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AUTOMATIC WEATHER STATION TRACEABILITY

AN EXAMPLE OF EMERGING NEED AND CALIBRATION PROCEDURE

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METEOMET Metrology for Meteorology

MMC Slovenija 2014 METROLOGY FOR METEOROLOGY AND CLIMATE

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not ony weather forecast

Climate Consulting is a private company founded in 2010 on the tradition of Osservatorio Meteorologico Milano Duomo and Osservatorio Astronomico Milano Brera, measuring temperature in Milan since 1763.

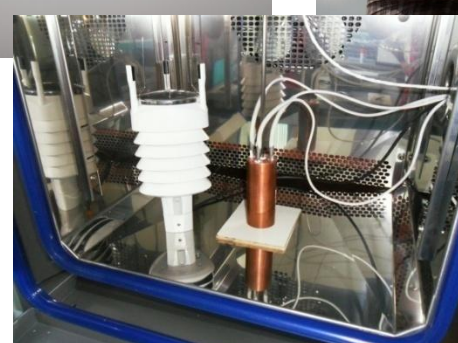
The core business of the company is to provide **high quality and certified meteorological data measured in urban areas** to support:

- Energy industries
- Building and Transport sectors
- Financial and Insurance companies
- all the activities where meteorological data imply economical value

The economical impact of minimal deviations on measures could be significant. This is the reason why a NEW APPROACH has to be developed regarding meteorological measures, especially in urban areas.

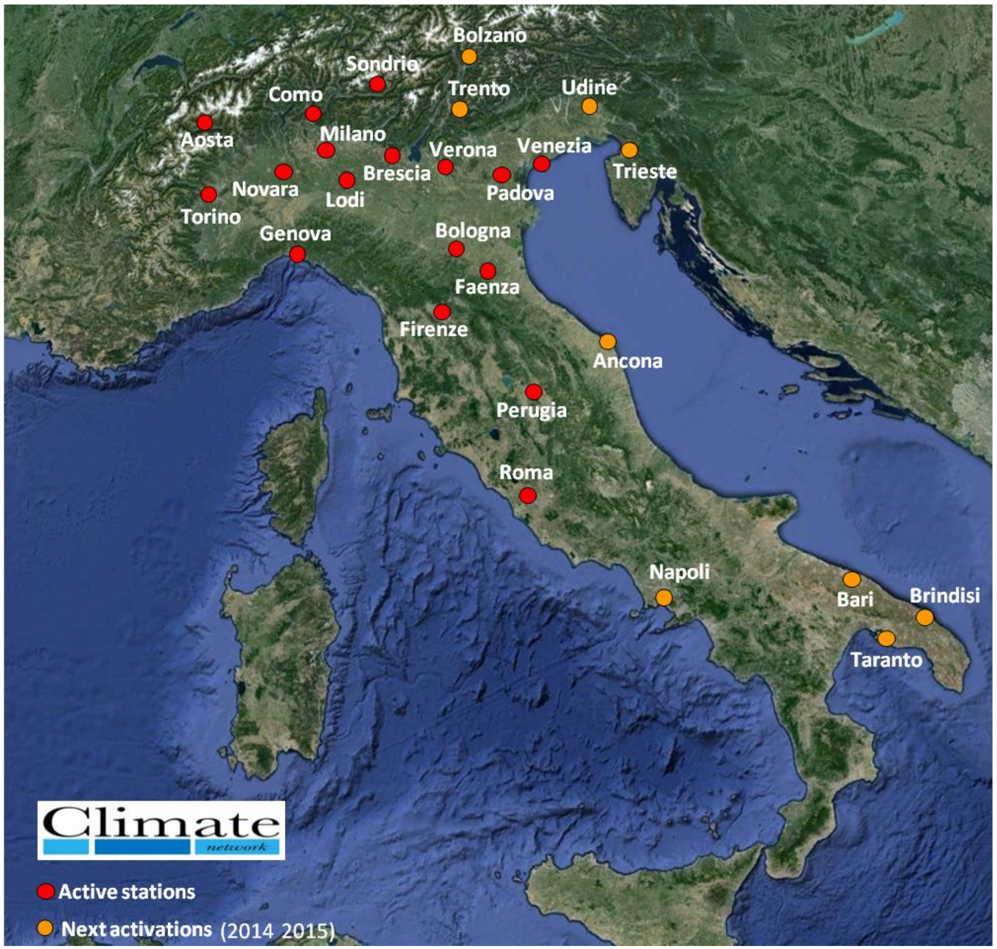







New approach: Climate Network®

- National coverage: Stations located in the main Italian cities in URBAN areas, such as MILANO, TORINO, VERONA, PADOVA, VENEZIA, BOLOGNA, FIRENZE, ROMA ...
- Nowadays (Sep 2014): **38** fixed **stations** active on the national territory
- Within 2017: **80** fixed meteorological stations and some mobile stations



- **Variables measured**

  (resolution 10 min):

- **Temperature** (average, min, max)
- **Relative Humidity** (average, min, max)
- **Atmospheric pressure** (average, min, max)
- **Rain** (amount, intensity, duration)
- **Hail** (amount, intensity, duration)
- **Wind – speed, direction, gust** (ultrasonic biaxial sensor)
- **Solar radiation - global and diffuse** (not in all stations)

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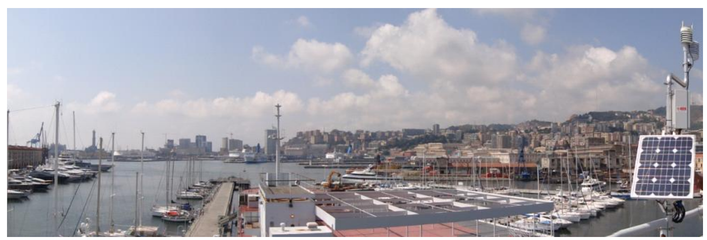
Climate Network® - traceability

TRACEABILITY was, from the beginning, the most important REQUIREMENT for the quality of measures of Climate Network.
The need of measure reference standards and operative procedures led us to collaborate with INRiM in MeteoMet Project.

One of the main results of this collaboration has been the Internal Calibration Laboratory:
we have a well documented traceability chain and we can manage periodical calibration in complete autonomy.



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Climate Network® - key strenghts

HIGH QUALITY and **CONSISTENCY** of WEATHER DATA,
using HIGH **METROLOGICAL STANDARDS**.

