

Comparative analysis of ultrafine particles across different sites in Berlin

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Introduction

Ultrafine particles (UFP; <100 nm) are urban air pollutants mainly emitted by combustion sources including traffic, residential heating, and industry. Their small size enables deep respiratory deposition and possible entry into the bloodstream, raising concerns about adverse health effects. Particle number concentration (PNC) characterizes UFP exposure, yet long-term monitoring remains limited. This study compares UFP at urban-background and traffic-influenced Berlin sites and examines associations with regulatory pollutants, Lung deposited surface area (LDSA), and meteorology.

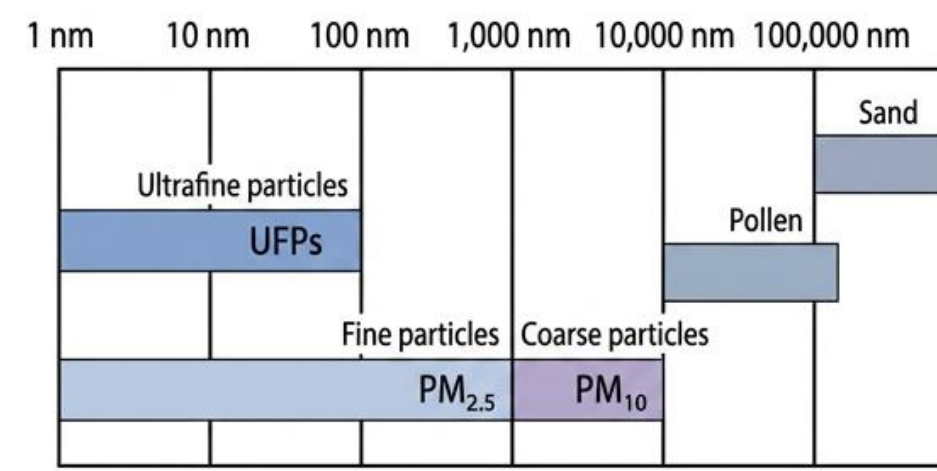


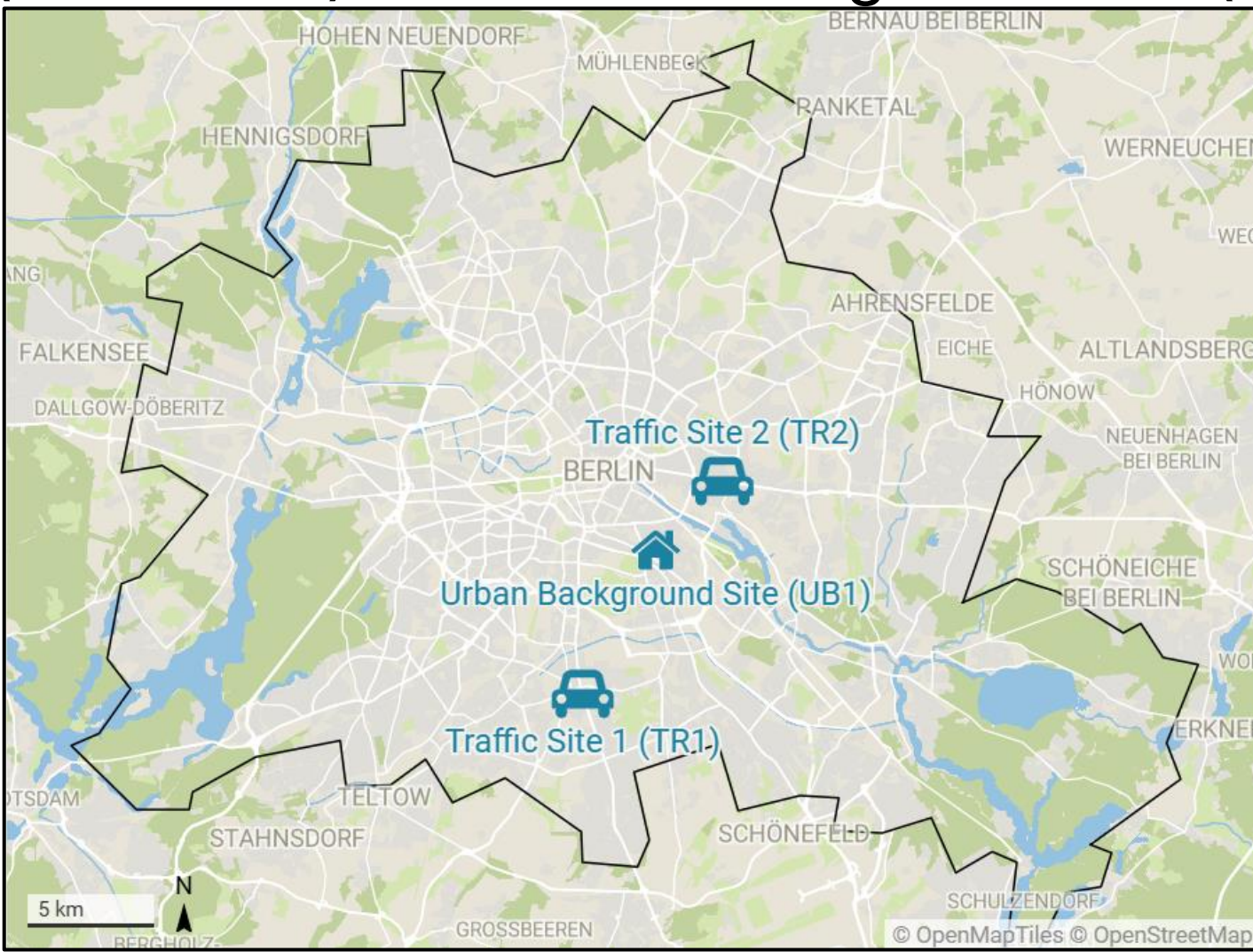
Figure 1. Size comparison of UFPs with fine and coarse particulate matter (PM_{2.5} and PM₁₀).

Objective

- ❖ Compare spatial and temporal patterns of hourly UFP concentrations across urban-background and traffic-influenced sites in Berlin.
- ❖ Characterise diurnal and weekly variability in UFP.
- ❖ Evaluate relationships between UFP, regulatory pollutants, LDSA, and meteorological conditions.
- ❖ Develop site-specific statistical and machine-learning models to assess predictors of hourly UFP.

Study Area

Berlin sites (below) were analyzed to compare traffic sites (TR1 & TR2) and urban background site (UB1)



Methodology

- ❖ UFP concentrations were measured using Airmodus condensation particle counters
- ❖ LDSA was measured using instruments developed by Naneos.
- ❖ Regulatory pollutant data were obtained from the Berlin Air Quality Monitoring Network (BLUME).
- ❖ Meteorological variables were obtained from ERA5 reanalysis data.

