6.2 RETENTION OF TRACER GAS FROM INSTANTANEOUS RELEASES OF SF6 IN AN URBAN ENVIRONMENT

J.C. Doran, K.J. Allwine
Pacific Northwest National Laboratory, Richland, WA
K.L. Clawson, R.G. Carter
NOAA Air Resources Laboratory Field Research Division, Idaho Falls, ID

1. Introduction

The Joint Urban 2003 tracer experiment was conducted in Oklahoma City from June 28 through July 31, 2003 (Allwine et al. 2004). The goals of the experiment included the study of the dispersion of tracers in an urban environment, the measurement of the meteorological conditions responsible for the observed patterns, and the use of the acquired tracer and meteorological data to evaluate the performance of a range of numerical models.

In addition to a series of continuous 30-minute releases of sulfur hexafluoride (SF6) tracer carried out over 10 intensive operation periods (IOPs), three or four instantaneous releases were also made during each of the IOPs. In this paper we discuss some of the characteristics of the puffs resulting from those releases and the implications for transport and dispersion in an urban area.

2. Instruments

The puff releases were accomplished by popping a balloon containing a known quantity of SF6. The tracer was subsequently sampled with ten fast response mobile detectors operated by personnel from NOAA's Air Resources Laboratory Field Research Division. The detectors were located in vans that could be moved to various locations to accommodate changes in the ambient wind directions. In practice, nine of the vans remained in fixed locations for a given IOP, although they were moved between IOPs, and one was operated in a roving mode during each IOP. Downwind distances of the sampling sites ranged from slightly less than 200 m to somewhat greater than 1 km. We restrict our analysis at this time to data collected from the vans in fixed locations. Data were recorded from each SF6 analyzer at a rate of 2 Hz and stored on a laptop computer. The minimum detection limit was approximately 5 parts per trillion volume (pptv); the maximum is nominally about 10,000 pptv but could be doubled using a dilution system. Additional information is given in Clawson et al. (2005). Figure 1 gives an example of the sampling positions of the fixed vans during one of the IOPs.

Released SF6 quantities ranged from 300 to 1000 gm. The usual procedure was to generate an instantaneous release at 20-minute intervals. If continuous releases preceded the puff releases (IOPs 5-10), the latter were not begun until 90 minutes after the conclusion of the last continuous release. When the puff releases were carried out first (IOPs 1-4), the continuous releases did not begin until 60 minutes after the last puff release. For this paper we analyze the tracer behavior during IOPs 3 through 8. On those occasions the sampling vans were located in favorable positions so that multiple hits were obtained for many of the samplers for each puff release. For other IOPs there were a larger number of misses and the data sets are less complete.

There was an abundance of instruments deployed during Joint Urban 2003 that can be used to characterize various aspects of the mean and turbulent atmospheric conditions during the IOPs (e.g., Brown et al. 2003). For this work we only use the wind velocity data collected from a meteorological station located on the roof of the Civic Center Music Hall (Figure 1); the sensor height was approximately 37 m above ground level (AGL). This instrument had good exposure for all of the IOP periods considered and is only a few blocks from the tracer release points.

Corresponding author address: J.C. Doran Pacific Northwest National Laboratory, P.O. Box 999, MSIN K9-30, Richland, WA 99352; email: Christopher.doran@pnl.gov

