COMPLEX AIR FLOWS AROUND URBAN INTERSECTIONS: CHALLENGES FOR MODELLERS

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1. Introduction

- Management of local air quality and emergency response following a hazardous release requires knowledge of pollutant dispersion through networks of urban streets.
- Urban buildings interact with background winds to modify turbulent flow structures within street networks.
- Street canyons are commonly studied and simple models have been proposed aiming to describe helical recirculating flows that form within them[1,2].
- However, street networks also contain intersections which influence how pollutants are distributed to adjoining streets[3-6].
- **Can we develop a generic understanding of the flow structures within intersections and how they may depend on the local building geometry, and background wind speed and direction?**

2. Aims of Study

- To use in-street & reference flow data from two different intersections: the DAPPLE site in Central London, and the Headingley site in Leeds to explore the influence of local geometries on air flows through the intersection & adjoining streets.

3. Study Sites

- **DAPPLE:** centred around the intersection between Marylebone Rd and Gloucester Place. See www.dapple.org.uk for details[7].
- Four sonics (10 Hz) were deployed at heights of 7.90 m for top sonics and 4 m for bottom sonics at sites 1,2 on opposite lampposts within the intersection (Fig 1a).
- A sonic was deployed at site 3 at 4.15m within the Marylebone Rd street canyon for comparison.
- A reference sonic (20Hz) was located on the SW corner of WCH library roof (S in Fig 1a).
- **Leeds:** centred around the junction between North Lane and Headingley Lane.
- North Lane is an irregular street canyon ~15m wide and lined by a mixture of two storey buildings (10-12m) and 3 storey buildings (20 m), giving a H:W ≈ 0.67-1.3, depending on wind direction.
- The two sonics (10Hz) used here are marked with stars in Fig 1b.
- Reference data was taken from the roof of a Leeds University building ~2 km to the south of the site (represented by subscript hlds).
- Reported wind directions use a Cartesian vector system with respect to either Marylebone Rd or North Lane so that the reference wind directions (θ_{ref}, θ_{hlds}) are positive anti-clockwise from 0° when the wind blows along North Lane/Marylebone Rd (roughly towards the East) and +90° when the wind is blowing up Gloucester Place at the DAPPLE site (from SSE to NNW); and presented in the wind vector sense.

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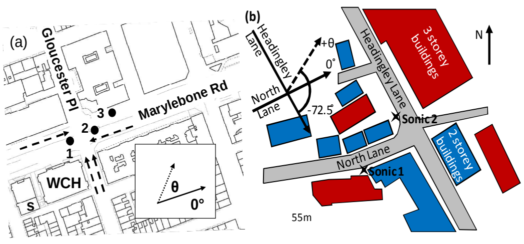

Figure 1: Site schematic for (a) the DAPPLE site (Copyright Edina map) (b) the Headingley intersection in Leeds.

4. Mean Flow Patterns

Do the mean flows at the sites resemble the helical flows predicted for a typical street canyon?

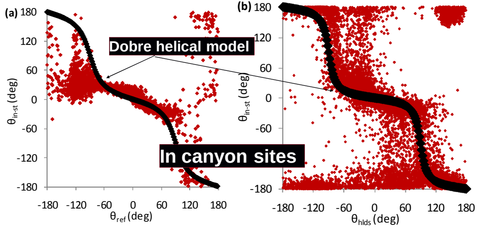

Figure 2: Relationship between θ_{ref} and in-street wind direction for (a) DAPPLE site 3 (b) the North Lane canyon, Leeds. 15-minute averages.

- For DAPPLE site 3 in the London Marylebone Rd. canyon and the North Lane canyon in Leeds, the helical flow assumption is reasonable for most θ_{ref} with a combination of flow channelling and flow reversal due to cross canyon re-circulation present in the flow patterns.
- Switching (channelling of recirculated weak mean flow in either direction along the street canyon) of the flow for near perpendicular roof-top wind directions, $+90 < \theta_{ref/hlds} < +120°$ and $-90 < \theta_{ref/hlds} < -120°$, leads to large scatter in the mean in-street flow direction at both sites.

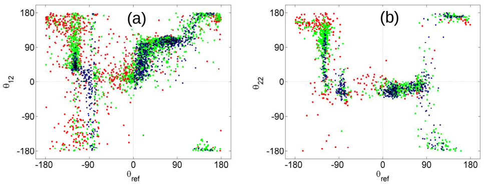

Figure 3: **Relationship between θ_{ref} and in-street wind direction for (a) Site 1 lower, (b) Site 2 lower. Roof-top wind speed (U_{ref}): ♦ $U_{ref} < 1.1$ m s^{-1}, ♦ $1.1 \leq U_{ref} \leq 2.5$ m s^{-1}, and ♦ $U_{ref} > 2.5$ m s^{-1}.**

- Fig 3 shows evidence of some in-street flow channelling and some flow reversal at sites within the intersection.
- **BUT!** there are areas where a narrow region of background flow directions can lead to a huge variety of in-street mean flow angles.
- Scatter is even greater for lower background wind speeds where additional sources of turbulence such as that produced by passing traffic may begin to dominate.
- Intersection sites do not show behaviour consistent with helical flow.
- Higher frequency analysis necessary to explain the wide scatter in mean flow angles.