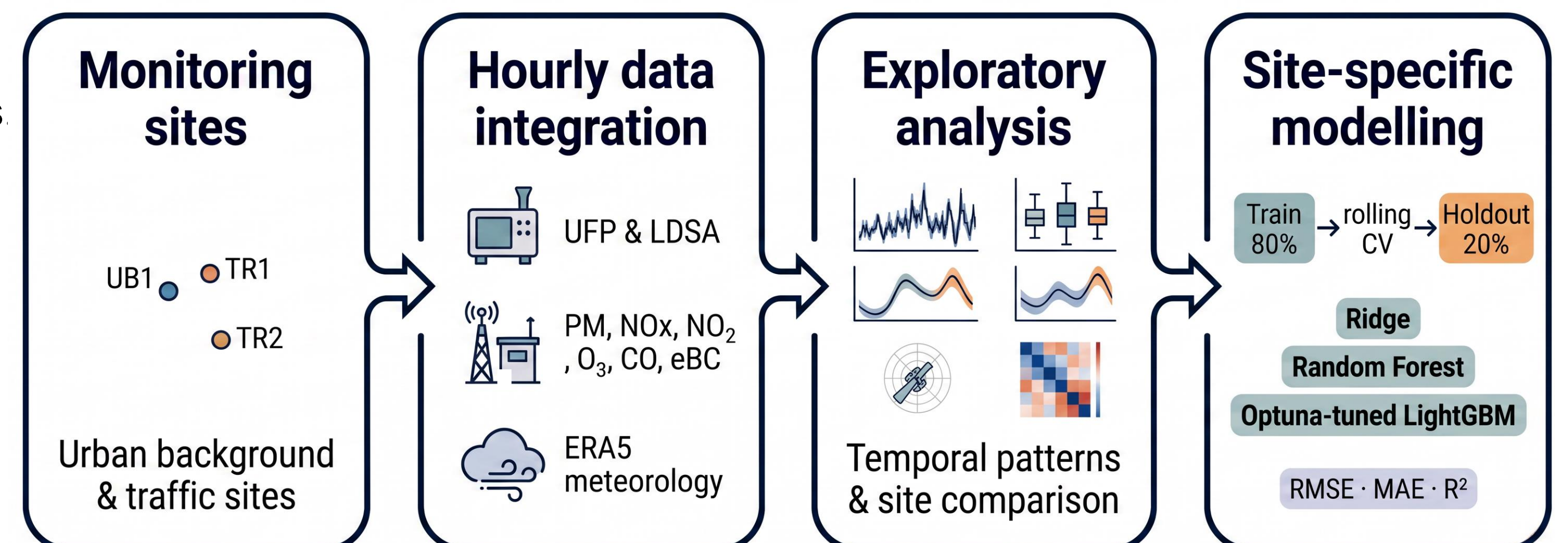


Figure 2. Workflow for site-specific UFP analysis, including multi-parameter data integration, exploratory analysis, and machine-learning model evaluation.

Preliminary Results

Distribution and Trends

- ❖ UFP concentrations differ clearly by site: TR2 has the highest typical levels, UB1 the lowest, and TR1 shows the largest variability and episodic peaks.
- ❖ A clear diurnal pattern is observed, with UFP concentrations generally rising from morning to evening.
- ❖ UFP concentrations are generally lower during weekends than on weekdays.
- ❖ Data coverage is intermittent due to technical issues. Therefore, the observed temporal patterns should be considered preliminary.

