3B.5 A FRESH LOOK AT TROPICAL CYCLONE PRESSURE-WIND RELATIONSHIPS USING RECENT RECONNAISSANCE-BASED "BEST TRACK" DATA (1998-2005)

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1. INTRODUCTION

Determining the relationship between minimum sea level pressure (MSLP) and maximum sustained surface winds (MSSW) in tropical cyclones (TC) has been difficult due to the lack of ground truth observations. Previous studies such as Kraft (1961) and Atkinson and Holiday (1977) used limited surface observations at landfall to determine pressure-wind (PW) relationships. In recent years, GPS dropwindsondes have greatly improved our ability to estimate the MSLP and MSSW of tropical cyclones (Franklin 2000; Franklin et al. 2003; Hock and Franklin 1999). More reliable "best-track" data, coupled with the recent increase in TC activity in the Atlantic Basin, provides new incentive to reexamine PW relationships in Atlantic TCs.

2. DATA

For this study, National Hurricane Center (NHC) best track data for the Atlantic Basin from 1998-2005 were examined for times when a reconnaissance aircraft "fix" was available within +/- 3-hr of a best track time of a tropical cyclone. During post-storm analysis, fixes within a +/- 3 hr time frame are generally used by NHC to determine each 6-hourly best track estimate of MSLP and MSSW.

Due to the unusually large number of tropical cyclones in the Atlantic Basin in 2005, NHC best track data had not been finalized for 2005 as of the time of this writing. The 2005 best track data used here therefore contain a combination of operationally-assessed MSLP and MSSW pairs and final post-storm analyzed best track pairs. It should be noted that the best tracks for Hurricanes Dennis, Katrina, Ophelia, and Wilma are in final form. Changes between the operationally assessed MSLP and MSSW values and the final NHC best track values rarely exceed 5 mb for MSLP and 10 kt for MSSW.

From 1998 to 2005, 1092 best track times satisfied the +/- 3-hr reconnaissance fix data criteria above. Once best track positions that were overland were excluded, 1053 best track MSLP and MSSW pairs were available for this study. Figure 1 shows the locations of the positions of the 1053 data pairs. Since reconnaissance aircraft typically do not intercept TCs east of 50°W, the best-track data pairs cover the area from 10°N to near 41°N, west of 51°W. This dataset is far larger than the 14 data pairs used by Kraft and the 76 pairs by Atkinson and Holiday for their studies.

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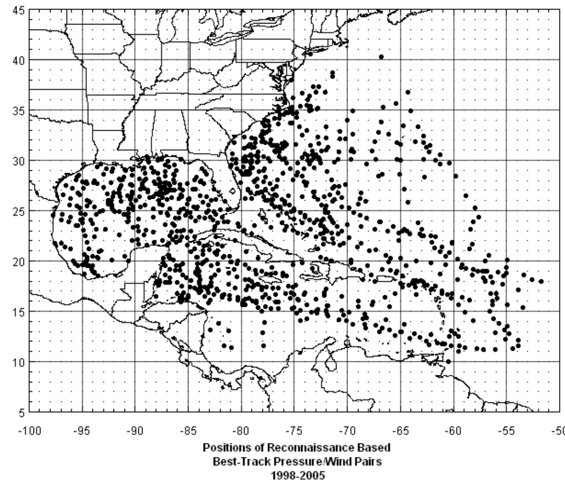

Figure 1. Positions of the 1053 best track MSLP and MSSW data pairs used for this study.

The recent increased TC activity and the unusually intense hurricanes of 2005 produced several very low MSLP observations. For this study, 13 data pairs had MSLP values 910 mb or less, with 5 of these values below 900 mb. These 13 data pairs were obtained from Mitch (1998), Ivan (2004), Katrina (2005), Rita (2005), and Wilma (2005). It should be noted that lowest MSLP values used in this study are three separate 892 mb points from Wilma. Wilma's Atlantic basin record minimum MSLP 882 mb (1200 UTC 19 October in the best track) did not have a reconnaissance fix within +/- 3 hours and therefore did not meet the criteria defined in this study.

