



High-resolution regional climate modelling with CNRM-AROME to study the urban climate of Paris (France) area and its evolution with climate change

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Acknowledgments : Sébastien Riette, Yann Seity, Antoinette Alias, Samuel Somot, Valéry Masson

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Modelling of urban climate

Different approaches

For most of climate models:

- Cities do not exist and urban processes are not modelled (= vegetation)
- Cities are described as rock covers with high roughness and treated by SVAT models
 - ▶ Imperviousness
 - ▶ Surface heating capacities at daytime
 - ▶ Roughness effect on airflow



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 - ▶ Roughness effect on airflow

But not account for radiative effects related to 3D urban geometry

► **2000s : new generation of urban canopy models**

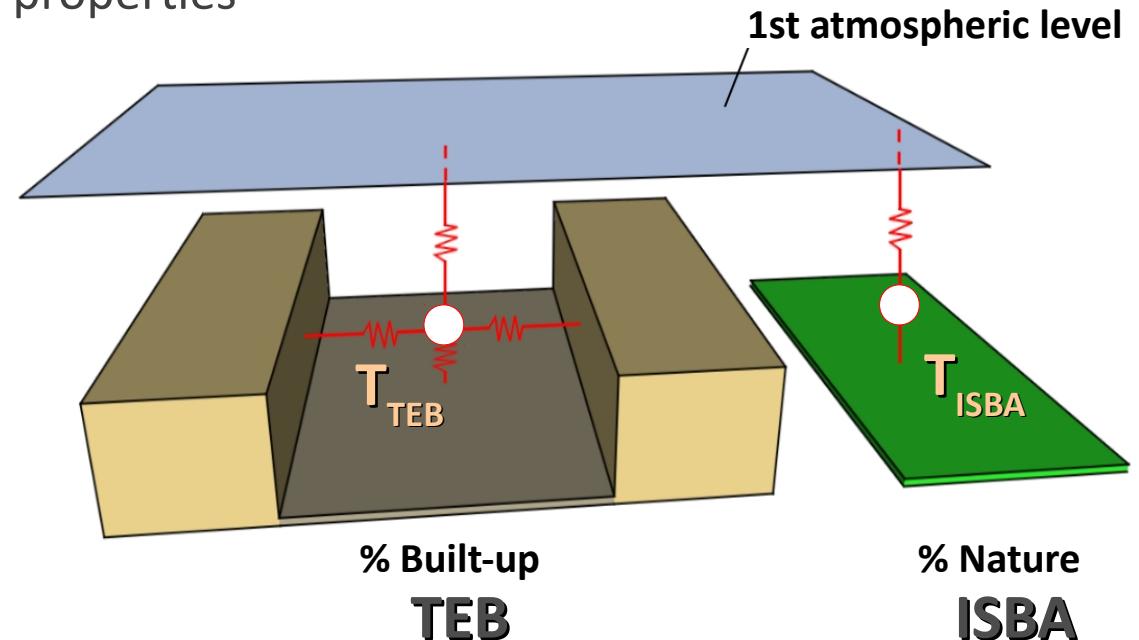
Modelling of urban climate

Town Energy Balance (TEB) model (Masson 2000)

- Concept of mean urban canyon (Oke 1982)
 - Urban elements: roof, road, walls
 - Mean morphological characteristics
 - Mean radiative and thermal properties



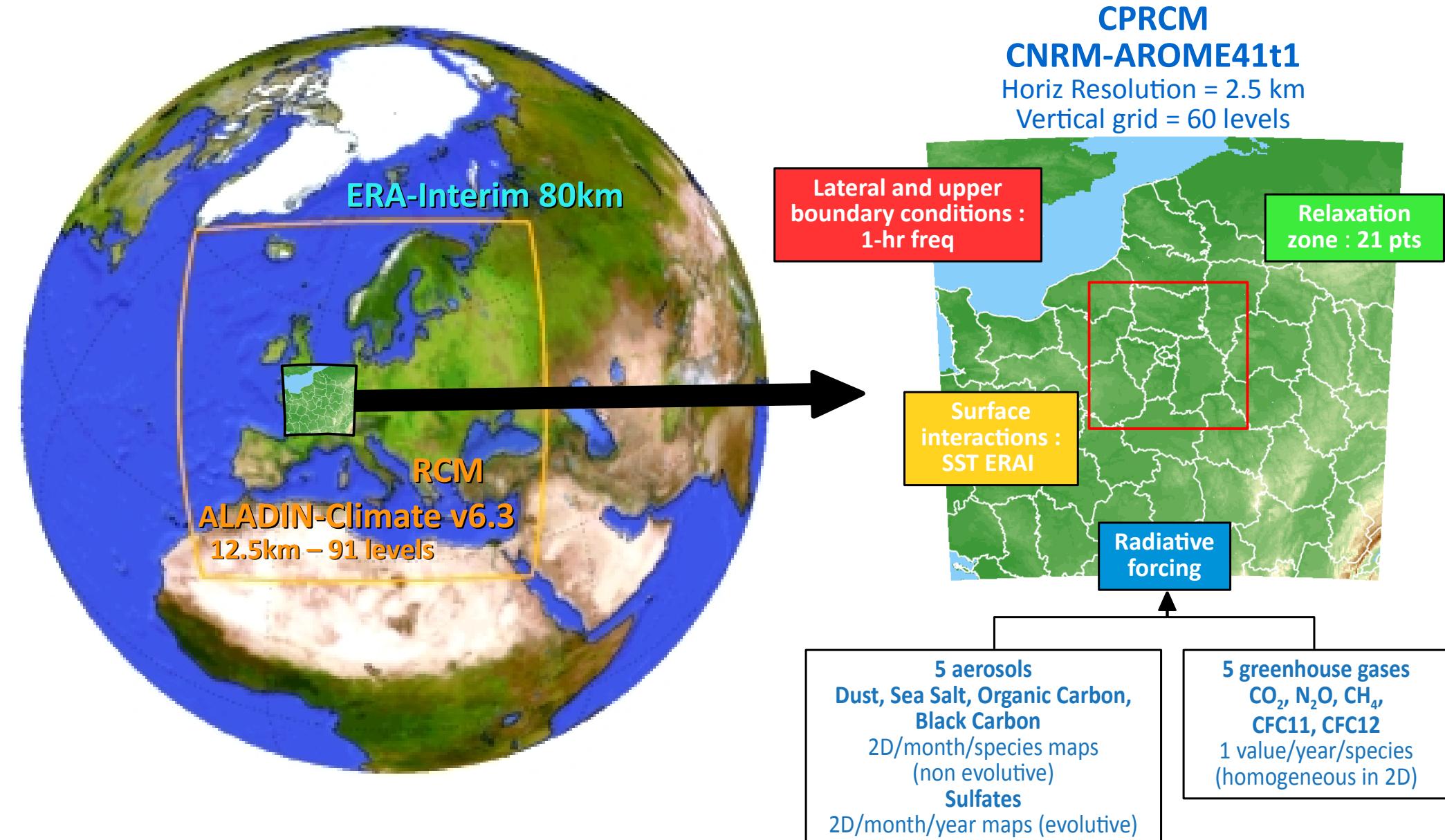
Source : Toulouse centre-ville, Google Earth



- Physical processes including :
 - Radiative and energetic exchanges
 - Water and snow
 - T,HU,U inside canyon

