J4.4 OPERATIONAL TESTING OF VARIOUS PRECIPITATION SENSORS IN SUPPORT OF THE UNITED STATES CLIMATE REFERENCE NETWORK (USCRN)

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1. INTRODUCTION

The U.S. Climate Reference Network (USCRN) is a NOAA-sponsored network being implemented to provide climate data for climate monitoring and other applications. Reliable, high quality precipitation data are necessary to detect climate change and to validate climate projections and climate models. Approximately 100 CRN sites are being installed nationwide. The National Climatic Data Center (NCDC) in Asheville, N.C., has conducted field tests of various precipitation gauges and shields in support of the CRN network since November 2003. These tests have been conducted at NOAA/National Weather Service (NWS) research sites at Sterling, Virginia, and at Johnstown, Pennsylvania. Precipitation gauges being evaluated include the Geonor, Frise, Ott AWPAG, TB3, and non-recording 8-inch gauges. The Geonor and Ott gauges are weighing gauges; the Frise and TB3 are tipping bucket gauges. Various gauge shields are being evaluated. These include the Alter, Double Alter, Tretyakov, SDFIR (Small Double Fence Inter-Comparison Reference) and the Large DFIR. Results of gauge and gauge/shield comparisons are presented. Results differentiated by warm and cold seasons are included. Also, comparisons for 60-minute maxima are presented. The performance of the Geonor gauge, selected as the primary CRN gauge, is of particular interest. A table of site gauge configurations is included.

There are five areas of evaluation. First is the overall comparison of the Geonor gauge to the other test gauges for the entire test period (16 months). Second is the evaluation of gauge functioning during warm and cold seasons. Third is an examination of the various gauge/shield combinations. Fourth is an evaluation of gauge functioning under high-intensity, short-term events (60 minutes). Finally, there is a brief examination of temperature and wind speed on gauge comparisons. The following discussions and data address these areas.

2. DATA AND PROCEDURES

Precipitation, wind and temperature data at one-minute intervals were collected at the two test sites, Johnstown and Sterling. Data were collected from November 2003 through March 2005. Data were summarized and processed in 24-hour totals. Average wind speed, temperature, wind gust and precipitation totals for each 24-hour period were calculated and totaled by month. In addition, the maximum precipitation totals for 60- minute periods were also calculated. Precipitation totals were further summarized for “warm” periods (May – October) and for “cold” periods (November – April). Because the Geonor gauge has been selected as the standard precipitation gauge for the CRN, precipitation totals for all gauges were compared to the Geonor gauge by calculating the ratio of gauge catch/Geonor catch. Table 5 lists the individual equipment at each site. All recording gauges had heated orifices to ensure satisfactory cold weather operations. During the warm season, the month of June 2004 had to be eliminated from the analysis at both Johnstown and Sterling because of overflow problems with the Geonor gauges. Also, for the cold season totals, two days in November 2003, and 17 days in November 2004 had to be eliminated from the analysis at Sterling because of problems with Ott 706. Ongoing site modifications are documented in Table 5.

3. RESULTS

3.1 Sterling Data

Data results for Sterling are shown in Table 1 and Figure 1. It should be remembered that the precipitation totals reflect the individual gauge and the associated shield. For total

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precipitation, all seasons, the Ott gauges caught more precipitation than the Geonor gauge by about 1.8 percent. The Frise gauges caught less as compared with the Geonor gauge by -3.5 percent. Much of that could be attributed to tipping bucket difficulties in solid precipitation events. The TB gauges caught more than the Geonor by about 1.5 percent.

For warm season events, May-October, results change somewhat. The Ott gauges exceeded the Geonor by a little over 1 percent, while the Frise gauges exceeded the Geonor by about 3 percent. The TB gauges exceeded the Geonor by about 4.5 percent.

During cold season (November-April) both tipping buckets caught less, as compared with the Geonor, with the Frise at a negative 7 percent. The Otts exceeded the Geonor gauge by about 2.5 percent. The non-recording 8-inch gauges caught less in all cases; but, this was due primarily to incomplete manual monitoring of the gauges.