The data were further stratified into sub-basins, with 305 pairs in the Gulf of Mexico, 257 in the Caribbean, and 491 in the Atlantic.

3. PRESSURE-WIND RELATIONSHIPS

Previous pressure-wind relationships have been derived from the cyclostrophic wind equation and are given in the from $V_m=a(b-p)^c$, where V_m is the MSSW (kt), p is the MSLP (mb), and a,b, and c are constants determined from a least-squares fit (c=0.5 for true cyclostrophic flow). Using this form of the relationship, the best track data yield the following equation, shown by the solid curve in Figure 2:

$$V_m= 8.354(1015.8-p)^{0.6143}$$

The curve yields a correlation of 0.96 (92% explained variance). The RMS error is 9.3 kt.

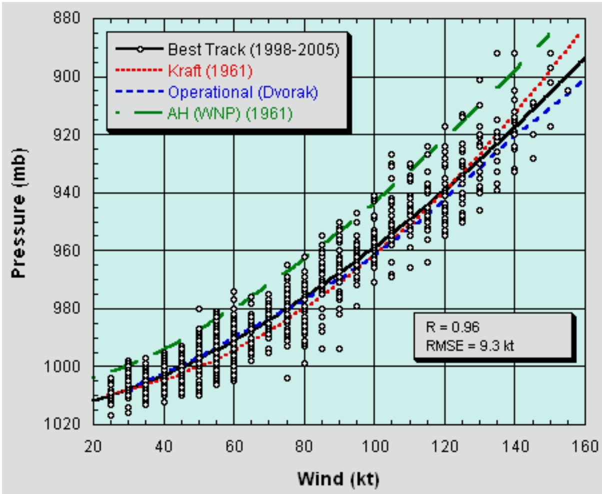

Figure 2. Scatter diagram of maximum sustained wind versus minimum pressure from reconnaissance-based NHC best track data, 1998-2005. The solid black curve is the least-squares non-linear best-fit to the data. Selected previously reported pressure-wind relationships are also shown as indicated.

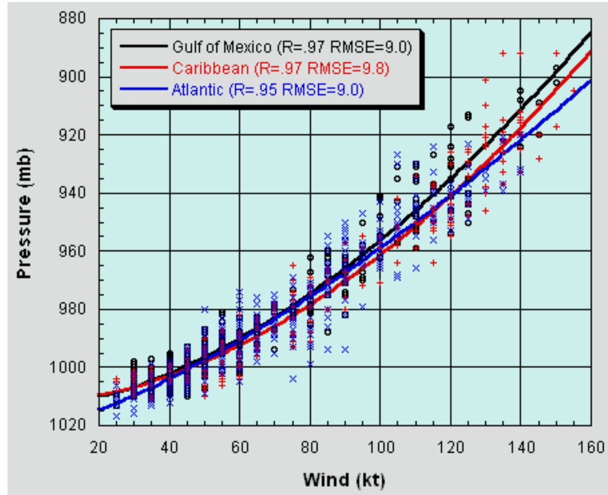

Figure 3. Comparison of the 1998-2005 reconnaissance-based PW curves for the Gulf of Mexico, Caribbean, and Atlantic sub-basins.

For comparison, the figure also shows some the previously defined pressure-wind relationships from Kraft, for the Atlantic, and AH for the western North Pacific (WNP). Also shown is a curve used operationally by NHC dating back to Dvorak (1975, 1984). The pressure-wind relationship determined from the 1998-2005 reconnaissance based best track data is remarkably close to the Dvorak operational relationship. (This was not a pre-ordained result, since the operational pressure-wind relationship is not heavily relied upon when reconnaissance data are present.) It is seen from the graph that the new best track PW curve is slightly to the left of the operational Dvorak PW relationship for TCs with MSLPs less than 970 mb (MSSW of about 90 kt or greater). This difference is only 1-2 kt and means that provided an equivalent MSLP, the new best track PW relationship yield only slightly weaker winds than the current operational Dvorak PW relationship. This difference was not noted by Brown and Franklin (2002), and it is the result of the recently added low MSLP data pairs.

