Tracking hurricanes Harvey and Irma using GPS tropospheric products

POSTER G21B-0734

AGU 100 FALL MEETING San Francisco, CA | 9–13 December 2019

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Abstract

The 2017 Hurricanes season was one of the most powerful severe weather events producing catastrophic socio-economic and environmental effects on the east coast of the United States. Therefore, tracking their path accurately is extremely useful. Today Global Navigation Satellite Systems (GNSS) tropospheric products, such as Zenith Wet Delays (ZWD), and Integrated Water Vapor (IWV) are used as complementary data sets in Numerical Weather Prediction (NWP) models. In this study, we employed GPS-derived IWV and horizontal tropospheric gradient information to monitor and investigate the complicated characteristics of hurricane events in their spatial and temporal distribution using a dense ground network of GPS stations. Our results show that a surge in GPS-derived IWV occurred several hours prior to the manifestation of the major hurricanes Harvey and Irma. We used the derived GPS-derived IWV information as input to spaghetti lines weather models, allowing us to predict the paths of Harvey and Irma hurricanes. As such, a parameter directly estimated from GPS can provide an additional resource for improving the monitoring of hurricane paths.

Introduction

Extreme meteorological events like hurricanes Harvey and Irma emphasised the need for tracking using additional observational tools to mitigate the risks. GPS tropospheric products can provide useful information to understand the structure and behavior of hurricanes better[1]. The use of GPS tropospheric products for regional severe storm prediction is an application that the geodetic community wishes to promote to meteorological research groups. The main motivation for this work is to track and characterize hurricane movements using GPS-derived local maxima IWV patterns. We introduce an emprical spaghetti model [2] using GPS-derived atmospheric water vapor fields and how these fields can potentially predict the path of hurricanes. From maps of IWV fields, we have constructed a pair of geodetic coordinate representing GPS-derived IWV local-maxima every 6-hour interval. Then, we employed the spaghetti model to provide early information on where a potential tropical storm or hurricane might occur. We have also compared the temporal distribution of the GPS-derived IWV content with the precipitation value from Tropical Rainfall Measuring Mission (TRMM) and Integrated Multi-Satellite Retrievals for Global Precipitation Measurement (GPM/IMERG) satellite mission.

Data and Methods

Retrieval of IWV: We have used the zenith total delay (ZTD) obtained at the Nevada Geodetic Laboratory (NGL)[3] using GIPSY/OASIS-II software in a precise point positioning (PPP) strategy [5] for a dense array of GPS stations shown in Fig. 1a. We have calculated IWV by subtracting ZHD (from VMF grided files) from the ZTD using the formula

$$IWV = \frac{(ZTD - ZHD)}{10^{-6}(K_2' + \frac{K_3}{T_m})R_v\rho} \tag{1}$$

where K_2 and K_3 are reflectivity constants, Rv is the ideal gas constant, ρ is the density of the water vapor, and T_m is the atmospheric column mean temperature. T_m are derived from the ECMWF.

Spaghetti model: To track the movement of Harvey and Irma, we constructed the GPS-IWV map for every 6 hour. Then, we extracted the local-maxima of GPS-IWV from the maps, estimating at a location (lon_o, lat_o) of a zero crossing of the first derivative of the IWV field, $IWV \propto f(lon, lat, t = 6\ hr)$.

$$\frac{\partial IWV(lon_o, lat_o)}{\partial lon}\Big|_{t=6hr\ priori} = \frac{\partial IWV(lon_o, lat_o)}{\partial lat}\Big|_{t=6hr\ priori} = 0, \tag{2}$$

where

$$IWV_{max} = IWV(lon_o, lat_o)\ . \tag{3}$$

Further, we employed the second-derivative to determine a local-maxima IWV and its coordinates. One could visualize each line in this model to be a single strand of spaghetti that is formed by connecting the individual local maximum. To introduce sufficient variation, we added white noise to the local IWV maxima.

$$f \sim f(lon, lat) = r(lon_o, lat_o) + \xi \tag{4}$$

where r is geodetic coordinate of IWV_{max} and ξ is assumed to Gaussian distributed noise with a certain mean and variance.

Presented at the AGU Fall Meeting, San Francisco, CA | USA | 9–13 December 2019.

