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The Hotplate Snow Gauge

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1. INTRODUCTION

Recent studies (Rasmussen et al. 1999, Rasmussen et al. 2000) have shown that the use of visibility to estimate snowfall rate can be misleading in many instances due to the wide variety of snow crystal types. The hazard identified for aviation is the “high snowfall rate – high visilibity” condition. Under this condition the liquid equivalent snowfall rate can exceed 2.5 mm/hr, the rate at which five of the major deicing accidents occurred (Rasmussen et al. 2000), while the visibility based snow intensity can be light. This is in fact the condition that occurred during the LaGuardia deicing accident on March 22, 1992 (Rasmussen et al. 2000). In order to overcome this problem, real-time estimates of the liquid equivalent snowfall rate updated every one minute are needed. The current ASOS systems provide hourly snowfall intensities based on visibility, which is clearly inadequate for aircraft ground deicing needs. A winter weather nowcasting system called the Weather Support to Deicing Decision Making (WSDDM) system (Rasmussen et al. 2001) has recently been developed that includes real-time weighing snowgauges as a key component. These types of gauges essentially weigh the snow as it falls into a bucket filled with a glycol based chemical and a thin layer of oil to prevent evaporation. Wind shields are also required to be used with these snow gauges in order to prevent undercatch of snowfall due to wind impacting the gauge itself. In order to adapt this gauge for real-time use, Rasmussen et al. (2001) added a temperature controlled heat tape on the collar of the gauge in order to prevent snow build up on the collar. While effective, these gauges typically require a wind shield to increase the catch, a regular re-charge of the collection bucket with fresh glycol and oil, and report snowfall rates that are averages over 5-10 minutes due to the accumulation nature of the gauge. In this paper we present a new snowgauge, called the “hotplate snowgauge” which provides a reliable, low maintenance method to measure snowfall rate every minute without the use of a wind shield.

2. Description of the Hotplate Snowgauge

The hotplate snowgauge (shown in figures 1,2 and 3) consists of two identical heated plates, one facing upwards and exposed to precipitation (Fig. 1) and the other facing downwards just below the top plate (Fig. 2). The lower plate is insulated from the top plate and is designed to serve as a reference plate that is only affected by wind and not by precipitation. The two plates are heated to nearly identical constant temperatures (~ 70 °C), which is hot enough to melt and evaporate small snow particles striking the plate in less than a second and large snowflakes in a few seconds. The plates are maintained at constant temperature during wind and precipitation conditions by increasing or decreasing the current to the plate heaters. During normal windy conditions without precipitation, the plates cool nearly identically due to their identical size and shape. During precipitation conditions, the top plate cools due to the melting and evaporation of precipitation while the bottom plate is only affected by the wind.

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Figure 1 Top view of hotplate. Diameter of plate is 13.0 cm.

Figure 2 View of lower plate. Diameter of plate is 13.0 cm.

The difference between the power required to cool the top plate compared to the bottom plate is then proportional to the precipitation rate. Three concentric rings are placed orthogonal to each plate in order to prevent snow particles from sliding off the top hotplate during high wind conditions. Due to its aerodynamic shape, the hotplate has minimal effect on the airflow around it, and thus does not require a wind shield. In addition, since all the snow melts and evaporates, it does not require any glycol or oil, making is very low maintenance. The hotplate snowgauge has undergone five years of testing at Marshall (a site near Boulder) and two years of testing at Mt. Washington, NH. In the next section we describe the hotplate snowgauge algorithm and in section 4 compare its performance to standard weighing snowgauges during a winter season. In section 6 an evaluation of the commercial version of the hotplate manufactured by Yankee Environmental is discussed. Concluding remarks are made in section 5.

3. Algorithm

3.1 *Calculation of precipitation rate*

The raw output of the hotplate system is the difference in power used to maintain the top and bottom plates at constant temperature. In order to convert this power difference to liquid equivalent rate, a theoretical calibration factor was developed based on the area of the hot plate, the heat capacity and density of water, and the latent heat of melting and evaporation. The value of the calibration factor, f, for a hotplate system with upper plate maintained at 75 °C is 0.0039 inches/hour liquid equivalent per power difference in Watts. In practice, this value was increased slightly depending on the hot plate to account for heat transfer losses.

