Charles University in Prague
Faculty of Mathematics and Physics
Dept. of Atmospheric Physics
V Holesovickach 2, Prague 8,
Czech Republic

ON THE ASSESSMENT OF URBAN LAND-SURFACE IMPACTS ON CLIMATE IN REGCM SIMULATIONS OVER CENTRAL EUROPE

-

COMPARISON OF BATS-SLUCM AND CLM-SLUCM

Tomáš Halenka, Peter Huszár, Michal Belda

E-mail: tomas.halenka@mff.cuni.cz

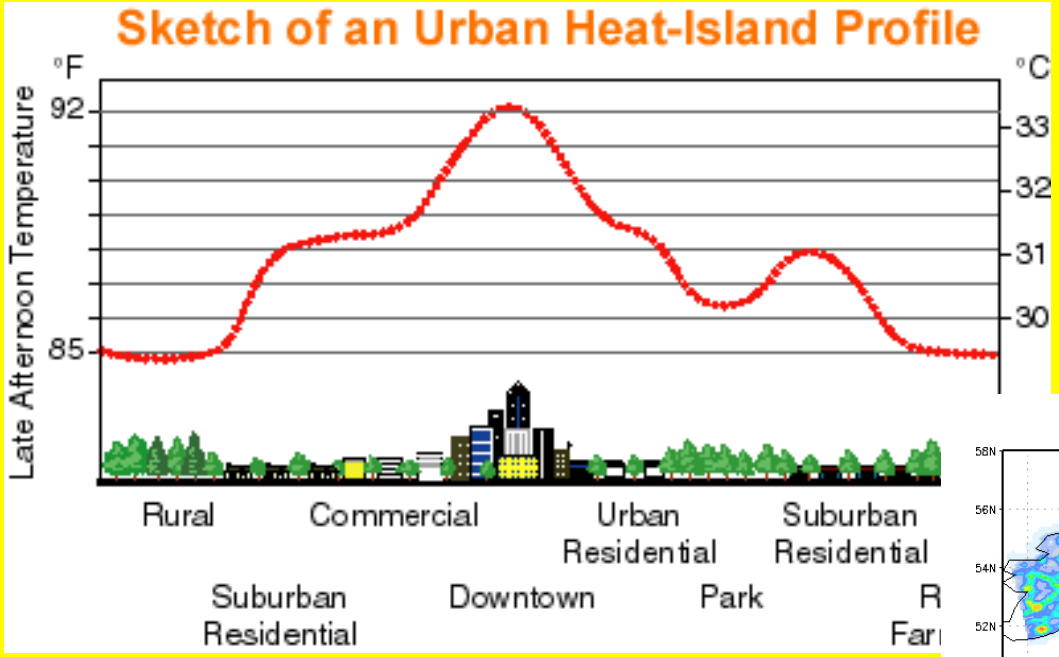
Content

1. Motivation, projects
2. Models and SLUCM implementation
3. Results and urban effects
4. Sensitivity tests
5. Applications (Air quality effects, urban planning, climate change)
6. Conclusions

Content

1. Motivation, projects
2. Models and SLUCM implementation
3. Results and urban effects
4. Sensitivity tests
5. Applications (Air quality effects, urban planning, climate change)
6. Summary, conclusions

Motivation

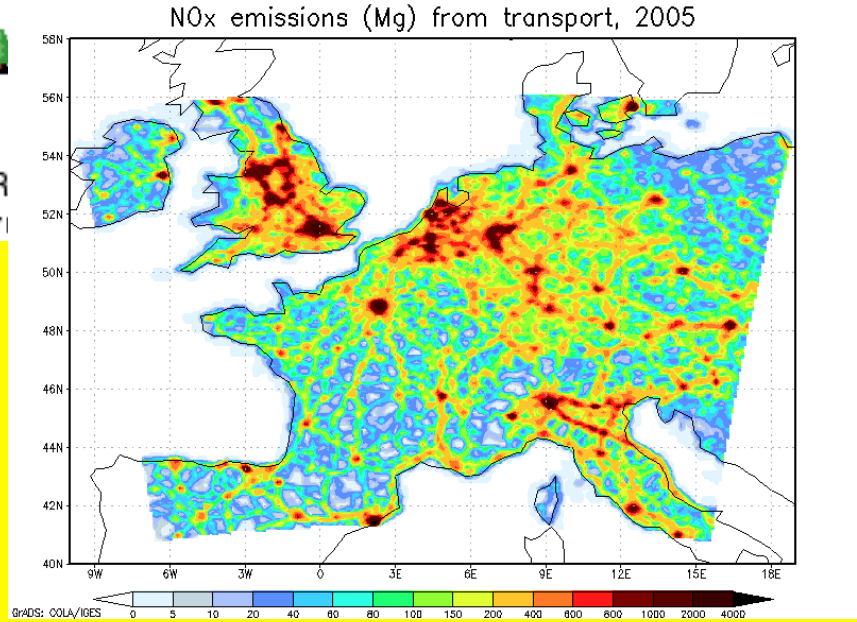


World:

- From 2009 - more than 50% of the world's population living in cities (UN, 2009)
- less than 0.1% of the Earth's surface

Europe:

- 2008 - 73% of the population in cities
- mid 21th century - 84%, representing a rise from 531 to 582 millions (UN, 2008)
- in the Czech Republic, a similar change from 73.5% to 83% is projected by the Czech Statistical Office.



MEGAPOLI TNO NOx emissions [Mg], 2005 from transport (S7)

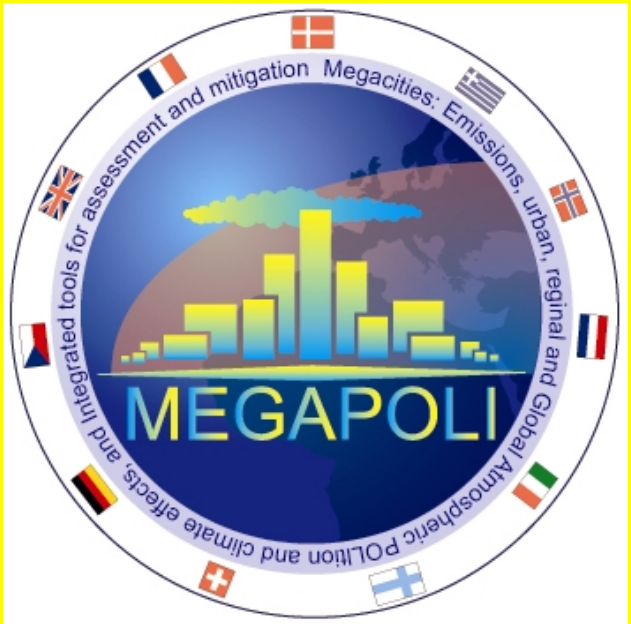
MEGAPOLI Project

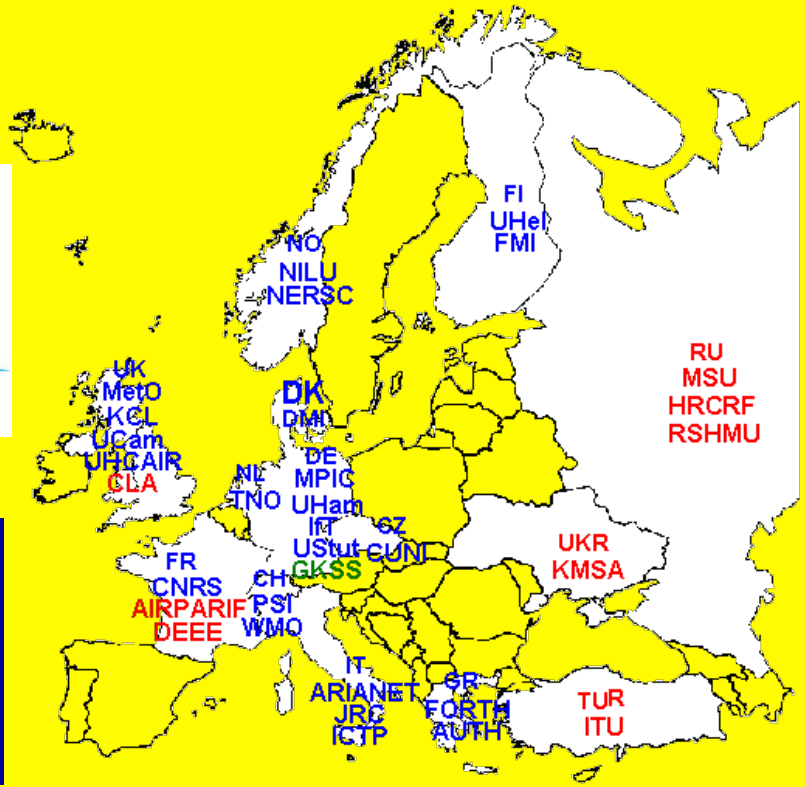
Objectives:

- to assess impacts of megacities and large air-pollution hot-spots on local, regional and global air quality,
- to quantify feedbacks among megacity air quality, local and regional climate, and global climate change,
- to develop improved integrated tools for prediction of air pollution in megacities

Duration: 1 October 2008 – 30 September 2011

Coordinator: DMI, Copenhagen, A. Baklanov





UHI Project - Development and Application of Mitigation and Adaptation Strategies and Measures for Counteracting the Global Urban Heat Island Phenomenon

Within framework of EC Operation Programme Central Europe (3CE292P3)

18 partners, coordinated by ARPA, Italy (Paolo Lauriola)

CENTRAL EUROPE
COOPERATING FOR SUCCESS.

EUROPEAN UNION
EUROPEAN REGIONAL DEVELOPMENT FUND

The UHI project pilot areas

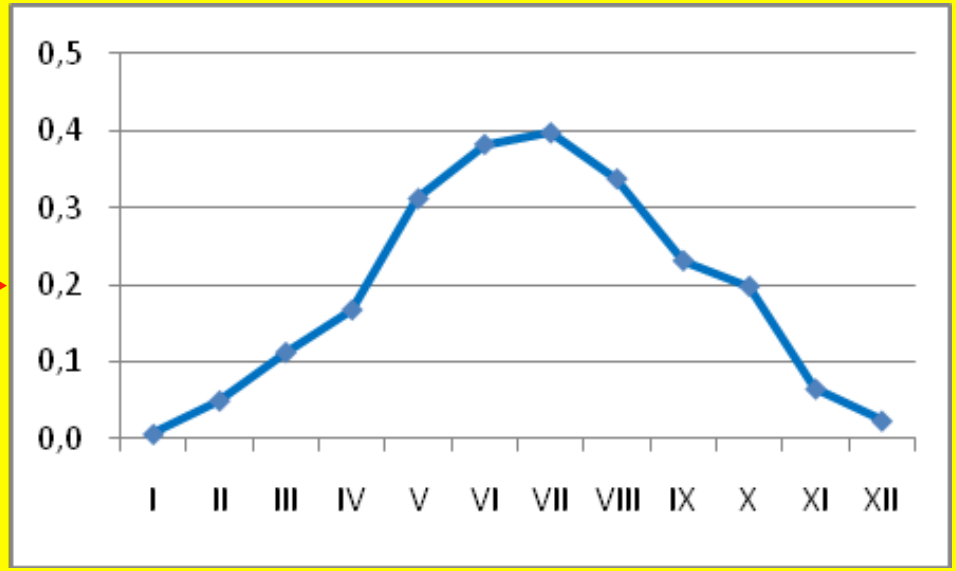
8 of the most relevant metropolitan areas and Metropolitan European Growth Areas (MEGAs) of CE area

CENTRAL EUROPE
COOPERATING FOR SUCCESS.

EUROPEAN UNION
EUROPEAN REGIONAL DEVELOPMENT FUND

Prague heat island

period	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	YEAR
1961-2009	2,2	2,3	2,2	2,2	2,2	2,4	2,3	2,2	2,0	2,0	2,2	2,2	2,2
1961-1990	2,2	2,3	2,2	2,1	2,1	2,2	2,2	2,0	1,9	2,0	2,2	2,2	2,1
1991-2009	2,2	2,3	2,3	2,3	2,4	2,6	2,6	2,4	2,1	2,2	2,2	2,2	2,3
Difference new - standard	0,01	0,05	0,11	0,17	0,31	0,38	0,40	0,34	0,23	0,20	0,07	0,02	0,19



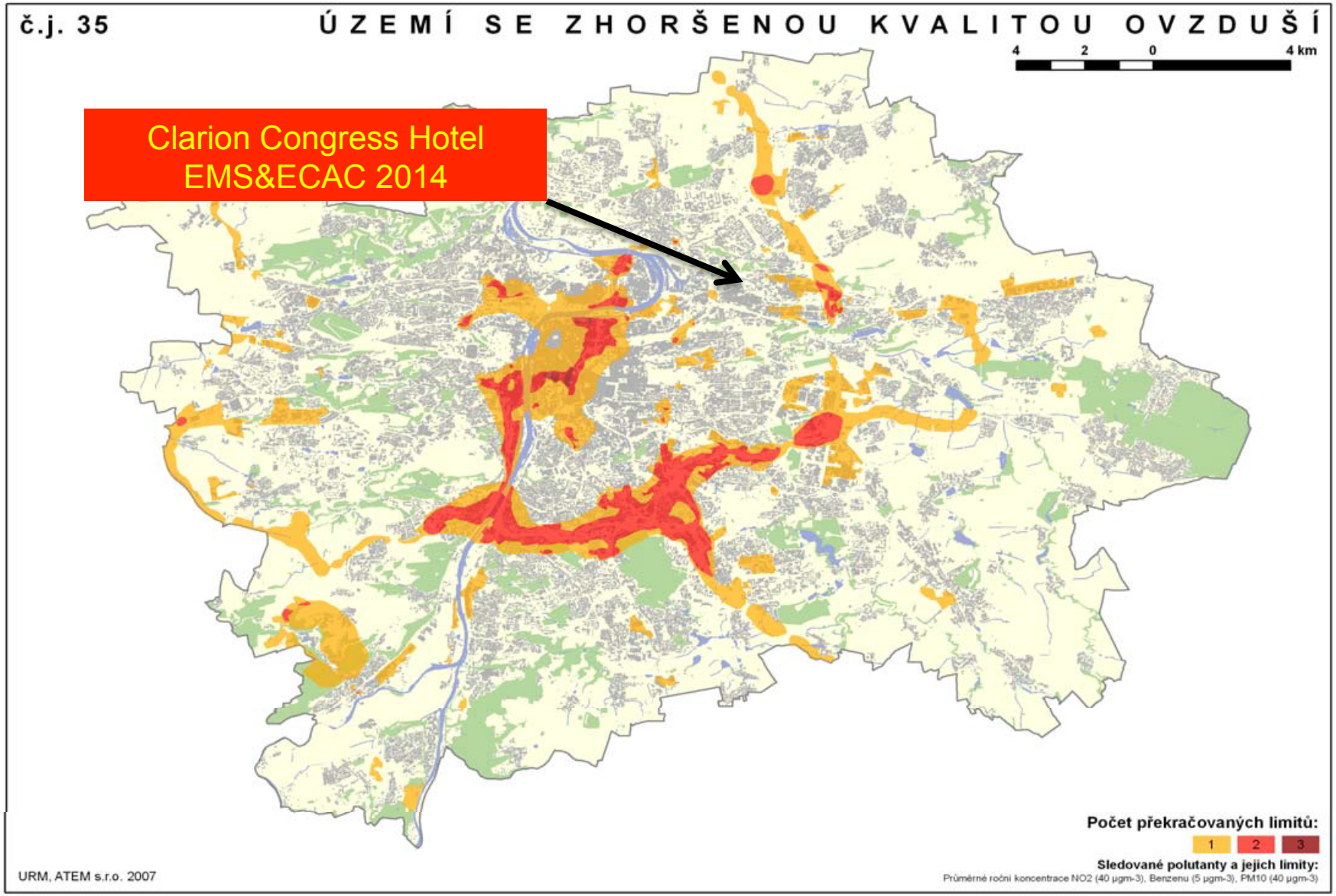
Klementinum
vs. Ruzyne

Pretel (2010)

CENTRAL EUROPE
COOPERATING FOR SUCCESS.

EUROPEAN UNION
EUROPEAN REGIONAL DEVELOPMENT FUND

Prague air quality



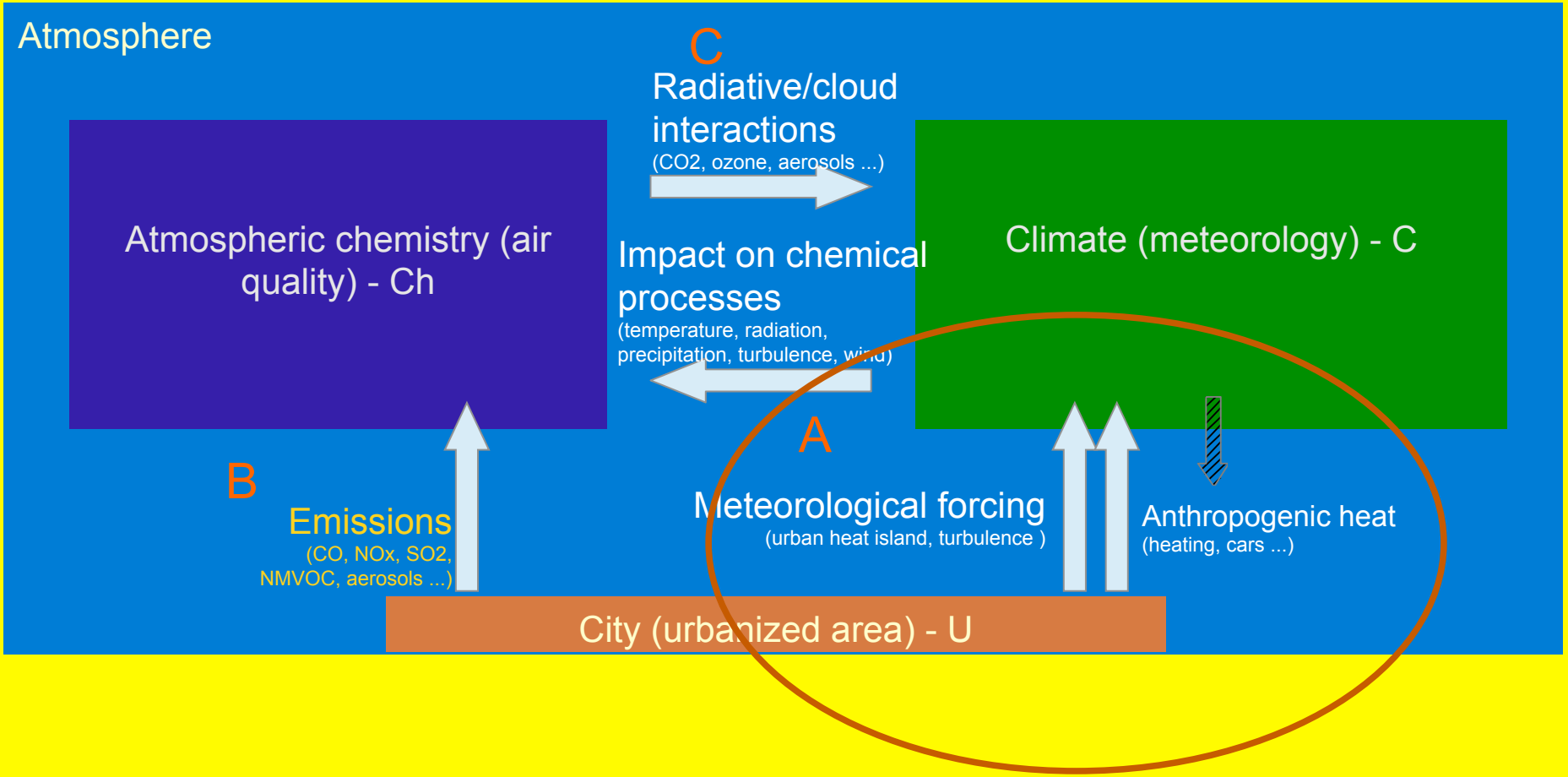
Goal

To use regional climate models and chemistry transport models to quantify the interaction:

Urban environment – climate – chemistry

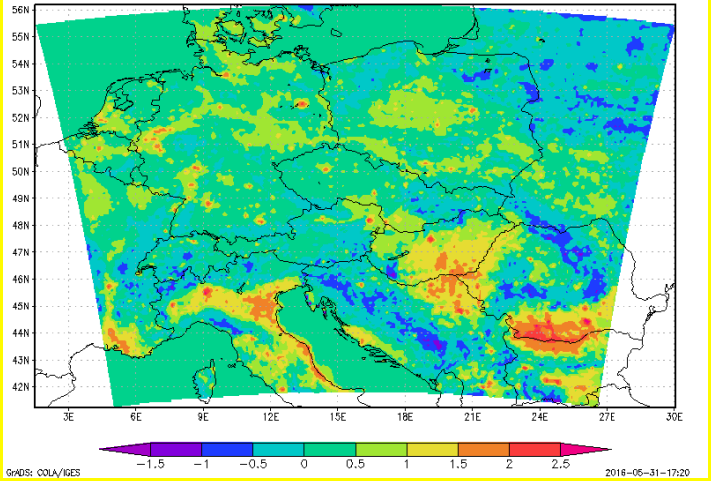
UCCh interaction (**U**rban–**C**limate–**Ch**emistry)

UCCh interaction

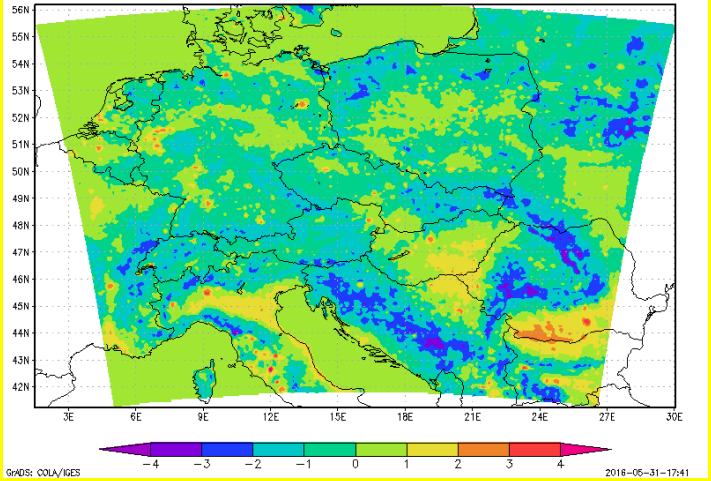


Primary view

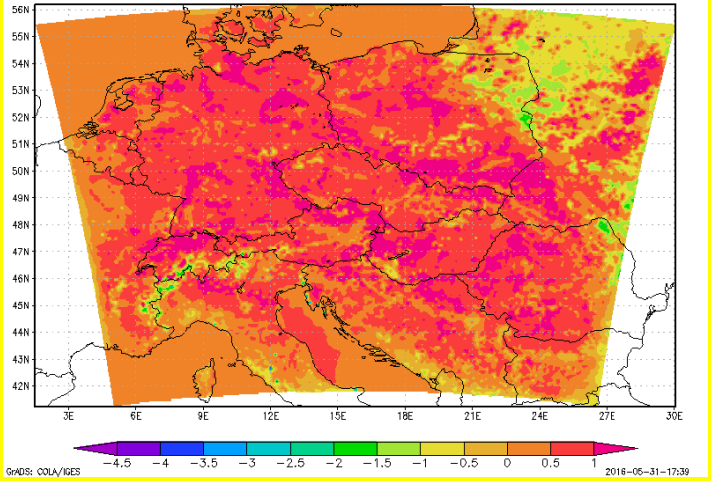
Tmean



Tmin



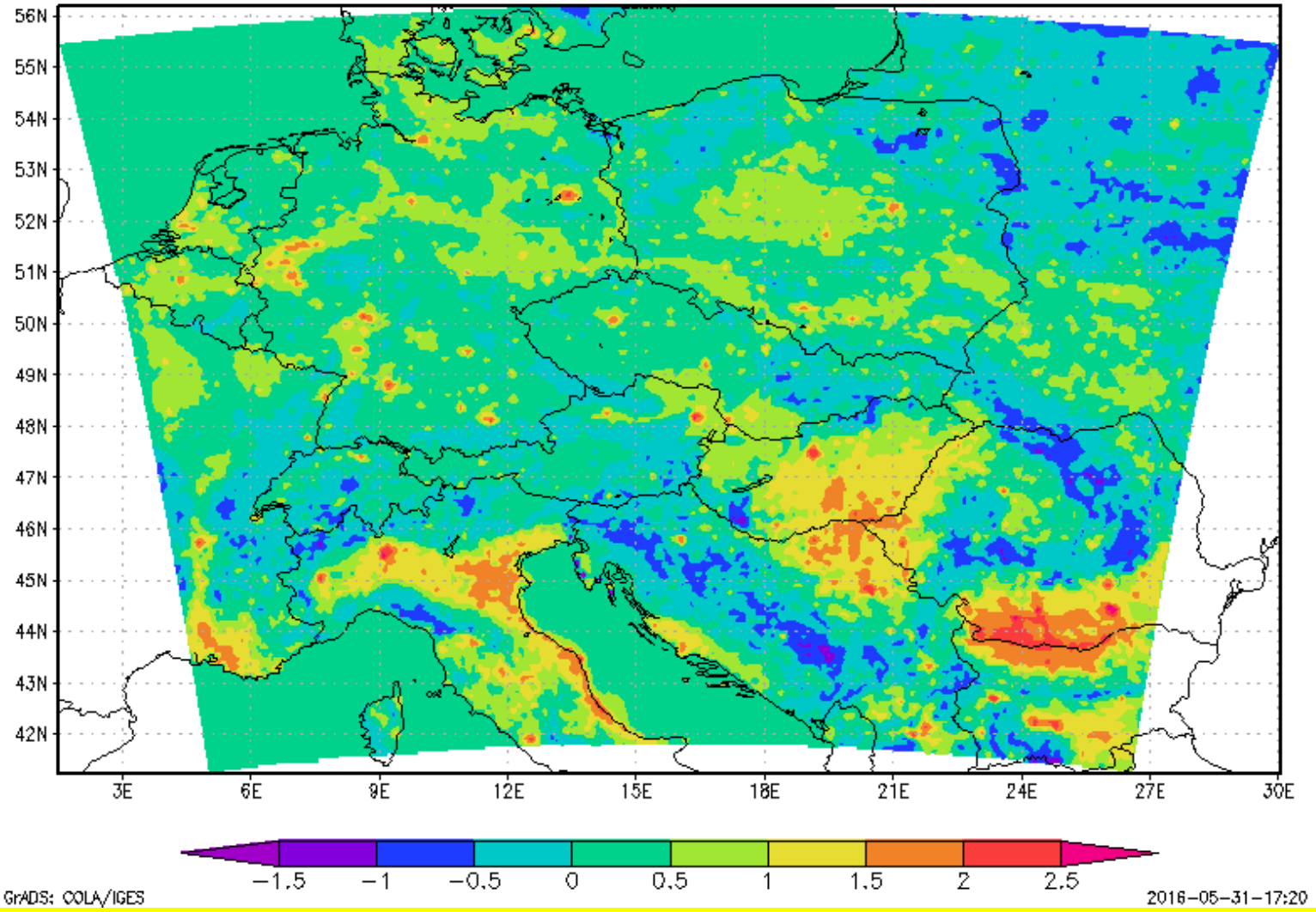
Tmax



RegCM4.5/CLM4.5 (implicitly with urban) – RegCM4.5/BATS (no urban land use) for July 2000

Primary view

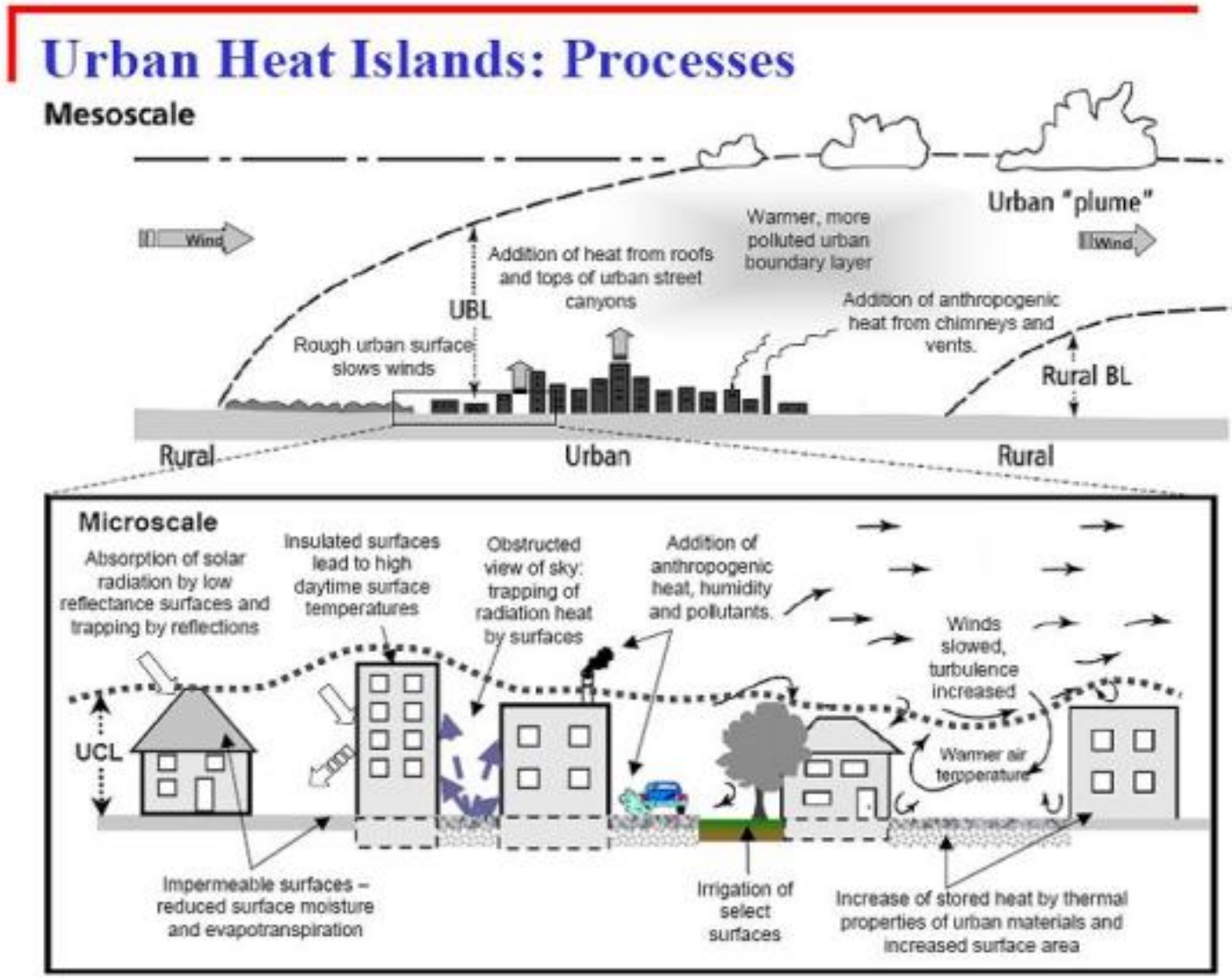
RegCM4.5/CLM4.5 (implicitly with urban) – RegCM4.5/ BATS for July 2000: Tmean



Content

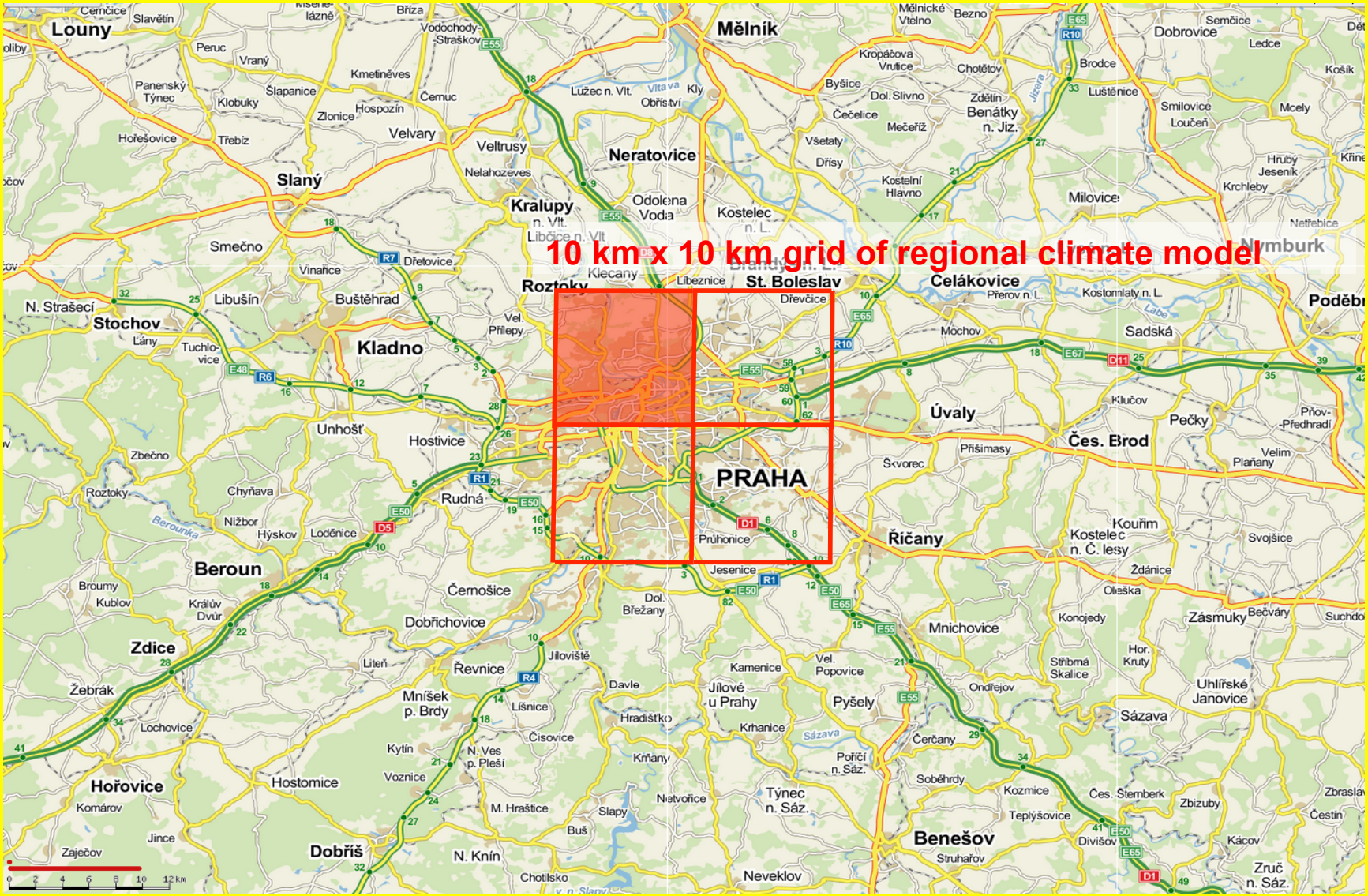
1. Motivation, projects
2. Models and SLUCM implementation
3. Results and urban effects
4. Sensitivity tests
5. Applications (Air quality effects, urban planning, climate change)
6. Summary, conclusions

Atmospheric processes in urban canopy layer

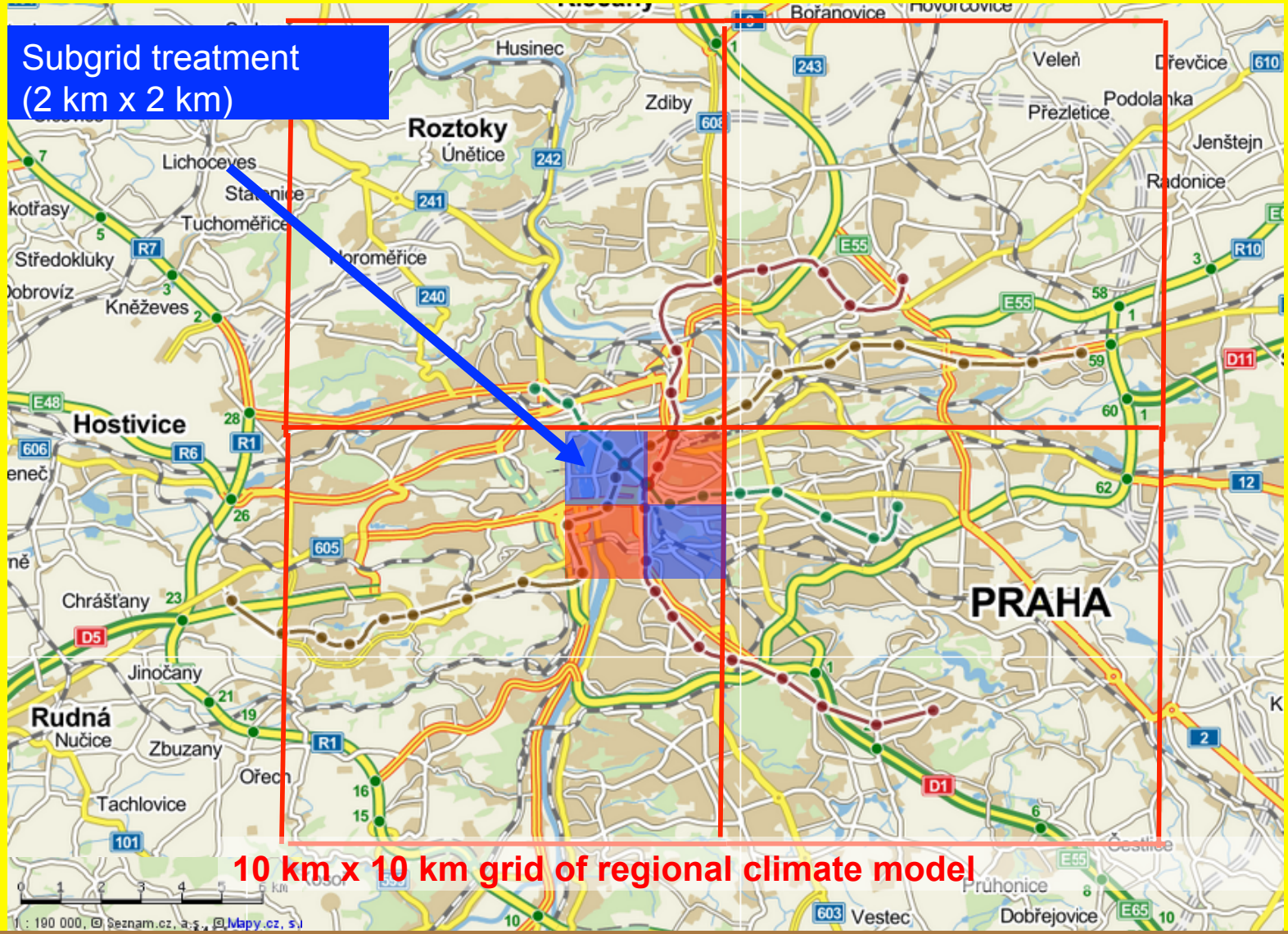


Regional climate model assessment of urban canopy meteorological effects – why we need urban parameterizations

