Investigating Dispersion of Buoyant Emissions from Low Level Sources in Urban Areas: Water Channel Modeling

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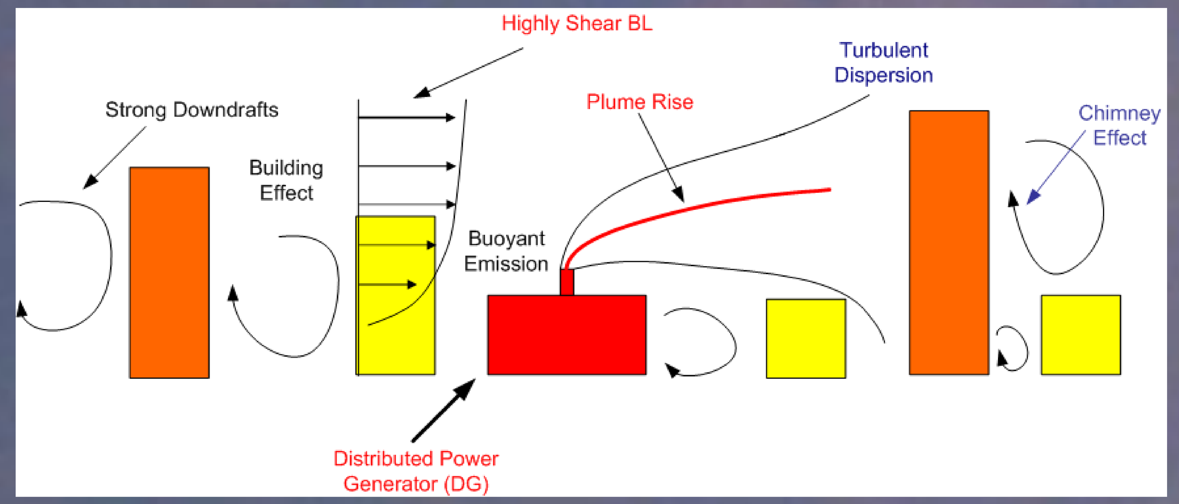
Introduction

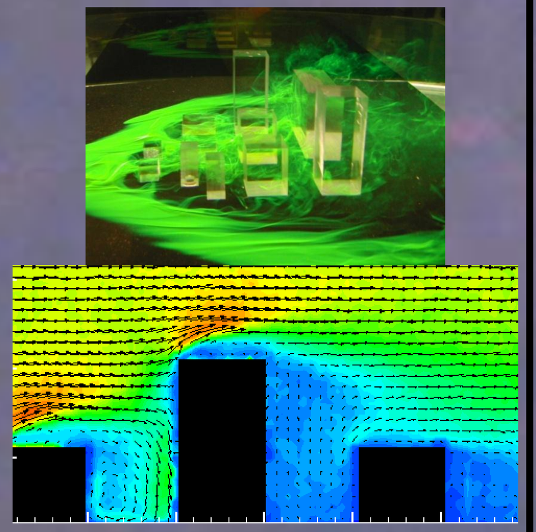
Rapid increase in the distributed power generation have raised the concerns on significant effect of distributed generators (DG) on air quality in urban areas. Although many recent studies (Allison and Lents, 2002; Heath et al., 2006) have focused on the air quality impact of DGs, very few of them address the impact of DGs on ambient ground level concentrations.

Why DGs?

After the western U.S energy crisis in 2000 and 2001, schools, businesses and hospitals moved toward the independency from central power plants by installing on site small scale power generators, known as distributed power generators (DGs) .

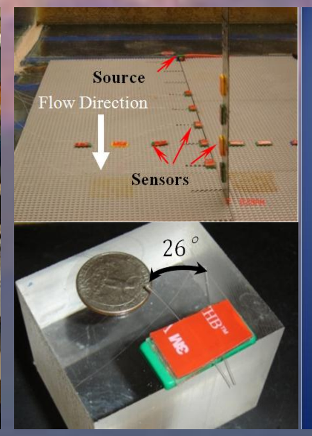
Although DGs were beneficial for local industries by providing power independency, they may have significant effect on air quality in urban areas. Their exhaust is released within the city, in vicinity of businesses, schools, restaurants and hospitals, where it can be captured in the wake produced by surrounding buildings.
The process of dispersion in these kind of environments is mostly affected by the complex geometry of the buildings in urban area.