HOMOGENEITY OF THE STATIONS:

- Same criteria to locate all stations: terraces or top roofs in city centres (fulfilling WMO/TD-No. 1250 2006 requirements: correct representation of URBAN CANOPY LAYER)
- Same type of weather stations (VAISALA WXT520)
- Same calibration method for all temperature sensors

INTERNAL CALIBRATION LABORATORY:

Using referential instruments certified by the National Institute of Metrological Research of Torino, we calibrate temperature sensors:

CALIBRATION UNCERTAINTIES are:

$U_T < 0.2$ °C (at 20°C)

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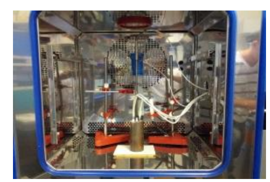

First line reference standard:
Secondary Reference Platinum Resistance Thermomether calibrated at INRIM, National Istitute of Metrology in TORINO

Second Line reference standard:
3 Resistance Thermometers (PT100 OHM)

Our sensor:
Weather trasmitter Vaisala WXT520

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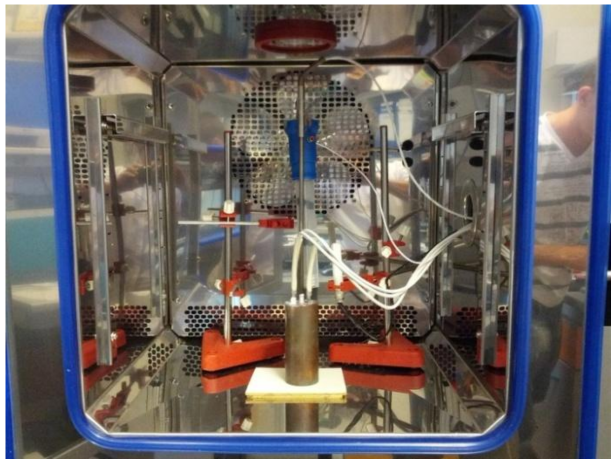
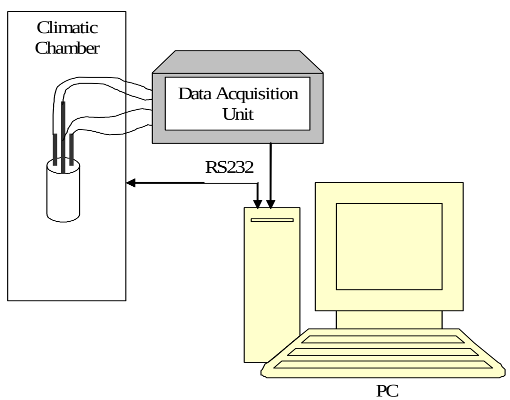
CALIBRATION: 1° STEP
Transfer standard

FIRST LINE REFERENCE STANDARD > CALIBRATION / TRANSFER STANDARD > SECOND LINE STANDARD

It is a Secondary Reference Platinum Resistance Thermometer (Fluke 5616) calibrated togheter with his multimeter (Fluke Hydra 2620A), at the National Institute of Metrology (INRIM) in Turin, Italy.
The first line standard and the multimeter have to be considered a single equipment: they have been calibrated together in order to maintain a single measurement chain.





Layout for calibration of second line standard

Both the first line reference standard and the second line standards are put into a copper block to ensure homogeneity of temperature during calibration.

The system is connected to a PC via serial lines to acquire first and the second line sensors data (in ohm) and to set the climate chamber calibration points using a Labview © automation program.

The second line standard are three Resistance Thermometers (PT 100 ohm in Class A according to IEC 751) and they are also connected to the multimeter Hydra 2620 (Data Acquisition Unit).

The regression function, used to describe the calibration curve of the second line standard compared to the first one, is a third degree polynomial; the maximum deviation obtained is 0.04°C.

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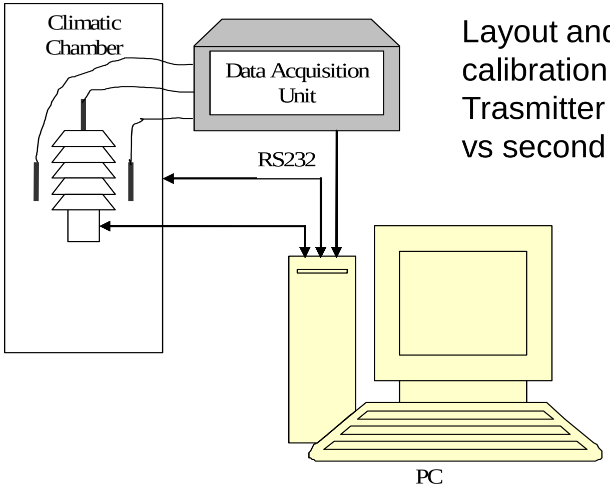
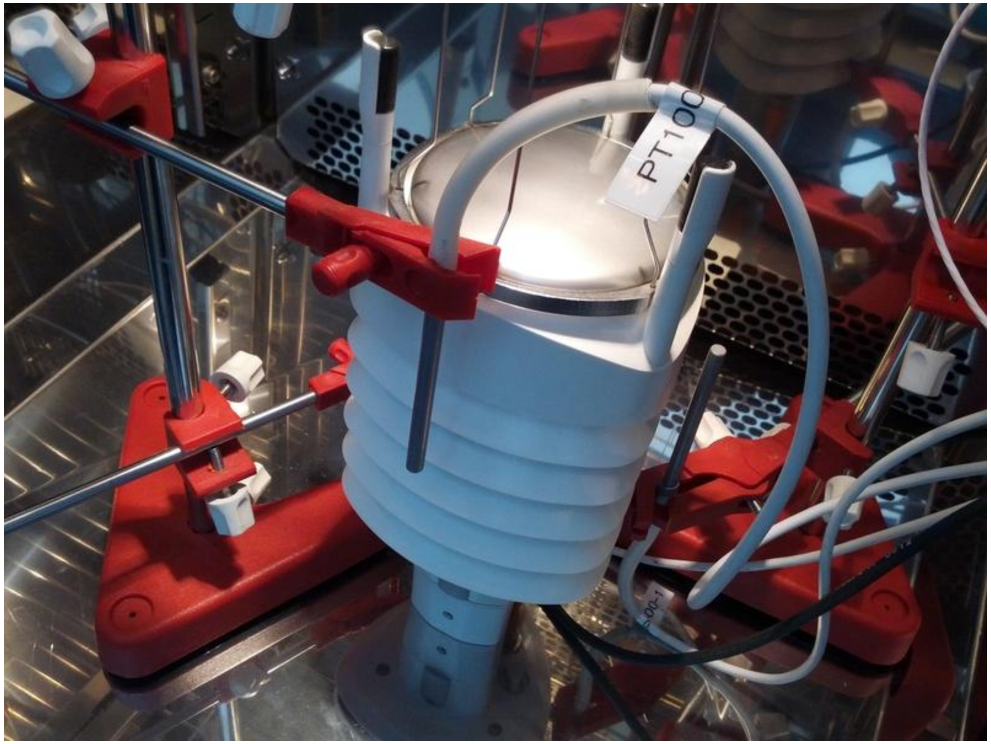
CALIBRATION: 2° STEP
Calibration of the Vaisala WXT520 weather transmitter



