La physque urbaine
“Predict to Protect"

Des nouveaux outils pour l’innovation et la coopération au service du projet territorial

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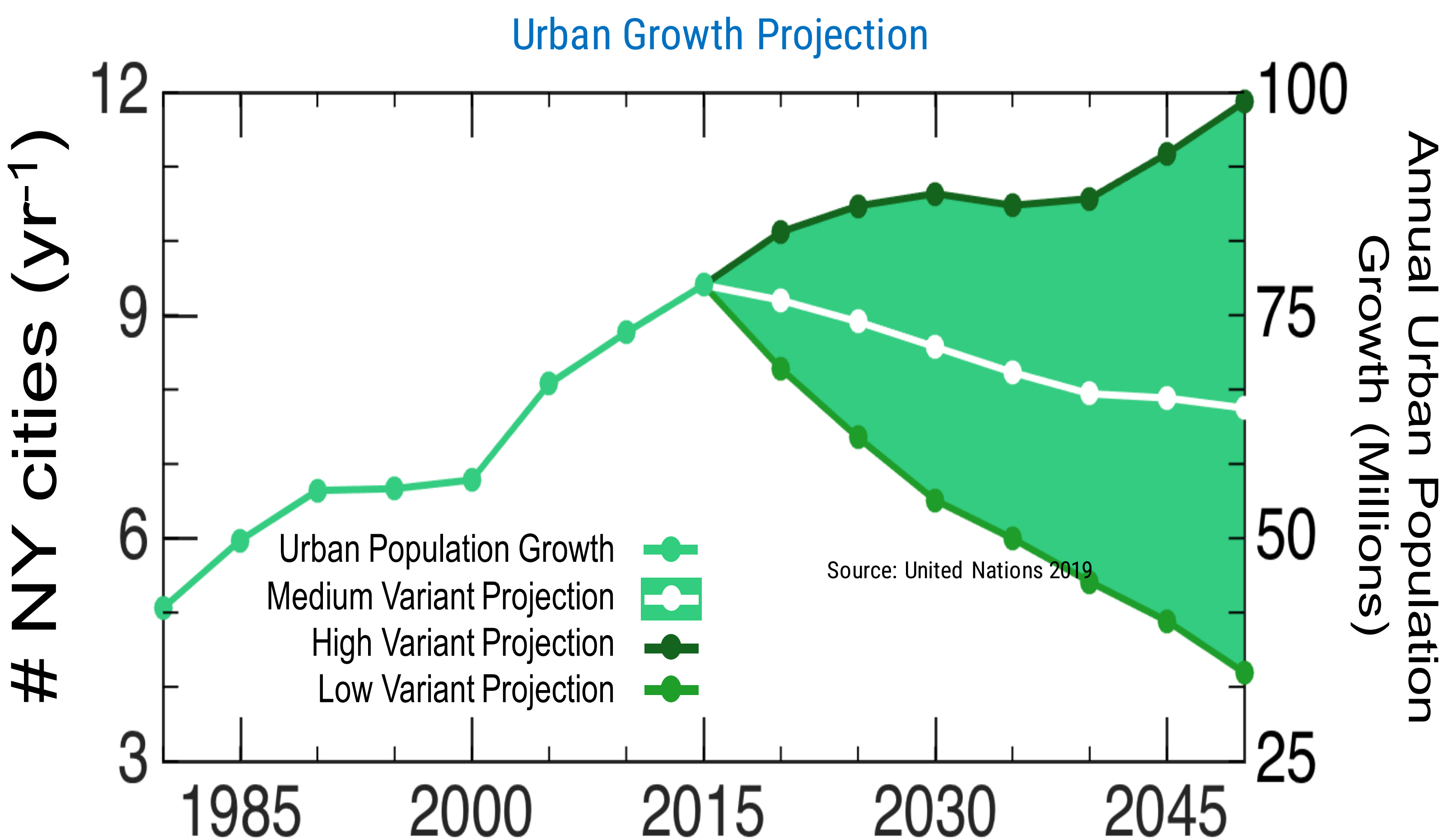
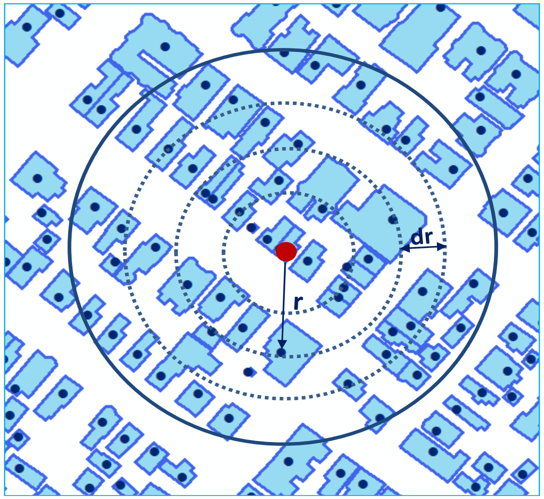
Contexte



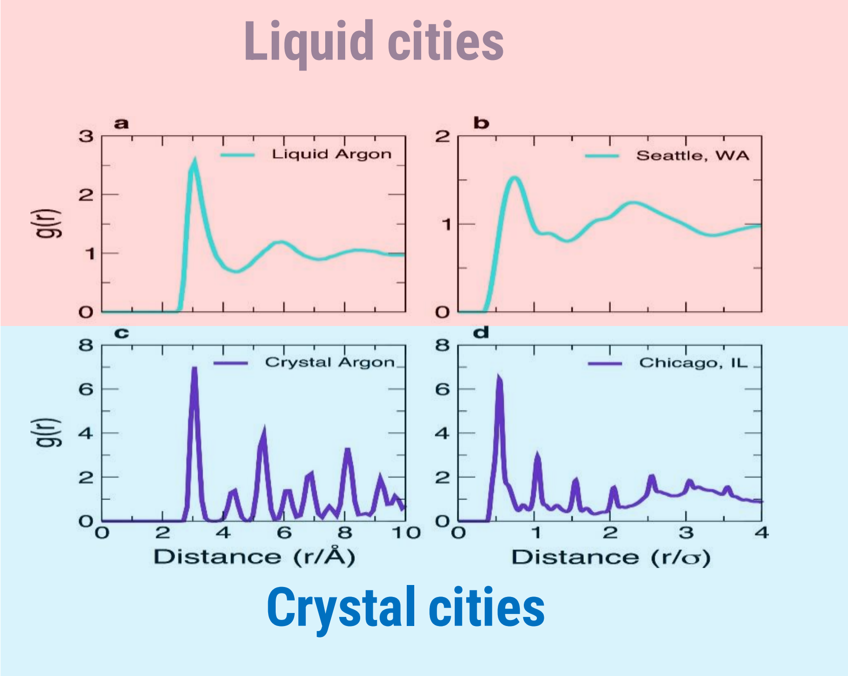
➔ Massive exodus toward cities

Physique Urbaine

➢ Using buildings positions from **Open Streets Map**,



➔ *Analogie avec la diffusion/diffraction des RX/neutrons… pour la structure des liquides et des solides*



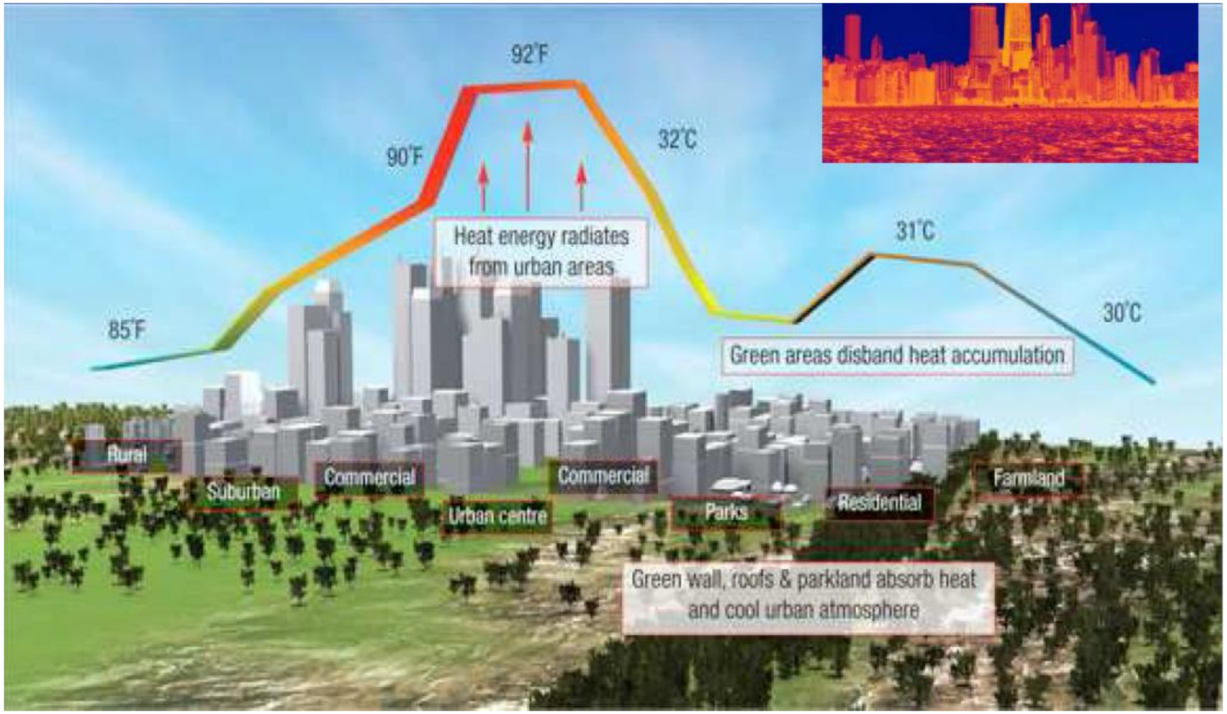
$$g(r) = \rho(r)/\langle\rho\rangle$$

$$C_n = 2\pi \int_0^R r g(r) \rho dr$$

$$\varphi = \frac{1}{C_n} \sum_{j=1}^{N} \exp(i C_n \theta_j)$$

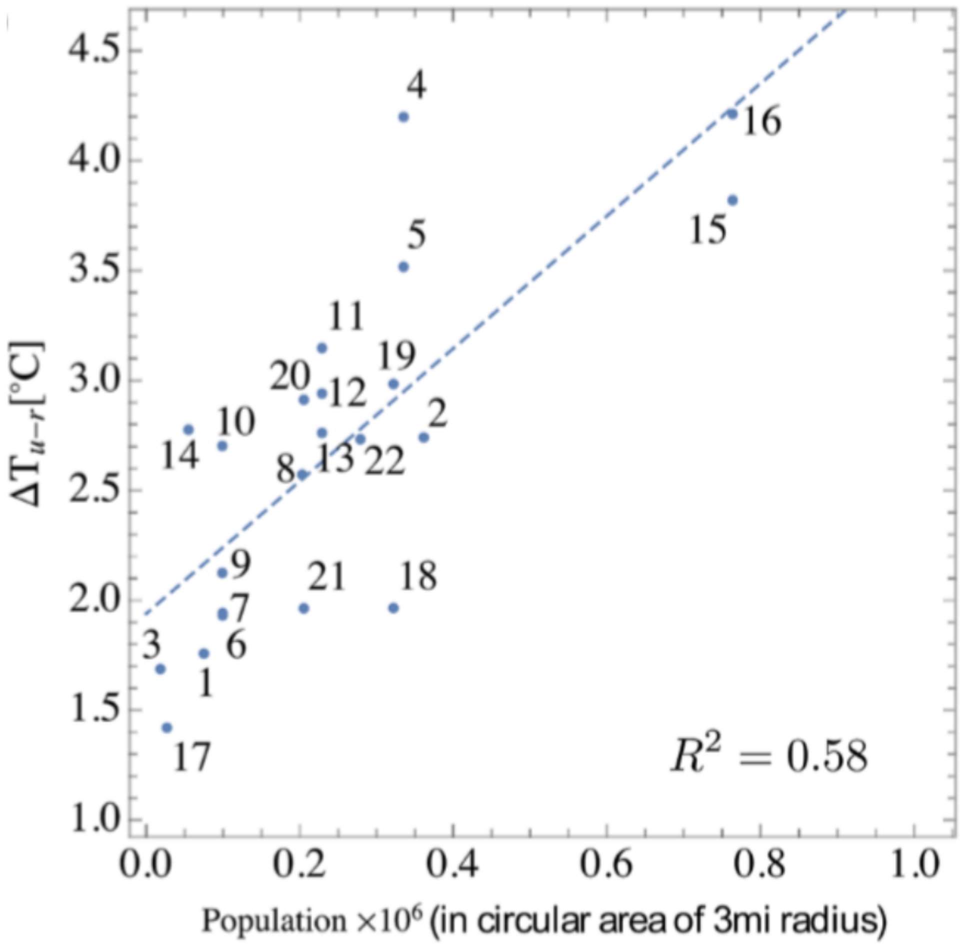
[Sobstyl et al, Phys. Rev. Letters, 2018]

Effet d’ilôts de chaleur urbain (ICU)



ICU

1. Austin, TX
2. Boston, MA
3. Chesapeake, VA
4. Chicago, IL (1)
5. Chicago, IL (2)
6. Dallas, TX (1)
7. Dallas, TX (2)
8. Hartford, CT
9. Houston, TX (1)
10. Houston, TX (2)
11. Los Angeles, CA (1)
12. Los Angeles, CA (2)
13. Los Angeles, CA (3)
14. London, UK
15. Louisville, KY
16. New York, NY (1)
17. New York, NY (2)
18. Oklahoma City, OK
19. Paris, France
20. Philadelphia, PA (1)
21. Philadelphia, PA (2)
22. Seattle, WA (1)
23. Seattle, WA (2)
24. Washington, DC



[Roxon, PhD MIT, 2020]

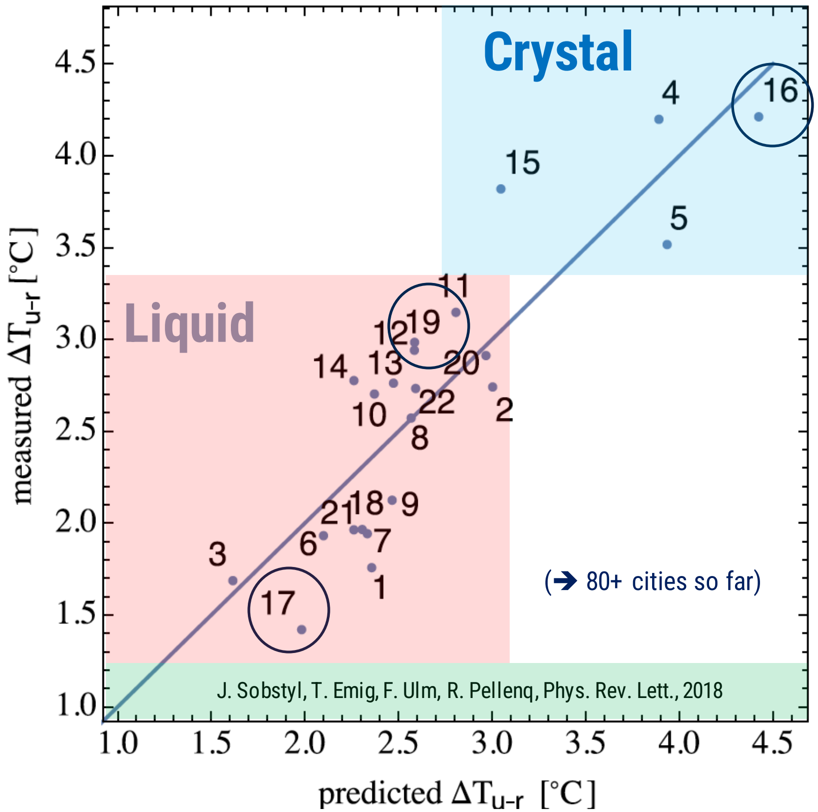
➔ les ICU ne sont pas directment liés à un effet de densité de surace construite

ICU

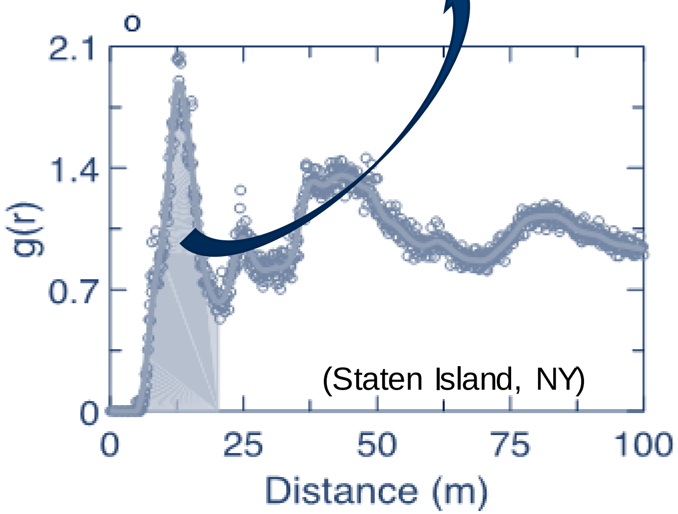
- Predicting UHI

- predicted $\Delta T_{u\text{-}r}$ = f [g(r), φ, prop. construction material]
- measured $\Delta T_{u\text{-}r}$ = $T_{city\text{-}center} - T_{airport}$

$$\Delta T_{u-r} = T_r\left[\gamma\left(1 + \frac{4L\bar{h}}{(L+d)^2}\right)^{\frac{1}{4}} - 1\right].$$



[Sobstyl et al, Phys. Rev. Letters, 2018]



L et d extracted from g(r) / open-street map, h is the building height

ICU

1. Austin, TX
2. Boston, MA
3. Chesapeake, VA
4. Chicago, IL (1)
5. Chicago, IL (2)
6. Dallas, TX (1)
7. Dallas, TX (2)
8. Hartford, CT
9. Houston, TX (1)
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12. Los Angeles, CA (2)
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14. London, UK
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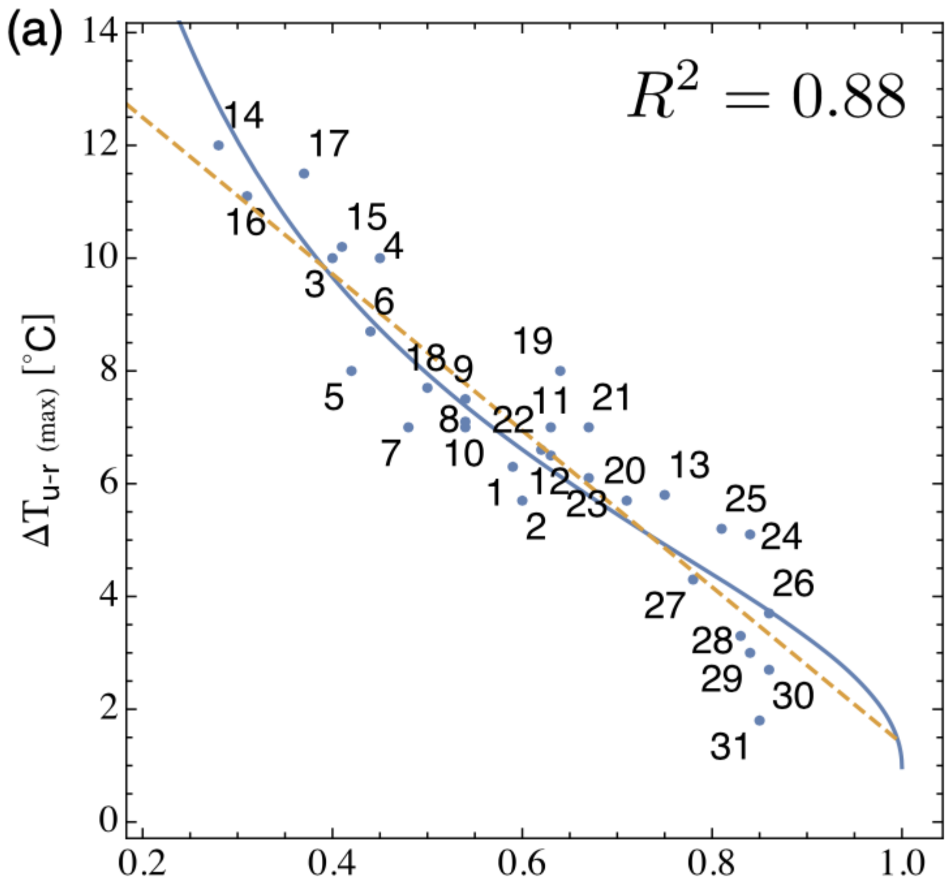
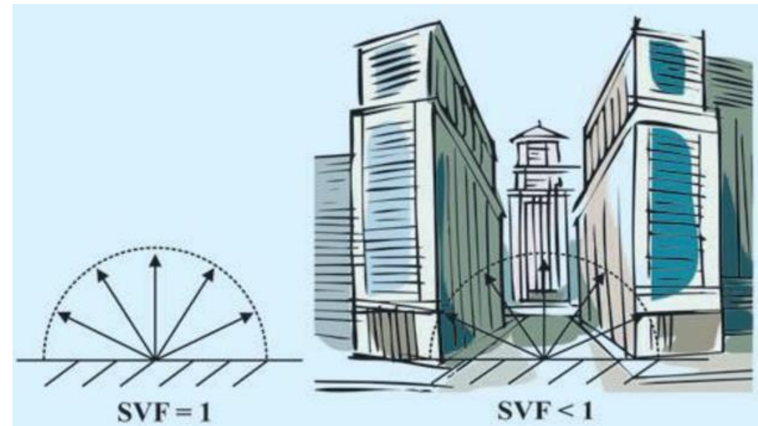
16. New York, NY (1)
17. New York, NY (2)
18. Oklahoma City, OK
19. Paris, France
20. Philadelphia, PA (1)
21. Philadelphia, PA (2)
22. Seattle, WA (1)
23. Seattle, WA (2)
24. Washington, DC





