9.4 Modeling Dispersion of Buoyant Emissions from a Low Level Source in an Urban Area

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Abstract

A tracer study was conducted in July 2008 in the vicinity of a 650 kW gas fired power plant located in Palm Springs, CA. The tracer, SF_6, was released with the exhaust gases, and sampled at 49 locations at distances ranging from 60 m to 2 km from the stack. The exhaust stack stands 2.3 m high above the flat roof of a 7 m high building surrounded by one storey residences. There were seven experiments, four during the night, and three during the daytime, during which tracer was released for 6 consecutive hours. Meteorological measurements were made with sonic anemometers at 11 m from the ground. The measurements indicated that the wind speeds were low, around 2 m/s, but the lateral turbulent intensities were around 0.5. The meteorological measurements were used in AERMOD, a state-of-the-art dispersion model developed by the USEPA, to estimate concentrations, which were compared with measured tracer concentrations. The evaluation indicated that AERMOD could provide adequate estimates of concentrations during the daytime hours. However, during the nighttime hours, concentrations were underestimated. This paper presents results from sensitivity studies conducted to explain the discrepancies between model estimates and observations during the night. It turns out that ground-level concentrations are sensitive to the details, such as vertical structure, of the stable boundary layer.

1. Introduction

Because small distributed sources of electrical power may serve a single home, neighborhood, or business more efficiently and reliably than centrally located power plants (Allison and Lents 2002), distributed generation (DG) is becoming popular in some states such as California. However, small DG units 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 dispersion 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 releases in urban areas. In this paper we report the measurements from a tracer study conducted at Palm Springs, Southern California during the summer of 2008, and relate their spatial and temporal variation to observed micrometeorology using AERMOD.

2. Field Study

The tracer experiment was conducted from July 15th, 2008 to July 21st, 2008 at the 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 650KW gas fired IC engine with heat recovery. 49 SF_6 samplers were arranged in arcs at distances from 60 m to 2000 m from the source during the releasing time. The sonic anemometer in an 11 m high tripod 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.

Fig. 1 indicates that Palm Springs field study is a low wind case. The wind speeds never exceeded 3.5 m/s, and they were below 2 m/s during most of the day, and below 1 m/s during most of the nighttime. The vertical turbulent velocities (σ_w as shown in Fig. 1) were below 0.4 m/s during most of the release periods, however the lateral

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turbulent velocities (σ_v as shown in Fig. 1) were above 0.5 m/s during most of the day; the lateral turbulent intensities (bottom left panel) were high and they were above 0.5 during most of the time, which indicates that the meandering is important.

