METEOROLOGICAL APPLICATIONS
Meteorol. Appl. **22**: 854–860 (2015)
Published online 6 July 2015 in Wiley Online Library
(wileyonlinelibrary.com) DOI: 10.1002/met.1506

Arctic metrology: calibration of radiosondes ground check sensors in Ny-Ålesund

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ABSTRACT: The Arctic research village of Ny-Ålesund (79 ° N, 12 ° E) on the Spitsbergen island of Svalbard archipelago, with its logistics and infrastructure, provides a unique access to the Arctic environment. Among the several international environmental and climate monitoring programmes constantly running there, the Global Climate Observing System (GCOS) Reference Upper Air Network (GRUAN) has established one of its stations at the Alfred Wegener Institute observatory. Calibration of sensors and measurement traceability are fundamental aspects of climate observations, as requested by the GRUAN measurement procedures. In the framework of the MeteoMet project, a transportable climatic chamber for the calibrations of air temperature and pressure sensors was studied and manufactured. In June 2014, a calibration campaign involved the transport and use of one of those systems in the Ny-Ålesund GRUAN station. The result of the campaign has been the complete calibration of temperature and pressure sensors for radiosonde pre-launch ground checks. The resulting calibration curves were obtained with lower uncertainties and more robust characterization of the sensors, with respect to the usual procedures adopted. Given the opportunity of the calibration device operating already in place and the presence of the metrology staff, the calibration was extended to the sensors equipping the Amundsen-Nobile Climate Change Tower. The present study reports on the 'Arctic metrology 2014' campaign and the plans for the establishment of a permanent laboratory for metrology in Ny-Ålesund. The aim is to address the measurement traceability needs arising from the multidisciplinary measurements made by the scientific community operating there.

KEY WORDS atmospheric sensors calibration; GRUAN; MeteoMet; metrology; Ny-Ålesund; radiosondes

Received 15 October 2014; Revised 28 January 2015; Accepted 21 February 2015

1. Introduction

A better understanding of the climate trends and the underlying causes of these changes requires an increasing knowledge of physical properties both at the surface of the Earth and throughout the atmospheric column. Existing records of upper-air measurements are insufficient for studying the climate change (GCOS-138, 2010). They greatly lack continuity, homogeneity and representativeness of data, because past observations were never intended for climate research, but were mainly carried out for the purpose of short-term weather forecasting.

Therefore, a ground-based reference observing system has been launched for measuring upper-air changes to enable the separation of climate change signals from the inevitable non-climatic effects caused by measurement biases, instrument instabilities and network inhomogeneities. The Global Climate Observing System (GCOS) Reference Upper Air Network (GRUAN) is an international reference observing network, designed to meet climate requirements and to fill a major void in the current global observing system. The GRUAN observations provide long-term, high-quality climate records from the surface, through the troposphere, and into the stratosphere. The GRUAN observation data will be used to determine trends, constrain and validate data from space-based remote sensors and to provide accurate data for the study of atmospheric processes.

Currently, about 16 stations contribute to the GRUAN network with their radiosonde measurements of temperature, humidity, pressure and wind. The first GRUAN-certified station has been the AWIPEV Research Base in Ny-Ålesund, Svalbard. Here, the Alfred Wegener Institute (AWI), Helmholtz Centre for Polar and Marine Research, launches a Vaisala RS92 radiosonde every day at local noon.

Prior to the launch, each radiosonde runs through additional ground check measurements to optimize the characterization of the sonde performance. Each radiosonde is operated in an artificial cloud, with 100% relative humidity under known temperature conditions. Furthermore, to define precisely the ambient meteorological conditions at launch time, the radiosonde temperature and humidity are simultaneously measured in a ventilated weather hut with ground instrumentation. An exact knowledge of the station-level pressure is needed to calculate the altitude information from the radiosonde profile (Maturilli *et al.*, 2014). The focus is set on the characterization of observational biases, with an effort to include evaluation of components of measurement uncertainty, and on the traceability of measurements by extended metadata collection and comprehensive documentation of observational methods.

