

Vulnerability of the city of Paris (France) to future heat waves: Impact of urban sprawl scenarios

Aude Lemonsu¹,
Vincent Viguié², Maxime Daniel¹, Valéry Masson¹

¹ *Météo-France / CNRS, Toulouse, France*

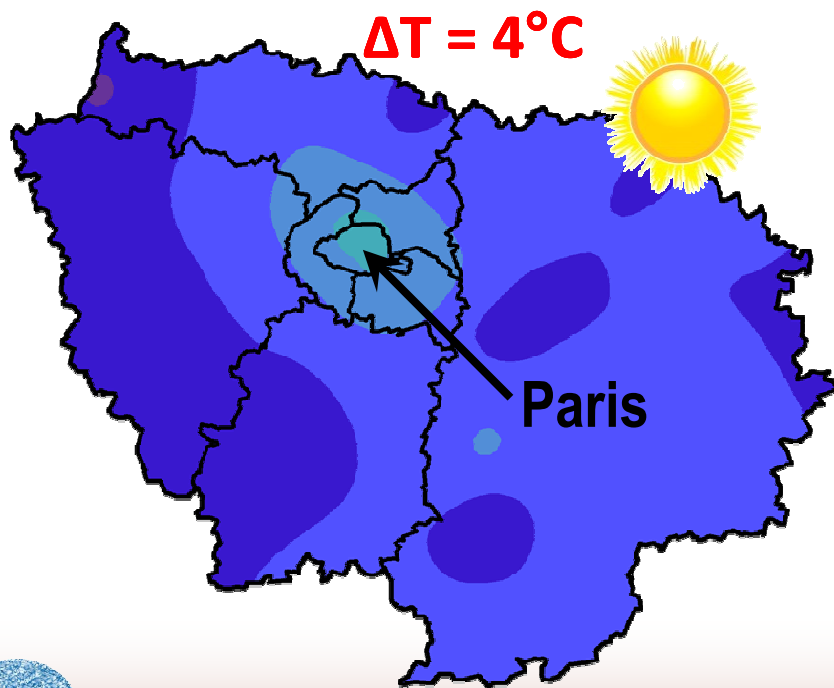
² *Centre International de Recherche sur l'Environnement et le Développement,
Nogent sur Marne, France*

Context and motivations

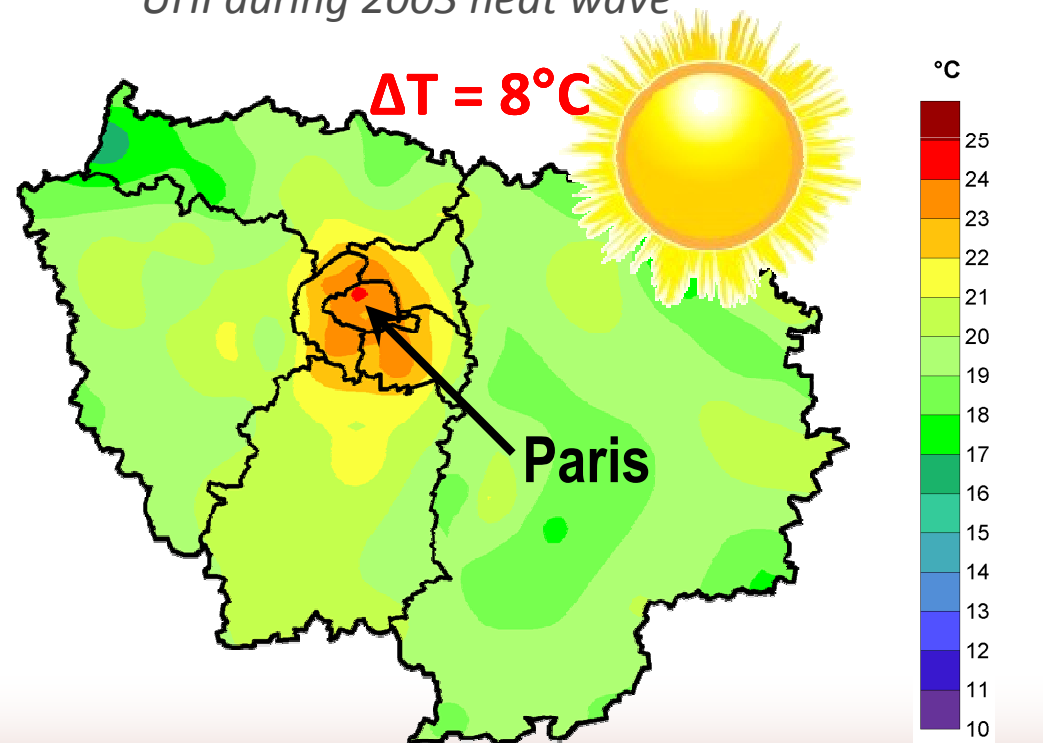
- 15000 extra deaths in France during 2003 heat wave
- 8,5% of excess mortality in Paris (= 3,7% of French population)

