Karlsruhe Institute of Technology

KIT-Campus Alpin
IMK-IFU: Atmospheric Environmental Research

Cool Cities – Clean Cities ?

Secondary impacts of urban heat island mitigation strategies on urban air quality

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STUTTGART

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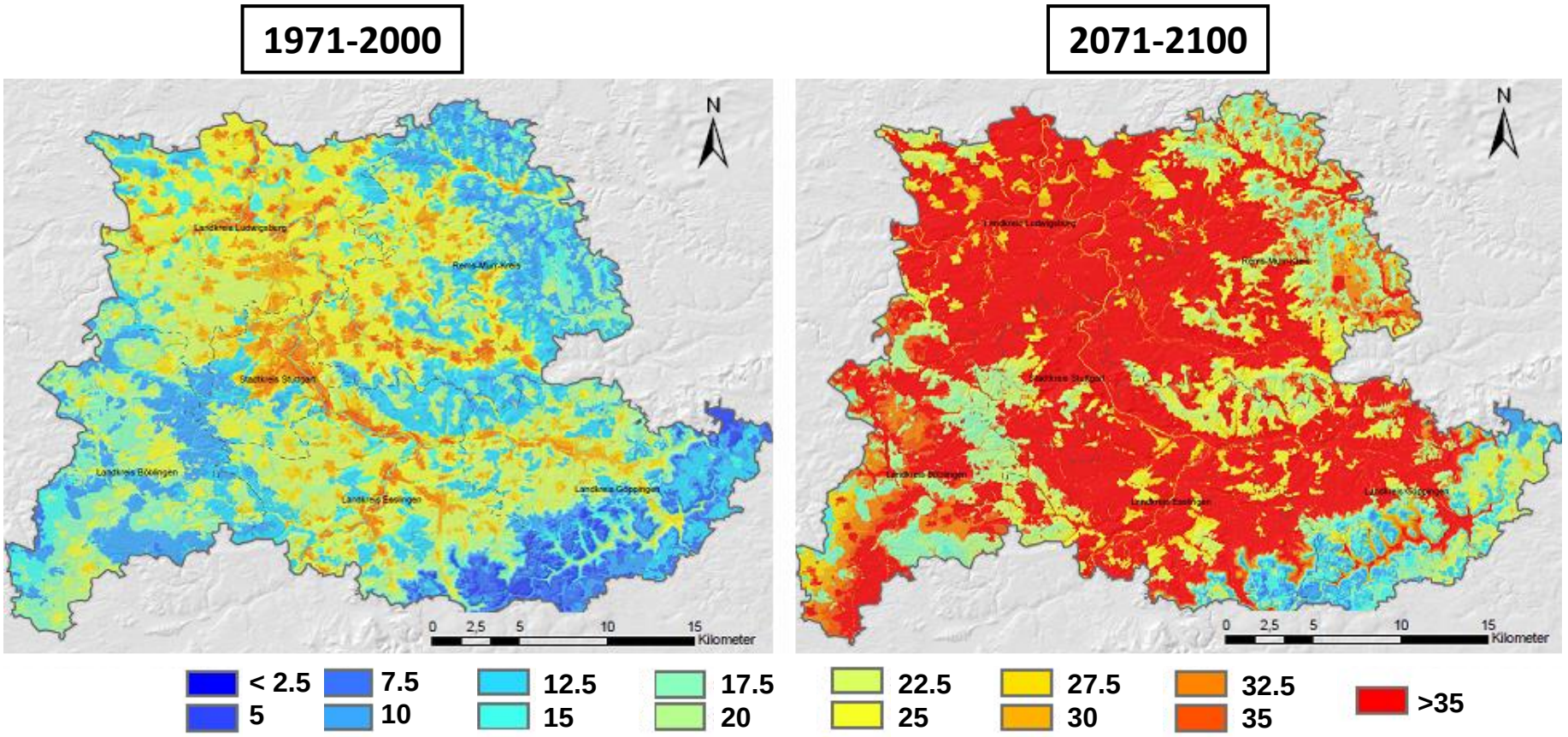
Heat stress in urban areas

‚Heat stress days' per year (greater Stuttgart area)



Source: Klimaatlas Region Stuttgart

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The Urban Heat Island

UHI mitigation strategies ?

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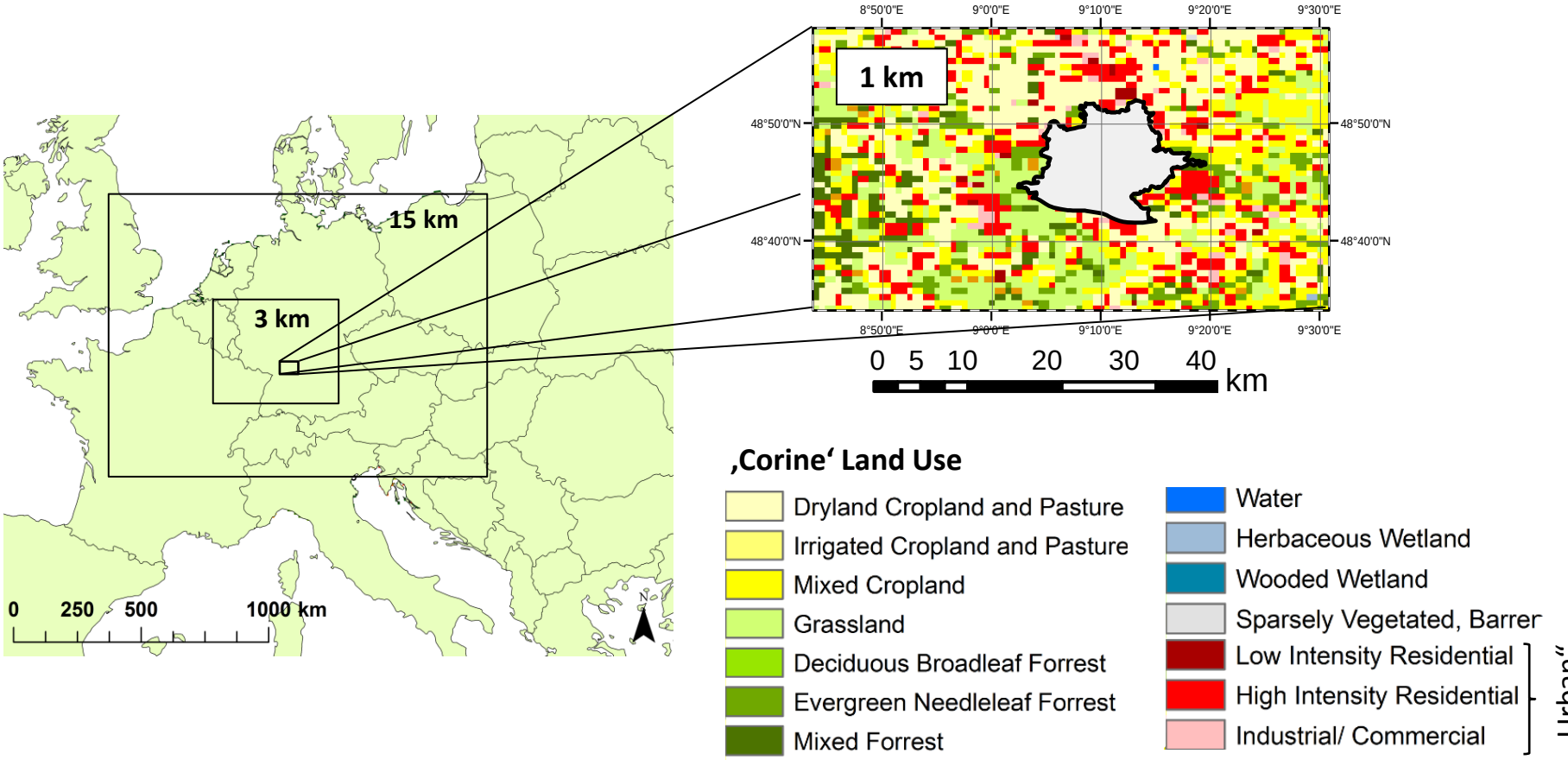
1. Step: Modeling of the Urban Heat Island (WRF)



- Initial- und dynamical boundary conditions: ***ERA-Interim 0.5°*** Reanalysis
- Land surface processes: ***NOAH LSM***
- Parametrization of sub-grid scale processes: ***BEP Urban Canopy Model***
- Modelling time frame**: Aug 8 – Aug 18 2003**

Evaluation: Fallmann et al. 2014

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Urban areas in mesoscale models

Urban Parameter	33	32	31
ZR: Roof level (building height) [m]	8.5	9.7	6.4
SIGMA_ZED: Standard Deviation o	6.8	6.4	4.5
ROOF_WIDTH: Roof (i.e., building	27.5	13.3	10
ROAD_WIDTH: road width [m]	19	16.2	9.8
AH: Anthropogenic heat [W m/m²]	90	50	20
FRC_URB: Fraction of the urban landscape which does not have natural vegetation [Fraction]	0.95	0.85	0.5
CAPR: Heat capacity of r [J m³/ K]	1.00E+06	1.00E+06	1.00E+06
CAPB: Heat capacity of [J m³/ K]	1.00E+06	1.00E+06	1.00E+06
CAPG: Heat capacity of grou ³/ K]	1.40E+06	1.40E+06	1.40E+06
AKSR: Thermal conductivity of roof [	0.67	0.67	0.67
AKSB: Thermal conductivity of building wal	0.67	0.67	0.67
AKSG: Thermal conductivity of ground (road) [J /m	0.4	0.4	0.4
ALBR: Surface albedo of roof [fraction]	0.2	0.2	0.2
ALBB: Surface albedo of building wall [fraction]	0.2	0.2	0.2
ALBG: Surface albedo of ground (road) [fraction]	0.2	0.2	0.2
EPSR: Surface emissivity of roof [-]	0.8	0.9	0.93

‚Morphology'

‚Material characteristics'

Albedo

Street Parameters

Urban Catego [index]	irection	street width [m]	building width [m]
33		19	25
33	90	19	25
32	0		13
32	90		13
31	0	18	10
31	90	18	10

Road network

Building Heights

height [m]	33 [%]	32 Percentage [%]	31 Percentage [%]
5		33	48
10	2	20	37
15	14	33	11
20	8		3
25	4		1
30	2	2	
35	2		

Building properties

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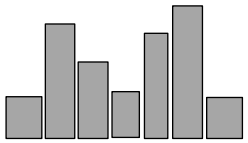
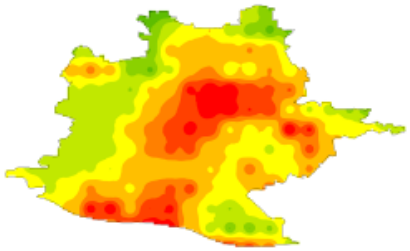
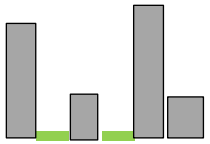
Simulation of UHI mitigation scenarios

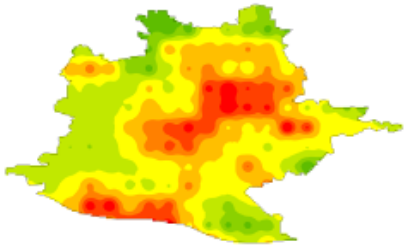
Control



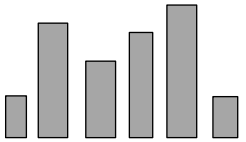


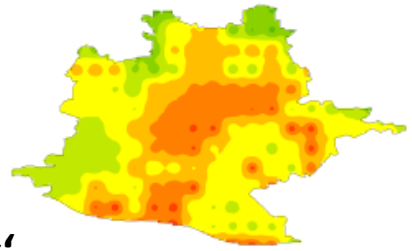
‚Many Parks'



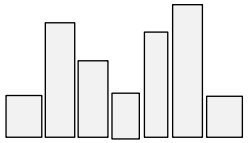


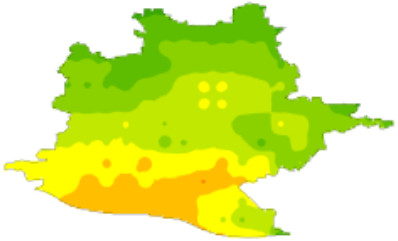
‚Density'



