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DIFFUSION TUBES: LOW-TECH BUT USEFUL

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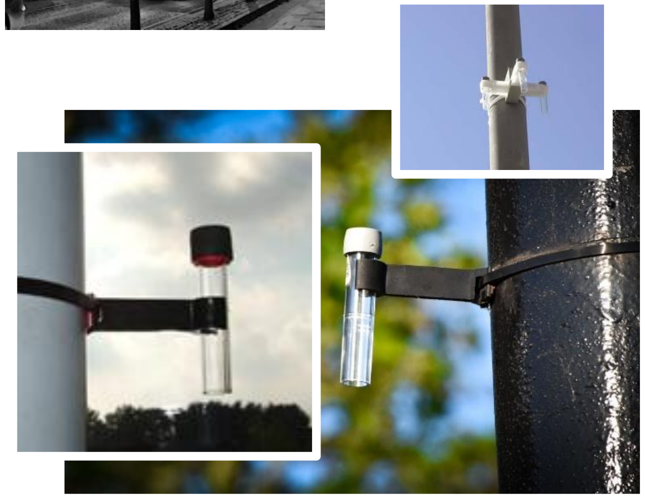
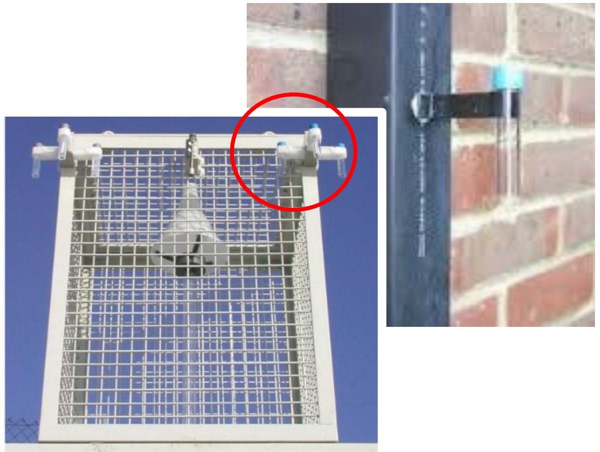
Nitrogen Dioxide (NO_2) Diffusion Tubes





Diffusion Tubes amongst the oldest and most widely used Environmental Monitoring tools:

- NO_2 tubes use a chemical absorbent, usually triethanolamine
- Sample air by ambient diffusion
- Typically provide 4-week to 1-month average measurements

Pros

Easy to Deploy
Low-Cost
Known Commodity

No in-use power and minimal infrastructure and permissions;
Few £s($s)/tube, so widely used in larger/longer-scale studies;
Well established method

Cons

Labour-Intensive
Delayed Reporting
Indicative Method
(Time Resolution?)

Manual deployment/collection;
Offline analysis and bias correction;
Less accurate/precise than continuous analyser, often ±15-25% but more recently ±12-15%, BUT still NOT strictly evidentiary

References: (1) Local Air Quality Management - Technical Guidance (TG16), April 2016. Defra and the Devolved Administrations [source]; (2) Pfeffer, U., Zang, T., Rumpf, E.M., Zang, S., 2010. Calibration of diffusive samplers for nitrogen dioxide using the reference method–Evaluation of measurement uncertainty, Gefahrstoffe, Reinhaltung der Luft, 11(12), pp.500-506 [source]; (3) European Union Directive 20/50/EC - on Ambient Air Quality and Cleaner Air for Europe, Official Journal of the European Union, L 152/1 - 44, June 2008 [source].

Case Study: the Bradford Clean Air Zone (CAZ)