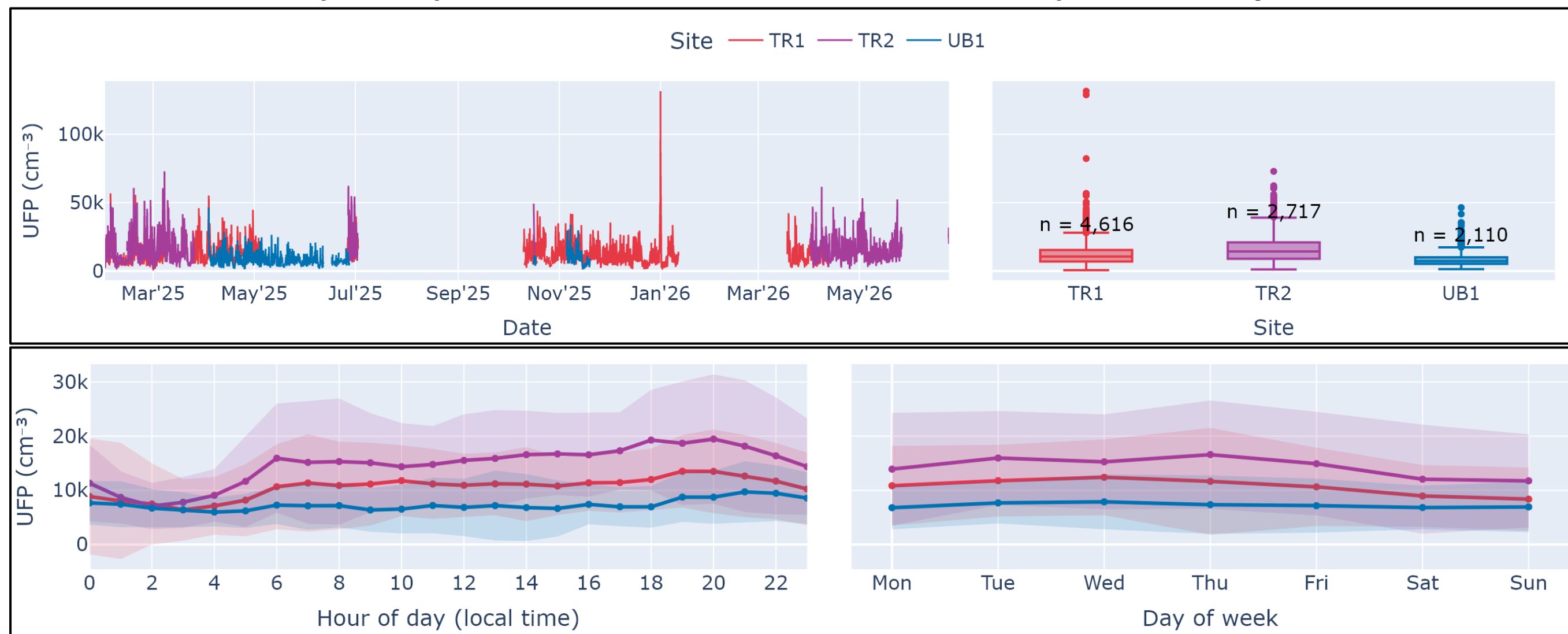


Figure 3. UFP variability across sites: (a) time series and distributions; (b) diurnal and weekly patterns.

Association and Transport

- ❖ At TR1, high-UFP events are linked to northerly-easterly winds; TR2 shows westerly low-UFP and easterly high-UFP occurrences.
- ❖ At UB1, high-UFP events occur mainly under easterly and northwesterly winds, showing site-specific wind-direction patterns.
- ❖ UFP correlates strongly with LDSA at TR1 and TR2 and is negatively correlated with wind speed and boundary-layer height (BLH), indicating the influence of atmospheric dispersion and vertical mixing processes.

