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BUREAU OF METEOROLOGY

Regional Instrument Centre

Instrument Test Report – 675

LABORATORY EVALUATION OF THE BUREAU DESIGNED HEATED TIPPING BUCKET RAIN GAUGE

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Aim

The aim of this report is to describe and discuss the testing of a Bureau designed heated Tipping Bucket Rain Gauge (TBRG) prototyped by McVann Pty Ltd (Rimco model 8020H). The structure of this document parallels that of the Bureau specification for tipping bucket rain gauges[1] with additional tests designed to assess the prototypes ability to measure precipitation in Australian alpine conditions. This report contains references to sections of the Bureau TBRG specification [1] considered relevant for RIC testing and does not include testing against all criteria.

Experimental

The testing comprised of two parts, the ability of the gauge to measure rainfall equivalent to water entering the device and the efficacy of the device in alpine conditions when subjected to simulated snow falls.

For testing the rainfall sensitivity of the gauge a rig known within the RIC as Rex was employed [2]. This system is fully automated in terms of water delivery, tip counting and data logging. The system determines the experimental value – *the number of tips for a fixed volume of water at a particular rainfall rate*. The results were put into the form, *corrections required per 100 tips* for each gauge at various rainfall rates producing graphs, which are employed to evaluate the gauges against the specification [1].

The water used in these tests was Melbourne tap water filtered through an Aquapure AP124 in-line water purification filter. Previous work has established that testing with filtered water does not significantly alter testing results when compared with distilled water [3].

To simulate alpine conditions the gauges were tested in a Heraus Model 4070 environmental chamber. The temperature of the chamber, TBRG buckets and the temperature of the siphon were measured using Pt100 resistive temperature devices previously verified in the RIC. For the measurement of siphon temperature the sensor tip of this probe was taped to the siphon inside the TBRG. The temperature of the base was measured by placing a Pt100 sensor against the base at the point where the bucket adjustment screws pass through the base cross arm. The chamber temperature was measured by a Pt100 sensor exposed to the chamber airflow. The temperatures from the Pt100s were logged with an Almos AWS while the ambient temperature within the test chamber was manually logged. The ambient temperature in the chamber was controlled to within +/-0.3^{o}C of the set-point.

For all experiments within the chamber the chamber light (approximately 70 watts) was off. The simulated conditions were therefore representative of night conditions; higher snow clearances rates could be expected during daytime operation.

Two McVann TBRGs were available (serial numbers 77470 & 77471) for testing.

The vertical wind speed was measured using a TSI Model 8384-M-GB hot wire anemometer serial number 01040518 calibrated at the CSIRO Atmospheric Research in July 2003.

The simulated snow equivalents were weighed on Denver Instruments Model DI4K electronic scales Serial Number DI002250 verified on August 2003 against the RIC reference mass set number M25.

Results

1. **Climatic Conditions** – as described in Part 11 of results.

2. **Reliability**
   The rain gauge must be capable of resolving rainfall events of 0.6 mm and greater.
   Pass – that is, one or more tips were detected from a 'dry' gauge for an injection of 20 ml of water into the gauge funnel.

3. **Tolerance –** See Section 9.

4. **Rainfall capability.**

This test is designed to evaluate whether the gauge will overfill during expected short duration intense rain events.
The gauge must accept water up to an equivalent rate of 350 mm/hour without the collecting funnel starting to fill. Pass

4.1 The gauge must accept volumes of water equivalent to the following extreme rainfalls without overflow of the collecting funnel:
a) 30 mm of rain over 1 minute = 970 ml/min for one minute Pass
b) 85 mm of rain over 5 minutes = 550 ml/min for five minutes Pass
c) 130 mm of rain over 10 minutes = 420 ml/min for ten minutes Pass
d) 250 mm of rain over 30 minutes = 270 ml/min for 30 minutes Pass

5. **Collector Details**

5.1 *Cross Section of rim between 200 and 205 mm in diameter* - Pass

5.2 *The overall height of the gauge must be between 250 and 360 mm ±0.5 mm*- Pass

5.2 *The gauge must be suitable for installing on a flat metal plate or concrete slab. Three mounting holes of 8 to 10 mm diameter shall be placed at 120° intervals on a 254 mm pitch circle diameter at the bottom of the gauge. The holes may be in three separate legs or in a circular base.* - Pass.

