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SUMMARY

A dispersion model is outlined for possible evaluation using the field data collected during May 1985 at the Andorra (Teruel) power plant. The dispersion model divides the boundary layer into different regimes which are determined from two independent dimensionless parameters: z/h, where z is height and h is the mixing height, and z/L where L is the Obukhov length. The model employs the latest concepts regarding the characterization of turbulence and diffusion in the atmospheric boundary layer. Provisions are made for accounting for the effects to diffusion of the buoyancy in the power plant plume. The evaluation results will provide the basis for developing a routine diffusion model for characterizing short-term concentrations at the Teruel site.

CONTENTS

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1 INTRODUCTION

A model for the dispersion of contaminants released from the 343 m high stack at the power plant in Andorra, Teruel, will be developed and tested against actual data from the site. Earlier meteorological studies in the area (Sivertsen, 1981) have shown that the meteorological conditions, especially during summer conditions, might be very complex. Later field studies have concentrated on somewhat simpler conditions with high winds from the north-west and west. It is believed that these high wind cases may be critical, and result in the highest ground level concentrations of air pollutants at distances from 5 to 20 km (Sivertsen, 1985).

In the model to be described, the dispersion in the vertical and lateral is treated separately. The choice of parameters for the dispersion model depends upon the actual state of the atmospheric boundary layer. The concentration distribution in the lateral direction is taken to be Gaussian, while for the vertical, several different approaches are suggested.

2 THE STATES OF THE PBL

In the different idealized states of the planetary boundary layer (PBL), different scaling parameters describe the dispersion of passive gaseous air pollutants. A discussion of the division of the PBL is given by Olesen et al. (1984), and Holtslag et al. (1985). With three length scales:

z = height above the surface
h = mixing height
L = Obukhov length

it is possible to establish two independent dimensionless parameters:

z/h which is a relative height, and
h/L which is a stability parameter for the whole mixing layer depth (h).

Figure 1 summarizes schematically the limits of validity of the different PBL regimes. The scheme has been discussed in greater detail by Holtslag and Nieuwstadt (1985).

