Incorporation and Evaluation of the RLINE Source Type in AERMOD For Mobile Source Applications

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U.S. Environmental Protection Agency
Office of Air Quality Planning and Standards
Air Quality Assessment Division
Research Triangle Park, NC

Preface

This document provides details for the reformulation of the RLINE Source Type for AERMOD version 23132 as part of the 2023 revisions to the *Guideline on Air Quality Models*. This reformulation process was needed based on user feedback through the BETA release and testing period after the AERMOD v19191 release. The goals of the reformulation were to "harmonize" multiple aspects of the dispersion calculations performed for the RLINE source type with calculations performed for the other AERMOD source types, such as AREA and VOLUME. Once this harmonization was complete, the model was reevaluated with the original evaluation databases, and it was determined that the parameterization for the horizontal and lateral spread coefficients would need to be adjusted to maintain model performance. This document describes the methods and results from this reformulation process.

Acknowledgments

The model code changes and analyses for this document were performed by WSP Environment & Infrastructure, Inc under contract number GS-00F-314CA 68HERH20F0394. EPA thanks the efforts of Michelle Snyder, Laura Kent, and Rebecca Miller for this project. EPA also acknowledges the contributions of The Federal Highway Administration through an Interagency Agreement (Agreement number 693JJ320N300057) to complete the RLINE reformulation in AERMOD. The Office of Air Quality Planning & Standards also thanks David Heist and R. Chris Owen of EPA's Office of Research and Development and Laura Berry of EPA's Office of Transportation & Air Quality for their efforts in updating RLINE.

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1.0 Introduction

The R-LINE model was originally developed by the US EPA's Office of Research and Development as a stand-alone model dubbed the "Research Line Model", or R-LINE model. R-LINE is based on a numerical integration scheme that approximates the line source as a series of point sources with the model formulation described by Snyder et al., (2013). The original formulation generally placed an emphasis on concentrations closest to the line source since this is where maximum impacts are expected from roadway emissions. The near-surface dispersion algorithms are based on new formulations of horizontal and vertical dispersion within the atmospheric surface layer, details of which are described by Venkatram et al., (2013). The dispersion curves for the POINT, VOLUME, and AREA source types in AERMOD are based on the Prairie Grass study (Barad, 1958). The new dispersion curves in R-LINE were based on a reevaluation of the Prairie Grass study, as well as new tracer dataset from Idaho Falls (Finn et al., 2010), with the new formulation based on eddy diffusivity and mass conservation. The model performance was evaluated by Heist (2013) which compared the performance for the new R-LINE model against the AREA and VOLUME source types in AERMOD, the ADMS model, and the CALINE3 & 4 models.

Based on the good performance of the R-LINE model, the EPA incorporated the R-LINE model as a new source type in AERMOD in 2019. The new "RLINE" source type was directly integrated into AERMOD version 19191 with no changes from the released version 1.2 of R-LINE. The source was designated as a one of the first "BETA" options in AERMOD, meaning that it had sufficient testing, documentation, and evaluations to potentially be used in a regulatory context, with approval from the EPA Regional Office and in concurrence with the EPA's Model Clearinghouse.

Since its release in 2019, significant testing has been conducted by the user community as well as within EPA. Through this testing in the BETA phase of the release, several areas for model improvement were identified. First, it was noted that several aspects of the RLINE formulation were not well matched with the formulation of other AERMOD source types (e.g., the weighting factor for plume meander differed slightly between RLINE and the POINT and VOLUME sources). Second, testing with real-world scenarios, where source-receptor distances are much greater than in the field studies used to develop and evaluate RLINE, it was noted that RLINE concentrations deviated significantly from concentrations from the VOLUME and AREA sources. The harmonization of the RLINE source with the existing AERMOD source types results in changes in the dispersion calculations that have implications for the original model formulation and evaluations. As a result, the EPA reexamined the dispersion curves originally formulated by Venkatram et al., (2013), to refit the dispersion parameters determined previously to the developmental field data, as well as improve the model-to-model based performance from the real-world scenarios. This document provides details of the updated formulation, the methodology for optimizing the dispersion coefficients, evaluation of the updated RLINE against tracer field study data, and a model intercomparison for two real-world cases.

2.0 Changes to the RLINE Source:

Modifications to the RLINE formulation occurred in three main areas: (1) Wind Speed calculation, (2) Harmonization with AERMOD sources, and (3) Dispersion Coefficients. The modifications were made in this order, with the wind speed and harmonization changes made first, then the reexamination of the parameters used in the vertical and lateral dispersion calculations. All these modifications were necessary to bring the RLINE source type into better agreement with other AERMOD source types and simultaneously not degrade the previous evaluation database results.

2.1 Wind speed

RLINE was developed under the assumption a vector-average wind speed would be supplied as input (i.e., a wind speed derived from time-averaged components of the wind speed vector) to the model. The supplied wind speed was converted to a scalar-averaged value using an approximate relationship (Merceret, 1995), and the resulting wind speed was used in dispersion calculations within the model. When RLINE was integrated into the AERMOD model as a new source type wind speeds did not need to be converted because winds in the available AERMET surface files were scalar-averaged wind speeds (i.e., speeds computed by time-averaging instantaneous wind speeds over time). To correct this issue, parts of the RLINE code where wind speeds had been enhanced with the following equation:

$$WS_{scalar} = \sqrt{WS_{vector}^2 + 2\sigma_v^2}$$

were removed, where WS_{scalar} is the scalar-averaged wind speed, WS_{vector} is the vector-averaged wind speed, and σ_v is the root-mean-square of the lateral velocity fluctuations.

RLINE selects the advecting wind speed (WS_{MOST}) in the dispersion calculation from a profile generated using Monin-Obhukov Similarity Theory (MOST). The profile is adjusted using a multiplicative factor, $f_{ws,adj}$, to ensure it passes through the measured wind speed at the reference height. Thus, $f_{ws,adj} = WS_{scalar}(z_{ref})/WS_{MOST}(z_{ref})$. In addition, there is a minimum wind speed enforced in the RLINE calculations such that $WS_{MOST} > WS_{min}$. However, in previous versions of AERMOD, the value of WS_{MOST} could fall below WS_{min} for cases when $f_{ws,adj} < 1$, because of the sequencing of applying $f_{ws,adj}$ and the minimum wind speed criteria. This sequencing has been corrected in version 23132 to ensure $WS_{MOST} > WS_{min}$, even for cases where $f_{ws,adj} < 1$.

2.2 Harmonization with Other AERMOD Sources

To better integrate the RLINE source type within the AERMOD framework, several changes were made to call native AERMOD functions, when possible, to calculate required parameters. To that end, RLINE now uses the gridded value of σ_v used by other source types in AERMOD, rather than calculating it in RLINE's own subroutines. Though the calculation is the same, any future changes to these calculations will be applied to all source types uniformly. Additionally, the RLINE source type now uses native AERMOD functions to calculate the fraction of the plume attributable to meander. This change introduces a gradual change in this fraction with increasing distance from the source, but matches the value originally used in RLINE for near-source calculations. The final change in this category involves the calculation of the vertical plume width, σ_z. The growth of σ_z had been limited to $\sqrt{2/\pi}\, z_i$, where z_i is the mixing height. In version 23132, this restriction has been removed, and instead, RLINE uses native AERMOD subroutines to account for reflections of the plume from the ground and the top of the mixed layer.

2.3 Re-evaluation of Dispersion Coefficients Using Optimization Techniques

As a result of the changes discussed above, particularly the changes in the wind speeds, it was necessary to re-evaluate the coefficients in the expressions for vertical and horizontal plume growth, σ_y and σ_z, respectively.

$$\sigma_y = c\frac{\sigma_v}{u_*}\sigma_z\left(1 + d_s\frac{\sigma_z}{L}\right) \qquad L > 0.0$$

$$\sigma_y = c\frac{\sigma_v}{u_*}\sigma_z\left(1 + d_u\frac{\sigma_z}{|L|}\right)^{-1/2} \qquad L < 0.0$$

$$\sigma_z = a\frac{u_*}{U_{eff}}x\left(1 + b_s\frac{u_*}{U_{eff}}\left(\frac{x}{|L|}\right)^{2/3}\right)^{-1} \qquad L > 0.0$$

$$\sigma_z = a\frac{u_*}{U_{eff}}x\left(1 + b_u\frac{u_*}{U_{eff}}\frac{x}{|L|}\right) \qquad L < 0.0$$

Since the lateral spread is dependent on the vertical spread, the optimization of the a, b_s, b_u, c, d_s, and d_u coefficients occurred together. The optimization process that was used involved previous databases, including Idaho Falls and Prairie Grass, and intelligently and iteratively solved for the coefficients in the vertical and lateral spread. The optimal coefficients were found using the R genetic algorithm "GA" package (https://cran.r-project.org/web/packages/GA/GA.pdf). This algorithm uses an intelligent method to reduce the solution space of a multivariate set of equations to optimize a metric, analogous to a best fit line optimizing coefficients to reduce residuals, usually reported as an R-squared value.

The Idaho Falls database is lateral spread, sigma-y, independent; the dispersion of a line source is only dependent on the downwind distance and the equation for vertical spread, sigma-z, given an "infinite" line source. Thus, the Idaho Falls data was crosswind integrated to obtain downwind concentrations as a function of downwind distance, as was done in Snyder et al., (2013).

The Prairie Grass database was used to determine the coefficients for the lateral dispersion. A Gaussian fit was used to determine the lateral spread based in the measured concentrations from each arc at each downwind distance. Then, the lateral dispersion constants c, d_s, and d_u coefficients were then determined to provide the best fit.

Again, the evaluation of RLINE was performed iteratively to optimize the fit to both the Idaho Falls and Prairie Grass data while restricting the dispersion equations to their current form. Multiple "best-fit" metrics were explored including R-squared, NMSE, and standard error. Ultimately, the R-squared statistics were used to optimize the fit for the lateral and vertical spread for both Prairie Grass and Idaho Falls, as shown in the Figures below. A Genetic Algorithm was used to optimize the combination of the six coefficients within the specified ranges given in Table 1 below. The intent was to obtain convergence on the "optimum value", however from the Figures below the model performance is not extremely sensitive to all the coefficients. In particular, the model evaluations show better model performance for smaller ranges of a, b_s, b_u, d_s, and d_u. However, there is little model sensitivity to the c-coefficient. Although, there are smaller ranges for five of the six coefficients there is not a single value which stands out as "the" value. Thus, selection of values within these smaller ranges were made to optimize the RLINE model performance for these datasets.

Table 1: Comparison of RLINE σ_y and σ_z coefficient values and ranges tested.

Coefficient	Original Value (Venkatram et al., (2013))	Range Tested	New Value
a	0.57	0.4 – 1.0	0.7
b_s	3.0	0.5 – 4.0	1.5
b_u	1.5	0.5 – 2.0	1.0
c	1.6	1.0 – 5.0	1.4
d_s	2.5	-2.5 – 2.5	1.5
d_u	1.0	2.0 – 3.5	2.5

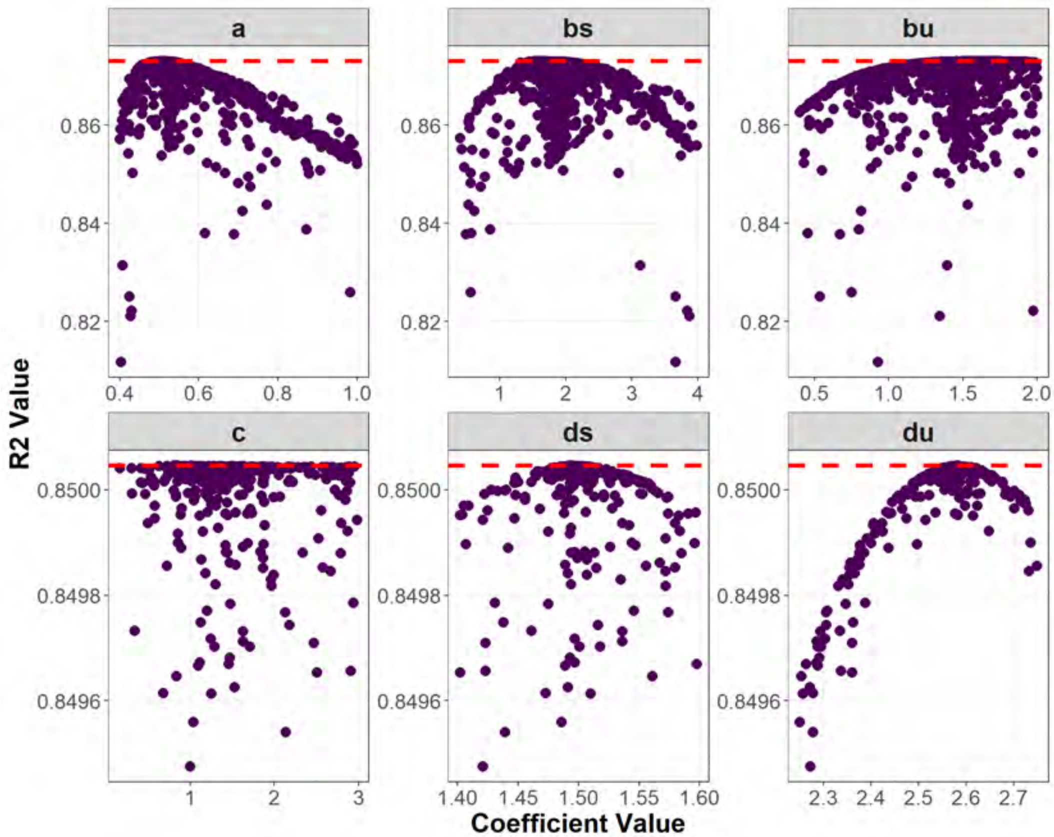

Figure 1: The 6-panel figure shows an example of the R-squared value for multiple combinations of the a, b_s, b_u, c, d_s, and d_u coefficients. Where the "best-fit" R-squared value is shown as a red dashed line in all panels.

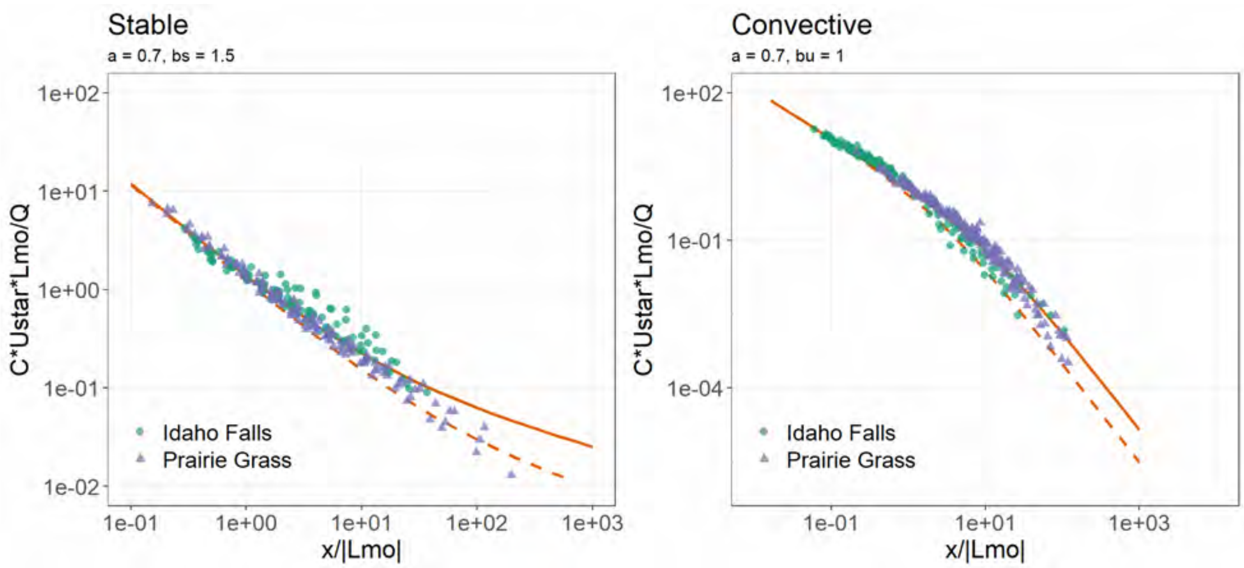

Figure 2: Idaho Falls 2009 (circles) and Prairie Grass (triangles) normalized concentration vs. x/|L|. The solid and dashed lines represent the new σ_z equations for stable and convective conditions for a range of u*/Ue values which are representative of the u*/Ue values for the Idaho Falls and Prairie Grass field studies.

3.0 Evaluation

After the RLINE calculations were modified to address the wind speed calculation, harmonization with other AERMOD sources, and optimization of the vertical and lateral dispersion coefficients, the model was evaluated against multiple datasets. These datasets included previous datasets which were used in the initial evaluation of RLINE (Venkatram et al., 2013) and Snyder et al., 2013), new datasets that have been explored since the 2013 publications, and complex hotspot analysis projects as a collaboration between EPA and FHWA.

3.1 Previous Field Study Evaluations with Idaho Falls & Caltrans 99 Tracer Experiments

As part of the original development of RLINE (Heist et al., 2013), the model was evaluated against two tracer data sets for line sources, including the 2008 Idaho Falls roadway study (Finn et al., 2010), which consists of 4 days of sampling at a wide array of receptors and the Caltrans 99 highway study (Benson, 1989), which consists of 14 days of sampling at 10 receptors. The performance of the reformulated RLINE source type within AERMOD has been assessed against these tracer studies again, and the results are presented below. Brief summaries of the studies provide details on each of these studies.