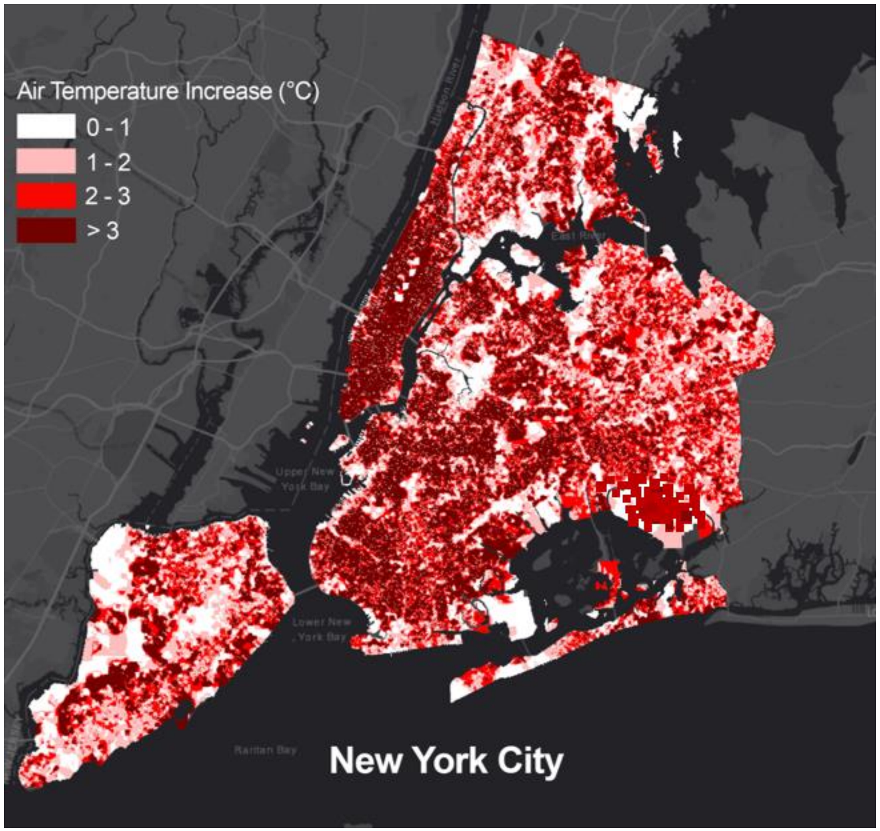
L et d extracted from g(r) / open-street map

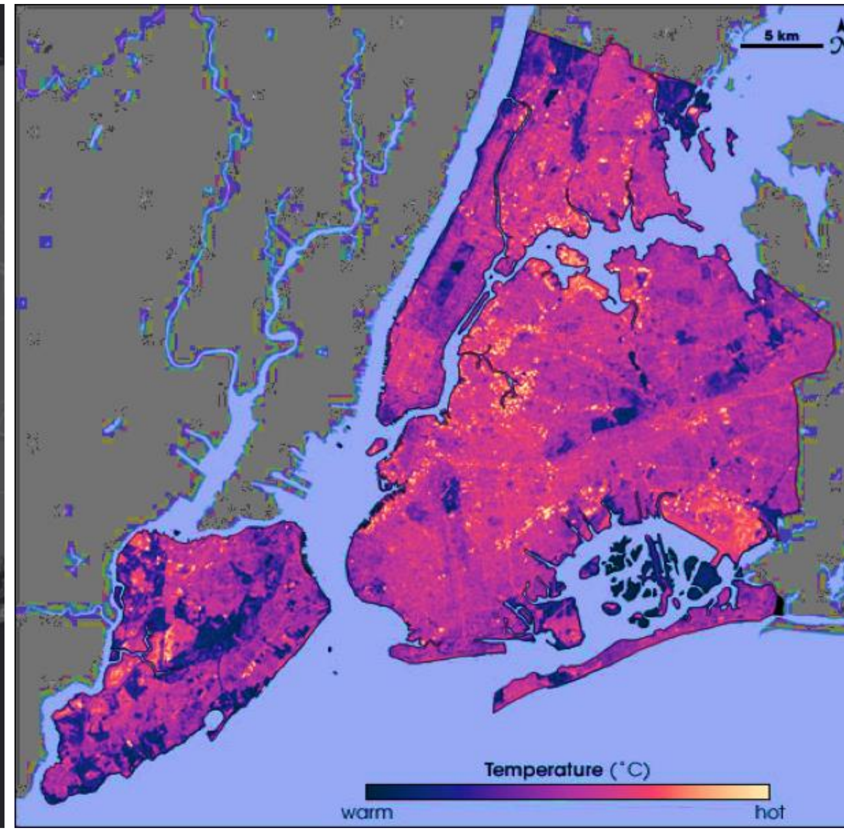
$$\Delta T_{u-r}(\psi_s) = T_r\left[\gamma\left(1 + \frac{2\frac{L}{d}\tan[\arccos(\psi_s)]}{(1+\frac{L}{d})^2}\right)^{\frac{1}{4}} - 1\right]$$

[Sobstyl et al, Phys. Rev. Letters, 2018]

ICU

At the scale of neighborhood (if h known → LIDAR-HD ?)





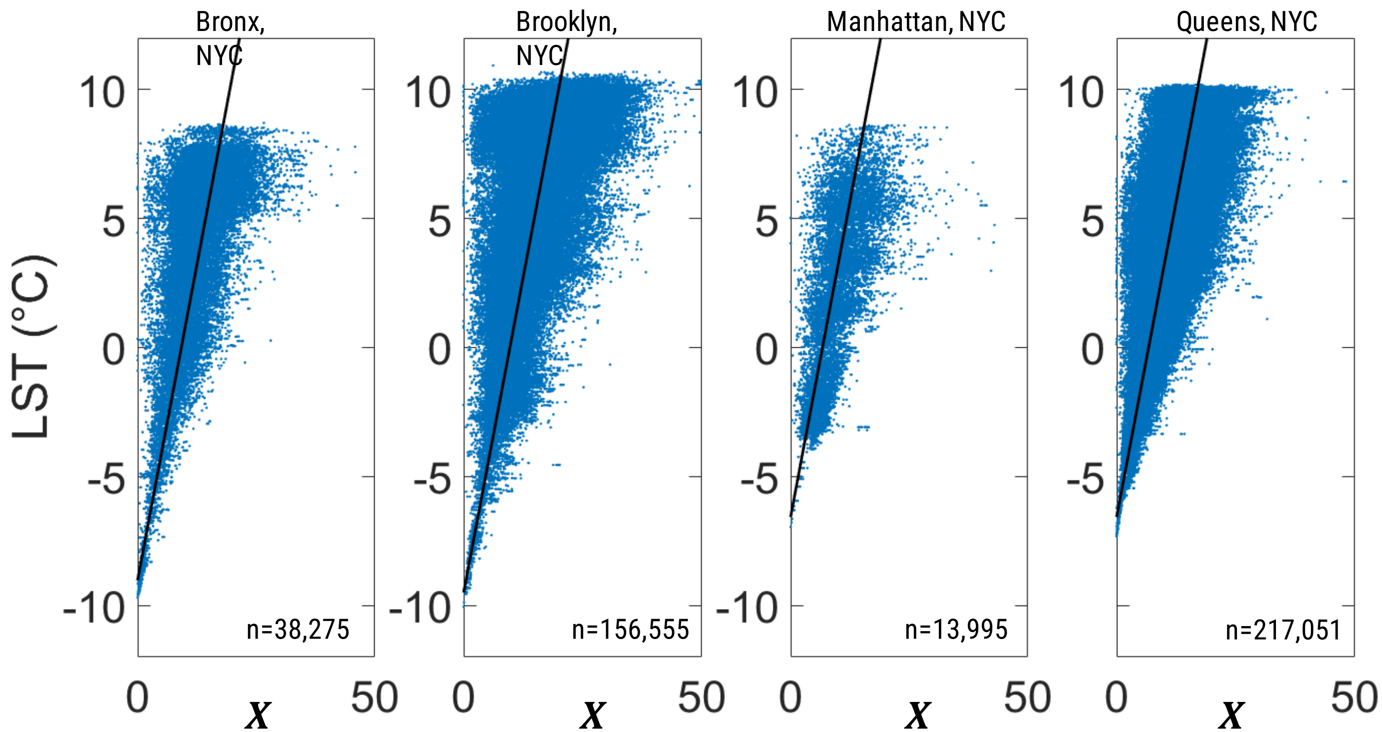
Prediction from urban texture

Infrared image at **NIGH !**

Land Temp is not UHI

ICU

Using City Texture parameters, can we predict Land Surface Temperature (LST) ?

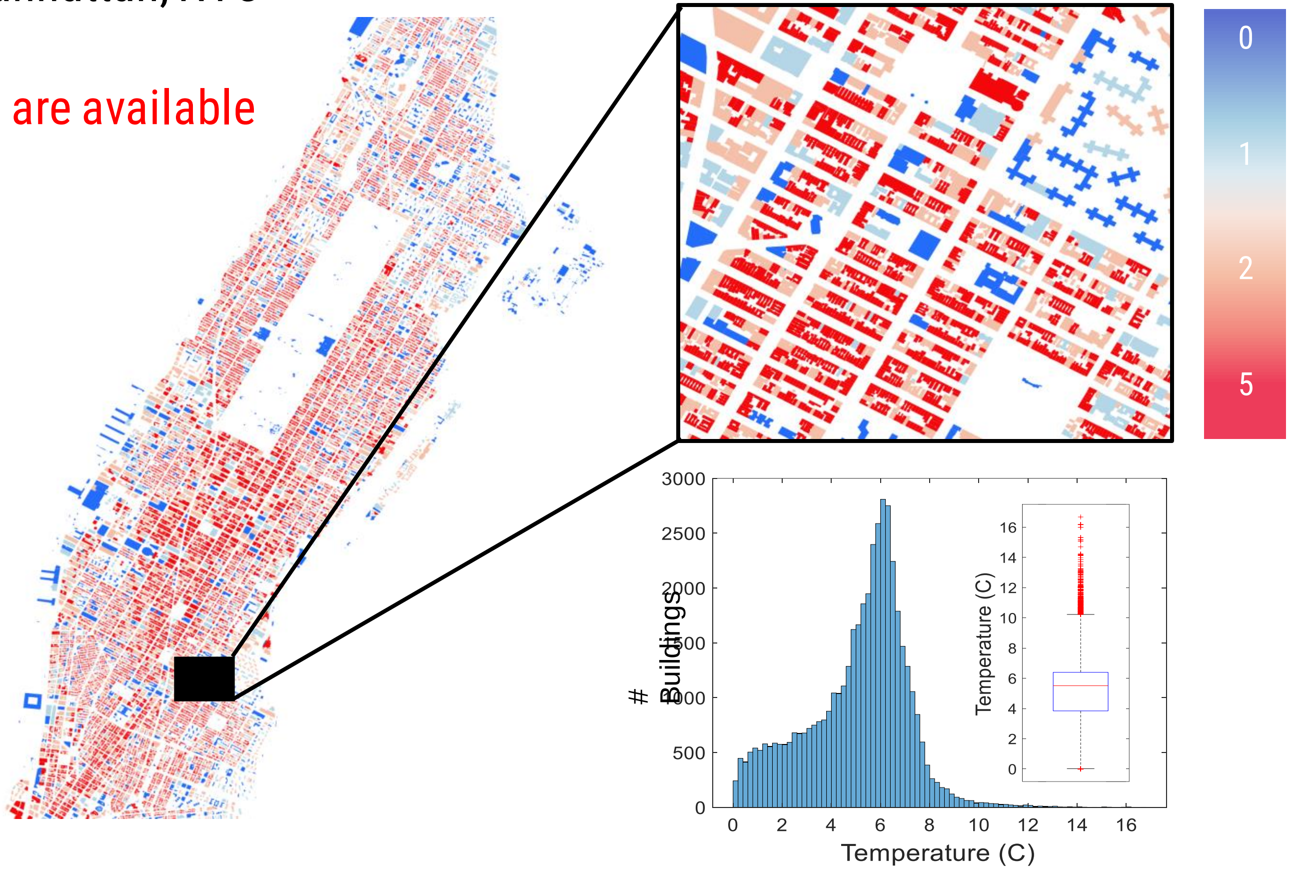


$$\mathrm{LST} = (C_n + 1) \times \frac{H \times L}{A} + a_1$$

ICU

UHI: Manhattan, NYC

In NYC, h are available



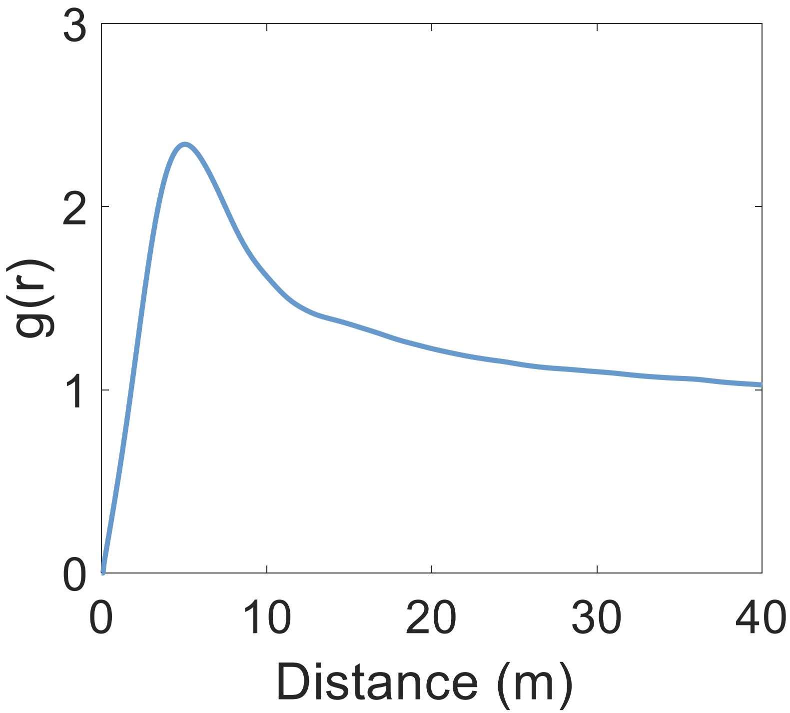
$$\Delta T_{u-r} = T_r\left[\gamma\left(1+\frac{4L\bar{h}}{(L+d)^2}\right)^{\frac{1}{4}}-1\right]$$

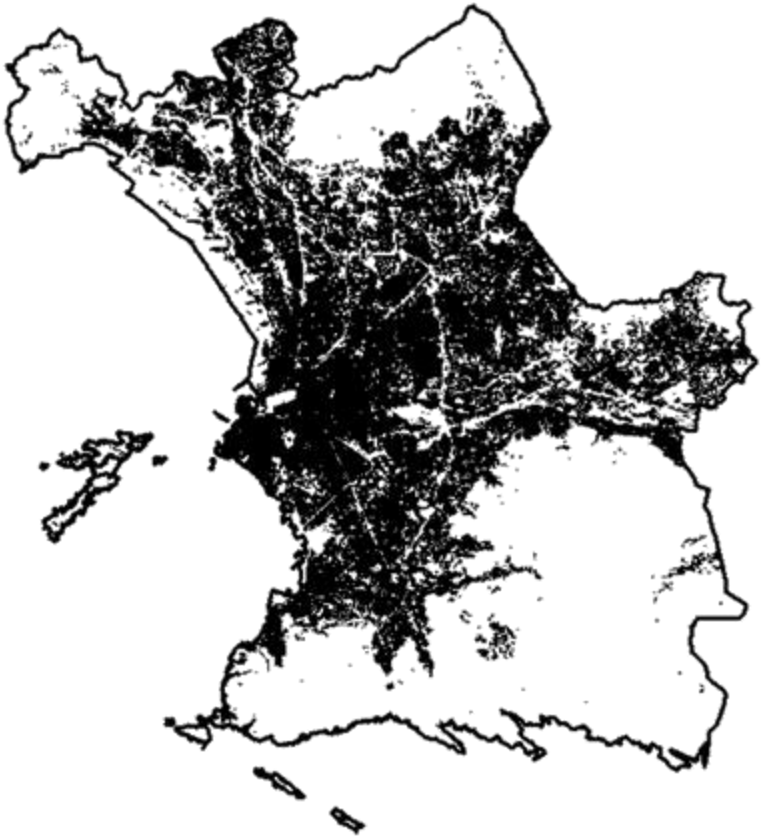
ICU

Marseille, France

Metro: 288,312 buildings

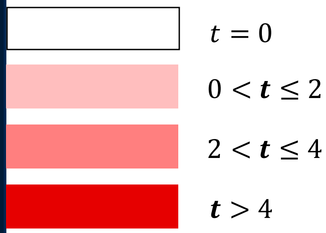
$C_n = 2$
$\varphi = 0.44$



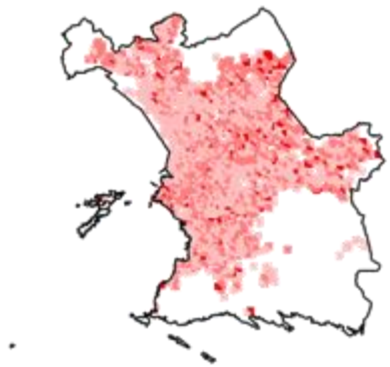


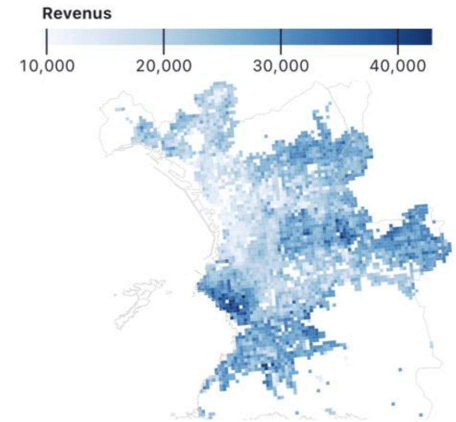
ICU

Marseille, France

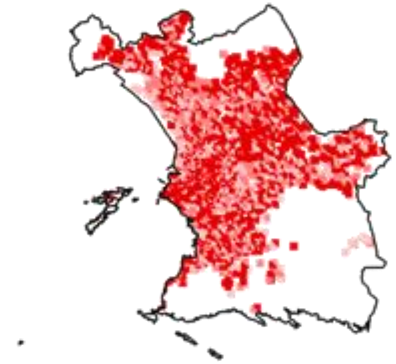


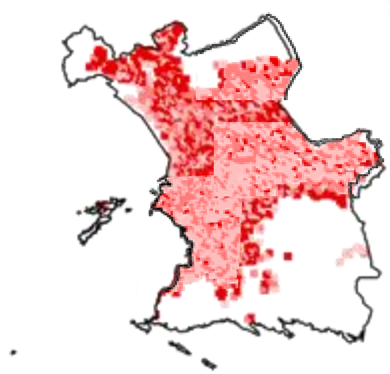
Building Height: 5m
Average Temp: $1.8°C$
Temp SD: $1.2°C$