➔ Intensification of urban heat island and aggravation of health impacts

UHI during a typical summer

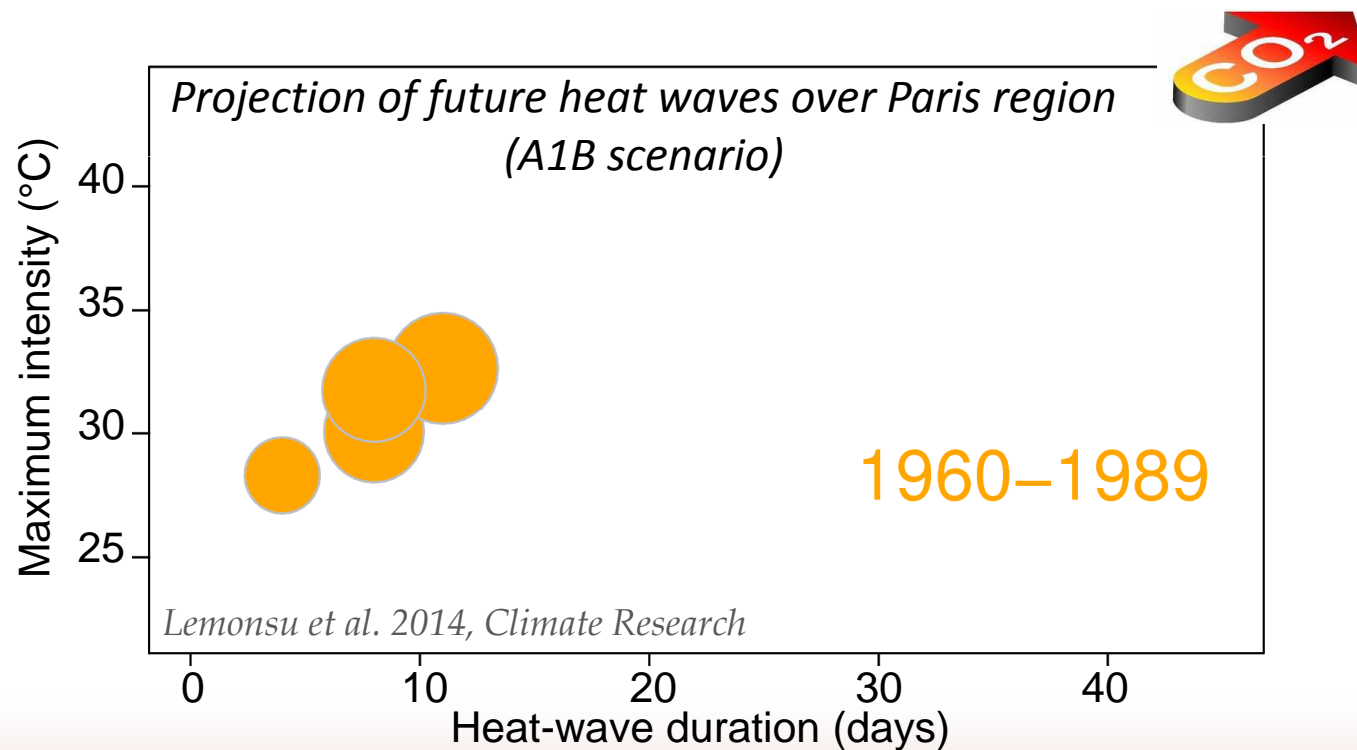


UHI during 2003 heat wave



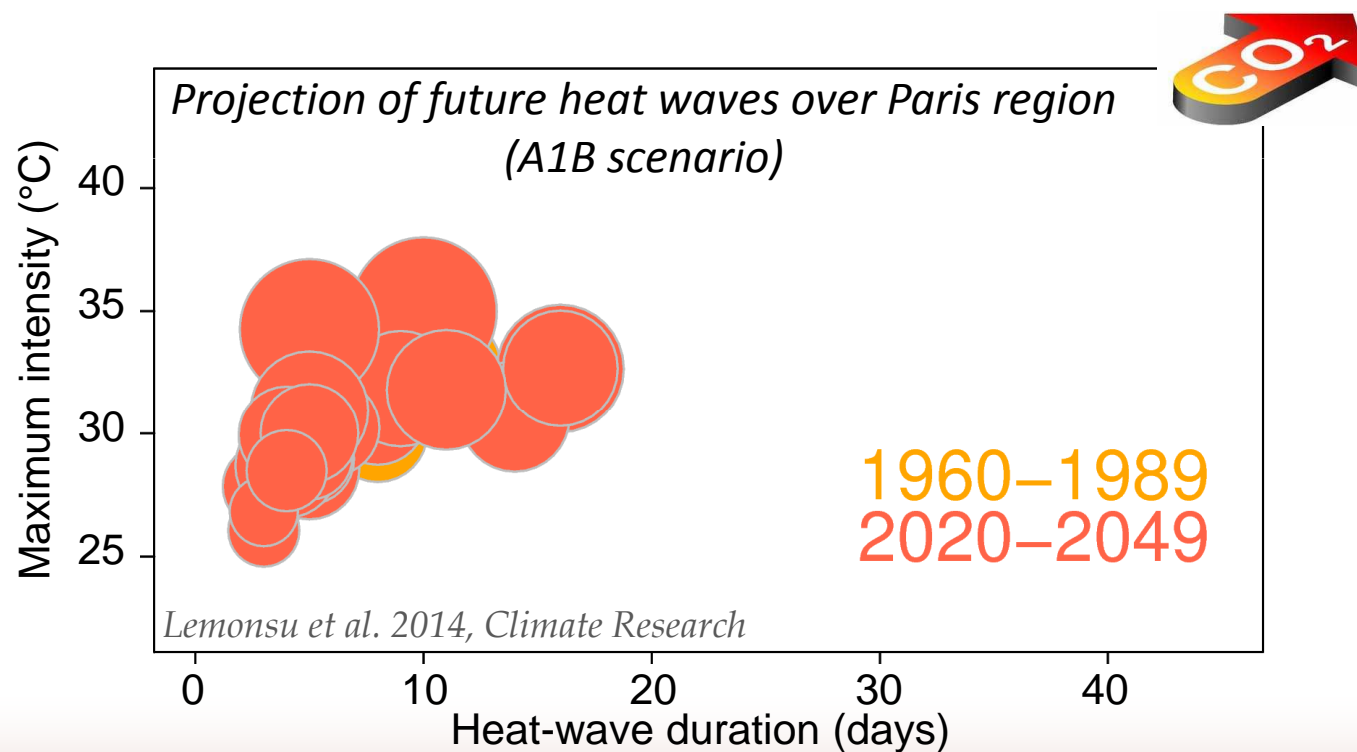
Context and motivations

- In the future, heat waves will be more frequent, longer and more intense
- In 2100, Paris will be affected each year, on average, by:
 - 1.4 heat wave
 - 11 heat-wave days



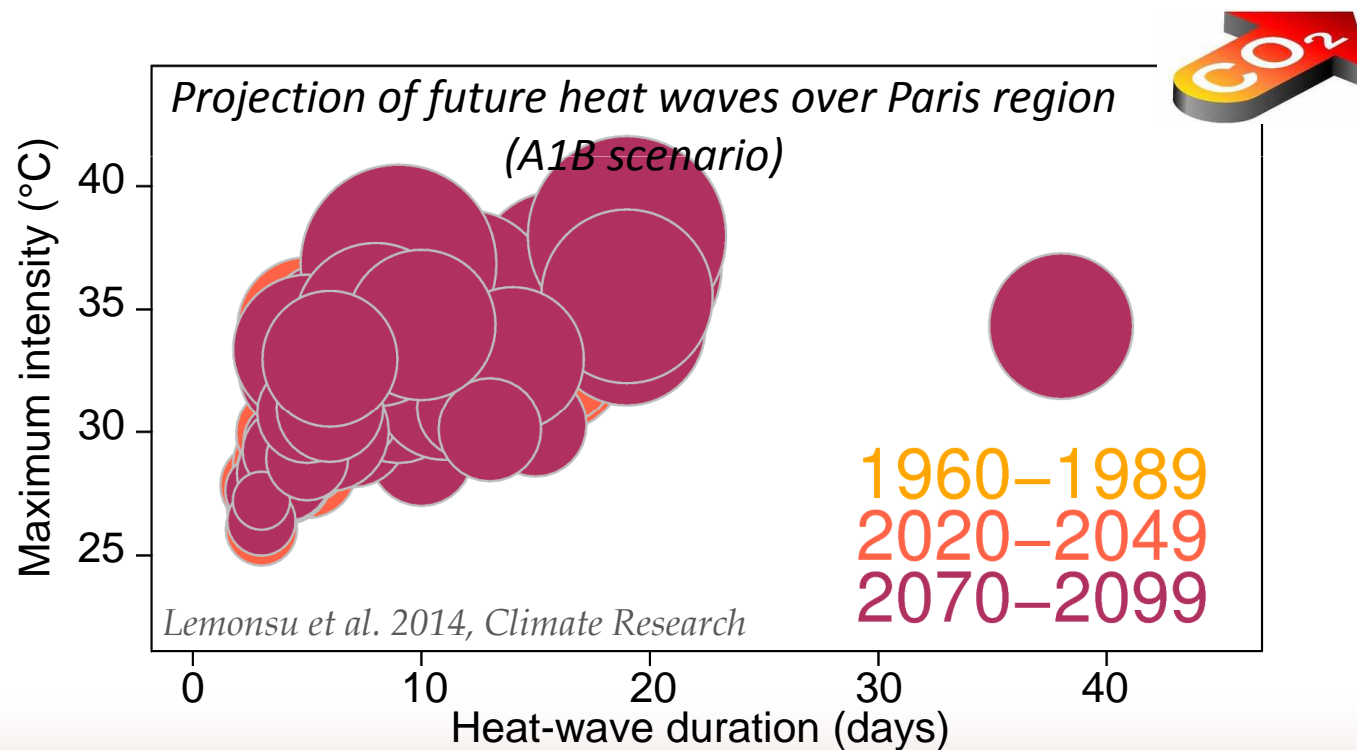
Context and motivations

- In the future, heat waves will be more frequent, longer and more intense
- In 2100, Paris will be affected each year, on average, by:
 - 1.4 heat wave
 - 11 heat-wave days



