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Analysis of PWD Precipitation Rate Estimates Compared to Hotplate Sensors

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Aurora Project 2015-01

Final Report
April 2017

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16. Abstract

In January 2015, personnel from the National Center for Atmospheric Research (NCAR) in Boulder, Colorado installed precipitation measurement sensors at two locations in Juneau, Alaska: one along Thane Road south of Juneau and another on top of Mt. Roberts at an existing weather station site

Both of these sites are part of the Alaska Department of Transportation and Public Facilities (DOT&PF) Road Weather Information System (RWIS). These two sites are separated by a straight two-dimensional, Euclidean distance of just more than 1 mile, but the altitude increases from the Thane Road location to the Mt. Roberts location by more than 500 meters (actually, by more than 1,732 feet).

The research team conducted a study using data collected from the Juneau, Alaska sites and the NCAR Marshall Field test site south of Boulder, Colorado to evaluate Vaisala present weather detector (PWD) parameter settings.

The results indicated that, overall, the Vaisala PWD sensors underestimated snowfall precipitation rates compared to Hotplate results. Additionally, the snowfall rate underestimate was more significant at higher snowfall rates.

Based on the data analyses, this study provided the Alaska DOT&PF with a corrected estimated rate, which could be used by other organizations, for snow events in Juneau to correct for the bias from the PWD sensors and new weather parameter settings, which were implemented.

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ANALYSIS OF PWD PRECIPITATION RATE ESTIMATES COMPARED TO HOTPLATE SENSORS

Final Report
April 2017

Authors
Scott Landolt, Site Manager, Reid Hansen, and Alex Trellinger,
National Center for Atmospheric Research
Research Applications Laboratory and
Jack Stickel, Transportation Information Group Manager (retired),
Alaska Department of Transportation and Public Facilities

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A report from
Aurora Program
Institute for Transportation
Iowa State University
2711 South Loop Drive, Suite 4700
Ames, IA 50010-8664
Phone: 515-294-8103 / Fax: 515-294-0467
www.intrans.iastate.edu

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BACKGROUND

The PWD series of present weather and visibility sensors are some of the latest optical-based detectors offered by Vaisala, Inc. (see Figure 1).

Figure 1. Vaisala PWD22 present weather detector

Vaisala describes the PWD22 present weather detector as a forward scatter visibility and present weather sensor (Vaisala 2013) that can detect precipitation type, intensity, and rate of solid and liquid precipitation. The PWD uses an infrared light-emitting diode (LED) source that emits a beam that is scattered in the forward direction by precipitation, or other atmospheric particles, to the detector (Vaisala 2004). Depending on the signal received by the detector, the PWD determines the precipitation types based on the principle that the light scattering caused by a precipitation particle is proportional to the particle's volume.

This generally applies well to rain, but can be problematic for frozen precipitation (especially snow) due to its crystalline structure and the varying particle shapes. To resolve this issue for frozen precipitation, an average of the volume of the particles is used.

Because the PWD can detect and measure both precipitation type and intensity/rate, it has become attractive to many organizations in saving the cost for both a present weather sensor and a precipitation gauge.

The PWD's ability to determine present weather type was tested by the National Weather Service (NWS) in the mid 2000s when the sensor was being considered to replace the one being used (the Light Emitting Diode Weather Identifier [LEDWI]) for the NWS Automated Surface Observing System (ASOS) program. One of the final reports from the NWS indicated the sensor worked sufficiently well at determining present weather type to replace the LEDWI, but other issues with other government organizations ultimately prevented the sensor from being incorporated into the NWS ASOS (Schmitt 2011).

The rate measurements from the PWD were never analyzed by the weather service, except to classify the precipitation according to the intensity categories of light, moderate, and heavy. Intensities for most forms of precipitation (including snow and drizzle) are typically determined based on the reduction in visibility caused by the precipitation. In the case of snow (and drizzle), light intensities are reported when the visibility is greater than or equal to 1/2 mile, moderate intensities are reported when the visibility is between 1/2 and 1/4 mile, and heavy intensities are reported when the visibility is less than 1/4 mile. Since the PWD can also determine visibility, combining the visibility measurements with the precipitation type can usually provide accurate information on snowfall intensity. This was mentioned and verified in the NWS report on the device's performance (Schmitt 2011).

The latest versions in the PWD series, however, take these measurements one step further and attempt to derive an actual numerical precipitation rate based on the both the forward scatter signal and output from the RAINCAP add-on sensor (Vaisala 2004). The optical forward scatter PWD12 component provides the visibility and precipitation particle size while the capacitive sensor supports the liquid differentiation. Liquid water content estimation is based on the particle size measurement in combination with the precipitation type identification.

The Vaisala DRD11A Rain Detector component of the PWD provides droplet detection rather than using signal level thresholds. (Vaisala 2015). The precipitation type identification uses liquid water content models that mirror the mean relationship between two parameters independent of the precipitation type. Uncertainties in the liquid versus solid differentiation can automatically induce uncertainties for the liquid water equivalent (LWE) estimation.

Tests have shown the PWD sensor has the capability to bring the LWE to an acceptable level by site-specific individual calibration. This process can be done remotely remote provisioning utility (RPU) access. The PWD factory calibration is 1.0. The Rain Intensity Scale can be adjusted up or down to bring the LWE closer to the actual measurement.

Various studies have been done comparing the PWD rates to other sensors and results have typically been mixed (Black et al. 2010, Rasmussen et al. 2012). While the rate values from the device are typically better for rain, snow conditions have shown different results, likely due to the varying types of snow (size, crystal habit, shape, water content, etc.) in different climate regimes.

To further assess the sensor's ability to determine accurate snowfall LWE rates, a study was undertaken in Juneau, Alaska that compared the LWE-derived rates from two PWD devices in different locations against collocated precipitation gauges. Hotplate precipitation gauges (Figure 2) were chosen for this study because of their small footprint, relatively high accuracy, and because the sensor did not require any type of windshield or chemical fluids (Rasmussen et al. 2011).

