

Modelling NO_2 concentrations in the urban area of Berlin / Brandenburg with WRF-Chem: model evaluation and sensitivity to traffic emissions

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Outline

NO_x: adverse effects on health, important precursor for secondary air pollutants (e.g. O_3)

WRF-Chem

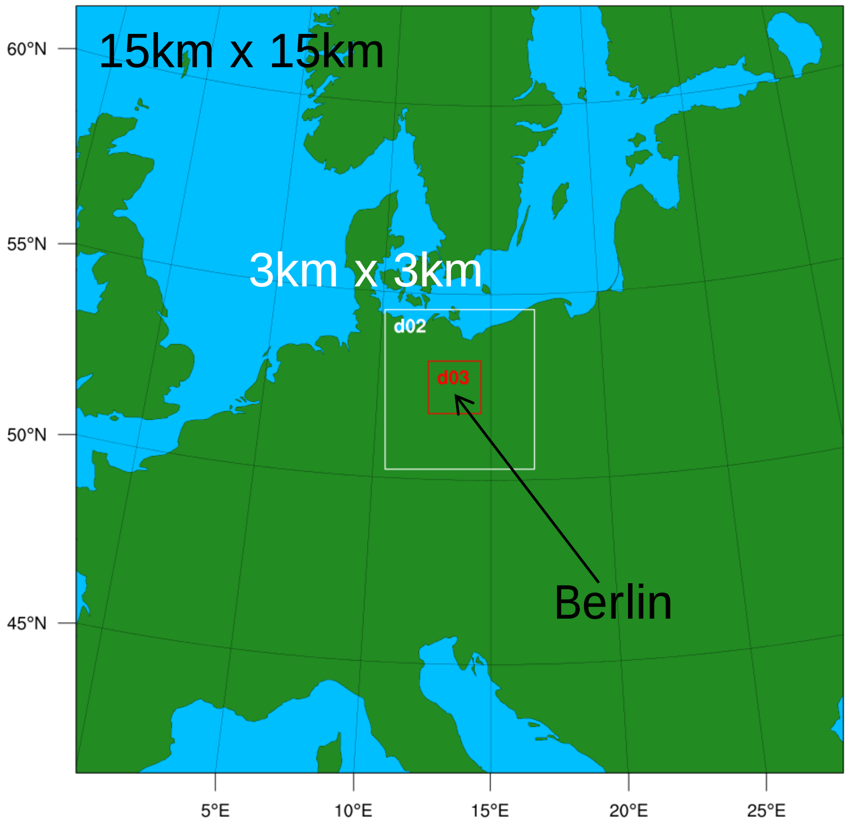
- assess potential changes in NO_2 concentrations with focus on the **urban scale**
- beyond NO_2: O_3 air pollution and other O_3 precursors

1. Introduction to WRF-Chem setup for the Berlin-Brandenburg area
2. Sensitivity simulations with focus on urban NO_2 emissions
3. Churkina et al. (2017): Effect of VOC emissions from vegetation on air quality in Berlin during a heatwave
4. Lupascu & Butler: Tagged ozone mechanisms for WRF-Chem

1. Introduction to WRF-Chem setup for the Berlin-Brandenburg area

Kuik et al., Geosci. Model Dev., 9, 4339-4363, 2016

1. WRF-Chem setup for Berlin-Brandenburg



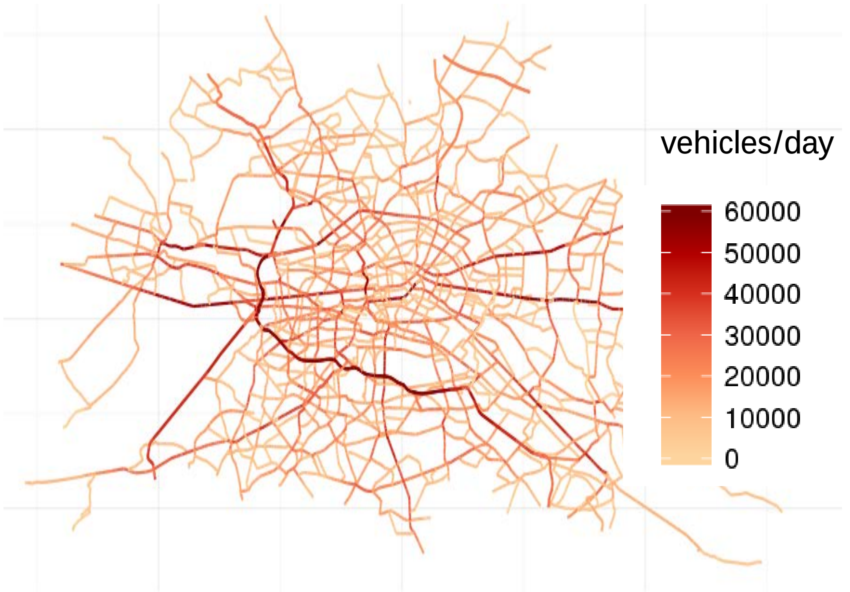
- Height of first model level: ~30m
- Chemistry + aerosols: **RADM2 + MADE/SORGAM (chem_opt=106)**
- PBL scheme: **MYNN**
- Urban parameterization: **SLUCM**
- Emissions: **TNO-MACC III**
  - downscaled to 1kmx1km
  - distributed into 7 layers
- Land use: **CORINE**
  - 3 urban land use categories
- Model version: 3.7.1/3.8.1

Kuik et al., Geosci. Model Dev., 9, 4339-4363, 2016

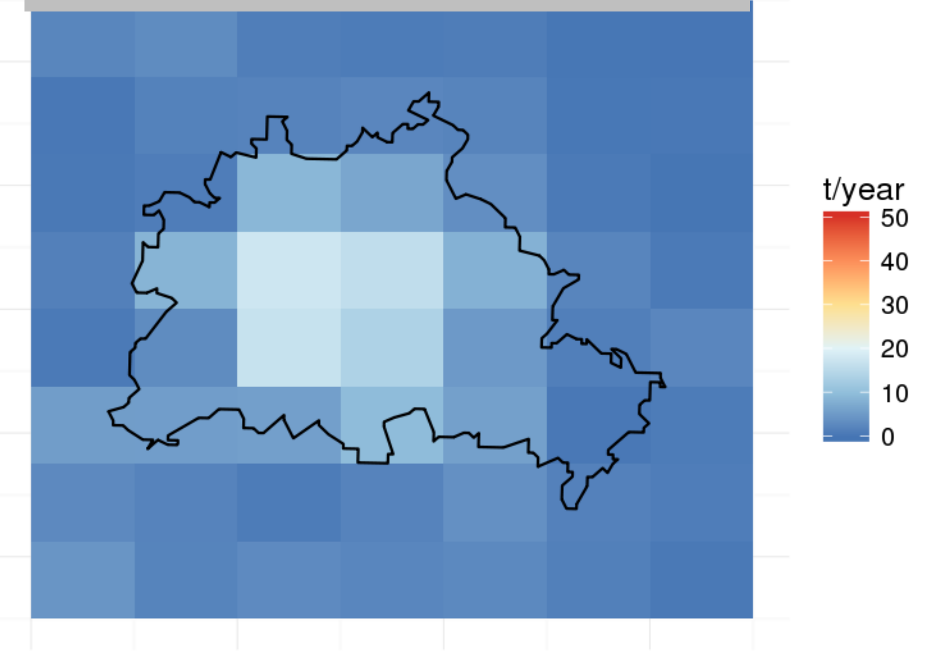
1. Traffic emissions

NO_x from road transport (exhaust diesel)

Average traffic densities, Berlin



TNO-MACC III, 7kmx7km



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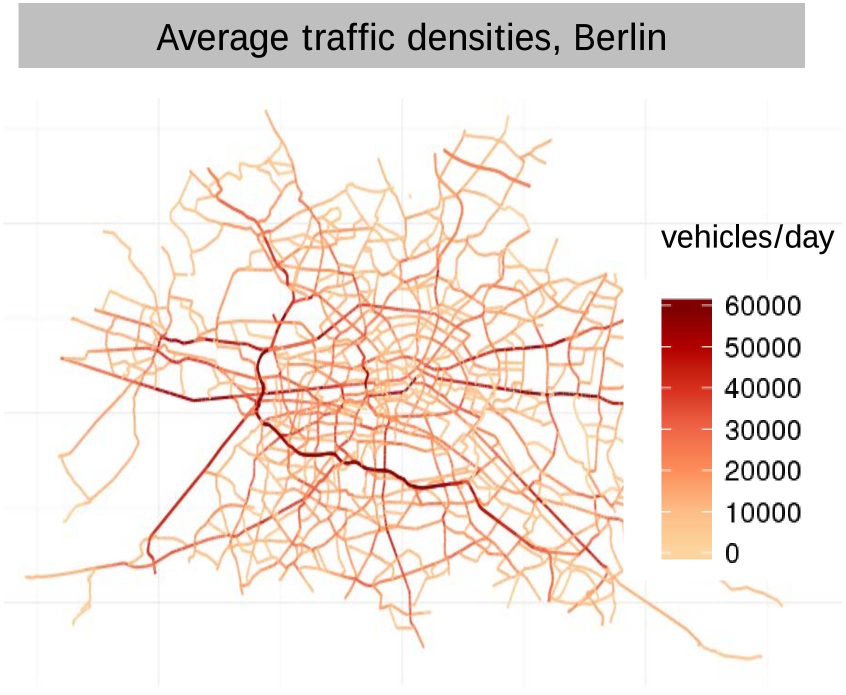
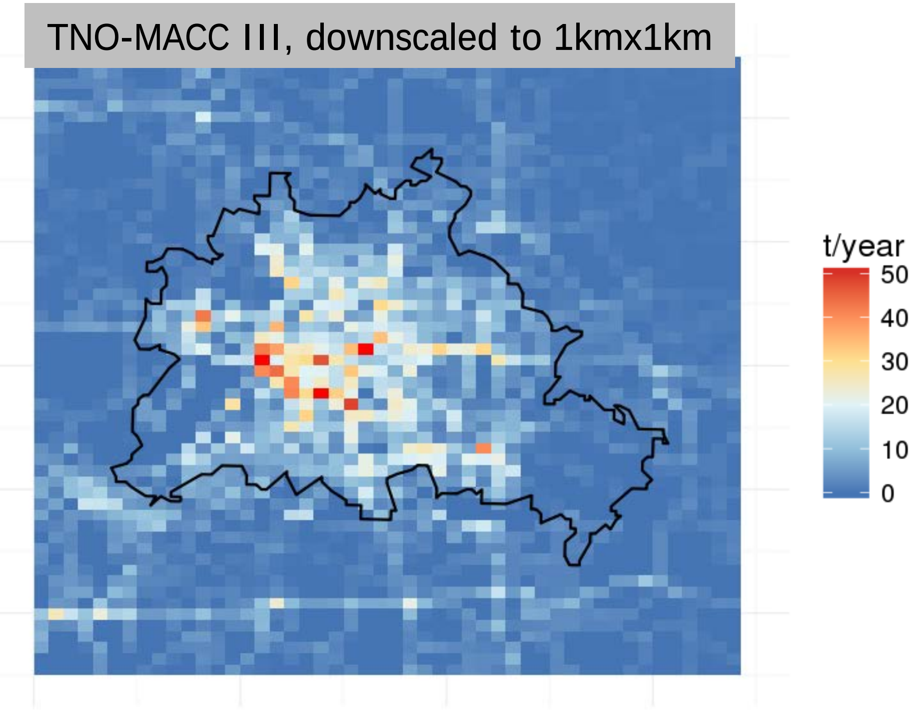