Context and motivations

- In the future, heat waves will be more frequent, longer and more intense
- In 2100, Paris will be affected each year, on average, by:
 - 1.4 heat wave
 - 11 heat-wave days



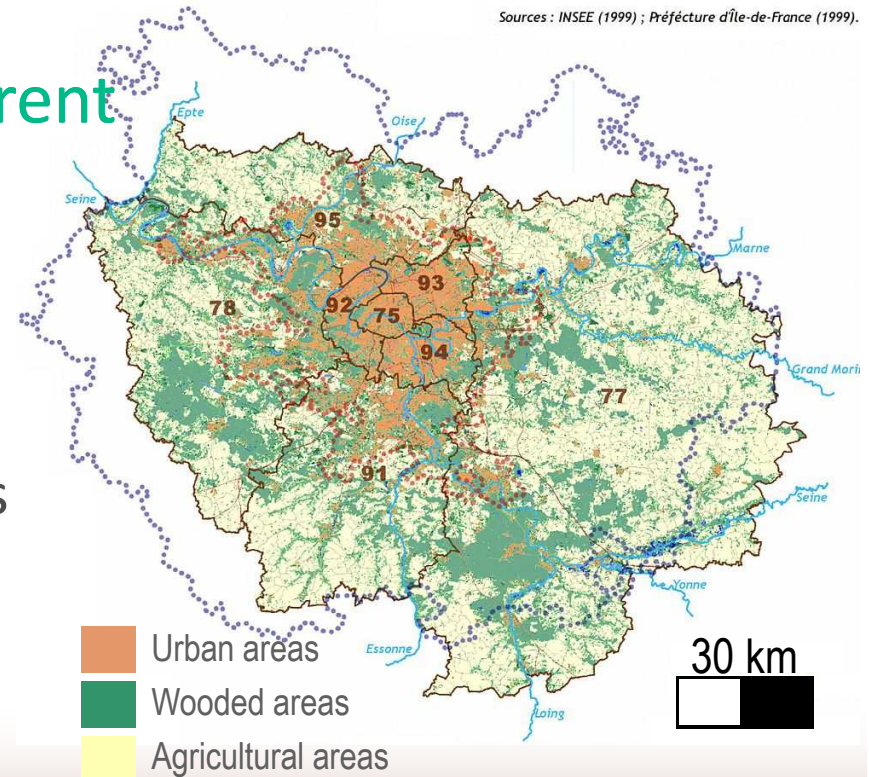
Objectives

- Study the interactions between climate change, urban climate, and urban expansion
- Evaluate and compare different urban planning policies
 - Focus on heat wave conditions
 - Paris (France) as case study
 - 2100 as time period of analysis

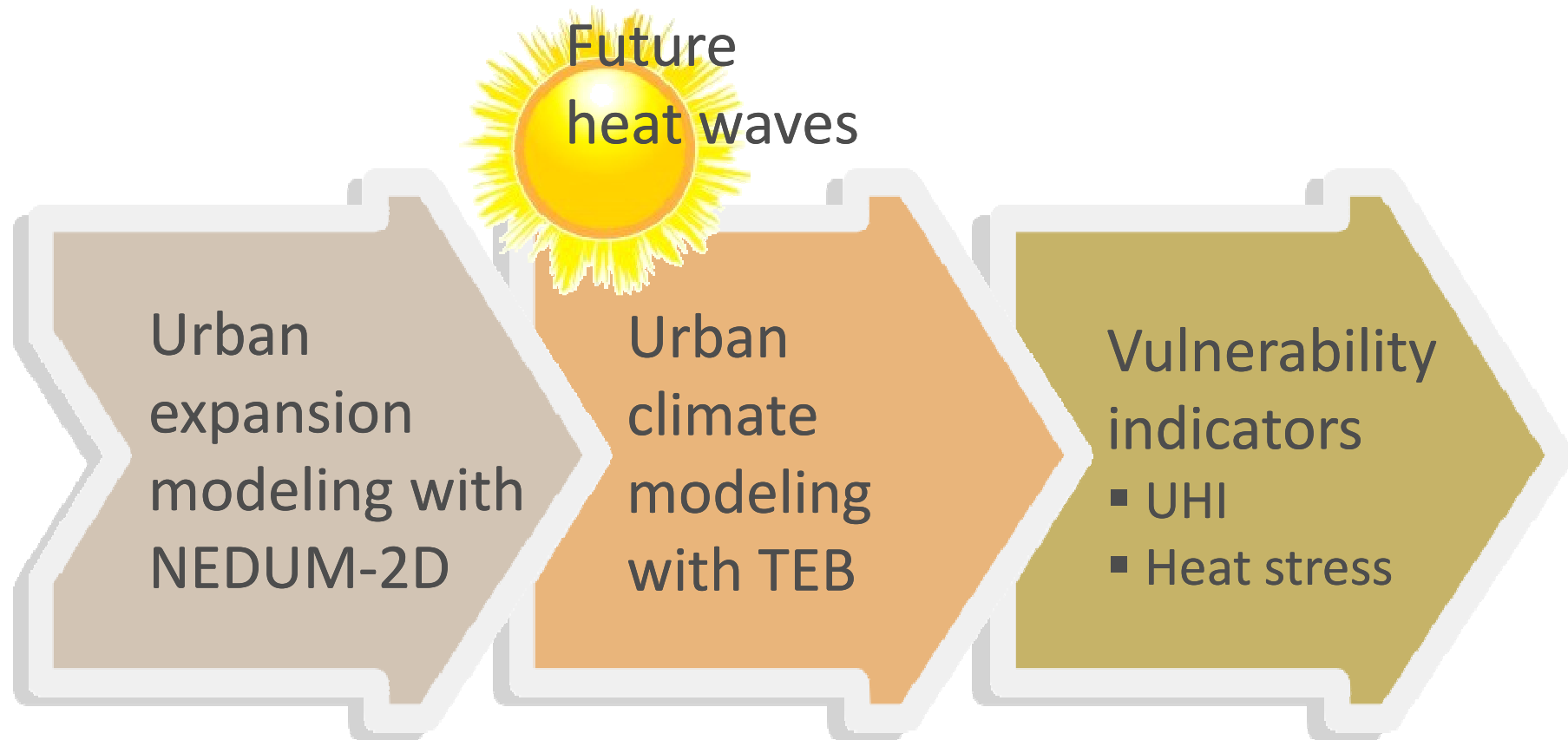
VURCA

ANR – VMCS 2008

Sources : INSEE (1999) ; Préfecture d'Île-de-France (1999).



