Adapting cities to heat wave risk:

A Systemic Modeling Approach

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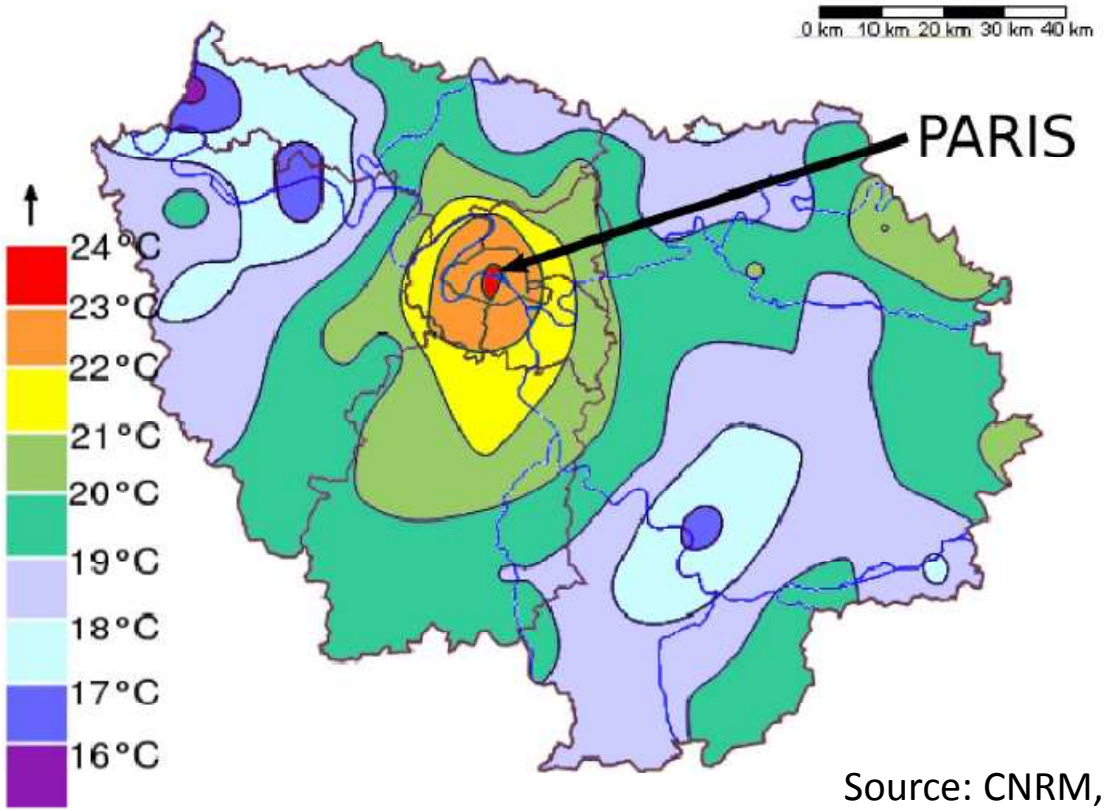
Adapting cities to heat waves leads to specific issues

- **Both climate evolution and city evolution matter for climate change vulnerability**

Example of the 2003 heat wave.



Source: CNRM, Météo-France
(V. Masson, G. Pigeon, A. Lemonsu, C. Marchadier)

Adapting cities to heat waves leads to specific issues

- **Both climate evolution and city evolution matter for climate change vulnerability**

- **Anticipating city evolution is needed, however a long-term analysis is required**
  - The whole XXIst century is the proper timescale to study climate change evolution
  - How can we anticipate strucural modifications of the city over such a long timescale?

- **Many issues are inter-related**
  - Urban forms matter for climate-change vulnerability
  - Urban forms matter for greenhouse gas emissions
  - Urban forms matter for many other policy objectives, e.g., related to social and spatial inequalities, competitiveness...

Several research projects, a systemic modelling approach

- **Integrated urban modelling, coupling both socio-economic and physical urban climate models**
- **Take into account both cities evolutions and climate evolutions over the whole 21st century**
- **Represent and study in a unified framework several processes**
  - Air temperature, energy consumption, transport etc.

Energy consumption

Heat waves risk

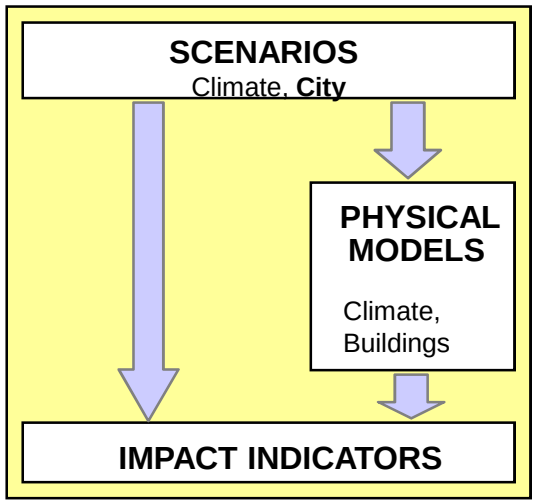
Focus on the modeling tool

These projects are funded by the French National Research agency (ANR-08-VULN-013 & ANR-09-VILL-0003) & STAE fundation

http://www.cnrm.meteo.fr/ville.climat/

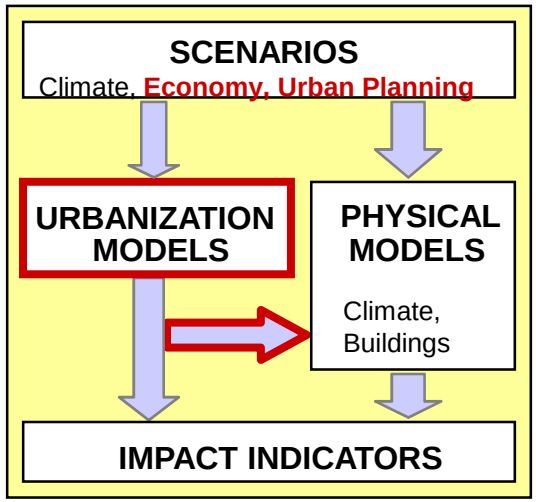
An usual modeling approach

- **What is usually done is this :**



Our approach

- **The systemic modeling approach :**



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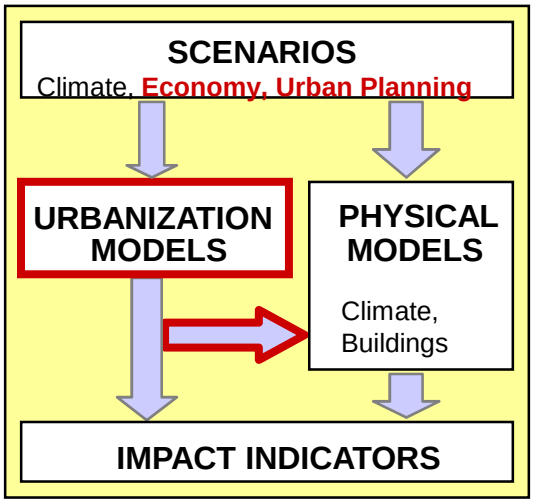


- **Urban growth models**
  - Urban growth: NEDUM, SLEUTH
  - Architectural evolutions: GENIUS
- **Physical models for impact & local climate studies**
  - UHI, Comfort Index, Energy consumption : TEB-BEM

Modelling urban form evolution over the long term: NEDUM-2D model

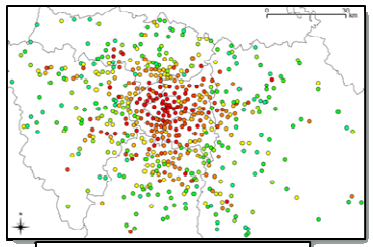
- **Standard urban economics modelling *(Alonso 1964, Mills 1967, Muth 1969)***

- **3 mechanisms :**
  1. Households' tradeoff:
     - Lower transportation costs and shorter commuting time when living close to the city center, and
     - Larger dwellings and lower rent in remote areas
  2. Investors optimize the housing density as a function of rents and construction costs
  3. Different evolution timescales for rents, population density, buildings etc.

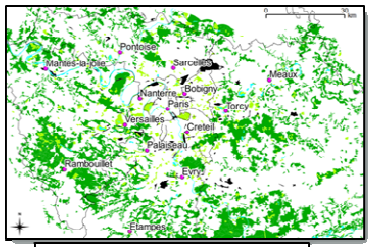
- **Simplifying hypotheses :**
  - All households have the same income.
  - One trip per day towards the city center.

