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SNOW MACHINE TESTING OF SPICE REFERENCE SNOW GAUGES

(Submitted by Matteo Colli et al.)

Summary and purpose of document

This document provides the results of the laboratory tests of the SPICE reference gauges performed in the snow machine.

ACTION PROPOSED

The Meeting is invited to take this information into consideration, when reviewing the required set-up of SPICE testsites and in particular the configuration of the site references.

Snow machine testing of SPICE reference snow gauges

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This short report details the wind-free laboratory testing of some of the factors which affect significantly the snowfall measurement accuracy performed by the Geonor T-200b three vibrating wire gauge and the OTT Pluvio2 weighing gauges which are employed as SPICE reference sensors. Specifically, these experiments will examine the combined effects of the environmental temperature and the snowfall rate and their subsequent effects on the various gauge components, as well as snow capping and the potential heat-plume problem associated with heating the gauges. The tested snow gauges were installed inside a cold chamber with an artificial snow-generation machine (Fig. 1a), a snowflake simulation system in which snowflake sizes and snowfall rates can be controlled in a wind-free environment. The cold room investigations were performed in a jointed effort by the WMO Lead Centre of Precipitation Intensity (University of Genova and Italian Air Force Met Service) and the National Centre for Atmospheric Research laboratories located in Boulder (CO, USA) and the Airport of Pratica di Mare (Italy).

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1) MECHANICAL VIBRATIONS AND VIBRATING WIRES NOISE

The firsts environmental chamber laboratory efforts for SPICE campaign were performed on May 2012 by the Lead Centre of Precipitation Intensity on the OTT PLUVIO2 and GEONOR T200B gauge by realizing constant flow rates generations of a liquid solution (with density approximated to distilled water). The results were presented by Maj. Emanuele Vuerich at the Boulder IOC meeting (11-15 June 2012) showing the relevance of the sensors noise on the measurement quality. A sample of this issue is represented by the Fig. 1 vibrating wires measurements performed under a liquid precipitation rate equal to 1.2 mm/h and an environmental temperature equal to 0 °C.

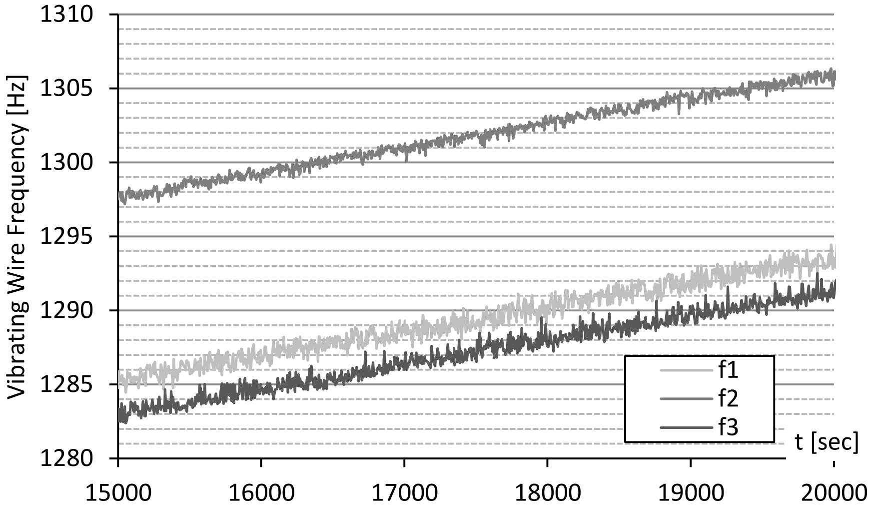

Fig. 1 Extract from the Lead Centre on Precipitation Intensity cold room tests (Pratica di Mare, 08/05/2012). The noise effect on three GEONOR T200B vibrating wires frequencies time series measured under a costant 1.2 mm/h liquid precipitation intensity.

A second laboratory controlled environment campaign was carried out at the NCAR Foothills Labs by using snow-generation machine (Fig. 2) which is equipped with a milling cutter system for breaking a distilled water ice core into snowflakes as shown on the right snapshot.