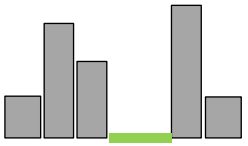


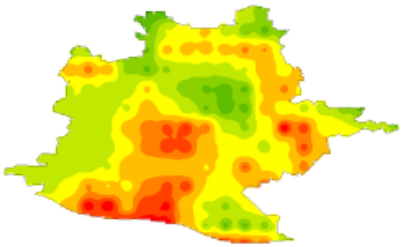
‚Albedo'





‚Central Park'





$T2_{pot}$ [°C]

31.5

33.5

Aug 13 2003 8pm

Evaluation: Fallmann et al. 2014

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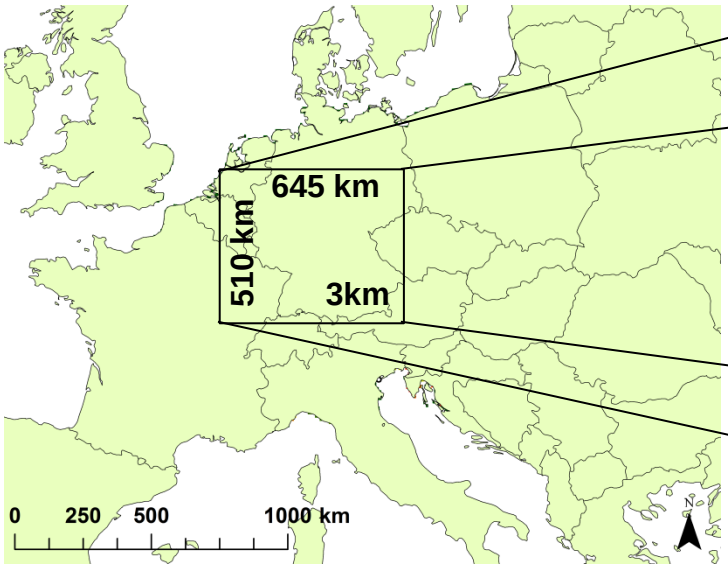
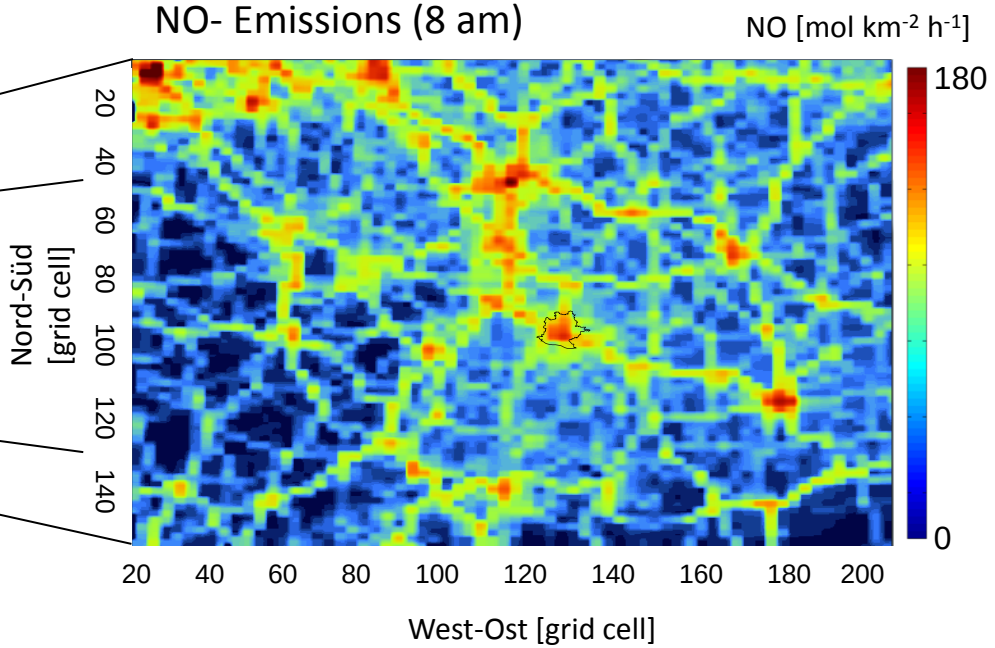
2. Step: Air Quality modeling (WRF-Chem)

WRF-Chem Domain



NO- Emissions (8 am)



- Initial- and dynamical boundary conditions from global model ***MOZART*** *(anthropogenic)* **und *MEGAN*** *(biogenic)*
- *RADM2 MADE/SORGAM chemical mechanism, MYJ PBL-scheme*
- Lower boundary conditions ***MACC Emissions 2003-2007***
- Modeled time frame: Aug **9 – Aug 18 2003**

Evaluation: Fallmann et al. 2015 (In Review)

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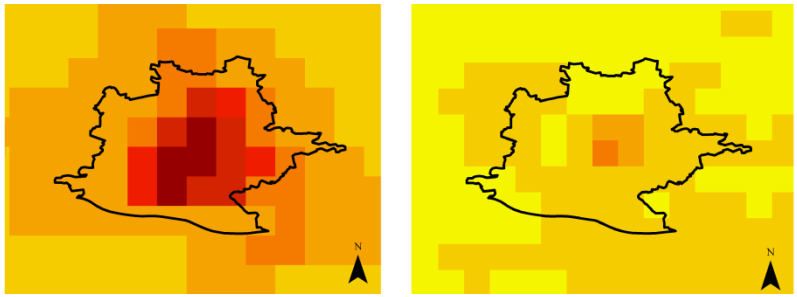
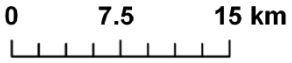
Effect of decreased temperature

Primary pollutants (e.g. CO)

‚Albedo-Control‘ ‚Park-Control‘

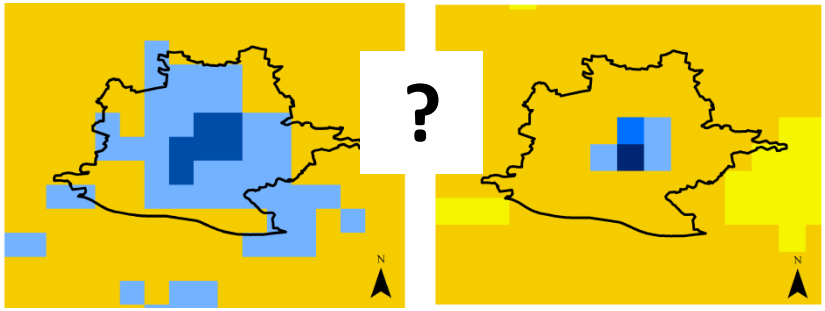


Delta CO [ppb]

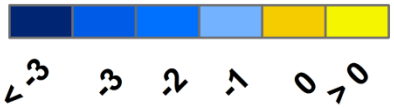


Secondary pollutants (e.g. O3)

‚Albedo-Control‘ ‚Park-Control‘



Delta O3 [ppb]



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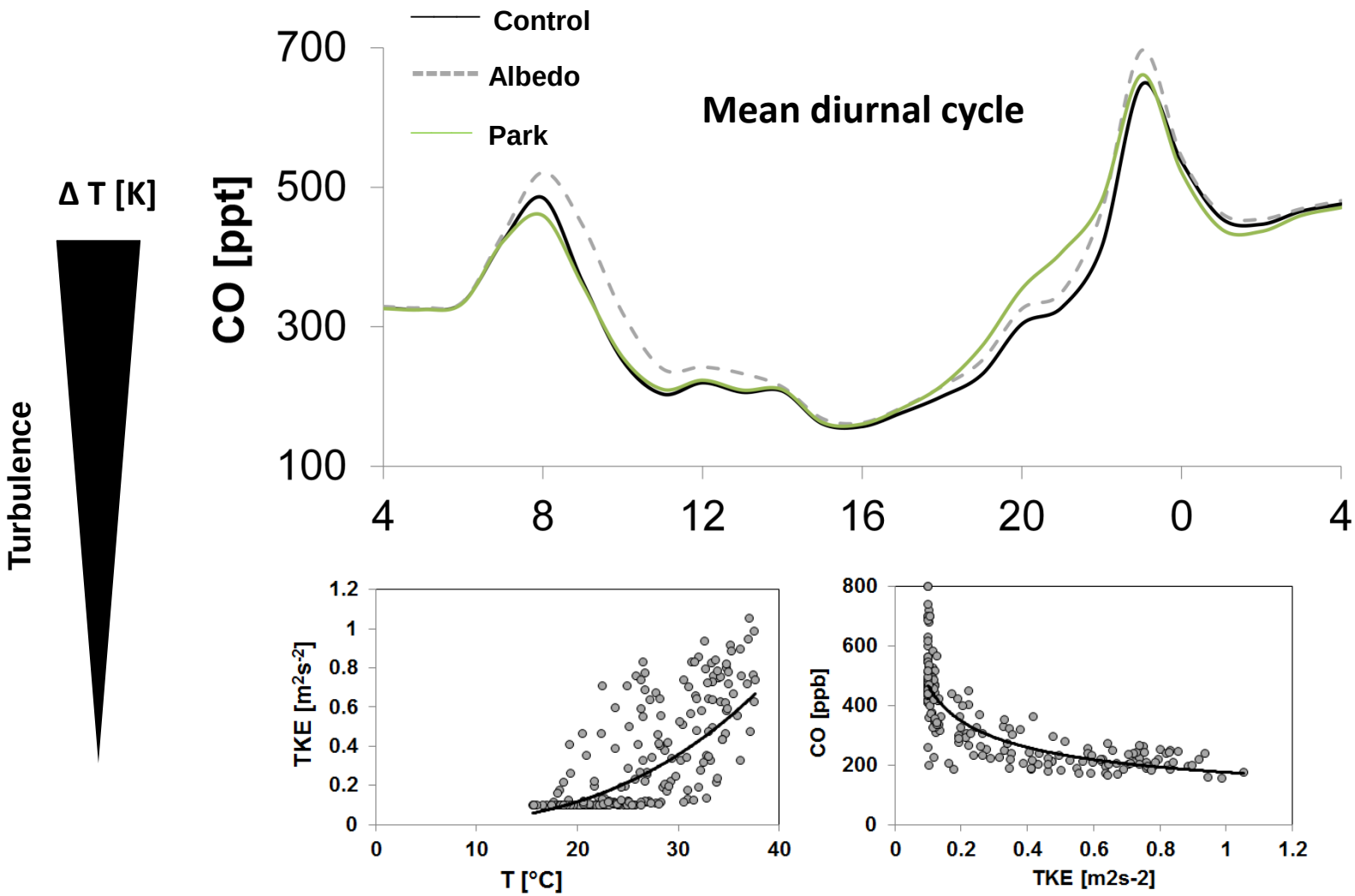
Primary pollutants(CO, NO) – Atmospheric dynamics