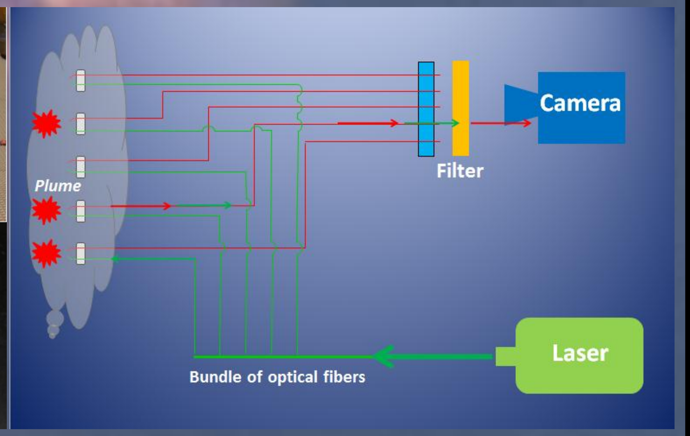




Laboratory Setup

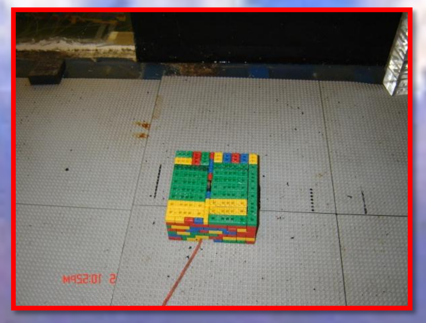
In order to understand the dispersion process of pollutants associated with these sources, a systematic laboratory study was conducted in a custom-designed water channel facility at University of California, Riverside.
Concentrations were measured through a newly developed system. This system, based on the concept of Laser Induced Fluorescence (LIF), utilizes optical fibers in order to measure the concentrations at selected points.



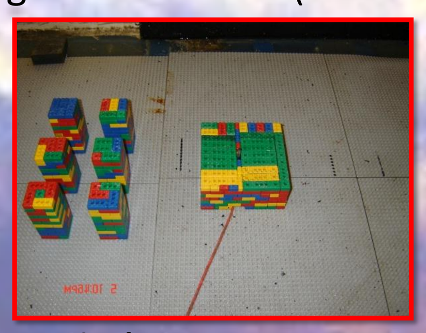


Dispersion Experiment

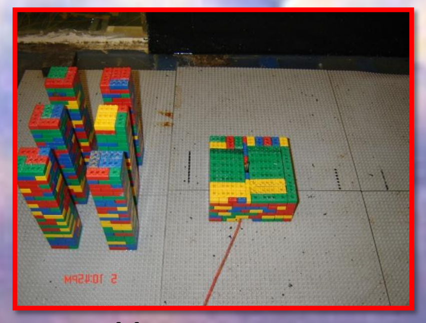
In order to investigate ground level concentrations associated with low level buoyant sources, Palm Springs DG building with stack height (H_s) of 9.3 m above ground level has been modeled in the water channel at scale of 1:100, and concentrations has been measured at 15 locations downstream of the stack.
Experiments regarding the air quality impact of DG have been done for three different cases: 1) DG with no upstream building; 2) DG with upstream buildings the same height as of the stack (single story); and 3) DG with upstream buildings of double the height of the stack (double story).



