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

Dr. Joachim Fallmann

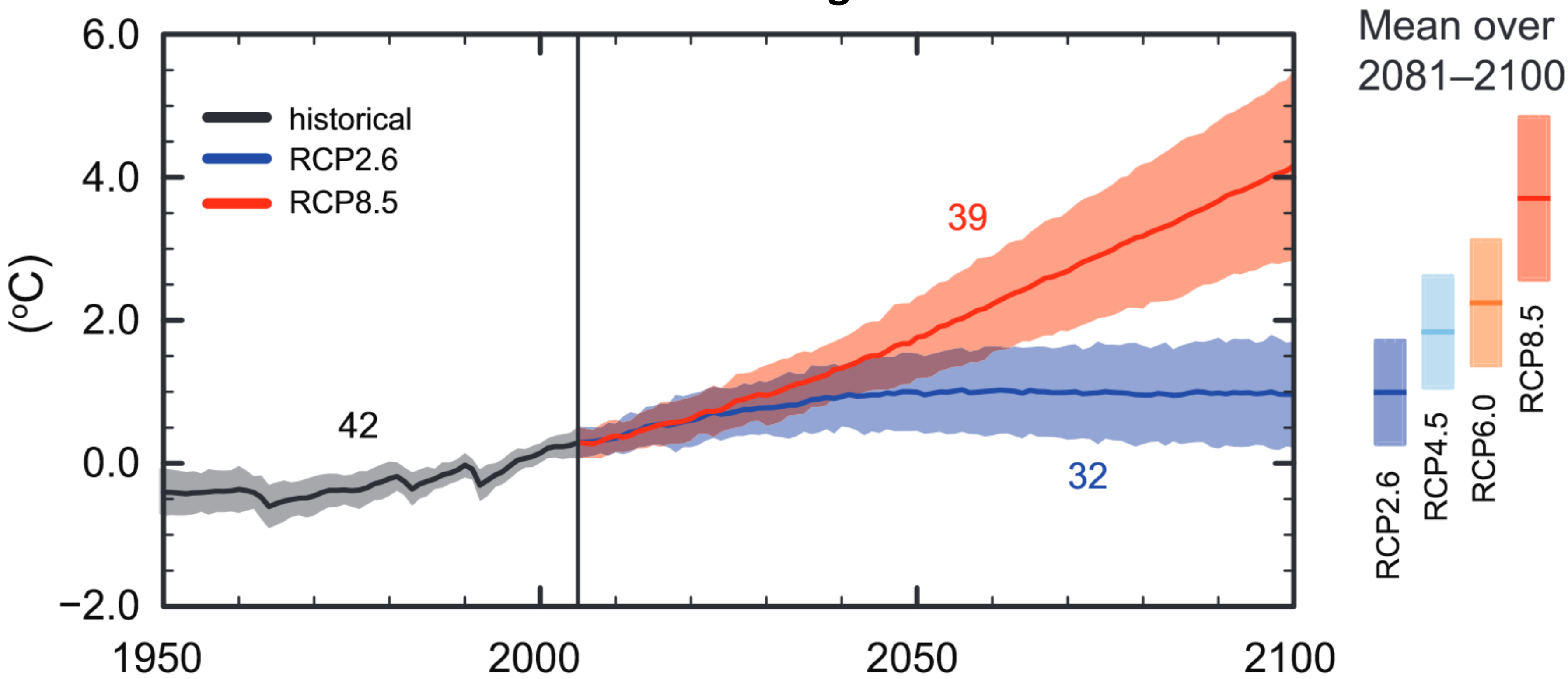
joachim.fallmann@kit.edu

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

The global scale

“2050: over 70% of people on earth will reside in cities [...]” (UN 2011)

Climate Change

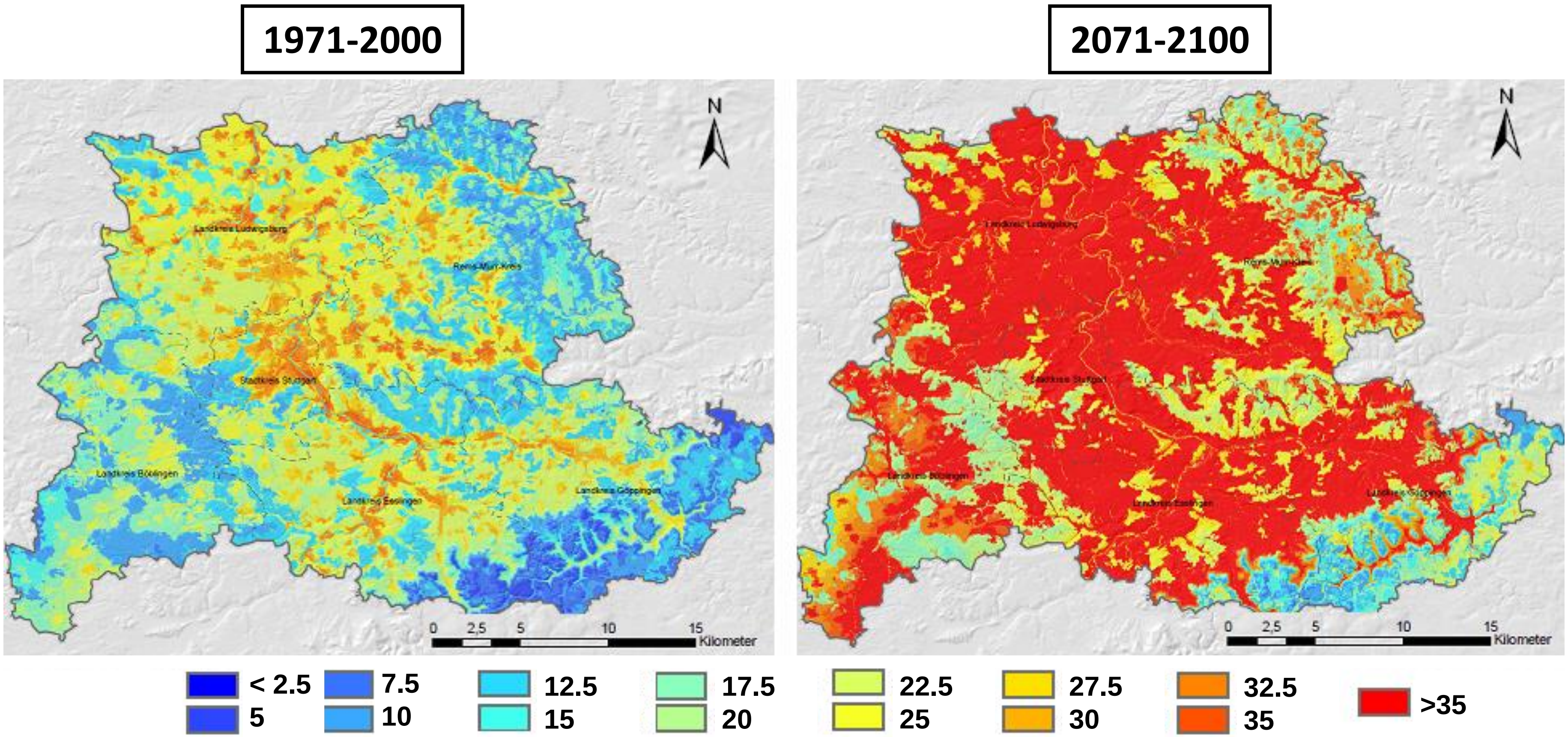


Source: IPCC AR5

joachim.fallmann@kit.edu

Heat stress in urban areas

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



Source: Klimaatlas Region Stuttgart

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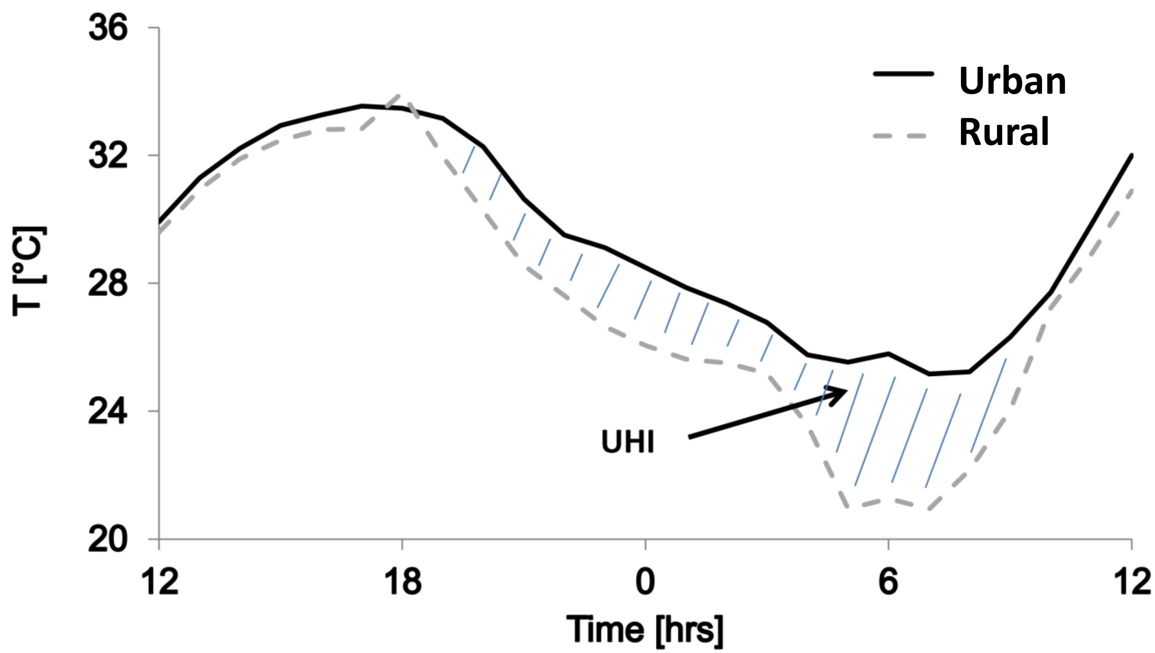
The Urban Heat Island