Figure 2. Hotplate TPS-3100 Total Precipitation Sensor

These gauges were calibrated against a known standard prior to the start of the study and are considered to be the truth measurement. Snowfall in Juneau tends to have higher water amounts due to the relatively warm conditions (near freezing) that occur during snowfall and because of its proximity to the Gulf of Alaska, which provides an ample source of moisture for incoming storms. To contrast these conditions, additional analyses were done using a PWD22 sensor and Hotplate sensor located at the Marshall Field test site just outside Boulder, Colorado to highlight any differences observed for a different and much drier climate regime. The Hotplate and PWD22 sensors used in this analysis were from two sensors that were already located at Marshall and did not involve any of the same sensors that were used in the Juneau study. The Marshall site experiences a wide range of conditions during snowfall from very cold temperatures (< 20°F) and small crystals, to temperatures near freezing with very large aggregates.

INTRODUCTION

In January 2015, personnel from the National Center for Atmospheric Research (NCAR) in Boulder, Colorado installed precipitation measurement sensors at two locations in Juneau, Alaska: one along Thane Road south of Juneau and another on top of Mt. Roberts at an existing weather station site in a sheltered location not far from the tram building. Both of these sites are part of the Alaska Department of Transportation and Public Facilities (DOT&PF) Road Weather Information System (RWIS) (http://roadweather.alaska.gov). These two sites are separated by a straight two-dimensional, Euclidean distance of just more than 1 mile (Figure 3), but the altitude increases from the Thane Road location to the Mt. Roberts station by more than 500 meters (actually, by more than 1,732.28 feet) (Figure4).

Original image: ©Google 2015

Figure 3. Locations of the Mt. Roberts and Thane Road sites by two-dimensional, Euclidean distance

Original image: ©Google 2015

Figure 4. Locations of the Mt. Roberts and Thane Road sites by difference in altitude

The Thane Road site was located at 58°16'58.40"N by 134°22'30.01"W at an elevation of 8 meters (26.25 feet). The Mt. Roberts site was located at 58°17'52.65"N by 134°23'14.17"W at an elevation of 536 meters (1,758.5 feet). It should be noted that the Thane Road site had a PWD12 sensor and the Mt. Roberts site had a PWD22 sensor. The sensors are similar in function, but the PWD22 has the ability to detect freezing precipitation (i.e., freezing drizzle and freezing rain).

Both sensors come equipped with the patented RAINCAP sensor to assist in more easily detecting light precipitation, but the PWD22 has two RAINCAP sensors to increase detection of light precipitation and improve rainfall estimates, whereas the PWD12 only has one. For the purposes of this report, data from both sensors were analyzed the same and the differences are not expected to have any effects on the outcome of the study.

A Hotplate precipitation sensor (hereafter referred to simply as the Hotplate) was installed at both locations. Each Hotplate was compared and calibrated against a Geonor precipitation gauge in a double fence intercomparison reference (DFIR) wind shield at the NCAR Marshall Field test site just south of Boulder, Colorado prior to deployment (see Figure 5).

Figure 5. DFIR wind shield at the NCAR Marshall Field test site

The DFIR shield helps slow the wind and prevent gauge undercatch (Rasmussen et al. 2012). It is considered by many to be the standard shield used for measuring snowfall, and NCAR has used one in combination with a Geonor precipitation gauge for more than 20 years.

In addition to the Hotplate, a Geonor T-200b weighing precipitation gauge was also installed at the Thane Road location as a backup sensor for comparing against the Hotplate (although it should be noted that all data shown in the analysis in this report were solely from the Hotplate and there were no Hotplate outages or other questionable data that required using the Geonor data instead).

Installation of a DFIR shield was not possible at the location due to the size of the DFIR shield (~40 ft in diameter). An Alter shield was used in place of the DFIR shield and transfer functions were derived to correct the precipitation undercatch due to wind for a Geonor in an Alter shield as compared to a DFIR shield (Rasmussen et al. 2001, Rasmussen et al. 2012). Figure 6 shows a sample comparison of the Hotplate and the Geonor during a multi-day rain event in January 2015 and highlights the near perfect agreement between the two sensors.

