Cooler City – Cleaner City?

Urban Heat Island Versus Air Quality - A numerical modelling study for a European city

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1. Motivation

- officially about **7 billion** people live on earth; growing rate: 78 million/year; around 60 % live in cities
- large urban areas impact **surface-atmosphere exchange processes (UHI)**
- UHI's raise demands of energy for air conditioning during summer periods → combustion processes → **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
- **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 significantly warmer than its rural surroundings (Oke 1982)
- Additional heat sources, roughness effects and albedo of urban surfaces 'design' specific atmospheric dynamics → urban-rural circulation patterns
- Regional secondary circulation patterns → transport of rural air pollutants (e.g. BVOC's) into city → reaction with urban pollutants
- Specific urban planning strategies can reduce negative effects (Taha 1997)

UHI mitigation scenarios

- Urban planning strategies:
  - effect of white roofs by increasing the albedo from 0.2 to 0.7 (Albedo)
  - replace urban surface by natural vegetation (grass) one park of 20 km² (Central Park) and several parks of the same accumulated size (many parks)
  - decrease building density by 20%

→ **Effect on urban air quality**

3. Urbanization of a mesoscale model

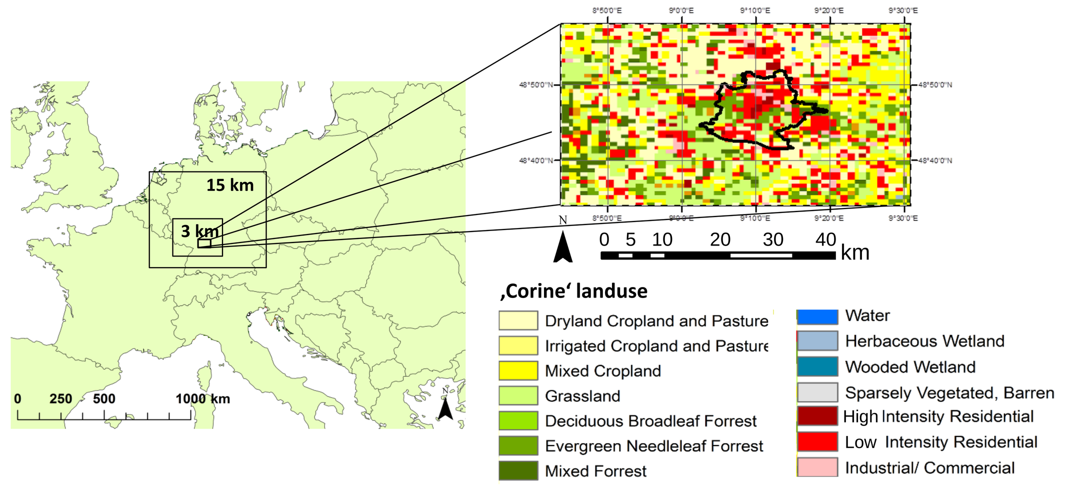

Fig. 1: WRF-Chem domain and map of land cover (left); schematic image of two WRF urban canopy models and evaluation of temperature (right)

Reduction of the urban temperature

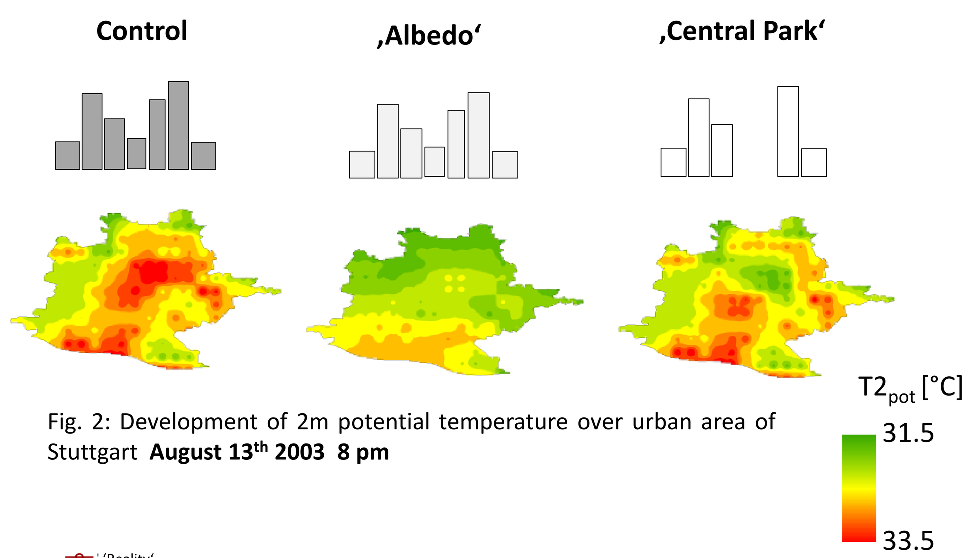

Fig. 2: Development of 2m potential temperature over urban area of Stuttgart **August 13th 2003 8 pm**