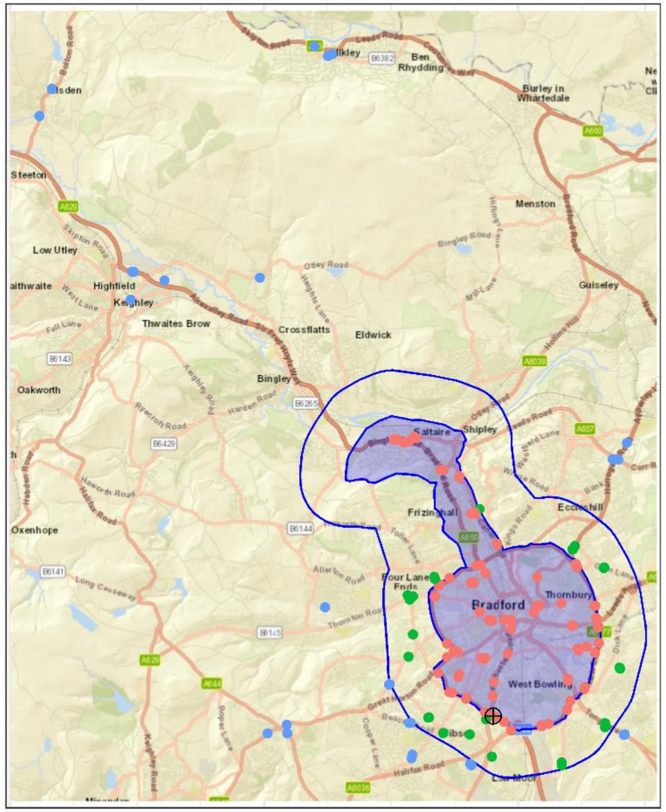
Bradford

UK Metropolitan Borough, City of Bradford and nearby towns (pop 0.56m, 9th largest), culturally diverse, disadvantaged (ca. 41% mainly urban core amongst most deprived in UK), but subject to efforts to 're-level'

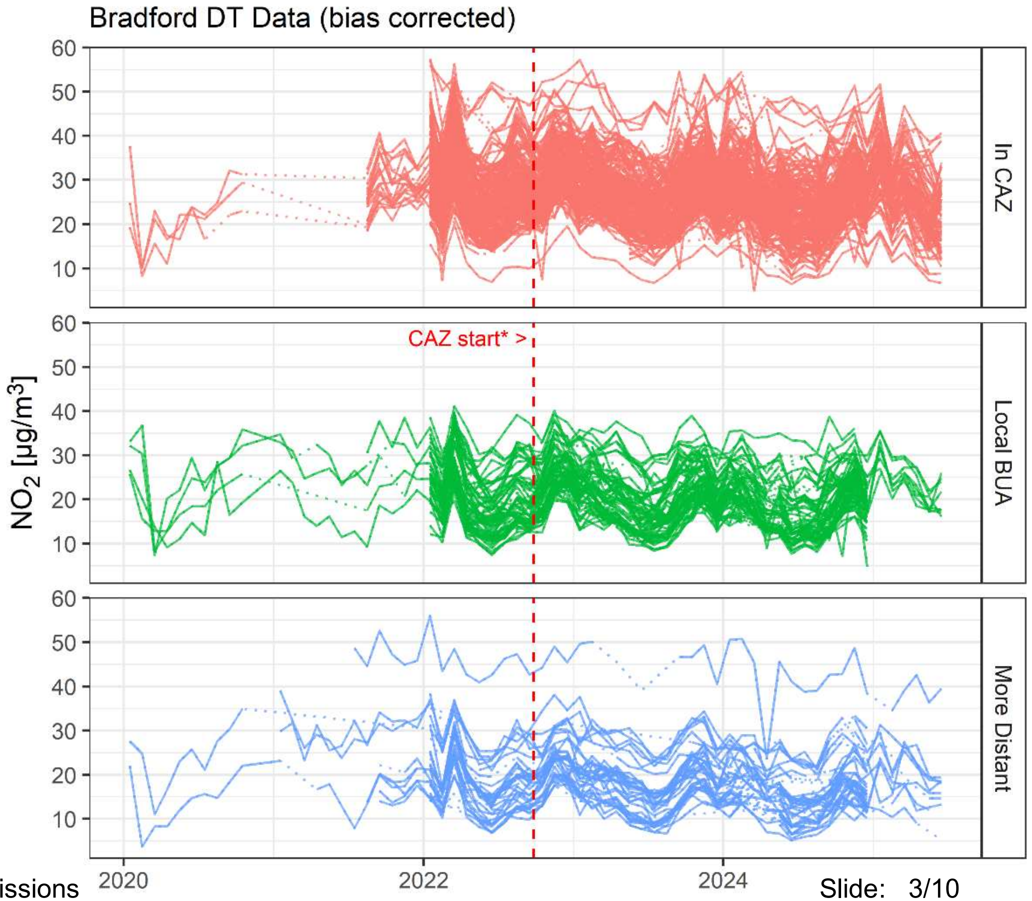
Dataset

10,408 samples
148 sites
67% in CAZ;
21% in the local built-up area (BUA)
12% more distant locations

At 64 Intervals
2020 to mid-2025
BUT focusing on 2022-2024 (high coverage period)



