
# User's Guide for AERSURFACE Tool

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## Preface

This document provides a technical description and user instructions specific to the AERSURFACE tool, version 24142 (dated May 22, 2024, representative of the code lock date). AERSURFACE was designed to aid in determining surface characteristic values required by AERMET, the meteorological processor for AERMOD. This version, 24142, includes minor updates and replaces version 20060. The updates in version 24142 have expanded the capability to read and process all available years (i.e., 1985 – 2023) of Annual National Land Cover Database (NLCD) land cover data which can be supplemented with percent tree canopy and percent impervious where available. Version 24142 maintains the interface that uses the path/keyword approach read from a control file, similar to AERMET, AERMAP, and AERMOD.

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## 1.0 Introduction

When applying the AERMET meteorological processor (EPA, 2024a) to process meteorological data for the AERMOD model (EPA, 2024b), the user must determine appropriate values for three surface characteristics: surface roughness length, noontime albedo, and daytime Bowen ratio. The surface roughness length is related to the height of obstacles to the wind flow and is, in principle, the height at which the mean horizontal wind speed is zero based on a logarithmic profile. The surface roughness length influences the surface shear stress and is an important factor in determining the magnitude of mechanical turbulence and the stability of the boundary layer. The albedo is the fraction of total incident solar radiation reflected by the surface back to space without absorption. The Bowen ratio, an indicator of surface moisture, is the ratio of sensible heat flux to latent heat flux and, together with albedo and other meteorological observations, is used for determining planetary boundary layer parameters for convective conditions driven by the surface sensible heat flux. Further details regarding the AERMOD model formulations and their dependence on surface characteristics are provided in Cimorelli, et al. (2004).

The AERSURFACE tool has been developed to aid users in obtaining realistic and reproducible surface characteristic values for albedo, Bowen ratio, and surface roughness length, for input to AERMET. The tool uses data from the National Land Cover Database (NLCD) from the United States Geological Survey (USGS) and look-up tables of surface characteristic values that vary by land cover type and season. This user's guide provides a technical description of the AERSURFACE tool, including information on the data used by AERSURFACE to provide these surface characteristics for AERMET. Detailed user instructions for application of AERSURFACE are also provided.

### 1.1 When to Use AERSURFACE

User-defined values for the surface characteristics referenced above must be developed for input to AERMET when processing site-specific surface meteorology, commonly collected onsite near the emission source, and/or surface meteorology collected at National Weather

Service (NWS)/Federal Aviation Administration (FAA) surface meteorological stations, typically located at airports across the country. AERMET can also accept prognostic meteorology generated by the Weather Research Forecast (WRF) model and extracted using the Mesoscale Model Interface (MMIF) program (EPA, 2019b). User-defined surface characteristics are not needed when prognostic data are extracted using MMIF since surface characteristics are included in the formatted MMIF output.

When processing site-specific and NWS/FAA surface data simultaneously with AERMET and the NWS/FAA wind data are used to substitute missing site-specific wind data, AERMET requires user-defined surface characteristic values for both meteorological station locations. In that case, the site-specific station is considered the primary site, and the NWS/FAA site is considered the secondary site. When NWS/FAA surface data are processed without site-specific data, the NWS/FAA site is considered the primary site since it is the only source of surface meteorology.

AERSURFACE is not a regulatory component of the AERMOD Modeling System as listed in Appendix A to the *Guideline on Air Quality Models* (published as "Appendix W" to 40 CFR Part 51), which includes the AERMAP and AERMET terrain and meteorological preprocessors, respectively, in addition to the AERMOD dispersion model. However, Section 8.4.2(b) of the *Guideline* recommends the use of the latest version of AERSURFACE for determining surface characteristics when processing measured meteorological data through AERMET (i.e., representative site-specific data or data from a nearby National Weather Service or comparable station). Where it is not possible to run AERSURFACE, Section 8.4.2(b) recommends using the methods in AERSURFACE to determine surface characteristic values. The methods implemented in AERSURFACE are also discussed in the AERMOD Implementation Guide (EPA, 2024c).

### 1.2 Changes from Version 20060 to 24142

AERSURFACE has been updated from version 20060 to version 24142 (dated May 22, 2024, representative of the code lock date). This version represents refined updates to version 20060 to improve user experience. The updates include:

- Added additional file checks for user input files (i.e., land cover, impervious, and canopy data).

- Updated the DATAFILE keyword to allow processing of all current and future NLCD years which can be supplemented with perent impervious and percent tree canopy data, where available.

- Renames the Airport (AP) and Non-Airport (NONAP) flags to LOWZ0 and HIGHZ0 respectively to improve user understanding of when to apply these flags.

- Made changes to the file resolution tolerance to accommodate for NLCD files downloaded from the MRLC that do not have an exact 30 x 30-meter resolution.

- Made updates to prevent users from using input files (i.e., land cover, impervious, and canopy data) with grid sizes less than or equal to 10 x 10-kilometer.

### 1.3 Status of AERSURFACE, Version 24142

The EPA is releasing AERSURFACE version 24142 as a replacement for version 20060. The EPA recommends the following when using version 24142 of the AERSURFACE tool:

- The default method for determining surface roughness length (ZORAD) should be used. The ZOEFF method is considered research grade and should be used only for testing and evaluation purposes.

- Land cover data should only be supplemented with concurrent percent impervious and percent tree canopy data (i.e., data representative of one year should not be substituted for another year).

- For the NLCD year of the land cover being processed, if only one of impervious or tree canopy data is available, or neither is available, then the land cover data should be processed by itself without the use of the impervious or tree canopy data. Land cover data should not be supplemented with impervious data only or tree canopy data only.

As an example, to demonstration the last two bulleted items above, the 2023 NLCD includes land cover and percent impervious data for the conterminous US (CONUS) but does not include percent tree canopy data. When relying on the 2023 NLCD to determine surface characteristic values for input to AERMET, the 2023 land cover should be processed with AERSURFACE by itself and not supplemented with percent impervious and/or percent tree canopy data since the 2023 NLCD does not include both percent impervious **and** percent tree canopy data that are concurrent with the 2023 land cover data.

## 2.0 Technical Description of AERSURFACE

This section discusses the land cover data that are input to AERSURFACE and a technical description of how those data are processed to determine representative values of albedo, Bowen ratio, and surface roughness length.

## 2.1 Description of the National Land Cover Database

AERSURFACE requires the input of land cover data from the NLCD to determine the land cover types at a user-specified location. NLCD products are created by the Multi-Resolution Land Characteristics Consortium (MRLC), https://www.mrlc.gov/) a partnership of Federal agencies led by the USGS and serves as the definitive Landsat-based land cover database for the Nation. At the time of the release of AERSURFACE version 24142, the MRLC has released annual NLCD products for the contiguous US (CONUS) for all years between 1985 and 2023. The release of the 2024 Annual NLCD updates the previous 2021 versions of landcover products. Version 24142 of AERSURFACE has been modified to accept all annual NLCD years as well as new years of NLCD data as they are released.

The original 1992 NLCD used a 21-class land cover classification scheme. With the 2024 NLCD updates, all years of available land cover data (i.e., 1985 – 2023) now use the 16 Anderson Level II classes. Beginning with the 2001 NLCD, the datasets were expanded to include land cover for Alaska, Hawaii, and Puerto Rico for certain years. In addition, new products were added to the NLCD to include data which supplement the land cover data with the percent area of the surface in a land cover grid cell that is impervious material and the percent area of the grid cell that is covered with a tree canopy. Percent impervious data is available for all annual NLCD years (i.e., 1985 – 2023) and tree canopy data is available for 2011 through 2021 for CONUS. AERSURFACE version 24142 has the capability to process the impervious and tree canopy data as a supplement to land cover. Refer to EPA's recommendations above for processing NLCD files based on available data products. Refer to the Multi-Resolution Land Characteristics (MRLC) Consortium website at https://www.mrlc.gov for information on NLCD data products.

**Note: The USGS has indicated that support for the original 1992 NLCD has been discontinued and will no longer distribute the original 1992 NLCD, though the capability to process the 1992 NLCD has been retained in AERSURFACE version 24142. Sources for obtaining model-ready NLCD files are provided in Section 2.2. Also note, as with 19039_DRFT and version 20060, the 1992 NLCD "binary" (.bin) state files, previously**

**available from the USGS, are not supported by AERSURFACE version 24142. Future versions of AERSURFACE will no longer support the original 1992 NLCD and the EPA encourages users to switch to the new annual NLCD products available from the MRLC.**

The NLCD identifies the predominant land cover at a resolution of 30 x 30-meter grid cells. Recently, in 2024, land cover files downloaded from the MRLC have not had exact 30 x 30-meter grid resolutions. The resolutions of some files have been off by as much as five hundredths of a meter. AERSURFACE version 24142 has an increased file resolution tolerance to accommodate for the resolution differences we have observed.

AERSURFACE assigns each land cover category within each 30 x 30-meter land cover grid cell seasonal values of albedo, Bowen ratio, and surface roughness. Temporally representative average values (e.g., annual, seasonal, or monthly) are calculated for the area of interest from the seasonal values. AERSURFACE results are output in a format that is input ready for AERMET.

The original 1992 NLCD is based on a 21-category system while the current annual NLCDs use a 16-category system with 4 additional categories that are specific to Alaska. Category codes and names for each of the two classification systems are shown in Table 2-1 and Table 2-2. Complete category descriptions are provided in Section 5.0. The seasonal values assigned to albedo, Bowen ratio, and surface roughness length, by land cover category, for each of the two classification systems (original 1992 NLCD and annual NLCD) are provided in Section 6.0. Discussions of the methods implemented in AERSURFACE to calculate representative values for the three surface characteristics (albedo, Bowen ratio, and roughness length) are provided in Section 2.4.

**Table 2-1. Original 1992 NLCD Classification Categories**

| Classification | Category Number | Category Name |
|---|---|---|
| Water | 11 | Open Water |
| | 12 | Perennial Ice/Snow |
| Developed | 21 | Low Intensity Residential |
| | 22 | High Intensity Residential |
| | 23 | Commercial/Industrial/Transportation |
| Barren | 31 | Bare Rock/Sand/Clay |
| | 32 | Quarries/Strip Mines/Gravel Pits |
| | 33 | Transitional |
| Forested Upland | 41 | Deciduous Forest |
| | 42 | Evergreen Forest |
| | 43 | Mixed Forest |
| Shrubland | 51 | Shrubland |
| Non-natural Woody | 61 | Orchards/Vineyards/Other |
| Herbaceous Upland | 71 | Grasslands/Herbaceous |
| Herbaceous Planted/Cultivated | 81 | Pasture/Hay |
| | 82 | Row Crops |
| | 83 | Small Grains |
| | 84 | Fallow |
| | 85 | Urban/Recreational Grasses |
| Wetlands | 91 | Woody Wetlands |
| | 92 | Emergent Herbaceous Wetlands |

**Table 2-2. Annual NLCD Classification Categories**

| Classification | Category Number | Category Name |
|---|---|---|
| Water | 11 | Open Water |
| | 12 | Perennial Ice/Snow |
| Developed | 21 | Developed, Open Space |
| | 22 | Developed, Low Intensity |
| | 23 | Developed, Medium Intensity |
| | 24 | Developed, High Intensity |
| Barren | 31 | Bare Land (Rock/Sand/Clay) |
| Forest | 41 | Deciduous Forest |
| | 42 | Evergreen Forest |
| | 43 | Mixed Forest |
| Shrubland | 51 | Dwarf Scrub (Alaska Only) |
| | 52 | Shrub/Scrub |
| Herbaceous | 71 | Grassland/Herbaceous |
| | 72 | Sedge/Herbaceous (Alaska Only) |
| | 73 | Lichens (Alaska Only) |
| | 74 | Moss (Alaska Only) |
| Planted/Cultivated | 81 | Pasture/Hay |
| | 82 | Cultivated Crops |
| Wetlands | 90 | Woody Wetlands |
| | 95 | Emergent Herbaceous Wetlands |

Versions of AERSURFACE prior to 19039_DRFT were limited to the use of the original 1992 NCLD which subsequently limited its application to the conterminous U.S. As previously stated, AERSURFACE can now process land cover data from the 1985 to 2023 NLCDs. Where available, percent impervious and percent tree canopy data can be input into AERSURFACE to supplement land cover data. This is a refinement for certain annual NLCD land cover categories that are more difficult to assign roughness values due to a broader characterization of land cover for those categories (e.g., the “Developed” categories in the annual NLCD classification).

The NLCD files processed by AERSURFACE require a spatial resolution of 30 meters, mapped using an Albers Conic Equal Area projection. The files input to AERSURFACE must be in the Georeferenced Tagged Image File Format (GeoTIFF) (Aldus, 1992; Ritter and Ruth, 1995). In addition, AERSURFACE requires that the land cover data are stored in the GeoTIFF as a single byte (8-bit) integer and the data are not compressed.

**Note: The USGS no longer supports the original 1992 NLCD as it has been replaced by the new annual NLCD products. Further, the MRLC website will no longer distribute the 1992 NLCD. Sources for obtaining model-ready NLCD GeoTIFF files are provided in Section 2.2. Also note, as with 19039_DRFT and version 20060, the 1992 NLCD "binary" (.bin) state files, previously available from the USGS, are not supported by AERSURFACE version 24142.**

### 2.2 NLCD Sources

Refer to the "NLCD Sources for AERSURFACE" file on EPA's SCRAM website for the most up to date information on where and how to obtain NLCD products for the conterminous US, Alaska, Hawaii, and Puerto Rico for use with AERSURFACE. The MRLC Consortium (https://www.mrlc.gov/) should be considered the primary source for information about current NLCD data products. The website includes reports, journal articles, and conference articles and abstracts that document product types, methods for generating the products, coverage, update cycles, and other product specifics. All data types (land cover, percent impervious, and percent tree canopy) are not available for all years and all locations. Users are reminded to refer to Section 1.3 for EPA's recommendations for processing NLCD products with AERSURFACE based on data availability.

### 2.3 Assignment of Surface Characteristics by Land Cover Category

Each of the land cover categories in the two classification systems is mapped within AERSURFACE to a set of seasonal values of albedo, surface roughness length, and Bowen ratio. However, there are categories for which one or more of these surface characteristics

cannot be adequately represented by a single seasonal value due to the climate of the area or the physical setting and broader use of the area, such as if the location is an airport. This section addresses the assignments of seasonal values and the special cases that are considered. The seasonal values to the surface characteristics, by land use category, are provided in Section 6.0.

### 2.3.1 Seasonal Values

The values of the surface characteristics, by land cover category, were developed for five seasonal categories. The seasonal categories and the default months that comprise each season are listed in Table 2-3. These seasonal categories are the same as those used by the AERMOD model (EPA, 2024b) for the gas deposition algorithms (GDSEASON keyword). When seasonal surface values are generated for input to AERMET, default monthly assignments will be used. For monthly and annual values, the user is given the option of assigning the individual months to a seasonal category that is appropriate for the climate and conditions at the specific location. This option will allow a more locally appropriate estimate that is more reflective of the area. Otherwise, the user can select to use the program's default setting which assigns the months of March, April, and May to "Transitional spring with partial green coverage or short annuals;" June, July, and August to "Midsummer with lush vegetation;" and September, October, and November "Autumn with unharvested cropland." The user can indicate whether the area experiences continuous snow cover in the winter. If the area experiences periods of continuous snow cover during the winter, then the months of December, January, and February are assigned to "Winter with continuous snow on ground." If the area does not experience continuous snow cover, then the months of December, January, and February will be paired with surface characteristic values listed "Late autumn after frost and harvest, or winter with no snow." The user can opt to redefine the month-to-season assignments and separately identify which months experience continuous snow cover and those that do not. Further details regarding these user options are provided in Section 3.0.

**Table 2-3. AERSURFACE Season Definitions**

| Season Description | Default Month Assignments |
|---|---|
| Midsummer with lush vegetation | Jun, Jul, Aug |
| Autumn with unharvested cropland | Sep, Oct, Nov |
| Late autumn after frost and harvest, or winter with no snow | Dec, Jan, Feb |
| Winter with continuous snow on the ground | Dec, Jan, Feb |
| Transitional spring with partial green coverage or short annuals | Mar, Apr, May |

### 2.3.2 Surface Roughness Adjustments by Sector

In both the original 1992 and annual NLCD classification systems, there are categories that are more broadly defined and can have a mix of land cover that make it difficult to assign surface roughness values. More specifically, these are category 23, Commercial/Industrial/Transportation, in the original 1992 NLCD and categories 21-24 in the Developed class of the annual NLCD which include the Open Space, Low Intensity, Medium Intensity, and High Intensity categories, respectively. Surface roughness value assignments are more challenging in the annual NLCD since there is less specificity in the differentiation of the four Developed categories referenced above. They are made up of a more diverse mix of land cover types than the original 1992 NLCD Commercial/Industrial/Transportation category. The Developed categories in the annual NLCD are defined based on types and percentages of residences, vegetation (trees and grass), parks, roadways, runways, and industrial parks. The main distinction between these categories is the difference in the amount of vegetation and impervious surfaces, but the category definitions do not give much insight as to the types of impervious surfaces or the types of vegetation.

Additionally, in the annual NLCD, three categories in the original 1992 NLCD that delineated between Row Crops, Small Grains, and Fallow (categories 82-84 respectively), which can have different roughness values based on type and season, have been condensed into the single category of Cultivated Crops (82) in the annual NLCD classification scheme.

Thus, this simplification in the more recent classification scheme represents a loss of information helpful to determining roughness.

As a refinement, when available, AERSURFACE can now read and apply the percent impervious and percent tree canopy values to these annual NLCD "Developed" categories. When the land cover is supplemented with these data, the assigned values of surface roughness are weighted based on the amount of the grid cell that is impervious vs. covered with a tree canopy. This method of weighting the surface roughness is discussed in more detail below in Section 2.4.1.

Surface roughness values can be calculated and adjusted for user-defined wind sectors. Previous versions of AERSURFACE adjusted surface roughness values by defining a location or sector as "airport" or "non-airport". As described above, some sectors that are predominately made up of one or more categories that are ambiguous in their description may have a makeup that is more typical of an "airport" while others may not. If the site is described as an "airport", AERSURFACE will use surface characteristics that reflect an area dominated by transportation type land cover such as roadways, parking lots, and runways. For "non-airport" descriptions, AERSURFACE will choose higher surface roughness values that are more representative of an area dominated by buildings associated with commercial and industrial sites. Like the original 1992 NLCD, AERSURFACE assumes "airports" have lower roughness due to the presence of roads, runways, and other paved surfaces while "non-airport" descriptions are assumed to have higher roughness due to the presence of more buildings (i.e., lesser coverage of hard smooth surfaces at ground-level). As for vegetation, there is generally more grassy areas, common between the runways, than trees.

In rural areas, surface roughness adjustments can be made to sectors that are predominantly cultivated land to inform AERSURFACE to use roughness values that represent higher roughness if land cover is predominantly row crops and lower roughness if predominantly small grains or fallow. This reasoning has also been extended to the Pasture/Hay category (81) to delineate between higher roughness (tall grasses and hays) and lower roughness (short grasses).

Beginning with the draft version 19039_DRFT and carried forward in version 20060, individual sectors can be identified as either "airport" or "non-airport" sectors to more accurately represent the makeup of those sectors (e.g., a "Developed" category that is predominately made up of airport runways or paved lots vs buildings or structures). A sector can be identified as "airport" or "non-airport" independently of whether the meteorological tower is physically located at an airport and should be judged by the predominant land use within a kilometer radius of the meteorological tower, giving more weight to land use nearest the tower. Beginning with AERSURFACE version 24142, site and sector surface roughness values for categories described in this section may be described with the former "airport" or "non-airport" designation but may also be described with "lowz0" or "highz0." Use of these designations are described in sections 3.2.9 and 3.2.10.

### 2.3.3 Climate

Albedo, Bowen ratio, and roughness length can each be influenced differently for certain land cover categories based on if the region typically experiences arid conditions. The land cover categories that are differentiated based on arid vs non-arid conditions are those associated with the Barren, Shrubland, and Planted/Cultivated classes in the original 1992 NLCD and annual NLCD classification systems. In general, the albedo and Bowen ratio will be higher and the surface roughness lower for arid regions than for non-arid regions. **Note: If the user specifies that the location experiences continuous snow cover for at least one month during the year, AERSURFACE assumes that the area is non-arid.**

In addition, different values are assigned to Bowen ratio based on surface moisture due to precipitation and whether the site has experienced wetter than normal, dryer than normal, or average (normal) conditions, in general. The surface moisture condition for the site may vary depending on the meteorological data period for which the surface characteristics will be applied. AERSURFACE applies the surface moisture condition for the entire data period. Therefore, if the surface moisture condition varies significantly across the data period, then AERSURFACE may need to be applied multiple times to account for those variations. The surface moisture condition can be determined by comparing precipitation for the period of data

to be processed to the 30-year climatological record. It is recommended the user specify “wet” conditions if precipitation is in the upper 30th-percentile, “dry” conditions if precipitation is in the lower 30th-percentile, and “average” conditions if precipitation is in the middle 40th-percentile. However, the reader should consider that what is normal varies for different regions. A dry (or wet) climate could be more normal for an area, so even if the amount of precipitation is normal for a time period, the area might be more appropriately classified as “dry” (or “wet”). In these cases, the user should justify their categorization.

## 2.4 AERSURFACE Calculation Methods

Determining effective surface characteristics for processing meteorological data for use with the AERMOD model presents challenges. AERMOD is a steady-state plume model which assumes spatially uniform meteorological conditions across the modeling domain for each hour of meteorology, while land cover across the domain is typically very heterogeneous. A sound understanding of the important physical processes represented in the AERMOD model algorithms (Cimorelli, et al., 2004) and the sensitivity of those algorithms to surface characteristics is needed to properly interpret the available data and make an appropriate determination.

The recommendations for determining surface characteristics are presented in the AERMOD Implementation Guide (EPA, 2024c) and have been incorporated into AERSURFACE. These recommendations are summarized below, along with some additional options that are included for evaluation and feedback, to refine the methods currently used and extend the use of AERSURFACE with more recent land cover data (e.g., annual NLCD 1985-2023).

### 2.4.1 Surface Roughness Length

Based on model formulations and model sensitivities, the relationship between the surface roughness upwind of the measurement site and the measured wind speeds is generally the most important consideration. The surface roughness length should be based on an upwind distance from the measurement site that captures the net influence of surface roughness elements on the measured wind speeds needed to properly characterize the magnitude of mechanical turbulence in the approach flow. Such changes in surface roughness result in the development of an internal boundary layer (IBL) which grows with distance downwind of the roughness change, and defines the layer influenced by the roughness elements.

The default method in AERSURFACE calculates surface roughness length as an inverse distance weighted geometric mean, based on the land cover within the area around the meteorological tower out to a default fixed radial distance of a 1 kilometer (km) from the tower. Refer to the AERMOD Implementation Guide (EPA, 2024c) for a more detailed discussion of the selection of the default value of 1 km as it relates to growth of the IBL relative to the location and height of the wind measurements, as well as conditions for possible exceptions to this default distance. Beginning with version 19039_DRFT and carried forward in 20060 and 24142, this method is referred to as the "ZORAD" (fixed radius) option for estimating surface roughness length in AERSURFACE and is considered the program default. Also, beginning with version 20060 and carried forward in 24142, a research grade method, "ZOEFF" (effective roughness), was added that does not limit the upwind fetch to a fixed 1 km distance from the tower. Rather, the distance and resulting area over which the roughness length is estimated is based on the estimated growth of the IBL from the land cover encountered as the air flows toward the meteorological tower. The distance over which roughness is determined is sector dependent.

Surface roughness length can be computed as a single value over the full circular area around the tower or may be varied by multiple wind sectors based on variations in land cover around the tower. Sector widths are limited to a minimum of 30 degrees for a maximum of 12 sectors for use in AERMET. A new the option has been added to generate roughness length

values for 16 sectors, 22.5 degrees each, for comparison with a standard wind rose plot; however, this option is for diagnostic purposes only and cannot be input into AERMET.

The two distinct methods for estimating surface roughness length, ZORAD and ZOEFF, and the incorporation of impervious and tree canopy data are discussed in the next sections. As mentioned previously, AERSURFACE can now incorporate percent impervious and percent tree canopy data into the roughness calculation for several land cover categories in the annual NLCD that have somewhat ambiguous or broad definitions. The method for incorporating these data into the roughness calculations is independent of the roughness option specified and will be discussed in a subsequent section.

#### 2.4.1.1 ZORAD – Default Method for Determining Roughness Length

The default method for determining surface roughness length (ZORAD) in AERSURFACE is based on an inverse distance-weighted geometric mean. The mean is calculated from the roughness values associated with the land cover category that defines each land cover grid cell within the area or individual sectors out to a fixed radial distance from the meteorological tower. The recommended and default radial distance as previously stated is 1 km.

The roughness values associated with each grid cell are weighted based on the inverse distance from the meteorological tower. This is due in part to the fact that the width of a sector increases with distance from the measurement site, such that there are more grid cells included as the distance from the tower increases. Without including an inverse-distance weighting, the land cover farther from the site would receive a higher effective weight than land cover closest to the site if a direct area-weighted averaging approach were used. In addition, a geometric mean is recommended for calculating the surface roughness length due to the fact that the AERMOD formulations are dependent on the natural log (ln) of the roughness length. The arithmetic average of the natural log of the roughness length is mathematically equivalent to

the geometric mean of the roughness length. The inverse distance-weighted geometric mean roughness ( $\overline{Z_0}$ ) is computed as follows:

$$\overline{Z_0} = exp\left(\frac{\sum_{i=1}^{n}\left(\frac{1}{d_i{}^p} * ln(Z_{0i})\right)}{\sum_{i=1}^{n}\frac{1}{d_i{}^p}}\right) \qquad 1$$

where: *n* is the total number of grid cells over which the geometric mean is computed, *i* is one of *n* grid cells, *d* is the distance between the center of the grid cell and the meteorological tower, *p* is 1, and $Z_0$ is the surface roughness length for individual grid cell *i*.

Individual monthly mean roughness values are computed separately for each sector. Annual or seasonal values are then computed from the monthly values as simple arithmetic means for each sector based on the temporal frequency of values specified by the user in the control file. The input requirements for the ZORAD option are provided in Section 3.2.

#### 2.4.1.2 ZOEFF – Experimental Method for Determining Roughness Length

A research grade method (ZOEFF) for determining the effective surface roughness length for the tower location has been added to AERSURFACE. The ZOEFF option is based on the calculated growth of the internal boundary layer (IBL) as roughness elements are encountered approaching the meteorological tower. Rather than computing the average roughness over a default 1 km distance, the ZOEFF method estimates the distance required for IBL growth to a certain predefined height defined as some multiple of the wind measurement height. The fetch is computed separately for each month and sector. Monthly values of the effective roughness length are then computed separately for each sector based on the derived sector-specific fetch. The input requirements for the ZOEFF option are provided in Section 3.2 and a technical description of the ZOEFF method and its implementation in AERMOD is presented in Section 9.0 (Appendix E).

As with the ZORAD method, individual roughness values are computed separately for each month and sector. Annual or seasonal values are then computed from the monthly values as simple arithmetic means for each sector based on the temporal frequency of values specified by the user in the control file.

#### 2.4.1.3 Supplemental Percent Impervious and Canopy Data

Regardless which method is specified for determining roughness length, ZORAD or ZOEFF, annual land cover data can be supplemented with percent impervious and percent tree canopy data, when available. These data products report the percent (0-100) of each grid cell that is covered by an impervious surface and the percent (0-100) covered by tree canopy, respectively. The percent impervious surface and percent tree canopy for a given cell can sum to less than 100 percent, but the sum should not exceed 100 percent. AERSURFACE checks the total for each grid cell. If the total should exceed 100%, AERSURFACE normalizes the individual percentages based on the total percentage reported so that they sum to 100 percent.

When impervious and canopy data are used to supplement land cover data, the Developed categories (21, 22, 23 and 24) of the annual NLCDs are adjusted based on values assigned to original 1992 NLCD categories that better define land use. The Developed categories are reassigned as a mix of the original 1992 categories that make up High Intensity Residential (22), Bare Rock/Sand/Clay (31), Mixed Forest (43), and Urban/Recreational Grasses (85). Low $z_o$ (airport)sectors assume a majority of the impervious area is bare rock/sand/clay to represent the runways, while high $z_o$ (non-airport) sectors assume a majority of the impervious area is more similar to the original 1992 category High Intensity Residential to account for a greater percentage of buildings. The Mixed Forest portion is further weighted based on the percent of the area that is tree canopy while the Bare Rock/Sand/Clay and High Intensity Residential categories are weighted based on the percent of the grid cell that is impervious. The Urban/Recreational Grasses portion is weighted based on the amount that is neither impervious nor tree canopy. As mentioned previously, a substantial percent of the impervious surfaces for some portion of an airport will be runways, which are not present at non-airport sites. A substantial amount of the vegetation at an airport is grass between and

around the runways, rather than trees. Reassigning the annual NLCD Developed categories with weighted values from the original 1992 NLCD classification is an attempt to better estimate the roughness for a given grid cell where the category description is not specific to the type of impervious surface or vegetation. NOTE: Beginning with AERSURFACE v20060, users now have the option to separately characterize individual wind sectors as "airport" or "non-airport" based on the predominant land use within each sector (refer to Sections 3.2.9, and 3.2.10). Since these characterizations may be made outside of an airport location AERSURFACE version 24142 has replaced the "airport" and "non-airport" descriptors with "low $z_o$" and "high $z_o$" respectively. A decision tree for the annual NLCD Developed categories, as implemented in AERSURFACE, is provided in Figure 2-1 that demonstrates how the surface roughness values are reassigned for an individual grid cell using the impervious and canopy data.

Similarly, surface roughness length for the annual NLCD Woody Wetlands category (91) is redefined as a mixture of: Woody Wetlands (91), weighted by the fraction of the grid cell that is tree canopy; Bare Rock/Sand/Clay (31), weighted by the fraction of the cell that is impervious; and the original 1992 category Urban/Recreational Grasses (85), weighted by the fraction of the grid cell that is neither canopy nor impervious. Whether or not the sector is identified as "low $z_o$" (airport), or "high $z_o$" (non-airport) is not considered in this case.

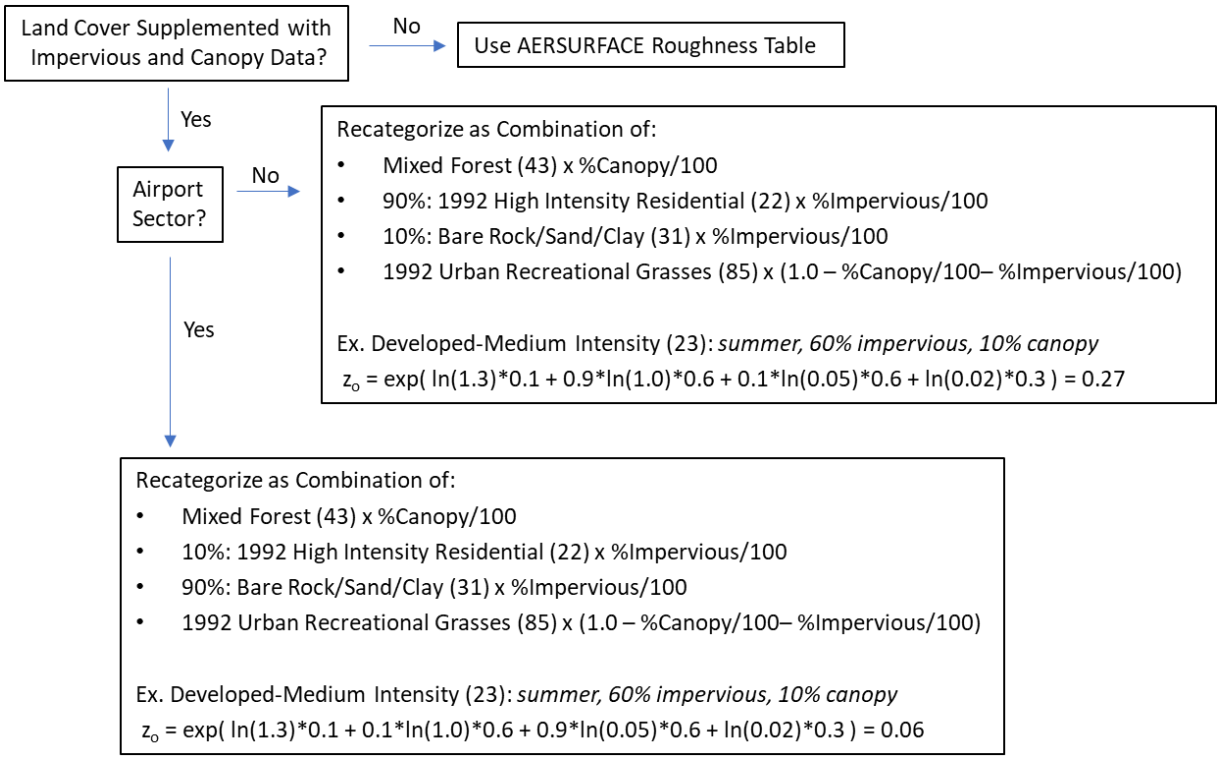



**Figure 2-1. Surface Roughness Value Adjustment to Annual NLCD Developed Categories (21-24) Using Percent Impervious and Canopy Data.**

### 2.4.2 Daytime Bowen Ratio

Bowen ratio is calculated as the simple geometric mean of the Bowen ratio values of the individual grid cells that make up the 10 km x 10 km area centered on the measurement site. The Bowen ratio is an unweighted value in the sense that there is no distance or directional dependency in the calculation. Each grid cell in the 10 km x 10 km area is given equal weight in the calculation of the mean value over. The simple, unweighted geometric mean Bowen ratio ( $\overline{B}$ ) is calculated using the following equation:

$$\bar{B} = exp\left(\frac{\sum_{i=1}^{n} ln(B_i)}{n}\right) \qquad 2$$

where: *n* is the total number of grid cells over which the geometric mean is computed, *i* is one of *n* grid cells, $B_i$ is the Bowen ratio for the individual grid cell *i*.

Individual monthly mean Bowen ratio values are computed. Annual or seasonal values are then computed from the monthly values as simple arithmetic means based on the temporal frequency of values specified by the user in the control file.

### 2.4.3 Noontime Albedo

Albedo is calculated as the simple arithmetic mean, also unweighted (i.e., no direction or distance dependency), for the same 10 km by 10 km area defined for Bowen ratio. The simple arithmetic mean albedo ( $\overline{\alpha}$ ) is calculated using the following equation:

$$\bar{\alpha} = \frac{\sum_{i=1}^{n} \alpha_i}{n} \qquad 3$$

where: *n* is the total number of grid cells over which the geometric mean is computed, *i* is one of *n* grid cells, $\alpha_i$ is the albedo for the individual grid cell *i*.

Individual monthly mean albedo values are computed. Annual or seasonal values are then computed from the monthly values as simple arithmetic means based on the temporal frequency of values specified by the user in the control file.

## 3.0 Detailed keyword reference

AERSURFACE has been updated to read an ASCII text input control file that makes use of the path/keyword approach, to inform AERSURFACE of user options, similar to AERMOD, AERMET, and AERMAP. This section provides a detailed description of the keywords and related parameters, their use, and the format of the control file.

### 3.1 Overview

The descriptive keywords and parameters that make up the control file informs AERSURFACE of the user-defined options and parameters to apply during processing. These include specific processing options, control values, and input/output directory paths and filenames. Each line of the control file consists of a 2-character pathway ID, a primary keyword, and a parameter list. The keywords specify the type of option or input data being entered on each line of the input file, and the parameters following the keyword define the specific options or input data that will be used during processing. Some of the parameters are also input as descriptive secondary keywords.

#### 3.1.1 Pathway IDs

The AERSURFACE control file is divided into two functional "pathways." The pathways IDs and the order in which they should appear in the control is as follows:

- CO - for specifying overall job COntrol options; and
- OU - for specifying OUtput options.

The pathway ID must be present on the first and last input lines of the ID block of text but may be omitted on the lines in between. However, the primary keyword that would follow the pathway ID **must begin in column 4** of the control file. An example control is provided in Section 3.4.

### 3.1.2 Starting and ending a Pathway Block

Regarding the format of a control file, a basic rule is that all inputs for a particular pathway must be contiguous within a block of text, i.e., all inputs for the CO pathway must come first, followed by the inputs for the OU pathway. The beginning of each pathway is identified with a "STARTING" keyword, and the ending of the pathway with the "FINISHED" keyword. Thus, the first functional record of each control file must be "CO STARTING," followed by the separate lines for each primary keyword and related parameter list. The CO pathway is then ended with “CO FINISHED” and, subsequently, the OU pathway is started with “OU STARTING,” and the last functional record of each control file must be "OU FINISHED" which ends the OU pathway. As shown in the example control file in Section 3.4, the pathway ID (e.g., CO and OU) do not need to be included on every record except the first and last records of the pathway. This is to improve the readability of the control file. The pathway ID does not have to be omitted; however, on those records where the pathway ID is omitted, the primary keyword **must begin in column 4**, and columns 1 through 3 should be filled with blank spaces.

### 3.1.3 Blank Lines and Comments

Two special provisions to increase flexibility in the structuring of the control file include: allowing blank records to separate input data for readability and comment lines that enable the user to annotate the control file. Comment lines are identified with two asterisks (“**”) in the pathway field (i.e., first two columns of a line). Any input image that has "**" for the pathway ID will be ignored. While comment lines are useful for including descriptions in the control file, it may also be used to "comment out" certain options for a run without deleting the options and associated data completely from the input file.

The information in the remainder of this section is organized by pathway ID and function, i.e., the keywords are grouped by pathway. The syntax for each keyword is provided, and the keyword type is specified as mandatory, optional, or conditional and either repeatable or non-repeatable. Unless noted otherwise, there are no special requirements for the order of keywords

within each pathway. Any keyword which has special requirements for its order within the pathway is so noted following the syntax and type description.

The syntax descriptions in the following sections use certain conventions. Primary keywords are in all capital letters (may also contain numbers). Primary keywords are not underlined. Parameters that are in all capital letters and underlined in the syntax description are secondary keywords that are to be entered as indicated for that keyword. Other parameters are given descriptive names to convey the meaning of the parameter and are italicized. Parentheses around a parameter indicate that the parameter is optional for that keyword. The default that is taken when an optional parameter is left blank is explained in the discussion for that keyword.

## 3.2 Control Pathway (CO)

The CO pathway contains the keywords that provide the overall control of the preprocessor run. The CO pathway must be the first pathway in the control file.

### 3.2.1 Title information (TITLEONE, TITLETWO)

There are two keywords that allow the user to specify up to two lines of title information. The title is included as comment cards in the output data file. The first keyword, TITLEONE, is mandatory, while the second keyword, TITLETWO, is optional. The syntax and type for the keywords are summarized below:

| | |
|---|---|
| **Syntax:** | CO TITLEONE *title1*<br>CO TITLETWO *title2* |
| **Type:** | TITLEONE - Mandatory, Non-repeatable<br>TITLETWO - Optional, Non-repeatable |

The parameters *title2* and *title2* are character parameters of length 200, which are read as a single field from columns 13 to 200 of the input record.

### 3.2.2 Options (OPTIONS)

The OPTIONS keyword is not required but can be included to specify non-default options. The options available and usage is shown below:

| | | | |
|---|---|---|---|
| **Syntax:** | CO OPTIONS | PRIMARY<br>*or*<br>SECONDARY | ZORAD<br>*or*<br>ZOEFF |
| **Type:** | Optional, Non-repeatable | | |

The PRIMARY and SECONDARY options inform AERSURFACE whether the site processed is the primary or secondary location. This determines which keywords to include in the output file that contains the surface characteristic values and that are input directly into AERMET. AERMET can require up to two sets of surface characteristic values (primary and secondary), depending on the meteorological data that are processed. A set of surface characteristic values for the primary meteorological site is always required. The primary site is the location of the National Weather Service (NWS)/Federal Aviation Administration (FAA) weather station if only NWS/FAA surface data collected at an airport are processed. When site-specific meteorological data are processed, the primary location is the site-specific meteorological tower. AERMET can substitute missing site-specific wind data with NWS/FAA data if NWS/FAA data are provided as input. In that case, AERMET requires a set of secondary surface characteristic values for the location of NWS/FAA met tower. The primary set of surface characteristics are defined for AERMET through the three keywords FREQ_SECT, SECTOR and SITE_CHAR used to specify the temporal frequency, number of sectors, and the site characteristics (albedo, Bowen ratio, and surface roughness length), respectively. The secondary set of site characteristics are specified using similar keywords, FREQ_SECT2, SECTOR2, and SITE_CHAR2. AERSURFACE can only process a single site at a time and will need to be run twice when site-specific meteorological data are to be processed with AERMET and NWS/FAA data will be used to substitute missing wind data. (Refer to the AERMET User's Guide (EPA, 2024a) for more information on processing site-specific meteorological data and data substitution using

concurrent NWS/FAA surface data.) AERSURFACE will generate the required AERMET keywords for the primary site by default if the OPTIONS keyword is not included in the CO pathway or if PRIMARY or SECONDARY is not included with the OPTIONS keyword.

The ZORAD and ZOEFF options inform AERSURFACE of the method to use to calculate surface roughness length. ZORAD is the default method used in previous versions and described above. This method calculates the average roughness from the meteorological tower out to a default radial distance of 1 km. ZOEFF is a research grade method that estimates fetch based the growth of the IBL due to changes in roughness downwind. Average roughness is computed over the estimated fetch, approaching the meteorological tower. Roughness length can be calculated for individual user-defined wind sectors using either method. When ZOEFF is specified, the fetch over which the roughness is calculated is estimated separately for each wind sector specified.