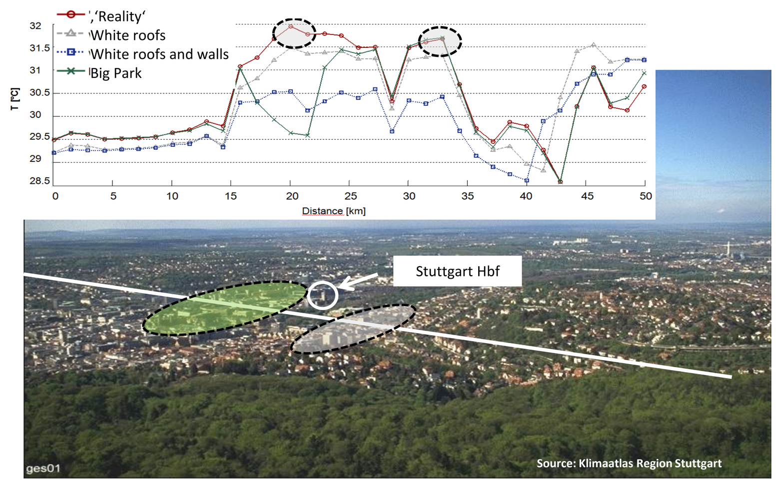

Fig. 3: Development of 2m potential temperature over cross section (left) and for the urban area of Stuttgart (right) **August 13th 2003 8 pm**

Reduction of the UHI

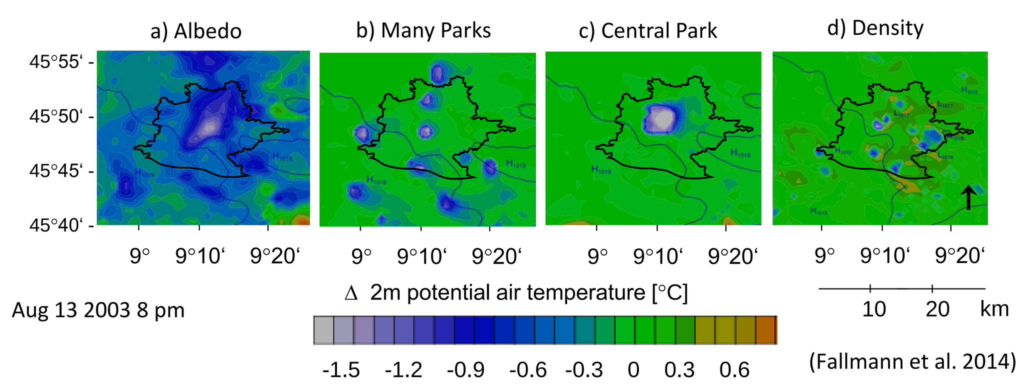

Fig. 4: Difference in potential 2m air temperature between 'Control' and 'Scenario'

Scenario	Control	Albedo	Many Parks	Big Park	Density
UHI [°C]	2.52	0.84	1.47	1.19	1.32