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Results-1

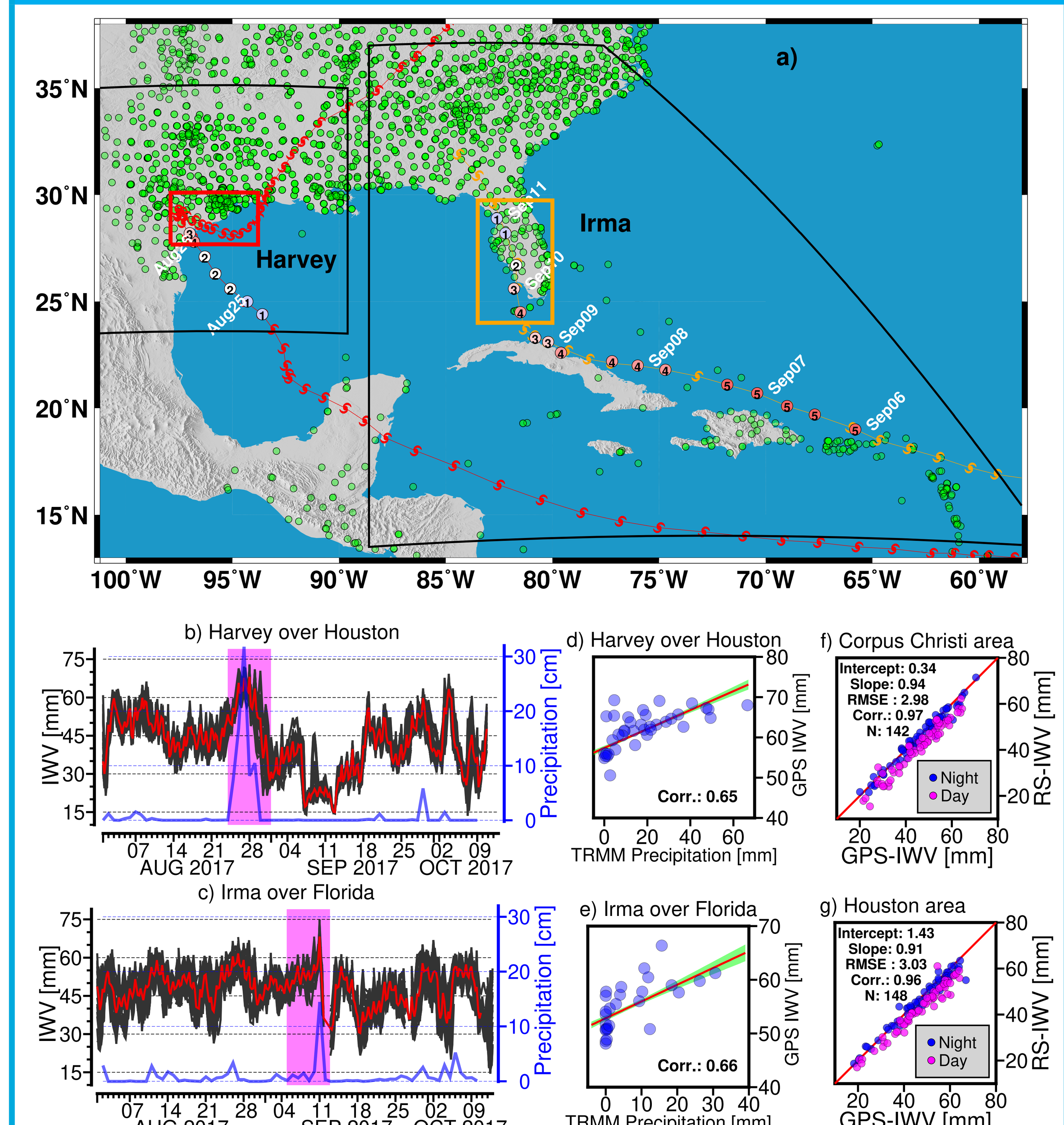

Fig.1 a) Distribution of GPS stations shown as green circles. The red and orange lines are the actual paths of hurricanes Harvey and Irma. The numbers on these lines indicate the categories of the hurricane. (**b–c**) Six hour resolution stacked time series of GPS-IWV of individual GPS stations (black-lines) and averaged (red-line) superimposed on daily GPM/IMERG precipitation (blue-line) time series for the two hurricanes: Harvey (within the red rectangle in **a**), Irma (within the orange rectangle in **a**). The magenta shaded regions illustrate the periods where each hurricane show a maximum change in GPS-IWV and precipitation. (**d–e**) scatter plots represent the regression between TRMM derived precipitation and GPS-IWV. The red line is the estimated linear regression, and the green shadow is the 95% confidence interval. Regression is carried out with a three-hour resolution over the time periods (i.e. 25–31 August 2017 for Harvey over Houston, and 6–12 September 2017 for Irma over Florida. (f) The Radiosonde station at Corpus Christi (CRP) and GPS station, TXCC, and (g) the RS station Lake Charles (LCH) at Houston and GPS station LAC1. The red line is the estimated linear regression. The number of data samples (N), Pearson correlation, slope, intercept and root mean square error are given in the legends. The blue dots indicate the data in nighttime while the magenta dots indicate the date in daytime.

