1.03 THE CHARACTERIZATION OF SURFACE BOUNDARY CONDITIONS WHEN MODELLING DISPERSION OVER A COMPLEX SITE

Keith D. Harsham[1] and Michael Bennett[2]
[1]BP International Ltd., Sunbury-on-Thames, UK
[2]UMIST, Manchester, UK

INTRODUCTION

As part of a wider study of the application of Lidar measurements to the validation of several regulatory dispersion models (*Harsham K.D.,* 2002; *Harsham K.D. and M. Bennett,* 2004), we have made a detailed comparison of various standard methods for the aerodynamic characterization of moderately complex terrain. The site studied was a shoreline chemical plant (Figure 1), around which we made Lidar and meteorological measurements over three weeks between September 1996 and May 1998.

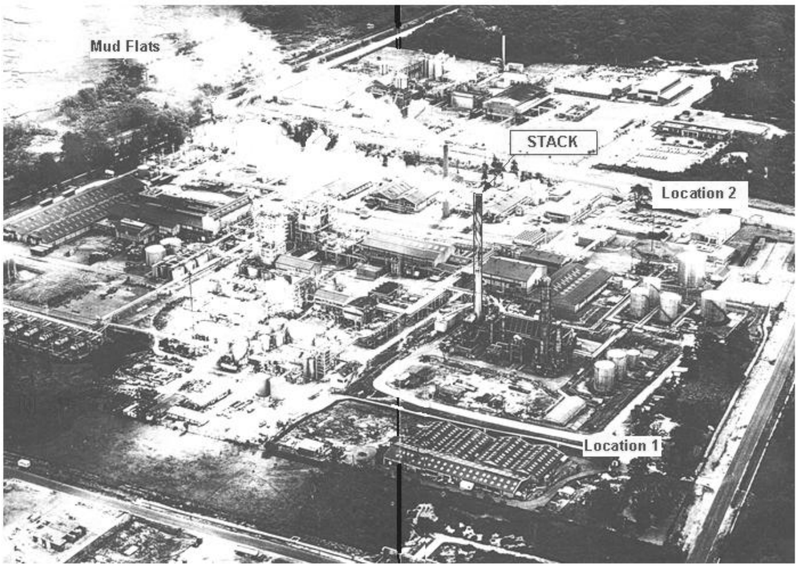

Figure 1. Aerial photograph of the site.

The Lidar used was that described in *Bennett M. at al.* (1992). Over the course of the surveys, it was used to obtain 67 runs, each nominally of 30 min duration. Depending upon the geometry imposed by the wind direction, these could be analysed as either longitudinal or cross-wind scans in order to obtain plume heights and spreads as functions of downwind distance.

The source was a 72 m stack attached to a combustion plant, having a thermal output of typically 3.1 MW. The plant is sited on gently sloping terrain on the South side of Southampton Water. None of the nearby topography is very high, with maximum heights above datum not exceeding 40 m. Nevertheless, it is extremely complex on a modest scale, with process plant, storage tanks, abandoned quarries, woodland and suburban development.

The purpose of this paper is to describe how we analysed this terrain in order to obtain surface boundary conditions which could be used in regulatory dispersion models. When applied to the simplest plume parameter, namely buoyant plume rise, however, it appears that these sophisticated techniques did not improve the agreement between theory and measurement.

