4-29-2020

Estimating Surface Wind Speed in Tropical Cyclones through Integration of NOAA Hurricane Hunter Aircraft Observations

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Estimating Surface Wind Speed in Tropical Cyclones through Integration of NOAA Hurricane Hunter Aircraft Observations

by

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An Honors Capstone

submitted in partial fulfillment of the requirements

for the Honors Diploma

to

The Honors College

of

The University of Alabama in Huntsville

29 April 2020

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Table of Contents

Abstract 2

I: Introduction 3

II: Background 4

III: Hypothesis and Research Questions 5

IV: Research Methods 6

V: Results 8

- A: Individual Conditions 8
- B: Combined Conditions 9
- C: Tables 10

VI: Discussion and Analysis 11

- A: Adjustment Factor Comparison 11
- B: Impacts on the Adjustment Factor 12

VII: Conclusion 14

VIII: Future Work 14

IX: Acknowledgements 15

X: Figures and Tables 16

References 24

Appendix A: Adjustment Factor Tables 26

- 1: Adjustment Factor based on Distance 26
- 2: Adjustment Factor based on Flight Level Wind Speed 27

Appendix B: List of Flights Used in Analysis 28

Abstract

Measuring surface wind speed in tropical cyclones is an important, yet difficult, task to accomplish. Currently forecasters estimate the surface wind speed by applying a constant adjustment factor to flight-level wind speed measurements made by hurricane reconnaissance aircraft. Observations have shown that this constant adjustment factor is not always accurate and can vary broadly during a flight. Using new and updated instruments on the NOAA Hurricane Hunter aircraft, an improved adjustment factor that varies based on storm properties is developed.

It is shown that the adjustment factor varies based on cyclone intensity, flight-level wind speed, aircraft distance from the storm center, and aircraft altitude. The adjustment factor is also impacted by individual cyclone properties including eyewall slope and storm asymmetry. The greatest variability in the adjustment factor is found near the center of the cyclone in the eye and eyewall where the flight-level and surface wind speed change rapidly and at different rates. Further from the storm center, the adjustment factor decreases and varies less. Generally, the new, variable adjustment factor is much lower than the constant factor that is currently used indicating a much larger difference between the flight-level and surface wind speed than previously expected.

I. Introduction

The NOAA Atlantic Oceanographic and Meteorological Laboratory's Hurricane Research Division (HRD) conducts the annual Hurricane Field Program experiment by flying the NOAA WP-3D and G-IV aircraft into tropical cyclones (TC) for reconnaissance and research purposes. The aircraft are equipped with numerous instruments for measuring many aspects of the atmosphere; however, measuring the surface wind speed in tropical cyclones has proved difficult.

Currently, the National Hurricane Center (NHC) estimates the surface wind speed in TCs by applying a constant adjustment factor to the wind speed measured by the aircraft at specific pressure altitudes. However, observations have shown that a constant adjustment factor is not always accurate and can vary broadly during a flight (Franklin, 2013).

Using other instruments on the aircraft in addition to the dropsondes, a more accurate wind speed adjustment factor that varies based on storm properties can be developed. This project will integrate wind speed measurements from several instruments on the P-3 aircraft including the Tail Doppler Radar (TDR), Stepped Frequency Microwave Radiometer (SFMR), dropsondes, and flight-level measurements. These measurements will be compared with the surface wind speed measured by the SFMR to develop a new, more accurate adjustment factor that accounts for storm intensity and structure. In addition, the adjustment factor will be designed to work at height altitudes, thus eliminating the requirement to fly at a constant pressure level and allowing the aircraft to be flown at a constant height. With more accurate surface wind speed estimates, the storm intensity can be better determined, and improved preparation guidance can be delivered to the public.

II. Background

The adjustment factor currently used by NHC was initially developed by Franklin et. al. (2003) using measurements from dropsondes released from the aircraft. Operationally, forecasters estimate the surface wind in tropical cyclones by applying a flight-level adjustment factor of 90% at 700mb, 80% at 850mb, and 75% at 825mb (Franklin, 2013). The flight-level wind is usually stronger than the surface wind, so these factors reduce the flight-level wind to a smaller value. Since the adjustment factor only applies to specific pressure altitudes, it can only be used if the aircraft is flying at a constant pressure. This is not always possible due to safety and observational concerns, especially in storms with extremely low center pressure. With the addition of new instruments and the improvement of older ones on the aircraft, namely the SFMR (Uhlhorn, et. al., 2006) and TDR (Mello, et. al., 2019), a more accurate adjustment factor that is based on height altitude can be developed.

The surface wind speed measured by the SFMR on the aircraft was assumed to be the ground truth for developing the comparison with the aircraft measured wind speed. The SFMR measures brightness temperature from microwave emissions off the ocean surface at six frequencies between 4.55 and 7.22 GHz. Surface wind speed greater than 10 m/s causes foam to form on the ocean which acts approximately like a blackbody at microwave frequencies (Uhlhorn and Black, 2003). Barrick and Swift (1980) found that the percentage of foam coverage on the sea surface increases monotonically with wind speed. Assuming a constant sea surface temperature, an increase in sea foam coverage results in an increase in microwave brightness temperature (Webster et al. 1976). Given this relationship, the surface wind speed is calculated as a function of brightness temperature measured by the SFMR as a system of equations for each frequency (Uhlhorn an Black, 2003).

The adjustment factor for flight level to surface wind speed was calculated using the following equation:

$$AdF = \frac{WS_{SFMR}}{WS_{flt\ lvl}} \times 100\ (\%)$$

An adjustment factor less than 100% indicates that the flight level wind speed is greater than the wind speed at the surface. Conversely, an adjustment factor greater than 100% indicates that the flight level wind speed is less than the wind speed at the surface.

This project utilizes data from 123 individual flights in 28 different tropical cyclones ranging from tropical depressions through category 5 hurricanes between 2012 and 2019. Table 1 lists the number of flights for each storm category. A complete list of flights with dates and the storms flown in is included in Appendix B.

III. Hypothesis and Research Questions

It is believed that the ratio, and thus the adjustment factor, between the flight level and surface wind speed varies based on storm properties including overall intensity, wind speed, and structure. In the development of the new adjustment factor, three primary research questions are:

1. How does the adjustment factor relate to the storm intensity represented by its category on the Saffir-Simpson scale?

2. How does the flight level wind speed relate to the adjustment factor?

3. How does the distance of the aircraft from the storm's center ("eye") relate to the adjustment factor?

The first question asks if the adjustment factor should vary based on the storm's category. Considering the storm category adds a dimension to studying the structure of the storm since more intense TCs are usually more organized and symmetric than weaker TCs. The convective structure of a TC, which varies based on its intensity, can affect how well higher winds aloft are mixed down to the surface.

In addition to comparing the factor with the storm's maximum wind speed (i.e. category), it will be compared with the fluctuating flight level wind speed throughout the duration of the flight. This second question suggests that the factor responds differently to faster and slower wind. This would provide more variability to the adjustment factor instead of a constant value for the entire storm.

The third question adds to the consideration of storm structure by asking if the distance between the aircraft and the storm center impacts the adjustment factor. This relationship would most likely be related to the various maximum wind radii within the TC (Wang and Wu, 2004).

