Central Region Technical Attachment

Number 24-01

March 2024

A Comparison of Spotter-Estimated Winds to Observed Winds in the Midwest

W. Scott Lincoln, National Weather Service Chicago, Illinois

1.0 Introduction

Estimated wind gusts received from weather spotters during periods of active weather are widely considered uncertain, but this belief is supported by only limited quantitative data. Multiple studies have indicated likely issues with estimated wind gusts compared to observed winds (Edwards et al. 2018), but limited quantitative analysis exists. In recent years, the National Weather Service (NWS) Chicago office has attempted to emphasize reporting damage from strong thunderstorm winds instead of merely estimating a wind speed value as one way to reduce this uncertainty. While this effort has appeared to reduce the number of estimated wind reports, they have not been eliminated and are still widely collected and used across the region. A direct comparison between individual estimates of wind gusts and observed gusts at nearby weather stations could help inform the potential usefulness (or lack thereof) of estimates.

Agdas et al. (2012) tested the perception of 76 college-aged persons in a wind tunnel when faced with random wind speeds at 10 mph increments ranging from 10 to 60 mph, at a constant speed, over a 20-second duration. They found that the average estimate of wind speed was very close to the actual wind speed at both 10 mph and 20 mph, but became higher than observed with an increasing high bias as wind speeds reached and exceeded 30 mph (Figure 1). Due to the very large range of estimates provided by the test subjects, the observed wind speed was within the range of one standard deviation at all speeds, however. Agdas et al. (2012) also found that the overestimation of wind speeds remained, but was reduced, for test subjects that experienced multiple tropical storms prior to the test.

Edwards et al. (2018) provided a large summary of relevant literature on wind estimation, and analyzed the collection of estimated wind reports found in *Storm Data*, the National Oceanic and Atmospheric Administration's (NOAA's) official record of hazardous weather. Edwards et al. (2018) noted problems with multiple studies on human perception of wind, including the relative lack of study of wind speeds above the "severe" threshold of 58 mph, but found multiple studies suggesting a reduced over-estimation bias with greater experience. Edwards et al. (2018) also commented on the limitations of the Agdas et al. study, specifically mentioning that the results may not be directly comparable to convective wind gusts due to the steady speed used in testing, the lack of dust or heavy precipitation, the lack of reference indicators such as those used by the Beaufort Scale, and the lack of overlapping noise from thunder or precipitation. It was also found that the distribution of estimated wind gusts had notable "anomalies" at speeds ending with "0" or "5," and more estimates at 59 mph than would be expected, likely due to weather spotters rounding their estimates or picking a number just above severe wind gust criteriion (58 mph).

While review of estimated wind reports in the aggregate can provide helpful insights, they may not be applicable to individual wind estimates. Wind tunnel testing might be more meaningful to a spotter's individual wind estimate, but this method has limitations that reduce the applicability to convective wind gusts. In this study, we present a method of directly comparing estimated wind gust reports with observed wind gusts from nearby Automated Surface Observing System (ASOS) and Automated Weather Observing System (AWOS) sites. The intent of this effort is to directly quantify how estimated wind gusts have differed from nearby observations in recent decades.

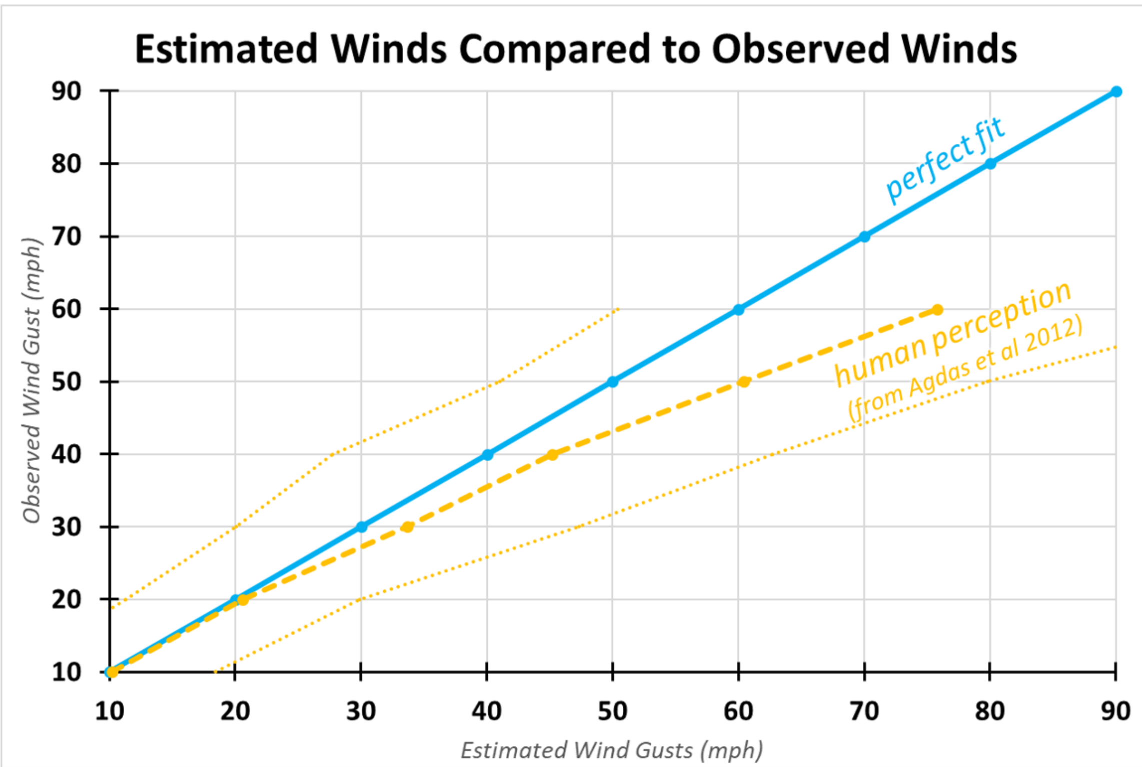

Figure 1. Comparison of estimated wind speeds and observed wind speeds from Agdas et al. 2012. Dotted orange lines correspond to the 1 standard deviation range.