To fulfil the principle of traceability better, uncertainty evaluation and calibration documented procedures, the GRUAN Working Group established a collaboration with the metrology community. Metrologists now sit in the GRUAN WG, and

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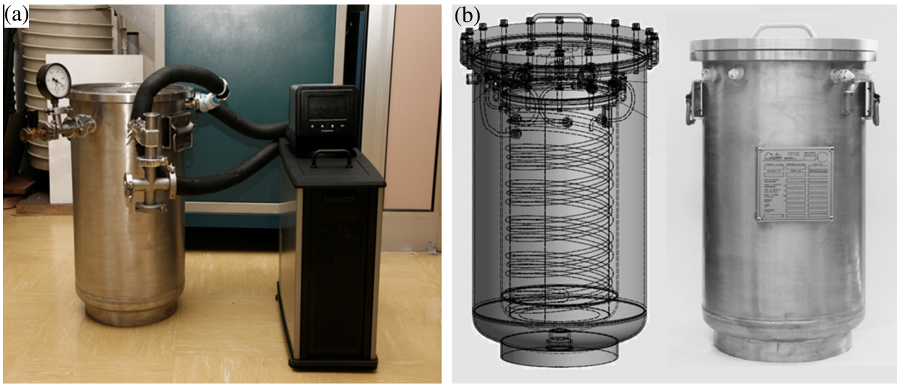

Figure 1. (a) Earth Dynamics Investigation Experiment 1 (EDIE1) and external thermostat (b) EDIE1 climatic chamber project drawing.

a formal collaboration has been signed with the major joint research project funded by the European metrology community. In 2011, the European Association of National Metrology Institutes (EURAMET), through the European Metrology Research Programme (EMRP), funded the 3 year project MeteoMet, Metrology for Meteorology, addressing the need for new stable and comparable measurement standard protocols, sensors and calibration procedures, data fusion and uncertainty evaluation methods. This project, which started in October 2011, focuses on the traceability of measurements involved in climate change: surface and upper-air measurements of temperature, pressure, humidity, wind speed and direction, solar irradiance and reciprocal influences between these measurands.

Among the many MeteoMet deliverables, in its work package 3, there are five tasks inherent to the *in situ* calibration of temperature, pressure and humidity sensors of weather observing stations, including Automatic Weather Stations (AWSs). This task includes both procedures and proposals and construction of dedicated facilities. A robust metrological approach to full traceability requires a proper calibration of the instruments leading to the evaluation of the calibration curve and the associated uncertainty. This can be done by generating the complete variability of the quantity the sensor will meet when operating in the field and comparing its reading with those of a traceable standard placed in the same controlled environment. Such a principle surpasses the usually adopted test procedure, which is limited to a check of the instrument response when compared with a travelling standard, usually at a single value of the measured quantity. This test procedure does not represent a calibration nor can it generate any uncertainty evaluation. The work presented here reports on a full calibration, with documented and calculated uncertainty.

In 2013, a special calibration chamber was studied and manufactured to be installed in the Everest Pyramid observatory, for the calibration of the several weather sensors operating in the Nepalese side of Mount Everest up to 7000 m of altitude (Merlone *et al.*, 2014). The work reported here refers to a similar campaign organized in 2014 under this GRUAN–MeteoMet collaboration, aiming at giving a direct traceability to national standards to those atmospheric measurements of temperature and pressure used as pre-launch ground checks of radiosonde sensors, performed by the GRUAN station of Ny-Ålesund.

The present study is organized into sections, and it first presents the portable calibration chamber and the reference instruments used in the calibration. A section is then dedicated to the calibration campaign starting from its planning, describing the activities and measurements carried out in Ny-Ålesund. The last sections report on calibration results, a general discussion related to the results themselves, the significance of the activity and the future prospects and a summarized conclusion.

2. Calibration chamber

In the MeteoMet 'Arctic metrology 2014 campaign', a special calibration chamber has been used. The new chamber coded EDIE 1 (Earth Dynamics Investigation Experiment 1) was manufactured at the Italian Institute of Metrology (Istituto Nazionale di Ricerca Metrologica, INRiM) in the framework of the MeteoMet project to ensure data traceability and to obtain more comprehensive data on the performance of pressure and temperature sensors. The device allows simultaneous and independent control of pressure and temperature over the whole range of ground atmospheric variability in Ny-Ålesund station (Maturilli *et al.*, 2013).

The chamber is equipped with reference sensors directly traceable to national standards, to obtain more accurate calibration results and to guarantee well-documented calibration uncertainty.

The chamber used for this work can calibrate temperature and pressure sensors, evaluating the mutual influences between these two quantities. The scheme and a picture of EDIE1 are presented in Figure 1. A further improvement will be the development of humidity generator for hygrometer calibrations in temperature and pressure variable conditions, starting from the metrological research already present in the field (Heinonen, 1999; Hudoklin *et al.*, 2008; Hudoklin and Drnovšek, 2008; Heinonen *et al.*, 2012) and also allowing the calibration of thermometers and barometers under different humidity values as quantity of influence. Indeed, the apparatus is designed to allow the humidity control and thus to complete the characterization of the whole AWS pressure–temperature–humidity (PTU) modulus.

