May 2016

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Recommended Citation

Harris, Austin Reed, "On Establishing a Climatology of Gust Factors and Assessing Their Ability to Forecast Wind Gusts in Milwaukee, WI" (2016). *Theses and Dissertations*. 1150.
https://dc.uwm.edu/etd/1150

ON ESTABLISHING A CLIMATOLOGY OF GUST FACTORS AND ASSESSING THEIR ABILITY TO FORECAST WIND GUSTS IN MILWAUKEE, WISCONSIN

by

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A Thesis Submitted in

Partial Fulfillment of the

Requirements for the Degree of

Master of Science

in Mathematical Science

at

The University of Wisconsin-Milwaukee

May 2016

ABSTRACT

ON ESTABLISHING A CLIMATOLOGY OF GUST FACTORS AND ASSESSING THEIR ABILITY TO FORECAST WIND GUSTS IN MILWAUKEE, WISCONSIN

by

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The University of Wisconsin-Milwaukee, 2016
Under the Supervision of Professor Jon Kahl

Wind gust forecasts are difficult given the small spatial and temporal scales at which they occur. As a result, a variety of statistical and numerical modeling approaches are used to forecast wind gusts, but a best practice has yet to be determined. One statistical approach, called a gust factor, is advantageous in its simplicity, and is often used operationally. Derived empirically from hourly and one-minute wind observations, we establish a climatology of gust factors for the 2000 to 2014 period at Milwaukee, WI. The gust factors are then stratified by wind speed, direction, time of day and year, and stability to gain insight into the potential sensitivities of the gust factor. Once the climatology of gust factors was established, the ability of the gust factor to forecast wind gusts was assessed deterministically for a variety of wind scenarios. The results suggest that gust factors derived from the standard hourly observational data tend to under-forecast the peak wind each hour. Some stratified gust factors show improvements relative to the non-stratified, mean gust factors. However, nearly all gust factor models show improvements relative to persistence and climatology forecasts.

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ASOS	Automated Surface Observing System
GF	Gust Factor
MAE	Mean Absolute Error
MOS	Model Output Statistics
NCDC	National Climatic Data Center
PBL	Planetary Boundary Layer
PDF	Probability Density Function
TKE	Turbulent Kinetic Energy
WFO	Weather Forecasting Office
WGE	Wind Gust Estimate

1. Introduction

Windstorms cause many fatalities each year in the United States. The majority of these casualties are due to tornadic winds; however, strong non-convective winds associated with the passage of extratropical cyclones comprise a large percentage of these deaths too (Ashley and Black, 2007). The societal impacts of severe winds is not limited to the loss of life, but is also felt by our infrastructure and economy through the damaging of buildings, bridges, and power lines. Thus, wind and wind gust forecasts are in high demand.

The surface wind speed is influenced by pressure gradients and near-surface friction. The sudden, brief increases in the speed of the wind known as wind gusts (American Meteorological Society, 2015) are understood to be the result of stronger wind aloft being deflected towards the surface through vertical mixing by turbulent eddies. Therefore, the magnitude of a wind gust is influenced by predictable meteorological variables such as the velocity of the winds aloft and the amount of vertical mixing within the planetary boundary layer (PBL), of which the latter is determined through the atmospheric stability (Carter, 1974), vertical wind shear, and the surface roughness (Schreur and Geertsema, 2008).

Despite understanding the causes of wind gusts, forecasting the phenomenon remains difficult given the small spatial and temporal scales at which they occur. Given these challenges, a variety of approaches in three broad categories have been used to tackle this problem. *Physical methods* simulate the deflection of wind towards the surface in a numerical weather prediction model. Examples include the use of model-generated soundings to identify source regions for gusts (Hart and Forbes, 1999), a turbulence parameterization through friction velocity (Schulz, 2008) or a combination of local turbulent kinetic energy and buoyancy (Brasseur, 2001) to simulate the deflection of the wind gust towards the surface. *Statistical methods* employ empirical knowledge or regression analysis to forecast gusts. The most widely known example of a statistical method is model output statistics (Rudak, 2006). The third category involves the use of *gust factors*, which are the ratio between wind gust and wind speed observations for a particular location. Gust factors are similar to statistical methods in that the gust factor is empirically derived; however, a gust factor is advantageous in its simplicity.

1.1 Physical Methods

Several of the physical forecast techniques estimate the wind gust with model-generated soundings. In particular, this technique begins with an estimation of the wind speed at the highest model-level from which it is believed that momentum can be transferred downward towards the surface, which is typically assumed to be the top of the predicted PBL or a near-surface stable layer. The forecast wind gust is then that predicted wind speed at the top of the PBL, or a wind speed at an adjacent model level. Although this technique has shown skill with the GFS, NAM, and RUC model-soundings, the method tends to overestimate gusts (Hart and Forbes, 1999; Green and Porembia, 2008). As a result, the wind speeds at model levels midway through the PBL tend to provide a more accurate prediction of the surface wind gusts (Green and Porembia, 2008). Regardless of the model level selected, an obvious shortcoming of this approach is that they heavily depend on the success of the model-based PBL stability forecast, which itself is a difficult quantity to predict (Hart and Forbes, 1999).

Turbulence parameterizations are also chosen to forecast the wind gusts based on the obvious reasoning that gusts represent the amount of vertical mixing in the PBL. Thus, these approaches typically exploit the relationship between a model-predicted near-surface wind speed and a momentum transfer quantity like the friction velocity, bulk Richardson number, or drag coefficient. Variations of these techniques are used by the British Met Office in the MetUM model (Panofsky and Dutton, 1984), and by the German Meteorological Service in the COSMO-EU models (Schulz, 2008). Meanwhile, the approach of Schreur and Geertsema (2008) utilizes the turbulent kinetic energy (TKE), which employs the friction velocity and the Monin-Obukhov estimation of stability.

Perhaps the most sophisticated of the physical techniques is the Wind Gust Estimate (WGE) of Brasseur (2001). This approach utilizes the TKE to make an estimation of the altitude from which momentum can be transferred downward towards the surface. The forecast wind gust is then the average of the winds speeds at the model-levels where the TKE exceeds the buoyant inhibition. Although several authors cite the benefits of WGE (Agustsson and Olafsson, 2009; Nilsson et al, 2007; Chan et al, 2011), there is reason to believe that the WGE has a tendency to overestimate wind gusts (Pinto et al 2009). Furthermore, the only comparison with any other technique suggests little improvements relative to the gust factor (Brasseur, 2001). Therefore, there is little evidence to support the superiority of WGE over any other wind gust forecast techniques.

1.2 Statistical Methods

Statistical methods employ empirical and regression-based techniques to make a wind gust forecast. An example of this technique is the NOAA National Digital Forecast Database's Model Output Statistics (MOS) (Rudak, 2006), where forecast equations were established via regression for nearly 1800 stations across the U.S. The variables used in the wind gust equations include: the wind speeds at 10m, 925mb, 850mb, 700mb, and 500mb, the relative humidity, the relative vorticity, the amount of turbulence, and the ratio between the 925mb and 10m wind speeds. The MOS approach is skillful in the short-term, but there is virtually no skill in predicting whether or not a gust will occur by 72h into the future (Rudak, 2006).

Another common statistical approach to forecasting the wind gusts is a probability density function (PDF). Generalised Linear Models, for example, assume that gusts conform to an exponential-type (Poisson) PDF, while generalized extreme value theory assumes that gusts exhibit an asymptotic Pareto distribution (Friedrichs et al, 2009). These approaches are advantageous in that they capture the net effect of all relevant processes. As a result, they are well suited to predict the probability of a gust exceeding a specified threshold. Moreover, it can be argued that this probabilistic approach is the most appropriate approach given that wind gusts are a naturally stochastic phenomenon. However, these statistical approaches are difficult to refine and improve, especially since there are no known comparisons amongst these methods.

1.3 Gust Factors

Gust factors (GFs) are similar to the aforementioned statistical techniques in that they are empirically derived, but are fairly well studied and are advantageous in their simplicity. First defined by Sherlock (1952), a *GF* is the ratio of the observed wind gust ($Gust_{obs}$) to the observed wind speed ($Wind\ Speed_{obs}$):

$$GF = \frac{Gust_{obs}}{Wind\ Speed_{obs}} \quad (1)$$

When averaged over a period of time, a GF reflects the climatological gustiness of the wind. Once a GF is known, it is then multiplied by a forecast wind speed (often from an NWP model) to yield a prediction of the wind gust ($Gust_{fcst}$):

$$Gust_{fcst} = GF\ x\ Wind\ Speed_{fcst} \quad (2)$$

In this way, the GF can be used as a simple means to estimate the gust from a forecast wind speed.

Studies suggest that the GFs are sensitive to the meteorological conditions. For example, GFs tend to be smaller as the mean wind speed increases (Davis, 1968; Carter, 1974; Agustsson and Olafson, 2004; Cook, 2008; Kramer, 2013). In addition, GFs are strongly influenced by surface roughness (Carter, 1974; Agustsson, 2004); Shellard, 1965) where rougher surfaces have a higher GF. Typical values for a GF range from 1.3 over open water to 2.3 in the middle of large cities, where the surface roughness is largest (Weiringa, 1973). Finally, GFs increase as atmospheric stability decreases (Carter, 1968; Kramer, 2013), although there is reason to believe this relationship as not as strong as with the mean wind (Davis, 1968; Agustsson and Oladsson, 2004). Several Weather Forecasting Offices (WFOs) have established gust factors in their service areas including: Wichita, KS (Cook, 2008), Charleston, SC (Kramer, 2013), the UK MetOffice (Panofsky and Dutton, 1984), and Raleigh, NC for tropical cyclones (Blaes, 2014). Despite establishing GFs, it does not appear that these WFOs account for the GF sensitivity to changing meteorological conditions.

1.4 The Project

Comparisons amongst the physical, statistical, and GF techniques are scarce (Brasseur, 2001), which provides little evidence to support a “best practice” in wind gust forecasting. However, the GF methods are well documented and have a slight advantage in their simplicity. Thus, this project will establish a climatology of GFs for Milwaukee, WI, followed by an assessment of the GF’s skill in forecasting the wind gusts.

The project will be unique from other GF studies in the following ways: 1) gust factors are established and compared using two datasets with varying temporal resolutions; 2) the GF climatology includes a stratification of the GFs by various meteorological variables; 3) the wind gust forecasts are evaluated independent of the errors associated with the forecast wind speed. The data and methodology used in the study is described in Sections 2 and 3, respectively. The

GF climatology is reported in Section 4, while the wind gust forecast results are shown in Section 5.

2. The Data

2.1 Station Information

Automated Surface Observing System (ASOS) wind speed, wind gust, wind direction, and cloud observations were obtained from the National Climatic Data Center (NCDC) for the period of Jan 2000 to Dec 2014 at Milwaukee, WI (Station ID KMKE). Located at General Mitchell International Airport (42.5682°N, 87.5382°W), KMKE is situated approximately five miles south of downtown Milwaukee and one mile west of Lake Michigan. As with all ASOS stations, KMKE reports these observations every hour (ASOS User's Guide, 1998); however, the NCDC collects observations at one-minute intervals for a few sites as well, and KMKE is one of them. With both the standard hourly ($ASOS_h$) observations and the higher resolution one minute-observations ($ASOS_m$) available at KMKE, both were included in the study. This allows us the opportunity to examine the sensitivity of the GF to the observations from which they are derived.

2.2 One minute ($ASOS_m$) Observations

Every minute, wind speed and wind gusts are archived in the $ASOS_m$ dataset (ASOS User's Guide, 1998). Specifically, the $ASOS_m$ wind speed is defined as the two-minute average of the "instantaneous wind," which itself is a five-second running average. The $ASOS_m$ wind gust observation is the highest instantaneous wind observed during that minute. This data only receives a limited quality control from the NCDC and, consequently, contains periods of undecipherable output (such as non-integers, symbols, or blank spaces) or unrealistic values (negative wind or gusts, winds exceeding 70 kts, or winds greater than the gust). This occurred most frequently between Jul 2000 and Dec 2001, where as much as 20% of the data from this period was unusable. This period was excluded from the study. After removing all erroneous data, n=103,138 hours of wind and gust observations were available for analysis, which is 78% of all hours during the 2000-2014 study period (Table 1).

2.3 One hour (ASOS$_h$) Observations

The wind speed and wind gusts reported in the standard hourly ASOS$_h$ observations were obtained for the same period 2000-2014 period. The hourly wind speed reported in the ASOS$_h$ dataset (hereafter called the reported wind) is defined as the two-minute average of the instantaneous wind from the 51-52nd minutes of the hour only. The ASOS$_h$ gust observation (hereafter called the reported gust) is defined as the highest instantaneous wind recorded during the ten-minute period between the 43-52nd minutes of each hour (ASOS User's Guide, 1998). Thus, the ASOS$_h$ reported wind and reported gust effectively ignores 97% and 83% of the wind and gust observations, respectively, during each hour.

The ASOS$_h$ data also differs from the ASOS$_m$ data in that the reported gust is only recorded for 12.9% of the available hours, as reporting criteria must be met first. For a gust to be reported in the ASOS$_h$ dataset, the difference between the reported gust and the reported wind must be 3 knots or more, the reported wind must be greater than 2 knots, and the reported gust must exceed the minimum instantaneous wind speed by 10 knots or more between the 43-52nd minutes. The minimum reported gust in the ASOS$_h$ dataset is 14 knots with associated reported winds ranging from 3 to 11 knots. There are n=15,273 hours in which both wind and gust observations are available in the ASOS$_h$ dataset (Table 1).

3. Methods

3.1 Calculating the Gust Factors

Gust factors were calculated using both the ASOS_m and ASOS_h observations. The process of calculating the GF from the ASOS_h observations (GF_h) is straightforward, as each hourly report contains only one wind observations and, if the reporting criteria are met, one gust observation:

$$GF_h = \frac{Reported\ Gust}{Reported\ Wind} \quad (3)$$

To our knowledge, the GFs reported in the existing literature on GFs and GF-based gust models have used this dataset or its equivalent. Although the ASOS_m observations offer the opportunity to create a gust factor for every minute, we calculate one GF per hour from this dataset to allow for a more direct comparison with the GF_h. In particular, we define a "mean wind" as the average of all 60 ASOS_m wind observations in the hour, while the "peak gust" is the highest ASOS_m gust observation in the hour (i.e the highest instantaneous wind speed during the entire hour). The ratio of the peak gust and the mean wind combine to create a gust factor, GF_m:

$$GF_m = \frac{Peak\ Gust}{Mean\ Wind} \quad (4)$$

We stress that the high resolution of the ASOS_m data was utilized to include observations throughout the entire hour in determining the GF_m. This is in contrast to GF_h, which uses the smaller observations periods in the reported wind and reported gusts. Figure 1 offers a visual representation of how the GF_m and GF_h are calculated each hour. For this particular example hour, the ratio of the ASOS_m peak gust (53 kts) to the ASOS_m mean wind (27 kts) results in a GF_m of 1.96. The ratio of the ASOS_h reported gust (41 kts) to the ASOS_h reported wind (22 kts) results in a GF_h of 1.86.

As shown in Figure 1, the differences in wind and gust observation periods between the $ASOS_m$ and $ASOS_h$ datasets can result in sizeable differences between the GF_m and the GF_h. The $ASOS_h$ reporting criterion creates additional differences between the GF_m and GF_h as the GF_h (n=15,273) is restricted to stronger wind events than the GF_m (n=103,138). Thus, a key aspect of this project is to elucidate the influence of the reporting criteria and observation periods on the GFs and their subsequent climatologies.

3.2 Stratifying the Gust Factors

In addition to elucidating the differences between the GF_m and the GF_h, we create a GF climatology by stratifying the GFs according to wind speed, wind direction, season, month, time of day, and atmospheric stability. Our motivation for this stratification exercise is to gain insight on the conditions that influence gust factors, which could prove useful in wind gust forecasting.

The wind speed stratification was accomplished by stratifying the GF_m (GF_h) by the mean (reported) wind speed. On the other hand, the wind direction stratification was achieved by stratifying both GFs with the $ASOS_h$ wind direction data only. This is because the 0-59 minute average of the $ASOS_m$ wind direction data is nearly indistinguishable from the $ASOS_h$ wind direction, which is the average of the 51-52nd minutes in the hour (Figure 2). An examination of the differences ($ASOS_m - ASOS_h$) between these wind direction observations reveals a normal distribution with a mean of -0.96^o, a median of 0.0^o, and a standard deviation of 10.94^o (Figure 3). Furthermore, since the wind direction stratifications were made using 30^o bins, we do not anticipate any issues with stratifying the GF_m and the GF_h by the $ASOS_h$ wind direction data only.

Nearly all of the stratifications are easily accomplished given the available data. The exception is with stability. As with the majority of ASOS stations, co-located soundings are not available for KMKE, nor would their temporal resolution (00z and 12z) allow us to adequately assess the near-surface stability throughout the entire day. Therefore, the method of Pasquill (1961) was chosen to estimate the atmospheric stability, as it only requires surface observations of cloud coverage and wind speed. The stability categories used in the study is shown in Table 2.

The Pasquill approach requires a subjective categorization of the insolation into three categories using the solar angle and cloud cover observations. In particular, we utilized ASOS_h cloud data from the lowest available altitudes, Sky Level 1, where the coverage was reported as either clear (0% coverage), few (> 5 to ≤ 25% coverage), scattered (> 25 to ≤ 50% coverage), broken (>50% to ≤ 87% coverage), or overcast (> 87% to 100% coverage). Similarly to Luna and Church (1972), the insolation was classified as strong when the a) the solar angle is $\geq 50^o$ or b) $50^o >$ solar angle $\geq 40^o$ with clear, few, or scattered cloud coverage. The insolation was moderate when a) the solar angle is $\geq 40^o$ with broken skies or b) $30^o \leq$ solar angle $< 40^o$ or c) $20^o \leq$ solar angle $< 30^o$ with clear, few, or scattered cloud coverage. The insolation was classified as slight when a) $20^o \leq$ solar angle $< 30^o$ under broken skies or b) the solar angle $< 20^o$ or c) the skies were overcast. A combination of the wind speed and insolation was used to determine the stability classes (Table 2). The cloud cover was also used to differentiate between mixed categories (eg. A-B), where clear, few, and scattered skies fell into the more unstable category, while broken and overcast fell into the more stable category.

3.3 Using Gust Factors to Forecast the Wind Gust

GFs are multiplied by a forecast wind speed to obtain a forecast wind gust (Eq. 2) and therefore, any error in the gust forecast includes the error associated with the forecast wind speed. In this study, however, we replace the forecast wind speed with a wind speed observation for the forecast hour. In other words, we make a "perfect" wind speed "forecast" to isolate the skill of the GF in forecasting gusts. Obviously, a major drawback of this approach is that it cannot be directly applied operationally; however, such an approach offers insight on the maximum possible skill that can be achieved when using a GF to forecast a wind gust.

One byproduct of exploiting the wind speed observations in this manner is that lead times cannot be considered. Wind gust forecasts were thus made for all hours in the entire 2000-2014 observation period for which wind and gust observations were available. In addition, forecasts were evaluated for subsets of the overall period, when the observed gusts exceeded 25 knots and 30 knots to examine forecast performance for the more extreme events.

Several variations of the GF_m and the GF_h were used to forecast the wind gust (Eq. 2). The non-stratified GFs used in the study are the mean GF_m and the mean GF_h. The stratified GFs include stratifications by wind speed, wind direction, time of day and season, and the Pasquill stability category. In addition, GFs stratified by a combination of both wind speed and direction stratifications, and the wind speed and time of day and season stratifications were tested. Both the stratified and non-stratified GFs were compared to the no-skill models of persistence (forecast gust = gust observation from previous hour) and climatology (forecast gust = average gust for the particular season and hour in the day).

The verification metrics chosen were the bias (forecast – observation) and the absolute error (|forecast – observation|). All variations of the GF_m forecasts were verified against the peak gust observations from the $ASOS_m$ dataset. The GF_h forecasts were verified against the reported gust from the $ASOS_h$ dataset, which is limited by the shortened observation periods. We also verify the GF_h forecasts against the peak gust observations from the $ASOS_m$ dataset to assess their skill in predicting the true highest wind observation in the entire hour. Statistical significance testing with the Signs Test was performed on the mean absolute error distributions for selected pairs of models (Mendenhall et al, 1989).

4. Gust Factor Climatology

The gust factor (GF) is the ratio of the observed wind gust to the observed wind speed (Eq. 1). Both the numerator and denominator are sensitive to the averaging periods and reporting criteria associated with the one minute $ASOS_m$ and $ASOS_h$ datasets. Therefore, before presenting the GF climatology we first examine these sensitivities.

4.1 Mean Wind ($ASOS_m$) vs. Reported Wind ($ASOS_h$)

Recall that (Fig. 1) the mean wind is calculated by taking the average of all one-minute $ASOS_m$ wind observations throughout the entire hour. By contrast, the reported wind in the $ASOS_h$ data is simply a two-minute average of the wind during the 51-52nd minutes of each hour. Overlapping histograms of these $ASOS_m$ and $ASOS_h$ wind observations are shown in Figure 4. These distributions include all hours for which gust factors can be determined, which results in n=103,138 $ASOS_m$ mean winds and n=15,273 $ASOS_h$ reported winds. The limited availability of reported winds is due to the $ASOS_h$ gust reporting criteria (Section 2.3), which, as seen in Fig. 4 biases the reported winds toward higher velocities. The mean wind and reported wind exhibits means of 8.80 and 14.56 kts, medians of 8.31 and 14.0 kts, and standard deviations of 4.05 and 3.62 kts, respectively.

We now examine the influence of the observation periods on the wind speeds, independent of the influence of the gust criterion. This is done in Figure 5 where histograms of the mean wind and reported wind are shown for all available hours when a gust is reported in both datasets (n=13,859). Recall that the mean wind determined using $ASOS_m$ data is an average over all 60 minutes of each hour, while the $ASOS_h$ reported wind is a two-minute average over minutes 51-52. Despite the smaller averaging period in the reported wind, the distributions are remarkably similar. In particular, the mean and reported wind exhibits means of 14.34 and 14.58 kts, while the 10th, 50th, and 90th percentiles of the wind differences (mean wind –reported wind) are -2.7 kts, -0.2 kts, and 2.2 kts, respectively, with little sensitivity to the wind speed (Fig. 6). This is not surprising, given the known gap in the wind speed energy spectrum occurring between periods of a few minutes and a few hours (Stull, 1998).

4.2 Peak Gust ($ASOS_m$) vs. Reported Gust ($ASOS_h$)

Histograms of the $ASOS_m$ peak (n=103,138) and the $ASOS_h$ reported gusts (n=15,273) are shown in Figure 7. The $ASOS_h$ gust criterion biases the reported gusts towards higher velocities, which leads to stark differences in the peak and reported gust distributions. In particular, the reported and peak gusts exhibit means of 14.5 and 22.1 kts, medians of 14.0 and 21.0 kts, and standard deviations of 4.5 and 6.5 kts, respectively. When restricting both the peak and reported gust histograms to the hours for when the $ASOS_h$ gust criteria are met (Fig. 8), the impacts of the reporting practices become clear. As expected, the peak gust is always greater than or equal to the reported gust. The differences between peak gust and reported gust are shown in Figure 9. More specifically, the 10th, 50th, and 90th percentiles of the gust differences (peak gust – reported gust) are 0.0 kts, 1.0 kts, and 5.0 kts, respectively. The difference (peak gust – reported gust) becomes much larger with increasing gustiness. Gust factors determined using $ASOS_h$ data, therefore, tend to underestimate the actual GF (i.e using one-minute $ASOS_m$ data).

4.3 Gust Factor Climatology

The aforementioned differences in the reported wind (reported gust) and the mean wind (peak gust) are seen in the GF_m and GF_h. When averaged throughout the 2000-2014 period, the mean GF_m is 1.69 while the mean GF_h is 1.55, a difference of 8%. Furthermore, the median GF_m and GF_h is 1.64 and 1.5, while the standard deviation is 0.277 and 0.248, respectively. Figure 10 shows the overlapping histograms of all available GF_m (n=103,138) and GF_h (15,273). The histograms are restricted to the hours in which both GFs are calculated (n=13,859) in Figure 11 to isolate the influence of the reporting practices. The 10th, 50th, and 90th percentiles of the GF differences (GF_m - GF_h) are -0.14, 0.15, and 0.42, respectively (Fig. 12). Overall, we conclude that the gust criterion and observation periods result in important differences in the GF_m and the GF_h. Furthermore, we conclude that the difference between the peak and reported gust has a larger influence on the GF than the difference between the mean and reported wind.

4.4 Wind Speed Stratification

Stratifying the GF_m by the mean wind (Fig. 13) and the GF_h by the reported wind (Fig. 14) suggests that the GFs decrease with increasing wind speed. This is consistent with the findings of Davis (1968), Carter (1974), and Agustsson and Olafson (2004). In particular, the mean GF_m decreases from 1.86 to 1.60 when the mean winds increase from 0-5 kts to 30 kts (Table 3), while the mean GF_h decreases from 4.77 to 1.33 over the same range (Table 4). These relationships appear to be quite strong, considering that the standard deviation of the mean GF_m and GF_h is 0.277 and 0.248, respectively. Furthermore, this relationship is especially strong at low wind speeds. However, the mean and median GF_m appears to have little dependence on the wind speed for winds greater than 10 kts. Note that few observations were available with wind speeds ≥ 30 kts or GF_h wind speeds < 5 kts.

4.5 Stability Stratification

Despite being commonly used in the fields of air quality and boundary layer meteorology (Pasquill, 1961; Luna and Church, 1972), there has not been an accuracy assessment of the observation-based Pasquill Stability classification scheme. Although such a study is beyond the scope of this project, histograms of each stability type (A-F) are shown in Figures 15 and 16 to provide a general sense of scheme's ability to assess the stability throughout the day. In both datasets, unstable classifications were restricted to the daylight hours (solar angle > 0) and were most frequent around the noon hour. Meanwhile, the neutral and slightly stable conditions were most common at night (solar angle < 0). Although this is by no means a rigorous testing of the appropriateness of using the scheme, the findings are consistent with our understanding of the near-surface stability.

As mentioned in Section 3.2, the Pasquill-Stability classification scheme requires observations of the wind speed. Thus, we established the Pasquill stability scheme twice: one with the mean wind (Fig. 15) and one with the reported wind (Fig. 16). When using the reported wind to classify the Pasquill stability (Table 5), the stability is most frequently categorized as neutral (n=10,272) and slightly unstable (n=3,136). The stability was classified as moderately unstable (n=326) and extremely unstable (n=13) only a small fraction of the time, while the stability was never classified as stable for any hour throughout the 14-year period. The lack of stable and extremely unstable cases is unrealistic; however, this is not surprising knowing that the stable, moderately unstable, and extremely unstable cases require wind speeds less than 10 kts, which are extremely uncommon our ASOS_h dataset. Given this limitation, a gust factor forecast model was not created from the Pasquill stability stratification with the ASOS_h data. The categories appear to be more well distributed when using the unbiased mean wind (Table 6), where neutral stability is most frequent (n=42,402), followed by slightly unstable (n=25,083), slightly stable (n=22,246), moderately unstable (n=15,582), stable (n=4,584), and extremely unstable (n=1,411).

Previous studies examining the relationship between the GF and stability suggest the GF decreases as the atmosphere becomes more stable (Carter, 1968; Kramer, 2013; Davis, 1968; Agustsson and Oladsson, 2004). This is seen when transitioning from unstable to neutral conditions in the GF_h and GF_m (Tables 5, 6). However, these GFs increase again when transitioning from neutral to stable conditions. Seeing that the wind speed varies considerably between categories, it is possible that the GF sensitivity to the wind speed is masking any GF sensitivity to the stability stratification. We attempted to minimize this possible effect by stratifying the GF_m for smaller ranges of mean wind speeds (Tables 7, 8). In these cases, the GF_m decreases when moving from unstable to neutral conditions, but changes little from neutral to stable conditions. Our results thus offer limited confirmation of the previously-cited results suggesting that GFs decrease with increasing stability. We do not see this relationship as stability increases from neutral to stable, however.