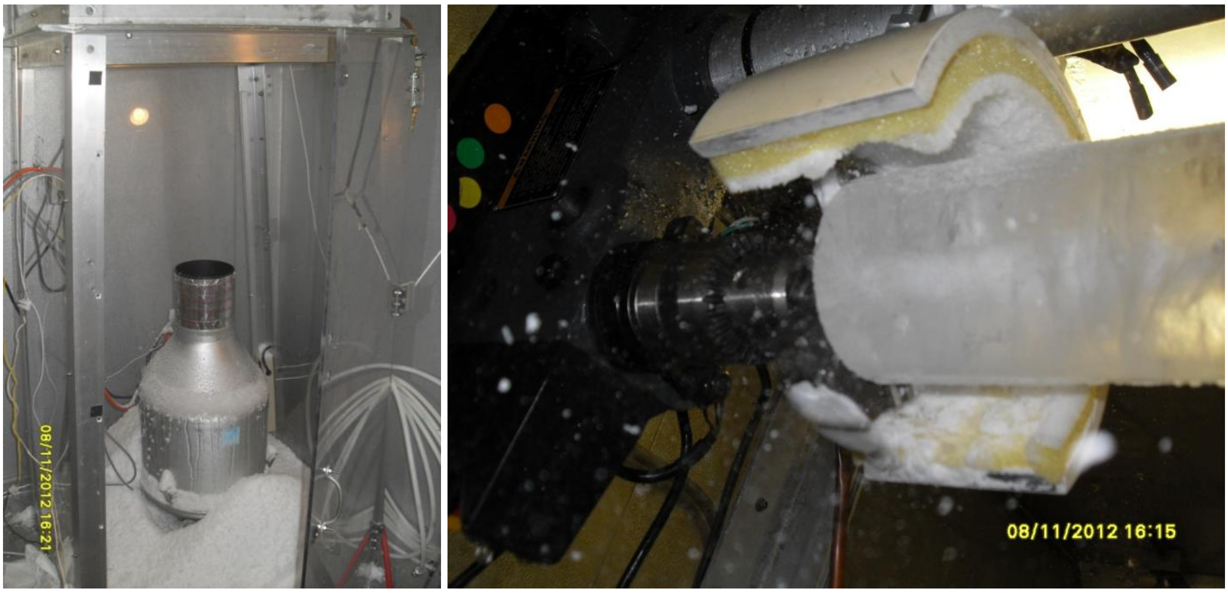

Fig. 2: a) (left picture) the GEONOR T200B in the snow-generation machine chamber; b) (right picture) particular of the snow flakes generation system feeded by the distilled water ice core

Nine different combination of testing conditions were obtained by setting the cold room temperatures (T_{air}) around time-averaged values equal to -10, -5 and -2 °C and mantaining the snow-generation rates (*SR*) constant on 0.5, 1 and 2 mm/h of equivalent water. An excursion of the instantaneos cold room temperature values equal to +/- 2°C around the mean was observed and it's due to the latency of the cold room refrigeration system. Fig.3 shows a sample of the cold room and snowgauge orifice temperatures (grey scale time series) and the GEONOR T-200B vibrating wires frequencies f_i (colour time series) measured by realizing a *SR* value equal to 1 mm/h and T_{air} =10°C in averaged terms.

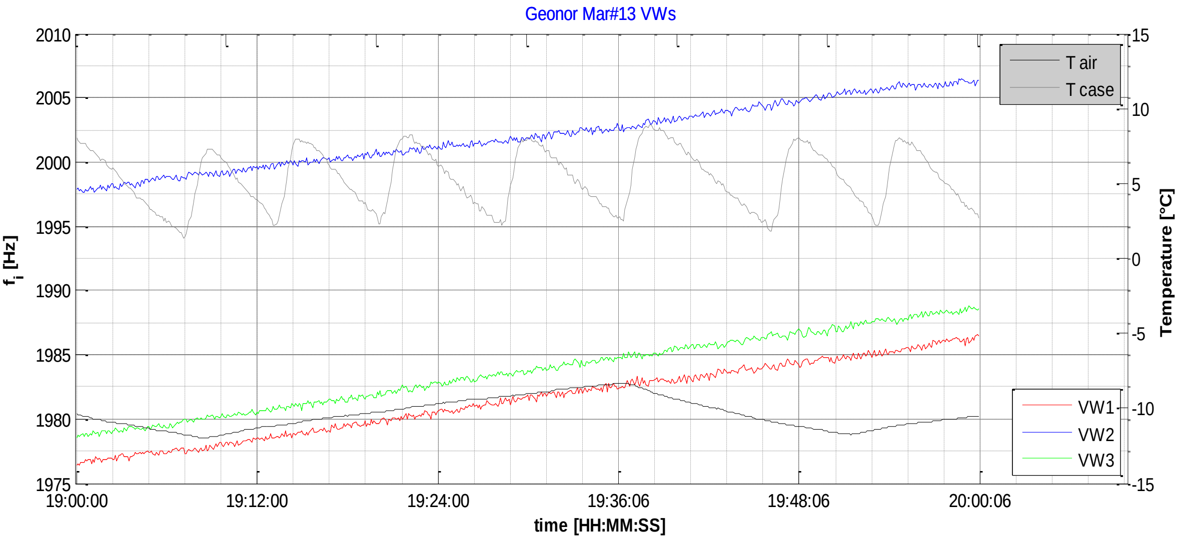

Fig. 3: Sample of the measurement set from a snow machine test with avg(SR)=1 mm/h amd avg(T_{air})= 10°C. The GEONOR T200B3 vibrating wires frequecies f_i (colored plots) , the orifice T_{case} temperature and the cold room T_{air} environmental temperature (respectively light and dark grey).

The first evidence arising by the vibrating wires plots is the high noise of the frequency time series observed along the whole test duration. Once having excluded any signal disturbance of electrical nature by means of dedicated verifications the research was focused on the mechanical vibrations transmitted from the environment to the snowgauge under different testing conditions (Tab. 1). The modified standard uncertainty $u_{80\%}(f_{VW})$ of the vibrating wire signal recorded under no precipitation conditions is the parameter here considered for the quantification of the noise magnitude. This value is evaluated basing on the noisy data sample standard deviation under a no precipitation condition, representing the noise magnitude around the mean value, which is then multiplied by a scaling factor k = 1.28 in order to contain the 80% of the noise data population.

