The MeteoMet Week,
INRIM, September 14, 2017.

METEOMET
Metrology for Meteorology

FONDAZIONE OMD

The operational urban Climate Network® in Milano: metrological achievements in the Meteomet framework.

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

Introduction

- The nationwide operational urban Climate Network® (CN)
  - Technical characteristics
  - “Metrological “ criteria
  - Operational procedures
- Activities in the framework of MeteoMet
- Assessing measure uncertainty in the urban environment
  - Method
  - Results for Temperature ...
  - ... and for Relative Humidity
- Conclusions and further developments

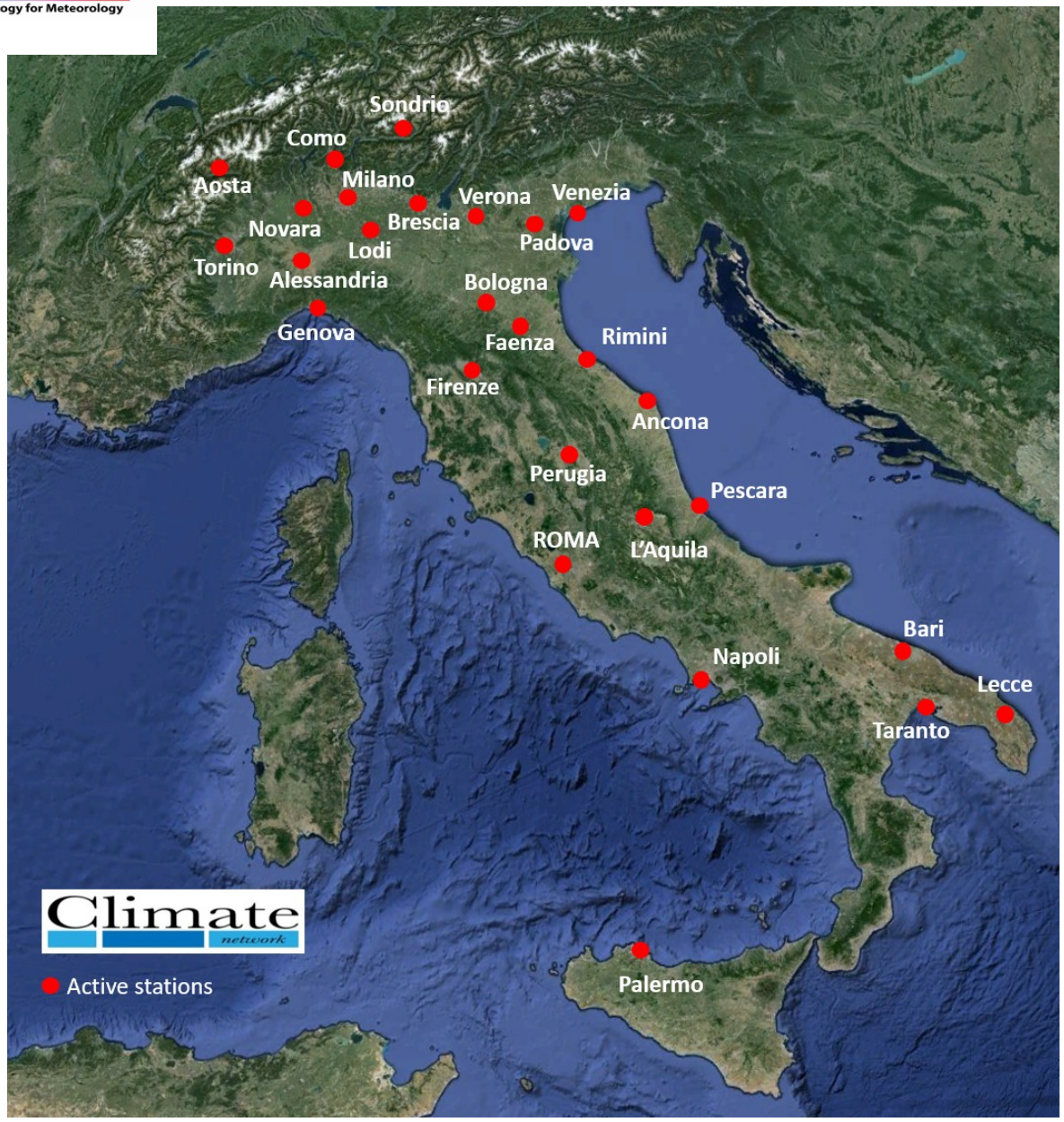
The nationwide operational urban Climate Network®

- Project and set up by Climate Consulting Srl 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