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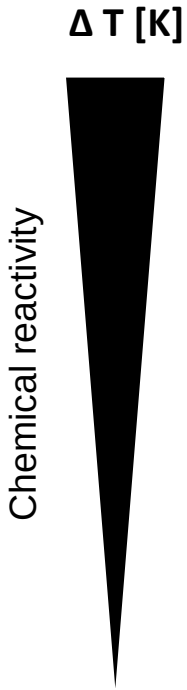
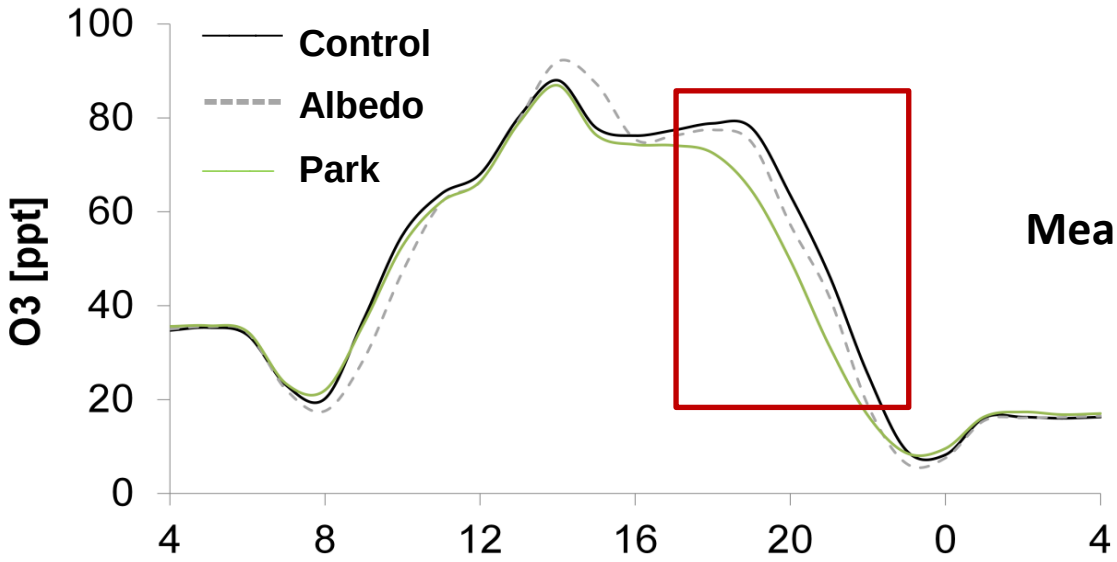
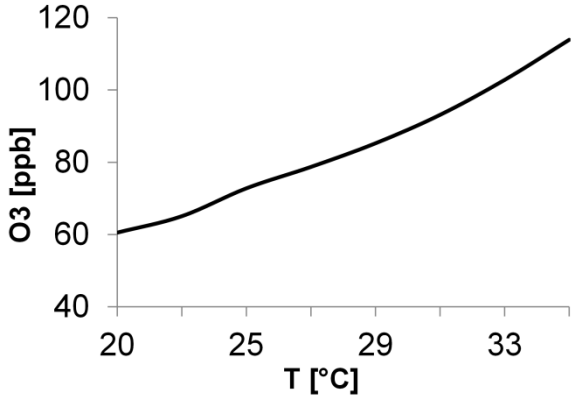
Secondary pollutants (Ozone) – Chemical reactivity

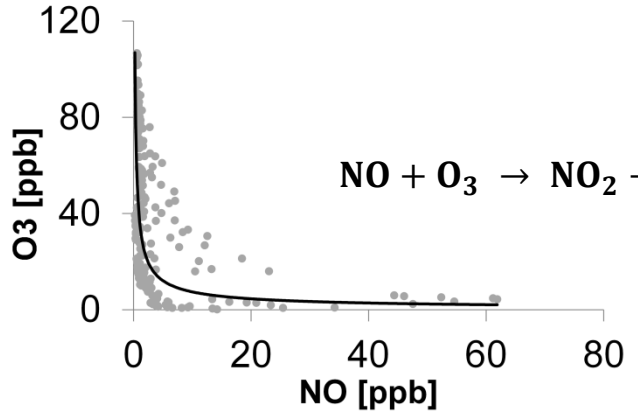


RADM boxmodel
(Stockwell 1988)



Mean diurnal cycle





$$NO + O_3 \rightarrow NO_2 + O$$

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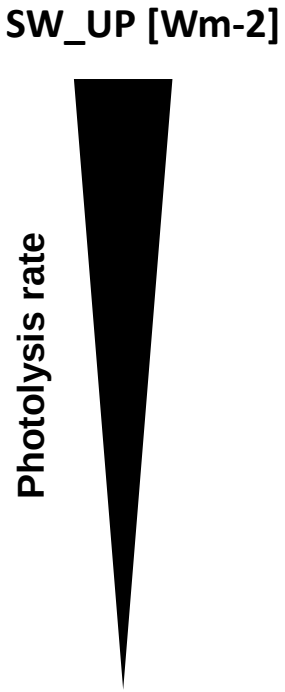
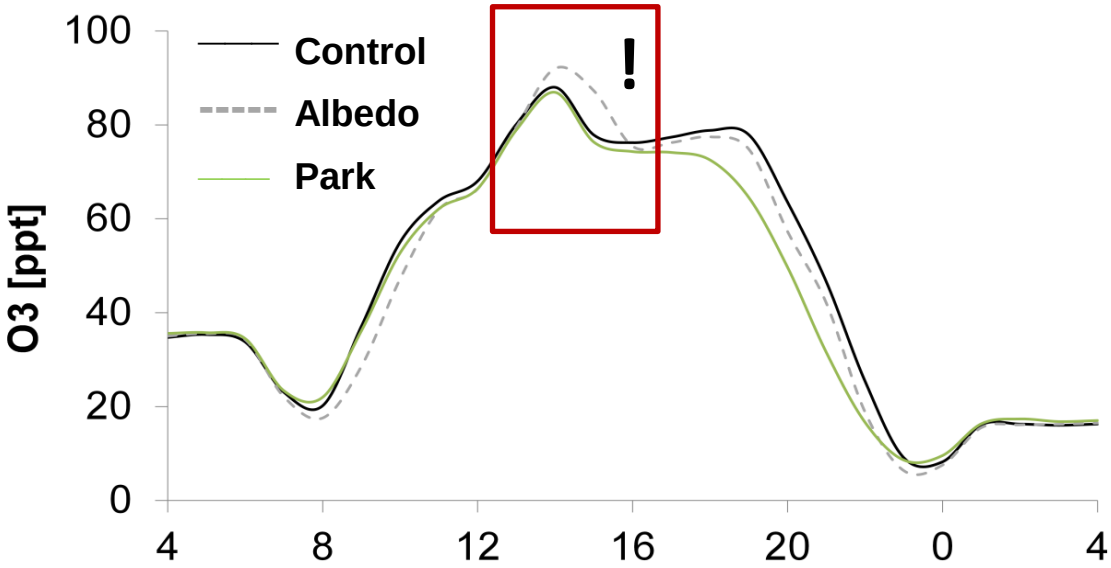
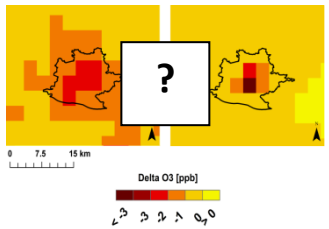
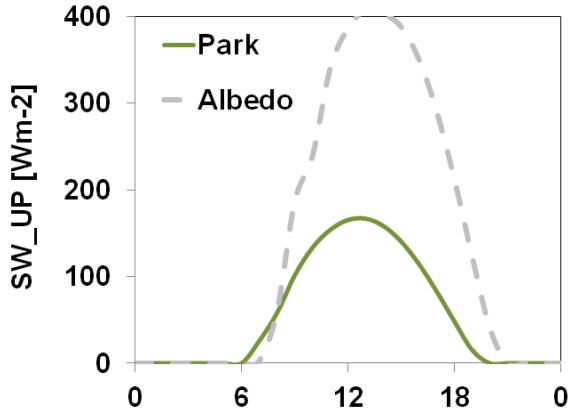
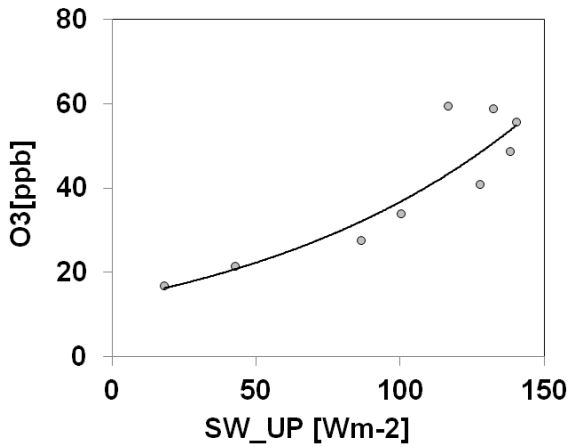
Secundary pollutants (Ozone) - Photolysis











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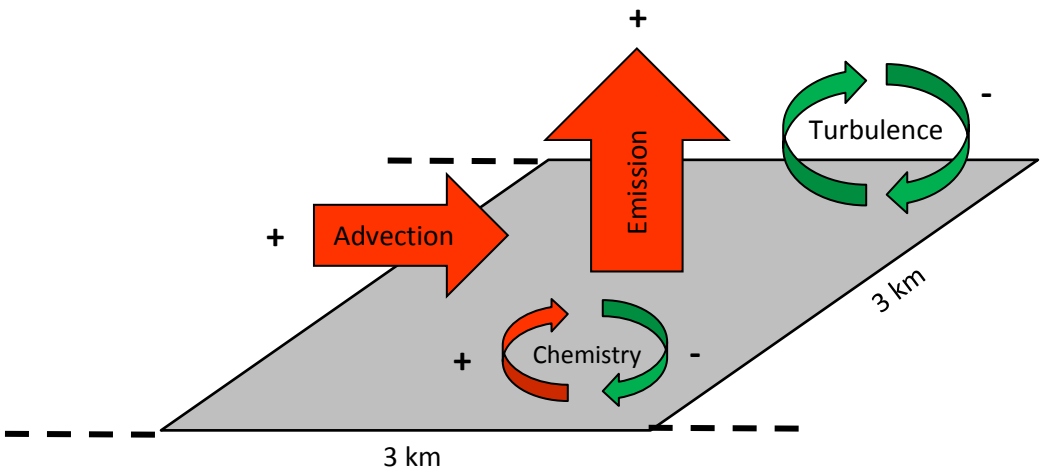
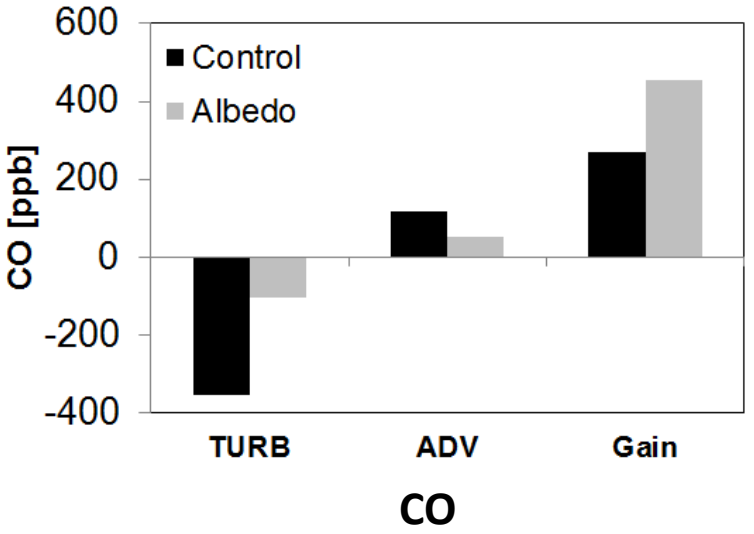
Quantification via tendency terms

- Impact of chemistry and dynamics on concentration of pollutants on the basis of hourly budgets (7 - 8 am) [ppb h^{-1}]
- **'Tendency terms'**:
  - chemical production/loss tendency (CHEM)
  - Turbulent vertical mixing (TURB)
  - Advection (ADV)
  - Emission (EMIS)

Balance:

Gain/Loss = EMIS + CHEM + TURB + ADV





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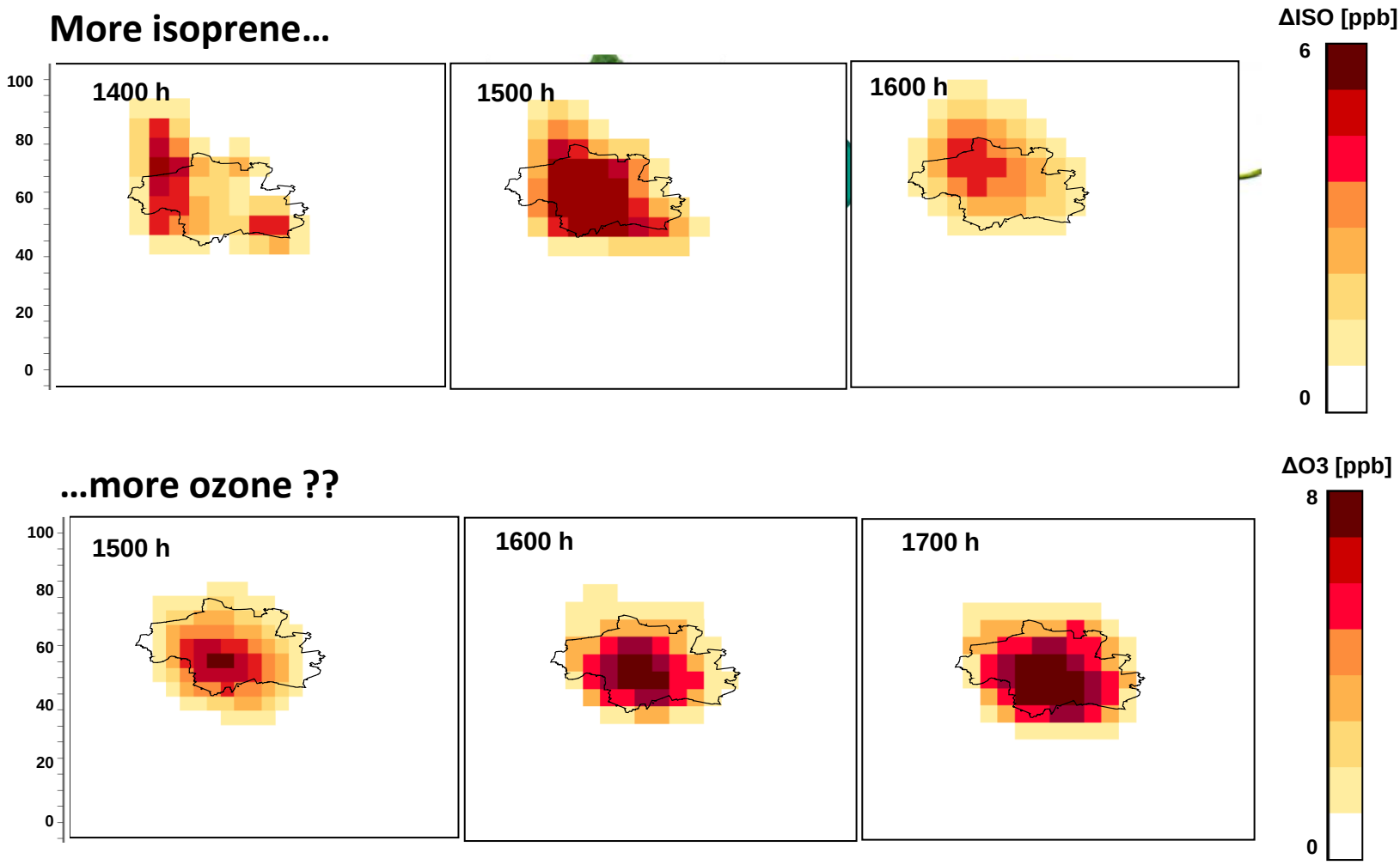
Case Study: Planting the ‚wrong' tree ?!



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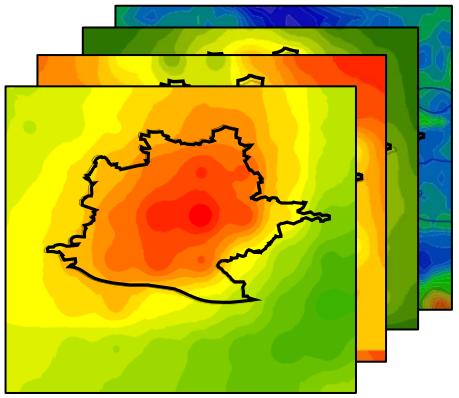
Summary



- Urban Heat Island mitigation strategies?
  - Surface reflectivity
  - Urban greening
  - Reduction of building density

- **Feedback** on urban air quality?
  - Primary vs. Secondary pollutants

Primary: Increase of CO and NOx

→ Reduction of the temperature dependent turbulent mixing

→ **Dynamics dominate**

Secondary I: Reduction of ozone levels

→ temperature dependency

Secondary II: Increase of peak ozone concentrations for ‚white roofs'

→ increased photolysis rates due to reflected UV

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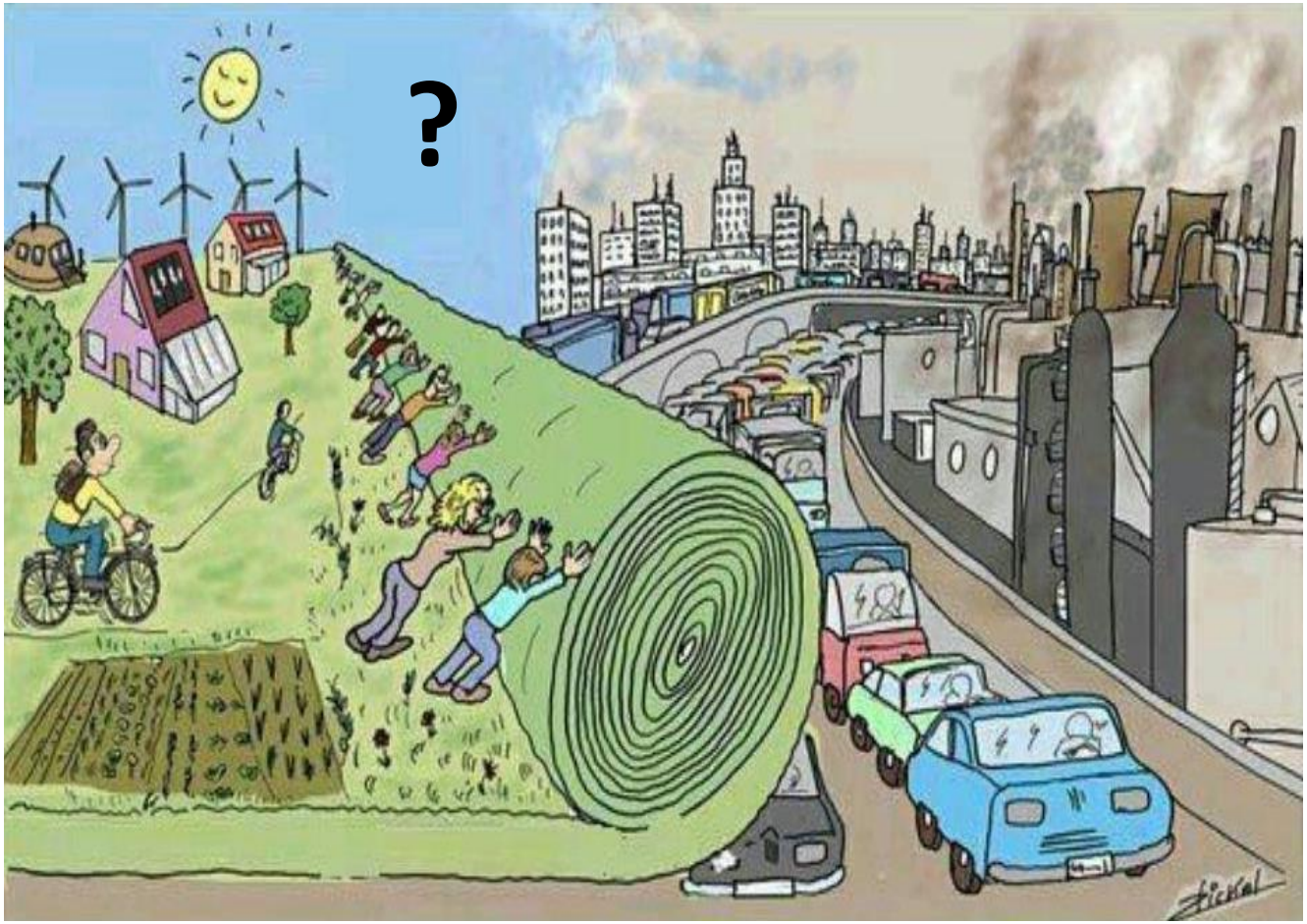
Merci Beaucoup



PHD-Thesis: http://kups.ub.uni-koeln.de/view/creators/Fallmann=3AJoachim=3A=3A.html

Fallmann et al. 2014 Erde

Fallmann et al. 2015 Atm Env (In Review)

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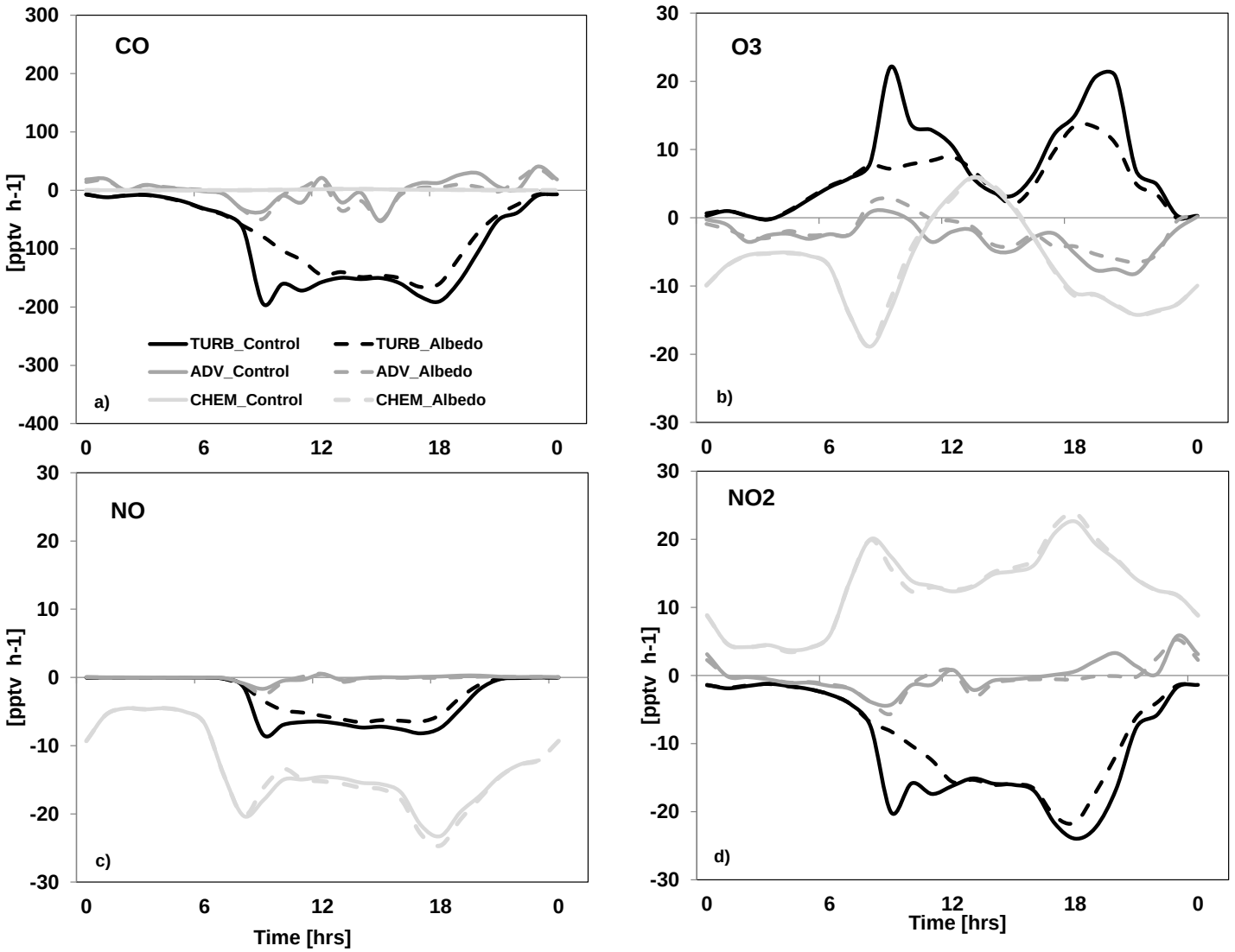
Diurnal variation of tendency terms



