Evaluating the sustainability of low enthalpy geothermal applications in a subsurface heat island

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Subsurface thermal regime in urban areas

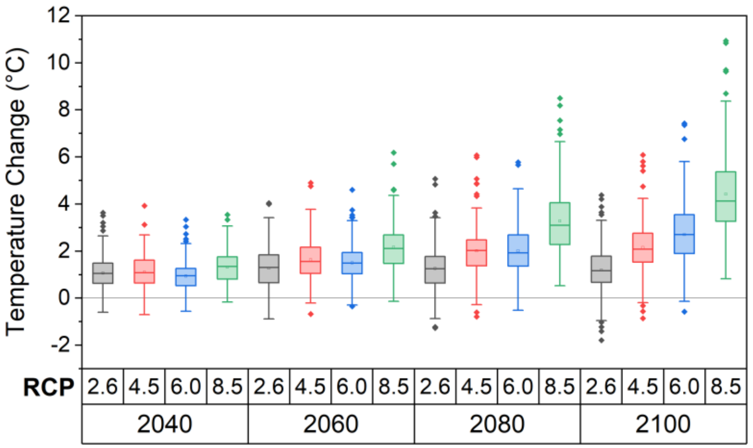
Climate

- Air temperature
- Precipitation (GW recharge)

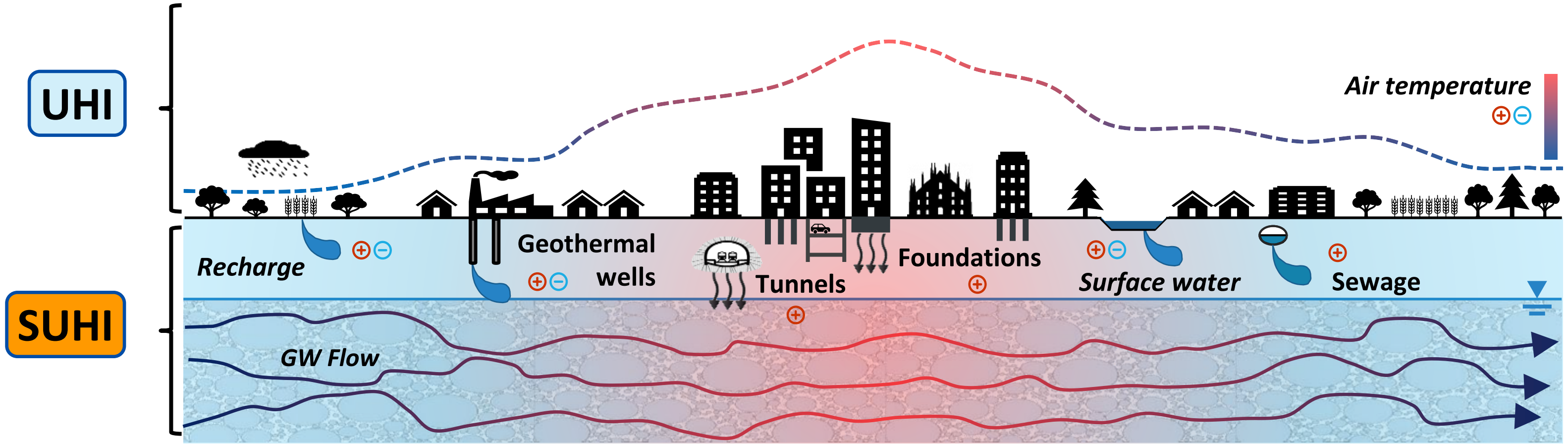
+

Urbanization (Heat island effect)

- Anthropogenic heat sources
- Land cover/sealing
- Groundwater uses



Data from CMIP5 experiment retrieved from: www.climateknowledgeportal.worldbank.org



Heat accumulation in the urban subsurface due to human activities

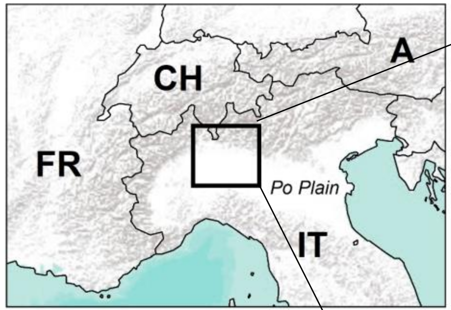
Problem ?

Usable resource ?

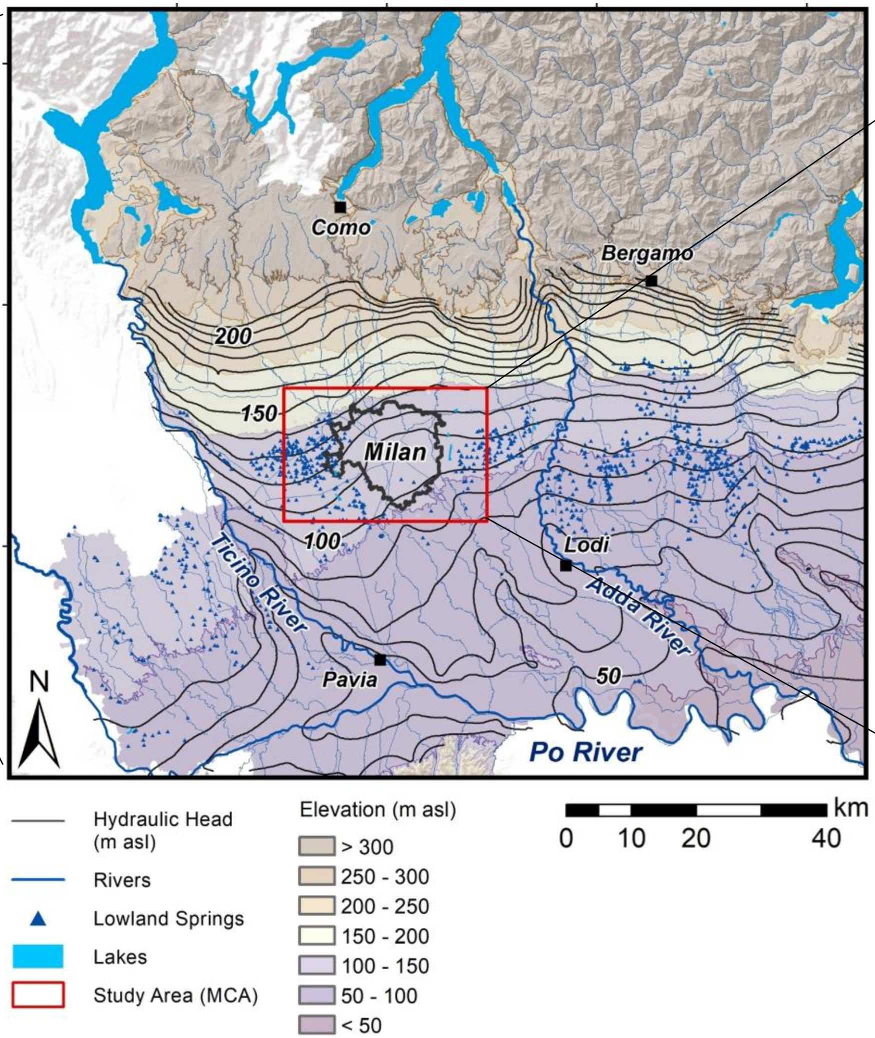
Need of quantification tools!