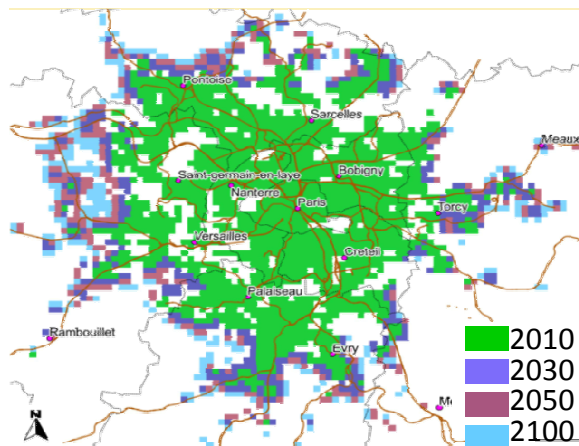
Systemic modeling methodology



Urban
expansion
modeling with
NEDUM-2D

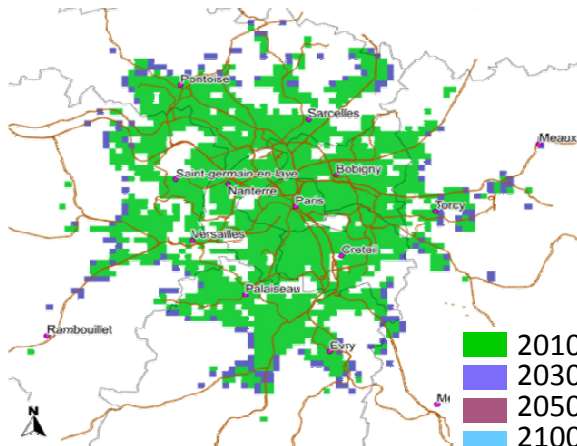
Long-term scenarios simulated with the land-use transport interaction model NEDUM-2D

- Macro-scale socio-economic constraints (energy cost, demography trends)
- Various local-scale urban planning policies



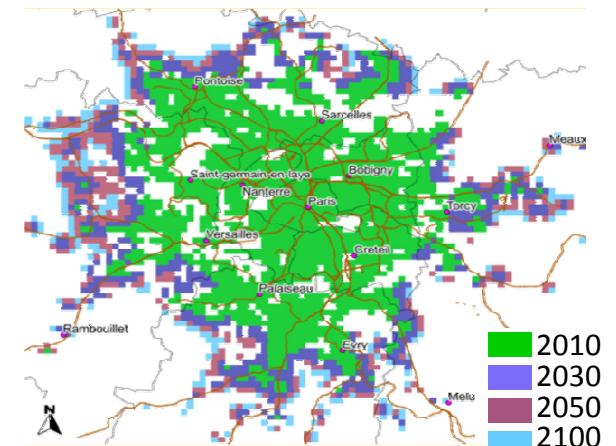
SPREAD-OUT CITY

2550 km²



COMPACT CITY

1900 km²



**GREEN CITY
10/30/50%**

2800/3450/4300 km²

Urban
climate
modeling
with TEB

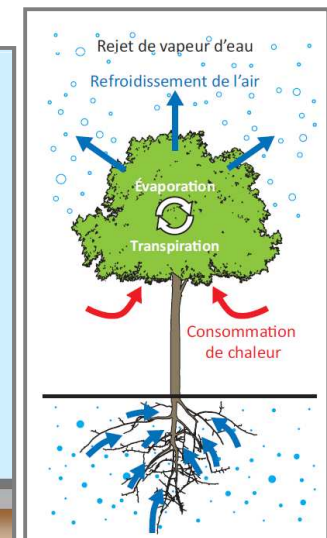
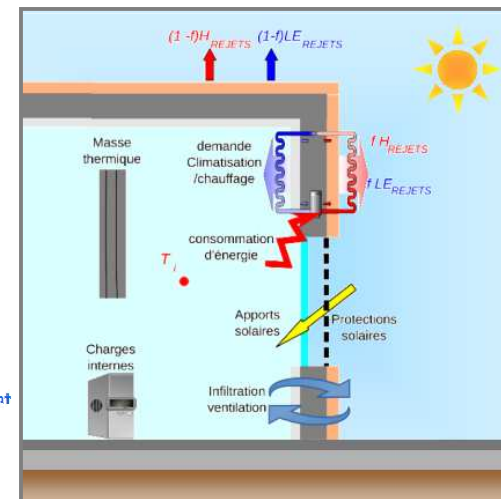
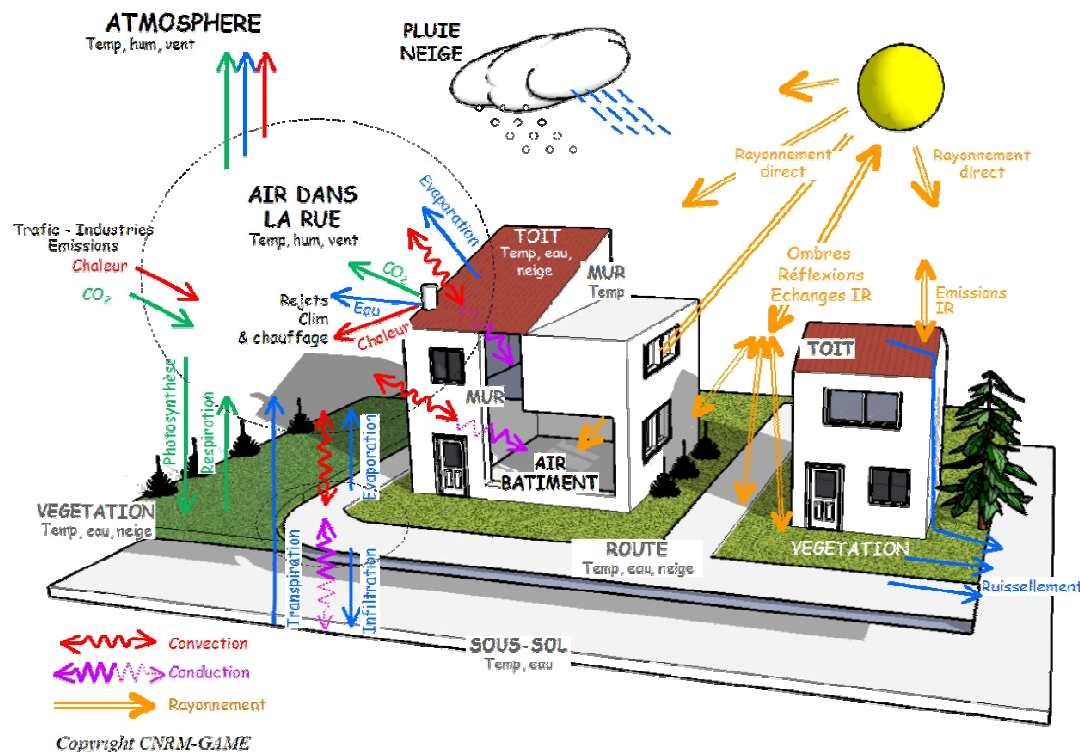
Physically-based urban canopy model TEB

- Key physical processes in urban climate development
- Building energetics
- Urban green areas

