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THREE-DIMENSIONAL AIRFLOW ANALYSIS INSIDE SNOW GAUGE SHIELDING TO DETERMINE SNOW GAUGE COLLECTION EFFICIENCIES

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1. Introduction

Previous studies have established that precipitation gauges, located above ground and freely exposed to the wind, consistently collect lesser amounts of precipitation as compared to gauges protected from the wind (Alter 1937, Goodison et al. 1998, Yang et al. 1998, Rasmussen et al. 2001). Because precipitation gauges cause deformations to the wind field, some hydrometeors that would normally be collected by the gauge are forced over or around the gauge resulting in lower precipitation measurements. Though the ideal measurement location for minimizing wind effects on gauges may be at ground level where wind speed and hydrometeor deflection is small, this requires burying the precipitation gauge so that the orifice opening is level with the surrounding ground surface. While this approach helps decrease wind effects, other effects such as snow drifting and scouring as well as splash in/out from rain can be much more disadvantageous to measurements than attempting to account for wind effects. Additionally, burying the gauge is impractical at many locations, particularly in mountainous environments where the ground tends to be more rock than soil.

Since precipitation rarely occurs in the absence of wind, it is necessary to account for and reduce wind effects on gauge measurements. Wind speeds of just a few meters per second can drastically decrease the amount of precipitation, particularly snow, collected by unshielded gauges. To address the problem of wind effects on gauge measurements collected above ground level, various wind breaks and shielding have been designed. The Alter shield and the DFIR shield are two shields that are commonly used in the United States (figure 1). While each of these shield designs increases the amount of precipitation the gauge collects, each shield collects a different amount of precipitation due to its unique design. In an effort to determine which shield provides the best estimation to ‘truth’, the World Meteorological Organization (WMO) began the Solid Precipitation Measurement Intercomparison Project in 1985 to determine the magnitude of the errors of various shield/gauge combinations (WMO/CIMO 1985, Goodison et al. 1998). The results of the study designated the DFIR shield with a Tretyakov gauge as the standard reference shield/gauge combination (Golubev 1985a-b, Goodison et al. 1998).

Figure 1 – Left) Single Alter Shield, Right) Double Fenced Intercomparison Reference Shield

Though the WMO selected the DFIR shield as the standard, its large size makes it impractical for deployment at various gauge locations, particularly at airports where gauges are commonly located. For this reason, many gauge sites across the United States use an Alter shield around the gauge calibrated to the DFIR/Tretyakov combination. While corrections for various shield/gauge combinations have been developed, it is not fully understood why some shield/gauge combinations produce higher accumulations than others. Since both horizontal and vertical air currents are the likely reason for the accumulation differences, a study was conducted using three-dimensional sonic anemometers to examine the airflow patterns inside different shields (figure 2). Additionally, GEONOR casings were placed around one of the sonics to study the effect of the casing on the airflow patterns (figure 3).

Figure 2 – Example of a three dimensional sonic anemometer deployed inside a single Alter shield.

Four sonic anemometers were used for the study conducted at the National Center for Atmospheric Research's Marshall Instrument Test Site. One anemometer each was placed inside an Alter shield with 18 inch laths, an Alter shield with 18 inch laths and a GEONOR casing, and a DFIR shield with a GEONOR casing. The fourth sonic was placed in the free-stream winds as a reference sonic. Each sonic anemometer was installed at gauge height inside the shield approximately two meters above ground. To minimize the influence each sonic anemometer/shield setup may have on one another, each individual setup was located a minimum of 100 feet from the next. Leveling of the anemometers was done as accurately as possible with a digital level; however, even a minor tilt of the sonic can lead to erroneous vertical and horizontal measurements. Each sonic anemometer collected data for a two week period with a sampling rate of 20 measurements per second after which a planar fit method was used following Wilczak et al., 2001 to correct any further leveling problems with the anemometers. The shields and casings were then installed around the anemometers.

Figure 3 – Example of a three dimensional sonic anemometer deployed inside a single Alter shield with a GEONOR casing.

2. Data Analysis

To ensure the sonic anemometers were calibrated correctly, a comparison was done before shield installation of the horizontal wind speeds versus a co-located propellor anemometer located 3 meters above ground. Figure 4 shows all anemometers in very close agreement with each other.