6. **Durability of materials** – Not evaluated in this study

7. **Measuring system details**

7.1 *The bucket mechanism must not retain more than 0.2 ml of water on the surface of the bucket side after its water has been discharged. A suitable coating such as Teflon may be used if necessary, in order to minimize the amount of water retained.* Pass.

7.2 *A surge suppression device of the Metal Oxide Varistor (MOV) type must be connected across each contact set. The MOV should have a voltage rating of not less than 25 volts but no more than 50 volts.* - Pass.

8. Data Logger Cradle – Pass.

9. Construction of Heated TBRG

The heating of the TBRG is done by two resistive coils. One coil covering the inside of the funnel shown in orange in figure 1, and the other encircling the base of the gauge as shown in figure 2.

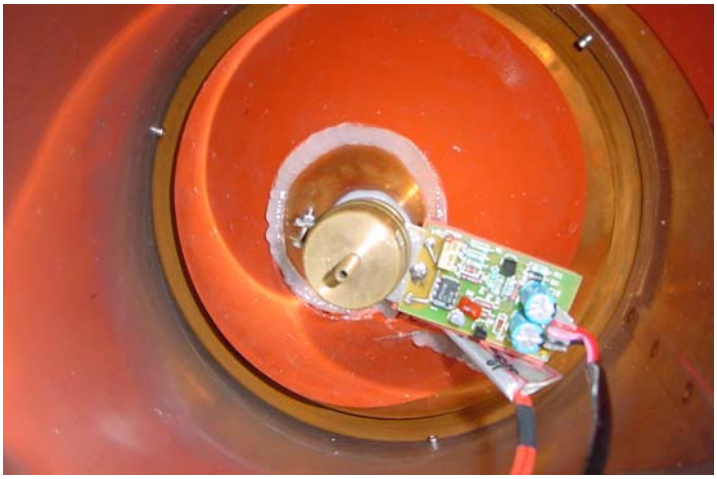

Figure 1. The interior of the TBRG funnel showing the temperature sensor printed circuit board mounted on the siphon. The orange area on funnel shows the area of the funnel covered by the heating element.

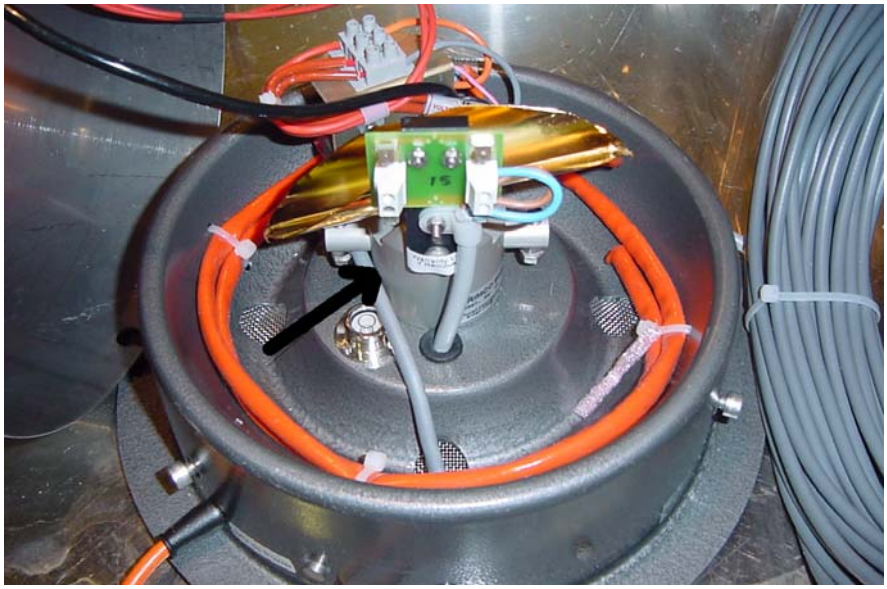

Figure 2. The TBRG base showing base heating coil (orange) and the lead for the Pt100 temperature sensor fitted below the buckets (indicated with black arrow).