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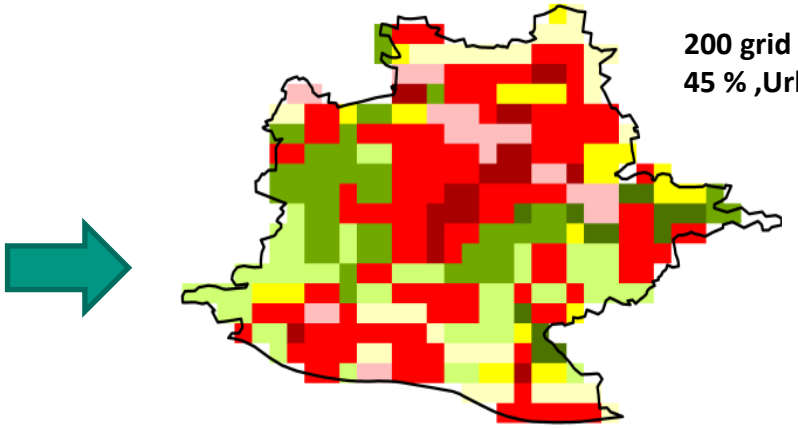
Urban areas in mesoscale models

33: Industrial/ Commercial

32: High Density Residential

31: Low Density Residential

WRF Landuse



200 grid cells: 45 % ‚Urban‘

Low Density Residental
High Density Residential
Industrial/Commercial

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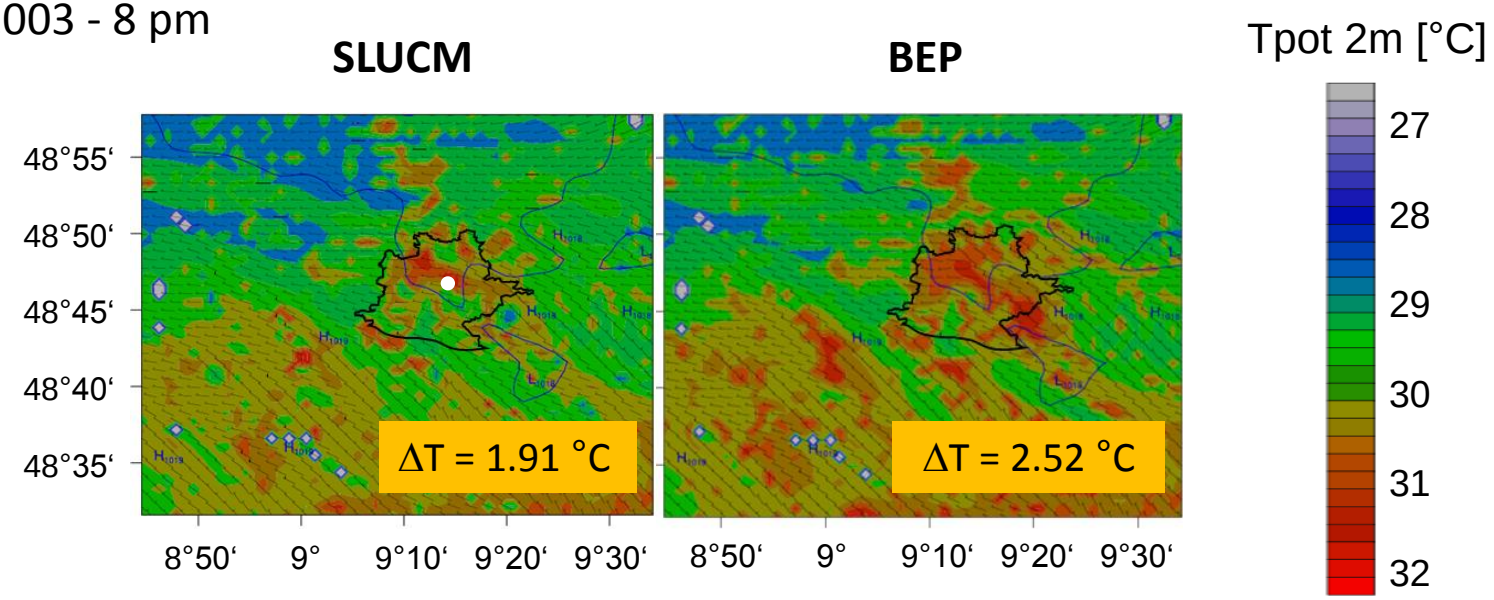
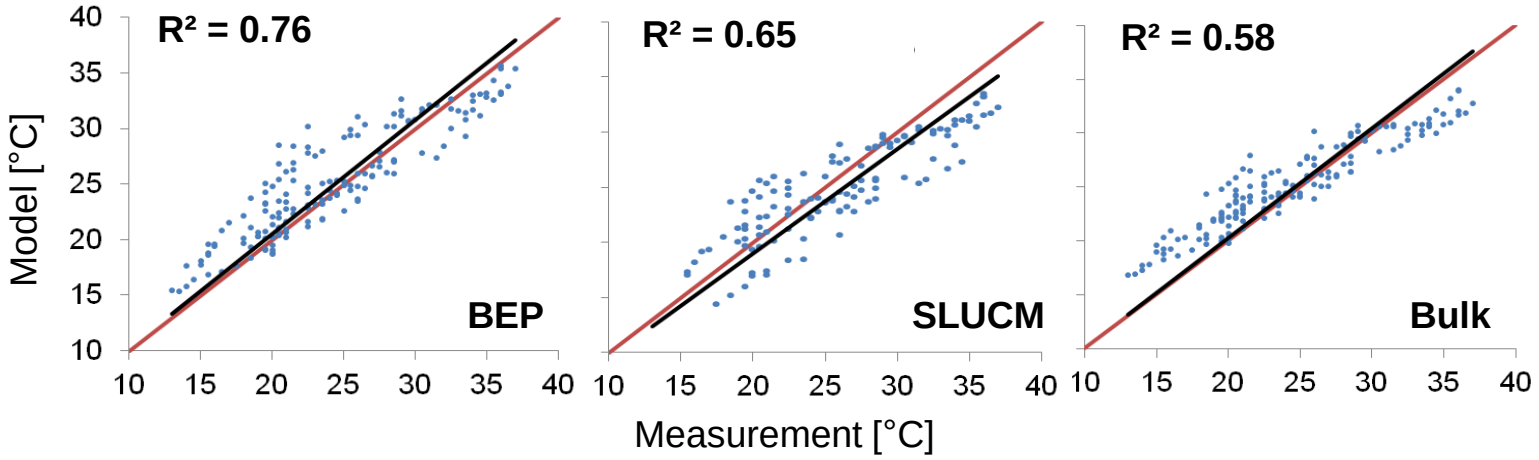
Model evaluation – Point vs. Pixel

Aug 13 2003 - 8 pm





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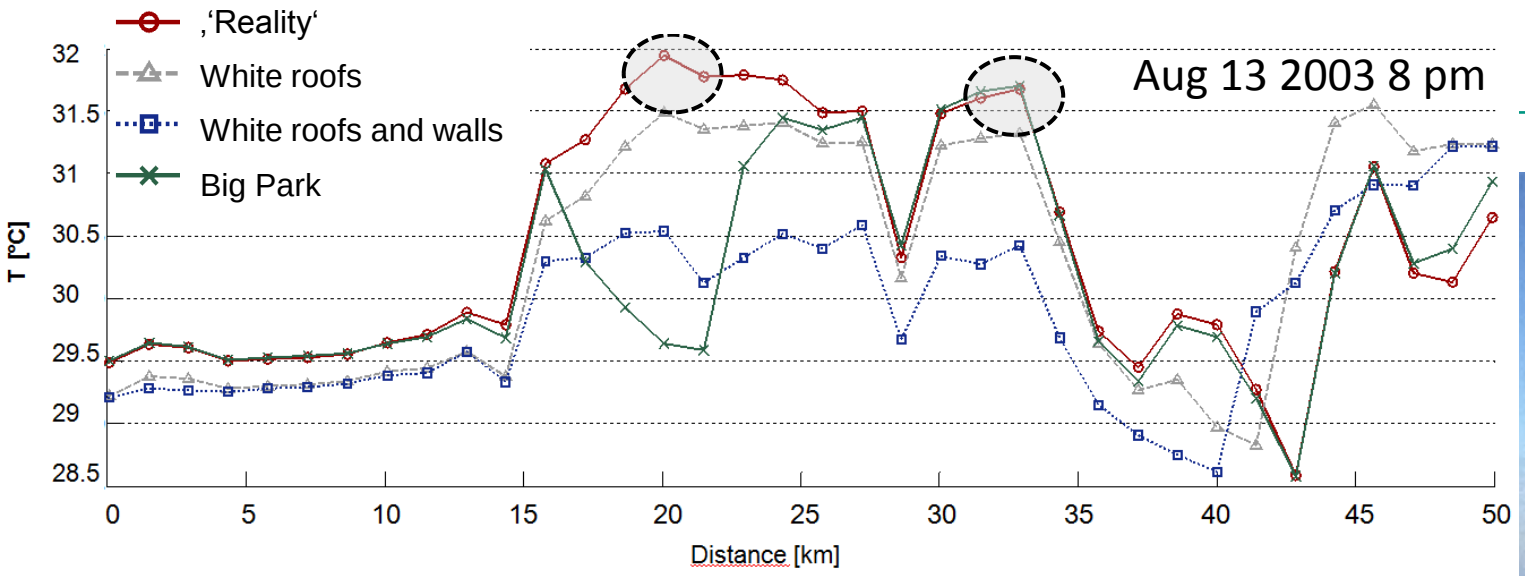

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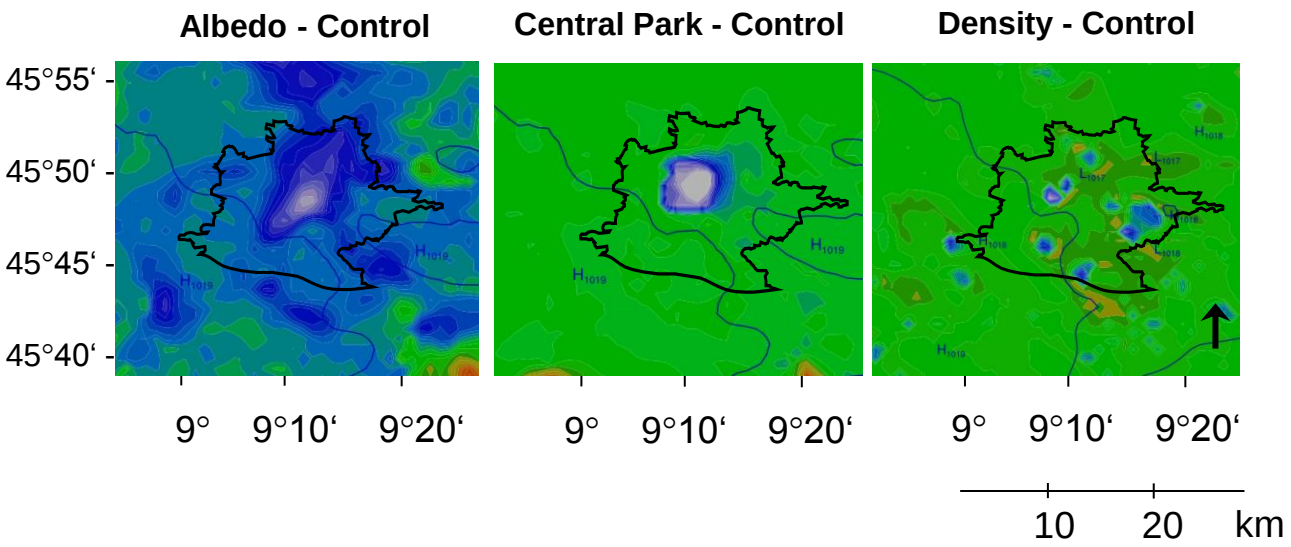
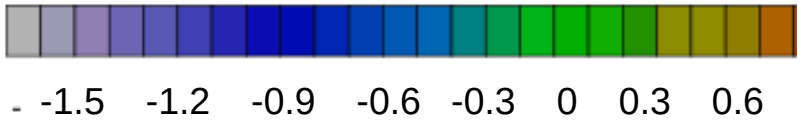
‚Efficiency‘



Aug 13 2003 8 pm

Δ 2m potential air temperature [°C]



(Fallmann et al. 2014)

