7.3 DEVELOPMENT OF THE ALL-WEATHER PRECIPITATION ACCUMULATION GAUGE FOR ASOS

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1. INTRODUCTION

The Frise heated tipping bucket (HTB) is the standard liquid precipitation accumulation gauge used with the Automated Surface Observing System (ASOS). The sensor measures liquid accumulation, but is not specifically designed to accurately measure freezing or frozen precipitation. The accurate measurement of liquid equivalent accumulations in all types of liquid, freezing, solid, and mixed precipitation is an important part of weather observations. The National Weather Service (NWS) ASOS Product Improvement (PI) team conducted concept exploration testing of commercially available all-weather precipitation accumulation gauges (AWPAG) over four winter seasons beginning in 1996. Based on the results of those tests, a determination was made that improved technology was available to replace the existing ASOS Frise tipping bucket with a total precipitation gauge.

A contract for design and development of ten pre-production gauges was awarded in September 2001, to C.C. Lynch and Associates of Pass Christian, Mississippi, in partnership with Ott Hydrometry of Kempton, Germany. In 2002 field testing of four early prototype gauges, which included the most significant proposed performance modifications, demonstrated improvements in gauge catch, accuracy, increased capacity, and communications. Qualification testing of gauges was conducted during the winter of 2002 - 2003, at test sites located in Sterling, Virginia and Johnstown, Pennsylvania. This paper presents the results of the qualification testing. At the conclusion of testing, a contract option was awarded for 20 limited production AWPAGs. Operational Acceptance Testing (OAT) was conducted at selected ASOS sites across the United States. This paper also presents the results of the OAT.

2. TEST APPROACH

The qualification testing was conducted at the Sterling, VA and Johnstown, PA test sites. One minute data were collected from all test sensors using a personal computer based data acquisition system (DAS). Frise HTB data were included in the data collection. Data from all ASOS sensors at Sterling and Johnstown were available for use in post-processing. Typical reference weather sensors include the following: freezing rain, visibility, temperature/dew point, wind speed and direction, precipitation identification, and ceilometer. Additionally, a heated sonic anemometer was installed at gauge orifice height in proximity to the precipitation gauges to assess wind-induced effects. These reference data were used in post-processing, in verifying any false precipitation reports from the test gauges, and in case study analyses.

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2.1 Performance Requirements

The hydro-meteorological performance requirements for the NWS AWPAG (Specification No. D113-SP001) are summarized as follows:

1. The AWPAG response shall be linear over the entire measurement range, with an accuracy of ±4% or ± 0.02 inch, whichever is greater, when compared to a standard National Weather Service 8-inch non-recording precipitation gauge installed at the standard height with a National Weather Service Alter shield. Comparisons will be made on hourly accumulations and event accumulations.

2. When compared to the standard National Weather Service 8-inch non-recording gauge described above, the AWPAG shall not false report (report accumulation in the absence of precipitation) more than 0.09 inches for a single, continuous 30-day period. The goal is that there be no false reports.

3. It is recognized that smoothing or filtering algorithms may be required in order to reduce false precipitation reports. If such algorithms are required, the maximum acceptable delay in reporting of precipitation due to filtering shall be five (5) minutes.

2.2 Sensor Description

2.2.1 Ott AWPAG

Two 56-inch capacity AWPAGs were tested at each site. Figure 1 depicts an installation of an AWPAG that would be typical at an ASOS site, including mounting on a 3-inch pipe, 18 inches high, with a free standing Tretyakov windshield one-half inch above the 59-inch orifice height.

Figure 1 Ott AWPAG

2.2.2 Frise Heated Tipping Bucket (HTB)

Two standard ASOS Frise HTBs (Figure 2), were used as comparison sensors for this test. The Frise tipping bucket gauges were not used to evaluate measurement accuracy of the AWPAGs, but provide data for assessing improvements to ASOS precipitation measurements as a result of AWPAG deployment. Frise gauge data were also used as an aid to determine false reports. The HTBs were installed with the standard ASOS vinyl wind shields one inch above the orifice height.

Figure 2 Frise tipping bucket gauge

2.2.3 NWS 8 inch guage

Four standard NWS 8-inch non-recording gauges were used for reference measurements of all types of precipitation at each test site. For each test site, two of the gauges were designated as hourly references and two as event reference gauges. At Sterling and Johnstown, the orifice height was five feet. Alter-style wind shields were installed one inch above the orifice height on all of the reference gauges.

