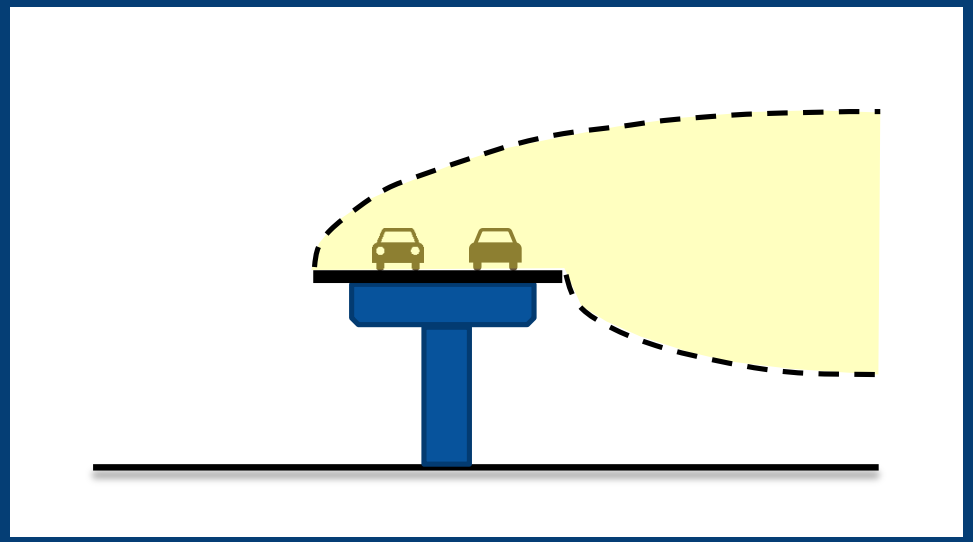
Development and Evaluation of a Model for Pollutant Dispersion from Elevated Roads



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HARMO 20

14-18 June 2021

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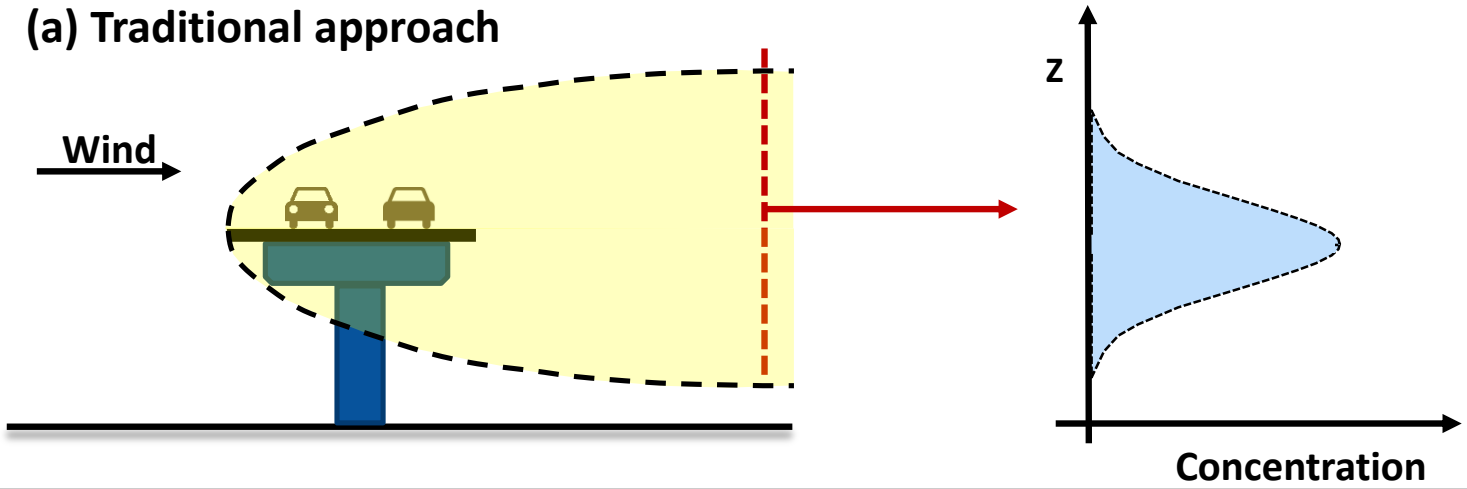
Environmental Software and Services

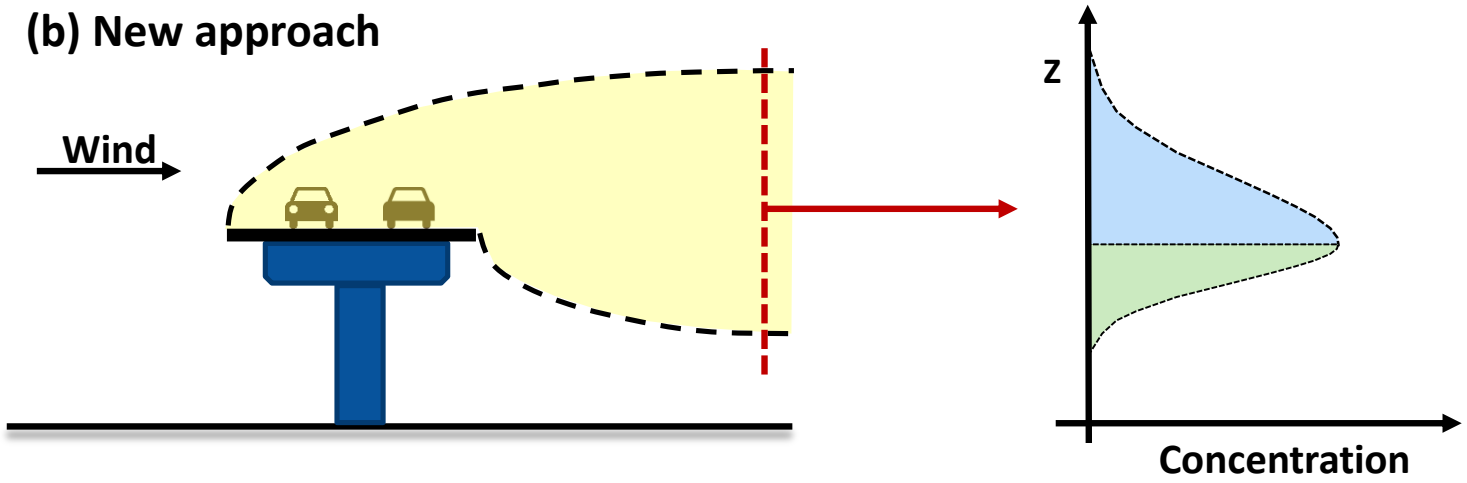
Motivation

(a) Traditional approach



- Plume **disperses freely** through road surface
- Vertical concentration distribution: **Single Gaussian** curve* (with reflections)