Five different installation situations were tested without precipitation:

- Outside the cold room
- Cold room installation
- Cold room installation with the snow machine motor activated
- Cold room installation with vibration damping legs
- Cold room installation with vibration damping legs and snow machine motor activated

Tab.1 : Modified standard uncertainty $u_{80\%}$ of vibrating wires frequency and equivalent water accumulation measurements due to the noise induced by mechanical vibrations noise under different installation conditions

Cold chamber *[-]*	**Snowmachine ON** *[-]*	**Vibration dampings** *[-]*	$u_{80\%}$ **(f)** *[Hz]*	$u_{80\%}$**(h)** *[mm]*
			0.011	0.004
X			0.051	0.017
X	X		0.645	0.210
X		X	0.065	0.021
X	X	X	0.127	0.041

The installation of the GEONOR T200B within the cold room results in an increasing of the signal noise, $u_{80\%}(h)$ passes from 0.004 to 0.017 mm, which is not effectively reduced by the employment of vibration damping legs. The activation of the snow-generation machine causes a 0.210 mm modified standard uncertainty that is damped to 0.041 mm by the employment of rubber legs. Following these indications the vibrating wires noise quantification activity was then extended to real world vibrating wires measurements recorded in case of high horizontal wind speed at the Marshall field site as sampled on Fig.4

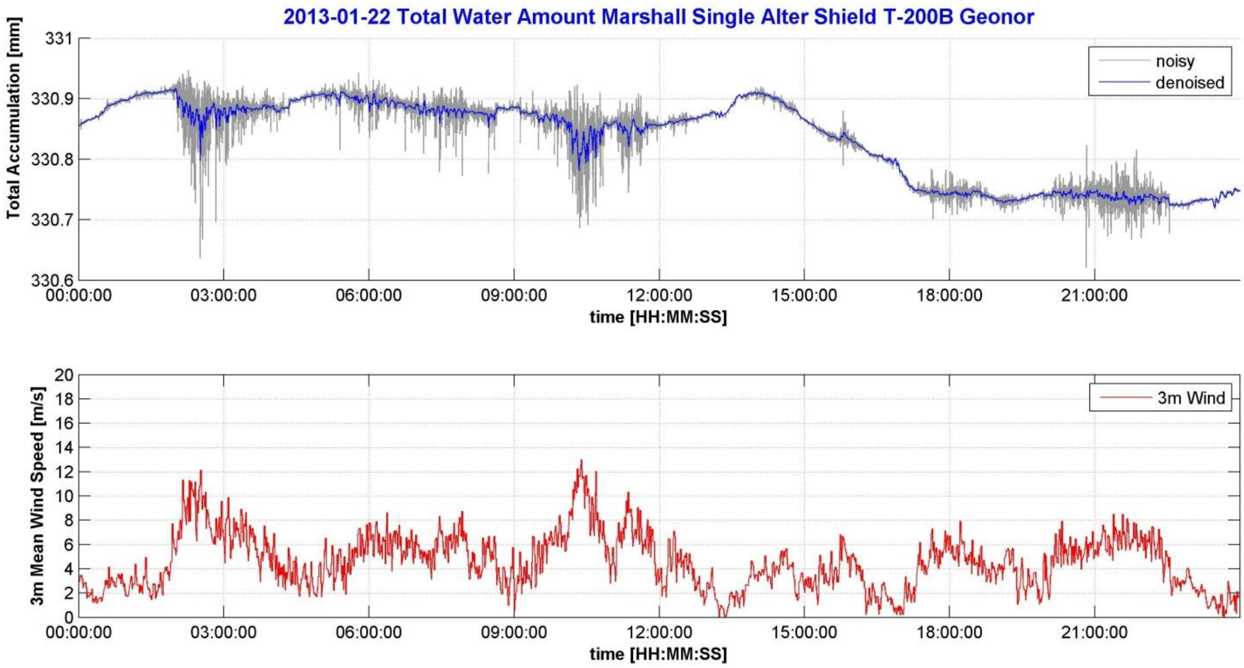

Fig. 4: Sample of the Marshall Single Alter shield GEONOR T200B total water accumulation (top plot) measured during a significan horizontal wind event (bottom plot) with no precipitation involved. The noisy behavior of the original 6-sec measurements (grey line) shows an evident correlation with the horizontl wind speed (red line) and could be effectively reduced by applying a de-noising technique.

Starting from the Boulder IOC meeting (11-15 June 2012) the noise problem was extensively reported in the SPICE teleconference and the Data Analysis Team decided to deal with this issue by testing different filtering techniques and then providing a unified methodology during the 2013 IOC meeting in Davos (Switzerland).

2) THE SNOW CAPPING

The snow capping represent one of the more challenging source of errors affecting the snowfall measurements as it requires the availability of a heating system of the gauge orifice, funnel and, in case of mechanical measuring principle like tipping bucket, the sensor itself. The power requirements of the heaters, the algorithm that manages the working cycles and possible interference with the snow measurements are all matters of today discussion within SPICE.