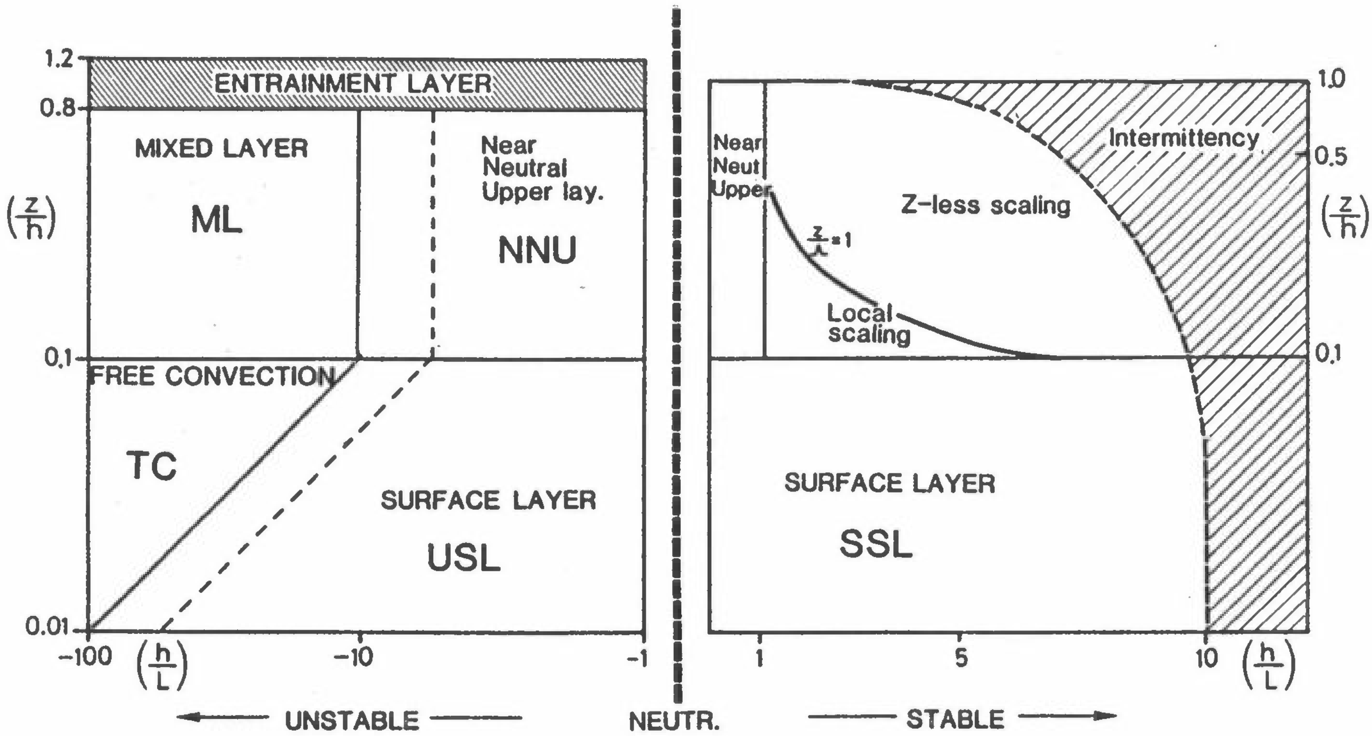

Figure 1: A schematic view of the different scaling regimes for unstable and stable atmospheric boundary layers.

The Obukhov length L reflects the height at which the contributions to the turbulent kinetic energy from buoyancy forces and from the shear stress are comparable.

At the Teruel site, where wind speed and temperature profiles are available form a meteorological tower, L can be expressed as:

$$L = u_* / (k\theta_* \quad (g/T)) \qquad (1)$$

where u_* is the friction velocity (a function of surface roughness z_0), g/T is the buoyancy parameter (g=9.81 m/s, T is ambient temperature), k is the von Karman constant (0.4) and θ_* is the surface layer scaling temperature.

Applying the profile method, the vertical profiles of wind speed, U(z), and and potential temperature, $\theta(z)$, can be expressed as functions of u_*, θ_*, z_o and L in the surface layer (McBean, 1979). From data collected at the Teruel site all the necessary scaling parameters can be determined.

3 DISPERSION ESTIMATES

3.1 LATERAL DISPERSION

Most dispersion experiments conducted at the Teruel site show the lateral dispersion of the plume to resemble a Gaussian distribution (Haugsbakk and Sivertsen, 1985). Figure 2 depicts the results for experiment 4 conducted at 1215-1230 GMT during 6 May 1985. The SF_6 tracer was released into the stack gases just before entering the 343 m stack. The lateral concentration distributions sampled near the surface along the three traverses (8 km, 24 km and 48 km) are close to Gaussian.

Pasquill (1971) derived from Taylor's statistical theory for plume dispersion the following expression, for estimating the standard deviation of the lateral crosswind concentration distribution:

$$\sigma_y = \sigma_v t \; f_y \; (t, T_y), \qquad (2)$$

where f_y is a universal function of transport time, t, and a time scale, T_y, for the dispersion process. Draxler's (1976) scheme was found by Irwin (1983) to perform best when:

$$f_y = (1+(t/2T)^{1/2})^{-1}. \qquad (3)$$

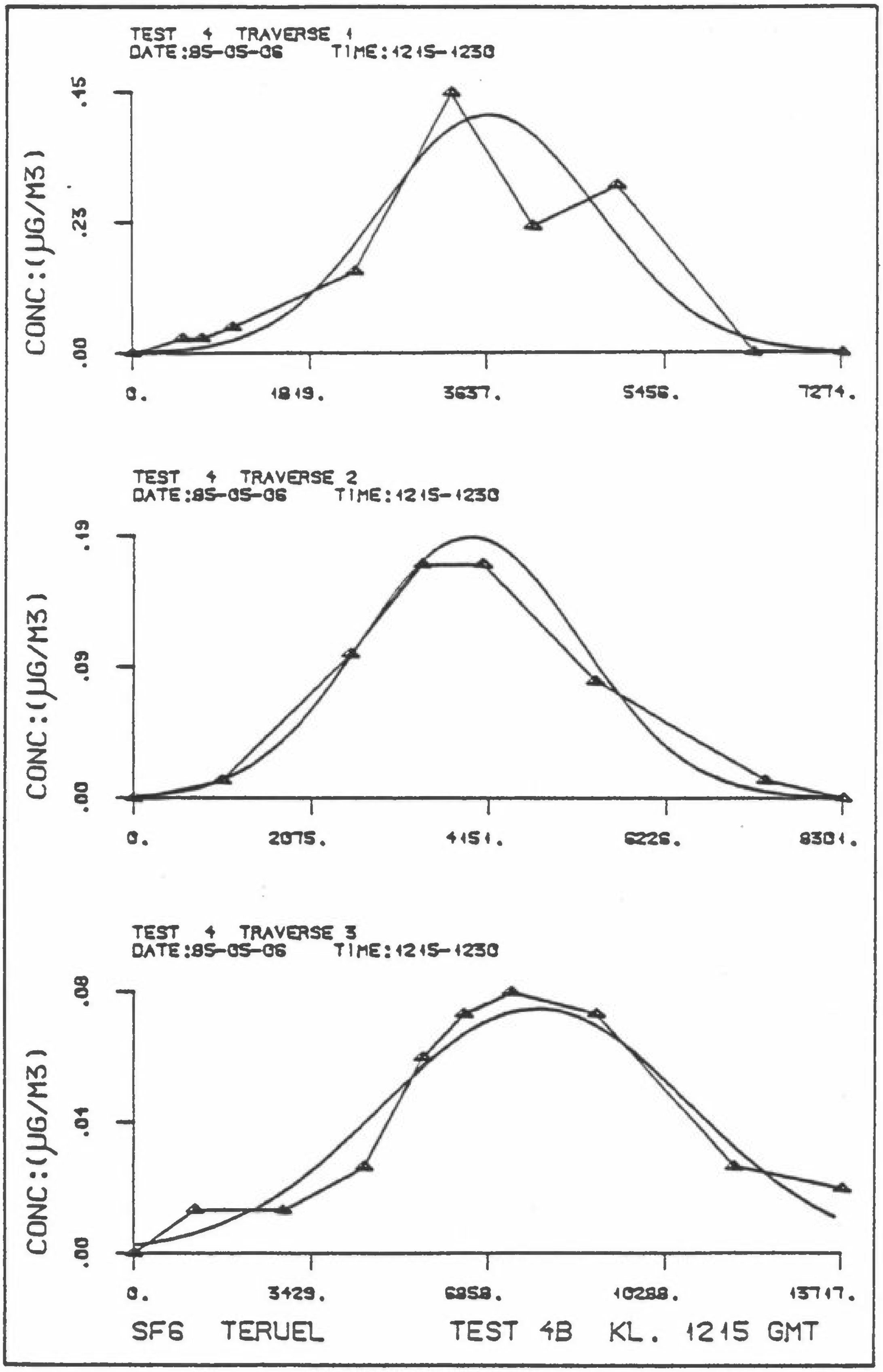

Figure 2: The lateral crosswind concentration distribution along traverses 1-3 during test 4B. Traverse 1 is at 8 km and traverses 2 and 3 are at 24 and 48 km, respectively.

Eq. (3) is also in agreement with the findings of Gryning and Lyck (1984), and Sivertsen (1978). For practical use it is suggested that $T_y \sim 600$ s for for elevated sources, and $T_y \sim 200$ s for sources in the surface layer. The standard deviation of wind fluctuation, σ_v, (or wind direction fluctuation σ_θ) should be measured directly. For the tracer experiment σ_v or σ_θ are measured over an averaging time, corresponding to the measured concentrations. If the wind fluctuations are not measured directly, σ_v can be estimated from u_*, L and h, as given by Irwin et al. (1985),

$$(\sigma_v/u_*)^2=0.7(-h/L)^{2/3}+2.7(1-z/h)^2/(1+2.8z/h)^{2/3} \tag{4}$$

For diffusion of buoyant plumes within the mixed layer, traditional methods for estimating σ_y are applicable when F* is less than 0.1, Briggs (1985). Here F* is the plume buoyancy parameter and is computed as $F^* = F_0/(uw_*^2\ h)$ where $F_0 = gv_s d^2 \Delta T/(4T_s)$ and the other variables have their traditional meanings. For cases with F* >0.1, the diffusion of the plume, both in the lateral and in the vertical, is strongly affected by the lofting of the buoyant plume against the capping stable layer above the mixed layer.

In simple terms, the plume reaches the height of the capping inversion but little plume material penetrates into the stable layer above. Rather, the plume appears to flatten against the capping inversion, much as smoke would as it encounters the ceiling of a room. Such an interaction strongly affects the diffusion process and hence the resulting surface concentrations. Research has only just begun to consider ways to parameterize these effects. Briggs (1985) suggest the lateral dispersion can be approximated as,

$$\sigma_y/h = 1.6F^{*1/3}\ X^{2/3}, \tag{5}$$

where $X = (x/h)(w_*/u)$

3.2 VERTICAL DISPERSION

In the following, methods are given for estimating the crosswind integrated concentrations $\chi_y(x)$, at a distance, x, for the different regimes presented in Figure 1. When these values of χ_y are estimated, the concentration at a given point downwind, X(x,y), can be calculated from:

$$X(x,y) = X_y \exp(-y^2/2\sigma_y^2)/(\sigma_y(2\pi)^{1/2}). \tag{6}$$

This method is capable of treating non-Gaussian vertical concentration distributions.