Study area

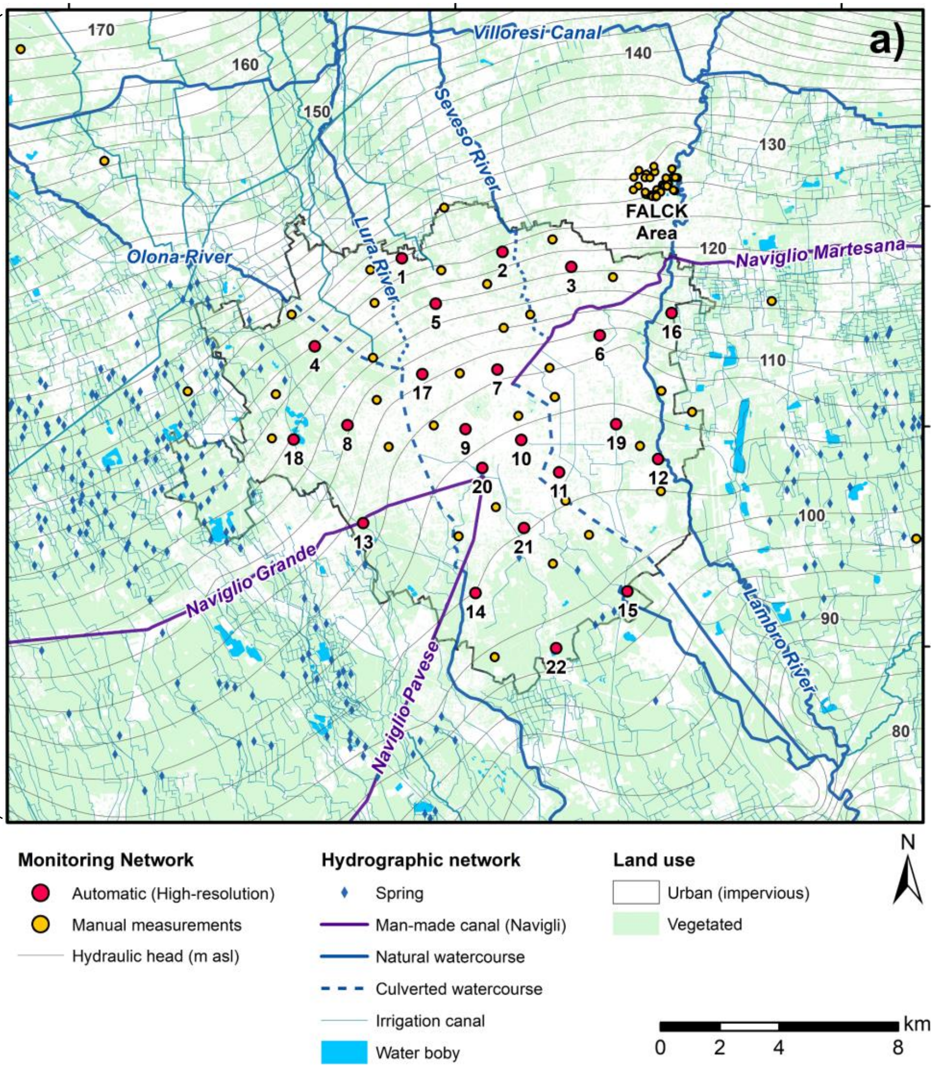
Overview



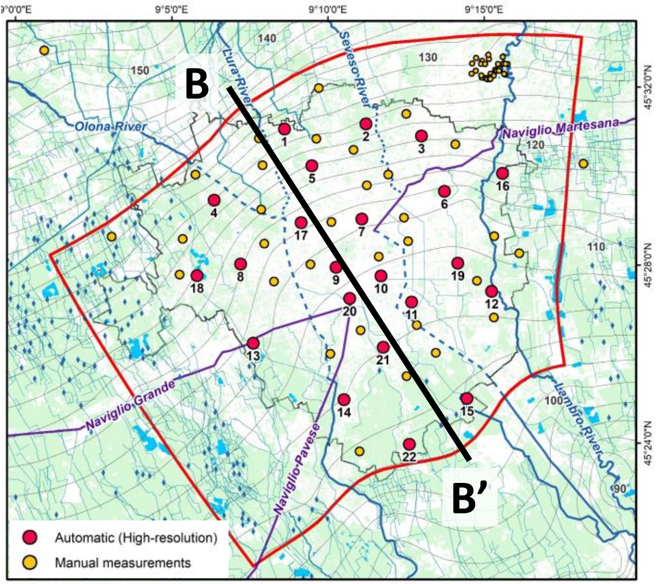
Regional scale

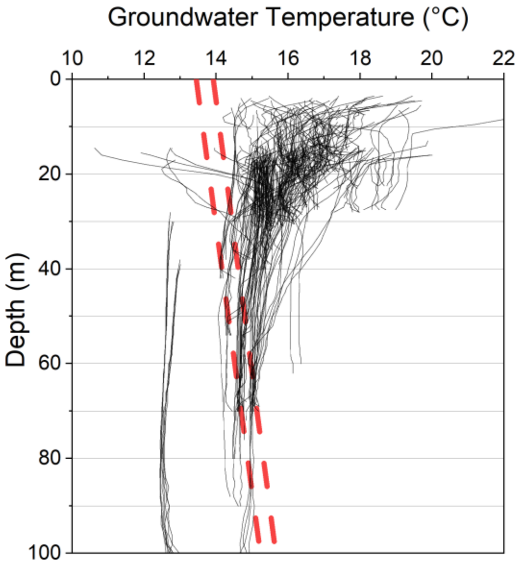


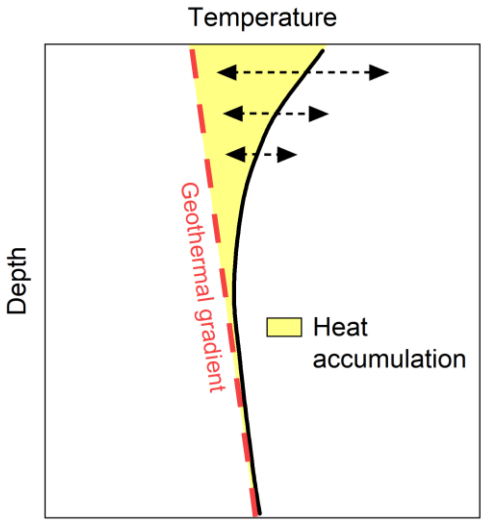
Milan city area



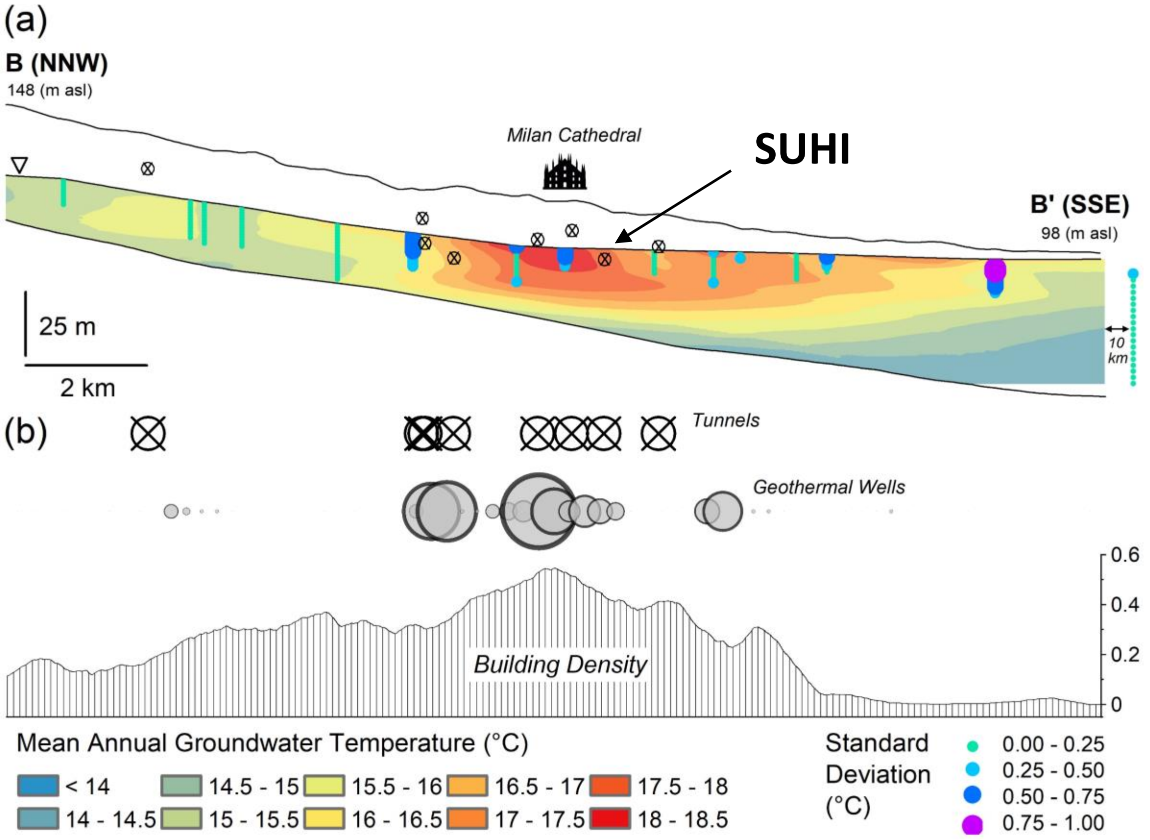
Urban groundwater monitoring network in the Milan city area







N-S section showing the subsurface urban heat island effect



Previati, A., & Crosta, G. B. (2021). **Characterization of the subsurface urban heat island and its sources in the Milan city area, Italy.