Traceability and Catch-Efficiency of the Lambrecht rain[e]H3 Automated Precipitation Gauge for Measuring Precipitation in Canadian Operational Networks

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ABSTRACT

As organizations are looking to streamline observation networks, many are transitioning from manual observations to automated gauges for the measurement of precipitation. In order to help ensure homogeneity, intercomparisons with reference methods and gauges are acutely important. These studies ultimately lead to better precipitation data with fewer errors and biases. The key condition of providing these intercomparisons is the availability of overlapping data between the old and new systems or with reference precipitation observations along with the continuous support and maintenance of these intercomparison research sites. Since climate research and models rely on accurate meteorological measurements, it is important to know the limitations of gauges and methods used to collect data.

The aviation weather monitoring network operated by NAV CANADA, in an effort to modernize, is installing Lambrecht rain[e]H3 heated tipping bucket / weighing type gauges to replace manual (Nipher or Type B gauges or snow ruler) observations of precipitation. This has implications on the accuracy of reporting precipitation, especially snow events which are more substantially prone to measurement errors. Collaboration between NAV CANADA and Environment and Climate Change Canada (ECCC) has provided an opportunity to analyze existing overlapping manual and automated measurements. The overall intercomparison study includes four sites across Canada: Downsview (ON), Prince George (BC), Whitehorse (YT), and Dorval (QC). Additionally, overlapping observations of the Lambrecht gauge and DFAR (Double Fence Automated Reference) measurements are available for the 2021-22 winter season at the ECCC Bratt's Lake (SK) supersite. Preliminary results of two setups from Downsview and Bratt's Lake show that wind speed and precipitation phase greatly impact the Lambrecht gauge catch efficiency.

INTRODUCTION

Errors in solid precipitation measurements due to gauge configuration and wind speed are well documented (e.g. Sevruk *et al*., 1991; Goodison *et al*., 1998; Kochendorfer *et al*., 2017a). The systematic bias due to wind induced undercatch can lead to the underestimation of solid precipitation and is an important consideration when selecting and deploying new automated precipitation gauges and accompanying wind shields to cold regions.

Measurement intercomparisons using overlapping observations are crucial for long term data homogeneity, especially given that manual observation networks are in decline across Canada (Mekis *et al*., 2018). As an example, overlapping observations were utilized in the development of

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the Adjusted and Homogenized Canadian Climate Dataset (AHCCD) precipitation time series (Vincent and Mekis, 2009; Mekis and Vincent, 2011). For many AHCCD stations, it was necessary to merge observations from nearby stations to produce longer time series of rainfall and snowfall for trend analysis. Standardized ratios comparison procedures of the overlapping observations were used to determine if changes in precipitation observations created any artificial discontinuities at the joining dates. Similarly, to ensure data continuity, adjustments may be required when switching to new precipitation gauge configurations, making the availability of overlapping reference observations essential.

This extended abstract compares precipitation measurements from the Lambrecht rain[e]H3 heated tipping bucket / weighing gauge to reference methods and gauges from the ECCC Bratt's Lake supersite and the ECCC Downsview site. The overall project objective is twofold: 1) setup a possible transfer function between the old manual to the new automated systems observations and 2) assess the accuracy and wind bias of the Lambrecht gauge using the reference DFAR installation. Some preliminary results are indicated here for each.

DATA AND METHODOLOGY

The single Alter (SA) shielded Lambrecht gauge was installed at both the Downsview and Bratt's Lake locations. The Lambrecht installation at Bratt's Lake is shown in Figure 1. First the 20-second Lambrecht data obtained from the data logger were converted to 1-minute intervals by taking the sum of the non-missing values in each 1-minute time interval. The 1-minute data were further aggregated to match the reference observation periods of each site (described below). Quality control (QC) included the removal of duplicate time stamps and the creation of equidistant time series with no missing time stamps. It also included the filtering out of periods with missing values as well as periods where an error was reported in the Lambrecht data such as heating errors or temperature sensor errors. Additionally, visual examination of the Lambrecht gauge time series was completed for further erroneous data identification.

Figure 1. Single Alter shielded Lambrecht rain[e]H3 heated tipping bucket / weighing gauge installed at the Bratt's Lake (SK) supersite.