### 3.2.3 Debug Options (DEBUGOPT)

AERSURFACE provides several debug options using the DEBUGOPT keyword which will generate various output files that contain different types of diagnostic information. The syntax for the DEBUGOPT keyword and the different options are summarized below:

| | |
|---|---|
| **Syntax:** | CO DEBUGOPT EFFRAD *and/or* GRID *and/or* TIFF *or* ALL |
| **Type:** | Optional, Non-repeatable |

The order of the secondary keywords is not important. A description the output file that each option will generate follows:

EFFRAD: File containing the effective radius for surface roughness computed for each sector/month (only applicable for ZOEFF option specified with the OPTIONS keyword).

GRID: Separate grid file of land cover data and, if applicable, impervious, and canopy data, displaying the 10x10 km grid of values extracted from each GeoTIFF data file.

TIFF: Separate file for each GeoTIFF data file containing a list of all TIFF tags, GeoKeys, and associated values read from the file.

ALL: This option can be used to inform AERSURFACE to generate all debug files listed above without having to list each debug option separately.

Each file generated from the debug options has a default filename. Default filenames can be overridden with user-defined filenames using file-specific keywords on the OU pathway (refer to Section 3.3). AERSURFACE automatically generates a log file that includes a summary of TIFF parameters, land cover counts by category for each sector for surface roughness and land cover counts by category for the 10km x 10km domain used for Bowen Ratio and Albedo. The log file also includes tables of final calculated roughness values and the fetch used, by month and sector, to compute the roughness.

### 3.2.4 Location of Meteorological Tower (CENTERXY, CENTERLL)

The location of the meteorological tower where representative values of the surface characteristics will be calculated can be specified using either the Universal Transverse Mercator (UTM) coordinate system or latitude and longitude. UTM coordinates are entered using the CENTERXY keyword while latitude and longitude are entered using the CENTERLL keyword. The syntax and required parameters are discussed below:

| | |
|---|---|
| **Syntax:** | CO CENTERXY *easting northing utm_zone datum*<br>*or*<br>CO CENTERLL *latitude longitude datum* |
| **Type:** | Mandatory, Non-repeatable |

where:

*easting*: UTM easting coordinate in meters.

*northing*: UTM northing coordinate in meters.

*utm_zone*: UTM zone entered as a positive integer.

*latitude*: Latitude in decimal degrees. (Northern hemisphere = positive value)

*longitude*: Longitude in decimal degrees. (Western hemisphere = negative value)

*datum*: Geodetic datum on which coordinates are based. The datum should be entered using one of the following secondary keywords: NAD27 or NAD83, which refer to the North American 1927 datum and the North American 1983 datum, respectively. NAD83 should also be used for coordinates referenced to the WGS84 ellipsoid since the small differences between NAD83 (which uses the GRS80 ellipsoid) and WGS84 are inconsequential for the purposes of AERSURFACE. See note immediately below when processing locations in Hawaii and Puerto Rico.

**NOTE: Included with the AERSURFACE executable file are NAD Grid conversion files (conus.los and conus.las) for converting coordinates between North American Datums NAD27 and NAD83 for the CONUS and Alaska. Earlier versions of AERSURFACE that processed only the original 1992 NLCD allowed the user to specify coordinates referenced to either the NAD27 datum or NAD83 and AERSURFACE would convert user coordinates or coordinates derived from the NLCD file to be consistent. This capability has been**

**carried forward for the CONUS and also works for Alaska. When conversion is needed between NAD27 and NAD83 for the CONUS or Alaska, the NAD Grid conversions files (e.g., conus.las, conus.los, alaska.las, alaska.los) provided with the AERSURFACE executable (aersurface.exe) need to be stored in the directory with the executable. However, AERSURFACE has not been extended to make similar conversions for older datums specific to Hawaii and Puerto Rico. When running AERSURFACE for locations in Hawaii and Puerto Rico, the coordinates entered by the user should be referenced to the NAD83 datum or the WGS84 ellipsoid, and NAD83 should be specified as the datum entered in the AERSURFACE control file. AERSURFACE treats NAD83 and WGS84 identically. (NLCD files from the MRLC Consortium website are referenced to either NAD83 or WGS84, depending on the product.)**

### 3.2.5 NLCD Filenames (DATAFILE)

NLCD data filenames, including the names of impervious and canopy files when used to supplement land cover data, are specified using the DATAFILE keyword. The keyword is repeatable so that multiple file types can be specified when more than one type of data will be processed. At a minimum, a land cover file is required. At most, three files can be processed including a single land cover file, a single impervious file, and a single canopy file. The syntax and type of the keyword are summarized below:

| | |
|---|---|
| **Syntax:** | CO DATAFILE *data_type* *path_filename* |
| **Type:** | Mandatory, Repeatable |

The *data_type* is entered using a secondary keyword to represent the type of data and year the data represent. The *data_type* must be an 8-digit alphanumeric input starting with the 4-digit data type abbreviation, followed by the 4-digit year, with no spaces. The data type abbreviations include: *NLCD* for land cover, *MPRV* for impervious, and *CNPY* for canopy data. AERSURFACE will now accept all NLCD release years available for download from the MRLC. However, users should note that this version of AERSURFACE cannot process the

newly available pre-1993 NLCD years (i.e., 1985 to 1992) if the corresponding 4-digit year (e.g., "NLCD1985", "NLCD1992", etc.) is used due to differences in the land cover classification system used in the latest edition of these NLCD years and those hard coded in AERSURFACE. Users should use the 1993 DATAFILE keyword (i.e., "NLCD1993") to process annual NLCD for years 1985 to 1992. If processing an older edition of the 1992 NLCD, the 1992 DATAFILE keyword (i.e., "NLCD1992") should be used to ensure this data is processed using the 1992 NLCD classification scheme with 21 classes. If more than one file is input, all must have the same year. Be sure to clearly document in the input control file the representative NLCD year and edition that is processed (i.e., newly released annual NLCD or legacy NLCD). The following are examples of secondary keywords for *data_type*:

| | |
|---|---|
| NLCD2021: | 2021 NLCD land cover |
| MPRV2021: | 2021 percent impervious |
| CNPY2021: | 2021 percent canopy |

The *path_filename* can be entered using either the relative or absolute path. The relative path is relative to the working directory. Enter the *path_filename* using the syntax that is appropriate for the operating system on which AERSURFACE is run. For example, when running under the Microsoft Windows command prompt, the path and filename are not case-sensitive, but directory names should be separated with a "\" rather than a "/". Conversely, the path and filename are case-sensitive on Unix/Linux systems and directory names should be separated with a "/". Regardless, the operating system, a path and filename that includes spaces should be wrapped in double quotes (""). The combined path and filename is limited to a maximum of 200 characters in AERSURFACE.

### 3.2.6 Fixed Radial Distance for Roughness (ZORADIUS)

When the default method (ZORAD) is used to calculate the surface roughness length, the default radial length of 1 km, the distance over which the roughness length is averaged from the tower, can be overridden by the user using the ZORADIUS keyword. This keyword is only applicable when ZORAD is included with the OPTIONS keyword or both ZORAD and ZOEFF are omitted in which case, ZORAD is the default method. The syntax for the ZORADIUS keyword is as follows:

| | |
|---|---|
| **Syntax:** | CO ZORADIUS *radius* |
| **Type:** | Optional, Non-repeatable |

where *radius* is the distance from the meteorological tower in kilometers over which the effective surface roughness will be computed. The valid range for the user-defined radius is 0.5 km to 5.0 km; however, any distance other than the 1 km default radius may require justification and should be discussed with the reviewing agency. If the ZORADIUS keyword is omitted, the recommended default radius of 1.0 km will be used.

### 3.2.7 Anemometer Height (ANEM_HGT)

When the method ZOEFF is used to calculate the surface roughness length, the ANEM_HGT keyword is required to specify the height of the anemometer is required. The syntax and parameters associated with the ANEM_HGT keyword is summarized below:

| | |
|---|---|
| **Syntax:** | CO ANEM_HGT *anem_ht* *(ibl_factor)* |
| **Type:** | Mandatory, Non-repeatable |

where *anem_ht* is the height, in meters, at which the wind measurements are taken at the site that will be processed. The accepted value for *anem_ht* ranges from 1.0 meter to 100.0 meters.

The *ibl_factor* is an optional unitless parameter, ranging from 5.0 – 10.0, used to compute the reference height of the IBL at the location of the meteorological tower. The IBL reference height is the product of the *anem_ht* and the *ibl_factor*. The default value for *ibl_factor* is 6.0 based on Wieringa's suggested 60 m "roughness blending height" (Wieringa, 1976) and given that 10 m is a common anemometer height at NWS/FAA meteorological stations. Refer to Section 9.0 (Appendix E) for more information on the implementation of the ZOEFF method in AERSURFACE.

### 3.2.8 Climate, Surface Moisture, and Continuous Snow Cover (CLIMATE)

As previously discussed in Section 2.4, the surface characteristic values calculated by AERSURFACE can vary based on local climate and surface moisture conditions, including whether the site experienced extended periods of continuous snow cover. The CLIMATE keyword is used to inform AERSURFACE of this information. This is an optional keyword for which default entries will be assumed if the CLIMATE keyword is omitted. The syntax for the CLIMATE keyword and related parameters is summarized below:

| | |
|---|---|
| **Syntax:** | CO CLIMATE *sfc_moisture snow_cover arid_condition* |
| **Type:** | Optional, Non-repeatable |

where *sfc_moisture* refers to the surface moisture based on precipitation amounts for the period that will be modeled, relative to the previous 30-year climatological record for the region; *snow_cover* indicates whether the site experienced one or more extended periods of continuous snow cover; and *arid_condition* defines the typical climate of the region as arid such as desert-like or non-arid.

*sfc_moisture* should be entered as either WET, DRY, or AVERAGE (or AVG), where, in general, WET is defined as precipitation amounts equal to or greater than the 70$^{th}$ percentile of the 30-year climatological records; DRY is equal to or less than the 30$^{th}$ percentile; and AVERAGE is between the 30$^{th}$ and 70$^{th}$ percentiles. However, as previously discussed, the reader should consider that what is normal varies for different regions. A dry (or wet) climate could be more normal for an area, so even if the amount of precipitation is normal for a time period, the area might be more appropriately classified as “dry” (or “wet”). In these cases, the user should justify their categorization. If omitted, AERSURFACE assumes an AVERAGE default surface moisture. A recommended approach is to determine moisture conditions either seasonally or monthly, then run AERSURFACE separately for each condition and use the results to compile a single input file for AERMET that contains the appropriate seasonal or monthly surface characteristic values.

Whether the site experienced periods of continuous *snow_cover* during the winter should be specified using either the SNOW or NOSNOW secondary keywords. If omitted, AERSURFACE assumes a default of NOSNOW, meaning there were no winter months that experienced periods of continuous snow cover. Continuous snow cover is defined as a calendar month during which the ground was covered with snow more than 50% of the time. If the secondary keyword SNOW, is specified, then AERSURFACE will treat all winter months assigned to "Winter with continuous snow on the ground," as having continuous snow cover. The user has the option to use the default month-to-season assignments or to reassign months to each of the five seasons recognized by AERSURFACE, listed in Table 2-3, using the SEASON keyword discussed in Section 3.2.11, below. If default assignments are used, then all winter months will be treated as either having continuous snow or having no snow. The default winter months, per Table 2-3, are December, January, and February.

The last parameter associated with the CLIMATE keyword, *arid_condition*, is only applicable if NOSNOW was entered for *snow_cover* and should be specified using the secondary keyword ARID or NONARID where ARID refers to a desert-like climate. The default condition is NONARID when the CLIMATE keyword is omitted. AERSURFACE also assumes NONARID if any month experiences continuous snow cover. **Note: AERSURFACE will abort processing and report an error if the secondary keywords SNOW and ARID are used in combination with each other.**

To summarize, if the CLIMATE keyword is omitted from the control file, AERSURFACE assumes the following settings by default: AVERAGE, NOSNOW, and NONARID.

### 3.2.9 Temporal Frequency (FREQ_SECT)

Surface characteristics should reflect how they change temporally for a location. Depending on the climatology and land cover, there may be little change throughout the year, or there may be large changes on a seasonal or even monthly basis. The FREQ_SECT keyword defines time period over which the surface characteristics will be computed. This keyword is also used to specify the number of wind sectors that will be defined when determining roughness length and whether adjustments will be made to sector roughness values (e.g., "low$z_o$"/ "airport" or "high$z_o$"/ "non-airport"). The syntax and usage of the mandatory FREQ_SECT keyword is summarized below:

| | |
|---|---|
| **Syntax:** | CO FREQ_SECT *frequency number_sectors roughness_flag* |
| **Type:** | Mandatory, Non-repeatable |

where *frequency* is the period of time for which the surface characteristics are calculated which include ANNUAL, SEASONAL, or MONTHLY. When ANNUAL or MONTHLY is entered, the user has the option to override program defaults and reassign months to seasons based on local climatology. The default assignments, which are always used when SEASONAL is specified, are as follows:

**Table 3-1. Default Month/Season Assignments in AERMET**

| Season # | Season | Default Months |
|---|---|---|
| 1 | Winter* | December, January, February |
| 2 | Spring | March, April, May |
| 3 | Summer | June, July, August |
| 4 | Autumn | September, October, November |

** Winter will either be defined as winter with continuous snow cover or winter with without snow based on the option specified with the CLIMATE keyword, discussed previously.*

The *number_sectors* parameter should be entered as the integer number of wind sectors that will later be defined using the SECTOR keyword. Wind sectors are only applicable to roughness length. The number of sectors can range from 1 to 12 or 16. AERMET allows a maximum of 12 sectors, but AERSURFACE can calculate roughness for 16 sectors which can be useful for comparing roughness lengths to a standard 16-direction wind rose plot. When 16 sectors are specified, AERSURFACE results cannot used as input to AERMET.

The last parameter, *roughness_flag*, requires a secondary keyword that determines whether AERSURFACE will adjust roughness values to all wind sectors, or if the sectors vary. The *roughness_flag* should be specified using one of the following secondary keywords*:* LOWZ0, HIGHZ0 or VARYZ0 where: LOWZ0 indicates lower roughness values will be applied to all sectors; HIGHZ0 indicates that higher roughness values will be applied; and VARYZ0 informs AERSURFACE to treat each sector separately based on how the sector is identified using the SECTOR keyword discussed next.

NOTE: In previous versions of AERSURFACE, this keyword was referred to as the *airport_flag* with AP, NONAP, and VARYAP options. These options are still available in AERSURFACE v24142 and are defined as LOWZ0, HIGHZ0, and VARYZ0, respectively. Users may want to consider characterizing sectors at an airport for which the impervious surfaces are predominantly buildings rather than paved surfaces or that are predominantly vegetation as non-airport. Similarly, sectors at a measurement site that is not at an airport, but the impervious surfaces are predominantly paved surfaces, can be characterized as airport. (Refer to Sections 2.3.2 for additional discussion on airport vs non-airport characterization of a measurement site or individual sectors.)

### 3.2.10 Surface Roughness Length Wind Sectors (SECTOR)

Individual wind sectors for which roughness length is determined are defined using the SECTOR keyword by specifying a starting and ending wind direction for each sector. As mentioned above, the SECTOR keyword is also used to indicate whether lower or higher

roughness values should be applied to individual sectors. The usage and syntax of the SECTOR keyword are summarized below:

| | |
|---|---|
| **Syntax:** | CO SECTOR *sector_index* *start_dir* *end_dir* *roughness_flag* |
| **Type:** | Conditional, Repeatable |

While there are circumstances for which the SECTOR keyword is not required, when included, the number of occurrences of the SECTOR keyword must match the number of sectors (*number_sectors*) specified with the FREQ_SECT keyword. The *sector_index* links a specific sector to a set of site characteristics and should be entered as consecutive integers beginning with the number 1. As discussed, the number of sectors can range from 1 to 12 for input to AERMET, and sectors must be a minimum of 30°. AERSURFACE can also generate surface characteristic values for a discrete number of 16 sectors that are each 22.5° that may be useful for comparing roughness length by sector to a standard 16-direction wind rose plot but cannot be used as input to AERMET.

Sectors should be defined in a clockwise manner and must cover the full 360° circle around the meteorological tower without gaps or overlap. (i.e., They must be defined so that the end of one sector corresponds to the beginning of another.) The starting direction (*start_dir*) is considered part of the sector, while the ending direction (*end_dir*) is excluded from the sector. The starting and ending directions reference the wind direction, the direction from which the wind is blowing. A sector can cross through north (e.g., 345 - 15) or can start and stop at north (e.g., 0 - 30 and 270 - 360). AERSURFACE will verify that the entire 360° circle is covered.

The *roughness_flag* (previously, *airport_flag*) on the SECTOR keyword identifies whether the individual sector should be processed with lower (airport) or higher (non-airport) surface roughness length values. This attribute is required when the secondary keyword VARYZ0 or VARYAP is entered as the *roughness_flag* attribute for the FREQ_SECT keyword which means each sector will be assigned individually. When that is the case, the *roughness_flag*

should be specified using the secondary keyword LOWZ0 or AP to indicate lower roughness values or HIGHZ0 or NONAP to indicate higher surface roughness values. (Refer to Sections 2.3.2 for additional discussion on airport vs non-airport characterization of a measurement site or individual sectors.)

When 1, 8, 12 or 16 is entered for the number of sectors on the FREQ_SECT keyword, the SECTOR keyword may be omitted, and default sectors can be used unless VARYZ0 is entered as the *roughness_flag* attribute for the FREQ_SECT keyword. For those cases in which 1, 8, 12, or 16 sectors are specified, and the SECTOR keyword is omitted, AERSURFACE will, by default, generate one 360-degree, eight 45-degree, twelve 30-degree, or sixteen 22.5-degree sector(s), respectively. Eight sectors are centered on 0, 45, 90, etc. degrees. Twelve sectors are centered on 15, 45, 75, etc. degrees. Sixteen sectors are centered on 0, 22.5, 45, etc. degrees. When VARYZ0 is specified on the FREQ_SECT keyword, the SECTOR keyword is required and the *roughness_flag* attribute is required for each sector, though the starting and ending directions may be omitted if default directions are intended.

### 3.2.11 Assigning Months to Seasons (SEASON)

AERSURFACE provides the option to override default month-to-season assignments when the temporal resolution for the surface characteristics, or the *frequency* attribute on the FREQ_SECT keyword, is ANNUAL or MONTHLY. When the *frequency* is SEASONAL, the default assignments are used, listed in

Table 3-1, above. This is to maintain consistency with AERMET and its seasonal definitions. Calculating annual or monthly surface characteristic values and reassigning months from the default season assignments provides for greater representativeness for those areas of the country that do not experience the traditional seasons. The SEASON keyword is used to override the default assignments. The usage and syntax of the SEASON keyword are summarized below:

| **Syntax:** CO SEASON *season* *months* (space delimited list) |
|---|

| **Type:** | Optional, Repeatable |
|---|---|

where *season* is a secondary keyword that identifies one of five seasonal definitions and *months* is a space-delimited list of integer months assigned to the season. Valid secondary keywords used to specify *season*, along with the season definition are listed in Table 3-2, below. Valid entries for the attribute *months* are a "0" to indicate no months are being reassigned to the season or a space-delimited list with each value ranging from 1 to 12 where 1 represents January and 12 represents December. A season may be specified only once. The months reassigned to a season should be listed on a single record separated by at least one space. A month can only be assigned to one season. It is only necessary to specify the seasons/months that are to be reassigned. If 0 is entered for a season, then default assignments will be used for any month that is not listed for a different season.

**Table 3-2. Season Secondary Keywords and Definitions**

| Secondary Keyword | Season Description | Default Month Assignments |
|---|---|---|
| SUMMER | Midsummer with lush vegetation | June, July, August |
| AUTUMN | Autumn with unharvested cropland | September, October, November |
| WINTERNS | Late autumn after frost and harvest, or winter with no snow | December, January, February |
| WINTERWS | Winter with continuous snow on the ground | December, January, February |
| SPRING | Transitional spring with partial green coverage or short annuals | March, April, May |

### 3.2.12 To Run or Not (RUNORNOT)

Before beginning to read and process the datafiles, AERSURFACE will read through all of the inputs in the control file regardless of any errors or warnings that may be encountered. If a fatal error is encountered, then further program calculations will be aborted. Otherwise, the program will attempt to run. The RUNORNOT keyword has been included on the CO pathway to allow the user to specify whether to RUN the program and perform all the calculations, or

only process the control file and check for warnings and errors and summarize the setup information. The syntax of the RUNORNOT keyword is summarized below:

| | |
|---|---|
| **Syntax:** | CO RUNORNOT RUN or NOT |
| **Type:** | Mandatory, Non-repeatable |

### 3.3 Output Pathway (OU)

The **OU**tput pathway is used to specify user-defined filenames for program generated output files that cannot be entered as an argument at the command prompt when AERSURFACE is executed. Those that can be entered as a command-line argument include: 1) an input summary file that replicates the control file inputs and includes a summary of warnings and errors encountered during processing and 2) a log file that records more detailed information about the input data that are read during program execution (see Section 3.0). The OU pathway is required to be included in AERSURFACE input control file; however, all file-specific keywords are optional. If the user prefers that default filenames are assigned, the OU pathway can be empty with only the OU STARTING and OU FINISHED records specified and AERSURFACE will used the default filenames shown in Table 3-3. All output files that can be specified in the OU pathway are generated based on the debug options that are specified with the DEBUGOPT keyword in the CO pathway (see Section 3.2.3) in combination with the types of data that are used to derive the surface characteristic values specified with the DATAFILE keyword in the CO pathway (i.e., land cover, percent impervious, and percent canopy). It preferable to specify user-defined filenames rather than use default filenames to avoid unintentionally overwriting files with the same name output from previous AERSURFACE runs.

#### 3.3.1 Surface Characteristic Values File for AERMET (SFCCHAR)

As referenced above, the user can specify the name of the file that will contain the surface characteristic values calculated by AERSURFACE that will be formatted input to AERMET. It

is entered in the OU pathway with the SFCCHAR keyword. IF SFCCHAR is omitted from the OU pathway, the default filename, *sfc_chars.out*, will be assigned. The usage and syntax of SFCCHAR keyword is summarized below:

| | |
|---|---|
| **Syntax:** | OU SFCCHAR *path_filename* |
| **Type:** | Optional, Non-repeatable |

where *path_filename* is the user-defined path and filename of the surface characteristics file. The path can be entered as the absolute path or a relative path, relative to the working directory. If the path is omitted, the file will be created in the working directory. The combined path and filename is limited to 200 characters and should be enclosed in quotes (“”) if either the path or filename includes spaces.

### 3.3.2 Debug Output Files

There are several debug files that can be generated by AERSURFACE. A file’s creation is based on the debug options that are specified with the DEBUGOPT keyword in the CO pathway (see Section 3.2.3) and the types of data that are input to AERSURFACE (i.e., land cover, percent impervious, and percent canopy). The user has the option to enter a user-defined path and filename for any of these debug files by specifying the primary keyword associated with the debug file, followed by a path and filename. For any keyword and path\filename combination that are omitted on OU pathway, AERSURFACE will use the default filename and create the file in the working directory. There is a distinct primary keyword associated with each debug file. The general usage and syntax for the keywords is summarized below and a list of the keywords as well as the associated debug option, description, and default filename is provided in Table 3-3. **Note: Though the entry of any of the debug file keywords and associated path and filenames are optional, each keyword that is specified must include an associated filename and a filename must be preceded by the associated keyword.**

| | |
|---|---|
| **Syntax:** | OU *primary_keyword path_filename* |
| **Type:** | Optional, Non-repeatable (each primary keyword in Table 3-3 can only be used once) |

where *primary_keyword* is a primary keyword from Table 3-3 and *path_filename* is the user-defined path and filename of the output file. The path can be entered as the relative or absolute path. A relative path is relative to the working directory. The combined path and filename are limited to 200 characters and should be enclosed in quotes (“”) if either the path or filename includes spaces.

**Table 3-3. OU Pathway Primary Keywords and Default Filenames**

| Keyword | DEBUGOPT | Description | Default Filename |
|---|---|---|---|
| SFCCHAR | | Surface characteristic values formatted for input to AERMET | sfc_chars.out |
| EFFRAD | EFFRAD | Table of effective radius values by sector and month | effective_rad.txt |
| NLCDGRID | GRID | Land cover grid for import into GIS | landcover.txt |
| MPRVGRID | GRID | Impervious data grid for import into GIS | impervious.txt |
| CNPYGRID | GRID | Canopy data grid for import into GIS | canopy.txt |
| NLCDTIFF | TIFF | Land cover debug file containing TIFF tag and GeoKey values | lc_tif_dbg.txt |
| MPRVTIFF | TIFF | Impervious debug file containing TIFF tag and GeoKey values | imp_tif_dbg.txt |
| CNPYTIFF | TIFF | Canopy debug file containing TIFF tag and GeoKey values | can_tif_dbg.txt |

In addition to the files listed in Table 3-3, AERSURFACE will also automatically generate an input summary file that replicates the control file inputs and a summary of warnings and errors encountered during processing and a log file that records more detailed information

about the input data that are read during program execution. These filenames can be defined by the user at the time the program is executed at the command-line prompt. Refer to Section 1.0 details about how to run AERSURFACE from the command-line and how to specify the paths and filenames for the input control file, log file, and summary file. Refer to Section 4.3 for additional descriptive information about the various output files generated by AERSURFACE.

### 3.4 Sample AERSURFACE Control File

Figure 3-1 is a sample AERSURFACE control file for the location of the meteorological tower at the Raleigh-Durham International Airport (RDU) using the 2016 NLCD. This example is for demonstration purposes only, to demonstrate the usage of various keywords and is not intended to be representative of how the site would normally be processed. A summary of the options used in the sample control file follows.

In this example, the RDU station is processed as the PRIMARY meteorological station which means site-specific data are not used. Otherwise, the NWS/FAA station would be specified as the SECONDARY station. The default ZORAD option will be used to calculate the surface roughness length. Because default options are used, the OPTIONS keyword and parameters could be omitted in this case. For the ZORAD option, a default radius of 1 km will be used to compute surface roughness length. Because this is the default radius value, the ZORADIUS keyword and parameter could be omitted. Surface characteristics will be based on 2001 land cover which is supplemented with both impervious and canopy data. GRID and TIFF debug files will be generated for each of the land cover, impervious, and canopy GeoTIFF data files. Per the OU pathway, user-defined filenames will be used for the GRID debug files, but default filenames will be used for the TIFF debug files.

The CLIMATE keyword indicates that moisture conditions are AVERAGE, but there is at least one month with continuous snow cover (SNOW), and the regional climate conditions are non-arid (NONARID). Months are reassigned from the default season assignments with March reassigned from Spring to winter without continuous snow cover, and January is defined as

having continuous snow cover meaning more than 50% of the month experienced continuous snow cover. Note, because SNOW was specified on the CLIMATE keyword, AERSURFACE will assume all winter months experience continuous snow cover unless winter months are explicitly assigned to either winter **with** continuous snow (WINTERWS) or winter **without** continuous snow (WINTERNS).

Based on the FREQ_SECT and SECTOR keywords, monthly values of surface characteristics will be computed. Surface roughness length will be computed for three wind sectors and only sector 2 which is largely comprised of runways will be processed using airport surface characteristic values (lower surface roughness values). Figure 3-2 Shows the three sectors defined in the sample control file in Figure 3-1, overlaid with land cover from the 2001 NLCD for RDU.

The RUNORNOT keyword indicates that AERSURFACE will attempt to run after checking the control file.

```
** Sample control file - for demonstration purposes only

CO STARTING
   TITLEONE  Sample AERSURFACE Control File
   TITLETWO  RDU - Met Tower, 2016 NLCD

** Using default options for OPTIONS keyword and parameters
   OPTIONS   PRIMARY  ZORAD

   DEBUGOPT  GRID  TIFF

   CENTERLL  35.892300   -78.781900   NAD83

   DATAFILE  NLCD2016  "RDU_2016_NLCD_LC.tiff"
   DATAFILE  CNPY2016  "RDU_2016_NLCD_Can.tiff"
   DATAFILE  MPRV2016  "RDU_2016_NLCD_Imp.tiff"

** Use default 1 km radius
   ZORADIUS  1.0

   CLIMATE   AVERAGE  SNOW   NONARID

** Get monthly values for three sectors
** Vary AP/Non-AP sectors
   FREQ_SECT   MONTHLY    3  VARYAP

**        index  start    end
   SECTOR   1    30.00   60.00   NONAP
   SECTOR   2    60.00  225.00   AP
   SECTOR   3   225.00   30.00   NONAP

** Reassign months with continuous snow cover in January
   SEASON   WINTERNS   12 2 3
   SEASON   WINTERWS   1
   SEASON   SPRING     4 5
   SEASON   SUMMER     6 7 8
   SEASON   AUTUMN     9 10 11

   RUNORNOT  RUN
CO FINISHED

OU STARTING
   SFCCHAR    "rdu_2016_lc_can_imp_zorad_sfc.txt"
   NLCDGRID   "rdu_2016_lc_can_imp_zorad_lc_grid.txt"
   CNPYGRID   "rdu_2016_lc_can_imp_zorad_can_grid.txt"
   MPRVGRID   "rdu_2016_lc_can_imp_zorad_imp_grid.txt"
OU FINISHED
```

**Figure 3-1. Sample AERSURFACE Control File**

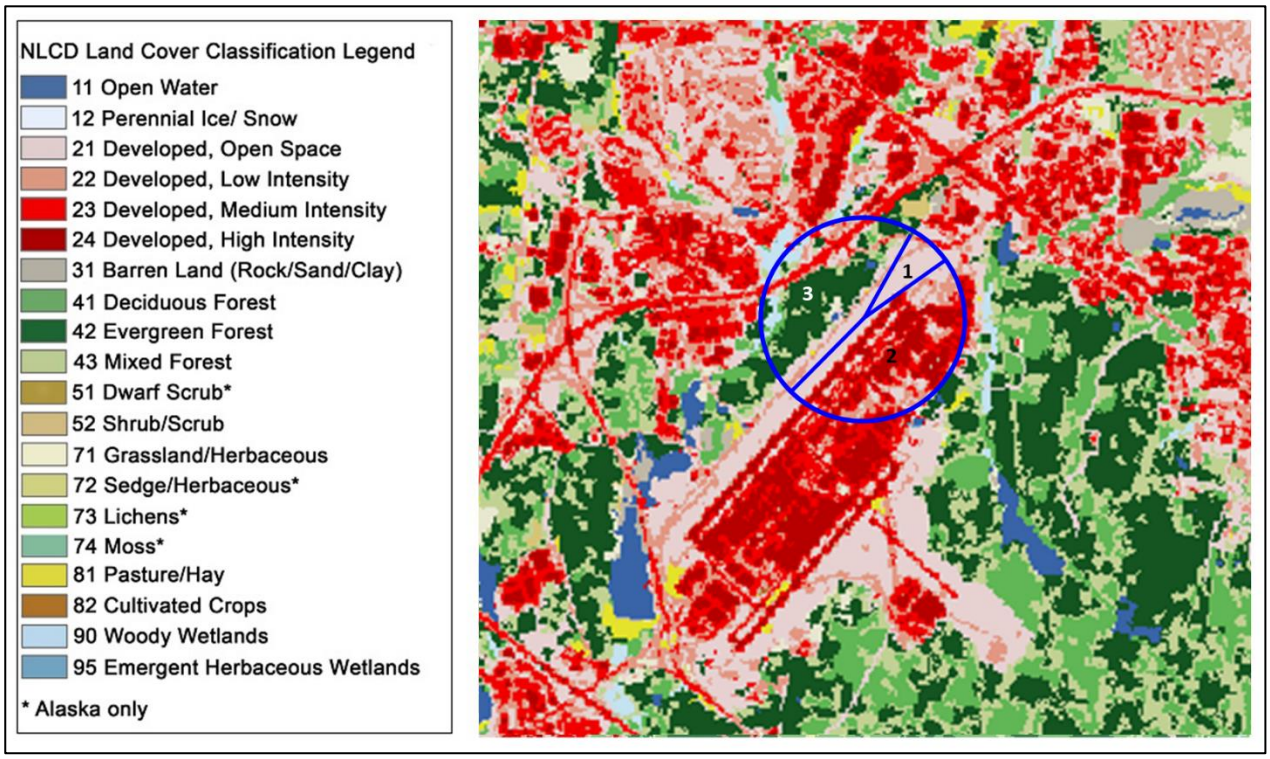



**Figure 3-2. 2016 NLCD for RDU International with Wind Sectors Starting at 30, 60, and 225 Degrees**

## 4.0 Running AERSURFACE

### 4.1 Command Prompt and Command-line Arguments

The AERSURFACE executable file[1] available on EPA's SCRAM website has been compiled for the Microsoft Windows operating system and runs at a command prompt. AERSURFACE, can be run from the command prompt by entering the path and filename of the AERSURFACE executable file (e.g., aersurface.exe) with up to three command-line arguments which can be included to specify the path and filename of the input control file, the output summary file, and the output log file, in that order. This is demonstrated as follows:

Path-to-aersurface.exe\aersurface

Path-to-aersurface.exe\aersurface *path\control_file*

Path-to-aersurface.exe\aersurface *path\control_file* *path\summary_file*

Path-to-aersurface.exe\aersurface *path\control_file* *path\summary_file* *path\log_file*

The first example assumes that the control file is located in the working directory and is named *aersurface.inp*. When executed in this way, the default names *aersurface.out* and *aersurface.log* will be used for the names of the summary and log files, respectively. In the remaining examples, the path and filename of the control file is specified. If the path and filename of the summary file or subsequently the log file is not included, AERSURFACE will get the base path and filename of the control file (without the extension) and set the path and filename of the summary and log files equal to the base path and filename and add the extension *.out* and *.log*, respectively. The

[1] Included with the AERSURFACE executable file are NAD Grid conversion files (conus.los and conus.las) for converting coordinates between NAD27 and NAD83 datums for the conterminous U.S. (CONUS) and Alaska. Earlier versions of AERSURFACE that processed only the 1992 NLCD allowed the user to specify coordinates referenced to either the NAD27 datum or NAD83 and AERSURFACE would convert user coordinates or coordinates derived from the NLCD file to be consistent. This capability has been carried forward for the CONUS and also works for Alaska. When conversion is needed between NAD27 and NAD83, the NAD Grid conversions files provided with the AERSURFACE executable (aersurface.exe) need to be stored in the directory with the executable. However, AERSURFACE has not been extended to make similar conversions for older datums specific to Hawaii and Puerto Rico. When running AERSURFACE for locations in Hawaii and Puerto Rico, the coordinates entered by the user should be referenced to the NAD83 datum or the WGS84 ellipsoid, and NAD83 should be specified as the datum entered in the AERSURFACE control file. AERSURFACE treats NAD83 and WGS84 identically.

path to each of the files entered in the command prompt can be entered as an absolute or relative path (i.e., relative to the working directory).

### 4.2 Error and Warning Messages

While processing the control file and input data files, AERSURFACE writes messages to the summary file, log file, and to the screen. These could be in the form of errors and warnings that were encountered when initially checking the format of the control file as well as dependencies in the options selected or issues encountered while reading the data input files during processing. Informational messages may also be recorded to document specific information about the data that were processed. Errors, such as a malformed control file, invalid options, or missing or incorrectly formatted data files will cause AERSURFACE to abort processing prematurely. These errors will need to be corrected before AERSURFACE can complete successfully. Warnings, however, do not halt processing, but should be evaluated by the user after AERSURFACE has completed to ensure results were not affected. Some examples of warnings include data values that are out-of-bounds or a default value is assumed. The user should inspect both the summary and log output files and review all messages that were recorded during processing and determine if the control file or data need to be evaluated to ensure the results were not impacted in an adverse or unexpected manner.

### 4.3 Summary of Output Files Generated by AERSURFACE

This section provides a summary of the different files that can be generated by AERSURFACE and their contents. The files that are described include the summary and log files that are generated automatically during each AERSURFACE run, the required surface characteristics file that contains the calculated values and is formatted for input to AERMET, and the various optional debug files. For additional information on the output options used to generate specific files, refer to Section 3.2.

### 4.3.1 Auto-generated Files

Each time an AERSURFACE run is performed, a summary file and a log file are automatically generated. The default filenames for these two files if not provided by the user are *aersurface.out* and *aersurface.log*, respectively. These default filenames can be overridden with user-defined names when AERSURFACE is executed from the command-prompt (see Section 4.1). Additional descriptions of these two files and their contents are provided in the next two sections.

#### 4.3.1.1 Summary File (*aersurface.out*)

The first part of the summary file replicates the AERSURFACE control file verbatim as a record of the control file structure and exact options and inputs. The summary file also indicates if the setup completed successfully, meaning there were no formatting issues or conflicts with the options specified in the control file when it was checked before processing. If the setup completes without error, then the summary file will subsequently indicate if processing the data files completed successfully. All error, warning, and informational messages encountered are listed at the bottom of the summary file.

#### 4.3.1.2 Log File (*aersurface.log*)

The log file records detailed information about the datafiles as they are read such as the filename and if the file was opened successfully, the spatial resolution of the file, the number of rows and columns of data, and the organization of the data in the file. The log file also provides the counts of each land category by sector within the area used to calculate the surface characteristics values. Detailed warning and error messages are also recorded in the log file as processing continues.

### 4.3.2 Surface Characteristics

As stated in Section 3.3.1, the keyword SFCCHAR and the user-defined path and filename of the surface characteristics file that contains calculated surface characteristic values formatted for input to AERMET are the only required entries in the OU pathway. This file includes a compact summary, in list format, of the processing options specified in the control file. The lines that make up the summary of options contain the double asterisks (**) in the first two columns of each line so that AERMET will ignore them. Following the options summary are the frequency, number of sectors, and roughness flag, along with the sector definitions and surface characteristic values formatted with the appropriate keywords as required by AERMET.

### 4.3.3 Debug Files

Whether or not debug files are created by AERSURFACE and which files are created is controlled with the DEBUGOPT keyword on the CO pathway (see Section 3.2.3) in conjunction with the type of datafiles processed in addition to land cover (i.e., impervious and canopy), and the method used to calculate surface roughness length (i.e., ZORAD or ZOEFF, see Sections 2.4.1 and 3.2.2). Regardless which method is chosen or which debug options are selected, AERSURFACE will only create those debug files that are consistent with the method specified and the data that are input. AERSURFACE will not generate an error or abort processing if debug options on the CO pathway or file types specified on the OU pathway are inconsistent with the surface method specified or data that are input. For debug files created that are not specified on the OU pathway, AERSURFACE will use the default filenames.

There are three categories of debug files: effective radius, TIFF debug, and grid files. Each of these are ASCII text files that can be opened with a standard text editor. A summary of the contents of each these are discussed in the sections that follow.

#### 4.3.3.1 Effective Radius File (default = *effective_rad.txt*)

The effective radius file is only applicable with the ZOEFF option for calculating effective surface roughness. AERSURFACE generates this file when the ZOEFF secondary keyword is specified with the OPTIONS keyword on the CO pathway and the EFFRAD secondary keyword is specified with the DEBUGOPT keyword, also on the CO pathway. This file provides a summary, by sector and month, of the calculated fetch, the effective roughness computed traversing from the tower location, the effective roughness computed traversing toward the tower, the final effective roughness value, and the mean roughness computed for each concentric ring from the tower to just beyond 5 km. The default path and filename of this file can be overridden using the EFFRAD primary keyword on the OU pathway. If omitted from the OU pathway, the default filename, *effective_rad.txt*, will be used, the file will be created in the working directory.

#### 4.3.3.2 TIFF Debug Files (defaults = *lc_tif_dbg.txt*, *imp_tif_dbg.txt*, and *can_tif_dbg.txt*)

AERSURFACE will create a separate TIFF debug file for each TIFF datafile processed (i.e., land cover, impervious, and canopy) when the TIFF option is specified with the DEBUGOPT keyword on the CO pathway (see Section 3.3.2). These debug files contain a record of each of the TIFF tags and GeoKeys read during processing. The TIFF tags and GeoKeys store information about the organization of the data within the file and how the data are georeferenced for extraction and interpretation. This information can be used to troubleshoot the data files if warnings are issued during processing or results are questionable. The default paths and filenames of these files can be overridden using the primary keywords NLCDTIFF, MPRVTIFF, and/or CNPYTIFF on the OU pathway. If omitted from the OU pathway, the default filenames, *lc_tif_dbg.txt*, *imp_tif_dbg.txt*, and *can_tif_dbg.txt*, will be used, and the files will be created in the working directory.

#### 4.3.3.3 Grid Files (defaults = *landcover.txt*, *impervious.txt*, and *canopy.txt*)

Similar to the TIFF debug files, AERSURFACE will create separate grid debug files for each TIFF datafile processed (e.g., land cover, impervious, and canopy) when the GRID option is specified with the DEBUGOPT keyword on the CO pathway (see Section 3.3.2). Each of these debug files contain a grid of the values extracted from the corresponding datafile with reference information about the number of rows, columns, and the horizontal resolution of the data. The default paths and filenames of these files can be overridden using the primary keywords NLCDGRID, MPRVGRID, and/or CNPYGRID on the OU pathway. If omitted from the OU pathway, the default filenames, *landcover.txt*, *impervious.txt*, and *canopy.txt*, will be used, and the files will be created in the working directory.

