The Non-Linear Relationship Between Road Traffic Emissions and Pollutant Concentrations

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Outline of talk

- Background
- Vehicle-induced turbulence
- Initial mixing height
- Non-exhaust emissions
- Conclusions

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Background

Road traffic emissions can be modelled in a number of ways:

Basic linear models	←	Complex non-linear models
✓ Quick, easy to use		X Less easy to use
X Not very accurate		✓ More accurate

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Background
UK Design Manual for Roads and Bridges (DMRB)

- Screening model
- Old version:
  - Concentrations given ‘per 1000 vehicles/hr at 100km/hr’ at distances from the road
  - Adjustments for:
    - Speed
    - Light/heavy vehicles
    - Year

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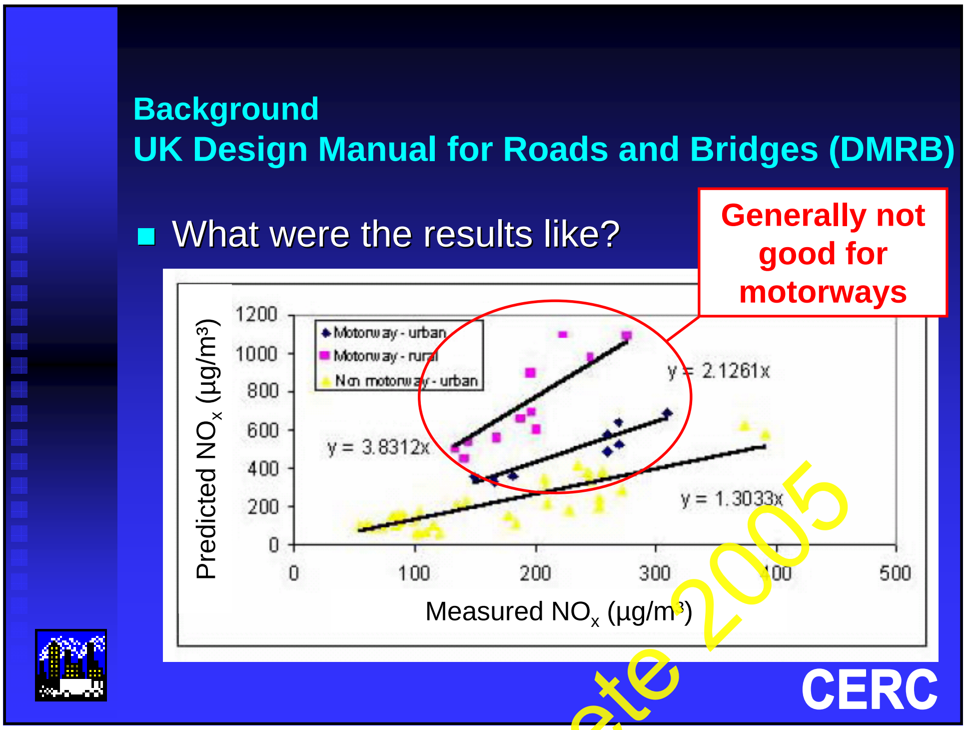
Background
UK Design Manual for Roads and Bridges (DMRB)
What were the results like?
Generally not good for motorways
Motorway - urban
Motorway - rural
Non motorway - urban
y = 3.8312x
y = 2.1261x
y = 1.3033x
Predicted NOx (µg/m³)
Measured NOx (µg/m³)
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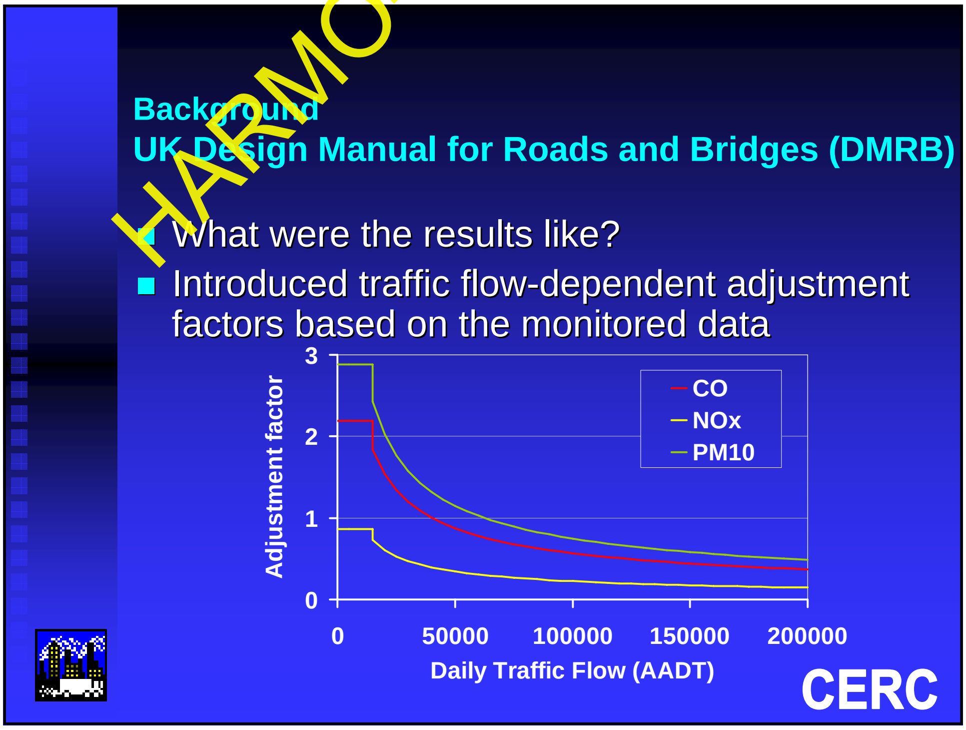
Background
UK Design Manual for Roads and Bridges (DMRB)
What were the results like?
Introduced traffic flow-dependent adjustment factors based on the monitored data
CO
NOx
PM10
Adjustment factor
Daily Traffic Flow (AADT)
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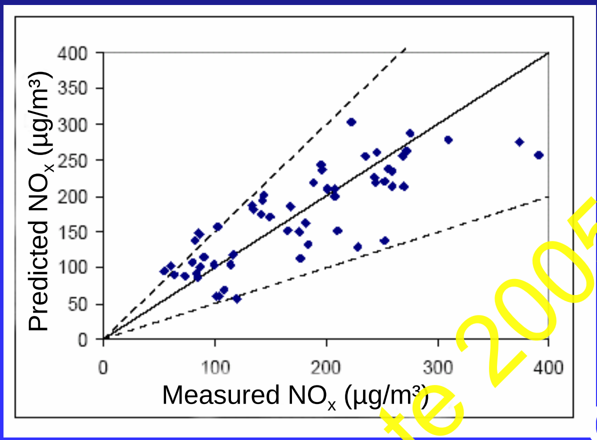
Background
UK Design Manual for Roads and Bridges (DMRB)