** Hydrogeology Journal, 29(7), 2487-2500. https://doi.org/10.1007/s10040-021-02387-z

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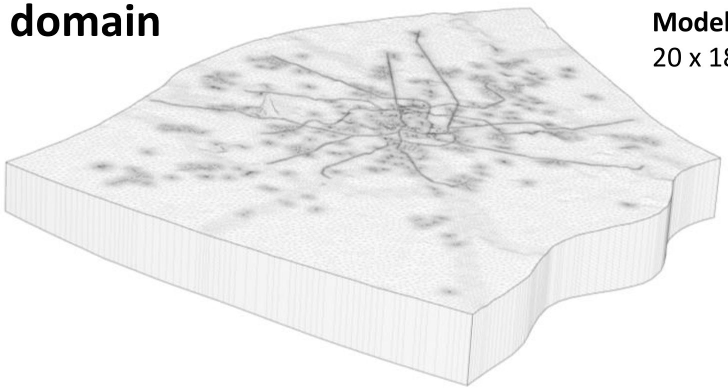
City-scale model domain

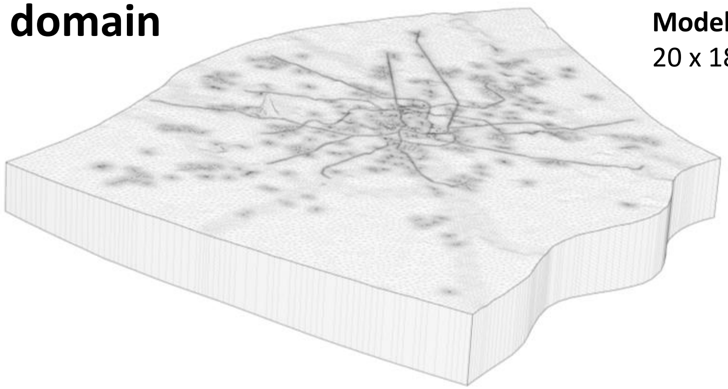


Model size:
20 x 18 km x 250 m

Number of elements:
6,260,000 (49 slices)

Element size:
3 – 200 m

City-scale model domain



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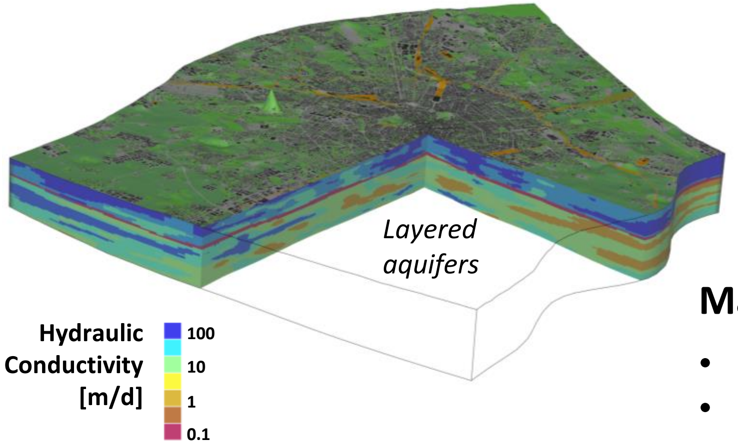
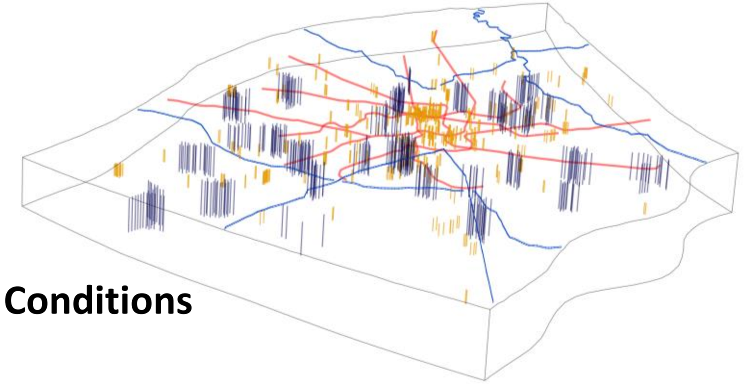


