FONDAZIONE OMD

The AWS based operational urban network in Milano: achievements and open questions.

Frustaci Giuseppe, *Curci Savino, Pilati Samantha, Lavecchia Cristina, Paganelli Chiara*

Fondazione Osservatorio Meteorologico Milano Duomo (FOMD) - Milano (I)

WORLD METEOROLOGICAL ORGANIZATION

WEATHER CLIMATE WATER

O1-8

INTERNATIONAL CONFERENCE ON AUTOMATIC WEATHER STATIONS

ICAWS-2017

Outline

- **AWS Urban Climate Network®**
- **Technical characteristics**
- **“Metrological “ criteria and Operational procedures**
- **Urban measure uncertainty estimates for Temperature and Relative Humidity**
- **Conclusions and further developments**

The Italian nationwide operational urban Climate Network®

- Project and set up by Climate Consulting Srl since 2011
  for **urban energy and other applications** at national level

- Now owned and managed by:
  Fondazione Osservatorio Meteorologico Milano Duomo (**OMD**)

- **Unique operational urban** network in Italy
  with **homogeneous** sensors and procedures

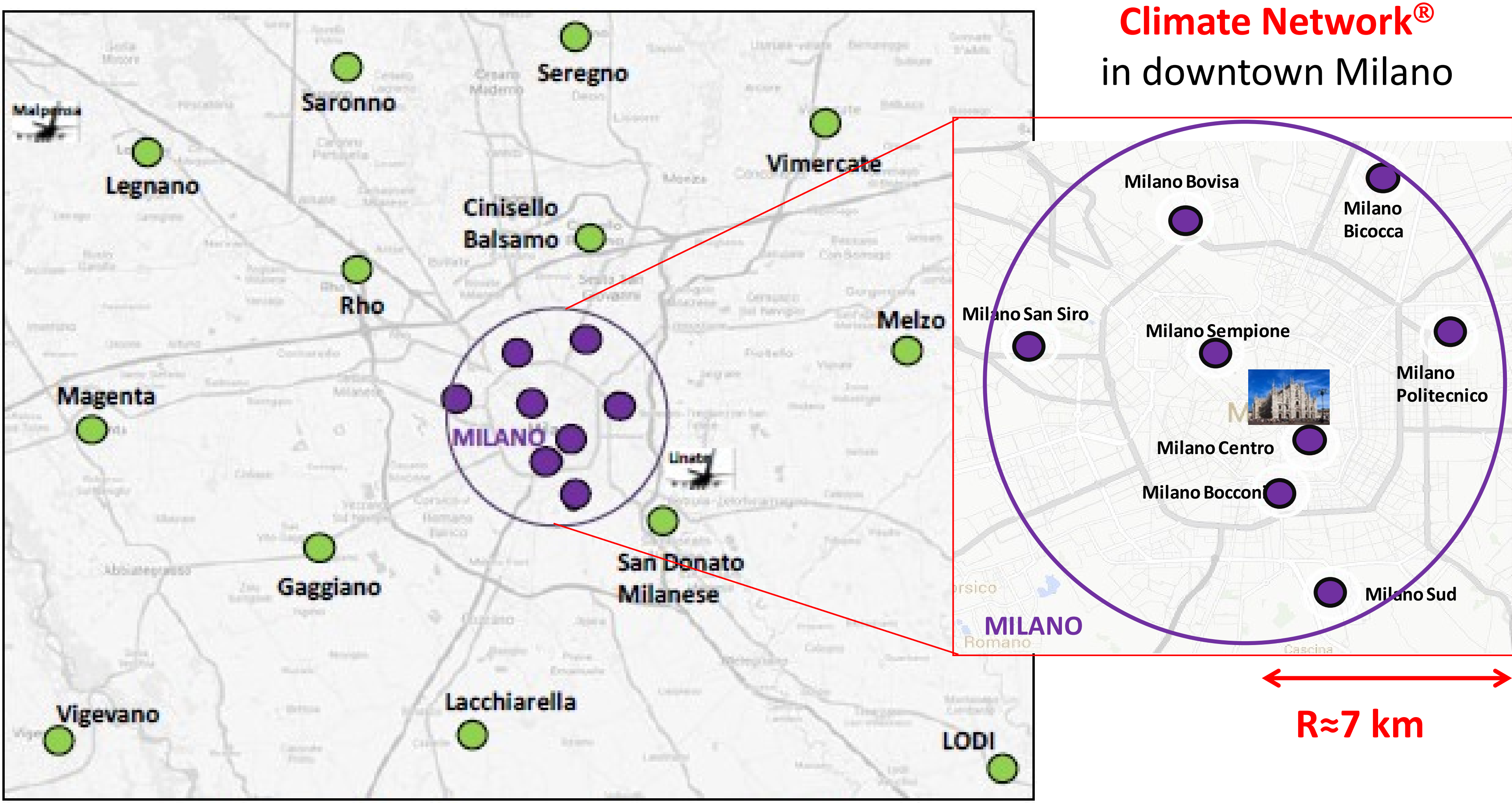
- Project and operations based on strict "**metrological" criteria**
  and **documented metadata**

