Guest presentation at RMI

Multi-scale urban climate and air-quality modelling improvement and scenarios with COSMO-CLM and AURORA

Hendrik Wouters (VITO/KUL), Koen De Ridder (VITO), Nicole van Lipzig (KUL), Erwan Brisson (KUL), Matthias Demuzere (KUL), Sajjad Saeed (KUL), Erwan Brisson (KUL), Gerd Vogel (DWD), Shaun Carl (KUL)

DEPARTMENT OF EARTH AND ENVIRONMENTAL SCIENCES
K.U.LEUVEN - BELGIUM

CLM Community

MACCBET — Modelling atmospheric composition and climate for the Belgian territory

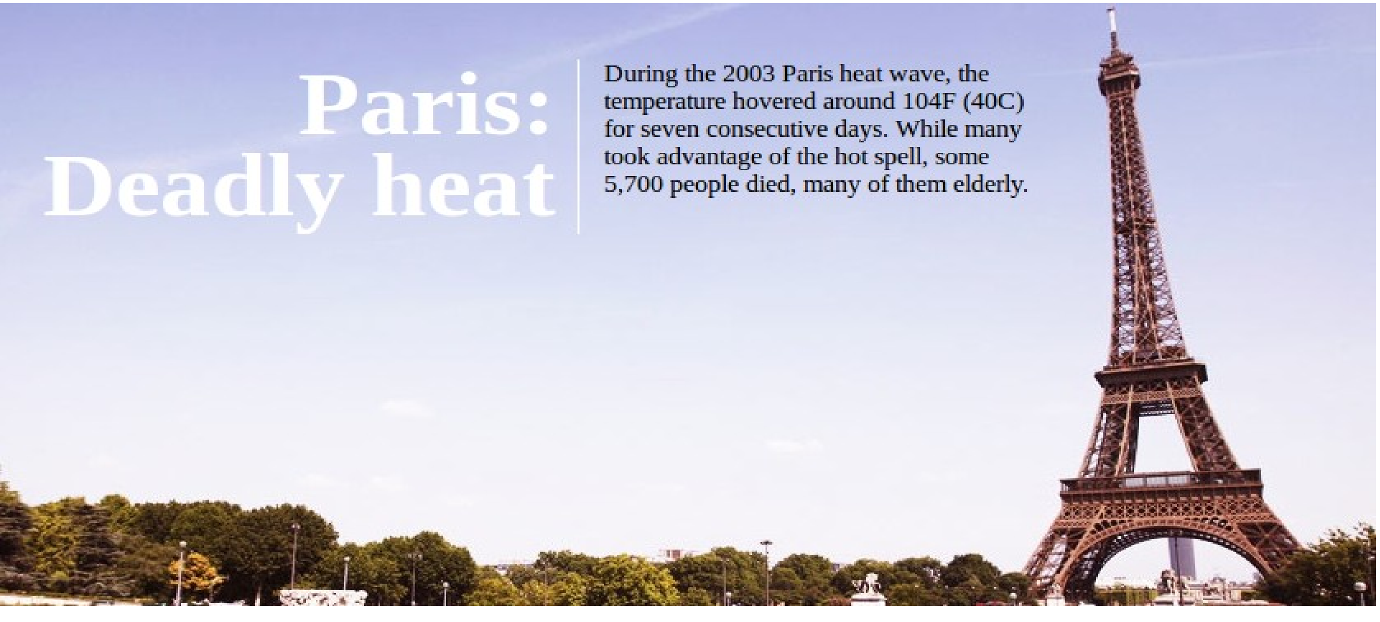
vito — vision on technology

Short overview

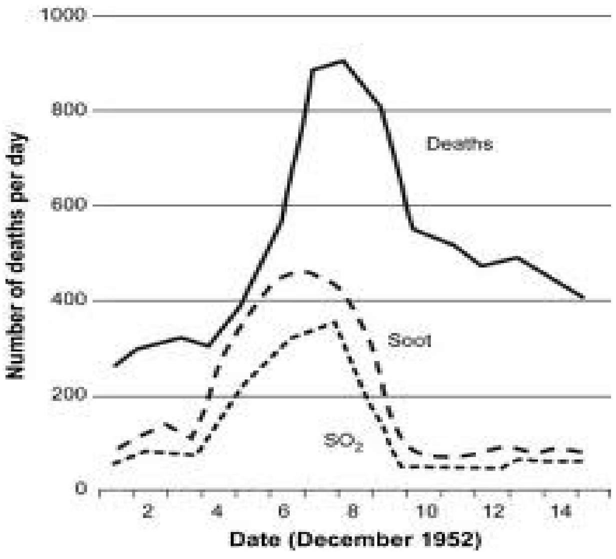
- Introduction:
  - Motivation
  - Overview of urban parametrizations in the CLM-community
  - Overview of activities of VITO
- Urban parametrizaton of TERRA-ML
  - 'Offline' evaluation for Marseille and Toulouse
- Urban parametrization of COSMO-CLM/TERRA_ML
  - Test results over Europe
- Further outlook

Motivation (1/2)

- Large discrepancy exists between urban and natural areas
- Cities: where most people of the world live!
- Urban climate and air quality affects human health



London smog episode

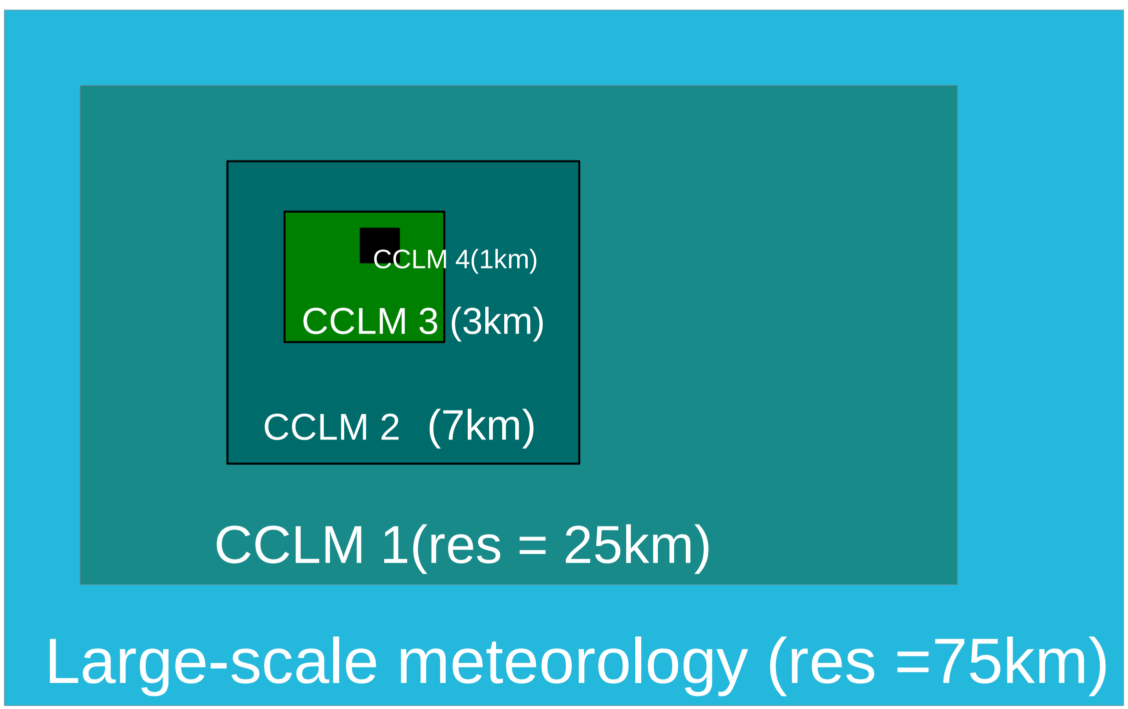


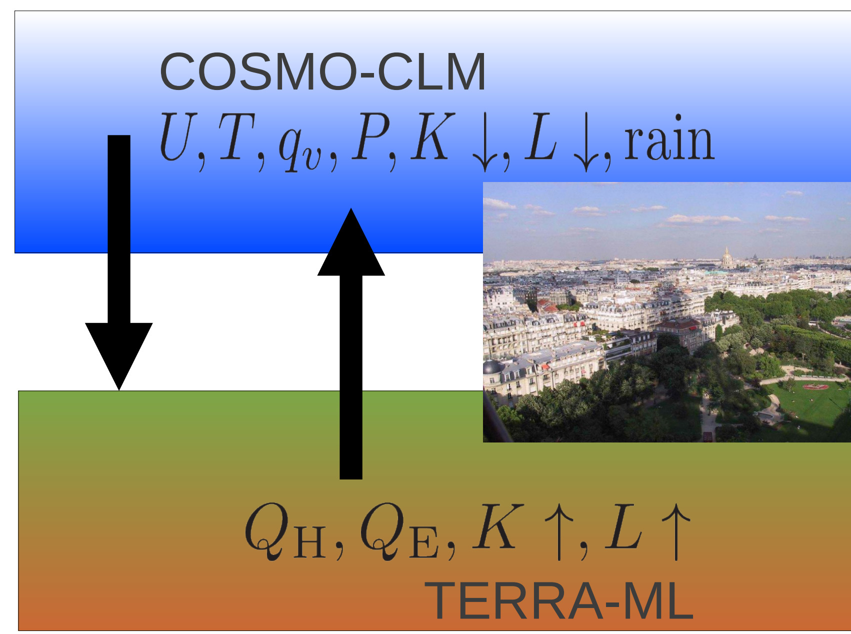
Motivation (2/2)

- How to counter these hazardous effects?
  - Investigate processes with regional climate and air-quality simulations
- Therefore, a correct **representation** of **urban climate** is **needed**

Regional climate model COSMO-CLM

- Based on COSMO, developed at DWD
- Horizontal resolution: up to 1km x 1km
- Developed and used by an active and growing european cooperation: CLM-community
- ‘Nesting’-capability





Overview of different urban parametrizations within the CLM-community

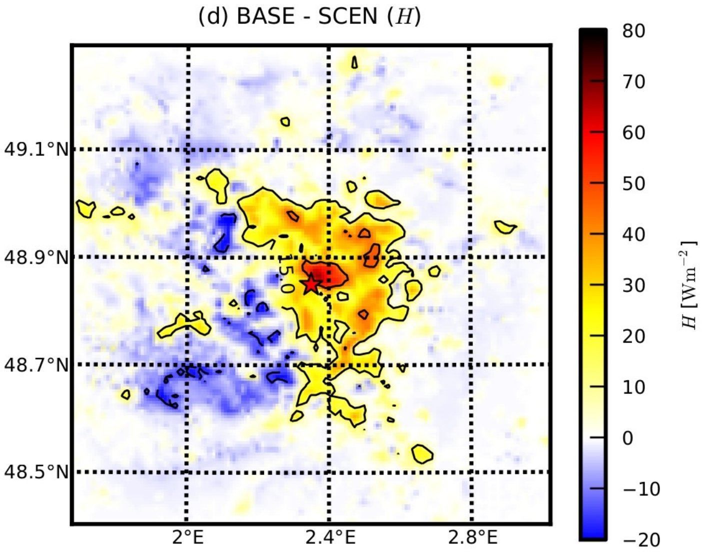
Name	TEB alongside TERRA_ML	TEB inside CLandM	TERRA_MLU	TERRA_ML / PEB
Responsability	Kristina Trusilova	Matthias Demuzere	Hendrik Wouters	Sebastian Schubert
Features	inner building temperature snow model, water skin layer roofs/walls/roods, tiled urban fraction	idem	Direct representation of the urban surface using a tile approach, new surface-layer transfer coefficients, anthropogenic heat and water puddles	Street canyon model advanced double-canyon radiation scheme, shadows, radiation trapping, roof/wall/ground fluxes
input		Urban properties dataset	Urban fraction (EEA), Yearly-averaged anthropogenic heat (NCAR)	Full 3D cityGML
References	Trusilova et al 2008, Masson 2001	Masson 2001, Oleson et al. 2008, Jackson et al. 2010	Wouters et al. 2012, Flanner 2010, Demuzere et al. 2008, De Ridder, 2006	Schubert et al. 2012, Martilli et al. 2002,Gröger et al. 2008
Aims	Urban climate of Europe and Germany	Urban climate mitigation for Melbourne (Australia)	urban climate impact on Air-quality simulations over Antwerp, Urban climate of Europe	Urban climate of Berlin and Basel

Different urban parametrizations in COSMO-CLM. Why?

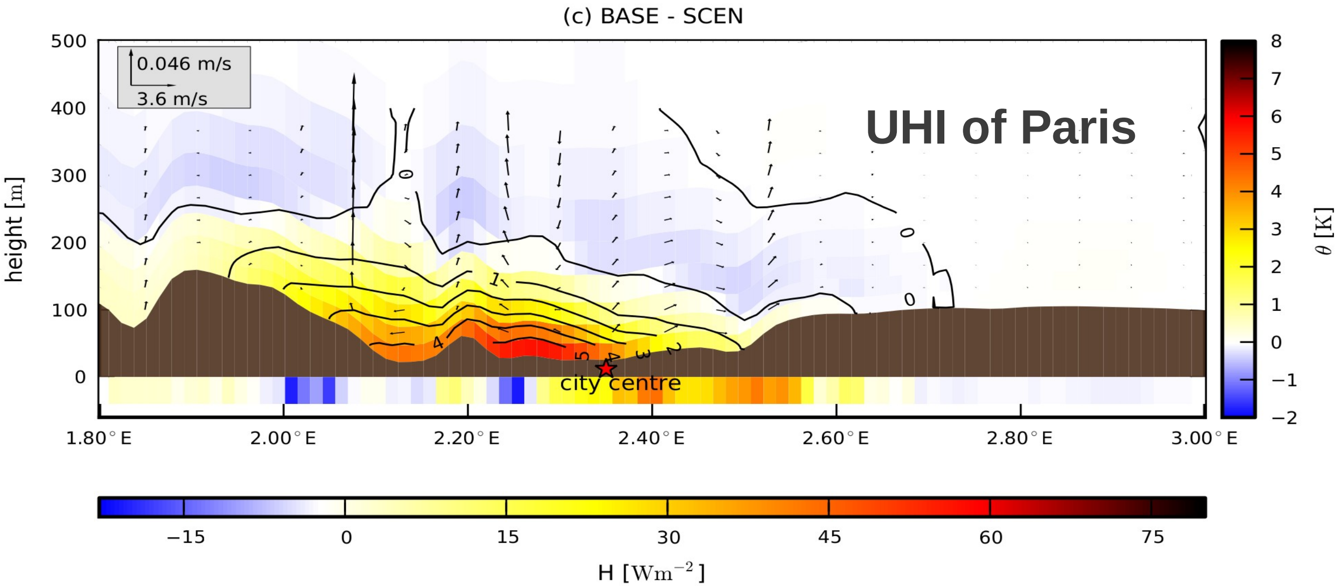
- There is no perfect model...
  - Large vs. Small # of parameters
  - Computational cost vs. Speed
  - Built-in extension vs. External module
  - Different approaches have different applications
- Comparison study is planned: as the urban parametrizations are implemented into one single climate model (COSMO_CLM), one can discover more precisely the strengths and weaknesses of each
- Eventually, features that are found most important may be transferred from one to another.

