Evaluation of Addition of Terrain Treatment to the RLINE Source Type in AERMOD

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Preface

This document provides details for the incorporation of terrain into the RLINE Source Type. The RLINE source type is a unique implementation, therefore the incorporation of terrain could not exactly mirror that of POINT, VOLUME, and AREA sources in AERMOD, however the methods in RLINE with terrain followed those of other source types with terrain as closely as possible. Details include model formulation, AERMOD code modification, evaluation of suggested code changes, and comparison to other AERMOD source types which include terrain.

Acknowledgements

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1.0 Introduction

The RLINE model is a dispersion model originally developed by the US EPA's Office of Research and Development. The model is based on a steady-state Gaussian formulation and is designed to simulate line-type source emissions from near-surface releases. The RLINE source type was initially developed for use in flat terrain, which ignored the localized elevation and hill height variations at source and receptor locations. The restriction of the RLINE source to only flat terrain ignores complex terrain in the calculation of dispersion. Currently, the treatment of terrain by the POINT, AREA, VOLUME, and OPENPIT sources use the concept of the two-plume model based on (Venkatram et al., 2001). This approach simulates one plume's concentration at the receptor height and the other plume's concentration at the receptor height plus the terrain height and the composite of the two plumes accounts for the total concentration from each source. The objective of this work is to incorporate terrain dispersion treatment into the RLINE source type using the existing two-plume methodology in AERMOD. Implementation of terrain treatment for the RLINE source was tested with a variety of meteorological data. When possible, the behavior of the RLINE source incorporating terrain was compared to the other AERMOD source types (AREA/LINE and VOLUME) to ensure similar results when considering terrain.

2.0 Terrain Treatment in AERMOD

The AERMOD system uses multiple preprocessors before the computation of dispersion concentrations. One preprocessor is a terrain preprocessor, AERMAP (U.S. EPA, 2018), that handles variability in terrain heights in the modeling domain. AERMAP uses gridded terrain data, usually from national databases, to determine source and receptor terrain heights and these heights are input into AERMOD. These terrain heights are then used in the computation of a critical height and the weighting factor used in computation of dispersion from the emission source at each receptor location. The following sections describe the computation of the terrain heights, critical height and weighting factor, then finally the computation of the dispersion concentration.

2.1 Calculation of Critical Height and Terrain Weighting Factor

The two-plume model utilized by AERMOD calculates the dispersion plume for two cases: a horizontal terrain impacting plume and a terrain following plume illustrated in Figure 1 (U.S. EPA, 2022). Figure 2 represents how these two plumes are computed separately, then combined by the weighting factor, which represents the proportion of plume mass in the horizontal impacting state.

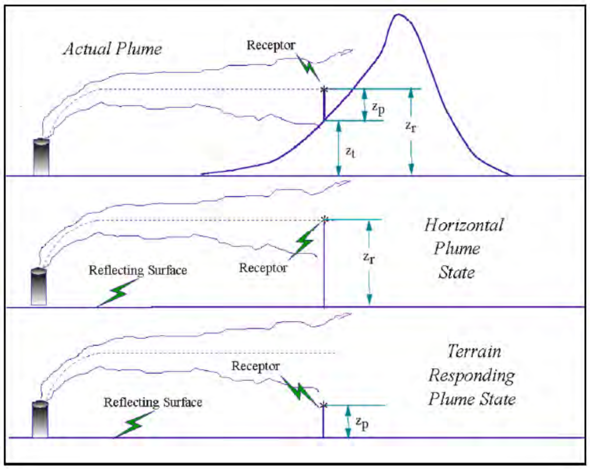

Figure 1: AERMOD two plume approach. The total concentration predicted by AERMOD is the weighted sum of the two plumes. Figure from (U.S. EPA, 2023)

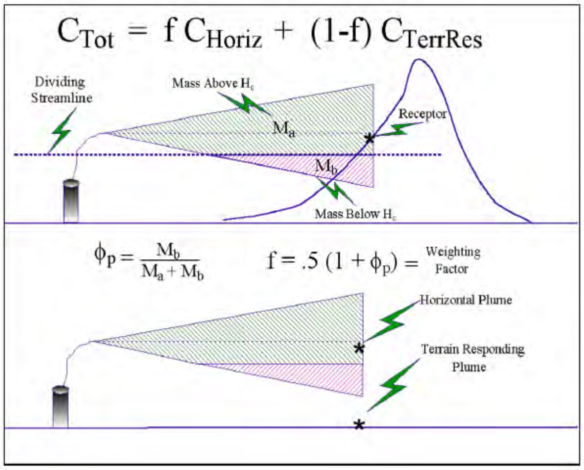

Figure 2: Construction of the weighting factor between two-plumes of terrain in AERMOD. Figure from (U.S. EPA, 2023)

The dividing streamline assumes the air below the critical height tends to move around the terrain object (the horizontal plume state, middle panel of Figure 1) and the air above the critical dividing streamline will travel over the terrain object (the vertical terrain responding plume state, bottom panel of Figure 1). Thus, AERMOD first computes the critical height, then divides the plume using the dividing streaming concept.

The critical height, H_c is the height at which the parcel of air has just enough kinetic energy to reach the receptor height. The calculation of the critical height, is given by Eq. 1, originally published as Eq. 7 in (Venkatram et al., 2001):

$$\frac{1}{2}u^2\{H_c\} = \int_{H_c}^{z} (z - \zeta)N^2(\zeta)d\zeta \tag{1}$$

Where,

$u\{H_c\}$ is the wind speed at the critical height

z is the receptor height,

H_c is the critical height,

ζ is the potential temperature,

$N(\zeta)$ is the Brunt-Vaisala frequency which is defined as $\sqrt{\frac{g}{\zeta}\frac{d\xi}{dz}}$

Only the lowest height that satisfies Eq. 1 is necessary to show that there is sufficient kinetic energy to maintain a streamline i.e., terrain-following. Eq. 1 from (Venkatram et al., 2001) defines H_c in relation to the terrain following height at each receptor location.

AERMOD uses the hill height scale, h_c from AERMAP to calculate the critical height, H_c. The hill height scale is the height with the greatest influence on dispersion for each receptor. The calculation of the critical height uses the hill height scale, as defined in Eq. 49 of the AERMOD Model Formulation (U.S. EPA, 2023) document (MFD).

$$\frac{1}{2}u^2\{H_c\} = \int_{H_c}^{h_c} N^2(h_c - z)dz \tag{MFD Eq. 49}$$

The fraction of mass below the critical height, Φ_p, can be calculated using the critical height as shown in MFD Eq. 50 (U.S. EPA, 2023):

$$\Phi_p = \frac{\int_0^{H_c} C_s\,\{x_r, y_r, z_r\}dz}{\int_0^{\infty} C_s\,\{x_r, y_r, z_r\}dz} \tag{MFD Eq. 50}$$

Where,

$C_s\,\{x_r, y_r, z_r\}$ is the concentration of the plume in the absence of the hill for stable conditions, The plume weighing factor, f, can be calculated from ϕ_p using Eq. 2. The value of ϕ_p is between 0 and 1; therefore, f will have a value between ½ and 1. The weighting factor is only used during stable conditions. When the atmosphere is neutral or convective the plume is entirely above the critical dividing streamline height and $f = \frac{1}{2}$.

$$f = \frac{1}{2}(1 + \phi_p) \tag{2}$$

The horizontal and terrain following plume concentrations are then combined using the weighing factor in MFD Eq. 48 (U.S. EPA, 2023).

$$C_T \{x_r, y_r, z_r\} = f * C_{c,s} \{x_r, y_r, z_r\} + (1 - f) * C_{c,s} \{x_r, y_r, z_p\} \tag{MFD Eq. 48}$$

Where,

$C_T \{x_r, y_r, z_r\}$ is the total concentration of the plume,

$C_{c,s} \{x_r, y_r, z_r\}$ is the contribution from the horizontal plume state (subscripts c and s refer to convective and
stable conditions, respectively),

$C_{c,s} \{x_r, y_r, z_p\}$ is the contribution from terrain-following state,

f is the plume state weighting factor,

$\{x_r, y_r, z_r\}$ is the coordinate representation of a receptor (with r defined relative to stack base elevation),

$z_p = z_r - z_t$ is the height of a receptor above local ground, and z_t is the terrain height at a receptor.

2.2 Calculation of Total Concentration

The POINT source was used to illustrate the typical procedure for calculating the total concentration and how terrain is incorporated into AERMOD. The POINT source was used as the example method for the incorporation of terrain since it accounts for the impacts of meander. RLINE also includes meander in concentration calculations.