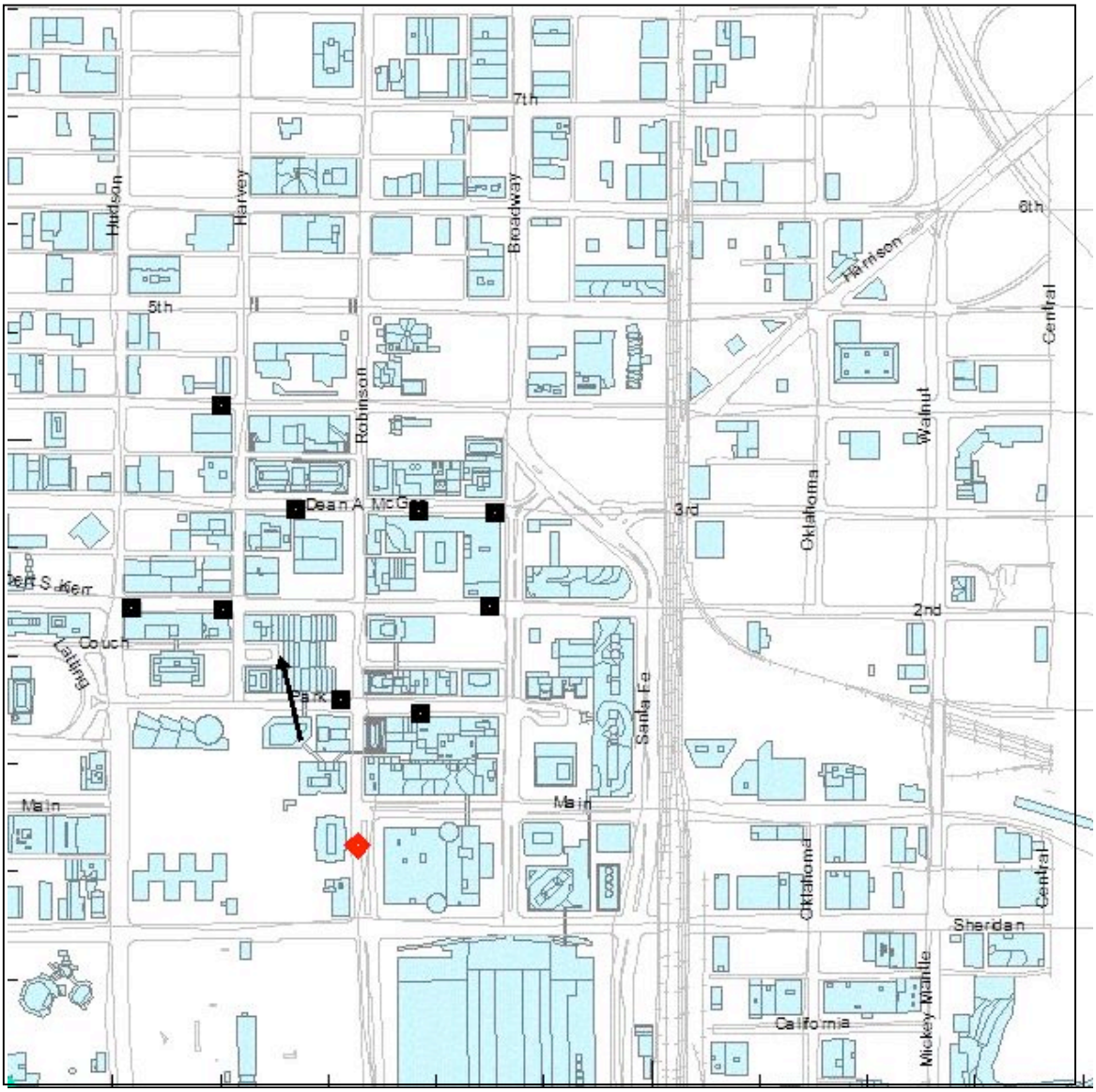

Figure 1. Map of the downtown Oklahoma City area showing the locations of nine tracer samplers during one of the IOPs (black squares), the locations of the tracer release site for this IOP (red diamond), and the wind direction measured on the top of the Civic Center Music Hall during one of the puff releases (arrow).

Data Analysis

Most analyses of dispersion in urban areas have concentrated on descriptions of continuous plumes with relatively little attention given to the behavior of instantaneous releases or puffs. For some circumstances (e.g., explosions), however, puffs are the more likely mode of introduction of a hazardous material into the atmosphere. We were interested in how long significant concentrations of tracer would remain in an area under various conditions and anticipated that the retention times would be affected by factors such as ambient wind speed, building and street canyon morphology, and possibly stability, although in an urban environment it has been suggested that predominantly neutral conditions can be expected to prevail (e.g., Britter and Hanna 2003), even at night.