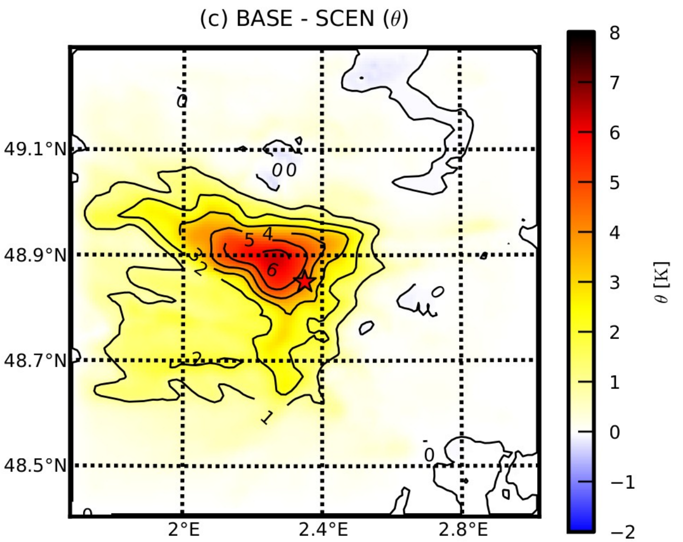
Urban upgrade of TERRA_ML

urban upgrade from scratch in the line of earlier studies with ARPS/LAICA



ARPS/LAICA: Sarkar and De Ridder., 2010
Wouters et al., 2013 (under review)

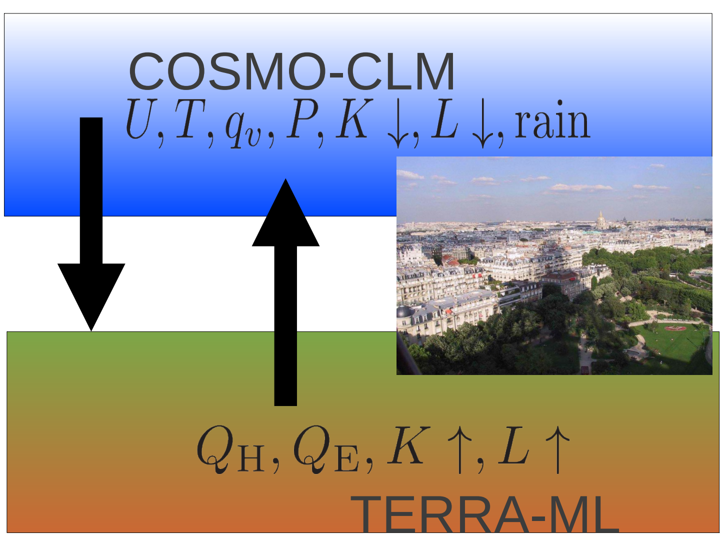




Urban implementation strategy

- **Urban** implementation in **TERRA-ML standalone**
- Offline evaluation **TERRA-MLU** at urban sites
- Apply this upgrade to the coupled model

  → COSMO-CLM/TERRA-MLU



Urban implementation strategy

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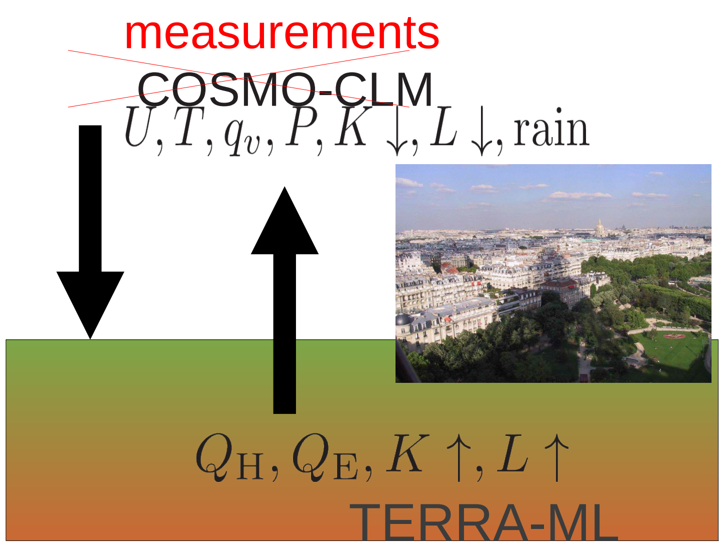
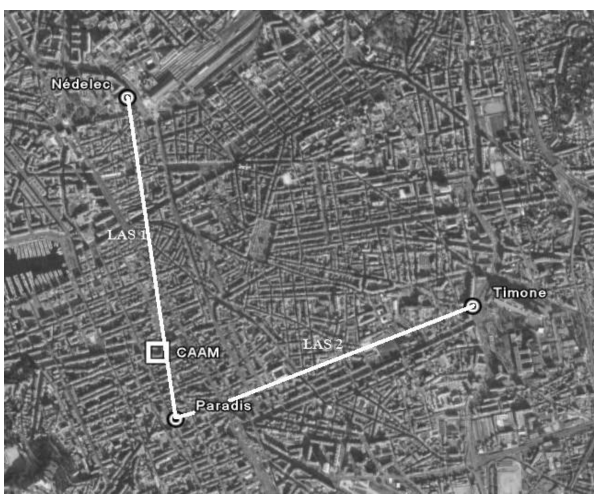


Urban upgrade of TERRA-ML standalone

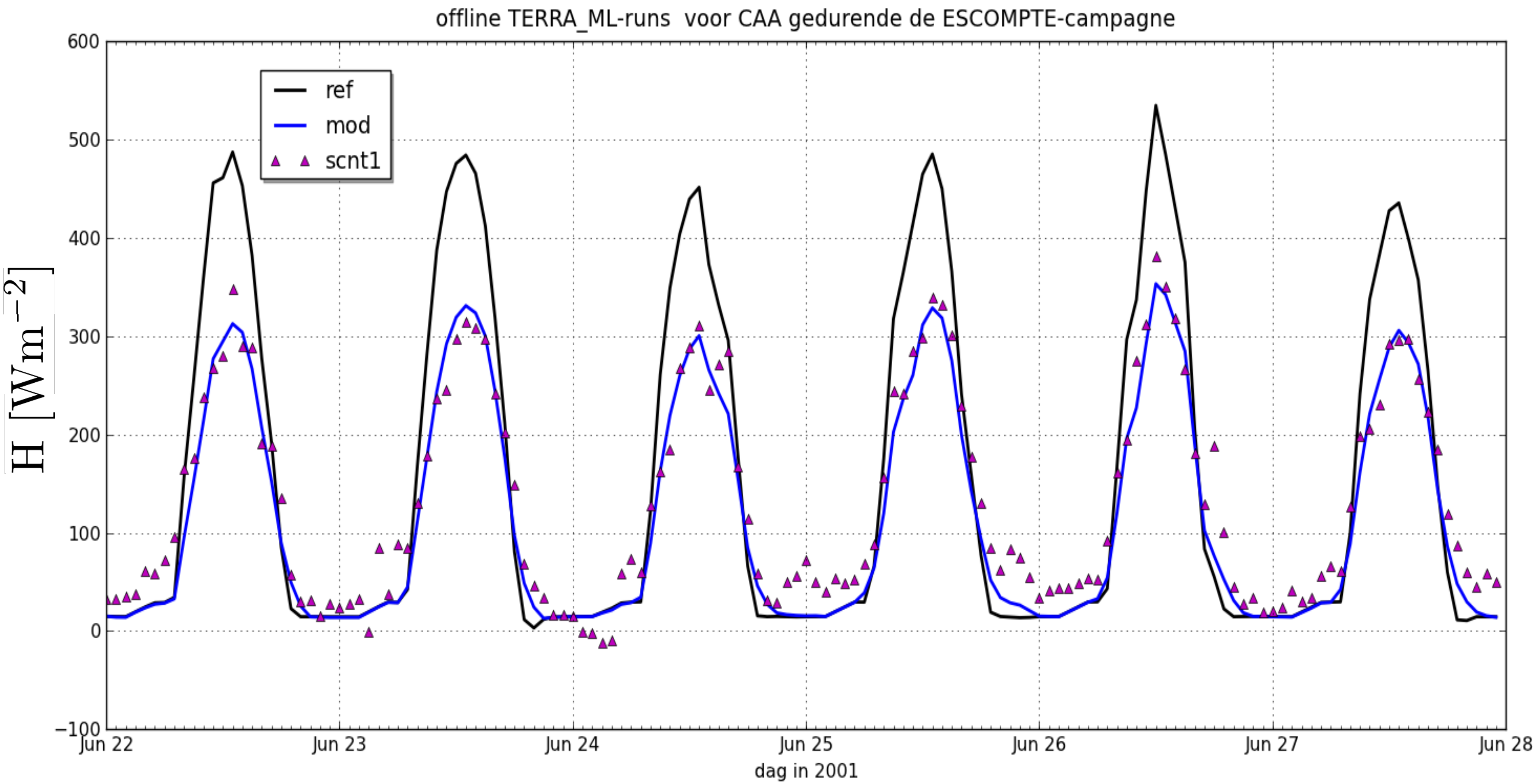
- Urban **aerodynamic upgrade***:*
  - ***Bluff-rough thermal roughness length parametrization*** *is valid for urban surfaces (De Ridder 2006), which can represent the heat trapping inside the street canyons*
  - *Therefore the* ***Zilitinkevich (1993)*** *Bluff-rough thermal roughness parametrization is adopted which was tested by Demuzere et al. (2008)*
  - *A* ***non-iterative procedure*** *for the calculation of* ***surface-layer transfer coefficients*** *is adopted as well (Wouters et al., 2012), replacing the Louis-type scheme*
- **urban land-use** class with specific surface parameters *(Sarkar and De Ridder, 2010)***:** albedo, emissivity, conductivity, heat capacity
- **Anthropogenic heat**
- **A water 'puddle' store** for the impervious urban surface

A first evaluation



- **Marseille Escompte campaign** (Cros et al., 2003): *Expérience sur Site pour COntraindre les Modèles de Pollution atmosphérique et de Transport d'Emissions*
- **Tower measurements** for offline forcing:
  - $U, T, q_v, P, K\downarrow, L\downarrow, \text{rain}$
- **Scintillometry measurements** of sensible heat during a 6-day summer clear-sky period

A first evaluation



Offline runs with CAPITOUL

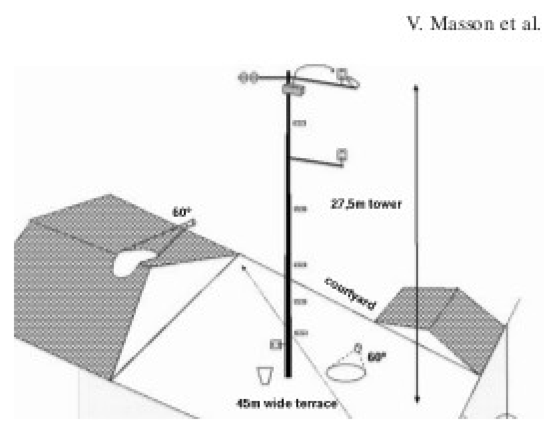
- **CAPITOUL** (Masson et al., 2008): The Canopy and Aerosol Particles Interactions in TOulouse Urban Layer experiment
- Measurements for **offline forcing** of the surface model:

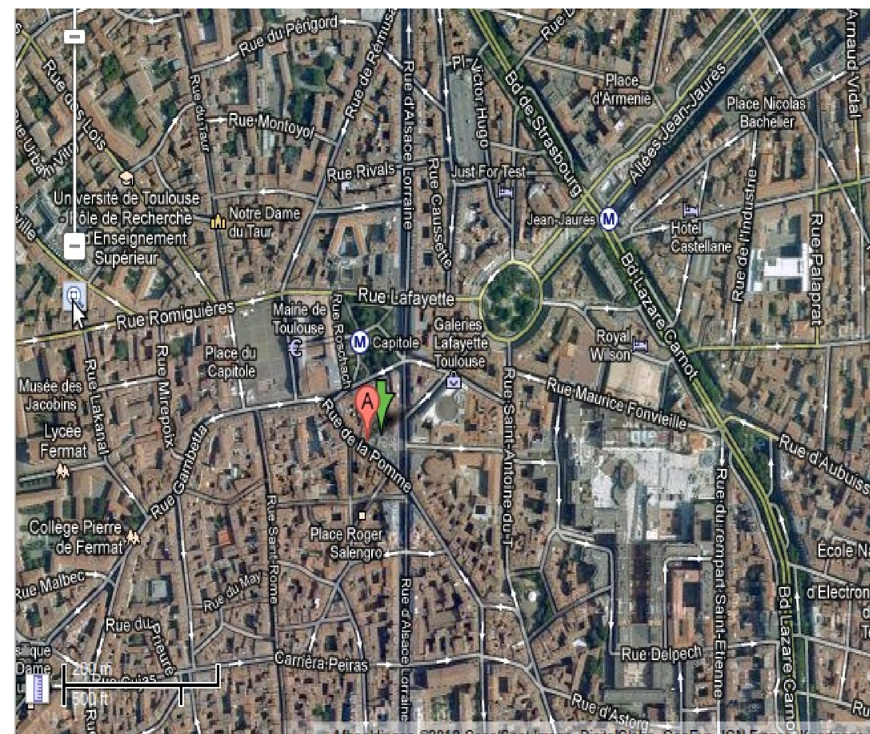
$$U, T, q_v, P, K\downarrow, L\downarrow, \mathrm{rain}$$

- Measurements for **validation**:

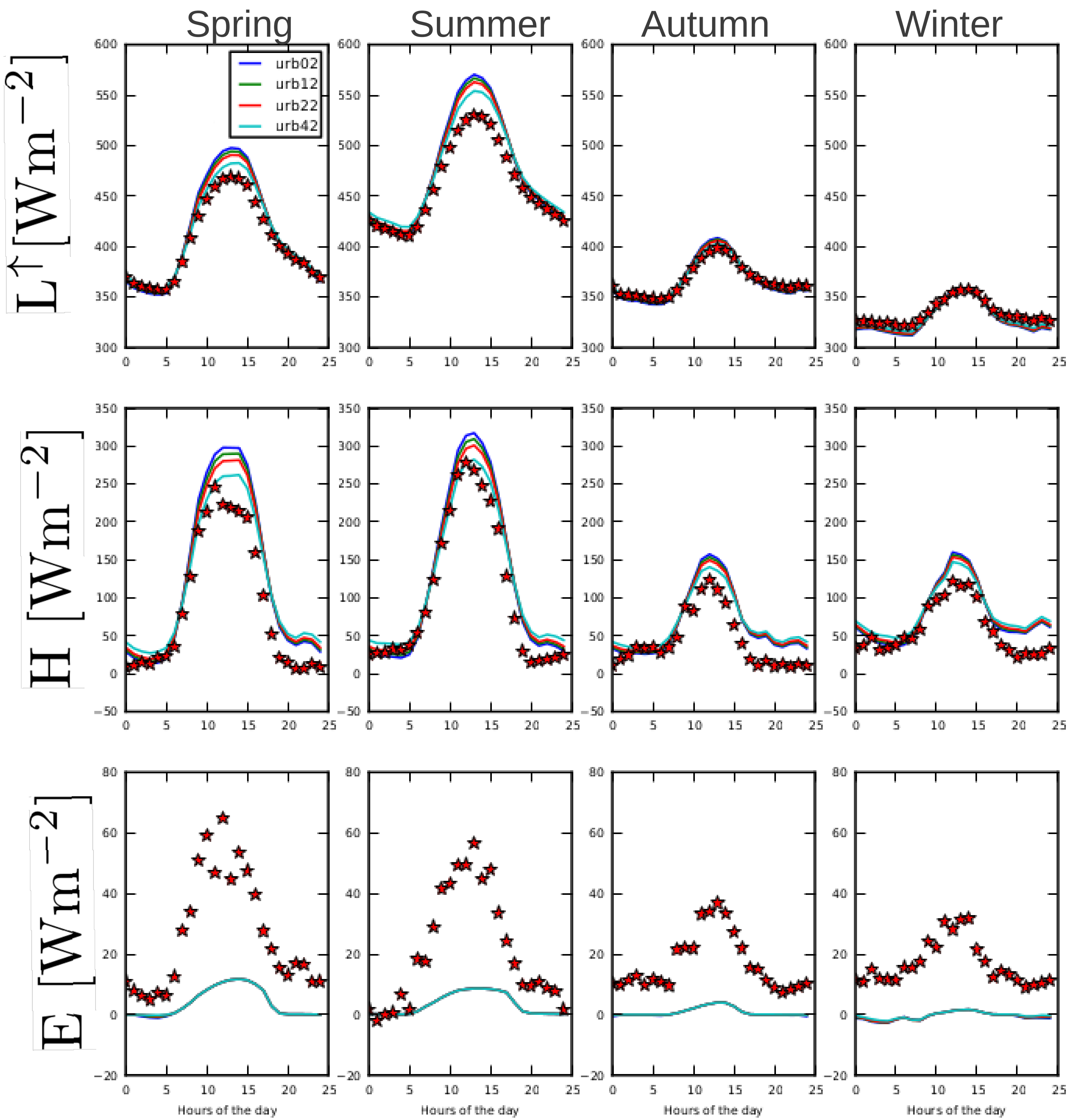
$$Q_{\mathrm{H}}, Q_{\mathrm{E}}, K\uparrow, L\uparrow$$

- One-year (!) offline runs are possible
  - Evaluation for every seaon
  - Sensitivity tests for finding the best parameter values for the urban surface





Evaluation without 'urban evaporation'



$$\mu = \sqrt{\lambda c_p}$$

$$\begin{aligned} \mu_{02} &= 1.65 \\ \mu_{12} &= 1.82 \\ \mu_{22} &= 2.01 \\ \mu_{32} &= 2.23 \\ \mu_{42} &= 2.46 \end{aligned}$$

$$\cdot 10^3 \mathrm{Jm^{-2}s^{1/2}K^{-1}}$$

Evaluation without 'urban evaporation'

	Q_L				Q_H			
winter	urb12	urb22	urb32	urb42	urb12	urb22	urb32	urb42
RMSE	4.978	4.571	4.253	**4.058**	26.349	25.246	24.296	**23.551**
MAE	5.956	5.553	5.221	**4.938**	28.937	28.735	**28.592**	28.661
BIAS	5.373	5.031	4.673	**4.277**	**-21.493**	-22.294	-23.184	-24.243
R2	0.977	0.980	0.982	**0.983**	0.848	0.860	0.870	**0.879**
spring	urb12	urb22	urb32	urb42	urb12	urb22	urb32	urb42
RMSE	11.752	9.904	8.110	**6.520**	32.365	30.129	28.387	**27.484**
MAE	10.729	9.383	8.221	**7.313**	37.474	36.172	35.154	**34.364**
BIAS	-8.851	-8.283	-7.689	**-7.061**	-34.504	-32.943	-31.353	**-29.709**
R2	0.992	0.993	**0.993**	0.993	**0.960**	0.959	0.958	0.957
summer	urb12	urb22	urb32	urb42	urb12	urb22	urb32	urb42
RMSE	13.542	11.393	9.173	**6.918**	29.589	28.053	27.114	**27.095**
MAE	15.113	14.815	14.497	**14.125**	28.315	27.242	**26.516**	26.712
BIAS	-15.110	-14.815	-14.497	**-14.125**	-20.822	-20.149	-19.433	**-18.608**
R2	0.995	0.995	0.996	**0.996**	**0.965**	0.964	0.963	0.962
fall	urb12	urb22	urb32	urb42	urb12	urb22	urb32	urb42
RMSE	6.649	5.685	4.751	**3.846**	25.002	24.322	23.763	**23.396**
MAE	5.334	4.530	3.790	**3.104**	**28.210**	28.336	28.608	29.018
BIAS	0.284	**-0.063**	-0.359	-0.612	**-22.408**	-22.902	-23.398	-23.886
R2	0.991	0.993	0.995	**0.996**	**0.840**	0.838	0.836	0.834

