

Cool Cities – Clean Cities ?

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

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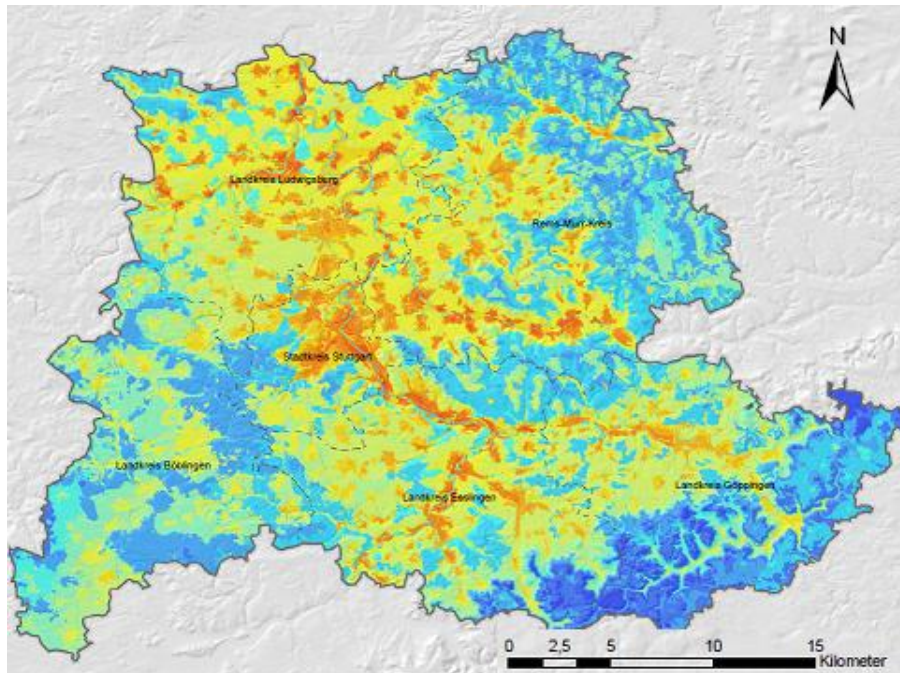


Institute of Meteorology and Climate Research (IMK-IFU) of the Karlsruhe Institute of Technology (KIT), Campus Alpine

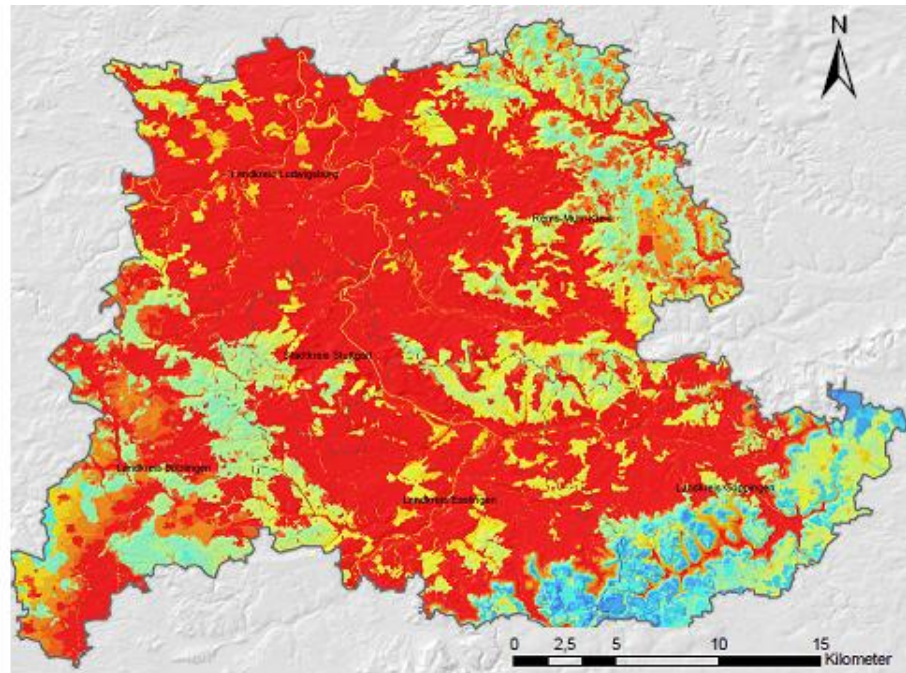


„Heat stress days‘ per year (greater Stuttgart area)

1971-2000



2071-2100

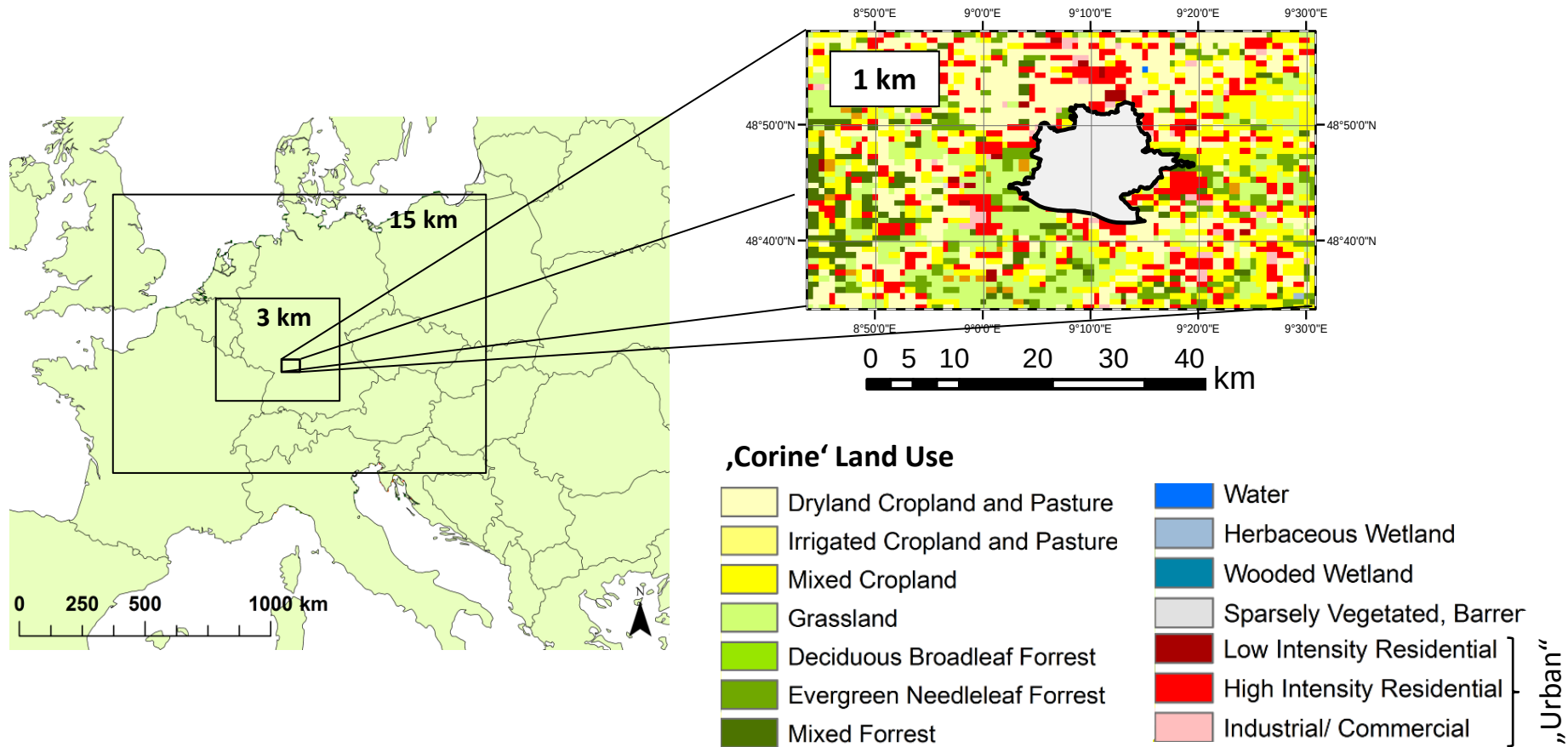


Source: Klimaatlas Region Stuttgart

➡ UHI mitigation strategies ?



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

Urban areas in mesoscale models

Urban Parameter

ZR: Roof level (building height) [m]
SIGMA_ZED: Standard Deviation of building height [m]
ROOF_WIDTH: Roof (i.e., building) width [m]
ROAD_WIDTH: road width [m]
AH: Anthropogenic heat [W m/m²]
FRC_URB: Fraction of the urban landscape which does not have natural vegetation [Fraction]
CAPR: Heat capacity of roof [J m³/ K]
CAPB: Heat capacity of building wall [J m³/ K]
CAPG: Heat capacity of ground (road) [J m³/ K]
AKSR: Thermal conductivity of roof [W m/K]
AKSB: Thermal conductivity of building wall [W m/K]
AKSG: Thermal conductivity of ground (road) [W m/K]
ALBR: Surface albedo of roof [fraction]
ALBB: Surface albedo of building wall [fraction]
ALBG: Surface albedo of ground (road) [fraction]
EPSR: Surface emissivity of roof [-]

‘Morphology’

‘Material characteristics’

