Using a virtual Doppler LiDAR and Large Eddy Simulation to quantify wind velocity measurement errors of ground-based Doppler LiDAR

Author Name(s): Veronica Escobar-Ruiz[1*], Janet F. Barlow[1], and Zheng-Tong Xie[2]
[1]Meteorology Department, School of Mathematical, Physical and Computational Sciences, University of Reading, Reading, Berkshire [2]Faculty of Engineering and the Environment, University of Southampton, Southampton
[*] E-mail: v.escobaruiz@reading.ac.uk

1 INTRODUCTION.

Doppler Wind LiDARs (DWLs) are remote sensing instruments that emit a near-infrared laser pulse at a certain frequency and the frequency shift of the backscattered signal is used to calculate radial velocities along the line of sight of the lidar beam. The ability of DWLs to obtain wind profiles with height or horizontal distance and their relatively easy deployment makes them more popular compared with point measurements such as traditional anemometers [1]. However, DWL scanning techniques assume a homogenous horizontal wind vector over the sensed volume. In cities, this entails a great challenge mainly because the urban building canopy influences the homogeneity of the wind and turbulence [2]. Furthermore, depending on the application, care should be taken with the selection of scanning patterns and their configuration. In the most common scanning method, Velocity Azimuth Display (VAD – see Fig. 3), the beam is scanned around a cone centred on the zenith and is analysed to obtain a 2D vertical wind profile [3]; however, it requires a long time to complete the full 360° measurement and the mean wind vector is assumed to be horizontally homogeneous across the cone. Nonetheless, altering the configuration of the scan can compensate for errors in estimating wind velocity, including the number of beams in a single scanning cycle and the choice of averaging interval.

Large-Eddy Simulation (LES) models provide high spatial resolution unsteady wind velocity fields, allowing realistic turbulent motions. Hence, applying LES in urban environments represents a suitable method to estimate errors derived from different DWL scanning techniques. PALM is a parallelised LES model offering several components for application in urban environments to study atmospheric boundary layers [4]. A virtual Doppler Lidar (VDL) tool for PALM version 6.0 has been developed and applied over a homogenous flat surface ins an attempt to estimate errors related to the VAD scanning technique [5]. The VDL simulates a laser beam path and estimates radial velocities from gridded LES wind vectors over its trajectory. Applying this toolbox in a complex topography urban environment (e.g., Bristol, UK) can provide more insight into possible wind velocity errors in space and time related to the scanning techniques and the underlying flow field. Furthermore, comparing simulated wind profiles with one year of DWL field observations can be used as a form of validation of the VDL-PALM tool.

DWLs have been used in urban environments to provide information about air quality [6], wind speed [1] and knowledge of the urban boundary layer [7] which is useful for a more accurate weather forecast [8]. The city of Bristol (UK) was selected as a study area for the ASSURE Project (Across-Scale Processes in Urban Environments), given its compactness and unique topography. Here, a network of DWLs operating different scanning strategies was deployed in spring/summer 2024 at different locations to characterise the urban boundary layer across space and time. This research aims to: 1) explore errors in measured wind vectors under the VAD scheme, 2) assess VAD performance for measurement of a wind profile climatology under different atmospheric conditions, and 3) aid comparison between PALM simulations and ground-based DWL data, given the flow inhomogeneities caused by the topography. This paper describes the setup and methods for preliminary experiments that will be reported at the WES conference.

2 METHODS

2.1 Study area

The unique physical geography of Bristol, with the long Avon Gorge running from south-east to north-west and south-west to north-east valley in which the city centre lies, provides a suitably high level of complexity for the study of an urban boundary layer with significant topography. The ASSURE field observations comprise a network of five DWLs (Fig. 1) to capture vertical and horizontal wind variations

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across the city. The sites comprise three ground-level locations, to the west (Fenswood Farm, BRFENS), and east (Digital Futures, BRDIFU and Pomphrey Hill, BRPOMP). The remaining DWLs are located on building rooftops, one on Bristol University Physics Building (BRPHYS) and one at the Tobacco Factory building in the city centre (BRTOBA). For this paper, we focused on simulating the BRTOBA DWL.

