Integration of heterogenous data to high resolution temperature maps for urban planning and management in the ClimaMi project.

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The ClimaMi Project

Partners

Fondazione Osservatorio Meteorologico Milano Duomo
Fondazione Ordine Ingegneri Provincia di Milano
Fondazione dell'Ordine degli Architetti, Pianificatori, Paesaggisti e Conservatori della Provincia di Milano
FLA Fondazione Lombardia per l'Ambiente

Cofinancer

Fondazione CARIPLO

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Objectives:

- *Set up of a functional urban climatology for the metropolitan Milano area*
- *Promote a more effective knowledge and consideration of the local climate in urban planning and management*
- *Keynote adaptation to climate change in cites consistently with regional and national plans*

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In 2019 (1° year) :

- *DB of Milan urban climate (Strumento Informativo Clima Urbano: SI-CU)*
- *First application to a real case: Comune di Melzo*
- *Capacity building activities for engineers, architects and agronomists*

In 2020 (2° year):

- *Extension of SI-CU with Climatic Temperature Atlas*
- *Functional applications to more projects (Milano and Pavia)*
- *Further capacity building activities*

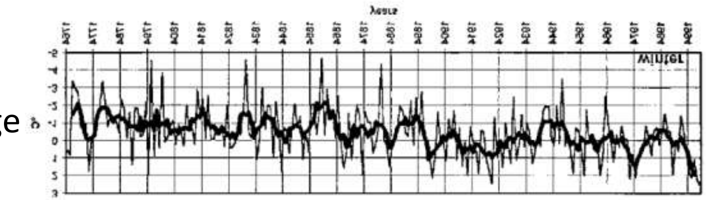
Stakeholders

Regione Lombardia
Città metropolitana di Milano
Comune di Milano
Comune di Pavia
Città di Melzo
Centro Studi PIM
Legambiente Lombardia
meteonetwork
Politecnico di Milano
Ordine degli Architetti, Pianificatori, Paesaggisti e Conservatori della Provincia di Milano
Ordine dei Dottori Agronomi e dei Dottori Forestali di Milano
CESI
MM
RSE

Urban Climatology

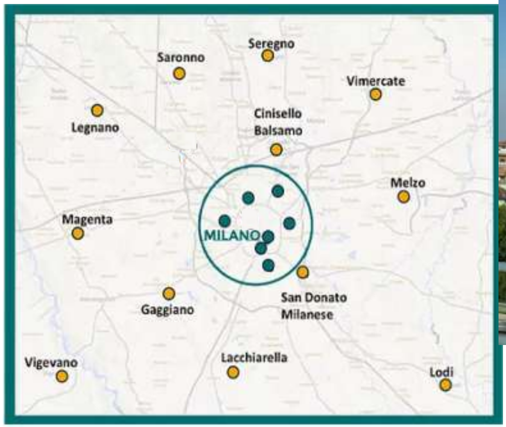
- In general based on long term series by historical observatories (Milano Brera), or nearby synoptic stations (Linate airport)

but inadequate to the emerging needs in evolving cities and climate change



- Strong need for appropriate measurements to describe and monitor the complex urban environment, but ….
- Missing specialized networks and climatological procedures

- In Italy only few urban stations, in general for air quality monitoring, but …
- OMD has a nationwide urban climatological network since 2011 with more than 20 stations at top of UCL in and around Milano



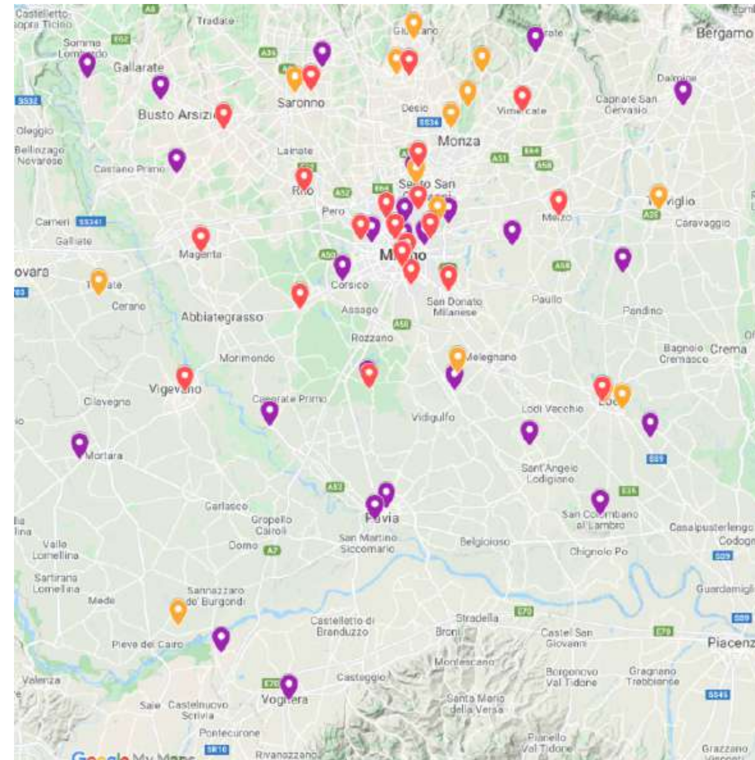
High resolution urban climatology for applications