Sterling- Nov 2003-Mar2005															
(All data)															
			cum	cum	cum	cum	cum	cum	cum	cum	cum	cum	cum	cum	cum
temp-C	wind-m/s	gust-m/s	TB#1-inch	Geonor #1	TB#2	Geonor #2	Frise-C1	Frise-D3	Ott-286	Ott-705	Ott-704	Ott-706	8"N	8"S	8" unshiel
10.12	1.72	5.36	52.6	52.2	53.38	52.52	50.88	50.23	53.13	52.45	53.45	54	46.55	46.59	43.76
Ratios compared to Geonor 1			1.01	1.00	1.02	1.01	0.97	0.96	1.02	1.00	1.02	1.03	0.89	0.89	0.84
Difference in Ratios			0.01	0.00	0.02	0.01	-0.03	-0.04	0.02	0.00	0.02	0.03	-0.11	-0.11	-0.16
Sterling- May-Oct 2004															
(Warm Season)															
19.56	1.4	4.96	20.18	19.51	20.71	19.67	20.32	19.99	19.54	19.51	20.06	20.04	17.36	17.34	17.25
Ratios compared to Geonor 1			1.03	1.00	1.06	1.01	1.04	1.02	1.00	1.00	1.03	1.03	0.89	0.89	0.88
Difference in Ratios			0.03	0.00	0.06	0.01	0.04	0.02	0.00	0.00	0.03	0.03	-0.11	-0.11	-0.12
Sterling- Nov 03-Apr04 and Nov 04-Mar05															
(Cold Season)															
4.21	1.94	5.67	32.42	32.69	32.67	32.85	30.56	30.24	33.59	32.94	33.39	33.96	29.19	29.25	26.51
Ratios compared to Geonor 1			0.99	1.00	1.00	1.00	0.93	0.93	1.03	1.01	1.02	1.04	0.89	0.89	0.81
Difference in Ratios			-0.01	0.00	0.00	0.00	-0.07	-0.07	0.03	0.01	0.02	0.04	-0.11	-0.11	-0.19

Table 1. Sterling Data

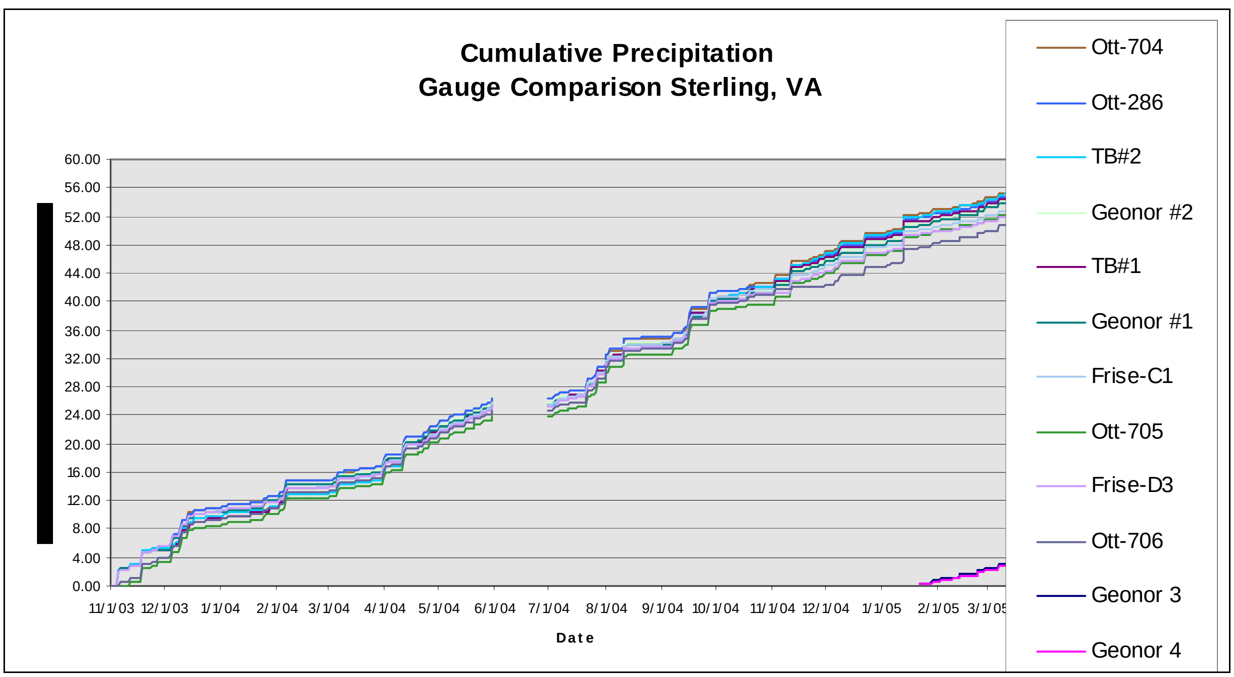

Figure 1. Sterling Mass Curves of Precipitation

3.2 Johnstown Data

The data from Johnstown, Table 2 and Figure 2, tell a somewhat different story from Sterling. At Johnstown, the Geonor gauge caught more precipitation than all other gauges consistently in every category. For all data, the Ott gauges caught less compared with the Geonor by about -5.6 percent. The Frise caught less by about -8 percent, while the TB caught less by about -13 percent.

