5A.7 # GUST FACTORS IN HURRICANE AND NON-HURRICANE CONDITIONS

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1. INTRODUCTION

The question of whether gust factors observed in hurricanes differ from those observed in non-hurricane conditions has proven to be a rather contentious one. A number of authors have argued that they are indeed higher in hurricanes, when compared to those observed for the equivalent terrain conditions in non-hurricane conditions, while others have argued that there is no difference between the two sets of values.

Krayer and Marshall (1992) were the first to consider the question and found that, after standardizing a number of wind records measured in hurricane conditions to a height of 10 m and open terrain conditions, the resulting gust factors were higher than those obtained by Durst (1960) for extra-tropical cyclones. More recently Paulsen and Schroeder (2005) came to a similar conclusion after comparing gust factors measured using mobile towers in both hurricane and non-hurricane conditions, albeit at different locations and under differing terrain conditions. Conversely Vickery and Skerlj (2005), in re-examining the wind speed records used by Krayer and Marshall (1992) supplemented by data from a number of more recent landfalling storms, found that, after adjusting the records for height and averaging time using a standard boundary layer model for extra-tropical wind conditions, the resulting gust factors did not differ appreciably from those associated with extra-tropical winds.

Part of the problem in comparing gust factors observed in hurricane and non-hurricane conditions is that a number of a priori assumptions about the behaviour of the atmospheric boundary layer with height above ground under these conditions are usually required in order to establish some form of equivalency between the observed gust factors. Further complications arise in that a consistent methodology has not generally been used to determine the gust factors in both hurricane and non-hurricane conditions which then leads to further differences.

In this paper, rather than trying to compare gust factors observed under differing terrain and measurement conditions in both hurricane and non-hurricane conditions, we simply pose the question are gust factors observed at a particular location during the passage of a hurricane significantly different from those observed under non-hurricane conditions at the same location. In this way we ensure that the observed gust factors are defined in a consistent manner for the same terrain conditions.

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2. DATA

Wind speed data for seven ASOS stations along the Gulf and Atlantic coastlines of the United States was obtained from the National Climatic Data Centre. The data records obtained covered a 7-year time period extending from June 1998 through to August 2005, during which time a total of 21 hurricanes that affected one or more of the selected stations were identified. The data itself consisted of the 2-minute mean wind speed and direction, together with the peak 5-second gust and direction observed in the preceding minute, at 1-minute intervals.

For each station the wind speed data record was first resampled to obtain a set of independent values for the 2-minute mean wind speed and direction, as well as the maximum value of the peak 5-second gust and direction that occurred in each 2-minute interval. This resampled record was then used to calculate a set of independent values for the 10-minute mean wind speed and direction. A gust factor based on the 10-minute mean wind speed and the maximum value of the peak 5-second gust within each 10-minute interval was then calculated. At the same time the difference in direction between the 10-minute mean wind speed and the maximum value of the peak gust wind speed was also calculated.

Rather than attempt to classify the terrain conditions at each station on the basis of either a visual examination of aerial photographs of the site surrounds or some other measure such as the turbulence intensity, which in any case was unavailable, the exposure at each station was split into twelve 30^o-wide sectors, centred on 0^o, 30^o, etc. through to 330^o. The calculated gust factors were then sorted by sector based on the 10-minute mean wind direction. To further ensure that the calculated gust factors were representative of the upstream terrain conditions in a given sector, a limit of 15^o was imposed on the maximum difference between 10-minute mean wind direction and the associated peak gust wind direction in order for the gust factor to be used for further analysis.

The final step was to split the processed data into hurricane and non-hurricane wind speed records. This was achieved through a combination of visual examination of the wind speed record for each station, National Hurricane Centre (NHC) tropical cyclone reports, and Geographic Information System (GIS) software. Once a particular storm passing by a given station had been identified, a 24- or 48-hour window centred on the time of the maximum 10-minute mean wind speed observed during the passage of the storm was used to define hurricane conditions. The choice of a 24- or 48-hour window was dictated primarily by a visual examination of the wind speed record for the period and the point at which the 10-minute mean wind speed exceeded a threshold of 5 m/s. In cases where the wind speed record was incomplete due to failure of the station during passage of the storm the window was centred on a 'best guess' of the time at which the peak wind speed occurred.

