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ASSESSING MEASURE UNCERTAINTY IN URBAN ENVIRONMENTS

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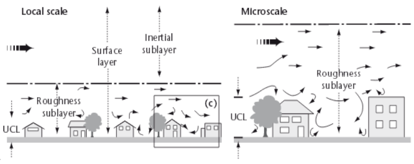
CLIMATE NETWORK OVERVIEW

CLIMATE NETWORK® (CN) is a private and professional network of urban meteorological stations in Italy, with commercial purposes.
It mainly supports the needs of energy industries and utilities: continuous supply of air temperature and relative humidity data for energy billing and thermal plants management and maintenance. CN users require comparable and high quality data about climates (thermal parameters and phenomena, i.e. UHI) in the main Italian towns, to evaluate performances and business. Consequently CN was designed and set up in urban context (city centres) with the constraint of combining strict siting homogeneity at national level, local scale representativeness, high metrological standards, easy maintenance.
The operative compromise was adoption of the following criteria:
- uniform rules for positioning stations at top Urban Canopy Layer;
- same last generation sensors in each station (Vaisala WXT520), with redundant temperature sensor, without moving parts;
- solar-powered stations, installed at roof level on enough tall masts;
- stations management and maintenance according to UNI EN ISO 9001 and Quality Assurance and Quality Control (QA/QC) procedures;
- daily remote instruments control and data validation performed by both automatic procedures and experienced meteorologists.

Besides air temperature, all CN stations measure relative humidity, atmospheric pressure, wind speed and direction, gusts, rain and hail. In Milano, only one station measures global solar radiation.

INTRODUCTION

Urban meteorology and climatology have been relevant research topics since several decades and have been considering more and more important due to growing worldwide urbanization. Several social and economical needs have to be addressed and require denser and more accurate measurements. Considering the complexity of urban environments, such topics are more difficult to deal with in comparison with synoptic ones. As a consequence of this complexity, the WMO station classification scheme [WMO-No.8, 2008 Editon, P-I_Ch-1, Annex 1.B] puts urban observational sites in the last two classes (classes 4 and 5), assigning to them very large uncertainties (up to 5°C). Measure uncertainty evaluation is only occasionally discussed in literature. The subject of specific recent WMO publications (Duvernoy, 2015) and it finds a stimulating reference frame in MeteoMet /MMC Projects [Merlone et al., 2015].
At the same time, availability of almost 5 years dataset by CN in Milano allows a quantitative investigation of how siting and exposure [Oke, WMO/TD No. 1250, 2006] affect measurements in cities and suggests a method to estimate additional uncertainties, if some pre-requisites are satisfied.
A first methodological approach has been tested.



CN stations are mainly installed on the roof terrace of typical buildings, measuring top UCL

METHODOLOGY

In first approximation the urban meteorological measure M can be broken up as the sum of several and independent contributions:

$$M = M_0 + \Delta M_m + \Delta M_s + \Delta M_i$$

where:
M_0 is the synoptic value, the greatest contribution uniquely determined by the large scale meteorological situation;
ΔM_m is a lower order effect due to meso/local scale meteorological phenomena;
ΔM_s is a lower order effect related to siting and exposure of the sensors;
ΔM_i is a lower order effect depending on instrumental and calibration uncertainties.

The contribution ΔM_i is known for CN weather stations, in according to WMO specifications that require well specified measurement and calibration uncertainties.
In order to investigate the uncertainty uniquely related to siting and exposition (ΔM_s) on the basis of data itself, it is necessary to select a database of meteorological situations where synoptic and mesoscale patterns (perturbations and front passages, fohn episodes, fog, etc.) do not cause considerable horizontal gradient of meteorological parameters inside the town. Moreover, in relation to very high percentage of stability conditions characterizing Milano and Po Valley, it is mandatory to single out Urban Heat Island (UHI) episodes that can produce a horizontal temperature difference of several degrees among city centre and suburb areas, as well as induced secondary circulations and related phenomena. Clearly, all these phenomena could overwhelm measure differences only due to different siting and/or exposition of individual sensors and must be eliminated or at least minimized.

Some criteria has been implemented to remove, from the initial database, measurements (hourly values) corresponding to such synoptic and meso/local scale phenomena. The database so selected consists of hourly data that satisfy the following requirements:
- mean urban hourly wind speed (i.e. average of the 8 stations corresponding values) less than or equal to 3 m/s;
- difference between maximum and minimum of mean hourly wind speed among all stations less than or equal to 2.5 m/s;
- difference between maximum and minimum of mean hourly temperature among all stations less than or equal to 2°C;
- difference between maximum and minimum of mean hourly relative humidity among all stations less than or equal to 10%.

This "*reduced dataset*" can be considered homogeneous and consistent from a meteorological point of view in relation to the aim of the study.

