Limitation of A Dispersion Model on Prediction the Boundary Layer Height in An Urban Area

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ABSTRACT
(ADMS) is one of the dispersion models used for predicting air quality. However, predictions of air quality under some meteorological situations can be poor when compared with observations or field measurements. One parameter that influences the calculation of air quality is the boundary layer height. This can be either input or calculated by the ADMS Met Pre-processor. In this study, comparison of the atmospheric boundary layer height has made between ADMS 4 and pulsed Doppler LiDAR measurements for central London over a three week period. Days were chosen where the meteorological conditions were convective, mostly cloud free with little large scale forcing. Statistical analysis of boundary layer height carried out between ADMS 4 and LiDAR shows that the average correlation coefficients were less than 0.5 except on one day which achieved an R^2 value of 0.79, showing that ADMS 4 and LiDAR data are mostly not well correlated. On average ADMS 4 boundary layer height is shown to be underestimated compared to the LiDAR data for this dataset. In this work a simple urban surface model is used to determine modifications to the input variables for ADMS 4 in order to test whether a better urban surface description improves the models performance. The simple urban model enables a more detailed urban morphology to be modelled in order to create inputs for ADMS 4. Comparisons of the new modelled boundary layer height will be shown.

1. INTRODUCTION

The atmospheric boundary layer height (*h*) is a parameter that is used by ADMS model in its Met-pre-processor to predicting air quality. In calculation the atmospheric boundary layer height, sometimes the output of the model can be poor, especially in an urban area. This condition may be caused by the meteorological situation and characteristics of an urban area that is not as simple as the model prediction.

In this study, comparison is made between ADMS 4 prediction and Lidar measurements to see the limitation of ADMS 4 in predicting the atmospheric boundary layer height (*h*) that is used in its Met pre-processor. A simple model is used to improve the performance of ADMS in predicting *h* in an urban area.

2. ADMS 4

Atmospheric Dispersion Modelling System, ADMS, is a dispersion model that simulates buoyant and neutrally buoyant particles and gasses [3]. The model can predict the boundary layer structure in its Met pre-processor. The model uses a normal Gaussian distribution for instable and neutral condition [9]. ADMS has been developed by government and industry consortium in the UK [8]. ADMS 4 is the latest version of the ADMS model.

ADMS 4 requires information of meteorological conditions that are not measured routinely. The process of estimating parameters which are not measured routinely is known as *meteorological pre-processing*. One of the parameters which is determined in the meteorological pre-processor of ADMS 4 is the atmospheric boundary layer height (*h*). ADMS has weaknesses as a dispersion model. One of the weaknesses of ADMS is when using the Met pre-processor. For the meteorological parameters that are not input in the input met file, the met pre-processor makes a number of assumptions, approximations or models. Most of these assumptions are inexact, have some limitation or uncertainties [10].

According to [10], the first weakness of ADMS4 is that the effect of topography and non-uniformities in the surface properties are neglected. The second weakness is in predicting the atmospheric boundary layer parameters. The ADMS 4 assumes the atmospheric boundary layer height is determined by surface properties, whereas in reality, the atmospheric boundary layer height is influenced by the air mass, vertical advection, static stability aloft and baroclinicity. Furthermore, a third weakness is that is difficult to describe the atmospheric boundary layer height in stable conditions because of under such conditions the flow is very sensitive to small slopes, topography and details of surface properties. ADMS puts an arbitrary limit of 50 m to the smallest value of *h*.

3. SALFORD DOPPLER HALO LIDAR

The Salford Halo Doppler LiDAR (see Figure 1) is an autonomous instrument for atmospheric remote sensing. It operates at a wavelength of 1.5 microns, employs novel optical technology and an eye-safe design and has low power. The system has three separate units, the optical base unit, the weather-proof monostatic / antenna, and the signal processing and data acquisition unit. The optical base unit contains an optical source, interferometer, receiver and electronics. The weather-proof antenna is connected to a base unit using an umbilical. The antenna can be placed in the outside, whilst the base unit and data acquisition system must be housed within a laboratory environment [2].

Figure 1. *Salford Halo Doppler LiDAR*
Source: [4].