Given the high variability and complexity of the urban structure, even the specialized OMD network lacks in accurately describing and resolving the UCL for a number of important applications:

- therefore, other 40 AWS from third parties have been included in the 2nd year of ClimaMi Project after evaluation of:
  - siting and exposure suitability
  - measurement accuracy
  - sufficient data availability
- but engineers, architects and urbanists often require very high spatial resolution (<100 m)

Several approaches are possible:

- Interpolation of measured air temperatures
- Use of Remote sensing data (LST)
- HR Urban Modelling



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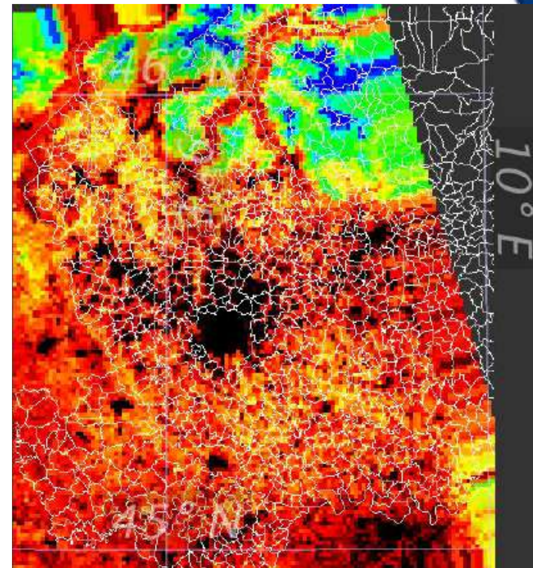
A first approach: remote sensing from space

Platform choice:

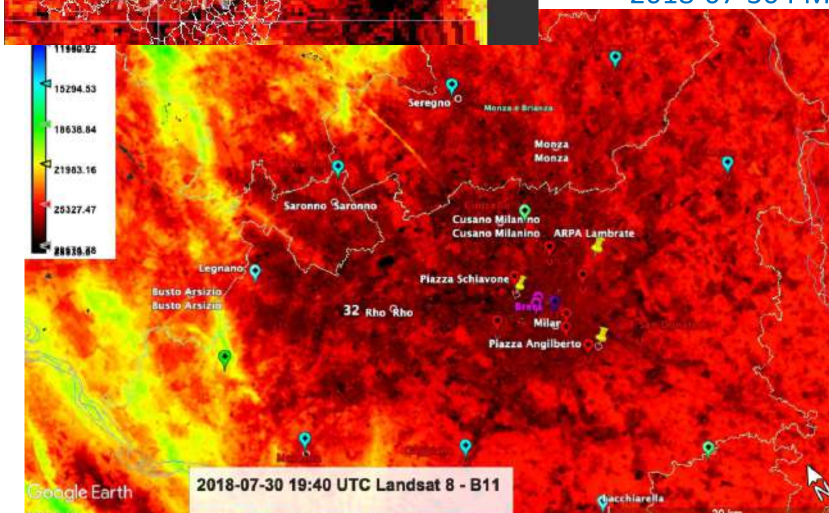
1. Sentinel-3 (ESA-Copernicus):
   - Pros: 2 sat. (A & B) since April 2018 (A since 2016), data easy accessible, LST directly provided by ESA
   - Cons: lower resolution (1 Km)

2. Landsat-8 (NOAA-USGS):
   - Pros: since 2013, higher resolution (30÷100 m)
   - Cons: LST (still) not directly provided (but several methods available), some calibration problems in one IR Channel

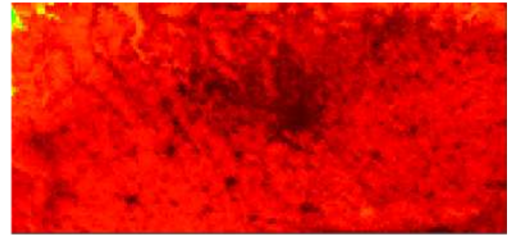


Sentinel-3 LST
2018-07-31 PM

Landsat-8 B11
2018-07-30 PM



LST: data and algorithms



Milan UHI by Sentinel 3 LST Product
2018 07 19 09:25 UTC

- Sentinel-3A&B: acceptable number of useful frames

  in the ClimaMi Project time span

  (a total of 54 useful pictures selected)

