NH13C-0823

Department of Geological Sciences

NH13C-0823

Department of Geological Sciences

Comprehensive Severe Weather Impact Assessment and Monitoring using Synthetic Aperture Radar and Auxiliary Data

Esayas Gebremichael[1], Andrew Molthan[2], Jordan R Bell[2], Lori A Schultz[3], Christopher Hain[2]

1. Department of Geological Sciences, Texas Christian University, Fort Worth, TX 2. NASA Marshall Space Flight Center, Huntsville, AL 3. University of Alabama in Huntsville, Huntsville, AL

ABSTRACT

Remote sensing datasets, particularly acquired by Synthetic Aperture Radar (SAR) sensors, have become increasingly important in severe weather disaster impact studies given their ability to observe the Earth largely irrespective of weather and sunlight conditions. The reliability of existing SAR change detection products applied on a pair of SAR images is constrained by the limitation of current methods to differentiate and classify disaster-specific changes from anthropogenic surface alterations. Moreover, the inherent properties of the sensors, variations in SAR backscatter due to changes in surface conditions, and other factors exacerbate these limitations. We proposed a novel procedure expanding on earlier SAR-based change detection methods to exclude anthropogenic alterations and other sources of ambiguity that might lead to inaccurate mapping of the impacts of severe weather disasters. We applied the proposed procedure that is based on long-term interferometric and amplitude-based change detection analyses of Sentinel-1 SAR imagery to two study sites recently impacted by severe weather disasters (Flooding post severe weather events in urban centers; Hailstorm damage on crops). For the first case study, Sentinel-1 SLC scenes from two flood events in the Houston area (April 2016 flooding event and Hurricane Harvey of August-September 2017) were used to construct a flood map depicting areas repeatedly affected by the flood. Pixels with consistent coherence values in the pre-disaster coherence stack were retained for comparison with the pre- and post-disaster coherence stack and pixels with significant decline (greater than 60%) in coherence values were retained in the final flood map. The findings of the applied technique were calibrated and validated through datasets from NOAA/NWS Service storm reports, aerial imaging (NOAA and Civil Air Patrol), Federal Emergency Management Agency (FEMA) reporting, and targeted collections of NASA's L-band UAVSAR data. Findings and products derived from the adopted methodology can be useful in disaster response and mitigation activities.

BACKGROUND

- Hydrometeorological events (severe weather) comprised of heavy rainfall, flooding, tornadoes, hail, and strong winds are often accompanied by extensive, lingering cloud cover and night-time conditions that prevent land surface mapping from optical sensors.
- Synthetic Aperture Radar (SAR) remote sensing complements optical approaches in natural hazard and disaster-related studies by acquiring Earth observations in day, night, and widely varying weather conditions .
- Results and interpretations based on individual SAR scenes are complex, affected by various forms and sources of errors and factors that might impact the reliability of the derived products.
- Change detection methods that highlight temporal changes in the property and reflectivity of the same area on the Earth's surface at different times have proven to be more robust in detecting surface changes using multiple SAR acquisitions .
- Analyses based on multiple SAR acquisitions will be a robust way of mapping areas repeatedly impacted by severe weather induced floods, such as parts of Houston city, by eliminating false signals that might arise due anthropogenic surface alterations/natural processes.

OBJECTIVES

The purpose of this study is to generate flood risk map (map recurrently flood affected areas) of Houston city and surroundings by applying a novel procedure to exclude anthropogenic alterations and other sources of ambiguity that might lead to inaccurate mapping .