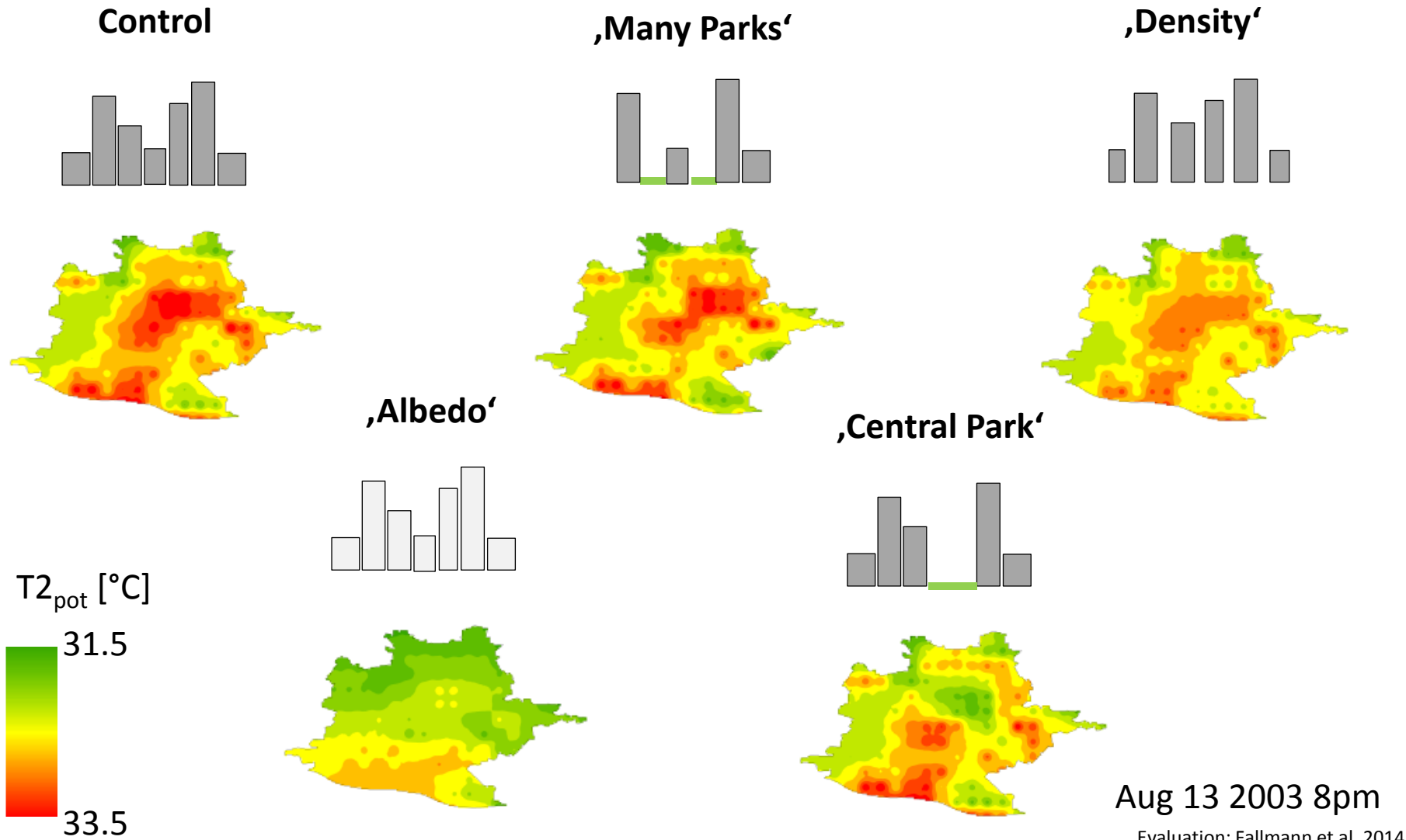
Street Parameters

Urban Category [index]	Direction [°]	street width [m]	building width [m]
33	0	19	25
33	90	19	25
32	0	13	13
32	90	13	13
31	0	18	10
31	90	18	10

Road network

	33	32	31	
8.5	9.7	6.4		
6.8	6.4	4.5		
27.5	13.3	10		
19	16.2	9.8		
90	50	20		
0.95	0.85	0.5		
1.00E+06	1.00E+06	1.00E+06		
1.00E+06	1.00E+06	1.00E+06		
1.40E+06	1.40E+06	1.40E+06		
0.67	0.67	0.67		
0.67	0.67	0.67		
0.4	0.4	0.4		
0.2	0.2	0.2		Albedo
0.2	0.2	0.2		
0.2	0.2	0.2		
0.8	0.9	0.93		
Building Heights	33	32	31	
height [m]	Percentage [%]	Percentage [%]	Percentage [%]	
5	33	33	48	
10	28	20	37	
15	14	13	11	
20	8	8	3	
25	4	4	1	
30	2	2		
35	2			

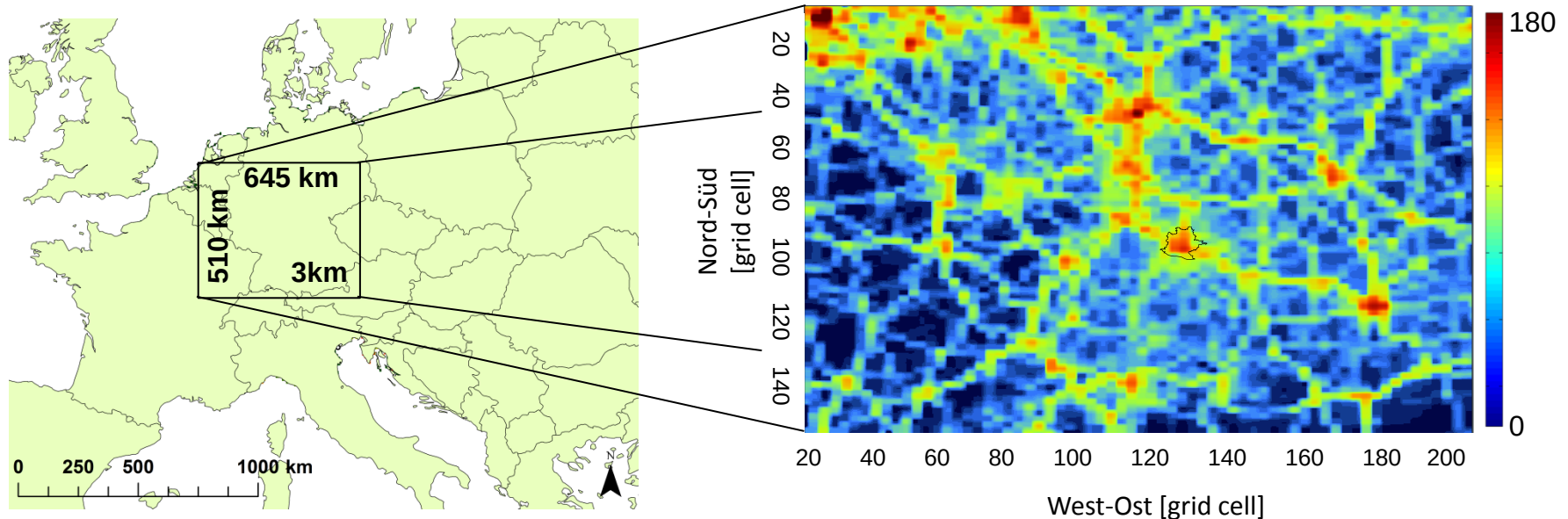
Building properties





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

WRF-Chem Domain



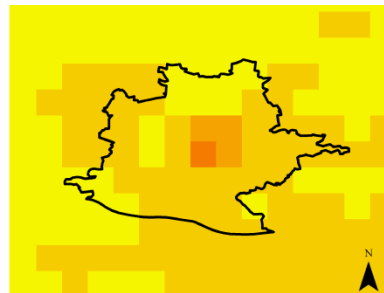
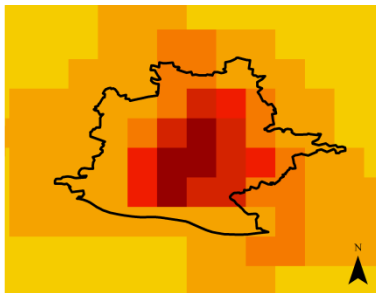
- Initial- and dynamical boundary conditions from global model **MOZART** (*anthropogenic*) und **MEGAN** (*biogenic*)
- **RADM2 MADE/SORGAM** chemical mechanism, **MYJ PBL-scheme**
- Lower boundary conditions **MACC Emissions 2003-2007**
- Modeled time frame: **Aug 9 – Aug 18 2003**

Evaluation: Fallmann et al. 2015 (In Review)

Primary pollutants (e.g. CO)

„Albedo-Control“

„Park-Control“



Delta CO [ppb]

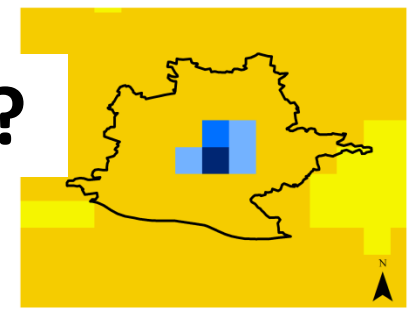
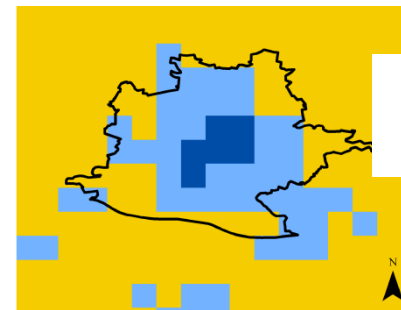


0 7.5 15 km

Secondary pollutants (e.g. O₃)