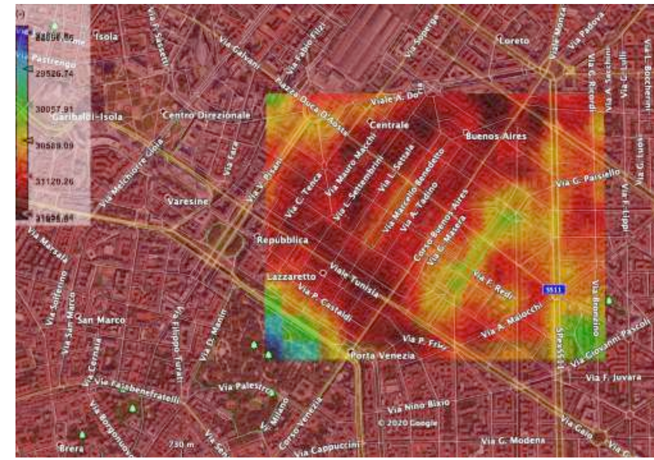
- Landsat-8:

  very few useful frames, used only for

  single cases and limited urban areas

  (ClimaMi experimentations: Melzo, Milano Piazza Angilberto, etc.)

Milan Corso Buenos Aires area
Landsat 8 – Band 10
2019-07-30 10:10 UTC



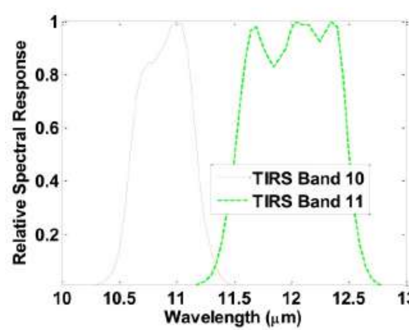
- Split-Window method adopted

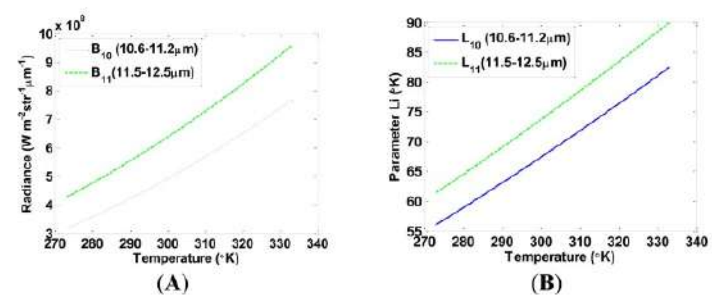
  for Landsat 8: using 6 channels

  as in Rozenstein et al. .

  Sensors 2014, 14, 5768-5780

$LST = a + b\,T_{10} + c\,T_{11}$; $RMSE \approx 1°C$





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Data Selection Criteria for ClimaMi

- Cloud masks:

  Must be null over the domain,

  but clouds are frequent over the hills in summer

  and fog in the Po Valley during winter!

- Full (or almost full) coverage of the Project area: 45-46 °N, 8 – 10 °E

  Not always satisfied because of orbit geometry

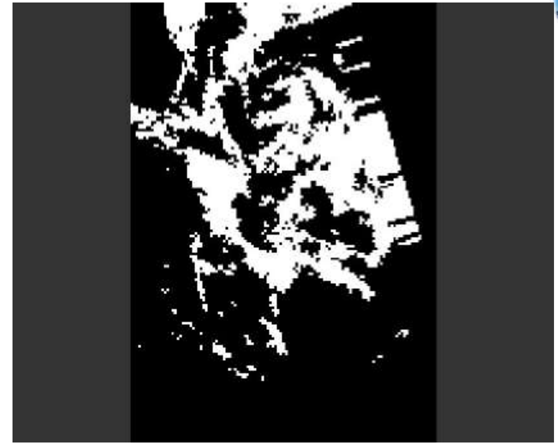
- Meteorology:

  Specific (clear sky) weather types based on different

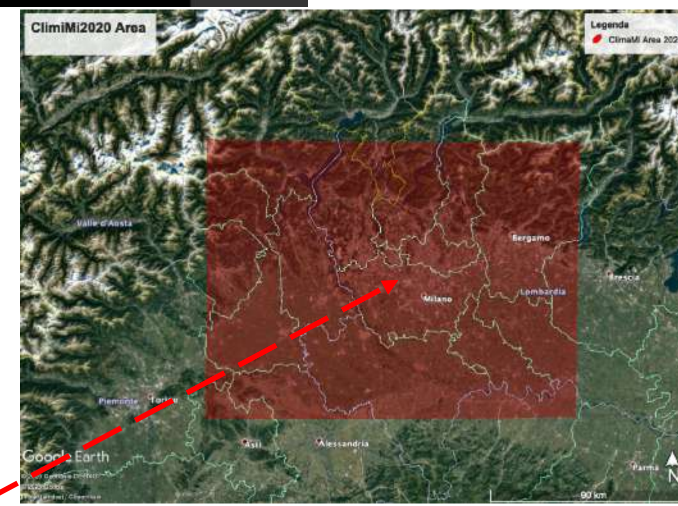
  frequently observed spatial thermal distributions

  of interest for practical applications

  (defined by in situ measurements only)