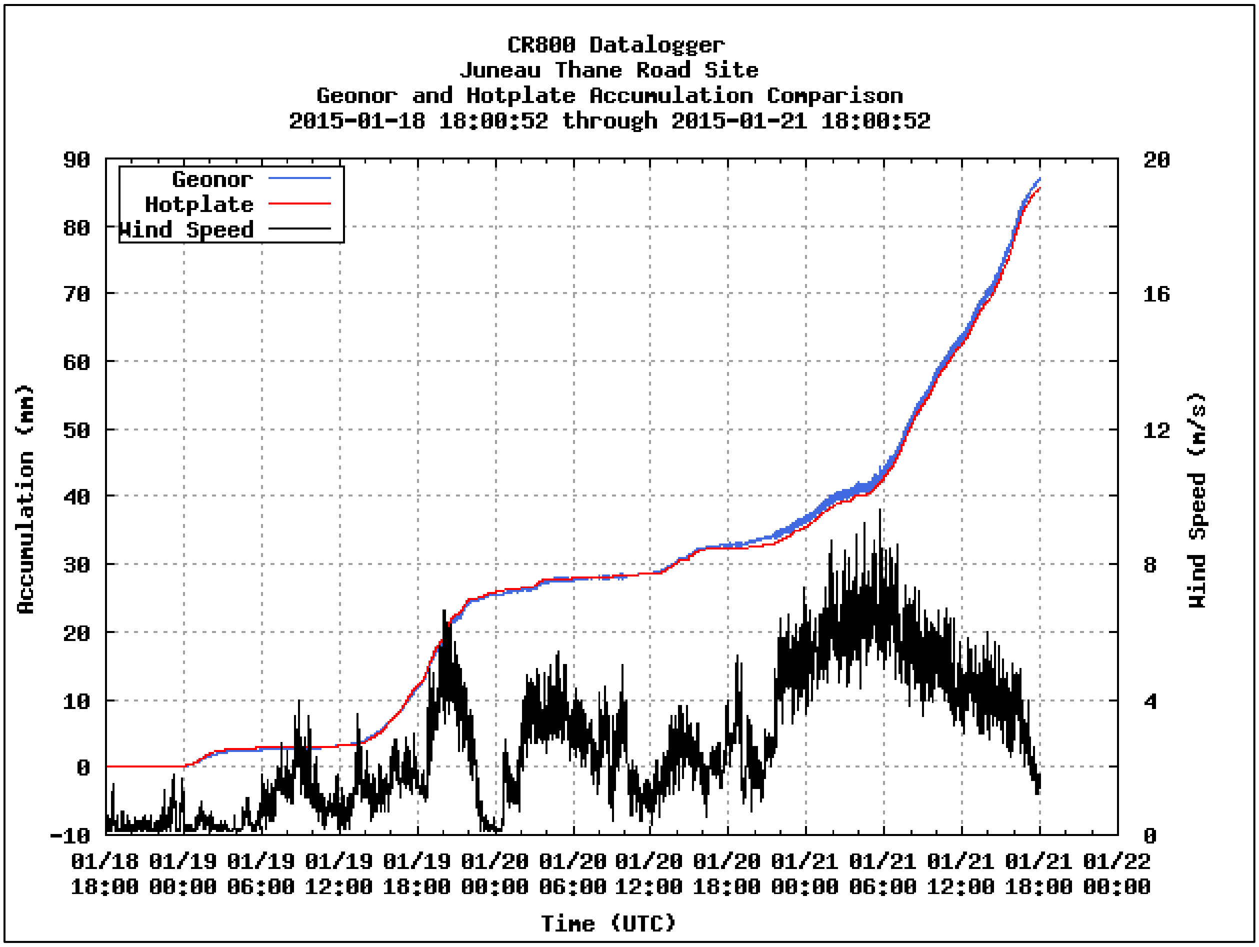

Figure 6. Sample Hotplate and Geonor accumulations and corresponding wind speeds

A rain event is shown in Figure 6 because rain is significantly less impacted by wind than snow and shows how well the Hotplate is calibrated, even when wind speeds exceed 8 m/s (18 mph).

The researchers collected data from the Thane Road and Mt. Roberts sites from January 2015 through May 2016 at one-minute intervals. Data analysis of the precipitation rates began by classifying each precipitation event as rain, snow, or mixed precipitation (rain/snow combination) based on the reported precipitation type from each PWD sensor.

Events where the precipitation phase changed over time were further analyzed to determine the times that the changes occurred and the events were further broken down and classified according to rain and snow periods. Once these classifications were complete, analysis began on the rain events and the snow events separately. Mixed phase periods were removed and not analyzed for this study.

SNOWFALL ANALYSIS

Rates from the PWD sensors were compared to the rates derived from the Hotplates. Snow was the initial focus of the analysis and all rates from all snow events for both the Thane Road and Mt. Roberts sites were included in the analysis. It was hypothesized initially that the Mt. Roberts site may have different snow characteristics (crystal type, size, etc.) than the Thane Road site, because of its higher elevation and potentially colder temperatures. Both sites were initially analyzed individually, but the results were similar, indicating that the difference in altitude between the two sites was not having much impact on the type of snow falling at each location. The datasets for each site were therefore combined into one large dataset. Figure 7 shows a scatter plot of the PWD rates compared to the Hotplate rates.

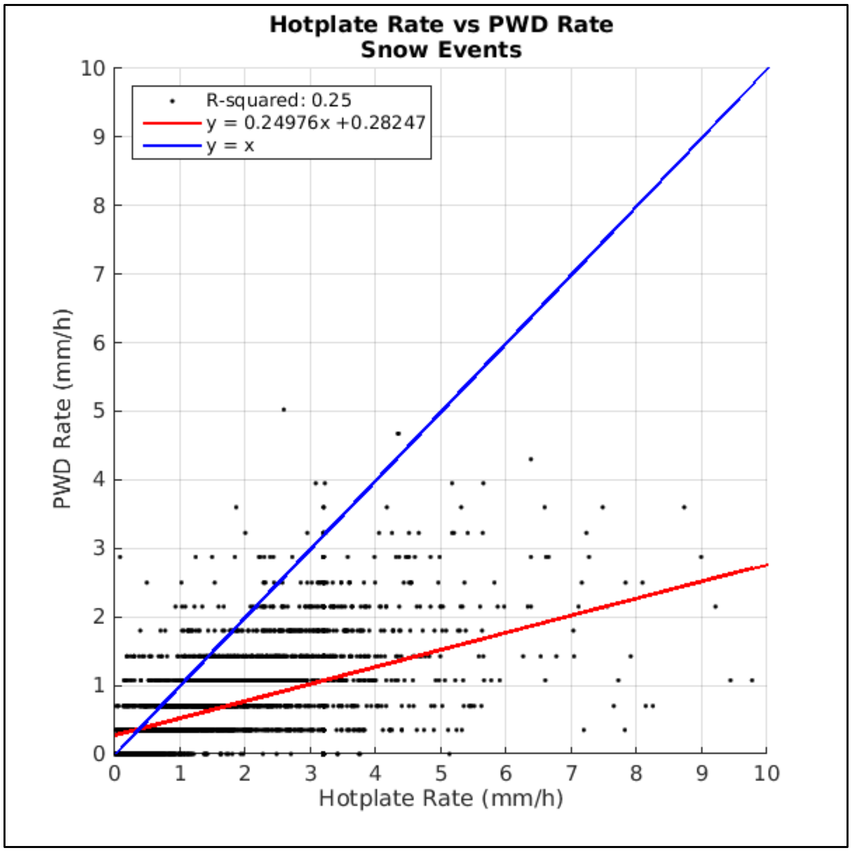

Figure 7. Hotplate rates versus PWD rates for snowfall events from both the Thane Road and Mt. Roberts sites

The horizontal “lines” of black dots evident in the comparison chart are due to the relatively coarse resolution of the PWD (which only reported in increments of 0.254 mm/hr). A line of best fit (shown in red) was applied to determine how well correlated the PWD was to the Hotplate. The one-to-one line (shown in blue) is provided for reference.