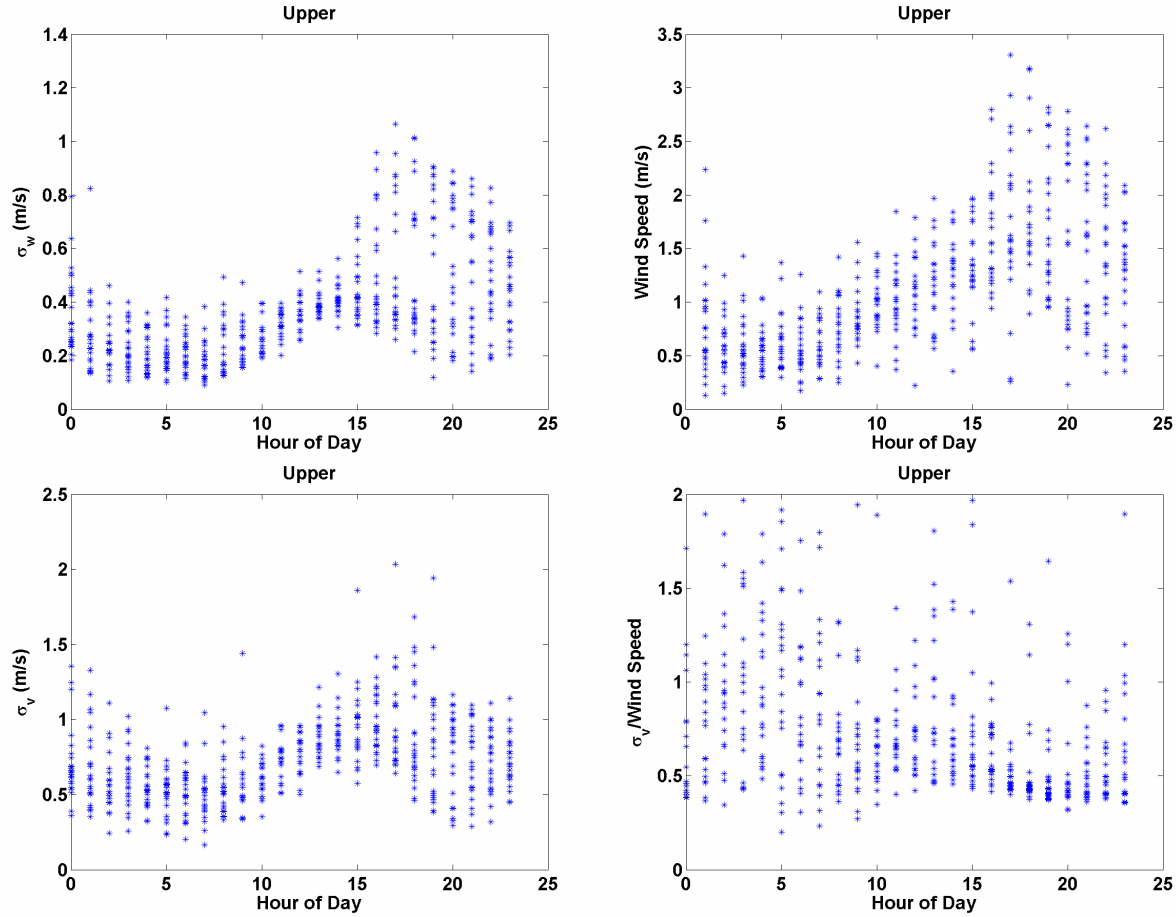


Fig. 1. Variation of dispersion parameters during the experiment by "Upper" station.

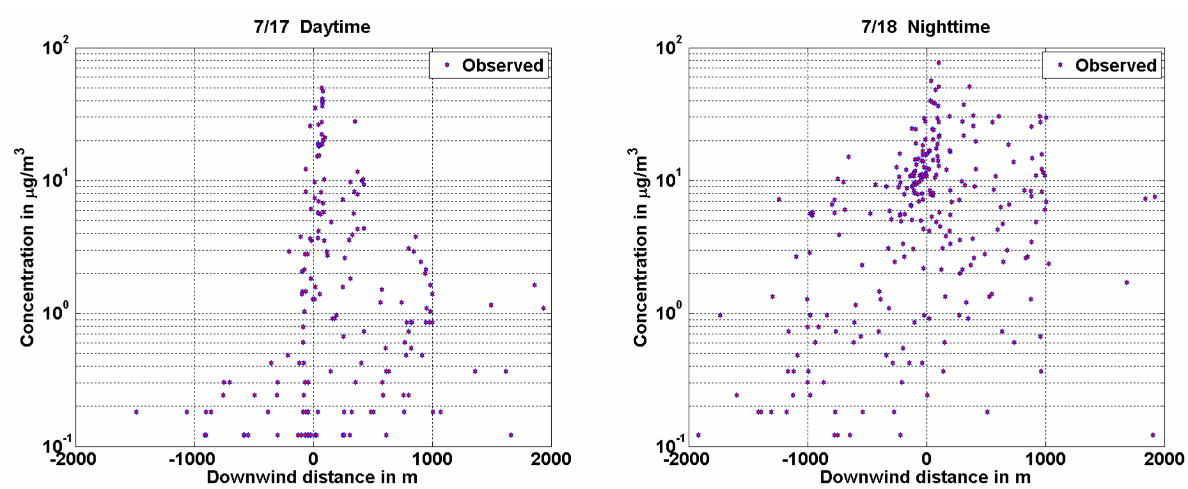


Fig. 2. Observed concentrations as a function of downwind distance on 17th, and 18th July, 2008

Fig. 2 shows typical daytime and nighttime observed ground-level concentrations as a function of downwind distance. The daytime concentrations dropped rapidly with the downwind distance as a result of daytime mixing in the boundary layer, and the upwind concentrations were negligible.

