Southwark Council
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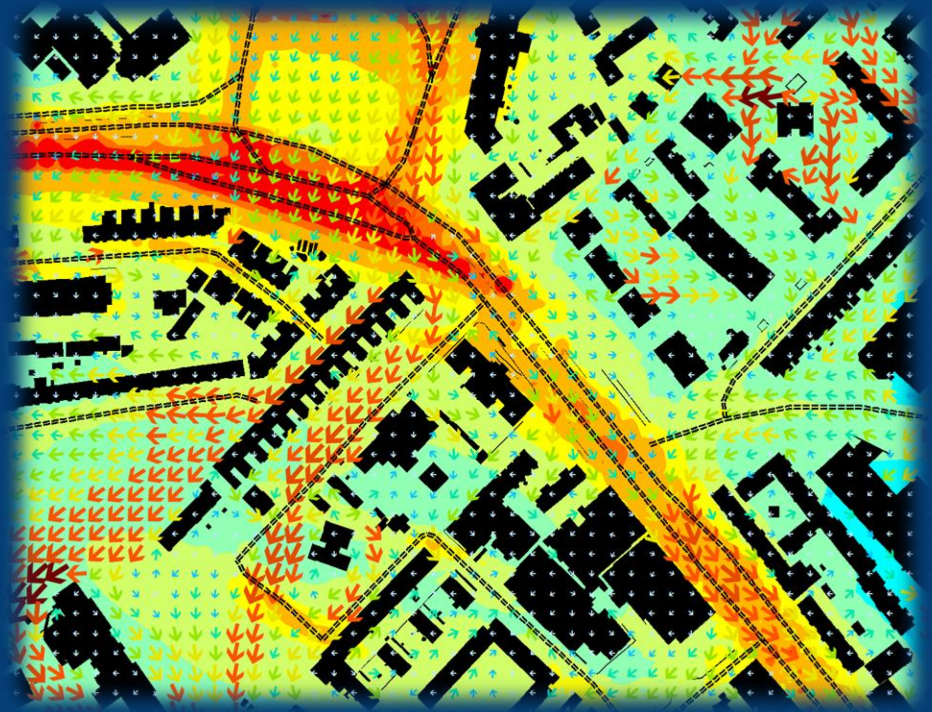
Driving ADMS using wind and turbulence data from CFD models



Jenny Stocker, CERC

ADMS-Urban & ADMS-Roads User Group Meeting

17 November 2022

Birmingham

Outline

- Motivation
- Conceptual & practical challenges
- Using the ‘User-input 3D flow field data’ option in ADMS-Urban
- Case study: ‘Old Kent Road Opportunity Area’ air quality study for the London Borough of Southwark
- Practical lessons learnt
- Future directions

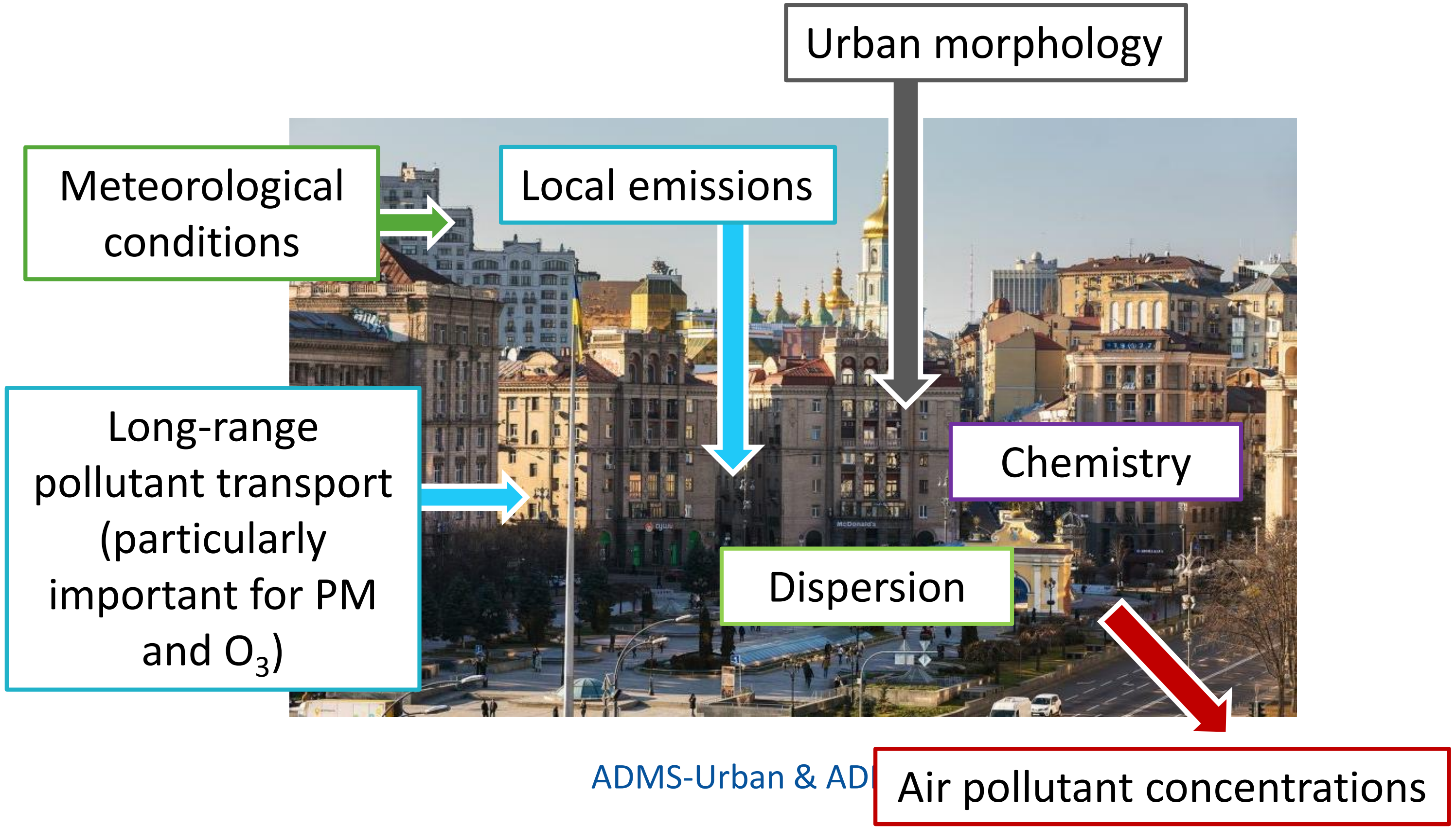
CFD = Computational Fluid Dynamics

Motivation

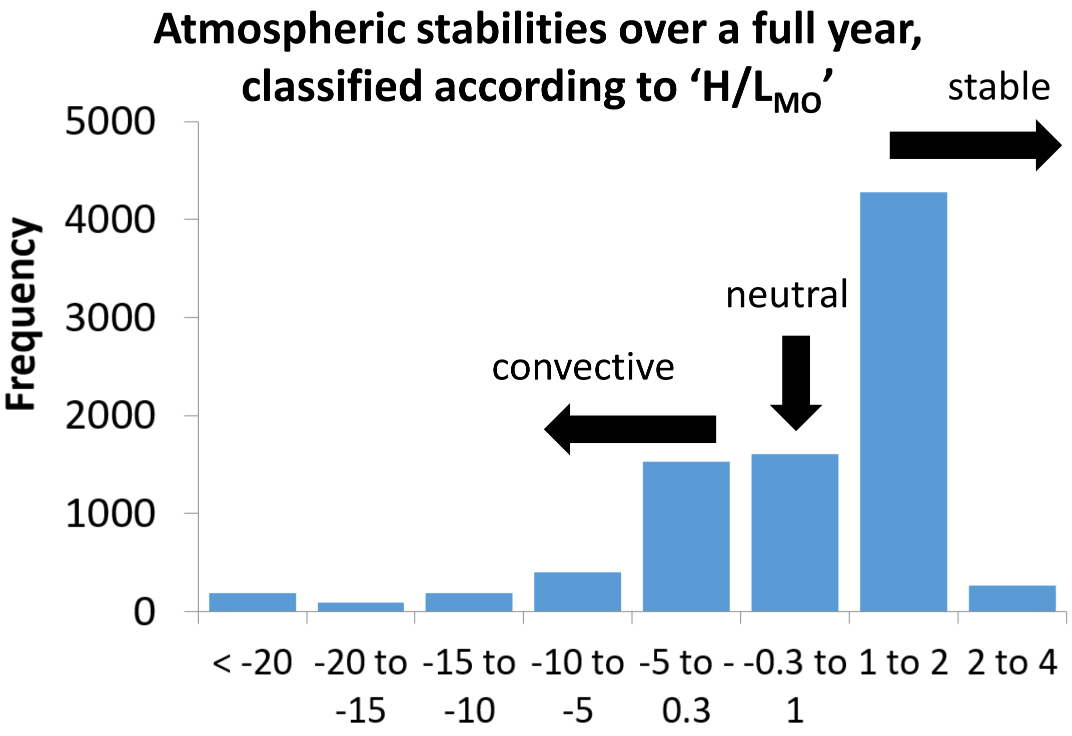
- Pollutant dispersion processes are governed by wind speed and turbulence conditions
- ADMS-Urban/Roads approximates wind speed and turbulence variations within the urban environment e.g. through the use of parameterised boundary layer profiles, surface roughness lengths, urban canopy flows, street canyon parameterisations etc
- These approximations work well for the majority of applications but in cases where:
  - Complex urban morphologies and /or
  - Fine scale AQ concentrations are required

the use of CFD outputs to drive AQ models *may* help to:

  - Identify pollution hotspots and
  - Inform urban development to reduce such hotspots



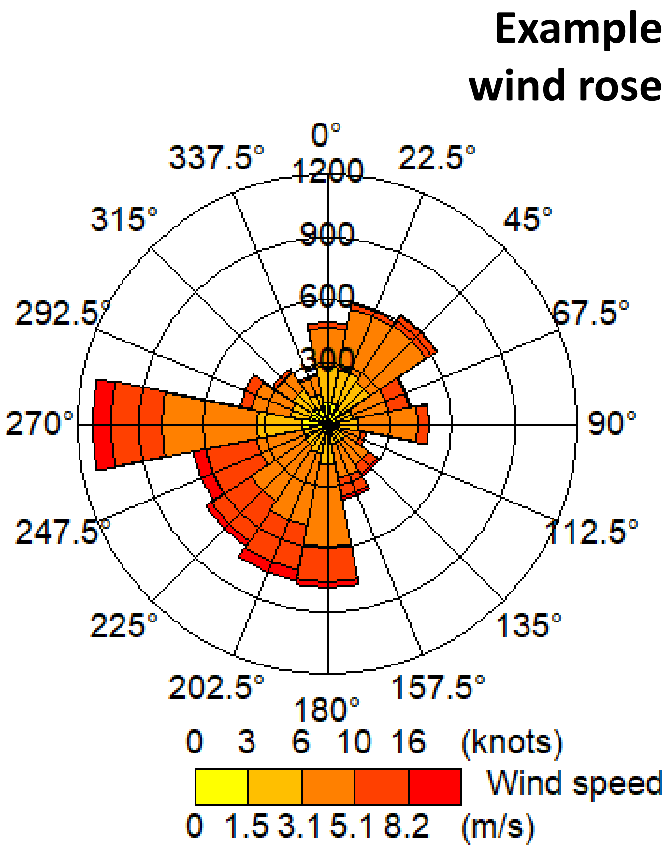
Conceptual challenges (1 of 4)