Overall, the data show the PWD sensor significantly underreports the snowfall rates and the underreporting increases as snowfall rates increase. The R^2 value is also shown and gives an indication of how well correlated the sensors are. A value of 1 would indicate a perfect correlation while a value of 0 would indicate no correlation. In this instance, the R^2 value of 0.25 shows a very poor correlation, indicating that, regardless of the observed undercatch bias in the PWD, the PWD sensor rates do not correlate well with the Hotplate rates.

One other concerning observation in Figure 7 is the number of observations where the PWD indicated snow, but the rates were zero (as indicated by the number of points shown on the graph where the PWD shows a rate of zero but the Hotplate shows a non-zero rate). It is unclear why the PWD would not report a rate when it is reporting precipitation, although the manufacturer might be able to explain this.

The researchers conducted further analysis on the data to determine if other variables were impacting the PWD's ability to accurately detect the snowfall rates. Figure 8 shows the same plot as Figure 7, but the individual points have been color-coded according to the ambient air temperature measured at the time of the rate measurements.

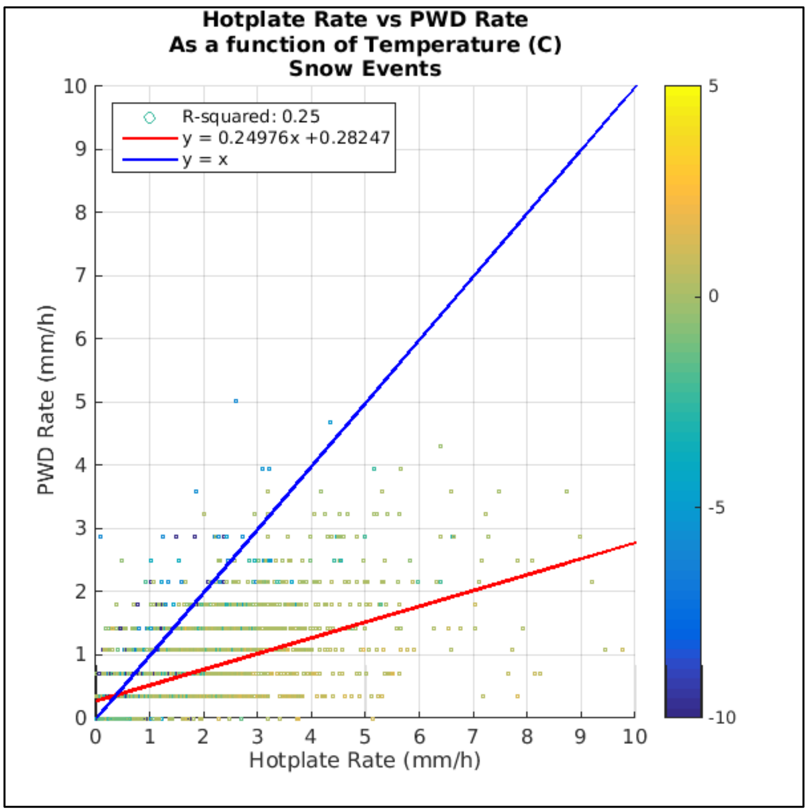

Figure 8. PWD versus Hotplate rates as a function of ambient air temperature (color bar on the right) from both the Thane Road and Mt. Roberts sites

The color-coded points correspond to the color bar on the right side of the plot. Some correlation can be seen, with most of the cold temperatures (in the -5 to -10°C or 14 to 23°F range) falling near the one-to-one line and most of the warm temperatures (above 0°C or 32°F) falling below the line of best fit. This may indicate that there is a temperature dependency on rate that the PWD sensor is not correctly accounting for in its rate derivations.

Because wind speed can often have an impact on snowfall measurements in some instruments, the researchers plotted Figure 9 in a similar manner to Figure 8, except each point was color-coded according to the wind speed observed at the time of the rate measurements instead of the temperature.

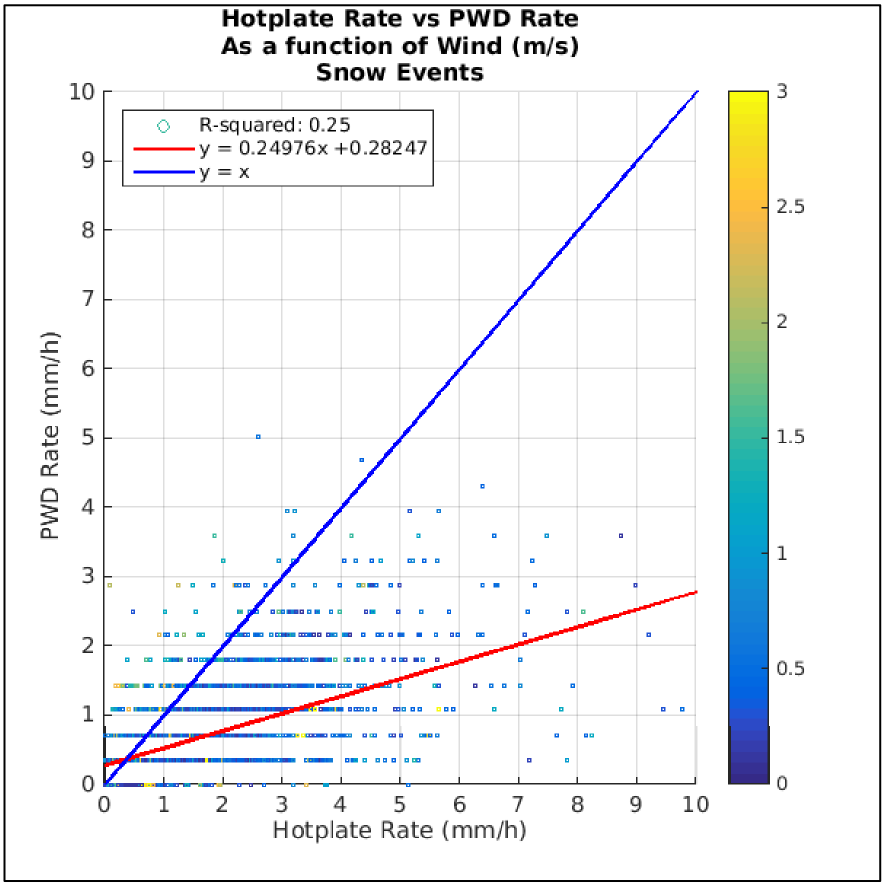

Figure 9. PWD versus Hotplate rates as a function of wind speed from both the Thane Road and Mt. Roberts sites

