# Modeling of the Urban Heat Island and its effect on air quality using WRF/WRF-Chem


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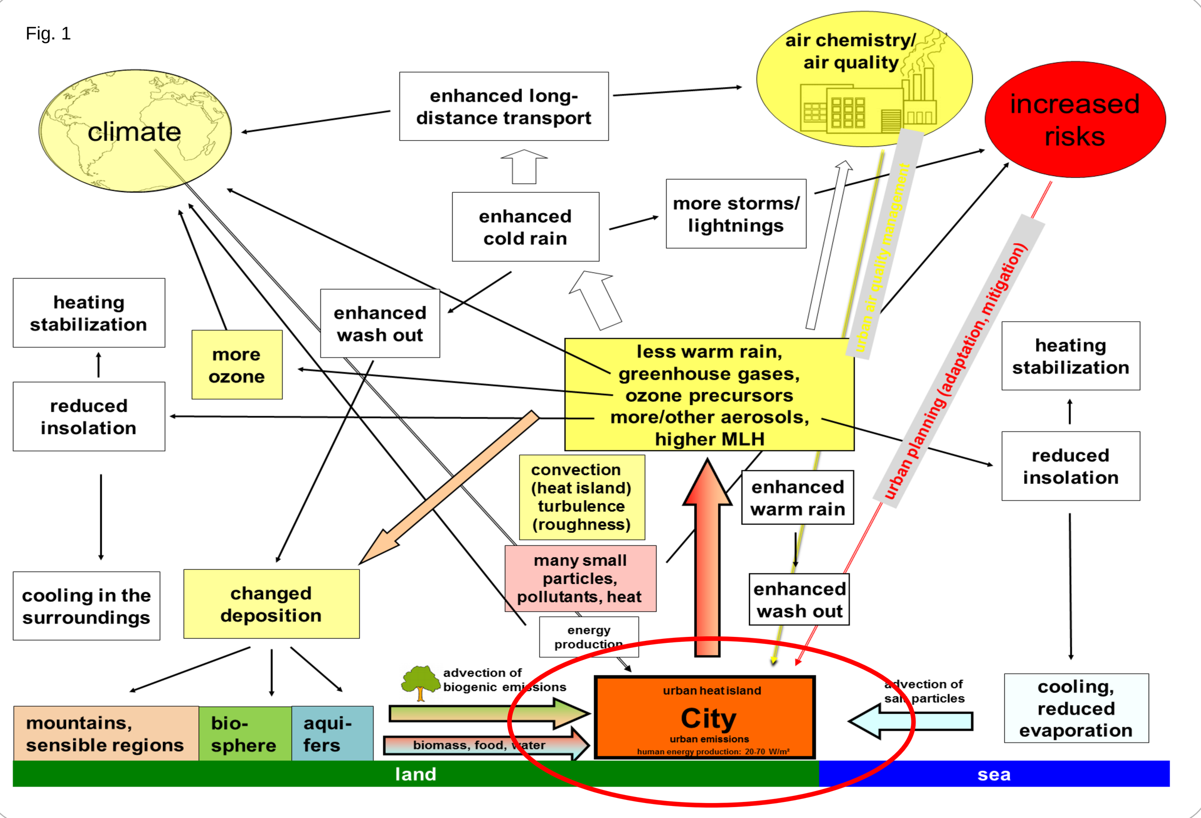
Fig. 1



## 1. Motivation

- officially about **7 billion** people live on earth; growing rate: 78 million/year
- by **2030**, around **60%** living in cities, in 2000 nearly 2900 cities with more than 100000 inhabitants
- large urban areas impact **surface-atmosphere exchange processes (UHI)** → 'Urbanized Atmosphere'
- UHI's raise demands of energy for air conditioning during summer periods → power plants rely on fossil fuels → increase of air pollutants and **greenhouse gas emissions** (EPA, 2013)
- primary pollutants include SO2, NOx, PM, CO etc. → contribution to complex **air quality** problems such as ground level ozone (SMOG), fine PM or acid rain
- Elevated temperatures can directly increase the rate of ground-level ozone formation
- **Climate change** will have specific urban expressions: altered urban heat island phenomena, impacts on regional circulation systems, air pollution levels, radiative feedback mechanisms of aerosols and **human health**