We are unaware of a standard quantitative definition of retention time so we have adopted the following operational description for our

analysis. We began by averaging the output from each of the real-time samplers into block averages of 5 seconds duration. Figure 2 shows such a block-averaged time series of tracer concentration measured by one of the real-time samplers during one of the IOPs. We define the arrival time, t_a, as the time after the release that the measured concentration first exceeds and remains above a specified threshold for at least 20 seconds. The peak time, t_p, is the time after release until the maximum sampler concentration is reached. For high sampler concentrations the sampler may saturate and there will then be some ambiguity in choosing the maximum value for a particular release but this did not appear to cause any significant problems. Finally, we define the retention time, t_r, as the time required for 99.9% of the exposure to occur at a given sampler (shown as the shaded area in Figure 2) minus the arrival time. Alternate definitions of t_r are, of course, possible, e.g., the time required for the concentration to fall below some threshold value, but we found this approach less satisfactory. With such a definition the retention times are more sensitive to the amount of material released and are difficult to describe unambiguously when the concentration values show strong intermittency. It is thus difficult to compare the results for different releases and sampler locations.

We chose 50 pptv as our threshold value used to define the arrival time. This is well above the minimum detectable value for the SF6 analyzers but helped to ensure that the material being sampled was from the latest release and not residual tracer from an earlier puff. As can be seen from Figure 2, the increase in concentration with time is typically very steep on the leading edge of the puff so that the choice of a different threshold value will make relatively little difference in the identification of the arrival time. If the previous puff appeared not to have cleared a sampling location by the time of the next release, then the starting time for that release was not tabulated. If the threshold value was not reached and retained for at least 20 seconds, the data for that particular sampler and puff were not used. Finally, if the total exposure had not reached the 99.9% level at least 20 seconds before the end of the sampling period, the retention time for that release was not tabulated. This puts an upper limit of slightly less than 20 minutes on the retention time for most releases; if the release was the last of an IOP the upper limit was slightly less than 30 minutes, the length of time sampling continued after the release. As will be seen this limitation has little effect on the distribution of retention times that were computed. For the six IOPs that were analyzed we were able to use results from 134 time series from tracer samplers that were in the paths of the dispersing puffs and whose concentrations values fit the criteria listed above.

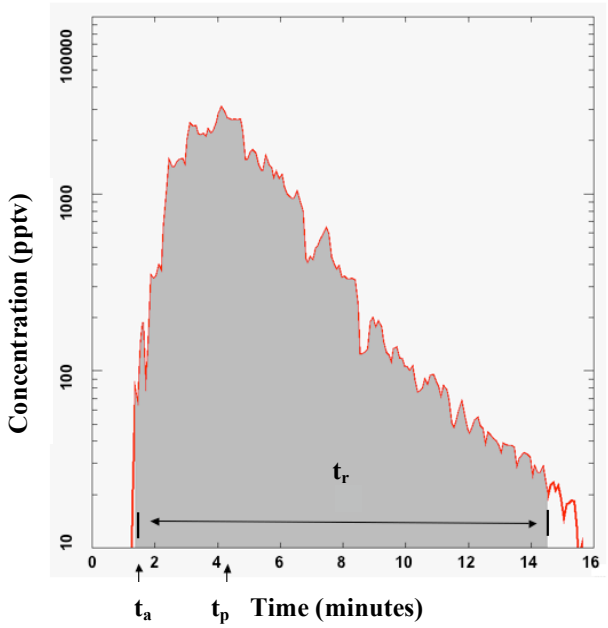

Figure 2. Time series of tracer concentration at a sampler during one of the IOPs. The arrival, peak, and retention times are indicated. The gray area contains 99.9% of the total exposure at the sampler locations for one puff release.