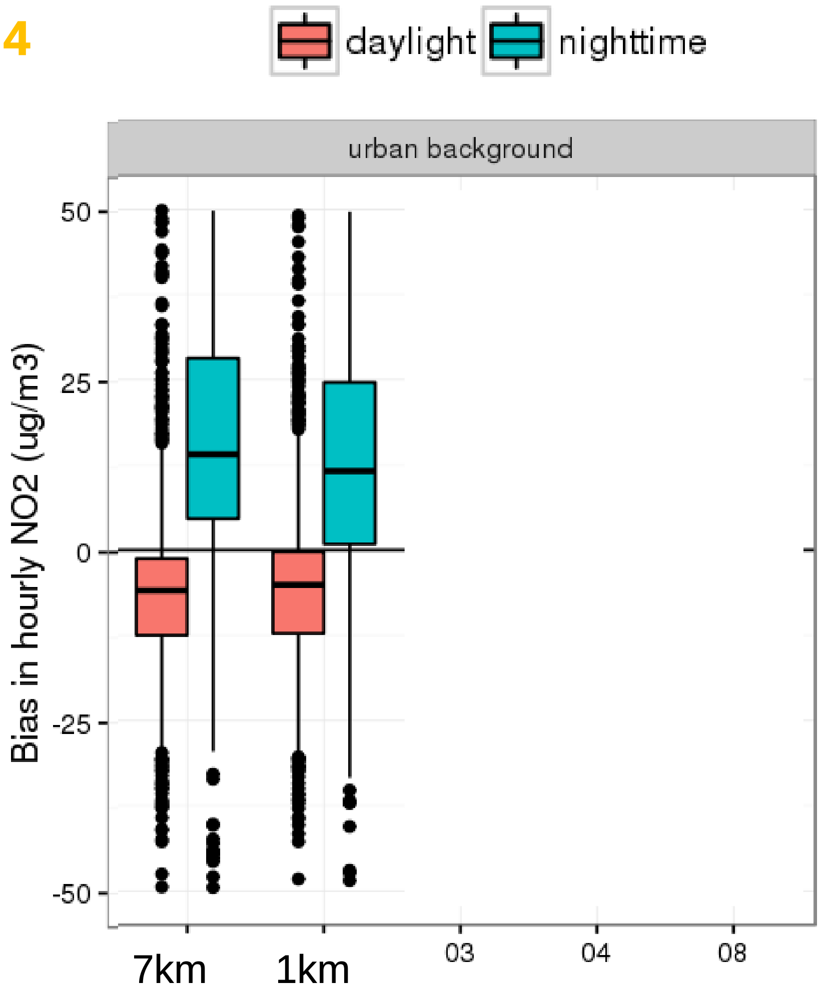
Kuik et al., Geosci. Model Dev., 9, 4339-4363, 2016; emissions: Kuenen et al., 2014;
traffic densities: Berlin Senate Department for the Environment, Transport and Climate protection

2. Sensitivity simulations with focus on urban NO_2 emissions

Kuik et al. (in preparation)

2. Bias in modeled hourly NO_2 concentrations Berlin (3km model resolution)

1 -14 June 2014



Emissions

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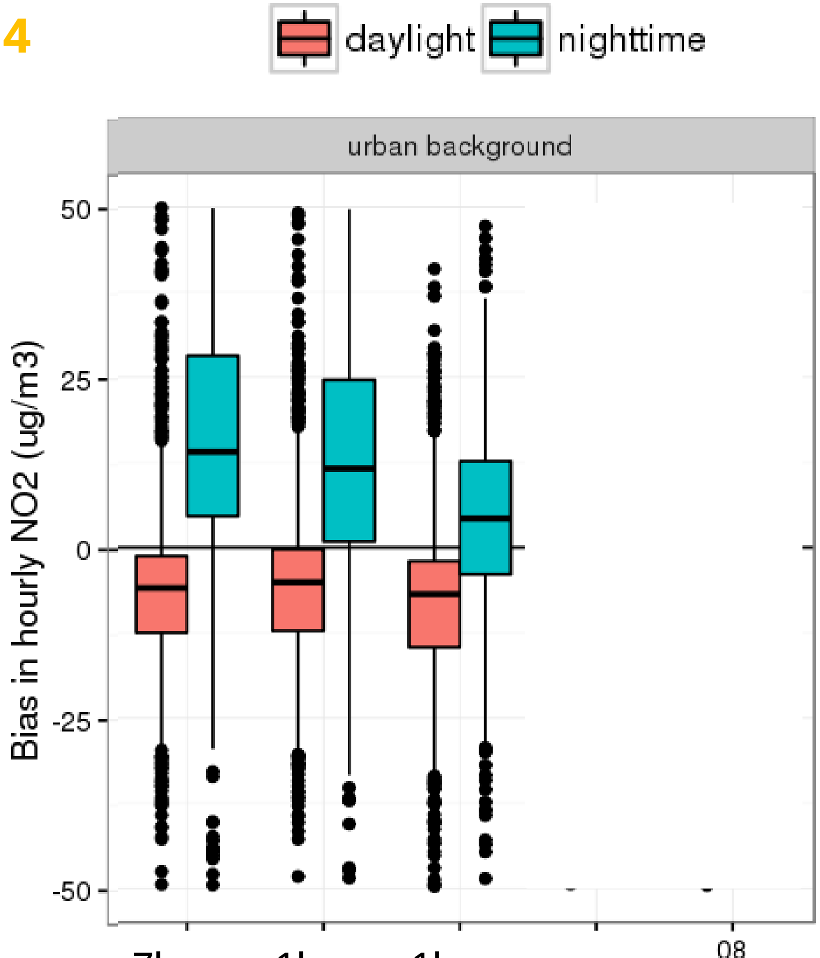


Emissions

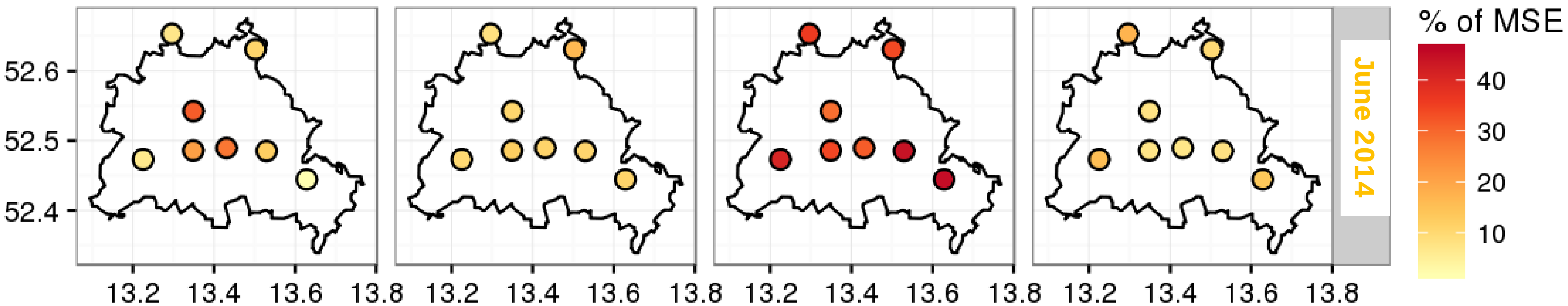
7km

1km

1km vertical distribution

2. Contribution of different spectral components of NO_2 time series to MSE

Long term > 21 days	Synoptic (2.5 – 21 days)	Diurnal (12h – 2.5 days)	intra-diurnal (< 12h)



