DEVELOPMENT OF A NEW LAGRANGIAN AIR POLLUTION MODEL FOR DENMARK

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MOTIVATION

Health impact assessments of air pollution:

- "Air pollution is now recognized as the single largest environmental threat to human health and well-being" (WHO, 2021)
- Yearly worldwide premature deaths: 4.2 million (2016) (WHO, 2016)
- Yearly Danish premature deaths: 4,600 (2019) (Ellermann et al., 2021)

Epidemiological studies:

- Epidemiological studies → health impact assessments
- Exposure: modeled data validated against measurements

OBJECTIVES

Overall goal:

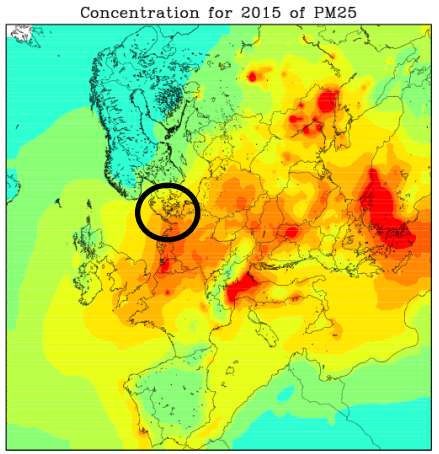
- Advancement of our understanding and methodologies for high-resolution air pollution modelling for use in:
  - human air pollution exposure
  - health impact assessment
- Development of a new model – revising the Urban Background Model (UBM) with a high-resolution air pollution module suitable for 2022 and beyond
- Integrated in the DEHM/UBM/OSPM air pollution modelling system, developed at ENVS, AU

Background:

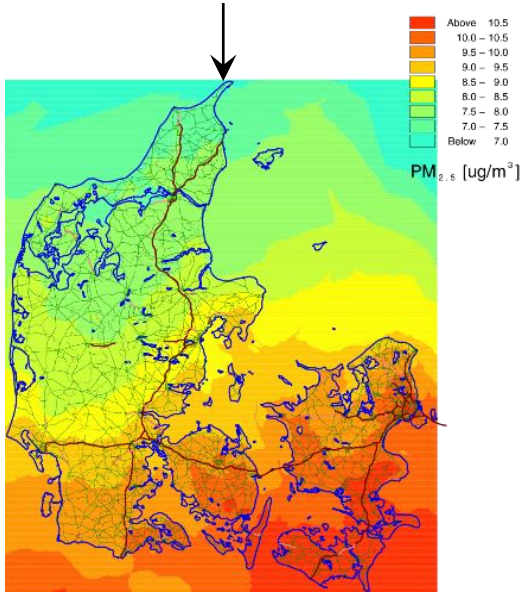
- Increased computational power
- Availability of high-resolution and high-quality emission data (Plejdrup et al., 2021)

UBM

DEHM:



UBM:



Model specification:

- Concentrations at the urban (local) background level
- Model chain: WRF → DEHM → UBM → OSPM
- Gaussian plume in grid model (contribution of sources; 25 km upwind)
- Simple description of the planetary boundary layer
- Simple photochemistry for NO, NO2, and O3

Applicability:

- High-resolution and long-term runs of 40 years for the Nordic countries
- Spatial resolution: 1 km x 1 km - Temporal resolution: hourly
- ➢ Danish national monitoring program and many research/advisory projects

Primary limitation: Its simplicity → challenges in areas with large spatial variability in the planetary boundary layer, topography, and landuse

THE LAGRANGIAN APPROACH

- Huge set of independent random particle trajectories
- Conservation of species mass in the absence of deposition and chemistry

Advantages:

- ➢ CFL condition is not necessary for stability
- ➢ Less numerical diffusion compared to Eulerian models
- ➢ Local dispersion can be described more accurately close to emission sources
- ➢ Sub-grid information is retained
- ➢ Atmospheric transport can be traced back to its individual sources
- ➢ Computational cost of passive transport is independent of the number of species
- ➢ Ideal to parallelize

Noticeable disadvantages …

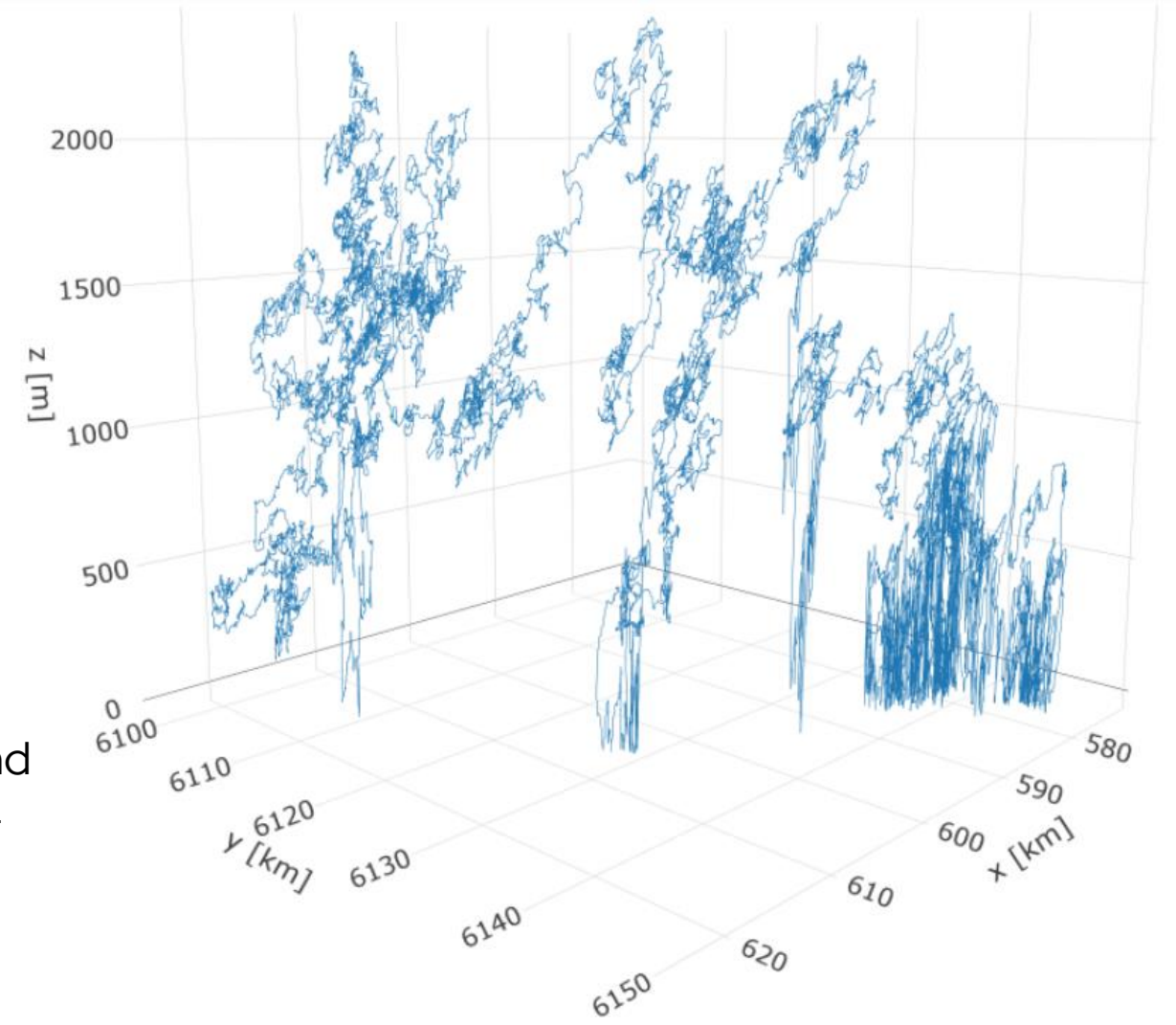
THE WALK OF A SINGLE LAGRANGIAN PARTICLE