Results

We may estimate the speed with which the puff is transported by dividing the distance between the release point and a sample with either t_a or t_p; we refer to the speed derived from the arrival time of the puff as the arrival speed and that derived from the peak of the puff as the peak speed. We anticipated that the speeds defined in this way would be reasonably well correlated with each other and with the ambient wind speeds measured at the Music Hall, although some scatter and a significant reduction in the magnitude were expected in the latter case. The correlation between the arrival and peak speeds

was, in fact, reasonably good ($R^2 \sim 0.73$) but neither showed good correlation with the Music Hall wind speeds ($R^2 \sim 0.14$-0.16), with the latter speeds having much higher values. The distribution of arrival speeds had a surprisingly narrow distribution, with a mean value of 2.6 ms^{-1} and a standard deviation of 0.8 ms^{-1}. For comparison, the Music Hall speeds had a mean value of 5.8 ms^{-1} and a standard deviation of 1. 7 ms^{-1}.

Release times ranged from 0500 - 0600 Central Daylight Time (CDT) for IOPs 7 and 8 to 0900 - 1000 CDT for IOPs 3 and 4 to 1500-1600 CDT for IOPs 5 and 6. The Music Hall wind speeds for IOPs 3 and 4 averaged almost 60% larger than those for IOPs 7 and 8 but the arrival speeds averaged only about 13% higher. Thus, the effective puff transport speeds, as reflected in the arrival times of the puffs at the various sampling stations, were remarkably insensitive to the ambient wind speeds at 37 m AGL. A similar lack of sensitivity was found for the puff speeds computed from the peak times.

The decay of the tracer concentrations at the various sampling sites varied widely from one IOP to the next. Figure 3 shows the decrease with time of the concentrations at all of the sampling sites for IOPs 5 and 7. The concentrations have been normalized with the peak concentration measured at a given sampler for each release. The shaded areas mark the bounds of the 10th and 90th percentile times for various normalized concentrations values, and the central red line marks the median of the distribution of the times for those same values. The median values in the figure can be roughly fitted with a straight line, suggesting an exponential falloff of concentration with time. This is similar to the findings of Clawson et al. (2005) for the decay of concentrations following the termination of the continuous releases during the same field experiment. The time constants for the top and bottom panels are approximately 80 and 100 seconds, respectively. Roughly similar results can be obtained with a simple Gaussian puff model, but in the absence of some clear relationships between the dispersion coefficients and the meteorological conditions and building morphology, little additional insight is obtained through its use.