Layout and positioning for calibration of the Weather Trasmitter WXT520 vs second line standard



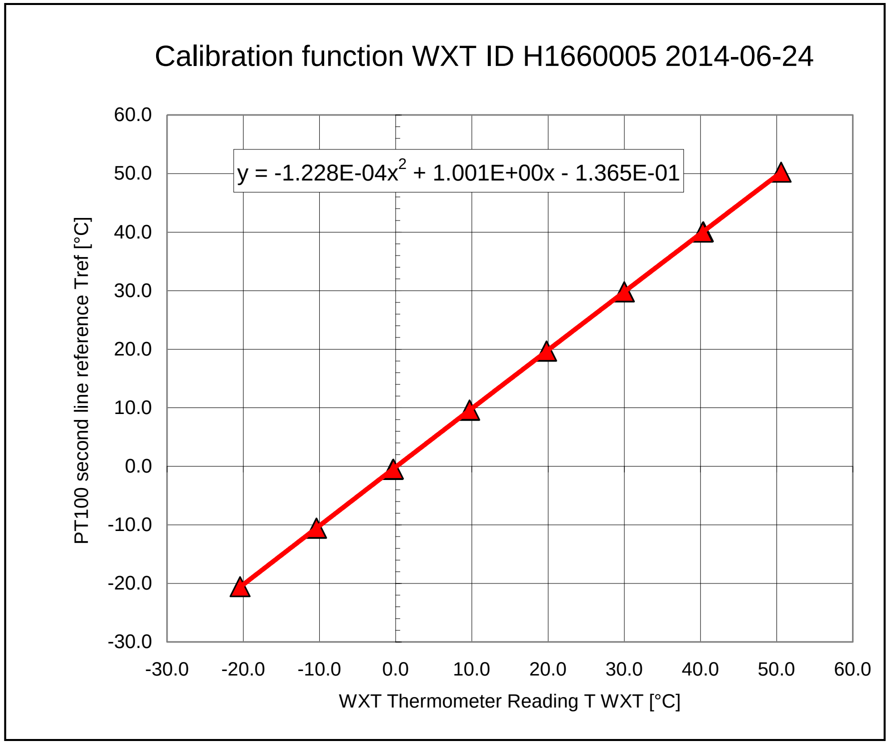
Calibration takes place in a ventilated climatic chamber. The process consists of a sequence of temperature points that, in steps of 10°C:

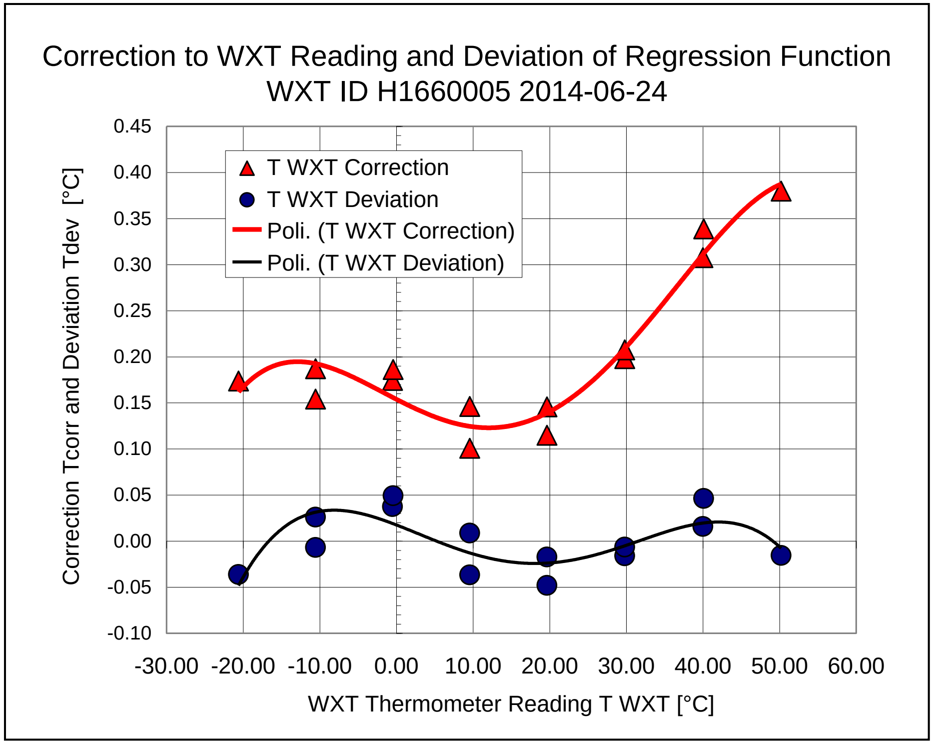
- starts at 30°C
- climbs up to 50°
- drops to -20°C
- climbs again up to 20°C

By doing so, the process involves the sensor hysteresis and provides data useful to estimate uncertainties.
WXT520 station is positioned within the climate chamber and the second line standards are placed around the WXT520, parallel to the internal PTU module.
The final measured value is transmitted to the computer via serial line, thus avoiding errors caused by A/D signal conversion.
The reference temperature is the average of correct measurements of the three second line standards.
The calibration sequence is identical to that used in the second line standards calibration.

CALIBRATION: Result

Calibration of the Vaisala WXT520 weather transmitter





For the calibration function or correction function we chose a second-degree polynomial regression function: so we have contained the gap between the corrected value measured by Vaisala WXT 520 and the reference value within 0.1°C in absolute value.