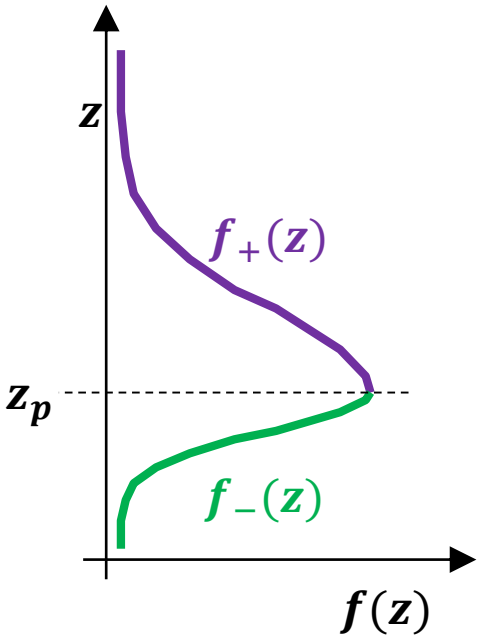
(b) New approach



- Road **surface shielding** - **reduced downward dispersion** until off road edge
- Vertical concentration distribution: **Two half-Gaussians** (with reflections)

*In stable/neutral met. conditions (skewed Gaussian in convective met. conditions)

Methodology



Gaussian models: $C = \frac{Q}{U} f(z) g(y)$

$$f(z) = f_-(z)\big(1 - H(z - z_p)\big) + f_+(z) H(z - z_p)$$

H – Heaviside step function

Same amplitude – Ensures continuity

$$f_-(z) = \alpha \exp\left(\frac{-(z - z_p)^2}{2\sigma_{z-}^2}\right)$$

$$f_+(z) = \alpha \exp\left(\frac{-(z - z_p)^2}{2\sigma_{z+}^2}\right)$$

Different standard deviations (spreads)

Conservation of mass: $\int_{z=-\infty}^{z=z_p} f_-(z)\mathrm{d}z + \int_{z=z_p}^{z=+\infty} f_+(z)\mathrm{d}z = 1 \quad \Rightarrow \quad \alpha = \frac{2}{\sqrt{2\pi}(\sigma_{z-} + \sigma_{z+})}$

$$f(z) = \frac{2}{\sqrt{2\pi}(\sigma_{z-} + \sigma_{z+})}\left[\exp\left(\frac{-(z - z_p)^2}{2\sigma_{z-}^2}\right)\big(1 - H(z - z_p)\big) + \exp\left(\frac{-(z - z_p)^2}{2\sigma_{z+}^2}\right) H(z - z_p)\right]$$

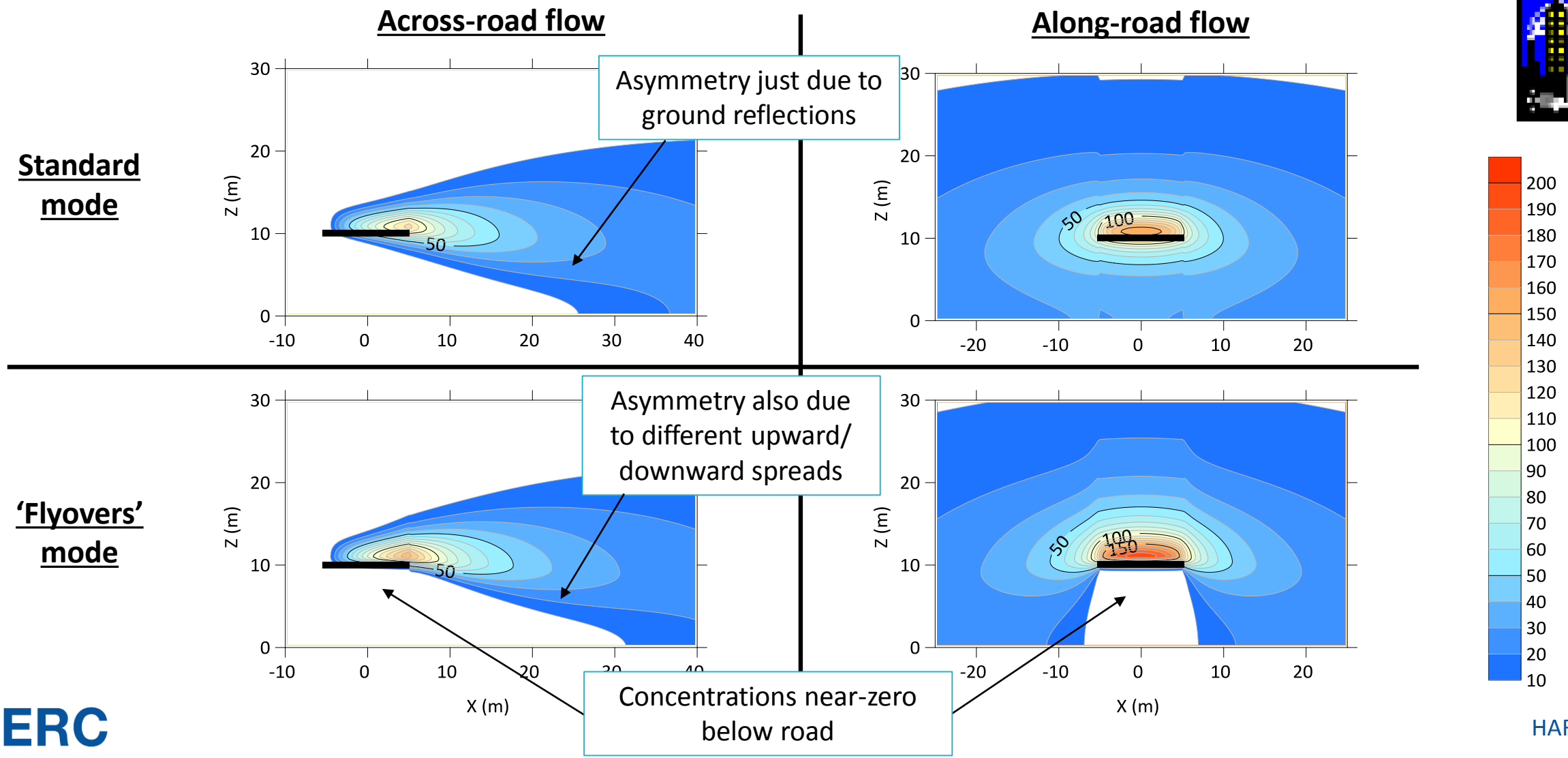
Downward spread (σ_{z-}) limited to 1 m (initial road mixing height) while over road surface

Full derivation includes reflection terms: See Stocker et al. (2020)

Implementation

- New methodology implemented in ADMS – widely used urban dispersion model

v5.0.1



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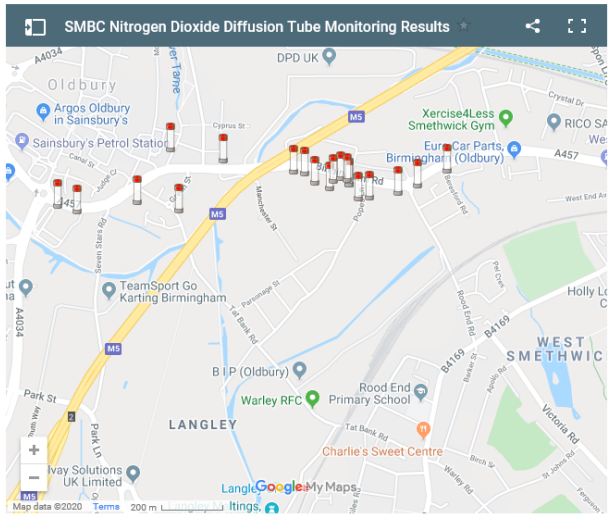
Evaluation: Summary