4.6 Season and Hour Stratification

With a range in the mean GF_m (GF_h) from 1.66 (1.53) in the winter to 1.70 (1.58) in the summer, the season and month appear to have a smaller influence on the GF ranges than the wind speed and the Pasquill stability (Table 9, 10). If we assume that the summer is typically more unstable than in the winter, these results tend to be in agreement with the stability findings in Carter (1974) and Davis (1968), which suggests the GF is highest when the atmosphere is unstable.

The range in the mean GF_m (GF_h) from 1.62 (1.51) to 1.74 (1.57) throughout the day suggests this relationship is stronger than with the season and month, but weaker than with the wind speed (Table 11, 12). In particular, the GF_m appears to be lowest during the afternoon and highest around sunrise. This is counterintuitive, as the aforementioned stability findings suggest that the GF may be highest during the afternoon when the atmosphere is most unstable. However, these findings are likely influenced by the wind speed (see Section 4.4), which also varies throughout the day too (Table 11). To isolate the effect of diurnal stability variations on GFs and remove the effect of wind speed, we restricted the GF_m stratification to a small range of mean wind speeds (Table 13). These restrictions produced a minimum GF_m of 1.65 during the overnight and a maximum of 1.78 around noon, which is more consistent with our understanding of GF sensitivity to stability.

4.7 Wind Direction Stratification

The GFs were also stratified by the $ASOS_h$ wind direction data (Tables 14-17). The wind direction appears to have a sizeable impact on the GF_m (Table 14). In particular, the minimum in the GF_m of 1.59 occurs in the direction of Lake Michigan (90-120°), while a maximum of 1.75 occurs from inland (240-300°). To ensure that the wind direction stratification is not being influenced by the wind speed, we again limited the stratification to small wind speed ranges (Tables 15, 16). In both cases, the minimum in the GF_m occurs when the winds come from Lake Michigan, while the maximums occur from inland. These results are consistent with the findings in Weiringa (1973) that higher GFs are associated with larger surface roughness. The GF_h exhibits a smaller range of 1.53 -1.55 (Table 17), which continues the general trend for the GF_h to be less sensitive to the stratifications than the GF_m. Unfortunately, we do not have an explanation for why this is the case.

5. Forecast Performance

In this section, we assess the skill of the GF in forecasting wind gusts. Recall from Equation 2 that a wind gust forecast is made by multiplying a GF by a forecast wind speed. Therefore, wind gust forecasts made using GFs contain errors associated with the forecast wind speed, and errors associated with the GFs themselves. In this study, we replace the forecast wind speed with observations from the forecast hour. By doing so, we make a perfect wind speed "forecast" to isolate the skill of the GF in forecasting the wind gust. Thus, all forecast errors in this evaluation are associated with the GF only.

A variety of GFs are used to create the wind gust predictions. These include GFs derived from the one-minute resolution $ASOS_m$ data (GF_m) (Section 2.2) and those calculated from the standard hourly $ASOS_h$ data (GF_h), of which the latter are limited by shortened observation periods and a reporting criterion that biases the observations toward higher velocities (Section 2.3). As shown in Section 4, both the GF_m and the GF_h are sensitive to the wind speed, surface roughness, and stability. We account for these sensitivities in the forecast by stratifying the GFs according to: wind speed, wind direction, Pasquill stability categories, and the season and time of day. To take this one step further, we include a few gust forecasts using GFs with multiple stratifications (i.e a combination of wind speed and direction, and a combination of the wind speed, hour, and season). These GF stratifications are shown in the appendix. We then compare the stratified GF forecasts to the non-stratified, mean GF forecasts and the forecasts made with the "no-skill" models of persistence (forecast gust = gust observation from previous hour) and climatology (forecast gust = average gust for the particular season and hour of the day).

The mean and standard deviation of the bias (forecast – observation) and the absolute error (|forecast – observation|) were chosen as the verification metrics for the deterministic wind gust forecasts. In particular, the gust predictions made with variations of the GF_m were verified against the peak gust observations from the $ASOS_m$ data. Meanwhile, the forecasts made with the GF_h were verified against the reported gust from the $ASOS_h$ dataset to elucidate the skill of the GF_h in forecasting the true highest wind speed each hour. In addition, we verified the GF_h

forecasts against the peak gust observations to elucidate the ability of the GF_h to predict the true highest wind gust in the entire hour. Statistical significance testing was performed on the mean absolute error (MAE) distributions for select cases via the Signs Test (Mendenhall et al., 1989).

The wind gust forecasts were made for multiple evaluation periods. The first assessment of wind gust forecast performance was made for all hours where observations exist during the entire Jan 2000 – Dec 2014 period (Section 5.1). We then restrict the forecast evaluation for the more extreme wind events, where the gusts exceed 25 knots (Section 5.2), and 30 knots (Section 5.3).

5.1 Forecast Performance for the Jan 2000 – Dec 2014 Evaluation Period

Wind gust forecasts were made and evaluated for all hours in which observations are available throughout the 2000-2014 period. The results are shown in Table 18. All forecast models (including the GF_m, GF_h, persistence, and climatology), their stratifications (if applicable), and the observations used for verification (peak gust or reported gust) are listed. The forecasts are sorted by increasing MAE, while the no-skill models of persistence and climatology are highlighted in grey. Notice that the MAE ranges from 1.22 – 4.84 kts between all forecasts. In regards to the mean biases, most models appear to have a slight tendency to over-forecast the wind gusts; however, the GF_h models verified against the peak gusts under-forecast the gust with mean biases 1.45 – 1.92 kts.

Since the differences in the MAEs and mean biases between the best and worst performing forecasts are only a few knots, one may be inclined to find the differences between the forecasts physically insignificant. However, recall that we mitigated some of the forecast error by utilizing the wind speed observations to make the gust forecasts. In reality, the wind gust forecasts made by this method will exhibit larger errors. Secondly, the above ranges are for the

MAEs and mean biases for a large dataset, and so there are still a number of individual cases in which these errors are large. For example, Figure 17 shows a histogram of the MAEs for forecasts made using the mean GF_m model. In this case, there are 752 times (0.73%) when the absolute errors exceed 5 kts, 153 times (0.15%) when the absolute errors exceed 10 kts, 57 times (0.06%) when the absolute errors exceed 15 kts, and 14 times (0.01%) when the absolute errors exceed 20 kts. In fact, even similarly performing models exhibit large differences in absolute errors at times. For example, the difference in the absolute errors between the GF_m and GF_h models exceeds 5 kts 151 times (1.1%), and 10 kts 34 times (0.25%) (Fig 18). Therefore, we argue that the differences in the MAEs and mean biases between forecasts may have physical relevance.

We now compare the "no-skill" models of persistence and climatology to the GF models. Recall that the $persistence_m$ ($persistence_h$) forecasts are calculated as the peak (reported) gusts from the previous hour, if observations exist. These forecasts exhibit a MAE of 2.01 kts (2.60 kts) and a mean bias of 0.01 kts (0.06 kts). In comparison, the non-stratified, mean GF_m (GF_h) forecasts exhibit a lower MAE of 1.44 kts (2.47 kts) and a higher mean bias of 0.34 kts (0.54 kts) than the persistence models when verified against the peak (reported) gusts. When verified against the peak gust, the GF_h has a lower MAE of 2.98 kts when compared to persistence, and a mean bias of -1.45 kts. Although the differences in the MAEs between the GF_m (GF_h) and $persistence_m$ ($persistence_h$) forecasts are only a few tenths of a knot, these differences are highly statistically significant (>99% confidence level). Therefore, we conclude that the mean GFs outperform the persistence models for this evaluation period, with the exception of the mean GF_h verified against the peak gust.

Recall that the climatology$_m$ (climatology$_h$) forecasts are calculated as the mean peak (reported) gusts observed for each hour in every season. These means are shown in Table 21 (25). First, notice that the mean peak (reported) gusts range from 10 kts (19 kts) on summer nights to 18 kts (23 kts) during spring days. Also note that the mean peak gusts change by approximately 5 knots between the morning and the afternoon, while on the other hand, the mean reported gust exhibits little to no changes throughout the day. The latter is unlikely to be representative of the actual mean wind gusts experienced throughout the day due to the ASOS$_h$ wind gust reporting criteria, and therefore illuminates another limitation of using the ASOS$_h$ wind gust data. Furthermore, the small ranges in the mean reported gust could explain why the GF$_h$ is less sensitive than the GF$_m$ to the stratifications shown in Section 4.

In regards to the forecast evaluation in Table 18, the climatology$_m$ (climatology$_h$) forecasts are the worst with a MAE of 4.84 kts (3.40 kts). Statistical significance testing allows us to say with confidence that the forecasts made using the mean GF$_m$ (GF$_h$) models verified against the peak (reported) gusts outperform the "no-skill" forecasts of persistence and climatology for this evaluation period. And although the mean GF$_h$ (verified against the peak gust) does not outperform the persistence forecasts, the GF$_h$ forecast MAEs are lower than climatology.

One important aspect of this study is to elucidate the differences between the GF$_m$ and the GF$_h$. Thus, we now establish their skill in forecasting the wind gust. The mean GF$_m$ exhibits a MAE of 1.44 kts and a mean bias of 0.34 kts when verified against the peak gusts. In contrast, the GF$_h$ exhibits a larger MAE of 2.47 kts and higher mean bias of 0.54 kts when verified against the reported gust. The differences in the MAE between these model forecasts were highly statistically significant (>99% confidence level). The mean GF$_h$ verified against the peak gust exhibits a MAE of 2.98 kts and a mean bias of -1.45 kts. Thus, the GF_h is worse than the GF_m at forecasting the highest wind gust throughout the entire hour. Furthermore, it should be noted that the differences in the GF_h forecast performance when verifying against the peak and reported gusts further elucidates the potential drawbacks of using the $ASOS_h$ gust observations for forecast verification.

To see if the GF stratifications improve the wind gust forecast, we now compare the forecast skill of the stratified GFs relative to the non-stratified, mean GFs. Recall that the mean GF_m (GF_h) exhibits a MAE of 1.44 kts (2.47 kts) when verified against the peak (reported) gusts. All forecasts made by the stratified GF_m (GF_h) models improve upon the mean GFs with MAEs ranging from 1.22 kts (1.81 kts) to 1.41 kts (2.46 kts) when verified against the peak (reported) gusts. The largest improvement upon the mean GF_m and GF_h occur when GFs are stratified by the wind speed, the combination of wind speed and direction, and the combination of the wind speed and time of day/season. Even the forecasts made with the worst performing stratifications, such as the Pasquill stability and the time of day and season, improve upon the mean GFs with statistical significance. Therefore, we conclude that the stratified models outperform the non-stratified, mean GFs for this evaluation period.

5.2 Forecast Performance for Gusts ≥ 25 knots

Wind gust forecasts are also made and evaluated for all available hours in which peak and reported gust observations are 25 knots or greater throughout the 2000-2014 period. The results are shown in Table 19. As with the previous evaluation in Table 18, all forecast models (including the GF_m, GF_h, persistence, and climatology), their stratifications (if applicable), and the observations used for verification (peak gust or reported gust) are listed. The forecasts are again sorted by increasing MAE, while the no-skill models of persistence and climatology are highlighted in grey. Notice that the MAE ranges from 1.81 - 3.91 kts, while the mean biases range from -3.22 to 0.8 kts between all forecasts. Most of these forecasts exhibit larger MAEs and more under-forecasting of the wind gusts than when compared to the unrestricted evaluation period (Table 18).

Now we compare the forecasts between the "no-skill" models of persistence to the forecasts made by the mean GF models. First, recall that the persistence$_m$ (persistence$_h$) forecasts are calculated as the peak (reported) gusts from the previous hour. These GF$_m$ and GF$_h$ forecasts exhibit a MAE of 3.07 kts (3.23 kts) and a mean bias of -1.47 kts (-1.39 kts). In comparison, the non-stratified, mean GF$_m$ (GF$_h$) has a lower MAE of 2.40 kts (3.07 kts) with less of a mean bias of -0.02 kts (0.80 kts) when verified against the peak (reported) gusts. The differences in MAEs between the mean GF$_m$ and the persistence$_m$ forecasts are statistically significant; however, the differences between the mean GF$_h$ and the persistence$_h$ forecasts were not.

Recall that the climatology$_m$ (and climatology$_h$) forecasts are calculated as the mean gusts observed during every hour in each season. The mean peak (reported) gusts restricted to 25+ kt observations are shown in Table 22 (26). The climatology$_m$ (and climatology$_h$) forecasts exhibit a MAE of 2.88 kts (2.57 kts), which is better than all of the aforementioned persistence and mean GF forecasts, with the exception of the GF$_m$. The improved performance of the climatology forecasts is not surprising, since the climatologies are restricted to the gustier events with smaller standard deviations. In summary, we conclude that the mean GF$_m$ forecasts outperform the "no-skill" persistence$_m$ and climatology$_m$ forecasts. On the other hand, the mean GF$_h$ forecasts perform similarly to the "no-skill" persistence$_h$ forecasts and worse than climatology$_h$.

The skill of the mean GF forecasts decreases when restricting the evaluation to 25+ kts; however, the superiority of the GF$_m$ over the GF$_h$ remains. In particular, the MAE for the mean

GF_m forecast is 2.40 kts with a mean bias of -0.02 kts when verified against the peak gusts. In comparison, the mean GF_h forecast exhibits a larger MAE of 3.07 kts with a mean bias of 0.80 kts when verified against the reported gusts. Lastly, the mean GF_h forecasts verified against the peak gusts again performs the worst with a MAE of 3.36 kts and a mean bias of -1.23 kts. The differences between these forecasts are statistically significant (>99% confidence level).

With MAEs ranging from 1.81 kts (2.64 kts) to 2.50 kts (3.06 kts) when verified against the peak (reported) gusts, most of the GF_m (GF_h) stratifications still improve upon the mean GF_m (GF_h). However, the GF_m wind speed and Pasquill stability stratifications verified against the peak gust show a slight decrease in performance relative to the mean GF_m with a MAE of 2.50 kts and 2.41 kts, respectively. The combined stratifications of wind speed and direction performed the best overall with a MAE of 1.81 kts (2.11 kts) and a mean bias of 0.07 kts (0.08 kts); however, all stratifications that improved upon the mean GF were statistically significant. In summary, we conclude that the majority of the stratified GF models improve the wind gust forecasts relative to the non-stratified, mean GFs for when wind gusts are 25 kts or greater.

5.3 Forecast Performance for Gusts ≥ 30 knots

Wind gust forecasts are made and evaluated for all available hours when the peak and reported gust observations are 30+ kts. The results are shown in Table 20. As with the evaluations in Tables 18-19, all forecast models (including the GF_m, GF_h, and persistence), their stratifications (if applicable), and the observations used for verification (peak gust or reported gust) are included. The forecasts are again sorted by increasing MAE, while the no-skill models of persistence are highlighted in grey. Notice that the MAEs range from 2.09 - 4.09 kts, which is larger than the MAEs in Tables 18-19. Meanwhile, the mean biases range from -3.71 - 0.26 kts, larger under-forecasts than in Tables 18-19.

Now we compare the forecasts between the "no-skill" models of persistence to the forecasts made by the mean GF models. The persistence$_m$ (persistence$_h$) forecasts exhibit a MAE of 3.99 kts (4.16 kts) and a mean bias of -2.52 kts (-2.53 kts). In comparison, the non-stratified, mean GF$_m$ (GF$_h$) exhibits a lower MAE of 2.83 kts (3.37 kts), and less of a mean bias at -0.72 kts (0.26 kts) when verified against the peak (reported) gusts. Even the mean GF$_h$ forecasts verified against the peak gusts outperform persistence, with a MAE of 2.95 kts and a mean bias of -1.83 kts. All of these differences are highly statistically significant. These are the only no-skill models included in the evaluation; as shown in Table 24 (28), the sample sizes for the mean climatology$_m$ (and climatology$_h$) forecasts are too small to be included when the gusts are 30+ kts. In summary, we conclude that the mean GF$_m$ (GF$_{h)}$ outperforms the "no-skill" persistence$_m$ (persistence$_h$) models for this evaluation period.

Recall that the mean GF$_m$ forecast exhibits a MAE of 2.83 kts with a mean bias of -0.72 kts when verified against the peak gusts. In comparison, the mean GF$_h$ forecast has a larger MAE of 3.37 kts with a mean bias of 0.26 kts when verified against the reported gusts. When verified against the peak gusts, the GF$_h$ is not too far behind with a MAE of 3.95 kts and a mean bias of -1.83 kts. The differences between these forecasts are statistically significant (>99% confidence level).

The MAEs for the stratified GF$_m$ (GF$_h$) forecasts range from 2.09 kts (2.17 kts) to 3.16 kts (3.95 kts) when verified against the peak (reported) gusts for this evaluation period. The GF$_m$ (GF$_h$) wind direction and combined stratifications of wind speed and direction forecasts outperform the mean GF$_m$ (GF$_h$) with a MAE of 2.68 kts (3.37 kts) and 2.09 kts (2.17 kts), respectively. All other stratified forecasts perform similarly or worse than the mean GFs. Thus, we conclude for these gusty conditions that only the wind direction stratification and the combination of the wind speed and direction stratification improve the wind gust forecasts relative to the non-stratified, mean GFs.

6. Summary

Wind gusts occur on small spatial and temporal scales and, consequently, are difficult to predict. As a result, there are a variety of approaches to forecasting wind gusts; however, there is little evidence to support a “best practice” to do so. With that being said, GFs are arguably the most documented approach, and their simplicity makes them useful in operational meteorology.

Despite multiple studies suggesting the sensitivity of the GF to the wind speed, stability, and surface roughness, such sensitivities have not been accounted for when forecasting the wind gust. In addition, previous evaluations of wind gust forecasts made using GFs incorporate the errors associated with the forecast wind speed (Eq. 2). As a result, there has not been a true determination of the skill of the GF removed from these errors in forecasting wind gusts. Furthermore, ASOS wind and gust data is offered at minute ($ASOS_m$) and hourly ($ASOS_h$) resolutions; however, comparisons between GFs derived from these datasets have not been made. We addressed these gaps in the literature while establishing a climatology of GFs for Milwaukee, WI (KMKE), followed by an assessment of the GF’s skill in forecasting the wind gusts.

6.1 Implications of the $ASOS_m$ and $ASOS_h$ Observations on the GF

The differences in wind and gust observation periods between the $ASOS_m$ and $ASOS_h$ datasets can result in sizeable differences between the GF_m and the GF_h each hour (Fig. 1). In particular, the differences between the peak gust (highest gust during minute 0-59) and reported gust (highest gust during minute 43-52) have a larger impact on the GF than the difference between the mean wind (average of the 0-59 minute wind speeds) and the reported wind (average of the 51-52 minute wind speeds). When averaged throughout the 2000-2014 observation period at KMKE, the GF derived from the $ASOS_m$ data (GF_m) is larger than the GF derived from the $ASOS_h$ data (GF_h) with means of 1.69 and 1.55, respectively.

When forecasting the wind gusts for all evaluation periods, the GF_m forecasts (verified against the peak gusts) frequently outperform the GF_h forecasts (verified against the reported gusts) in terms of MAE. Meanwhile, the GF_h forecasts (verified against the peak gusts) exhibit the worst MAE of the three and tend to under-forecast the gusts, thus elucidating the issues in using the GF_h to forecast the highest wind gust observed throughout the entire hour. In conclusion, we suggest that the $ASOS_m$ observations should be used to establish a GF_m for operational use, if they are available. Otherwise, one should be aware of the reduced performance in using the GF_h to forecast the wind gusts, especially when forecasting the peak wind gust observed throughout the entire hour.

6.2 GF_m and GF_h Sensitivities

Previous studies suggest a relationship between the GF and wind speed, stability, and surface roughness. Therefore, we stratified the GF_m and GF_h by the wind speed, the Pasquill Stability Categories, the time of day and season, and wind direction to establish a climatology of GFs for Milwaukee, WI. Stratifying the GF_m and GF_h by the wind speed shows a strong decrease in the GF with increasing wind speed. Meanwhile, stratifying the GF_m and GF_h by the Pasquill Stability categories suggests that the GFs decrease when transitioning from unstable to neutral conditions; however, our findings were inconclusive when transitioning from neutral to stable conditions. Stratifying the GF_m and GF_h by the hour in the day and season suggests the GFs are somewhat larger (smaller) during summer afternoons (winter nights), which supports the notion that the GF is highest when the atmosphere is most unstable. Lastly, stratifying the GF_m and GF_h

by wind direction shows that the GF is highest (lowest) when the winds are coming from inland (Lake Michigan), which is a relatively rough (smooth) surface. With the exception of the transition from neutral to stable conditions, all of our relationships between the GF and wind speed, stability, and surface roughness support the previous literature. However, we found that the GFs are most sensitive to the wind speed. In fact, the relationship between wind speed and the GF was strong enough to mask the stratifications by the Pasquill Stability, the time of day, and the season.

6.3 Using the GF_m and GF_h to Forecast Wind Gusts

The ranges in the mean absolute errors from all of the forecasts made in this study are only a few knots. Thus, it's easy to conclude that the differences in performance between models are insignificant. However, we mitigated some of the forecast errors by utilizing the wind speed observations to make the gust forecasts. In other words, we made perfect wind speed "forecasts" to isolate the skill of the GF only. Therefore, the forecast results should be viewed as an upper limit in forecast performance when using GFs to forecast wind gusts.

Wind gust forecasts made with the GF_m (GF_h) typically outperform the "no-skill" forecasts made by persistence and climatology (when available). This is especially apparent for the gustier evaluation periods. Thus, we believe the GF are a viable option to forecasting wind gusts.

Stratifying the GF_m (GF_h) generally improves upon the mean, non-stratified GF_m (GF_h), at least for the unrestricted 2000-2014 evaluation period. However, the non-stratified, mean GF_m (GF_h) forecasts outperform most of the stratified GF_m (GF_h) for the gustier evaluation periods. The exceptions are the forecasts made using the combined stratification of wind speed and wind direction, which improves upon the mean GFs, and is the superior GF_m (GF_h) models overall. In conclusion, we recommend using GFs stratified by wind speed and direction to forecast the wind gusts, especially for the more extreme events.

6.4 Recommendations for Future Work

The GF forecasts evaluated in this study were deterministic. Since wind gusts are naturally stochastic, it may be advantageous to evaluate probabilistic GF forecasts. In particular, one might assess the skill of the GF at forecasting the probability of wind gusts exceeding some threshold. Moreover, we believe that more follow-up work could be done to evaluate forecasts made by additional sets of stratifications, such as a combination of wind speed, wind direction, and stability, with the intention of establishing an ideal set of stratifications for operational use. Additional ideas for future work include an expansion of the GF climatology geographically, or an extension of the forecast evaluation to strong extra-tropical cyclones or thunderstorm wind events. Of course, these suggestions do not determine whether or not GFs are the most skillful approach to forecasting wind gusts. Thus, we believe any comparisons between the best performing stratified GFs to other statistical and physical techniques will be beneficial to the meteorological community as well.

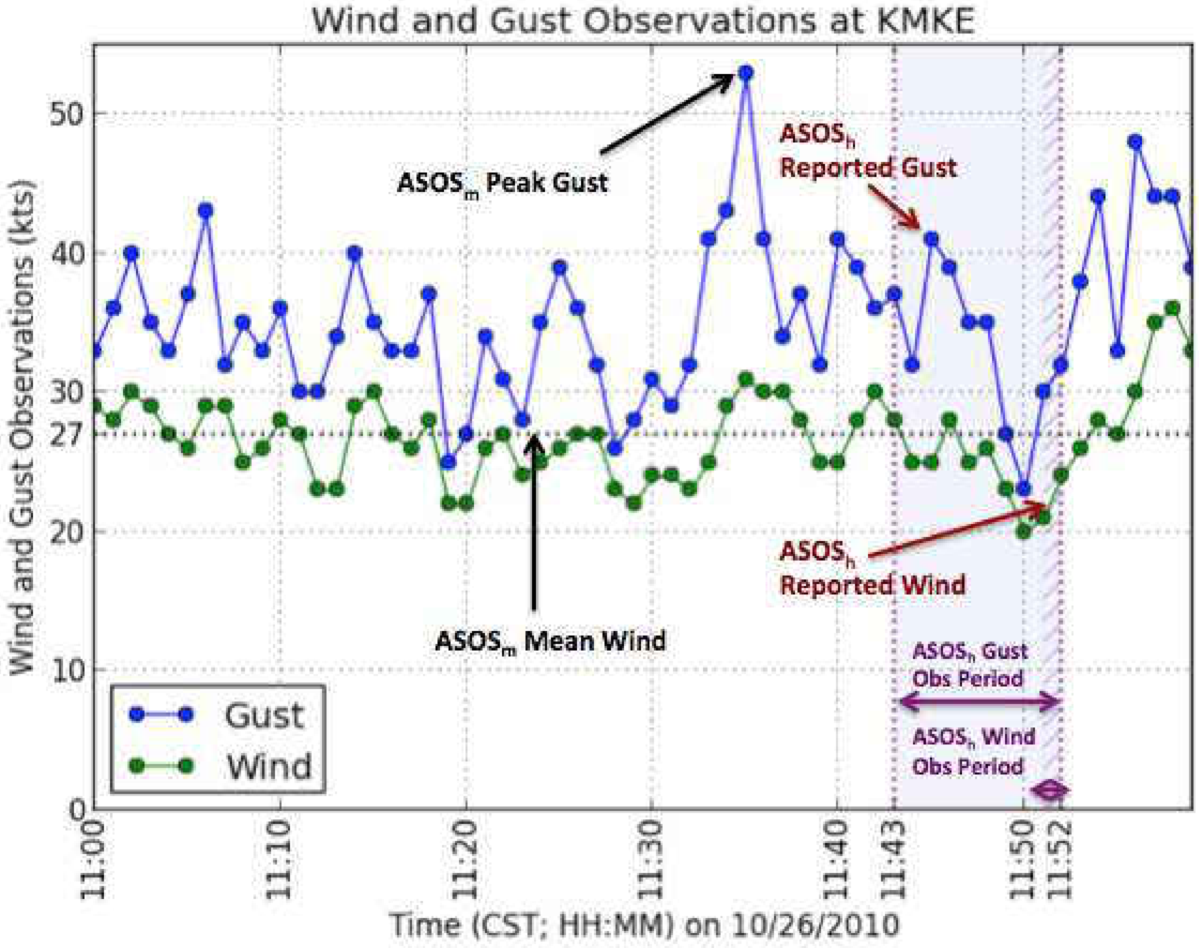

Figure 1: One-minute ASOS$_m$ wind (green) and gust (blue) observations are shown for one sample hour at Milwaukee, WI to illustrate the potential limitations of the reporting practices in the ASOS$_h$ observations, and to demonstrate how the GFs are calculated. The *reported gust* (red) from the ASOS$_h$ data is the highest instantaneous wind speed during the 10-min observation period occurring between minute 43-52 (purple shaded). Meanwhile, the *reported wind* (red) in the ASOS$_h$ data is the average of the instantaneous winds between the minute 51-52 (purple hatched). Thus, the subsequent gust factor (GF$_h$) is derived from observations that effectively ignore a large portion of the winds each hour. By utilizing the ASOS$_m$ wind and gust observations throughout the entire hour, we propose a more ideal way of determining a gust factor by calculating the *peak gust* (blue) and the *mean wind* (black dashed). The peak gust is the highest ASOS$_m$ gust observation in the entire hour. Meanwhile, the mean wind is the average of all ASOS$_m$ wind speed observations in the hour. Therefore, the gust factor determined from the peak gust and mean wind (GF$_m$) incorporates data from the entire hour.