For the warm season, the Otts caught less by -1.3 percent, the TB by -4 percent while the Frise matches the Geonor performance. In the cold season, however, the statistics change even more. The Frise tipping bucket caught less by -13 percent, the TB by -18 percent and the Otts by -8.3 percent. Again, the 8-inch non-recording gauges caught significantly less in all cases due, primarily, to manual monitoring issues.

Johnstown- Nov 2003-March2005											
(All Data)											
			cum-in	cum	cum	cum	cum	cum	cum	cum	cum
temp-C	wind-m/s	gust-m/s	TB#1	Geonor#1	Frise-705	Ott-726	Ott-722	Ott-729	8"N	8"S	8"u
5.44	2.92	7.08	62.32	71.74	65.66	66.39	66.18	70.13	33.63	34.22	31.36
Ratios compared to Geonor			0.87	1.00	0.92	0.93	0.92	0.98	0.47	0.48	0.44
Difference in Ratios			-0.13	0.00	-0.08	-0.07	-0.08	-0.02	-0.53	-0.52	-0.56
Johnstown- May-Oct 2004											
(Warm Season)											
16.01	2.02	5.51	23.58	24.56	24.47	24.23	24.23	24.17	10.86	10.83	10.64
Ratios compared to Geonor			0.96	1.00	1.00	0.99	0.99	0.98	0.44	0.44	0.43
Difference in Ratios			-0.04	0.00	0.00	-0.01	-0.01	-0.02	-0.56	-0.56	-0.57
Johnstown-Nov 03-Apr 04 and Nov 04-Mar 05											
(Cold Season)											
-0.11	3.4	7.95	38.74	47.18	41.19	42.16	41.95	45.96	22.77	23.39	20.72
Ratios compared to Geonor			0.82	1.00	0.87	0.89	0.89	0.97	0.48	0.50	0.44
Difference in Ratios			-0.18	0.00	-0.13	-0.11	-0.11	-0.03	-0.52	-0.50	-0.56