3. DATA ANALYSIS

Data were analyzed on an event-by-event basis and an hour-by-hour basis, and reference gauge data was used to validate each event prior to AWPAG evaluations. The reference gauges were located on opposite sides of the test bed and outward from the test gauges to bracket each test bed to verify uniform spatial distribution of precipitation over the test bed. Data from the reference gauges were compared and a valid event was defined as an event in which the two event reference gauges agree within the greater of ±4% or ±0.02 inches of each other.

Wind speed data at orifice height in each test bed was used in conjunction with the reference gauge measurements to validate results. Wintry events with wind speeds at orifice height that exceed approximately 10 knots required scrutiny to eliminate possible contaminated results. For example, if blowing snow was a factor during the event, causing the reference gauge measurements to be non-uniform (difference exceeds the greater of ±4% or ±0.02 inch), the event was not used in the statistical results.

In addition, AWPAGs underwent Operational Acceptance Testing (OAT) at selected ASOS sites in 2003 by comparing collocated Frise HTBs in liquid precipitation.

4. RESULTS

4.1 Qualification Test Results

The results of the hourly comparisons show that the Ott AWPAGs were within the NWS accuracy requirements nearly 100% of the time. A total of 430 hourly observations were taken, with 303 of these classified as frozen or mixed precipitation and 127 as liquid precipitation. One AWPAG at Johnstown (#085), was 0.03 inches low (0.02 vs 0.05) on one hourly observation. The other AWPAG at Johnstown (#087) was non-compliant for one hourly comparison because of under-reporting by 0.03 inches (0.03 vs 0.06).

Fifty events were evaluated in this test comprising a total of 100 AWPAG comparisons. Of these 100 comparisons, 76% of the AWPAG event totals met the NWS AWPAG reporting requirements. The gauges did not over-report, but were non-compliant 24% of the time because of under-reporting. The amount of under-reporting averaged 3.5 to 4.5% among the AWPAGs. Overall, the comparison ASOS HTBs met the same requirements for event totals only 52% of the time during the test and under-reported by an average of 9.5 to 25%. Table 1 summarizes the results at Sterling and Table 2 summarizes the results at Johnstown.

Sterling Event Comparisons										
	Total		Liquid		Freezing		Frozen		Mixed	
Test Gauge	# of Events	% pass	# of Events	% pass	# of Events	% pass	# of Events	% pass	# of Events	% pass
AWPAG #088 *	22	73	16	81	1	100	3	67	2	0
AWPAG #089	40	73	28	79	1	0	9	78	2	0
AWPAG #754	18	78	12	83	0	--	6	67	0	--

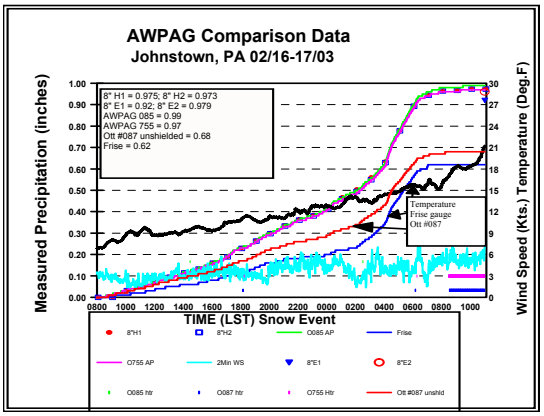
Table 1 Sterling Event Comparison

Johnstown Event Comparisons										
	Total		Liquid		Freezing		Frozen		Mixed	
Test Gauge	# of Events	% pass	# of Events	% pass	# of Events	% pass	# of Events	% pass	# of Events	% pass
AWPAG #085	10	80	0	--	1	100	7	71	2	100
AWPAG #087 *	3	67	0	--	1	100	2	50	0	--
AWPAG #755	7	100	0	--	0	--	5	100	2	100

Table 2 Johnstown Event Comparison *AWPAGs 088 and 087 were replaced by limited production 754 and 755 respectively in Jan 2003.