The concentration for the POINT source including terrain is calculated in the following three step calculation process:

1. Computation of concentrations from the two coherent plumes:
    a. Horizontal impacting plume (receptor height = flagpole + terrain)
    b. Terrain following plume (receptor height = flagpole)
    c. Combine using the *terrain* weighting fraction.
2. Computation of meander plume:
    a. Horizontal impacting plume (receptor height = flagpole + terrain)

   b. Terrain following plume (receptor height = flagpole)
   c. Combine using the *terrain* weighing fraction.
3. Computation of total concentration: combine the coherent plume and the meander plume using the *meander* weighting fraction.

The order of the calculation for the POINT source is important as it shows that terrain is incorporated before the impacts of meander are considered. Note, the VOLUME source calculations are a special application of the POINT source calculation, so it would follow this same process. In addition, the AREA (and LINE, a special case of the AREA calculation) follows the same general procedure but does not include the meander and meander weighting components, so it would only have the computation of the coherent plume (step 1). The goal of the current effort is to follow the same calculations and general procedure, as closely as possible, for the RLINE source type calculations. This would need to involve the entire 3-step process, since RLINE includes the meander weighting.

3.0 Original RLINE Source Type

The RLINE source type was developed to simulate line type source emissions by integrating point sources along the line, and it can include the effects of barriers or depressed roadway segments. The original RLINE source does not account for the effects of terrain when calculating the total concentration, which can lead to over/under estimation of concentrations, depending on the source and receptor orientation.

When RLINE calculates concentrations, it adjusts the coordinate system so that the source lies along the Y-axis (perpendicular to the wind direction). The concentration of an RLINE source is found by approximating the line as a series of point sources using a Gaussian plume formulation, and the concentration at the receptor at (x_r, y_r, z_r) can be expressed as a summation of the point sources along the line, as shown in Eq. 3, originally published in (Snyder et al., 2013) as Eq. 10

$$C(x_r, y_r, z_r) = \int_{Y_1}^{Y_1+L} dC_{pt} \tag{3}$$

Where,

$C(x_r, y_r, z_r)$ is the concentration at the receptor,
Y_1 is the initial point of the RLINE source,
L is the length of the RLINE source,
dC_{pt} is the contribution from an elemental point source.

The number of points necessary for convergence is variable and is a function of the distance from the source line to the receptor.

3.1 Wind speed calculation for RLINE source type

The POINT, AREA, VOLUME, and OPENPIT sources calculate the critical height using 87 gridded profile heights, 0 to 5000 meters, to calculate the effective wind speed. AERMOD calculates the vertical wind profile using the Monin-Obukhov similarity theory, MFD Eq. 28 (U.S. EPA, 2023).

$$u = u\{7z_0\}\left[\frac{z}{7z_0}\right] for\ z < 7z_0$$

$$u = \frac{u_*}{k}\left[\ln\left(\frac{z}{z_0}\right) - \Psi_m\left\{\frac{z}{L}\right\} + \Psi_m\left\{\frac{z_0}{L}\right\}\right] for\ 7z_0 \le z < z_i \qquad \text{(MFD Eq. 28)}$$

$$u = u\{z_i\}\ for\ z > z_i$$

Where,

u is wind speed (m/s),
u_* is surface friction velocity (m/s),
z_0 is the surface roughness length (meters),
z_i is the mixing height (meters),
z is the height (meters),
L is the Monin-Obukhov length,
Ψ_m is the stability function for momentum which is defined in Table 1.

AERMOD interpolates the wind speed at the observed profile height by calculating the wind speed using the similarity theory at the gridded profile height directly above and below the observed profile height.

The RLINE source differs from the other AERMOD sources in the wind speed profile calculations. There are two major differences to the wind speed calculations in RLINE compared to AERMOD. First, RLINE follows the MFD Eq. 28 expect above the boundary layer height, $z > z_i$, where RLINE continues to use the equation for $7z_0 \le z < z_i$. AERMOD keeps the wind speed constant above the boundary layer, and RLINE continues to calculate an increasing wind speed. The second major difference is that RLINE includes the displacement height in Ψ_m. The changes to the calculation of Ψ_m in RLINE and AERMOD are described in Table 1.

Table 1: Comparison of the stability function equations used in AERMOD generally and in RLINE

	Parameter	AERMOD	RLINE
Stable	$\Psi_m\left\{\frac{z}{L}\right\}$	$-17\left(1 - e^{\frac{-29z}{L}}\right)$	$-17\left(1 - e^{\frac{-29(z-dh)}{L}}\right)$
	$\Psi_m\left\{\frac{z_0}{L}\right\}$	$-17\left(1 - e^{\frac{-29z_0}{L}}\right)$	
Convective	$\Psi_m\left\{\frac{z}{L}\right\}$	$2\log\left(\frac{1+X_0}{2}\right) + \log\left(\frac{1+X_0^2}{2}\right) - 2\tan^{-1}(X_0) + \frac{\pi}{2}$	
		$X_0 = \left(1 - \frac{16z}{L}\right)^{0.25}$	$X_0 = \left(1 - \frac{16(z-dh)}{L}\right)^{0.25}$
	$\Psi_m\left\{\frac{z_0}{L}\right\}$	$2\log\left(\frac{1+X_{z0}}{2}\right) + \log\left(\frac{1+X_{z0}^2}{2}\right) - 2\tan^{-1}(X_{z0}) + \frac{\pi}{2}$	
		$X_{z0} = \left(\frac{1-16z_0}{L}\right)^{0.25}$	

Where,

z_0 is the surface roughness length (meters),
z is the height (meters),
L is the Monin-Obukhov length,
dh is the displacement height (meters).

3.2 Original Calculation of Total Concentration for RLINE Source

The original RLINE source order of the calculations are as follows, calculation of:

1. Concentrations from the coherent plume (receptor height = flagpole)
2. Concentrations from the meander plume (receptor height = flagpole)
3. Total concentration by combining meander and coherent plumes using the ***meander*** weighting fraction.

4.0 Modification of RLINE Source Type Calculations to Include Terrain Treatment

The original RLINE source did not account for the effects of terrain when calculating the total concentration, which can lead to over/under estimation of concentrations. In AERMOD terrain is included by weighting the coherent and random portions of the plume, and when incorporating terrain into RLINE the same methods were followed.

4.1 Calculation of critical height and terrain weighting factor using RLINE's wind speed profile

The RLINE source type incorporates terrain by first calculating the critical height and a terrain weighing factor using the critical height. The computation of critical height depends on the wind speed as a function of height. Again, RLINE has a wind speed profile slightly different from the other AERMOD source types, as was described in Section 3.0. A wind speed profile is computed for the same heights as the other AERMOD sources and is used instead of the AERMOD wind speed array in the computation of critical height.

4.2 Modified calculation of total concentration to account for terrain

The steps to calculate the concentration of RLINE source that incorporate terrain include, the calculation of:

1. Computation of concentrations from the two coherent plumes:
    a. Horizontal impacting plume (receptor height = flagpole + terrain)
    b. Terrain following plume (receptor height = flagpole)
    c. Combine using the *terrain* weighting fraction.
2. Computation of meander plume:
    a. Horizontal impacting plume (receptor height = flagpole + terrain)
    b. Terrain following plume (receptor height = flagpole)
    c. Combine using the *terrain* weighing fraction.

3. Computation of total concentration: combine the coherent plume and the meander plume using the *meander* weighting fraction.

5.0 Model Intercomparison Setup

AERMOD was run with two sets of meteorological data and seven different receptor grids. The seven receptor grids were designed to test the impacts of terrain at a variety of slope angles chosen based on the thresholds for AERMAP (U.S. EPA, 2018). The smaller set of meteorological data was used for most of the testing to examine impacts of a variety of stability conditions and wind speeds. The larger, yearlong dataset included a multitude of wind directions, atmospheric conditions, and surface roughness values, and was used to test the impacts of terrain on runtimes and in a wide range of realistic meteorology conditions.

5.1 Meteorology

The AERMOD runs used a simple, representative meteorology, created from MAKEMET (U.S. EPA, 2022), which includes 22 hours covering 6 stability conditions and wind speeds ranged from 0.5 – 18.0 m/s. One run was done for a year of meteorological data which used data from Raleigh-Durham International Airport (RDU) during the entire year of 2018. This captured a wide range of real meteorological conditions and scenarios which were not shown in the representative meteorology dataset.

5.1.1 Representative Meteorology

The influence of terrain on the total concentration at a receptor varies depending on the meteorological conditions; therefore, various conditions were tested. Most of the model runs used a simple representative meteorology created from MAKEMET. Winds are from 270 degrees in all hours, which would blow along the positive x-axis for all source and receptor configurations. A range of surface roughness values from 0.01m to 1.0m was used to generate 22 hours of representative meteorology; however, only a subset was selected for specific presentation in this document.