- Multiple sites used:
  - Two AURN reference monitors next to elevated section of M4, London (UK)
  - Diffusion tube measurements near to elevated M5 section, Birmingham (UK)
  - Limited-duration field measurement campaign near flyover, Antwerp (Belgium)
- Only AURN monitor validation presented here; see Stocker et al. (2020) for others

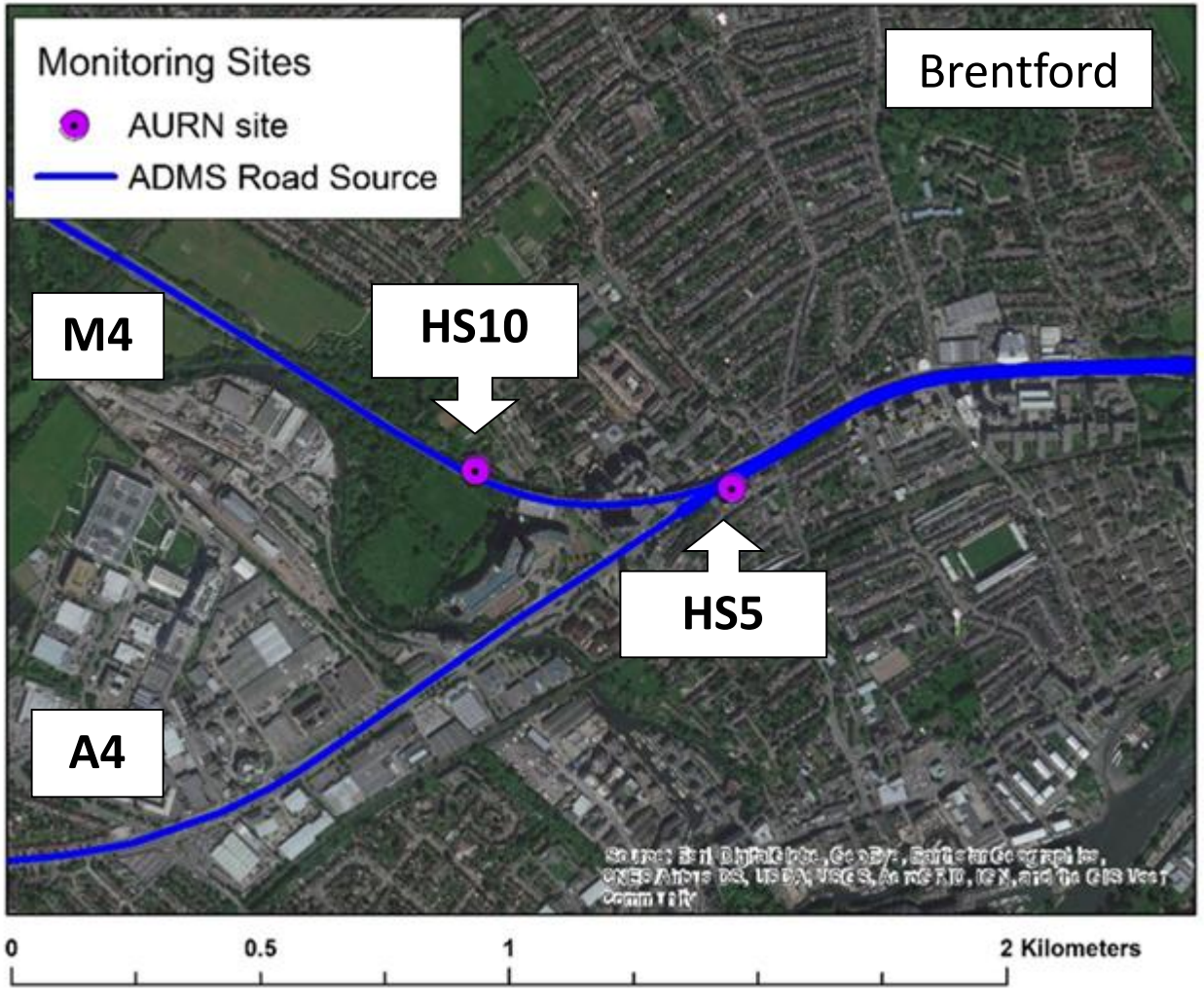
London (ESRI)

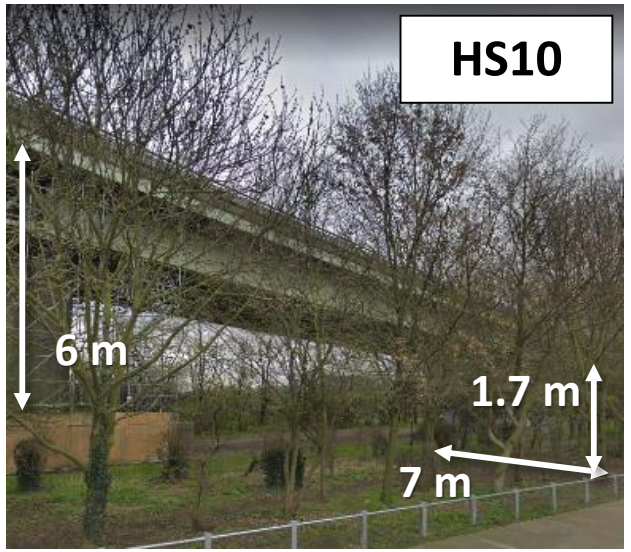


Birmingham (Google Maps)

Antwerp (Van Poppel et al., 2012)

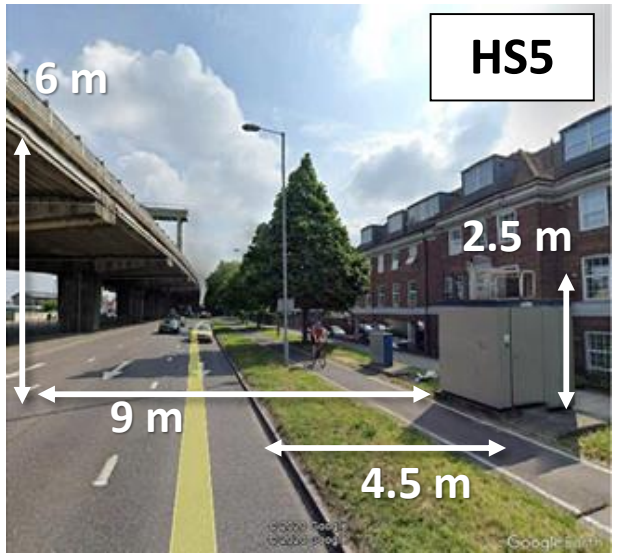
Evaluation: London site





- HS10: Elevated M4 only nearby major road source →

Ideal for validation



- HS5: Elevated M4 and ground level A4 both major road sources → can compare relative impact