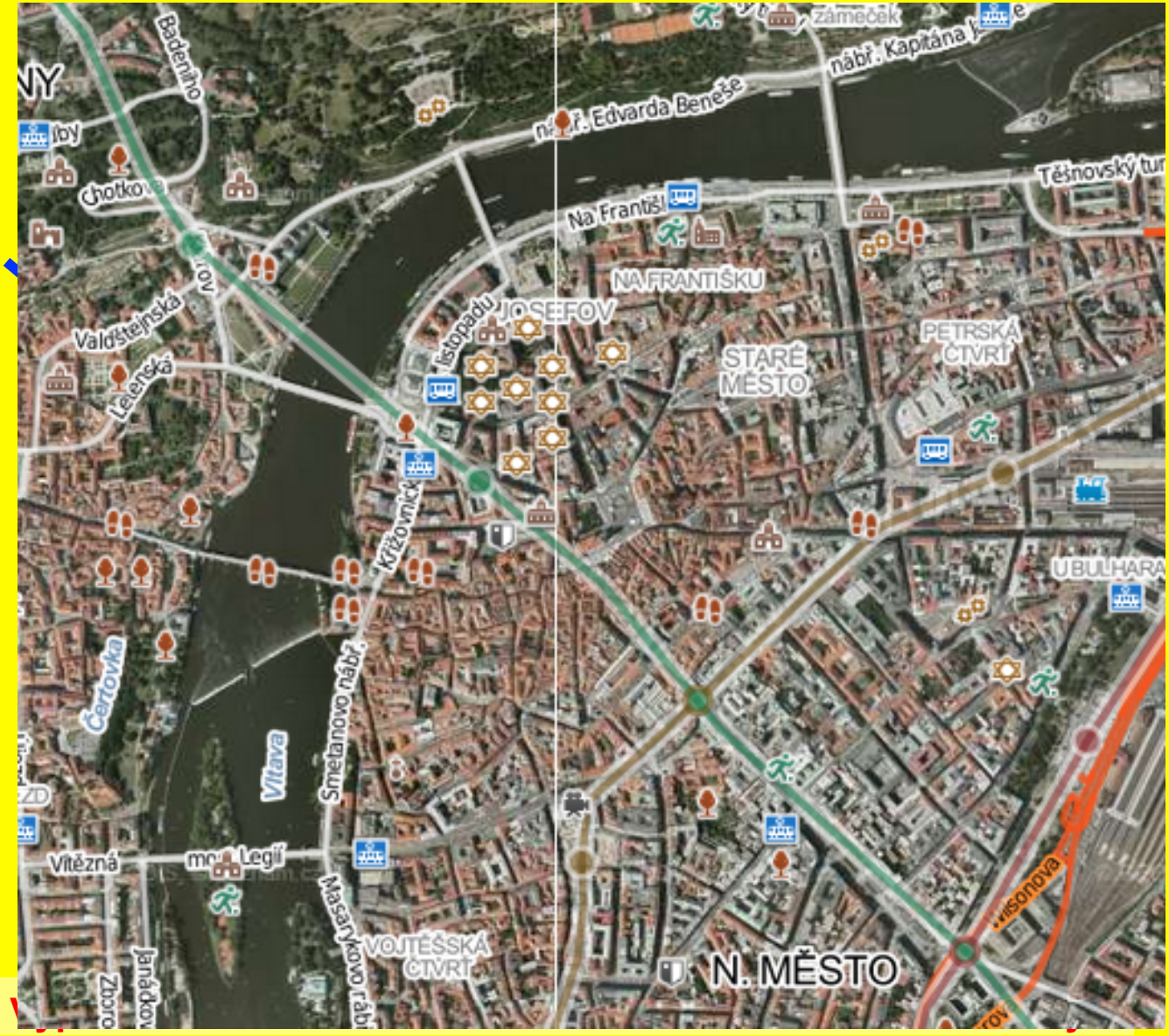
Regional climate model used – ICTP RegCM4 model



Regional climate model assessment of urban canopy meteorological effects



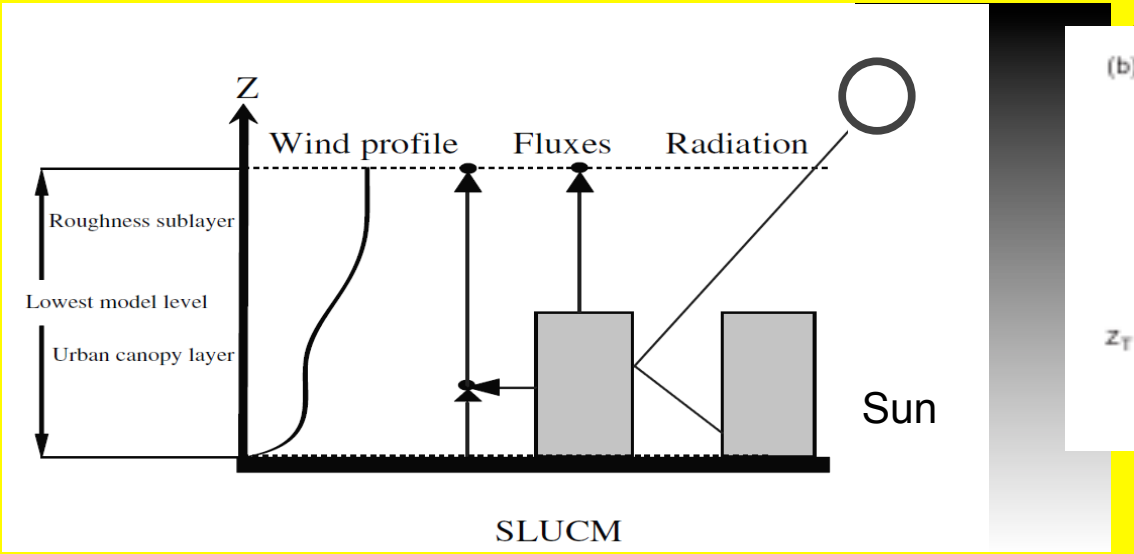
Regional climate model assessment of urban canopy meteorological effects

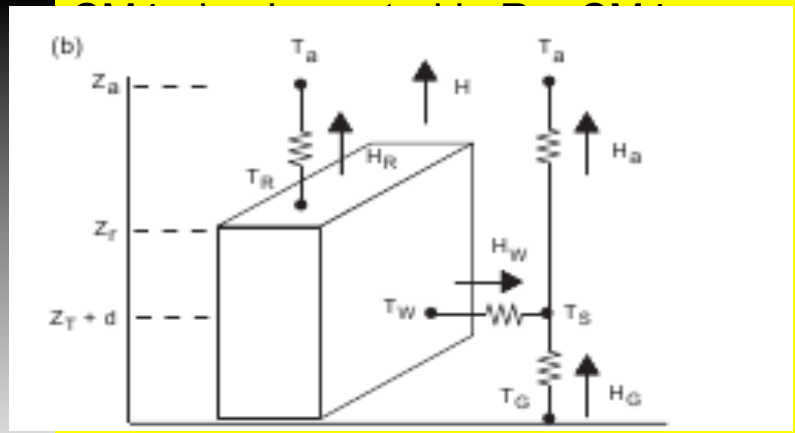


Modeling atmospheric process in urban canopy

Possible urban surface parameterizations within RegCM4

SLUCM (Single-Layer urban Canopy Model) + BATS surface model including subgrid treatment (SUBBATS)



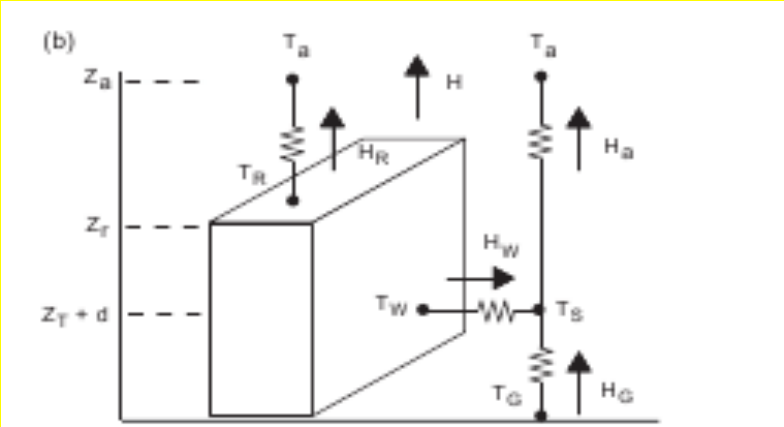


Kusaka and Kimura (2004)

Urban canopy parameterization in RegCM4

- SLUCM – Single Layer Urban Canopy Model
- Kusaka et al. (2001), as implemented into WRF (Chen et al. 2010)

Energy fluxes and temperatures in the street canyon:



from Kusaka and Kimura (2004)

T_a - air temperature at reference height z_a
T_R - building roof temperature
T_W - building wall temperature
T_G - the road temperature
T_S - temperature defined at z_T+ d.
H - the sensible heat exchange at the reference height.
H_a is the sensible heat flux from the canyon space to the atmosphere
H_W - from wall to the canyon space
H_G - from road to the canyon space
H_R - from roof to the atmosphere

Single Layer Urban Canopy Model

- Urban geometry - infinitely-long street canyons
- In a street canyon - shadowing, reflections, and trapping of radiation are considered
- Exponential wind profile is prescribed
- Prognostic variables: surface skin temperatures at the roof, wall, and road (calculated from the surface energy budget) and temperature profiles within roof, wall and road layers (calculated from the thermal conduction equation).
- Monin-Obuchov similarity theory for surface heat fluxes from each surface
- Canyon drag coefficient and friction velocity is computed using a similarity stability function for momentum.

Implementation into RegCM4 (RegCM4/SLUCM)

- Coupled online trough the RegCM's surface model BATS with subgrid surface treatment (SUBBATS)
- Two “urban” landuse categories defined “urban”/”suburban” - landuse created from Corine and GLC2000 (where Corine is not available) database
- SLUCM is called by BATS when it finds subgrid boxes with “urban”/”suburban” cover. The BATS fluxes and large scale meteorological fields are passed to SLUCM
- SLUCM returns the total sensible heat flux from the roof/wall/road to BATS, as well as the total momentum flux
- The total friction velocity is aggregated from urban and non-urban surfaces and passed to RegCM's boundary layer scheme.
- Urban parameters (street canyon width, average building height, roof area, artificial heat) estimated for Prague – sensitivity tests are being run.

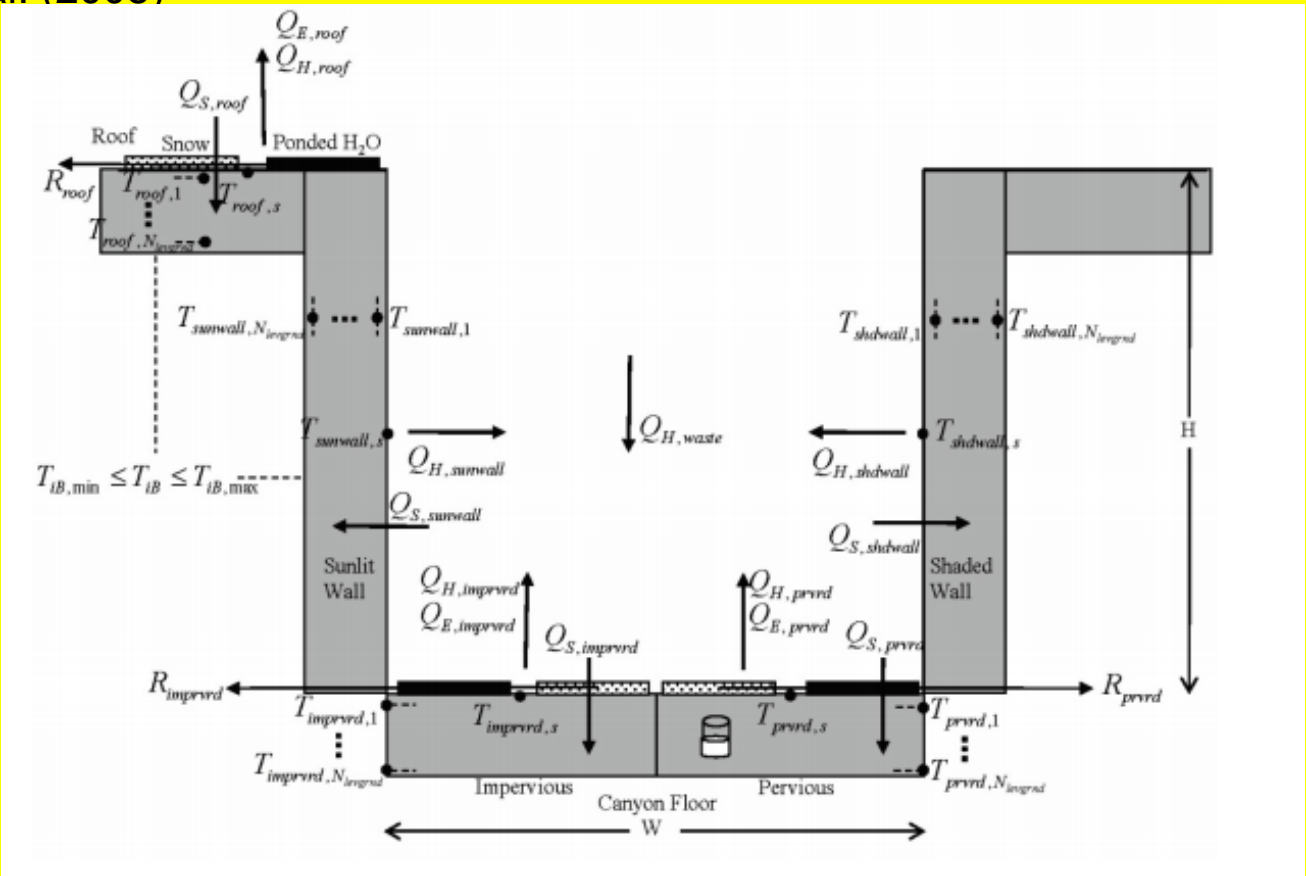
Modeling atmospheric process in urban canopy

Possible urban surface parameterizations within RegCM

CLMUrban + CLM4.5 (Community Land Model version 4.5) – no subgrid treatment but considers fractional land-use

Oleson et al. (2008)

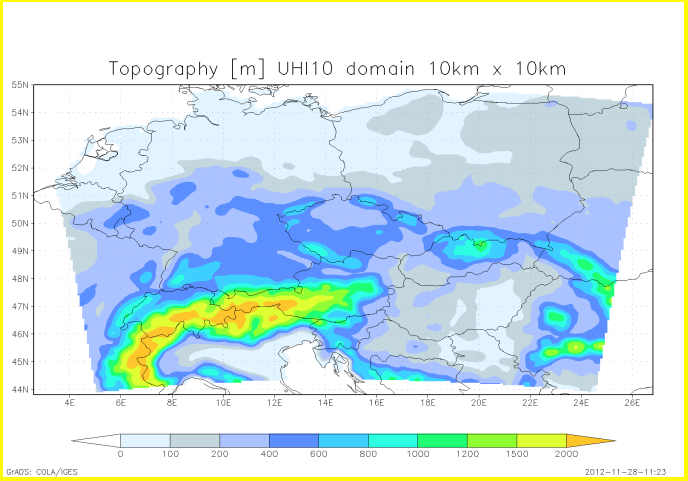
Schematic representation of the urban land unit.

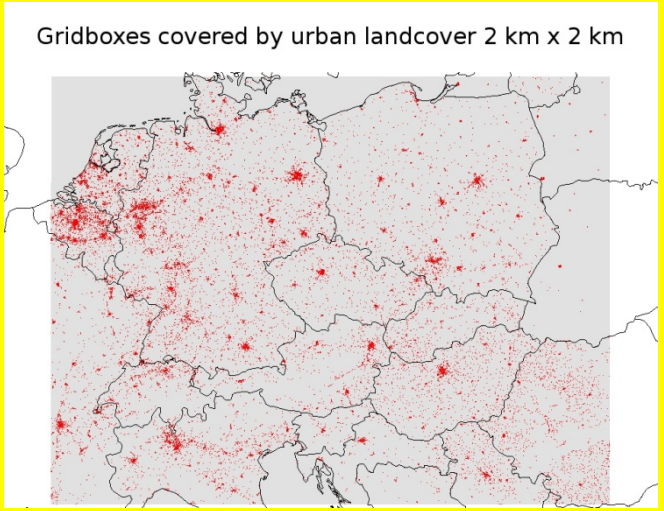


Experiments

European domain **10 km x 10 km** (160 x 120 grid points), 23 vertical levels up to 50 hPa (subgrid for BATS – 2 km x 2 km)

- 2001-2010, ICBC ERA Interim
- **Simulations:**
- BATS/SLUCM
- CLM4.5/CLMU
- **Experiments:**
- **URBAN** – all urban surfaces considered;
- **NOURBAN** – no urban surfaces considered





Other models settings

RegCM

- Regional Climate Model: Giorgi et al. (1993a,b), Giorgi et al. (1999), and Pal et al. (2005).
- Being developed in ICTP, http://users.ictp.it/~pubregcm/RegCM3
- MM5 dynamical core
- 23 vertical σ-levels reaching up to 70hPa, with time step of 30 s, 10 km resolution.
- Surface scheme BATS by Dickinson et al. (1993)
- SUB-BATS (Giorgi et al 2003), **urbanisation of the parameterization**

CAMx

- Eulerian chemical transport model (ENVIRON Corp.)
- http://www.camx.com
- Meteorology from RegCM
- Chemistry schemes: CB-IV+Aerosols
- IC – clean conditions (background)
- BC – provided by 50km x 50km runs
- Emissions – EMEP (Europe, 50km) via TNO emission (10km) or local databases, biogenic emissions of isoprene and monoterpenes by the model