Only DG Building



Single Story Upstream Buildings

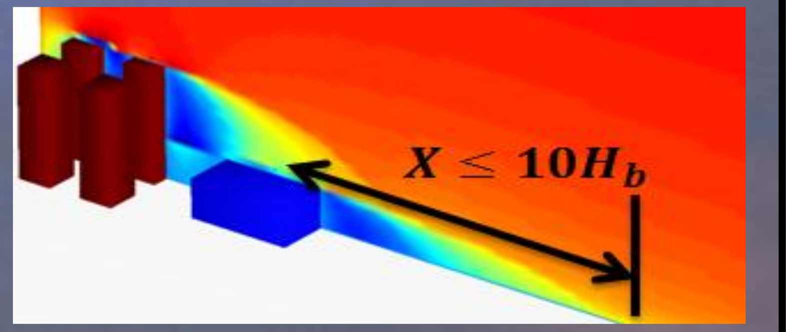


Double Story Upstream Buildings

Model Modification

To overcome the problems mentioned in previous section for AERMOD predictions of the ground level concentrations, AERMOD has been modified in the sense that it treats the near source dispersion different than far from source dispersion. The near source dispersion in AERMOD has been modified by assuming that there are no upstream buildings in the setup. Instead we used the measured meteorology of the stack region as the input meteorology and allow the AERMOD to predict concentrations up to 10 Building heights from the DG which are called $C_{near\ field}$. After this distance AERMOD predicts concentrations assuming that all buildings are in the setup and input meteorology is the same as that of ambient. Concentrations predicted with this approach are called $C_{far\ field}$. However, this modification can cause a discontinuity in the concentration field. To overcome this problem, the straight forward solution is to use an interpolating function between these two approaches such as:

$$C = (1-\lambda)C_{near\ field} + \lambda C_{far\ field} \qquad 0 < \lambda < 1$$

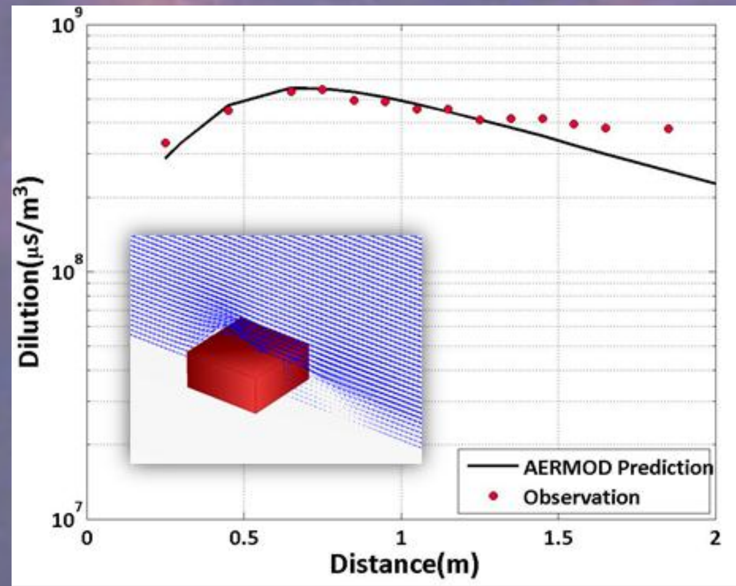


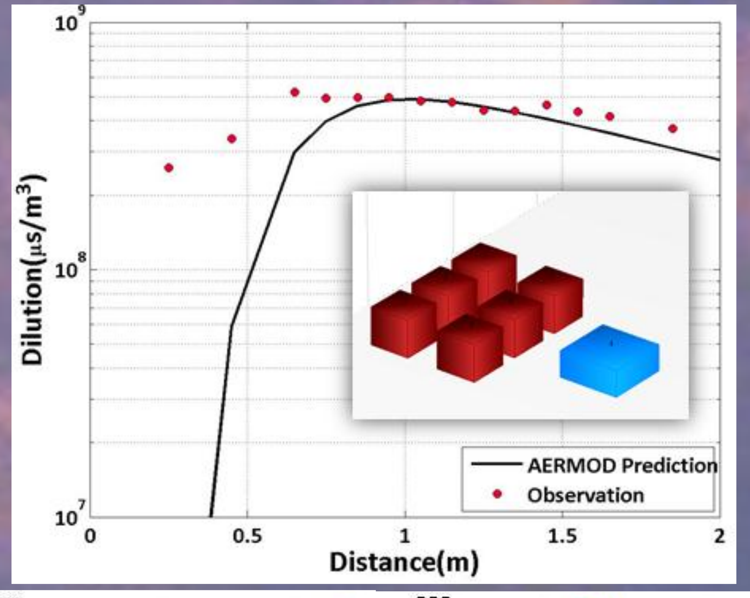
where $\lambda = 0$ for $X \leq 10H_b$ and $\lambda = 1$ for $X \geq 13H_B$.