The sensor and reference plate temperatures are set such that the power difference (ΔP in Watts, power of the sensor plate minus the power of the reference plate, Ps-Pr) is about 0 Watts when there is no precipitation falling. The top and bottom plates were made identical in order to minimize any wind speed dependence on the power consumed by either plate, thus making ΔP independent of wind speed as much as possible.

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Figure 3 Commercial version of the hotplate snow gauge deployed at the NCAR Marshall Field Site just south of Boulder, CO.

However, it was found in practice that ΔP still had a small dependence on wind speed that needed to be taken into account. Thus, the equation to calculate precipitation rate can be given as:

$$\text{Rate (mm/hr)} = (\Delta P - (a + b^{*}w + cw^{2}))^{*}f \quad (1)$$

where w is the wind speed in m/s and a, b, and c are coefficients of the curve fit between ΔP and w during non-precipitation conditions.

Using equation (1), the rate is calculated every minute, and then a five minute running average formed. If this five minute average rate does not exceed a threshold of 2 Watts, it is assumed that it is not precipitating. A 2 Watt threshold is used to account for wind variations on the top and bottom plates and also the diurnal solar heating of the hotplate. Once the five minute rate is greater than the threshold, precipitation is assumed to have started. During precipitation, rates are calculated every minute until the rate drops below zero.

A two hour time series of the sensor power, reference power, and the power difference is given in figure 4. During the first 20 minutes of the time series no snow is falling, and the sensor and reference power traces are nearly equal as expected. After 20 minutes, snow commences and the traces separate, with the sensor power being larger than the reference power as expected. The delta power trace shows a power difference of approximately 10 - 20 Watts during this period.

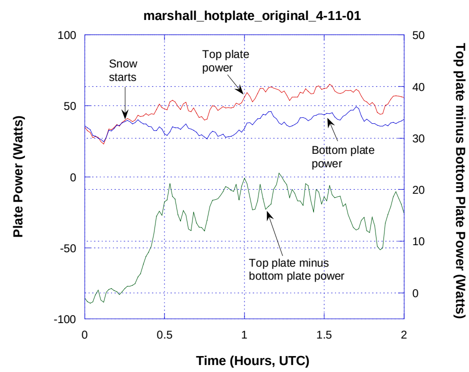

Figure 4 Two hour sensor, reference, and delta power time series from the hotplate during a snow event.

Applying the conversion factor discussed above, the delta power trace shown in figure 4 can be converted to a snowfall rate trace and accumulation trace as shown in figure 5.

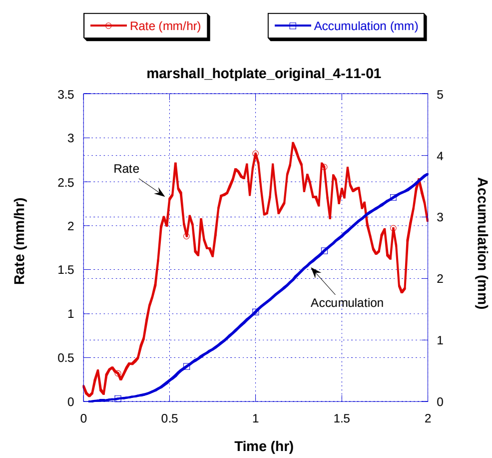

Figure 5 Two hour time series of snowfall rate and accumulation derived from the power time series in figure 4.

3.2 Accounting for under-catch due to wind effects

Comparison of the hotplate accumulation with a weighing snowgauge in a WMO standard

Double Fence Intercomparison Reference (DFIR) shield revealed that the hotplate under-estimated snow accumulations when the winds were above 3 m/s. On April 10-11, 2001 a snow event occurred in which the wind speed gradually increased during the event, as shown in Fig. 6. Note that a peak wind speed of 11.5 m/s is reached at 1120 UTC.