Figure 2 shows the positioning of the Pt100 temperature sensor (feed cable indicated by black arrow) with respect to the bucket cradle. The sensor was placed in this position during simulated snow events so that the buckets were free to move.

The heating coils are controlled by a semi conductor temperature sensor mounted on a printed circuit board attached to the siphon within the TBRG (figure 1). The temperature measured by this device is assumed to be close to that of the funnel and siphon.

The electronic circuit is designed to switch current ON when the sensed temperature falls below 4°C and switch OFF when it senses more than 5°C. The heating current is either on, or off. The level of current is not controlled. The heating coils consume approximately 1.75 amps at 24V therefore delivering a total power of 42 watts. The critical parameter is the division of electrical power between the two coils. McVann advises that the funnel heating coil consumes approximately 21 W which is the amount of power available to melt snow in the funnel.

10. Rainfall performance

The gauge is a heated version of the Model 8020. The rainfall characteristics of the gauge were assessed. The critical difference between this gauge and the Model 8020 are the heating circuits. Among other differences these gauges also incorporated metal end covers to retain the bucket spindle whereas the Model 7499 had plastic end pieces.

Each TBRG was tested in line with previous RIC testing [4]. Each gauge displayed some ‘bedding in’ but remained within specification for both trials. The gauges displayed a similar characteristic to that of earlier gauge designs from McVann [4]. The results are displayed in figure 3 for gauge s/n 77470.

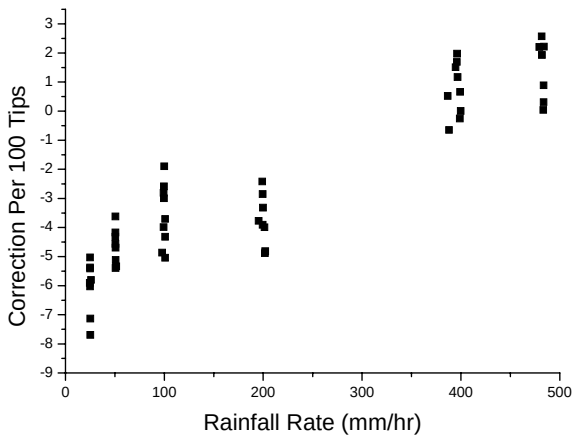

Figure 3. Plot of corrections per 100 tips versus rainfall rate for the heated TBRG s/n 77470. Each point represents one trial approximately 300 tips in total.

11. Performance in simulated alpine conditions

For this work NCC was consulted as to the most likely ground level conditions during a snow event at an Australian alpine site [5]. From this consultation the following assumptions have been made:

1. The ground level temperature will be in the range –10 to 10°C.
2. The highest snowfall rate expected is approximately 10 cm/hr or 10 mm of water equivalent per hour.
3. Most snow will fall with an ambient air temperature in the range 5 to 10°C with that temperature rapidly falling to 0°C.
4. When snow strikes the ground its temperature is approximately 0°C.
5. The energy required to melt ice at 0°C is given in Table 1 and is very much larger than that required to raise the temperature of the ice by 1°C and therefore the energy required to heat the ice to 0°C will be ignored.

Table 1. Assumed properties of water and ice [6].

Substance	Specific Heat (J/g.^{o}C)	Heat of Fusion/Vaporization (J/g)
Ice	2.09	333
Water	4.18	2260

The two coils equally divide the total power and hence 21 W is available to heat the funnel. This implies that at 0°C the funnel has sufficient heat to melt 227 g of ice per hour. This equates to approximately 7 mm of equivalent rainfall per hour.