However, the nighttime concentrations showed a very different pattern. High concentrations were found all over the place. The upwind concentrations as well as those observed at downwind beyond 500 m were not negligible. This indicates that the DG plume was trapped in a relatively shallow boundary layer at night, and was spread in all directions by the meandering wind.

We chose AERMOD to simulate the dispersion from the DG. AERMET was used to generate the meteorological inputs.

Fig. 3 compares AERMOD results with observations in terms of scatter plots and 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 daytime, and it captures the peak ground-level concentrations for both daytime and nighttime; however it performs differently at different nights, and it tends to under estimate concentrations at certain nights, for example, 18th July and 19th July.

3. AERMOD Performance

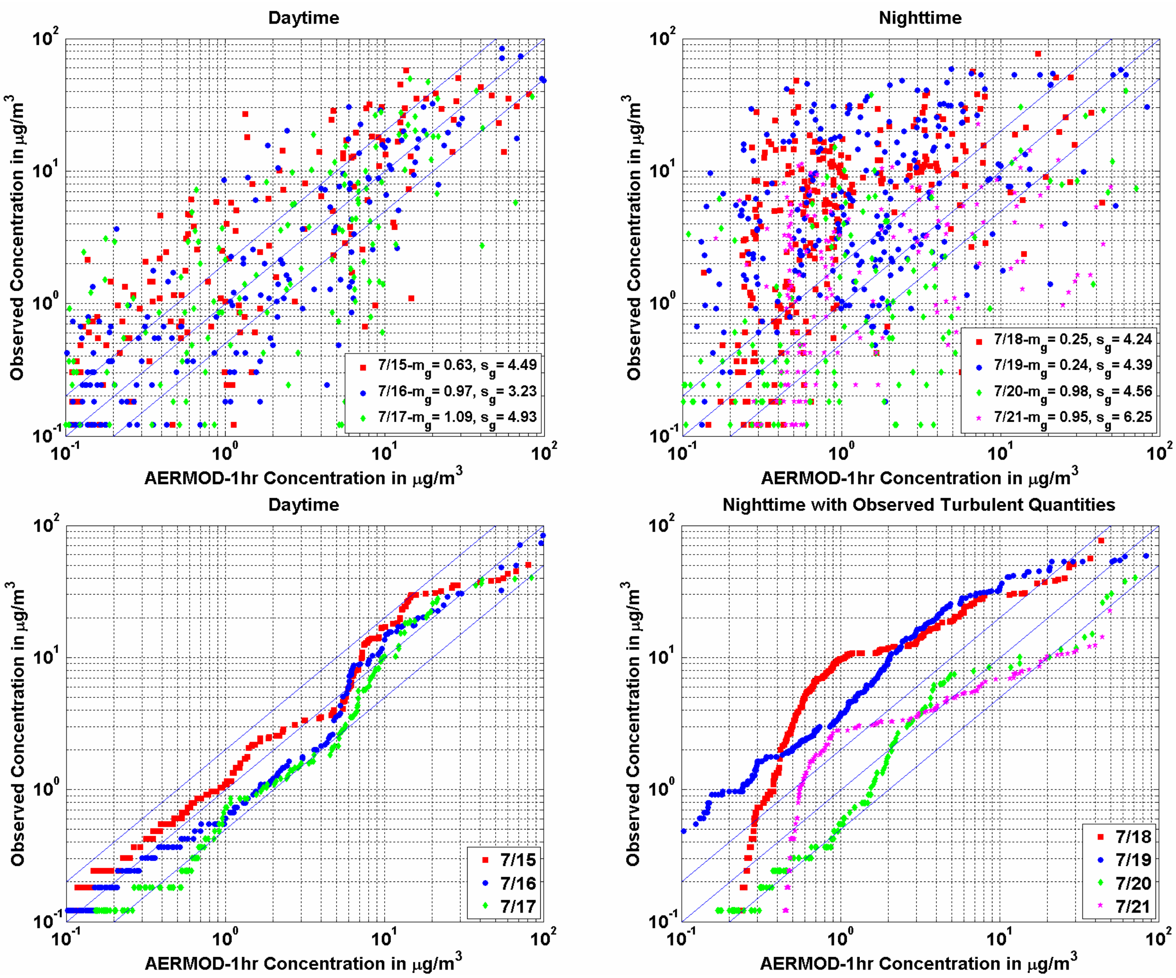


Fig. 3. Comparison of observed and estimated concentration distributions using scatter plots (upper panels) and Q-Q plots (lower panels).