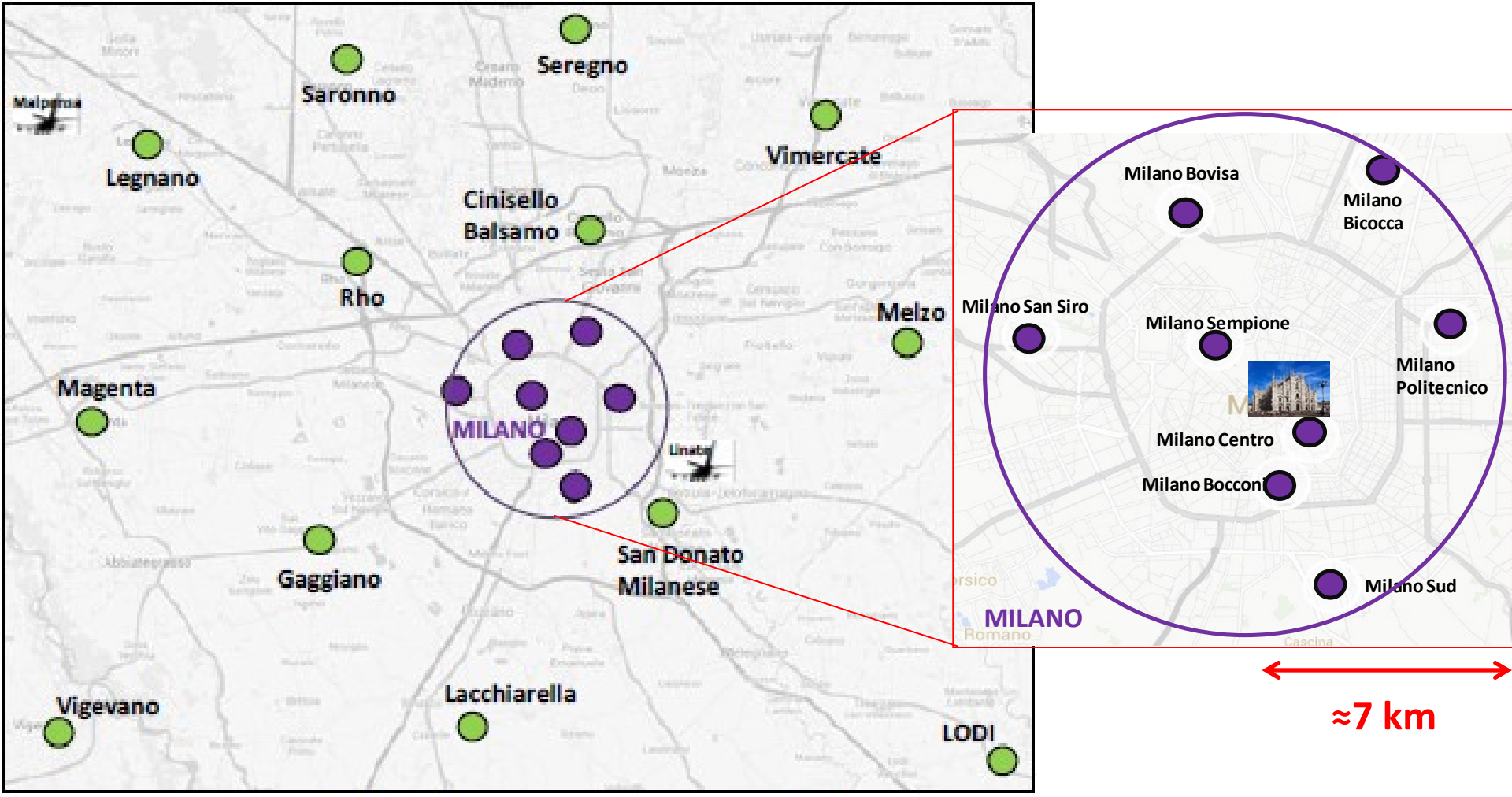


Climate Network® national coverage

Italy: 50 CN AWSs

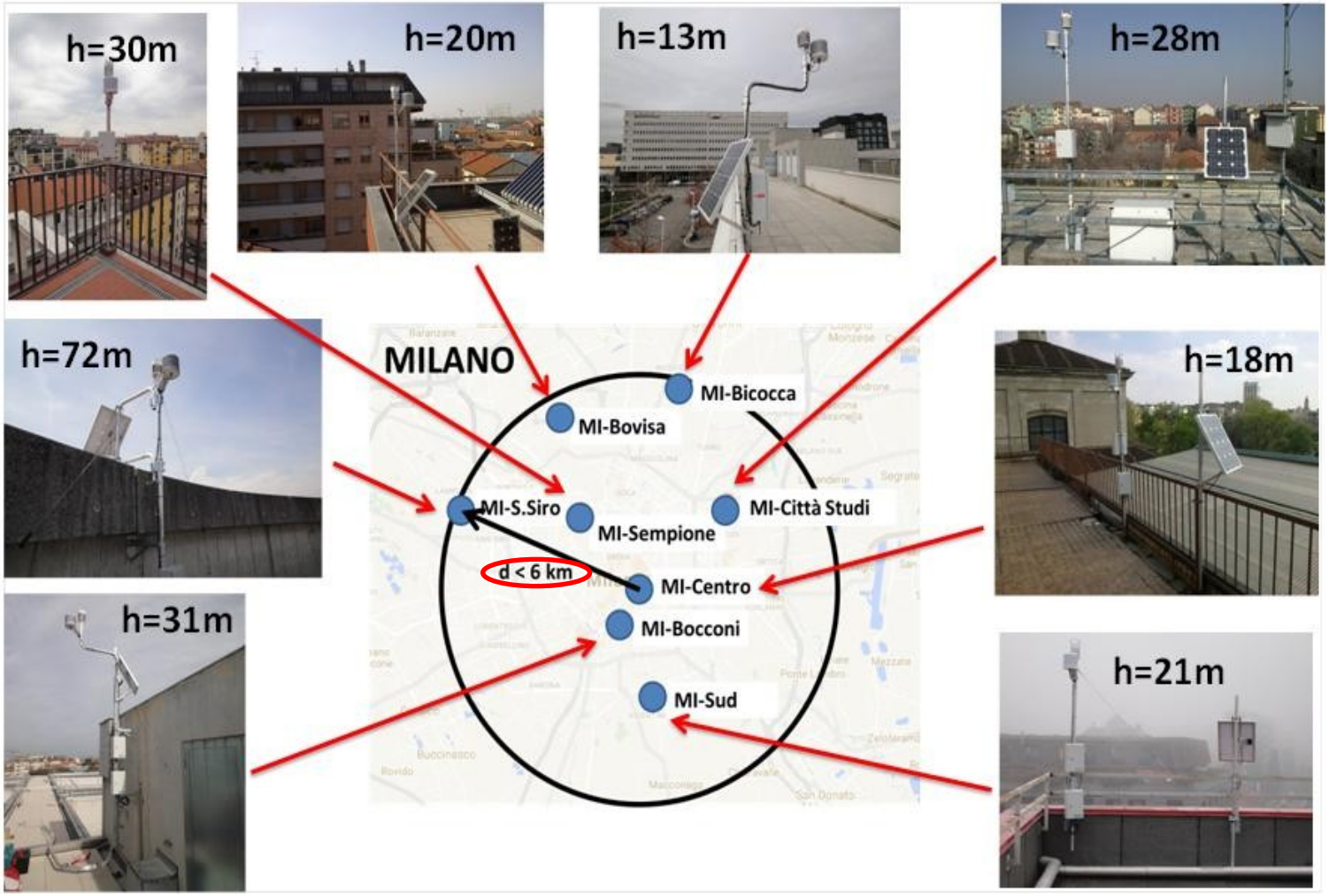
- **8 in Milano**
- **2 in Firenze**
- **2 in Roma**

Climate Network®
in and around Milano



Climate Network® in the Milano metropolitan area

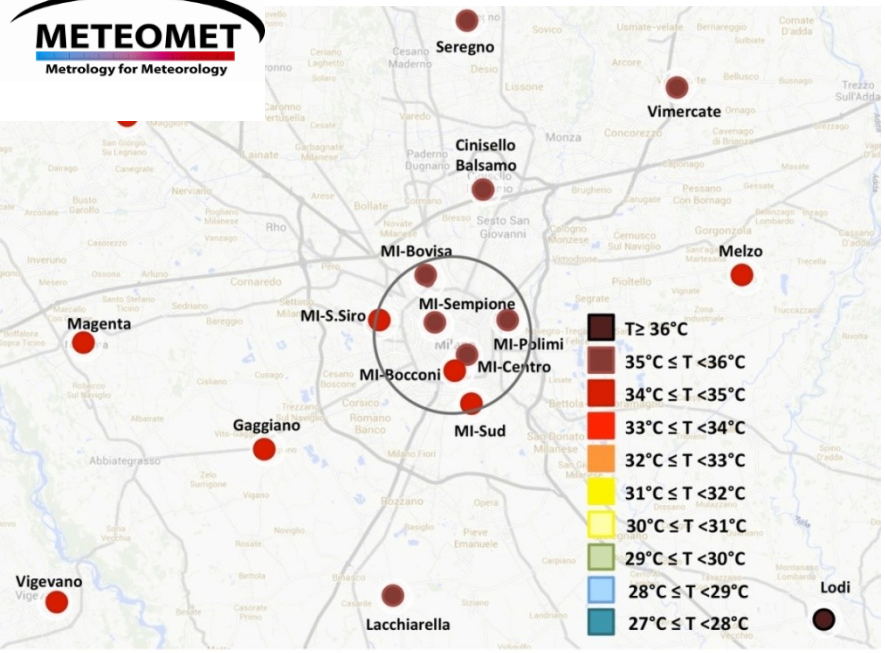
Sitings of the 8 CN AWSs in Milano downtown



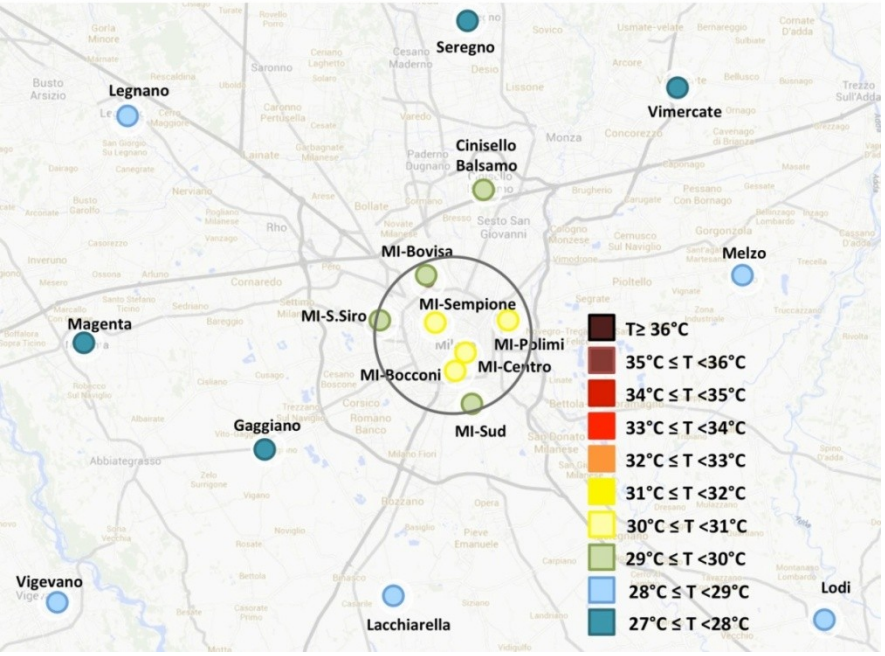
Pictures show details of the different station sitings and sensor exposures.

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

Urban Heat Island (UHI) as observed by CN



- 21 August 2012, 15:00-16:00



- 22 August 2012, 00:00-01:00

Technical characteristics

Key strengths of Climate Network® are:

- same type of weather stations (VAISALA WXT520)
- traceable measurements
- same calibration method and standards for all sensors
- same control and assurance procedures
- 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 requirements

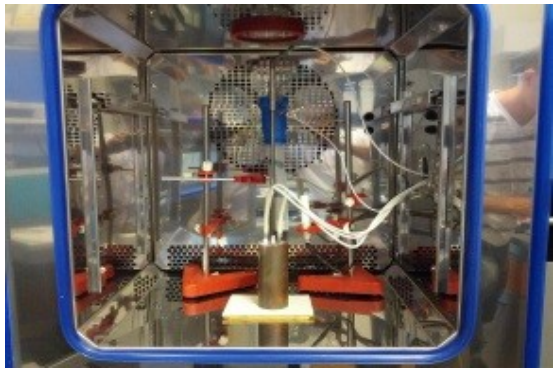
(… but some logistic constraints!)

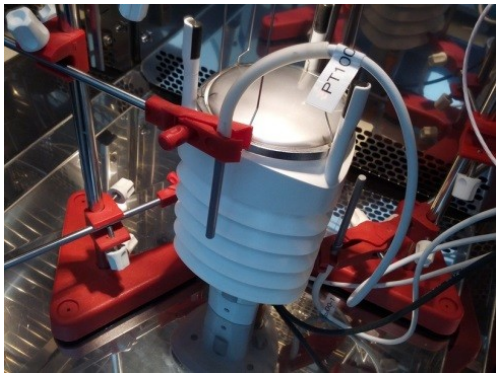
BUILDING TRACEABILITY CHAIN

Choosing calibration procedures: thermal bath or climatic chamber?

?

Solution: INRiM ISTITUTO NAZIONALE DI RICERCA METROLOGICA





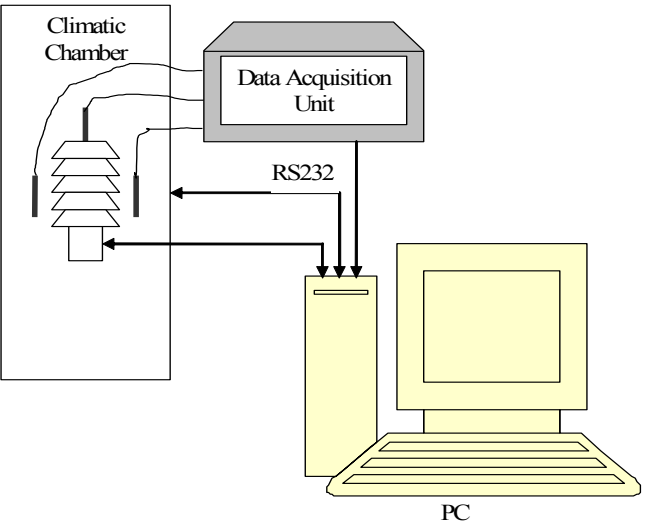
Three steps calibration:

