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Improved Monitoring and Tracking Hurricanes using GPS Atmospheric Water Vapour

Military University of Technology

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Abstract

Hurricanes produce devastating economic, social and environmental impacts in the areas they strike. The 2017 Atlantic hurricane season was one of the most active on record, witnessing the third highest number of major hurricanes in a single year of the past century, surpassed only by the 1961 and 2005 seasons. Accurately predicting their path and intensity is therefore extremely valuable. The Global Positioning System (GPS) captures water vapour distributions in the atmosphere within a few millimetres of accuracy under all weather conditions and in real time. We used an integrated water vapour (IWV) retrieved with GPS receiver to track and explore the complex properties of storm events in their spatial and temporal distribution, using a network of ground-based GPS receivers. Our results show that a surge in GPS-retrieved IWV occurred several hours prior to the manifestation of the three major hurricanes to hit the USA's East Coast in 2017 and 2018, namely Florence, Harvey and Irma. For our ensemble forecasts, we used the derived GPS-retrieved IWV data as input to spaghetti lines empirical weather models, enabling us to predict the paths of hurricanes Harvey and Irma. Hence, a directly estimable parameter derived from GPS can provide an additional resource for improving the monitoring of hurricane paths, hitherto not reported. The GPS-retrieved IWV and satellite rainfall products Global Precipitation Measurement Integrated MultisatellitE Retrievals and Tropical Rainfall Measuring Mission (GPM IMERG and TRMM) exhibit a strong coupling associated with the footprint of the hurricanes. A correlation of 65 % between the two parameters was found.

Introduction

Extreme meteorological events like hurricanes Harvey, Irma and Florence emphasised the need for tracking using additional observational tools to mitigate the risks. GPS tropospheric products can provide useful information to better understand the structure and behavior of hurricanes[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. In regions inside and around the dense clouds and heavy precipitation of hurricanes, GPS provides independent measurements of atmospheric processes where visible, infrared and microwave-based satellite measurements are largely contaminated. In the present study, the zenith total delay (ZTD) from a network of GPS receivers on the East Coast of the USA and Gulf of Mexico were estimated and converted to IWV. We introduce a novel methodology for the use of geodetic troposphere observations to monitor atmospheric water vapour content.

Data and Methods

Distributions of GPS stations on the East Coast of the USA and Gulf of Mexico:

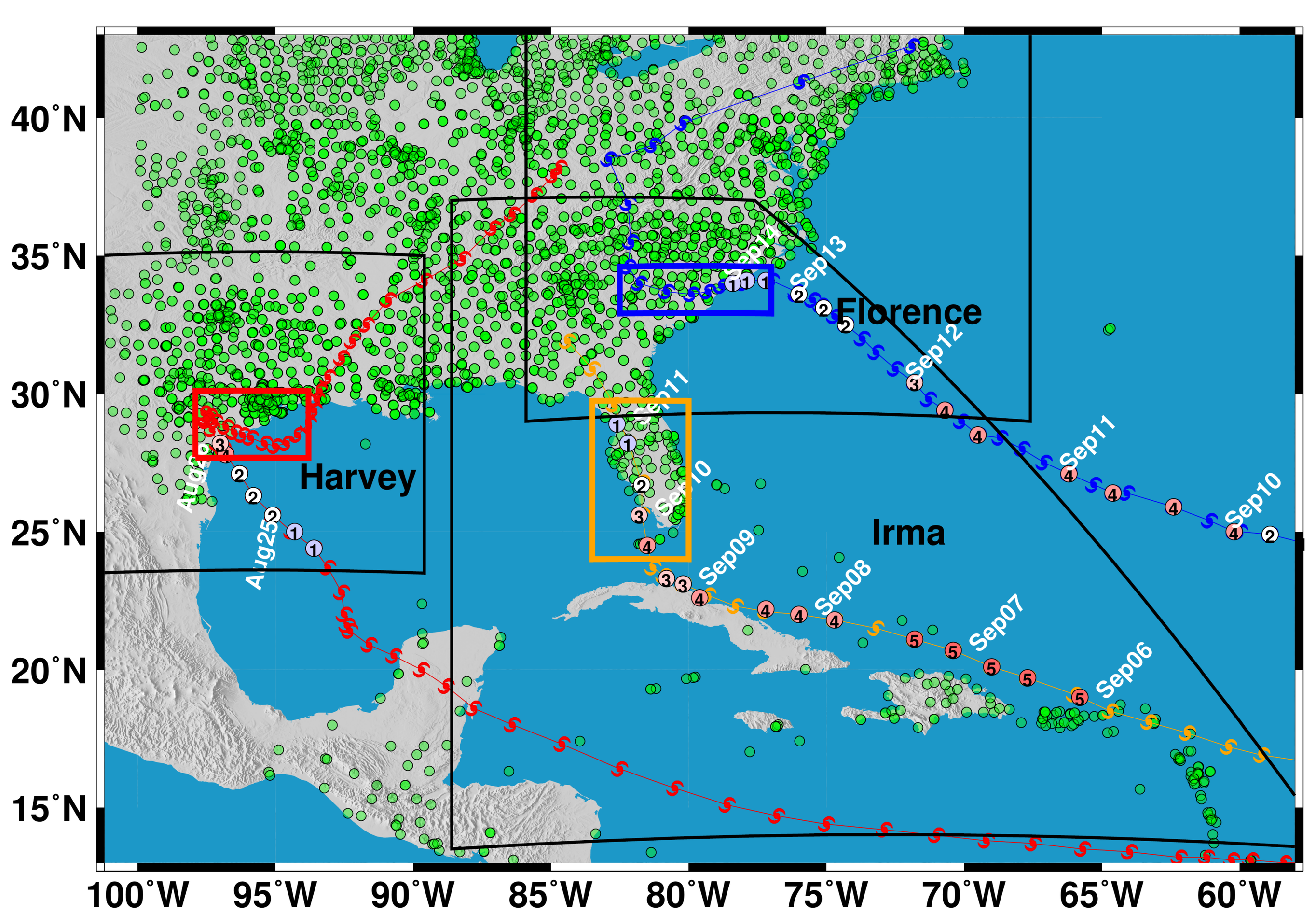

Fig.1: Distribution of GPS stations displayed as green circles. The red, orange and blue lines are the actual paths of hurricanes Harvey, Irma and Florence, respectively. The numbers within the circles indicate Saffir-Simpson hurricanes wind category scale. The network consists of 360, 562 and 839 GPS stations for hurricanes Harvey, Irma and Florence, respectively.

Retrieval of IWV from GPS ZTD: During the GPS data processing, the total zenith delays were estimated. The ZHDs were calculated using the Vienna Mapping Functions (VMF) gridded files. The ZWD were converted to IWV (see e.g [2]) using mean weighted temperature measurements from VMFG data at `http://vmf.geo.tuwien.ac.at`.

Results-1

Figure 2 displays the stacked time series of GPS-derived IWV and its correlation with satellite rainfal. The regession was analysed with a three-hour resolution on the basis of each hurricane's peak value.