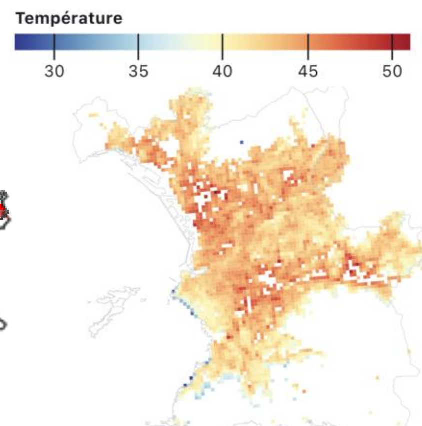




Building Height: 15m
Average Temp: $4.4°C$
Temp SD: $2.6°C$







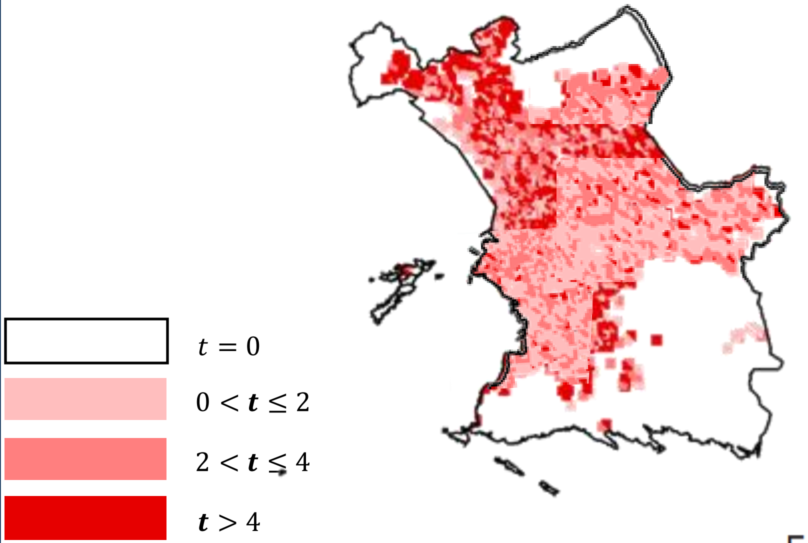
Our prediction

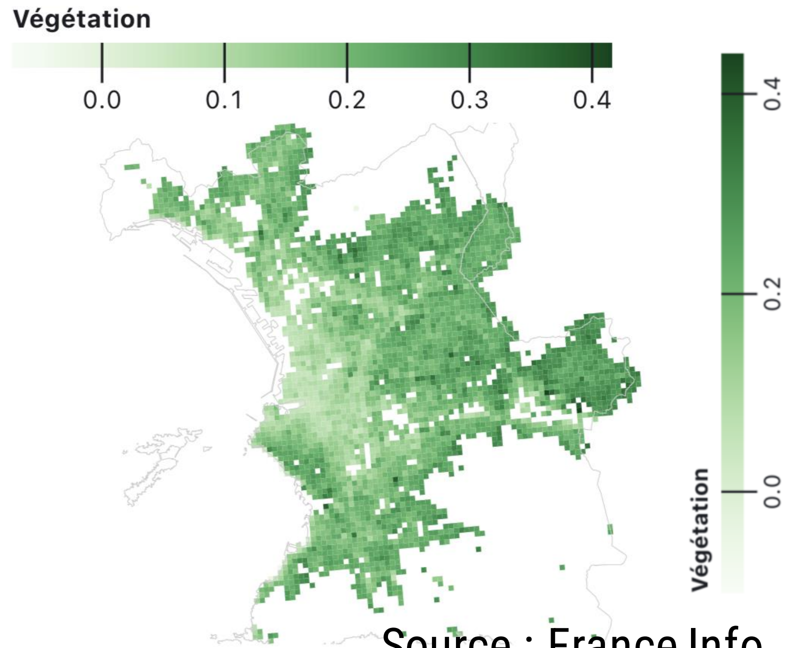
IR-Satellite measurement

ICU et végétalisation

Downtown Lyon, France

Marseille, France





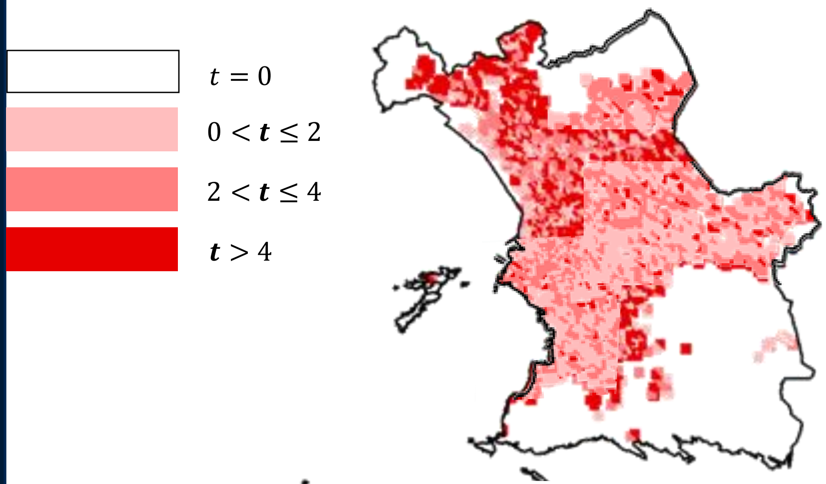
Source : France Info

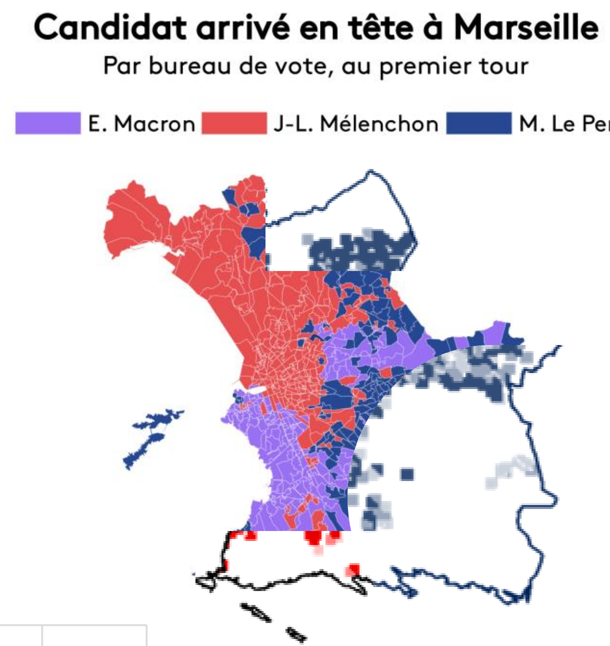
$$\Delta T_{u-r} = T\left[\gamma\left(1+\frac{4L\bar{h}}{(L+d)^2}\right)^{\frac{1}{4}}-1\right].$$

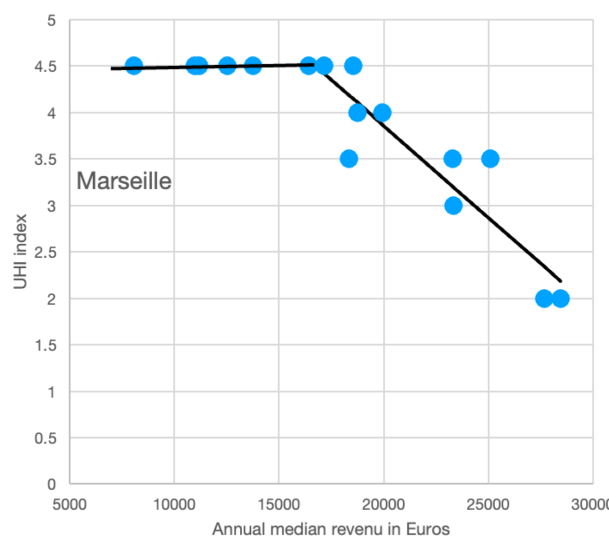
➔ What if scenarios en jouant sur **l'émissivité de surface des materiaux** et le role de la **végétation urbaine** (transition de phase du 1er ordre d'eau-liquide en eau-vapeur dans les stomates (pores) :" transpiration des végétaux")

ICU et Sciences Po

Marseille, France







Source : France Info

ICU

Paris, France

$t = 0$

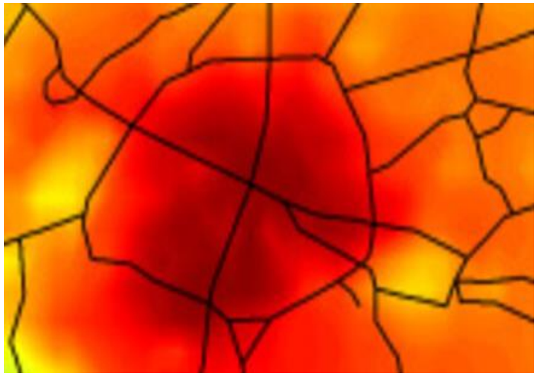
$0 < \boldsymbol{t} \leq 2$

$2 < \boldsymbol{t} \leq 4$

$\boldsymbol{t} > 4$

Building Height: 20m
Average Temp: $3.3°C$
Temp SD: $1.9°C$

Paris center = one big UHI !

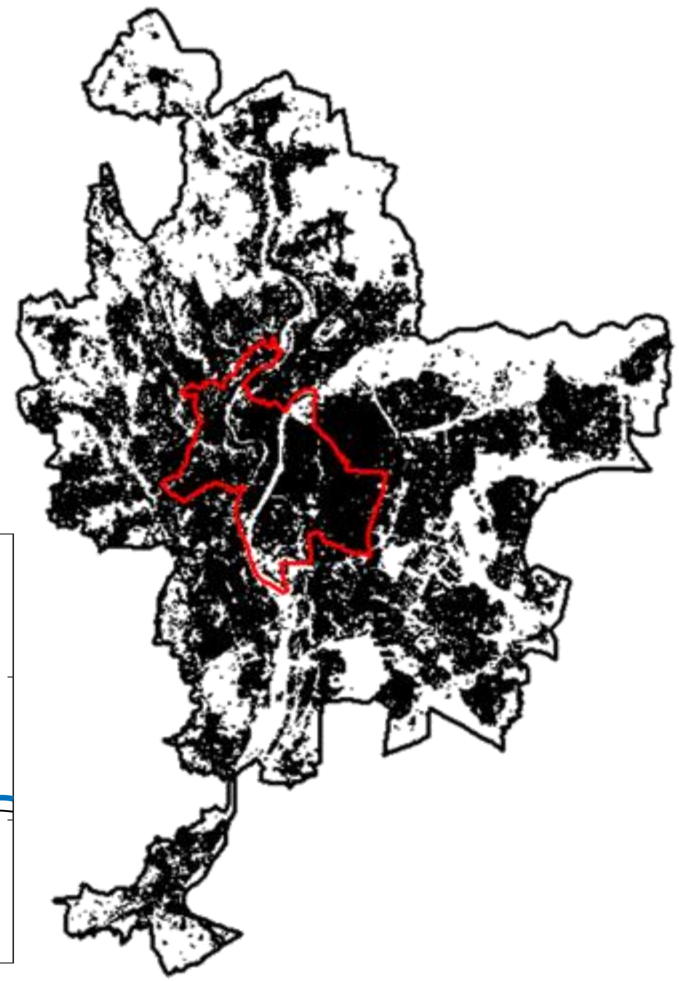


ICU

Lyon, France

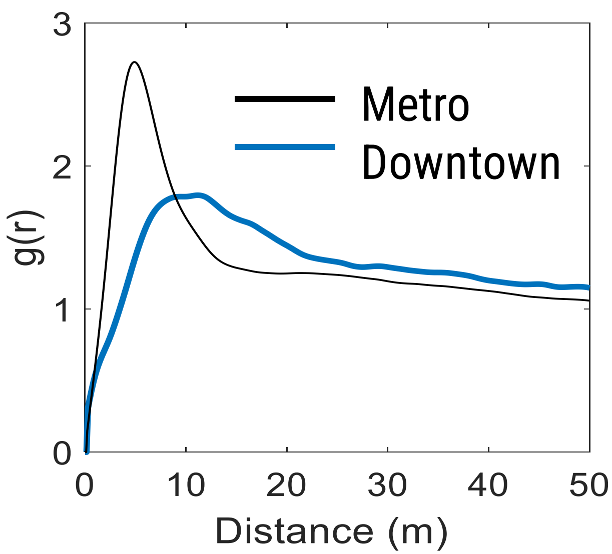
Metro: 316,530 buildings

Downtown: 46,454 buildings



Metro:
$C_n = 2$
$\varphi = 0.48$

Downtown:
$C_n = 3$
$\varphi = 0.41$

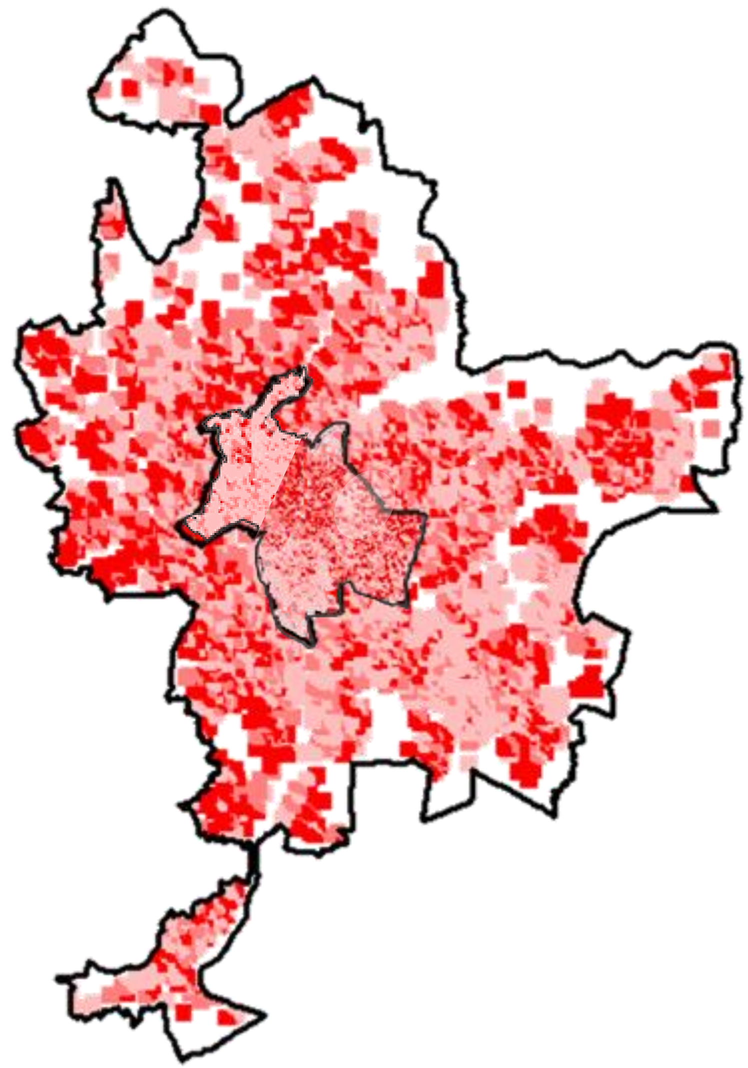


ICU

Lyon, France

Building Height: 9.5m (UHI paper)

(white)	$t = 0$
(light pink)	$0 < \boldsymbol{t} \leq 1.5$
(pink)	$1.5 < \boldsymbol{t} \leq 3$
(red)	$\boldsymbol{t} > 3$