3.1.1 Idaho Falls Roadway Study

> A tracer study of dispersion from a near ground-level line source was carried out in 2008 near Idaho Falls, ID, on an open field test site designed for transport and dispersion tracer studies (Finn et al., 2010). In this study, two parallel sites were set up, one with a noise barrier and one without. Tracer releases were performed simultaneously at both sites. In each case, sulfur hexafluoride (SF6) was released uniformly along a 54 m long source, positioned 1 m above ground level, beginning 15 minutes before the first sampling period and continuing through a 3 h experiment consisting of 12 consecutive 15-minute sampling periods. Background levels of SF_6 at the study site were measured to be between 6 and 8 pptv, whereas measurements in the center of the grid were the order of thousands or tens of thousands of pptv. Only data from the non-barrier site were used in the results of the model inter-comparison presented in this document. Experimental data are available from four separate days, capturing a wide range of atmospheric stabilities and wind speeds… (excerpted from Heist et al., 2013).

Samplers were arrayed downwind of the site in a grid that extended from 18 m to 180 m downwind of the source and extending from 108 m in each direction along the source from its center (Figure 3). Sampling occurred on four tests days which were characterized as 1) near-neutral, 2) convective, 3) weakly stable, and 4) moderate to strongly stable.

Figure 4 shows model results (using the RLINE source type) plotted against measured concentrations for the four test days of the Idaho Falls Roadway Study for AERMOD version 22112 and 23132. Despite the changes described above in 23132, there are only small changes in model performance observed for the Idaho Falls study, especially for the neutral and convective test days. For the weakly stable day, the highest concentrations remain relatively unchanged though agreement between measured and modeled concentrations is reduced somewhat for lower concentrations; however, they remain within a factor two of each other. For the strongly stable test day, the highest overpredictions by version 22112 have been reduced by version 23132, and now lie below the factor of two line to a greater degree.

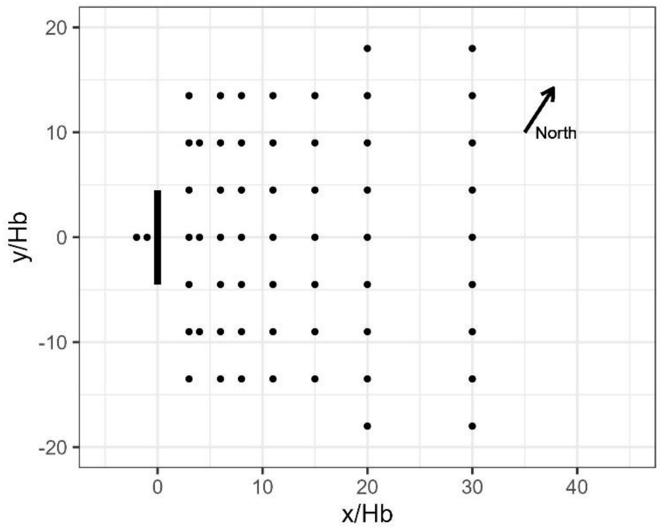

Figure 3: Idaho Falls Study layout. Source is indicated with vertical line along x/Hb = 0 (from y/Hb = -4.5 to 4.5). Filled circles show the locations of bag samplers. North is indicated by the direction of arrow.

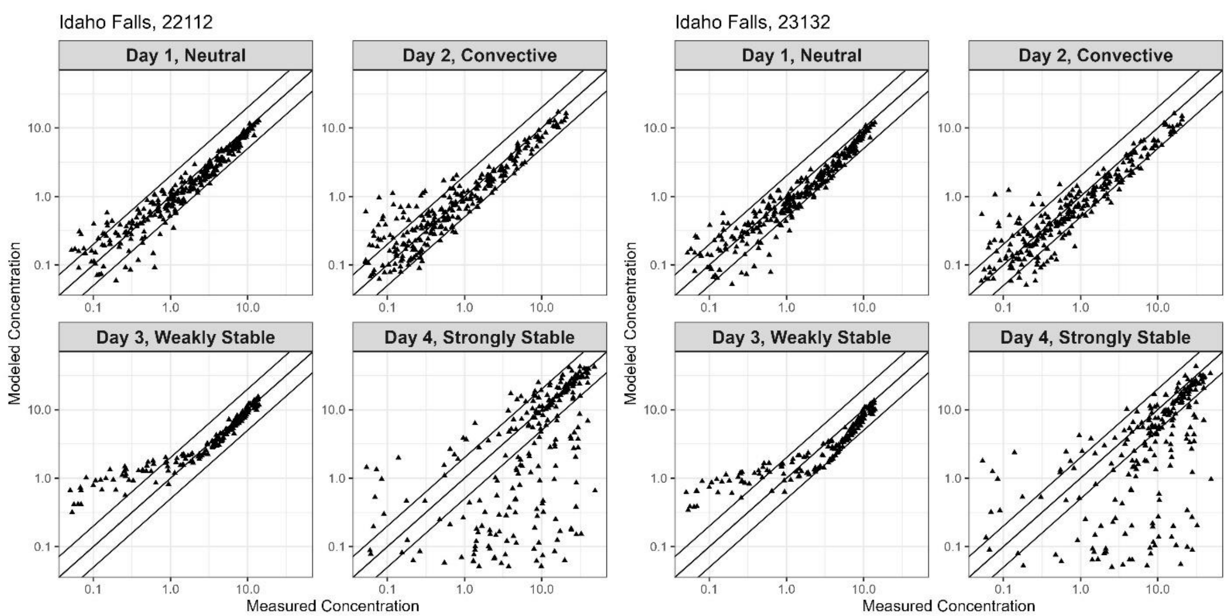

Figure 4: Modeled vs measured SF6 concentration (in ppb) using the RLINE source type for all test days at Idaho Falls. AERMOD ver. 22112 (left four plots) and ver. 23132 (right four plots).

Each symbol represents a 15 min. average. The three lines in each plot are the 1:2, 1:1, and 2:1 lines.

3.1.2 Caltrans 99 Highway Study

A tracer study was performed in the early 1980s using SF_6 released from the tailpipes of eight specially modified automobiles traveling with traffic on Highway 99 outside Sacramento (Benson, 1989). The study was conducted along a straight segment of the highway aligned from northwest to southeast consisting of four lanes and a 14 m wide median. The highway carried approximately 35,000 vehicles daily. The surrounding terrain was generally flat, and nearby land use consisted of open park land, fields, and scattered residential developments. Eight automobiles releasing the tracer circulated up and down a 4 km segment of the highway beginning one hour before sampling started. Half of the modified vehicles were driven in the right-hand lane and the other half in the left-hand lane to distribute emissions evenly across the lanes of the highway. SF_6 monitors were arrayed on both sides of the road (spaced at 50, 100 and 200 m from the center of the road) and at four locations along the median (spaced approximately 800 m apart) (Figure 5). Samplers were positioned 1 m above ground level. Samples were collected in Tedlar bags for four consecutive 30-minute periods and analyzed using gas chromatography. Two cup and vane anemometers were installed on a 12 m meteorological tower near the sampling array at heights of approximately 6.5 m and 11.4 m. (excerpted from Heist et al., 2013)

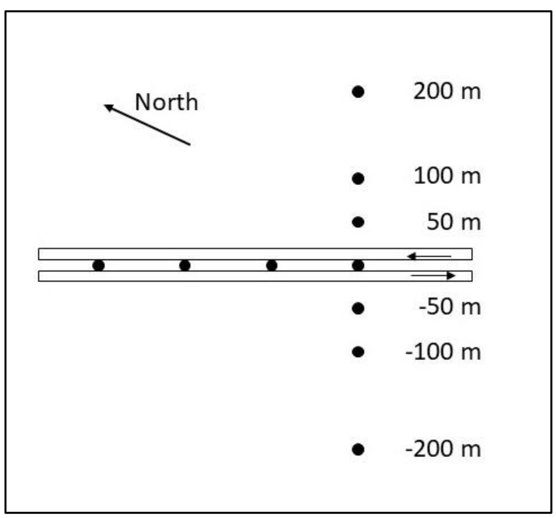

Figure 5: Caltrans 99 Highway Study layout. Tracer was released along the roadway with samplers arrayed on either side extending from 50 m to 200 m with four additional samplers in the median of the roadway.

Figure 6 shows model results (using the RLINE source type) plotted against measured concentrations for the Caltrans 99 Highway Study for AERMOD versions 22112 and 23132. As with the Idaho Falls results above, the results from the Caltrans 99 study show only minor differences between these two versions of the model. The most noticeable change is the reduction in concentration for the five outlier points in the upper left part of each plot.

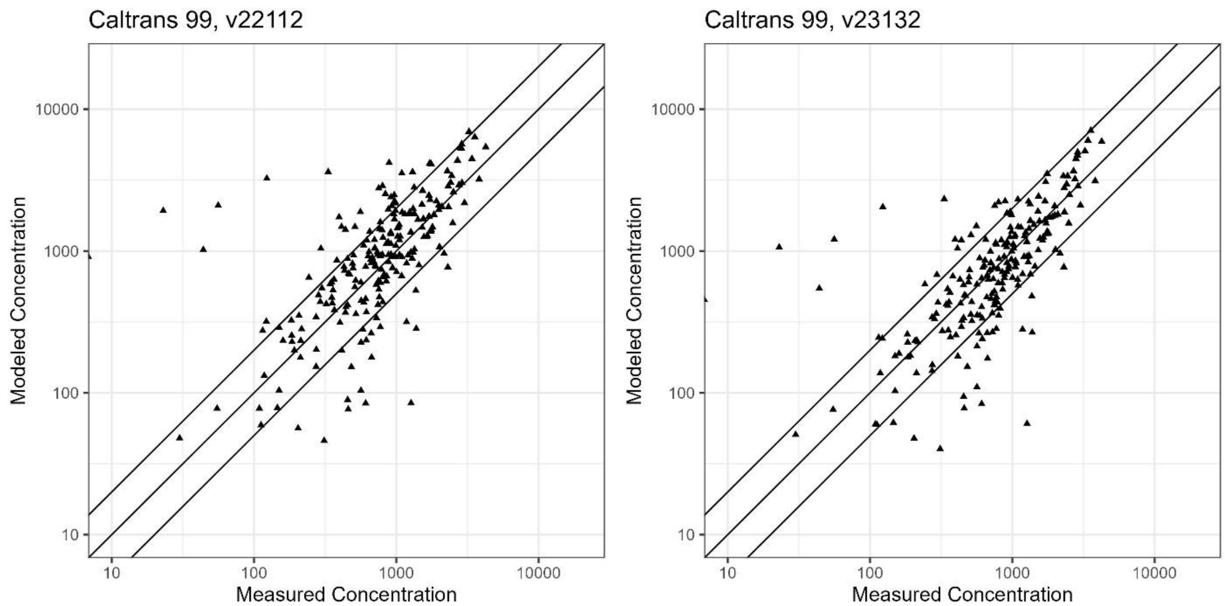

Figure 6: Modeled vs measured normalized concentrations using the RLINE source type for the Caltrans Highway 99 tracer study for receptors located downwind of the roadway. AERMOD version 22112 (left plot) and version 23132 (right plot). Each symbol represents a 30 min. average. The three lines in each plot are the 1:2, 1:1, and 2:1 lines.

3.2 New Field Study Evaluations with GM Sulfate Dispersion Experiment

The previous evaluations used datasets included in the initial RLINE evaluations (Snyder et al., 2013 and Heist et al., 2013). Two additional datasets were included in the evaluation of the new RLINE formulation, both of which included tracer studies on roadways with measurements are multiple distances form the roadway.

3.2.1 GM Sulfate Dispersion Experiment

The General Motors (GM) Sulfate Dispersion Experiment, conducted from late September through October of 1975, measured vehicle emissions of sulfate in a near-road environment. During the study, a tracer gas (SF6) was released from trucks evenly dispersed throughout the 352-vehicle fleet, which were organized into 11 packs of vehicles. On-site meteorology and tracer gas concentrations were measured throughout the study period. Data are available for 17 days between 29 September 1976 and 30 October 1976, with about 4 samples per day between 8AM and 10AM. The study was designed to be conducted under ‘worst-case’ meteorological conditions, as such, experiment days were selected to have westerly winds with low wind speeds (Cadle et al., 1976).

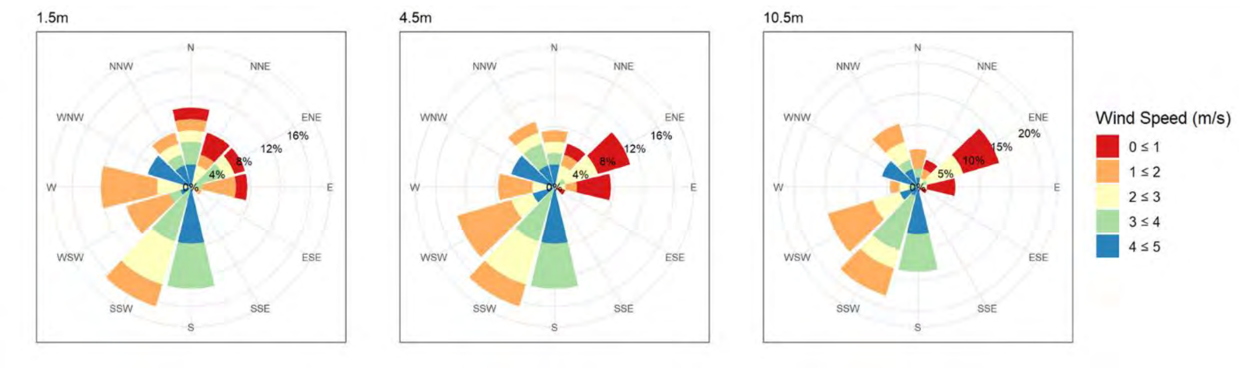

Figure 7 Onsite wind speed (color) and direction by height (panels) for the average of measurement towers 1, 5, and 6.

3.2.1.1 <u>Location Description</u>

The GM Sulfate Dispersion Experiment study site is in Milford, Michigan on the GM Proving Ground (Figure 8). The GM Proving Ground is located 30 km north of Ann Arbor and 50 km northwest of Detroit in southeastern Michigan. The nearest major highways are I-96 (7 km to the south) and M-23 (6 km to the west). The GM Proving Ground (Figure 8) consists of 140-miles of roadway distributed among numerous tracks, road courses, and highways. Specifically, the 10 km North-South Straightaway was chosen for this study since the track would allow high density traffic to achieve high speeds. The North-South straightaway is located on the western edge of the Proving Grounds shown in Figure 8 by the green and purple line. The measurement (receptor) locations are identified by purple triangles.

On the North-South straightaway, the track consists of three 5 km long lanes in either direction, but the turns, at either end of the straightaway, only allow for two lanes in each direction. Therefore, this study only uses two lanes in each direction (Cadle et al., 1976).

Sampling towers were positioned on either side of the roadway at varying distances in the middle of the straightaway section of track, as shown in Figure 9. Tower locations were purposeful to limit the influence of surrounding trees and small hills on pollutant dispersion (Cadle et al., 1976).

Figure 8 General Motors Proving Ground in Milford, MI.

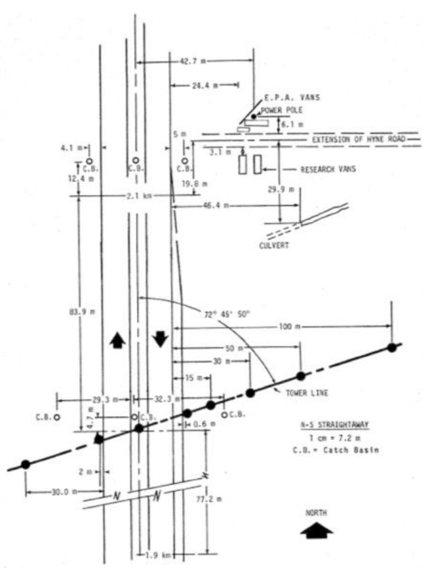

Figure 9: Survey of Sampling Area (reprint Cadle et al. 1976 Figure 4).

3.2.1.2 Source Characterization

SF6 was released from the exhaust pipe of 8 trucks, evenly spaced between the 32 packs of cars, split between the two lanes. Each pack contained 11 cars. SF6 emission rates were measured for each truck for each day of the experiment (Cadle et al., 1976).

Two roadway (RLINE) sources are used to characterize each of the north and southbound straightaways, representing two lanes in each direction, for a total of four sources. Each lane was defined with a length of 4,000 meters, reflecting the nearly due north/south orientation of the sources excluding the banked turns. Each source has a width of 3.3 meters. The release height and initial vertical dispersion parameters are set at 1.5m, based on the truck's emission release height.

3.2.1.3 Receptors

Sampling was conducted at eight tower locations shown as the black dots on the dashed line in Figure 9, hereon referenced as towers 1 through 8, numbered from west to east. Towers 1 through 6 contained three sampling heights which are 0.5 m, 3.5 m, and 9.5 m above ground, and towers 7 and 8 contained one sampling height at 0.5 m above ground. Sampling points were aligned along a 45° angle across the roadway to provide the least possible interference from the small surrounding hills. More sampling location were placed on the west side of the track since this was anticipated to be downwind. Figures 8 and 9 illustrate tower locations. Note, in the modeling files, the sampling height is represented as a flagpole receptor specified at the sampling height which is the height above the terrain at which the sample is collected. Model receptors are located at the eight sampling towers with the respective sampling heights.