Material Properties

- *Fluid Flow*
- *Heat Transport*

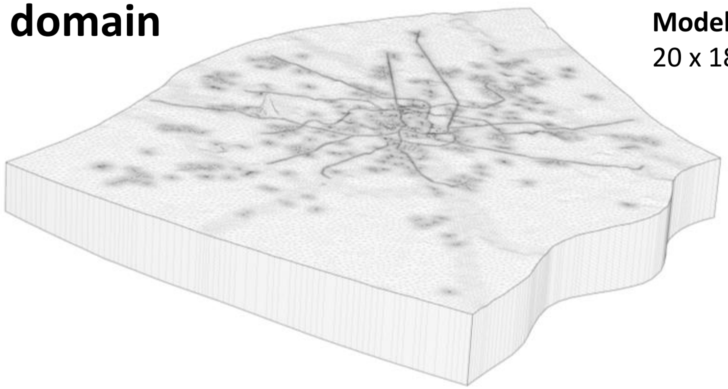


Boundary Conditions

- *Natural*
- *Anthropic*

From monitoring to modeling…

City-scale model domain



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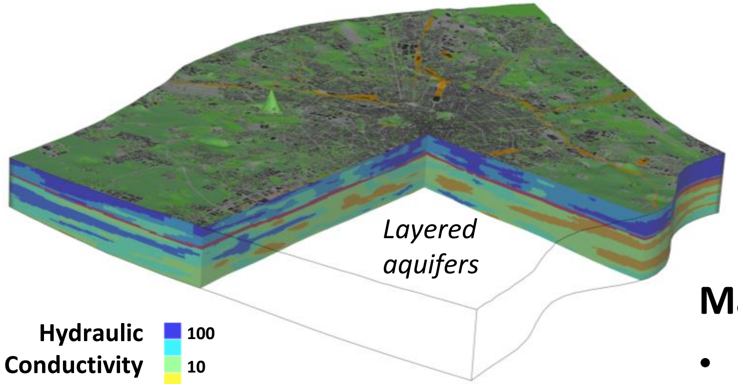
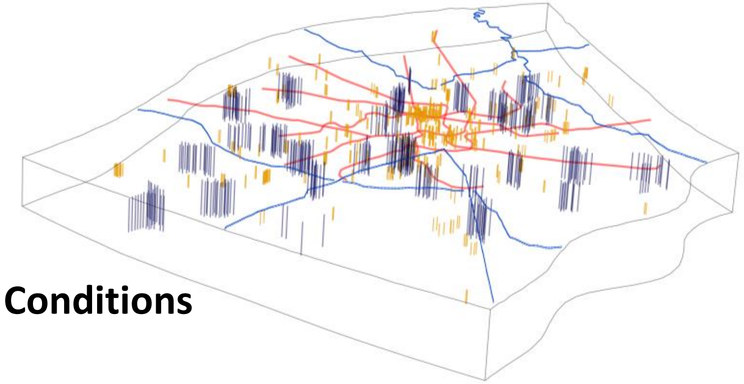


Hydraulic Conductivity [m/d]
100
10
1
0.1

Material Properties

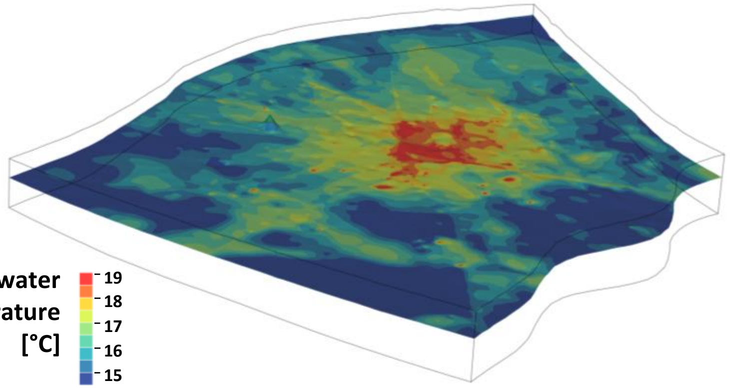
- *Fluid Flow*
- *Heat Transport*



Boundary Conditions

- *Natural*
- *Anthropic*

Thermal Regime



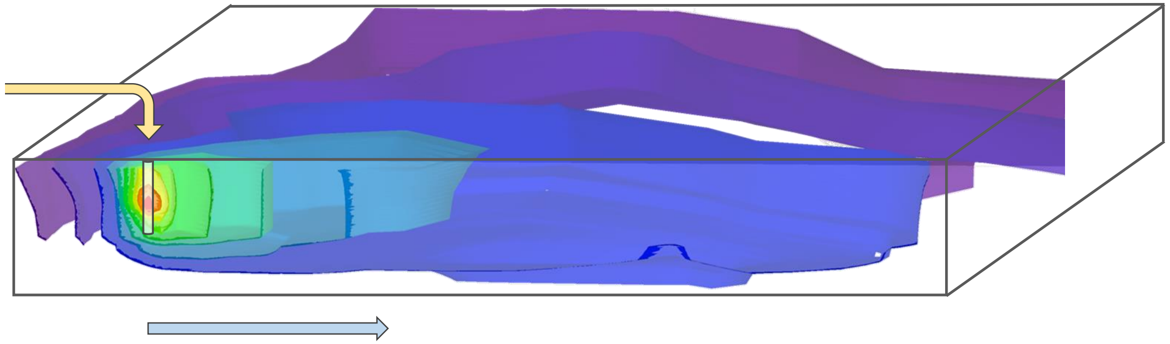
Groundwater Temperature [°C]
19
18
17
16
15

Previati, A., Epting, J., & Crosta, G. B. (2022). **The subsurface urban heat island in Milan (Italy) - A modeling approach covering present and future thermal effects on groundwater regimes.** Science of The Total Environment, 810, 152119. https://doi.org/10.1016/j.scitotenv.2021.152119

Thermal plume

Heat injection

Advective + conductive heat transport!



GW Flow

Initial conditions:

temperature distribution from adopted scenarios

Thermal Sink/Source

± ∞

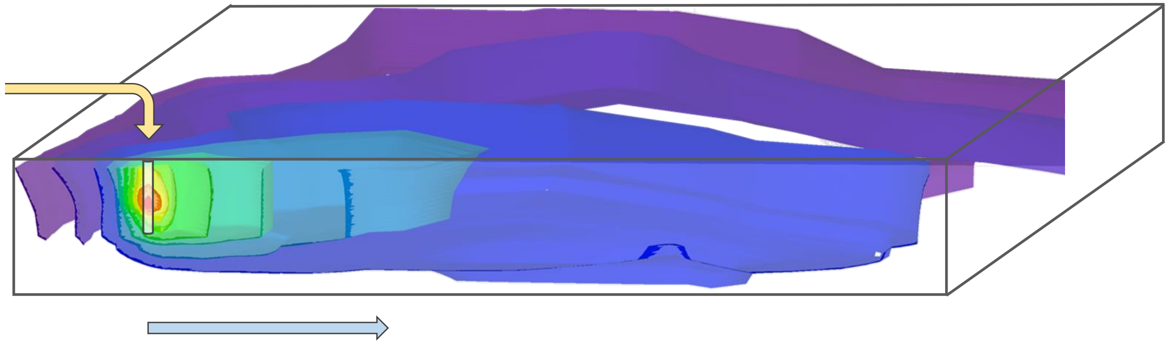
Thermal perturbation

Constrained

Thermal plume

Heat injection

Advective + conductive heat transport!