CLWRF, WRF-Chem - urbanization

Results

Impact of urban surfaces on regional climate over central Europe

SLUCM – NOURBAN

CLMU - NOURBAN

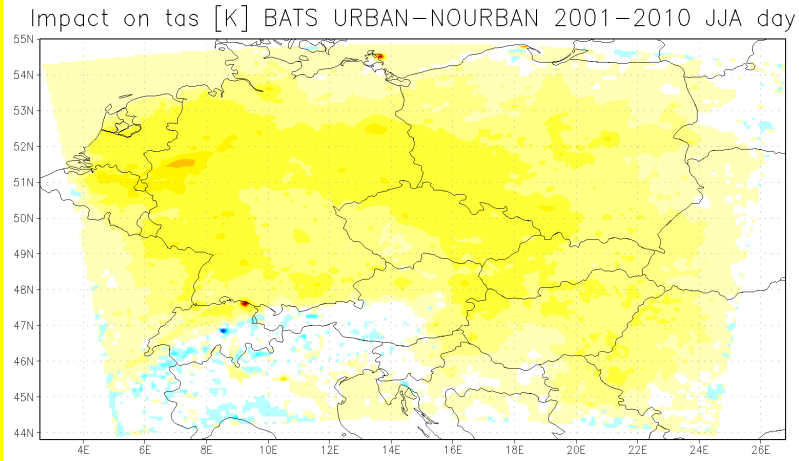
Near surface temperature

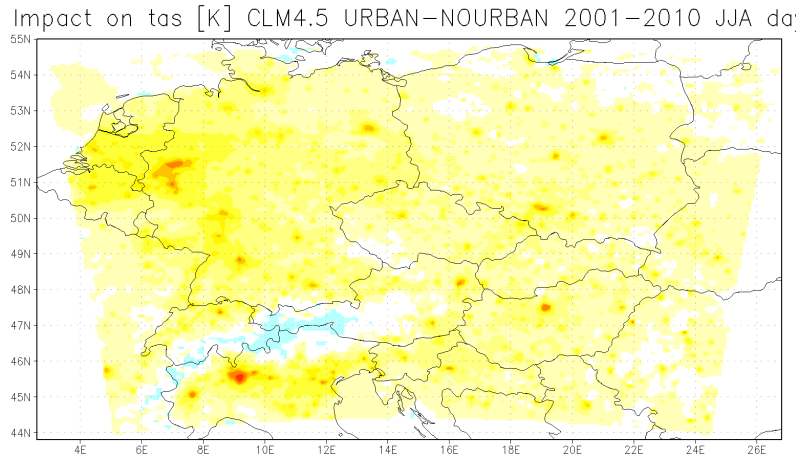
summer

BATS/SLUCM

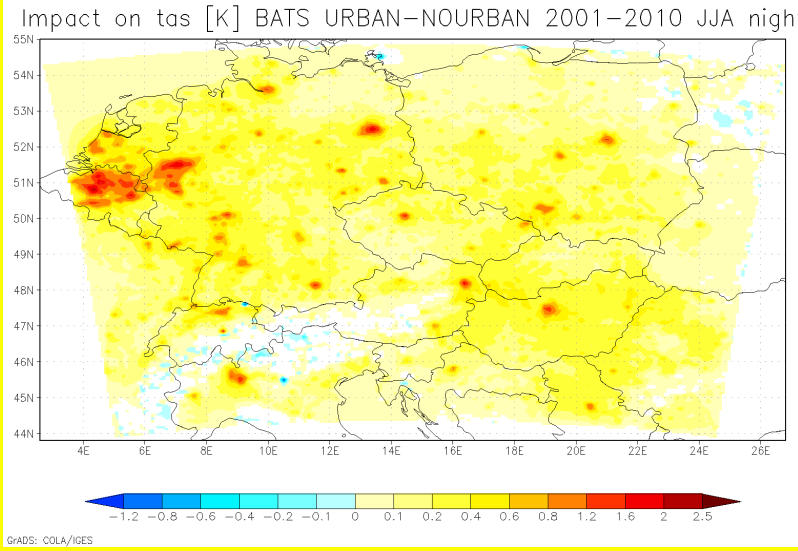
CLM4.5/CLMU

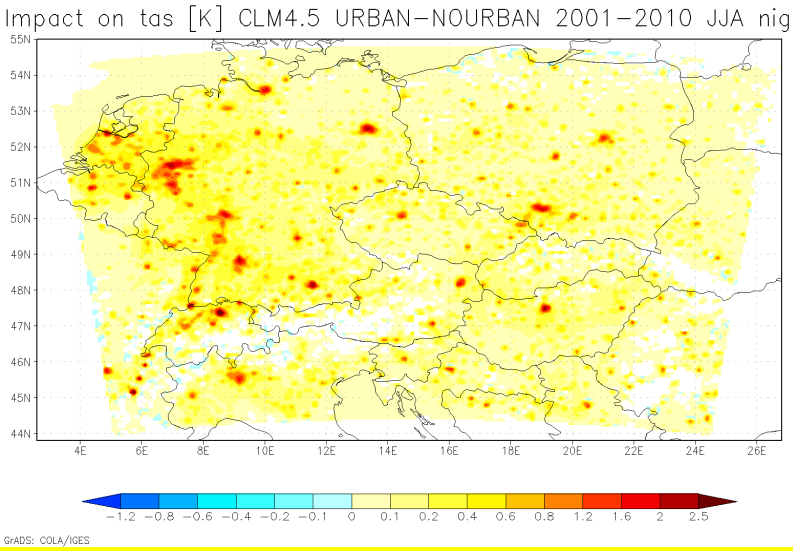
day





night





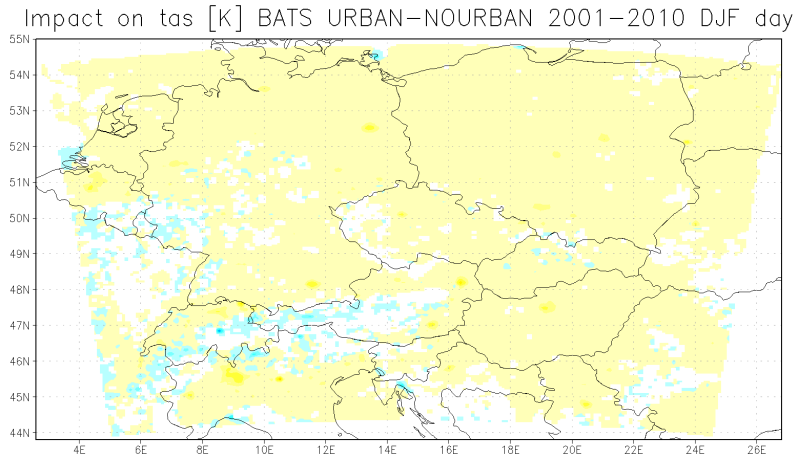
Near surface temperature

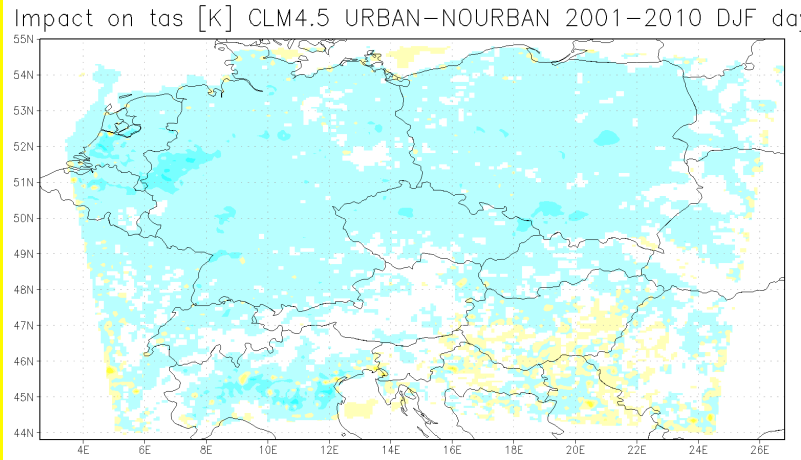
winter

BATS/SLUCM

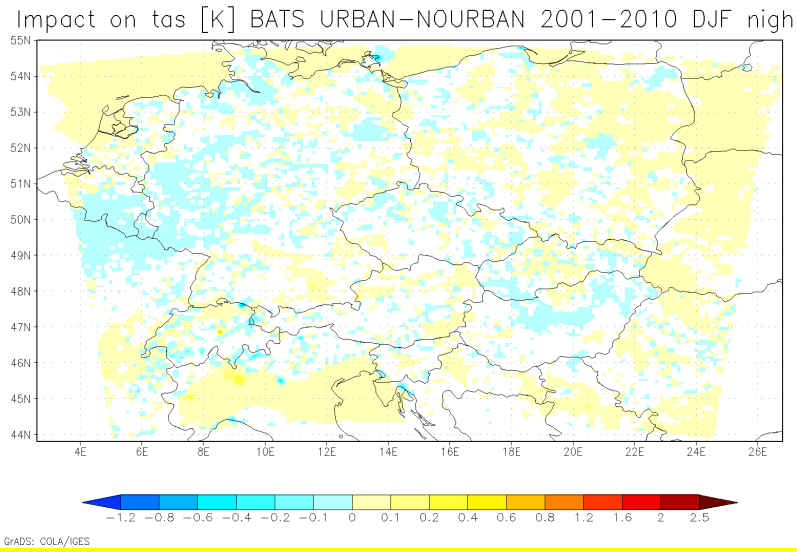
CLM4.5/CLMU

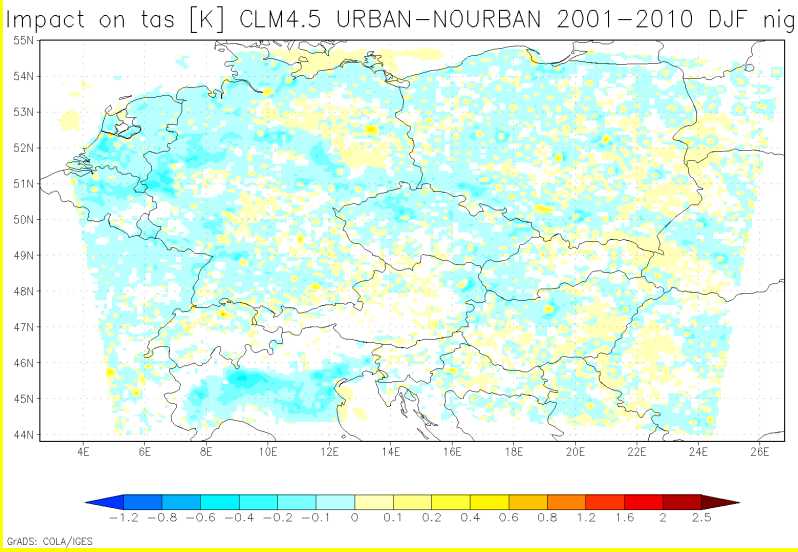
day





night





Near surface humidity

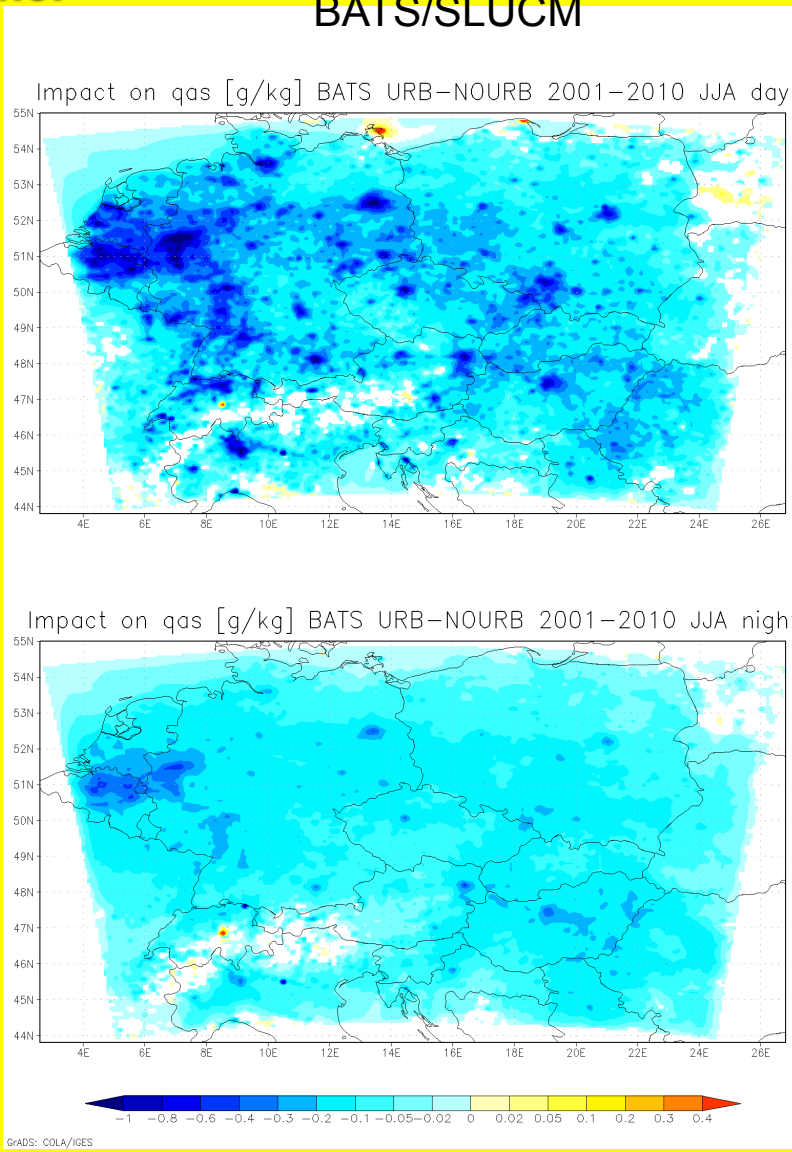
summer

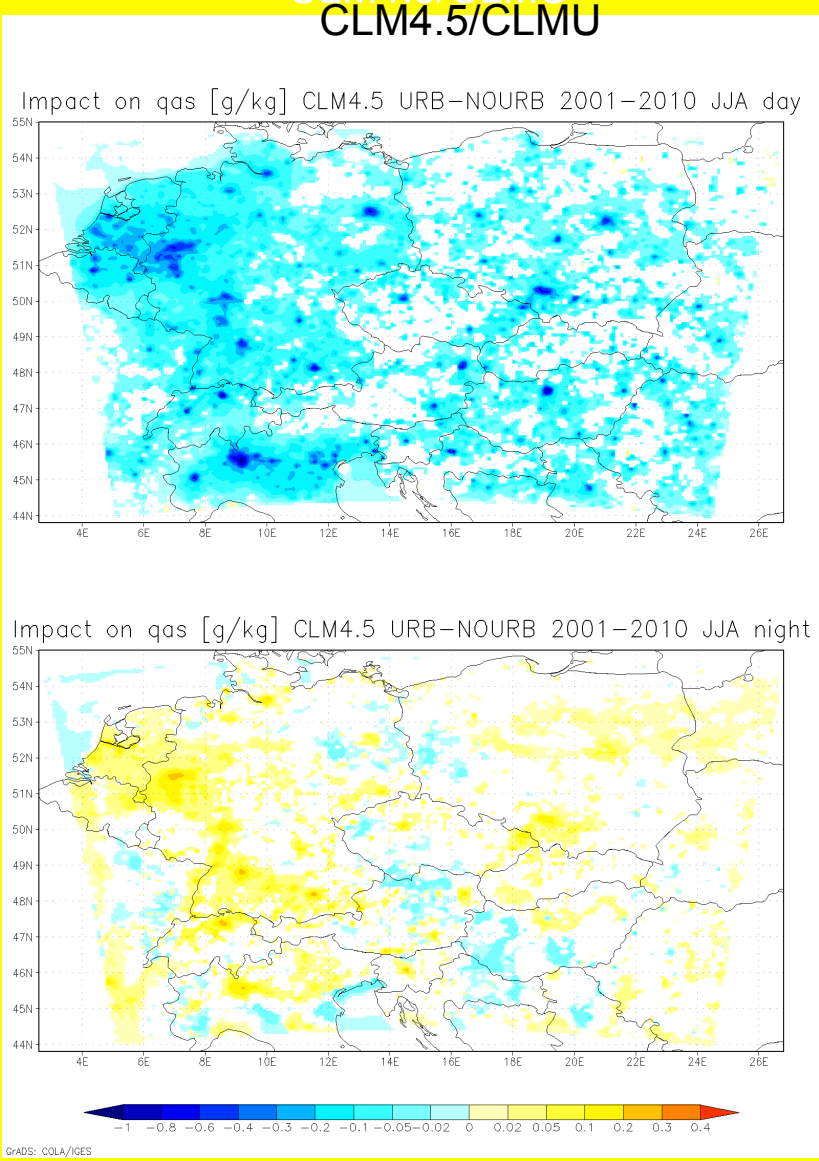
BATS/SLUCM

