P 1.8 **STATISTICAL CHARACTERISTICS OF THE WIND DEPENDENCE OF SNOW AND FREEZING FOG EVENTS AT SEVERAL MAJOR AIRPORTS FOR IMPROVING RUNWAY VISUAL RANGE (RVR) PERFORMANCE**

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1. INTRODUCTION

The inherent design of Runway Visual Range (RVR) visibility sensors (VS) implies that they will suffer from partial blockage of snowfall when this snowfall is accompanied by winds that cause the sensor's common scattering volume to be obstructed or shadowed from the natural flow of snowfall. The problem will normally result in an underestimate of extinction coefficient measurements, since the scattering volume will necessarily be partially shielded from snowfall, thereby reducing the amount of light scattered from the volume into the sensor's receiver. Thus, less scattering will occur than would be expected from the amount of snowfall that is present in the free atmosphere in the vicinity of the sensor. Although considered unlikely, shadowing under very unusual conditions might also result in enhanced scatter, if the effect is to enhance or focus the flow of snow into the scattering volume. Another phenomenon that can affect sensor performance in snowfall occur when high winds force snow or ice into the protected sensor head shields, producing partial or complete clogging or blockage of either a receiver or transmitter optical window. This effect may occur even though the sensor transmitter and receiver components are protected by heated covers and directed slightly downward. When these rare events occur, modern VS detect such conditions and automate failed mode reports to users. The preferred solution to these problems is to have a sensor design that reduces shadowing or blockage effects to improve performance levels and reduces the possibility of snow or ice clogging occurrences. Related aspects of sensor design are discussed in more detail by West et al. (1997), while somewhat analogous effects of wind direction on sensor response variations to fog were examined by Burnham et al. (1997) and Pawlak et al. (1998). Since sensor redesign of otherwise acceptable commercial products can be high risk and costly, any alternative means that would reduce the probability of occurrences of sensor scattering volume shadowing and blockage deserve consideration.

An approach that simultaneously addresses both issues involves setting the orientation of the sensor mounting device (fork) so as to minimize the probability that moderate to heavy snowfall events will be accompanied by shadowing or blockage that might affect the ability of the sensor to measure atmospheric extinction coefficients to within their specified operational limits or force the sensor into a default failed condition. This paper demonstrates how local climatology data may be used as a guide to reduce the possibility of these effects affecting the operation of RVR VS during snowfall events. This task would be accomplished by orienting the sensor mounting structure or fork in such a way as to significantly reduce the probability or occurrences that visibility measurements during moderate and severe snowfall events would be impacted by either shadowing or blockage effects. Performance of the technique may be assessed by comparing a VS oriented using this methodology with co-located VS oriented in a standard direction using techniques such as boxplots of the relative responses versus wind angle discussed in Graedel (1977), Pawlak et al. (1998) and McKinney et al. (2004) or by comparing responses of co-located sensors oriented in different directions.

1.1 Background

1. DATA SOURCE: Sample sets of weather data from ASOS/AWOS stations at several representative airports for three winters (November through April), namely, the winters of 2004-2005, 2005-2006 and 2006-2007 were collected, processed and analyzed. The airports chosen for the analysis were: Cincinnati/Northern Kentucky International (KCVG), Denver International (KDEN), Chicago O'Hare International (KORD) and Otis Air National Guard Base near Falmouth, MA (KFMH). The ASOS data are archived in METAR format (hourly surface observation reports with additional special observation reports issued as conditions warrant).

Data for a particular airport and period were extracted from the national archive data files using a software utility designed for the purpose. The utility inputs the dates and the airport's 4-letter ICAO Location Identifier and outputs the raw METAR data.

2. RELEVANT DATA: Data extracted for each airport were then screened for snow, blowing snow and freezing fog events during the three winter seasons. The snow events were further classified in accordance with intensity levels (light, moderate, heavy, blowing snow; coded -SN, SN, +SN, and BLSN, respectively in the METAR reports). Freezing fog events (coded FZFG) were also included in the analysis. Frequencies of all such events were then generated and examined relative to wind speed and wind direction conditions.

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3. EVENT CLASSIFICATIONS: The frequencies of occurrence for SN, +SN, BLSN and SN/+SN, BLSN/SN/+SN and BLSN/-SN/SN/+SN (termed 'all snow') combinations and of FZFG were computed and charted as functions of wind direction using 10° wide bins, centered at 10^o intervals beginning at 0^o. Wind speed ranges included [all wind speeds; wsp ≥ 10kts; wsp ≥ 15 kts; wsp ≥ 20 kts; 0 ≤ wsp ≤ 10kts] . These classifications were used to discern whether certain wind patterns dominate snowfall events at each airport. Since wind direction is generally highly variable about a given direction, additional smoothing was accomplished by including adjacent wind direction bins in the averaging process at each 10^o interval in order to smooth the resultant distributions (care was taken to properly account for the north wind transition).

The foregoing classifications enabled the results to be presented in various graphical formats, including ways that portray frequencies of prevailing wind directions using histograms and wind roses. Wind directions associated with the lowest frequencies of potential snow impingement on sensor scattering volume could then be considered for selecting preferred orientation of the VSs at an airport.

4. FORK GEOMETRY: Since the geometry of VS forks is such that transmitter and receiver heads are aligned approximately in the same near-vertical plane, the effects of interest are the same for any angle and its opposite straight line component. These results are plotted as frequency versus wind direction deviation $\pm 90^o$ from the north again using 10° wide bins. The plots are then used to determine preferred orientations that would best minimize the frequency of snow impingement or clogging.

The foregoing methodology would be readily applicable to any airport where the NGRVR or PC-based RVR VS are installed. It should also prove useful for orienting other RVR forward scatter VSs to improve their performance, since the inherent design of most, if not all, forward scatter VS is expected to result in some degree of shielding or clogging when snowfall occurs under wind conditions that affect the flow of snow entering the scattering volume of the sensors or contribute to clogging of transmitter or receiver protective hoods.

2. RESULTS

Wind Direction Frequencies - To illustrate the procedure, a sample analysis for KORD is presented. The plots are of two types – histograms and rose plots. Histograms of frequencies of SN, +SN, BLSN, SN/+SN, BLSN/SN/+SN, all snow and FZFG for all wind speeds are shown in Figs. 1-7, respectively. Corresponding rose plots are shown in Figs. 8-14. The histograms show the frozen precipitation frequencies as a function of wind direction. The rose plots perform the same purpose in a cylindrical coordinate system. As noted previously, neighboring wind direction bin counts are averaged to smooth the wind direction bin counts at each 10^o interval, giving average results over 30^o sectors. The distributions for wind speeds exceeding 10, 15 and 20 kts and in the 0-10 kts range were also considered.