Climate Network® national coverage

Italy: **50** CN AWSs

- **8** in Milano
- **2** in Firenze
- **2** in Roma

Climate Network®
in and around Milano

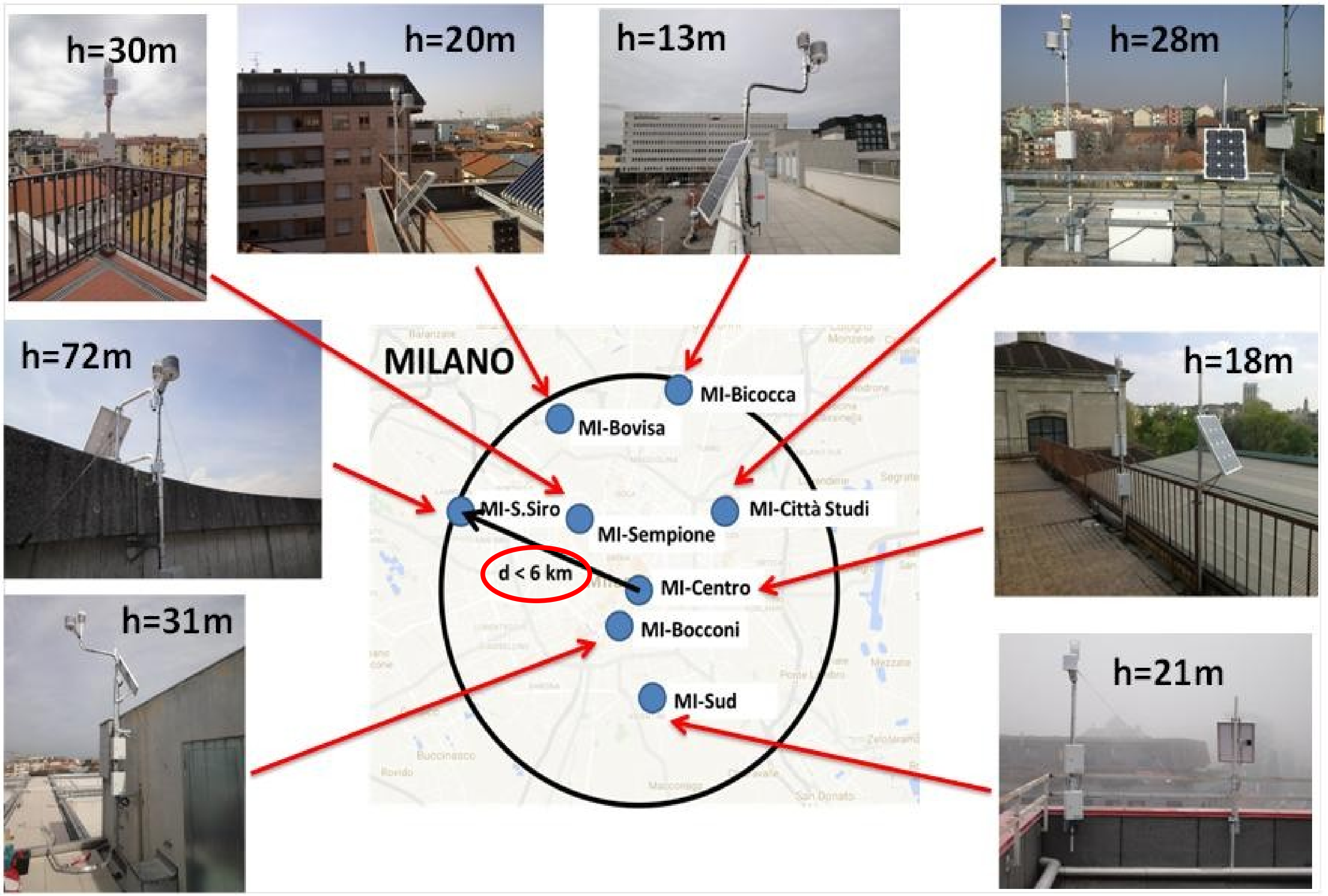


Climate Network®
in downtown Milano

R≈7 km

Climate Network® in the larger Milano metropolitan area

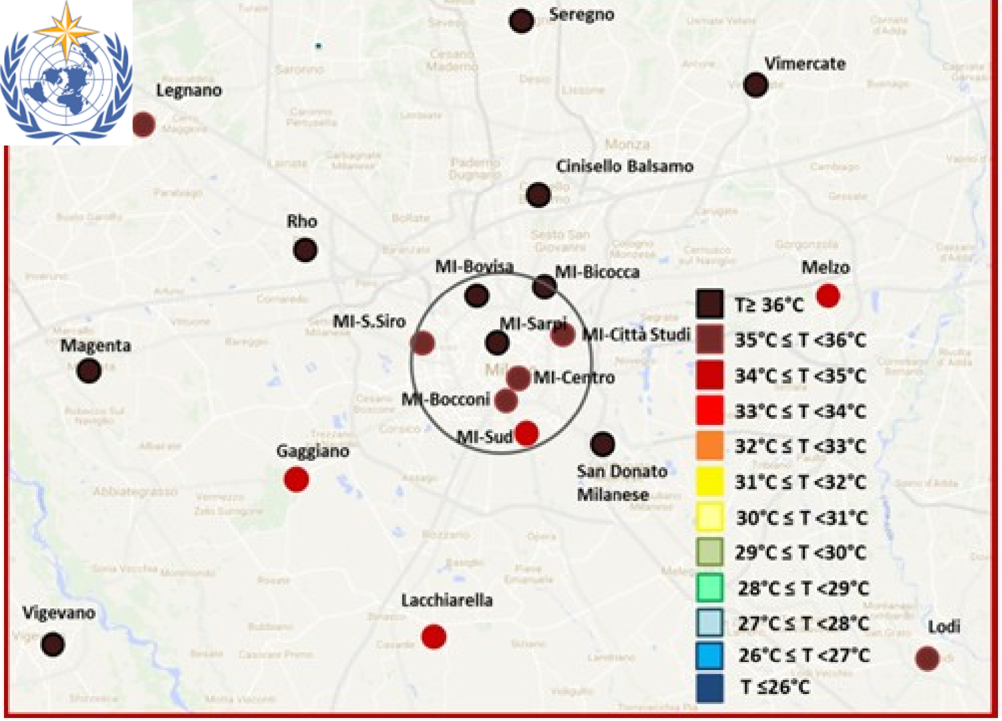
Sitings of the 8 CN AWSs in Milano downtown

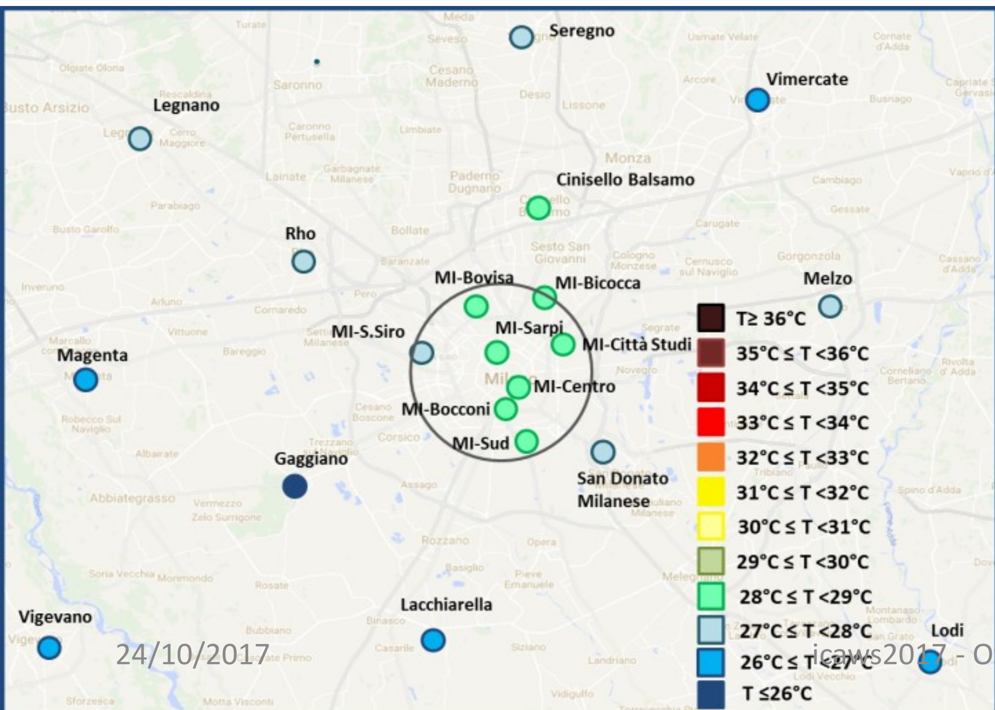


Pictures show details of the different **station sitings** and **sensor exposures**.

Height over <u>local ground</u> (h) is also indicated.

Urban Heat Island (UHI) as observed by CN





- **03 August 2017, 17:00-18:00**
- **04 August 2017, 02:00-03:00**

Temperature differences among CN stations downtown Milano and in the neighbouring small towns:

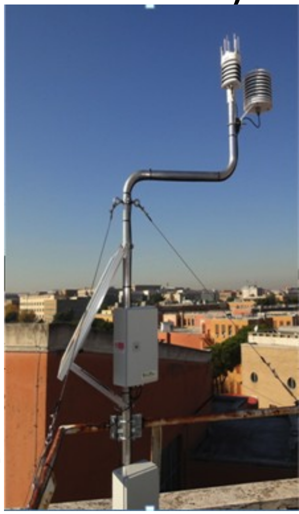
– larger in the night

– with an evident meridional gradient

Technical characteristics

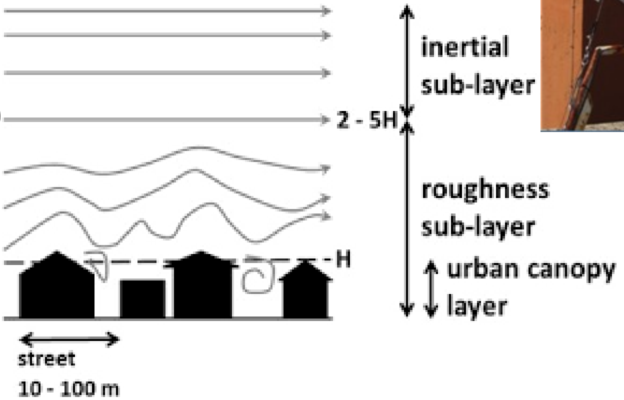
Key strengths of Climate Network® are:

- **same** type of weather stations with last generation sensors (VAISALA WXT520)
- **same** calibration method and standards for all sensors
- **same** control and assurance procedures
- maintenance and management according to **UNI EN ISO 9001**
- **traceable** measurements
- daily **gross error check** and final **data validation** by meteorologists



ClimateNetwork® target and task:

- to measure the **Urban Canopy Layer** (UCL)
  for "urban" energy applications
  (measurements at building top height)



ClimateNetwork® siting criteria:

- urban sites, building roofs, free of very local effects,
  fulfilling WMO/TD-No. 1250 2006 and CIMO Guide 2014 requirements

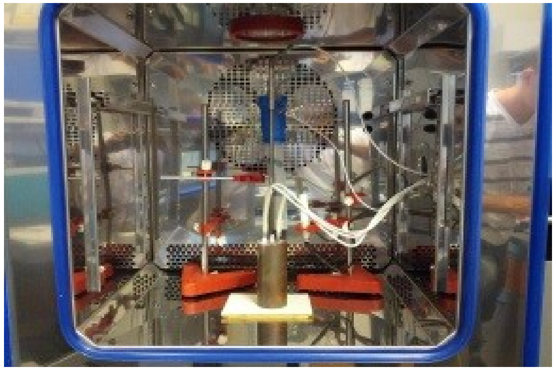
(... but some logistic constraints!)

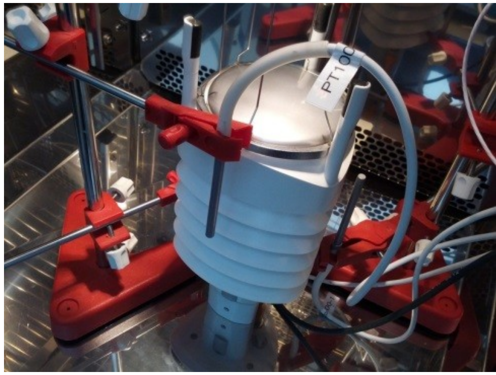
BUILDING TRACEABILITY CHAIN

Choosing calibration procedures: thermal bath or climatic chamber?