Observations Stuttgart



IPCC AR5: "[…] the relative warmth of a city compared with surrounding rural areas, […] changes in runoff, effects on heat retention, and changes in surface albedo […]"

joachim.fallmann@kit.edu

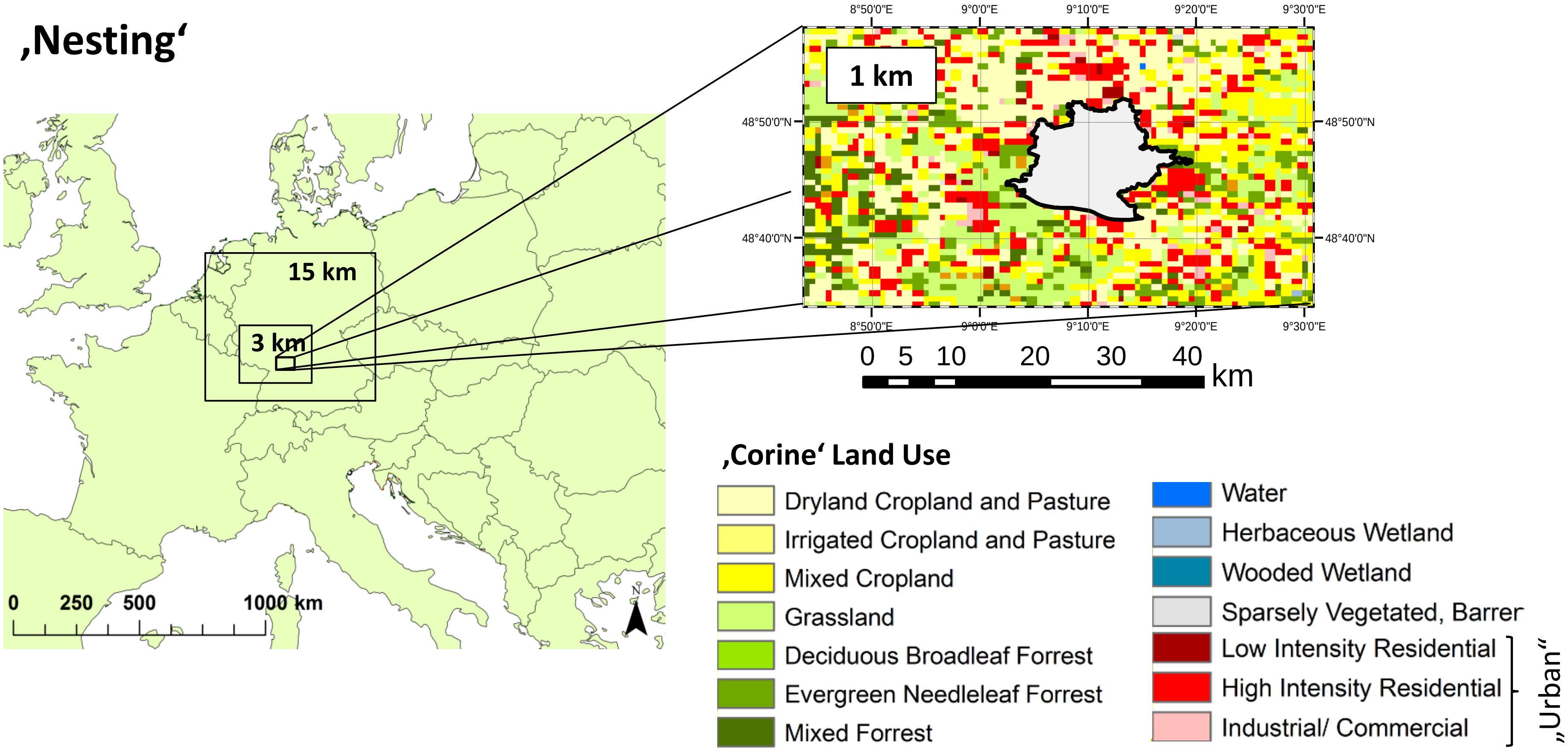
Basic questions

➡ **UHI mitigation strategies ?**

www.stadtklima-stuttgart.de

Modelling of the Urban Heat Island (WRF)

‚Nesting'



- Initial- und dynamical boundary conditions: ***ERA-Interim 0.5°*** Reanalysis
- Lower boundary conditions: ***NOAH LSM***
- Modelling time frame**: Aug 8 – Aug 18 2003**

joachim.fallmann@kit.edu

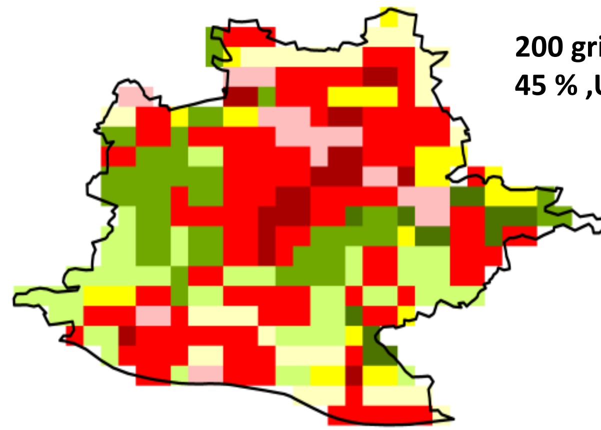
Classifying urban land use in the model

33: Industrial/ Commercial

32: High Density Residential

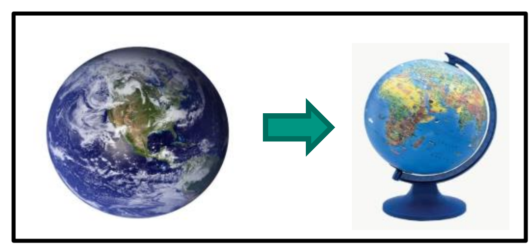
31: Low Density Residential

WRF Landuse



200 grid cells:
45 % ‚Urban‘

- Low Density Residental
- High Density Residential
- Industrial/Commercial



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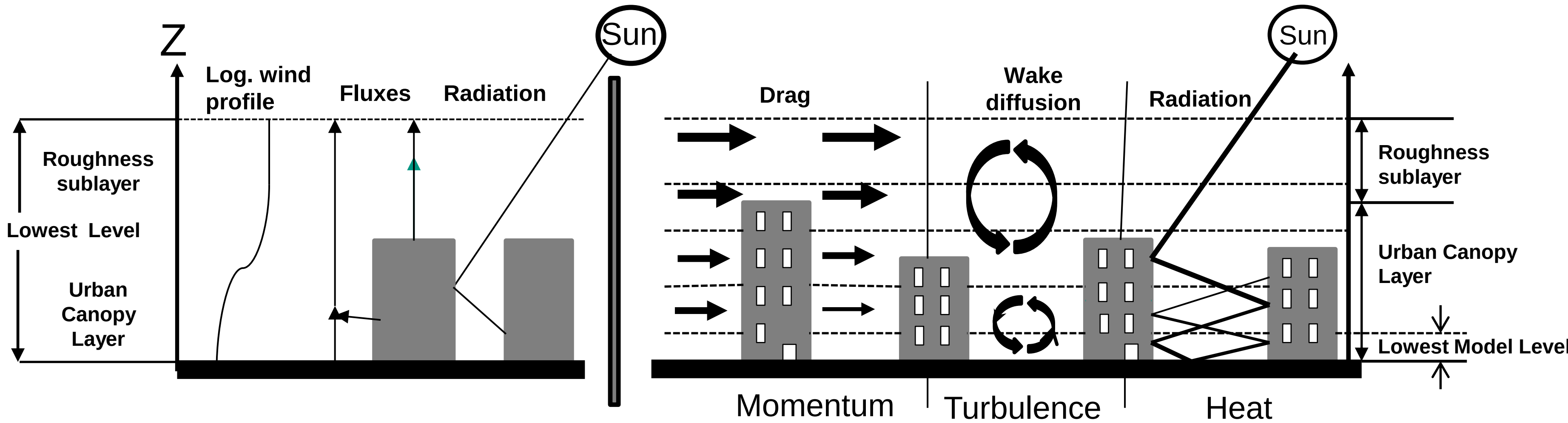
Urban Canopy Model