NEDUM-2D model

INPUTS

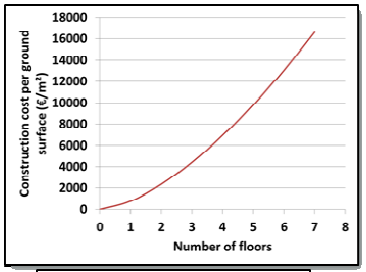


Employment centers and number of jobs and related households income



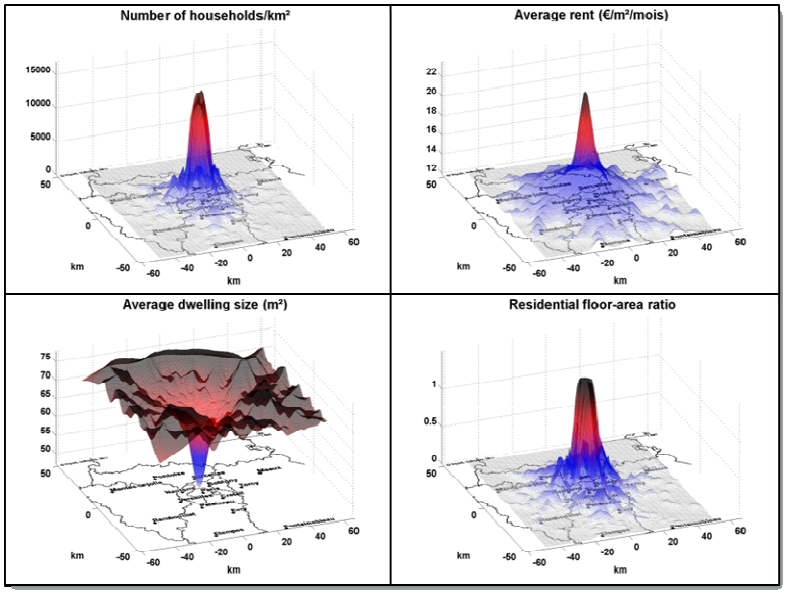
Land-use constraints

Transport times and costs



Construction costs

OUTPUTS



Rents, population density, floor-area ratio, and average dwelling size

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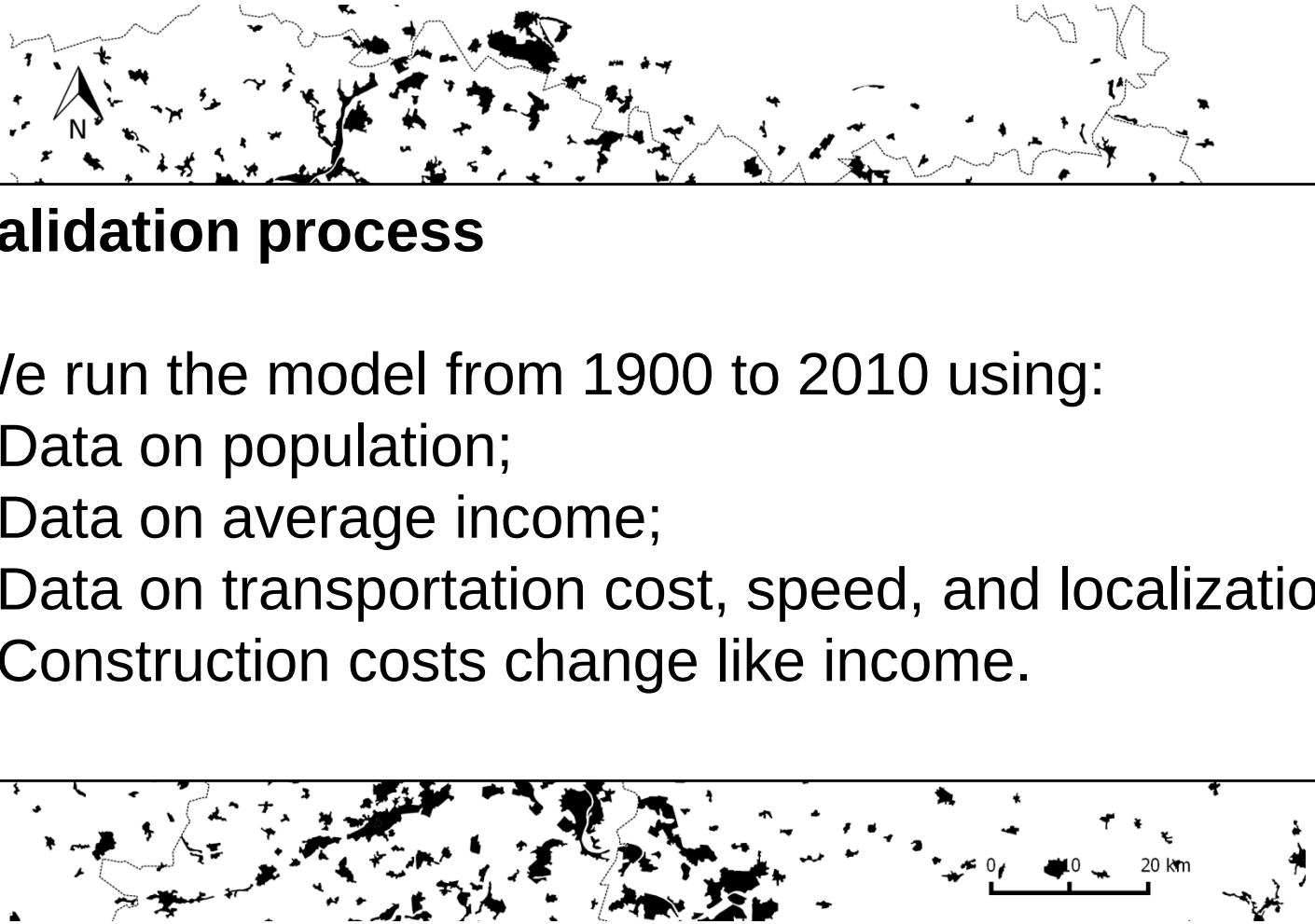
Paris, 2006



Validation process

We run the model from 1900 to 2010 using:

- Data on population;
- Data on average income;
- Data on transportation cost, speed, and localization;
- Construction costs change like income.

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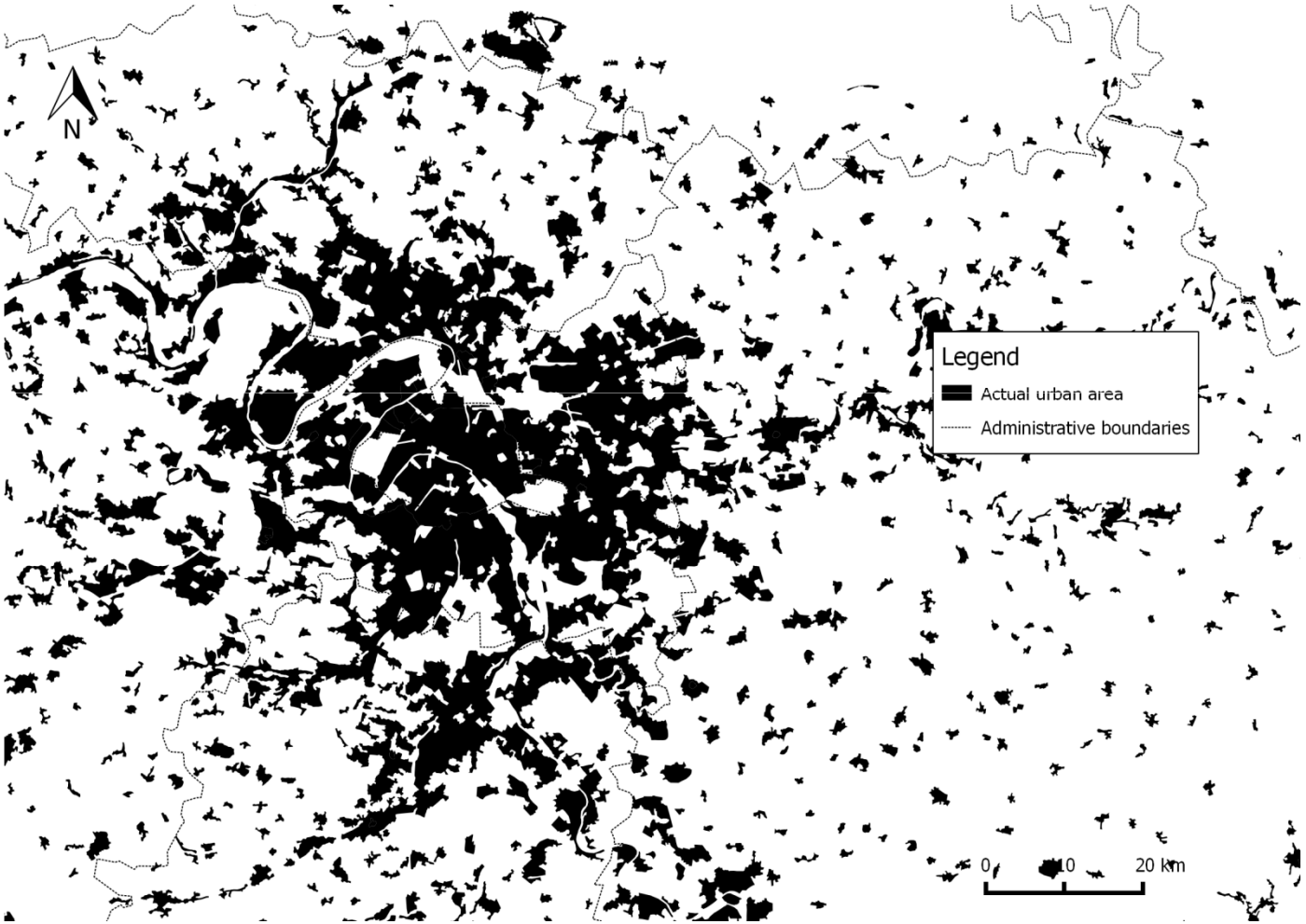

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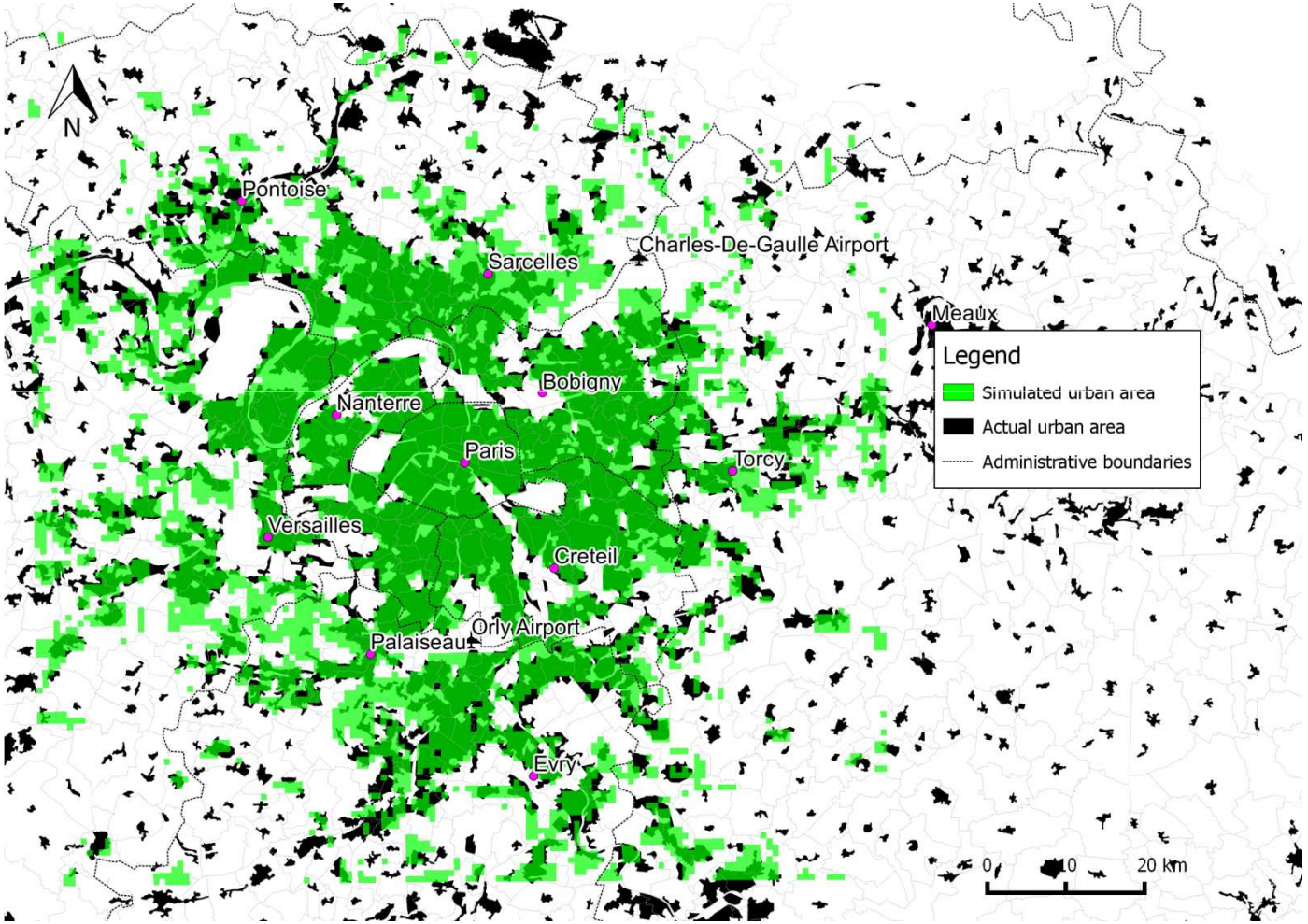

