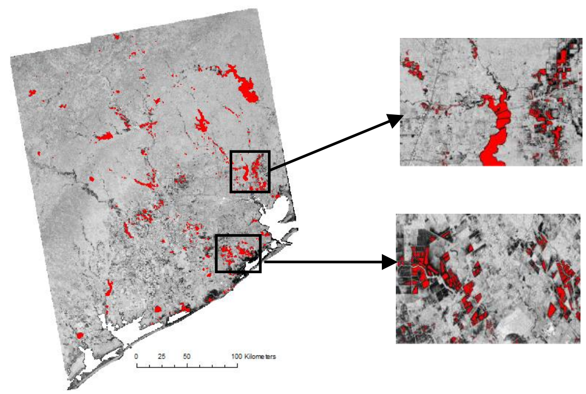

Fig. 2. Sentinel-1A imagery acquired on August 29, 2017 over the city of Houston, TX and surrounding area. Manually-derived water validation data (red polygons) are overlaying the imagery. The top zoom is an area in Harris County, TX and the bottom zoom is an area in Brazoria County, TX.

3. METHODOLOGY

3.1. Agricultural Flood Monitoring Procedure

All Sentinel-1A images are first preprocessed with calibration to sigma naught, Range Doppler terrain correction and de-speckling (median 5x5 speckle filter) using the open source Sentinel Application Platform (SNAP) toolbox, which can be downloaded from the Copernicus Services Access Hub https://scihub.copernicus.eu/. The preprocessed images are mosaicked using Hexagon's ERDAS Imagine 2016 software. A log transformation is then applied to all individual scenes to enhance the lower gray level value (dark) water body pixels and compress the higher pixel values of other land cover types as shown in Figure 3. The log image histogram is evaluated to determine the threshold for binary recoding into water and other categories.

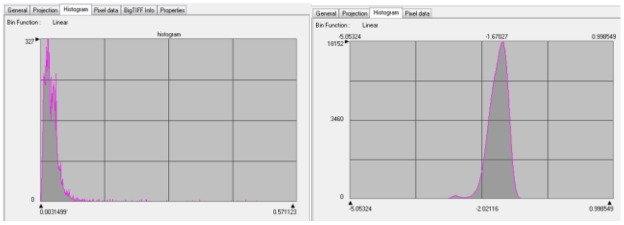

Fig. 3. *Left* – Original Sentinel-1 A image histogram before log transformation, *Right* - Image histogram after log transformation.

Inundated areas or water bodies in the Sentinel-1 images as shown in Fig. 4A and 4B, are segmented with the manual thresholding method for both pre- (August 5, 2017) and post-flood (August 29, 2017) event images. The thresholding inundated areas or water bodies are represented in blue as shown in Fig. 4C and 4D. Fig. 4E shows cropland (green), which is defined using the NASS Cultivated Layer, and Pasture/Hay (light brown), which is defined using the NASS 2016 CDL. A change assessment between pre- and post-flood thresholded images is conducted to locate and identify inundated areas due to flooding as shown in Fig. 4F. Red indicates inundated cropland and yellow indicates inundated pasture/hay.

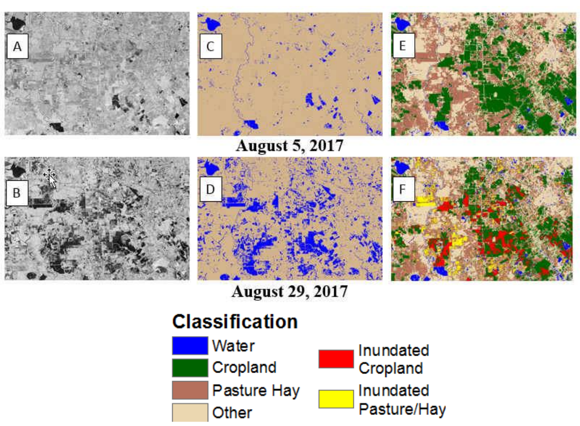

Fig. 4. (A) - Pre-flood Sentinel-1A image near Houston TX; (B) - Post flood Sentinel 1-A image, (C) - Manual thresholding result of pre-flood image classification (water – blue, other – tan); (D) - Manual thresholding result of post flood image classification; (E) - Overlay NASS 2016 Cultivated Layer and Pasture/Hay; (F) Post flood cropland classification which identifies cropland inundated based on change detection between pre- and post-flood images.

Resulting crop inundation layers are intersected with the NASS 2017 CDL to identify specific crops that are inundated by flooding. Inundated cropland, pasture, and specific crop pixels, identified in the 2017 CDL, are counted to estimate the extent of flooding of agricultural land.