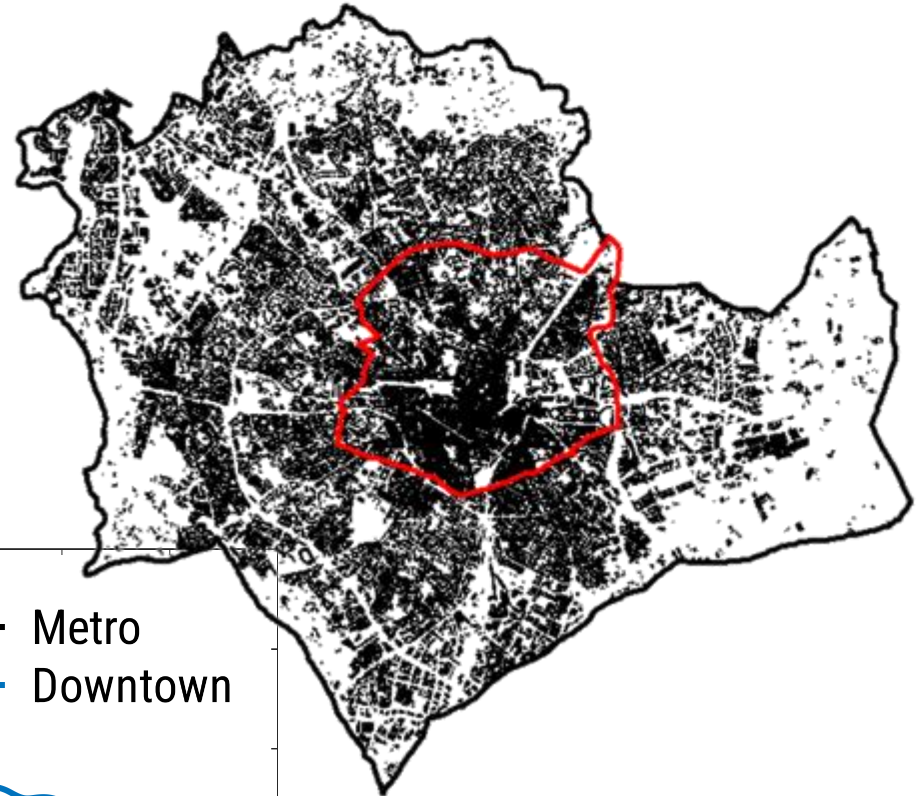
ICU

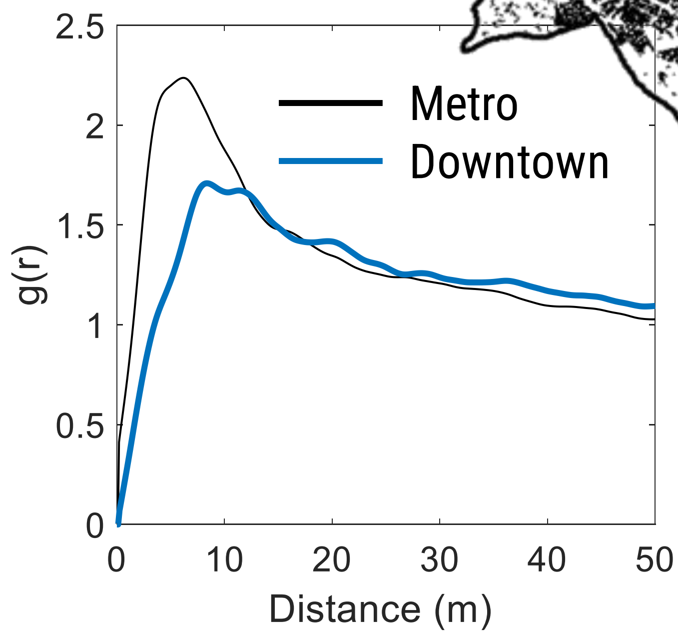
Montpellier, France

Metro: 63,529 buildings
Downtown: 14,858 buildings

Metro:
$C_n = 2$
$\varphi = 0.45$

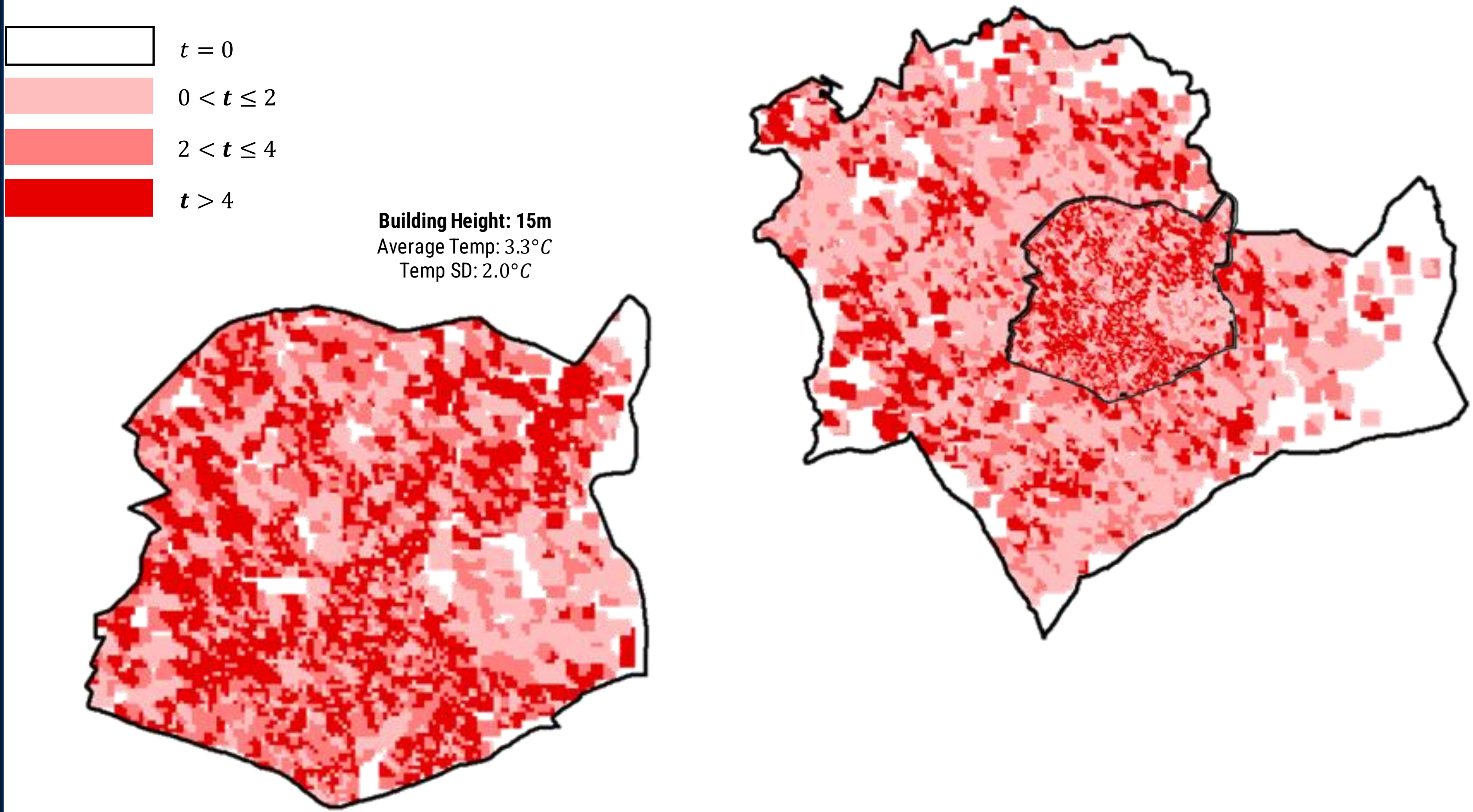
Downtown:
$C_n = 3$
$\varphi = 0.4$





ICU

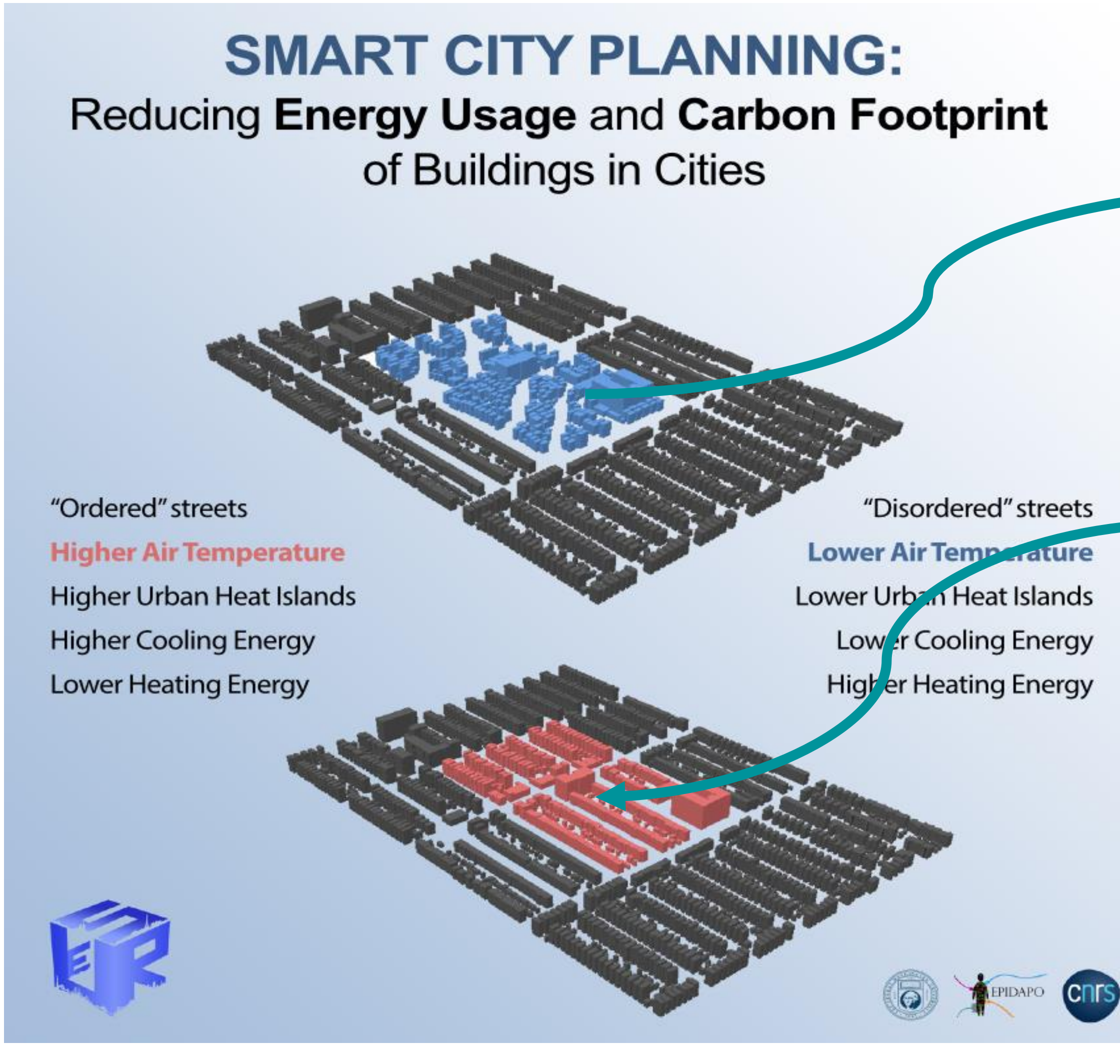
Montpellier metro, France



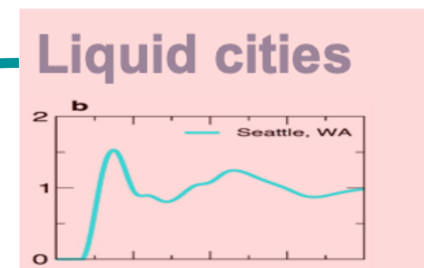
Montpellier downtown, France

SURe : a serious game

Downtown Manhattan, NY, US



"Ville des 15mn de C. Moreno ?"



(Reverse Monte-Carlo)

www.sure-tech.fr

Tempêtes de vent

Tempête de vent

Simple derivation of building codes

$$\boxed{\text{Pressure} = \frac{1}{2} C_D \rho v^2}$$

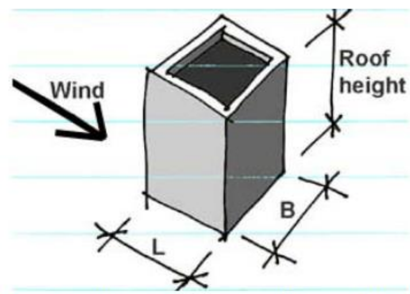


Fig. 1. *Plan dimensions "L" and "B"*

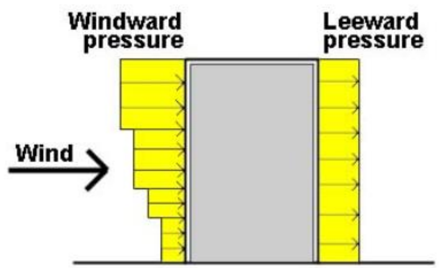


Fig. 2. *Windward and leeward wind pressure*

city	wind speed (mph) if 'other'	wind speed used (mph)	exposure	roof height (ft)	Importance
Other	180	180	D	64	IV=essential

Kd	Kt
0.85	1

L (ft)	B (ft)
100	100

height above grade (ft)	windward pressure (psf)	leeward pressure (psf)	combined pressure (psf)
64	73.1	-45.69	118.79
60	72.29	-45.69	117.98
50	70.03	-45.69	115.72
45	68.76	-45.69	114.45
40	67.36	-45.69	113.05
35	65.82	-45.69	111.51
30	64.08	-45.69	109.77
25	62.08	-45.69	107.77
20	59.71	-45.69	105.4
15	56.8	-45.69	102.49

Using ICC rule, a multistory building located on the Southern Coast has to be able to withstand a combined wind pressure of:
100-120psf (4750-5750 Pa)
→ **Cat.5 Hurricane**

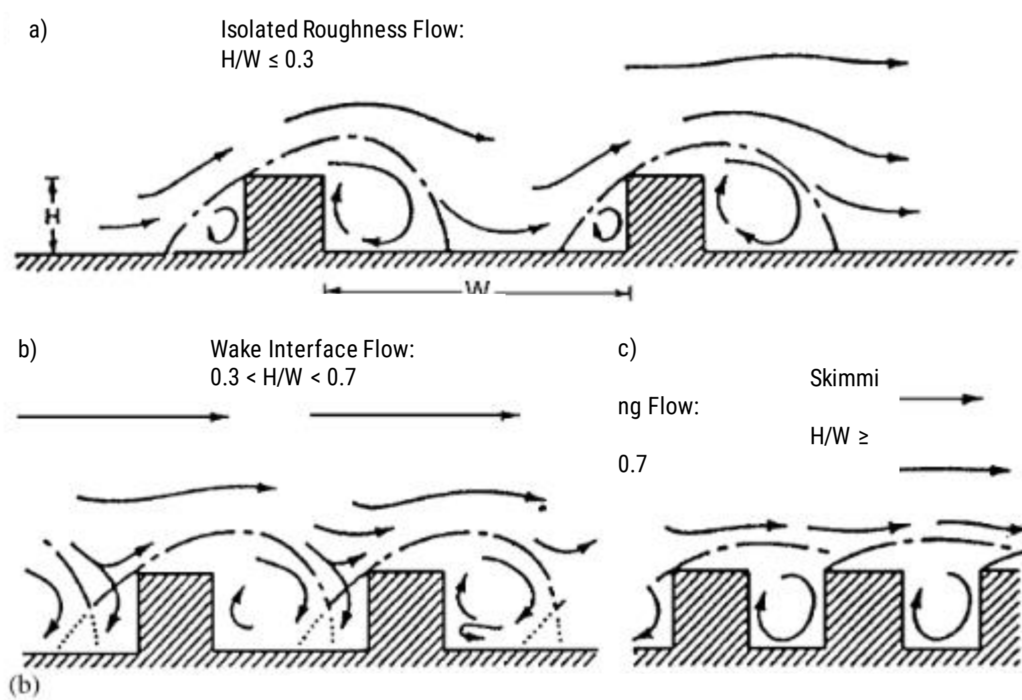
IS THIS ENOUGH?

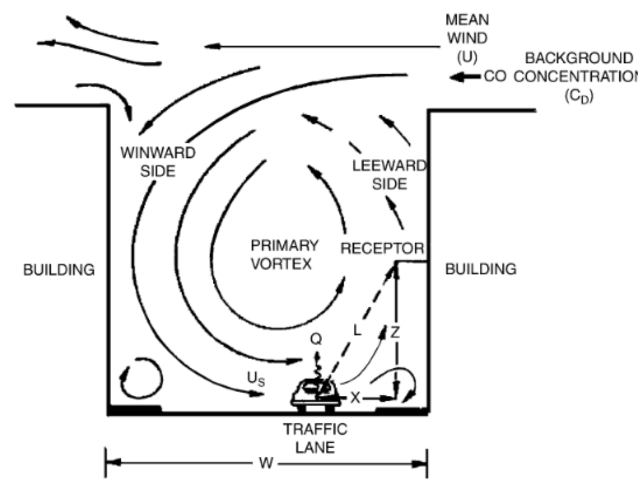
https://courses.cit.cornell.edu/arch264/calculators/example2.4/

Tempête de vent

Urban Canyons impact flow regimes

$$\text{Pressure} = \frac{1}{2} C_D \rho v^2$$





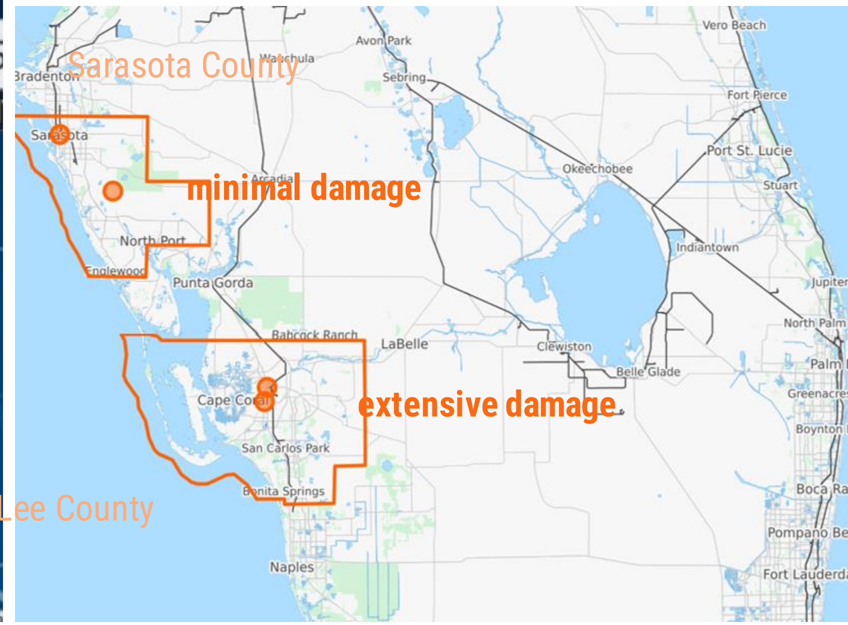
Dabberdt et al, 1973

Oke, 1987

Depending on the structure, ultimate and nominal wind speed may be much higher than ICC's climatic maps state

Tempête de vent

City Texture study of Sarasota and Lee Counties in FL



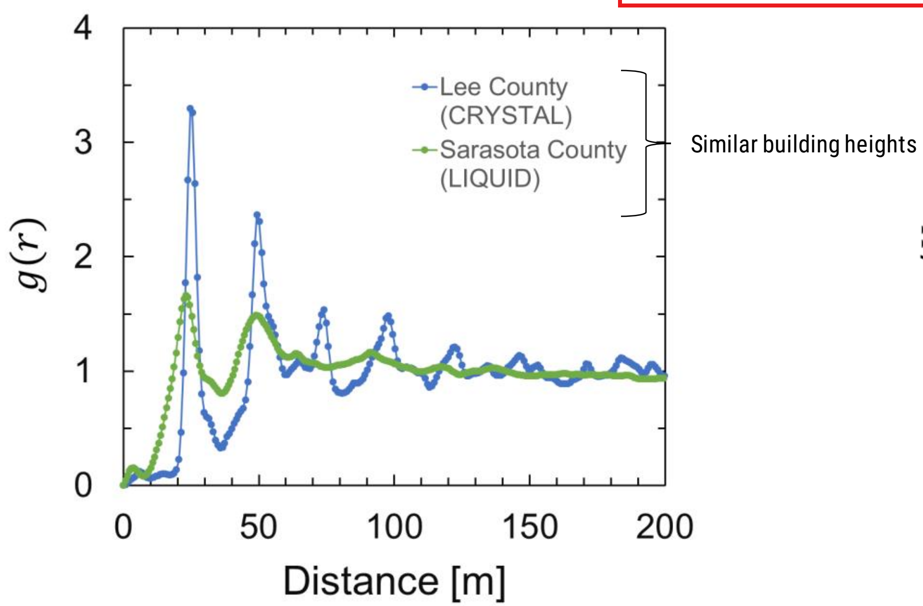
J. Roxon, PhD, thesis, MIT, 2020

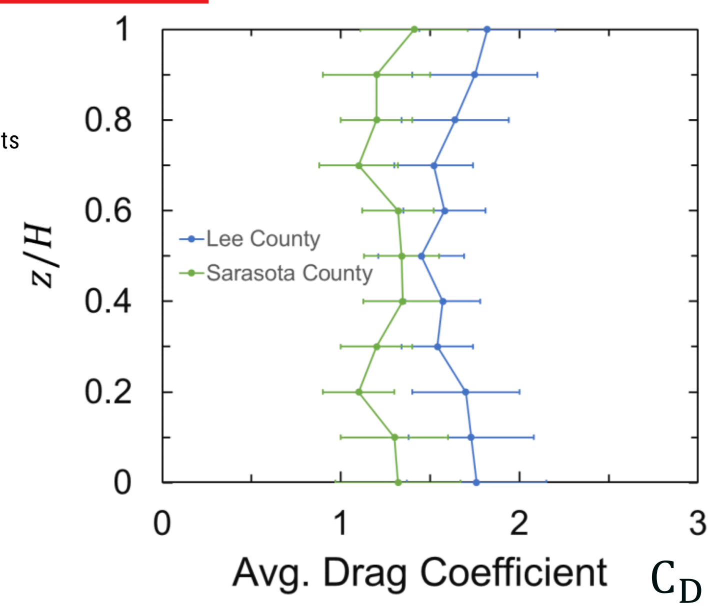
→ What is the role of CITY TEXTURE in Hurricane Damage?

