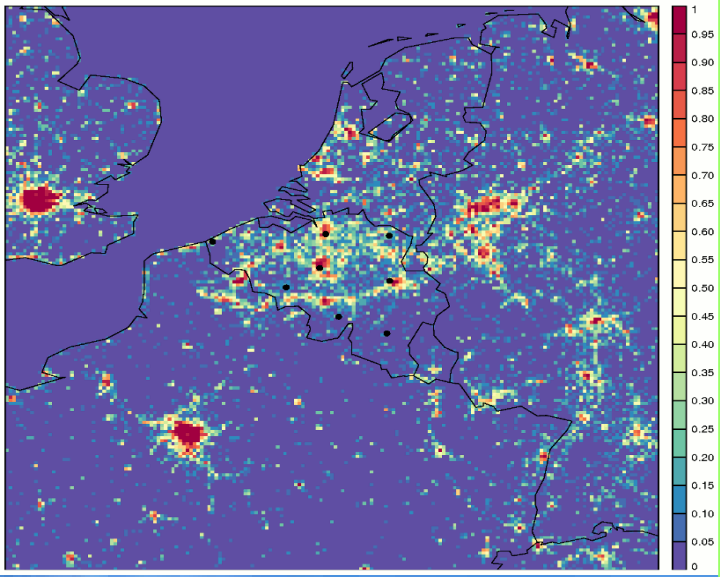
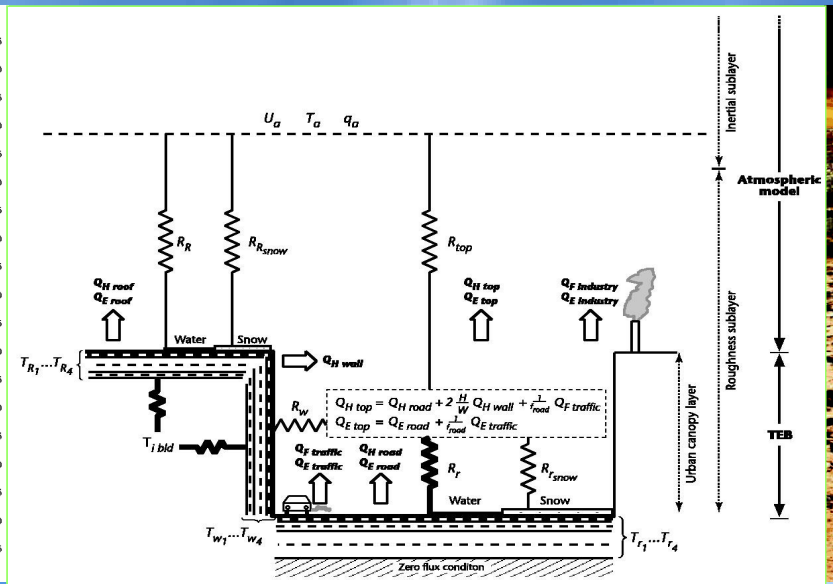
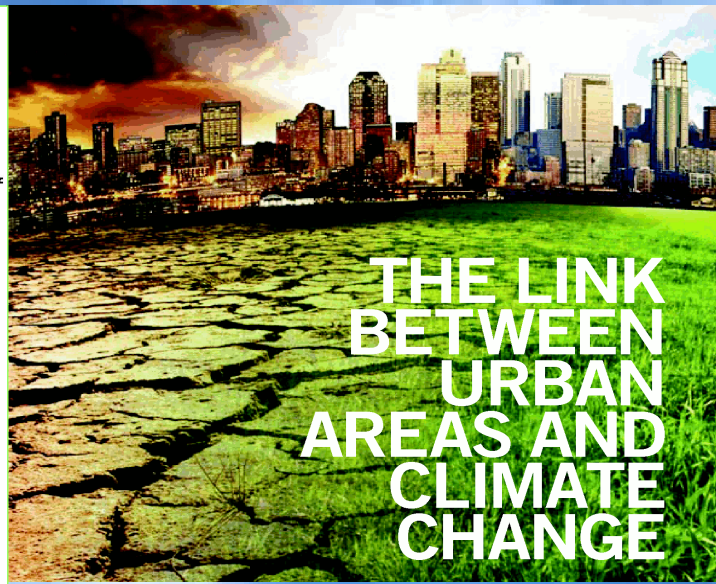
# Assessment of three dynamical urban climate downscaling methods

**Rafiq Hamdi**

Royal Meteorological Institute, Brussels, Belgium.





# ACCEPTED

## Assessment of Changing Conditions, Environmental Policies, Time-activities, Exposure and Disease.

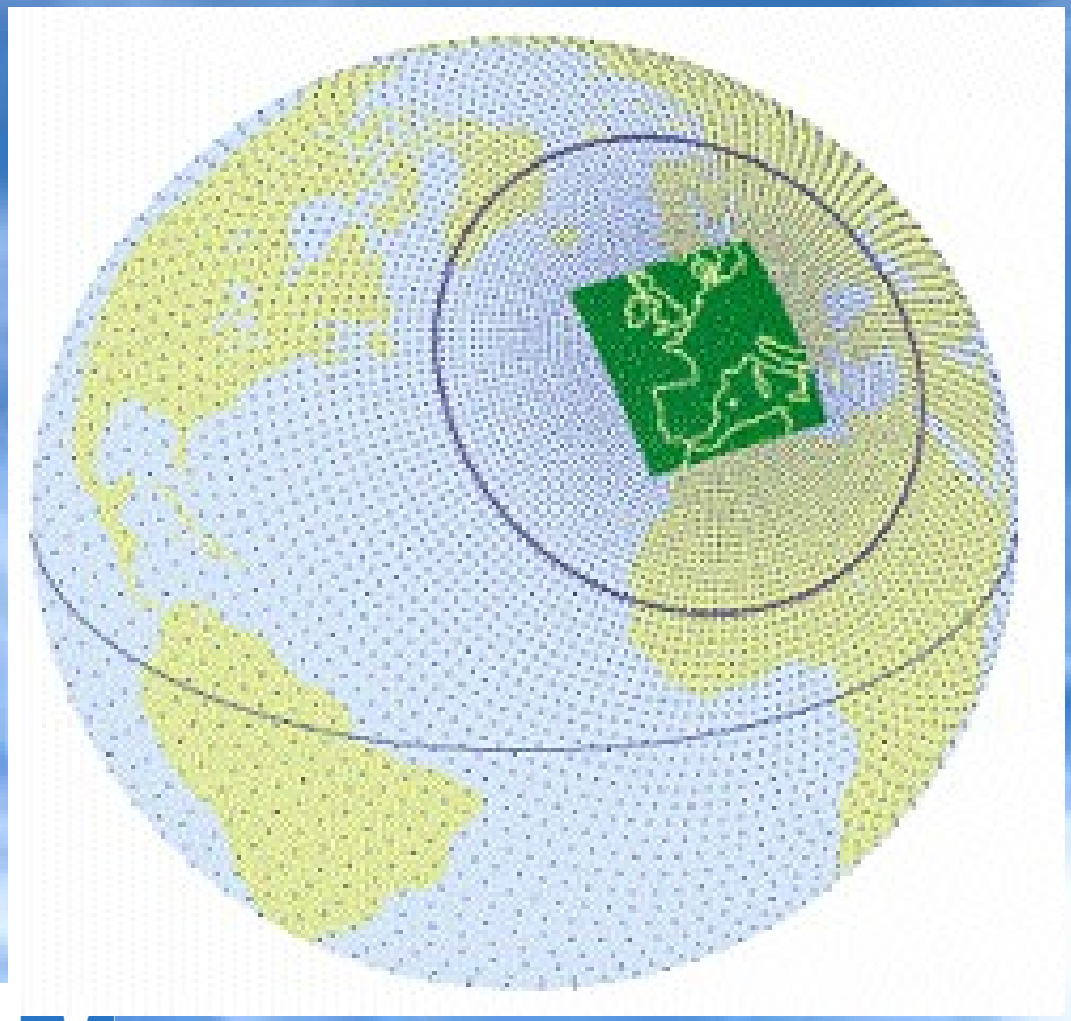
ACCEPTED is a research program that aims to improve our understanding of future exposure situations in cities and their impact on health, from an interdisciplinary approach. This will be achieved by using various state-of-the-art atmospheric models and measurements describing effects on exposure together with epidemiological studies and reviews.

Started in December 2012 and finished in 2015. ACCEPTED involves 11 different partners and is funded by the European network ERA-ENVHEALTH.

# RMI task in WP1

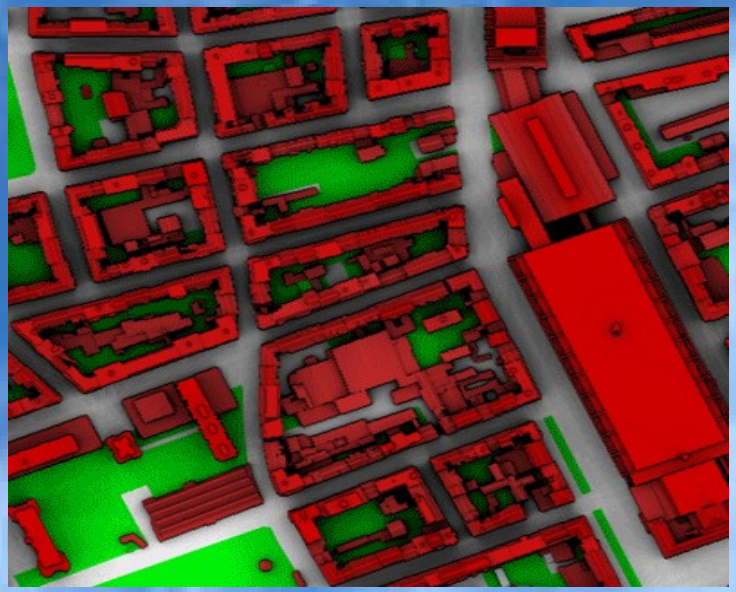
## Interaction between global climate change and the urban environment

~ 200 km



?

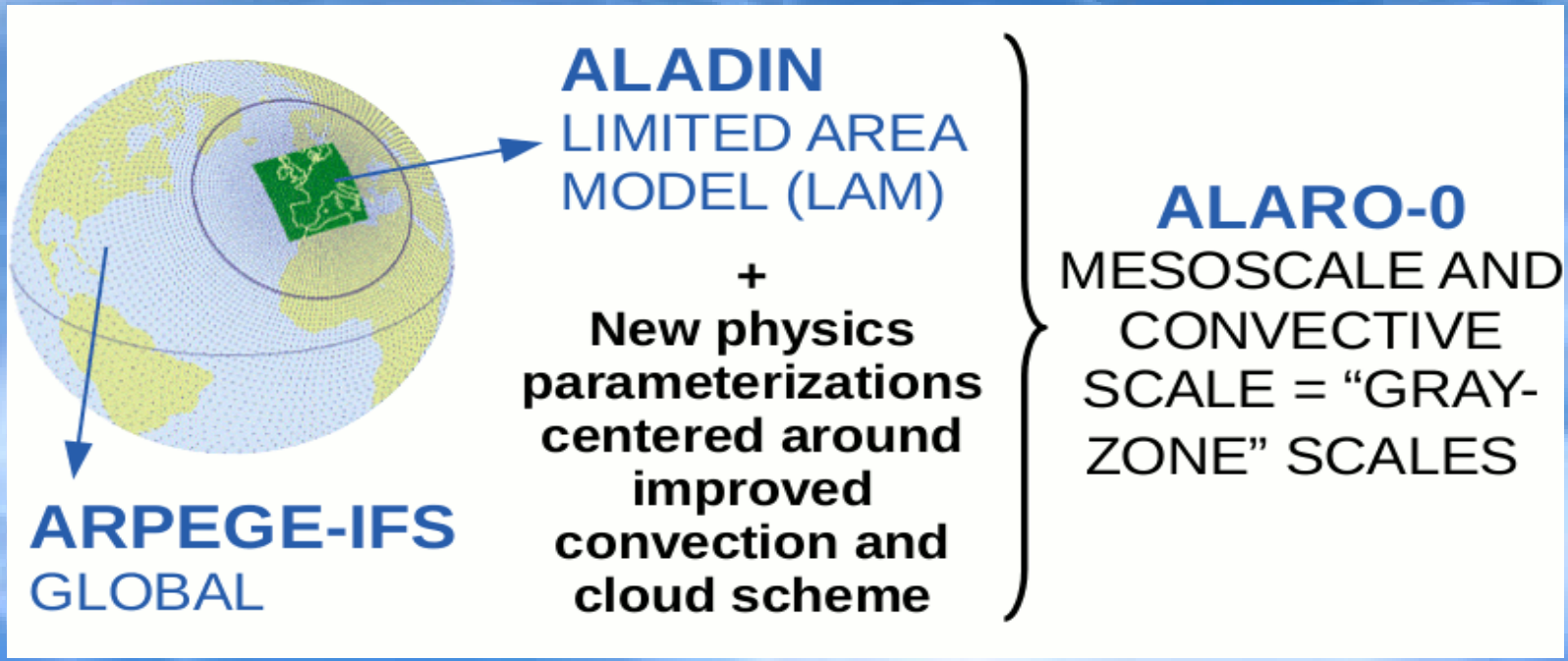
< 1 km



**At the RMI, ALARO-0, is a version of the ARPEGE-ALADIN operational LAM with a revised and modular structure of the physical parametrizations (Gerard et al. 2009).**

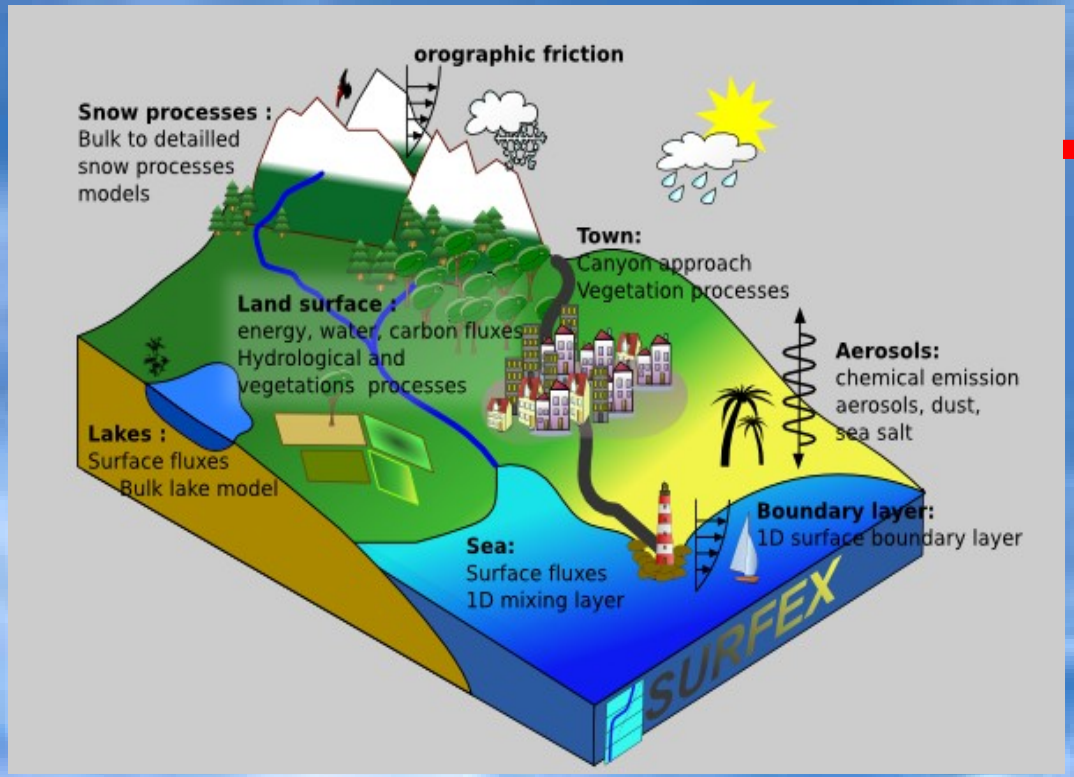
**A specific approach is adopted, with an integrated sequential treatment of resolved condensation, deep convection, and microphysics together with the use of prognostic variables. This new version allows for the production of consistent and realistic results at resolutions ranging from 10 km down to less than 4 km.**

