Mapping the Extent and Magnitude of Severe Flooding Induced by Hurricanes Harvey, Irma, and Maria with Sentinel-1 SAR and InSAR Observations

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Introduction

Hurricanes can induce flooding due to both heavy rainfall and storm surge. In August and September 2017, Hurricanes Harvey, Irma and Maria made landfall over Texas, Florida and Puerto Rico causing severe flooding, which led to destruction and damage. Flood mapping is important for water management and to estimate risks and property damage. The commonly used water gauges provide high temporal records of water levels, but are normally distributed sparsely. To map flooding extent and magnitude of these extreme events, we use Synthetic Aperture Radar (SAR) observations acquired by the European satellite constellation Sentinel-1. We obtained two acquisitions from before each flooding event, a single acquisition during the hurricane, and two after each event, a total of five acquisitions for each flooding event.

Objectives

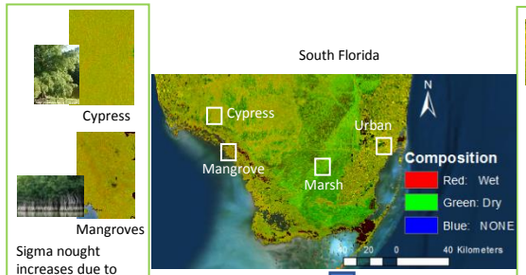
Our major objectives include:

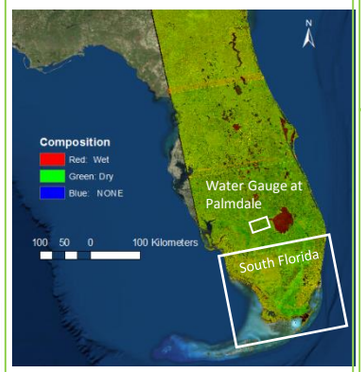
1. Map the extent of flooding induced by the Hurricanes by analyzing change of normalized radar cross section (sigma nought).
2. Detect water level change by calculating phase changes between two acquisitions, where the coherence remains high.
3. Use the available water gauges data to verify water level change result.

Data Acquisition and Preprocessing

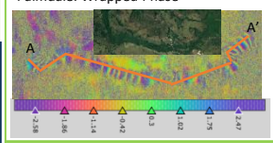
Our dataset is Sentinel-1 C band Level 1 acquisitions, which consist of Interferometric Wide (IW) swath mode Ground Range Dectection (GRD) image and Single Look Complex (SLC) image over the area of Houston, South Florida and Puerto Rico. The spatial resolution of GRD is 20*22m for range * azimuth and of SLC is 2.7-3.5 * 22m. The data were acquired with a 250km swath.

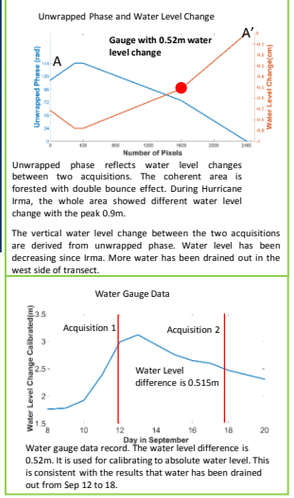
Hurricane Irma- South Florida





We generate a composition of two image layers using green and red bands to show changes of sigma nought values between acquisitions. Green band represents observations before Hurricane Irma (dry image), and the red band represents acquisition during Hurricane Irma (wet image). Green color shows sigma nought decrease, while red color shows increase.





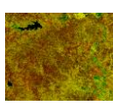
Unwrapped phase reflects water level changes between two acquisitions. The coherent area is forested with double bounce effect. During Hurricane Irma, the whole area showed different water level change with the peak 0.9m.

The vertical water level change between the two acquisitions are derived from unwrapped phase. Water level has been decreasing since Irma. More water has been drained out in the west side of transect.

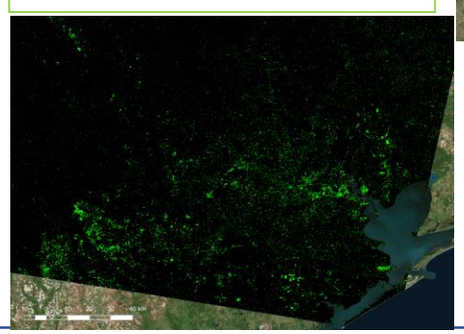
Water gauge data record. The water level difference is 0.52m. It is used for calibrating to absolute water level. This is consistent with the results that water has been drained out from Sep 12 to 18.

