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QA/QC Procedures for *in-Situ* Calibration of a High Altitude Automatic Weather Station: The Case Study of the AWS Pyramid, 5050 m asl, Khumbu Valley, Nepal

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Abstract

In-situ **calibrations of weather stations are usually performed by positioning standard instruments close to the station under calibration and comparing the obtained results. This procedure could be useful to evaluate the proper functioning of the monitoring equipments, but do not allowed the determination of a calibration curve that allow the corrections of the acquired parameters. Thus, the development of a dedicated facility for** ***in-situ*** **calibration of weather stations, enabling simultaneous generation of a wide range of temperatures and pressures could offer important improvements in this framework, particularly if this facility is applied to high mountains monitoring stations where the weather stations calibrations could be very difficult. This paper will present the calibration chamber developed in the framework of the EMRP-METEOMET (Metrology for Meteorology) Project, which aims is to bring metrological traceability to high altitude meteorological instruments and through this experience will provide a general overview on the importance of the application of this methodology at different levels.**

Keywords

Automatic Weather Station, Himalaya, Climate Monitoring, AWSs Calibration, QA/QC Procedure

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1. Introduction

Weather observation data are currently used for the real-time preparation of weather analyses, forecasts and severe weather warnings, for the study of climate, for local weather-dependent operations, for hydrology and agricultural meteorology, and for research in meteorology and climatology. All these applications need the execution of high-quality measurements. Weather stations need to be equipped with well calibrated sensors in order to improve the reliability of measurements. Observation locations, sensitivity to exposure to wind and solar irradiance, sampling rates and operating procedures are fundamental parameters which need to be considered and standardized to achieve high-quality meteorological data. In addition, accurate standardized methods for *in-situ* calibrations of weather stations, including those operating in extreme weather conditions, are currently absent. Input from National Metrological Institutes (NMIs) in defining procedures, developing capabilities, calibration standards and traceability chains is necessary. At present, many climatological stations are not equipped with certified instruments traceable to national standards and the issues related to this lack is still missing in some nations and ignored by many weather and meteorological services. Furthermore, a general lack of standardized/harmonized procedure for the calibration of meteorological sensors is still existing. *In-situ* calibrations of weather stations are usually performed by a direct comparison made by positioning standard instruments close to the station under calibration. This procedure has several weak points: standard sensors are not always suitable for operation in open air; it is not possible to cover the whole range of the quantities; it is not possible to evaluate the mutual influence between parameters [4]. Thus, the development of a dedicated facility for *in-situ* calibration of weather stations, enabling simultaneous generation of a wide range of temperatures and pressures could offer important improvements in this framework. This facility will enable *in-situ* calibrations to be widely adopted, thus improving the robustness of wide-area ground based measurements, especially for the monitoring of stations operating in extreme environments such as remote mountain regions where the weather stations calibrations could be very difficult.

In the framework of the EMRP-METEOMET (Metrology for Meteorology) Project, which aims is to bring metrological traceability to high altitude meteorological instruments, a dedicated climatic chamber has been developed at the INRiM laboratories (Italy) and installed at the Ev-K2-CNR/NAST Pyramid International Laboratory Observatory, 5.050 m asl, in Nepal, in Mt. Everest region. This represents the first tentative to implement a calibration campaign for temperature and pressure sensors in the Khumbu Valley, where a long-term meteorological network is operative in the framework of the SHARE (Stations at High Altitude for Research on the Environment) Project [1]. This climatic chamber, designed at INRiM (Istituto Nazionale di Ricerca Metrologica, Italian national metrology institute) allows the simultaneous control of temperature and pressure, for calibrating the sensor by comparison against standards previously calibrated at INRiM. This experimental campaign has been carried out with the support of the Nepalese technicians working at the Pyramid, who have been trained on metrological base knowledge to ensure the proper conduct of this calibration campaign (**Figure 1**).