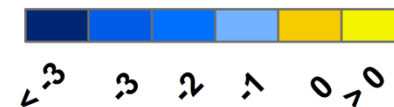
„Albedo-Control“

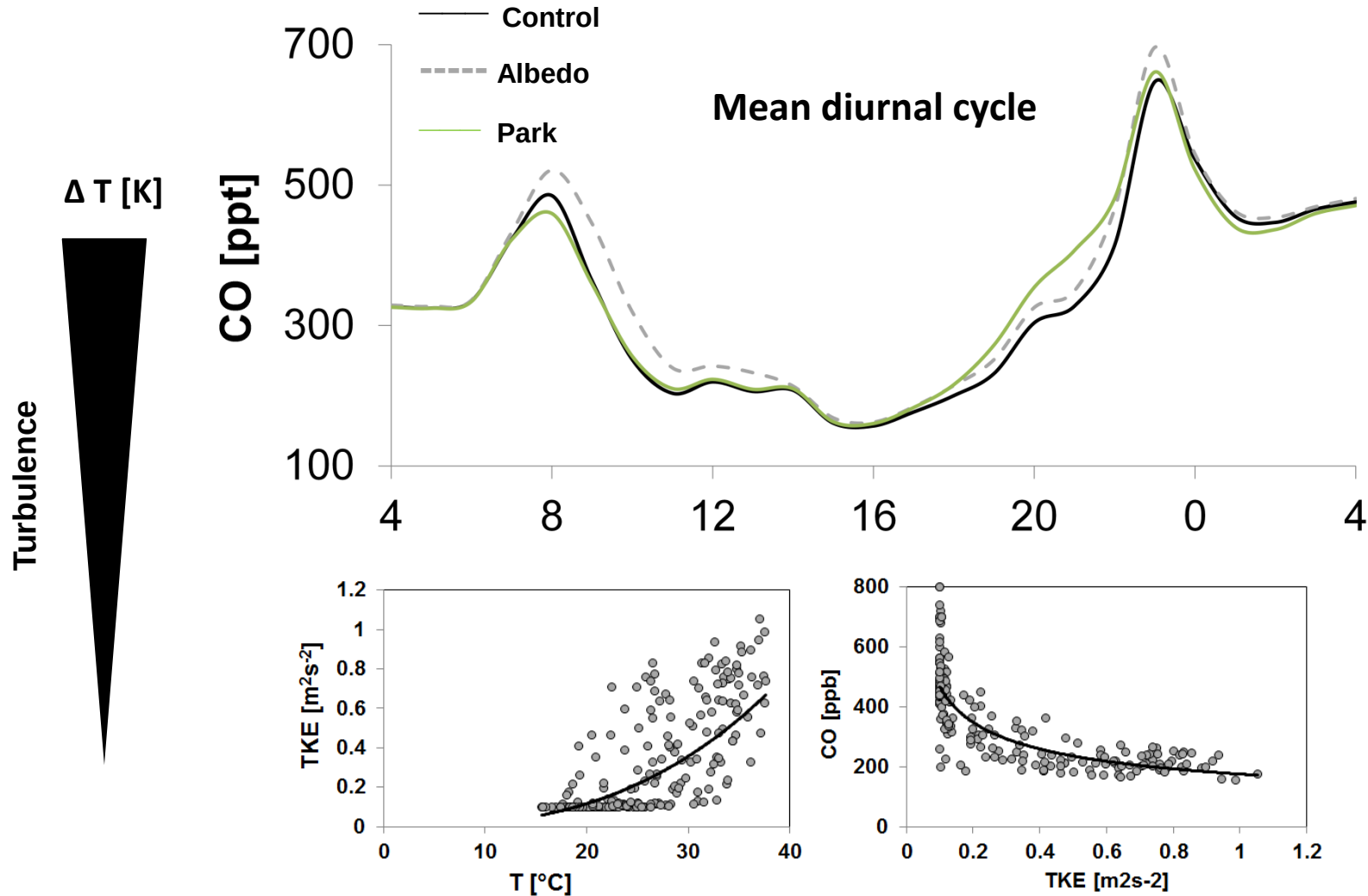
„Park-Control“



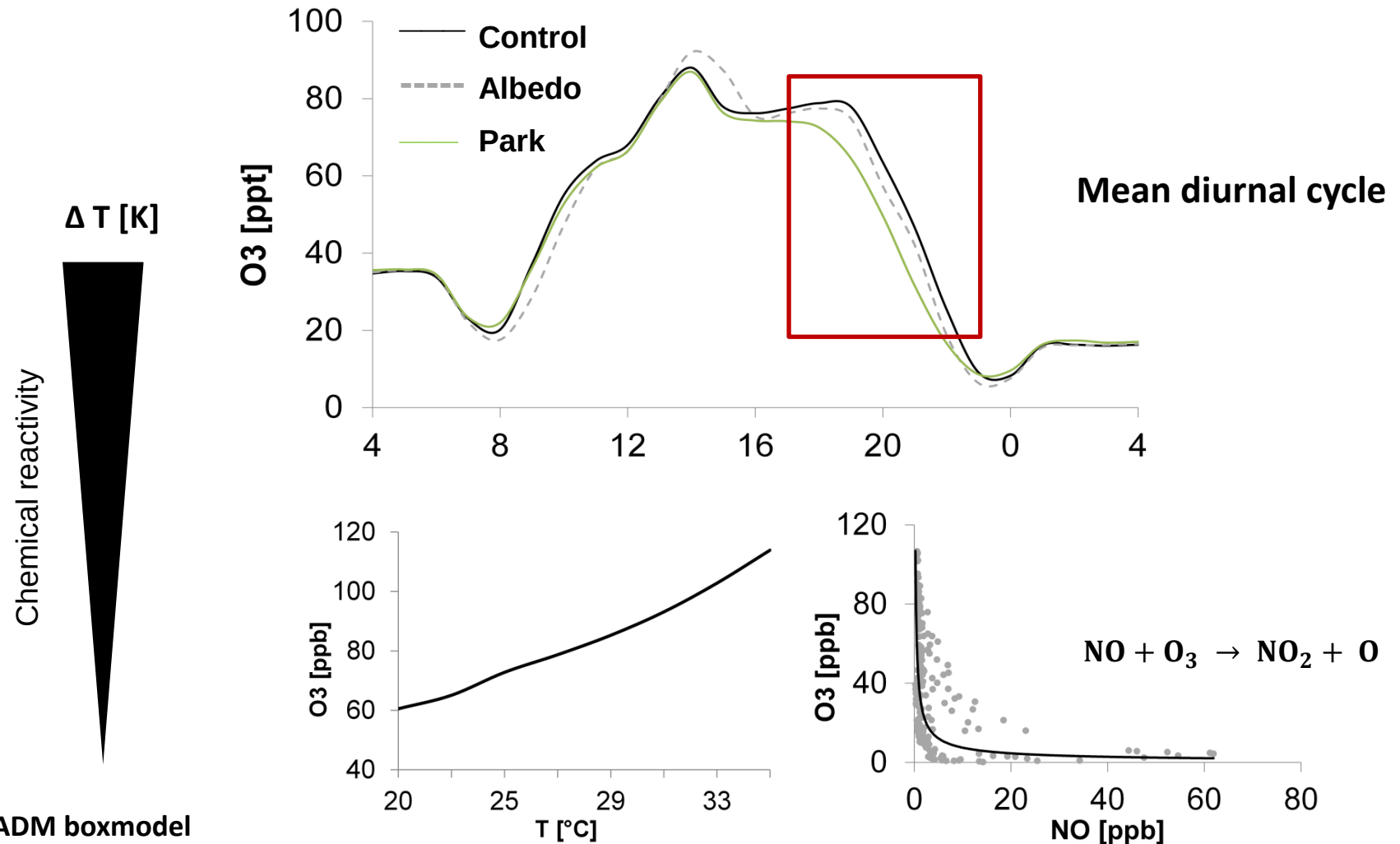
?

Delta O₃ [ppb]





Secondary pollutants (Ozone) – Chemical reactivity

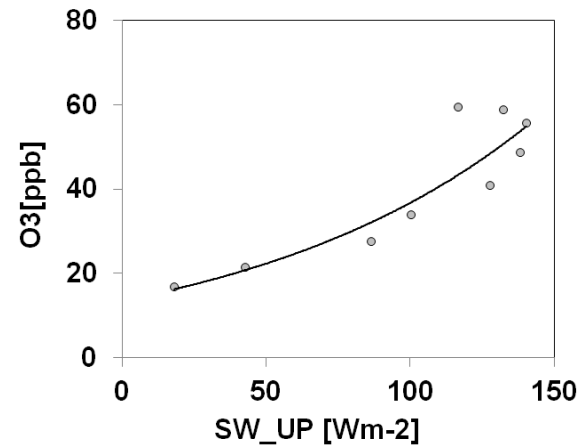
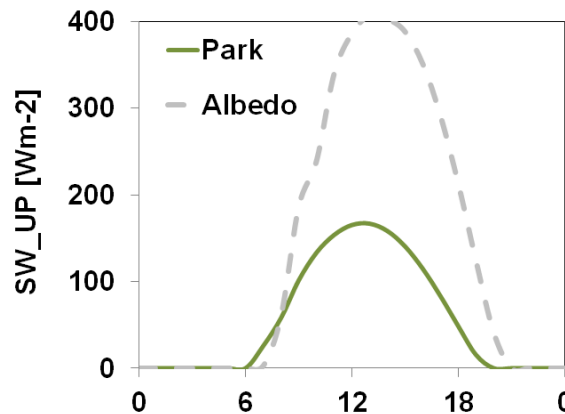
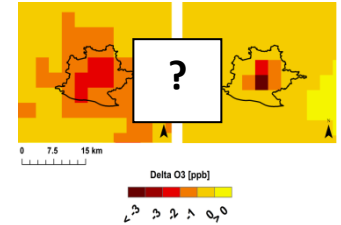
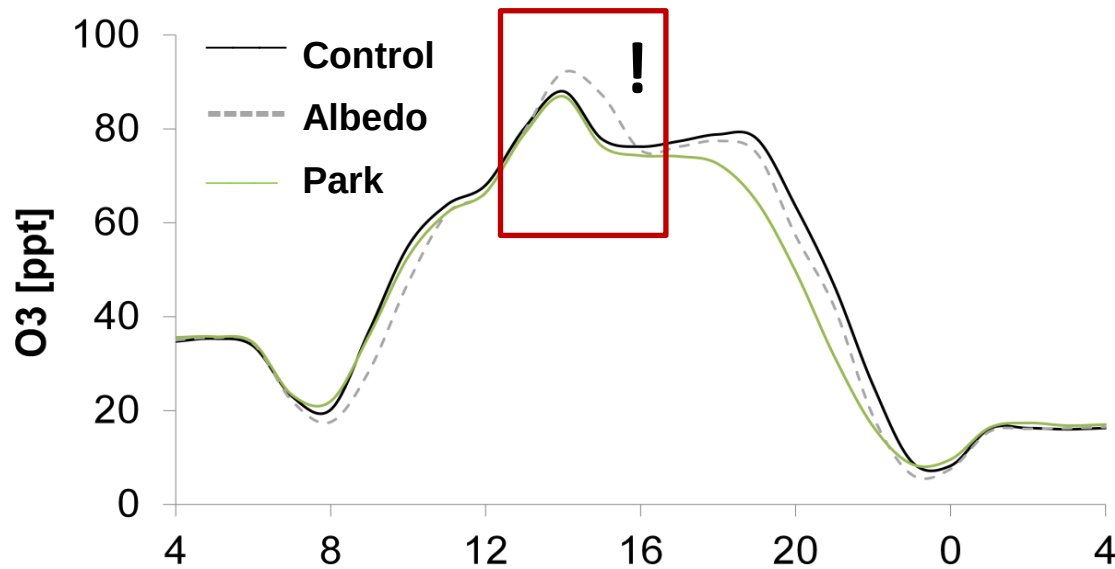


RADM boxmodel
(Stockwell 1988)

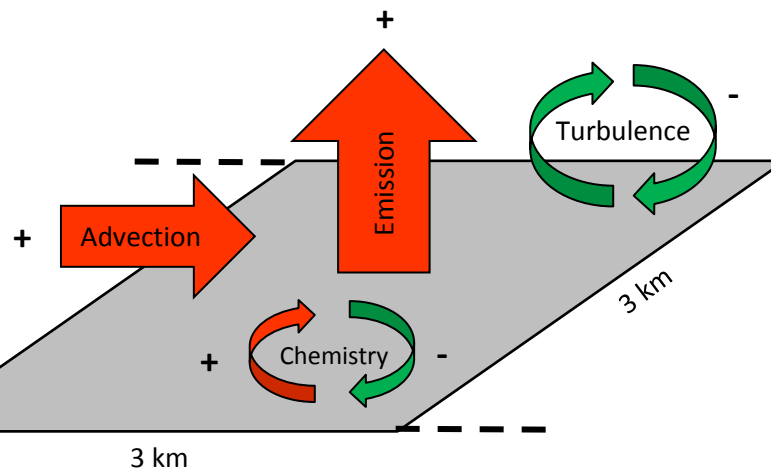
Secondary pollutants (Ozone) - Photolysis

SW_UP [Wm⁻²]

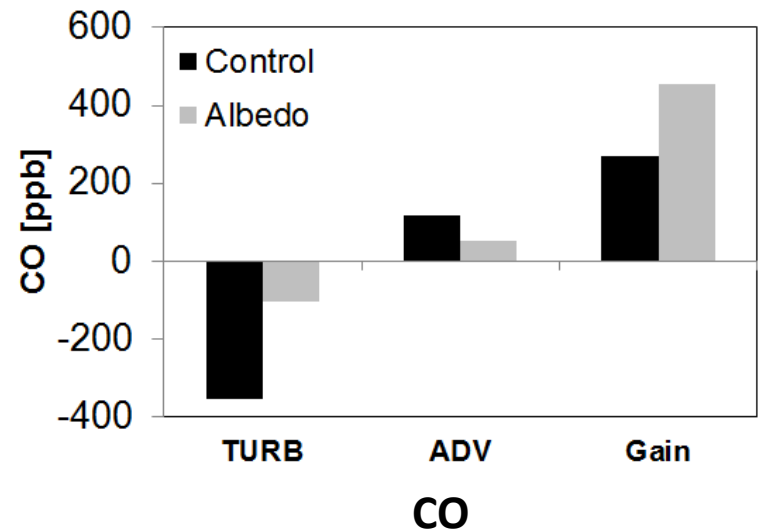
Photolysis rate



- 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)