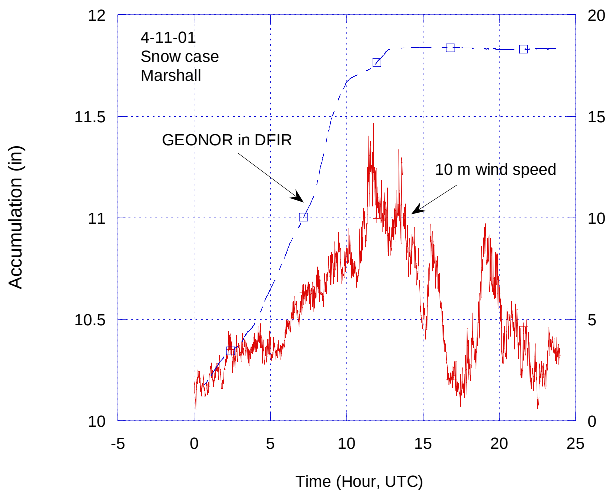

Figure 6 Ten meter wind speed and GEONOR in the DFIR shield accumulation for April 11, 2001

During this event the difference between the hotplate accumulation and the GEONOR increased with increasing wind speed. In order to further quantify this result, we examined the hourly GEONOR and hotplate accumulations and formed the hourly accumulation ratio. If the ratio is 1.0, then the hotplate is estimating the same accumulation as the GEONOR in the DFIR shield. The results are shown in figure 7. Note that the catch efficiency decreases linearly with increasing wind speed. Thus, the catch of both hotplates is reduced to 50% for a wind speed of 5 m/s, and by 80% for a wind speed of 10 m/s. Beyond 10 m/s the catch efficiency is set to 0.2. Thus, the effect of the wind needs to be taken into account in the hotplate algorithm to prevent undercatch.

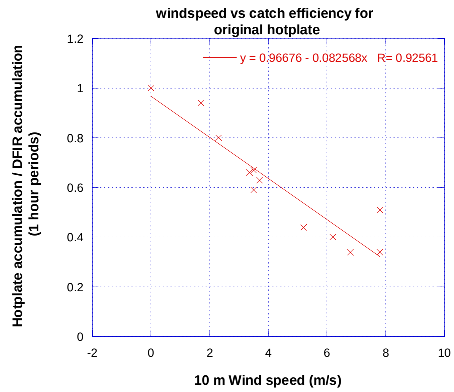

Figure 7 Catch efficiency for the hotplate as a function of wind speed using data from April 11, 2001.

Applying both the wind catch correction algorithm and the baseline wind correction described above, false precipitation during non-precipitation days have been reduced to less than 0.01 in/hr

Based on these results the algorithm sets to zero all precipitation rates less than 0.01 in/hr, and thus requires a threshold of 0.01"/hr before precipitation is recorded. An example of the performance of the hotplate for a high wind case is shown in figure 8.

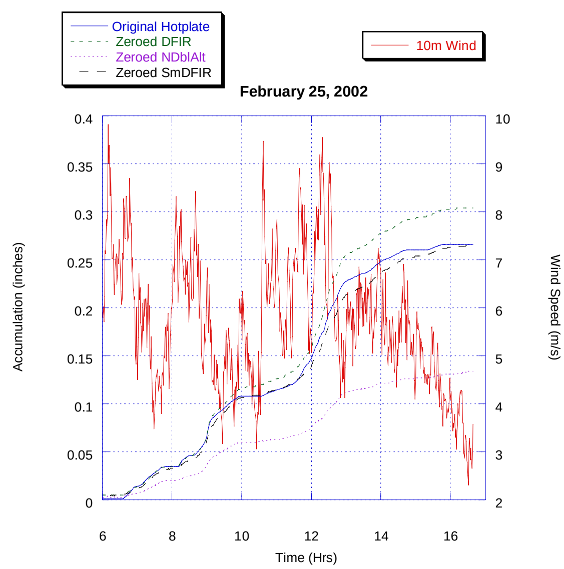

Fig. 8 Hot plate accumulation compared to GEONOR snowgauge in DFIR shield, GEONOR in a small DFIR shield, and GEONOR in a double Alter shield.