The reference at the Bratt's Lake supersite is the internationally recognized World Meteorological Organization Solid Precipitation Inter-Comparison Experiment (WMO-SPICE) DFAR with a Pluvio^2 automated gauge in the middle. The study period is Oct 2021 – Apr 2022. Precipitation and ancillary 1-minute data were downloaded directly from site data loggers and filed into equidistant monthly files with no missing time stamps. The DFAR precipitation data were quality controlled through an automated process which removed out-of-range outliers and data jumps related to gauge servicing (bucket emptying and/or charging). This was followed by manual inspection and removal of any erroneous data missed by the automated QC process. The DFAR cumulative time series was then filtered using the Supervised Neutral Aggregating Filter (NAF-S) to adjust for evaporation and other spurious data (Ross *et al*., 2020). DFAR precipitation was accummulated and wind speed and temperature were averaged over 24-hour periods. The 1-minute Lambrecht data were summed to match the 24-hour periods selected for comparison. Precipitation phase was determined using WMO-SPICE air temperature (T_{air}) thresholds where snow is defined as T_{air} < -2ºC, mixed precipitation as -2ºC ≤ T_{air} ≤ 2ºC, and rain as T_{air} > 2ºC (Kochendorfer *et al*., 2017b).

The intercomparison at the Downsview site involved manual reference observations as is described below. The comparison was completed for the longer Nov 2019 – Jun 2021 period. Manual observations were obtained from the web-based COOLTAP (Cooperative Online Temperature and Precipitation) reporting system. Observations from COOLTAP include maximum and minimum temperatures, rainfall, snowfall, and snow depth data taken once or twice daily. Data entered by users are first stored and then synchronized in the COOLTAP database every few minutes. Given that manual precipitation observations can be made with various methodologies (i.e. Nipher or Type B gauge or snow ruler) and reported as rainfall, snowfall, or SWE (Snowfall Water Equivalent) and that our objective is to compare total precipitation accumulations, Table 1 outlines the procedure used to calculate Total Precipitation from the reported manual observations. For example, Case 3 describes that when COOLTAP reports Snowfall > 0 cm, SWE > 0 mm, and Rainfall = 0 mm, then Total Precipitation is derived from the COOLTAP SWE column. COOLTAP quality control included filing the data into a non-equidistant time series based on observation date/time, the removal of duplicate time stamps, and time zone conversion from local to UTC. In most cases, manual observations were conducted at approximately 8 am and 4 pm local time creating uneven precipitation accumulation periods of approximately 8 and 16 hours. Overlapping Lambrecht (1-minute) and ancillary data were then aggregated to these reference observation periods with temperature and wind speed averaged and Lambrecht data summed. For precision, the initial Lambrecht data was aggregated to the minute instead of the hour because some manual observations were conducted 15 to 30 minutes from the top of the hour. Precipitation phase was derived through the COOLTAP 'remarks' column where available, and via the air temperature thresholds described earlier when human precipitation type observations were not available.

Table 1. Downsview COOLTAP manual observation procedure applied for deriving total precipitation. Rainfall was measured using a Type B gauge, snowfall was measured using a snow ruler, and Snowfall Water Equivalent (SWE) was derived from either a Type B or Nipher gauge.

Downsview procedure for deriving total precipitation

Case	Rainfall (mm)	Snowfall (cm)	SWE (mm)	Total Precipitation (mm)
1	0	0	0	0
2	0	0	>0	SWE
3	0	>0	>0	SWE
4	>0	0	0	rainfall
5	>0	>0	0	rainfall
6	0	>0	0	10 x snowfall
7	>0	0	>0	rainfall + SWE
8	>0	>0	>0	rainfall + SWE

RESULTS

The accumulated precipitation observation time series for each site was plotted for visual assessment of the accuracy and effectiveness of the Lambrecht gauge performance when compared to the respective references (Figure 2). In addition, statistical measures were calculated including 1) total number of events for each precipitation phase; 2) probability of detection (% of events where both Lambrecht > 0 & reference > 0); 3) false alarm reporting (% of events where Lambrecht > 0 & reference = 0); 4) relative total catch (total accumulated Lambrecht precipitation compared to the reference expressed as %); 5) root mean square deviation (RMSD) normalized to the range of reference observations (maximum reference observation minus minimum reference observation);

and 6) correlation coefficient (r) between the Lambrecht gauge and the reference (Tables 2 & 3). The statistics excluded any observation periods where the reference and Lambrecht gauge both reported 0 mm. The climate characteristics of the two tested locations were quite different. For precipitation events (all phases combined), the mean wind speed was 5 m s^{-1} at Bratt's Lake and 1 m s^{-1} at Downsview, while the mean air temperature was -11.7 °C at Bratt's Lake and 7.4 °C at Downsview.