Table 2. Johnstown Data

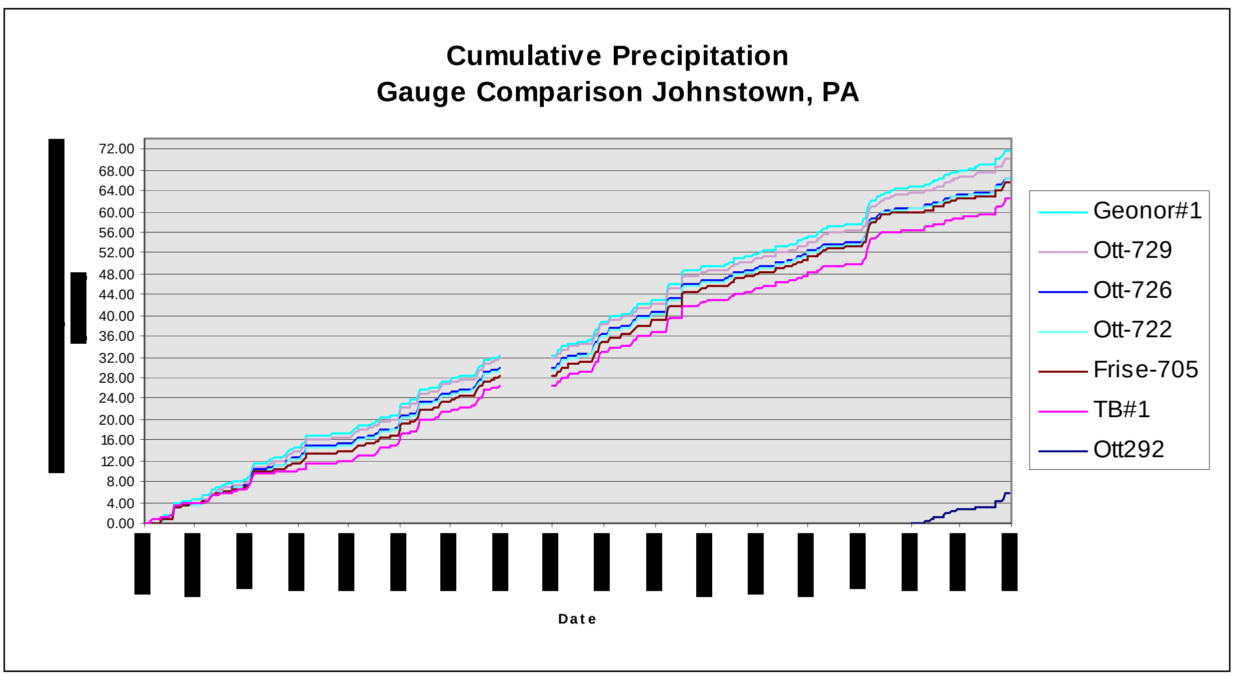

Figure 2. Johnstown Mass Curves of Precipitation

3.3 Overall Gauge/Shield Performance

The need to provide gauge shielding is readily apparent in the data from both Sterling and Johnstown. The Tretyakov, Alter, Automated Surface Observing System (ASOS), and SDFIR all provide beneficial shielding for the gauges, though there are advantages and disadvantages with each. At Johnstown, Ott 729 (Tretyakov/SDFIR) caught -3 percent less than the Geonor, while Ott 726 and 722, each with just Tretyakov shields, caught -11 percent less. Thus, the SDFIR would appear to have increased solid precipitation catch at Johnstown by about 8 percent during solid events. The 8-inch non-recording gauges also provide useful shield information. 8-inch N and 8-inch S both have Alter shields. They had solid precipitation catch deficiencies of -52 and -50 percent compared with the Geonor. The 8-inch U has no shield and had a deficiency of -56 percent. The Alter shield, by itself, resulted in an increase in catch of 5 to 6 percent.

At Sterling, it is possible to make several interesting shield comparisons. Ott 286 and 706 have Tretyakov shields plus the SDFIR. Ott 704 and 705 have only the Tretyakov shields. Ott 286 and 706 had a plus ratio for cold season of +3.5 percent, while Ott 704 and 705 have a plus ratio of 1.5 percent. Thus, the SDFIR seems to have provided an additional catch factor of about 2 percent. It should be remembered that even though this is cold season data, at Sterling actual solid precipitation events are minimal compared with Johnstown. TB1 has an Alter shield, while TB2 has a SDFIR. For the cold season, TB1 had a comparison ratio of -1 percent while TB2 had 0 percent. Again, the SDFIR seems to have provided slightly more solid precipitation protection than the Alter by itself. Looking at the 8-inch non-recording gauges, 8-inch N and 8-inch S have Alter shields while 8-inch U has no shield. For the cold season, both 8-inch shielded gauges caught -11 percent less as compared with the Geonor, while the unshielded 8-inch gauge caught -19 percent less. The Alter shield alone provided an additional catch of about 8 percent.
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The ASOS shield, a vinyl shield on the Frise gauge, can be compared to the Alter, which is on the TB gauge. Both gauges are tipping buckets, so the major difference is with the shields. At Sterling, during the cold season, the Frise gauges caught -7 percent less than the Geonor, while the TBs caught -1 percent less. At Johnstown, the Frise caught -13 percent less, while the TB was at -18 percent. Thus, the results for the vinyl ASOS shield versus the metal Alter shield during the cold season were mixed.

The SDFIR has been shown in this study to provide additional gauge protection. However, the SDFIR takes considerable effort to construct and maintain and takes significant area to install. Therefore, it was decided, rather late in the study, to install several Geonor gauges with the Double Alter shields for comparison purposes. At Sterling, Geonor 3 and 4 were installed with the Double Alter. These two gauges were installed in late January 2005, so there was about two months of data for comparison. From January 22 to the end of March, Geonor 3 and 4 caught, respectively, 6.51 and 6.23 inches of precipitation. By comparison, Geonor 1, with an Alter and SDFIR, caught 6.56 inches of precipitation. The Double Alter, therefore, caught less precipitation than Geonor 1 by a little over -2 percent. It would appear though, given the minimal data available, that the Double Alter may be a reasonably good replacement for the SDFIR if that would be desired for reasons of limited area or other construction issues.