CNRM-AROME modelling configuration

Application to Paris urban area



CNRM-AROME modelling configuration

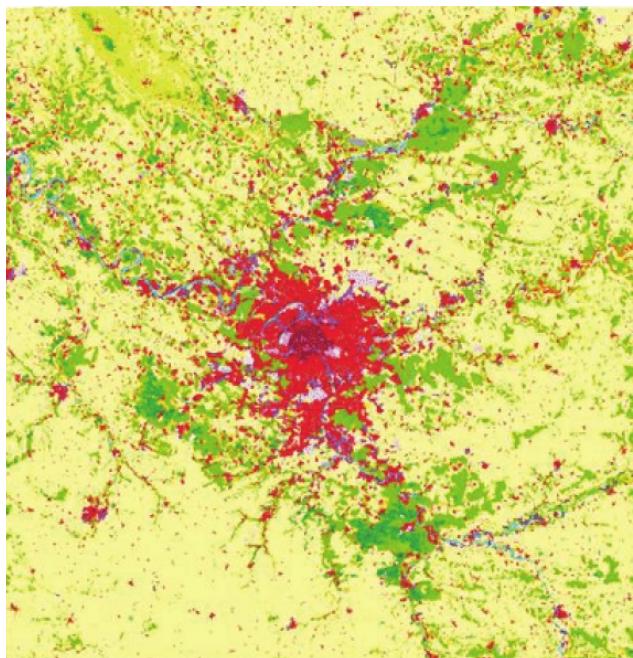
Application to Paris urban area

Simulation domain

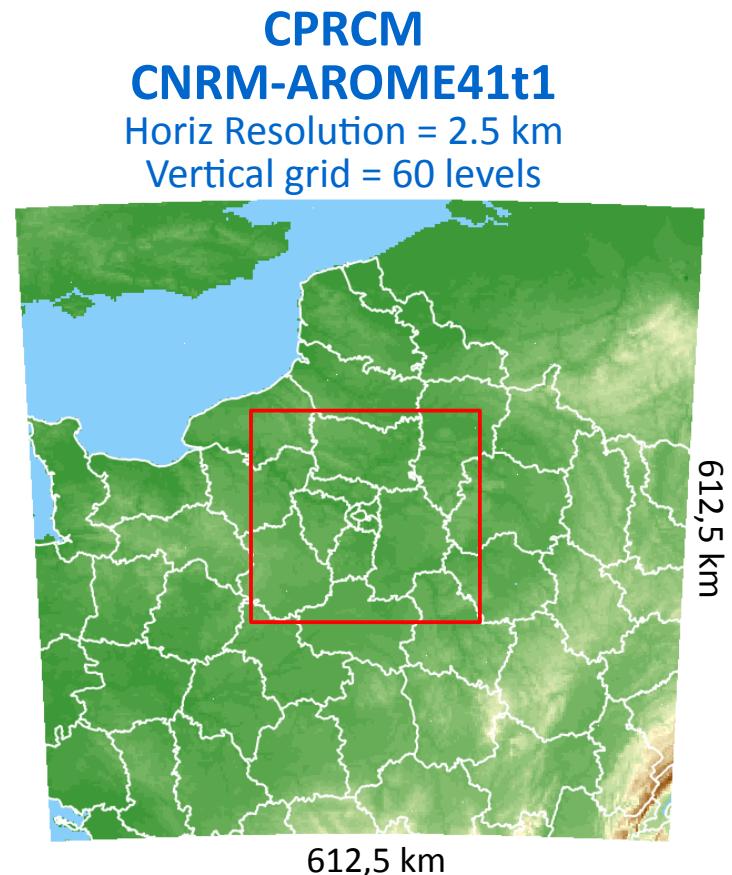
- North of France : 245 pts x 245 pts

SURFEX land surface modeling system

- **ISBA-DF** for natural soils and vegetation
- **TEB** for urban areas
- **ECOCLIMAP v1** database for land surface covers mapping and properties



- Urban continuous fabric
- Urban discontinuous fabric
- Industrial and commercial areas
- Airports
- Mineral extraction sites
- Green urban areas
- Sport and leisure facilities



CNRM-AROME modelling configuration

Application to Paris urban area

Simulation domain

- North of France : 245 pts x 245 pts

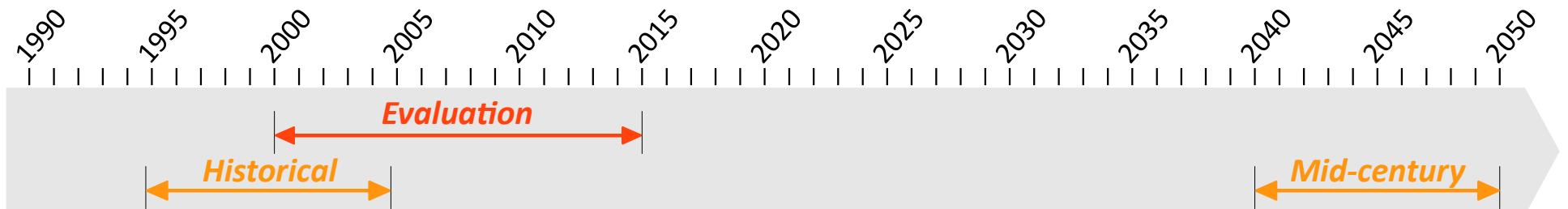
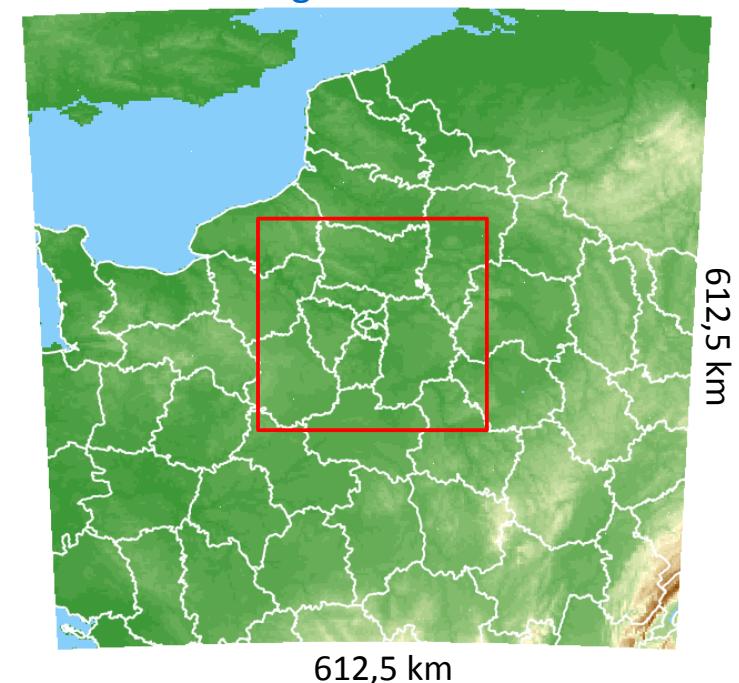
Evaluation configuration

- ERAI + RCM ALADIN
- Domain over Paris region $\approx 200 \text{ km} \times 200 \text{ km}$
- Time period 2000-2015 (+ 2-yr spin-up)

Scenario RCP8.5

- GCM ARPEGE + RCM ALADIN
- Historical period 1996-2005 (+ 2-yr spin-up)
- Future period 2041-2050 (+ 2-yr spin-up)
- >> Only 4 years of simulation for now

