vEGU21-16430

High resolution air temperature maps for urban planning and management

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FONDAZIONE OMD

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RATIONALE

- **Urban meteorological networks are** undoubtedly useful but generally **unfit** to climatological studies and unable to describe Air Temperature in the **Urban Canopy Layer** (UCL) with **sufficient spatial resolution**, as required by several professional activities and for local adaptation measures to climate change.
- **Remote sensing data from space** are offering a higher spatial resolution (even if a still very low frequency) of surface characteristics as the **Land Surface Temperature** (LST) and are easily accessible.
- Often used to describe the Surface Urban Heat Islands (S-UHI), **LST** has not a simple correlation with **UCL Air Temperature**, which is the most required variable for planning and management purposes in cities.
- **Using both** high quality in situ measurements of Air Temperature at top of UCL obtained by a dedicated

  urban network (FOMD CN) and other selected AWS as a **primary variable**,

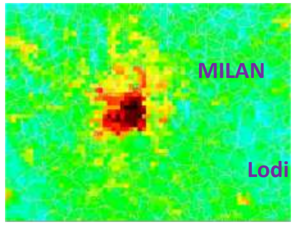
  and satellite derived LSTs as the **secondary** one,

  a **Co-Kriging based methodology** has been developed and tested

  to obtain medium to high spatial resolution UCL Air Temperature maps
- **Instantaneous** as well as **mean fields** of **fine spatially resolved Air Temperature** find relevant application not only in monitoring and assessing activities of adaptation and mitigation measures in the urban environment, but also in urban climate studies.

Workflow

- **1st Variable**: T_{air} measured by surface meteorological networks in the UCL (z_1)



- **2nd Variable**: LST obtained by IR radiation remotely sensed from space (z_2)

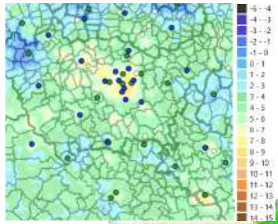
Co-Kriging of 1st (primary) and 2nd (secondary) variables:

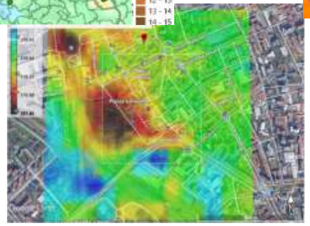
$$z_1^*(x_0) = \sum_{\propto=1}^{n_1} \lambda_\alpha \cdot z_1(x_\alpha) + \sum_{\propto=1}^{n_2} \omega_\alpha \cdot z_2(x_\alpha)$$

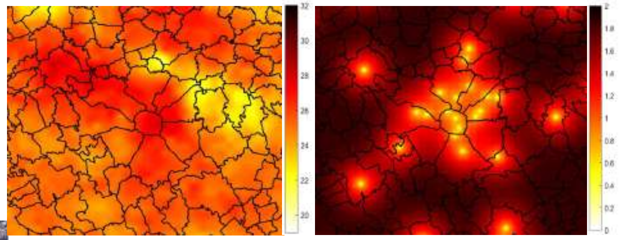
⇒ **Results**: Medium- to high-resolution T_{air} fields in UCL and associated <u>uncertainties</u>

⇒ **Applications**:

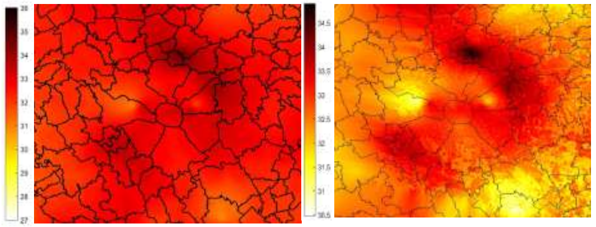
- Climatology of UHI and HW
- Air Temperature Atlas
- Assessment of urbanistic modifications for adaptation to Climate Change







Medium resolution (10^2m x 10^2m) COK interpolation: T_a and $U(T_a)$ 2018-07-07: 22UTC

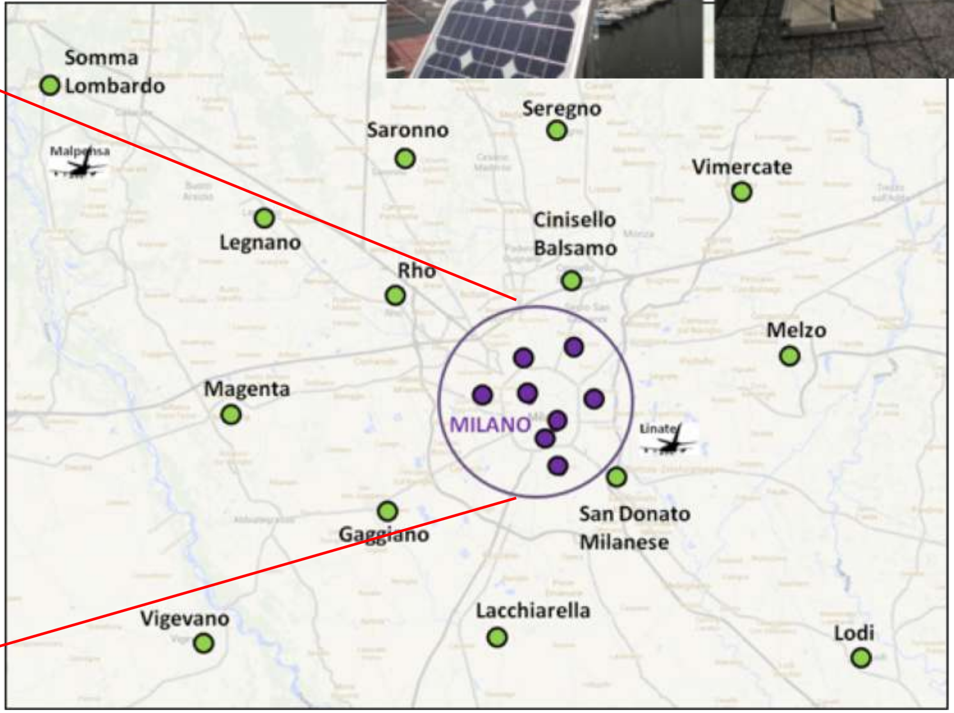


Medium (left) and high (right: 30 m x 30 m) COK interpolated T_a: 2019-07-26:10utc

Primary Variable (1):
T_{air} from a high quality meteorological network (under sampled)

1) **FOMD Italian Urban Climate Network (CN), Milan subnet (21 AWS)** **(Curci et al., MST, 2017):**

T_{air} and other **ECVs** at top of **UCL** in Milan and surroundings measured with metrological criteria since 2011 (*MeteoMet Project*)



Primary Variable (2):
T_{air} from supplementary meteorological networks (under sampled)

- **Selected** (Frustaci et al., EGU 2019) stations for T_{air} :
  - in the city (urban Air Quality network)
  - and outside the city (rural stations)

  from **Regional Meteorological Service**

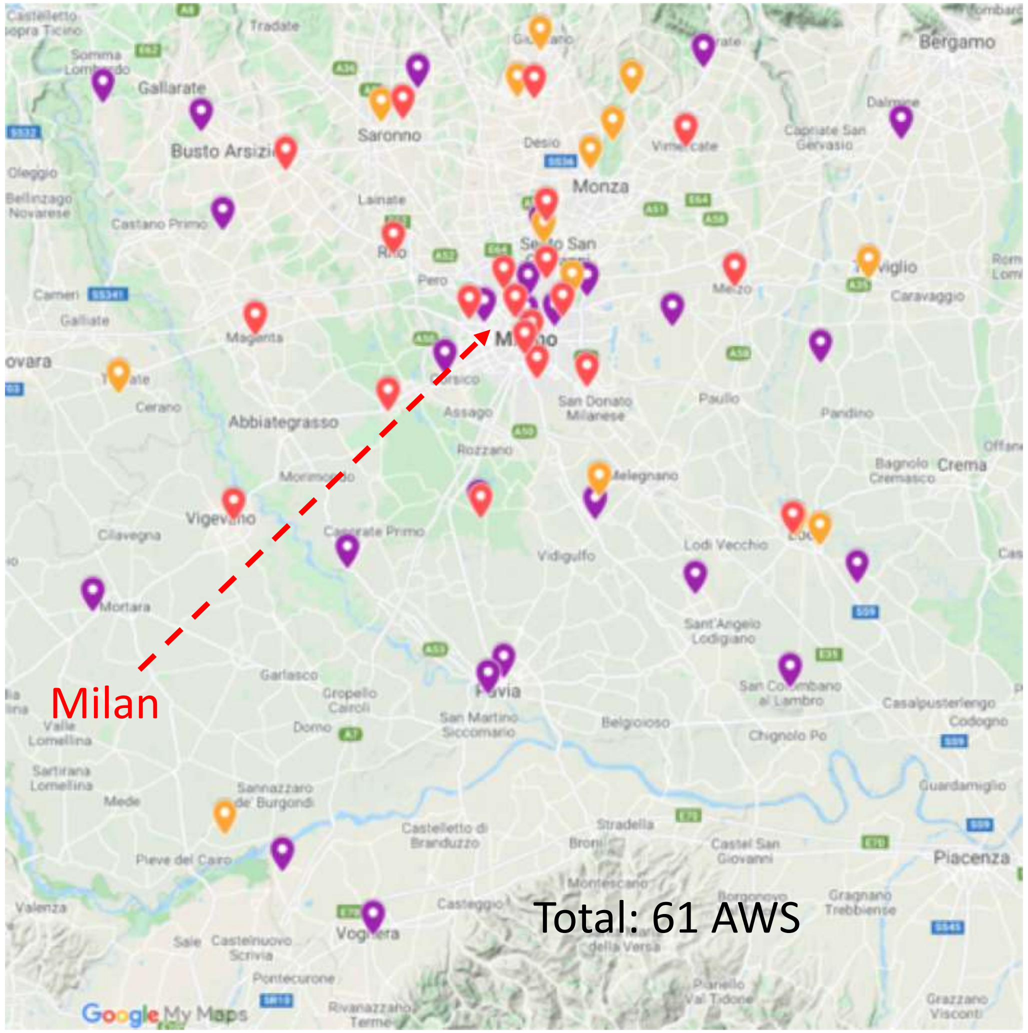
  (26 AWS, ARPA Lombardia:

  https://www.arpalombardia.it/):

- **Selected** stations for T_{air} from amateur network, **14 AWS**)

  (**Meteonetwork: https://www.meteonetwork.it/**):

  Climate Network – FOMD (CN, 21 AWS):
  (https://www.fondazioneomd.it/)

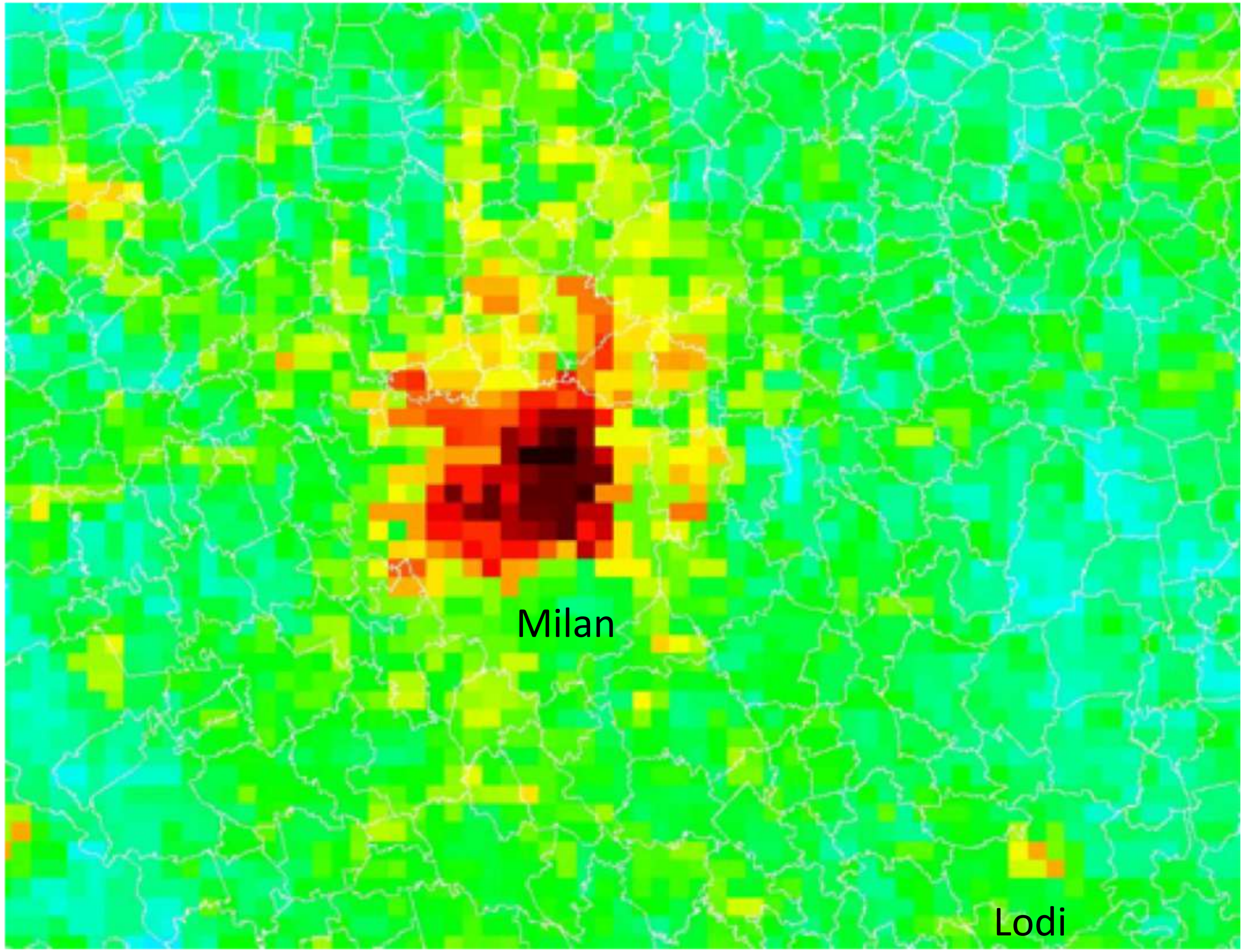


Secondary Variable (1): T_s remotely sensed from space (LST)

- **Land Surface Temperature (LST)**
  at medium resolution (1000 m)
  from Sentinel 3 A&B– ESA-Copernicus

(**Sobrino et. al., Remote Sensing of Env., 2016**)

Good spatial sampling!



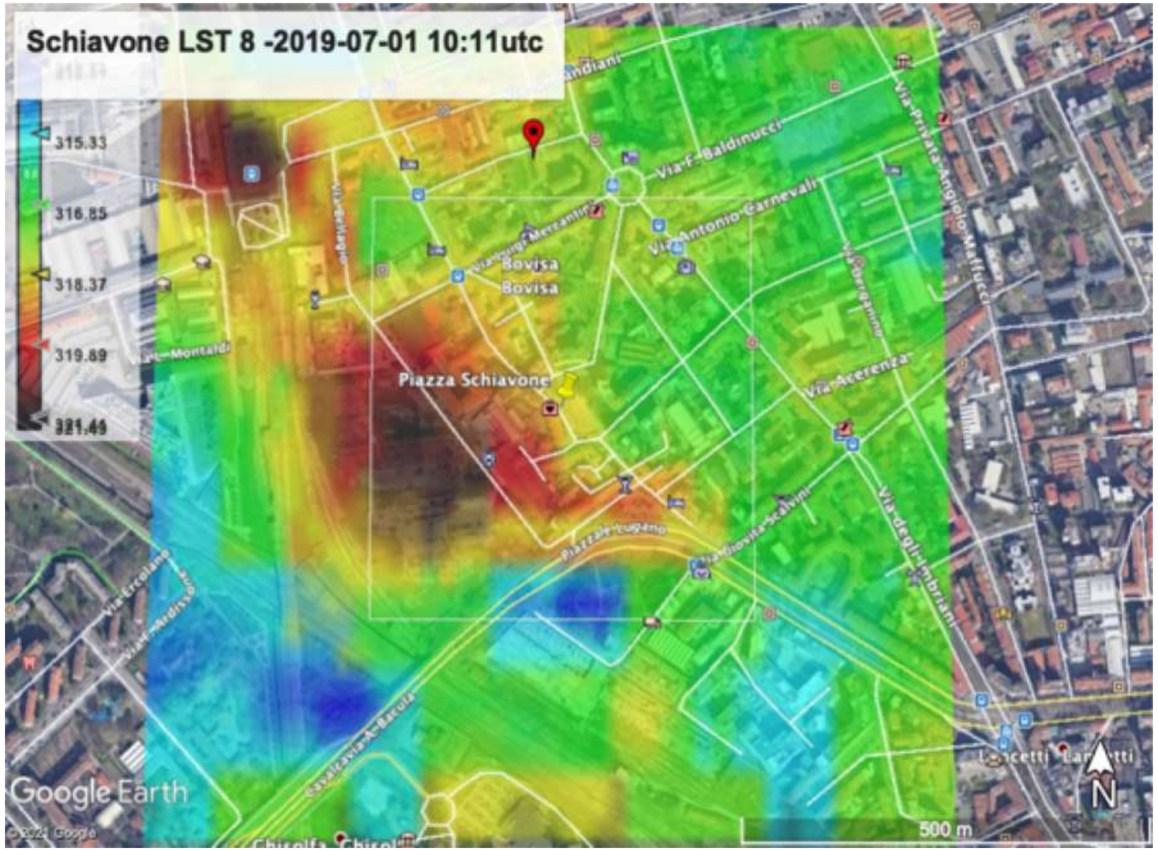
Sentinel 3 (LST, 1 km resolution):
Milan and surroundings, 2018-07-07 09:10 UTC

Secondary Variable (2):
T_s remotely sensed from space (LST)

- **Land Surface Temperature (LST)**
  at high resolution (30 m)
  from Landsat 8 (NOAA & USGS)

  (**Ermida et al., Remote Sensing 2020**)

  Very good spatial sampling!