2.0 Methodology

2.1 Collecting and Filtering Spotter-Estimated Wind Reports

Reports of spotter-estimated winds were collected from the online *Storm Data* database bulk data download (https://www.ncei.noaa.gov/pub/data/swdi/stormevents/csvfiles/). All detailed event entries were retrieved for calendar years 2000-2022. Some filtering was required on the exported reports from *Storm Data* to prepare these data for the analysis. First, reports were filtered to the central Midwest, including Minnesota, Wisconsin, Michigan, Iowa, Illinois, Indiana, and Missouri (Figure 2). Second, reports were filtered to only include the “Thunderstorm Wind” event type. Third, the magnitude type was filtered to only estimated winds. Fourth, any report without a latitude and longitude location were removed. Finally, the source of the estimated wind gust was reviewed for sources that likely indicated something other than a spotter estimate. Wind reports with a source indicated as “NWS Storm Survey” were assumed to be based upon wind estimates from EF-scale damage indicators and were removed. Wind reports with a source of “ASOS,” “AWOS,” “mesonet,” or “official NWS observation” were assumed to be entered erroneously as “estimated” and were removed. After filtering, a dataset of 58,397 estimated wind reports was available for further analysis.

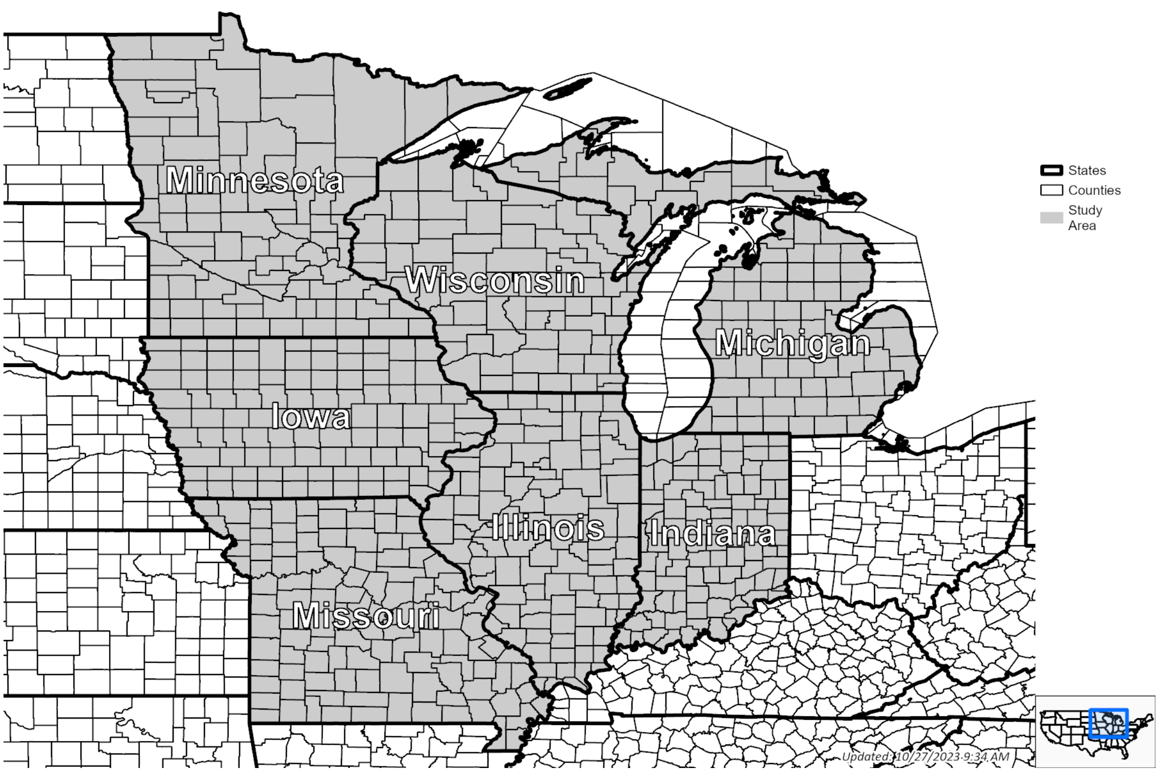

Figure 2. A map of the study area, with included states highlighted in gray and labeled.

2.2 COLLECTING ASOS AND AWOS LOCATIONS

ASOS and AWOS locations for the study area were retrieved from the Iowa Environmental Mesonet Network Location Tables page (https://mesonet.agron.iastate.edu/sites/networks.php?network=IL_ASOS&format=csv). Locations of ASOS/AWOS sites for each of the states in the study area were combined into a single CSV file, and then converted to a GIS shapefile. Sites were indicated as just "ASOS" by various Iowa Environmental Mesonet pages and download applications, but the list does include both ASOS and AWOS locations. Although 476 ASOS/AWOS sites were collected for comparison with estimated wind reports (Figure 3), a given site may not be active at all times during the 2000-2022 study period.