Cloud mask "thin cirrus" by Sentinel 3: 2017-08-26-20:37 UTC



Milan

Project domain used in LST extraction from Sentinel 3 (at 1 km spatial resolution)

Climatic weather types, UHI and HW

Database : average **hourly data** from 1/7/2015 to 31/08/2019

We considered episodes with:

- atmospheric stability: high pressure
- low ventilation: average wind < 1.3 m/s in Milan
- intense heat island: **UHI ≡ $T_u – T_r$** > 3 °C at 11-12 UTC+1 and 22-23 UTC+1 (typical times of satellite passes)

  u: OMD urban stations in Milano; r: selected stations in the Milan rural neighborhood
- different UHI configurations (UHI maximum in one or more the 8 stations downtown Milan):

Station (area)	Frequency of occurrence (%) Winter Morning	Frequency of occurrence (%) Winter Night	Frequency of occurrence (%) Summer Morning	Frequency of occurrence (%) Summer Night
Bicocca (NE)	17.8	0.5	0.0	2.3
Bocconi, Centro, Sarpi (downtown)	45.6	79.4	0.0	58.4
Bovisa (NW)	3.3	0.0	0.0	19.7
Città Studi (E)	15.6	18.7	0.0	17.6
San Siro (W)	15.6	1.4	0.0	0.6
Sud (S)	2.2	0.0	0.0	1.4

Separately considered : Heat Waves (at least two consecutive days with minimum and maximum temperatures above a certain threshold)

Sentinel 3 - LST and T_{air}: Correlations?

- Bilinear correlations obtained for some test cases:

LST = f (Ta; NDVI)

Ta: near surface Air Temperature

NDVI: Norm. Diff. Vegetation Index

- computed from ≈ 40 in situ independent measurements (OMD + ARPA Lomb.).
- AM episodes:

R^2 up to 0,9

Std. Err. as low as 0,5°C

- PM episodes results are generally worse

(use of morning Vis channels to obtain NDVI)

	Bilinear	Regression		LST = f (T; NDVI)					
AM Episods & NDVI		2	4	6	9	10	11	12a	12b
Regression	R^2	0,03	0,8	0,8	0,8	0,7	0,7	0,6	0,9
	m (T)	-0,3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0,8	0,5
	m (NDVI)	6,7	-16,5	0,3	-16,5	-7,6	-3,4	0,5	-7,1
	c	2,0	40,0	28,6	26,7	15,9	4,4	0,0	4,7
	Std. Err. (LST)	**2,7**	**1,2**	**0,8**	**0,9**	**1,2**	**1,2**	**1,2**	**0,5**
	F (sign. if ≳ 40)	1	83	77	99	40	37	28	112
Other info	Missing stations	6	6	5	6	0	5	5	6
	Nr. Flags Nubi	9	0	0	0	1	6	35	9
	Δ=[∑(LST-T)] /n	4,3	8,1	12,2	6,5	5,0	2,7	-1,0	-1,0
	σ(Δ)	3,2	4,4	5,9	3,4	1,9	1,5	1,2	1,2
	T mean	**-1,6**	**24,6**	**29,6**	**27,1**	**19,6**	**7,3**	**6,1**	**8,6**

	Bilinear	Regression		LST = f (T; NDVI) (evening hours and morning NDVI)					
PM Episods with AM NDVI		2	4	6	9	10	11	12a	12b
Regression	R^2	0,3	0,5		0,3	0,4			
	m (T)	0,3	[illegible]		[illegible]	0,9			
	m (NDVI)	-6,7	-7,9		-7,5	-4,0			
	c	-1,4	13,6		18,8	-5,7			
	Std. Err. (LST)	**1,4**	**1,7**		**1,9**	**1,2**			
	F (sign. if ≳ 40)	8,2	17,7		9,2	39,7			
Other info	Missing stations	6	11		6	1			
	Nr. Flags Nubi	2	0		6	88			
	Δ=[∑(LST-T)] /n	-0,7	-1,4		-1,6	-9,7			
	σ(Δ)	1,7	1,9		2,3	2,8			
	T mean	**-3,0**	**20,0**		**23,1**	**23,6**			

A second approach:
Air temperatures via cokriging (COK)

STEP 1

Building of the **empirical semivariogramm** γ for both air temperature and LST satellite data