The tested heating system of the GEONOR T200B is manufactured by Marathon composed by two silicone flexible blankets rated at 100 W AC. It's important to note that this configuration is different from the SPICE reference heater which should work with a lower power requirement and DC electric current. Since the heating produced by the tested configuration is bigger than the SPICE one, it's valuable to consider the following results with reference purposes and to note that they constitute the best achievable performance in terms of snow capping but also the more relevant evaporation and heating plume effects observable in field. Furthermore, a slightly modified version of the CRN heating algorithm was used with the purpose of allowing the activation of the system for all the orifice temperature values $T_{orifice}$ falling below +2°C while preserving the original algorithm updating interval (equal to 1 min).

Differently from the GEONOR T200B case, the OTT PLUVIO2 comes with an embedded heating control system. During the present work the manufacturer system was activated and deactivated externally following modified version of the modified CRN algorithm and considering the actual orifice temperature as measured by an additional temperature probe installed on the purpose.

The images showed on Fig. 5 and 6 compare the snow accumulation after 1 mm of water equivalent precipitation at different rates *SR* and environmental temperatures T_{air}. It's evident how the simulated snow tends to accumulate more conspicuously by increasing the temperature rather than snow rates. Meanwhile the tested GEONOR heater is able to avoid snow capping around the orifice rim even under the worst environmental conditions, a non-negligible accumulation of snow is observed on the Pluvio2 collection edge in case of temperature equal to 10°C irrespectively of the snow rates.

Fig. 5: Snow accumulation of the GEONOR T200B case after 1 mm of equivalent water. The gauge was equipped with an internal and an external AC heater stripe (2000W) managed by the modified CRN algorhitm for three different environmental temperatures: a) avg(T_{air}) = -10°C; b) avg(T_{air}) = -5°C; c) avg(T_{air}) = -2°C