## 5.0 Appendix A: National Land Cover Database Definitions

### Table 5-1. Original 1992 NLCD Class and Category Descriptions and Color Legend

| Class\ Value | Classification Description |
|---|---|
| **Water** | *areas of open water or permanent ice/snow cover.* |
| 11 | **Open Water** - areas of open water, generally with less than 25% cover of vegetation/land cover. |
| 12 | **Perennial Ice/Snow** - areas characterized by year-long surface cover of ice and/or snow. |
| **Developed** | *areas characterized by a high percentage (30 % or greater) of constructed materials (e.g. asphalt, concrete, buildings, etc.).* |
| 21 | **Low Intensity Residential** - areas with a mixture of constructed materials and vegetation. Constructed materials account for 30% to 80% of the cover. Vegetation may account for 20% to 70 % of the cover. These areas most commonly include single-family housing units. Population densities will be lower than in high intensity residential areas. |
| 22 | **High Intensity Residential** - areas highly developed where people reside in high numbers. Examples include apartment complexes and row houses. Vegetation accounts for less than 20% of the cover. Constructed materials account for 80% to100% of the cover. |
| 23 | **Commercial/Industrial/Transportation** - areas of infrastructure (e.g. roads, railroads, etc.) and all highly developed areas not classified as High Intensity Residential |
| **Barren** | *areas characterized by bare rock, gravel, sand, silt, clay, or other earthen material, with little or no "green" vegetation present regardless of its inherent ability to support life. Vegetation, if present, is more widely spaced and scrubby than that in the green vegetated categories; lichen cover may be extensive.* |
| 31 | **Bare Rock/Sand/Clay** - perennially barren areas of bedrock, desert pavement, scarps, talus, slides, volcanic material, glacial debris, beaches, and other accumulations of earthen material. |
| 32 | **Quarries/Strip Mines/Gravel Pits** - areas of extractive mining activities with significant surface expression. |
| 33 | **Transitional** - areas of sparse vegetative cover (less than 25% of cover) that are dynamically changing from one land cover to another, often because of land use activities. Examples include forest clear cuts, a transition phase between forest and agricultural land, the temporary clearing of vegetation, and changes due to natural causes (e.g. fire, flood, etc.). |
| **Forest** | *areas characterized by tree cover (natural or semi-natural woody vegetation, generally greater than 6 meters tall); tree canopy accounts for 25% to 100% of the cover.* |
| 41 | **Deciduous Forest** - areas dominated by trees where 75% or more of the tree species shed foliage simultaneously in response to seasonal change. |
| 42 | **Evergreen Forest** - areas dominated by trees where 75% or more of the tree species maintain their leaves all year. Canopy is never without green foliage. |
| 43 | **Mixed Forest** - areas dominated by trees where neither deciduous nor evergreen species represent more than 75% of the cover present. |
| **Shrubland** | *areas characterized by natural or semi-natural woody vegetation with aerial stems, generally less than 6 meters tall, with individuals or clumps not touching to interlocking. Both evergreen and deciduous species of true shrubs, young trees, and trees or shrubs that are small or stunted because of environmental conditions are included.* |
| 51 | **Shrubland** - areas dominated by shrubs; shrub canopy accounts for 25 to 100% of the cover. Shrub cover is generally greater than 25% when tree cover is less than 25%. Shrub cover may be less than 25% in cases when the cover of other life forms (e.g. herbaceous or tree) is less than 25% and shrubs cover exceeds the cover of the other life forms. |
| **Non-natural woody** | *areas dominated by non-natural woody vegetation; non-natural woody vegetative canopy accounts for 25% to 100% of the cover. The non-natural woody classification is subject to the availability of sufficient ancillary data to differentiate non-natural woody vegetation from natural woody vegetation.* |

| | |
|---|---|
| 61 | **Orchards/Vineyards/Other** - orchards, vineyards, and other areas planted or maintained for the production of fruits, nuts, berries, or ornamentals. |
| **Herbaceous Upland** | *upland areas characterized by natural or semi-natural herbaceous vegetation; herbaceous vegetation accounts for 75% to 100% of the cover.* |
| 71 | **Grasslands/Herbaceous** - areas dominated by upland grasses and forbs. In rare cases, herbaceous cover is less than 25%, but exceeds the combined cover of the woody species present. These areas are not subject to intensive management, but they are often utilized for grazing. |
| **Planted/Cultivated** | *areas characterized by herbaceous vegetation that has been planted or is intensively managed for the production of food, feed, or fiber; or is maintained in developed settings for specific purposes. Herbaceous vegetation accounts for 75% to 100% of the cover.* |
| 81 | **Pasture/Hay** - areas of grasses, legumes, or grass-legume mixtures planted for livestock grazing or the production of seed or hay crops. |
| 82 | **Row Crops** - areas used for the production of crops, such as corn, soybeans, vegetables, tobacco, and cotton. |
| 83 | **Small Grains** - areas used for the production of graminoid crops such as wheat, barley, oats, and rice. |
| 84 | **Fallow** - areas used for the production of crops that do not exhibit visible vegetation as a result of being tilled in a management practice that incorporates prescribed alternation between cropping and tillage. |
| 85 | **Urban/Recreational Grasses** - vegetation (primarily grasses) planted in developed settings for recreation, erosion control, or aesthetic purposes. Examples include parks, lawns, golf courses, airport grasses, and industrial site grasses. |
| **Wetlands** | *areas where the soil or substrate is periodically saturated with or covered with water as defined by Cowardin et al., (1979).* |
| 91 | **Woody Wetlands** - areas where forest or shrubland vegetation accounts for 25% to 100 % of the cover and the soil or substrate is periodically saturated with or covered with water. |
| 92 | **Emergent Herbaceous Wetlands** - areas where perennial herbaceous vegetation accounts for 75% to 100% of the cover and the soil or substrate is periodically saturated with or covered with water. |
| *Reproduced from the Multi-Resolution Land Characteristics Consortium Website at http://www.mrlc.gov* | |

## Table 5-2. Annual NLCD Class and Category Descriptions and Color Legend

| Class\ Value | Classification Description |
|---|---|
| **Water** | |
| 11 | **Open Water** - areas of open water, generally with less than 25% cover of vegetation or soil. |
| 12 | **Perennial Ice/Snow** - areas characterized by a perennial cover of ice and/or snow, generally greater than 25% of total cover. |
| **Developed** | |
| 21 | **Developed, Open Space** - areas with a mixture of some constructed materials, but mostly vegetation in the form of lawn grasses. Impervious surfaces account for less than 20% of total cover. These areas most commonly include large-lot single-family housing units, parks, golf courses, and vegetation planted in developed settings for recreation, erosion control, or aesthetic purposes. |
| 22 | **Developed, Low Intensity** - areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 20% to 49% percent of total cover. These areas most commonly include single-family housing units. |
| 23 | **Developed, Medium Intensity** - areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 50% to 79% of the total cover. These areas most commonly include single-family housing units. |
| 24 | **Developed High Intensity** -highly developed areas where people reside or work in high numbers. Examples include apartment complexes, row houses and commercial/industrial. Impervious surfaces account for 80% to 100% of the total cover. |
| **Barren** | |
| 31 | **Barren Land (Rock/Sand/Clay)** - areas of bedrock, desert pavement, scarps, talus, slides, volcanic material, glacial debris, sand dunes, strip mines, gravel pits and other accumulations of earthen material. Generally, vegetation accounts for less than 15% of total cover. |
| **Forest** | |
| 41 | **Deciduous Forest** - areas dominated by trees generally greater than 5 meters tall, and greater than 20% of total vegetation cover. More than 75% of the tree species shed foliage simultaneously in response to seasonal change. |
| 42 | **Evergreen Forest** - areas dominated by trees generally greater than 5 meters tall, and greater than 20% of total vegetation cover. More than 75% of the tree species maintain their leaves all year. Canopy is never without green foliage. |
| 43 | **Mixed Forest** - areas dominated by trees generally greater than 5 meters tall, and greater than 20% of total vegetation cover. Neither deciduous nor evergreen species are greater than 75% of total tree cover. |
| **Shrubland** | |
| 51 | **Dwarf Scrub** - Alaska only areas dominated by shrubs less than 20 centimeters tall with shrub canopy typically greater than 20% of total vegetation. This type is often co-associated with grasses, sedges, herbs, and non-vascular vegetation. |
| 52 | **Shrub/Scrub** - areas dominated by shrubs; less than 5 meters tall with shrub canopy typically greater than 20% of total vegetation. This class includes true shrubs, young trees in an early successional stage or trees stunted from environmental conditions. |
| **Herbaceous** | |
| 71 | **Grassland/Herbaceous** - areas dominated by gramanoid or herbaceous vegetation, generally greater than 80% of total vegetation. These areas are not subject to intensive management such as tilling, but can be utilized for grazing. |
| 72 | **Sedge/Herbaceous** - Alaska only areas dominated by sedges and forbs, generally greater than 80% of total vegetation. This type can occur with significant other grasses or other grass like plants, and includes sedge tundra, and sedge tussock tundra. |
| 73 | **Lichens** - Alaska only areas dominated by fruticose or foliose lichens generally greater than 80% of total vegetation. |

| | |
|---|---|
| 74 | **Moss** - Alaska only areas dominated by mosses, generally greater than 80% of total vegetation. |
| **Planted/Cultivated** | |
| 81 | **Pasture/Hay** - areas of grasses, legumes, or grass-legume mixtures planted for livestock grazing or the production of seed or hay crops, typically on a perennial cycle. Pasture/hay vegetation accounts for greater than 20% of total vegetation. |
| 82 | **Cultivated Crops** - areas used for the production of annual crops, such as corn, soybeans, vegetables, tobacco, and cotton, and also perennial woody crops such as orchards and vineyards. Crop vegetation accounts for greater than 20% of total vegetation. This class also includes all land being actively tilled. |
| **Wetlands** | |
| 90 | **Woody Wetlands** - areas where forest or shrubland vegetation accounts for greater than 20% of vegetative cover and the soil or substrate is periodically saturated with or covered with water. |
| 95 | **Emergent Herbaceous Wetlands** - Areas where perennial herbaceous vegetation accounts for greater than 80% of vegetative cover and the soil or substrate is periodically saturated with or covered with water. |
| *Reproduced from the Multi-Resolution Land Characteristics Consortium Website at http://www.mrlc.gov* | |

## 6.0 Appendix B. Surface Characteristic Lookup Tables

Table 6-1 through Table 6-6 provide the values of albedo, Bowen ratio, and surface roughness, respectively, based on the original 1992 NLCD land cover categories. Each table includes a column containing references used in estimating the values for each surface characteristic parameter and each land cover category. As explained in Section 2.0, more than one value of surface characteristics may be listed for certain land cover categories depending on user responses to specific prompts regarding the site location.

## Table 6-1. Seasonal Values of Albedo for the original 1992 NLCD

| Class Number | Class Name | Seasonal Albedo Values[1] | | | | | Reference |
|---|---|---|---|---|---|---|---|
| | | *1* | *2* | *3* | *4* | *5* | |
| 11 | Open Water | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | AERMET[2,3] |
| 12 | Perennial Ice/Snow | 0.7 | 0.7 | 0.6 | 0.6 | 0.6 | Stull & Garratt[4] |
| 21 | Low Intensity Residential | 0.18 | 0.45 | 0.16 | 0.16 | 0.16 | Estimate[5] |
| 22 | High Intensity Residential | 0.18 | 0.35 | 0.18 | 0.18 | 0.18 | Stull[6] & AERMET[7] |
| 23 | Commercial/Industrial/Transp | 0.18 | 0.35 | 0.18 | 0.18 | 0.18 | Stull[6] & AERMET[7] |
| 31 | Bare Rock/Sand/Clay *(Arid Region)* | 0.2 | NA | 0.2 | 0.2 | 0.2 | Garratt[8] |
| | Bare Rock/Sand/Clay *(Non-arid Region)* | 0.2 | 0.6 | 0.2 | 0.2 | 0.2 | Garratt[8] & AERMET[7] |
| 32 | Quarries/Strip Mines/Gravel | 0.2 | 0.6 | 0.2 | 0.2 | 0.2 | Garratt[8] & AERMET[7] |
| 33 | Transitional | 0.18 | 0.45 | 0.18 | 0.18 | 0.18 | Estimate[9] |
| 41 | Deciduous Forest | 0.17 | 0.5 | 0.16 | 0.16 | 0.16 | Stull[6] & AERMET[7] |
| 42 | Evergreen Forest | 0.12 | 0.35 | 0.12 | 0.12 | 0.12 | Stull[6] & AERMET[7] |
| 43 | Mixed Forest | 0.14 | 0.42 | 0.14 | 0.14 | 0.14 | Estimate[10] |
| 51 | Shrubland *(Arid Region)* | 0.25 | NA | 0.25 | 0.25 | 0.25 | Stull[6] |
| | Shrubland *(Non-arid Region)* | 0.18 | 0.5 | 0.18 | 0.18 | 0.18 | Estimate[11]&AERMET[7] |
| 61 | Orchards/Vineyards/Other | 0.18 | 0.5 | 0.14 | 0.18 | 0.18 | Estimate[12] |
| 71 | Grasslands/Herbaceous | 0.2 | 0.6 | 0.18 | 0.18 | 0.18 | AERMET[2] |
| 81 | Pasture/Hay | 0.18 | 0.6 | 0.14 | 0.2 | 0.2 | AERMET2,13 |
| 82 | Row Crops | 0.18 | 0.6 | 0.14 | 0.2 | 0.2 | AERMET2,13 |
| 83 | Small Grains | 0.18 | 0.6 | 0.14 | 0.2 | 0.2 | AERMET2,13 |
| 84 | Fallow | 0.18 | 0.6 | 0.18 | 0.18 | 0.18 | Garratt[8] |
| 85 | Urban/Recreational Grasses | 0.18 | 0.6 | 0.15 | 0.15 | 0.15 | Estimate[14] |
| 91 | Woody Wetlands | 0.14 | 0.3 | 0.14 | 0.14 | 0.14 | Stull[6] & AERMET[7] |
| 92 | Emergent Herbaceous Wetlands | 0.14 | 0.3 | 0.14 | 0.14 | 0.14 | Stull[6] & AERMET[7] |

1 Values are listed for the following seasonal categories: *1 - Late autumn after frost and harvest; or winter with no snow; 2 - Winter with continuous snow on ground; 3 - Transitional spring with partial green coverage or short annuals; 4 - Midsummer with lush vegetation; 5 - Autumn with unharvested cropland*

2 Estimate based on AERMET User's Guide, Table 4-1.

3 We assume no freeze of the water and no seasonal changes in albedo.

4 Estimate based on Stull, Table C-7 and Garratt, Table A8. Assume fresher snow and more ice in seasonal categories 3 & 4 and older snow in seasonal categories 1, 2, & 5.

5 Assume an equal mix of three classes: "High Intensity Residential", "Mixed Forest", and "Urban/Recreational Grasses."

6 Estimate based on Stull, Table C-7.

7 Estimate based on AERMET User's Guide, Table 4-1 albedo value for winter with continuous snow cover.

8 Estimate based on Garratt, Table A8.

9 Assume "Transitional" is similar to Class 84: "Fallow". A warning will be issues to the user if this category appears in more than 10% of the land cover data.

10 Estimate based on the average of Classes 41 and 42.

11 Estimate based on the non-arid shrubland having more vegetation that the arid-region shrubland.

12 Estimate based Class 51: "Shrubland (non-arid region)" for seasonal categories 1, 2 & 4 and AERMET User's Guide ("Cultivated Land") for seasonal categories 3 & 5.

13 Estimate based on AERMET User's Guide; assume more vegetation in summer and soil being wetter in spring than in fall.

14 Estimate based on AERMET User's Guide ("Cultivated Land") for seasonal category 3 & 4, and Garratt, Table A8 for seasonal categories 1, 2 & 5.

## Table 6-2. Seasonal Values of Bowen Ratio for the original 1992 NLCD

| Class Number | Class Name | Seasonal Bowen Ratio[1] Average | | | | | Seasonal Bowen Ratio[1] Wet | | | | | Seasonal Bowen Ratio[1] Dry | | | | | Reference |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | *1* | *2*[2] | *3* | *4* | *5* | *1* | *2*[2] | *3* | *4* | *5* | *1* | *2*[2] | *3* | *4* | *5* | |
| 11 | Open Water | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | AERMET&Oke[3] |
| 12 | Perennial Ice/Snow | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | AERMET&Oke[3] |
| 21 | Low Intensity Residential | 1.0 | 0.5 | 0.8 | 0.8 | 1.0 | 0.6 | 0.5 | 0.6 | 0.6 | 0.6 | 2.5 | 0.5 | 2.0 | 2.0 | 2.5 | Estimate[4] |
| 22 | High Intensity Residential | 1.5 | 0.5 | 1.5 | 1.5 | 1.5 | 1.0 | 0.5 | 1.0 | 1.0 | 1.0 | 3.0 | 0.5 | 3.0 | 3.0 | 3.0 | AERMET&Oke[3] |
| 23 | Commercial/Industrial/Transp | 1.5 | 0.5 | 1.5 | 1.5 | 1.5 | 1.0 | 0.5 | 1.0 | 1.0 | 1.0 | 3.0 | 0.5 | 3.0 | 3.0 | 3.0 | AERMET&Oke[3] |
| 31 | Bare Rock/Sand/Clay *(Arid Region)* | 6.0 | NA | 3.0 | 4.0 | 6.0 | 2.0 | NA | 1.0 | 1.5 | 2 | 10.0 | NA | 5.0 | 6.0 | 10 | AERMET&Oke[3] |
| | Bare Rock/Sand/Clay *(Non-arid Region)* | 1.5 | 0.5 | 1.5 | 1.5 | 1.5 | 1.0 | 0.5 | 1.0 | 1.0 | 1.0 | 3.0 | 0.5 | 3.0 | 3.0 | 3.0 | AERMET&Oke[3] |
| 32 | Quarries/Strip Mines/Gravel | 1.5 | 0.5 | 1.5 | 1.5 | 1.5 | 1.0 | 0.5 | 1.0 | 1.0 | 1.0 | 3.0 | 0.5 | 3.0 | 3.0 | 3.0 | AERMET&Oke[3] |
| 33 | Transitional | 1.0 | 0.5 | 1.0 | 1.0 | 1.0 | 0.7 | 0.5 | 0.7 | 0.7 | 0.7 | 2.0 | 0.5 | 2.0 | 2.0 | 2.0 | Estimate[5] |
| 41 | Deciduous Forest | 1.0 | 0.5 | 0.7 | 0.3 | 1.0 | 0.4 | 0.5 | 0.3 | 0.2 | 0.4 | 2.0 | 0.5 | 1.5 | 0.6 | 2.0 | AERMET&Oke[3] |
| 42 | Evergreen Forest | 0.8 | 0.5 | 0.7 | 0.3 | 0.8 | 0.3 | 0.5 | 0.3 | 0.2 | 0.3 | 1.5 | 0.5 | 1.5 | 0.6 | 1.5 | AERMET&Oke[3] |
| 43 | Mixed Forest | 0.9 | 0.5 | 0.7 | 0.3 | 0.9 | 0.35 | 0.5 | 0.3 | 0.2 | 0.35 | 1.75 | 0.5 | 1.5 | 0.6 | 1.75 | Estimate[6] |
| 51 | Shrubland *(Arid Region)* | 6.0 | NA | 3.0 | 4.0 | 6.0 | 2.0 | NA | 1.0 | 1.5 | 2.0 | 10.0 | NA | 5.0 | 6.0 | 10.0 | AERMET&Oke[3] |
| | Shrubland *(Non-arid Region)* | 1.5 | 0.5 | 1.0 | 1.0 | 1.5 | 1.0 | 0.5 | 0.8 | 0.8 | 1.0 | 3.0 | 0.5 | 2.5 | 2.5 | 3.0 | Estimate[7] |
| 61 | Orchards/Vineyards/Other | 0.7 | 0.5 | 0.3 | 0.5 | 0.7 | 0.4 | 0.5 | 0.2 | 0.3 | 0.4 | 2.0 | 0.5 | 1.0 | 1.5 | 2.0 | AERMET&Oke[3] |

| | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 71 | Grasslands/Herbaceous | 1.0 | 0.5 | 0.4 | 0.8 | 1.0 | 0.5 | 0.5 | 0.3 | 0.4 | 0.5 | 2.0 | 0.5 | 1.0 | 2.0 | 2.0 | AERMET&Oke[3] |
| 81 | Pasture/Hay | 0.7 | 0.5 | 0.3 | 0.5 | 0.7 | 0.4 | 0.5 | 0.2 | 0.3 | 0.4 | 2.0 | 0.5 | 1.0 | 1.5 | 2.0 | AERMET&Oke[3] |
| 82 | Row Crops | 0.7 | 0.5 | 0.3 | 0.5 | 0.7 | 0.4 | 0.5 | 0.2 | 0.3 | 0.4 | 2.0 | 0.5 | 1.0 | 1.5 | 2.0 | AERMET&Oke[3] |
| 83 | Small Grains | 0.7 | 0.5 | 0.3 | 0.5 | 0.7 | 0.4 | 0.5 | 0.2 | 0.3 | 0.4 | 2.0 | 0.5 | 1.0 | 1.5 | 2.0 | AERMET&Oke[3] |
| 84 | Fallow | 0.7 | 0.5 | 0.3 | 0.5 | 0.7 | 0.4 | 0.5 | 0.2 | 0.3 | 0.4 | 2.0 | 0.5 | 1.0 | 1.5 | 2.0 | AERMET&Oke[3] |
| 85 | Urban/Recreational Grasses | 0.7 | 0.5 | 0.3 | 0.5 | 0.7 | 0.4 | 0.5 | 0.2 | 0.3 | 0.4 | 2.0 | 0.5 | 1.0 | 1.5 | 2.0 | AERMET&Oke[3] |
| 91 | Woody Wetlands | 0.3 | 0.5 | 0.2 | 0.2 | 0.2 | 0.1 | 0.5 | 0.1 | 0.1 | 0.1 | 0.2 | 0.5 | 0.2 | 0.2 | 0.2 | Estimate[7] |
| 92 | Emergent Herbaceous Wetlands | 0.1 | 0.5 | 0.1 | 0.1 | 0.1 | 0.1 | 0.5 | 0.1 | 0.1 | 0.1 | 0.2 | 0.5 | 0.2 | 0.2 | 0.2 | AERMET&Oke[3] |

1 Values are listed for the following seasonal categories: *1 - Late autumn after frost and harvest; or winter with no snow; 2 - Winter with continuous snow on ground; 3 - Transitional spring with partial green coverage or short annuals; 4 - Midsummer with lush vegetation; 5 - Autumn with unharvested cropland*

2 Values for seasonal category 2 are based on the AERMET User's Guide (EPA, 2018a) and Oke (1978), Tables 4-2a-c, Bowen ratio values for winter with continuous snow cover, except for class 11 with the assumption the water does not freeze.

3 Values for seasonal categories 1, 2, 3 & 5 are based on AERMET User's Guide (EPA, 2018a), Tables 4-2a-c and Oke (1978).

4 Estimate based on composition being an equal mix of three classes: "High Intensity Residential", "Mixed Forest", and "Urban/Recreational Grasses.

5 Estimate based on the Bowen ratio of "Transitional" being between the Bowen ratio of Classes 31 and 71.

6 Assume "Mixed Forest" is composed of equal parts of "Deciduous Forest" and "Evergreen Forest."

7 Estimate based on comparison to Bowen ratio for other classes.

**Table 6-3. Seasonal Values of Surface Roughness (m) for the original 1992 NLCD**

| Class Number | Class Name | Seasonal Surface Roughness[1] (m) | | | | | Reference |
|---|---|---|---|---|---|---|---|
| | | *1* | *2* | *3* | *4* | *5* | |
| 11 | Open Water | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | Stull[2] |
| 12 | Perennial Ice/Snow | 0.002 | 0.002 | 0.002 | 0.002 | 0.002 | Stull[2] |
| 21 | Low Intensity Residential | 0.30 | 0.30 | 0.40 | 0.40 | 0.40 | Estimate[3] |
| 22 | High Intensity Residential | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | AERMET[4] |
| 23 | Commercial/Indust/Transp *(Airport)* | 0.07 | 0.07 | 0.07 | 0.07 | 0.07 | Estimate[5] |
| | Commercial/Industrial/Transp *(Non-airport)* | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | Estimate[5] |
| 31 | Bare Rock/Sand/Clay *(Arid Region)* | 0.05 | NA | 0.05 | 0.05 | 0.05 | Slade[6] |
| | Bare Rock/Sand/Clay *(Non-arid Region)* | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | Slade[6] |
| 32 | Quarries/Strip Mines/Gravel | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | Estimate[7] |
| 33 | Transitional | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | Estimate[8] |
| 41 | Deciduous Forest | 0.6 | 0.5 | 1.0 | 1.3 | 1.3 | AERMET[4] |
| 42 | Evergreen Forest | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 | AERMET[4] |
| 43 | Mixed Forest | 0.9 | 0.8 | 1.1 | 1.3 | 1.3 | Estimate[9] |
| 51 | Shrubland *(Arid Region)* | 0.15 | NA | 0.15 | 0.15 | 0.15 | 50% Cat. 51 (Non-Arid)[10] |
| | Shrubland *(Non-arid Region)* | 0.3 | 0.15 | 0.3 | 0.3 | 0.3 | AERMET[4] |
| 61 | Orchards/Vineyards/Other | 0.1 | 0.05 | 0.2 | 0.3 | 0.3 | Garratt[11] |
| 71 | Grasslands/Herbaceous | 0.01 | 0.005 | 0.05 | 0.1 | 0.1 | AERMET[4] |
| 81 | Pasture/Hay | 0.02 | 0.01 | 0.03 | 0.15 | 0.15 | Garratt[11] & Slade[12] |
| 82 | Row Crops | 0.02 | 0.01 | 0.03 | 0.2 | 0.2 | Garratt[11] & Slade[12] |
| 83 | Small Grains | 0.02 | 0.01 | 0.03 | 0.15 | 0.15 | Garratt[11] & Slade[12] |
| 84 | Fallow | 0.02 | 0.01 | 0.02 | 0.05 | 0.05 | Estimate[13] |
| 85 | Urban/Recreational Grasses | 0.01 | 0.005 | 0.015 | 0.02 | 0.015 | Randerson[14] |
| 91 | Woody Wetlands | 0.4 | 0.3 | 0.5 | 0.5 | 0.5 | Estimate[15] |
| 92 | Emergent Herbaceous Wetlands | 0.2 | 0.1 | 0.2 | 0.2 | 0.2 | AERMET[4] |

1 Values are listed for the following seasonal categories: *1 - Late autumn after frost and harvest; or winter with no snow; 2 - Winter with continuous snow on ground; 3 - Transitional spring with partial green coverage or short annuals; 4 - Midsummer with lush vegetation; 5 - Autumn with unharvested cropland*

2 Estimate based on Stull, Fig 9.6. We have specified a larger roughness than the AERMET "calm open sea" roughness value because we have assumed that most of the water is closer to land and will experience waves and be closer to the shoreline, increasing roughness.

3 Assume 50% "High Intensity Residential" (22), 25% "Mixed Forest" (43), and 25% "Urban/Recreational Grasses" (85), using a weighted geometric mean value.

4 Based on the AERMET User's Guide (EPA, 2018a).

5 For airport sites, assume 90% of land cover is "Transportation" with roughness similar to Class 31 (Bare Rock/ Sand/ Clay) and 10% is "Commercial/Industrial" with roughness similar to Class 22 (High Intensity Residential). For non-airport, assume 10% of land cover is "Transportation" and 90% is "Commercial/Industrial". Weighted geometric mean values are used.

6 Estimate based on Slade, Table 3-1, assuming the surface is not completely level due to inclusion of some larger rocks.

7 Estimate reflecting "significant surface expression"

8 Estimate reflecting significant mix of different land cover classes. A warning will be issued to the user if this category appears in more than 10% of the land cover data.

9 Assume "Mixed Forest" is 50% "Deciduous Forest" and 50% "Evergreen Forest", using a weighted geometric mean value.

10 Assume arid region would have approximately 50% less vegetation than a non-arid region.

11 Estimate based on Garratt, Table A6.

12 Estimate based on Slade, Table 3-1

13 Based on class 31 ("Bare Rock/Sand/Clay") for seasonal categories 1 &2 and 81, 82, 83 ("Pasture/Hay", "Row Crops" & "Small Grains") for seasonal categories 3, 4, & 5, with seasonal category 5 having a more similar amount of vegetation to seasonal category 3 and, therefore, the same roughness.

14 Estimate based on Randerson, Table 5.4

15 Assume 50% Mixed Forest (43) and 50% Emergent Herb Wetlands (92), using a weighted geometric mean value.

## Table 6-4. Seasonal Values of Albedo for the Annual NLCD

| Class Number | Class Name | Seasonal Albedo Values[1] | | | | | Reference |
|---|---|---|---|---|---|---|---|
| | | *1* | *2* | *3* | *4* | *5* | |
| 11 | Open Water | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | NLCD 1992 Cat. 11 |
| 12 | Perennial Ice/Snow | 0.7 | 0.7 | 0.6 | 0.6 | 0.6 | NLCD 1992 Cat.12 |
| 21 | Developed, Open Space | 0.18 | 0.6 | 0.15 | 0.15 | 0.15 | NLCD 1992 Cat. 85 |
| 22 | Developed, Low Intensity | 0.18 | 0.45 | 0.16 | 0.16 | 0.16 | NLCD 1992 Cat. 21 |
| 23 | Developed, Medium Intensity | 0.18 | 0.18 | 0.18 | 0.18 | 0.18 | NLCD 1992 Cat. 23 |
| 24 | Developed, High Intensity | 0.18 | 0.25 | 0.18 | 0.18 | 0.18 | NLCD 1992 Cat. 23 |
| 31 | Barren Land (Rock/Sand/Clay) *(Arid Region)* | 0.2 | NA | 0.2 | 0.2 | 0.2 | NLCD 1992 Cat. 31 |
| | Barren Land (Rock/Sand/Clay) *(Non-arid Region)* | 0.2 | 0.6 | 0.2 | 0.2 | 0.2 | NLCD 1992 Cat. 31 |
| 32 | Unconsolidated Shore | 0.14 | 0.3 | 0.14 | 0.14 | 0.14 | NLCD 1992 Cat. 91 |
| 41 | Deciduous Forest | 0.17 | 0.5 | 0.16 | 0.16 | 0.16 | NLCD 1992 Cat. 41 |
| 42 | Evergreen Forest | 0.12 | 0.35 | 0.12 | 0.12 | 0.12 | NLCD 1992 Cat. 42 |
| 43 | Mixed Forest | 0.14 | 0.42 | 0.14 | 0.14 | 0.14 | NLCD 1992 Cat. 43 |
| 51 | Dwarf Scrub *(Arid Region)* | 0.25 | NA | 0.25 | 0.25 | 0.25 | NLCD 1992 Cat. 51 |
| | Dwarf Scrub *(Non-arid Region)* | 0.18 | 0.5 | 0.18 | 0.18 | 0.18 | NLCD 1992 Cat. 51 |
| 52 | Shrub/Scrub *(Arid Region)* | 0.25 | NA | 0.25 | 0.25 | 0.25 | NLCD 1992 Cat. 51 |
| | Shrub/Scrub *(Non-arid Region)* | 0.18 | 0.5 | 0.18 | 0.18 | 0.18 | NLCD 1992 Cat. 51 |
| 71 | Grasslands/Herbaceous | 0.2 | 0.6 | 0.18 | 0.18 | 0.18 | NLCD 1992 Cat. 71 |
| 72 | Sedge/Herbaceous | 0.2 | 0.6 | 0.18 | 0.18 | 0.18 | NLCD 1992 Cat. 71 |
| 73 | Lichens | 0.2 | 0.6 | 0.18 | 0.18 | 0.18 | NLCD 1992 Cat. 71 |
| 74 | Moss | 0.2 | 0.6 | 0.18 | 0.18 | 0.18 | NLCD 1992 Cat. 71 |
| 81 | Pasture/Hay | 0.18 | 0.6 | 0.14 | 0.2 | 0.2 | NLCD 1992 Cat. 81 |
| 82 | Cultivated Crops | 0.18 | 0.6 | 0.14 | 0.2 | 0.2 | NLCD 1992 Cat. 82 |
| 90 | Woody Wetlands | 0.14 | 0.3 | 0.14 | 0.14 | 0.14 | NLCD 1992 Cat. 91 |
| 91 | Palustrine Forested Wetland | 0.14 | 0.3 | 0.14 | 0.14 | 0.14 | NLCD 1992 Cat. 91 |
| 92 | Palustrine Scrub/Shrub Wetland | 0.14 | 0.3 | 0.14 | 0.14 | 0.14 | NLCD 1992 Cat. 91 |
| 93 | Estuarine Forested Wetland | 0.14 | 0.3 | 0.14 | 0.14 | 0.14 | NLCD 1992 Cat. 91 |
| 94 | Estuarine Scrub/Shrub Wetland | 0.14 | 0.3 | 0.14 | 0.14 | 0.14 | NLCD 1992 Cat. 91 |
| 95 | Emergent Herbaceous Wetland | 0.14 | 0.3 | 0.14 | 0.14 | 0.14 | NLCD 1992 Cat. 92 |
| 96 | Palustrine Emergent Wetland (Persistent) | 0.14 | 0.3 | 0.14 | 0.14 | 0.14 | NLCD 1992 Cat. 92 |
| 97 | Estuarine Emergent Wetland | 0.14 | 0.3 | 0.14 | 0.14 | 0.14 | NLCD 1992 Cat. 92 |
| 98 | Palustrine Aquatic Bed | 0.14 | 0.3 | 0.14 | 0.14 | 0.14 | NLCD 1992 Cat. 92 |
| 99 | Estuarine Aquatic Bed | 0.14 | 0.3 | 0.14 | 0.14 | 0.14 | NLCD 1992 Cat. 92 |

1 Values are listed for the following seasonal categories: *1 - Late autumn after frost and harvest; or winter with no snow; 2 - Winter with continuous snow on ground; 3 - Transitional spring with partial green coverage or short annuals; 4 - Midsummer with lush vegetation; 5 - Autumn with unharvested cropland*

## Table 6-5. Seasonal Values of Bowen Ratio for the Annual NLCD

| Class Number | Class Name | Seasonal Bowen Ratio[1] Average | | | | | Seasonal Bowen Ratio[1] Wet | | | | | Seasonal Bowen Ratio[1] Dry | | | | | Reference |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | *1* | *2* | *3* | *4* | *5* | *1* | *2* | *3* | *4* | *5* | *1* | *2* | *3* | *4* | *5* | |
| 11 | Open Water | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | NLCD 1992 Cat. 11 |
| 12 | Perennial Ice/Snow | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | NLCD 1992 Cat.12 |
| 21 | Developed, Open Space | 0.7 | 0.5 | 0.3 | 0.5 | 0.7 | 0.4 | 0.5 | 0.2 | 0.3 | 0.4 | 2.0 | 0.5 | 1.0 | 1.5 | 2.0 | NLCD 1992 Cat. 85 |
| 22 | Developed, Low Intensity | 1.0 | 0.5 | 0.8 | 0.8 | 1.0 | 0.6 | 0.5 | 0.6 | 0.6 | 0.6 | 2.5 | 0.5 | 2.0 | 2.0 | 2.5 | NLCD 1992 Cat. 21 |
| 23 | Developed, Medium Intensity | 1.2 | 0.5 | 1.1 | 1.1 | 1.2 | 0.8 | 0.5 | 0.8 | 0.8 | 0.8 | 3.0 | 0.5 | 3.0 | 3.0 | 3.0 | Estimated[2] |
| 24 | Developed, High Intensity | 1.5 | 0.5 | 1.5 | 1.5 | 1.5 | 1.0 | 0.5 | 1.0 | 1.0 | 1.0 | 3.0 | 0.5 | 3.0 | 3.0 | 3.0 | NLCD 1992 Cat. 23 |
| 31 | Barren Land (Rock/Sand/Clay) *(Arid Region)* | 6.0 | NA | 3.0 | 4.0 | 6.0 | 2.0 | NA | 1.0 | 1.5 | 2.0 | 10.0 | NA | 5.0 | 6.0 | 10.0 | NLCD 1992 Cat. 31 |
| | Barren Land (Rock/Sand/Clay) *(Non-arid Region)* | 1.5 | 0.5 | 1.5 | 1.5 | 1.5 | 1.0 | 0.5 | 1.0 | 1.0 | 1.0 | 3.0 | 0.5 | 3.0 | 3.0 | 3.0 | NLCD 1992 Cat. 31 |
| 32 | Unconsolidated Shore | 0.2 | 0.5 | 0.2 | 0.2 | 0.2 | 0.1 | 0.5 | 0.1 | 0.1 | 0.1 | 0.2 | 0.5 | 0.2 | 0.2 | 0.2 | NLCD 1992 Cat. 91 |
| 41 | Deciduous Forest | 1.0 | 0.5 | 0.7 | 0.3 | 1.0 | 0.4 | 0.5 | 0.3 | 0.2 | 0.4 | 2.0 | 0.5 | 1.5 | 0.6 | 2.0 | NLCD 1992 Cat. 41 |
| 42 | Evergreen Forest | 0.8 | 0.7 | 0.3 | 0.3 | 0.8 | 0.3 | 0.5 | 0.3 | 0.2 | 0.3 | 1.5 | 0.5 | 1.5 | 0.6 | 1.5 | NLCD 1992 Cat. 42 |
| 43 | Mixed Forest | 0.9 | 0.5 | 0.7 | 0.3 | 0.9 | 0.35 | 0.5 | 0.3 | 0.2 | 0.35 | 1.75 | 0.5 | 1.5 | 0.6 | 1.75 | NLCD 1992 Cat. 43 |
| 51 | Dwarf Scrub *(Arid Region)* | 4.0 | NA | 2.0 | 3.0 | 4.0 | 1.5 | NA | 0.8 | 0.9 | 1.5 | 7.0 | NA | 4.0 | 6.0 | 7.0 | Estimated from Cat 52 |
| | Dwarf Scrub *(Non-arid Region)* | 1.5 | 0.5 | 1.0 | 1.0 | 1.5 | 1.0 | 0.5 | 0.8 | 0.8 | 1.0 | 3.0 | 0.5 | 2.5 | 2.5 | 3.0 | NLCD 1992 Cat. 51 |
| 52 | Shrub/Scrub *(Arid Region)* | 6.0 | NA | 3.0 | 4.0 | 6.0 | 2.0 | NA | 1.0 | 1.5 | 2.0 | 10.0 | NA | 5.0 | 6.0 | 10.0 | NLCD 1992 Cat. 51 |
| | Shrub/Scrub *(Non-arid Region)* | 1.5 | 0.5 | 1.0 | 1.0 | 1.5 | 1.0 | 0.5 | 0.8 | 0.8 | 1.0 | 3.0 | 0.5 | 2.5 | 2.5 | 3.0 | NLCD 1992 Cat. 51 |
| 71 | Grasslands/Herbaceous | 1.0 | 0.5 | 0.4 | 0.8 | 1.0 | 0.5 | 0.5 | 0.3 | 0.4 | 0.5 | 2.0 | 0.5 | 1.0 | 2.0 | 2.0 | NLCD 1992 Cat. 71 |

| | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 72 | Sedge/Herbaceous | 1.0 | 0.5 | 0.4 | 0.8 | 1.0 | 0.5 | 0.5 | 0.3 | 0.4 | 0.5 | 2.0 | 0.5 | 1.0 | 2.0 | 2.0 | NLCD 1992 Cat. 71 |
| 73 | Lichens | 1.0 | 0.5 | 0.4 | 0.8 | 1.0 | 0.5 | 0.5 | 0.3 | 0.4 | 0.5 | 2.0 | 0.5 | 1.0 | 2.0 | 2.0 | NLCD 1992 Cat. 71 |
| 74 | Moss | 1.0 | 0.5 | 0.4 | 0.8 | 1.0 | 0.5 | 0.5 | 0.3 | 0.4 | 0.5 | 2.0 | 0.5 | 1.0 | 2.0 | 2.0 | NLCD 1992 Cat. 71 |
| 81 | Pasture/Hay | 0.7 | 0.5 | 0.3 | 0.5 | 0.7 | 0.4 | 0.5 | 0.2 | 0.3 | 0.4 | 2.0 | 0.5 | 1.0 | 1.5 | 2.0 | NLCD 1992 Cat. 81 |
| 82 | Cultivated Crops | 0.7 | 0.5 | 0.3 | 0.5 | 0.7 | 0.4 | 0.5 | 0.2 | 0.3 | 0.4 | 2.0 | 0.5 | 1.0 | 1.5 | 2.0 | NLCD 1992 Cat. 82 |
| 90 | Woody Wetlands | 0.2 | 0.5 | 0.2 | 0.2 | 0.2 | 0.1 | 0.5 | 0.1 | 0.1 | 0.1 | 0.2 | 0.5 | 0.2 | 0.2 | 0.2 | NLCD 1992 Cat. 91 |
| 91 | Palustrine Forested Wetland | 0.2 | 0.5 | 0.2 | 0.2 | 0.2 | 0.1 | 0.5 | 0.1 | 0.1 | 0.1 | 0.2 | 0.5 | 0.2 | 0.2 | 0.2 | NLCD 1992 Cat. 91 |
| 92 | Palustrine Scrub/Shrub | 0.2 | 0.5 | 0.2 | 0.2 | 0.2 | 0.1 | 0.5 | 0.1 | 0.1 | 0.1 | 0.2 | 0.5 | 0.2 | 0.2 | 0.2 | NLCD 1992 Cat. 91 |
| 93 | Estuarine Forested Wetland | 0.2 | 0.5 | 0.2 | 0.2 | 0.2 | 0.1 | 0.5 | 0.1 | 0.1 | 0.1 | 0.2 | 0.5 | 0.2 | 0.2 | 0.2 | NLCD 1992 Cat. 91 |
| 94 | Estuarine Scrub/Shrub | 0.2 | 0.5 | 0.2 | 0.2 | 0.2 | 0.1 | 0.5 | 0.1 | 0.1 | 0.1 | 0.2 | 0.5 | 0.2 | 0.2 | 0.2 | NLCD 1992 Cat. 91 |
| 95 | Emergent Herbaceous | 0.1 | 0.5 | 0.1 | 0.1 | 0.1 | 0.1 | 0.5 | 0.1 | 0.1 | 0.1 | 0.2 | 0.5 | 0.2 | 0.2 | 0.2 | NLCD 1992 Cat. 92 |
| 96 | Palustrine Emergent Wetland | 0.1 | 0.5 | 0.1 | 0.1 | 0.1 | 0.1 | 0.5 | 0.1 | 0.1 | 0.1 | 0.2 | 0.5 | 0.2 | 0.2 | 0.2 | NLCD 1992 Cat. 92 |
| 97 | Estuarine Emergent Wetland | 0.1 | 0.5 | 0.1 | 0.1 | 0.1 | 0.1 | 0.5 | 0.1 | 0.1 | 0.1 | 0.2 | 0.5 | 0.2 | 0.2 | 0.2 | NLCD 1992 Cat. 92 |
| 98 | Palustrine Aquatic Bed | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | NLCD 1992 Cat. 11 |
| 99 | Estuarine Aquatic Bed | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | NLCD 1992 Cat. 11 |

