JP1.8 Modeling Dispersion of Buoyant Releases in an Urban Area

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1. Introduction

Small (< 20 MW) distributed sources of electrical power are becoming popular in some states such as California because they can serve a single home, neighborhood, or business more efficiently and reliably than centrally located power plants (Allison and Lents 2002). However, such distributed generators (DG) have the potential of causing air quality problems because they emit pollutants from relatively short stacks, and they are usually located in populated urban neighborhoods. Their impact can be estimated using dispersion models. However, current models such as AERMOD (*A*merican Meteorological Society/*E*PA *R*egulatory *Mod*el, (Cimorelli et al. 2005)) have not been evaluated with data corresponding to DGs- buoyant sources in the midst of buildings. In summer 2008, we conducted a tracer study in Palm Springs, California, to obtain data to evaluate the performance of AERMOD in estimating the air quality impact of urban DG units. This paper reports on the preliminary analysis of the data.

2. Field Study

The tracer experiment was conducted from July 15th, 2008 to July 21st, 2008 at Sunrise Park in Palm Springs. During the experiment, Sulfur hexafluoride (SF_6) was released at the same temperature as the exhaust air from the top of DG stack which is situated at the top of a 7 m high building surrounded by one storey residences. The stack is 2.3 m high above roof top. The DG is driven by a 650 KW gas fired IC engine with heat recovery.

Fig. 1 shows the locations of the source and the SF_6 samplers. SF_6 concentrations were measured continuously in arcs at distances ranging from 60 m to 2000 m from the source during the release time. At each sampling location, SF_6 was draw at a height of 1 m and transferred through polyethylene tubes to a trailer where concentrations were sampled at 5 Hz.

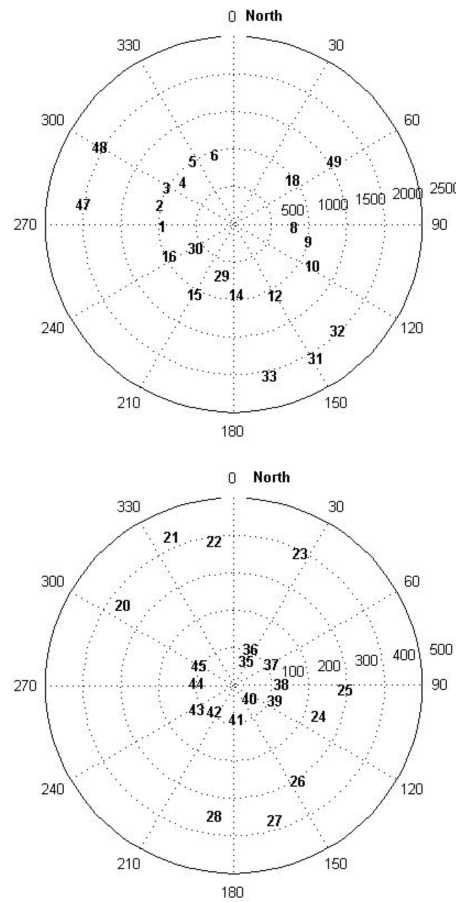

Fig. 1. The locations of SF6 sampling sites. The center denotes the source; the boldface numbers indicate sampling sites; the numbers along different circles are the radius (in meter); and the numbers along the outer circle are the degrees from the North.

The meteorological instrumentation consisted of two 3-D Sonic Anemometers (CSAT3), two Krypton Hygrometers (KH20), one Net Radiometer (CNR1), one Temperature and RH Probe (HMP45C), two Temperature Probes (Campbell Sci. Model 107), one Infrared Temperature Sensor (Apogee Instruments IRR-P), and two Data Loggers (Campbell Sci. CR5000). There were two groups of instruments: one on a

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tower (referred to as the "Lower" station) and another on a tripod (called the "Upper" station). Each group was connected to a CR5000 Data Logger. The Lower station was deployed on the 10-m high meteorological tower located on a trailer near sampling site 37 (See Fig. 1) in the parking lot of Sunrise Park. The station consisted of a sonic anemometer (CSAT3) and a KH20 at 4 m above ground level (AGL), a CNR1 at 9.5 m AGL, a Model 107 at 5.2 m AGL, another Model 107 at 3.2 m AGL, an IRR-P at 2.2 m AGL, and a HMP45C at 1.5m AGL. The Upper station was deployed on a 4-m high tripod located on the roof of the building near the source (see Fig. 1). The station consisted of a CSAT3 and a KH20 at 3.6 m above the roof, i.e., approximately 10.5 m AGL. Both the sonic anemometers were pointed toward true North.