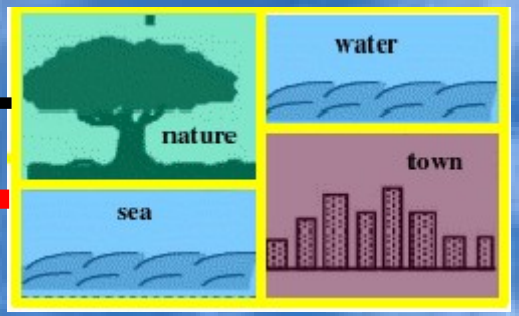
**A version at ~4km resolution has been in use operationally since 2009.**



## Tiling

One important feature of the externalized surface: each grid cell is divided into 4 elementary units called tiles according to the fraction of covers in the grid cell




1: bare ground
2: rocks
3: permanent snow
4: deciduous forest
5: conifer forest
6: evergreen broadleaf trees
7: C3 crops
8: C4 crops
9: irrigated crops
10: grassland
11: tropical grassland
12: garden and parks

**ECOCLIMAP database**

Masson et al., 2013, GMD
Faroux et al., 2013, GMD

Surfex coupled to alaro each time step

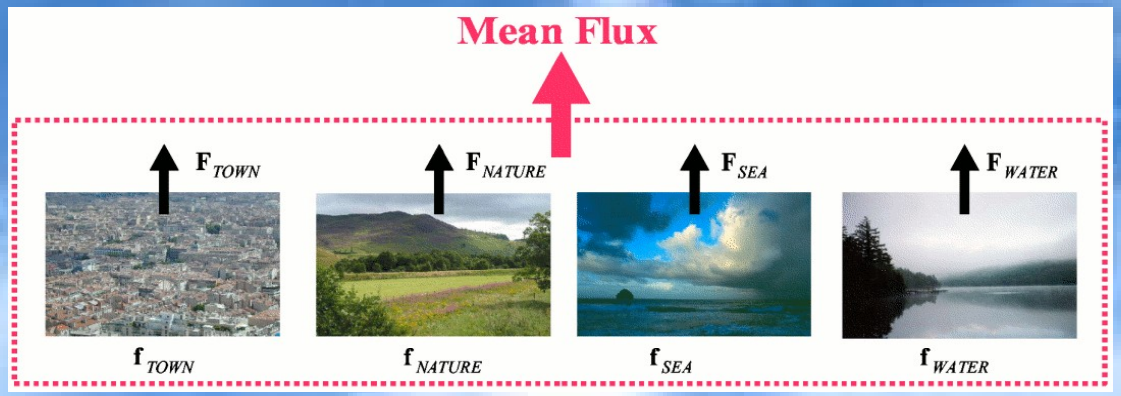
## INLINE MODE

**Surfex output as surface boundary conditions for atmospheric radiation and turbulent scheme.**

albedo
emissivity
radiative temperature
momentum flux
sensible heat flux
latent heat flux
$CO_2$ flux
chemical flux

**ALARO model**

Atmospheric forcing
Sun position
Downward radiative flux

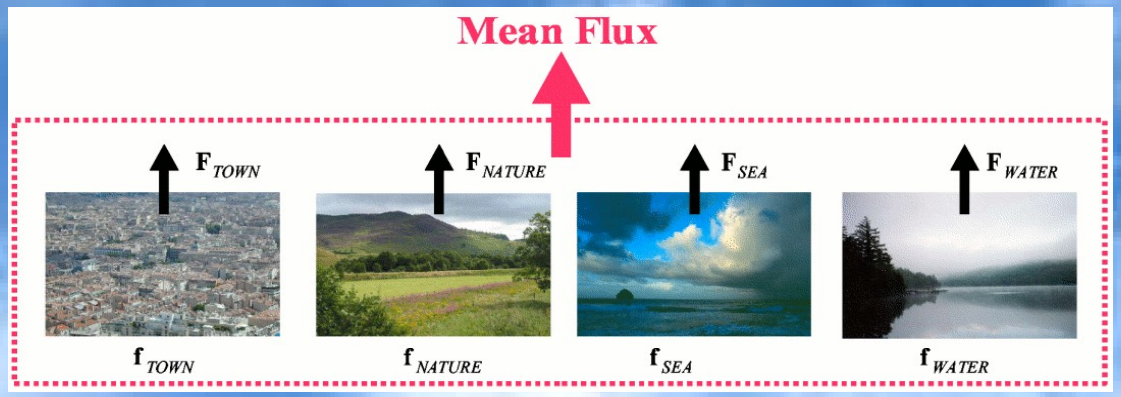



Hamdi et al., 2014, GMD

# OFFLINE MODE

albedo
emissivity
radiative temperature
momentum flux
sensible heat flux
latent heat flux
$CO_2$ flux
chemical flux

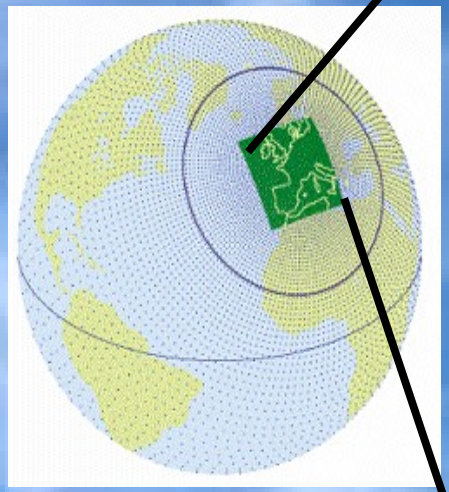
Atmospheric forcing
Sun position
Downward radiative flux



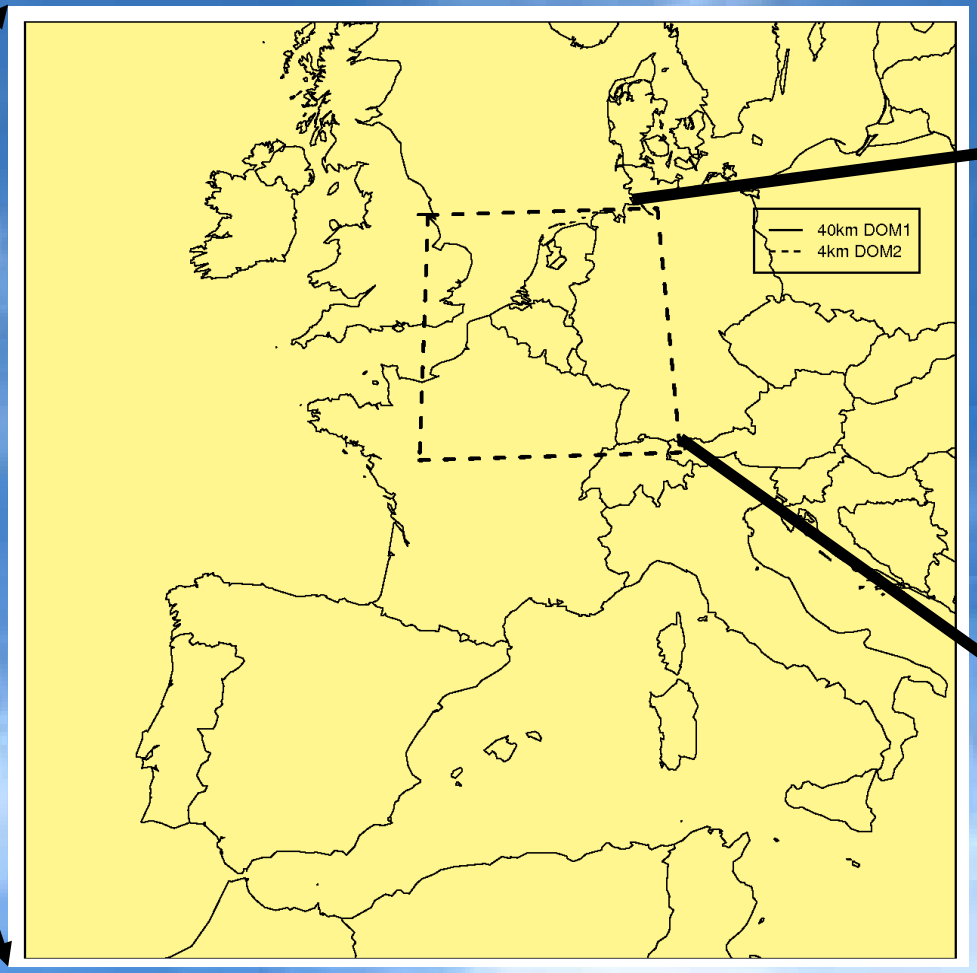

Hamdi et al., 2009, JAMC
Hamdi et al., 2012, IJC

# Regional climate simulations using ALARO+SURFEX+TEB

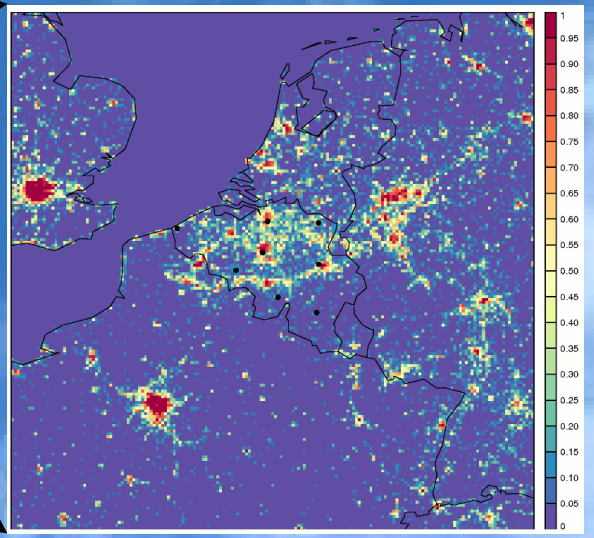
## GLOBAL



## 20 km

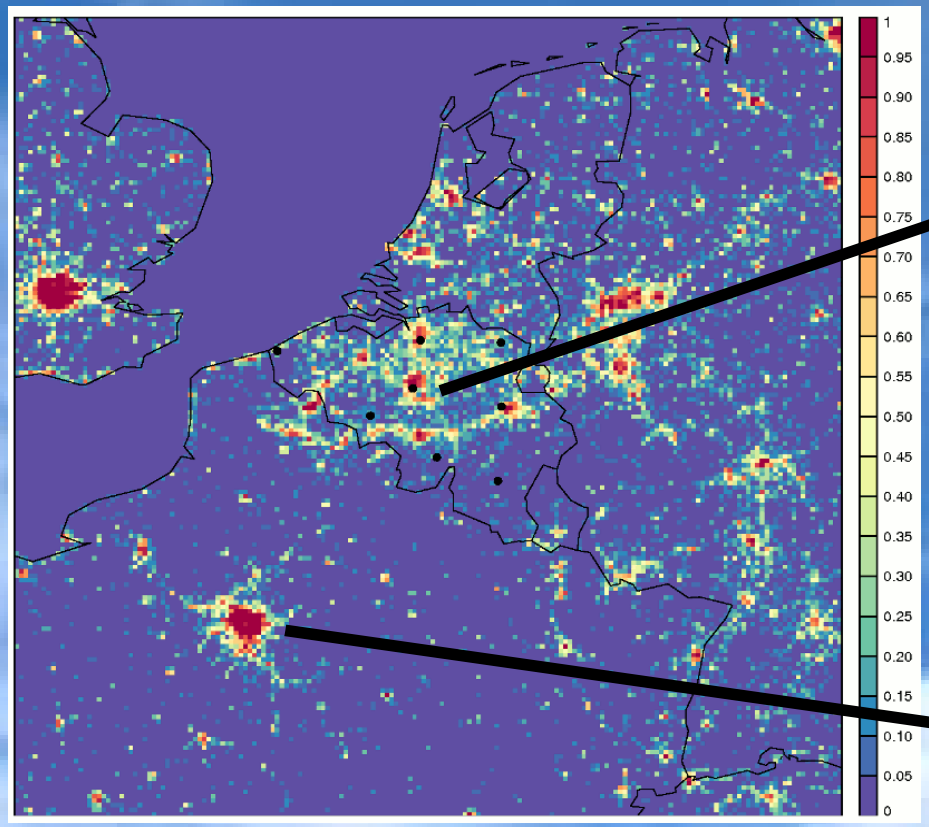



## 4km

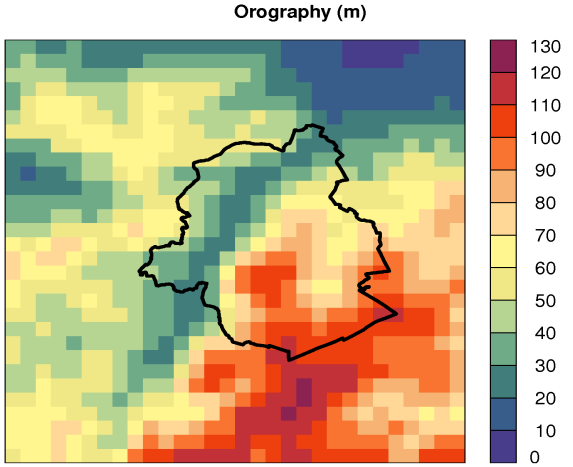


# Urban climate simulations using SURFEX+TEB+SBL

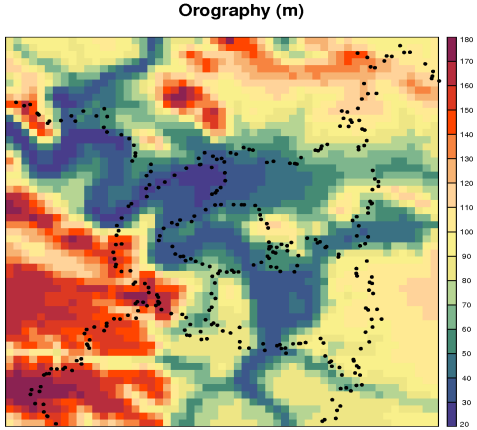
## ALARO+SURFEX INLINE 4km




## SURFEX OFFLINE 1 km, Brussels, 30x30

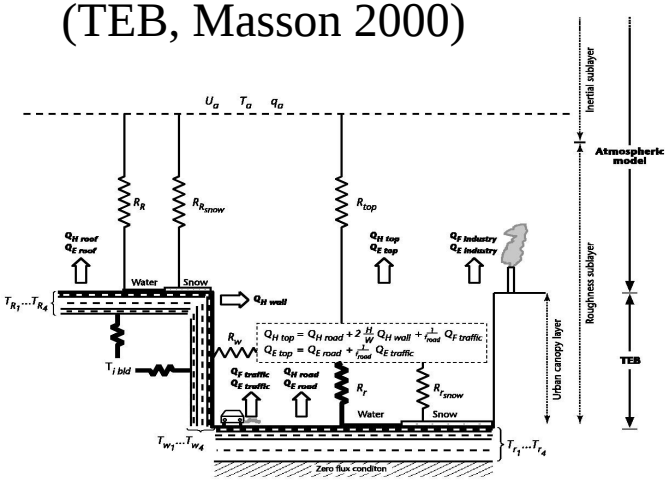



## SURFEX OFFLINE 1 km, Paris, 55x55

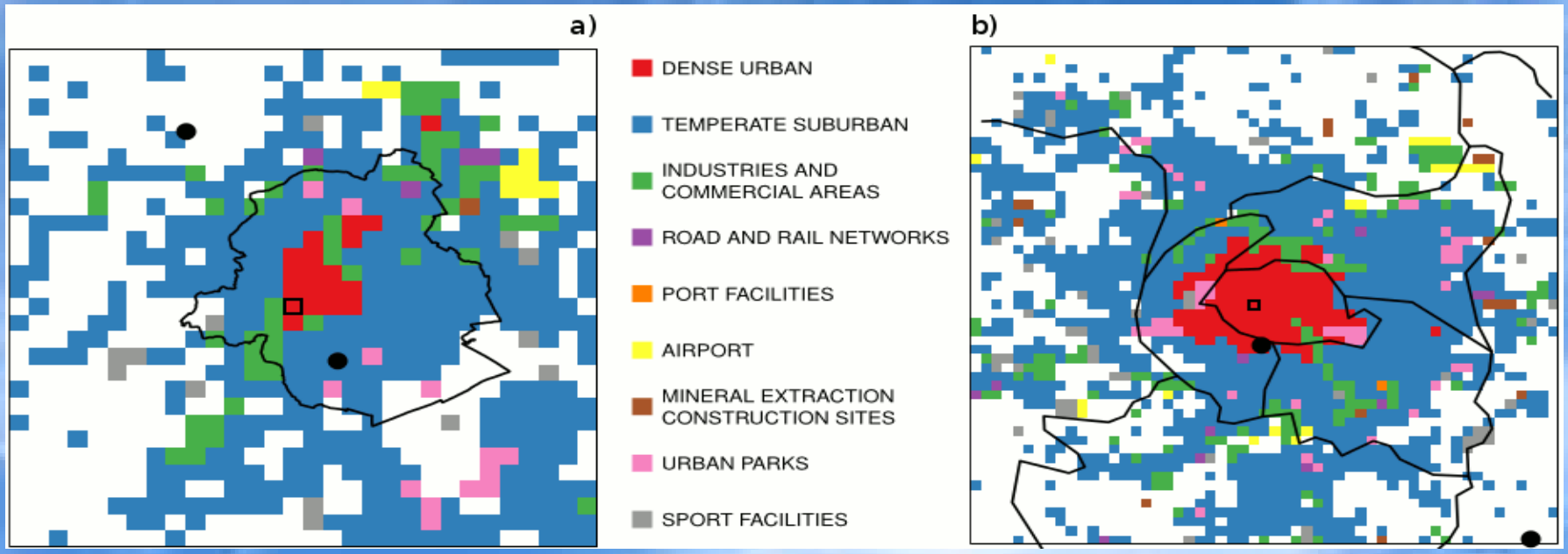


# Town Energy balance

(TEB, Masson 2000)