CLM4.5/CLMU

day

night





Near surface humidity

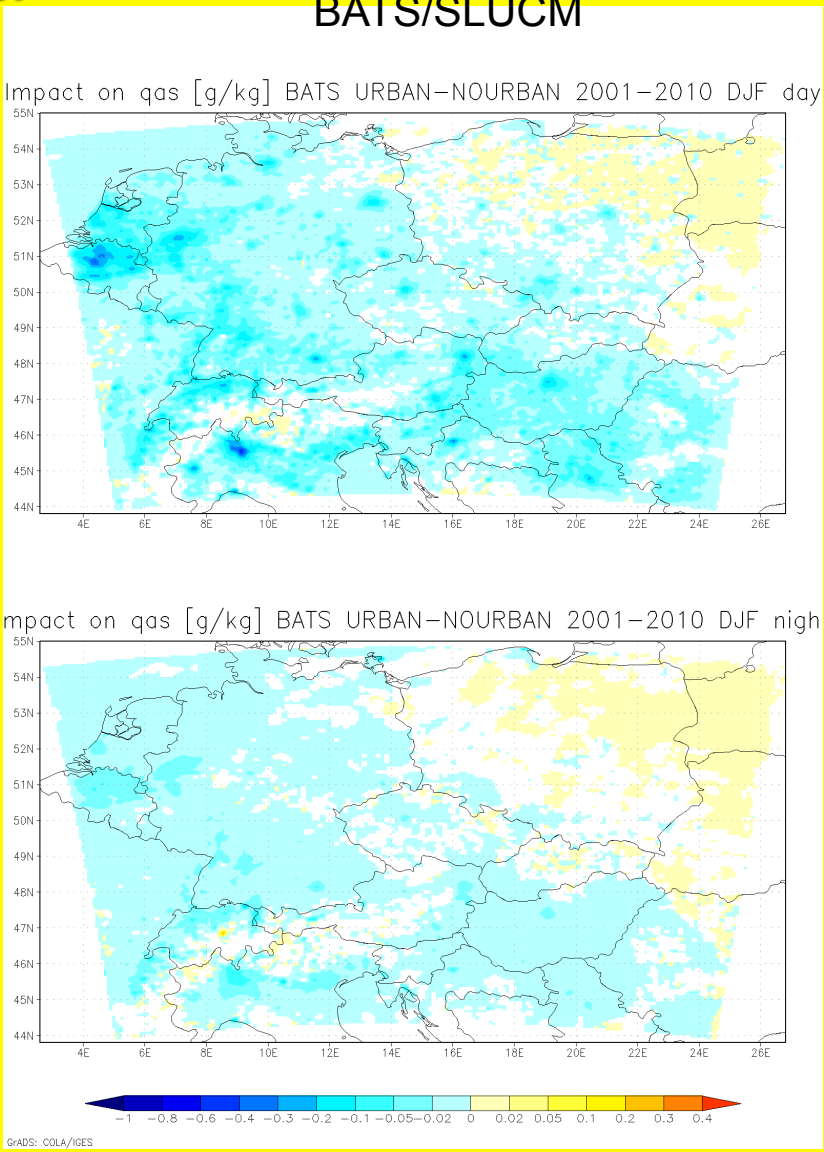
winter

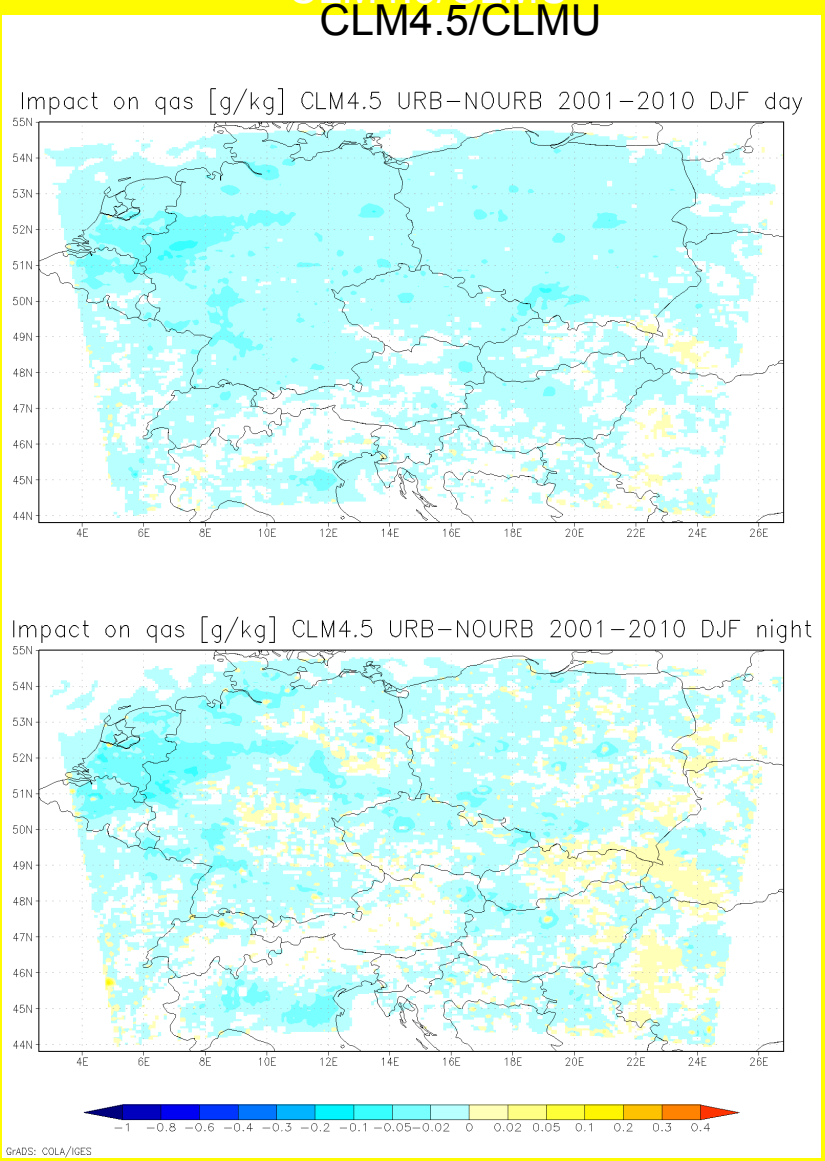
BATS/SLUCM

CLM4.5/CLMU

day

night





Surface sensible heat flux

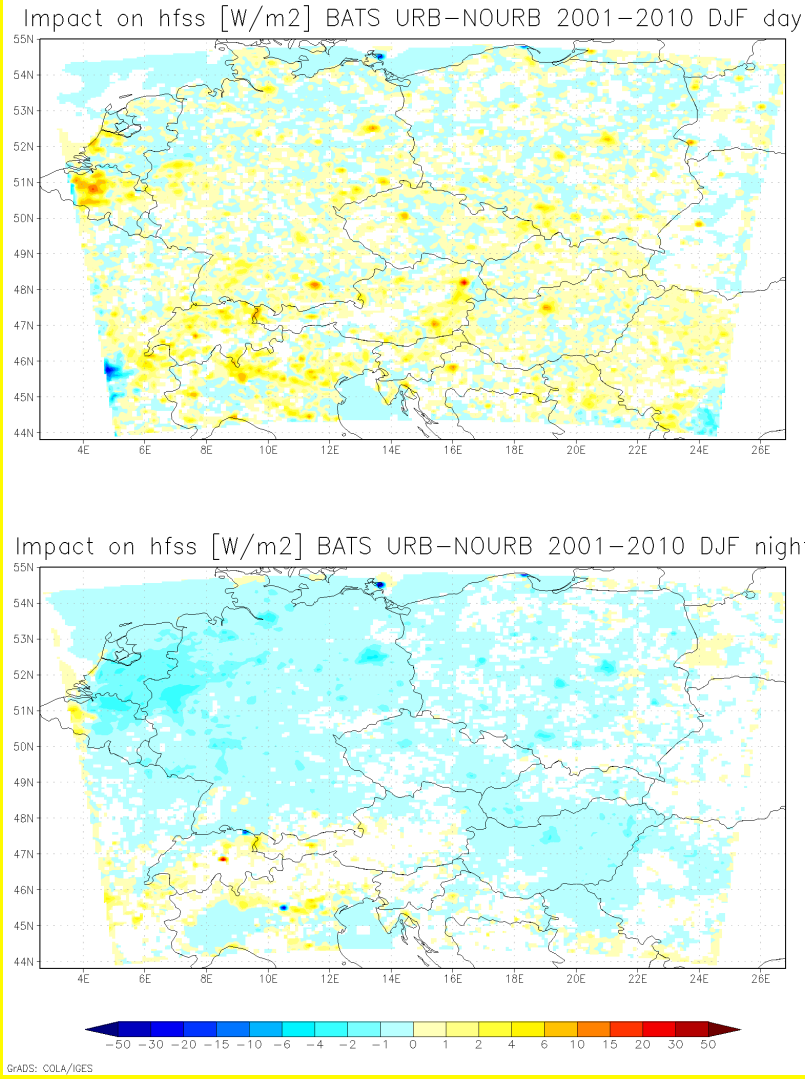
winter

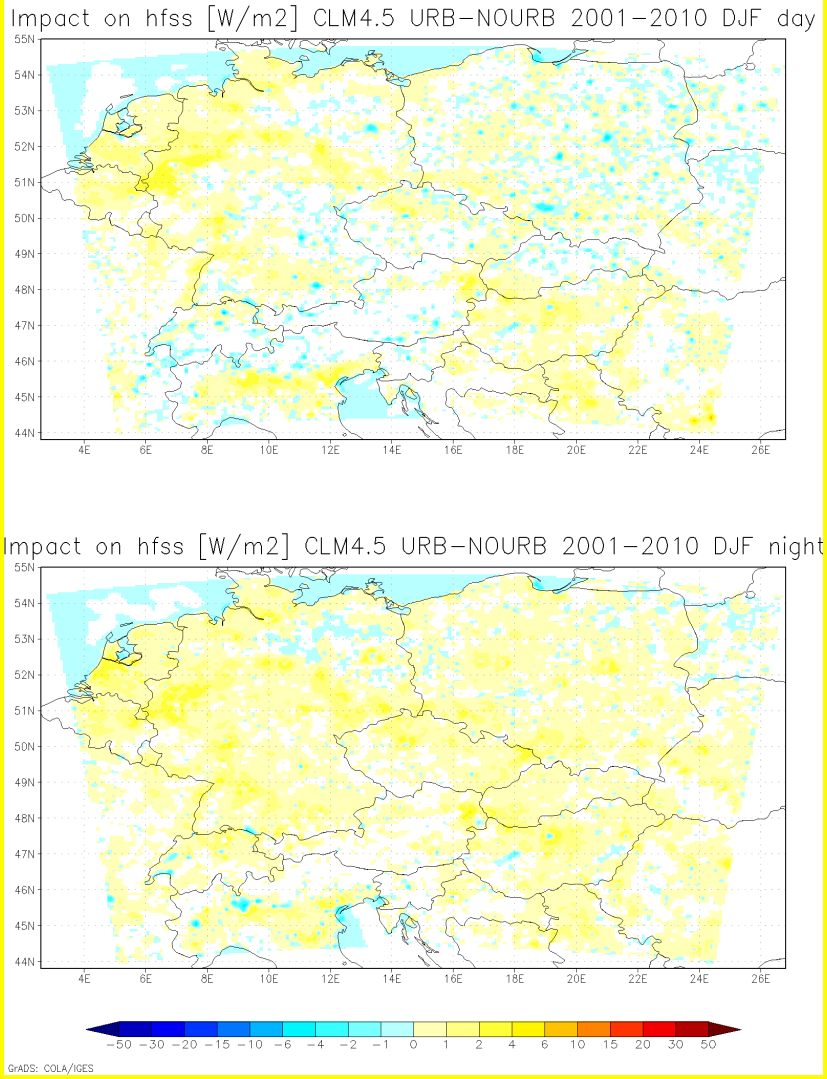
BATS/SLUCM

CLM4.5/CLMU

day

night





Surface sensible heat flux

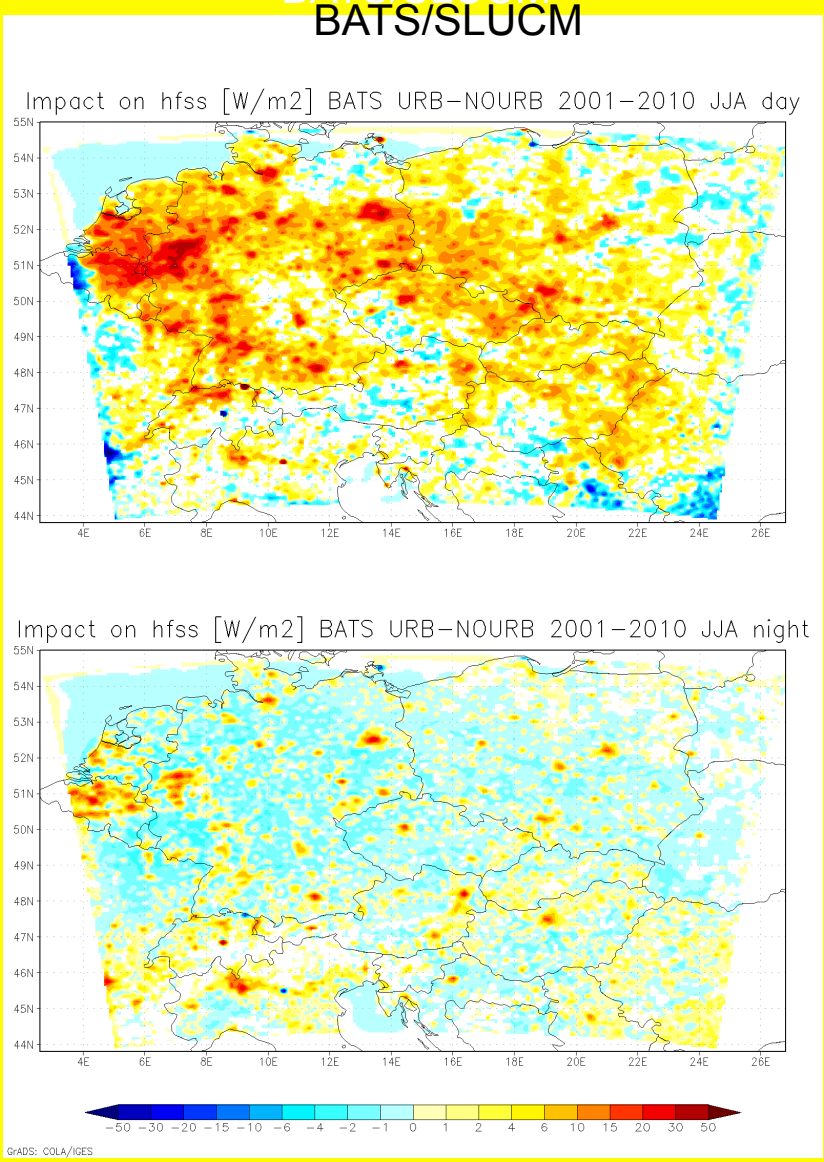
summer

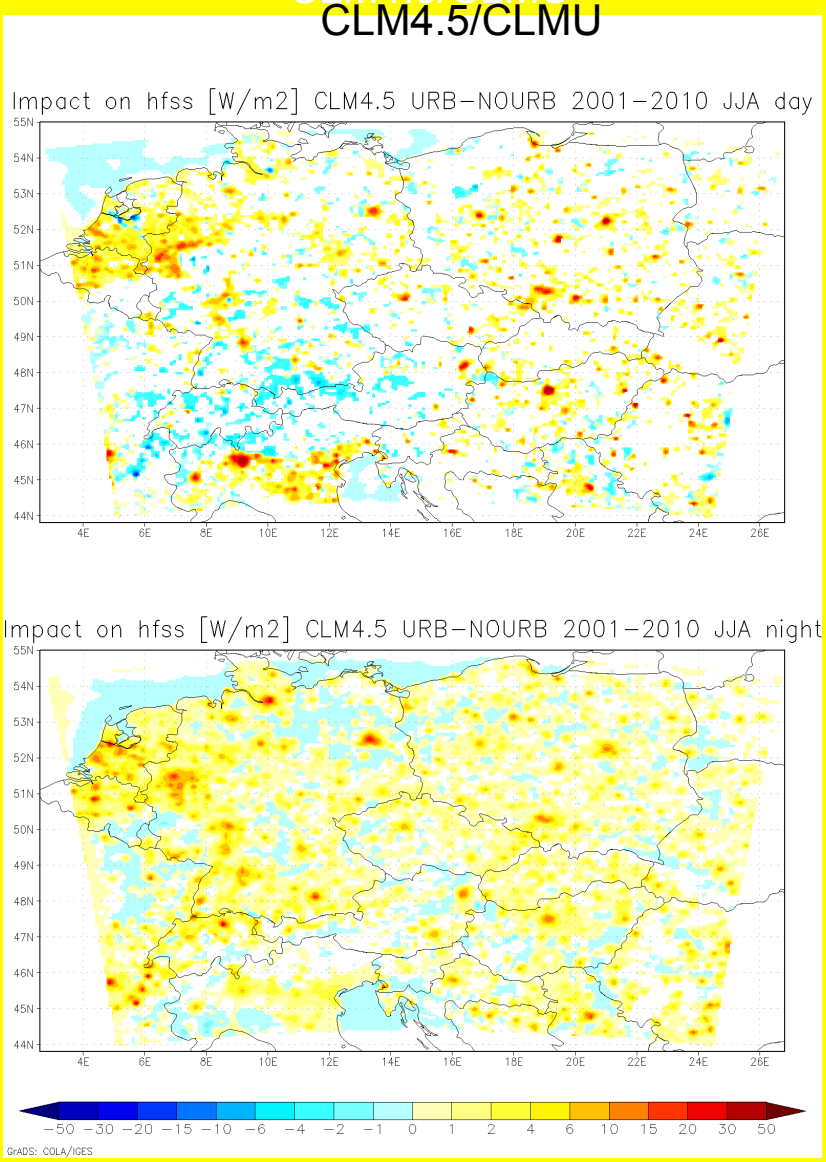
BATS/SLUCM

CLM4.5/CLMU

day

night





Boundary layer height

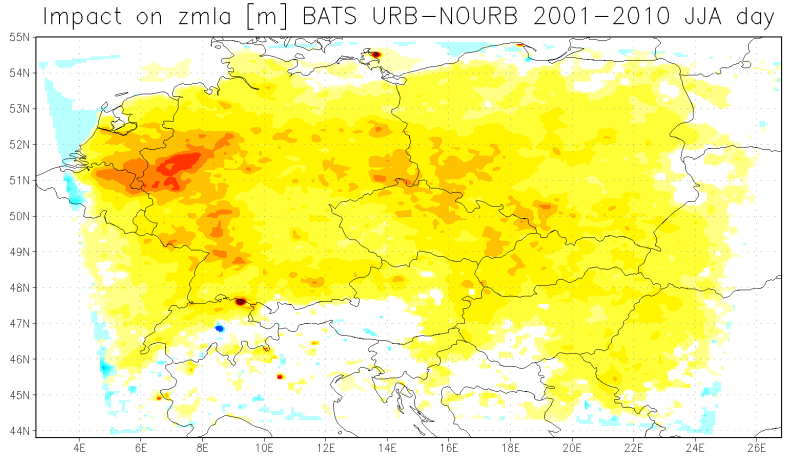
summer

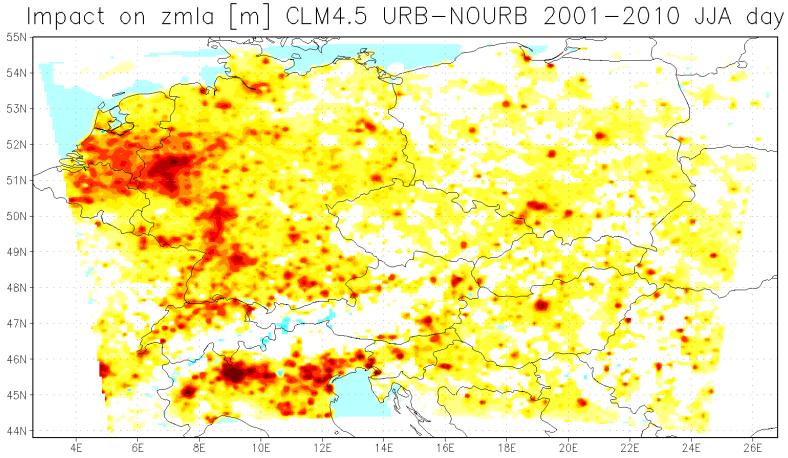
BATS/SLUCM

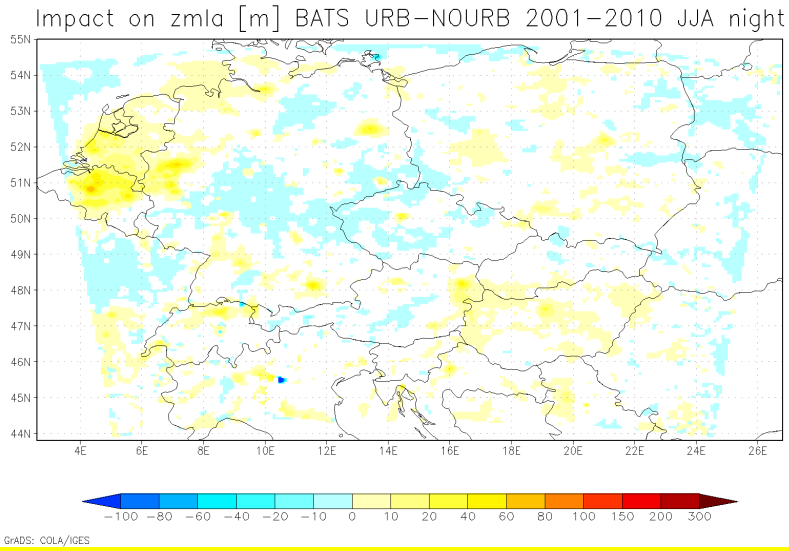
CLM4.5/CLMU

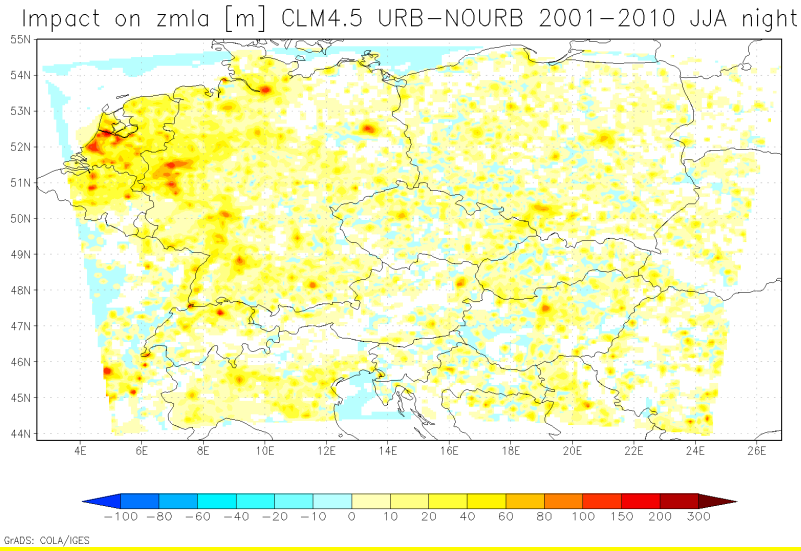
day

night