3.4 Gauge/Shield Performance during Maximum Hourly Precipitation

Maximum hourly precipitation was calculated several times per month for each gauge during the period November 2003 through February 2005. The Geonor gauges at both the sites were outfitted with Alter shields and enclosed in the SDFIR. The Ott gauges were all shielded with Tretyakov shields. Some Otts were enclosed in the SDFIR and some were not. As a consequence of the various gauge/shield combinations, the more meaningful comparisons can be made between the Otts and Tipping Buckets with and without SDFIRs. Catch ratios between the Otts and Geonors are calculated, but these should be viewed somewhat skeptically due to shielding differences. See Table 3.

The following tables (3 and 4) detail the various gauges at both test sites, along with maximum 60-minute catches of liquid and frozen precipitation. Catch ratios for gauges (e.g., Ott 706) with missing data were compensated for by deleting relevant Geonor values for the missing data period. All gauge ratios in heavier precipitation fall within + or -3 percent of the Geonor gauge. The Tipping Bucket (without SDFIR) totaled slightly less than 97 percent of the Tipping Bucket in the SDFIR. The Otts are extremely consistent, SDFIR or no. A possible explanation is that larger raindrops are less subject to the vagaries of wind effects.

The second part of the following table tells a decidedly different story. The Frises show undercatches of 11 to 14 percent as compared with the Geonor. Catch ratios between the Otts and Geonors reverse signs in snow, the Otts suggesting 4-6 percent undercatch, regardless of SDFIR or no SDFIR. The Otts without SDFIRs lag the Otts with SDFIRs by only 1 to 2 percent; but, these events were not influenced by unduly windy conditions.

Comparing the maximum 60-minute data at Sterling to the warm season statistics results in the following. The tipping bucket ratios all decrease (e.g., Frise C1 goes from 1.04 for warm season to .98 for 60-minute data). The Ott ratios stayed the same or increased (e.g., Ott 705 went from 1.0 for warm season to 1.03 for 60-minute liquid events). Comparing cold season statistics, the tipping bucket ratios decreased (e.g., Frise D3 went from .93 for cold season to .86 for 60-minute data) as did the Otts (e.g., Ott 704 went from 1.02 to .94).

Selected Maximum Hourly Liquid Precipitation at Sterling VA Test site (23 events)									
Gauge	Geonor1	Geonor2	TB2	Ott706	TB1	Frise1	Frise2	Ott705	Ott704	Ott754
Totals	11.59	11.71	11.66	10.2	11.25	11.1	10.97	10.81	10.91	11.7
Ratio to	1	1.01	1.01	1.03	0.99	0.98	0.97	1.03	1.03	1.02
Geonor1										
To Ott706				1	0.97	0.96	0.95	1	1	1
Selected Maximum Hourly Frozen Precipitation at Sterling (7 events)										
Totals	0.8	0.79	MM	0.77	MM	0.71	0.69	0.77	0.75	0.6
Ratio to	1	0.99		0.96		0.89	0.86	0.96	0.94	0.9
Geonor 1										
To Ott706				1		0.93	0.9	1	0.98	0.9

Table 3. Maximum Hourly Data at Sterling

Selected Maximum Hourly Liquid Precipitation at Johnstown, PA Test Site (28 events)							
Gauge	Geonor	Ott729	Ott755	TB	Frise	Ott722	Ott726
Totals	9.38	9.7	4.49	9.2	8.75	9.8	9.82
Ratio to	1	1.03	1.02	0.98	1.01	1.04	1.05
Geonor							
To Ott729		1	1	0.95	0.97	1.01	1.01
Selected Maximum Hourly Frozen Precipitation at Johnstown (8 events)							
Totals	0.8	0.88	0.79		0.64	0.74	0.76
Ratio to	1	1.1	0.99		0.8	0.93	0.95
Geonor							
Otts in DFIR/Otts No DFIR: 1.67/1.50= 1.11							

Note: Ott 755 was out of service during several precipitation events. Relevant totals were subtracted from the Geonor, enabling a valid comparison.

Table 4. Maximum Hourly Data at Johnstown

At Johnstown, Table 4, results are similar to those at Sterling for rain. The Otts report 2 to 5 percent more precipitation than the Geonor, the Tipping Bucket 2 percent less. In snow, however, the Otts in a SDFIR catch about 11 percent more than the Otts without SDFIRs in the eight cases shown. The Frise with ASOS shield continues to show significant undercatch. While the snow cases cited are too few to establish definitive conclusions, they do point to the likelihood that the SDFIR enhances snow catch.