Solution:

ISTITUTO NAZIONALE DI RICERCA METROLOGICA





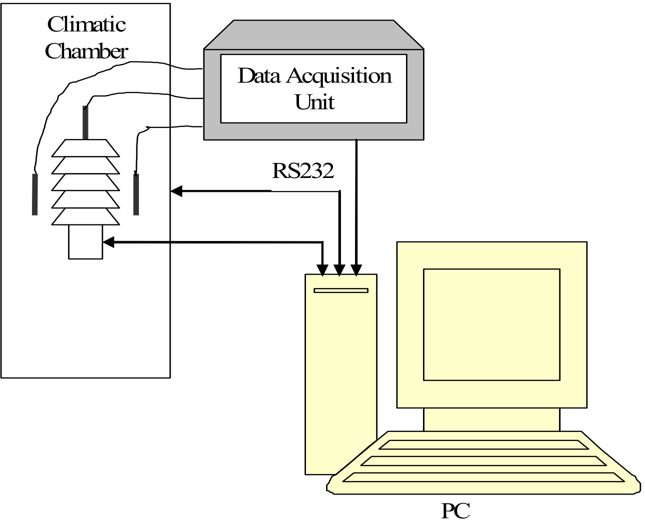
Three steps calibration:

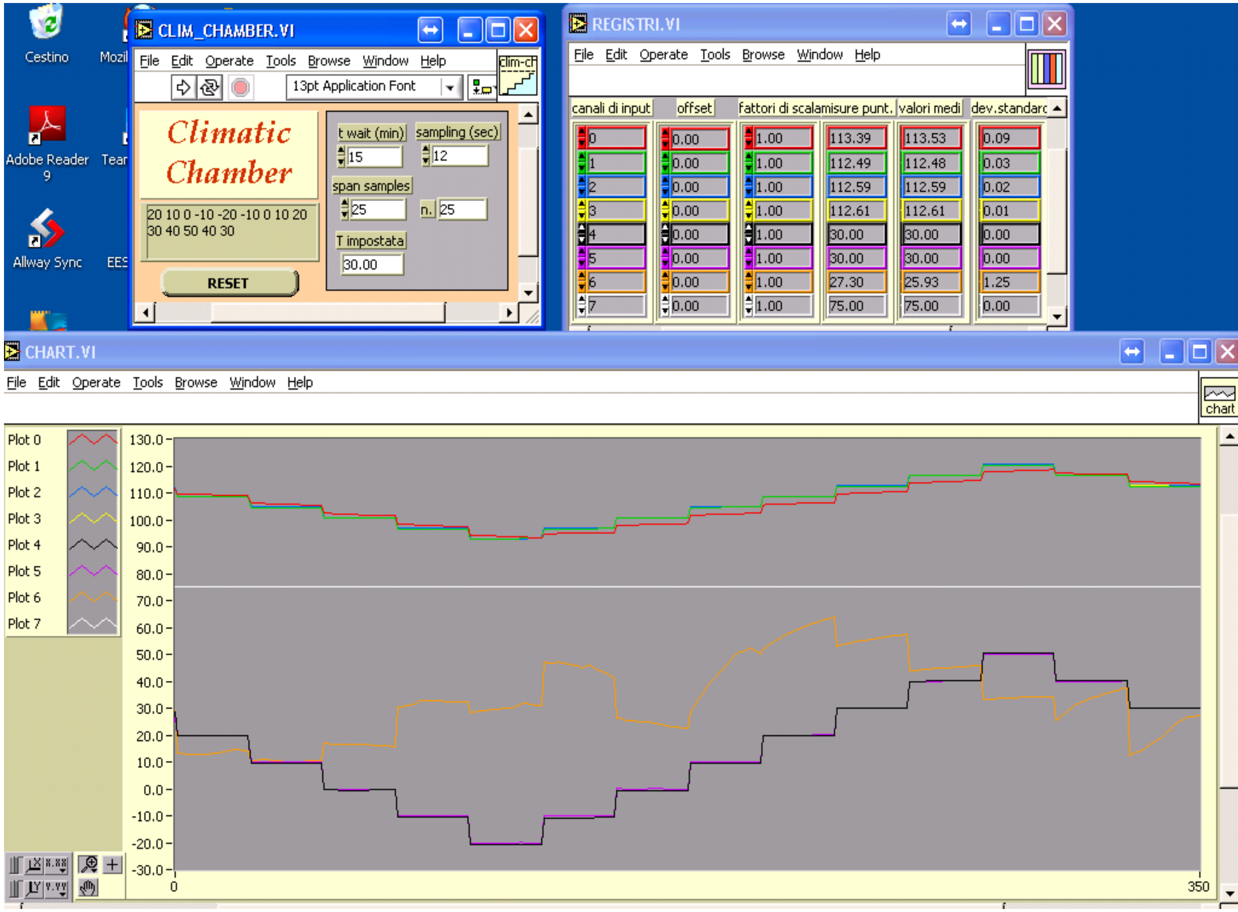
INRIM calibrates our **first line standard thermometer**

Transfer standard from first line to **second line thermometers** in **our own climatic chamber**

WXT520 Calibration using **three** second line thermometers

AUTOMATING CALIBRATION PROCEDURES

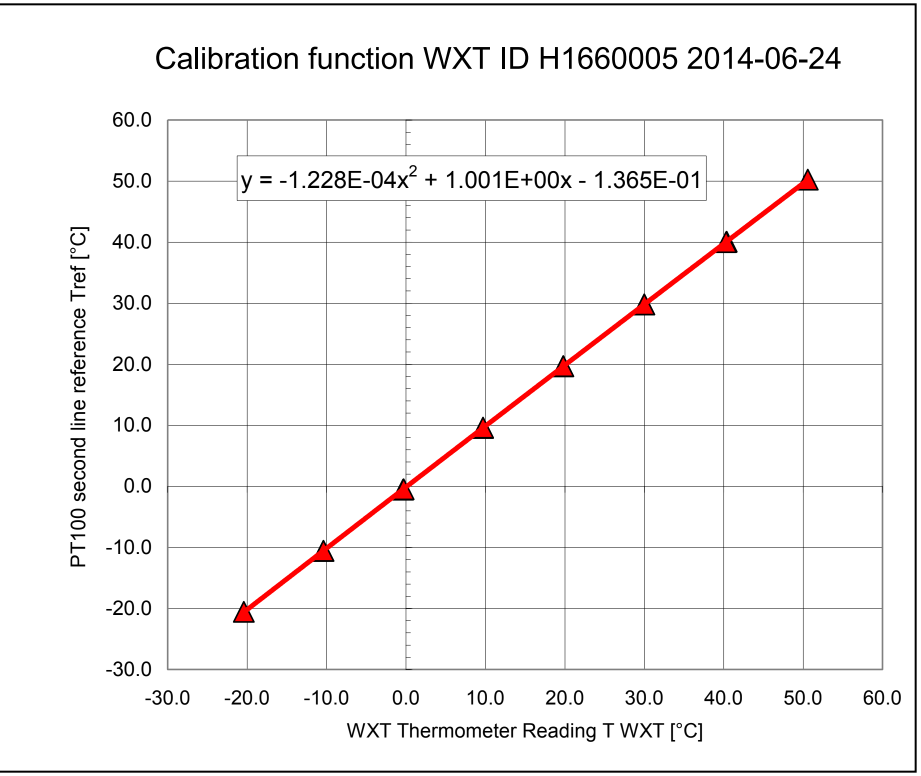


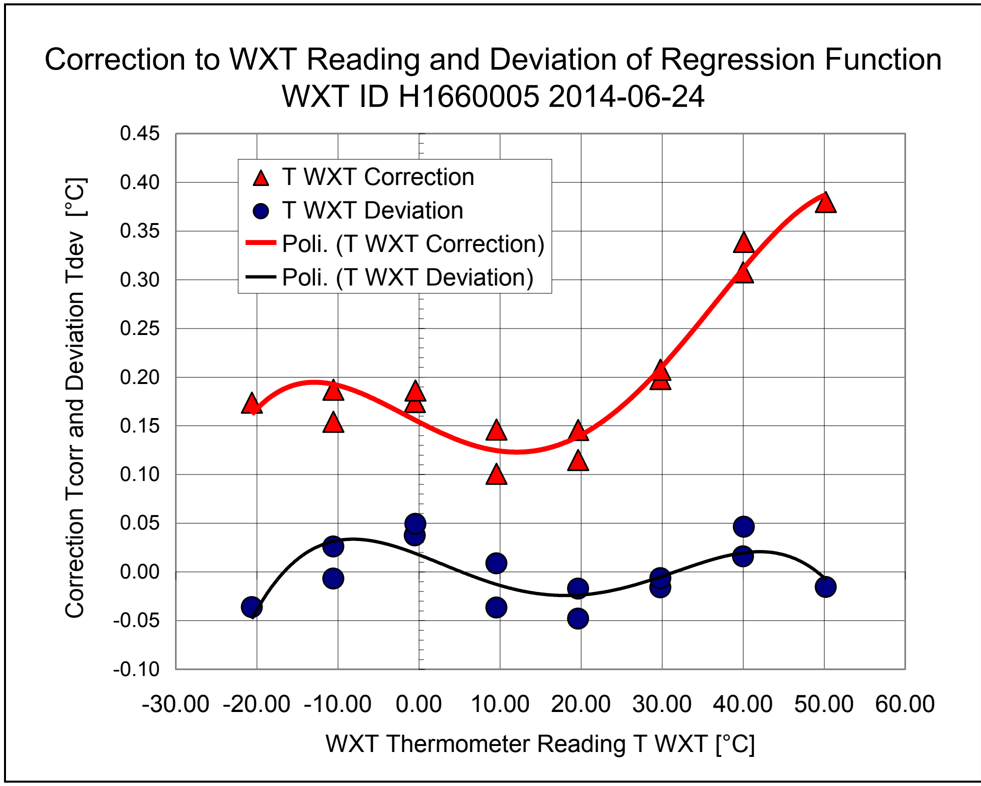


The system is connected to a PC via serial lines to acquire first and the second line sensors data (in ohm) and to set the climate chamber calibration points using a **fully automated Labview © program, developed internally**.