Spectral decomposition: Kolmogorov-Zurbenko filter

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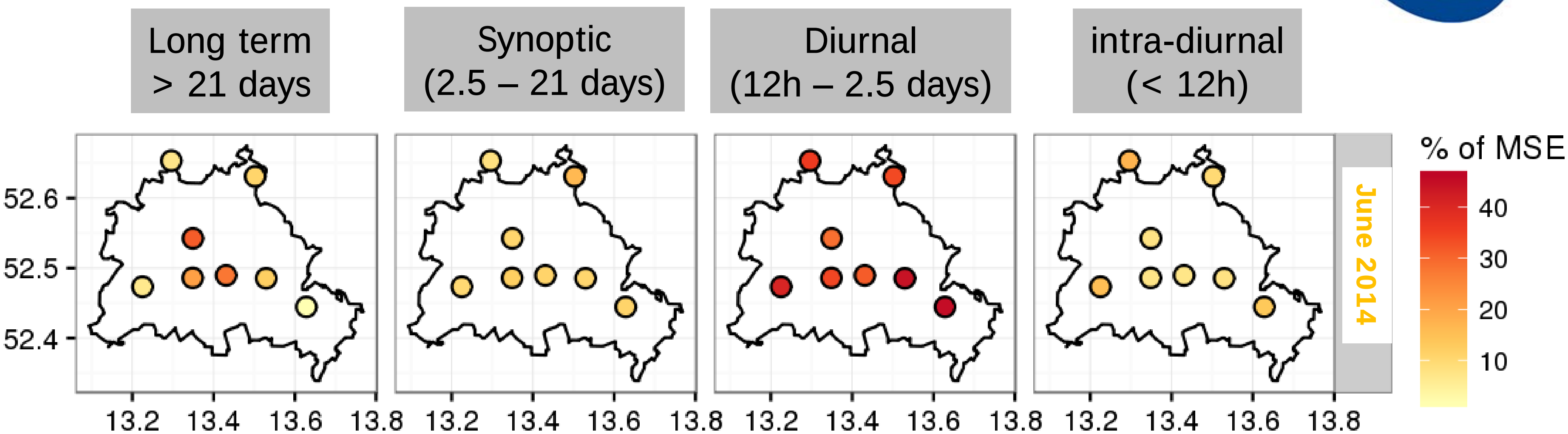

Spectral decomposition: Kolmogorov-Zurbenko filter

Error of the diurnal component has the largest contribution to model-observation mismatch

- ➢ PBL, mixing?
- ➢ Traffic emissions (diurnal cycle)?

2. Bias in modeled hourly NO_2 concentrations Berlin (3km model resolution)

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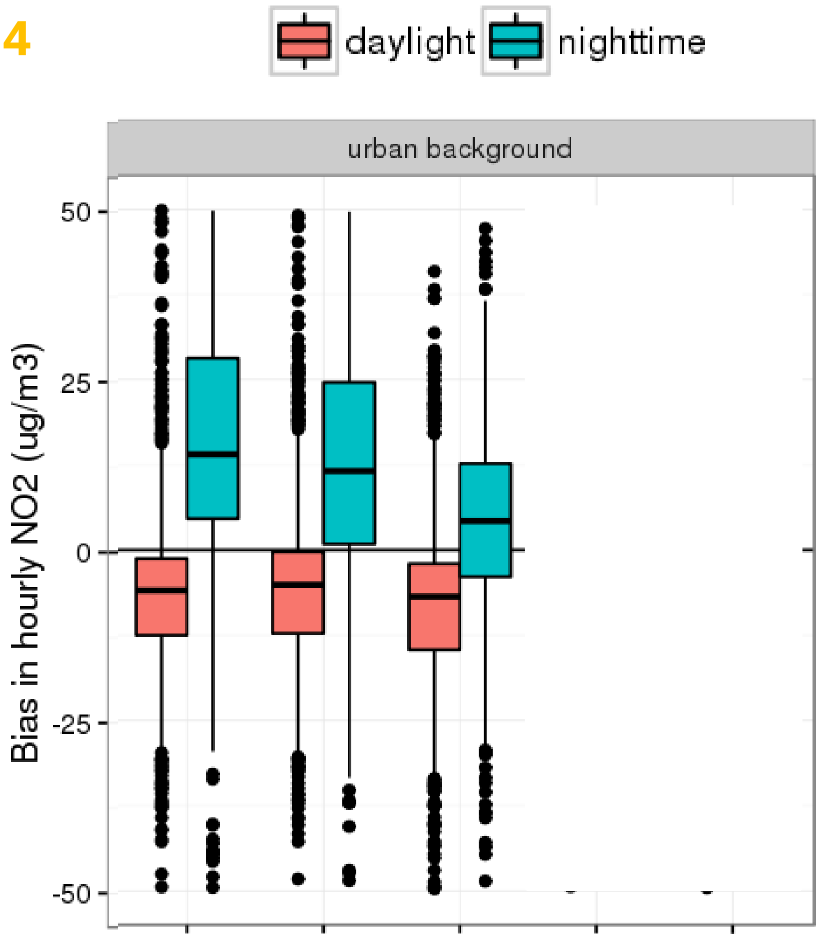

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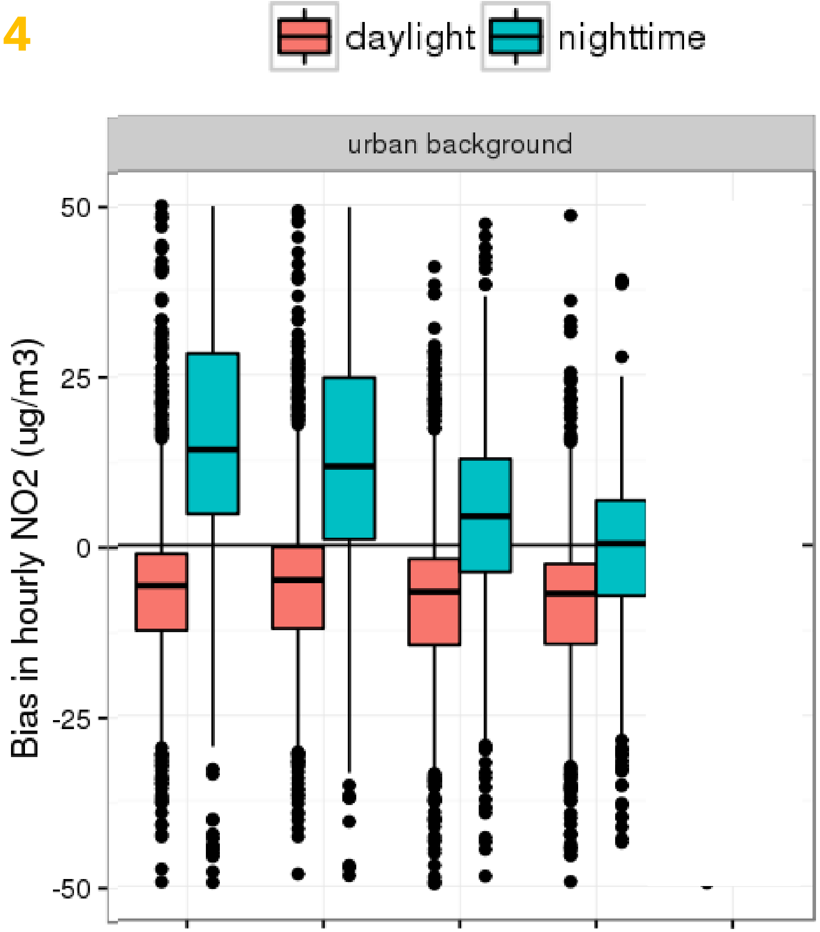