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

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

Changed from Chen (2011)

joachim.fallmann@kit.edu

Urban Parameter Table

Karlsruhe Institute of Technology

Urban Parameter	33	32	31
ZR: Roof level (building height) [m]	8.5	9.7	6.4
SIGMA_ZED: Standard Deviation o[illegible]	6.8	6.4	4.5
ROOF_WIDTH: Roof (i.e., building[illegible]	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[illegible] [J m³/ K]	1.00E+06	1.00E+06	1.00E+06
CAPB: Heat capacity of [illegible] [J m³/ K]	1.00E+06	1.00E+06	1.00E+06
CAPG: Heat capacity of grou[illegible] ³/ K]	1.40E+06	1.40E+06	1.40E+06
AKSR: Thermal conductivity of roof [[illegible]	0.67	0.67	0.67
AKSB: Thermal conductivity of building wa[illegible]	0.67	0.67	0.67
AKSG: Thermal conductivity of ground (road) [J /m[illegible]	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[illegible] [index]	[illegible]direction [illegible]N]	street width [m]	building width [m]
33	[illegible]	19	25
33	90	19	25
32	0	[illegible]	13
32	90	[illegible]	13
31	0	18	10
31	90	18	10

Road network

Building Heights

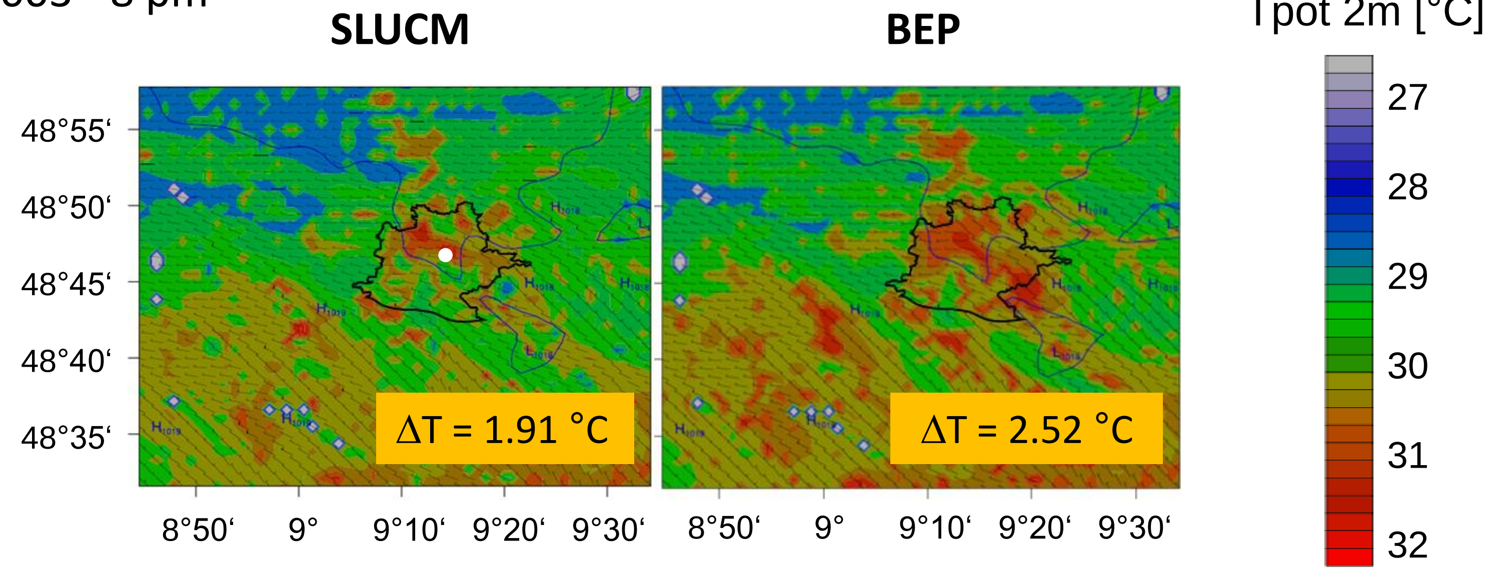
height [m]	33 P[illegible]e [%]	32 Percentage [%]	31 Percentage [%]
5	[illegible]	33	48
10	20	20	37
15	14	[illegible]	11
20	8	[illegible]	3
25	4	[illegible]	1
30	2	2	
35	2		