In Lopardo *et al.* (2014), EDIE1's specifications are described and its characterization is presented. The nominal ranges of the chamber are: absolute pressure from 50 to 110 kPa and temperature from −25 to 50 °C. For the specific purpose of this work, the system was improved with a more powerful external thermostat to extend the temperature range towards lower temperatures (down to −35 °C) in order to cover also the environment conditions occurring in such extreme regions.

In temperature sensor calibration, the spatial uniformity and temporal stability of the generated value play a key role in contributing to the uncertainty. The EDIE1 air temperature uniformity over space has been evaluated with previous tests (Lopardo *et al.*, 2014). The radial homogeneity can be assumed to be linear and the maximum gradient observed in the calibration range is 0.02 °C cm^{-1}. The vertical air temperature shows a gradient that can be assumed linear over the central vertical area of the inner chamber, 12 cm away from the top and the bottom.

Air temperature stability over time is constantly evaluated during calibration measurements, and short-term stability has been preliminarily estimated to be in the order of magnitude of ±1 mK for 10 min.

The EDIE1 is intended to be used in measurement campaigns in locations where there is no possibility to have a permanent calibration service, and for this purpose, it is easy and transportable.

The good compromise between measuring inner chamber (inner diameter 220 mm and volume of around 15l) and external total dimensions (350 mm × 650 mm) makes it transportable for *in situ* calibration campaigns, allowing the majority of weather temperature and pressure sensors to be hosted, including those embedded in compact weather station structures.

The system may be partially disassembled to be shipped in an easy way. The whole equipment needed to allow EDIE1 to work as a stand-alone calibration service consists of the following components:

- climatic chamber;
- thermostat;
- thermostat fluid;
- external pressure line connections and valves;
- vacuum pump;
- manual pump;
- multimeter and GPIB-US HS converter;
- DC power supply;
- laptop;
- reference barometer and reference Pt100s;
- 'calibration tree', the support structure for sensors to be placed inside the climatic chamber.

In the calibration campaign described here, the EDIE1 has been equipped with two thermometers and a digital pressure meter, directly referred and traceable to INRiM standards.

The selected reference thermometer, named GS01, is a metallic-enclosed Pt100 with particular structure intended to perform air temperature measurement.

It has been calibrated in the range from −40 to +50 °C with a calibration uncertainty of 0.007 °C for measured temperatures >0 °C and 0.011 °C for lower temperatures ($k = 1$). Moreover, GS01 resistance measurement is performed with a Keithley 2002, a high performance 8 ½ digital multimeter, which, when settled for achievement of best performance, gives an uncertainty of 0.006 °C.

The reference pressure meter is a Baratron MKS622, calibrated in the range from 20 to 120 kPa with a total calibration uncertainty of 12 Pa ($k = 1$). This instrument needs a ±15 V DC power supply and outputs a DC voltage, which is measured with the Keithley 2002 multimeter. The contribution to the pressure uncertainty due to the voltage reading and voltage-to-pressure translation corresponds to an equivalent uncertainty contribution of 1.1 Pa and is included in the 'pressure reference calibration' contribution of Table 3.

3. 'Arctic metrology 2014' mission

The Arctic calibration campaign was planned with the aim to provide the required metrological support to the atmospheric measurements performed in Ny-Ålesund, in the Arctic region, and represents a notable example of the feasibility and working capability of the calibration facility realized in the project.

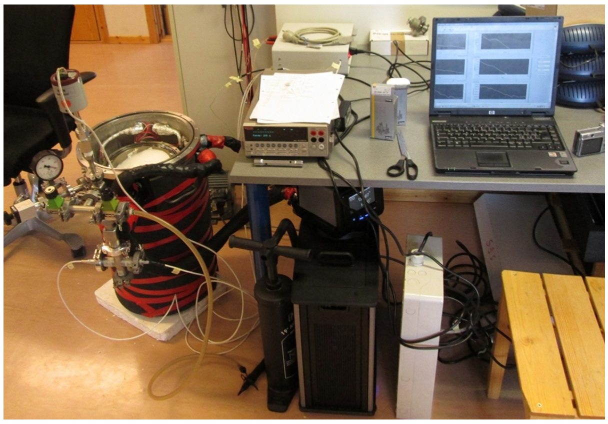

Figure 2. Earth Dynamics Investigation Experiment 1 (EDIE1) assembled in the Alfred Wegener Institute (AWI) station without top covers.

The collaboration with AWI began inside the already established co-operation MeteoMet–GRUAN, and the feasibility of a joint activity between AWI and INRiM was considered starting from February 2013 at the GRUAN Implementation and Coordination Meeting in De Bilt, The Netherlands. The mission preparation, equipment adaptation, calibration tests, scheduling, transport and the technical details for the organization of the campaign took most of the period between March 2013 and May 2014.

