798 HIGH TEMPORAL RESOLUTION TROPOSPHERIC WIND PROFILE OBSERVATIONS AT NASA KENNEDY SPACE CENTER DURING HURRICANE IRMA

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1. INTRODUCTION

The National Aeronautics and Space Administration's (NASA) Kennedy Space Center (KSC) operates a 48-MHz Tropospheric/Stratospheric Doppler Radar Wind Profiler (TDRWP) on a continual basis generating wind profiles between 2-19 km (~6.6-62.3 kft) in the support of space launch vehicle operations. A benefit of the continual operability of the system is the ability to provide unique observations of severe weather events such as hurricanes. On the evening of 10 September 2017, Hurricane Irma passed within 160 km (87 nmi) to the west of KSC through the middle of the Florida peninsula. The hurricane was responsible for power outages to approximately 2/3 of Florida's population (Stein, 2017). This paper will provide an overview of the TDRWP system, describe the characteristics of the wind observations from the TDRWP during Irma passage, provide a comparison to previous TDRWP observations from Hurricane Matthew in 2016, and provide the location where TDRWP data is available to the meteorological community.

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2. KSC TROPOSPHERIC/STRATOSPHERIC DOPPLER RADAR WIND PROFILER

The TDRWP at KSC, co-located on the United States Air Force's Eastern Range (ER) at the Cape Canaveral Air Force Station (CCAFS), is a multi-beam, multi-mode capable vertically pointing radar designed to detect Doppler shift of clear-air turbulence to measure vertical profiles of wind (McLaughlin et al. 2017). It is a continuously operating, steerable antenna system comprised of 640 Yagi elements over a 5 acre area (Figure 1) transmitting a 2-micro sec pulse at a peak power of 250 kW, but currently operating at 180 kW to reduce interference in the HAM radio frequencies. In this configuration, the system is capable of producing wind profiles every 5 minutes from approximately 1.8-19 km (~6.0-62.3 kft) at an output of 150 m (~500 ft) altitude intervals. Vertical and horizontal wind estimates are determined through applying a multi-beam, multi-mode strategy where the system transmits a beam through 4 pointing azimuths over a 5-min cycle time to measure the return Doppler spectra (Figures 2 and 3). The return signal is processed through a median filter, known as the Median Filter First Guess algorithm (Reed et al. 2017), to eliminate transient signals and constrain the spectra integration window to the atmospheric signal return prior to calculating the horizontal and vertical winds.

Figure 1. Aerial view of NASA KSC TDRWP. System electronics are housed in trailer on the bottom left of photo.

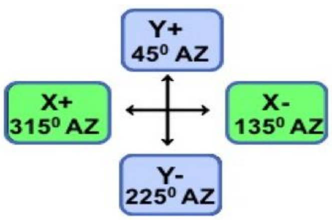

Figure 2. Four beam pointing azimuths with a 'lug nut' scan strategy transmitted by the TDRWP (Reed et al. 2017).

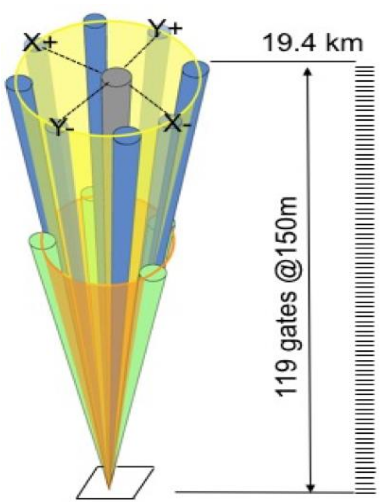

Figure 3. Four beam pointing strategy over altitude range coverage by TDRWP. System capable of steering in any direction but does not transmit the vertical beam (gray) in current scan configuration (Reed et al. 2017).

3. HURRICANE OBSERVATIONS

The primary use for the TDRWP is to support space launch vehicle operations. Another benefit is the ability to provide a unique observation into severe weather events, such as tropical storms and hurricanes, in the vicinity of the facility. Over the past two hurricane seasons the TDRWP had been operating during the passage of Hurricane Irma in September 2017 and Hurricane Matthew in October 2016. Both passed within 185.2 km (100 nmi) of the KSC area (Figure 4).