CALIBRATION RESULTS

Calibration of the Vaisala WXT520 weather transmitter

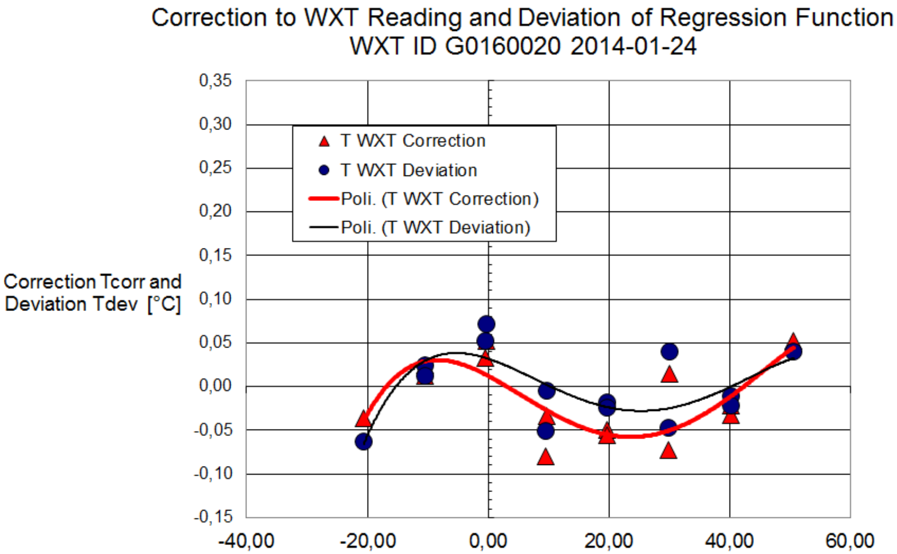


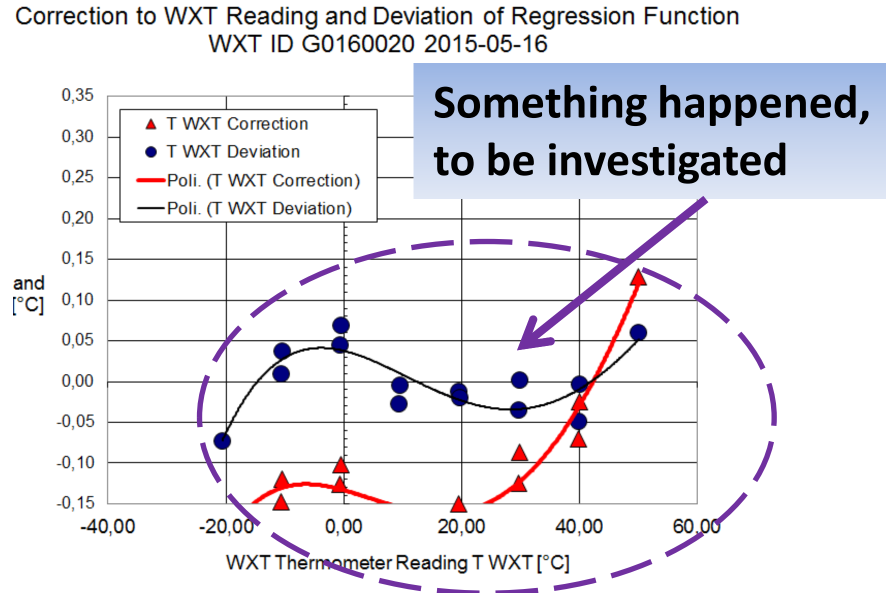


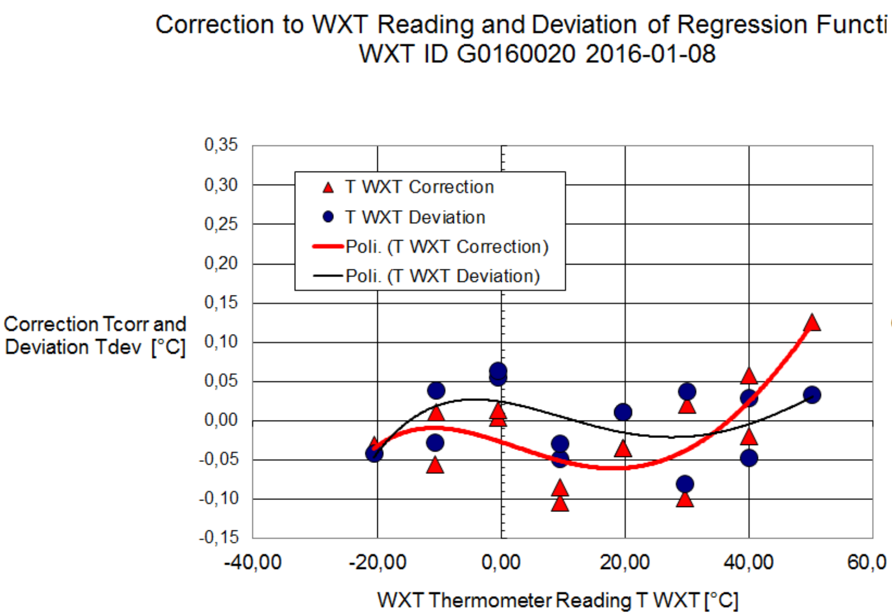
Calibration function: **second-degree polynomial regression** to contain the gap between the corrected value measured by WXT520 and the reference value **within 0.1°C**.

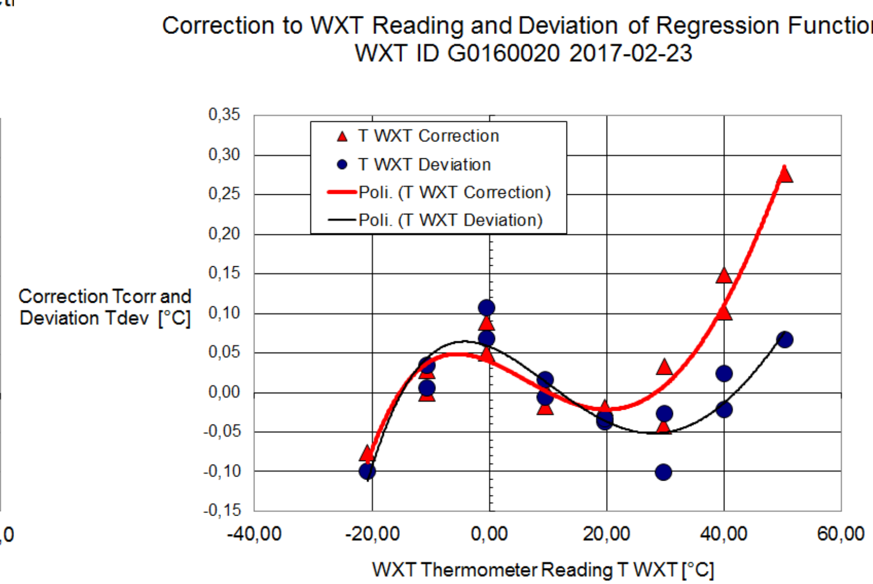
The absolute difference between WXT520 data and second line standard values is normally **within accuracy specifications** declared by Vaisala, ranging:
from **±0.2°C (at -50°C)** to **±0.7°C (at +60°C)**.