CPRCM
CNRM-AROME41t1
 Horiz Resolution = 2.5 km
 Vertical grid = 60 levels



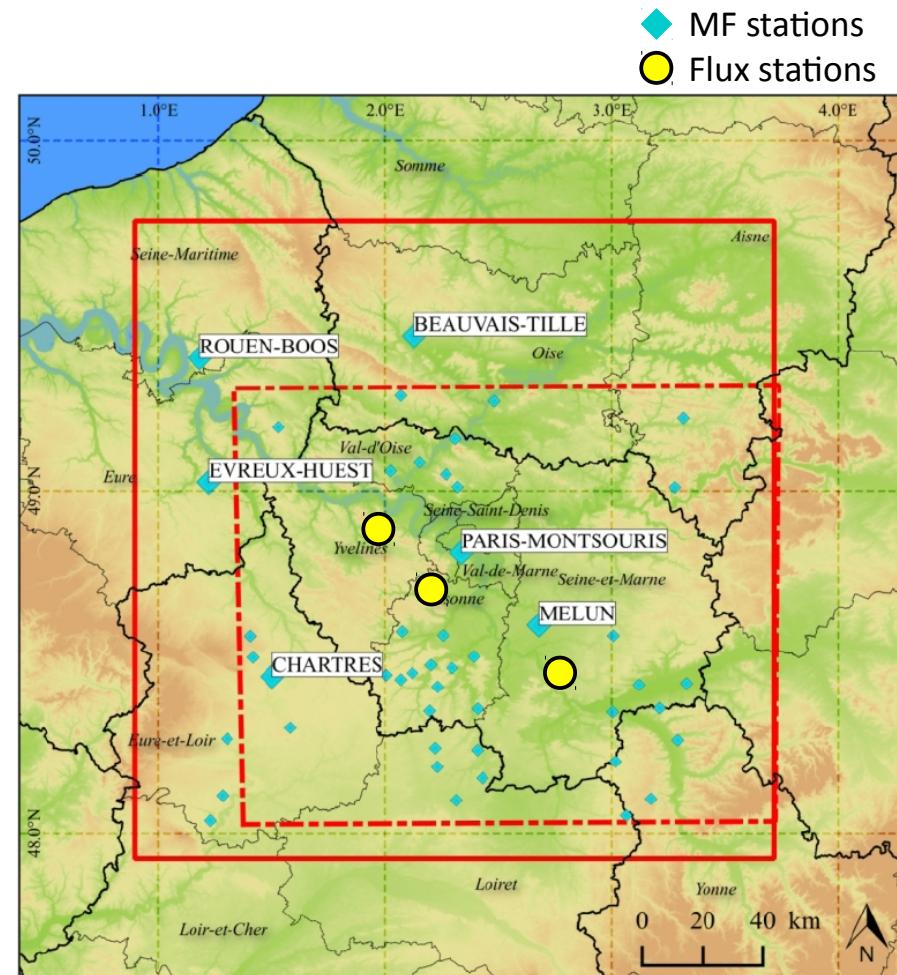
Evaluation of CNRM-AROME

Long-term observations

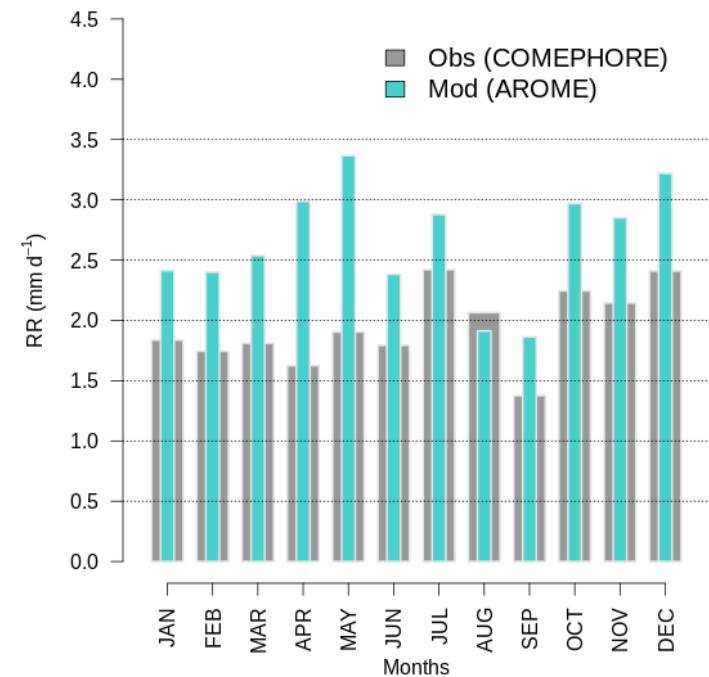
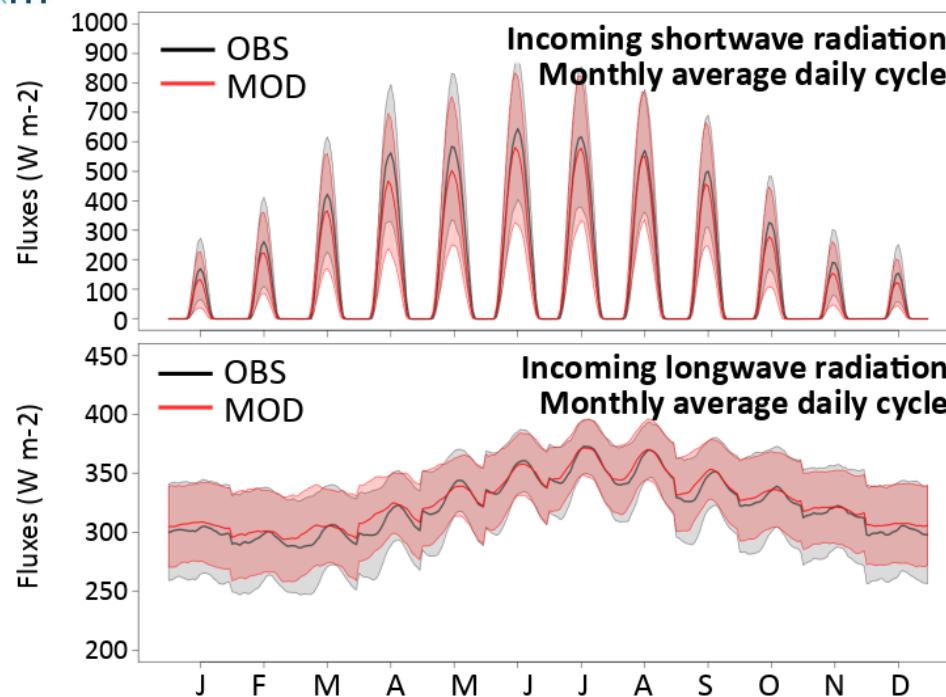
- **Maps of daily min and max near-surface temperatures**
 - ✓ Product from Paris Region Meteo-France center over 2000-2017
 - ✓ 1.25 km spatial resolution
 - ✓ Interpolation from Meteo-France station data accounting for topography and urbanization (based on Ecoclimap DB)

- **Maps of daily precipitation**
 - ✓ Reanalyses COMEPHORE 1997-2012 (radars and raingauges)
 - ✓ 1 km spatial resolution

- **Flux stations**
 - ✓ SIRTA (2003-)
 - ✓ Grignon (2004-)
 - ✓ Barbeau – Fontainebleau (2005-)



Evaluation of CNRM-AROME

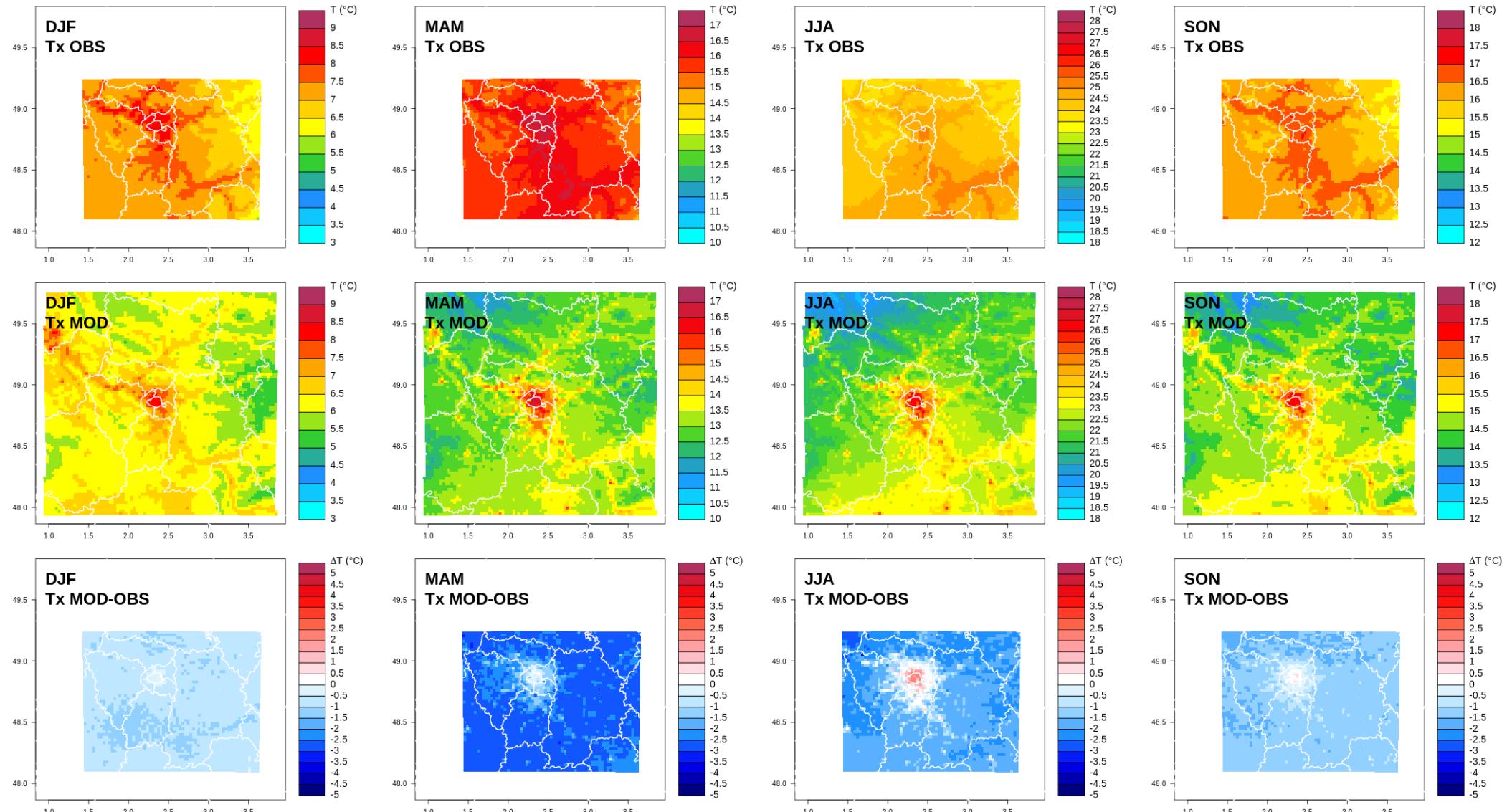


Seasonal biases (mod - obs)

	DJF	MAM	JJA	SON
Daily precip rate (mm day ⁻¹)	+0,68	+1,18	+0,30	+0,64
Incoming solar rad (W m ⁻²)	-7,2	-29,8	-19,1	-10,7
Incoming infrared rad (W m ⁻²)	+5,5	+5,1	+1,1	+3,0
Tmin (°C)	+0,75	+0,41	+0,88	+0,68
Tmax (°C)	-0,88	-2,51	-1,68	-1,28