The subset consists of three hours as shown in Table 2**Error! Reference source not found.**. The three hours represented all atmospheric stability conditions and a range of wind speeds. The terrain algorithm behaves differently in convective and stable conditions, as described in Section 0. These three hours show variable response to the ridge terrain feature in each atmospheric stability condition and are compared with the terrain response of the LINE and VOLUME source types in Section 6.0.

Table 2: Subset of representative meteorology used in analysis

Datetime	Wind Speed (m/s)	Surface Roughness (m)	U* (m/s)	W* (m/s)	Mixing Height (m)	Monin-Obukhov Length (m)	PG
1/1/2000 20:00:00	0.5	0.01	0.048	-9	24	13.4	6
2/17/2000 12:00:00	4		0.284	1.8	756	-7.4	1
2/26/2000 6:00:00	10		0.589	1.2	1041	-285.2	4

5.1.2 One Year of Meteorology

The most recent year of pre-processed meteorological data from the North Carolina Department of Environmental Quality (NCDEQ) for RDU was downloaded and used for this analysis (https://www.deq.nc.gov/about/divisions/air-quality/air-quality-permitting/modeling-meteorology/meteorological-data). The year of meteorological data from RDU was paired with concurrent upper air data from the Piedmont Triad International Airport (GSO) in Greensboro, NC, and the AERSURFACE options reflect "wet" conditions for 2018. This data set covered a wide range of values which are described in Table 3. The total number of valid hours is 8714 of the possible 8760 for 2018, which represents 99.5% completeness. This large set of meteorological hours show variable response to the ridge terrain feature and are compared with the terrain response of the LINE and VOLUME source types in Section 6.0.

Table 3: Range of values from Raleigh-Durham International Airport during 2018

Wind Speed (m/s)	Wind Direction (deg)	Surface Roughness (m)	U* (m/s)	W* (m/s)	Mixing Height (m)	Monin-Obukhov Length (m)	PG
0.0 - 12.16	0 - 360	0.0170 – 1.2860	0.017 - 1.98	0.010 – 1.894	5 - 4000	-8888.0 – 8888.0	1-6

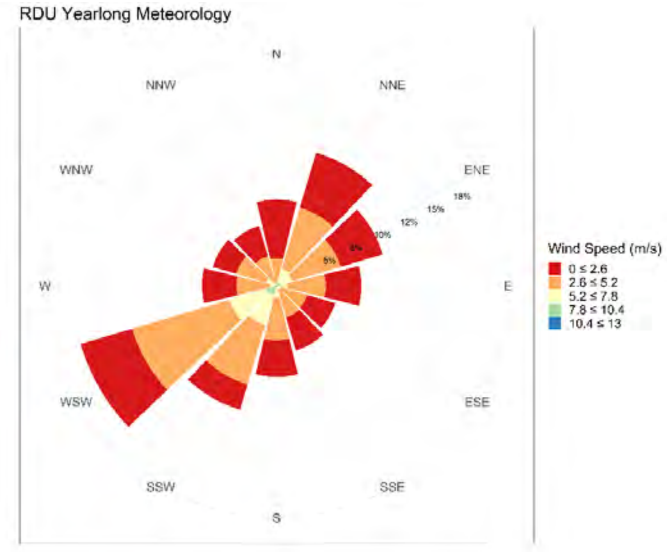

Figure 3: Windrose containing the wind speed and direction information for the year of meteorological data that came from Raleigh-Durham International Airport

5.2 Source Input

The RLINE roadway source was centered at the origin and runs along the x=0 axis of the receptor grid with a width of 3.6 meters and length of 600 meters. Equivalent LINE and VOLUME sources were generated for direct comparison with the RLINE source type. Source parameters for each source type are shown in Table 4, where each source type will have a total emission of 216 g/s.

Table 4: AERMOD input source parameters for the different source types.

Source	Number of Sources	σ_z (m)	σ_y (m)	Length (m)	Width (m)	Release Height (m)	Emission rate
RLINE	1	2.0	N/A	600	3.6	1.3	0.1 g/ m^2/s
LINE							0.1 g/m^2/s
VOLUME	167		1.674	N/A	N/A		1.2934 g/s

5.3 Receptors

A dense spatial grid of receptors (-500 m – 500 m) with 10 m spacing in the x and y directions was used for all cases, for a total of 10,200 receptor locations. Rather than using AERMAP, a similar process was used to determine the terrain and hill heights for all receptor locations in the spatial grid.

Four types of receptor grids were used for analysis to fully resolve the impacts of terrain at different elevation gradients. Table 5 describes the different combination of terrain types and elevation profiles which were used to make the receptor grids.

Table 5: Receptor grid slope angles and terrain types

Terrain Type	Slope Angle	Upslope Starts	Peak	Downslope Ends	Max Height
Flat	None	N/A	N/A	N/A	0.0 m
Ridge	5-degrees	x = 110 m	x = 250 m	x = 390 m	12.5 m
	10-degrees				24.69 m
	30-degrees				80.83 m

Figure 4 spatially represents all terrain and angle combinations, colored by terrain elevation. In the ridge terrain example, there is a clear line of elevated terrains.

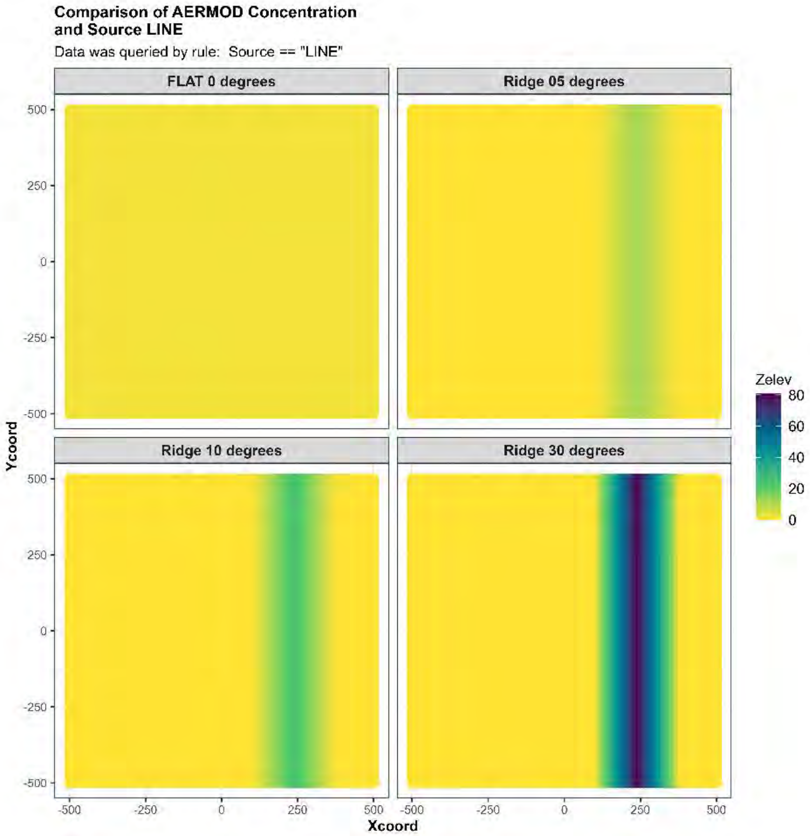

Figure 4: Terrain elevation (Zelev) for all receptor grids and slope angles examined.

6.0 Model Evaluation and Comparison: Results

The RLINE terrain implementation is compared with the VOLUME and LINE sources, which both incorporate terrain and can approximate a line/roadway type source equivalent to an RLINE source. During comparison, note the LINE source type does not include meander like the VOLUME and RLINE sources; therefore, only the downwind concentrations are examined. Also, consider that during low wind conditions the LINE source type may overpredict compared to VOLUME and RLINE due to the lack of a low wind meander plume.

6.1 Low Wind Speed – Stable

The stable hour from the 22 hours of representative meteorology that was used for discussion of the RLINE source with terrain is shown in Table 6. During stable atmospheric conditions, the terrain weighting factor will vary between ½ and 1 as described in Section 2.1. The resulting concentrations in this section will fully represent the impacts of terrain.

Table 6: Stable hour with low wind speeds from the representative meteorology

Datetime	Wind Speed (m/s)	Surface Roughness (m)	U* (m/s)	W* (m/s)	Mixing Height (m)	Monin-Obukhov Length (m)	PG
1/1/2000 20:00:00	0.5	0.01	0.048	-9	24	13.4	6

The gradient plots in Figure 5 shows the concentration for each model and terrain type along Y = 0 m (which is the center of the source and terrain feature) and X > -25 m (to remove upwind concentrations from analysis). In all terrain cases, RLINE concentrations are lower than the LINE and VOLUME source concentrations. The RLINE source with ridge terrain feature has a larger decrease in concentrations in response to the terrain than the LINE or VOLUME sources. The RLINE source type was affected further upwind and downwind of the terrain feature than LINE or VOLUME. There is also a noticeable difference in the peak concentration for each source type. This is due to a few factors: the VOLUME source has an exclusion zone, so not all volume sources contribute to the concentration at receptors closest to the source roadway source; the AREA/LINE source does not include meander treatment, so when receptors are within the source width only the portion of the source upwind of the receptor contributes to the receptor concentration. The discrepancy in peaks is particularly noticeable for the receptor at 0 m.

