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Quantifying the gap between Gaussian and CFD dispersion models in complex urban flow

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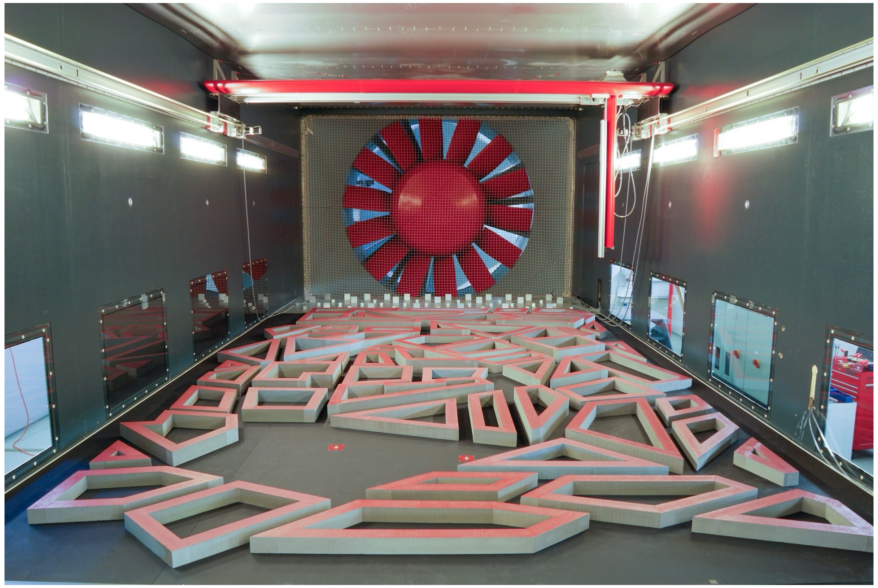
Motivation

- Urban emergency response requires fast, reliable dispersion predictions
- Gaussian plume models are part of the operational standard, but their assumptions break down in dense urban street networks
- CFD offers more physical realism but is too slow for real-time emergency response

How large is the predictive gap, and can we quantify it?