AQ models allow for full range of atmospheric conditions

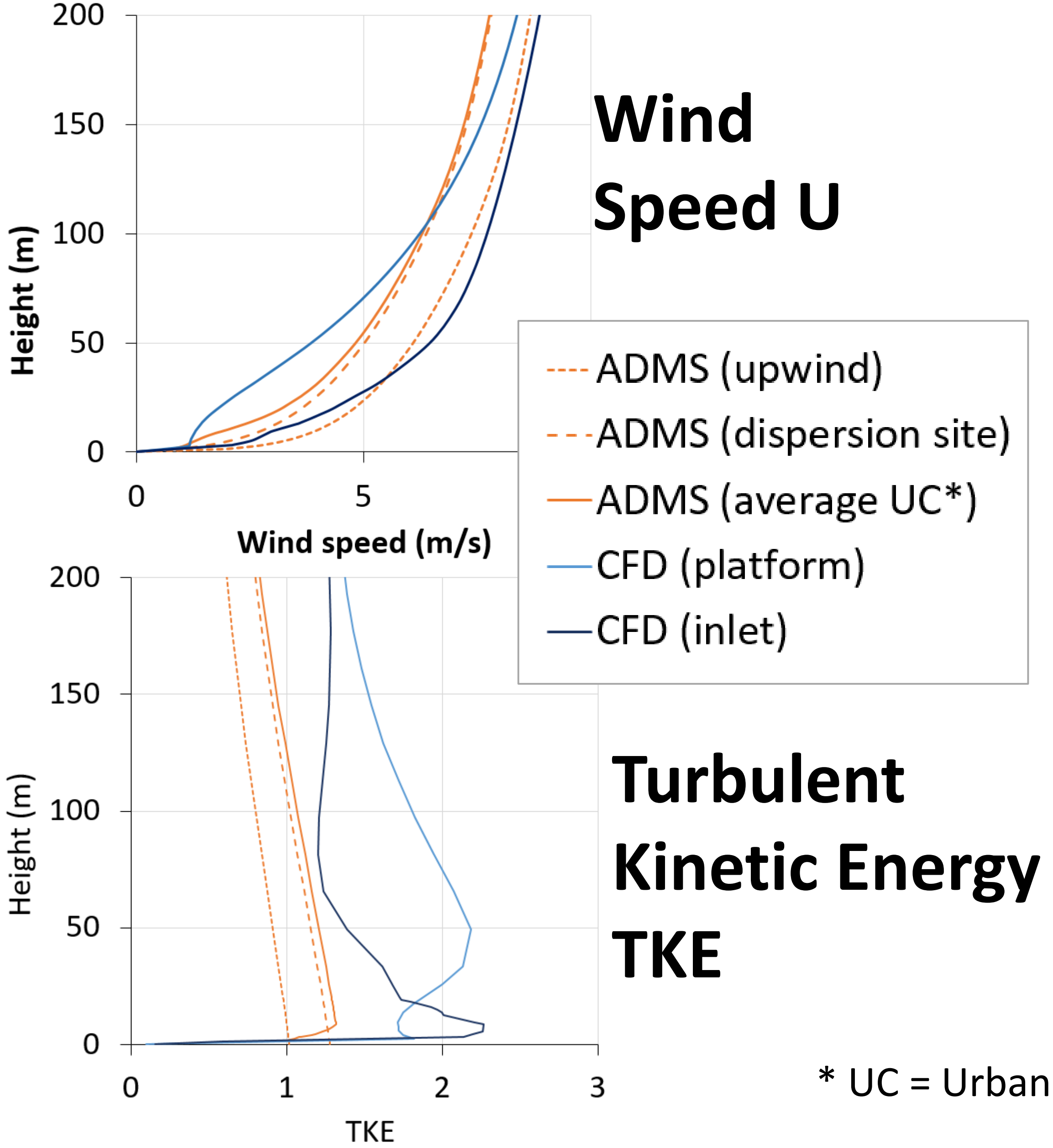
CFD models *usually* only represent:

- neutral atmospheric conditions
- for a limited number of wind directions



AQ limit values relate to annual statistics, so CFD outputs need to be 'scaled' to represent the range of atmospheric conditions in a full year

Conceptual challenges (2 of 4)



* UC = Urban Canopy

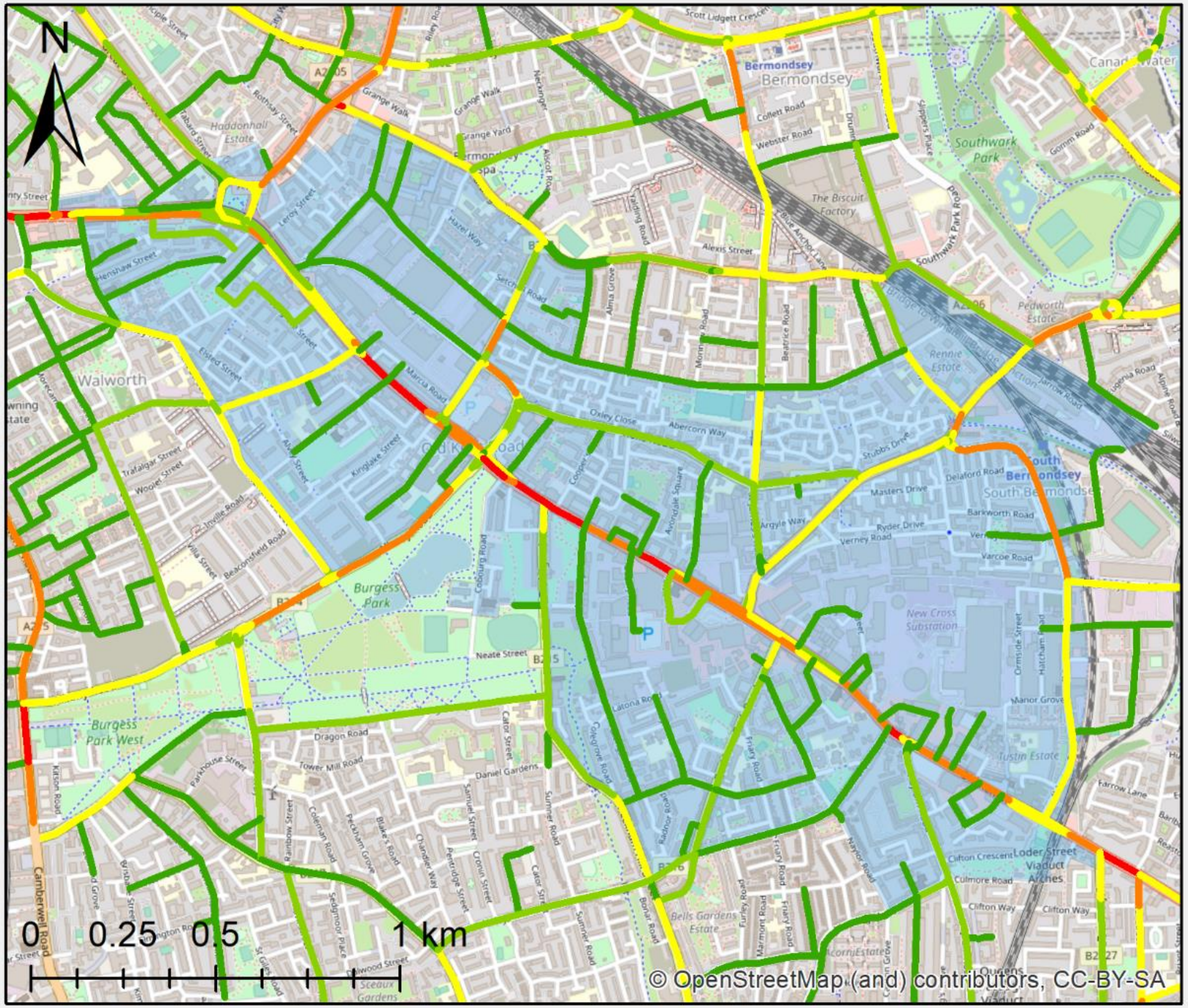
Input wind profile for the CFD model is not consistent with the majority of ‘upwind’ conditions in the AQ model

The turbulence parameterisations in AQ models may not be consistent with those within CFD models

Modelled concentrations are inversely proportional to the wind speed and directly affected by the turbulence values, so it is difficult to perform ‘like for like’ calculations, even for single neutral wind speed cases

Vehicles influence in-street flow and turbulence, particularly for low wind conditions – not accounted for in CFD

Conceptual challenges (3 of 4)



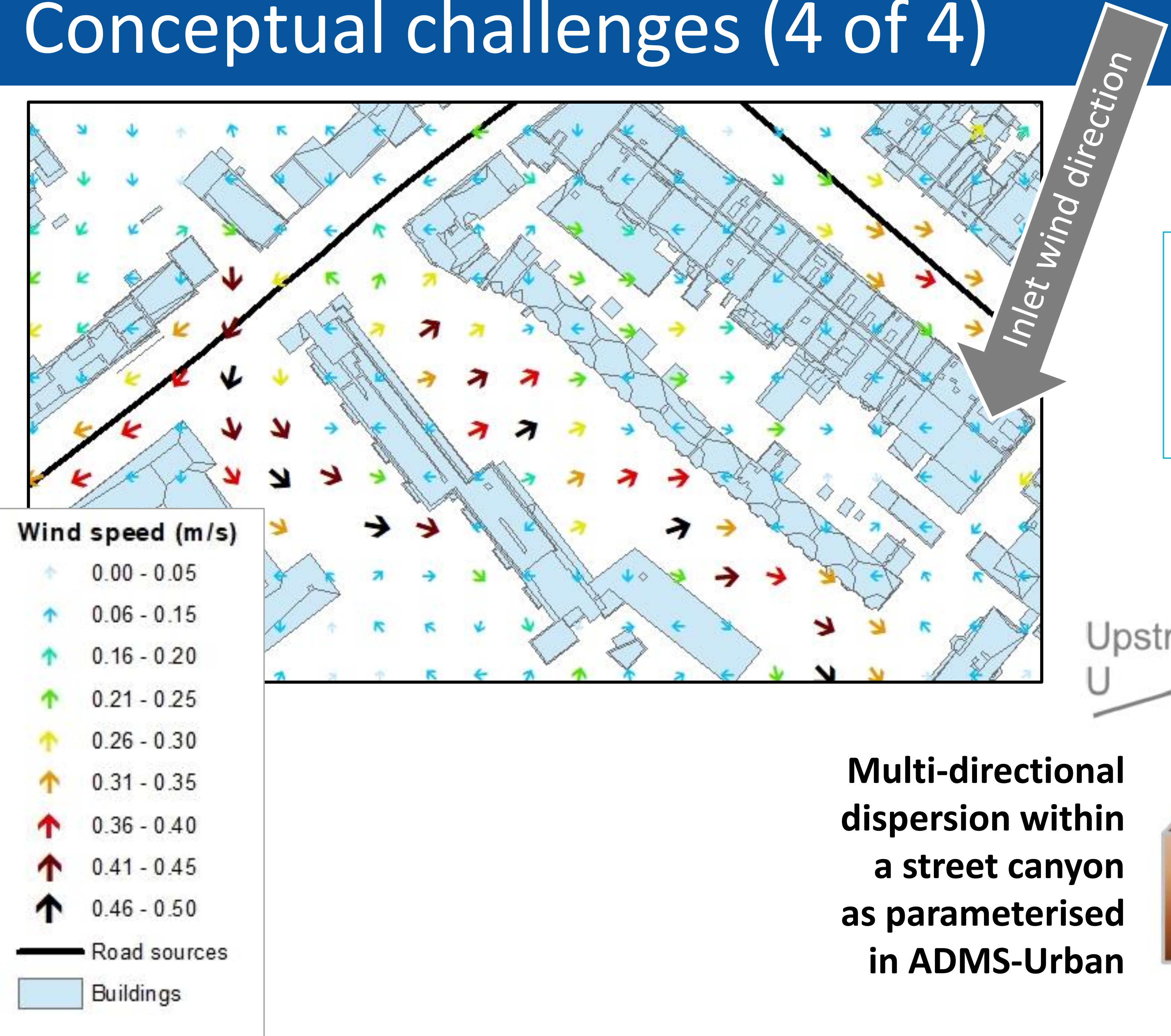
If the resolution of the emissions is not 'microscale' (e.g. don't account for the variation of traffic speeds and driver behaviour at junctions), are modelled concentrations more 'accurate' with high-resolution flows?