## 2. Research Focus

### The Urban Heat island

- The tendency for an urbanized area to remain warmer than its surroundings → **urban- rural interactions**
- Additional heat sources, roughness effects and albedo of urban surfaces 'design' specific atmospheric dynamics
- Stable weather conditions with low wind speeds can produce strong inversion layers → trapping of air pollutants
- Regional secondary circulation patterns → transportation of rural air pollutants (e.g. BVOC's) into city → reaction with urban pollutants → **Urban Plume**
- Specific urban planning strategies can reduce negative effects → **mitigation measures**

### Challenging the complexity

- downscaling mesoscale model WRF to city scale (1km)
- testing the effects of land use changes on meteorological conditions during summer heat waves using different urban parameterization approaches in WRF
- Simulate simple **mitigation strategies** : 1.effect of **white roofs** by increasing the albedo up to 0.70; 2.replace urban surface by natural **vegetation**; 3.decrease **building density by 20%**
- Conduct scenario-runs (10 days) for the area of **Stuttgart** and rural surroundings for both WRF and WRF-Chem

## 3. Strategies

### a) WRF- meteorological part

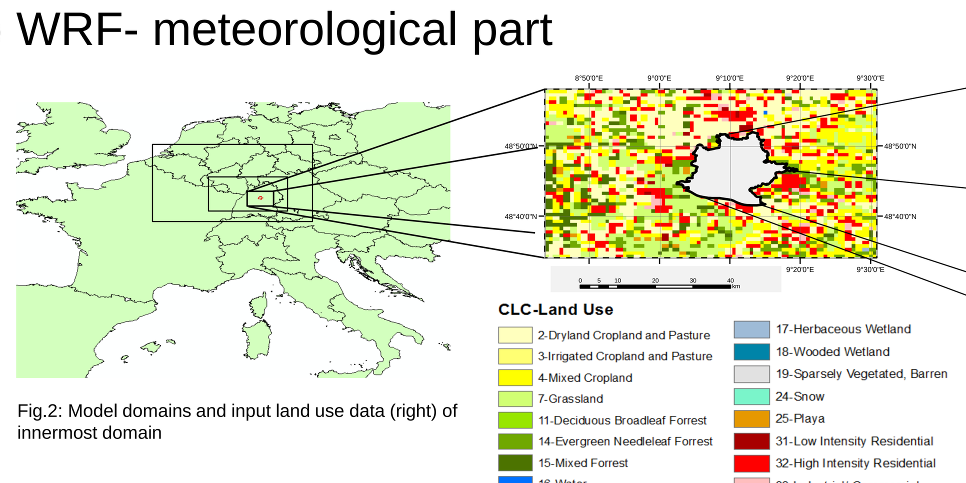


Fig.2: Model domains and input land use data (right) of innermost domain

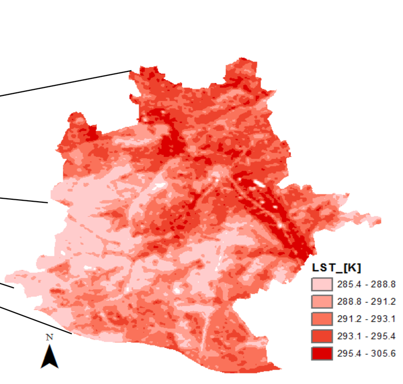
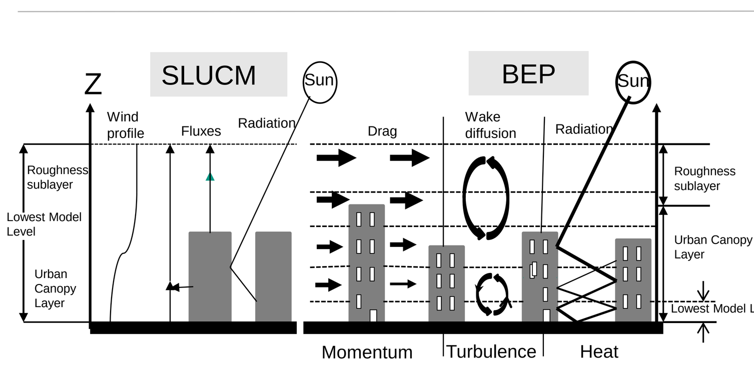
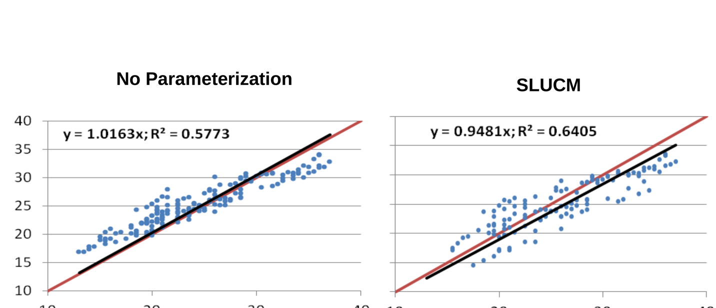


Fig. 3: Surface temperature extracted from Landsat TM5 19.09.2005 10:05 (Source: USGS)





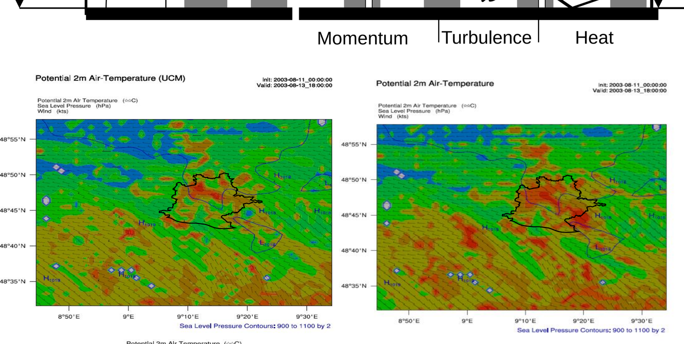
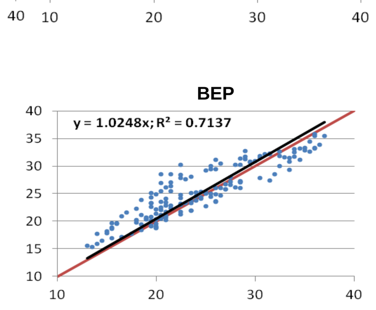


Fig.4: Different parameterization strategies SLUCM approach (KUSAKA ,2001 - left) and BEP (MARTILLI, 2002 – right) – up left

Fig. 5:Correlation of modeled potential 2m temperature with point observation data for the city-centre of Stuttgart – up and right