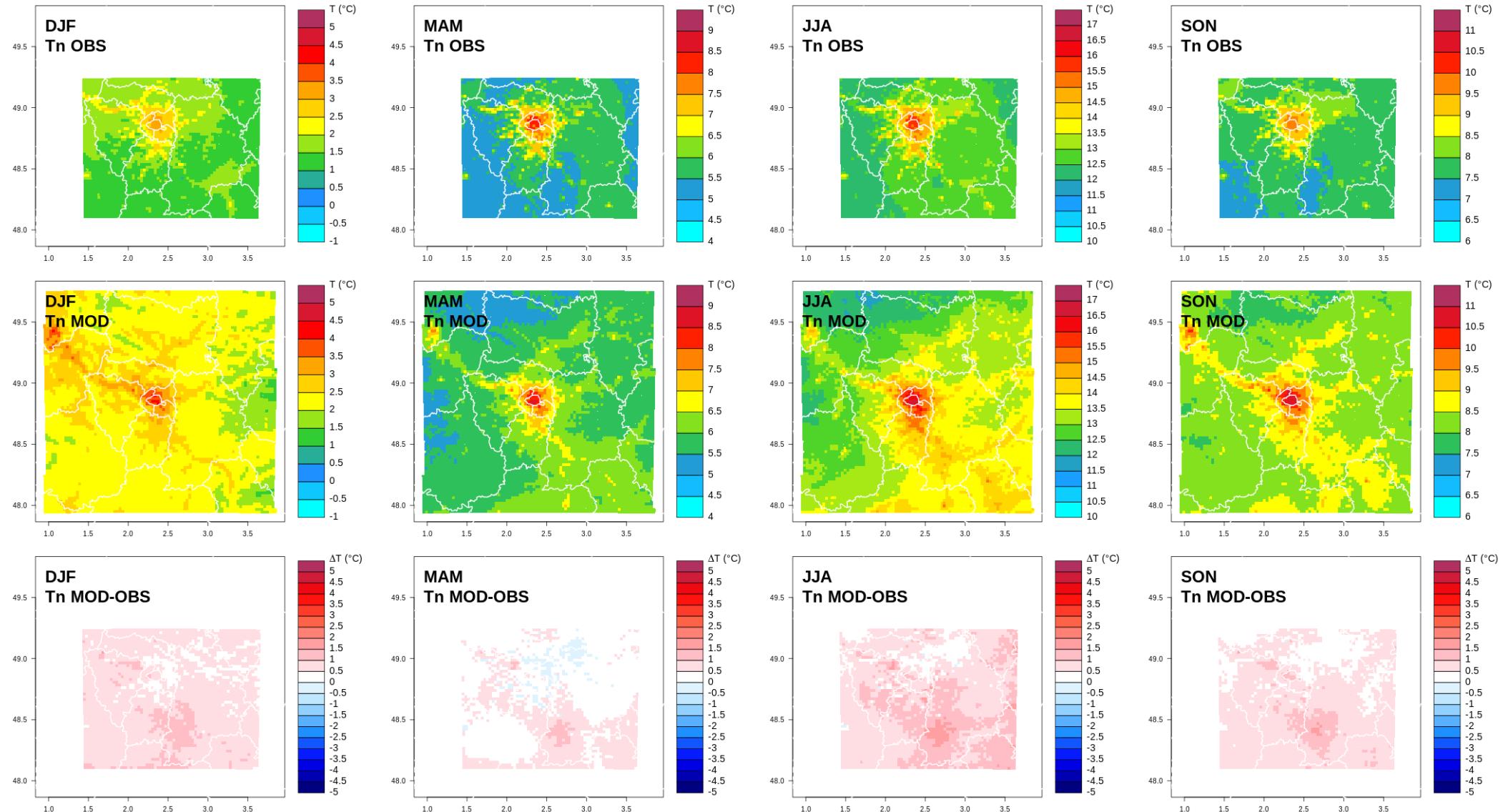
Evaluation of CNRM-AROME

Seasonal average of daily maximum temperatures



Evaluation of CNRM-AROME

Seasonal average of daily minimum temperatures

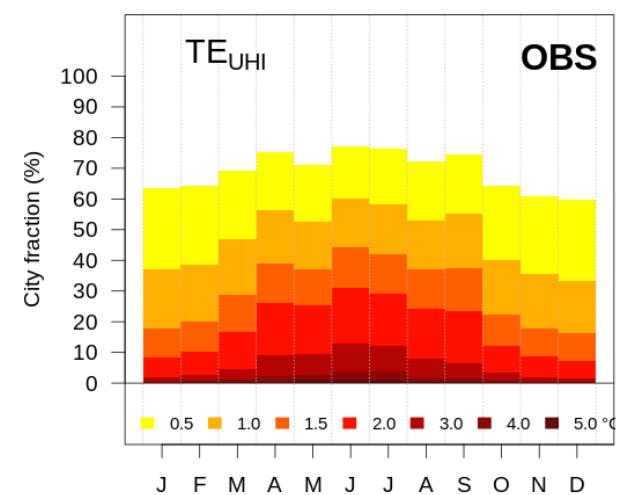
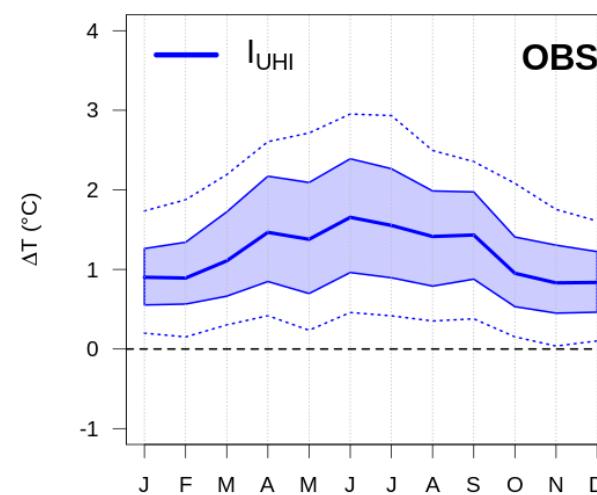
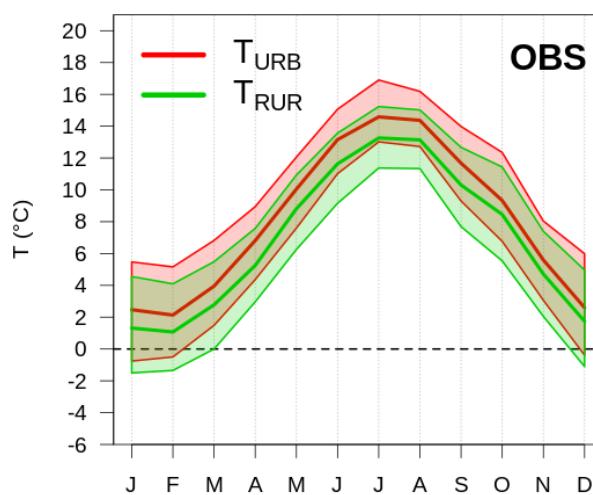


Urban Heat Island (UHI) indicators

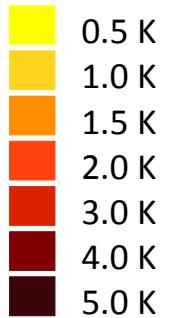
Nighttime UHI

1) UHI intensity : $I_{UHI} = \overline{T_{urb}} - \overline{T_{rur}}$

2) UHI spatial extend : $TE_{UHI}(k) = \frac{\sum P_{urb}[T \geq \bar{T} + \Delta T]}{\sum P_{urb}}$
 Source : Le Roy et al. 2019



- Comparison of rural and urban temperatures
- Seasonal variability of UHI's intensity and spatial extend
 - >> Strong effect of heat storage during summer
 - >> Effect of anthropogenic heat fluxes in winter