2018 final network

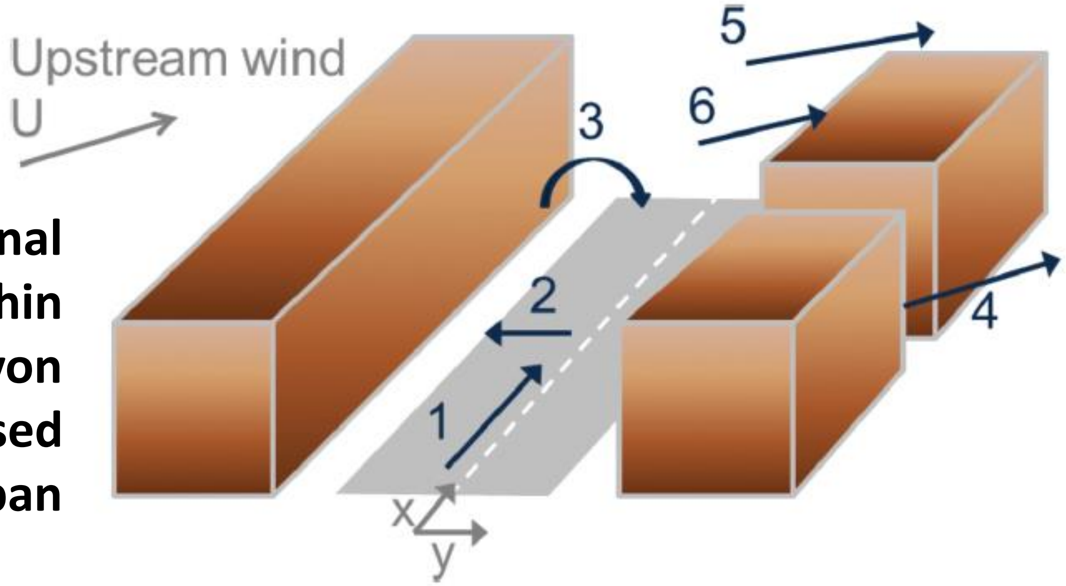
NO_x emissions (g/km/s)

- 0.00 - 0.05
- 0.05 - 0.10
- 0.10 - 0.20
- 0.20 - 0.30
- 0.30 - 0.68
- OKROA boundary

Conceptual challenges (4 of 4)



CFD models generate multi-directional winds, but Gaussian plume models have limited ability to take account of reverse flow regions



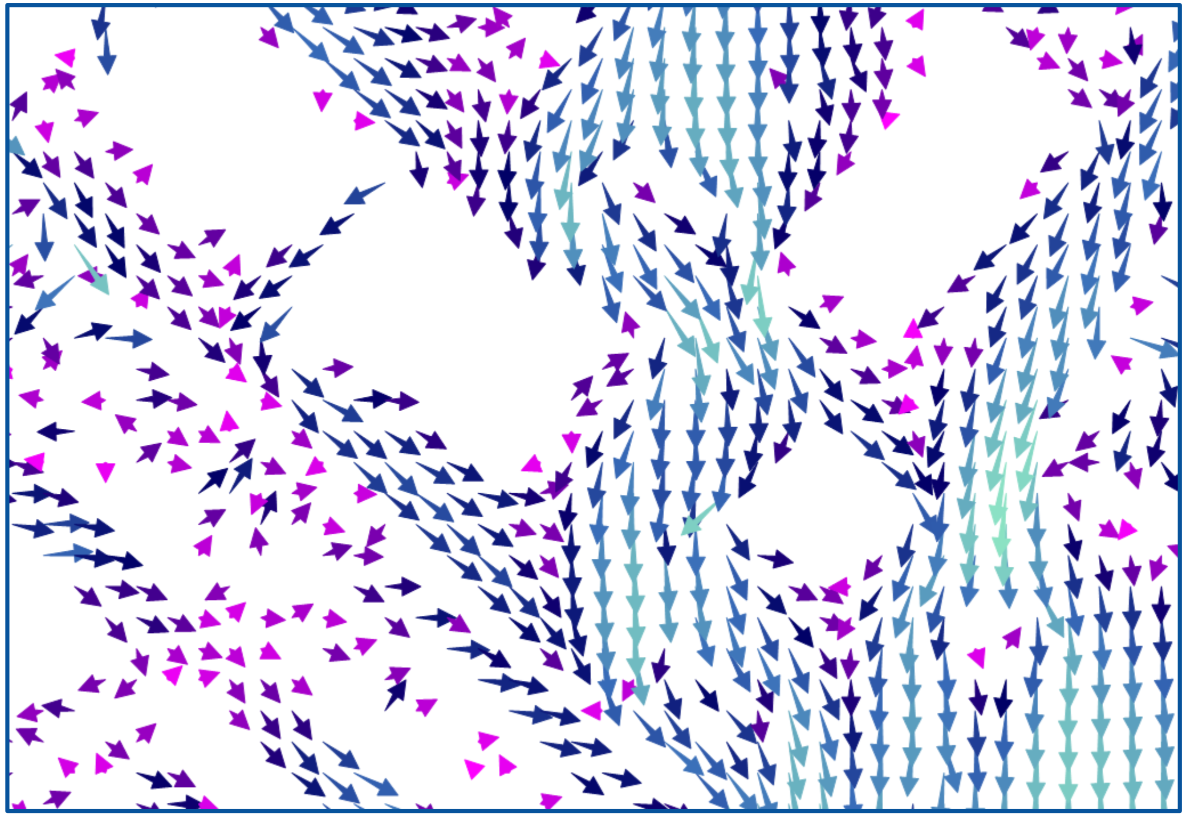
Multi-directional dispersion within a street canyon as parameterised in ADMS-Urban

Practical challenges (1 of 2)

CFD models don't have any flow within buildings but AQ models need some 'information' in these areas – what values should be used?

CFD models can generate ultra-high resolution flow fields, but what horizontal and vertical resolution CFD data should be used as input to the AQ model?

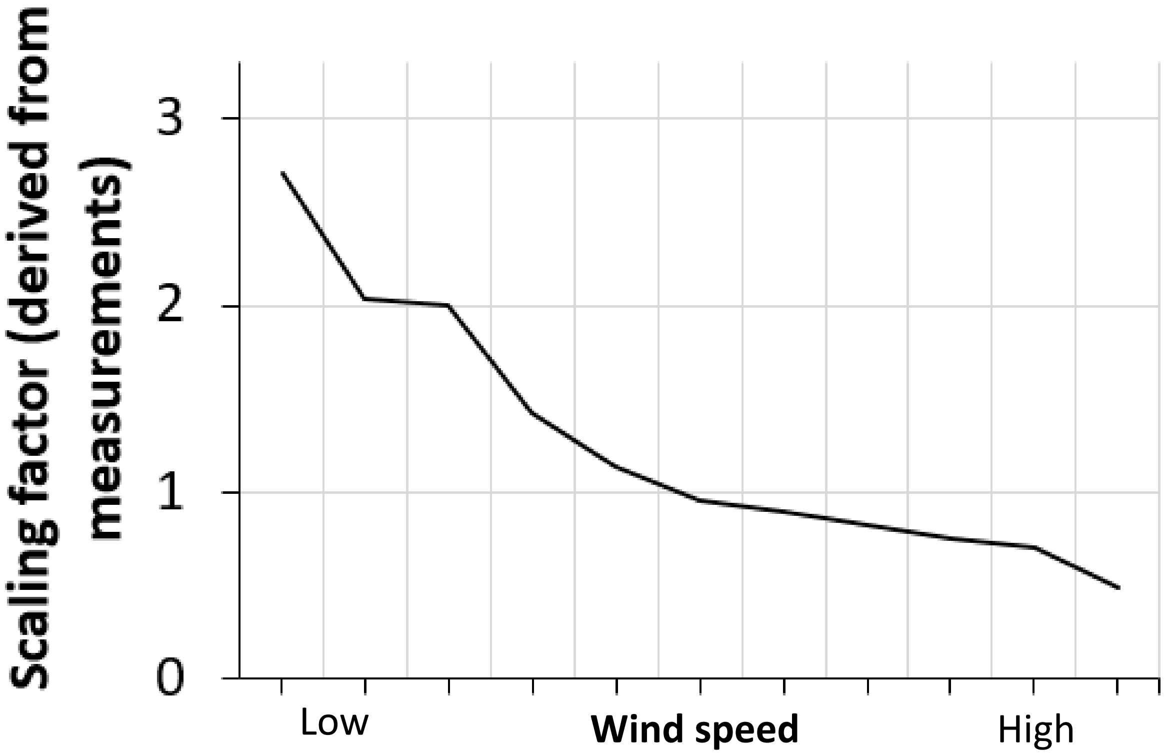
In ADMS, streamlines follow the flow from each source segment. How sensitive are modelled concentrations to the density of streamlines / segments?

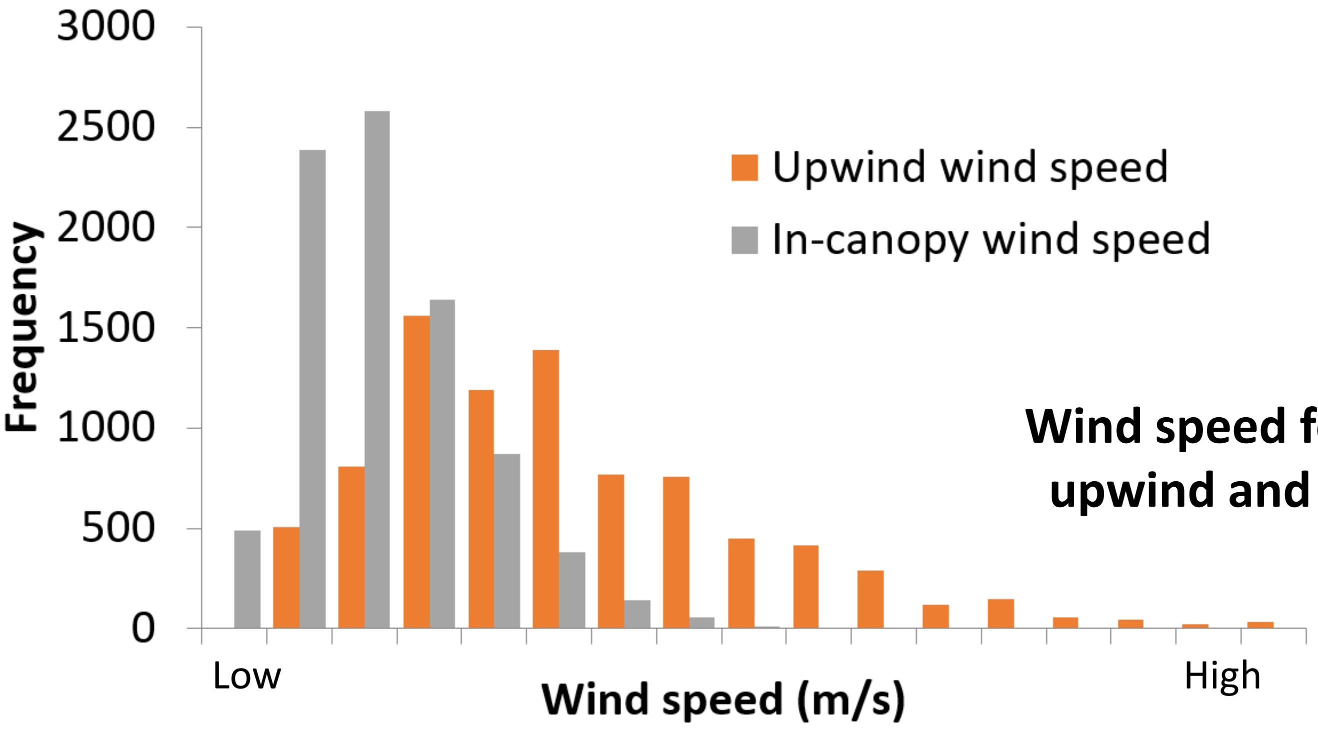


Illustrative CFD flow vector output

Practical challenges (2 of 2)

How do we scale CFD flows to represent different atmospheric conditions (in order to calculate ‘annual’ values to compare to AQ limits)? What are we ‘losing’ by only scaling with wind speed?