- What are the **new** results like? **✓ Good**



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Background
UK Design Manual for Roads and Bridges (DMRB)

- What are the **new** results like? **✓ Good**

But……

- Issues with models based on monitored data:
  - Correlations biased towards the chosen dataset
  - Factors different for each pollutant - unphysical
  - Adjustments have to be recalculated each time basic model updated (eg emissions datasets)
- Better to include non-linear, near-field processes

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Vehicle-induced turbulence
Proposed Formulation

- Extra lateral spread, $\sigma_{y_{vehicle}}$

$$\sigma_{y_{vehicle}} = \sigma_{v_{vehicle}} t \left\{ 1 + \left(\frac{t}{t_d} \right)^2 \right\}^{-1/2}$$

Increased vertical turbulence from OSPM:

$$\sigma_{v_{vehicle}} = b \left(\frac{N_H U_H A_H + N_L U_L A_L}{W} \right)^{1/2}$$

NumConstant [illegible] m²

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Vehicle-induced turbulence
Proposed Formulation

- Extra lateral spread, $\sigma_{y_{vehicle}}$

$$\sigma_{y_{vehicle}} = \sigma_{v_{vehicle}} t \left\{ 1 + \left(\frac{t}{t_d} \right)^2 \right\}^{-1/2}$$

Road-receptor travel time

Turbulence decay time: $t_d = \left(\frac{W}{\tau} \right) / \sigma_{v_{vehicle}}$

Constant derived from monitor data

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Vehicle-induced turbulence

Proposed Formulation

- Extra lateral spread, $\sigma_{y_{vehicle}}$, represents 2 regimes:

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Vehicle-induced turbulence

Proposed Formulation

- Extra lateral spread, $\sigma_{y_{vehicle}}$, represents 2 regimes:
  - Near field: $t << 1 \quad \sigma_{y_{vehicle}} \rightarrow \sigma_{v_{vehicle}} t$

    i.e. plume spread dominated increased lateral turbulence from traffic

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Vehicle-induced turbulence
Proposed Formulation

- Extra lateral spread, $\sigma_{y_{vehicle}}$, represents 2 regimes:
  - Near field: $t << 1$ $\sigma_{y_{vehicle}} \rightarrow \sigma_{v_{vehicle}} t$

    i.e. plume spread dominated increased lateral turbulence from traffic
  - Far field: $t \rightarrow \infty$ $\sigma_{y_{vehicle}} \rightarrow \frac{W}{\tau}$

    i.e. plume spread independent of speed and number of vehicles

Note this formulation is for an OPEN ROAD

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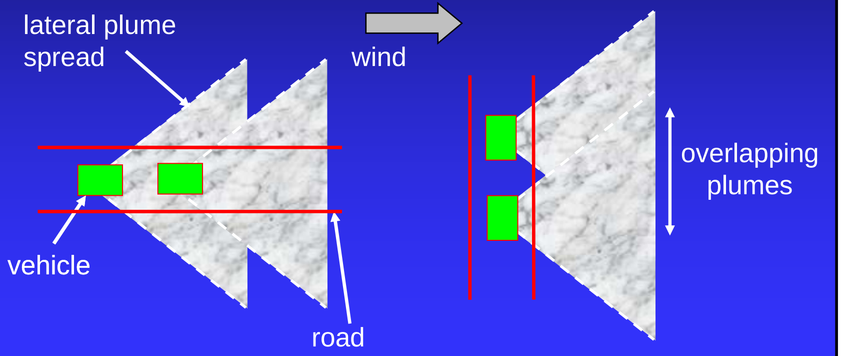
Vehicle-induced turbulence
Wind-direction dependence

Wind direction	
Parallel to road	Perpendicular to road



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Vehicle-induced turbulence
Results

- Constant τ =0.1 (validation exercise)
- Cross-sectional areas of light and heavy vehicles:
  A_L=4m^2, A_H =16m^2
- Investigate urban and rural areas (roughness z0=0.2 and 0.75m respectively)

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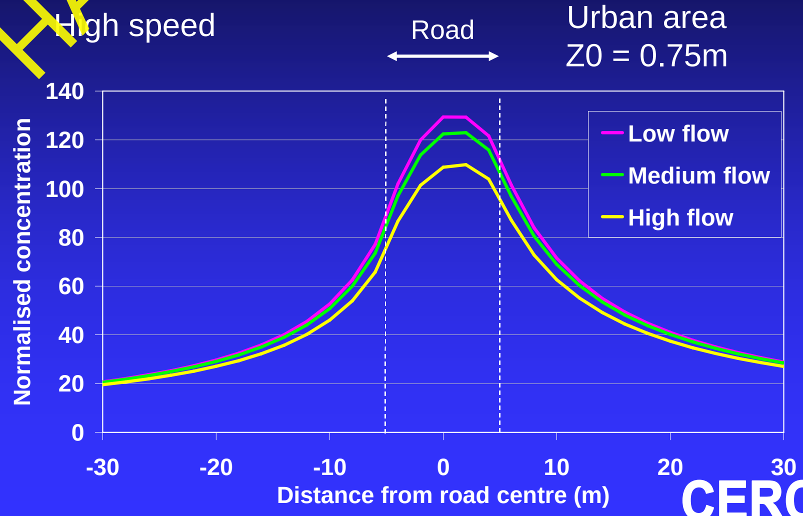
Vehicle-induced turbulence
Results – ADMS-Urban: annual average concentrations