1 Values are listed for the following seasonal categories: *1 - Late autumn after frost and harvest; or winter with no snow; 2 - Winter with continuous snow on ground; 3 - Transitional spring with partial green coverage or short annuals; 4 - Midsummer with lush vegetation; 5 - Autumn with unharvested cropland*

2 Estimated from categories 22 (Developed - Low Intensity) and 24 (Developed – High Intensity).

**Table 6-6. Seasonal Values of Surface Roughness for the Annual NLCD**

| Class Number | Class Name | Seasonal Surface Roughness[1] (m) | | | | | Reference |
|---|---|---|---|---|---|---|---|
| | | *1* | *2* | *3* | *4* | *5* | |
| 11 | Open Water | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | NLCD 1992 Cat. 11 |
| 12 | Perennial Ice/Snow | 0.002 | 0.002 | 0.002 | 0.002 | 0.002 | NLCD 1992 Cat. 12 |
| 21 | Developed, Open Space *(Airport)* | 0.02 | 0.01 | 0.02 | 0.03 | 0.03 | Estimated[2] |
| | Developed, Open Space *(Non-airport)* | 0.02 | 0.01 | 0.03 | 0.04 | 0.03 | Estimated[2] |
| 22 | Developed, Low Intensity *(Airport)* | 0.03 | 0.02 | 0.03 | 0.04 | 0.03 | Estimated[2] |
| | Developed, Low Intensity *(Non-airport)* | 0.07 | 0.05 | 0.09 | 0.1 | 0.09 | Estimated[2] |
| 23 | Developed, Medium Intensity *(Airport)* | 0.05 | 0.04 | 0.06 | 0.06 | 0.06 | Estimated[2] |
| | Developed, Medium Intensity *(Non-airport)* | 0.3 | 0.2 | 0.3 | 0.3 | 0.3 | Estimated[2] |
| 24 | Developed, High Intensity *(Airport)* | 0.07 | 0.07 | 0.07 | 0.08 | 0.08 | Estimated[2] |
| | Developed, High Intensity *(Non-airport)* | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | Estimated[2] |
| 31 | Barren Land (Rock/Sand/Clay) *(Arid Region)* | 0.05 | NA | 0.05 | 0.05 | 0.05 | NLCD 1992 Cat. 31 |
| | Barren Land (Rock/Sand/Clay) *(Non-arid Region)* | 0.05 | 0.01 | 0.05 | 0.05 | 0.05 | NLCD 1992 Cat. 31 |
| 32 | Unconsolidated Shore | 0.05 | 0.01 | 0.05 | 0.05 | 0.05 | NLCD 1992 Cat. 31 |
| 41 | Deciduous Forest | 0.6 | 0.5 | 1.0 | 1.3 | 1.3 | NLCD 1992 Cat. 41 |
| 42 | Evergreen Forest | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 | NLCD 1992 Cat. 42 |
| 43 | Mixed Forest | 0.9 | 0.8 | 1.1 | 1.3 | 1.3 | NLCD 1992 Cat. 43 |
| 51 | Dwarf Scrub *(Arid Region)* | 0.05 | NA | 0.05 | 0.05 | 0.05 | NLCD 1992 Cat. 51 |
| | Dwarf Scrub *(Non-arid Region)* | 0.1 | 0.05 | 0.1 | 0.1 | 0.1 | NLCD 1992 Cat. 51 |
| 52 | Shrub/Scrub *(Arid Region)* | 0.15 | NA | 0.15 | 0.15 | 0.15 | NLCD 1992 Cat. 51 |
| | Shrub/Scrub *(Non-arid Region)* | 0.3 | 0.15 | 0.3 | 0.3 | 0.3 | NLCD 1992 Cat. 51 |
| 71 | Grasslands/Herbaceous | 0.01 | 0.005 | 0.05 | 0.1 | 0.1 | NLCD 1992 Cat. 71 |
| 72 | Sedge/Herbaceous | 0.01 | 0.005 | 0.05 | 0.1 | 0.1 | NLCD 1992 Cat. 71 |
| 73 | Lichens | 0.01 | 0.005 | 0.05 | 0.05 | 0.05 | Estimated |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 74 | Moss | 0.01 | 0.005 | 0.05 | 0.05 | 0.05 | Estimated |
| 81 | Pasture/Hay *(Airport)* | 0.02 | 0.01 | 0.02 | 0.03 | 0.03 | NLCD 1992 Cat. 21 |
| | Pasture/Hay *(Non-airport)* | 0.02 | 0.01 | 0.03 | 0.15 | 0.15 | NLCD 1992 Cat. 81 |
| 82 | Cultivated Crops *(Airport)* | 0.02 | 0.01 | 0.02 | 0.03 | 0.03 | NLCD 1992 Cat. 21 |
| | Cultivated Crops *(Non-airport)* | 0.03 | 0.014 | 0.04 | 0.2 | 0.2 | Estimated |
| 90 | Woody Wetlands | 0.4 | 0.3 | 0.5 | 0.5 | 0.5 | NLCD 1992 Cat. 91 |
| 91 | Palustrine Forested Wetland | 0.4 | 0.3 | 0.5 | 0.5 | 0.5 | NLCD 1992 Cat. 91 |
| 92 | Palustrine Scrub/Shrub Wetland | 0.2 | 0.1 | 0.2 | 0.2 | 0.2 | NLCD 1992 Cat. 92 |
| 93 | Estuarine Forested Wetland | 0.4 | 0.3 | 0.5 | 0.5 | 0.5 | NLCD 1992 Cat. 91 |
| 94 | Estuarine Scrub/Shrub Wetland | 0.2 | 0.1 | 0.2 | 0.2 | 0.2 | NLCD 1992 Cat. 92 |
| 95 | Emergent Herbaceous Wetland | 0.2 | 0.1 | 0.2 | 0.2 | 0.2 | NLCD 1992 Cat. 92 |
| 96 | Palustrine Emergent Wetland (Persistent) | 0.2 | 0.1 | 0.2 | 0.2 | 0.2 | NLCD 1992 Cat. 92 |
| 97 | Estuarine Emergent Wetland | 0.2 | 0.1 | 0.2 | 0.2 | 0.2 | NLCD 1992 Cat. 92 |
| 98 | Palustrine Aquatic Bed | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | Estimated |
| 99 | Estuarine Aquatic Bed | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | Estimated |

1 Values are listed for the following seasonal categories: *1 - Late autumn after frost and harvest; or winter with no snow; 2 - Winter with continuous snow on ground; 3 - Transitional spring with partial green coverage or short annuals; 4 - Midsummer with lush vegetation; 5 - Autumn with unharvested cropland*

2 Surface roughness lengths for categories 21-24 that make up the Developed class of categories in the annual NLCD are calculated as a weighted geometric mean of a combination of the following original 1992 NLCD categories (see applied weights in tables below):

- High Intensity Residential (22)
- Bare Rock/Sand/Clay (31)
- Mixed Forest (43)
- Urban/Recreational Grasses (85)

*1992 NLCD Values are italicized on gray background* — Roughness length assigned to 2001, 2006, 2011 categories on orange background

Applied weights are on yellow background — AP = Airport, NonAP = Non-airport, GM = Geometric Mean

Season 1 - Late autumn or Winter without snow:

| 1992 Cat: | 22 | 31 | 43 | 85 | |
|---|---|---|---|---|---|
| 2001 Cat | *1* | *0.05* | *0.9* | *0.01* | GM |
| 21 AP* | 0.05 | 0.05 | 0.05 | 0.85 | 0.017 |
| 21 NonAP** | 0.05 | 0.05 | 0.1 | 0.8 | 0.021 |
| 22 AP | 0.05 | 0.3 | 0.05 | 0.6 | 0.026 |
| 22 NonAP | 0.3 | 0.05 | 0.1 | 0.55 | 0.068 |
| 23 AP | 0.1 | 0.55 | 0.05 | 0.3 | 0.048 |
| 23 NonAP | 0.6 | 0.05 | 0.1 | 0.25 | 0.269 |
| 24 AP | 0.1 | 0.8 | 0.05 | 0.05 | 0.072 |
| 24 NonAP | 0.85 | 0.05 | 0.05 | 0.05 | 0.680 |

Season 2- Winter with snow:

| 1992 Cat: | 22 | 31 | 43 | 85 | |
|---|---|---|---|---|---|
| 2001 Cat | *1* | *0.05* | *0.8* | *0.005* | GM |
| 21 AP | 0.05 | 0.05 | 0.05 | 0.85 | 0.009 |
| 21 NonAP | 0.05 | 0.05 | 0.1 | 0.8 | 0.012 |
| 22 AP | 0.05 | 0.3 | 0.05 | 0.6 | 0.017 |
| 22 NonAP | 0.3 | 0.05 | 0.1 | 0.55 | 0.046 |
| 23 AP | 0.1 | 0.55 | 0.05 | 0.3 | 0.039 |
| 23 NonAP | 0.6 | 0.05 | 0.1 | 0.25 | 0.224 |
| 24 AP | 0.1 | 0.8 | 0.05 | 0.05 | 0.069 |
| 24 NonAP | 0.85 | 0.05 | 0.05 | 0.05 | 0.653 |

Season 3 - Transitional spring:

| 1992 Cat: | 22 | 31 | 43 | 85 | |
|---|---|---|---|---|---|
| 2001 Cat | *1* | *0.05* | *1.1* | *0.015* | GM |
| 21 AP | 0.05 | 0.05 | 0.05 | 0.85 | 0.024 |
| 21 NonAP | 0.05 | 0.05 | 0.1 | 0.8 | 0.030 |
| 22 AP | 0.05 | 0.3 | 0.05 | 0.6 | 0.033 |
| 22 NonAP | 0.3 | 0.05 | 0.1 | 0.55 | 0.086 |
| 23 AP | 0.1 | 0.55 | 0.05 | 0.3 | 0.055 |
| 23 NonAP | 0.6 | 0.05 | 0.1 | 0.25 | 0.304 |
| 24 AP | 0.1 | 0.8 | 0.05 | 0.05 | 0.074 |
| 24 NonAP | 0.85 | 0.05 | 0.05 | 0.05 | 0.701 |

Season 4 - Midsummer with lush vegetation:

| 1992 Cat: | 22 | 31 | 43 | 85 | |
|---|---|---|---|---|---|
| 2001 Cat | *1* | *0.05* | *1.3* | *0.02* | GM |
| 21 AP | 0.05 | 0.05 | 0.05 | 0.85 | 0.031 |
| 21 NonAP | 0.05 | 0.05 | 0.1 | 0.8 | 0.039 |
| 22 AP | 0.05 | 0.3 | 0.05 | 0.6 | 0.039 |
| 22 NonAP | 0.3 | 0.05 | 0.1 | 0.55 | 0.103 |
| 23 AP | 0.1 | 0.55 | 0.05 | 0.3 | 0.060 |
| 23 NonAP | 0.6 | 0.05 | 0.1 | 0.25 | 0.332 |
| 24 AP | 0.1 | 0.8 | 0.05 | 0.05 | 0.076 |
| 24 NonAP | 0.85 | 0.05 | 0.05 | 0.05 | 0.717 |

Season 5 - Autumn with unharvested cropland:

| 1992 Cat: | 22 | 31 | 43 | 85 | |
|---|---|---|---|---|---|
| 2001 Cat | *1* | *0.05* | *1.3* | *0.015* | GM |
| 21 AP | 0.05 | 0.05 | 0.05 | 0.85 | 0.025 |
| 21 NonAP | 0.05 | 0.05 | 0.1 | 0.8 | 0.031 |
| 22 AP | 0.05 | 0.3 | 0.05 | 0.6 | 0.033 |
| 22 NonAP | 0.3 | 0.05 | 0.1 | 0.55 | 0.088 |
| 23 AP | 0.1 | 0.55 | 0.05 | 0.3 | 0.055 |
| 23 NonAP | 0.6 | 0.05 | 0.1 | 0.25 | 0.309 |
| 24 AP | 0.1 | 0.8 | 0.05 | 0.05 | 0.075 |
| 24 NonAP | 0.85 | 0.05 | 0.05 | 0.05 | 0.707 |

* GM =EXP(LN($B$3)*B4+LN($C$3)*C4+LN($D$3)*D4+LN($E$3)*E4)

## 7.0 Appendix C. Alphabetical keyword reference

This appendix provides an alphabetical listing of all of the keywords used by the AERSURFACE program. Each keyword is identified as to the pathway for which it applies, the keyword type: mandatory (M), optional (O) or conditional (C), and either repeatable (R) or non-repeatable (N), and with a brief description of the function of the keyword. For a more complete description of the keywords, including a list of associated parameters, refer to the Detailed Keyword Reference in Section 3.0 or the Functional Keyword/Parameter Reference in Section 8.0.

**Table 7-1. All Primary Keywords Available in AERSURFACE**

| Keyword | Path | Type | Keyword Description |
|---|---|---|---|
| ANEM_HGT | CO | O - N | Anemometer height (for ZOEFF roughness option) |
| CNPYGRID | OU | O - N | Debug file - Canopy data grid |
| CNPYTIFF | OU | O - N | Debug file - Canopy debug file containing TIFF tag and GeoKey values |
| CENTERLL* | CO | M - N | Met tower coordinates in latitude and longitude |
| CENTERXY* | CO | M - N | Met tower location in UTM coordinates |
| CLIMATE | CO | O - N | Climate and moisture parameters of study area |
| DATAFILE | CO | M - R | Land cover input datafiles (including impervious and canopy data) |
| DEBUGOPT | CO | O - N | Debug options for debug files |
| EFFRAD | OU | O - N | Table of effective radius values by sector and month |
| FREQ_SECT | CO | O - N | Indicates temporal frequency of surface values, number of roughness sectors and whether surface roughness adjustments are made and if they vary by sector. |
| FINISHED | ALL | M - N | Identifies the end of pathway inputs |
| MPRVGRID | OU | O - N | Debug file - Impervious data grid |
| MPRVTIFF | OU | O - N | Debug file - Impervious debug file containing TIFF tag and GeoKey values |
| NLCDGRID | OU | O - N | Debug file - Land cover data grid |
| NLCDTIFF | OU | O - N | Debug file - Land cover debug file containing TIFF tag and GeoKey values |
| OPTIONS | CO | O - N | Processing options |
| RUNORNOT | CO | M - N | Indicates to stop execution after checking control file setup or continue processing if not errors found |
| SFCCHAR | OU | M - N | Averaged surface characteristic values formatted for input to AERMET |
| SEASON | CO | O - R | Used to reassign months to seasons to override default assignments |
| SECTOR | CO | C - R | Define roughness sectors and indicate if lower or higher values should be used. |
| STARTING | ALL | M - N | Identifies the end of pathway inputs |
| TITLEONE | CO | M - N | First line of title for output |
| TITLETWO | CO | O - N | Optional second line of output title |
| ZORADIUS | CO | O - N | Fixed radius for averaging roughness (for ZORAD roughness option) |
| * User must specify either CENTERXY or CENTERLL. | | | |

Type: M - Mandatory N - Non-Repeatable
O - Optional R - Repeatable
C - Conditional

## 8.0 Appendix D. Functional keyword/parameter reference

This appendix provides a functional reference for the keywords and parameters used by the control for the AERSURFACE program. The keywords are organized by functional pathway, and within each pathway the order of the keywords is based on the function of the keyword within the preprocessor. The pathways used by the preprocessor are as follows, in the order in which they appear in the control file and in the tables that follow:

**CO** - for specifying overall job **CO**ntrol options; and
**OU** - for specifying **OU**tput file information.

The pathways and keywords are presented in the same order as in the Detailed Keyword Reference in Section 3.0.

Two types of tables are provided for each pathway. The first table lists all of the keywords for that pathway, identifies each keyword as to its type (either mandatory or optional and either repeatable or non-repeatable), and provides a brief description of the function of the keyword. The second type of table presents the parameters for each keyword in the order in which they should appear in the control file where order is important and describes each parameter in detail.

The following convention is used for identifying the different types of input parameters. Parameters corresponding to secondary keywords which should be input "as is" are listed on the tables with all capital letters (they are underlined in the table). Other parameter names are given with an initial capital letter and are not input "as is." In all cases, the parameter names are intended to be descriptive of the input variable being represented, and they often correspond to the Fortran variable names used in the preprocessor code. Parentheses around a parameter indicate that the parameter is optional for that keyword. The default that is taken when an optional parameter is left blank is explained in the discussion for that parameter.

**Table 8-1. Description of Control Pathway Keywords**

| CO Keywords | Type | Keyword Description |
|---|---|---|
| STARTING | M - N | Identifies the start of pathway inputs |
| TITLEONE | M - N | First line of title for output |
| TITLETWO | O - N | Optional second line of title for output |
| OPTIONS | O – N | Processing options |
| DEBUGOPT | O – N | Debug options for debug files |
| CENTERXY* | M - N | Met tower location in UTM coordinates |
| CENTERLL* | M - N | Met tower coordinates in latitude and longitude |
| DATAFILE | M - R | Land cover input datafiles (including impervious and canopy data) |
| ZORADIUS | O – N | Fixed radius for averaging roughness (for ZORAD roughness option) |
| ANEM_HGT | O - N | Anemometer height (for ZOEFF roughness option) |
| CLIMATE | O - N | Climate and moisture parameters of study area |
| FREQ_SECT | M - N | Indicates temporal frequency of surface values, number of roughness sectors and whether surface roughness adjustments are made and if they vary by sector. |
| SECTOR | C - R | Define roughness sectors and indicate if lower or higher values should be used. |
| SEASON | O - R | Used to reassign months to seasons to override default assignments |
| RUNORNOT | M - N | Identifies whether to run program or process setup information only |
| FINISHED | M - N | Identifies the end of pathway inputs |
| * User must specify either CENTERXY or CENTERLL. | | |

Type: M - Mandatory N - Non-Repeatable
O - Optional R - Repeatable
C - Conditional

**Table 8-2. Description of Control Pathway Keywords and Parameters**

| Keyword | Parameters | |
|---|---|---|
| TITLEONE | *title1* | |
| where: | *title1* | First line of title for output, character string of up to 200 characters |
| TITLETWO | *title2* | |
| where: | *title2* | Second line of title for output, character string of up to 200 characters |
| OPTIONS | PRIMARY or SECONDARY | ZORAD or ZOEFF |
| where: | PRIMARY | Site processed for primary surface characteristics and will generate keywords for primary values for AERMET (default) |
| | SECONDARY | Site processed for secondary surface characteristics and will generate keywords for secondary values for AERMET. |
| | ZORAD | Calculates the average roughness from the meteorological tower out to a default radial distance of 1 km. (default) |
| | ZOEFF | Research grade method for calculating roughness that estimates fetch based the growth of the IBL due to changes in roughness downwind. Average roughness is computed over the estimated fetch, approaching the meteorological tower. |
| DEBUGOPT | EFFRAD and/or GRID and/or TIFF or ALL | |
| where: | EFFRAD | Generates file containing the effective radius for surface roughness computed for each sector/month (only applicable for ZOEFF option specified with the OPTIONS keyword) |
| | GRID | Generates grid file of land cover data and, if applicable, separate files for impervious, and canopy data, displaying the 10x10 km grid of values extracted from each GeoTIFF data file |
| | TIFF | Generates debug file containing a list of all TIFF tags, GeoKeys, and associated values read from the land cover file and, if applicable, separate files for impervious and canopy data files |
| | ALL | Generates all debug files listed above without having to list each debug option separately |

| | | |
|---|---|---|
| CENTERXX | *easting northing utm_zone datum* | |
| where: | *easting* | UTM easting coordinate in meters |
| | *northing* | UTM northing coordinate in meters |
| | *utm_zone* | UTM zone entered as a positive integer |
| | *datum* | Geodetic datum on which coordinates are based. The datum should be entered using one of the following secondary keywords: NAD27 or NAD83, which refer to the North American 1927 datum and the North American 1983 datum, respectively. NAD83 should also be used for coordinates referenced to the GRS80 and WGS84 datums since the small differences are inconsequential for the purposes of AERSURFACE.<br><br>User must specify either CENTERXY or CENTERLL. |
| CENTERLL | *latitude longitude datum* | |
| where: | *latitude* | Latitude in decimal degrees (Northern hemisphere = positive value) |
| | *longitude* | Longitude in decimal degrees (Western hemisphere = negative value) |
| | *datum* | Geodetic datum on which coordinates are based. The datum should be entered using one of the following secondary keywords: NAD27 or NAD83, which refer to the North American 1927 datum and the North American 1983 datum, respectively. NAD83 should also be used for coordinates referenced to the GRS80 and WGS84 datums since the small differences are inconsequential for the purposes of AERSURFACE.<br><br>User must specify either CENTERXY or CENTERLL. |
| DATAFILE | *data_type path_filename* | |

| | | |
|---|---|---|
| where: | *data_type* | Type of data and year the data represent. Data type includes: NLCD for land cover, MPRV for impervious, and CNPY for canopy. Valid release years include: 1992, 2001, 2006, 2011, 2013, 2016, 2019, and 2021.The following are examples of valid secondary keywords for *data_type*:<br><br>NLCD2021: 2021 NLCD land cover<br>MPRV2021: 2021 percent impervious<br>CNPY2021: 2021 percent canopy |
| | *path_filename* | User-defined path and filename. The combined path and filename are limited to 200 characters and should be enclosed in quotes (“”) if either the path or filename includes spaces. |
| ZORADIUS | *radius* | |
| where: | *radius* | Distance from the meteorological tower in kilometers over which the surface roughness length will be averaged |
| ANEM_HGT | *anem_ht (ibl_factor)* | |
| where: | *anem_ht* | Height, in meters, at which the wind measurements are taken at the site that will be processed. The accepted value for *anem_ht* ranges from 1.0 meter to 100.0 meters. Only applicable for the ZOEFF option for calculating roughness. |
| | *(ibl_factor)* | Optional unitless parameter, ranging from 5.0 – 10.0, used to compute the reference height of the IBL. The IBL reference height is the product of the *anem_ht* and the *ibl_factor*. The default IBL factor is 6.0. The IBL factor is an experimental value for which a recommended value has not yet been established. |

| | | |
|---|---|---|
| CLIMATE | *sfc_moisture snow_cover arid_condition* | |
| where: | *sfc_moisture* | Surface moisture based on precipitation amounts for the period that will be modeled, relative to the previous 30-year climatological record for the region. Valid entries: WET, DRY, or AVERAGE (or AVG) (default = AVERAGE) |
| | *snow_cover* | Site experienced continuous snow cover within at least on month during the winter. Valid entries: SNOW or NOSNOW (default = NOSNOW) |
| | *arid_condition* | Enter ARID (desert-like) or NONARID (default = NONARID), NONARID is an invalid entry in combination with continuous snow cover (SNOW) |
| FREQ_SECT | *frequency number_sectors roughness_flag* | |
| where: | *frequency* | Period of time for which the surface characteristics are calculated, valid entries: ANNUAL, SEASONAL, or MONTHLY. |
| | *number_sectors* | Integer number of roughness sectors that will be defined using the SECTOR keyword. Sectors are only applicable to roughness length. The number of sectors can range from 1 to 12 or 16. AERMET allows a maximum of 12 sectors, but AERSURFACE can calculate roughness for 16 sectors which can be useful for comparing roughness lengths to a standard 16-direction wind rose plot. When 16 sectors are specified, AERSURFACE results cannot used as input to AERMET. |
| | *roughness_flag* | Indicates whether AERSURFACE will apply lower or higher roughness values to all wind sectors, or if the sectors vary. Valid entries*:* LOWZ0, HIGHZ0, VARYZ0, AP, NONAP, or VARYAP where: LOWZ0/AP indicates lower roughness values will be applied to all sectors; HIGHZ0/NONAP indicates that higher values will be applied; and VARYZ0/VARYAP informs AERSURFACE to treat each sector separately based on how the sector is identified with SECTOR keyword. |

| | | |
|---|---|---|
| SECTOR | *sector_index start_dir end_dir roughness_flag* | |
| where: | *sector_index* | Links a specific sector to a set of site characteristics and should be entered as consecutive integers beginning with the number 1. |
| | *start_dir* | Starting direction of the sector in whole degrees. Considered part of the sector. |
| | *end_dir* | Ending direction of the sector in whole degrees but excluded from sector.<br><br>Sectors should be defined in a clockwise manner and must cover the full 360° circle around the meteorological tower without gaps or overlap. (i.e., They must be defined so that the end of one sector corresponds to the beginning of another. When 2 – 12 sectors are defined, each sector must be a minimum of 30°. 16 sectors must each be 22.5°. When 1, 8, 12 or 16 is entered for the number of sectors on the FREQ_SECT keyword, the SECTOR keyword may be omitted, and default sectors used unless VARYAP is entered as the *airport_flag* attribute for the FREQ_SECT keyword. |
| | *roughness_flag* | Identifies whether the individual sector should be processed using lower or higher related roughness length values. This attribute is required when the secondary keyword VARYZ0/VARYAP is entered as the *roughness_flag* attribute for the FREQ_SECT keyword which means each sector will be assigned individually. When that is the case, the *roughness_flag* should be specified using the secondary keyword LOWZ0/AP to indicate lower surface roughness values or HIGHZ0/NONAP to indicate higher roughness values. |
| SEASON | *season months* | |
| where: | *season* | Secondary keyword that identifies one of five seasonal definitions: SUMMER, AUTUMN, WINTERNS, WINTERWS, SPRING. |
| | *months* | Space-delimited list of integer months assigned to the season. Valid entries are 0 – 12, where 1 = Jan, 2 = Feb … 12 = Dec. Zero (0) indicates no months are being reassigned to the season. A season may be specified only once. The months reassigned to a season should be listed on a single record separated by at least one space. A month can only be assigned to one season. It is only necessary to specify the seasons/months that are to be reassigned. If 0 is entered for a season, then default assignments will be used for any month that is not listed for a different season. |
| RUNORNOT | RUN or NOT | |
| where: | RUN | Indicates to run full preprocessor calculations. |
| | NOT | Indicates to process setup data and report errors, but to not run full preprocessor calculations. |

**Table 8-3. Description of Output Pathway Keywords**

| OU Keywords | Type | Keyword Description |
|---|---|---|
| STARTING | M - N | Identifies the start of output pathway inputs |
| SFCCHAR | M - N | Averaged surface characteristic values formatted for input to AERMET |
| EFFRAD | O - N | Table of effective radius values by sector and month |
| NLCDGRID | O - N | Land cover data grid |
| MPRVGRID | O - N | Impervious data grid |
| CNPYGRID | O - N | Canopy data grid |
| NLCDTIFF | O - N | Land cover debug file containing TIFF tag and GeoKey values |
| MPRVTIFF | O - N | Impervious debug file containing TIFF tag and GeoKey values |
| CNPYTIFF | O - N | Canopy debug file containing TIFF tag and GeoKey values |
| FINISHED | M - N | Identifies the end of output pathway inputs |

**Table 8-4. Description of Output Pathway Keywords and Parameters**

| Keyword | Parameters | |
|---|---|---|
| SFCCHAR<br>EFFRAD<br>NLCDGRID<br>MPRVGRID<br>CNPYGRID<br>NLCDTIFF<br>MPRVTIFF<br>CNPYTIFF | *path_filename* | |
| where: | *path_filename* | User-defined path and filename. The combined path and filename is limited to 200 characters and should be enclosed in quotes (“”) if either the path or filename includes spaces. |

## 9.0 Appendix E: Implementation of ZOEFF Option in AERSURFACE, Version 20060

### 9.1 Method

A research grade method (ZOEFF) for computing an effective surface roughness length, $Z_0$, using land cover data from the National Landcover Database (NLCD) was first implemented in 19039_DRFT and carried forward in version 20060 for further evaluation. The method used to compute roughness in prior versions has been retained as the default option and is hereon referred to as the ZORAD option. The default method (ZORAD) computes $Z_0$ as an inverse distance weighted geometric mean of the representative roughness values extracted from the NLCD for a default fixed upwind radial distance of 1 kilometer, relative to the location of the meteorological measurement site. $Z_0$, can be calculated for multiple wind sectors to account for substantial directional differences in land cover type.

The experimental method, ZOEFF, determines the upwind distance from the meteorological tower, or fetch, over which to compute an effective roughness value, rather than using a fixed radial distance. The method is based on the distance required to grow the internal boundary layer (IBL) to some defined height at the measurement tower due as changes in surface roughness are encountered as the air flows toward the tower. A final effective roughness length is then calculated over the derived fetch. As with the original default method, $Z_0$ can be computed for multiple wind sectors. The estimated fetch for which the effective roughness is computed will vary by sector.

### 9.2 Scientific Basis

The growth of the IBL is influenced, in part, by the mechanical forcing due to friction caused by the roughness of the earth's surface. This method (ZOEFF) for calculating effective roughness is based on the cumulative growth of the IBL as air flow encounters surface roughness elements as it approaches the tower.

This method was adapted from a model coding abstract (MCA) and MATLAB code developed by Dr. Akula Venkatram[2], based on methods proposed by Miyake (1965) and Wiering (1993), to estimate surface roughness as a function of the growth of the internal boundary layer (IBL). A review of methods for estimating the height of the IBL, which discusses Miyake's related work, was performed by Garratt (1990). Venkatram's original MCA (edited) is included as Section 10.0 of this User's Guide.

As described by Wieringa (1993) and stated in Venkatram's MCA and Garratt (1990), the growth of the IBL ($h$), with distance ($x$) over a constant roughness, can be described by the following equation:

$$\frac{dh}{dx} = \frac{u_*}{U(h)} = \frac{k}{ln\left(\frac{h}{Z_0}\right)} \qquad 4$$

where, $Z_0$ is the surface roughness, $k$ is 0.4 (von Kármán constant), $u_*$ is the surface friction velocity, and $U(h)$ is the mean wind speed at the height of the IBL.

As described in Venkatram's MCA, integrating Equation *4* between two points, $x_i$ and $x_{i+1}$, produces the following equation for the growth of the IBL and can be used to calculate the growth of the IBL between two points based on the average roughness and distance between them:

$$h_{i+1}\left(ln\left(\frac{h_{i+1}}{Z_{0avg}}\right) - 1\right) = h_i\left(ln\left(\frac{h_i}{Z_{0avg}}\right) - 1\right) + k(x_{i+1} - x_i) \qquad 5$$

where $Z_{0\text{avg}}$ is the average roughness between the two points $x_i$ and $x_{i+1}$. (Whereas Venkatram used a simple arithmetic mean of the two roughness values at $x_i$ and $x_{i+1}$, the implementation of this method (ZOEFF) in AERSURFACE uses a geometric mean of the two roughness values for consistency with

[2] Dr. Akula Venkatram is a professor at the University of California, Riverside in the Department of Mechanical Engineering. Venkatram was an original member of the American Meteorological Society/Environmental Protection Agency Regulatory Model Improvement Committee (AERMIC) during the development and promulgation of AERMOD.

the default method in AERSURFACE version 13016, retained in this version (20060) as the ZORAD method).

By setting a target IBL height, $h_{ref}$, at the measurement site based on some multiple of the measurement height and setting a fixed distance to represent delta *x* over which each $Z_{0\text{avg}}$ is computed, the change in the IBL height can be calculated for each delta *x* to determine the distance, $x_{rad}$, required for the cumulative growth for each delta *x* from an initial $h = Z_0$ at $x_{rad}$. The current implementation uses a default value for $h_{ref}$ that is equal to 6 times the anemometer height. This factor can be changed through user input.

Once *xrad* has been determined, per Venkatram, the effective roughness ($Z_{0eff}$) for the sector is computed over the distance xrad as the solution to the following equation:

$$h_{ref}\left(ln\left(\frac{h_{ref}}{Z_{0eff}}\right)-1\right)+ Z_{0eff} = k(x_{rad}) \qquad 6$$

### 9.3 Implementation

The horizontal grid resolution of the land cover data processed by AERSURFACE is 30 meters. To implement the ZOEFF method for determining $Z_{0eff}$, AERSURFACE first divides the land cover into concentric rings out to an initial radial distance of 5 km from the meteorological tower, with each ring having a depth equal to the horizontal grid resolution of the data (30 meters). The rings are then subdivided by sector as shown in Figure 9-1.

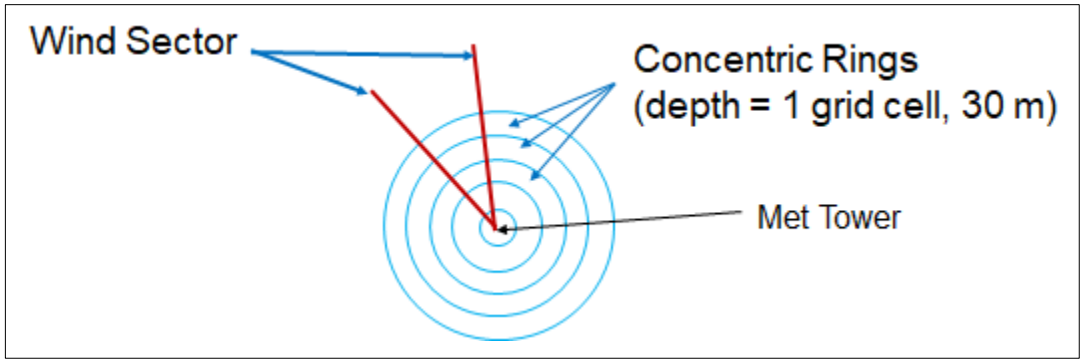



**Figure 9-1. Concentric Rings Defined around Meteorological Tower to Calculate IBL Growth**

As with previous versions of AERSURFACE, seasonal roughness values have been assigned to each land cover category and are stored in a data table in the AERSURFACE source code. Monthly values of $Z_0$ are computed for each ring segment within each sector using the seasonal lookup tables and the values associated with the season to which each month is assigned. The monthly $Z_0$ value for a ring segment is computed as an inverse distance weighted geometric mean of the roughness values associated with each of the grid cells that make up the ring segment based on the distance of each grid cell from the meteorological tower. The inverse distance weighted geometric mean is computed using equation *1* in Section 2.4.1.1 for the default ZORAD option but limited to the grid cells that comprise the ring segment. Like the ZORAD option, an inverse distance weighted approach is used because the width of a sector increases with distance from the measurement site. Thus, ring segments farther from the met tower are comprised of more grid cells than ring segments closer to the tower. If a direct area weighted approach were used, the land cover farther from the site would receive a higher effective weight than land cover closest to the site when the fetch is derived as described next.

Using Equation *5* above, the amount of fetch required for the cumulative growth of the IBL to a default height of six (6) times the height of the anemometer at the tower location is determined. The value, six (6), is referred to as the IBL factor and can be set by the user. The default value for the IBL factor is based on Wieringa's "roughness blending height" of 60 m (Wieringa, 1976) given that 10 m is a common anemometer height at NWS/FAA weather stations. As Venkatram points out in his MCA and is discussed by Wierenga (1993), Miyake's research was based on surface releases when the

vertical plume spread is of the order of $h_{ref}$. The IBL factor may need to be varied based on the release height or anemometer height.

The fetch ($x_{rad}$) required to grow the IBL to a target height ($h_{ref}$) is determined by summing smaller changes in the height of the IBL that are associated with fixed, shorter lengths of assumed homogeneous roughness based on the previously computed $Z_0$ values for the individual ring segments within a sector. Within a user-defined sector, the fetch is first estimated by starting at the tower location and summing incremental IBL heights across the concentric ring segments out from the tower. The geometric mean of the roughness ($Z_{0avg}$) of two adjacent rings is computed and treated as the homogenous surface and distance over which to compute an incremental change in the height of the IBL. The distance is taken to be from the center of one ring segment to the center of the adjacent ring, 30 meters. This occurs outward across the concentric rings until the sum of the individual heights equals or exceeds $h_{ref}$. If $h_{ref}$ is not reached within a 5 km radial distance from the tower (which can occur for very long fetches over a very smooth surface), the estimated fetch is limited to 5 km. The effective roughness is then computed for the sector from the tower out to the distance for this estimated fetch using equation *6*, above.

The fetch ($x_{rad}$) is recomputed iterating across the concentric rings going toward the tower, starting at the distance determined from the first set of iterations and stopping at the location of the meteorological tower. If the height of the IBL at the tower is computed to be higher than the $h_{ref}$, then the fetch is recomputed starting one ring closer to the tower than the original estimated fetch. If the computed height of the IBL at the tower is lower than the target IBL, the fetch is recomputed starting one ring width farther than the original estimated fetch. An interpolated distance based on the target IBL height at the tower is taken as $x_{rad}$ iterating across the rings toward the tower. The average effective roughness is then computed for the sector for this new value of $x_{rad}$ using equation *6*, above. The final value for $Z_{0eff}$ is computed as the simple arithmetic mean of the two calculated effective roughness values based on the calculated for the distance $x_{rad}$ iterating outward from the tower and the calculated distance $x_{rad}$ iterating over the rings toward the tower.

These steps are repeated to compute monthly values of $Z_{0eff}$ for each user-defined sector. Annual and seasonal values are then computed from the monthly values based on the temporal frequency specified by the user in the control file.

## 10.0 Appendix F: Venkatram Model Coding Abstract – Estimating Effective Roughness

# On estimating effective roughness

Akula Venkatram
December 24, 2009

If wind speed is measured on a tower located in a spatially inhomogeneous area, we need an effective roughness height to estimate the surface friction velocity and other micrometeorological variables. This effective roughness should represent the combined effect of the roughness elements that the boundary layer encounters on its way to the measurement location. A heuristic approach to this calculation is based on estimating the combined effect of the internal boundary layers associated with the changes in the roughness as the air travels over a spatially inhomogeneous path. If we assume that the roughness is constant between two points along this path, the change in the internal boundary layer height, ***h***, between these two points is given by (Miyake, 1965 quoted in Wieranga, BLM, 63, 323-363, 1993):

$$\frac{dh}{dx} = \frac{u_*}{U(h)} = \frac{k}{ln\left(\frac{h}{z_0}\right)} \qquad 7$$

Integrating this equation between points, $x_i$ and $x_{i+1}$, gives

$$h_{i+1}\left(ln\left(\frac{h_{i+1}}{z_{0avg}}\right) - 1\right) = h_i\left(ln\left(\frac{h_i}{z_{0avg}}\right) - 1\right) + k(x_{i+1} - x_i) \qquad 8$$

where

$$z_{0avg} = (z_0(i) + z_0(i+1))/2. \qquad 9$$

This implicit equation can be used compute the height of the internal boundary layer as a function of distance from the measurement location.

At the measurement location, the combined internal boundary height has a vertical structure that reflects the roughness elements contributing to its growth. The lowest part of the boundary layer is representative of the roughness elements closest to the measurement location, and the upper part of the boundary layer reflects the roughness elements furthest from the location. This suggests calculating $h$ with the initial $h_1 = z_{01}$ and then stopping the integration when the internal boundary height reaches a multiple, $\beta$, of $z_{meas}$ given by $h_{ref} = \beta z_{meas}$. The radius of influence, $x_{rad}$, is the distance at which this boundary layer height reaches $h_{ref}$.

Then, the effective roughness is the solution of the integral of Equation *7*, assuming that an effective constant roughness, $z_{0eff}$, applies to the region $0$ to $x_{rad}$:

$$h_{ref}\left(ln\left(\frac{h_{ref}}{z_{0eff}}\right)-1\right)+ z_{0eff} = kx_{rad} \qquad 10$$

This equation can be solved numerically to yield $z_{0eff}$.

