COMPARISON OF PRECIPITATION RATE INTENSITIES AS DETERMINED BY VISIBILITY VERSUS LIQUID WATER EQUIVALENT MEASUREMENTS

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1. Introduction

Currently, precipitation intensity (light, moderate, and heavy) is determined on the Automated Surface Observing System (ASOS) by using visibility. This method of diagnosing intensity can misrepresent the actual precipitation rate because it doesn't directly measure the precipitation water content. Thus, an alternative method for determining precipitation intensity should be considered. Liquid Water Equivalent (LWE) instruments measure the amount of liquid water in precipitation to determine intensity. The amount of liquid water collected by these instruments relates directly to the performance of aircraft de/anti-icing fluids. LWE rates are also used in the holdover timetables for ground de-icing to determine the maximum allowable time between de-icing and take-off. These tables are issued by Society of Automotive Engineers (SAE) International. This study examines how ASOS precipitation intensities compare to LWE gauge precipitation intensities.

2. ASOS Intensity

The ASOS visibility algorithm is based on the principle that heavier precipitation rates yield lower visibility. The thresholds for determining the precipitation intensity from visibility are given in Table 1 as stated in the Federal Meteorological Handbook No. 1 (FMH-1).

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Intensity	Criteria
Light	Visibility > 0.805 km
Moderate	0.805 km > Visibility > 0.402 km
Heavy	Visibility < 0.402 km

Table 1 - Intensity of Snow or Drizzle based on the FMH-1 (2005).

3. LWE Intensity

An LWE instrument determines the amount of liquid present in falling precipitation from which a rate and an accumulation can then be calculated. The two types of LWE precipitation gauges used for this comparison are the GEONOR in a Double Fenced Intercomparison reference (DFIR) shield (Figure 1) and the Yankee Environmental Systems Inc. Hotplate (Figure 2). Precipitation rates calculated from snow pan data were also collected according the SAE International guidelines for de/anti-icing fluid testing and used in this analysis. Table 2 gives the thresholds for determining the intensity of precipitation from an LWE precipitation rate.

Figure 1 - GEONOR precipitation gauge in a DFIR shield.

Figure 2 - Yankee Environmental Systems Inc. Hotplate precipitation gauge.

Intensity	Criteria
Light	1.0 mm/hr > Precip Rate > 0.4 mm/hr
Moderate	2.5 mm/hr > Precip Rate > 1.0 mm/hr
Heavy	Precip Rate > 2.5 mm/hr

Table 2 - Intensity of Snow determined by an LWE precipitation gauge.

4. Comparison of ASOS precipitation intensity algorithm to precipitation intensity of an LWE gauge

4.1 Snow Pan Data

The first comparison was conducted with instruments deployed at the National Center for Atmospheric Research (NCAR) Marshall Field Site in Boulder, Colorado. Manual snow pan measurements were collected at this site during the 2007-2008 winter season. The snow pan data collection procedure followed guidelines set by the SAE for conducting holdover timetable tests. Snow pan data were collected every 10 minutes with one pan horizontal to the ground and a second pan inclined at a 10° angle from horizontal to simulate an airplane wing. Both pans were rotated into the prevailing wind direction at the beginning of each 10-minute observation. A LWE precipitation rate over the 10-minute observation period was calculated from the collected snow pan data. Visibility data taken from a Viasala PWD22 were averaged over the same 10-minute time period the snow pan data were collected. The precipitation rate from a GEONOR in a DFIR shield (referred to as the DFIR) was also compared to the PWD22 visibility by averaging the snowfall rate over the same time period as the snow pan observations.

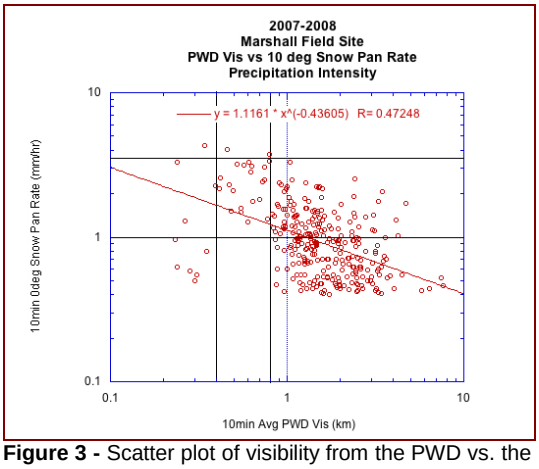

Figure 3 - Scatter plot of visibility from the PWD vs. the rate from the 10° snow pan.