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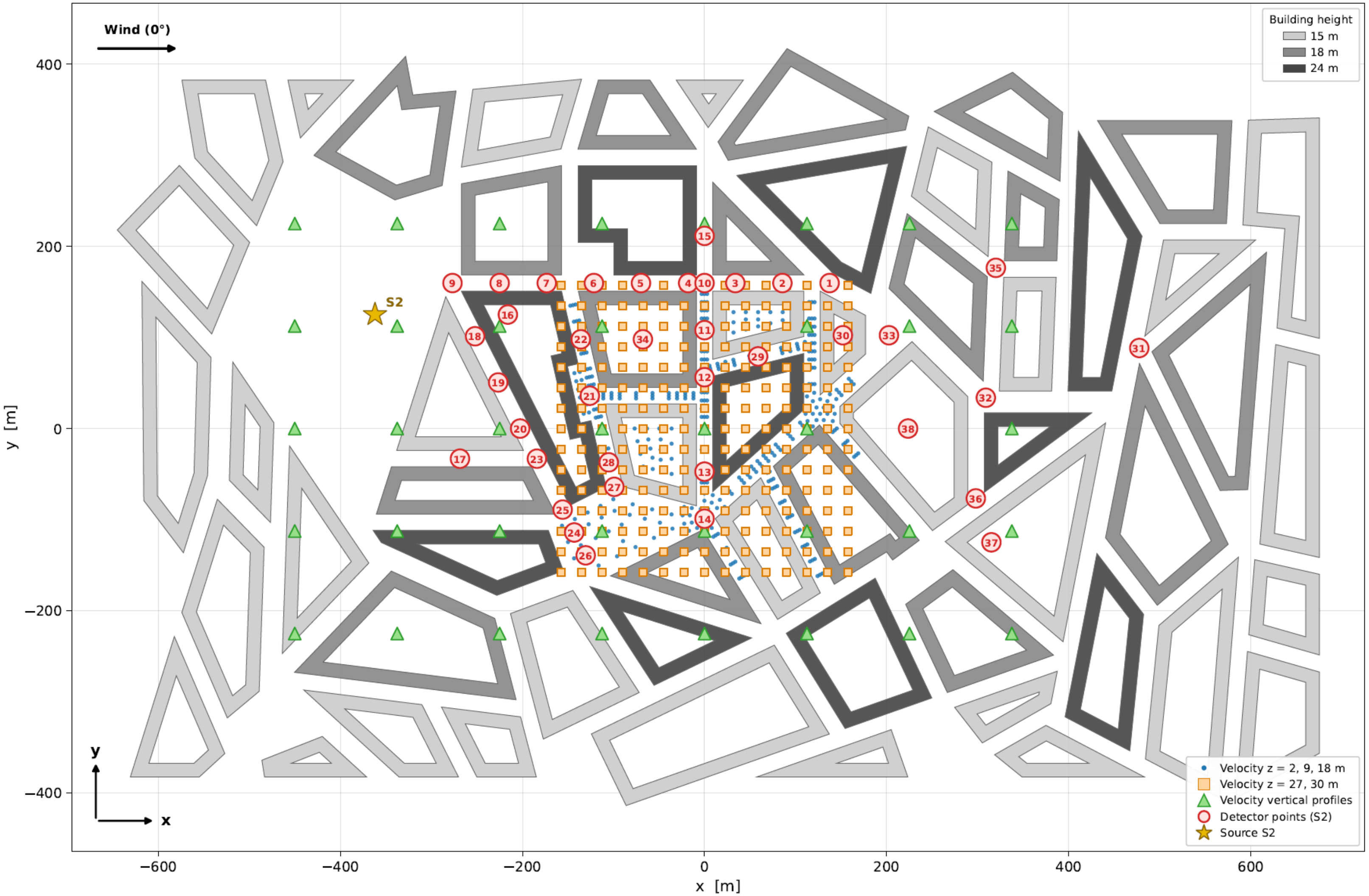