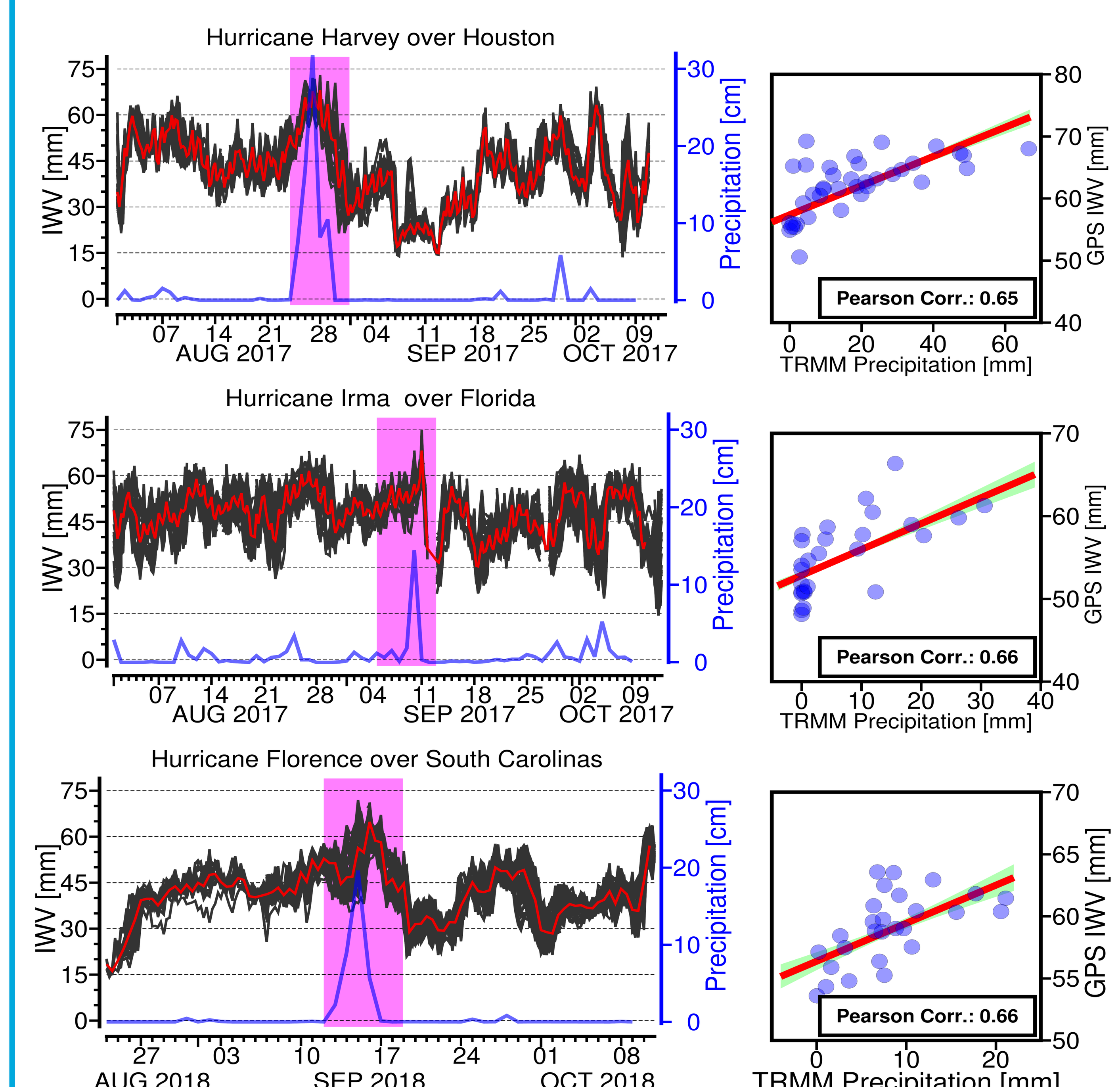

Fig.2 Stacked time series of GPS-IWV of individual GPS stations (black lines) and averaged (red line) superimposed on daily accumulated time series of GPM IMERG precipitation (blue line) for the three hurricanes; Harvey (stations within the red rectangle in Fig.1). Irma (stations within the orange rectangle in Fig.1). Florence (stations within the blue rectangle in Fig.1). The magenta shaded regions illustrate the periods where each hurricane show a maximum change in precipitation and maximum change in GPS-derived IWV. The right-hand scatter plots represent the regression between GPM IMERG satellite derived precipitation and GPS-derived IWV. The red line is the estimated linear regression and the green shadow is the 95% confidence interval.