We also plotted maximum hourly concentrations against wind speed in Fig. 4. AERMOD concentrations increase rapidly with the wind speed, because the higher wind speed can bend over the plum earlier, which will decrease the plume rise and increase ground-level concentrations. In the real world the ground-level concentration is not so sensitive to wind speed; however we still see the trend of increase in the left panel of Fig. 4.

We also found in the left panel that the peak ground-level concentration of Palm Springs field study was actually observed during daytime. This indicates that although the dispersion is high during daytime and is low at night, it does not necessarily mean that the ground-level concentrations are higher at night.

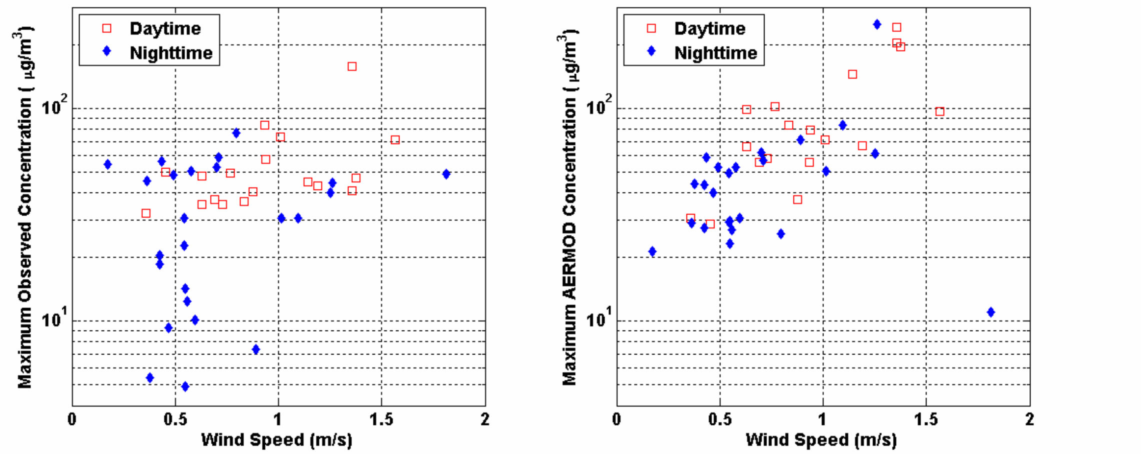


Fig. 4. Maximum hourly concentration as a function of wind speed

Fig. 5 shows the maximum arc concentration against radial distance. As we can see that the daytime arc maximum concentration drops more rapidly with radial distance than nighttime, and nighttime concentrations at distance of 1 km are not negligible.

Furthermore, we see that near the source the peak concentration was observed during daytime, because the daytime convection mixes the plume rapidly down with the ambient atmosphere. AERMOD does capture this peak value. Further downwind, the peak concentration was observed at night, because at the distance far away from the source, the daytime plume was diluted, but the nighttime plume was just trapped.

Again, we found in the right panel of Fig. 5 that AERMOD tends to underestimate ground-level concentrations at certain nights.