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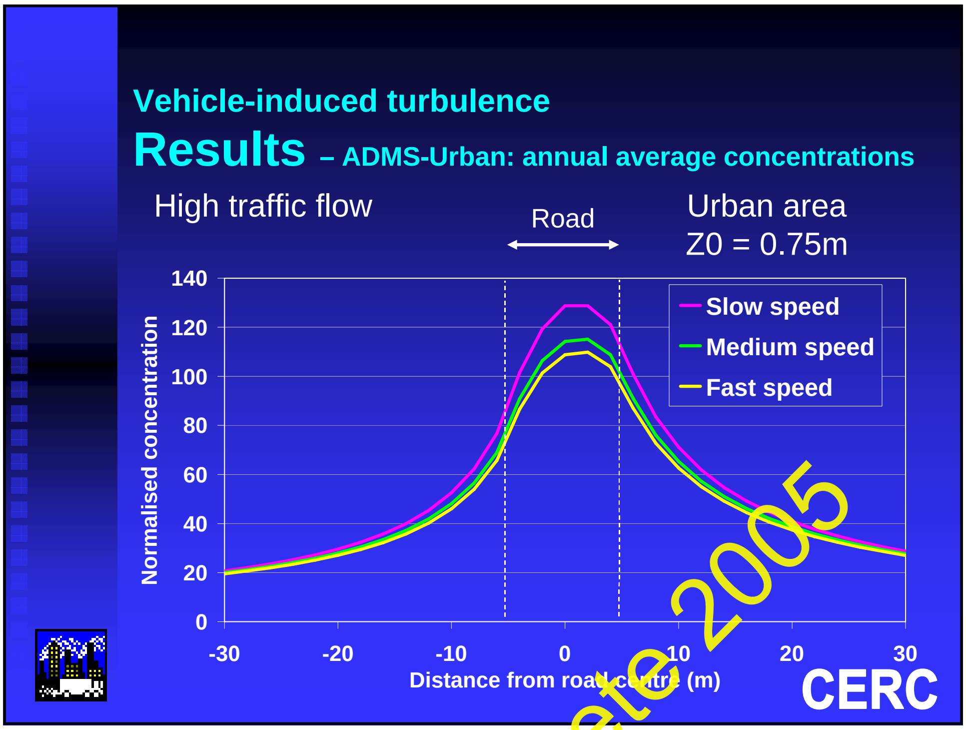
Vehicle-induced turbulence
Results – ADMS-Urban: annual average concentrations
High traffic flow
Road
Urban area
Z0 = 0.75m
Normalised concentration
Slow speed
Medium speed
Fast speed
140
120
100
80
60
40
20
0
-30
-20
-10
0
10
20
30
Distance from road centre (m)
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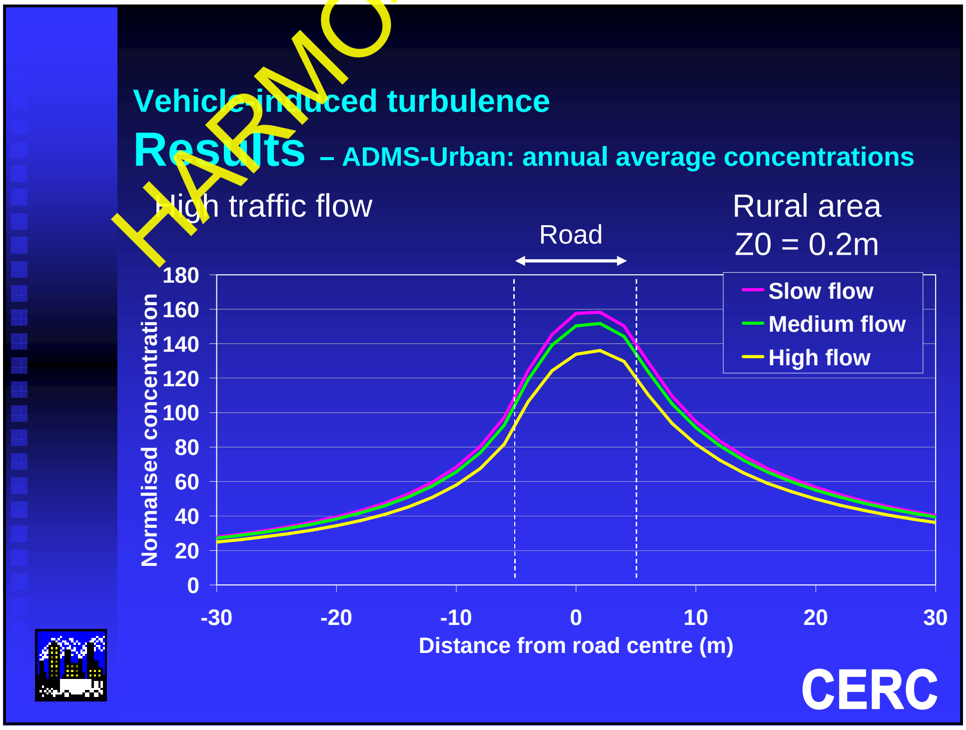
Vehicle-induced turbulence
Results – ADMS-Urban: annual average concentrations
High traffic flow
Road
Rural area
Z0 = 0.2m
Normalised concentration
Slow flow
Medium flow
High flow
180
160
140
120
100
80
60
40
20
0
-30
-20
-10
0
10
20
30
Distance from road centre (m)
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Vehicle-induced turbulence
Results