ACQUISITION AND PROCESSING OF TOPOGRAPHIC DATA

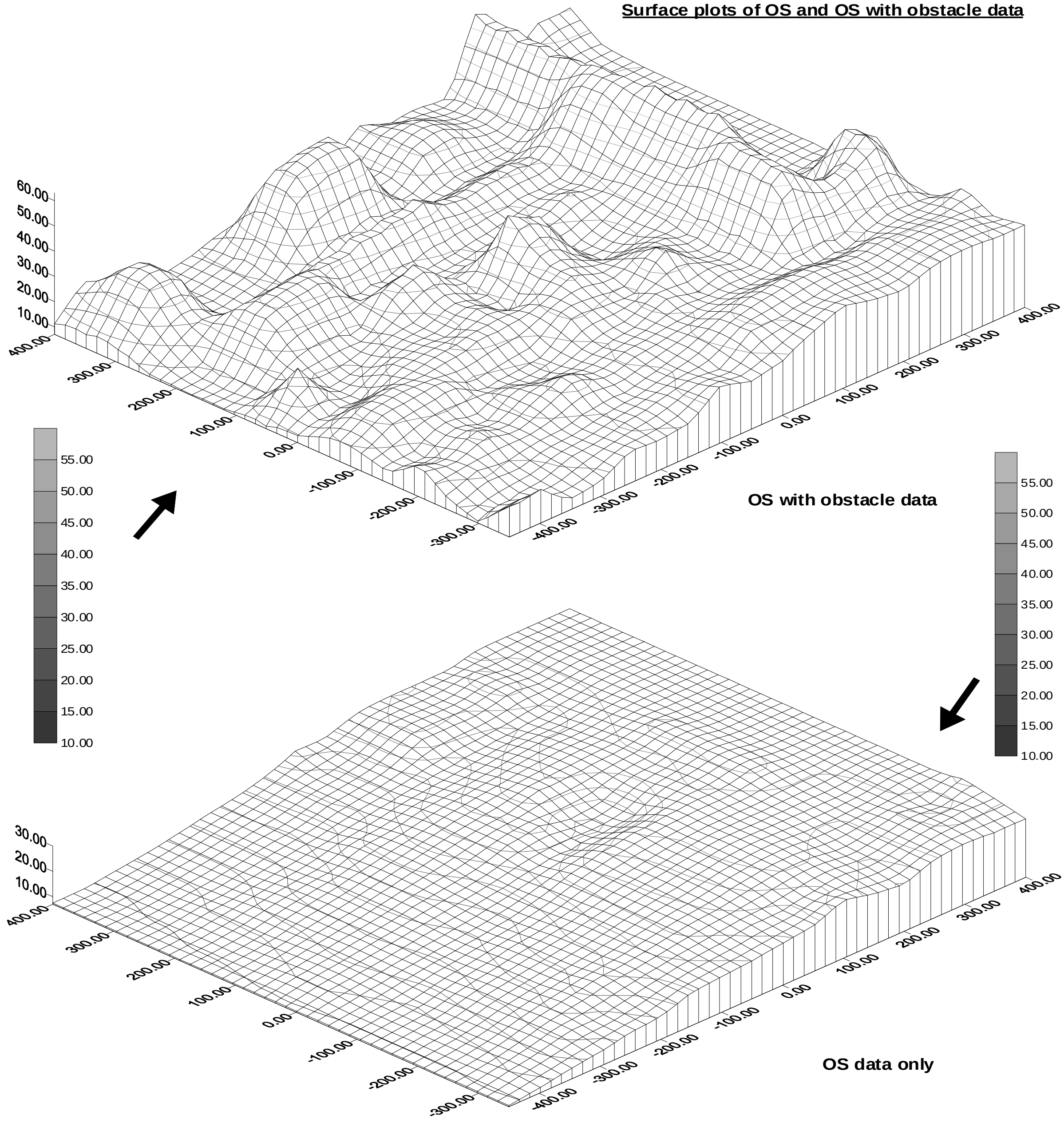

Figure 2. Smoothed contour maps of site. Lower image - ground surface only; upper image - including obstacles. Scales are in m.

Many existing sites suffer from a lack of up-to-date maps of plant and elevations. Consequently, when regulatory atmospheric dispersion modelling is required for a given site, we usually have to start from scratch using OS maps, surveying, or other techniques. The chosen site was no exception. In this study a range of techniques was used in an attempt to characterize the site as accurately as possible. Initially, a site survey was undertaken using a 20’ theodolite. By combining the aerial view (Figure 1) and these survey data it was possible to construct a 3D image of the site using Kriging techniques (*Isaaks E.H. and R.M. Srivastara*, 1989). As a sensitivity study, however, it was decided also to run several other interpolation techniques, such as triangulation, radial basis, and inverse-square. Figure 2 shows a Kriged version with and without obstacles.