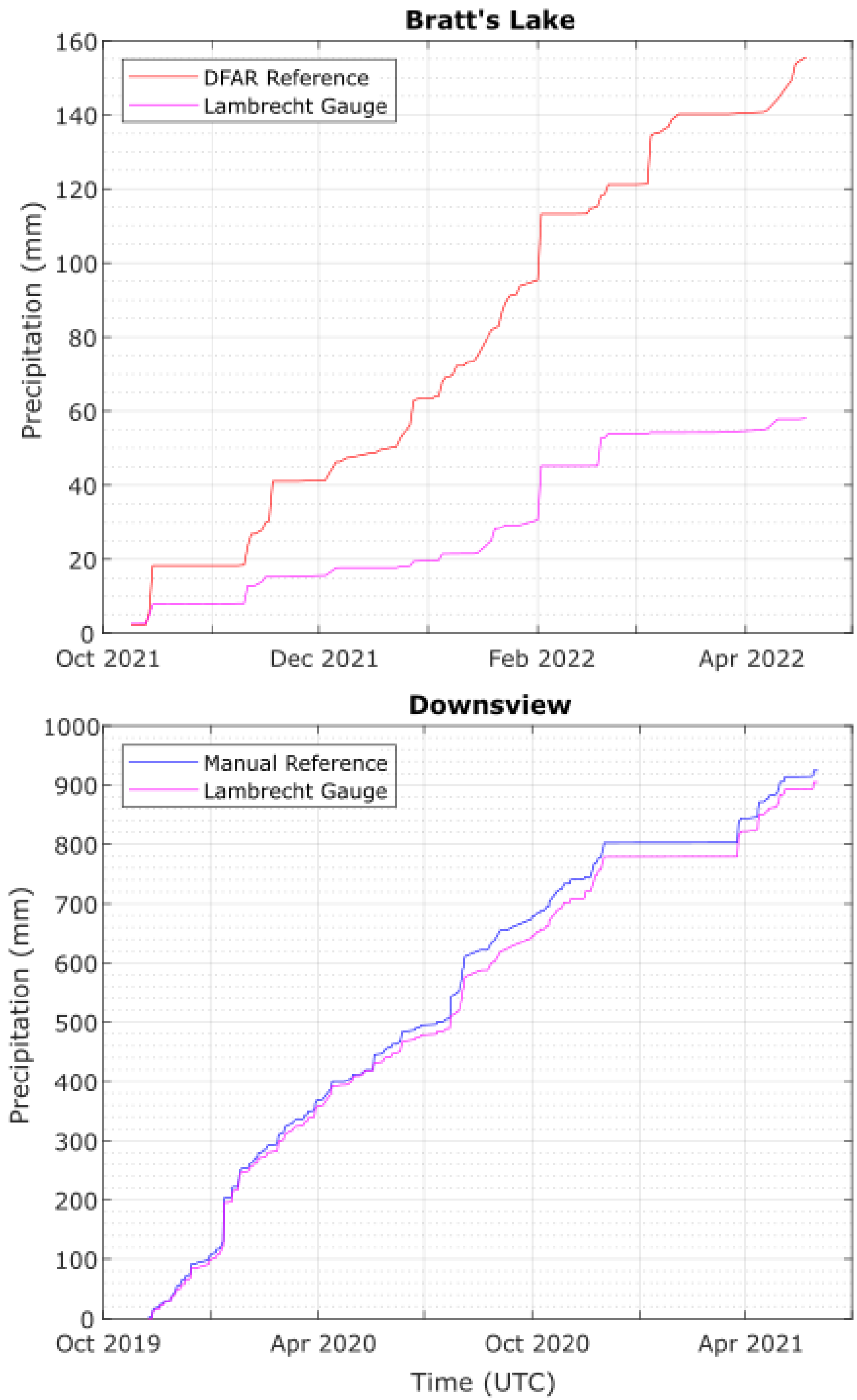

Figure 2. Accumulated precipitation observation time series for all precipitation phases at Bratt's Lake (top) and Downsview (bottom). Note that data from Bratt's Lake is only available for the winter of 2021-22.