The absolute difference between WXT520 data and second line standard values is normally comprised within by the accuracy specifications declared by Vaisala, ranging from ± 0.2°C (in correspondence with -50°C) to ± 0.7°C (in correspondence with +60°C).

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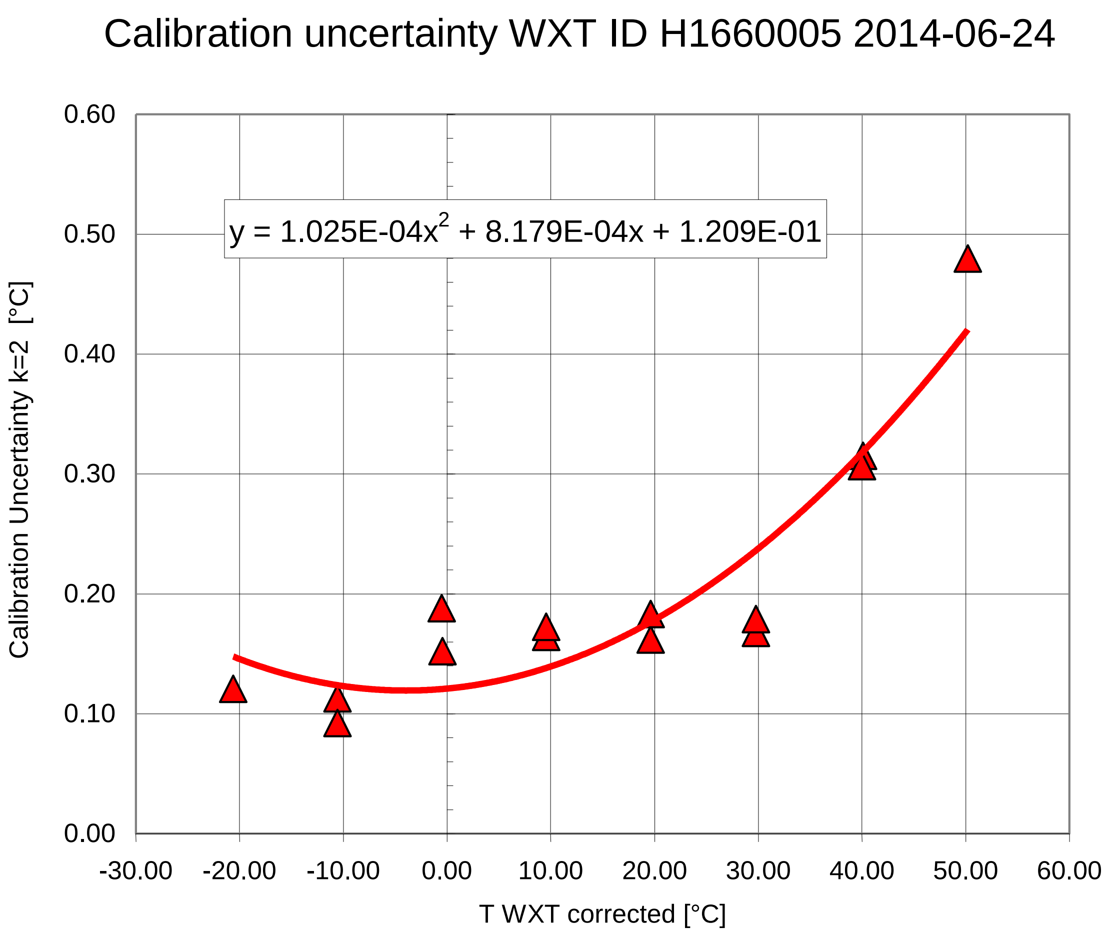
CALIBRATION: Uncertainty estimation



The uncertainty is calculated for each point of calibration with the square sum of uncertainty components:

1. Uncertainty of reference standard thermometer;
2. Resolution of WXT520;
3. Standard deviation of reference samples;
4. Deviation of regression function;
5. Standard deviation of three second line standard measures;
6. Standard deviation of WXT samples

Points 3 and 6 refer to the stability over time of temperature measures when the climatic chamber has reached a stable temperature control point.
Point 4 refers to the linearity of sensors and the histeresys due to alternate rising and falling of calibration points.
Point 5 is concerning the inhomogeneity on temperature distribution in the space near the sensor under calibration.

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ON FIELD MEASUREMENTS UNCERTAINTY

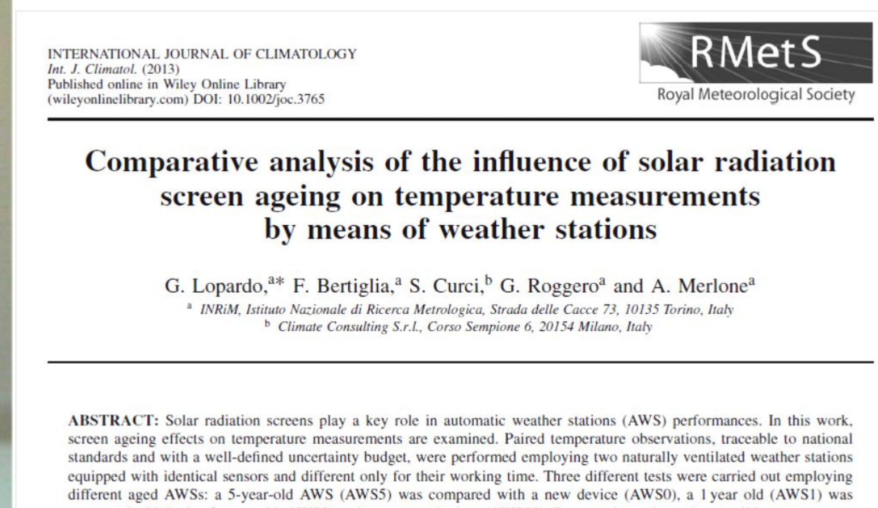
The response of a temperature sensor can be quite different weather it is exposed OUTDOOR or in a closed and controlled enviroment such as a climatic chamber.
Outdoor we have the influence of wind, rain, humidity, air pollution and especially solar radiation.

At present the best way we found to estimate the uncertainties of our sensors in real conditions is the comparison of measurements got by placing two identical sensors in the same test site on field.
Our temperature test site is located on the terrace of Climate Consulting headquarters.
We can measure all the parameters including solar radiation by means of direct serial data connection with the laboratory PC's, then we use the Normalized Error Test to evaluate the influence of the other meteorological parameters on measurements.