In this case, no real trends are observed for the different wind speeds; although, interestingly, the wind speeds rarely reached above 3 m/s when it was snowing. Wind direction could also play a role, especially if there were obstacles upstream that may block the precipitation from certain directions. Unfortunately, wind direction data was not collected as part of this research due to the instruments used, so these effects cannot be studied.

RAINFALL ANALYSIS

Similar plots were created for rainfall measurements. Figure 10 shows the rate comparison of the PWD to the Hotplate for all rain events from both the Thane Road and Mt. Roberts locations.

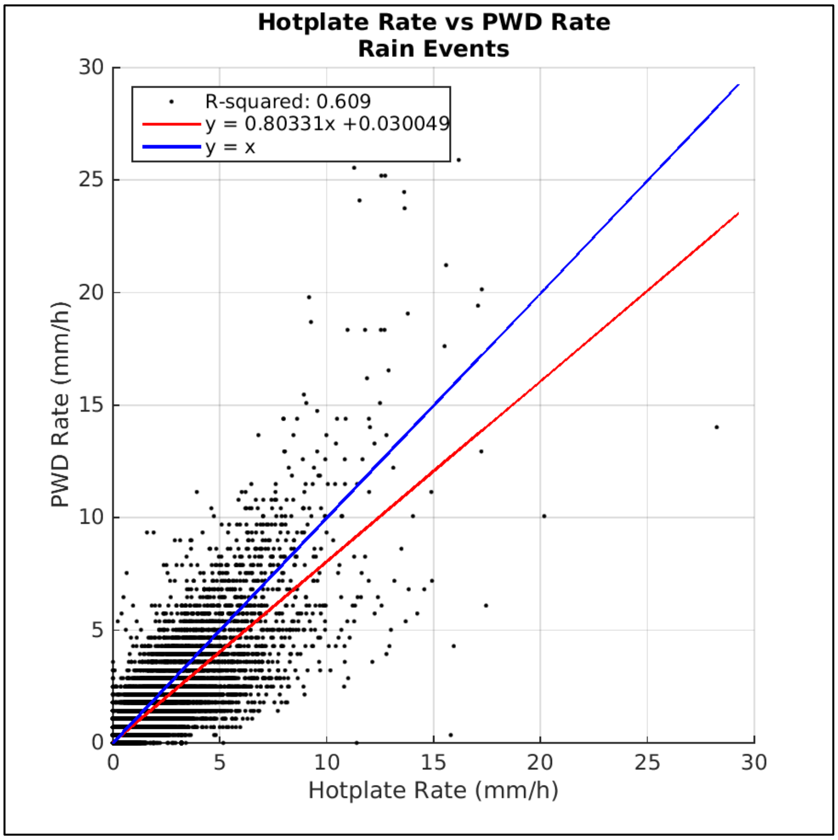

Figure 10. PWD versus Hotplate rates for rainfall events from both the Thane Road and Mt. Roberts sites

This figure shows a better correlation, with an R^2 value of 0.61. There is also much less of a bias for the PWD to underreport, but there is also still substantial variability in the comparisons. That variability also appears to increase at an increasing rate, as some of the largest outliers appear at the higher Hotplate rates.

Figures 11 and 12 show the same plot as Figure 10, but each comparison point was again color-coded according to the ambient air temperature and wind speed, respectively, at the time of each rate measurement. Unlike with snow, no obvious trends are shown with ambient air temperature (see Figure 11).