IV. Research Methods

For this project, all calculations, visualizations, and analyses were produced in Python using integrated datasets for the 123 flights.

For each flight a single dataset was generated by integrating the data from each instrument on the P-3, the HRD storm track, and the NHC best track, facilitating rapid examination and research. Each instrument on the aircraft measures at different rates and are often started at different times during the flight. To overcome this issue, the data from each instrument were converted to be in terms of seconds since the flight started. With this framework, data from different instruments can be compared directly regardless of measurement rate or start time. In addition, to address the independent motion of the storm and the aircraft, the data were arranged to be in storm relative coordinates. This accounts for the storm's motion by continually updating the location of the data measured from the aircraft with each storm center fix in the HRD storm track. The datasets were developed as netCDF files and full descriptions were provided with each variable.

This "integrated dataset" contains time, wind speed, and location information for the aircraft, SFMR, TDR, storm track, and dropsondes. It also contains variables related to the adjustment factor including time, aircraft location and aircraft altitude. Furthermore, the dataset includes additional atmospheric variables measured by the aircraft such as temperature, dewpoint, and pressure. To aid in comparison with other flights, the dataset includes storm metadata from the NHC best track including storm category, maximum wind speed, and minimum pressure during the flight period.

Each of the three research questions were initially considered individually. This was accomplished by:

1. (Intensity): The integrated datasets were separated by storm category.
2. (Wind Speed): Each individual adjustment factor was binned for ranges of flight level wind speed: 0-33, 34-63, 64-82, 83-95, 96-112, 113-136, 137+ knots. These are the same wind speed conditions for storm category.
3. (Distance): Each individual adjustment factor was binned by ranges of distance from the storm center: 0-20, 21-50, 51-80, 81-100, 100-200 kilometers.

For each condition, box and whisker plots were generated to show the distribution of the adjustment factor over the associated bins. While inspecting each condition individually yielded some results, it was more useful to consider the conditions together for creating a more comprehensive adjustment factor. The initial box and whisker plots were refined to show the distribution of the adjustment factor over the distance or wind speed bins for a specific category. Furthermore, the aircraft altitude every 500m was included in these plots.

Using the results from the box and whisker plots, tables of the average adjustment factor for a specific storm category, aircraft distance, flight level wind speed, and aircraft altitude were produced. These tables were developed into a Python function that takes the four conditions as inputs and then outputs the adjustment factor for those conditions to be used in wind speed analyses.

V. Results

A. Individual Conditions

The adjustment factor considered solely by category (Figure 1) was generally about the same for all hurricane-strength storms with most of the values near 75%. The factors for tropical depressions (TD) and tropical storms (TS) had a larger spread with averages of about 85%.

The factor considered by only flight level wind speed (Figure 2) showed that all but the 0-33 kt bin had small spreads meaning most of the values were near the average. The 0-33 kt bin had a much larger average and spread indicating large variability for low wind speeds.

The factor considered only by aircraft distance (Figure 3) shows that the average of the factor decreases slightly with further distance from the storm center. Additionally, the spread of the values is greatest near the center and smaller further away.

B. Combined Conditions

Combining the adjustment factor conditions creates two versions of the adjustment factor. One based on aircraft distance from the storm center and the other based on flight-level wind speed. Due to the use of multiple variables, many plots for different conditions were created. Two examples of plots generated using the combined conditions are discussed below and the full results are presented in the subsequent tables.

The first example is the adjustment factor for category 1 storms when the aircraft is at 3-km altitude. The box and whisker plot for the distance-based adjustment factor is shown in Figure 4. This plot shows that the average of the factor decreases with distance from the center. Additionally, the spread of the data also decreases with distance, which means that the average adjustment factor is more reliable at estimating the surface wind further away from the storm center.

The adjustment factor for this example based on flight level wind speed is plotted in Figure 5. For this case, the factor as well as the spread of the values decreases with faster wind speed. Considering this plot is for category 1 storms which have a maximum sustained wind speed of 82 kts, the values on the plot for bins greater than 82 kts were ignored. These out-of-range values are not unexpected, since flight-level winds are typically stronger than surface winds in TCs, which are used to define a storm's category. They could also be attributed to gusts that are not representative of the maximum sustained wind speed.

The second example is the adjustment factor for category 5 storms when the aircraft is at 3-km altitude. Figure 6 shows the plot of the distance-based factor. Contrary to the factor for category 1 storms, the factor for category 5 storms does not steadily decrease with distance. It decreases to about 80km from the center before slightly increasing farther away. In the nearest 20km, the average of the factor is greater than 100% indicating that, on average, the surface wind speed is actually greater than the flight-level wind speed. This is much larger than the average factors further away that have values near 70%. Additionally, the spread of the factor in the nearest 20km is larger than the factors further away showing significant variability near the storm center. These large adjustment factors and variability are likely caused by a combination of a sloping eyewall and slow winds in the eye that can be large enough in category 5 storms to encompass the 0-20km bin.

The adjustment factor based on flight level wind speed for this example is plotted in Figure 7. The average of the factor for low wind speed (0-33 kts) is 128% which is significantly larger than the rest of the wind speed bins that have averages around 70%. The distributions of the adjustment factor for the wind speed bins between 34-136 kts have almost the same average. For wind speed greater than 137 kts, the spread of the factor is very small with values generally larger than the slower wind. There are very few observations with wind speed greater than 137 kts which could cause the small spread. It is also possible that the adjustment factors have less variability in the eyewall, where mesoscale forcing is stronger and convective-scale variability is less important than at larger radii and smaller wind speeds.

C. Tables

Tables 1-6 included in Appendix A contain the average adjustment factors for the given conditions. The tables contain factors for altitudes of 2.0, 2.5, and 3.0 km. Plots of the factor were created for altitudes up to 6km; however, the data for altitudes greater than 3km were sparse and therefore not included in the results.

The adjustment factor based on wind speed does not change much with faster wind when excluding the 0-33kt bin. This can be seen in Figure 8 which shows the results from the adjustment factor table based on flight level wind speed for an altitude of 3km. Each line on the plot is the factor for a different storm category. In general, the factor decreases slightly between TS-force winds and category 1-force winds and then remains fairly constant as wind speed increases. Figure 9 shows the same information but includes the 0-33kt bin. The average adjustment factor values for these low wind speeds is much greater, sometimes even over 100%, than the factors for faster wind.

A similar plot is shown in Figure 10 which shows the results from the distance-based adjustment factor table at an altitude of 3km. This plot shows the general decreasing trend that the factor exhibits with distance from the storm center. Unlike the factor based on wind speed, the distance factor varies much more between categories as well as between distance bins.

Overall, Figures 8-10 show that the adjustment factors are consistently lower than those suggested for 700 hPa by Franklin et. al. (2003, 2013). The lower adjustment factors mean that the difference between the faster flight-level and slower surface wind speed is greater than previously expected.