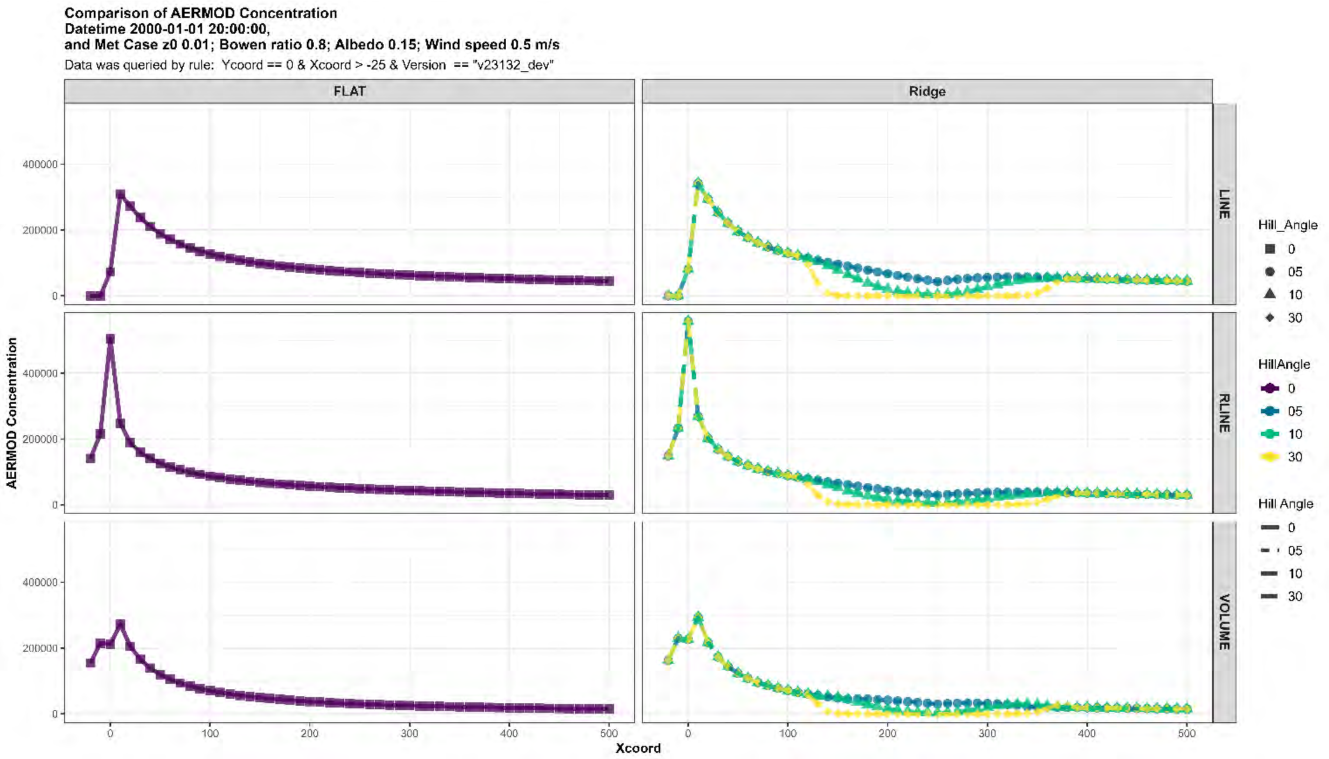

Figure 5: Gradient plot of LINE, RLINE, and VOLUME source types for all terrain cases during the stable hour

The case with no terrain and a flat elevation profile was used as a baseline to test if the incorporation of terrain into RLINE had impacts that were unexpected and identify the differences in concentrations between the three source types.

The spatial plots shown in Figure 6 show the difference in the spread of concentrations in the LINE source type compared to RLINE and VOLUME. Along the x-axis the RLINE and LINE concentrations are similar, and the VOLUME concentrations are significantly lower and decrease more quickly with an increased downwind distance.

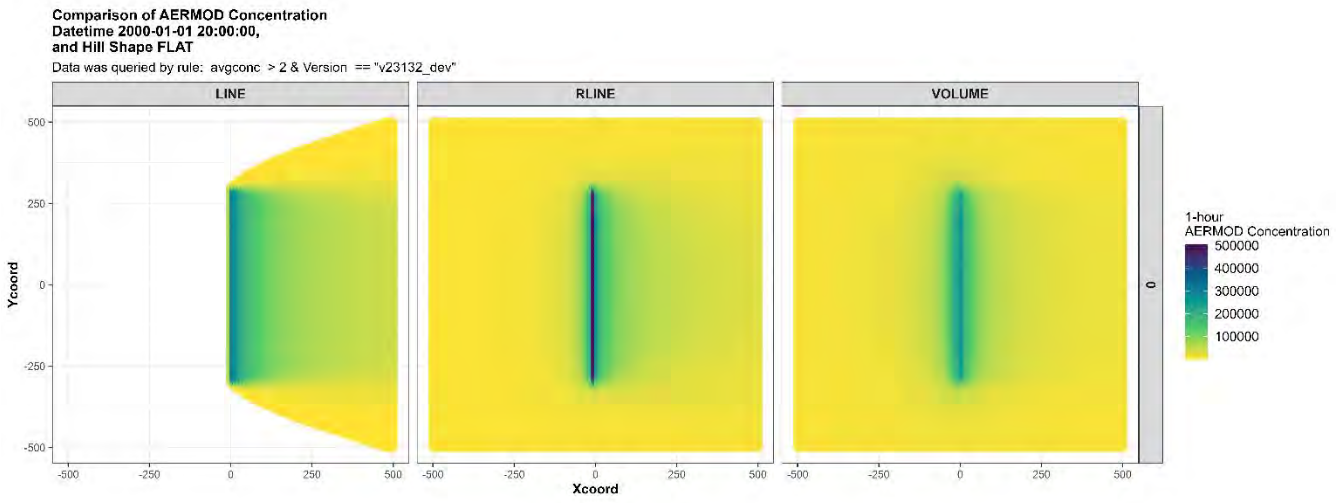

Figure 6: Spatial plot of the LINE, RLINE, and VOLUME source types for flat terrain during the stable hour

One of the terrain shapes, the ridge, was run for three slope angles, 5-, 10-, and 30-degrees. The spatial plots showing the concentrations for the three source types, Figure 7, show a similar result to the flat terrain case. RLINE concentrations downwind of the terrain feature are slightly higher than those for the LINE and the VOLUME sources. The area of low concentration over the terrain feature is slightly wider for the RLINE source than the other two source types. The overall shape of the concentration changes is the same between the three sources.