The results show excellent performance of the hotplate for winds up to 9 m/s. Additional testing has shown that this correction curve applies up to 15 m/s. This algorithm has been tested on a variety of snowstorms since 2001 and proven to be robust. Thus, taking into account wind effects is crucial to the proper performance of the hotplate.

4. Full Winter Season Performance Evaluation

In this section we evaluate the performance of the hotplate using the above described algorithms. The reference snow measurement is a GEONOR snowgauge located in a DFIR shield at the Marshall test site. The DFIR is the WMO standard snow shield for use with weighing gauges. In our previous studies, we have shown that the GEONOR in the DFIR shield meets or exceeds the NWS 8" can with a single Alter shield in all cases. The criteria for the intercomparison was:

1) the absolute value of the difference between the Geonor in the DFIR hourly accumulation and the original hotplate hourly accumulation was less than or equal to 0.02 inches, or 4% of the hourly total, whichever is greater, and;

2) no measurable precipitation during non-precipitation events (less than 0.12 mm in an hour).

The above criteria is used by the National Weather Service ASOS Program Office to evaluate the performance of weighing snow gauges.

Seven storms have been analyzed from 2001, as shown in table 1, consisting of 137 hours of precipitation. In addition, three days without precipitation have also been analyzed (March 13,13,14, and 15 2001).

Table 1. Precipitation events at Marshall test site evaluated

Date (2001)	Depth	Type	Liquid
1. 7-9 Feb	5"	snow	0.33"
2. 14 Feb	3.5"	snow	0.29"
3. 10-12 March	8"	snow	0.75"
4. 17 March	1.5"	snow	0.19"
5. 25-26 March	7"	snow	0.56"
6. 31 March	0.5"	snow	0.09"
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Total	25"		2.11"

All 137 hours with precipitation passed the above criteria, as well as the 66 non-precipitation hours. The non-precipitation days had false reports of accumulations no greater than 0.004 inches per hour and maximum false reports of 0.001- 0.002 inches in an hour.

5. Case Study Evaluation of Commercial Hotplate Manufactured by Yankee Environmental

In the following two cases comparing two commercial versions of the hotplate described above are evaluated using two recent snow events.

5.1 April 10-11, 2005 Event

A rain event started just before 0530 UTC on April 10, 2005. Around 1000 UTC the rain transitioned to snow and ice pellets and continued on and off until 1130 UTC on the 11^{th}. Observations from a Light Emitting Diode Weather Identifier (LEDWI) were used along with a collocated Weather Identifier & Visibility Sensor (WIVIS) to determine the precipitation type. Three hotplates were available for evaluation during this event, two Hotplates built by YES, Inc. (YES Hotplate #1 and YES Hotplate #2) and the original hotplate, whose results were described above. The accumulation from each hotplate was compared with a weighing snowgauge in a WMO standard Double Fenced Intercomparison Reference (DFIR) Shield (Fig. 9). The accumulation from each hotplate is in excellent agreement with the truth gauge throughout the rain portion of the event. Wind speeds from 0.5 to 10 m/s had no effect on the collection efficiency of the gauge. Once the precipitation transitioned to snow and ice pellets, the hotplates slightly underestimated the precipitation rates as compared with the truth gauge. Since no human observer was present, it is assumed that some type of solid precipitation (ice pellets or graupel) was present. Winds varied throughout the event from 0 to 14 m/s. The hotplates underestimated the total accumulation for the event due to the precipitation rates dropping below 0.25 mm/hr or 0.01"//hr (minimum detectable rate) for portions of the event. The average rate for the event from all of the gauges differed by less than 0.25 mm/hr. Accumulation measurements from YES Hotplate #1 and #2 resulted in a difference of less than 1.5 mm for the entire event.

The wind speed derived from the reference plate power and ambient temperature was compared with a propeller anemometer mounted 10-meters AGL (Fig. 10). Both YES Hotplates show very good agreement with the propeller anemometer. A one-to-one comparison (Fig. 9) shows excellent correlation between the hotplate's wind speed measurement and the true wind speed.