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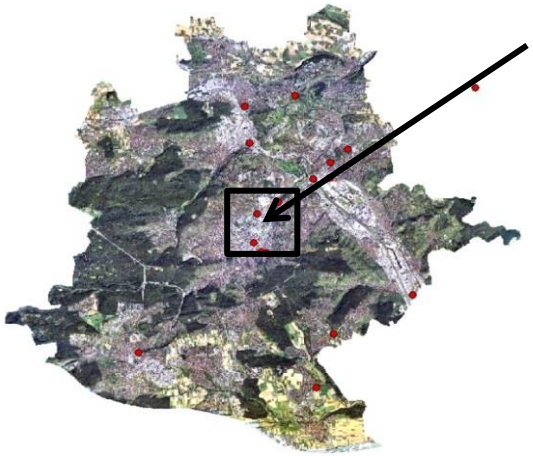
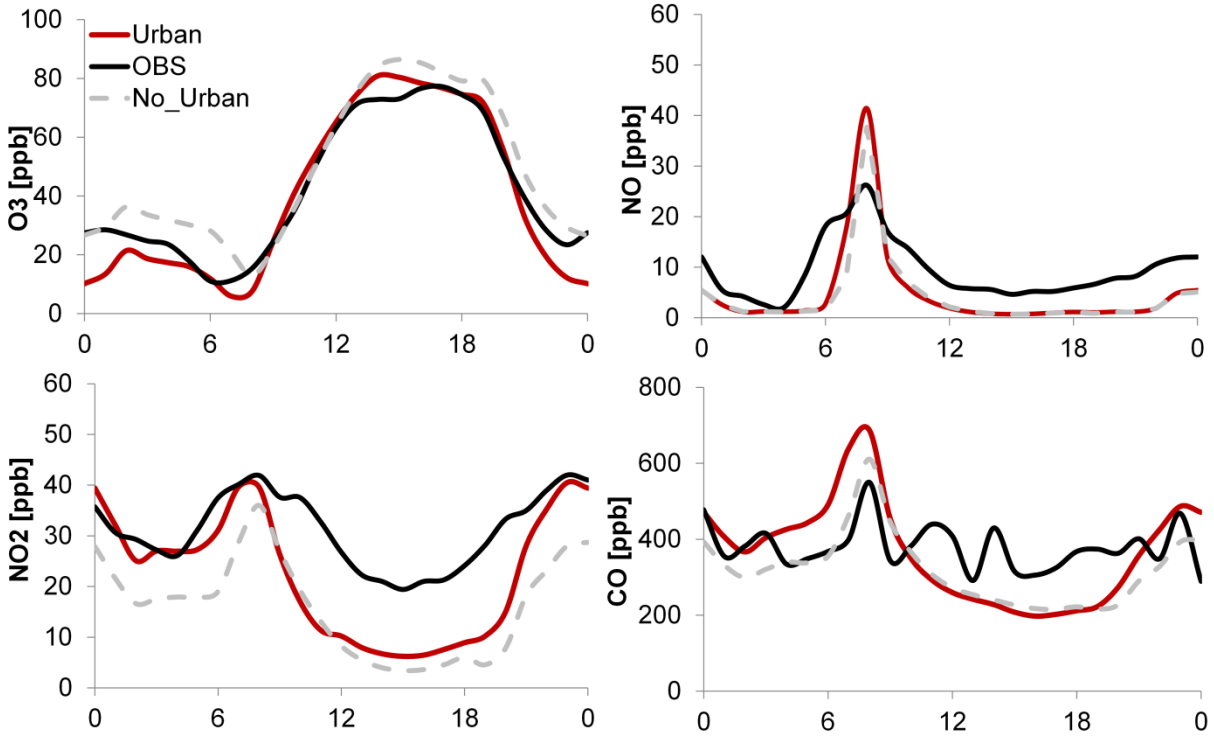
Model evaluation – point vs. grid cell



Mean over 3 Stations:

- Bad Cannstadt
- Schwabenzentrum
- Mitte – Arnulf-Klett Platz



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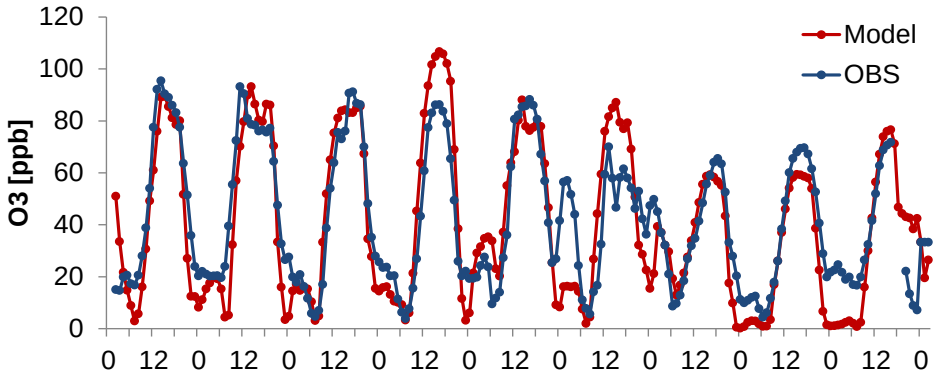
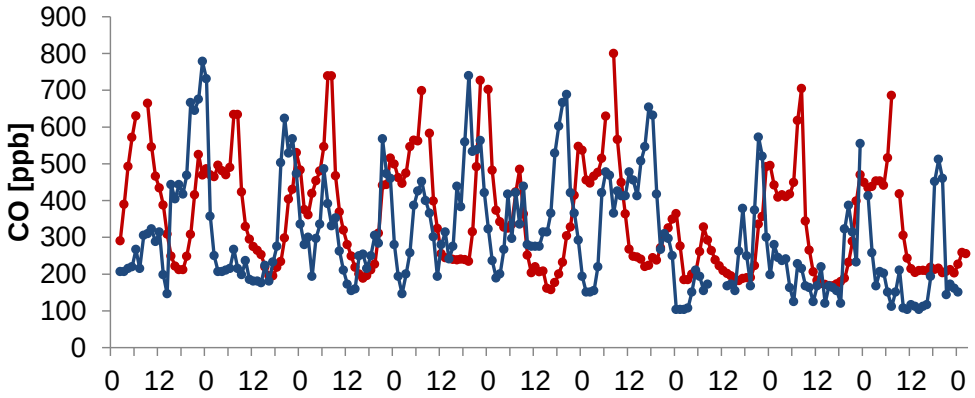
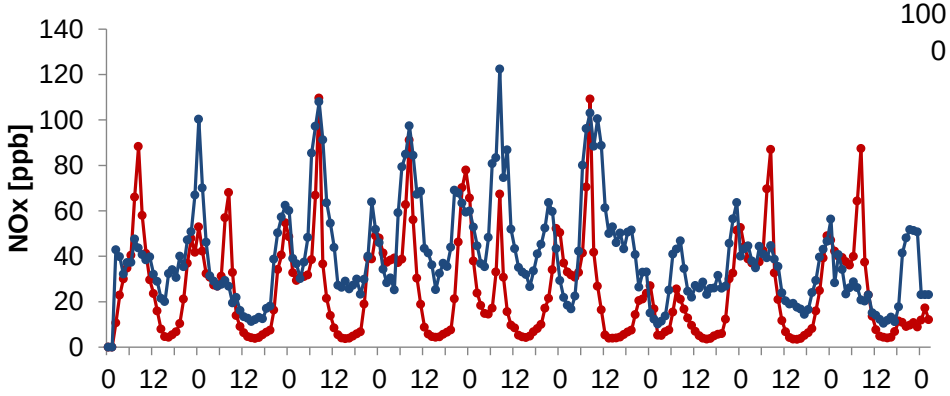
Model evaluation – point vs. grid cell







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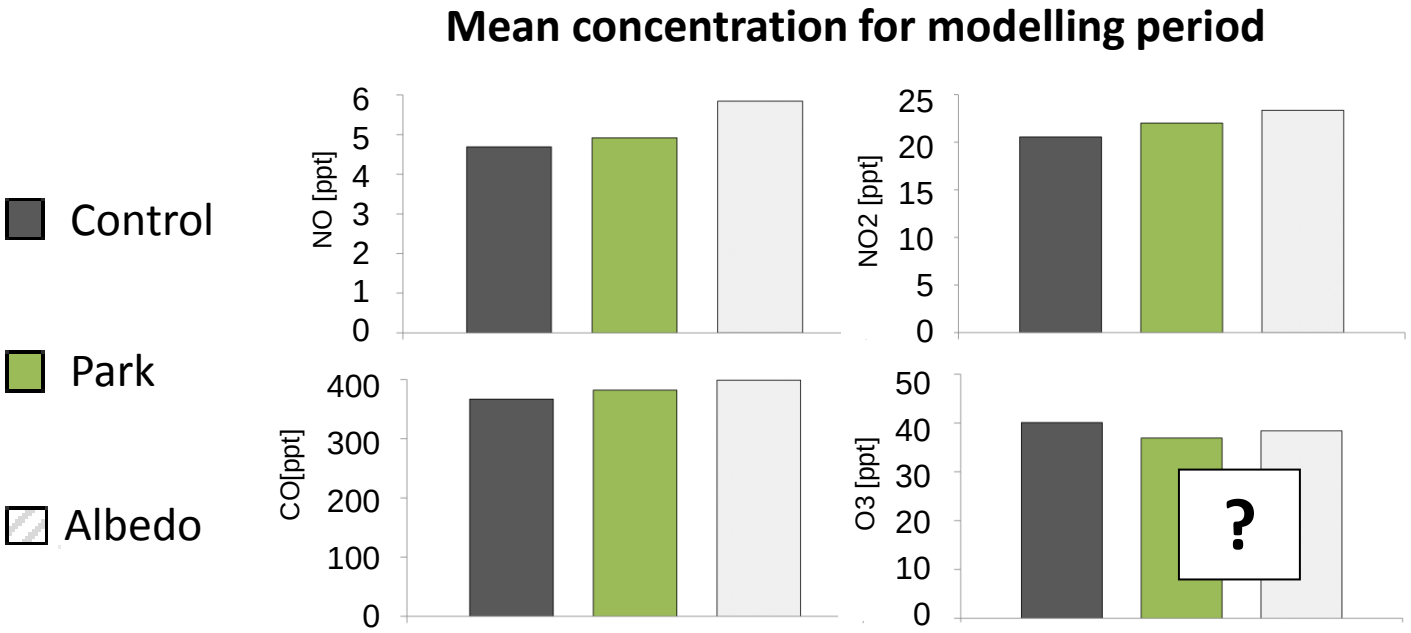
Effect on near surface mixing ratios



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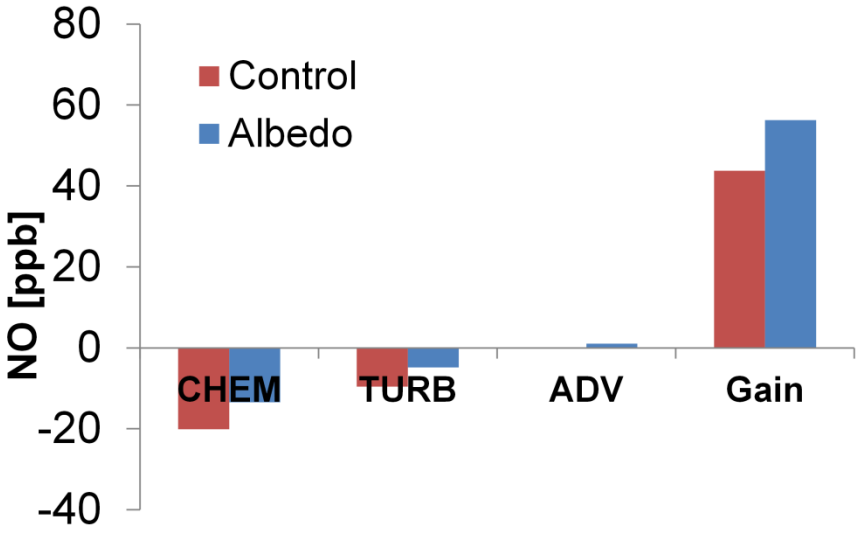
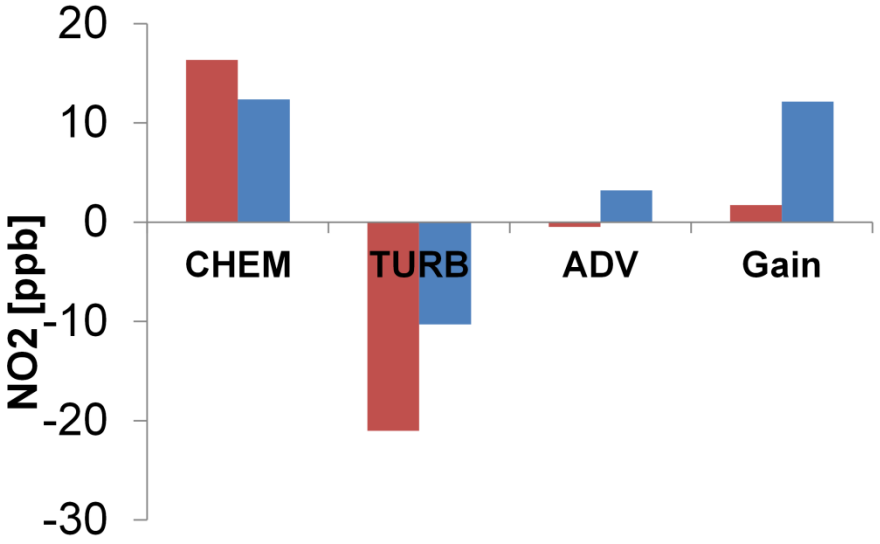
NO and NO2