Tempête de vent

Results: more LIQUID CITY TEXTURE is safer

$$\text{Pressure} = \frac{1}{2} C_D \rho v^2$$

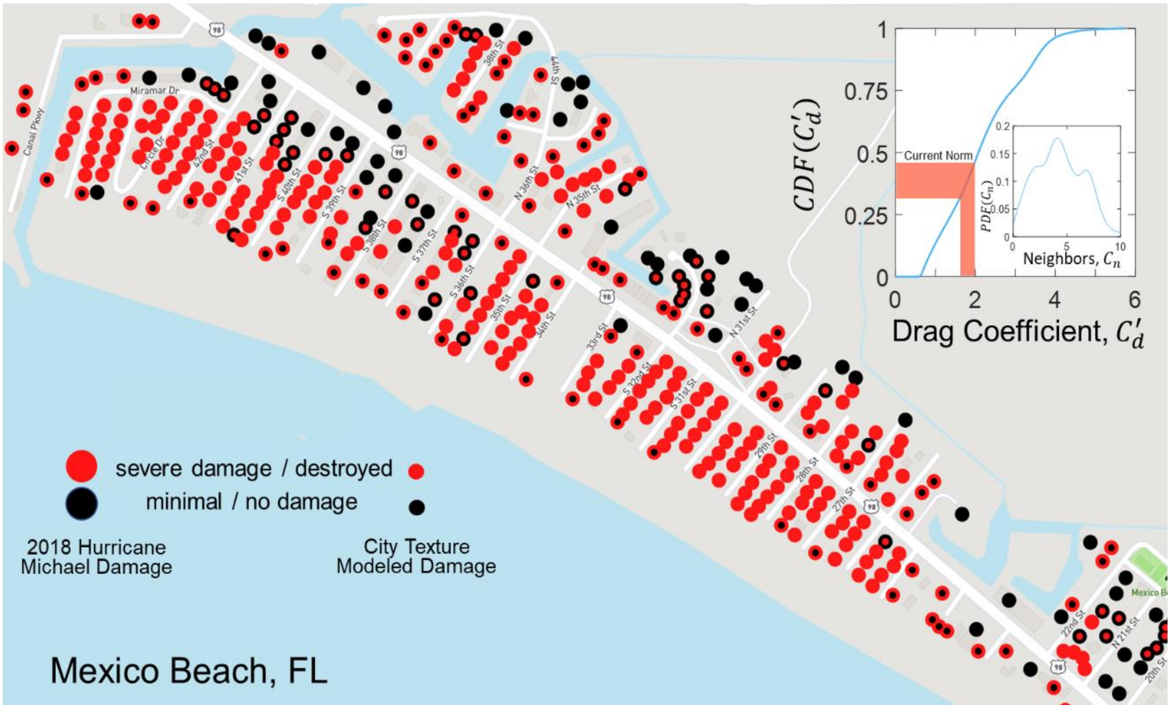




Geometrical Layouts in Sarasota County offer lower drag coefficients for buildings than in Lee County, which results in lower wind loads

J. Roxon, PhD, thesis, MIT, 2020

Tempête de vent



➔ We predict 70 % of destructions. in Mexico-Beach City, FL, Hurricane Michael, 2018

J. Roxon, PhD, thesis, MIT, 2020

$$P_{wind} = \frac{1}{2}\rho v^2 \times C_d$$

$$C_d = C_n \lambda_f^{1/2} + C_{d,0}$$

$$= C_n \times \left(\frac{(C_n + 1)\times L_{local} \times H}{\pi\left(1.35 \times R_g(r)\right)^2}\right)^{1/2} + C_{d,0}$$

City texture

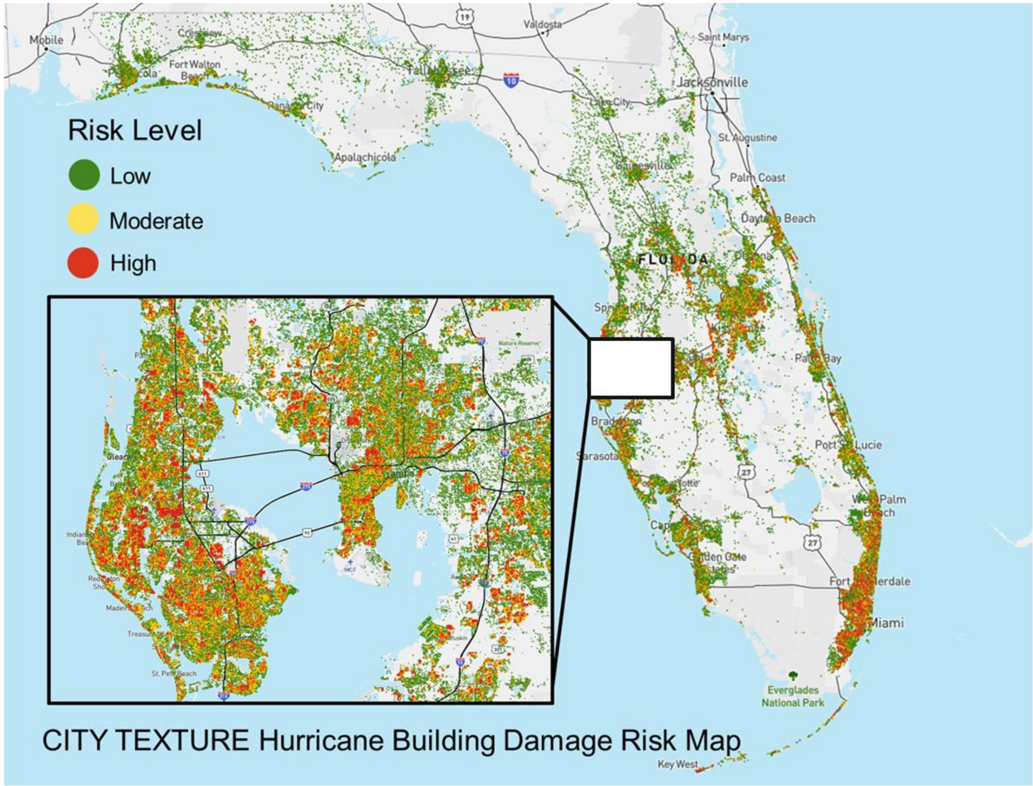
Single

Tempête de vent

➔ Material Science and Engineering / building design do matter !!!

image: NY-Time, 2018

Tempête de vent

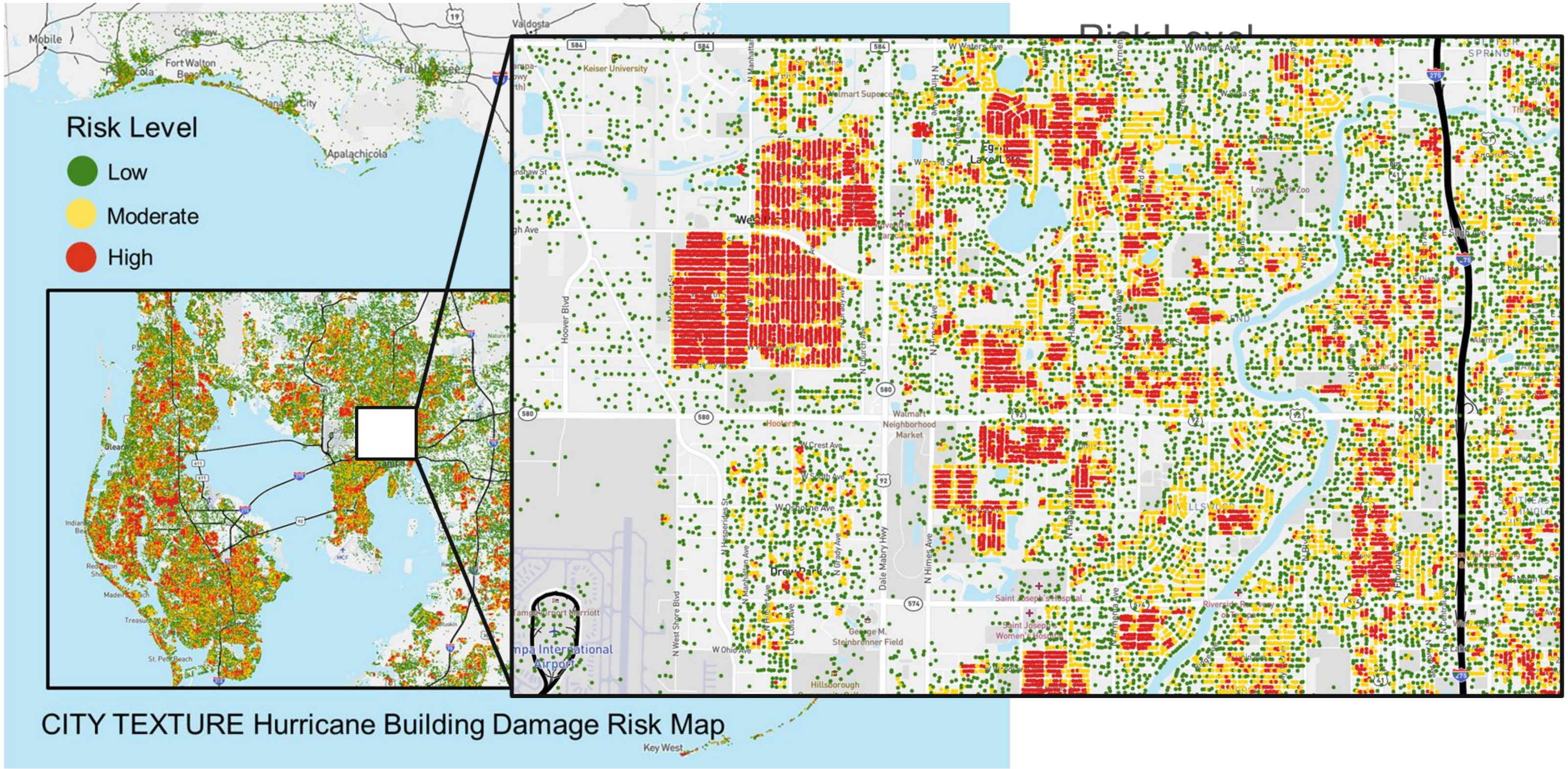


Risk Level

	Low	≤ Current Norm
	Moderate	$2 < C_d \leq 3$
	High	$3 < C_d$

J. Roxon, PhD, thesis, MIT, 2020

Tempête de vent

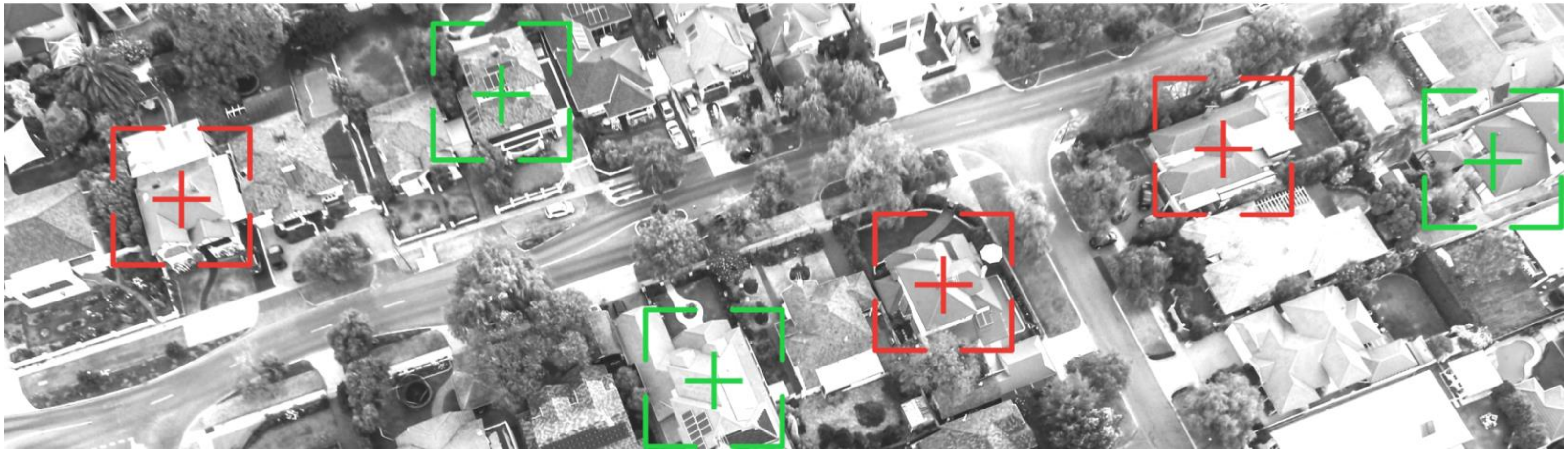


J. Roxon, PhD, thesis, MIT, 2020

Some streets may be at higher risk damage

Tempête de vent

- Establishing Resilience Safety Grading A-F
- Refining design codes
- Additional variable for INVESTMENT decisions

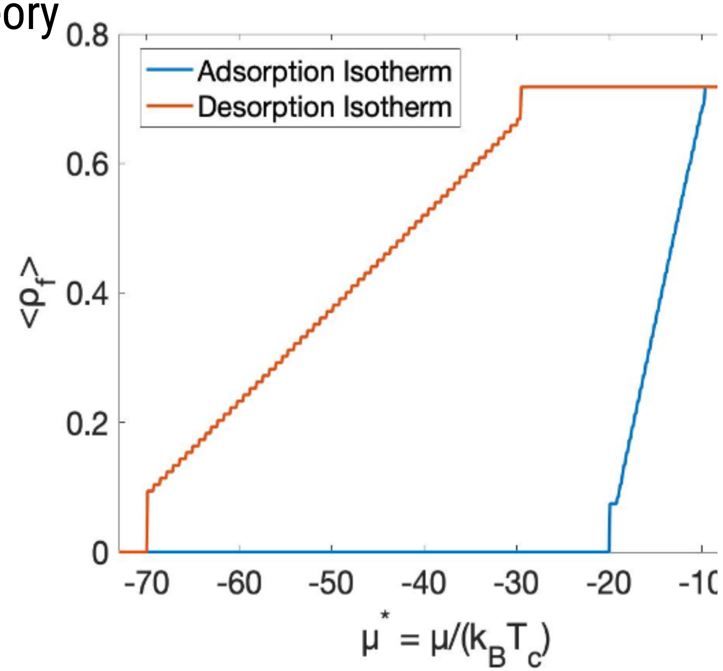


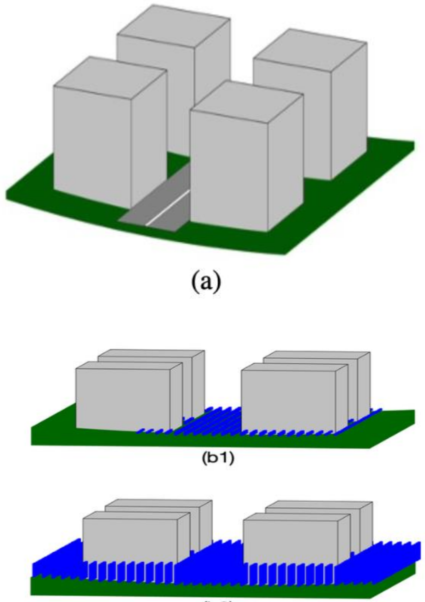
J. Roxon, PhD, thesis, MIT, 2020

CRUES

Predicting flooding

Density Functional theory





(a)

(b1)

(b2)

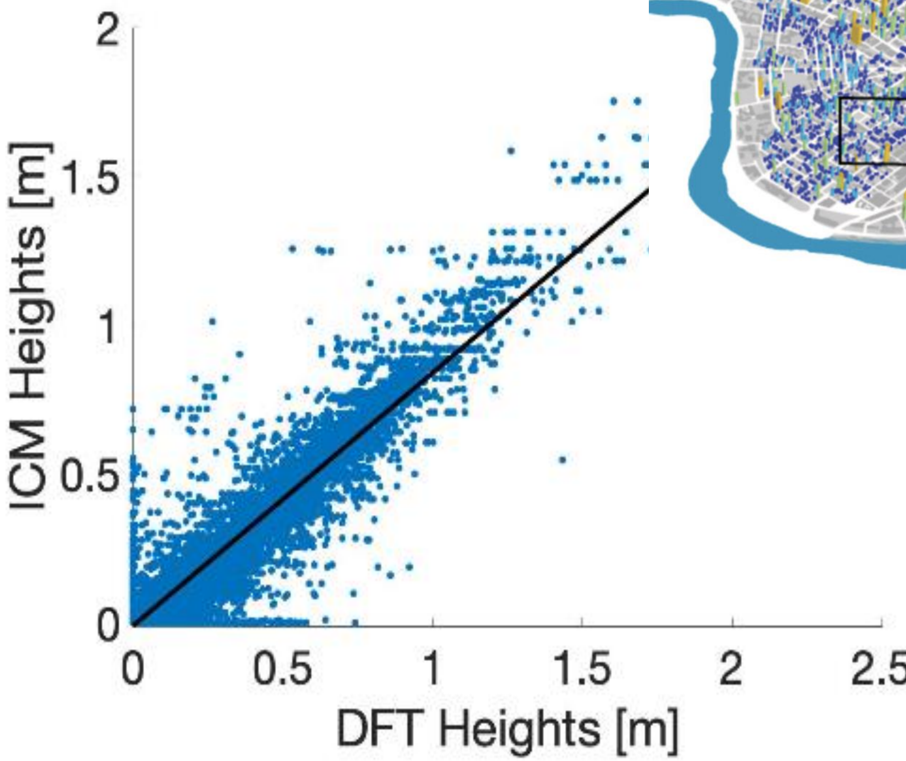
$$\frac{\Omega}{k_B T_c} = \min_{\rho_i} \Bigg(T^* \sum_i [\rho_i \ln \rho_i + (\eta_i - \rho_i) \ln (\eta_i - \rho_i)]$$
$$- \sum_{<i,j>} (\overline{w}^i_{ff} \rho_i \rho_j + \overline{w}^i_{sf} [\rho_i (1-\rho_j) + \rho_j (1-\eta_i)])$$
$$-\mu^* \sum_i \rho_i \Bigg)$$
$$= T^* \sum_i \eta_i \ln (1 - \frac{\rho_i}{\eta_i}) + \sum_{<i,j>} \overline{w}^i_{ff} \rho_i \rho_j$$

where the local density of sites i read:

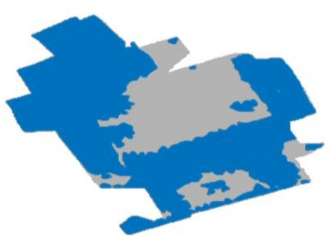
$$\rho_i = \eta_i [1 + \exp\left(-\frac{\overline{v}^{eff}_i}{T^*}\right)]^{-1}.$$

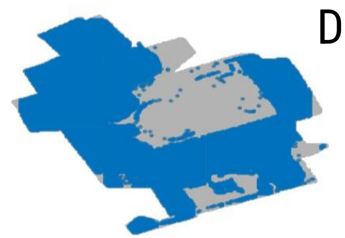
➔ same theory at the nanoscale will describe gas-liquid transition in stomach (vegetals) or cement/clay nanopores

Predicting flooding



ICM





DFT

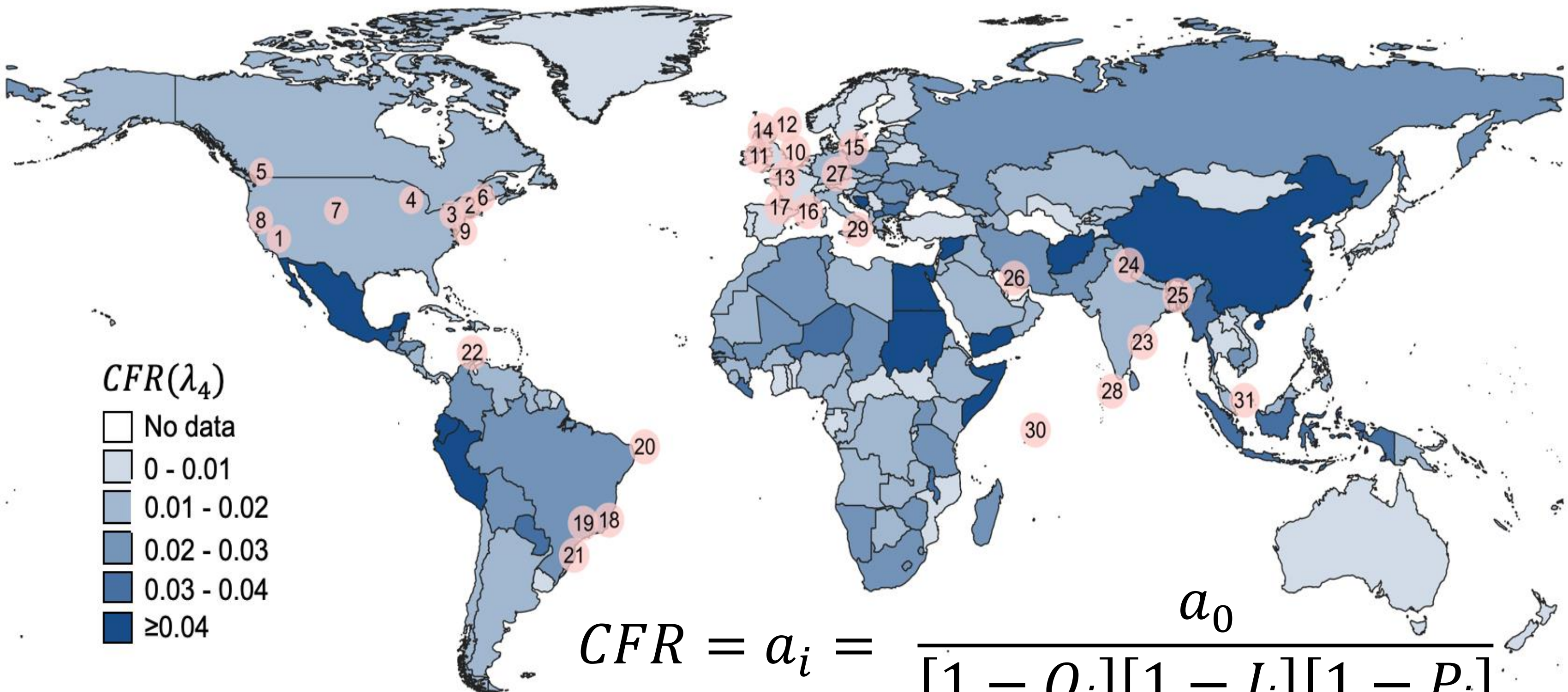
Cambridge MA, US

Physique Urbaine

Santé publique en milieu urbain

Santé Publique

COVID19 CFR around the world,



$$CFR = a_i = \frac{a_0}{[1 - O_i][1 - I_i][1 - P_i]}$$

$$O_i = w_{Sbu}\, S^i_{bu} + w_\varphi\, \varphi_i + w_{RH}\, RH \; with \; 0 \le w_{Sbu}, w_{RH}, w_\varphi \le 1$$

$$I_i = \left[w_{hi} \left[1 - \frac{1}{h_i} \right] + w_{\rho i} \left[1 - \frac{1}{\rho_i} \right] \right] \; with \;\; 0 \le w_{hi} \; and \; w_{\rho i} \;\; \le 1$$