2. Experimental and Methods

2.1. Climatic Chamber Facility

The climatic chamber built in the framework of EMRP METEOMET Project (**Figure 2**) allow the simultaneous calibration of temperature and pressure sensors over the range T_{min}-T_{max} (˚C) and P_{min}-P_{max} Pa, respectively. The calibration facility is formed of three parts: the test chamber, the auxiliary thermostat and the pressure line. The chamber is completed with two thermoresistance Pt100 and their dataloggers (Fluke 1524-Hart Scientific) and a barometer (Additel 681) as temperature and pressure standards. The climatic chamber can control and set independently temperature and pressure. The chamber internal temperature is controlled through an external thermostat and a coil that wraps up the chamber. The thermostat (total power consumption: 2.5 kW) operates with an ethyl alcohol bath. Pressure is managed through an external manual pump connected to the chamber by regulating valve.

The external chamber is made up of steel, while the cover is in aluminum in order to reduce the total weight of the system. Copper is used for the internal chamber, cover and coil. The coil is positioned also on the cover and in the bottom part of the chamber to reduce the thermal gradient inside.

External chamber and tubes that connect it to the thermostat are covered by armaflex, an insulating material. The total weight of the chamber is 30 kg, while the thermostat is about 35 kg: this allow the calibration chamber

Figure 1. The calibration campaign at the Ev-K2-CNR/NAST Pyramid Laboratory-Observatory, 5050 m asl, Nepal.

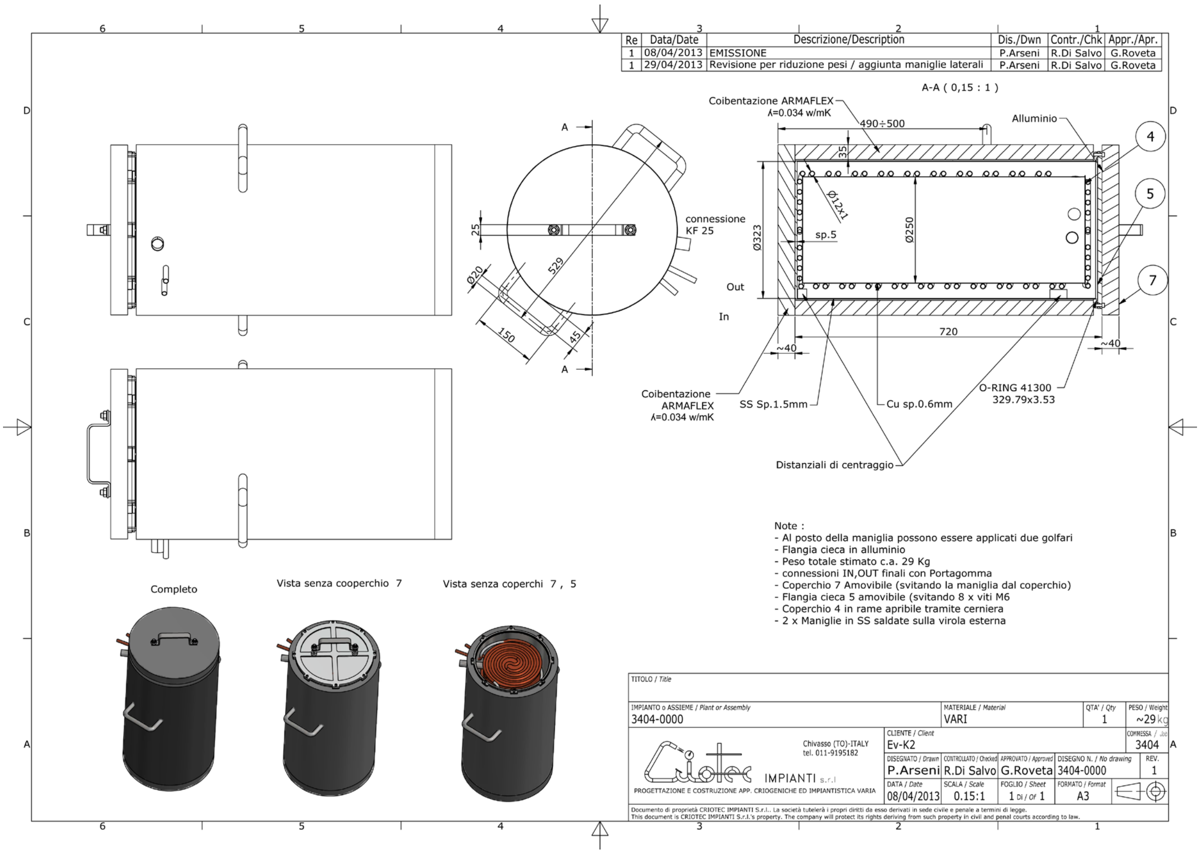

Figure 2. Climatic chamber design.