Histograms - Fig. 1 is the histogram for SN. It shows that SN is most frequent for NE winds and practically nonexistent for SW-W winds. The histogram for +SN in Fig. 2 is similar to Fig. 1 except that the most frequent +SN occurs when the wind direction is NNE; also, the wind directions with no +SN are broader, ranging from S through NW. +SN frequency is less than that for SN. Fig. 3 shows three directional ranges in BLSN frequency when the wind direction is between N and E, SW and W, and NNW and N. No BLSN was reported when the wind direction is E through SSW and W through NW. Figs. 4 and 5 show the combined SN/+SN and BLSN/SN/+SN frequencies, respectively. The principal peak frequency is when the wind direction is NE and the minimum frequency is when the wind is from the W. The 'all snow' frequencies plotted in Fig. 6 also includes –SN. The lowest frequency occurs when the wind direction is from the ESE or SSE and highest when the wind direction is from the NNW; two other significant peaks occur in the NE and WSW directions.

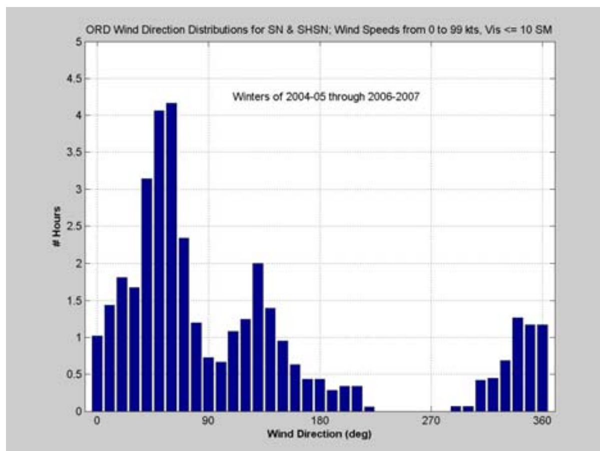

Fig. 1. Histogram of SN Frequencies versus Wind Direction for all Wind Speeds.

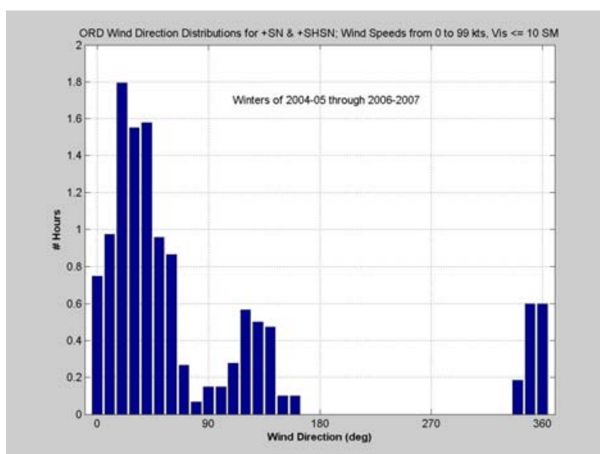

Fig. 2. Histogram of +SN Frequencies versus Wind Direction for all Wind Speeds.

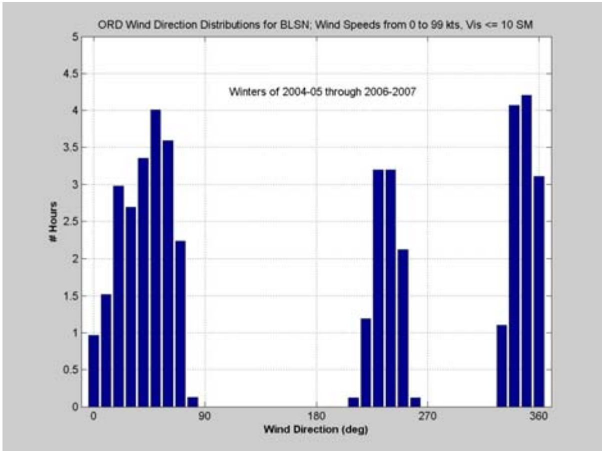

Fig. 3. Histogram of BLSN Frequencies versus Wind Direction for all Wind Speeds.

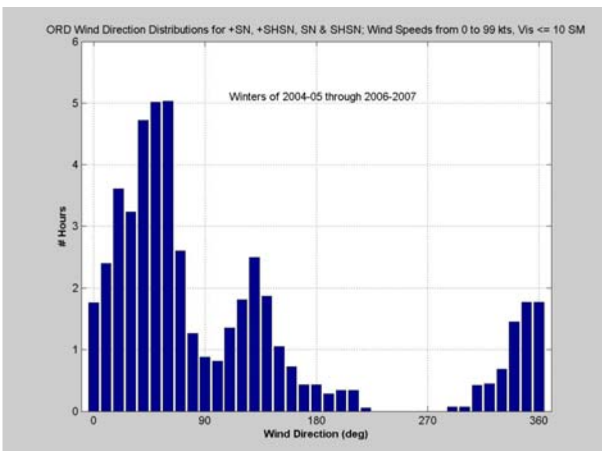

Fig. 4. Histogram of SN/+SN Frequencies versus Wind Direction for all Wind Speeds.

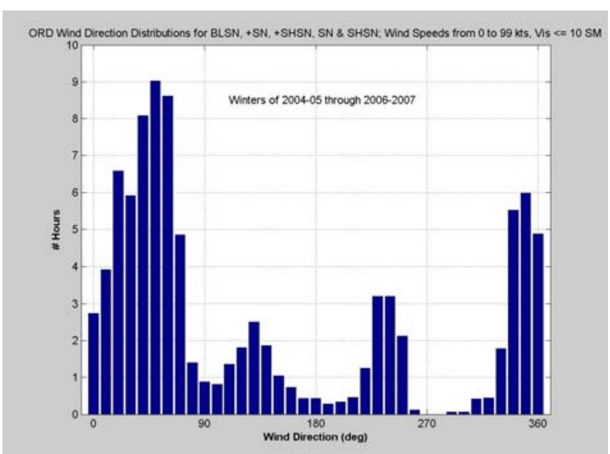

Fig. 5. Histogram of BLSN/SN/+SN Frequencies versus Wind Direction for all Wind Speeds.