It is clear that $\beta$ is a critical parameter that needs to be determined by comparing the computed effective $z_0$ with a value inferred from simultaneous measurements of surface friction velocity and wind speed using sonic anemometers. Then,

$$z_{0eff}\,(measured) = z_{meas}\,exp\left(\frac{-kU}{u_*}\right) \qquad 11$$

The computed $z_{0eff}$ is likely to apply only to surface releases, and only when the vertical plume spread is of the order of $h_{ref}$. If we want to estimate dispersion from an elevated source, we might have to calculate a $z_{0eff}$ for a $h_{ref}$ corresponding to a multiple of the release height. This means that $z_{0eff}$ will vary with source height.

## 11.0 Appendix G: Inter-comparison of AERSURFACE

An inter-comparison of values of surface roughness length, estimated using AERSURFACE version 20060, is presented, as well as a comparison of corresponding AERMOD results for several different source types and configurations. This inter-comparison was first presented as Appendix G of the AERSURFACE User's Guide (EPA, 2019a) for version 19039_DRFT of AERSURFACE in which meteorological processing was performed with AERMET version 18081 and dispersion modeling was performed with AERMOD version 18081. The inter-comparison has been updated using AERSURFACE version 20060 and version 19191 of AERMET and AERMOD. The original inter-comparison was performed using the 2011 edition of the 2001 National Land Cover Database (NLCD). With the generation and release of the 2016 NLCD by the Multi-Resolution Land Characteristics (MRLC) Consortium, led by the US Geological Survey (USGS), the 2001 NLCD land cover and percent impervious data were also updated with corrections and refinements. Those updates were carried forward through subsequent updates of the 2006 and 2011 NLCD data years released as new versions at the time of the release of the 2016 NLCD. The update to the 2001 NLCD did not include an update to the 2001 percent tree canopy data; therefore, the 2001 NLCD that is currently available from the MRLC does not include 2001 percent tree canopy data. For consistency, the inter-comparison presented in this appendix to the AERSURFACE User's Guide for version 20060 is also based on the 2011 edition of the 2001 NLCD which was used for the inter-comparison presented in Appendix G to the AERSURFACE User's Guide specific to version 19039_DRFT. Unless otherwise stated, references to the 2001 NLCD are meant to refer to the 2011 edition of the 2001 NLCD. Also included in this update to the inter-comparison is a comparison of surface characteristic values estimated using the 2016 NLCD with those estimated using the 2011 edition of the 2001 NLCD.

Surface characteristics were estimated using the two AERSURFACE options for estimating surface roughness length (ZORAD and ZOEFF) and by varying combinations of input data (i.e., land cover, percent impervious, and percent canopy). The comparisons that are presented below are not an evaluation of the updated AERSURFACE tool. Rather, because version 20060, like version 19039_DRFT, includes a research grade method (ZOEFF) for estimating surface roughness length and the use of supplemental percent impervious and percent canopy data beginning with the release of the

2001 NLCD, this comparison is a limited demonstration of differences in results using the different roughness options and varying the NLCD input data. Estimated values of albedo and Bowen ratio are unaffected by the choice of option for estimating surface roughness length or the use of the impervious and canopy data; therefore, albedo and Bowen ratio are not presented as part of this comparison.

### 11.1 AERSURFACE Scenarios and Meteorological Data Processing with AERMET

Three NWS/FAA meteorological sites were selected for this comparison, including: Hartsfield-Jackson Atlanta International Airport (ATL), Baton Rouge Metropolitan Airport (BTR), and Raleigh-Durham International Airport (RDU). Because the version of the 2001 NLCD (2011 edition) that was available at the time this comparison was first performed included land cover, impervious, and canopy data, this comparison primarily uses the 2011 edition of the 2001 NLCD. Based on historical satellite imagery, BTR appears to have experienced only a small amount of change in land use from 1992 to 2001 in the near proximity to the tower. Thus, additional comparisons of surface roughness values estimated using the ZORAD and ZOEFF options with the 1992 NLCD land cover data were performed to show differences in results between the two NLCD datasets (1992 and 2001). The 1992 NLCD land cover data combined with the default ZORAD is equivalent to running AERSURFACE version 13016 with land cover data only from the 1992 NLCD.

As discussed in Section 2.1, the land cover classification scheme changed from the 1992 to the 2001 NLCD for certain land cover categories. These changes prompted adding the capability to AERSURFACE to supplement land cover with impervious and canopy data beginning with the 2001 NLCD.

For each station location, surface characteristic values were estimated for the AERSURFACE scenarios listed in Table 11-1. Table 11-2 lists the additional AERSURFACE scenarios for which surface characteristic values were estimated for BTR using the 1992 NLCD.

**Table 11-1. 2001 NLCD (2011 Edition) AERSURFACE Scenarios for ATL, BTR, and RDU**

| Roughness Option | 2001 NLCD (2011 Edition) Data Inputs | Scenario Name |
|---|---|---|

| | | |
|---|---|---|
| ZORAD | Land Cover<br>Percent Impervious<br>Percent Canopy | 2001-LC-IMP-CAN-ZORAD |
| | Land Cover<br>Percent Impervious | 2001-LC-IMP-ZORAD |
| | Land Cover<br>Percent Canopy | 2001-LC-CAN-ZORAD |
| | Land Cover | 2001-LC -ZORAD |
| ZOEFF | Land Cover<br>Percent Impervious<br>Percent Canopy | 2001-LC-IMP-CAN-ZOEFF |
| | Land Cover<br>Percent Impervious | 2001-LC-IMP-ZOEFF |
| | Land Cover<br>Percent Canopy | 2001-LC-CAN-ZOEFF |
| | Land Cover | 2001-LC-ZOEFF |

**Table 11-2. 1992 NLCD AERSURFACE Scenarios for BTR**

| Roughness Option | 1992 NLCD Data Inputs | Scenario Name |
|---|---|---|
| ZORAD | Land Cover | 1992-LC-ZORAD |
| ZOEFF | Land Cover | 1992-LC-ZOEFF |

Seasonal surface characteristic values were estimated using AERSURFACE for each scenario in Table 11-1 and Table 11-2, assuming average surface moisture, a non-arid climate, and without continuous snow during the winter. The center of the study area was defined as the location of the meteorological tower associated with the ASOS station at each airport. Wind sectors were defined for each site to estimate surface roughness length, based on changes in roughness within a radial distance out to 1 km from the meteorological tower. Sectors were individually identified as either airport or non-airport based on visual inspection of satellite imagery. Sectors that consisted primarily of runways or open parking lots were treated as an airport. Sectors that consisted primarily of buildings or vegetation were treated as non-airport sectors. (Refer to Sections 2.3.2, 2.4.1.3 and 3.2.9 for more discussion on the characterization of sectors as airport or non-airport.) The coordinates of the meteorological tower

for each station, sector definitions, and whether airport or non-airport reference values were used to compute surface roughness length, by sector, are listed in Table 11-3. Figure 11-1 through Figure 11-3 show 2001 satellite imagery from Google Earth for each of the airport sites and identifies the 10 x 10 km area for which albedo and Bowen ratio are estimated and the circular area around the tower, out to 1 km, including the individual wind sectors for which roughness length is estimated.

**Table 11-3. NWS/FAA Meteorological Tower Location and Wind Sector Definitions**

| NWS/FAA Station | Latitude | Longitude | Sector | Reference Surface Values |
|---|---|---|---|---|
| ATL | 33.629691 | 84.442249 | 90° – 145° | Non-airport |
| | | | 145° – 270° | Non-airport |
| | | | 270° – 90° | Airport |
| BTR | 30.537804 | -91.146804 | 50° – 210° | Airport |
| | | | 210° – 280° | Airport |
| | | | 280° – 50° | Non-Airport |
| RDU | 35.892300 | -78.781900 | 30° – 60° | Non-airport |
| | | | 60° – 225° | Airport |
| | | | 225° – 30 | Non-airport |

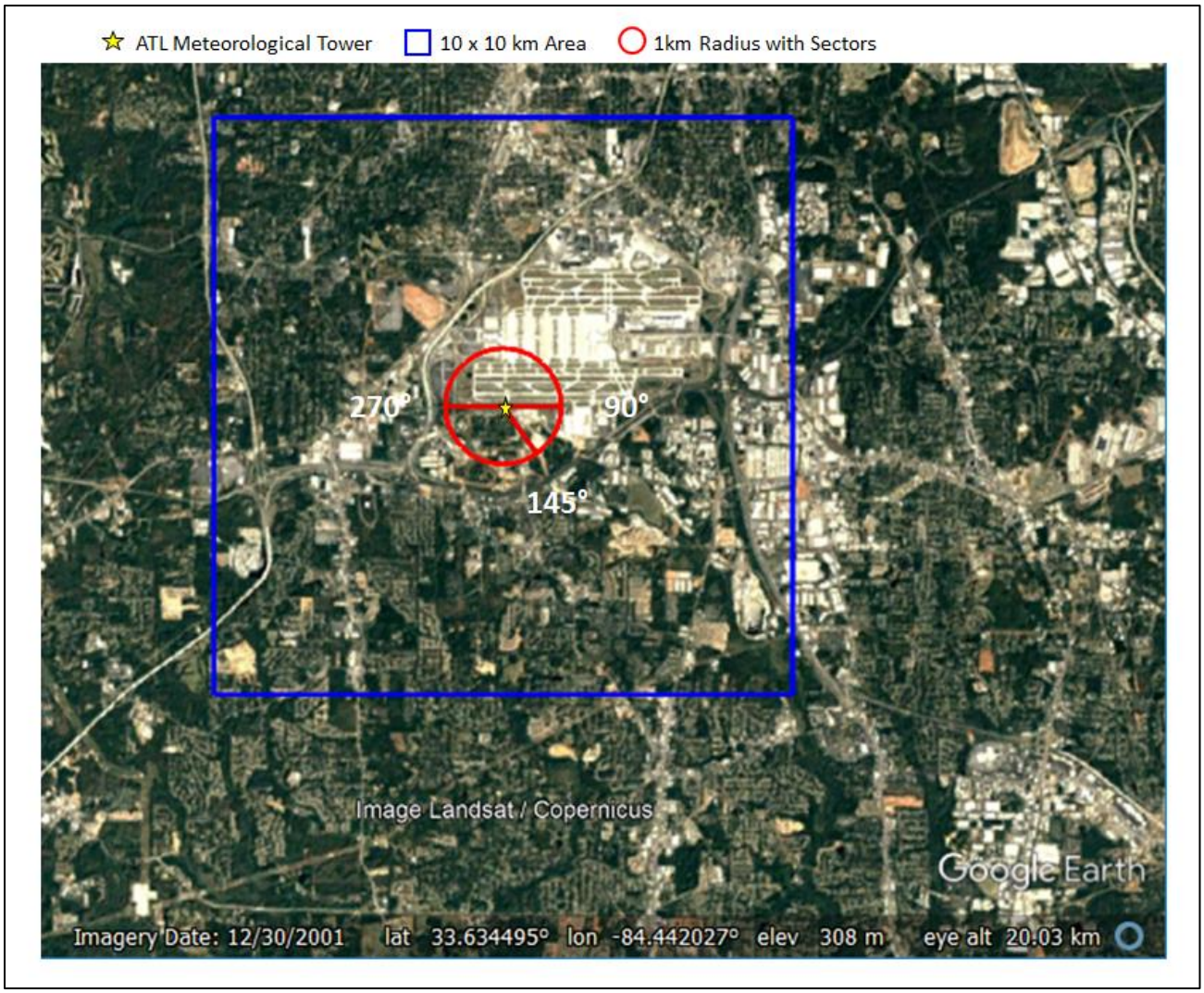



**Figure 11-1. ATL 10 x 10 km Area and 1 km Radius with Wind Sectors**

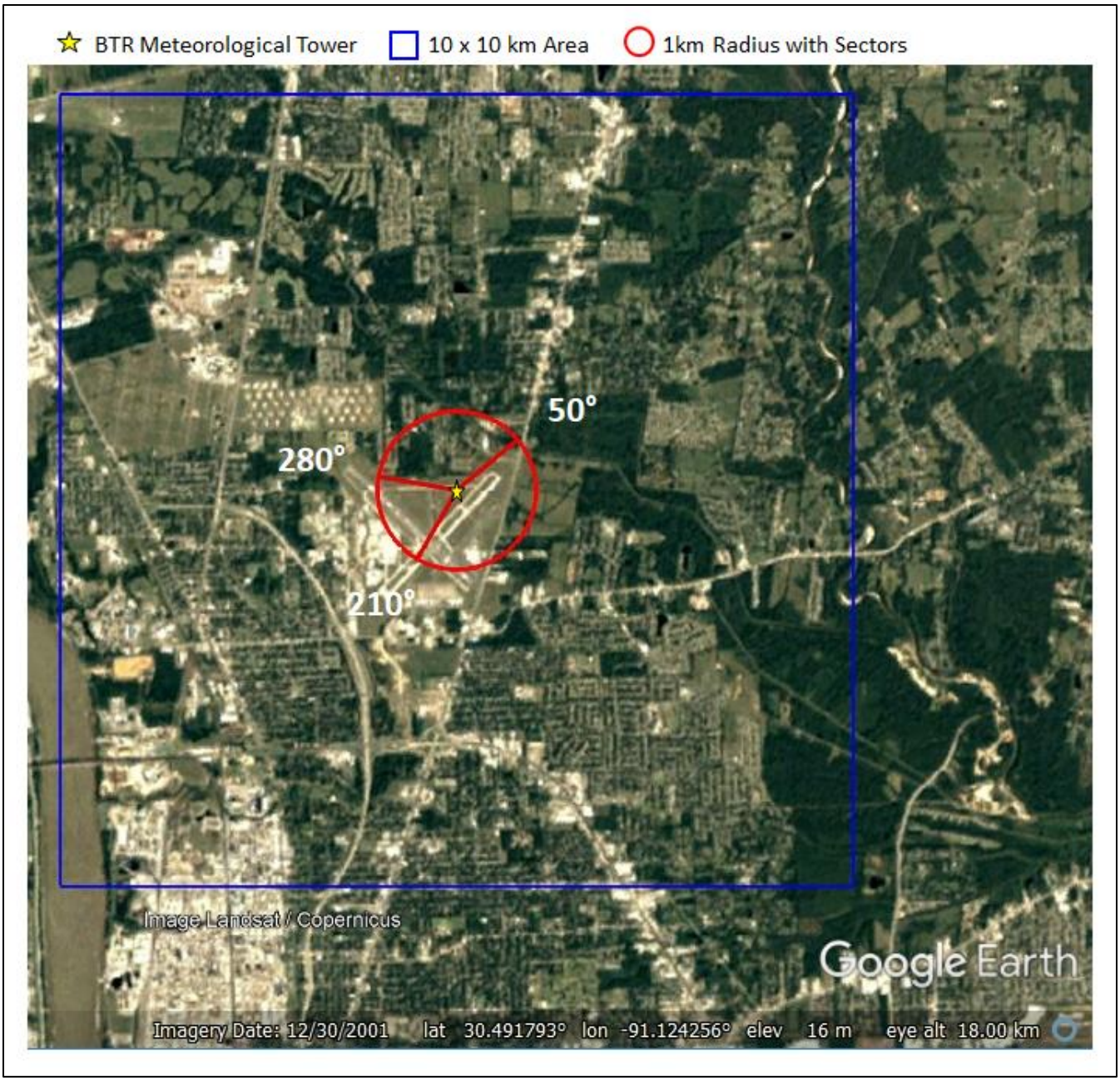



**Figure 11-2. BTR: 10 x 10 km Area and 1 km Radius with Wind Sectors**

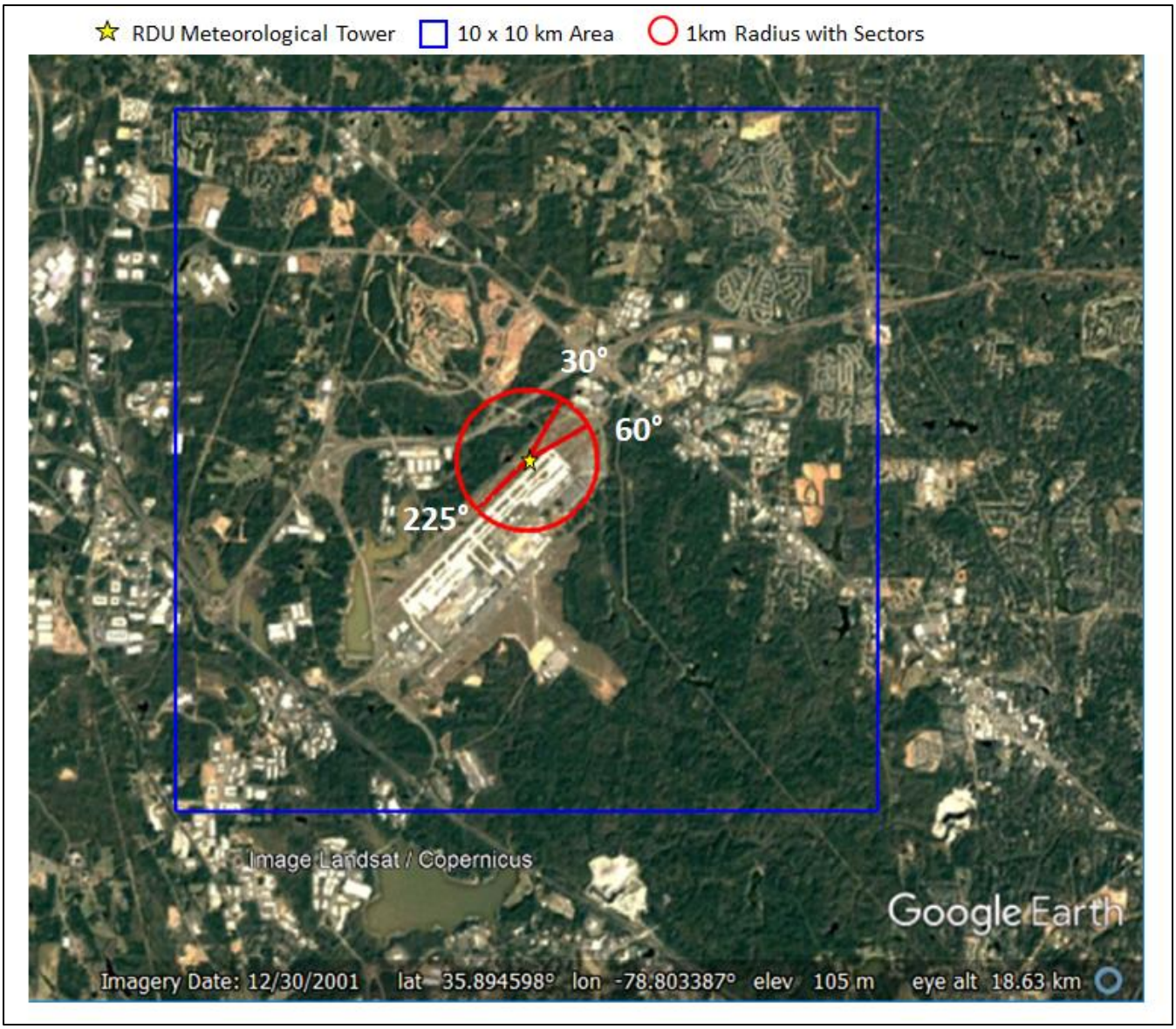



**Figure 11-3. RDU: 10 x 10 km Area and 1 km Radius with Wind Sectors**

Figure 11-4 through Figure 11-10 show the land cover, percent impervious, and percent canopy data from the 2001 NLCD (2011 edition) for each of the three sites and the 1992 NLCD land cover for BTR.

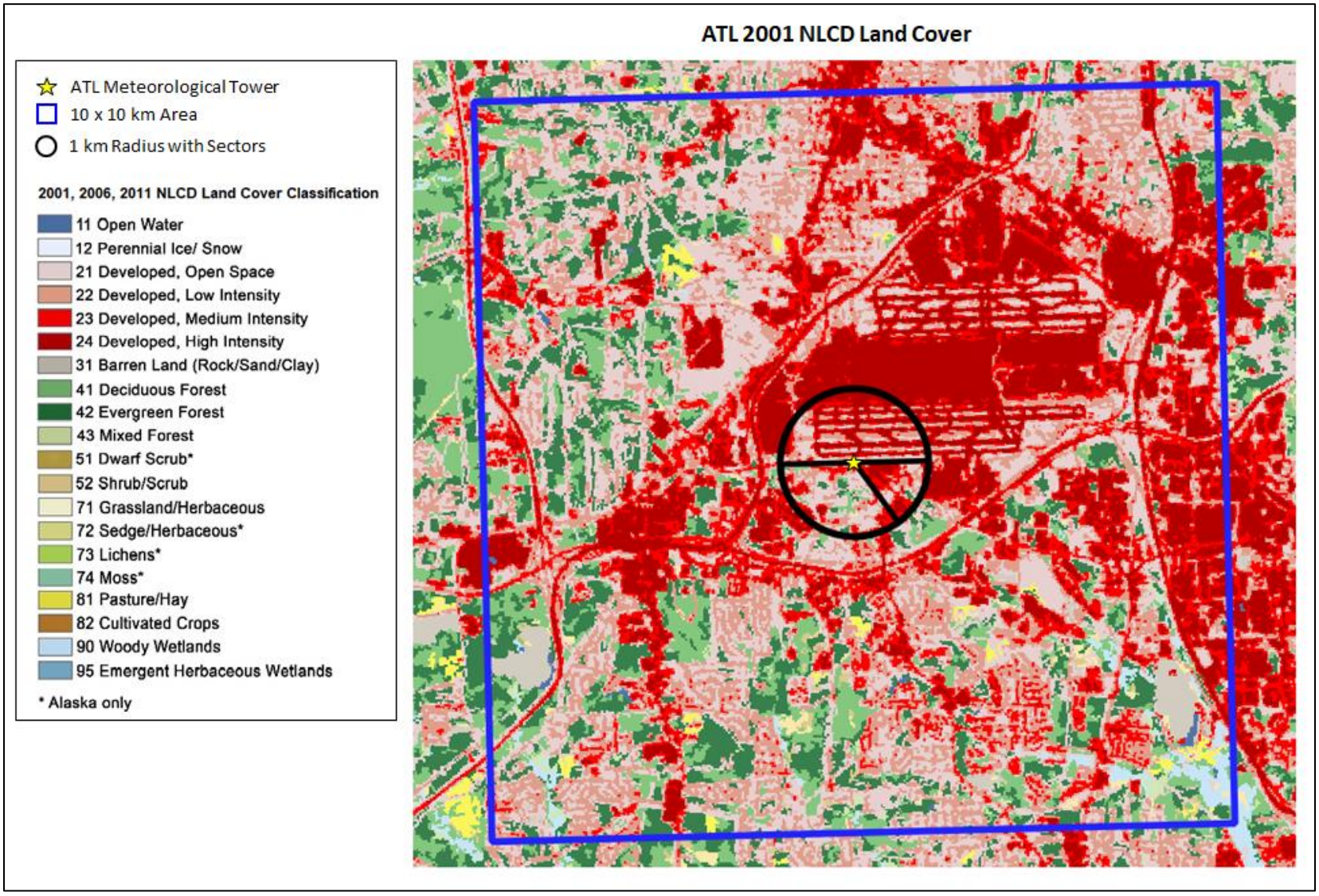



**Figure 11-4. 2001 NLCD (2011 Edition) Land Cover for ATL**

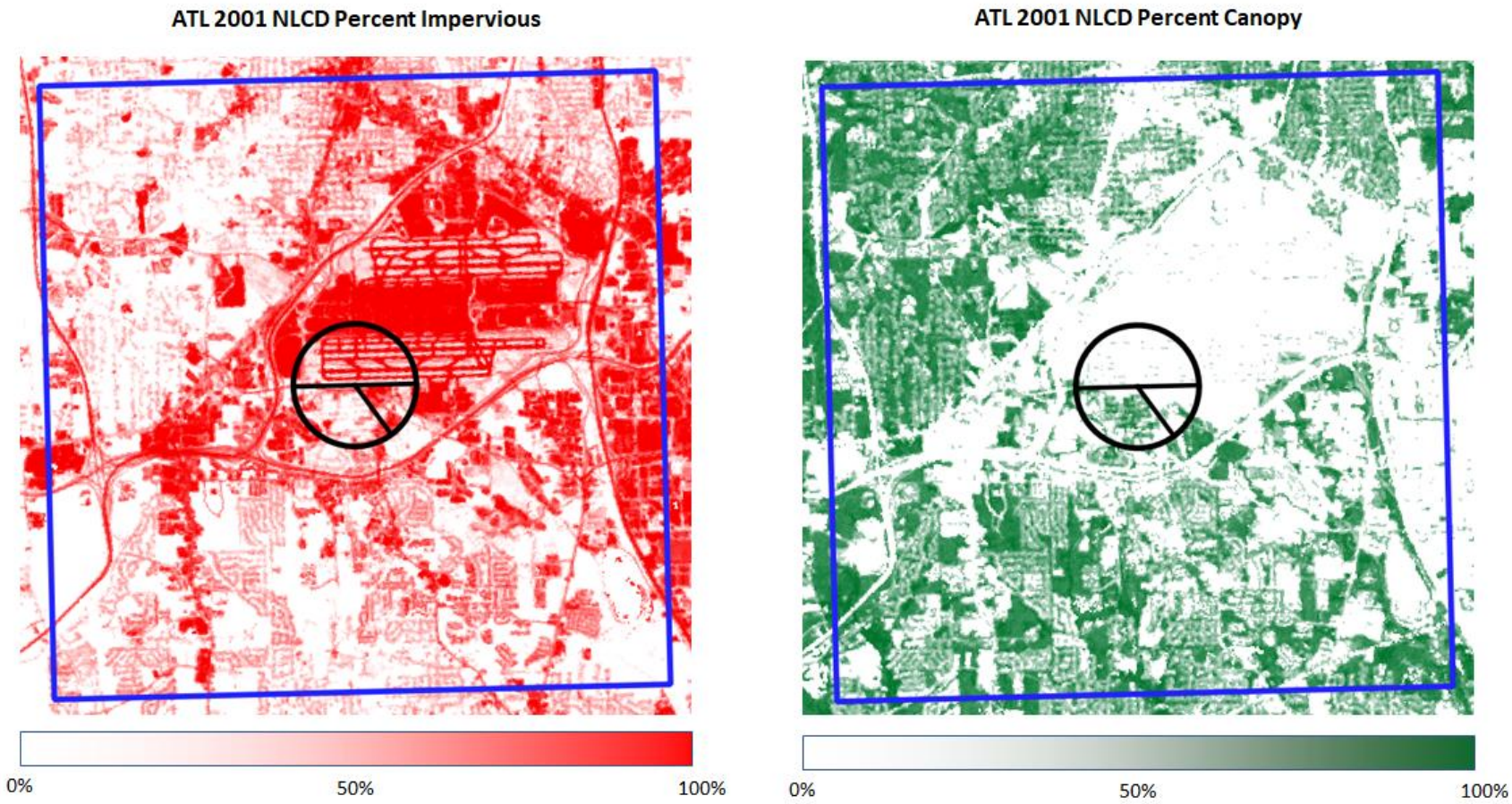



**Figure 11-5. 2001 NLCD (2011 Edition) Percent Impervious and Percent Canopy for ATL**

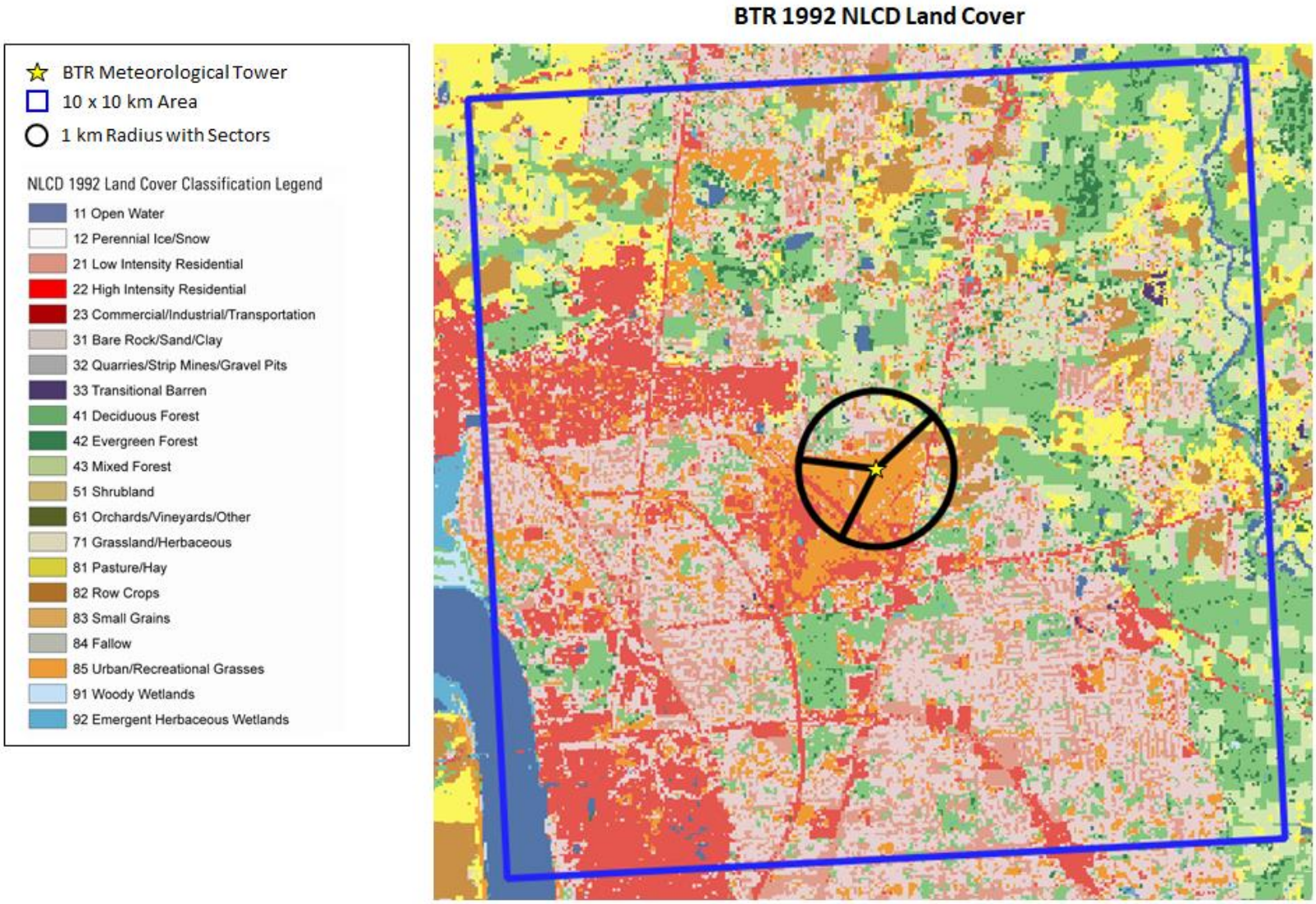



**Figure 11-6. 1992 NLCD Land Cover for BTR**

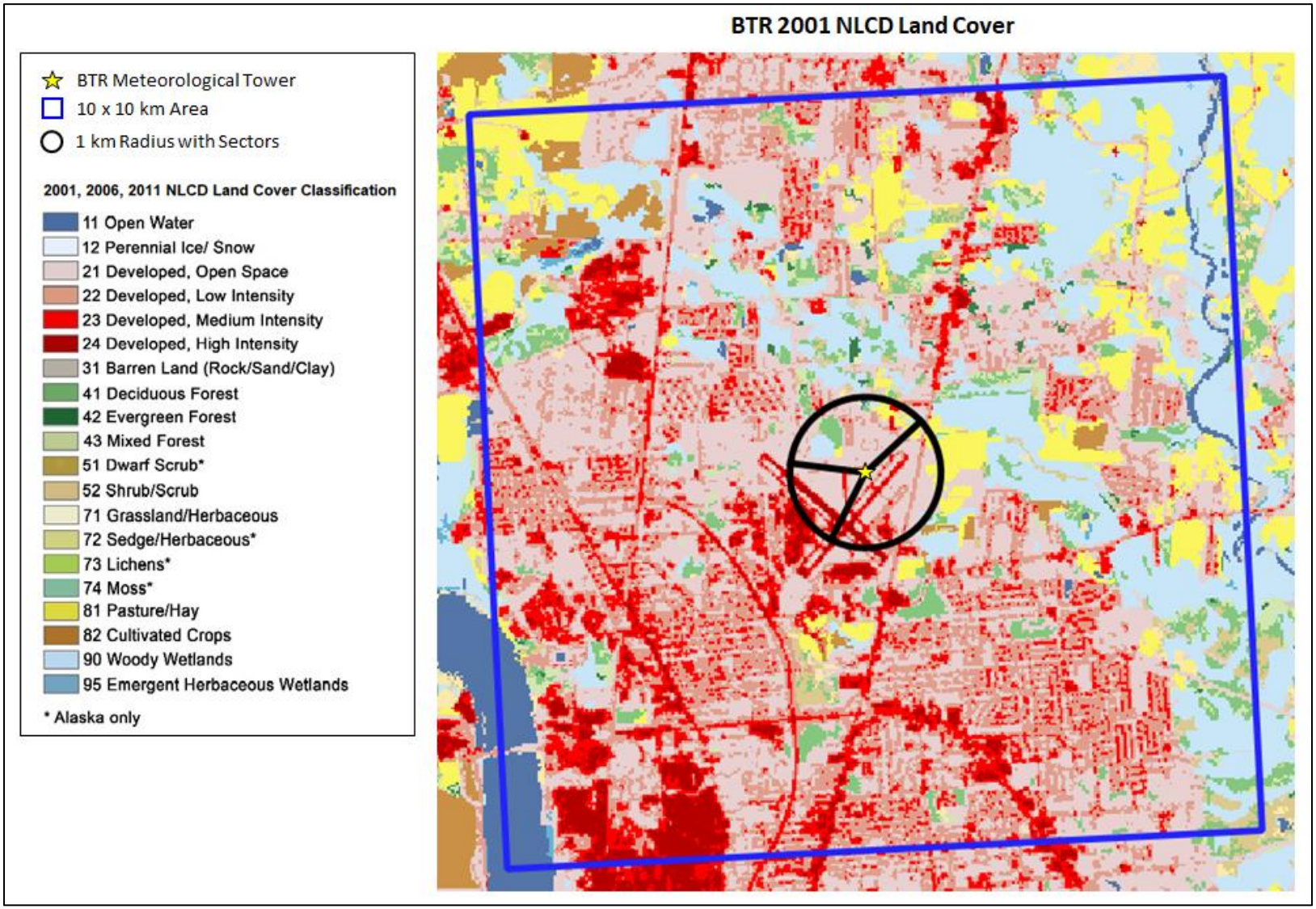



**Figure 11-7. 2001 NLCD (2011 Edition) Land Cover for BTR**

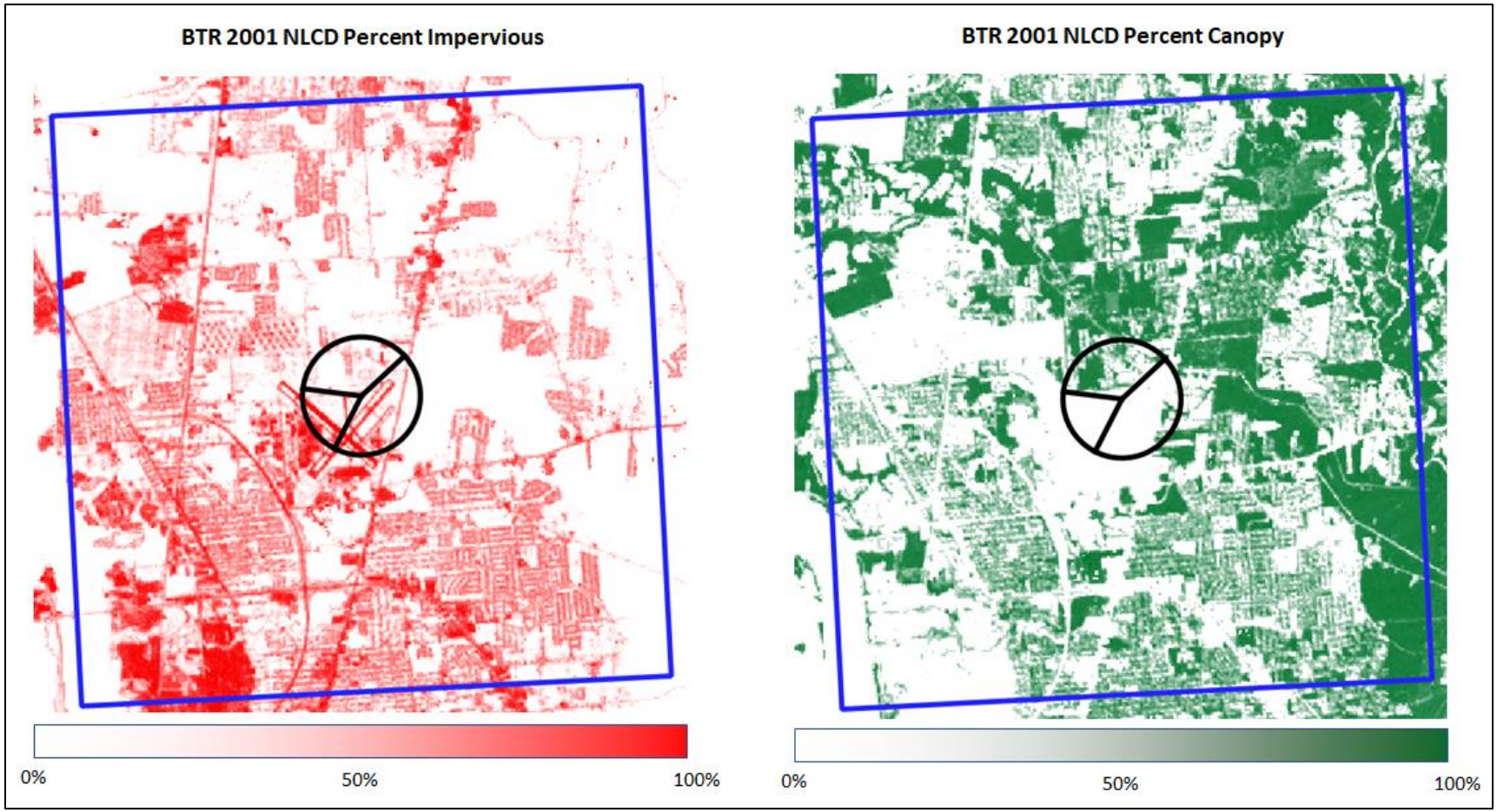



**Figure 11-8. 2001 NLCD (2011 Edition) Percent Impervious and Percent Canopy for BTR**

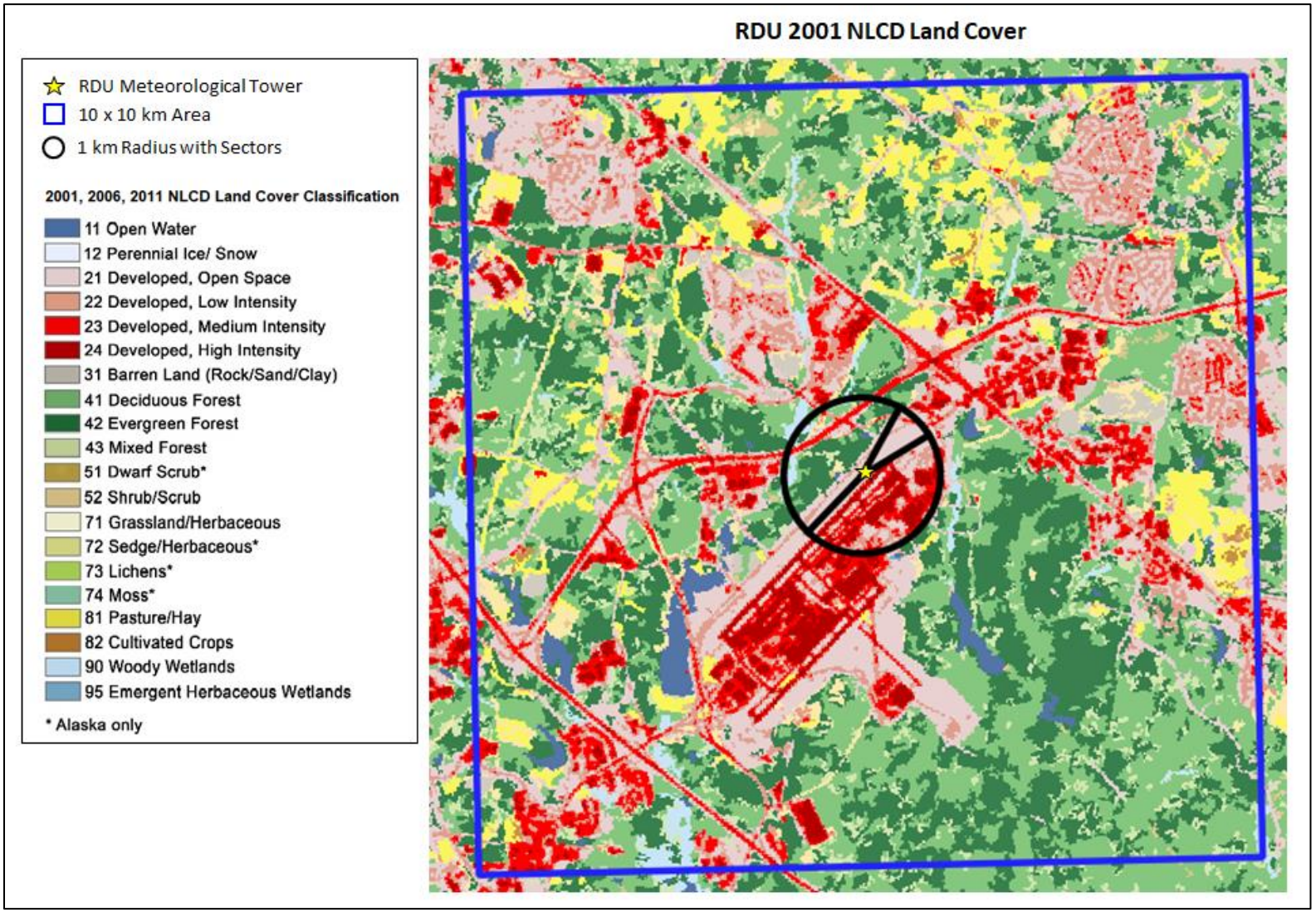



**Figure 11-9. 2001 NLCD (2011 Edition) Land Cover for RDU**

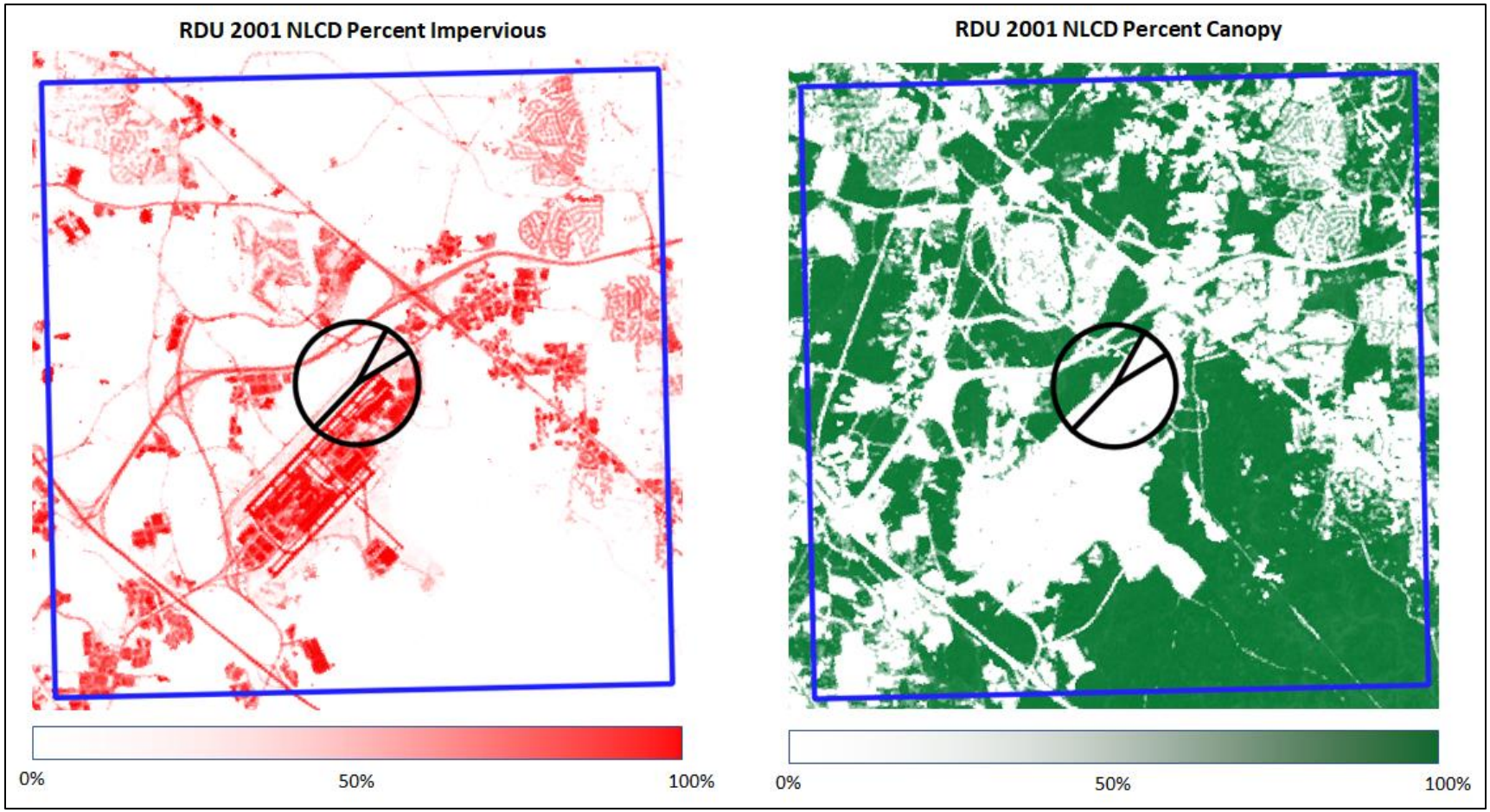



**Figure 11-10. 2001 NLCD (2011 Edition) Percent Impervious and Percent Canopy for RDU**

AERMET version 19191 was used to process meteorological data for input to AERMOD for each of three NWS/FAA station locations (ATL, BTR, and RDU). 2001 surface meteorological observations for each station were retrieved from the National Centers for Environmental Information (NCEI), archived in the Integrated Surface Hourly (ISH) format, and paired with concurrent upper air data from a nearby upper air station. Table 11-4 lists the upper air station that was paired with each surface station. Concurrent 1-minute ASOS wind data was also retrieved from the NCEI for each station and processed with AERMINUTE version 15272 to generate hourly wind data for input to AERMET as a replacement for the hourly wind data extracted from the ISH format. For each surface station, a separate set of AERMOD-ready 2001 meteorological data files were generated for each of the AERSURFACE scenarios listed in Table 11-1. An additional set of 2001 meteorological files were generated using surface characteristic values based on the 1992 NLCD land cover for BTR for the AERSURFACE scenarios listed in Table 11-2. AERMET was run identically for all scenarios using only regulatory default options without the adjusted u-star (ADJ_U*) option. A minimum wind speed of 0.5 m/s was used as the minimum threshold applied to the 1-minute ASOS wind data.