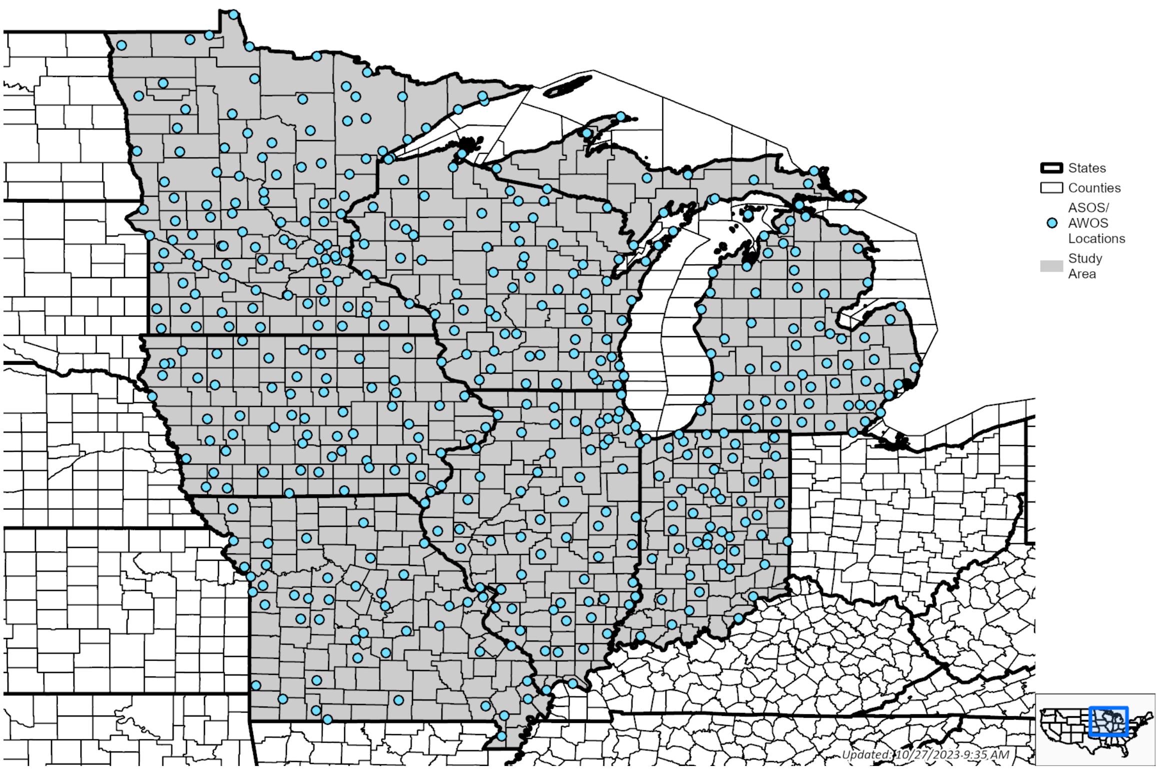

Figure 3. A map of ASOS and AWOS locations used in this study, indicated by blue dots.

2.3 CONNECTING WIND REPORTS TO ASOS/AWOS LOCATIONS

Four buffers were created around each ASOS/AWOS site, using a 0.5-mile, 1-mile, 2-mile, and 4-mile distance (Figure 4). The shapefile of spotter-estimated wind reports was then joined to each of these buffers to create four different sets of reports, each with an attribute of nearest ASOS/AWOS location. A count of wind reports within a given buffer distance of ASOS/AWOS locations is provided by Table 1. A very small number of these reports may be duplicates (no more than 2% for any given buffer distance) due to situations where buffers from multiple ASOS/AWOS locations overlap. With the time of the estimated wind gust and the nearest ASOS/AWOS location as attributes for each report in the shapefile, the process of retrieving the peak observed wind could be automated.

Table 1. Number of estimated wind reports captured by each of the buffer distances from ASOS/AWOS locations. A very small number of these reports may be duplicates due to situations where buffers from multiple ASOS/AWOS locations overlap. For reference, the total number of estimated wind reports covering the entire study domain (filtered as indicated in section 2.1) is indicated.

ASOS/AWOS Buffer Distance	Wind Reports Within Distance
0.5-mile	122
1-mile	511
2-mile	2,188
5-mile	11,366
All Reports/Distances	58,397

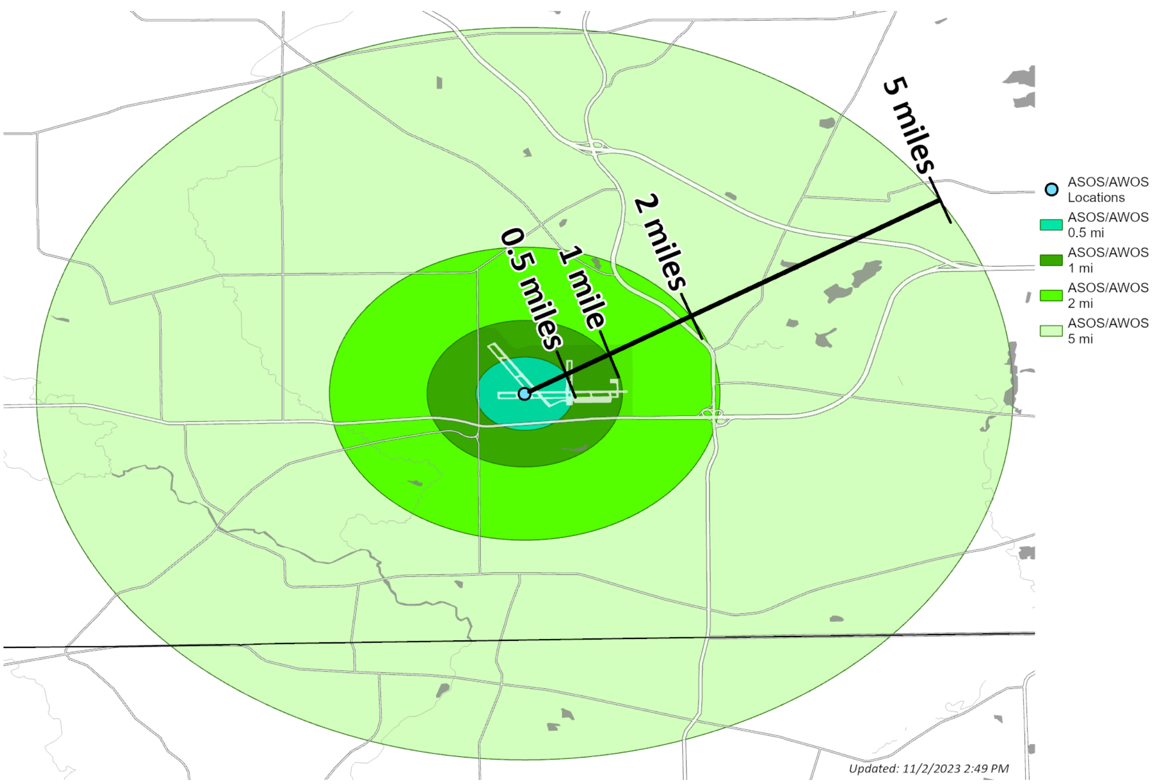

Figure 4. Example of the 0.5-mile, 1-mile, 2-mile, and 5-mile buffers applied to an ASOS/AWOS location. The buffers were then used to determine which estimated wind reports should be compared to ASOS/AWOS locations.

2.5 Retrieval of Observed Wind Gusts near Estimated Wind Reports

A script was written to automate retrieval of observed wind gusts for ASOS/AWOS locations near each estimated wind gust report. For each filtered report, the script used the date and time associated with each filtered report to retrieve the observations at the nearby ASOS/AWOS for the indicated calendar day. The script utilized the Iowa Environmental Mesonet's METAR download application (https://mesonet.agron.iastate.edu/request/download.phtml?network=IL_ASOS) to retrieve comma-delimited observations of "wind gust" and "peak wind gust," with all report types selected ("MADIS/5-minute ASOS," "Routine / Once Hourly," and "Specials"). After data were retrieved, observations were filtered to only include those within a window of time from 15 minutes before to 15 minutes after the time specified for the estimated wind report. The maximum value was calculated for both "wind gust" and "peak wind gust." Script output was a file indicating the spotter-estimated wind gust and the maximum observed gust. Estimated and observed wind gusts were compared for each of the four buffer distances.