Figure 4. Image of TBRG in the test chamber.

Heating circuit

Figure 5 shows a plot of the temperature of the buckets and the temperature within the environmental chamber during a rapid ramping down in temperature from 22 to –10°C. It can be seen that the heating circuit switched on in this case at an ambient air temperature of approximately –7°C. At this point in time the bucket temperature was 5°C and the funnel surface approximately 4°C. This apparent late switching on of the heating current is to be expected due to the large thermal mass of the TBRG. Figure 5 also demonstrates that the temperatures of the working components of the TRBRG did not fall to 0°C or below at any time during rapid cooling implying that the gauge was operational throughout. Water was passed through the gauge confirming operation at this temperature. The bucket temperature did not drop below 5°C.

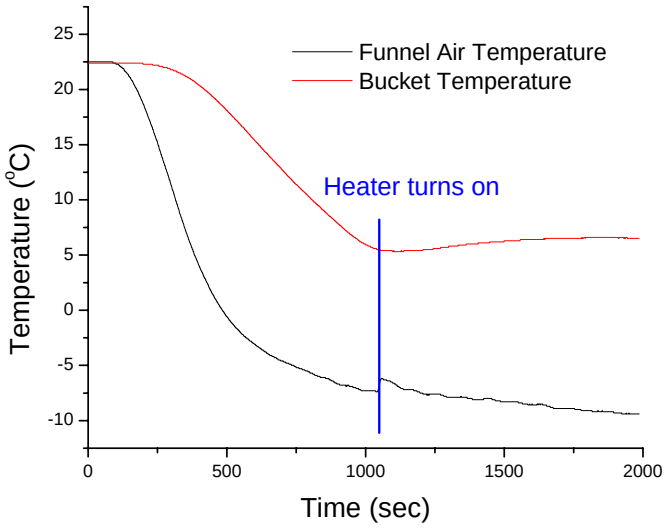

Figure 5. The temperature versus time for the funnel air temperature and the temperature of the tipping buckets.

At a stable chamber temperature of –10°C the temperature on the surface of the siphon was approximately 1.0°C while that of the buckets was -0.4°C implying that the TBRG was no longer operational since ice would accumulate in the buckets negating the relationship between water volume passing through the siphon and tips.

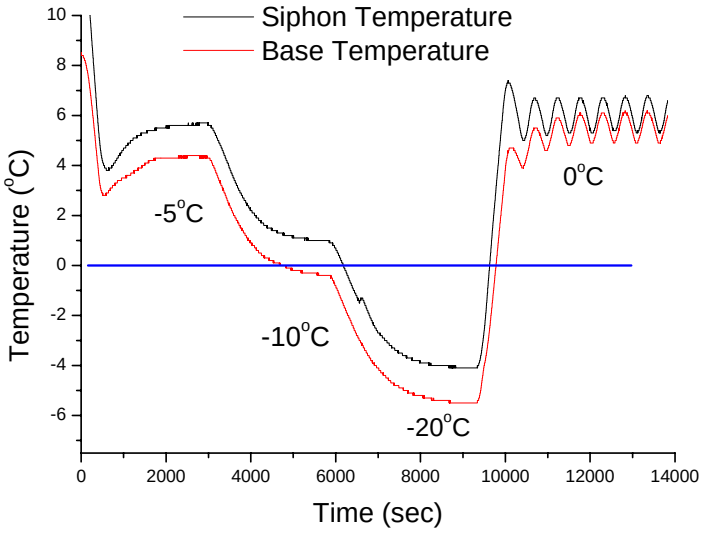

Figure 6. Plot of the funnel and base temperatures for stable chamber temperatures as indicated during temperature cycling of the environmental chamber.

From figure 6 it can be seen that position of the sensor for the heating circuit within the TBRG leads to the temperature of the siphon oscillating within the range 5.5 to 6.5°C while the base's temperature oscillates over the range 5.0 to 6.0°C when the ambient temperature is around 0°C.