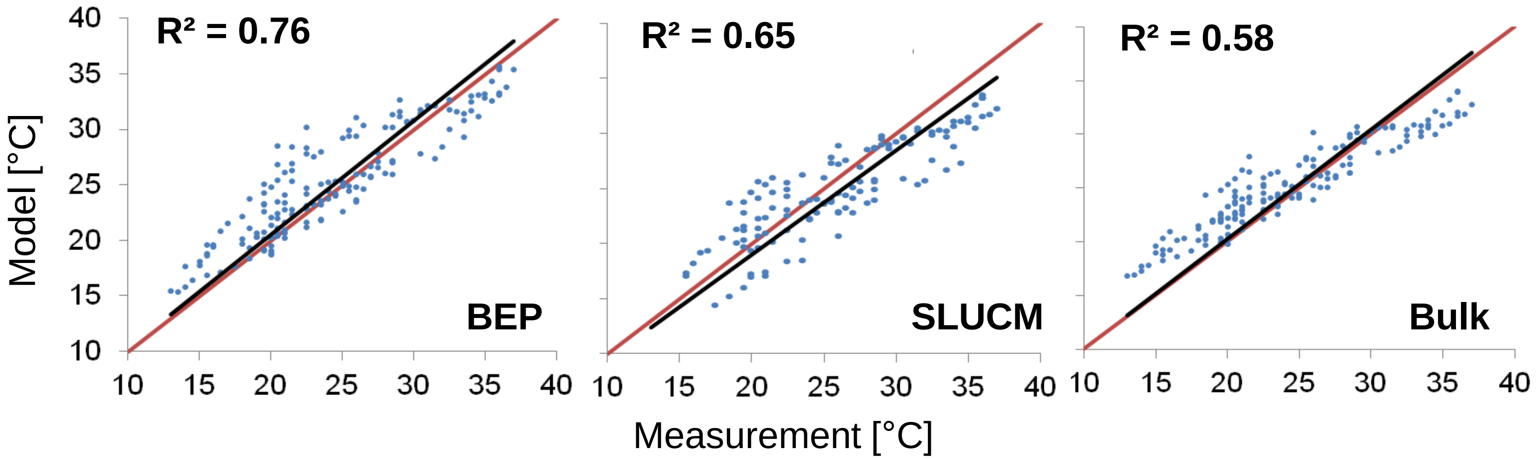
Building properties

joachim.fallmann@kit.edu

Model evaluation – Point vs. Pixel

Aug 13 2003 - 8 pm





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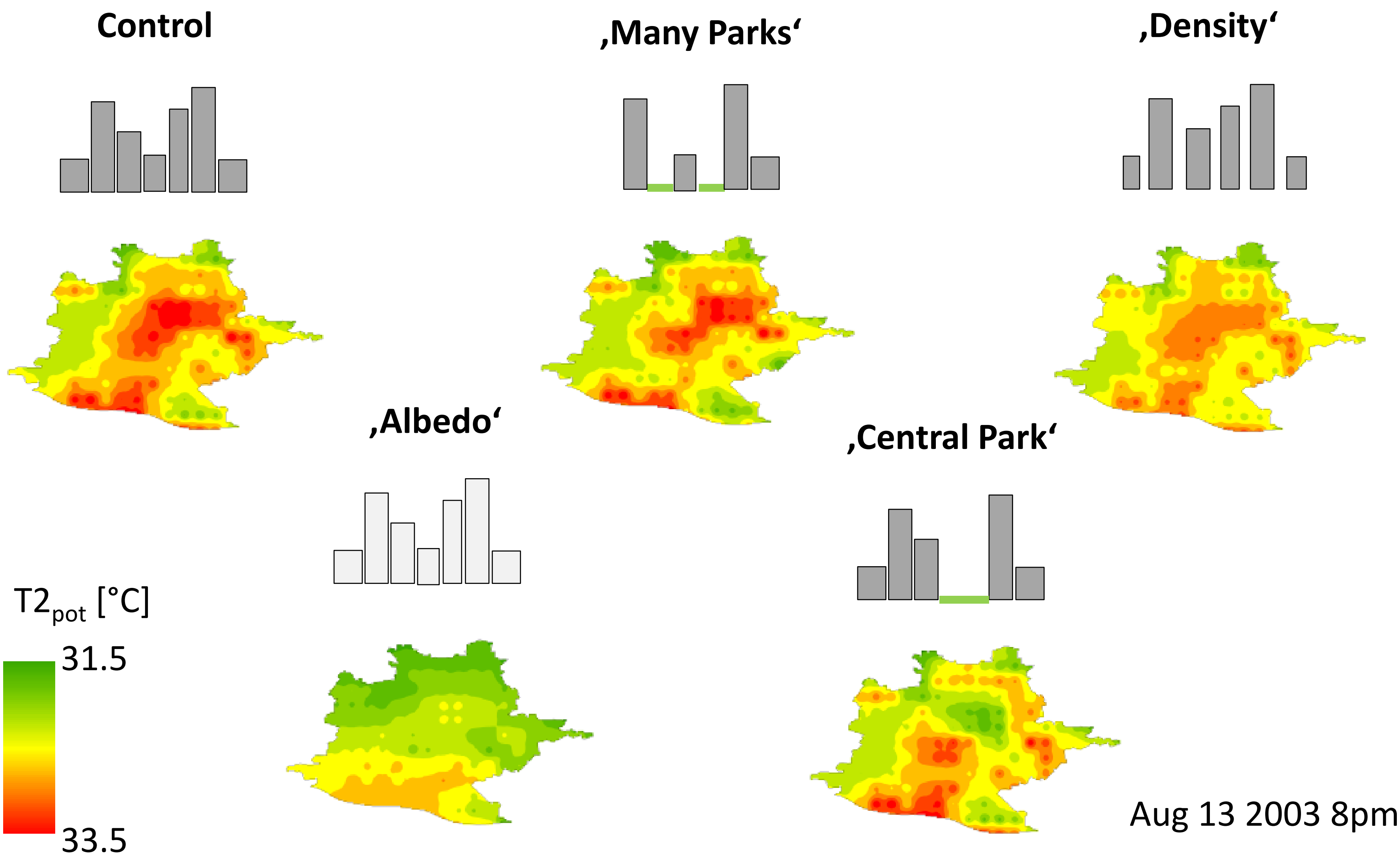
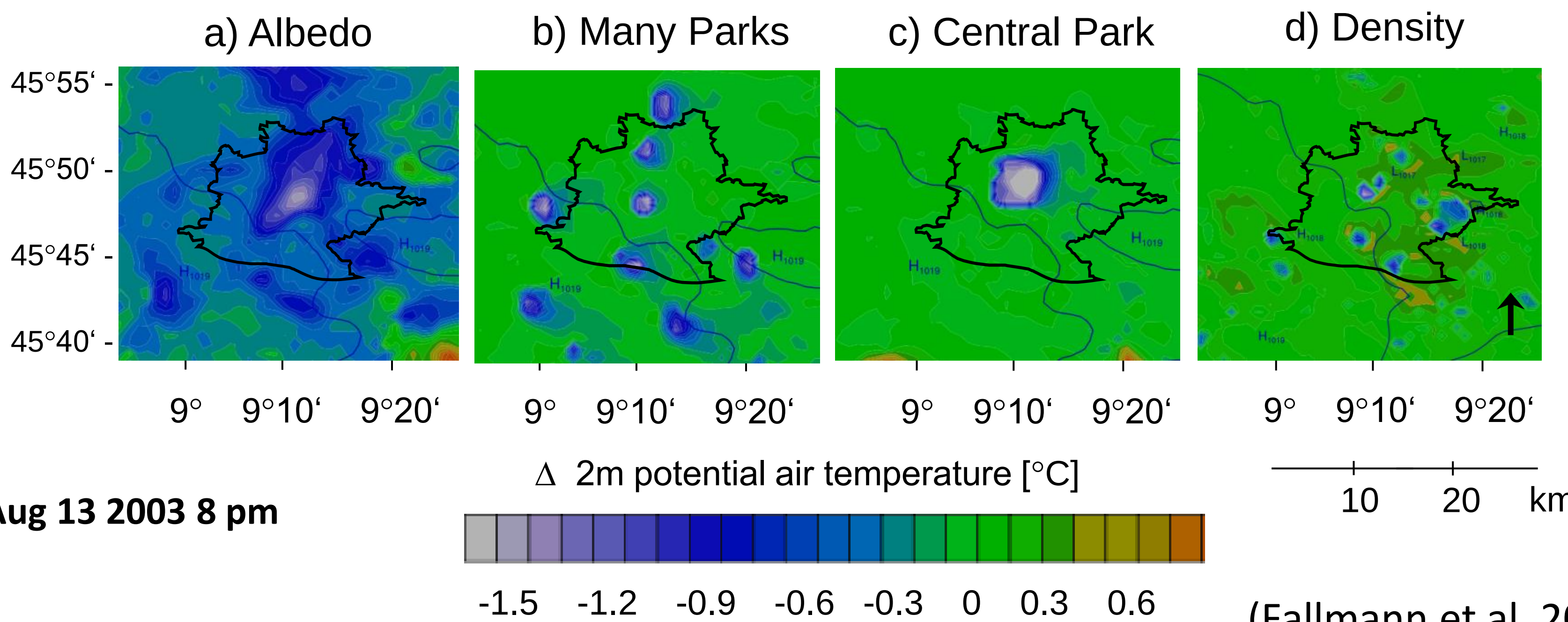
UHI mitigation scenarios



Urban Heat Island Intensity

Aug 13 2003 8 pm

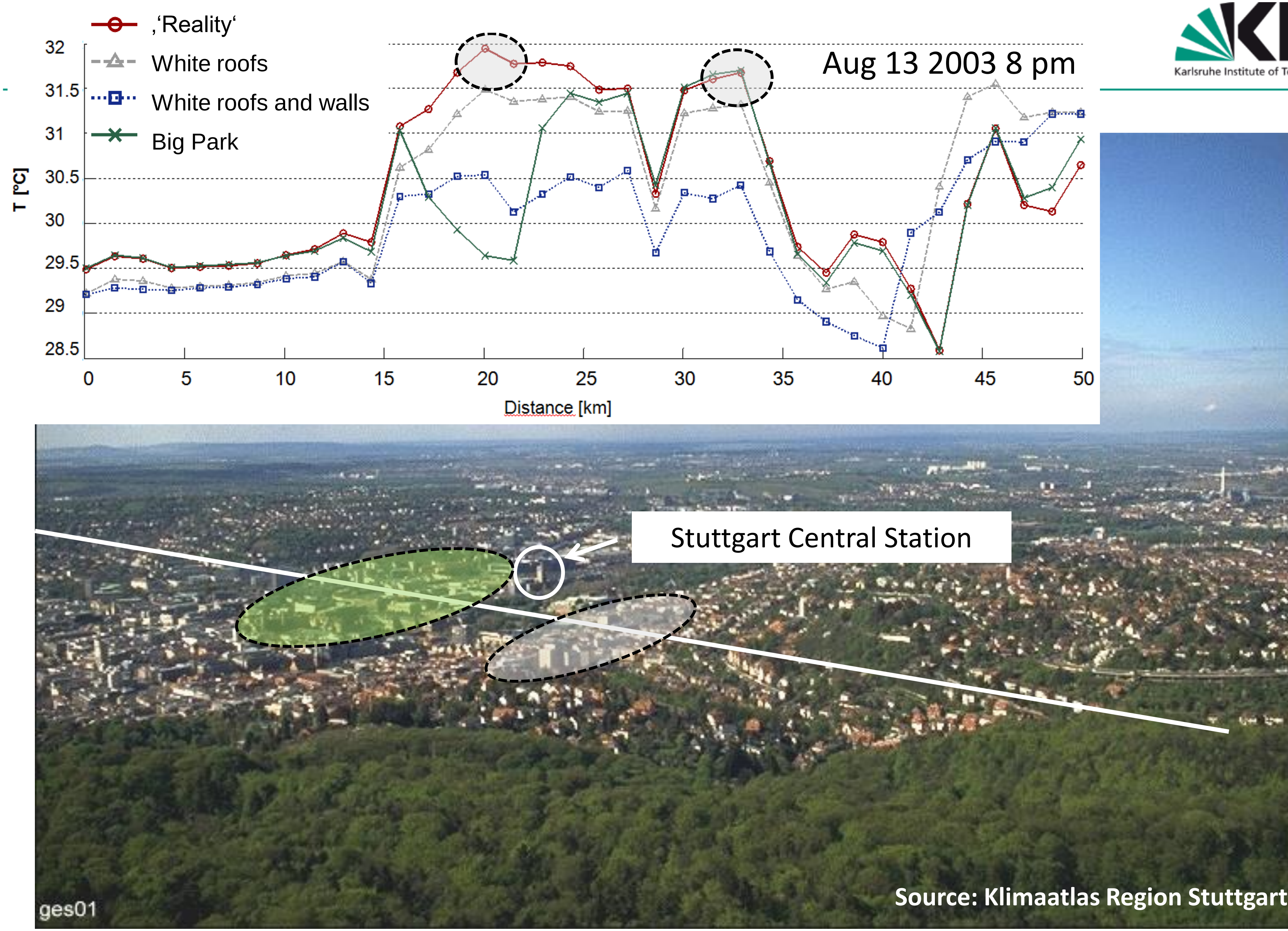


(Fallmann et al. 2014)

T (Urban) – T (Rural)