Here it is presented the method used for TEMPERATURE. It consists of two further steps:
- identification of Urban Reference Temperature;
- statistical analysis of temperature differences respect to Urban Reference Temperature for each station on hourly basis.

METADATA

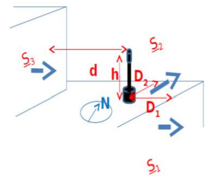
Extended metadata for each station have been established since the set up in a way very similar to that used in Birmingham [Müller et al., 2013; Chapman et al., 2015], with topo/photographic documentation of siting at different scales and detailed exposure parameters quantification.
Metadata have been then more recently completed with albedo measurements of the areas where the stations are located. The albedo was measured at the height of the instruments, with a secondary standard albedometer (i.e., CMA11 by Kipp & Zonen). In the urban network of Milano, subject of this study, the albedo show differences that do not exceed 7%: from 0,14 of MI-Sud station to 0,21 of MI-Bicocca. These values are mainly influenced by the roofing materials, mostly light gray concrete tiles, as their signal prevails in the field of view of the albedometer over that of the background.

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	

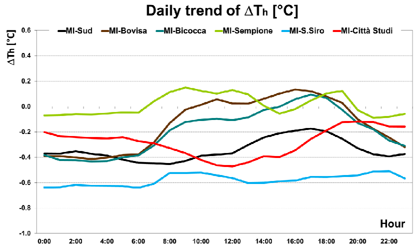
- h (m) - Height from roof top
- D1 (m) - Distance from 1st wall
- D2 (m) - Distance from 2nd wall
- S1 (m) - Height of 1st wall
- dir S1 - Exposure of 1st wall
- S2 (m) - Height of 2nd wall
- dir S2 - Exposure of 2nd wall
- d (m) - Distance from an eventual 3rd wall
- S3 (m) - Height of 3rd wall
- dir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



MI-Bicocca metadata as an example, with albedo measurements of the underlying surface

DATASET AND ANALYSIS: TEMPERATURE

1) Reduced Dataset and Urban Reference Temperature

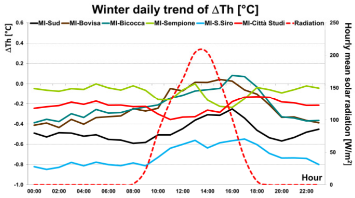


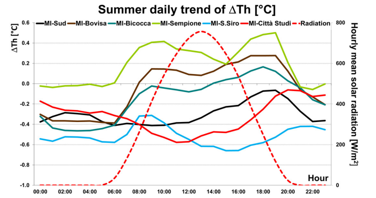
The target area is Milano and its 8 CN stations in the period from 01/12/2012 to 21/09/2015. The Reduced Dataset consist of the mean hourly temperatures for each station equal to 69% of complete database.
At first the reference temperature was estimated as the hourly mean of all urban weather stations. Comparing hourly temperature differences between each station and such reference temperature, we could observe similar behaviours (biases and reduced amplitudes) for 2 weather stations: MI-Centro and MI-Bocconi.
Both these stations are in Milano downtown and best comply with CN siting criteria.

Therefore, only MI-Centro and MI-Bocconi have been hourly averaged to define *Urban Reference Temperature* (T_{ref}).
Deviations from this reference (ΔT_h) have then been studied for each of the other 6 weather stations.

ΔT_h mean daily trends appear to be modulated with different amplitudes, periodicities and times of maxima/minima for each station. But in all cases they are evidently influenced by solar radiation.
Considering only nocturnal hours, when solar radiation is completely absent, ΔT_h show everywhere a constant trend and are lower than T_{ref}.
It has been interpreted as evidence that diurnal ΔT_h variation depends mainly on solar radiation due to exposure.

2) Seasonal Daily Trends





In winter ΔT_h mean daily trends show an increase in variability during daylight hours. Some features are worthy of attention:
- nighttime MI-Sempione shows ΔT_h values close to T_{ref} and two minima recorded at 10 a.m. and 4 p.m., in a limited range of values;
- MI-Bovisa, MI-Bicocca, MI-Sud and MI-S.Siro, although characterized by different night biases, have the same trend. In the morning ΔT_h increases starting by bias until they reach a maximum in the afternoon, at about 4-5 p.m.;
- MI-Città Studi has an opposite trend, showing a minimum around 12 a.m..

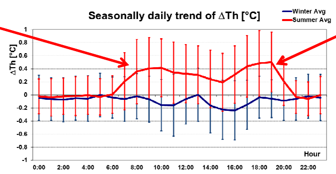
In summer ΔT_h variability is higher compared to winter everywhere. We can note:
- during night MI-Sempione shows ΔT_h which are close to T_{ref} as in winter but trend becomes bimodal daytime with two maxima of 0.4°C and 0.5 °C at 9 a.m. and 8 p.m. respectively;
- MI-Bovisa, MI-Bicocca and MI-Sud have very close nighttime biases; but during daylight they show different increasing trends and reach the maximum in the afternoon around 6 or 7 p.m.;
- MI-Città Studi shows an opposite trend with minimum at 11-12 a.m., as in winter;
- MI-S.Siro shows an increasing trend, related only to sunrise hours.