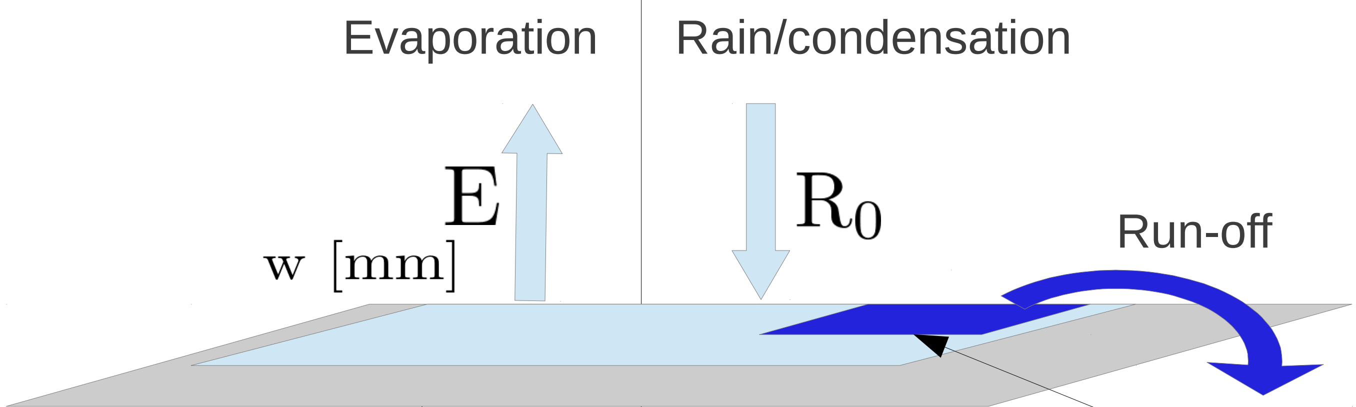
$$\mu = \sqrt{\lambda c_p}$$

$$\mu_{02} = 1.65$$
$$\mu_{12} = 1.82$$
$$\mu_{22} = 2.01$$
$$\mu_{32} = 2.23$$
$$\mu_{42} = 2.46$$

$$\cdot 10^3 \mathrm{J m^{-2} s^{1/2} K^{-1}}$$

Puddle store for impervious soil

Inspired by a formulation for tree canopy interception De Ridder (2001)



Evaporation

$$\frac{dw}{dt} = -E = -E_p\left(1 - e^{-\frac{w}{w_f}}\right)$$

Solution:

$$\mathrm{w(t{+}\Delta}t) = w_f \ln\left[e^{-E_p\frac{\Delta t}{w_f}}\left(e^{\frac{w(t)}{w_f}} - 1\right) + 1\right]$$

w_f: water storage at which the evaporation diminishes with respect to the maximum potential evaporation (E_p)

→ controls how fast water evaporates

Run-off

$$\frac{dw}{dt} = R_f = R_0\left[1 - e^{-c_f\left(1 - \frac{w}{w_m}\right)}\right]$$

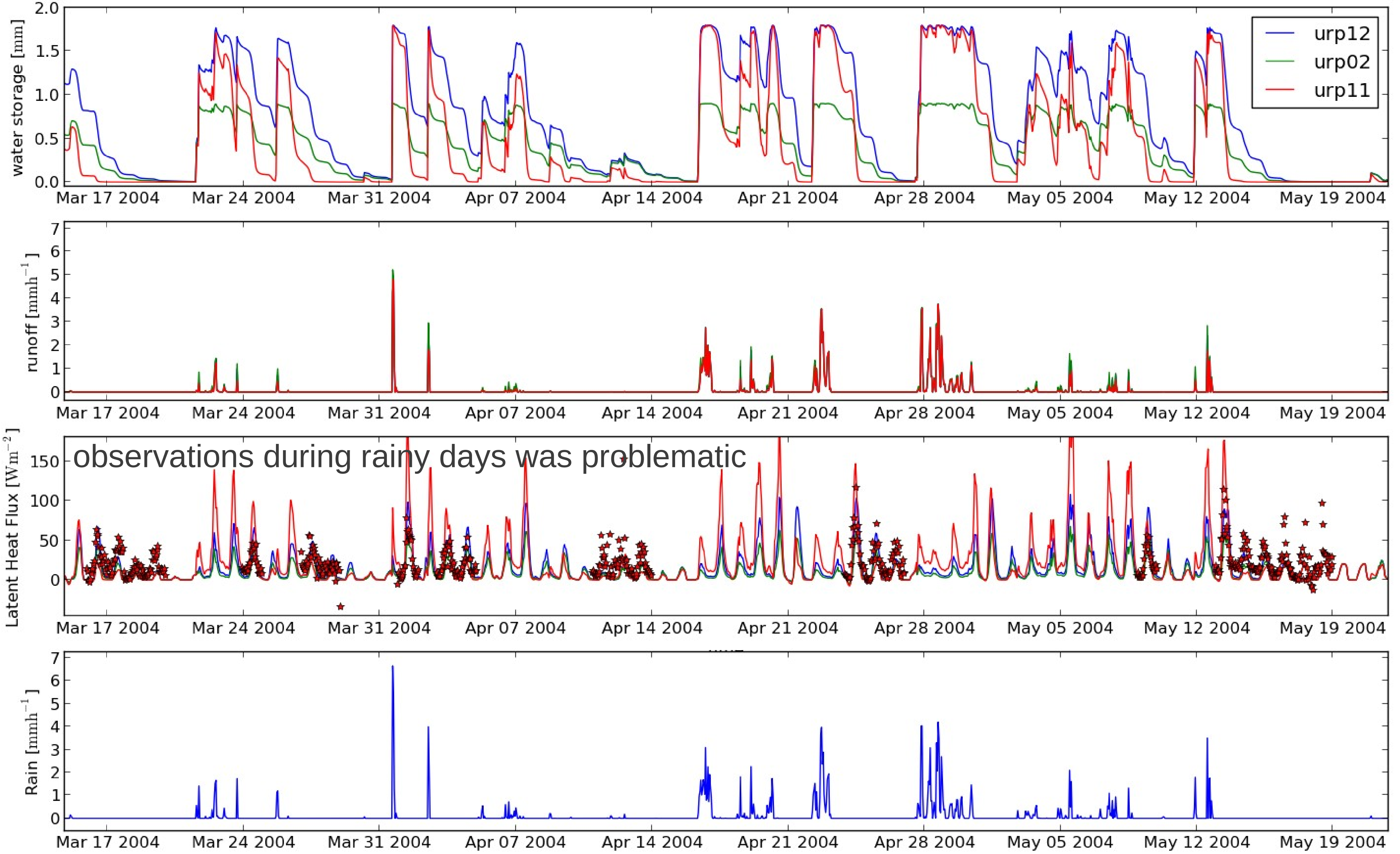
Solution:

$$\mathrm{w(t{+}\Delta}t) = (w_m - \frac{w_m}{c_f}\ln\left[1 - \left(1 - e^{c_f\left(1 - \frac{w(t)}{w_m}\right)}\right) e^{-c_f\frac{R\Delta t}{w_m}}\right]$$

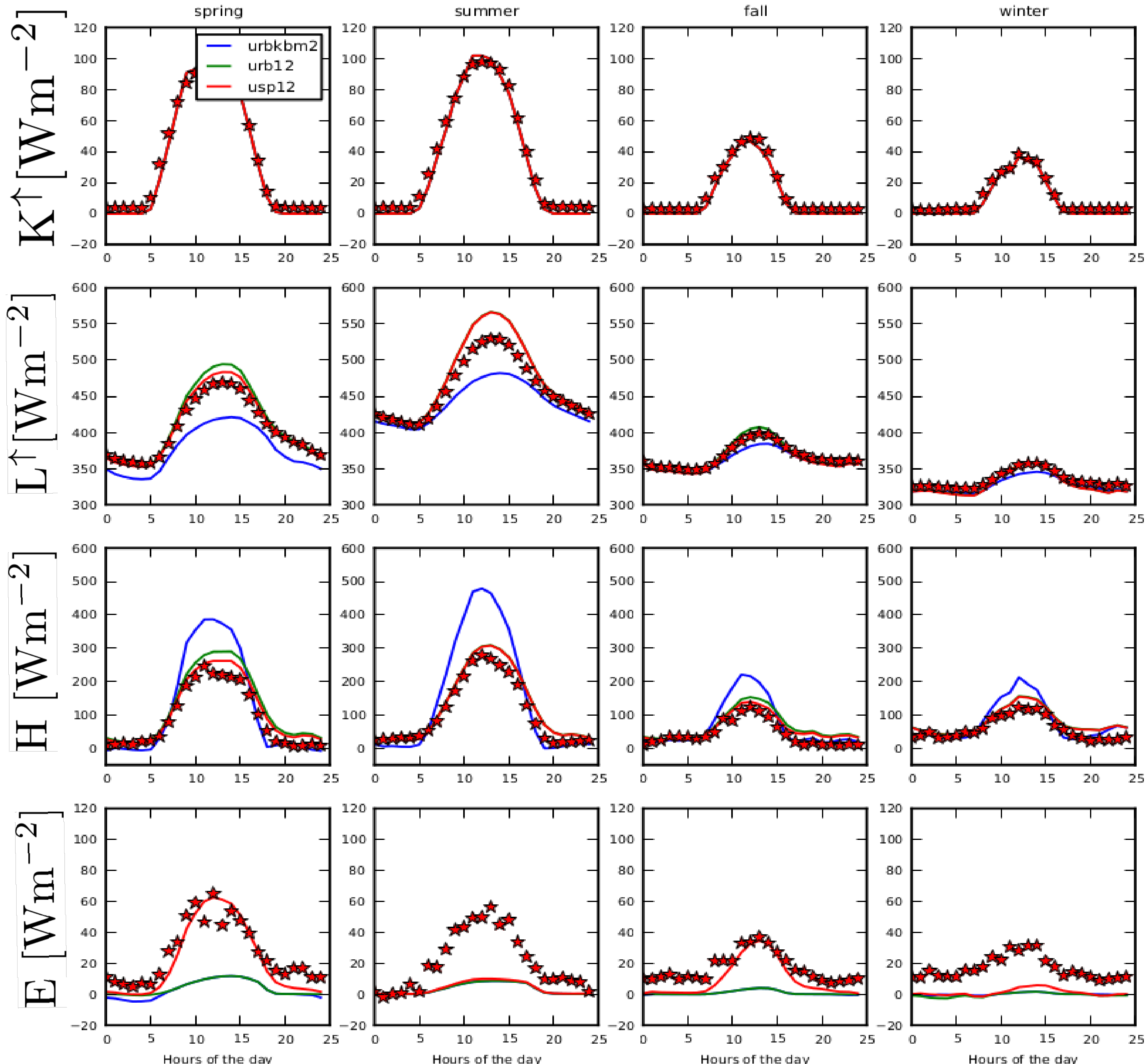
w_m: ~ maximum water storage

→ controls how much water evaporates (or otherwise goes to run-off)

Puddle store



One-year offline evaluation of TERRA-MLU



One-year offline evaluation of TERRA-MLU

	Q_L			Q_H			Q_E		
winter	urbkbm2	urb12	usp12	urbkbm2	urb12	usp12	urbkbm2	urb12	usp12
RMSE	**4.394**	4.978	4.782	40.044	**26.349**	26.825	14.098	13.604	**12.645**
MAE	7.168	**5.956**	6.230	35.560	28.937	**28.274**	17.331	17.669	**16.434**
BIAS	7.168	**5.373**	5.882	-22.378	-21.493	**-19.951**	16.783	17.279	**15.593**
R2	**0.982**	0.977	0.979	0.824	**0.848**	0.842	0.362	0.412	**0.523**
spring	urbkbm2	urb12	usp12	urbkbm2	urb12	usp12	urbkbm2	urb12	usp12
RMSE	16.137	11.752	**8.593**	82.244	32.365	**27.993**	18.615	19.370	**14.816**
MAE	28.612	10.729	**7.402**	64.857	37.474	**27.751**	23.642	22.738	**12.314**
BIAS	28.612	-8.851	**-3.887**	-34.424	-34.504	**-21.652**	23.642	22.689	**4.537**
R2	0.947	0.992	**0.995**	0.943	**0.960**	0.959	0.708	0.687	**0.851**
summer	urbkbm2	urb12	usp12	urbkbm2	urb12	usp12	urbkbm2	urb12	usp12
RMSE	16.776	13.542	**13.482**	93.184	29.589	**29.541**	23.757	23.757	**23.520**
MAE	20.547	15.113	**14.677**	74.168	28.315	**27.737**	20.094	20.094	**19.605**
BIAS	20.547	-15.110	**-14.641**	-51.336	-20.822	**-19.823**	18.267	18.267	**17.683**
R2	0.968	0.995	**0.995**	0.965	**0.965**	0.965	**0.639**	**0.639**	0.607
fall	urbkbm2	urb12	usp12	urbkbm2	urb12	usp12	urbkbm2	urb12	usp12
RMSE	**4.741**	6.649	5.146	44.429	25.002	**22.900**	**13.220**	13.287	13.719
MAE	6.120	5.334	**4.955**	34.021	28.210	**23.171**	16.999	16.951	**12.721**
BIAS	6.110	**0.284**	2.727	-25.772	-22.408	**-16.303**	16.130	16.066	**7.247**
R2	0.989	0.991	**0.991**	**0.868**	0.840	0.849	0.522	0.527	**0.533**

Conclusions for the standalone/offline runs

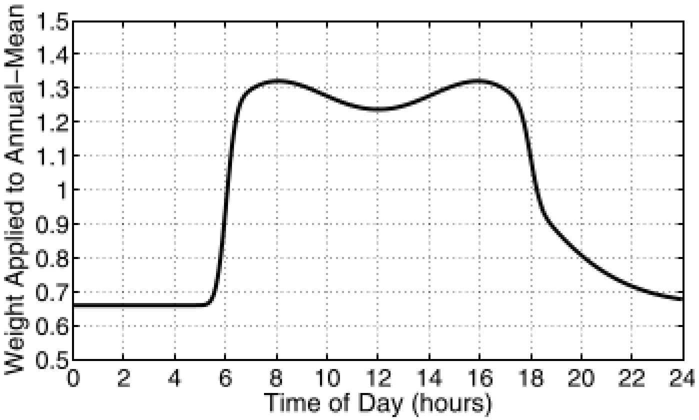
- **TERRA-MLU** module is **able to simulate** the **surface fluxes** for an **urban** site in Toulouse **very well** by prescribing **urban key parameters**.
  - **Improvements** are **obtained** when subsequently applying the bluff-rough **urban aerodynamic upgrade** and implementing a **water puddle store**
  - It is verified that a **bluff-rough thermal roughness parametrization** is **necessary and suitable** for **urban surface-flux simulations**
- The **latent heat remains** a **difficult** process to model and to observe, even for simpler water processes for urban areas compared to vegetative sites

Urban upgrade COSMO-CLM/TERRA-ML coupling

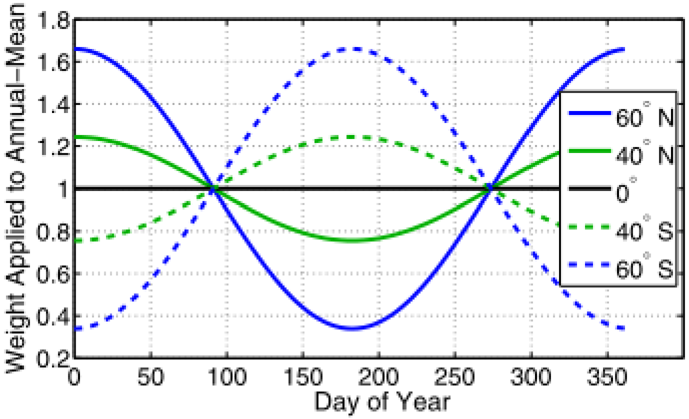
- **Tile approach** for TERRA_ML in COSMO_CLM → easily extendable for other tiles
- **TERRA-ML → TERRA-MLU**
  - **In addition, implementation of (the diurnal/annual cycle of) anthropogenic heat based on Flanner (2009)**