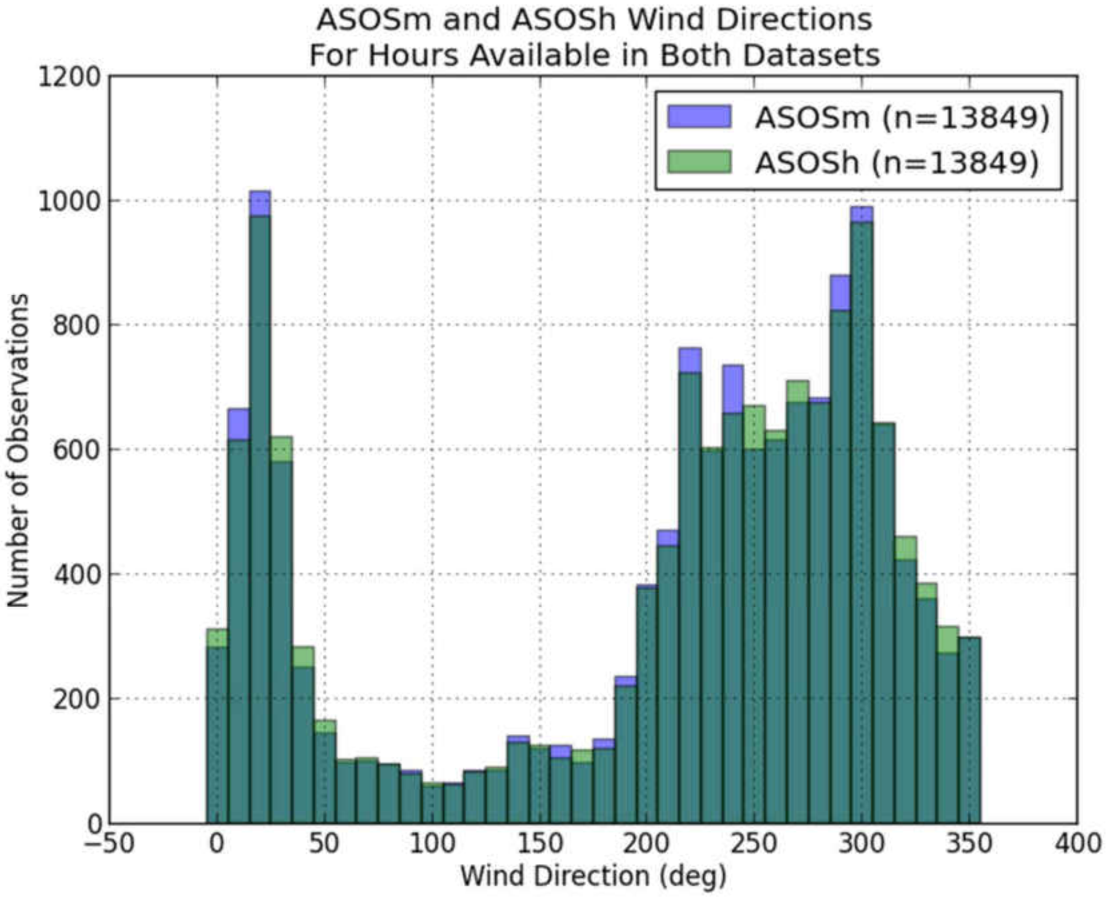

Figure 2: Histograms for all ASOS$_m$ wind direction observations (degrees) averaged for the 0-59 minutes each hour (blue), and the ASOS$_h$ reported wind direction (green) observations (degrees), which are the average of the 51-52 minutes, are shown for the Jan 2000 – Dec 2014 period at KMKE. The overlapping portions of the two histograms are shown in turquoise.

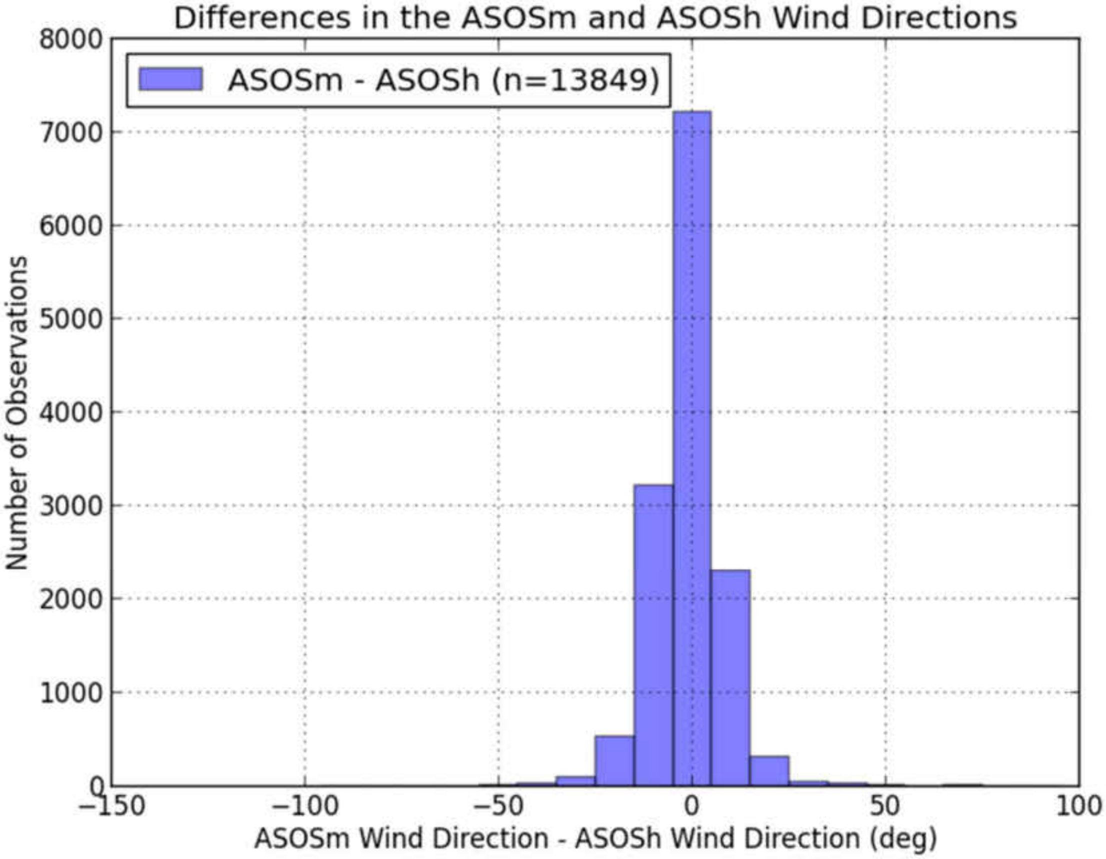

Figure 3: The differences ($ASOS_m$ – $ASOS_h$) between the $ASOS_m$ wind direction observations (degrees) averaged for the 0-59 minutes each hour (blue), and the $ASOS_h$ reported wind direction (green) observations (degrees), which are the average of the 51-52 minutes, are shown for the Jan 2000 – Dec 2014 period at KMKE. The mean of the distribution is -0.96^o, the median is 0.0^o, and the standard deviation is 10.74^o. Out of the n=13849 observations examined, only 278 hours exhibit differences greater than or equal to 30^o, which accounts for 2.0% of the data. Furthermore, only 71 hours exhibit differences exceeding 50^o, while 16 hours exhibit differences exceed 100^o. Most of the latter hours occur during the passage of a lake breeze.

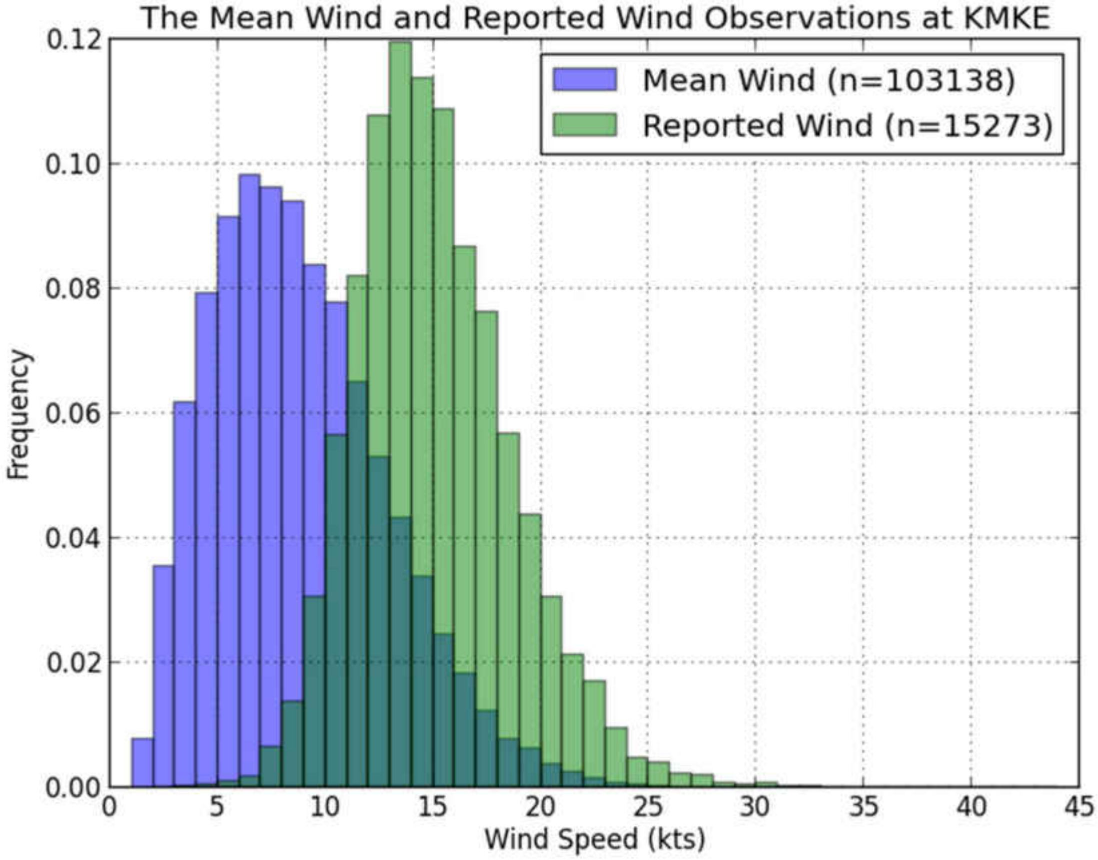

Figure 4: Histograms for all mean wind observations determined from the $ASOS_m$ data (blue) and the reported wind (green) observations in the $ASOS_h$ data are shown for the Jan 2000 – Dec 2014 period at KMKE. The overlapping portions of the two histograms are shown in turquoise. The reported wind observations only include those used to calculate the GF_h, and are therefore limited to the observations for when the $ASOS_h$ gust criterion is met (see section 2.3). This gust criterion explains the fewer observations in the reported wind (n=15,273) than mean wind (n=103,138), and results in a bias towards higher wind speeds than with the mean wind (blue).

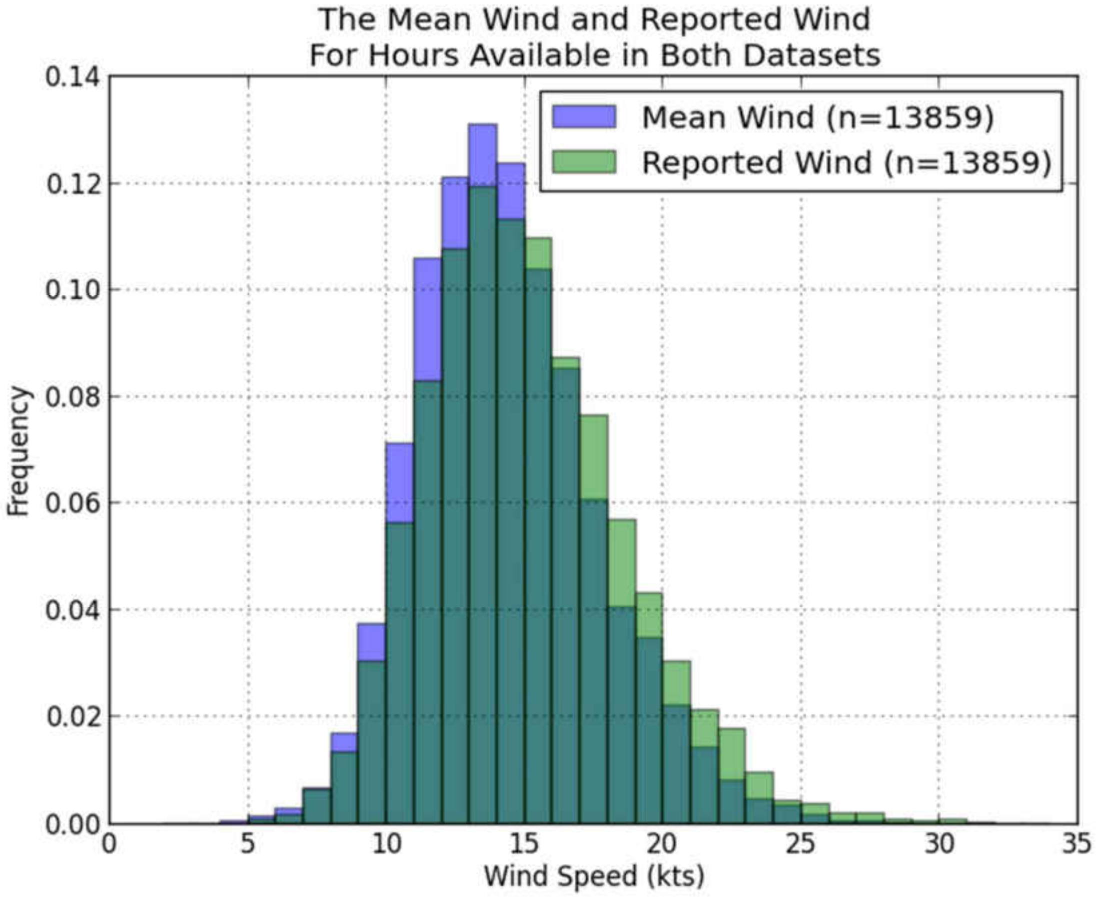

Figure 5: Histograms for mean wind observations determined from the $ASOS_m$ data (blue) and the reported wind (green) observations in the $ASOS_h$ data are shown for the hours in which both $ASOS_m$ and $ASOS_h$ gusts are reported in the Jan 2000 – Dec 2014 period at KMKE. The overlapping portions of the two histograms are shown in turquoise. By restricting the mean wind and reported wind to the times for when gusts are reported in both datasets, the influence of the gust criterion (Section 2.3) is removed. This elucidates the impact of the averaging periods on the mean wind (average of the 0-59th minute wind) and reported wind (average of the 51-52nd minute wind).

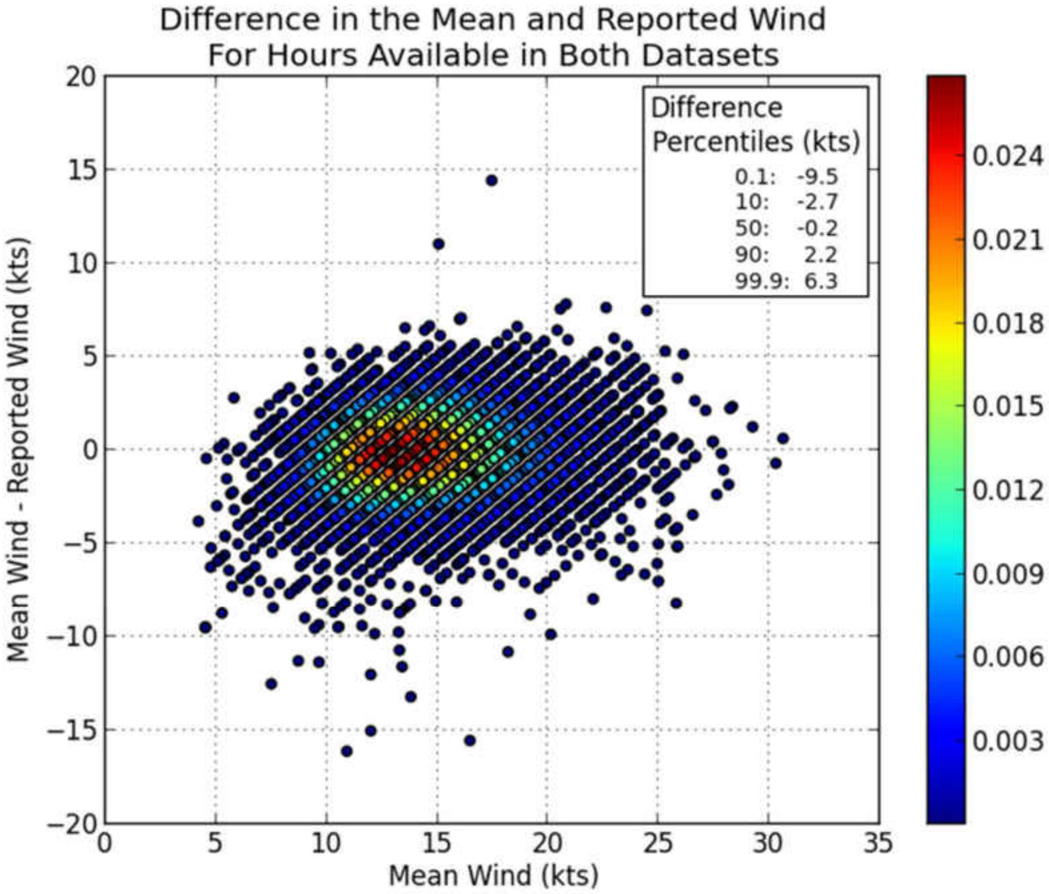

Figure 6: The difference in the mean wind and reported wind (n=13,859) is shown as a function of mean wind at KMKE for times when the gust criterion is met during the 2000-2014 period. By restricting the mean wind and reported wind to the times for when gusts are reported in both datasets, the influence of the gust criterion (Section 2.3) is removed. This elucidates the impact of the averaging periods on the mean wind (average of the 0-59th minute wind) and reported wind (average of the 51-52nd minute wind). The percentiles of the differences (mean wind – reported wind) are shown (top right), while the red (blue) values indicate regions in which the values are most (least) frequent.

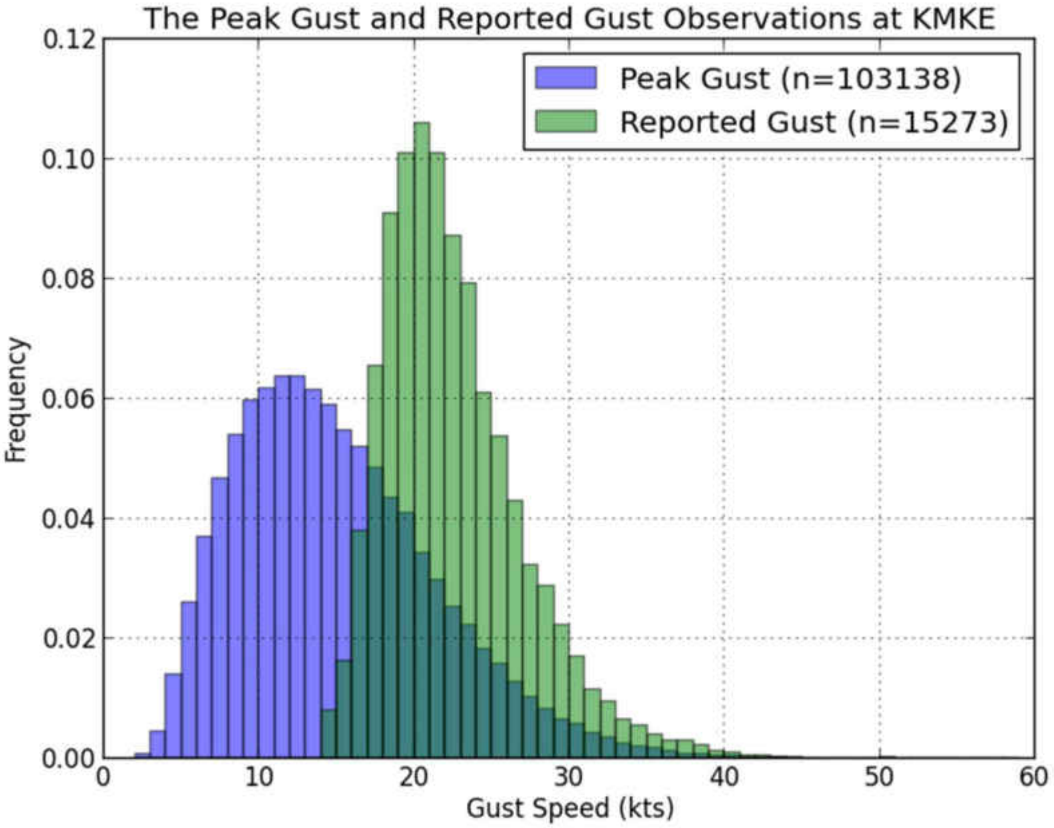

Figure 7: Similarly to Figure 2, histograms for all peak gusts observations determined from the $ASOS_m$ data (blue) and the reported gusts (green) observations in the $ASOS_h$ data are shown for the Jan 2000 – Dec 2014 period at KMKE. The overlapping portions of the two histograms are shown in turquoise. The peak gusts are the highest instantaneous wind speed observed in the hour, while the reported gust is the highest instantaneous wind speed during the 43-52nd minutes of the hour. The reported gust observations shown are limited to the observations for when the $ASOS_h$ gust criterion is met (see section 2.3). This explains the fewer observations in the reported gust (n=15,273) than peak gust (n=103,138), and results in a bias towards higher speeds for the reported gust.

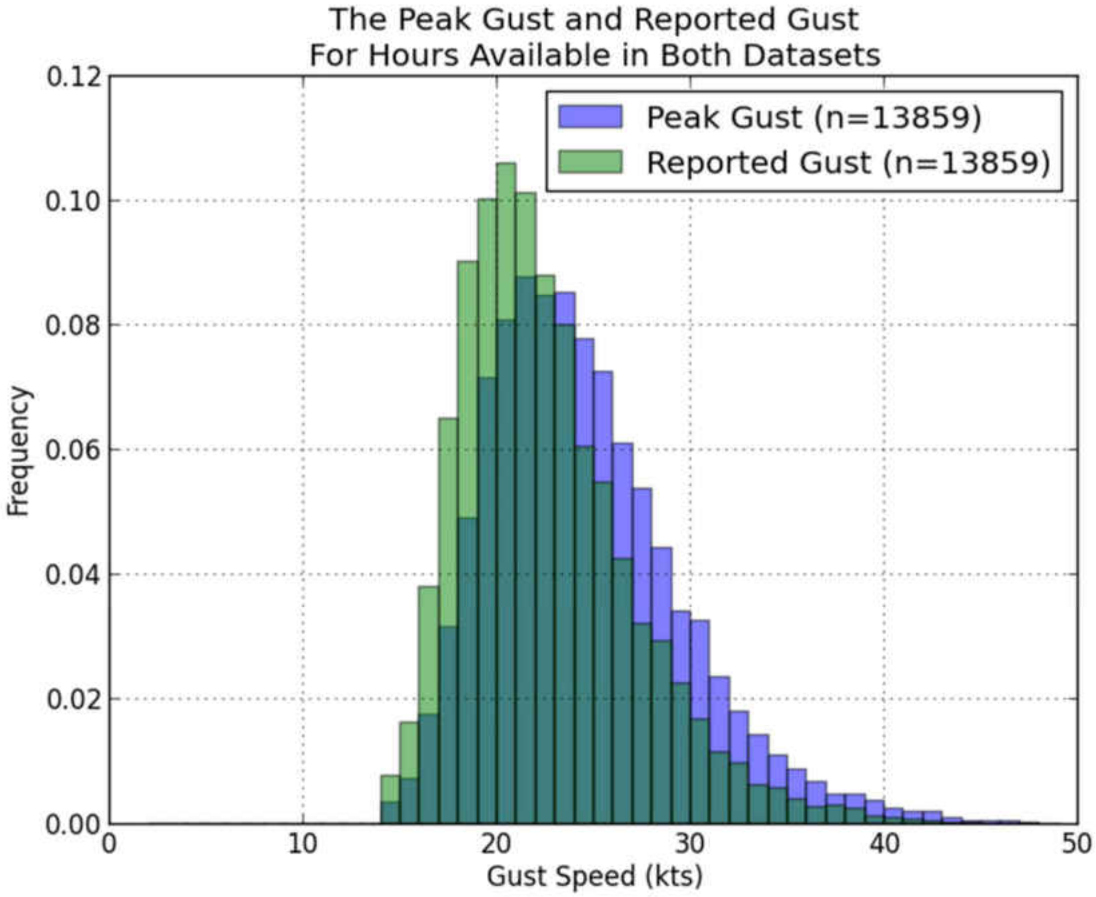

Figure 8: Similarly to Figure 3, histograms of peak gust observations determined from the $ASOS_m$ data (blue) and reported gust (green) observations in the $ASOS_h$ data are shown for the hours in which both $ASOS_m$ and $ASOS_h$ gusts are reported in the Jan 2000 – Dec 2014 period at KMKE. The overlapping portions of the two histograms are shown in turquoise. By restricting the histograms to the times for the when both observations are reported, we can clearly see the impact of the averaging periods on the peak gust (highest gust during minutes 0-59) and reported gust (highest gust during minute 43-52).

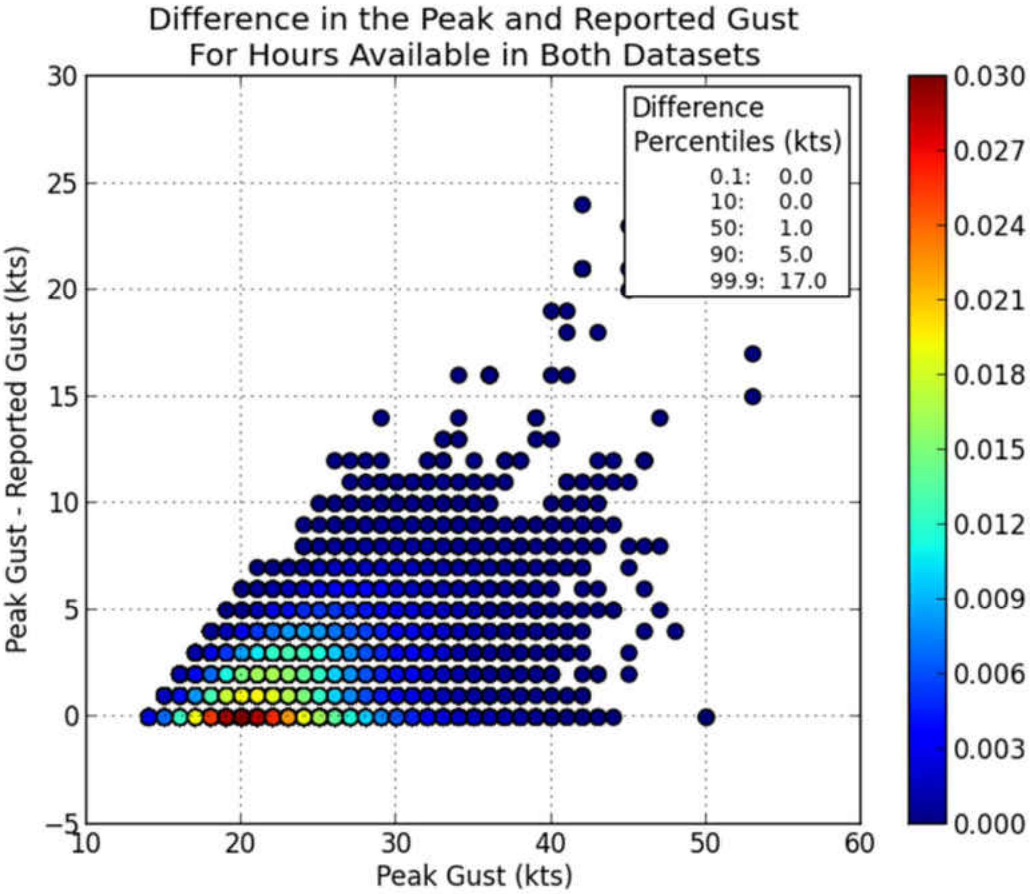

Figure 9: Similarly to Figure 4, the difference in the peak gust and reported gust (n=13,859) is shown as a function of peak gust at KMKE. By restricting the peak gust and reported gust to the times for when gusts are reported in both datasets, the influence of the gust criterion (Section 2.3) is removed. This elucidates the impact of the averaging periods on the peak gust (highest gust during minutes 0-59) and reported gust (highest gust during minutes 43-52). The percentiles of the differences (peak gust – reported gust) are shown (top right), while the red (blue) values indicate regions in which the values are most (least) frequent.