4. WRF-Chem

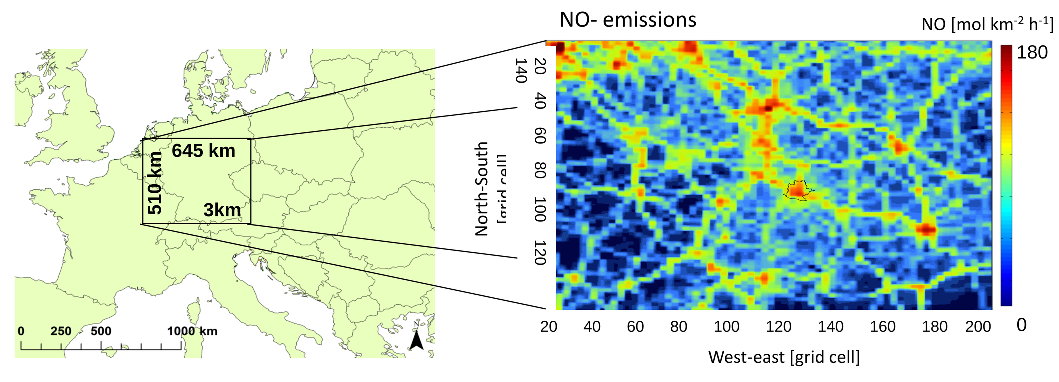

Fig. 5: WRF-Chem domain and map of NO emissions

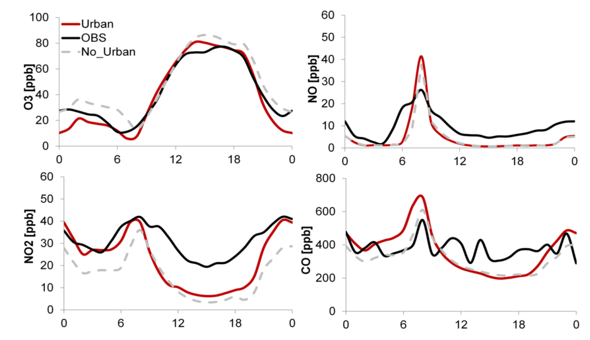

Fig. 6: Comparison between simulated WRF-Chem variable at a central urban grid point and average value of 4 observations within that 3x3 km cell for an average daily cycle. From up left to right: O3, NO2, NO and CO

→ RADM2/ MADE SORGAM, NOAH LSM, BEP urban canopy model, MOZART/MEGAN chemical BC and IC, MACC 2003-2007 emission inventory, FastJ Photolysis, modelling time Aug 9 – Aug 18 2003

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Primary pollutants | Secondary Pollutants | Ozone – 1500 h

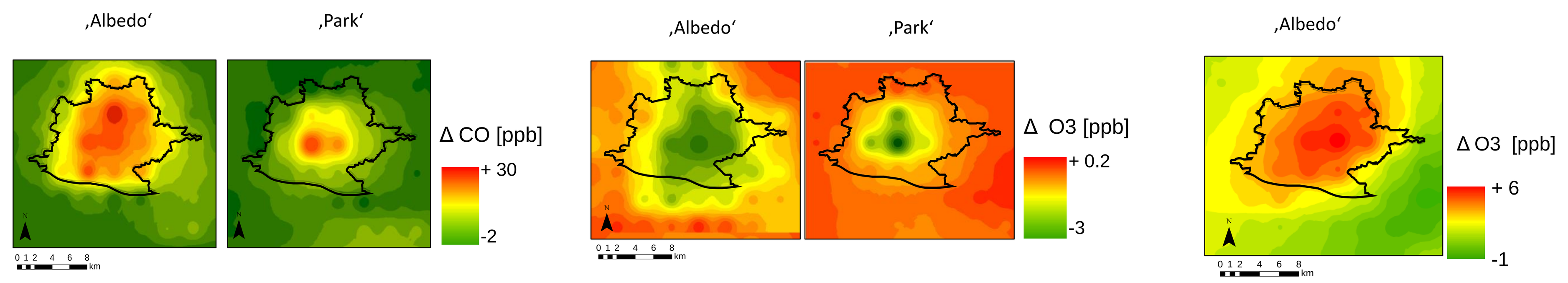

Fig. 7: Mean Difference between control- and scenario run [ppb] for modelling period for carbon monoxide (left), ozone (middle) and difference in peak ozone concentration at 1500 h (right)

Turbulence

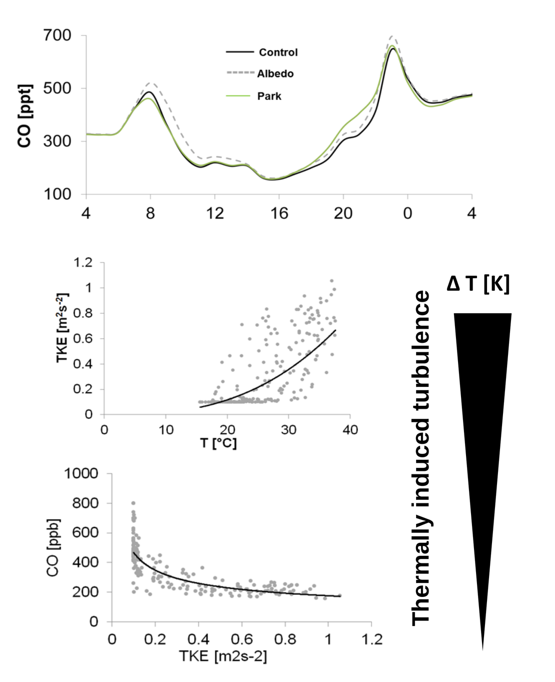

Fig. 8: Diurnal cycle of CO concentration for 3 scenarios (top), correlation between TKE and temperature/CO concentration at the lowest model level