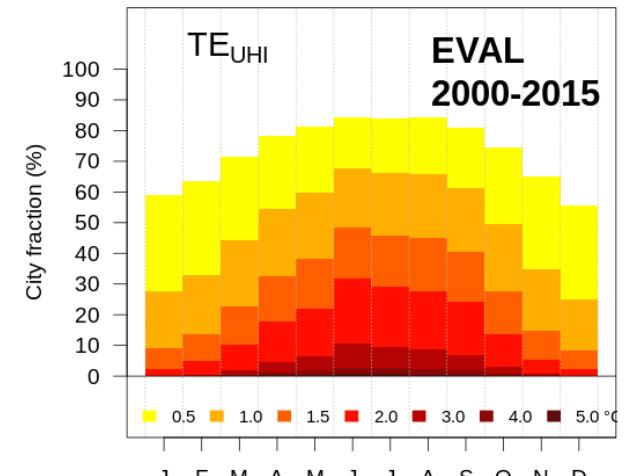
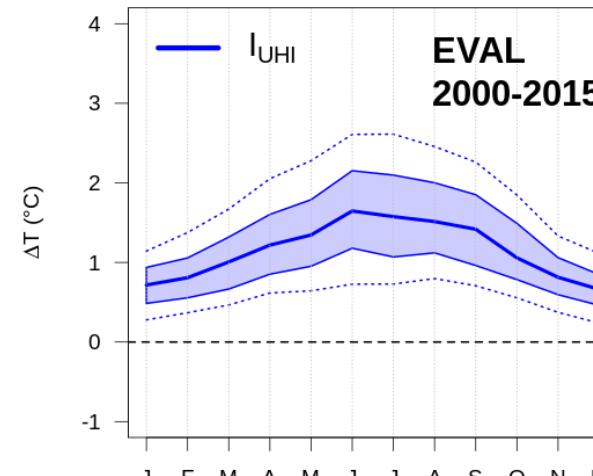
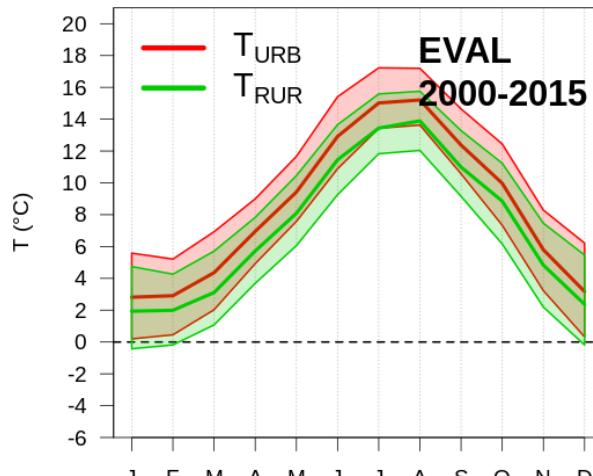
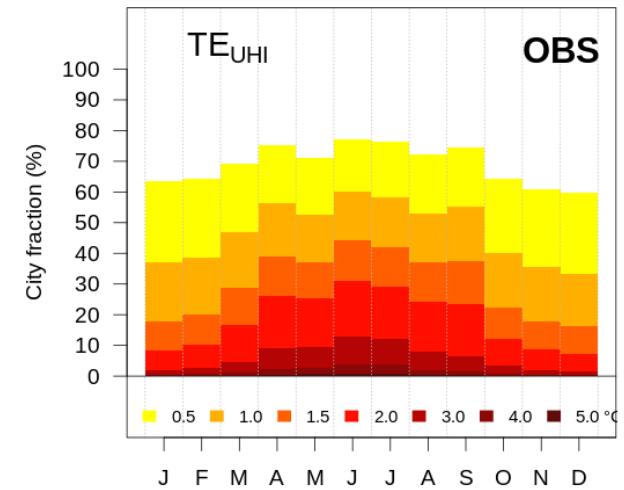
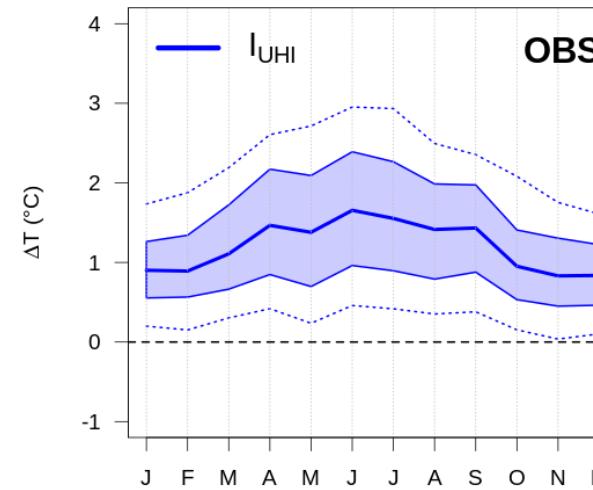
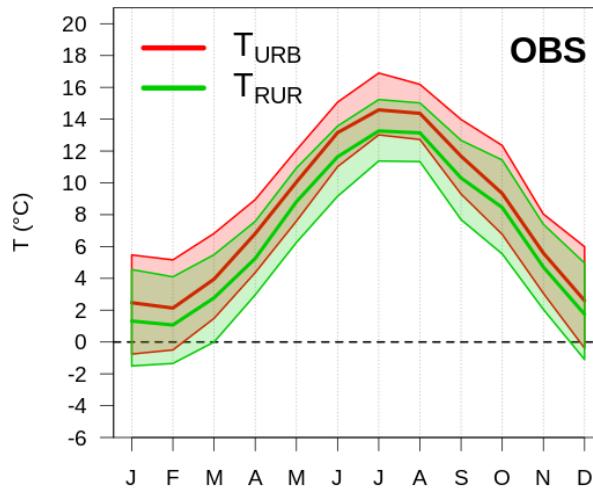


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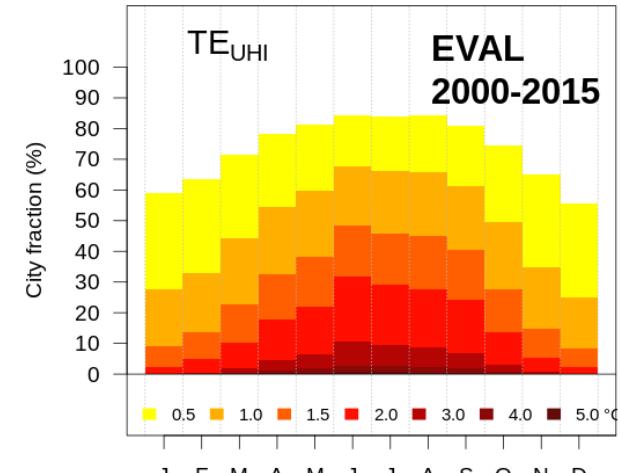
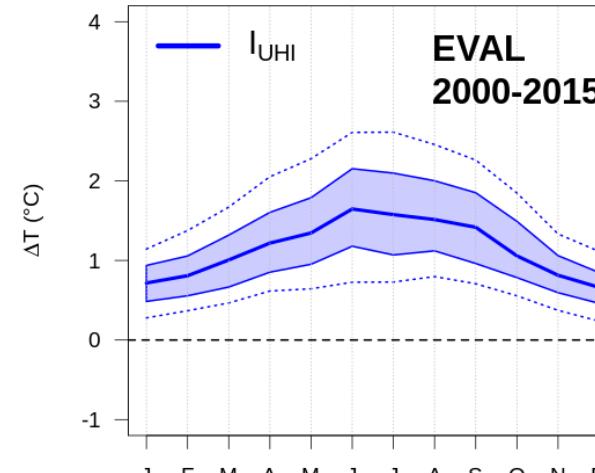
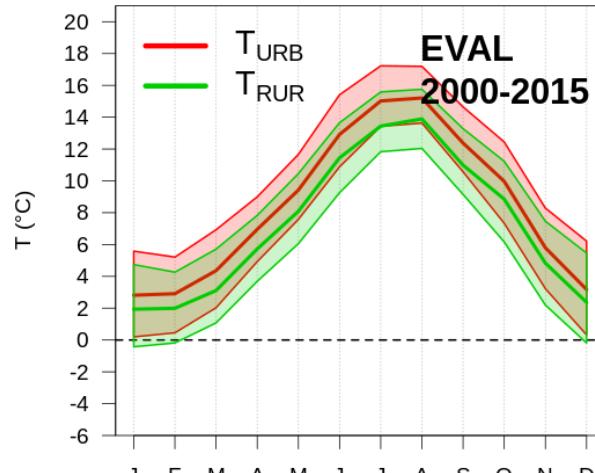
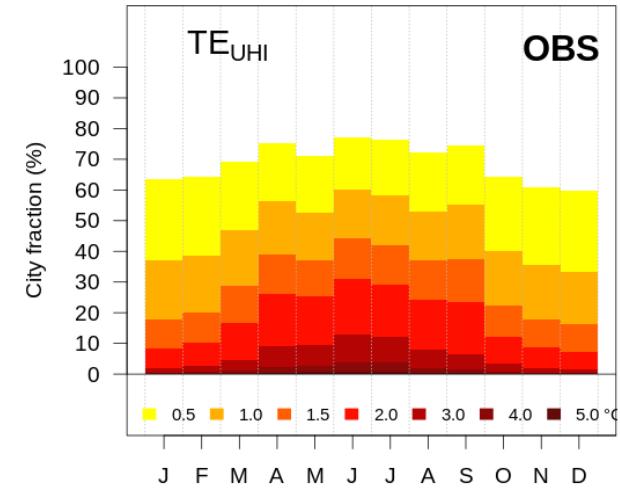
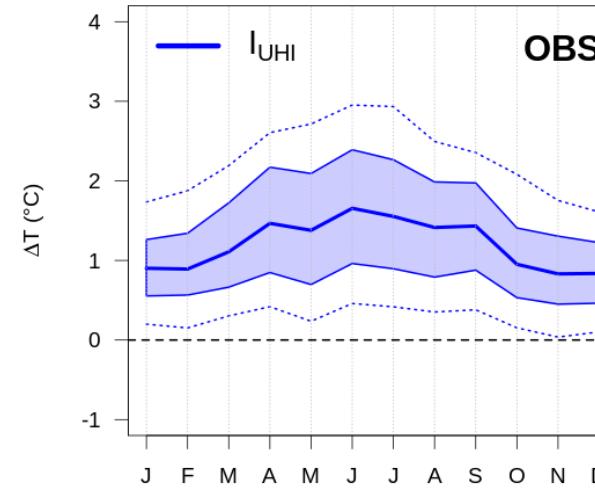
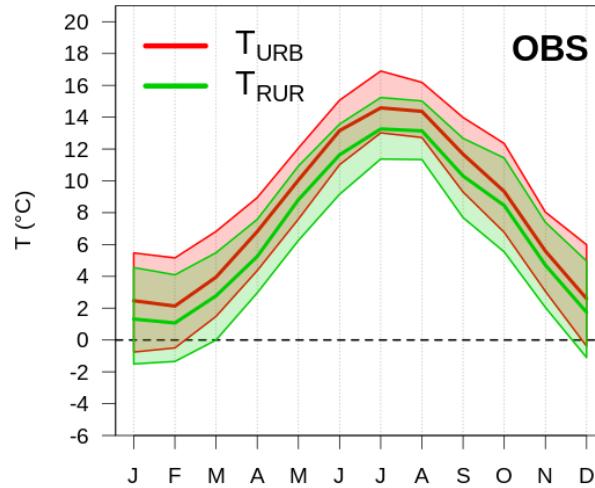
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Urban Heat Island (UHI) indicators