### b) WRF-Chem - chemical Part

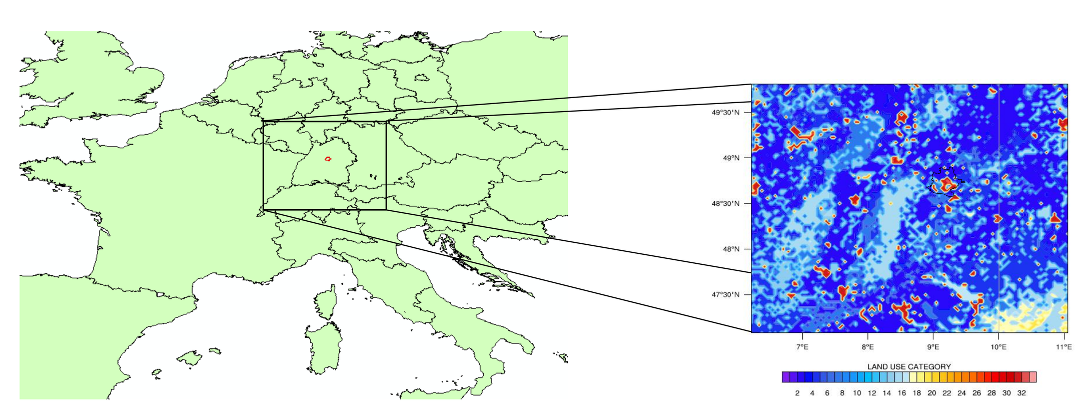


Fig. 6: WRF-Chem domain and map of land cover

Tab. 1: WRF-Chem configurations

| | |
|---|---|
| geographical input data | 30 Deg USGS land use with 33 classes |
| dx, dy | 3km |
| west-east | 120 |
| south-north | 100 |
| vertical layers | 36 |
| lowest model level | 20m |
| meteorological boundary conditions | 0.5 Deg ERA-Interim reanalysis |
| chemical boundary conditions | Mozart global data |
| biochemistry | Megan |
| chemical option | RADM2 chemical mechanism; MADE/SORGAM aerosols |
| emission data | 7km MACC emission for Europe |
| start time | 8/9/03 |
| end time | 9/18/03 |
| microphysics | Lin et al |
| longwave | RRTMG |
| shortwave | RRTMG |
| land surface model | Noah LSM |
| urbanization scheme | BEP |
| boundary layer | MYJ |
| cumulus scheme | Grell-Devenyi ensemble scheme |
| photolysis | FastJ |

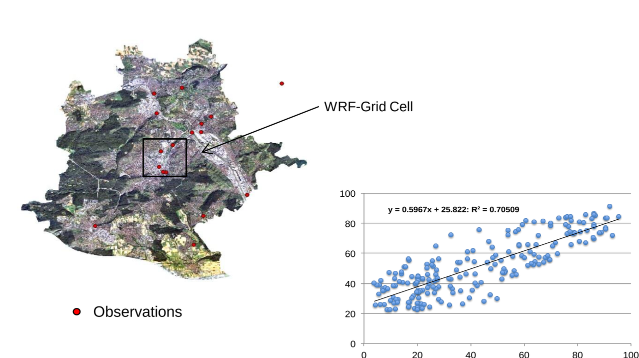


Fig. 7: Model validation by comparing 3x3km WRF-grid value of O3 with average value of 4 measurement stations in the area of the grid cell (left)