GW Flow

Initial conditions:

temperature distribution from adopted scenarios

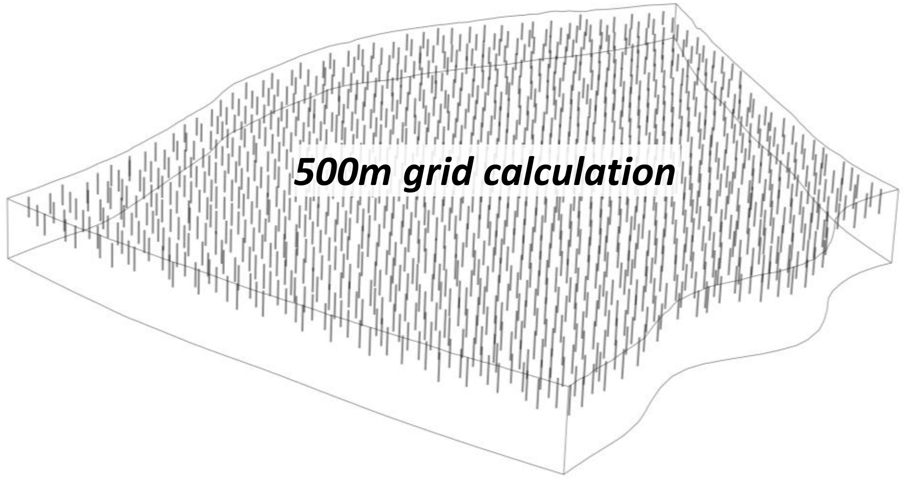
Thermal Sink/Source

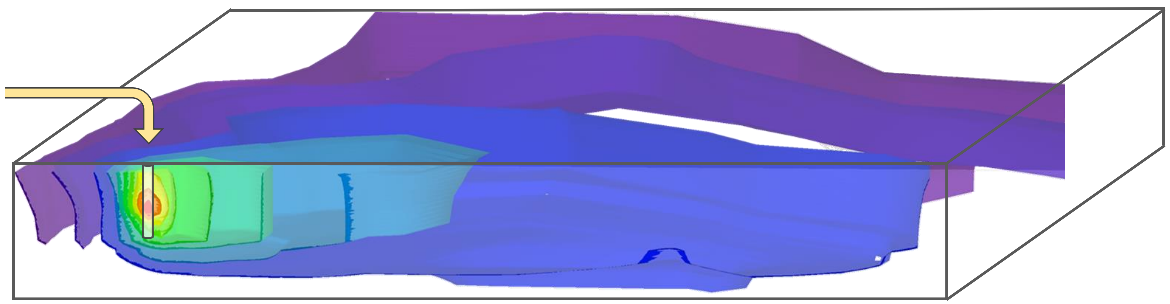
± ∞

Thermal perturbation

Constrained

A ***thermal perturbation*** *is applied* ***iteratively*** *at each location*





Initial conditions:

temperature distribution from adopted scenarios

Thermal Sink/Source

$\pm \infty$

Thermal perturbation

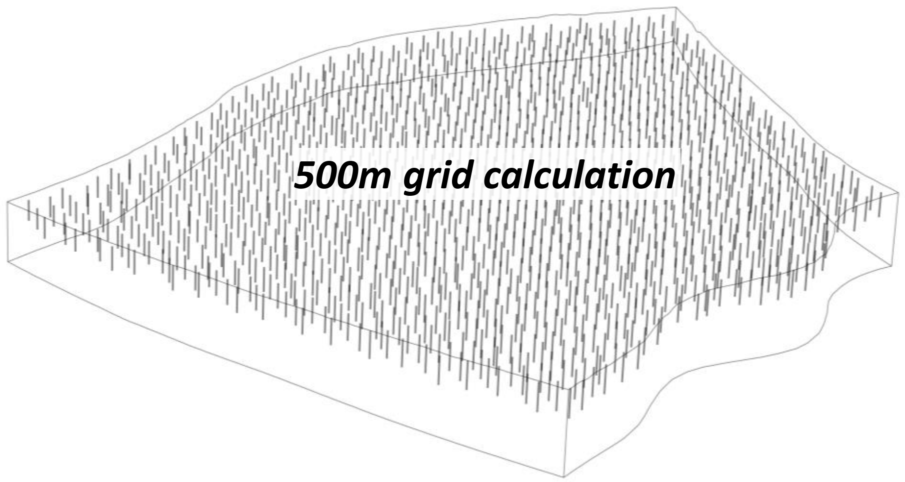
Constrained

Max specific **potential [W/m³K]**

$$P_T = \rho c_{fluid} \nabla(\boldsymbol{q} \cdot T) + \lambda_{bulk} \nabla^2 T$$

*Max thermal sink/source to reach a **unit temperature variation** in a unit volume*