VI. Discussion and Analysis

A. Adjustment Factor Comparison

The adjustment factor tables were tested by comparing the surface wind speed calculated by the adjustment factor with the surface wind speed measured by the SFMR. The factor estimated surface wind was calculated for each flight by applying the adjustment factor that met the given conditions (altitude, category, distance, wind speed) to each flight level wind speed measurement. The average difference between the SFMR surface wind and the factor calculated wind speed was computed for each flight. This process was repeated for all 123 flights and the average overall difference was calculated to find the factor error. The error was calculated for a constant 90%, the factor tables based on distance, the factor tables based on wind speed, and an average of the distance and wind speed factor tables. The average errors for each factor are shown in Table 2. The factor based on wind speed performed slightly better than the factor based on distance while the average factor performed the best. The error of the average factor was 6.79 knots which means that, on average, the surface wind speed calculated by the adjustment factor is about 7 knots off the SFMR measured wind speed.

Since the error of 7 kts is an average, it does not always accurately represent the range of error resulting from using the adjustment factor. Figure 11 shows the adjustment factor error for one flight in Hurricane Irma, a category-five storm at the time. The factor performs the worst in the eye and eyewall of the storm with errors as high as 60 knots. Further away from the eye, the factor's performance improves and is closer to the average error. The large error of the adjustment factor in the eye is expected based on the large spread of possible values seen on the box and whisker plots earlier.

B. Impacts on the Adjustment Factor

The ratio between the flight-level and surface wind speed, and thus the adjustment factor, could be impacted by many other variables. In many TCs the eyewall slopes sharply into the eye. This means that the wind speed changes from its highest intensity in the eyewall to almost no wind in the eye. This sharp slope can be seen in a vertical profile of a storm like the one displayed in Figure 12. This figure shows the vertical profile of the adjustment factor based on the TDR measured wind speed at levels up to 18km from one pass through the eye during the flight in Hurricane Irma discussed previously. Near the eye, the adjustment factor increases rapidly as the aircraft flies at a constant altitude. At the 20-km radius on the inbound side (left of the eye), the adjustment factor is 100% or greater for the entire profile. Since the eyewall slopes outward, at this radius higher altitudes are in the eye with low wind speeds, while the surface is still in the eyewall and recording high wind speeds. This leads to large adjustment factors greater than 100% near the eye and demonstrates why the adjustment factor increases rapidly with closer distance to the storm center.

Another impact affecting the performance of the adjustment factor is the asymmetry of a TC. Figure 13 shows the aircraft track for the flight in Hurricane Irma colored by the flight level wind speed bins used in the adjustment factor analysis. Winds to the north of the storm center are of category-1 strength while the wind speed on the west and south of the storm is much slower in the TS and TD ranges. The goal of producing an adjustment factor based on flight level wind speed was designed to overcome the issue with asymmetry, which the distance-based factor would not be able to distinguish.

In addition, the ratio between the flight level and surface wind speed (the adjustment factor) is asymmetric as seen in Figure 14. This figure shows the flight track in Irma colored by the adjustment factor. The factor is near 100% in the southwest quadrant of the storm, much lower further from the storm center, and over 100% near the center. While the distance-based adjustment factor can partially account for these asymmetries, there are still variations between sections of the cyclone.

Intensity changes in a tropical cyclone could also impact the adjustment factor. TC intensity change is determined from the change in surface wind speed (Kaplan and DeMaria 2003). Consequently, the time it takes for intensity changes at the surface to translate upward to the flight level can affect the ratio between the flight level and surface wind speeds. This time delay can impact the adjustment factor if the flight level observations are lagging behind the intensity change.

Additional variables that impact the adjustment factor could also include mesoscale dynamics, convection in the eyewall and rainbands, strong turbulence causing more mixing between the surface and aloft, and the variation of eyewall structure.

VII. Conclusion

There are many variables that impact the relationship between the flight-level and surface wind speed, and the adjustment factor is most accurate when they are considered together. The adjustment factor requires improvement for use near the center of a TC, which can be accomplished by considering additional aspects of storm structure and dynamics. The adjustment factor as a function of storm category, aircraft altitude, flight level wind speed, and aircraft distance from the storm center can be used to produce improved surface wind speed estimates in tropical cyclones. This is especially useful as an alternative method for measuring surface wind speed when the SFMR is not available or able to make accurate measurements.

VIII. Future Work

To continue improving the adjustment factor, TC intensification over a 24-hour period will be considered. The datasets will be separated based on intensification, weakening, or neutral and compared with the other variables associated with the adjustment factor. Additionally, the vertical profile measured by the TDR will be incorporated into the adjustment factor calculation to account for the structure of the eyewall as well as the overall structure of the storm. Finally, the adjustment factor will be compared with model simulations of category 5 hurricanes to compare the small amount of observations that have category 5 intensity winds with idealized expectations. The comparison for the factor resulting from this future work will be improved by performing a verification on an independent dataset unrelated to those used to derive the adjustment factor.

IX. Acknowledgments

I would to like to express my appreciation for Dr. Patrick Duran from the NASA Short-term Prediction and Research Transition (SPoRT) Center and Dr. Jon Zawislak from the NOAA/AOML Hurricane Research Division. This project was made possible through their mentorship, support, and advice. I also thank Mr. Ryan Wade from the University of Alabama in Huntsville Department of Atmospheric and Earth Science who served as the project director.

X. Figures and Tables

Storm Category	Number of Flights
TD	5
TS	47
Cat 1	28
Cat 2	10
Cat 3	12
Cat 4	14
Cat 5	7

Table 1: Number of flights per storm category used in this project

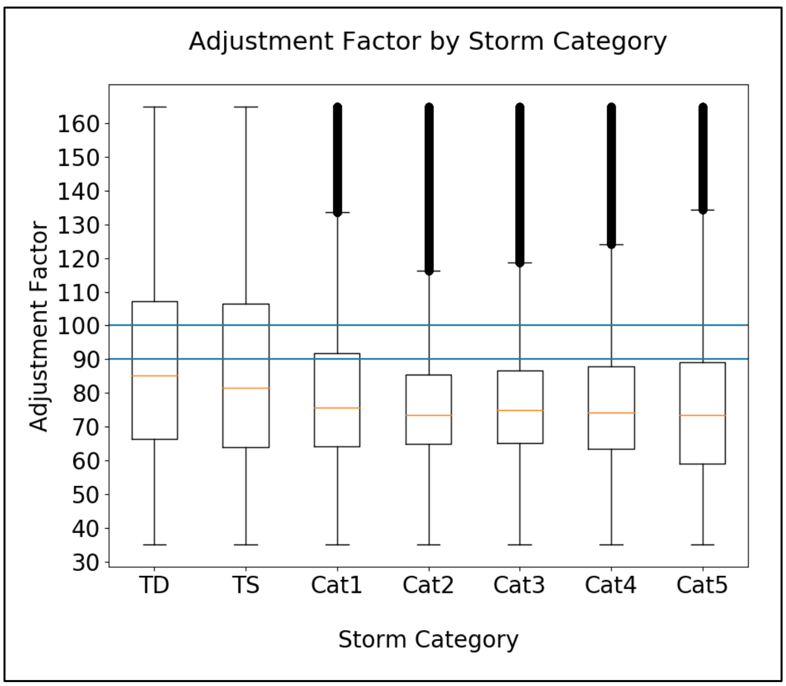

Figure 1: Box and whisker plot showing the distribution of the adjustment factor binned by storm category for all 123 flights.