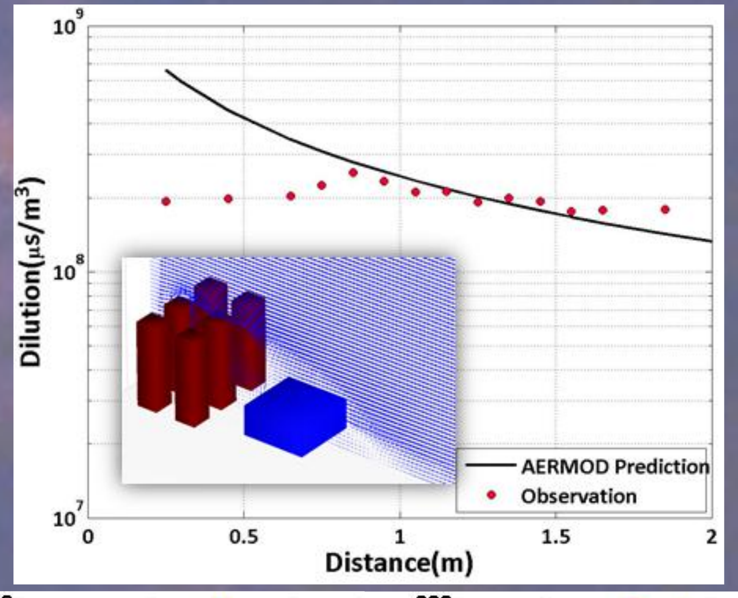
More model modifications regarding dispersion in complex urban geometries can be found in Venkatram et al.(2010).

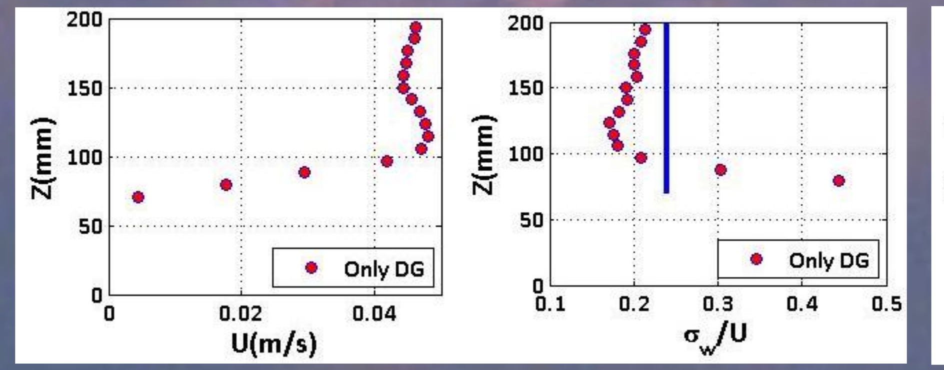
Results

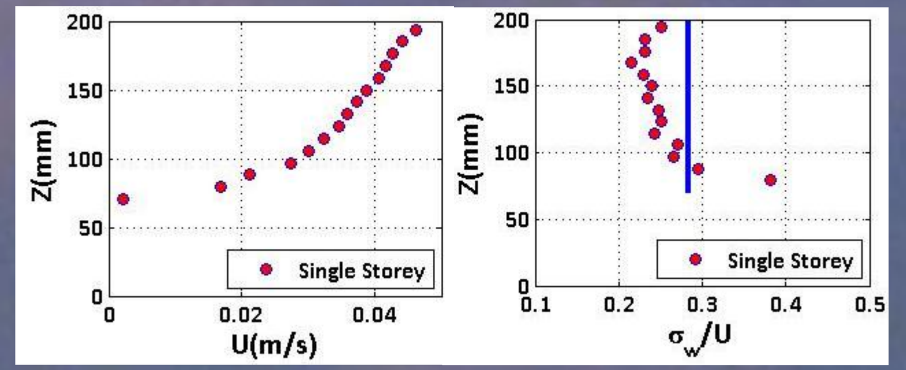
Results from concentration measurements have been compared with AERMOD (Cimorelli et al., 2005), a Gaussian based dispersion model, predictions. Comparisons show that AERMOD predicts well the concentrations associated with a DG without any building in the vicinity, while underestimate/overestimate concentrations associated with the presence of single/double story upstream buildings respectively. Results also shows that the presence of upstream buildings reduce concentrations close to stack.