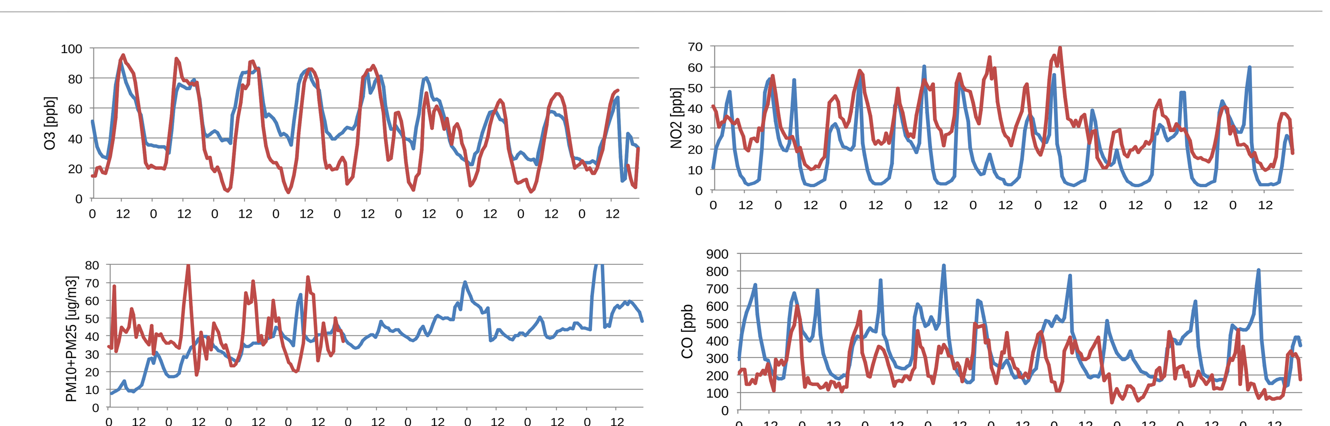


Fig. 8: Comparison between simulated WRF-Chem variable at a central urban grid point and average value of 4 observations within that 3x3 km cell for the time period Aug 08 – Aug 18 2003 (from up left to right: Ozone, Nitrogen Dioxide, Particulate Matter and Carbon Monoxide); UTC

## 4. Results – Mitigation Scenarios

### a) WRF

| Scenario | Albedo | Density | Many Parks | Big Park | Real Case |
|---|---|---|---|---|---|
| T mean urban [°C] | 32 | 32.4 | 32.46 | 32.34 | 33.1 |
| T max [°C] | 32.7 | 33 | 33.5 | 33.3 | 34.3 |
| Std dev. [°C] | 0.32 | 0.48 | 0.52 | 0.42 | 0.5 |
| UHI; ΔT [°C] | **0.84** | **1.32** | **1.47** | **1.19** | **2.52** |

Tab. 2: UHI-Intensity expressed as difference between average 2m temperature of urban area and that of rural surrounding for the particular scenario; **August 13th 2003 18:00**

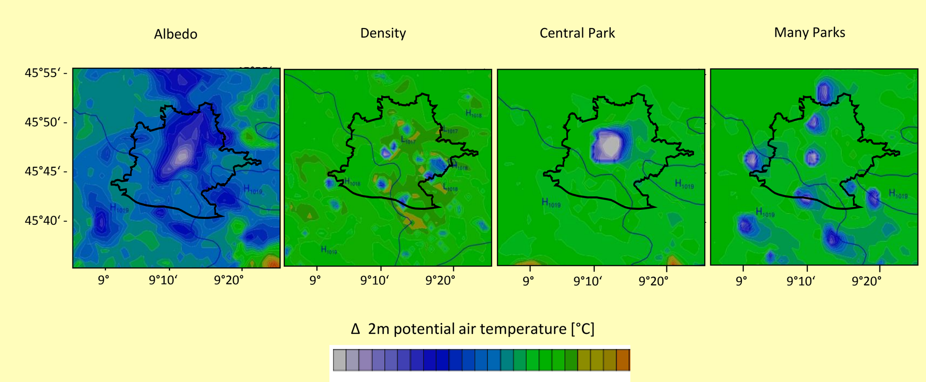


Fig. 9: Difference in 2m potential temperature between 'Scenario' and 'Real Case' run; **August 13th 2003 18:00**

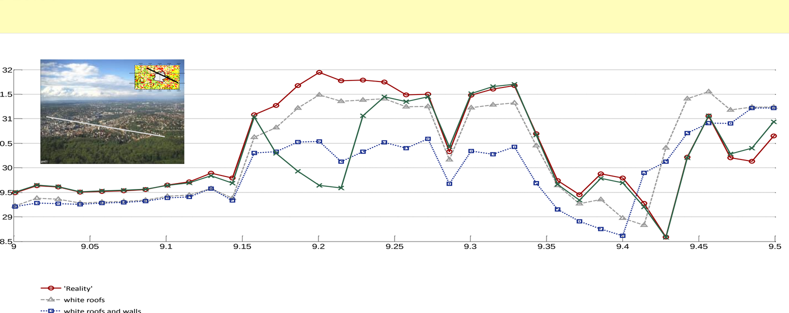


Fig. 10: Development of 2m potential temperature over cross section (upper left); **August 13th 2003 18:00**