4. RESULTS AND DISCUSSION

Results of the Sentinel-1 SAR agricultural flood monitoring analysis show that approximately 290,314 hectares of cropland in the study area were inundated by flooding during Hurricane Harvey. This represents 10.16% of total cropland. Further, 140,763 hectares of pasture/hay or 3.68% of total pasture/hay were inundated. Table 1 shows the specific crop types of interest that were inundated. However, some fields may have already been harvested before Hurricane Harvey occurred. These estimates were derived by intersecting the Hurricane Harvey post flood cropland classification (shown in Figure 5) with the 2017 CDL and converting the pixel size (30 meters) to hectares.

The detected water areas in the pre- and post-flood crop classifications were validated using the manually derived ground reference validation data (Fig. 2). Across the entire study area, 329,631 hectares of water bodies were delineated in the pre-flood validation file and 354,598 hectares of water bodies were delineated in the post-flood validation file. Greater than 95% producer accuracies were recorded.

Table 1. Total hectares, inundated hectares and percent inundated of major crops and pasture hay in the study area,

Crop Type	Total (hectares)	Inundated (hectares)	Percent Inundated
Corn	424,373	61,710	14.54%
Cotton	382,422	55,547	14.53%
Fallow/Idle Cropland	443,348	41,965	9.47%
Oats	50,866	5,283	10.39%
Rice	268,054	19,923	7.43%
Sorghum	251,507	64,687	25.72%
Winter Wheat	37,315	4,271	11.45%
Total Cropland	2,857,651	290,314	10.16%
Pasture/Hay	3,823,615	140,763	3.68%

5. CONCLUSION

Sentinel-1 A C-band SAR is a valuable data source to conduct accurate, efficient, timely and affordable agricultural flood monitoring in an operational setting. Sentinel-1A SAR's cloud penetration capability and short latency enabled us to effectively detect and estimate the extent of cropland, pasture hay and specific crops inundated during and shortly after the Hurricane Harvey flood event. The operational process based on thresholding is effective and straightforward and provides accurate results with accuracies over 95% as assessed using independent, manually-derived reference data based on image interpretation of both SAR and optical data. Combining the flood classifications with the NASS 2016 Cultivated Layer and 2017 CDL enables the estimation of inundated cropland, pasture hay and specific crops in near real-time. The preliminary estimates of inundated cropland, pasture and crops are delivered to USDA NASS within 48 hours of the flood event. This study shows that the Sentinel-1A based agricultural flood monitoring is sufficiently accurate, affordable and efficient for operational use, and can provide decision makers with an accurate and timely estimate of the impact of flooding on agricultural land.

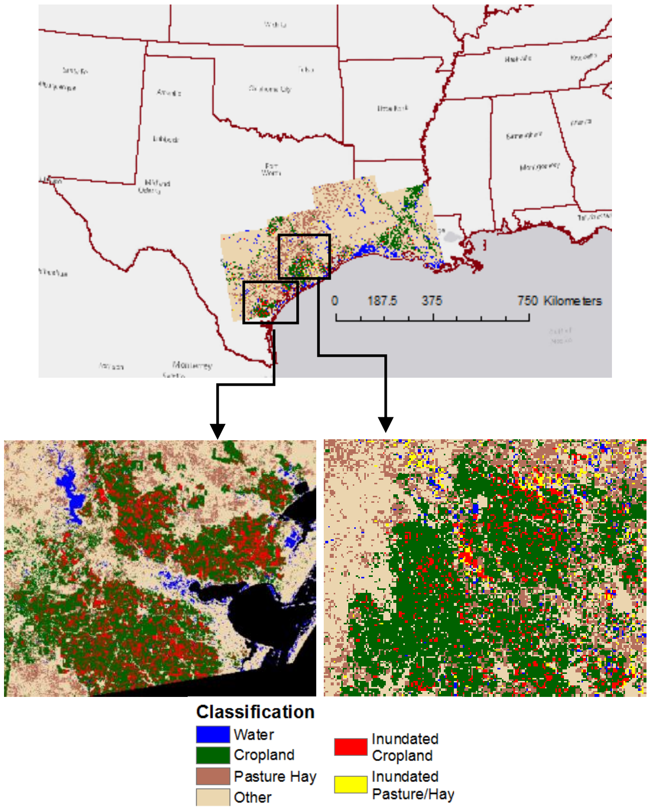

Fig. 5. Hurricane Harvey post-flood cropland classification which identifies cropland and pasture that was inundated from Hurricane Harvey.

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