- Constant τ =0.1 (validation exercise)
- Cross-sectional areas of light and heavy vehicles:

  A_L=4m^2, A_H =16m^2
- Investigate urban and rural areas (roughness z0=0.2 and 0.75m respectively)
- Most effect on high flow, high speed, thin roads in rural areas

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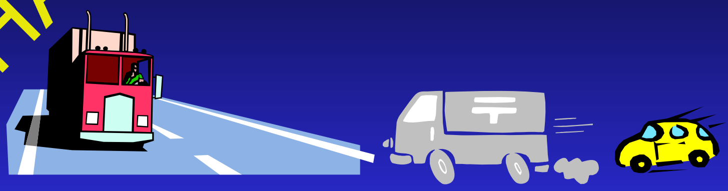
Initial mixing height
Proposed Formulation



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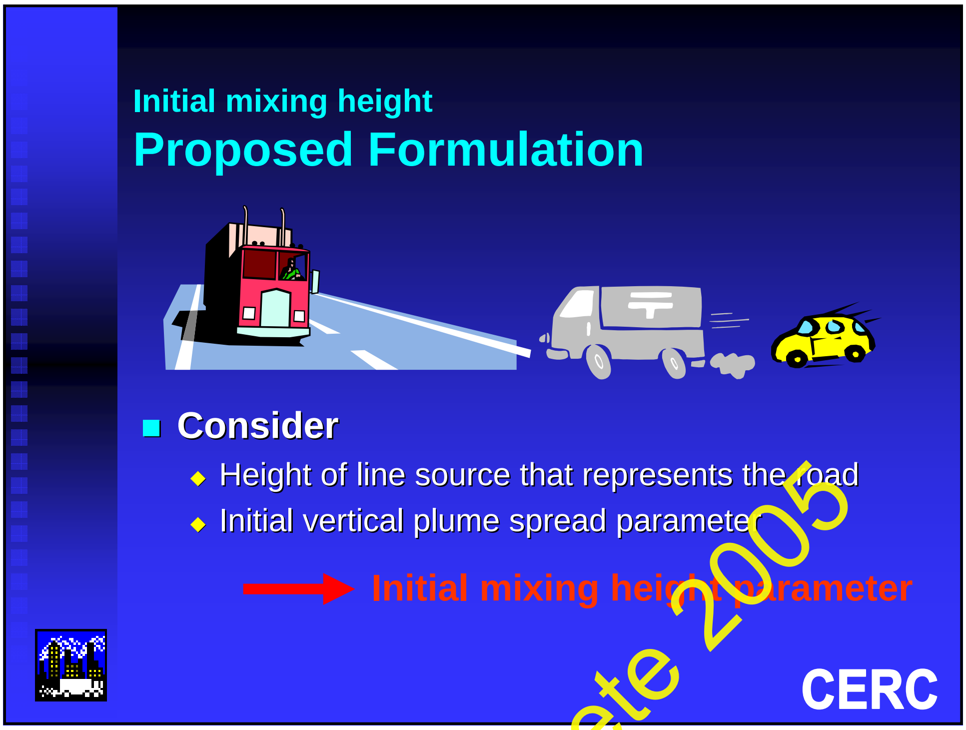