Landsat 8 (LST, 30 m resolution):
Milan, Piazza Schiavone and surroundings, 2019-07-01 10:11 UTC

Kriging of T_{air} and LST: co-kriging (1)

STEP 1

Empirical **semi-variograms γ** for $\mathbf{T_{air}}$ and for **LST** data:

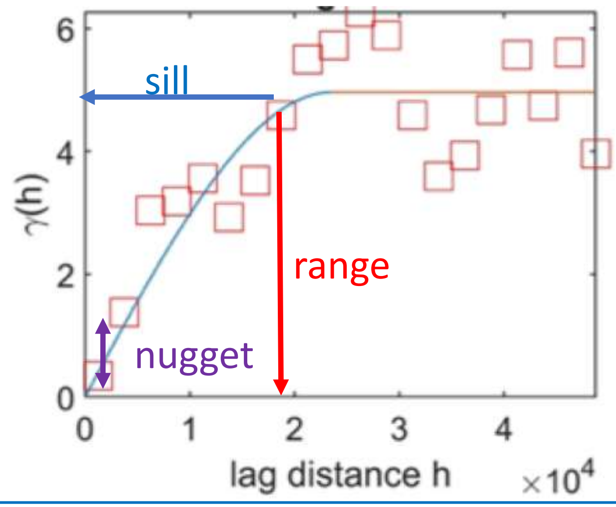
$$\gamma(h) = \frac{1}{2N(h)} \sum_{i=1}^{N(h)} [z(x_i) - z(x_i + h)]^2$$

- **Z**: regionalized variable
- $\boldsymbol{x_i}$: position in the domain
- ***h***: distance between points
- ***N(h)***: *number of point pairs* separated by *h.*

STEP 2

Fitting of a modell for the semi-variogram (a *sferical model proves to be the best one):*

$$\gamma(h) = \begin{cases} c\left[1{,}5 \cdot \left(\frac{r}{a}\right) - 0{,}5 \cdot \left(\frac{r^3}{a^3}\right)\right] & r = |h| \le a \\ c & r = |h| \ge a \end{cases}$$



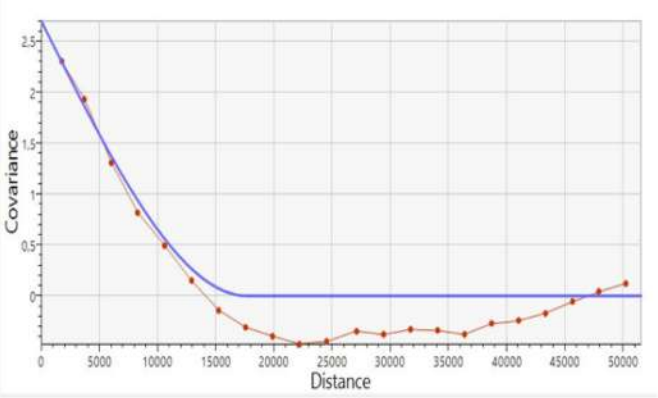
⇒ **a: Range**

⇒ **c: Sill**

(Nugget ≈ 0)

STEP 3

Cross-variogram
(build with the covariances of $\mathbf{T_{air}}$ *and* ***LST*** *and fitted again with a spherical model)*



$$\gamma'(h) = \frac{1}{N(h)} \sum_{i=1}^{N(h)} [z_1(x_i) - Z_1][z_2(x_i + h) - Z_2]$$

Z_1, Z_2: Mean values

Kriging of T_{air} and LST: co-kriging (2)

STEP 4: co-kriging Interpolation

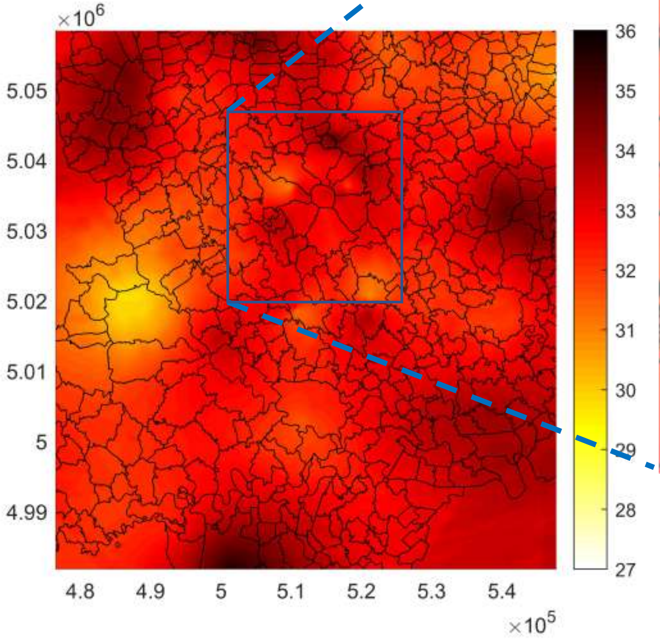
$$z_1^*(x_0) = \sum_{\propto=1}^{n_1} \lambda_\alpha \cdot z_1(x_\alpha) + \sum_{\propto=1}^{n_2} \omega_\alpha \cdot z_2(x_\alpha)$$

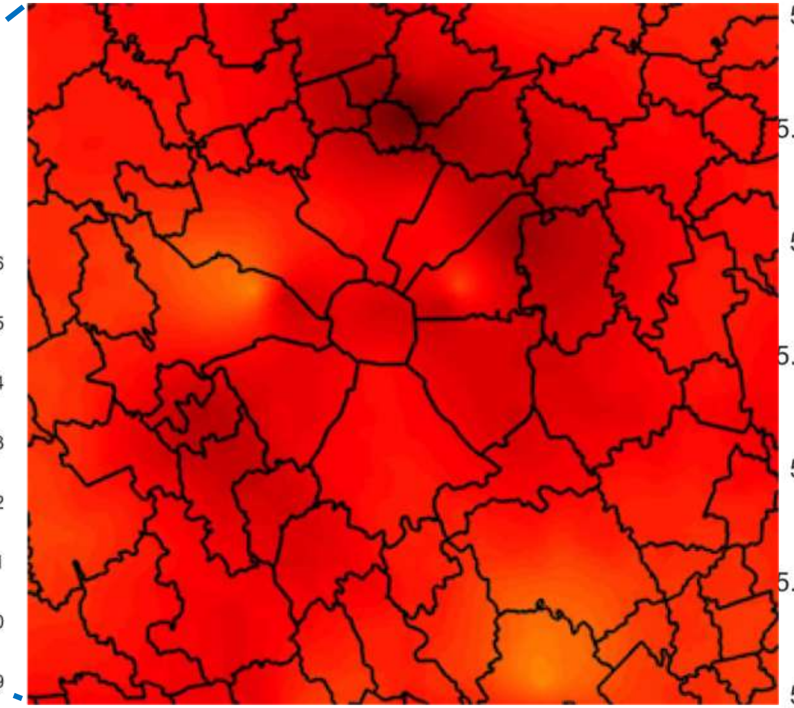
where z_1 is T_{air} and z_2 is the LST value (λ_α *and* ω_α *are the correspondent weights*)

The weights are obtained as solutions of a linear equation system (Linear Model of Coregionalization), with the condition of positive definiteness (Bourgault et al. 1991)

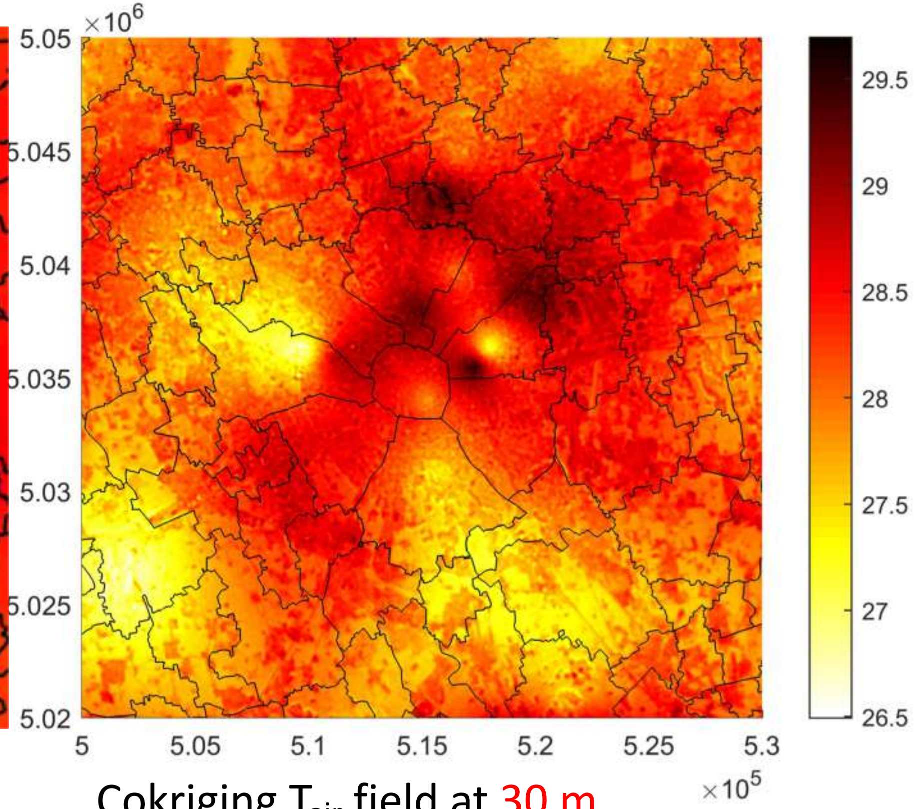
Example: Heat Wave episode and Milan UHI at 100 m and at 30 m resolution