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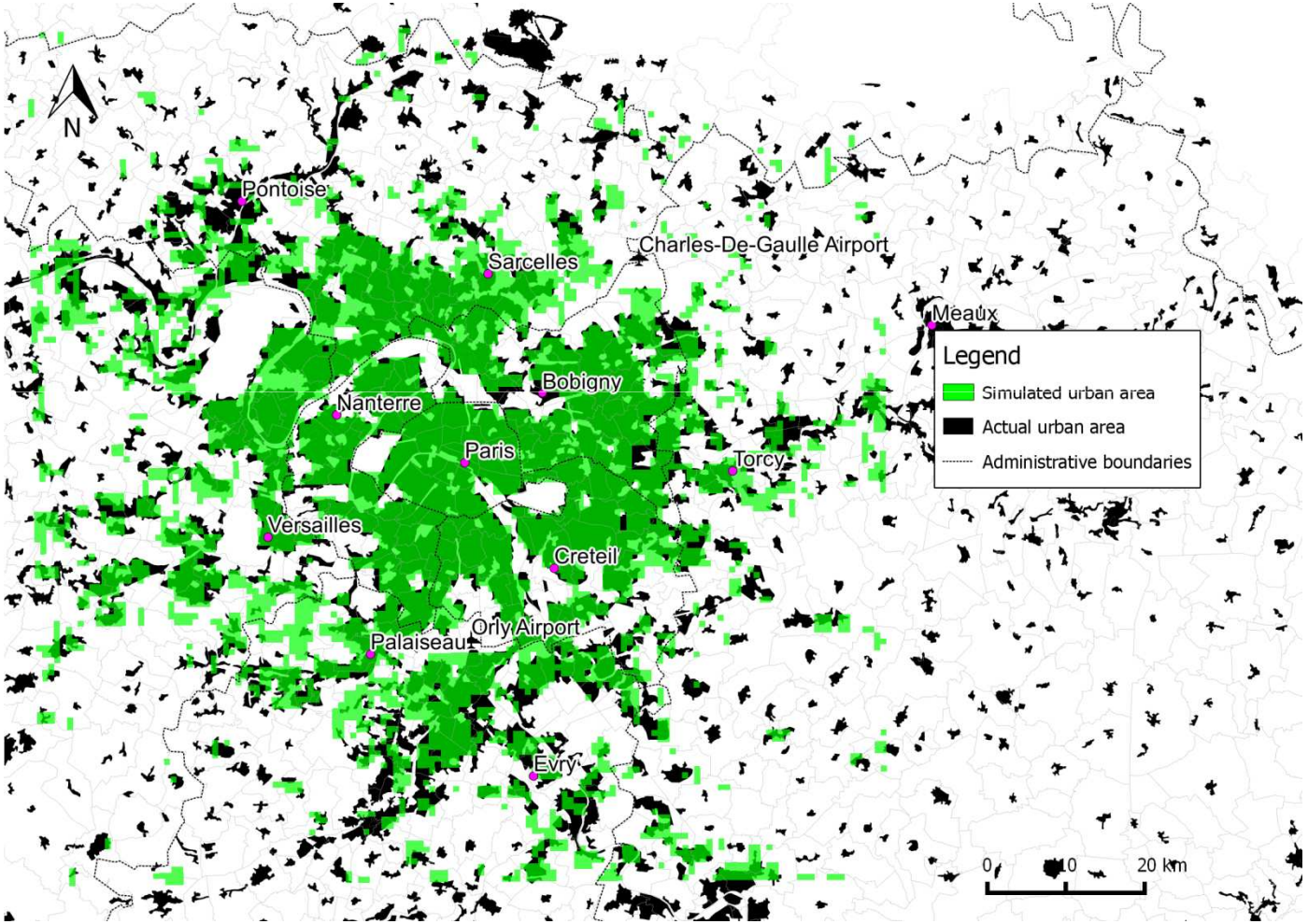
Paris, 1990



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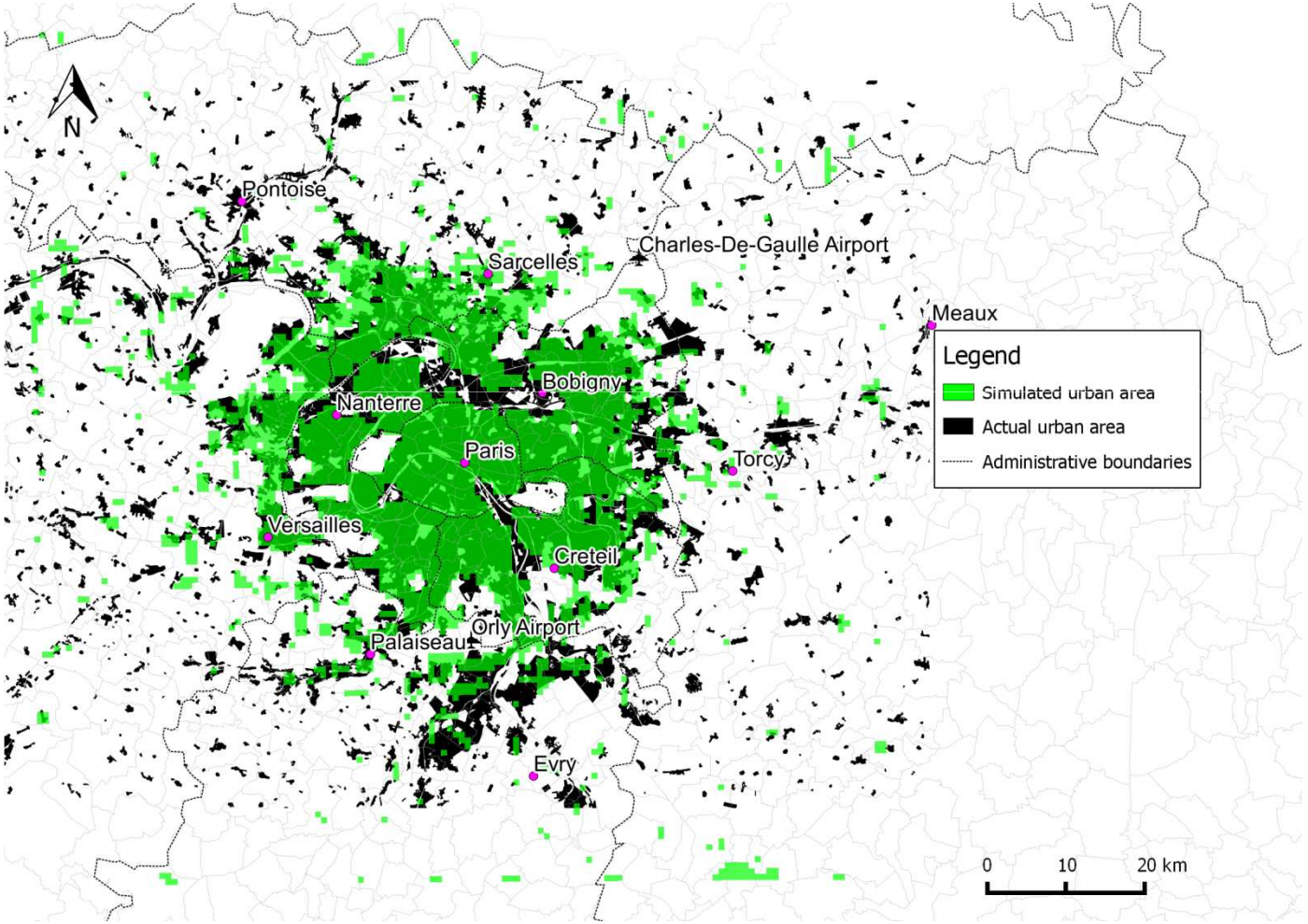
Paris, 1960