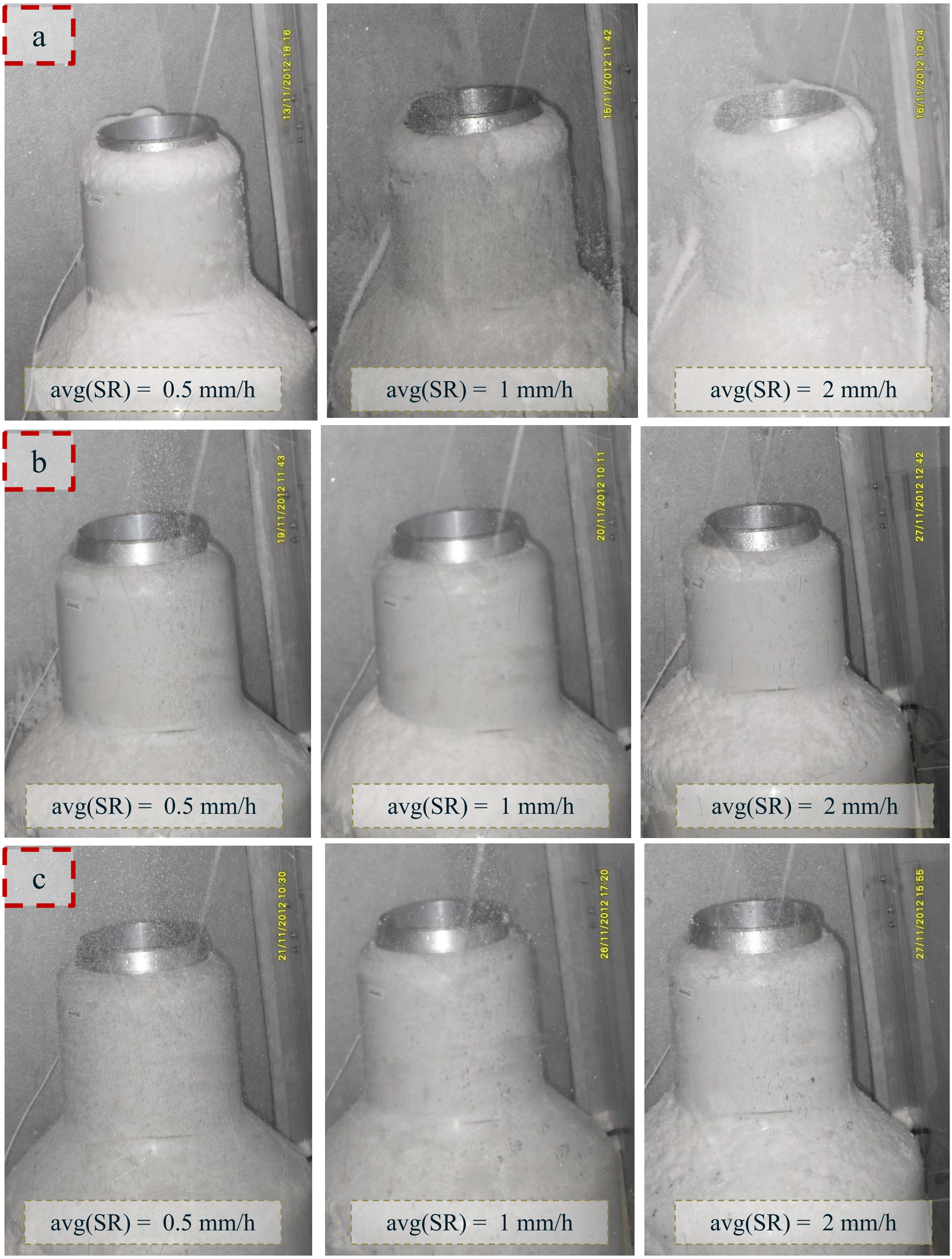

Fig. 6: Snow accumulation of the OTT Pluvio2 case 1 mm of equivalent water. The gauge was equipped with the manufacturer embedded heater, the activation and deactivation of such heating system was managed externally by the modified CRN algorhitm for three different environmental temperatures: a) avg(T_{air}) = -10°C; b) avg(T_{air}) = -5°C; c) avg(T_{air}) = -2°C

It's important to stress the fact that such cold room investigations don't consider the wind contributes, the authors intention is to focus the tests on the heating related issues simplifying the interference of other environmental conditions such as horizontal wind speed, solar radiation and temperature gradients.

3) THE HEATING SYSTEM LATENCY

During the cold room testing particular attention was paid to the dynamic behaviour of the gauges orifice temperatures managed by the respective heating system, the CRN heating algorithm (applied to the GEONOR gauge) and the OTT algorithm.

The GEONOR T200B orifice temperature time serie $T_{orifice}$ was sampled with a 0.5 Hz frequency and plotted together with the heater status (ON/OFF) and the environment temperature during a avg(T_{air}) ≈ -10°C test, an example is shown in Fig. 7. The "saw-teeth" shaped oscillatory behavior of $T_{orifice}$ is not influenced by the lower frequency fluctuations of T_{air} showing values that span from +2°C and +9.6°C. The power requirement of the tested heaters along with the thermal conductivity of the GEONOR T200B collecting walls resulted in a variable waiting time dt_{off}, defined as the interval between two subsequent ON status, which could be approximated to 10 min meanwhile in all the observed situations the heater lasted on the activated status for only one minute.

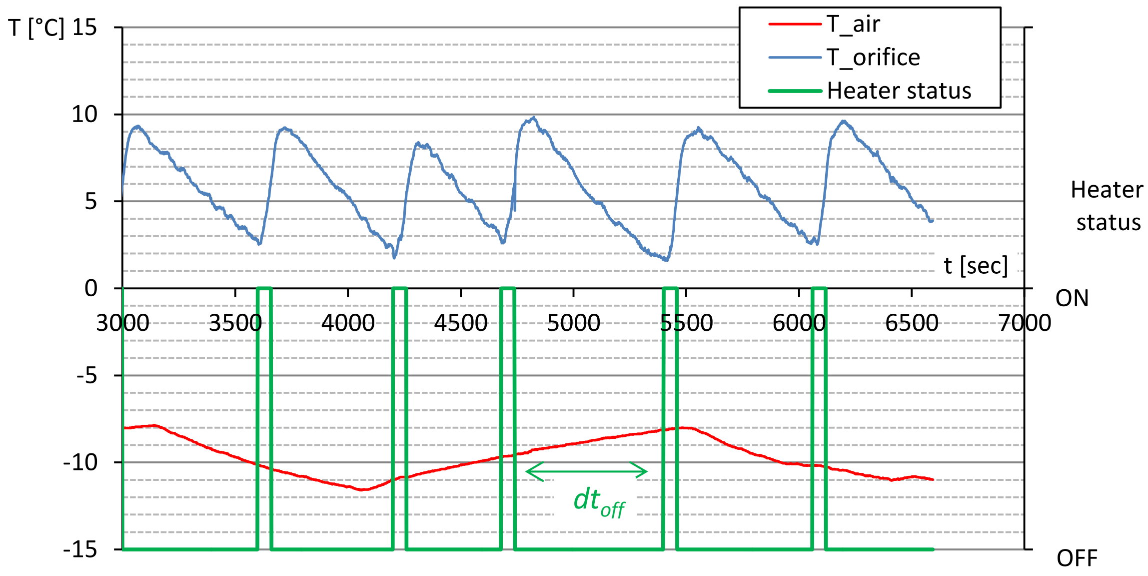

Fig. 7: GEONOR T200B orifice tempeature $T_{orifice}$ (blue line), environmental temperature T_{air} (red line) and heater status (green line) sampled with a 2 sec period during a cold room test.

In this situation the long duration of the deactivation phase dt_{off} and the high orifice temperature (the oscillation reach +9.5 °C) are ascribable to the refreshing time of the CRN algorithm which updates its status with a one minute resolution. Zooming the previous plot as shown in Fig. 8 is possible to verify that $T_{orifice}$ continues is increasing up to 3 additional Celsius degrees with respect to the temperature reached at the end of the heater activation time.