Results-2

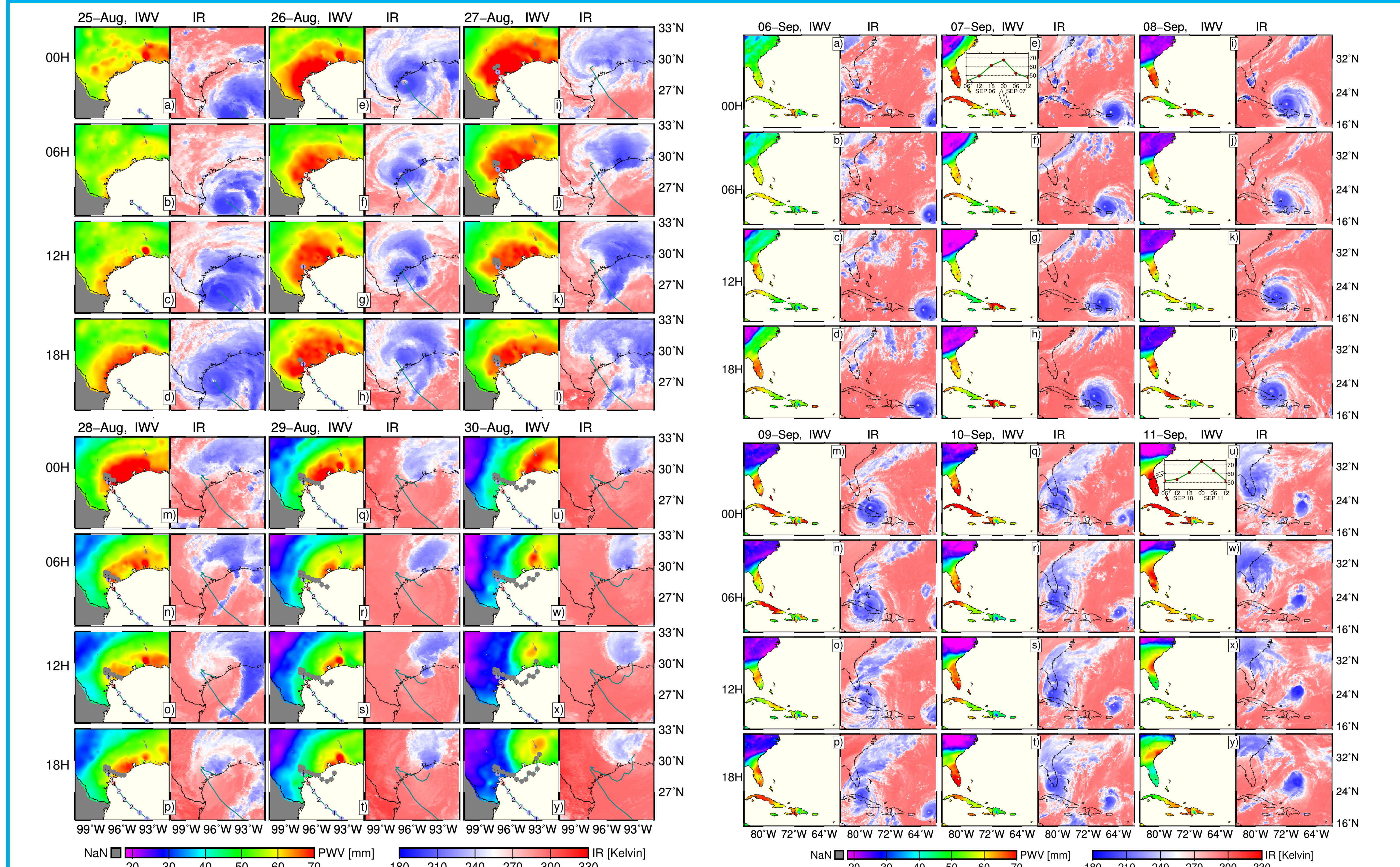

Fig.3. Hourly distribution maps of GPS-IWV and Infra-red brightness temperatures centered on Harvey (right) and Irma (left).