Masson 2000 Hamdi and Masson 2008

Bueno et al. 2012; Pigeon et al. 2014

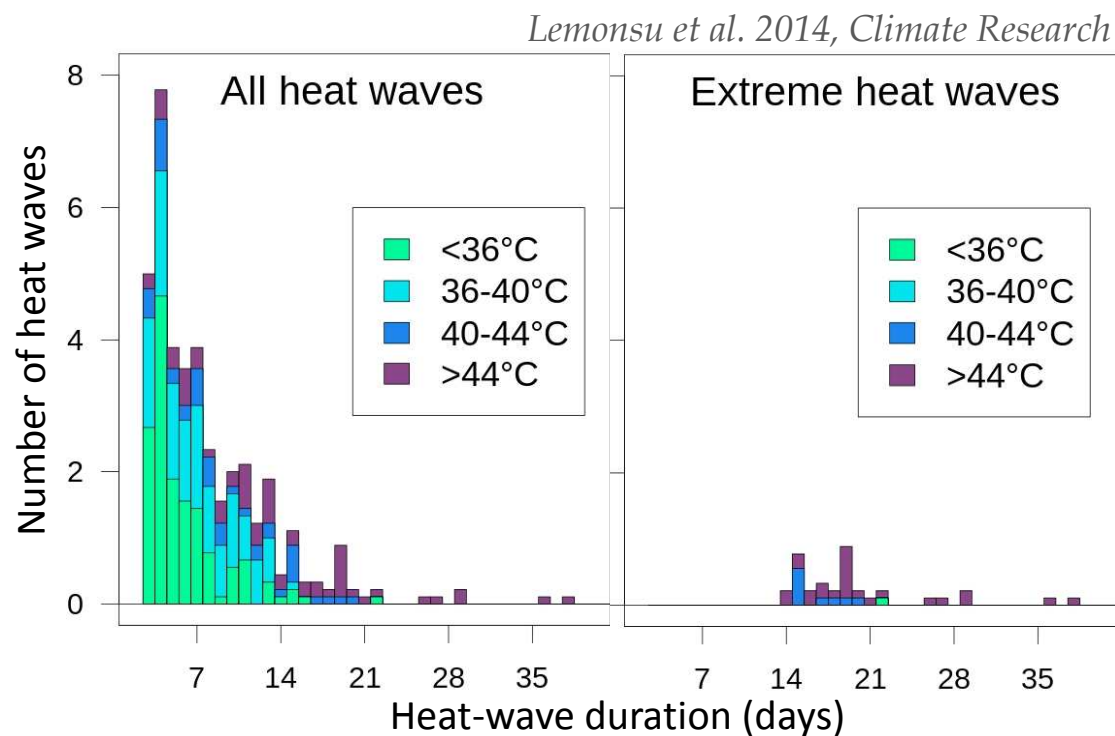
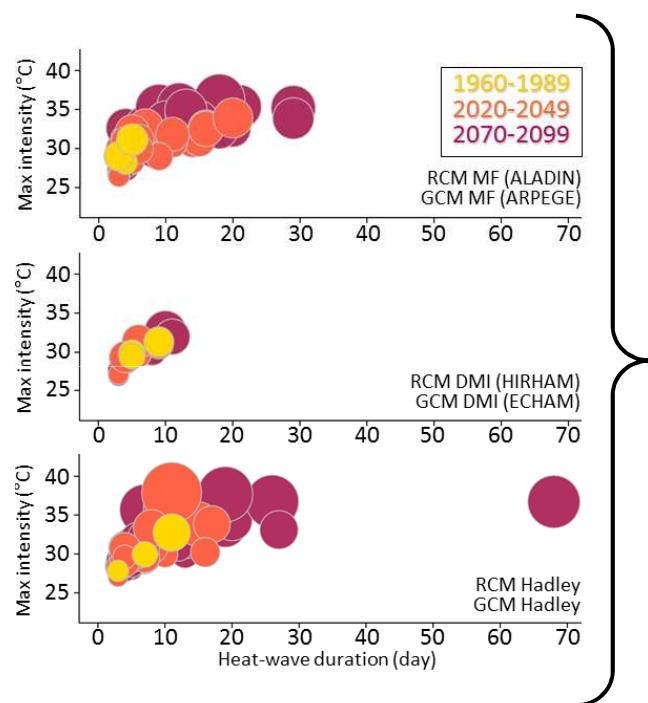
Lemonsu et al. 2012; de Munck et al. 2013



Source : APUR



Characteristics of future heat waves based on the RCM projections analysis



➡ Urban climate modelling for heat waves of various intensities and durations representative of future events