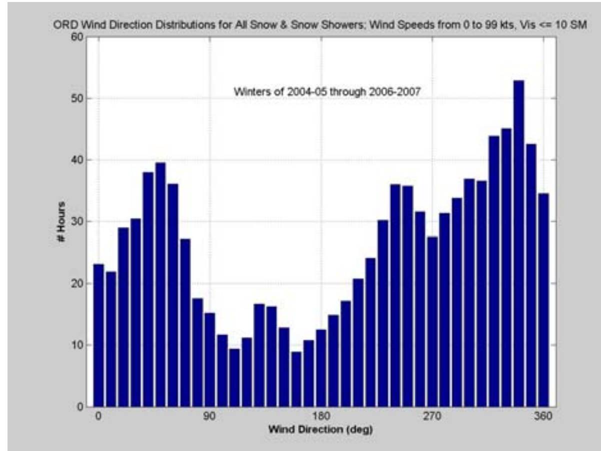

Fig. 6. Histogram of All Snow Frequencies versus Wind Direction for all Wind Speeds.

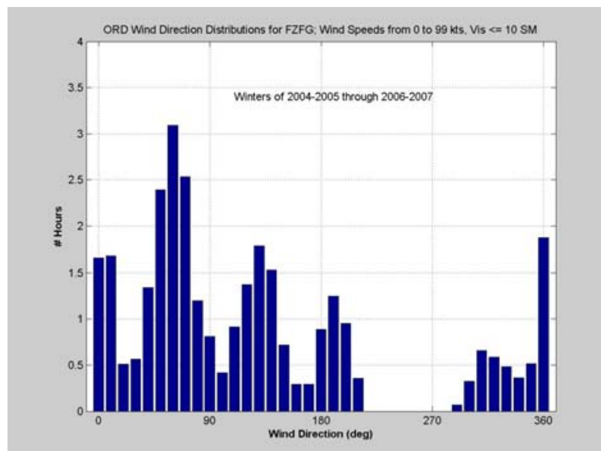

Fig. 7. Histogram of FZFG Frequencies versus Wind Direction for all Wind Speeds.

Fig. 7 provides data on FZFG. No FZFG was found when the wind direction is from the SW through the W. FZFG was most frequent when the wind direction is from the NE and ENE; other peaks are evident near N, SE and SSW directions.

Rose Plots – Examination of the rose plots provides a more convenient way of gauging possible impingement effects on VS, since frequencies in any direction and its opposite straight line element are readily apparent. Thus, Figs. 8-14 suggest that possible impingement from differing snow intensities and FZFG is least likely with a VS fork orientation aligned near the E-W line. The angular range of decreased potential snow impingement is wider for BLSN than for snowfall or FZFG as seen in Fig. 10 because of its multimodal features with respect to wind direction. SN, +SN, SN/+SN, BLSN/SN/+SN and FZFG have the highest frequencies when the wind is near the NE according to Figs. 8, 9, 11, 12 and 14, respectively. It should also be noted that greatly increased snow and FZFG frequencies occur at wind directions only ~20-30° away from the most favorable VS orientation directions. The all snow plot in Fig. 13 shows that the addition of light snow alters the overall results considerably, resulting in dominance when the wind is generally from the NNW.

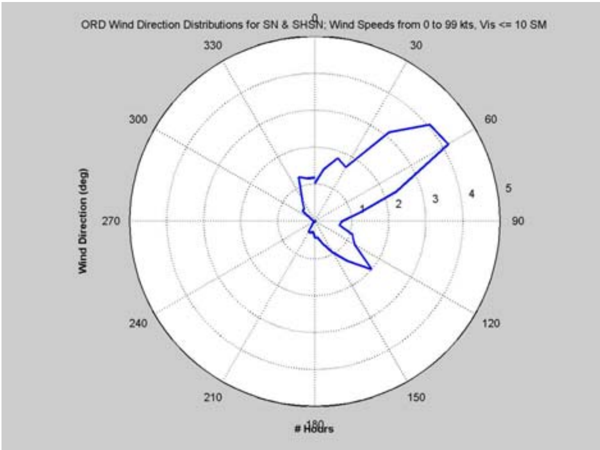

Fig. 8. Rose Plot of SN Frequencies versus Wind Direction for all Wind Speeds.

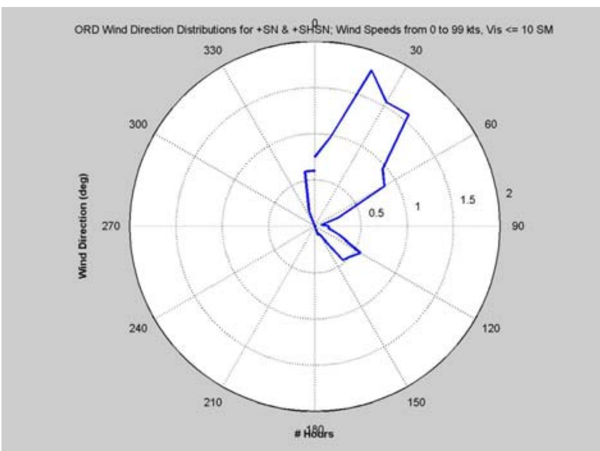

Fig. 9. Rose Plot of +SN Frequencies versus Wind Direction for all Wind Speeds.

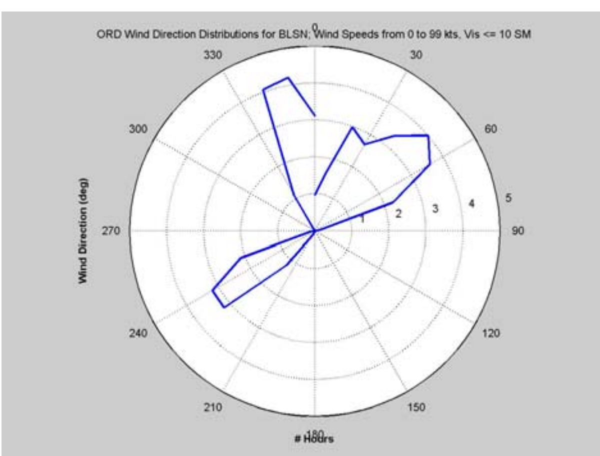

Fig. 10. Rose Plot of BLSN Frequencies versus Wind Direction for all Wind Speeds.