Emissions

7km

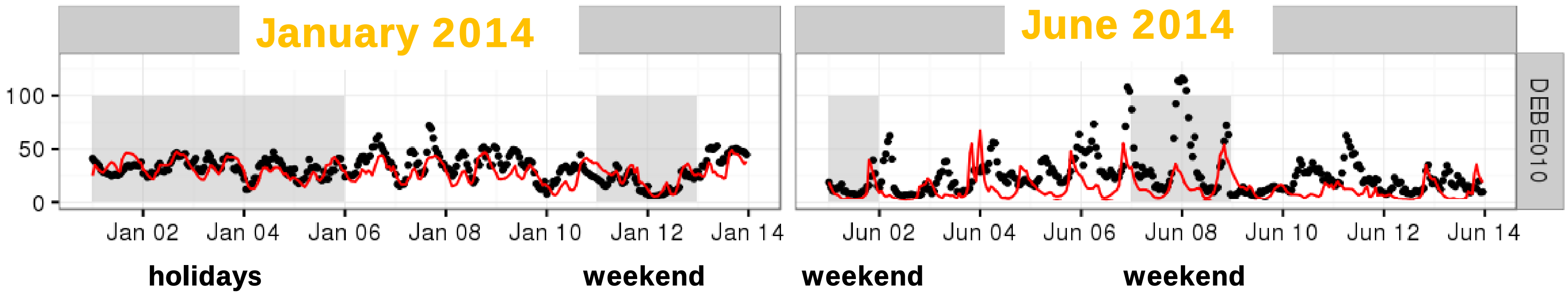
1km

1km
vertical
distribut

1km
vertical distribution
diurnal cycle adjusted
increased nighttime mixing

2. Modeled hourly NO_2 concentrations: winter and summer, Berlin **(urban background)**

NO_2 in µg/m³ **--- observations** **--- model results (3kmx3km)**



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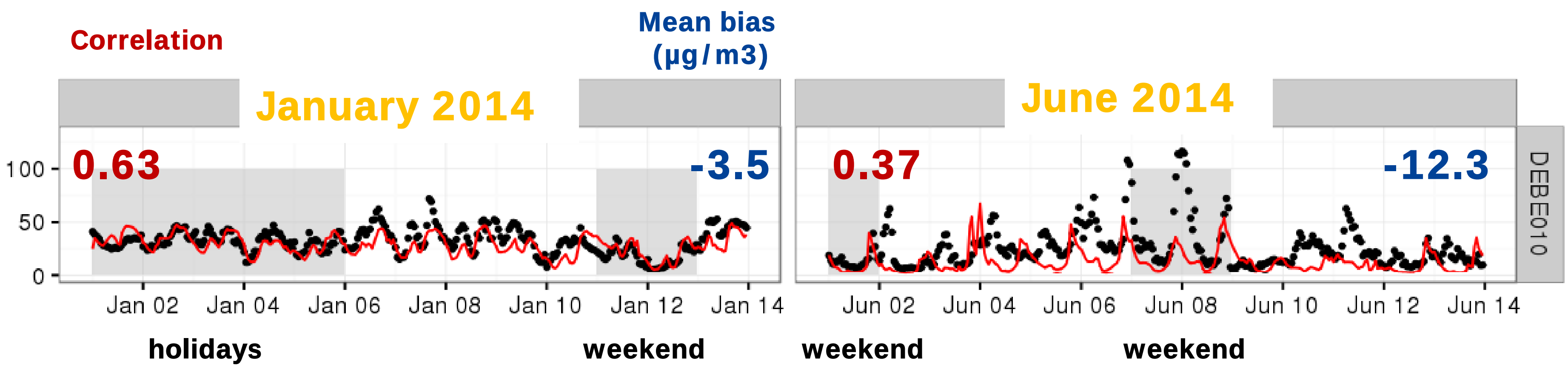
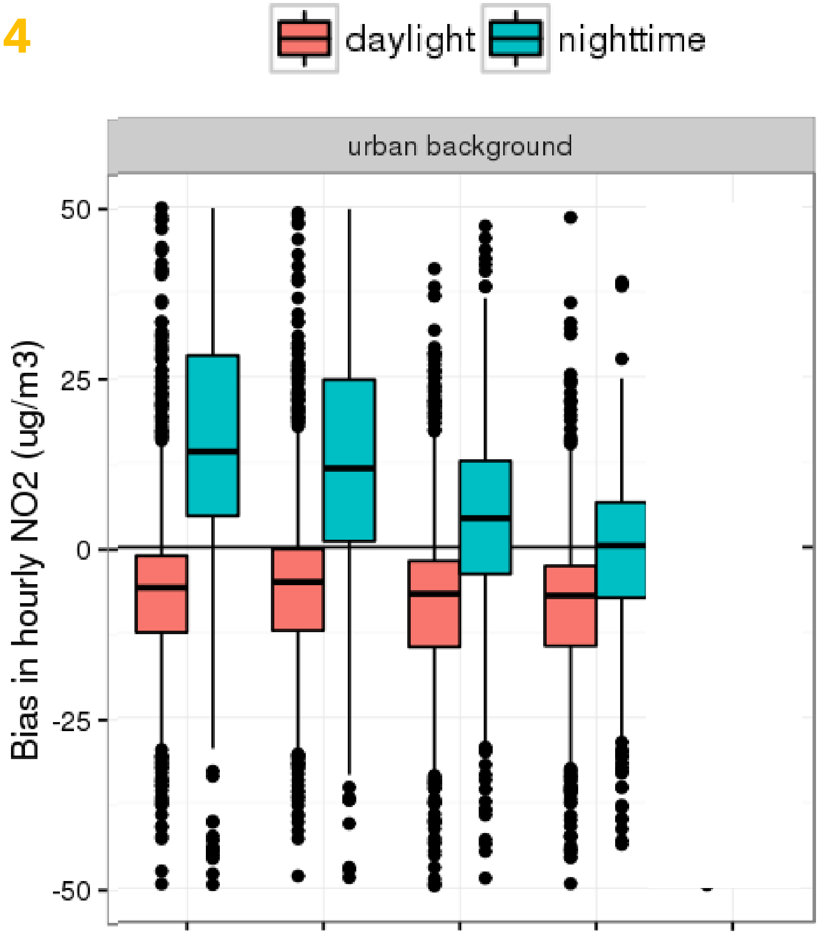


WRF-Chem underestimates observed daytime NO2 concentrations (mostly during weekdays)

2. Are NO_2 traffic emissions too low during daytime?

1 -14 June 2014



Emissions

7km

1km

1km
vertical
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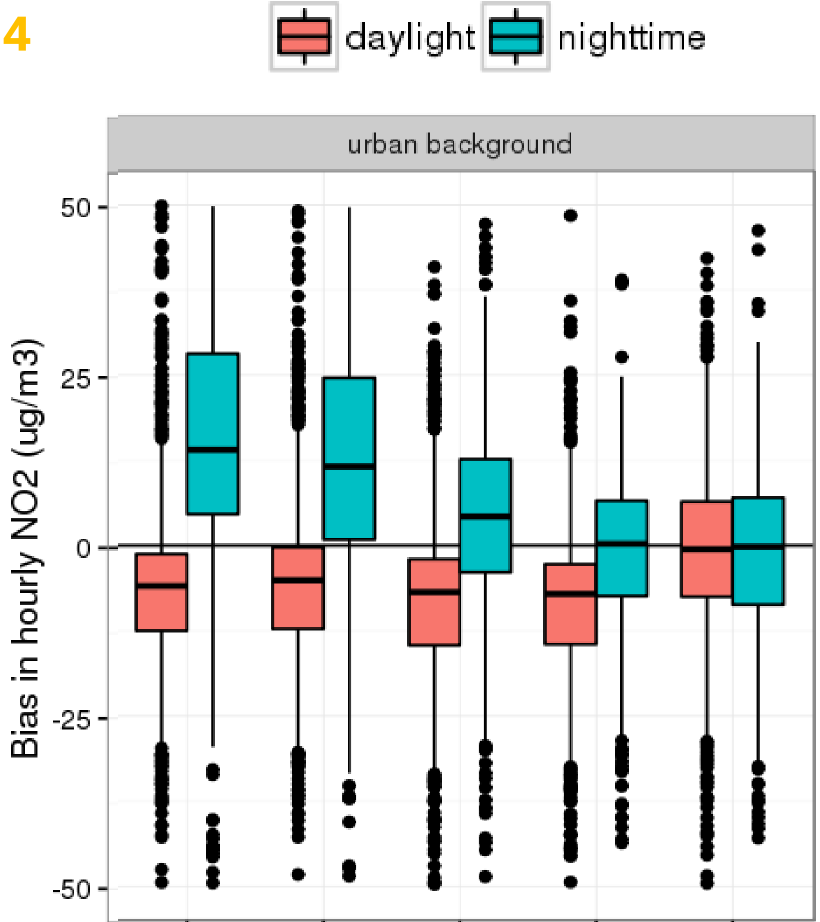

Emissions

7km

1km

1km
vertical
distribut

1km
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1km
vertical distribution
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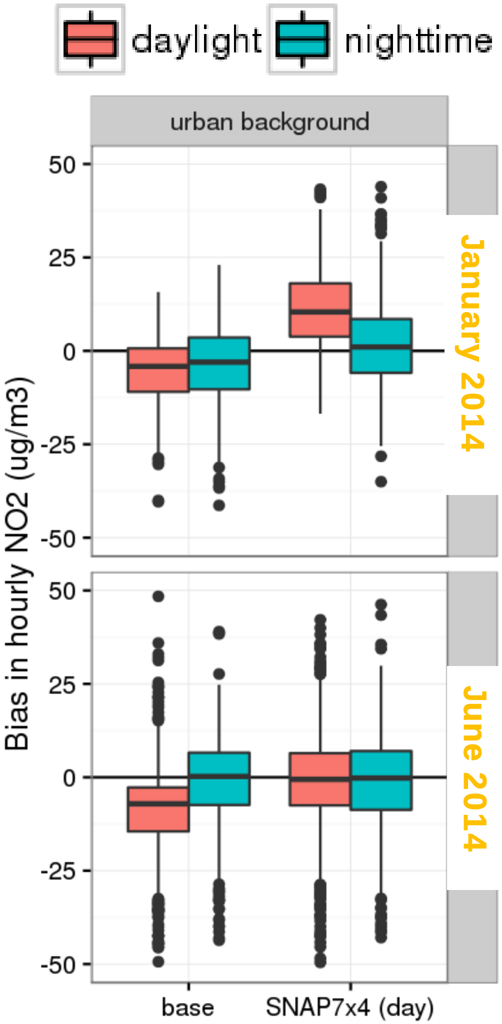
increased nighttime mixing
x4 traffic emissions (daytime)

2. Are NO_2 traffic emissions too low during daytime?



Different behaviour in January

- Partly due to large number of holidays

Possible reasons for an underestimation of NO_2 emissions

- Underestimation of the frequency of traffic situations with high congestion
- Underestimation of emission factors
- Underestimation of traffic emissions from cities in general (distribution), ...

Next steps

- How does it look like for longer seasons/other periods?

