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Climate Consulting

UNDERSTANDING THE MEASURE UNCERTAINTIES OF A URBAN METEOROLOGICAL NETWORK

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OMD Osservatorio Meteorologico di Milano Duomo

CLIMATE NETWORK OVERVIEW

CLIMATE NETWORK® is a private and professional network of urban meteorological stations in Italy. Its aim is providing high quality weather data to industries and service sectors. Climate Network is particularly interesting for subjects operating in urban contexts and for whom the weather and climate data are sensitive variables in decision-making and management.

CLIMATE NETWORK® is designed, built and organized expressly to ensure high quality and consistency of data with high metrological and managerial standards.

The aim of maintaining and improving the quality of Climate Network data is supported by a constant attention to scientific research and development. Therefore our staff participate in important international projects of meteorological metrology and modelling.

Once completed, within the next 3 years, the network will consist of approximately 80 stations and it will cover the main national urban centres (fig. 1).

In cities with vast metropolitan areas We are realizing "weather urban networks". The weather urban network of Milano metropolitan area currently consists of 19 stations, 8 of which in Milano, and it has been working for two years (fig. 2).

The network can supply daily the max, min and average measurements with a maximum time resolution of ten minutes, for the following meteorological parameters: TEMPERATURE (2 sensors, one of them redundant), RELATIVE HUMIDITY, ATMOSPHERIC PRESSURE, RAIN – amount, intensity and duration, HAIL – amount, intensity and duration, WIND SPEED AND DIRECTION, gust included (ultrasonic bi-axial sensor).

Some stations are also specialized to measure: SOLAR RADIATION - GLOBAL, NET, UV

Climate network

Main towns monitored by Climate Network®

Milan weather urban network

THERMOMETRIC UNCERTAINTY BUDGET

The air temperature measurement is still an unresolved question. For example the traditional meteorological approach don't consider the definition of measurand as an uncertainty contribution.

Nevertheless the signing of CIPM-MRA (Comitè International des Poids et de Measure – Mutual Recognition Agreement) by the WMO gave to the meteorologist's community useful instruments to estimate uncertainties.

Metrologists can aquire useful informations and data from the real world of measures too.

Temperature is a well defined parameter by metrological institutes. But we have to specify air temperature when we talk of meteorological measures and air isn't a good thermal conductor.

This is the reason why the uncertainty on air temperature measurements is higher than uncertainty on liquids temperature measurements.

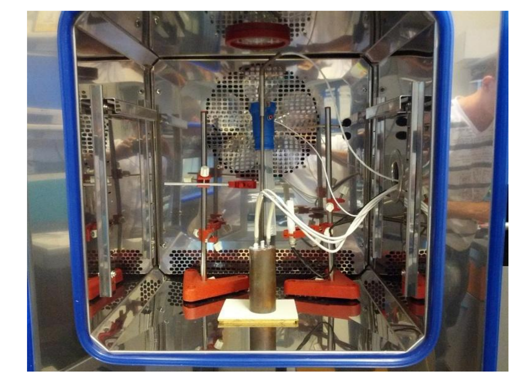
We have also to define where we measure the air temperature and what is the purpose of measures. This is very important to define the uncertainty threshold.

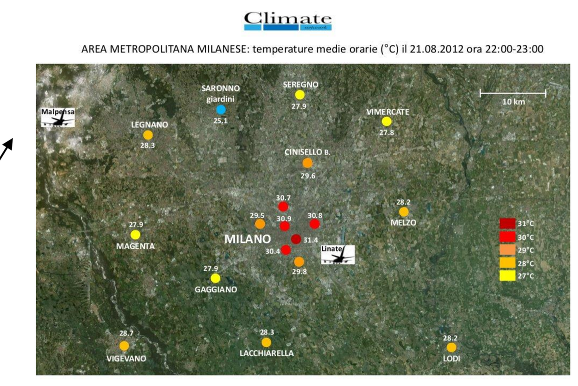
For example the first class of WMO's classification, the highest in terms of representativeness can be used for climatological studies where the highest level of uncertainty is required to detect minimum differences in temperature trend .