2019-07-26, AM:
Heatwave episode with the Milan UHI maximum shifted to NE





Cokriging T_{air} field at 100 m using LST data from Sentinel 3



Cokriging T_{air} field at 30 m using LST data from Landsat 8

Weather types selection for applications

Selection Criteria:

- **I_{UHI} < 3°C:** Well developed Urban Heat Island over the city (at least one of eight downtown AWS)
- **Max (I_{uhi}) position in the city:** the 6 most frequent choices **(NE, E, S, W, NW, Centre)**
- **V_x < 1.3 m/s:** low winds, relative to the local climatology (Po valley) **(**Frustaci et al., Climatology of the Milano Canopy Urban Heat Island by means of an operational urban meteorological network, 2° National Congress AISAM, Neaples, 2019**)**
- **Weather Type:** high pressure anticyclonic **(**Borghi S., Giuliacci M.,….. , 1979**)**
- **Heat Waves (**WMO, Heatwaves and Health: Guidance on Warning-System Development, 2015**)**

Further:

- Only **Winter** (DJF) and **Summer** (JJA) months
- Only **Morning** (10 to 12 LT) and **evening** (21 to 23 LT) **hours** (Satellite passes)

Zone	No of events	Percentage (%)
NE	1	0,5
Centre	166	79,4
NW	0	0,0
E	39	18,7
W	3	1,4
S	0	0,0
TOTAL	**209**	**100**

Winter evenings

Zone	No of events	Percentage (%)
NE	16	17,8
Centre	41	45,6
NW	3	3,3
E	14	15,6
W	14	15,6
S	2	2,2
TOTAL	**90**	**100**

Winter mornings

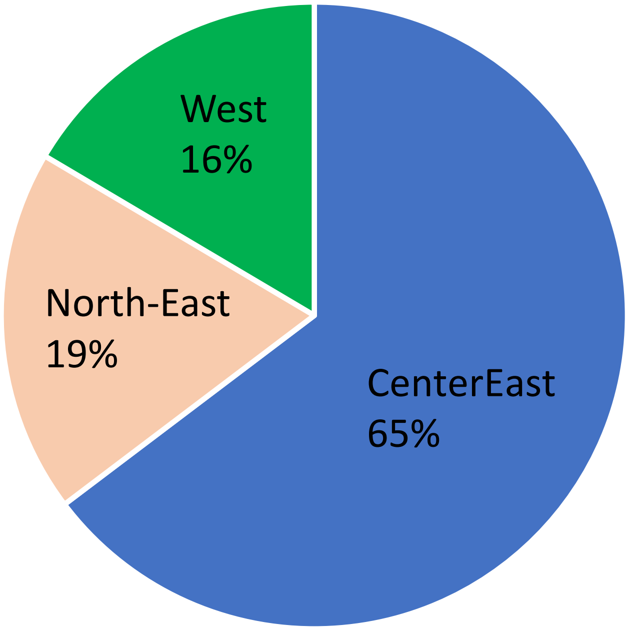
Summer mornings: None (no I_{uhi} ≥ 3 °C)

Zone	No of events	Percentage (%)
NE	8	2,3
Centre	202	58,4
NW	68	19,7
E	61	17,6
W	2	0,6
S	5	1,4
TOTAL	**346**	**100**

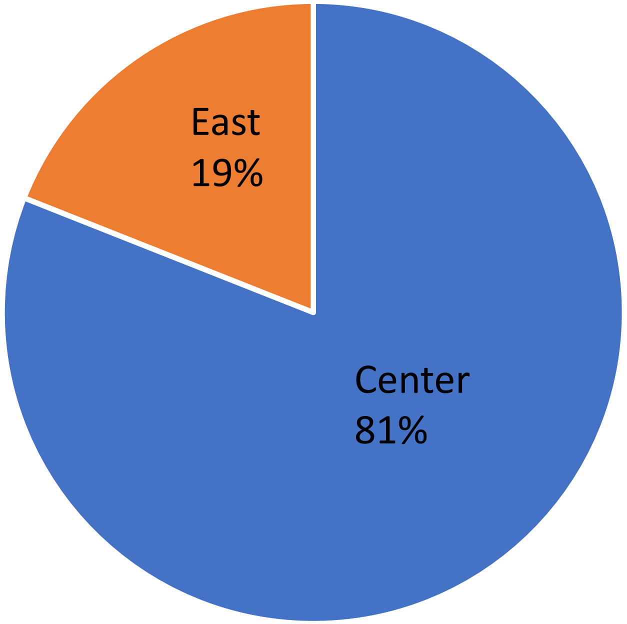
Summer evenings

Frequencies of selected Weather Types for applications

Winter UHI 11:00 UTC+1

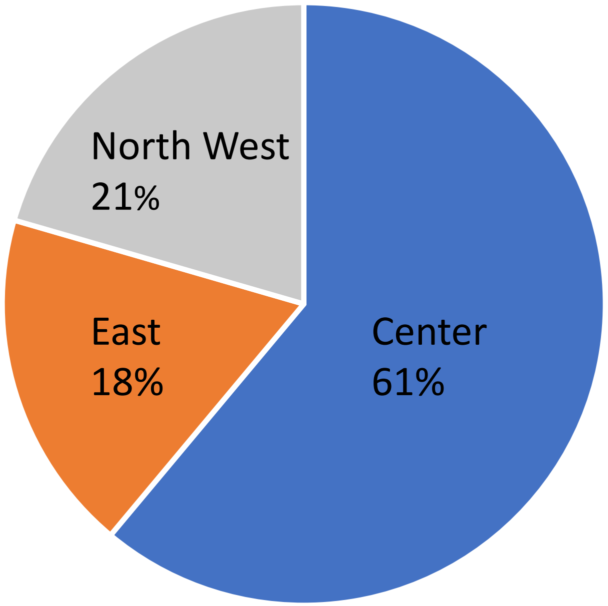


Winter UHI 22:00 UTC+1



No UHI > 3°C in summer mornings!