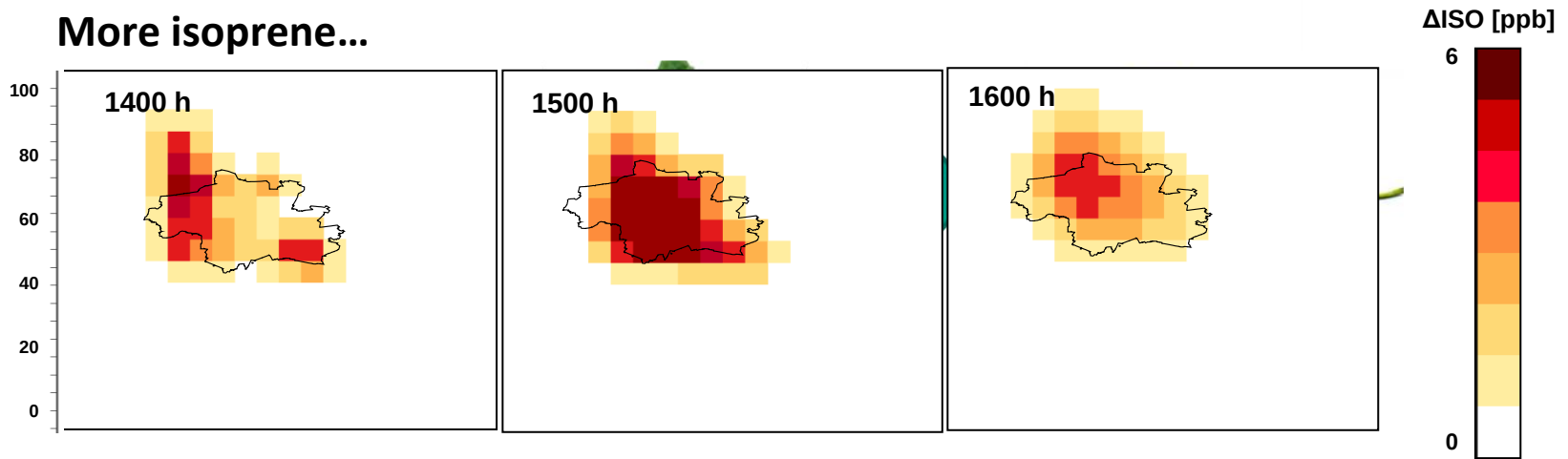


Balance:
Gain/Loss = EMIS + CHEM + TURB + ADV

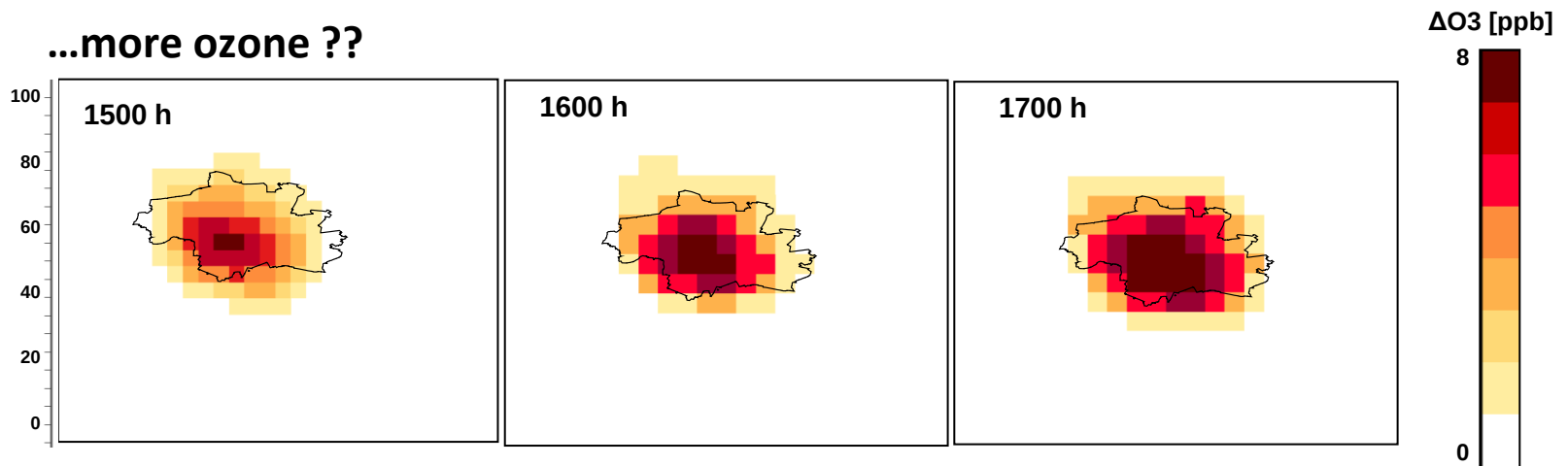


Case Study: Planting the ,wrong' tree ?!

More isoprene...

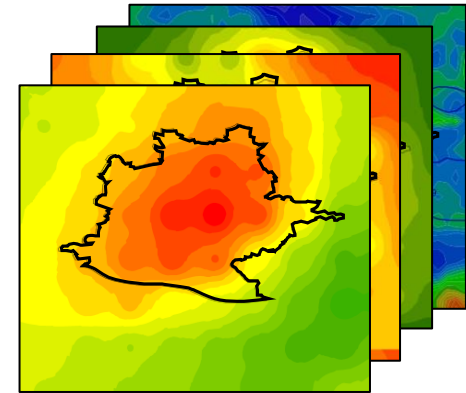


...more ozone ??