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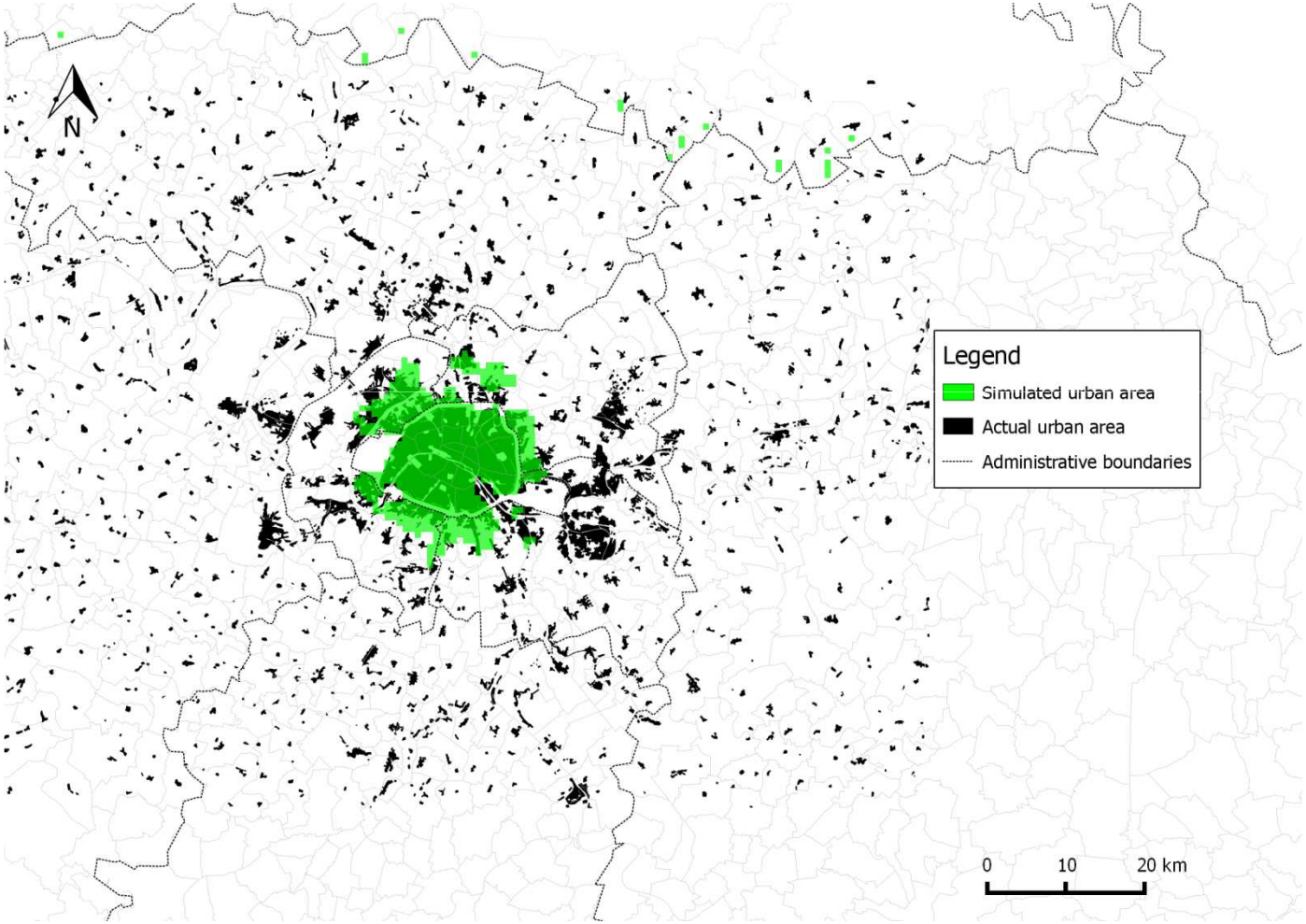
Paris, 1900



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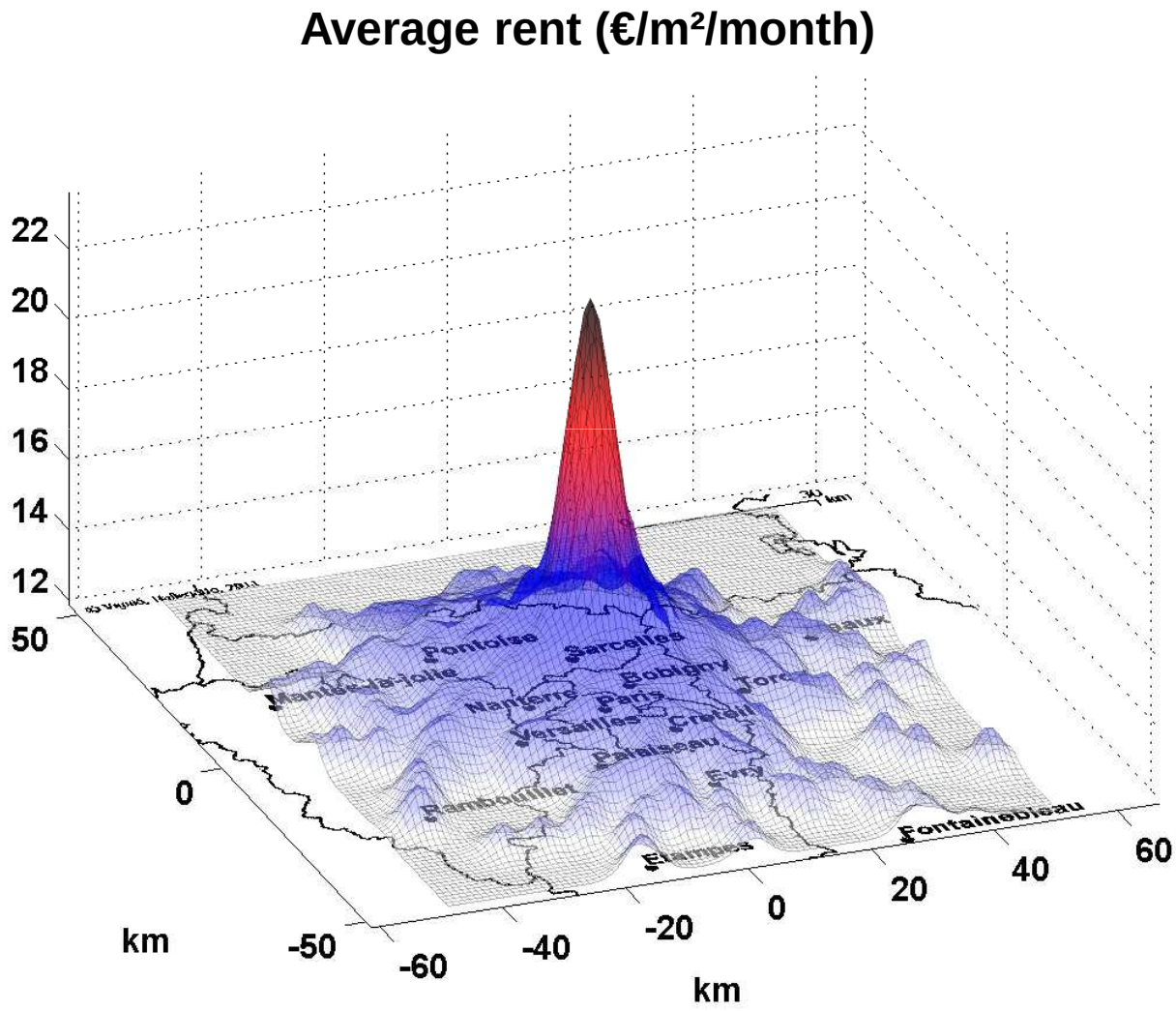
Model results: Rents (2008)