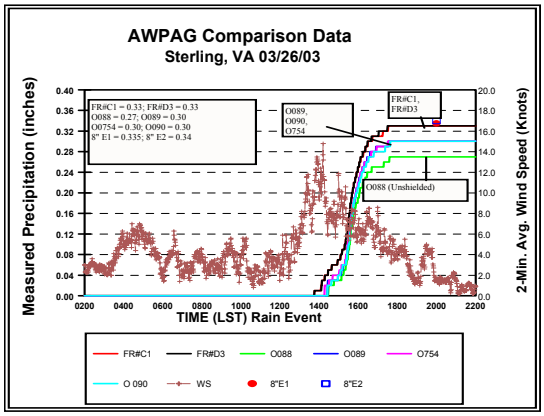
The AWPAGs met the requirements for false reports 100% of the time. A limited production gauge was installed at Johnstown during a very cold, blowing snow event. For 10 days after installation, this gauge exhibited a tendency to report false accumulations; but after a thawing period in early February 2003, the gauge met the requirements for false reports in the remainder of the test. Snow and ice had apparently intruded into a critical area of the weighing mechanism during installation. This indicates that installation and maintenance of AWPAGs should only be performed in fair weather conditions. The following charts are case studies of events in Sterling and Johnstown.

Case study 1 is a heavy snow event at Johnstown which shows the comparability of the AWPAG to the hourly reference measurements. AWPAG #085 reported 0.99 inches and AWPAG #755 reported 0.97, while the two hourlies reported 0.975 and 0.973 inches. AWPAG #087 (unshielded for this event) reported a much lower result of only 0.68 inches. The HTB which typically under reports in snow, also came in much lower at only 0.62 inches.



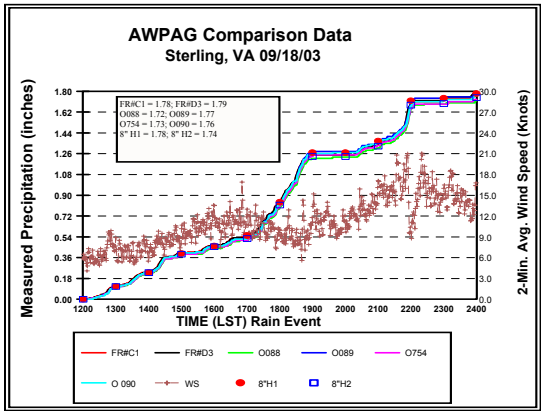
Case Study 1 Johnstown Snow Event

Case Study 2 is a light rain event at Sterling. Both AWPAGs reported 0.30 inches, slightly less than the HTBs 0.33 inches. This was an identified problem with Firmware 3.55 and has since been addressed in version 3.58. We hope to present data on version 3.58 at the AMS conference. The unshielded AWPAG #088 reported much less than the Frise HTBs. Shields are absolutely necessary for proper measurements.



Case Study 2 Sterling Light Rain Event

Case Study 3 is a heavy rain and high wind event at Sterling. This event demonstrates comparability of the AWPAG to the hourly reference data. AWPAG #088 reported 1.72 inches and AWPAG #089 reported 1.77 inches, while the two reference measurements were 1.78 inches and 1.75 inches. High winds did not result in lower accumulations by the AWPAGs.



Case Study 3 Sterling Heavy Rain Event

4.2 Operational Acceptance Test Results

The Operational Acceptance Testing (OAT) validated the Sterling and Johnstown testing and demonstrated operational compliance when compared to the HTB during liquid precipitation events. The data from ten ASOS OAT sites with collocated AWPAGs and HTBs were analyzed. Table 3 is the data set for all cases and sites.

Total Accumulations and Differences (inches)				
03/06/03 - 08/01/03				
Site	Minutes	AWPAG Total	HTB Total	Diff
KABR	1646	5.34	5.3	0.04
KAMA	1681	4.68	4.76	-0.08
KAVP	12264	15.31	13.81	1.5
KBOI	4138	2.1	2.28	-0.18
KGRB	6431	5.22	5.38	-0.16
KLAN	4710	6.63	6.5	0.13
KMCN	9135	25.12	24.68	0.44
LPWM	12171	8.16	7.81	0.35
KSPI	7272	12.4	12.43	-0.03
KTRI	11536	22.27	21.92	0.35
Total	70984	107.23	104.87	2.36

Table 3 OAT Data Set

In light rain events where accumulation was less than or equal to 0.1 in/hr, 106 cases and nearly 53,000 minutes of data were collected. There is a negligible difference between the AWPAG and HTB.

Chart 1 shows the results for light rain events. The x-axis represents the difference between the AWPAG and the HTB. The y-axis represents the number of events. The chart is nearly symmetrical.