Hurricane Irma tracked along the interior western peninsula after its second landfall near Marco Island, FL at 1935 UTC on 10 September (Figure 4). The system had an expansive footprint of destructive winds within the right front quadrant, reaching from its center (which tracked northward along the interior western peninsula) over to KSC during the period from 18 UTC on 10 September through 15 UTC on 11 September 2017 (Huddleston et al. 2017). Sustained winds of 14.1 m/s (34 kt) extended out to 666 km (360 nmi) nearest the time of maximum observed 5-min average 10-m wind speed observation of 27.3 m/s (53.1 kt) at KSC (Huddleston et al. 2017). The closest distance between the center of circulation and KSC during the passage was 161.3 km (87.1 nmi) at 0540 UTC on 11 September (Huddleston et al. 2017).

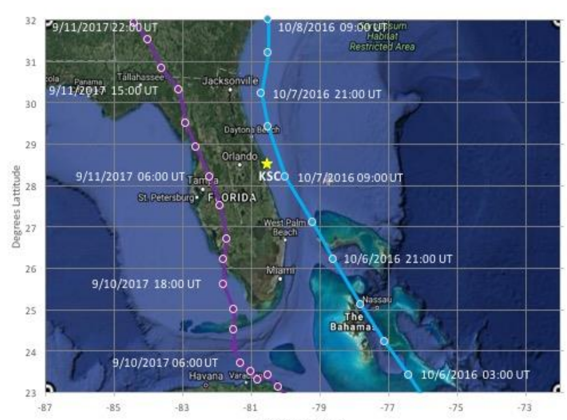

Figure 4. Surface tracks of Hurricanes Irma in 2017 (purple) and Matthew (Blue) in 2016 within proximity to the KSC TDRWP site (yellow star) (Huddleston et al. 2017).

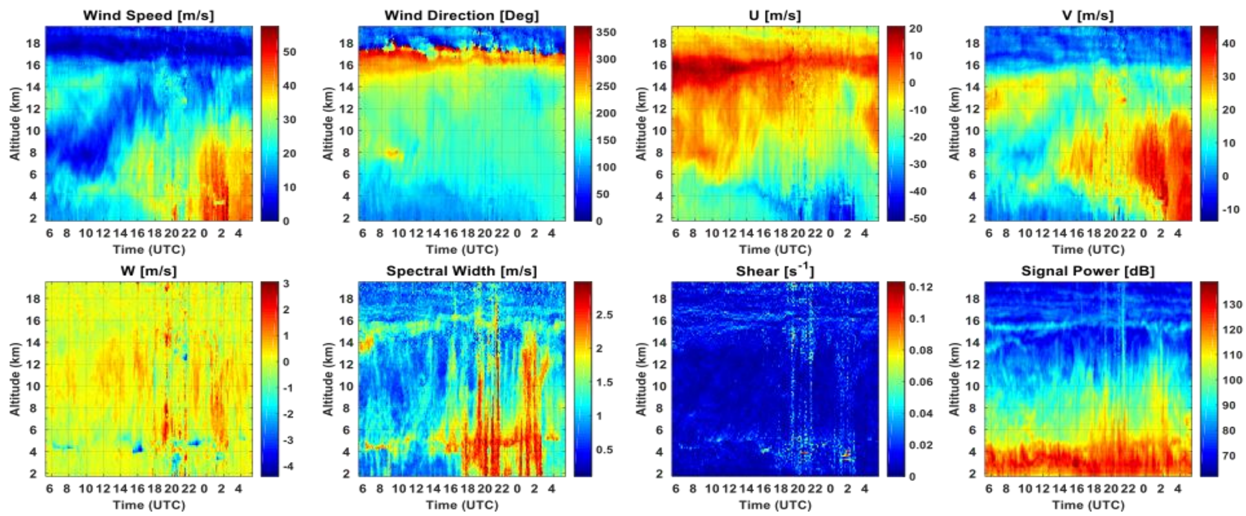

Figure 5. TDRWP output from 0524 UTC on 10 Sept 2017 to 0524 UTC on 11 Sept 2017. TDRWP experienced power outage at ~0530 UTC on 11 Sept 2017. Time is in UTC, altitude is in km, and velocities are in m/s. All quantities represent the average value from all four beams.