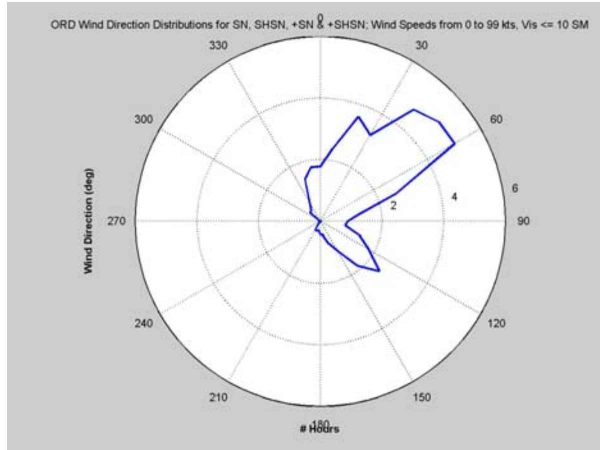

Fig. 11. Rose Plot of SN/+SN Frequencies versus Wind Direction for all Wind Speeds.

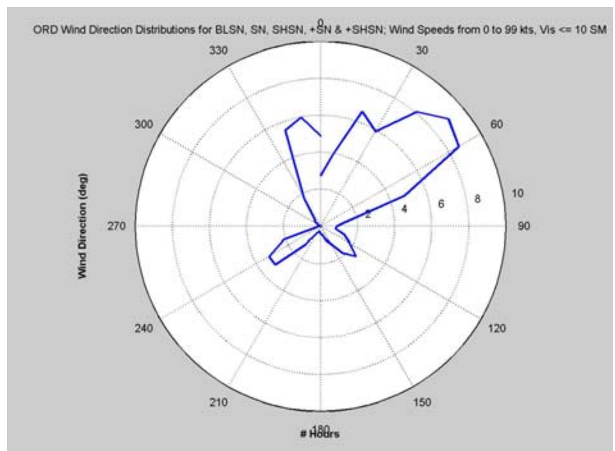

Fig. 12. Rose Plot of BLSN/SN/+SN Frequencies versus Wind Direction for all Wind Speeds.

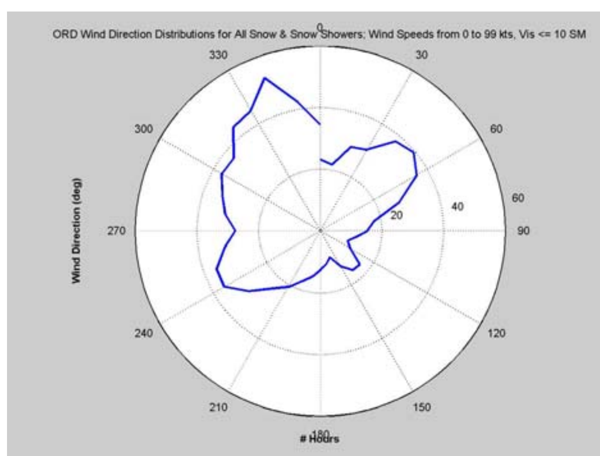

Fig. 13. Rose Plot of All Snow Frequencies versus Wind Direction for all Wind Speeds.

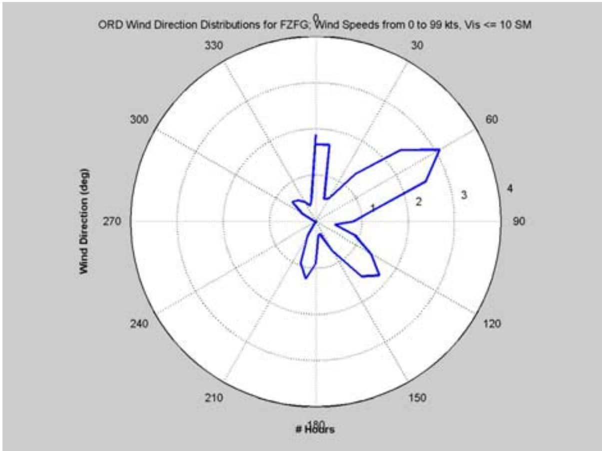

Fig. 14. Rose Plot of FZFG Frequencies versus Wind Direction for all Wind Speeds.

Sensitivity to Minimum Wind Speed Criteria – Plots similar to Figs. 1-14 were generated using the wind criteria described above. The remaining discussion will focus on consideration of histograms of all snow and FZFG conditions.

Figs. 15, 16 and 17 are histograms of all snow frequencies for minimum wind speeds of 10, 15 and 20 kts, respectively. The results can be contrasted with the all snow results in Fig. 6, which indicate minimum frequencies at wind directions of 110° and 160° for all wind speeds and a maximum at 340°. Fig. 15 shows a distinct minimum frequency at 160° and generally lower frequencies for wind directions from 80-200° and at 10°. The distributions are very similar to the shapes in Fig. 6, indicating that the distributions for all snow, all-wind conditions are dominated by wind conditions over 10-kts. The frequencies are higher when the wind direction is from 20-70° and from 200-350°. Figs. 16 and 17 show that there is a general decline in all snow frequency with increased minimum wind speeds with the strongest decline occurring when the wind direction is from ~200-360°.

Histograms of FZFG frequencies when the minimum wind speeds were 10, and 15 kts, respectively, are shown in Figs. 18 and 19. The frequencies of FZFG decrease nearly uniformly with increasing minimum wind speed. Furthermore, the wind direction range with no FZFG reports broadens only slightly with increasing minimum wind speeds up through 15 kts. The wind angle range with no FZFG is 220-280° for all wind speeds according to Fig. 7. The wind direction ranges with no FZFG reports is 100-110° and 220-320° as seen in Fig. 19. Although not shown, no FZFG was reported when the minimum wind speed was 20 kts.

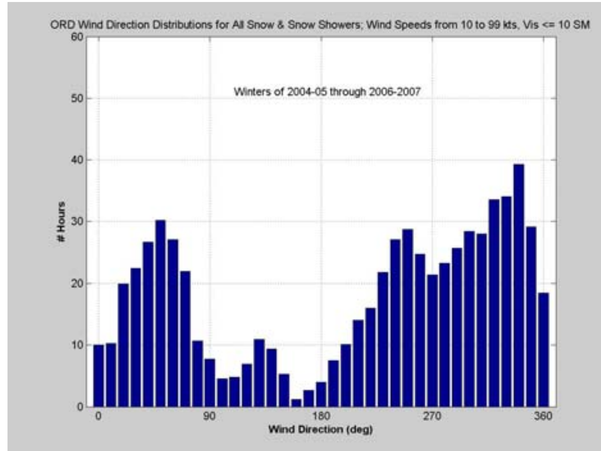

Fig. 15. Histogram of All Snow Frequencies versus Wind Direction for Wind Speeds ≥ 10 kts.