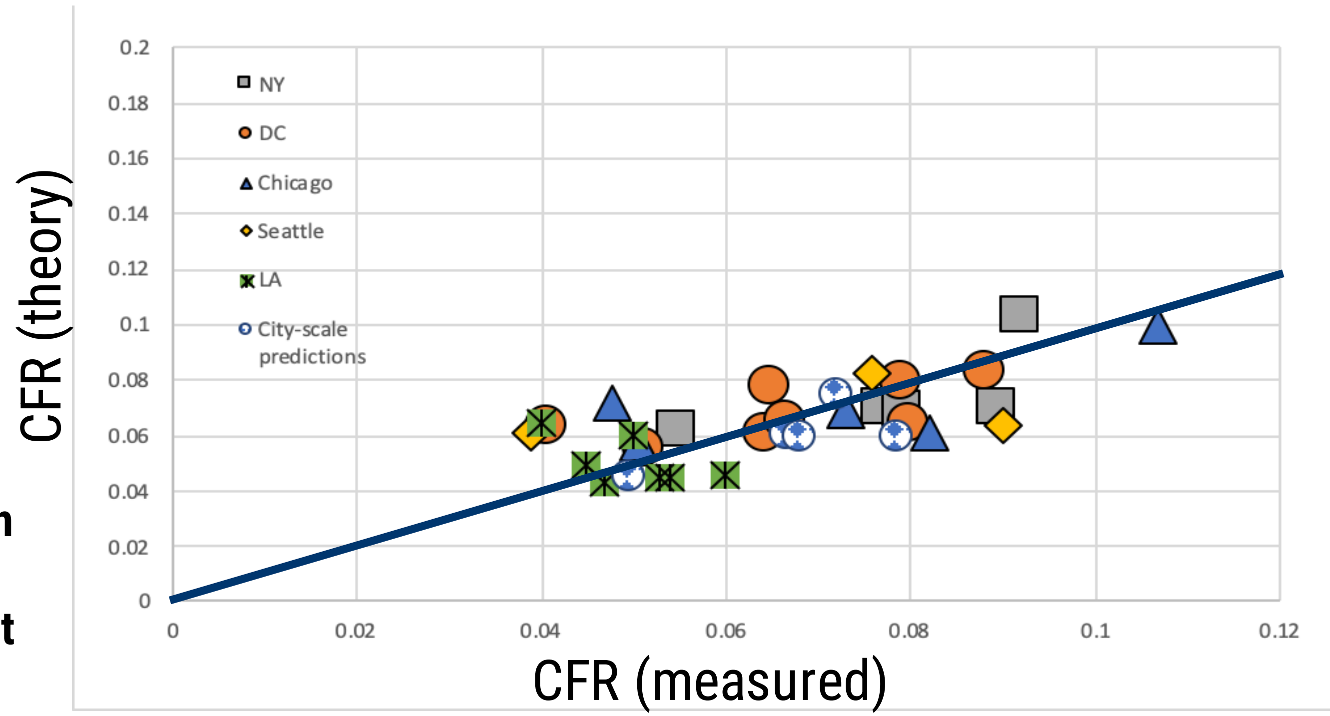
$$P_i = w_{>65\,yo}\, {}^{N_{>65}}\!/_{N_0} + w_{<50\,k\$/y}\, {}^{N_{<50\,k\$/y}}\!/_{N_0} \; with \;\; 0 \le w_{>65\,yo} \; and \; w_{<50\,k\$/y} \le 1$$

a0 is the "natural" CFR of Covid-19 for a young enough (<65 yo) and wealthy population **not** affected by city texture nor building design

Santé Publique

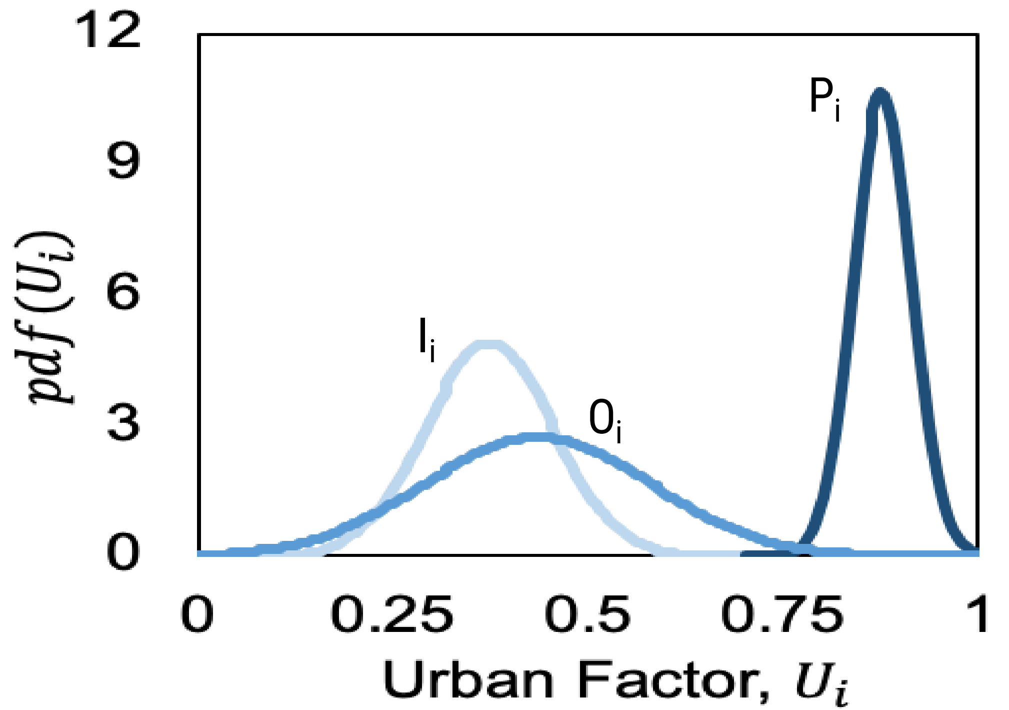
Urban public health

Public health and spread of airborne diseases in urban environments: Covid19, Asthma, … (in the case of Covid19, we're predicting the severity of the disease i.e. the Case Fatality Ratio, CFR)



→ Developing Physics-informed AI models with applications in Data Driven Urban Planning and Disaster Risk Management

Santé Publique

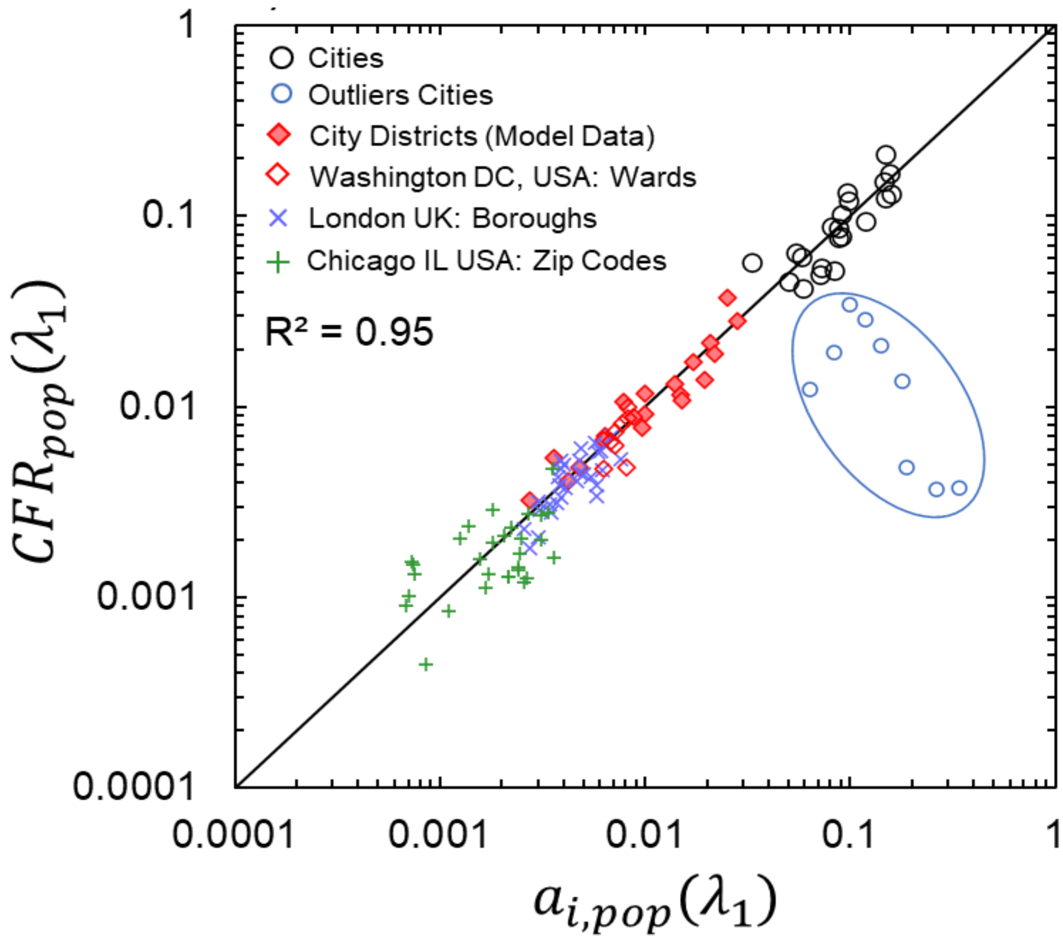


Weight	value
w_{φ}	0.12
w_{bus}	0
w_{RH}	0.88
w_{hi} , note $w_{pi} = [1 - w_{hi}]$	0.44
$w_{>65\,yo}$, *note* $w_{<50\,k\$/y} = [1 - w_{>65\,yo}]$	1
a_0	0.0099

Santé Publique

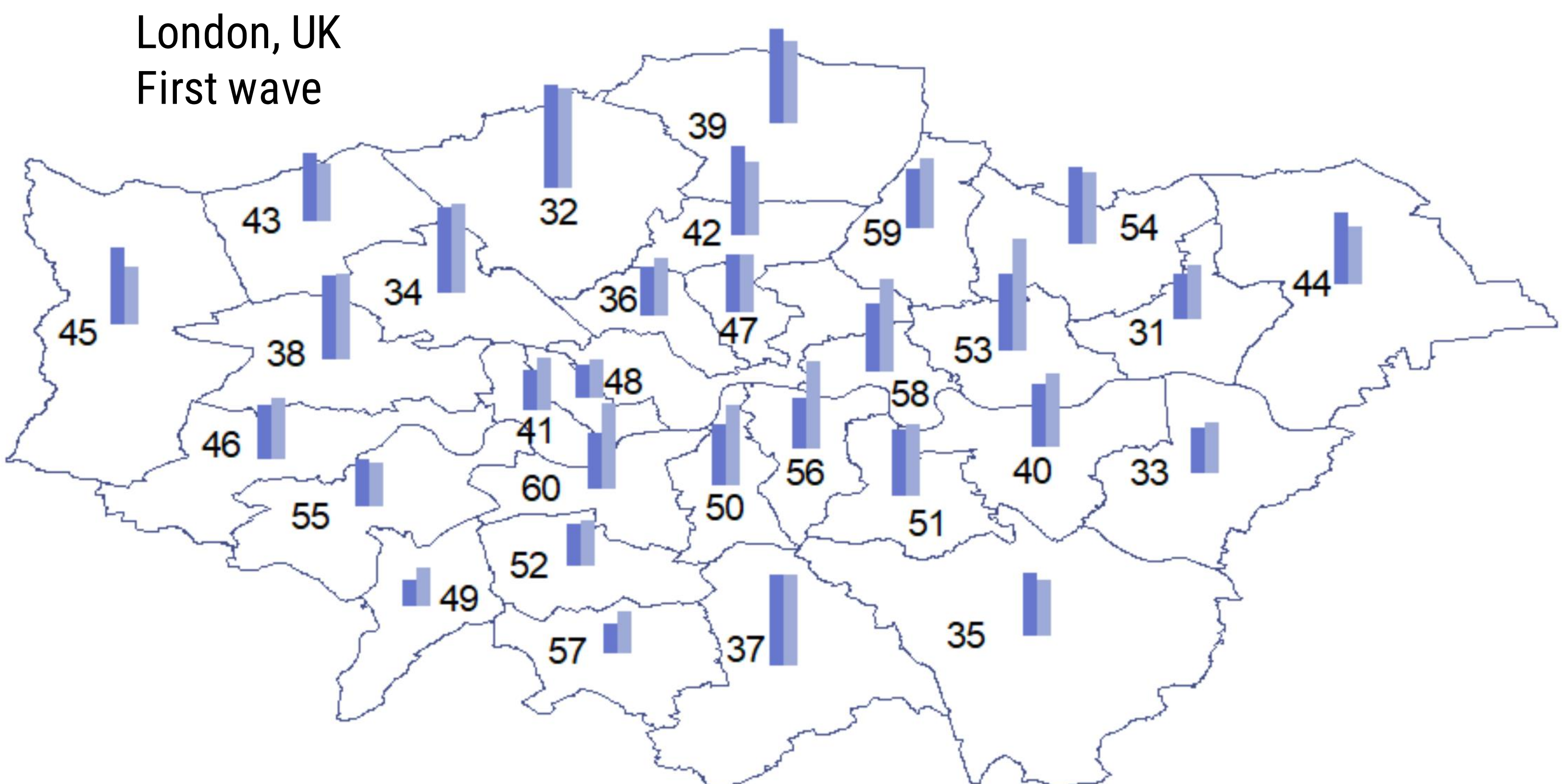
- Preuve de concept : Prédire la sévérité de la COVID19, (a = #_deaths / #_cases)

$$\mathrm{CFR}(i) = \frac{a_0}{[1-O_i][1-I_i][1-P_i]} \quad with\ a_0 = 0.01\ (first\ wave)$$



Santé Publique

- Prédire la sévérité de la COVID19, (a = #_deaths / #_cases)



Roxon et al, https://www.medrxiv.org/content/10.1101/2022.06.17.22276576v1

$Population\ fraction\ per\ zip\ code \times\ measured\ CFR(\lambda_1)$

$Population\ fraction\ per\ zip\ code$

Merci pour votre attention

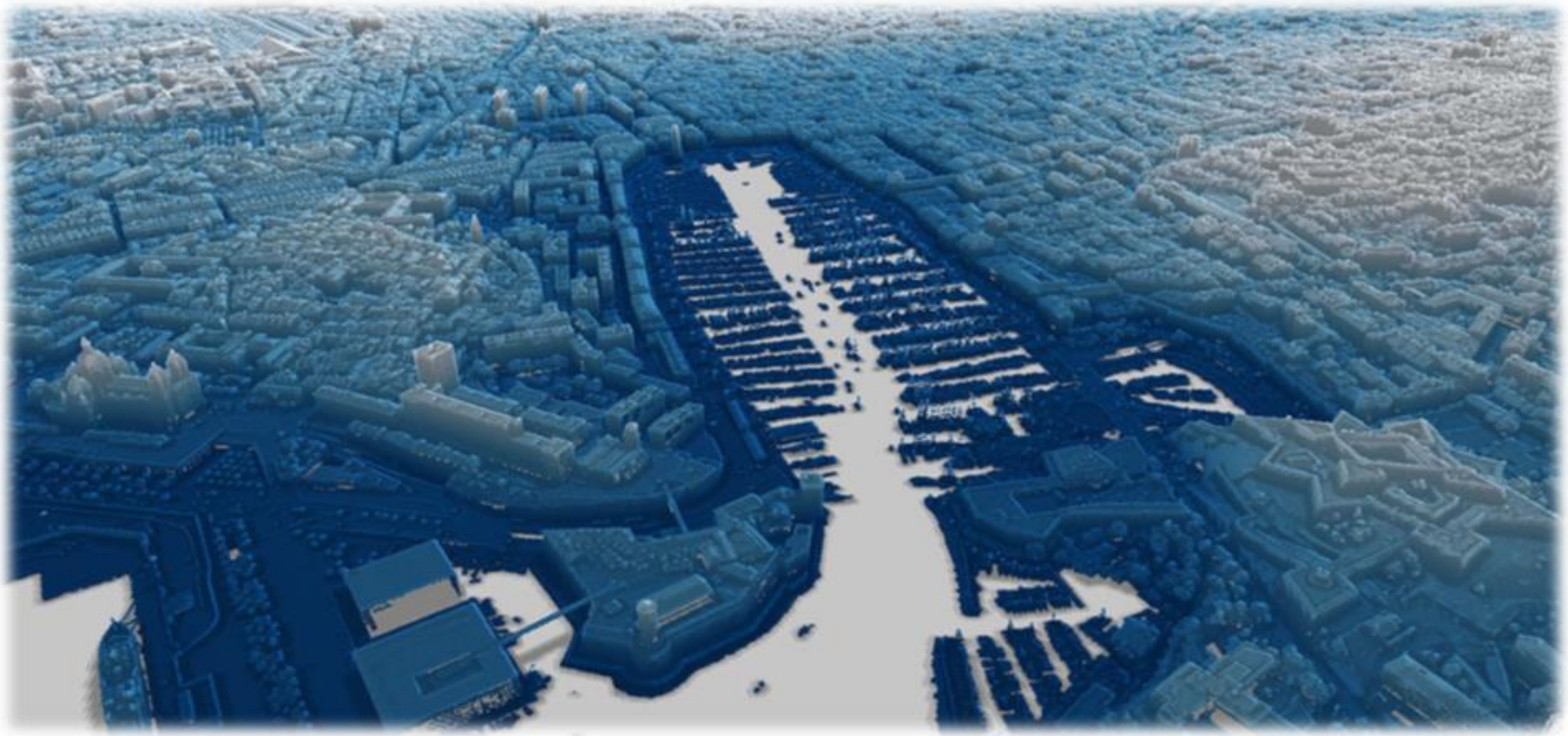


Illustration des données LIDAR (https://geoservices.ign.fr/lidarhd), XYZ&Classification bientôt disponibles pour tout le territoire [extrait le 21/11/22]

https://geoservices.ign.fr/sites/default/files/2022-05/DT_LiDAR_HD_1-0.pdf

Conclusion

La Physique Urbaine englobe le développement **d'outils** pour évaluer les **risques météorologiques, de santé publique**, etc.. en milieu urbain dans le contexte du changement climatique.