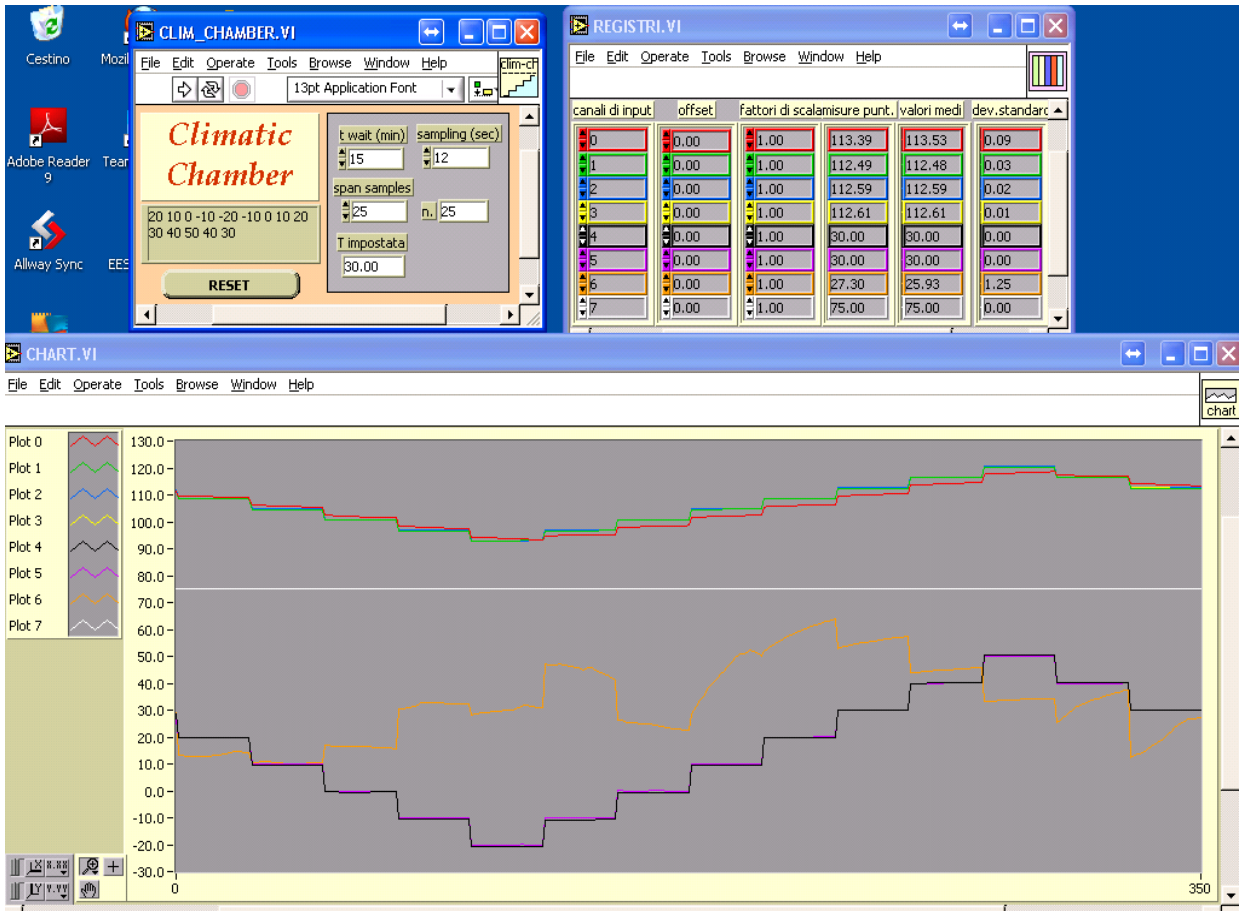
INRIM calibrates our first line standard thermometer

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

WXT520 Calibration using three second line thermometers

AUTOMATING CALIBRATION PROCEDURES

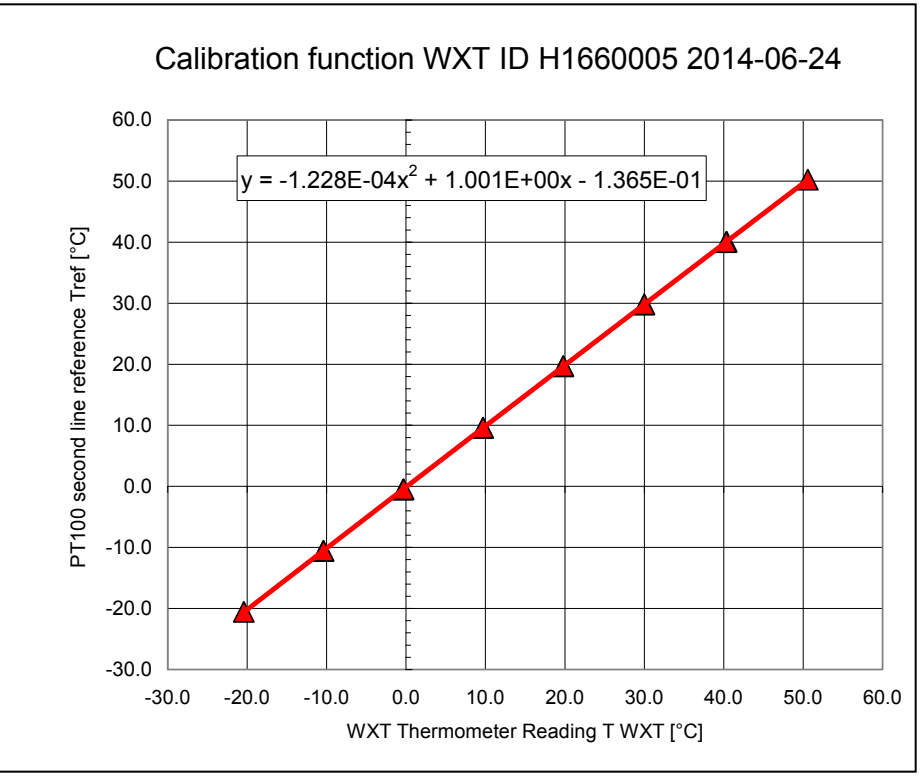


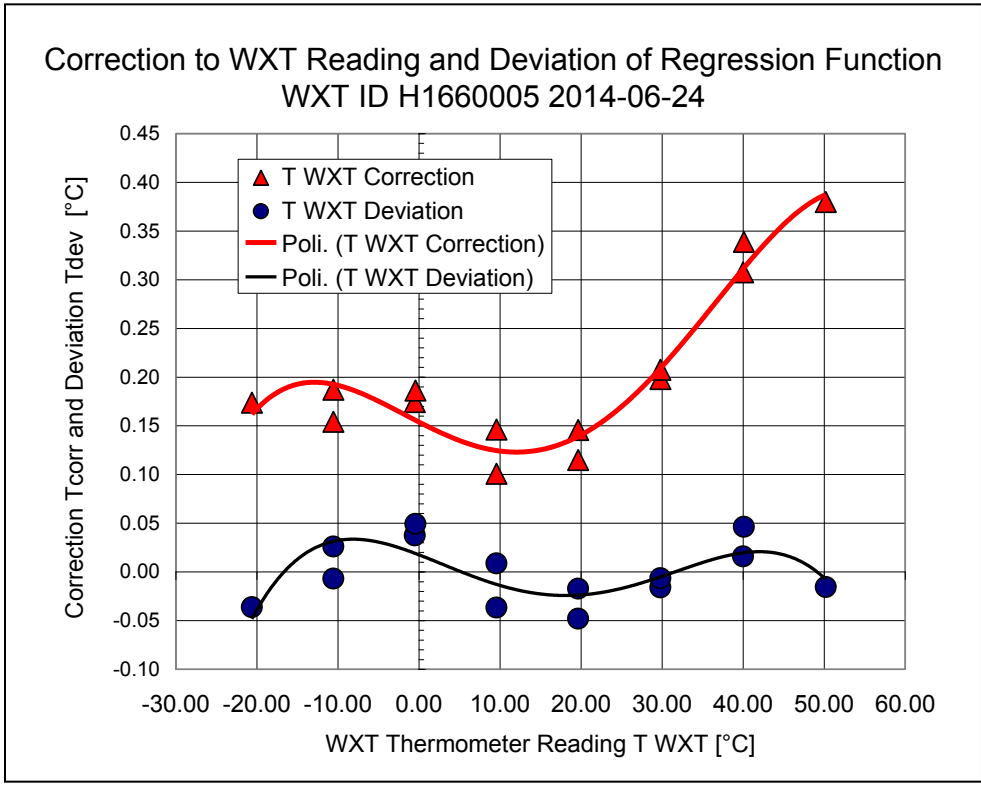


The system is connected to a PC via serial lines to acquire first and the second line sensors data (in ohm) and to set the climate chamber calibration points using a fully automated Labview © program, developed internally.

CALIBRATION RESULTS

Calibration of the Vaisala WXT520 weather transmitter

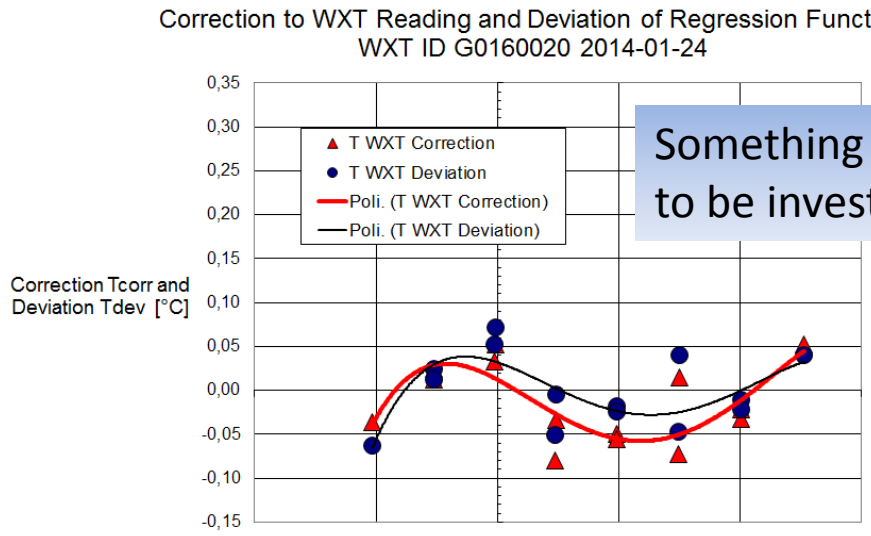




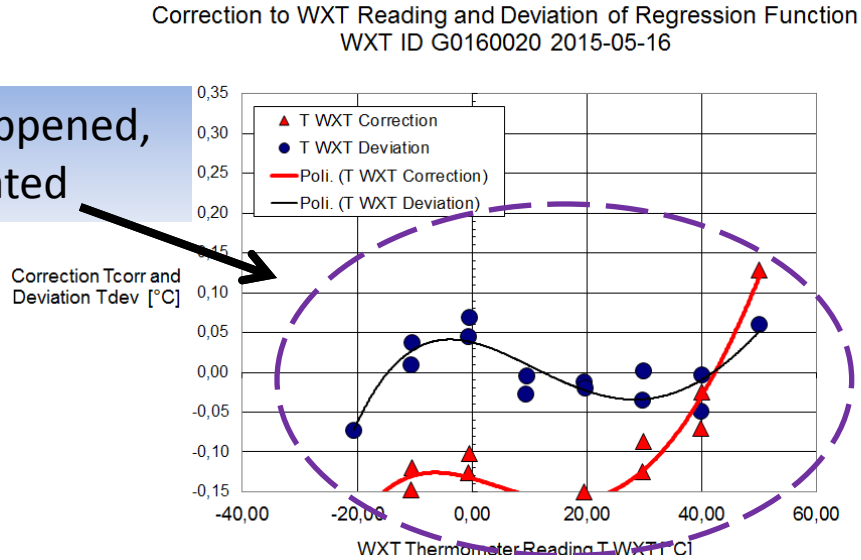
Calibration function: second-degree polynomial regression to contain the gap between the corrected value measured by WXT520 and the reference value within 0.1°C.