The sonic anemometer sampled the three components of the velocity and temperature at 10 Hz. The SF_6 was released continuously over seven 6-hour periods between 15th and 21st July 2008. There were three daytime releases (15th, 16th, and 17th July 2008, from 09:00 to 15:00 PDT) and four nighttime releases (18th, 19th, 20th, and 21st July 2008, from 01:00 to 07:00 PDT). For analysis, the concentrations and meteorological measurements were averaged over 1 hour periods.

3. Observations

Fig. 2 shows the variation of meteorological parameters as a function of time of a day over the experiment. The wind speeds were lower than 1 ms^{-1} during most of the nighttime hours. The wind speeds started to increase around 8:00 hours and reached a maximum of about 2 ms^{-1} around 17:00 hours. The dominant wind directions were easterly during most of the day. The figure also shows that the lateral turbulent velocities (σ_v as shown in Fig. 2) were above 0.5 ms^{-1} during most of the day; the large lateral turbulent intensities (bottom left panel), above 0.5 most of the time, indicate the importance of plume meandering.

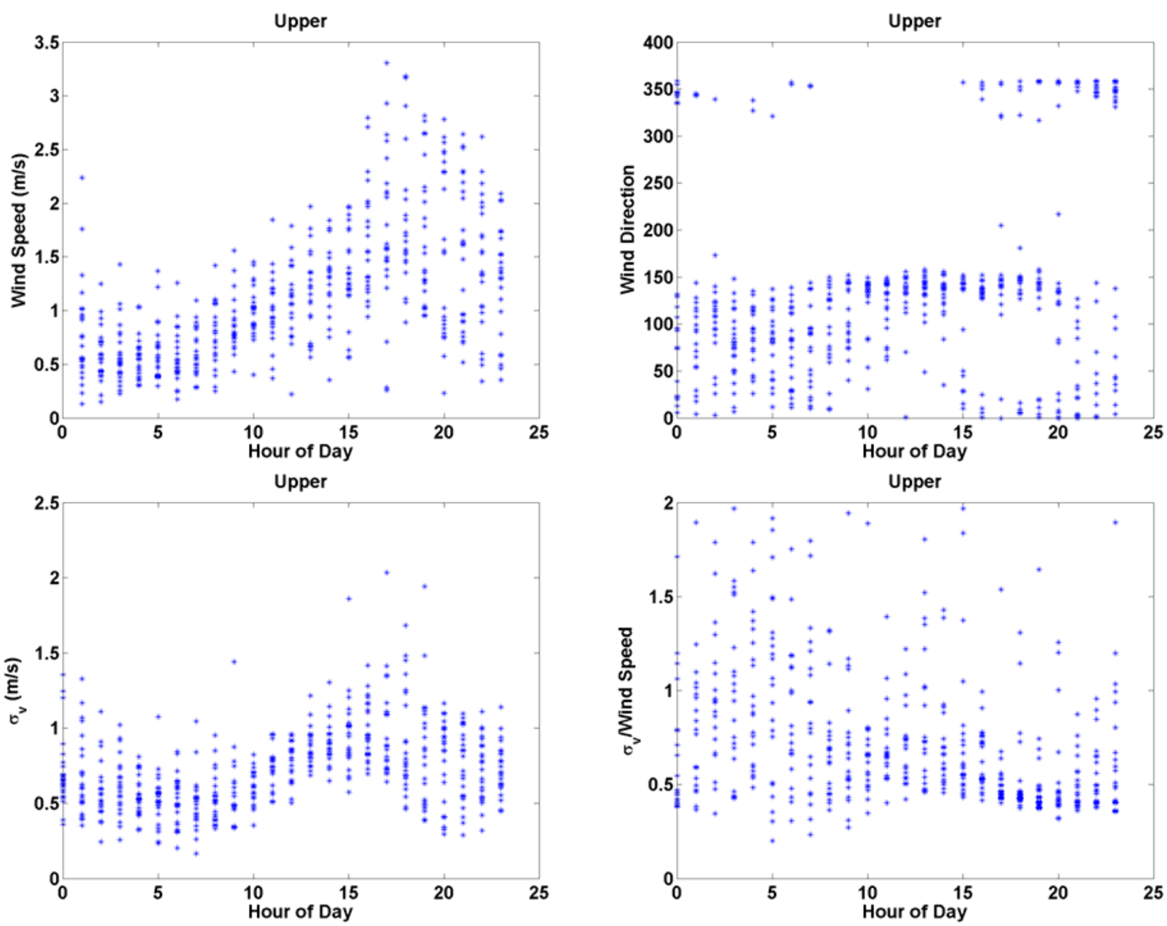

Fig. 2. Variation of dispersion parameters during experiment by "Upper" station.

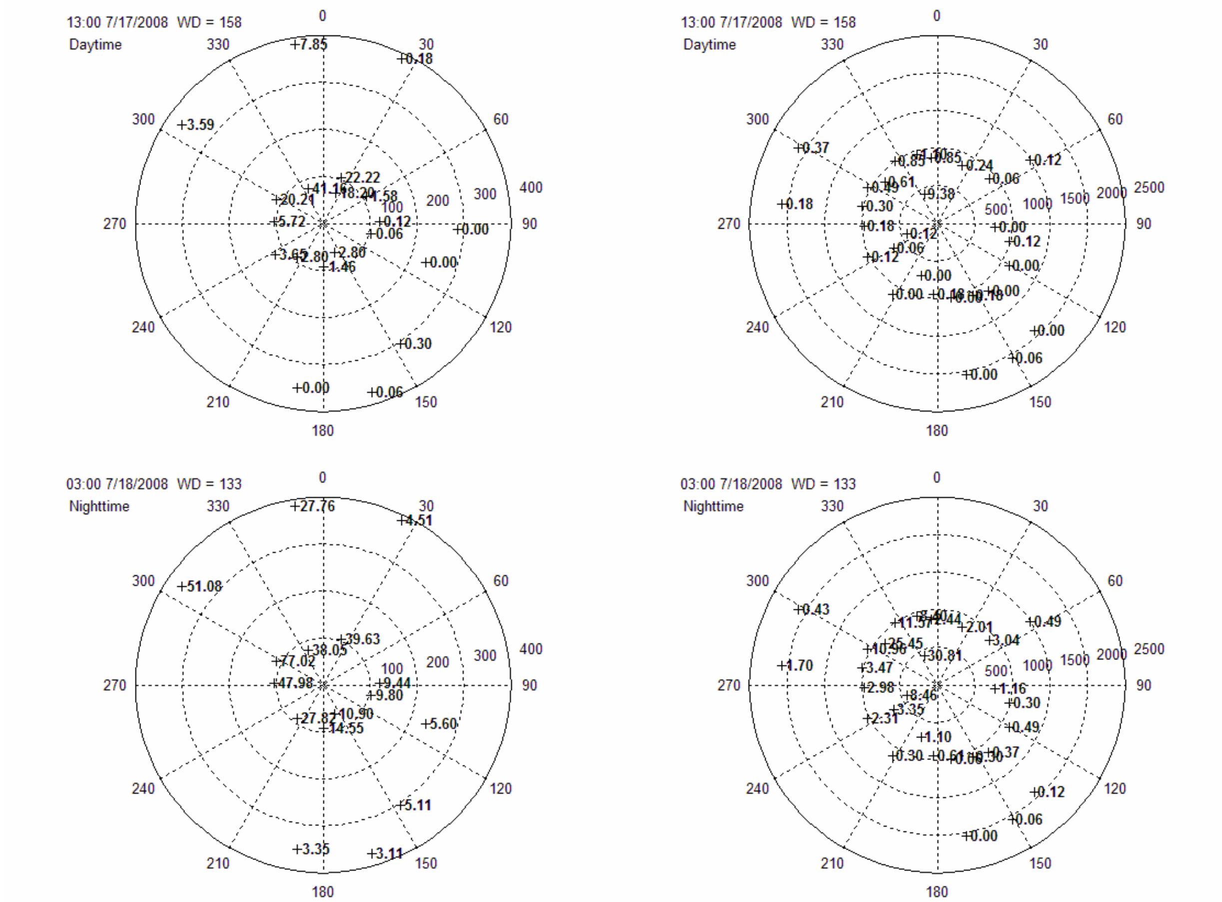

Fig. 3. Observed concentrations (μgm^{-3}, dubbed as boldface numbers) at 17th, and 18th July, 2008 (See Fig. 1.)