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Evaluation: Model setup

ADMS

- **M4** (6m) and **A4** (ground-level) modelled as **explicit** road sources
- Traffic flows:
  - M4: **WebTRIS** data (hourly) used to calculate AADT and hourly emission factors
  - A4: **DfT** traffic data (single 12-hr period). M4 data used to scale to other periods
- Road emissions:
  - Calculated from traffic flow data using **EFT v9.0**
  - Real-world **NOx adjustments** (Hood et al., 2018)
- Other sources: **Volume** (10m), emission rates from **LAEI***
- Background concentrations: wind-direction-dependent combination of 4 '**rural background**' AURN monitors
- Met: Heathrow, **one year** (2019) of hourly data
- GRS Chemistry scheme used
- A4 section modelled as **asymmetric street canyon** (Hood et al., 2021)

HS5

*London Atmospheric Emissions Inventory

Evaluation: Model setup

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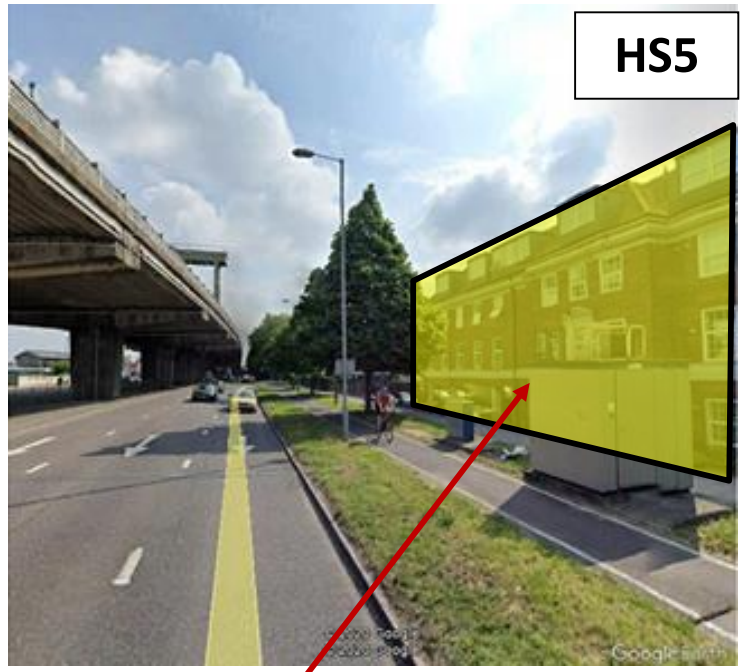