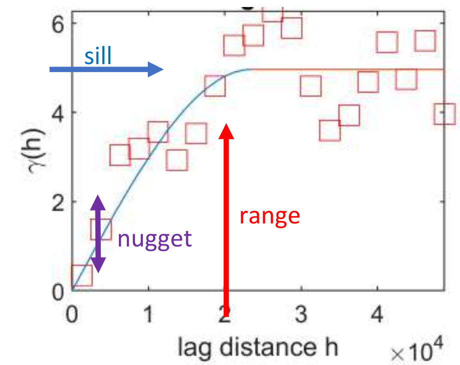
$$\gamma(h) = \frac{1}{2N(h)} \sum_{i=1}^{N(h)} [z(x_i) - z(x_i + h)]^2$$

Z is the the regionalized variable, x_i the position in the domain, *h* the separation distance between two points and *N(h)* the pairs of points separated by *h.*

STEP 2

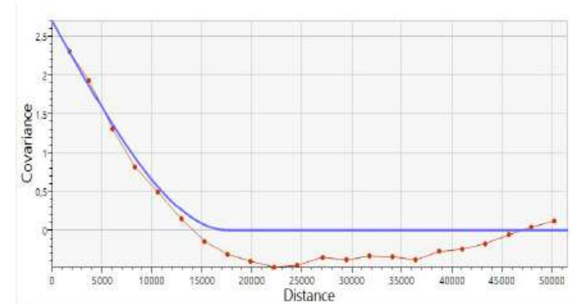
Fitting of a model to the empirical semivariogram *(spherical model).*

RANGE, SILL, NUGGET



STEP 3

Building and **fitting** the **crossvariogram** *(covariance)*



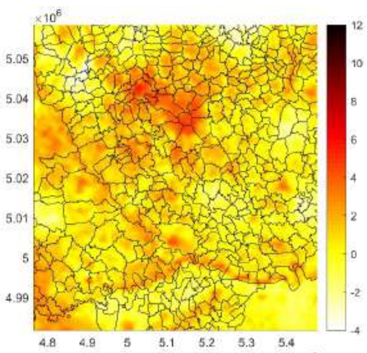
STEP 4

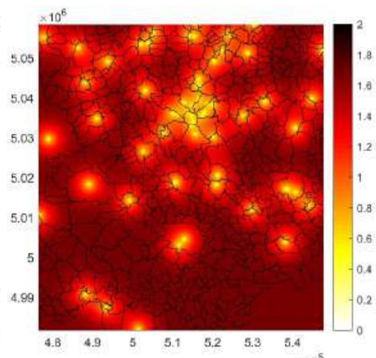
Performing the **cokriging interpolation**

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

where z_1 is air temperature and z_2 is the LST

$(\lambda_\alpha$ *and* ω_α *are the corresponding weights*$)$





2017-01-29

Estimated air temperature

Error on estimated air temperature

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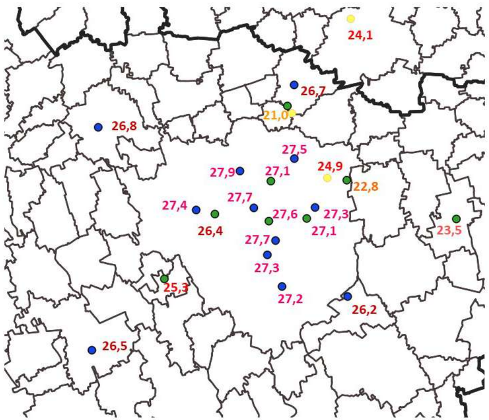
First results for the the ClimaMi Atlas (end 2020)



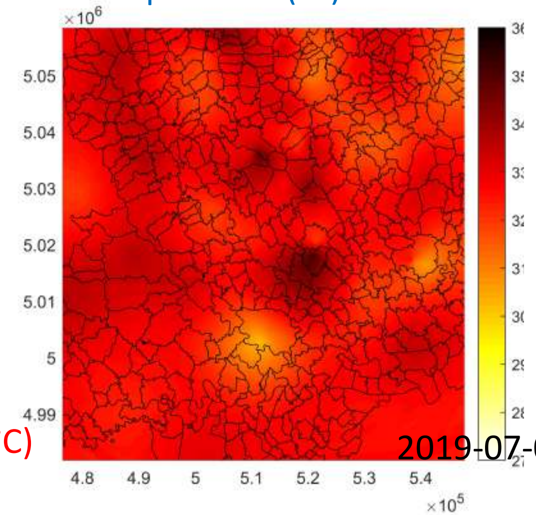
Air Temperature measured by the surface network

Air temperature at top of UCL:
HQ hourly data at low spatial resolution (> 1000 m)
(primary variable)