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

joachim.fallmann@kit.edu

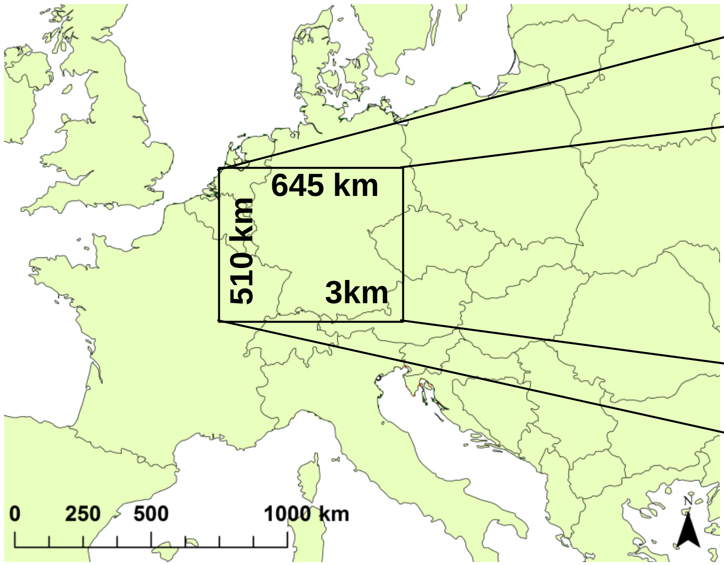


joachim.fallmann@kit.edu

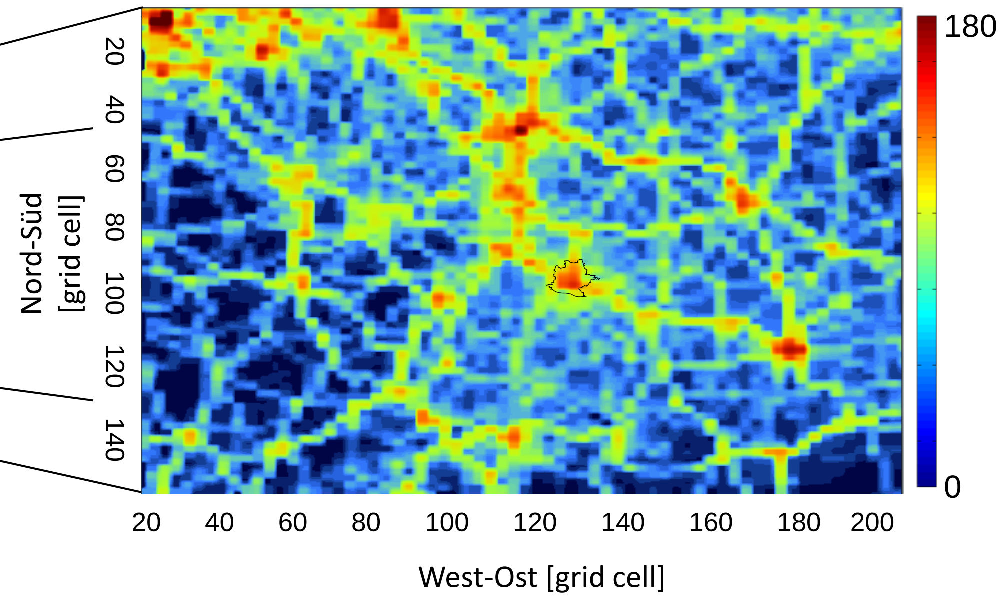

And now?

Air Quality modelling (WRF-Chem)

WRF-Chem Domain

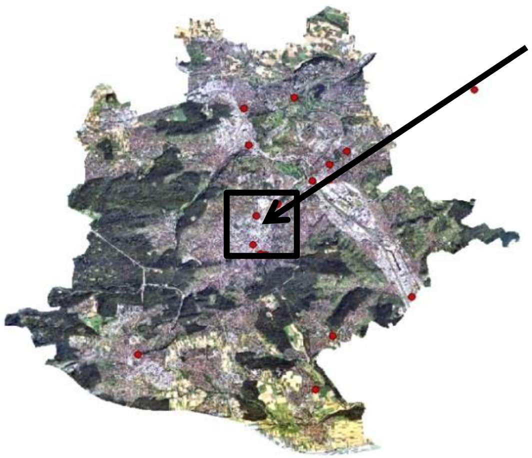


NO- Emissions

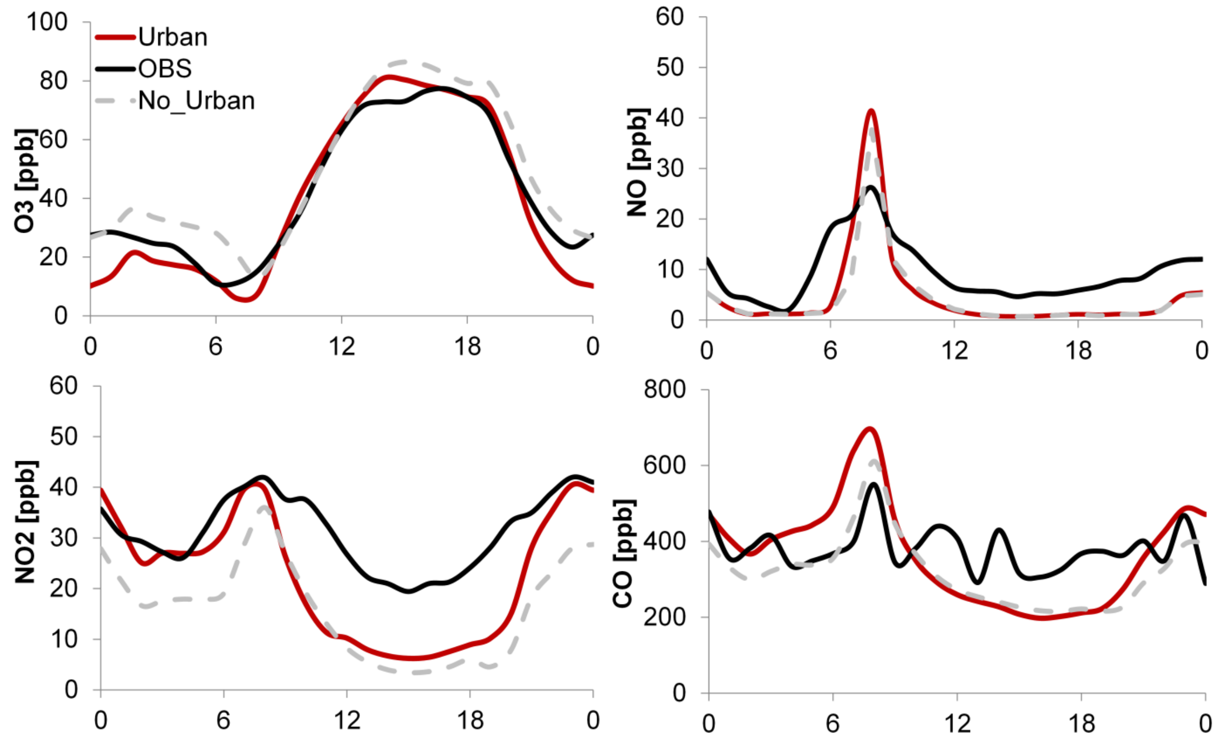


- Initial- and dynamical boundary conditions from global model ***MOZART*** *(anthropogenic)* **und** ***MEGAN*** *(biogenic)*
- Lower boundary conditions ***MACC Emissions 2003-2007***
- Modeled time frame: Aug **9 – Aug 18 2003**

Model evaluation – point vs. grid cell



WRF-Chem grid cell



• Observation

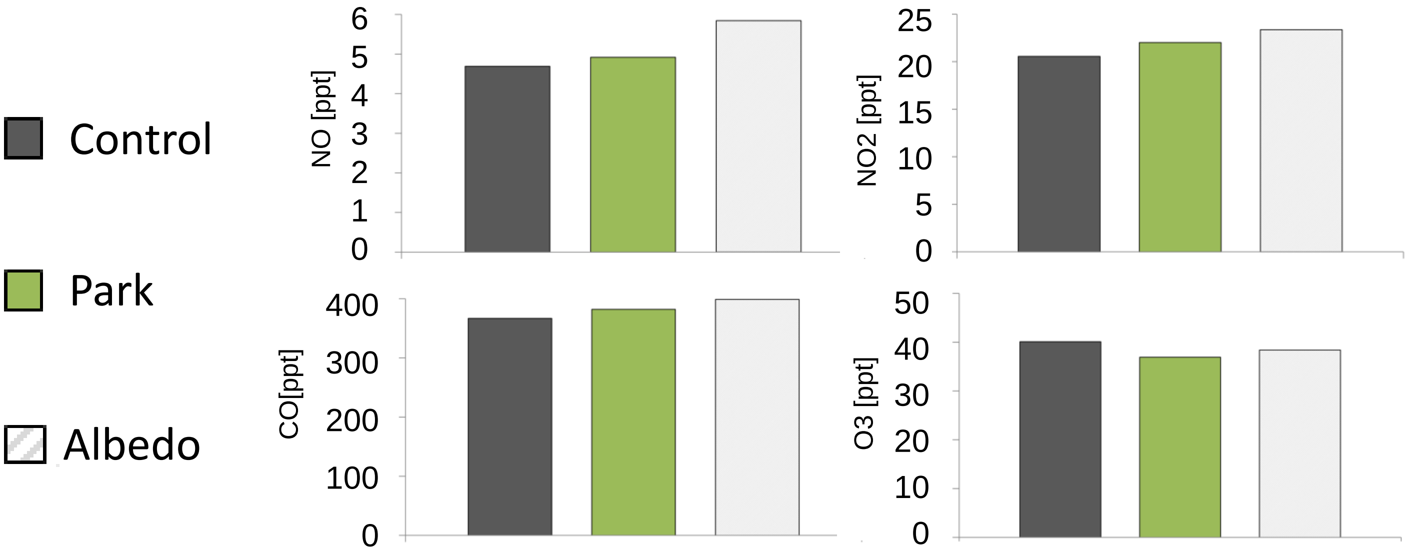
Mean over 3 Stations:

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

joachim.fallmann@kit.edu

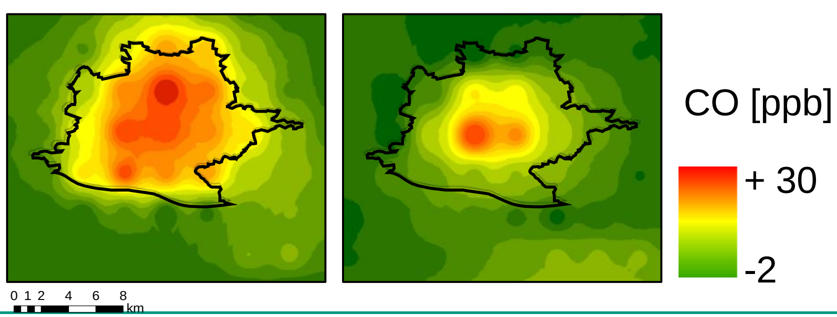
Effect on near surface mixing ratios

Mean concentration for modelling period



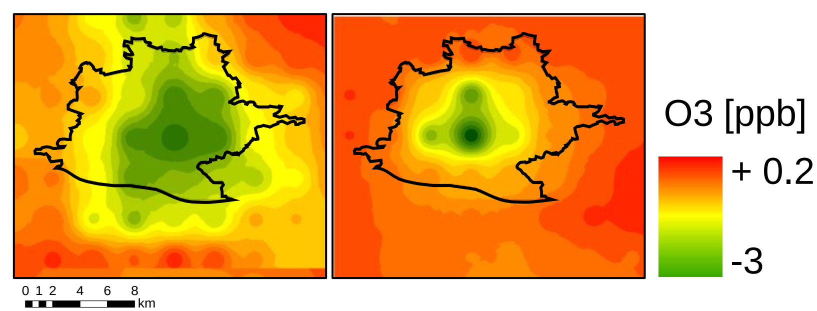
Primary pollutants (e.g. CO)

‚Albedo' ‚Park'



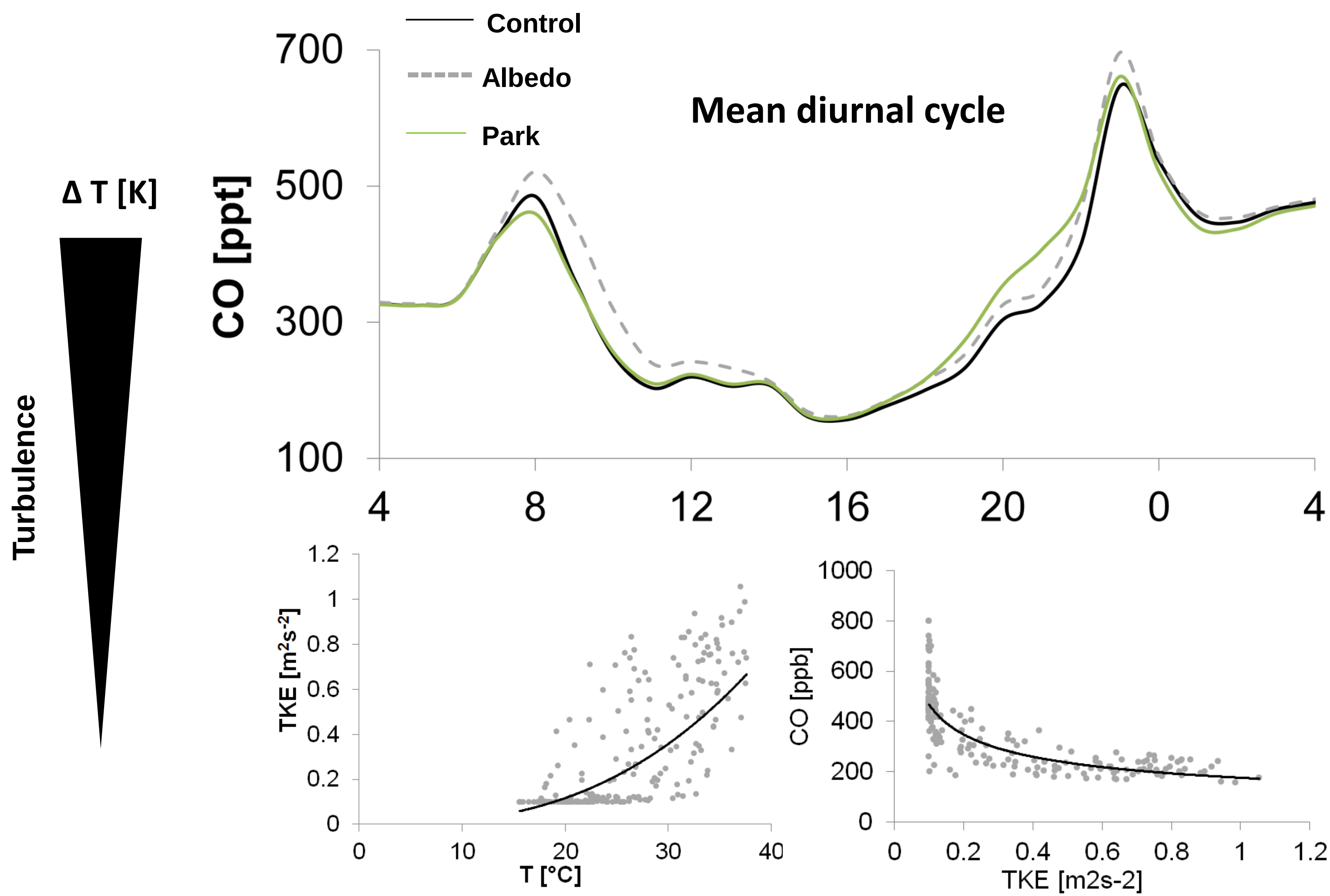
Secondary pollutants (e.g. O3)

‚Albedo' ‚Park'