Hurricane Harvey- Houston

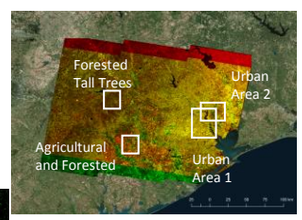
We observe green in the border of the body of water marking dry areas before the hurricane, which were inundated during the hurricane. Similar observations can be seen in the agricultural areas next to the river. Tall forested areas show a red color indicating amplitude increase, probably due to vegetation change, such as loss of foliation.



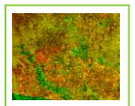
Forested Tall trees



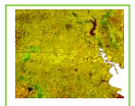
RGB Red 20170830 (wet) – Green 20170818 (dry)



Urban Area 2: Green areas along the water bodies indicate inundation. Urban regions maintain a strong backscattered signal in both acquisitions.



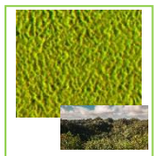
Agriculture and forested



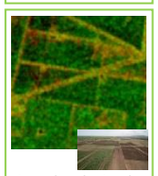
Urban Area 1

Flooding induced by Hurricane Harvey

Hurricane Maria- Puerto Rico

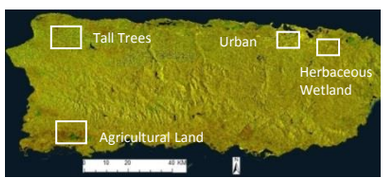


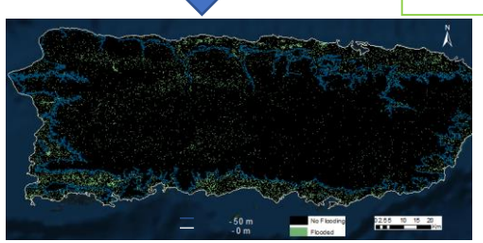
Tall Trees: Sigma nought remains the unchanged because trees are dense.



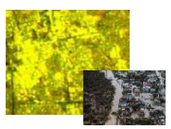
Agricultural Land: Sigma nought decreases when flat agricultural land is flooded.

RGB Red 20170922 (wet) – Green 20170916 (dry)

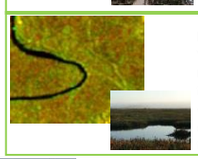




The figure on the left shows the flooded area (green area) and the 50m contour. Majority of flooded areas in Puerto Rico are located in low level area, below 50 meters.



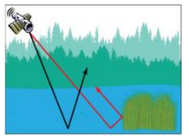
Urban Area: Sigma nought increases in flooded urban area due to double bounce from the structures.



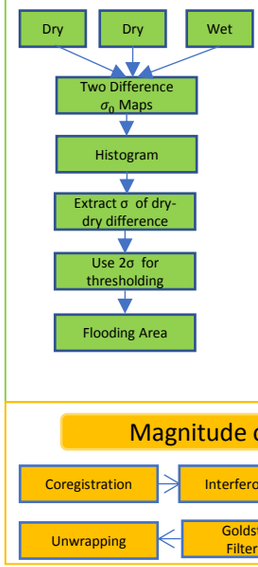
Herbaceous Wetland: Sigma nought increases in flooded herbaceous wetlands due to double bounce from trees and plants.

Methodology

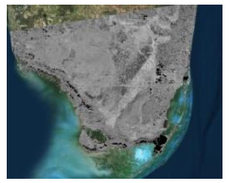
Extent of Flooding



When sparse forest is flooded, sigma nought will increase due to double bounce or decrease due to specular reflectance.



To map flooding extents, we use amplitude images from before, after and if possible during the hurricane pass. A calibration is used to convert the image raw data to backscatter coefficient, termed sigma nought.



Amplitude differential map between two images were acquired less than a month prior to the hurricane. A histogram of all pixel values is examined and a confidence level 2σ is used to define the threshold for natural variation. One of the dry image acquired just before to the hurricane and another one acquired during the hurricane to generate differential map again. Pixels value beyond the natural variation is considered to be caused by flooding.

Magnitude of Flooding

Conclusion

Preliminary results show that the three hurricanes caused flooding condition over wide areas, over both rural and urban areas.

- The extents of flooding area by Hurricane Harvey, Irma and Maria in Houston, South Florida and Puerto Rico have been mapped.
- The flooding in Everglades National Park in Florida following Hurricane Irma covered area 1087.35 km^2. Flooding in Puerto Rico's main island was limited to low flat areas covering 287.84 km^2.
- During Hurricane Irma, the phase image study area shows different water level change, with the peak water level change of 0.9m. After Irma, the water drained out from west to the east, and water level was flattened.
- Phase observation expands the measurements of water gauges to a larger meander area.

Acknowledgement:

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