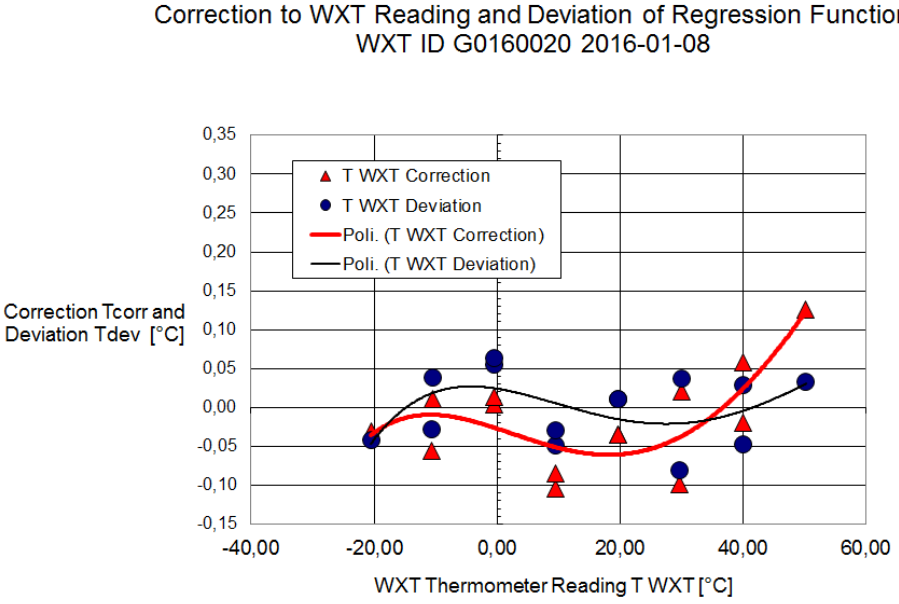
The absolute difference between WXT520 data and second line standard values is normally within accuracy specifications declared by Vaisala, ranging from ± 0.2°C (at -50°C) to ± 0.7°C (at +60°C).

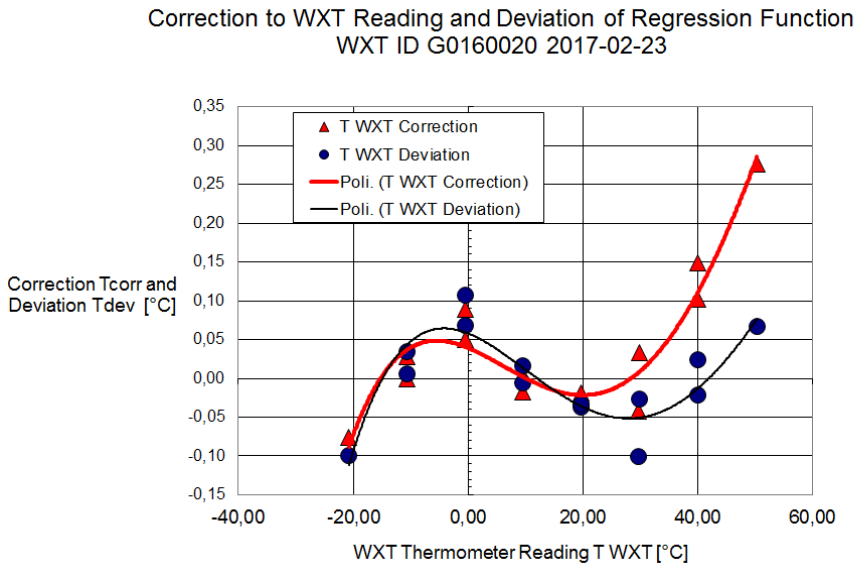
Calibration stability over years



Something happened, to be investigated

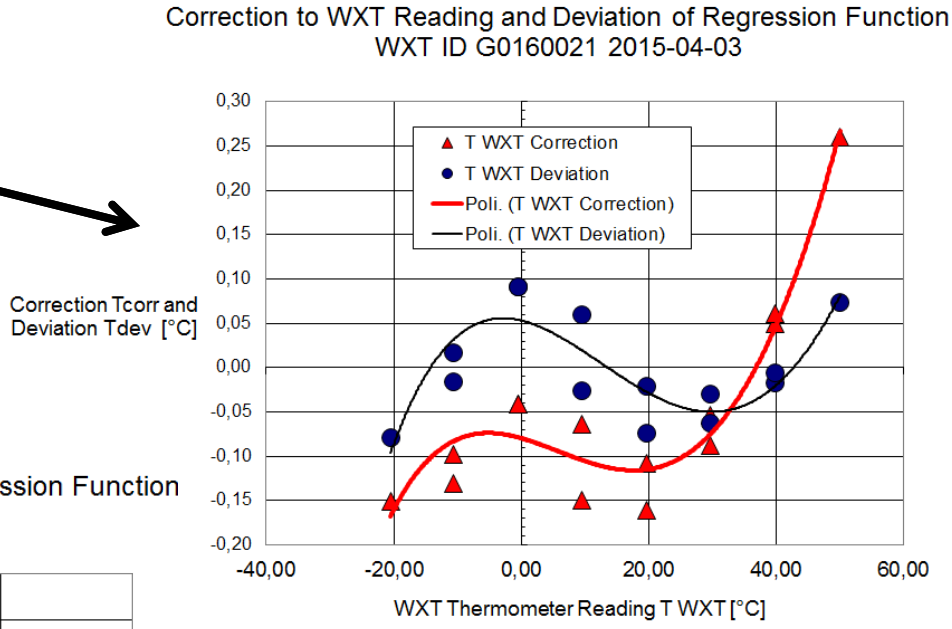


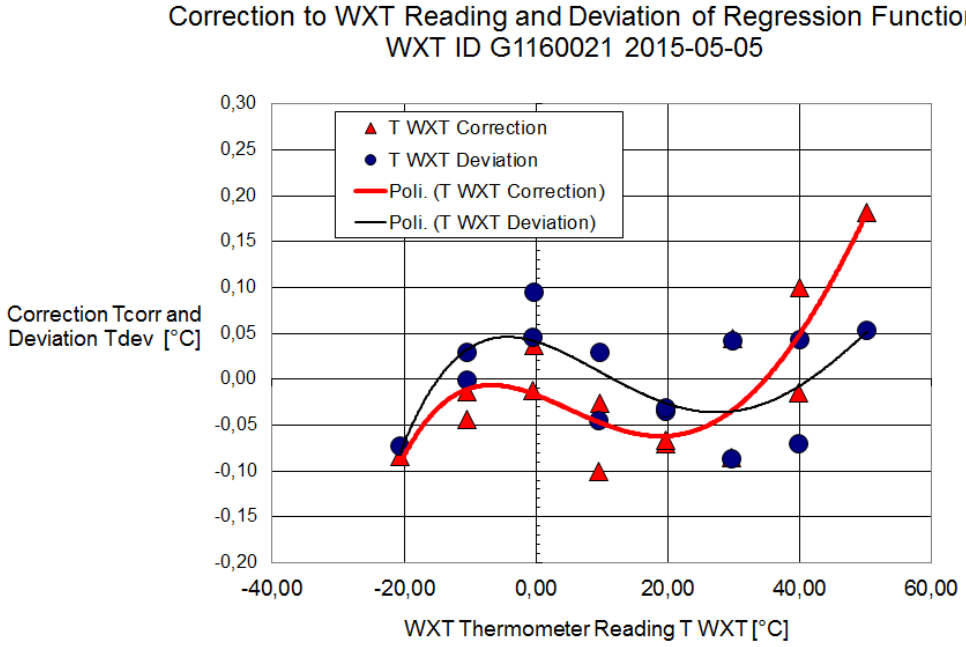




Calibration stability: 1 month

WXT's calibration repeated on same conditions in one month





Calibration data base in numbers

64 WXT 520

50 OPERATING STATIONS

274 WXT'S CALIBRATIONS SINCE 2013

3 TEMPERATURE FIRST LINE STANDARD CALIBRATIONS AT NATIONAL METROLOGICAL INSTITUTE

7 INTERNAL TRANSFER STANDARD CALIBRATION FOR TEMPERATURE SECOND LINE STANDARD

1 HIGROMETER AND 1 BAROMETER FIRST LINE STANDARD CALIBRATION AT SLOVENIAN METROLOGICAL INSTITUTE

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 trasmission 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