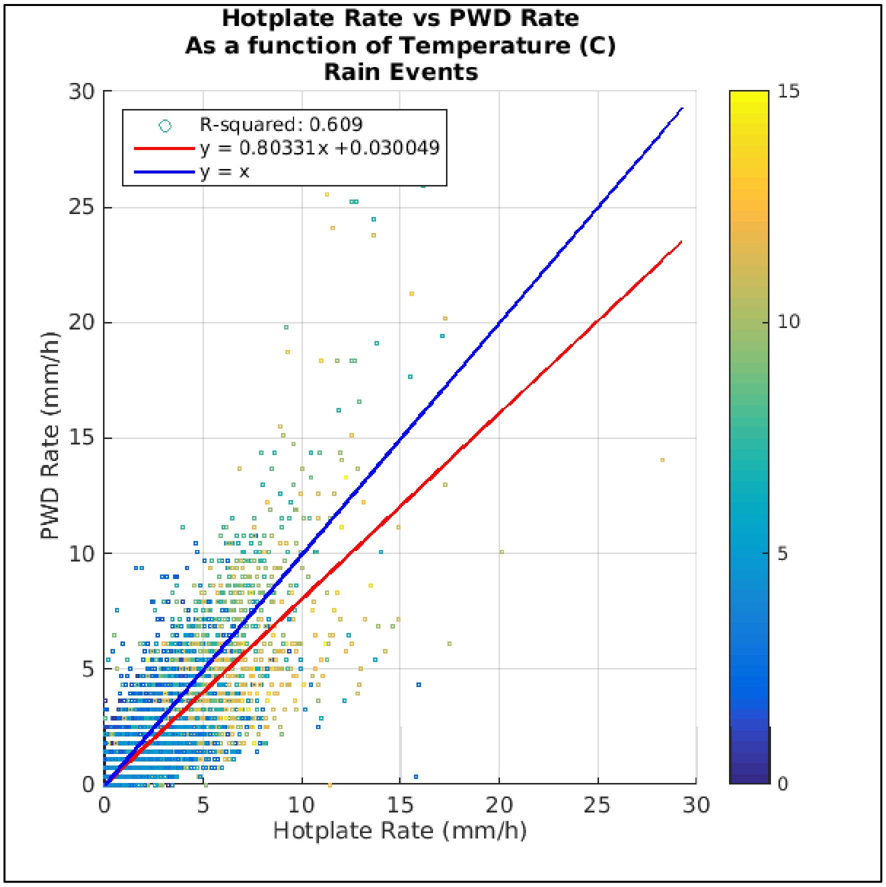

Figure 11. PWD versus Hotplate rates for rainfall events as a function of temperature from both the Thane Road and Mt. Roberts sites

Also unlike with snow, there do seem to be some slight trends with wind speed (see Figure 12).

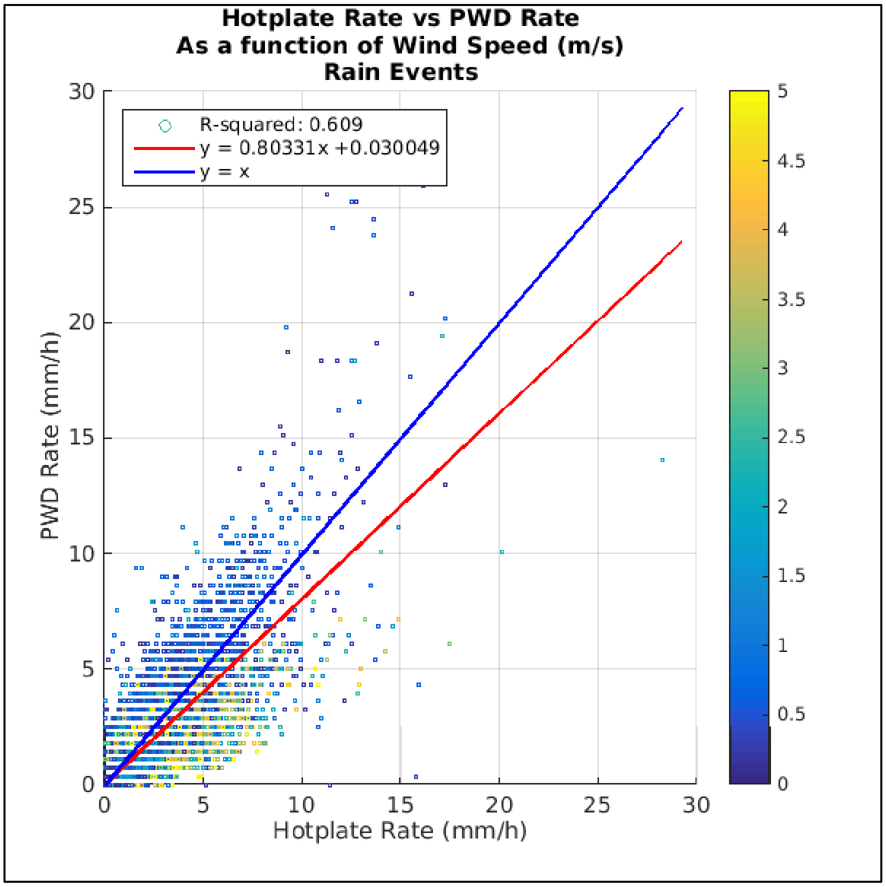

Figure 12. PWD versus Hotplate rates for rainfall as a function of wind speed from both the Thane Road and Mt. Roberts sites

For example, it appears that the PWD tends to overestimate rain in light wind speeds (< 2 m/s) and underestimate in higher wind speeds. This could indicate a problem with the sensor incorrectly determining the fall speed of the particles, and thus indicating an incorrect rate.

MARSHALL FIELD SITE DATA

The Marshall Field site is located at the base of the eastern Rocky Mountains along the Colorado Front Range, just south of Boulder, Colorado. This site is located at 39°56'59.9"N and 105°11'47.0"W at an elevation of 1742 meters (5,715 feet). The Marshall site is significantly different from the Juneau sites because it resides in a semi-arid continental climate regime. The site typically receives snow due to upslope snow conditions associated with easterly flow at the surface when low-pressure systems pass across the southern portion of the state. Temperatures at the site during snowfall conditions can range from near-freezing to -15°C (5°F) and colder.

A similar comparison of the PWD22 to the Hotplate data from the Marshall site was done to determine if any differences existed between the two different climates. Figure 13 shows the comparison of the PWD22 against the Hotplate data for the Marshall site snowfall events from November 1, 2015 to March 31, 2016.