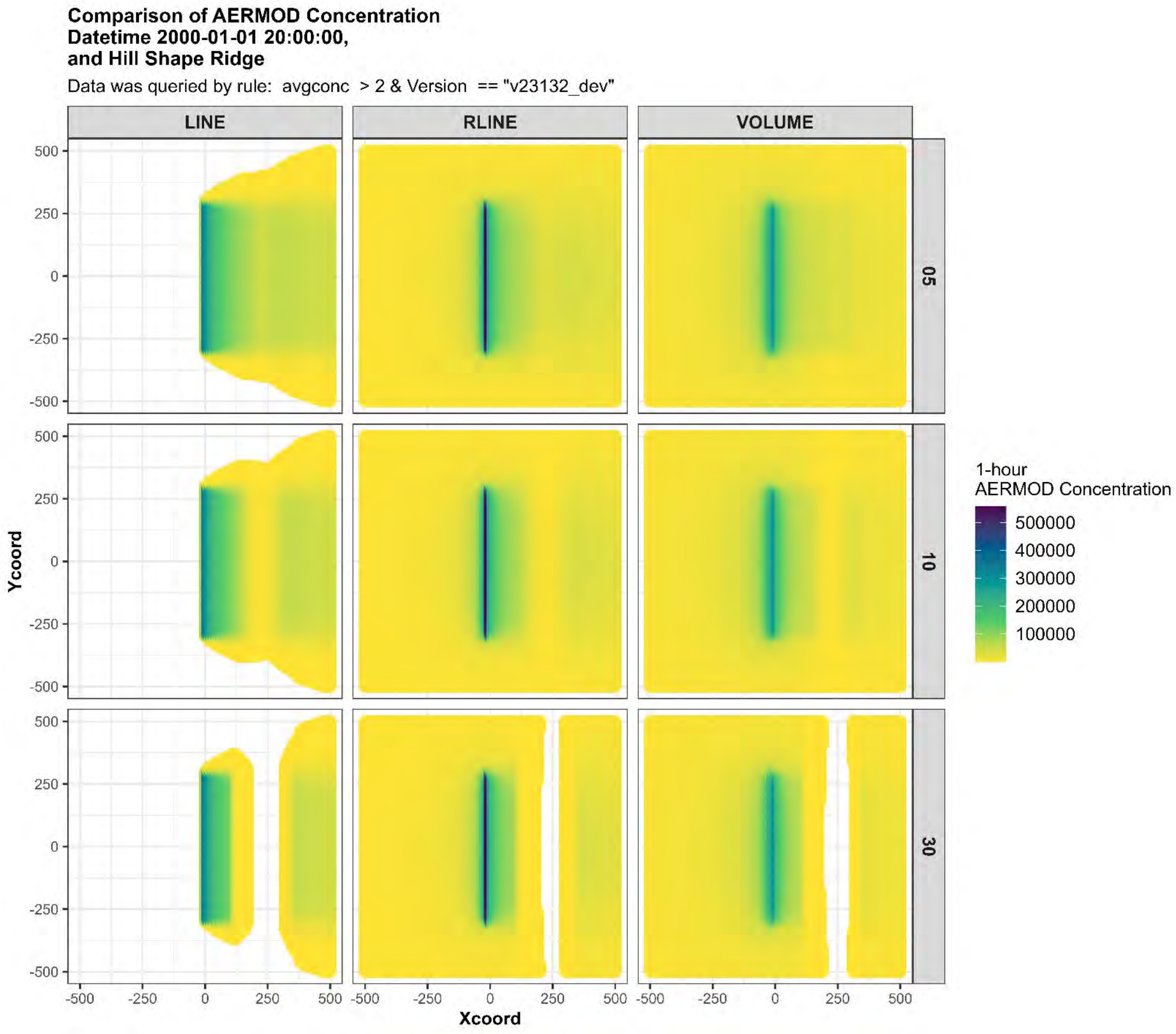

Figure 7: Spatial plot of the LINE, RLINE, and VOLUME source types for ridge terrain during the stable hour

6.2 Moderate Wind Speed – Convective

The convective hour highlighted for discussion is shown in Table 7. Recall from Section 2.1, during convective conditions the terrain weighting factor is set to ½ as the plume is assumed to be entirely above the critical dividing streamline height.

Table 7: Convective hour with moderate wind speeds from the representative meteorology

Datetime	Wind Speed (m/s)	Surface Roughness (m)	U* (m/s)	W* (m/s)	Mixing Height (m)	Monin-Obukhov Length (m)	PG
2/17/2000 12:00:00	4	0.01	0.284	1.8	756	-7.4	1

The gradient plots in Figure 8 show the concentration for each model and terrain type. Each figure is queried to Y = 0 to highlight the center of the source and terrain feature, and X > -25 m to remove upwind concentrations from analysis. In the flat terrain case, RLINE concentrations are slightly below the LINE and VOLUME source concentrations. The results from the variety of terrain cases continued this trend in concentrations.

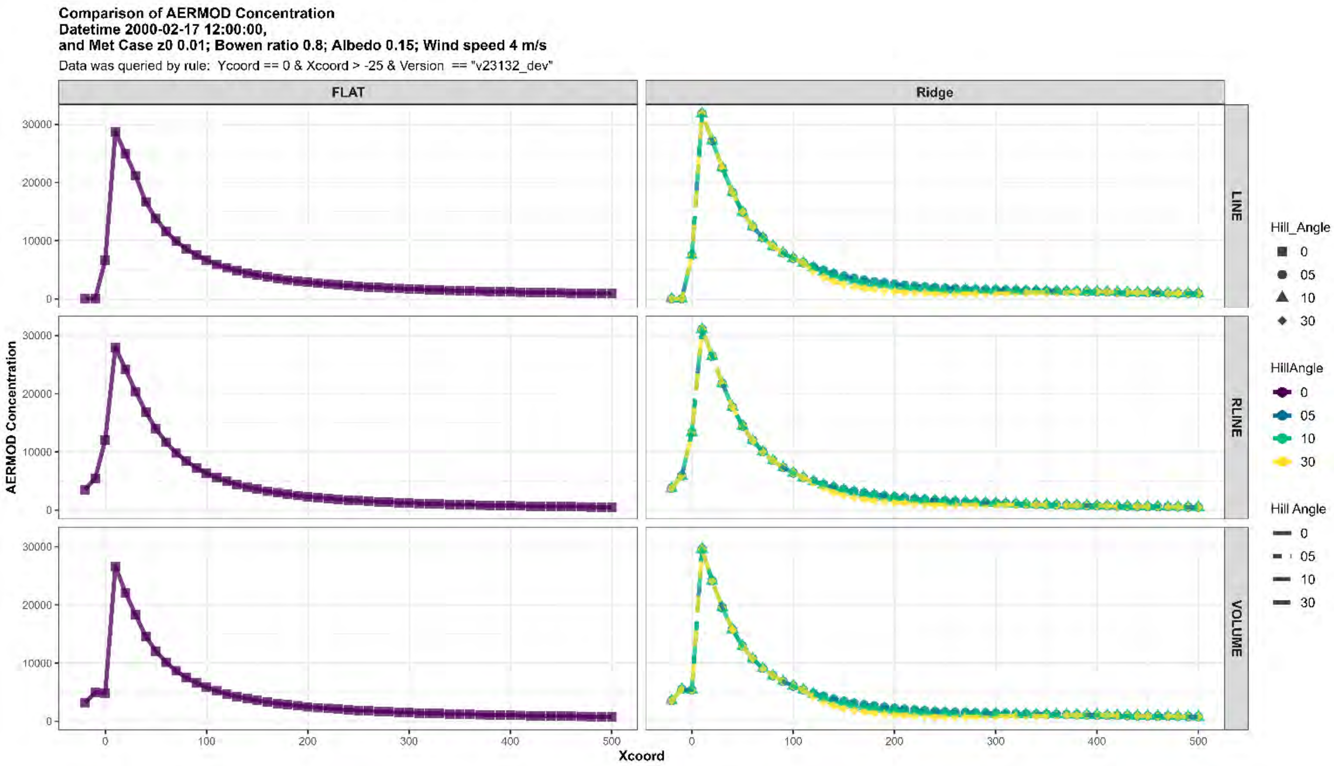

Figure 8: Gradient plot of LINE, RLINE, and VOLUME source types for all terrain cases during a convective hour

The case with no terrain and a flat elevation profile was used as a baseline to test if the incorporation of terrain into RLINE had impacts that were unexpected and was used as a baseline for the differences in concentrations between the three source types.

The spatial plots shown in Figure 9 show the difference in the spread of concentrations in the LINE source type compared to RLINE and VOLUME. However, along the x-axis, the concentrations are similar, VOLUME and LINE appear to have higher concentrations away from the source, which is centered on (0,0). The concentrations for the RLINE source type decrease more quickly with increased downwind distance at all points along the source when compared to the VOLUME and LINE sources.

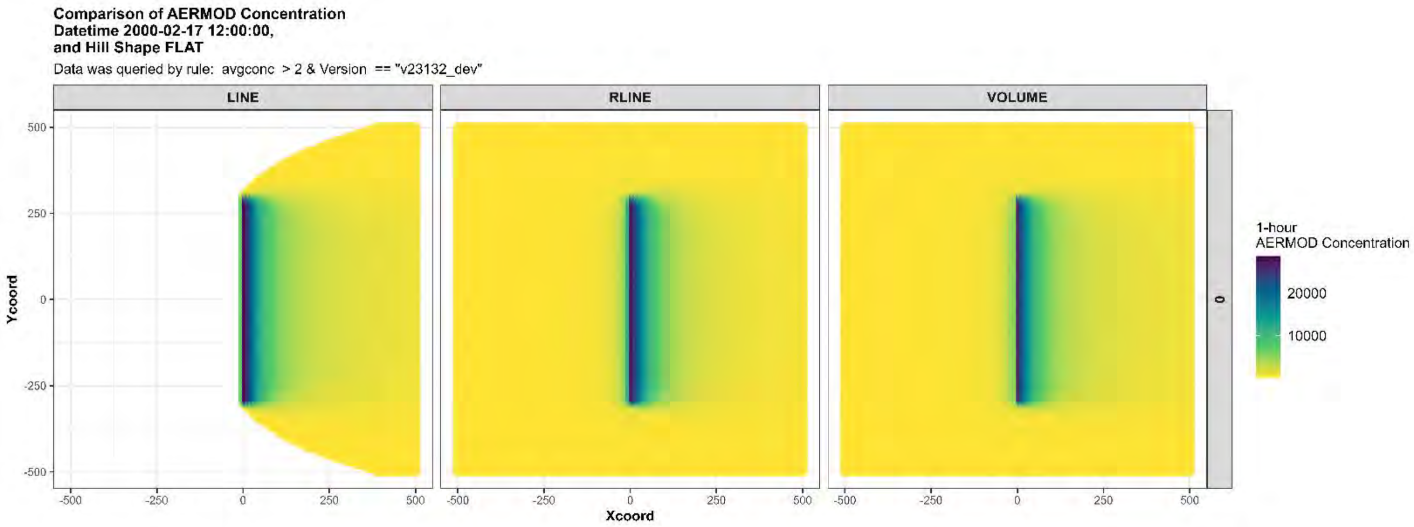

Figure 9: Spatial plot of the LINE, RLINE, and VOLUME source types for flat terrain during a convective hour

The ridge terrain shape was run for three slope angles, 5-, 10-, and 30-degrees. The spatial plots showing the concentrations for the three source types, Figure 10, show a similar result to the flat terrain case. The RLINE source has a sharper decrease in concentrations with increased downwind distance and an overall slightly lower concentrations than the VOLUME or LINE sources.