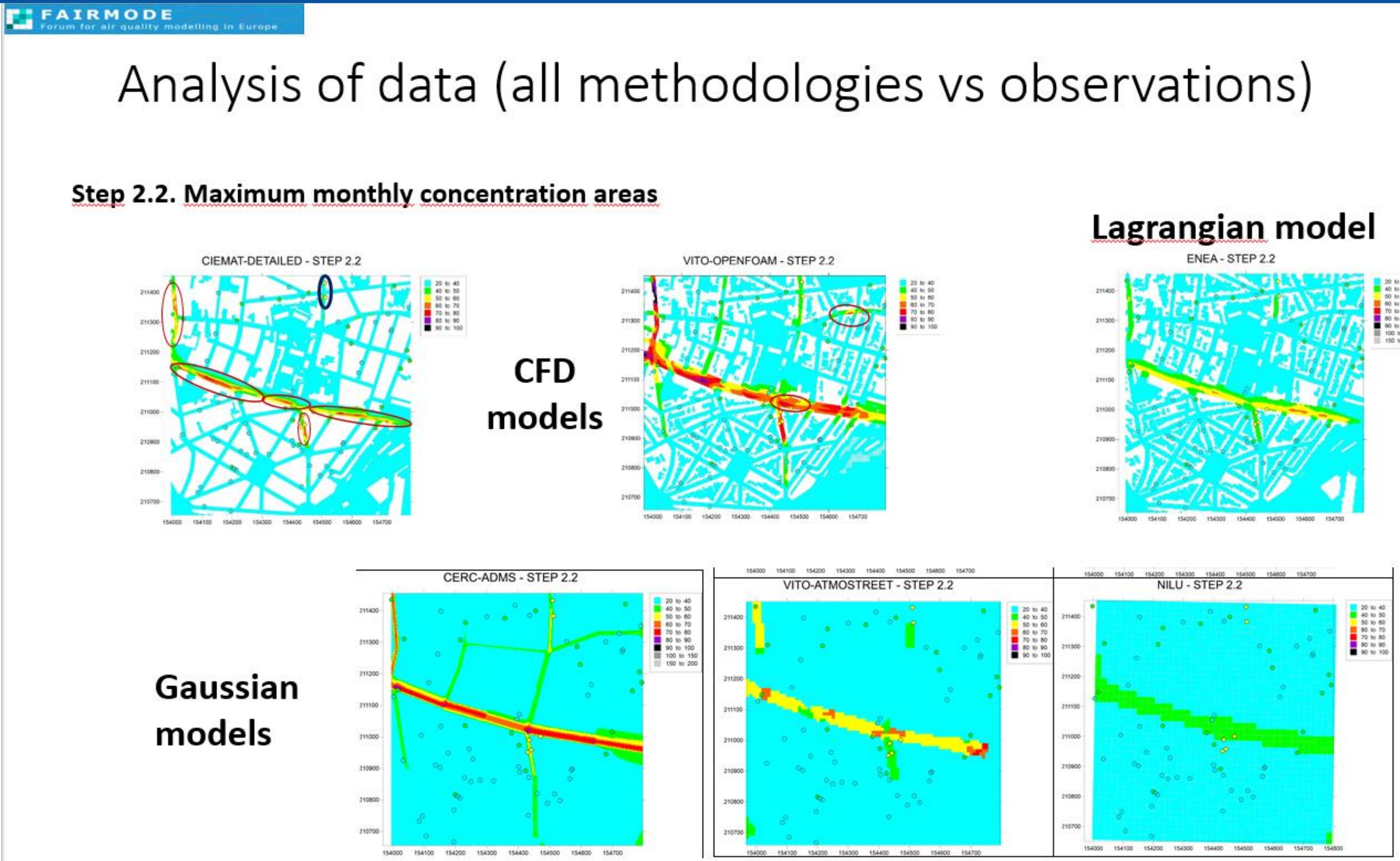


Wind speed for full year, upwind and in-canopy

How do we scale CFD flows to represent different wind speeds? Is a linear approach sufficient?

Hot topic – other people are looking at this

- A sub-group within FAIRMODE* is looking at microscale modelling. ADMS has been used in an inter-comparison study
- The UK Urban Environmental Quality (UK-UEQ) WG are interested in generating guidance to help the community understand for what applications CFD modelling could be necessary / preferable

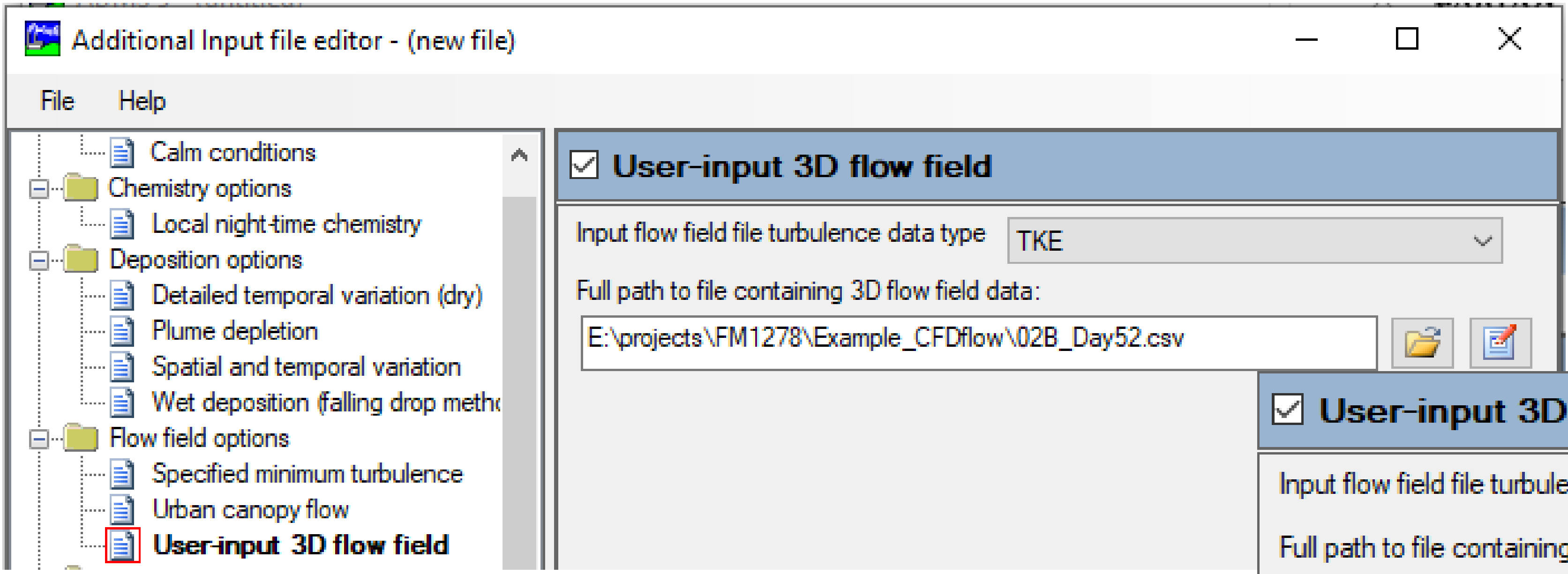


*'Forum for Air Quality Modelling' *Slide courtesy of Fernando Martin (CEIMAT) (leads CT4 microscale activity)*

Using the 'User-input 3D flow field data' option in ADMS (1 of 3)

- Flow field and turbulence data input on a regular 3D grid (NX x NY x NZ points)
  - Flow field components (U, V, W)
  - Turbulent velocities (σ_U, σ_V, σ_W) or Turbulent Kinetic Energy (TKE)
- Data file specified via the .aai / .uai* file
- Option requires **Complex Terrain** to be used, with a dummy terrain file specified (e.g.'terrain.ter' in Data subdirectory)

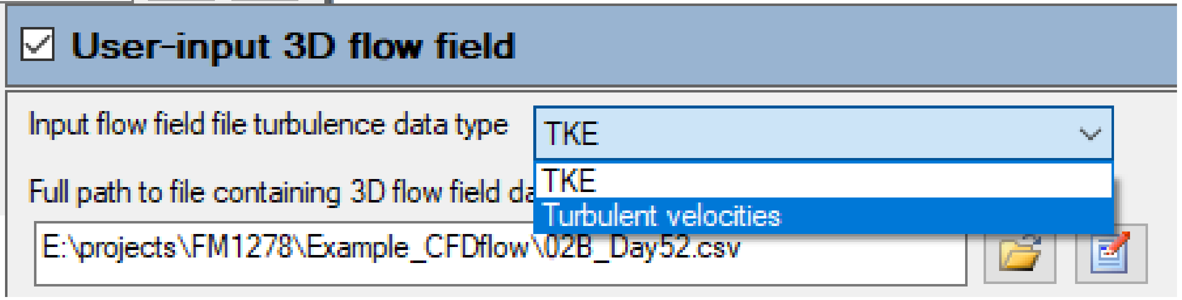
* Option currently available in ADMS 5, and implemented as a beta version in ADMS-Urban & ADMS-Roads



File formats:

```
NX  NY  NZ
X  Y  Z  U  V  W  TKE
...
```

```
NX  NY  NZ
X  Y  Z  U  V  W  SigU  SigV  SigW
...
```



Using the ‘User-input 3D flow field data’ option in ADMS (2 of 3)

Guidance

- A consistent ADMS *.met* file containing the meteorological conditions upstream of the domain covered by the 3D flow field must be specified e.g. generated through post-processing of Urban Canopy flow field module outputs
- Higher vertical resolution at release height(s) will improve modelling results

Consistency

- To ensure consistency between the turbulence magnitude between ADMS and CFD models, CFD TKE / turbulent flow parameters are scaled within ADMS:

$$\mathrm{TKE_{scaled}}(x,y,z) = \frac{\overline{\mathrm{U}}_{\mathrm{ADMS}}(z)}{\overline{\mathrm{U}}_{\mathrm{CFD}}(z)} \, \frac{\overline{\mathrm{TKE}}_{\mathrm{ADMS}}(z)}{\overline{\mathrm{TKE}}_{\mathrm{CFD}}(z)} \, \mathrm{TKE_{CFD}}(x,y,z)$$