to be transported rather easily also to remote locations, like the Pyramid Observatory.

2.2. Pyramid Automatic Weather Station (AWS)

The Pyramid AWS (**Figure 3**) has been installed at 5.050 m asl, very close to the Pyramid Laboratory, by Ev-K2-CNR in collaboration with NAST (Nepal Academy of Science and Technology) in 2000. The AWS is

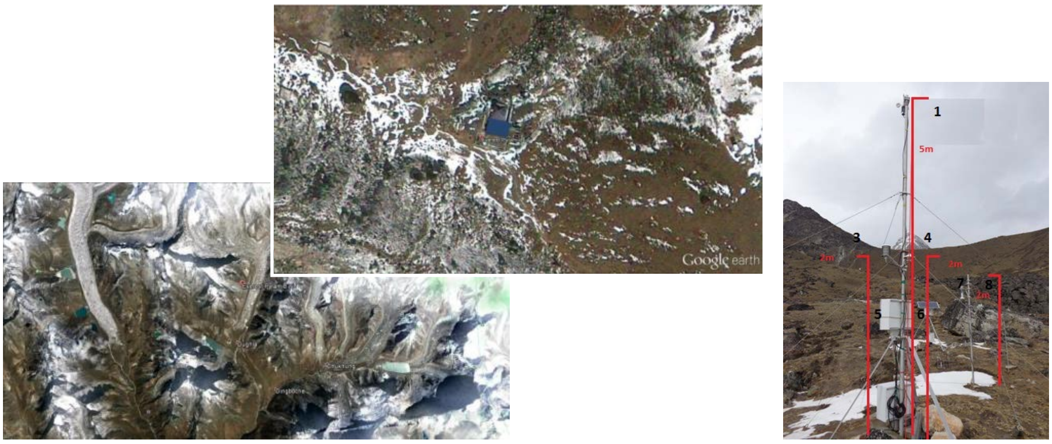

Figure 3. AWS Pyramid (Khumbu valley, Himalayas) 27˚57'3.6''N; 86˚48'3.6''E 5050 m asl, scheme underling the distances of the instruments from the surface. (1) Wind speed and direction; (2) Rain gauge; (3) Thermo-hygrometer; (4) Global radiation; (5), (6) Pressure sensor inside datalogger box; (7) Snowlivel; (8) Net radiation; (9) Datalogger.

managed in collaboration with the Institute of Atmospheric Sciences and Climate of the Italian National Research Council that supervise QA/QC protocols for data gathering and that is in charge of data validation in compliance with WMO guidelines [7].

The AWS is currently equipped for the continuous measurement of air temperature and relative humidity, atmospheric pressure, wind speed and direction, total precipitation, four components radiation (long wave in and out, shortwave in and out), soil temperature (at −5 and −20 cm), soil moisture and heat flux (at −5 cm) and snow level. Power is supplied by two solar panels (40 W) and a lead gel battery. Data are transmitted in near real time through UHF connection to the Pyramid Laboratory and the through satellite to Italy.

The station is part of the environmental monitoring network of the £v-K2-CNR/SHARE Project which is composed by AWSs and Atmospheric Observatories in the highest mountains ranges of the world such as Himalaya, Karakorum, Rwenzori, Andes and Italian Alps. SHARE aims at contributing to the study of climate change and its impact on mountain regions, supplying unique information to the international scientific community and decision-makers on sustainable development and mitigation strategies.