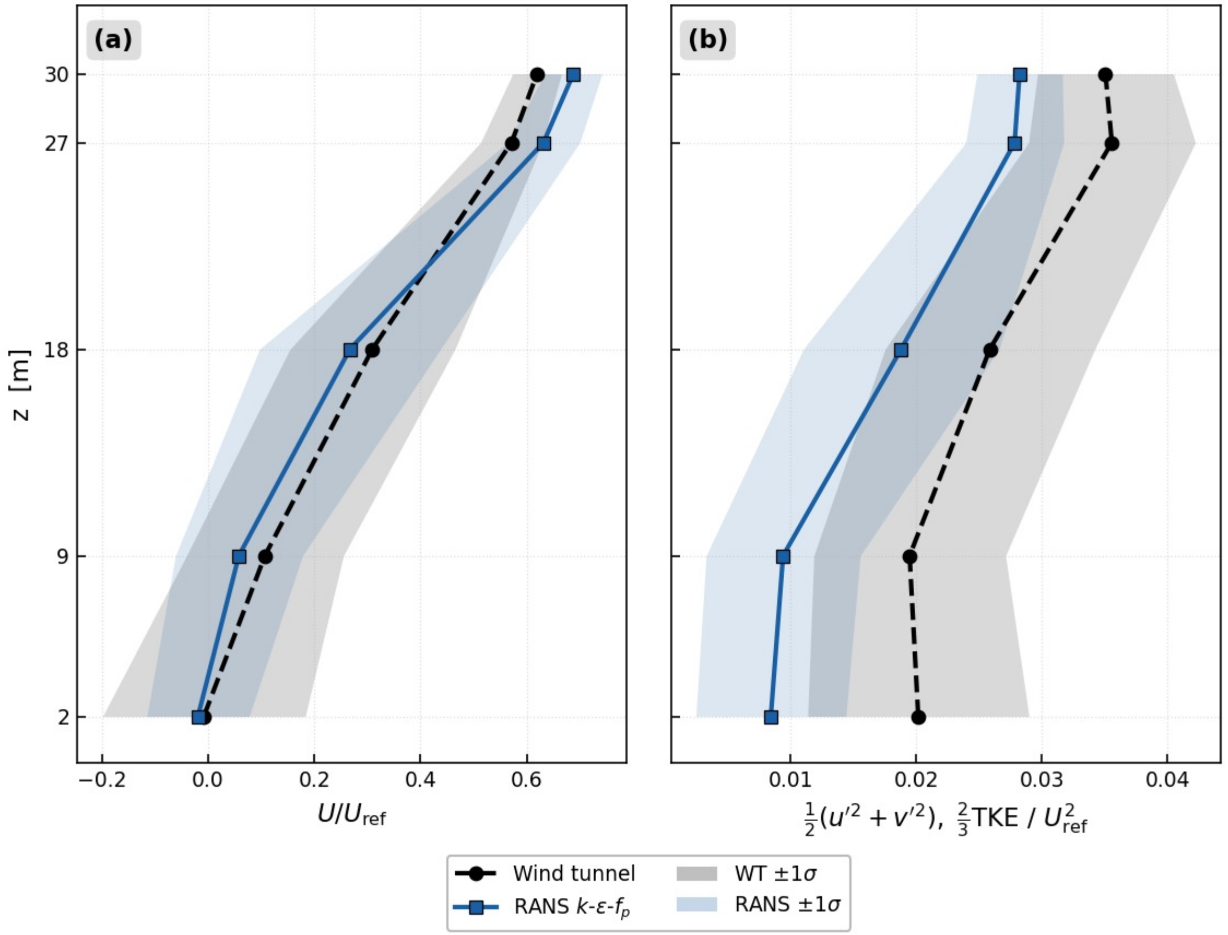
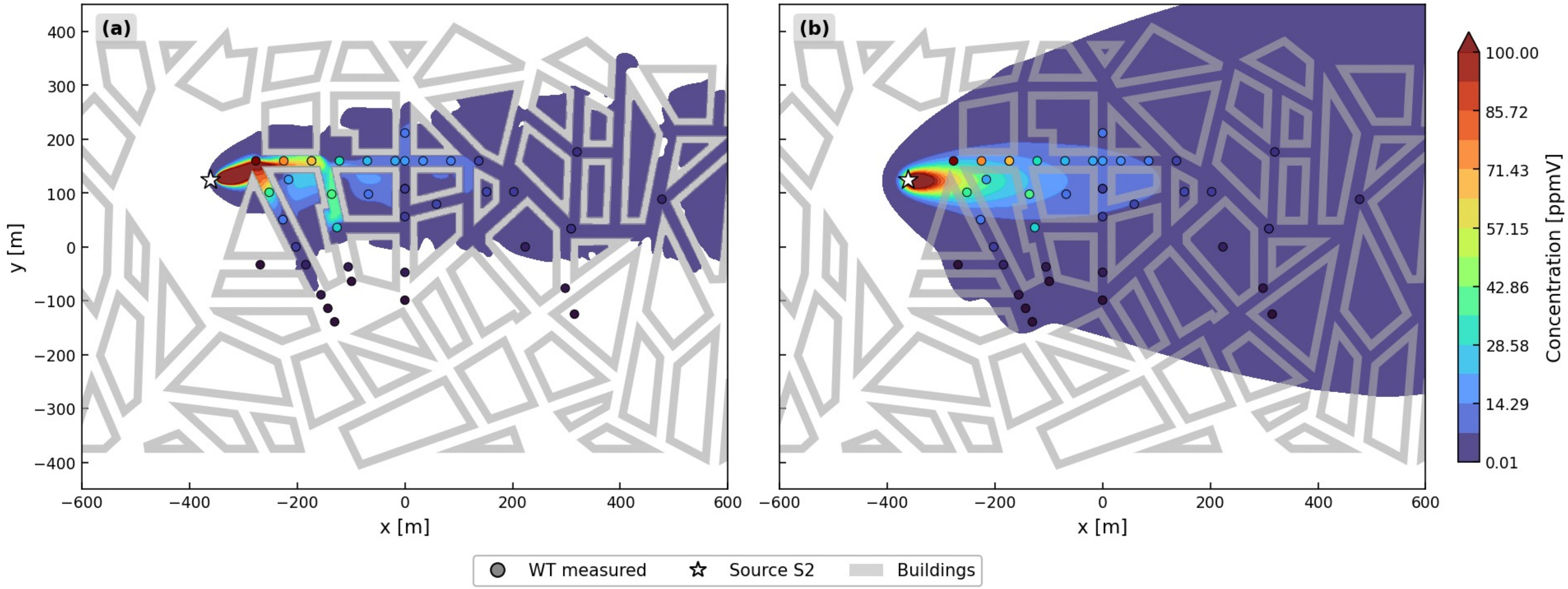