Initial mixing height
Proposed Formulation
Consider
Height of line source that represents the road
Initial vertical plume spread parameter
Initial mixing height parameter
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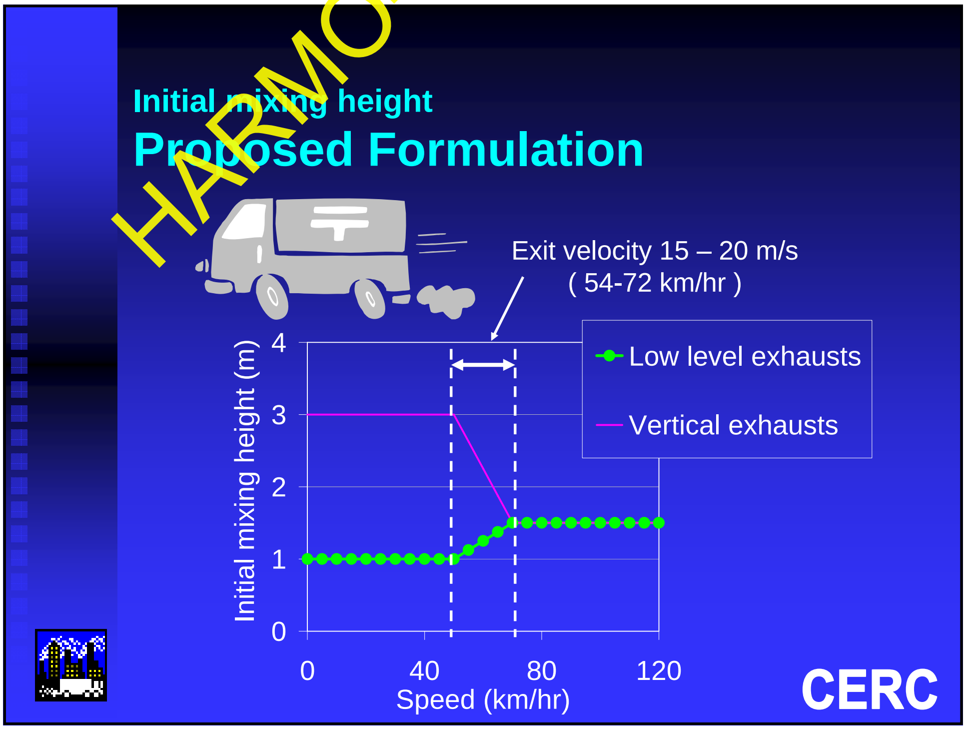

Initial mixing height
Proposed Formulation
Exit velocity 15 – 20 m/s
(54-72 km/hr)
Low level exhausts
Vertical exhausts
Initial mixing height (m)
0
1
2
3
4
0
40
80
120
Speed (km/hr)
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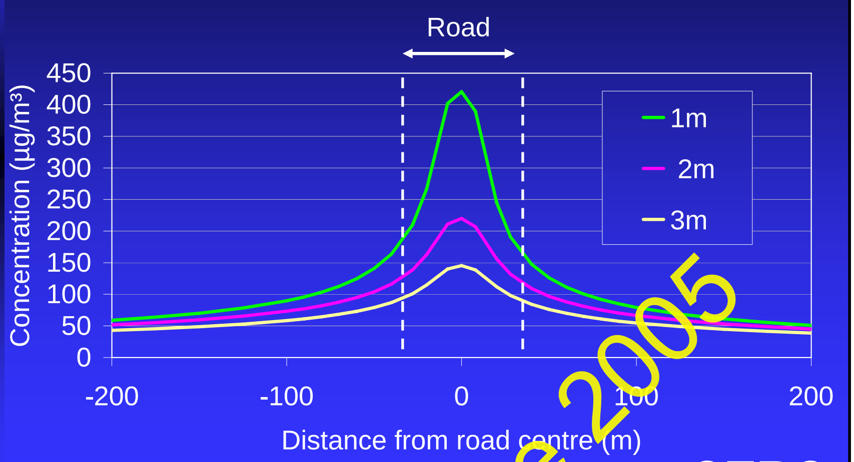
Initial mixing height