### b) WRF-Chem

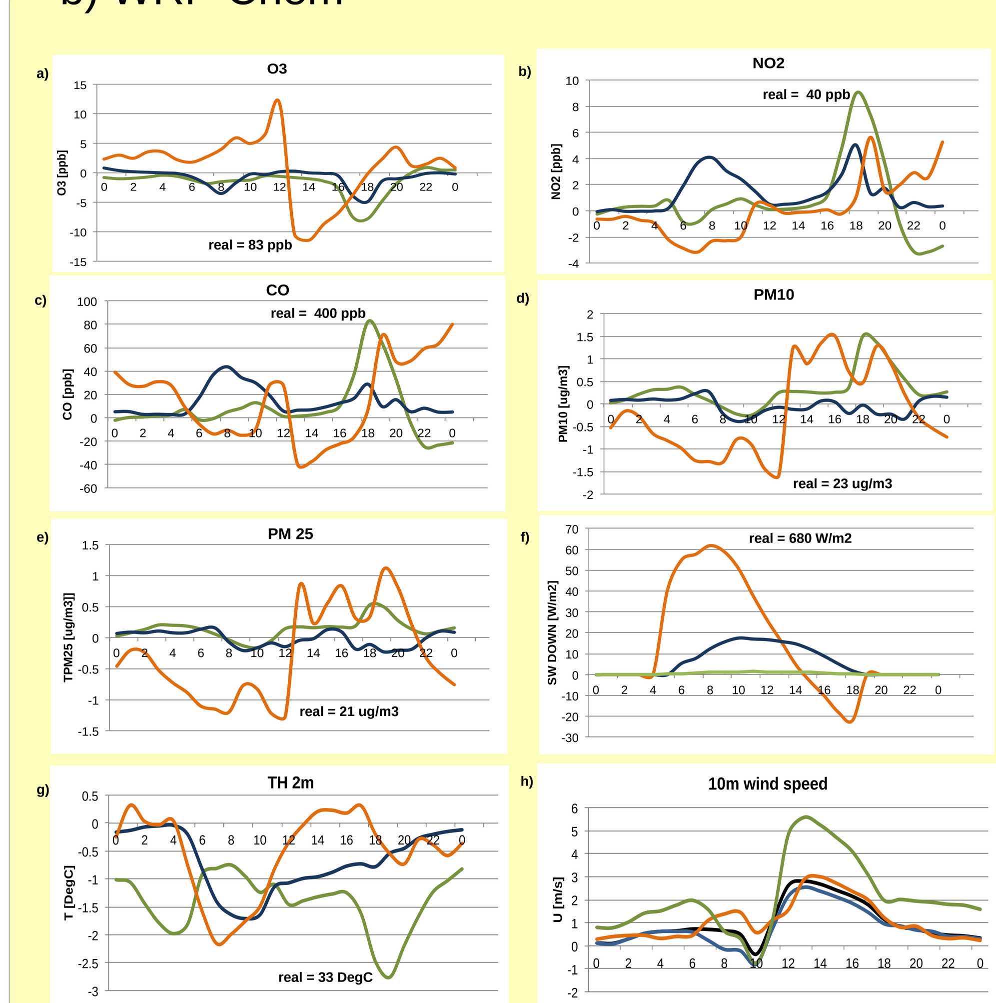


Fig. 11: a)-g) Difference of variable compared to the real case, using BEP approach, for central urban grid cell. Scenarios are the same like in the WRF study. Negative values reflecting a decrease of the variable according to the specific scenario. h) Effective simulated values of 10m wind speed; Period of time: **Aug 13th 2003**; time in **UTC**. 'real' value within each graph reflecting effective value of simulated variable for real case at equivalent time

## 5. Conclusions

- WRF nesting approach shows reasonable results for different urban planning scenarios and their effect on potential 2m temperature, especially during extreme case scenarios
- Difficulties in reproducing effects on atmospheric chemistry → higher resolution of emission data is needed, bigger domain, nesting etc.
- Effects of different urban planning scenarios not consistent → further studies scheduled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