 joachim.fallmann@kit.edu

Primary pollutants(CO, NO) – Atmospheric dynamics



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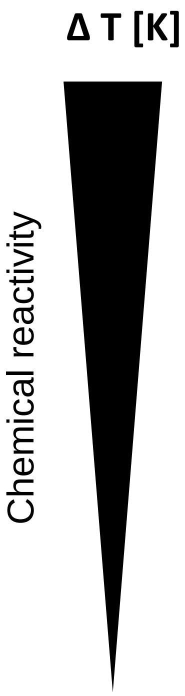
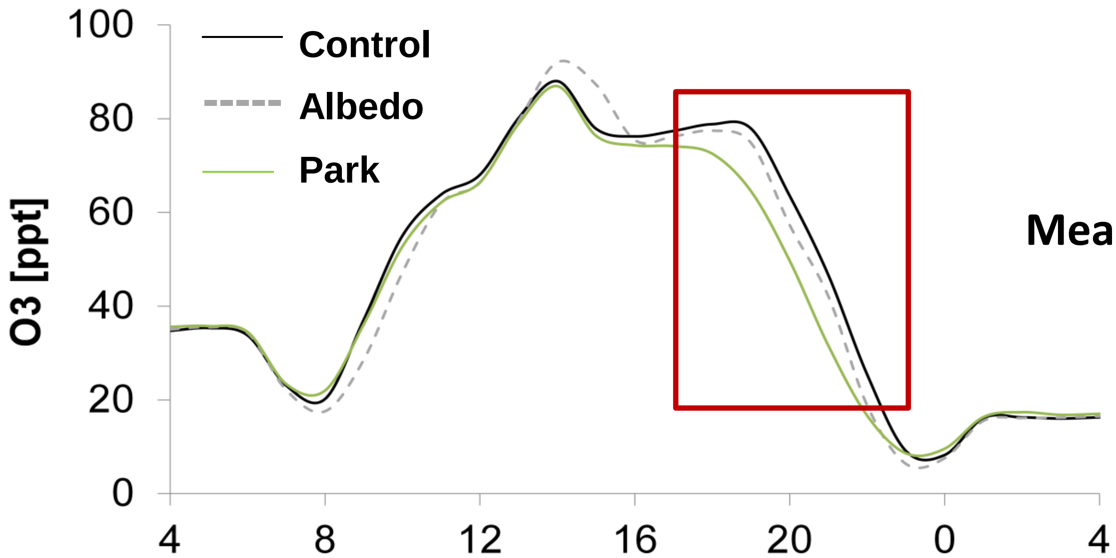
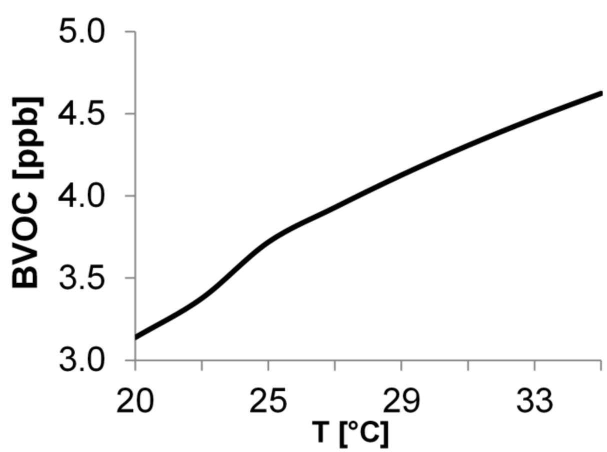
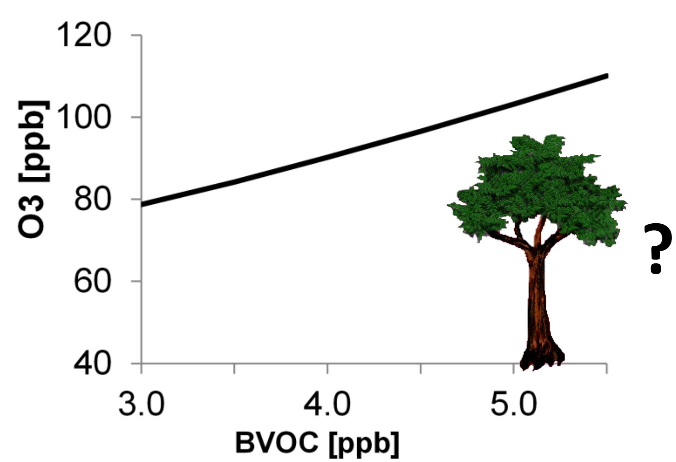
Secondary pollutants (Ozone) – Chemical reactivity





Mean diurnal cycle

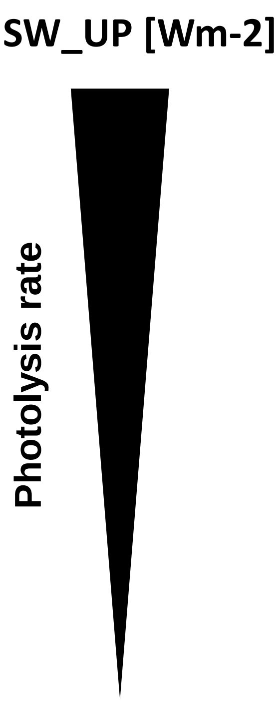


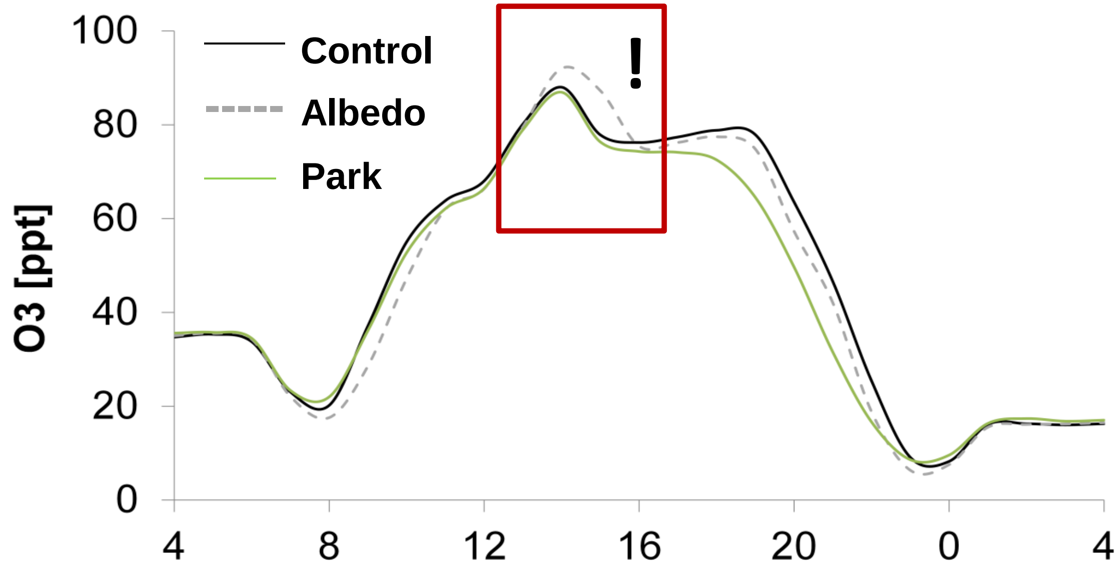


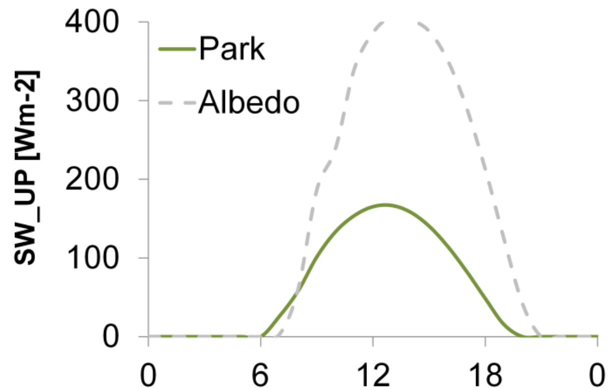
RADM boxmodel
(Stockwell 1988)

 joachim.fallmann@kit.edu

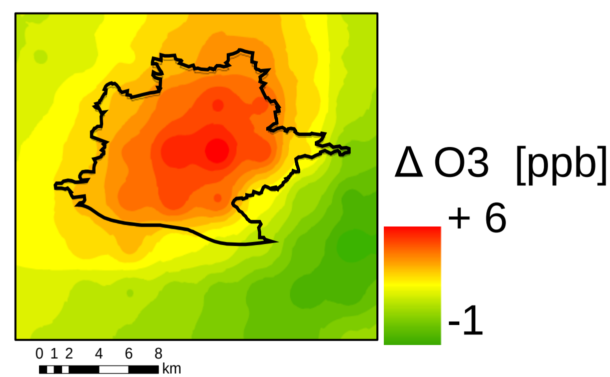
Secundary pollutants (Ozone) - Photolysis







Ozone (3 pm)



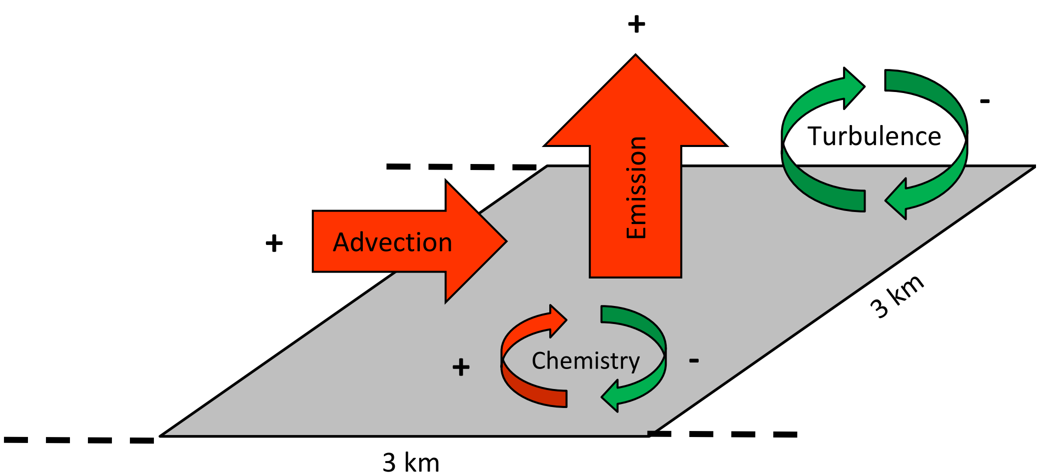
joachim.fallmann@kit.edu

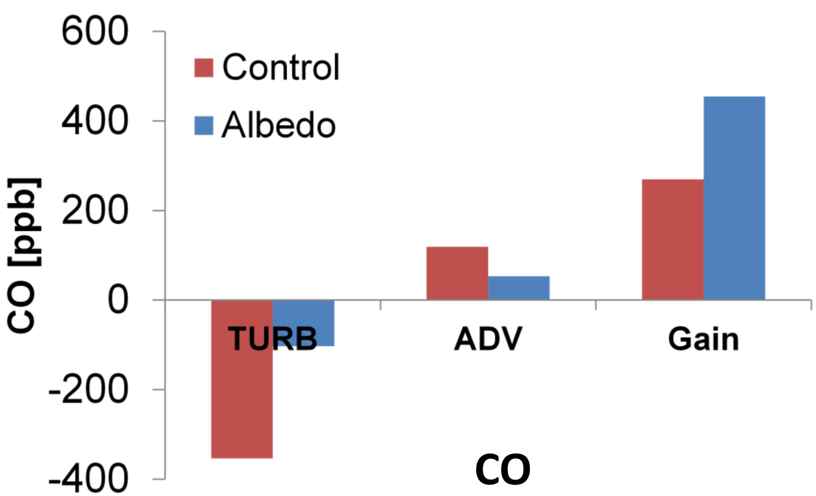
Quantification via tendency terms

- 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:

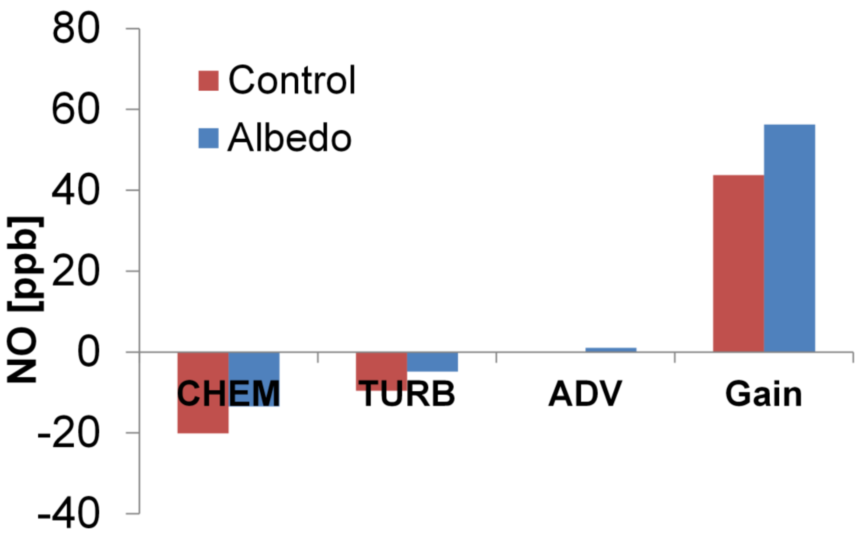
Gewinn/Verlust = EMIS + CHEM + TURB + ADV

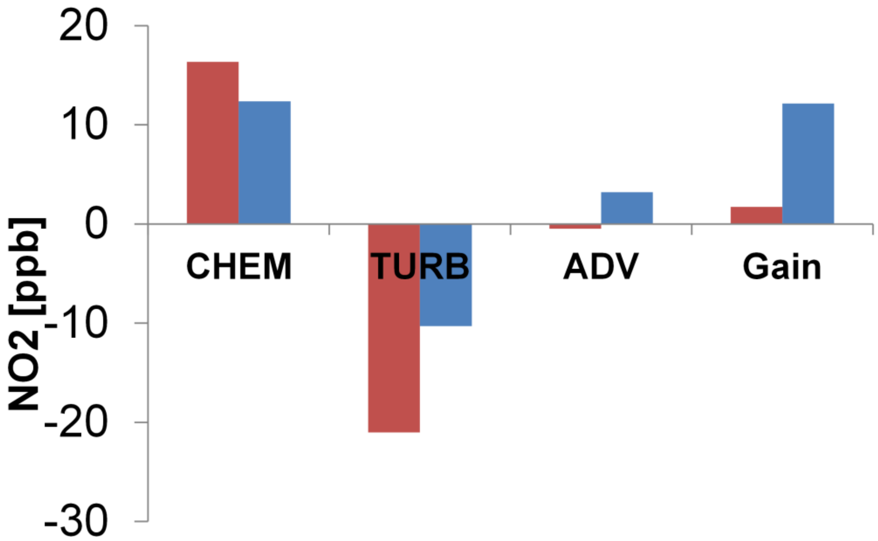




joachim.fallmann@kit.edu

NO and NO2



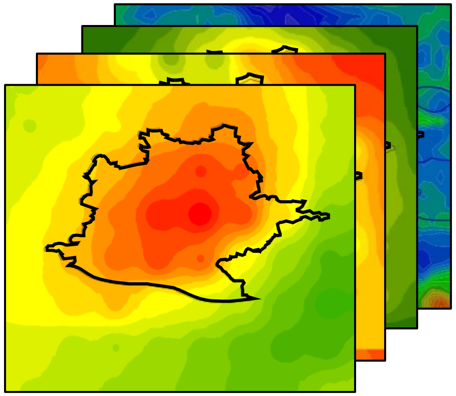


NOx-Cycle

$$\mathbf{NO + HO_2 \rightarrow NO_2 + OH}$$

$$\mathbf{NO + O_3 \rightarrow NO_2 + O}$$

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

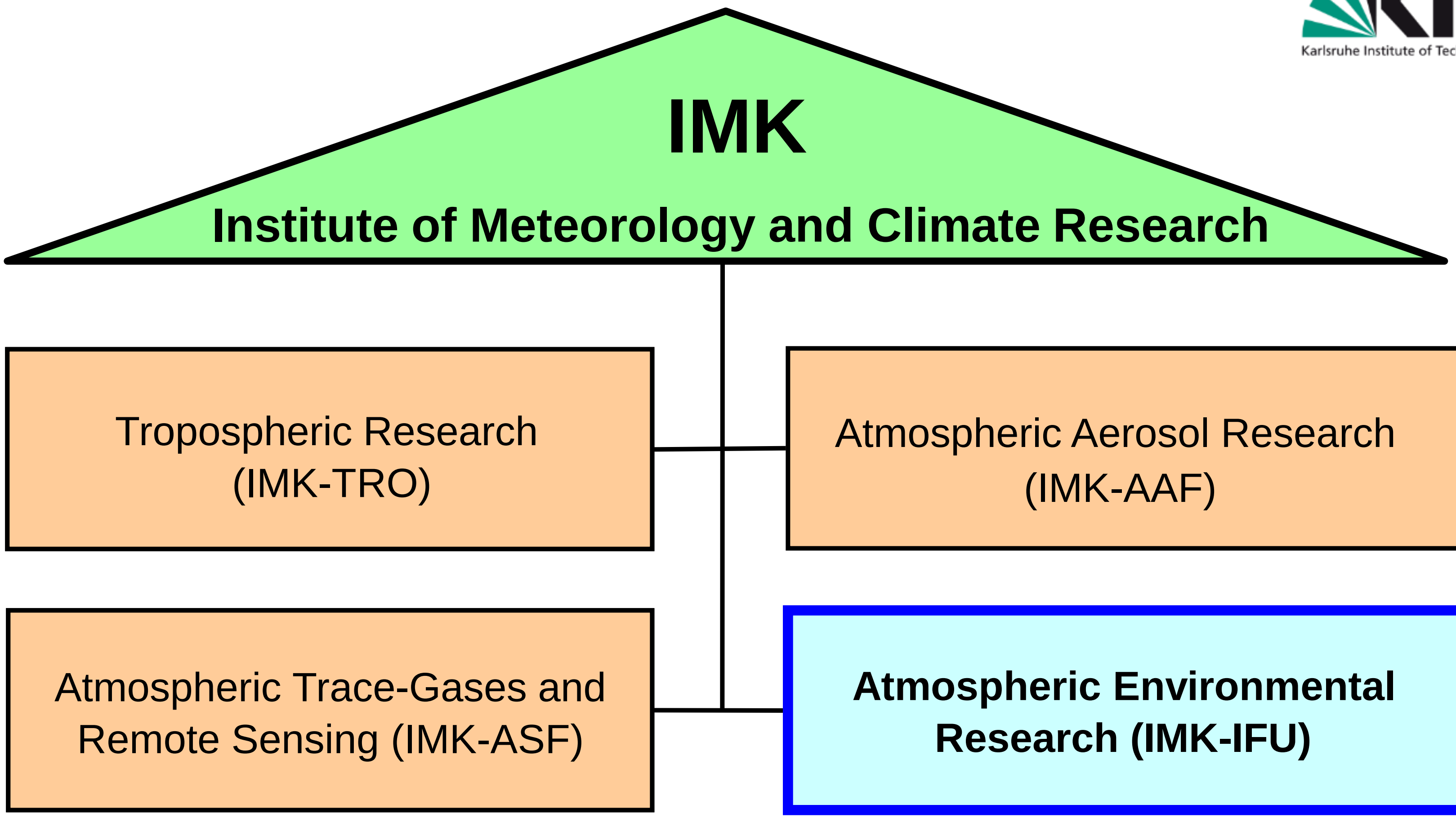
Secondary II: Increase of peak ozone concentrations for ‚white roofs'

→ increased photolysis rates due to reflected UV

Institute of Meterology and Climate Research – Atmospheric Environmental Research (IMK-IFU)

joachim.fallmann@kit.edu

Organisation



~ **150 Members** & Guests

joachim.fallmann@kit.edu

Thank you

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joachim.fallmann@kit.edu