The INRiM staff prepared the calibration chamber, and the whole equipment that has been housed in a box weighing <200 kg was shipped from the INRiM on 20 May; the box arrived in Ny-Ålesund by boat preceding the arrival of the INRiM staff in the middle of June.

The stay planned for the INRiM staff was only of 3 days for two researchers and 7 days for a third one. Two rounds of calibration were scheduled and additionally, a short training for the AWI staff on the use of the calibration chamber, procedures, calibration curves and uncertainties was arranged. For this reason, all the procedures for the assembling and the start-up of the device were previously studied in order to reduce at minimum operational times.

After the training of the local staff, and after the departure of the metrology group, the EDIE1 remained in Ny-Ålesund for an additional one month to complete the calibration campaign of further instruments.

Half a day was required to set the EDIE1 completely in measurement condition. The first step was the assembling and start up of the system in the designated location inside the AWI observatory (see Figure 2). The pressure system has been mounted and pressure stability performance verified.

The two reference Pt100s were checked at 0 °C in a melting ice–fixed point measured with the same water used in the calibration of the sensor at the INRiM to verify the eventual discrepancy with calibration due to transportation. The water was transported together with the chamber from Italy. During this test, one of the two sensors showed an anomalous behaviour and its use was discarded for the calibration.

The chamber dimension allows calibrating more than one sensor at the same time.

The temperature sensors under calibration were then fixed to the support structure, as shown in Figure 3, for the insertion in the chamber, close to the standard thermometer, in the mid-vertical zone of the chamber, where the thermal gradient was found to be reduced during the previous characterization. Special care has

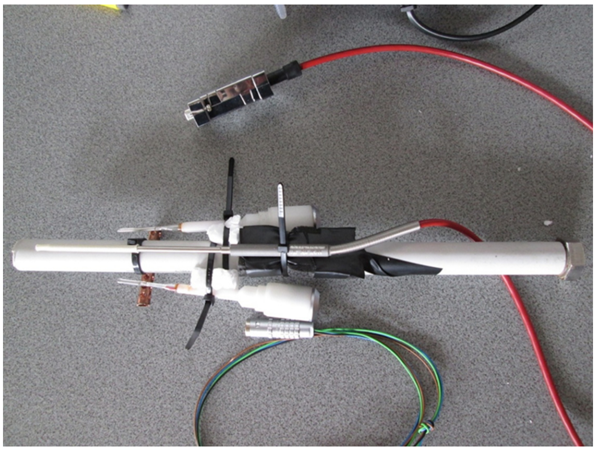

Figure 3. Pt100 mounted on the 'calibration tree', the support structure for sensors to be placed inside the climatic chamber.

been paid to the positioning of the sensors so that the sensing elements lie at the same depth as the reference one, to further reduce thermal gradient component in the calibration uncertainty budget.

The pressure sensor was placed at the bottom of the chamber. The pressure sensor readings are expected to be only slowly dependent on the temperature in this range. The nominal temperature value is therefore enough to evaluate the temperature dependence of the sensors' response. In this case, there is no need to fully evaluate the thermal gradients of the order of few tens of millikelvin, as done for the temperature sensor calibration.

The difference in height between the sensor under calibration position inside the chamber and the reference pressure meter, Baratron MKS622, has been evaluated in order to correct for the effect of the immersion in the resulting air column. The reference sensor is in fact positioned outside the chamber, to be constantly kept at room temperature, since it was calibrated at the INRiM primary pressure calibration laboratory, where standard procedures request the calibration of any pressure gauge at 20 °C. The pressure value, corrected for the immersion effect, is calculated from the expression: $p_{imm} = p_{ref} + \rho\ g\ h$ where $g = 9.83\ \mathrm{ms}^{-2}$, as measured locally in Ny Ålesund, $h = 73$ cm is manually measured after positioning the pressure sensor in calibration inside EDIE1 and ρ is the air density calculated at each temperature T and pressure P.

The instrumentation, thermometers and pressure gauges used for the GRUAN radiosonde pre-launch ground check procedures have been calibrated during the campaign.

In the first calibration campaign, one common analogue Pt100 thermometer, two DTM5080 Pt100 digital thermometers and a DIGIQUARTZ 6000 digital pressure meter have been enclosed inside EDIE1.

Measurements were performed automatically with data loggers that store data on the computer with a timestamp: this allows to perform the calibration for the whole measurement chain, from the sensor to the digital value acquired on the computer.

The calibration range was set in agreement with the AWI staff to cover the real environmental conditions at the ground check of the radiosondes.

The requested temperature range was from −30 to 10 °C and set points selected were: −30, −15, 0 and 10 °C, while pressure points covered the requested range from 95 to 105 kPa with steps of 1 kPa.