At a stable chamber temperature of –20°C the temperature on the siphon temperature was approximately -4.0°C while that of the base was -–5.5°C implying that the TBRG was no longer operational since ice would block the siphon and no water would reach the buckets. These results are displayed in figure 7. The gauge will not operate if the temperature of either the buckets or siphon/funnel combination falls below 0°C since ice will form. The TBRG at this point will be incapable of melting falling snow.

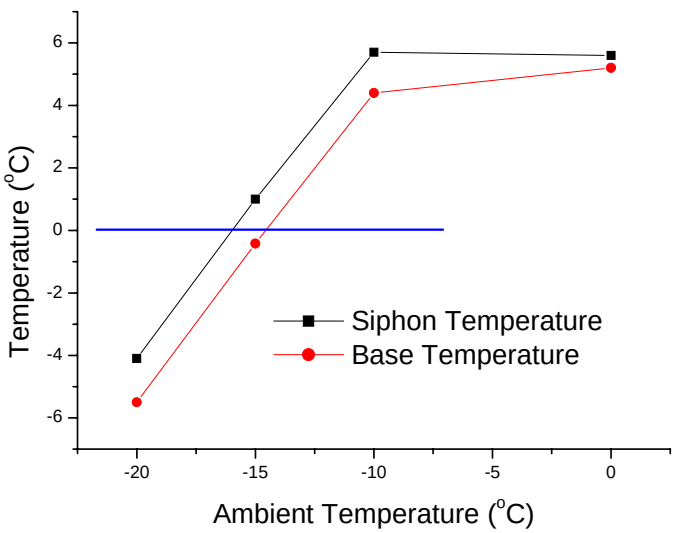

Figure 7. Plots of base and siphon temperatures versus stable ambient temperature.

From figure 7 it can be deduced that in the absence of any snow or hail the gauge will cease functioning when the ambient temperature is at or below -15°C due to the buckets reaching a freezing temperature. Above this temperature the TBRG will melt snow at a rate dependent on the ambient temperature.

Simulated snow dumps

To examine the ability of the gauge to clear heavy snow falls pre-weighed masses of simulated snow were spread into the funnel at ambient temperatures of between –5 and 5°C. The output of the TBRG was logged via an Almos AWS as 1 second data. A typical plot of total rainfall versus time is shown in figure 8.

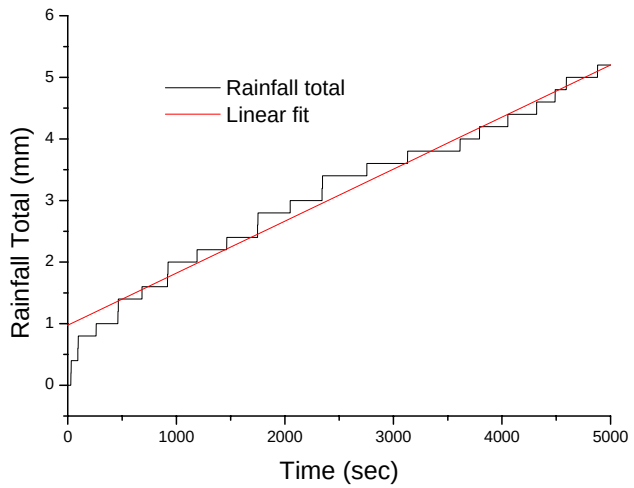

Figure 8. The accumulated rainfall versus time for a simulated snow dump at –5°C ambient.

From figure 8 it can be deduced that the rate at which the TBRG melts the snow is approximately linear and limited by the heat supplied by the heating coils. From fits of these data it can be estimated that the gauge melted approximately 3 mm of equivalent water per hour (at –5°C). Therefore the gauge would not be able to pass 10 mm/hr of equivalent water (10 cm/hr of snow) without a buildup of snow, but the gauge was capable of clearing a heavy snowfall eventually if the ambient temperature was above –15°C. These characteristics lead to a loss of temporal resolution in the precipitation record as the accumulated snow passed through the gauge, but a it would give a reasonable estimate of the total snow accumulation.