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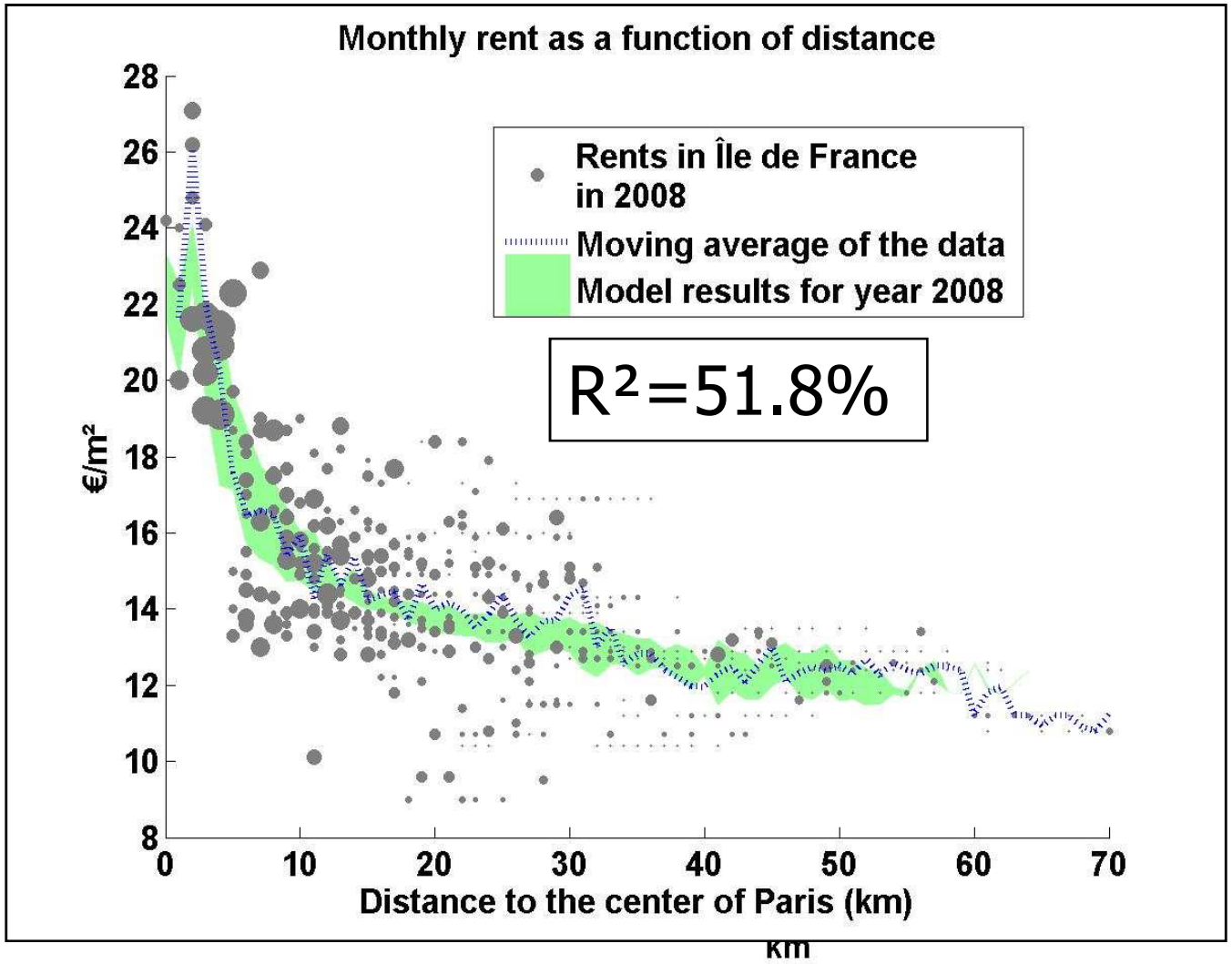
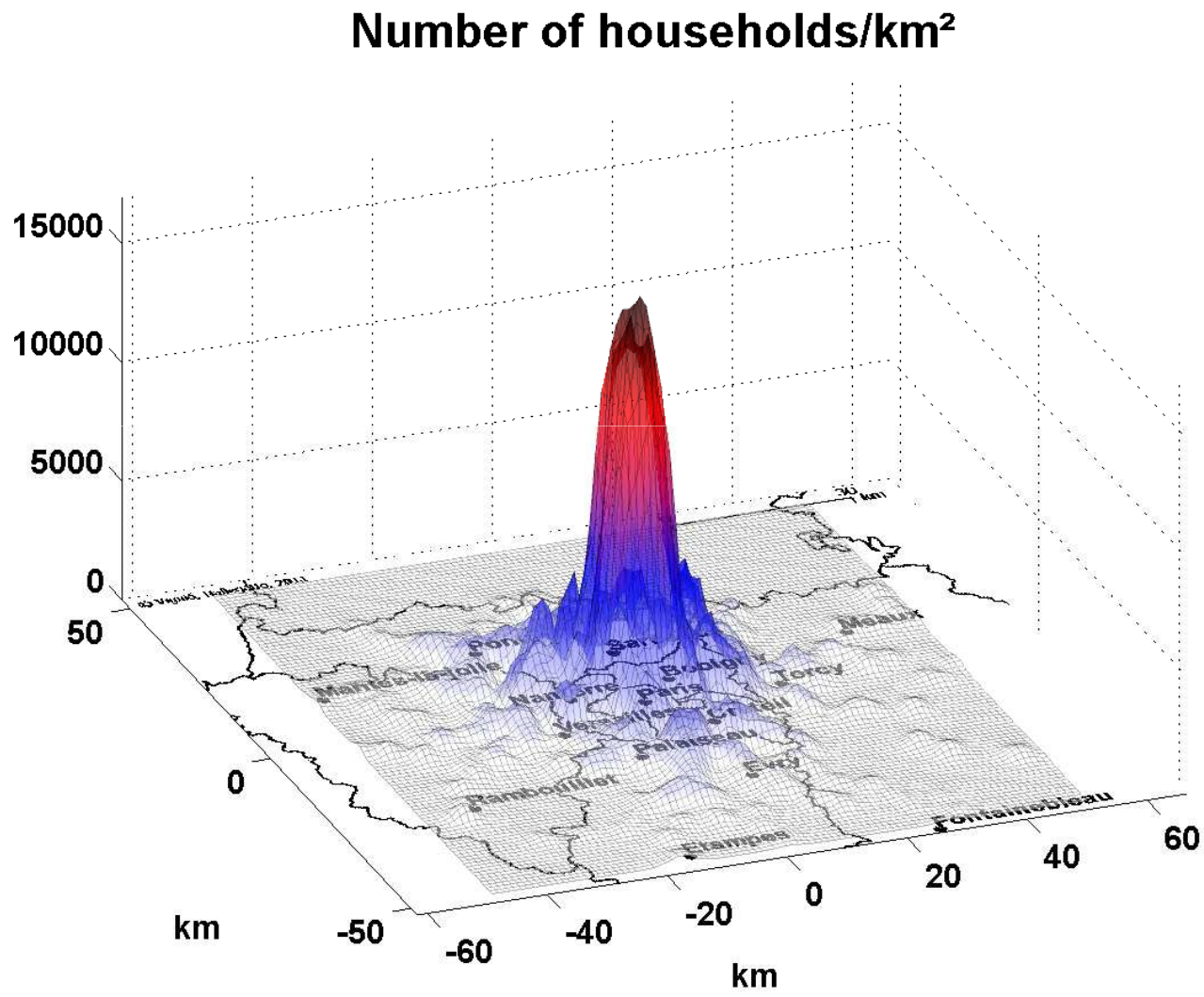
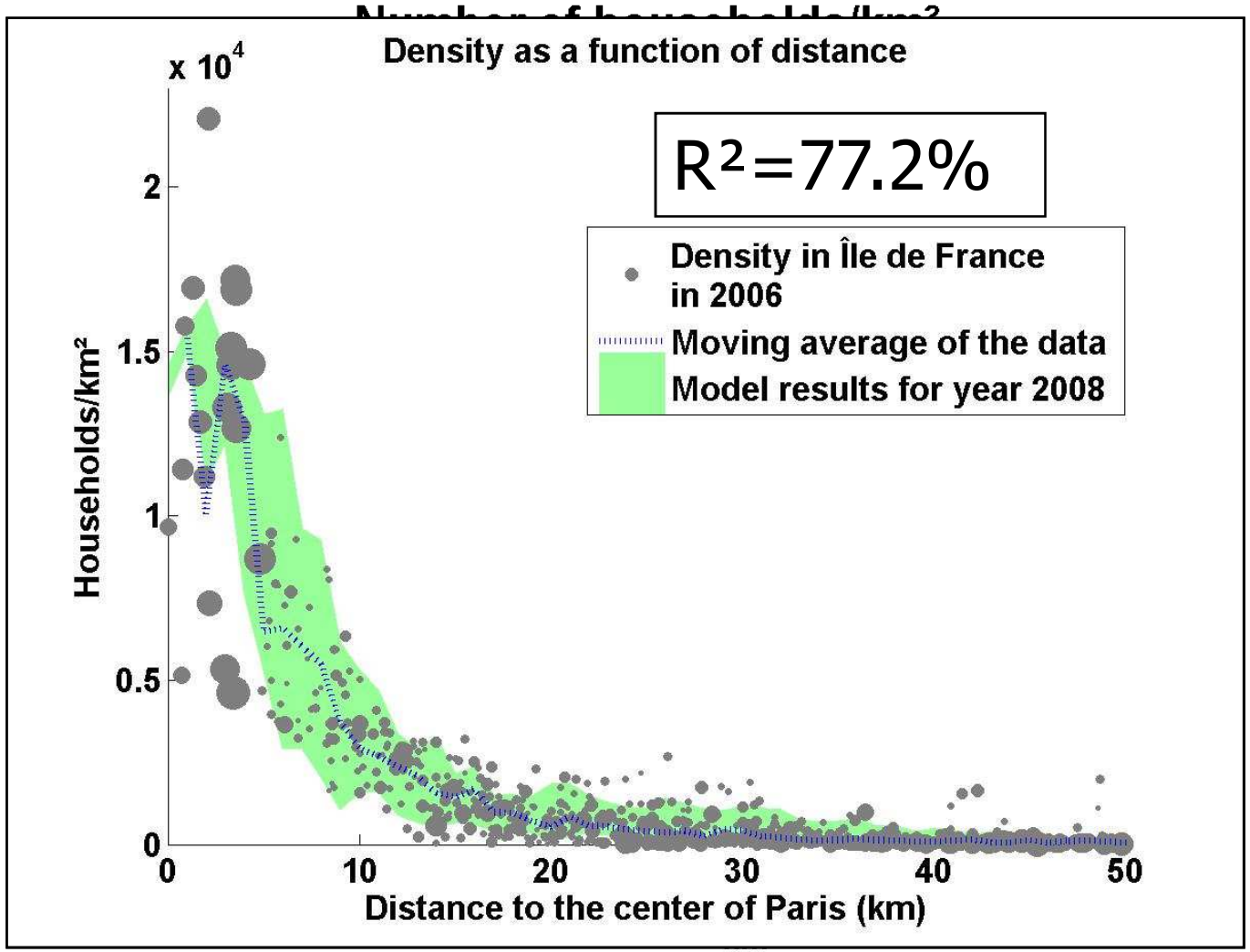


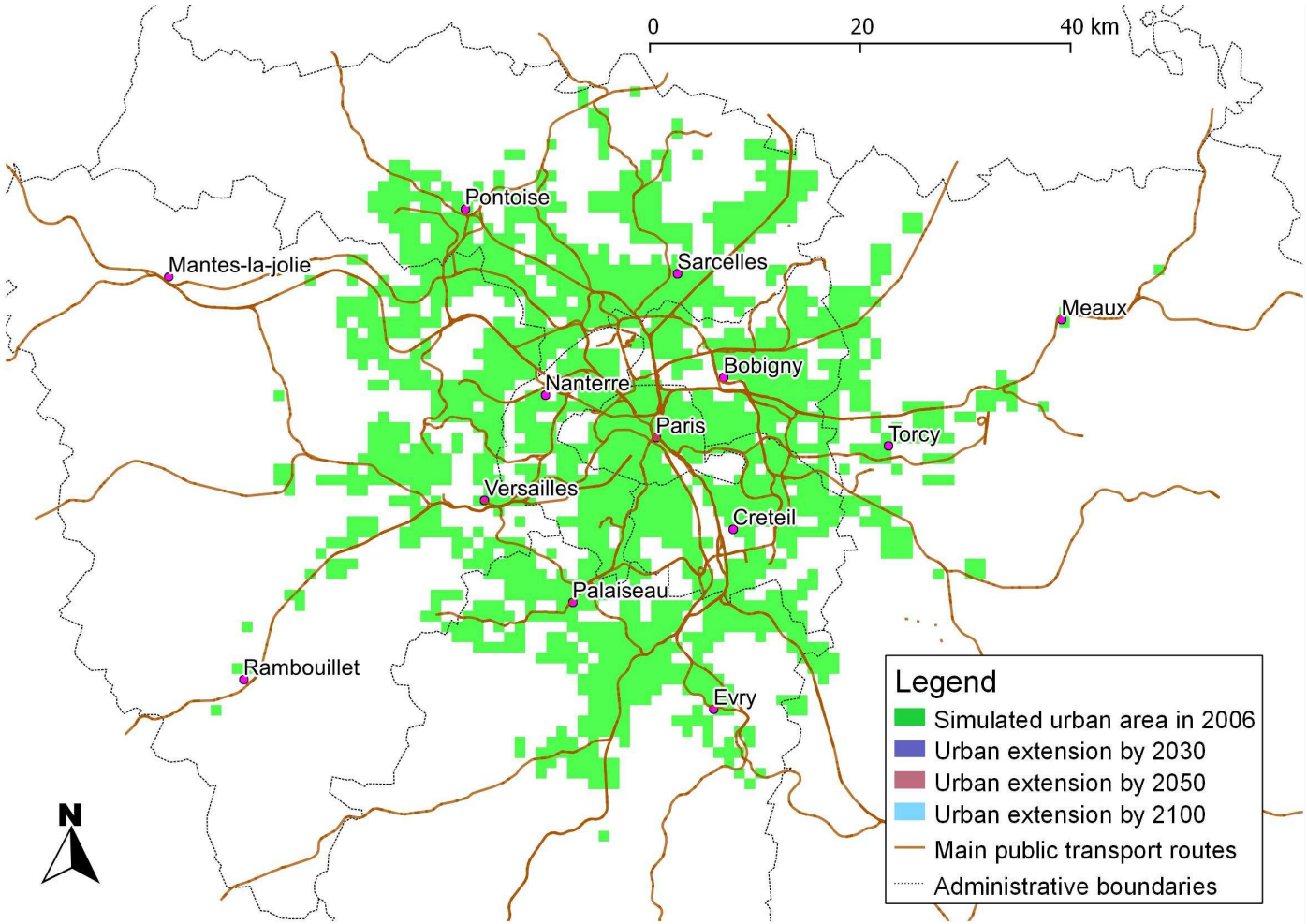
Model results: Population density (2006)



Model results: Population density (2006)