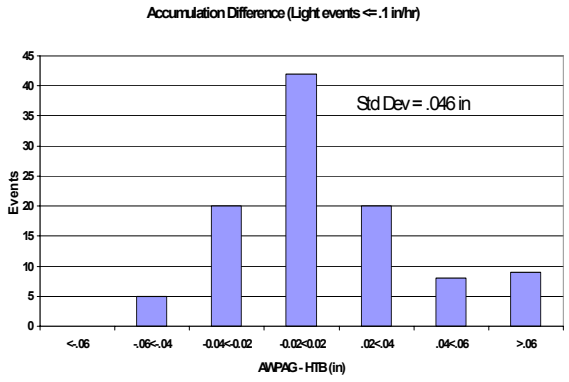


Chart 1 Light Rain Events

In Moderate and Heavy events where accumulation rates exceeded 0.1 in/hr, 94 cases and nearly 18,000 minutes of data were collected. The AWPAG has a slightly higher accumulation than the HTB.

Chart 2 shows the results of moderate and heavy rain events. This chart is asymmetrical, indicating the higher totals for the AWPAG.

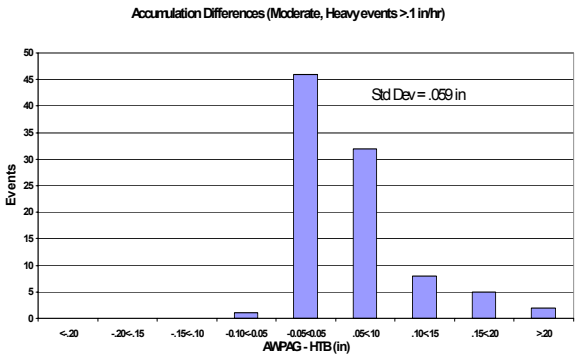
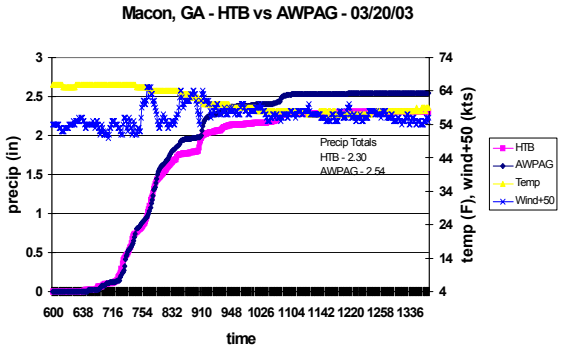


Chart 2 Moderate and Heavy Events

Summing all events at all locations shows only a slightly higher accumulation in the AWPAG. The higher accumulations occurred in moderate and heavy events.

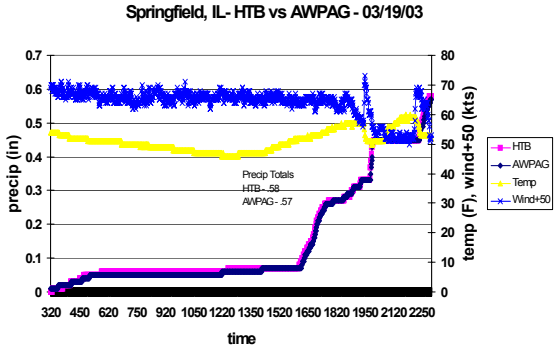
The following case studies were selected from the ten OAT sites, which were originally chosen for climatic diversity.

Case study 4 is a very heavy rain event. The AWPAG outperformed the HTB. Neither wind or temperature appear to affect the AWPAG in this case.



Case Study 4 Heavy Rain Event

Case Study 5 is a moderate rain event in which the winds and temperature show large fluctuations. The AWPAG performs very well. There is a negligible under-catch due to the rapid temperature drop, but this issue has been addressed in Firmware version 3.58. False accumulation due to high winds was addressed in version 3.55 and is no longer a problem.



Case Study 5 Moderate Rain Event

5. CONCLUSIONS

Testing at Sterling and Johnstown as well as operational testing at 10 ASOS sites has shown that the AWPAGs can meet the NWS hourly requirements, but not always meet the event requirements due to slight under-reporting. The AWPAGs performed well in moderate to heavy precipitation events and under-reported in light precipitation. Initial testing of new firmware version 3.58 has shown promise by increasing sensitivity without inducing false reports. New data may be presented at the conference. Shields are absolutely necessary for proper measurements. AWPAGs outperformed HTBs in liquid events and are expected to far surpass the HTBs in ASOS for freezing and frozen precipitation.

6. ACKNOWLEDGMENT

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