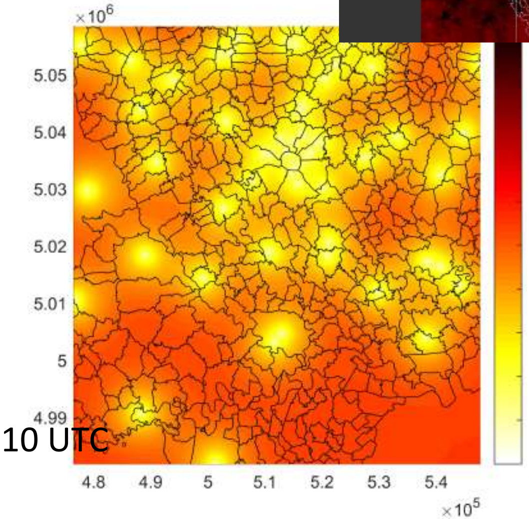
Land Surface temperature:
remotely sensed twice a day for selected situations (100 m)
(secondary variable)

<u>CoKriging</u>

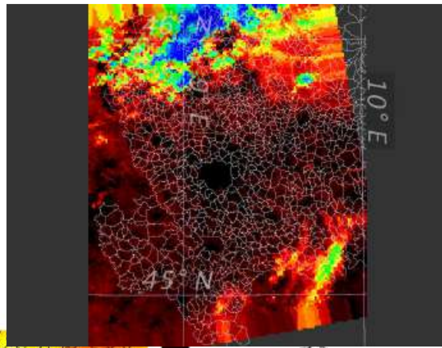
Air Temperature (Ta)