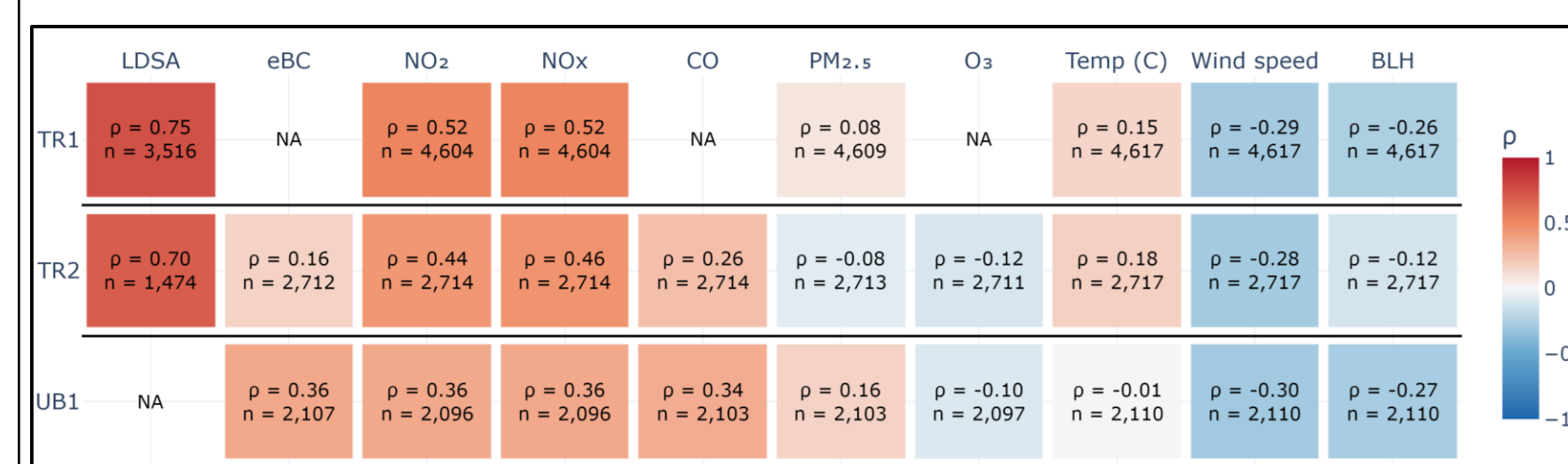


Figure 4. Spearman correlations of UFP with co-pollutants and meteorological variables.