➤ 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 NO_x

→ Reduction of the temperature dependent turbulent mixing

→ **Dynamics dominate**

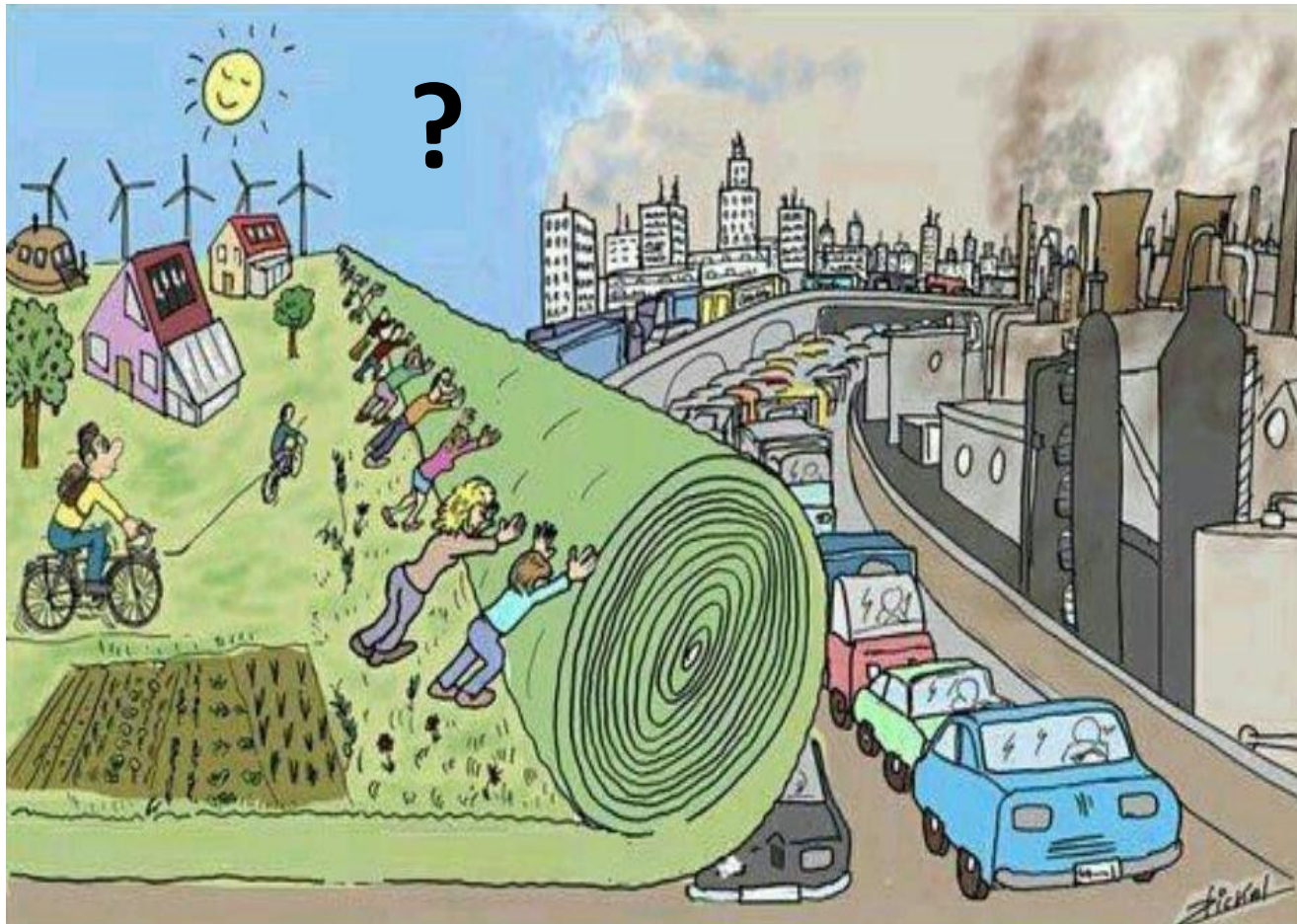
Secondary I: Reduction of ozone levels

→ temperature dependency

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

→ increased photolysis rates due to reflected UV

Merci Beaucoup



STUTTGART 



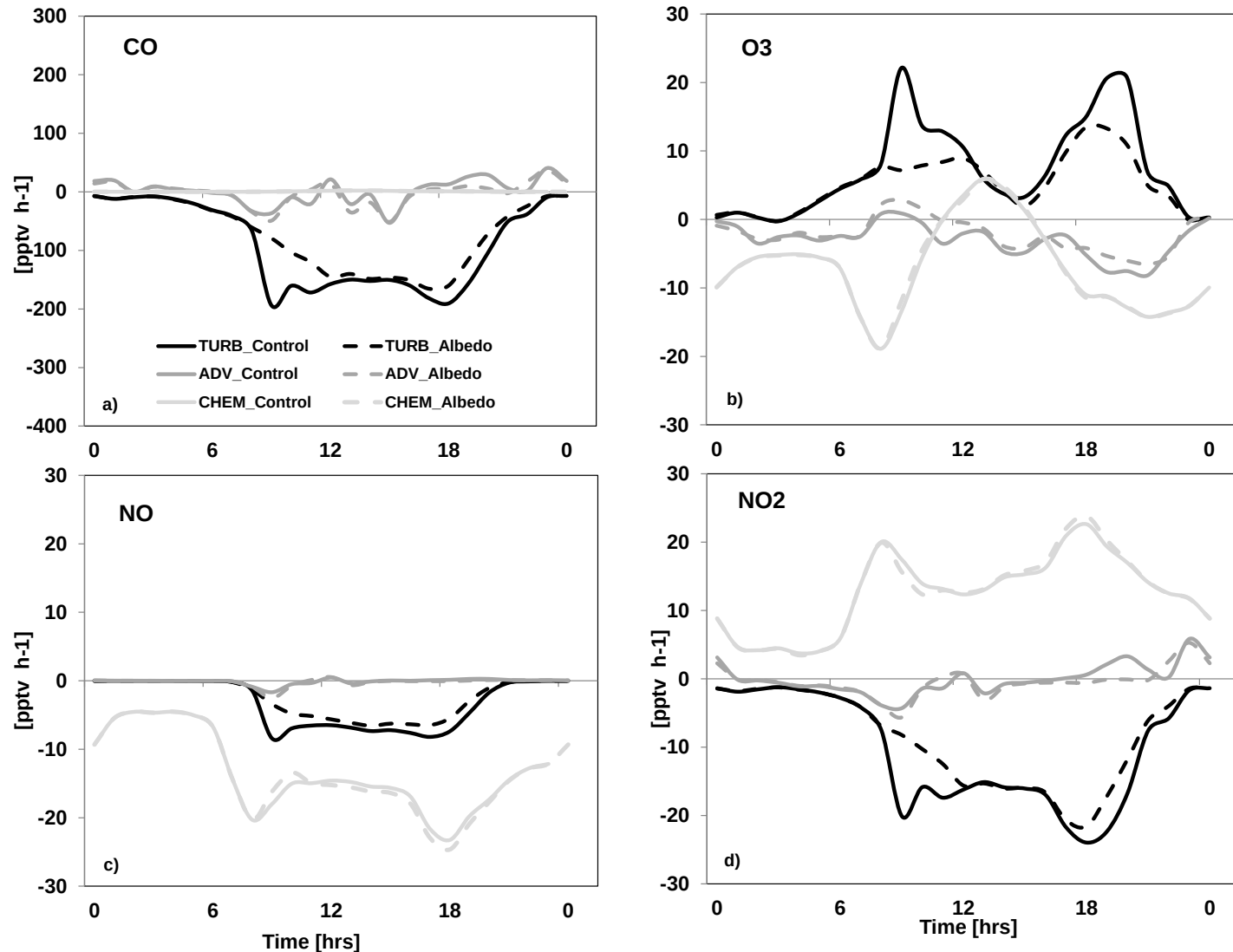
TNO innovation
for life

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)

Diurnal variation of tendency terms



Urban areas in mesoscale models

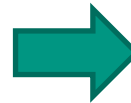
33:
Industrial/
Commercial



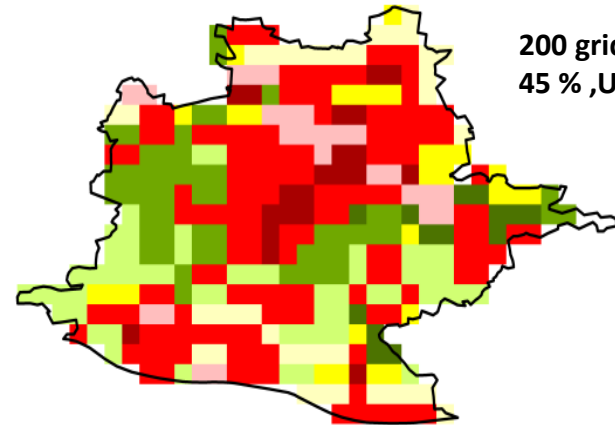
32:
High Density
Residential



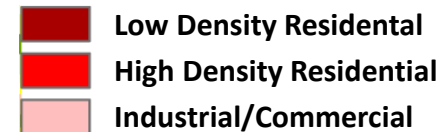
31:
Low Density
Residential



WRF Landuse

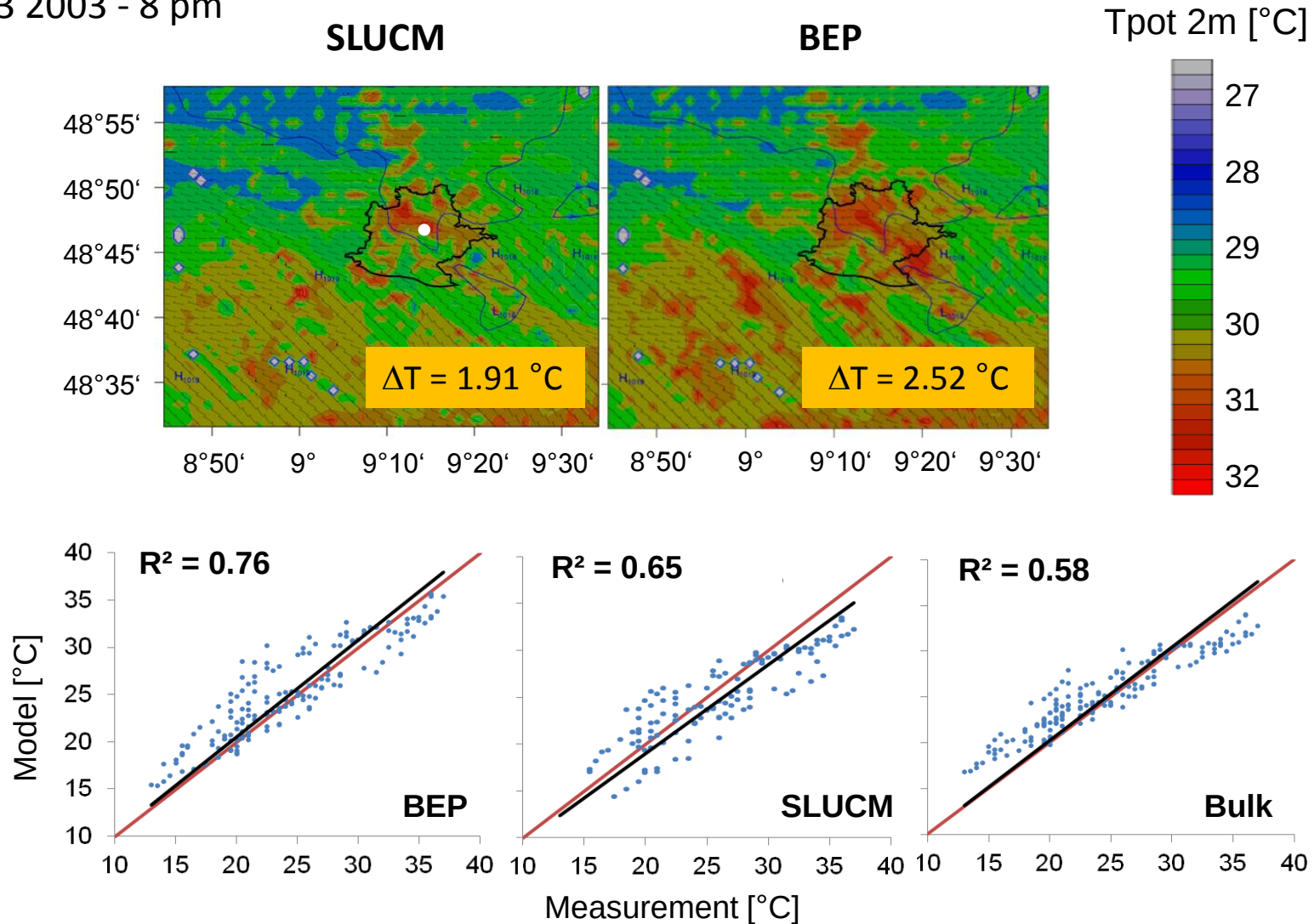


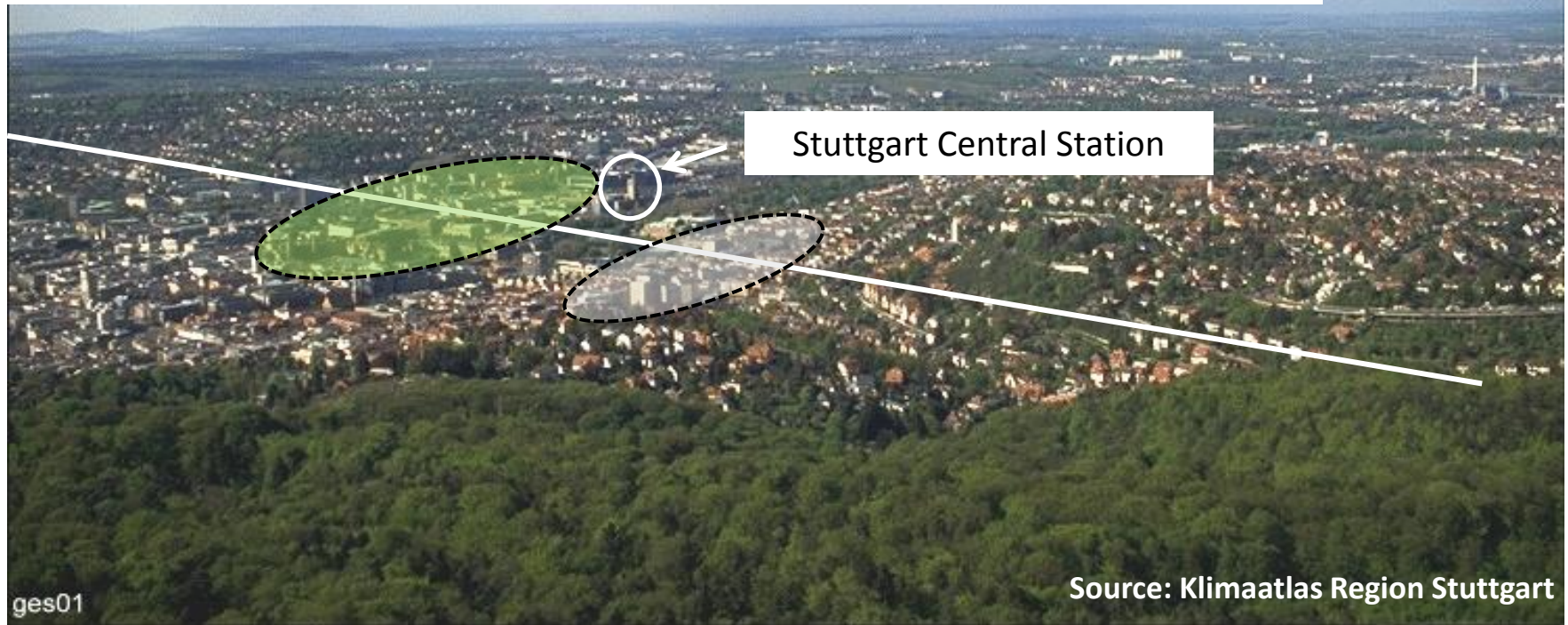
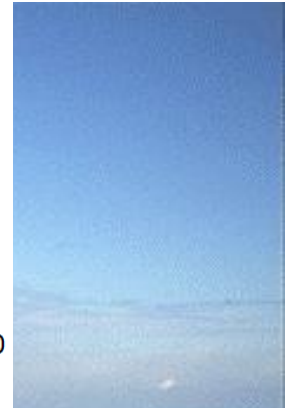
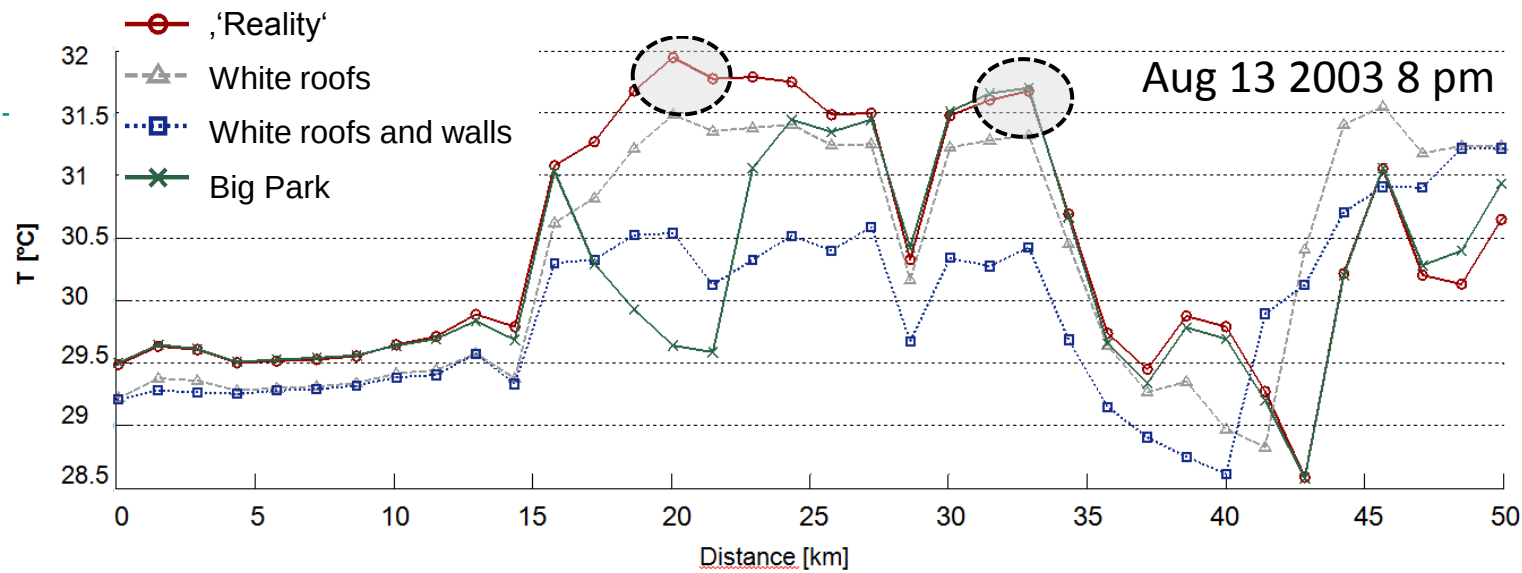
200 grid cells:
45 % ,Urban'