The planned procedure was to set a temperature value starting from −30 °C, than to wait until a temperature stability within 0.001 °C is reached inside the chamber, and finally to start the temperature values recording. Afterwards, pressure calibration was performed at each temperature, starting from 95 to 105 kPa, while at the 0 °C temperature, the pressure points were repeated by both increasing and decreasing the pressure back to 95 kPa to notice any hysteresis effect. Pressure stability reached at each calibration point was of few pascals (<5 Pa).

Taking into account the evaluated settling time of about 10 h for each temperature set point and 5–15 min for pressure point, the time required for the calibration was approximately 3–4 days.

Redundancy of the GRUAN equipment and instrumentation guarantees the daily execution of the ground check during the calibration days. The calibration was performed on instruments not in use in the same period for the ground check, but installed in the weather hut immediately after their calibration.

A second round of calibration has been performed including three further Pt100 sensors of AWI and a sensor owned by CNR (Consiglio Nazionale delle Ricerche). This additional instrument is a Vaisala Thermohygrometer used on the new Amundsen-Nobile Climate Change Tower (CCT) that has a height of 32 m and a large capacity to host and operate many instruments (Vitale, 2009). The CCT is part of the Climate Change Tower Integrated Project (CCT-IP) that creates an experimental platform to investigate the Arctic atmospheric boundary layer, energy budget and the role played by different processes involving air, aerosols, clouds, snow, ice and land, permafrost and vegetation. The main objective of the CCT-IP is to contribute to reducing the fragmentation of measurements, by integrating and finalizing them to the most important scientific question related to the climate of the Arctic region (Viola *et al.*, 2010).

4. Calibration results

The results of the calibration are shown in Figure 4. ΔT represents the difference between the temperature reading of the sensor under test (T_m) and the reference sensor readings. The calibration curve to be evaluated is $T_c(T_m)$, where T_m is the uncorrected reading and T_c is the value corrected with the following calibration curve:

$$T_c(T) = T - \Delta T(T) = T + a + bT + cT^2 \qquad (1)$$

The temperature calibration curve is evaluated using a second-order polynomial interpolation, coherently with the Callendar–Van Dusen equation (Van Dusen, 1925) used for the calibration of the standard PRT according to IEC 60751 (2008).

The calculated co-efficients of Equation (1) are reported in Table 1.

Regarding the pressure sensor, the differences, Δp, between the pressure values measured by the reference and those measured by the sensor under test have been evaluated. Δp also includes the pressure correction due to the immersion, as reported above. Pressure calibration points were repeated at each temperature set point. The measurement results obtained during pressure calibration are shown in Figure 5.

Because of the observed dependence of the pressure measurement on the temperature, a calibration surface in function of both the pressure and the temperature inside the chamber has been evaluated interpolating the data with the following curve:

$$p_c(p, T) = p + a + bp + cT + dpT + eT^2 \qquad (2)$$

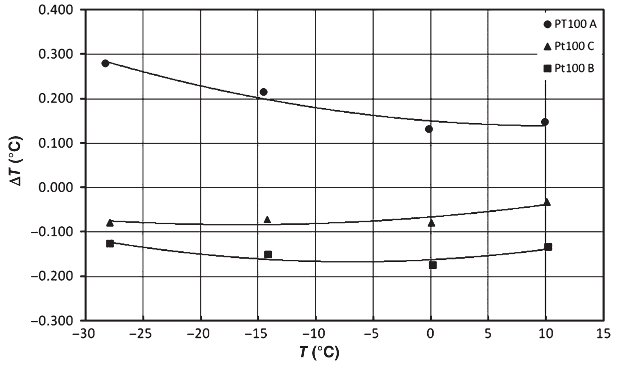

Figure 4. Calibration curves for temperature sensors. ΔT represents the difference between the temperature value measured by the reference and the sensor under test.

Table 1. Calibration curves co-efficients for temperature sensors.

Sensor	a (C)	b	c (C^{-1})
Pt100 A	0.150	0.00204	0.00096
Pt100 B	−0.163	0.00137	0.000101
Pt100 C	−0.067	0.00214	0.000066

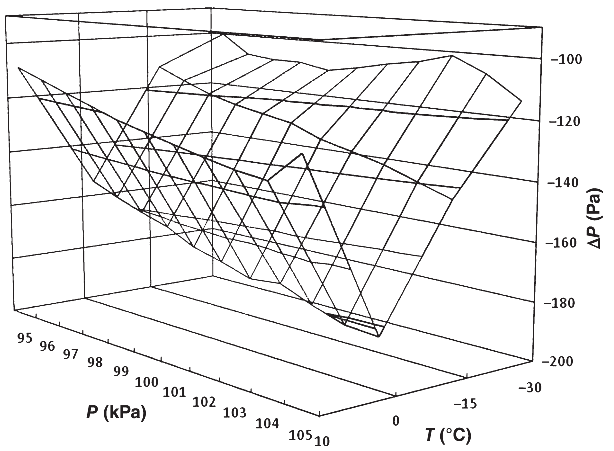

Figure 5. Calibration measurements for pressure sensor as a function of the pressure and the temperature. Δp represents the difference between the pressure value measured by the reference and by the sensor under test.

where $a = 39.84$ Pa, $b = -0.002299$, $c = 4.835$ Pa °C^{-1}, $d = -3.87\text{E}{-05}$ °C^{-1} and $e = 0.09729$ Pa °C^{-2}.