Tracking hurricane paths using GPS

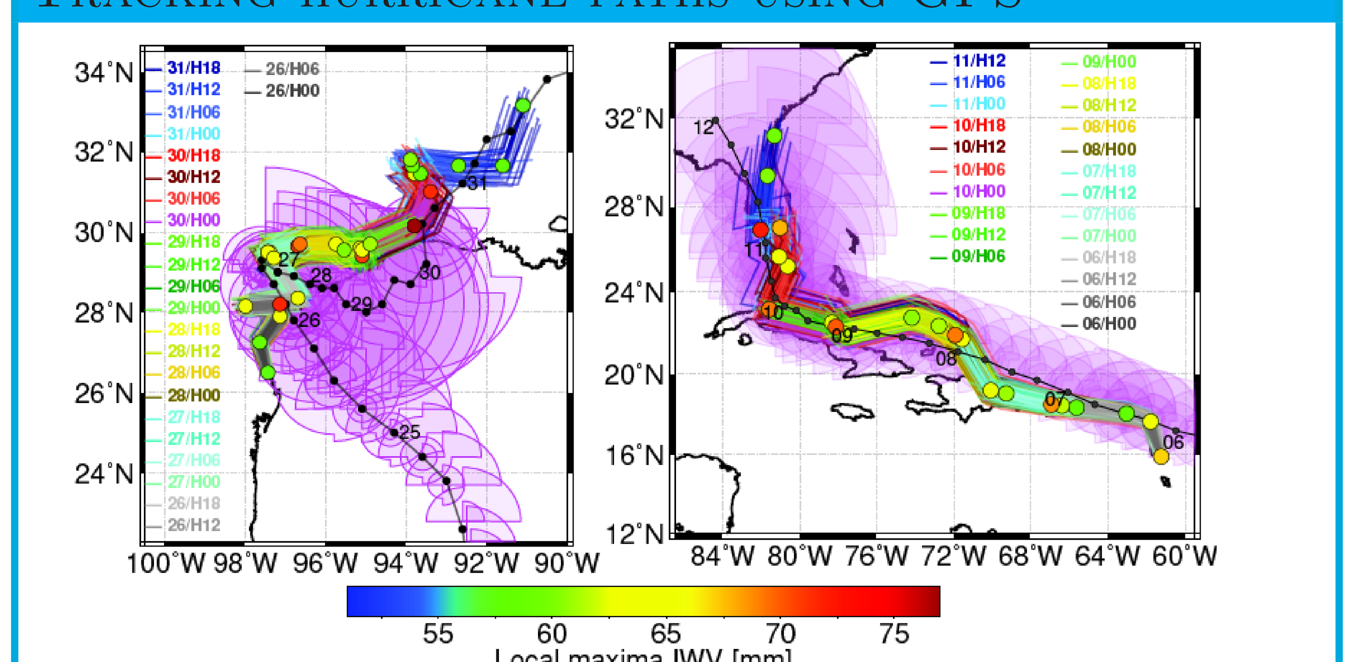

Fig.4: Spaghetti line plots (blue lines) based on local maxima GPS-IWV(colored circles) for hurricanes Harvey (left) and Irma (right). The magenta polygons show the best tracks from the National Hurricane Center (NHC) model, based on a post-storm analysis of all available data.

Discussion and summary

- An increase in GPS-IWV on average 28 mm (i.e 46 -74 mm) is commonly observed in the vicinity of the area crossed by a storm.
- We found a peak IWV before and during the arrival of the storm and be able to construct a spaghetti model to predict the potential hurricane paths.
- All our estimated local IWV maxima were shown to be within the cone of influence obtained from the National Hurricane Center (NHC) model.
- The main advantage of GPS-derived IWV is that it is possible to produce IWV distribution maps in real or near real time (i.e. less than every 15 minutes).

Acknowledgements

Support was provided by the Luxembourg National Research Funds National de la Recherche with project code O18/12909050/VAPOUR/, Foundation for Polish Science, grant no. UMO-2016/21/B/ST10/02353, and Ethiopian Space Science and Technology Institute. We acknowledgement the Nevada Geodetic Laboratory and NASA for providing the GPS tropospheric products and precipitation data, respectively.

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