$$u_i = \overline{U}_i + u_i'$$

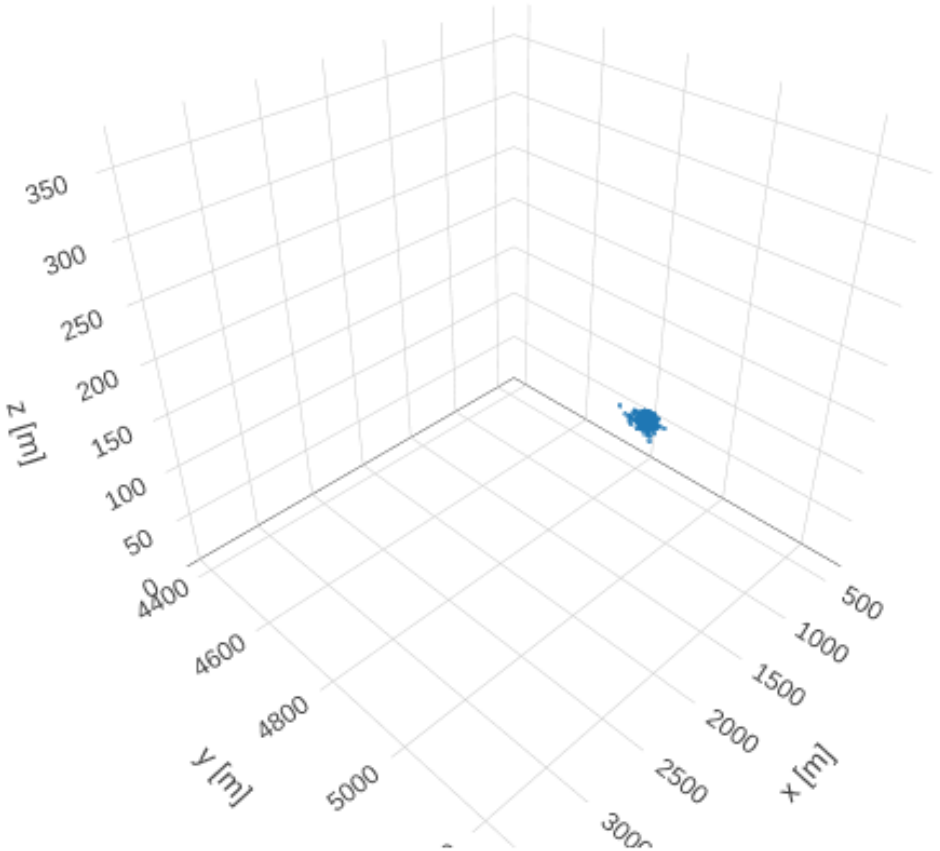
$$du_i' = a_i(\mathbf{x}, \mathbf{u}, t)dt + b_{ij}(\mathbf{x}, \mathbf{u}, t)ds_j$$