(All map layers: (c) OpenStreetMap/ESRI contributors)



Difference-in-Differences (DiD)

A ‘treatment’ and ‘control’ model that attempts to estimate the causal effect of an intervention by comparing changes over time in similar but not explicitly identical groups

preprocessing, deseasonalise: $[NO_2]_{ds} = [NO_2] - f(\text{day-of-year})$

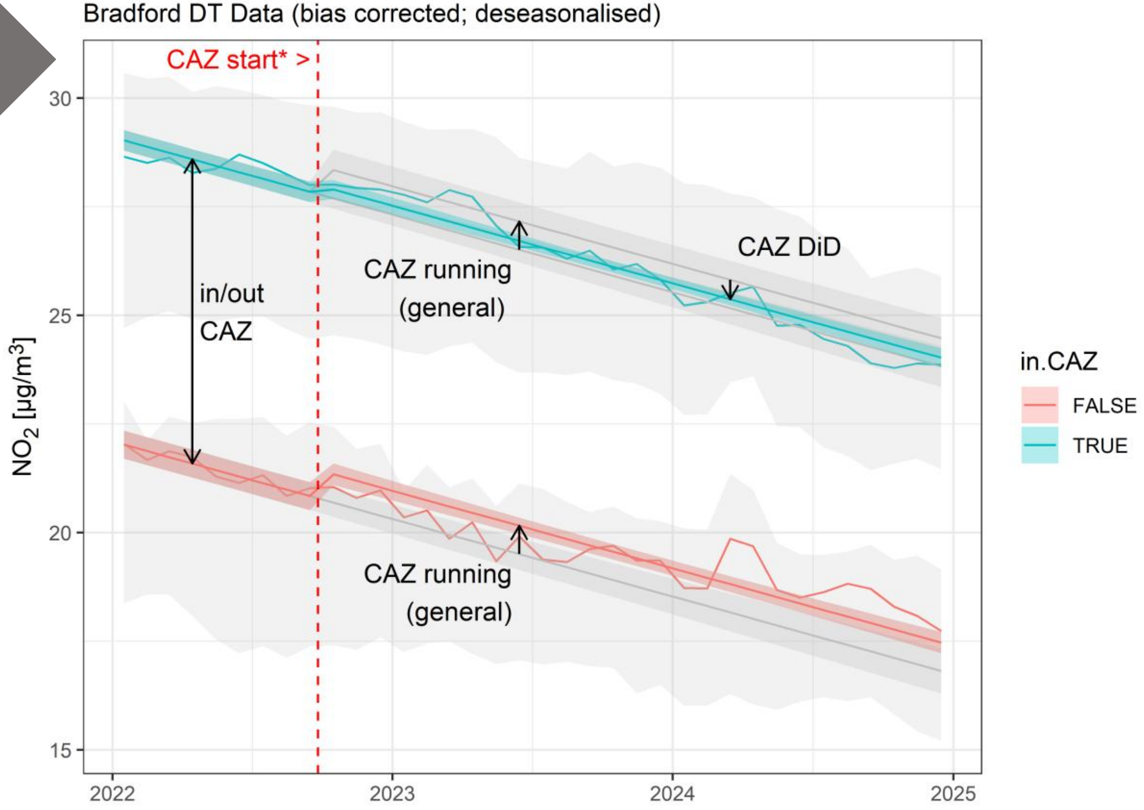
Model

$[NO_2]_{ds}$ = f(date) + [CAZ.running] + [in.CAZ] + [DiD]

[CAZ.running] + [in.CAZ]: Dummy Variables: yes=1/no=0

[DiD]: Interactive Term: CAZ.running × in.CAZ

Output



Predicted NO_2 Trends:

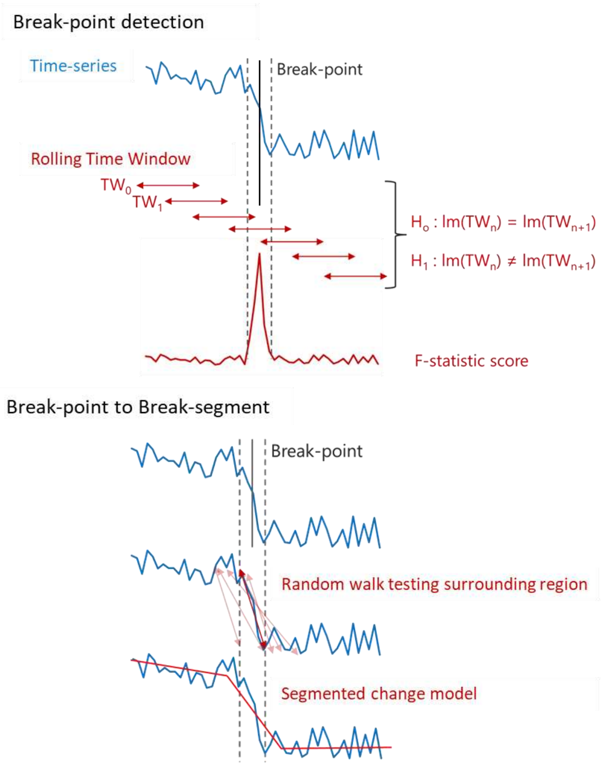
- *A pre-CAZ decrease of ca. 0.005 µg/m³/day (ca. 1.5 µg/m³/year)*
- *Levels inside the CAZ of ca. 7.0 µg/m³ higher than those outside the CAZ*
- *After the CAZ started, decreases were not as rapid and by end-of-2024 levels were on average 0.65 µg/m³ higher than expected pre-CAZ*
- *(This is general in AND out CAZ, and could just mean the rate of regional improvement was slowing)*
- *BUT in the CAZ by comparison to outside the CAZ NO_2 levels were ca. 0.45 µg/m³* better

Supporting Evidence: Break-Points/Segments (BP/S)

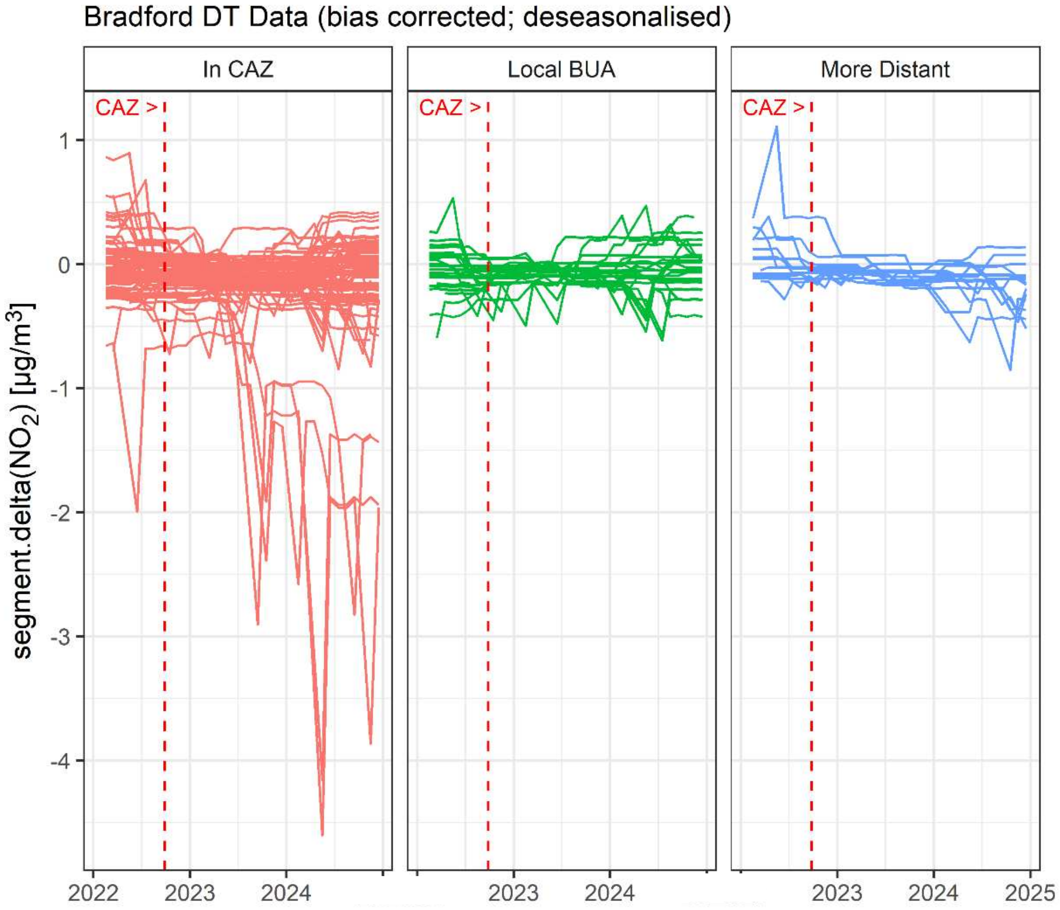
A 'rolling window' strategy that looks for points in a time-series where conditions change