		DJF	JJA
IUHI OBS ($^{\circ}\text{C}$)	Mean (Q90)	0.88 (1.74)	1.54 (2.79)
IUHI EVAL ($^{\circ}\text{C}$)	Mean (Q90)	0.73 (1.21)	1.58 (2.56)

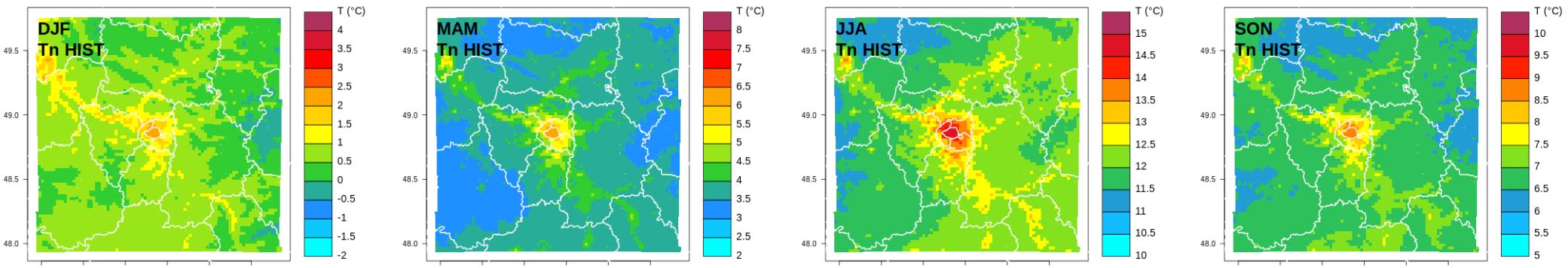
	DJF	JJA
TEUHI OBS (%)	18	41
TEUHI EVAL (%)	10	46



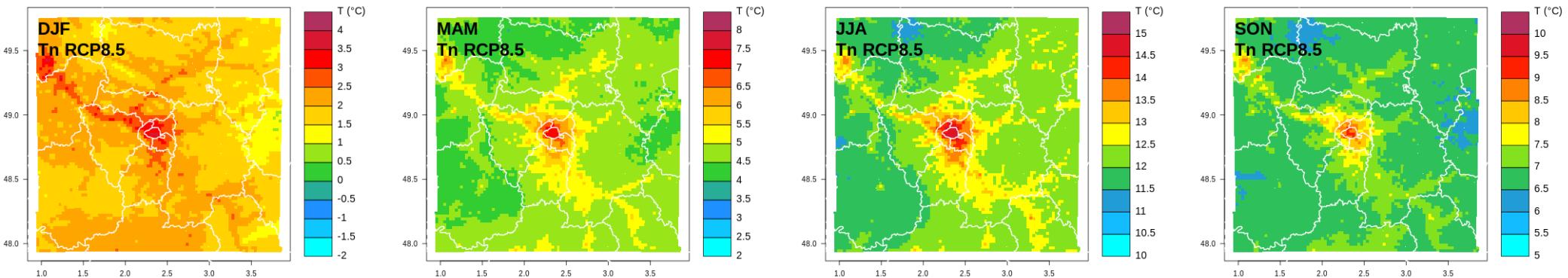
Urban Heat Island (UHI) indicators

Evolution with climate change ?

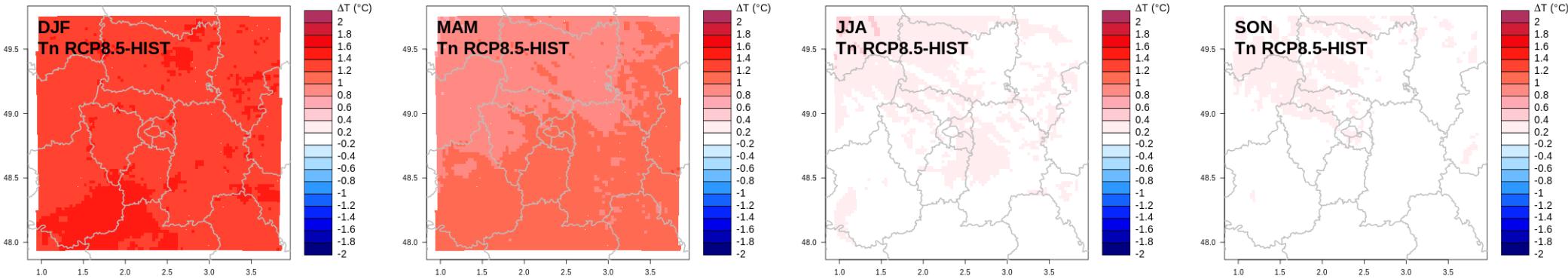
Historical run (1996-1999)



RCP8.5 run (2041-2044)

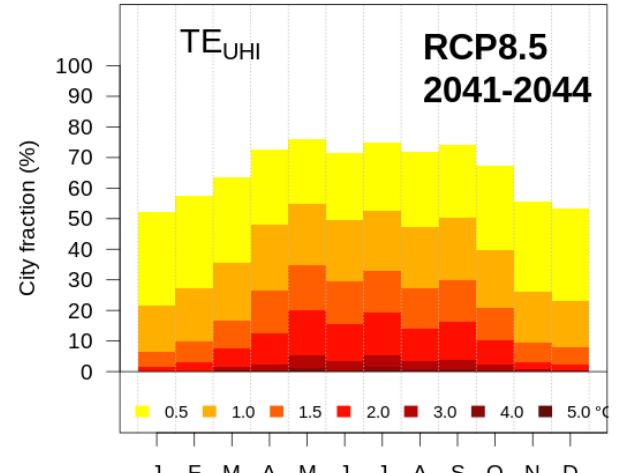
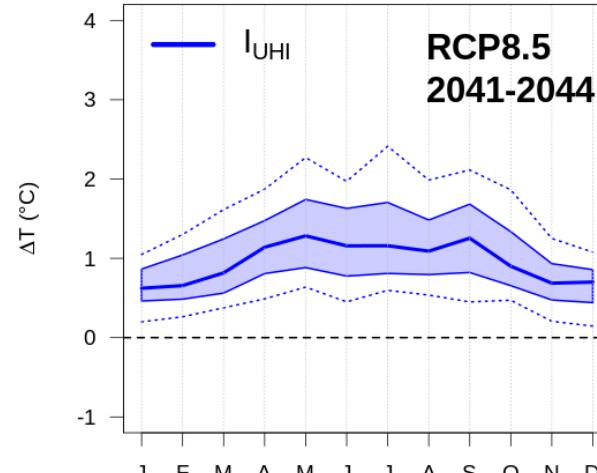
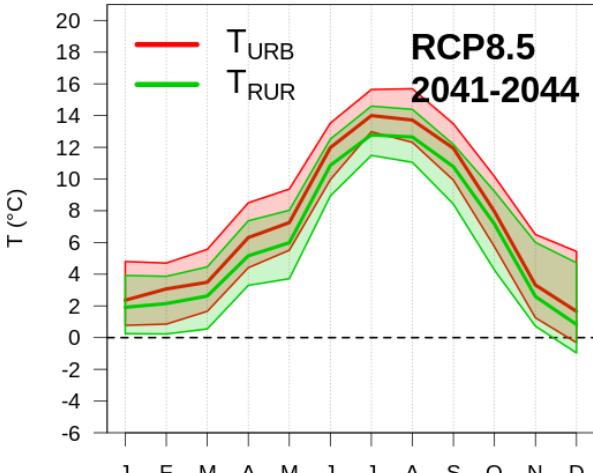
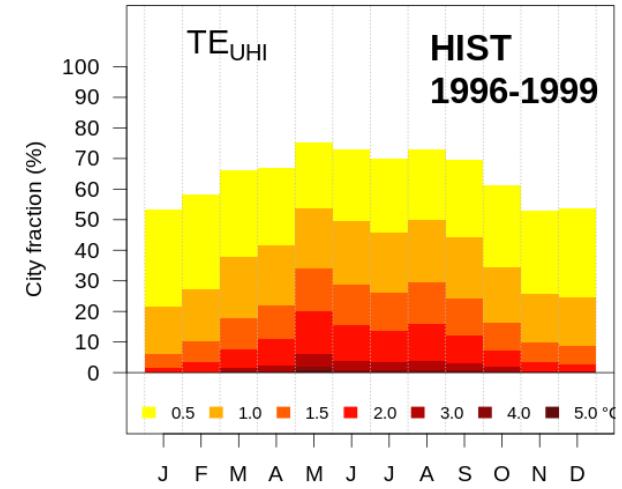
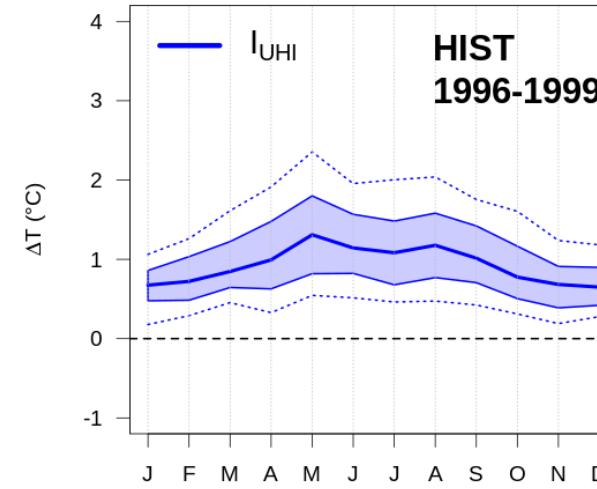
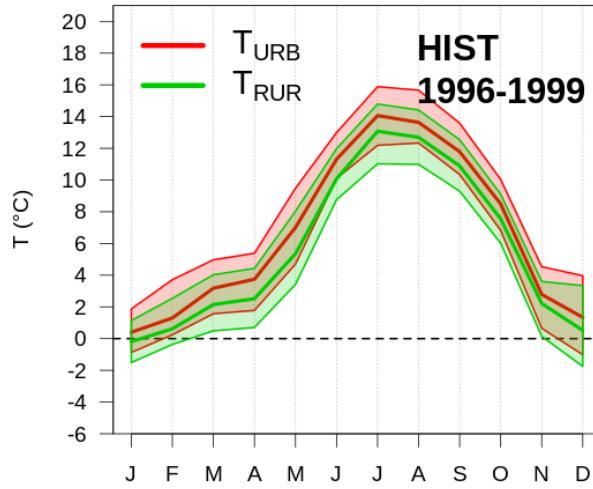