Figure 3 shows a scatter plot of the visibility from the PWD22 versus the rate from the 10° snow pan. The intensity thresholds for visibility are shown as black vertical lines, from heavy to light in the increasing x-direction, and as black horizontal lines for LWE rates, from light to heavy in the increasing y-direction. The visibility algorithm categorizes the majority of the data as light precipitation intensity. Examination of the 'light' intensity data points classified by visibility show that the corresponding rates from the 10° pan range from light to moderate intensity. The data points that fall into the light visibility category and the moderate snow pan category are examples where using visibility-based estimates is hazardous to aviation because the amount of liquid in the precipitation is underestimated. Additional comparisons for the 0° snow pan and DFIR rates verses visibility intensity are shown in Figures 4 and 5 with similar results. As with the 10° snow pan, a large number of visibility intensity data points underestimate the amount of liquid water present. These plots also show the large amount of scatter in the relationship between visibility and LWE precipitation rate.

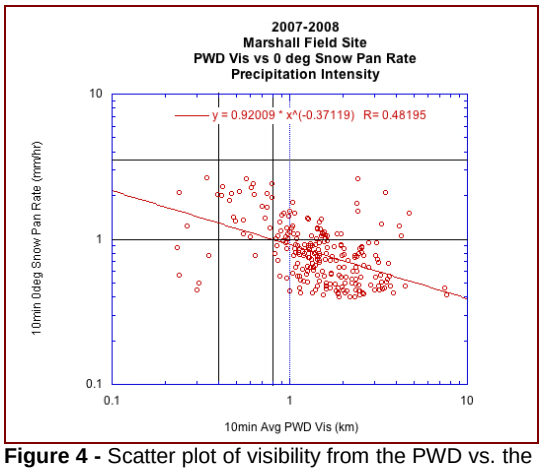

Figure 4 - Scatter plot of visibility from the PWD vs. the rate from the 0° snow pan.

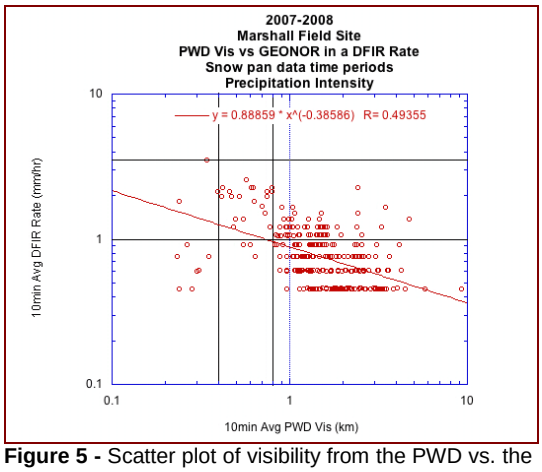

Figure 5 - Scatter plot of visibility from the PWD vs. the rate from a GEONOR in a DFIR shield for the same time periods as the snow pan data.

Tables 3, 4, and 5 show statistics of visibility and LWE that correspond to the scatter plots previously presented. H is heavy precipitation, M is moderate, and L is light. The cells are color-coded with pink indicating visibility intensities that underestimate the liquid precipitation, green indicating when the visibility and LWE intensities agree, and yellow where the visibility over-estimated the intensity. The pink cells are of most concern to aviation safety. The comparison of the PWD22 versus the 10° snow pan shows that 38% of the data points fall in to these hazardous conditions. Similarly, a comparison with the 0° snow pan yields 20%, and the DFIR yields 20% of the data points in unsafe conditions.

4.2 Multiple Sites and Instrumentation

The second comparison evaluates visibility measurements from different sensors compared to precipitation rates from various precipitation gauges at multiple sites. These sites are the Marshall field site (MAR), Denver International Airport (DIA) instrumentation site 1 (DIA1), and DIA instrumentation site 2 (DIA2). The dataset contains only snow events from the 2007-2008 winter season. Ten-minute running averages of the precipitation rate from the LWE gauge and the visibility sensor over the same time periods were calculated.