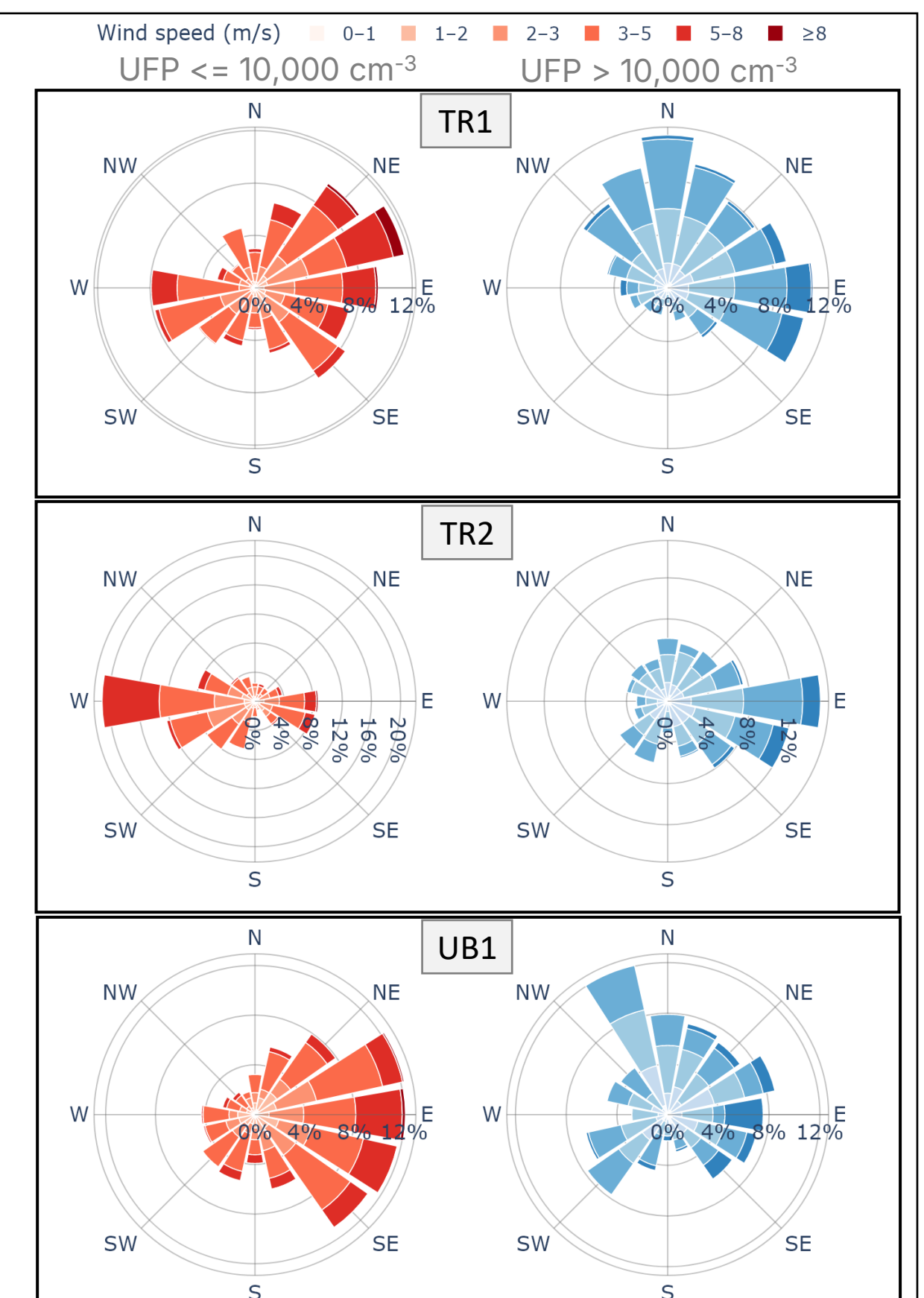


Figure 5. Wind-direction distributions under low (<10,000 cm⁻³) (Left) and high (>10,000 cm⁻³) (Right) UFP conditions across sites.

Modelling

- ❖ LightGBM outperforms Random Forest across all sites, capturing nonlinear UFP relationships more effectively.
- ❖ LDSA is the dominant predictor at TR1 and TR2, while BLH is most important at UB1.
- ❖ NO₂ and NO_x are important secondary predictors, indicating combustion-related influences on UFP variability.
- ❖ Wind direction influences UFP predictions at all sites, especially TR1, highlighting directional source effects.
- ❖ Hour of day contributes notably at TR2 and UB1, reflecting recurring diurnal patterns.

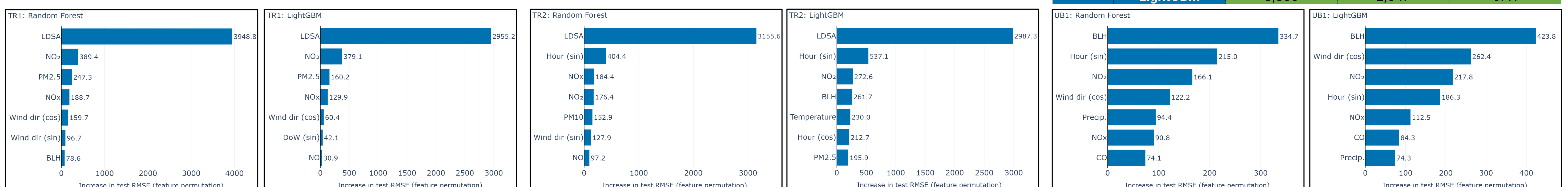


Figure 6. Permutation feature importance for UFP models at TR1, TR2, and UB1 where bars show the increase in test RMSE after feature permutation.

Table 1. Performance of UFP prediction models across sites

Site	Model	RMSE (cm ⁻³)	MAE (cm ⁻³)	R ²
TR1	Ridge	-	-	-
	Random Forest	5,078	3,648	0.43
	LightGBM	4,944	3,545	0.46
TR2	Ridge	9,406	6,971	-0.54
	Random Forest	5,751	4,801	0.42
	LightGBM	5,514	4,525	0.47
UB1	Ridge	6,021	4,016	-0.43
	Random Forest	4,029	2,813	0.36
	LightGBM	3,856	2,647	0.41

Summary and Outlook

- ❖ Preliminary results show clear site-specific UFP variability: LDSA dominates predictions at TR1/TR2, whereas atmospheric mixing (BLH) is more influential at UB1.
- ❖ LightGBM provides the best predictive performance across sites, while pollutant, and meteorological variables provide complementary information on UFP variability.
- ❖ Net4Cities monitoring through 2027 will enable robust seasonal analysis; future modelling will incorporate traffic-count data to improve interpretation of local influences.

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