Anthropogenic heat *(Flanner, 2009):*

Diurnal cycle



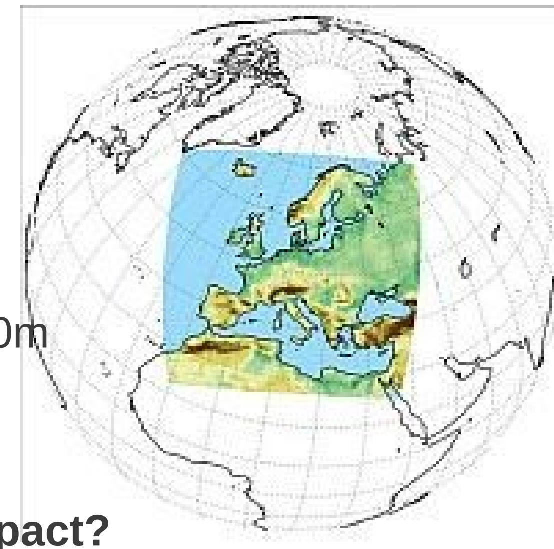
Annual cycle

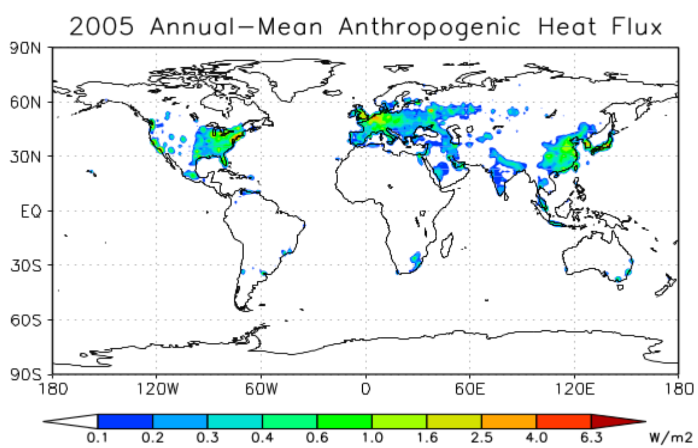


Test configuration of COSMO-CLM

- **CORDEX EU** domain (25km resolution)
- **Input:**
  - **External parameters** (elevation, NDVI, LAI, surface type and roughness lengths...) from **EXPAR**-tool of the CLM-community
  - **annual-mean Anthropogenic heat** (*Flanner 2009*)
  - Satellite-derived **urban** impervious **fraction** (soil-sealing @ 100m resolution) from EEA
- **Boundary conditions: ERA-INTERIM** (75km resolution)
- **2 runs during 1999**: *with* vs. *without* urban surface features → **impact?**

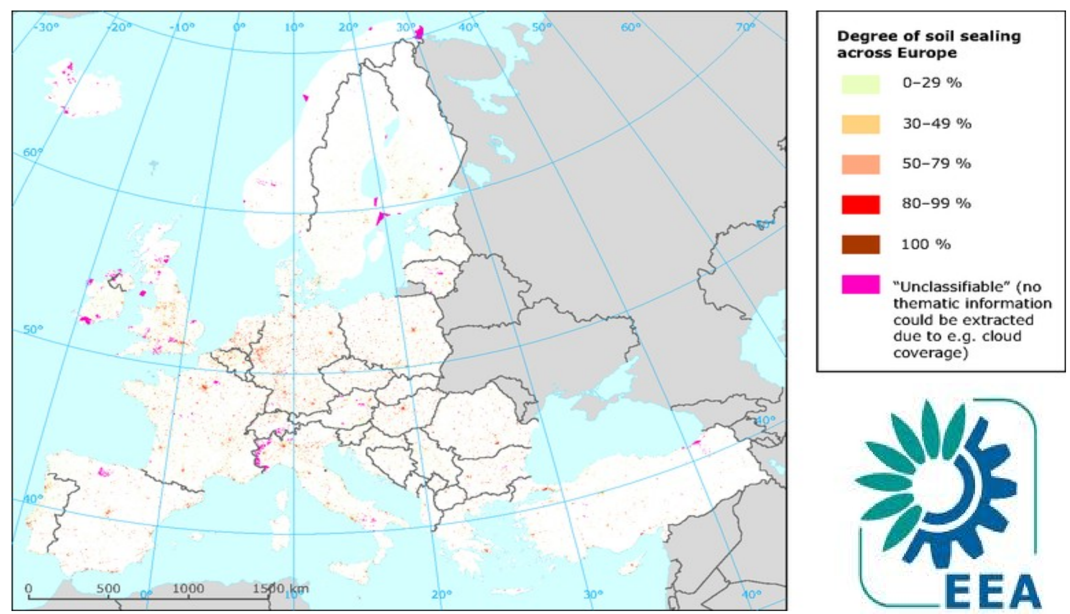
CORDEX Europe





Flanner (2009)

NCAR



EEA

Test configuration of COSMO-CLM

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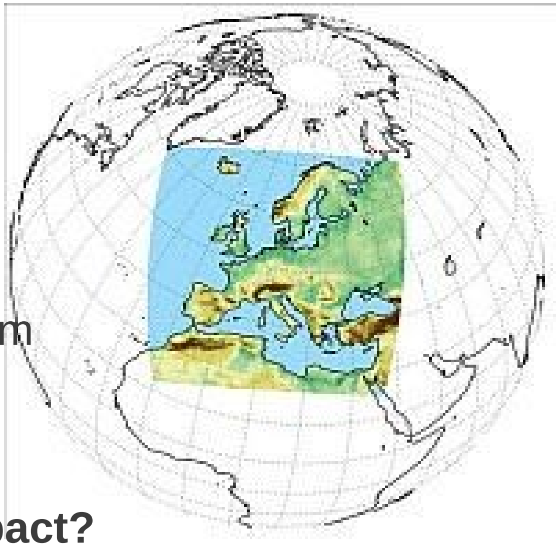
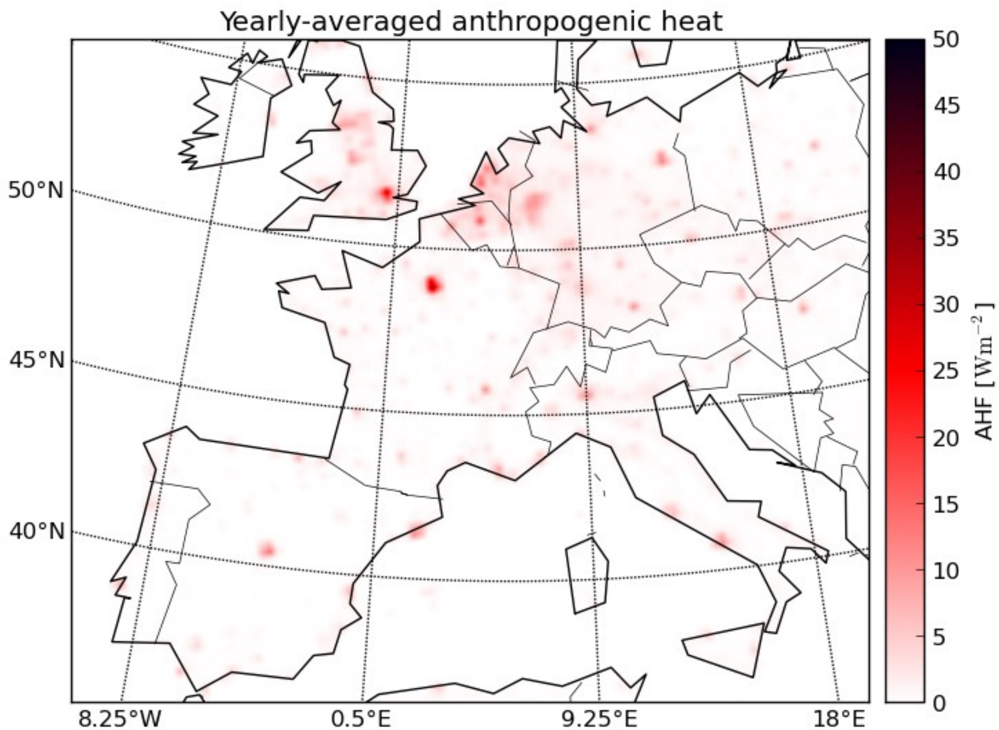
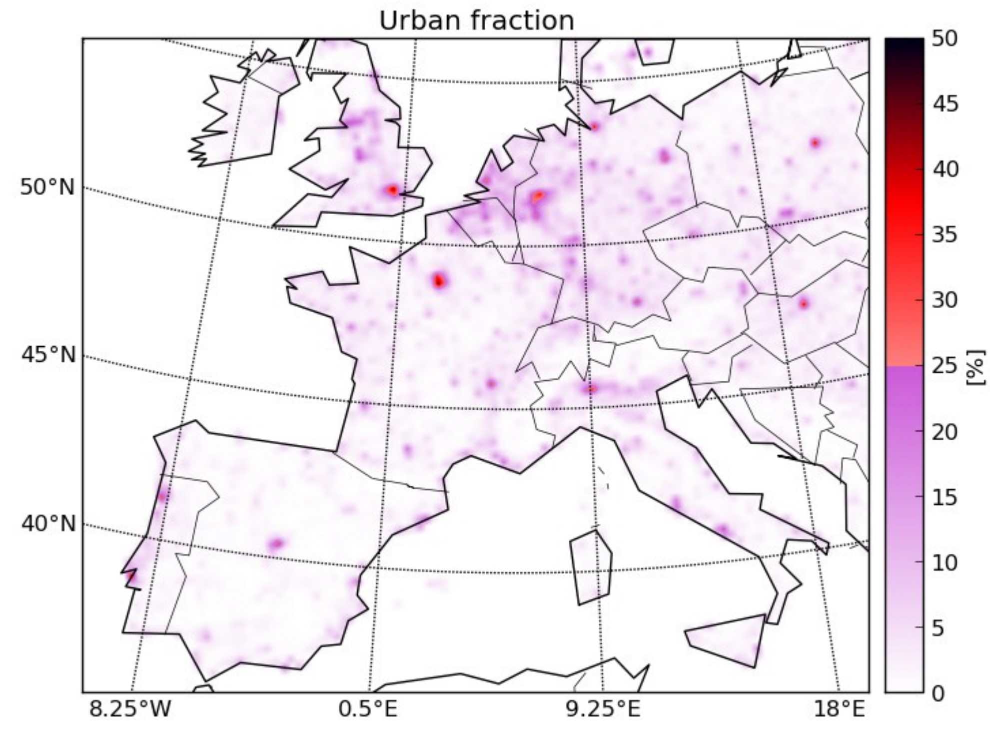
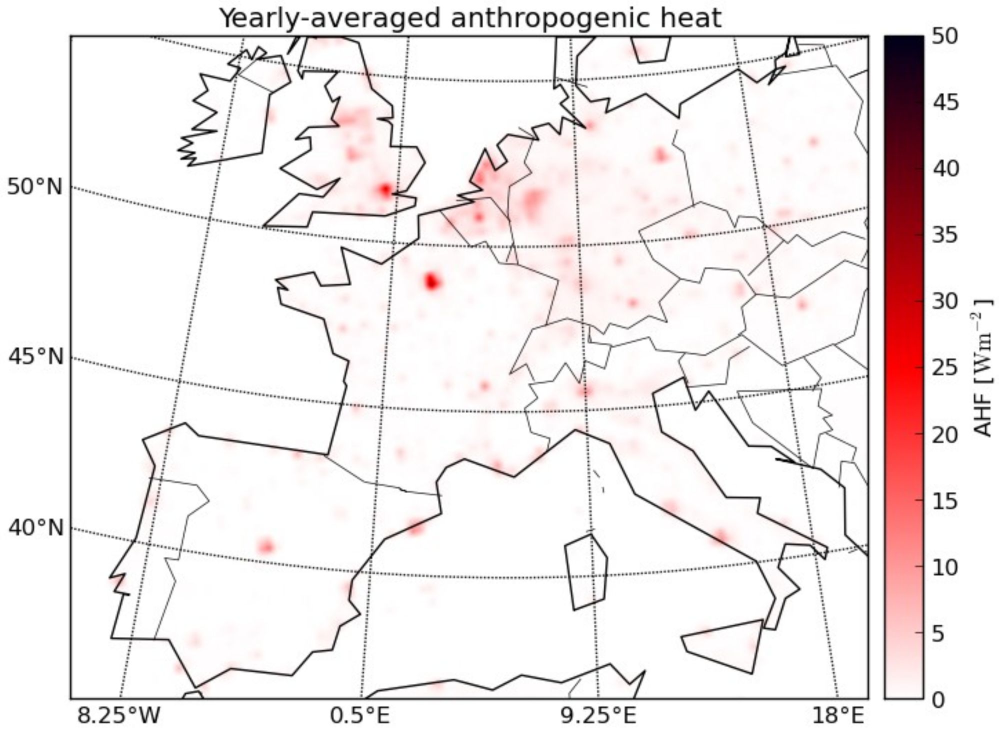
CORDEX Europe



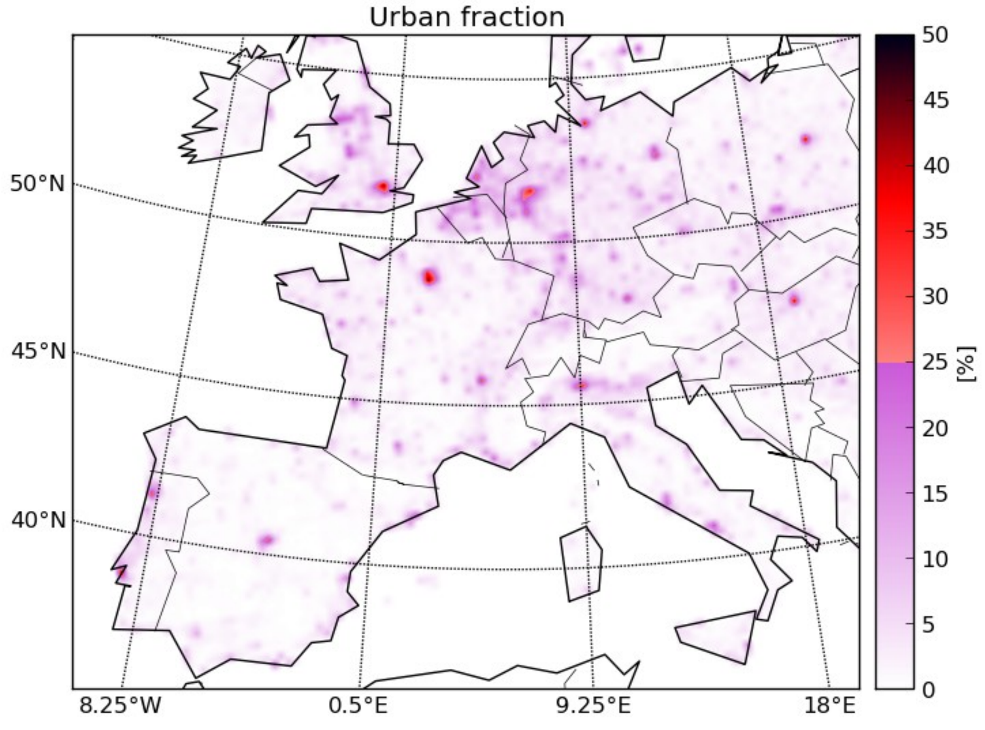




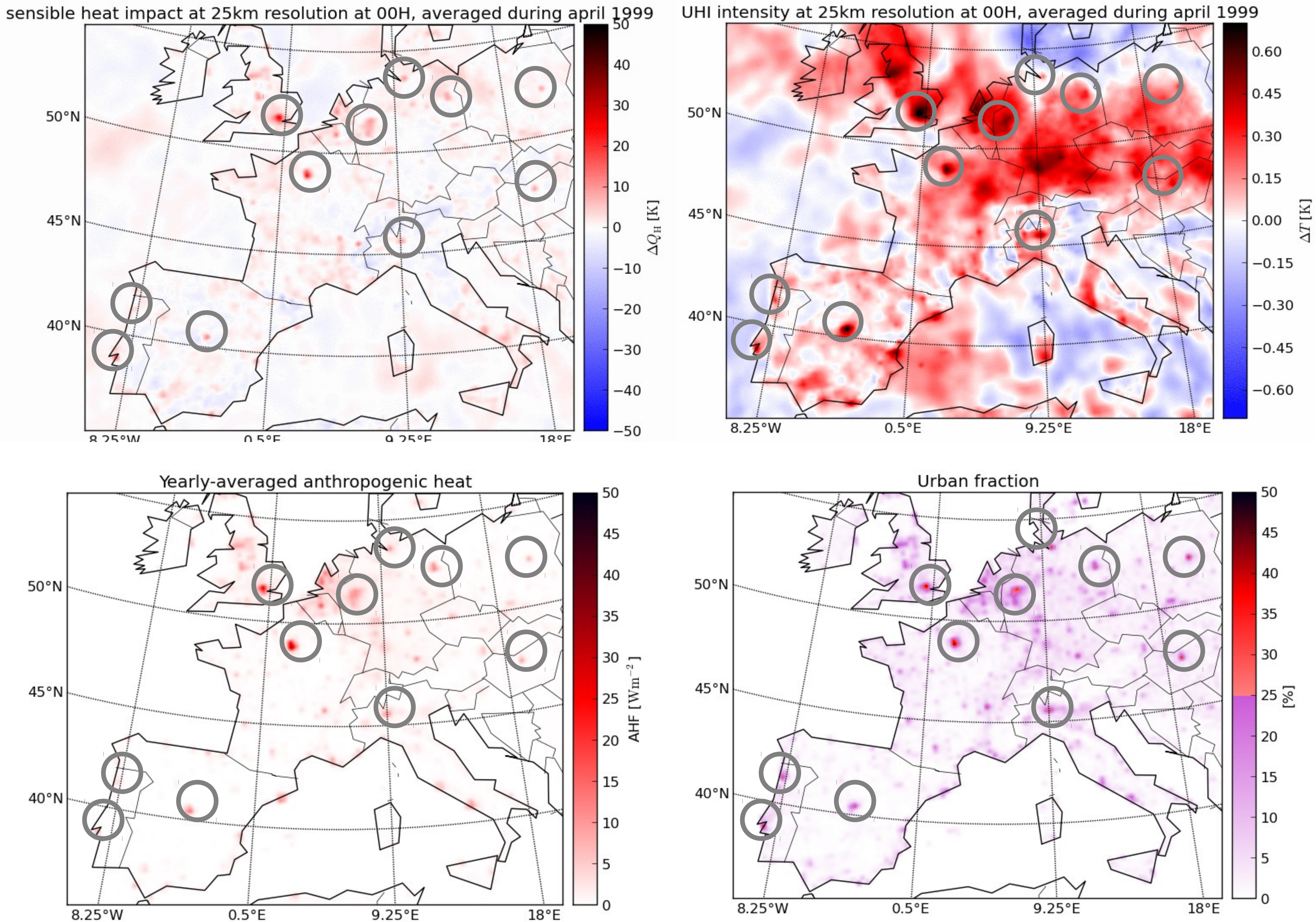
Results



Yearly-averaged anthropogenic heat
50°N
45°N
40°N
8.25°W
0.5°E
9.25°E
18°E
AHF [$\mathrm{Wm^{-2}}$]
0
5
10
15
20
25
30
35
40
45
50