Simulated snow dumps were repeated at ambient temperatures of 0° and 5°C. At 0°C the clearance rate was approximately 8 mm/hr or equivalent rainfall. Figure 9 shows the base and funnel temperatures during this event. It can be seen that the temperature at the base of the TBRG rises considerably during this event due to continuous heating.

It was not possible to determine the error in snow accumulation if the gauge rim was below the snow depth.

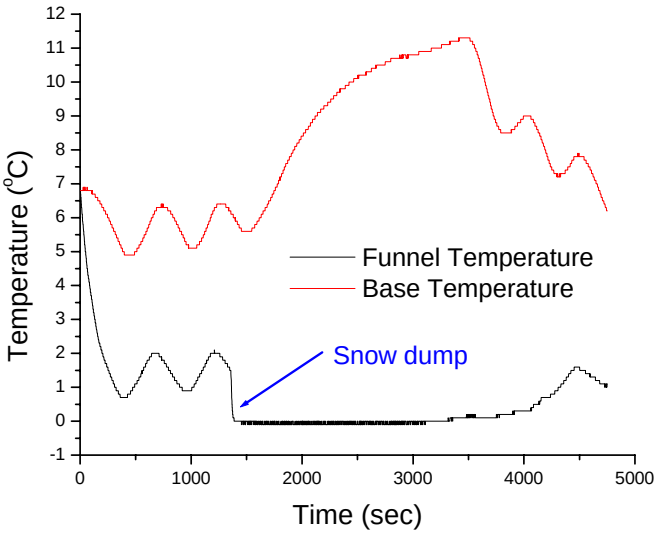

Figure 9. The base and funnel temperatures during a simulated snow dump at 0°C ambient.

At 5°C the clearance rate was 13 mm/hr. The clearance rates are summarized in figure 10. These data imply that the gauge will be able to clear snowfalls at the highest expected rates for temperatures above approximately 2°C. Below 2°C snow will accumulate in the funnel of the gauge and the snow will pass through the gauge at a rate dependent on the ambient temperature.

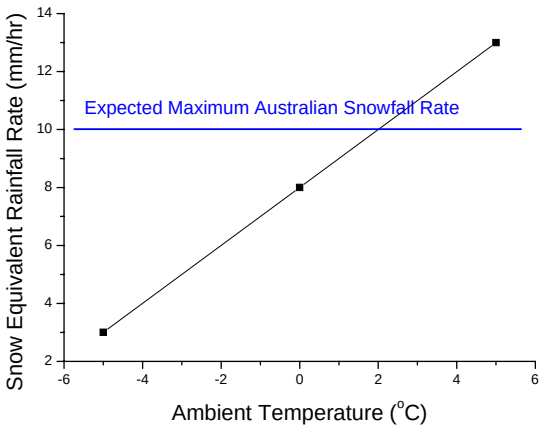

Figure 10. Plot of heated TBRG snow clearance rate versus ambient temperature.

Linear extrapolation of the clearance rates suggests that the rate of snow melting will be zero at approximately –8°C which is similar to the inferences from the siphon and base temperature measurements.

Thermal plume measurements

The combination of a heated TBRG funnel in a cold ambient environment may lead to the development of convective flow above the funnel during calm conditions[7]. This flow was measured using a calibrated hot wire anemometer mounted within the chamber to measure vertical flow rate. This measurement is of importance since vertically rising air will tend to deflect lightly falling snow away from the funnel and bias the equivalent water measurement downward.

The airflow measurement was made at a height of 50 mm above the rim of the TBRG and just inside the funnel while the environmental chamber was turned off and artificial circulation had ceased.

For all ambient temperatures between –5 and 5°C no plume was detectible. Therefore if there was vertically rising air above the gauge its vertical velocity was less than 0.1 m/s. This result is consistent with the earlier data indicating that over the temperature range tested the funnel temperature was not greatly raised above ambient by the heating coils.