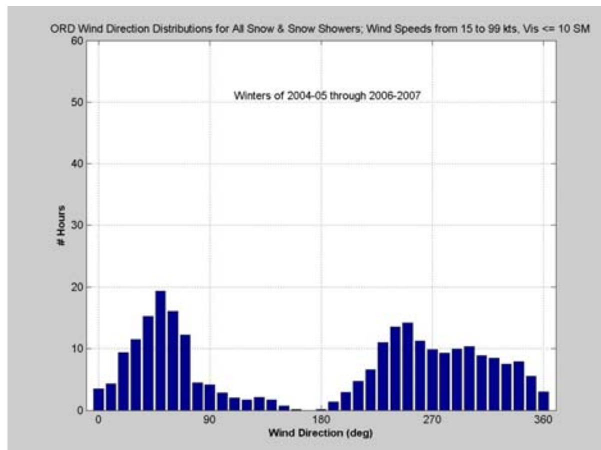

Fig. 16. Histogram of All Snow Frequencies versus Wind Direction for Wind Speeds ≥ 15 kts.

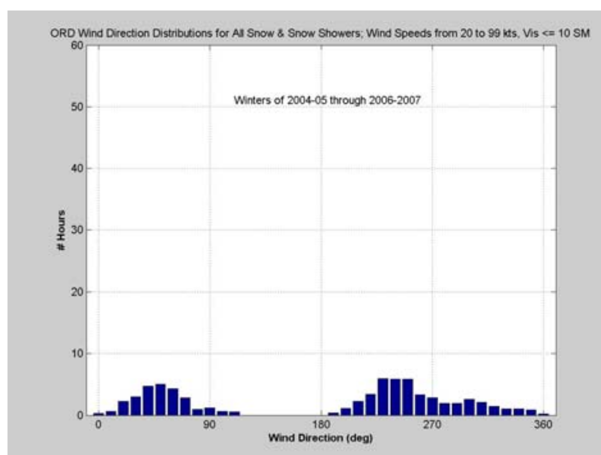

Fig. 17 – Histogram of All Snow Frequencies versus Wind Direction for Wind Speeds ≥ 20 kts.

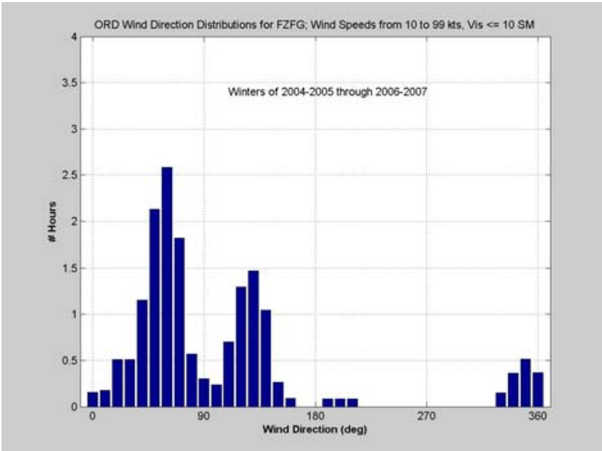

Fig. 18. Histogram of FZFG Frequencies versus Wind Direction for Wind Speeds ≥ 10 kts.

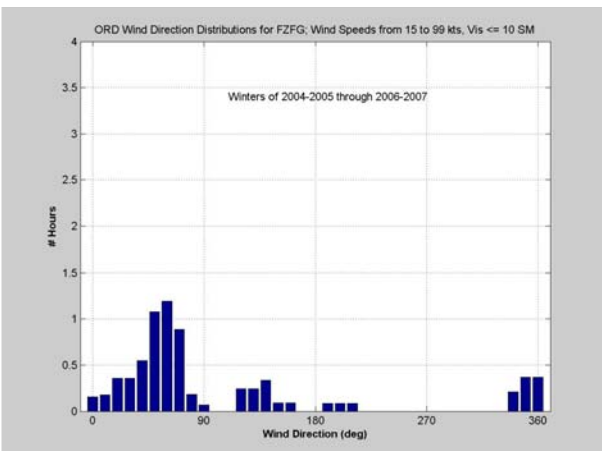

Fig. 19. Histogram of FZFG Frequencies versus Wind Direction for Wind Speeds ≥ 15 kts.

Low Wind Speeds - The other wind criterion examined is the 0-10 kts wind speed range. Winds in this range are also relevant in that these speeds are such that snowfall, with typical terminal fall speeds between ~0.5-2.5 m-s^{-1} (Barthazy and Schefold, 2006), could readily combine to produce significant shielding of the VS scattering volume.

Low wind speed histograms for all snow and FZFG are shown in Figs. 20 and 21, respectively. The frequency for all snow in Fig. 20 was fairly uniform with slightly lower frequency when the wind direction was near the E, SE and W directions. FZFG frequencies, shown in Fig. 21, peaked when the wind blew from the N and were nonexistent when the wind directions were at ~10° and between 220-280° and 340-350°.

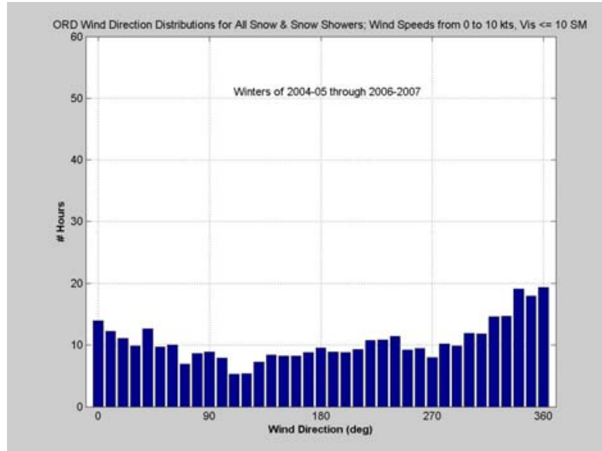

Fig. 20. Histogram of All Snow Frequencies versus Wind Direction for Wind Speeds 0-10 kts.