Results – ADMS-Urban: annual average concentrations



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Non-exhaust emissions

Estimation of contribution to concentrations

- Compare monitored and modelled (ADMS-Urban) concentrations:
  - NO_x and NO_2 – good
  - PM_{10} – generally modelled results low
- Analysis of ‘roadside’ and ‘urban background’ sites

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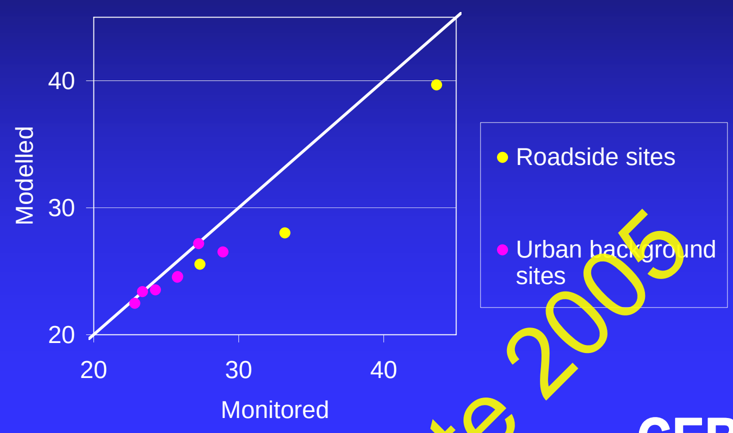
Non-exhaust emissions
Estimation of contribution to concentrations

Raw data



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Non-exhaust emissions
Estimation of contribution to concentrations

- Compare monitored and modelled (ADMS-Urban) concentrations:
  - NO_x and NO_2 – good
  - PM_{10} – generally modelled results low
- Analysis of ‘roadside’ and ‘urban background’ sites
- Calculate average difference (Monitored – Modelled) for each site type
- Use this value to represent non-exhaust emissions