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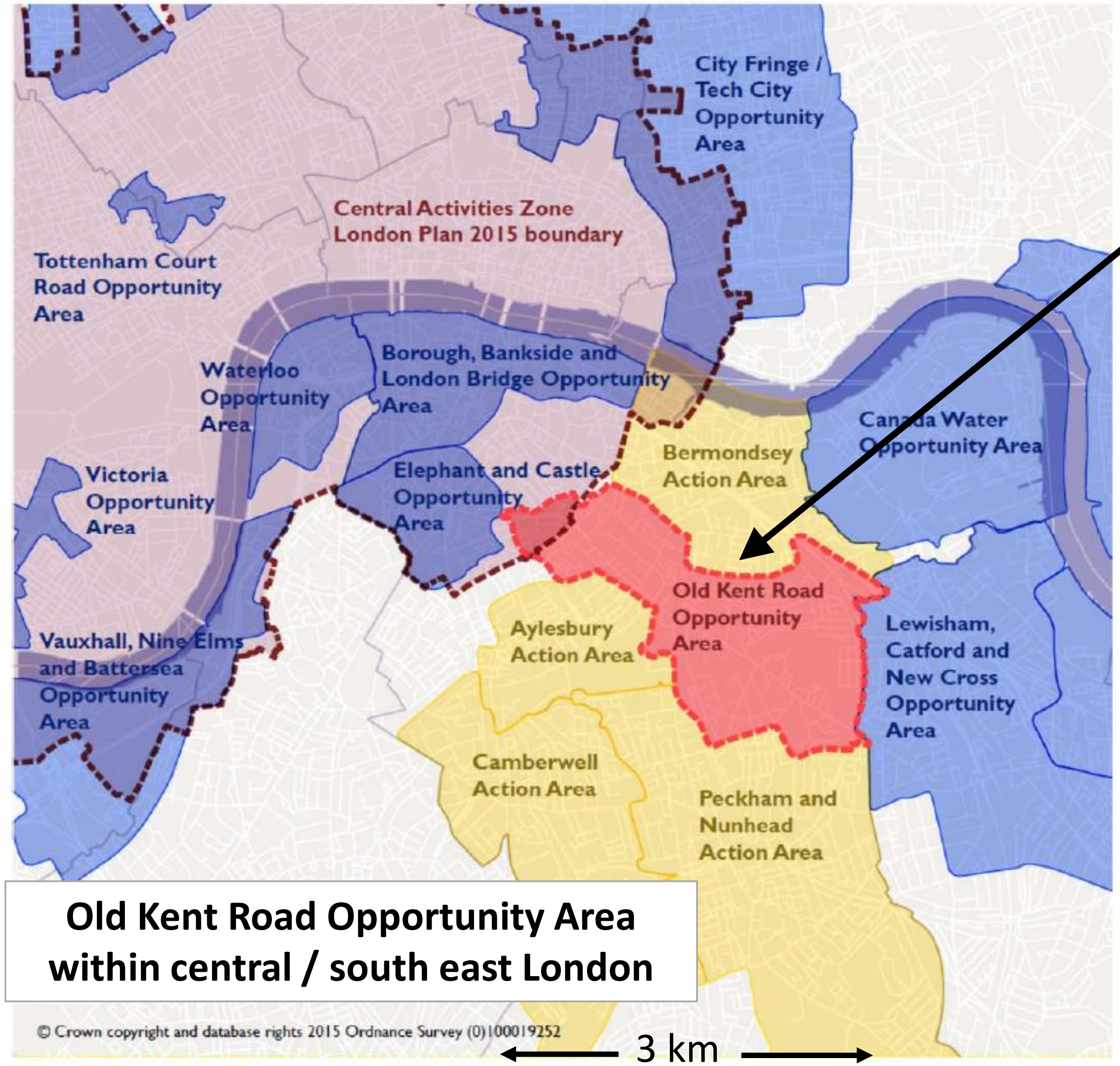
Using the ‘User-input 3D flow field data’ option in ADMS (3 of 3)

Restrictions

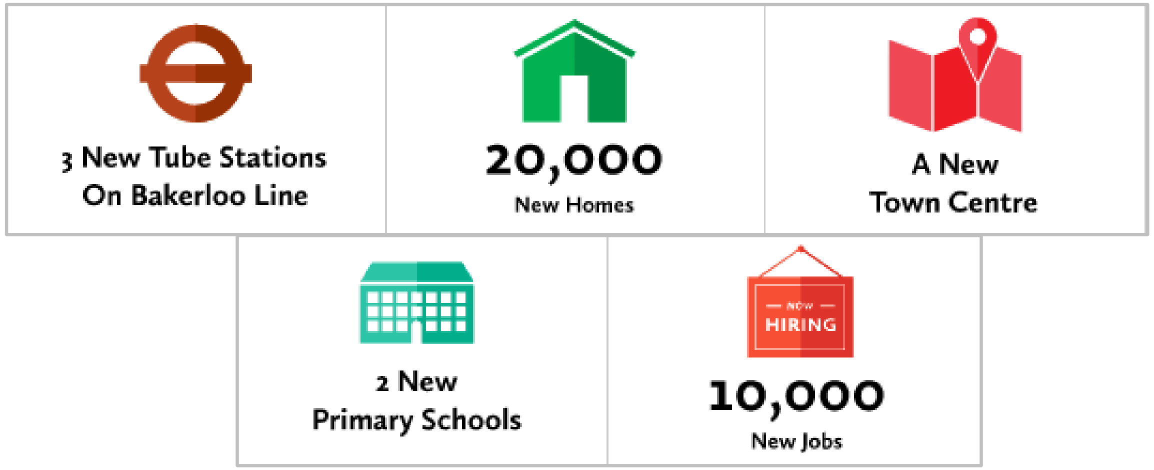
- User-input 3D flow field data can only be used for short-term runs with one line of meteorological data.
- Currently (in ADMS 5) there are limitations on the number of points specified in the 3D file, but this is likely to be relaxed in future releases
- The model assumes that the flow field data are defined on a complete rectangular grid – so flow within buildings needs to be ‘estimated’
- The geographical extent covered by the flow field data must be larger than the modelling region, where the modelling region comprises of all of the sources, buildings, specified output points and the output grid:
  - the flow field data must cover a region at least 10% larger than the modelling region &
  - the region covered by the flow field data must be at least 500 m larger than the modelling region in each direction

Case study: Background



Old Kent Road Opportunity Area within central / south east London

- 'Old Kent Road Opportunity Area' (www.oldkentroad.org.uk):



- 'Old Kent Road Opportunity Area' AQ study for the London Borough of Southwark
  - High resolution AQ modelling to identify pollution hotspots
  - Assessment of baseline and future year AQ, accounting for planned developments

Case study: Background

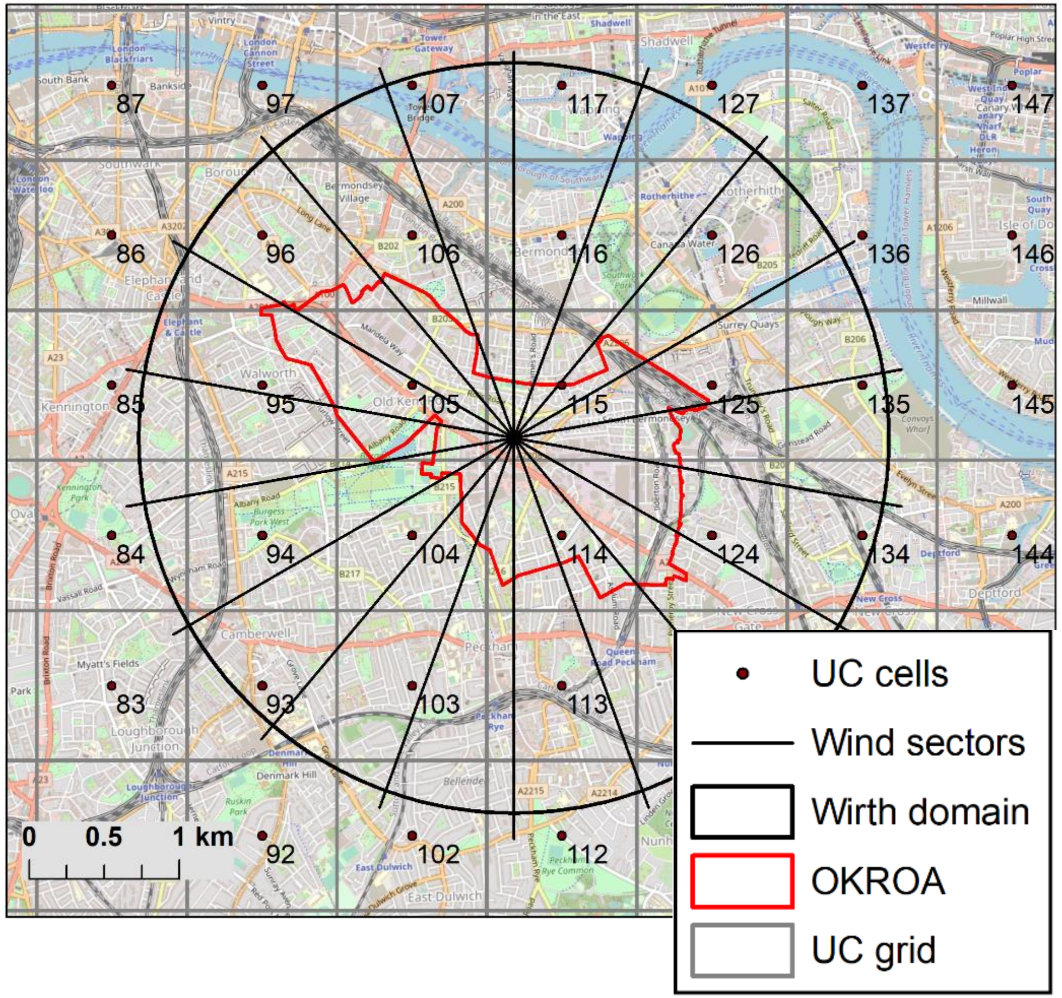
- Task 1: Strategic air quality modelling
  - Baseline & future year AQ modelling for the Old Kent Road
  - Street canyon modelling using VU-City data
- Task 2: Detailed 3D dispersion modelling (following slides)
- Contributors:
  - London Borough of Southwark: funding, traffic and other data
  - Wirth Research (www.wirthresearch.com): CFD data
  - VU-City (www.vu.city): detailed 3D buildings

Example VU.City geometry

Case study: Steps required for ADMS-Urban to use CFD data

- Task 2: Detailed 3D dispersion modelling:
  - Modify ADMS-Urban to allow input of 3D flow field data
  - Derive upwind conditions for use in CFD modelling:
    - Wind speed & turbulence calculated hourly for full year at selected 20° sector Urban Canopy (UC) cells upwind of the domain
    - 'Upwind' profiles calculated as the average over hours where the wind direction is within the sector
  - Ideally, 'upwind' profiles would have been used as input to the CFD modelling, but Wirth concluded they were sufficiently similar to their default profiles, so they were not implemented

CFD domain: 5 km diameter circle
(Numbering corresponds to Urban Canopy cells)