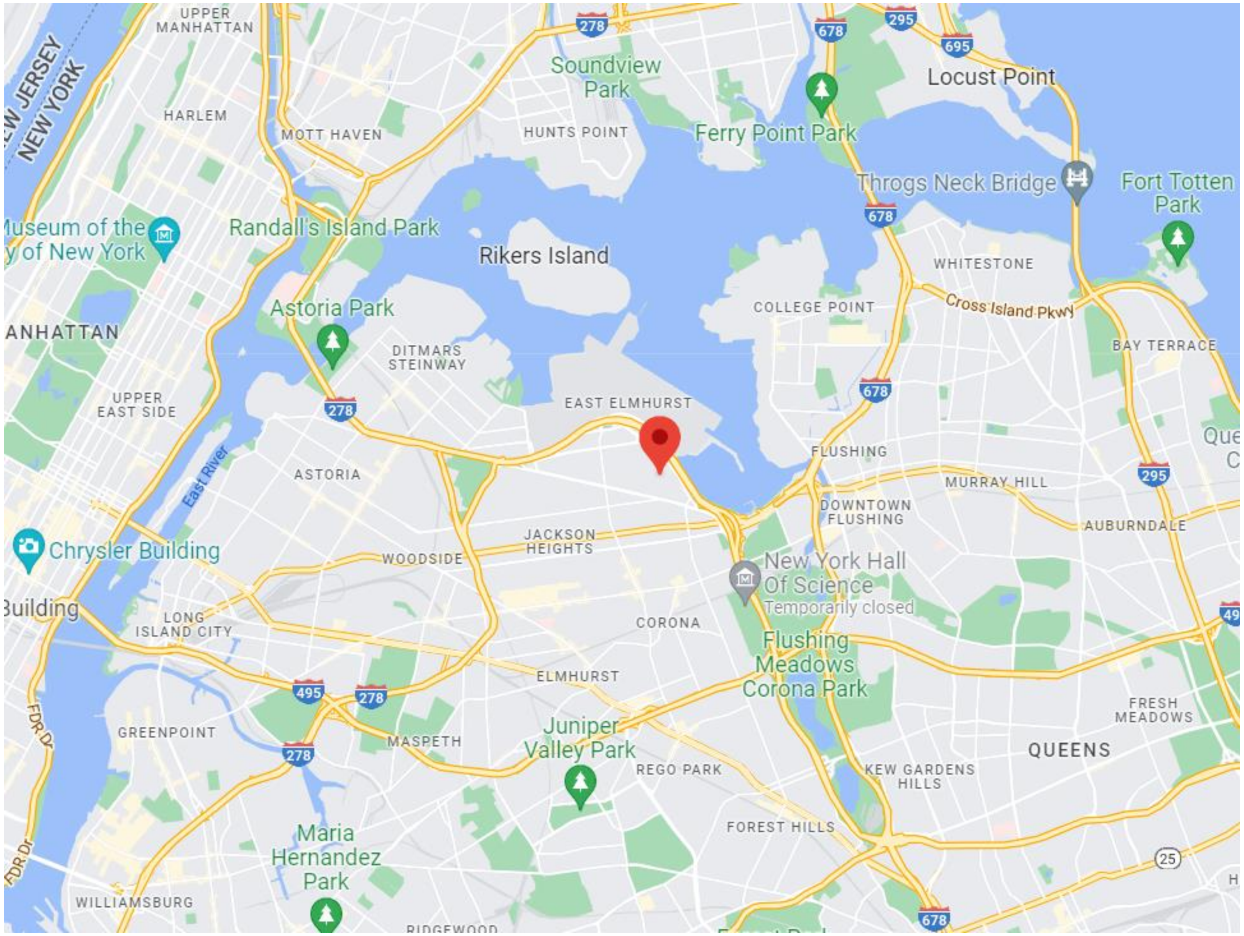
L'objectif est de proposer de **nouvelles formes de villes** basées sur des **méthodes de modélisation et d'optimisation** pour **améliorer l'environnement urbain.**

Numériquement **sobre** : La physique Urbaine a besoin de données de capteurs/satellites pour valider les modèles... mais in fine fabrique des « données synthétiques » ➔ faible coût

« **Prédire pour Protéger** »: La physique Urbaine vise à orienter la planification urbaine vers des **villes plus résilientes et durables**, permettant **d'améliorer la vie des habitants** tout **en atténuant les effets du / sur le climat.**

SURe : a serious game

Downtown Queens, NY, US

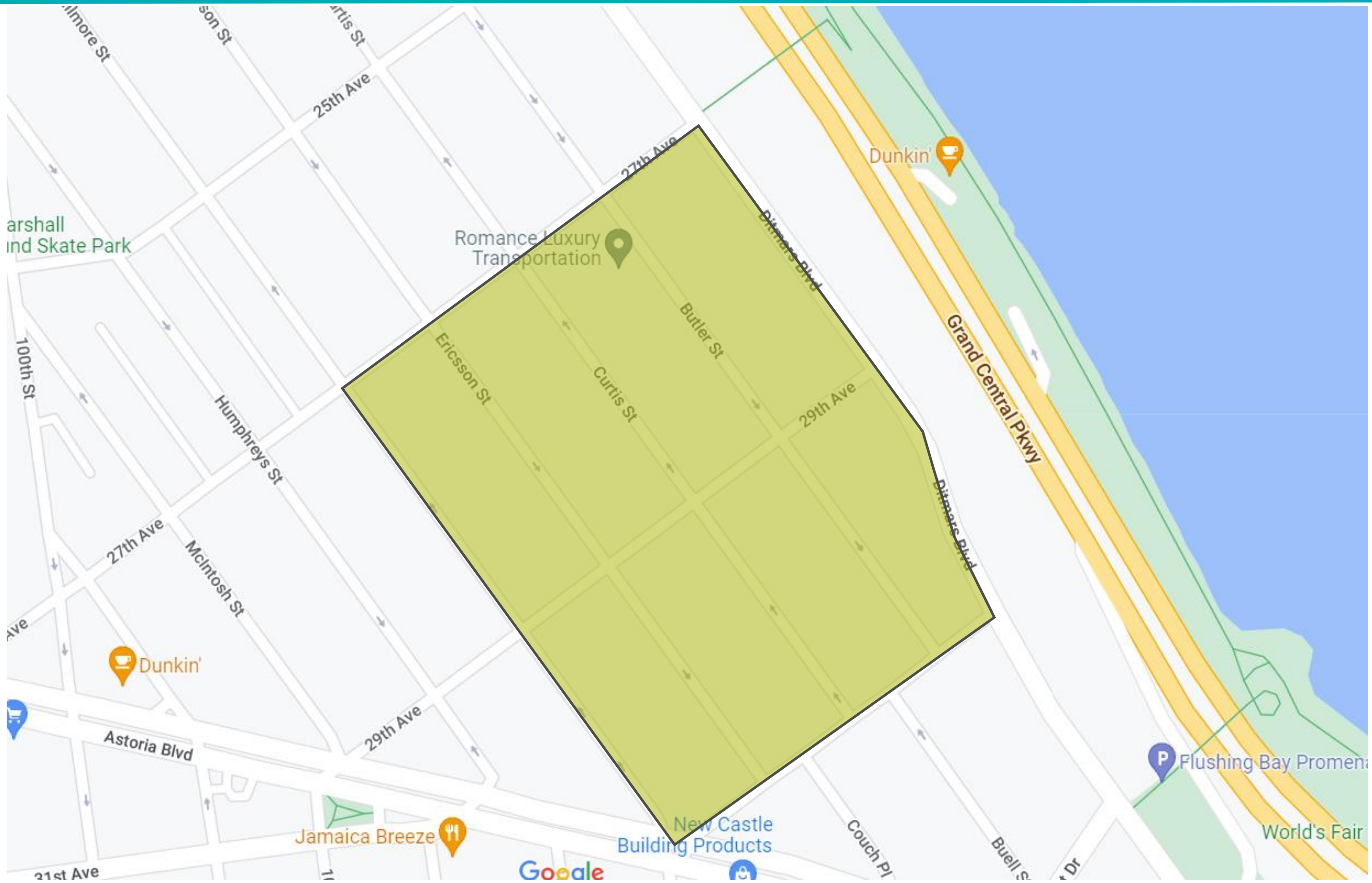


Location of study: Queens, NYC

www.sure-tech.fr

SURe : a serious game

Downtown Queens, NY, US



Location of study: Queens, NYC

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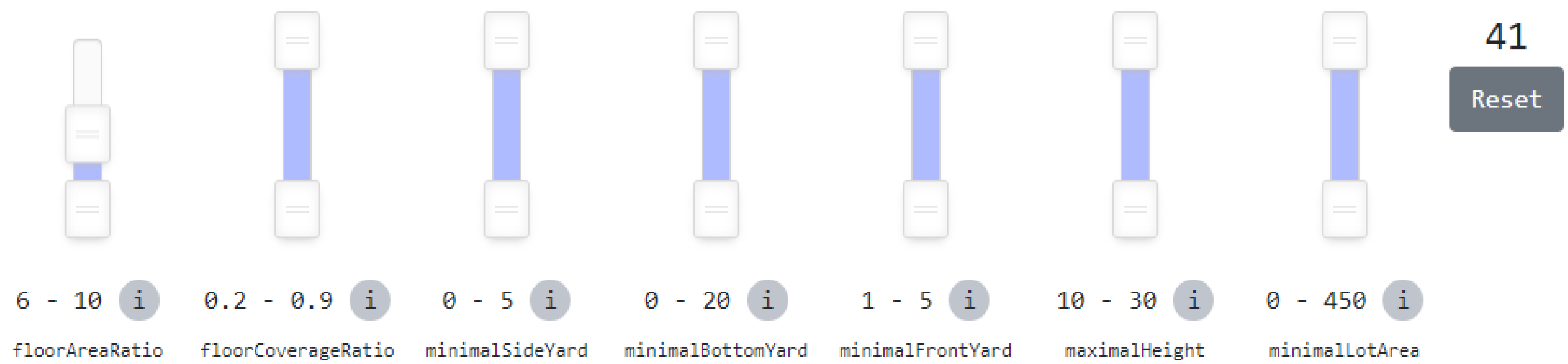
SURe : a serious game

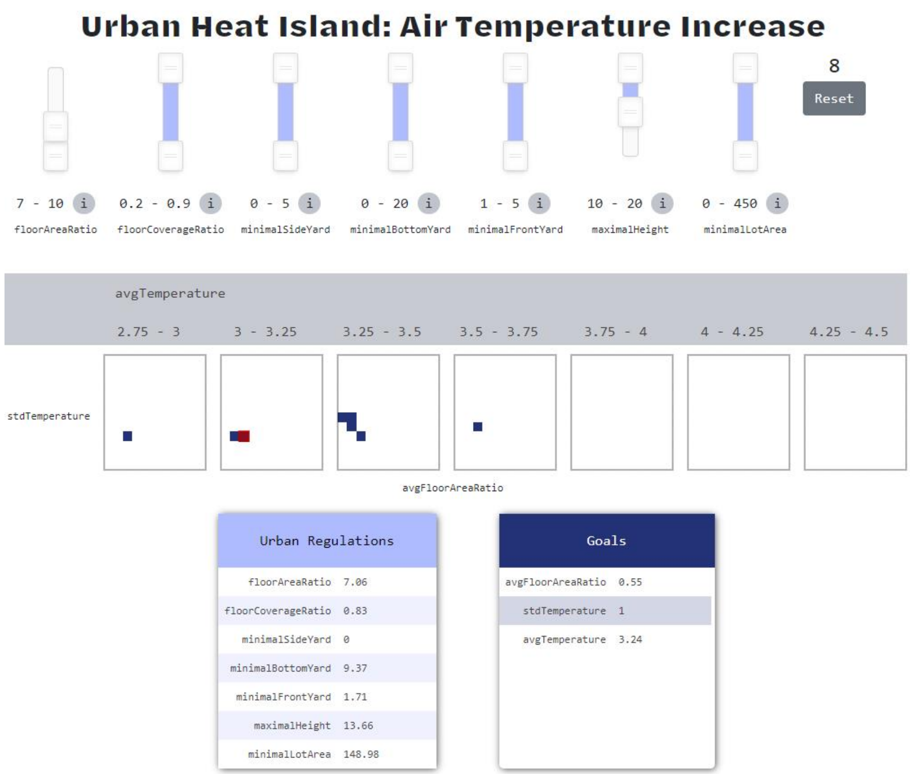


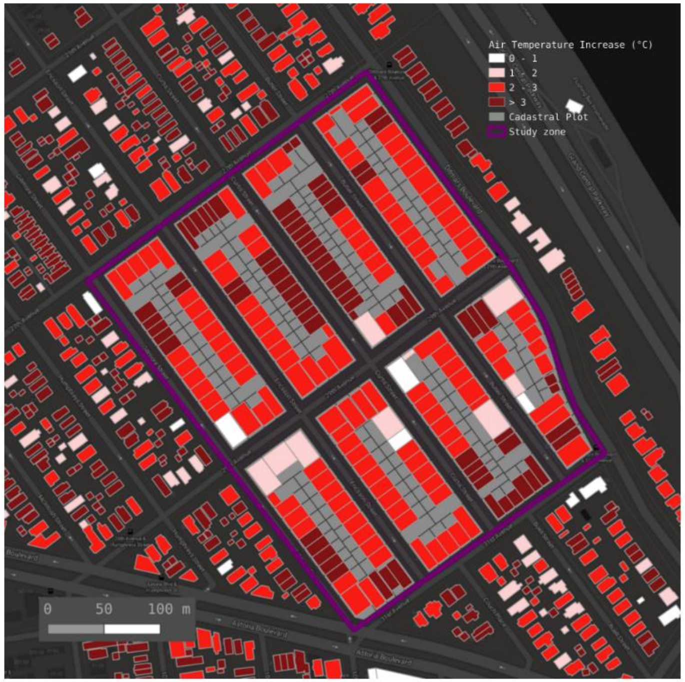
Implement current regulations imposed by NYC

- **minimalLotArea** = minimum area of the land parcel to allow building to be built in m2
- **maximalHeight** = maximum height of buildings in meters
- **minimalFrontYard** = minimum distance to the street from the building in meters
- **minimalBottomYard** = minimum distance to the back of the land parcel from the back of the building in meters
- **minimalSideYard** = minimum distance to the side of the land parcel from the building in meters
- **floorCoverageRatio** = ratio between floor area and the land parcel (1 means building covers the entire land parcel)
- **floorAreaRatio** = floorCoverageRatio multiplied by the number of floors

SURe : a serious game

Downtown Queens, NY, US



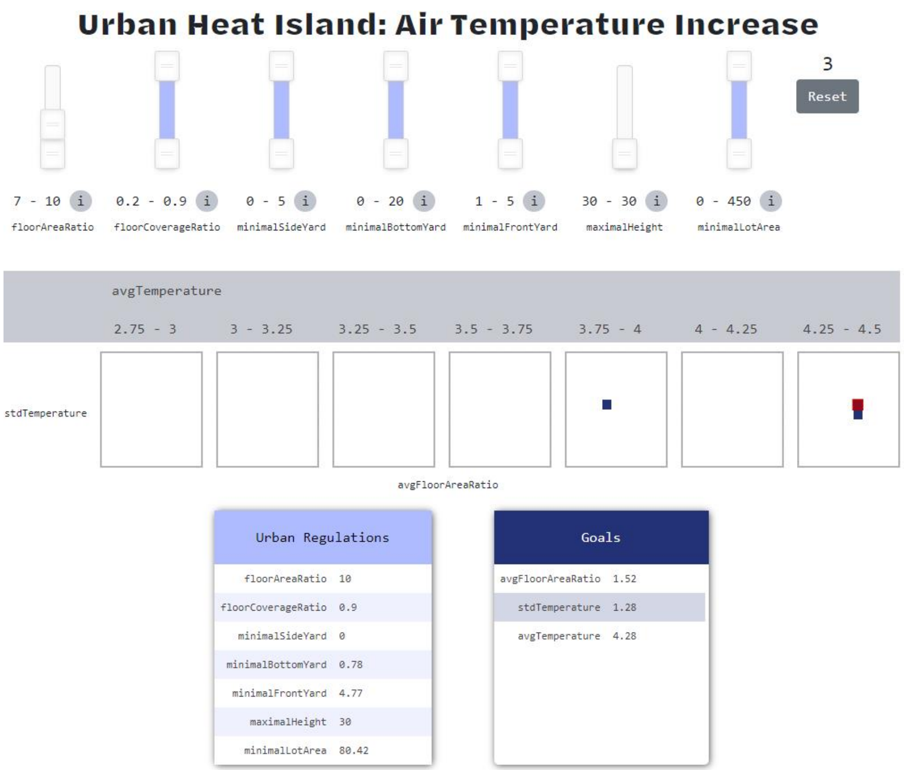


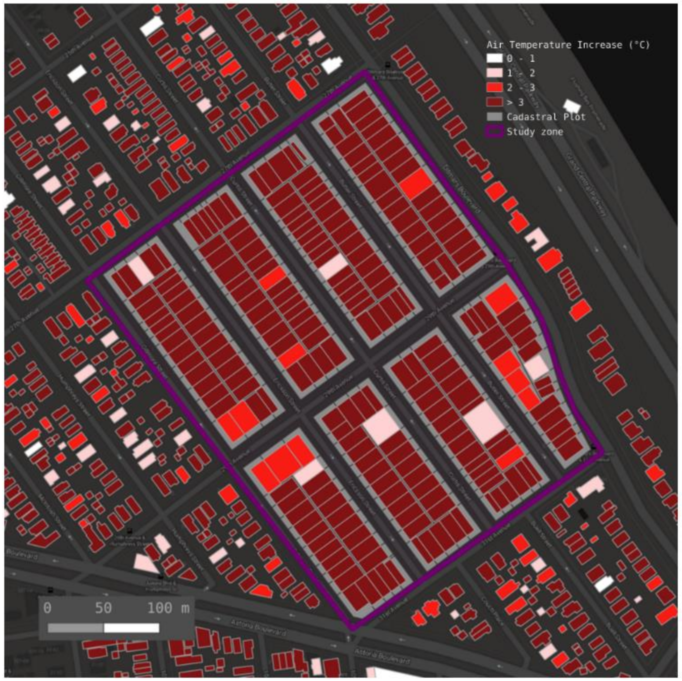
➔ Shorter buildings lead to lower UHI

Collaboration with Trempoline (CNRS spin-off, ISC-PIF)

SURe : a serious game

Downtown Queens, NY, US



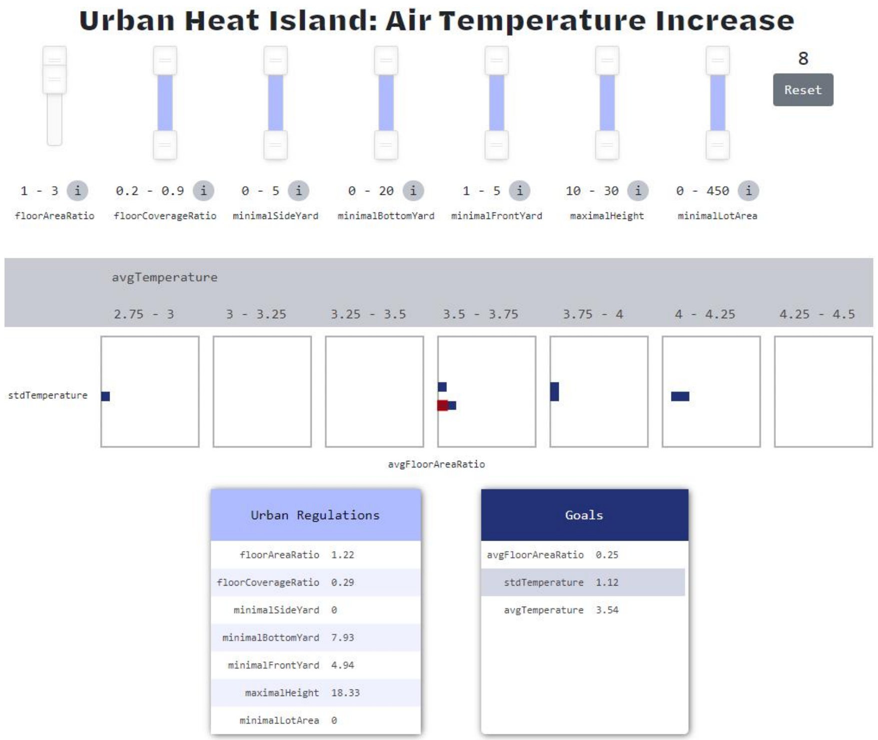


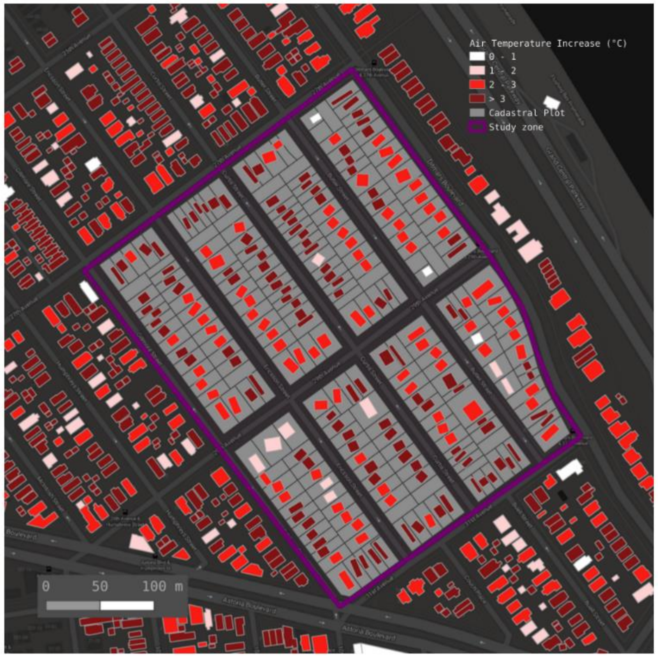
➔ Taller buildings lead to higher UHI

Collaboration with Trempoline (CNRS spin-off, ISC-PIF)