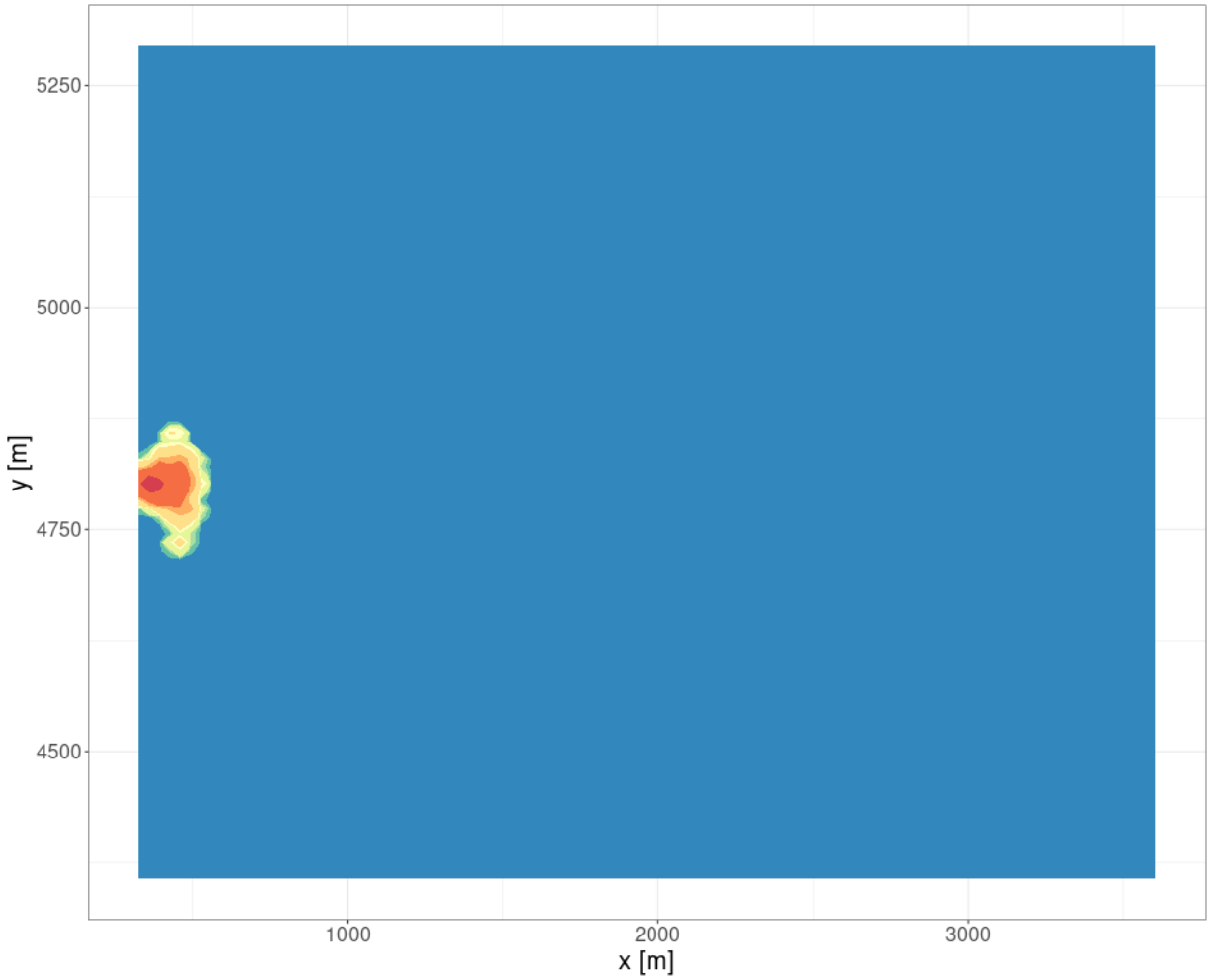
$$ds \sim \mathcal{N}(\mu = 0, \sigma = \sqrt{dt})$$

- One-month long simulation
- Only dispersion – no advection
- Varying meteorology
- Perfect reflection at the ground surface and at the top of the planetary boundary layer