*A **thermal perturbation** is applied **iteratively** at each location*



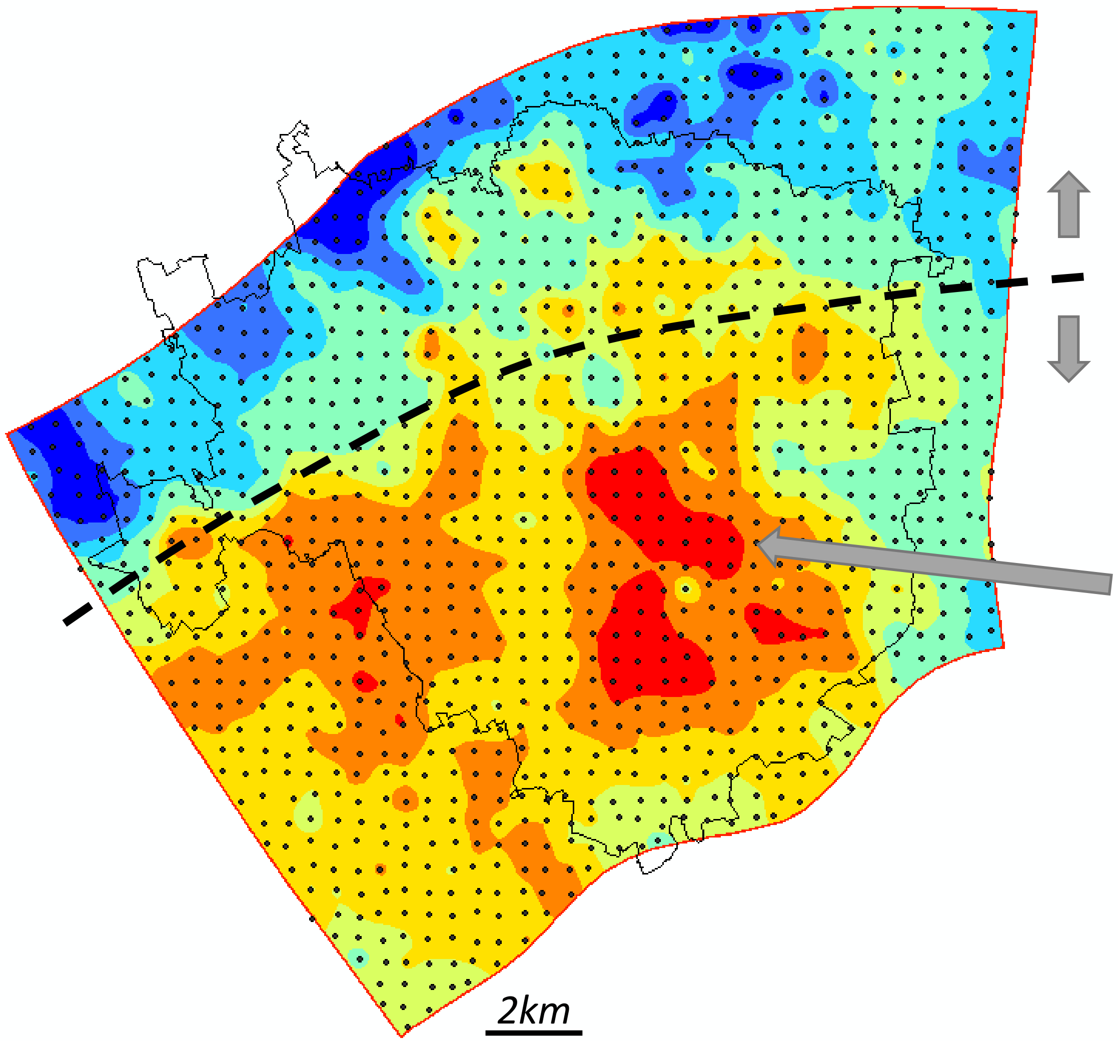
Actual specific **potential [W/m³]**

$$\Delta T = \begin{cases} 5, & |T_{GW} - T_{lim}| \geq 5 \\ |T_{GW} - T_{lim}|, & |T_{GW} - T_{lim}| < 5 \end{cases}$$

*Max thermal sink/source to reach a **threshold temperature variation** in a unit volume*

Max specific **potential** **[W/m³K]**

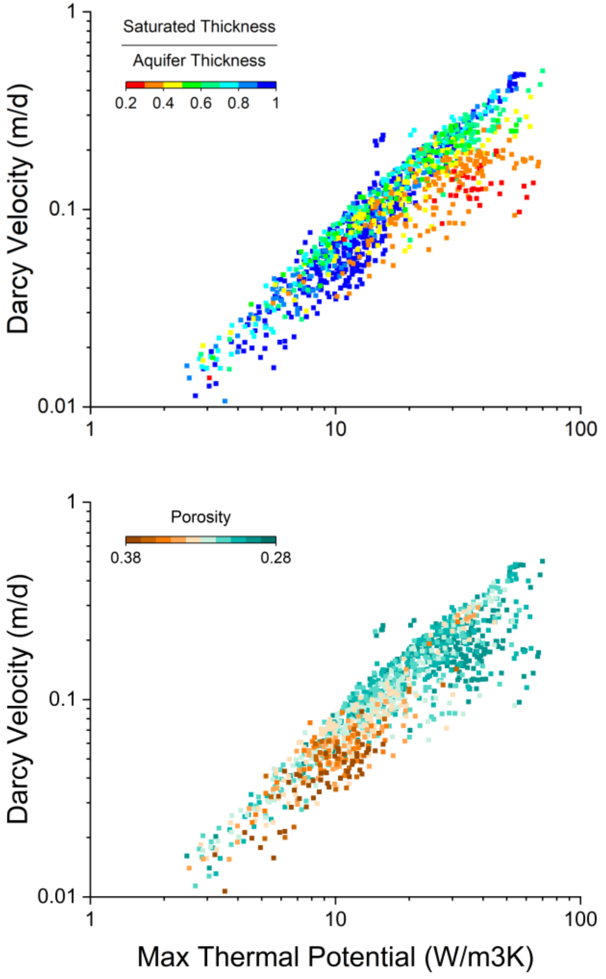
- 1 - 5
- 5 - 10
- 10 - 15
- 20 - 30
- 15 - 20
- 30 - 40
- 40 - 50
- 50 - 70



Higher gradient
Higher permeability

Lower gradient
Lower permeability

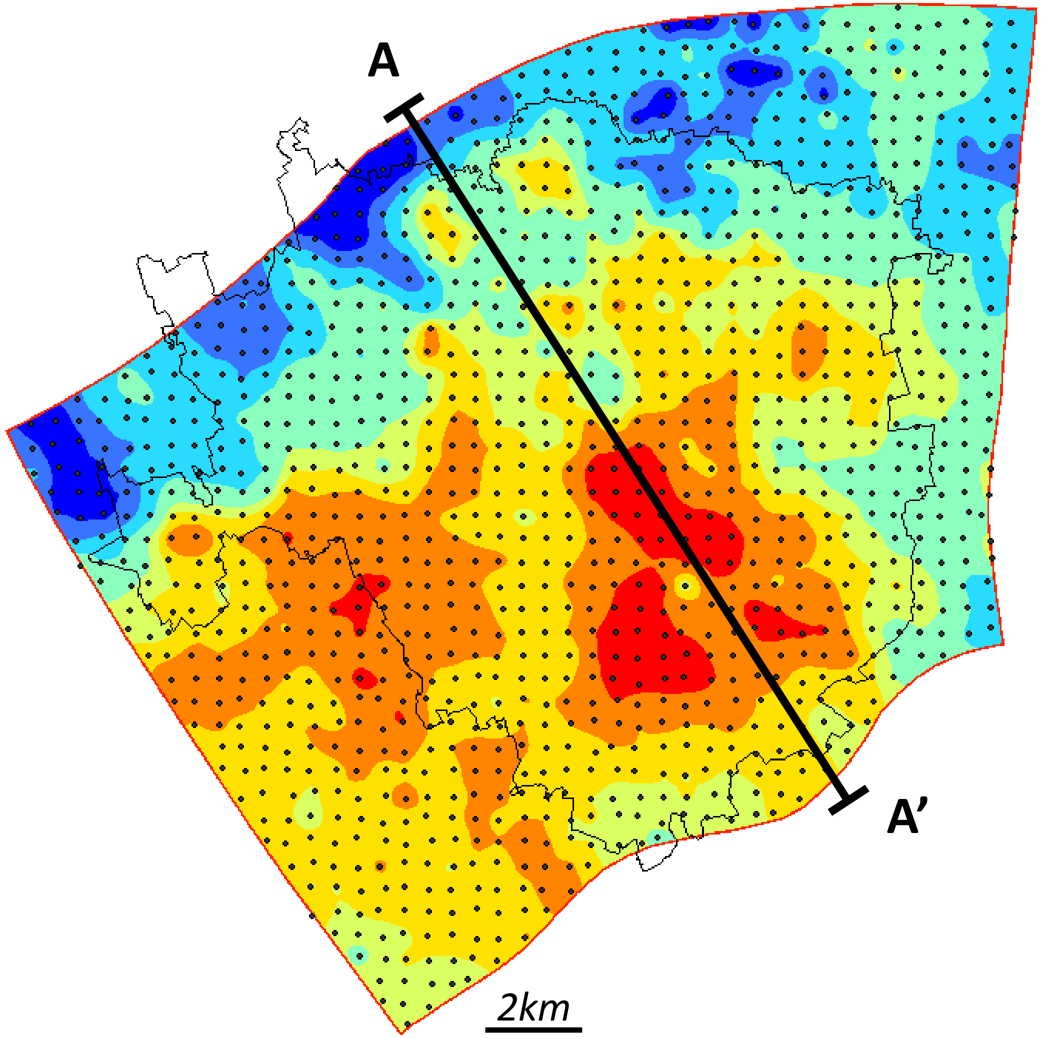
Very low gradient due to intense groundwater abstraction (Barrier effect)