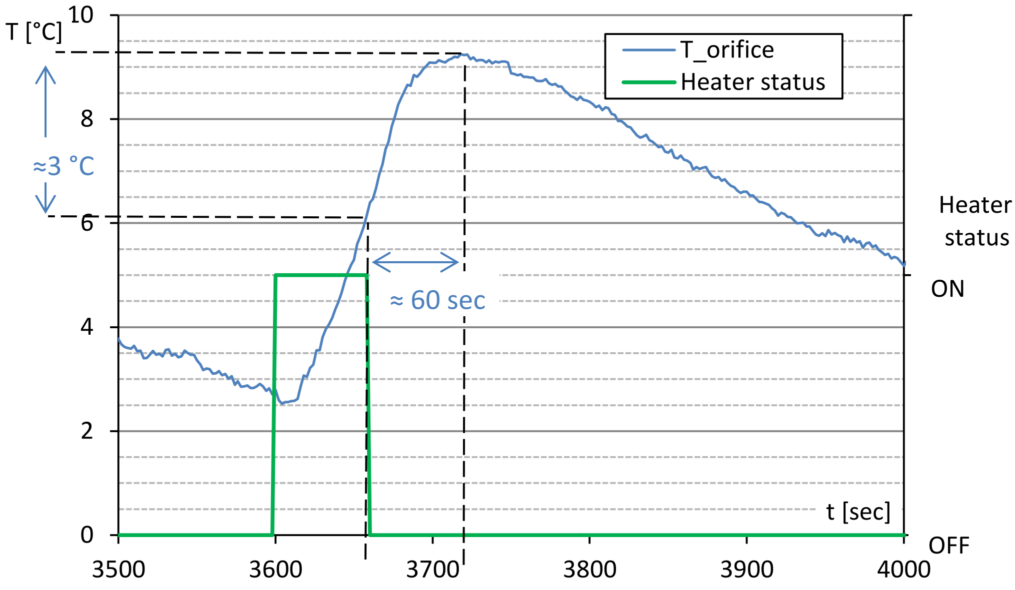

Fig. 8: Particular of the GEONOR T200B orifice tempeature $T_{orifice}$ (blue line) and the heater status (green line) sampled with a 2 sec period during a cold room test.

Similarly to what showed in Fig.7 for the GEONOR snow gauge a similar test was carried out for the Pluvio2 heating system which produced a $T_{orifice}$ time series characterized by an oscillatory behaviour with two main frequency content as illustrated in Fig. 9.

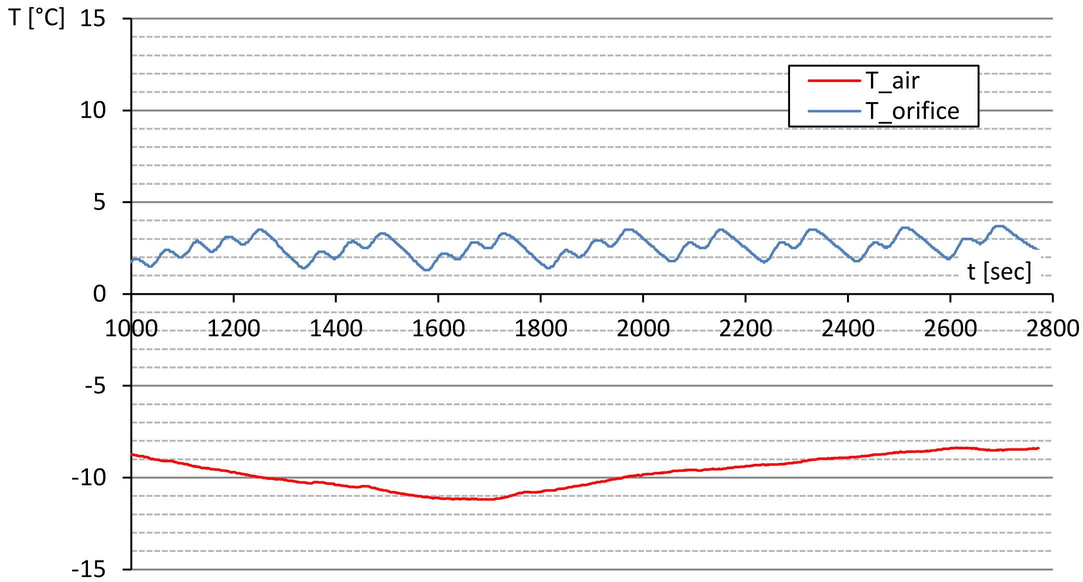

Fig. 9: OTT PLUVIO2 orifice tempeature $T_{orifice}$ (blue line) and environmental temperature T_{air} (red line) sampled with a 2 sec period during a cold room test.

In this case the orifice temperature spans over only 2 °C due to the faster response of the heaters and of the managing algorithm.

4) THE PRESENCE OF THE HEATING PLUME

A relevant point investigated during the laboratory activity is the verification of the possible presence of plumes above the orifice surfaces due to heating exchange with the air. This effect together with the evaporation of snow particles attached to the inner wall of the orifice would lead to an underestimate of the precipitation measurements.
The first evidence of such underestimate was revealed during the snow machine testing by comparing the GEONOR T200B measurements made with the heating system deactivated and then switched on under the same snow rate conditions and temperature. The tests where repeated at least three times for each environmental condition and the evaluation of the snowfall rate underestimation was made using the relative percentage errors between SR measurements made with and without the heating system as follows:

$$e[\%] = \frac{SR_{heated} - SR_{unheated}}{SR_{unheated}}$$

The e values showed on Fig. 10 are referred to the GEONOR T200B measurements underestimation and the representation is subdivided for the three different tested environmental temperatures.