Moreover, even if many daily trends show a bimodal behavior we can only partially explain. Further studies and analysis should be required.

3) Peculiarities

Milano Sempione

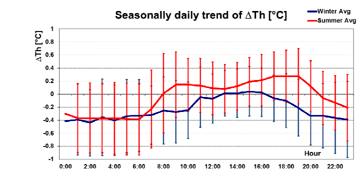
The bimodal character is clearly evident in summer (stronger irradiation) with morning and afternoon maxima.



During morning, underlying wall facing NE is directly irradiated by sun. This induces an upward flow of warm air that reaches AWS and causess an increase of ΔT_h (first maximum)

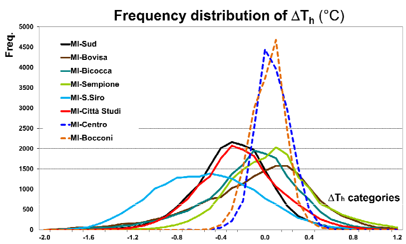
The same effect happens again in late afternoon when the NW wall is exposed to the sun, producing the second maximum.

Milano Bovisa



Strict connection with solar radiation is further supported by different start/end times of increase and decrease of ΔT_h according to the different seasonal daylight hours. Among all stations, MI-Bovisa shows the highest positive variability of diurnal ΔT_h compared to nocturnal ΔT_h. It was supposed that this higher increase is due to combined effects generated by air flow rising from underlying wall and from solar panels placed behind station.

4) Uncertainty

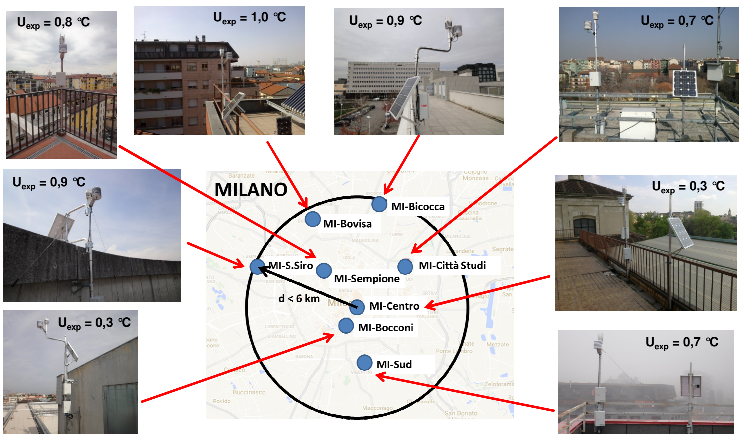


Dashed lines for MI-Centro and MI-Bocconi, taken as reference in analysis

The frequency distribution of ΔT_h is clearly different in each weather stations. Two stations (MI-Centro and MI-Bocconi) have a very similar and nearly Gaussian distribution, with low and comparable standard deviations, as expected. This result supports their choice as references. The other stations show a variety of biases, amplitudes and also deviations from the Gaussian form, that can be explained by metadata itself at some extend.
In relation to MI-Centro and MI-Bocconi we can assume that the standard deviation of distribution is an approximate measure of the added uncertainty due to siting (which affect mainly bias) and exposure (affecting mostly data distribution around the mean).
In order to asses expandend uncertainty U_{exp}, we apply a coverage factor k=2 to standard deviation, corresponding to the 95% confidence level.
For the reference stations **MI-Centro and MI-Bocconi we get the minimum value U_{exp}=0,3°C, while MI-Bovisa shows the maximum U_{exp}=1,0°C.**

CONCLUSIONS

Statistical analysis of temperature differences respect to a suitable urban reference has been performed for a 3 years database, representative of meteorological conditions quite homogeneous in the area of study at synoptic and meso/local scale. It revealed for some stations a strict dependence on explicitly defined exposure parameters, especially related to distance from underlying vertical walls exposed to solar irradiation and to shadowing. Moreover, with clearly stated objectives (in our case measurements at top UCL for operational urban energy applications), homogeneous sensor technical characteristics, well documented technical, siting and exposure metadata and a correct metrological procedure, **the additional uncertainty on long term hourly averages of temperature due to siting/exposure can be estimated at less than 1°C also in typically complex urban environments**. This is much less than the estimated 5°C uncertainty indicated by WMO Guide No.8, but significantly larger than the calibration uncertainty of about 0.2 °C.



Climate Network weather stations in Milano and their uncertainties due to siting/exposure

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