Comparing the new PW relationship with Kraft (1961), for storms with MSLPs between 960 and 1000 mb, the new PW equation yields MSSW 3-5 kt lower than what Kraft found. However, the opposite is seen for TCs with extremely low MSLPs. For storms with MSLPs less than 920 mb, the new PW relationship would yield winds that are about 3-5 kt higher than Kraft.

4. SUB-BASIN AND LATITUDINAL RESULTS

Separate PW relationships were computed for the Gulf of Mexico, Caribbean Sea, and Atlantic. The following PW equations were obtained:

Gulf of Mexico: $V_m = 9.457(1014\text{-}p)^{0.5819}$

Caribbean Sea: $V_m = 11.941(1012.2\text{-}p)^{0.5412}$

Atlantic: $V_m = 5.169(1021.3\text{-}p)^{0.7171}$

Differences between the curves have not been tested for statistical differences. Small differences are seen at both extremes (high and low MSLP) between the Caribbean Sea and Atlantic PW curves (Figure 3). These differences range from 2-3 kt for weak TCs to about 5-7 kt for very strong TCs. However, the difference is very small for the majority of TC wind speeds. It should be noted that there were no Atlantic data pairs with MSLP lower than 920 mb. The Gulf of Mexico PW curve is left of (weaker MSSW) both the Atlantic and Caribbean Sea curves for TCs with equivalent MSLPs. For example, using the defined sub-basin equations, a TC with a MSLP of 920 mb would have a MSSW of 133 kt in the Gulf of Mexico, 138 kt in the Caribbean, and 142 kt in the Atlantic.

A comparison between the new Gulf of Mexico PW relationship and a Gulf of Mexico PW relationship derived by Landsea et al. (2004) using best track data from 1970-1997 was performed. For TCs with MSLPs lower than 965 mb, the new PW relationship yields MSSW about 3-4 kt lower than Landsea et al.

Since the data abundant portion of the Atlantic and Caribbean PW curves are very similar, it seems the pressure wind relationship is not very sub-basin dependent. However, previous studies have noted that the PW relationship is very much latitude dependent. The 1053 MSLP and MSSW data pairs were sub-divided at 25N yielding 579 data pairs south of 25°N and 474 data pairs north of 25°N. PW relationships were derived for both sets of data with the following results:

South of 25N: V_m= 10.205(1014.4-p)$^{0.5736}$

North of 25N: V_m= 8.636(1015-p)$^{0.5989}$

Figure 4 is a comparison of the latitude defined PW curves. TCs north of 25°N have weaker winds compared to TCs south of 25°N. In terms of pressure, tropical storms north of 25°N have MSLPs about 1-2 mb lower than for tropical storms south of 25°N. The differences are about 3-5 mb for Category 1 and 2 hurricanes and about 5-8 mb for major hurricanes (MSSW 100 kt or greater).

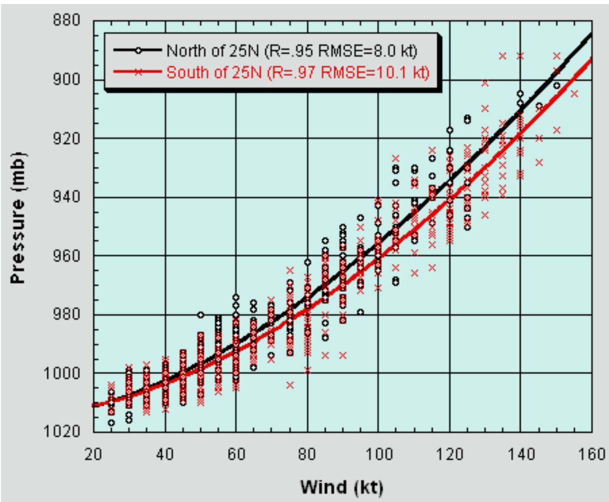

Figure 4. Comparison of the 1998-2005 reconnaissance-based PW curves for the entire Atlantic basin north of 25°N and south of 25°N.