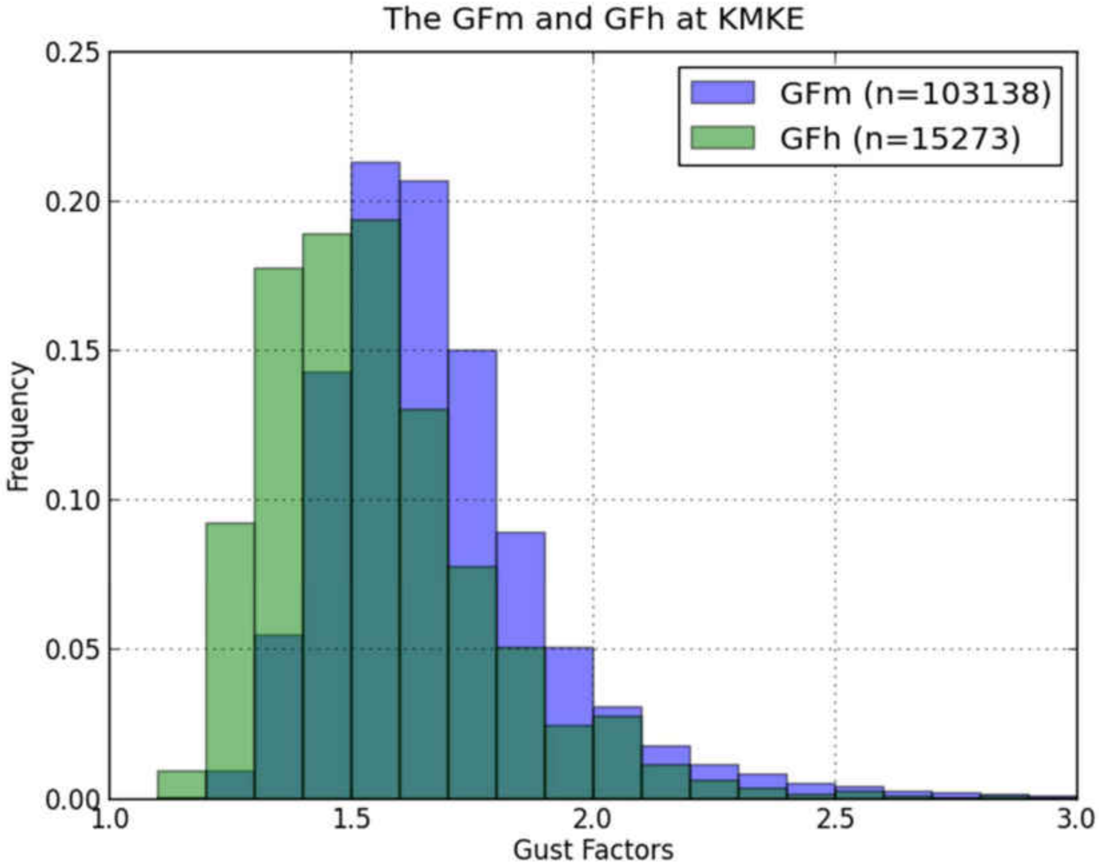

Figure 10: Histograms for all the GF_m derived from the $ASOS_m$ data (blue) and the GF_h derived from the $ASOS_h$ data (green) is shown for the Jan 2000 – Dec 2014 period at KMKE. The overlapping portions of the two histograms are shown in turquoise.

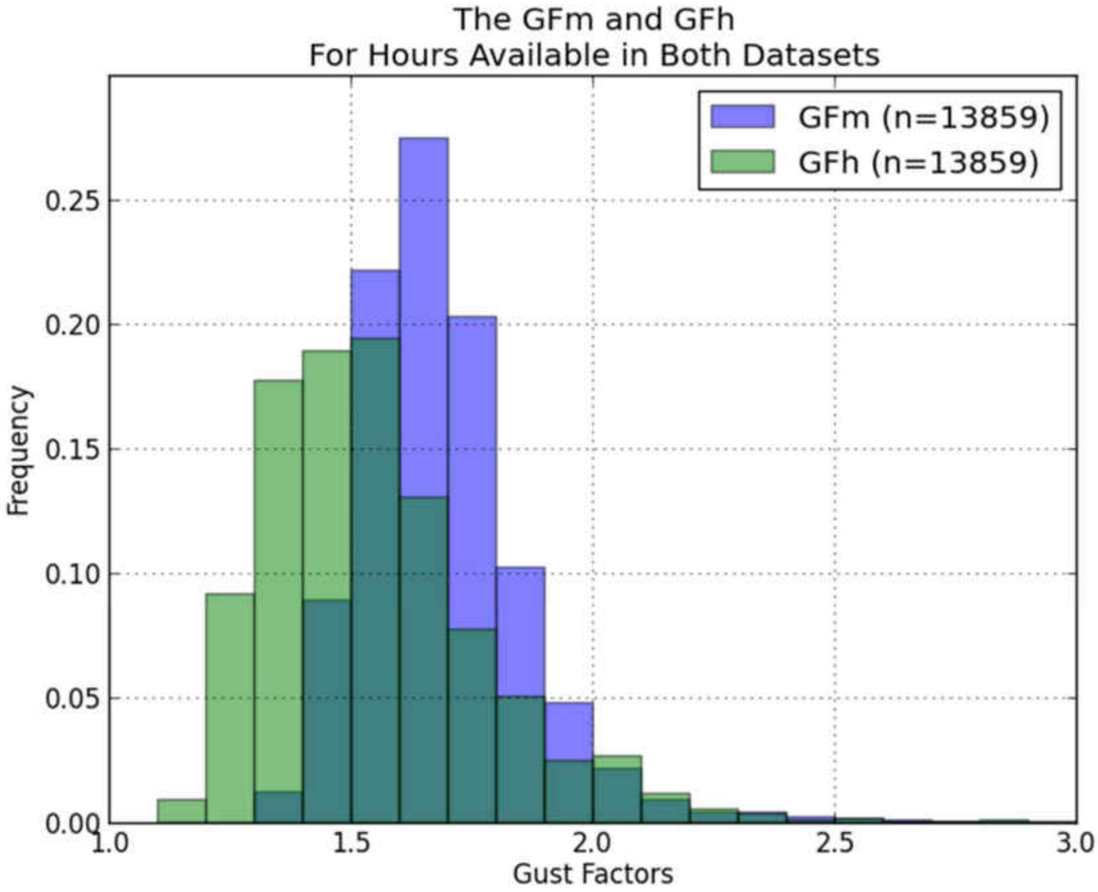

Figure 11: Histograms for the GF_m derived from the $ASOS_m$ data (blue) and the GF_h derived from the $ASOS_h$ data (green) are shown for the hours in which both GFs were available in the Jan 2000 – Dec 2014 period at KMKE. By restricting the histograms to the times for the when both GFs were available, we can clearly see the impact of the averaging periods from the peak and reported gusts (Figures 8-9), as well as with the mean and reported wind (Figures 5-6). The overlapping portions of the two histograms are shown in turquoise.

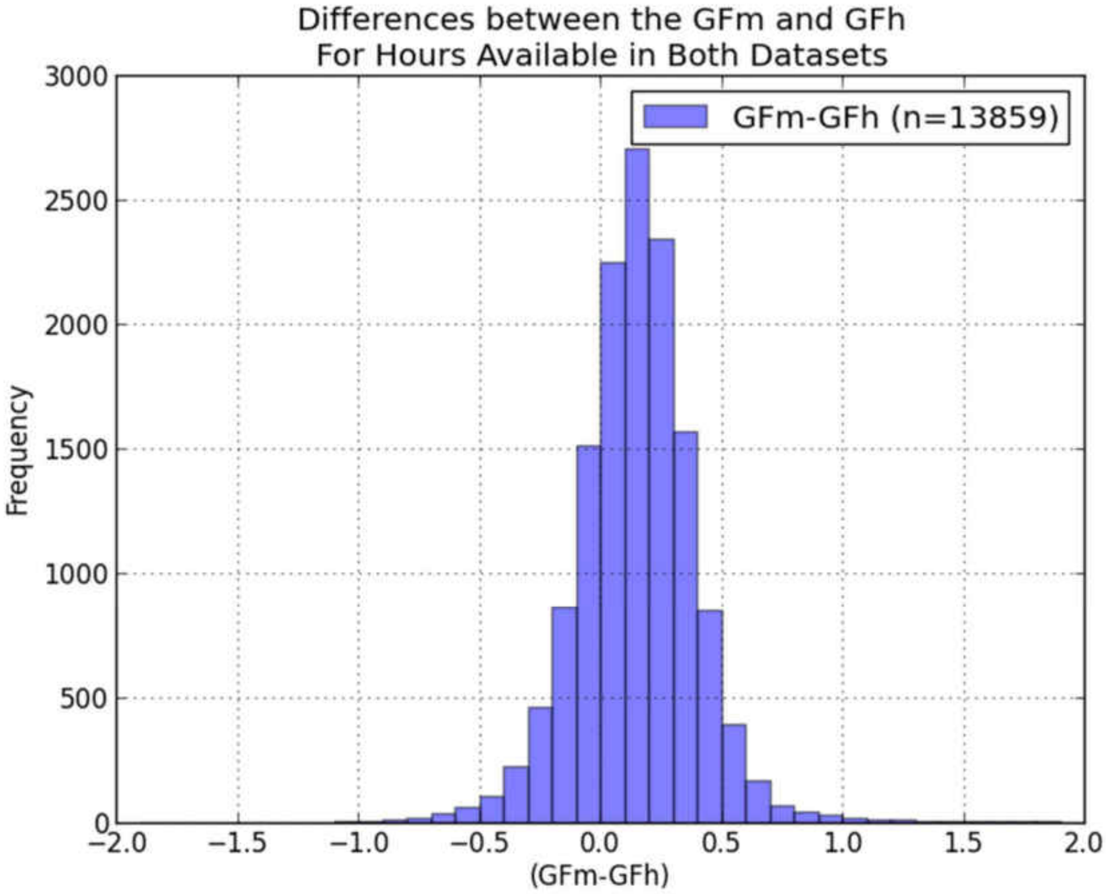

Figure 12: A histogram of the differences between the GF_m and GF_h ($GF_m - GF_h$) is shown for when gusts are reported in both the $ASOS_m$ and $ASOS_h$ data. The 10th, 50th, and 90th percentiles of the GF differences are -0.14, 0.15, and 0.42, respectively. These differences are largely the result of differences in the peak and reported gust, as shown in Figures 8-9.

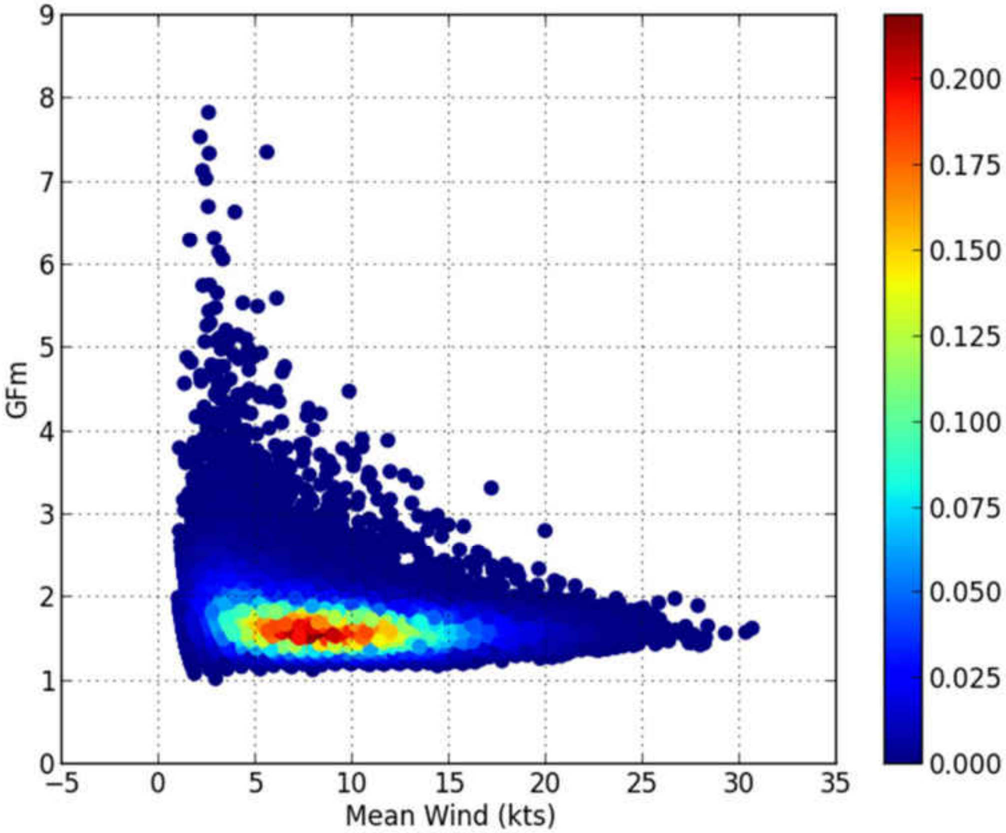

Figure 13: The GF_m is shown as a function of mean wind speeds (n=103,138) at KMKE throughout the 2000-2014 year period. Red (blue) values indicate regions in which the GF_m is most (least) frequent.

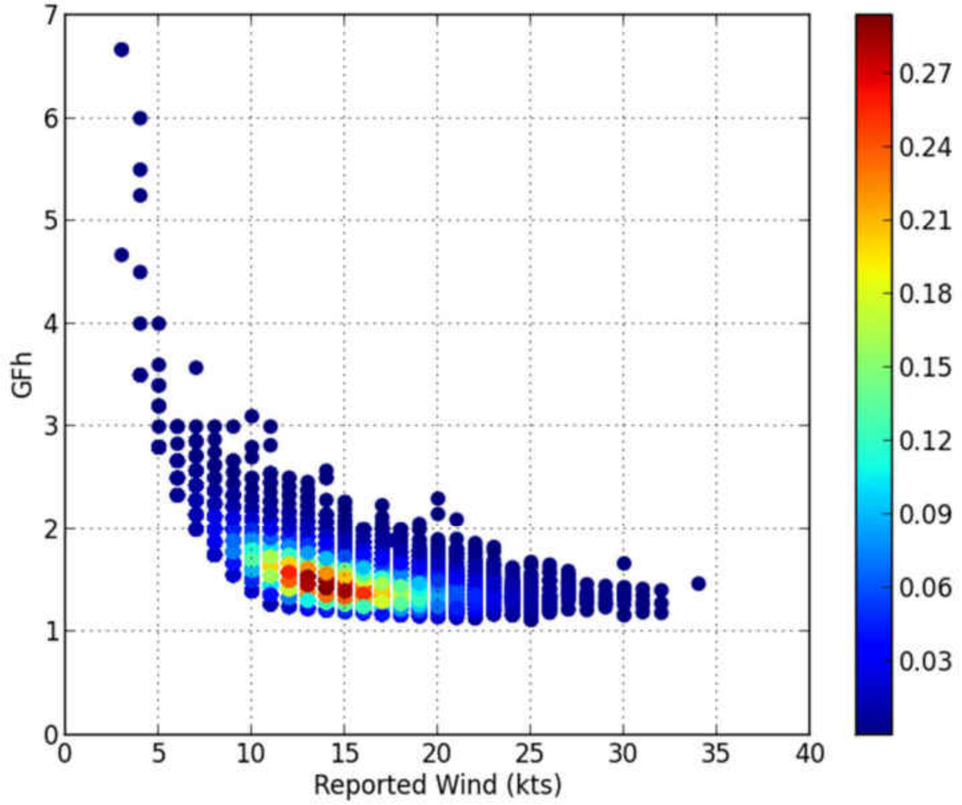

Figure 14: The GF_h is shown as a function of reported wind speeds (n=15,273) throughout the 2000-2014 year period at KMKE. Red (blue) values indicate regions in which the GF_h is most (least) frequent.

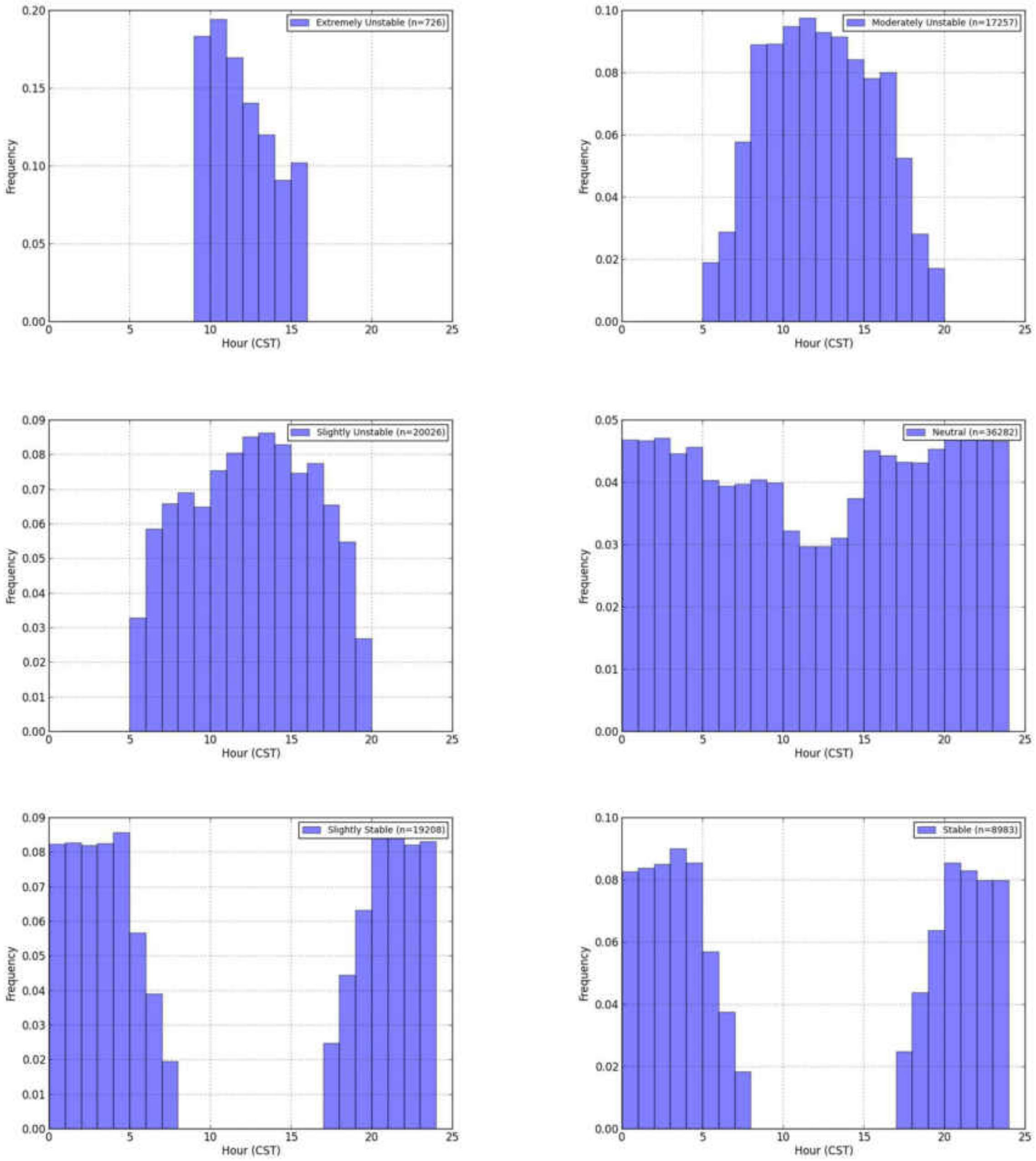

Figure 15: The frequency of each Pasquill stability category (A-F) is shown for each hour in the day (CST) for the 2000-2014 period available at KMKE. The stability categories are: extremely unstable (A), moderately unstable (B), slightly unstable (C), neutral (D), slightly stable (E), and stable (F). The Pasquill stability categories are determined from the mean wind speed from the $ASOS_m$ data and the lowest, Sky Level 1 cloud data from the $ASOS_h$ dataset.

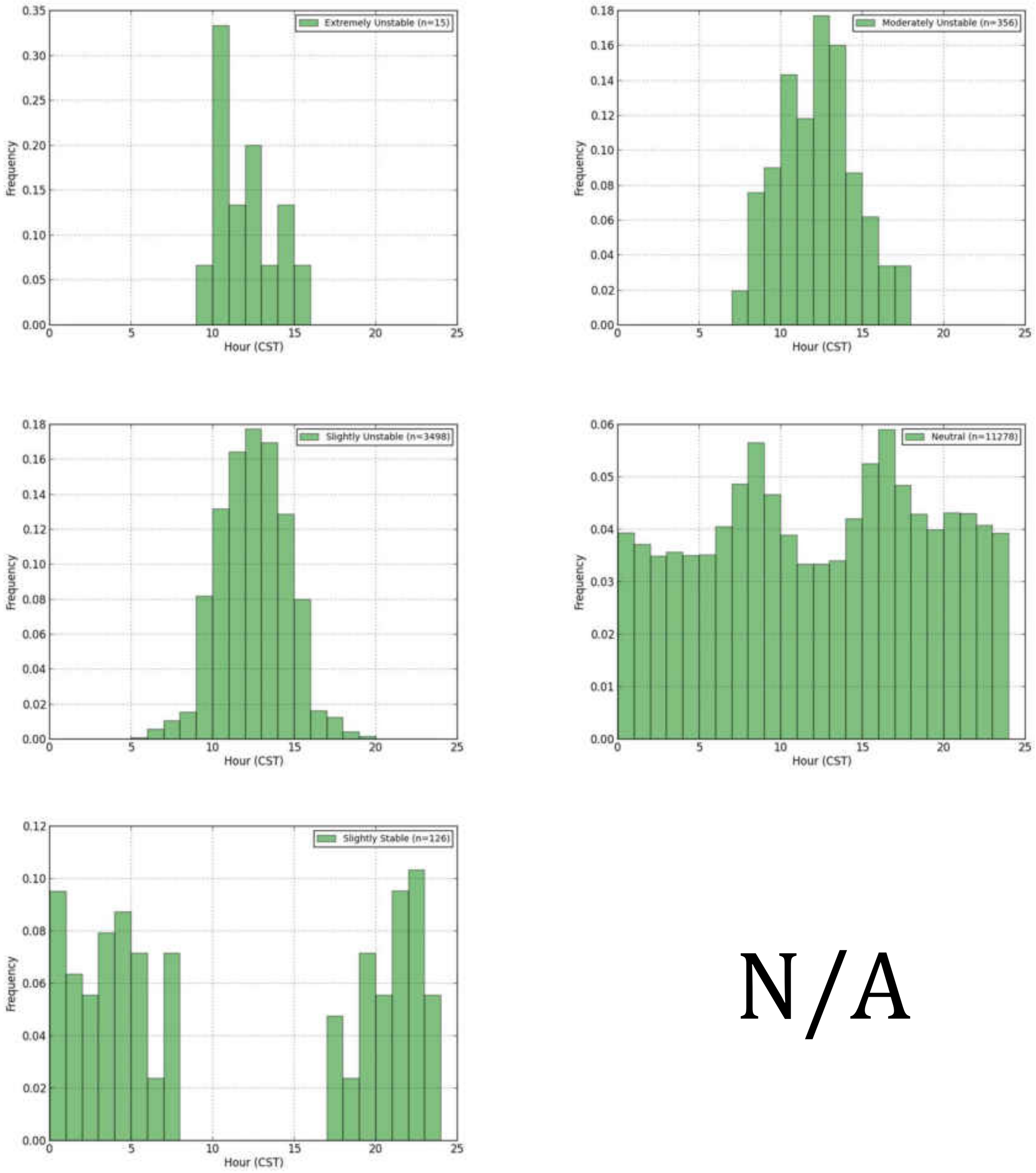

Figure 16: As with Figure 13, but the reported wind speed is used instead of the mean wind. The frequency of each Pasquill stability category (A-F) is shown for each hour in the day (CST). The stability categories are: extremely unstable (A), moderately unstable (B), slightly unstable (C), neutral (D), slightly stable (E), and stable (F).The Pasquill stability categories are determined from the reported wind speed and the lowest Sky Level 1 cloud data from the ASOS_h This is done for the 2000-2014 period at KMKE (n=15,273). None of the hours in this dataset qualified for the stable category, as the reported winds are high biased due to the gust criterion.

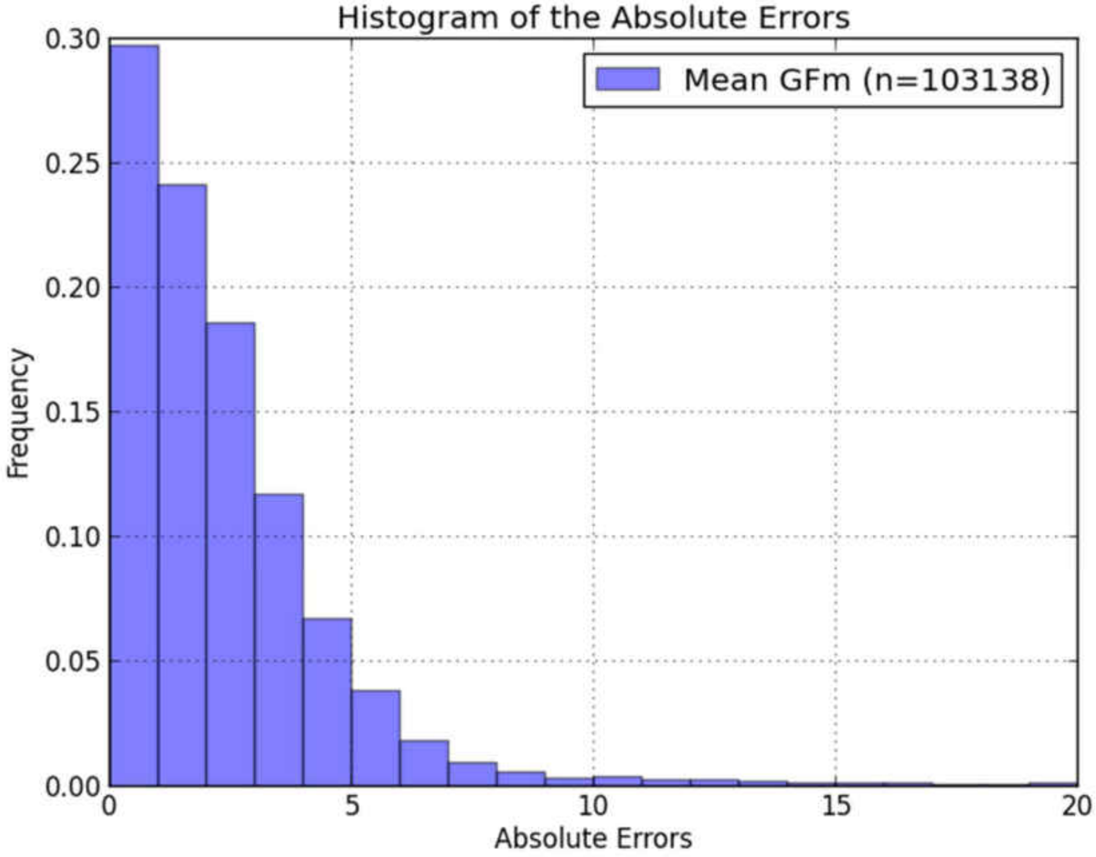

Figure 17: The frequency of the absolute errors (forecast – observed peak gust) in the wind gust forecast from the mean $GF_m = 1.69$ is shown for all available hours (n=103,138) between 2000-2014 in KMKE. As they are with all forecast models, the majority of these errors are only a few knots. However, there are still a number of cases in which the absolute errors are large. In this particular example, there are 752 times when the absolute errors exceed 5 knots, 153 times when the absolute errors exceed 10 knots, 57 times when the absolute errors exceed 15 knots, and 14 times when the absolute errors exceed 20 knots.