During the second cycle of calibration, the CCT Vaisala Thermohygrometer was calibrated by directly measuring the voltage output signal, in function of the temperature reading of the reference sensor, in the range from −25 to 10 °C. Data are interpolated with a linear regression. The measured values and calibration curve are shown in Figure 6.

4.1. Uncertainty budget calculations

The uncertainties associated with the temperature calibration curves were evaluated according to the Guide to the Expression of Uncertainty in Measurement (GUM, 2008).

Regarding the reference thermometer, both the uncertainty due to the calibration and the repeatability of the sensor are combined. The contribution related to the sensor under test combines its resolution and the repeatability of the measurement readings during the calibration.

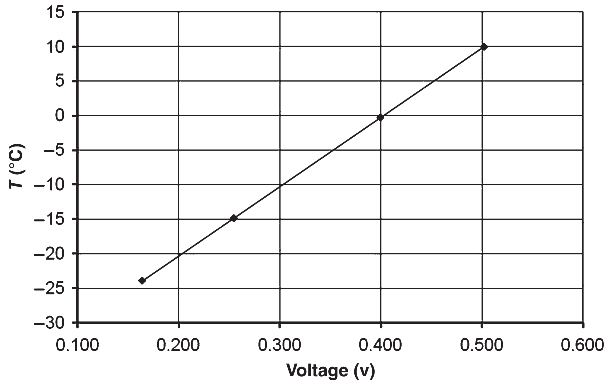

Figure 6. Calibration curve for Vaisala Thermohygrometer.

Chamber uniformity related to vertical temperature gradient is evaluated in Lopardo *et al.* (2014) as worst case approximation with the value of 0.072 °C over a distance of 0.02 m, giving 3.76 mK mm^{-1}. This gradient value is then used to evaluate the uncertainty due to spatial position and dimension of thermometers under calibration.

The contribution to the calibration curve uncertainty due to the interpolation process with a second-order polynomial is evaluated using residuals.

The amount of the different contributions to the standard uncertainty and the temperature expanded uncertainty with coverage factor $k = 2$ are reported in Table 2.

The uncertainty associated with the pressure calibration curve is calculated in the same way by combining the contribution of the repeatability and calibration of the INRiM reference sensor, the uniformity of the chamber, the repeatability of the sensor calculated during the calibration procedure and the contribution of the interpolation. The uncertainty contribution due to the correction for the immersion was evaluated to be negligible. These contributions are listed in Table 3, together with their associated values.

5. Discussion and future development

The portable calibration system used for this campaign, purposely designed as a deliverable of the MeteoMet project, allowed the calibration of temperature and pressure sensors used as ground check of the radiosondes. This calibration chamber also allows to contemporarily generate and control both quantities for a more complete analysis on the sensors under calibration. If a sensor made to measure a quantity A is found to have a measurable dependence from a different quantity B, two solutions can be adopted for the calibration and use of the device. If a calibration system such as the EDIE chamber used here is available to generate both quantities A and B, the sensor's dependence $A(B)$ can be determined. If $A(B)$ is found to be larger than the sensor resolution and sensibility over the whole measuring range, then a correction curve can be calculated. When, after the calibration, the sensor is then used for measuring the quantity A, that is, in the field, then a further sensor measuring primarily the quantity B need to be associated. In this way, the correction curve can be applied to the sensor reading, from the values of the quantity B, with an associated uncertainty contribution to the measurement uncertainty. If the auxiliary sensor measuring B cannot be

Table 2. Uncertainty budget contributions for temperature measurement.

Uncertainty contribution	Pt100 A (°C)	Pt100 B (°C)	Pt100 C (°C)	Vaisala Thermohygrometer (°C)
Temperature reference sensor	0.011	0.011	0.011	0.004
Chamber uniformity	0.006	0.009	0.019	0.011
Sensor under calibration	0.007	0.008	0.014	0.011
Calibration curve	0.026	0.017	0.018	0.003
Standard uncertainty	**0.029**	**0.022**	**0.026**	**0.012**
Expanded uncertainty (k = 2)	**0.058**	**0.044**	**0.052**	**0.025**

Table 3. Uncertainty budget contributions for pressure measurement.