3.0 Results and Discussion

The collected wind gust observations compared to the estimated wind gusts generally followed the expectation that wind gust estimates would be higher than observations. The vast majority of estimated wind gusts in *Storm Data* from 2000-2022 were higher than the maximum observed wind gust from a nearby ASOS or AWOS station, within 15 minutes of the reported time of the estimate. This behavior was noted with all four of the buffer distances from ASOS/AWOS locations. It was also noted that not all wind estimates could be matched with an observed wind gust (Table 2); in many instances, an observed value of 0 mph was returned from the script which appeared to coincide with time periods when the given ASOS/AWOS station was out of service or not reporting any wind gusts. The percent of estimated wind reports that could be matched with an ASOS/AWOS observation at the 0.5-mile, 1-mile, 2-mile, and 5-mile distances were 72%, 66%, 65%, and 63%, respectively.

Table 2. Number of estimated wind reports captured by each of the buffer distances from ASOS/AWOS locations, and the number of these reports that could be matched with an observed wind gust. For reference, the total number of estimated wind reports covering the entire study domain (filtered as indicated in section 2.1) is indicated.

ASOS/AWOS Buffer Distance	Wind Reports Within Distance	Reports with Observation
0.5-mile	122	88
1-mile	511	335
2-mile	2,188	1,420
5-mile	11,366	7,176
All Reports/Distances	58,397	

3.1 Results Using the 0.5-Mile Buffer

Using the 0.5-mile buffer from ASOS/AWOS locations, 88 estimated wind reports were matched with a valid wind gust observation. The overwhelming majority of estimated wind gusts were higher than the corresponding maximum observed wind gust within 15 minutes (Figure 5). The linear regression fit was similar to, but just slightly lower than, the mean estimated wind line from Agdas et al. (2012), and not outside of one standard deviation. Note that the linear regression began at estimated wind gusts of 50 mph, in contrast to the data from Agdas et al. (2012) which began at 10 mph, due to the available data. There was a significant range in observed wind gusts for a given estimated wind value, and the correlation between estimated gusts and observed gusts was weak, both visually and from the coefficient of determination (R^2 = 0.05). Assuming the observed wind gust values are accurate, more estimated wind reports were overestimated than underestimated and reasonably estimated (within 10 mph) combined (Figure 6).

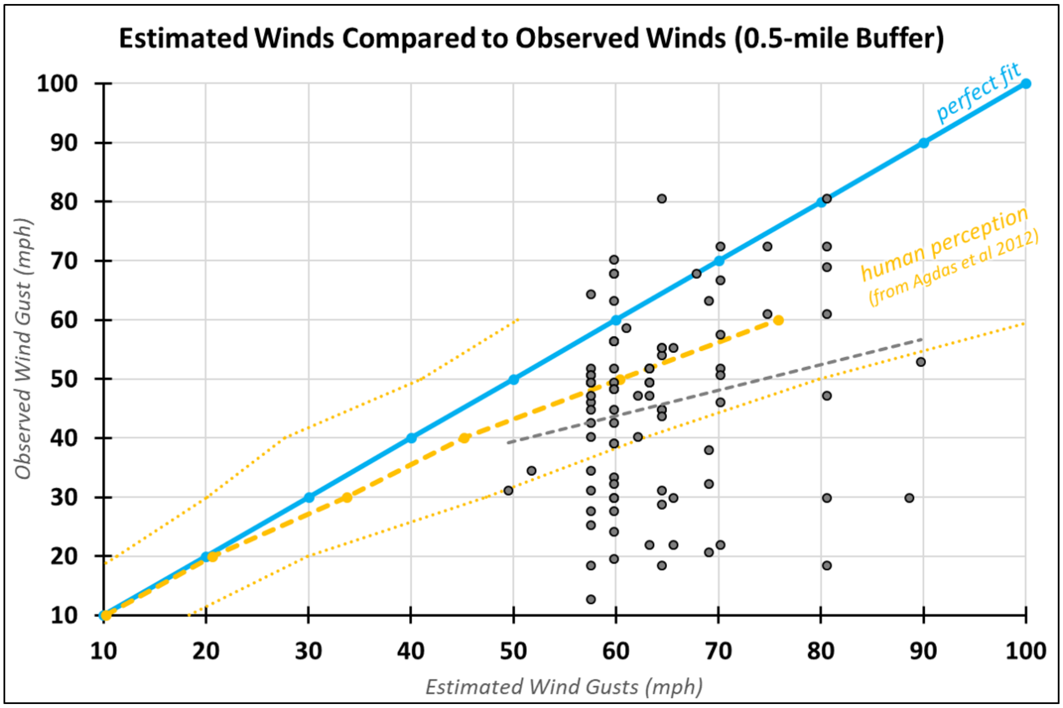

Figure 5. Estimated wind reports in Storm Data *from 2000-2022 compared to observed wind gusts within 15 minutes at ASOS or AWOS stations within 0.5 miles. Dashed gray line is a simple linear regression. Blue line is the line of perfect fit and the orange line represents the mean estimated wind speed for a given observed wind speed published by Agdas et al. (2012). Dotted orange lines correspond to the 1 standard deviation range.*