**Table 11-4. Surface and Upper Air Station Pairings for Meteorological Data Processing**

| Surface Station | Upper Air Station | Upper Air Station Name | Upper Air Station City |
|---|---|---|---|
| ATL | FFC | Atlanta Regional Airport | Atlanta, GA |
| BTR | SIL | Slidell Airport | Slidell, LA |
| RDU | GSO | Piedmont Triad International Airport | Greensboro, NC |

## 11.2 Emission Sources and AERMOD Setup

One-hour ground-level concentrations of a generic inert pollutant were predicted using AERMOD version 19191. A separate model run was performed using each of the meteorological datasets generated for the different AERSURFACE scenarios (Table 11-1 and Table 11-2) for each of three meteorological surface stations. Emission sources were collocated at the meteorological tower

and included in each AERMOD simulation. The emission sources and configurations modeled are listed in Table 11-5. AERMOD was run using the regulatory default (DFAULT) option.

**Table 11-5. Emission Sources**

| **Point Sources** | | | | | |
|---|---|---|---|---|---|
| **Source ID** | **Emission Rate (g/s)** | **Release Height (m)** | **Exit Temperature (K)** | **Exit Velocity (m/s)** | **Stack Diameter (m)** |
| P1 | 100.0 | 10.0 | 432.0 | 11.7 | 2.4 |
| P2 | 100.0 | 35.0 | 432.0 | 11.7 | 2.4 |
| P3 | 100.0 | 55.0 | 432.0 | 11.7 | 2.4 |
| P4 | 100.0 | 100.0 | 432.0 | 18.8 | 4.6 |
| P5 | 100.0 | 200.0 | 432.0 | 26.5 | 5.6 |
| **Area Source** | | | | | |
| **Source ID** | **Emission Rate (g/s-m$^2$)** | **Release Height (m)** | **Initial X Dimension (m)** | **Initial Y Dimension (m)** | |
| A1 | 0.00001 | 0.01 | 100.0 | 100.0 | |
| **Volume Source** | | | | | |
| **Source ID** | **Emission Rate (g/s)** | **Release Height (m)** | **Initial Sigma Y (m)** | **Initial Sigma Z (m)** | |
| V1 | 100.0 | 100.0 | 14.0 | 16.0 | |

Concentrations were estimated using a polar receptor grid, centered on the meteorological tower and extending out to 10 km from the tower. Receptors were defined every 10 degrees around the tower at the following distances from the tower: 100-meter intervals out to 500 meters; 250-meter intervals out to 1 km; 500-meter intervals out to 5 km; 1000-meter intervals out to 10 km. The receptor grid for each station was comprised of 720 receptors. Receptors were processed for each station using AERMAP version 18081 with 1-arcsecond terrain data from the National Elevation Dataset (NED) to determine receptor elevations and hill heights.

## 11.3 Inter-comparison of AERSURFACE and AERMOD Results

Figure 11-11, Figure 11-24, and Figure 11-40, at the end of this section, compare estimated surface roughness lengths across the different AERSURFACE scenarios, seasons, and sectors for ATL, BTR, and RDU, respectively. Refer to Table 11-1 and Table 11-2 for descriptions of the different AERSURFACE scenarios for which surface values were generated. Figure 11-12, Figure 11-25, and Figure 11-41 plot the AERMOD estimated highest 1-hour (H1H) concentrations for each scenario by source type for each of the three sites, while Figure 11-13, Figure 11-26, and Figure 11-42 plot the second highest (H2H) estimated 1-hour concentrations.

The remaining figures at the end of this section are collections of scatter plots for each of the sites that compare AERMOD results by source type for the different scenarios, paired in space. Specifically, each of the scatter plots compares either the H1H or H2H predicted concentrations at each receptor, for two of the scenarios. The data points on the scatter plots are colorized based on the distance from the emission source. For each site, a default "base" scenario is defined. The base scenario is that scenario that incorporates all three 2001 NLCD data products including land cover, impervious and canopy data and utilizes the ZORAD roughness option (i.e., LC-IMP-CAN-ZORAD). The base scenario is compared to each of the other scenarios at the respective site. Similarly, there are scatter plots that compare each scenario that utilized the ZORAD roughness option to the analogous scenario that utilized the ZOEFF roughness option (e.g., LC-IMP-CAN-ZORAD vs. LC-IMP-CAN-ZOEFF)

For each of the three sites, there are generally only small differences (0.01-0.02 meters) in the roughness length estimated using the research grade ZOEFF option for estimating surface roughness compared to the default ZORAD option, when comparing scenarios that used the same combination of NLCD data files (see Figure 11-11, Figure 11-24, and Figure 11-40). This suggests the two methods for estimating roughness length are comparable to each other. There are, however, greater differences in the estimated roughness lengths when comparing scenarios that used the same roughness option and different combinations of NLCD products. The largest differences for the three sites are shown in Figure 11-11, at ATL, where there is a difference of about 0.2 meters in the roughness values estimated for Sector 2 during the summer when land cover data are supplemented with both impervious and

canopy data (2001-LC-IMP-CAN-ZORAD) versus when land cover data are supplemented with canopy data only (2001-LC-CAN-ZORAD) and similarly, between 2001-LC-CAN-ZORAD and 2001-LC-ZORAD in which land cover data is not supplemented with either impervious or canopy data. However, these are the largest differences between estimated values for any sector and season across the different scenarios for any of the three locations. There is a much smaller difference between 2001-LC-IMP-CAN-ZORAD which includes impervious and canopy data and 2001-LC-ZORAD which is based solely on land cover data. For each of the sites, when comparing the scenario that includes both impervious and canopy data to the scenario that uses only land cover data, the difference in the derived roughness is generally much less than 0.1 meter.

In general, H1H and H2H concentrations for all scenarios are comparable to the base case (ratio close to 1.0). ATL resulted in the largest differences in modeled concentrations when comparing scenarios that used different combinations of NLCD products. In Figure 11-12, a comparison of the difference in the H1H modeled concentrations (not paired in space or time) for source P1 represents a 20% decrease in the scenarios using the ZORAD roughness option for which land cover was supplemented with both impervious and canopy data (2001-LC-IMP-CAN-ZORAD) compared with supplementing land cover with canopy data only (2001-LC-CAN-ZORAD). For the same two scenarios, there is 44% increase in the concentration for the P3 source. P1 is the lowest level point source which has a 10-meter release height. P3 is also a point source with a release height of 55 meters. For each of the sites, the greatest differences estimated concentrations occur for the low-level point source, P1. (Refer to Table 11-5 for the source characteristics of each of the modeled emission sources.) In keeping with the comparison of roughness values, there are generally smaller differences in H1H and H2H estimated concentrations, not paired in time or space) when comparing the scenario that includes both impervious and canopy data to the scenario that uses only land cover data. The scatter plots, however, do illustrate greater differences in the estimated concentrations across the different scenarios when paired in space which highlights the sensitivity of AERMOD to roughness.

A comparison of the base case, which uses the 2001 NLCD (2011 Edition), to the scenarios that use the 1992 NLCD at BTR (Figure 11-27 and Figure 11-28), where there has been little change over the years in the vicinity of the met tower, shows very little difference in the derived roughness lengths

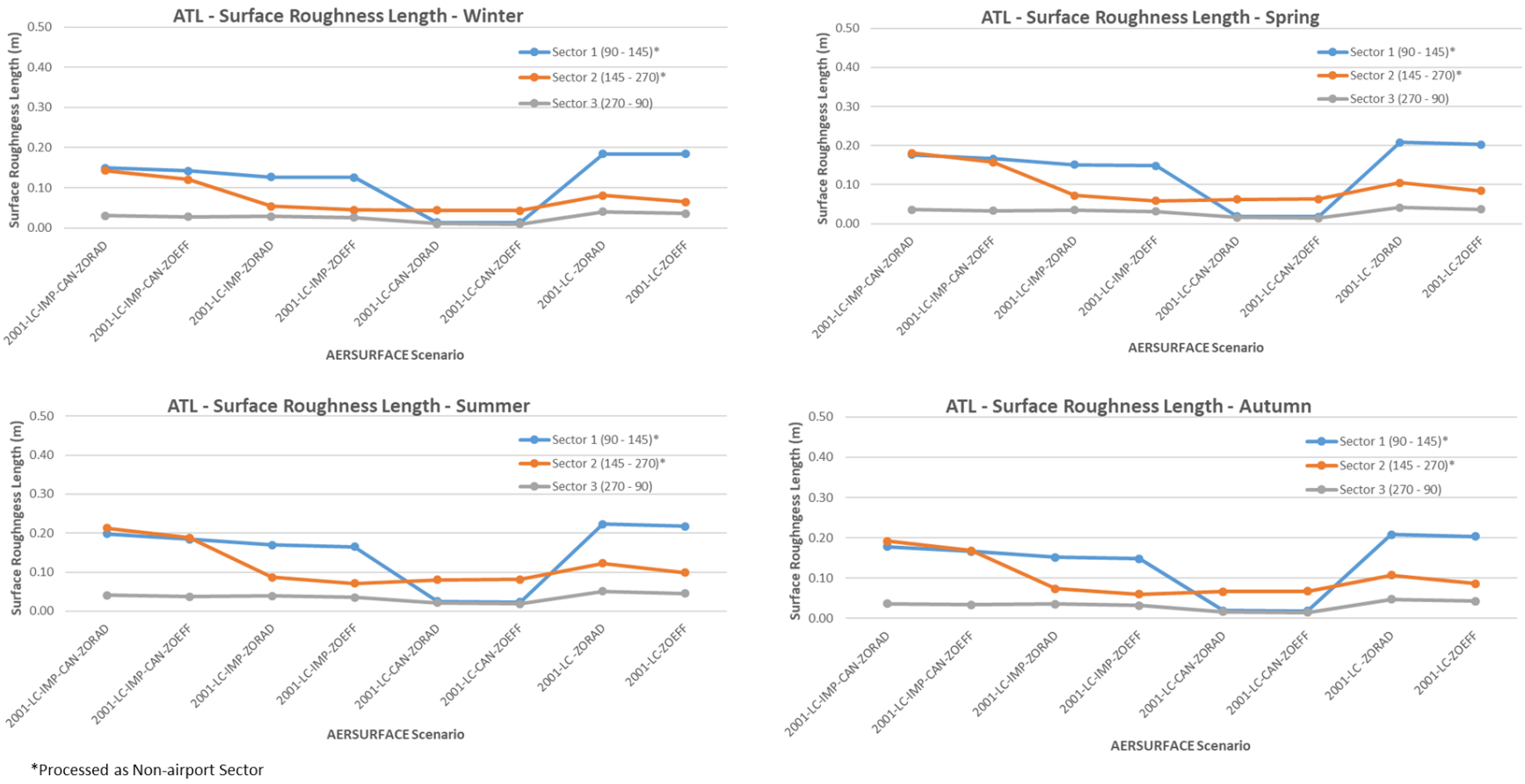
(< 0.04 meters) for all seasons and sectors, suggesting that the default base scenario which incorporates 2001 land cover, impervious, and canopy data is comparable to using the 1992 NLCD land cover data only.

To summarize:

- Supplementing the 2001 land cover data with impervious and canopy data appears to yield comparable results to the 1992 land cover when there has been little change in land use overall.

- Supplementing the 2001 land cover data with impervious and canopy data appears to be more comparable to using land cover data only than supplementing with only impervious or canopy data.

- A comparison of estimated AERMOD concentrations, paired in space, highlights the sensitivity of low-level sources to even small changes roughness length.




*Processed as Non-airport Sector

**Figure 11-11. ATL Surface Roughness Length by Season, Sector, and AERSURFACE Scenario**

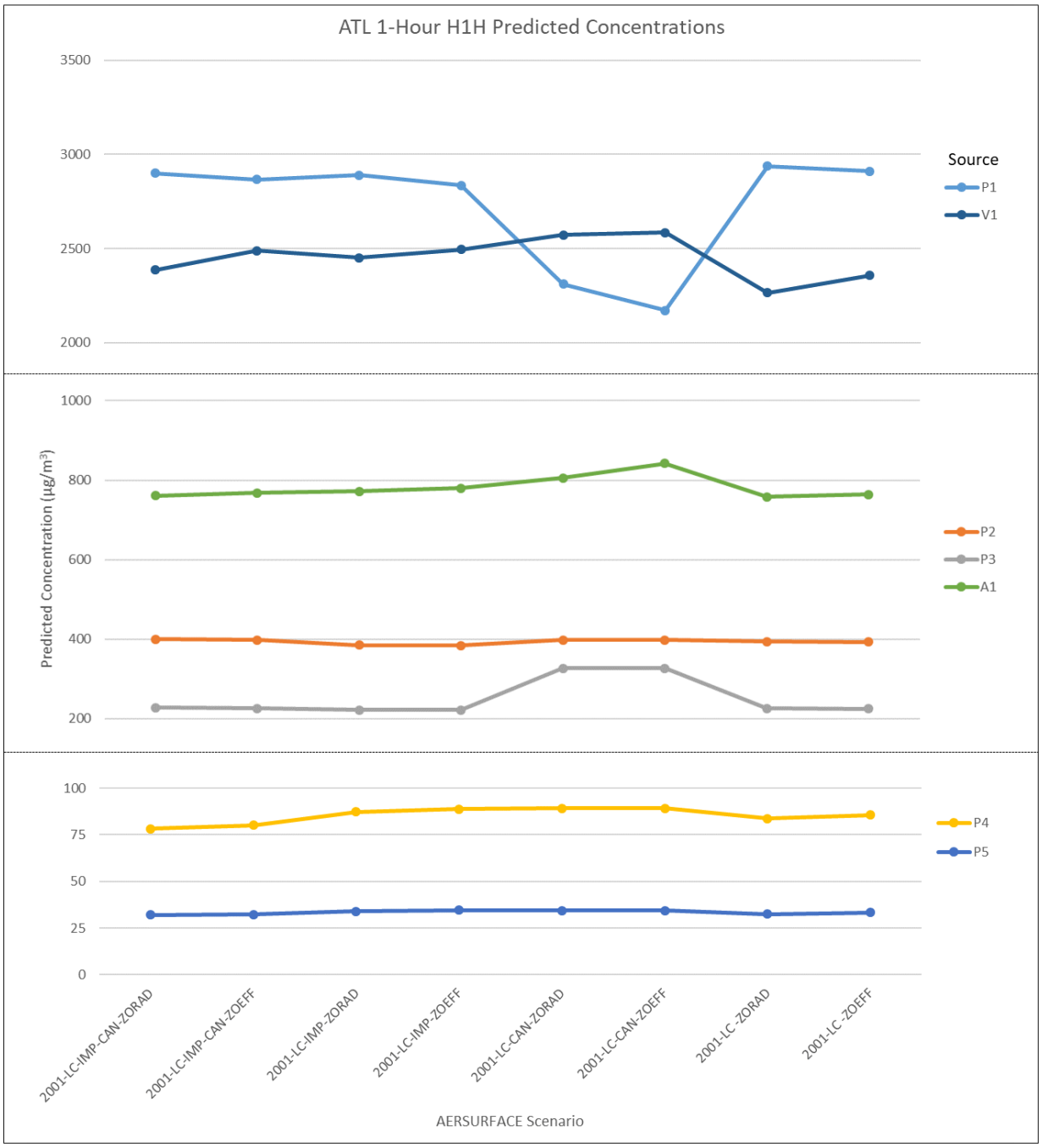



**Figure 11-12. ATL H1H Predicted Concentrations by AERSURFACE Scenario and Emission Source**

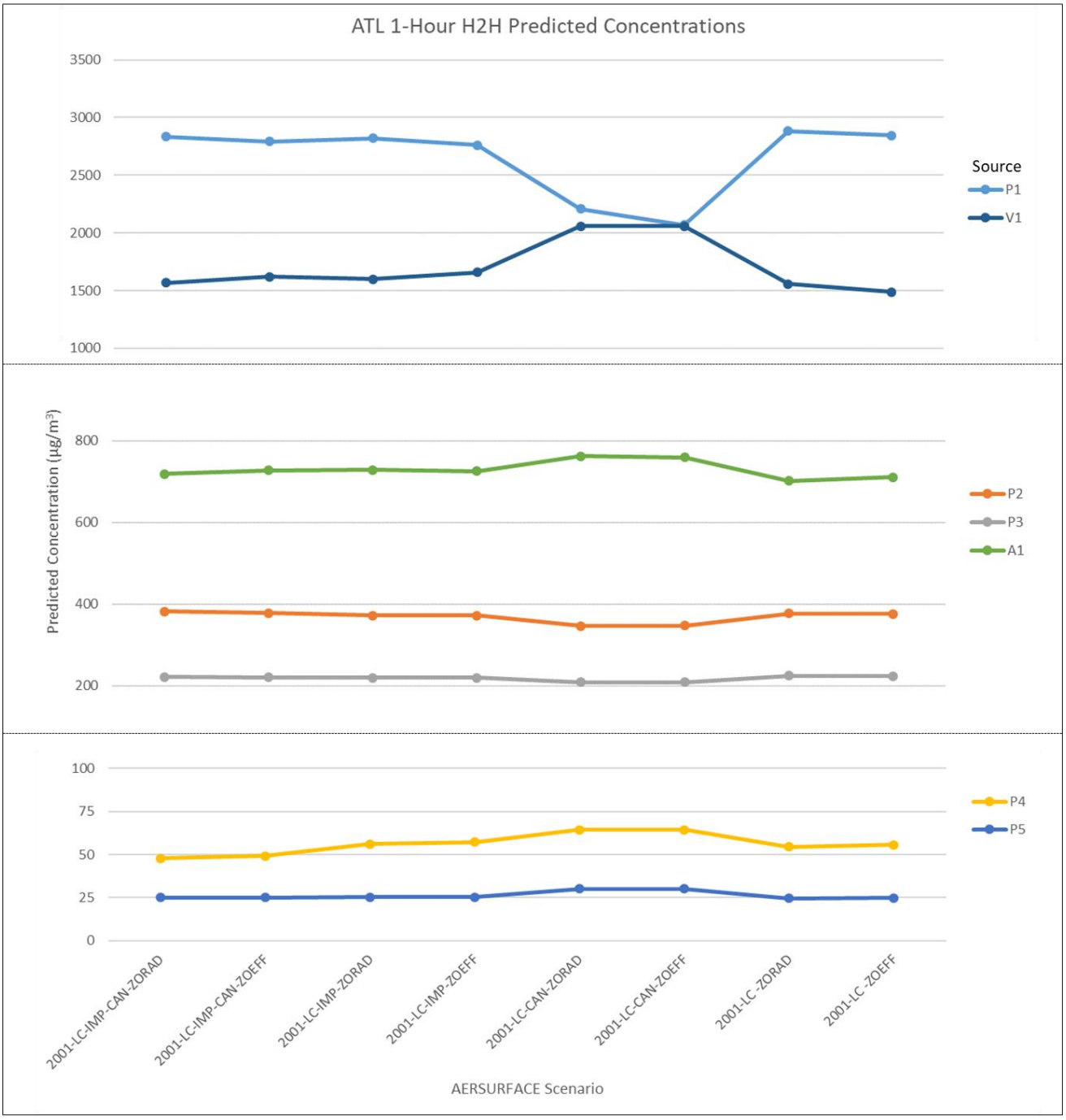



**Figure 11-13. ATL H2H Predicted Concentrations by AERSURFACE Scenario and Emission Source**

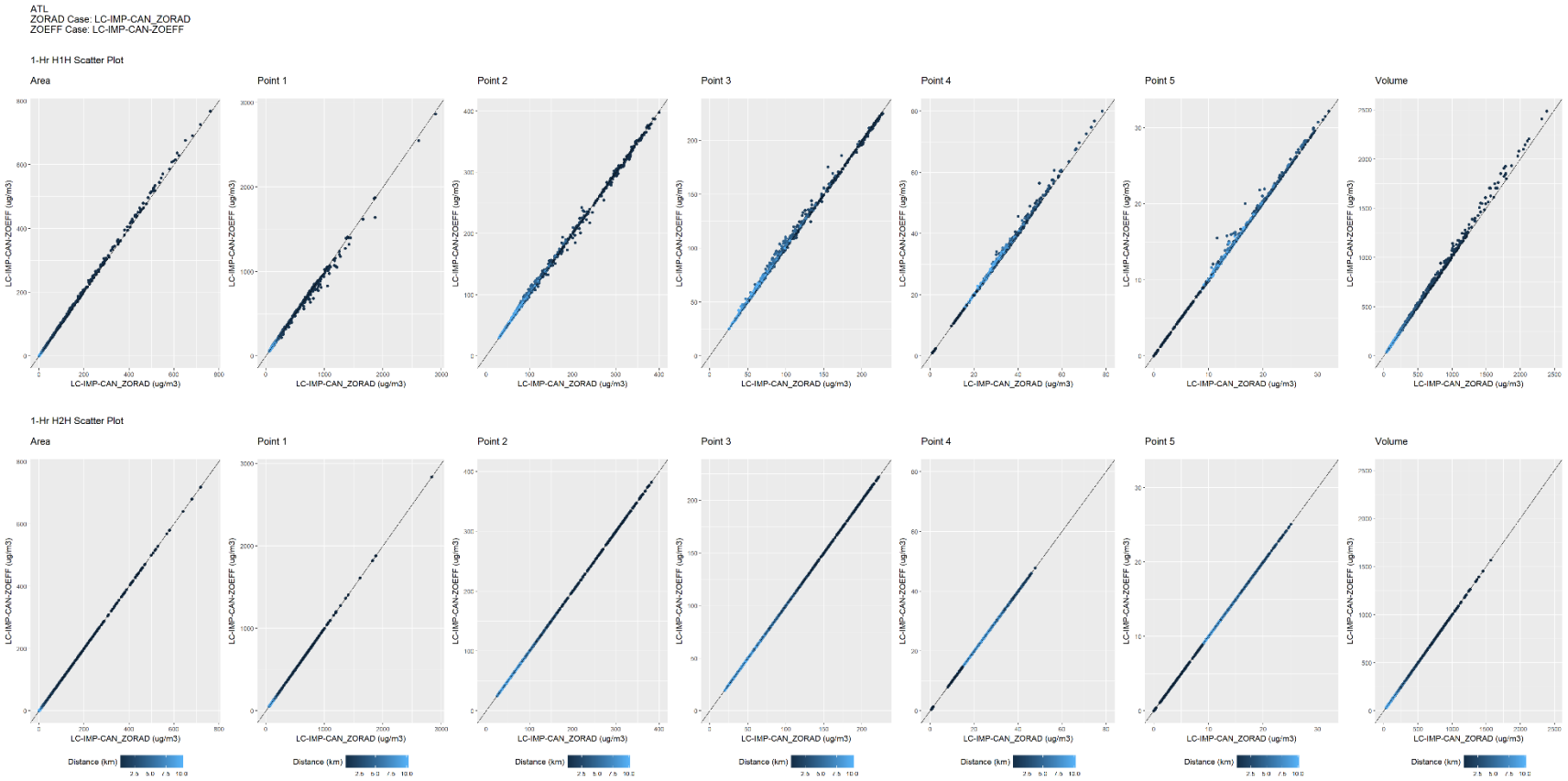



**Figure 11-14. ATL, Scatter Plots, H1H and H2H at each Receptor, 2001 Base Case, LC-IMP-CAN-ZORAD Vs. 2001 LC-IMP-CAN-ZOEFF**

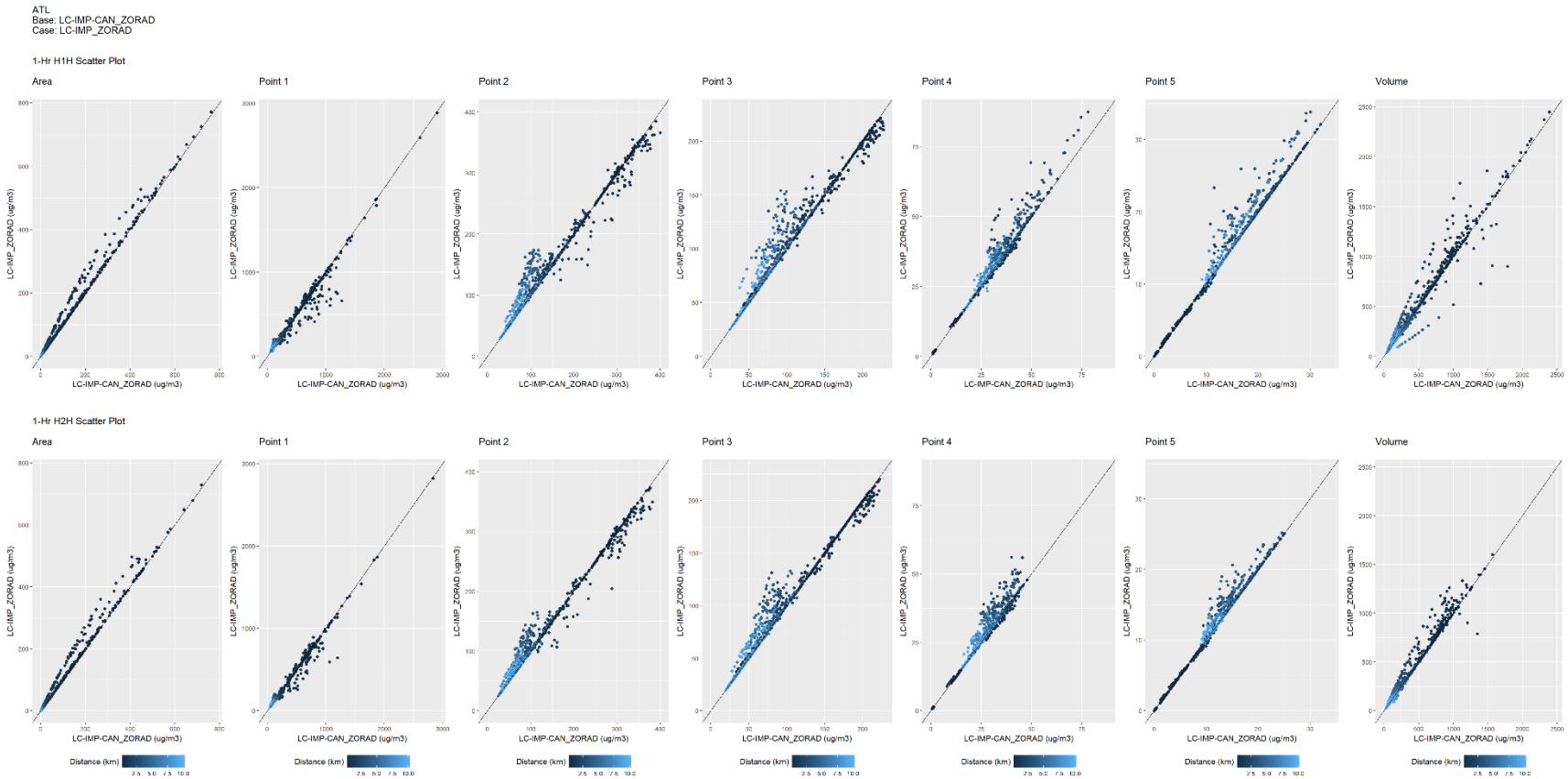



**Figure 11-15. ATL, Scatter Plots, H1H and H2H at each Receptor, 2001 Base Case, LC-IMP-CAN-ZORAD Vs. 2001 LC-IMP-ZORAD**

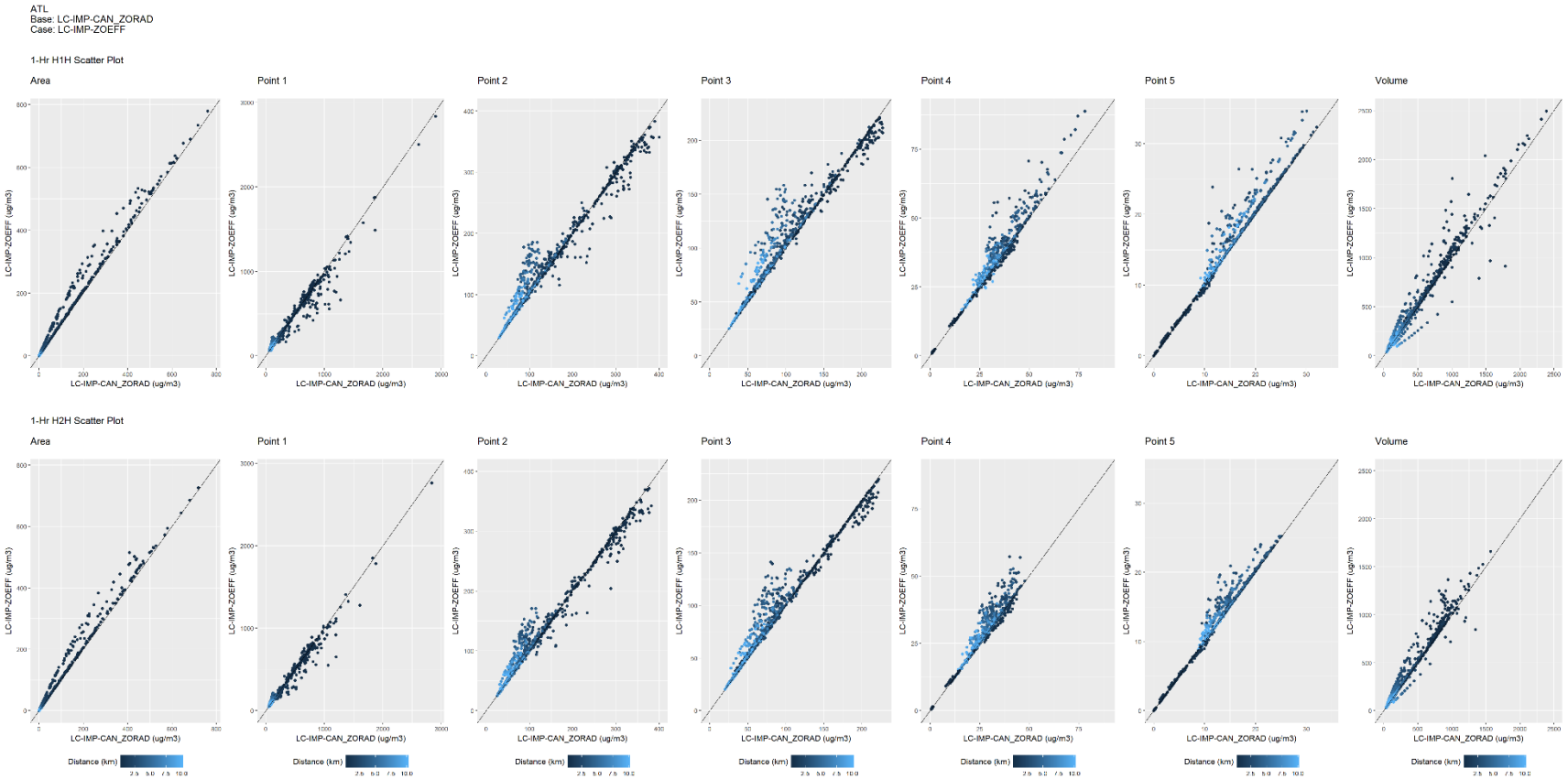



**Figure 11-16. ATL, Scatter Plots, H1H and H2H at each Receptor, 2001 Base Case, LC-IMP-CAN-ZORAD Vs. 2001 LC-IMP-ZOEFF**

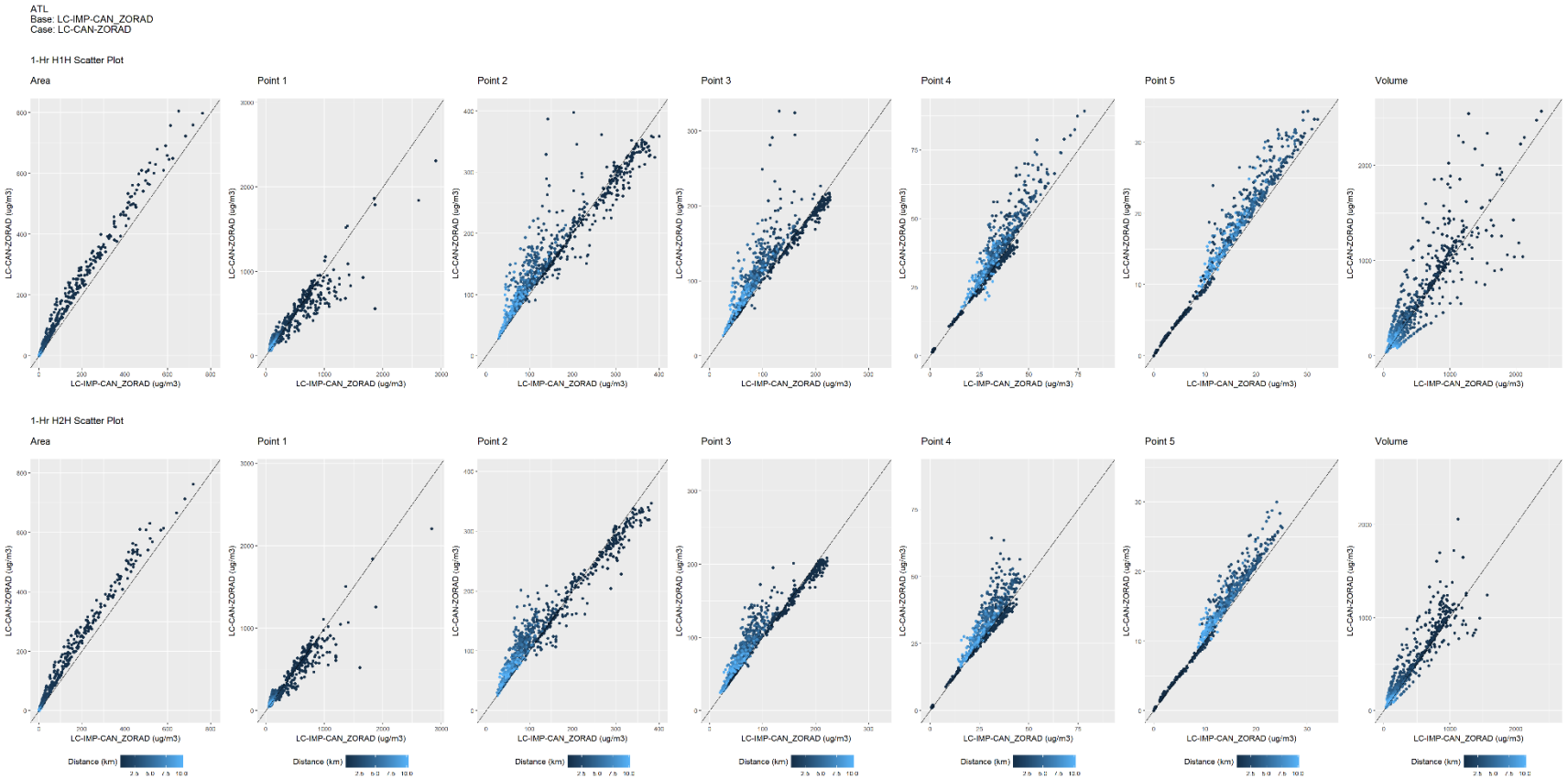



**Figure 11-17. ATL, Scatter Plots, H1H and H2H at each Receptor, 2001 Base Case, LC-IMP-CAN-ZORAD Vs. 2001 LC-CAN-ZORAD**