Finally we can divide uncertainty budget into three different contributions:

- **Calibration uncertainty** - we take into account the uncertainty at the end of traceability chain using the air in a climatic chamber, not liquids, as transfer standard medium;
- **Measurement uncertainty** - we take into account the effect of ventilated or non-ventilated screens, the screen ageing, the minimum variability among identical thermometers, the influence of others meteorological parameter, etc.
- **Measurand definition uncertainty** - An incomplete definition of the measurand introduces into the uncertainty of the result of a measurement a component that may or may not be significant relative to the accuracy required.. We need a deep knowledge of the urban environment to choose a valid and representative site, this is the reason why we installed almost 20 stations in Milan area at the mean building top height.

On this base now we can define the Climate Network temperature measurement as "temperature of the air over the canopy layer in a urban residential site in the center of the city".





MEASUREMENTS UNCERTAINTIES

ON FIELD TESTING

A good laboratory pratice isn't enough to guarantee good measures. While we can control many of the influence parameters in laboratory, we can't do the same on field.

We have many ways to study sensor's behaviour:

- simulating field condition in laboratory (system choosed by the national institute for metrology in the Meteomet project);
- comparing different sensors, with different principles of measure in order to evaluate biases;
- comparing identical sensors, in the same site with the same reference for calibration, in order to evaluate the minimum variability and get a real measure uncertainty along with the calibration uncertainty.

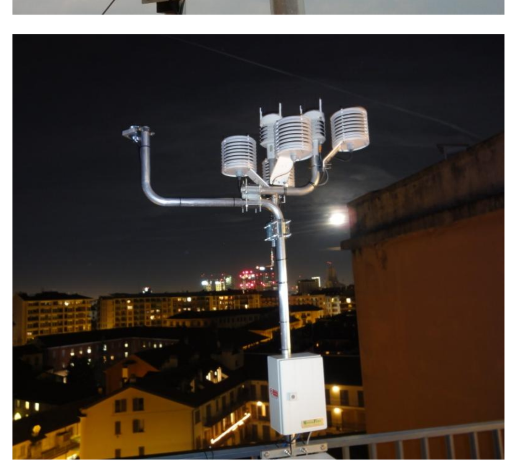
We have designed some sites specialized on a specific measurand (Milano Bicocca - Rain, Milano Politecnico – Solar Radiation, Torino – Wind).

In these sites we can test different instruments with different principles of measure, to get field data and to improve our knowledge of measure.

Climate Consulting is a partner

METEOMET Metrology for Meteorology — EMRP European Metrology Research Programme

Metrology for pressure, temperature, humidity and airspeed in the atmosphere



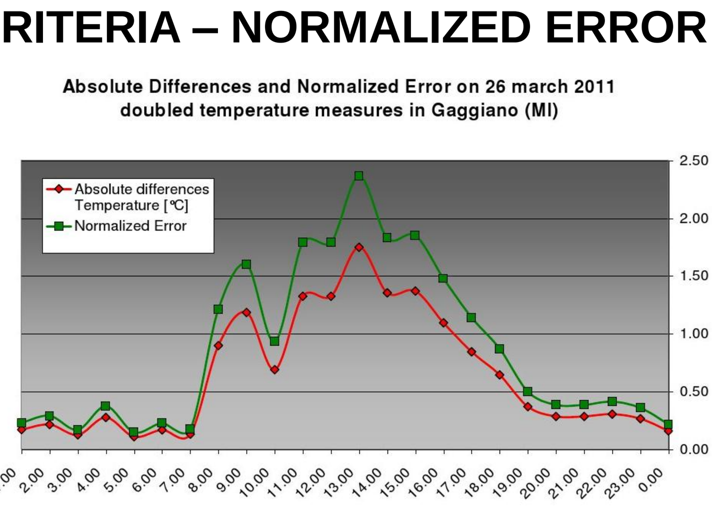
COMPARISON CRITERIA – NORMALIZED ERROR TEST

The statistical parameter used for the verification of calibration and comparative tests among different shelters and locations is the Normalized Error En defined as:

$$E_n = (X_{lab} - X_{ref})/(U^2_{lab} + U^2_{ref})^{1/2}$$

where
•Xlab, Xref are the independent measures of the same measurand
•Ulab, Uref are the extended uncertainties of the respective measures

If the normalized error or index of compatibility En lies between -1 and 1, it is possible to state that the two measures are compatible and both are correct assessments of the measurand.