Comparing warm season statistics to 60-minute statistics at Johnstown results in the following. The tipping buckets ratios increase (e.g., TB goes from .96 for warm season to .98 for 60-minute data) as do the Otts (e.g., Ott 729 goes from .98 for warm season to 1.03 for 60-minute data). For the cold season, the tipping bucket ratios decrease (e.g., Frise goes from .87 to .81) while the Otts increase (e.g., Ott 729 goes from .97 to 1.09).

3.5 Temperature, Wind Speed and Gauge Ratios at Sterling and Johnstown

This section relates gauge ratios to wind speed and temperature. Multiple events were selected for each site (11 events at Sterling and 10 at Johnstown). The following Figures (3 and 4) demonstrate the effect of average wind, wind gusts, and temperature on the average ratios of the various gauges (TB, Frise and Ott) as compared with the Geonor gauge. In general, while temperature and wind events were not extreme, minimal changes in gauge ratios were observed. At Johnstown, some drop off in gauge ratios were apparent for wind above 4 mps, while at Sterling, there was no significant drop off up to 3 mps. Gauge ratios were generally greater than 1 at Sterling and less than 1 at Johnstown.

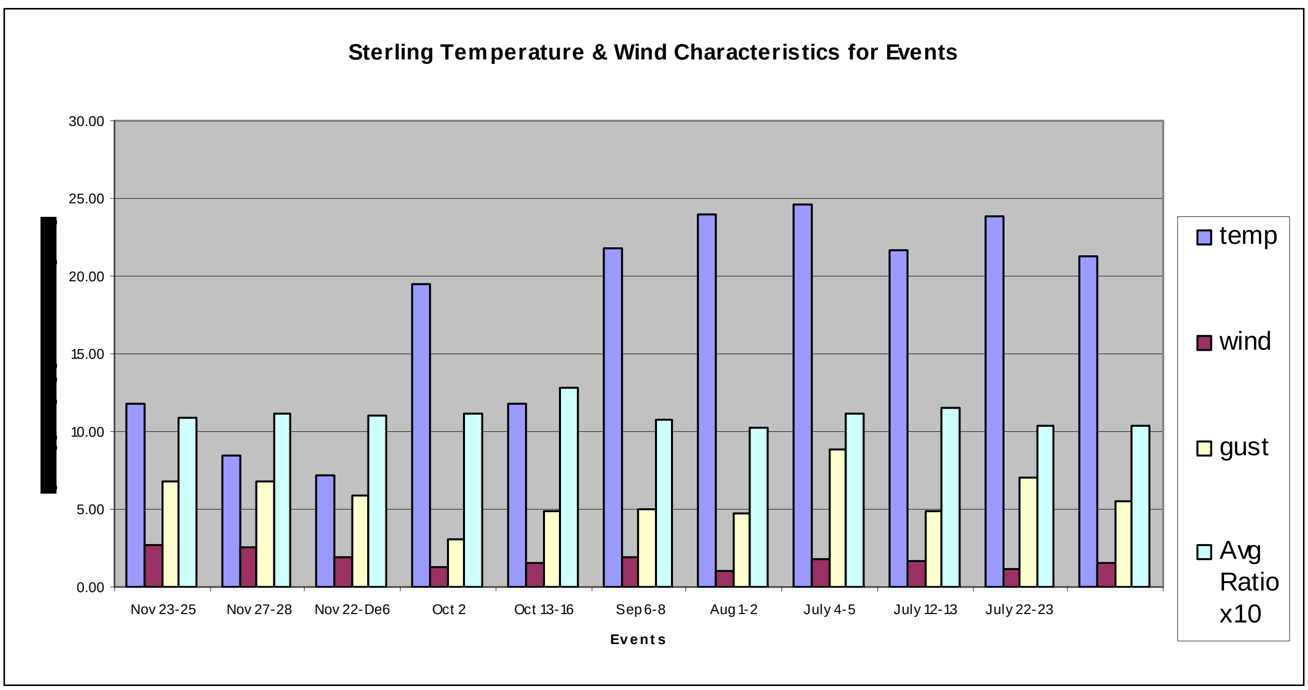

Figure 3. Sterling Temperature and Wind Characteristics for Events

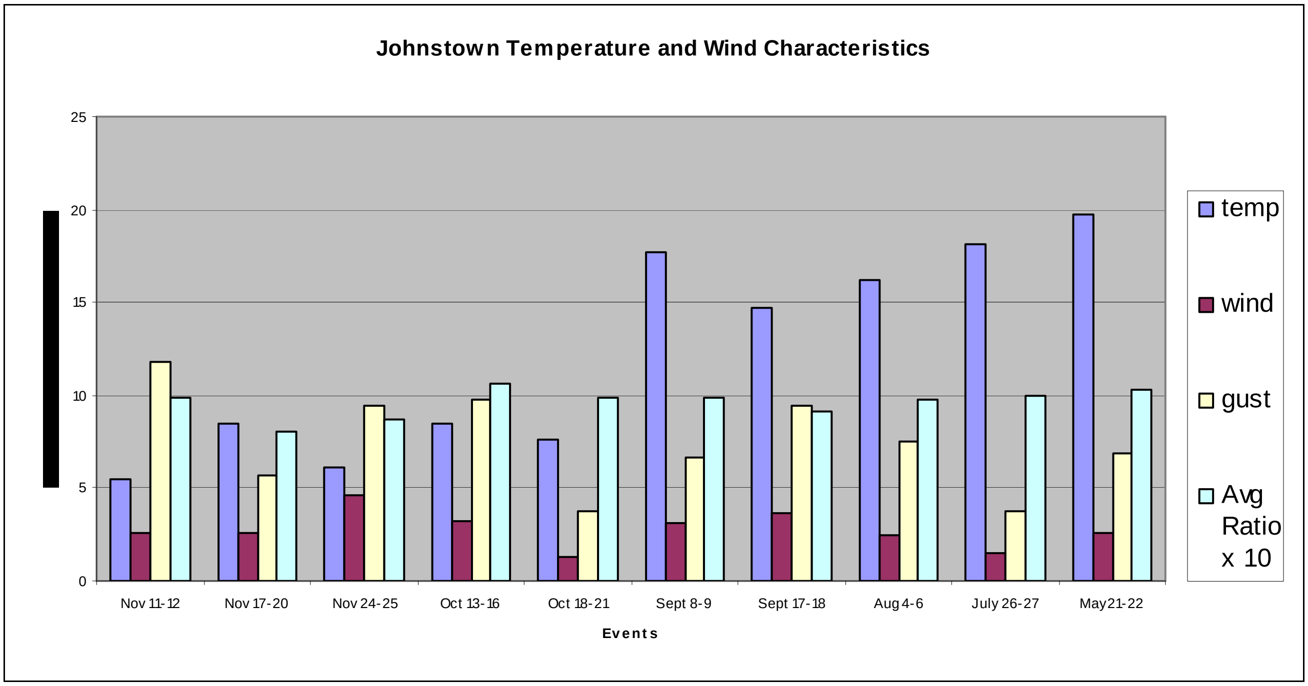

Figure 4. Johnstown Temperature and Wind Characteristics

4. DISCUSSION