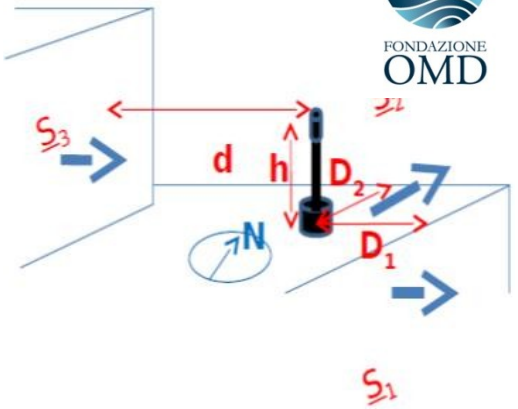
MONITORING SITE

☐ 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

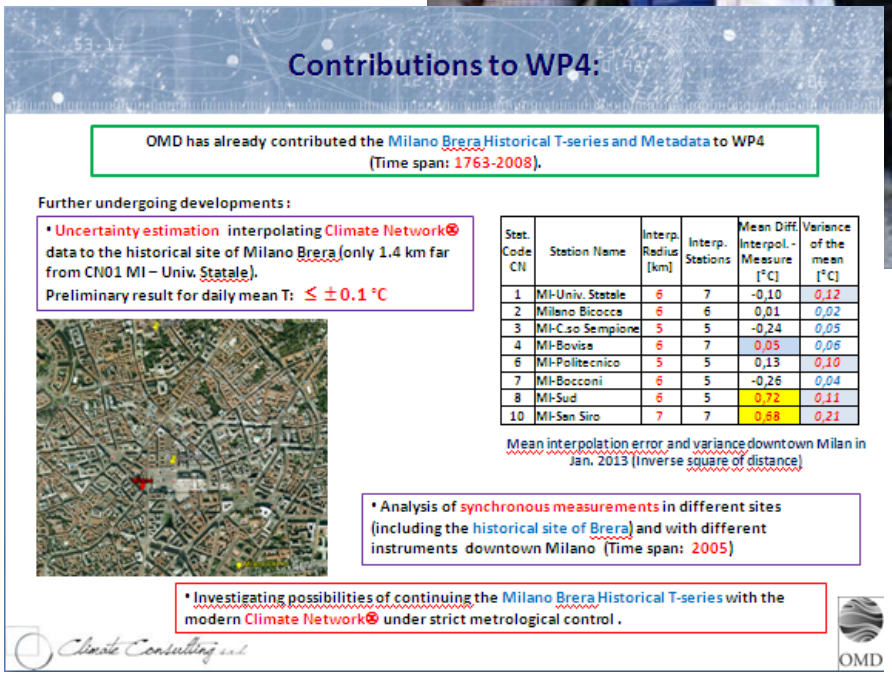


Extended metadata with topo/photographic documentation of siting at different scales and detailed exposure parameters, together with albedo measurements of the underlying surfaces. The albedo, measured at the height of the instruments, with a secondary standard albedometer (i.e., CMA11 by Kipp&Zonen,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

Osservatorio Meteorologico Milano Duomo (OMD) as MeteoMet collaborator

- **Kick-off** Meeting in Moncalieri **2011**

- Torino **2013**



Stat. Code CN	Station Name	Interp. Radius [km]	Interp. Stations	Mean Diff. Interpol. - Measure [°C]	Variance of the mean [°C]
1	MI-Univ. Statale	6	7	-0,10	0,12
2	Milano Bicocca	6	6	0,01	0,02
3	MI-C.so Sempione	5	5	-0,24	0,05
4	MI-Boviso	6	7	0,05	0,06
6	MI-Politecnico	5	5	0,13	0,10
7	MI-Bocconi	6	5	-0,26	0,04
8	MI-Sud	6	5	0,72	0,11
10	MI-San Siro	7	7	0,68	0,21

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 $\Delta T^*_{AWS0-AWS5} = -1.63\,^{\circ}C$ and $\Delta T^*_{AWS1-AWS3} = -0.73\,^{\circ}C$. 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.

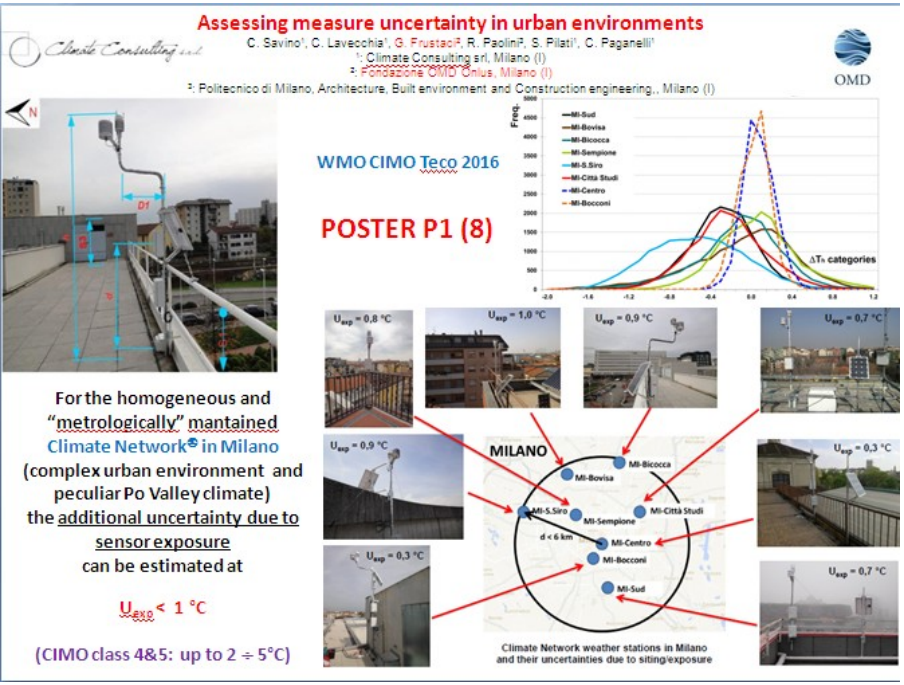
Table I. AWSs employed in the experiments and their working time.

	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

Osservatorio Meteorologico Milano Duomo (OMD) as MeteoMet collaborator

- **MeteoMet Brdo 2014**
- **MeteoMet + CIMO-Teco Madrid 2016**



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

Estimate Methodology (1)

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

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

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:

$$M \approx M_0 + M_e$$

Estimate Methodology (2)

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:

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

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

Estimate Methodology (3)

Data selection

- 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.

  - **Specific objective criteria** have been implemented to remove from the initial database measurements corresponding to relevant synoptic and meso/local scale episodes.

Reduced dataset

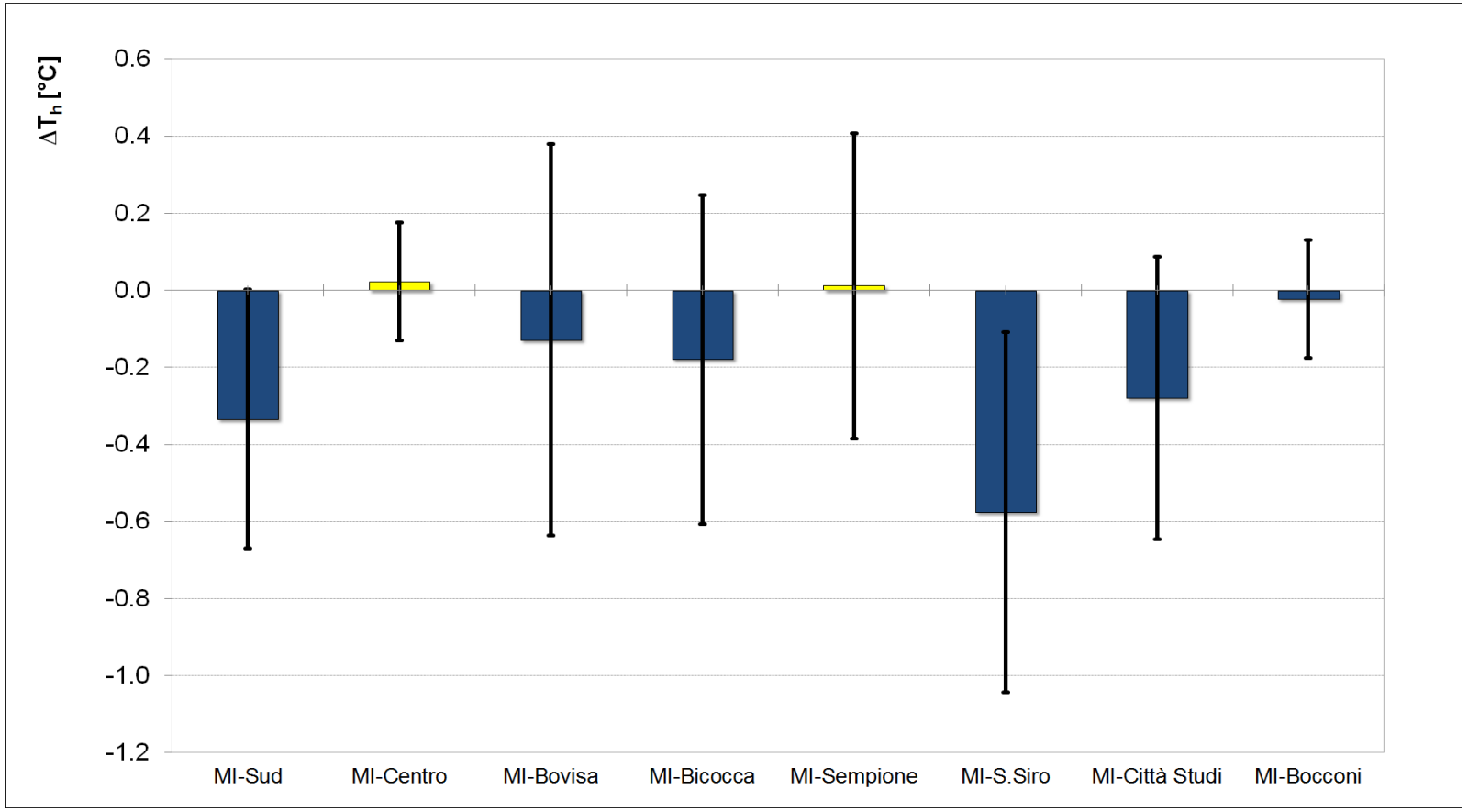
Mean hourly data that satisfy the following **requirements**:

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

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

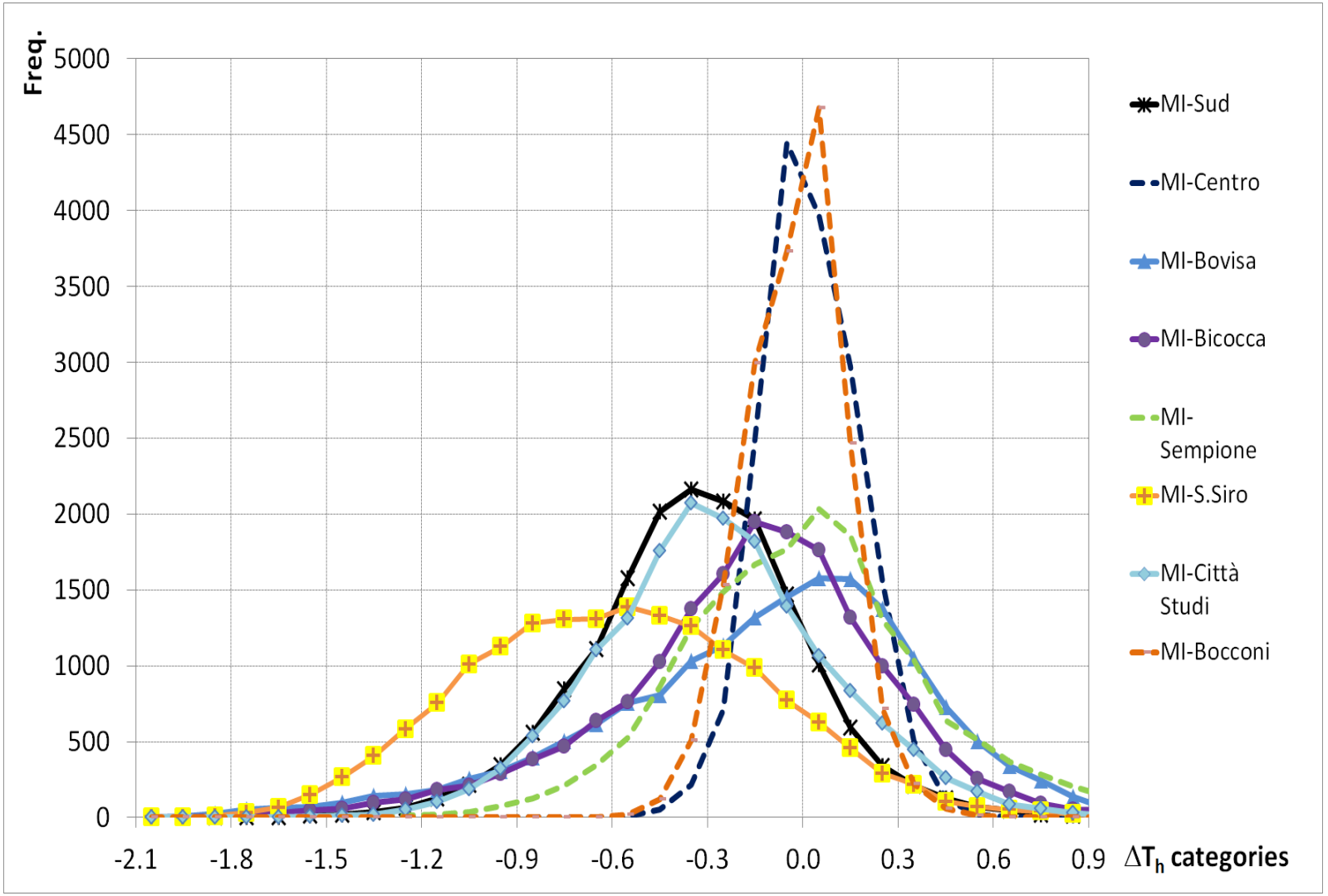
17059 hourly records that correspond to **69 %** of starting CN database, sufficiently **well distributed** among hours and months.

Station differences in the reduced dataset

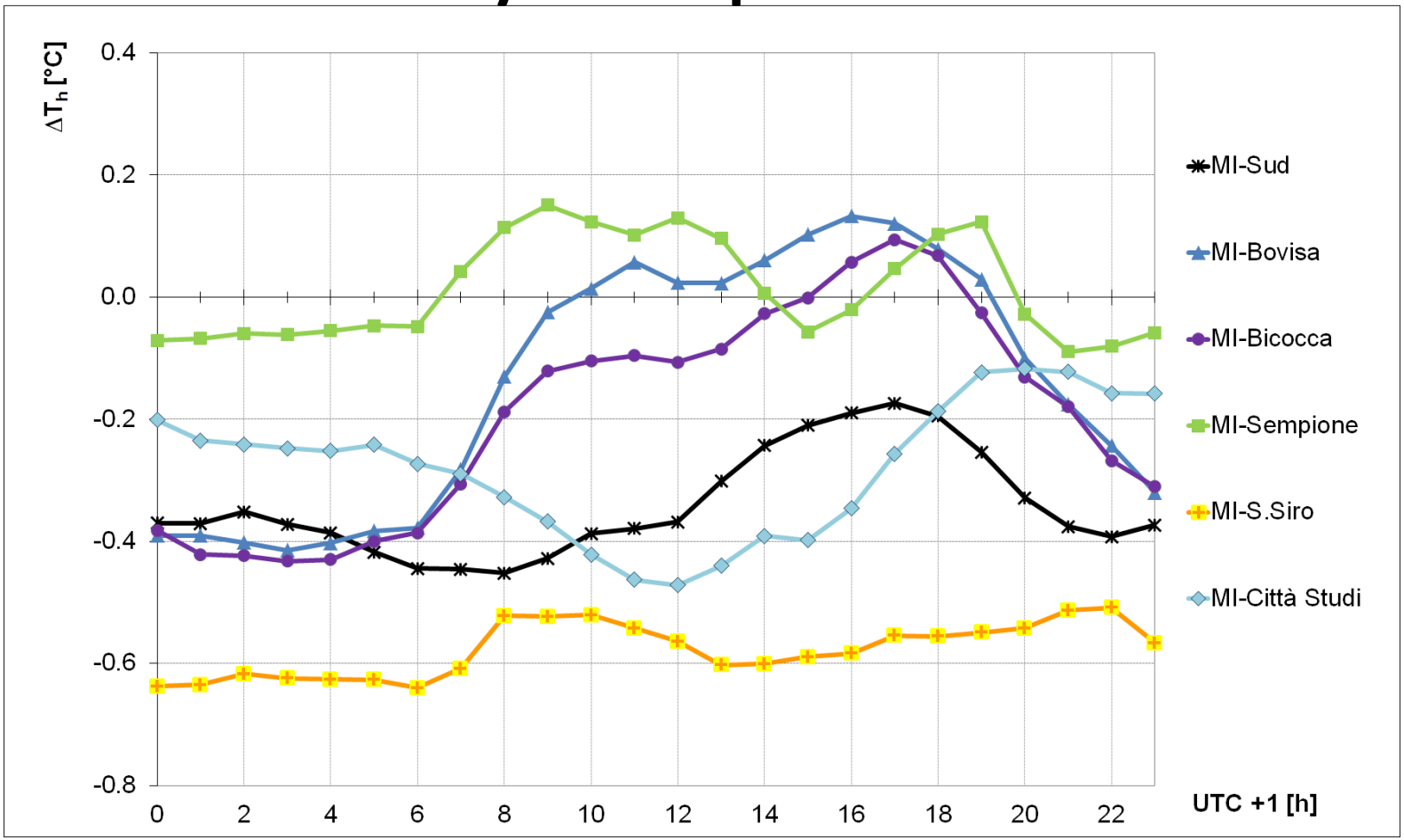


Biases (columns) and standard deviations (bars) of ΔT_h for all the 8 Milano CN stations.