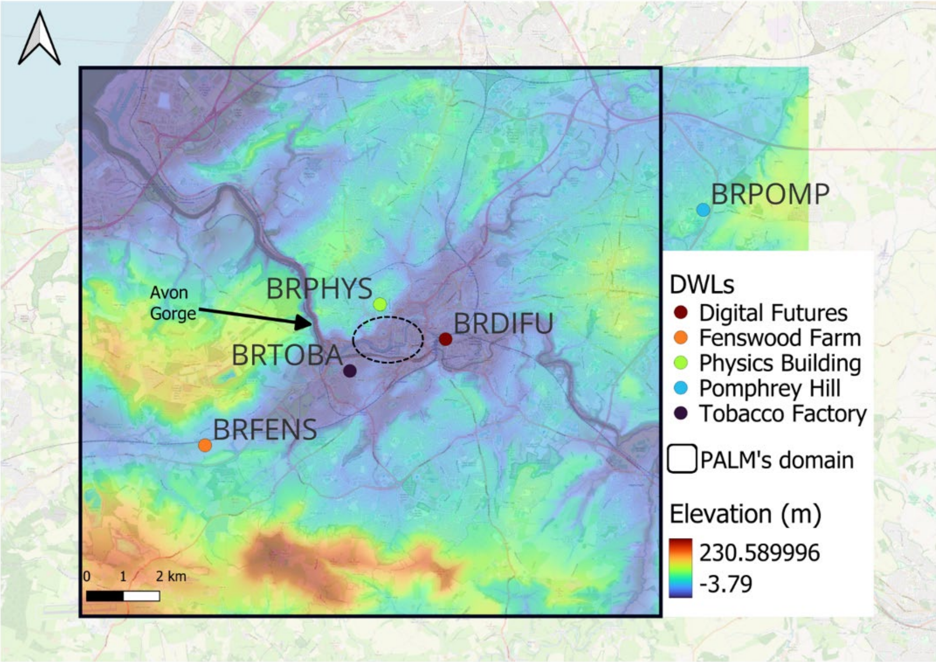

Figure 1, Location of the Doppler Wind LiDARs (DWLs)across Bristol, UK. The city centre is delimited by dotted lines and PALM's domain of 15 km x 15 km.
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2.2 Large-Eddy Simulation (LES) simulations and Virtual Doppler Lidar (VDL)

PALM [4] is a parallelized LES model that solves incompressible Navier–Stokes equations using the Boussinesq approximation. Turbulence closure of 1.5 order is used according to [9] for the parametrisation of subgrid-scale (SGS) terms. Discretisation of the domain is accomplished by using finite differences at horizontal-equidistant grid spacing, and time-stepping uses a combination of upwind-biased fifth-order differencing and third-order Runge–Kutta schemes.

Dirichlet or Neuman boundary conditions can be chosen for velocity components (u,v), potential temperature (θ), specific humidity (qv) and perturbation pressure (p^*) at the top and bottom of the domain. PALM follows Monin–Obukhov similarity theory (MOST) in which a constant flux layer can be assumed as a boundary condition between the surface and the first grid level where scalars and horizontal velocities are defined. For resolving solid obstacles (buildings and orography), the method given in [10] is used.

Model setup

The model domain size was 15x15x1 km^3 with a grid size of 5m (x-, y- and z-direction, Fig. 2). Topography in the model domain included buildings and orography of Bristol city. Synthetic turbulence generation (STG) [11] was used at the inlet. The dimensionless mean velocity and the Reynolds stresses for the STG method were obtained from EnFlo wind tunnel experiments in neutral conditions [12]. Along the y-direction, these were set as cyclic boundary conditions. On the bottom boundary, Neumann conditions were selected for the scalar and potential temperature, while for velocities, Dirichlet conditions were used. To consider the thermal stratification effects, a constant surface kinematic sensible heat flux was set on the bottom boundary, and a consistent potential temperature was set at the inlet. A roughness length of 0.1 m was chosen for our case [13]. The model was initialised by horizontally homogenous vertical profiles of temperature and passive scalar. The simulation was run for 2 hrs with a length of time step of 0.5 seconds.