5. WEAKENING VERSUS STRENGTHENING RESULTS

The data were subdivided using 12 h best track MSSW changes. Strengthening (weakening) TCs were defined as systems that had a MSSW increase (decrease) of 5 kt or more in 12 hours. A small number of data pairs did not have a prior 12 h best track MSSW and these data were not included. The strengthening, weakening, and no change subsets were then plotted and the resulting PW relationships were computed:

Strengthening: V_m= 9.397(1014.4-p)$^{0.5955}$

No Change: V_m= 10.15(1013.5-p)$^{0.5704}$

Weakening: V_m= 8.306(1015.9-p)$^{0.6039}$

Figure 5 is a comparison of the resulting PW equations. The graph shows that for TCs with equivalent MSLPs, weakening TCs have lower MSSW than TCs that are strengthening. For example, a TC with a MSLP of 940 mb, yields 113 kt when it is weakening, 118 kt when there is no intensity change, and 122 kt when it is strengthening. The difference is about 10-12 kt for category 4 and 5 hurricanes.

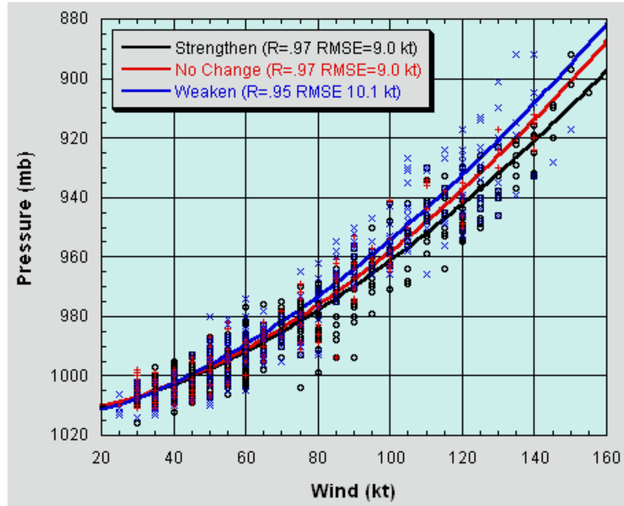

Figure 5. Comparison of the 1998-2005 reconnaissance-based PW curves for strengthening, no change, and weakening TCs. Intensity change based on 12 h best track MSSW differences.

6. CONCLUSIONS

The increased tropical cyclone activity over the last few years has resulted in a marked increase in the amount of reconnaissance-based best track data available for this type of study. During this very active period three of the lowest six lowest MSLPs ever recorded in the Atlantic basin have been observed. Despite the abundance of new data, the results yield PW equations that are consistent with previous studies. However, the new 1998-2005 data provide additional high MSSW and low MSLP data pairs that help build confidence in the PW curves. The new PW equation produces slightly lower MSSW for equivalent MSLPs than the current operational Dvorak PW curve.

Sub-basin results indicate that for equivalent MSLPs, weaker MSSW are found in the Gulf of Mexico than in the Caribbean Sea or Atlantic. Since the Caribbean and Atlantic PW relationships were fairly similar, the data were then subdivided by latitude. This resulted in a pronounced difference between the PW relationship north of 25°N versus south of 25°N. Additionally, PW equations were computed for strengthening, weakening, and no 12 h intensity changes. Weakening systems have much lower MSSW than strengthening systems of equivalent MSLPs.

It can be seen from Fig 1. that large variations in MSSW for a given pressure do occur. Our results suggest that more precise estimates can be obtained by considering factors such as latitude and/or intensity change. As general rule, using the new PW equation, 50% of the time it will be within 7 kt of the best track MSSW, 75% of the time within 12 kt and 90% within 16 kt.

It is hoped that this look at recent Atlantic PW relationships can help explain some of the variations in the PW relationships that occurs. Perhaps, future studies can look at other factors such as the radius of maximum winds or overall size of the TC to quantify some of these differences. Hopefully, these new PW equations can be used operationally and in reanalysis projects when accurate MSLP are available, but corresponding MSSW are not.

7. REFERENCES

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