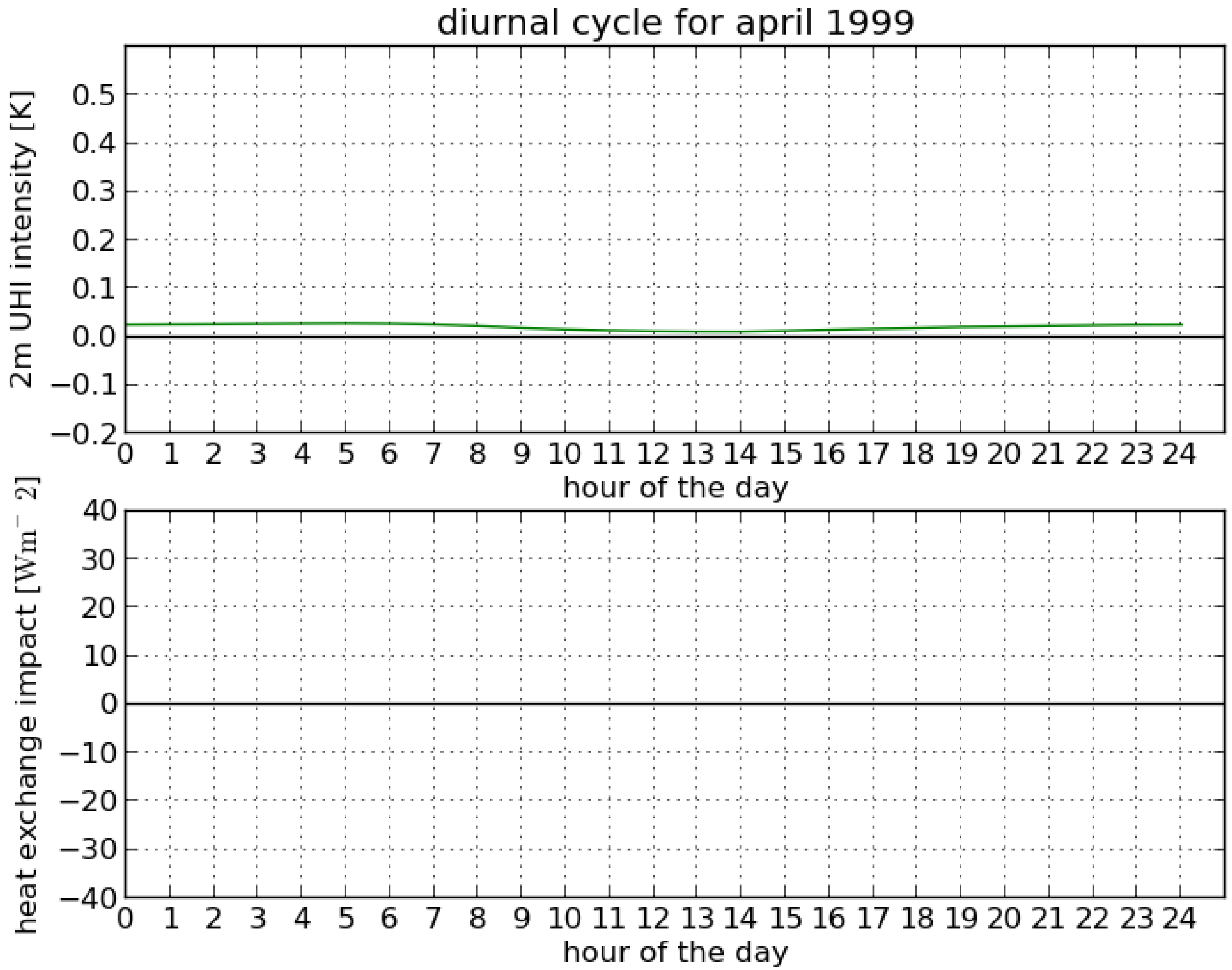


Urban fraction
50°N
45°N
40°N
8.25°W
0.5°E
9.25°E
18°E
[%]
0
5
10
15
20
25
30
35
40
45
50

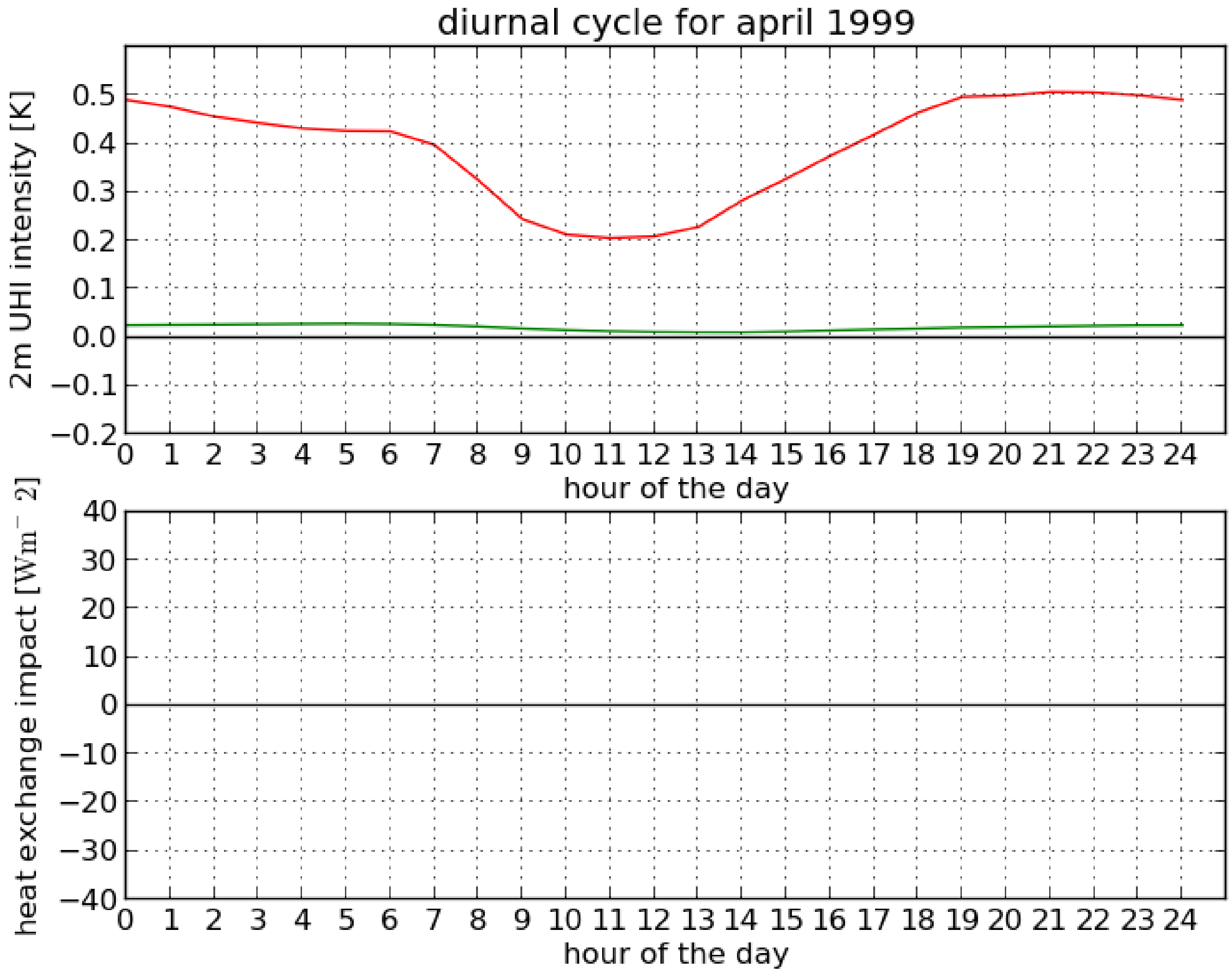


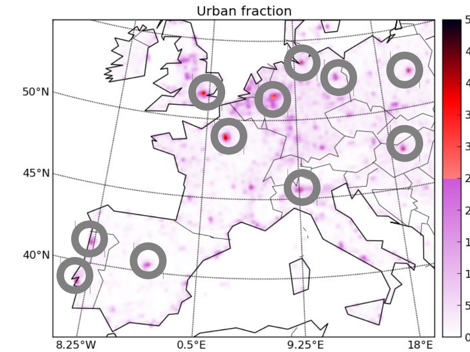
sensible heat impact at 25km resolution at 00H, averaged during april 1999
50°N
45°N
40°N
8.25°W
0.5°E
9.25°E
18°E
ΔQ_H [K]
50
40
30
20
10
0
−10
−20
−30
−40
−50
UHI intensity at 25km resolution at 00H, averaged during april 1999
ΔT [K]
0.60
0.45
0.30
0.15
0.00
−0.15
−0.30
−0.45
−0.60
Yearly-averaged anthropogenic heat
AHF [Wm^{-2}]
50
45
40
35
30
25
20
15
10
5
0
Urban fraction
[%]

Results



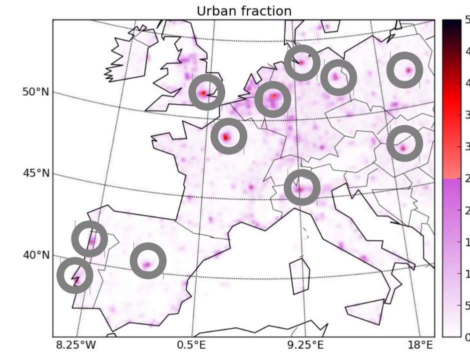
domain-averaged





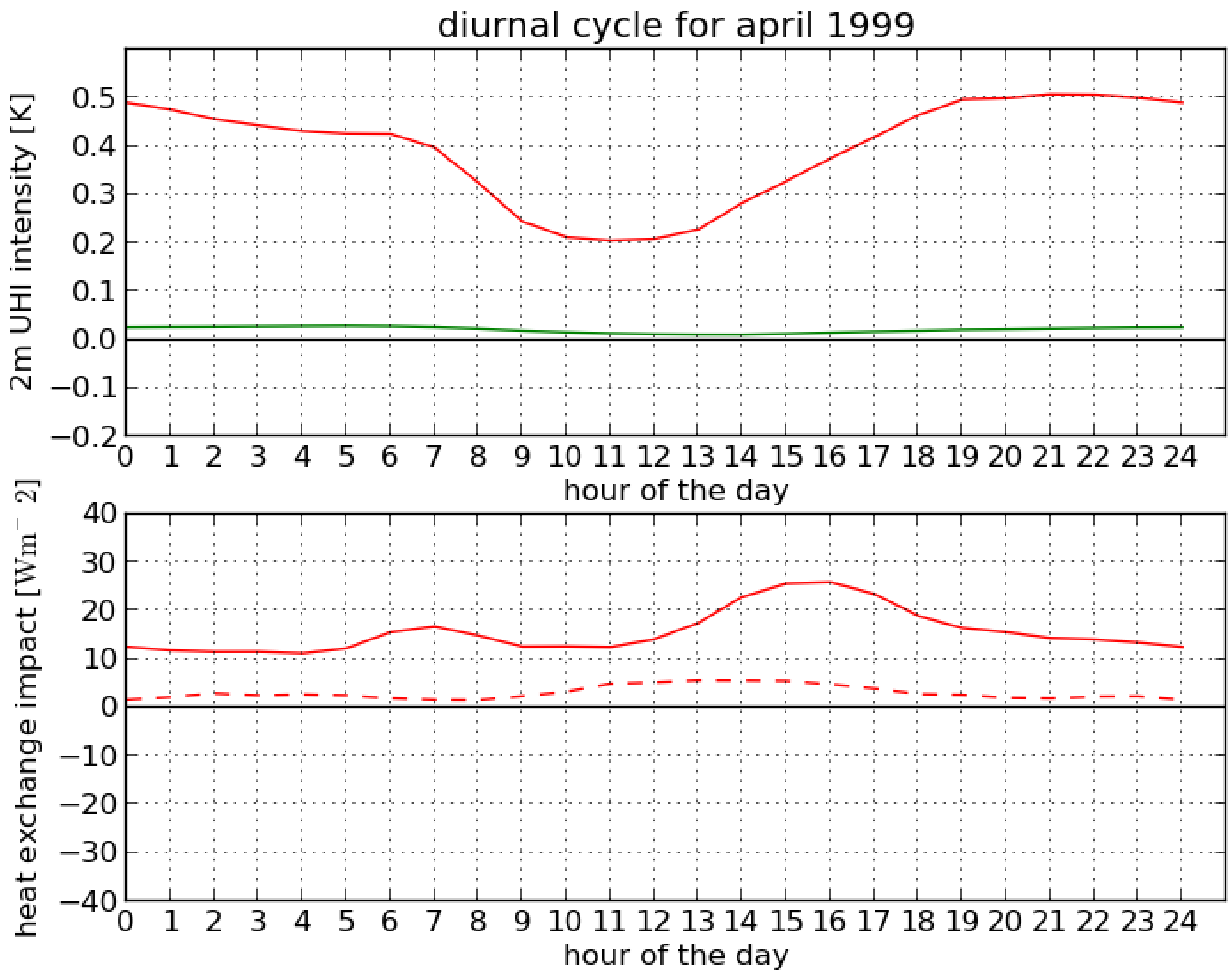
Urban (> 25%)

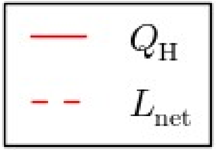
domain-averaged

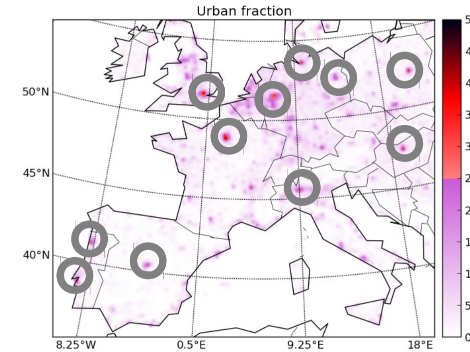


Urban (> 25%)

domain-averaged







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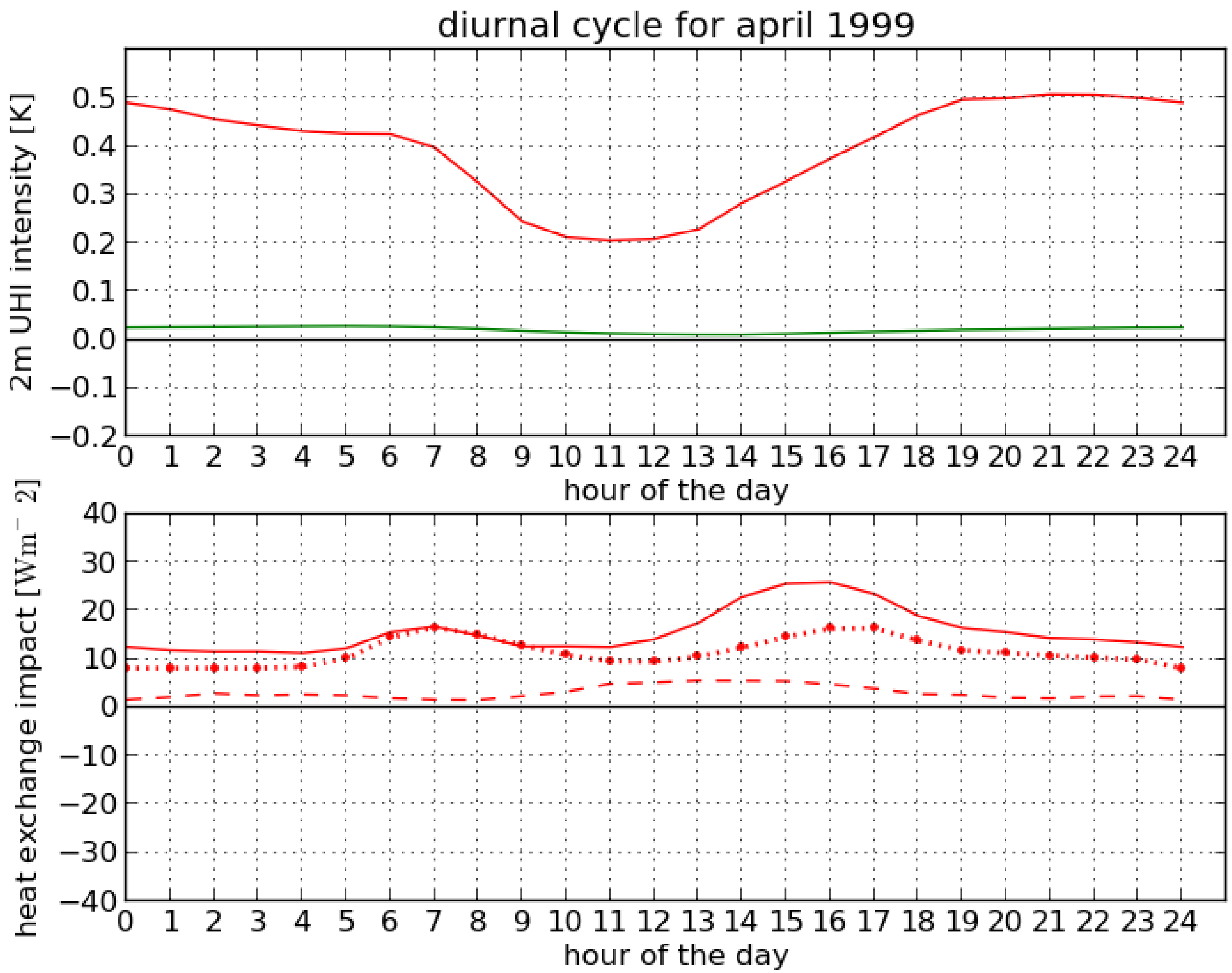