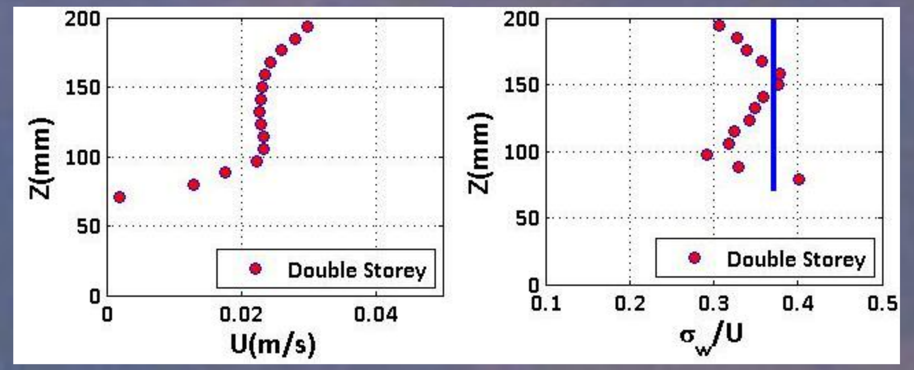




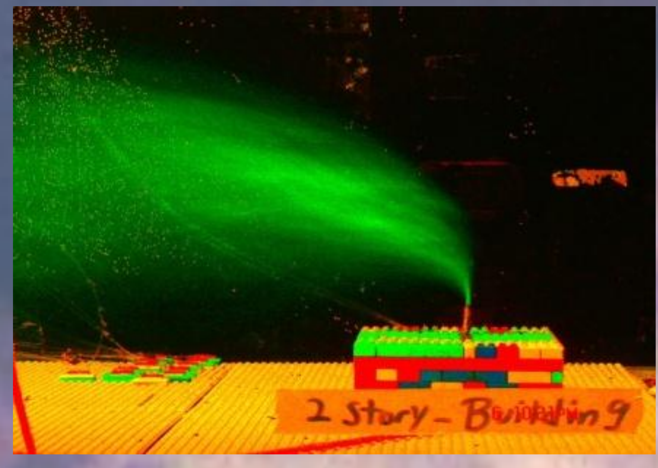




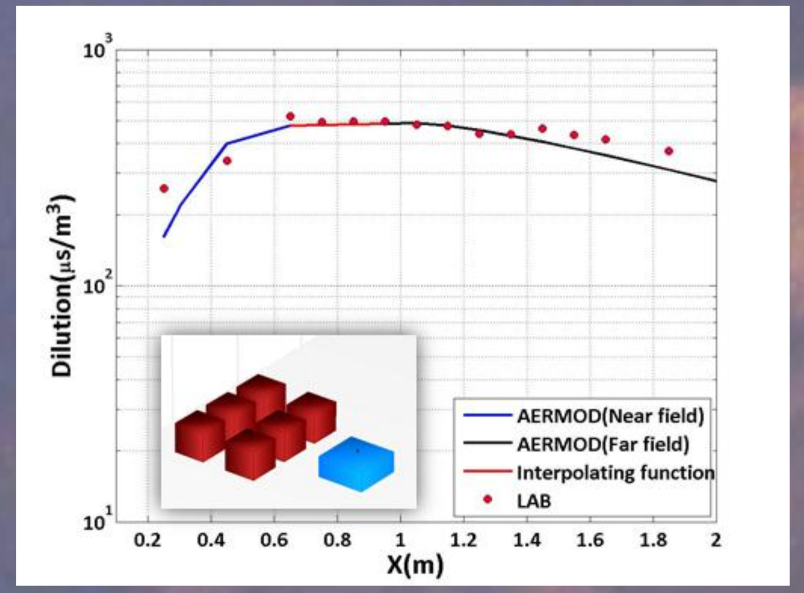


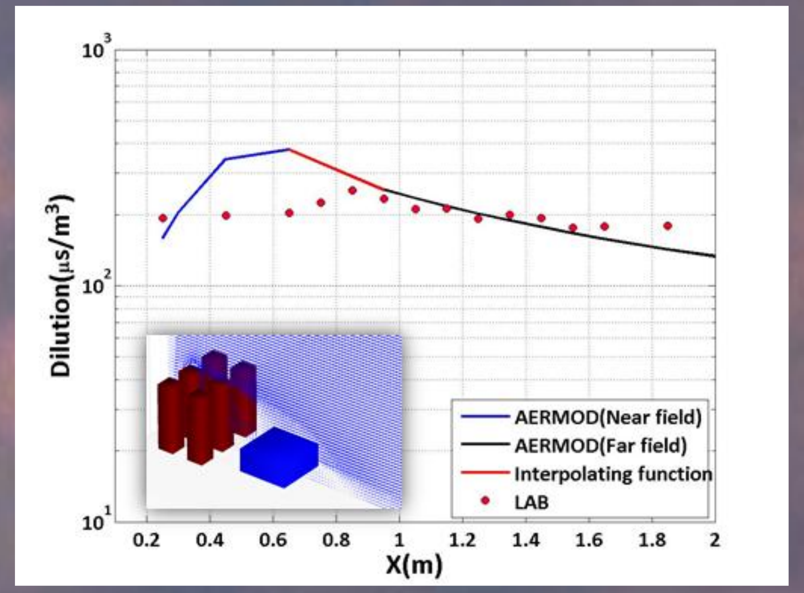


We also conducted some visualizations to examine the behavior of the plume in the presence of upstream buildings. Plume visualizations indicate that upstream buildings decrease the wind speed near the stack and increase the plume rise. However, at the same time, upstream buildings increase turbulent intensities near the stack resulting in rapid vertical mixing. A higher plume rise lowers the concentrations while increased vertical mixing increases ground level concentrations.



Modified Results





Summary & Conclusion

1. Laboratory measurements were done to investigate the impact of DGs on ground level concentrations.
2. AERMOD performance in explaining laboratory results were examined.
3. AERMOD is unable to explain dispersion in complex cases.
4. Using near field meteorology, AERMOD performance has been improved.
5. Plume rise and turbulent intensity play a major role in determining near field ground level concentrations.
6. The presence of buildings results in effects that counteract each other in changing the ground-level concentrations.

References

1. Allison KE and Lents J (2002) Encouraging distributed generation of power that improves air quality: can we have our cake and eat it too? J. Energy Policy, 30, 737-752
2. Cimorelli AJ, Perry SG, Venkatram A, Weil JC, Paine RJ, Wilson RB, Lee RF, Peters WD, Brode R (2005) AERMOD: A dispersion model for industrial source applications. Part I: General model formulation and boundary layer characterization. J. App. Meteorology., 44(5), 682-693
3. Heath GA, Granvold PW, Hoats AS, Nazaroff WW (2006) Intake fraction assessment of the air pollutant exposure implications of a shift toward distributed electricity generation. Atmos. Environ., 40, 7164-7177.
4. Venkatram, A., Pournazeri, S., Princevac, M., Pankratz, D., Jing, Q. (2010) Dispersion of Buoyant Emissions from Low Level Sources in Urban Areas , ITM – NATO/SPS International Technical Meeting on Air Pollution Modeling and its Application , Turin , Italy , September 2010

Background image : http://www.nasa.gov/connect/chat/bad_ozone_chat.html