COMPARATIVE TESTS: Effect of screen ageing

Comparative analysis of the influence of solar radiation screen ageing on temperature measurements by means of weather stations[1]

This work was the first result of Meteomet collaboration with **INRiM**. We were interested in evaluating the influence of screen ageing on our oldest station and, thanks to the evidence found, we decided to periodically paint our stations.



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RMetS
Royal Meteorological Society

Comparative analysis of the influence of solar radiation screen ageing on temperature measurements by means of weather stations

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ABSTRACT: 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. Three different tests were carried out employing different aged AWSs: a 5-year-old AWS (AWS5) was compared with a new device (AWS0), a 1 year old (AWS1) was compared with both a 3 years old (AWS3) and a new one devices (AWS00). Due to solar and weather conditions exposure a

[1]G. Lopardo, F. Bertiglia, S. Curci, G. Roggero, A. Merlone "Comparative analysis of the influence of solar radiation screen ageing on temperature measurements by means of weather stations", International Journal of Climatology, 2013, DOI: 10.1002/joc.3765

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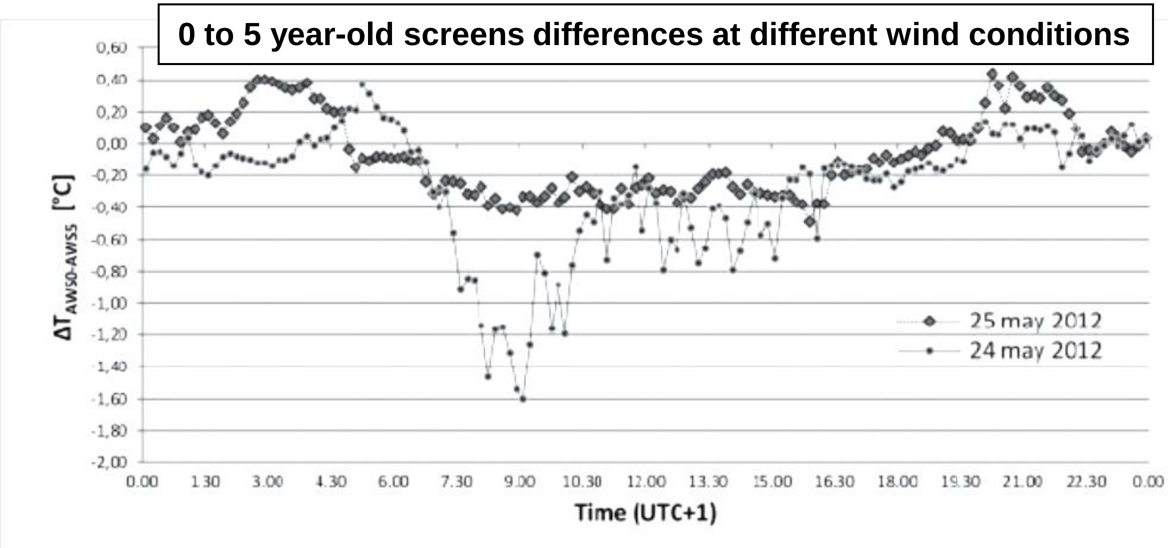
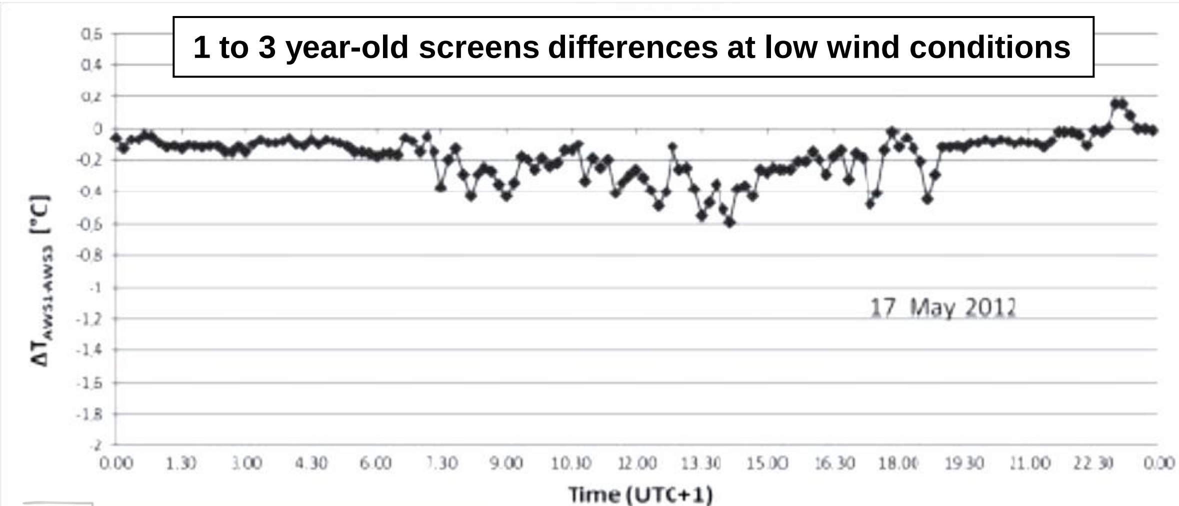
COMPARATIVE TESTS: Effect of screen ageing





During the comparison of 0 to 5 and of 1 to 3 year-old screens, significant temperature differences were recorded at different times of the day. The differences, wider than the uncertainty amplitude, demonstrate a systematic effect.

The temperature measured with the older screen is higher, and the maximum instantaneous difference was 1.63 °C (for 0 to 5 years comparison) in daytime hours. During night-time the two AWS's measure the same temperature (within the uncertainty amplitude).

This behaviour, increasing with the increasing of solar radiation intensity and decreasing with the increasing of wind speed, is attributed to a radiative heating effect.

The screen ageing has compromised the shield effectiveness introducing a significant change in temperature evaluation. 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.

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COMPARATIVE TESTS USING NORMALIZED ERROR

Normalized Error Test

By the Normalized Error Test we can identify abnormal differences between two indipendent measurement of a same measurand.

The **Normalized Error En** is defined as:

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

where
X_{lab}, X_{ref} are the independent measures of the <u>same measurand</u>
U_{lab}, U_{ref} 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 <u>**two measures are compatible and both are correct assessments of the measurand**</u>.