Example of a prospective scenario



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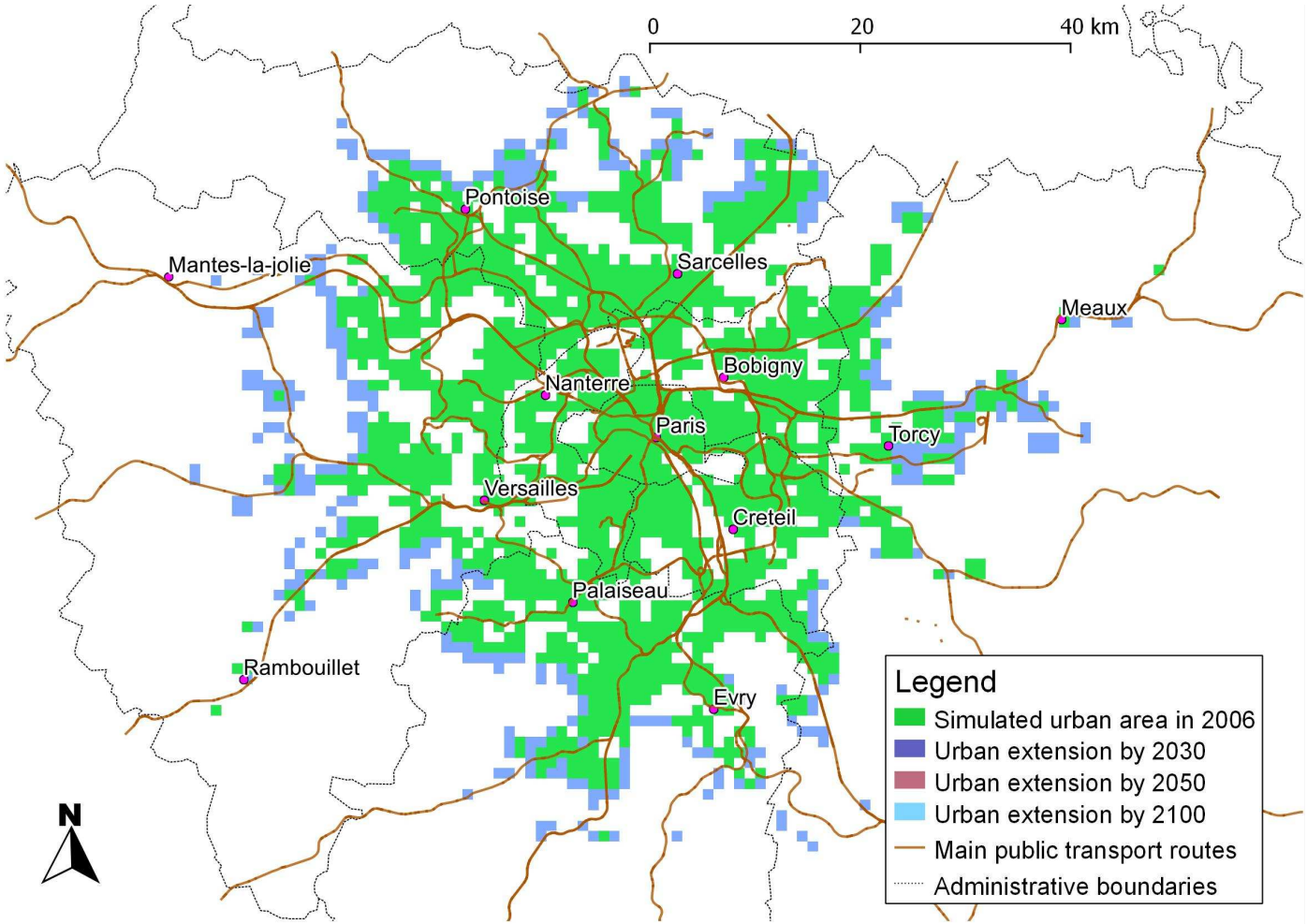

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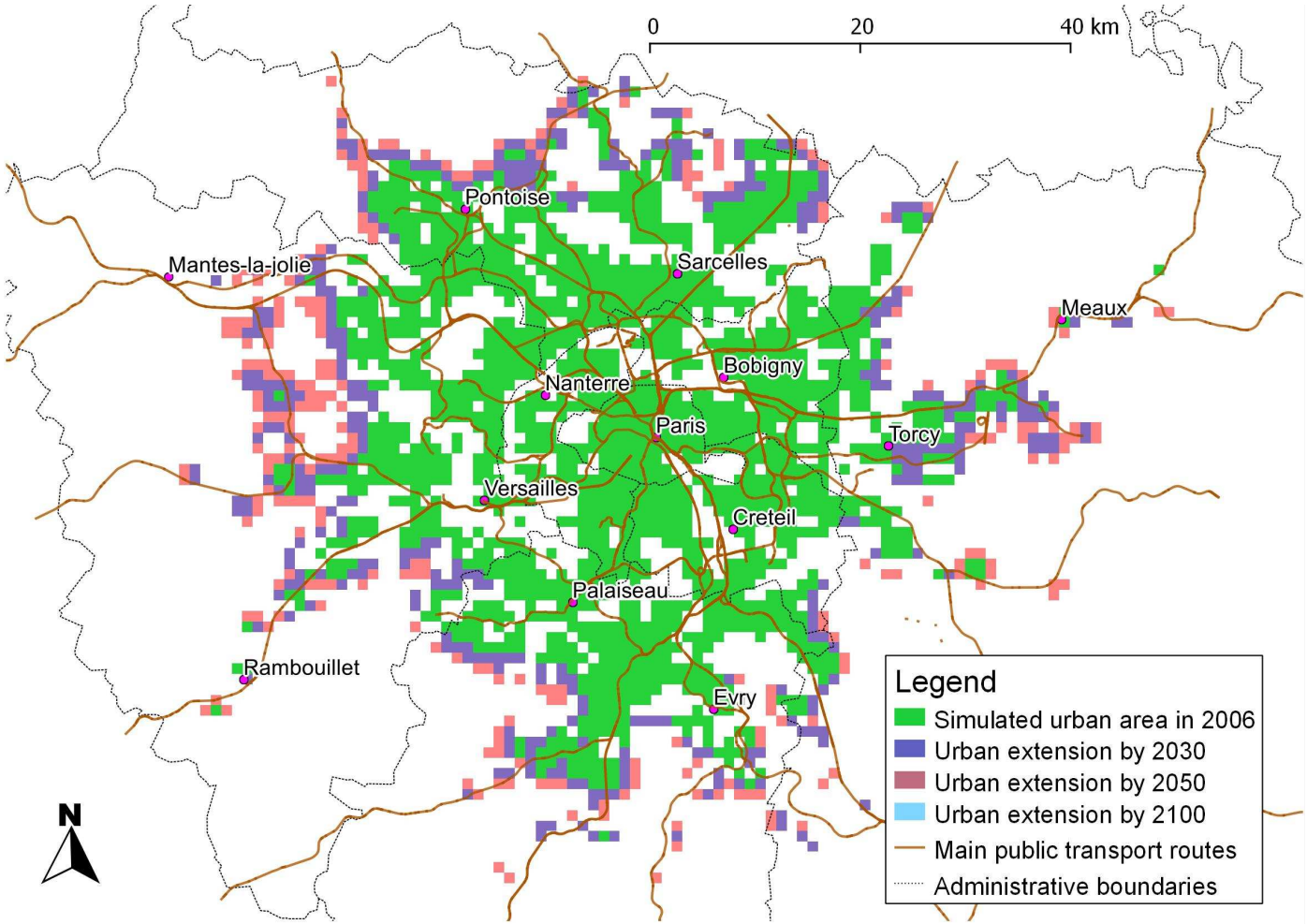

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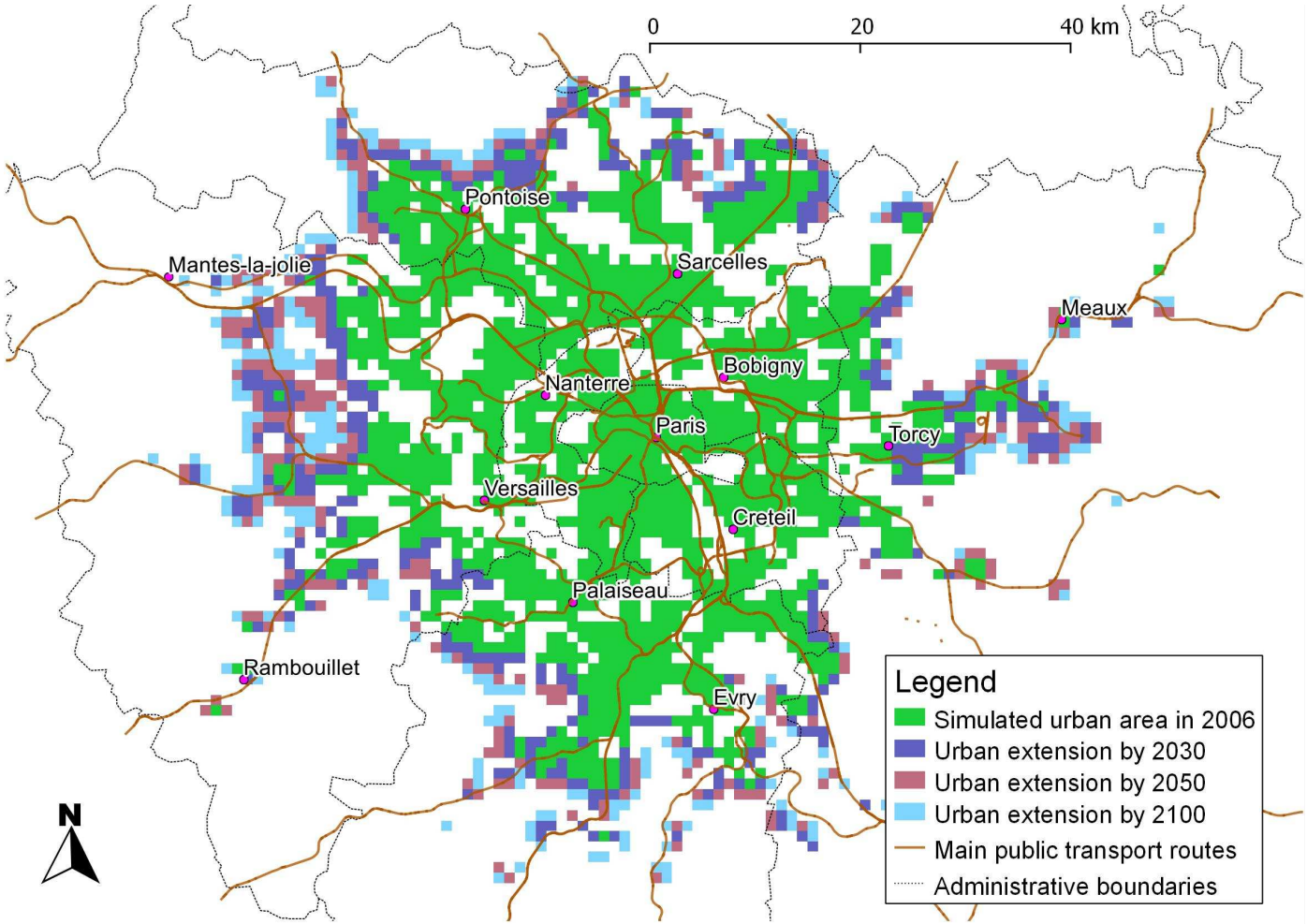