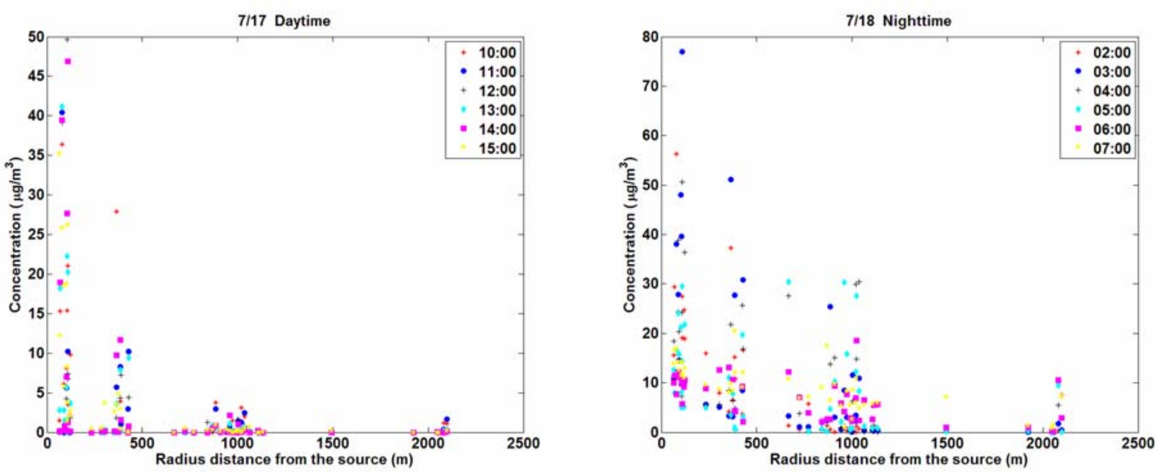

Fig. 4. Observed concentrations as a function of radius distance at 17th, and 18th July, 2008

Fig. 3 shows examples of observed daytime and nighttime concentrations at each site. The upper two panels show daytime concentrations. During the period 12:00 to 13:00 (denoted as 13:00 7/17/2008 in Fig. 3), the wind direction was 158 degree, and the maximum ground concentrations were found at downwind sites located in the northwest and at about a hundred meters form the source; also, as expected, the daytime mixing in the boundary layer resulted in a rapid decrease in concentration with downwind distance. This is confirmed in the left panel of Fig. 4.

However, the nighttime concentrations showed a very different pattern. The concentrations at downwind sites beyond 500 m still are high relative to those found during daytime; high concentrations were also found at almost every site in the vicinity of the source, not only those located downwind. This suggests that the DG plume was trapped in a relatively shallow boundary layer during the night, and was spread in all directions by the meandering wind. This can also be seen in the right panel of Fig. 4. High concentrations were found at the sites 1 km from the source, and even the concentrations of sites of 2 km radius were not negligible.

4. Performance of AERMOD

Fig. 5 shows average concentrations as a function of the deviation of the wind direction from the line joining the center of the source to the receptor. These averages concentrations were obtained by averaging every day of the measured hourly concentrations over 10º sectors. We see that the highest concentrations occurred downwind of emission source during the daytime; however at night, the concentrations occurred everywhere. The concentration distribution predicted by AERMOD during the daytime shows a sharp peak in the downwind direction, which is absent in the observed distribution; at other wind angles the estimated magnitudes are similar to the observed values. AERMOD underestimates nighttime ground concentrations at all angles relative to the wind direction.

The difference in model performance between day and night is shown in Fig. 6, which compares the performance of AERMOD in terms of quantile-quantile (Q-Q) plots (Venkatram 1999). We see that AERMOD yields concentration estimates within a factor of two of the observed values over most of the concentration range during the daytime; however AERMOD underestimates concentrations substantially during the night.