Atmospheric wind profile observations from the TDRWP provide insight into the evolution and structure of the right front quadrant as Irma moved northward during this period (Figure 5). The vertical extent of winds associated with Irma over this period were observed up to 12 km as shown in Figure 5. The onset of easterly winds (U component) over KSC in the mid-troposphere began early on 10 September, gradually increased, and peaked to ~45-50 m/s (87.5-97.2 kt) on the 11th from 0-2 UTC in the layer from 2-4 km (~6.6-13.1 kft). As the system tracked northward, the southerly wind (V component) peaked to near 40 m/s (~78 kt) below 8 km (~26.3 kft) on the 11th from roughly 0-5 UTC. Vertical velocity (W component) magnitudes reached around 4 m/s (7.8 kt), which is very significant for the region. These are correlated with outer rainband thunderstorms observed by the NWS Melbourne, FL WSR-88D radar at 1903 UTC (Figure 6).

Hurricane Matthew tracked northward along the east Florida coastline during the 24-hour period from 2100 UTC on 6 October to 2100 UTC on 7 October 2016. During the system movement, the TDRWP measured wind profiles within the left front and left rear quadrants in the vicinity of the eyewall as the center of Matthew tracked within 46.3 km (25 nmi) of KSC (Huddleston et al. 2017).

While KSC was in the left front quadrant, prior to the eyewall approach on the 7th, the TDRWP measured easterly winds of approximately 35 m/s (68.0 kt) below 4 km (13.1 kft) from 6-10 UTC. Northerly winds were near 40 m/s (77.6 kt) at these altitudes from roughly 10-13 UTC. Wind magnitude peaked at roughly 40 m/s (77.6 kt). Elevated vertical velocities, resulting from deep convection near eyewall, from 10-14 UTC between10-14 km (32.8-45.9 kft) correlated well to

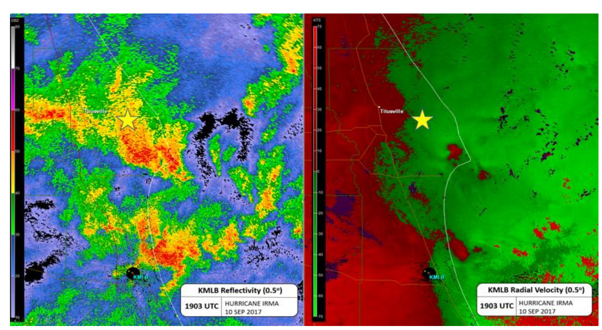

Figure 6. Hurricane Irma depictions as sampled by the NexRad Doppler radar located at the National Weather Service Office in Melbourne, FL. Low-level (0.5 degree elevation) reflectivity (dBZ) is on the left and corresponding radial velocity (knots) is on the right. Both are from 1903 UTC on September 10, 2017, depicting storms over the TDRWP site. Note that with increasing distance from the radar, the beam increases in height, having a center beam height of ~500m (1500 ft) over the TDRWP site shown by the yellow star.