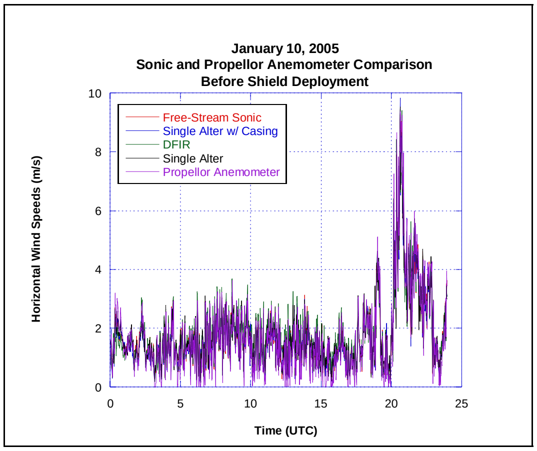

Figure 4 - Propellor and sonic anemometer comparison.

Once the shields were installed around the anemometers, data was collected over a several month period. A case study is shown below with examples of data collected during a snow event. All data was averaged over a five minute time period to reduce noise.

2.A Case Study, 13 March 2005

On March 13, 2005, a snow event was observed beginning at approximately 0315 UTC and accumulating 0.6 inches of liquid before ending around 1730 UTC. Wind speeds throughout the event varied from 1 m/s to 6 m/s. Figure 5 shows a comparison of both the horizontal and vertical winds in the DFIR shield to those of the free-stream sonic anemometer. The horizontal wind speeds in the DFIR are decreased by at least half while vertical wind speeds show very little upward or downward air movement until the end of the event when the DFIR shows a slight upward movement of air.

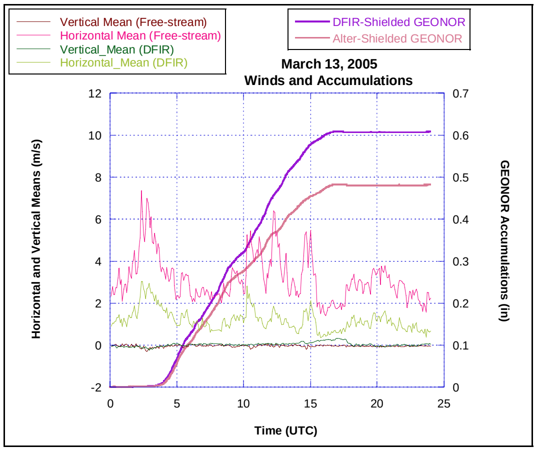

Figure 5 – Horizontal and vertical wind speeds from the DFIR and the free-stream anemometers with overlaid GEONOR accumulations.

Figure 6 shows the horizontal and vertical speeds from both Alter shielded anemometers compared to the free-stream anemometer. Both of these shields track eachother relatively closely in both horizontal and vertical wind speeds though at times the Alter shield without a GEONOR casing decreases the horizontal wind speeds more than the Alter with the casing. Both shields show downward air movement when the free-stream wind exceeds 4 m/s.

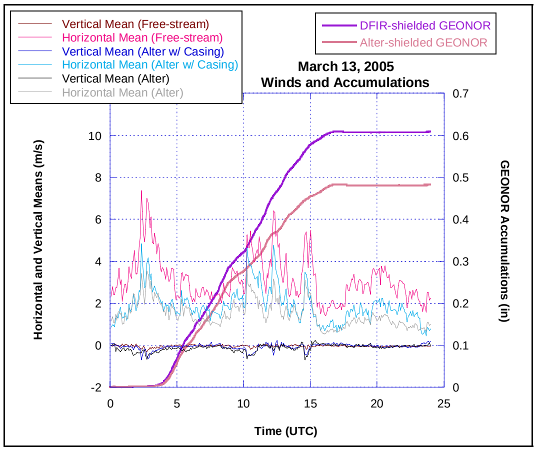

Figure 6 - Horizontal and vertical wind speeds from the Alter, the Alter with a GEONOR casing and the free-stream anemometers with overlaid GEONOR accumulations.

Since higher wind speeds seem to induce downward air movement within the Alter shields, but not the DFIR, vertical wind speed data from all three shields was compared against the horizontal winds of the free-stream anemometer. Figure 7 shows these results. It is clear that the DFIR shows little variability in with vertical winds, while both the Alter shields show increasing downward moving air as horizontal wind speeds increase. The likely reason for this is the design of the Alter shield forcing air down as higher horizontal wind speeds cause the laths to swing in towards the anemometer .