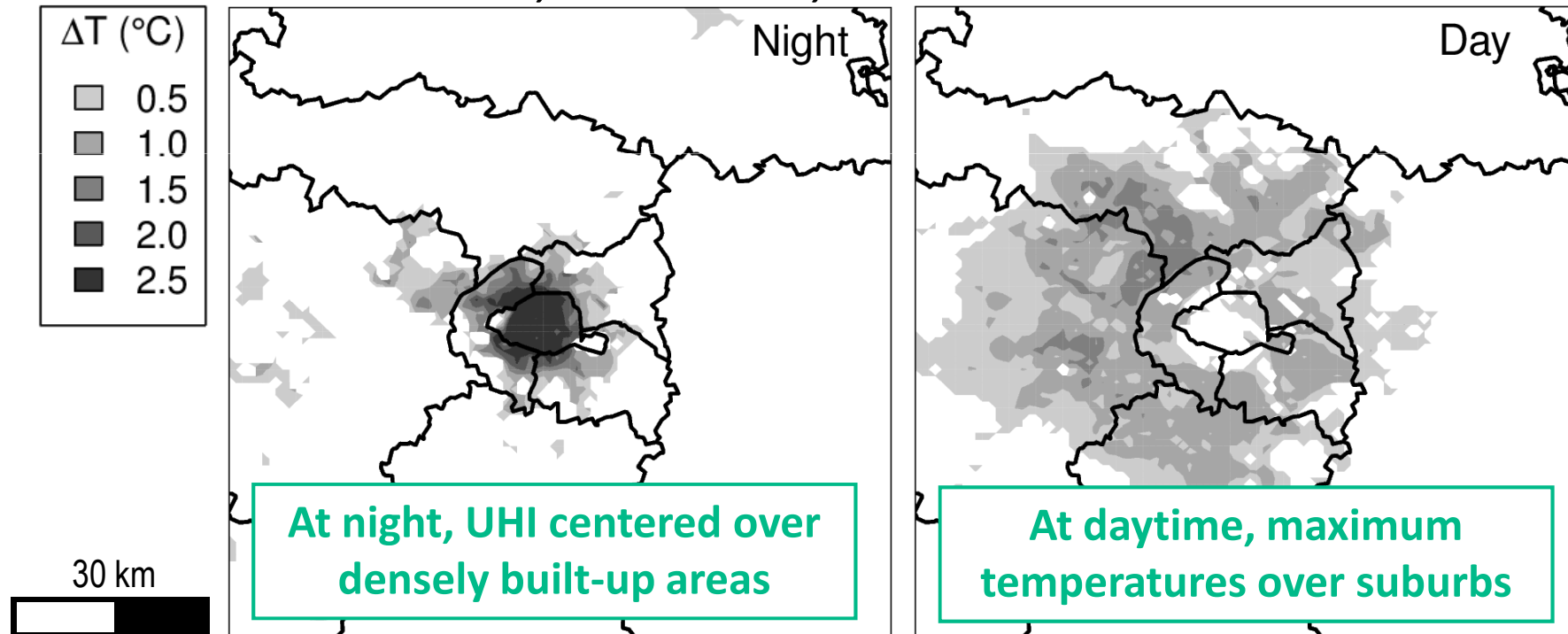
Vulnerability indicators

- UHI
- Heat stress

➤ Sensitivity to urban heat island

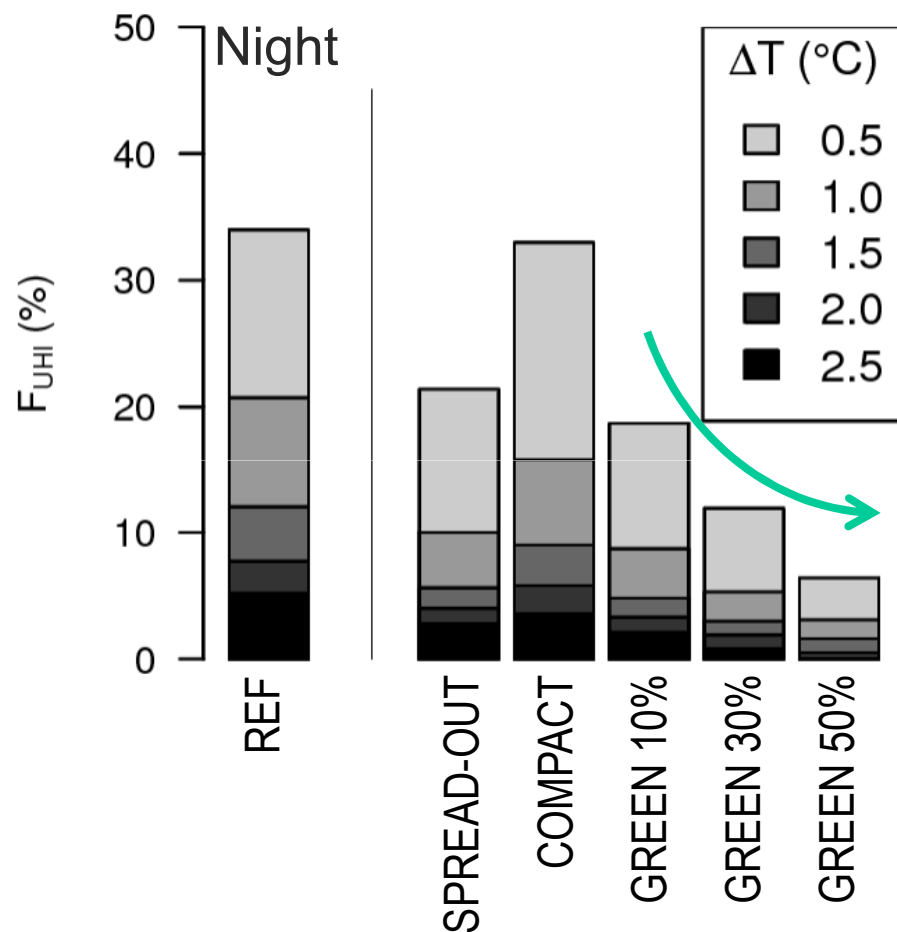
- $\text{UHI } (^{\circ}\text{C}) = \text{Urban Heat Island} = T - T_{\text{rural(ref)}}$
- $F_{\text{UHI}} (\%) = \text{Fraction of city affected by UHI}$
- $P_{\text{UHI}} (\%) = \text{Fraction of population affected by UHI}$

Today Paris • 7-days heat wave • $T_{\text{max}} = 38^{\circ}\text{C}$

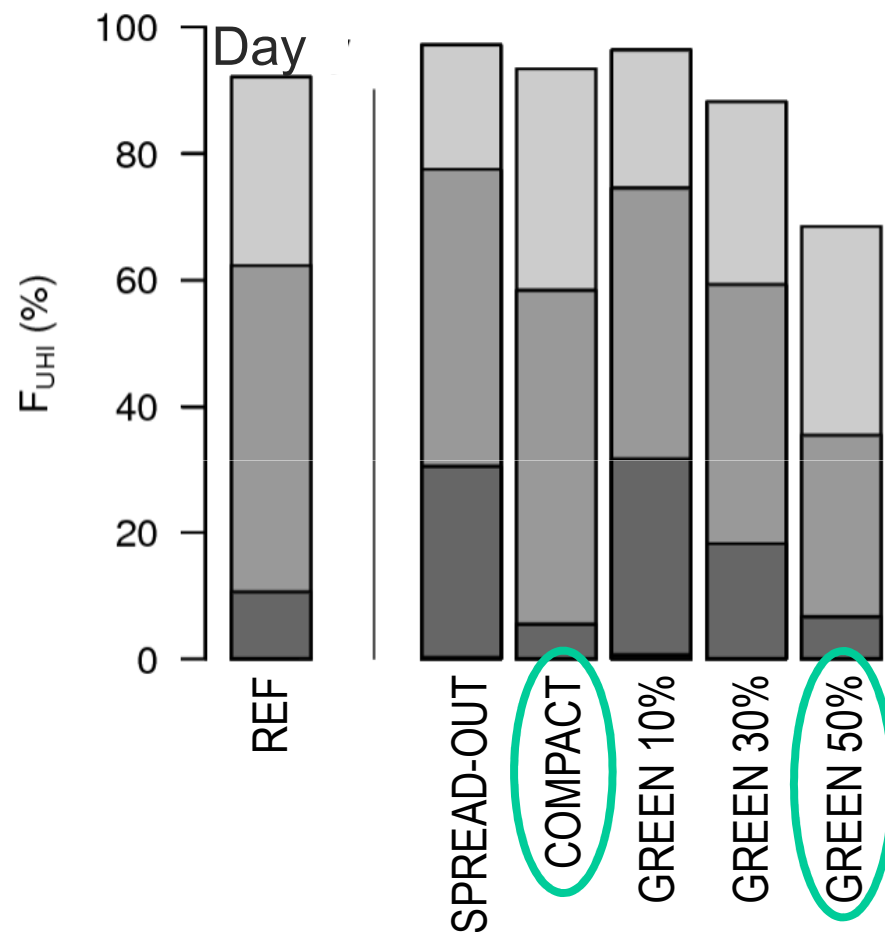


Sensitivity of the city to UHI

Fraction of city affected • 7-days heat wave • $T_{max} = 38^{\circ}\text{C}$



At night, urban greening
(and less urban compacity)
has a positive effect



At daytime, compacity
reduces sunshine and
warming

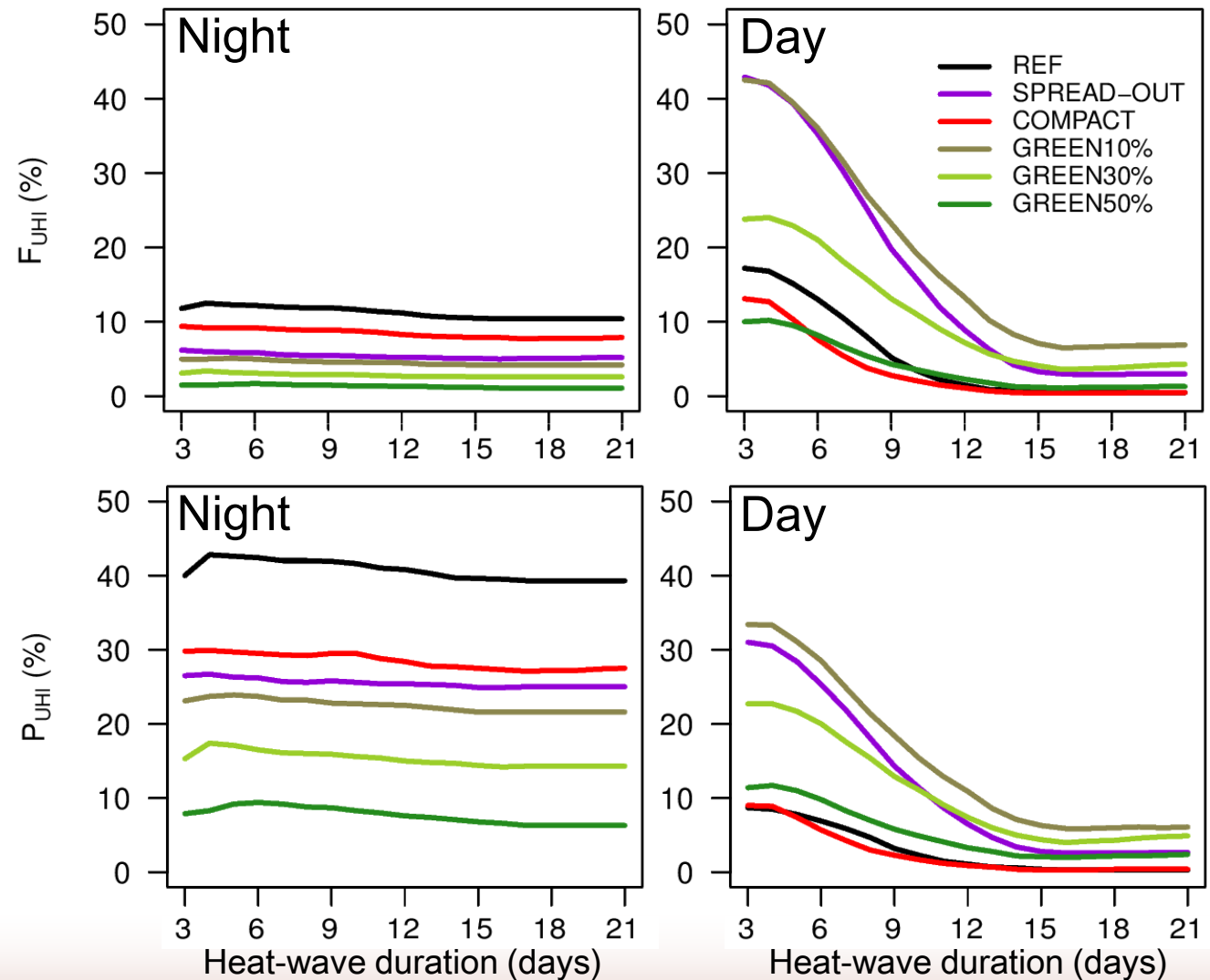
Sensitivity of city and population to UHI