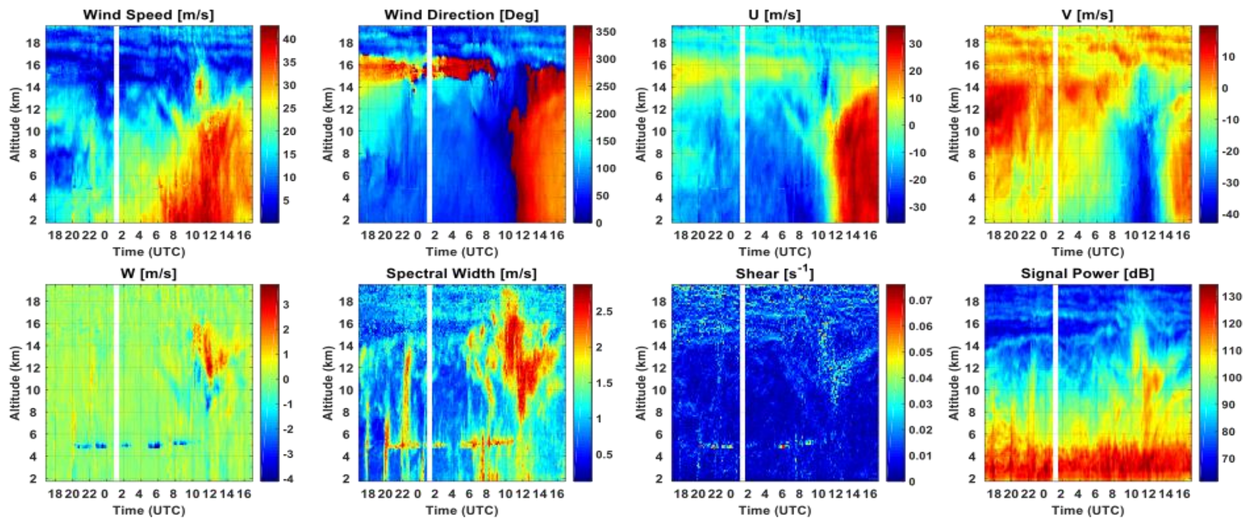

Figure 7: TDRWP output from 1659 UTC on 6 October 2016 to 1659 UTC on 7 October 2016. The vertical white column at ~0130 UTC indicates missing or removed data. The TDRWP experienced a power outage at 1700 UTC on 7 October 2016. Time is in UTC, altitude is in km, and velocities are in m/s. All quantities represent the average value from all four beams.

increased spectral width and signal power return as shown in Figure 7 (Reed, 2017). As with Hurricane Irma, observations from the TDRWP ceased around 1700 UTC on the 7th from an unplanned power outage at the site.

4. KSC WEATHER ARCHIVE

The TDRWP data, as well as other meteorological data from KSC and CCAFS is available on the Spaceport Weather Archive at https://kscwxarchive.ksc.nasa.gov/, which is a public facing website. The home page is shown in Figure 8. To access TDRWP data, select the "Wind Profilers" tab on the left side of the page.

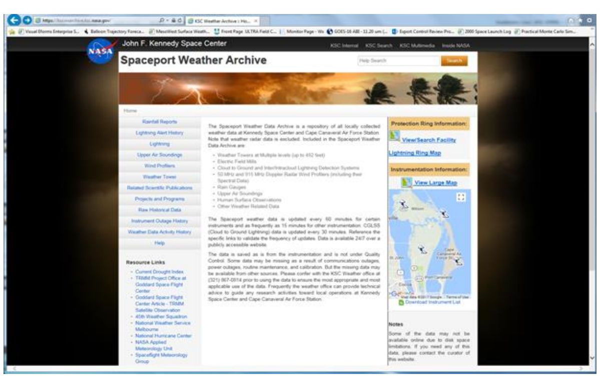

Figure 8. Home page of the NASA KSC Spaceport Weather Archive site.

The Doppler Radar Wind Profilers (DRWP) page will appear as shown in Figure 9. Currently, the page has the terminology of the old 50-MHz DRWP instrument, but the site will be updated in 2018 to reflect the 48-MHz Tropospheric Doppler Radar Wind Profiler description. This will not prevent the user from accessing the data from either the old or the new instrument however. Select the "Search 50 MHz" button retrieve selection criteria page.