# Rocks



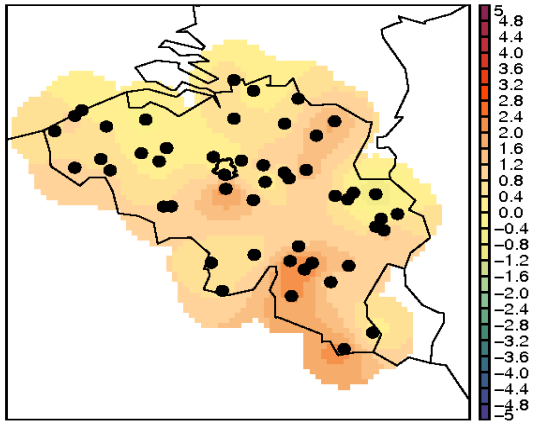
Two simulations are done with and without TEB where the city is considered just as rock.

This is to mimic what is done in the state-of-the-art regional climate model.

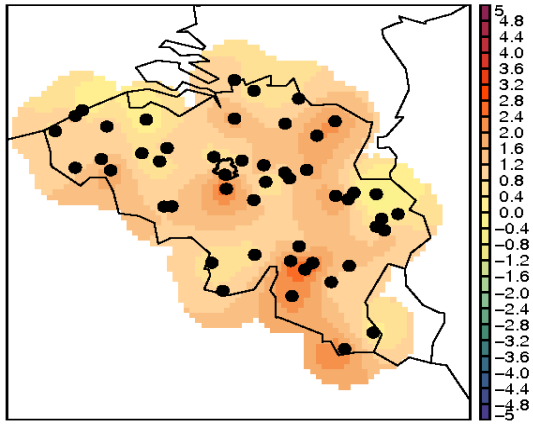
Table 1: Description of the numerical experiments.

| | | Regional Climate simulation | | Urban climate simulation | |
|---|---|---|---|---|---|
| | | Rock | TEB | Rock | TEB |
| ERA-40 | **1961-1990** | | | | |
| | ERA_RF | yes | | yes | |
| | ERA_OF | yes | | | yes |
| | ERA_IN | | yes | | yes |
| ARP | **1961-1990** | | | | |
| | ARP_RF | yes | | yes | |
| | ARP_OF | yes | | | yes |
| | ARP_IN | | yes | | yes |
| A1B | **2071-2100** | | | | |
| | A1B_RF | yes | | yes | |
| | A1B_OF | yes | | | yes |
| | A1B_IN | | yes | | yes |

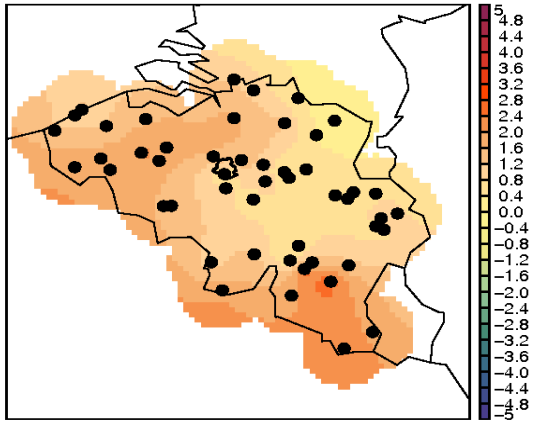
ERA_RF, T_MIN, 50 stations mean bias= 0.77 °C