When comparing the Lambrecht gauge to the reference WMO-SPICE DFAR at Bratt's Lake, the accumulated winter precipitation time series shows considerable differences. This underlines the overall undercatch of the Lambrecht gauge compared to the reference under cold and windy conditions. In contrast, the Lambrecht gauge performs comparatively well to the manual reference at Downsview with the two time series tracking closely to each other.

Table 2. Bratt's Lake daily [24 hour] statistics for rain, snow, mixed, and all precipitation phases.

Bratt's Lake statistics						
	Total Number of Events	Probability of Detection (%)	False Alarm Reporting (%)	Relative Total Catch (%)	Normalized RMSD (mm)	*r*
Rain	7	100	14	88.4	0.100	0.97
Snow	72	44	38	32.1	0.145	0.64
Mixed	12	67	60	31.7	0.217	0.97
All	91	51	39	37.4	0.141	0.65

Table 3. Downsview 8 and 16 hour statistics for rain, snow, mixed, and all precipitation phases.

Downsview statistics						
	Total Number of Events	Probability of Detection (%)	False Alarm Reporting (%)	Relative Total Catch (%)	Normalized RMSD (mm)	*r*
Rain	182	94	16	98.1	0.044	0.95
Snow	67	87	34	93.8	0.063	0.93
Mixed	22	100	36	101.5	0.045	0.99
All	271	93	22	97.7	0.040	0.95

At Bratt's Lake, relative total catch was moderately high for rain at 88% but very low for snow and mixed precipitation at around 32%. The probability of detection was perfect at 100% for rain (although the number of rain events is low during the study period) and only 44% for snow. False alarm reporting was the highest at 60% for mixed precipitation, followed by 38% for snow, and 14% for rain. The correlation coefficient (*r*) is high for rain and mixed events at 0.97 but relatively low for snow at 0.64. There were also a large number of snow events not detected by the Lambrecht gauge (i.e. the catch efficiency was 0). Out of the 72 snow events, 32 had the Lambrecht catch efficiency equal to 0. The DFAR reported 45.7 mm of precipitation (out of the total accumulation of 155.4 mm) for these 32 events where the Lambrecht reported 0 mm. This amount represents 29% of the total DFAR precipitation.

At Downsview, the relative total catch was very high (98% for rain, 94% for snow, and 102% for mixed precipitation). Probability of detection was also high for all precipitation phases with the lowest at 87% for snow. Similarly, snow had the lowest correlation coefficient at 0.93. False alarm reporting was 16% for rain, 34% for snow, and 36% for mixed precipitation. At Downsview, 2/3 of the cases were rain events while the number of mixed events (within the -2 °C and +2 °C range) were comparatively low (22 out of the total 271 events). The normalized RMSD for each precipitation phase was lower at Downsview when compared to Bratt's Lake.

The use of two different references is an important consideration when interpreting these results. When the manual Nipher gauge is used for comparison of the snow events at Downsview, its catch efficiency has the potential to be more influenced by wind as compared to the expectancy for a

DFAR configuration. However, because of the low wind speeds observed during this experiment at Downsview, the catch efficiency of the Nipher will be quite high and close to 100% (see Goodison, 1978). If the Nipher gauge would have been used in a similar fashion at Bratt's Lake (rather than the DFAR), its performance may not be as good because wind speeds are considerably higher at this location.

CONCLUSIONS

The present study compares the Lambrecht rain[e]H3 gauge performance to manual observations at Downsview (ON) and to DFAR reference observations at Bratt's Lake (SK). It was found that the Lambrecht gauge performed relatively well at Downsview but poorly at Bratt's Lake when compared to the respective references. The Lambrecht measurements correlate well to the manual observations at Downsview for all precipitation phases. At Bratt's Lake, significant deviations exist between the Lambrecht and DFAR observations with considerable undercatch for snow and mixed precipitation.