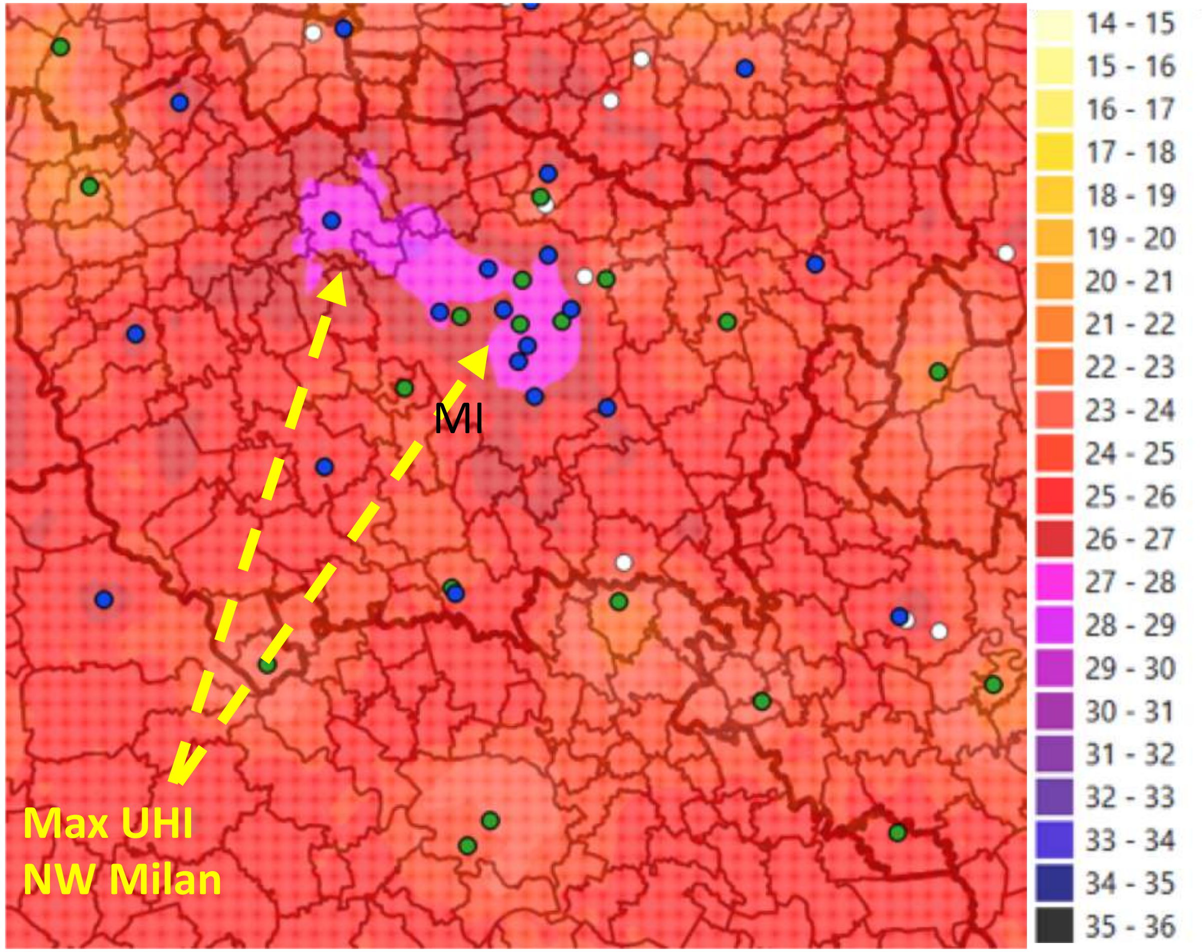
Summer UHI 22:00 UTC+1



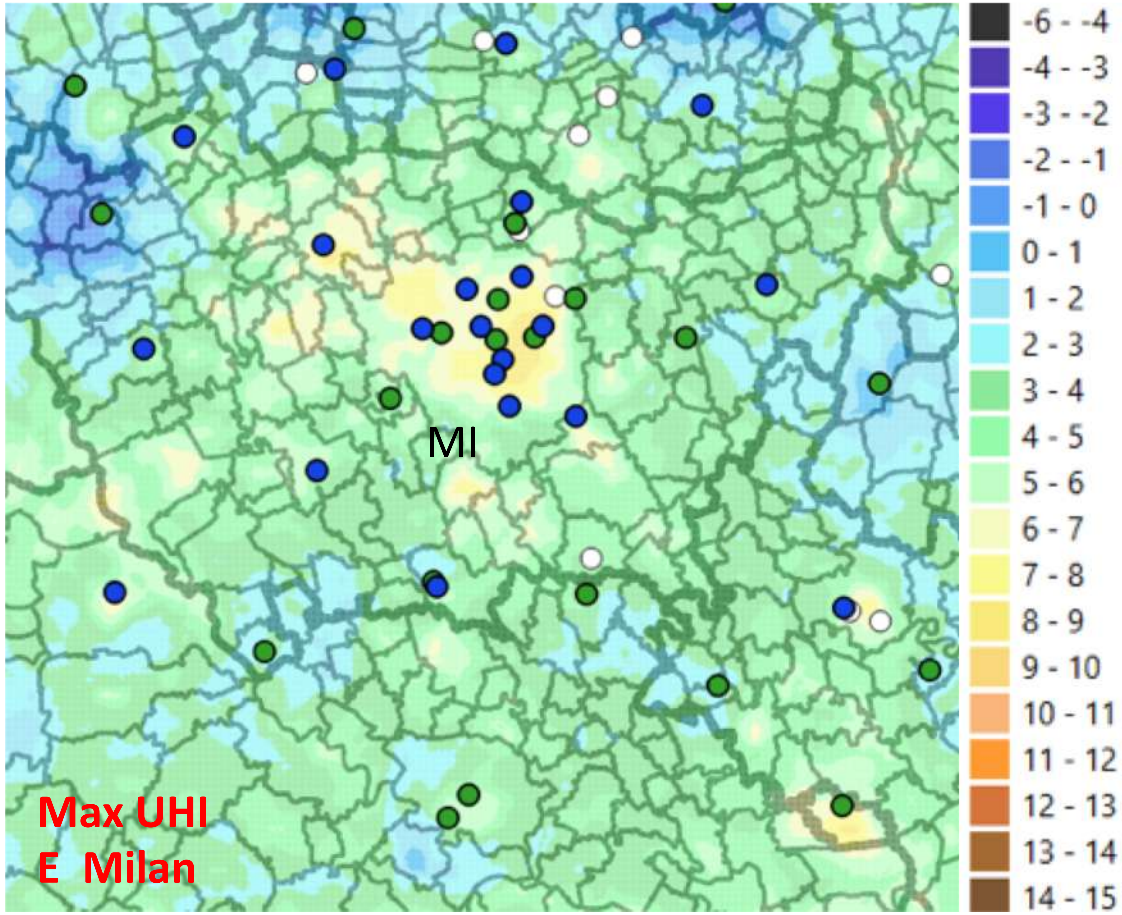
G. Frustaci et al. -vEGU21 - 16430

Example: Mean T_{air} in and around Milan at 100 m resolution

Mean T_{air} for STC «Summer _UHI_evening_NW»

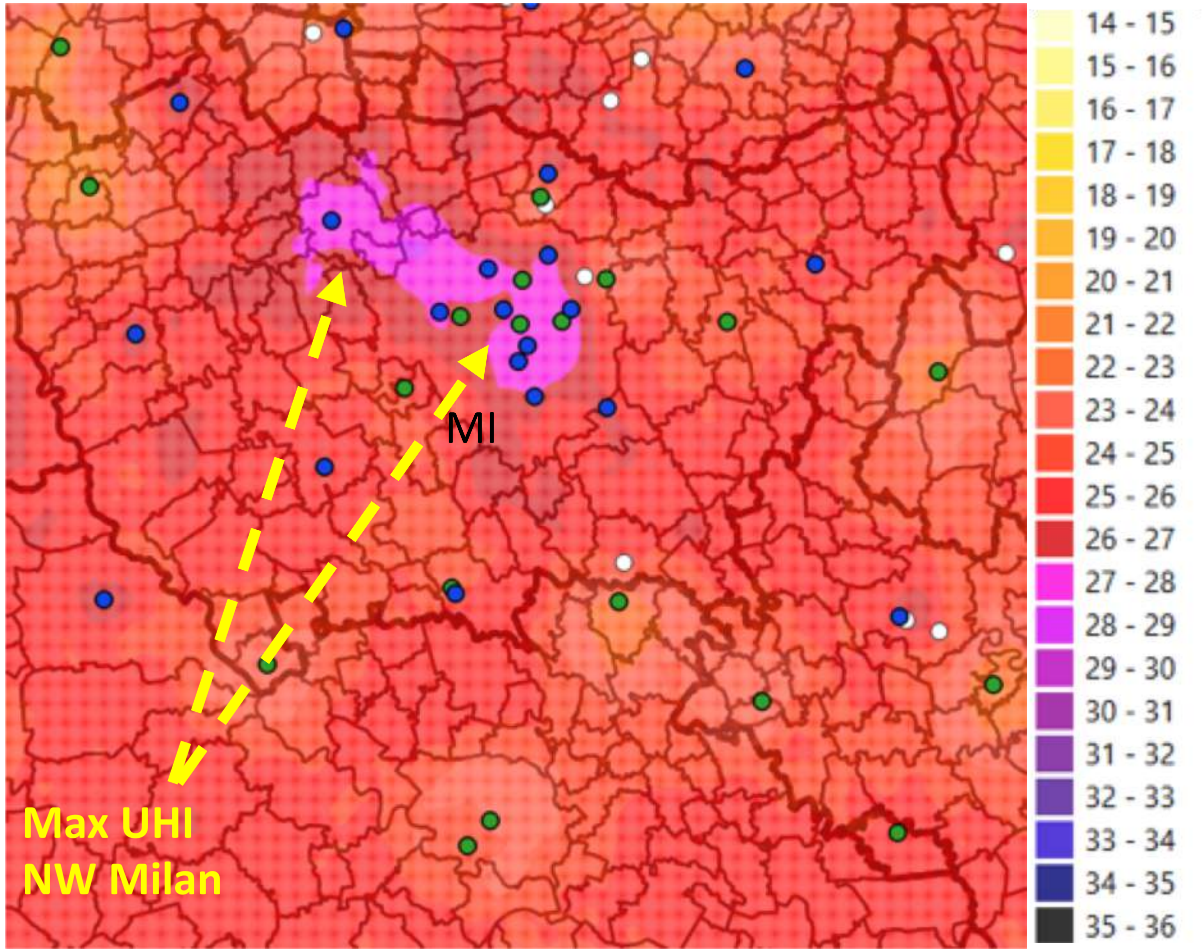


Mean T_{air} for STC «Winter _UHI_evening_E»