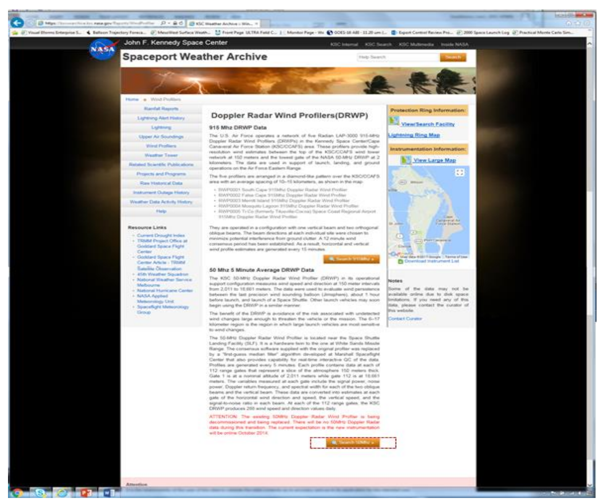

Figure 9. *Doppler Radar Wind Profilers (DRWP)* description page on the KSC Spaceport Weather Archive site.

Upon arriving at the 50 MHz Doppler Radar Wind Profiler Filters page (shown in Figure 10), enter the desired date and time span as well as any altitude or wind direction filters. Data from the TDRWP is typically available in the archive within an hour from the measurement time. Currently, due to the large volume of data, the date and time span is limited to 24 hours. However, this can be temporarily expanded by contacting the website curator or website editor using the links on the pages.

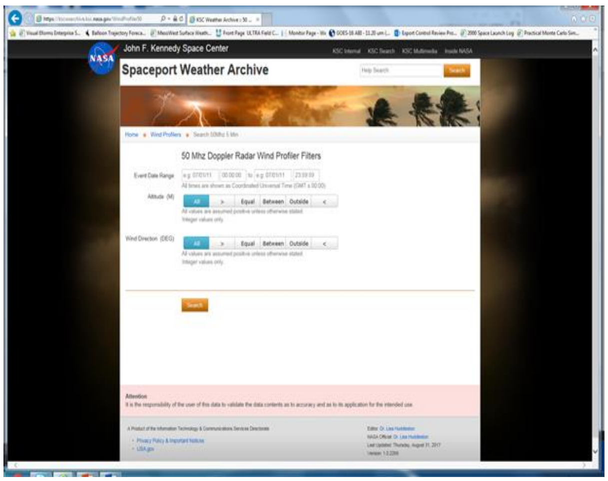

Figure 10. *50 MHz Doppler Radar Wind Profiler Filters* page.

The default fields available after entering the search criteria are UTC date, UTC time, Altitude (m), Wind Direction (degrees), Wind Speed (kts), and Wind Shear (/sec). Other fields can be made available by clicking the “View” tab on the upper right side of the results. The data can be exported in a csv file format by clicking the export tab. Additional fields available include WW (m/s, vertical velocity, positive up), S1 (dBs) Signal power (average of E-W pair of beams), S2 (dBs) Signal power (average of N-S pair of beams), S3 (dBs) Signal power (average of all 4 oblique beams), N1 (dBs) Noise level (average of E-W pair of beams), N2 (dBs) Noise level (average of N-S pair of beams), N3 (dBs) Noise level (average of all 4 oblique beams), WID1 (m/s) Spectral width (average of E-W pair of beams), WID2 (m/s) Spectral width (average of N-S pair of beams), WID3 (m/s) Spectral width (average of all 4 oblique beams), G1 First Guess Propagation (max value for the E-W pair of beams), G2 First Guess Propagation (max value for the N-S pair of beams), and Quality Control (QC) Flag. Tables of QC flag values are available by contacting the website curator or editor. Output is provided in daily ASCII text files in 24-hr format.

5. CONCLUSION

Data from the KSC TDRWP are available from the KSC Spaceport Weather Archive for use by the meteorological community. Currently, the TDRWP is capable of producing wind profiles every 5 minutes from approximately 1.8-19 km (~6.0-62.3 kft) at 150 m (~500 ft) altitude interval. While the TDRWP is primarily used in the support of space launch vehicle operations, observations from the TDRWP has shown high resolution tropospheric wind structure of hurricane systems when in the vicinity of KSC and the Florida peninsula during the past two years.

6. REFERENCES

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Stein, P, “Irma weakens to a tropical storm after knocking out power to millions in Florida.” •The Washington Post 11 September 2017. Web. 15 Oct 2017.