HOUSTON CITY AND SURROUNDINGS

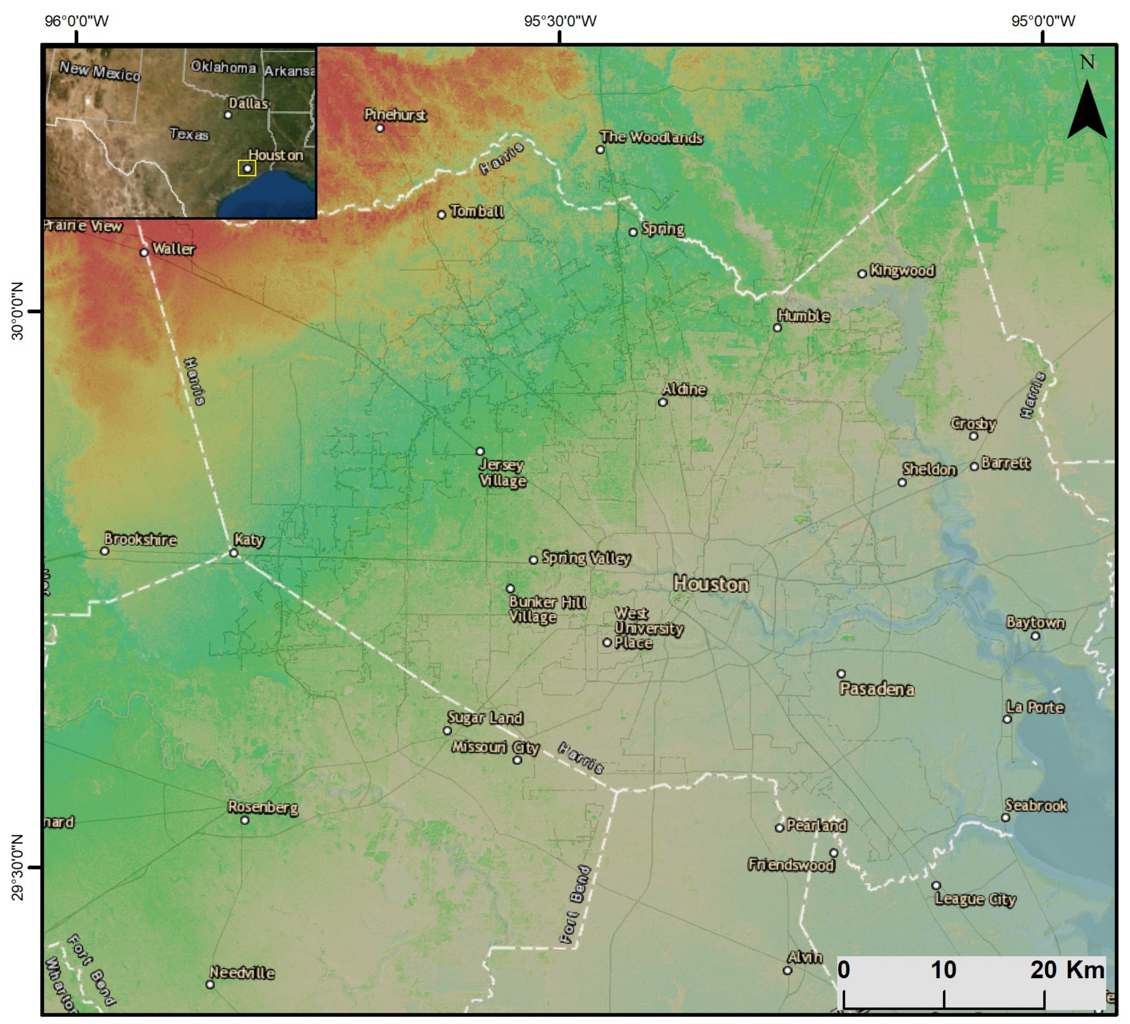


Fig.1: Houston city and surrounding area.

- Houston city and surrounding areas have recurrently been adversely impacted by severe weather-induced flooding. Recent major floods/severe weathers include:
  - The Houston Tax Day flood (April 2016)
  - Hurricane Harvey (September 2017)
  - Tropical Storm Imelda (September 2019)
- Hurricane Harvey (2017) sparked extreme flooding in Houston city and surrounding areas causing an estimated economic damage worth $125 billion worth damage (second only to Hurricane Katrina in the period of record) and the deadliest hurricane to hit Texas since 1961 (NOAA, 2018).
- With the prevalence of routinely acquired (multi-temporal) and wide swath satellite imagery, it is possible to map areas in the study area that are recurrently affected by severe weather induced floods. Such results will benefit planners as well as in post-disaster response and recovery activities.

