Atmospheric Environment 98 (2014) 461–473

Contents lists available at ScienceDirect

Atmospheric Environment

journal homepage: www.elsevier.com/locate/atmosenv

A combined model for improving estimation of atmospheric boundary layer height

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HIGHLIGHTS

- Comparison boundary layer height from ADMS 4 and lidar measurement.
- Develop a combined model to improve atmospheric boundary layer height prediction.
- Comparison boundary layer height from the combined model and lidar measurement.
- The combined model improve the prediction of the atmospheric boundary layer height.

ARTICLE INFO

Article history:
Received 13 May 2014
Received in revised form
6 September 2014
Accepted 9 September 2014
Available online 10 September 2014

Keywords:
Boundary layer height
ADMS
Lidar
Combined model

ABSTRACT

Atmospheric boundary layer height is one of the most important parameters in atmospheric dispersion modelling because it has a large effect on predicted air quality. Comparisons between Atmospheric Dispersion Modelling System, version 4 (ADMS 4) and lidar data were carried out on boundary layer height data from central London. The comparison showed that the boundary layer height predicted by the ADMS 4 was, on average, lower than lidar for the subset of data taken. ADMS 4 has a very simple surface scheme which is not representative of complex urban environments and the results from this research imply that there is not sufficient surface roughness within the model to produce a large enough boundary layer height. The aim of this study is to create an improved model to better forecast the growth of the daytime urban boundary layer and predict boundary layer height, *h*, in an air quality dispersion model using lidar measurements. The combined model was developed by using a surface model and an atmospheric boundary layer height model. Measurements of atmospheric boundary layer height by lidar used vertical velocity variance and the overall conclusion was that the combined model improved the performance of ADMS in urban areas.

1. Introduction

Development within urban areas is inevitably followed by the problem of air pollution. Air pollution problems attract more attention from around the world because they have a detrimental effect on humans and the environment. In the 20th century, air pollution problems have occurred around the world and the World Health Organisation (WHO) confirm that air pollution is a major environmental risk to health causing approximately two million premature deaths worldwide per year (WHO, 2008). In an effort to assess the effects on human health caused by air pollution, United Kingdom (UK) authorities use a combination of monitoring and modelling of air quality. Monitoring is carried out for current air quality and modelling is used to gauge current air quality in locations where no monitoring equipment is available, or for future air quality purposes. Modelling air quality to predict air pollution incidents has been used since the late 1950s, when atmospheric dispersion models were used to predict air quality. The first model was developed by Pasquill in the UK, and extended by Gifford in the USA and others elsewhere (Carruthers et al., 1994). A number of models for predicting air quality have been developed around the world. In the USA, improving national air quality is done by modelling new and existing air pollution sources for compliance with the National Ambient Air Quality Standards (NAAQS) (U.S. EPA, 2008). The UK has used a combination of monitoring and modelling for air quality management, under Part IV of the Environmental Act 1995. In the air quality strategy for England, Scotland, Wales and

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http://dx.doi.org/10.1016/j.atmosenv.2014.09.028

Northern Ireland, there is also a process for national modelling for future air quality (DEFRA, 2007).

The use of atmospheric dispersion models for predicting air quality is essential for developing the UK air quality strategy and local authorities have routinely used dispersion models and in particular the Atmospheric Dispersion Modelling System (ADMS) (Davies et al., 2007). ADMS is a computer code for modelling the dispersion of gases and particles emitted into the atmosphere (Carruthers et al., 1994). ADMS has a number of component modules, one of which is a meteorological pre-processor that allows a variety of meteorological data to be input or calculated, including atmospheric boundary layer height (h) which is a key parameter required for correct predictions of air pollution concentrations. h is an important parameter in dispersion models because it determines the height of spread of aerosols and pollutants, and effectively determines the volume available for pollutant dispersion, although this also depends on meteorological parameters, surface turbulent fluxes and physical parameters (Fisher et al., 2005). The limits on the vertical diffusion of the plume of material released are determined by h. In ADMS, h is also used to calculate other meteorological parameters, such as turbulence, wind speed, velocity, heat, moisture and momentum (Dandao et al., 2009).