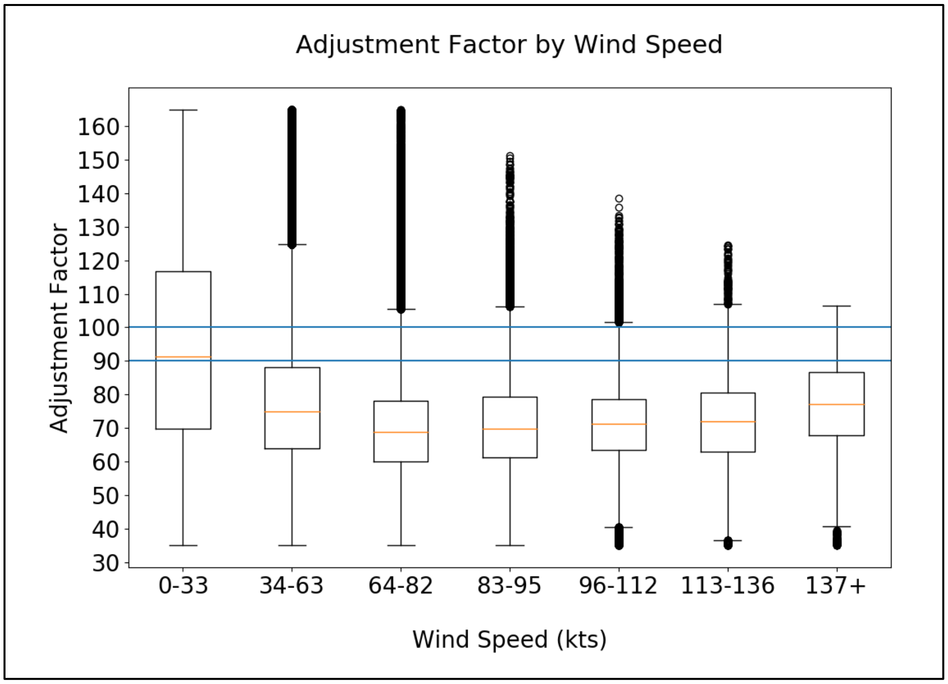

Figure 2: Box and whisker plot showing the distribution of the adjustment factor binned by flight level wind speed in knots for all 123 flights.

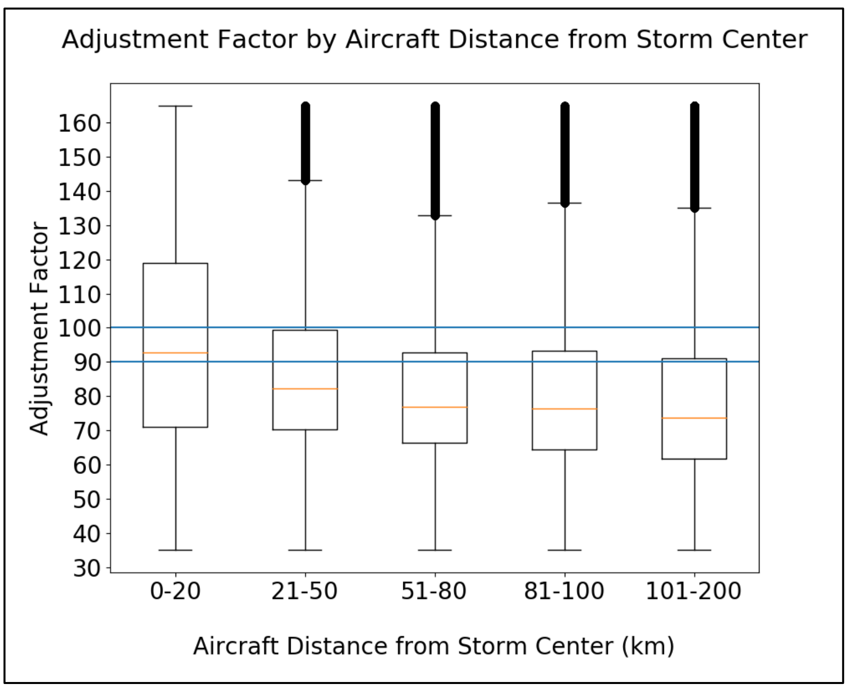

Figure 3: Box and whisker plot showing the distribution of the adjustment factor binned by aircraft distance from storm center in kilometers for all 123 flights.

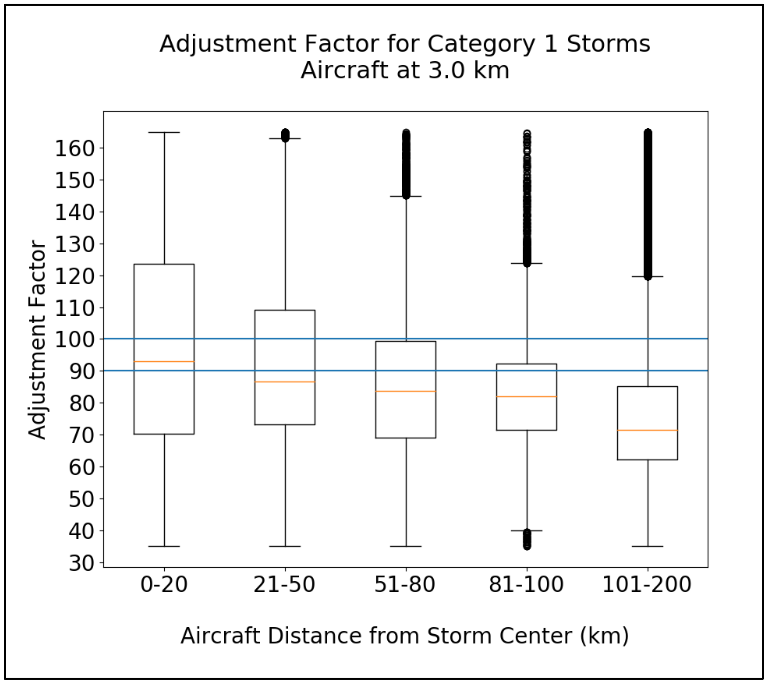

Figure 4: Box and whisker plot showing the distribution of the adjustment factor binned by aircraft distance from storm center in kilometers for flights in category 1 TCs and aircraft altitude of 3.0km.