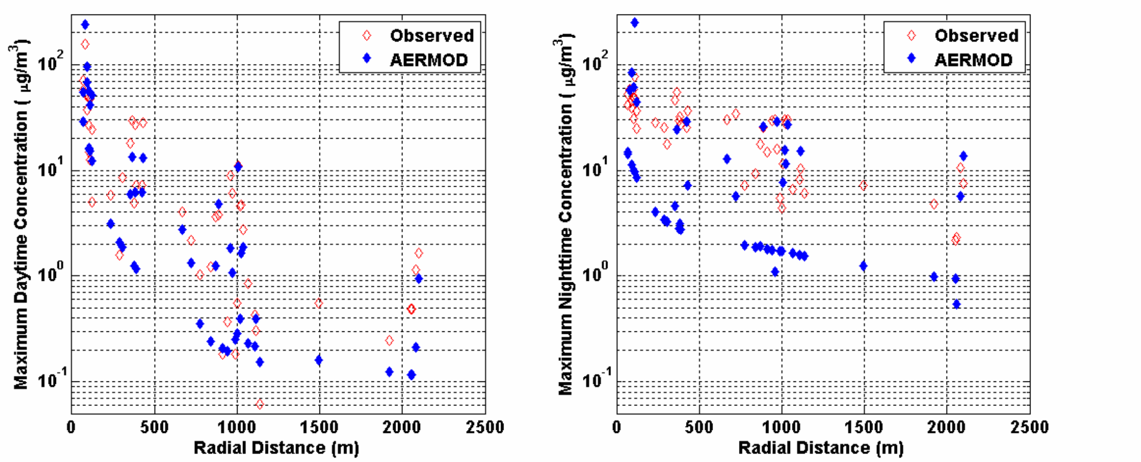


Fig. 5. Maximum arc concentration as a function of radial distance

4. Sensitivity study

Fig. 6 shows one night concentration against another for both observations and modeled results.

Although both of them show that 20th July has the lowest concentrations, the difference is obvious: The observations are different from night to night; the modeled results are similar to each other. Consequently, AERMOD performances are different from night to night.

To investigate why AERMOD performs differently at different nights, that is, why AERMOD predicts similar results at different nights, we conducted sensitivity studies.

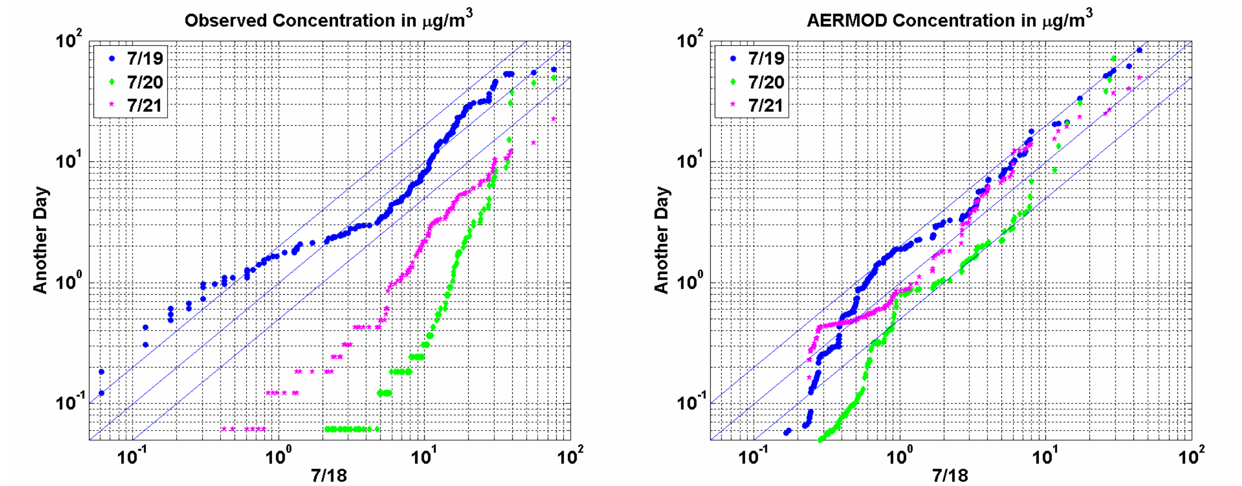


Fig. 6. Comparison of observed/AERMOD concentrations among different nights using a Q-Q plot

4.1. Urban configurations in AERMOD

We switched urban source option off in the AERMOD, which basically shut down the nighttime enhanced turbulence caused by the temperature difference between the cool air above the urban and the warm air within it. However after this change, the estimated concentration shows no change, which indicates the nighttime enhanced turbulence resulted from the small population (46185) in Palm Springs area is negligible.

We also removed all the buildings around the stack in AERMOD, which will take away the building downwash effect. The PRIME algorithm in AERMOD tests the trajectory angle of the rising plume to determine if the plume will escape the effects of the building. The critical angle is set to be 20 degrees from horizontal determined by a 'best fit' to a developmental database in Bowline (Brode 2002). AERMOD barely shows any difference after building downwash was shut down in this study, which indicates the low wind speed in Palm Springs area during nighttime releases allows the plume to rise to a high level which vicinal buildings stand below, or the trajectory angle of the rising plume is beyond the critical value determining if wake effects apply.