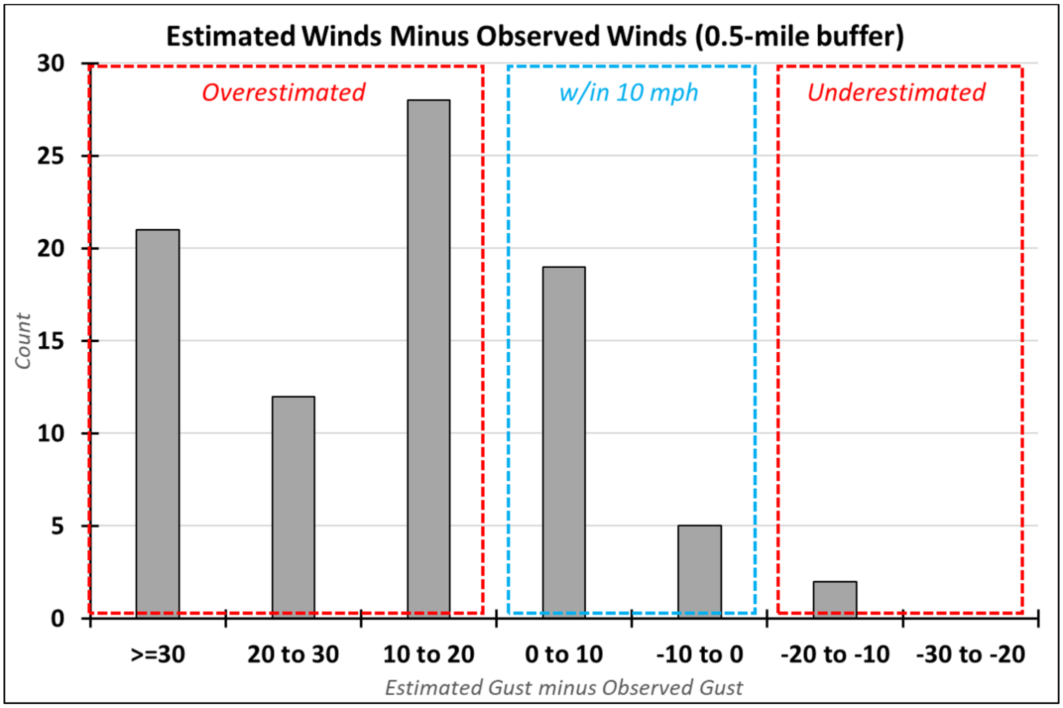

Figure 6. Difference between estimated wind reports in Storm Data *from 2000-2022 and observed wind gusts within 15 minutes at ASOS or AWOS stations within 0.5 miles.*

3.2 Results Using the 1-Mile Buffer

Using the 1-mile buffer from ASOS/AWOS locations, 335 estimated wind reports were matched with a valid wind gust observation. The overwhelming majority of estimated wind gusts were higher than the corresponding maximum observed wind gust within 15 minutes (Figure 7). The linear regression fit was similar to, but just slightly lower than, the mean estimated wind line from Agdas et al. (2012), and not outside of one standard deviation. There was a significant range in observed wind gusts for a given estimated wind value, and the correlation between estimated gusts and observed gusts was weak, both visually and from the coefficient of determination (R^2 = 0.03). Assuming the observed wind gust values are accurate, more estimated wind reports were overestimated than underestimated and reasonably estimated (within 10 mph) combined (Figure 8). Clustering of estimated wind gust values ending with “0” and “5” was also noted, along with clustering at 58 mph, the threshold for “severe” winds.

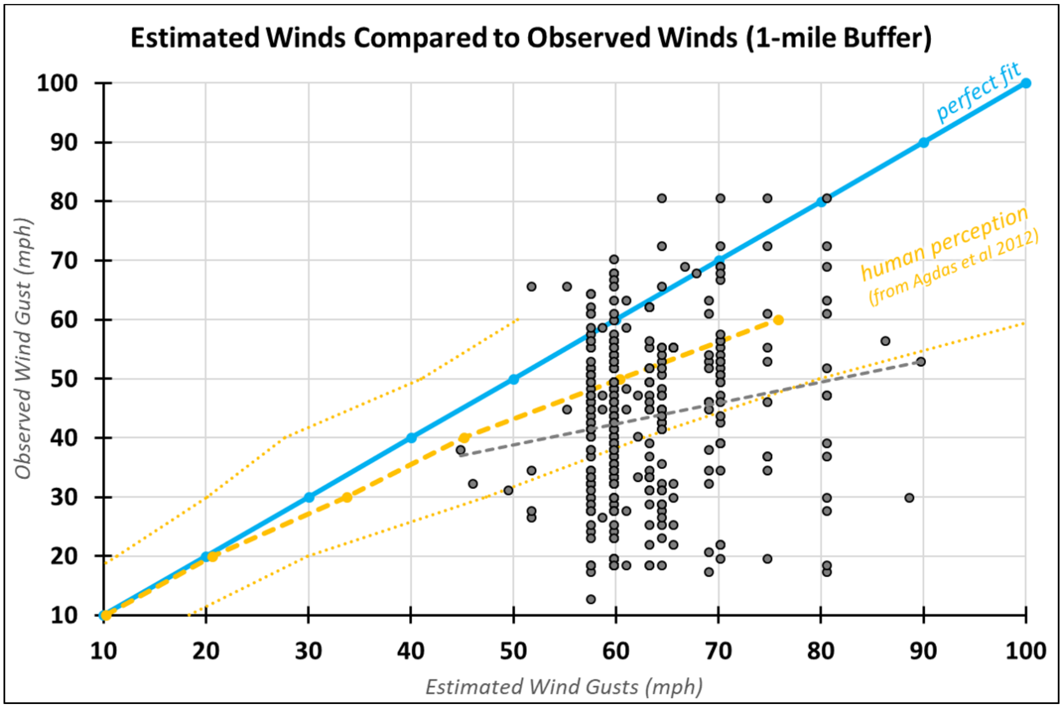

Figure 7. Estimated wind reports in Storm Data *from 2000-2022 compared to observed wind gusts within 15 minutes at ASOS or AWOS stations within 1 mile. Dashed gray line is a simple linear regression. Blue line is the line of perfect fit and the orange line represents the mean estimated wind speed for a given observed wind speed published by Agdas et al. (2012). Dotted orange lines correspond to the 1 standard deviation range.*