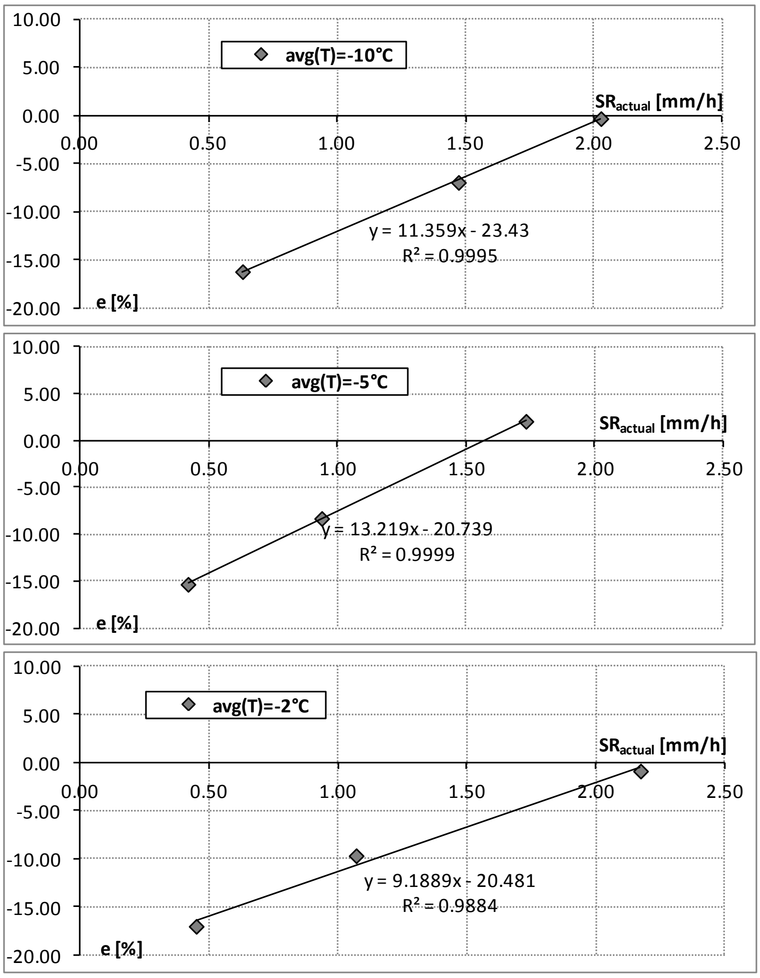

Fig. 10: Relative percentage errors *e* of the snow rates measurements made by the OTT PLUVIO2 with the heating system turned on. This value are observed with different reference snow rates SR_{actual} and averaged environment temperature *avg(T)*: -10 °C (top graph), -5 °C (center graph) and -2 °C (bottom graph).

Even if a clear dependence of *e* on the tested snow rate SR_{actual} is appreciable, it was not possible to define clearly the influence of the environmental temperature on the heater related errors and a certain experimental variability on the results must be taken into account. Anyway, the main indication provided by this investigation is the fact that, as the actual snow rate lies below 2 mm/h, an underestimation of the measurements related to the heating is observed and it could affect the measurement up to –15%. An example of the vibrating wires averaged total water accumulations measured before and after deactivating the heating system are plotted together with their linear fits on Fig. 11 showing the smaller rate of the heated case. The time series shown in the graph were observed by simulating an artificial snow rate approximated to 0.5 mm/h and an averaged air temperature equal to -5 °C. The same investigation on the OTT Pluvio2 errors has still to be completed because of problems occurred with the snow generation system.