The accuracy of predicted h is important in urban air quality modelling because it affects near-surface pollutant concentration predictions (Dandao et al., 2009). As an example, a large difference in pollutant concentrations was found between ADMS 3.1 and AERMOD PRIME 02222 when modelling emissions from tall stacks (Sidle et al., 2004). It was found that the difference in predicted concentrations was due to the different predictions of h within the models. h can be determined by atmospheric dispersion models but the estimation of h by these models may be incorrect. Davies et al. (2007) compared estimated h from the UK Meteorological Office Unifed Model (UM) and ADMS, to pulsed Doppler lidar measurements. ADMS was run under three settings, an 'urban' roughness, a 'rural' roughness and a 'transition' roughness ('transition' means meteorological data from an airport but pollution dispersion from over a city). The results showed that occasionally h was overestimated by the UM model. Meanwhile, ADMS gave accurate results in predicting h for the rural and transition settings, but overestimated h for the urban setting. Based on the evidence that dispersion models still cannot accurately predict boundary layer height in urban areas, it is necessary to analyse this parameter further. The aim of this study was to create an improved model to better forecast the growth of the daytime urban boundary layer in an air quality dispersion model, and to use lidar measurements to validate the new model.

2. Methods

This study is split into three stages: Stage 1 is a comparison of the boundary layer height from ADMS 4 and from lidar vertical velocity variance measurements; Stage 2 shows the development a combined model for improving atmospheric boundary layer height prediction – the new model is a combination of the surface model from Grimmond and Oke (1999), and the atmospheric boundary layer height model from Batchvarova and Gryning (1991); Stage 3 is a comparison of the boundary height from the combined model and lidar vertical velocity variance measurements. This study focuses on the growth of the atmospheric boundary layer height from sunrise in fully convective conditions. Therefore, the data used was between 08:00 and 14:00 local time. This because, it is assumed under the particular conditions of the measurements, the atmospheric boundary layer height starts to grow at 08:00 and reaches a peak height at 14:00 local time. It is important for dispersion models to estimate the correct h in this time range because, under convective conditions, morning boundary layer growth is crucial in determining the development and final maximum height.

2.1. Study area and data

For this study lidar data were derived from the Salford University Halo lidar manufactured by Halo Photonics Ltd. and operated as part of the UK University Facility for Atmospheric Measurement (UFAM) instrument pool (Pearson et al., 2009). The instrument has been deployed in various activities, including atmospheric boundary layer monitoring at the Salford University Urban and Built Environment Research Base (SUBERB) in 2006 (Bozier et al., 2006), observation of Russian forest fire plumes over Helsinki in 2007 (Bozier et al., 2007), and the Convective and Orographically Induced Precipitation Study (COPS) in Germany in 2007 (Wulfmeyer et al., 2008).

The data used in this research were collected for the Regent's Park and Tower Environmental Experiment (REPARTEE) II campaign, which was an experiment to study atmospheric chemical processes and parameters which affect atmospheric aerosol concentrations in London (Barlow et al., 2011). The meteorological instruments employed in the REPARTEE II campaign and used in this study were a three-axis ultrasonic anemometer (R3-50) and weather station (Vaisala WXT510), installed on the top of the British Telecom Tower (latitude 51° 31′ 17.31″N and longitude 0° 8′ 20.12″W, 1.2 km to the east of the lidar site) (Barlow et al., 2011). The lidar data were collected using the Salford Halo Lidar which was installed in a car park at the University of Westminster on Marylebone Road (latitude: 51° 31′ 20″N and longitude: 0° 09′ 22″ W). The instruments were run continuously for three weeks between 24th October and 14th November 2007.

For the London case study, local surface meteorological data were not available. It is not standard procedure for the UK Met Office to collect meteorological data in urban centres as data taken from such sites is influenced by local effects such as shadowing and hard surfaces. Consequently no meteorological data was taken at the lidar site at the University of Westminster. The lack of meteorological data was overcome by using surface meteorological data from stations around London. These meteorological data are standard Met Office measurements, taken from the surface meteorological site at Northolt (latitude: 51° 32′ 55″ N and longitudinal: 0° 25′ 1″ W).

The Northolt meteorological location is in an airport area. The surface roughness length, z_0, at the airport is very low and has a value of 0.02 m (the value chosen in ADMS 4 for fairly smooth grassland). Meanwhile, the surface roughness in the pollution site (lidar location) was set to an urban area surface roughness, $z_0 = 1.5$ m (the value chosen in ADMS 4 for urban areas). ADMS 4 uses input meteorological data, such as wind speed (m/s), wind direction (degrees), cloud amount (oktas), temperature (C), sensible heat flux (W/m^2), precipitation rate (mm/hour) and relative humidity (%). ADMS allows inputs for both the meteorological site and the pollution site and allows each site to have different roughness lengths. This allows for the situation where pollution dispersion is occurring over, for example, an industrial power plant, but the meteorological data is being collected from the nearest airport site.

2.2. The combined model

Most computational algorithms within dispersion models for predicting surface layer behaviour are based on empirical models of relatively smooth surfaces. Therefore there has been much work recently on urban surface morphology and dispersion of pollution