SURe : a serious game

Downtown Queens, NY, US



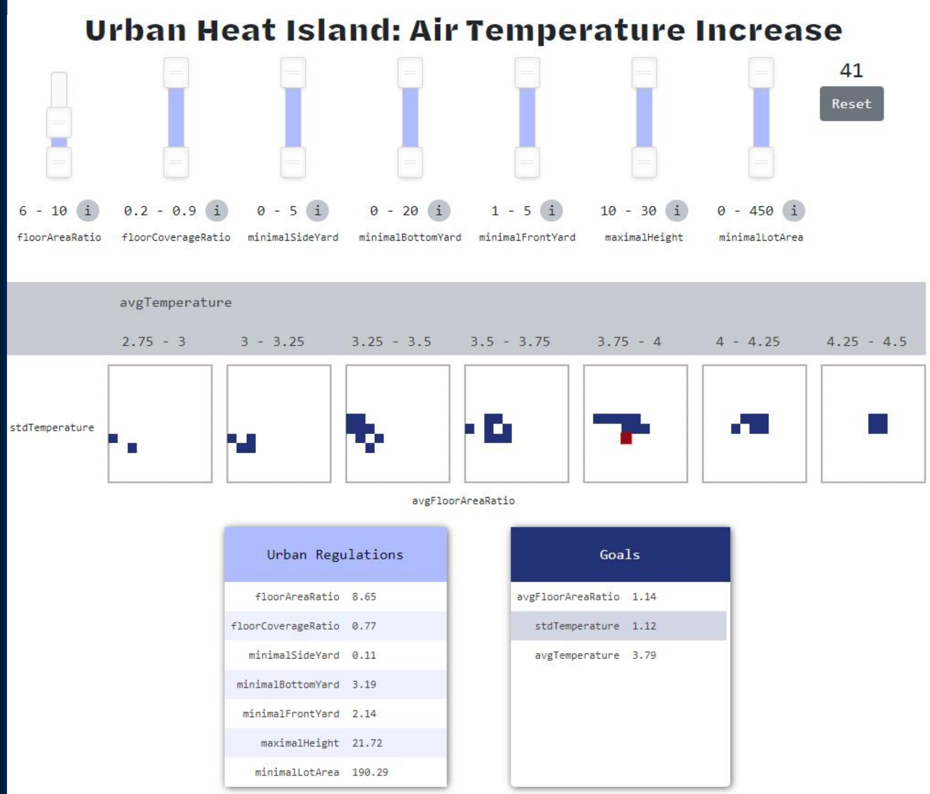


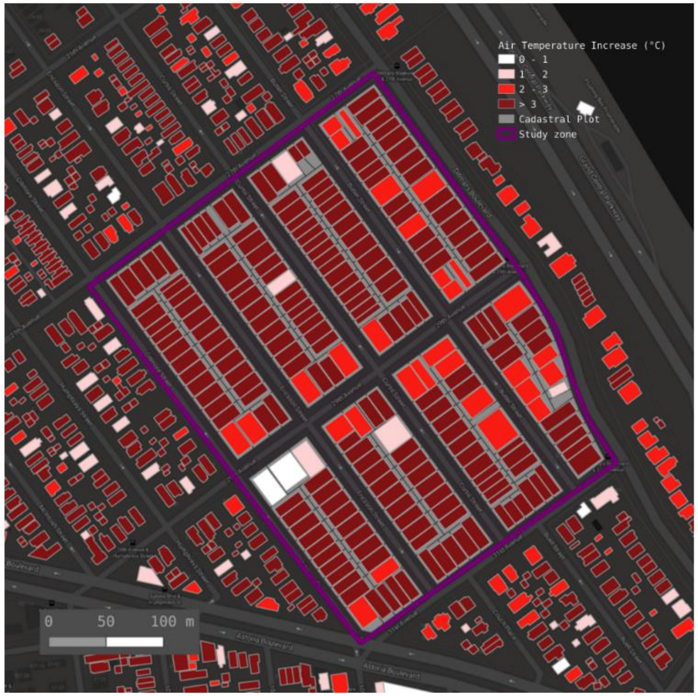
➔ Smaller buildings lead to lower UHI

Collaboration with Trempoline (CNRS spin-off, ISC-PIF)

SURe : a serious game

Downtown Queens, NY, US





➔ Larger buildings lead to higher UHI

Solutions for Urban Resilience

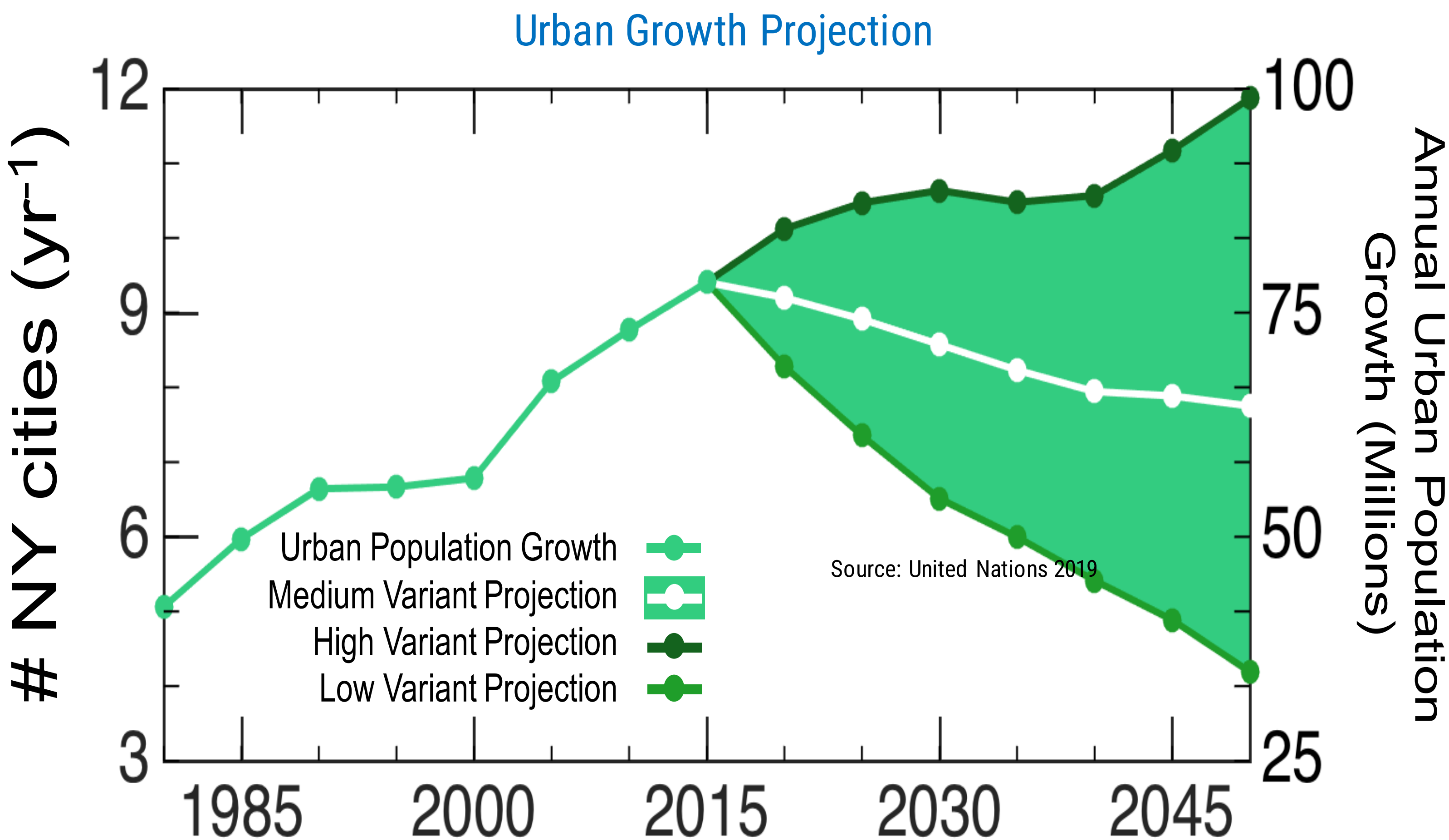
CNRS INNOVATION

SURe

www.sure-tech.fr

"From Risks Prediction to Urban Forms Optimization"

Contexte



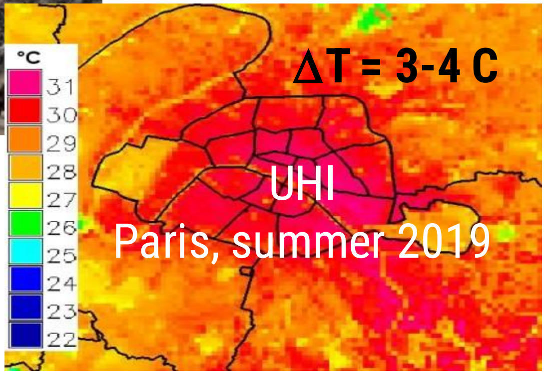
➔ Massive exodus toward cities

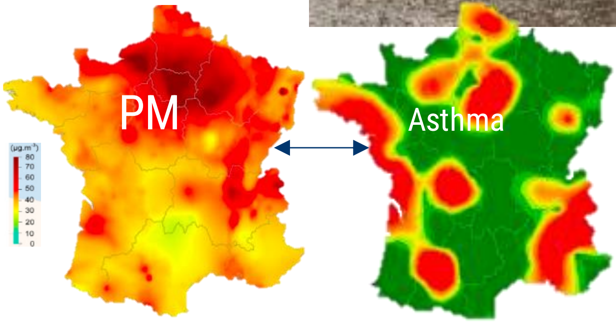
Contexte

Climate extreme events

Atmospheric pollution

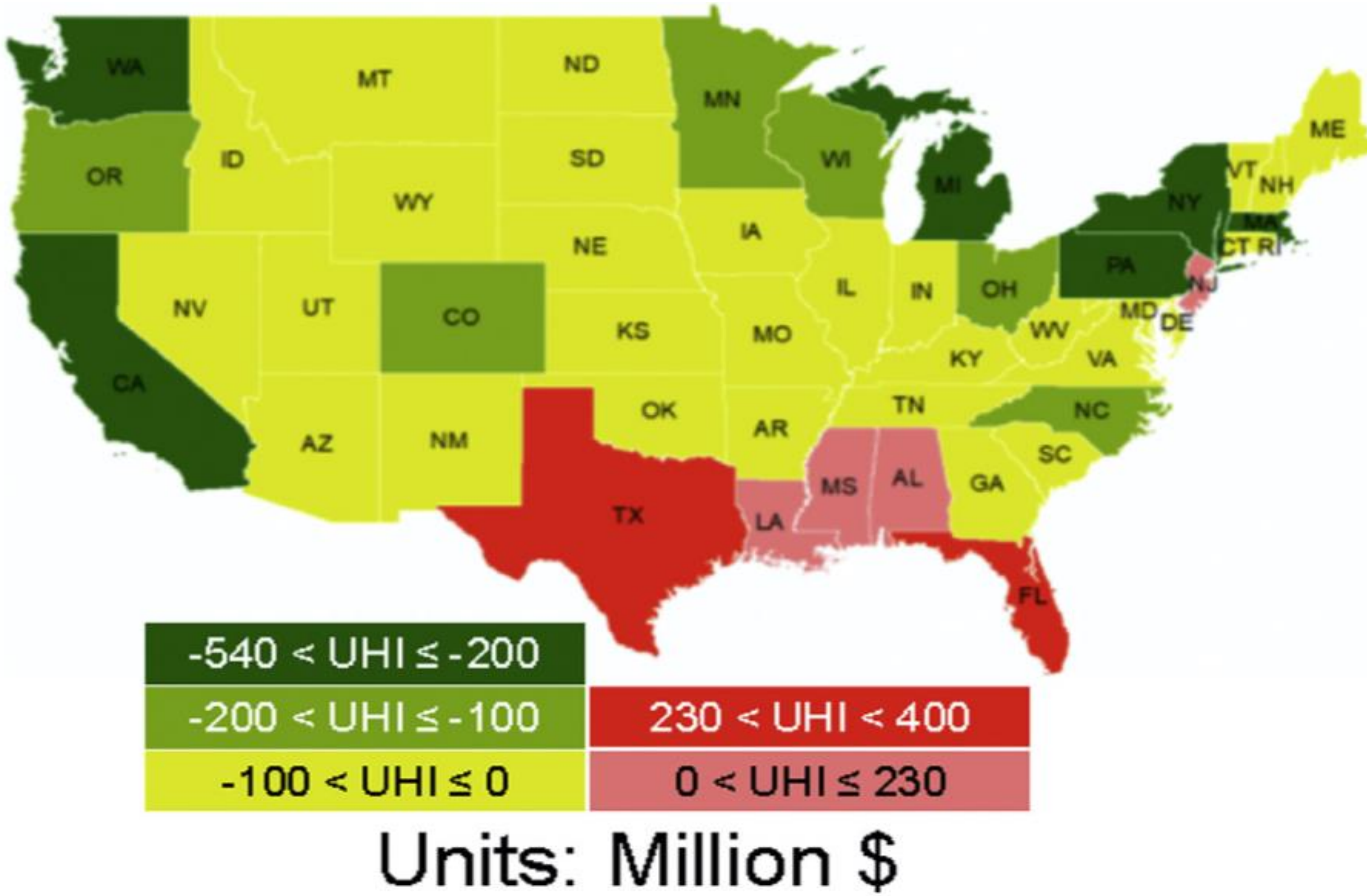
Public health





➔ Cities are not equipped for resilience in the face of these threats. There is a need for a municipality to have quantitative and predictive tools to assess these climatic and health risks / constraints in urban areas in order to propose urban planning solutions to deal with them..

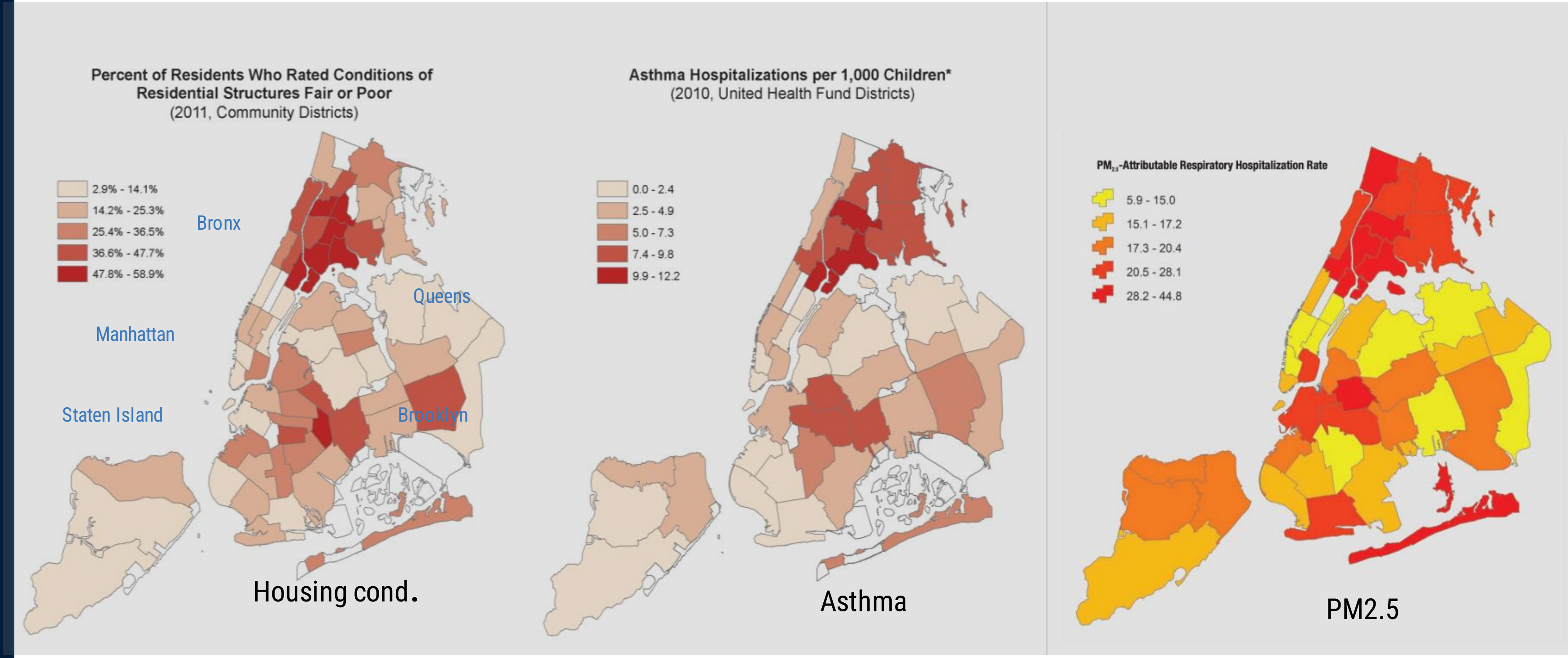
ICU et économétrie



J. Roxon, F. Ulm, R. Pellenq, Urban Climate, 2020

Santé Publique

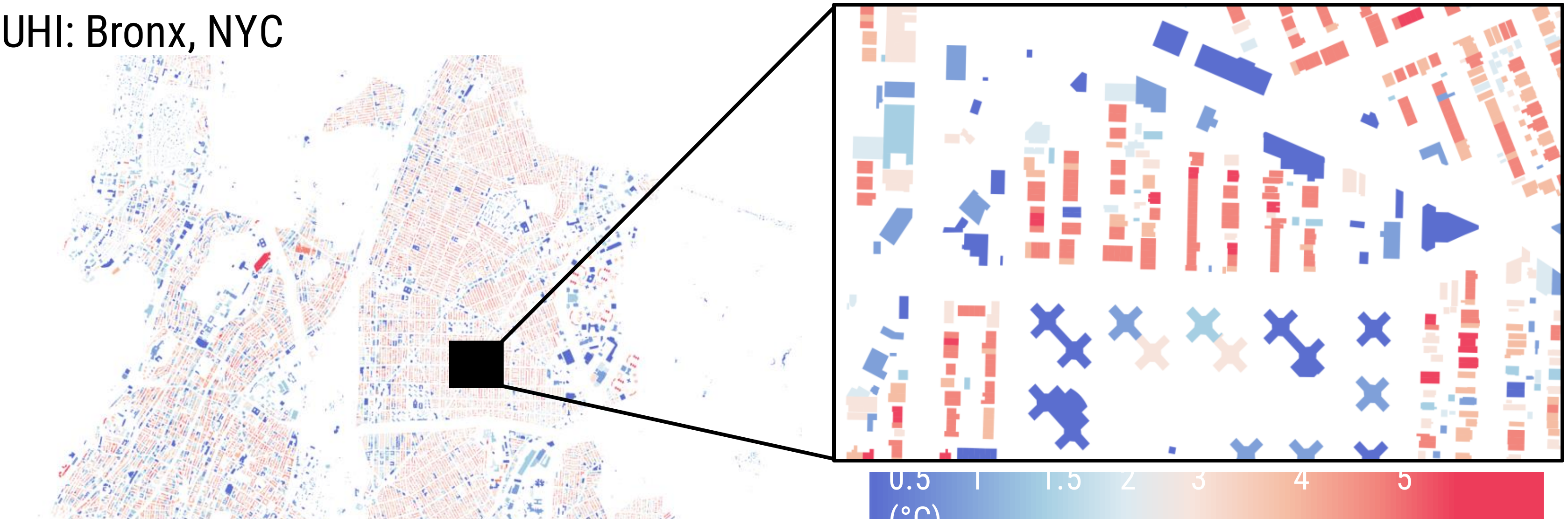
- Asthma / PM2.5 / Housing conditions

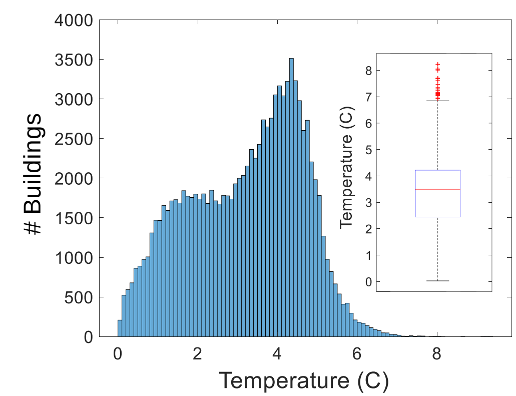


➔ Just correlation ?

ICU

UHI: Bronx, NYC





$$\Delta T_{u-r} = T_r\left[\gamma\left(1 + \frac{4L\bar{h}}{(L+d)^2}\right)^{\frac{1}{4}} - 1\right].$$