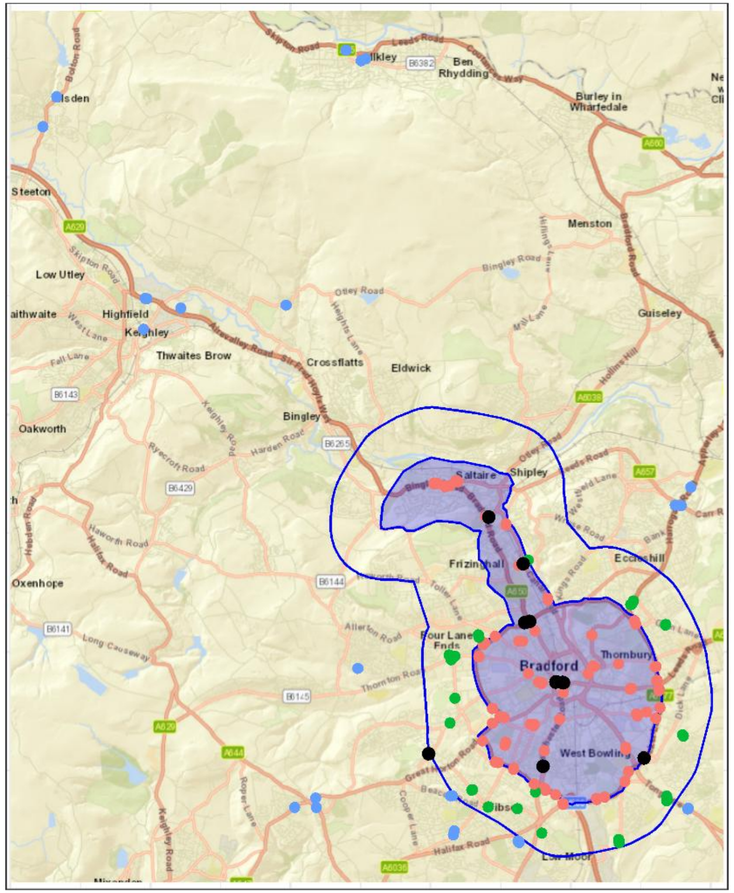
Method

BP/S($[NO_2]_{ds}$)
3-month time windows



By-location testing shows large and persistent decreases BUT only at some sites, and more often starting 2023-2024…