DERIVATION OF AERODYNAMIC SURFACE BOUNDARY CONDITIONS

The simplest way to define the surface boundary conditions is to examine the site map in conjunction with a standard table of roughness lengths, z_o and displacement heights, d for different terrain types (e.g. *Stull, R.B.* 1994, p380). Several quantitative techniques are also available. *Kondo, J. and H. Yamazoura* (1986) propose the following relationship for z_0:

$$z_o = \frac{0.25}{S_T} \sum_{i=1}^{N} h_i s_i = \frac{0.25}{L_T} \sum_{i=1}^{N} h_i w_i \quad , \quad (1)$$

where s_i and h_i are the horizontal plan area and height occupied by element i, within a given catchment, and N the total number of elements, occupying a total plan area S_T. A more sophisticated recent approach along these lines is that of *Macdonald, R.W. et al.* (1998). This proposes the following parameterization:

$$\frac{z_o}{H_o} = \left(1 - \frac{d}{H_o}\right) \exp - \left(0.5 \beta \frac{C_D}{k^2} \left(1 - \frac{d}{H_o}\right) \lambda_f \right)^{0.5} , \qquad (2)$$

where β, is a sheltering effect factor, C_D=1.2 is the obstacle drag coefficient, k=0.4 is the von Karman constant, d is the displacement height, H_o is the height of obstacles and λ_f. is the ratio of their frontal to their plan area.

A different approach is that of *Wieringa, J.* (1976), which uses a statistical treatment of wind mast measurements located in the area of concern. The method assumes that the turbulence level calculated from σ_u/u increases with increasing z_o and is consequently often referred to as "gustiness" analysis. The value of z_o obtained is thought to approximately be representative of an area of about 5 km^2 (r = 1.3 km).
The procedure applied to generate contour and 3D plots is summarised in Figure 3.

Table 1. A summary of the aerodynamic roughness lengths $\mathbf{z_o}$ *derived for the site.*

Method	z_o (m)	Comment
1. Localised, site only, from OS (Ordnance Survey) map 1:10000	0.25 – 0.8	The lower estimate is derived
2. Area with 1.5km radius (after Kondo) with 1:10000 OS map		
Kondo's method	0.15-0.18	
Estimate	0.08 – 0.2	The 0.08 is derived by an assistant
3. Wieringa	0.3 – 2.1	Dependent upon wind direction

COMPARISONS OF MODELLED AND MEASURED PLUME RISE

The conventional Briggs' model of the buoyant plume rise above the streamline into which it is emitted is given by (*Bennett, M. et al.,* 1992):

$$z = \frac{C_B \left(\frac{F_b}{\pi} \right)^{1/2} x^{2/3}}{u} \left(1 + \frac{u\tau}{x} \right)^{1/3} = C_B Br\,(F_b, x, u)\ , \quad (3)$$

where C_B is a numerical parameter, F_b is the buoyancy flux, u the wind speed at plume height, x the distance downwind and τ the cross-over time from a momentum-dominated jet to a buoyancy-dominated plume. For this source, $F_b \approx 86$ m^4 s^{-3} and $\tau \approx 1.4$ s. It follows that the initial momentum of the plume has a minimal influence on its subsequent rise.