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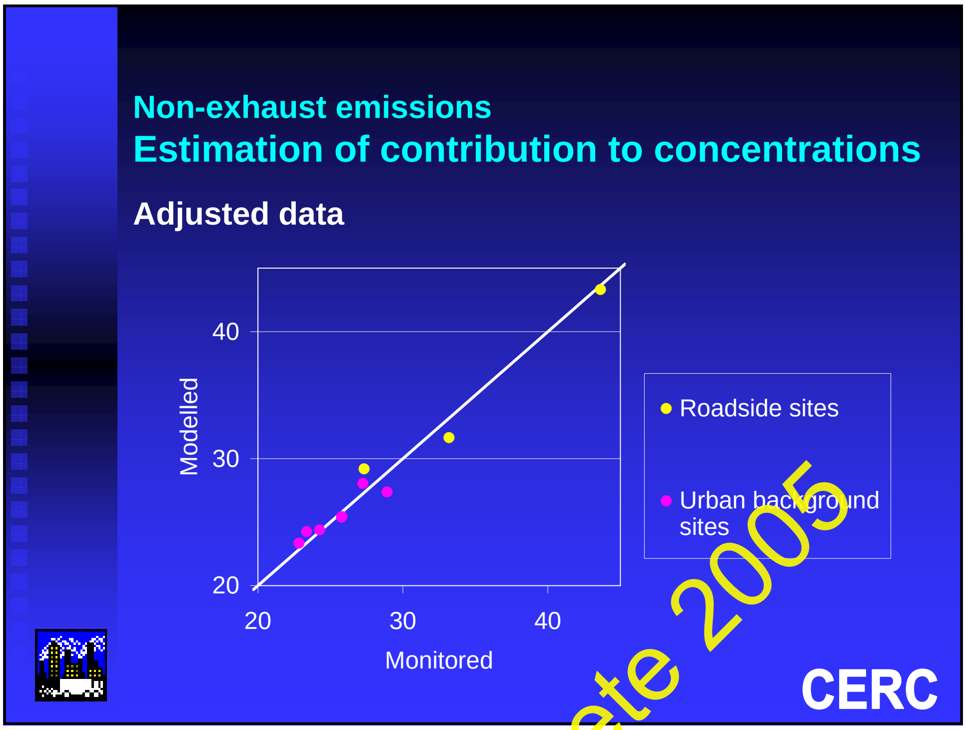
Non-exhaust emissions
Estimation of contribution to concentrations
Adjusted data
Modelled
20
30
40
20
30
40
Monitored
Roadside sites
Urban background sites
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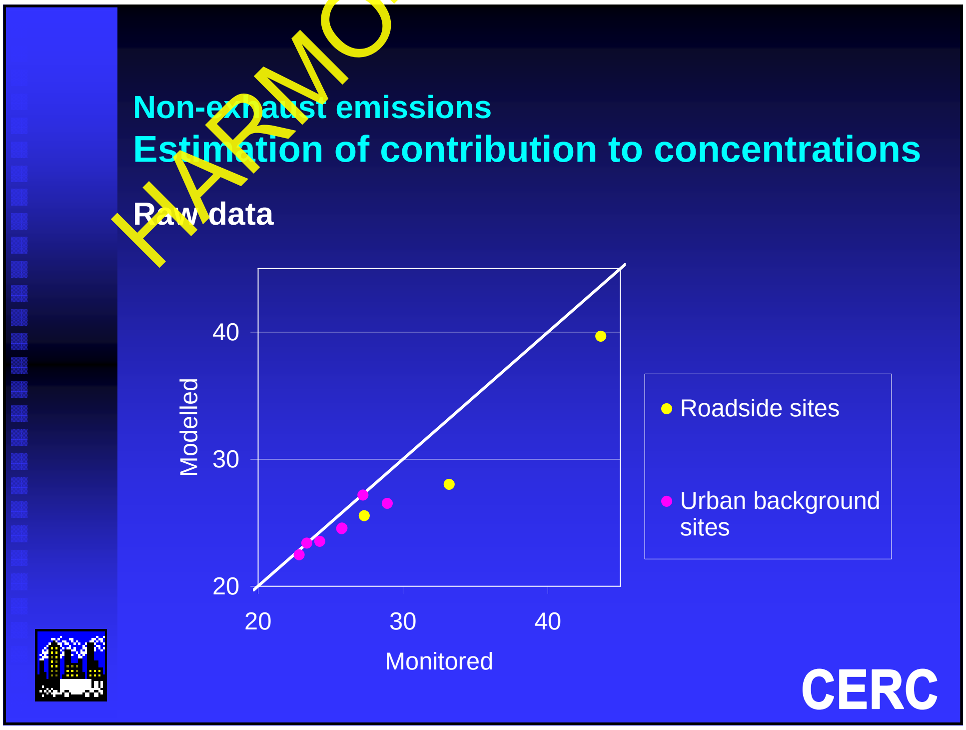
Non-exhaust emissions
Estimation of contribution to concentrations
Raw data
Modelled
20
30
40
20
30
40
Monitored
Roadside sites
Urban background sites
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Non-exhaust emissions
Required work

- Need to parameterise the non-exhaust emissions
- Likely that emissions related to nature of flow (eg stop/start), road surface type rather than linear with exhaust emissions

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Non-exhaust emissions
Required work

- Need to parameterise the non-exhaust emissions
- Likely that emissions related to nature of flow (eg stop/start), road surface type rather than linear with exhaust emissions
- CERC involved in project with:
  - TRL (UK)
  - Environmental Health & Risk Management Division, University of Birmingham (UK)
- Aim of project: Review, Development of new non-exhaust emissions model, Integration of new model into ADMS-Urban, Validation of emissions estimates, Validation of concentration estimates, Abatement options

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Conclusions

- Relationship between vehicle flow rate and pollutant concentrations is non-linear
- Processes include:
  - Vehicle-induced turbulence
  - Initial mixing height
  - Non-exhaust emissions

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Thank-you for your attention

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