Ta Errors



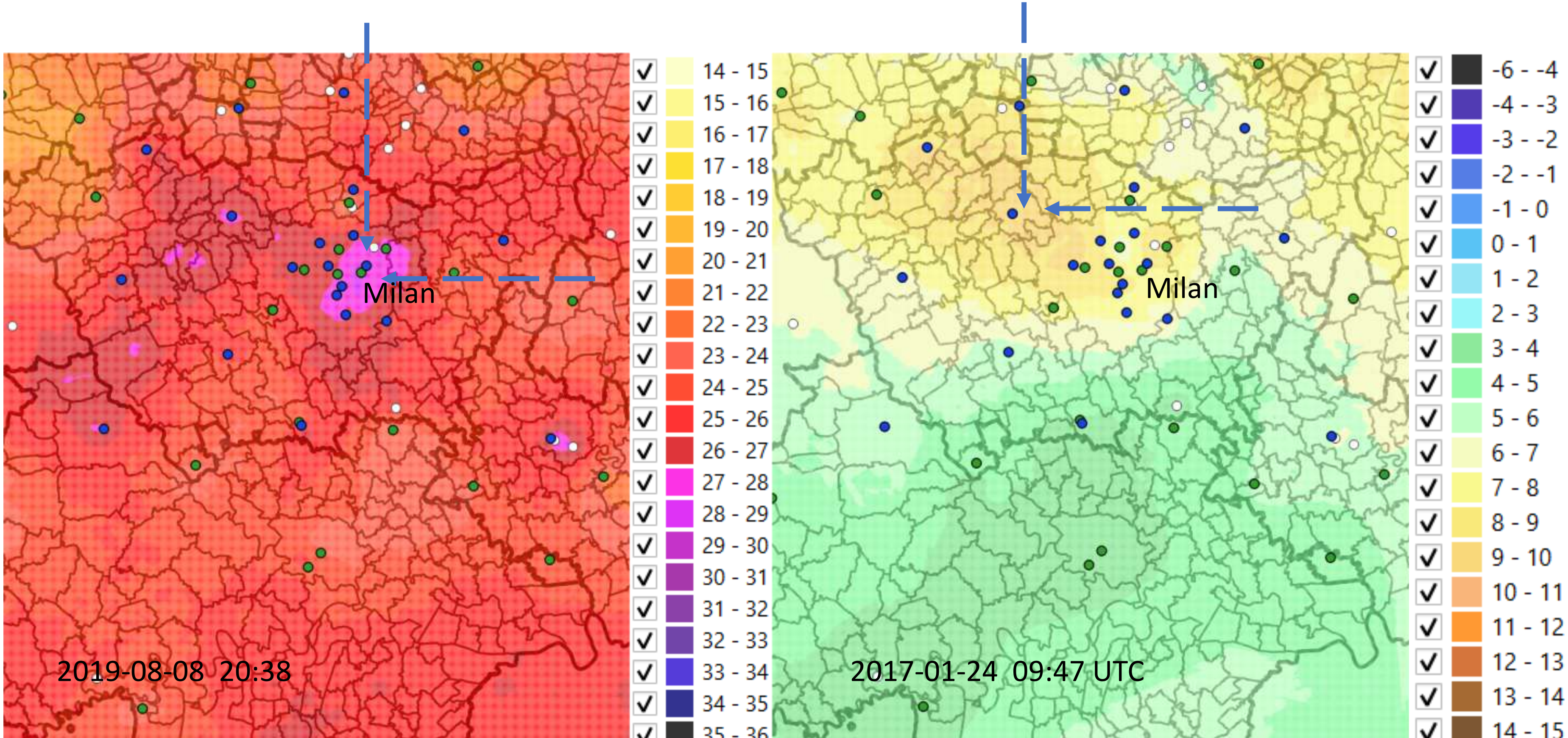
2019-07-01 10 UTC



Sentinel 3 Land Surface Temperature

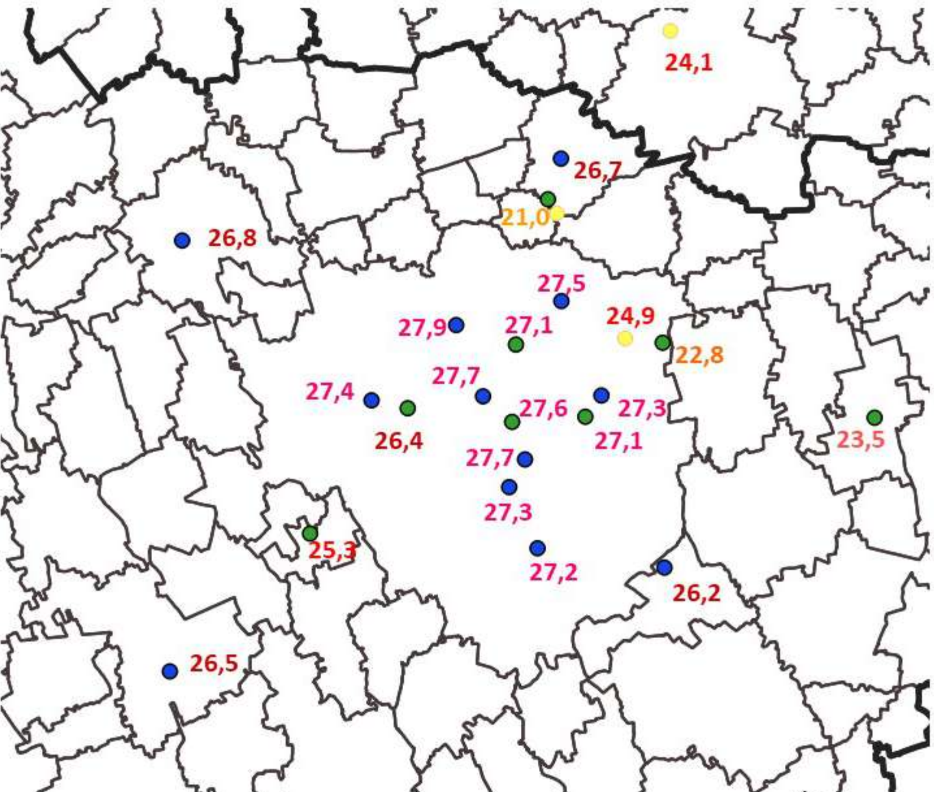
⇒ High Resolution (100 m) maps
of Air temperature
with Low Uncertainty (< 1.5°C)