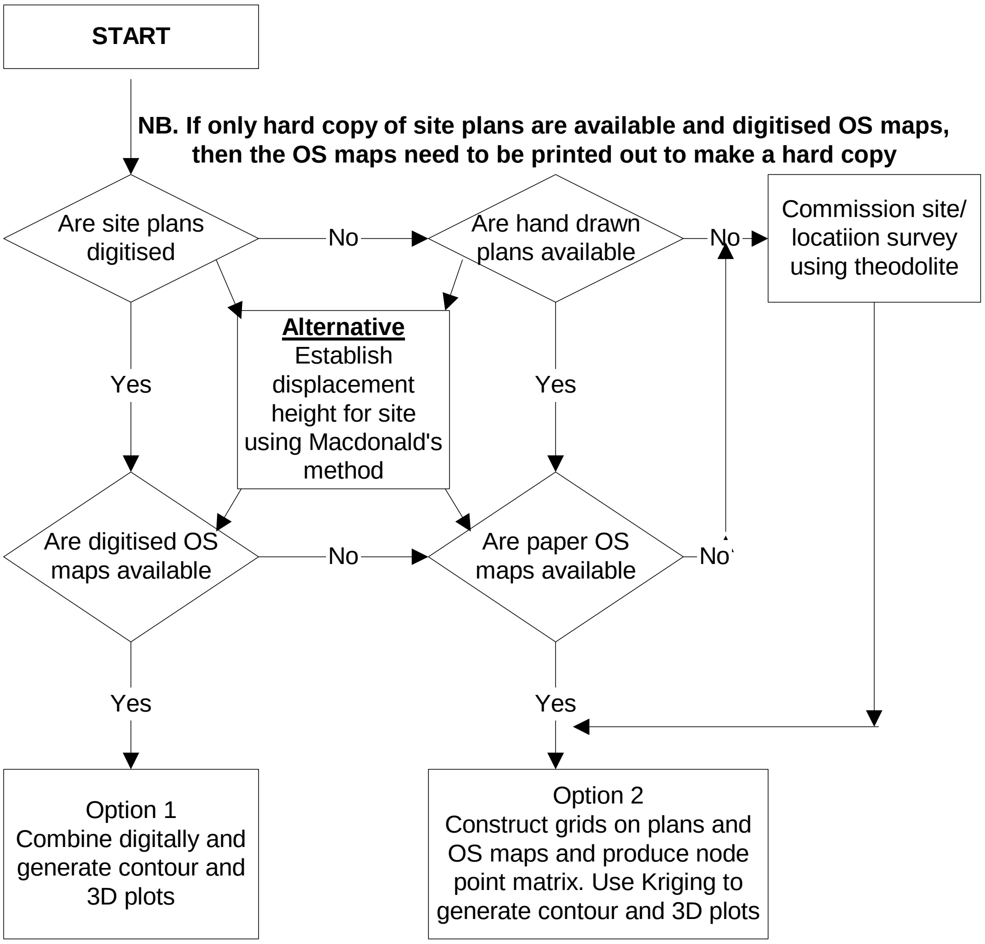

Figure 3. Method used to derive site contour and 3D plots

This predicted buoyant rise could of course be compared with the height of the plume as measured by the Lidar. Some correction has to be made, however, for the displacement of the streamlines by the underlying topography as the plume is transported away from the stack. For simplicity, we have assumed here that the streamlines flow parallel to the underlying topography, but how is this topography to be defined? Table 2 shows the effect of four possible topographies derived from the foregoing analysis. The first line shows the base case of flat terrain; subsequent lines show the effect of including successively more sophisticated corrections.

Table 2. Regression of measured plume rise, Δh, against Br.

Streamline correction	Slope, C_1	Correlation coefficient, r
None	1.26	0.61 $n = 92$
Ground surface	1.12	0.56
+ buildings	0.83	0.62
+ smoothed buildings	0.84	0.54

From equation (3), it may be seen that we should expect a unit correlation, r=1, between Δh and *Br*. The accepted value of C_1 is around 1.6. All our observed values here are smaller than this, the discrepancy becoming larger as we make 'better' corrections for the terrain. Likewise, the correlation coefficient does not improve as we 'improve' our topographic correction factors.

CONCLUSIONS

Given the large random component in the plume rise measurements, it is not at all clear that such a sophisticated treatment of the topography is really justified.

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