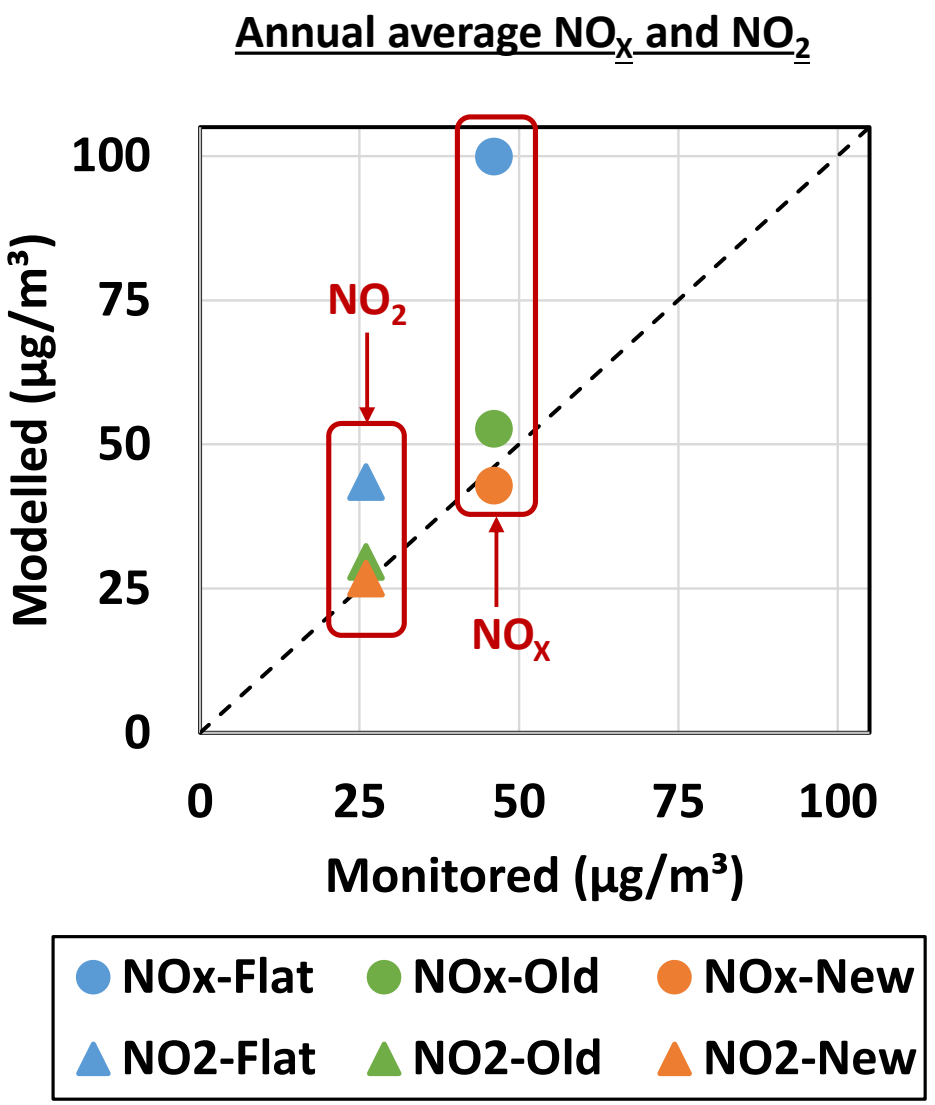
*London Atmospheric Emissions Inventory

Evaluation: HS10 (M4 only) results

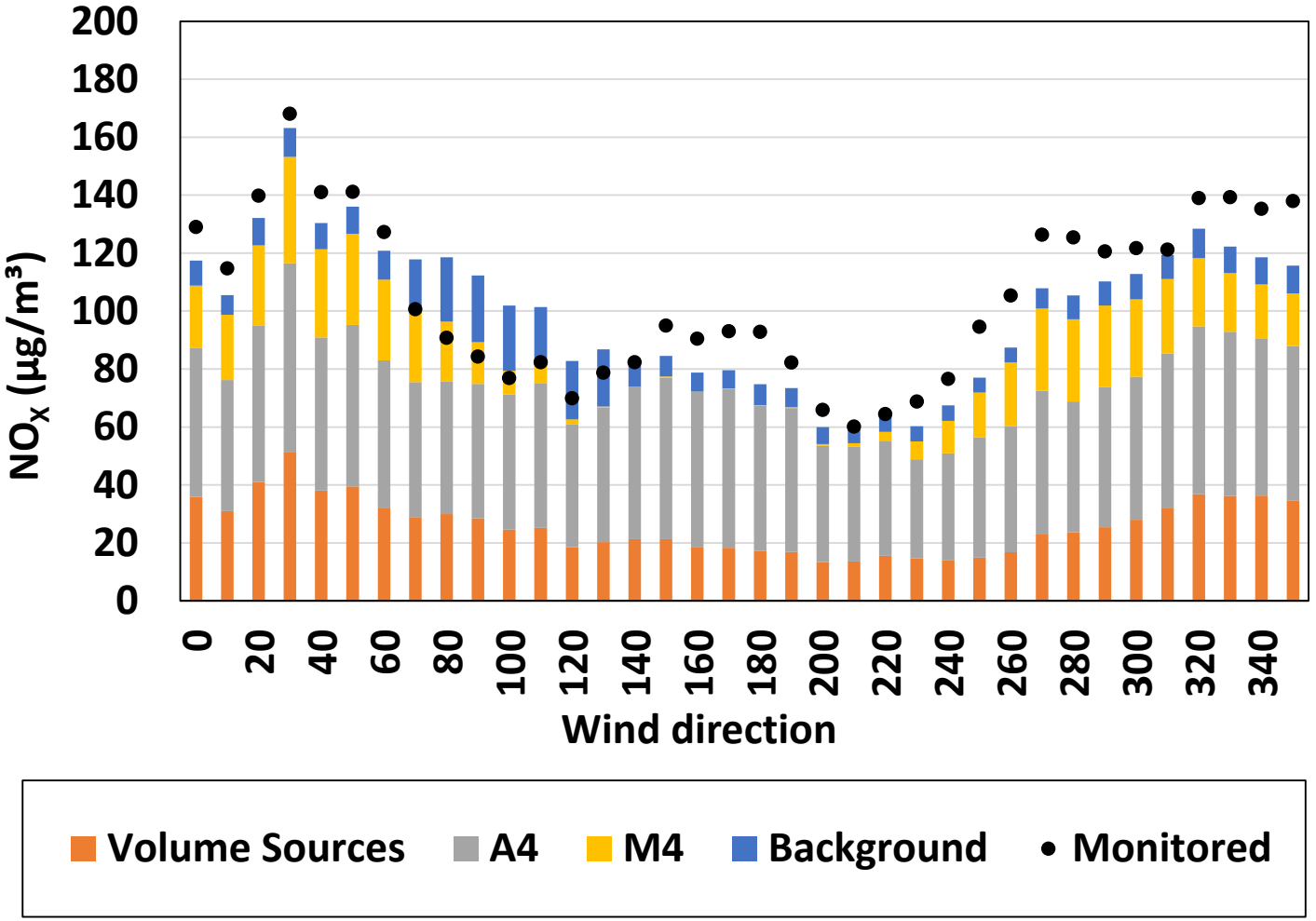
NO_2	NMSE	Correlation	Fac2	fb
Flat	0.872	0.496	0.584	0.503
Old	0.387	0.628	0.785	0.130
New	0.360	0.646	0.802	0.026

NO_X	NMSE	Correlation	Fac2	fb
Flat	2.443	0.344	0.362	0.735
Old	1.211	0.515	0.621	0.131
New	1.285	0.557	0.708	-0.076

- Generally **better statistics** using **new** approach
- Modelling at **elevation vs flat** has much **larger bearing** on accuracy than old vs new approach

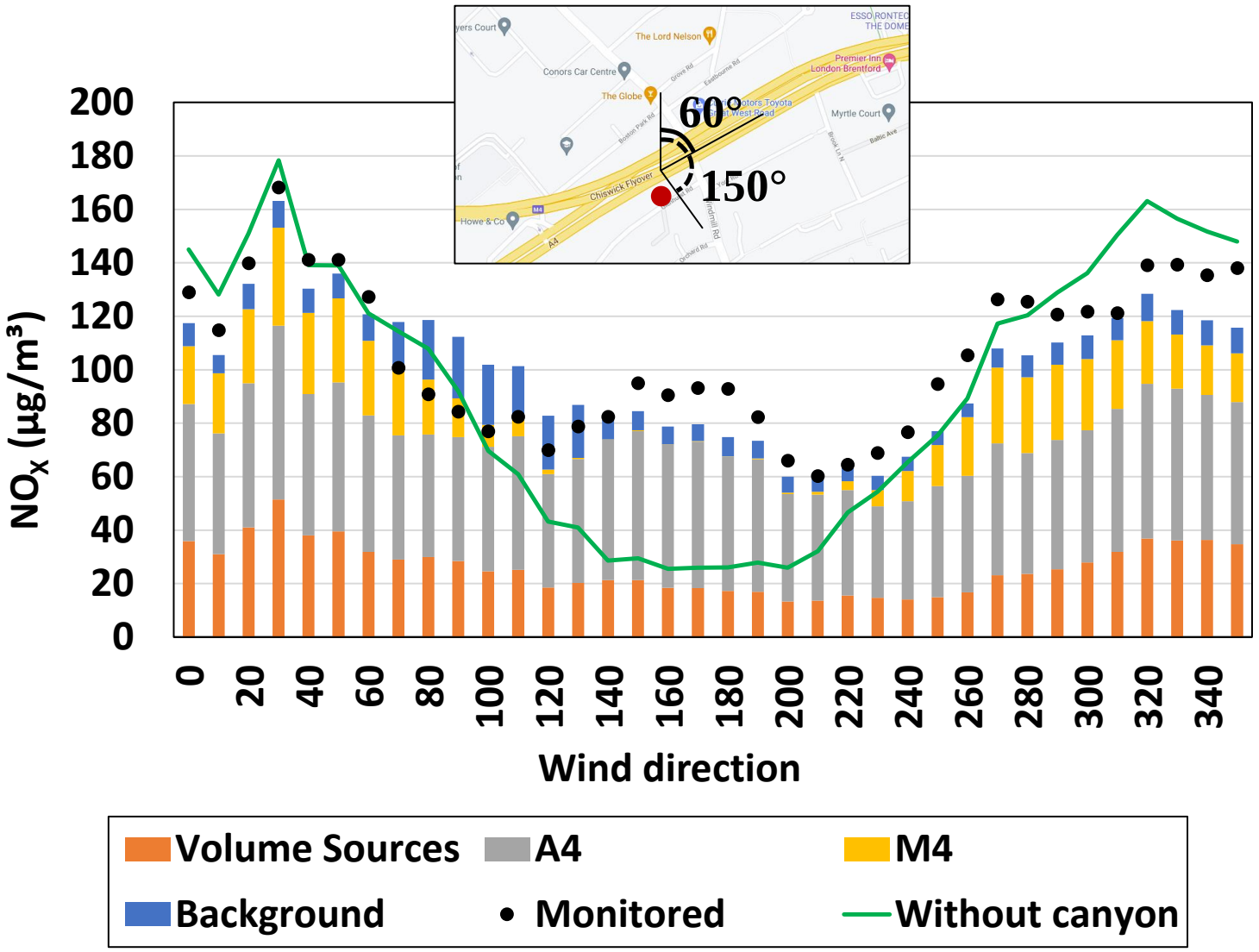


Evaluation: HS5 (M4 and A4) results



- NO_X concentrations **binned** into 10° wind sectors
- **Good overall agreement** with monitored data
- Source apportionment: Significantly **larger contribution** from ground-level A4 than elevated M4 (despite ~1/2 the emissions) due to flyover having:
  - Increased vertical and horizontal source-receptor distance
  - Increased wind speed with elevation → greater dispersion
  - No plume 'folding' until ground-level reflections occur

