8.6 THE HOTPLATE SNOWGAUGE

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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 5 minutes 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 type 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 are relatively expensive and require regular re-charge of the bucket with fresh glycol and oil. In this paper we present a new snowgauge, called the “hotplate snowgauge” which provides a reliable, low maintenance method to measure snowfall rates in real time.

2. DESCRIPTION OF HOTPLATE SNOWGAUGE

The hotplate snowgauge (shown in figure 1) 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 the reference plate that is only affected by wind and not by precipitation. The two plates are heated to nearly identical constant temperatures (near 75 °C), which is hot enough to melt and evaporate snow particles striking the plate in less than a second. 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 effected by the wind.

Figure 1 Top view of hotplate. Diameter of plate is 13.3 cm.

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Figure 2 View of lower plate. Diameter of plate is 13.3 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. A number of different versions of the hotplate have been tested, including an "original" version, Mt. Washington hotplate, coil hotplate, and a frisby hotplate. A photo of all the different hotplate versions is given in figure 3. Also note the comparison in size to a typical wind shield used for weighing snowgauges in the background of this photo. In this paper we discuss the "original" hotplate.

The original hotplate has undergone three 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 algorithm and in section 4 compare its performance to standard weighing snowgauges. 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.

Figure 3 From left to right, "original" hotplate, Mt. Washington hotplate, coil hotplate, frisby hotplate. Left 1/3 of a half scale Wyoming shield is shown in the upper right of the photo.

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 –3 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. 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:

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

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 is negative, it is assumed that it is not precipitating. Once the five minute rate is positive, precipitation is assumed to have started. During precipitation, rates are calculated every minute until the rate drops below zero.

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 would underestimate snow accumulation when the winds were above 3 m/s. On April 10-11, a snow event occurred in which the wind speed gradually increased during the event, as shown in Fig. 4. Note that a peak wind speed of 11.5 m/s is reached at 1120 UTC.

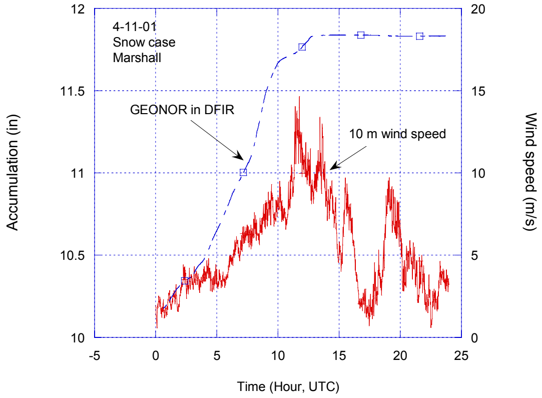

Figure 4 Ten meter wind speed and GEONOR in the DFIR shield accumulation for April 11, 2001

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 5. Note that the catch efficiency decreases linearly for both the original and Mt. Washington hotplate with nearly the same slope and y intercept. 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.

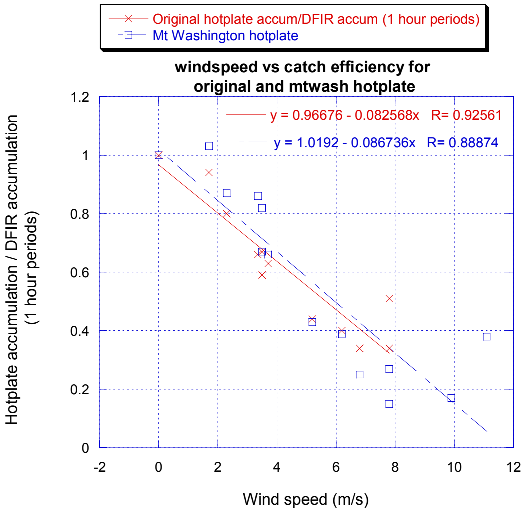

Figure 5 Catch efficiency for the Original and Mt. Washington hotplates as a function of wind speed using data from April 11, 2001.

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 0.006 in/hr

Based on these results the algorithm sets to zero all precipitation rates less than 0.006 in/hr. Thus, the onset threshold for the algorithm is set to 0.006 in/hr. An example of the performance of the hotplate for a high wind case is shown in figure 6.

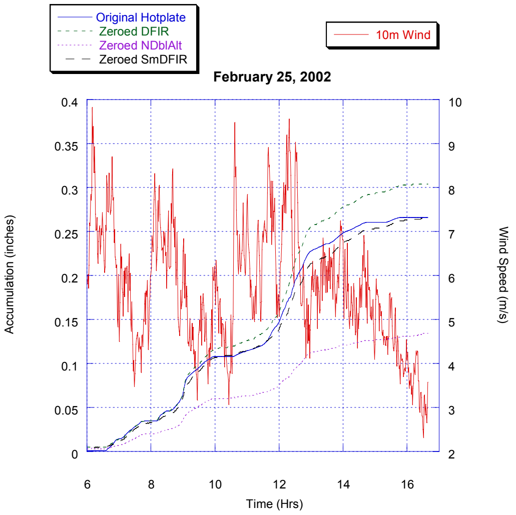

Fig. 6 Hot plate accumulation compared to GEONOR snowgauge in DFIR shield, GEONOR in a small DFIR shield, and GEONOR in a double Alter shield.

The results show excellent performance of the hotplate for winds up to 9 m/s. Thus, taking into account wind effects is crucial to the proper performance of the hotplate.

4. PERFORMANCE EVALUATION

In this section we evaluate the performance of the hotplate using the above described algorithms. The reference snow measurement is made with a GEONOR snowgauge located in a DFIR shield at the Marshall test site. The DFIR is the WMO standard 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	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. CONCLUSIONS

The above analysis shows that the hotplate snowgauge is capable of providing excellent estimates of real-time liquid equivalent snowfall rates every minute as long as wind speed effects on the baseline and catch efficiency are accounted for. The hot plate snowgauge requires no shielding, no side-wall heating, nor does it use any glycol or oil and has a relatively small footprint. The hot plate is also expected to be relatively low cost. Future work will be directed towards testing a version of the hotplate for all precipitation types and higher precipitation rates. The version of the hotplate described in this paper is designed for precipitation rates up to 12 mm/hr, which makes it ideal for snowfall rate measurement. It is currently being made available for commercialization.

6. ACKNOWLEDGEMENT

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7. REFERENCES

Rasmussen, R.M., M. Dixon, F. Hage, J. Cole, C. Wade, J. Tuttle, S. McGettigan, T. Carty, L. Stevenson, W. Fellner, S. Knight, E. Karplus, and N. Rehak, 2001: Weather Support to Deicing Decision Making (WSDDM): A Winter Weather Nowcasting System. *Bulletin of the American Meteorological Society*, **82**, 579 – 595.

Rasmussen, R.M., J. Cole, K. R.K. Moore, and M. Kuperman, 2000: Common Snowfall Conditions Associated with Aircraft Takeoff Accidents. *J. of Aircraft,* **37**, 110 – 116.

Rasmussen, R.M., J. Vivekanandan, J. Cole, B. Myers, and C. Masters, 1999: The Estimation of Snowfall Rate Using Visibility. *J. Appl. Met.*,38, 1542 – 1563.