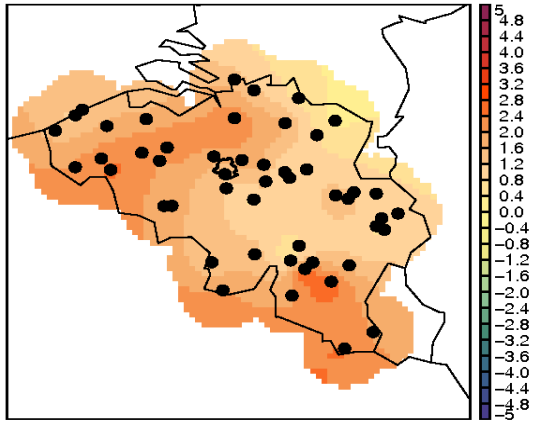

ERA_IN, T_MIN, 50 stations mean bias= 1.15 °C



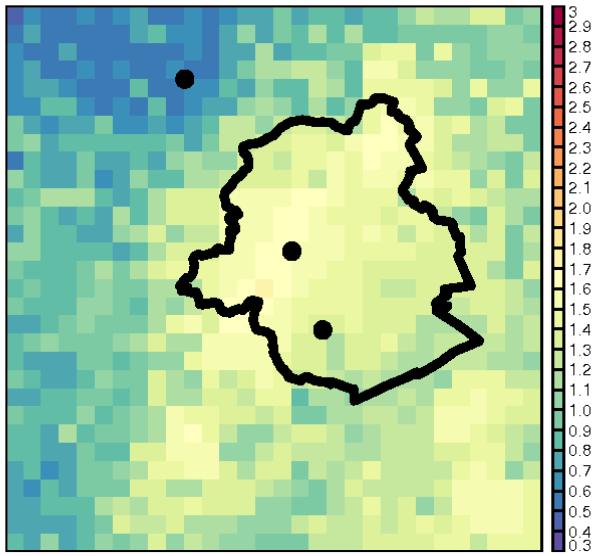

ERA_RF, T_MAX, 50 stations mean bias= 1.2 °C



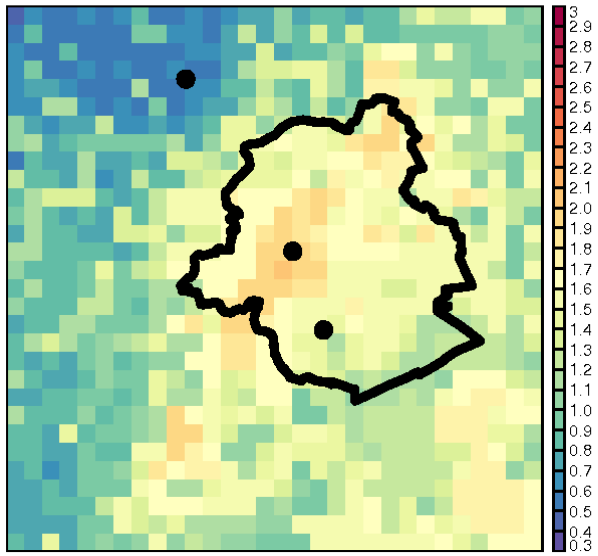

ERA_IN, T_MAX, 50 stations mean bias= 1.48 °C



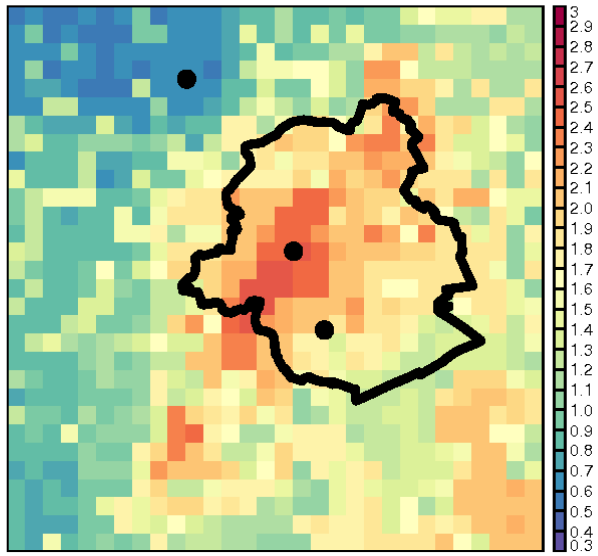
ARP_RF, UHI[T_MIN] = 1.71 °C



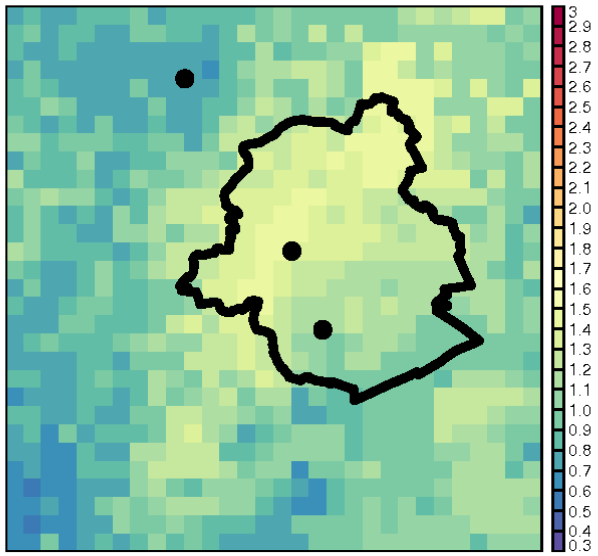
ARP_OF, UHI[T_MIN] = 1.97 °C



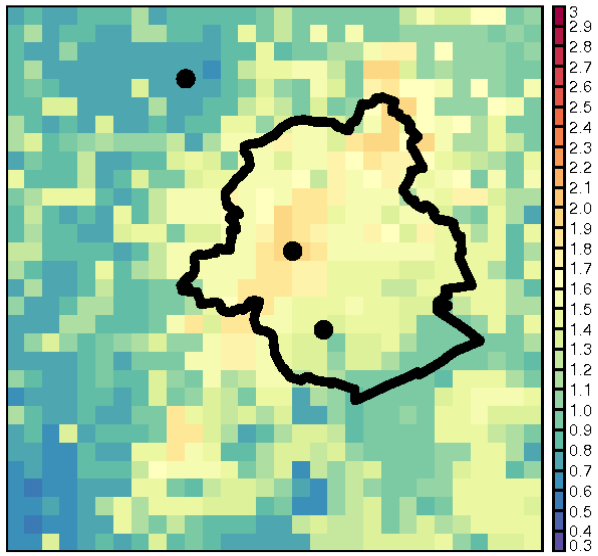
ARP_IN, UHI[T_MIN] = 2.56 °C



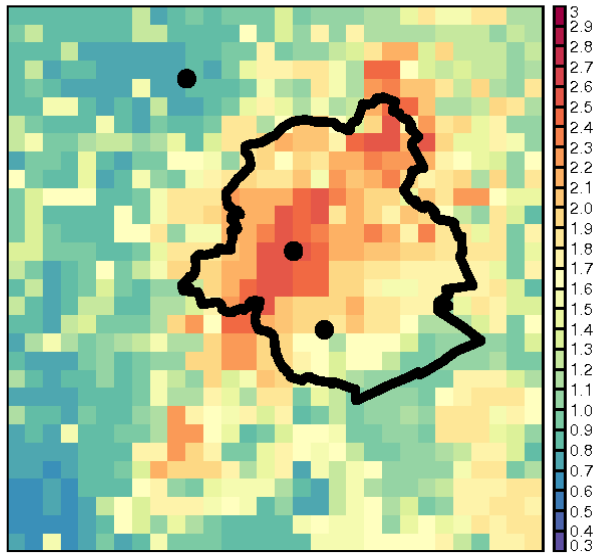
ERA_RF, UHI[T_MIN] = 1.46 °C



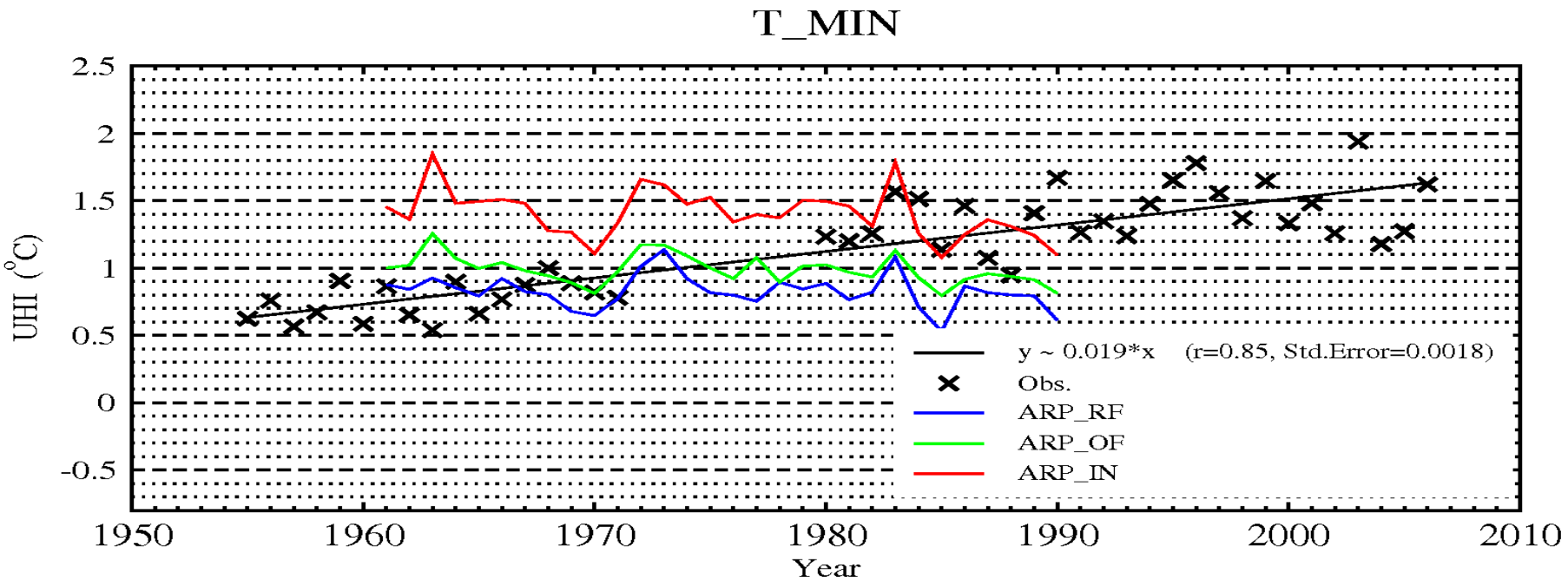
ERA_OF, UHI[T_MIN] = 1.86 °C

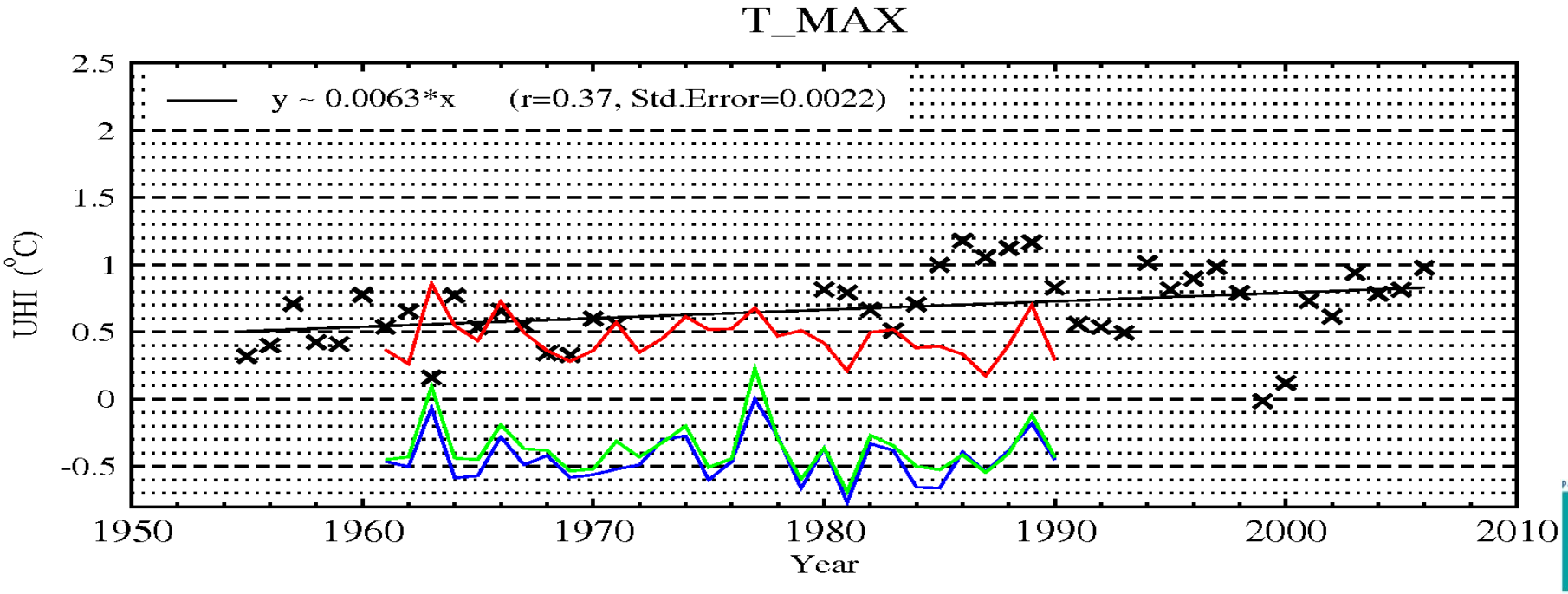


ERA_IN, UHI[T_MIN] = 2.54 °C



Hamdi et al., 2014, IJC

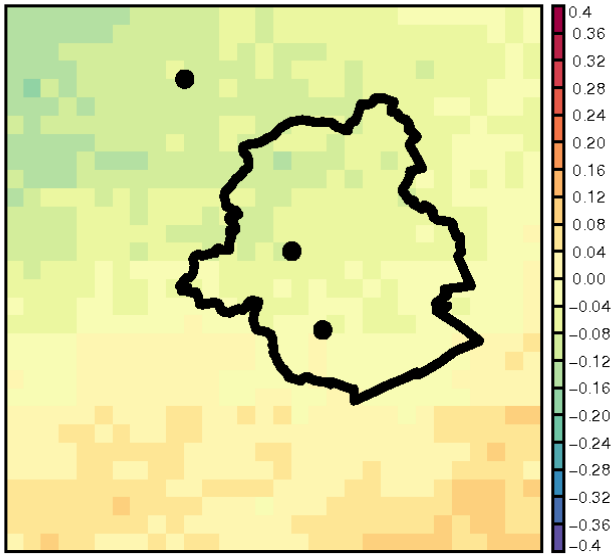

T_MIN
UHI (°C)
2.5
2
1.5
1
0.5
0
-0.5
1950
1960
1970
1980
1990
2000
2010
Year
y ~ 0.019*x (r=0.85, Std.Error=0.0018)
Obs.
ARP_RF
ARP_OF
ARP_IN


T_MAX
UHI (°C)
2.5
2
1.5
1
0.5
0
-0.5
1950
1960
1970
1980
1990
2000
2010
Year
y ~ 0.0063*x (r=0.37, Std.Error=0.0022)

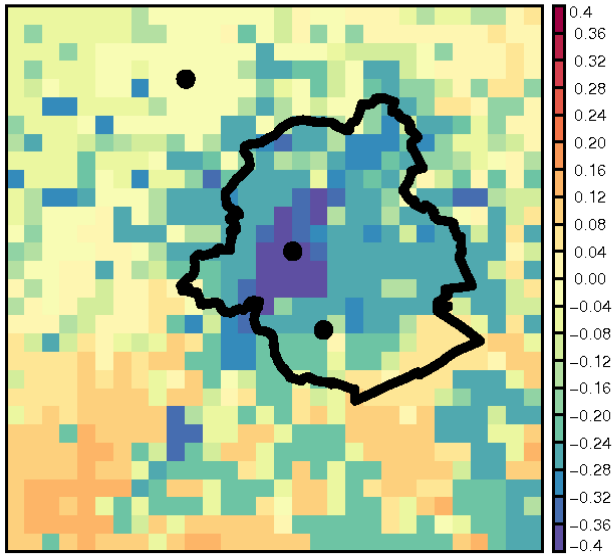
## Future warming at the end of century

| | | T_MIN | | | T_MAX | | |
|---|---|---|---|---|---|---|---|
| | | 1961-1990 | 2071-2100 | Δ | 1961-1990 | 2071-2100 | Δ |
| Reference | City center | 14.08 | 16.26 | 2.18 | 23.62 | 26.41 | 2.79 |
| | Suburban (Uccle) | 13.76 | 15.98 | 2.22 | 23.32 | 26.21 | 2.89 |
| | Rural (Brussegem) | 13.01 | 15.19 | 2.18 | 23.83 | 26.60 | 2.77 |
| Offline | City center | 14.36 | 16.21 | 1.85 | 23.62 | 26.30 | 2.68 |
| | Suburban (Uccle) | 13.94 | 15.90 | 1.96 | 23.40 | 26.19 | 2.79 |
| | Rural (Brussegem) | 13.01 | 15.19 | 2.18 | 23.83 | 26.60 | 2.77 |
| Inline | City center | 15.21 | 17.21 | 2.00 | 24.63 | 27.27 | 2.64 |
| | Suburban (Uccle) | 14.65 | 16.71 | 2.06 | 24.59 | 27.32 | 2.73 |
| | Rural (Brussegem) | 13.32 | 15.48 | 2.16 | 24.18 | 26.89 | 2.71 |