The graph shows a series of field measures made on 26 March 2011 by two temperature sensors.

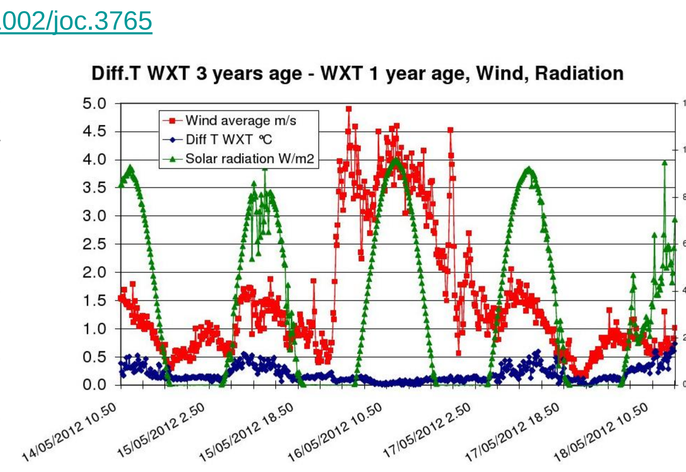
When the difference rises over 0,74 °C (the quadratic sum of the respective intervals of uncertainty) also the Normalized Error rises over the unit, pointing out the possible malfunction of one of two sensors.

The same criteria can be applied analyzing calibration data or comparing measures from different kind of sensors

COMPARATIVE ANALYSIS OF THE INFLUENCE OF SOLAR RADIATION SCREEN AGEING ON TEMPERATURE MEASUREMENTS*

*INTERNATIONAL JOURNAL OF CLIMATOLOGY http://onlinelibrary.wiley.com/doi/10.1002/joc.3765

Solar radiation screens play a key role in automatic weather stations (AWS) performances. In this work, screen ageing effects on temperature measurements are examined. Paired temperature observations, traceable to national standards and with a well-defined uncertainty budget, were performed employing two naturally ventilated weather stations equipped with identical sensors and different only for their working time. The differences, wider than the uncertainty amplitude, demonstrate a systematic effect. The temperature measured with the older screen is larger, and the maximum instantaneous difference was 0.76 °C . During night-time the two AWS's measure the same temperature (within the uncertainty amplitude). This behaviour, increasing with increasing solar radiation intensity and decreasing with increasing wind speed, is attributed to a radiative heating effect. The experimental results of a further comparison, between 0- and 1-year-old screens, confirm the same conclusion showing a negligible ageing effect, within the uncertainty amplitude.



MEASURAND DEFINITION UNCERTAINTY - REPRESENTATIVENESS

Urban areas represent, from the climatic point of view, a sort of "hot spot" due to the heat island effect. Thus we need a solid study base to position meteorological stations in cities. Thanks to the large number of stations in Milan we can make a sort of validation of Climate Network positioning criteria and general approach to the urban climate.

CN measuring target and task:
– Urban canopy layer (UCL) for (urban) energy applications, to more exactly measure the urban roughness sublayer (at building top height) characteristics.
CN siting criteria:
– Urban sites, building roofs, free of very local effects, fulfilling WMO/TD-No. 1250 2006 requirements, but in some cases logistics conditioned!
Verification:
– Through interpolation of nearby stations and comparison with measured data results for winter 2012-13

Conclusions: With few exceptions (likely in the real UCL because of atypical sites more isolated and at higher elevation over ground) the CN is able to reproduce measured data when the average ΔT, with small standard deviation, is comparable to measurement uncertainty (0.25°C).