2.3. Climatological Description of the Pyramid Site (2002-2012)

The seasonal variation of atmospheric conditions is influenced both by the local mountain wind system (with a strong diurnal valley wind and a weak mountain night-breeze), and by the large-scale Asian monsoon circulation [2] [6].

Averages , maximum , minimum and other information, calculated for a period from 2002 to 2012, of atmospheric pressure (P), air temperature (T), relative humidity (RH), precipitation (Rain) and wind velocity (WV) are presented in **Table 1**.

Pressure is characterized by higher values from June to October and lower values from November to March. Temperature is characterized by maximum values during the summer period, the highest and the major extreme values being measured in July. Lower T values were recorded during winter with minimum observed in January-February (below −15˚C). Relative humidity behavior was characterized by very low value from the end of November to January/February (values below 40%) and very high value from the end of May to the end of September (values over 90%). Since RH behavior in the Southern Himalayas is strongly influenced by the South Asian monsoon cycle due the transport of moist air masses from the Indian Ocean: This parameter, together with the seasonal shift of local wind regime, is frequently used to evaluate the monsoon phase over this region [2] [5].

The annual precipitation recorded at Pyramid Meteorological Station is low mainly due to the high altitude of its location in the inner Himalayas. For the ten years (2002-2012) examined, the total averaged cumulated annual precipitation is around 300 mm. Nearly 90% of it was recorded between June and September, while in the summer monsoon period (June to September) average cumulated precipitation was around 270 mm. From June to September, precipitation occurred on more than 60% of the days with highest frequency in August/September. It should be clearly stated that precipitation can be significantly underestimated due to loss of solid precipitation

Table 1. Pyramid site climatology (2002-2012).

Data	Months											
	J	F	M	A	M	J	J	A	S	O	N	D
T (˚C)												
Daily Ave	−7.4	−7.7	−5.9	−3.5	−1.1	2.6	3.4	2.9	1.2	−2.1	−3.9	−5.3
Daily Max	3.9	3.0	4.4	5.9	7.0	8.8	8.6	8.4	7.3	6.4	6.0	5.5
Daily Min	−18.6	−17.4	−15.1	−10.6	−8.0	−2.9	−0.2	−1.2	−3.8	−9.8	−12.0	−15.9
Pres. (hPa)												
Daily Ave	549	548	550	552	552	552	55	554	554	553	552	550
Daily Max	554	553	555	555	555	555	556	556	556	556	555	555
Daily Min	543	543	545	548	538	548	551	551	549	541	548	545
RH (%)												
Daily Ave	29.4	39.8	53.2	65.9	78.1	91.0	96.9	96.9	91.1	70.9	40.5	25.6
Daily Max	96.0	96.1	97.8	98.2	98.6	99.5	100	100	98.1	99.6	92.3	96.8
Daily Min	4.0	4.3	5.2	9.5	11.8	41.6	67.6	63.7	34.9	10.9	4.7	3.7
Wv (m·s^{-1})												
Daily Ave	2.20	2.22	2.20	2.07	2.16	2.26	1.95	1.96	1.97	2.00	1.74	2.01
Daily Max	8.74	8.97	8.62	7.17	7.97	8.05	5.47	5.68	8.59	6.25	7.69	7.42
Daily Min	0.03	0.05	0.03	0.03	0.00	0.00	0.00	0.00	0.05	0.00	0.05	0.02
Tot. P (mm)												
Tot. Ave Prec.	0.4	0.8	3.4	7.1	7.6	32.5	92.0	98.6	50.7	5.0	0.5	0.1

by the rain gauge, especially during the cold months when air-temperature is frequently lower than 0˚C. WS is characterized by an average value of 2 m·s^{-1}. Thus, despite its elevation, the measurement site does not appear to be an extremely windy location, thanks to the sheltering effect of the mountain ridge.

3. Calibration Operations at the Pyramid International Laboratory Observatory, 5050 m asl

The calibration chamber has been installed in September 2013 (**Figure 4**) to generate pressure and temperature simultaneously and in a controlled manner and to maintain stable and uniform the conditions during the calibration process. This chamber has been tested at the Pyramid International Laboratory with the aim of specifically adapt this device to the environmental and logistic conditions of the Khumbu valley, the possibility to extent the temperature calibration range from −30˚C to +30˚C has been studied to guarantee an expected calibration uncertainty of 0.1˚C for the temperature sensor and 200 Pa for the pressure sensor. A series of logistic and operative constraints concerning the maximum allowed weight of devices, power consumption has been considered for an accurate implementation.