3.2.1.4 Meteorology

Site-specific meteorology was collected during the study period; however, this data only consisted of wind speed, wind direction, and ambient temperature. Wind speed and wind direction were measured at 1.5, 4.5, and 10.5 meters above ground at towers 1 through 6. Towers 7 and 8 only measured wind speed and direction at 1.5m. Temperature was measured at towers 1 and 6 at 1.5 meters. Note, SF6 measurement heights vary by 1 meter compared with meteorological measurement heights at the same tower location.

The Bishop International Airport (KFNT; Weather Bureau Army Navy (WBAN) Station 14826) was identified as the nearest permanent meteorological site and provided secondary surface and upper air meteorological measurements throughout the study period, though on-site data was available during all measurement periods. KFNT airport meteorological station is located at 42.967°N and 83.750°W, approximately 26.4 miles north of the center of the study area and has an elevation of 235 meters.

AERMOD/AERMET models typically use one-hour averaging times. The GM experiment was conducted with half hour measurements. To maintain the maximum number of datapoints, two runs were performed for each half-hour of the experiment. One run represented the meteorology specific to the first half of the hour to represent data collected in the first half hour and a second run with meteorology specific to the second half of the hour. During analysis, data was regrouped into the appropriate order to be paired with the monitor data.

3.2.1.5 AERSURFACE

AERSURFACE version 20060 was used to create reproducible albedo, Bowen ratio, and surface roughness lengths, representative of surface characteristics at the study measurement sites, for inclusion in AERMET. 2011 land cover, impervious surface percentage, and tree canopy cover percentage data were obtained from the National Land Cover Database (NLCD) Multi-Resolution Land Characteristics (MRLC) Consortium. The oldest available NLCD dataset was created in 1992, the closest date to the GM experiment study period. Post-1992 NLCD dataset land cover categories were updated from a 21- to a 16-category system which also now includes percentage area of grid cell that is impervious and percentage area of grid cell that is covered with tree canopy. More information about the surface classification categories can be found in the AERSURFACE User's Guide (EPA, 2020). Model results using the NLCD 2011 dataset were in better agreement with GM experiment observations than the NLCD 1992 dataset (not shown). For all AERSURFACE runs tower 5 was used as the center point, as this tower is located in the middle of the test section and the terrain is homogeneous.

3.2.1.6 AERMET

AERMET input files include the site-specific measured wind speed, wind direction, and ambient temperature. Since AERMET accepts only one measurement location, towers 1, 5, and 6 are averaged together at their respective heights and assigned to tower 5's location. The meteorological measurements were not found to vary greatly between these three towers (not shown). In addition, the Bishop International Airport (KFNT) surface meteorological measurements were used as the secondary data option to the on-site measurements. ISH surface data and FSL upper air data were obtained from KFNT for AERMET processing, augmenting the on-site measured data. Automated Surface Observing Systems (ASOS) 1-minute data was not available for the study period. The AERMET adjust u* (ADJ_U*) option was used to adjust the surface friction velocity (u*) under low wind speed, stable conditions. AERMOD-ready surface (.SFC) and profile (.PFL) files were generated with the most-recent version (v23132) of the AERMET meteorological data preprocessor as of July 2023.

3.2.1.7 AERMOD

AERMOD version 23132 was used for this analysis. The GM Proving Ground is located outside of Milford, MI, which had a population of 6,175 in April 2010 (https://www.census.gov/quickfacts/fact/table/milfordvillagemichigan/PST045222). The study site is located 30 km north of Ann Arbor and 50 km northwest of Detroit in southeastern Michigan with low population density. Therefore, the URBAN model options were not used in the AERMOD runs.

Elevation decreases from approximately 685 meters, above sea level, at the southern endpoints of the roadway sources to approximately 665 meters at the northern endpoints of the roadway sources. Over the four-kilometer-long sources a change in elevation of 20 meters is a 0.5% grade. The non-default FLAT model option was applied to each of the AERMOD source types, resulting in the exclusion of source and receptor elevations in concentration calculations.

3.2.1.8 Results and Discussion

Model results are shown for each measurement height in Figure 10 colored by tower location and colored by wind speed and wind direction in Figure 11. Results suggest that the RLINE source does a reasonable job predicting concentrations. On average the model slightly underpredicts concentrations, however there are a few significant over predictions, greater that a factor of two. These overpredictions are at the 1.5 m and 4.5 m heights with wind speeds less than 1 m/s and winds out of the North to East-North-East. Thus, these could be time periods when the wind is blowing along the roadway test section, instead of across the test section. This could suggest that the RLINE model overpredicts when the winds are extremely light, and possibly in near-parallel wind conditions. Further investigation is needed.

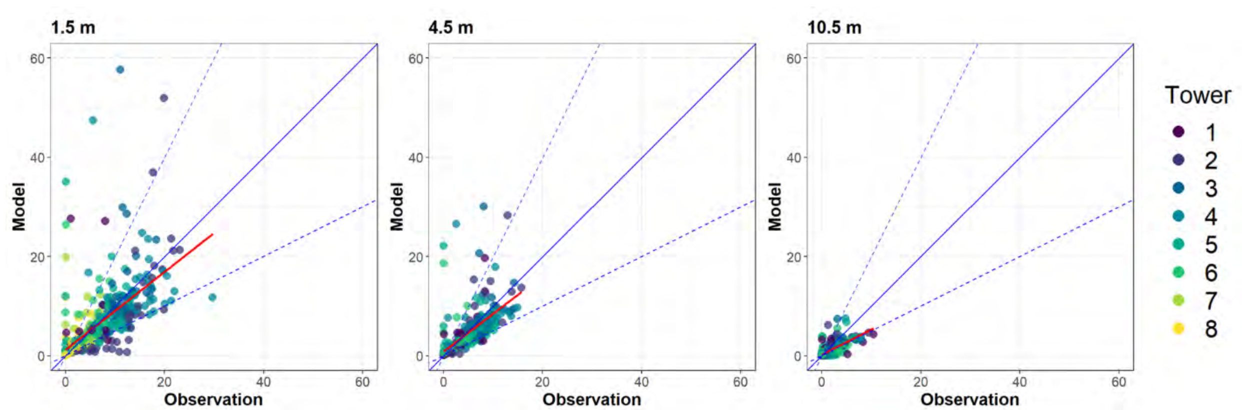

Figure 10 AERMOD v23132 run with AERMET v23132 NLCD 2011 surface characteristics compared with GM experiment observations (μg/m^3). Panels labeled by measurement height and colored by tower number.

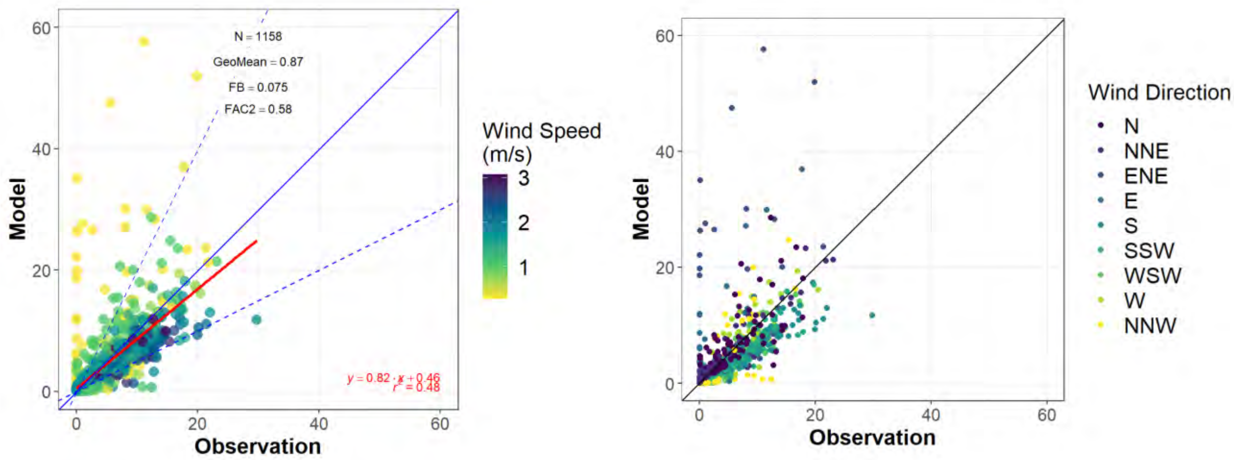

Figure 11 AERMOD v23132 run with AERMET v23132 NLCD 2011 surface characteristics compared with GM experiment observations (µg/m^3). Colored by wind speed (m/s, left) and wind direction (right).

3.3 Hotspot Analyses Model Intercomparisons

The EPA and FHWA have coordinated on model intercomparisons of the new RLINE source formulation to the existing AREA and VOLUME source formulations, as applied to real-world hot-spot evaluations. These evaluations each include a large section of a highway modification project, with an extensive receptor network to determine project design concentrations (DC). The advantage of this type of comparison is that it exercises the models in meteorological scenarios beyond what's available in the relatively short field studies, it uses multiple and complicated source configurations, and has source-receptor distances and orientations beyond what is available from the tracer datasets for mobile source emissions. The obvious disadvantage is the lack of measurement data to make comparisons against, but the AREA and VOLUME source types in AERMOD have been used since 2005 by the regulated community and have a proven performance record that can serve as a benchmark against the RLINE results.

This section presents the results from two real-world PM hot spot scenarios that are used to evaluate air quality impacts from roadway projects. The examples are referenced as Project A, which includes a $PM_{2.5}$ analysis for both the daily (98th percentile) and annual standards , and Project B , which includes a PM10 analysis for the daily standard (6th highest concentration).

3.3.1 Project A - $PM_{2.5}$ Hot-spot Analysis

Project A analyzes the intersection of two inter-state freeways, using standard receptor placement for a typical hot-spot analysis (e.g., a receptor grid around the perimeter of the project, starting at 5-m from the edge of the roadway), using 5-years of meteorology. Figure 12 and Figure 13 show the project layout, with receptors colored by the design concentration, with Figure 12 showing the results from AERMOD version 22112 and Figure 13 showing the results from AERMOD version 23132.

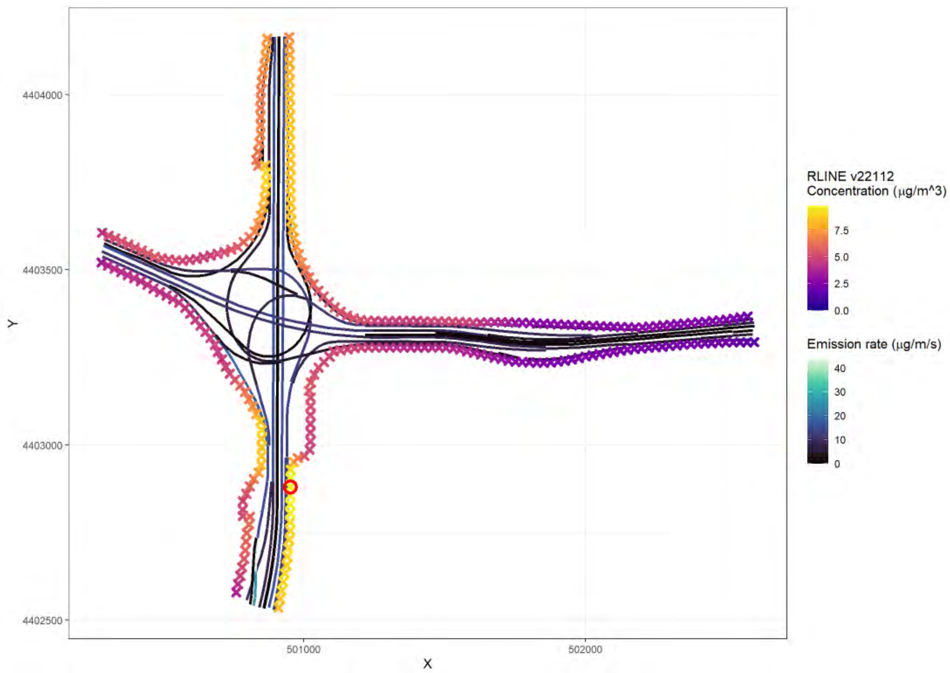

Figure 12 Project layout for Project A hot spot analysis. RLINE emission source drawn as lines with emission rate shaded (black - blue - green). Receptor locations indicated with X's and RLINE v22112 model concentrations shaded (purple - yellow). Design concentration receptor location indicated with red circle.

Figure 13 Project layout for the Project A hot spot analysis. RLINE emission source drawn as lines with emission rate shaded (black - blue - green). Receptor locations indicated with X's and RLINE v23132 model concentrations shaded (purple - yellow). Design concentration receptor location indicated with red circle.

Consistent with the approach for computing design concentrations for a PM-hot spot analysis, we compute the annual average (average of each model year, averaged across the 5 model years) and daily (98th percentile of the daily average concentrations, averaged across the 5-model years) at each receptor. The resulting design concentration is the maximum annual and 98th percentile concentration from all receptors for the project. Meteorological data was derived from a nearby airport, which was decommissioned in 1995. The meteorological data for the model runs here were the same used for the hotspot analysis conducted by the state, which was from 1990-1994, which included using the adjusted u* option in AERMET. Project design concentrations (i.e., the highest design concentration from all receptors) are summarized in Table 2, while Figure 14 - Figure 17 compare the annual and daily PM2.5 design concentrations from all receptors, comparing RLINE to the AREA and VOLUME source characterization for AERMOD versions 22112 and 23132.

Table 2 Project A design concentrations (PM2.5, $\mu g/m^3$).

<table>
<tr><th>Source Type</th><th>v22112 H8H</th><th>v23132 H8H</th><th>v22112 Annual Avg</th><th>v23132 Annual Avg</th></tr>
<tr><td>RLINE</td><td>9.78</td><td>7.40</td><td>3.72</td><td>3.20</td></tr>
<tr><td>VOLUME</td><td colspan="2">7.69</td><td colspan="2">3.30</td></tr>
<tr><td>AREA</td><td colspan="2">7.97</td><td colspan="2">2.93</td></tr>
</table>

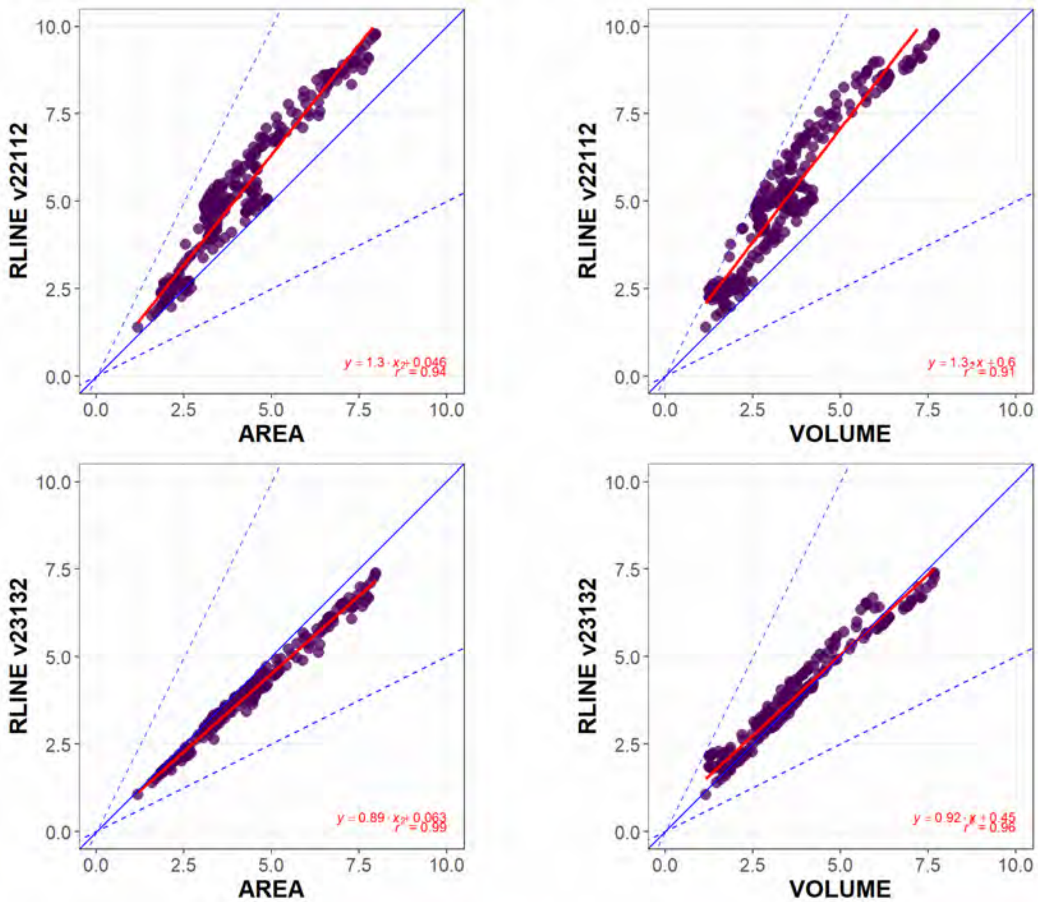

Figure 14 Comparison of RLINE 8th highest 24-hour concentrations of PM2.5 (μg/m^3) for all receptors between source type (AREA, left column and VOLUME, right column) and AERMOD version (top, v22112 and bottom, v23132). Model runs for Project A.