Milano Station Name	Interpol. Radius [km]	Interpol. stations	Average $\Delta(T_{Interpol.} - T_{meas})$ [°C]	± 1σ [°C]	Remarks
Milano Centro	6	7	-0.24	0.24	Urban, residential
Milano Bicocca	6	6	0.05	0.15	"
Milano Sempione	5	5	-0.16	0.19	"
Milano Bovisa	6	7	0.01	0.21	"
Milano Politecnico	5	5	0.14	0.23	"
Milano Bocconi	6	5	-0.20	0.18	"
Milano Sud	6	5	0.42	0.31	Outskirts
Milano S.Siro (stadium)	7	7	0.61	0.30	atypical site! 62 m over flat ground

CALIBRATION UNCERTAINTIES

METROLOGICAL TRACEABILITY

Traceability is the property of a measurement result, where the result can be related to a reference through a documented unbroken chain of calibrations, each contributing to the measurement uncertainty.

Our traceability chain starts from a Secondary Reference Platinum Resistance Thermometer (Fluke 5616) and has been calibrated, along with his multimeter (Fluke Hydra 2620A), at the National Institute of Metrology (INRIM) in Turin, Italy. The first line standard and the multimeter are combined in a single equipment: they have been calibrated together in order to maintain a single measurement chain.

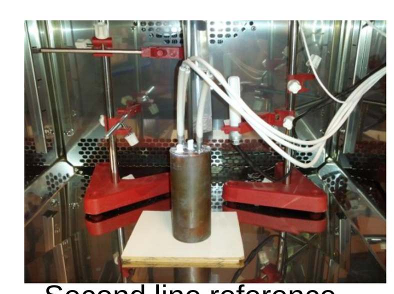
INRiM ISTITUTO NAZIONALE DI RICERCA METROLOGICA

Primary standard

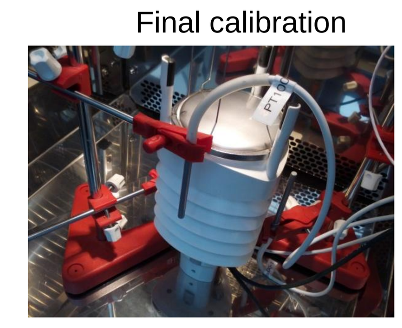
Transfer standard

Final calibration

First line reference standard U@ 20 ° C 0,03 ° C



Second line reference standard U@ 20 ° C 0,04 ° C



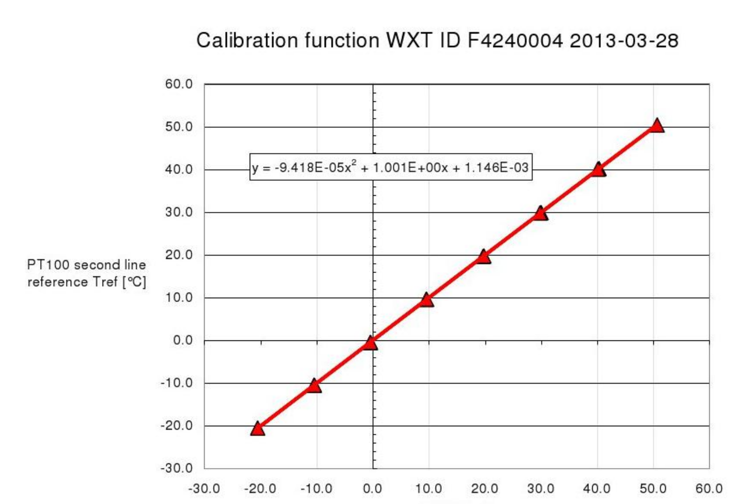
Weather trasmitter Vaisala WXT520 U@ 20 ° C 0,14 ° C

In our climatic chamber the first line reference standard is used to calibrate three Resistance Thermometers (PT 100 ohm in Class A according to IEC 751) and they are also connected to the multimeter Hydra 2620. The process consists of a sequence of temperature points. The calibration starts at 30°C then, by steps of 10 °C each, climbs up to 50°, drops down to -20°C, climbs again to 20°C.

By doing so, the process involves the sensor hysteresis and provides data used to estimate uncertainties.

The first line and second line standards are included in a comparison copper block in order to ensure temperature homogeneity. Finally we calibrate all our Vaisala WXT520 weather stations in the same climatic chamber, comparing them to the secondary reference standard thermometer.

Calibration program panel



Calibration function graph

CALIBRATION UNCERTAINTY ESTIMATION

The uncertainty estimation is a fundamental part of calibration process.