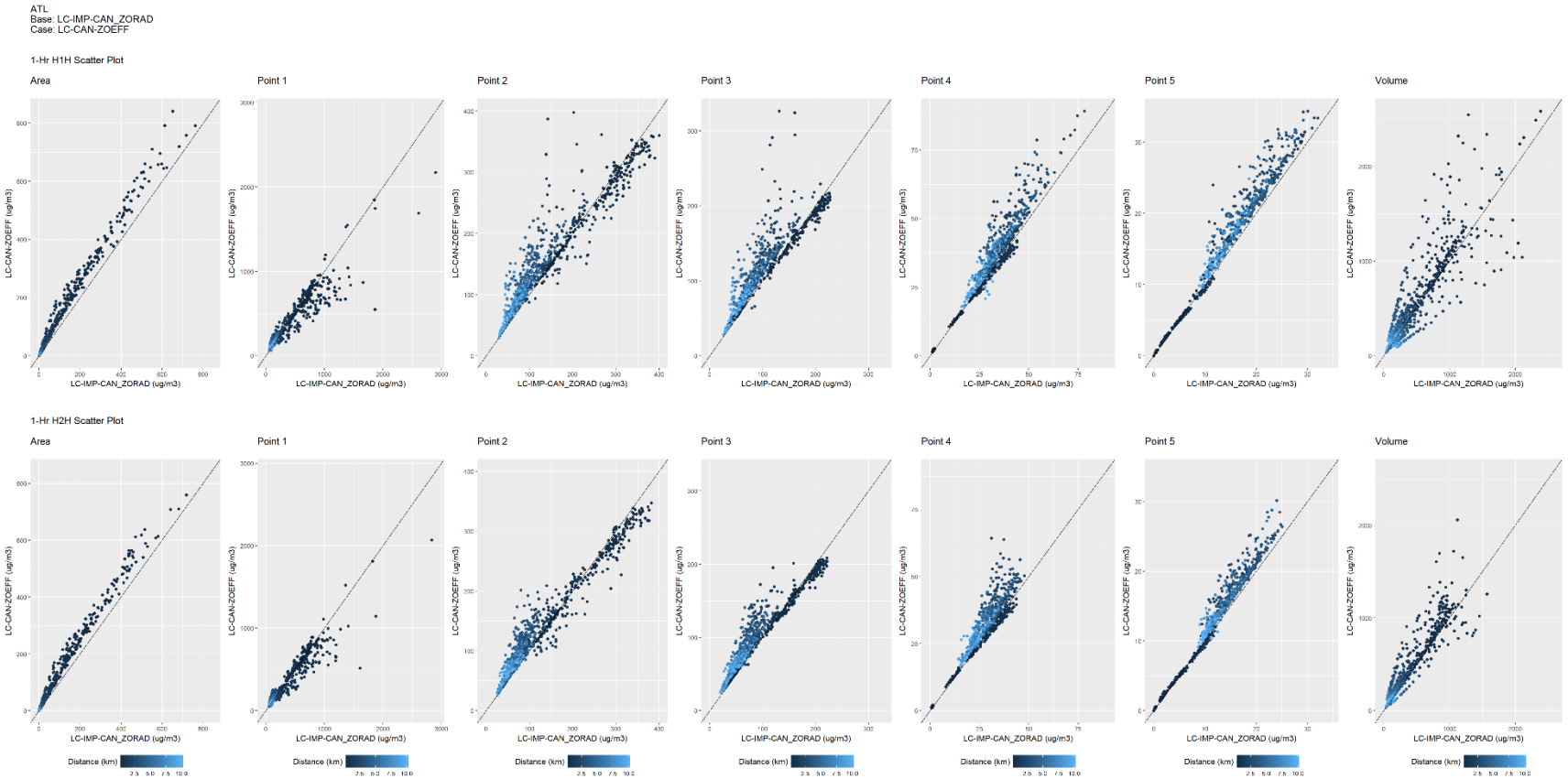



**Figure 11-18. ATL, Scatter Plots, H1H and H2H at each Receptor, 2001 Base Case, LC-IMP-CAN-ZORAD Vs. 2001 LC-CAN-ZOEFF**

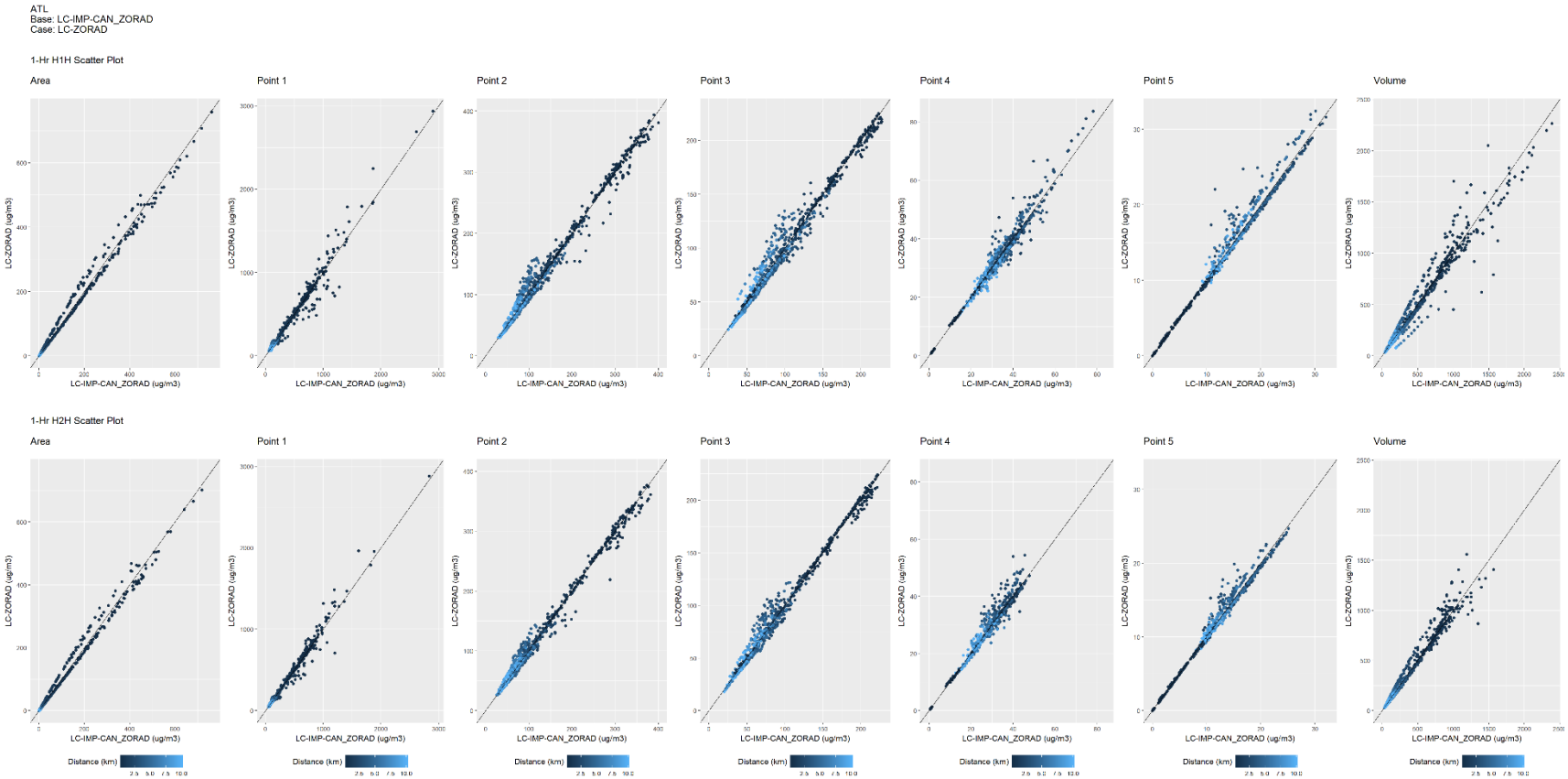



**Figure 11-19. ATL, Scatter Plots, H1H and H2H at each Receptor, 2001 Base Case, LC-IMP-CAN-ZORAD Vs. 2001 LC-ZORAD**

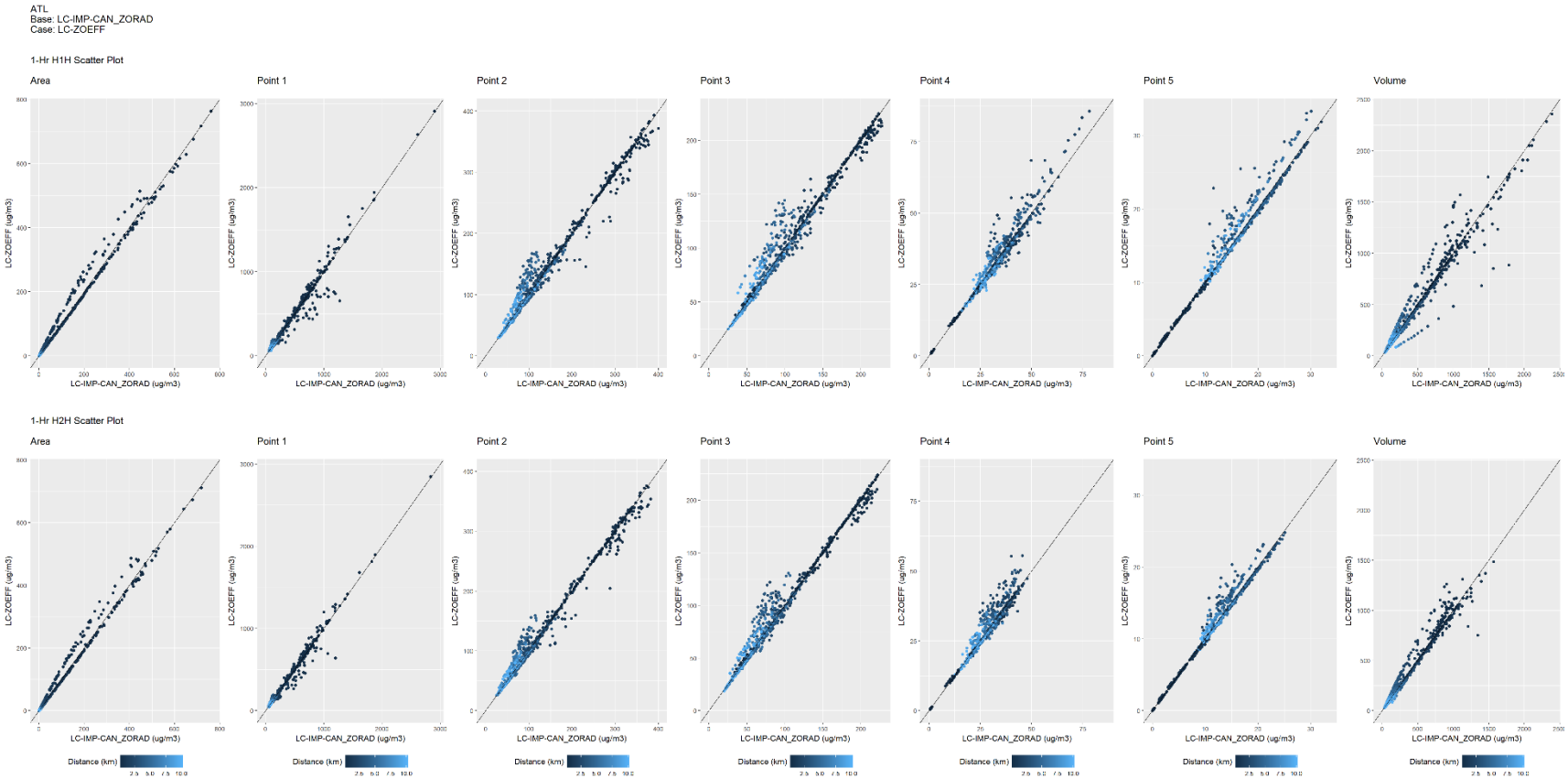



**Figure 11-20. ATL, Scatter Plots, H1H and H2H at each Receptor, 2001 Base Case, LC-IMP-CAN-ZORAD Vs. 2001 LC-ZOEFF**

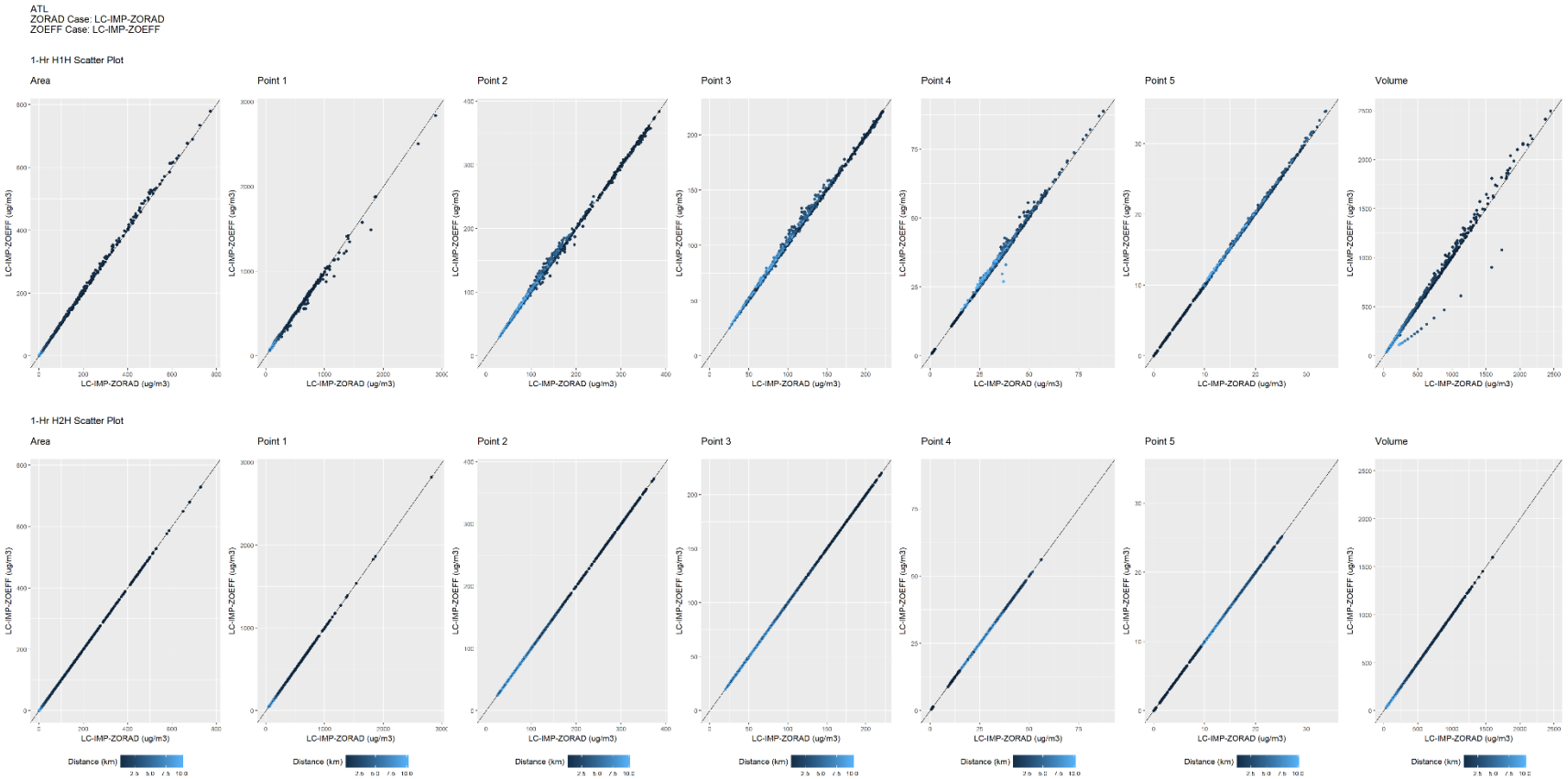



**Figure 11-21. ATL, Scatter Plots, H1H and H2H at each Receptor, 2001 LC-IMP-ZORAD Vs. 2001 LC-IMP-ZOEFF**

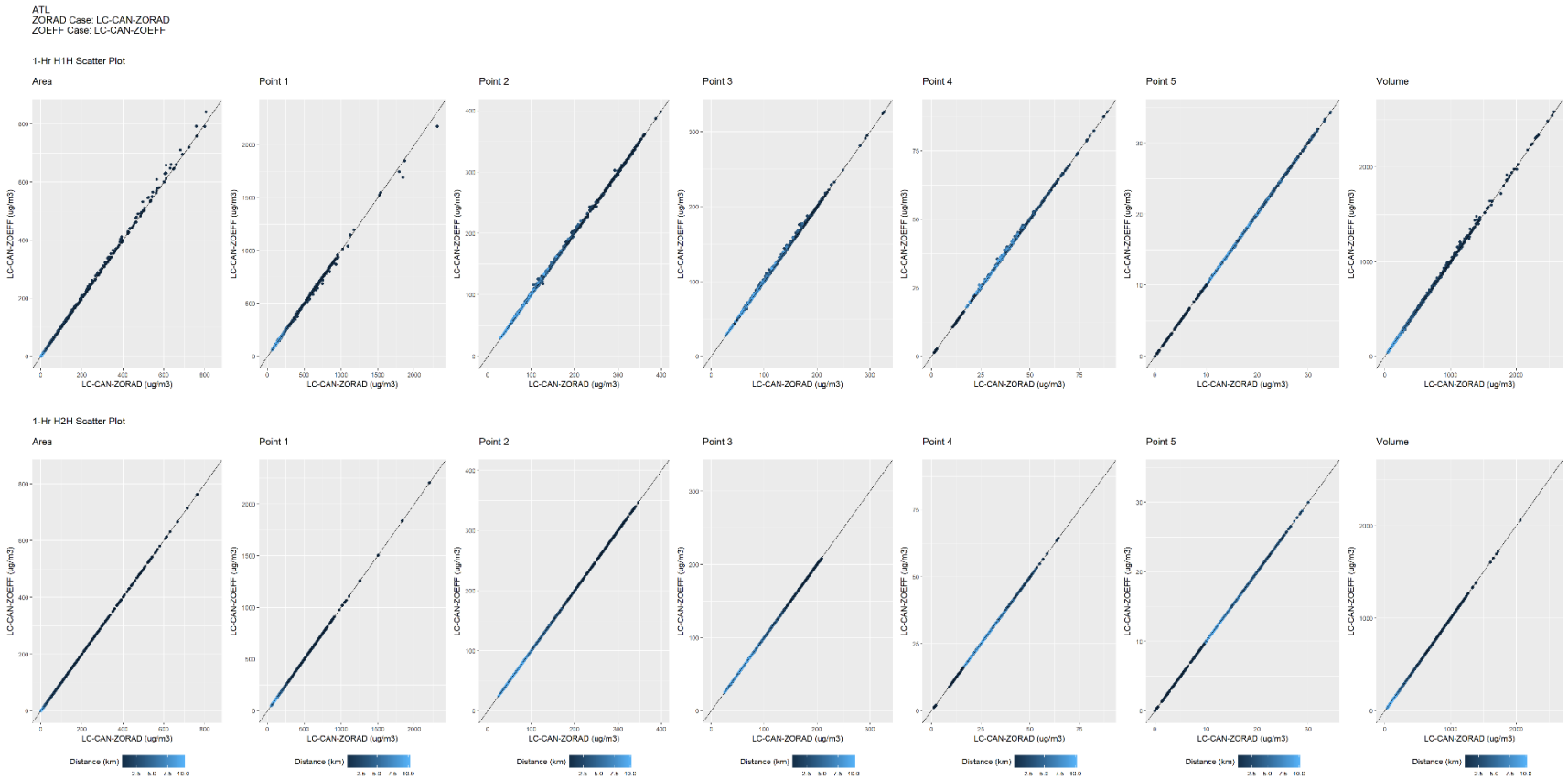



**Figure 11-22. ATL, Scatter Plots, H1H and H2H at each Receptor, 2001 LC-CAN-ZORAD Vs. 2001 LC-CAN-ZOEFF**

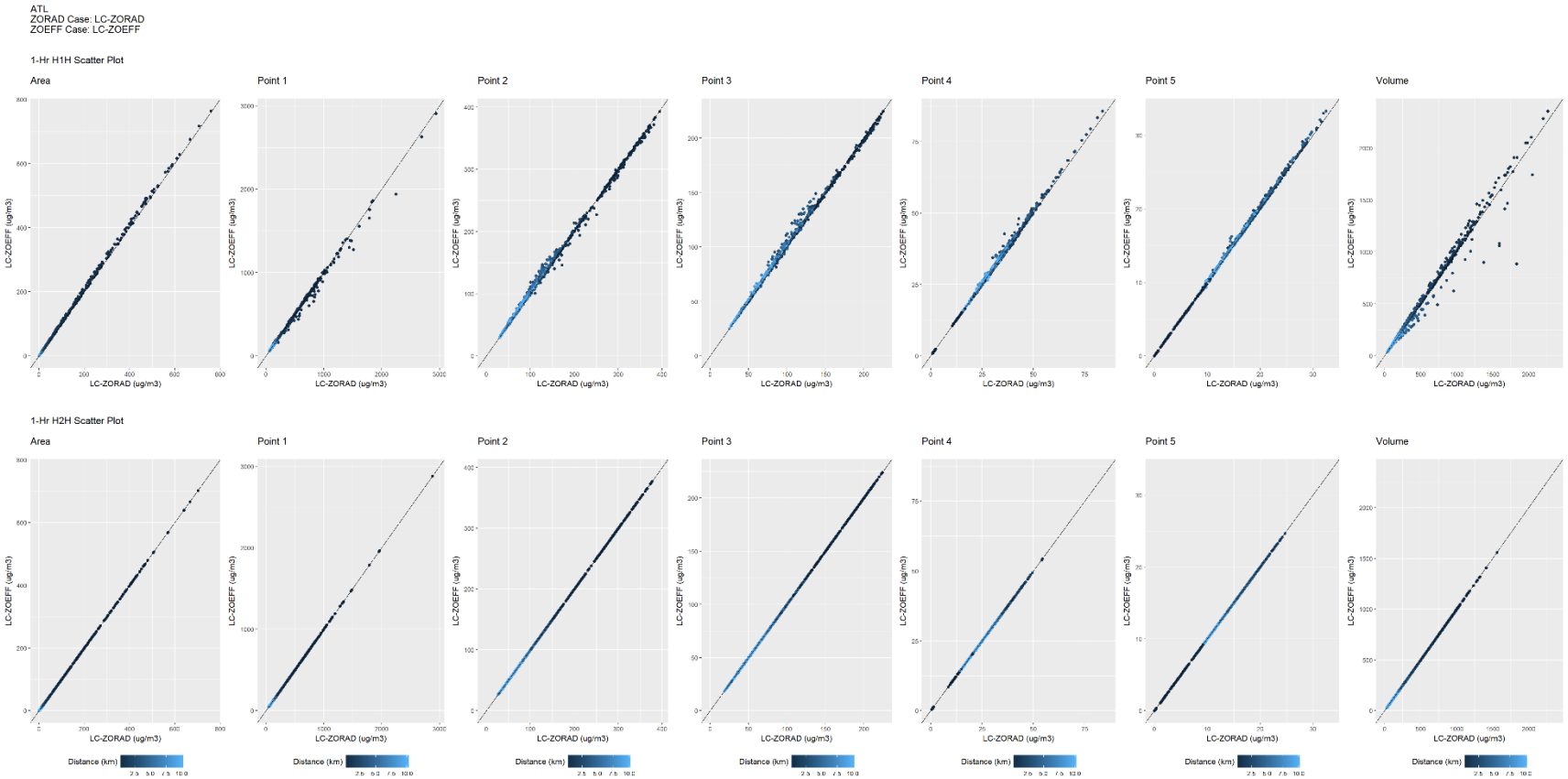
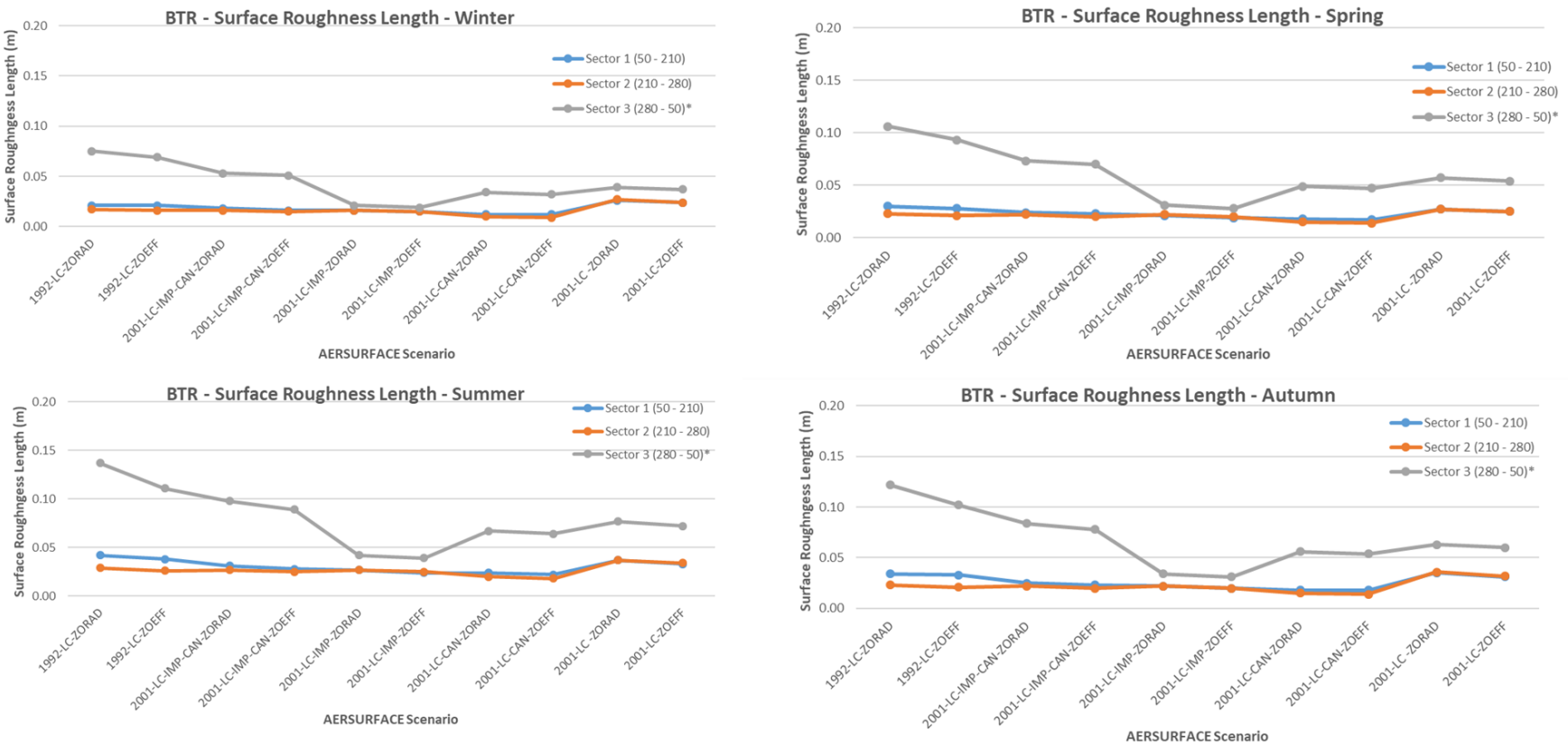



**Figure 11-23. ATL, Scatter Plots, H1H and H2H at each Receptor, 2001 LC-ZORAD Vs. 2001 LC-ZOEFF**




*Processed as Non-airport Sector

**Figure 11-24. BTR Surface Roughness Length by Season, Sector, and AERSURFACE Scenario**

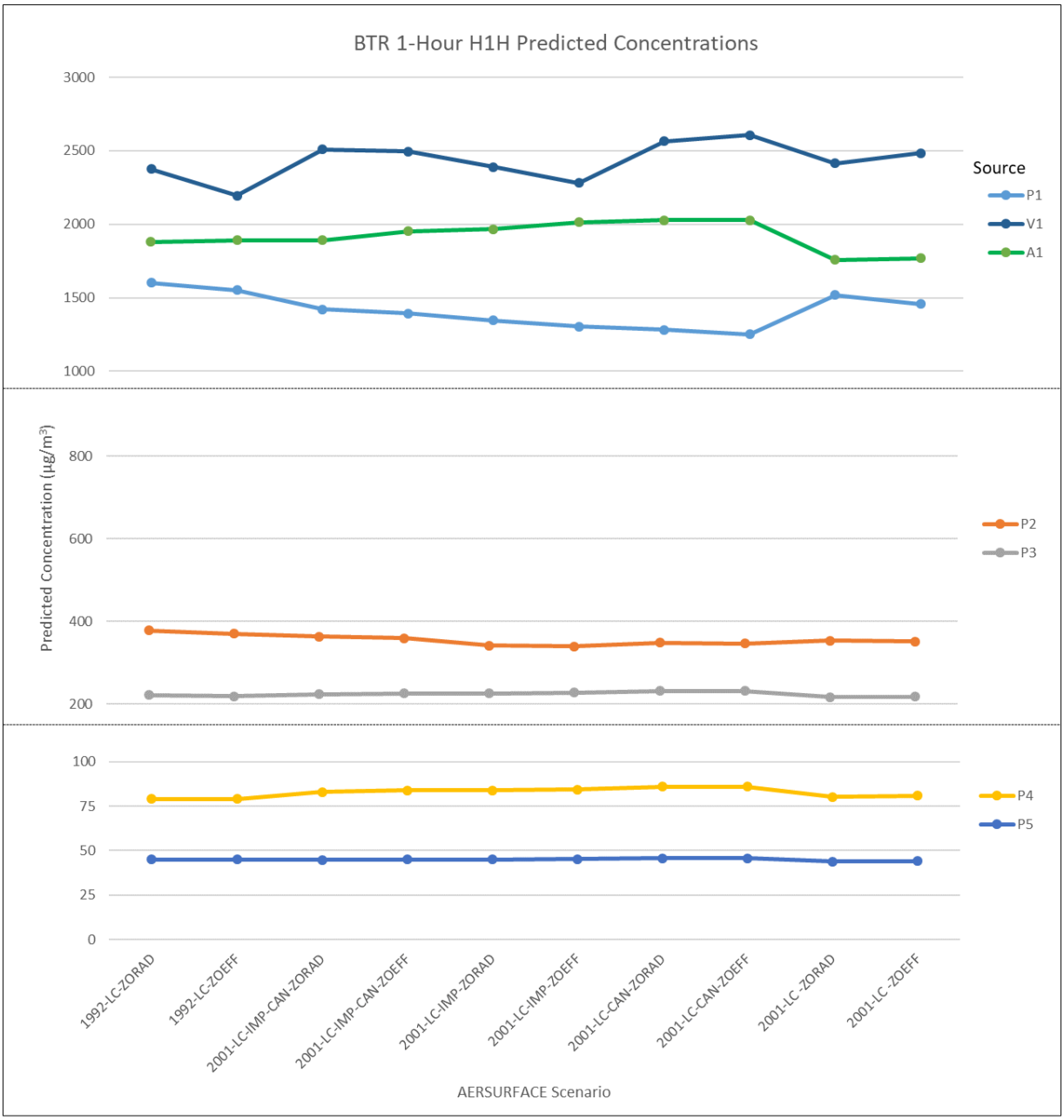



**Figure 11-25. BTR H1H Predicted Concentrations by AERSURFACE Scenario and Emission Source**

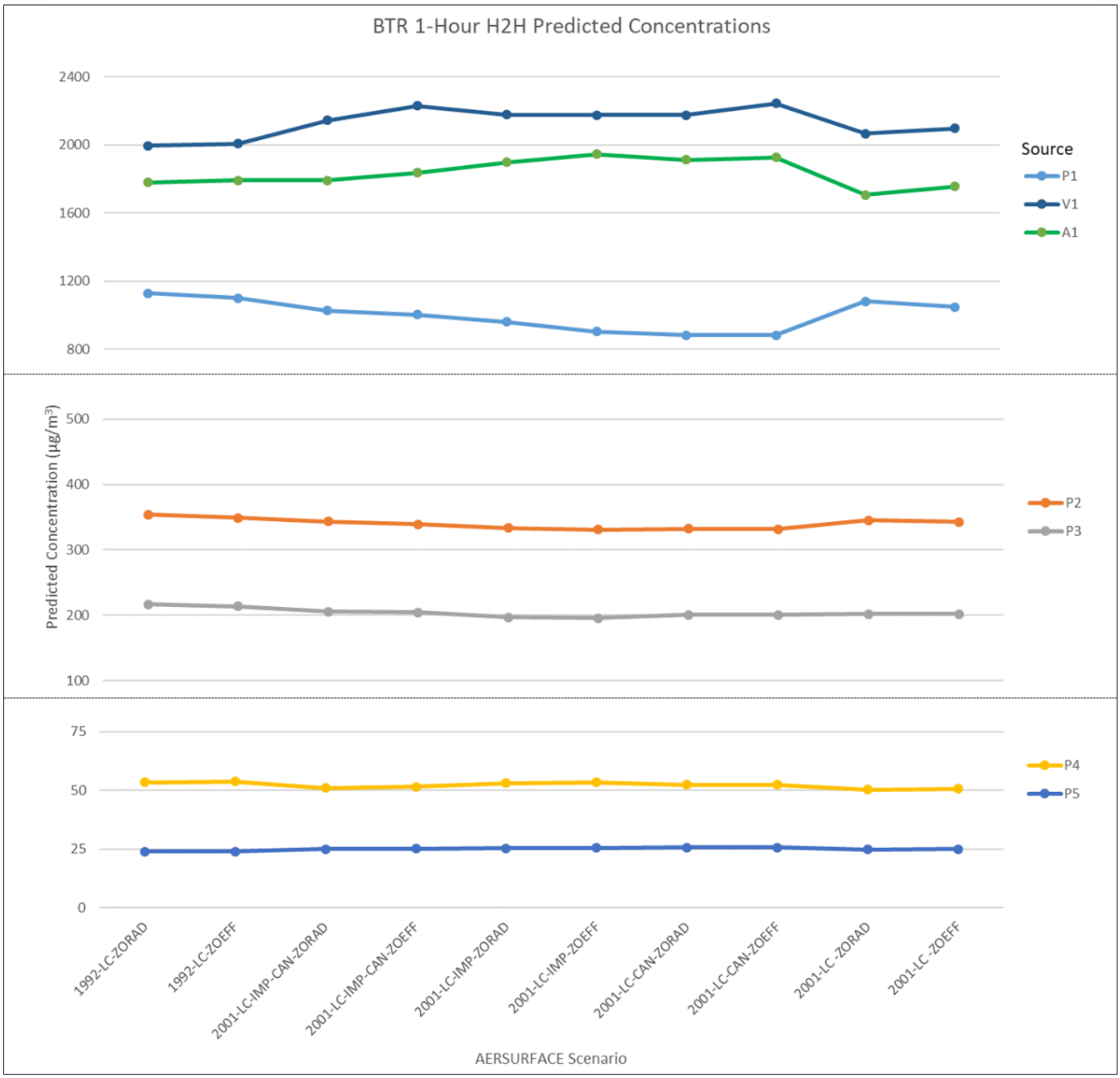



**Figure 11-26. BTR H2H Predicted Concentrations by AERSURFACE Scenario and Emission Source**

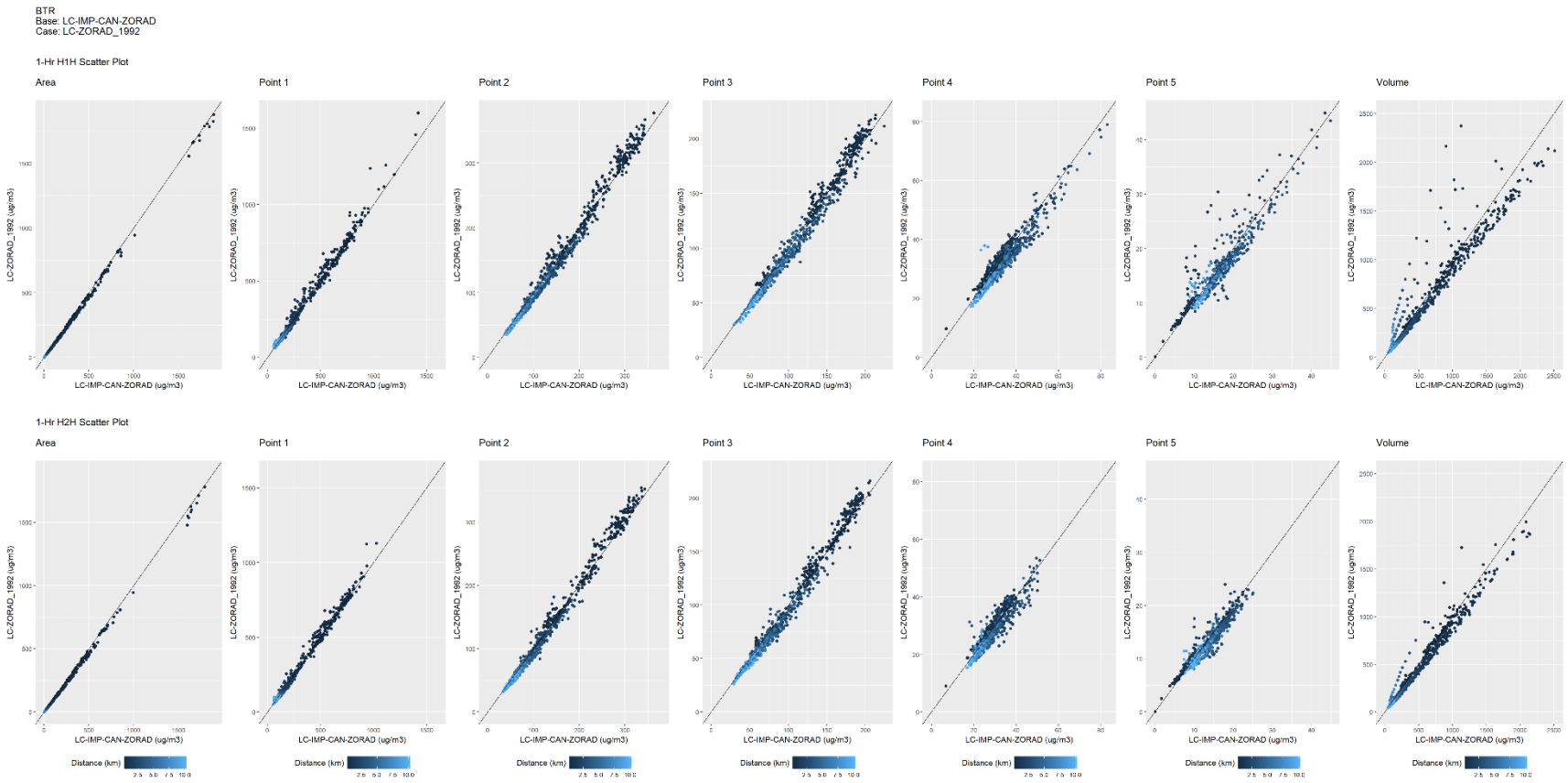



**Figure 11-27. BTR, Scatter Plots, H1H and H2H at each Receptor, 2001 Base Case, LC-IMP-CAN-ZORAD Vs. 1992 LC-ZORAD**

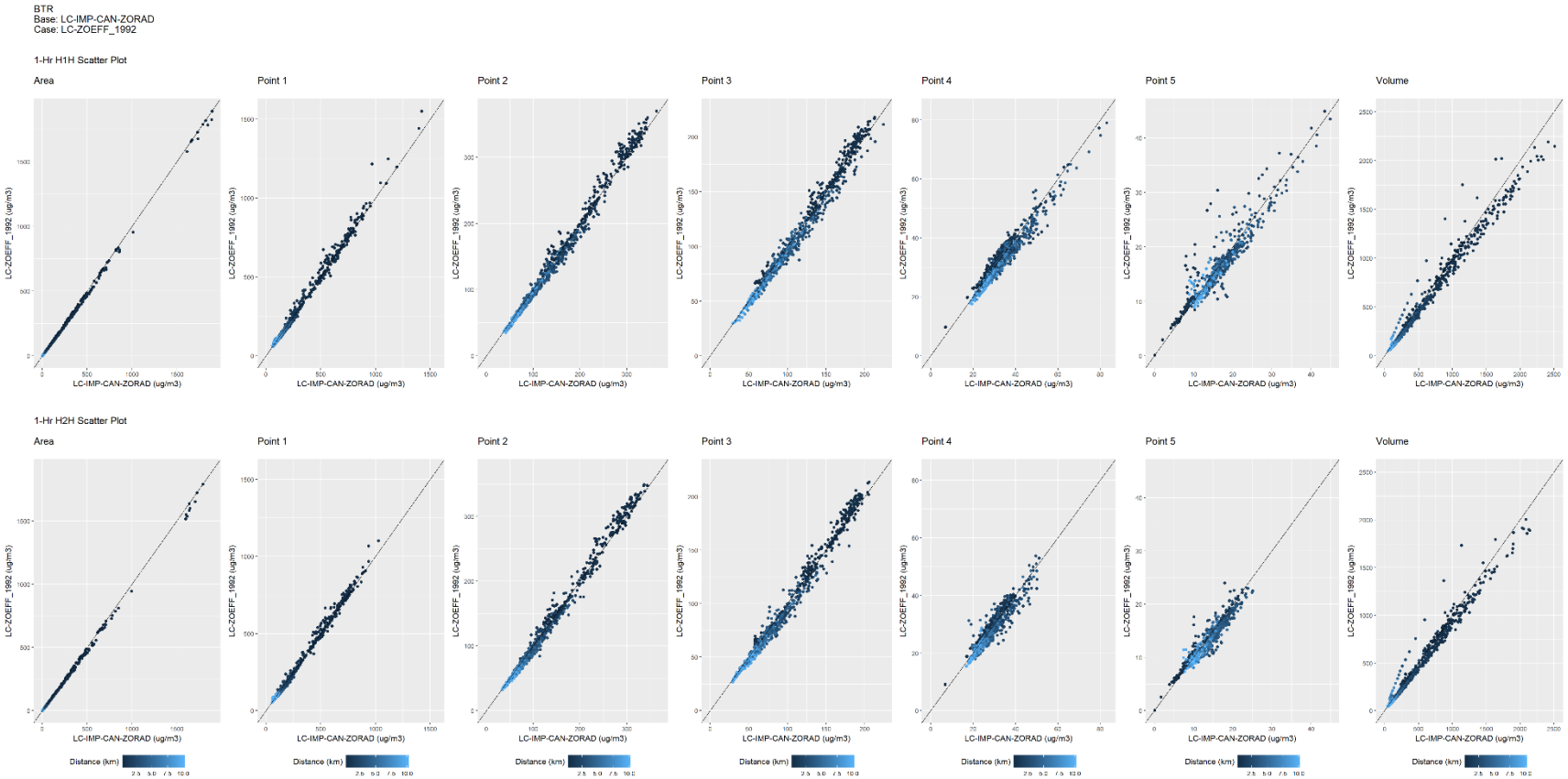



**Figure 11-28. BTR, Scatter Plots, H1H and H2H at each Receptor, 2001 Base Case, LC-IMP-CAN-ZORAD Vs. 1992 LC-ZOEFF**

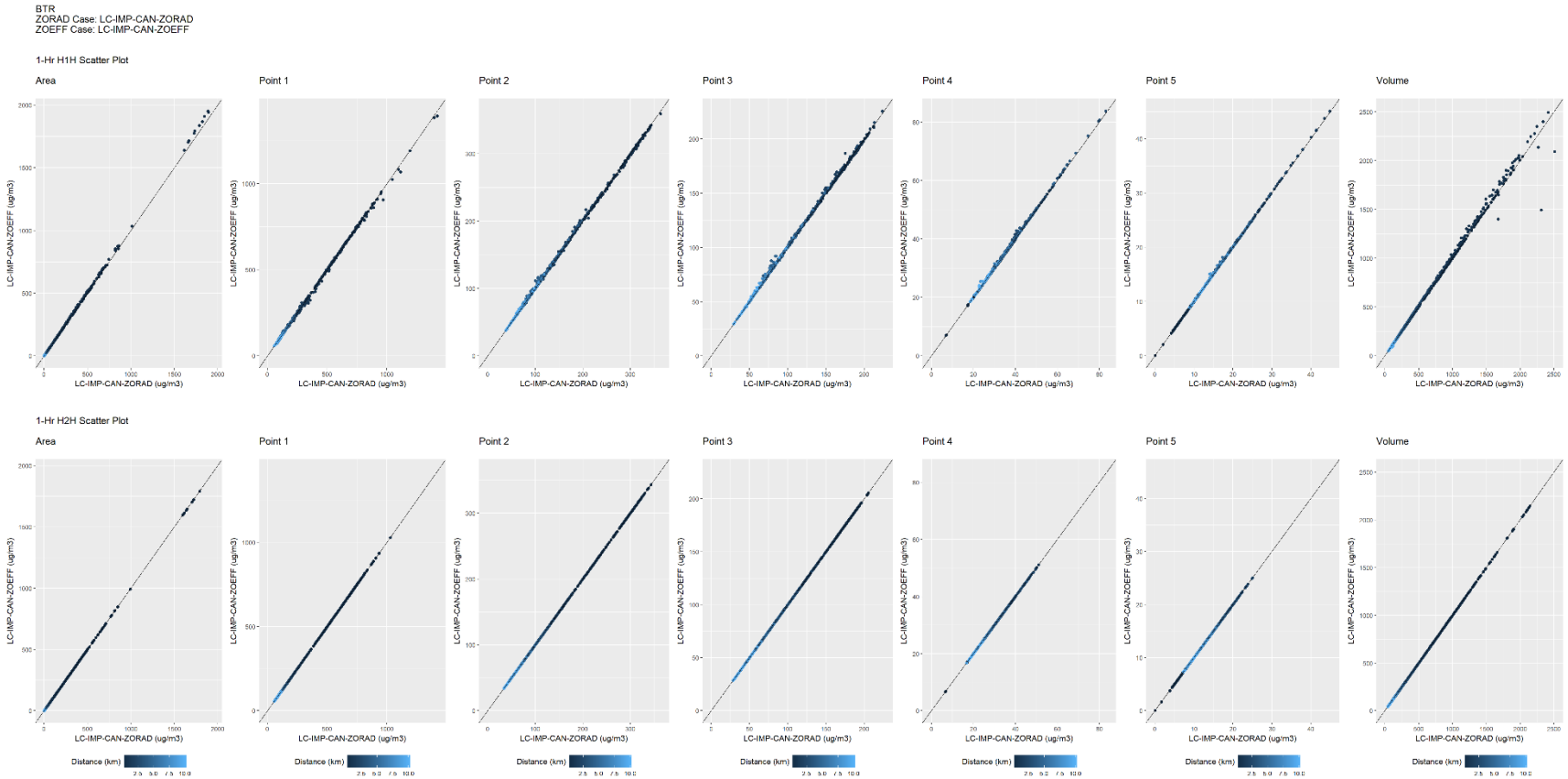



**Figure 11-29. BTR, Scatter Plots, H1H and H2H at each Receptor, 2001 Base Case, LC-IMP-CAN-ZORAD Vs. 2001 LC-IMP-CAN-ZOEFF**