**Fraction of
city affected**
3-21 days heat wave
 $T_{max} = 38^{\circ}\text{C}$



**Fraction of
population affected**
3-21 days heat wave
 $T_{max} = 38^{\circ}\text{C}$

UHI threshold = 1.5K



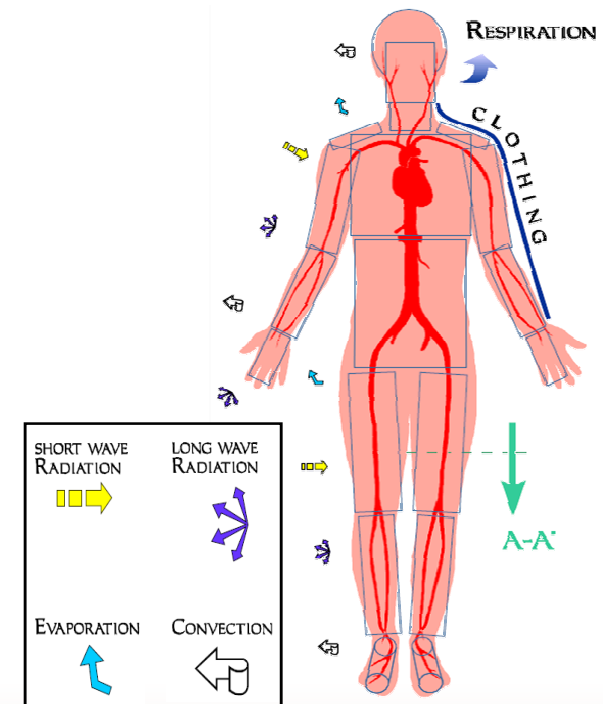
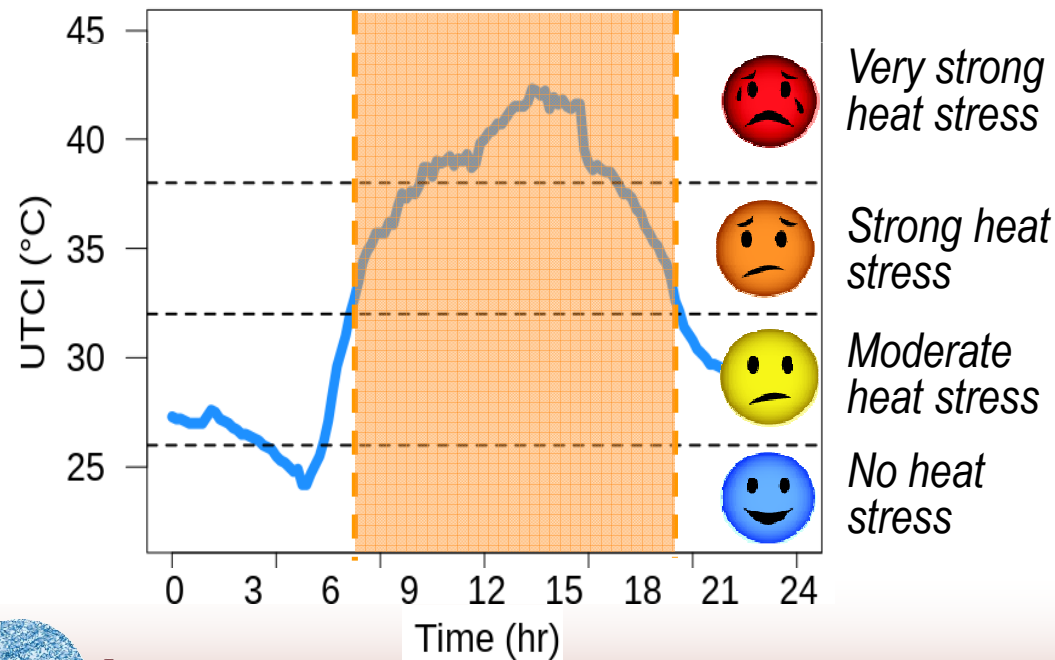
Vulnerability indicators

- UHI
- Heat stress

➤ Sensitivity to urban heat island

➤ Outdoor thermal comfort for population

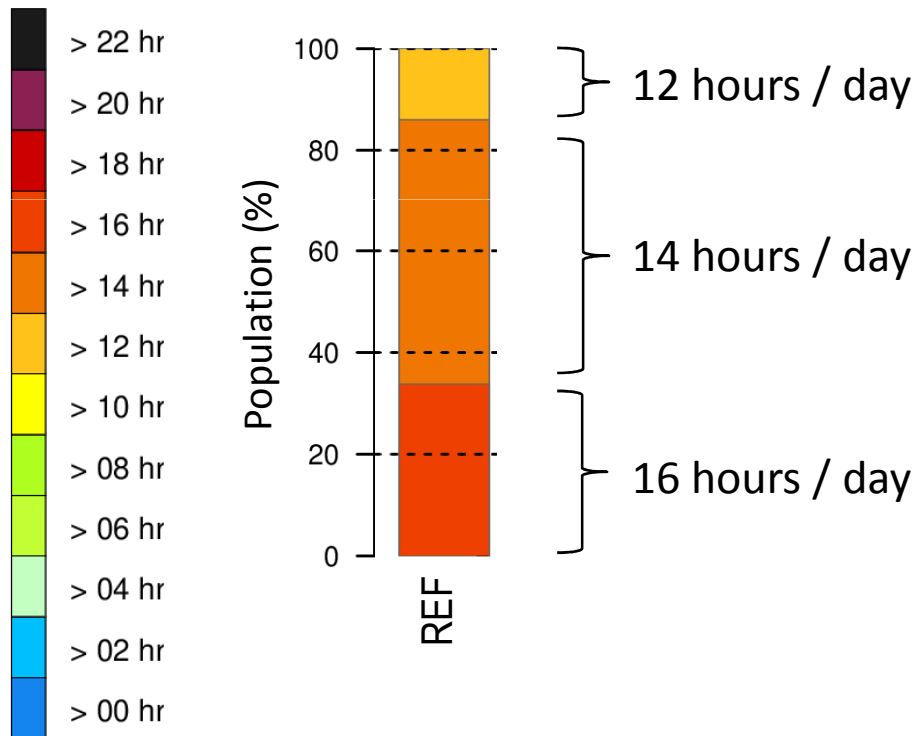
- Universal thermal climate index (UTCI)
- Heat stress levels