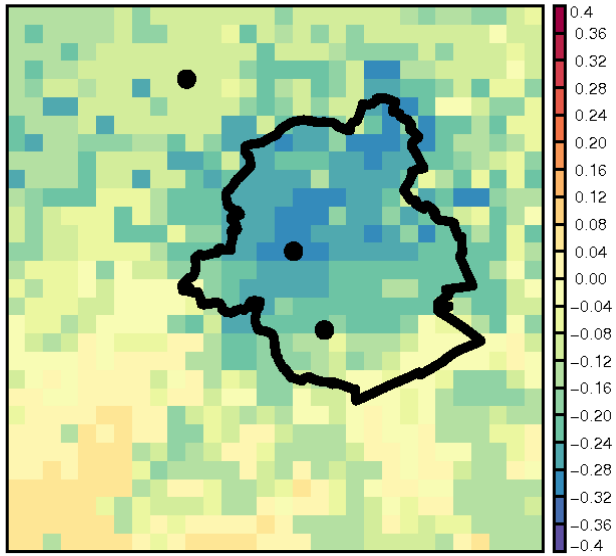
A1B_RF–ARP_RF, D–UHI[T_MIN] = –0.07 °C



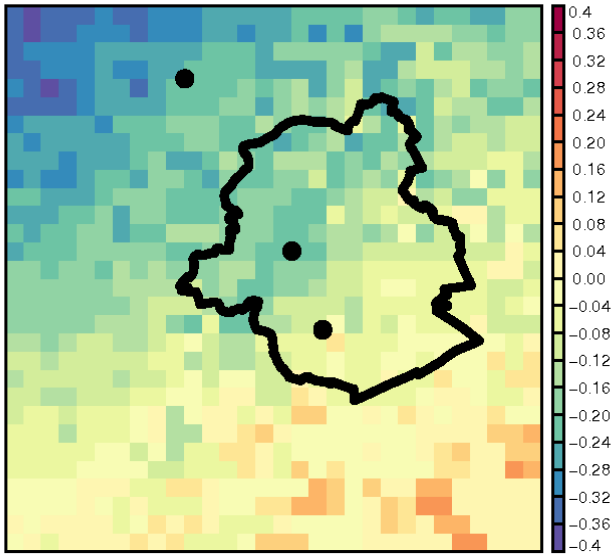

A1B_OF–ARP_OF, D–UHI[T_MIN] = –0.36 °C



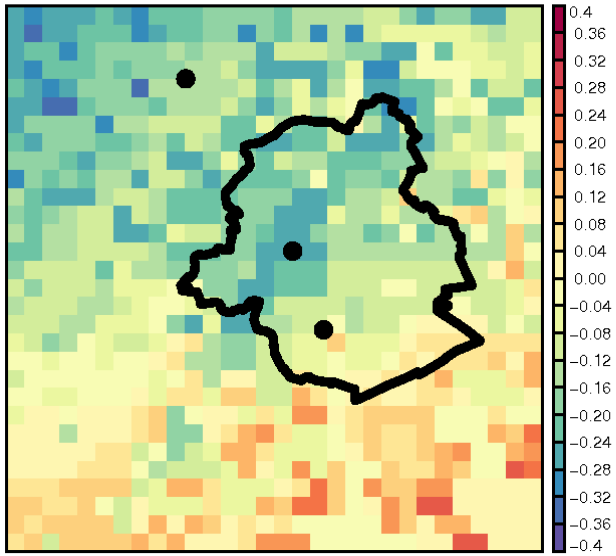

A1B_IN–ARP_IN, D–UHI[T_MIN] = –0.26 °C



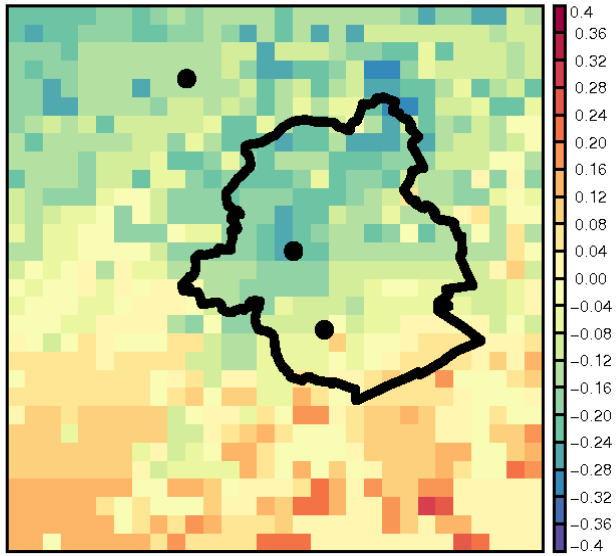

A1B_RF–ARP_RF, D–UHI[T_MAX] = –0.21 °C

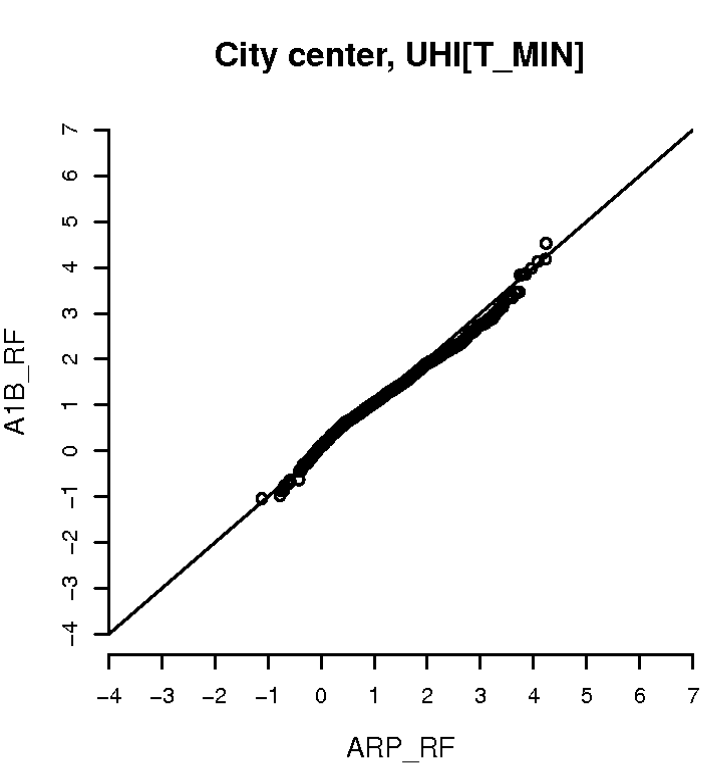


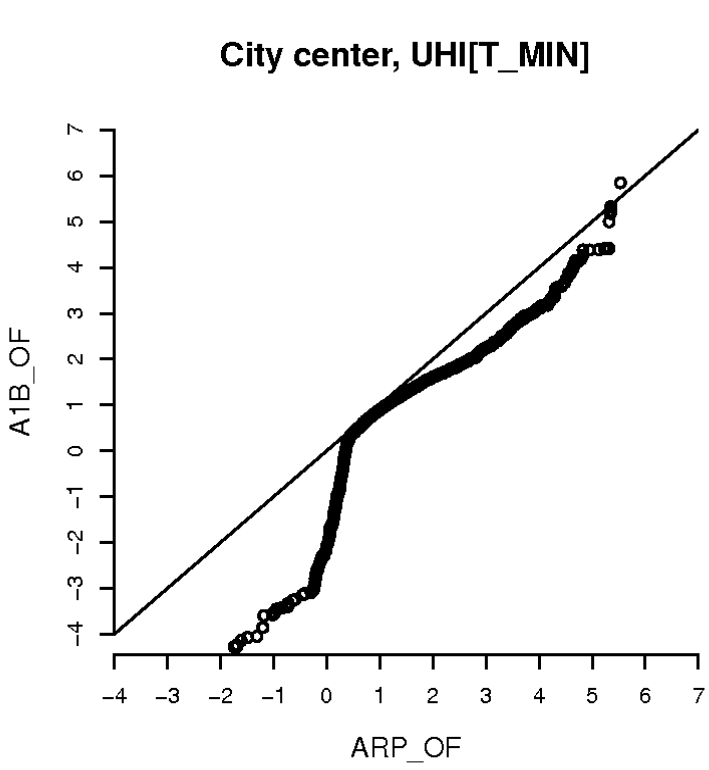

A1B_OF–ARP_OF, D–UHI[T_MAX] = –0.24 °C

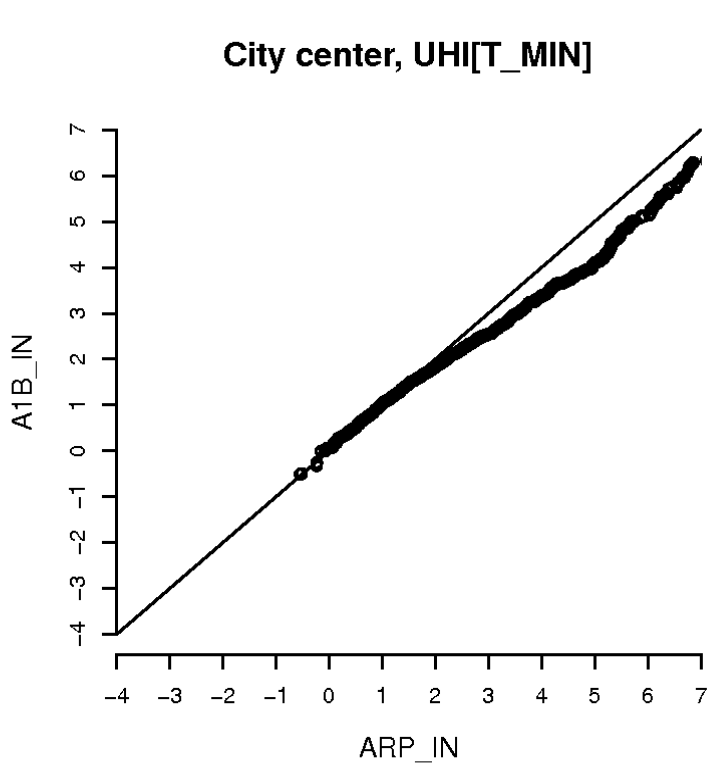


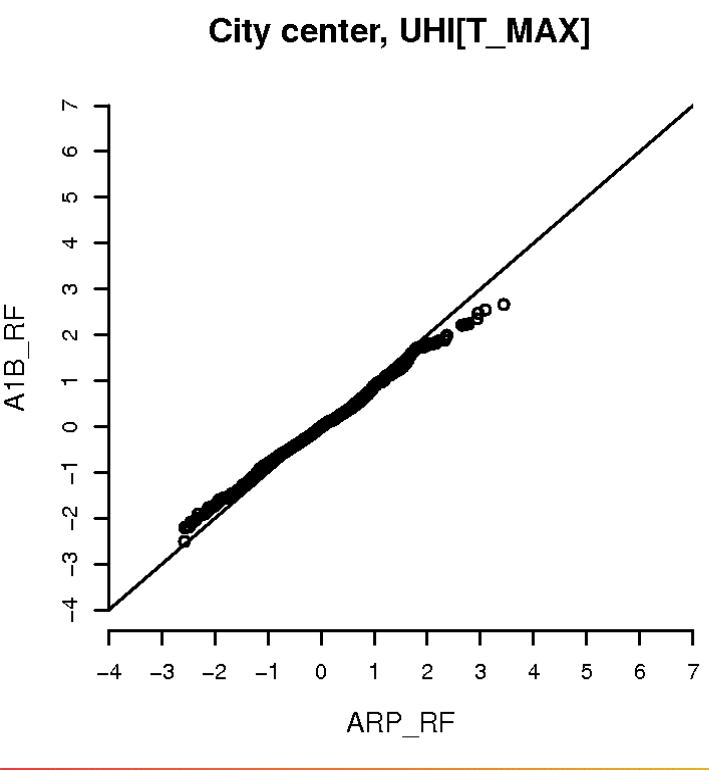

A1B_IN–ARP_IN, D–UHI[T_MAX] = –0.2 °C

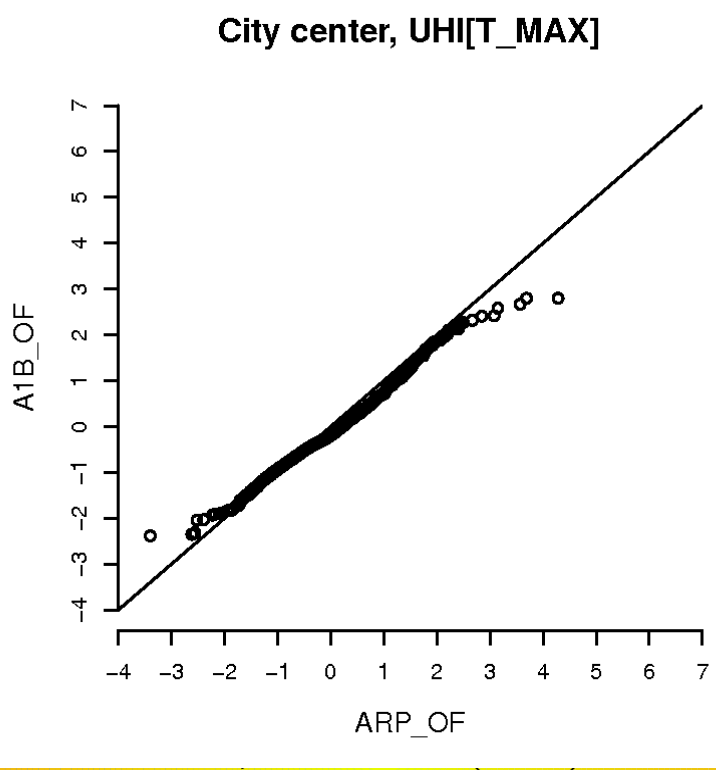


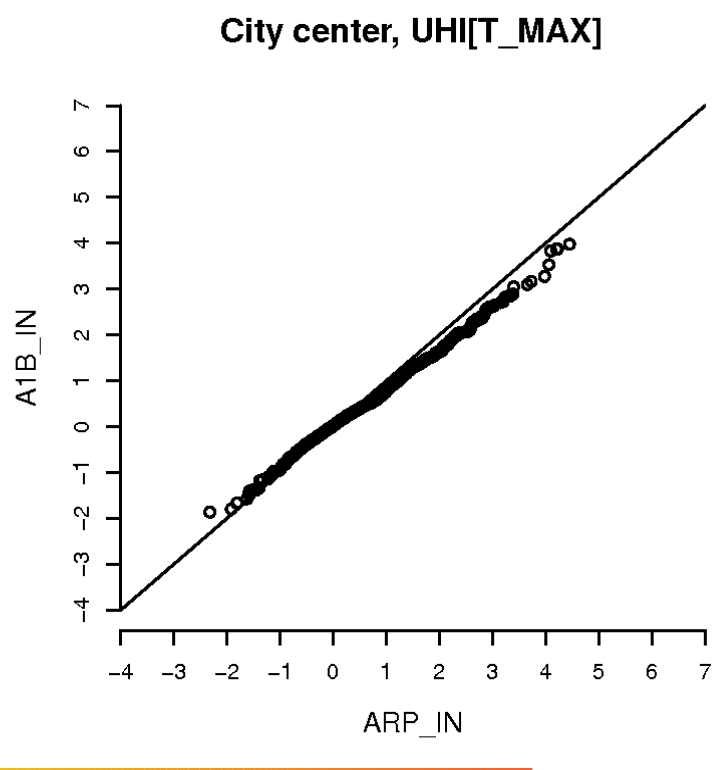

City center, UHI[T_MIN]
A1B_RF
ARP_RF


City center, UHI[T_MIN]
A1B_OF
ARP_OF


City center, UHI[T_MIN]
A1B_IN
ARP_IN


City center, UHI[T_MAX]
A1B_RF
ARP_RF


City center, UHI[T_MAX]
A1B_OF
ARP_OF


City center, UHI[T_MAX]
A1B_IN
ARP_IN

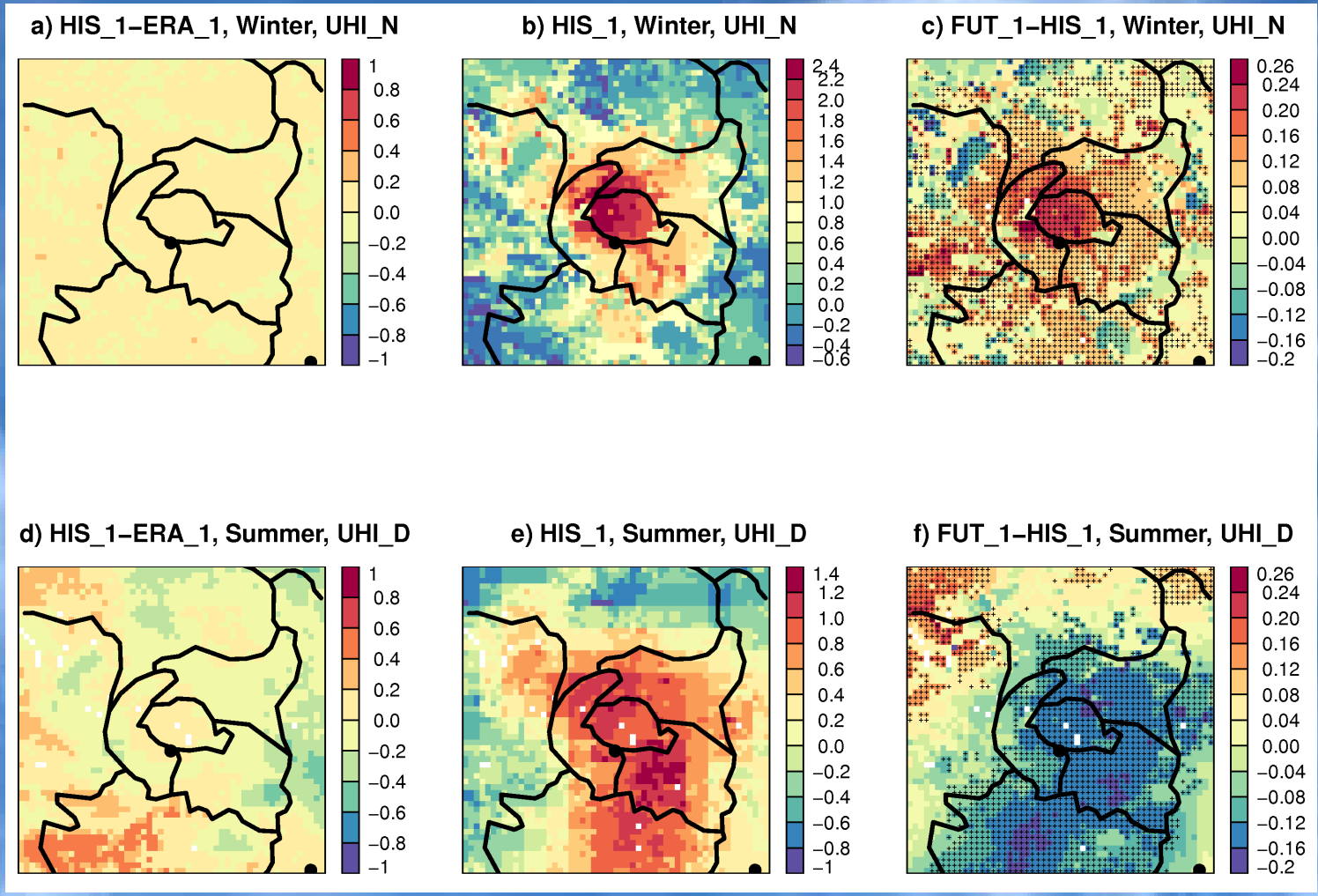
1. The responses of urban and rural areas to climate change are NOT THE SAME.

2. The feedback between urban environment and climate change is very important for urban impact studies.

3. Compared to the warming due to climate change (an increase of few degrees), changes in the magnitude of the UHI remain very low (a decrease of of a few tens of degrees in the city center)

4. The decrease of the UHI of Brussels is due to a drying of the soil in the future where the projected summer precipitation for Brussels will decrease by 35%

# Evolution of the UHI of Paris

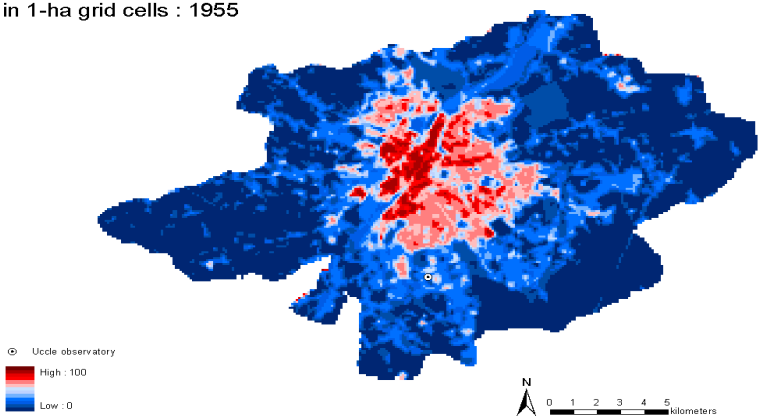



POSTER 3: CCMA - Climate modelling tools, impact studies and adaptation strategies · 21/Jul/2015: 3:00pm-4:00pm

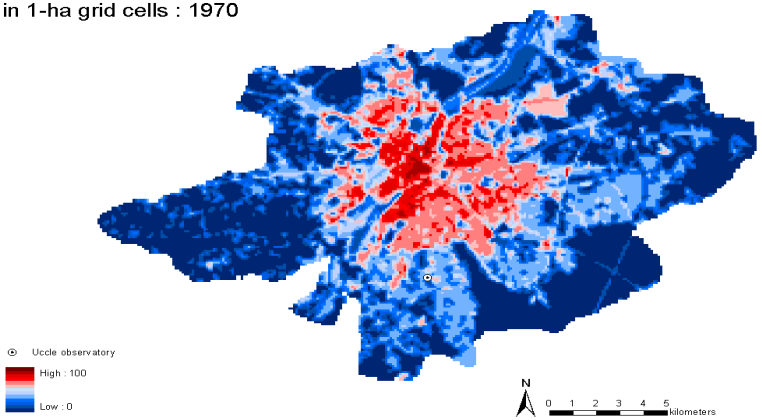
Future climate of Brussels and Paris for the 2050s under the A1B scenario


Thank you for
your attention
Merci pour votre
attention

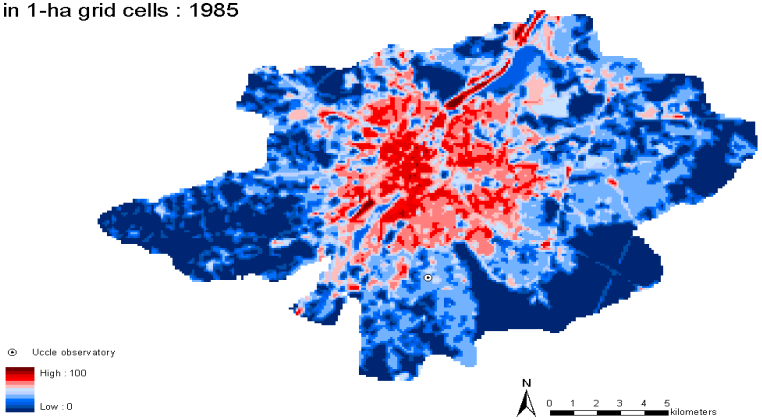
Percentage of impervious surfaces
in 1-ha grid cells : 1955