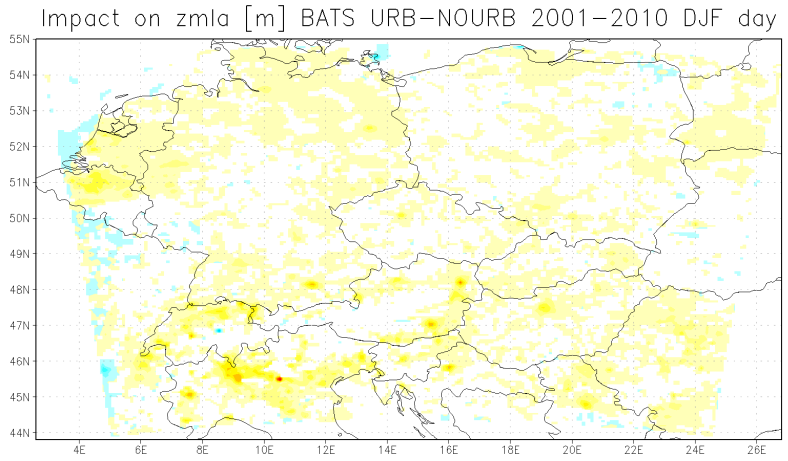
Boundary layer height

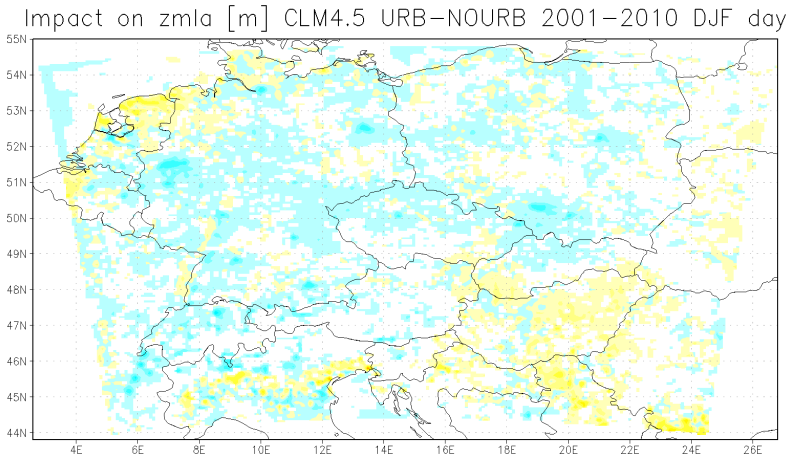
winter

BATS/SLUCM

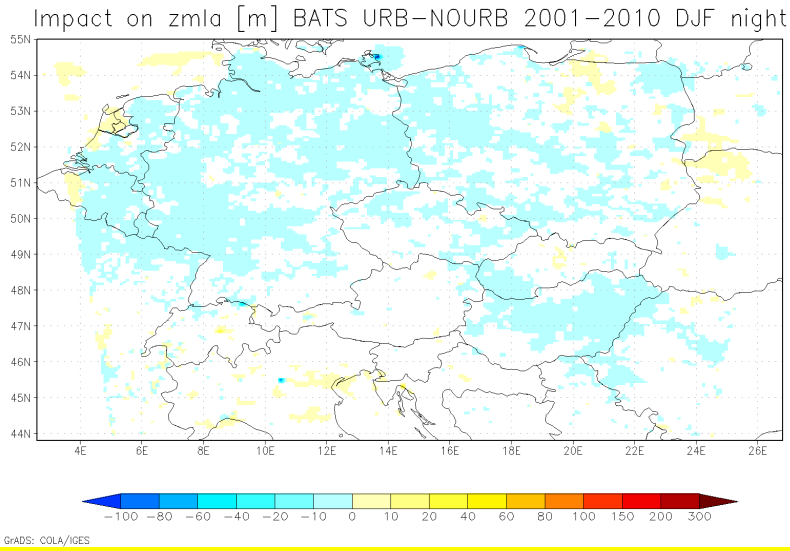
CLM4.5/CLMU

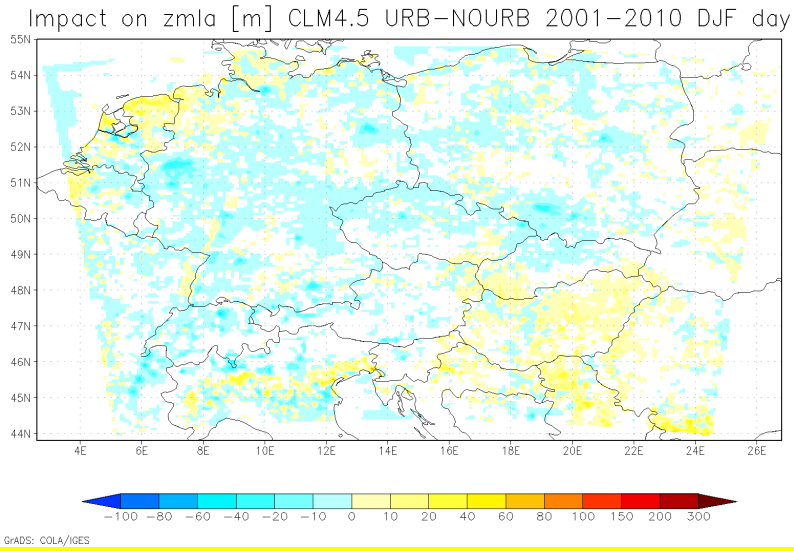
day





night

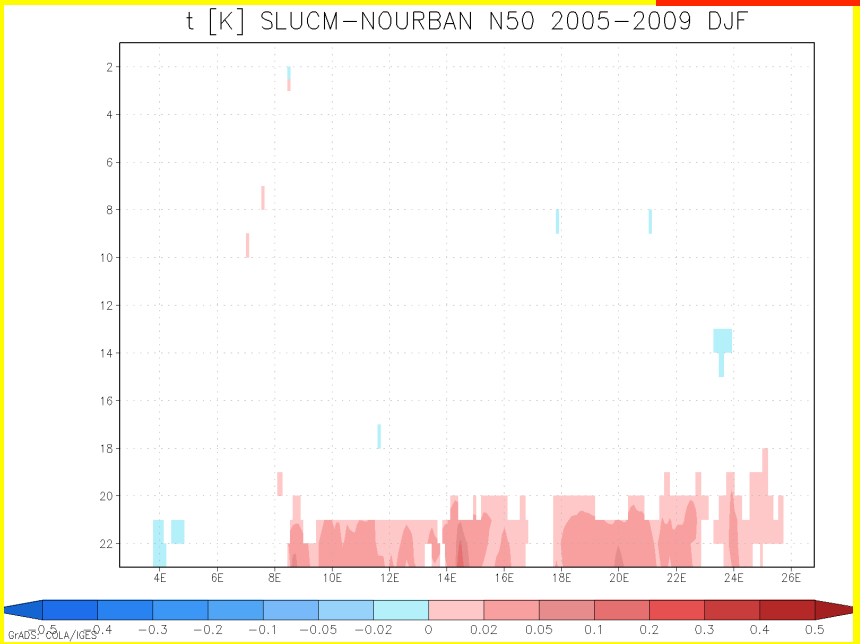


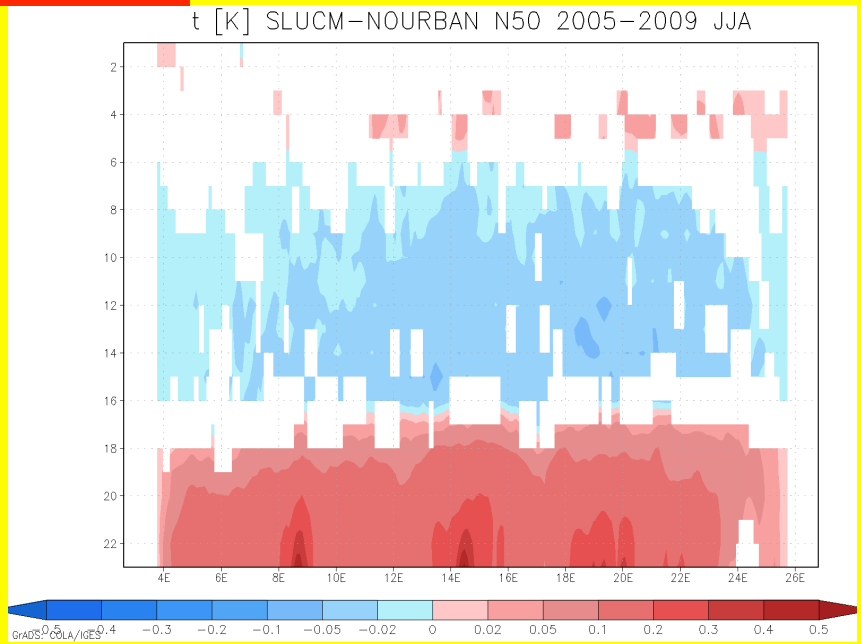


SLUCM – NOURBAN 2005-2009
vertical cross-section at 50N

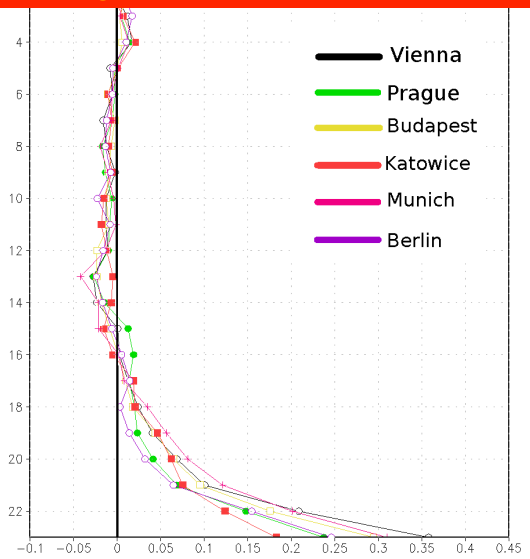
winter **summer**

temperature



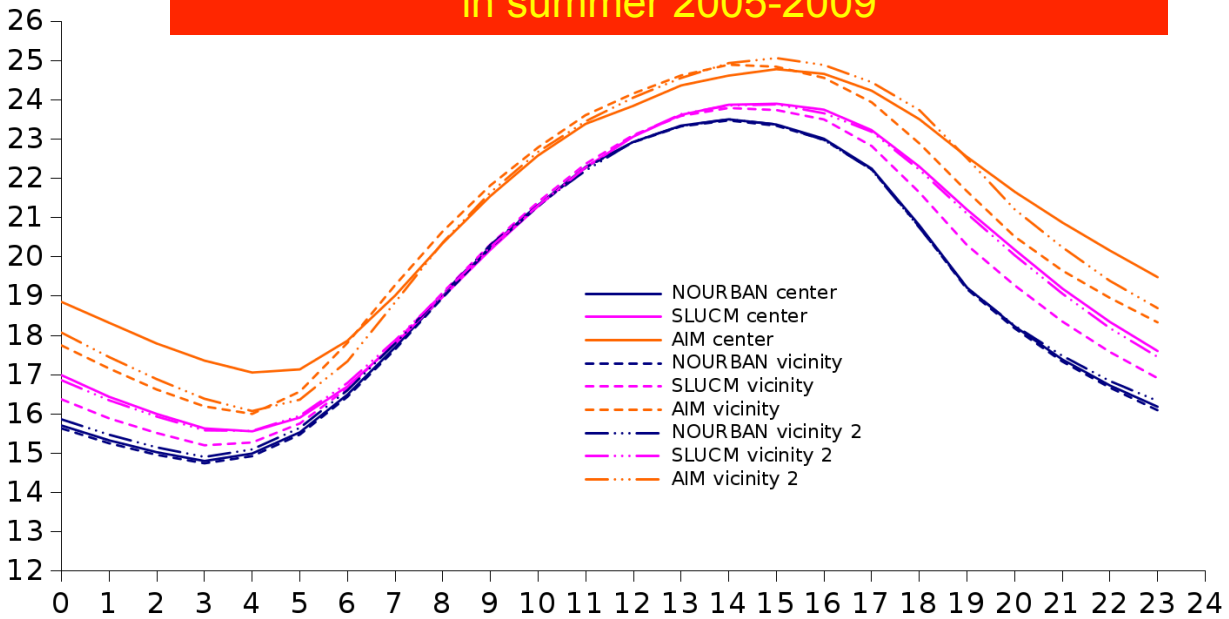


Vertical profile of temperature changes over selected cities

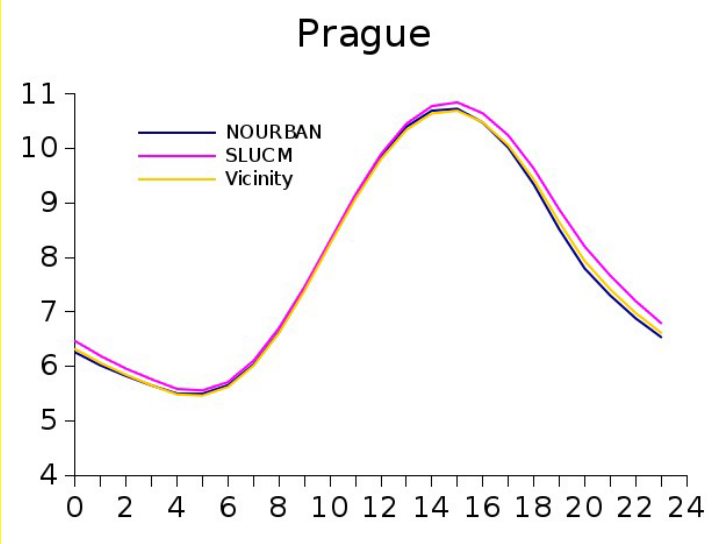


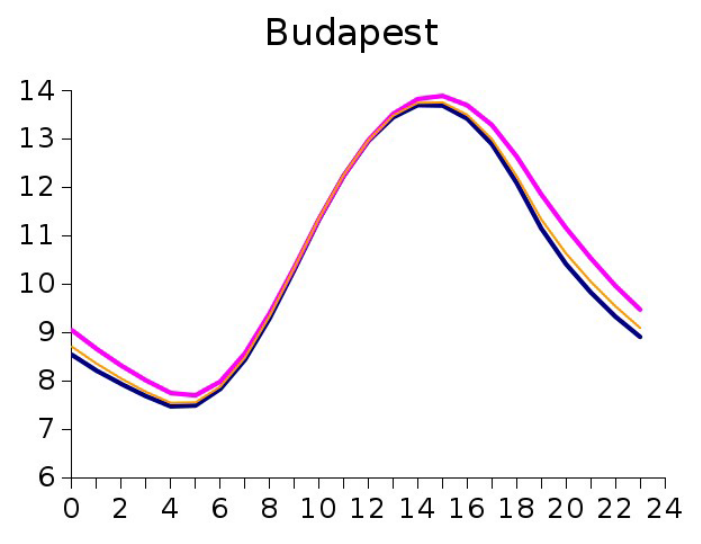
GrADS: COLA/IGES

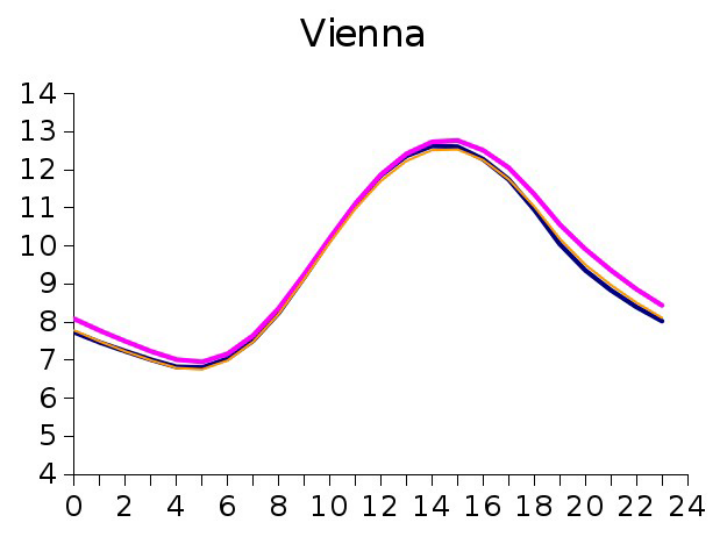
Daily course of temperature for Prague in summer 2005-2009