4.2. Meteorological inputs

The meteorological data are important inputs for dispersion models in the stable boundary layer (Van Ulden and Holtslag 1985; Venkatram and Cimorelli 2007). Researchers are also devoted themselves to improve the meteorological inputs (Isakov et al. 2007; Princevac and Venkatram 2007; Venkatram and Princevac, 2008).

Fig. 7 compares the observed friction velocities (u_*) during the release periods of each night in terms of a Q-Q plot using 5-minute averaged data. As we can see that 20th July has the highest u_*, consequently it may have a highest stable boundary according to Zilitinkevich (1972), which could be one of the reasons why 20th July has the lowest concentrations,

Fig. 8 compares AERMOD results with observed meteorological inputs (Hs, u_*, σ_v, and σ_w) against observations. AERMOD improves slightly, especially for the mid-range concentration distributions of 18th July and 21st July (Recall bottom right panel of Fig. 3), but it still underestimates the concentration of 18th July and 19th July.

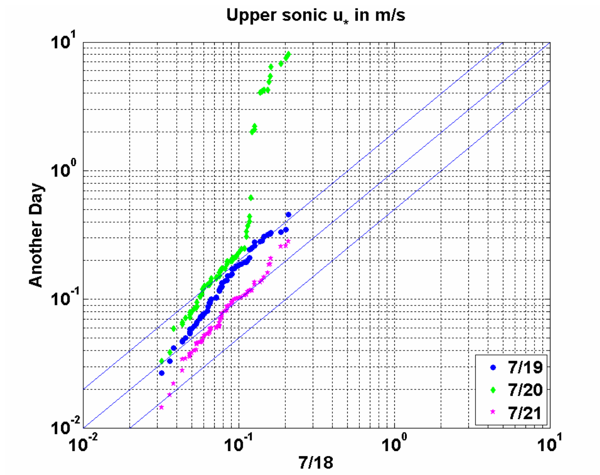


Fig. 7. Comparison of observed u_* using a Q-Q plot.

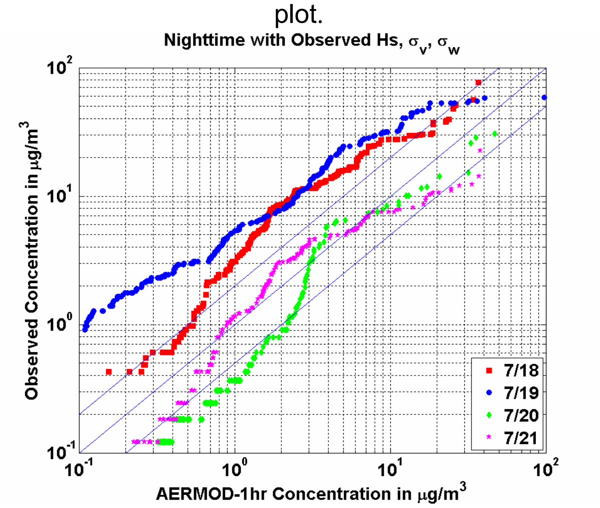
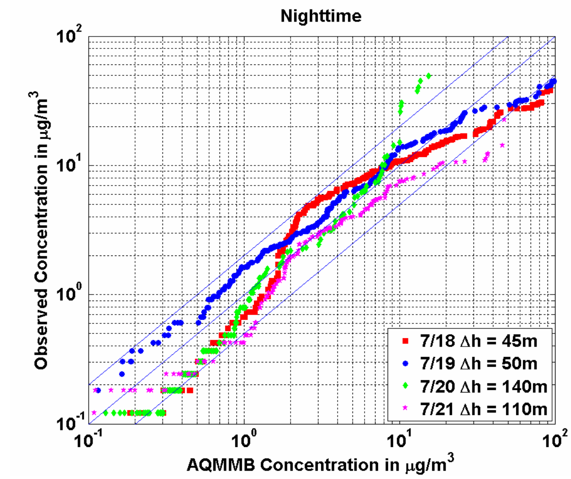


Fig. 8. Performance of AERMOD with observed meteorological inputs using a Q-Q plot

4.3. Plume rise

We built an **A**ir **Q**uality **M**odel with **M**eandering and **B**uoyancy induced dispersion (AQMMB; Venkatram et al. 2004; Cimorelli et al. 2004; Venkatram et al. 2005), and fitted the concentration data to optimize the plume rise. The AQMMB is similar to AERMOD. The results are shown in Fig. 9.