Calibration stability over years







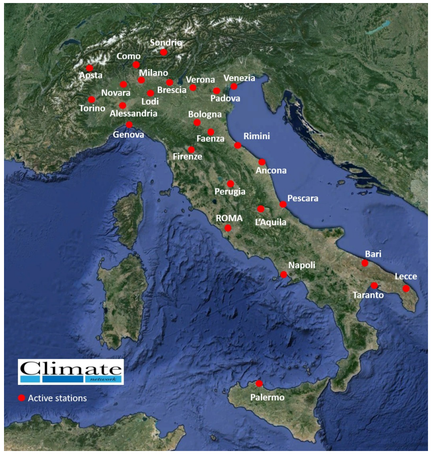


Calibration data base in numbers

FONDAZIONE OMD

64 WXT 520

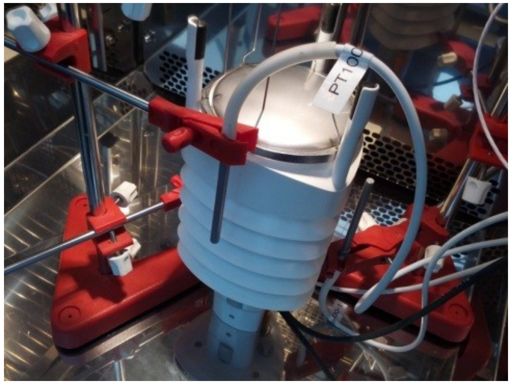
50 OPERATING STATIONS



274 WXT Calibrations since 2013

3 Temperature first line standards calibrated at National Metrological Institute (INRiM)

INRiM ISTITUTO NAZIONALE DI RICERCA METROLOGICA



7 Internal transfer standards calibration for temperature second line standards

1 Hygrometer and **1** Baromter first line standards calibrated at Slovenian Metrological Institute

REPUBLIC OF SLOVENIA
MINISTRY OF ECONOMIC DEVELOPMENT AND TECHNOLOGY
METROLOGY INSTITUTE OF THE REPUBLIC OF SLOVENIA

Operational procedures

- Every WXT operating in the field has to be substituted, cleaned and calibrated, once a year.
- The maintenance database contains all the work done in the field or in the laboratory of ordinary or extraordinary maintenance.
- The failure and anomalies data base is also a good tool to keep the Network under control.

Data transmission and data validation procedures

- Every **10 seconds** the WXT 520 provides a data string containing temperature, pressure, humidity, wind and rain measurements, and also provides power supply and the WXT's serial number.

- The **data logger** processes the collected data by **correcting the raw** WXT data with the calibration parameters set at the time of installation and provides **10 minutes averages** transmitted via GSM to the DataMet server.

- Each 10-minute string therefore contains time stamp, WXT serial number, and also the parameters of the calibration correction curve used. This ensures **total traceability of the data** for a possible back-correction.

- The **data validation** is carried out daily both by automatic procedures (gross error check) and expert meteorologists.

Metadata

N

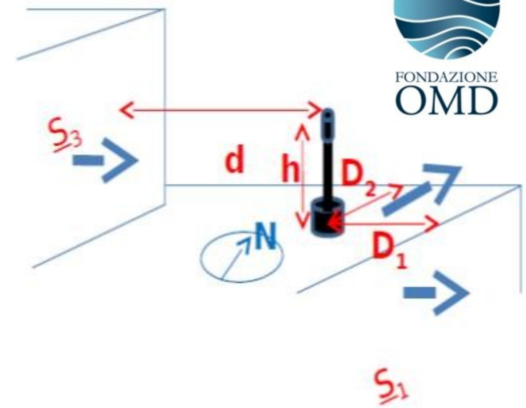
MONITORING SITE

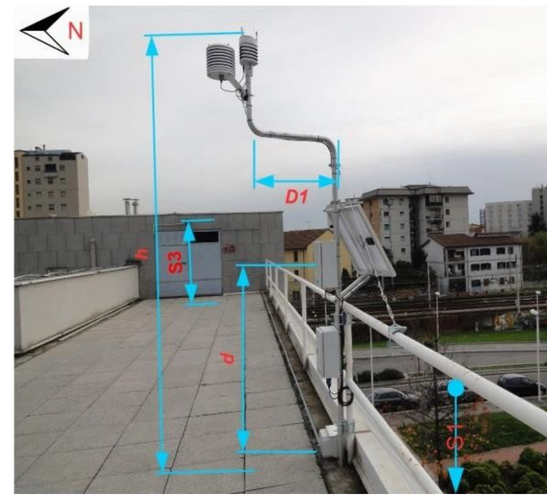
☐ Roof top ■ Terrace ☐ Ground ☐ Canopy ☐ Other

SURFACE COVER: Concrete Tiles

Surface Albedo							
North		South		East		West	
K_DOWN	K_UP	K_DOWN	K_UP	K_DOWN	K_UP	K_DOWN	K_UP
901	194	921	194	891	193	884	180
0,21		0,21		0,21		0,20	

- h (m) - Height from roof top
- D1 (m) - Distance from 1st wall
- D2 (m) - Distance from 2nd wall
- S1 (m) - Height of 1st wall
- dir S1 - Exposure of 1st wall
- S2 (m) - Height of 2nd wall
- dir S2 - Exposure of 2nd wall
- d (m) - Distance from an eventual 3rd wall
- S3 (m) - Height of 3rd wall
- dir S3 - Exposure of 3rd wall





Extended metadata with topo/photographic documentation of siting at different scales and detailed exposure parameters, together with albedo measurements of the underlying surfaces. The albedo, measured at the height of the instruments, with a secondary standard albedometer (i.e., CMA11 by Kipp&Zonen, provided by Politecnico Milano), shows for CN AWS in Milano differences that do not exceed 7%.

Shelter aging effect

2.2.2. Meteorological observatory of the Duomo of Milano

The field experiment was performed in May 2012 at the testing site of the Meteorological Observatory of the Duomo of Milano in the city center (45°27′50.98″N, 9°11′25.21″E at 122 m asl).

....

The temperature measurements recorded by old and new screens were compared, in both sites, and significant differences were found when AWSs with higher working time apart are compared: 0–5 and 1–3 years old screens. The temperatures measured by the AWS5 (respectively AWS3) were larger than the AWS0 (AWS1). The maximum differences measured were $\Delta T^*_{AWS0-AWS5} = -1.63\,°C$ and $\Delta T^*_{AWS1-AWS3} = -0.73\,°C$. The maximum differences recorded in the comparison 0–5 years were always bigger than that in 1–3 years to demonstrate that the ageing effect depends by paints degradation degree. Instead, in the case 0 to 1-year-old screens temperature differences are not evident.

Table I. AWSs employed in the experiments and their working time.

	Employed in Milano site			Employed in Torino site	
	AWS00	AWS1	AWS3	AWS0	AWS5
Model	WXT520	WXT520	WXT520	WXT520	WXT510
Working time	New	2011	2009	New	2007

Comparative analysis of the influence of solar radiation screen ageing on temperature measurements by means of weather stations: Lopardo G., Bertiglia F., **Curci S.**, Roggero G., Merlone A., 2014, International Journal of Climatology 34, pp. 1297-1310. https://doi.org/10.1002/joc.3765

Uncertainty Estimate

In first approximation, an urban meteorological measurement M may be broken up as sum of several and **independent contributions**:

$$\mathbf{M = M_0 + M_m + M_e + M_i} \qquad \text{where:}$$

M_0: synoptic value, determined by the large scale meteorological situation (cost. for all stations)

while for the **3 correction terms**, of a lower order:

M_m: meso/local scale meteorological phenomena, varying at urban scale;

M_e : specific siting of each station and sensor exposure;

M_i : instrumental and calibration uncertainty (cost. for all stations)

Skipping **M_i** and reducing **M_m** to 0 as much as possible, above equation becomes:

$$\mathbf{M \approx M_0 + M_e}$$

Estimate Methodology

It is convenient to analyze only measure **differences**. Defining a **measure reference** as:

$$M_{ref} \equiv \Sigma\, M_n / N = \Sigma\, (M_{0,n} + M_{e,n}) / N$$

the difference between a single station measure and the reference is:

$$\Delta M_n \equiv (M_{0,n} + M_{e,n}) - M_{ref} = M_{0,n} + M_{e,n} - \Sigma M_{0,n} / N - \Sigma M_{e,n} / N$$

Filtering out meso/synoptic and other local gradients: $M_{0,n} \approx M_0$

Considering siting and exposure effects casually distributed: $\Sigma\, M_{e,n} / N \approx 0$

equation simplifies as:

$$\Delta M_n \approx M_{0,n} + M_{e,n} - M_{0,n} = M_{e,n}$$

⇒ The difference of each station value from reference **depends only** on its specific siting and exposure.

Reduced dataset

- **Select meteorological situations** where **synoptic and mesoscale** patterns do not cause considerable horizontal gradient of meteorological parameters inside town.
- Moreover, in relation to very high percentage of stability conditions characterizing Milano and Po Valley, it is mandatory also to **single out UHI episodes**.