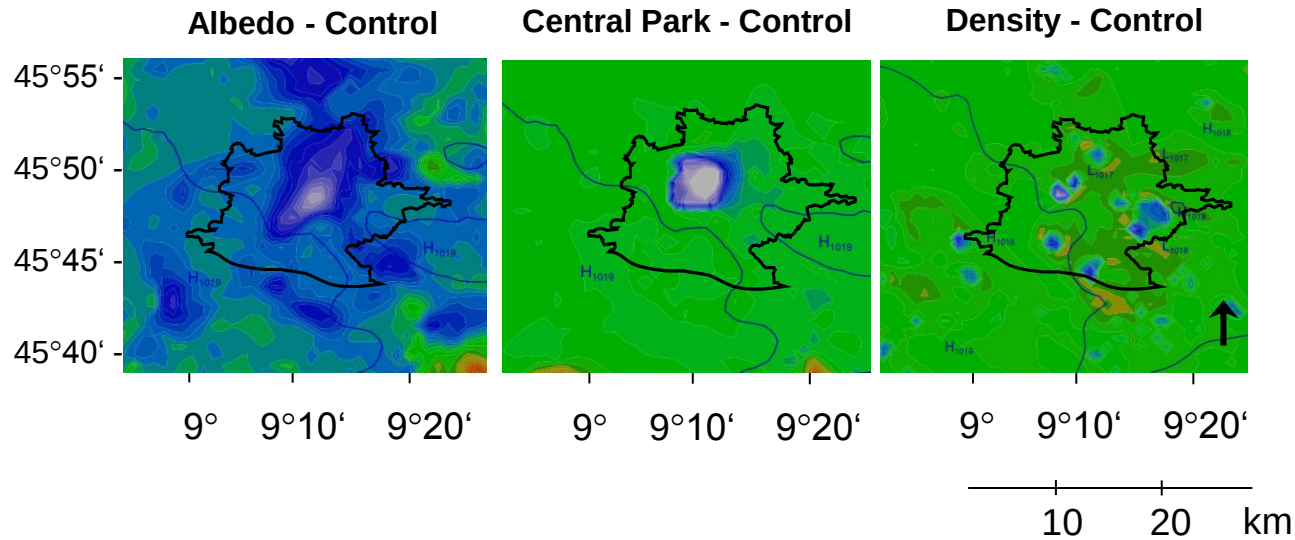


Model evaluation – Point vs. Pixel

Aug 13 2003 - 8 pm

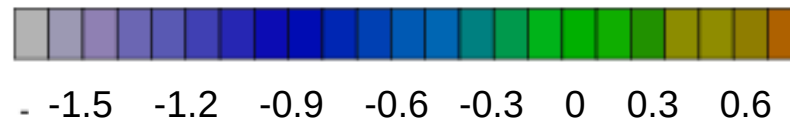






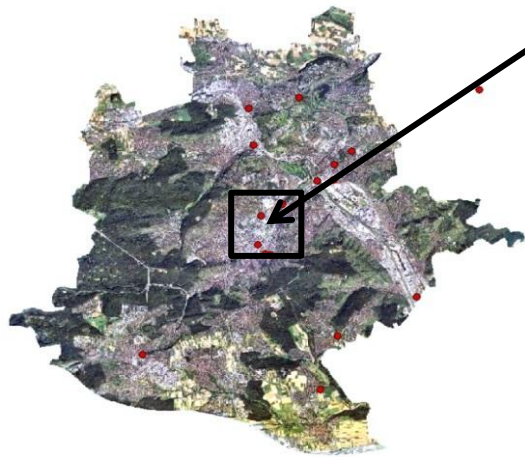
Aug 13 2003 8 pm

Δ 2m potential air temperature [°C]



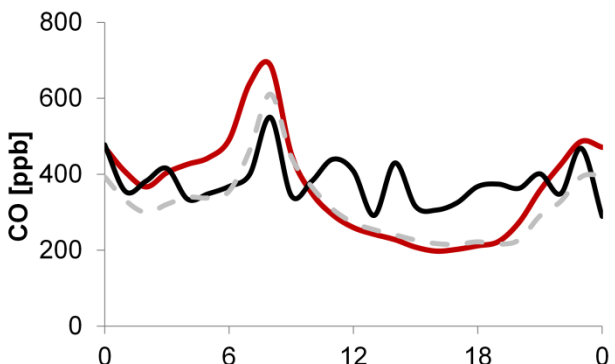
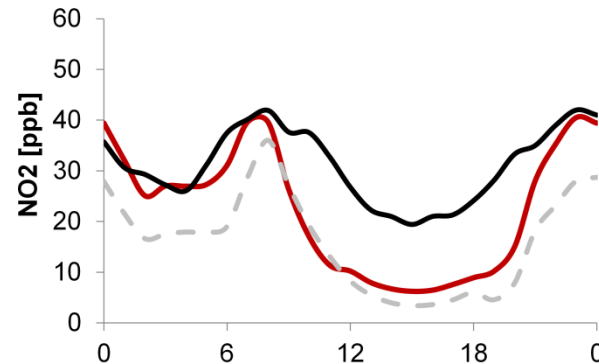
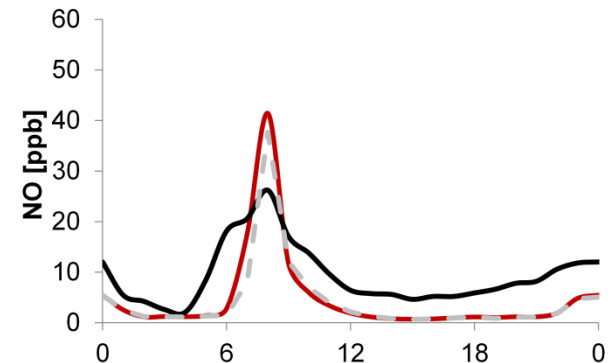
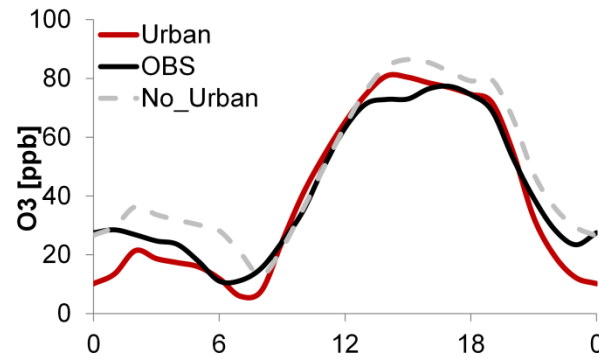
(Fallmann et al. 2014)