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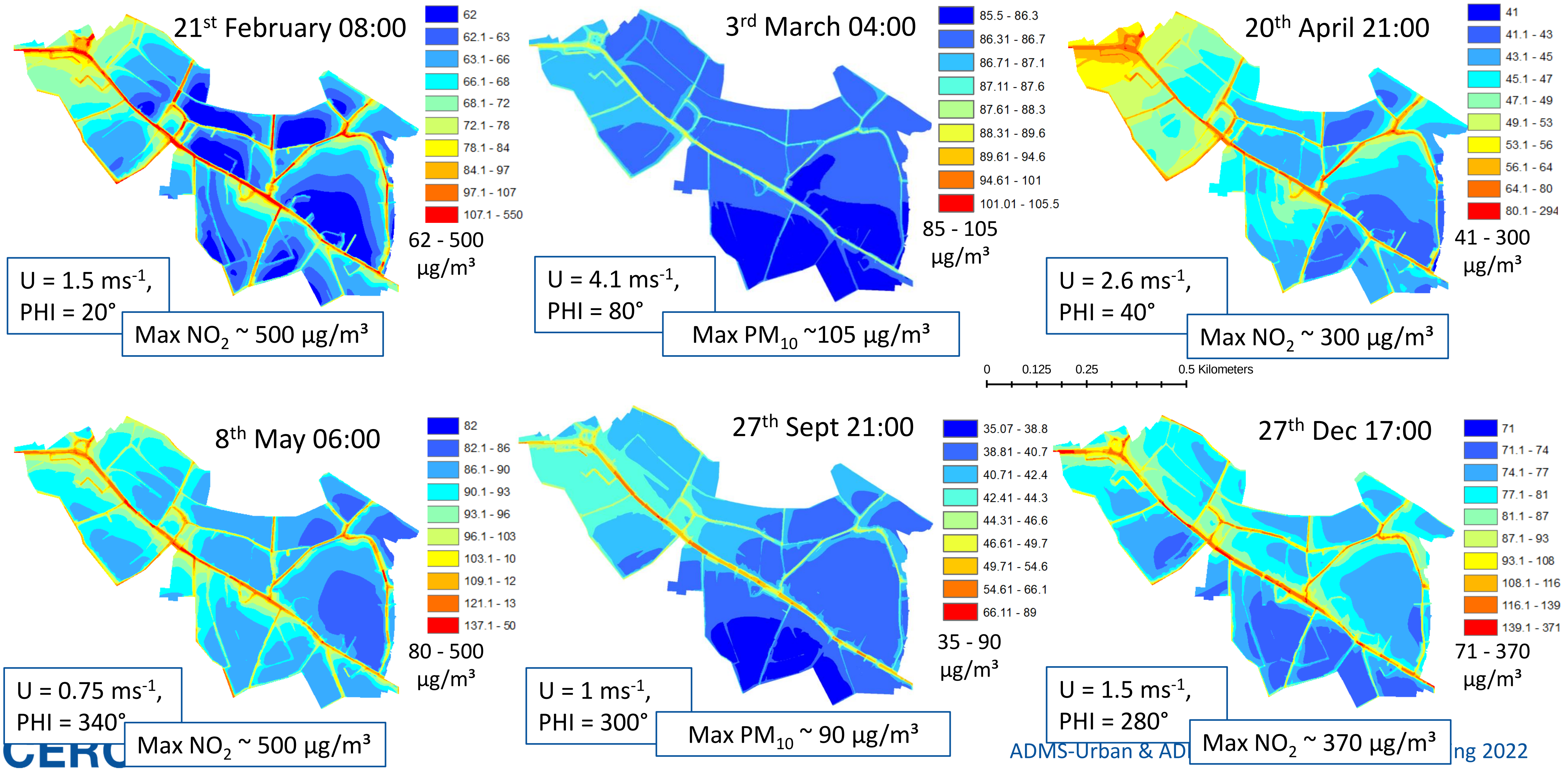
Case study: Steps required for ADMS-Urban to use CFD data

- Task 2: Detailed 3D dispersion modelling:
  - A post-CFD, pre-ADMS flow field processing utility was written:

Scale the CFD flow and turbulence to fit with the UC upwind profile and input meteorological condition → In-fill flow outside the CFD domain using UC profile data → In-fill flow in buildings using scaled UC profile data (reduce flow, direct wind vectors to outside building and set turbulence to layer average)

  - Inspect scatter plot of hourly ADMS-Urban baseline modelled & observed time series to identify **6 worse case meteorological conditions**

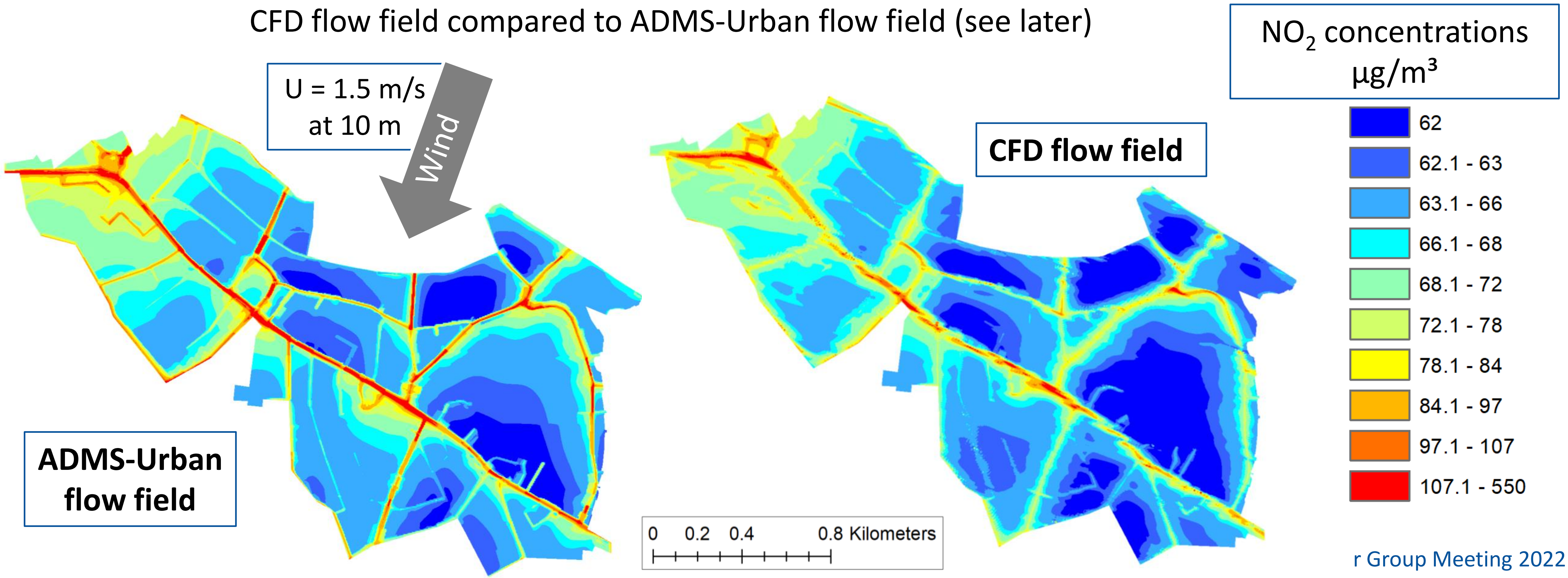
Case study: ‘Baseline ADMS-Urban outputs (2018) – 6 worse case hours



Case study: Baseline and CFD ADMS-Urban compared – NO_2, 21st February 08:00

Overall comparison:

- Similar high concentration magnitudes
- Canyon parameterisation in ADMS-Urban leads to continuous high along-road concentrations, CFD flows generate irregular impacts
- Wider impact of road emissions, with generally lower concentrations for CFD flow field compared to ADMS-Urban flow field (see later)

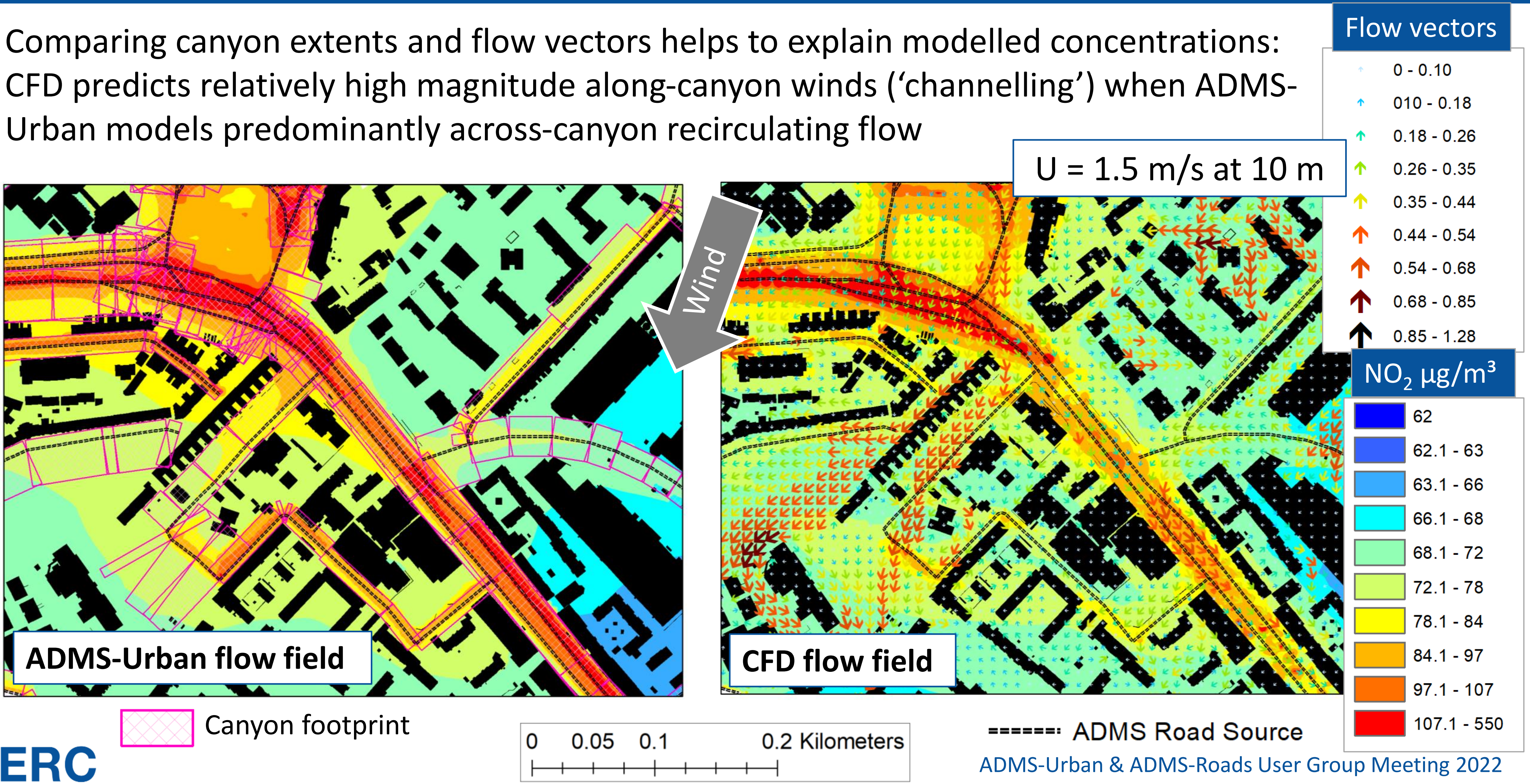


Case study: Baseline and CFD ADMS-Urban compared – NO_2, 21st February 08:00

- Zooming in to a hotspot location shows similar high concentration magnitudes, but extent of high concentrations reduced when CFD flows modelled

Case study: Baseline and CFD ADMS-Urban compared – NO_2, 21st February 08:00

- Comparing canyon extents and flow vectors helps to explain modelled concentrations: CFD predicts relatively high magnitude along-canyon winds ('channelling') when ADMS-Urban models predominantly across-canyon recirculating flow