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Results-2

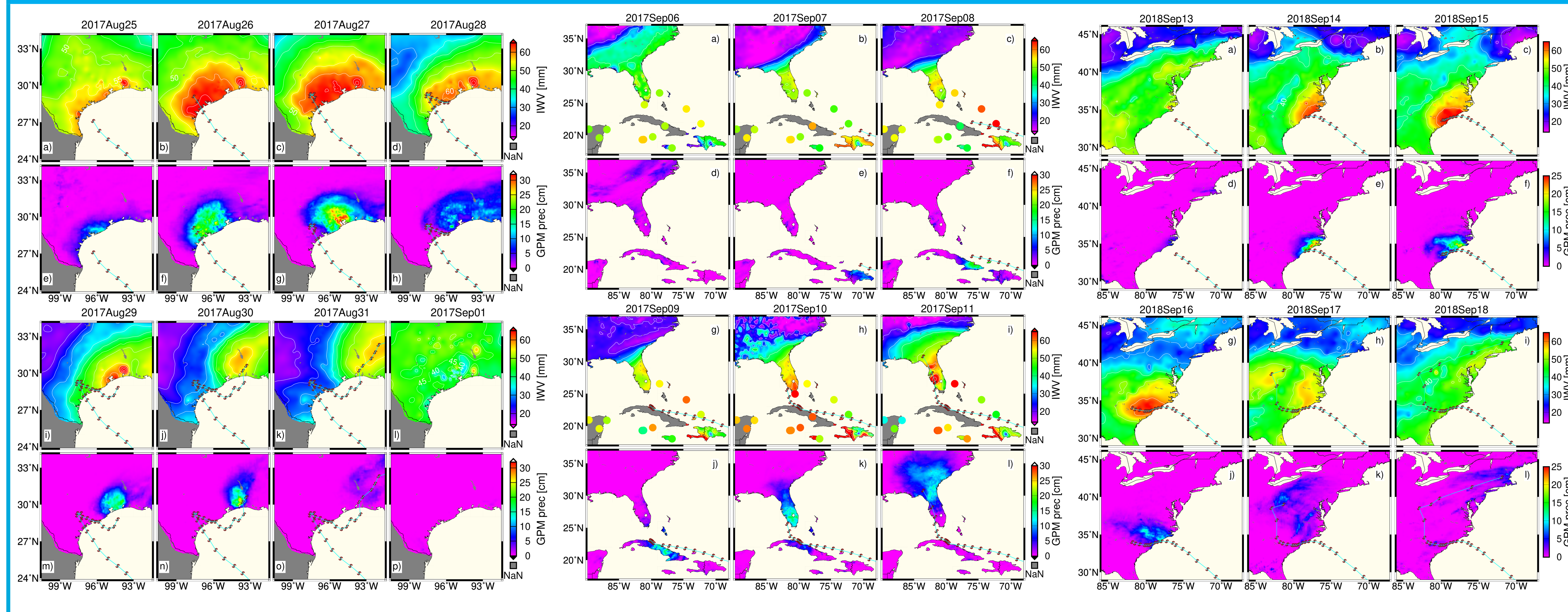

Fig.5. Distribution maps for Hurricane Harvey. GPS-IWV (first row *a* to *d* and third row *i* to *l*) and accumulated precipitation (second row *e* to *h* and fourth row *m* to *p*) during Harvey between 25 August-1 September 2017. Harvey's path is plotted as the cyan line and the hurricane symbol as brown, respectively.

Fig.6: Distribution maps for Hurricane Irma. GPS-IWV (first row *a* to *c* and third row *g* to *f*) and accumulated precipitation (second row *d* to *f*, and fourth row *j* to *l*) during Irma between 6–11 September 2017. Irma's path is plotted as the cyan line and the hurricane symbol as brown, respectively.

Fig.7: Distribution maps for Hurricane Florence. GPS-IWV (first row *a* to *c* and third row *g* to *f*) and precipitation accumulated (second row *d* to *f* and fourth row *j* to *l*) during Florence between 13–18 September 2018. Florence's path is plotted as the cyan line and the hurricane symbol as brown, respectively.