3. Effect of VOC Emissions from Vegetation on Air Quality in Berlin during a Heatwave

Churkina, Kuik, Bonn, Lauer, Grote, Tomiak and Butler, Environ Sci Technol., 2017

3. Effect of VOC Emissions from Vegetation on Air Quality in Berlin during a Heatwave

Effect of vegetation in cities

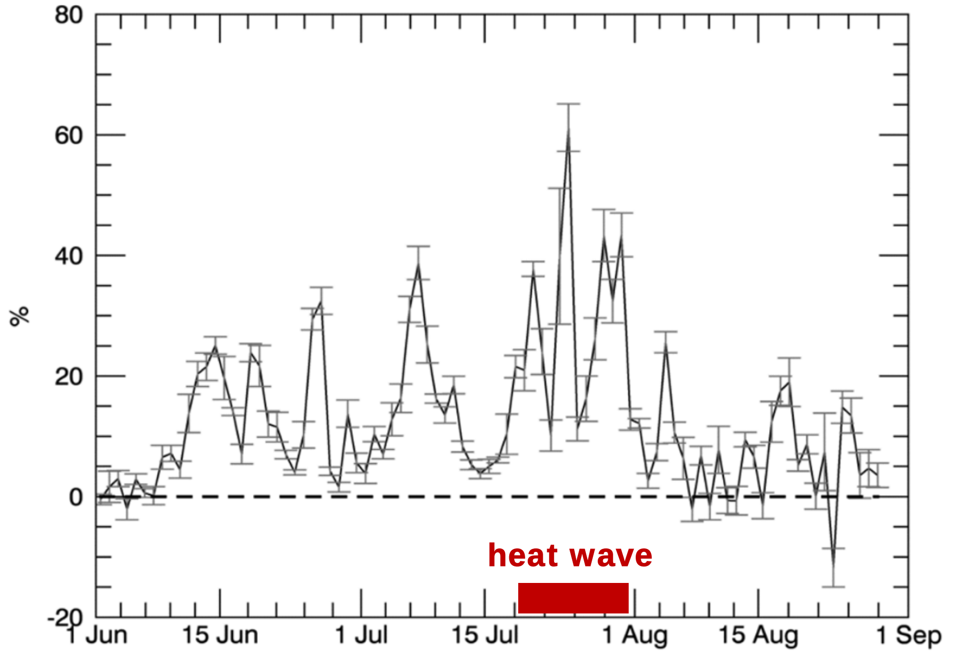
- Removal of air pollution
- Enhancement of air pollution via VOC emissions
- ➢ **important during heatwaves**

<u>This study:</u> **What is the contribution of VOC emissions from vegetation in urban areas to ozone concentrations?**

<u>Methods:</u>

- WRF-Chem and MEGAN
- Modification of input data to MEGAN for the urban area
  - Fraction and type of vegetation
  - Leaf area index

Contribution of VOC emissions from vegetation to ozone concentrations (MDA8), average over 6 stations in Berlin, 2006



Biogenic VOCs have a larger contribution to O_3 concentrations during hot days

Comparison with observations: isoprene underestimated in urban vegetated areas

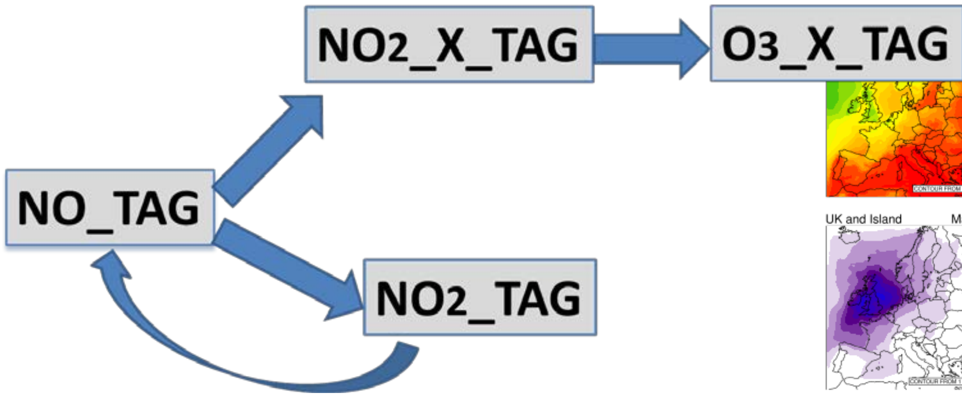
Churkina, Kuik, Bonn, Lauer, Grote, Tomiak and Butler, Environ Sci Technol., 2017

4. Tagged Ozone Mechanisms for WRF-Chem

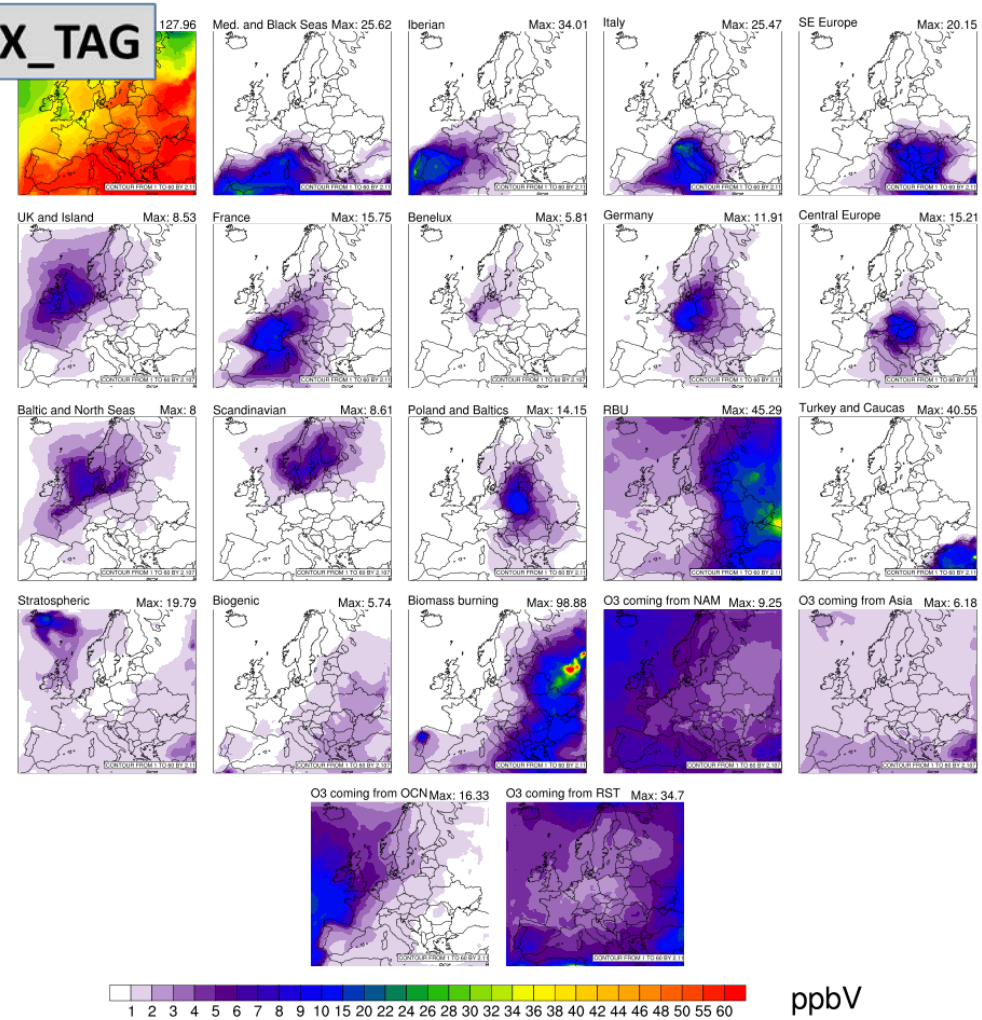
Lupascu & Butler (in preparation)

4. Lupascu & Butler: Tagged Ozone Mechanisms for WRF-Chem

Questions: aurelia.lupascu@iass-potsdam.de



MDA8 O3 (ppbV) - August 2010



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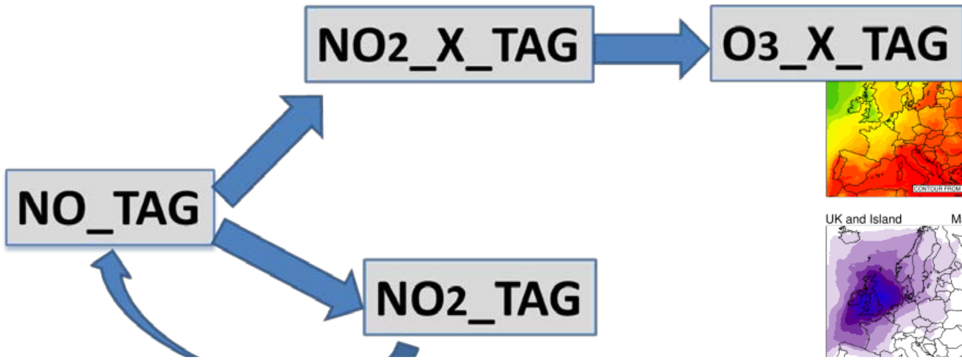