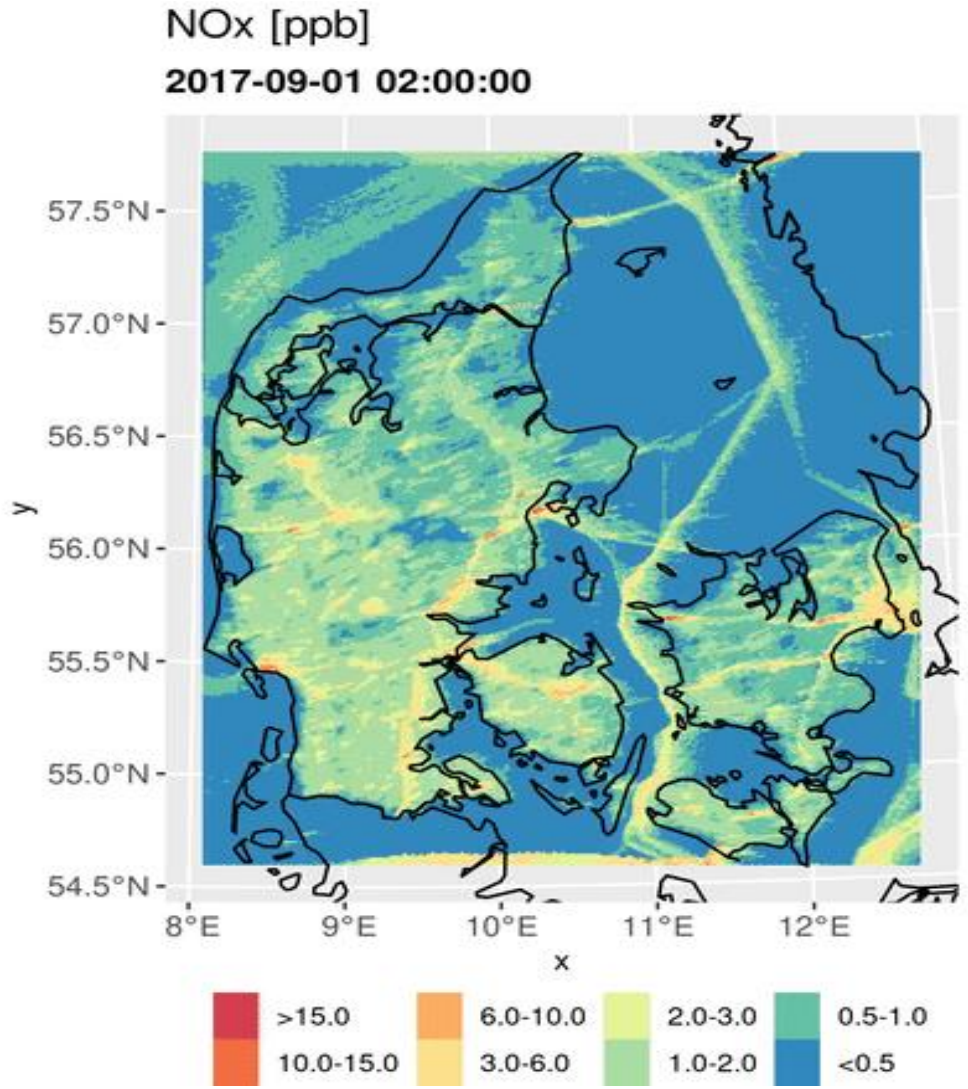


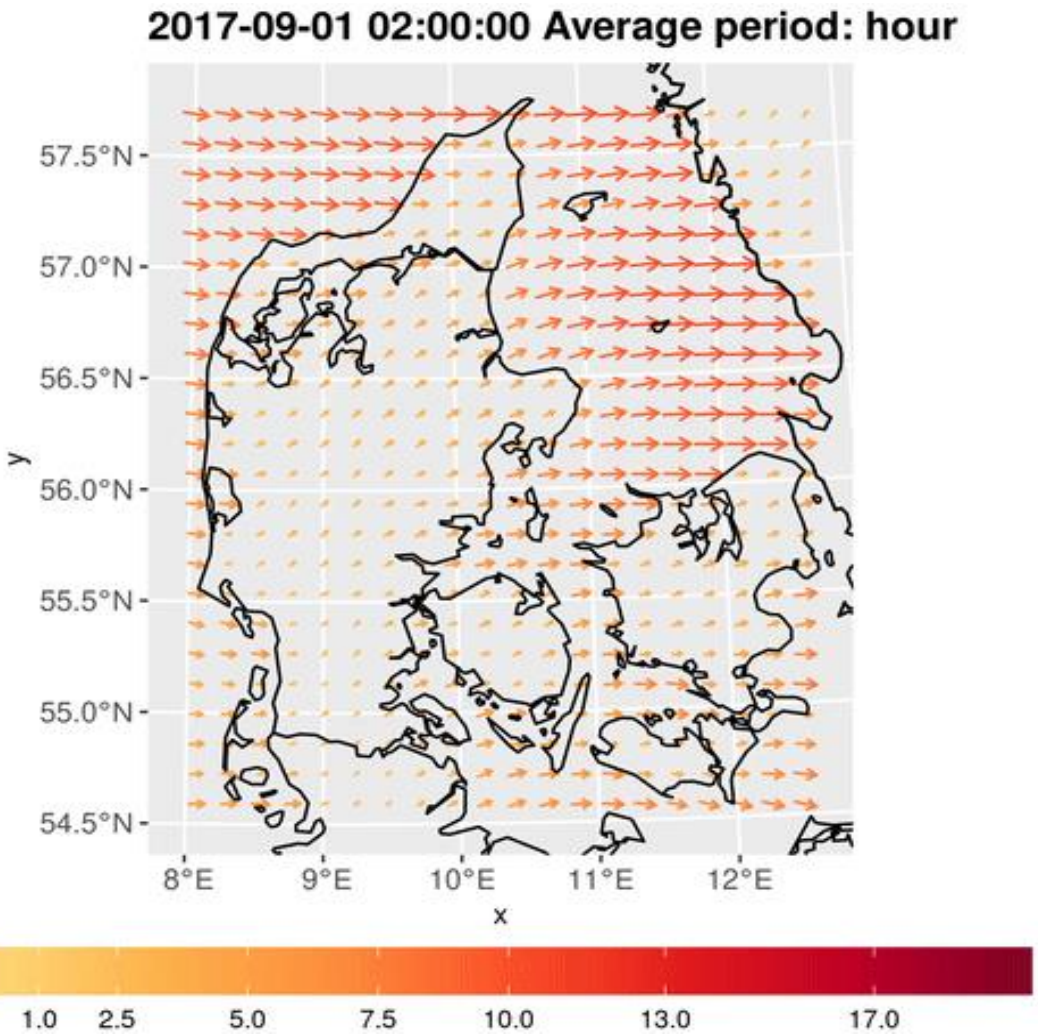
A SINGLE PARTICLE SOURCE



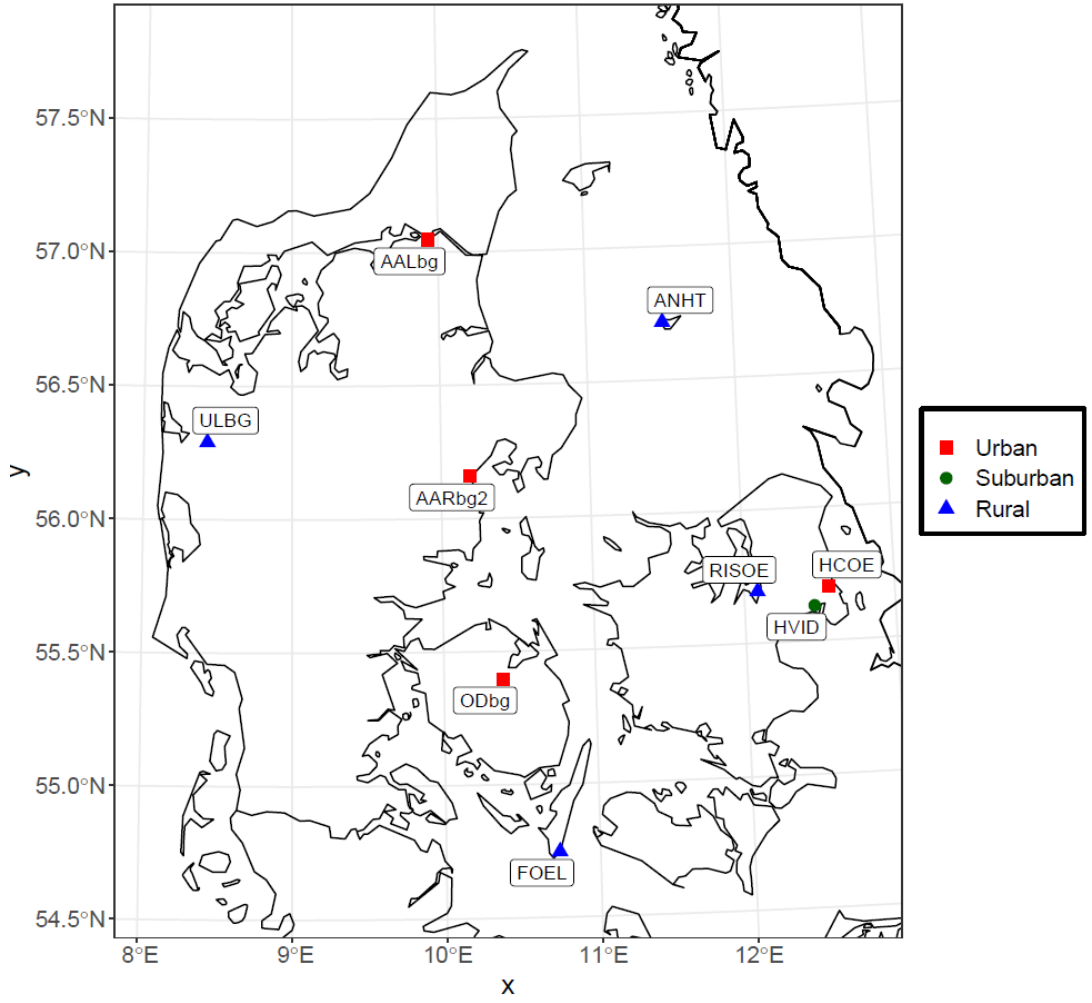


UBML-SIMULATION





MODEL VALIDATION

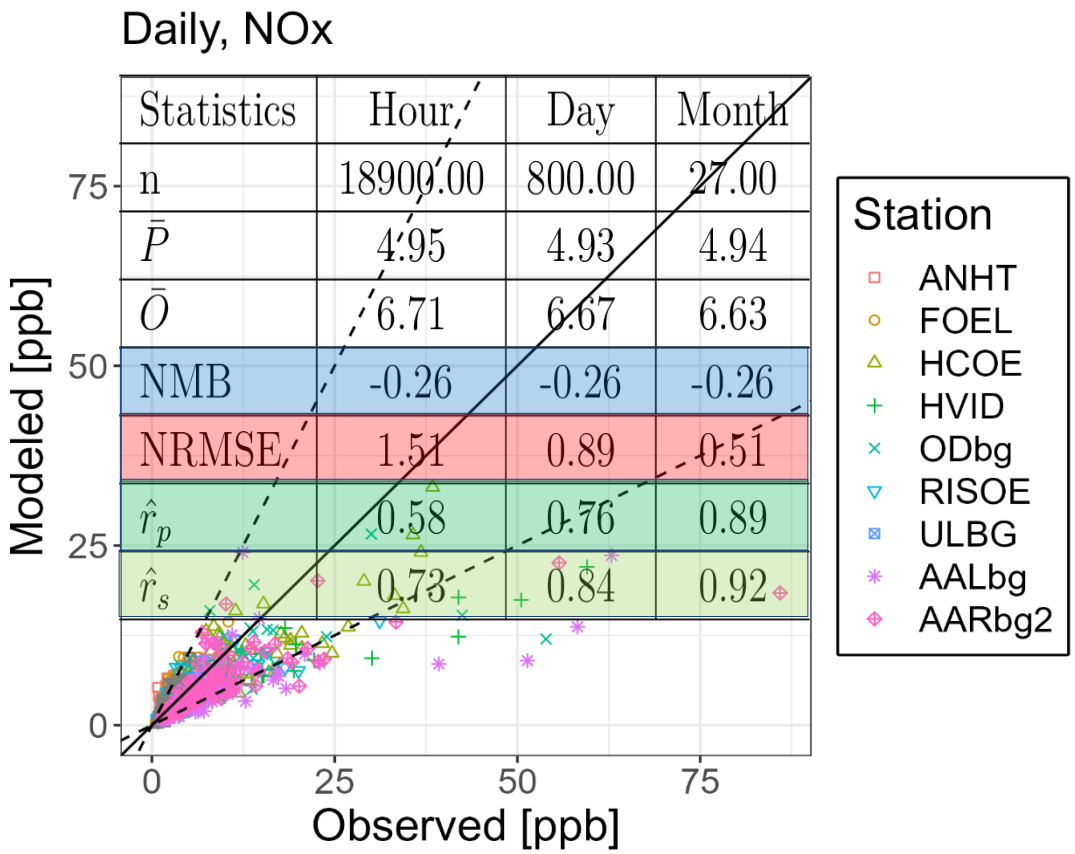


We chose the definition: "*Validation is a demonstration that a model within its domain of applicability possesses a satisfactory range of accuracy consistent with the intended application of the model.*" (Rykiel Jr., 1996)