Statistical differences in temperature



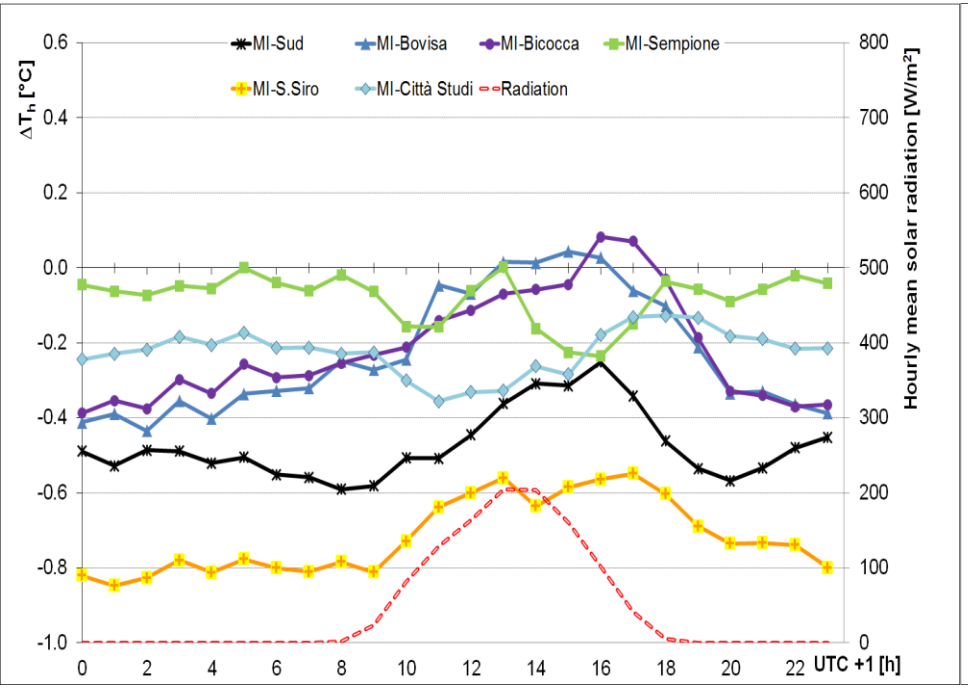
Mean hourly temperature trends



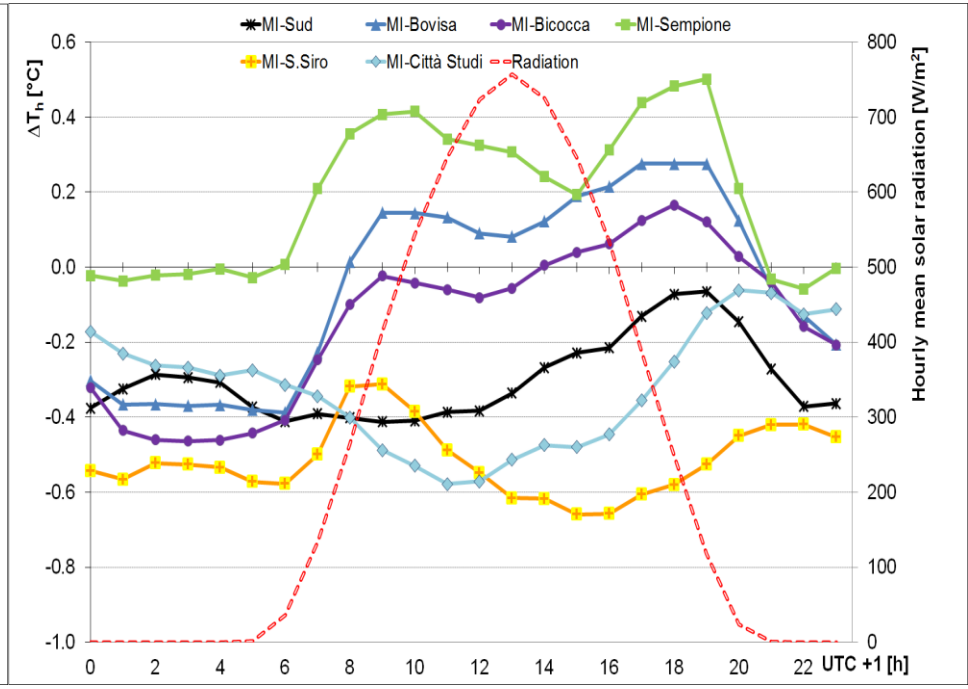
Hourly trends of ΔT_h, referring to T_{ref} defined as average of MI-Centro and MI-Bocconi mean hourly temperatures for the "*reduced dataset*".

Temperature

Winter



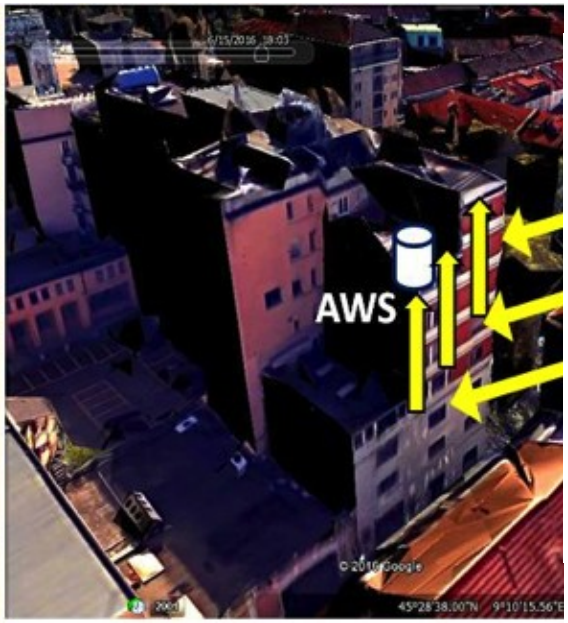
Summer

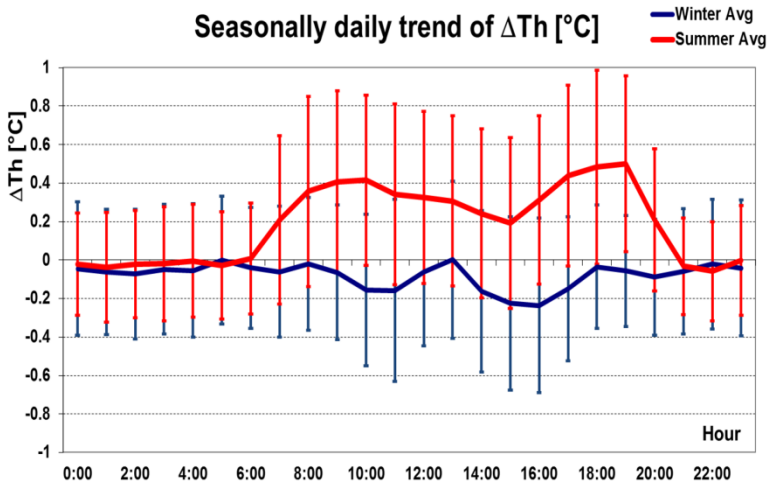


ΔT_h hourly trends in winter (left) and summer (right).

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

MI-Sempione





a) morning **b) afternoon**

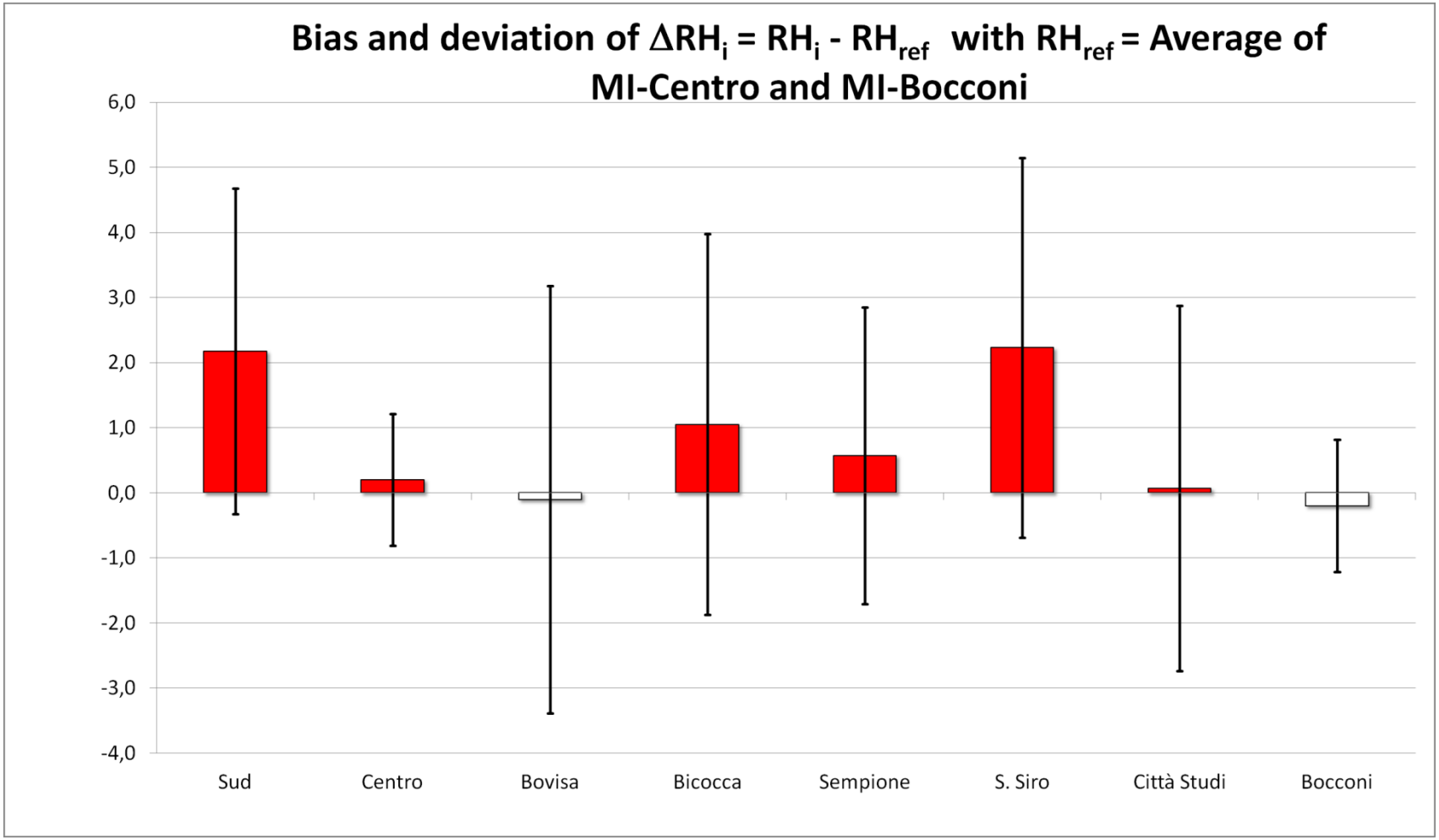
Summer exposures and direct solar illumination of underlying vertical walls at different day times for MI-Sempione Automatic Weather Station (AWS in pictures).