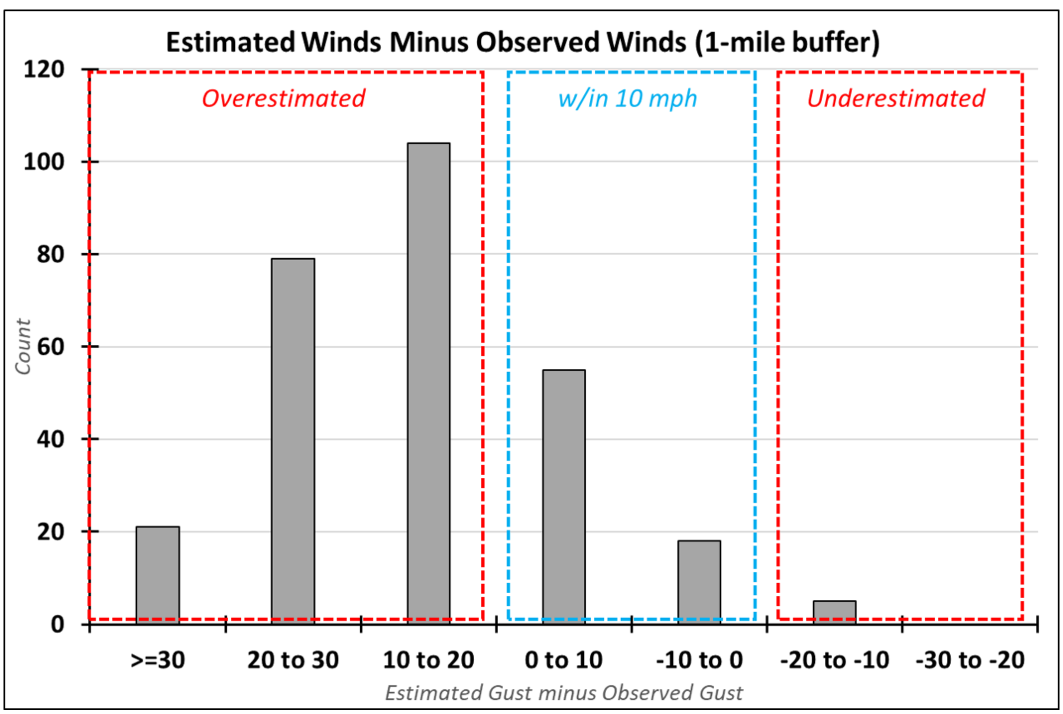

Figure 8. Difference between estimated wind reports in Storm Data *from 2000-2022 and observed wind gusts within 15 minutes at ASOS or AWOS stations within 1 mile.*

3.3 RESULTS USING THE 2-MILE BUFFER

Using the 2-mile buffer from ASOS/AWOS locations, 1420 estimated wind reports were matched with a valid wind gust observation. The overwhelming majority of estimated wind gusts were higher than the corresponding maximum observed wind gust within 15 minutes (Figure 9). The linear regression fit was somewhat similar to the mean estimated wind line from Agdas et al. (2012), but was near one standard deviation lower. There was a significant range in observed wind gusts for a given estimated wind value, and the correlation between estimated gusts and observed gusts was weak, both visually and from the coefficient of determination (R^2 = 0.02). Assuming the observed wind gust values are accurate, more estimated wind reports were overestimated than underestimated and reasonably estimated (within 10 mph) combined (Figure 10). Clustering of estimated wind gust values ending with "0" and "5" was also noted, along with clustering at 58 mph, the threshold for "severe" winds.

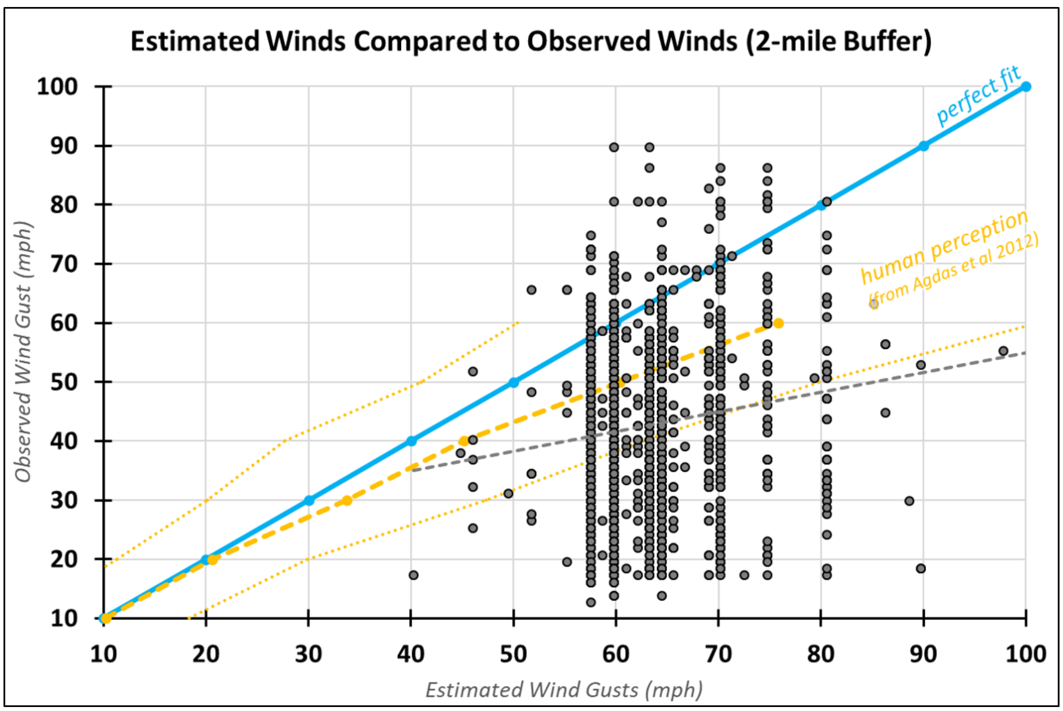

Figure 9. Estimated wind reports in Storm Data *from 2000-2022 compared to observed wind gusts within 15 minutes at ASOS or AWOS stations within 2 miles. Dashed gray line is a simple linear regression. Blue line is the line of perfect fit and the orange line represents the mean estimated wind speed for a given observed wind speed published by Agdas et al. (2012). Dotted orange lines correspond to the 1 standard deviation range.*

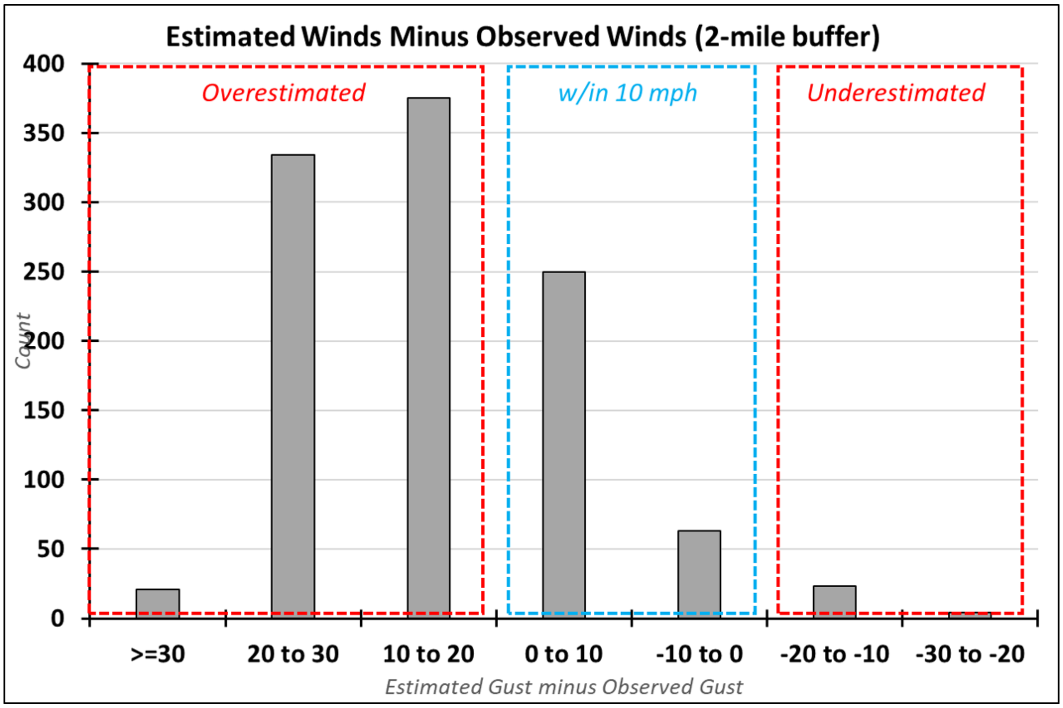

Figure 10. Difference between estimated wind reports in Storm Data *from 2000-2022 and observed wind gusts within 15 minutes at ASOS or AWOS stations within 2 miles.*