Temperature

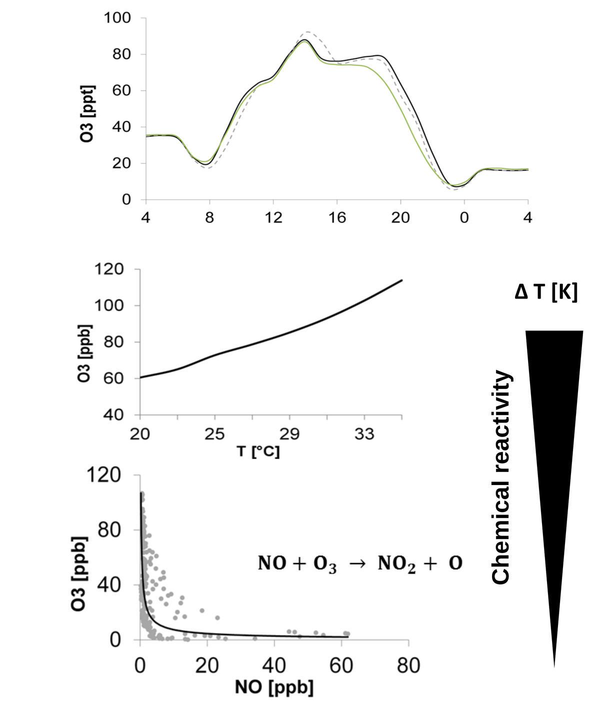

Fig. 9: Diurnal cycle of O3 for 3 scenarios (top), correlation of temperature and O3 (middle), correlation between NO and O3 in the lowest model level (bottom)

Photolysis

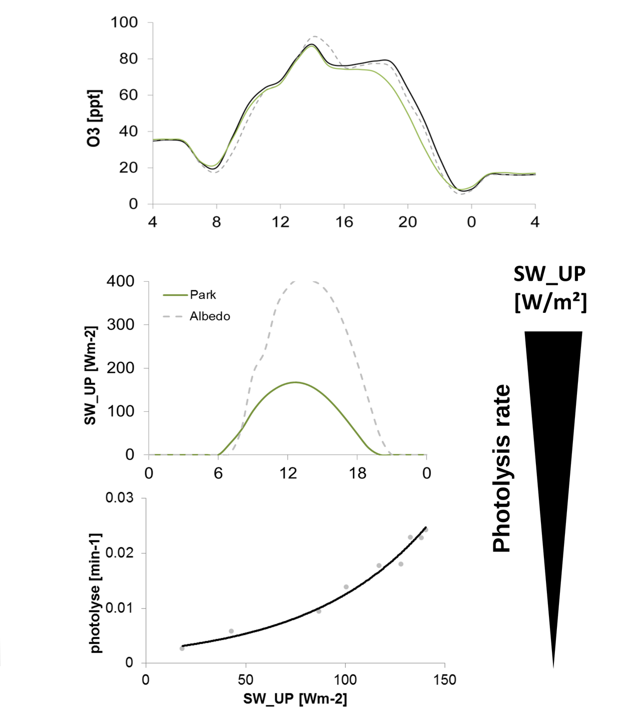

Fig. 10: Diurnal cycle of O3 for 3 scenarios (top), diurnal cycle of reflected SW radiation (middle), correlation between reflected SW and photolysis rate in the lowest model level (bottom)

5. Conclusion

- UHI mitigation strategies generate **negative effects** on primary and some secondary pollutants
- Reduced temperature leads to a reduction of turbulence → **increase of primary pollutants**
- Reduced temperature leads to a reduction of chemical reactivity → **decrease of ozone**
- Higher **albedo** leads to an increased amount of reflected SW radiation → **increase of peak ozone**

References
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