Outdoor heat-stress conditions

Number of hours per day spent in strong heat stress ($UTCI > 32^{\circ}\text{C}$)

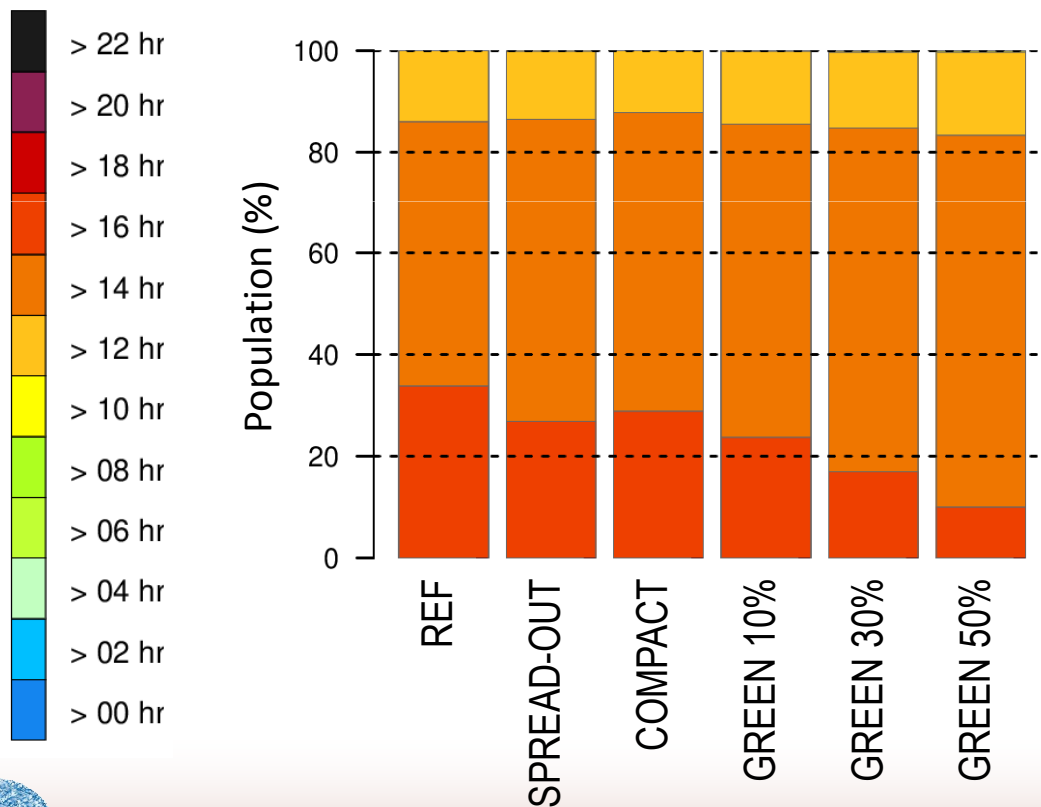
- Computed for all modeled heat waves (all intensities/all durations)
- Weighted according to the occurrence probabilities of heat waves



Outdoor heat-stress conditions

Number of hours per day spent in strong heat stress ($UTCI > 32^{\circ}\text{C}$)

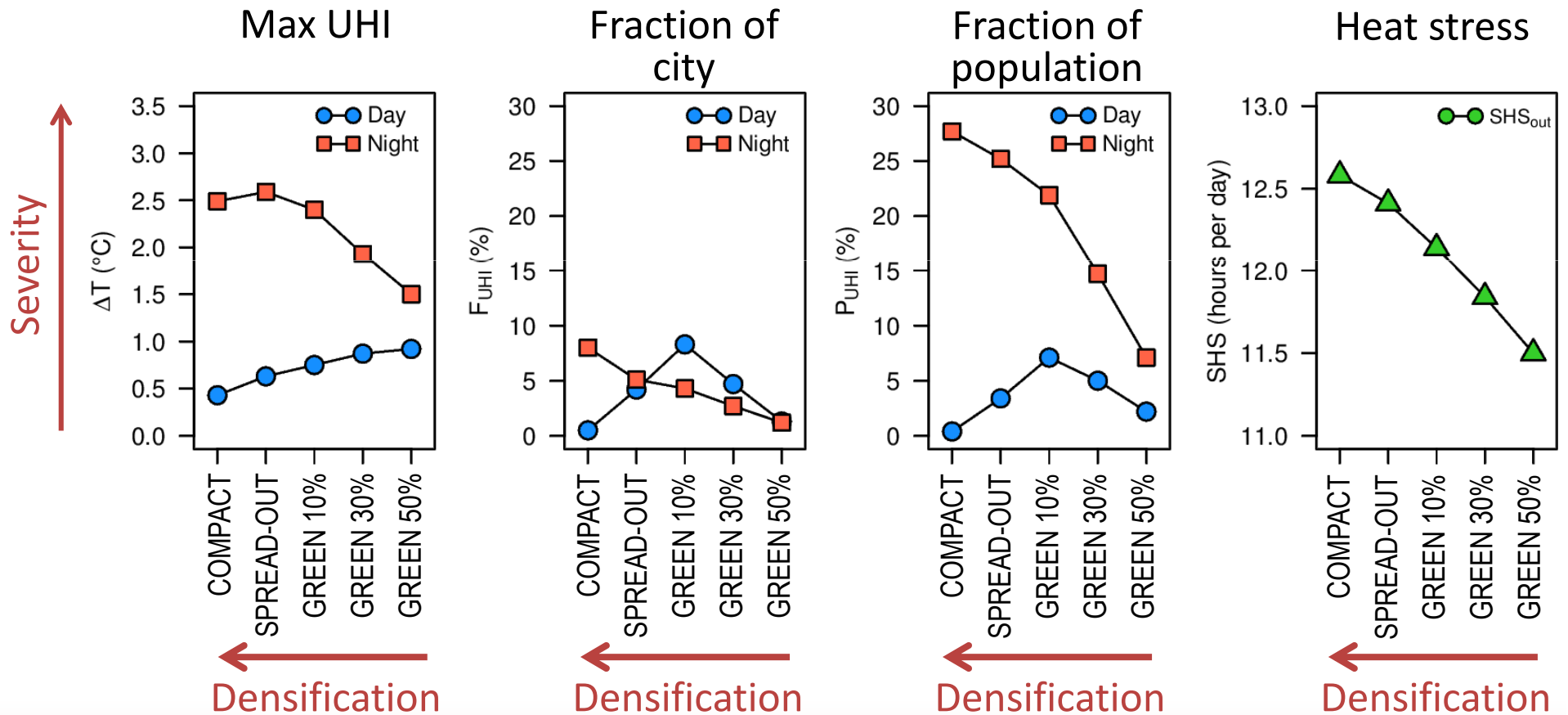
- Computed for all modeled heat waves (all intensities/all durations)
- Weighted according to the occurrence probabilities of heat waves



Heat stress is reduced for less compact and more vegetated cities

Conclusions

➤ Influence of choice of indicators in the evaluation



Conclusions

- Influence of choice of indicators in the evaluation
- Interest of multi-criteria and interdisciplinary evaluation
- Involvement of public stakeholders and urban planners

- Efficiency of spread-out cities compared to compact city in mitigating UHI and heat stress
- ... but increase in CO₂ emissions due to transportation

- Efficiency of greening scenarios
- ... but crucial issue of water consumption and water resource management in urban environment

Thank you for your attention

Contact: aude.lemonsu@meteo.fr

Lemonsu A., Viguié V., Daniel M., Masson V., 2015: Vulnerability to heat waves: impact of urban expansion scenarios on urban heat island and heat stress in Paris (France), Urban climate, in revision