REFERENCES: [1]Dobre, A., et al., 2005: Flow field measurements in the in the proximity of an urban in London, UK. *Atmos. Environ.*, **39**, 4647-4657; [2]Barlow, J.F., et al.,, 2009: Referencing of street-level flows: results from the DAPPLE 2004 campaign in London, UK. *Atmos. Environ.,* **43,** 5536-5544; [3]Robins, A., et al., 2002: Spatial variability and source–receptor relations at a street intersection. *Water Air & Soil Pollut. Focus,* **2**, 381-393; [4]Scaperdas, A., A.G. Robins, R.N. Colville, 2000: Flow visualisation and tracer dispersion experiments at street canyon intersections. *Int. J. Env. Poll.*, **14**, 526-537;
[5]Soulhac, L., V. Garbero, P. Salizzoni, P. Mejean, R.J. Perkins, 2009: Flow and dispersion in street intersections. *Atmos. Environ.*, **43**, 2981-2996; [6]Tomlin, A.S. et al., 2009: A field study of factors influencing the concentrations of a traffic related pollutant in the vicinity of a complex urban junction. *Atmos. Environ.*, **43**, 5027-5037;
[7]Wood, C.R, et al., 2009: Dispersion experiments in central London: The 2007 DAPPLE project. *Bull. Am. Met. Soc.,* **90**, 955-970.

5. Short Time-scale Analysis

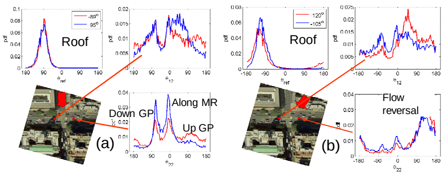

Figure 4. Wind direction pdfs for 1 hr segments of 10 Hz data at DAPPLE sites.

- Width of background distribution suggests significant short time-scale variability in θ_{ref} throughout the hour of up to 180°.
- This leads to multi-modal characteristics of in-street wind angles at site 1 (θ_{12}) and site 2 (θ_{22}) due to rectification of fluctuations in θ_{ref} by surrounding buildings.
- Features such as channelled flow along Gloucester Place, and Marylebone Rd are seen, as well as evidence of corner vortices and in-street recirculation and resulting flow reversal.
- The averaging of these modal peaks leads to the scatter in the longer time-averaged data shown in Fig 3.
- Suggests that 15-minute mean flow direction data does not give accurate picture of bifurcation type behaviour at the intersection; better shown by multi-modal peaks in pdf's.
- Very small changes in mean θ_{ref} and its pdf dramatically change relative strength of modal peaks in in-street pdf's.

Are similar features seen in Headingley canyon?

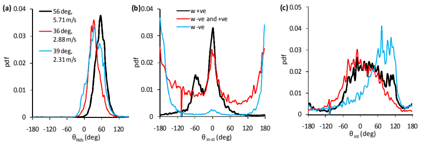

Figure 5 (a) Pdf of θ_{hlds} in three 2 hr periods. Corresponding distributions in (b) North Lane (c) at the intersection.

- Bi-modal in-street channelling common for oblique sector shown in Fig 5 due to off-perpendicular orientation of streets, and high windward building on S side of North Lane.
- During high wind speeds (black) flow channels up North Lane towards intersection (0°) with +ve vertical velocities: consistent with in-street recirculation (Fig 6a). At intersection flow fluctuates between channelling from Headingley & North Lane.
- During low wind speeds (red) in-street and intersection flow characteristics are more complex. Within North Lane, bi-modal distributions of channelled flows with both updrafts & downdrafts observed; corresponding to in-street recirculation and flow convergence respectively.
- In period 3 (blue), despite background flow being more oblique than in period 1 (black), reversed channelling is seen due to low wind speeds and weak in-street recirculation. Negative vertical velocities are consistent with converged flow within North Lane. At the intersection, the wind direction is dominated by channelled flow up Headingley Lane (+90°). Competition between flows leads to downdrafts at the in-street sonic but a forced updraft of flow coming from North lane (Fig 6b).

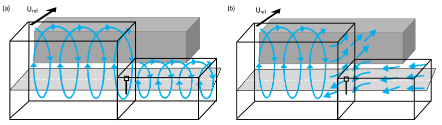

Figure 6 - Schematic of flow in North Lane (a) helicoidal flow (b) converged flow.

6. Overall Conclusions

- Two intersections sites with different geometries show multi-modal wind direction distributions; driven by fluctuations in background flows on short time-scales (~1 minute).
- The ability to represent such multi-modal behaviour and its sensitivity to background wind speed/direction would be a challenge for models attempting to represent the air flow through an asymmetric intersection.
- The 3-dimensional features seen indicate that flow near intersections is not always planar.