Uncertainty contribution	Value (Pa)
Pressure reference repeatability	0.3
Pressure reference calibration	12
Chamber uniformity	2.5
Sensor under calibration	0.3
Calibration curve	26
Standard uncertainty	**29**
Expanded uncertainty (k = 2)	**58**

operated continuously in parallel, or if the local value of B is not measured by other sensors, it is not possible to obtain the input data for the correction curve. In such a case, and also if the $A(B)$ relation is recognized to be limited of the order of the sensor resolution or sensibility, then the maximum amplitude of the dependence $A(B)$, over the range of the sensor use, can just be included in the uncertainty budget as a non-comparable uncertainty component. In a similar analysis following a calibration campaign for high altitude sensors in the Himalayas, this last solution was adopted (Merlone *et al.*, 2014), since in this case it is very difficult to guarantee the reliability of both simultaneous measurements, the sensors drift due to extreme environment and the possibility to apply the correction curve correctly. The total range of the pressure sensor's response to temperature change, on the order of 100 Pa, was included as a source of uncertainty. This indeed increased the total uncertainty, but with the benefit of a general accuracy all over the measuring period between two calibrations. In such a mountain environment, moreover, the frequency between calibration depends also on the weather conditions allowing the removal, calibration and re-installation of the sensors, also having the calibration facility now permanently on site. In the case of Ny-Ålesund, where laboratories are placed close to the measuring site, with high-level equipment and several redundant measurements for checking, the first option can be adopted. For this reason, the pressure calibration curve is expressed in this work as a relation in three dimensions $p_c(p,T)$ as shown in Figure 5. The major contribution to the pressure calibration uncertainty budget is given by the interpolation process resulting from the residuals. This contribution should be reduced by increasing the calibration points and/or using a more complex tridimensional relation, but the more reliable solution is to declare a total uncertainty suitable to cover the variability of the curve all over the range. This summarizing value was calculated to be equal to 58 Pa with covering factor $k = 2$, and represents an acceptable result, considering that it gives the added value of including the temperature dependency, all over the range of temperature.

The procedures and results presented here were the subject of a further discussion between the involved metrologists and the research staff operating in the Arctic area, aiming at planning the feasibility for the establishment of a permanent laboratory for metrology in Ny-Ålesund to support the research stations in Svalbard.

The general goal expressed by the GRUAN manual and guide is to fully evaluate the measurement uncertainty of a vertical profile obtained by means of radiosonde sensors. The follow-up activities of this work, in collaboration with the GRUAN Ny-Ålesund station, will concern the evaluation of the contribution due to the pre-launch transfer taking into account the ambient uniformity and the positioning in the ground check procedure.

As the Arctic region is a fundamental observation point for climate change (IPCC, 2007) and considering the examples of an integrated project such as the CCT, the relevance of this work is also to underline the opportunity to perform calibration and traceability on site. The aim is to give direct metrological robustness to measurement related to environmental and climate studies to improve the comparability and representativeness of data sets and possibly evaluate and reduce measurement uncertainty.

The proposal will initially deal with temperature (of air, water, ice, soil, permafrost), pressure and radiance (direct solar radiation and albedo). The availability of a metrology laboratory on site can surely facilitate research communities dealing with calibration and instrument performance tests, avoiding at the same time transfer of instrumentation to calibration services in the mainland. Having a metrology laboratory on site, moreover, will surely extend awareness on metrological needs and benefit in this field. Such a project proposal from the metrology community can also be an added value to the Svalbard Integrated Earth Observing System (SIOS). The SIOS is an international infrastructure project involving partners from Europe and Asia with the essential objective of establishing better co-ordinated services for the international research community with respect to access, data and knowledge management, logistics and training. The SIOS shall co-ordinate and develop the existing and new research infrastructure in Svalbard, and the proposal of a permanent metrology laboratory in Ny-Ålesund can perfectly fit the SIOS mission.

6. Conclusions

A portable calibration system developed at the Istituto Nazionale di Ricerca Metrologica (INRiM) was used for on-site calibration in the Alfred Wegener Institute (AWI)–Global Climate Observing System (GCOS) Reference Upper Air Network (GRUAN) radiosondes station in Ny-Ålesund, demonstrating good performance and ease of use. The uncertainty obtained for temperature calibration curve was significantly lower than that of about 0.1 K declared in previous calibrations for the same instruments.

Moreover, the calibration of temperature sensors in air, instead of immersing them in a liquid bath, is more representative of the effective use of those instruments, making the associated uncertainty closer to the measurement uncertainty final value.