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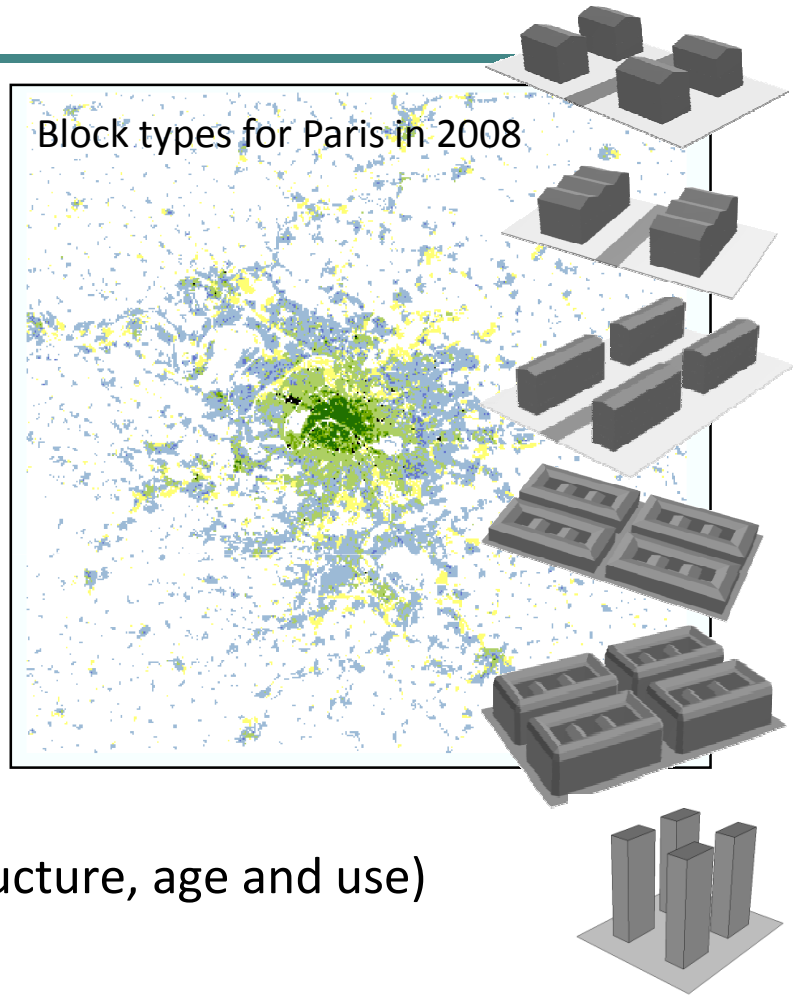
GENIUS model: The GENerator of Interactive Urban blockS

- **An architectural model of city blocks**

- **General Methodology:**
  - Identification of 7 Urban Blocks types

- **Implementation:**
  - For each grid cell (250m x 250m) :
  - identifies block type
  - + 60 indicators
  - (geometrical information & building structure, age and use)

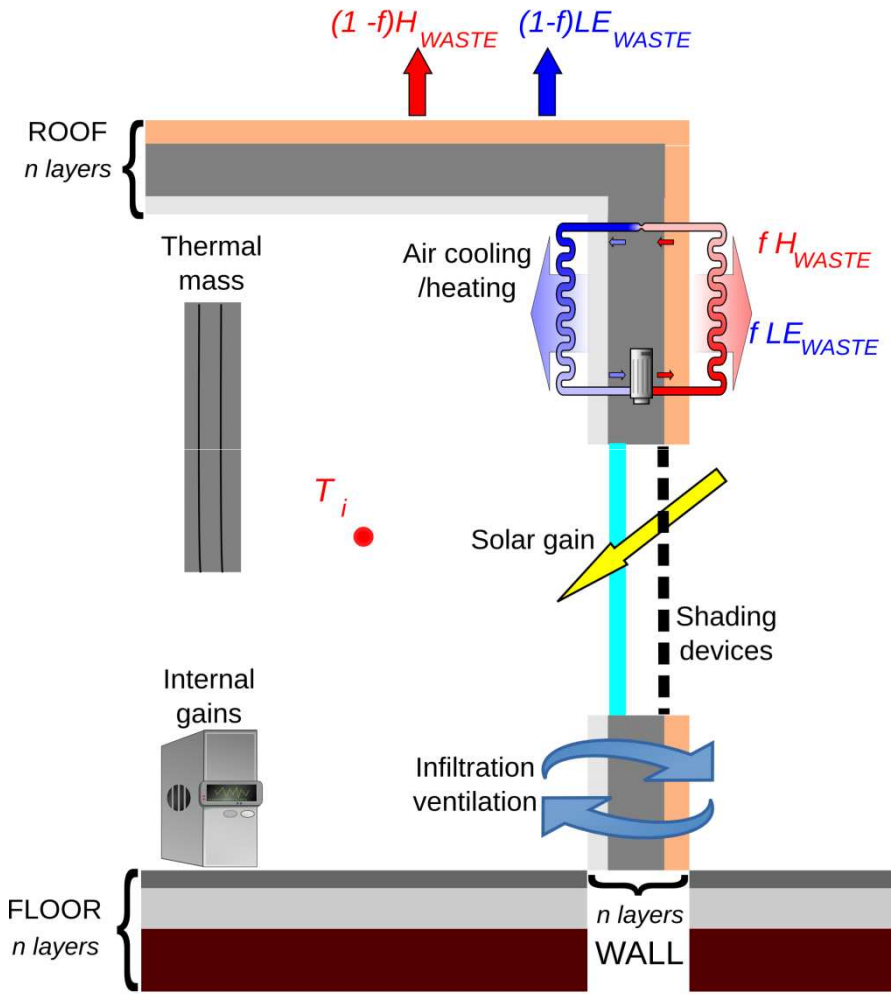


- **Architectural expertise is used to derive information for TEB**

TEB-BEM

- **TEB-BEM allows to compute Energy demands**
  - 1 thermal zone and 1 thermal mass
  - Solar heat gains by glazing
  - Internal heat gains
  - Ventilation, infiltration
  - Internal energy balance
  - heating/air cooling
  - Real HVAC systems
  - Shading devices
  - Natural ventilation (window opening)
- **Strong validation against experimental data**
- **TEB(-BEM) is an open-source code**