In order to make reliable and "true" precipitation measurements, several requirements must be met. First, a reliable and accurate gauge must be utilized. The gauge should be easily maintained, present a minimal obstacle to the air-stream, and be able to function in all environments. Second, a site must be selected carefully. The site should represent the surrounding area, be level, free of individual obstacles and, if possible, provide natural gauge protection. Finally, the gauge must be combined with a suitable shield. The purpose of a gauge shield, regardless of the type, is to enable the gauge to accurately and reliably make a "true" catch of precipitation. To accomplish this, the shield must reduce horizontal wind flow around the gauge, thus reducing turbulence in the vicinity of the gauge orifice. If turbulence around and over the gauge orifice can be reduced to near zero under all conditions, reliable and accurate precipitation measurements can be made.

Precipitation gauge comparison studies generally assume that the gauges that catch the "most" precipitation are functioning the best. In general, this is usually true. However, other considerations come into play. Are the gauges located close to each other and at the same heights? Do the gauge locations honestly represent the surrounding microclimate? Are the gauges similarly protected? Is the surrounding area level and free of individual obstacles? In the case of Johnstown and Sterling, these sites were carefully selected and, therefore, the requirements for good gauge comparisons have been met. The exception in this study is that the different test gauges have different shields. So, the gauge comparisons herein necessarily reflect not only the physical operation of the individual gauges, but also the combined effect of the shield and the gauge.