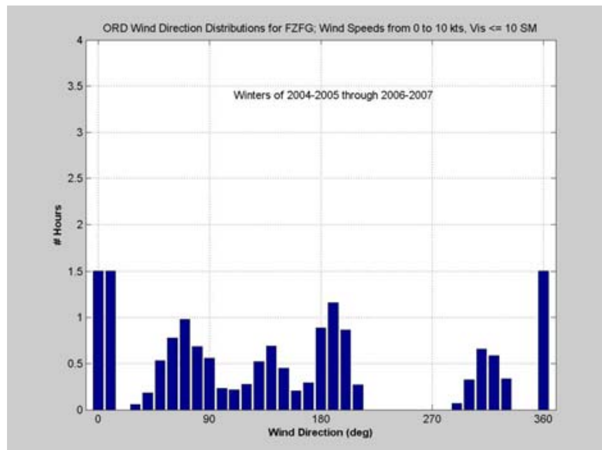

Fig. 21. Histogram of FZFG Frequencies versus Wind Direction for Wind Speeds 0-10 kts.

Wind Direction Deviations - Fig. 22 shows frequency histograms of SN plotted vs. wind direction deviation from N for all wind speeds at KORD. A positive deviation is defined as being E of N. Fig. 23-28 are similar plots for +SN, BLSN, SN/+SN, BLSN/SN/+SN, all snow, and FZFG respectively. As with the previous histograms, averaging neighboring wind direction bin counts were employed. The results are presented relative to N and combine wind directions with a northerly component with their respective straight line southerly components. Examination of these plots confirms the prior finding that VS orientation near the E-W line would best minimize the likelihood of snow impingement, including benefiting from a wider range of decreased impingement for BLSN. It should also be noted from these plots that greatly increased snow and FZFG frequencies occur at wind directions only ~20-30° away from the most favorable VS orientation directions.

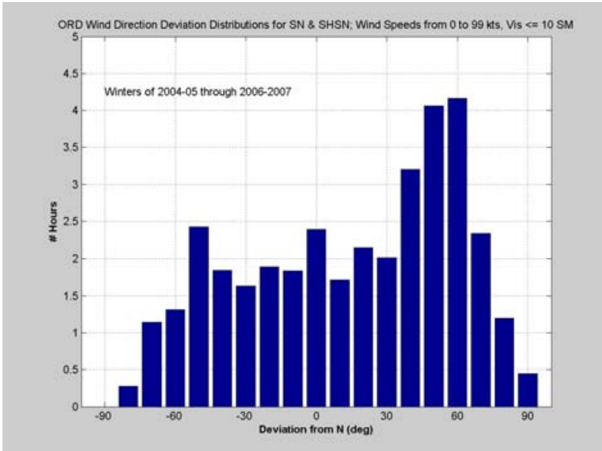

Fig. 22. Histogram of SN Frequencies versus Wind Direction Deviation from N for all Wind Speeds.

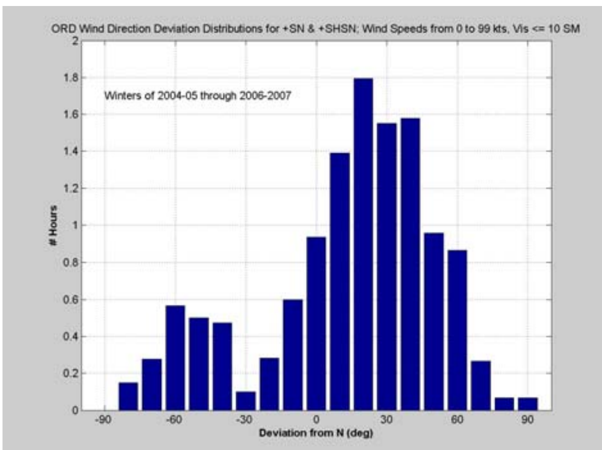

Fig. 23. Histogram of +SN Frequencies versus Wind Direction Deviation from N for all Wind Speeds.

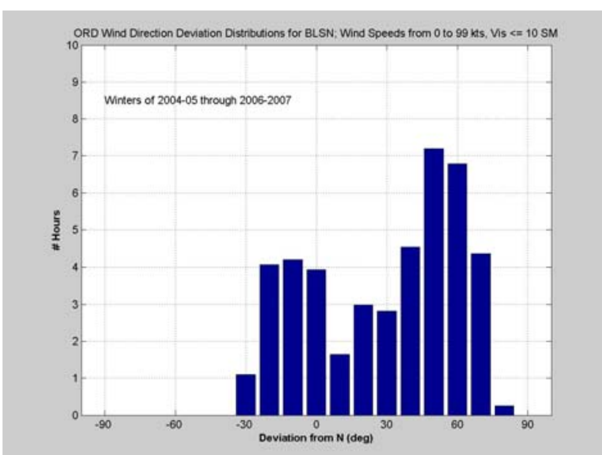

Fig. 24. Histogram of BLSN Frequencies versus Wind Direction Deviation from N for all Wind Speeds.

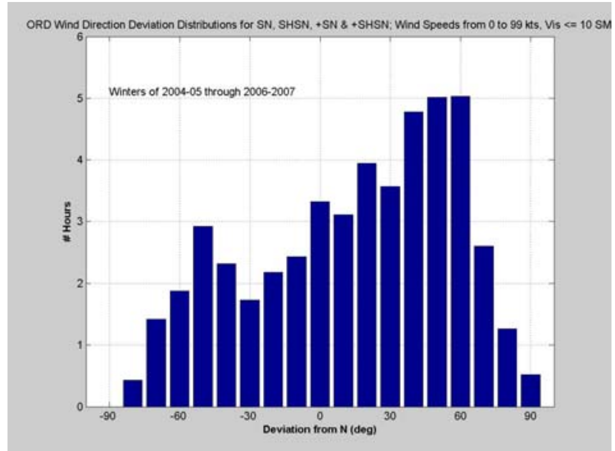

Fig. 25. Histogram of SN/+SN Frequencies versus Wind Direction Deviation from N for all Wind Speeds.

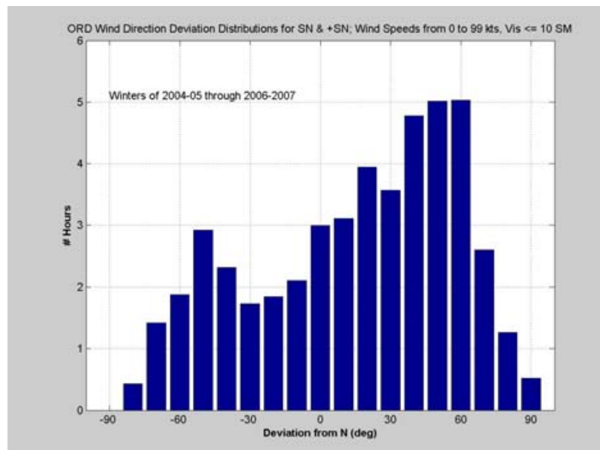

Fig. 26. Histogram of BLSN/SN/+SN Frequencies versus Wind Direction Deviation from N for all Wind Speeds.