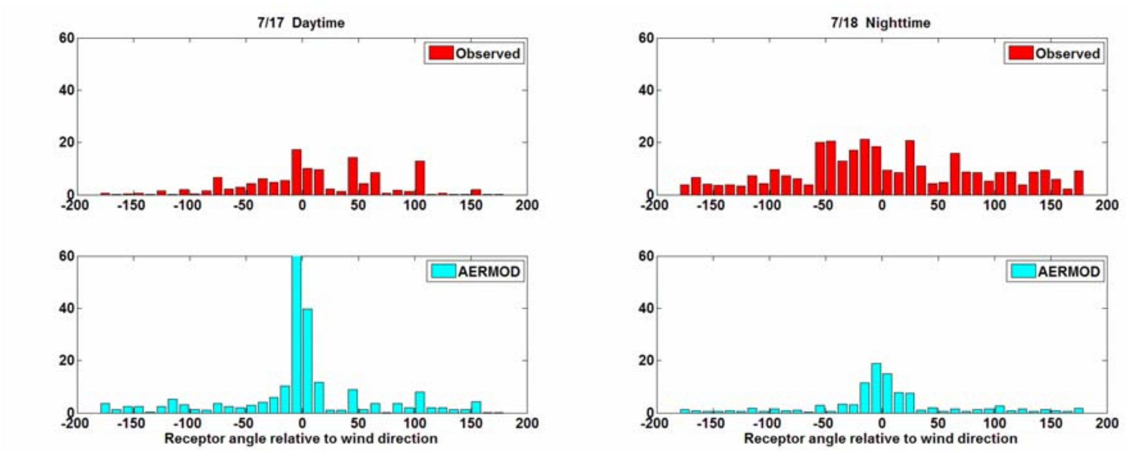

Fig. 5. Concentrations as a function of the deviation of the wind direction from the line joining the center of the source to the receptor. Hourly concentrations averaged over 10º sectors.

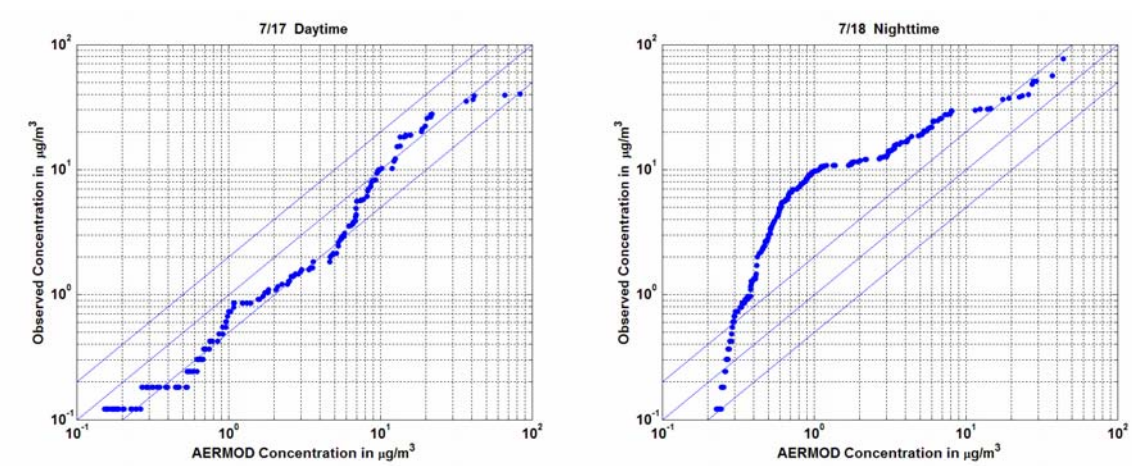

Fig. 6. Comparison of observed and estimated concentration distributions using a Q-Q plot.

5. Summary

The results from the Palm Springs tracer study indicate there are substantial differences in dispersion of buoyant releases between daytime and nighttime under low wind conditions. During the day, concentrations fell off rapidly with distance from the source in response to vigorous convective mixing. During the night, ground-level concentrations varied little with distance from source indicating the possible effects of trapping of the emissions in a shallow nighttime mixed layer. Meandering plays a major role in the spatial distribution of concentrations.

AERMOD explains the daytime concentrations reasonably well. However, it underestimates concentrations by more than a factor of two during nighttime. The spatial distribution of concentrations cannot be described by simply reducing the boundary layer height in AERMOD. It appears that we may need to account for unsteady back and forth “sloshing” of the trapped pollutants to explain the relatively high concentrations at 1000 m from the source.

6. Acknowledgements

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