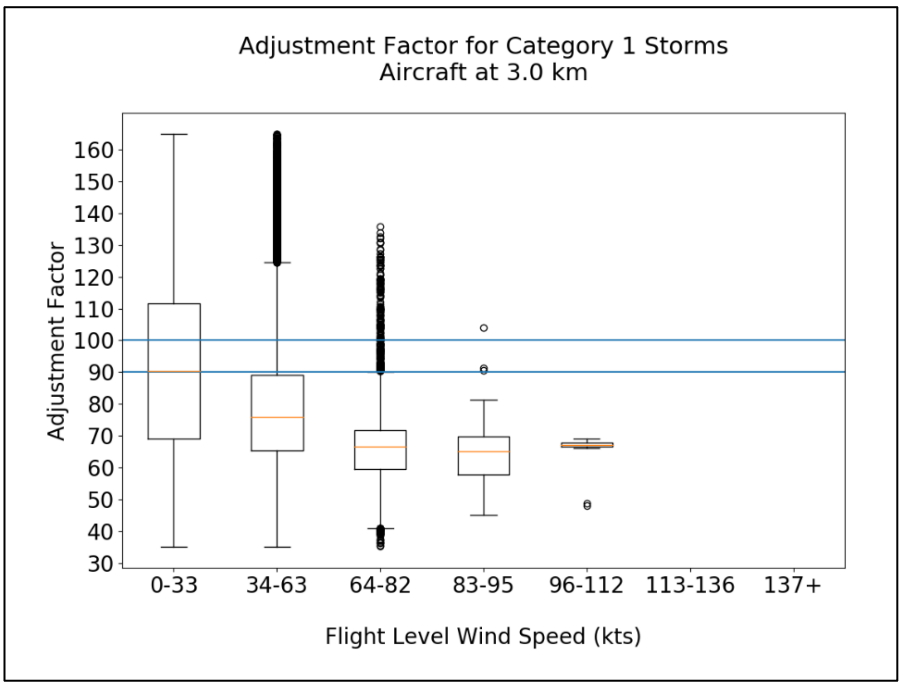

Figure 5: Box and whisker plot showing the distribution of the adjustment factor binned by flight level wind speed in knots for flights in category 1 TCs and aircraft altitude of 3.0km.

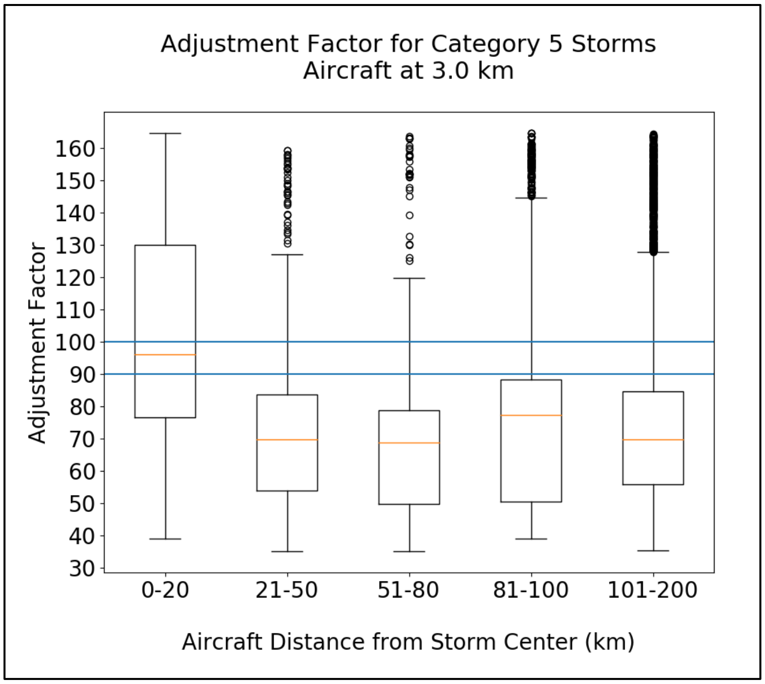

Figure 6: Box and whisker plot showing the distribution of the adjustment factor binned by aircraft distance from storm center in kilometers for flights in category 5 TCs and aircraft altitude of 3.0km.

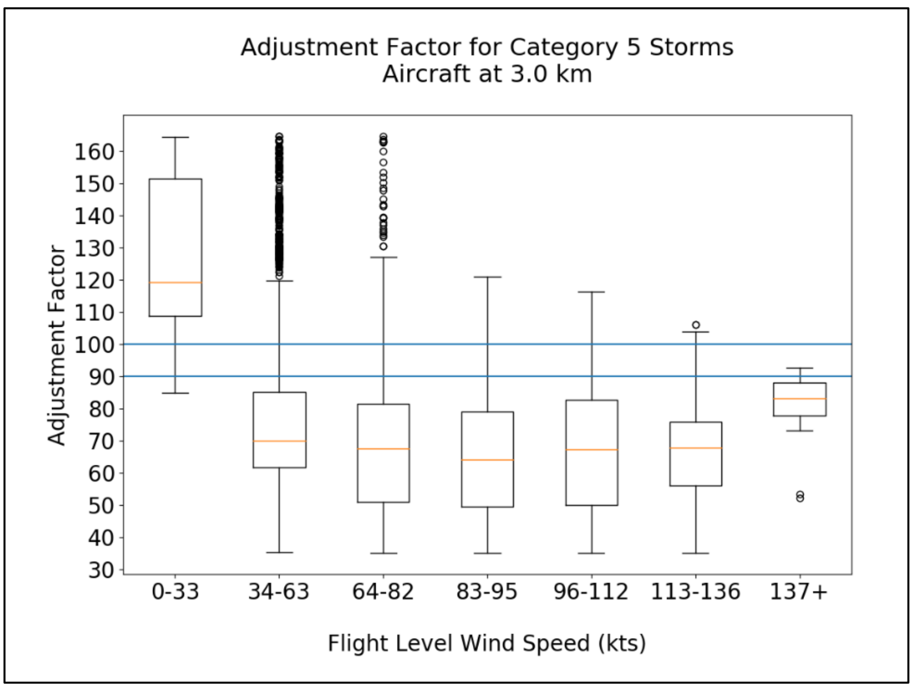

Figure 7: Box and whisker plot showing the distribution of the adjustment factor binned by flight level wind speed in knots for flights in category 5 TCs and aircraft altitude of 3.0km.

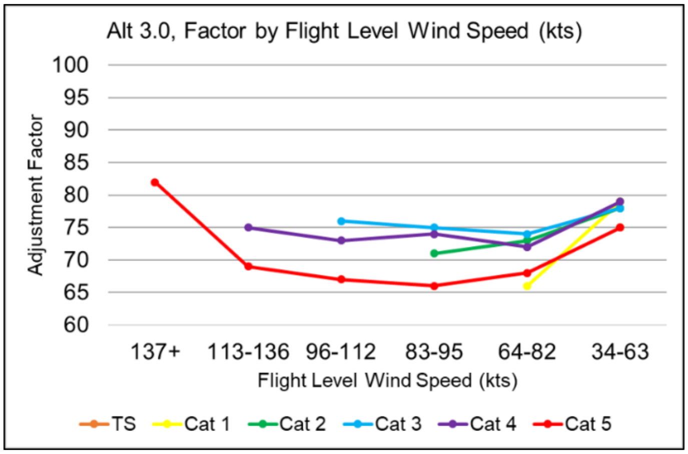

Figure 8: Average adjustment factors for each wind speed bin and storm category at aircraft altitude of 3km. Excluding the 0-33kt bin.