MI-Sempione

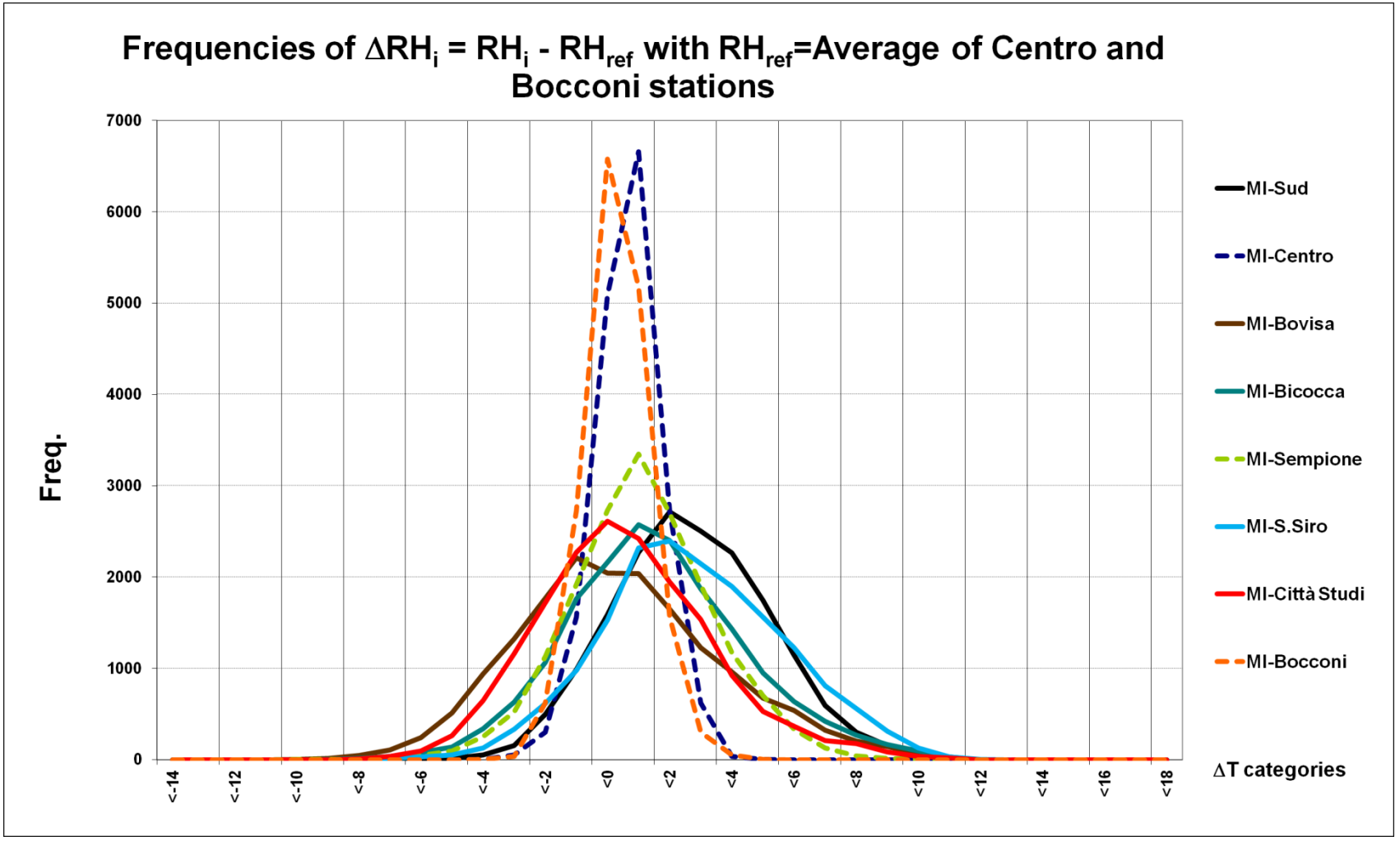
a) morning **b) afternoon**

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.

Relative Humidity Uncertainty estimates

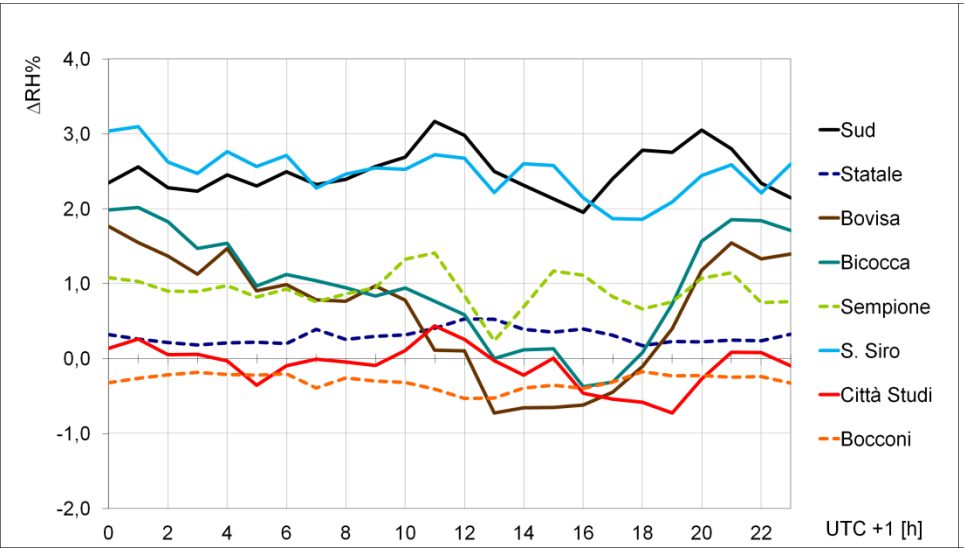


Statistical differences in Relative Humidity

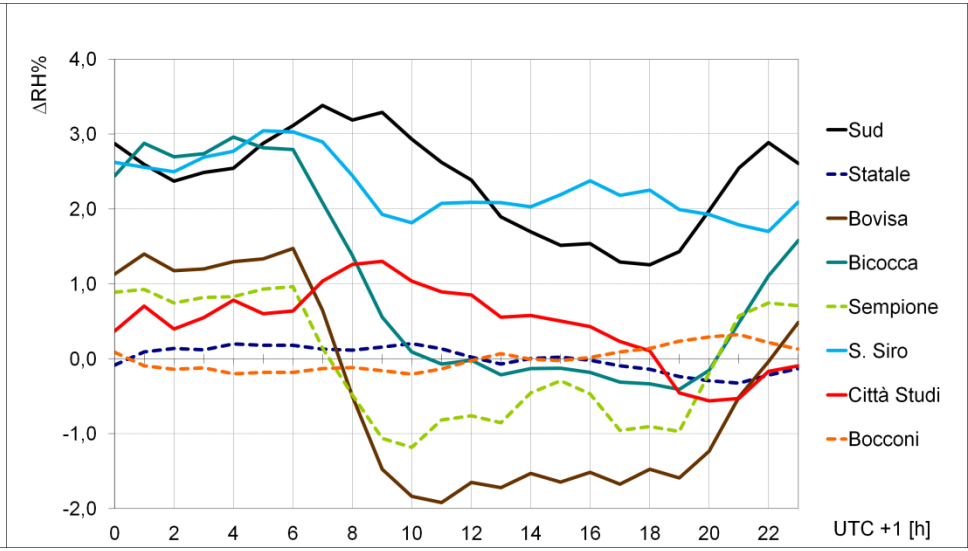


Relative Humidity

Winter



Summer



$\Delta(RH_h)$ hourly trends in winter (left) and summer (right).

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**.

Conclusions

- Collaboration **with INRIM in the MeteoMet framework:**
  motivation and stimulus ***to investigate specific metrological*** aspects of our urban measurements *(OMD contribution to a published paper)*

- **Methodology** developed and tested to estimate measure uncertainties in the ***urban environment*** *(published paper)*

- 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

- Implementation of **metrological procedures** to all the other variables
- Extension of the **uncertainty estimates** to all the measured variables

- Detailed investigation of the effects of urban local sources
  (**siting** near green areas, watersheds, etc.)

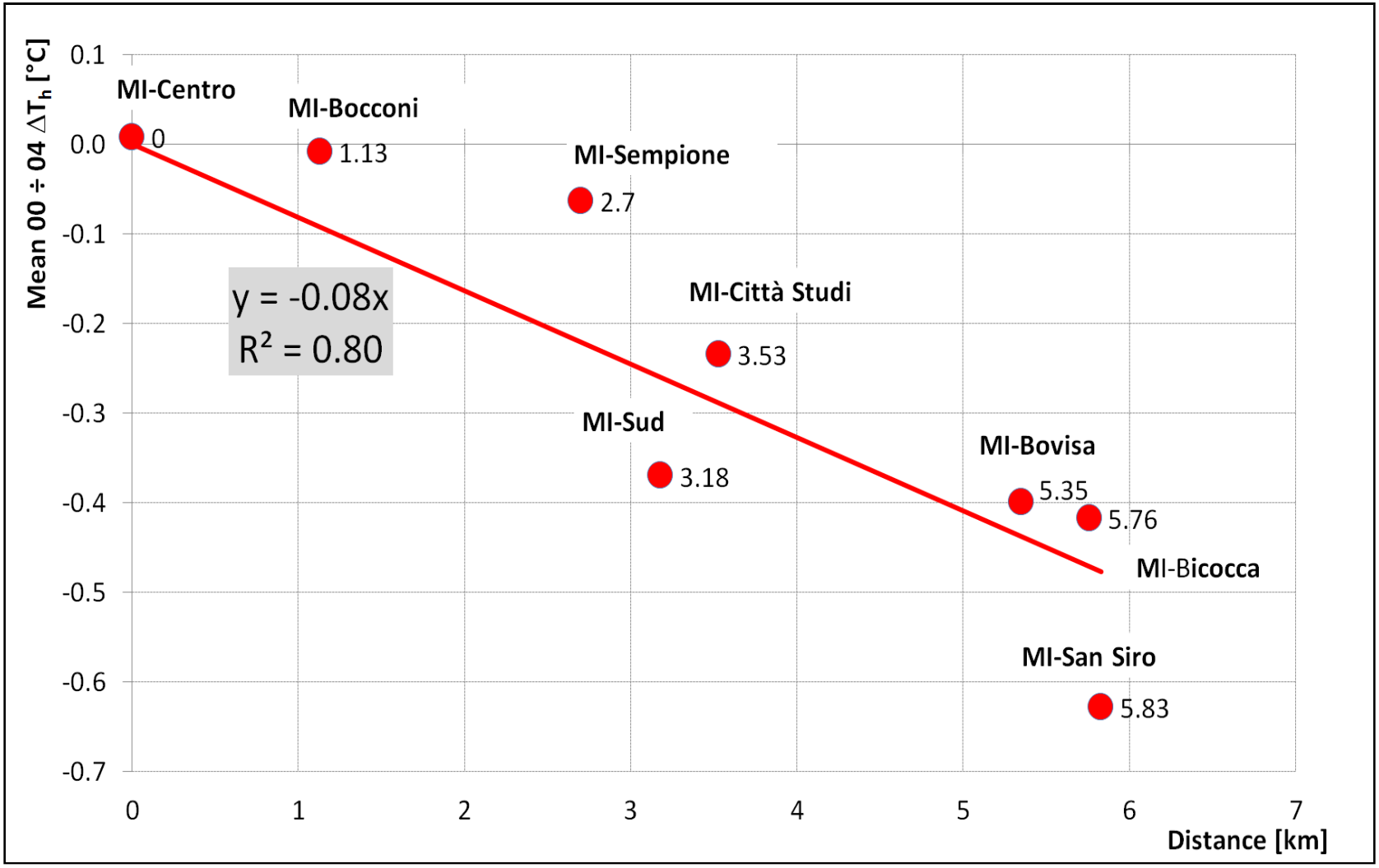
- Quantitative study of uncertainties and **exposure** metadata (**Milano** as a ***testbed?***)

- Comparison with other **types** of urban stations (at street level, for air quality monitoring, etc.)

..... ***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.).