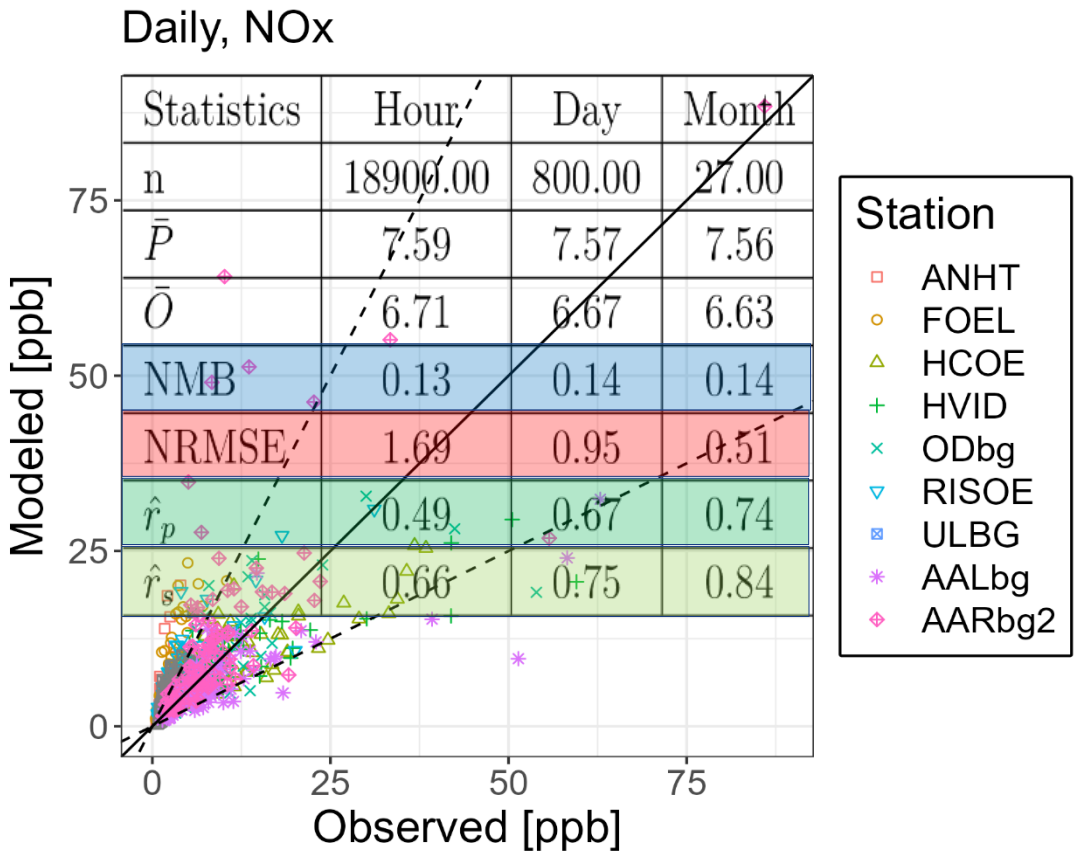
- UBML validation: measurements from the Danish monitoring network, available from the 1990s:
  - temporal statistics (time series)
  - global statistics (scatter plots)
- Chemical species implemented in UBML:
  - NOx, CO, PM2.5, PM10, EC, OC
- UBML and UBM validated against measurements for three months in 2017, focusing on NOx