RCP8.5 (2041-2044) - Historical run (1996-1999)



Urban Heat Island (UHI) indicators

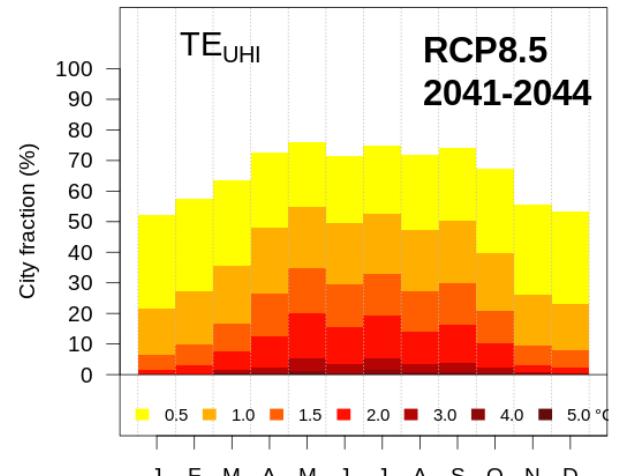
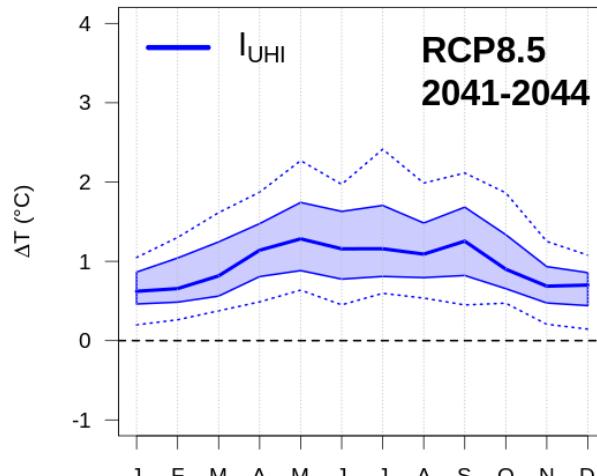
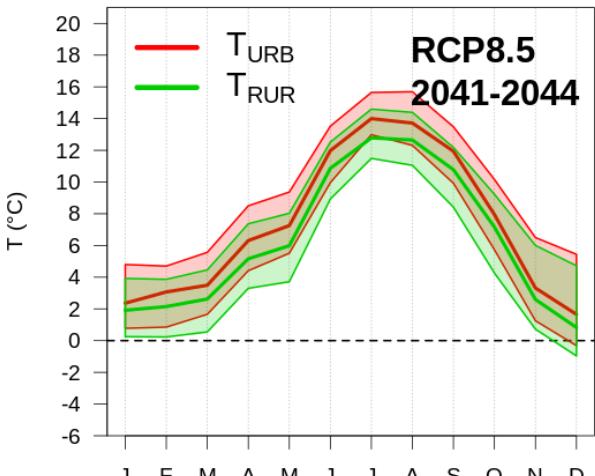
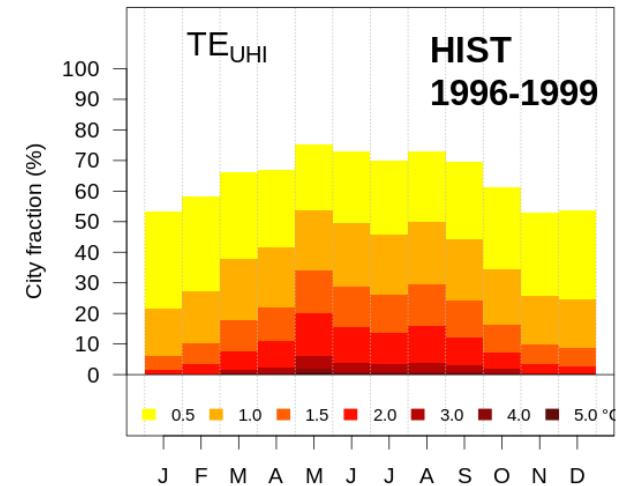
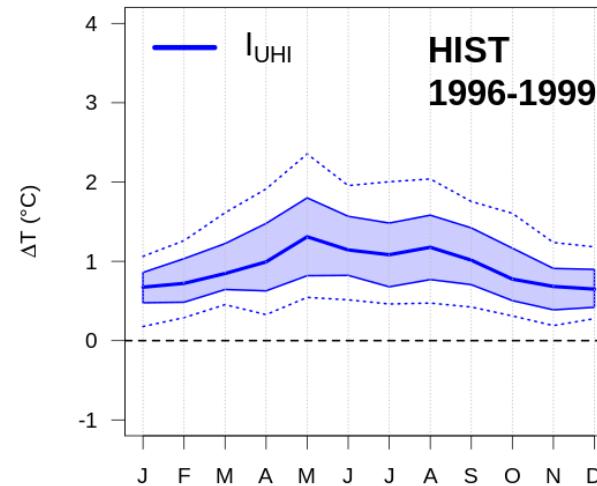
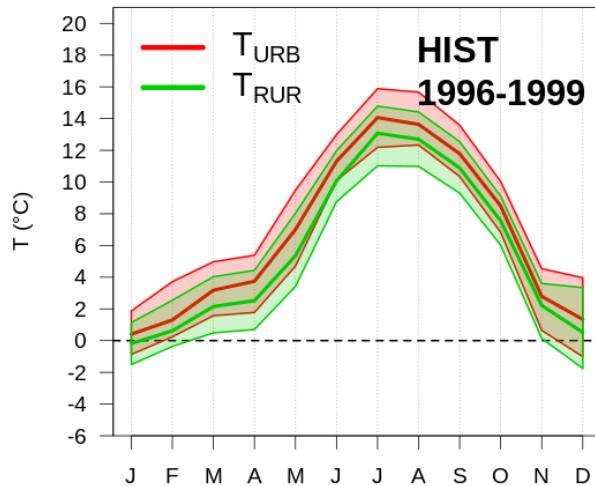
Evolution with climate change ?