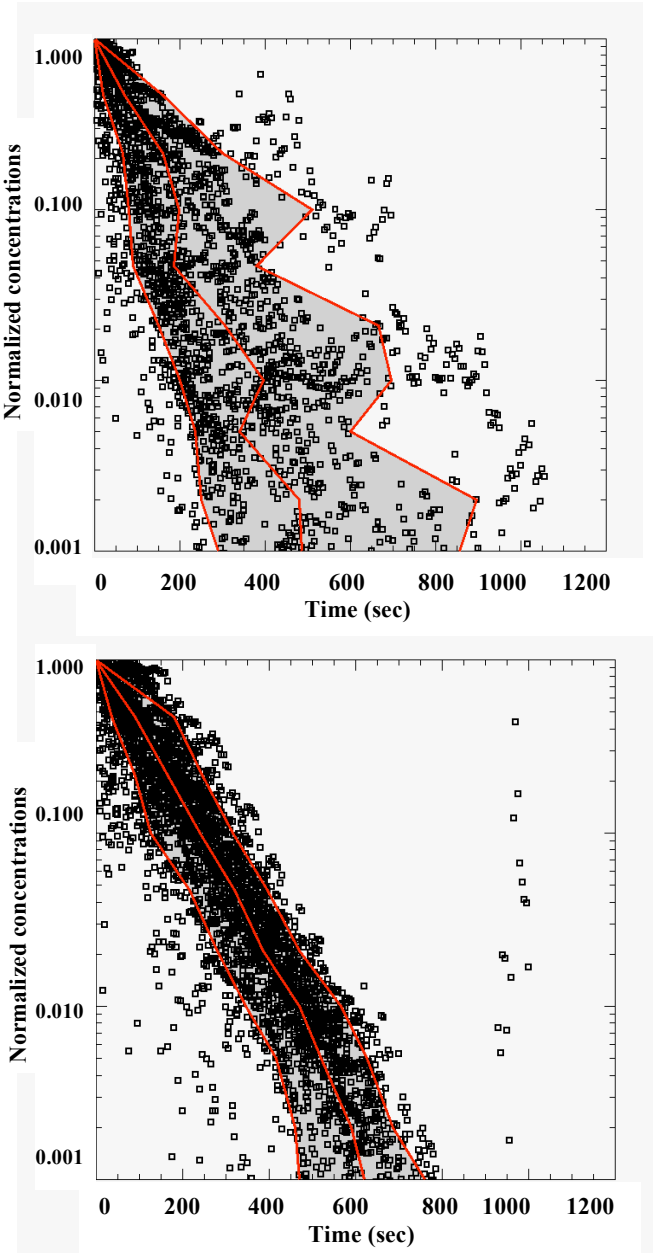

Figure 3. Decay of tracer concentrations with time for IOPs 5 (top) and 7 (bottom). Concentrations are normalized by the peak values measured at each sampler for each puff. The gray areas show the 10th and 90th percentile bounds for the decay times; the central red line in each figure marks the median values.

Figure 4 shows a histogram of the distribution of retention times for all of the IOPs analyzed. The median and mean values for the collection of six analyzed IOPs are both 590 seconds, or slightly less than 10 minutes. Contrary to the behavior

of the arrival or peak speeds, the concentration decay and the retention times do show significant variations among the IOPs. For IOPs 7 and 8, during which the puff releases took place in the early morning (0500-0600 CDT), the median (mean) retention time was 650 (680) seconds; for the other IOPs the corresponding values were 530 (530) seconds. There was relatively less difference between the results for IOPs 3 and 4 and for IOPs 5 and 6.

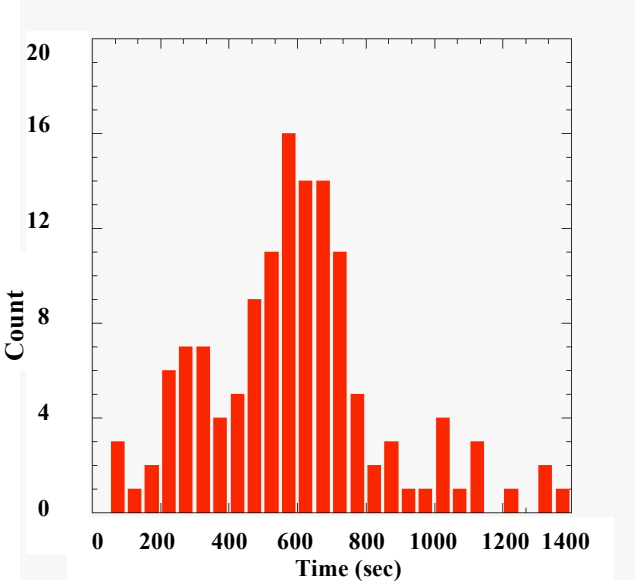

Figure 4. Distribution of retention times for all samplers during IOPs 3-8.

A feature that stands out in Figure 3 and in an examination of the retention times at individual stations for the various IOPs is that the spread in values for IOP 7 are quite narrow compared to all of the other IOPs. The wind directions during this IOP ranged between 210° and 225° and the puffs drifted predominantly east of the railroad tracks shown in Figure 1, the only IOP for which this occurred. This region of the city was much less built up than the regions to the north and northwest of the release points. The influence of the buildings in the latter areas can be clearly seen in this behavior.

Conclusions

The widely divergent dispersion characteristics for the puffs measured at the samplers for the six IOPs studied here provide strong indications of the influence of building morphology of plume retention times. There is also some suggestion that atmospheric stability may have played a role. The puffs releases for IOPs 7 and 8, for example, were both done between 0500 and 0600 CDT, and these two IOPs had the longest median retention times. The ambient wind directions, however, differed markedly between the two IOPs and as a result the puffs drifted over sections of the city with strongly contrasting building densities. Additional analyses are ongoing and may help to sort out the relative importance of these mechanisms.

Acknowledgments

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