Flowfield comparison



- U_{ref} = 6.0 m/s
- good agreement with wind-tunnel measurements for mean velocity (RMSE = 0.09 U_{ref}, bias ≈ 0) across all heights and locations
- TKE is moderately underestimated (RMSE = 0.011 U_{ref}^2) → possible over-correction from the 2/3 isotropic assumption applied to the 2-component wind-tunnel data

Dispersion Field, z = 7.5 m



- RANS captures building-induced plume channelling compared to the Gaussian puff model, which overestimates lateral spread and misses street-canyon effects

Agreement map

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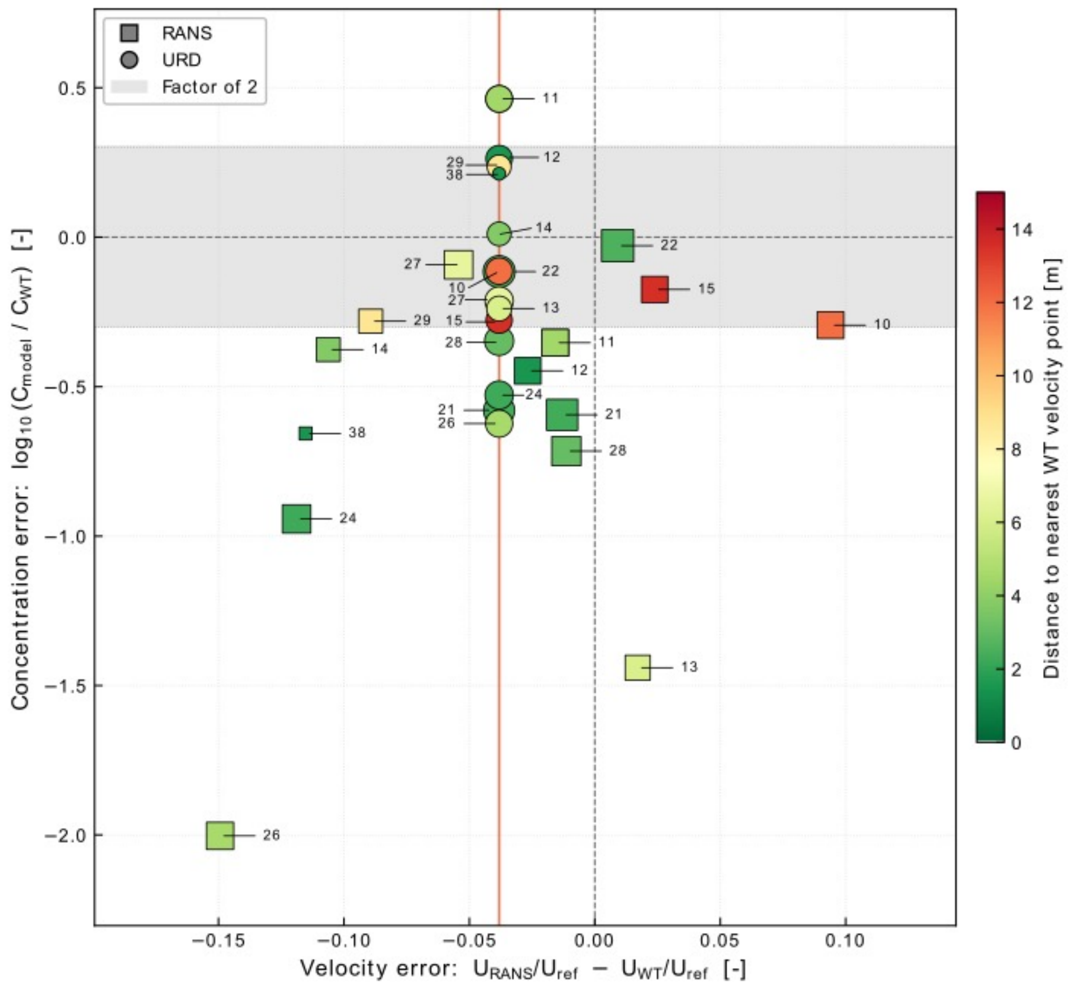
- URD reproduces concentrations within a factor of 2 at most receptor points using a single reference wind speed
- RANS: concentration underprediction is systematic and not clearly correlated with local velocity error, suggesting dispersion performance is driven by factors beyond velocity accuracy alone