Pressure sensors have been calibrated too, measuring also the influence of the temperature on their response. The total uncertainty on the pressure calibration curve was of the same order as that obtained by the AWI staff, from previous external calibration campaigns. The advantage arising from the present work is that with the campaign described here, the instruments can be corrected from their temperature dependence and an uncertainty can be associated with this correction. The activities reported here opened the opportunity to extend the on-site calibration to further instruments and sensors. An ‘Arctic metrology campaign 2015’ is being planned, involving direct calibration of thermometers for measurements of permafrost, ice and water in Ny-Ålesund against secondary travelling standards. Such preliminary work will set the basis for a possible permanent calibration laboratory, to be hosted by one of the Arctic bases.

The proposed on-site metrological laboratory, equipped with specific devices, can establish long-term direct traceability of the measurements in the polar area, with a direct link to primary standards of the European National Metrology Institutes. This will benefit the quality and comparability of data available in the immediate short period as well as for the future generation of climatologists.

Acknowledgements

This work is being developed within the frame of the EMRP (European Metrology Research Programme) joint research project ‘METEOMET’. The EMRP is jointly funded by the EMRP participating countries within the EURAMET and the European Union. The authors thank the CNR (Consiglio Nazionale delle Ricerche) staff of the Dirigibile Italia station in Ny-Ålesund for the essential logistic support.

References

GCOS. 2010. Update of the Implementation Plan for the Global Observing System for Climate in Support of the UNFCCC. GCOS-138 (GOOS-184, GTOS-76, WMO-TD/No. 1523).

GUM. 2008. BIPM, IEC, IFCC, ILAC, ISO, IUPAC, IUPAP, and OIML. Evaluation of measurement data – guide to the expression of uncertainty in measurement. Joint Committee for Guides in Metrology, JCGM 100:2008.

Heinonen M. 1999. A humidity generator with a test chamber system. *Measurement* **25**: 307–313.

Heinonen M, Anagnostou M, Bell S, Stevens M, Benyon R, Bergerud RA, et al. 2012. Investigation of the equivalence of national dew-point temperature realizations in the −50 °C to +20 °C range. *Int. J. Thermophys.* **33**: 1422–1437.

Hudoklin D, Drnovšek J. 2008. The new LMK primary standard for dew-point sensor calibration: evaluation of the high-range saturator efficiency. *Int. J. Thermophys.* **29**: 1652–1659.

Hudoklin D, Bojkovski J, Nielsen J, Drnovšek J. 2008. Design and validation of a new primary standard for calibration of the top-end humidity sensors. *Measurement* **41**: 950–959.

IEC 60751. 2008. Edition 2.0 2008-07. Industrial platinum resistance thermometers and platinum temperature sensors.

Intergovernmental Panel on Climate Change (IPCC). 2007. *Climate Change 2007: The Physical Science Basis*, Solomon S, Qin D, Manning M, Chen Z, Marquis M, Averyt KB, Tignor M, Miller HL (eds). Cambridge University Press: New York, NY.

Lopardo G, Bellagarda S, Bertiglia F, Merlone A, Roggero G, Jandric N. 2014. A calibration chamber for automatic weather station. Presented at the *Metrology for Meteorology and Climate Conference*, 15–18 September 2014, Brdo, Slovenia.

Maturilli M, Herber A, König-Langlo G. 2013. Climatology and time series of surface meteorology in Ny-Ålesund, Svalbard. *Earth Syst. Sci. Data* **5**: 155–163, DOI: 10.5194/essd-5-155-2013.

Maturilli M, Herber A, König-Langlo G. 2014. Surface radiation climatology for Ny-Ålesund, Svalbard (78.9° N), basic observations for trend detection. *Theor. Appl. Climatol.*, 16 May 2014 DOI: 10.1007/s00704-014-1173-4.

Merlone A, Roggero G, Verza GP. 2014. In situ calibration of meteorological sensor in Himalayan high mountain environment. Presented at the *Metrology for Meteorology and Climate Conference*, 15–18 September 2014, Brdo, Slovenia.

Van Dusen MS. 1925. Platinum-resistance thermometry at low temperatures. *J. Am. Chem. Soc.* **47**(2): 326–332.

Viola A, Vitale V, Udisti R, Argentini S, Nardino N, Lanconelli C, *et al.* 2010. Climate Change Tower Integrated Project (CCT-IP). A scientific platform in the Arctic to investigate processes at the surface and low troposphere. *European Geosciences Union General Assembly*, 2–7 May 2010, Vienna.

Vitale V. 2009. Current state of the Climate Change Tower Integrated Project (CCT-IP) and future developments of the Italian activities at Ny Ålesund. Presented at the *31st NySMAC Meeting*, 3–5 November 2009, Seoul.