The calibration is an operation under specified conditions firstly establishes a relationship between the quantity values with measurement uncertainties provided by measurement standards and corresponding indications with associated measurements uncertainties and secondly, uses this information to establish a relation for obtaining a measurement results from an indication.

The performing of this operation using a climatic chamber allows to derive the calibration curve of a sensor (T and P in this specific case), giving metrological traceability to the measures of this sensor. In particular differences between reference sensor (referring directly to primary measured standard) measurements and measurements of the sensor in calibration are determined.

Figure 4. Calibration chamber at the Pyramid site.

The implementation of this calibration facility in the context of international programs such as SHARE, which aims at contributing to the study of the impact climate change in remote mountain regions through the installation of permanent monitoring networks, can be considered a challenge in the frame of climate change assessment which depends crucially on the uncertainties associated with these measurements and the robustness of climate data. Measurement uncertainties can be determined and hence minimized if proper consideration is given to the metrological traceability of the measurements results to stated standards. This aspect is particularly relevant remote regions like Himalaya and Karakorum, where ground based data coverage is still lacking or characterized by poor quality. The monitoring of high mountain regions with calibrated instruments addresses a crucial issues, given the growing attention of the international scientific community to the importance of mountains environments as early indicators of climate change [1].

4. Concluding Remarks

This methodological approach demonstrates scientific and technological excellence; quality, originality and innovation by manufacturing a facility for the *in-situ* calibration of weather stations. The developed device is particularly suitable to be applied in remote high-mountain sites, thus providing a significant advance in the accuracy of weather data in these regions. It will allow simultaneous calibration of temperature and pressure sensors, covering the whole expected range according to the stations locations. The two independently generated quantities are measured by means of instruments directly calibrated against the primary standards. This device is intended for making of the traceability chain to the real *in-situ* measurements. In particular, this activity could provide a relevant contribution to the still-lacking protocols capable of ensuring the traceability of weather and climate measurements from remote, high altitude areas. This device could be also adapted and improved in terms of ranges, for the calibration of weather stations and instruments used for the monitoring of high altitude environmental parameters.

Usually *in-situ* calibrations of weather stations are performed by positioning standard instruments, close to the station under calibration. Standard instruments are left for a short period and the calibration is performed by comparison. This procedure allows to perform a check of sensors functioning but not to determine calibration functions to correct the measurements.

The use of this innovative and high technical calibration chamber can allow filling the gap concerning the calibration of ground-based high altitude and remote stations, facilitating technical and logistics problems related to the performing of these operations, but also helping data processing and elaborations further to a guarantee QA/QC protocol for data acquisition. The described methodology is appropriate because standard reference sensors are not always made to operate in open air; especially in high mountain regions where strong winds and ice rimming could compromise the correct functioning. This specifically designed facility allowing the calibration of weather stations by comparison with standard instruments, traceable to national standard, would make the *in-situ* calibration widely adopted, thus enforcing the robustness of wide-area ground based measurements. It would also allow a defined traceability to national standards, still missing in several nations and ignored by many weather and meteorological services. This will have a direct impact on the possibility to reduce and better define the uncertainty budget [3], contributing to more accurate climate models, more reliable databases and best defined historical analysis and an indirect impact on international communities interest in climate change evaluation and consequent definition of mitigation strategies.

Future perspectives of this activity will be devoted to an improvement of the apparatus for the calibration of additional environmental sensors for soil, water, ice and permafrost temperatures. Moreover the application of this methodology in countries such as Nepal, where this experiment has been conducted, will also contribute to improve capacity building and technology transfer, in fact one additional future implications will be the promotion of the implementation of a certified calibration laboratory in Kathmandu at NAST Laboratories, the mail local counterpart of this activity.

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