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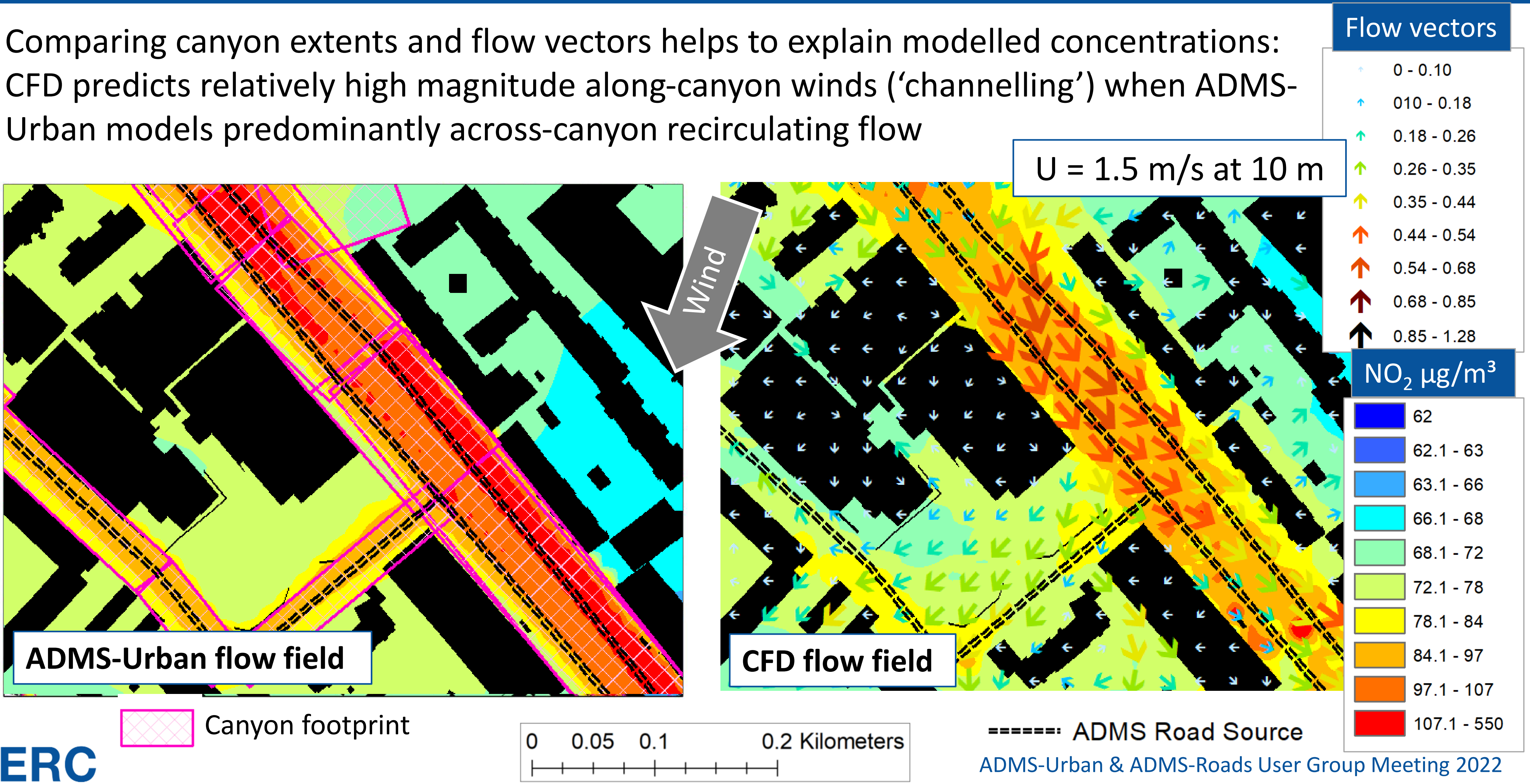
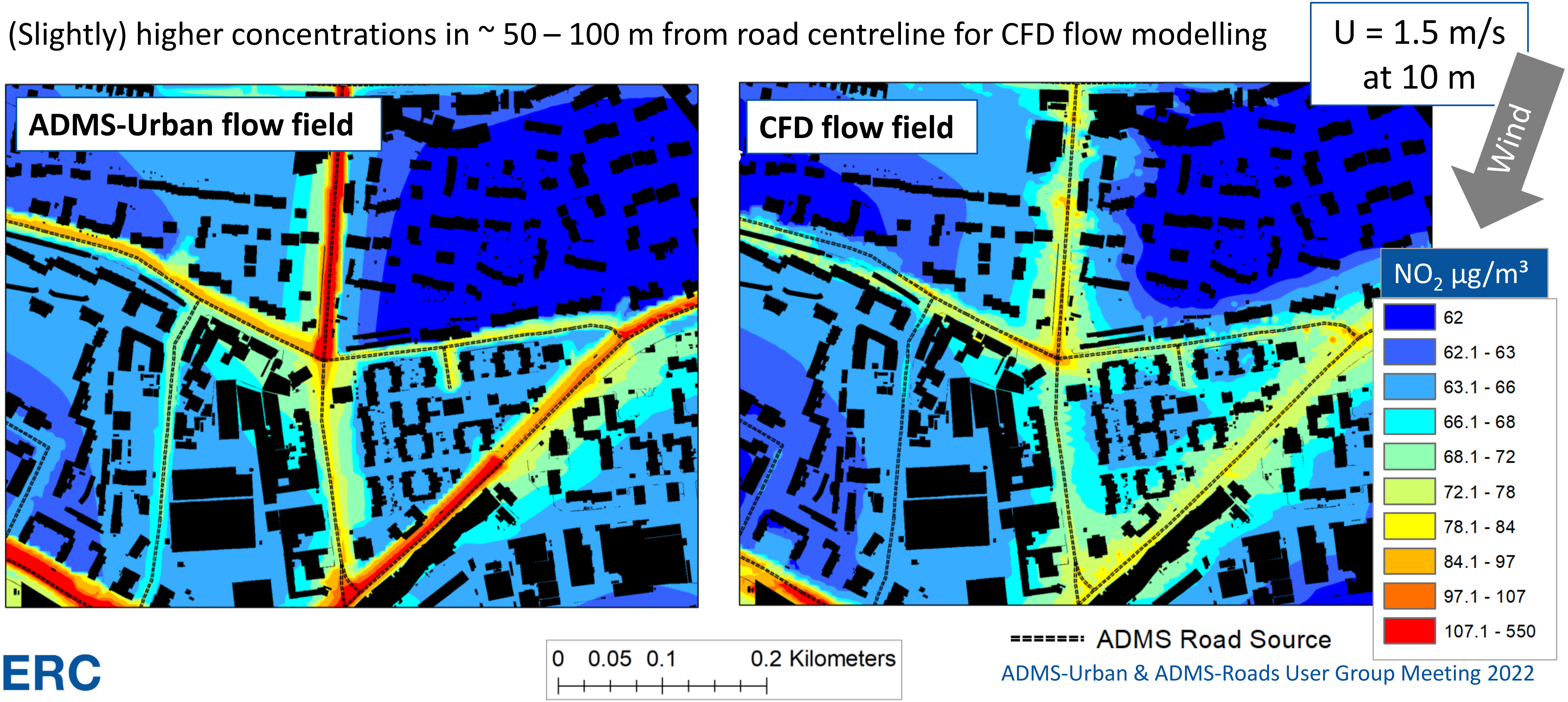


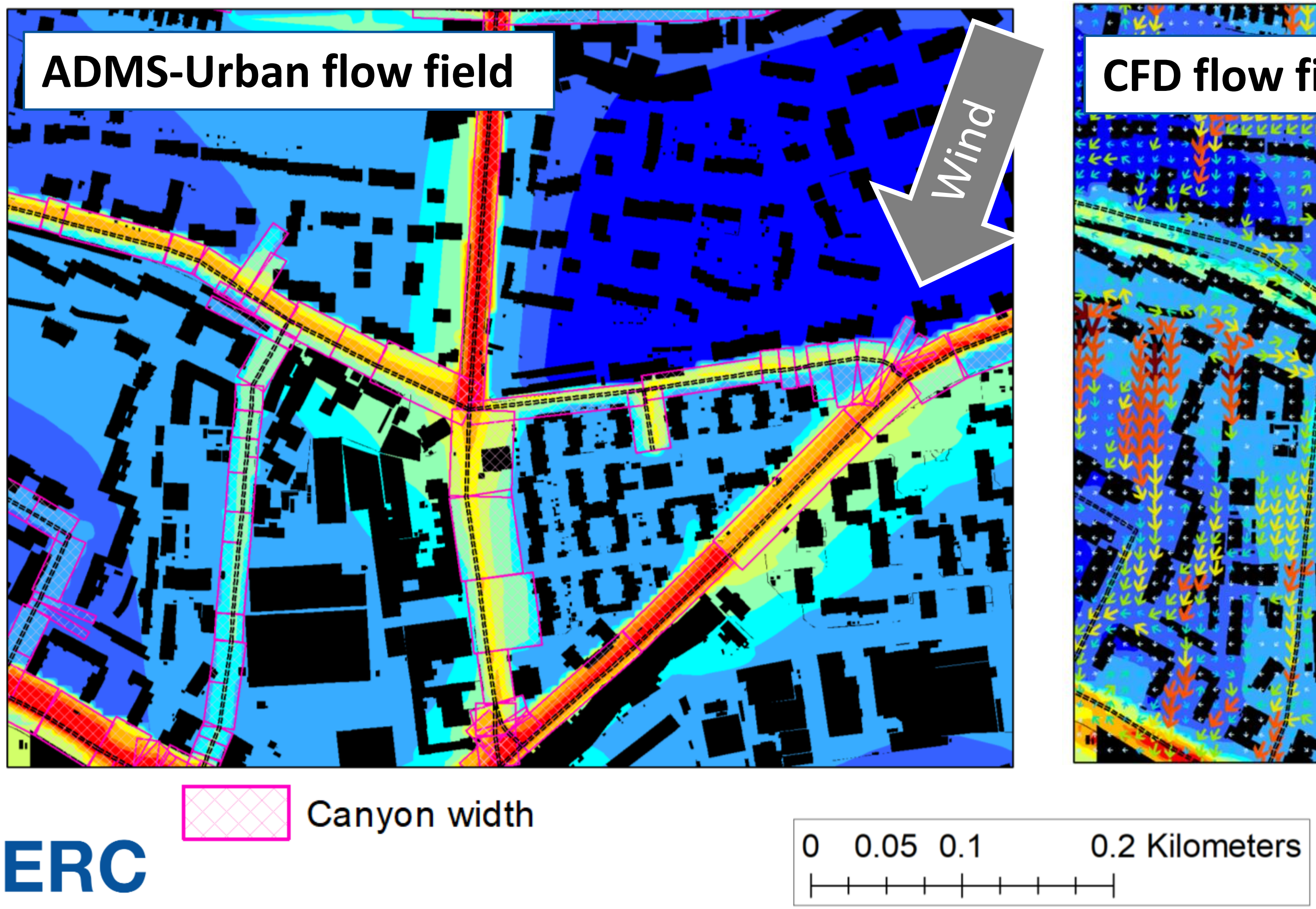
Case study: Baseline and CFD ADMS-Urban compared – NO_2, 21st February 08:00

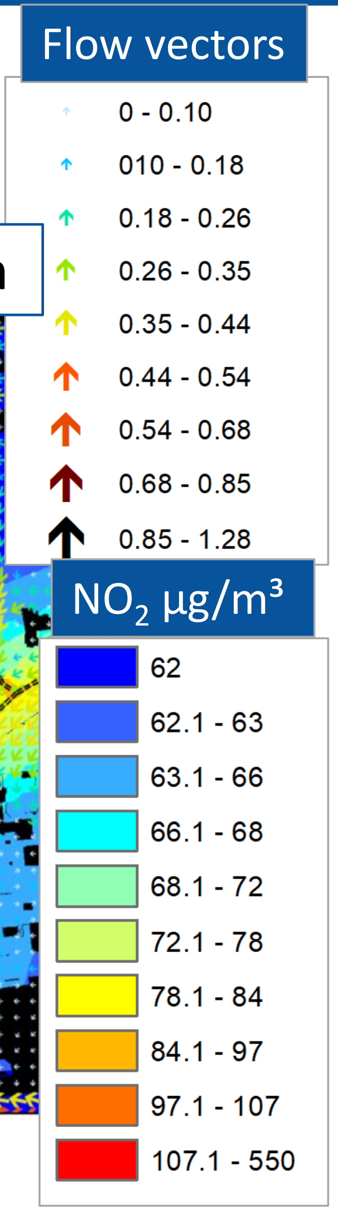
- Other locations show the spreading out of concentrations between buildings when the CFD flow field is used
- (Slightly) higher concentrations in ~ 50 – 100 m from road centreline for CFD flow modelling