… and the 'black sites' above are where we see most of these larger improvements

Supporting Evidence: Cluster Analysis

Grouping of samples based on time profile similarities

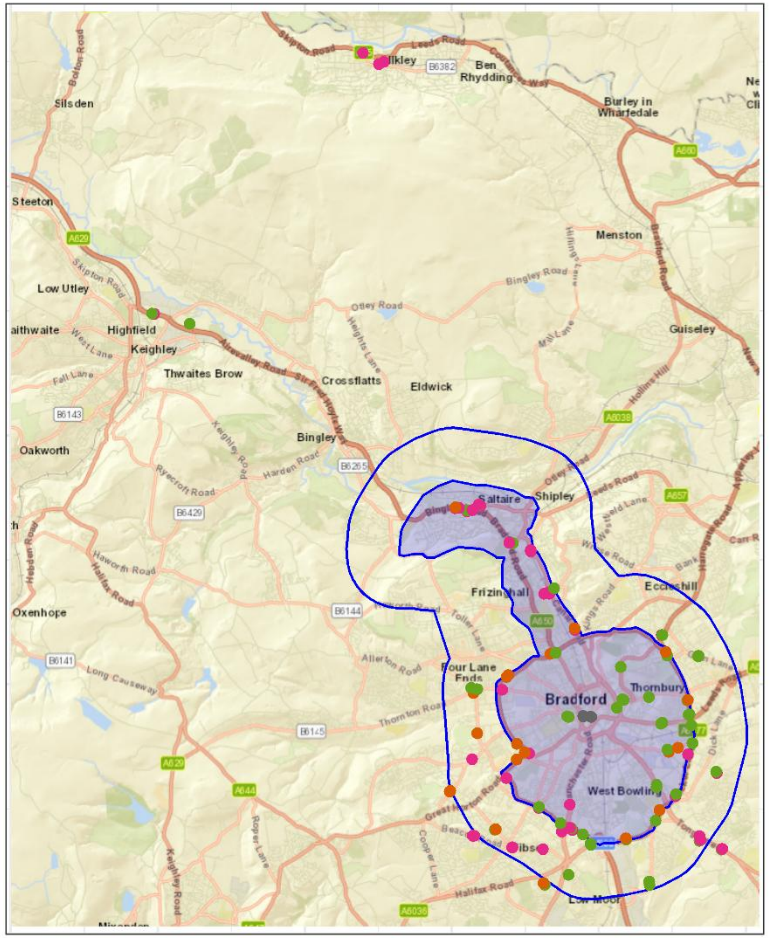
Step 1 Normalising $[NO_2]_{ds}$

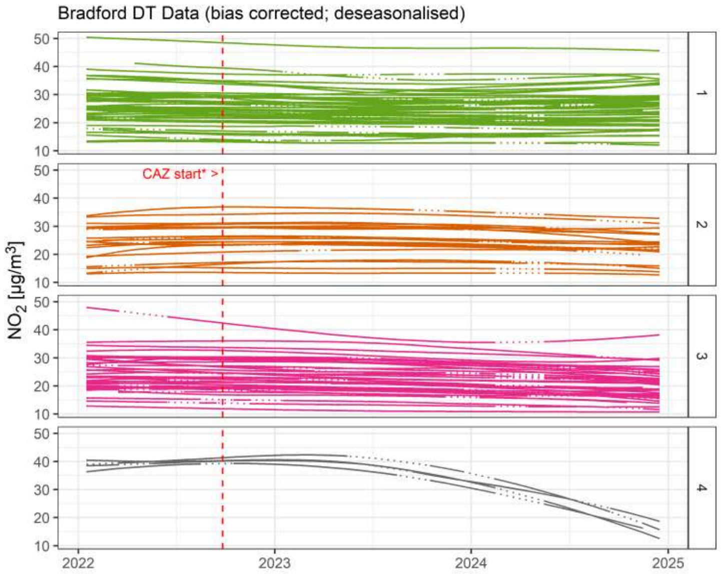
$$\mu_i = [NO_2]_{ds} / \overline{[NO_2]_{ds}}$$

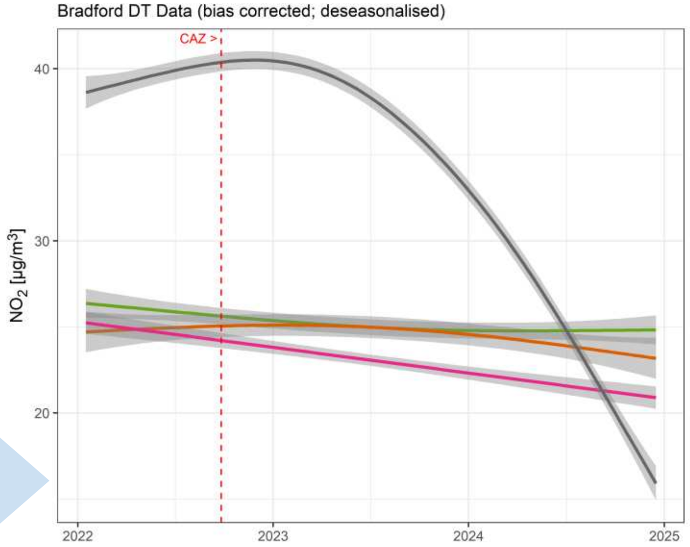
Step 2 Silhouette test to determine number of clusters

Step 3 Cluster, using the 'clara' model for large datasets

$$y_i = \sum_{cl=1}^{CL} \sum_{z=1}^{Z} S_{cl(0,1)}(\mu_{i,cl}) + e_i$$







Indicates large benefits at the CAZ centre, different behaviour split roughly to west and east, BUT also notable heterogeneity

Regional Model (1); Build

Using ambient data, [NO_2], because aim here is to apportion contributions…

Step 1 [NO_2] = f(date) + f(day-of-year) + [CAZ.running] + [in.CAZ] + [DiD] (DiD MODEL)

Adding seasonal term f(day-of-year) to Model

Step 2 Extract response functions for date and day-of-year from DiD MODEL (BACKGROUND)

Step 3 Build Main Model allowing for limited nonlinearity (applying by location)
[NO_2] = spline(BACKGROUND) + spline(IMPACT) (MAIN MODEL)