  http://redmine.cnrm-game-meteo.fr/projects/teb

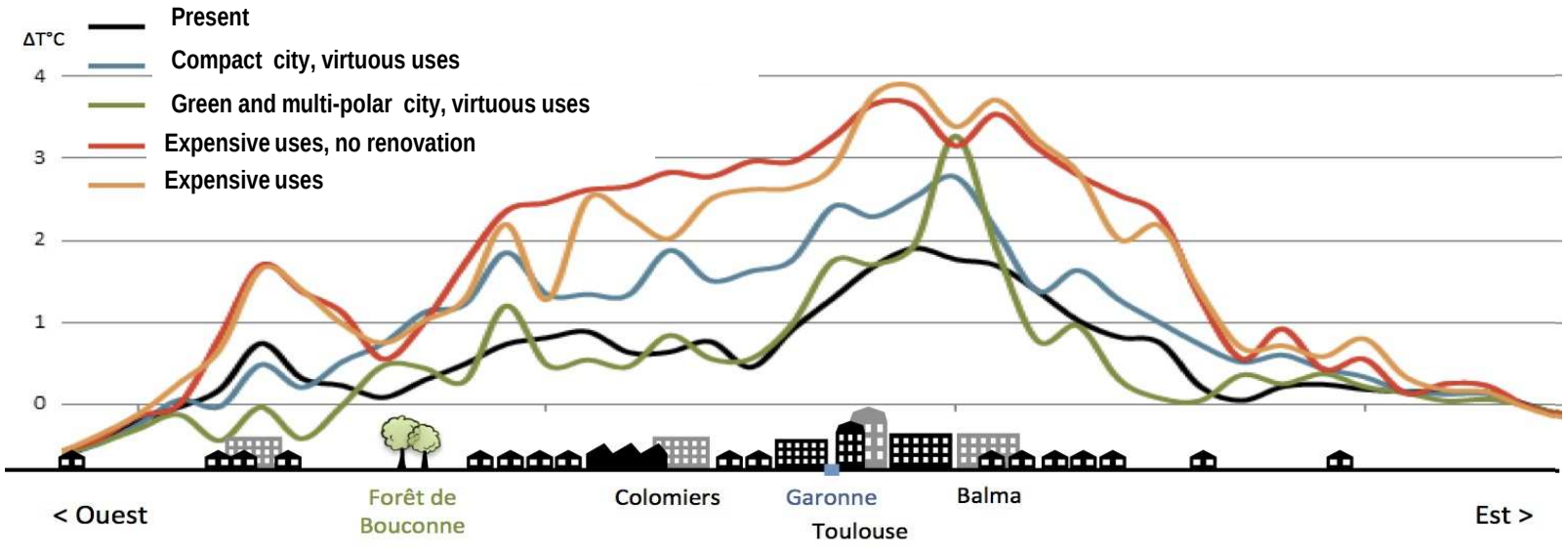


Bueno et al 2012
Pigeon et al 2014

Example of conclusion: 1. future heat island effect in Toulouse

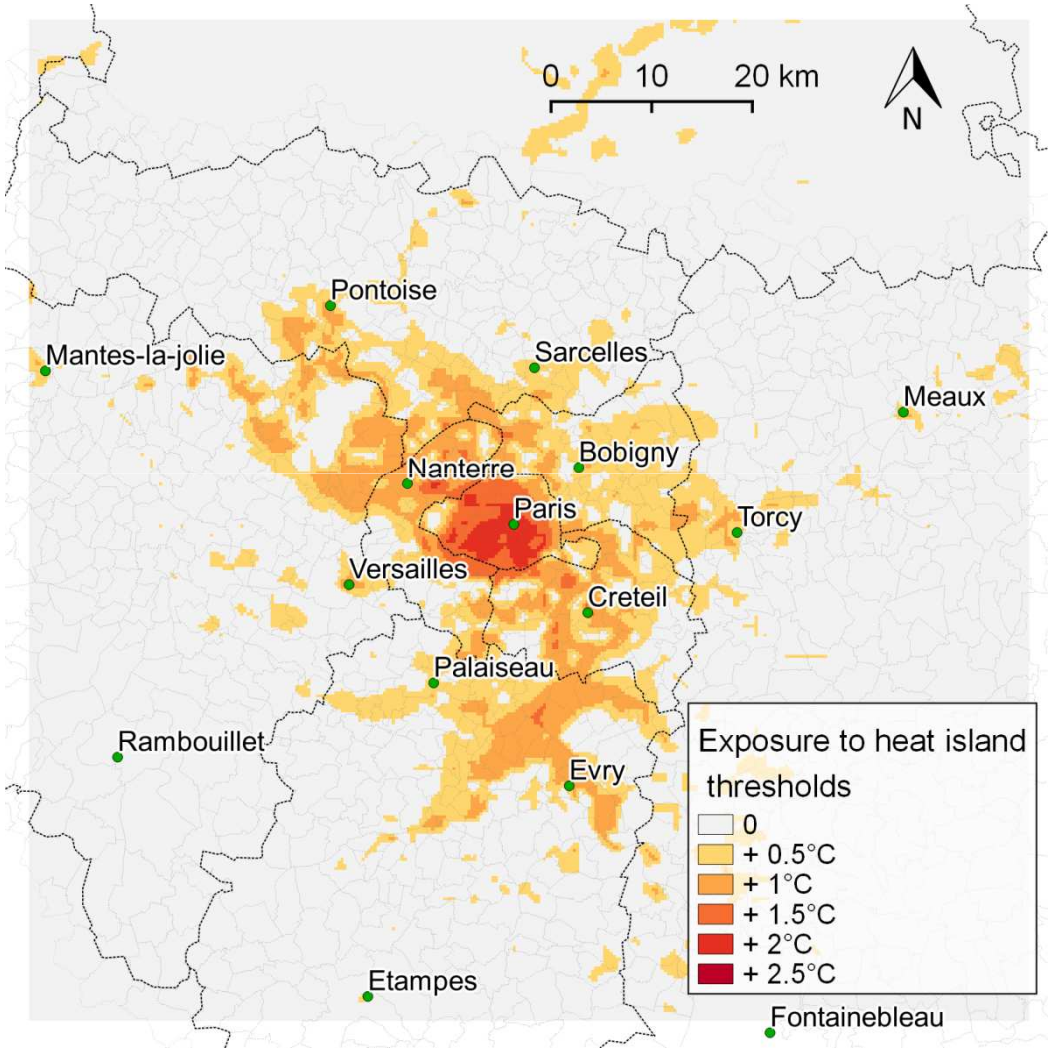
- ACCLIMAT project on Toulouse: simulations with 4 contrasted scenarios

- Urban sprawl = UHI from +1 to +3°C
- Global warming = +2 to 6°C
- Future urban climate on Toulouse = from +3°c to +9°C



Example of conclusion: 2. heat and density (1/3)

- **Simulated Heat island effect :**
  - outdoor temperature positive anomaly
  - 2m above ground
  - In the shadow
  - Average over all nights of August
- **Sprawled city scenario, projected 2100 climate**



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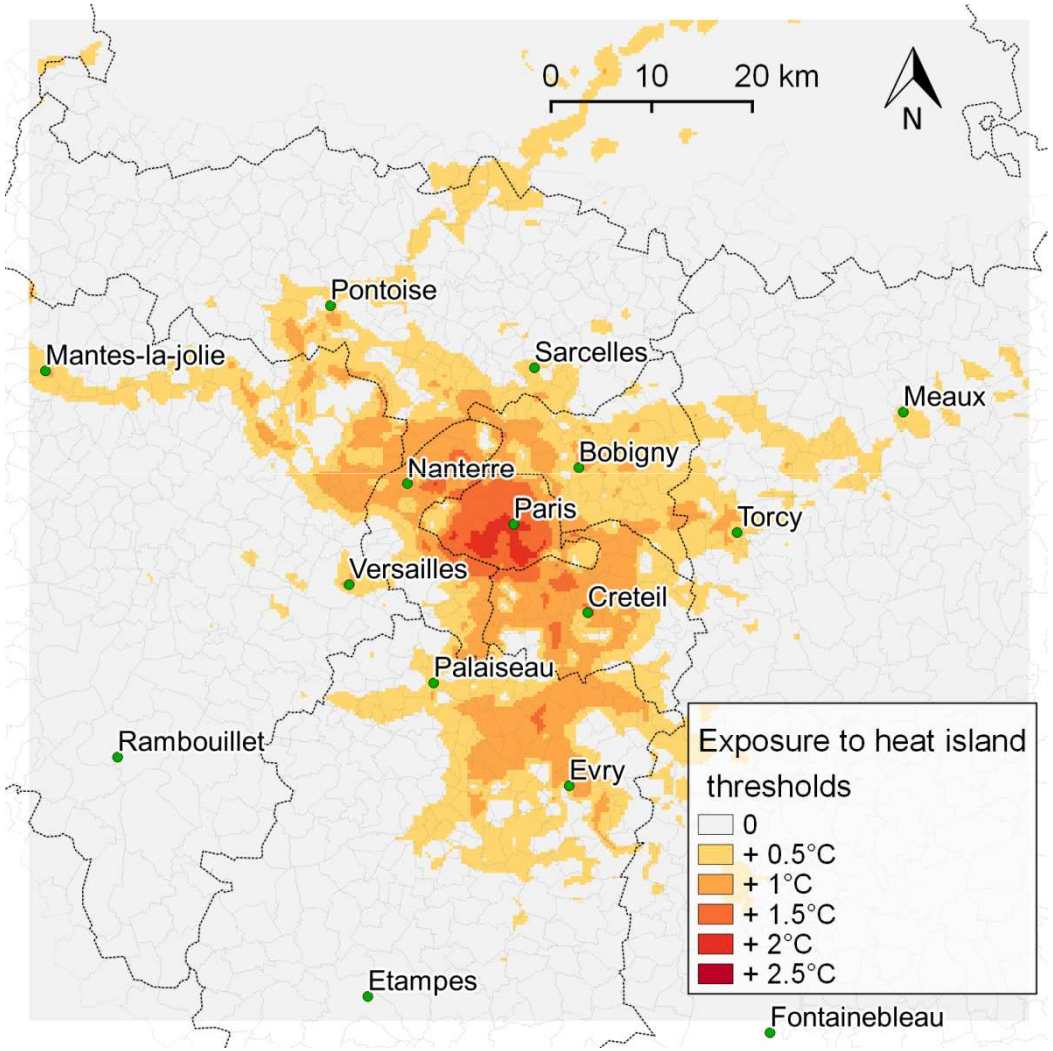
Example of conclusion: 2. heat and density (2/3)

- **Simulated Heat island effect :**
  - outdoor temperature positive anomaly
  - 2m above ground
  - In the shadow
  - Average over all nights of August
- **<u>Compact</u> city scenario, projected 2100 climate**



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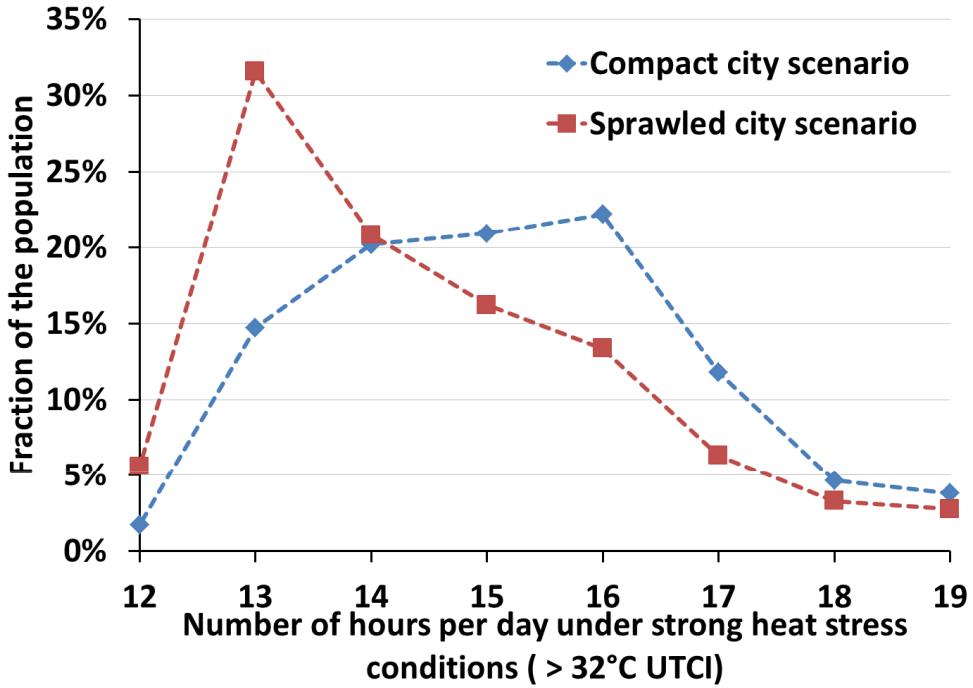
Example of conclusion: 2. heat and density (3/3)



- **In our simulations, at night, UHI tends to be higher when the city is denser**
  - However temperature differences are small (below 1°C, often below 0.5 °C) compared to UHI absolute value
  - City densification scenarios only have a moderate impact on air temperature
- **Taking into account population repartition in the city changes the picture**
  - When the city is denser, more people live in dense neighborhoods close to the center of the city, i.e. in places where UHI is higher

Example of conclusion: 3. Inhabitants habits are a potential important lever

- **Choice between intensive or moderate AC use:**
  - Using AC to maintain 26°C instead of 23°C saves 80% of AC electricity use

- **Using solar protections during the day (shutters…)**
  - Saves 32% of AC electricity use

- **Inhabitants habits can play a role as important as architectural choices or technological choices**

Conclusions

- **Urban adaptation analysis can only be done in a interdisciplinary way.**
  - Modeling helps !
- **City evolution up to 2100 can be as important as climate change**

➔ ***For more details, other presentations during this conference:***

- *Thursday 11:00am "Watering practices and urban thermal comfort improvement under heat wave conditions"*
- *Thursday 4:30pm "Evaluation of greening scenarios to reduce Paris city vulnerability to future heat waves"*
- *Monday 4:30pm "Vulnerability to heat waves: impact of urban expansion scenarios on urban heat island and heat stress in Paris (France)"*