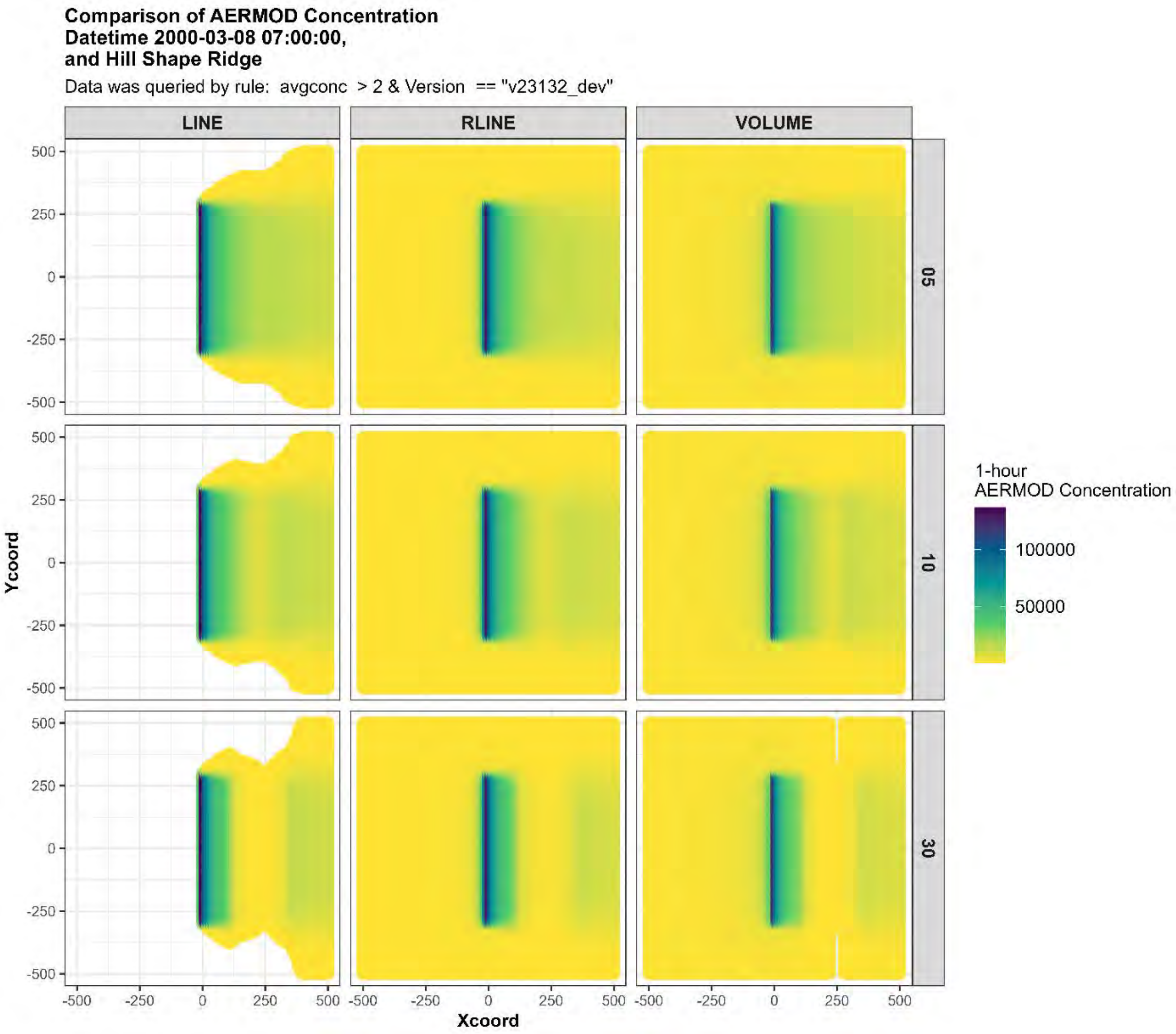

Figure 10: Spatial plot of the LINE, RLINE, and VOLUME source types for ridge terrain during a convective hour

6.3 High Wind Speed – Neutral

One neutral hour from the 22 hours of representative meteorology was used for discussion of the RLINE source with terrain. During neutral stability conditions the terrain weighting factor is set to ½ as the plume is assumed to be entirely above the critical dividing streamline height.

Table 8: Neutral hour with high wind speeds from the representative meteorology

Datetime	Wind Speed (m/s)	Surface Roughness (m)	U* (m/s)	W* (m/s)	Mixing Height (m)	Monin-Obukhov Length (m)	PG
2/26/2000 6:00:00	10	0.01	0.589	1.2	1041	-285.2	4

The gradient plots in Figure 11 shows the concentration for each model and terrain type along Y = 0 which is the center of the source and terrain feature and where X > -25 m to remove upwind concentrations from analysis. In the flat terrain case RLINE concentrations are between the LINE and

VOLUME source concentrations. The results from the variety of terrain cases continued this trend in concentrations. The RLINE source with ridge terrain feature and a 30-degree slope angle has a larger decrease in concentrations in response to the terrain than the LINE or VOLUME sources.

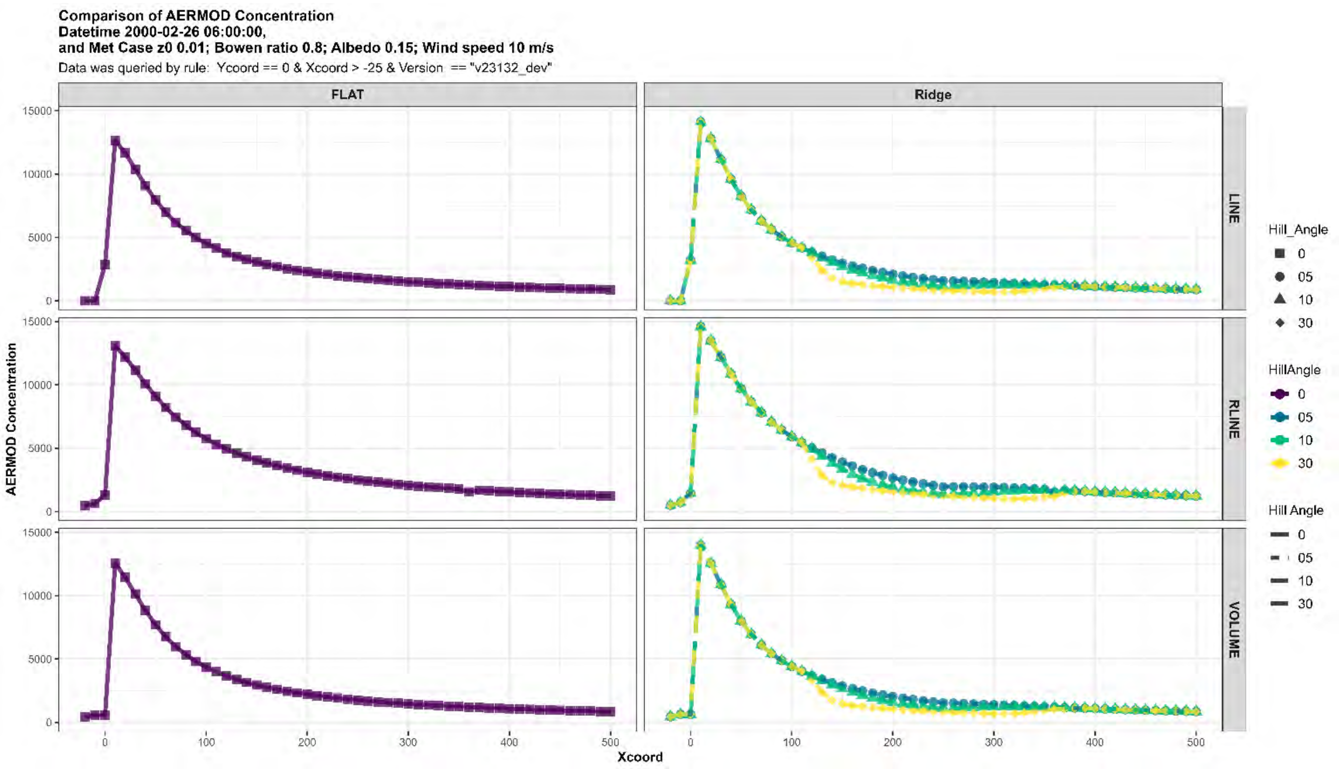

Figure 11: Gradient plot of LINE, RLINE, and VOLUME source types for all terrain cases during the neutral hour

The case with no terrain and a flat elevation profile was used as a baseline to test if the incorporation of terrain into RLINE had impacts that were not expected and identify the differences in concentrations between the three source types.