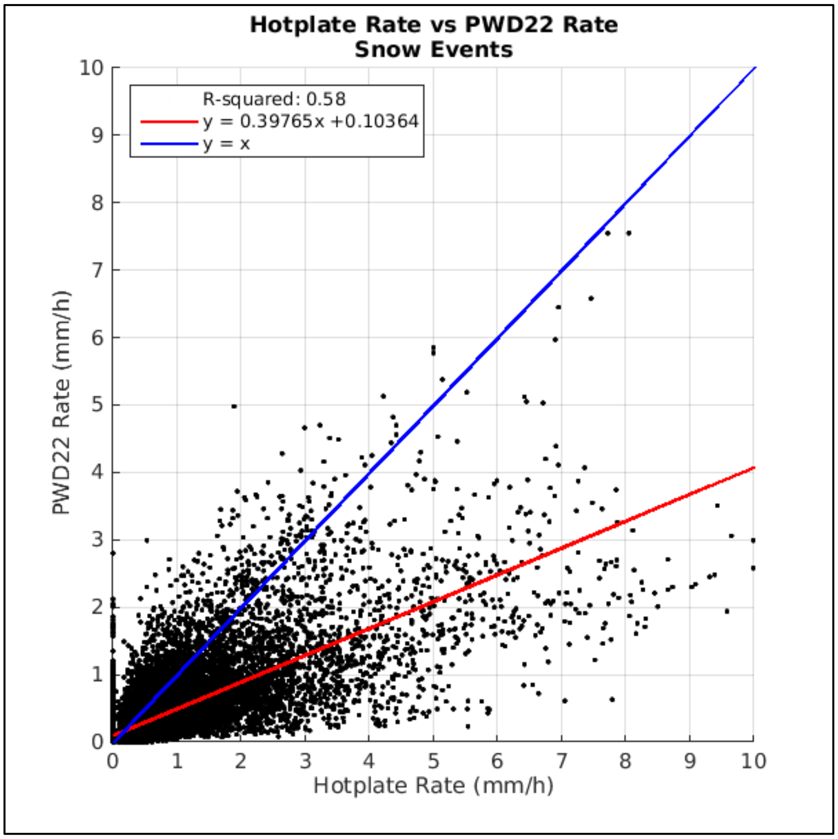

Figure 13. Hotplate rates versus PWD22 rates for snowfall events at Marshall Field site

It should be noted that the Marshall data shown are only for periods where the wind speeds were 3 m/s or less, so that the data could be directly compared to the Juneau data. Also of note in these plots is the improved resolution of the PWD22 sensor data. Whether that is a function of the model of the sensor at Marshall versus the Alaska sensors is unknown.

The data show very similar trends to the ones seen in Alaska with the PWD22 typically underestimating the snowfall rates. Figures 14 and 15 also show similar trends noted in the Juneau data, with snowfall at colder temperatures better correlated to the Hotplate than snowfall at warmer temperatures, and no correlation noted in the wind data.

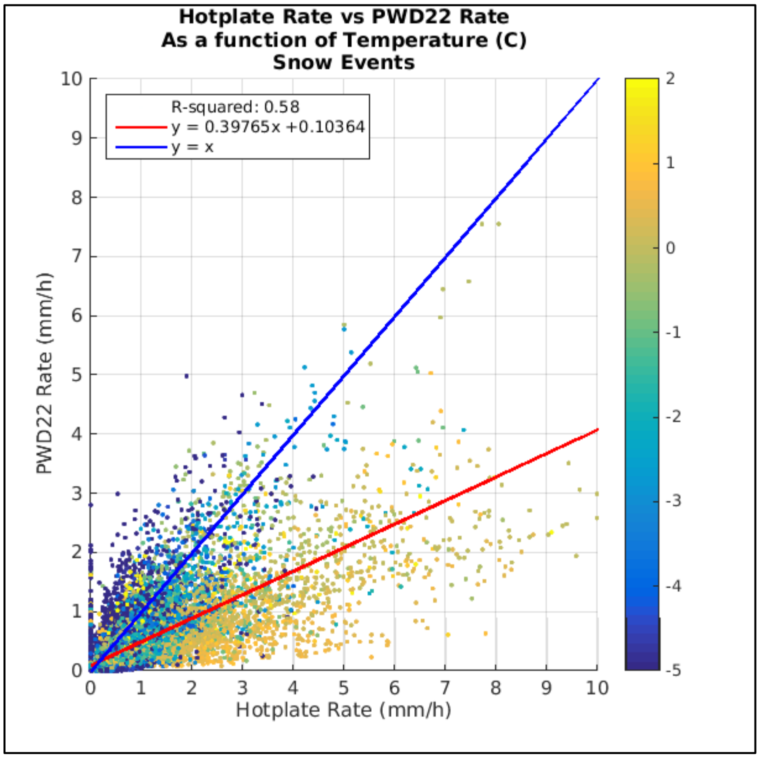

Figure 14. PWD22 versus Hotplate rates as a function of ambient air temperature at the Marshall Field site

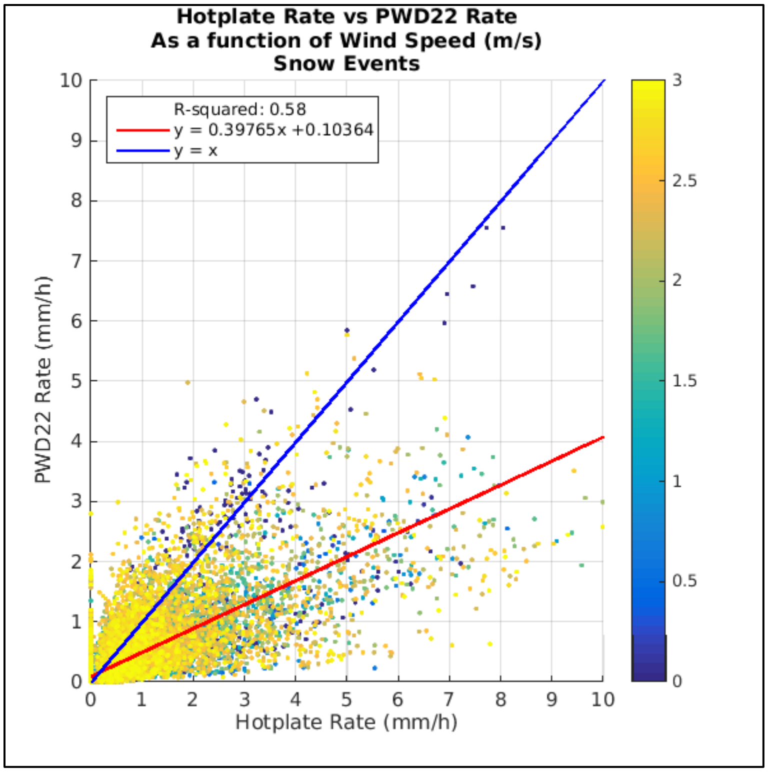

Figure 15. PWD22 versus Hotplate rates as a function of wind speed at the Marshall Field site

RESULTS AND CONCLUSIONS

An analysis of both the Juneau and Marshall datasets indicates that, overall, the PWD underestimates snowfall precipitation rates as compared to the Hotplate. Additionally, the snowfall rate underestimate is more significant at higher snowfall rates. A correlation does appear to exist with temperature where the correlation for snowfall at cold temperatures (-10°C or 14°F and lower) is closer in agreement to the Hotplate than at temperatures near freezing. This was noted in both the Marshall and the Juneau data, indicating that this isn't due to the varying types of snow at the individual locations (due to the different climates), but more of a problem related to how the sensor derives the snowfall precipitation rates.