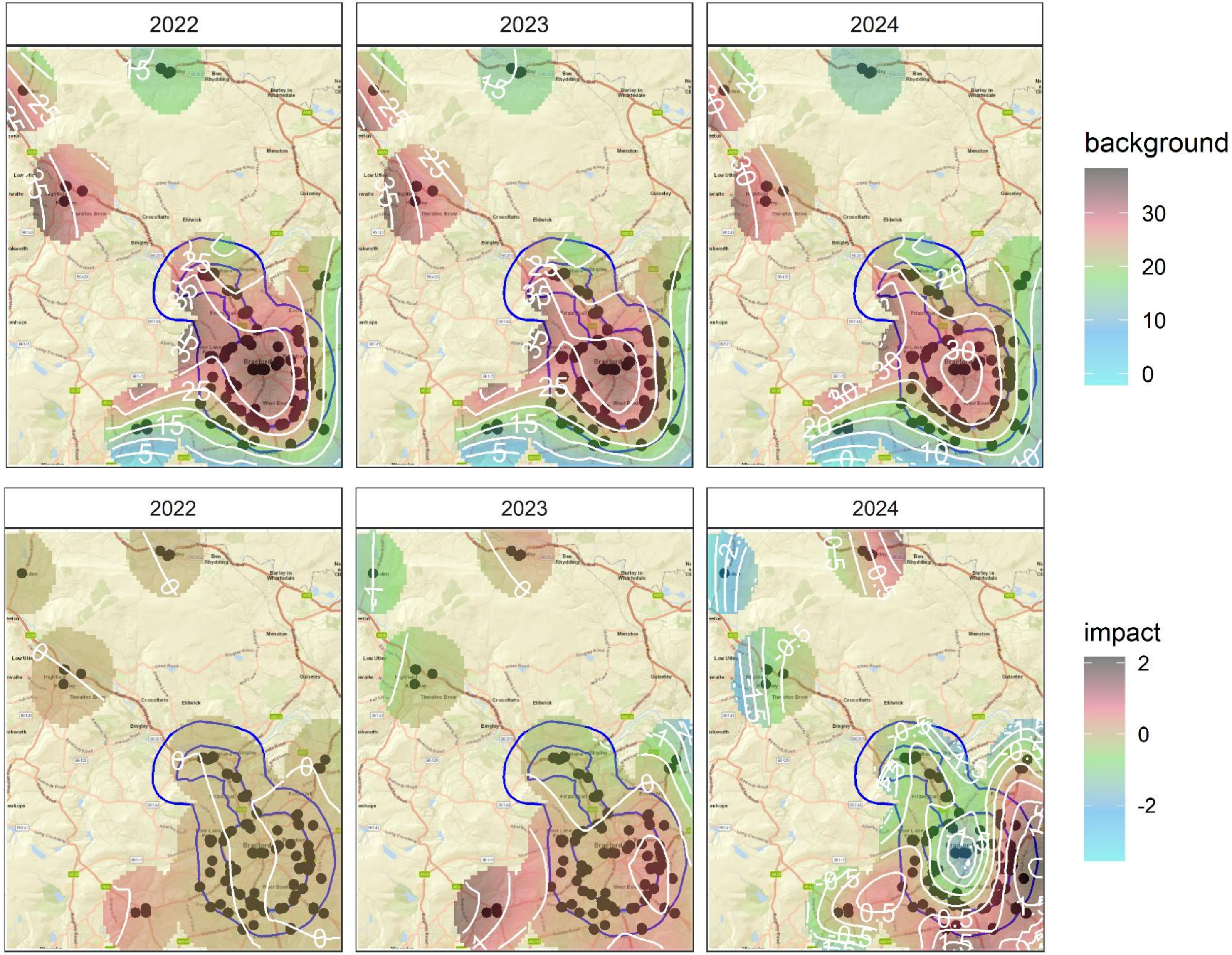
where IMPACT = { 0 before CAZ starts,
date - CAZ start date afterwards

Step 4 Extract BACKGROUND and IMPACT response functions from MAIN MODEL
Fit surfaces as generalised (and smoothed/conservative) descriptors (OUTPUTS)