Near surface Air Temperatures: summer and winter cases

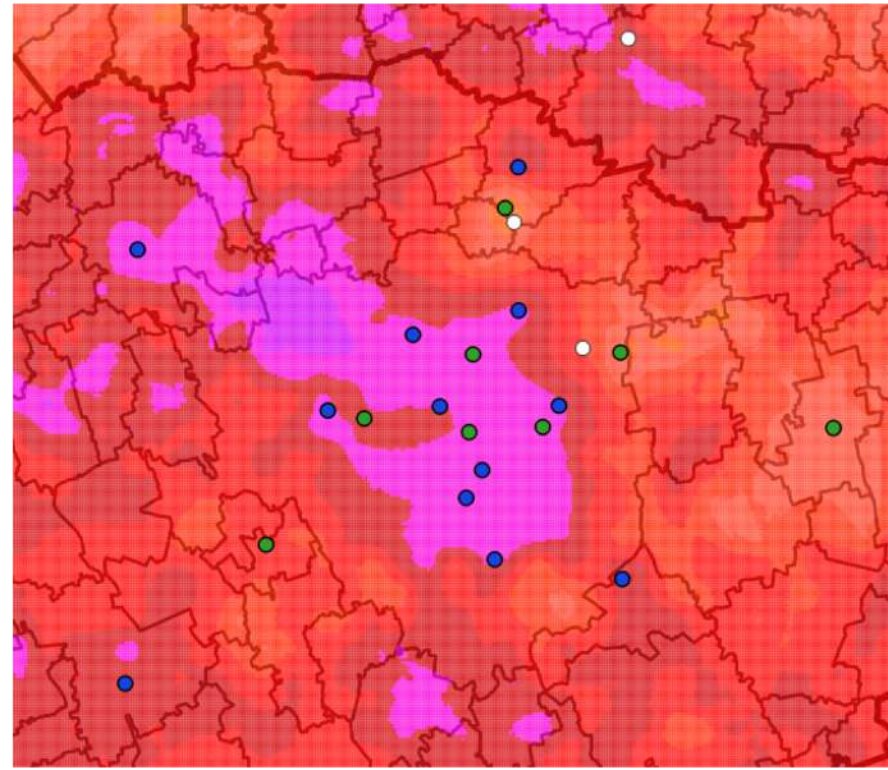


Close up for an evening episode

UCL Air Temperatures by AWS



UCL Air Temperature obtained via co-Kriging



2018 – 07 – 08 21 UTC

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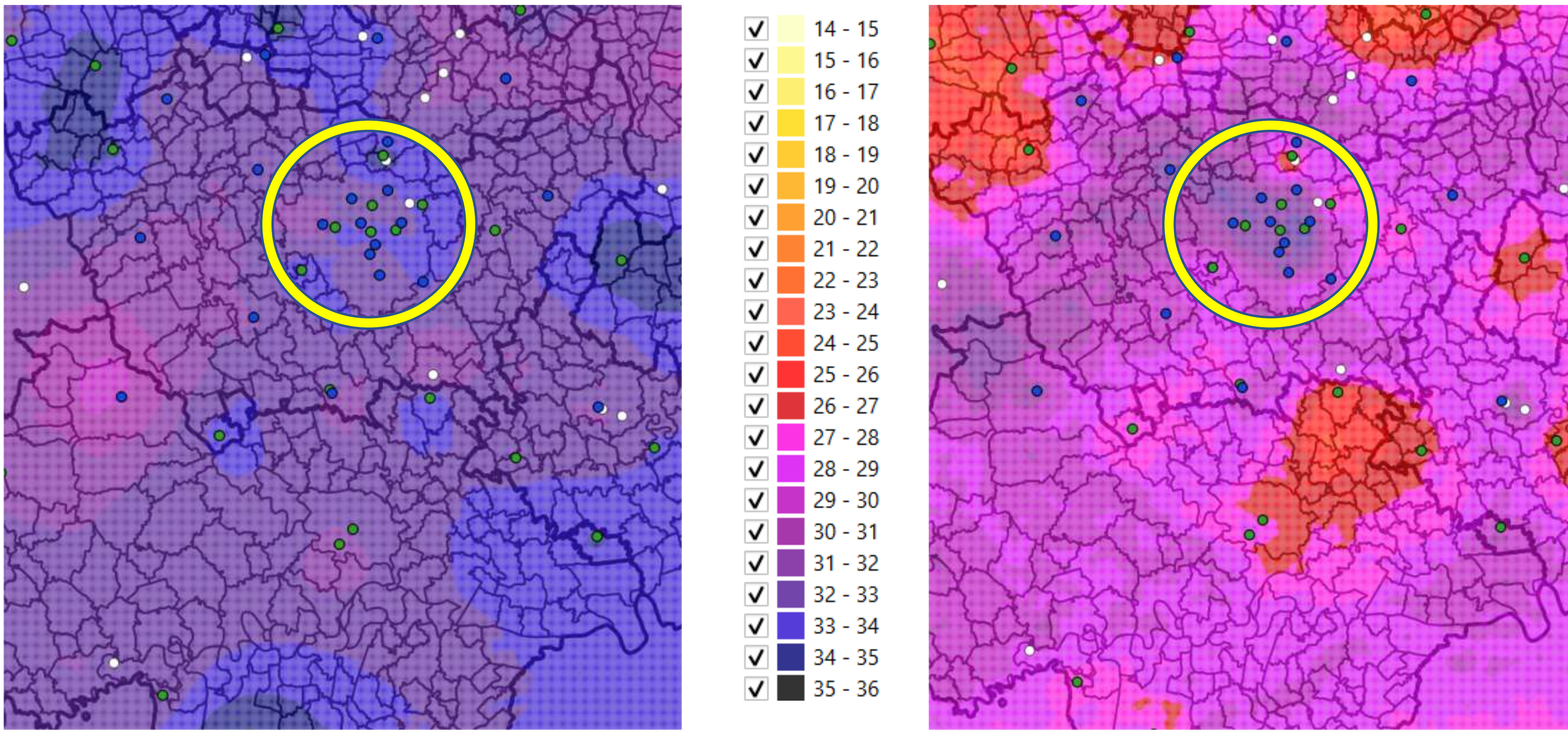
Near surface Air Temperatures: Heat Waves



2019-06-26_10 UTC **2019- 06- 26_21 UTC**

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Summary

- Starting from in situ “ad hoc“ urban measurements . . .
- Selecting climatic relevant weather situations . . .
- Integrating “remote sensing” data . . .
- Using an appropriate and efficient co-Kriging method . . .

Thank you for listening!
Any question?

to obtain a

high resolution and climatically representative thermal mapping

for urban adaptation and resilience applications

https://www.progettoclimami.it/

https://www.fondazioneomd.it/

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Further developments:

- *Time span extension and larger statistics*
- *Future platforms and higher resolution*
- *Improving regression and co-kriging methods*