Restrictions based on local regulations

Max specific **potential** **[W/m³K]**

- 1 - 5
- 5 - 10
- 10 - 15
- 20 - 30
- 15 - 20
- 30 - 40
- 40 - 50
- 50 - 70



Actual potential [W/m³]

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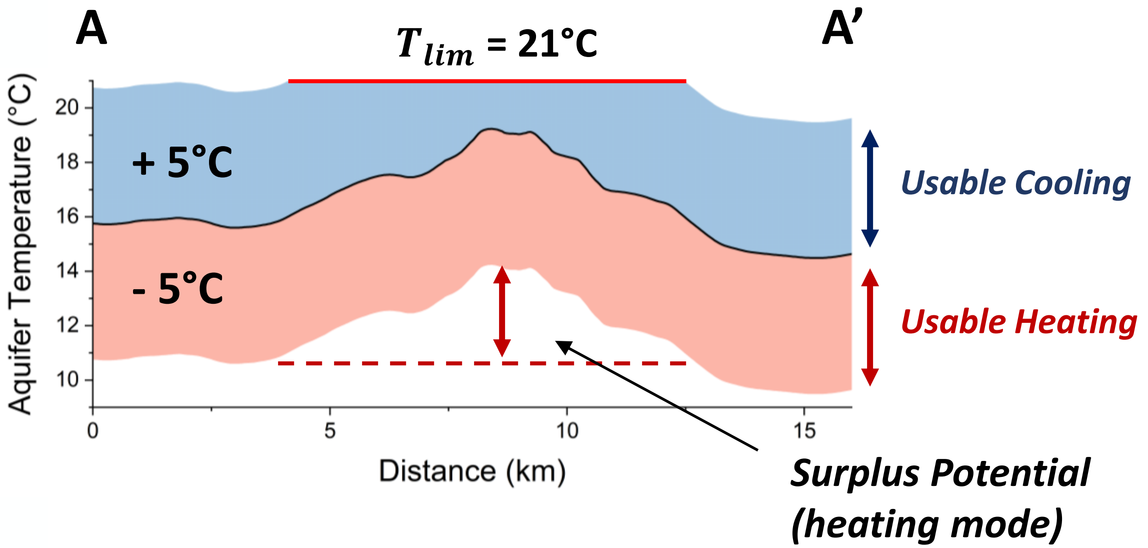
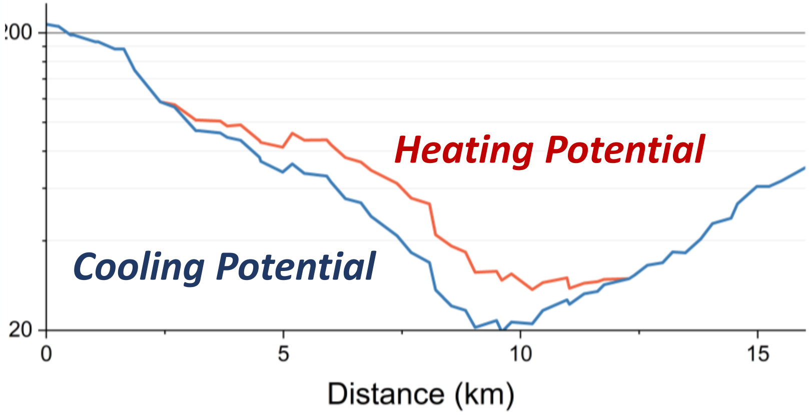
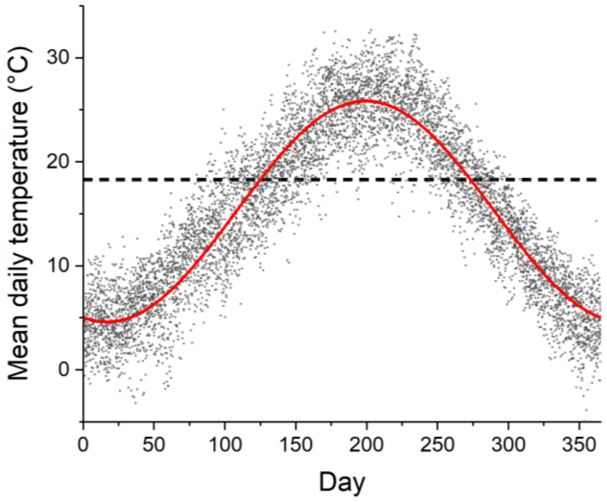
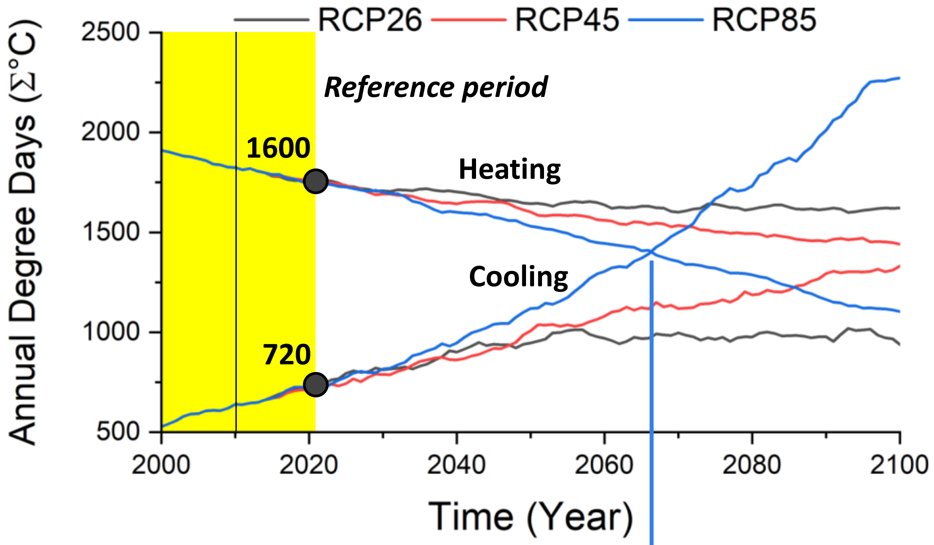