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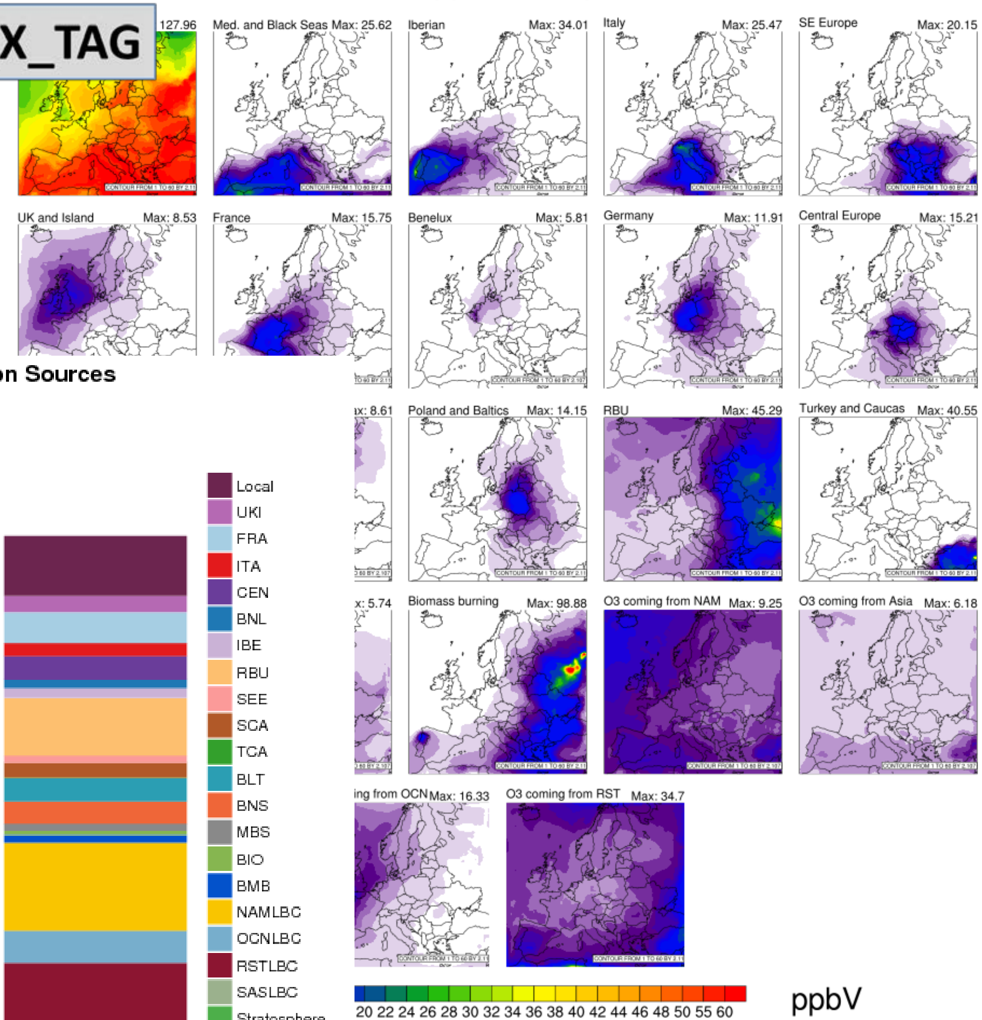
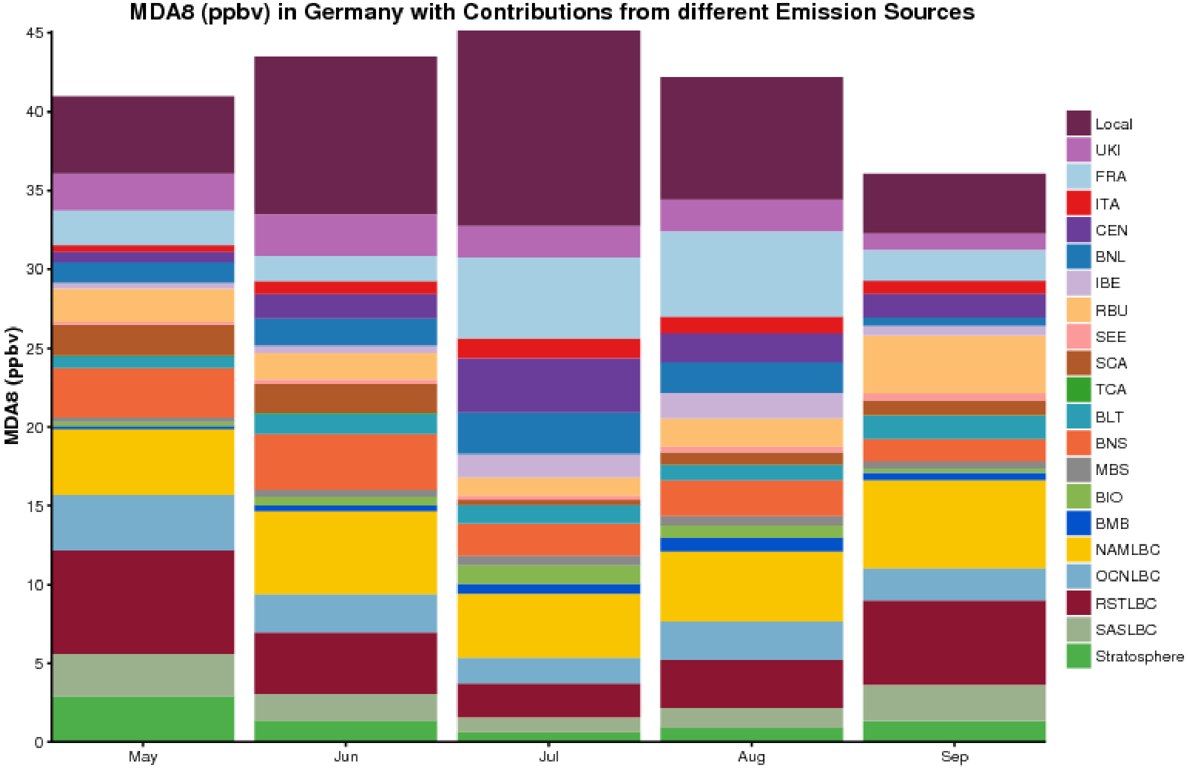


MDA8 (ppbv) in Germany with Contributions from different Emission Sources



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Extra slides

Physics and chemistry schemes

Process	Scheme	Remarks
Cloud microphysics	Morrison double-moment	
Radiation (short wave)	RRTMG	called every 15 min
Radiation (long wave)	RRTMG	called every 15 min
Boundary layer physics	**MYNN**	
Urban scheme	Single-layer urban canopy model	3 categories: roofs, walls, streets
Land surface processes	Noah LSM	CORINE land use input data
Cumulus convection	Grell–Freitas	switched on for all domains
Chemistry	RADM2	KPP version (chem_opt = 106)
Aerosol particles	MADE/SORGAM	
Photolysis	Madronich F-TUV	

3. Air quality benefits if emission standards were met

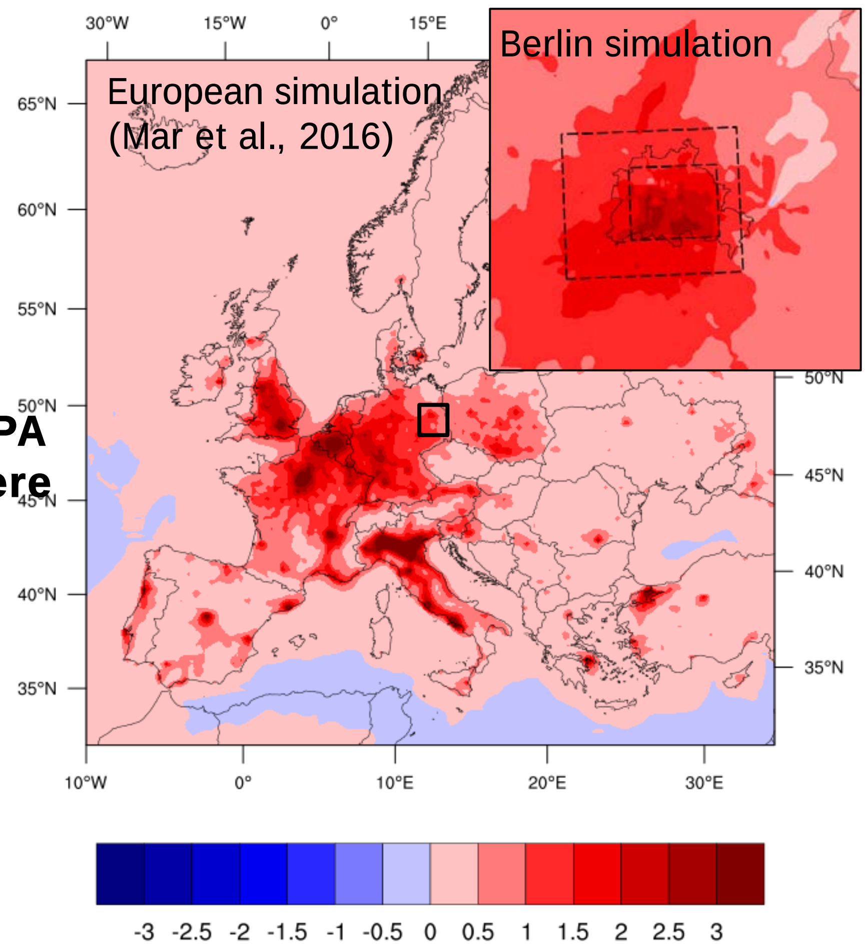
How much could NO_2 concentrations be reduced if emission standards were met (‚diesel gate ')?

Obs.-based calculations		Berlin simulation	European sim.
13 ± 3.2	1.6 ± 0.54	2.0 [1.1,2.8]	1.7 [1.2, 2.0]

Berlin roadside

Berlin urban background

Reduction in NO_2 concentrations if US EPA emission standards were met (µg/m³, July 2011)



- Potential reductions smaller for compliance with Euro 5 standards, but still substantial

- Potential reductions even higher when using city fleet composition (passenger cars)

Extra slides

Spectral decomposition: Kolmogorov-Zurbenko-Filter

$$\mathrm{KZ}_{m,p} = R_{i=1}^{p}\left\{ J_{k=1}^{W_i}\left[\frac{1}{m} \sum_{j=-\frac{m-1}{2}}^{\frac{m-1}{2}} S\left(t_i\right)_{k,j} \right] \right\} \begin{cases} R: \text{iteration} \\ J: \text{running window} \\ W_i = L_i - m + 1 \\ L_i = \text{length of } S(t_i) \end{cases} \quad (1)$$

- Decompose time series using iterative moving average approach
- Here
  - Long term: LT = $kz_{103,5}(\mathbf{x}(t))$ (21 – 90 days)
  - Synoptic: SY = $kz_{13,5}(\mathbf{x}(t)) - kz_{103,5}(\mathbf{x}(t))$ (2.5 – 21 days)
  - Diurnal: DU = $kz_{3,3}(\mathbf{x}(t)) - kz_{13,5}(\mathbf{x}(t))$ (12h – 2.5 days)
  - Intra-diurnal: ID = $\mathbf{x}(t) - kz_{3,3}(\mathbf{x}(t))$ (< 12h)
- References: Solazzo and Galmarini, 2015, 2016; Galmarini et al., 2013; Hogrefe et al., 2000; Kang et al., 2008; Rao et al., 2007