10deg SNOW PAN vs. FHM1 PWD					
#	#	FHM1 PWD Vis Based Intensity			
#	#	H	M	L	TOTAL
10deg SNOW PAN	H	0.69%	3.78%	0.69%	5.15%
Based	M	0.69%	3.78%	33.68%	38.14%
Intensity	L	2.06%	0.00%	54.64%	56.70%
TOTAL		3.44%	7.56%	89.00%	100.00%
TOTAL COUNT:	291				

Table 3 - Statics from PWD visibility vs. 10° snow pan rate intensities, calculated as percent of data points that fall into each category.

0deg SNOW PAN vs. FHM1 PWD					
#	#	FHM1 PWD Vis Based Intensity			
#	#	H	M	L	TOTAL
0deg SNOW PAN	H	0.42%	0.42%	0.42%	1.27%
Based	M	1.27%	8.47%	19.49%	29.24%
Intensity	L	2.12%	0.42%	66.95%	69.49%
TOTAL		3.81%	9.32%	86.86%	100.00%
TOTAL COUNT:	236				

Table 4 - Statistics from PWD visibility vs. 0° snow pan rate intensities, calculated as percent of data points that fall into each category**.**

DFIR vs. FHM1 PWD					
#	#	FHM1 PWD Vis Based Intensity			
#	#	H	M	L	TOTAL
DFIR	H	0.35%	0.35%	0.00%	0.70%
Based	M	0.70%	6.32%	19.65%	26.67%
Intensity	L	2.46%	1.05%	69.12%	72.63%
TOTAL		3.51%	7.72%	88.77%	100.00%
TOTAL COUNT:	285				

Table 5 - Statistics from PWD visibility vs. DFIR rate intensities, calculated as percent of data points that fall into each category.

4.2.1 Marshall Field Site Data

At MAR, the LWE rate was calculated from a GEONOR in a DFIR (referred to as DFIR) and then compared to visibility data from a Vaisala PWD22. Figure 6 displays a scatter plot of the 10-minute average PWD22 visibility versus the 10-minute average precipitation rate from the DFIR. The intensity thresholds are the same as previous plots. This plot shows similar results as the snow pan comparison. The visibility underestimates the precipitation rate a large percent of the time, including the indication of light or moderate intensities when the LWE rate shows that these data points were heavy. This plot also displays the large amount of scatter in the data and that the correlation between visibility and LWE rate is not a strong one. The statistics from Table 6, similar to the tables used in the previous analysis, show that visibility underestimated the precipitation intensity 15% of the time during snow events.

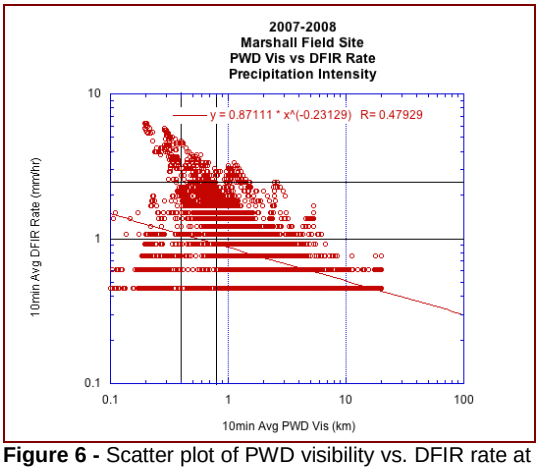

Figure 6 - Scatter plot of PWD visibility vs. DFIR rate at Marshall Field site.

4.2.2 Denver International Airport Instrumentation Site 1

The DIA1 dataset uses the LWE rate from a Yankee Environmental Systems Hotplate and visibility from a Biral HSS sensor. Figure 7 shows a scatter plot, of the 10-minute visibility from the HSS versus the 10-minute LWE rate from the Hotplate. There is a slightly better correlation between the hotplate rate and the HSS visibility than

seen in the previous comparisons. The visibility continues to underestimate the precipitation intensity for a number of data points. There is also a large amount of scatter in this comparison. The statistics in Table 7 show that visibility underestimated the precipitation intensity 10% of the time during snow events.

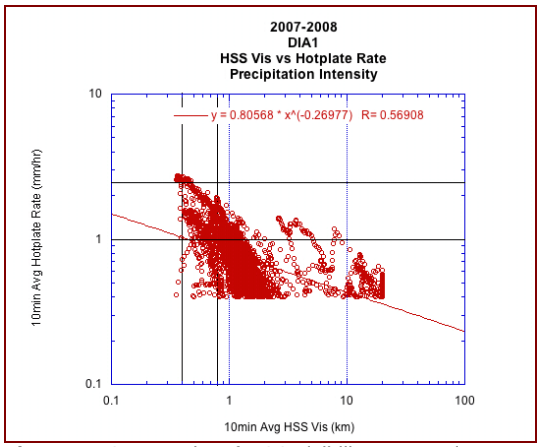

Figure 7 - Scatter plot of HSS visibility vs. Hotplate rate at DIA1.