Percentage of impervious surfaces
in 1-ha grid cells : 1970




Percentage of impervious surfaces
in 1-ha grid cells : 1985




Percentage of impervious surfaces
in 1-ha grid cells : 2006

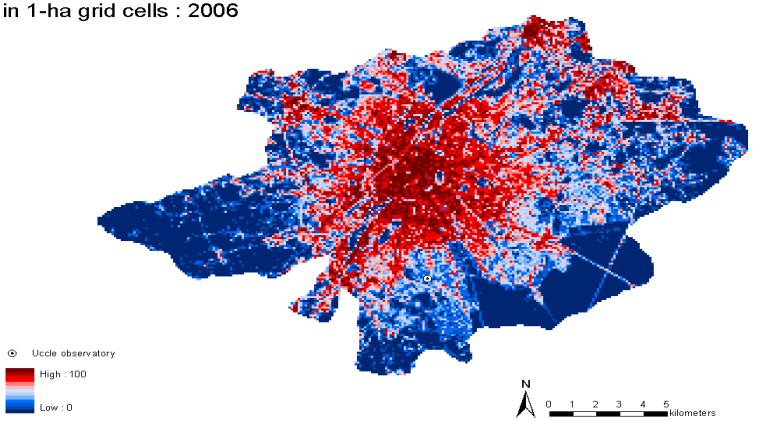
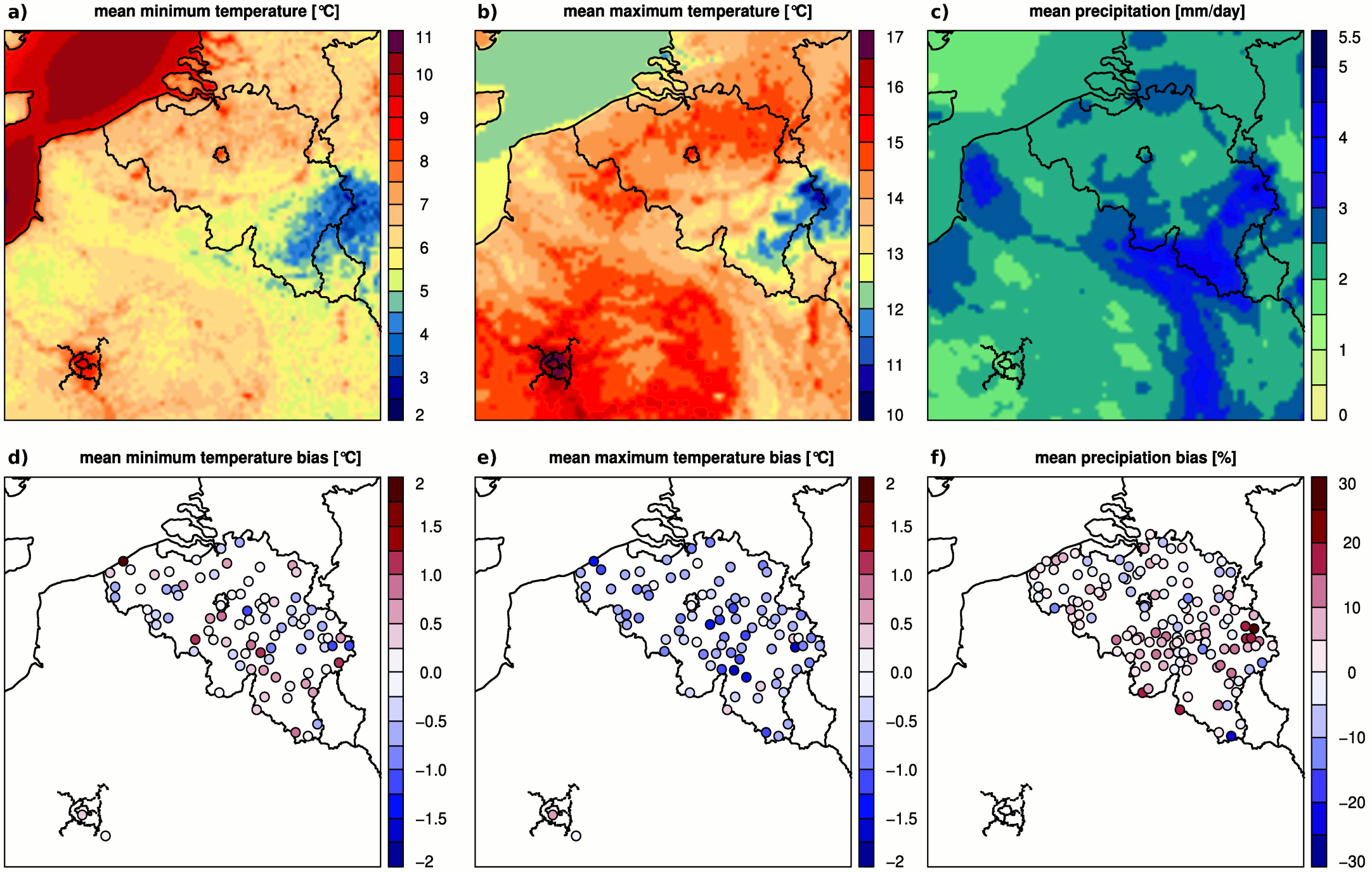
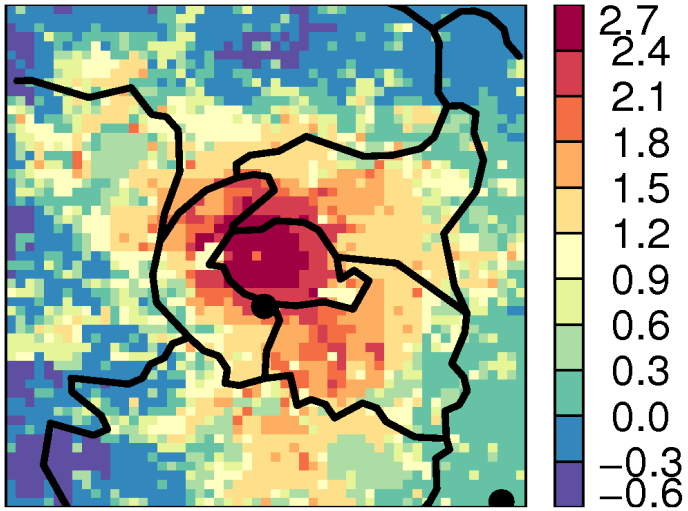


**Table 1**
Description of the numerical experiments.

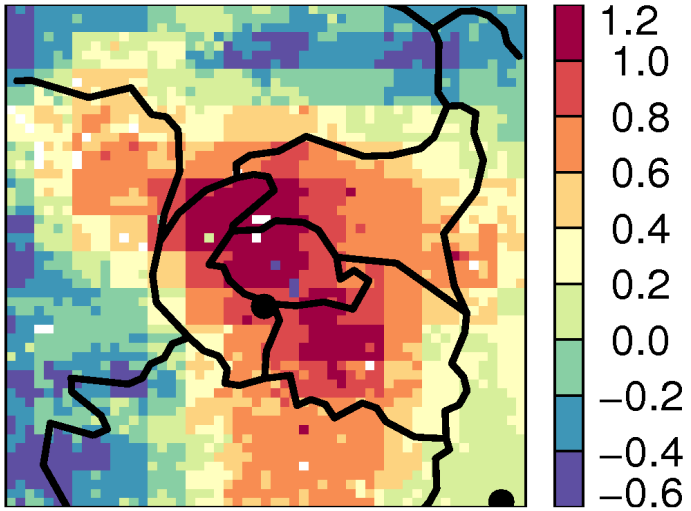
| Acronym in the text | Coupling | Simulation period | Resolution (km) |
|---|---|---|---|
| *Regional climate simulations* | | | |
| ERA_4 | ERA-INTERIM re-analysis | 2001–2010 | 4 |
| HIS_4 | ARPEGE-Climate, hereafter CNRM-CM3 | 1990–1999 | |
| FUT_4 | ARPEGE-Climate, hereafter CNRM-CM3 | 2046–2055 | |
| *Urban climate simulations* | | | |
| ERA_1 | ERA_4 | 2001–2010 | 1 |
| HIS_1 | HIS_4 | 1990–1999 | |
| FUT_1 | FUT_4 | 2046–2055 | |


a)
mean minimum temperature [°C]
11
10
9
8
7
6
5
4
3
2
b)
mean maximum temperature [°C]
17
16
15
14
13
12
11
10
c)
mean precipitation [mm/day]
5.5
5
4
3
2
1
0
d)
mean minimum temperature bias [°C]
2
1.5
1.0
0.5
0.0
−0.5
−1.0
−1.5
−2
e)
mean maximum temperature bias [°C]
2
1.5
1.0
0.5
0.0
−0.5
−1.0
−1.5
−2
f)
mean precipiation bias [%]
30
20
10
0
−10
−20
−30