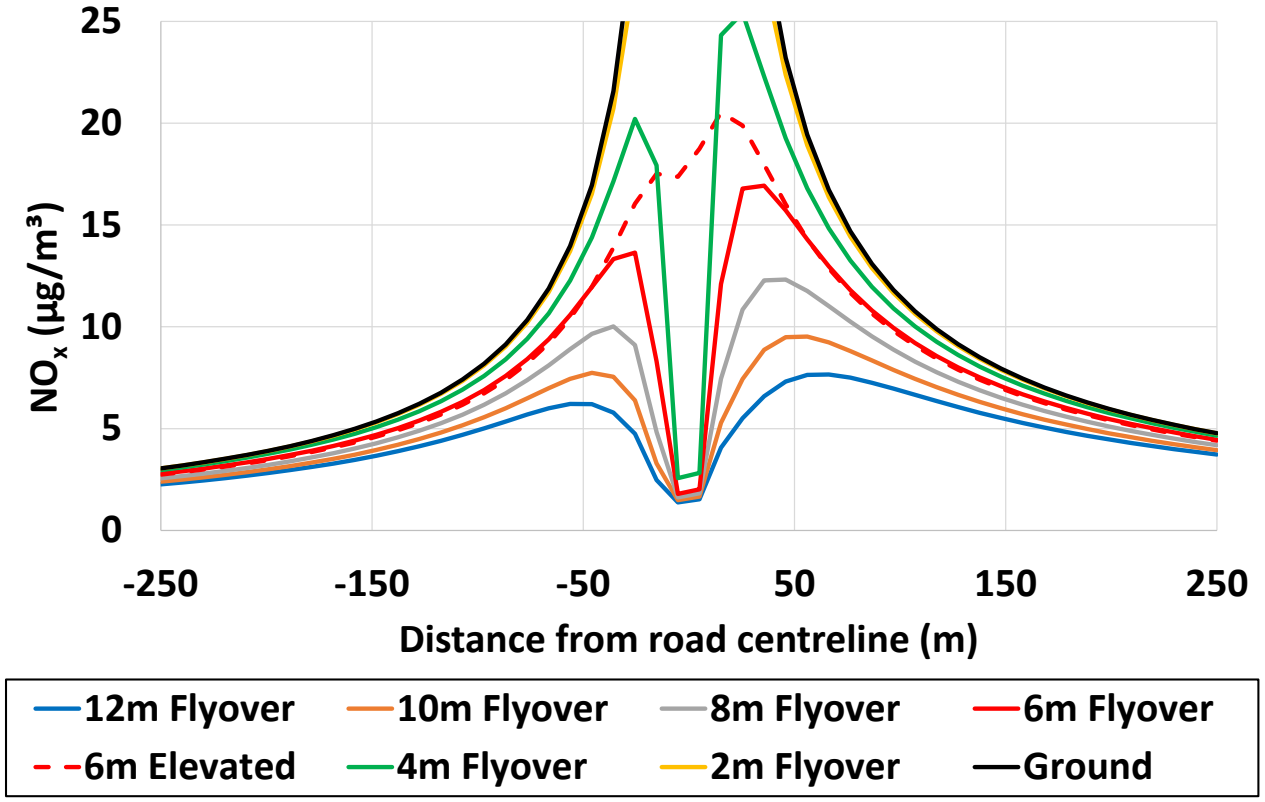
Evaluation: HS5 (M4 and A4) results



- **M4** contribution:
  - **Min**. when wind from **monitor towards road**
  - **Max**. when wind **aligned with road** → plume largely passes **over monitor** when wind from **road to monitor**
- **A4** contribution:
  - Remains fairly **constant**, even when wind from monitor to road → **recirculating cell**
  - Confirmed by running model **without canyon**
- **Elevating roads can mitigate canyon effects** → lower ground-level concentrations

Sensitivity testing

- Same model setup used for HS10 site (M4 only), **multiple road elevations** tested
- Compare near-ground (2m) annual average NOx concs along perpendicular transect



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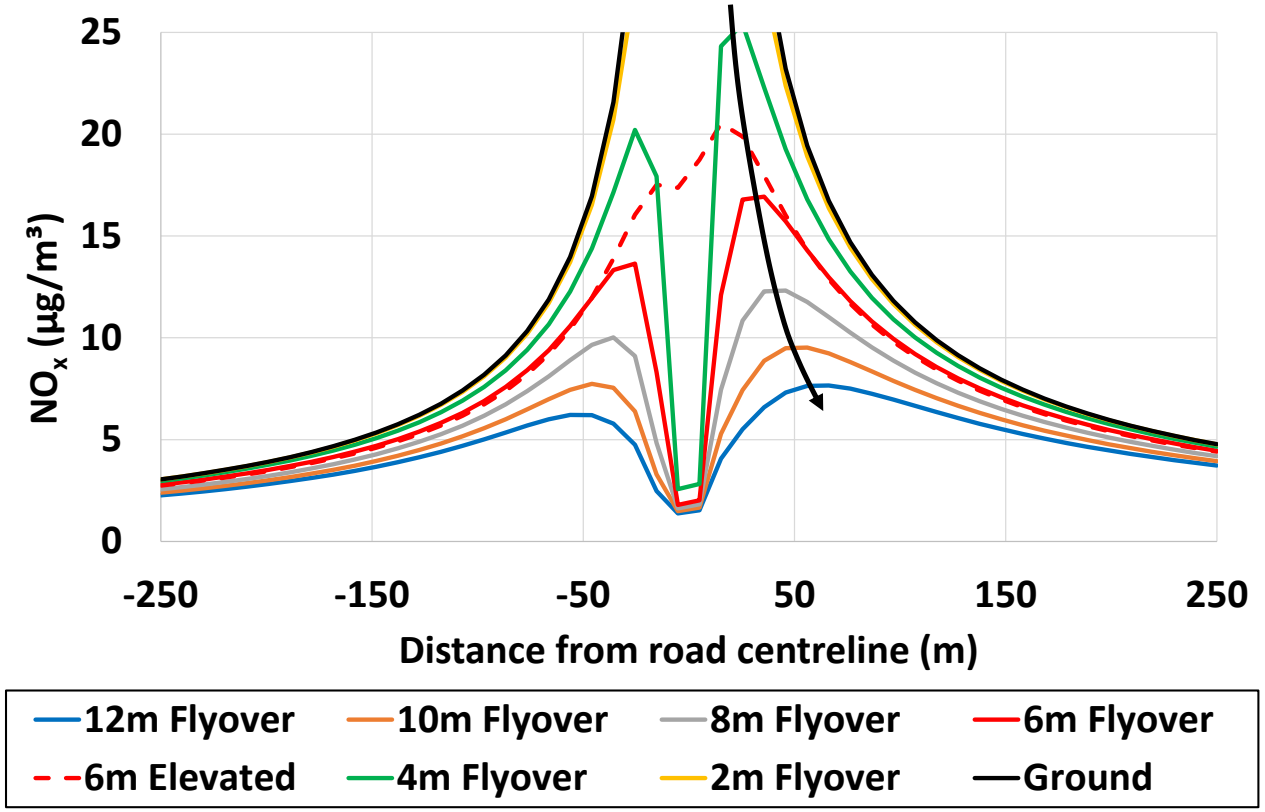