Model evaluation – point vs. grid cell



• Observation

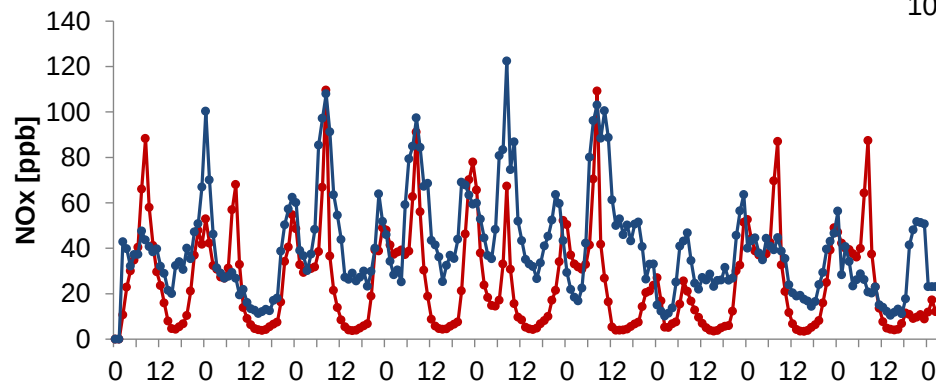
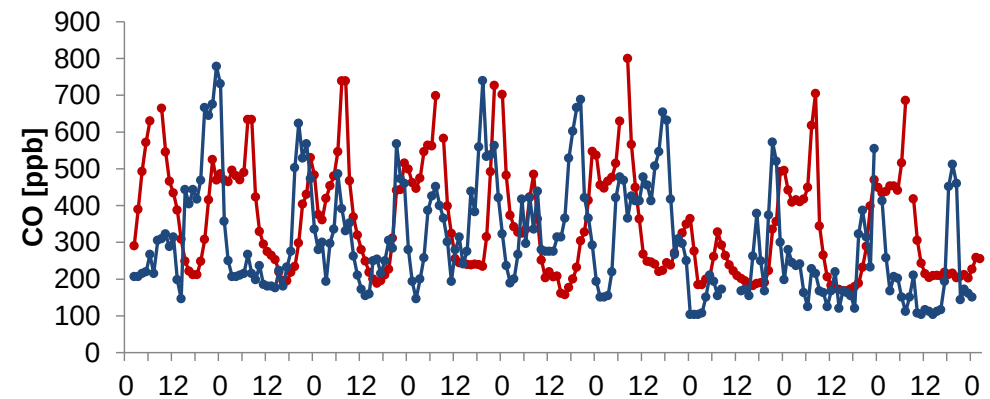
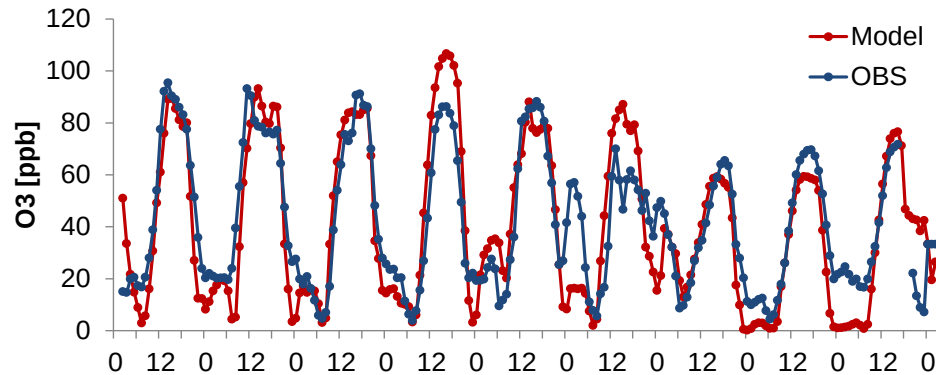
WRF-Chem grid cell



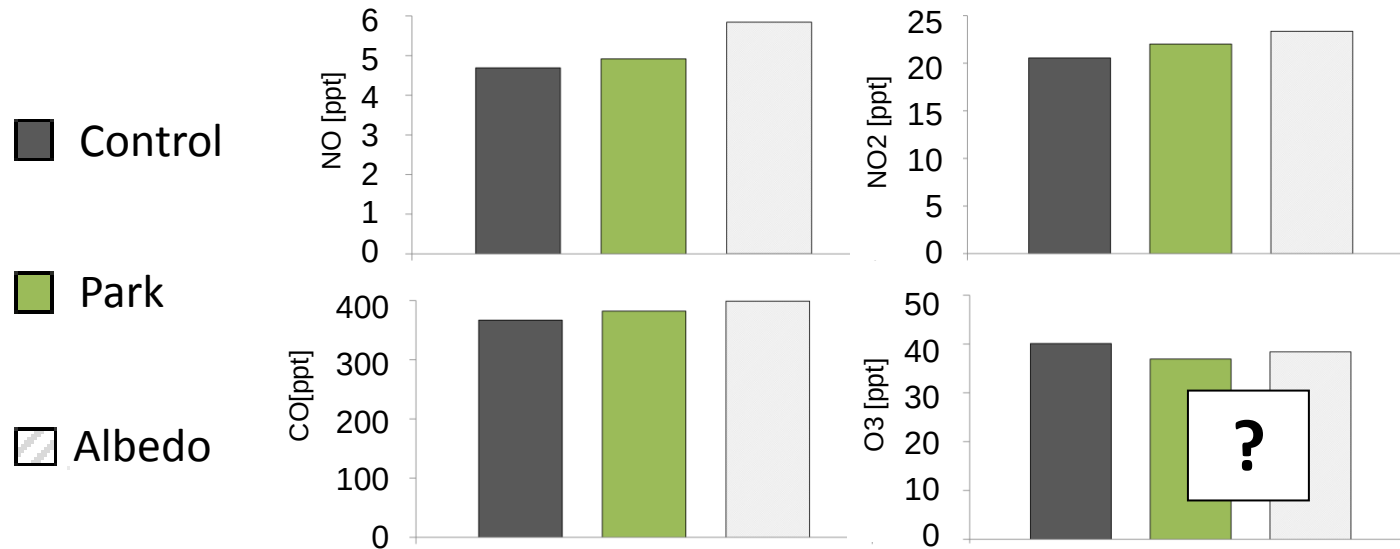
Mean over 3 Stations:

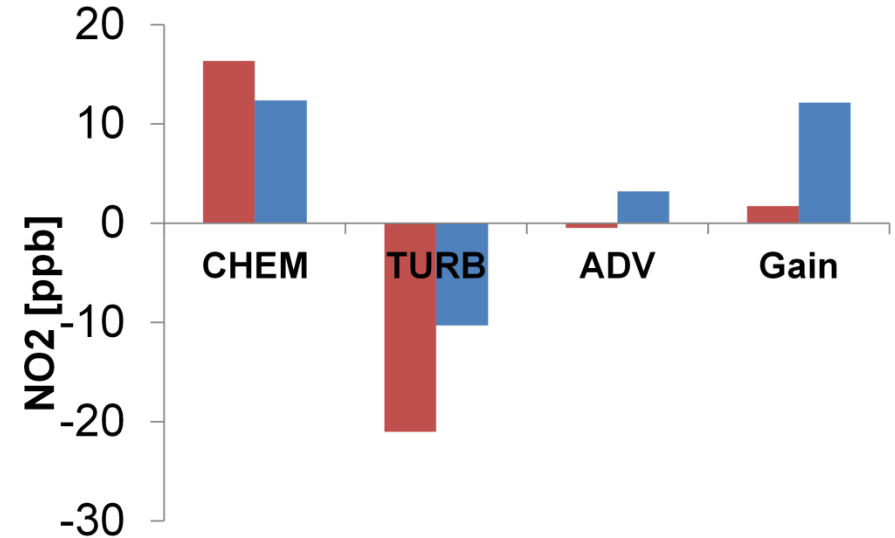
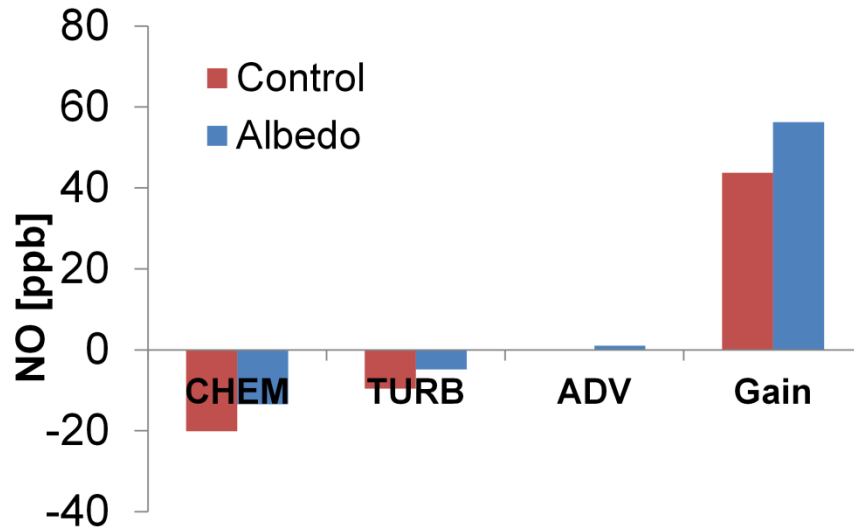
- Bad Cannstadt
- Schwabenzentrum
- Mitte – Arnulf-Klett Platz

Model evaluation – point vs. grid cell

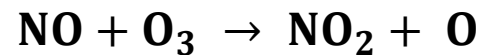
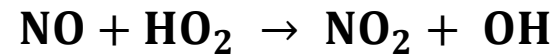