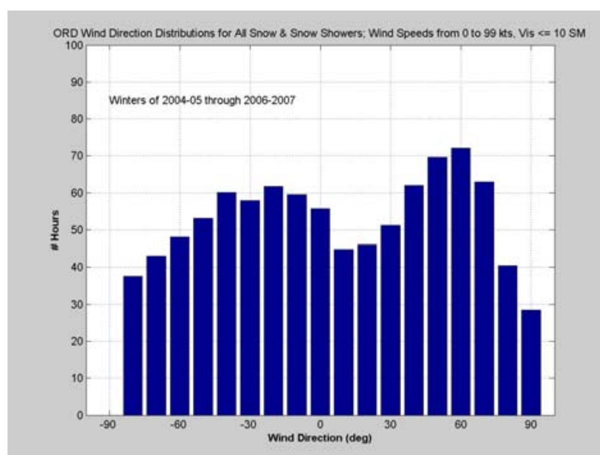

Fig. 27. Histogram of All Snow Frequencies versus Wind Direction Deviation from N for all Wind Speeds.

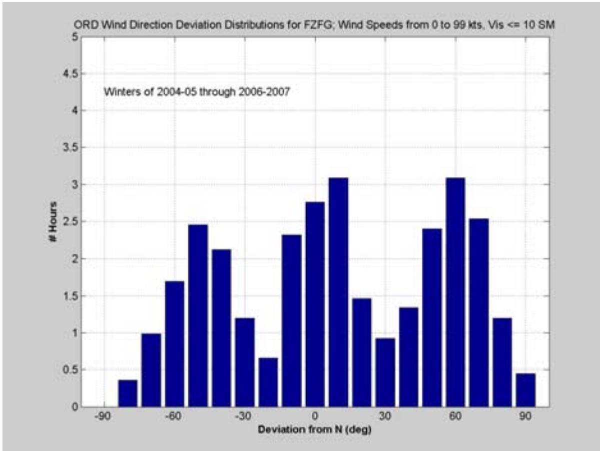

Fig. 28. Histogram of FZFG Frequencies versus Wind Direction Deviation from N for all Wind Speeds.

Sensitivity to Minimum Wind Speed Criteria - Histograms plotted using minimum wind speed criteria described above were also generated. Plots for all snow and FZFG are shown in Figs. 29-31 and 32-33, respectively. The frequencies for all snow decrease for all wind direction deviations and this decrease is most pronounced at deviations 40-80° W and 40-70° E of the N-S line. Figs. 29-31 show that the range of VS orientations with decreased likelihood of all snow impingement widens with increasing minimum wind speeds in the northern and westward directions. The range for FZFG also widens with increased minimum wind speed but from the W-E line. Declines in frequency were most pronounced near the -50° and +60° lines from N. As stated previously, no FZFG was found at minimum wind speeds of 20 kts.

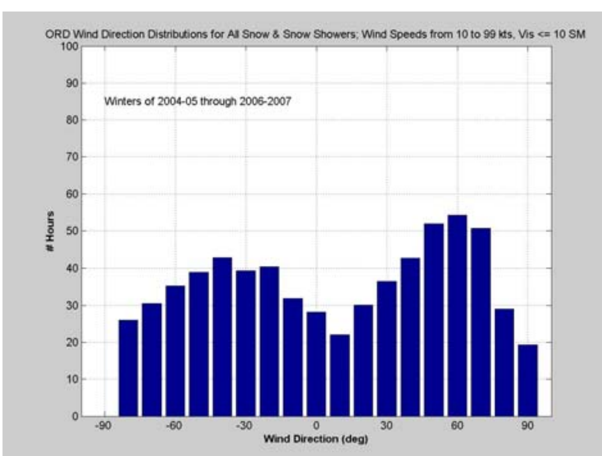

Fig. 29. Histogram of All Snow Frequencies versus Wind Direction Deviation for Wind Speeds ≥ 10 kts.

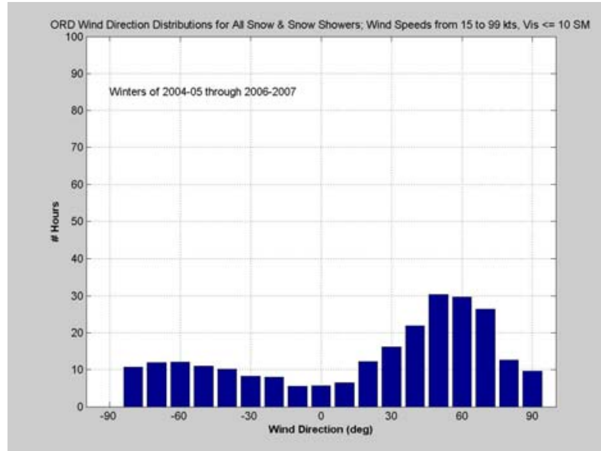

Fig. 30. Histogram of All Snow Frequencies versus Wind Direction Deviation for Wind Speeds ≥ 15 kts.

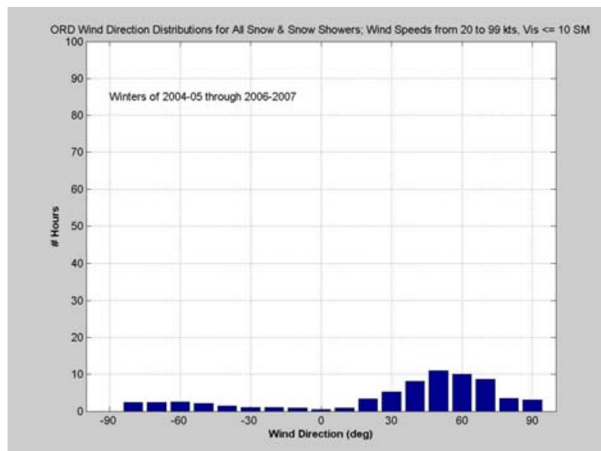

Fig. 31. Histogram of All Snow Frequencies versus Wind Direction Deviation for Wind Speeds ≥ 20 kts.