DATASETS

Dataset/Source	Intended purpose
Sentinel –1 A/B	• Generate flood/inundation mapping products (all flooding events) • Validation (Tropical Storm Imelda)
L-band quad-pol Uninhabited Aerial Vehicle Synthetic Aperture Radar (UAVSAR) imagery	• Generate flood/inundation mapping products (Hurricane Harvey) • Validation
NOAA Aerial Imagery	• Validation
USGS Hazards Data Distribution System Dataset	• Validation

METHODOLOGY

- In this study, approaches were developed to address the mapping of land surface changes resulting from major flooding from periods of heavy rainfall. Interferometric Coherent Change Detection (CCD) approach was integrated with combined with ancillary datasets and methods to provide greater physical insight, calibration, and validation.

A. CCD Timeseries

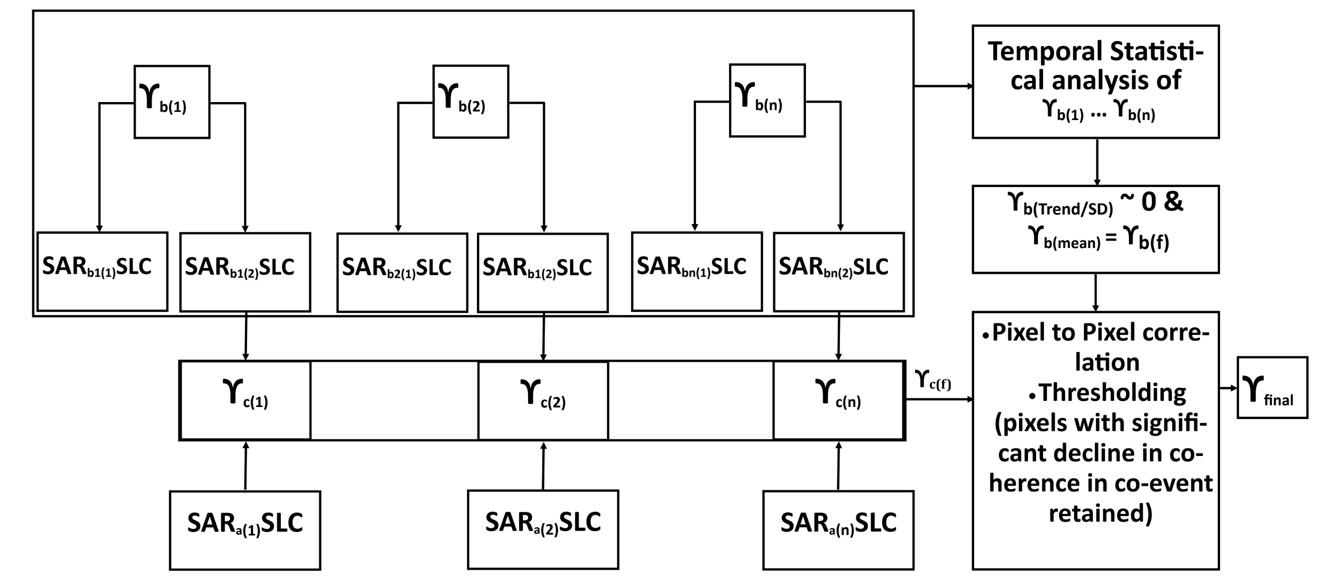


Figure 2: Flowchart portraying procedures to map inundated areas using CCD. $SAR_{bn(n)}$ and $SAR_{a(n)}$ refers to the pre- and post-disaster SAR images respectively; $\Upsilon_{b(n)}$ signifies pre-disaster while $\Upsilon_{c(n)}$ refers to co-event coherence products. $\Upsilon_{b(f)}$ and $\Upsilon_{c(f)}$ refer to (final) analyses products of the pre-event pairs, and the co-event pairs respectively. Υ_{final} denotes the final coherence change product.