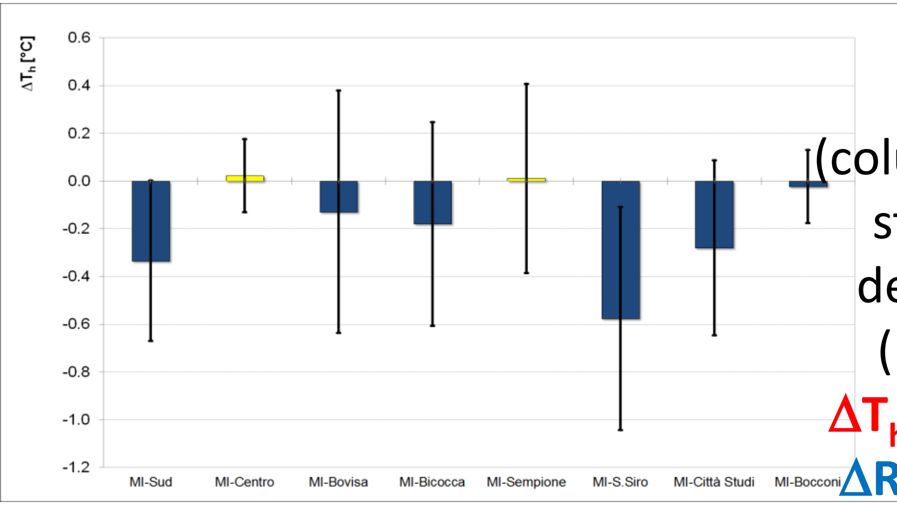
Mean hourly data that satisfy the following **requirements**:

- **$\underline{V} \le 3$ m/s** (average of the N = 8 stations values)
- **MAX [$\Delta (V_i - V_j)$] ≤ 2.5 m/s** ($\forall$ i , j = 1 $\div$ N)
- **MAX [$\Delta (T_i - T_j)$] ≤ 2.0 °C** ($\forall$ i , j = 1 $\div$ N)
- **MAX [$\Delta (RH_i - RH_j)$] ≤ 10 %** ($\forall$ i , j = 1 $\div$ N)

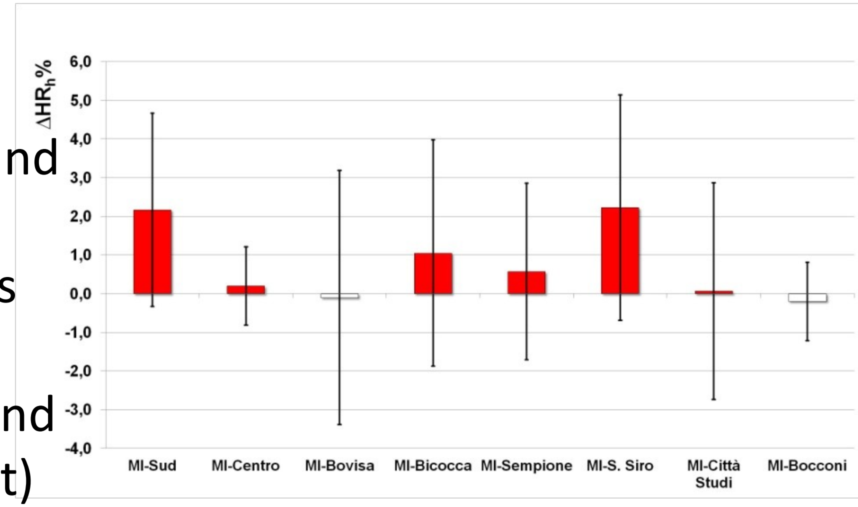
$\Rightarrow$ ***"reduced dataset"*** homogeneous and meteorologically consistent

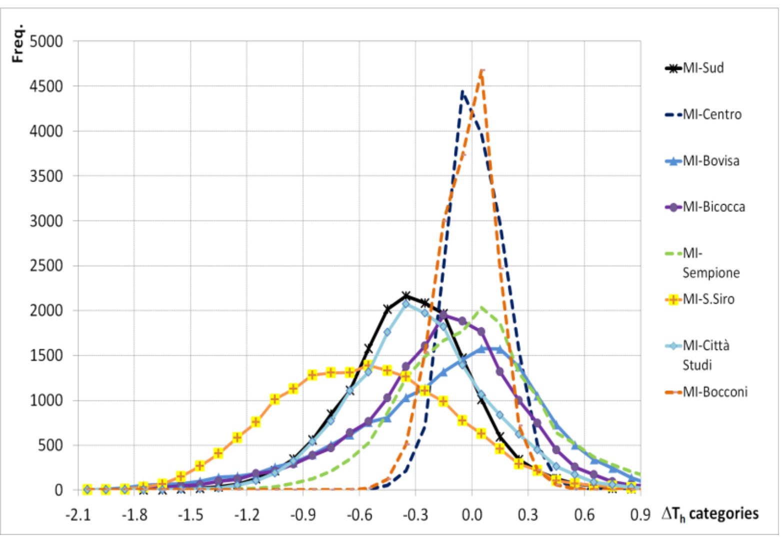
$\Rightarrow$ **17059 hourly records** that correspond to **69 %** of starting CN database, sufficiently **well distributed** among hours and months.

Station differences in the reduced dataset

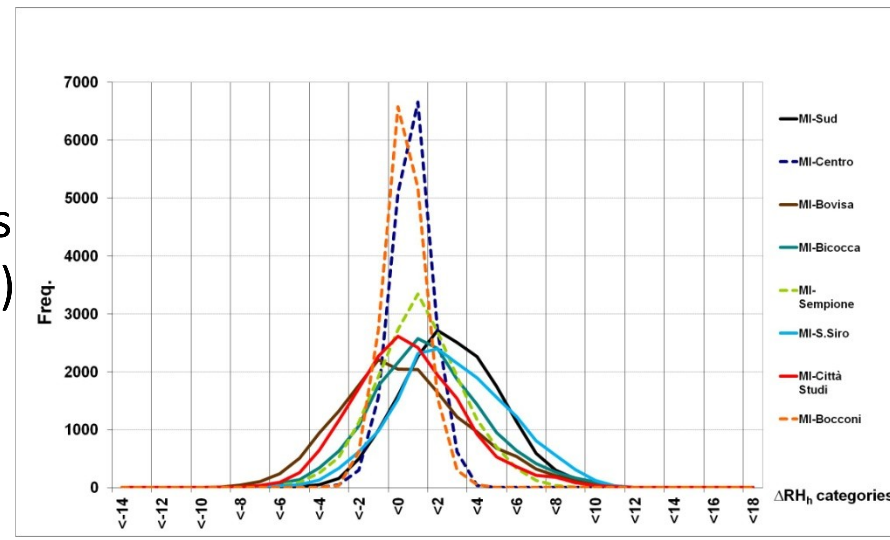


Biases (columns) and standard deviations (bars) of ΔT_h (left) and ΔRH_h (right)



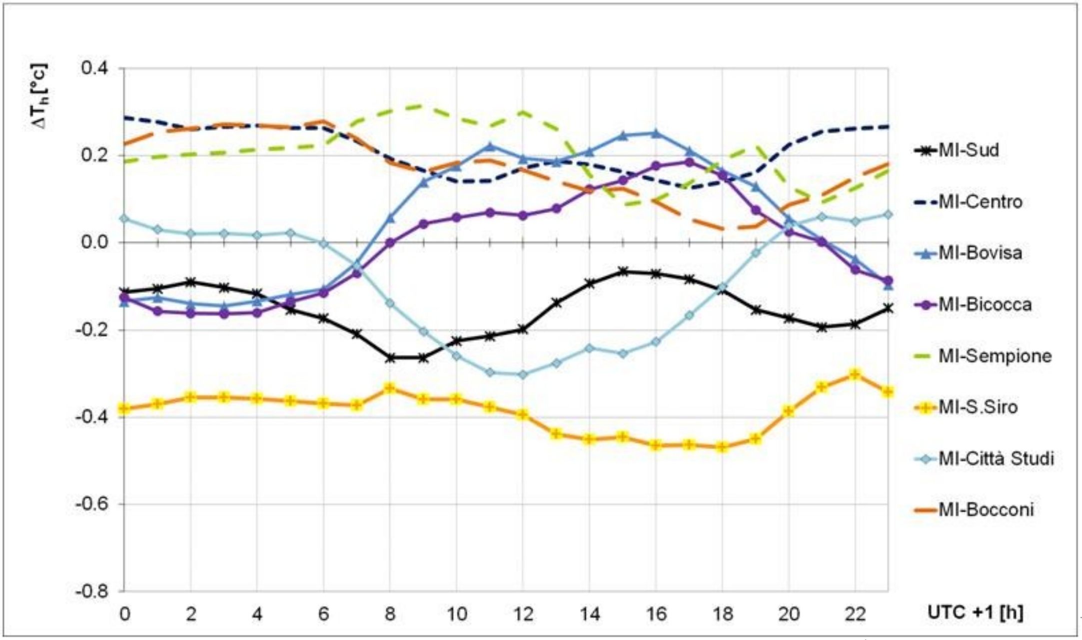


Statistical differences in ΔT_h (left) and ΔRH_h (right)

