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# Source characterization refinements for routine modeling applications

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## HIGHLIGHTS

- Dispersion modeling source characterizations for unique facilities are described.
- Highly industrialized areas causing a heat island effect can be modeled as urban.
- Stacks with waste heat countering downwash can apply weighting to these effects.
- Extra rise for moist plumes is realistically estimated for use in “dry” models.
- Stacks in a row with merged plumes can be better represented to improve modeling.

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## ABSTRACT

Steady-state dispersion models recommended by various environmental agencies worldwide have generally been evaluated with traditional stack release databases, including tracer studies. The sources associated with these field data are generally those with isolated stacks or release points under relatively ideal conditions. Many modeling applications, however, involve sources that act to modify the local dispersion environment as well as the conditions associated with plume buoyancy and final plume rise. The source characterizations affecting plume rise that are introduced and discussed in this paper include: 1) sources with large fugitive heat releases that result in a local urbanized effect, 2) stacks on or near individual buildings with large fugitive heat releases that tend to result in buoyant “liftoff” effects counteracting aerodynamic downwash effects, 3) stacks with considerable moisture content, which leads to additional heat of condensation during plume rise – an effect that is not considered by most dispersion models, and 4) stacks in a line that result in at least partial plume merging and buoyancy enhancement under certain conditions. One or more of these effects are appropriate for a given modeling application. We present examples of specific applications for one or more of these procedures in the paper.

This paper describes methods to introduce the four source characterization approaches to more accurately simulate plume rise to a variety of dispersion models. The authors have focused upon applying these methods to the AERMOD modeling system, which is the United States Environmental Protection Agency's preferred model in addition to being used internationally, but the techniques are applicable to dispersion models worldwide. While the methods could be installed directly into specific models such as AERMOD, the advantage of implementing them outside the model is to allow them to be applicable to numerous models immediately and also to allow them to remain applicable when the dispersion models themselves are updated. Available evaluation experiences with these techniques, which are discussed in the paper, indicate improved model performance in a variety of application settings.



## 1. Introduction

The AERMOD dispersion model (Cimorelli et al., 2005), recommended by United States Environmental Protection Agency (USEPA) for general short-range modeling applications out to a distance of 50 km, is widely used in air quality permit and compliance applications on an international scale (EPA Victoria, 2015). This model has been tested and evaluated against a number of traditional stack release databases (USEPA, 2003). However, aside from traditional building downwash situations, model evaluations for AERMOD and models used in other countries generally

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**Abbreviations**

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| ADMS | Atmospheric Dispersion Modelling System, an air quality dispersion model used for industrial emissions developed by Cambridge Environmental Research Consultants |
| AERMOD | A short range, steady-state air quality dispersion modeling system developed by the American Meteorological Society/U.S. Environmental Protection Agency Regulatory Model Improvement Committee (AERMIC) |
| ASTER | Advanced Spaceborne Thermal Emission and Reflection Radiometer, an instrument aboard the polar orbiting satellite called Terra |
| CALPUFF | A non-steady state air quality dispersion modeling system used for long range transport maintained and distributed by Exponent |
| HIA | Highly Industrialized Areas |
| OML | Short range air quality dispersion model that incorporates low wind effects related to aerodynamic downwash |
| PRIME | Plume Rise Model Enhancements, a building downwash algorithm used in the AERMOD model |
| SCICHEM | SCIPUFF air quality dispersion modeling system that includes chemistry |
| SCIPUFF | Second-order Closure Integrated Puff, an air quality dispersion modeling system maintained and distributed by Sage Management |
| $SO_2$ | Sulfur Dioxide |
| TAPM | The Air Pollution Model, a photochemical grid modeling system |
| USEPA | U.S. Environmental Protection Agency |

do not include scenarios in which the emission source itself substantially alters the dispersion environment. Because model performance can be an even greater challenge for some nontraditional emission sources, accurate representation of the source and its surrounding environment that influence plume rise is important.