Quantitative comparison

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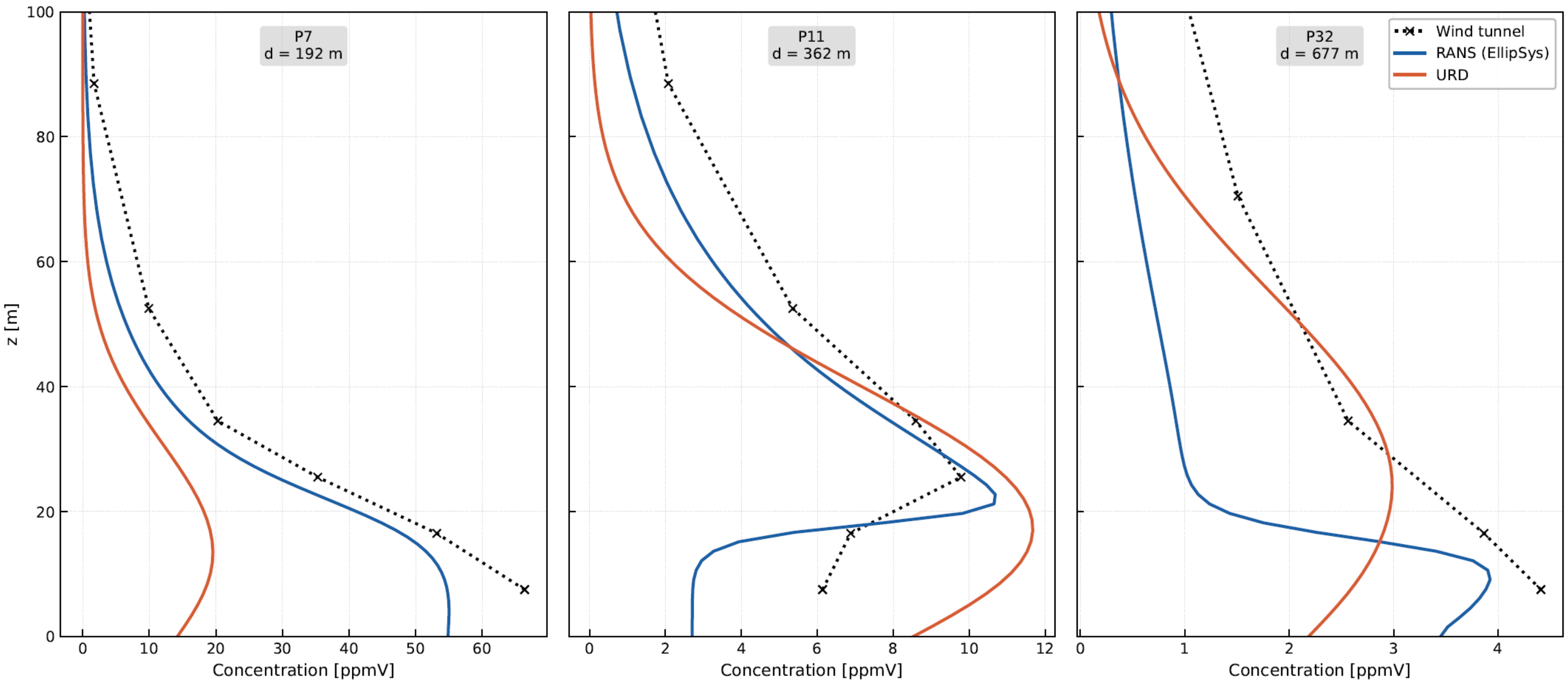
- At receptors with detectable concentration and co-located velocity measurements, URD outperforms RANS (FAC2 = 0.70 vs 0.40), though this subset lies predominantly along URD's main plume axis.