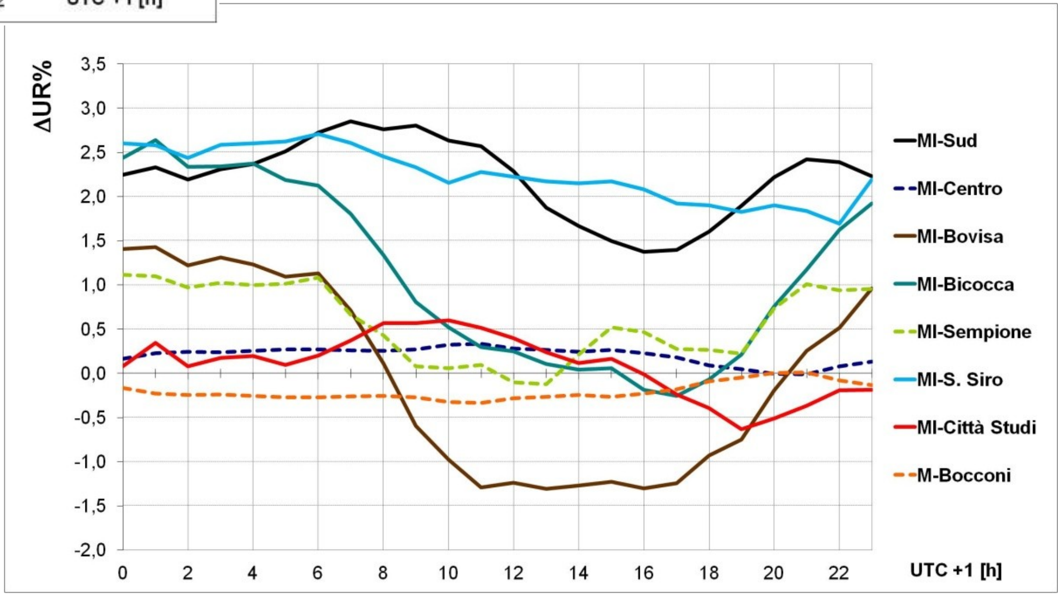


Reference values: average of MI-Centro and MI-Bocconi (dashed lines).

Mean hourly trends in ΔT and ΔRH

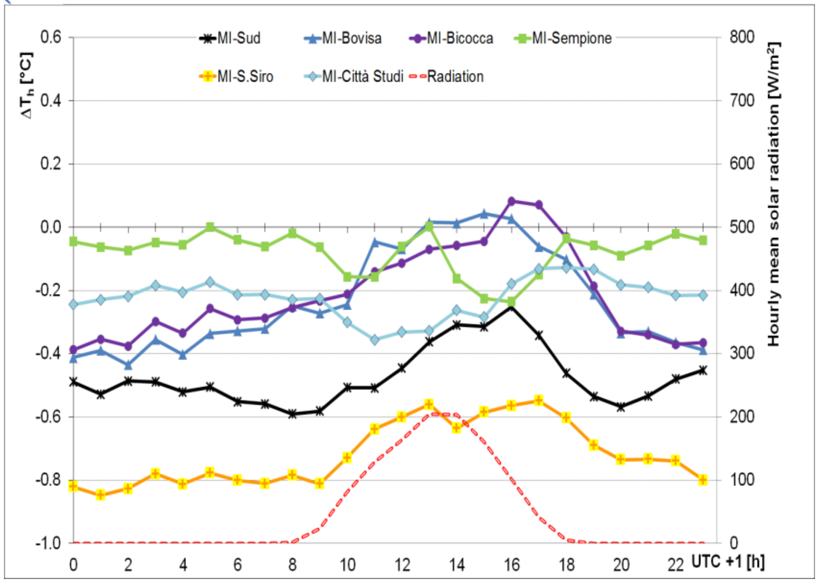


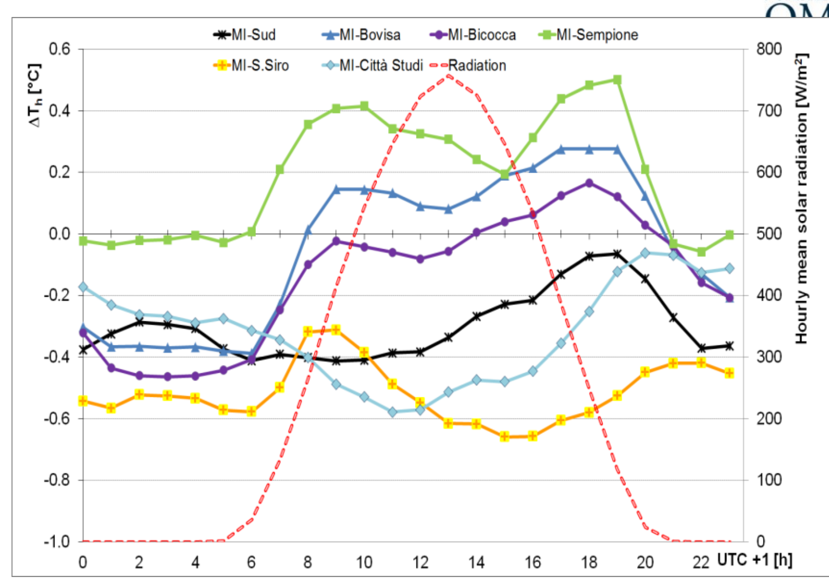
Hourly trends of ΔT_h (left) and ΔRH_h (right) for the "*reduced dataset*".



Reference values: average of MI-Centro and MI-Bocconi (dashed lines).

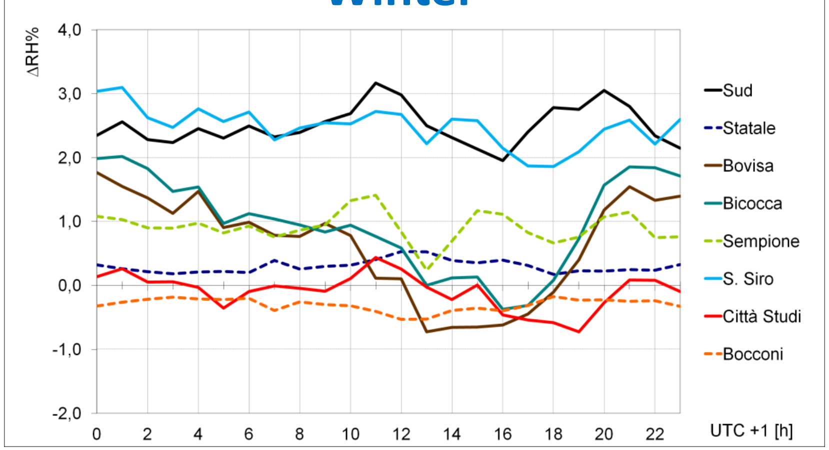
Seasonal effect





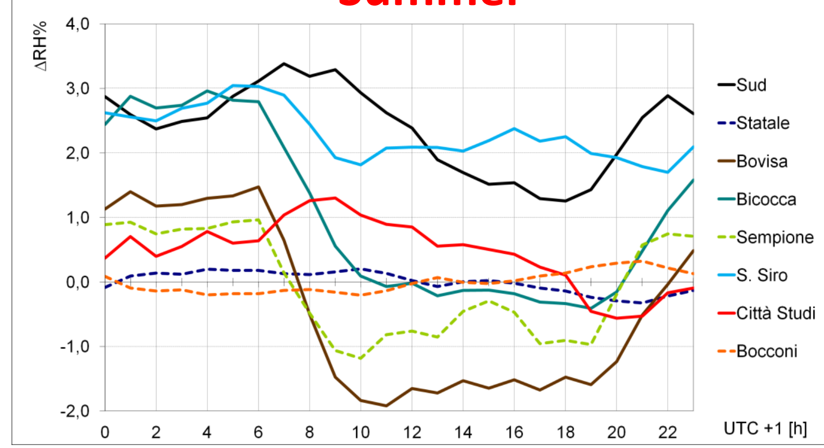
ΔT_h

Winter



ΔRH_h

Summer



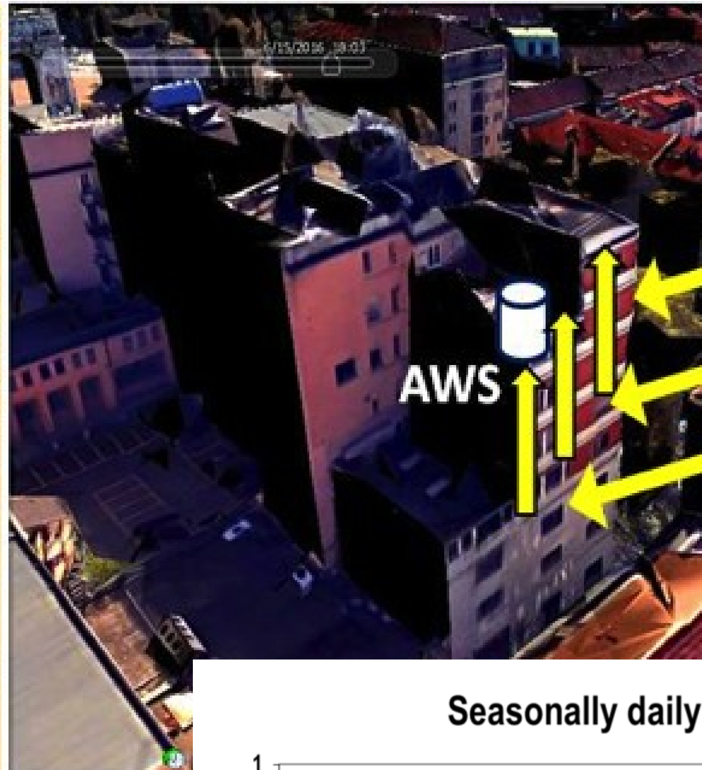
ΔT_h (top) and ΔRH_h (bottom) hourly trends in winter (left) and summer (right).