MODEL VALIDATION – NOX GLOBAL

UBML – 2017, daily NOx averages:



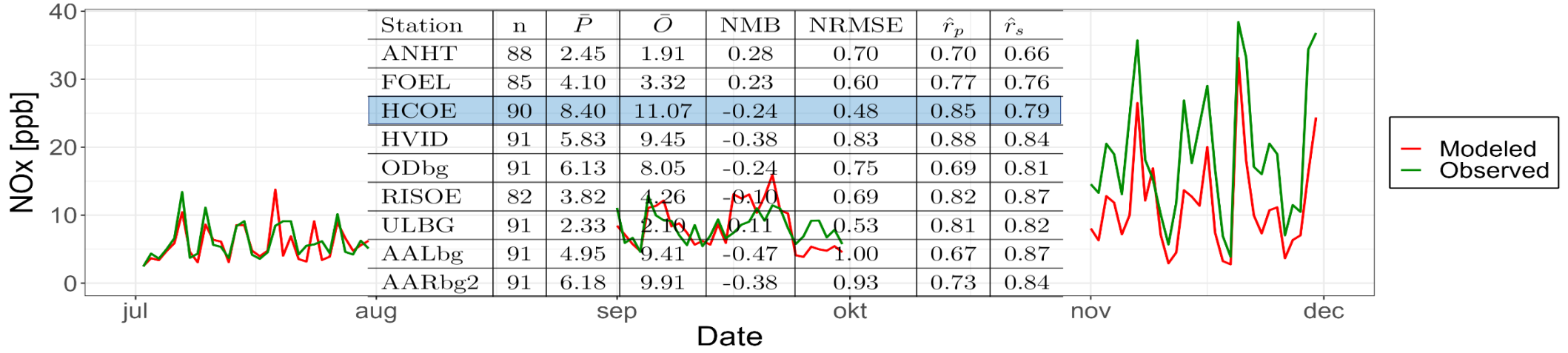
UBM – 2017, daily NOx averages:



MODEL VALIDATION – NOX, HCOE, DAILY

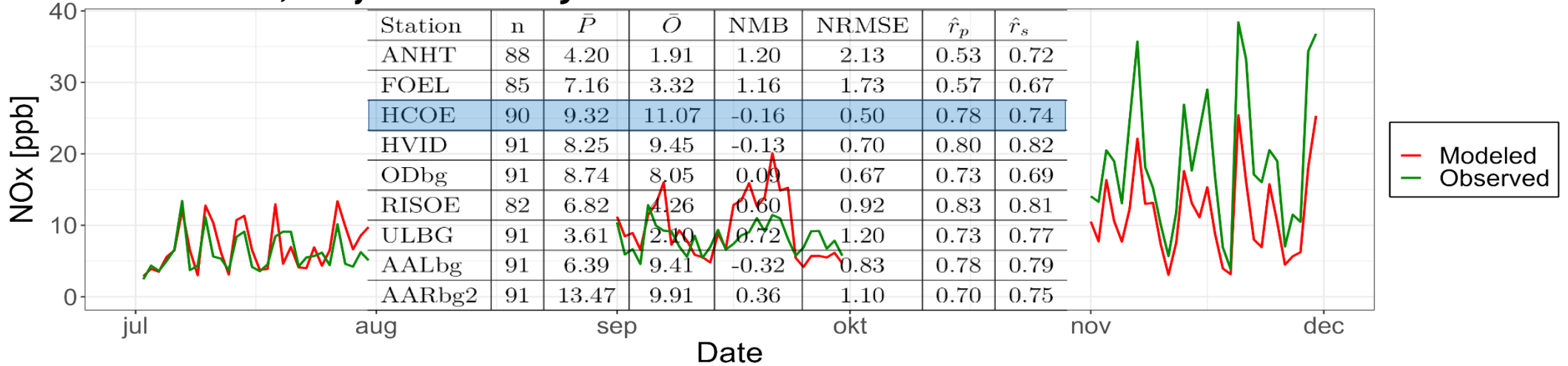
UBML – HCOE 2017, daily NOx averages:

Station	n	$\bar{P}$	$\bar{O}$	NMB	NRMSE	$\hat{r}_p$	$\hat{r}_s$
ANHT	88	2.45	1.91	0.28	0.70	0.70	0.66
FOEL	85	4.10	3.32	0.23	0.60	0.77	0.76
HCOE	90	8.40	11.07	-0.24	0.48	0.85	0.79
HVID	91	5.83	9.45	-0.38	0.83	0.88	0.84
ODbg	91	6.13	8.05	-0.24	0.75	0.69	0.81
RISOE	82	3.82	4.26	-0.10	0.69	0.82	0.87
ULBG	91	2.33	2.10	0.11	0.53	0.81	0.82
AALbg	91	4.95	9.41	-0.47	1.00	0.67	0.87
AARbg2	91	6.18	9.91	-0.38	0.93	0.73	0.84



UBM – HCOE 2017, daily NOx averages:

Station	n	$\bar{P}$	$\bar{O}$	NMB	NRMSE	$\hat{r}_p$	$\hat{r}_s$
ANHT	88	4.20	1.91	1.20	2.13	0.53	0.72
FOEL	85	7.16	3.32	1.16	1.73	0.57	0.67
HCOE	90	9.32	11.07	-0.16	0.50	0.78	0.74
HVID	91	8.25	9.45	-0.13	0.70	0.80	0.82
ODbg	91	8.74	8.05	0.09	0.67	0.73	0.69
RISOE	82	6.82	4.26	0.60	0.92	0.83	0.81
ULBG	91	3.61	2.10	0.72	1.20	0.73	0.77
AALbg	91	6.39	9.41	-0.32	0.83	0.78	0.79
AARbg2	91	13.47	9.91	0.36	1.10	0.70	0.75