3.4 Results Using the 5-Mile Buffer

Using the 5-mile buffer from ASOS/AWOS locations, 7176 estimated wind reports were matched with a valid wind gust observation. The overwhelming majority of estimated wind gusts were higher than the corresponding maximum observed wind gust within 15 minutes (Figure 11). The linear regression fit was somewhat similar to the mean estimated wind line from Agdas et al. (2012), but was near one standard deviation lower. There was a significant range in observed wind gusts for a given estimated wind value, and the correlation between estimated gusts and observed gusts was weak, both visually and from the coefficient of determination (R^2 = 0.02). Assuming the observed wind gust values are accurate, more estimated wind reports were overestimated than underestimated and reasonably estimated (within 10 mph) combined (Figure 12). Clustering of estimated wind gust values ending with “0” and “5” was also noted, along with clustering at 58 mph, the threshold for “severe” winds. Significant ranges of estimated winds were noted for a given observed wind gust value; for example, observed wind gusts of 50 mph may have been estimated as any speed from approximately 40 mph to approximately 100 mph.

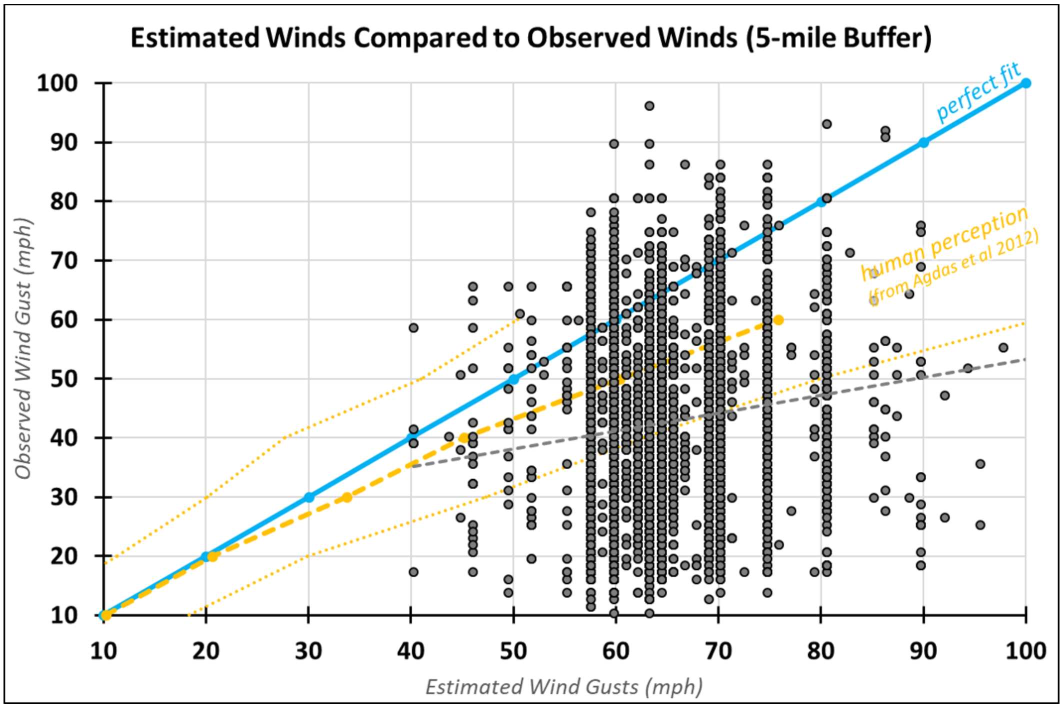

Figure 11. Estimated wind reports in Storm Data *from 2000-2022 compared to observed wind gusts within 15 minutes at ASOS or AWOS stations within 5 miles. Dashed gray line is a simple linear regression. Blue line is the line of perfect fit and the orange line represents the mean estimated wind speed for a given observed wind speed published by Agdas et al. (2012). Dotted orange lines correspond to the 1 standard deviation range.*

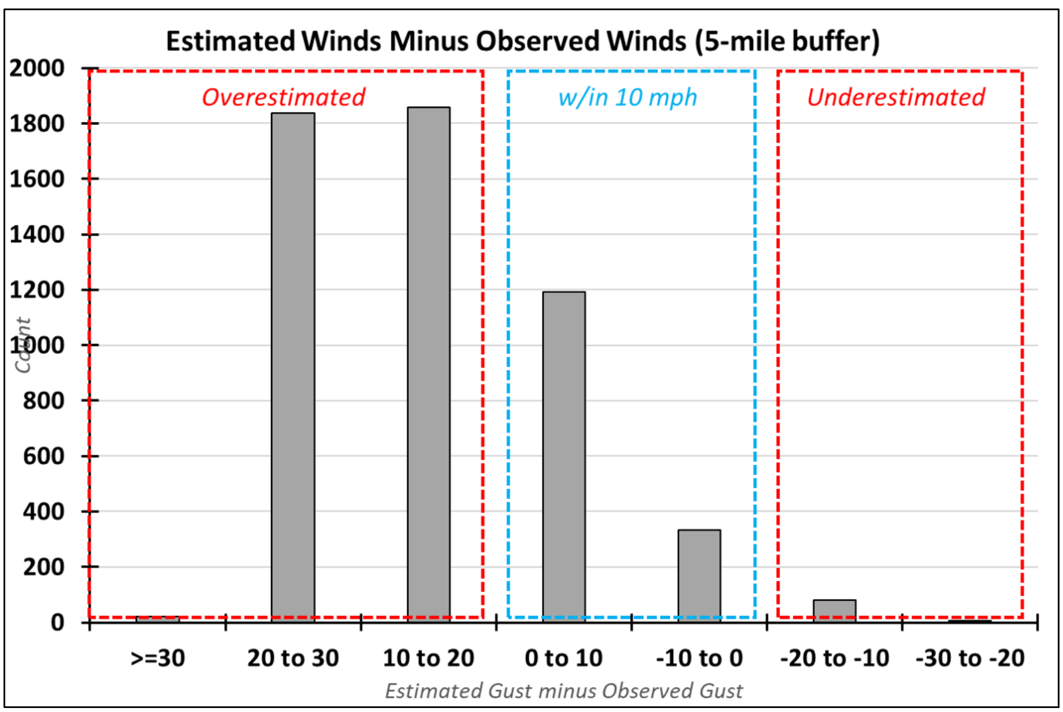

Figure 12. Difference between estimated wind reports in Storm Data *from 2000-2022 and observed wind gusts within 15 minutes at ASOS or AWOS stations within 5 miles.*