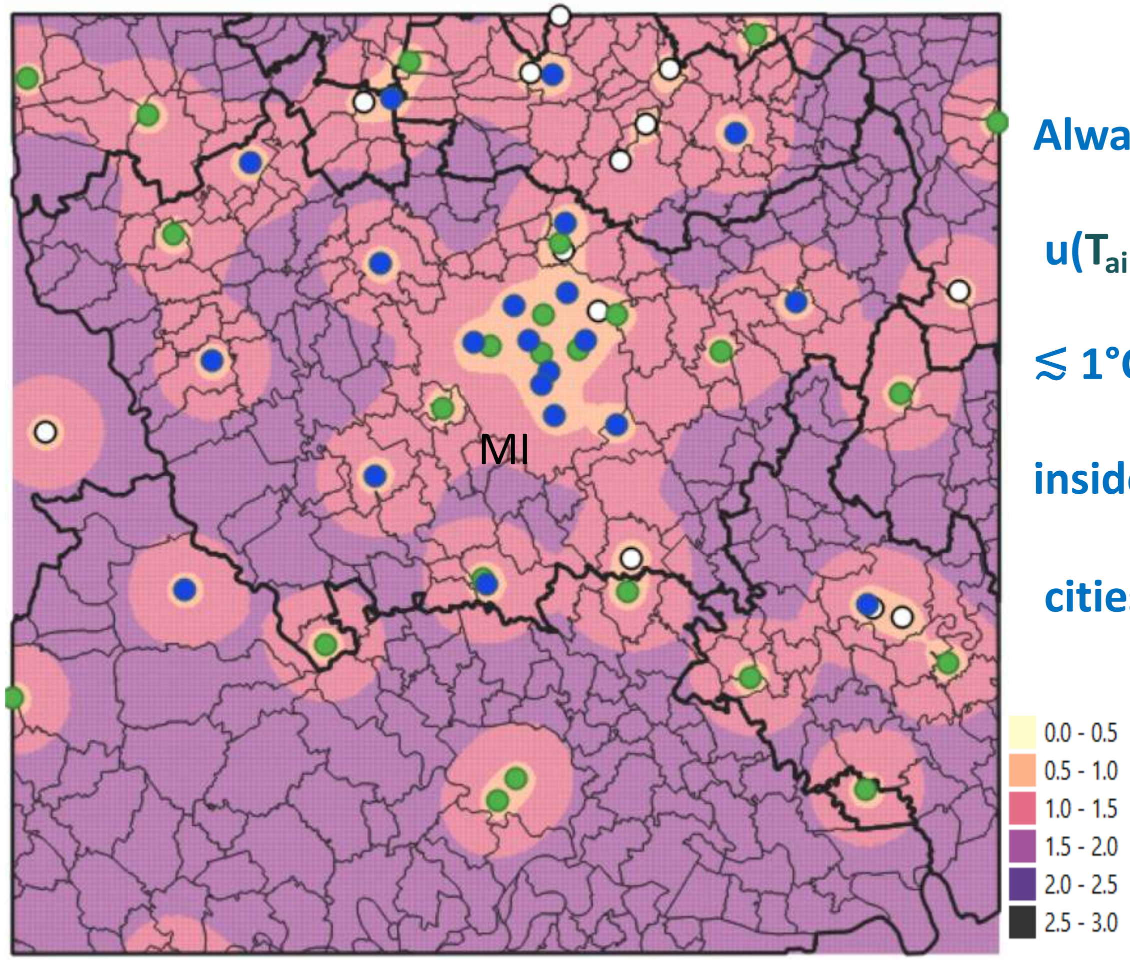


Example: Mean T_{air} uncertainties at 100 m resolution

Mean T_{air} Summer _UHI_NW_22 UTC+1



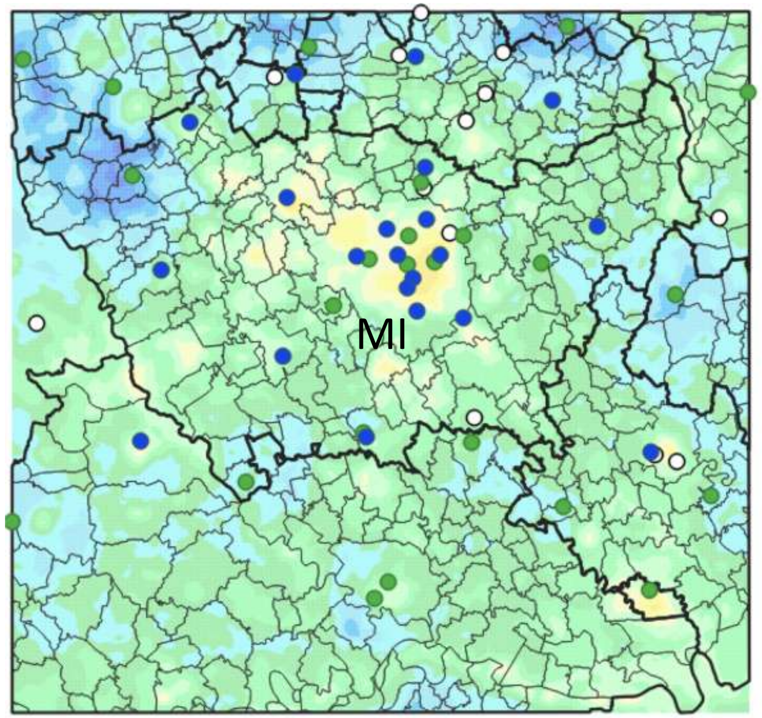
T_{air} uncertainty Summer _UHI_NW_22 UTC+1



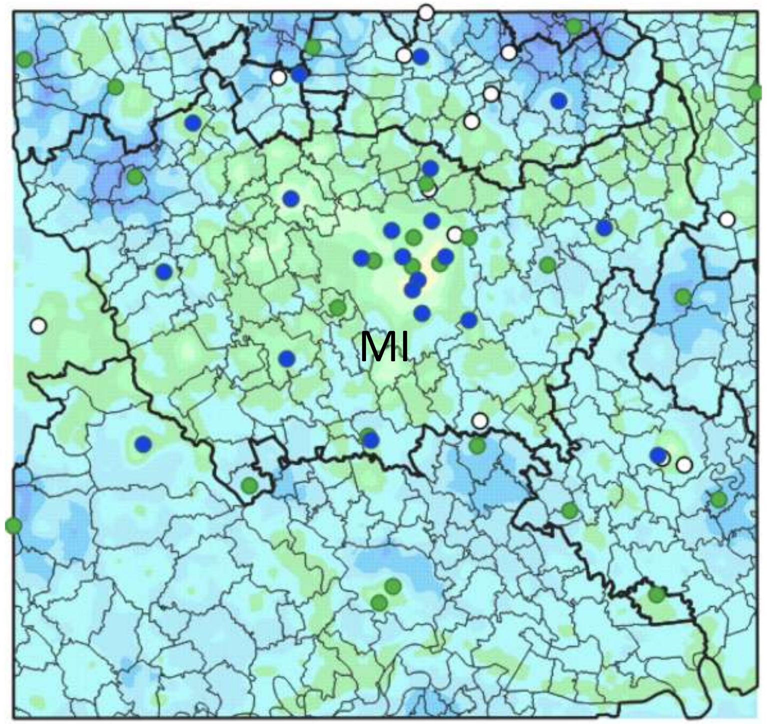
Always $u(T_{air}) \lesssim 1°C$ inside cities

Application for adaptation: Milan T_{air} Atlas

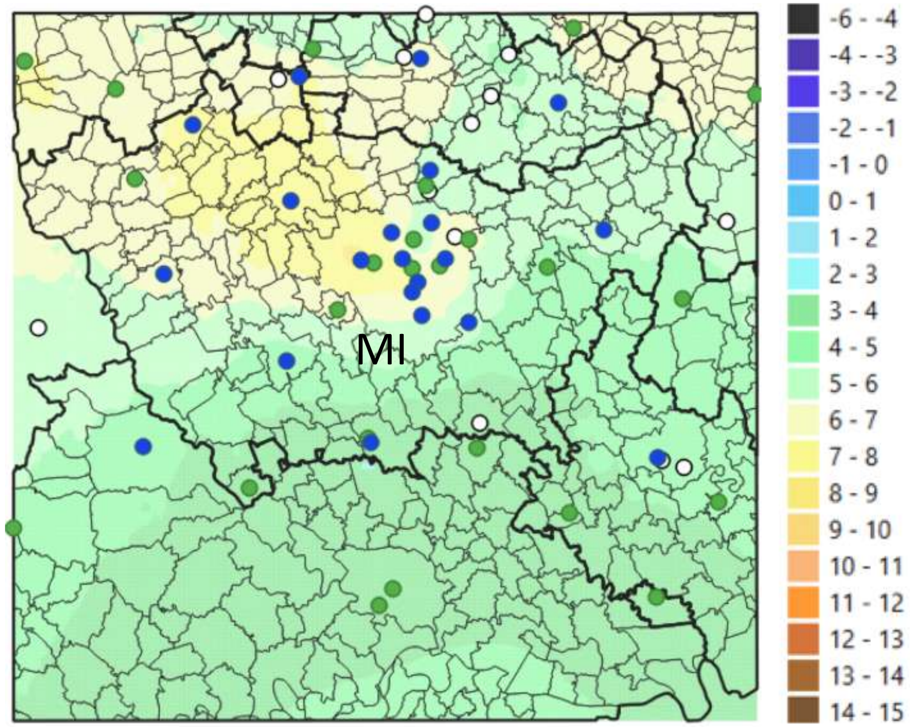
ClimaMi Project: ***https://www.progettoclimami.it/atlante*** ***(48 maps)***