MODEL VALIDATION – NOX, FOEL, DAILY

UBML – FOEL 2017, daily NOx averages:

Station	n	$\bar{P}$	$\bar{O}$	NMB	NRMSE	$\hat{r}_p$	$\hat{r}_s$
ANHT	88	2.45	1.91	0.28	0.70	0.70	0.66
FOEL	85	4.10	3.32	0.23	0.60	0.77	0.76
HCOE	90	8.40	11.07	-0.24	0.48	0.85	0.79
HVID	91	5.83	9.45	-0.38	0.83	0.88	0.84
ODbg	91	6.13	8.05	-0.24	0.75	0.69	0.81
RISOE	82	3.82	4.26	-0.10	0.69	0.82	0.87
ULBG	91	2.33	2.10	0.11	0.53	0.81	0.82
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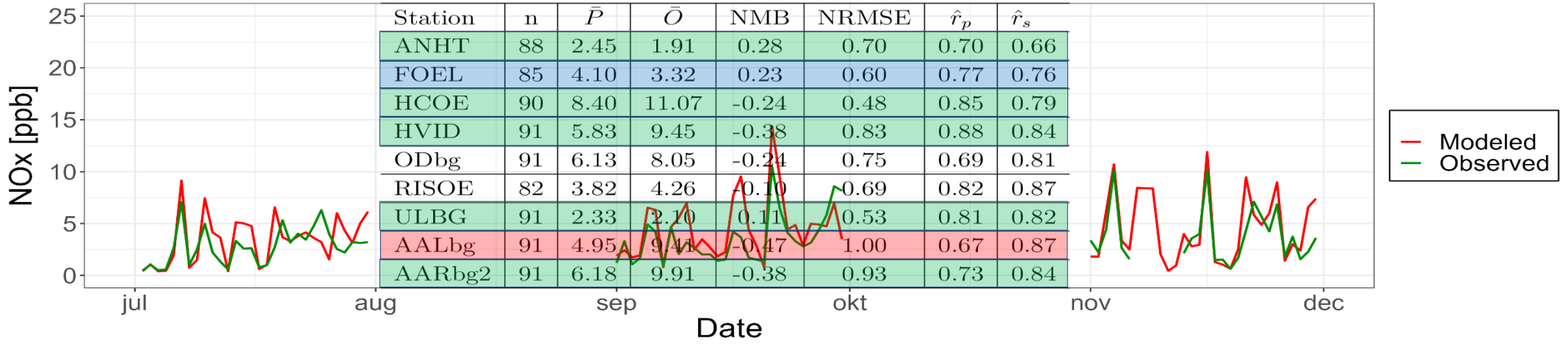

UBM – FOEL 2017, daily NOx averages:

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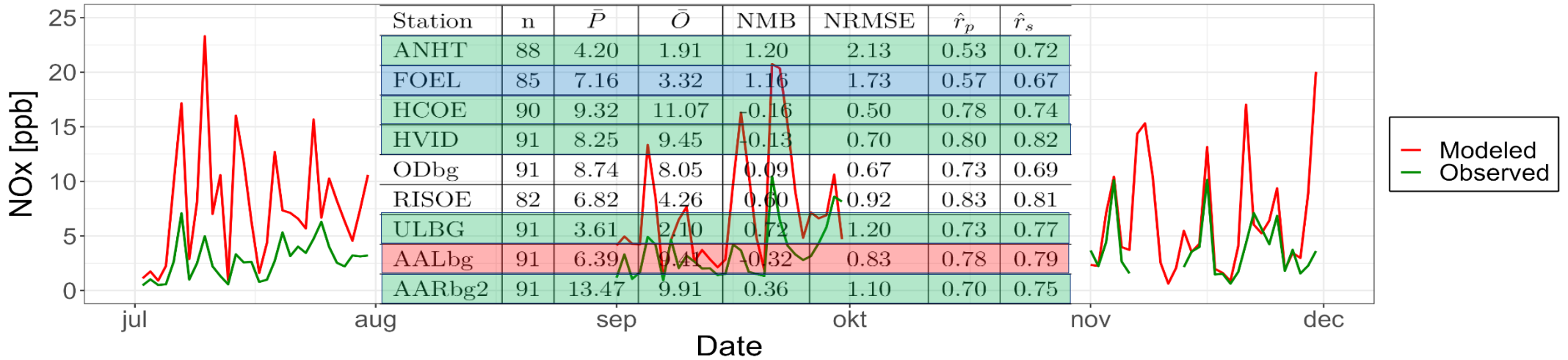
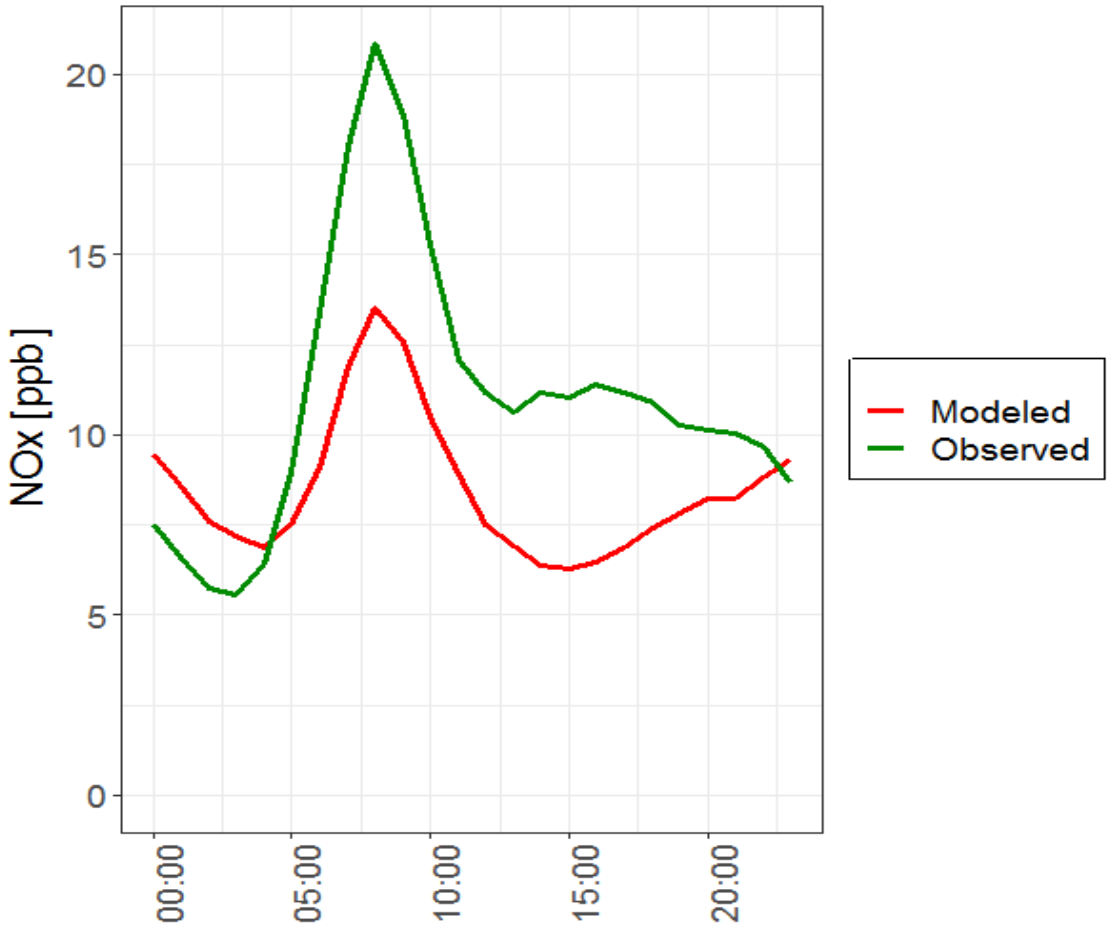
FOEL	85	7.16	3.32	1.16	1.73	0.57	0.67
HCOE	90	9.32	11.07	-0.16	0.50	0.78	0.74
HVID	91	8.25	9.45	-0.13	0.70	0.80	0.82
ODbg	91	8.74	8.05	0.09	0.67	0.73	0.69
RISOE	82	6.82	4.26	0.60	0.92	0.83	0.81
ULBG	91	3.61	2.10	0.72	1.20	0.73	0.77
AALbg	91	6.39	9.41	-0.32	0.83	0.78	0.79
AARbg2	91	13.47	9.91	0.36	1.10	0.70	0.75