The Parameters of the Salford Halo Doppler LiDAR, can be seen in Table 1. Parameters, such as range gate, maximum range, number of pulses accumulated for each measurement and the spectral resolution of the Doppler measurements can be set by the user. The LiDAR system can be monitored and controlled by remote access software which transfers data over a network connection [2]. The Salford Halo Doppler Lidar measures two parameters; i.e. the aerosol backscatter and the radial (line of sight) Doppler velocity.

Table 1. *The Salford Halo Doppler LiDAR Parameters*

Parameter	**Value**
Operating wavelength	1.55 µm
Pulse repetition frequency	20 kHz
Beam divergence	50 µrad
Range gate	Variable: 20-60 m
Minimum range	~50 m
Maximum range	7 km
Temporal resolution	0.1-30 s

Source: [4].

As an optical remote sensing instrument, LiDARs use aerosol as a tracer of atmospheric motion. It is found that the vertical aerosol distribution changes with the thermal structure of the atmospheric boundary layer. In a well mixed boundary layer, the atmospheric boundary layer height can be determined by the level to which aerosols are mixed. Typically above the boundary layer the air is much cleaner. The pollution and aerosols are trapped in the boundary layer by a temperature inversion at the top of the boundary layer. The height at the boundary layer can therefore be inferred by the aerosol backscatter profile [6].

4. A SURFACE AND SIMPLE MODEL

In this study, it is used two models, a surface model [7] to calculate the surface roughness and this output will be used as input to calculate the atmospheric boundary layer (*h*) using a simple model [1]. In calculation the surface model, the data required is characteristic of buildings in urban area, i.e. mean building height, area of building dimensions and total area using for this study. These data are needed for getting frontal area index that used to calculate the surface roughness.

The output of the surface model (surface roughness) is used as input to the simple model. The simple model is developed by [1] for the growth of the day time mixed layer. In calculation the simple model, the inputs required are friction velocity (calculation from wind speed and surface roughness), Monin-Obukhov length and sensible heat flux.

5. RESULT AND DISCUSSION

ADMS was run for four meteorological stations near central London; Andrewsfield, Charlwood, Heathrow and Northolt. All of these meteorological locations constitute airport areas with surface roughness, z_0, 0.02 m (the value for fairly smooth grassland). Meanwhile, the surface roughness in the pollution site was set to urban areas with surface roughness, z_0, 1.5 m (the value for urban areas). ADMS 4 uses input meteorological data, such as wind speed, wind direction (degrees), cloud amount (oktas), temperature (C), sensible heat flux (W/m^2), precipitation rate (mm/hour) and relative humidity (%).

The figures below show comparison of ADMS 4 and LiDAR data for the clear days i.e. 29 and 30 October, 4, 6, 9, and 12 November 2007 in the day times from 08.00 to 18.00 (UTC). The comparison can be seen in Figure 2 below:

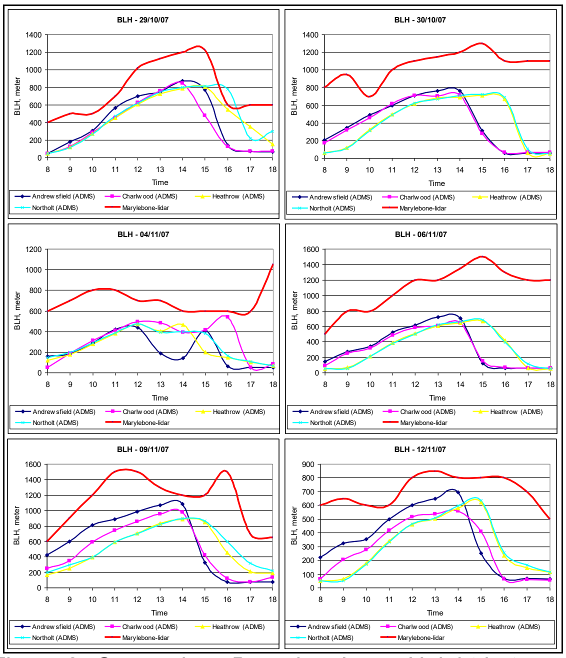

Figure 2. *Comparison Boundary Layer Height between ADMS 4 and LiDAR Data*

The figure 2 shows boundary layer heights measured by the LiDAR are higher than those predicted by ADMS 4. The highest *h* shown by the LiDAR data was 1500 m on 6 and 9 November 2002, and ADMS predicted the highest boundary layer height to be 1100 m on 9 November 2007.