Every calibration increases uncertainty and we get, at the end of the traceability chain, the final calibration uncertainty.

Normally we can find uncertainty as a list of values. But we need uncertainty to be valued for every single value measured.

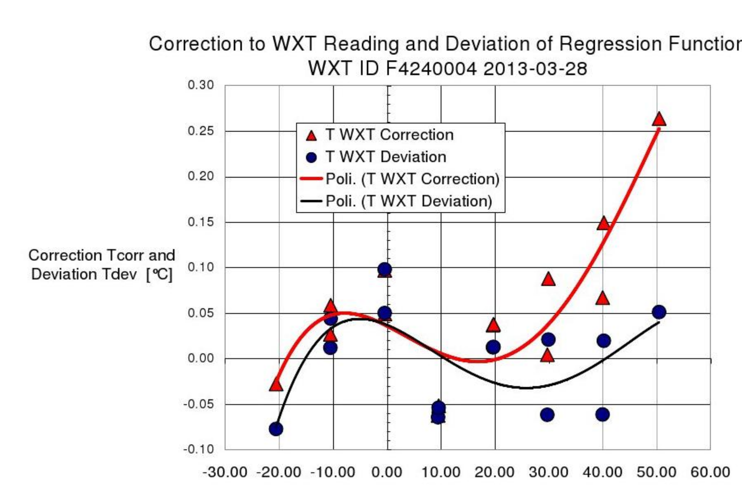
This is the reason why we express uncertainty as a function, in this way we can associate for every single value measured its own uncertainty.

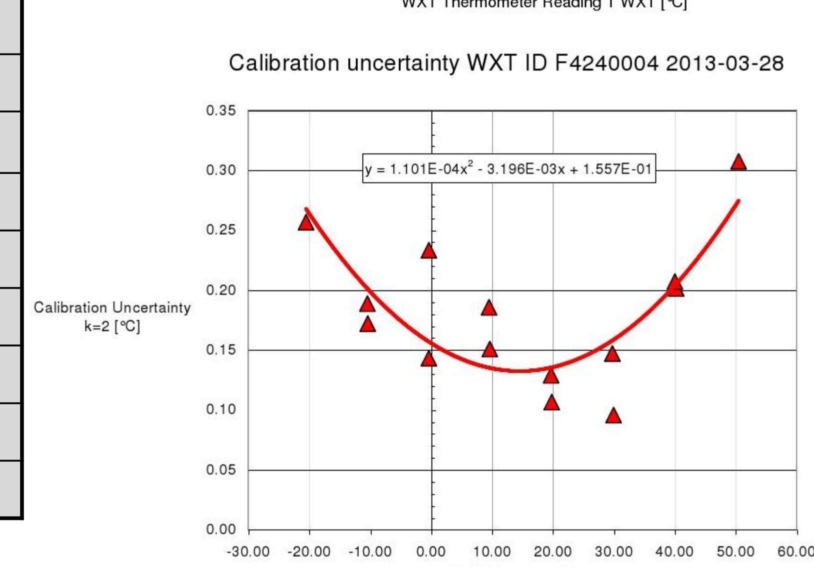
This is a good starting point but we are doing comparative tests on field in order to estimate the variability due to influence parameters such as: wind, humidity, solar radiation, shelters ageing and so on .

With these additional data we are going to give our clients an uncertainty of measure in real conditions.

We know that a few decimal points of temperature's measurements move million euros, it is important, therefore, to know the uncertainty level of data and their confidence interval.

WXT Corrected	WXT Correction	WXT regression deviation	WXT Uncertainty U k=2
29.93	0.09	0.02	0.10
40.21	0.15	0.02	0.20
50.46	0.26	0.05	0.31
39.99	0.07	-0.06	0.21
29.73	0.00	-0.06	0.15
19.66	0.04	0.01	0.13
9.50	-0.06	-0.06	0.19
-0.40	0.10	0.10	0.23
-10.47	0.03	0.01	0.19
-20.55	-0.03	-0.08	0.26
-10.41	0.06	0.04	0.17
-0.40	0.05	0.05	0.14
9.60	-0.05	-0.05	0.15
19.78	0.04	0.01	0.11





Calibration uncertainty function graph and calibration data table