4.2.3 Denver International Airport Instrumentation Site 2

This comparison used visibility data from the Denver ASOS which is located on the east side of the airport and the LWE rate from a GEONOR in a DFIR at DIA2 which is located on the west side of the airport (approximately 4 miles apart). ASOS uses a Belfort sensor for visibility measurements. The scatter plot in Figure 8 displays Denver ASOS 10-minute average visibility verses the DIA2 DFIR 10-minute average rate. The plot again shows that visibility underestimates the precipitation intensity and that there is a large amount of scatter in the correlation. The underestimation occurs 6% of the time during snow events.

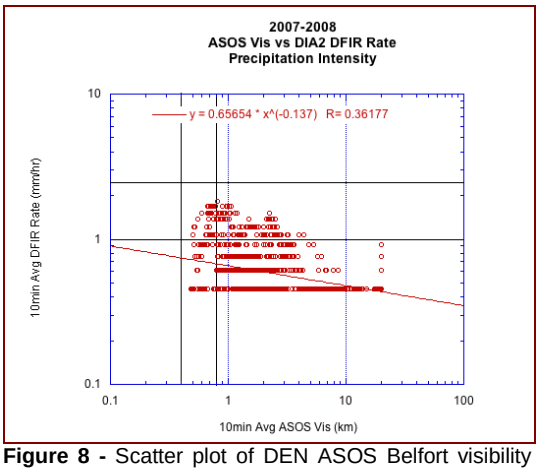

Figure 8 - Scatter plot of DEN ASOS Belfort visibility vs. DFIR rate at DIA2

5. Results

These comparisons show that visibility is not an accurate measure of precipitation rate due to the amount of scatter in the data. In addition, the use of a visibility-based precipitation intensity instead on an LWE rate-based intensity can lead to hazardous conditions for aviation by underestimating the amount of liquid in the precipitation.

Future studies will include comparison of the intensity output by an LWE system algorithm, which uses multiple instruments to calculate a precipitation intensity and visibility from a PWD22 that is co-located at the site. Evaluations of the intensity from LWE systems deployed at Chicago's O'Hare International Airport and Cleveland's Hopkins International Airport with visibility from the nearest ASOS will also be conducted. Similar comparisons to those presented here will be conducted for drizzle, freezing drizzle, and freezing rain conditions.

DFIR vs. FHM1 PWD					
#	#	FHM1 PWD Vis Based Intensity			
#	#	H	M	L	TOTAL
DFIR	H	1.36%	1.23%	0.63%	3.22%
Based	M	1.53%	5.86%	13.17%	20.56%
Intensity	L	4.96%	1.19%	70.07%	76.22%
TOTAL		7.86%	8.28%	83.87%	100.00%
TOTAL COUNT:	9254				

Table 6 - Statistics from MAR PWD visibility vs. DFIR rate intensities, calculated as percent of data point that fall into each category.

Hotplate vs. FHM1 HSS					
#	#	FHM1 HSS Vis Based Intensity			
#	#	H	M	L	TOTAL
Hotplate	H	0.74%	0.33%	0.00%	1.08%
Based	M	0.22%	14.16%	9.70%	24.08%
Intensity	L	0.15%	5.83%	68.86%	74.84%
TOTAL		1.11%	20.33%	78.56%	100.00%
TOTAL COUNT:	2691				

Table 7 - Statistics from DIA1 HSS visibility vs. Hotplate rate intensities, calculated as percent of data points that fall into each category.

DIA2 DFIR vs. FHM1 DEN ASOS					
#	#	FHM1 DEN ASOS Vis Based Intensity			
#	#	H	M	L	TOTAL
DFIR	H	0.00%	0.00%	0.00%	0.00%
Based	M	0.00%	2.65%	6.15%	8.80%
Intensity	L	0.00%	3.24%	87.96%	91.20%
TOTAL		0.00%	5.89%	94.11%	100.00%
TOTAL COUNT:	1512				

Table 8 - Statistics from DEN ASOS visibility vs. DIA2 DFIR rate intensities, calculated as percent of data point that fall into each category.

6. Acknowledgements

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7. References

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