Regional Model (2); Results

Background

CAZ Impact



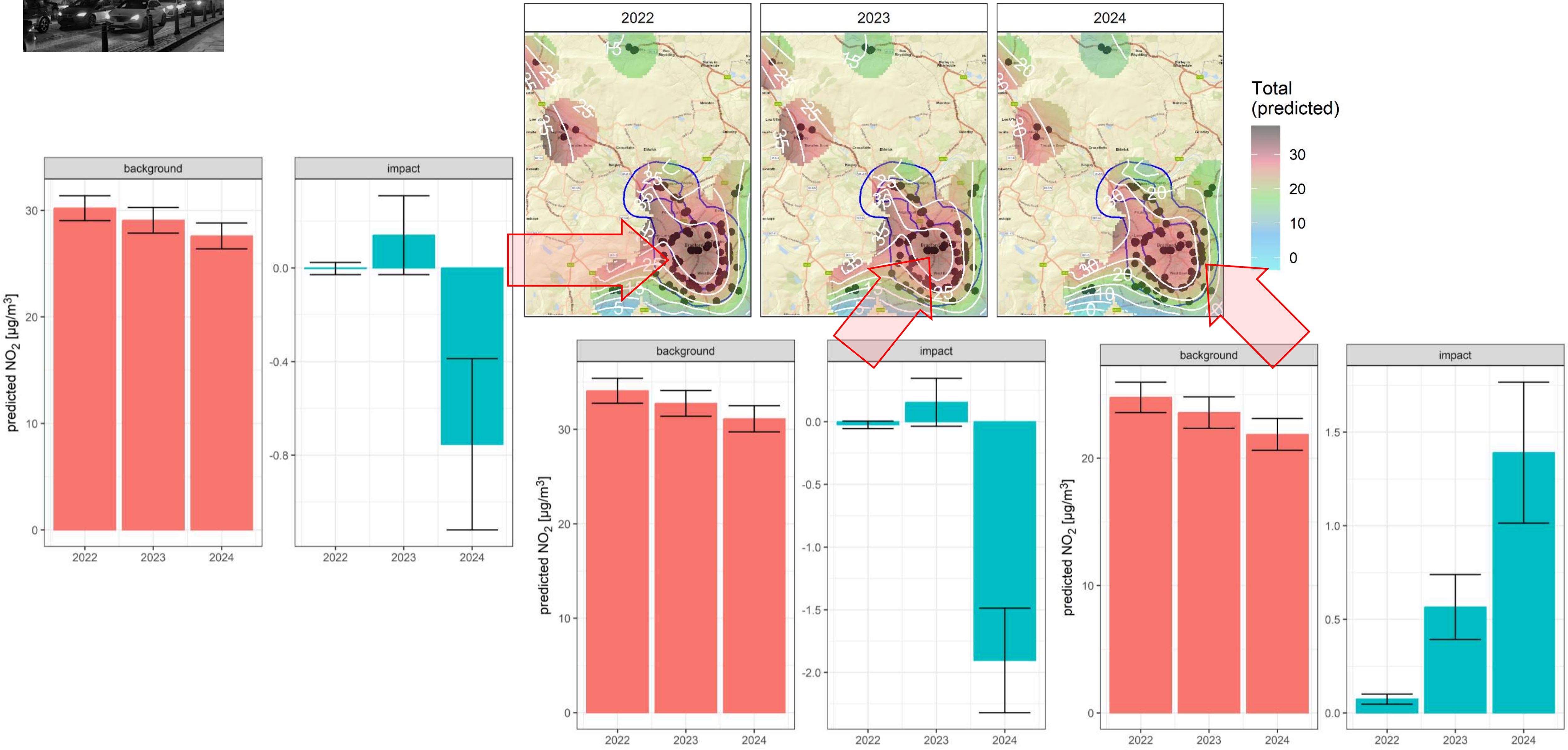
Background NO_2 Trends:

Seen across region ca. 1.5 µg/m^3/year (like DiD Prediction)

CAZ Impact NO_2 Trends:

Much more heterogeneous

Regional Model (3); Selected Results



Conclusions and Comments

Key Findings:

- NO_2 Improvements in Bradford in recent years are likely due to combination of regional/background and CAZ-related contributions
- The regional/background contribution is estimated at -1.5 µg/m^3/year
- The CAZ-related contribution is much more heterogeneous, may have been delayed, and is conservatively estimated to range from -1.9 µg/m^3 in the CAZ to 1.3 µg/m^3 at its eastern boundary and in the surrounding area; consistent with a combination of improvements and dirty-vehicle displacement from the city centre into the surrounding area

Outputs:

- Software developed as part of this work
- (https://github.com/karlropkins/DTEval)

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- The views and opinions expressed herein by the authors are their own and do not necessarily reflect those of UK Government or any agency thereof