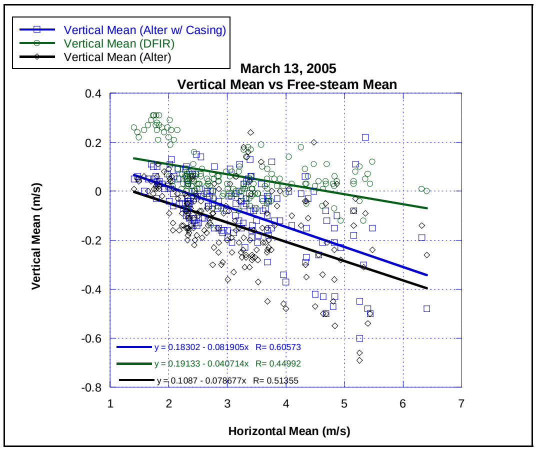

Figure 7 – Scatter plot of vertical wind speeds from anemometers inside the Alter and DFIR shields vs the horizontal wind speeds from the free-stream sonic anemometer.

To further understand what may be going on inside the shields, the standard deviation of the vertical winds was calculated and plotted in figure 8. Interestingly, the DFIR had the highest standard deviation. The Alter shields were very similar to each other throughout the event. They also matched the DFIR closely during relatively low horizontal wind speeds (< 4 m/s), but have a lower standard deviation during higher wind speeds.

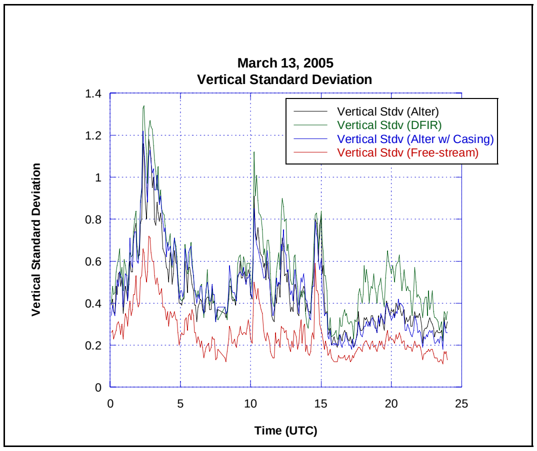

Figure 8 – Standard Deviation of the vertical winds inside the shields.

3. Results

The March 13, 2005 case study provides some preliminary results of airflow tendencies within the Alter and DFIR shields. The DFIR appears to decrease horizontal winds by 1/2 to 2/3 from ambient. The DFIR also appears to have little bias towards upward or downward moving air as evidenced in figure 5. However, the DFIR has the highest standard deviation as seen in figure 8. This would seem to indicate a high degree of turbulence inside the shield.

Both Alter shields decrease the horizontal winds by approximately 1/3 of the ambient wind speed as seen in figure 6. The horizontal wind speeds in the Alter shield with the GEONOR casing do appear to be somewhat affected by the casing as the winds are not always as low as the Alter shield without the casing. However, there appears to be little to no effect from the casing in the vertical winds. Also, figure 7 clearly shows a downward bias in vertical measurements with increasing horizontal wind speeds. While the vertical wind speed standard deviations for both shields are similar to the DFIR for horizontal wind speeds < 4 m/s, the increasing downward movement of air for wind speeds greater than 4 m/s seem to have a negative effect on accumulations as seen in figures 5 and 6 where single Alter accumulations are not increasing as quickly as the DFIR accumulations.

4. Conclusions

While the DFIR clearly accumulates more precipitation than the single Alter, there appears to be a combination of reasons for it. While both shields act to decrease horizontal winds, the DFIR decreases the horizontal wind more than the Alter. The vertical wind speeds in the DFIR show little to no bias towards upward or downward air movements regardless of wind speed. The Alter shields seem to have a small downward vertical wind speed bias for horizontal wind speeds < 4 m/s, but show stronger downward motions during periods when the ambient horizontal wind speeds exceed 4 m/s.

The high standard deviation values for the DFIR appear to be indicative of turbulence within the shield. While the Alter shields also have matching vertical standard deviations to the DFIR for ambient horizontal wind speeds < 4m/s, the standard deviation isn't as high as the DFIR when wind speeds are greater than 4 m/s.

Based on this case study, we speculate that the DFIR shield collects more snow because it slows the horizontal wind speeds more than the Alter shields (as evidenced in both figures 5 and 6). We also speculate that the downward air movements inside the Alter shields have a negative effect on gauge collection as gauge accumulations from the Alter shield were noticeably less than the DFIR during times where horizontal wind speeds exceeded 4 m/s.

Analysis of more case studies is planned to test these conclusions. Additionally, rain events will be examined to see if precipitation type plays a role in the downward air movement seen in the Alter shields. Additional shields will also undergo a similar study.

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