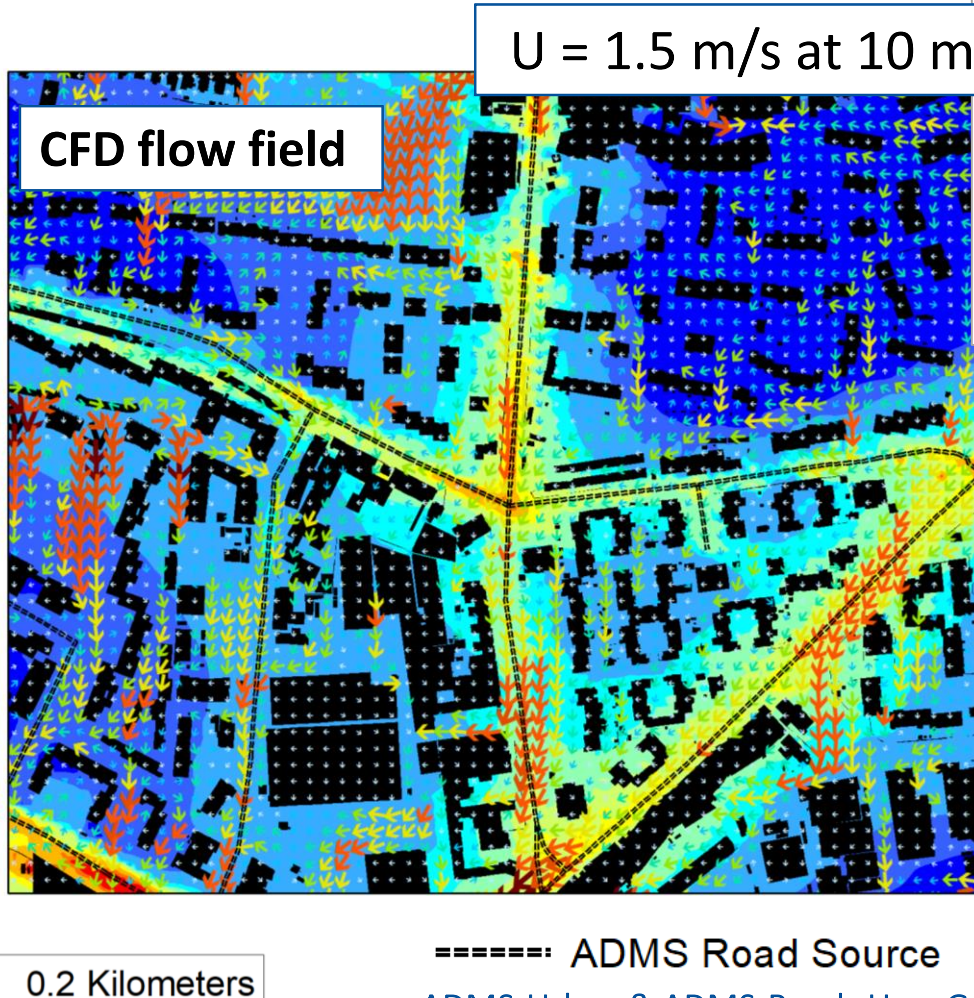


Case study: Baseline and CFD ADMS-Urban compared – NO_2, 21st February 08:00

- Strong variations in wind speed don't appear to strongly influence concentrations



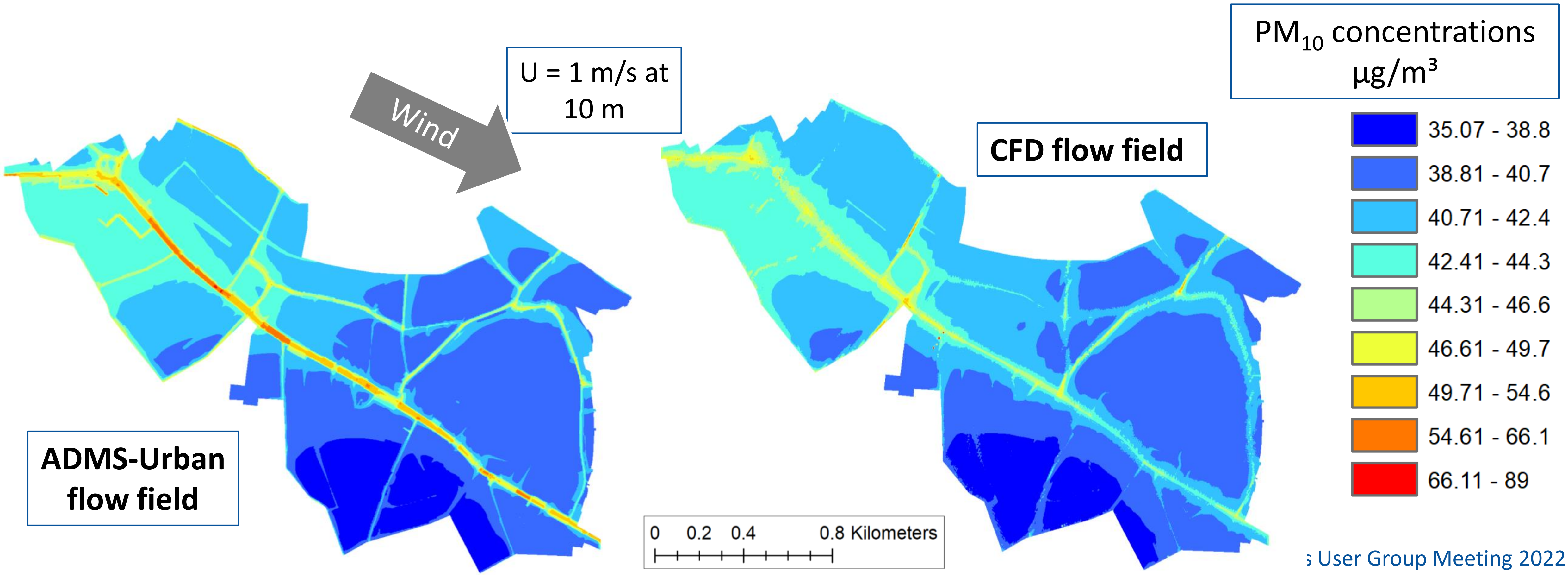




Case study: Baseline and CFD ADMS-Urban compared – PM_{10}, 27th September 21:00

Overall comparison:

- Canyon parameterisation in ADMS-Urban leads to continuous high along-road concentrations, CFD flows generate irregular impacts
- Some anomalous high concentrations for CFD run – needs investigation



Case study: Practical lessons learnt

- Processing step between ‘raw’ CFD outputs and input to ADMS-Urban is required
- Important to perform sensitivity testing, for example:

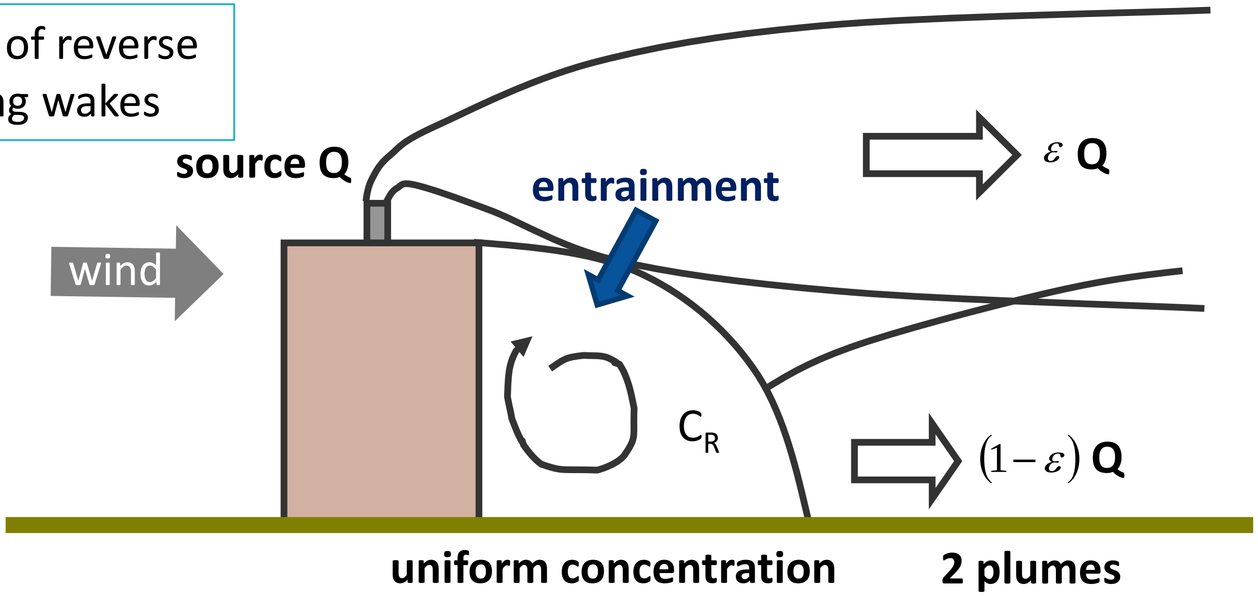
Parameter tested	Outcome in terms of pollution maps	Explanation for outcome
Output point resolution	Very sensitive	High concentration gradients can occur at irregular locations, not just adjacent to roads
Plotting resolution	Insensitive	Output point resolution is set to be sufficiently high
In-building flow	Not very sensitive	The in-building flow has been defined to flow towards the outer edges of the buildings, to encourage along-building dispersion
Number of road vertices	Not very sensitive	Streamline density relates to the number of road segments, so it could be that for other configurations this parameter would alter results

- Run times using CFD flows as input can be long (~hours) but manageable (Run spatial splitting / Run Manager)

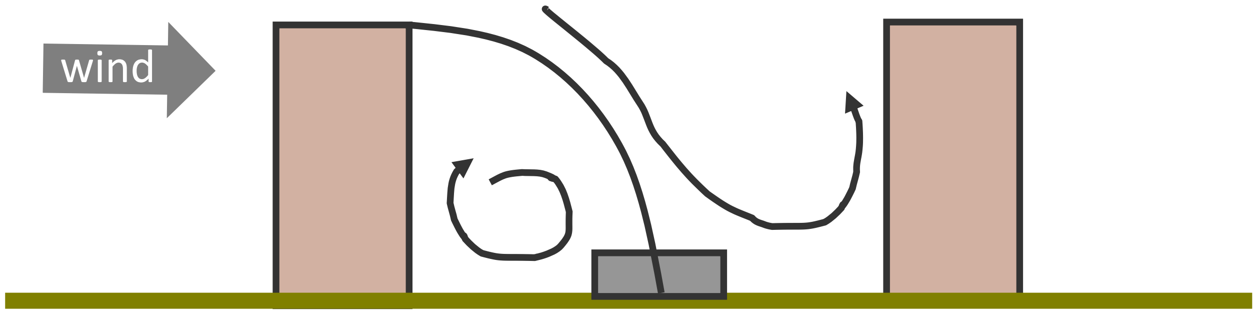
Future directions (1 of 2)

- In terms of ADMS:
  - ✓ ADMS is able to use CFD wind field and turbulence data to drive dispersion calculations
  - ✓ CFD datasets require processing prior to use in the model
  - ✓ High output point resolution required due to the spatial variability of steep concentration gradients
  - Treatment of reverse flow regions in the vicinity of buildings may need improving

'Full' treatment of reverse flow in building wakes



When running with CFD flow field data, only partial treatment of reverse flow in in street canyons: high concentrations will result from a source segment being located in a reverse flow region, but currently entrainment is not modelled



Future directions (2 of 2)

- More generally
  - It is important to be aware of the limitations of both CFD and Gaussian dispersion (e.g. ADMS) models when modelling complex morphologies at high resolution
  - Datasets need to be compatible e.g. microscale emissions should be used alongside microscale dispersion models
  - At the current time, CFD simulations are likely only to be used for peak concentration analyses
  - Guidance / further study needed in order to avoid the use of misleading modelled concentrations as ‘evidence’ for policy and planning (higher-resolution modelling gives the illusion of accuracy)

Questions?

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