Urban Heat Island (UHI) indicators

	DJF	MAM	JJA	SON
I _{UHI} HIST (°C)	Mean (Q90) 0.68 (1.17)	1.05 (1.96)	1.13 (2.00)	0.82 (1.53)
I _{UHI} RCP8.5	Mean (Q90) 0.66 (1.14)	1.08 (1.92)	1.13 (2.12)	0.95 (1.74)

	DJF	MAM	JJA	SON
T _{EUHI} HIST (%)	8	25	28	17
T _{EUHI} RCP8.5	8	26	30	20



Conclusions

- Need to improve the current performances of CNRM-AROME over Paris region
- Challenge for evaluating in an appropriate way the capability of CNRM-AROME to simulate urban climate
 - Relevance of available observations (met stations located in urban parks)
 - Validity of T2M diagnostic of AROME
 - Spatial resolution (2.5 km) and tiling approach ISBA/TEB
 - ⇒ Sensitivity to a higher spatial resolution (1.3 km)
 - ⇒ Benefit of a more sophisticated version of TEB including vegetation
 - ⇒ Reliability of new observations (NetATMO) for UHI quantification
- Next steps :
 - ⇒ Evaluate climate change effects for complete 10-year time slices
 - ⇒ Explore effects at the end of the century
- Interest in investigating and comparing urban responses for other simulations performed with convection permitted models



Thank you for your attention

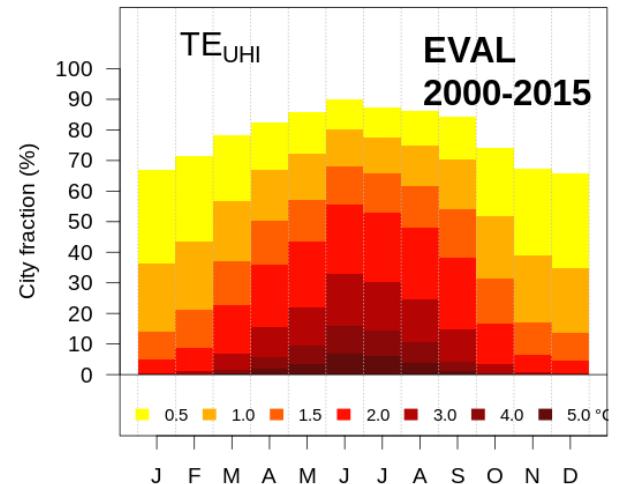
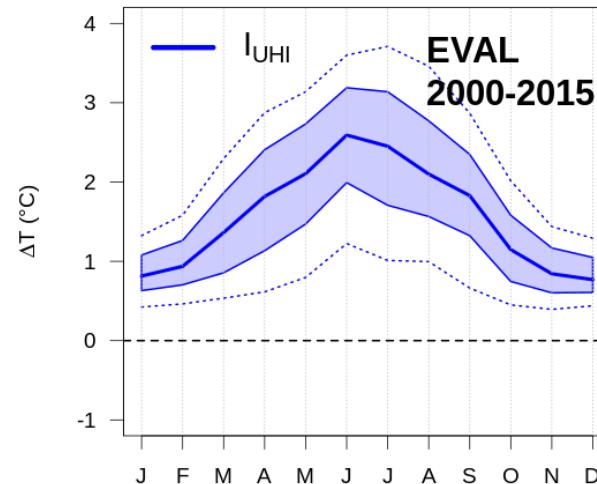
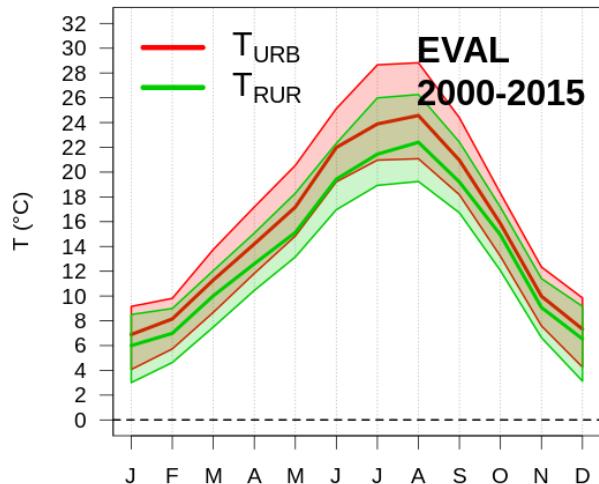
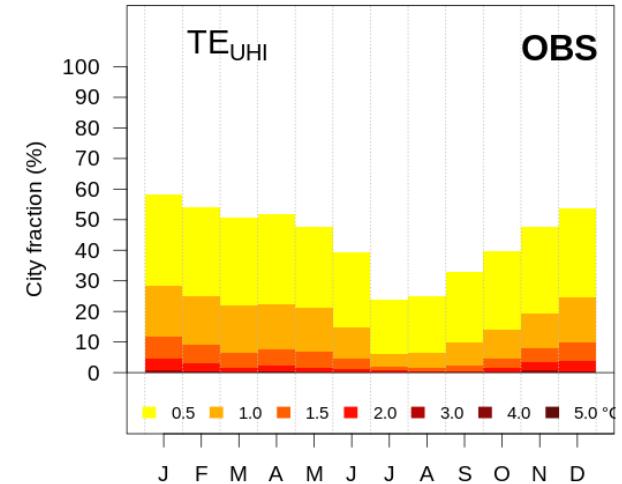
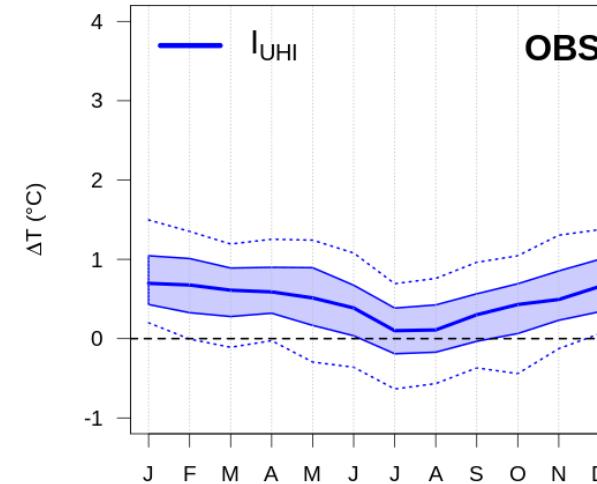
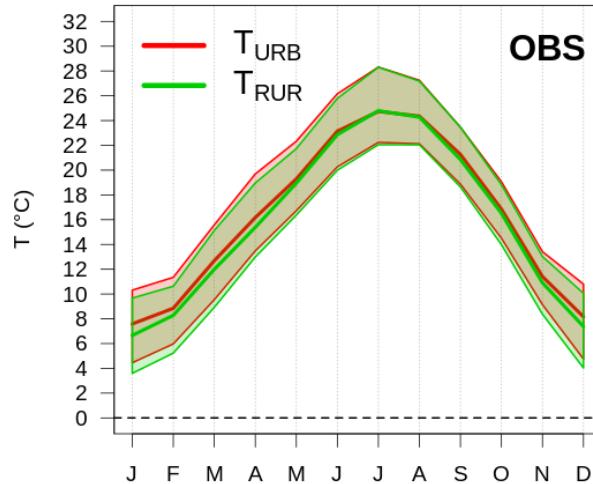
Contact : aude.lemonsu@meteo.fr

This work is supported by the European ERA4CS Project URCLIM (Advance on Urban Climate Services)



Urban Heat Island (UHI) indicators

Daytime UHI



Config AROME 41t1 2.5 km

From NWP AROME Cycle 41t1op1 (dec 2015)

Resolution : 2.5km – 60 vertical levels

Time step : 60s (*Termonia et al. 2018*)

DYNAMICS

Semi-lagrangian and semi-implicit **non-hydrostatic** ALADIN spectral dynamical core

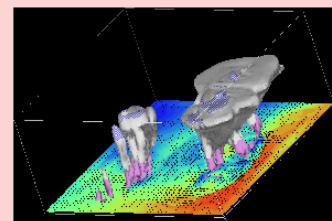


Fig : F. Bouttier

+ « Comad scheme » activated

SURFACE SCHEME Surfex 7.3

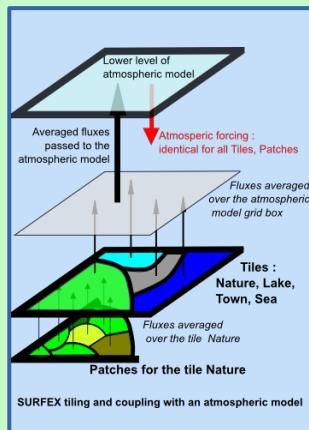


Fig : Masson et al. (2013a)

Physiographic data
ECOCLIMAP I 1km

Tiles
Nat : ISBA-3L
Town : TEB
Sea : COARE3
Lake : Charnok

Orography
GMTED2010
250m

Surface scheme : CANOPY
Snow model : D95

PHYSICS PARAMETERIZATIONS

(from MESO-NH for most of them)

Turbulence

CBR - Prognostic TKE equation



Cuxart et al. (2000)
Bougeault et Lacarrere (1989)

Clouds



Statistical cloud scheme

Bechtold et al. (1995) Pergaud et al. (2009)

Shallow convection

EDMF approach :
PMMC09



Pergaud et al. (2009)

Microphysics (+ sedimentation)

One-moment microphysics scheme
ICE 3

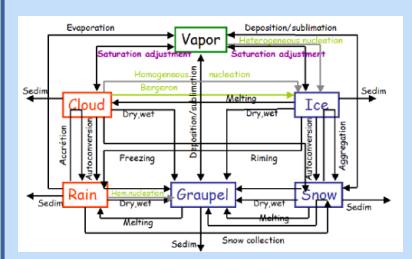


Pinty et Jabouille (1998)
Bouteloup et al. (2010)

Radiation

Version of the
ECMWF radiation
parameterizations

Longwave : RRTMG 16 bands
Iacono et al. (2008)
Mlawer et al. (1997)
Shortwave : FMR 6 bands
Fouquart and Bonnel (1980)
Morcrette (2001)



No deep convection scheme