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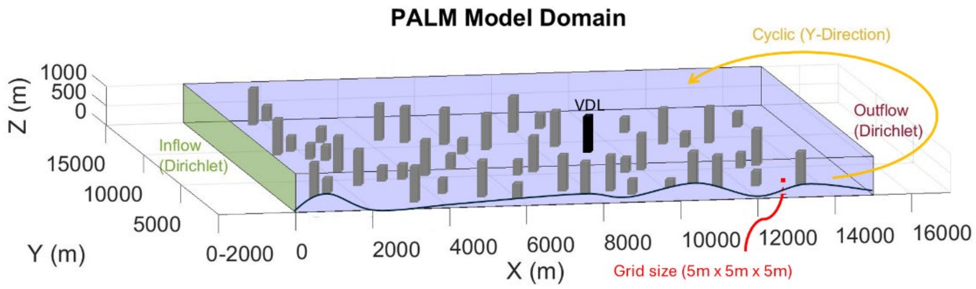

Figure 2, PALM model setup schematic. The Tobacco Factory building (BRTOBA) is represented by a black block in the middle of the domain where VDL is simulated. Topography in the model domain included buildings and the orography of Bristol.

Virtual Lidar

Implementing the VDL was possibly thought a code (user model) integrated with PALM, allowing the customisation of output variables. The VDL was previously developed to simulate VAD and DBS scanning patterns using three zenith angles and simulating different numbers of beams [5]. The VDL code calculates radial velocities from wind velocity data at LES grid points along the laser beam. An average of over 5 seconds of each beam is obtained which is analogous to the integration over several thousand laser pulses in real DWL systems, where a typical pulse repetition rate is around 10 – 20 kHz. Each scan takes 120 seconds to complete. Additionally, the VDL is located at the centre of the domain, and multiple scanning techniques can be run at the same time. For our study area, we adapted the VDL used previously by [5] to represent the field campaign scanning pattern at BRTOBA (see Table 2).

Table 2, Configuration of the Virtual Doppler Lidar scanning pattern (see also Fig. 3)

Scanning Method	VAD
Zenith Angle (Ø)	75°
Azimuth Angle Increment (θ)	30°
Number of Beams	12
Time per beam (sec)	5
Cycles	2
Total duration scan (sec)	120

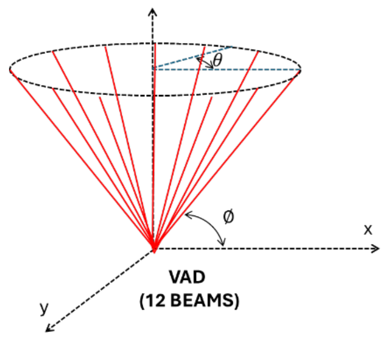

Figure 3, Schematic of the VAD scan technique at BRTOBA. Where Ø is Zenith Angle, θ the Azimuth Angle Increment and the red lines represent the number of beams (12).

Error quantification

RMSD will be used to quantify differences between the vertical wind profile derived from a VAD scan using the VDL and the profile directly taken from PALM model values. In future planned work, the Root Mean Square Deviation (RMSD) will be used to compare the retrieved wind profile from the VDL against DWL-measured values for specific case studies. Preliminary results related to the above error quantification based on a single simulated event/scenario will be reported at the conference.

3 FUTURE WORK

Planned future work includes a) assessing LES accuracy against measured data to better simulate Bristol's urban environment, b) case studies of specific meteorological events observed during the ASSURE field campaign and c) simulation of a set of DWLs across the city using different scanning strategies related to the measurement DWL campaign.

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