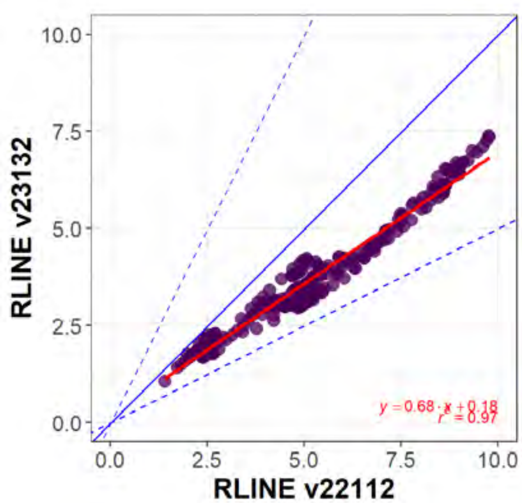

Figure 15 Comparison of RLINE 8th highest 24-hour concentrations of PM2.5 (μg/m^3) for all receptors between AERMOD versions. Model runs for Project A.

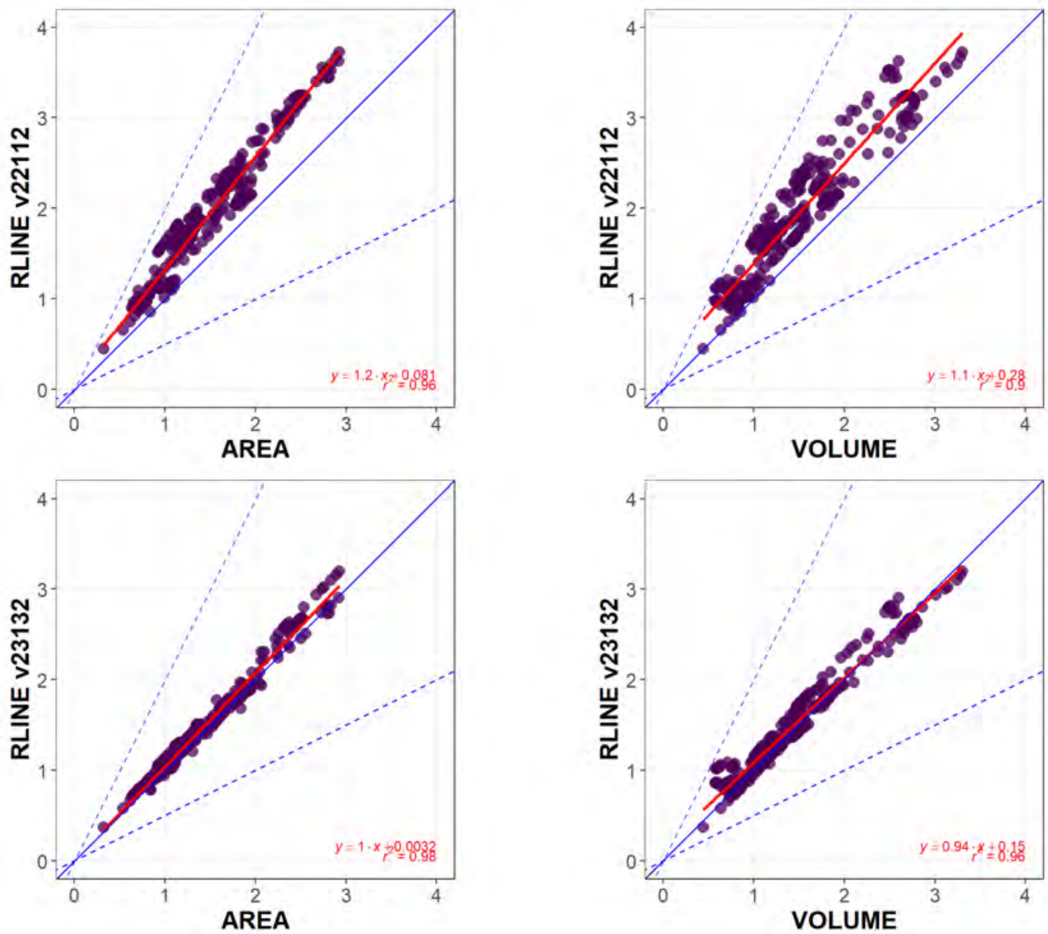

Figure 16 Comparison of RLINE 5-year annual average concentrations of PM2.5 (μg/m^3) for all receptors between source type (AREA, left column and VOLUME, right column) and AERMOD version (top, v22112 and bottom, v23132). Model runs for Project A.

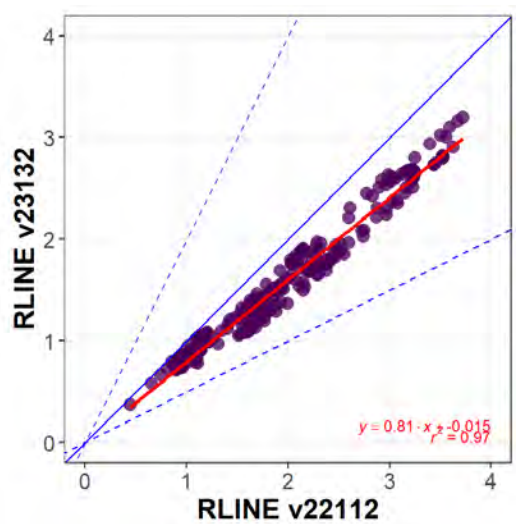

Figure 17 Comparison of RLINE 5-year annual average concentrations of PM2.5 (μg/m^3) for all receptors between AERMOD versions. Model runs for Project A.

To further investigate the design concentrations, the receptors associated with the design concentrations, for each source type, is selected. Then the dates are selected as those associated with the highest concentrations at these receptors. DV receptors and dates listed in Table 3.Hourly concentrations and select meteorological variables are then plotted for the DV dates (additional figures can be found in Appendix A).

For Project A, the design concentration (H8H) is the largest average concentration of the average of the 8th highest concentration for each year at the respective receptor. Thus, the selected design concentrations dates for Project A, are the dates associated with the design concentration receptor's highest average concentration (one date per year). Two receptors corresponding to the design concentrations are found (Table 3). RLINE v23132, AREA, and VOLUME source design concentrations occur at the same receptor, where RLINE v22112 occurs at a different receptor. The two DV receptors have the same highest average concentration dates, for each year. The comparison for the 1-hour results for these select receptors and hours of modeling for the RLINE source against the AREA and VOLUME sources for AERMOD versions 22112 and 23132 are shown in Figure 18 and Figure 19.

Table 3 Project A design concentration receptors and dates used for hourly analysis.

Source	Version	Receptor	Dates
RLINE	v23132	500952.8, 4402905.7	1990-01-15 1993-01-04 1991-02-08 1994-12-13 1992-12-17
RLINE	v22112	500952.7, 4402880.7	1990-01-15 1993-01-04 1991-02-08 1994-12-13 1992-12-17
AREA		500952.8, 4402905.7	1990-01-15 1993-01-04 1991-02-08 1994-12-13 1992-12-17
VOLUME		500952.8, 4402905.7	1990-01-15 1993-01-04 1991-02-08 1994-12-13 1992-12-17

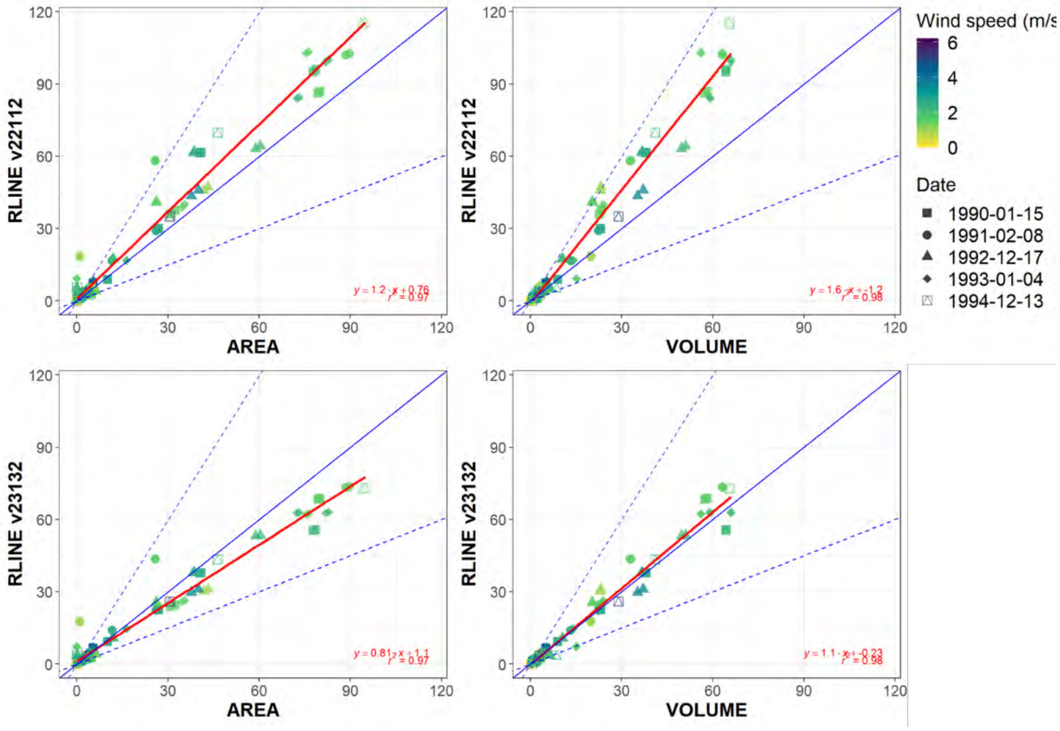

Figure 18 Comparison of RLINE hourly concentrations of PM2.5 (μg/m^3) for design concentration dates (shape) and wind speed (color) between source type (AREA, left column and VOLUME, right column) and AERMOD version (top, v22112 and bottom, v23132). Model runs for Project A.

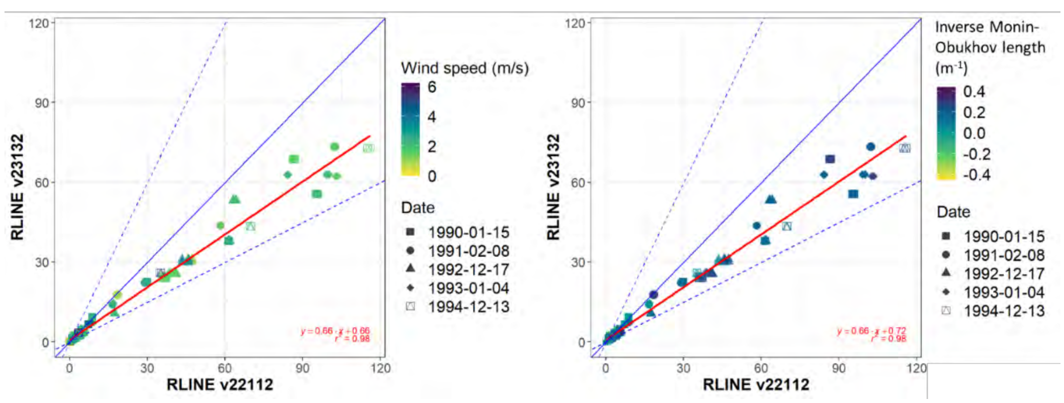

Figure 19 Comparison of RLINE hourly concentrations of PM2.5 (μg/m^3) for design concentration dates (shape), wind speed (color, left), and inverse Monin-Obukhov length (color, right) between AERMOD versions. Model runs for Project A.

3.3.2 Project B: PM_{10} Hot-spot Analysis

Project B is a 10.5-mile multi-modal corridor. The analysis here models a section an interstate freeway where a new connector to a new freeway will join the existing interstate when complete. As with Project A, we use a standard receptor placement for a typical hot-spot analysis (e.g., a receptor grid around the perimeter of the project, starting at 5-m from the edge of the roadway), using 5-years of meteorology.

Figure 20 and Figure 21 show the project layout, with receptors colored by the design concentration, with Figure 20 showing the results from AERMOD version 22112 and Figure 21 showing the results from AERMOD version 23132.

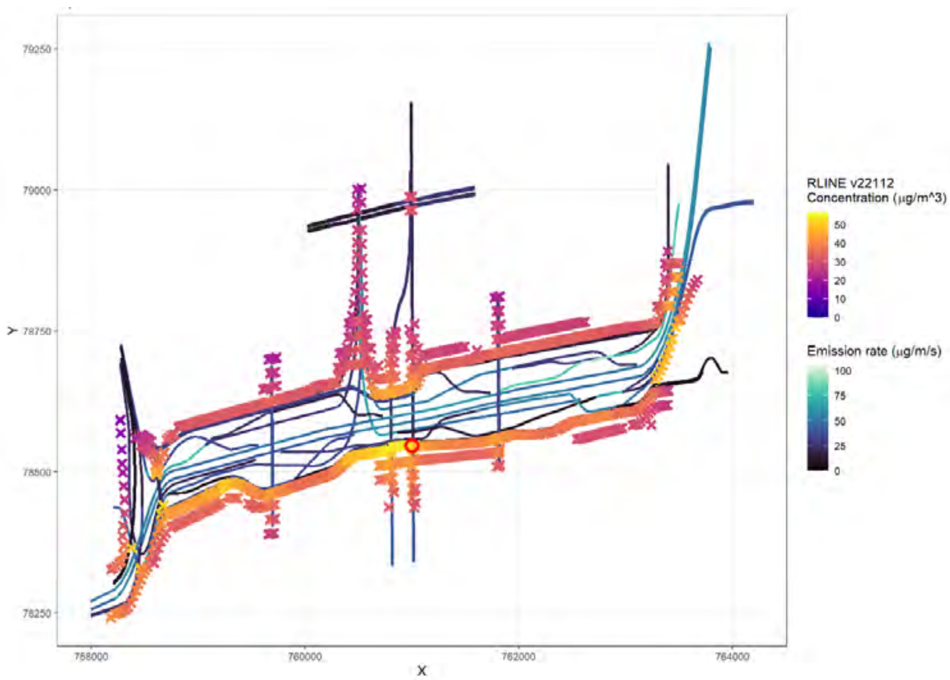

Figure 20 Project layout for the North Project B Corridor hot spot analysis. RLINE emission source drawn as lines with emission rate shaded (black - blue - green). Receptor locations indicated with X's and RLINE v23132 model concentrations shaded (purple - yellow). Design concentration receptor location indicated with red circle.

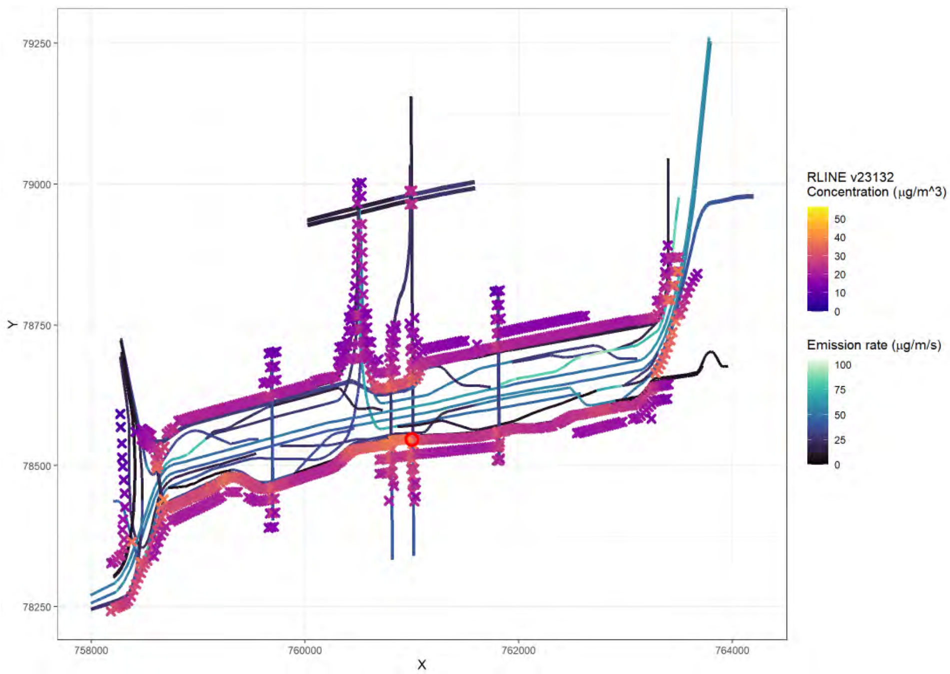

Figure 21 Project layout for the North Project B Corridor hot spot analysis. RLINE emission source drawn as lines with emission rate shaded (black - blue - green). Receptor locations indicated with X's and RLINE v22112 model concentrations shaded (purple - yellow). Design concentration receptor location indicated with red circle.

The form of the PM10 standard counts the number of daily averaged PM10 concentrations above the level of the standard (150 mg/m^3), with more than 3 days over three years of monitoring data above the level of standard to be considered a violation. If the 4th highest daily averaged concentration is less than the standard, then an area can be determined to pass. For modeling demonstrations that typically cover a 5-year period (rather than the 3-years used with ambient data to determine compliance), the test still allows for one concentration above the standard per year, meaning that five concentrations can be above the level of the standard and the 6th high value is used for the design concentration test, which is what is reported here, consistent with the model demonstration for the PM10 analysis for this project. Meteorological data was derived from Felts Field (SFF) general aviation relief airport in Project B, WA. The meteorological data for the model runs here were the same used for the hotspot analysis conducted by the state, which was from 2013-2019, which included using the adjusted u* option in AERMET. Project design concentrations (i.e., the highest design concentration from all receptors) are summarized in Table 4, while Figure 22 and Figure 23 compare the PM10 design concentrations from all receptors, comparing RLINE to the AREA and VOLUME source characterization for AERMOD version 22112 and 23132.