NOx-Cycle

$$NO + HO_2 \rightarrow NO_2 + OH$$

$$NO + O_3 \rightarrow NO_2 + O$$

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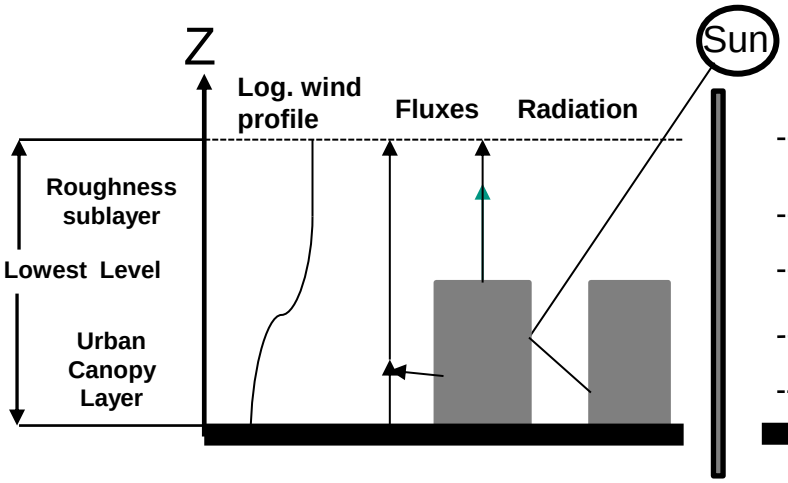
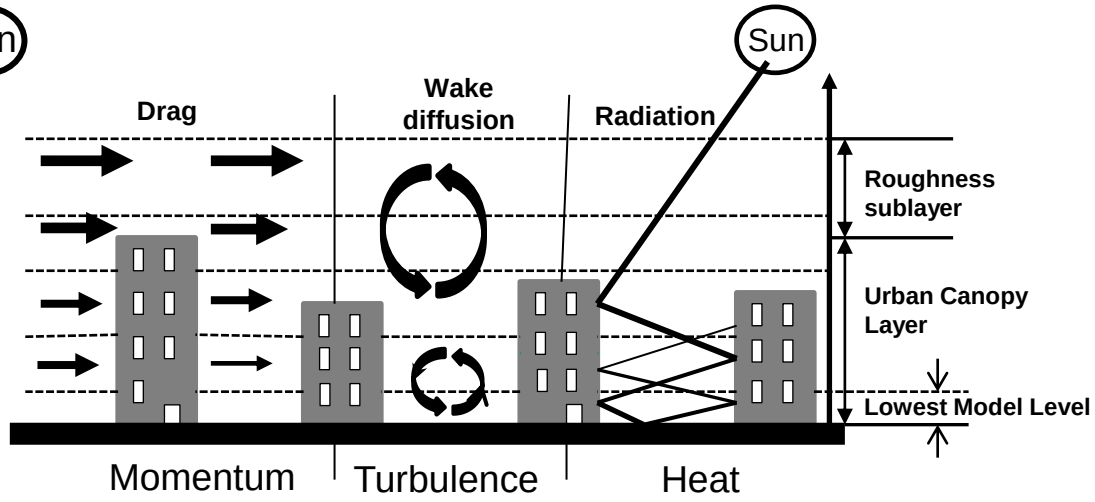
Parametrization of sub-grid scale processes

Urban Canopy Model



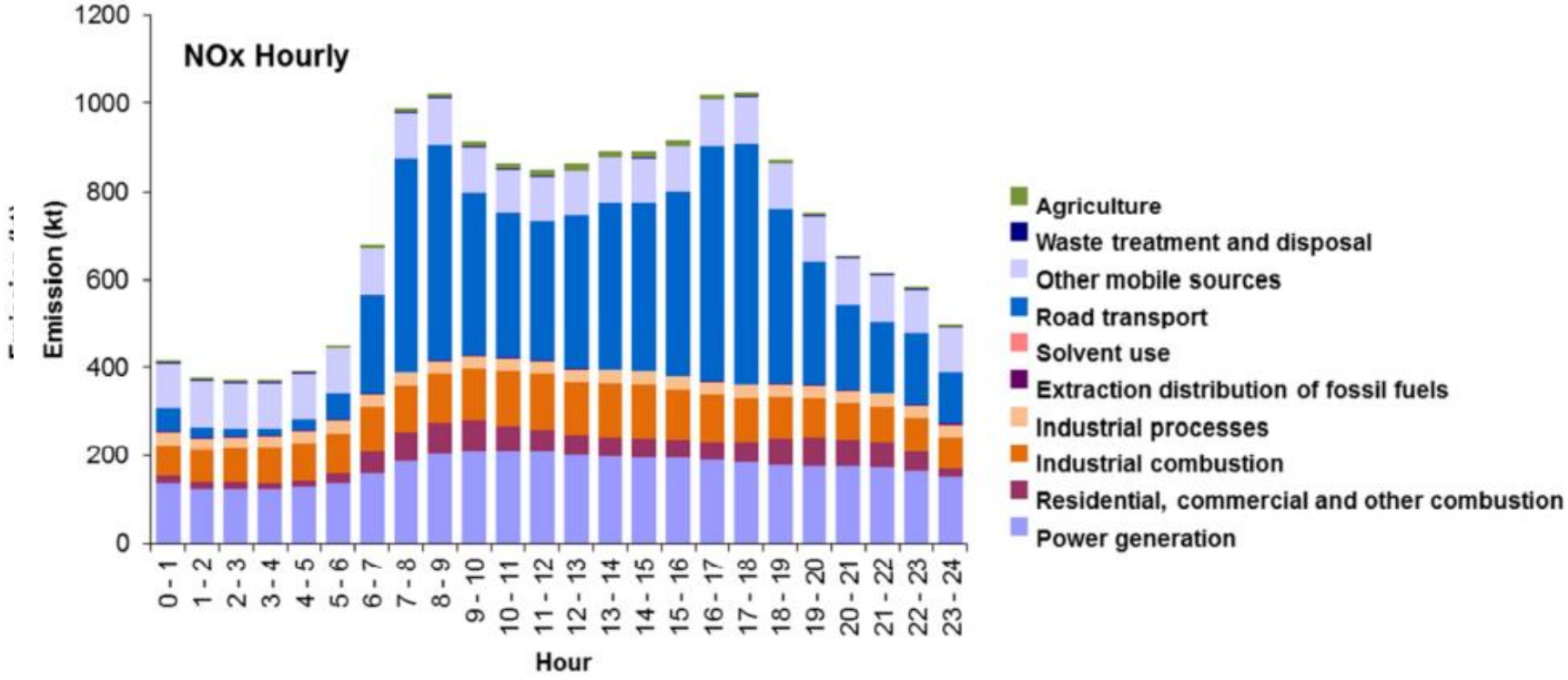


Single **L**ayer **U**rban **C**anopy **M**odel (Kusaka 2001)

Building **E**ffect **P**arameterization (Martilli 2002)

Changed from Chen (2011)

MACC Emission Inventory 2003-2007 - Quellstärken



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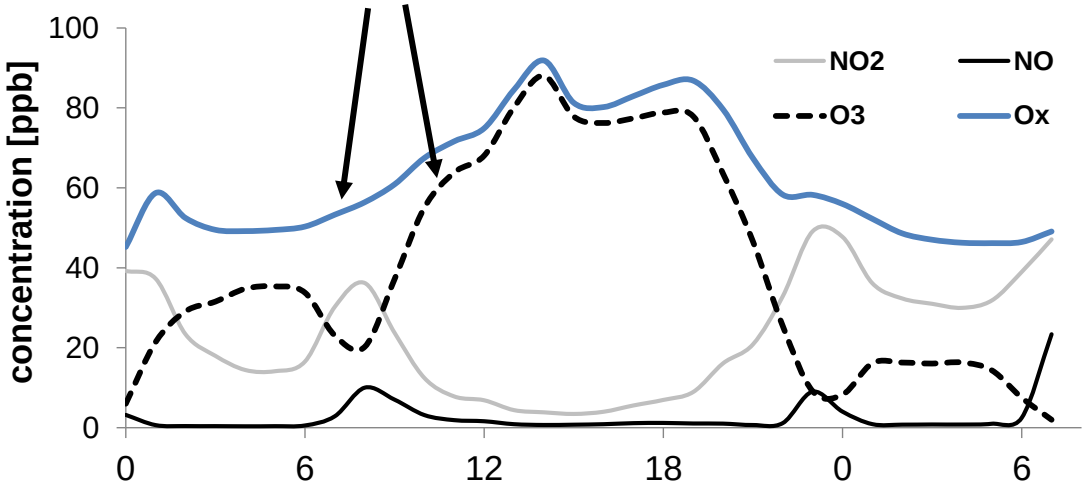
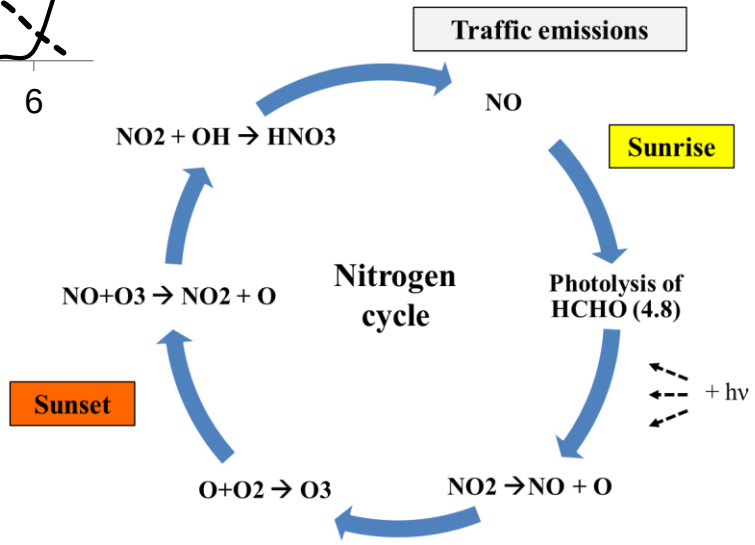
The nitrogen cycle – photochemical reactions