3. RESULTS

Figure 1 shows a typical scatter plot of the variation of the gust factor with the 10-minute mean wind speed for both hurricane and non-hurricane conditions for a particular ASOS station and wind direction, in this case for the ASOS station at Wilmington International Airport, NC, and a wind direction of 300°. Considerable scatter can be seen in the results, particularly at very low wind speeds where gust factors in excess of 4.0 can be noted. Much of this scatter at low wind speeds can be attributed to the stability of the atmosphere, and in particular to the impact of small-scale convective gusts on the gust factor at very low mean wind speeds. As the mean wind speed increases the scatter is significantly reduced and the observed gust factors tend towards an apparently constant value.

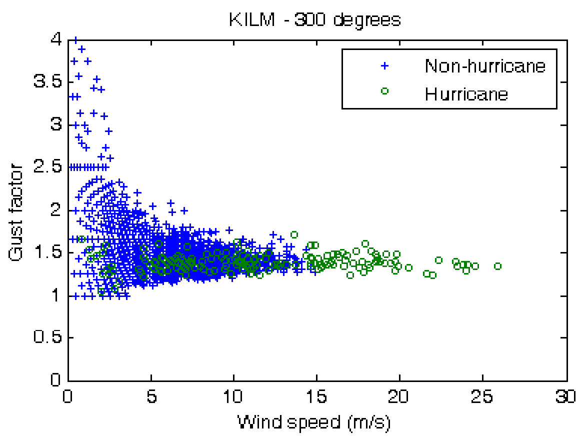

Figure 1: Gust factor versus 10-minute mean wind speed for a wind direction of 300° for Wilmington International Airport, NC.

Before making any further comparisons of the gust factors observed in hurricane and non-hurricane conditions for a given station/wind direction combination we firstly remove all those values where the 10-minute mean wind speed is less than 5 m/s. The choice of 5 m/s for a lower cut-off wind speed is somewhat arbitrary, but follows the example of Paulsen and Schroeder (2005) who used the same value in their analysis. After having removed all those values where the 10-minute mean wind speed is less than 5 m/s from the records for both hurricane and non-hurricane conditions we then calculate the mean and median value of the gust factor, together with histograms of the gust factors observed under both hurricane and non-hurricane conditions for each station/wind direction combination considered.

A typical example of the resulting gust factor histograms for both hurricane and non-hurricane conditions is shown in Figure 2, in this case for the ASOS station at Mobile Regional Airport, AL, and a wind direction of 150°. A visual examination of the figure suggests that the gust factors observed under hurricane conditions are indeed higher than those observed under non-hurricane conditions, as indicated by the apparent offset between the two distributions. This is confirmed by the mean gust factor values which are equal to 1.42 and 1.36 respectively for hurricane and non-hurricane conditions, the corresponding values for the median gust factor being 1.41 and 1.35. Although both the mean and median gust factors show some variation with wind direction at each station due to changes in the upstream terrain with direction, where there is an observable difference between the gust factors observed under hurricane conditions and non-hurricane conditions, the mean and median gust factors observed under hurricane conditions are always larger than those observed under non-hurricane conditions for a given station/wind direction combination.

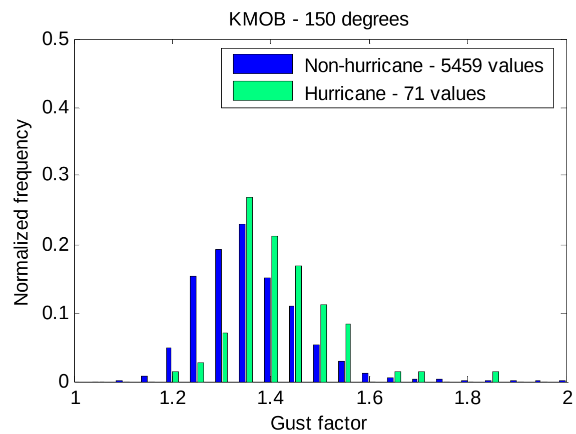

Figure 2: Histogram of observed gust factors for hurricane and non-hurricane conditions for a wind direction of 150° for Mobile Regional Airport, AL, and a lower cut-off wind speed of 5 m/s.

In an attempt to quantify the differences between the gust factor distributions for hurricane and non-hurricane conditions we apply two statistical tests. The first of these is the Kolmogorov-Smirnov test to compare the distribution of two samples – in this case the gust factor distributions observed under hurricane and non-hurricane conditions. The second test we apply is the Wilcoxon rank sum test for equal medians. In the case of the former the null hypothesis is that both samples are drawn from the same continuous distribution, while for the latter it is that the samples come from distributions with equal medians. Both tests are applied at a significance level of 5%. We also place a requirement that the number of gust factor values contained in the sample must be greater than 15 in order for the test results to be considered valid.