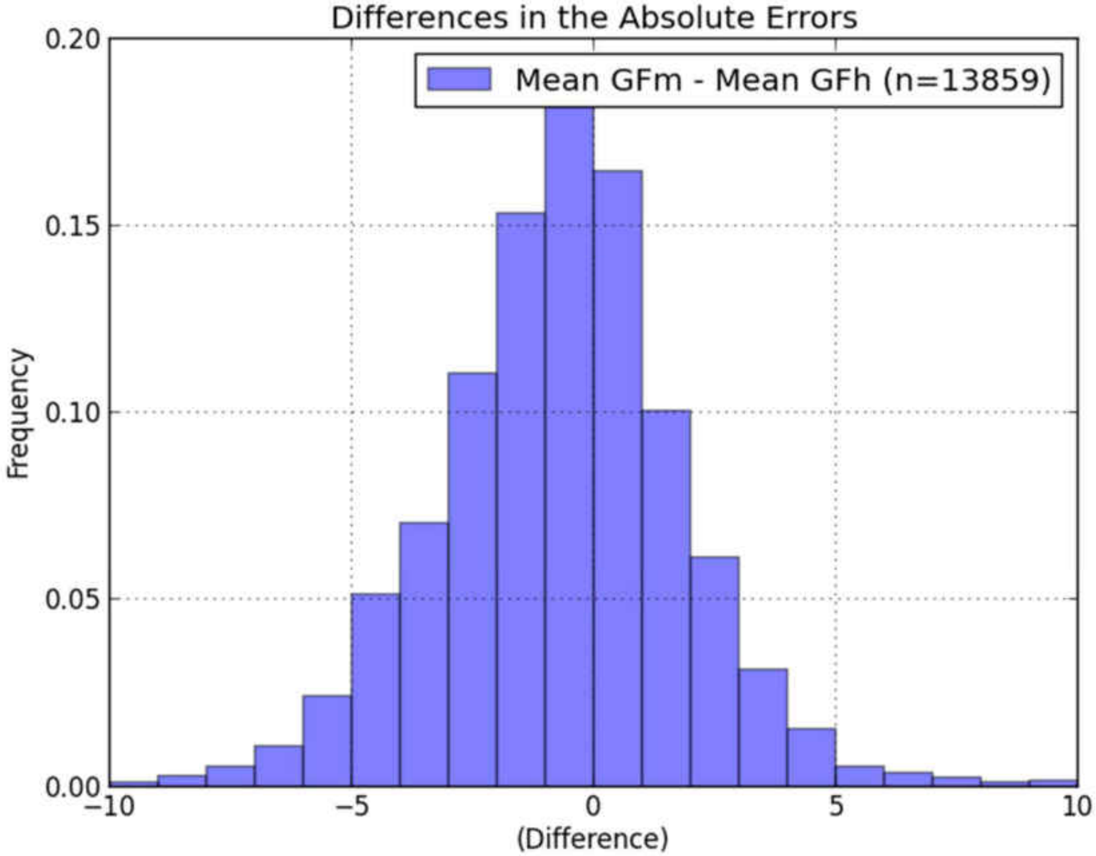

Figure 18: The frequency of differences in the absolute errors (forecast – observed gust) between the wind gust forecasts from the mean GF_m = 1.69 and the mean GF_h = 1.55 is shown for all available hours (n=13,859) between 2000-2014 in KMKE. The vast majority of these errors are very small; however, there are still 151 times the difference in the absolute errors exceeds 5 knots, and 34 times the differences exceed 10 knots.

Table 1: The number of hours with observations in the ASOS hourly ($ASOS_h$) and ASOS one-minute ($ASOS_m$) datasets is shown for the Jan 2000 – Dec 2014 period. The $ASOS_m$ has considerably more observations (n=103,138) than the $ASOS_h$ (n=15,273) due to the reporting criterion, which restricts the $ASOS_h$ data to the gustier hours. The number of matching observations (n=13,859) is the number of hours for which observations exist for both the $ASOS_m$ and $ASOS_h$ data.

Dataset	Abbreviation	Observation Period	Number of Total Observations (n)	Number of Matching Observations (n)
ASOS Hourly	$ASOS_h$	Jan 2000- Dec 2014	15,273	13,859
ASOS One Minute	$ASOS_m$	Jan 2000- Dec 2014	103,138	13,859

[1] ASOS: Automated Surface Observing System

Table 2: The Pasquill stability classes require a subjective estimation of insolation into slight, moderate, and strong. Strong insolation is defined by a solar angle ≥ 50° or when the solar angle is ≥ 40° with clear, few, or scattered cloud coverage. If the solar angle is ≥ 40° with broken skies, the insolation is defined as moderate. The insolation is also considered moderate when 30° ≤ solar angle < 40° or when 20° ≤ solar angle < 30° with clear, few, or scattered cloud coverage. The insolation is slight when 20° ≤ solar angle < 30° under broken skies. The insolation is classified as slight when the skies are overcast or when the solar angle < 20°. Using a combination of insolation and wind speed, the stability classifications (A-F) are defined as: extremely unstable (A), moderately unstable (B), slightly unstable (C), neutral (D), slightly stable (E), and stable (F). The cloud coverage was also used to differentiate between split categories (A-B, B-C etc.), where clear, few, and scattered skies fell into the more unstable category, while broken and overcast fell into the more stable category.

	Daytime Conditions (Solar angle > 0^o)			Night-time Conditions (Solar angle < 0^o)	
Surface Wind Speed (kts)	Strong Insolation	Moderate Insolation	Slight Insolation	> 3/5 cloud	<= 3/5 cloud
<4	A	A-B	B	E	F
4-6	A-B	B	C	E	F
6-10	B	B-C	C	D	E
10-12	C	C-D	D	D	D
12+	C	D	D	D	D

Table 3: The mean, median, and standard deviation (σ) of the GF_m stratified by mean wind speed.

Mean Wind Speed (kts)	**N**	**%**	**GF_m Mean**	**GF_m Median**	**GF_m σ**
All	103138	100.0	1.69	1.63	0.27
0 ≤ wind < 5	19028	18.4	1.86	1.78	0.41
5 ≤ wind < 10	47844	46.4	1.66	1.63	0.23
10 ≤ wind < 15	28144	27.3	1.61	1.60	0.17
15 ≤ wind < 20	7130	6.9	1.60	1.59	0.15
20 ≤ wind < 25	939	0.9	1.61	1.60	0.13
25 ≤ wind < 30	51	0.05	1.61	1.58	0.12
wind ≥ 30	2	0.002	1.60	1.60	0.02

Table 4: The mean, median, and standard deviation (σ) of the GF_h stratified by reported wind speed.

Reported Wind Speed (kts)	**N**	**%**	**GF_h Mean**	**GF_h Median**	**GF_h σ**
All	15273	100.0	1.55	1.50	0.248
0 ≤ wind < 5	12	0.08	4.77	4.58	1.17
5 ≤ wind < 10	821	5.3	2.03	2.00	0.32
10 ≤ wind < 15	7323	48.0	1.59	1.57	0.20
15 ≤ wind < 20	5687	37.2	1.44	1.41	0.15
20 ≤ wind < 25	1266	8.3	1.39	1.37	0.14
25 ≤ wind < 30	143	0.9	1.37	1.36	0.11
wind ≥ 30	21	0.1	1.33	1.33	0.11

Table 5: The GF_h, reported wind, and reported gusts stratified by the Pasquill stability scheme where the stability categories are: unstable (A), moderately unstable (B), slightly unstable (C), neutral (D), slightly stable (E), and stable (F), as defined in Table 2. This classification scheme requires wind speeds less than six knots for the stability to be classified as stable. Since the $ASOS_h$ reported winds are biased towards stronger wind speeds, no cases are classified as stable.

$GF_h = \frac{Reported\ Gust}{Reported\ Wind}$						Reported Wind		Reported Gust	
Stability	**N**	**%**	**Mean** (kts)	**Median** (kts)	**σ** (kts)	**Mean** (kts)	**σ** (kts)	**Mean** (kts)	**σ** (kts)
All	15273	100.0	1.55	1.50	0.248	14.57	3.62	22.03	4.48
Extremely Unstable	15	0.1	3.12	3.20	0.29	4.73	0.44	14.66	1.01
Mod Unstable	356	2.3	2.05	2.00	0.46	8.24	0.96	16.64	1.96
Slightly Unstable	3498	22.9	1.54	1.50	0.25	14.24	3.63	21.46	4.44
Neutral	11278	73.8	1.52	1.50	0.20	14.95	3.40	22.44	4.41
Slightly Stable	126	0.8	2.07	2.00	0.46	8.37	1.05	16.94	1.76
Stable	0	0.0	N/A	N/A	N/A	N/A	N/A	N/A	N/A

Table 6: The GF_m, mean wind, and peak gust stratified by the Pasquill stability scheme where the stability categories are: unstable (A), moderately unstable (B), slightly unstable (C), neutral (D), slightly stable (E), and stable (F).

$GF_m = \frac{Peak\ Gust}{Mean\ Wind}$						Mean Wind		Peak Gust	
Stability	**N**	**%**	**Mean** (kts)	**Median** (kts)	σ (kts)	**Mean** (kts)	σ (kts)	**Mean** (kts)	σ (kts)
All	103138	100.0	1.69	1.63	0.27	8.78	4.04	14.51	6.49
Extremely Unstable	726	0.7	1.94	1.87	0.41	5.20	0.54	10.05	1.99
Mod Unstable	17257	16.8	1.70	1.65	0.29	6.90	1.79	11.60	3.08
Slightly Unstable	20026	19.5	1.66	1.61	0.29	9.28	3.48	15.10	5.50
Neutral	36282	35.4	1.63	1.61	0.18	12.17	3.423	19.82	5.77
Slightly Stable	19208	18.7	1.73	1.67	0.31	5.87	2.19	10.01	3.73
Stable	8983	8.7	1.79	1.73	0.34	4.17	1.14	7.38	2.13

Table 7: The GF_m, mean wind and peak gust stratified by the Pasquill stability scheme for mean winds between 5-7 kts. This particular range was chosen to most effectively mitigate the influence of the wind speed on the GF stratification while ensuring the categorization of all stability types (see Table 2). The stability categories are: unstable (A), moderately unstable (B), slightly unstable (C), neutral (D), slightly stable (E), and stable (F).

$GF_m = \frac{Peak\ Gust}{Mean\ Wind}$ For 5 kts ≤ Mean Winds ≤ 7 kts						Mean Wind		Peak Gust	
Stability	**N**	**%**	**Mean** (kts)	**Median** (kts)	**σ** (kts)	**Mean** (kts)	**σ** (kts)	**Mean** (kts)	**σ** (kts)
All	19605	100.0	1.70	1.65	0.27	6.01	0.57	10.22	1.81
Extremely Unstable	474	2.7	1.86	1.80	0.32	5.54	0.28	10.33	1.78
Mod Unstable	5845	34.1	1.72	1.67	0.29	5.92	0.57	10.21	1.89
Slightly Unstable	2666	15.5	1.68	1.64	0.27	6.50	0.30	10.97	1.77
Neutral	2502	14.6	1.66	1.62	0.24	6.48	0.29	10.77	1.61
Slightly Stable	5489	32.1	1.68	1.64	0.24	5.97	0.58	10.06	1.77
Stable	2629	15.3	1.69	1.66	0.25	5.48	0.28	9.30	1.45

Table 8: The GF_m, mean wind and peak gust stratified by the Pasquill stability scheme for mean winds between 5.75 and 6.25 kts. This particular range was chosen to ensure the categorization of all stability types (see Table 2), but was intended to restrict the wind speed more than in Table 7. The stability categories are: unstable (A), moderately unstable (B), slightly unstable (C), neutral (D), slightly stable (E), and stable (F).

$GF_m = \frac{Peak\ Gust}{Mean\ Wind}$ For 5.75 kts ≤ Mean Winds ≤ 6.25 kts						Mean Wind		Peak Gust	
Stability	**N**	**%**	**Mean** (kts)	**Median** (kts)	**σ** (kts)	**Mean** (kts)	**σ** (kts)	**Mean** (kts)	**σ** (kts)
All	4997	100.0	1.70	1.65	0.26	6.00	0.14	10.20	1.63
Extremely Unstable	142	4.6	1.82	1.72	0.31	5.86	0.06	10.73	1.83
Mod Unstable	1483	18.2	1.72	1.68	0.27	5.96	0.14	10.27	1.64
Slightly Unstable	654	17.6	1.71	1.64	0.31	6.12	0.07	10.51	1.95
Neutral	693	22.5	1.66	1.62	0.26	6.12	0.07	10.20	1.61
Slightly Stable	1400	30.3	1.68	1.64	0.25	5.99	0.14	10.11	1.52
Stable	625	6.8	1.67	1.67	0.22	5.86	0.07	9.81	1.33

Table 9: The mean and standard deviations of the GF_m, mean wind, and peak gust stratified by season and month at KMKE for 2000-2014.

$GF_m = \frac{Peak\ Gust}{Mean\ Wind}$						Mean Wind		Peak Gust	
Season Month	**N**	**%**	**Mean** (kts)	**Median** (kts)	**σ** (kts)	**Mean** (kts)	**σ** (kts)	**Mean** (kts)	**σ** (kts)
All	103138	100.0	1.69	1.63	0.27	8.78	4.04	14.51	6.49
MAM	25132	24.4	1.68	1.62	0.28	9.52	4.42	15.63	7.02
MAR	8429	8.2	1.66	1.61	0.26	9.39	4.38	15.26	6.87
APR	8345	8.1	1.67	1.62	0.26	10.16	4.59	16.64	7.25
MAY	8358	8.1	1.70	1.64	0.30	9.00	4.20	14.99	6.81
JJA	25198	24.4	1.70	1.64	0.31	7.70	3.35	12.84	5.44
JUN	7540	7.3	1.73	1.66	0.31	8.00	3.60	13.56	6.00
JUL	8882	8.6	1.70	1.64	0.32	7.72	3.27	12.85	5.28
AUG	8776	8.5	1.68	1.62	0.30	7.42	3.18	12.20	5.02
SON	26552	25.7	1.69	1.64	0.27	8.64	4.01	14.35	6.59
SEP	8627	8.4	1.69	1.64	0.28	7.98	3.65	13.22	5.96
OCT	9159	8.9	1.70	1.65	0.28	8.82	4.09	14.72	6.76
NOV	8766	8.5	1.68	1.64	0.24	9.09	4.19	15.07	6.85
DJF	26256	25.5	1.66	1.63	0.23	9.31	4.06	15.24	6.45
DEC	9528	9.2	1.67	1.63	0.22	9.11	4.00	14.97	6.40
JAN	8776	8.5	1.66	1.63	0.23	9.54	3.89	15.63	6.21
FEB	7952	7.7	1.66	1.62	0.25	9.29	4.28	15.15	6.75

Table 10: The mean and standard deviations of the GF_h, reported wind, and reported gust stratified by season and month at KMKE from 2000-2014.

$GF_h = \frac{Reported\ Gust}{Reported\ Wind}$						Reported Wind		Reported Gust	
Season Month	**N**	**%**	**Mean** (kts)	**Median** (kts)	**σ** (kts)	**Mean** (kts)	**σ** (kts)	**Mean** (kts)	**σ** (kts)
All	15273	100.0	1.55	1.50	0.248	14.57	3.62	22.03	4.48
MAM	4860	31.8	1.53	1.47	0.27	15.26	3.78	22.83	4.69
MAR	1494	8.6	1.51	1.47	0.22	15.16	3.66	22.52	4.48
APR	1489	12.3	1.52	1.47	0.25	15.50	3.81	23.06	4.61
MAY	1489	9.1	1.55	1.50	0.32	15.06	3.86	22.86	4.98
JJA	2334	15.3	1.56	1.50	0.30	13.28	3.19	20.22	3.56
JUN	1008	5.8	1.55	1.50	0.27	13.76	3.24	20.85	3.79
JUL	727	5.0	1.57	1.50	0.33	13.14	3.25	20.06	3.53
AUG	599	4.0	1.58	1.50	0.32	12.63	2.90	19.37	2.93
SON	3918	25.6	1.56	1.50	0.23	14.41	3.57	22.08	4.57
SEP	966	6.2	1.57	1.53	0.25	13.74	3.40	21.15	4.33
OCT	1338	9.4	1.57	1.53	0.23	14.30	3.71	22.02	4.73
NOV	1614	10.3	1.55	1.50	0.22	14.91	3.47	22.70	4.47
DJF	4161	27.3	1.53	1.50	0.21	14.63	3.47	22.05	4.33
DEC	1228	9.7	1.53	1.50	0.21	14.59	3.51	22.02	4.56
JAN	1586	10.4	1.54	1.50	0.22	14.40	3.22	21.83	3.90
FEB	1347	9.2	1.52	1.50	0.20	14.94	3.68	22.33	4.57

Table 11: The mean and standard deviations of the GF_m, mean wind, and peak gusts stratified by the time of day in local military time (CST) at KMKE from 2000-2014.

$GF_m = \frac{Peak\ Gust}{Mean\ Wind}$						Mean Wind		Peak Gust	
Hour (CST)	**N**	**%**	**Mean** (kts)	**Median** (kts)	**σ** (kts)	**Mean** (kts)	**σ** (kts)	**Mean** (kts)	**σ** (kts)
All	103138	100.0	1.69	1.63	0.27	8.78	4.04	14.51	6.49
0	4063	3.9	1.71	1.66	0.28	7.73	3.99	12.94	6.49
1	4071	3.9	1.70	1.65	0.26	7.69	4.00	12.83	6.52
2	4069	3.9	1.70	1.65	0.26	7.63	3.97	12.70	6.46
3	4022	3.9	1.69	1.64	0.25	7.56	3.94	12.56	6.38
4	4089	4.0	1.70	1.65	0.29	7.55	3.86	12.58	6.22
5	4095	4.0	1.71	1.66	0.31	7.68	3.83	12.84	6.15
6	4212	4.1	1.74	1.67	0.37	8.04	3.80	13.61	6.05
7	4318	4.2	1.71	1.65	0.32	8.61	3.78	14.35	5.90
8	4408	4.3	1.68	1.63	0.27	9.21	3.84	15.17	5.99
9	4437	4.3	1.68	1.63	0.25	9.73	3.87	15.97	5.98
10	4465	4.3	1.67	1.62	0.25	10.09	3.86	16.51	5.97
11	4507	4.4	1.65	1.61	0.24	10.40	3.84	16.92	5.99
12	4520	4.4	1.64	1.60	0.24	10.66	3.77	17.25	5.97
13	4536	4.4	1.63	1.59	0.24	10.77	3.73	17.36	6.00
14	4550	4.4	1.62	1.59	0.22	10.70	3.73	17.18	6.12
15	4564	4.4	1.62	1.58	0.24	10.35	3.70	16.67	6.19
16	4559	4.4	1.64	1.61	0.24	9.65	3.71	15.76	6.25
17	4495	4.4	1.66	1.63	0.25	8.84	3.72	14.63	6.29
18	4420	4.3	1.69	1.64	0.26	8.15	3.75	13.66	6.37
19	4299	4.2	1.71	1.65	0.29	7.77	3.91	13.07	6.50
20	4202	4.1	1.72	1.66	0.30	7.68	3.99	12.96	6.60
21	4127	4.0	1.72	1.67	0.28	7.76	4.06	13.10	6.64
22	4068	3.9	1.71	1.65	0.28	7.82	4.05	13.12	6.64
23	4042	3.9	1.70	1.65	0.26	7.77	4.02	12.98	6.49

Table 12: The means and standard deviations of the GF_h, reported wind, and reported wind gusts stratified by the time of day in local military time (CST) at KMKE from 2000-2014.

$GF_h = \frac{Reported\ Gust}{Reported\ Wind}$						Reported Wind		Reported Gust	
Hour (CST)	**N**	**%**	**Mean** (kts)	**Median** (kts)	σ (kts)	**Mean** (kts)	σ (kts)	**Mean** (kts)	σ (kts)
All	15273	100.0	1.55	1.50	0.248	14.57	3.62	22.03	4.48
0	456	3.0	1.56	1.52	0.25	14.37	3.49	21.96	4.24
1	427	2.8	1.54	1.50	0.24	14.62	3.54	22.15	4.37
2	362	2.4	1.55	1.50	0.23	14.64	3.48	22.27	4.19
3	400	2.6	1.54	1.50	0.24	14.52	3.57	22.02	4.41
4	406	2.7	1.55	1.50	0.28	14.55	3.58	22.05	4.28
5	408	2.7	1.54	1.50	0.33	14.52	3.46	21.93	4.43
6	480	3.1	1.56	1.52	0.22	14.37	3.72	21.94	4.59
7	602	3.9	1.53	1.50	0.22	14.35	3.59	21.58	4.55
8	718	4.7	1.53	1.50	0.21	14.42	3.57	21.69	4.47
9	845	5.5	1.51	1.46	0.22	14.73	3.71	21.83	4.58
10	955	6.3	1.53	1.47	0.25	14.61	3.66	21.87	4.62
11	996	6.5	1.54	1.50	0.23	14.61	3.70	22.09	4.64
12	1064	7.0	1.54	1.47	0.27	14.62	3.74	21.94	4.49
13	1034	6.8	1.53	1.47	0.26	14.75	3.72	22.14	4.62
14	956	6.3	1.55	1.50	0.29	14.88	3.76	22.48	4.70
15	894	5.9	1.53	1.50	0.22	14.83	3.59	22.28	4.65
16	734	4.8	1.55	1.50	0.26	14.59	3.50	22.16	4.34
17	607	4.0	1.57	1.53	0.31	14.15	3.55	21.73	4.29
18	502	3.3	1.55	1.50	0.28	14.45	3.62	22.00	4.52
19	464	3.0	1.56	1.51	0.24	14.59	3.60	22.28	4.53
20	493	3.2	1.56	1.50	0.22	14.37	3.42	22.00	4.23
21	497	3.3	1.56	1.53	0.22	14.42	3.52	22.03	4.26
22	473	3.1	1.56	1.52	0.24	14.37	3.46	22.03	4.20
23	450	2.9	1.55	1.50	0.22	14.55	3.44	22.19	4.24

Table 13: The mean and standard deviations of the GF_m, mean wind, and peak gusts stratified by the time of day in local military time (CST) for mean winds between 5.5 and 6.5 knots at KMKE from 2000-2014. This range was chosen at these wind speeds are near average, as shown in Figure 3.

$GF_m = \frac{Peak\ Gust}{Mean\ Wind}$ For 5.5 kts ≤ Mean Winds ≤ 6.5 kts						Mean Wind		Peak Gust	
Hour (CST)	**N**	**%**	**Mean** (kts)	**Median** (kts)	**σ** (kts)	**Mean** (kts)	**σ** (kts)	**Mean** (kts)	**σ** (kts)
All	10039	100	1.70	1.64	0.27	6.00	0.29	10.21	1.69
0	436	4.4	1.67	1.62	0.23	5.99	0.27	10.02	1.44
1	415	4.1	1.67	1.63	0.21	5.97	0.29	10.00	1.35
2	412	4.1	1.65	1.61	0.20	6.02	0.26	9.97	1.31
3	473	4.7	1.65	1.60	0.22	5.99	0.28	9.91	1.45
4	442	4.4	1.68	1.63	0.25	6.00	0.28	10.08	1.62
5	492	4.9	1.69	1.62	0.26	5.98	0.28	10.13	1.60
6	464	4.6	1.73	1.68	0.29	5.98	0.27	10.37	1.87
7	455	4.5	1.73	1.70	0.26	6.01	0.27	10.45	1.66
8	392	3.9	1.72	1.69	0.27	6.02	0.27	10.39	1.69
9	376	3.7	1.74	1.71	0.24	6.00	0.28	10.45	1.47
10	300	3.0	1.77	1.72	0.26	6.00	0.29	10.63	1.58
11	324	3.2	1.78	1.73	0.27	6.02	0.27	10.75	1.74
12	286	2.8	1.78	1.73	0.30	6.02	0.28	10.72	1.84
13	255	2.5	1.76	1.70	0.44	6.04	0.27	10.62	2.54
14	294	2.9	1.68	1.65	0.23	6.04	0.27	10.20	1.45
15	316	3.1	1.65	1.58	0.30	6.00	0.27	9.96	1.98
16	378	3.8	1.67	1.60	0.34	6.04	0.28	10.10	2.09
17	479	4.8	1.66	1.60	0.24	6.01	0.28	10.00	1.51
18	509	5.1	1.69	1.65	0.28	6.00	0.27	10.17	1.76
19	523	5.2	1.67	1.62	0.21	6.00	0.27	10.07	1.35
20	438	4.3	1.68	1.63	0.31	6.00	0.27	10.13	1.91
21	406	4.0	1.69	1.62	0.26	5.98	0.28	10.15	1.64
22	416	4.2	1.69	1.62	0.30	5.99	0.29	10.15	1.88
23	406	4.0	1.68	1.65	0.23	6.01	0.28	10.16	1.45

Table 14: The mean and standard deviations of the GF_m, mean wind, and peak gust stratified by wind direction throughout the 2000-2014 year period at KMKE.

$GF_m = \frac{Peak\ Gust}{Mean\ Wind}$						Mean Wind		Peak Gust	
Wind Direction (degrees)	**N**	**%**	**Mean** (kts)	**Median** (kts)	**σ** (kts)	**Mean** (kts)	**σ** (kts)	**Mean** (kts)	**σ** (kts)
All	103138	100.0	1.69	1.63	0.27	8.78	4.04	14.51	6.49
0-30	8272	8.0	1.69	1.64	0.23	10.18	4.31	16.87	6.77
30-60	7595	7.4	1.64	1.58	0.27	8.83	3.78	14.13	5.65
60-90	4754	4.6	1.60	1.53	0.28	8.51	4.22	13.17	5.93
90-120	5040	4.9	1.59	1.52	0.29	8.26	4.02	12.75	5.73
120-150	7607	7.4	1.57	1.51	0.28	8.97	3.81	13.69	5.44
150-180	6860	6.6	1.67	1.61	0.28	7.68	3.35	12.57	5.26
180-210	9199	8.9	1.69	1.64	0.26	8.22	3.93	13.71	6.50
210-240	12784	12.4	1.66	1.60	0.27	9.58	4.38	15.59	6.90
240-270	10849	10.5	1.75	1.71	0.26	8.85	4.05	15.29	6.86
270-300	12273	11.9	1.75	1.70	0.26	8.71	4.13	15.04	7.05
300-330	11886	11.5	1.71	1.66	0.28	8.40	3.83	14.21	6.49
330-360	5862	5.7	1.73	1.68	0.27	8.62	3.66	14.71	6.13

Table 15: The GF_m, mean wind, and peak gust stratified by wind direction for mean winds between 7 and 8 knots at KMKE between 2000-2014. This range was chosen at these wind speeds are near average, as shown in Figure 3.