The spatial plots shown in Figure 12 show the difference in the spread of concentrations in the LINE source type compared to RLINE and VOLUME. Along the x-axis the concentrations are similar between the three sources. The concentrations for the RLINE source type decrease more quickly with increased downwind distance at all points along the source when compared to the VOLUME and LINE sources.

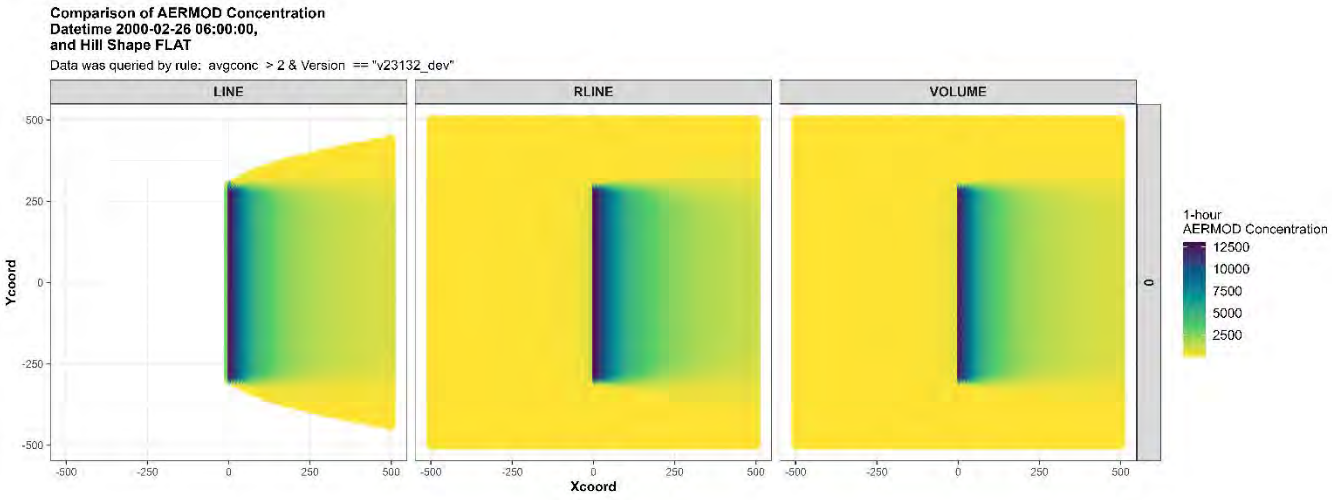

Figure 12: Spatial plot of the LINE, RLINE, and VOLUME source types for flat terrain during the neutral hour

One of the terrain shapes, the ridge was run for three slope angles, 5-, 10-, and 30-degrees. The spatial plots showing the concentrations for the three source types, Figure 13, show a similar result to the flat terrain case. The RLINE source has a sharper decrease in concentrations with increased downwind distance and overall, slightly lower concentrations than the VOLUME or LINE sources.

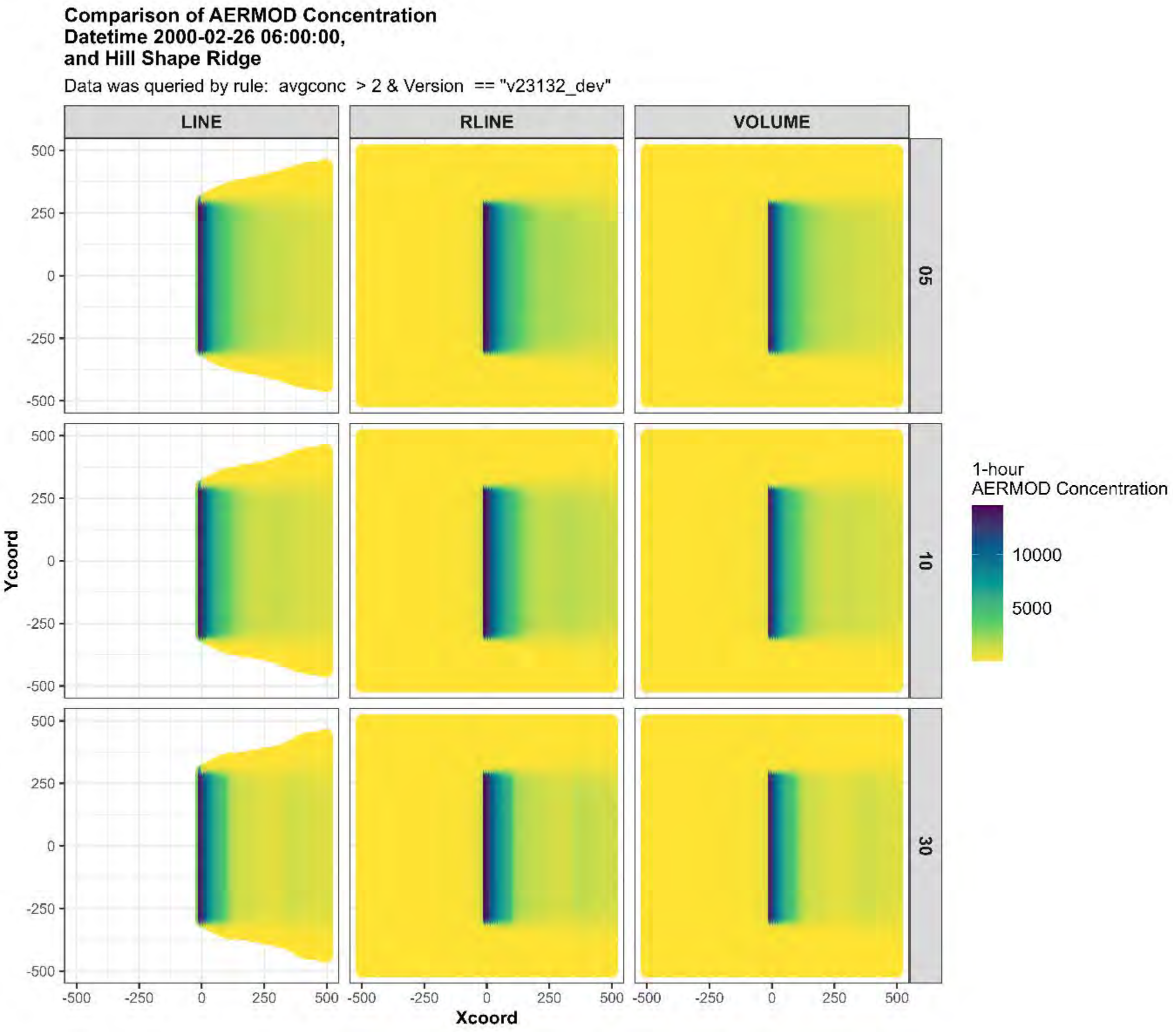

Figure 13: Spatial plot of the LINE, RLINE, and VOLUME source types for ridge terrain during the neutral hour

6.4 Yearlong Meteorology

In addition to the representative meteorology, one year of meteorology collected from RDU was used to gain a better understanding of the runtimes associated with the new algorithms and to see the impacts on the model in more diverse meteorological condition. A summary of the meteorological conditions can be found in Table 3. The results of these runs can be found in Figure 14. Overall, the RLINE concentrations are slightly lower than the LINE concentrations. This lower RLINE concentration is due to the treatment of meander, as some of the emissions mass is shifted into the meander plume.