As part of the analysis, the position of the centerline of the plume in the vertical must be determined. This can be accomplished using the method outlined by Turner (1985). The method takes advantage of the latest findings by Briggs (1985) of the vertical structure of meteorological parameters in estimating plume rise. The method assumes that temperature and wind speed are available at least at two levels above ground. It is also assumed that the mixing height is available. Finally, it is assumed that the meteorological data given at different levels is sufficiently dense in the vertical that linear interpolation of the parameters between levels yields reasonable values. The details of the method are presented by Turner (1985). The essence of the scheme is to compute the energy expended as the plume rises through each layer in the vertical. The work performed in lifting the plume through each level depletes the original buoyancy of the plume, F_0. At the top of each layer, the residual buoyancy, F_R, is computed. If $F_R > 0$, the the plume calculation is continued until final rise, Δh_F, is attained.

Once the effective height of the plume, $Z_s = h_s + \Delta h_F$, is determined, the appropriate regime in Figure 1 can be determined and hence the diffusion experienced by the plume. The diffusion characterizations are discussed in detail by Irwin et al. (1985) and Gryning et al. (1986).

Briefly the methods can be summarized as follows.

Scaling region	Turbulence description	Crosswind integrated concentration (χ_y/Q)
SURFACE LAYER	Similarity profiles $K(z), u(z), u_*, \theta_*$	$(A/z\bar{u}) \exp[-(Bz/\bar{z})^s]$ (Gryning et al., 1983)
FREE CONVECTION	u_f, θ_f	$0.9 \quad X^{-3/2}$ 1)
MIXED LAYER	w_*, θ_m, h	function of X and Z_s 1) (Briggs 1985)
NEAR NEUTRAL UPPER LAYER	σ_v, σ_w profiles	Gaussian plume model
LOCAL & Z-LESS	(Λ_*(local) σ_v, σ_w (measured)	(Gaussian plume)
INTER-MITTENCY LAYER	N = local Brunt Väisälä	No model available

1) dimensionless downwind distance $X = (w_*/h)(x/u)$
dimensionless source height $Z_s = z_s/h$

The above summary of methods is appropriate for nonbuoyant plumes. For a buoyant plume, extension of the methods presented is needed for characterizing diffusion within the mixed layer and within the near-neutral upper layer. During stable conditions, when $L > 0$, the elevated buoyant plume would significantly reach the surface only on hillsides or valley walls located near to or above the effective height of the plume.

For diffusion within the near-neutral upper layer, the total vertical dispersion, σ_z, is a combination of turbulent dispersion and the effects of buoyant rise, σ_{zb}, as

$$\sigma_z^2 = \sigma_{zo}^2 + \sigma_{zb}^2, \tag{7}$$

where σ_{zo} is estimated using traditional methods and σ_{zb} can be estimated as $\Delta h/\sqrt{10}$, Pasquill (1976).

For diffusion within the mixed layer, we can use traditional methods to estimate the crosswind integrated concentrations so long as $F^* < 0.1$. For cases when $F^* > 0.1$, the crosswind integrated concentrations can be estimated as,

$$C_y = \exp[-(7F^*/X)^{3/2}], \tag{8}$$

where C_y is the nondimensional crosswind integrated concentration and is equal to $\chi_y hu/Q$.

4 DISCUSSION

The dispersion characterizations outlined have been evaluated for nonbuoyant releases, Gryning et al. (1986) and Sivertsen and Bøhler (1986). These evaluations show that for nonbuoyant releases the characterizations suggested perform as well as or better than standard Gaussian plume modeling techniques.

Evaluation of these characterizations for strongly buoyant releases has yet to be accomplished. The Teruel field experiments, conducted during May 1985, provide the necessary data for evaluating the performance of these methods for characterizing buoyant plume diffusion. At least for the Teruel site, the meteorological conditions occuring during the May 1985 experiments are anticipated to be those conditions most likely to result in the highest 30-minute concentrations (Sivertsen, 1985).

As part of the effort for developing a diffusion model for routine use at the Teruel site, the diffusion characterizations should be evaluated not only with the high grade meteorological data collected during the experiments but also with such meteorological data as might be anticipated to be available routinely. Such an evaluation will provide useful information of the minimum on site meteorological measurement program required for routine diffusion estimates.

The data base currently available for the Teruel site is most useful for evaluating highest concentrations to be expected during 15 to 30 minute periods. Characterizations of highest concentrations during longer averaging periods, say 3 to 24 hours, will require further study and consideration of the local circulations induced by the terrain features at the Teruel site. Study of the effects of these local circulations on longer term concentrations would be best accomplished once evaluation of the methods outlined has been completed.

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TITLE

ABSTRACT (max. 300 characters, 7 lines)
A dispersion model is outlined for possible evauation of the Teruel power plant plume. Field data collected during May 1985 provide the basis for evaluating the model.

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