- ✓ We can also use the Normalized Error test to compare two different calibrations on the same sensor
- ✓ We can evaluate the minimum variability between two identical calibrated sensors placed in the same site.
- ✓ We can evaluate the sensor response in real conditions, investigating correlations of EN with other meteorological parameters (wind, rain, humidity, solar radiation).

In the next slides we'll show some application of En in outdoor tests comparison.

COMPARATIVE TESTS: Redundant sensors

Each Climate Network stations has a redundant thermometric sensor to ensure a constant control on measures. When the difference ΔT raises over a threshold limit value the system sends a warning signal and we make appropriate corrective actions on the sensors including substitution of main sensor Vaisala WXT520 with another one calibrated.

FIG. 1 Before

Absolute Differences and Normalized Error on 26 march 2011 doubled temperature measures in Gaggiano (MI)

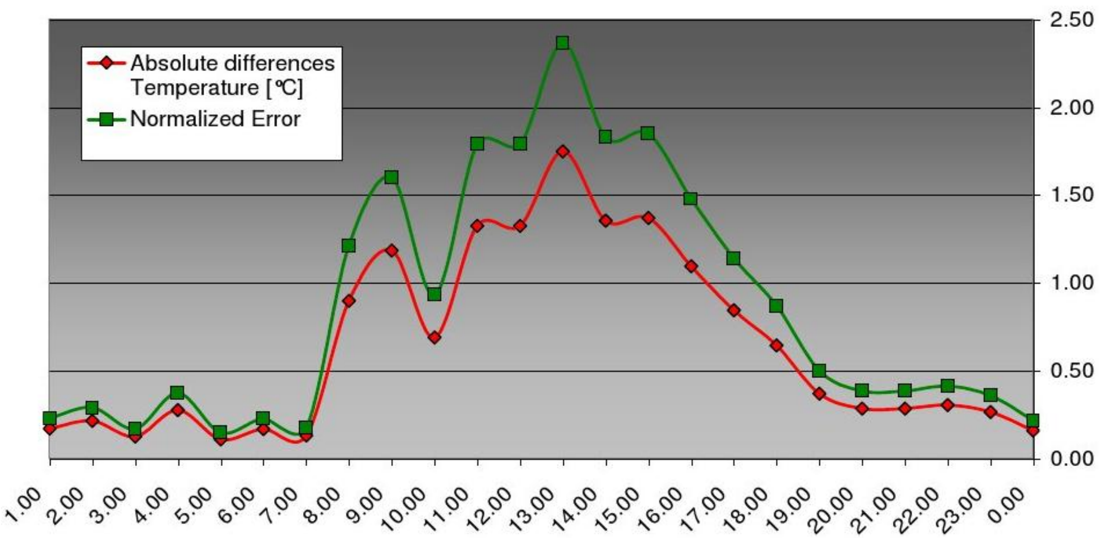

FIG. 2 After

The graph shows a series of field measures made on 26 April 2011 by two temperature sensors, T_{WXT} and $T_{Redundant}$, both characterized by an esteemed uncertainty of 0,2°C. You can observe that during daytime the Normalized Error reaches values higher than the limit. The Normalized Error points out that the redundant sensor (red circle) was near a radiant surface (FIG. 1). To solve the problem we moved the redundant sensor near the main sensor at the top of the pole and shifted the solar panel away from the pole (FIG. 2).

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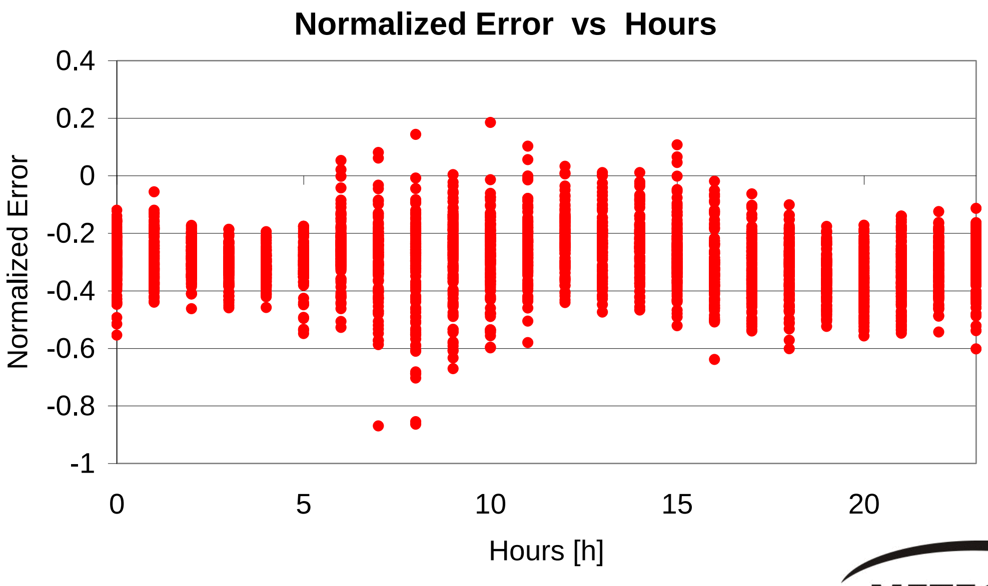
COMPARATIVE TESTS: Redundant sensors

Comparison of a ROTRONIC HYGROCLIP sensor and a CAMPBELL PT100 sensor place in the same shelter in our station of Somma Lombardo

Thanks to information collected by comparison tests on redundant thermometers measures, we designed a reduced version (“Light”) of Climate Nertwork standard station.

The Light station is equipped with a Rotronic Hygroclip Sensor, (T, UR) and a Campbell PT100 sensor (T).

Both sensors are placed in the same shelter and oriented from top to bottom, thus avoiding the self heating effect of electronic components of Rotronic sensor.



The Normalized Error didn’t exceed the threshold limit value but we can note a wide range of values during the daytime. Even if both sensors are placed into the same screen the effect of solar radiation can be clearly noted.