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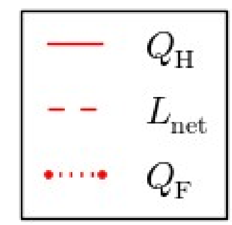

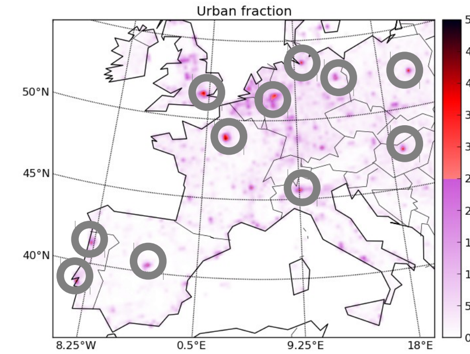

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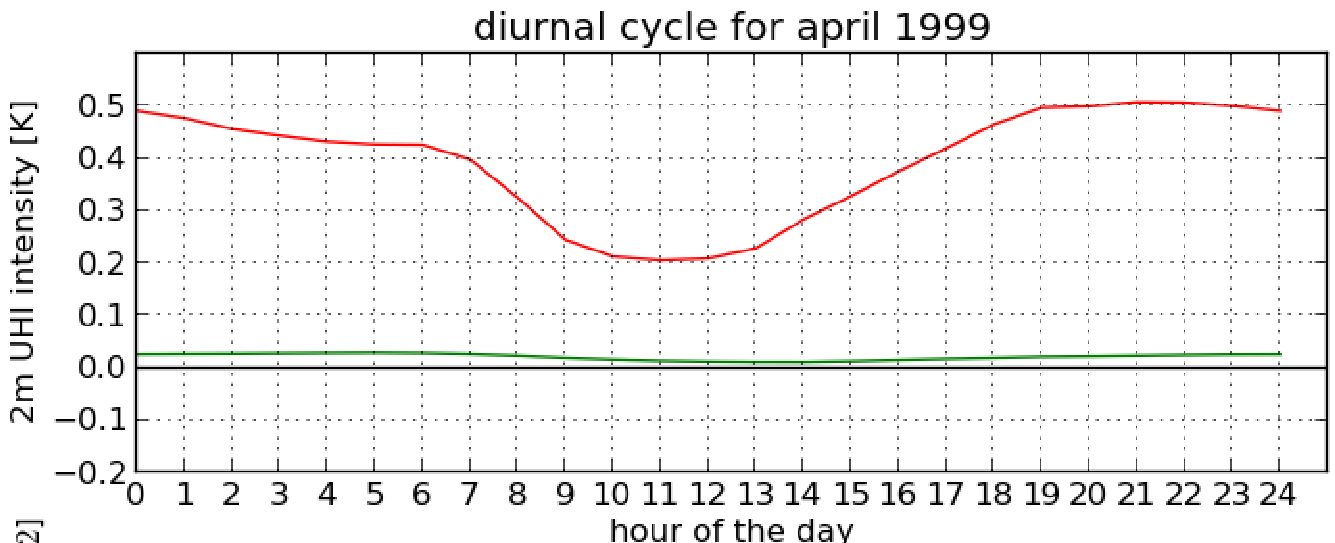

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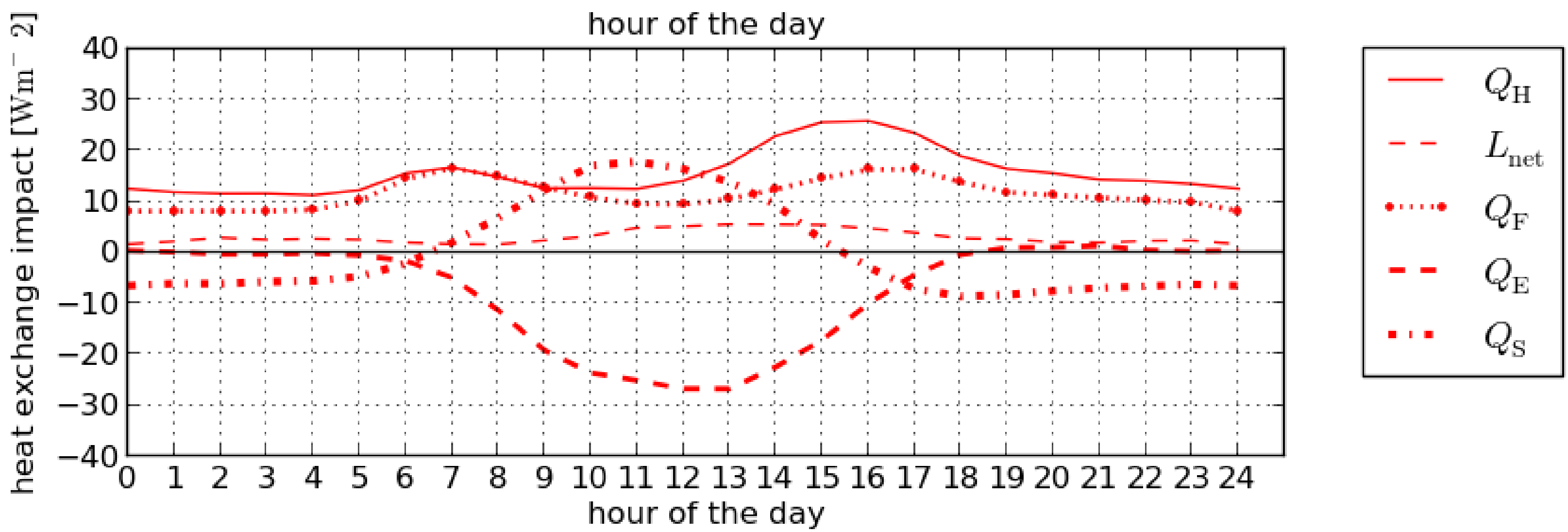
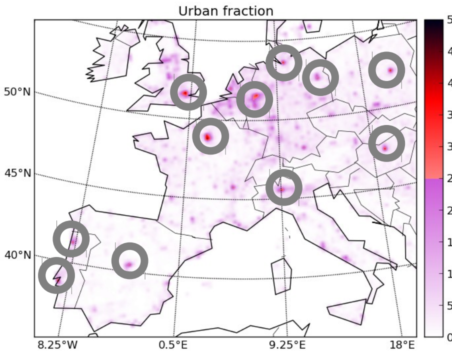
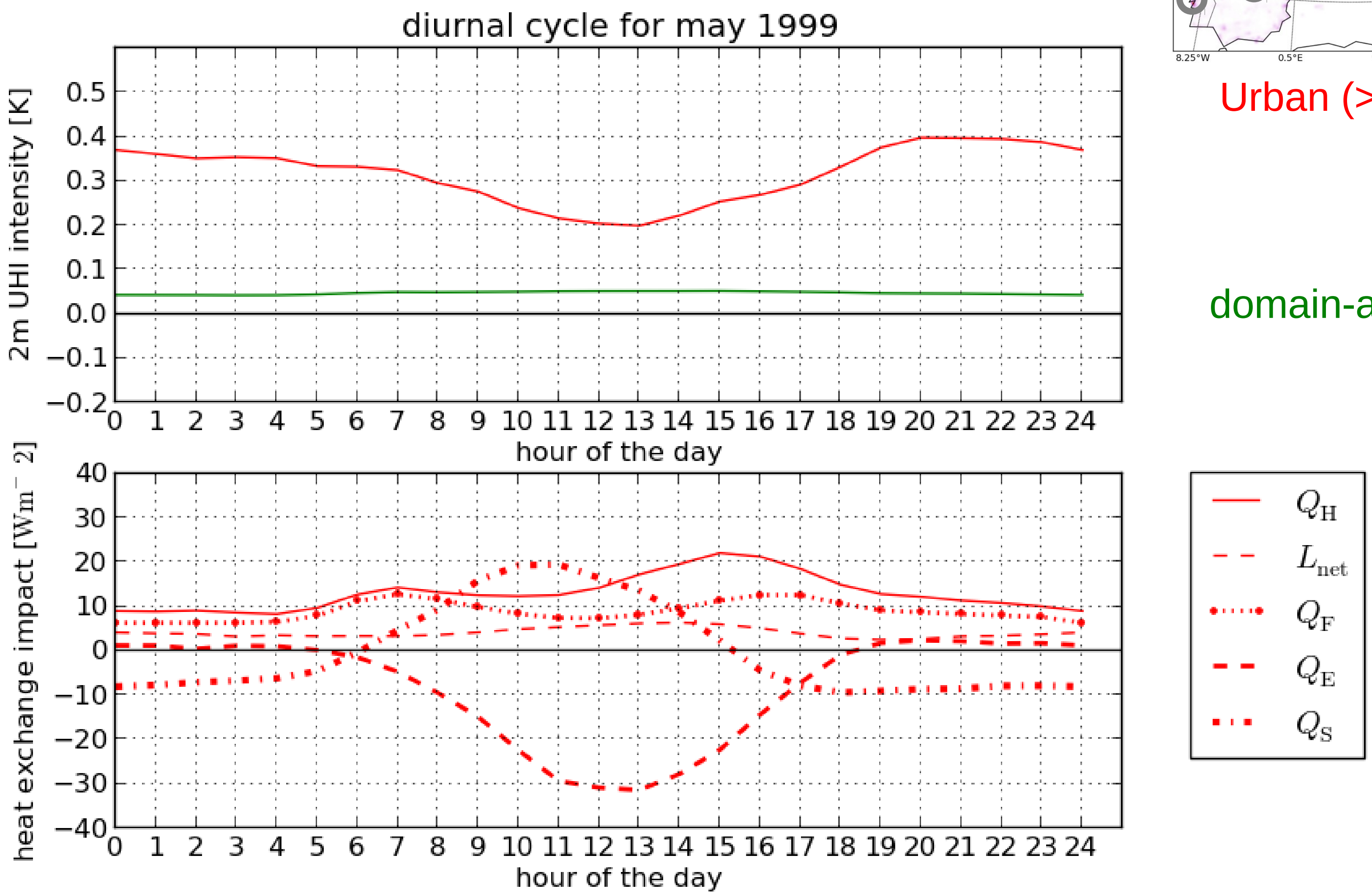




Urban (> 25%)



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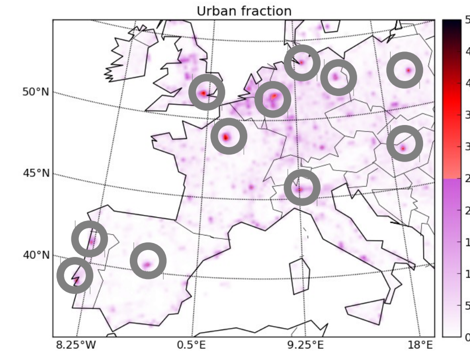

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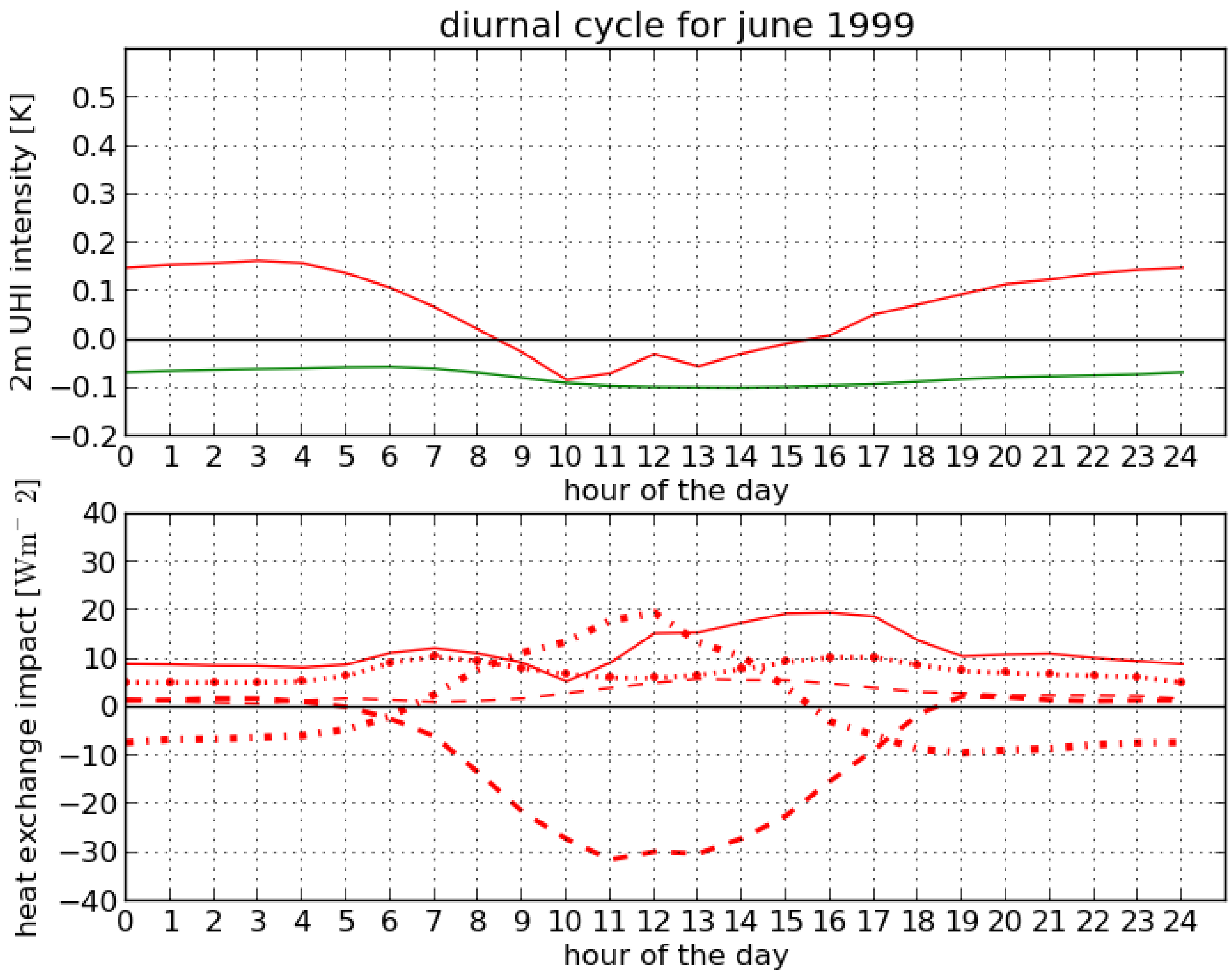

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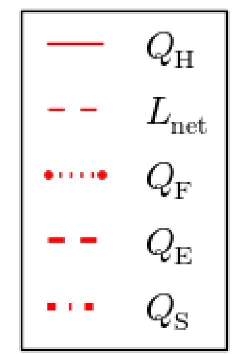