The difference in BLH from ADMS and LiDAR can due to different factors. Firstly, meteorological input used in ADMS 4, such as wind speed was from a meteorological station outside of the city where there was lower surface roughness [5]. Furthermore, ADMS 4 has a very simple surface scheme which is not representative of an urban area and the results show that there is not sufficient surface roughness within the model to produce a high enough boundary layer height. ADMS considers surface roughness as a uniform area, whereas in reality, urban areas have non-uniformities and this has an effect on the atmospheric boundary layer height (*h*). The non-uniformities of surface properties also effect the wind velocity and friction velocity (u_*). The friction velocity is one of the parameters which determine *h*. Therefore, the uniform of surface properties, that are assumed by ADMS, possibly caused the boundary layer height (*h)* from ADMS to be lower than that measured by the LiDAR.

Statistical analysis has been carried out between ADMS 4 and LiDAR. Table 2 shows coefficient of determination (R^2) and Table 3 shows % difference between ADMS 4 and LiDAR. The coefficient of determination represents the percent of the data that is the closest to the line of best fit. These data shows average R^2 values are less than 0.5 except on 29 October 2007 achieve 0.79. This means that ADMS 4 and LiDAR data are not well correlated. Meanwhile, average % differences ADMS 4 against LiDAR are from 51% to 71%. This means ADMS 4 data are underestimated compared to the LiDAR data.

Table 2. *Statistical analysis (Coefficient of determination)*

ADMS locations	R^2 (Coefficient of Determination) with LiDAR					
	29/10/07	30/10/07	04/11/07	06/11/07	09/11/07	12/11/07
Andrewsfield	0.85	0.01	0.00	0.01	0.27	0.20
Charlwood	0.77	0.01	0.05	0.06	0.36	0.33
Heathrow	0.85	0.30	0.01	0.45	0.51	0.55
Northolt	0.70	0.34	0.05	0.48	0.54	0.57
average	**0.79**	**0.17**	**0.03**	**0.25**	**0.42**	**0.41**

Table 3. *Statistical analysis (% difference)*

ADMS locations	% difference with LiDAR					
	29/10/07	30/10/07	04/11/07	06/11/07	09/11/07	12/11/07
Andrewsfield	54%	61%	69 %	69 %	49 %	52 %
Charlwood	60%	63%	54 %	72 %	58 %	61 %
Heathrow	47%	62%	63 %	72 %	57 %	60 %
Northolt	43%	62%	60 %	72 %	53 %	59 %
average	**51 %**	**62%**	**62 %**	**71 %**	**54 %**	**58 %**

From comparison of ADMS 4 and Lidar data, it can be shown that ADMS 4 has limitations. ADMS 4 under predicts *h* in comparison with the Lidar data. This might be due to the fact that the parameters that used in ADMS 4 are not suitable for urban areas (in this case was central London). The friction velocity formulation is based on surface wind velocity components, stability and surface roughness. In urban areas, the surface roughness elements are non-uniform. However, ADMS 4 does not consider the effect of non-uniformities in the surface properties [10].

In this study, the simple model has chosen to calculate the atmospheric boundary layer height (h). The area for calculation is 1 km2. Surface roughness is calculated with the mean building height (z_H) and frontal area index (λ_F) were acquired from [11]. The values of z_H and λ_F are 20.13 m and 0.42 separately. The calculated value for surface roughness is 2.35 m.

Comparison between ADMS 4, Lidar and the simple model has been made from 08.00 to 14.00, as shown in Figure 3 to Figure 8 below. This is to compare the mixed layer just through the morning period as the mixed layer grows.