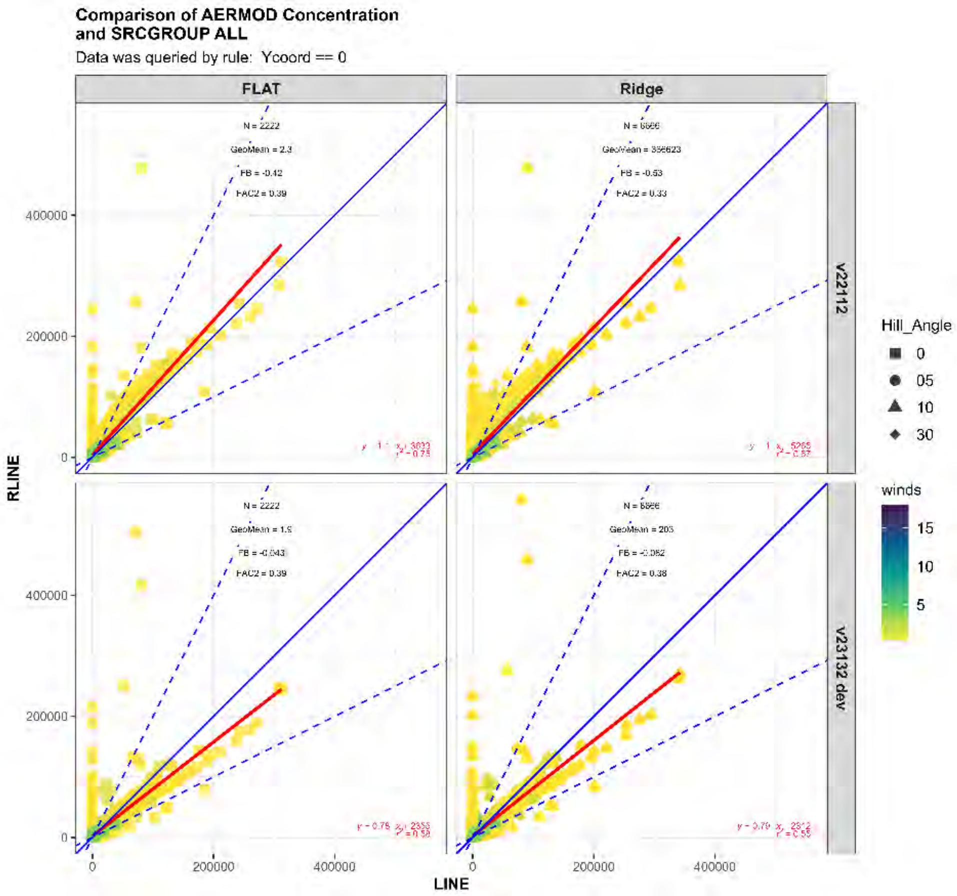

Figure 14: SRCTYPE LINE versus RLINE for v22112 and v23132 for the Flat and Ridge terrains along X-axis.

RLINE concentrations from v22112 (without RLINE terrain) v23132 (including RLINE terrain) are compared to the VOLUME source in Figure 15. The results of this intercomparison showed that during stable conditions concentrations were typically lower for small concentrations when accounting for terrain, but higher for the highest concentrations when accounting for terrain. However, concentrations are nearly identical during neutral and slightly higher in convective conditions.

Outliers in Figures 14 and 15, where RLINE concentrations are greater than a factor of two higher than the LINE and VOLUME sources are where receptors are located very close to the source. A similar observation was seen in the gradient plots (for e.g., Figure 11), where the RLINE peak was higher than the LINE and VOLUME sources due to exclusion of part of the source or exclusion zones for receptors very close to the source.

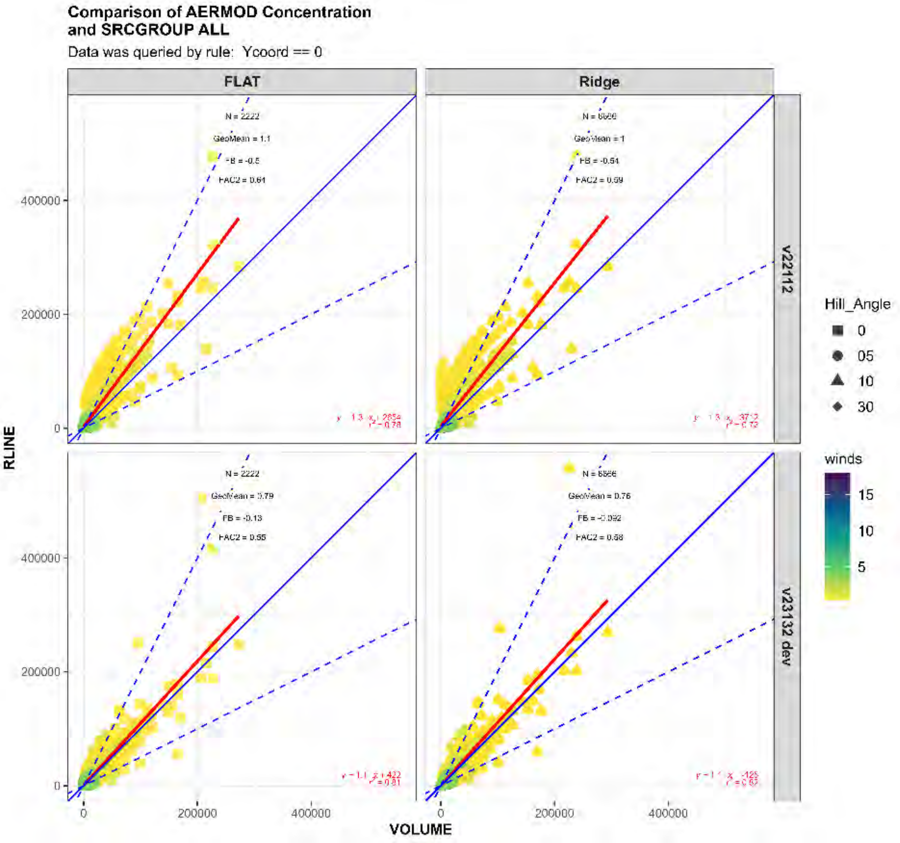

Figure 15: SRCTYPE VOLUME versus RLINE for v22112 and v23132 for the Flat and Ridge terrains along X-axis.

7.0 Discussion and Conclusions

The RLINE source type was developed for use in flat terrain, which ignored the localized elevation and hill height variations at source and receptor locations and the complex terrain in the calculation of dispersion. The addition of terrain into RLINE mimicked the implementation of terrain in the VOLUME and LINE sources as closely as possible. RLINE was developed as an independent source which was incorporated into AERMOD. There are multiple other differences between RLINE formulation and the other source types currently in the model, though it should be noted that there are differences in formulations between these other source types (e.g., the AREA source does not account for meander or only the POINT source can model plume rise). There are two differences that can have an impact on the implementation of terrain: 1) RLINE uses different dispersion curves and 2) RLINE estimates the transport windspeed as a function of height slightly different than the other AERMOD sources. Since the terrain weighting factor uses critical height, which is impacted by the wind speed profile, there will inherently be small differences in the RLINE terrain processing from the other AERMOD sources, though no more so than for dispersion without terrain considerations. Modifications to the calculation of critical height were made since RLINE generates a wind table which uses displacement height in the calculation of the vertical profile of wind speed, rather than a displacement height of 0 as is done in other AERMOD source types.

The incorporation of terrain into RLINE concentration calculations was tested with seven receptor grids, two meteorological datasets, and compared against two source types in AERMOD which include terrain. The analysis detailed in this document highlighted three hours of the 22 representative meteorology hours which covered three stability conditions and three wind speeds. During convective and neutral conditions, the terrain weighting factor is set to ½ for all source types and the results of the model analysis showed RLINE concentrations that were either between the VOLUME and LINE source or slightly below their concentrations. The RLINE source did have a larger response to terrain than either source, especially for the 30-degree slope. As noted above, some of the underlying differences in the RLINE formulation (dispersion curves and transport wind speeds, in addition to the lack of meander for the LINE source) will inherently lead to differences between the three model approaches.

The terrain weighting factor varies as a function of the wind speed and temperature gradient during a stable atmosphere and the results of the analysis during this meteorology hour showed the largest impacts of terrain on all three source types. RLINE again had slightly lower concentrations than either LINE or VOLUME sources at the terrain feature. RLINE also had a larger response to terrain for all slope angles.

A yearlong meteorological dataset was also used to gain a better understanding of the runtimes associated with the new algorithms and to see the impacts on the model in more diverse meteorological conditions. The yearlong model test did not reveal any potential issues and supports the conclusion that terrain processing has been successfully added to the RLINE source, consistent with the other AERMOD sources.

Overall, the new algorithms to incorporate terrain into RLINE appear consistent with the response for the other source types.

8.0 Future Work

There is still work that could be done to improve and further test the implementation of terrain into the RLINE source. As discussed in the previous section, due to the inclusion of calculating the direct and meander plume twice for each point along the integration line, there is a dramatic increase in runtime of the RLINE source compared to the LINE source. Finally, there is further testing that could be explored to ensure that the RLINE source is performing as expected. RLINE with terrain could be tested with deposition, MAXDCONT, NO_2 chemistry methods, and event processing.

9.0 References

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