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Relating plume spread to meteorology in urban areas☆

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Abstract

This paper examines relationships between dispersion and meteorology measured in a field study conducted in Barrio Logan, a suburb of San Diego, during 5 days of the period 21 August 2001–31 August 2001. The mean building height in Barrio Logan is about 4 m. The tracer, SF_6, was released at a height of 5 m from a shipyard on the shoreline, and the concentrations of the tracer were sampled on 4 arcs at 200, 500, 1000, and 2000 m from the source during ten hours of the day starting at 10 am. The meteorological conditions that governed dispersion were measured using sonic anemometers and a SODAR with a range of 200 m in the vertical.

It turned out that ground-level concentrations at the receptors used in this study were governed by the meteorological variables in the urban boundary layer above the urban roughness sublayer (RSL). In this region between 15 and 150 m above ground-level, the horizontal and vertical turbulent intensities were relatively uniform. This uniformity in turbulent intensities allowed the formulation of simple expressions for horizontal and vertical plume spreads that could be used in a Gaussian dispersion model. These expressions are similar to those proposed by Briggs (ERL, ARL USAEC Report ATDL-106, U.S. Atomic Energy Commission Oak Ridge, Tennessee, 1975) and Hanna et al. (Atmos. Environ. 37 (2003) 5069) to model dispersion in St. Louis and Salt Lake City, respectively. However, the application of these dispersion curves requires information on the meteorology of the boundary layer. It might be possible to use measurements above the average building height (4 m in our case) to infer these boundary layer properties.

The dispersion model based on boundary layer meteorological information explained about 63% of the variance of the maximum observed concentrations on each sampling arc, and 60% of these concentrations was within a factor of two of the corresponding model estimates. It was necessary to account for initial plume spread caused by building effects to explain concentrations on the 200 and 500 m arcs.

Keywords: Dispersion; Urban areas; Field experiment; Tracer study; Dispersion model; Data analysis; Barrio logan; Urban dispersion; Plume spread; Turbulent intensity

1. Introduction

The urban dispersion curves incorporated in currently used EPA models, such as the ISC model (Industrial Source Complex Model), are based on data from the St. Louis study conducted over the period 1963–1965. The study consisted of a series of 26 daytime and 16 evening experiments in which fluorescent zinc cadmium sulfide

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particles were released near ground level and traced across a relatively flat urban area. The release, which was typically 1 h long, was sampled on arcs at 800 m to 16 km from the release point. Surface concentration measurements were made at each arc near the anticipated plume centerline. In nine experiments, concentration measurements were made at various heights along a balloon tether about the expected plume centerline. A meteorological network of three stations on the outer area of the sampling area and an instrumented television tower tracked wind, temperature, and relative humidity. A TV tower instrumented at three levels measured profiles of wind and temperature. Winds were profiled to a height of a kilometer using a single-theodolite, free or tethered radiosonde ascents, and transponder-equipped tetroons. The standard deviation of horizontal wind direction fluctuations, σ_θ, was estimated at 39 and 140 m using variations of azimuth angle recorded on charts.

The horizontal plume spreads in the St. Louis study were derived from the observed surface concentration distributions, while the vertical plume spreads were inferred by matching concentration estimates from a Gaussian dispersion model to observed surface concentrations. These plume spreads were related to meteorological indices of dispersion, such as Richardson number and Pasquill stability class.

The plume dispersion data from St. Louis were fitted to power curves by Briggs (1974). These curves, referred to as McElroy–Pooler curves, are used in EPA models, such as ISC, to estimate dispersion in urban areas. For unstable (A and B stabilities) conditions in urban areas, these dispersion curves assume the form (EPA, 1995)

$$\sigma_z = 0.24x(1 + 0.001x)^{1/2},$$
$$\sigma_y = \frac{0.32x}{(1 + 0.0004x)^{1/2}}, \qquad (1)$$

Using data collected in a recent experiment conducted in Salt Lake City (Allwine et al., 2002), Hanna et al. (2003) have obtained a similar equation for dispersion under stable conditions in urban areas.

Because the leading coefficients of dispersion curves such as Eq. (1) correspond to turbulent intensities, these curves implicitly assume that turbulent intensities are uniform over the depth of the plume, which can occupy most of the boundary layer. The meteorological measurements made during the St. Louis experiment did not allow this assumption to be examined. Furthermore, the applicability of these curves to other urban areas has not been evaluated.

This paper describes the use of measurements made during a field study conducted in Barrio Logan, San Diego during the summer of 2001 to evaluate the underlying assumptions and the applicability of urban dispersion curves, such as Eq (1). This achieves several objectives: (1) identifies the processes that govern dispersion in urban areas and (2) determines the range of applicability of empirical dispersion curves used in current regulatory models.

2. Barrio Logan field study

The Barrio Logan tracer study was motivated by the need to evaluate air quality models for the CARB's (California Air Resources Board) Environmental Justice program. In 1999, the CARB initiated its Neighborhood Assessment Program to develop ways to assess the cumulative impacts of air pollutant emissions on a neighborhood or local scale. As the first step in developing these methods, the CARB has initiated several air quality field studies in California. The first study was conducted in Barrio Logan, a community of about 5000 people located on the eastern side of the Coronado Bridge in San Diego and surrounded by numerous small industries, large shipyards, and naval installations located to the south, south-west of residential areas. Fig. 1 shows an aerial photograph of Barrio Logan. The residential areas, consisting mostly of one storey buildings about 4 m high, are located downwind of the release point during the dominant southwesterly flows. The building density is relatively low with $\lambda_f = 0.11$ (frontal area/lot area; Grimmond and Oke, 1999) suggesting flow in which wake interference is small.

Five tracer release experiments were conducted from 21 August, 2001 to 31 August, 2001. Each experiment

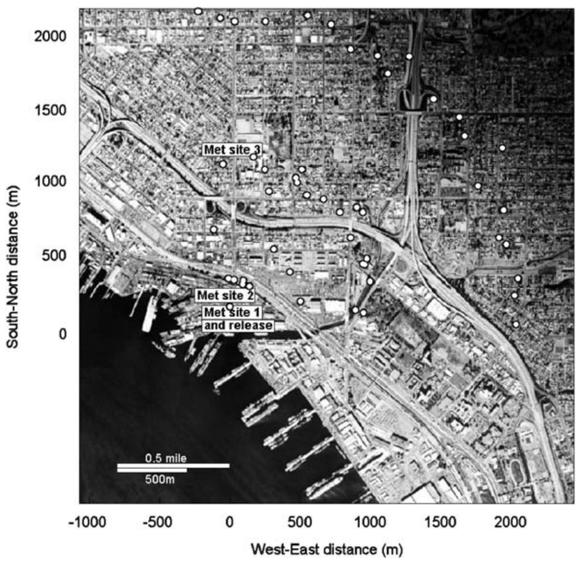

Fig. 1. Aerial map of Barrio Logan showing sampling sites marked as circles. Release location and meteorological sites are also marked in the figure. Average building height in the urban area is 4 m.