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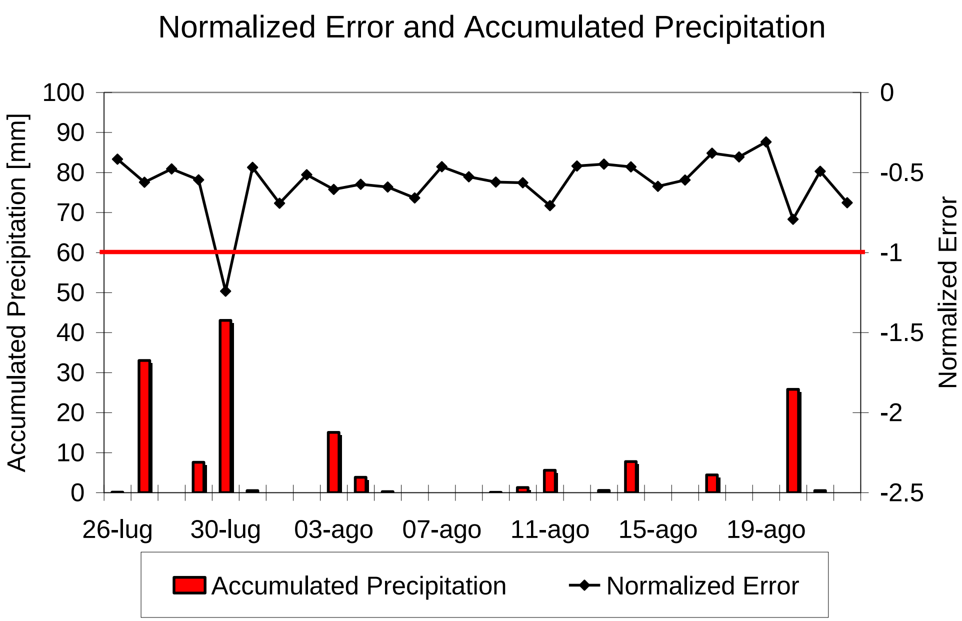
COMPARATIVE TESTS:
Two new Vaisala WXT520 in our test site



We can expect that two new identical sensors placed in the same position and calibrated using the same traceability chain should give quite the same measures.
Investigating the differences can give useful information on the behaviour of sensors.

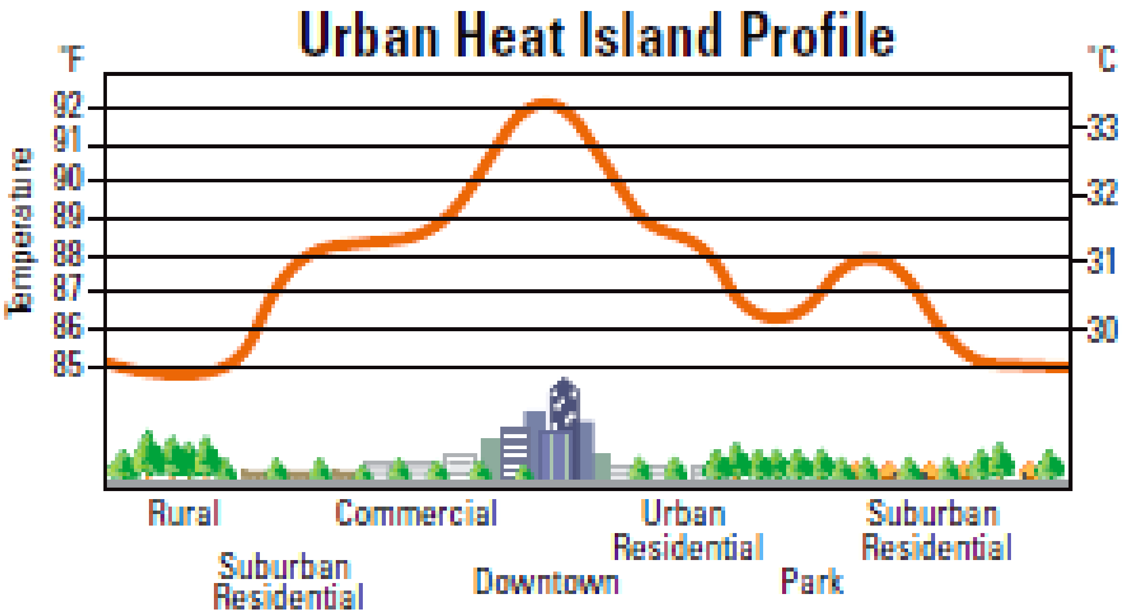
Thanks to availability of new WXT520, we did a comparison during the last two months.
We found a correlation between Normalized Error and episodes of rain. The correlation among the Normalized Error and others meteorological parameters wasn't so clear but the dynamics of solar radiation and the differences on response time could play a significant role. We have to investigate further.

MEASURAND DEFINITION UNCERTAINTY: Representativeness

What does **"city air temperature"** means ? Where should I measure to get representative city temperature?

An incomplete definition of the measurand "city air temperature" introduces a component into the uncertainty that may or may not be significant relative to the accuracy required.
From a climatic point of view, urban areas represent a very inhomogeneous environment. We have radiation effect of pavements and buildings, heat island profile. Thus we need a deep knowledge of the urban environment to choose a site where representative city air temperature can be measured.

We can improve site representativeness and measure uncertainty together, **defining** the **measurand** and a new class of meteorological stations not included into WMO classification.
The WMO classification establishes a scale of representativeness finalized to meteorological and climatological use of data. It doesn't include a **specific class for the urban meteorological stations** because it doesn't take into account the use of data for balance energy assessment.



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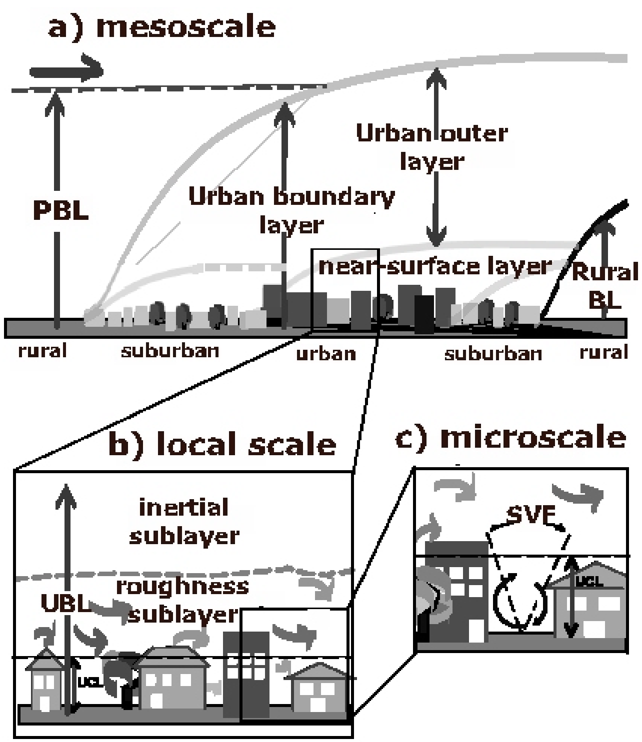
MEASUREMENTS IN URBAN ENVIRONMENT: Definition of measurand

Climate Network® target and task:

– to measure the Urban Canopy Layer (UCL) for "urban" energy applications (measurements at building top heigh).