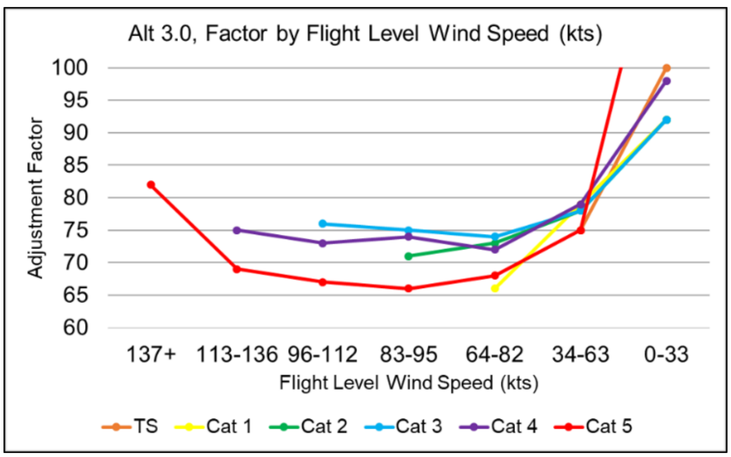

Figure 9: Average adjustment factors for each wind speed bin and storm category at aircraft altitude of 3km. Including the 0-33kt bin.

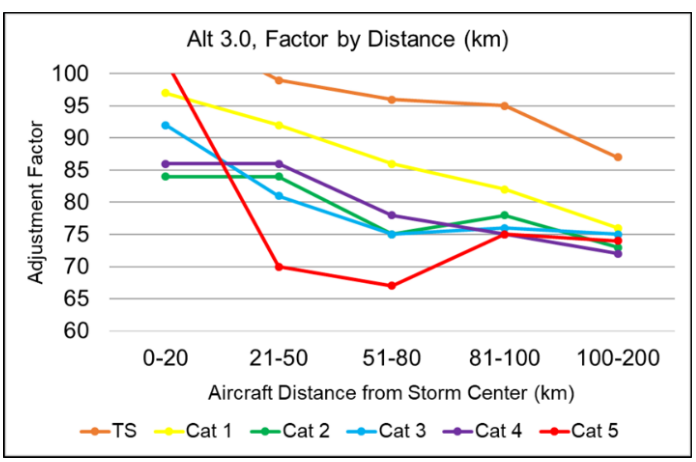

Figure 10: Average adjustment factors for each distance bin and storm category at aircraft altitude of 3km.

AdF Error:	WS_{sfmr} - WS_{AdF}
Factor	**Error (kts)**
90%	8.99
AdF Dist	7.05
AdF WS	6.98
Avg (D, W)	6.79

Table 2: The average error of each adjustment factor used to estimate the surface wind speed compared to the SFMR measured surface wind speed. AdF_Dist is the factor based on distance, AdF_WS is the factor based on flight level wind speed, and Avg (D, W) is the average of the distance and wind speed adjustment factors.

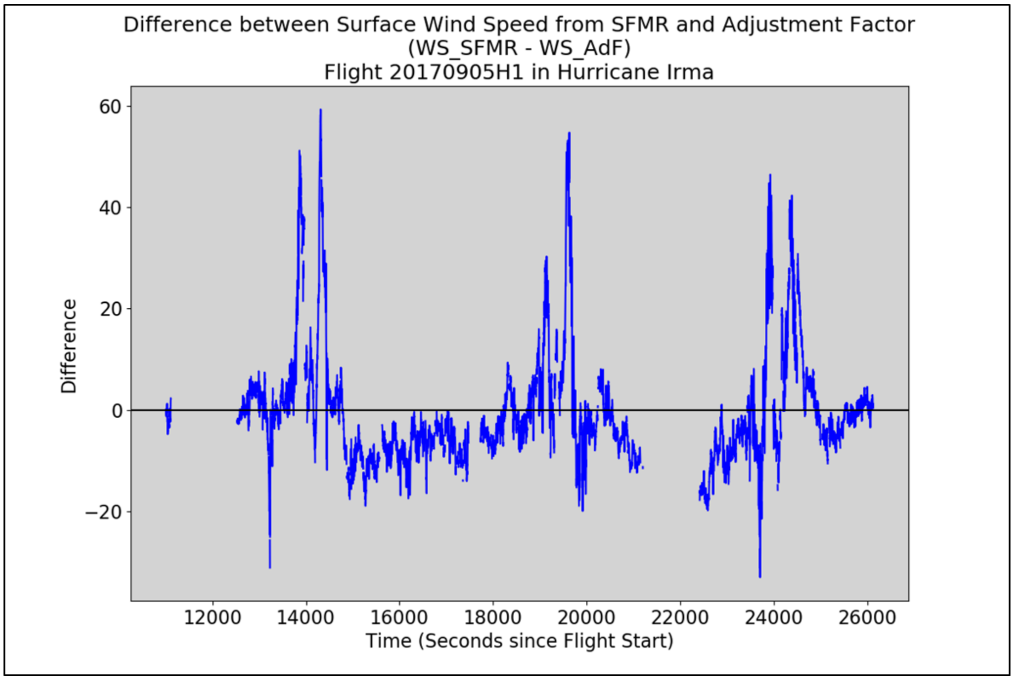

Figure 11: Error for surface wind speed calculated using the adjustment factor to the surface wind measured by the SFMR. This is for a single flight in Hurricane Irma on 05 Sept 2017.

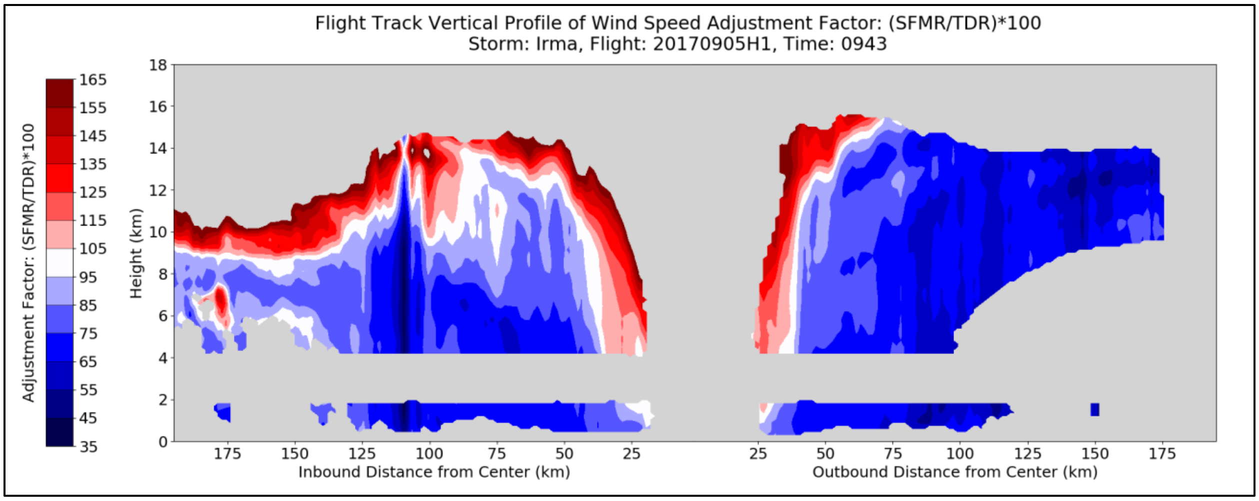

Figure 12: Vertical profile of the ratio between the TDR measured wind speed from 0-18km in altitude and the surface wind speed measured by the SFMR. This is from one center pass during a flight in Hurricane Irma on 05 Sept 2017.