Of the possible 84 test results that we can consider for each statistical test (7 stations x 12 wind directions/ station) we consider 75 results valid after taking into account the number of values contained in each sample. For the Kolmogorov-Smirnov test we find that for 80% of the valid test results we reject the null hypothesis, that is the gust factor distributions observed under hurricane conditions are not the same as those observed for the same station/wind direction combination in non-hurricane conditions. The results of the Wilcoxon rank sum test are very similar, in that for 79% of the valid test results we reject the null hypothesis that the two distributions have equal medians.

In choosing to use a value of 5 m/s for the lower cut-off wind speed we have selected a value that is somewhat lower than is conventionally used to define high wind situations. Wieringa (1973) used a lower cut-off value of 8 m/s to define high wind situations, while in many engineering applications a value of 10 m/s is commonly used. Accordingly we choose to rerun the analysis, only this time using a lower cut-off value of 10 m/s for the 10-minute mean wind speed in order to determine the impact of the selected cut-off wind speed on the results.

Figure 3 shows the resulting gust factor histograms for hurricane and non-hurricane conditions for the same station/wind direction combination shown in Figure 2. The impact of the higher cut-off wind speed can clearly be seen in the number of gust factor values selected for non-hurricane conditions which is only 132 compared to the 5459 values selected when a cut-off wind speed of 5 m/s is used. The impact on the number of gust factors selected for hurricane conditions is not as significant, 65 values being selected compared to the 72 selected when a cut-off wind speed of 5 m/s is used. It is also apparent from a visual examination of the figure that the difference between the two gust factor distributions is reduced when compared to that visible in Figure 2. Values for the mean gust factors are 1.41 and 1.40 for hurricane and non-hurricane conditions respectively, the median values being identical to the mean values.

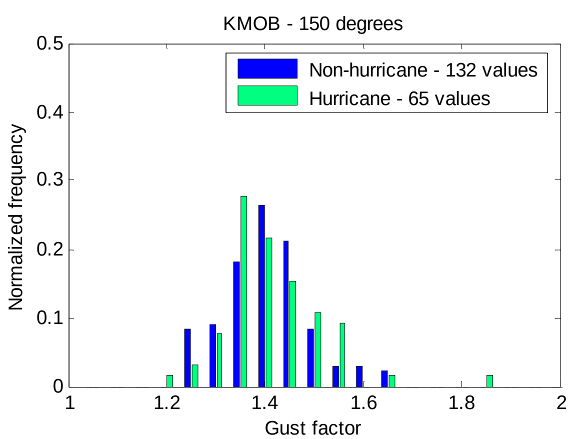

Figure 3: Histogram of observed gust factors for hurricane and non-hurricane conditions for a wind direction of 150^{o} for Mobile Regional Airport, AL, and a lower cut-off wind speed of 10 m/s.

If we consider the results of the Kolmogorov-Smirnov and Wilcoxon rank sum tests, although the number of valid test results is now only 40 because of the reduction in the number of values contained in each sample due to the higher cut-off wind speed, we find that for both tests we reject the null hypothesis for only 40% of the valid test results compared to the 80% that are rejected when a cut-off wind speed of 5 m/s is used. If we limit ourselves to considering only those test results that are valid for both cut-off wind speed values considered, we find that the percentage of test results in which we reject the null hypothesis for a cut-off wind speed of 5 m/s are 83% and 80% for the Kolmogorov-Smirnov and Wilcoxon rank sum tests respectively, which are virtually identical to the percentages observed when all the valid test results are considered for this cut-off wind speed.

Like Paulsen and Schroeder (2005) we are at a loss to explain the root cause of the differences found between the gust factor distributions observed in hurricane and non-hurricane conditions. It is clear from the results presented that these differences are a function of the 10-minute mean wind speed, and that as this increases the difference between the two separate gust factor distributions decreases. We therefore come to a similar conclusion to that of Vickery and Skerlj (2005), and conclude that under high wind speed conditions (10-minute mean wind speed > 10 m/s) gust factors for hurricane and non-hurricane conditions can apparently be described by the same models. The reasons for the differences observed at lower wind speeds are unknown, but we might hypothesize that they are in some way linked to increased convective activity in hurricane conditions at low wind speeds when compared to that found in non-hurricane conditions.

4. REFERENCES

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