12. Discussion

The heated TBRG cannot distinguish between snow, hail or rain. The Bureau does not currently have a specification for a heated TBRG or 'snow gauge'. The literature underlines the importance of wind shields for TBRGs in alpine areas since snow will tend to blow over the gauge [8]. It is also clear from the literature that the siting and wind shielding of the gauge will have a significant impact on the amount of water equivalent measured by the gauge.

The recent study by Rasmussen et al.[8] has shown that real time, accurate snow measurements can be made if the funnel/siphon combination are heated to 2°C. Rasmussen's work suggests that a definitive alpine rain/snow gauge would have a heating circuit that sensed the temperature of the funnel/siphon and adjusted it to approximately 2°C. From the experimental work outlined here (figure 7) it can be deduced that this funnel temperature will occur at ambient temperatures above of approximately –10°C. The plot of snow clearance rate versus ambient temperature (figure 10) intersecting the y-axis at approximately –8°C. These two experimental results are not widely divergent and suggest that the Bureau designed gauge will fail to clear snowfalls at ambient temperatures below approximately –8°C.

The heating power of the TBRG tested is considerably less than that of competing types but lessens the effects of heat pluming and evaporation. Heating of the TBRG will clear snowfalls in a timely fashion at most expected temperatures in the Australian mainland and Tasmania.

Most users of heated TBRGs also employ windshields to lessen the impact of wind on alpine TBRG catch rates. This has been done at some Australian sites and not at others.

13. Conclusions

The two Rimco Model 8020H TBRGs tested meet the Bureau specification [1] for use as a rain gauge. It was apparent during this testing that the gauge has sufficient heating (power) to clear snowfalls defined as likely in section 11. The rate of clearance was low at ambient temperatures below 0°C. This will affect the temporal record since brief severe events will be cleared through the gauge over time at a rate dependent on the ambient temperature.

The low power of the heating coils in this design leads to little difference between the siphon temperature and ambient which implies that the thermal plume developed above this gauge type is less than that exhibited by northern hemisphere gauges which employ nearly 10 times as much heating. This implies a better 'catch' for lightly falling snow for the Bureau designed heated TBRG.

Once an operational specification has been developed then the suitability of the TBRG for Bureau operations can be determined using the results from the work reported here.

Recommendations

That the Bureau develops a specification for heated TBRGs for deployment in mainland Australia and Tasmania and it include:

1. the minimum snow clearance rates at specified temperatures; and

2. the temperatures for the heater to switch on or off be defined to reduce evaporation or conversely the funnel temperature range be defined;

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[1] *Precipitation Gauge Tipping Bucket Type*, Equipment Specification A 1980 Revision 3, Commonwealth Bureau of Meteorology, 2002

[2] J.Gorman, *Evaluation of RIC Designed Pumped TBRG Tester (Rex*), Instrument Test Report 671, Commonwealth Bureau of Meteorology Sept. 2003

[3] M.Berechree, *Stability of Five McVann Model 7499 TBRG*, Instrument Test Report 660, Aug. 2001

[4] J.Gorman, *Evaluation of the Rimco Precipitation Gauge Tipping Bucket Model 7499*, Instrument Test Report 672, Bureau of Meteorology Feb. 2003

[5] Blair Trewin, *personal communication*, National Climate Centre, Commonwealth Bureau of Meteorology, Sept.2003

[6] Whitten K.W, Gailey K.D and Davis R.E, *General Chemistry*, Saunders College Publishing, 1988, Appendix. 15.

[7] Davis, K.W. and Tincher, W.I., "The Effect of Heating the Tipping Bucket Precipitation Gauge," USA National Weather Service, July 1970.

[8] Rasmmussen R.M., and co-authors, *Weather Support to De-icing Decisions: A Winter Weather Nowcasting System, Bull*. Am. Met. Soc., Vol 82 p.579-595, 2001