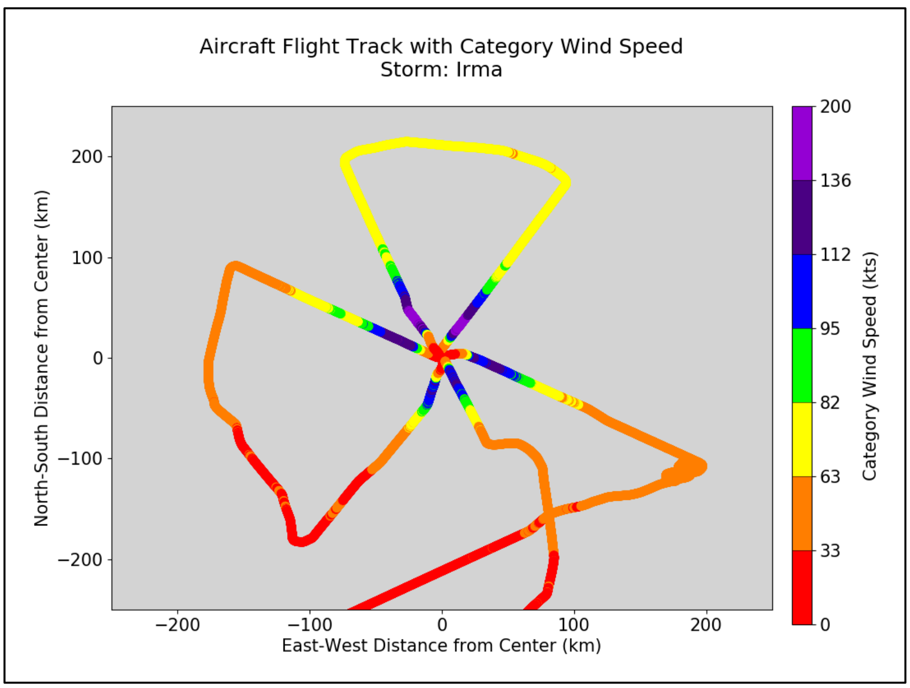

Figure 13: Aircraft flight track in Hurricane Irma on 05 Sept 2017. Colored by flight level wind speed binned by category ranges.

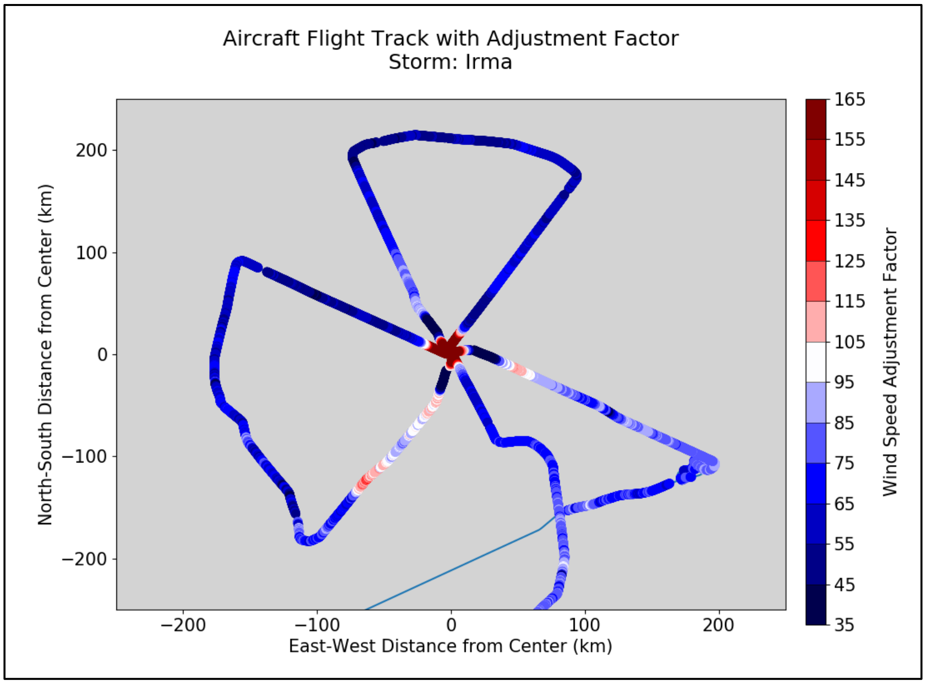

Figure 14: Aircraft flight track in Hurricane Irma on 05 Sept 2017. Colored by flight level to surface wind speed ratio (adjustment factor). The warmer colors indicate surface wind speed is greater than flight level wind speed while the cooler colors indicate surface wind speed is less than the flight level wind speed.

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Appendix A – Adjustment Factor Tables

1. Adjustment Factor based on Distance

Alt: 2.0	0-20	21-50	51-80	81-100	100-200
TS	122	125	102	88	84
Cat 1	93	78	68	71	65
Cat 2	93	78	73	74	71
Cat 3	94	83	76	73	70
Cat 4	91	79	79	80	78
Cat 5	89	80	81	76	72

Table 1: Adjustment factor for aircraft altitude of 2.0km (±250m) based on aircraft distance from storm center (km, columns) and storm category (rows).

Alt: 2.5	0-20	21-50	51-80	81-100	100-200
TS	95	85	85	82	78
Cat 1	102	90	78	76	72
Cat 2	94	79	72	74	78
Cat 3	90	75	70	73	84
Cat 4	93	75	72	74	81
Cat 5	72	71	75	82	79

Table 2: Adjustment factor for aircraft altitude of 2.5km (±250m) based on aircraft distance from storm center (km, columns) and storm category (rows).

Alt: 3.0	0-20	21-50	51-80	81-100	100-200
TS	108	99	96	95	87
Cat 1	97	92	86	82	76
Cat 2	84	84	75	78	73
Cat 3	92	81	75	76	75
Cat 4	86	86	78	75	72
Cat 5	102	70	67	75	74

Table 3: Adjustment factor for aircraft altitude of 3.0km (±250m) based on aircraft distance from storm center (km, columns) and storm category (rows).

2. Adjustment Factor based on Flight Level Wind Speed

Alt: 2.0	0-33	34-63	64-82	83-95	96-112	113-136	137+
TS	97	61					
Cat 1	79	70	74				
Cat 2	95	81	66	69			
Cat 3	99	83	74	75	77		
Cat 4	99	83	77	75	71	74	
Cat 5	121	81	81	84	77	71	72

Table 4: Adjustment factor for aircraft altitude of 2.0km (±250m) based on flight level wind speed (knots, columns) and storm category (rows).

Alt: 2.5	0-33	34-63	64-82	83-95	96-112	113-136	137+
TS	87	70					
Cat 1	94	77	66				
Cat 2	102	81	68	66			
Cat 3	97	82	71	68	69		
Cat 4	111	84	72	68	70	71	
Cat 5	96	86	65	63	59	67	81

Table 5: Adjustment factor for aircraft altitude of 2.5km (±250m) based on flight level wind speed (knots, columns) and storm category (rows).