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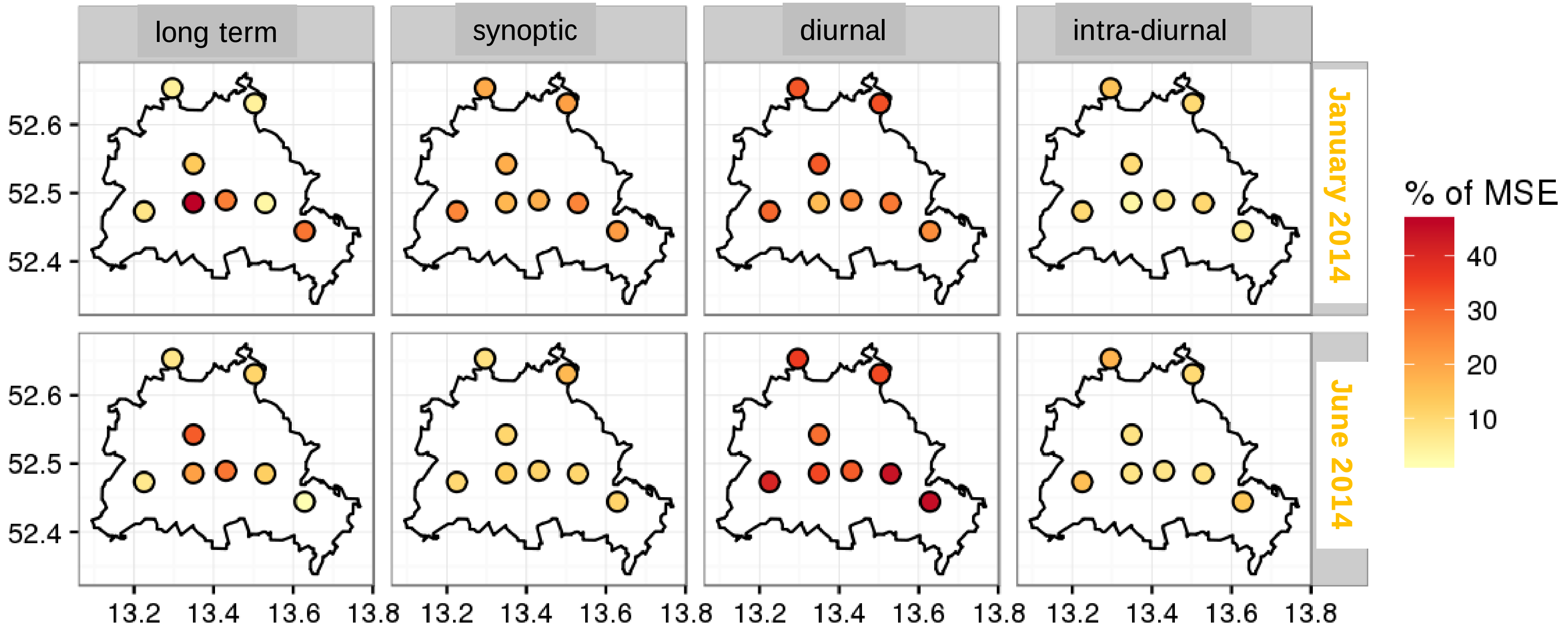


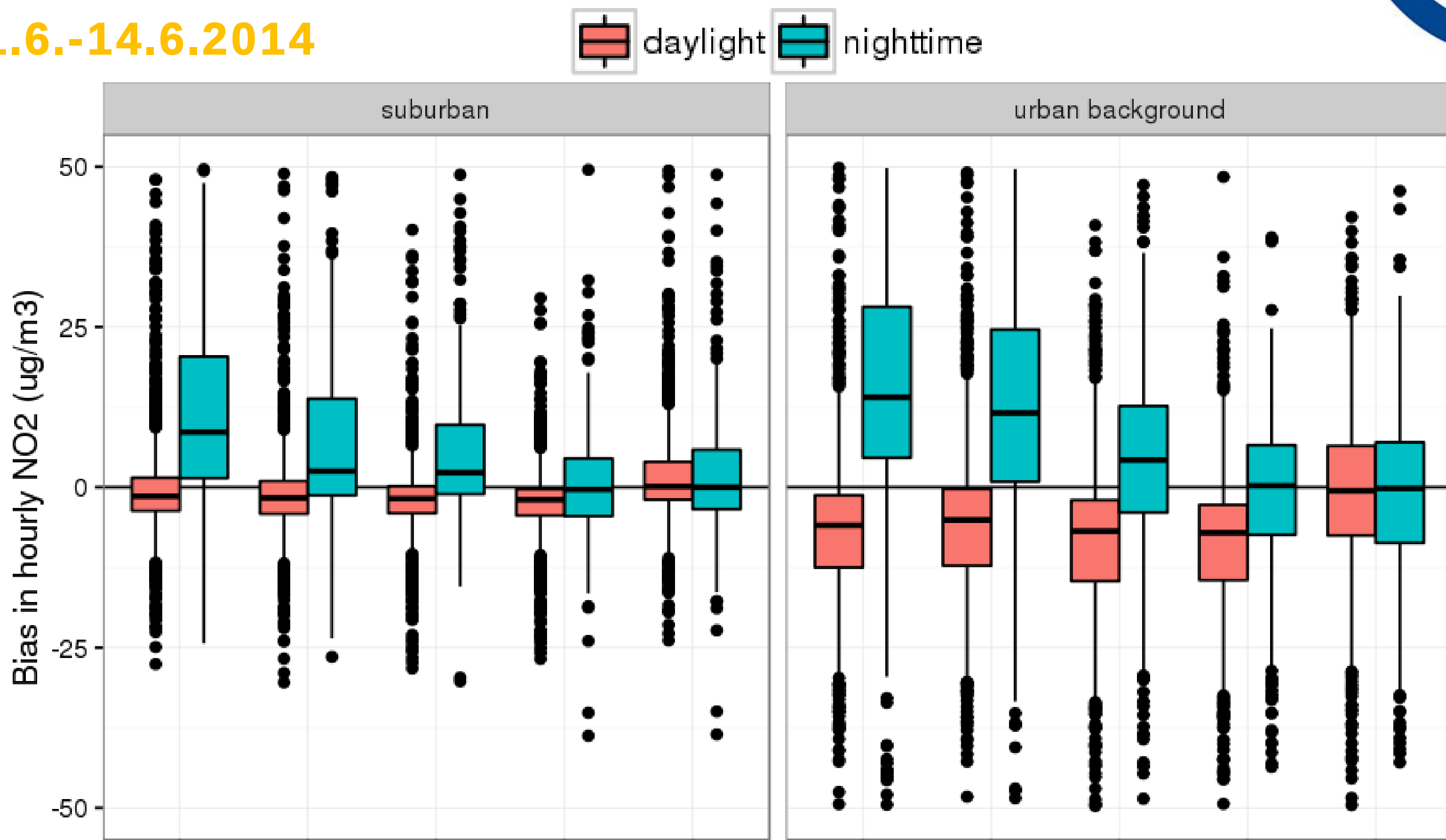
Spectral decomposition: Kolmogorov-Zurbenko filter

Error of the diurnal component has the largest contribution to model-observation mismatch

- PBL, mixing
- Emissions: underestimation during daytime (traffic)?

2. Are NO2 traffic emissions too low during daytime?

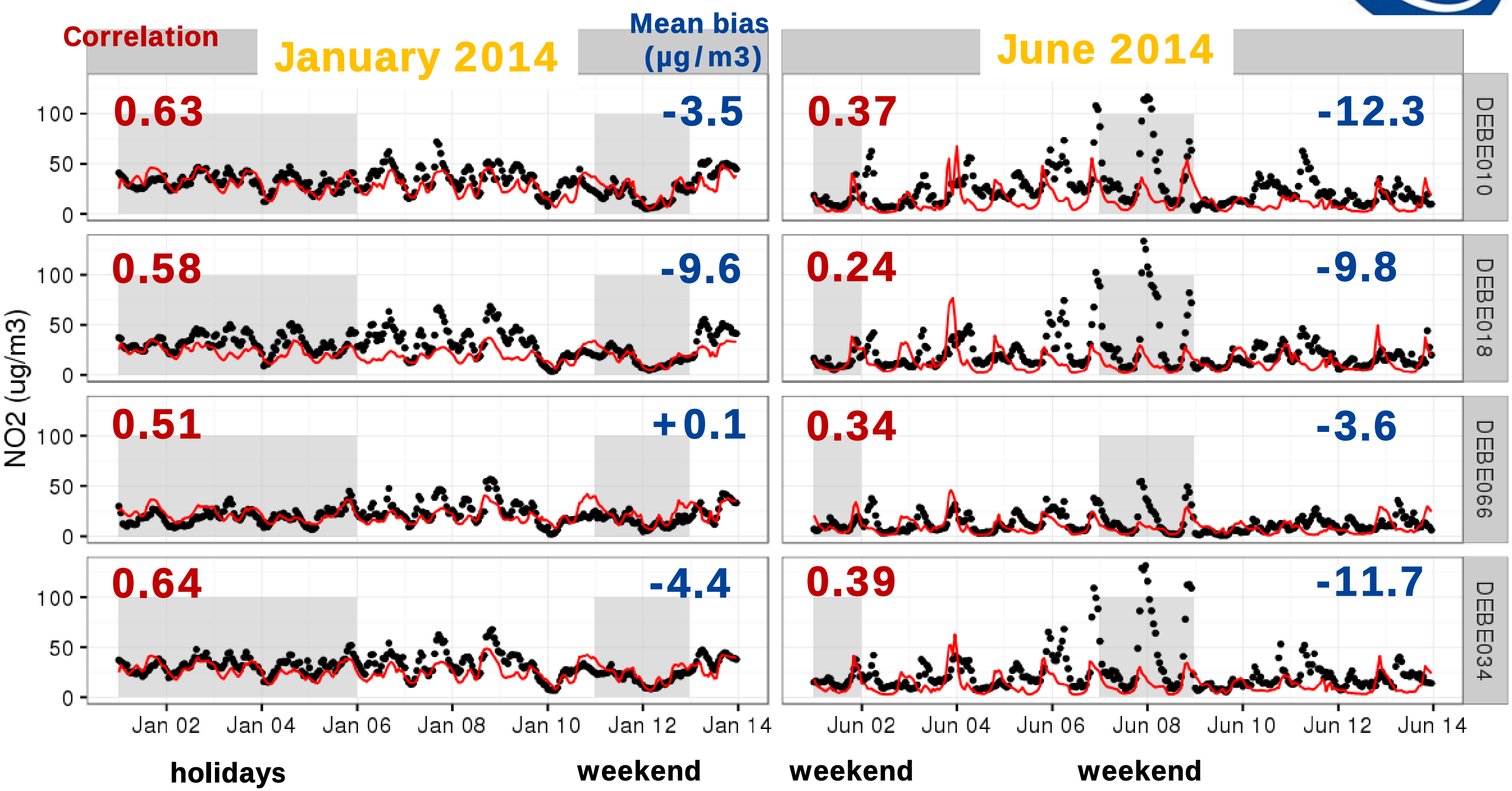
1.6.-14.6.2014



Emissions 7km | 1km | 1km vertical | 1k ve diu mi | 1km vertical diurnal cycle mixing x4 SNAP7 (daytime) | km | 1km | 1km vertical | 1 v d m | 1km vertical diurnal cycle mixing x4 SNAP7 (daytime)