Winter_Mean UHI_East_22 UTC+1



Winter_Mean UHI_Center_22 UTC+1

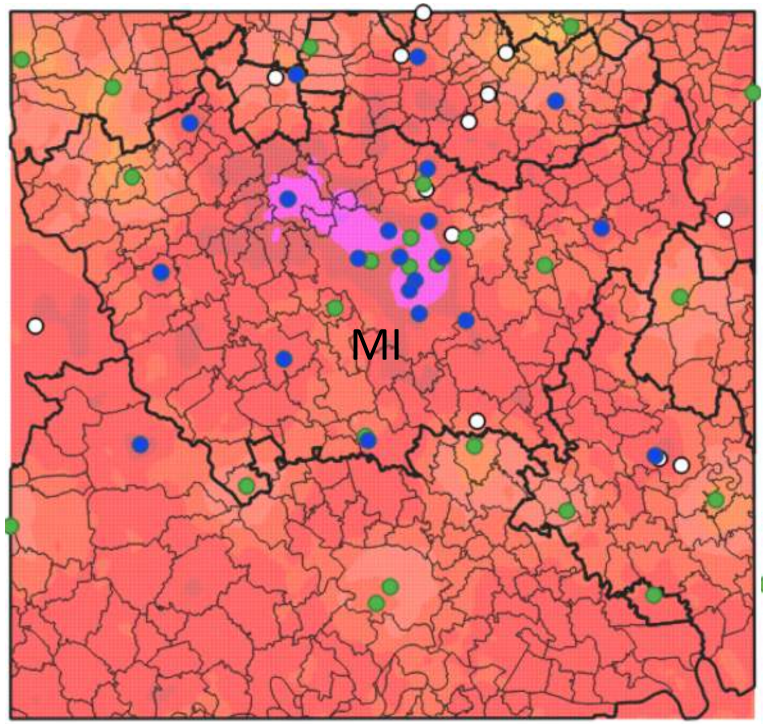


Winter_Mean UHI_West_11 UTC+1

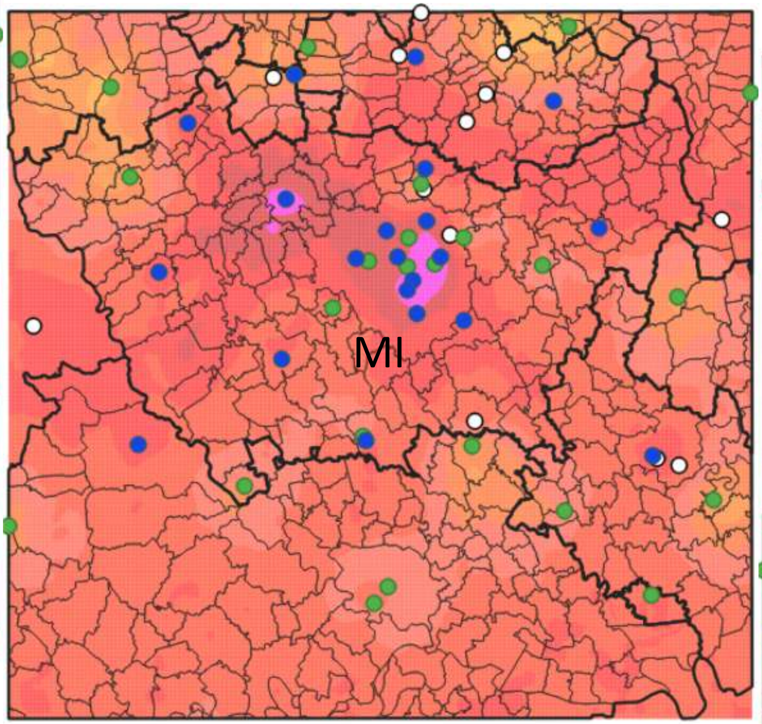
Maps , data and uncertainties at 100 m resolution

Application for adaptation: Milan T_{air} Atlas

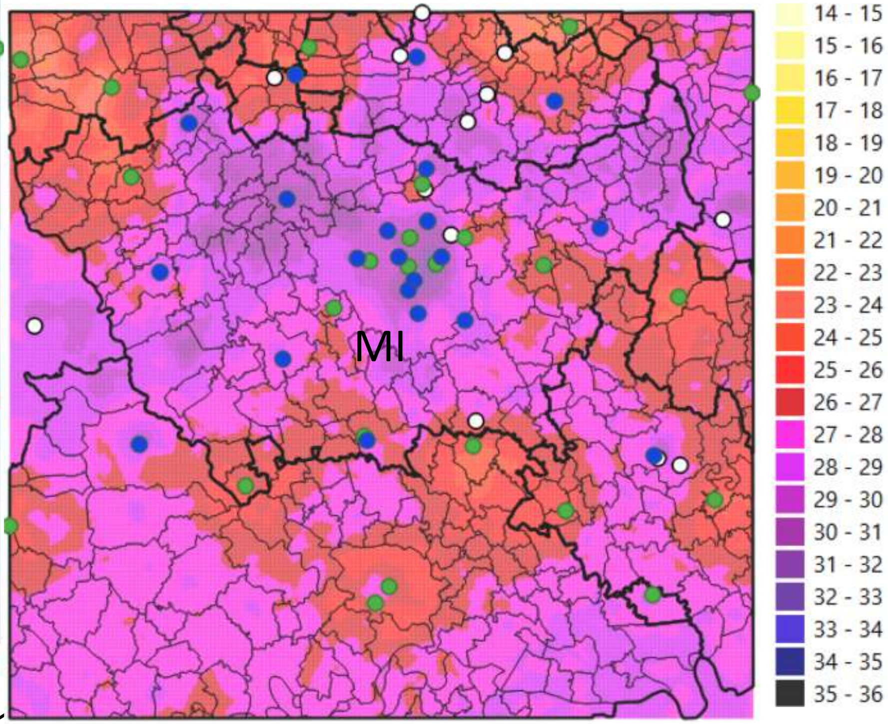
ClimaMi Project: https://www.progettoclimami.it/atlante ***(48 maps)***



Summer_Mean UHI_NW_22 UTC+1



Summer_Mean UHI_Center_22 UTC+1



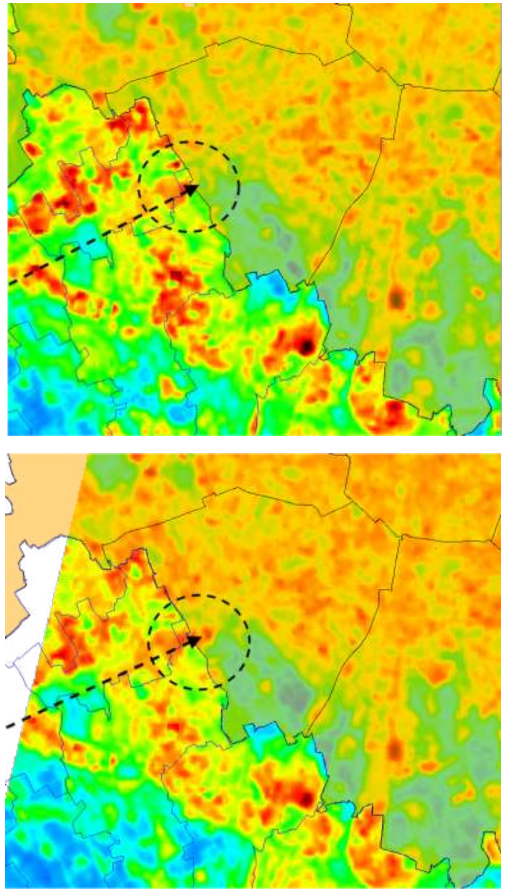
Summer_Mean HW_Centre_22 UTC+1

Maps, data and uncertainties at 100 m resolution

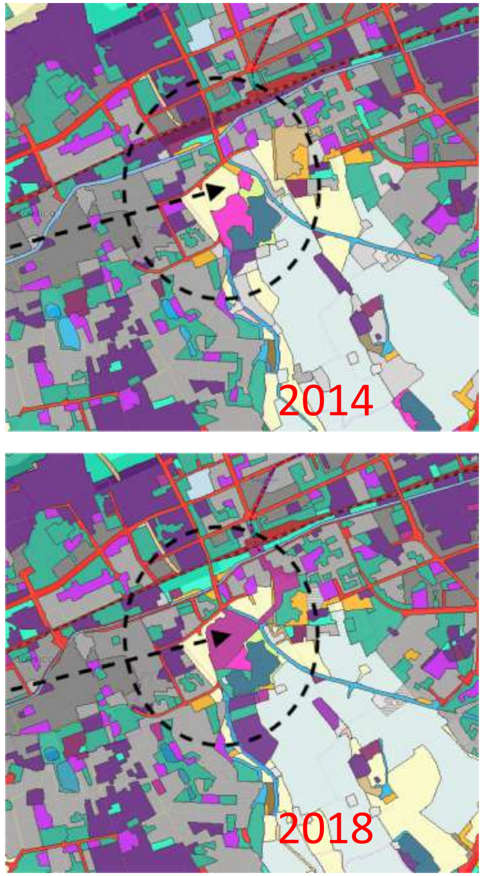
LST and COK-T_a differences as effect of an urbanistic variation