Alt: 3.0	0-33	34-63	64-82	83-95	96-112	113-136	137+
TS	100	75					
Cat 1	92	79	66				
Cat 2	92	78	73	71			
Cat 3	92	78	74	75	76		
Cat 4	98	79	72	74	73	75	
Cat 5	128	75	68	66	67	69	82

Table 6: Adjustment factor for aircraft altitude of 3.0km (±250m) based on flight level wind speed (knots, columns) and storm category (rows).

Appendix B – List of Flights Used in Analysis

Date	Flight ID	Storm	Cat
2012-10-15	H1	Rafael	1
2012-10-16	H1	Rafael	1
2012-10-25	H1	Sandy	2
2012-10-26	H1	Sandy	1
2012-10-27	H1	Sandy	1
2012-10-27	H2	Sandy	1
2012-10-28	H1	Sandy	1
2012-10-28	H2	Sandy	1
2013-09-13	I1	Ingrid	TS
2013-09-14	H1	Ingrid	TS
2013-09-14	I1	Ingrid	1
2013-09-15	H1	Ingrid	1
2013-10-03	H1	Karen	TS
2013-10-04	I1	Karen	TS
2013-10-04	H1	Karen	TS
2013-10-05	I1	Karen	TS
2014-07-02	H1	Arthur	TS
2014-07-02	I1	Arthur	TS
2014-07-03	H1	Arthur	1
2014-07-03	I1	Arthur	1
2014-08-03	H1	Bertha	TS
2014-08-04	I1	Bertha	1
2014-08-04	H1	Bertha	1
2014-08-23	I1	Cristobal	TS
2014-08-24	H1	Cristobal	TS
2014-08-24	I1	Cristobal	TS
2014-08-25	H1	Cristobal	TS
2014-08-25	I1	Cristobal	TS
2014-08-26	H1	Cristobal	1
2014-08-26	I1	Cristobal	1
2014-08-27	I1	Cristobal	1
2014-09-15	H1	Edouard	2
2014-09-15	I1	Edouard	2
2014-09-16	H1	Edouard	3
2014-09-16	I1	Edouard	2
2014-10-15	I1	Gonzalo	4
2014-10-16	I1	Gonzalo	4
2014-10-17	I1	Gonzalo	4
2015-08-21	I1	Danny	2
2015-08-22	I1	Danny	1
2015-08-23	I2	Danny	TS
2015-08-24	I1	Danny	TS
2015-08-25	I1	Erika	TS
2015-08-26	I1	Erika	TS
2015-08-26	I2	Erika	TS
2015-08-27	I1	Erika	TS
2015-08-28	I1	Erika	TS
2015-11-09	I1	Kate	TS
2015-11-10	I1	Kate	TS
2015-11-10	I2	Kate	TS
2016-08-02	I1	Earl	TS
2016-08-03	I1	Earl	TS
2016-08-03	I2	Earl	1
2016-08-29	I1	Hermine	TD
2016-08-29	I2	Hermine	TD
2016-08-30	I1	Hermine	TD
2016-08-31	I1	Hermine	TS
2016-09-01	I1	Hermine	TS
2016-09-20	I1	Karl	TS
2016-09-21	I1	Karl	TD
2016-09-22	I1	Karl	TS
2016-09-23	I1	Karl	TS
2016-09-23	I2	Karl	TS
2016-09-24	I1	Karl	TS
2016-09-30	I1	Matthew	4
2016-10-01	I1	Matthew	5
2016-10-05	I1	Matthew	3
2016-10-05	I2	Matthew	4

Date	Flight ID	Storm	Cat
2016-10-06	I2	Matthew	4
2016-10-07	I1	Matthew	3
2016-10-08	I1	Matthew	2
2016-10-08	I2	Matthew	2
2017-08-08	H1	Franklin	TS
2017-08-09	H1	Franklin	TS
2017-08-24	H1	Harvey	TS
2017-08-24	H2	Harvey	1
2017-08-25	H1	Harvey	1
2017-08-25	H2	Harvey	3
2017-09-04	H1	Irma	3
2017-09-04	H2	Irma	4
2017-09-05	H1	Irma	5
2017-09-05	H2	Irma	5
2017-09-08	H1	Irma	4
2017-09-08	H2	Irma	4
2017-09-09	H1	Irma	5
2017-09-17	H1	Jose	1
2017-09-22	H1	Maria	3
2017-09-23	H1	Maria	3
2017-09-24	H1	Maria	2
2017-09-24	H2	Maria	3
2017-09-25	H1	Maria	2
2017-09-25	H2	Maria	1
2017-09-26	H1	Maria	1
2017-09-26	H2	Maria	1
2017-10-06	H2	Nate	TS
2017-10-07	H1	Nate	1
2018-07-08	H1	Chris	TS
2018-07-08	H2	Chris	TD
2018-07-09	H1	Chris	TS
2018-07-09	H2	Chris	TS
2018-09-04	H1	Gordon	TS
2018-09-04	H2	Gordon	TS
2018-09-10	H1	Florence	4
2018-09-12	H2	Isaac	TS
2018-09-13	H1	Isaac	TS

Date	Flight ID	Storm	Cat
2018-09-14	H1	Isaac	TS
2018-10-09	H1	Michael	1
2018-10-09	H1	Michael	2
2018-10-09	H2	Michael	3
2018-10-10	H1	Michael	4
2019-08-26	H1	Dorian	TS
2019-08-27	H1	Dorian	TS
2019-08-28	H1	Dorian	1
2019-08-29	H1	Dorian	1
2019-08-29	H2	Dorian	3
2019-08-30	H1	Dorian	3
2019-08-31	H1	Dorian	5
2019-08-31	H2	Dorian	5
2019-09-01	H1	Dorian	5
2019-09-02	H2	Dorian	4
2019-09-03	H1	Dorian	4
2019-09-04	H1	Dorian	4
2019-09-05	H1	Dorian	3

THE UNIVERSITY OF ALABAMA IN HUNTSVILLE

David Cook <dac0010@uah.edu>

Re: Capstone Report

Ryan Wade <ryan.wade@uah.edu> Wed, Apr 29, 2020 at 10:43 AM
To: Nicholas Johnson <nej0004@uah.edu>
Cc: UAH aes-chair <aes-chair@uah.edu>, wilkerw@uah.edu, David Cook <dac0010@uah.edu>

Please find the approved & signed Capstone paper by Nicholas Johnson.

John: Please sign and return.

Great job Nicholas!

Ryan Wade
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On Fri, Apr 24, 2020 at 7:17 PM Nicholas Johnson <nej0004@uah.edu> wrote:

> Hi Mr. Wade,
>
> Attached is my Capstone report. The PDF file is the complete version with all the title pages required by the Honors College. The Word document is only the body text and figures for your review. Please let me know if you have any suggestions.
>
> Once you approve the report, the Honors College has these guidelines:
>
> If the Project Director approves it, s/he emails approval back to the student, and copies their Department Chair, the Honors Dean at wilkerw@uah.edu, and David Cook at dac0010@uah.edu. (Project Directors please note - copy all 3 of us!)
>
> The PD does not have to add an electronic signature (but can if she/he wants). The email itself will be recognized as an official signature since doing so requires login.
>
> Thanks,
> Nicholas

--

Ryan Wade
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Severe Weather Institute -
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University of Alabama in Huntsville

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