This may be a result of the sensor determining incorrect particle fall velocities (which the sensor uses as an intermediate step), which could lead to incorrect rate calculations. If a constant fall velocity is assumed for all snow by the sensor, this could be the reason for the temperature dependencies noted in the data, but the manufacturer would need to be consulted on this.

While the snowfall intensities (light, moderate, heavy) based on visibility measurements have been shown to be accurate based on past research, this research highlights the issues related to the derived precipitation rates and has clearly shown that there is a systematic bias with the PWD sensors for underreporting the actual rates. Any users relying on the PWD rates should be aware that the rates can be underestimated by 50% or more when the PWD reports a rate of just 1 mm/h or more at temperatures near freezing.

Recommendations

Based on the data analyses, any organization interested in using the rate data for snow events from the PWD sensors in Juneau should, at a minimum, attempt to correct the bias in the rates using the following equation (based on the best-fit line from Figure 7):

Corrected Estimated Rate = (PWD rate – 0.28247) ÷ 0.24976

This will not correct the scatter observed in the data, and some estimates may be over or under-estimates, but this should provide a better estimate of the actual rate.

To get a better idea of the rate corrections for snow for PWD sensors not at Juneau, Figure 16 shows a plot of the Juneau and Marshall snow data combined.

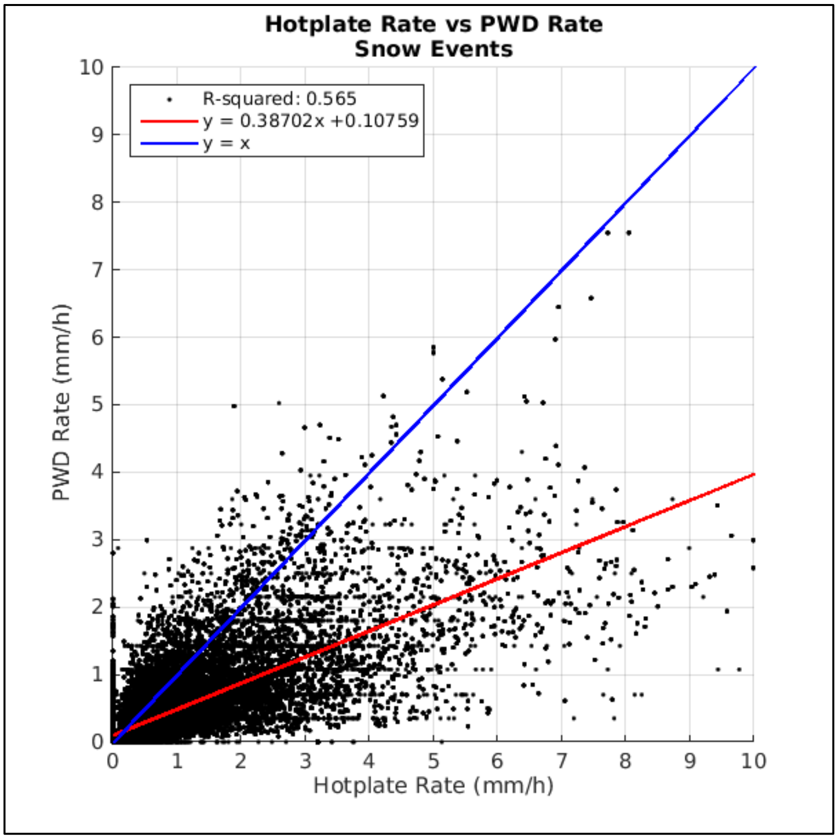

Figure 16. Hotplate rates versus PWD rates for snowfall events at both Marshall and Juneau

Assuming other PWD sensors are similar to the three used in this study, applying the following equation should similarly correct the bias in other datasets:

Corrected Estimated Rate = (PWD rate – 0.10759) ÷ 0.38702

The data from this study can be provided to Vaisala to assist in their efforts to improve their rate estimates if they find the raw data of use. If further improvements to the sensor are not possible, the researchers recommend that users either utilize the above equations to correct the bias errors in the PWD snowfall rates or compare their PWD sensor measurements against a known calibrated gauge to determine their own corrections in a similar manner.

Users of other PWD measurements should be aware that the corrections from this study assume all other PWD sensors have a similar bias (while the sensors may not), and the only way to confirm it is to do a similar comparison.

OUTCOME

Based on the preliminary results from this research, the ADOT&PF directed Vaisala to make an adjustment in the Rain Intensity Scale noted in this report. The Rain Intensity Scale for the Present Weather Detector PWD12 at the Juneau Thane Road site (Thane Road @ Snowslide Creek Avalanche Pat MP 1.9) was set to 1.3 from 1.0. This is based on the overall results of the study that the PWD12 sensor was underreporting the LWE by 30% when compared to the co-located Yankee Environmental Systems Hotplate sensor and Geonor gauge. The new PWD12 weather parameter settings are listed in Table 1.

Table 1. New PWD12 weather parameter settings for Juneau Thane Road site

Parameter	Setting
Precipitation Limit	40
Weather Update Delay	6
Rain Intensity Scale	1.3
Heavy Rain Limit	8.0
Light Rain Limit	2.0
Snow Limit	5.0
Heavy Snow Limit	600
Light Snow Limit	1,200
DRD Scale	1.0
DRD Dry Offset	841.1
DRD Wet Scale	0.0017

The PWD version 2.05 software was used for the Rain Intensity Scale setting update.

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