- Pixels that exhibited a near constant value in the pre-event coherence stack (as evidenced from the slope of the (linear regression) trend line and SD analysis) were retained and compared with the co-event pixels. This analysis ensures that pixels whose values significantly declined in the co-event pairs represent areas impacted by flooding rather than anthropogenic surface alterations.

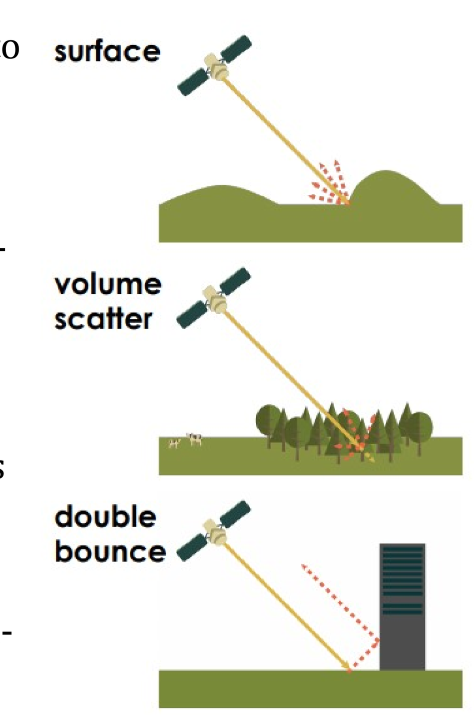
B.SAR Polarimetry

- Sentinel-1 satellite's and C-band SAR sensors are limited in their ability to penetrate the vegetation canopy to sample the underlying structure of the vegetation and surface. To validate flood detections, and develop an understanding of C-band capabilities, targeted L-band UAVSAR multiple (quadrature polarization (quad-pol) mode) polarimetric returns (in multi-looked cross products (MLC) format) were used.
- The received signals were initially extracted as a coherency matrix (T3) using PolSARpro V. 5.0.

$$T = \frac{1}{2}\left\langle \begin{bmatrix} (S_{HH}+S_{VV})(S_{HH}+S_{VV})^* & (S_{HH}+S_{VV})(S_{HH}-S_{VV})^* \\ (S_{HH}-S_{VV})(S_{HH}+S_{VV})^* & (S_{HH}-S_{VV})(S_{HH}-S_{VV})^* \end{bmatrix} \right\rangle$$

*refers to the complex conjugate , + the conjugate transpose, and ⟨⟩the spatial averaging

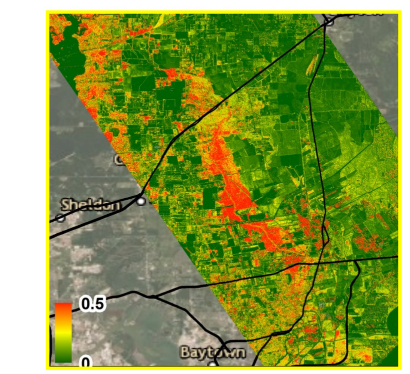
- Finally individual pixels are classified into three classes corresponding to:
  - a. double bounce—signifying corner reflector (in this case, double bounce between vegetation stalk and the underlying water indicating inundated vegetation) - designated as Freeman_Dbl
  - b. Volume scattering –signifying canopy/vegetation scatterer—designated as Freeman_Vol
  - c. surface scattering—single (odd) bounce scattering (in this case open water body) - designated as Freeman_Odd