Table 4 Project B design concentrations (PM10, μg/m^3).

Source	v22112 H6H	v23132 H6H
RLINE	56.54	43.12
VOLUME	38.98	
AREA	47.79	

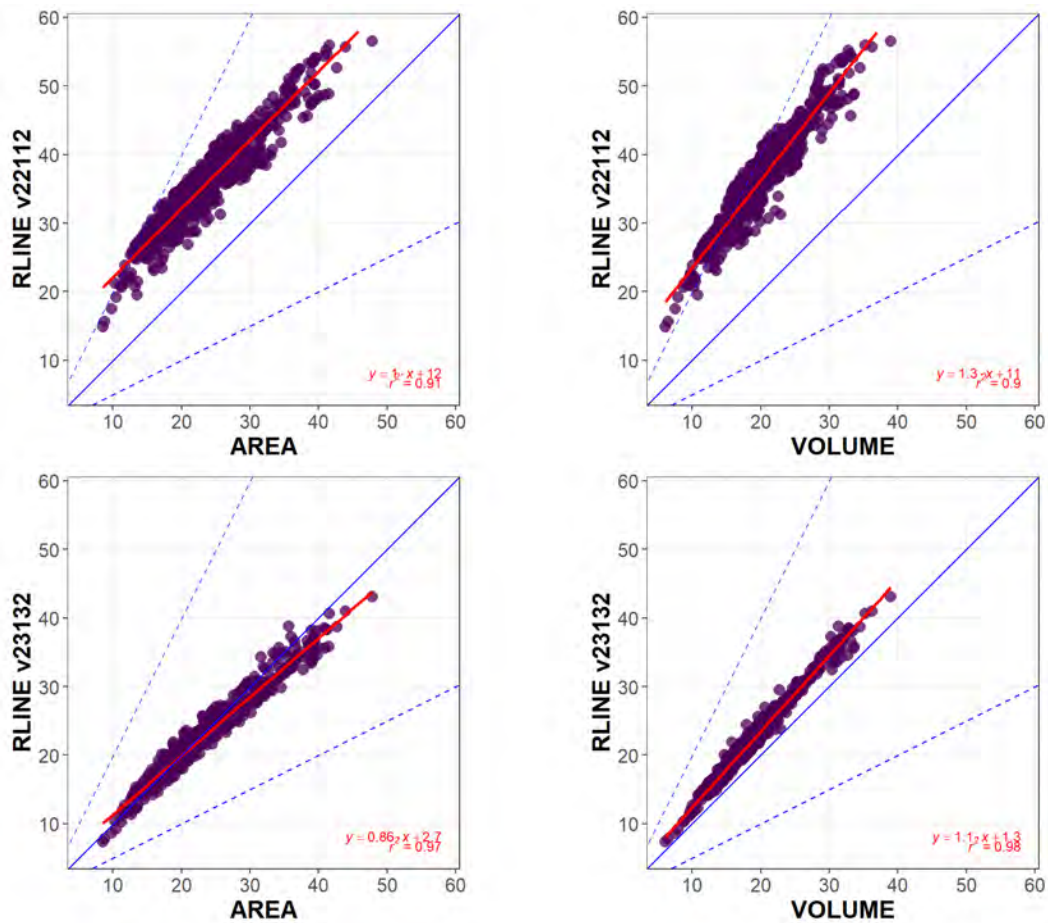

Figure 22 Comparison of RLINE 6th highest 24-hour concentrations of PM10 (μg/m^3) for all receptors between source type (AREA, left column and VOLUME, right column) and AERMOD version (top, v22112 and bottom, v23132). Model runs for Project B.

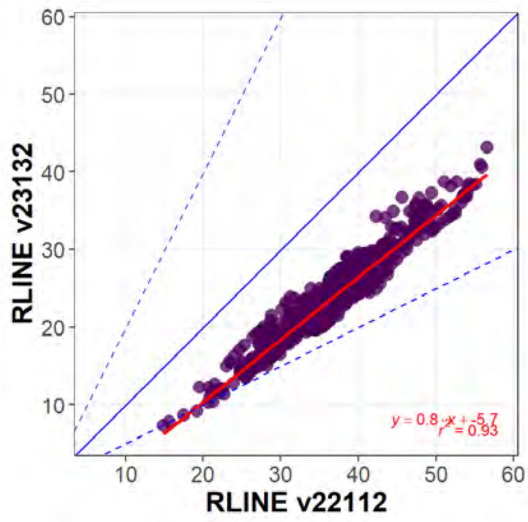

Figure 23 Comparison of RLINE 6th highest 24-hour concentrations of PM10 (µg/m^3) for all receptors between AERMOD versions. Model runs for Project B.

To further investigate the design concentrations (DC), the receptors associated with the maximum design concentrations, for each source type, is selected. Then the dates are selected as those associated with the design concentration concentrations at these receptors. DC receptors and dates are listed in Table 5. Hourly concentrations and select meteorological variables are then plotted for the DC dates (additional figures can be found in Appendix A).

For Project B, there is one DC receptor for all source types (Table 5). RLINE v23132, RLINE v22112, and VOLUME sources highest concentration occurs on the same date, where the AREA source occurs on a different date. Thus, there are two DC dates of interest. Table 5 summarizes the days selected for this analysis and Figure 24 and Figure 25 show the hourly concentrations from RLINE against the AREA and VOLUME source concentrations for the hours of interest.

Table 5 Project B design concentration receptors and dates used for hourly analysis.

Source	Version	Receptor	Date
RLINE	v23132	761001.6, 78547.1	2014-01-08
RLINE	v22112	761001.6, 78547.1	2014-01-08
AREA	v23132	761001.6, 78547.1	2014-12-07
VOLUME	v23132	761001.6, 78547.1	2014-01-08

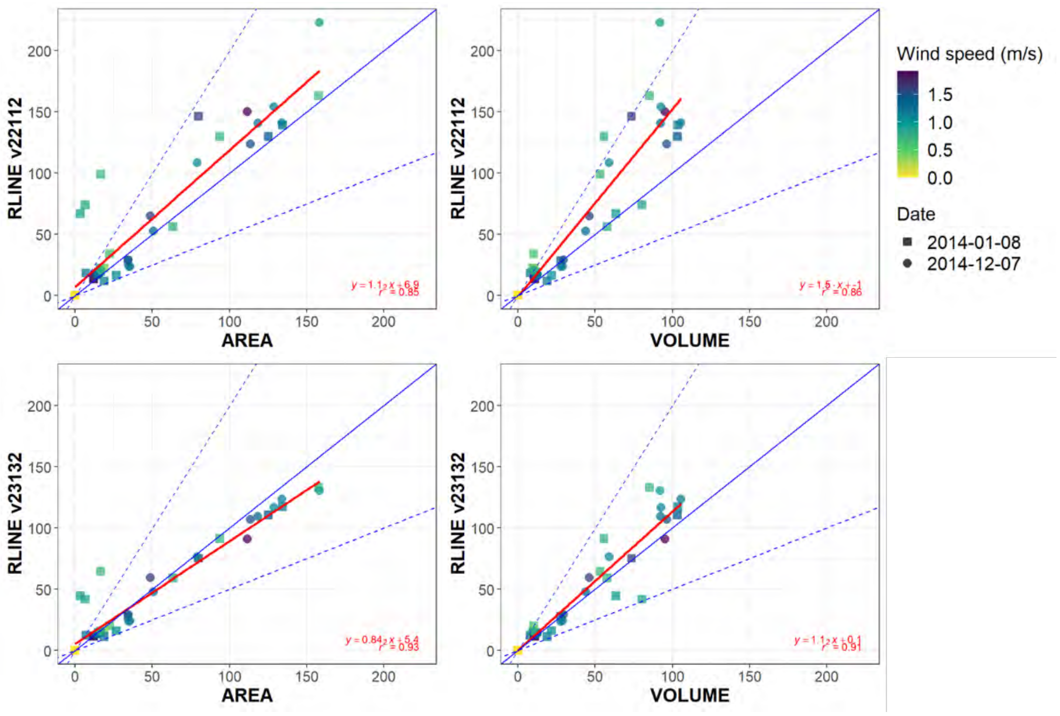

Figure 24 Comparison of RLINE hourly concentrations of PM10 (μg/m^3) for design concentration dates (shape) and wind speed (color) between source type (AREA, left column and VOLUME, right column) and AERMOD version (top, v22112 and bottom, v23132). Model runs for Project B.

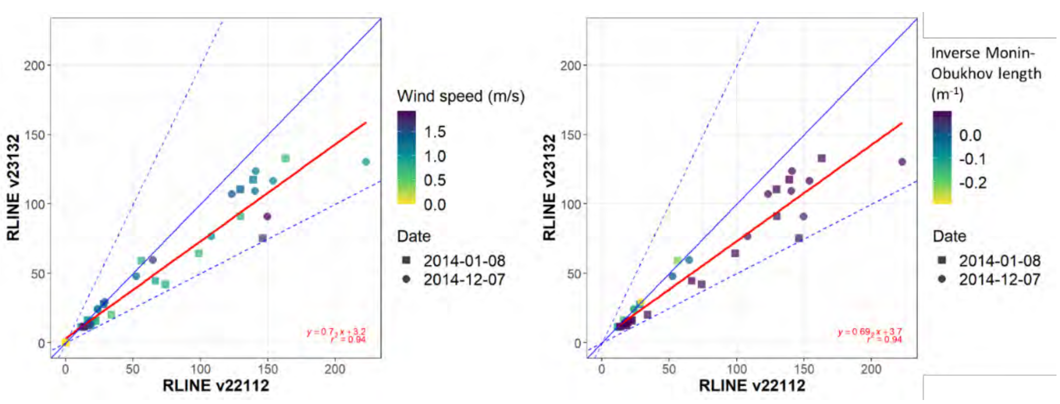

Figure 25 Comparison of RLINE hourly concentrations of PM10 (μg/m^3) for design concentration dates (shape), wind speed (color, left), and inverse Monin-Obukhov length (color, right) between AERMOD versions. Model runs for Project B.

4.0 Conclusions

This document describes modification to the formulation of the RLINE source in AERMOD, which include modifications to the dispersion and meteorology used by RLINE to use similar formulations as other AERMOD source types, bug fixes identified during the BETA release of RLINE, and the refitting of dispersion curves to field data resulting from changes to these first two model changes. The new model performance was evaluated against two field studies used previously, Idaho Falls and Caltrans 99, as well a previously unevaluated database, the GM Sulfate. For the Idaho Falls and Caltrans 99 field studies, modeled concentrations generally decreased, though the model agreed quite well for the newly analyzed GM Sulfate experiment. The updated RLINE formulation was also benchmarked against the existing AREA and VOLUME source characterization for two real-world hot-spot projects. Prior to the reformulation, RLINE design concentrations were 30-40% higher than those coming from the other source types. Following the reformulation, RLINE design concentrations fell between the two other source types, which would be expected given the formulation differences between the three source types. The model formulation presented here in AERMOD version 23132 balances performance with the evaluation datasets and the model intercomparisons with the hot-spot cases.

5.0 References

Barad, 1958. Project Prairie Grass. A Field Program in Diffusion. AFCRF-TR-58-235.

Benson, P.E., 1979. CALINE3—A Versatile Dispersion Model for Predicting Air Pollutant Levels Near Highways and Arterial Streets. Interim Report, Report Number FHWA/CA/TL-79/23. Federal Highway Administration, Washington, DC (NTIS No. PB 80-220841).

Cadle, S.H., D.P. Chock, J.M. Heuss, and P.R. Monson. 1976. "Results of the General Motors Sulfate Dispersion Experiment."

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., 2005. AERMOD: a dispersion model for industrial source applications. Part I: general model formulation and boundary layer characterization. Applied Meteorology 44, 682-693.

Environ. 77, 748–756.Venkatram, A., Brode, R., Cimorelli, A., Lee, R., Paine, R., Perry, S., Peters, W., Weil, J., Wilson, R., 2001. A complex terrain dispersion model for regulatory applications, Atmospheric Environment.

EPA, 2020. User's Guide for the AERSURFACE Tool. Office of Air Quality Planning and Standards Air Quality Assessment Division. Research Triangle Park, NC. EPA-454/B-20-008.

Finn, D., Clawson, K.L., Carter, R.G., Rich, J.D., Eckman, R.M., Perry, S.G., Isakov, V., Heist, D.K., 2010. Tracer studies to characterize the effects of roadside noise barriers on near-road pollutant dispersion under varying atmospheric stability conditions. Atmos. Environ. 44, 204–214.

Heist, D.K., Perry, S.G., Brixey, L.A., 2009. A wind tunnel study of the effect of roadway configurations on the dispersion of traffic-related pollution. Atmos. Environ. 43, 5101–5111.

Heist, D.K., Isakov, V., Perry, S., Snyder, M., Venkatram, A., Hood, C., Stocker, J., Carruthers, D., Arunachalam, S., Owen, R. C. 2013 Estimating near-road pollutant dispersion: A model inter-comparison. Transportation Research Part D, 25, 93-105.

Merceret, F.J., 1995. *The effect of sensor sheltering and averaging techniques on wind measurements at the Shuttle Landing Facility* (No. NAS 1.15: 111262).

Snyder, M.G., Venkatram, A., Heist, D.K., Perry, S.G., Petersen, W.B., Isakov, V., 2013. RLINE: a line source dispersion model for near-surface releases. Atmos.

Venkatram, A., Snyder, M.G., Heist, D.K., Perry, S.G., Petersen, W.B., Isakov, V., 2013a. Re-formulation of plume spread for near-surface dispersion. Atmos. Environ. 77, 846–855.

6.0 Appendix A

Additional plots from PM hot spot analyses model intercomparison.

6.1 Project A $PM_{2.5}$

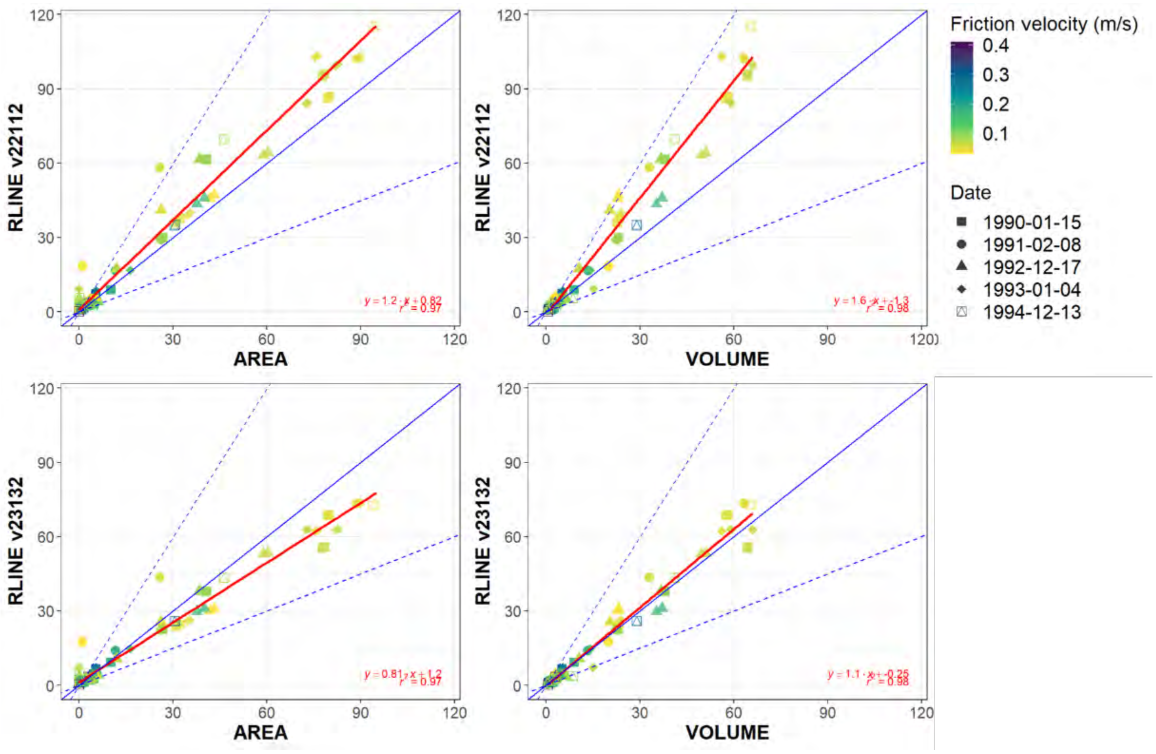

Figure 26: Comparison of RLINE hourly concentrations of $PM_{2.5}$ ($\mu g/m^3$) for design concentration dates (shape) and friction velocity (color) between source type (AREA, left column and VOLUME, right column) and AERMOD version (top, v22112 and bottom, v23132). Model runs for Project A.