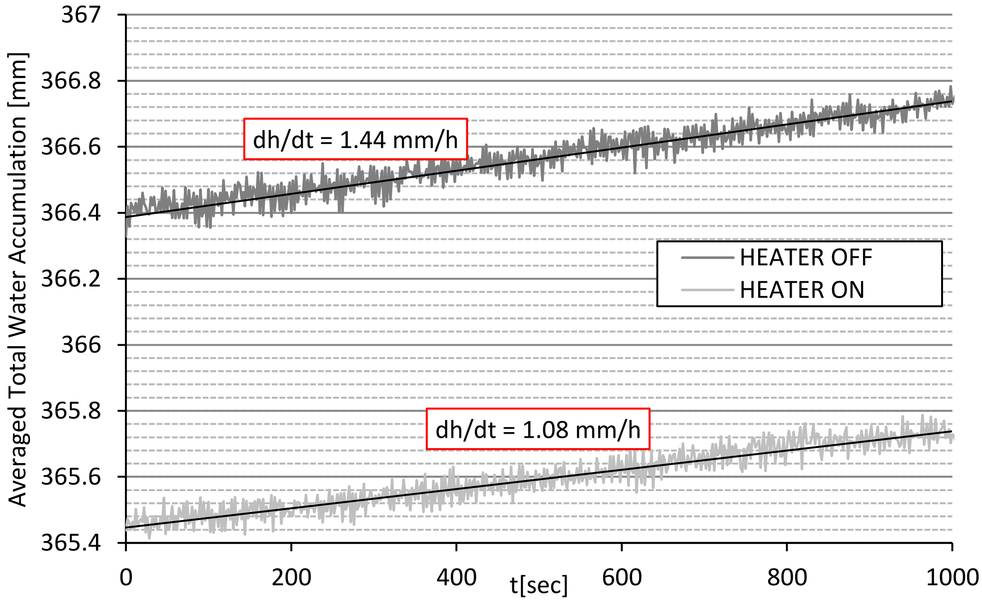

Fig. 11: GEONOR T200B total water accumulation measured before and after deactivating the heater from a sample test performed with *SR* = 0.5 mm/h and T_{air}= -5°C

The next step of this work was to verify (or exclude) the existence of a plume above the heated orifice in order to find out the physical reason behind the observed errors. The task was addressed by installing an high frequency camera at the level of the snow gauges collecting section and a black panel on the background scene with white vertical reference rows and lighting up the air domain just above the orifice rims as show in Fig. 12. A case study of *SR* equal to 2 mm/h and a -10 °C environmental temperature was shot with a movies duration larger than 30 sec.

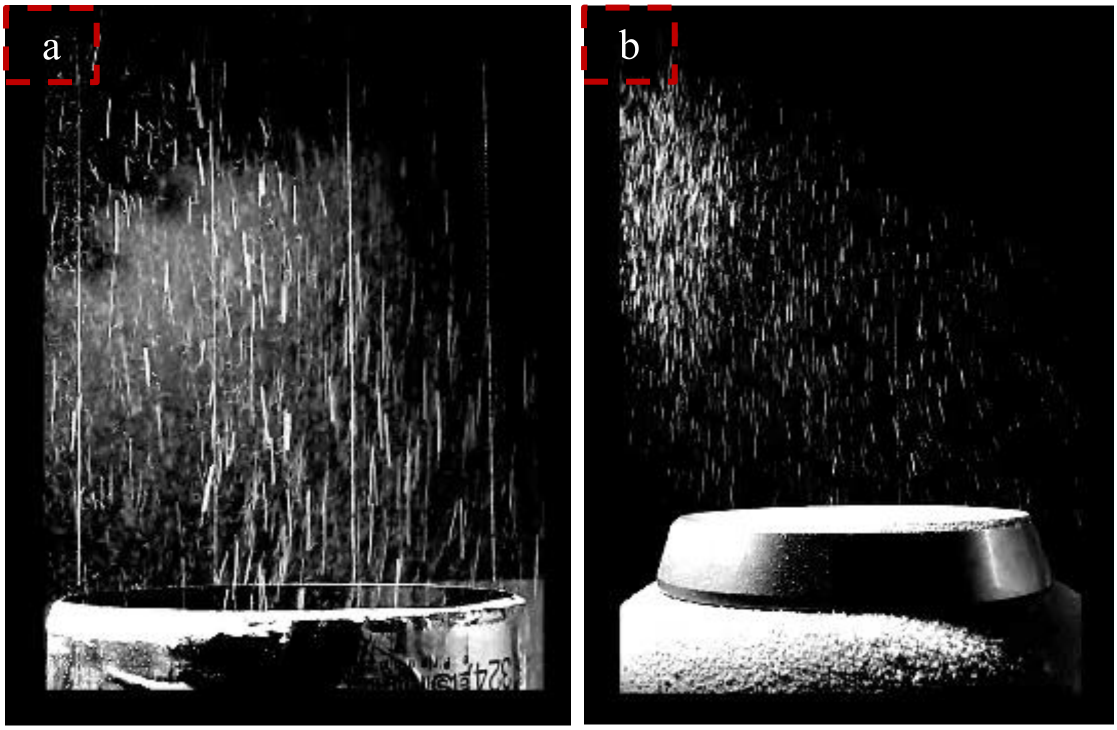

Fig. 12: Close views extracted from the movies shot above the orifice rims of the GEONOR T200B (figure a) and the OTT PLUVIO" (figure b) for the SR= 2mm/h and avg(T_{air})= -10°C case.

The two selected movies were displayed during the April 10^{th} 2013 SPICE teleconference and no evidences of heated plumes or subsequent upward airflows were detected by tracking the falling snow flakes trajectories.

The relevance of this outcome is summarized in the assumption that heaters of the SPICE reference snow gauges does not cause any plume or chimney effect since the higher power-consuming system of the GEONOR T200B tested in the laboratory was demonstrated to not affect the thermodynamic of the surrounding environment.

The last activity of this investigation should be the study of the last source of uncertainty directly ascribable to the usage of the heater: the evaporation of the melted snowflakes along the internal heated surfaces. This effect could impact appreciably on the GEONOR T200B measurements because of the size of its internal heated surface which is equal to 1655 cm^2, more than four times the correspondent of the OTT PLUVIO2 size (382 cm^2).