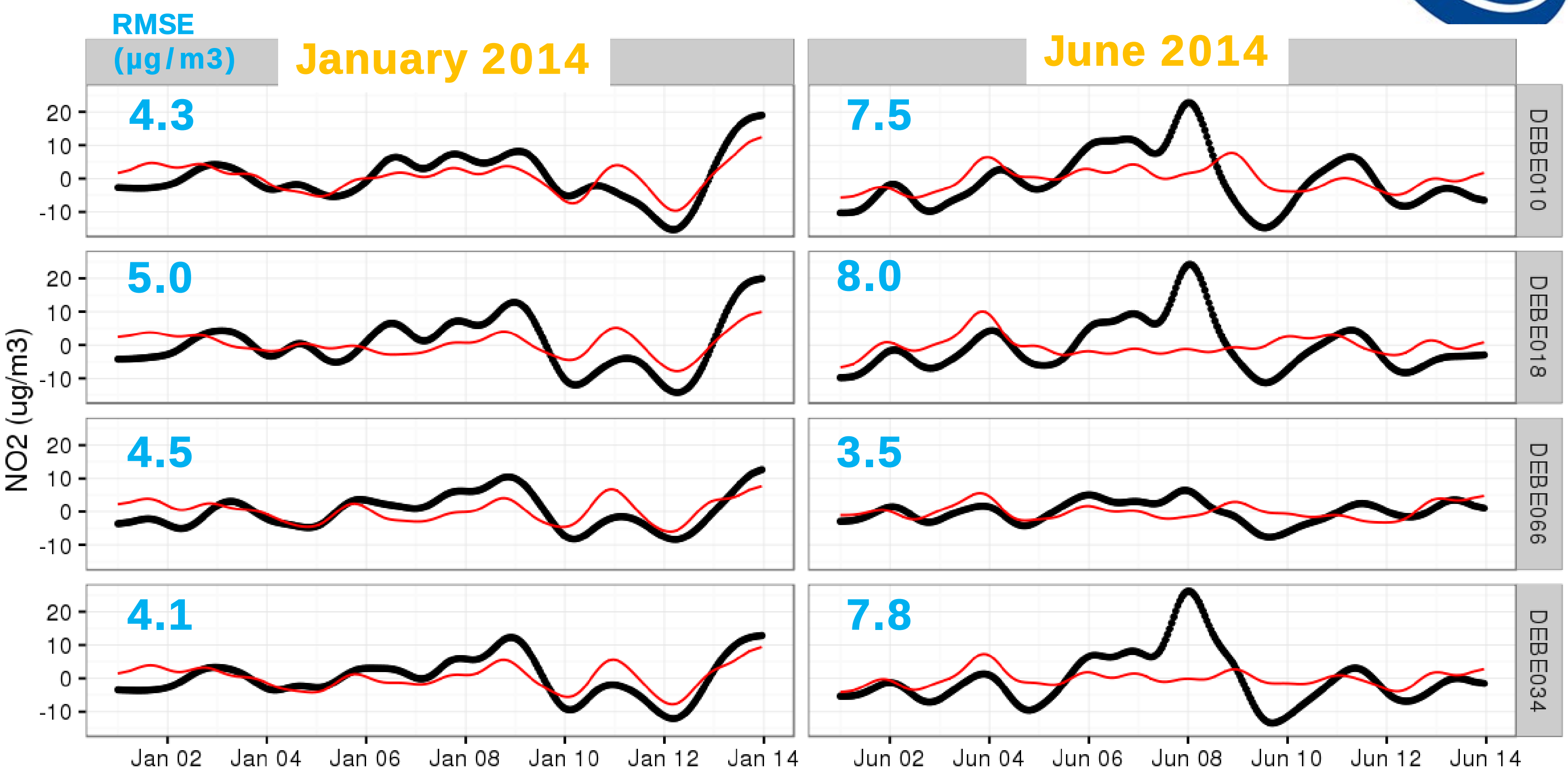
2. Modeled hourly NO2 concentrations: winter and summer, Berlin **(urban background)**

IASS POTSDAM



(Daytime) mismatch larger in summer and during weekdays

2. **Synoptic component** of hourly NO2: winter and summer, Berlin **(urban background)**

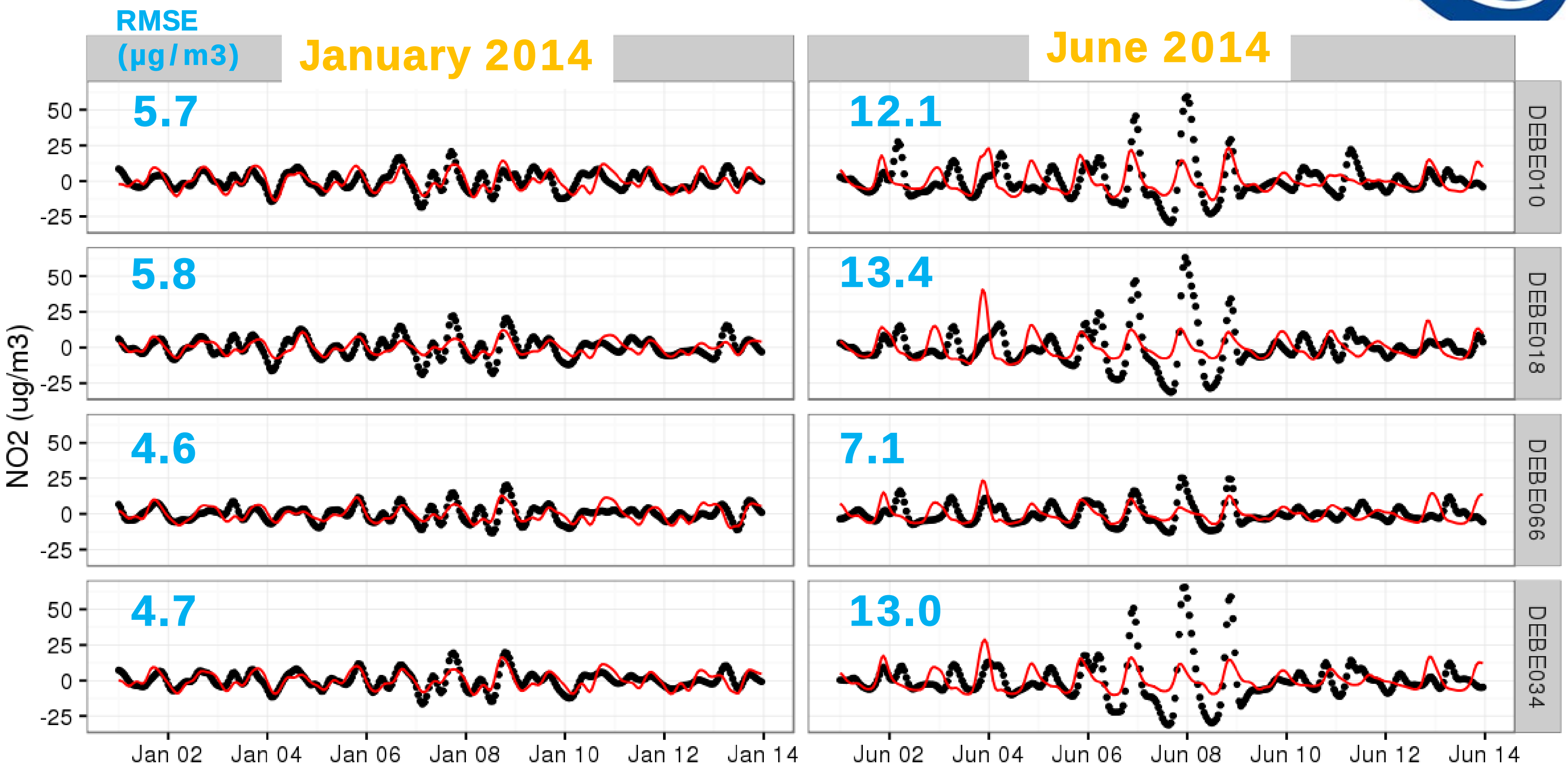


Spectral decomposion using the Kolmogorov-Zurbenko filter: assess error of different spectral components

E.g. synoptic component (2.5 – 21 days), diurnal component (12h – 2.5 days)

Solazzo and Galmarini, 2015, 2016; Galmarini et al., 2013; Hogrefe et al., 2000; Kang et al., 2008; Rao et al., 2007

2. **Diurnal component** of hourly NO2: winter and summer, Berlin **(urban background)**



Error of the diurnal component has the largest contribution to model-observation mismatch

2. Modeled hourly NO2 concentrations: winter and summer, Berlin (suburban)