Mean concentration for modelling period

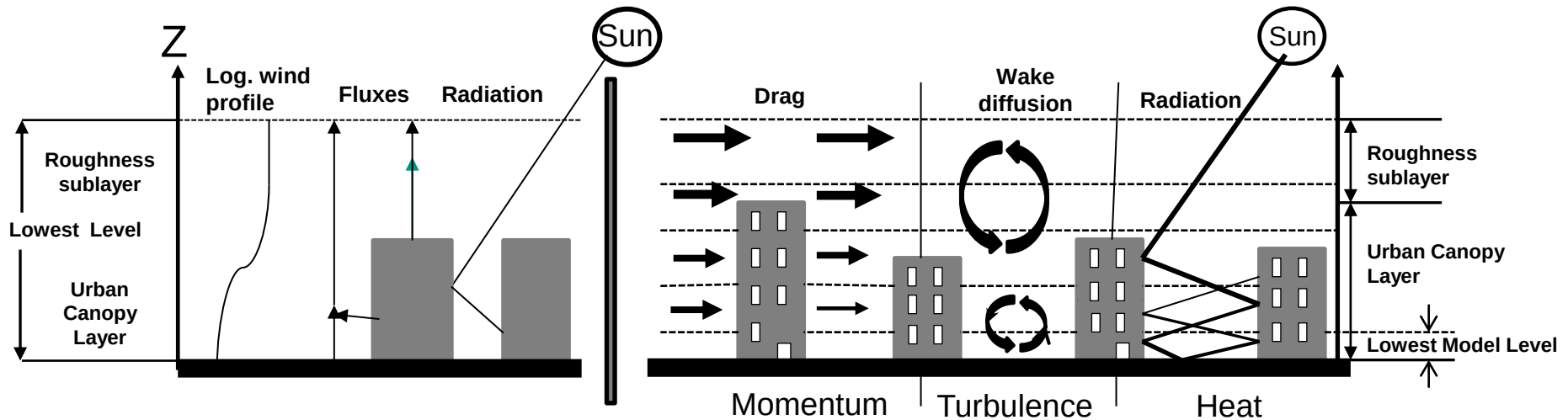




NO_x-Cycle



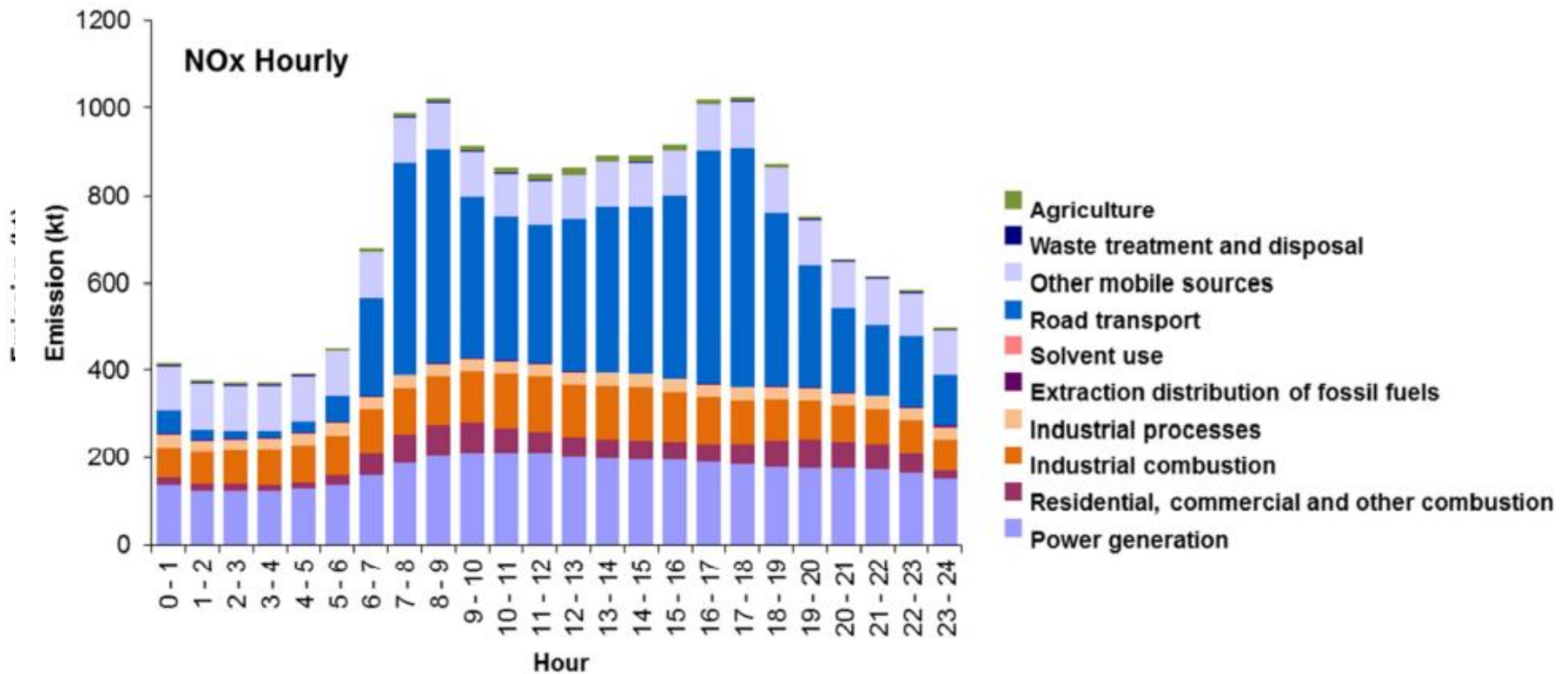
Urban Canopy Model



**Single Layer Urban
Canopy Model**
(Kusaka 2001)

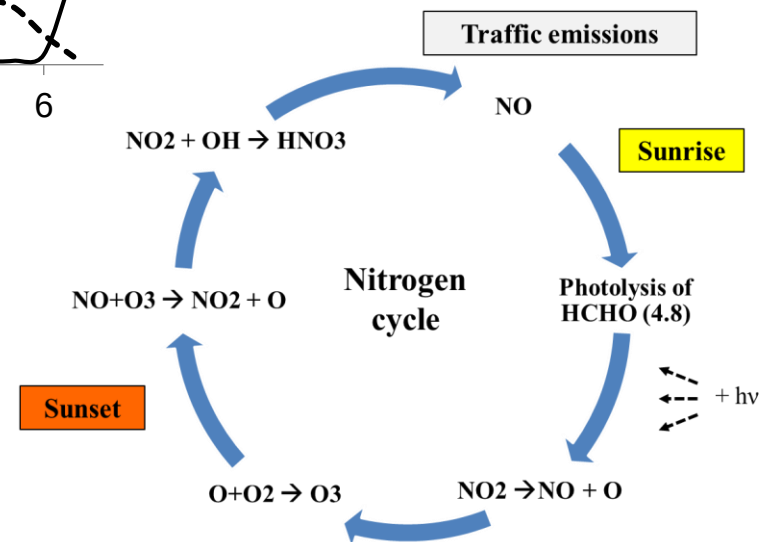
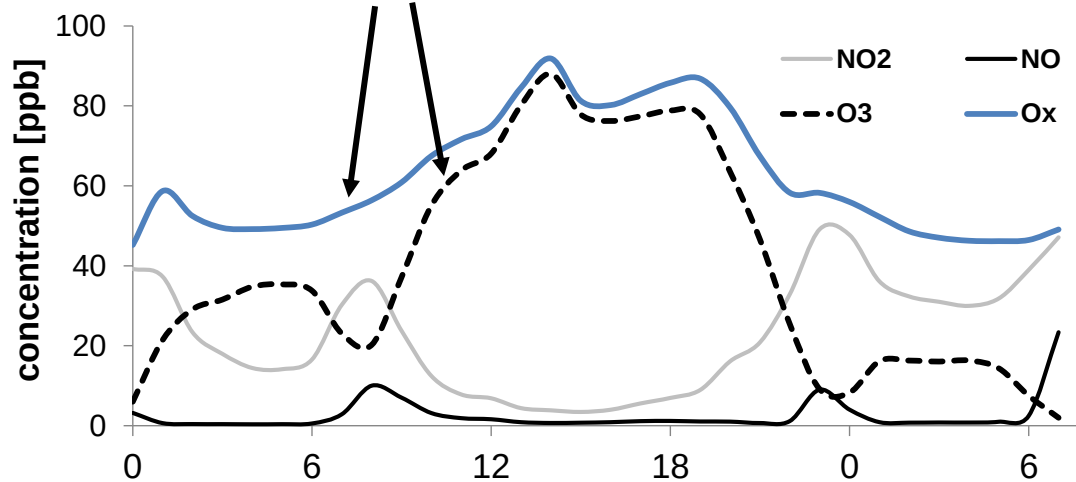
Building Effect Parameterization
(Martilli 2002)

Changed from Chen (2011)

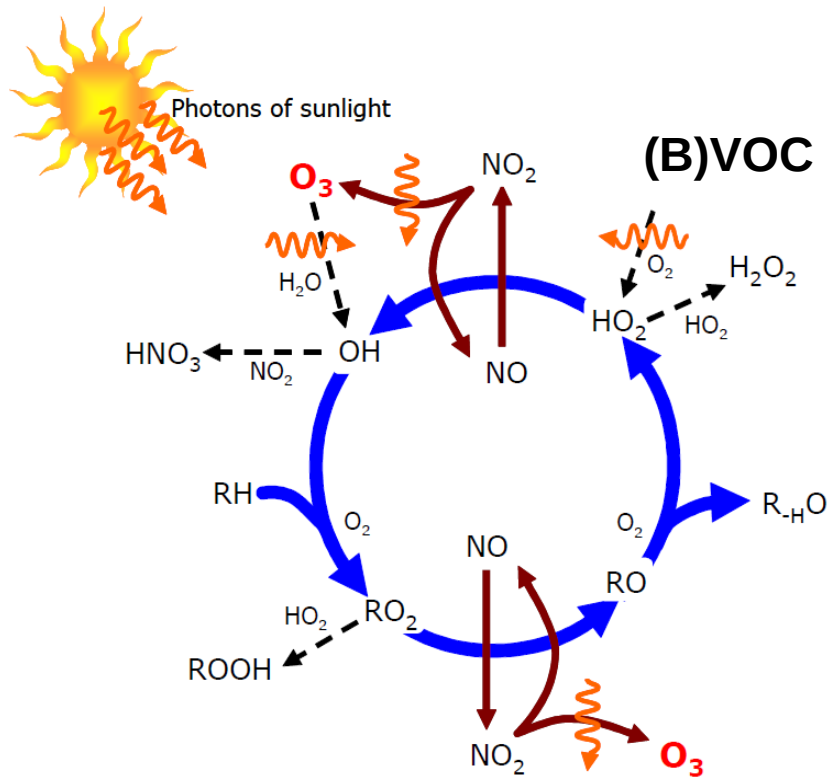


The nitrogen cycle – photochemical reactions

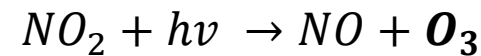
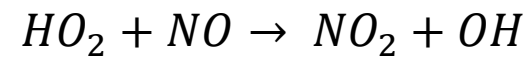
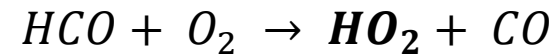
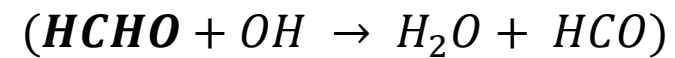
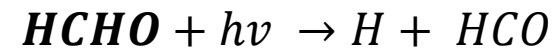
+ Advection and vertical transport from higher layers

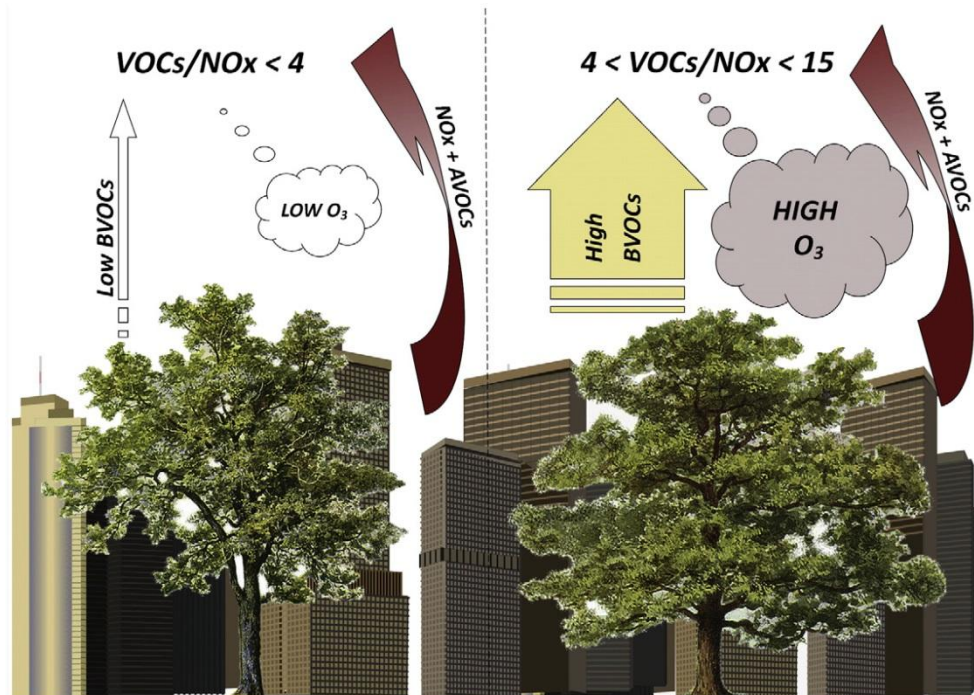


Biogene Emissionen als Vorläufer für Photosmog



Photolyse bzw. Oxidation von VOC





- 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 $\text{VOC}/\text{NO}_x < 4$
 - Optimum für O₃ Prod.:
 $15 < \text{VOC}/\text{NO}_x < 4$
 - NO_x-limitiert $\text{VOC}/\text{NO}_x < 15$

Urban Plume