Local maximum reduces and is further from road as elevation increases

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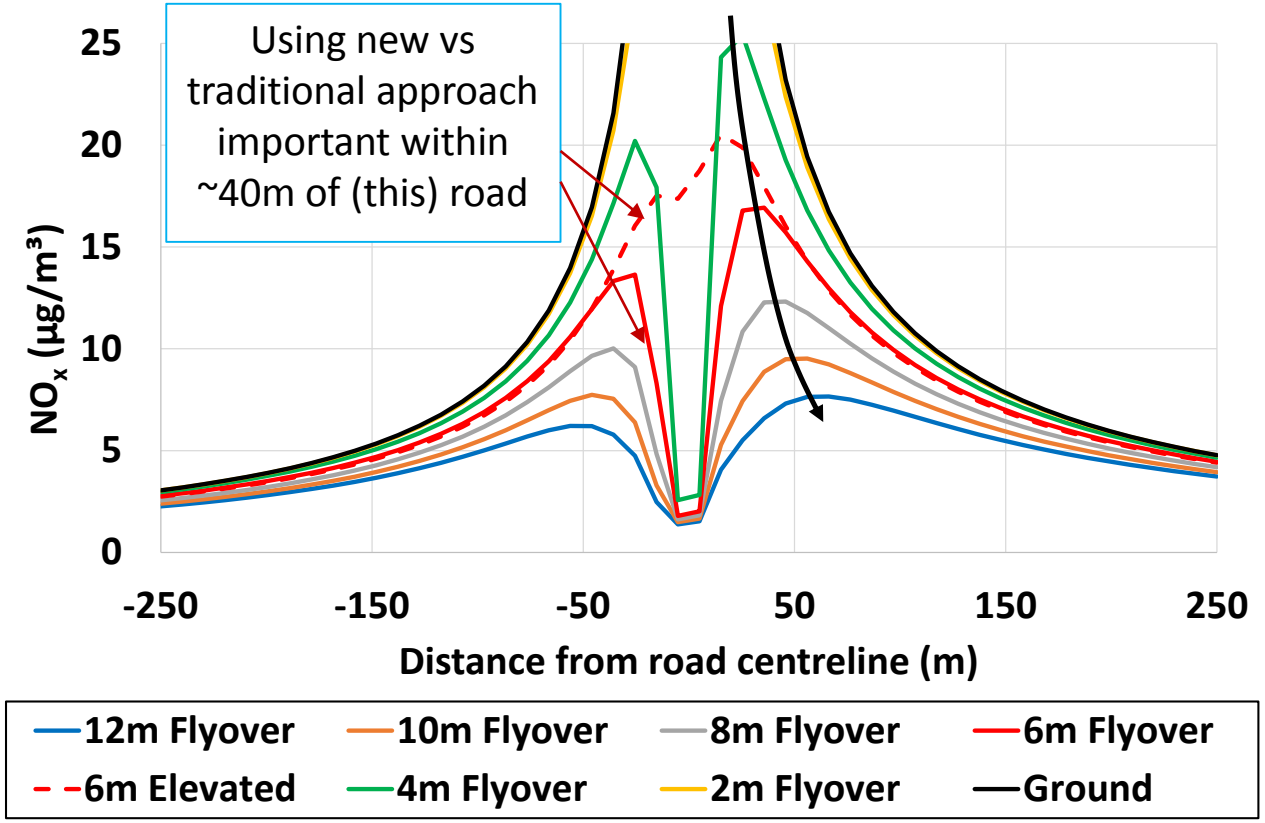