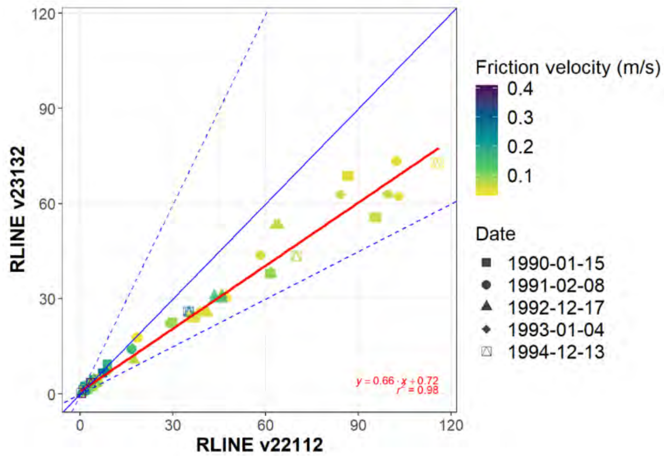

Figure 27: Comparison of RLINE hourly concentrations of $PM_{2.5}$ ($\mu g/m^3$) for design concentration dates (shape) and friction velocity (color) between AERMOD versions. Model runs for Project A project.

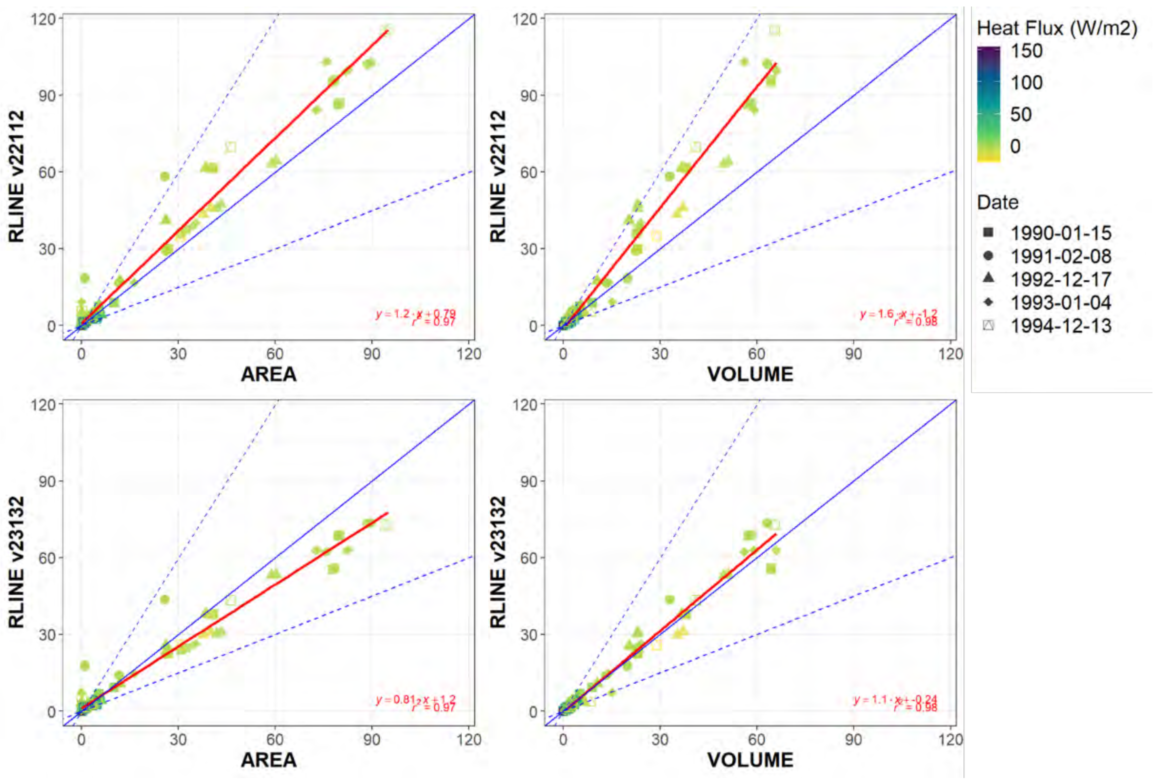

Figure 28: Comparison of RLINE hourly concentrations of PM2.5 ($\mu g/m^3$) for design concentration dates (shape) and surface heat flux (color) between source type (AREA, left column and VOLUME, right column) and AERMOD version (top, v22112 and bottom, v23132). Model runs for Project A.

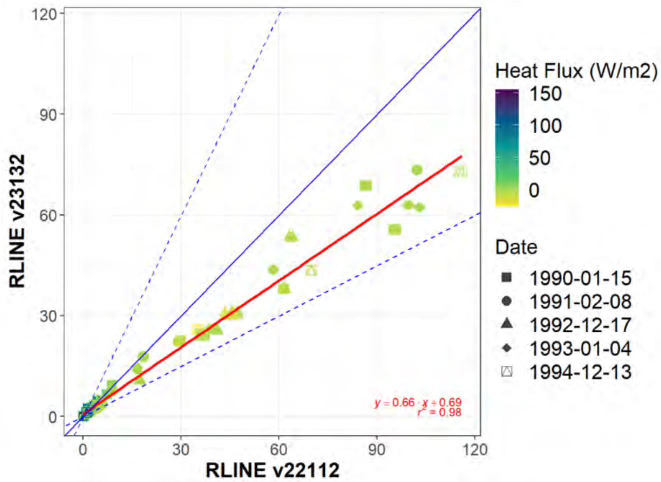

Figure 29: Comparison of RLINE hourly concentrations of PM2.5 (μg/m^3) for design concentration dates (shape) and surface heat flux (color) between AERMOD versions. Model runs for Project A.

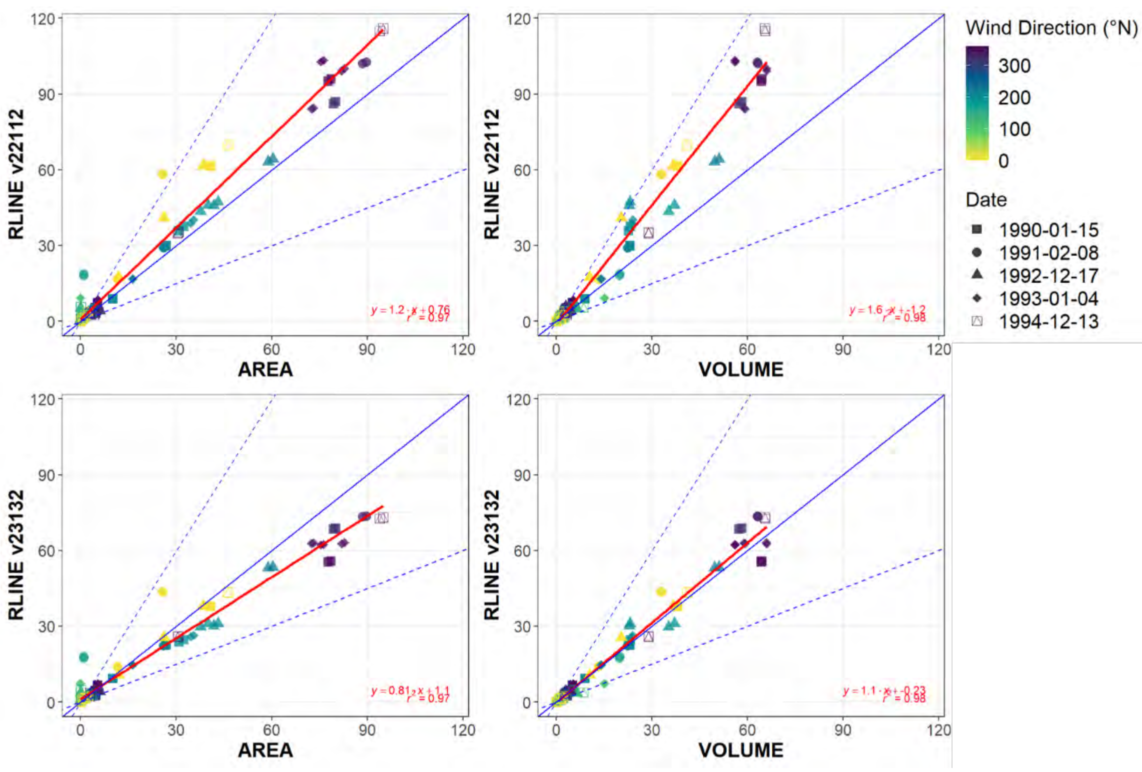

Figure 30: Comparison of RLINE hourly concentrations of $PM_{2.5}$ (μg/m^3) for design concentration dates (shape) and wind direction (color) between source type (AREA, left column and VOLUME, right column) and AERMOD version (top, v22112 and bottom, v23132). Model runs for Project A.

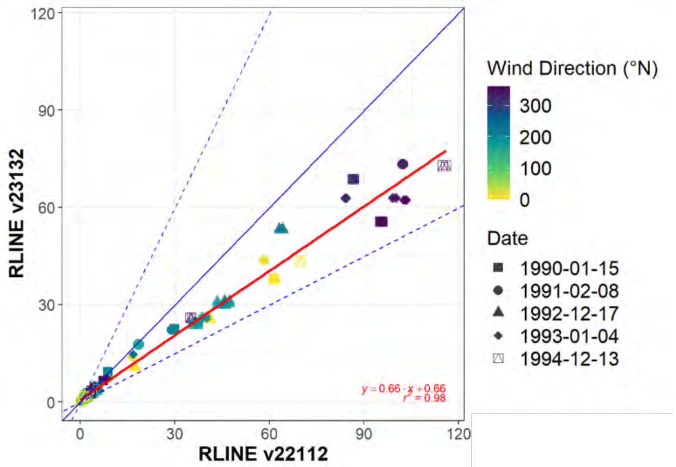

Figure 31: Comparison of RLINE hourly concentrations of $PM_{2.5}$ ($\mu g/m^3$) for design concentration dates (shape) and wind direction (color) between AERMOD versions. Model runs for Project A project.

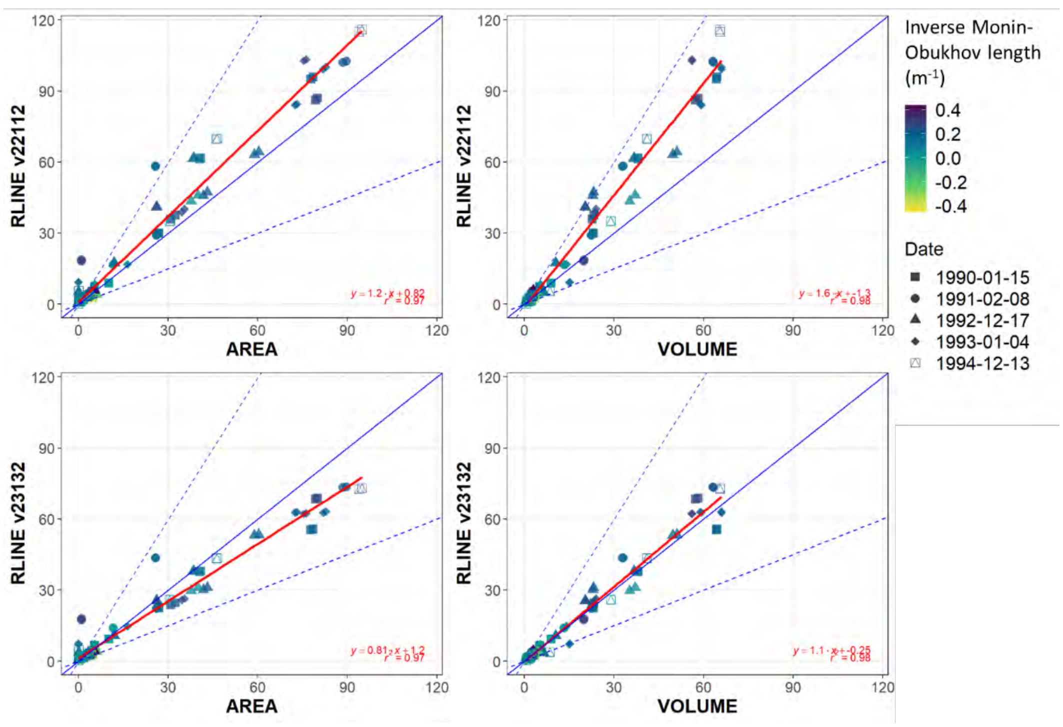

Figure 32: Comparison of RLINE hourly concentrations of $PM_{2.5}$ ($\mu g/m^3$) for design concentration dates (shape) and inverse Monin-Obukhov length (color) between source type (AREA, left column and VOLUME, right column) and AERMOD version (top, v22112 and bottom, v23132). Model runs for Project A.

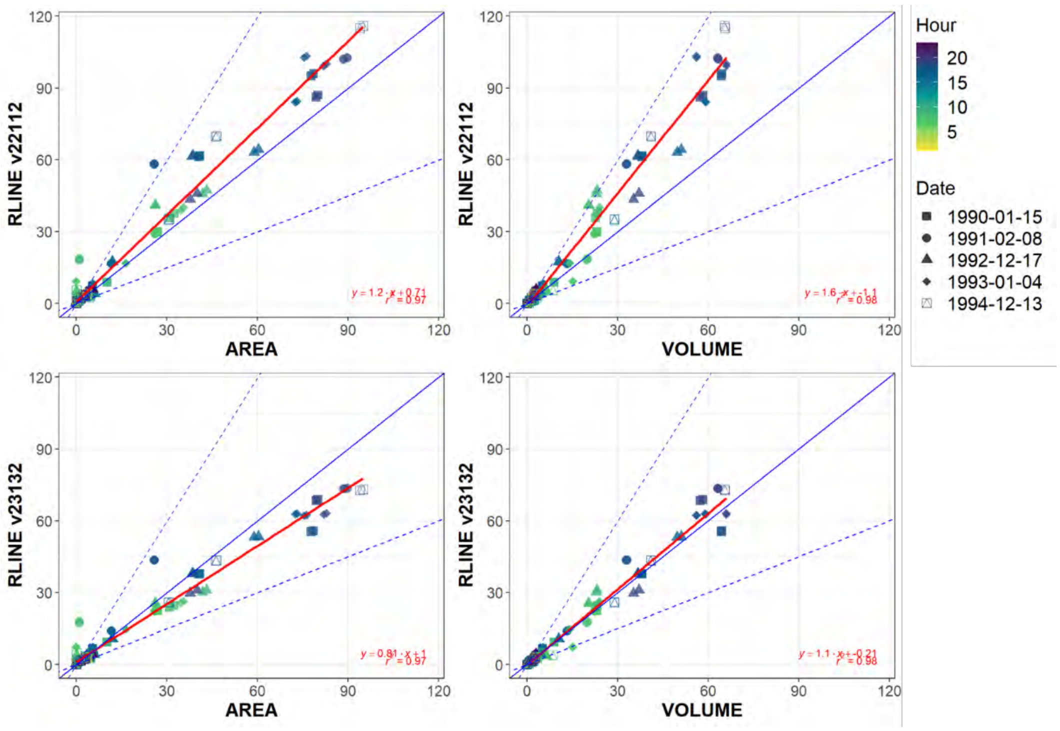

Figure 33: Comparison of RLINE hourly concentrations of $PM_{2.5}$ ($\mu g/m^3$) for design concentration dates (shape) and hour of day (color) between source type (AREA, left column and VOLUME, right column) and AERMOD version (top, v22112 and bottom, v23132). Model runs for Project A.

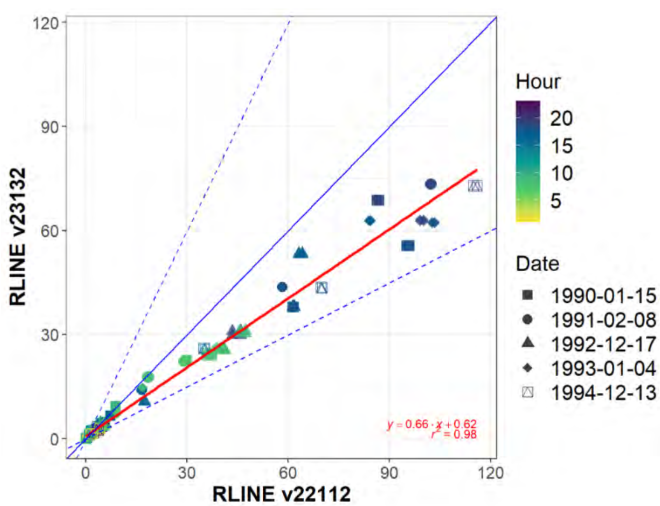

Figure 34: Comparison of RLINE hourly concentrations of $PM_{2.5}$ ($\mu g/m^3$) for design concentration dates (shape) and hour of day (color) between AERMOD versions. Model runs for Project A.