In general, the Geonor gauge caught slightly less precipitation at Sterling and slightly more at Johnstown compared with to the tipping bucket gauges (TB and Frise) and the Ott gauges (see Figures 3 and 4). The reason for this is not readily apparent. Part of the answer may be that the Johnstown climate is somewhat more severe (i.e., higher average wind speeds and colder temperatures) compared with the Sterling site. The tipping bucket gauges demonstrated their ability to function well in most liquid precipitation events, but showed their vulnerability during solid events and high-intensity events. During solid events, the tipping bucket gauges generally under reported significantly and had problems with timing (i.e., solid events were often reported the next day after melting had occurred). All the Ott gauges performed well in all environments and, with the Tretyakov shield and SDFIR, compared well to the Geonor gauge. The Alter shield, on both the TB and non-recording gauges, showed its effectiveness, especially in solid events. The Alter shield has the added advantage of swinging metal leaves which will not become “capped” in high-intensity, wet, solid events.

5. CONCLUSIONS

It is obvious from this study, and it has been shown in numerous similar studies, that it is difficult to accurately measure precipitation under all temperature and wind conditions. Solid precipitation events are especially difficult for tipping bucket gauges. Increased wind speed increases turbulence around the gauge orifice and thus reduces gauge catch efficiency for all gauges. Precipitation measurement errors increase for all gauges as the wind speed increases and the temperature decreases. Weighing gauges generally do better for conditions involving solid events. Heating of gauges, if not carefully done, can increase measurement errors due to evaporation and “chimney” effects at the gauge orifice. Proper site requirements are paramount when installing gauges for maximum accuracy and reliability. However, considering all the above, the Geonor gauge, combined with the Alter shield and SDFIR, or possibly the Double Alter, would seem to provide the best opportunity for obtaining accurate and reliable precipitation measurements under all conditions. The Geonor gauge combined with an Alter shield and the SDFIR, or possibly the Double Alter, performed reliably for 16 months under varying climatic conditions and, on average, met or exceeded the performance of the other test gauge configurations.

6. SITE GAUGE CONFIGURATIONS

Gauge Configurations at Sterling and Johnstown						
Location	gauge	shield	orifice dia	increment	type	notes
			inches			
Johnstown						
	Ott729	Tretyakov and SDFIR	6.28	.01 in	weighing	
	Ott726	Tretyakov	6.28	.01 in	weighing	
	Ott725	Tretyakov and SDFIR	6.28	.01 in	weighing	was #755, changed Jan 05
	Ott722	Tretyakov	6.28	.01 in	weighing	
	TB1	Alter	7.9	.2mm	tipping bucket	metric
	Geonor	Alter/SDFIR	6.28	.25mm	weighing	metric
	Frise	ASOS	12	.01 in	tipping bucket	
	8"	see notes	8	.01 in	non-recording	Four gauges, 2 with Alters, 1
						unshielded and 1 in a DFIR
	Ott 292	Tretyakov			started about 2/1/05, gauge has experimental wind	
					shield (fence) on 3 sides	
Sterling						
	TB1	Alter	7.9	.2mm	tipping bucket	metric
	TB2	SDFIR	7.9	.2mm	tipping bucket	metric
					Both TBs moved inside SDFIR on 1/18/05	
	Ott286	Tretyakov	6.28	.01 in	weighing	orifice 5" higher than other Otts
						Moved to DFIR on Oct 26,'04
						Formerly 754, changed to 286 on 1/18/05
	Ott705	Tretyakov	6.28	.01 in	weighing	
	Ott704	Tretyakov	6.28	.01 in	weighing	
	Ott706	Tretyakov and SDFIR	6.28	.01 in	weighing	
	Geonor1	Alter and SDFIR	6.28	.25mm	weighing	metric
	Geonor2	Alter and SDFIR	6.28	.25mm	weighing	metric
	Geonor 3	Double Alter	6.28	.25mm	weighing	Started 1/20/05
	Geonor 4	Double Alter	6.28	.25mm	weighing	Started 1/20/05
	FriseC1	ASOS	12	.01 in	tipping bucket	
	FriseD3	ASOS	12	.01 in	tipping bucket	
	8"	see notes	8	.01 in	non-recording	same as at Johnstown

Table 5. Site/Gauge Configurations