+ Advection and vertical transport from higher layers





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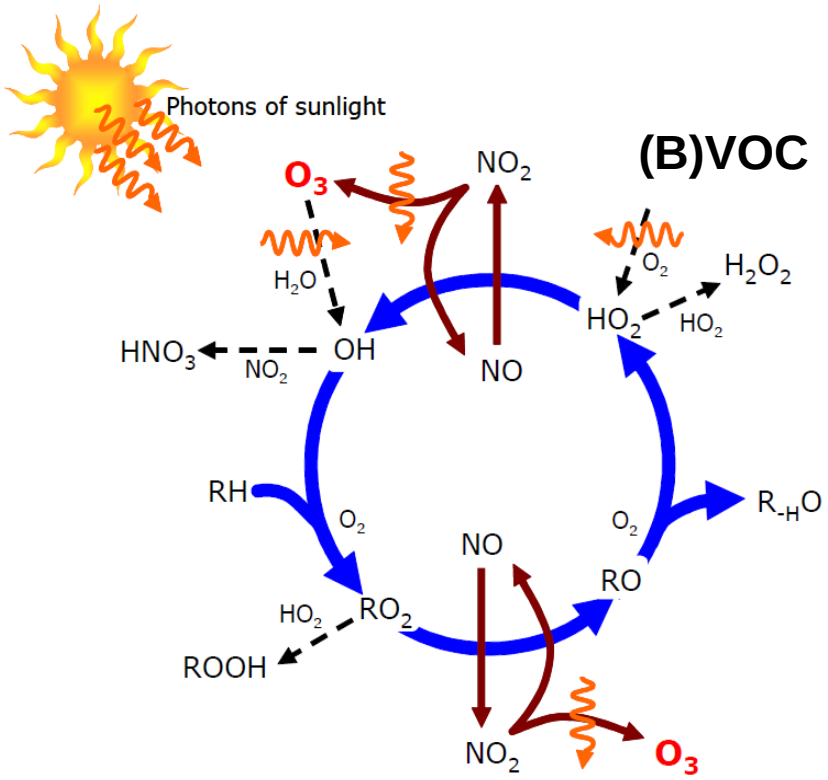
Biogene Emissionen als Vorläufer für Photosmog



Photolyse bzw. Oxidation von VOC

$$\boldsymbol{HCHO} + h\nu \rightarrow H + HCO$$

$$(\boldsymbol{HCHO} + OH \rightarrow H_2O + HCO)$$

$$HCO + O_2 \rightarrow \boldsymbol{HO_2} + CO$$

$$HO_2 + NO \rightarrow NO_2 + OH$$

$$NO_2 + h\nu \rightarrow NO + \boldsymbol{O_3}$$

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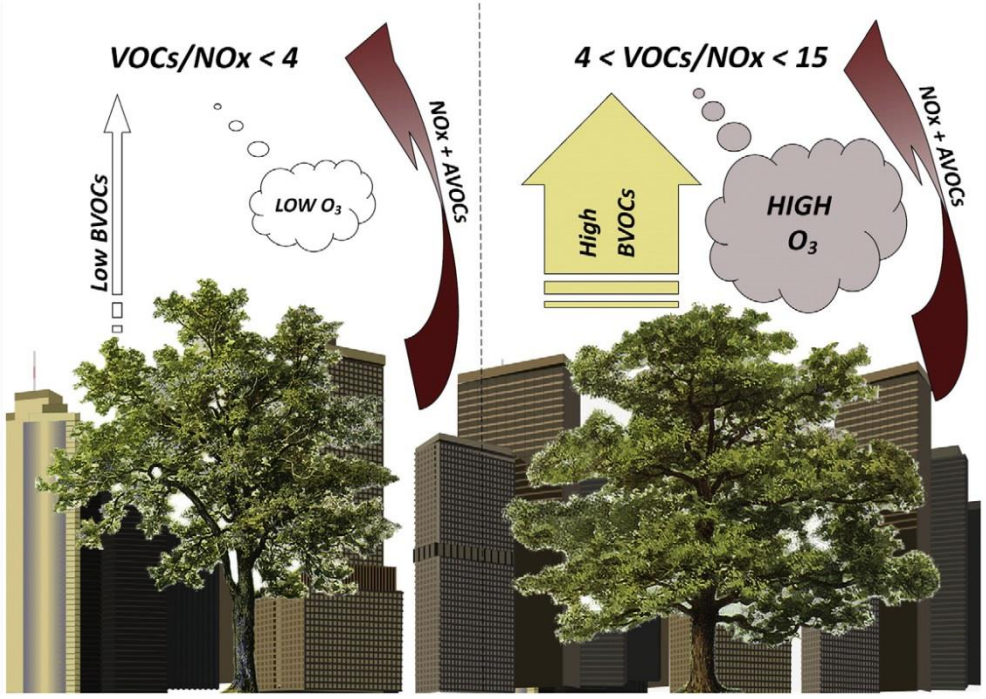
VOC/NOx Ratio als Grundlage für Ozon-Produktion



- Kein VOC: Photo-Stationärer Zustand, keine Ozon- Bildung
- VOCs dazu: schnelle Photo-Oxidation (mit OH)
- Menge an O3 abhängig von Menge an VOC
- OFP = Gramm O3 pro Gramm VOC

- Ratio:
  - VOC limitiert VOC/NOx < 4
  - Optimum für O3 Prod.: 15 < VOC/NOx < 4
  - NOx-limitiert VOC/NOx < 15

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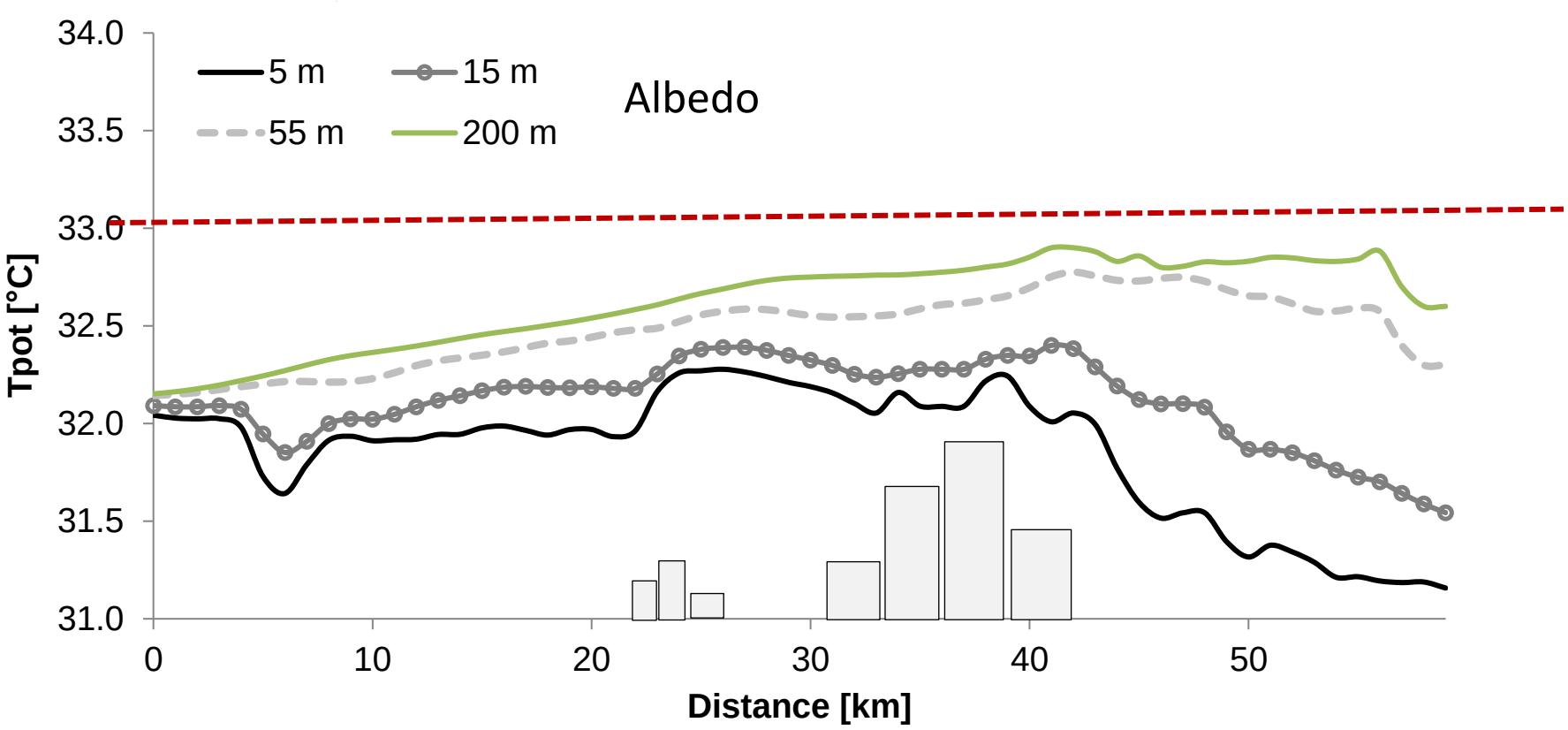
Urban Plume



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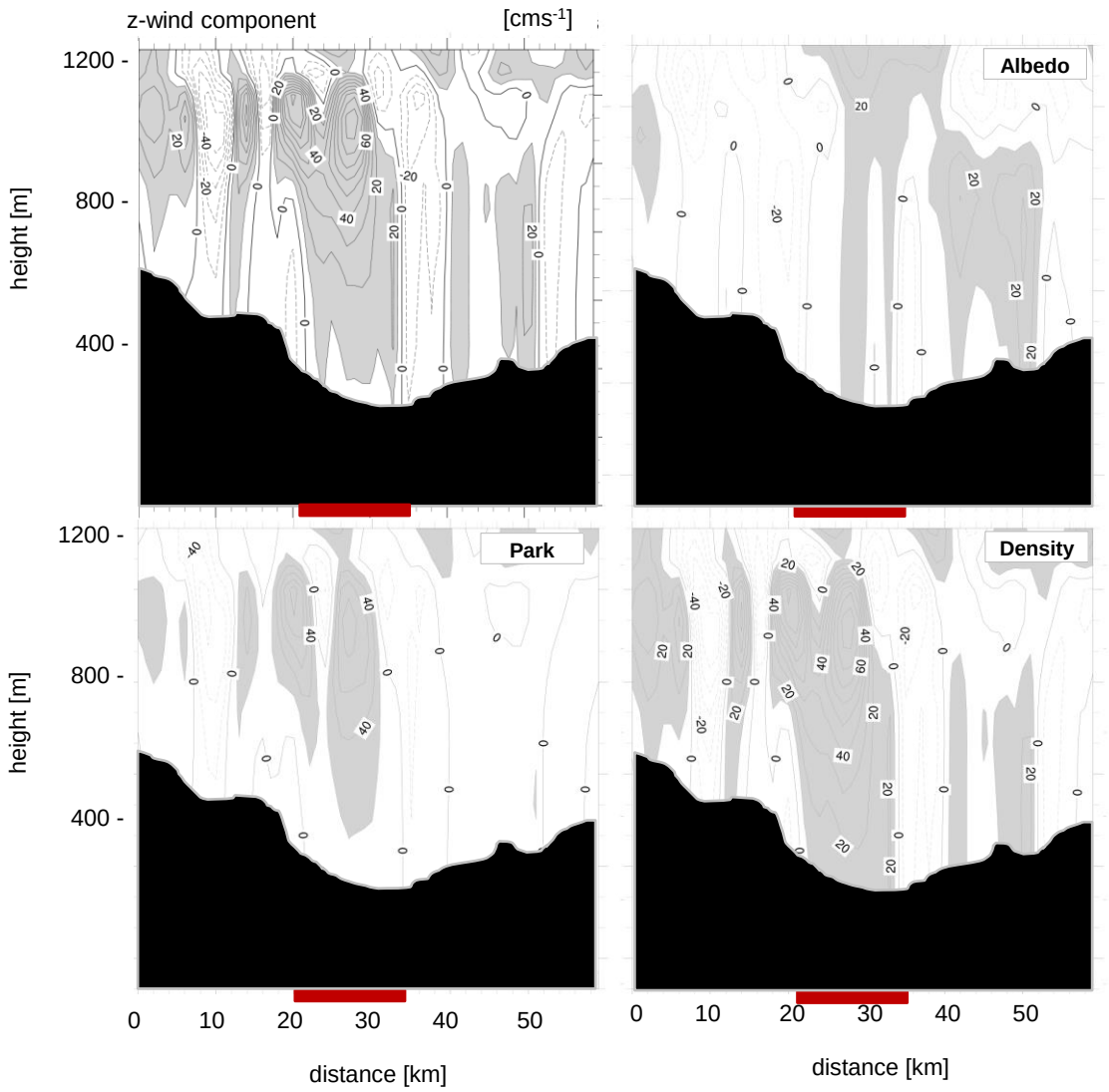
Querschnitt Vertikalgeschwindigkeit



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