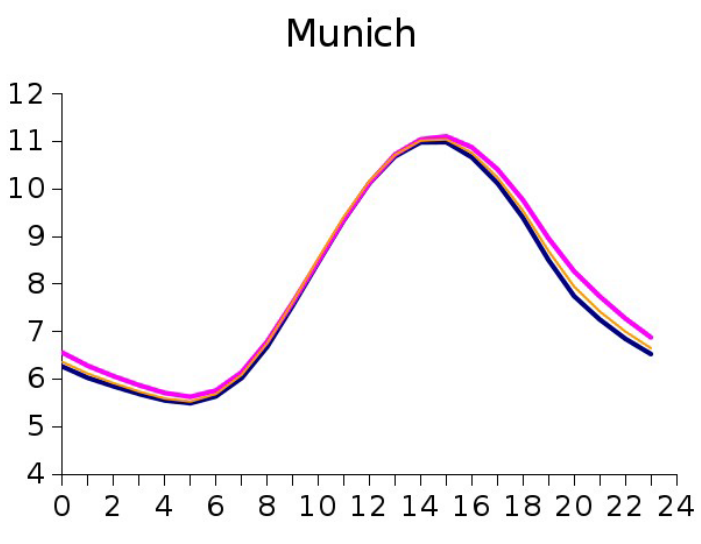


SLUCM – NOURBAN 2005-2009 and vicinity in diurnal variation

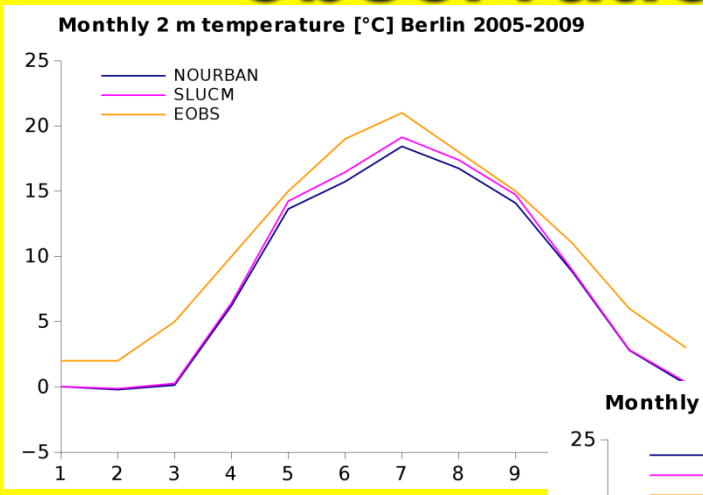


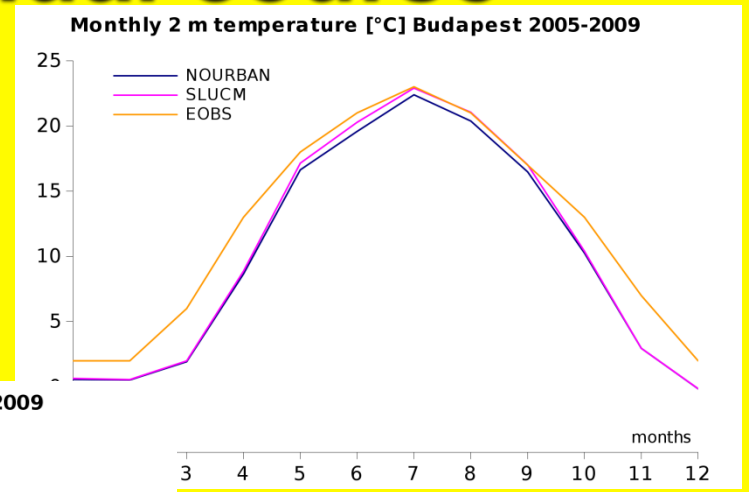


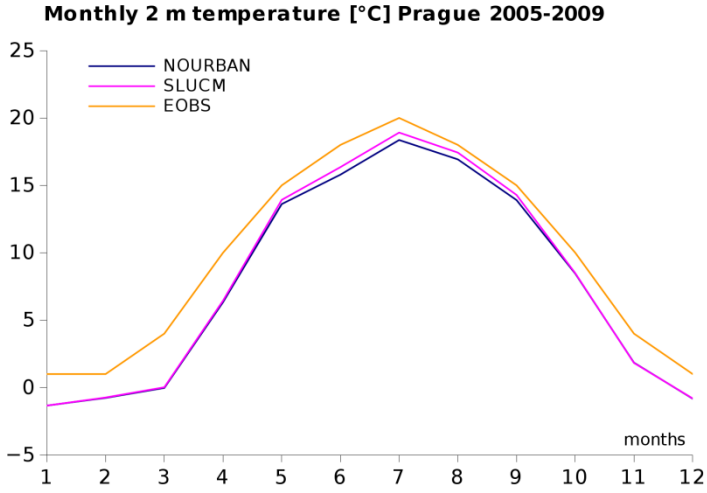


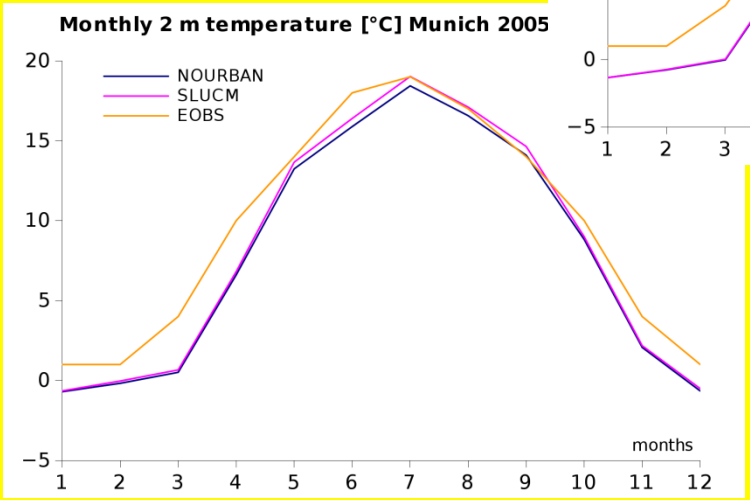


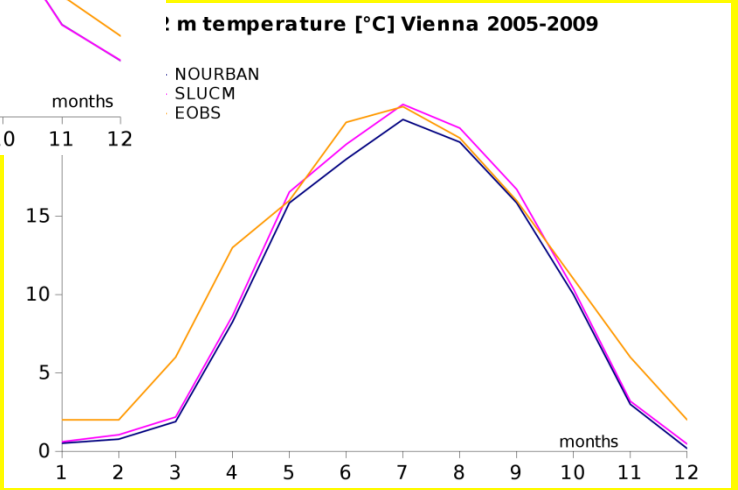
SLUCM – NOURBAN 2005-2009 and observations in annual course







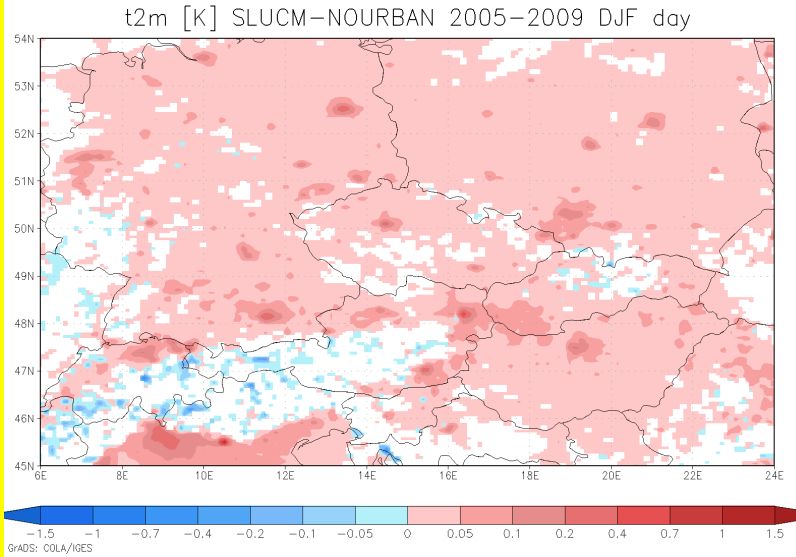


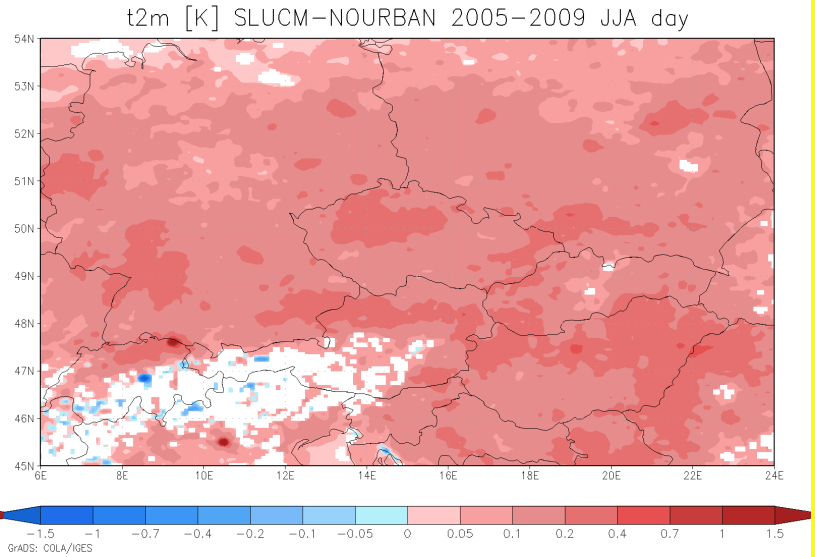


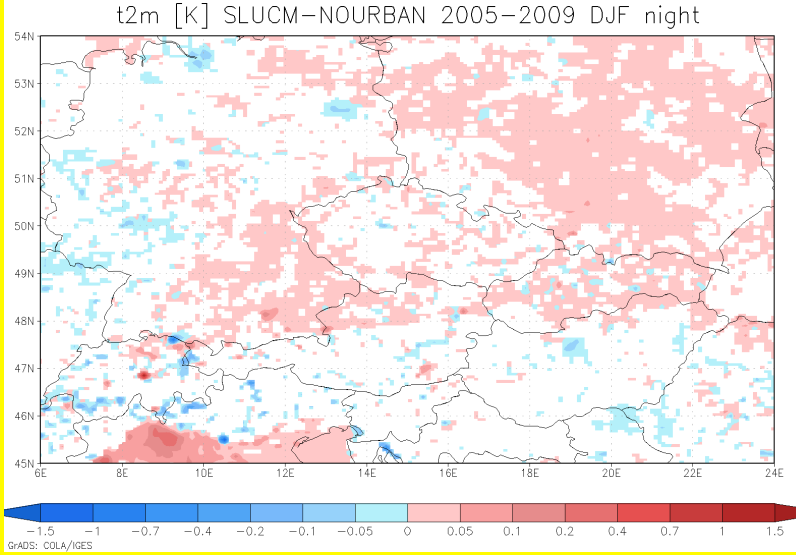
Content

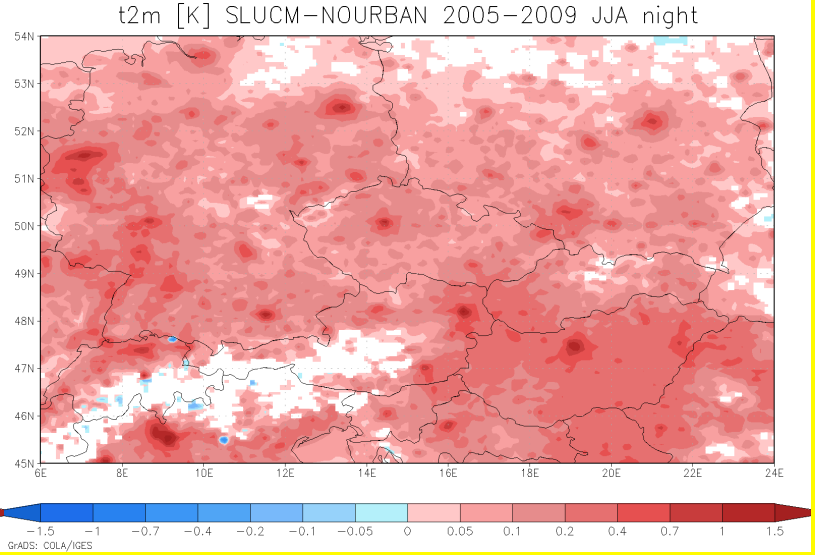
1. Motivation, projects
2. Models and SLUCM implementation
3. Results and urban effects
4. Sensitivity tests
5. Applications (Air quality effects, urban planning, climate change)
6. Summary, conclusions

Resolution effects tests

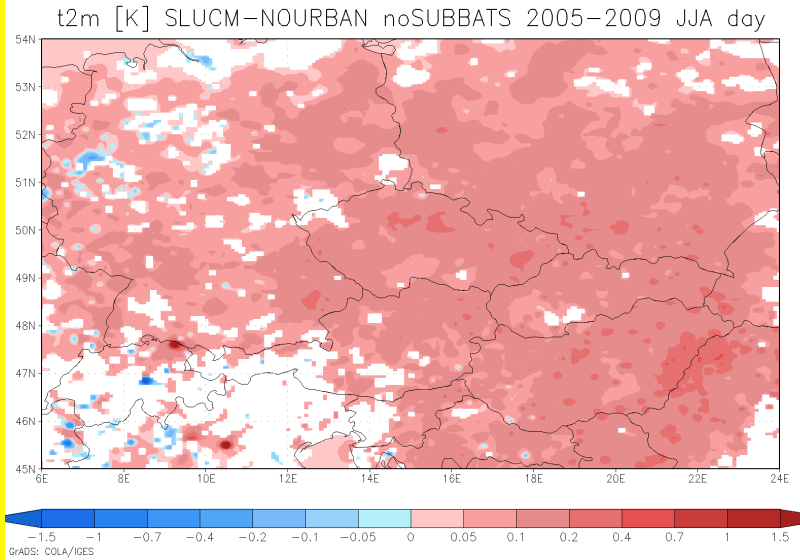


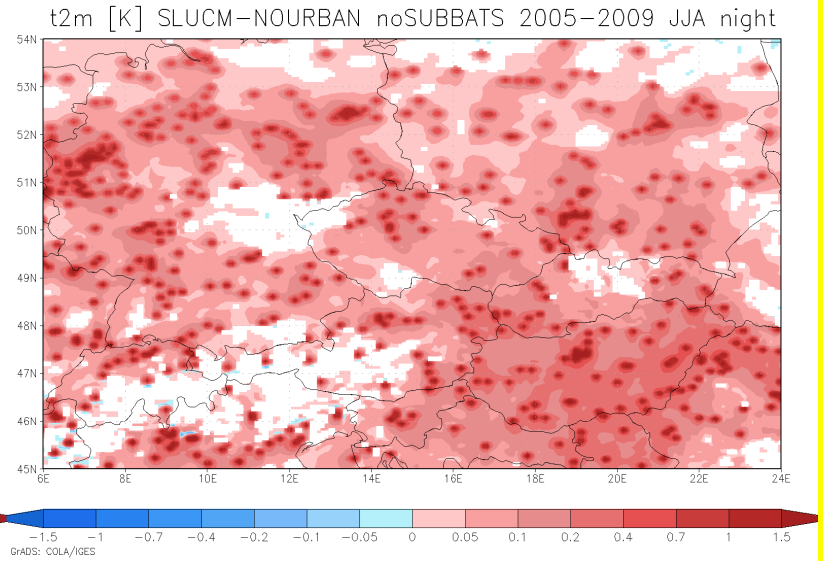


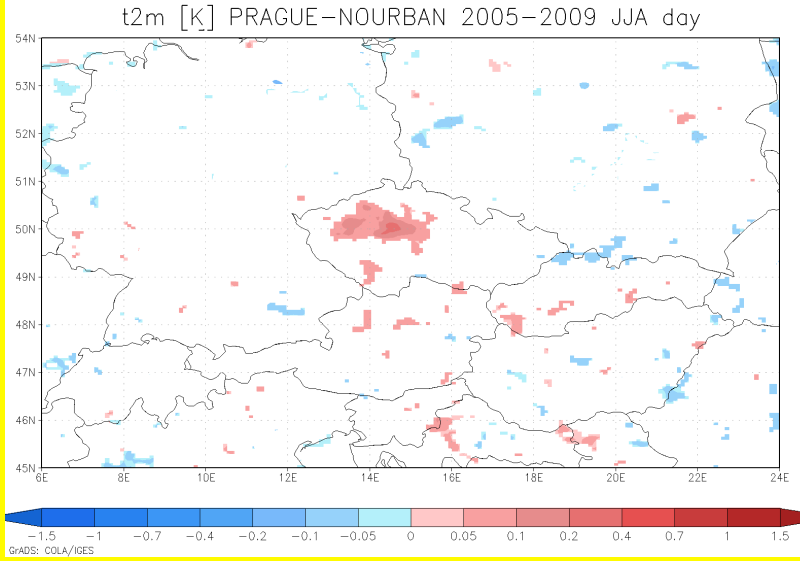


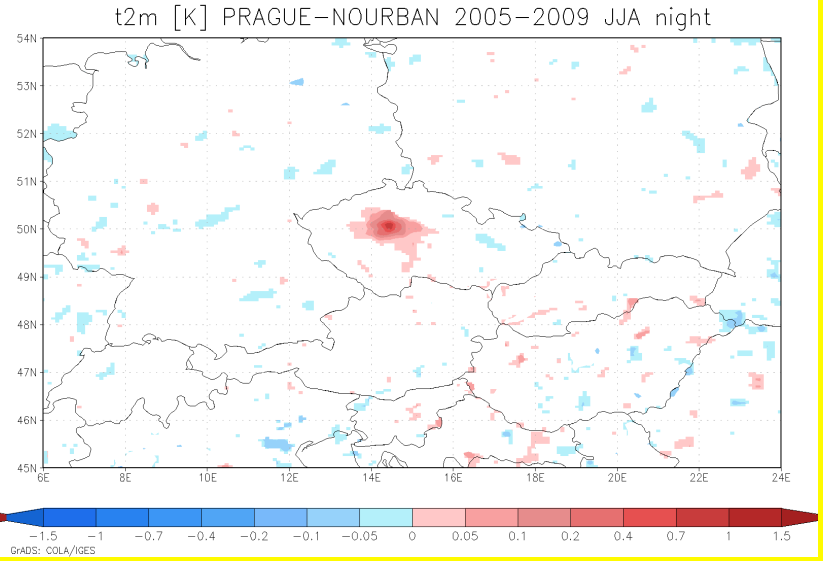


Resolution effects tests







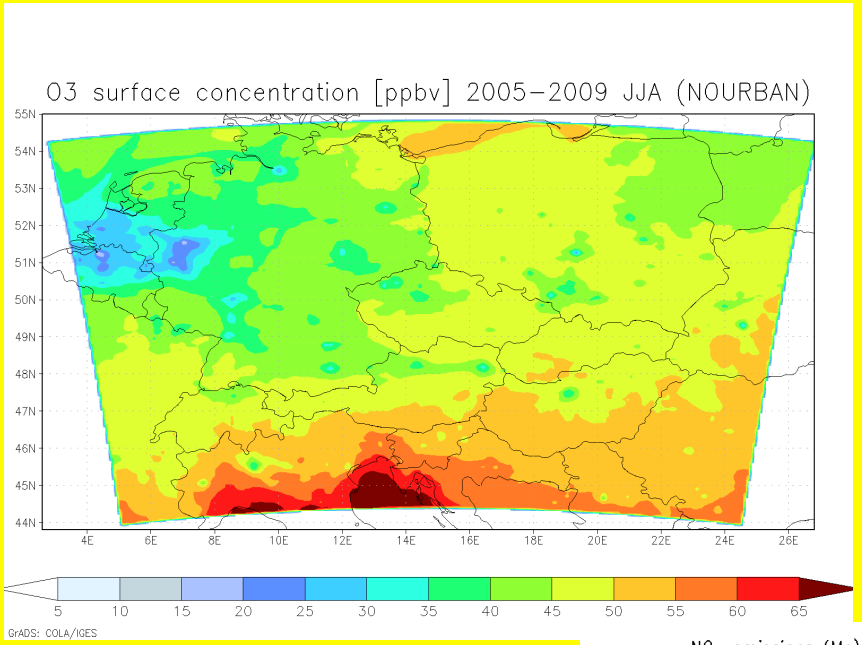


Content

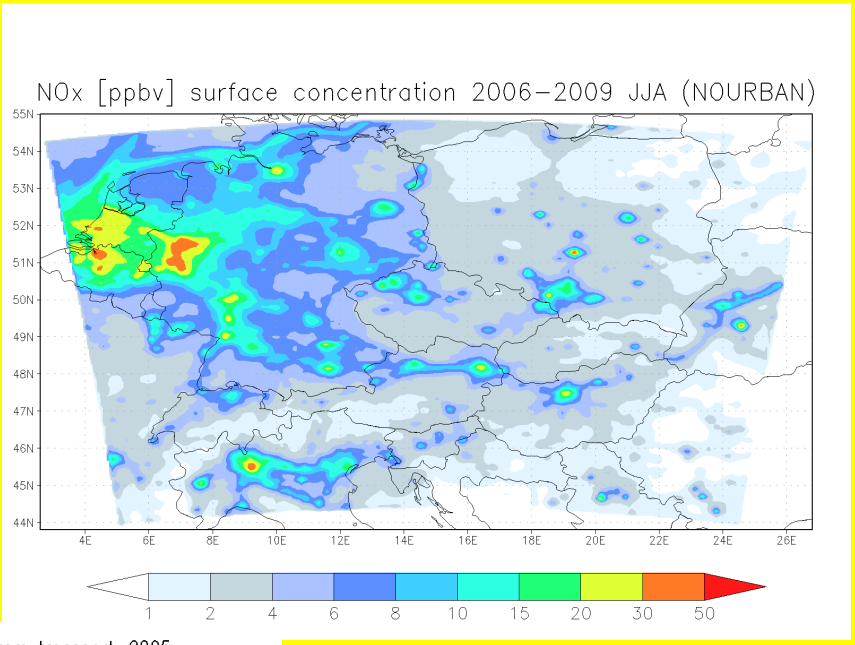
1. Motivation, projects
2. Models and SLUCM implementation
3. Results and urban effects
4. Sensitivity tests
5. Applications (Air quality effects, urban planning, climate change)
6. Summary, conclusions