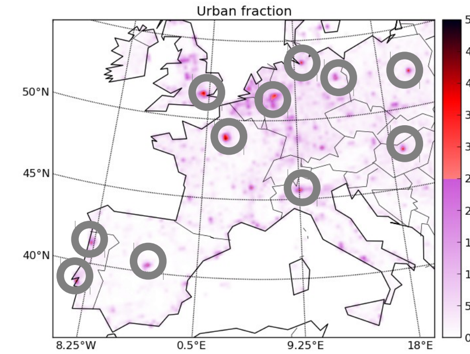

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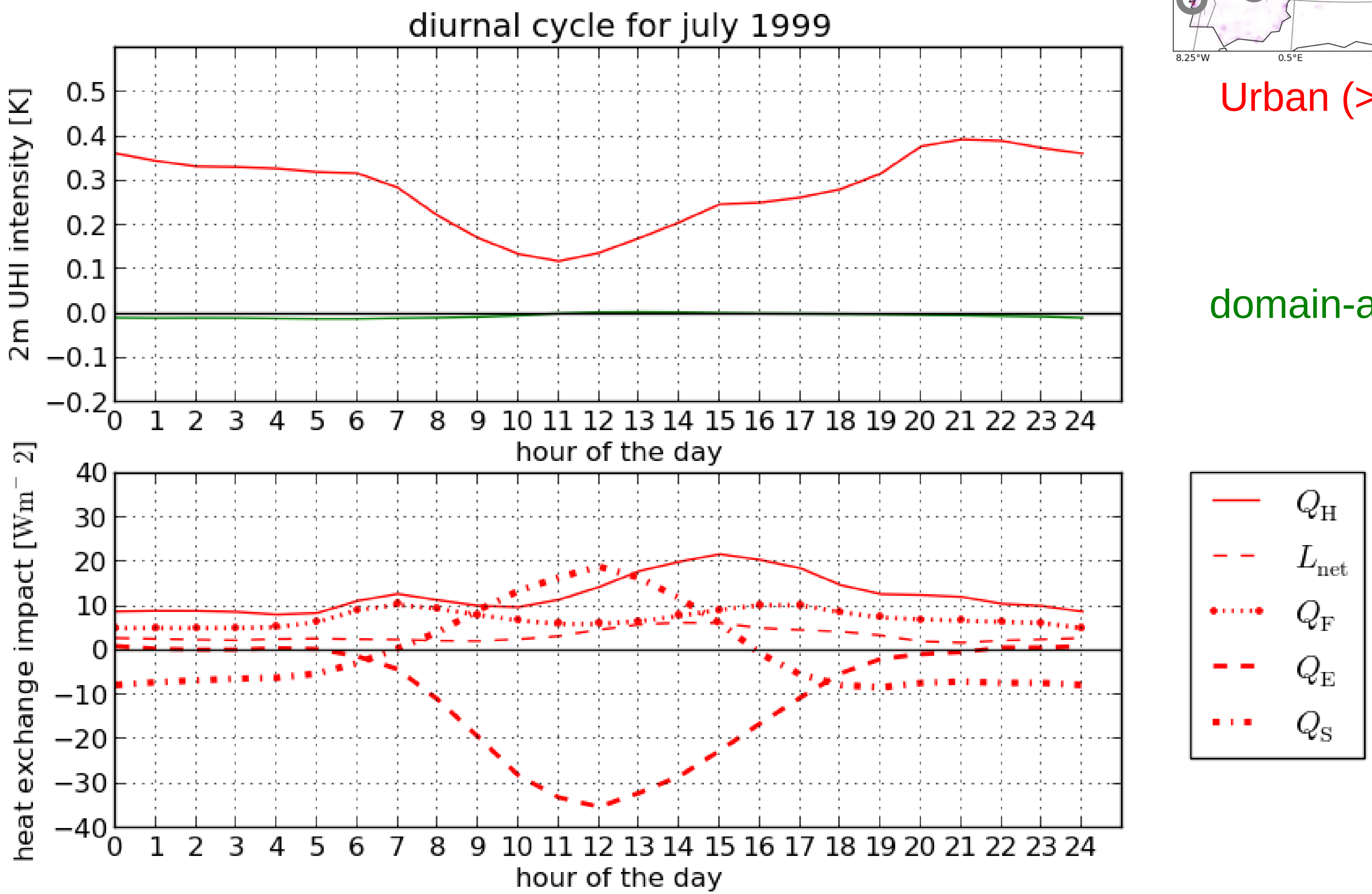

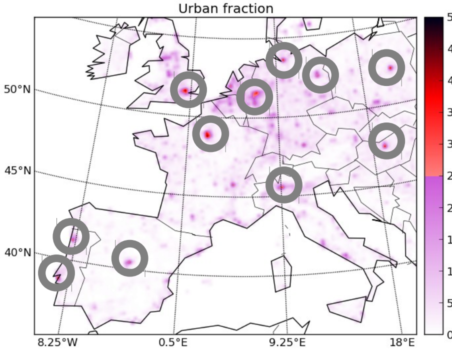

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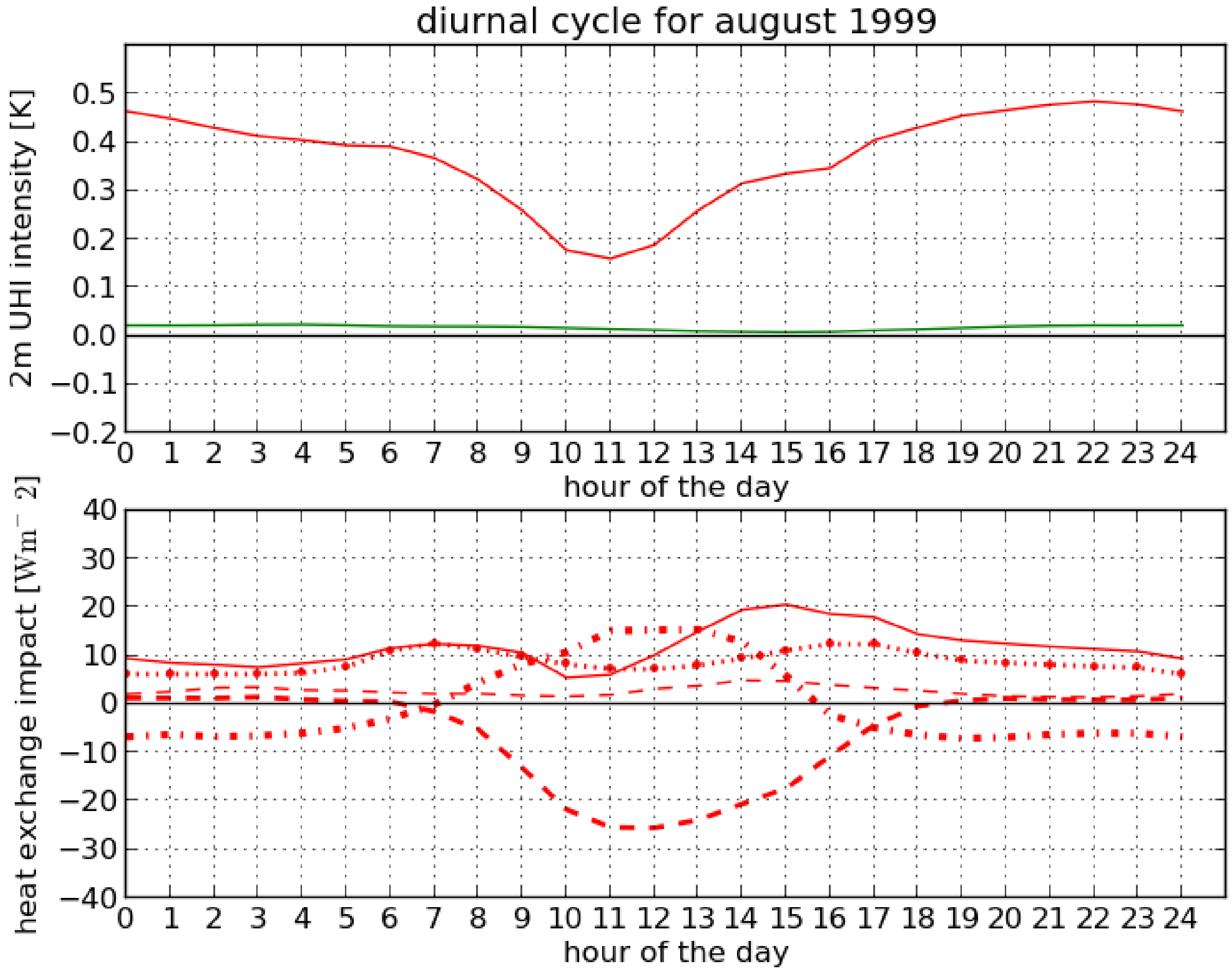

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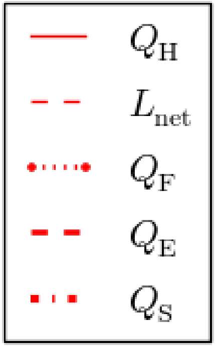

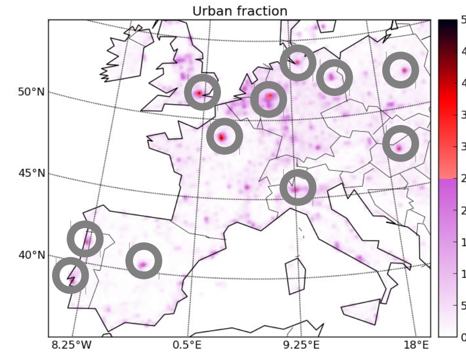

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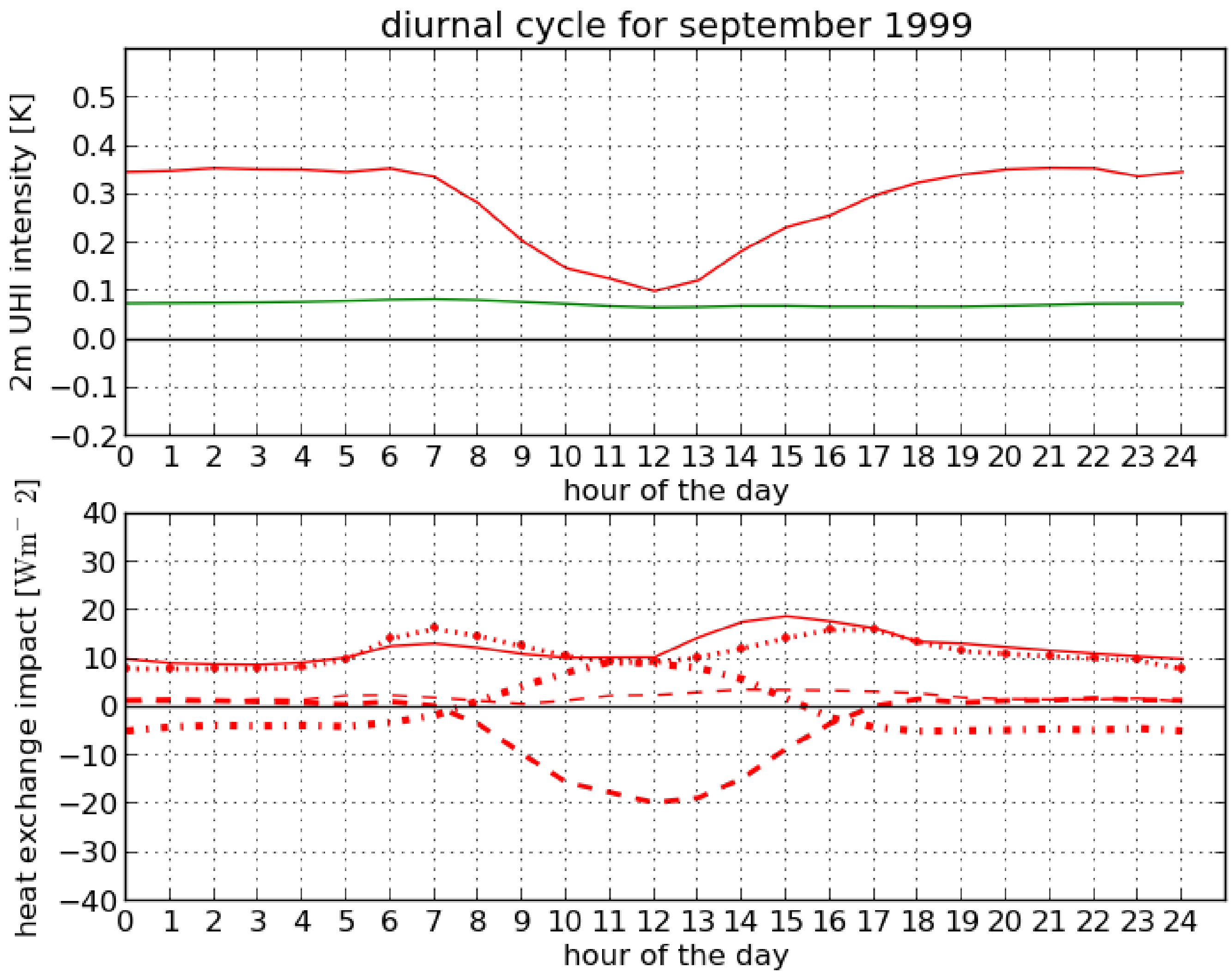

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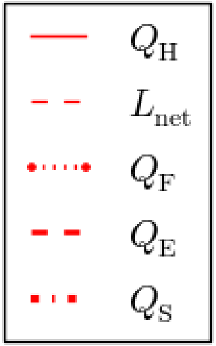

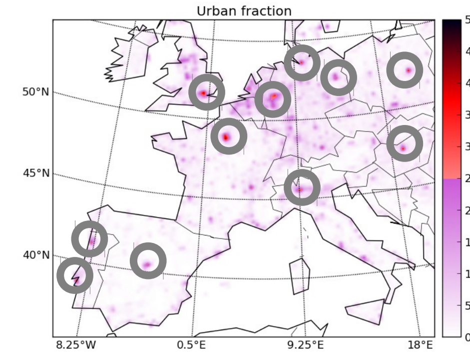

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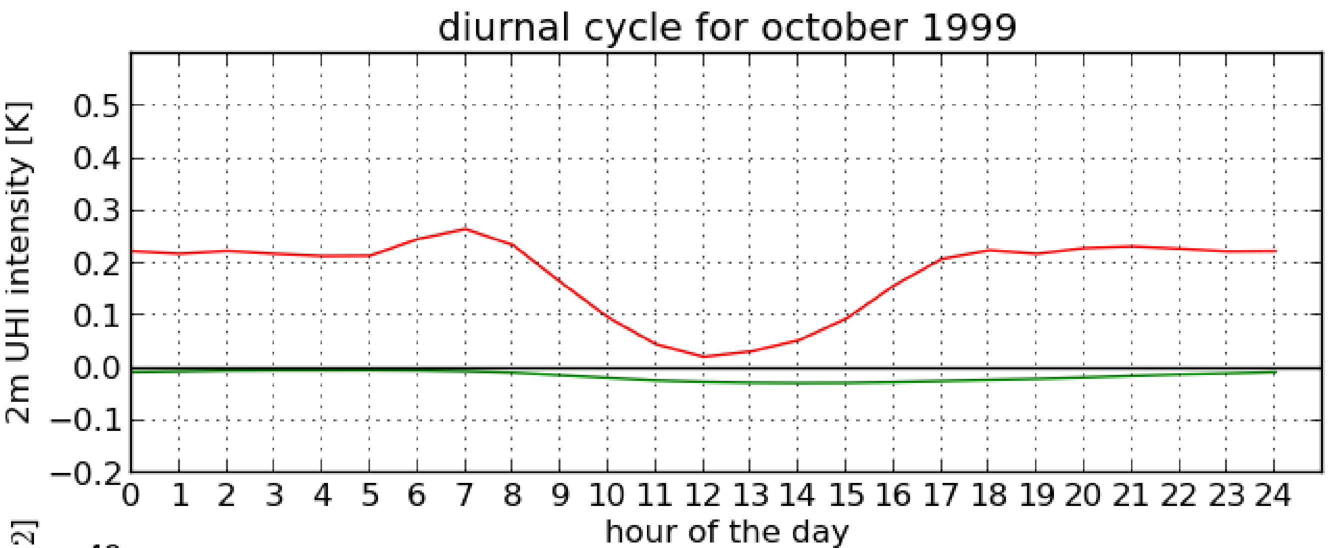

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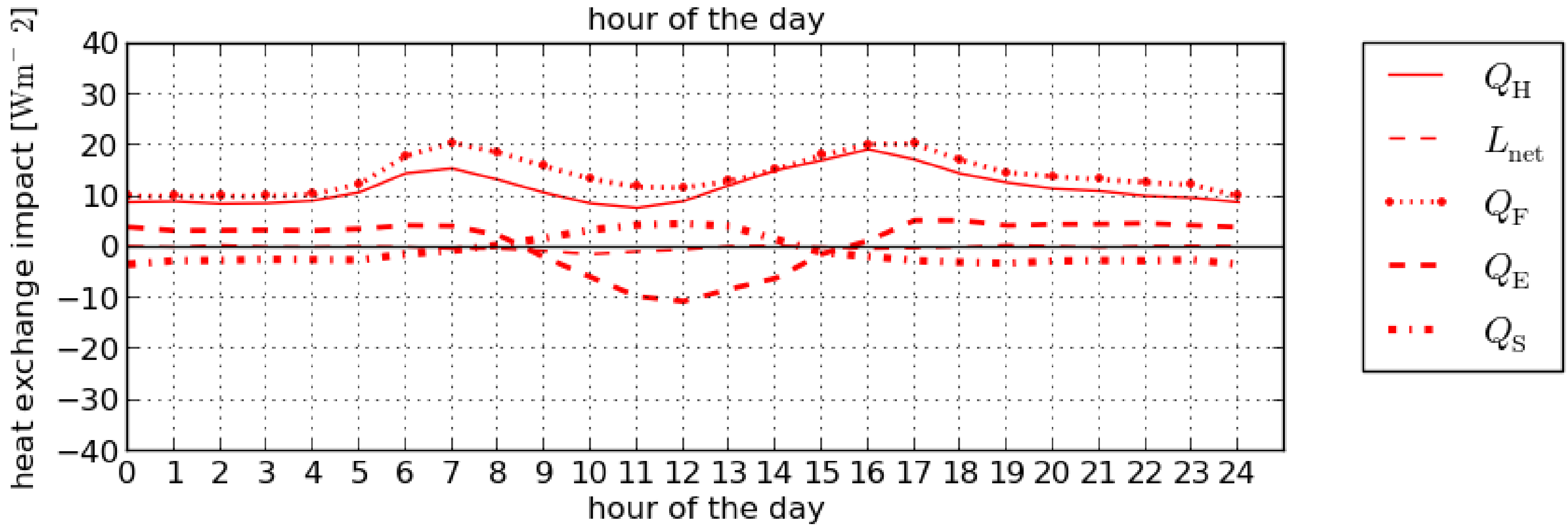