$GF_m = \frac{Peak\ Gust}{Mean\ Wind}$ For 7 kts ≤ Mean Winds ≤ 8 kts					Mean Wind		Peak Gust	
Wind Direction (degrees)	**N**	**Mean** (kts)	**Median** (kts)	**σ** (kts)	**Mean** (kts)	**σ** (kts)	**Mean** (kts)	**σ** (kts)
All	10104	1.66	1.63	0.22	7.50	0.29	12.46	1.75
0-30	650	1.70	1.66	0.19	7.51	0.28	12.77	1.54
30-60	845	1.62	1.58	0.19	7.50	0.29	12.20	1.49
60-90	475	1.57	1.53	0.20	7.48	0.29	11.75	1.55
90-120	595	1.54	1.51	0.20	7.51	0.29	11.63	1.57
120-150	717	1.57	1.52	0.23	7.50	0.28	11.79	1.71
150-180	811	1.63	1.58	0.22	7.49	0.28	12.21	1.75
180-210	965	1.65	1.62	0.21	7.48	0.29	12.39	1.66
210-240	1163	1.64	1.59	0.20	7.49	0.29	12.30	1.63
240-270	1035	1.72	1.68	0.22	7.50	0.29	12.94	1.77
270-300	1068	1.74	1.70	0.24	7.49	0.29	13.05	1.89
300-330	1123	1.70	1.66	0.22	7.51	0.28	12.81	1.76
330-360	643	1.70	1.66	0.22	7.51	0.28	12.79	1.70

Table 16: The GF_m, mean wind, and peak gust stratified by wind direction for mean winds between 14 and 15 knots at KMKE between 2000-2014. This range was chosen to highlight the difference between the GF_h stratification in Table 17, which exhibits similar mean winds.

$GF_m = \frac{Peak\ Gust}{Mean\ Wind}$ For 14 kts ≤ Mean Winds ≤ 15 kts						Mean Wind		Peak Gust	
Wind Direction (degrees)	**N**	**%**	**Mean** (kts)	**Median** (kts)	**σ** (kts)	**Mean** (kts)	**σ** (kts)	**Mean** (kts)	**σ** (kts)
All	3538	100	1.60	1.58	0.16	14.47	0.29	23.17	2.38
0-30	437	12.4	1.60	1.59	0.12	14.46	0.27	23.20	1.82
30-60	239	6.8	1.53	1.52	0.11	14.50	0.29	22.28	1.75
60-90	149	4.2	1.44	1.41	0.09	14.47	0.27	20.89	1.41
90-120	138	3.9	1.46	1.45	0.12	14.46	0.28	21.22	1.88
120-150	290	8.2	1.44	1.42	0.14	14.46	0.29	20.96	2.16
150-180	150	4.2	1.55	1.52	0.17	14.48	0.27	22.49	2.55
180-210	247	7.0	1.63	1.60	0.19	14.48	0.29	23.67	2.89
210-240	526	14.9	1.58	1.56	0.14	14.48	0.28	22.97	2.16
240-270	376	10.6	1.68	1.66	0.13	14.44	0.27	24.29	1.96
270-300	426	12.0	1.70	1.69	0.13	14.48	0.27	24.65	1.98
300-330	375	10.5	1.66	1.65	0.15	14.46	0.27	24.11	2.29
330-360	180	5.1	1.66	1.66	0.10	14.47	0.28	24.12	1.58

Table 17: The GF_h, reported wind speed, and reported wind gusts stratified by wind direction at KMKE between 2000-2014. Overall, there are n=14850 hours in which both the $ASOS_h$ wind direction and reported wind and gust values exist.

$GF_h = \frac{Reported\ Gust}{Reported\ Wind}$						Reported Wind		Reported Gust	
Wind Direction (degrees)	**N**	**%**	**Mean** (kts)	**Median** (kts)	**σ** (kts)	**Mean** (kts)	**σ** (kts)	**Mean** (kts)	**σ** (kts)
All	14850	100.0	1.55	1.50	0.248	14.57	3.62	22.03	4.48
0-30	2171	14.6	1.53	1.50	0.22	14.63	3.44	22.08	4.25
30-60	1188	8.0	1.54	1.50	0.26	14.40	3.39	21.84	4.33
60-90	710	4.8	1.55	1.50	0.25	14.50	3.62	22.07	4.64
90-120	714	4.8	1.56	1.50	0.29	14.63	3.59	22.26	4.34
120-150	1112	7.5	1.55	1.50	0.27	14.62	3.82	22.15	4.80
150-180	1031	6.9	1.54	1.50	0.25	14.75	3.63	22.23	4.45
180-210	1110	7.5	1.54	1.50	0.24	14.71	3.98	22.19	4.94
210-240	1360	9.2	1.53	1.50	0.22	14.51	3.59	21.94	4.48
240-270	1820	12.3	1.54	1.50	0.23	14.51	3.59	21.94	4.48
270-300	1339	9.0	1.54	1.50	0.24	14.64	3.64	22.05	4.47
300-330	1534	10.3	1.54	1.50	0.24	14.39	3.55	21.76	4.36
330-360	761	5.1	1.56	1.50	0.28	14.47	3.63	21.97	4.38

Table 18: Wind gust forecasts made with various GF_m and GF_h models, persistence, and climatology are verified against the peak and reported gusts for every available hour in the 2000-2014 period. The verification metrics include the mean and standard deviation (σ) of the bias (forecast – observation) and the absolute error (|bias|). The results are sorted by the mean absolute error. The no-skill models of persistence and climatology were included for comparison to the GF models, where the persistence is calculated as the observed gust from the previous hour, while the climatology defined as the mean gust observed during a particular hour for each season. No skill models are highlighted in grey, while these climatology values are presented in Table 21 and Table 24.

Evaluation Period: 2000-2014							
Model	**Stratified By**	**N**	**Obs Verified Against**	**Bias**		**Absolute Error**	
				Mean (kts)	**σ** (kts)	**Mean** (kts)	**σ** (kts)
GF_m	Wind Speed, Direction	103138	Peak Gust	0.03	1.74	1.22	1.24
GF_m	Wind Speed	103138	Peak Gust	0.00	1.86	1.32	1.32
GF_m	Wind Speed, Time of Day / Season	103138	Peak Gust	0.12	1.88	1.34	1.32
GF_m	Wind Direction	103138	Peak Gust	0.31	1.85	1.35	1.29
GF_m	Pasquill Stability	103138	Peak Gust	0.15	1.92	1.38	1.34
GF_m	Time of Day / Season	103138	Peak Gust	0.26	1.93	1.41	1.35
GF_m (1.69)	N/A	103138	Peak Gust	0.34	1.97	1.44	1.38
GF_h	Wind Speed	15273	Reported Gust	0.00	2.38	1.81	1.53
GF_h	Wind Speed, Direction	15273	Reported Gust	0.07	2.47	1.93	1.55
GF_h	Wind Speed, Time of Day / Season	15273	Reported Gust	0.20	2.56	2.01	1.59
$Persistence_m$	N/A	98935	Peak Gust	0.01	2.92	2.01	2.11
GF_h	Time of Day / Season	15273	Reported Gust	0.49	3.03	2.45	1.85
GF_h	Wind Direction	15273	Reported Gust	0.50	3.05	2.46	1.86
$GF_h = 1.55$	N/A	15273	Reported Gust	0.54	3.05	2.47	1.87
$Persistence_h$	N/A	9080	Reported Gust	0.06	3.47	2.60	2.29
GF_h	Wind Speed, Time of Day / Season	13859	Peak Gust	-1.75	3.29	2.77	2.50
GF_h	Wind Speed, Direction	13859	Peak Gust	-1.92	3.25	2.78	2.55
GF_h	Wind Direction	13859	Peak Gust	-1.51	3.58	2.93	2.56
GF_h	Time of Day and Season	13859	Peak Gust	-1.50	3.63	2.98	2.56
$GF_h = 1.55$	N/A	13859	Peak Gust	-1.45	3.66	2.98	2.57
GF_h	Wind Speed	13859	Peak Gust	-1.48	3.66	2.99	2.57
$Climo_h$	N/A	15273	Reported Gust	0.00	4.40	3.40	2.79
$Climo_m$	N/A	103137	Peak Gust	-0.01	6.13	4.84	3.76

Table 19: Wind gust forecasts made with various GF_m and GF_h models, persistence, and climatology are verified against the peak and reported gusts for every available hour in the 2000-2014 period where the peak and reported gusts are 25 knots or greater. The verification metrics include the mean and standard deviation (σ) of the bias (forecast – observation) and the absolute error (|bias|). The results are sorted by the mean absolute error. The no-skill models of persistence and climatology were included for comparison to the GF models, where the persistence is calculated as the observed gust from the previous hour, while the climatology defined as the mean gust observed during a particular hour for each season. No skill models are highlighted in grey, while these climatology values are presented in Table 22 and Table 25.

Evaluation Period: 2000-2014, Wind Gusts ≥ 25 kts							
Model	**Stratified By**	**N**	**Obs Verified Against**	**Bias**		**Absolute Error**	
				Mean (kts)	**σ** (kts)	**Mean** (kts)	**σ** (kts)
GF_m	Wind Speed, Direction	8073	Peak Gust	0.07	2.57	1.81	1.82
GF_h	Wind Speed, Direction	3447	Reported Gust	0.08	2.68	2.11	1.64
GF_m	Wind Direction	8073	Peak Gust	0.08	3.29	2.24	2.41
GF_m	Time of Day / Season	8073	Peak Gust	-0.36	3.41	2.37	2.48
GF_m	Wind Speed, Time of Day / Season	8073	Peak Gust	-0.91	3.35	2.38	2.52
$GF_m = 1.69$	N/A	8073	Peak Gust	-0.02	3.45	2.40	2.48
GF_m	Pasquill Stability	8073	Peak Gust	-0.97	3.38	2.41	2.55
GF_m	Wind Speed	8073	Peak Gust	-1.45	3.30	2.50	2.61
Climo_h	N/A	3447	Reported Gust	0.00	3.38	2.57	2.19
GF_h	Wind Speed, Time of Day / Season	3447	Reported Gust	-0.54	3.33	2.64	2.10
GF_h	Wind Speed	3447	Reported Gust	-1.17	3.33	2.74	2.23
Climo_m	N/A	8073	Peak Gust	0.01	3.79	2.88	2.47
GF_h	Wind Speed, Direction	3447	Peak Gust	-1.95	3.47	2.93	2.70
GF_h	Time of Day / Season	3447	Reported Gust	0.68	3.69	3.02	2.23
GF_h	Wind Direction	3447	Reported Gust	0.76	3.71	3.06	2.24
Persistence_m	N/A	7967	Peak Gust	-1.47	4.36	3.07	3.42
$GF_h = 1.55$	N/A	3447	Reported Gust	0.80	3.73	3.07	2.26
Persistence_h	N/A	3026	Reported Gust	-1.39	3.95	3.23	2.66
GF_h	Wind Direction	3447	Peak Gust	-1.26	4.24	3.36	2.87
GF_h	Time of Day / Season	3447	Peak Gust	-1.35	4.20	3.36	2.87
$GF_h = 1.55$	N/A	3447	Peak Gust	-1.23	4.25	3.36	2.87
GF_h	Wind Speed, Time of Day / Season	3447	Peak Gust	-2.53	3.92	3.53	3.05
GF_h	Wind Speed	3447	Peak Gust	-3.22	3.94	3.91	3.24

Table 20: Wind gust forecasts made with various GF_m and GF_h models, persistence, and climatology are verified against the peak and reported gusts for every available hour in the 2000-2014 period where the peak and reported gusts are 30 knots or greater. The verification metrics include the mean and standard deviation (σ) of the bias (forecast – observation) and the absolute error (|bias|). The results are sorted by the mean absolute error. The no-skill models of persistence and climatology were included for comparison to the GF models, where the persistence is calculated as the observed gust from the previous hour, while the climatology defined as the mean gust observed during a particular hour for each season. No skill models are highlighted in grey, while these climatology values are presented in Table 23 and Table 26.

Evaluation Period:
2000-2014, Wind Gusts ≥ 30 kts

Model	**Stratified By**	**N**	**Obs Verified Against**	**Bias**		**Absolute Error**	
				Mean (kts)	**σ** (kts)	**Mean** (kts)	**σ** (kts)
GF_m	Wind Speed, Direction	2542	Peak Gust	0.09	2.87	2.09	1.97
GF_h	Wind Speed, Direction	923	Reported Gust	0.08	2.69	2.17	1.59
GF_m	Wind Direction	2542	Peak Gust	-0.49	4.19	2.68	3.26
$GF_m = 1.69$	N/A	2542	Peak Gust	-0.72	4.27	2.83	3.27
GF_m	Time of Day, Season	2542	Peak Gust	-1.12	4.21	2.85	3.29
GF_m	Wind Speed, Time of Day / Season	2542	Peak Gust	-1.71	4.15	2.95	3.38
GF_m	Pasquill Stability	2542	Peak Gust	-1.79	4.18	2.99	3.42
GF_h	Wind Speed, Direction	923	Peak Gust	-2.00	3.70	3.13	2.81
GF_m	Wind Speed	2542	Peak Gust	-2.30	4.10	3.16	3.49
GF_h	Wind Speed, Time of Day / Season	923	Reported Gust	-1.52	3.81	3.17	2.61
GF_h	Time of Day / Season	923	Reported Gust	0.11	4.20	3.33	2.56
GF_h	Wind Direction	923	Reported Gust	0.24	4.22	3.37	2.55
$GF_h = 1.55$	N/A	923	Reported Gust	0.26	4.24	3.37	2.58
GF_h	Wind Speed	923	Reported Gust	-3.03	3.46	3.61	2.84
$GF_h = 1.55$	N/A	923	Peak Gust	-1.83	4.86	3.95	3.38
GF_h	Wind Direction	923	Reported Gust	-1.84	4.87	3.95	3.39
GF_h	Time of Day / Season	923	Peak Gust	-1.98	4.80	3.95	3.37
Persistence_m	N/A	1931	Peak Gust	-2.52	5.74	3.99	4.84
Persistence_h	N/A	628	Reported Gust	-2.53	4.66	4.16	3.28
GF_h	Wind Speed, Time of Day / Season	923	Peak Gust	-3.56	4.48	4.39	3.68
GF_h	Wind Speed	3447	Peak Gust	-3.71	3.69	4.09	3.26

Table 21: The mean and standard deviation (σ) of the peak gusts are shown for every hour during each season for the evaluation period of 2000-2014.

Climatology of Peak Gust
Evaluation Period: 2000-2014

Hr	**Spring**			**Summer**			**Fall**			**Winter**		
	N	**Mean** (kts)	**σ** (kts)	**N**	**Mean** (kts)	**σ** (kts)	**N**	**Mean** (kts)	**σ** (kts)	**N**	**Mean** (kts)	**σ** (kts)
0	992	13.81	7.0	952	10.41	4.92	1037	12.87	6.57	1081	14.46	6.51
1	990	13.8	7.2	947	10.38	5.17	1056	12.58	6.43	1078	14.34	6.36
2	995	13.63	7.04	954	10.27	4.93	1038	12.59	6.42	1082	14.12	6.5
3	978	13.5	6.91	947	10.11	4.72	1040	12.42	6.4	1057	14.03	6.48
4	998	13.46	6.74	958	10.26	4.55	1050	12.5	6.21	1083	13.93	6.45
5	1005	13.88	6.63	975	10.88	4.81	1045	12.54	6.06	1070	13.95	6.39
6	1031	14.95	6.59	1037	12.08	4.75	1067	13.13	6.11	1077	14.27	6.19
7	1067	15.89	6.28	1066	12.86	4.65	1093	14.05	6.03	1092	14.62	6.11
8	1081	16.63	6.3	1086	13.77	4.88	1143	15.03	6.17	1098	15.27	6.15
9	1082	17.25	6.23	1104	14.52	4.88	1154	16.11	6.22	1097	16.04	6.2
10	1088	17.75	6.35	1112	15.24	4.8	1164	16.65	6.19	1101	16.45	6.16
11	1091	18.14	6.43	1128	15.69	4.68	1171	17.09	6.2	1117	16.82	6.25
12	1099	18.37	6.49	1128	16.11	4.81	1186	17.33	6.1	1107	17.23	6.16
13	1096	18.51	6.51	1139	16.33	4.89	1189	17.43	6.11	1112	17.2	6.21
14	1108	18.37	6.77	1142	16.21	5.11	1185	17.15	6.13	1115	17.05	6.19
15	1109	17.93	6.78	1141	15.86	5.36	1189	16.48	6.18	1125	16.47	6.21
16	1108	17.28	7.02	1143	15.13	5.35	1178	15.07	6.09	1130	15.64	6.21
17	1103	16.27	6.86	1133	13.85	5.12	1142	13.6	6.39	1117	14.88	6.36
18	1076	14.83	6.87	1129	12.4	4.93	1119	12.78	6.6	1096	14.75	6.56
19	1045	13.89	7.02	1076	10.82	4.79	1090	12.82	6.64	1088	14.8	6.67
20	1013	13.69	7.05	1027	10.23	4.9	1063	13.06	6.73	1099	14.76	6.65
21	995	13.82	7.03	988	10.23	4.78	1063	13.2	6.9	1081	14.99	6.61
22	1000	13.81	7.1	950	10.36	4.96	1039	13.08	6.66	1079	14.95	6.7
23	982	13.83	7.0	935	10.36	4.83	1051	12.85	6.49	1074	14.63	6.54

Table 22: The mean and standard deviation (σ) of the peak gusts are shown for every hour during each season for when the peak gusts are 25 knots or greater during the evaluation period of 2000-2014.

Climatology of Peak Gust
Evaluation Period: 2000-2014, Wind Gust ≥ 25 kts

Hr	**Spring**			**Summer**			**Fall**			**Winter**		
	N	**Mean** (kts)	**σ** (kts)	**N**	**Mean** (kts)	**σ** (kts)	**N**	**Mean** (kts)	**σ** (kts)	**N**	**Mean** (kts)	**σ** (kts)
0	87	28.71	3.61	7	28.0	3.78	64	28.53	3.52	74	28.89	3.49
1	81	29.81	4.48	16	30.0	4.74	60	28.55	3.25	81	28.23	3.05
2	85	28.68	3.32	17	28.18	4.89	52	29.12	4.62	76	29.03	3.78
3	78	29.0	3.27	7	31.43	5.78	61	28.15	3.08	77	28.61	3.83
4	78	28.6	3.28	8	27.38	1.65	51	28.69	3.2	75	28.76	3.65
5	80	28.56	3.56	12	29.92	5.04	57	27.56	2.59	77	28.69	3.78
6	91	28.45	3.64	14	27.93	3.59	52	29.08	3.87	81	28.01	3.32
7	102	28.56	3.71	20	26.95	2.09	59	28.97	3.98	72	28.61	3.6
8	126	28.48	3.3	32	27.97	4.0	74	29.26	4.57	89	27.91	3.21
9	139	28.59	3.69	37	27.65	3.29	107	29.18	4.51	101	28.16	3.59
10	146	29.13	3.97	50	27.42	3.42	130	28.63	4.4	120	27.99	3.27
11	185	28.78	3.89	49	27.37	2.62	139	29.02	4.46	129	28.44	3.57
12	199	28.58	3.83	63	27.7	3.1	147	28.89	4.22	135	28.51	3.71
13	195	29.03	3.78	76	27.61	3.43	158	28.63	4.1	135	28.67	3.54
14	204	29.35	3.81	82	27.46	3.43	145	28.98	4.03	137	28.55	3.46
15	187	29.5	3.6	81	27.83	5.16	119	29.3	4.42	119	28.41	3.77
16	181	29.37	3.51	69	27.57	4.1	89	29.2	4.01	99	28.42	3.45
17	147	28.88	3.58	32	28.91	4.5	71	29.24	4.58	87	28.29	3.72
18	109	29.06	3.99	25	28.16	3.11	68	29.21	4.47	94	28.29	3.81
19	100	28.82	3.48	16	28.56	3.39	71	28.73	3.82	105	27.86	3.27
20	91	29.13	4.07	15	28.67	4.5	71	29.37	3.69	93	28.33	3.49
21	87	28.77	3.89	10	26.8	1.54	75	29.39	4.55	89	28.62	3.85
22	88	28.72	3.61	11	30.18	8.44	71	28.44	3.46	93	28.71	4.14
23	83	28.95	3.53	9	29.56	5.06	54	28.87	3.81	83	28.31	3.99

Table 23: The mean and standard deviation (σ) of the peak gusts are shown for every hour during each season for when the peak gusts are 30 knots or greater during the evaluation period of 2000-2014.

Climatology of Peak Gust
Evaluation Period: 2000-2014, Wind Gust ≥ 30 kts

Hr	**Spring**			**Summer**			**Fall**			**Winter**		
	N	**Mean** (kts)	σ (kts)	**N**	**Mean** (kts)	σ (kts)	**N**	**Mean** (kts)	σ (kts)	**N**	**Mean** (kts)	σ (kts)
0	29	33.1	2.64	2	33.0	3.0	18	33.17	3.02	25	32.88	2.79
1	31	34.35	3.91	6	35.17	3.58	16	33.19	2.35	22	32.32	2.32
2	31	32.42	2.32	2	39.5	6.5	18	33.72	4.94	27	32.89	3.68
3	30	32.43	2.25	4	35.75	3.77	16	32.38	2.62	26	32.62	3.89
4	27	32.37	2.31	1	31.0	0.0	12	33.42	2.69	25	32.88	3.25
5	29	32.45	2.87	6	33.67	4.46	11	32.0	1.91	24	33.25	3.37
6	26	33.27	3.03	2	35.0	4.0	22	32.82	2.93	21	32.52	3.05
7	31	33.19	3.34	3	31.0	0.0	19	33.74	3.35	21	33.24	3.18
8	36	32.61	2.97	8	33.5	4.47	28	33.96	4.08	20	33.1	2.61
9	44	33.07	3.09	7	33.71	2.37	33	34.55	4.49	21	34.14	3.03
10	56	33.18	3.42	8	34.13	3.59	37	34.0	4.8	29	32.79	2.86
11	63	33.25	3.27	6	33.0	2.71	43	33.77	5.23	41	32.83	2.89
12	63	33.24	3.32	11	33.09	3.32	50	33.38	4.29	46	32.67	3.36
13	71	33.11	3.12	14	33.43	4.05	51	33.2	4.26	42	32.95	3.09
14	85	32.98	3.04	11	34.82	3.74	53	33.26	3.43	44	32.66	2.95
15	79	32.91	2.78	14	36.57	7.44	42	34.1	3.98	38	33.11	2.93
16	76	32.74	2.69	11	35.45	4.87	34	33.56	2.91	31	32.71	2.65
17	50	33.1	2.59	9	34.89	4.23	27	33.89	4.24	23	33.26	3.74
18	38	33.42	3.6	6	33.0	2.24	23	34.17	4.27	22	33.91	3.74
19	38	32.66	2.37	3	35.0	0.82	20	33.45	3.87	25	32.56	3.2
20	37	33.08	3.48	4	34.5	4.97	31	32.94	2.54	28	32.75	2.95
21	29	33.31	3.3	1	30.0	0.0	26	34.58	3.83	30	33.0	3.44
22	25	33.32	3.39	3	39.67	11.56	21	32.95	2.68	30	33.57	3.83
23	26	33.35	2.62	3	35.33	4.5	17	33.59	3.11	22	33.82	3.65

Table 24: The mean and standard deviation (σ) of the reported gusts are shown for every hour during each season for when the reported gusts during the evaluation period of 2000-2014.

Climatology of Reported Gust
Evaluation Period: 2000-2014

Hr	**Spring**			**Summer**			**Fall**			**Winter**		
	N	**Mean** (kts)	**σ** (kts)	**N**	**Mean** (kts)	**σ** (kts)	**N**	**Mean** (kts)	**σ** (kts)	**N**	**Mean** (kts)	**σ** (kts)
0	130	22.59	4.59	35	19.49	2.32	101	22.3	3.99	147	21.91	4.27
1	120	23.13	4.98	34	20.47	4.74	101	22.04	4.15	127	22.28	4.01
2	113	23.19	4.16	28	20.36	4.55	100	22.03	4.38	121	22.31	4.02
3	112	22.81	4.32	24	19.58	3.43	115	21.79	4.41	118	22.16	4.49
4	123	22.38	4.47	24	19.42	2.43	94	22.11	3.97	127	22.09	3.83
5	115	22.23	4.73	37	20.19	3.39	92	21.92	4.12	121	22.3	4.52
6	155	22.08	4.52	59	19.75	3.59	112	21.84	4.45	118	22.17	4.6
7	198	22.01	4.73	81	19.46	2.71	123	21.88	4.77	147	21.57	4.43
8	216	22.0	4.62	100	20.17	3.58	179	21.88	4.68	152	22.21	4.5
9	231	22.49	4.75	136	19.82	3.62	205	22.3	5.05	194	22.05	4.29
10	268	22.41	4.66	158	19.74	3.37	245	22.16	4.98	208	22.18	4.5
11	272	22.85	4.94	162	20.14	3.67	267	22.12	4.52	208	22.51	4.61
12	292	22.7	4.52	177	20.1	3.55	282	21.96	4.78	204	22.74	4.48
13	294	22.78	4.71	170	20.65	3.64	261	22.2	4.8	206	22.5	4.61
14	263	23.59	5.09	171	20.8	3.69	227	22.76	4.88	208	22.27	4.28
15	261	23.38	4.88	152	21.11	3.59	207	22.51	5.04	199	21.7	4.35
16	228	23.51	4.39	128	20.72	3.79	162	21.84	4.37	154	21.92	4.11
17	181	22.88	4.49	89	20.33	3.28	128	21.87	4.67	152	21.28	4.01
18	136	23.29	5.0	61	19.72	3.14	118	21.79	4.53	150	22.11	4.37
19	128	23.52	4.95	36	19.86	3.44	114	22.11	4.09	145	22.33	4.51
20	127	23.03	4.61	47	19.81	3.13	117	22.56	4.44	155	21.74	3.88
21	132	22.8	4.63	37	19.76	2.46	129	21.77	4.37	151	22.09	4.19
22	124	22.93	4.14	44	19.73	3.58	100	22.26	4.27	156	21.88	4.31
23	120	23.18	4.01	26	20.73	4.09	108	21.75	4.19	148	21.95	4.19

Table 25: The mean and standard deviation (σ) of the reported gusts are shown for every hour during each season for when the gusts are 25 knots or greater during the evaluation period of 2000-2014.