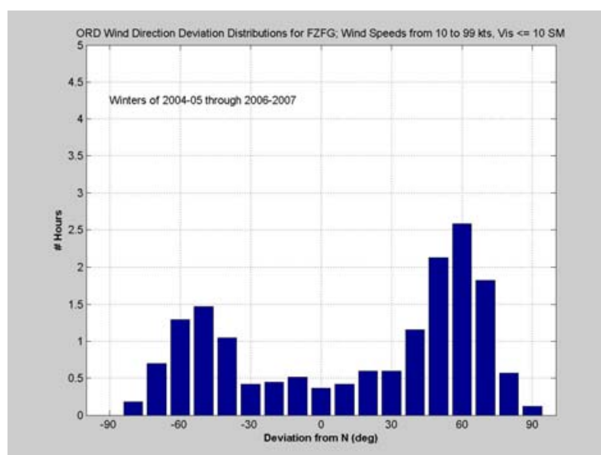

Fig. 32. Histogram of FZFG Frequencies versus Wind Direction Deviation for Wind Speeds ≥ 10 kts.

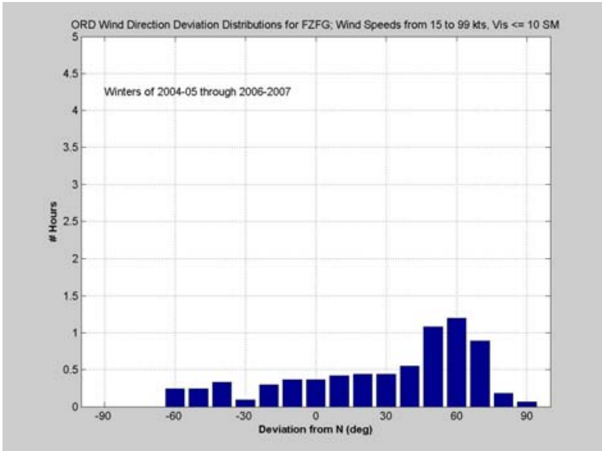

Fig. 33. Histogram of FZFG Frequencies versus Wind Direction Deviation for Wind Speeds ≥ 15 kts.

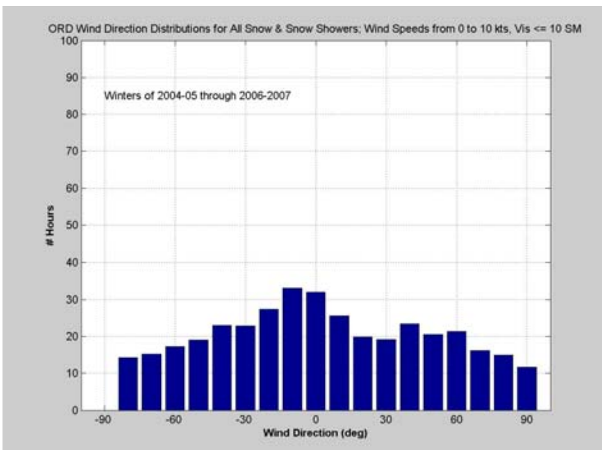

Fig. 34. Histogram of All Snow Frequencies versus Wind Direction Deviation for Wind Speeds 0-10 kts.

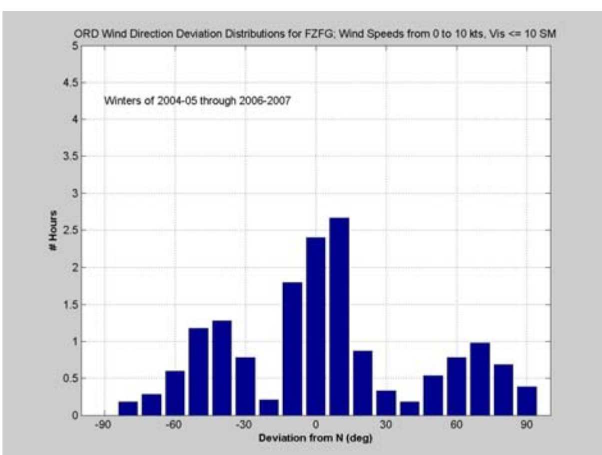

Fig. 35. Histogram of FZFG Frequencies versus Wind Direction Deviation for Wind Speeds 0-10 kts.

Low Winds - Histograms with 0-10 kts wind speed range were also examined. Plots for all snow and FZFG are shown in Figs. 34 and 35, respectively. Orientations near the E-W line appear again to be the least likely to produce sensor impingement from all snow, while N-S orientations appear to be least desirable. FZFG was least frequent at orientations -80°, -20° and 40° from N and most frequent at 10° from N with lesser peaks at -40° and 70° from N. FZFG was considerably less frequent than all snow for all wind direction deviations.

Comparison with Other Airports – METAR data from KCVG, KDEN and KFMH were also processed and plotted to gain some insights into the impact of geographic variations on wind direction distributions. KORD is located ~10-12 mi W of Lake Michigan. The shoreline is oriented NNW. KCVG is located a few mi S and SE of the Ohio River and is ~200 mi NNE of Lake Erie. KDEN is inland, about a mile above mean sea level with only a few small bodies of water nearby. KFMH is located on W Cape Cod with Cape Cod Bay to the NE and Buzzards Bay to the W. Both bays are fairly close to KFMH. Comparisons for all snow and FZFG stated below are for all wind speeds.

The results for KFMH are that a VS orientation near the E-W line, similar to KORD, should minimize potential impingement from all snow and FZFG.

An optimum VS orientation for KDEN may be anywhere between the NE-SW and E-W lines with sharply increased all snow and FZFG frequencies near the N-S line.

VS orientations near ~30° E of the N-S line appear to best minimize potential snow impingement for KCVG. The optimal orientation for mitigating against FZFG is near the E-W line, however.

3. SUMMARY

This paper outlined the procedures for using climatic-type data from three winter periods for orienting VSs to minimize the possibility of snow impingement effects on sensor performance by selecting wind directions with the lowest frequency of SN, +SN, BLSN and FZFG. A sample analysis was presented for KORD. Results suggest that an orientation near the E-W line would best minimize the likelihood of snow impingement. Three other airports were examined demonstrating unique results for each airport. Such differences are expected because snowfall climates will most likely differ due to topography and other geographical characteristics.

The results demonstrate the potential utility of using climatic-type analyses of snowfall to determine preferred orientations of RVR VSs in order to mitigate against possible shadowing and clogging effects. Improvements in the results need to be considered as well. These would include replacing METAR data with one-minute ASOS/AWOS reports and extending the time period to cover a more representative climatic period. The three winters considered in the sample analysis is a tenth of a commonly used 30-year climatologic epoch. Similar analyses spanning the last ten years would be desirable. Consideration should also be given to distributions when wind gusts are reported simultaneously during SN, +SN and/or BLSN and when the wind directions vary rapidly with time.

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