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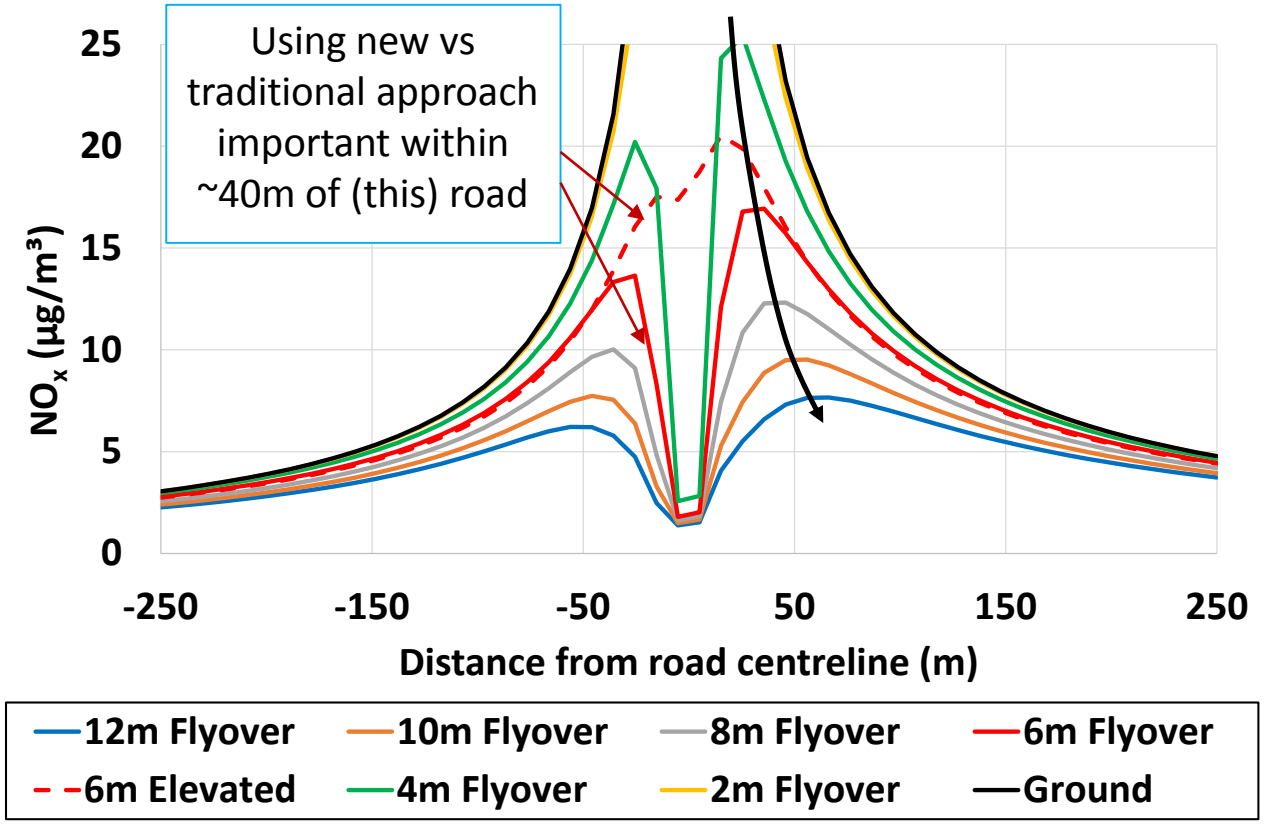
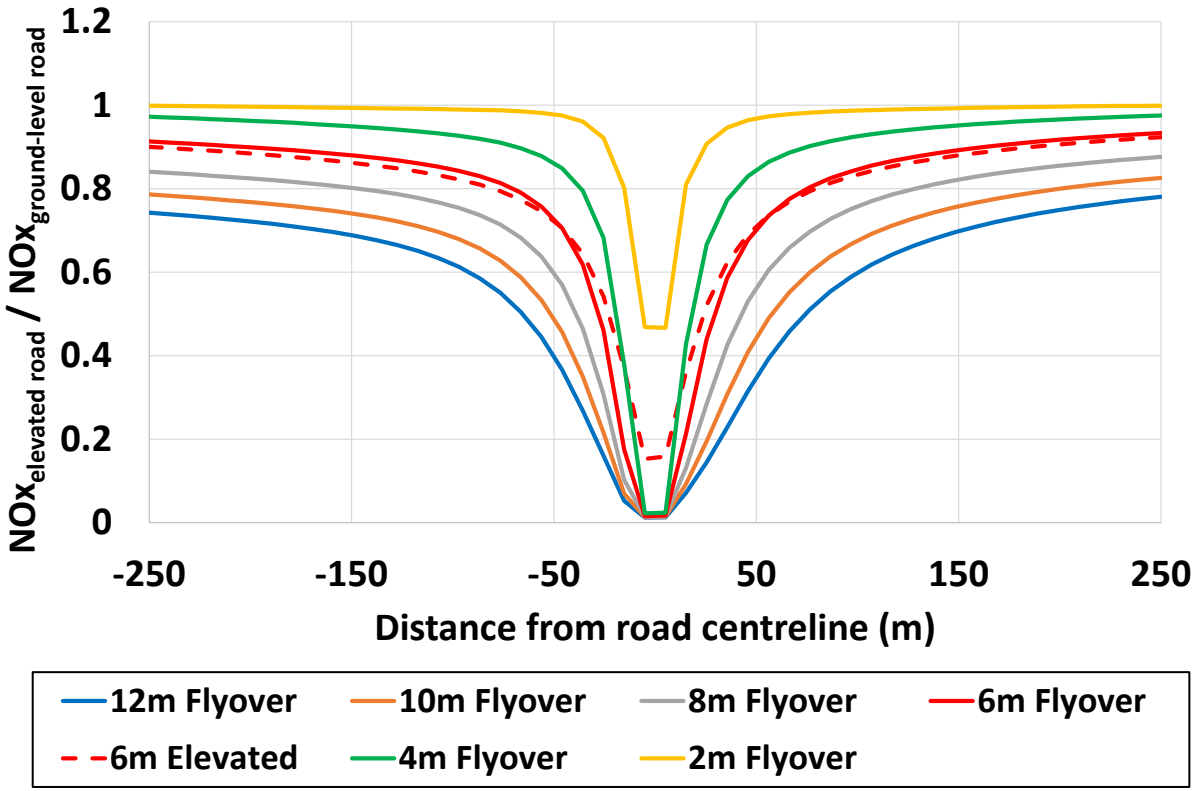


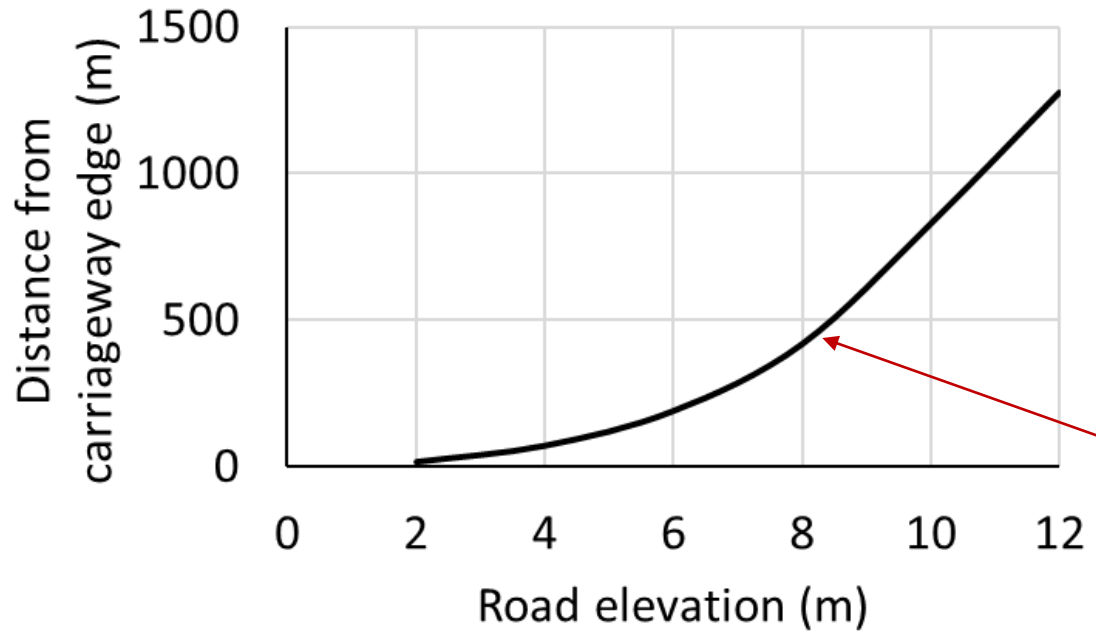


Local maximum reduces and is further from road as elevation increases

Impact of elevation decreases with increasing distance from road

Sensitivity testing

- When should road elevation be accounted for in the model? Depends on:
  - Elevation
  - Distance from road to receptor(s) of interest
  - Other factors (road geometry, stability etc.)



Distance at which near-ground concentration from elevated road reduces to within 10% of near-ground concentration from ground-level road (for M4 setup)

Still significant impact 0.5km from road for elevations > 8m

Summary

- **New method** for modelling ‘flyover’-type **elevated roads** which accounts for **surface shielding** implemented in widely-used ADMS dispersion model
  - **ADMS-Urban / ADMS-Roads v5.0.1**
- **Evaluation** against reference monitor data near elevated motorway section demonstrates **good model performance**
- Elevated roads help reduce nearby near-ground concentrations due to:
  - Increased vertical **source-receptor distance**
  - Increased wind speeds with height lead to **enhanced dispersion**
  - **Ground-level reflections**, which result in plume ‘folding’, are **delayed**
  - Can **mitigate street canyon recirculation effects**
- Benefit of accounting for road elevation in the model depends on road height and horizontal source-receptor distance

Acknowledgements & References

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  - The authors acknowledge Martine Van Poppel for sharing the dataset associated with the Antwerp field campaign study (not presented)

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Thank you for listening

Any questions?

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