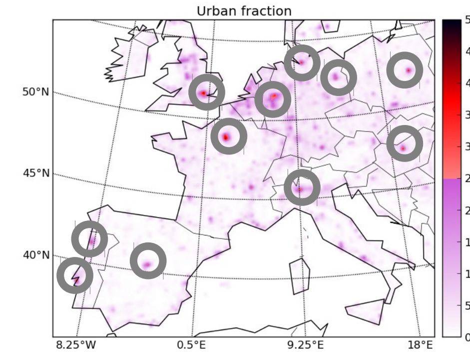

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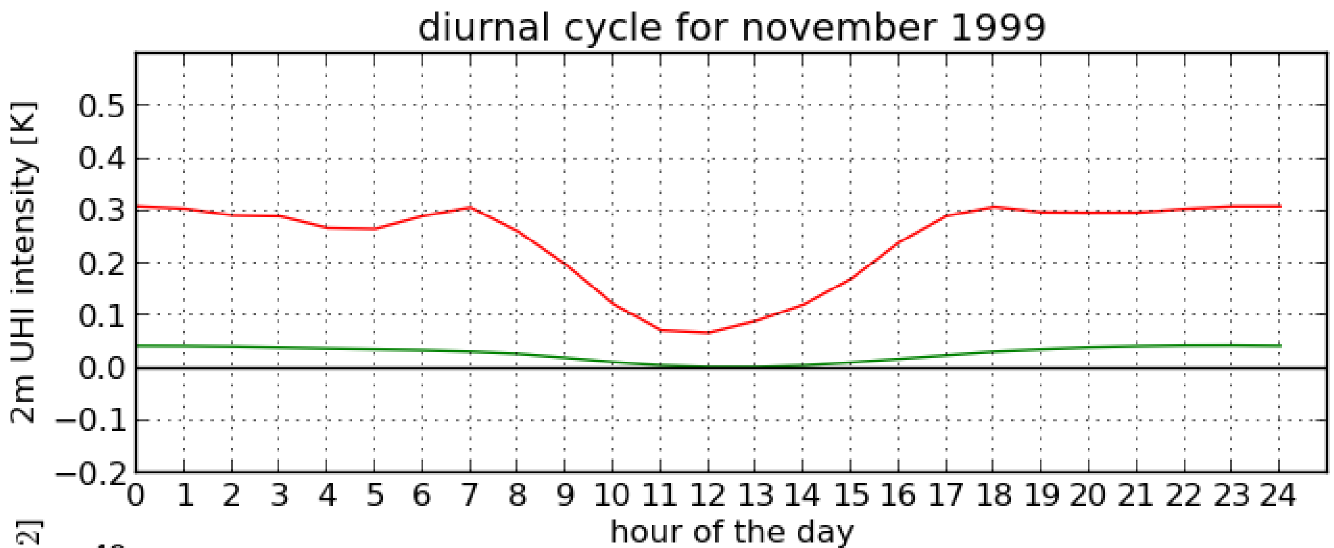

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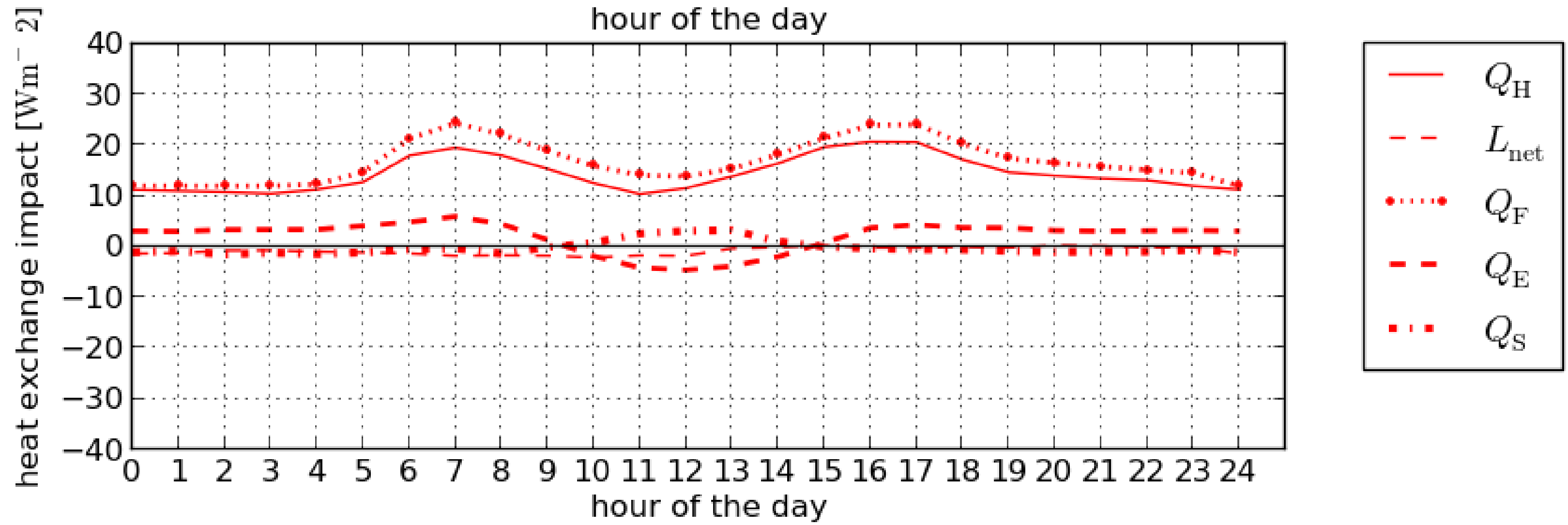
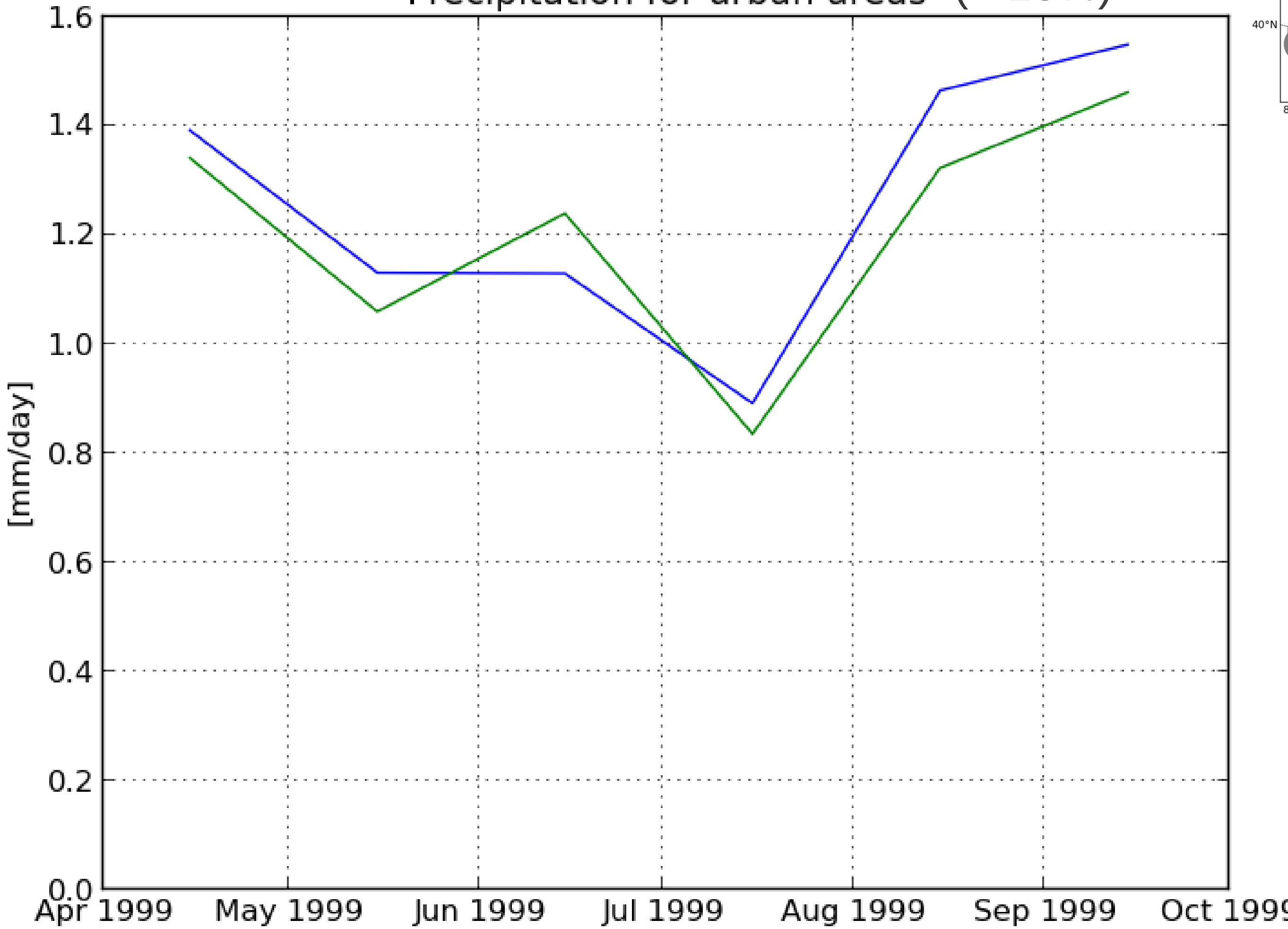
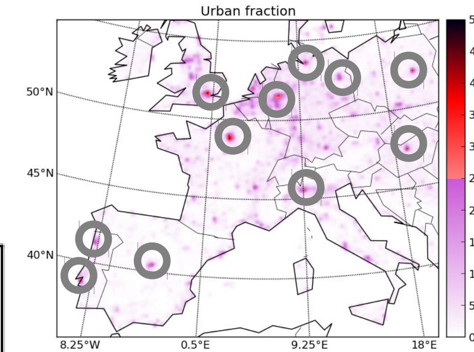


Precipitation for urban areas (> 25%)





Conclusions for the COSMO-CLM European test-runs

- The urban upgrade successfully captures urban climate features on the regional scale
  - Reduced evapotranspiration, increased thermal inertia, heat trapping and anthropogenic heat leads to a bigger storage heat which gets released during the night -> nocturnal UHI
  - The diurnal cycle of the UHI is related to, but different from the diurnal cycle of the sensible heat impact because of boundary-layer stability
  - Urban cooling during the day due to increased storage heat may occur as well because of high heat capacity of the urban surface
- Precipitation increase over urban areas is minimal (~4%)
- During Summer: Reduction of latent heat and anthropogenic heat are equal sources for the urban heat-island intensity
- During Winter: Anthropogenic heat gains importance

1. Air-quality model AURORA

- Developed at VITO

Emissions: traffic, industry, house heating, trees

Boundary conditions: from Large-scale air-quality model

meteorology: wind,temperature, pressure, humidity, radiation, turbulence

AURORA
http://aurora.vito.be

chemistry +transport+ diffusion

CORINE Land-use, GLC2000, SPOT VEGETATION

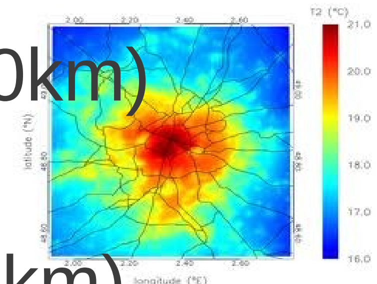
output

3D concentration fields of polluents
(ozon, NOx, PM10, PM2.5, aerosolen …) each hour

Applications: air-quality modeling (1/2)

2) What are the **driving processes determining the urban air quality**?

- **Relevance of mesoscale meteorology** (1-10km)

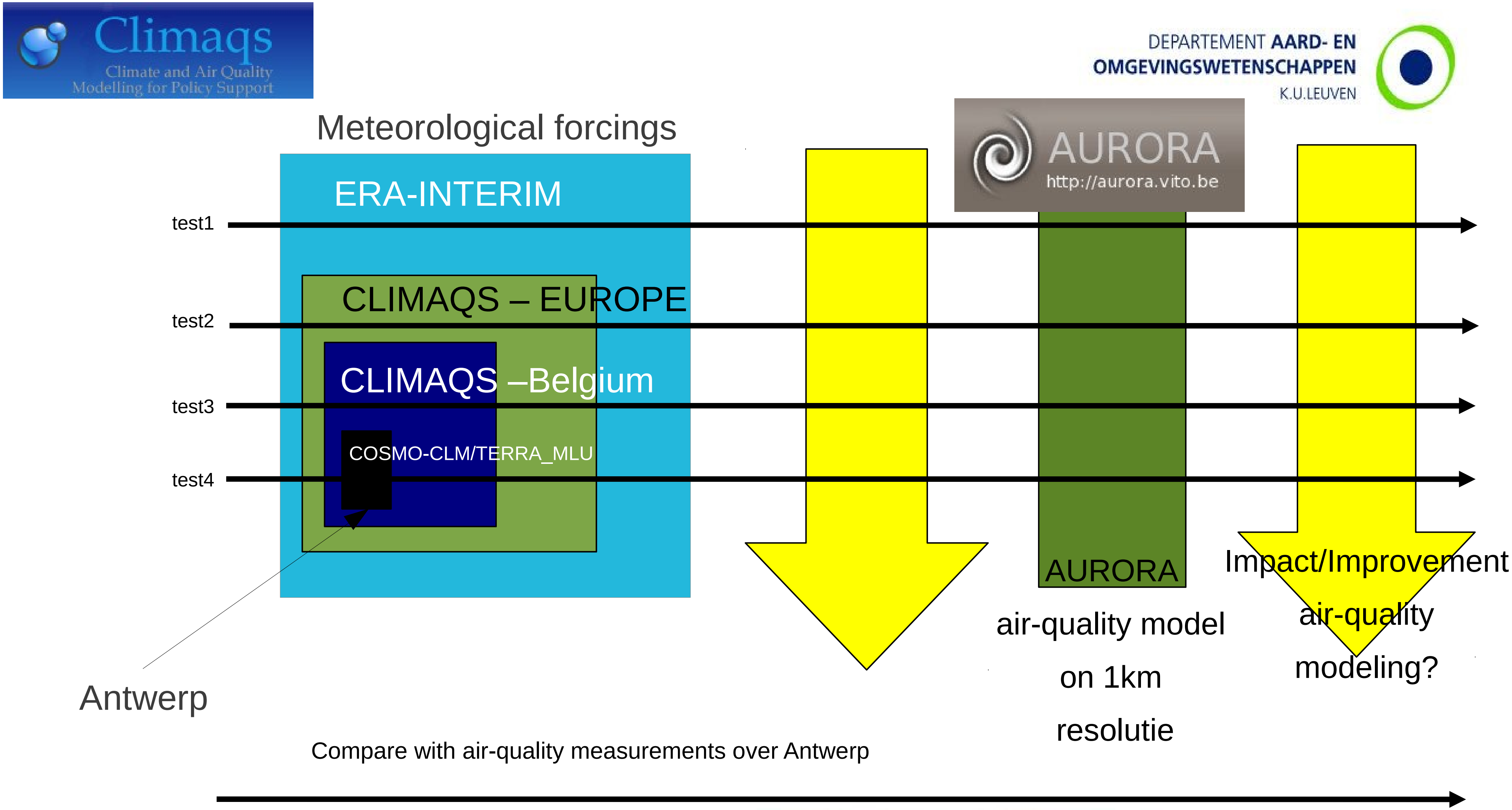


  - e.g. **urban heat island, topography...**
- **Versus large-scale meteorology** (100–1000km)
- **Versus** (uncertainty) **emissions**

3) Why do we care?

→ **Set priorities** for the **improvement** of **urban air-quality modelling**

Applications: air-quality modeling (2/2)



vito vision on technology

More applications

- Urban climate scenarios for Belgium **(MACCBET,** KU Leuven)
- The Urban Climate of the European continent: urbanization doubling (metropoles versus urban sprawl)
- Conditional water spray cooling for cities
- ...

Thank you for your attention!

Comments?

Questions?

Suggestions?