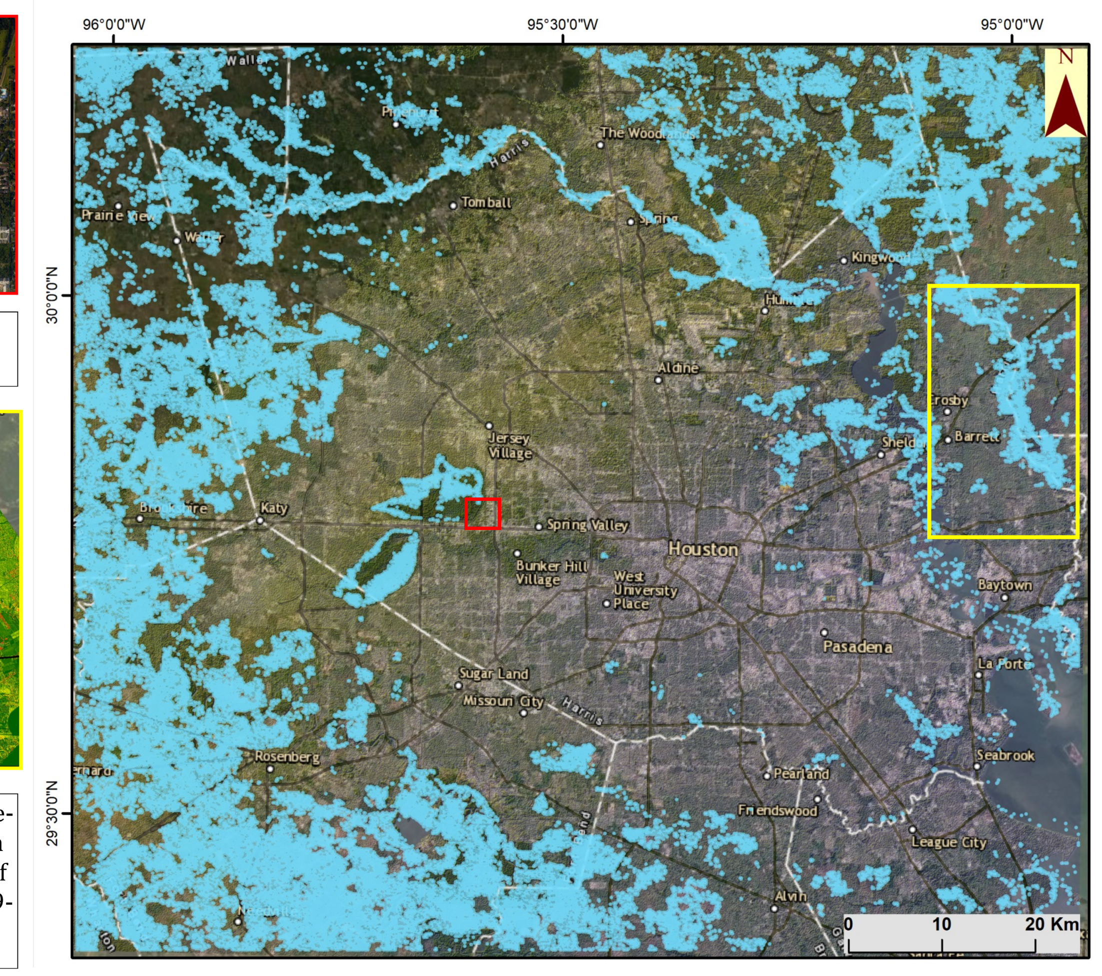
RESULTS

A. Flood Map (2016, 2017 (Hurricane Harvey) Flood Events)

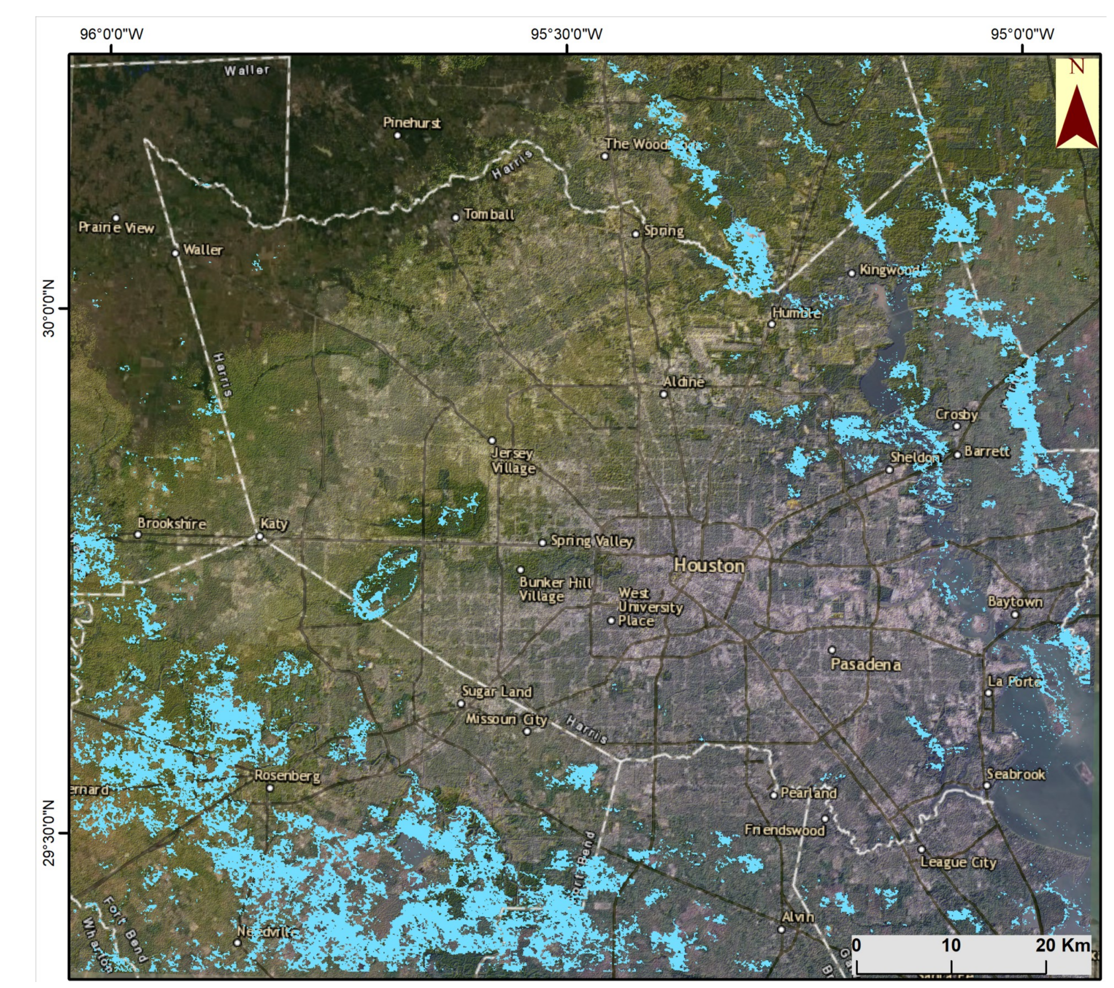
NOAA Aerial Photo (August 31, 2017)



Inundated vegetation (DBL) detected using Freeman-Durden polarimetric decomposition of UAVSAR image (Acquisition:09-02-2017; Track: 14939)



B.Tropical Storm Imelda



CONCLUSION

- Using multi-temporal Sentinel-1 imagery and adopting CCD time series analysis technique, we were able to map areas in Houston city and surroundings (that are prone to (recurrently impacted by) severe weather-induced flooding. Pixels that experience significant decline (greater than 60% of their original value) were used for analysis.
- We tested the adopted methodology on two flooding events (2016, 2017) and extended (validated) the method on the recent flood induced by Tropical Storm Imelda (although not intense and wide spread as the 2016 and 2017 flooding events) and obtained similar patterns of flooding in the storm affected areas.
- C-band based flood detection method (for inundated vegetation) largely corresponds well with L-band UAVSAR based detection.