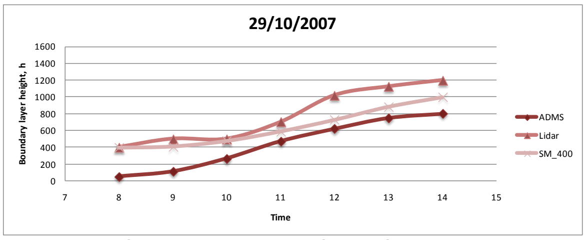

Figure 3. *Comparison ADMS 4, Simple Model and Lidar on 29/10/2007.*

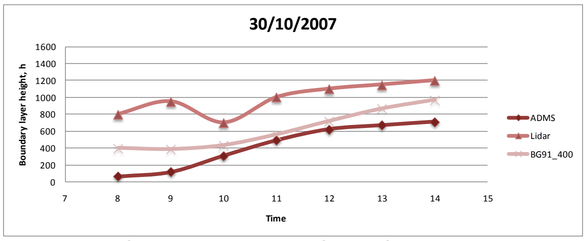

Figure 4. *Comparison ADMS 4, Simple Model and Lidar on 30/10/2007.*

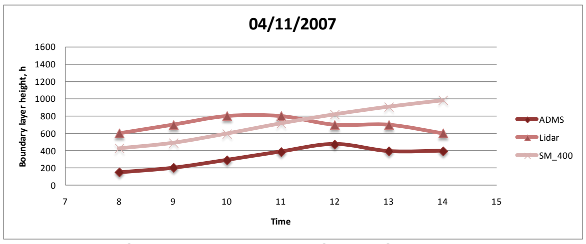

Figure 5. *Comparison ADMS 4, Simple Model and Lidar on 04/11/2007.*

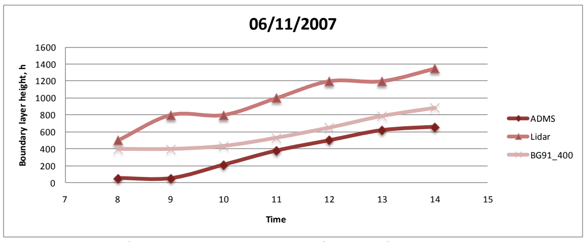

Figure 6. *Comparison ADMS 4, Simple Model and Lidar on 06/11/2007.*

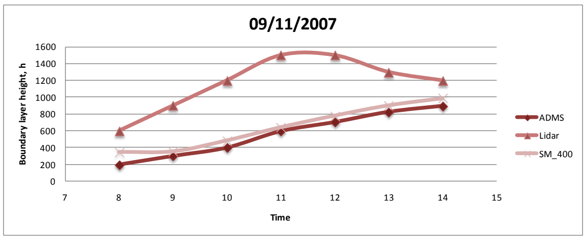

Figure 7. *Comparison ADMS 4, Simple Model and Lidar on 09/11/2007.*

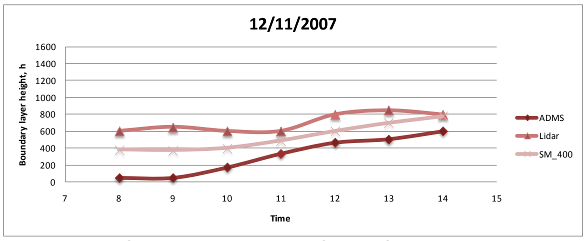

Figure 8. *Comparison ADMS 4, Simple Model and Lidar on 12/11/2007.*

Using data from the Lidar we have determined that the night time boundary layer height in London during this time is approximately 400m. The initial growth of the mixed layer calculated by the simple model starts at this level. Using this starting height the simple model shows an improved correlation with the lidar data than ADMS 4. Statistical analysis in Table 4 show simple model (SM) can reduce %difference of ADMS 57% to

26.7%. This means the simple model can improve the atmospheric boundary layer height (h) that is calculated by ADMS 4.

Table 4. *Statistical analysis (% difference with Lidar)*

	% difference with Lidar	
	ADMS	SM_400
29/10/07	50	15
30/10/07	59	38
04/11/07	53	-2
06/11/07	68	39
09/11/07	54	45
12/11/07	58	25
Average	**57**	**26.7**

6. CONCLUSION

Comparison between ADMS 4 and Doppler Lidar show that ADMS 4 has limitations on prediction the atmospheric boundary layer height (*h*). *h* calculated by ADMS 4 is too low compared with *h* measured by Doppler Lidar. The aim of this work is to improve the prediction of the urban mixed layer using a combination of surface model with a simple mixed layer height model. The effect of non-uniformities in urban area can be taken into account and using a simple mixed layer height model for calculating *h* we aim to improve the values of *h* closer to Lidar measurements. The next step in the work is to look at the urban effects on the sensible heat flux and to build this into the surface model. We are also looking at aerial average statistics for determination of roughness length statistics.

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