The optimized plume rises at 18th July and 19th July, around 50 m indicated by AQMMB, are less than those at 20th July and 21st July, which indicates that the plumes at 18th July and 19th July are less buoyant than those at the other two nights. It could be true that AERMOD overestimates the plume rise at nights when the buoyancy and turbulence are not too strong, for example, 18th July and 19th July, and then underestimates the ground-level concentrations at those nights.



5. Conclusions

This paper described a tracer study conducted in Palm Springs, and a simulation of the dispersion from a low level buoyant source in an urban area using AERMOD. The evaluation as well as the sensitivity study indicates that:

1) AERMOD captures the peak ground-level concentration;
2) AERMOD performs well in reproducing the concentration distributions for daytime convective releases as well as for highly buoyant releases during nighttime;
3) When the buoyancy and turbulence is not too strong and lead to high observed ground-level concentrations at night, AERMOD tends to underestimate them;
4) The details within the SBL, which affect the prediction of nighttime ground-level concentrations, should be reinvestigated.

6. Acknowledgements

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References

Allison, J. E. and Lents, J. (2002) Encouraging distributed generation of power that improves air quality: can we have our cake and eat it too? Energy Policy. 30(9):737-752.

Brode, R. W. (2002) Implementation and Evaluation of PRIME in AERMOD. The 12th Joint Conference on Applications of Air Pollution Meteorology with A&WMA, Norfolk, VA.

Cimorelli, A. J., Perry, S. G., Venkatram, A., Weil, J. C., Paine, R. J., Wilson, R. B., Lee, R. F., Peters, W. D., Brode, R. W. and Paumier, J. O. (2004) Aermod: Description of Model Formulation. U.S. Environmental Protection Agency Office of Air Quality Planning and Standards Emissions Monitoring and Analysis Division Research Triangle Park, North Carolina.

Cimorelli, A. J., Perry, S. G., Venkatram, A., Weil, J. C., Paine, R., Wilson, R. B., Lee, R. F., Peters, W. D. and Brode, R. W. (2005) AERMOD: A Dispersion Model for Industrial Source Applications. Part I: General Model Formulation and Boundary Layer Characterization. Journal of Applied Meteorology. 44(5):682-693.

Isakov, V., Venkatram, A., Touma, J. S., Koracin, D. and Otte, T. L. (2007) Evaluating the use of outputs from comprehensive meteorological models in air quality modeling applications. Atmospheric Environment. 41(8):1689-1705.

Princevac, M. and Venkatram, A. (2007) Estimating micrometeorological inputs for modeling dispersion in urban areas during stable conditions. Atmospheric Environment. 41(26):5345-5356.

Van Ulden, A. P. and Holtslag, A. A. M. (1985) Estimation of Atmospheric Boundary Layer Parameters for Diffusion Applications. Journal of Applied Meteorology. 24(11):1196-1207.

Venkatram, A. (1999) Applying a framework for evaluating the performance of air quality models. Proceedings of the Sixth International Conference on Harmonisation within Atmospheric Dispersion Modeling for Regulatory Applications, Rouen, France, 11-14 October, 1999.

Venkatram, A. and Cimorelli, A. J. (2007) On the role of nighttime meteorology in modeling dispersion of near surface emissions in urban areas. Atmospheric Environment. 41(4):692-704.

Venkatram, A., Isakov, V., Pankratz, D. and Yuan, J. (2005) Relating plume spread to meteorology in urban areas. Atmospheric Environment. 39(2):371-380.

Venkatram, A., Isakov, V., Yuan, J. and Pankratz, D. (2004) Modeling dispersion at distances of meters from urban sources. Atmospheric Environment. 38(28):4633-4641.

Venkatram, A. and Princevac, M. (2008) Using measurements in urban areas to estimate turbulent velocities for modeling dispersion. Atmospheric Environment. 42(16):3833-3841.

Zilitinkevich, S. S. (1972) On the determination of the height of the Ekman boundary layer. Boundary-Layer Meteorology. 3(2):141-145.