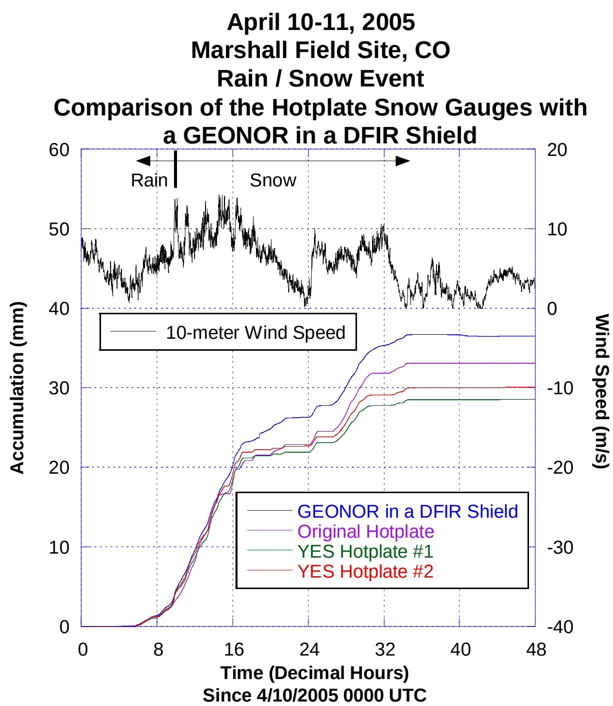

Figure 9

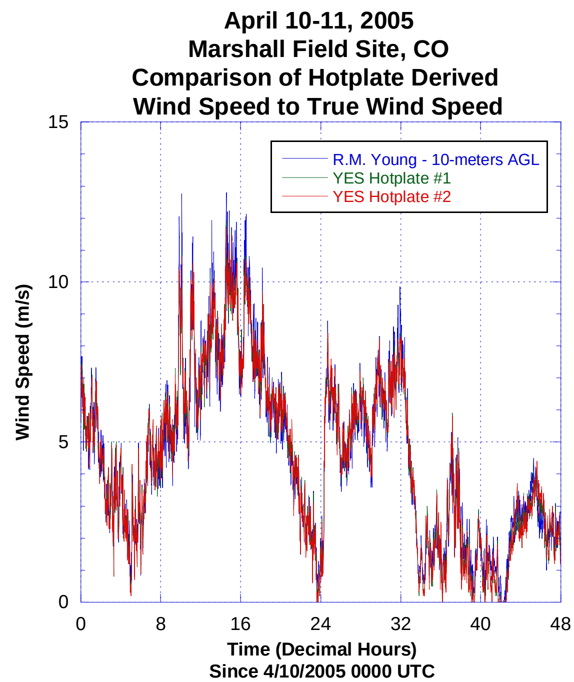

Figure 10

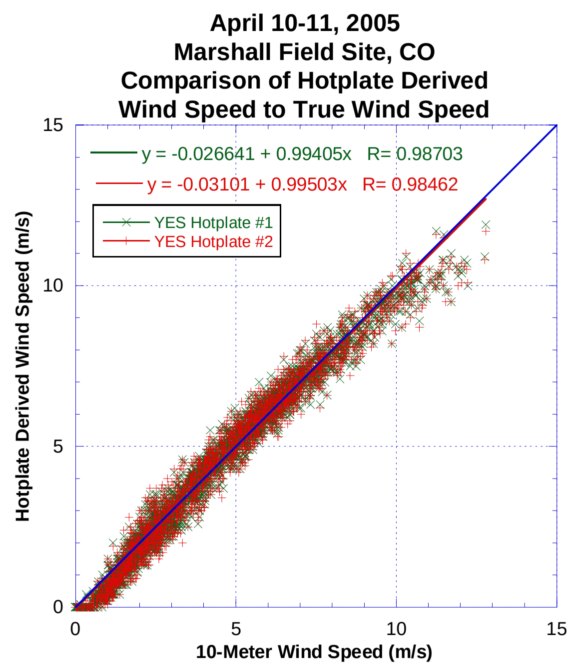

Figure 11

5.2 April 27-29, 2005

A rain event started at 2300 UTC on April 27, 2005. Around 0030 UTC on the 28^{th}, the rain transitioned to snow and continued through 1730 UTC on the 29th. The two YES Hotplates performed well during this event (Fig. 12). Table one shows that both the total accumulation and average rates during the event agreed well.