6.2 Project B PM_{10}

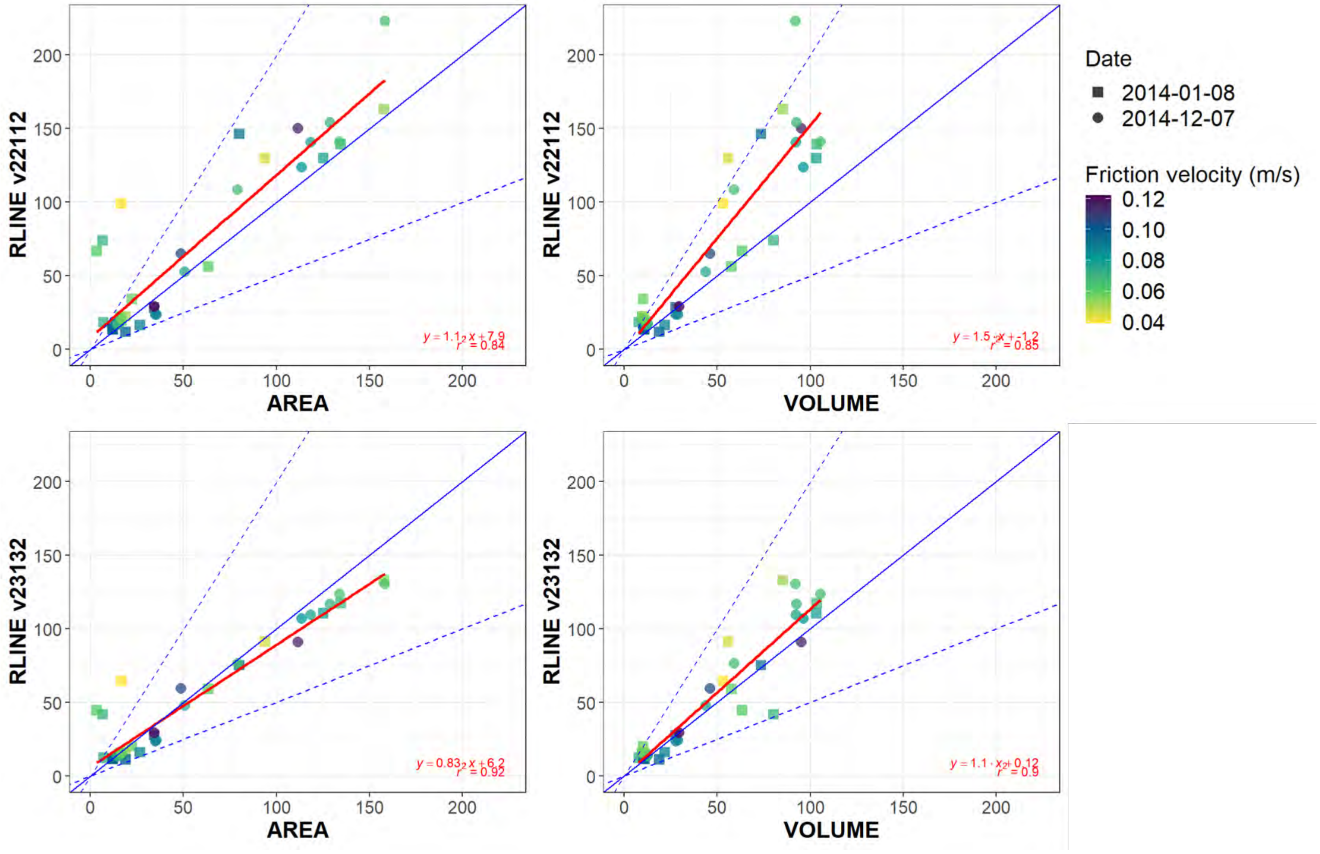

Figure 35 Comparison of RLINE hourly concentrations of PM10 (µg/m^3) for design concentration dates (shape) and friction velocity (color) between source type (AREA, left column and VOLUME, right column) and AERMOD version (top, v22112 and bottom, v23132). Model runs for Project B.

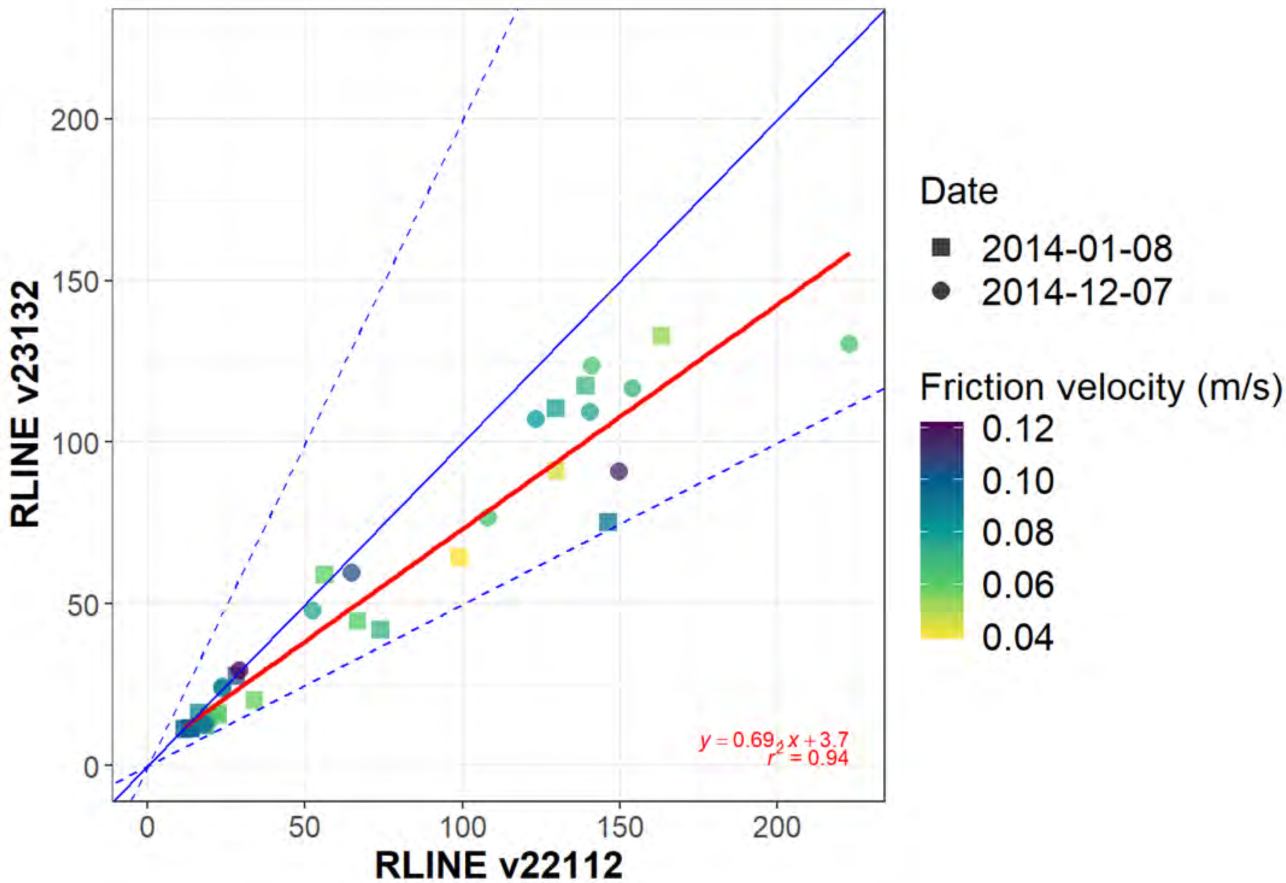

Figure 36. Comparison of RLINE hourly concentrations of PM10 (µg/m^3) for design concentration dates (shape) and friction velocity (color) between AERMOD versions. Model runs for Project B.

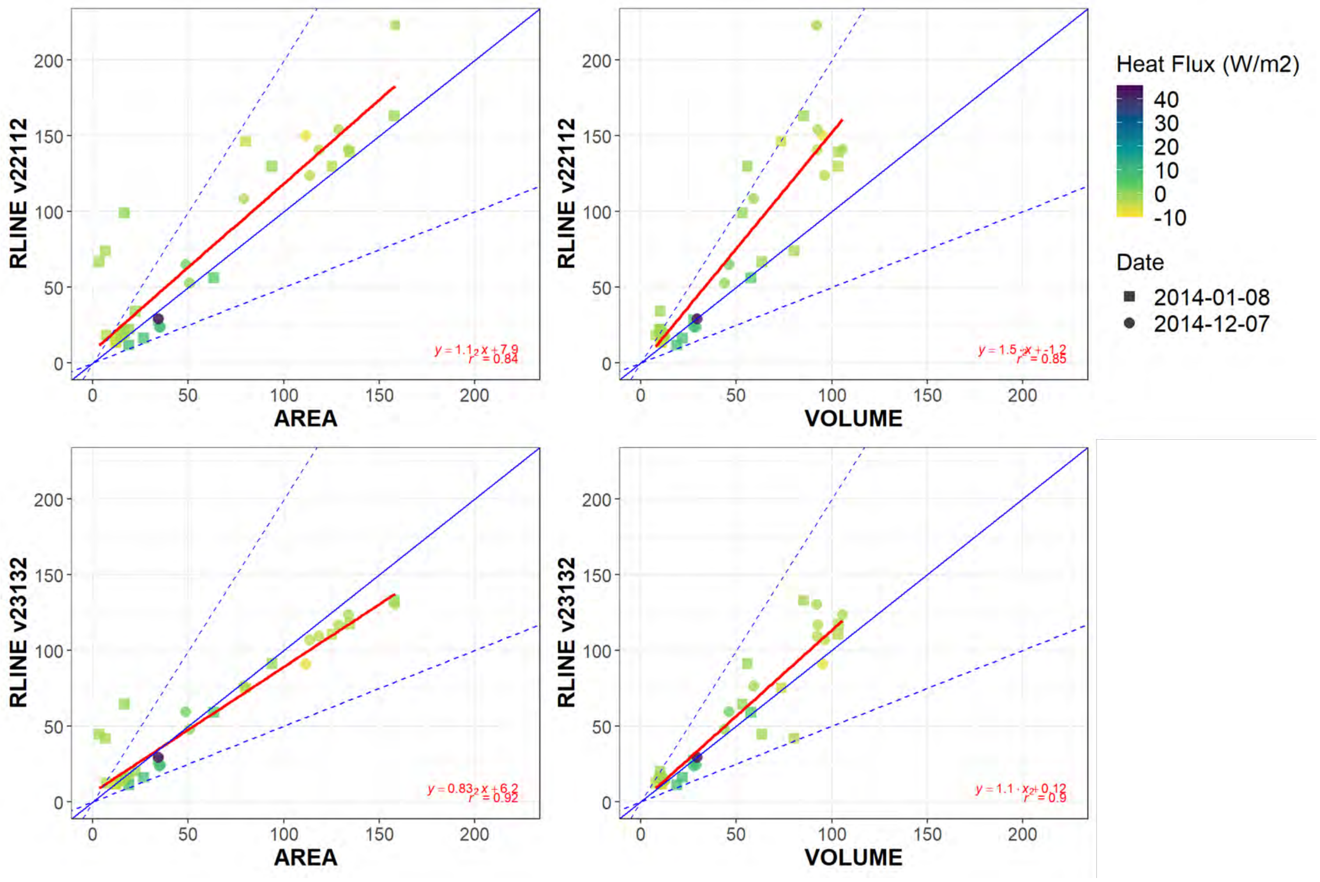

Figure 37. Comparison of RLINE hourly concentrations of PM10 (µg/m^3) for design concentration dates (shape) and surface heat flux (color) between source type (AREA, left column and VOLUME, right column) and AERMOD version (top, v22112 and bottom, v23132). Model runs for Project B.

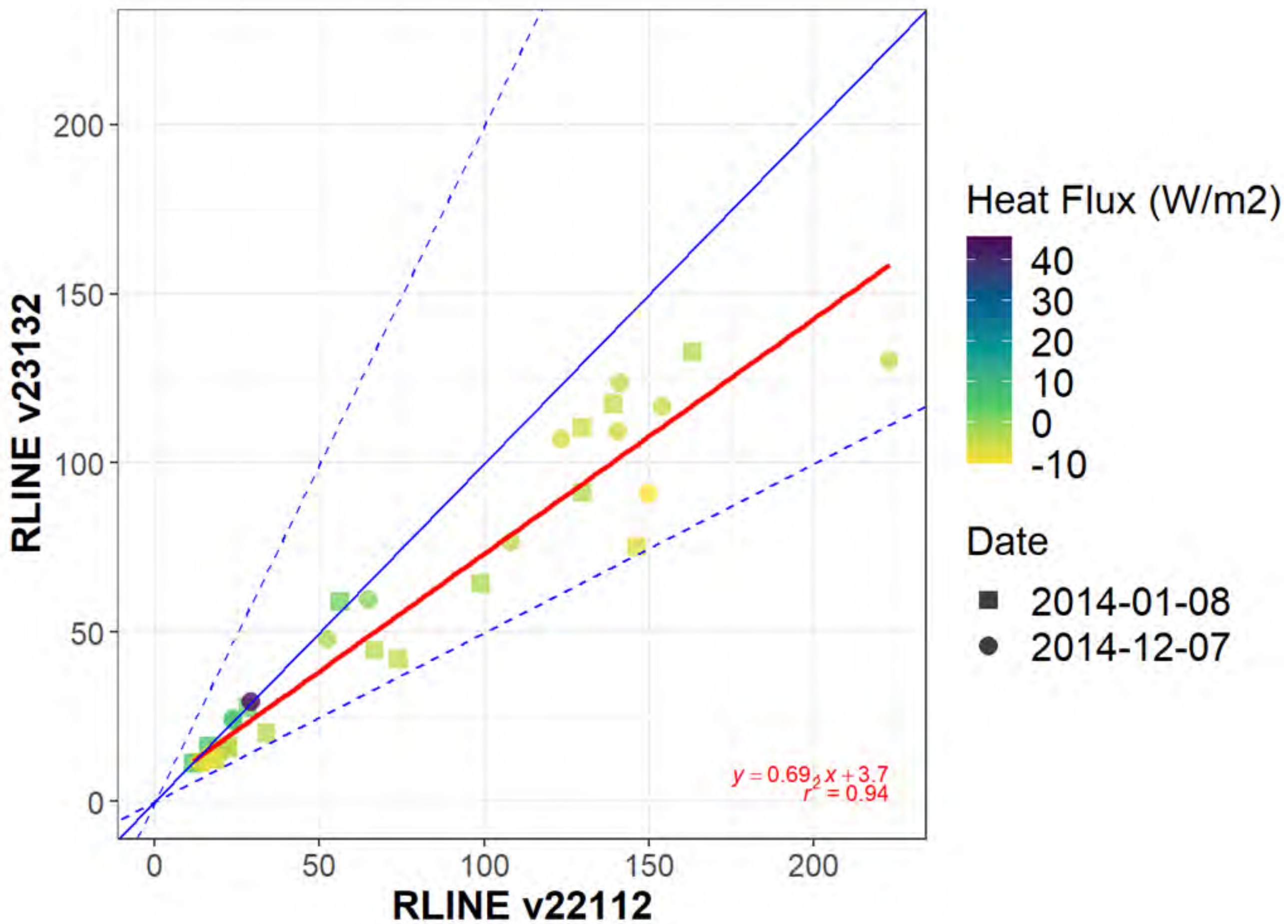

Figure 38. Comparison of RLINE hourly concentrations of PM10 (μg/m^3) for design concentration dates (shape) and surface heat flux (color) between AERMOD versions. Model runs for Project B.

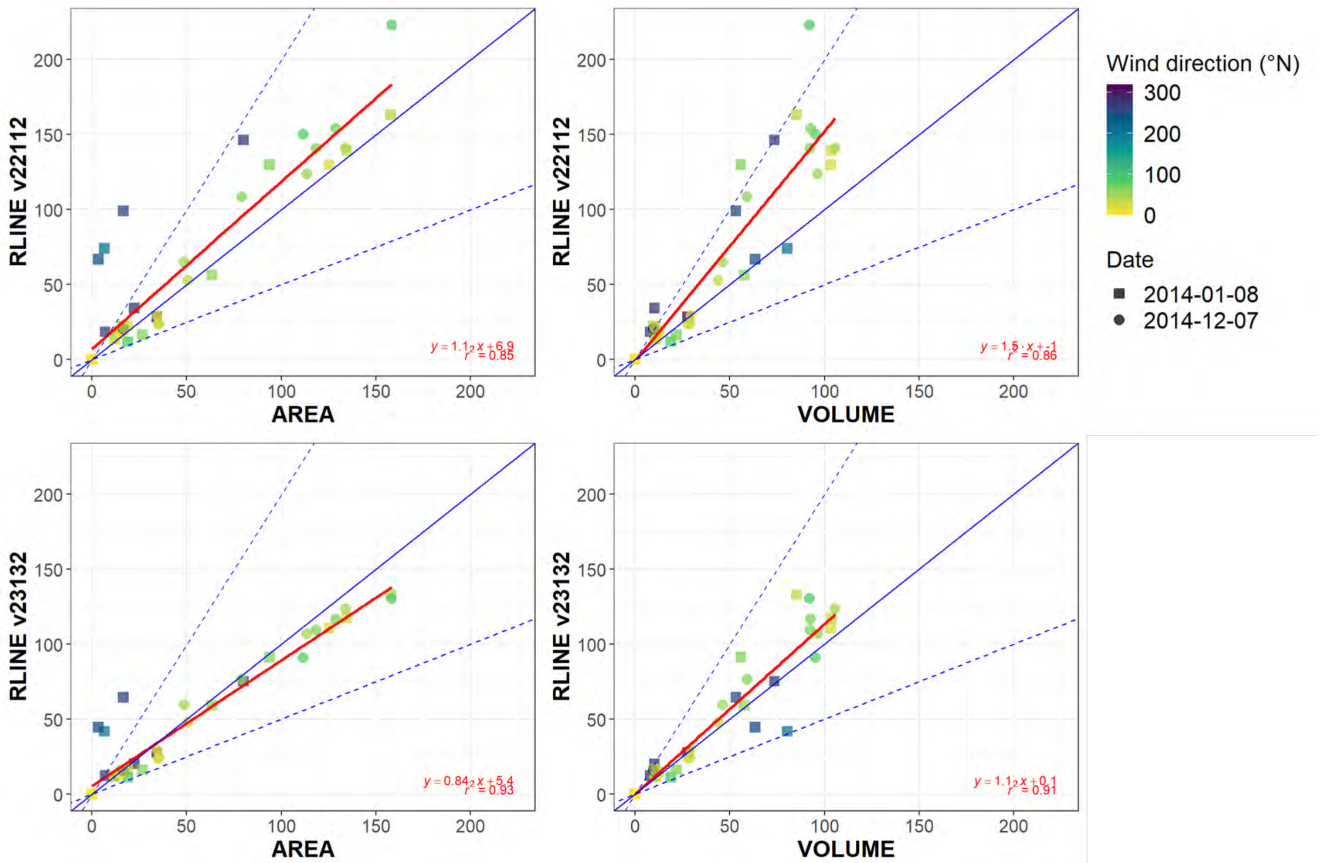

Figure 39. Comparison of RLINE hourly concentrations of PM10 (µg/m^3) for design concentration dates (shape) and wind direction (color) between source type (AREA, left column and VOLUME, right column) and AERMOD version (top, v22112 and bottom, v23132). Model runs for Project B.