Climatology of Reported Gust
Evaluation Period: 2000-2014, Wind Gust ≥ 25 kts

Hr	**Spring**			**Summer**			**Fall**			**Winter**		
	N	**Mean** (kts)	**σ** (kts)	**N**	**Mean** (kts)	**σ** (kts)	**N**	**Mean** (kts)	**σ** (kts)	**N**	**Mean** (kts)	**σ** (kts)
0	37	28.57	3.13	2	26.0	1.0	29	27.38	2.44	29	28.83	3.18
1	41	28.73	3.82	3	33.33	5.56	27	27.48	2.95	34	27.71	2.46
2	39	27.87	2.42	4	29.75	4.82	22	28.27	3.99	31	27.94	2.17
3	36	28.06	2.84	2	28.5	3.5	30	27.53	2.81	30	28.3	3.52
4	32	28.56	3.26	1	25.0	0.0	21	28.19	2.68	31	27.55	2.39
5	33	28.42	3.14	4	27.25	1.79	26	27.27	2.12	32	28.53	2.89
6	37	28.57	3.92	7	27.0	2.2	25	28.08	3.76	30	28.27	3.87
7	51	28.49	3.67	6	26.0	1.0	25	29.44	4.15	35	27.63	3.83
8	51	28.71	3.46	10	27.7	2.87	46	28.24	3.82	36	28.61	3.53
9	61	28.79	4.09	11	27.91	3.63	48	29.52	4.77	43	28.09	4.03
10	70	28.57	3.71	15	26.73	2.08	58	29.05	4.54	51	28.61	3.6
11	82	28.96	3.54	15	27.67	3.44	65	28.29	3.29	57	28.44	3.5
12	90	28.08	3.01	20	27.1	2.59	79	28.01	3.71	63	28.06	3.26
13	96	28.19	3.24	19	27.63	2.66	73	28.25	3.91	55	28.38	3.93
14	97	29.27	3.17	27	26.85	2.82	71	28.8	3.33	53	28.3	2.94
15	103	28.36	3.3	24	27.08	2.66	56	29.07	4.39	47	28.04	3.05
16	85	28.19	2.84	15	28.2	3.53	36	28.25	4.07	36	27.92	2.89
17	59	28.15	3.01	9	27.11	2.28	28	29.0	3.72	27	28.0	3.41
18	51	28.51	3.42	6	26.83	1.67	30	27.9	3.17	34	28.12	4.19
19	47	28.64	3.59	3	28.0	2.94	28	27.93	2.6	35	28.51	4.17
20	46	28.04	3.01	3	27.0	2.16	34	28.38	2.63	31	27.84	2.94
21	42	28.21	3.47	3	25.67	0.94	24	29.29	3.48	33	28.39	3.11
22	44	27.34	2.4	5	28.0	1.67	25	28.2	3.22	37	28.03	3.48
23	46	27.41	2.45	3	28.33	4.71	25	27.88	3.2	33	28.06	3.36

Table 26: The mean and standard deviation (σ) of the reported gusts are shown for every hour during each season for when the gusts are 30 knots or greater during the evaluation period of 2000-2014.

Climatology of Reported Gust
Evaluation Period: 2000-2014, Wind Gust ≥ 30 kts

Hr	**Spring**			**Summer**			**Fall**			**Winter**		
	N	**Mean** (kts)	**σ** (kts)	**N**	**Mean** (kts)	**σ** (kts)	**N**	**Mean** (kts)	**σ** (kts)	**N**	**Mean** (kts)	**σ** (kts)
0	12	32.58	1.71	0	N/A	N/A	5	31.6	1.96	9	32.56	2.95
1	11	34.36	2.57	2	36.0	5.0	4	33.25	2.86	7	31.71	1.75
2	13	30.85	0.95	1	38.0	0.0	6	33.17	4.49	9	30.78	1.23
3	8	32.13	2.89	1	32.0	0.0	4	33.25	2.86	6	33.83	3.98
4	9	32.56	3.02	0	N/A	N/A	6	31.83	1.21	7	31.43	1.05
5	10	32.4	2.42	0	N/A	N/A	5	30.8	0.75	10	32.0	1.95
6	11	33.27	3.84	1	31.0	0.0	6	33.0	4.55	8	33.13	4.31
7	14	33.57	2.82	0	N/A	N/A	11	33.18	3.46	7	33.71	4.56
8	15	33.07	2.98	3	31.67	0.94	10	34.0	3.9	12	33.0	2.2
9	19	34.05	3.12	3	32.67	3.77	19	34.32	4.09	9	35.22	2.82
10	23	32.78	3.49	1	33.0	0.0	20	34.05	4.25	14	33.57	2.72
11	29	32.93	2.74	3	33.33	3.4	18	32.72	2.8	16	33.31	2.52
12	25	32.04	2.37	3	32.33	1.25	16	33.5	4.8	13	33.38	2.84
13	25	32.64	2.78	4	32.0	1.41	19	33.0	4.77	10	35.6	3.56
14	36	32.78	2.08	4	32.5	2.6	26	32.46	2.41	18	31.61	2.29
15	26	32.88	3.03	5	31.4	1.96	19	33.95	4.03	13	32.31	1.9
16	24	31.88	2.19	4	33.0	2.92	12	33.17	3.41	10	31.8	1.99
17	15	32.6	2.09	1	33.0	0.0	9	33.67	2.67	6	33.33	3.09
18	15	33.07	2.69	1	30.0	0.0	8	32.5	2.12	9	34.0	3.92
19	15	33.13	2.7	1	32.0	0.0	7	31.57	1.59	9	34.11	4.33
20	12	32.08	2.87	1	30.0	0.0	10	31.9	1.04	8	32.13	1.83
21	10	33.4	3.29	0	N/A	N/A	9	33.22	2.15	8	32.88	2.93
22	4	33.25	2.17	1	31.0	0.0	7	32.57	2.06	7	34.14	3.14
23	9	31.56	1.42	1	35.0	0.0	6	32.83	2.48	8	33.38	2.06

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Table A1: The mean and standard deviations of the GF_m stratified by the time of day in local military time (CST) and season at KMKE from 2000-2014.

$GF_m = \frac{Peak\ Gust}{Mean\ Wind}$												
Hr	**Spring**			**Summer**			**Fall**			**Winter**		
	N	**Mean**	**σ**	**N**	**Mean**	**σ**	**N**	**Mean**	**σ**	**N**	**Mean**	**σ**
0	992	1.72	0.3	952	1.75	0.31	1037	1.7	0.26	1081	1.68	0.27
1	990	1.71	0.27	947	1.75	0.3	1056	1.7	0.27	1078	1.67	0.21
2	995	1.7	0.27	954	1.74	0.31	1038	1.69	0.25	1082	1.67	0.21
3	978	1.69	0.25	947	1.73	0.3	1040	1.71	0.27	1057	1.66	0.21
4	998	1.71	0.3	958	1.76	0.36	1050	1.7	0.28	1083	1.67	0.22
5	1005	1.73	0.38	975	1.78	0.38	1045	1.7	0.25	1070	1.66	0.22
6	1031	1.72	0.3	1037	1.8	0.44	1067	1.76	0.41	1077	1.7	0.32
7	1067	1.7	0.32	1066	1.73	0.28	1093	1.73	0.32	1092	1.72	0.38
8	1081	1.66	0.22	1086	1.73	0.35	1143	1.68	0.22	1098	1.68	0.29
9	1082	1.66	0.25	1104	1.72	0.29	1154	1.69	0.23	1097	1.66	0.24
10	1088	1.66	0.25	1112	1.71	0.3	1164	1.68	0.23	1101	1.64	0.21
11	1091	1.64	0.24	1128	1.68	0.27	1171	1.68	0.26	1117	1.64	0.2
12	1099	1.62	0.22	1128	1.65	0.28	1186	1.67	0.26	1107	1.63	0.19
13	1096	1.6	0.21	1139	1.64	0.28	1189	1.65	0.28	1112	1.64	0.19
14	1108	1.6	0.2	1142	1.62	0.26	1185	1.64	0.24	1115	1.63	0.19
15	1109	1.59	0.2	1141	1.62	0.28	1189	1.65	0.29	1125	1.63	0.19
16	1108	1.62	0.22	1143	1.62	0.28	1178	1.68	0.26	1130	1.66	0.22
17	1103	1.66	0.27	1133	1.64	0.27	1142	1.69	0.24	1117	1.68	0.23
18	1076	1.7	0.28	1129	1.69	0.29	1119	1.71	0.27	1096	1.68	0.21
19	1045	1.72	0.32	1076	1.72	0.34	1090	1.72	0.3	1088	1.68	0.23
20	1013	1.74	0.32	1027	1.74	0.35	1063	1.72	0.31	1099	1.69	0.24
21	995	1.75	0.34	988	1.76	0.31	1063	1.72	0.26	1081	1.69	0.24
22	1000	1.74	0.33	950	1.73	0.31	1039	1.7	0.26	1079	1.68	0.22
23	982	1.73	0.28	935	1.74	0.31	1051	1.7	0.25	1074	1.67	0.24

Table A2: The mean and standard deviations of the GF_h stratified by the time of day in local military time (CST) and season at KMKE from 2000-2014.

$$GF_h = \frac{Reported\ Gust}{Reported\ Wind}$$

Hr	**Spring**			**Summer**			**Fall**			**Winter**		
	N	**Mean**	**σ**	**N**	**Mean**	**σ**	**N**	**Mean**	**σ**	**N**	**Mean**	**σ**
0	130	1.55	0.3	35	1.59	0.23	101	1.56	0.22	147	1.56	0.21
1	120	1.55	0.26	34	1.58	0.25	101	1.54	0.24	127	1.56	0.24
2	113	1.52	0.2	28	1.63	0.35	100	1.55	0.21	121	1.57	0.24
3	112	1.52	0.24	24	1.68	0.45	115	1.58	0.23	118	1.52	0.18
4	123	1.55	0.38	24	1.53	0.18	94	1.58	0.22	127	1.54	0.23
5	115	1.5	0.18	37	1.61	0.23	92	1.56	0.22	121	1.53	0.2
6	155	1.52	0.22	59	1.58	0.19	112	1.6	0.25	118	1.58	0.24
7	198	1.5	0.23	81	1.55	0.22	123	1.57	0.22	147	1.56	0.23
8	216	1.53	0.24	100	1.55	0.23	179	1.55	0.21	152	1.52	0.2
9	231	1.48	0.21	136	1.56	0.27	205	1.53	0.21	194	1.51	0.21
10	268	1.52	0.25	158	1.57	0.33	245	1.56	0.24	208	1.51	0.2
11	272	1.52	0.23	162	1.55	0.25	267	1.55	0.25	208	1.57	0.21
12	292	1.52	0.31	177	1.57	0.29	282	1.57	0.25	204	1.53	0.21
13	294	1.55	0.27	170	1.55	0.34	261	1.55	0.24	206	1.52	0.22
14	263	1.53	0.39	171	1.58	0.31	227	1.56	0.24	208	1.54	0.21
15	261	1.51	0.23	152	1.54	0.21	207	1.58	0.26	199	1.52	0.19
16	228	1.51	0.21	128	1.57	0.39	162	1.6	0.26	154	1.56	0.21
17	181	1.56	0.27	89	1.65	0.54	128	1.59	0.25	152	1.55	0.22
18	136	1.54	0.22	61	1.59	0.25	118	1.6	0.25	150	1.51	0.2
19	128	1.58	0.25	36	1.54	0.25	114	1.56	0.23	145	1.54	0.23
20	127	1.57	0.24	47	1.6	0.22	117	1.56	0.22	155	1.54	0.22
21	132	1.55	0.23	37	1.6	0.26	129	1.57	0.2	151	1.54	0.22
22	124	1.55	0.28	44	1.62	0.25	100	1.59	0.23	156	1.56	0.23
23	120	1.55	0.22	26	1.65	0.3	108	1.54	0.18	148	1.55	0.23

Table A3: The mean, median, and standard deviations of the GF_m stratified by the mean wind speed and wind direction at KMKE from 2000-2014.

$$GF_m = \frac{Peak\ Gust}{Mean\ Wind}$$

Mean Wind Speed (kts)	**Wind Direction** (degrees)	**N**	**Mean**	**Median**	**σ**
0 ≤ wind < 5	0-30	1028	2.0	1.92	0.43
	30-60	1142	1.93	1.87	0.41
	60-90	1014	1.81	1.74	0.42
	90-120	922	1.84	1.76	0.43
	120-150	1229	1.81	1.74	0.36
	150-180	1573	1.84	1.77	0.38
	180-210	2020	1.86	1.79	0.4
	210-240	1942	1.89	1.81	0.42
	240-270	1942	1.94	1.86	0.41
	270-300	2430	1.88	1.81	0.38
	300-330	2797	1.78	1.68	0.47
	330-360	989	1.89	1.81	0.42
5 ≤ wind < 10	0-30	2854	1.75	1.71	0.24
	30-60	3983	1.65	1.61	0.23
	60-90	2521	1.6	1.55	0.24
	90-120	2381	1.58	1.54	0.22
	120-150	3578	1.55	1.52	0.21
	150-180	3620	1.62	1.58	0.23
	180-210	4182	1.68	1.64	0.22
	210-240	5645	1.63	1.59	0.22
	240-270	5006	1.73	1.7	0.23
	270-300	5016	1.75	1.72	0.23
	300-330	5877	1.7	1.66	0.26
	330-360	3181	1.7	1.66	0.24
10 ≤ wind < 15	0-30	2677	1.65	1.64	0.15
	30-60	2596	1.56	1.54	0.14
	60-90	1024	1.49	1.47	0.13
	90-120	863	1.49	1.47	0.15
	120-150	2500	1.45	1.43	0.13
	150-180	1479	1.55	1.53	0.15
	180-210	1539	1.65	1.62	0.17

	210-240	3725	1.59	1.56	0.16
	240-270	3089	1.69	1.67	0.18
	270-300	3275	1.72	1.7	0.17
	300-330	3679	1.67	1.65	0.17
	330-360	1698	1.68	1.67	0.16
15 ≤ wind < 20	0-30	926	1.62	1.61	0.12
	30-60	528	1.56	1.54	0.11
	60-90	400	1.46	1.44	0.1
	90-120	325	1.45	1.44	0.1
	120-150	408	1.47	1.46	0.12
	150-180	221	1.55	1.53	0.13
	180-210	423	1.64	1.62	0.15
	210-240	1310	1.57	1.55	0.14
	240-270	767	1.68	1.67	0.14
	270-300	754	1.72	1.71	0.14
	300-330	779	1.66	1.65	0.13
	330-360	289	1.67	1.66	0.11
20 ≤ wind < 25	0-30	149	1.61	1.61	0.11
	30-60	28	1.54	1.55	0.07
	60-90	46	1.47	1.44	0.11
	90-120	51	1.46	1.47	0.11
	120-150	48	1.48	1.48	0.09
	150-180	21	1.58	1.55	0.15
	180-210	41	1.63	1.62	0.14
	210-240	203	1.59	1.57	0.12
	240-270	148	1.69	1.67	0.13
	270-300	101	1.69	1.69	0.1
	300-330	70	1.66	1.66	0.12
	330-360	33	1.7	1.69	0.07
25 ≤ wind < 30	0-30	0	N/A	N/A	N/A
	30-60	7	1.52	1.52	0.07
	60-90	0	N/A	N/A	N/A
	90-120	1	1.48	1.48	0.0
	120-150	1	1.49	1.49	0.0
	150-180	0	N/A	N/A	N/A
	180-210	1	1.51	1.51	0.0
	210-240	18	1.63	1.62	0.13

	240-270	21	1.65	1.6	0.13
	270-300	1	1.79	1.79	0.0
	300-330	1	1.58	1.58	0.0
	330-360	0	N/A	N/A	N/A
wind ≥ 30	0-30	0	N/A	N/A	N/A
	30-60	0	N/A	N/A	N/A
	60-90	0	N/A	N/A	N/A
	90-120	0	N/A	N/A	N/A
	120-150	0	N/A	N/A	N/A
	150-180	0	N/A	N/A	N/A
	180-210	0	N/A	N/A	N/A
	210-240	1	1.58	1.58	0.0
	240-270	1	1.63	1.63	0.0
	270-300	0	N/A	N/A	N/A
	300-330	0	N/A	N/A	N/A
	330-360	0	N/A	N/A	N/A

Table A4: The mean, median, and standard deviations of the GF_h stratified by the reported wind speed and wind direction at KMKE from 2000-2014.

$$GF_h = \frac{Reported\ Gust}{Reported\ Wind}$$

Reported Wind Speed (kts)	**Wind Direction** (degrees)	**N**	**Mean**	**Median**	**σ**
0 ≤ wind < 5	0-30	0	N/A	N/A	N/A
	30-60	0	N/A	N/A	N/A
	60-90	1	6.67	6.67	0.0
	90-120	0	N/A	N/A	N/A
	120-150	0	N/A	N/A	N/A
	150-180	0	N/A	N/A	N/A
	180-210	0	N/A	N/A	N/A
	210-240	0	N/A	N/A	N/A
	240-270	1	4.67	4.67	0.0
	270-300	0	N/A	N/A	N/A
	300-330	0	N/A	N/A	N/A
	330-360	2	5.63	5.63	0.38
5 ≤ wind < 10	0-30	115	2.03	2.0	0.3
	30-60	48	1.96	1.89	0.27
	60-90	11	2.02	1.89	0.35
	90-120	9	2.17	2.0	0.41
	120-150	17	2.0	2.0	0.33
	150-180	26	2.01	2.0	0.27
	180-210	32	1.99	2.0	0.27
	210-240	117	2.06	2.0	0.33
	240-270	100	2.02	2.0	0.27
	270-300	104	2.03	2.0	0.28
	300-330	112	2.05	2.0	0.35
	330-360	48	2.1	2.0	0.36
10 ≤ wind < 15	0-30	919	1.61	1.58	0.2
	30-60	525	1.61	1.58	0.22
	60-90	124	1.58	1.57	0.18
	90-120	110	1.62	1.58	0.21
	120-150	158	1.59	1.54	0.2
	150-180	191	1.63	1.58	0.2
	180-210	371	1.59	1.57	0.19

	210-240	811	1.6	1.58	0.21
	240-270	932	1.6	1.58	0.19
	270-300	1039	1.61	1.58	0.2
	300-330	999	1.58	1.57	0.19
	330-360	455	1.6	1.57	0.19
15 ≤ wind < 20	0-30	708	1.45	1.44	0.16
	30-60	446	1.45	1.42	0.16
	60-90	134	1.44	1.41	0.14
	90-120	79	1.46	1.47	0.15
	120-150	96	1.44	1.42	0.16
	150-180	104	1.47	1.44	0.18
	180-210	251	1.45	1.42	0.16
	210-240	682	1.44	1.41	0.15
	240-270	758	1.43	1.4	0.15
	270-300	774	1.43	1.41	0.14
	300-330	725	1.44	1.41	0.15
	330-360	395	1.45	1.41	0.15
20 ≤ wind < 25	0-30	179	1.4	1.38	0.15
	30-60	103	1.39	1.38	0.13
	60-90	31	1.4	1.42	0.12
	90-120	13	1.41	1.4	0.13
	120-150	33	1.35	1.32	0.12
	150-180	22	1.42	1.39	0.16
	180-210	72	1.44	1.41	0.18
	210-240	150	1.4	1.35	0.14
	240-270	161	1.39	1.38	0.13
	270-300	162	1.39	1.36	0.13
	300-330	152	1.39	1.36	0.14
	330-360	97	1.37	1.36	0.12
25 ≤ wind < 30	0-30	26	1.4	1.39	0.12
	30-60	9	1.46	1.5	0.13
	60-90	3	1.29	1.28	0.05
	90-120	1	1.28	1.28	0.0
	120-150	2	1.44	1.44	0.04
	150-180	2	1.25	1.25	0.09
	180-210	9	1.35	1.35	0.06
	210-240	8	1.39	1.35	0.08

	240-270	14	1.34	1.32	0.1
	270-300	21	1.39	1.37	0.1
	300-330	1	1.38	1.37	0.12
	330-360	0	1.36	1.28	0.13
wind ≥ 30	0-30	0	1.41	1.43	0.13
	30-60	0	N/A	N/A	N/A
	60-90	0	N/A	N/A	N/A
	90-120	0	N/A	N/A	N/A
	120-150	0	N/A	N/A	N/A
	150-180	0	N/A	N/A	N/A
	180-210	0	1.26	1.26	0.0
	210-240	1	1.3	1.33	0.06
	240-270	1	N/A	N/A	N/A
	270-300	0	1.17	1.17	0.0
	300-330	0	1.28	1.29	0.07
	330-360	0	1.4	1.4	0.0

Table A5: The mean and standard deviations of the GF_m stratified by the time of day in local military time (CST), season, and mean wind speed at KMKE from 2000-2014.

$$GF_m = \frac{Peak\ Gust}{Mean\ Wind}$$

Mean Wind Speed (kts)	**Hr**	**Spring**			**Summer**			**Fall**			**Winter**		
		N	**Mean**	**σ**	**N**	**Mean**	**σ**	**N**	**Mean**	**σ**	**N**	**Mean**	**σ**
0 ≤ wind < 5	0	263	1.88	0.39	416	1.84	0.36	307	1.81	0.37	201	1.83	0.49
	1	260	1.84	0.33	409	1.83	0.33	312	1.84	0.36	197	1.79	0.29
	2	260	1.84	0.36	413	1.84	0.36	310	1.81	0.31	212	1.78	0.28
	3	267	1.83	0.32	410	1.82	0.33	322	1.84	0.34	212	1.77	0.29
	4	278	1.88	0.42	398	1.87	0.43	315	1.85	0.38	216	1.8	0.31
	5	246	1.96	0.6	377	1.92	0.47	286	1.85	0.32	210	1.81	0.32
	6	188	1.94	0.45	282	2.04	0.65	274	2.01	0.68	198	1.95	0.56
	7	135	2.01	0.65	212	1.97	0.39	210	1.95	0.44	185	2.01	0.7
	8	100	1.97	0.34	169	2.12	0.55	160	1.9	0.33	151	1.92	0.55
	9	68	2.09	0.54	131	2.12	0.38	112	2.03	0.38	123	1.92	0.44
	10	64	2.08	0.41	81	2.15	0.42	93	2.05	0.36	96	1.94	0.39
	11	64	2.08	0.41	81	2.15	0.42	93	2.05	0.36	96	1.94	0.39
	12	36	2.1	0.61	51	2.12	0.49	61	2.16	0.56	82	1.99	0.34
	13	38	1.96	0.35	32	2.3	0.55	57	2.11	0.54	62	1.88	0.28
	14	23	1.92	0.32	28	2.19	0.54	48	1.97	0.41	71	1.99	0.32
	15	26	1.84	0.35	32	2.07	0.43	46	1.94	0.49	62	1.9	0.36
	16	35	1.85	0.34	50	2.07	0.65	65	1.93	0.82	78	1.82	0.38
	17	73	1.8	0.32	67	1.89	0.45	115	1.84	0.32	123	1.8	0.34
	18	114	1.85	0.52	121	1.74	0.32	225	1.75	0.3	165	1.78	0.39
	19	186	1.81	0.39	221	1.78	0.38	331	1.78	0.32	187	1.79	0.32
	20	255	1.85	0.49	389	1.78	0.43	324	1.81	0.42	207	1.81	0.33
	21	299	1.88	0.43	436	1.83	0.45	313	1.82	0.42	206	1.85	0.35
	22	288	1.91	0.44	445	1.84	0.35	305	1.81	0.31	191	1.88	0.38
	23	269	1.85	0.4	398	1.82	0.35	304	1.8	0.37	196	1.82	0.34
5 ≤ wind < 10	0	254	1.91	0.37	389	1.84	0.36	313	1.79	0.33	207	1.82	0.37
	1	415	1.69	0.27	425	1.68	0.25	466	1.65	0.2	488	1.66	0.18
	2	431	1.67	0.24	438	1.68	0.25	494	1.65	0.19	518	1.67	0.19
	3	430	1.67	0.24	445	1.67	0.24	475	1.65	0.22	524	1.65	0.2
	4	416	1.66	0.23	453	1.66	0.24	479	1.65	0.23	503	1.64	0.18
	5	432	1.67	0.23	469	1.7	0.28	487	1.64	0.19	534	1.66	0.19

	6	444	1.69	0.26	494	1.7	0.29	511	1.64	0.2	534	1.64	0.18
	7	461	1.71	0.26	613	1.73	0.29	524	1.69	0.22	544	1.67	0.23
	8	469	1.7	0.24	627	1.68	0.22	537	1.7	0.29	534	1.69	0.27
	9	432	1.68	0.2	613	1.69	0.27	551	1.67	0.18	512	1.67	0.23
	10	448	1.69	0.22	608	1.71	0.24	532	1.68	0.18	472	1.65	0.2
	11	416	1.7	0.26	622	1.73	0.28	519	1.69	0.22	460	1.64	0.18
	12	416	1.7	0.26	622	1.73	0.28	519	1.69	0.22	460	1.64	0.18
	13	407	1.69	0.24	616	1.71	0.27	525	1.7	0.22	452	1.63	0.18
	14	391	1.67	0.25	570	1.69	0.28	507	1.7	0.25	447	1.64	0.22
	15	396	1.64	0.25	564	1.69	0.3	492	1.69	0.34	442	1.64	0.17
	16	410	1.62	0.23	559	1.64	0.25	509	1.66	0.23	456	1.63	0.19
	17	422	1.61	0.23	569	1.61	0.23	561	1.63	0.24	503	1.61	0.17
	18	450	1.6	0.24	615	1.61	0.27	657	1.67	0.27	544	1.65	0.23
	19	499	1.64	0.24	696	1.62	0.28	636	1.67	0.23	542	1.68	0.2
	20	531	1.69	0.27	711	1.65	0.27	528	1.68	0.24	516	1.67	0.19
	21	475	1.69	0.24	580	1.69	0.26	497	1.67	0.22	477	1.67	0.2
	22	429	1.7	0.27	493	1.67	0.23	482	1.68	0.27	487	1.66	0.2
	23	409	1.71	0.3	440	1.69	0.26	473	1.69	0.25	473	1.67	0.19
10 ≤ wind < 15	0	435	1.73	0.33	451	1.67	0.25	449	1.66	0.19	463	1.66	0.19
	1	434	1.68	0.23	436	1.67	0.24	467	1.68	0.21	472	1.66	0.19
	2	232	1.66	0.22	110	1.67	0.22	209	1.65	0.15	312	1.63	0.15
	3	212	1.65	0.18	90	1.67	0.3	192	1.64	0.17	278	1.61	0.14
	4	220	1.64	0.17	89	1.66	0.24	195	1.64	0.15	262	1.62	0.16
	5	214	1.62	0.16	81	1.67	0.31	184	1.66	0.16	265	1.62	0.15
	6	217	1.62	0.15	87	1.62	0.17	199	1.63	0.18	252	1.61	0.15
	7	234	1.63	0.16	94	1.66	0.2	199	1.64	0.15	249	1.63	0.15
	8	290	1.64	0.18	130	1.65	0.17	213	1.65	0.18	246	1.62	0.16
	9	345	1.6	0.15	214	1.63	0.16	290	1.62	0.16	279	1.62	0.13
	10	415	1.59	0.15	279	1.6	0.16	351	1.62	0.14	328	1.62	0.14
	11	410	1.6	0.16	327	1.6	0.18	410	1.61	0.15	384	1.61	0.13
	12	427	1.59	0.16	366	1.61	0.21	412	1.61	0.15	412	1.6	0.13
	13	427	1.59	0.16	366	1.61	0.21	412	1.61	0.15	412	1.6	0.13
	14	433	1.58	0.17	397	1.59	0.17	423	1.6	0.16	434	1.6	0.13
	15	451	1.58	0.18	457	1.57	0.18	467	1.6	0.17	449	1.59	0.13
	16	449	1.57	0.19	469	1.56	0.2	501	1.6	0.18	446	1.59	0.13
	17	450	1.57	0.17	467	1.57	0.23	496	1.59	0.2	458	1.6	0.15
	18	446	1.56	0.17	447	1.57	0.21	459	1.62	0.2	436	1.63	0.14
	19	415	1.6	0.19	406	1.6	0.23	330	1.64	0.18	370	1.63	0.14
	20	355	1.64	0.19	289	1.64	0.22	223	1.7	0.22	325	1.64	0.16