3.5 Discussion

The results presented here are generally consistent with past research and widely held beliefs about spotter-estimated wind gusts. Estimated wind gusts were usually higher than, sometimes similar to, and rarely lower than, observed wind gusts occurring within 15 minutes of the reported time of the estimate and within 0.5 to 5 miles of the reported location of the estimate. The correlation between estimated wind gust value and observed wind gust value was also poor, with significant ranges noted in observed wind gusts for a given estimated wind value. While the assumed explanation for these observations are likely contributing factors, issues with the available data and other sources of uncertainty may prevent robust conclusions from being made.

One potential issue with the data used for this analysis involves the provided location for each estimated wind gust report. The latitude and longitude coordinates provided in *Storm Data* are likely rounded to the nearest 0.01 degrees. Even if it is assumed that the location provided for each estimated wind gust is accurate, rounding of coordinates could move reports into and out of a given buffer if the provided precision is on the order of linear distances ranging from 0.5 to 5 miles (the buffer distances used for each ASOS and AWOS location). In the Chicago area, for example, a 0.01-degree difference in latitude yields a difference of 0.7 miles and a 0.01-degree difference in longitude yields a difference of 0.5 miles. This is potentially a significant source of uncertainty, especially when using the 0.5-mile buffer and 1-mile buffer. In addition, it is unlikely that the majority of wind reports in *Storm Data* are accurate to the indicated precision; they are likely estimates in many cases, as weather spotters do not typically provide an exact set of latitude and longitude coordinates when making a report.

Similar to issues with the location of the estimated wind report, there may also be uncertainty associated with the indicated locations of ASOS/AWOS stations. Observing equipment at airports sometimes moves due to construction or other reasons, and for larger airports the relocation distance can be on the order of a couple miles. This study made no attempt to improve the location precision of weather observing equipment located at each ASOS/AWOS station, and potential station moves were also not considered.

Another potential source of uncertainty is related to the times provided for each estimated wind gust report. Uncertainty with measured winds is likely much less, as an exact time to the minute is provided for every observed value, but estimated winds may not have occurred at the exact time the report provided, or instead may have occurred over a period of time that the spotter was perceiving the windy conditions. Although a 15-minute window of time was used to attempt to mitigate this issue, it cannot completely remove it. A test was conducted where a 60-minute window of time was used instead; despite potentially including periods of wind that were not related to the wind gusts being estimated, the noted difference in the collective relationship between estimated wind reports and observed winds was not significant.

Some differences between estimated wind speeds and observed wind speeds may also be explained by meteorological conditions, and not constitute a bias in wind estimation. For example, small-scale microbursts can have large differences in wind speeds over just a few miles, which could mean a spotter located near the microburst might accurately estimate severe wind gusts while a weather station a few miles away might sample much lower wind speeds. This source of uncertainty should, however, be mitigated by the fact that the reverse could also occur - a weather station could be closer to the hypothetical microburst than the observer. Variability in wind gusts can also occur with other scenarios and would not just be limited to a microburst.

During the early stages of data collection for this study it was noted that some observed wind gusts were coded as estimated wind gusts in *Storm Data*. For example, a wind gust indicated as an estimate might also list a source of “ASOS” or “mesonet.” An attempt was made to remove observed gusts erroneously coded as estimated gusts, as well as estimated gusts that were derived by damage indicators during a storm survey instead of provided by a spotter, but it remains possible that some coding errors such as this remain in the analyzed data. The effect of including an observed wind gust as an estimated gust would make any potential bias in estimated wind reports appear smaller.

While there are multiple sources of uncertainty, the provided data may still be helpful for the overall discussion on using estimated wind gusts in lieu of measured wind gusts or observed damage. The behavior of the presented relationship between estimated wind gust and observed wind gust occurring within 15 minutes was generally consistent regardless of the selected buffer distance from ASOS/AWOS observing location. Results were also generally consistent with past studies and the widely held belief that estimated wind gusts are generally high biased.

4.0 Conclusions

In this study, a method of directly comparing estimated wind gust reports to nearby observed wind gusts was presented. Estimated wind gusts were usually higher than, sometimes similar to, and rarely lower than, observed wind gusts occurring within 15 minutes of the reported time of the estimate and within 0.5 to 5 miles of the reported location of the estimate. More estimated wind reports were overestimated than underestimated or reasonably estimated (within 10 mph). Results were generally consistent with widely held beliefs about biases with spotter-estimated winds. The data used for this study have multiple potential sources of uncertainty, including the precision used to document estimated wind reports in *Storm Data* and the indicated locations of ASOS/AWOS stations. Future work on this topic should include efforts to improve quality control of wind estimate locations, and a review of the provided locations for ASOS/AWOS stations. Future work could also include the addition of more weather observing stations, such as calibrated mesonets operated by states or universities. The information presented in this study supports the concept of having spotters report observed damage in lieu of, or along with, estimated wind gusts.

5.0 Acknowledgements

The author would like to thank NWS Chicago summer student Eric Bjork for his efforts collecting and organizing data for this report. The author would also like to thank NWS Chicago Science and Operations Officer Kevin Donofrio and Jeff Manion of NWS Central Region Headquarters for their helpful comments and review.

6.0 Works Cited

Agdas, D., G.D. Webster, and F.J. Master. 2012. "Wind Speed Perception and Risk." *PLOS One* 7 (11): 1-8. doi:10.1371/journal.pone.0049944.

Edwards, R., J.T. Allen, and G.W. Carbin. 2018. "Reliability and Climatological Impacts of Convective Wind Estimations." *J. Appl. Meteor. Climatol.* 57: 1825-1844. doi:10.1175/JAMC-D-17-0306.1.