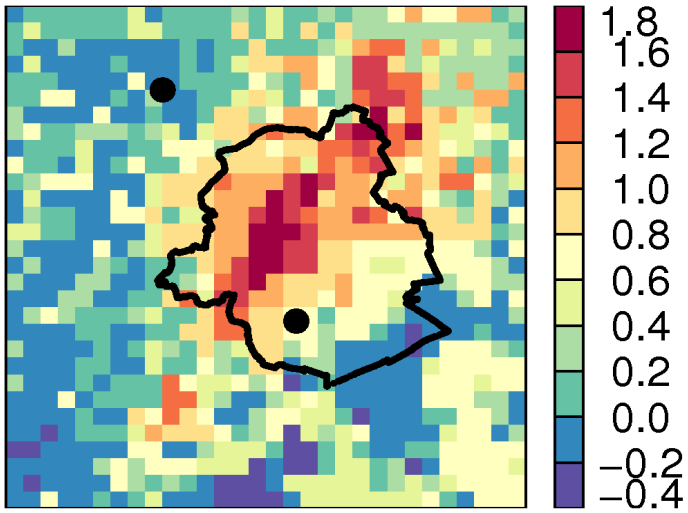
## a) UHI_N, Center = 2.6 °C



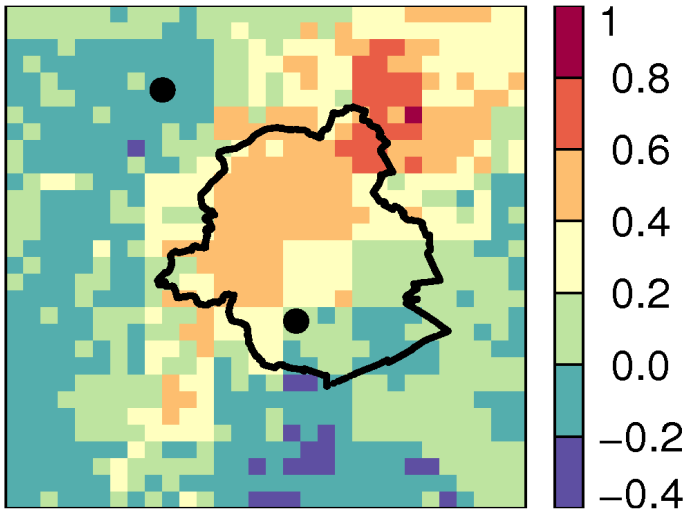

## b) UHI_D, Center = 1.1 °C

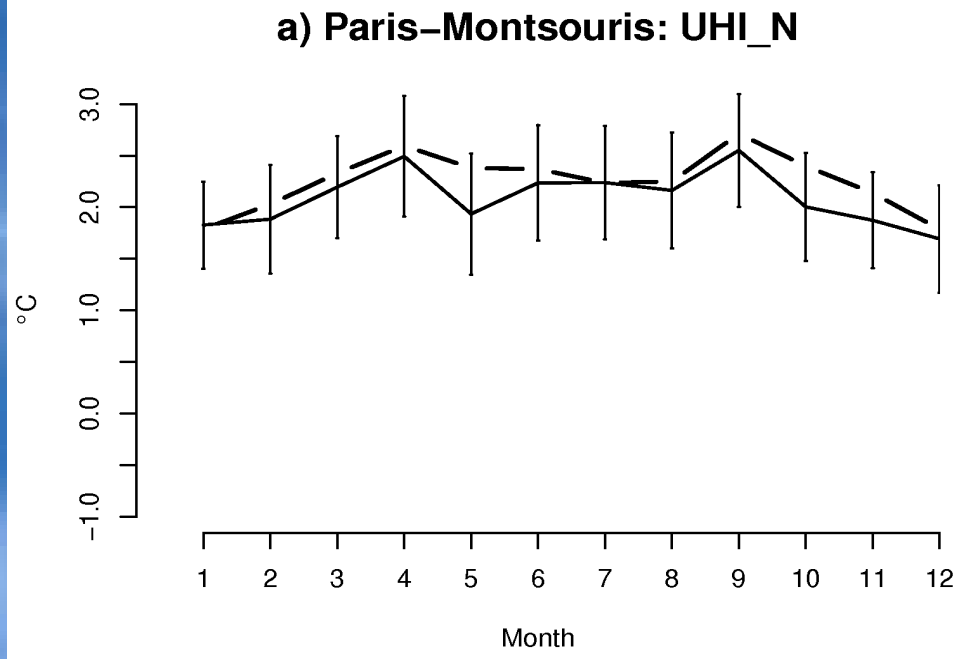


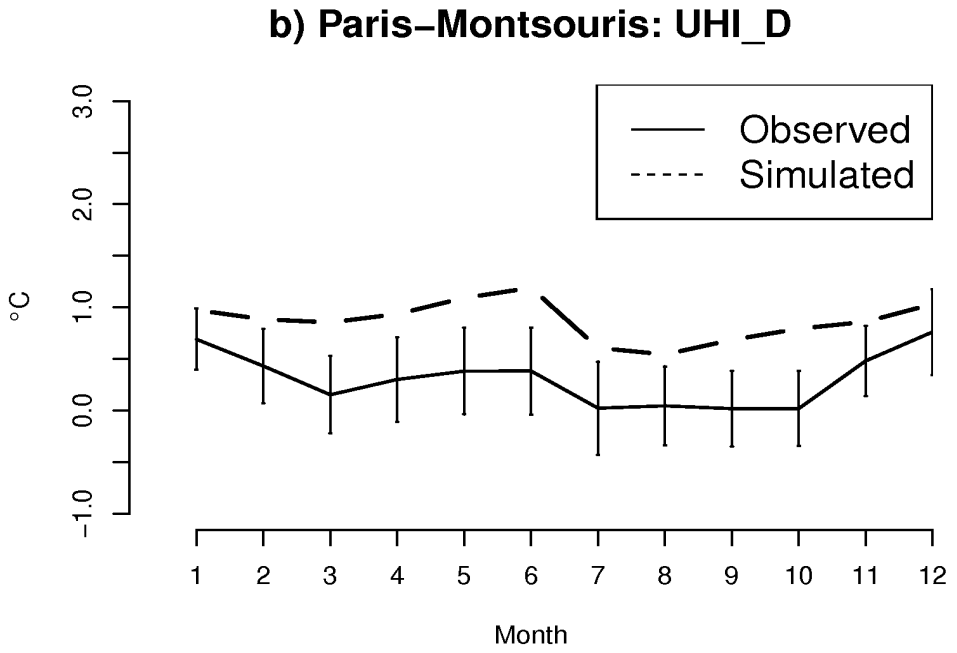

## c) UHI_N, Center = 1.6 °C

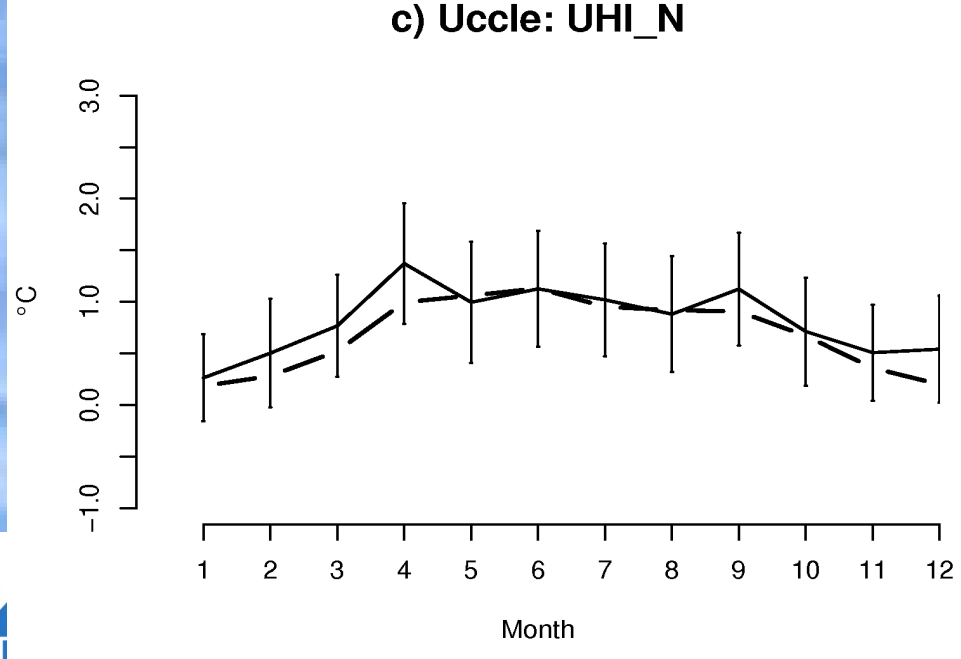


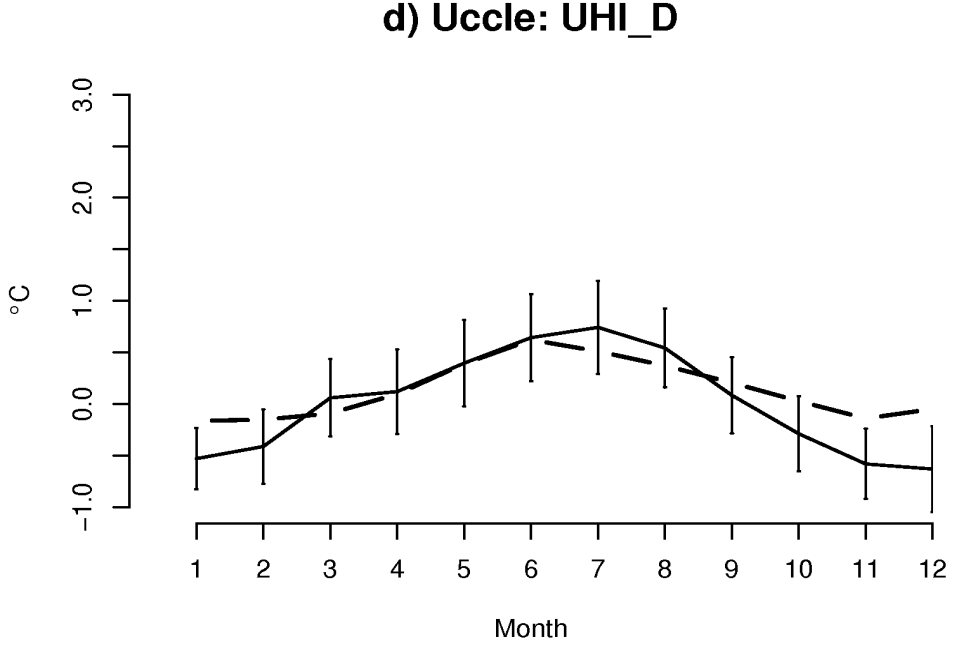

## d) UHI_D, Center = 0.5 °C



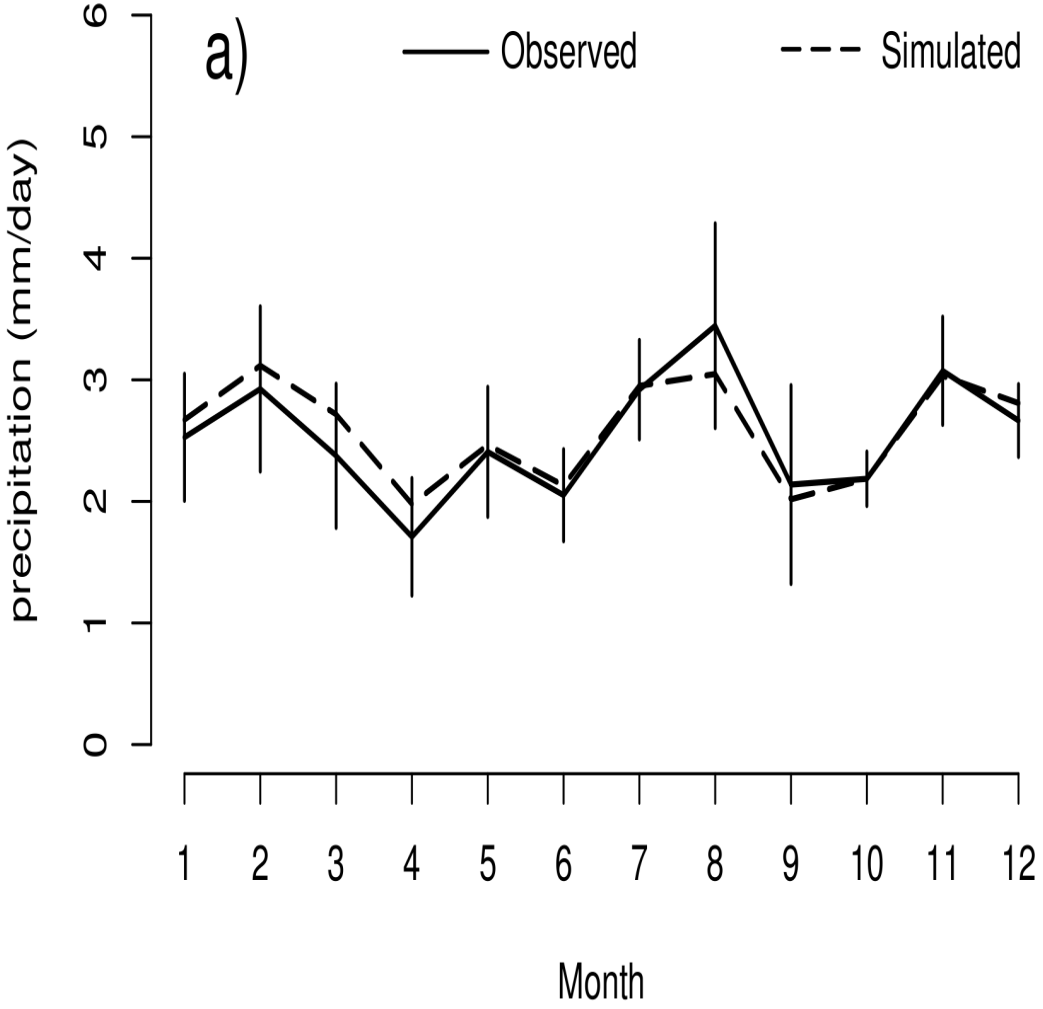

a) Paris–Montsouris: UHI_N
°C
−1.0
0.0
1.0
2.0
3.0
1 2 3 4 5 6 7 8 9 10 11 12
Month


b) Paris–Montsouris: UHI_D
Observed
Simulated
°C
−1.0
0.0
1.0
2.0
3.0
1 2 3 4 5 6 7 8 9 10 11 12
Month


c) Uccle: UHI_N
°C
−1.0
0.0
1.0
2.0
3.0
1 2 3 4 5 6 7 8 9 10 11 12
Month


d) Uccle: UHI_D
°C
−1.0
0.0
1.0
2.0
3.0
1 2 3 4 5 6 7 8 9 10 11 12
Month

# precipitation and cloud cover



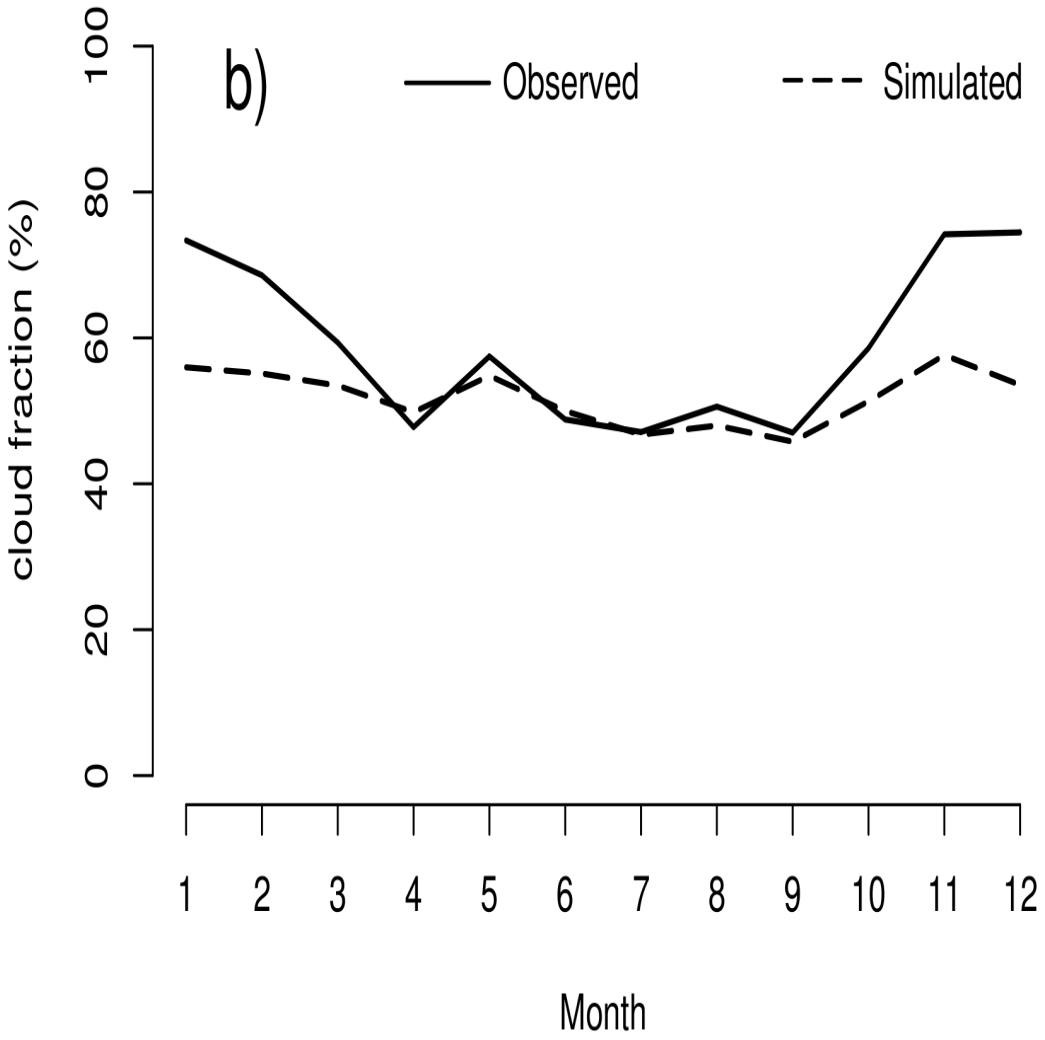



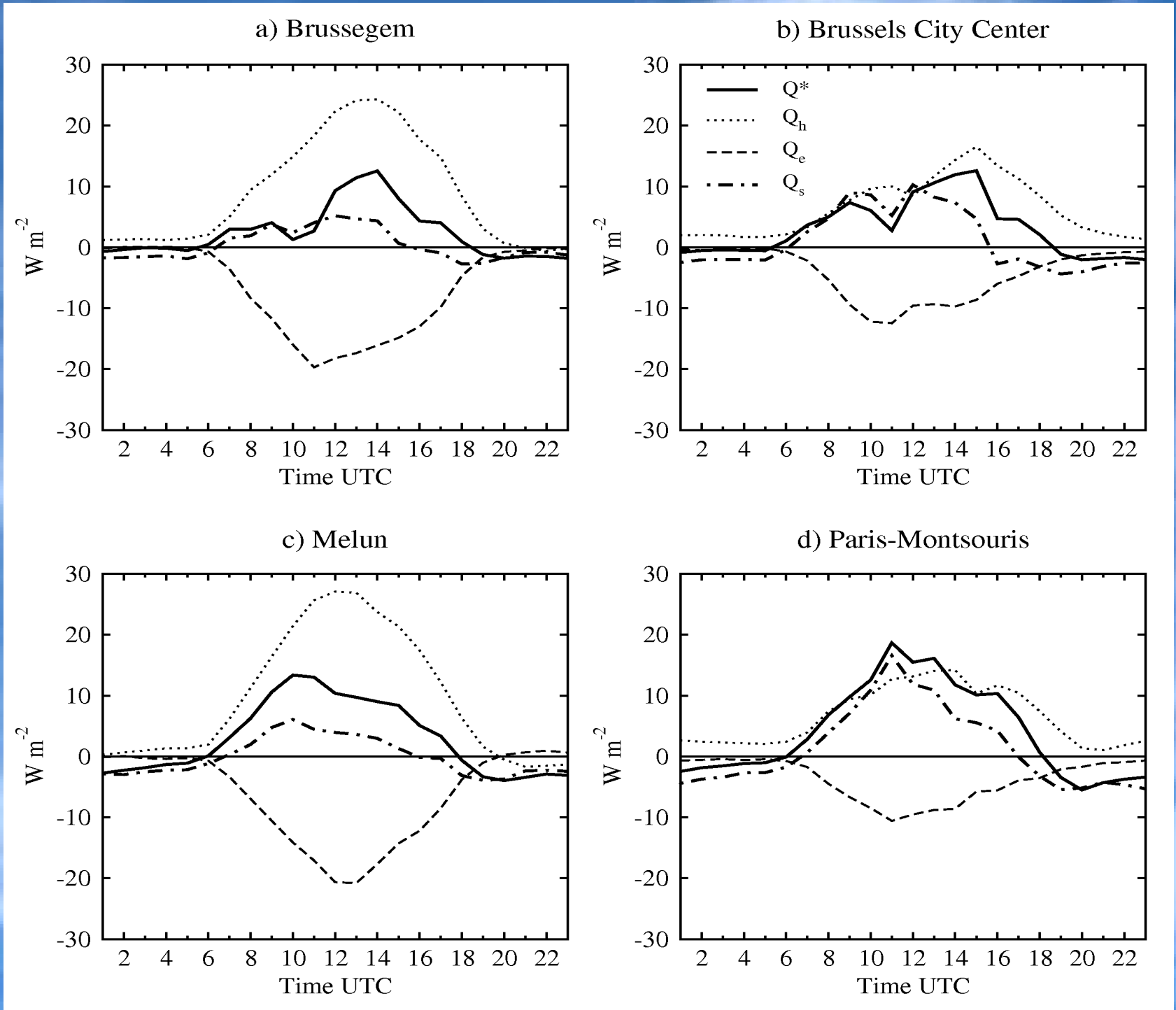
**Table 2**
The seasonal and annual mean temperature increase (FUT_1-HIS_1, in °C) for the 2050s horizon under the A1B emission scenario for the city center of Brussels, the rural (Brussegem) station, the city center of Paris and the rural (Melun) station.

| | Urban center (°C) | | Rural (°C) | |
|---|---|---|---|---|
| | BCR | GPR | BCR | GPR |
| Spring | 1.8 | 2.0 | 1.7 | 1.9 |
| Summer | 1.6 | 2.0 | 1.6 | 2.2 |
| Fall | 1.8 | 1.9 | 1.8 | 1.9 |
| Winter | 1.1 | 1.2 | 0.9 | 1.1 |
| Annual | 1.6 | 1.8 | 1.5 | 1.8 |

**Table 3**
The seasonal variation of the 10-year average nocturnal and daytime UHI (in °C) at the city center of Brussels and Paris calculated from: (i) ERA_1, (ii) HIS_1, and (iii) FUT_1 minus HIS_1. Significant results of the Student's *t*-test at the 95% confidence level are shown with *. Bold values present the largest and statistically significant changes.