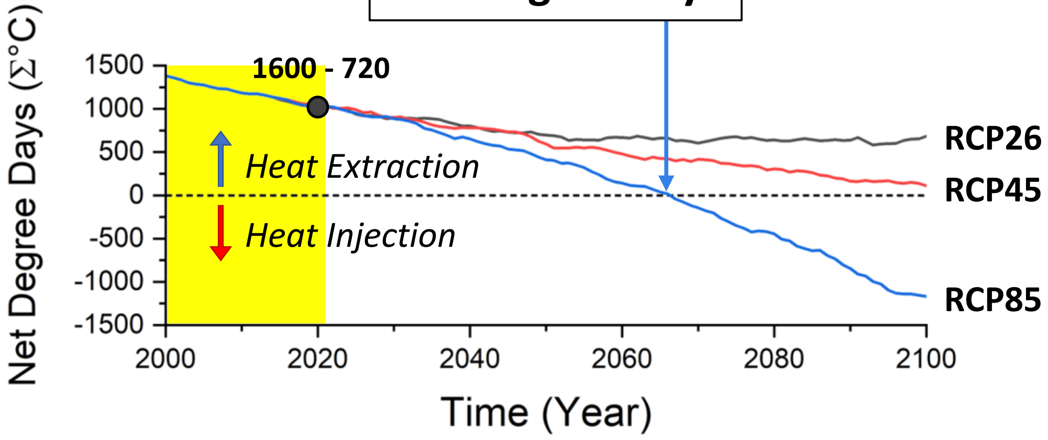
Actual degree days



Degree days future scenarios



Net Degree Days



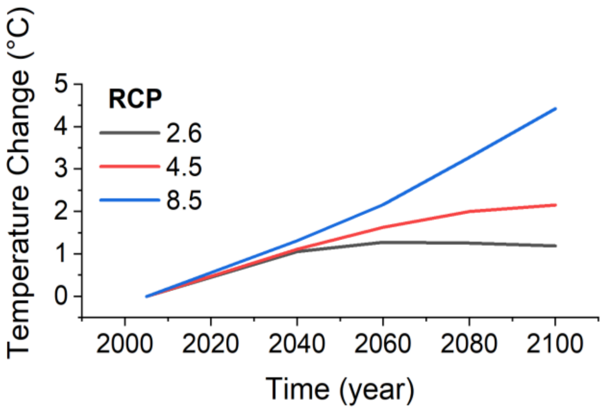
Expected increase in the cooling thermal demand

Future variation of the cooling potential?

Future scenarios → Cooling potential reduction

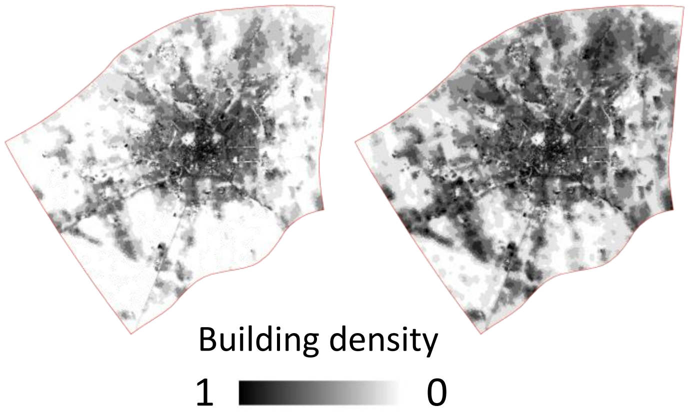
1) Air temperature change

Based on RCP scenarios



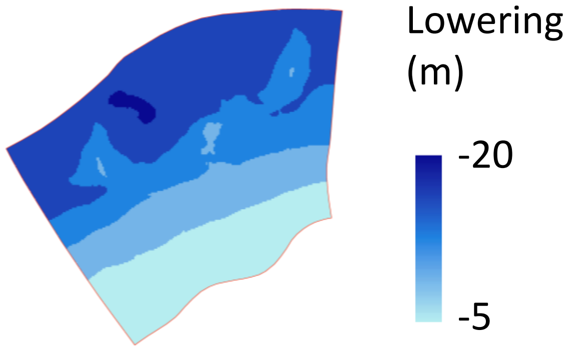
2) Land Use Change

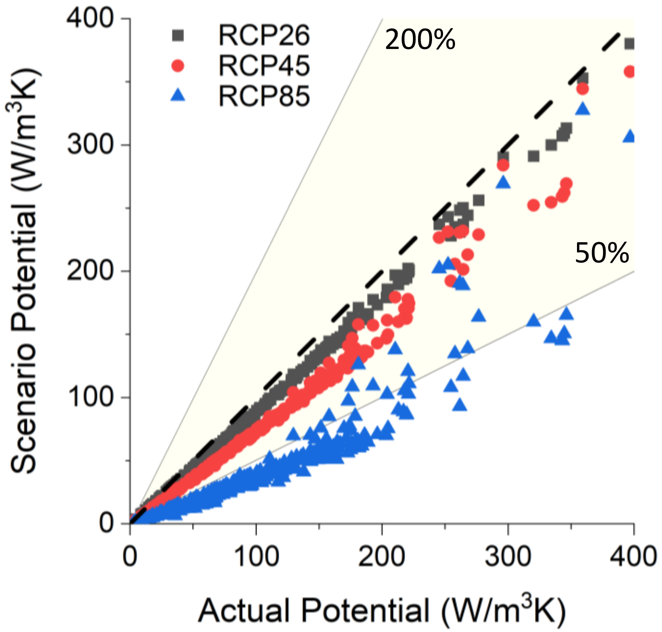
Based on city expansion

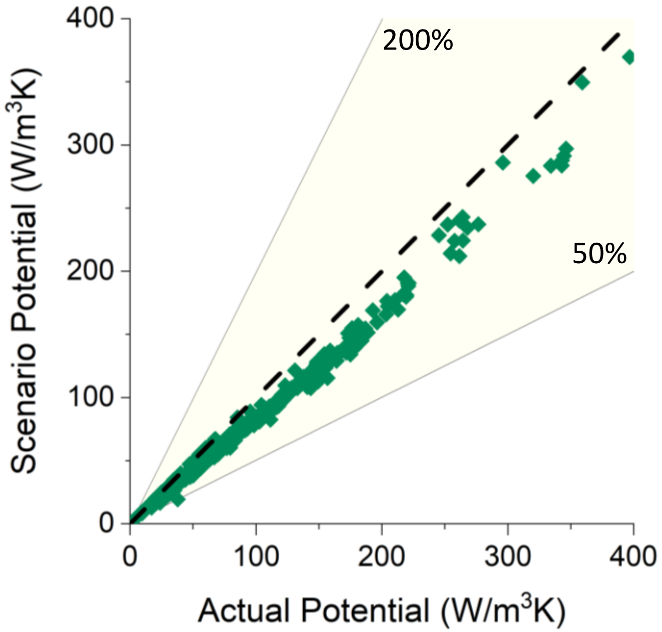


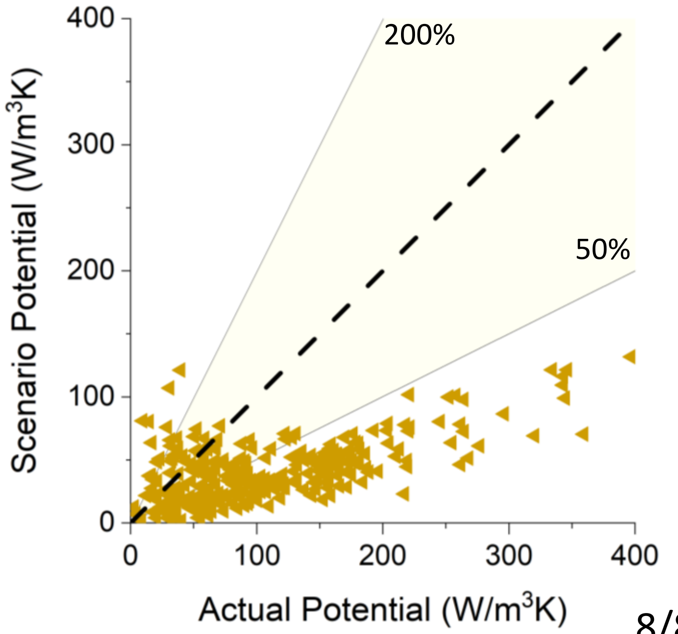
3) Groundwater Lowering

Based on historical GW levels









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Thank you for your attention!

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For any questions: alberto.previati@unimib.it

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