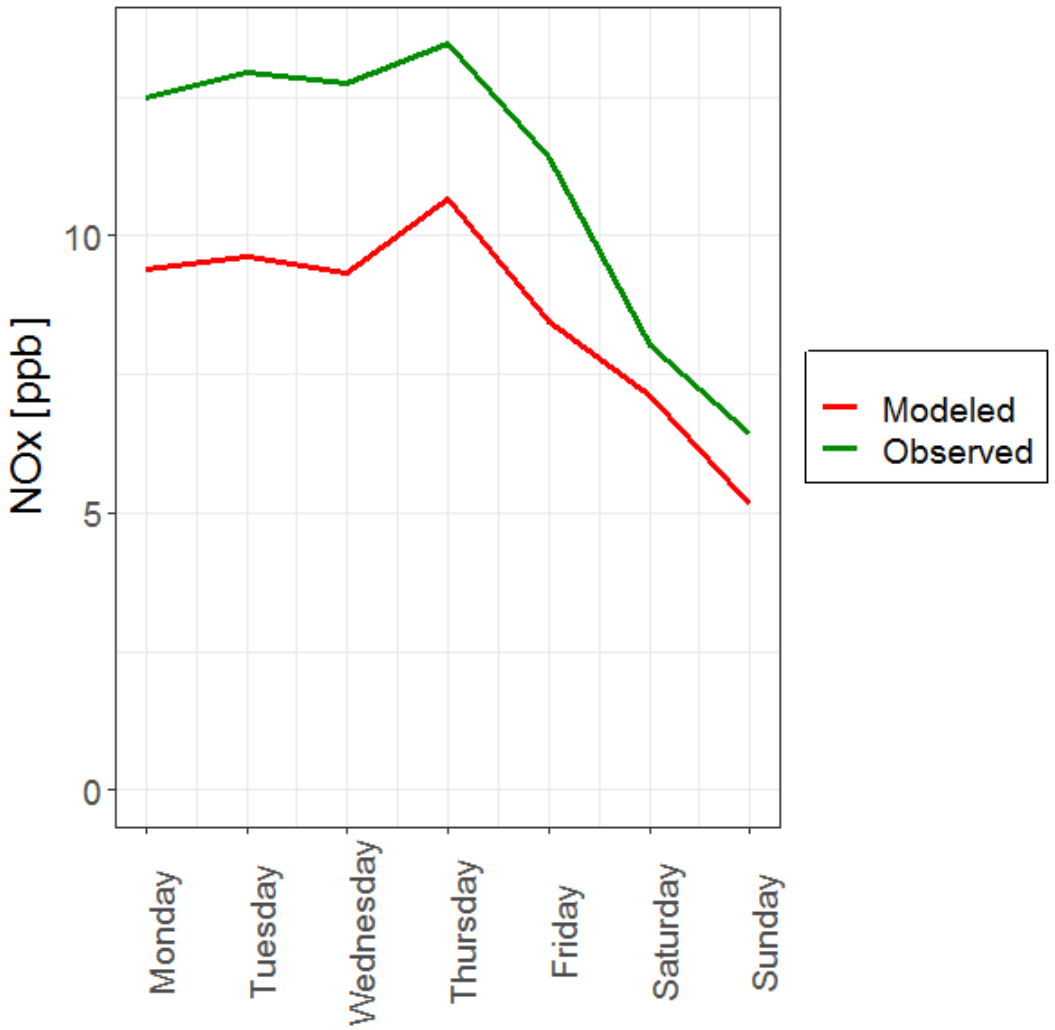


MODEL VALIDATION – NOX TIME VARIATION

UBML - Daily NOx variation - HCOE 2017:



UBML - Weekly NOx variation - HCOE 2017:



CONCLUSION / FUTURE WORK

- UBML has a better performance than UBM when validated against measurements

Future work:

- Better mixing height parameterizations
- Better parameterizations of the time variation of emissions
- Deposition schemes for dry and wet deposition and possibly resuspension
- Lagrangian chemistry module for more species
- Plume rise implementation
- Code optimization
- Longer validations for more species (up to 40 years)

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