- Off-axis receptors are excluded due to sub-threshold concentrations or absent velocity measurements, limiting the scope of the quantitative comparison.

		RANS			URD		
Point	d [m]	FAC2	FB	NMSE	FAC2	FB	NMSE
P22	228	✓	−0.07	0.00	✓	−0.26	0.07
P21	252	✗	−1.19	2.18	✗	−1.17	2.06
P28	304	✗	−1.35	3.39	✗	−0.76	0.67
P11	362	✗	−0.77	0.70	✗	+0.98	1.25
P10	364	✓	−0.65	0.48	✓	−0.26	0.07
P12	368	✗	−0.95	1.16	✓	+0.59	0.38
P15	372	✓	−0.40	0.16	✓	−0.62	0.42
P13	401	✗	−1.86	25.60	✓	−0.54	0.31
P29	423	✓	−0.63	0.43	✓	+0.53	0.30
P38	599	✗	−1.28	2.76	✓	+0.48	0.24
Overall		0.40	−0.91	0.68	0.70	−0.10	0.59


P7
d = 192 m
P11
d = 362 m
P32
d = 677 m
Wind tunnel
RANS (EllipSys)
URD
z [m]
Concentration [ppmV]
Concentration [ppmV]
Concentration [ppmV]

Take away messages

How large is the predictive gap, and can we quantify it?

- RANS reproduces mean velocity well (RMSE = 0.09 U_ref, bias ≈ 0), with moderate TKE underestimation
- RANS captures building-induced plume channelling while URD produces a smoother, more diffuse plume

- No systematic relationship between velocity error and concentration error was found
- Co-locating velocity and concentration data excluded near source receptor points, retaining only those along the main plume axis (likely disadvantaging RANS in the quantitative comparison)

- Vertical profiles reveal complementary strengths:
  - RANS captures street-canyon structure at mid-distance while URD better reproduces the vertical shape at far-field receptors
  - Neither model fully reproduces near-ground concentrations in the urban canopy

- Future datasets should aim for denser co-located measurements to enable a more complete and unbiased evaluation

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References

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- T. Mikkelsen, S. E. Larsen, S. Thykier-Nielsen, Description of the riso puff diffusion model, NuclearTechnologies 67:1 (1984).