The dashed line is the mean Global Solar Radiation as measured in MI-Città Studi.

AWS MI-Sempione

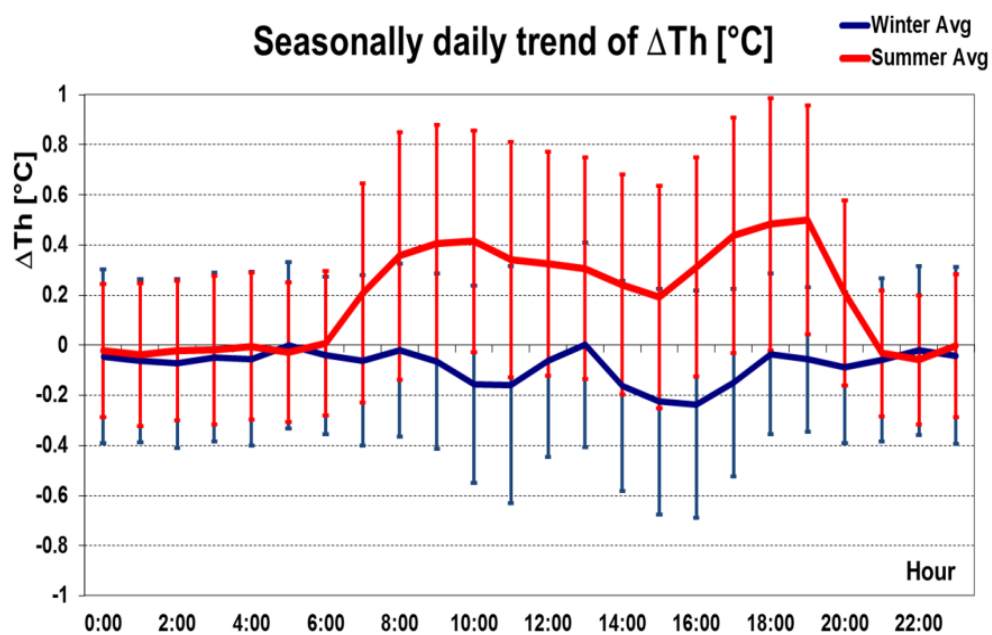
Clear effect of different solar irradiation during the day in different seasons

a) morning



b) afternoon

Summer exposures and direct solar illumination of underlying vertical walls at different day times for MI-Sempione Automatic Weather Station (AWS in pictures).



MI-Sempione

Shadowing of terrace at different times for MI-Sempione station. Pictures were taken after station removal: the AWS was originally placed on the left corner as shown.

Results for urban temperature and relative humidity uncertainties

$U_{exp\ (k=2)}$	MI-Sud	***MI-Centro***	MI-Bovisa	MI-Bicocca	MI-Sempione	MI-S.Siro	MI-Città Studi	***MI-Bocconi***
T [°C]	**0.7**	*0.3*	**1.0**	**0.9**	**0.8**	**0.9**	**0.7**	*0.3*
RH [%]	**5.0**	*2.0*	**6.6**	**5.9**	**4.6**	**4.2**	**5.6**	*2.0*

Added measure uncertainties for temperature and relative humidity (at coverage factor k=2, or 2σ or 95% confidence level) of the CN AWS in Milano due to the combined effect of **station siting and sensor exposure** (MI-Centro and MI-Bocconi as reference).

Assessing meteorology measure uncertainty in urban environments: S. Curci, C. Lavecchia, G. Frustaci, R. Paolini, S.Pilati and C. Paganelli, Measurement Science and Technology **28** (2017) 1004002 (8pp) https://doi.org/10.1088/1361-6501/aa7ec1

Conclusions

- **Climate Network®** is an operational, efficient, and affordable monitoring tool producing high quality data under **metrological criteria** in Italian urban environments for meteorological and climatological applications

  (**see also Poster P3-7**)

- The **methodology** developed and tested to estimate **measure uncertainties** in the **urban environment** (published paper) produced encouraging results:

  - In case of homogenous and well managed urban network measuring at top of UCL as the CN Network, the **added uncertainty** on long term hourly averages **due mainly to exposure effects** may be estimated to have an **upper limit of about 1°C for T** and of about **7% for RH.**

  - For temperature this is **much less** than the estimated value of up to 5°C uncertainty indicated by WMO - CIMO Guide No. 8, but still **significantly larger** than calibration uncertainties of 0.2 °C.

Further developments

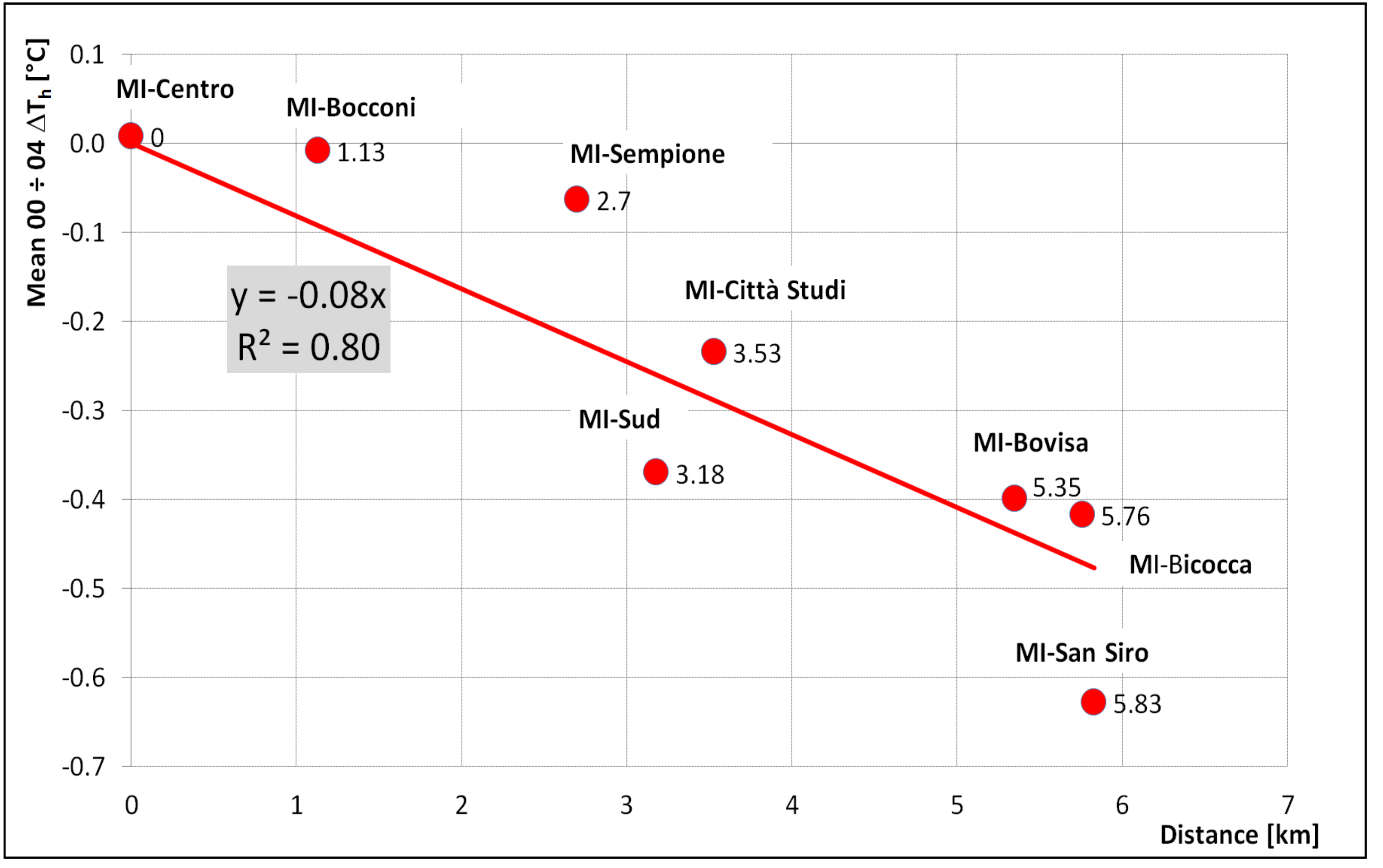
- GPRS for near **real time transmission** of raw data (no data logger)
- Implementation of **metrological procedures** to all the other variables
- Extension of the **uncertainty estimates** to all the measured variables
- **Quantitative study of uncertainties** and **exposure metadata**
  (**Milano** as a ***testbed*** *for urban measurements?*)
- **Comparison** with other **types** of urban stations (at street level, for AQ monitoring)

..... ***in order to better define uncertainties*** as a possible contribution
to WMO – CIMO Guide Nr. 8 ***for urban measurements***

...... and to step forward for a ***reference station definition***
for urban meteorology and climatology


Thank you!

Residual UHI effect



Mean temp. differences vs distance from city centre during nighttimes (00 ÷ 04 a.m.).