Climate Network® siting criteria:

– Urban sites, building roofs, free of very local effects, fulfilling WMO/TD-No. 1250 2006 requirements *(… but in some cases logistics conditioned !)*



(from Rotach et al. 2004)

Climate Network check by interpolation and comparison with measurements

Verification of siting criteria through interpolation of nearby stations and comparison with measured data results for winter 2012-13

RESULTS:

ClimateNetwork is able to reproduce measured temperature with errors less than 0,2°C downtown Milano.

We register few exceptions consisting in atypical sites in the UCL, very isolated or located at higher elevation over ground.

Station Nr and Name	Interpol. Radius [km]	Inter pol. statio ns	Mean difference Interp.-Meas. [°]	Variance [°C]	Remarks
01-Univ. Stat.	6	7	-0,10	**0,12**	Urban, residential
02-Bicocca	6	6	+0,01	**0,02**	"
03-Sempione	5	5	-0,24	**0,05**	"
04-Bovisa	6	7	+0,05	**0,06**	"
06-Politecnico	5	5	+0,13	**0,10**	"
07-Bocconi	6	5	-0,26	**0,04**	"
08-Milano Sud	6	5	+0,72	**0,11**	atypical site ! Industrial outskirts
10-S. Siro	7	7	+0,68	**0,21**	atypical site ! 62m over flat ground

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ClimateNetwork check by interpolation and comparison with measurements

Overall check of the network capabilities

Using 2012-2013 daily mean values by ClimateNetwork (CN) stations in Milan

Variables: Tn, TM, Tx, RH, R, W

Interpolation: at each CN site, excluding the station to be interpolated

Method: weighted mean with weights as squared distance up to a maximum radius of 30 km *and with a minimum (3) and maximum (7) of interpolating stations by recursive range increments of 3 km each*

$$\widetilde{X_n} = \sum_{1}^{N-1} W_i \cdot X_i$$

$$W_i = \frac{(R - d_i)^2}{\sum_1^{N-1}(R - d_i)^2} \qquad d_i < R$$

$$W_i = 0 \qquad d_i \geq R$$

where: $n \neq i$ (exclusion of the station to be interpolated) and N the total number of stations available

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Conclusions

- We have been working to estimate **OUTDOOR TEMPERATURE** measurement **UNCERTAINTY**

- We would like to estimate measurements **UNCERTAINTY** of **other meteorological parameters** (relative humidity: work in progress)

- We strongly hope that WMO will **include a specific class referred to urban environment in the WMO classification of meteorological stations**

Thank you

References

INITIAL GUIDANCE TO OBTAIN REPRESENTATIVE METEOROLOGICAL OBSERVATIONS AT URBAN SITES

Tim R. Oke (Canada) https://www.wmo.int/pages/prog/www/IMOP/publications/IOM-81/IOM-81-UrbanMetObs.pdf

SITING CLASSIFICATIONSFOR SURFACE OBSERVING STATIONS ON LAND

https://www.wmo.int/pages/prog/www/OSY/Meetings/CBS-GCOS-LeadCentres_Hamburg2011/Annex_1_Siting.pdf

G. Lopardo, F. Bertiglia, S. Curci, G. Roggero, A. Merlone "Comparative analysis of the influence of solar radiation screen ageing on temperature measurements by means of weather stations", International Journal of Climatology, 2013, DOI: 10.1002/joc.3765

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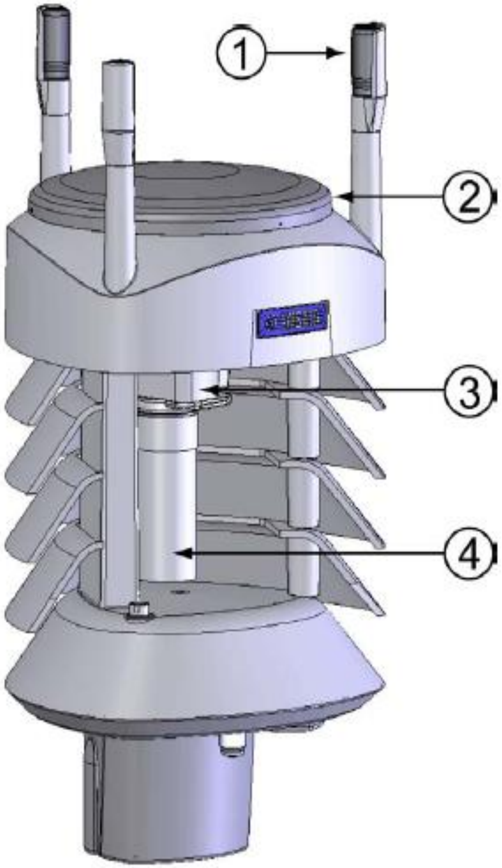
TECHNICAL SOLUTIONS, STANDARDIZATION



SENSOR TYPE:

advanced technology sensors (Vaisala WXT520), without mobile devices, have been selected to keep maintenance easier and performance more reliable

1 = Wind transducers (3 pcs)
2 = Precipitation sensor
3 = Pressure sensor inside the PTU module
4 = Humidity and temperature sensors inide the PTU module

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CALIBRATION

INRiM

+

Climate
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Manufacturter
Instr. Provider
Accredited Lab.

WMO SITING CLASSIFICATIONS surface observing stations on land

Class 1

- Flat, horizontal land, surrounded by an open space, slope less than 1/3 (19°);
- Ground covered with natural and low vegetation (< 10 cm) representative of the region;
- Measurement point situated:
  - at more than 100 m from heat sources or reflective surfaces (buildings, concrete surfaces, car parks, etc.)
  - at more than 100 m from an expanse of water (unless significant of the region)
  - away from all projected shade when the Sun is higher than 5°.

A source of heat (or expanse of water) is considered to have an impact if it occupies more than 10% of the surface within a circular area of 100 m surrounding the screen, makes up 5% of an annulus of 10m–30m, or covers 1% of a 10 m circle.