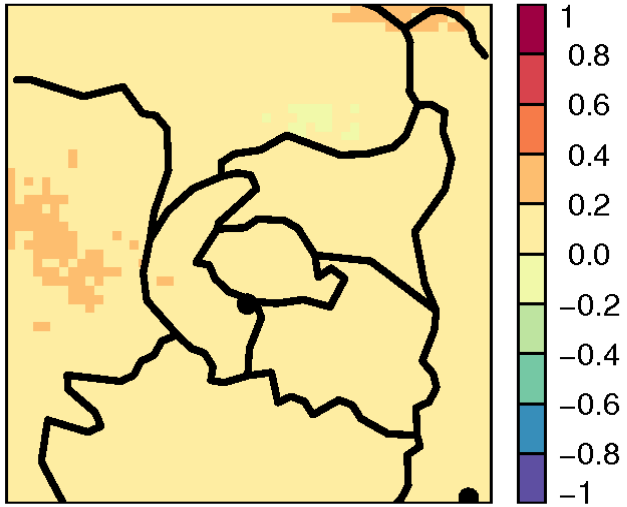
| | UHI_N (°C) | | | UHI_D (°C) | | |
|---|---|---|---|---|---|---|
| | ERA_1 | HIS_1 | FUT_1-HIS_1 | ERA_1 | HIS_1 | FUT_1-HIS_1 |
| *Paris city center* | | | | | | |
| Spring | 2.8 | 2.8 | 0.13 | 1.2 | 1.6* | 0.10* |
| Summer | 2.7 | 2.7 | −0.17* | 1.1 | 1.1 | **−0.14*** |
| Fall | 2.7 | 2.9* | 0.12 | 1.2 | 1.2 | −0.08* |
| Winter | 2.2 | 2.2 | **0.23*** | 1.2 | 1.4* | 0.06* |
| *Brussels city center* | | | | | | |
| Spring | 1.8 | 1.8 | 0.15* | 0.4 | 0.8* | 0.07* |
| Summer | 1.8 | 1.8 | −0.10 | 0.6 | 0.2* | **−0.11*** |
| Fall | 1.7 | 1.9* | 0.12 | 0.6 | 0.5* | −0.04 |
| Winter | 1.2 | 1.2 | **0.22*** | 0.5 | 0.6* | 0.07* |

# Evolution of the surface fluxes

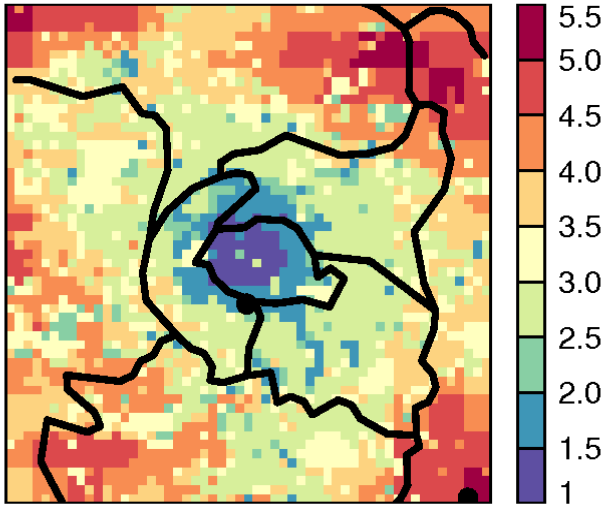


# Evolution of wind speed

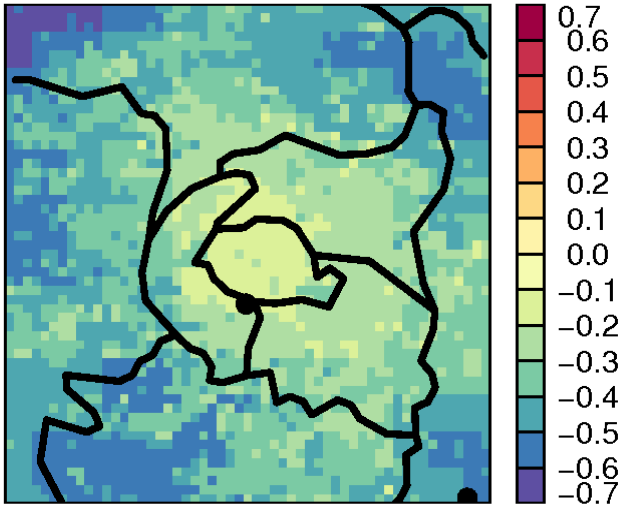
a) HIS_1–ERA_1, Winter, 10m WS



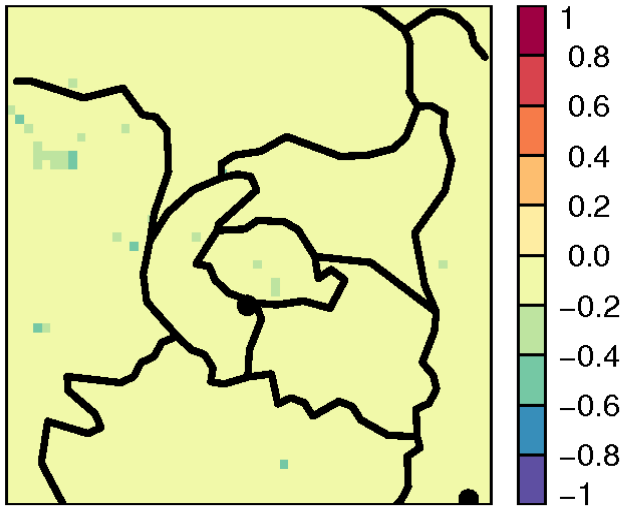

b) HIS_1, Winter, 10m WS



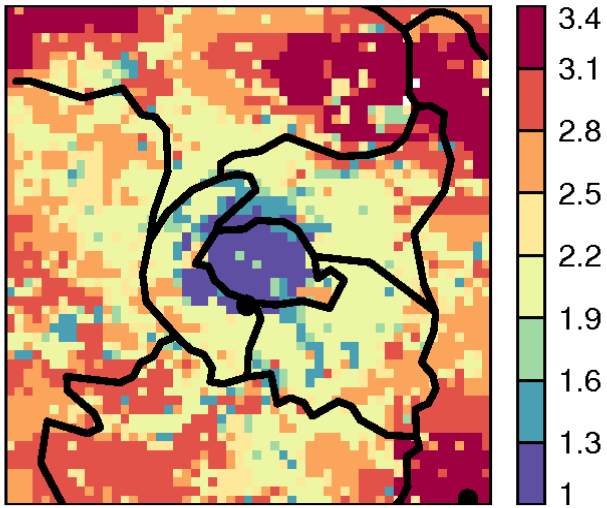

c) FUT_1–HIS_1, Winter, 10m WS



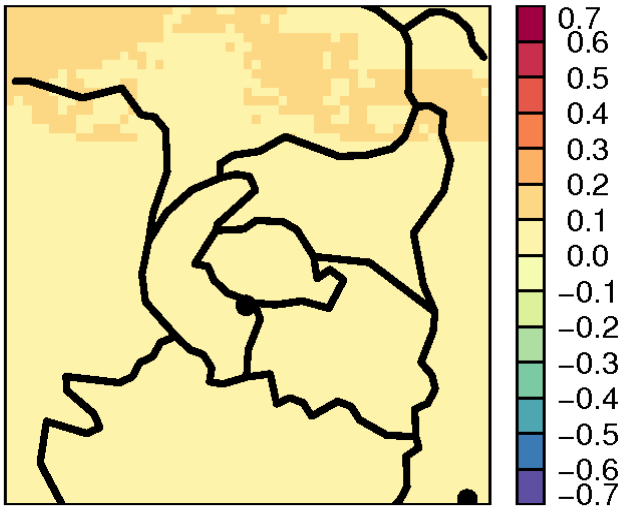

d) HIS_1–ERA_1, Summer, 10m WS



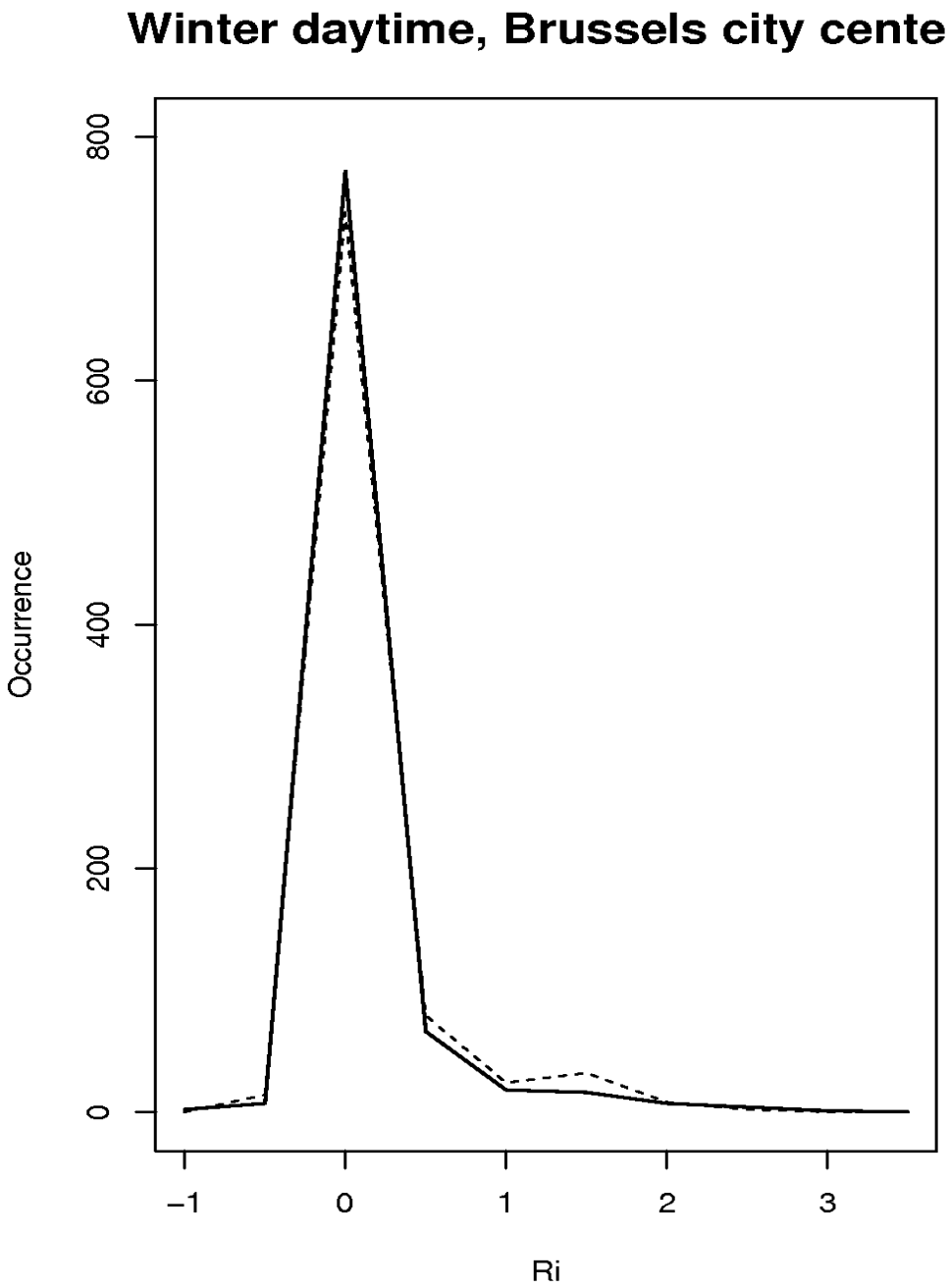

e) HIS_1, Summer, 10m WS

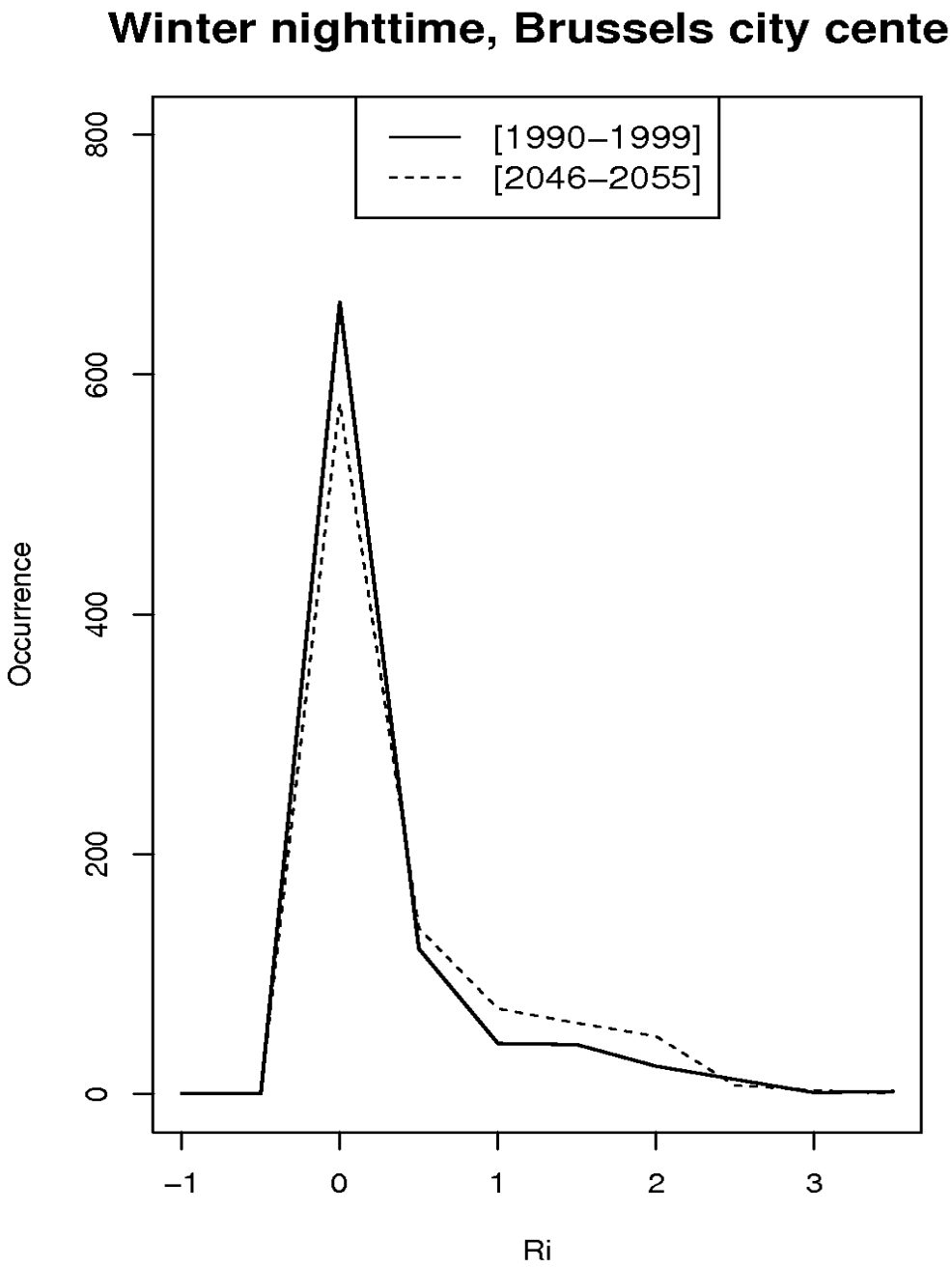



f) FUT_1–HIS_1, Summer, 10m WS



# Evolution of winter stable situations



1. The responses of urban and rural areas to climate change are NOT THE SAME.

2. The feedback between urban environment and climate change is very important for urban impact studies.

3. Compared to the warming due to climate change (an increase of few degrees), changes in the magnitude of the UHI remain very low (a decrease of of a few tens of degrees in the city center)

1. Significant changes of nocturnal (daytime) UHI are noted during winter (summer).

2. Decrease in daytime UHI during summer is related to soil drying over rural areas.

3. Increase in nocturnal UHI during winter is due to projected decrease of wind speed.

4. Climate change will, on average, have a limited impact on the UHI intensity, however, large impacts can be expected from the combination of urban development and potentially more frequent occurrence of extreme climatic events such as heat waves.

# References:


1. Rafiq Hamdi, H. Van de Vyver, R. De Troch, P. Termonia. Assessment of three dynamical urban climate downscaling methods: Brussels's future urban heat island under an A1B emission scenario. *International journal of climatology*, Volume 34, Issue 4, March 2014, Pages: 978–999, DOI: 10.1002/joc.3734, 2014.

2. Rafiq Hamdi et al., 2015: Future climate of Brussels and Paris for the 2050s under the A1B scenario. Urban Climate, 12, 160–182. http://dx.doi.org/10.1016/j.uclim.2015.03.003