During this event the propeller anemometer froze up and stopped reported at 0400 UTC on the 28th. Since the hotplate measures the wind speed using the bottom plate, a reliable wind speed measurement was maintained by both hotplates for the entire event (Fig. 13). Thus, the hotplate can be used to measure wind speed during severe icing conditions.

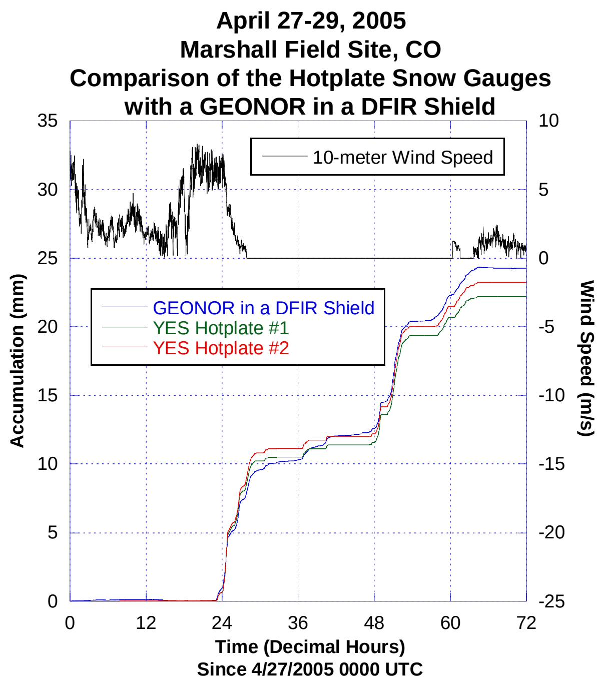

Figure 12

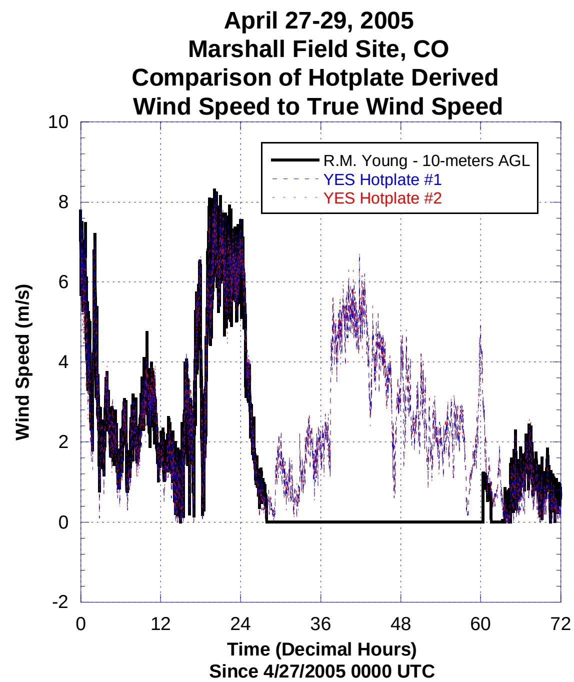

Figure 13

	Total Accumulation (mm)	Avg. Rate (mm/hr)
GEONOR	24.25	0.64
YES #1	22.21	0.53
YES #2	23.23	0.56

Table 1

6. Summary

A new hotplate snowgauge has been described consisting of two heated plates used to estimate snowfall mass by measuring the power to melt and evaporate snow on the upward facing sensor plate, compensated for wind effects by subtracting out the power on the lower plate facing downwards. The system measures liquid equivalent snowfall rate from 0.25 mm/hr to 25 mm/hr to within 10% of the WMO standard snow measuring wind shield/gauge setup. The hotplate was also shown to accurately measure wind speed even during severe icing conditions. The high update rate (precipitation rates, winds and temperatures every one minute), make this an ideal gauge for real-time applications such as aircraft deicing which requires update rates every minute. It can also be used as an accumulation gauge by integrating the one minute rates over time.

7. Acknowledgements

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