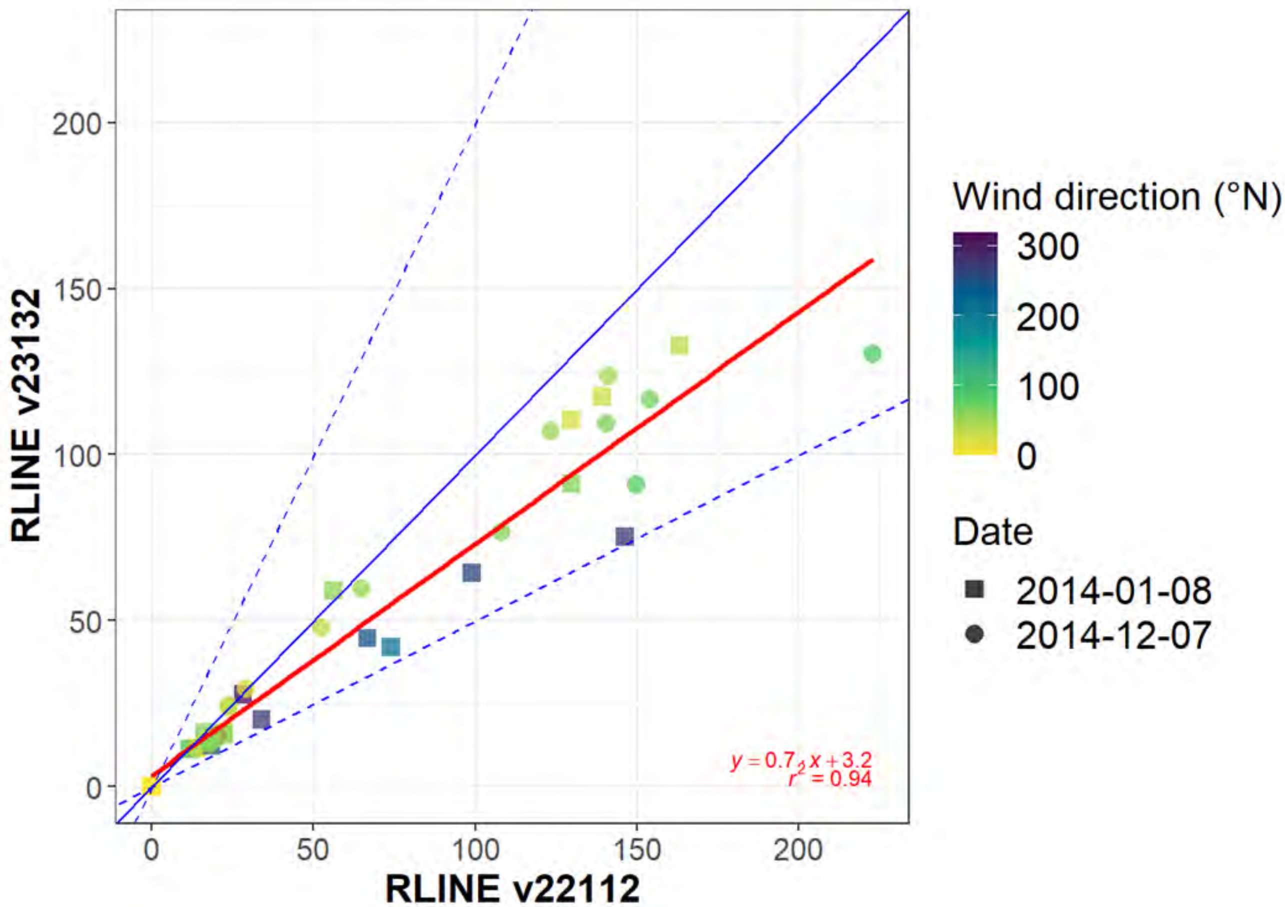

Figure 40. Comparison of RLINE hourly concentrations of PM10 (μg/m^3) for design concentration dates (shape) and wind direction (color) between AERMOD versions. Model runs for Project B.

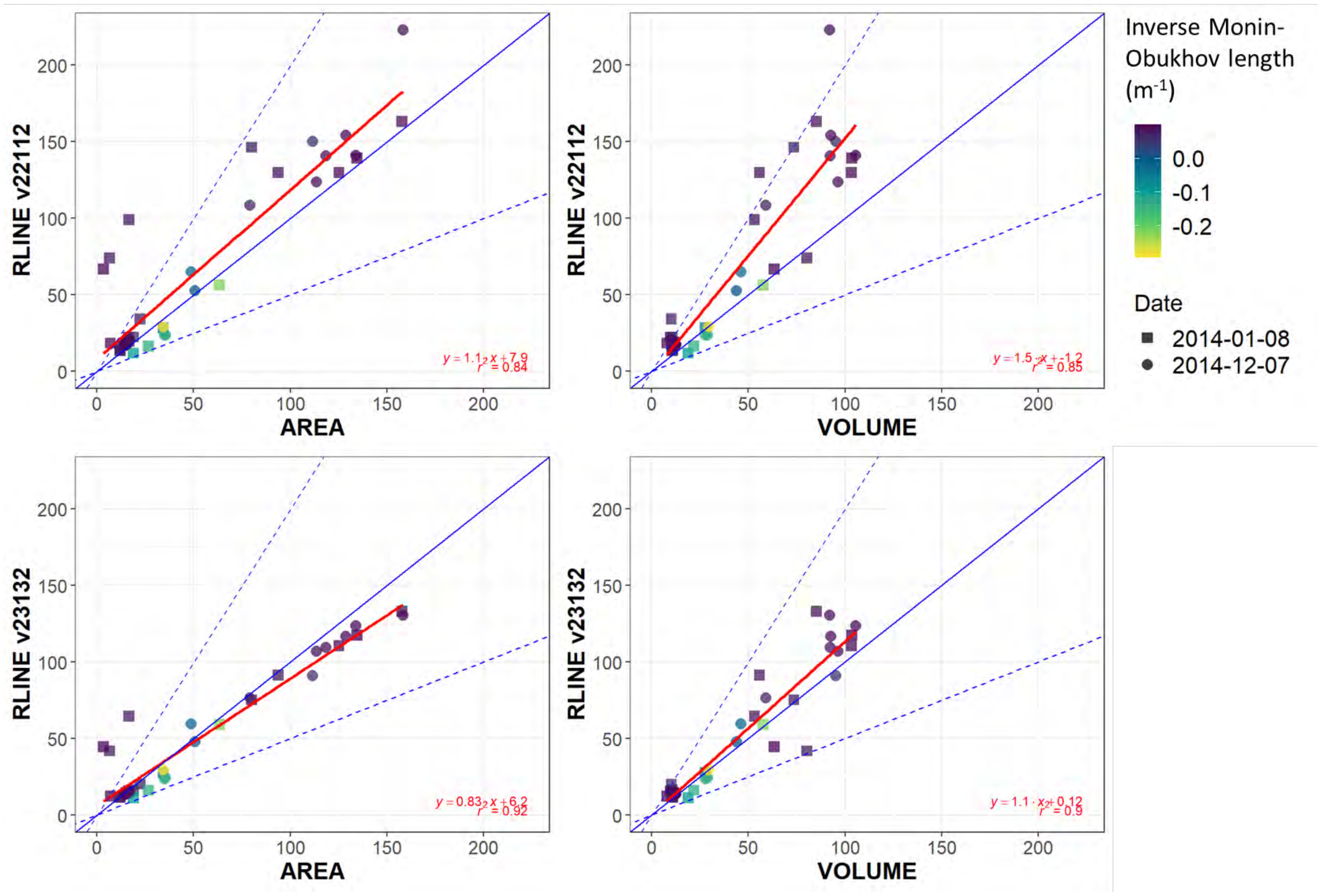

Figure 41. Comparison of RLINE hourly concentrations of PM10 (μg/m^3) for design concentration dates (shape) and inverse Monin-Obukhov length (color) between source type (AREA, left column and VOLUME, right column) and AERMOD version (top, v22112 and bottom, v23132). Model runs for Project B.

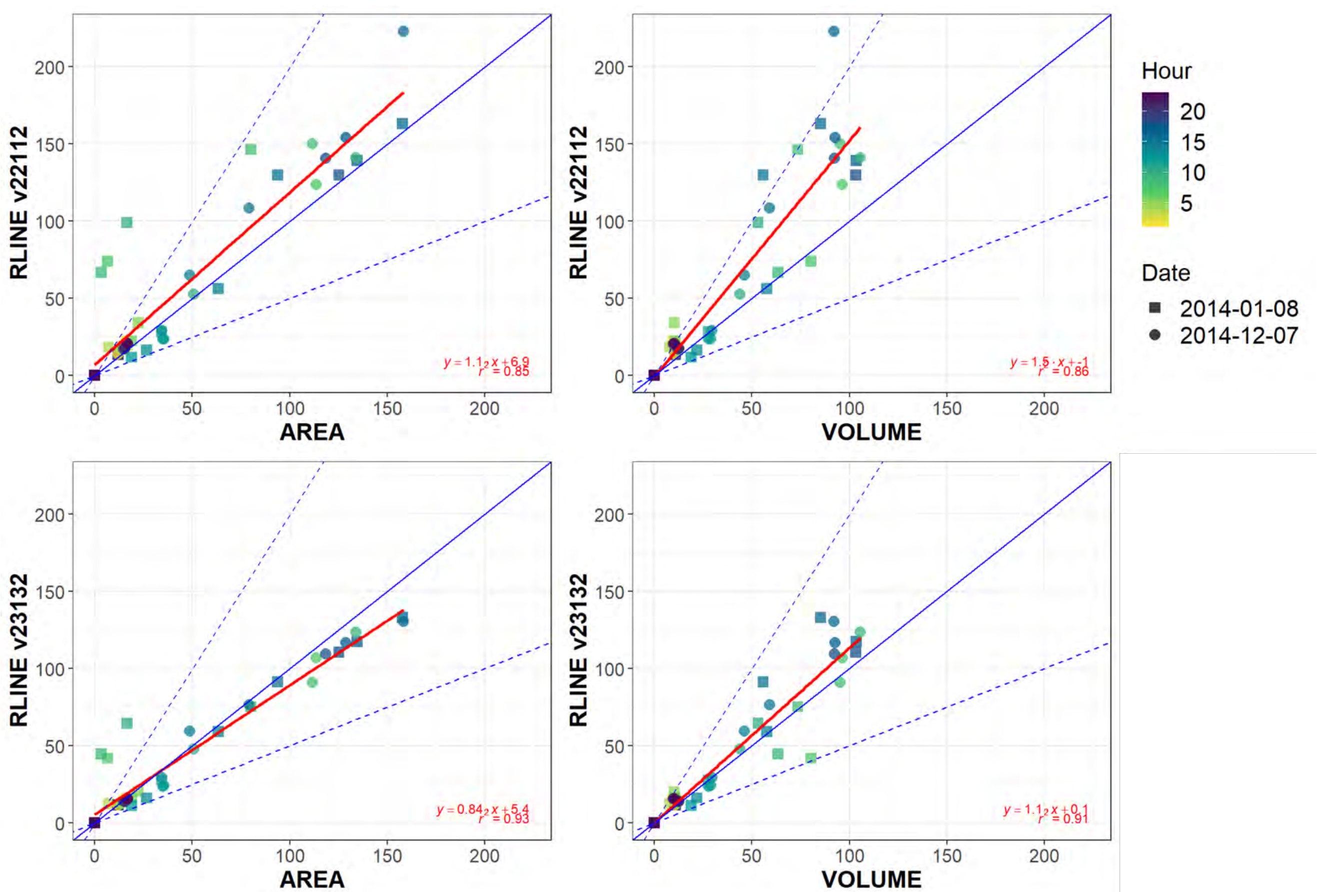

Figure 42. Comparison of RLINE hourly concentrations of PM10 (μg/m^3) for design concentration dates (shape) and hour of day (color) between source type (AREA, left column and VOLUME, right column) and AERMOD version (top, v22112 and bottom, v23132). Model runs for Project B.

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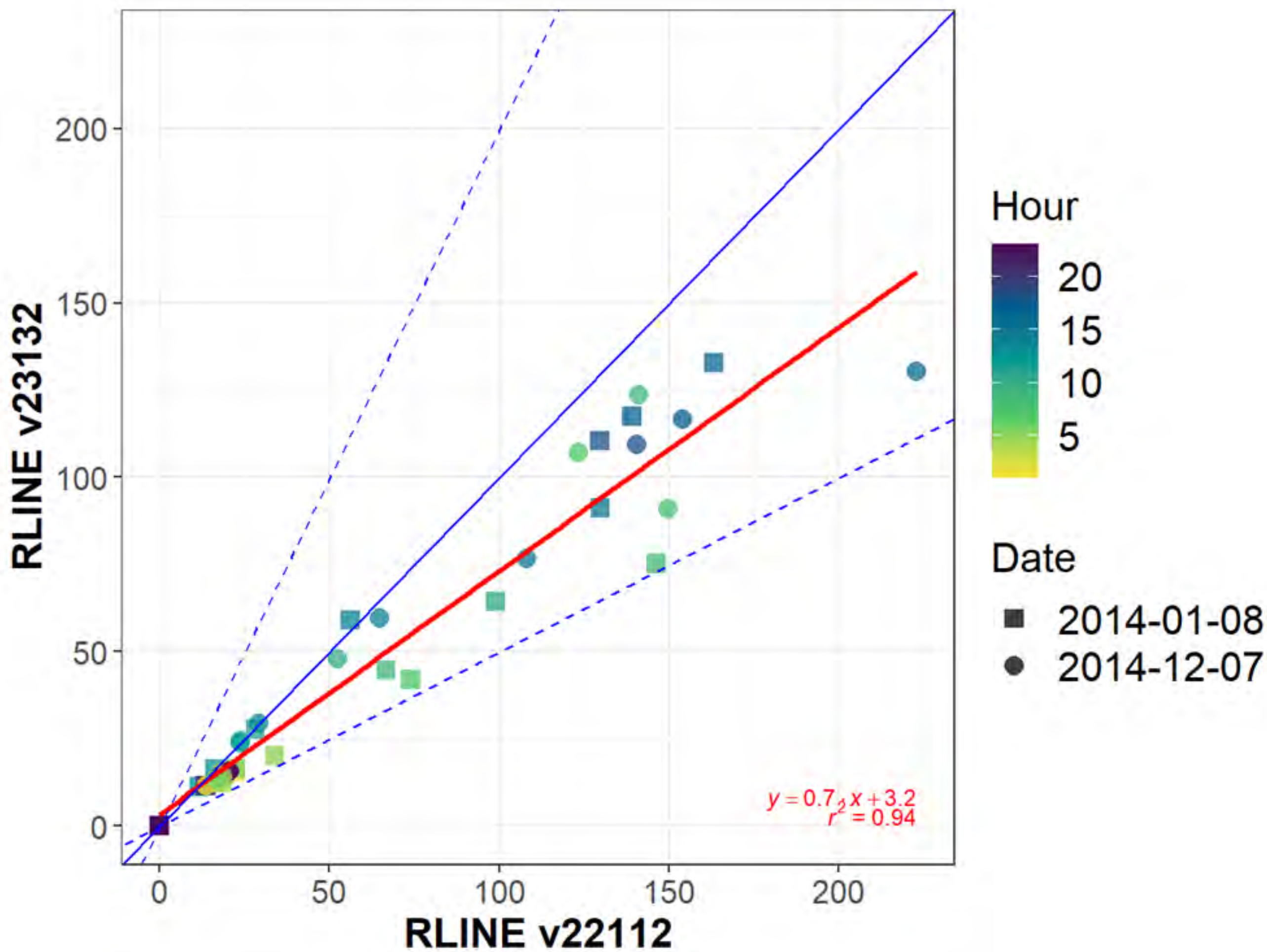

Figure 43. Comparison of RLINE hourly concentrations of PM10 (µg/m^3) for design concentration dates (shape) and hour of day (color) between AERMOD versions. Model runs for Project B.

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