	21	276	1.69	0.24	189	1.7	0.2	208	1.69	0.23	298	1.63	0.16
	22	236	1.68	0.22	99	1.69	0.28	215	1.69	0.2	306	1.64	0.16
	23	208	1.65	0.17	93	1.71	0.26	209	1.67	0.19	308	1.65	0.17
15 ≤ wind < 20	0	211	1.66	0.2	98	1.69	0.21	224	1.66	0.19	324	1.64	0.16
	1	206	1.65	0.2	94	1.65	0.23	231	1.66	0.19	326	1.63	0.15
	2	208	1.64	0.17	102	1.64	0.22	218	1.63	0.15	305	1.63	0.16
	3	65	1.59	0.14	2	1.63	0.21	52	1.65	0.17	72	1.6	0.16
	4	73	1.61	0.16	10	1.85	0.29	54	1.63	0.19	74	1.6	0.12
	5	74	1.62	0.16	6	1.63	0.09	53	1.62	0.16	71	1.62	0.14
	6	68	1.63	0.15	3	1.64	0.12	50	1.62	0.12	64	1.59	0.13
	7	62	1.64	0.16	4	1.58	0.14	47	1.61	0.15	72	1.59	0.14
	8	70	1.6	0.15	10	1.78	0.25	47	1.61	0.12	67	1.58	0.15
	9	78	1.61	0.13	11	1.63	0.14	51	1.64	0.18	77	1.58	0.15
	10	102	1.58	0.13	13	1.6	0.08	50	1.64	0.15	85	1.57	0.15
	11	116	1.6	0.12	23	1.62	0.15	68	1.61	0.15	100	1.57	0.14
	12	134	1.56	0.11	38	1.58	0.15	83	1.62	0.15	105	1.56	0.15
	13	158	1.57	0.12	42	1.58	0.12	126	1.59	0.12	118	1.57	0.13
	14	158	1.57	0.12	42	1.58	0.12	126	1.59	0.12	118	1.57	0.13
	15	182	1.57	0.14	60	1.58	0.13	143	1.61	0.13	129	1.58	0.14
	16	186	1.56	0.12	64	1.59	0.13	143	1.61	0.14	128	1.59	0.13
	17	192	1.57	0.14	74	1.59	0.15	136	1.62	0.14	138	1.6	0.15
	18	187	1.6	0.15	81	1.57	0.15	119	1.65	0.15	123	1.6	0.13
	19	165	1.6	0.14	72	1.64	0.3	92	1.65	0.15	94	1.6	0.16
	20	138	1.65	0.16	51	1.6	0.16	68	1.7	0.16	82	1.62	0.17
	21	115	1.61	0.14	27	1.62	0.16	49	1.67	0.15	75	1.59	0.14
	22	74	1.64	0.15	8	1.7	0.13	44	1.67	0.12	87	1.6	0.16
	23	65	1.65	0.17	7	1.61	0.07	45	1.61	0.14	86	1.59	0.14
20 ≤ wind < 25	0	66	1.65	0.18	5	1.65	0.08	51	1.67	0.17	89	1.6	0.17
	1	74	1.58	0.14	5	1.62	0.12	52	1.68	0.21	82	1.6	0.13
	2	83	1.6	0.14	7	1.81	0.42	48	1.62	0.12	83	1.61	0.15
	3	73	1.63	0.14	8	1.7	0.3	47	1.63	0.14	80	1.57	0.15
	4	17	1.6	0.1	0	N/A	N/A	3	1.63	0.19	8	1.67	0.16
	5	13	1.65	0.19	0	N/A	N/A	4	1.67	0.05	11	1.55	0.13
	6	11	1.57	0.13	0	N/A	N/A	3	1.77	0.09	13	1.6	0.21
	7	13	1.53	0.14	0	N/A	N/A	5	1.61	0.09	13	1.6	0.16
	8	9	1.53	0.09	0	N/A	N/A	2	1.64	0.0	9	1.7	0.14
	9	11	1.61	0.11	0	N/A	N/A	2	1.58	0.04	10	1.61	0.19
	10	13	1.59	0.12	1	1.94	0.0	4	1.62	0.09	12	1.56	0.14
	11	15	1.6	0.12	0	N/A	N/A	5	1.68	0.11	9	1.63	0.16

	12	17	1.55	0.1	2	1.54	0.07	11	1.67	0.12	7	1.51	0.14
	13	21	1.61	0.13	0	N/A	N/A	13	1.7	0.11	11	1.62	0.15
	14	21	1.59	0.1	1	1.6	0.0	12	1.71	0.14	14	1.54	0.09
	15	21	1.59	0.1	1	1.6	0.0	12	1.71	0.14	14	1.54	0.09
	16	32	1.58	0.12	4	1.59	0.07	16	1.61	0.14	20	1.58	0.14
	17	31	1.58	0.12	5	1.64	0.17	11	1.7	0.14	21	1.59	0.14
	18	35	1.6	0.11	4	1.53	0.04	11	1.73	0.2	13	1.58	0.11
	19	33	1.58	0.13	2	1.59	0.06	14	1.66	0.1	16	1.62	0.13
	20	40	1.58	0.12	3	1.68	0.11	11	1.73	0.17	14	1.63	0.1
	21	32	1.58	0.11	4	1.57	0.06	8	1.63	0.06	11	1.59	0.08
	22	20	1.63	N/A	0	N/A	N/A	9	1.75	0.16	9	1.66	0.18
	23	8	1.64	0.0	0	N/A	N/A	8	1.76	0.13	6	1.62	0.11
25 ≤ wind < 30	0	14	1.58	N/A	1	1.69	0.0	8	1.7	0.14	11	1.52	0.16
	1	11	1.57	N/A	0	N/A	N/A	8	1.62	0.07	8	1.56	0.13
	2	13	1.6	N/A	0	N/A	N/A	9	1.72	0.2	10	1.57	0.11
	3	6	1.68	N/A	0	N/A	N/A	7	1.65	0.11	9	1.58	0.07
	4	13	1.64	0.0	0	N/A	N/A	6	1.75	0.07	8	1.61	0.12
	5	0	N/A	0.0	0	N/A	N/A	0	N/A	N/A	0	N/A	N/A
	6	1	1.44	0.0	0	N/A	N/A	0	N/A	N/A	0	N/A	N/A
	7	0	N/A	0.0	1	1.57	0.0	2	1.75	0.13	0	N/A	N/A
	8	0	N/A	0.09	0	N/A	N/A	0	N/A	N/A	0	N/A	N/A
	9	0	N/A	0.09	0	N/A	N/A	0	N/A	N/A	0	N/A	N/A
	10	0	N/A	0.0	0	N/A	N/A	0	N/A	N/A	0	N/A	N/A
	11	1	1.56	0.03	0	N/A	N/A	1	1.7	0.0	0	N/A	N/A
	12	1	1.66	0.0	0	N/A	N/A	1	1.48	0.0	0	N/A	N/A
	13	1	1.55	0.02	0	N/A	N/A	2	1.7	0.04	0	N/A	N/A
	14	1	1.54	0.0	0	N/A	N/A	4	1.66	0.1	2	1.51	0.08
	15	2	1.67	N/A	0	N/A	N/A	1	1.65	0.0	1	1.63	0.0
	16	2	1.67	N/A	0	N/A	N/A	1	1.65	0.0	1	1.63	0.0
	17	1	1.51	0.0	0	N/A	N/A	3	1.85	0.15	0	N/A	N/A
	18	2	1.55	N/A	0	N/A	N/A	0	N/A	N/A	0	N/A	N/A
	19	1	1.66	N/A	0	N/A	N/A	1	1.94	0.0	2	1.57	0.01
	20	2	1.54	N/A	1	1.51	0.0	1	1.78	0.0	0	N/A	N/A
	21	1	1.55	0.0	0	N/A	N/A	1	1.74	0.0	0	N/A	N/A
	22	0	N/A	N/A	0	N/A	N/A	0	N/A	N/A	0	N/A	N/A
	23	0	N/A	N/A	0	N/A	N/A	0	N/A	N/A	1	1.54	0.0
wind ≥ 30	0	1	1.62	N/A	0	N/A	N/A	0	N/A	N/A	2	1.48	0.02
	1	0	N/A	N/A	0	N/A	N/A	1	1.58	0.0	1	1.46	0.0
	2	0	N/A	N/A	0	N/A	N/A	0	N/A	N/A	1	1.46	0.0

	3	0	N/A	N/A	0	N/A	N/A	0	N/A	N/A	1	1.52	0.0
	4	1	1.67	N/A	0	N/A	N/A	0	N/A	N/A	2	1.72	0.07
	5	0	N/A	N/A	0	N/A	N/A	0	N/A	N/A	2	1.53	0.05
	6	0	N/A	N/A	0	N/A	N/A	0	N/A	N/A	0	N/A	N/A
	7	0	N/A	N/A	0	N/A	N/A	0	N/A	N/A	0	N/A	N/A
	8	0	N/A	N/A	0	N/A	N/A	0	N/A	N/A	0	N/A	N/A
	9	0	N/A	N/A	0	N/A	N/A	0	N/A	N/A	0	N/A	N/A
	10	0	N/A	N/A	0	N/A	N/A	0	N/A	N/A	0	N/A	N/A
	11	0	N/A	N/A	0	N/A	N/A	0	N/A	N/A	0	N/A	N/A
	12	0	N/A	N/A	0	N/A	N/A	0	N/A	N/A	0	N/A	N/A
	13	0	N/A	N/A	0	N/A	N/A	0	N/A	N/A	0	N/A	N/A
	14	0	N/A	N/A	0	N/A	N/A	0	N/A	N/A	0	N/A	N/A
	15	0	N/A	N/A	0	N/A	N/A	0	N/A	N/A	0	N/A	N/A
	16	0	N/A	N/A	0	N/A	N/A	1	1.58	0.0	0	N/A	N/A
	17	0	N/A	N/A	0	N/A	N/A	1	1.58	0.0	0	N/A	N/A
	18	0	N/A	N/A	0	N/A	N/A	0	N/A	N/A	0	N/A	N/A
	19	0	N/A	N/A	0	N/A	N/A	1	1.63	0.0	0	N/A	N/A
	20	0	N/A	N/A	0	N/A	N/A	0	N/A	N/A	0	N/A	N/A
	21	0	N/A	N/A	0	N/A	N/A	0	N/A	N/A	0	N/A	N/A
	22	0	N/A	N/A	0	N/A	N/A	0	N/A	N/A	0	N/A	N/A
	23	0	N/A	N/A	0	N/A	N/A	0	N/A	N/A	0	N/A	N/A

Table A6: The mean and standard deviations of the GF_h stratified by the time of day in local military time (CST), season, and reported wind speed at KMKE from 2000-2014.

$$GF_h = \frac{Reported\ Gust}{Reported\ Wind}$$

Reported Wind Speed (kts)	**Hr**	**Spring**			**Summer**			**Fall**			**Winter**		
		N	**Mean**	σ	**N**	**Mean**	σ	**N**	**Mean**	σ	**N**	**Mean**	σ
0 ≤ wind < 5	0	0	N/A	N/A	0	N/A	N/A	0	N/A	N/A	0	N/A	N/A
	1	0	N/A	N/A	0	N/A	N/A	0	N/A	N/A	0	N/A	N/A
	2	0	N/A	N/A	0	N/A	N/A	0	N/A	N/A	0	N/A	N/A
	3	0	N/A	N/A	0	N/A	N/A	0	N/A	N/A	0	N/A	N/A
	4	1	5.25	0.0	0	N/A	N/A	0	N/A	N/A	0	N/A	N/A
	5	0	N/A	N/A	0	N/A	N/A	0	N/A	N/A	0	N/A	N/A
	6	0	N/A	N/A	0	N/A	N/A	0	N/A	N/A	0	N/A	N/A
	7	0	N/A	N/A	0	N/A	N/A	0	N/A	N/A	0	N/A	N/A
	8	0	N/A	N/A	0	N/A	N/A	0	N/A	N/A	0	N/A	N/A
	9	0	N/A	N/A	0	N/A	N/A	0	N/A	N/A	0	N/A	N/A
	10	0	N/A	N/A	0	N/A	N/A	0	N/A	N/A	0	N/A	N/A
	11	0	N/A	N/A	0	N/A	N/A	0	N/A	N/A	0	N/A	N/A
	12	0	N/A	N/A	0	N/A	N/A	0	N/A	N/A	0	N/A	N/A
	13	1	4.67	0.0	0	N/A	N/A	0	N/A	N/A	0	N/A	N/A
	14	0	N/A	N/A	0	N/A	N/A	0	N/A	N/A	0	N/A	N/A
	15	1	6.67	0.0	0	N/A	N/A	0	N/A	N/A	0	N/A	N/A
	16	0	N/A	N/A	0	N/A	N/A	0	N/A	N/A	0	N/A	N/A
	17	0	N/A	N/A	0	N/A	N/A	0	N/A	N/A	0	N/A	N/A
	18	0	N/A	N/A	1	6.0	0.0	0	N/A	N/A	0	N/A	N/A
	19	0	N/A	N/A	0	N/A	N/A	0	N/A	N/A	0	N/A	N/A
	20	0	N/A	N/A	0	N/A	N/A	0	N/A	N/A	0	N/A	N/A
	21	0	N/A	N/A	0	N/A	N/A	0	N/A	N/A	0	N/A	N/A
	22	0	N/A	N/A	0	N/A	N/A	0	N/A	N/A	0	N/A	N/A
	23	0	N/A	N/A	0	N/A	N/A	0	N/A	N/A	0	N/A	N/A
5 ≤ wind < 10	0	0	N/A	N/A	0	N/A	N/A	0	N/A	N/A	0	N/A	N/A
	1	5	2.02	0.24	4	2.01	0.14	3	1.96	0.05	8	1.96	0.12
	2	7	2.33	0.3	2	2.16	0.27	3	2.23	0.32	9	2.1	0.32
	3	5	1.87	0.16	3	2.37	0.55	5	1.96	0.14	6	2.1	0.24
	4	2	2.33	0.0	2	1.9	0.24	8	1.96	0.22	5	1.82	0.05
	5	3	2.08	0.06	1	2.0	0.0	2	1.94	0.06	6	2.06	0.39

	6	4	1.83	0.18	2	1.89	0.11	6	2.03	0.22	5	2.02	0.22
	7	7	2.0	0.23	8	1.81	0.12	8	2.14	0.3	7	2.01	0.18
	8	9	2.18	0.31	7	1.97	0.12	7	1.92	0.14	14	2.04	0.26
	9	15	2.01	0.2	8	1.95	0.35	12	1.9	0.17	7	1.87	0.12
	10	7	2.1	0.29	14	1.99	0.31	8	1.93	0.15	6	1.97	0.26
	11	11	2.0	0.45	20	2.08	0.41	18	2.04	0.27	7	2.0	0.22
	12	11	2.0	0.45	20	2.08	0.41	18	2.04	0.27	7	2.0	0.22
	13	13	2.03	0.26	10	2.14	0.32	15	1.96	0.43	5	2.13	0.25
	14	12	2.14	0.46	21	2.14	0.35	28	2.01	0.26	3	2.13	0.18
	15	17	2.24	0.41	14	2.21	0.45	21	2.0	0.28	13	1.9	0.11
	16	8	2.1	0.31	13	2.07	0.34	12	2.1	0.28	5	1.98	0.14
	17	9	2.15	0.38	8	1.86	0.12	7	1.95	0.16	5	1.93	0.11
	18	4	2.19	0.4	9	2.04	0.34	6	2.16	0.26	7	1.86	0.2
	19	9	2.22	0.68	10	2.01	0.13	10	2.07	0.22	10	1.92	0.12
	20	5	1.8	0.11	6	2.05	0.18	11	1.91	0.26	3	2.11	0.4
	21	9	2.13	0.2	3	2.1	0.4	9	2.03	0.16	6	2.13	0.32
	22	5	2.17	0.24	3	1.85	0.14	4	1.89	0.11	4	1.96	0.2
	23	6	1.99	0.39	2	2.11	0.0	3	1.93	0.21	7	2.08	0.25
10 ≤ wind < 15	0	7	2.08	0.58	5	1.94	0.24	4	1.98	0.13	10	1.9	0.21
	1	4	2.19	0.29	4	2.1	0.26	2	2.09	0.2	7	1.99	0.17
	2	58	1.6	0.16	24	1.59	0.15	50	1.66	0.21	80	1.61	0.17
	3	48	1.56	0.2	24	1.58	0.17	51	1.6	0.21	55	1.61	0.17
	4	42	1.63	0.17	20	1.57	0.18	49	1.62	0.19	57	1.64	0.2
	5	47	1.61	0.25	17	1.58	0.18	56	1.63	0.22	60	1.59	0.18
	6	65	1.56	0.17	16	1.56	0.15	47	1.66	0.2	57	1.59	0.17
	7	55	1.54	0.16	25	1.65	0.22	42	1.57	0.19	60	1.57	0.18
	8	72	1.59	0.18	35	1.58	0.18	53	1.64	0.21	61	1.64	0.22
	9	86	1.52	0.18	55	1.55	0.18	69	1.64	0.2	68	1.57	0.16
	10	95	1.6	0.19	60	1.56	0.18	90	1.6	0.18	63	1.6	0.18
	11	98	1.55	0.17	80	1.56	0.22	107	1.59	0.19	96	1.59	0.19
	12	106	1.59	0.2	85	1.54	0.17	110	1.61	0.2	97	1.57	0.17
	13	106	1.59	0.2	85	1.54	0.17	110	1.61	0.2	97	1.57	0.17
	14	112	1.61	0.2	101	1.58	0.17	128	1.62	0.21	106	1.62	0.19
	15	108	1.59	0.19	99	1.54	0.16	129	1.6	0.2	91	1.62	0.21
	16	120	1.6	0.2	87	1.56	0.21	108	1.59	0.21	81	1.6	0.23
	17	97	1.58	0.19	90	1.6	0.21	106	1.59	0.19	102	1.62	0.19
	18	88	1.6	0.21	84	1.59	0.19	106	1.63	0.29	104	1.56	0.19
	19	85	1.59	0.2	74	1.56	0.19	95	1.66	0.22	78	1.63	0.19
	20	82	1.61	0.17	51	1.63	0.26	63	1.63	0.21	85	1.62	0.19

	21	59	1.64	0.22	42	1.57	0.22	57	1.66	0.22	77	1.57	0.17
	22	49	1.64	0.23	21	1.52	0.14	52	1.62	0.18	66	1.62	0.18
	23	58	1.61	0.21	32	1.63	0.21	54	1.65	0.22	85	1.6	0.2
15 ≤ wind < 20	0	60	1.63	0.19	27	1.64	0.23	79	1.62	0.17	69	1.61	0.18
	1	41	1.65	0.23	31	1.62	0.21	54	1.68	0.22	75	1.64	0.19
	2	49	1.62	0.2	15	1.64	0.22	58	1.59	0.17	73	1.61	0.2
	3	53	1.45	0.18	7	1.35	0.11	39	1.45	0.15	47	1.46	0.17
	4	51	1.47	0.12	7	1.46	0.26	38	1.44	0.14	54	1.45	0.13
	5	55	1.43	0.14	3	1.49	0.19	39	1.42	0.15	49	1.47	0.16
	6	48	1.45	0.15	4	1.5	0.17	43	1.48	0.13	41	1.43	0.1
	7	38	1.48	0.14	7	1.38	0.11	40	1.48	0.19	56	1.46	0.16
	8	41	1.46	0.15	10	1.45	0.16	40	1.49	0.16	42	1.46	0.15
	9	61	1.41	0.14	15	1.46	0.14	43	1.48	0.12	34	1.44	0.14
	10	78	1.42	0.13	19	1.39	0.14	40	1.43	0.14	55	1.44	0.11
	11	78	1.42	0.17	28	1.42	0.12	59	1.45	0.15	64	1.42	0.15
	12	100	1.4	0.15	38	1.38	0.11	69	1.43	0.17	70	1.41	0.14
	13	119	1.43	0.14	49	1.39	0.15	93	1.43	0.14	80	1.41	0.13
	14	119	1.43	0.14	49	1.39	0.15	93	1.43	0.14	80	1.41	0.13
	15	102	1.42	0.16	44	1.39	0.15	97	1.44	0.15	82	1.47	0.17
	16	130	1.43	0.16	52	1.42	0.12	93	1.48	0.17	86	1.43	0.14
	17	117	1.46	0.16	64	1.37	0.1	110	1.46	0.15	89	1.43	0.14
	18	107	1.47	0.18	60	1.42	0.14	78	1.48	0.18	85	1.45	0.15
	19	118	1.44	0.15	55	1.43	0.16	77	1.49	0.18	75	1.44	0.15
	20	107	1.47	0.15	36	1.39	0.11	50	1.46	0.19	53	1.47	0.16
	21	65	1.47	0.14	27	1.4	0.13	45	1.46	0.17	45	1.39	0.12
	22	53	1.48	0.17	13	1.45	0.1	43	1.47	0.18	58	1.43	0.13
	23	51	1.48	0.16	10	1.45	0.15	47	1.44	0.13	62	1.42	0.16
20 ≤ wind < 25	0	48	1.52	0.16	12	1.45	0.15	44	1.45	0.17	53	1.45	0.15
	1	50	1.44	0.13	7	1.37	0.1	33	1.48	0.19	61	1.43	0.15
	2	59	1.48	0.16	8	1.42	0.18	34	1.45	0.12	56	1.44	0.17
	3	54	1.46	0.13	6	1.45	0.15	41	1.45	0.11	56	1.45	0.16
	4	13	1.44	0.14	0	N/A	N/A	9	1.37	0.1	12	1.4	0.2
	5	12	1.43	0.15	0	N/A	N/A	8	1.39	0.14	9	1.37	0.15
	6	11	1.4	0.09	1	1.4	0.0	6	1.46	0.07	8	1.37	0.11
	7	13	1.34	0.1	0	N/A	N/A	7	1.34	0.1	11	1.39	0.09
	8	13	1.39	0.1	0	N/A	N/A	5	1.41	0.17	7	1.37	0.12
	9	14	1.42	0.17	0	N/A	N/A	4	1.36	0.09	13	1.38	0.1
	10	12	1.4	0.15	1	1.55	0.0	7	1.35	0.12	16	1.42	0.21
	11	20	1.38	0.12	0	N/A	N/A	5	1.46	0.18	8	1.37	0.14

	12	25	1.36	0.11	4	1.45	0.11	16	1.42	0.12	17	1.44	0.18
	13	22	1.41	0.16	2	1.32	0.11	15	1.39	0.09	19	1.35	0.16
	14	28	1.39	0.16	3	1.35	0.11	17	1.46	0.16	24	1.44	0.14
	15	28	1.39	0.16	3	1.35	0.11	17	1.46	0.16	24	1.44	0.14
	16	39	1.37	0.1	6	1.25	0.08	24	1.37	0.13	15	1.49	0.14
	17	37	1.39	0.12	4	1.34	0.12	30	1.34	0.11	23	1.44	0.17
	18	35	1.38	0.16	3	1.51	0.08	18	1.37	0.1	18	1.36	0.15
	19	44	1.4	0.12	5	1.35	0.11	31	1.46	0.15	14	1.39	0.15
	20	42	1.38	0.13	5	1.26	0.08	16	1.47	0.22	14	1.46	0.14
	21	27	1.37	0.11	6	1.29	0.06	10	1.44	0.17	15	1.38	0.12
	22	24	1.4	0.12	0	N/A	N/A	9	1.47	0.2	10	1.34	0.11
	23	17	1.35	0.11	0	N/A	N/A	6	1.41	0.11	10	1.42	0.18
25 ≤ wind < 30	0	19	1.42	0.13	2	1.3	0.05	4	1.43	0.08	8	1.4	0.09
	1	14	1.36	0.09	0	N/A	N/A	14	1.46	0.12	12	1.32	0.1
	2	15	1.42	0.16	1	1.25	0.0	13	1.43	0.15	12	1.38	0.07
	3	16	1.33	0.11	0	N/A	N/A	8	1.42	0.15	15	1.38	0.14
	4	12	1.41	0.12	0	N/A	N/A	6	1.41	0.14	10	1.35	0.19
	5	0	N/A	N/A	0	N/A	N/A	0	N/A	N/A	0	N/A	N/A
	6	2	1.42	0.06	0	N/A	N/A	1	1.35	0.0	0	N/A	N/A
	7	0	N/A	N/A	1	1.36	0.0	1	1.59	0.0	1	1.36	0.0
	8	2	1.48	0.0	0	N/A	N/A	1	1.41	0.0	1	1.35	0.0
	9	2	1.27	0.08	0	N/A	N/A	0	N/A	N/A	1	1.12	0.0
	10	1	1.2	0.0	0	N/A	N/A	0	N/A	N/A	1	1.4	0.0
	11	2	1.29	0.09	0	N/A	N/A	1	1.65	0.0	0	N/A	N/A
	12	5	1.39	0.08	0	N/A	N/A	1	1.35	0.0	2	1.59	0.03
	13	3	1.43	0.18	0	N/A	N/A	2	1.4	0.05	1	1.48	0.0
	14	3	1.31	0.1	1	1.41	0.0	5	1.47	0.08	3	1.42	0.08
	15	2	1.44	0.12	0	N/A	N/A	5	1.41	0.12	0	N/A	N/A
	16	2	1.44	0.12	0	N/A	N/A	5	1.41	0.12	0	N/A	N/A
	17	5	1.43	0.09	1	1.52	0.0	3	1.32	0.06	0	N/A	N/A
	18	4	1.29	0.11	1	1.23	0.0	1	1.37	0.0	1	1.38	0.0
	19	5	1.31	0.08	1	1.36	0.0	3	1.38	0.14	5	1.45	0.11
	20	5	1.34	0.13	1	1.28	0.0	0	N/A	N/A	2	1.3	0.02
	21	3	1.29	0.05	0	N/A	N/A	0	N/A	N/A	1	1.19	0.0
	22	5	1.38	0.08	1	1.52	0.0	0	N/A	N/A	1	1.31	0.0
	23	1	1.52	0.0	0	N/A	N/A	1	1.33	0.0	2	1.43	0.05
wind ≥ 30	0	2	1.39	0.08	0	N/A	N/A	1	1.37	0.0	1	1.5	0.0
	1	0	N/A	N/A	0	N/A	N/A	1	1.28	0.0	3	1.48	0.0
	2	2	1.36	0.12	0	N/A	N/A	1	1.27	0.0	1	1.31	0.0

	3	1	1.4	0.0	0	N/A	N/A	1	1.42	0.0	2	1.35	0.03
	4	1	1.22	0.0	0	N/A	N/A	0	N/A	N/A	0	N/A	N/A
	5	1	1.32	0.0	1	1.3	0.0	1	1.37	0.0	2	1.35	0.01
	6	0	N/A	N/A	0	N/A	N/A	0	N/A	N/A	0	N/A	N/A
	7	0	N/A	N/A	1	1.28	0.0	0	N/A	N/A	0	N/A	N/A
	8	0	N/A	N/A	0	N/A	N/A	0	N/A	N/A	0	N/A	N/A
	9	0	N/A	N/A	0	N/A	N/A	0	N/A	N/A	1	1.35	0.0
	10	1	1.19	0.0	0	N/A	N/A	0	N/A	N/A	0	N/A	N/A
	11	0	N/A	N/A	0	N/A	N/A	0	N/A	N/A	0	N/A	N/A
	12	1	1.43	0.0	0	N/A	N/A	0	N/A	N/A	0	N/A	N/A
	13	0	N/A	N/A	0	N/A	N/A	1	1.33	0.0	0	N/A	N/A
	14	0	N/A	N/A	0	N/A	N/A	0	N/A	N/A	0	N/A	N/A
	15	1	1.33	0.0	0	N/A	N/A	1	1.33	0.0	0	N/A	N/A
	16	1	1.19	0.0	0	N/A	N/A	2	1.41	0.01	0	N/A	N/A
	17	1	1.19	0.0	0	N/A	N/A	2	1.41	0.01	0	N/A	N/A
	18	1	1.26	0.0	0	N/A	N/A	0	N/A	N/A	0	N/A	N/A
	19	0	N/A	N/A	0	N/A	N/A	1	1.67	0.0	0	N/A	N/A
	20	0	N/A	N/A	0	N/A	N/A	1	1.47	0.0	0	N/A	N/A
	21	1	1.17	0.0	0	N/A	N/A	0	N/A	N/A	0	N/A	N/A
	22	1	1.29	0.0	0	N/A	N/A	1	1.43	0.0	0	N/A	N/A
	23	0	N/A	N/A	0	N/A	N/A	1	1.33	0.0	0	N/A	N/A