Air quality, 2005-2009, summer NOURBAN

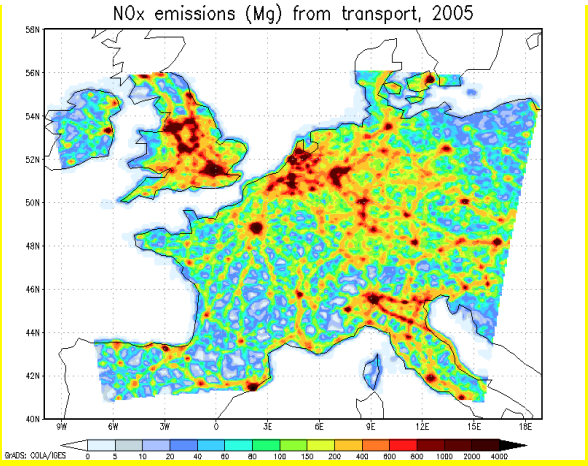
O_3 surface concentration



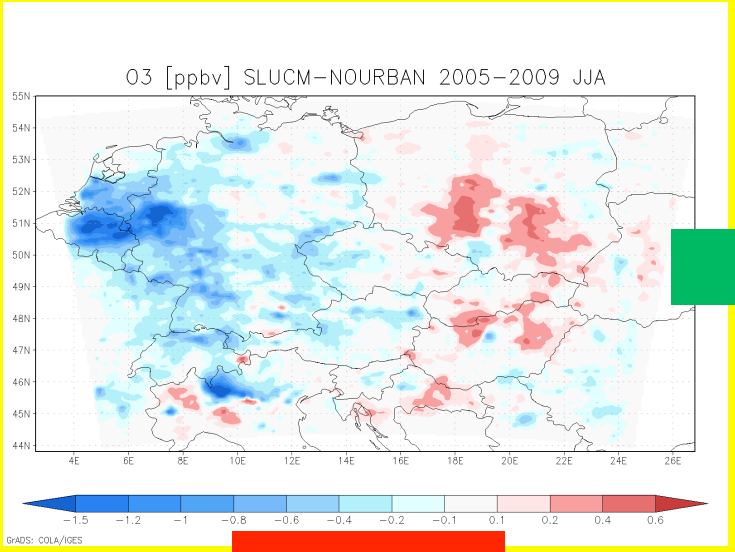
NO_x surface concentration



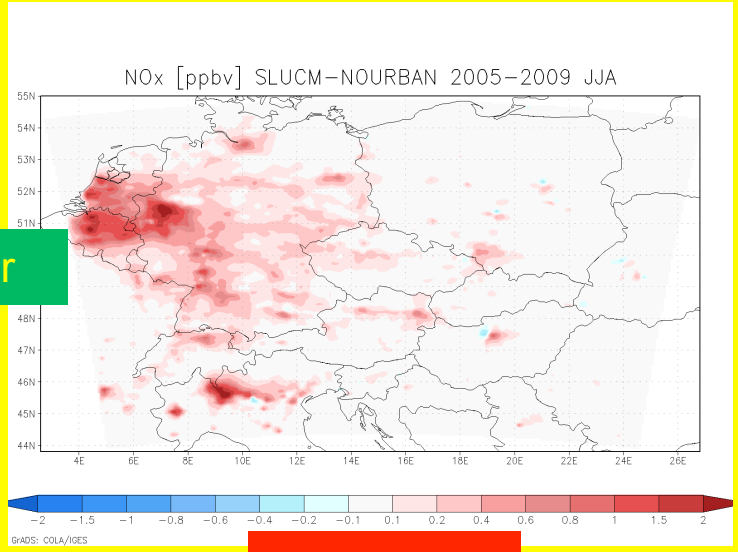
MEGAPOLI TNO NO_x emissions



Air quality, 2005-2009, urban effect

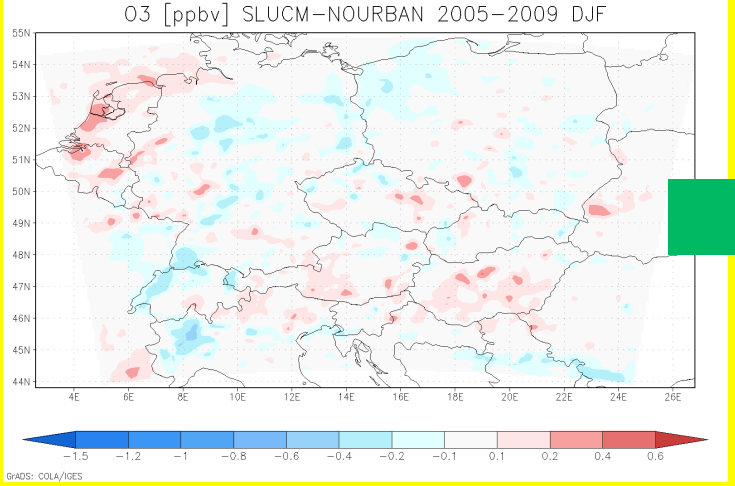


summer

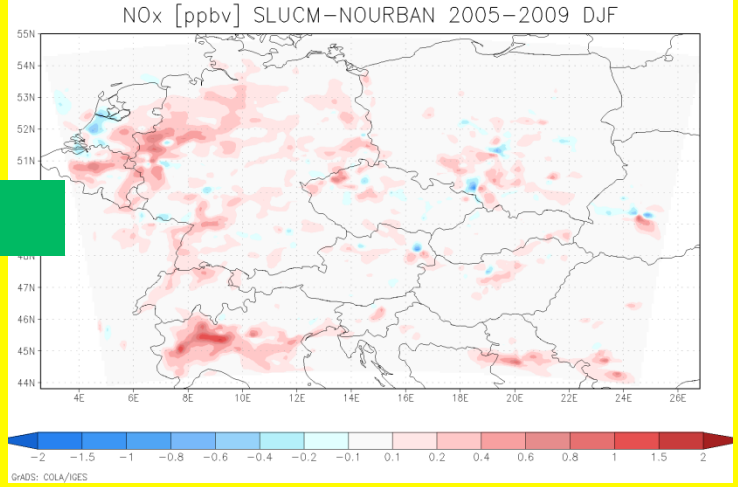


O_3

NO_x

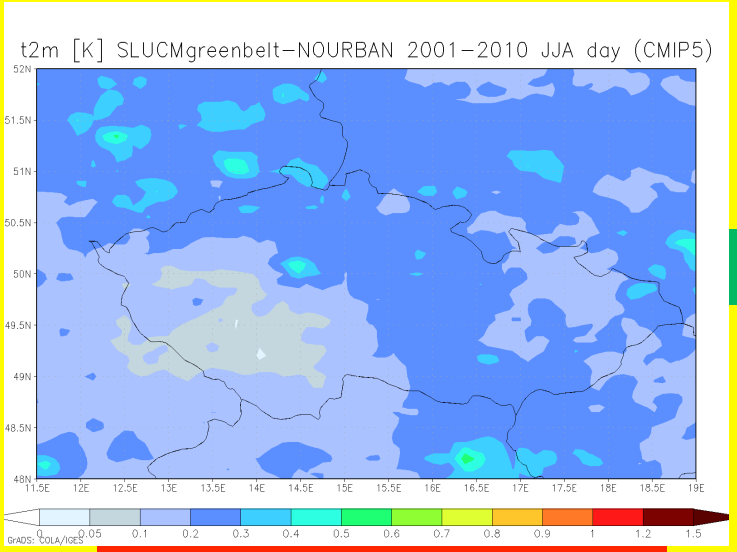


winter

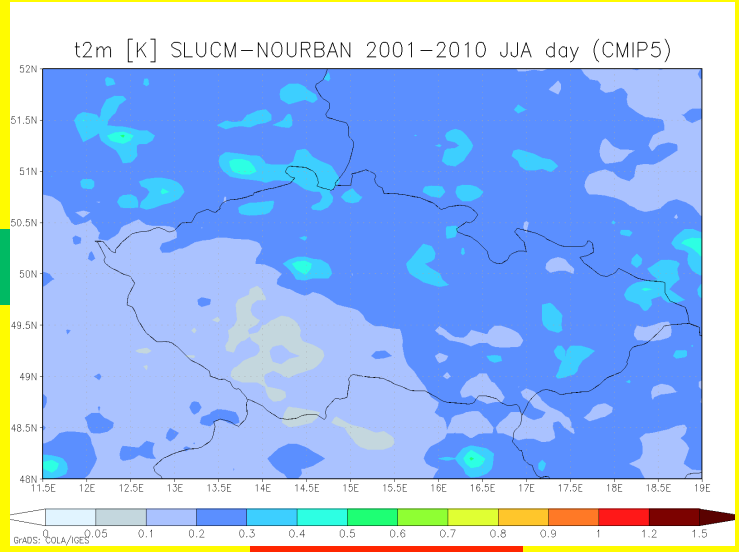


For more details and effect of urban emissions see (Huszar et al.)

Urban planning applications

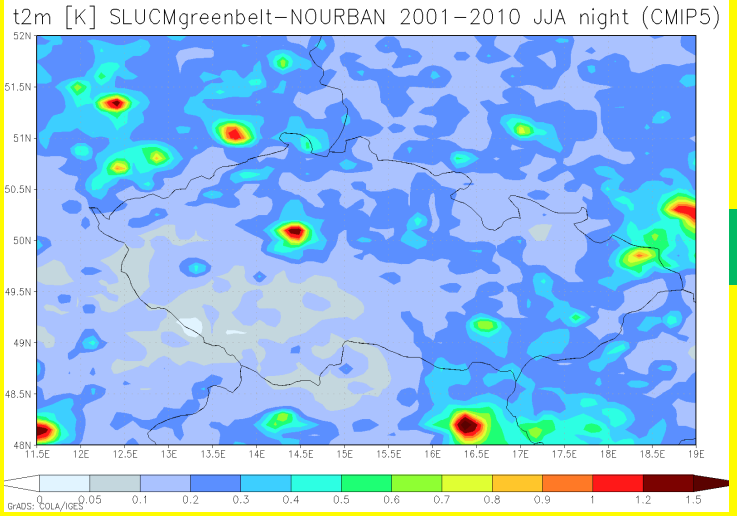


day

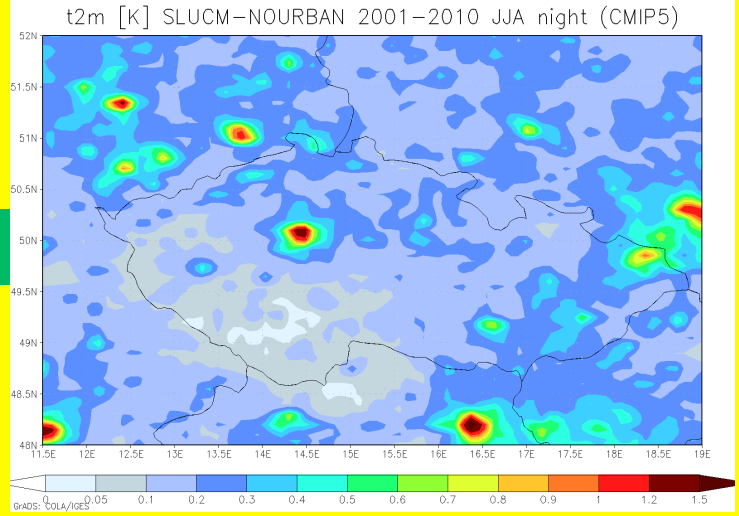


Prague with green belt

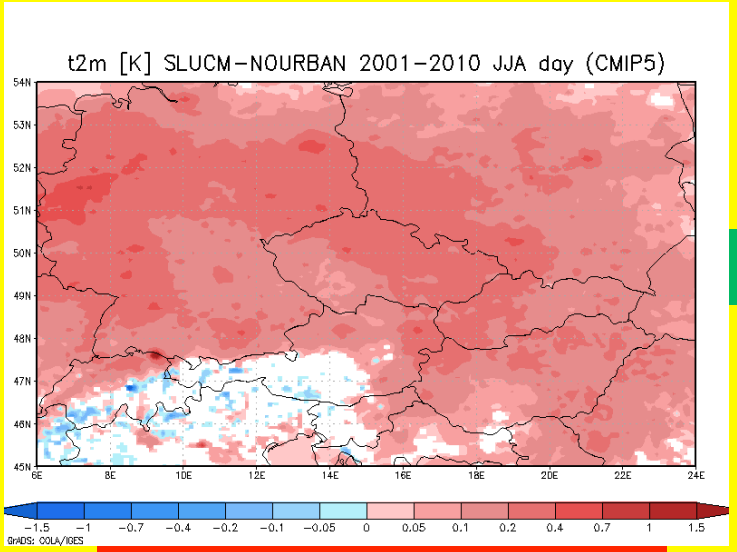
full city



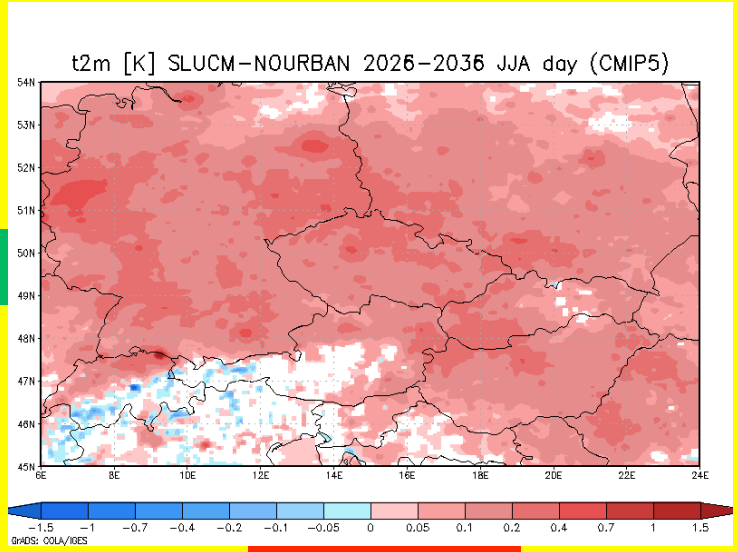
night



Climate change study

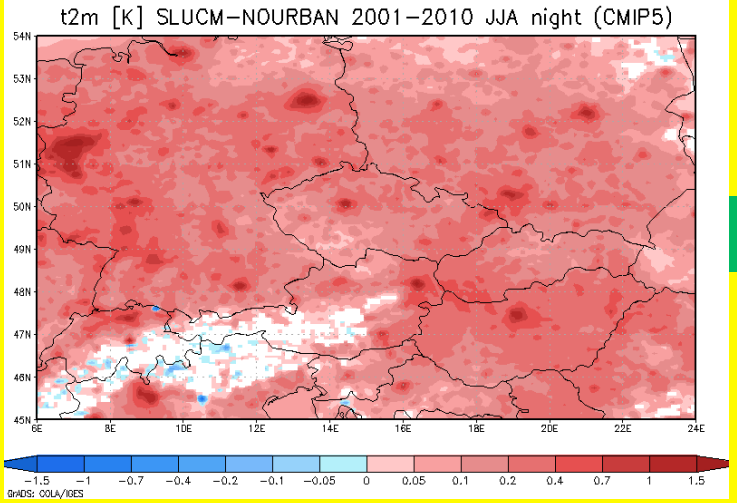


day

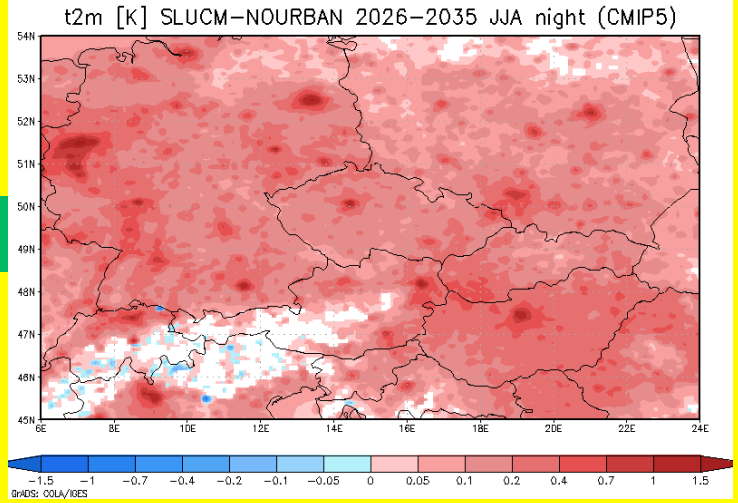


last decade

near future



night



Content

1. Motivation, projects
2. Models and SLUCM implementation
3. Results and urban effects
4. Sensitivity tests
5. Applications (Air quality effects, urban planning, climate change)
6. Summary, conclusions

RegCM4/SLUCM – summer impacts

- Temperature increase over most of the domain, over urban areas (Munich, Prague, Vienna, Budapest) up to 0.6-0.8°C, over Milan > 1.5°C
- Humidity decreases in cities (runoff, less evaporation) by over -0.8 g/kg in urban centers
- PBL height increase up to 200 m over many urban centres, over Milan and Zürich up to 300-500 m
- wind velocity decreases just over the cities (up to -0.2 m s^{-1}), with a small but statistically significant increase just around the cities (up to 0.2 m s^{-1}). During night-time, urban surfaces seem to increase the wind speed up to 0.3 m s^{-1}, not evident for all major urban centers throughout central Europe, rather for cities over the western part of the domain

Conclusions

- Urban surfaces have significant impact on the meteorological conditions and climate in Central Europe
- Urban heat island effect clearly identified, mainly during summer and nightime
- Significant effect of small urban units or areas, in highly populated urbanized areas like in Europe, it could affect the explanation of temperature increase under global warming, supposing the rapid development of the urbanization in the regions
- Impact on the surface concentration of ozone and Nox

CENTRAL EUROPE
COOPERATING FOR SUCCESS.

EUROPEAN UNION
EUROPEAN REGIONAL DEVELOPMENT FUND

Acknowledgement

The work performed under support by UHI project "Development and Application of Mitigation and Adaptation Strategies and Measures for Counteracting the Global Urban Heat Island Phenomenon" within the framework of EC Operation Programme Central Europe (3CE292P3), using the previous development achieved under EC FP6 STREP CECILIA and EC FP6 IP QUANTIFY, later under support by EC FP7 Project MEGAPOLI (Megacities and regional hot-spots air quality and climate), grant agreement no.: 212520 ,partially in framework of the project "Mathematical modelling of air quality with applications in risk management (1ET400300414) of National Programme on "Information Society" and in framework of Research Plan of MSMT under No. MSM 0021620860.


Thank you for your attention!