2013-07-16
10:13 UTC

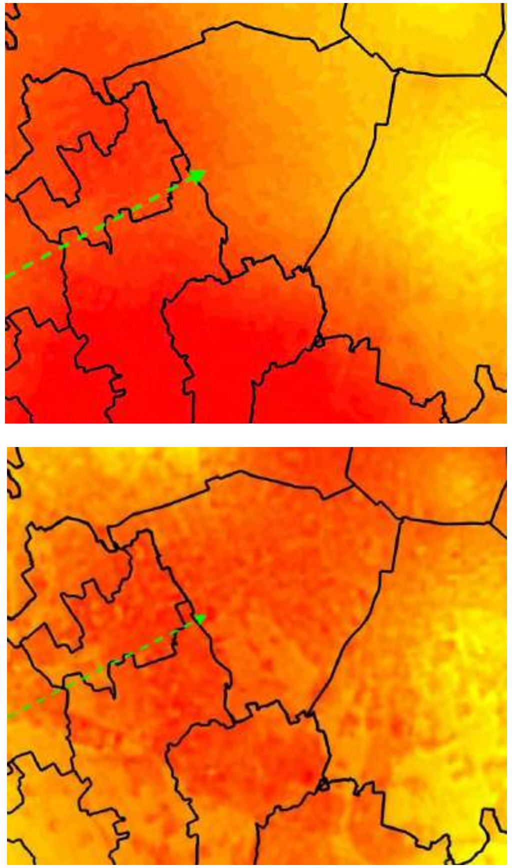
2019-07-17
10:10 UTC



Landsat 8 –LST (30 m)
9 km x 9 km area



Land use – DUSAF
ARPA Lombardia



COK-derived T_a (30 m)
from LST and surface obs.

Ronchetto sul Naviglio (MI):

SE Milan outskirt, about 5.7 km from city centre

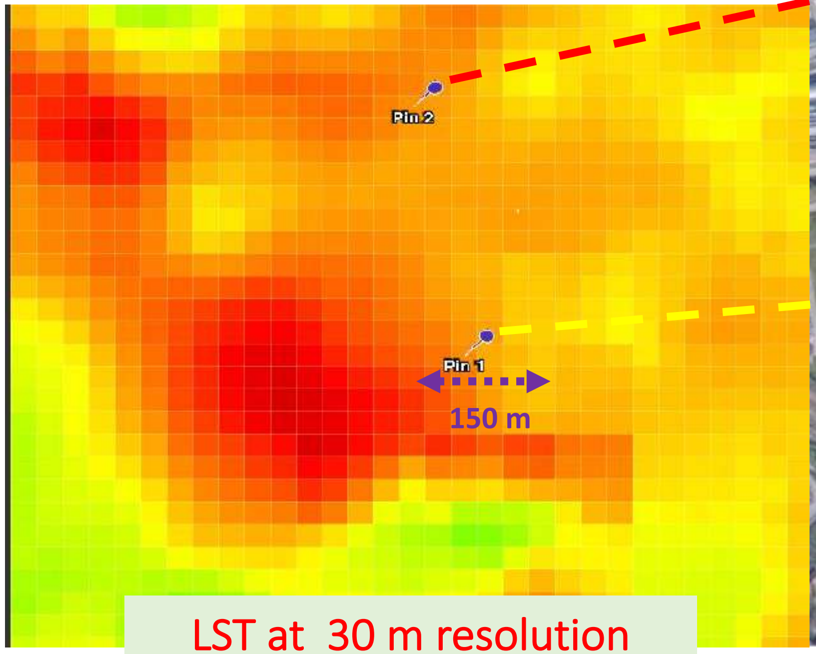
Land use change from arable land (2014) to industrial settlement (2018)

Planned: Schiavone Place in Milan at 30 m resolution

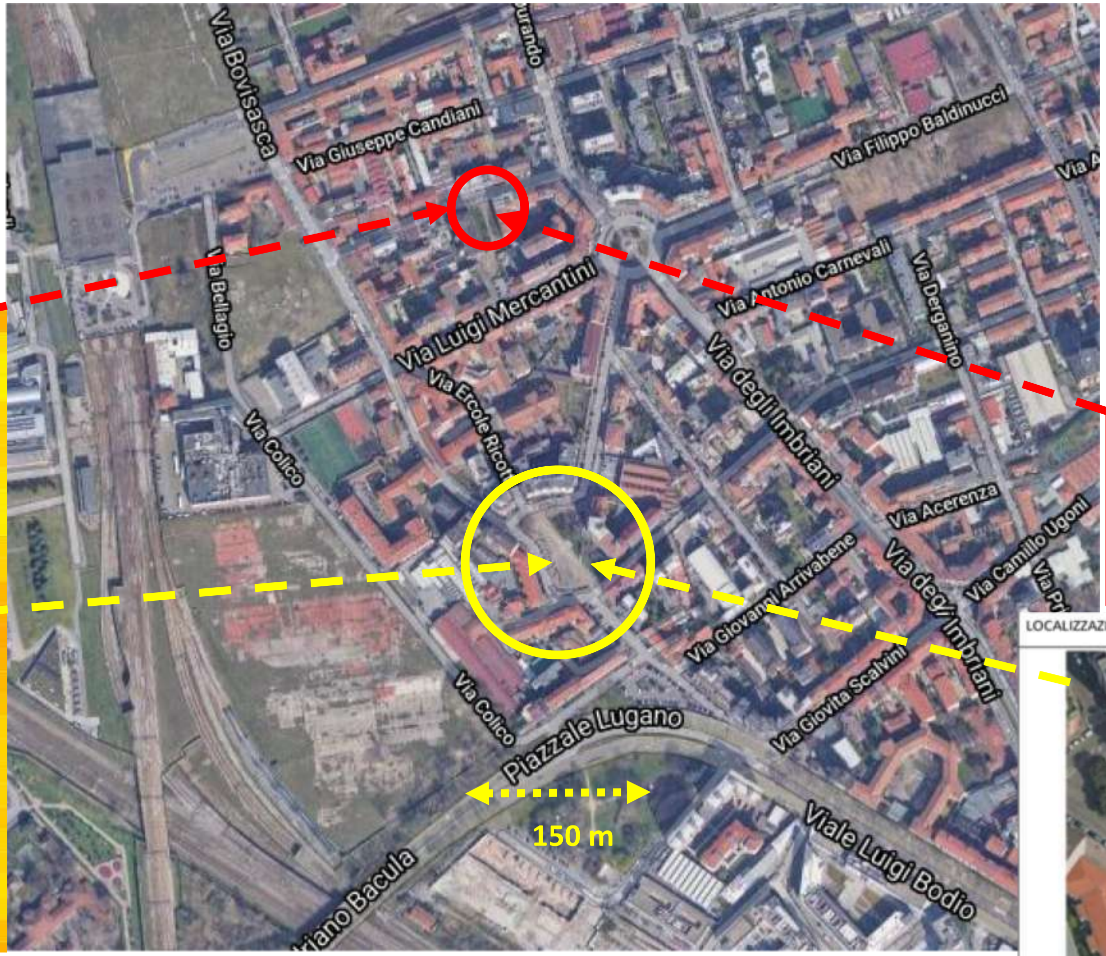
APPLICATION planned:

Assessing effects of adaptation projects in Piazza Schiavone (Milan)

2020-'21



LST at 30 m resolution
2019-07-01 10.11 utc
Piazza Schiavone, Milano



AWS CN04 MI Bovisa, Measuring T_{air} at top of UCL

Conclusions

In the framework of the ClimaMi Project (2019-2021)

a co-kriging methodology and procedure have been developed and tested making use of:

- **high quality air temperature measurements in the UCL by surface operational meteorological networks**
- **land surface temperatures remotely sensed form space (LST)**

to obtain medium- to high-resolution air temperatures fields for climatological as well as

for climate change adaptation purposes (Climatic Services)

Paper submitted for publication in Bull. of Atm. Science and Technology (BAST): High-resolution climatic characterization of air temperature in the Urban Canopy Layer, Montoli • Frustaci • Lavecchia • Pilati