Tracking hurricane paths using GPS

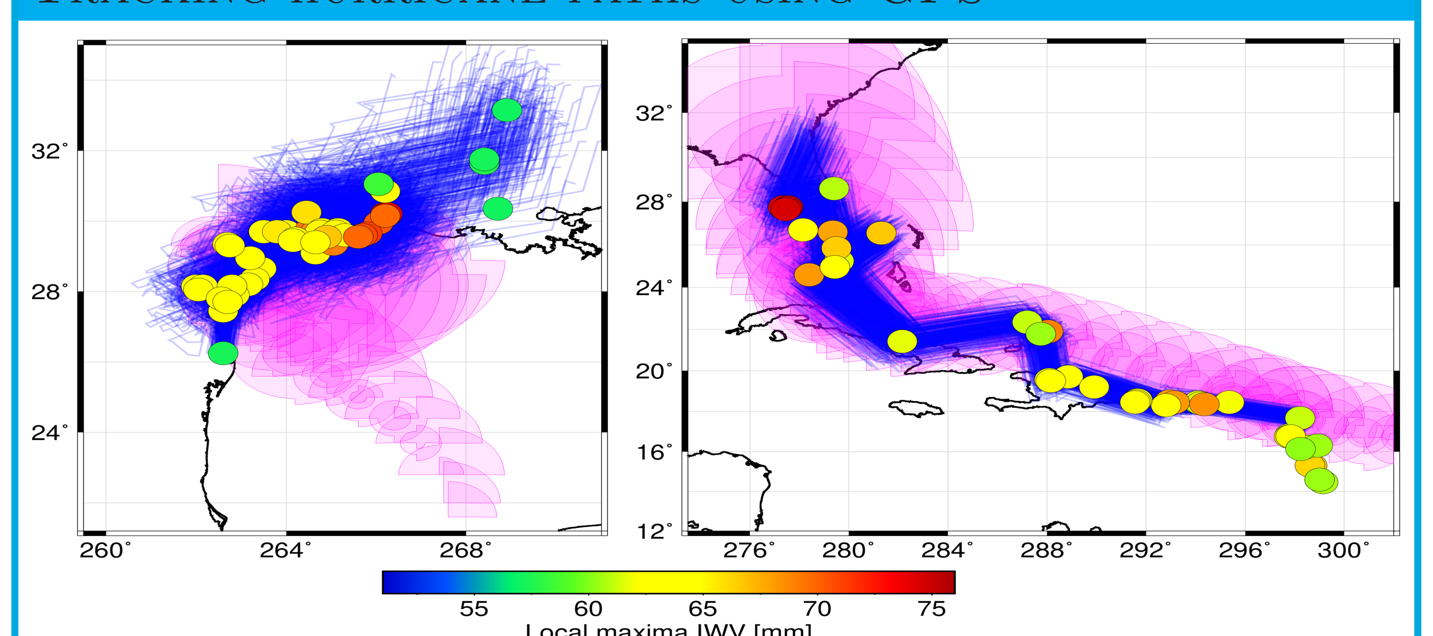

Fig.8: Spaghetti line plots (blue lines) based on our GPS-derived IWV maxima for hurricanes Harvey (on the left) and Irma (on the right). The colored circles show the local maxima 6-hour prior to the arrival of the storm. The light magenta polygons show the best tracks from a separate National Hurricane Center (NHC) model, based on a post-storm analysis of all available data. The best tracks from the NHC are based on the geodetic coordinates, maximum sustained surface winds and minimum pressures at sea level, presented at six-hourly intervals.

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Discussion and summary

- Three different intense hurricane events that hit the East Coast of the USA and Gulf of Mexico in 2017 & 2018 their GPS-derived IWV time series before, during and after each storm were examined.
- An increase in GPS-derived IWV on average 28 mm (ranging 46 -74 mm) is commonly observed in the general vicinity of the area crossed by a storm for four to five days.
- In all three storms, we found a peak IWV content 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).
- 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).

References

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