To address this general issue, we have implemented and tested four different source characterization procedures with AERMOD, which could also be implemented in other models. All of these approaches affect buoyant plume rise, and in the case of the urban approach for highly industrialized areas, also affects plume dispersion. These approaches are different than other dispersion modeling refinements that might affect chemical transformation of released pollutants (such as NOx) because they generally do not change meteorological processing or dispersion (except for the urban approach). These effects are also independent of (and do not duplicate or replace) the low wind AERMOD enhancements described by USEPA (2012). While AERMOD itself could be modified to incorporate these changes, applying the source characterizations outside the model is beneficial because the procedures can be applicable to other dispersion models and would be more readily available for implementation. Any model changes to AERMOD would likely take several years for formal incorporation into the USEPA regulatory version. Therefore, as designed, each of the advanced plume rise techniques can be performed now using processors outside of AERMOD. In countries where other models are recommended, the methods described in this paper can be considered for those models as well. Other models for which these approaches could be used include, among others, CALPUFF (Scire et al., 2000), The Air Pollution Model (TAPM) (Hurley, 2008), Atmospheric Dispersion Modelling System (ADMS) (CERC, 2015), SCIPUFF (Sykes et al., 1999), and OML (Olesen et al., 2007).

The first source characterization method addresses sources with large "fugitive" heat releases that result in a local urban-like dispersion environment. As used in this paper, "fugitive" refers to sources of heat that are not specifically considered as input to the dispersion model. While the stack exhaust temperature and velocity are considered for plume rise calculations, the heat releases of unrelated processes in large industrial complexes are generally ignored, although they affect the dispersion environment, as noted below. AERMOD estimates urban heat island effects using an urban/rural classification based on population or land use (USEPA, 2004a), but it does not consider the effects created by large industrial complexes located in remote, rural areas. The "highly industrialized area" (HIA) effect can be addressed by a technique that accounts for the heat from an industrial complex and derives an effective urban population equivalent to the scale of the HIA as input to AERMOD, which would model the source as urban.

A second source characterization issue unaccounted for within AERMOD is similarly related to fugitive heat releases on or near individual buildings that affect plume rise from nearby stacks. These unaccounted-for heat releases generally occur on a horizontal scale well below a kilometer and affect stack plume rise in the vicinity of individual buildings. While the areal extent of the fugitive heat releases may be too small to qualify as an urban-like HIA, they can exhibit a tendency to cause buoyant effects that counteract localized aerodynamic downwash effects that would otherwise result in plumes being caught in downdrafts behind buildings. Building aerodynamic effects are handled within AERMOD by the Plume Rise Model Enhancements (PRIME) (Schulman et al., 2000) model, which was developed with limited evaluation in low winds or with buildings associated with fugitive heat releases. To account for downwash effects for cases with fugitive heat releases from buildings, a procedure called "LIFTOFF" is described, along with a model-to-monitor field study evaluation demonstrating improved prediction of receptor impacts.

Thirdly, stacks with substantially moist plumes can lead to latent heat release of condensation after the plume exits the stack, providing additional plume rise relative to a "dry" plume scenario. Although some of the initial added buoyancy is later lost due to partial evaporation, a net gain in plume rise occurs. AERMOD (and many other steady-state plume models) have plume rise formulations that are based on the assumption of a dry plume, in that the chimney plume is considered to be far from being saturated and carries essentially no moisture. A procedure to incorporate the moist plume effect by adjusting the input exit temperature data can be performed prior to an AERMOD model analysis using a pre-processor called "AERMOIST." This pre-processor makes use of a European validated plume rise model called "IBJpluris" that already incorporates moist plume effects and has been found to accurately predict the final rise of a moist plume (Janicke and Janicke, 2001; Janicke Consulting, 2015). The adjustments to plume rise using IBJpluris with and without moist plume effects can be transferred to AERMOD (or other models, as appropriate) by adjusting the input stack temperature of each affected source on an hourly basis, as a function of ambient temperature and relative humidity.

Finally, multiple stacks in a line can result in plume merging and buoyancy enhancement under certain conditions. The tendency of adjacent stack plumes to at least partially merge is a function of several factors which include the separation between the stacks, the angle of the wind relative to the stack alignment, and the plume rise for individual stack plumes (associated with individual stack buoyancy flux and meteorological variables such as stack-top wind