The two results obtained above are not quite comparable, since the reference used in the studies are different, but a large contributor to the difference in performance is the contrasting climate conditions at the two sites. While Bratt's Lake typically has lower temperatures, higher wind speeds, and more snow, Downsview has higher temperatures, lower wind speeds, and more rain events. The greatest determining factors in catch efficiency are shown to be wind speed and precipitation phase. The Lambrecht gauge performed well for rain events with low wind speeds ($1\ m\ s^{-1}$) at Downsview, while higher wind speeds ($5\ m\ s^{-1}$) combined with snow and mixed precipitation at Bratt's Lake are shown to cause notable undercatch.

It is found that transitioning from manual precipitation observations to the automated Lambrecht rain[e]H3 gauge in operational networks will cause uncertainty and inhomogeneity on long term climate time series. This will presumably cause a decline in total precipitation amounts due to a higher probability of undercatch if the gauge is deployed in cold regions with high wind speeds. It is anticipated that the impact will be less pronounced in warmer regions with fewer snow events and under lower wind speed conditions. Next steps include intercomparisons of overlapping Lambrecht and reference precipitation observations at the Prince George (BC), Whitehorse (YT), and Dorval (QC) sites. Analyzing further climate conditions to assess the Lambrecht gauge catch efficiency and develop transfer functions from manual observations to the new automated Lambrecht gauge will help provide further details and ensure data continuity and homogeneity moving forward.

REFERENCES

Goodison B. 1978. Accuracy of Canadian snow gauge measurements. *Journal of Applied Meteorology*, **17**(10): 1542-1548. *https://doi.org/10.1175/1520-0450(1978)017<1542:AOCSGM >2.0.CO;2*

Goodison B, Louie P, Yang D. 1998. The WMO solid precipitation measurement intercomparison. *World Meteorological Organization-Publications-WMO/TD*, **872**: 212.

Kochendorfer J, Rasmussen R, Wolff M, Baker B, Hall ME, Meyers T, Landolt S, Jachcik A, Isaksen K, Brækkan R, Leeper R. 2017a. The quantification and correction of wind-induced precipitation measurement errors. *Hydrology and Earth System Science*, **21**: 1973-1989. *https:// doi.org/10.5194/hess-21-1973-2017*

Kochendorfer J, Nitu R, Wolff M, Mekis E, Rasmussen R, Baker B, Earle ME, Reverdin A, Wong K, Smith CD, Yang D, Roulet Y-A, Buisan S, Laine T, Lee G, Aceituno JLC, Alastrué J, Isaksen K, Meyers T, Brækkan R, Landolt S, Jachcik A, Poikonen A. 2017b. Analysis of single-Alter-shielded and unshielded measurements of mixed and solid precipitation from WMO-SPICE. *Hydrology and Earth System Sciences* **21**(7): 3525-3542. *https://doi.org/10.5194/hess-21-3525-2017*

Mekis E, Vincent LA. 2011. An overview of the second generation adjusted daily precipitation dataset for trend analysis in Canada. *Atmosphere-Ocean*, **49**(2): 163-177. *https://doi.org/10.1080/07055900.2011.583910*

Mekis E, Donaldson N, Reid J, Hoover J, Zucconi A, Li Q, Nitu R, Melo S. 2018. An overview of the surface-based precipitation observations at Environment and Climate Change Canada. *Atmosphere-Ocean*, **56**(2): 71-95. *https://doi.org/10.1080/07055900.2018.1433627*

Ross A, Smith CD, Barr A. 2020. An improved post-processing technique for automatic precipitation gauge time series. *Atmospheric Measurement Techniques*, **13**: 2979-2994. *https://doi.org/10.5194/amt-13-2979-2020*

Sevruk B, Hertig J-A, Spiess R. 1991. The effect of precipitation gauge orifice rim on the wind field deformation as investigated in a wind tunnel. *Atmosphere Environment*, **25A**: 1173-1179.

Vincent LA, Mekis E. 2009. Discontinuities due to joining precipitation station observations in Canada. *Journal of Applied Meteorology and Climatology*, **48**(1): 156-166. *https://doi.org/10.1175/2008JAMC2031.1*