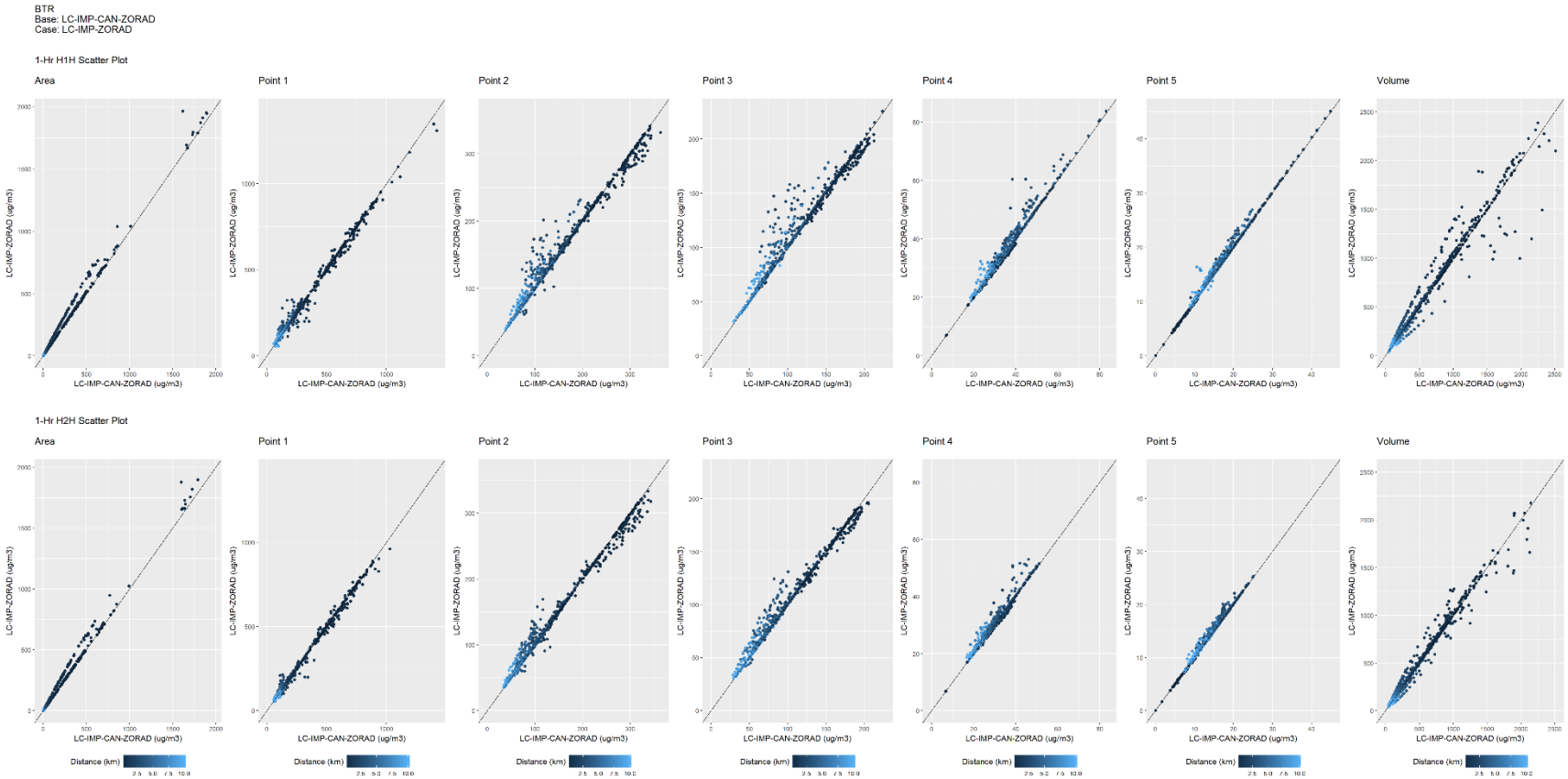



**Figure 11-30. BTR, Scatter Plots, H1H and H2H at each Receptor, 2001 Base Case, LC-IMP-CAN-ZORAD Vs. 2001 LC-IMP-ZORAD**

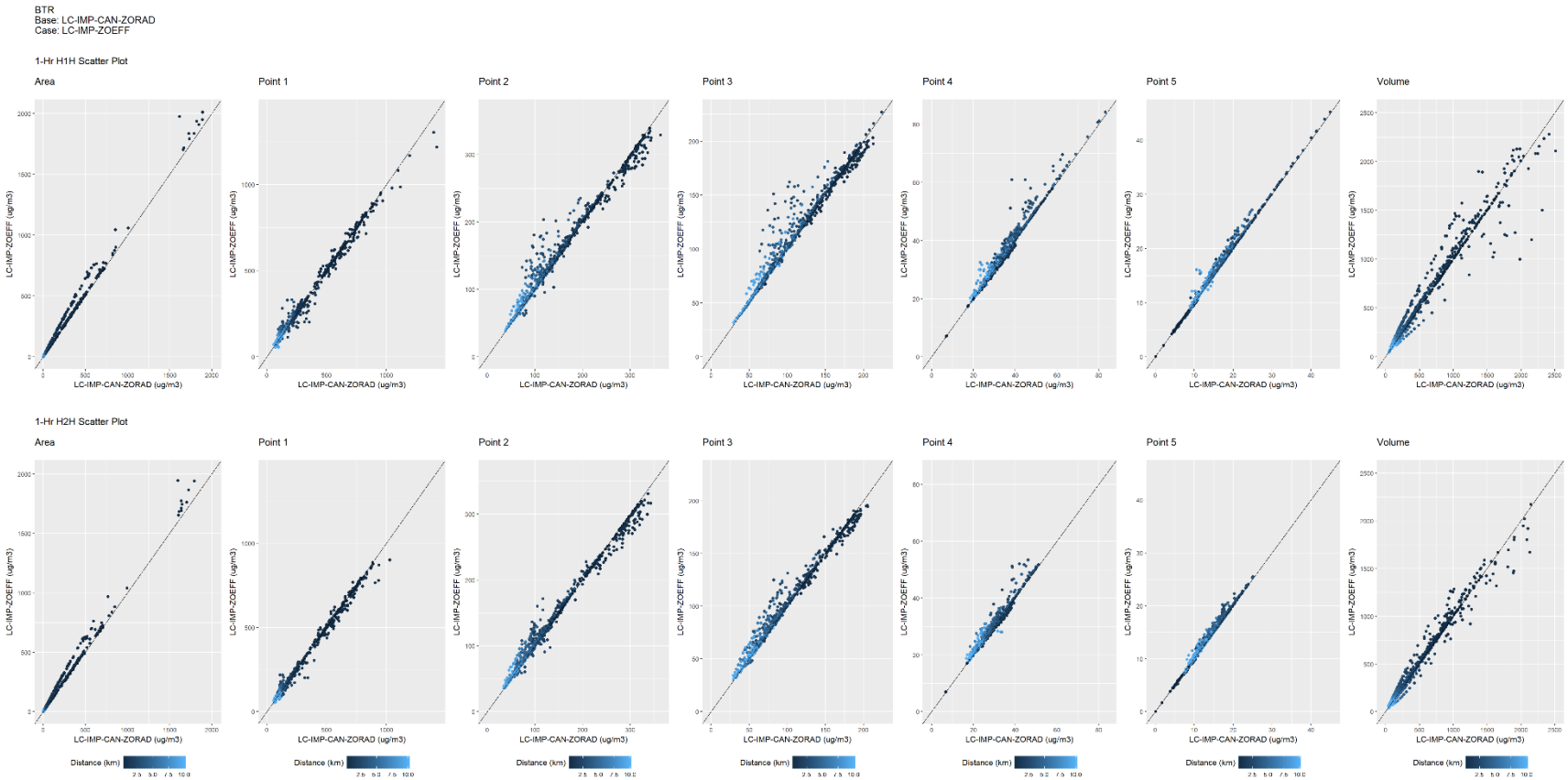



**Figure 11-31. BTR, Scatter Plots, H1H and H2H at each Receptor, 2001 Base Case, LC-IMP-CAN-ZORAD Vs. 2001 LC-IMP-ZOEFF**

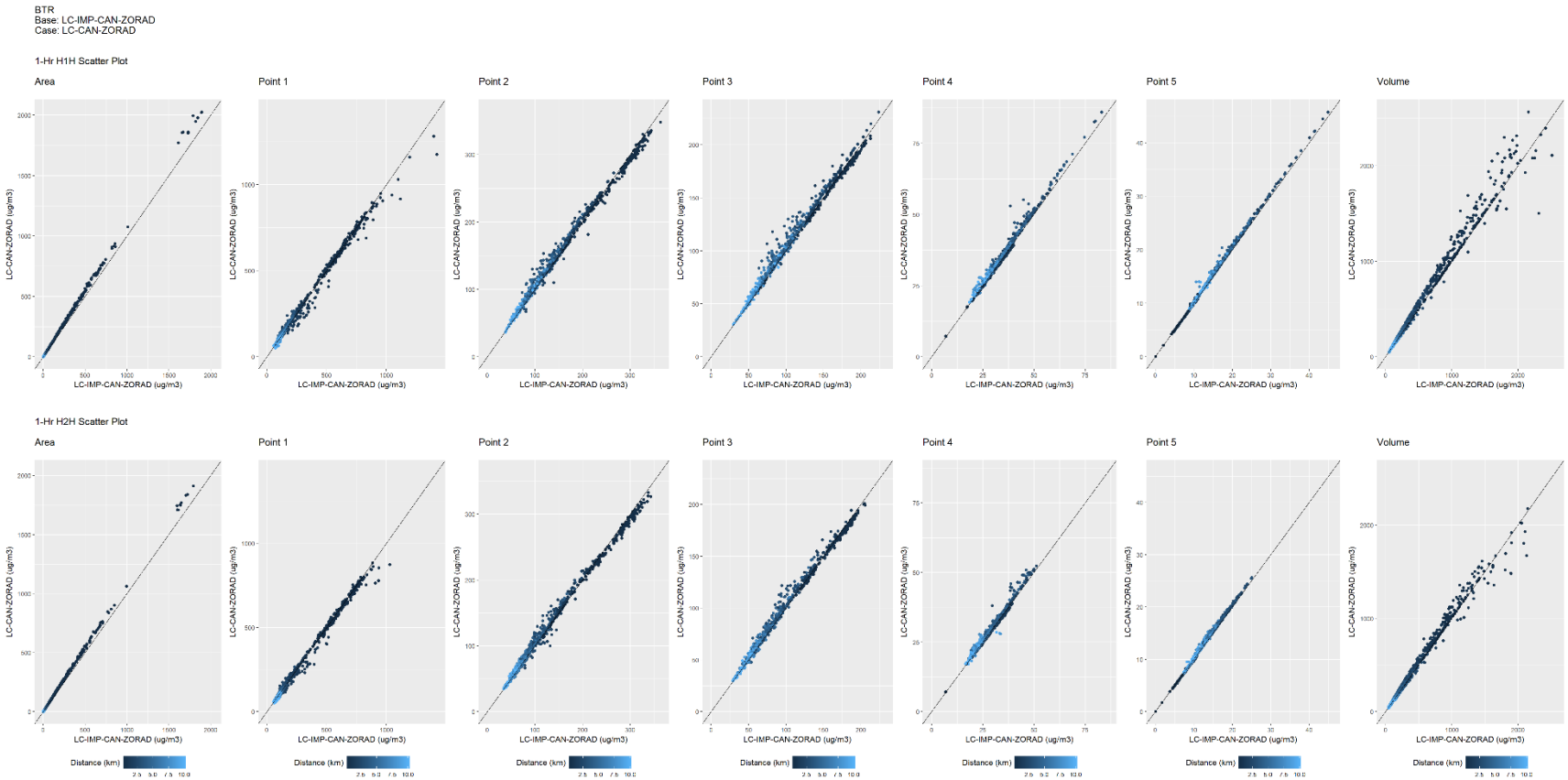



**Figure 11-32. BTR, Scatter Plots, H1H and H2H at each Receptor, 2001 Base Case, LC-IMP-CAN-ZORAD Vs. 2001 LC-CAN-ZORAD**

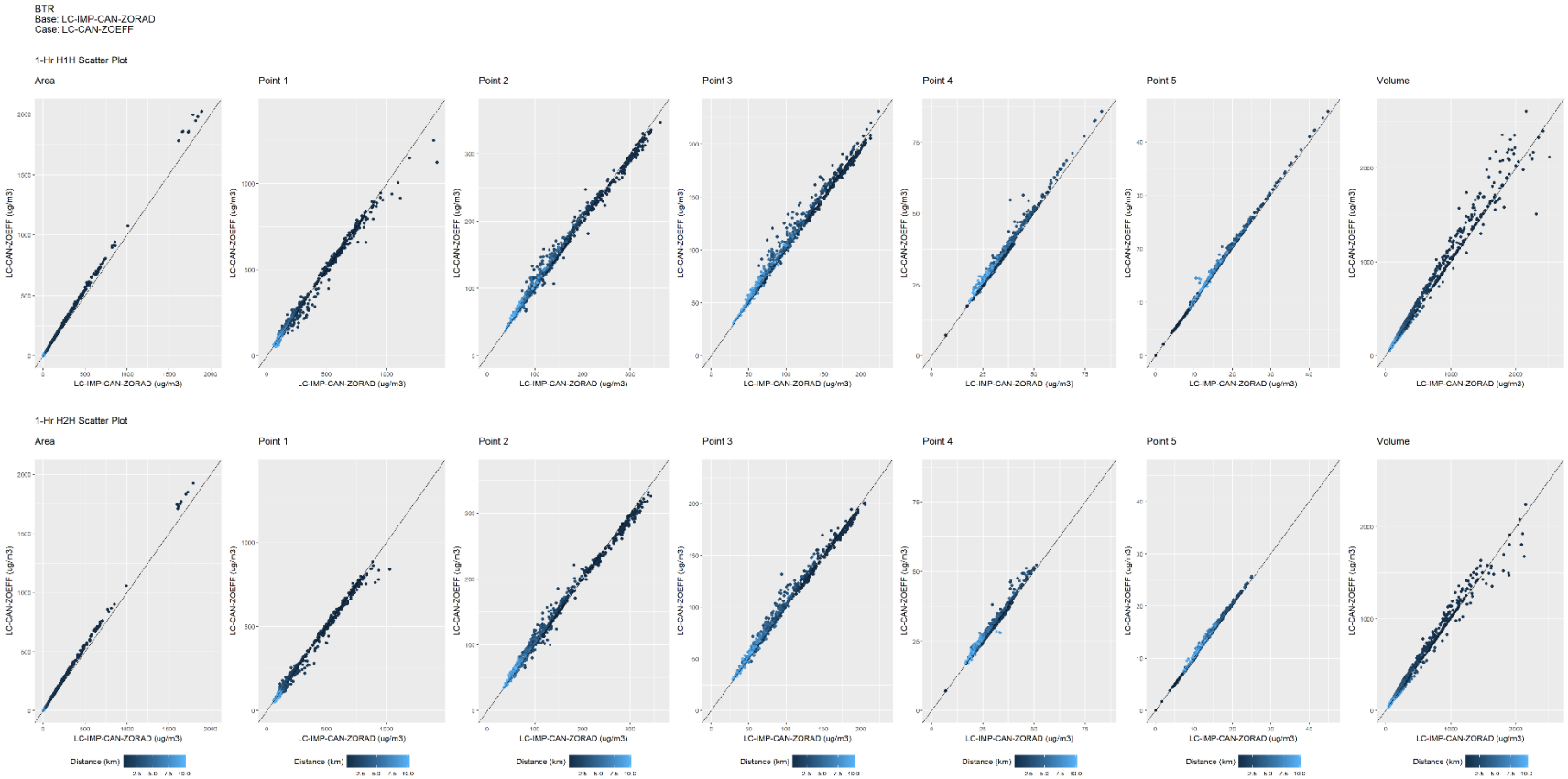



**Figure 11-33. BTR, Scatter Plots, H1H and H2H at each Receptor, 2001 Base Case, LC-IMP-CAN-ZORAD Vs. 2001 LC-CAN-ZOEFF**

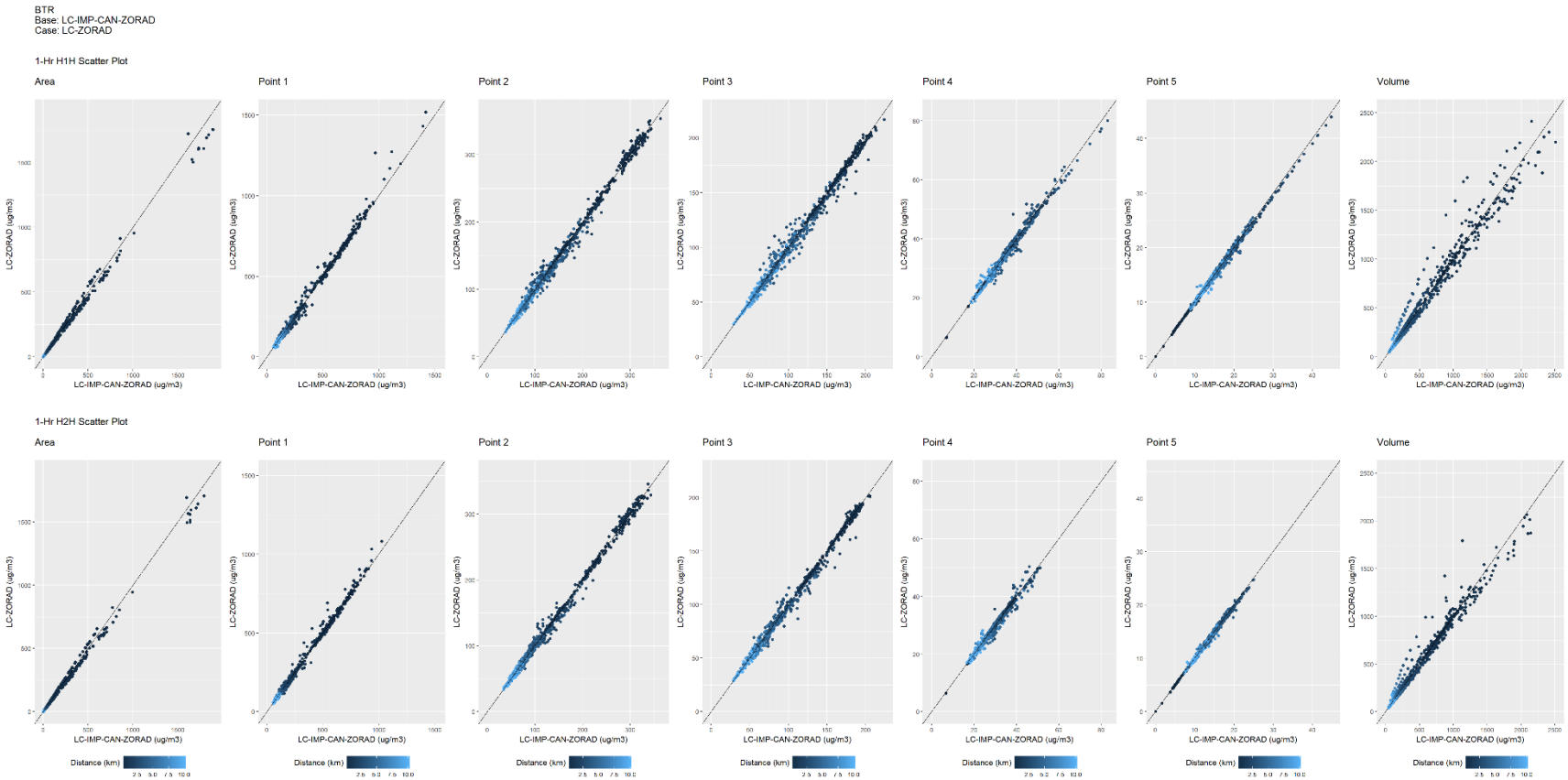



**Figure 11-34. BTR, Scatter Plots, H1H and H2H at each Receptor, 2001 Base Case, LC-IMP-CAN-ZORAD Vs. 2001 LC-ZORAD**

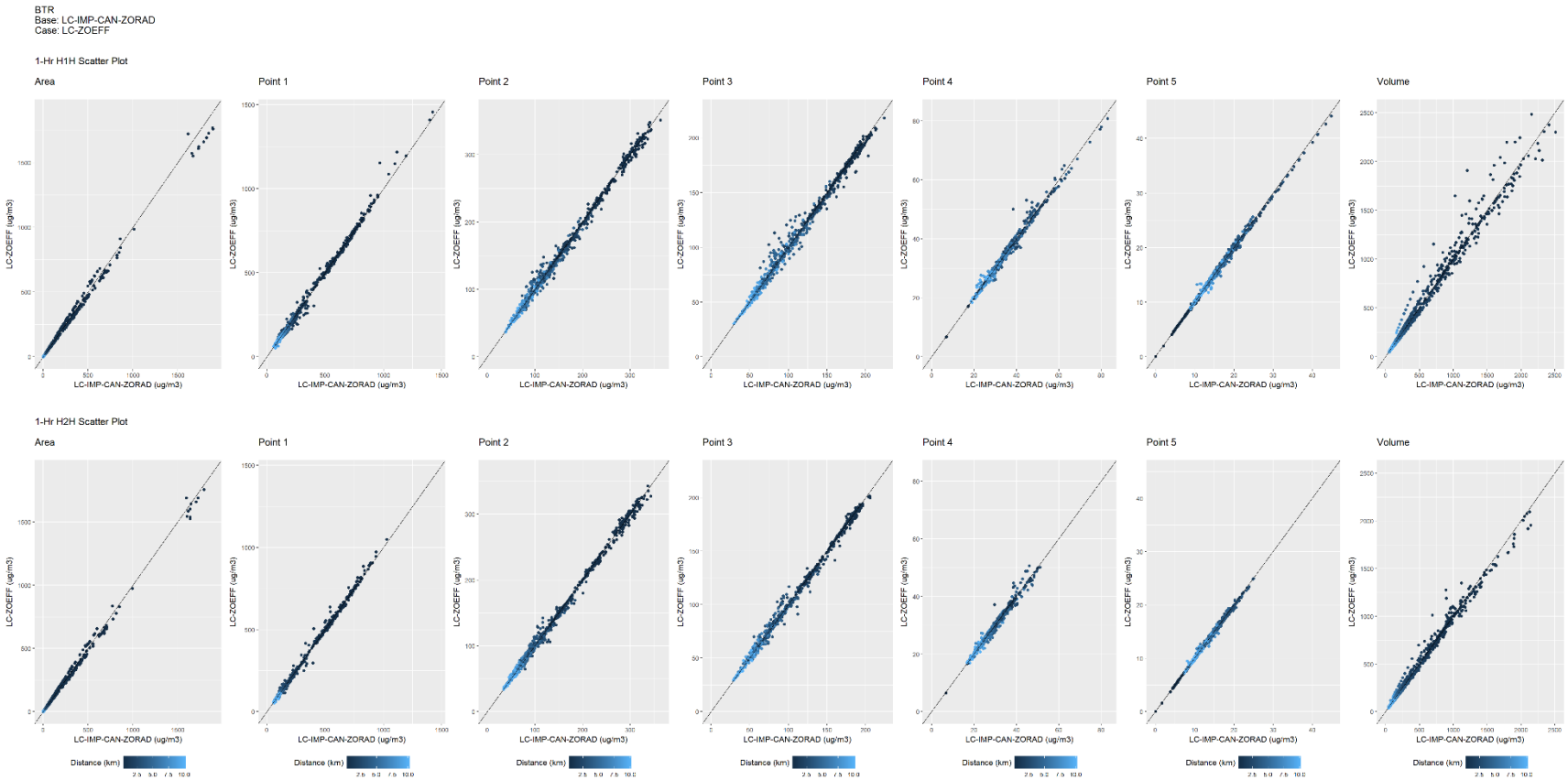



**Figure 11-35. BTR, Scatter Plots, H1H and H2H at each Receptor, 2001 Base Case, LC-IMP-CAN-ZORAD Vs. 2001 LC-ZOEFF**

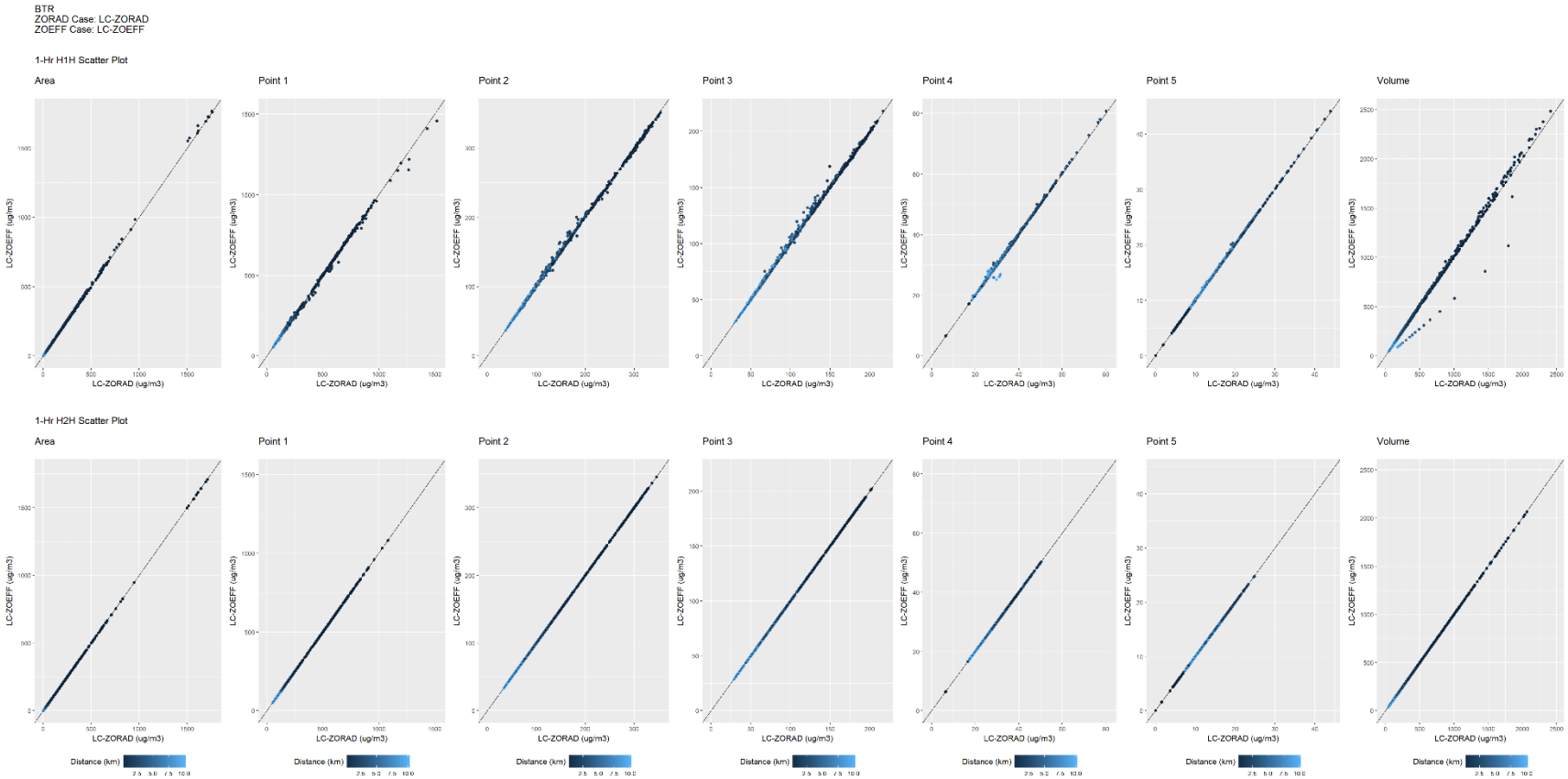



**Figure 11-36. BTR, Scatter Plots, H1H and H2H at each Receptor, 1992 LC-ZORAD Vs. 1992 LC-ZOEFF**

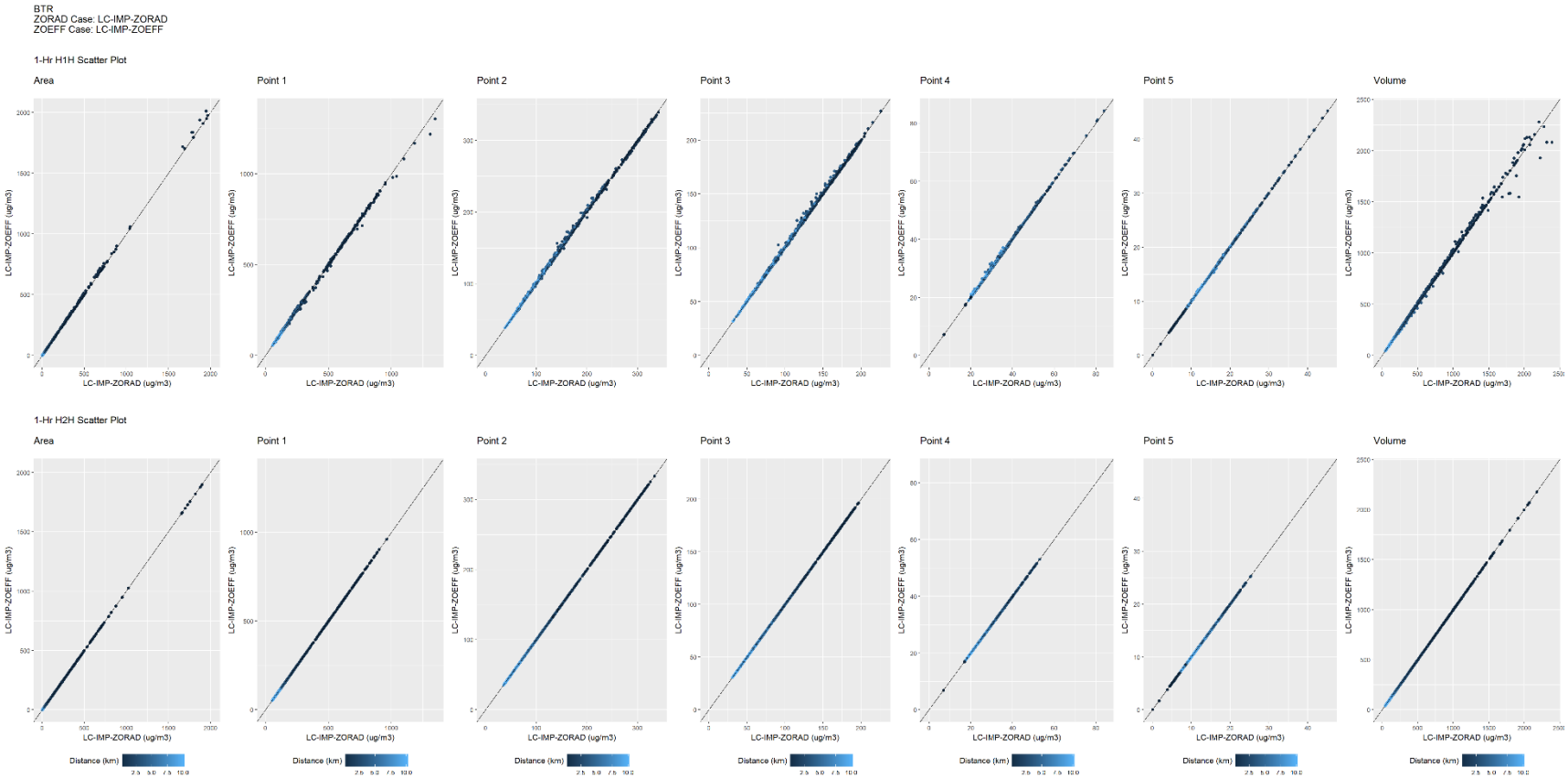



**Figure 11-37. BTR, Q-Q Plots, H1H and H2H at each Receptor, 2001 LC-IMP-ZORAD Vs. 2001 LC-IMP-ZOEFF**

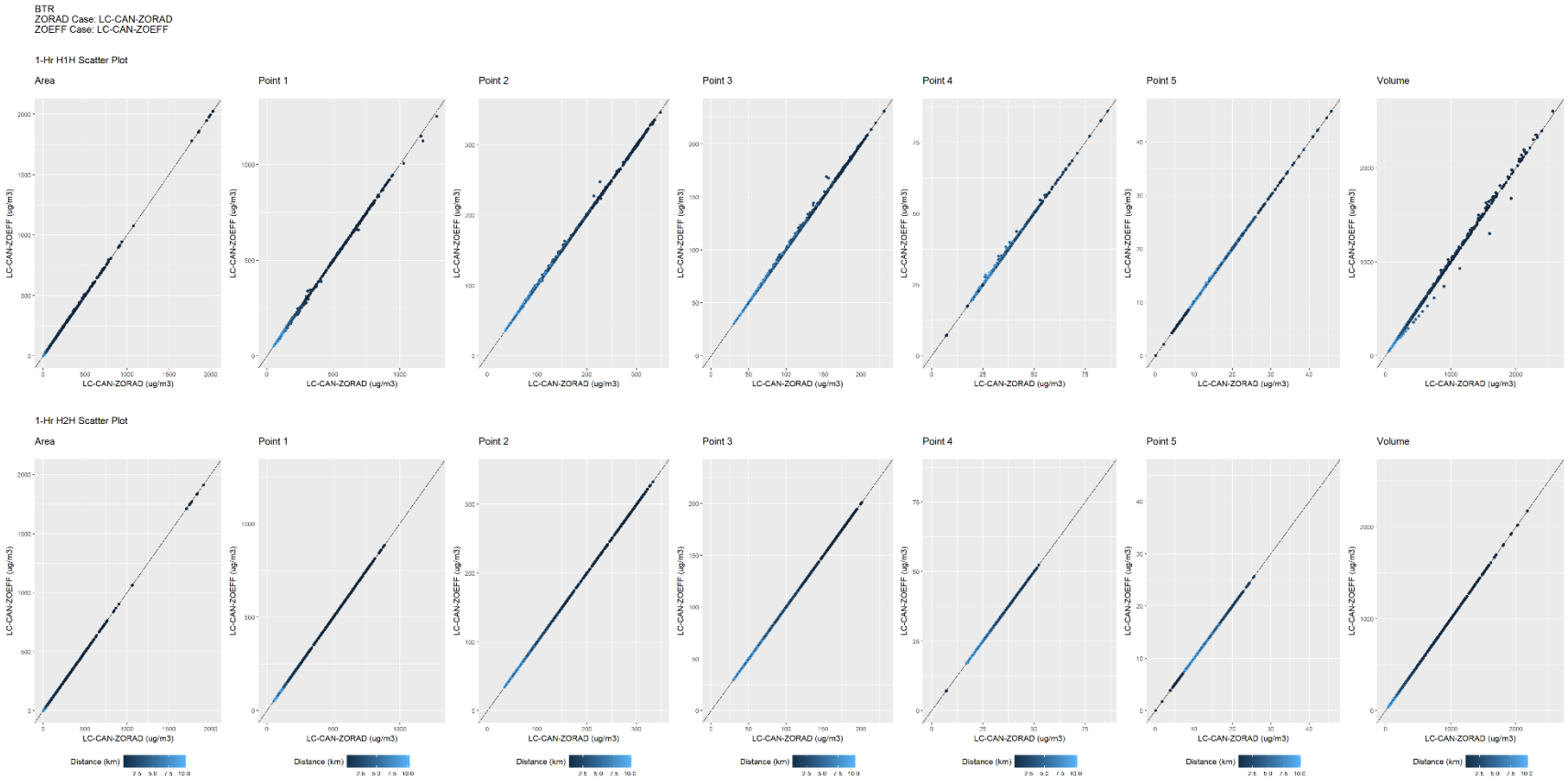



**Figure 11-38. BTR, Scatter Plots, H1H and H2H at each Receptor, 2001 LC-CAN-ZORAD Vs. 2001 LC-CAN-ZOEFF**

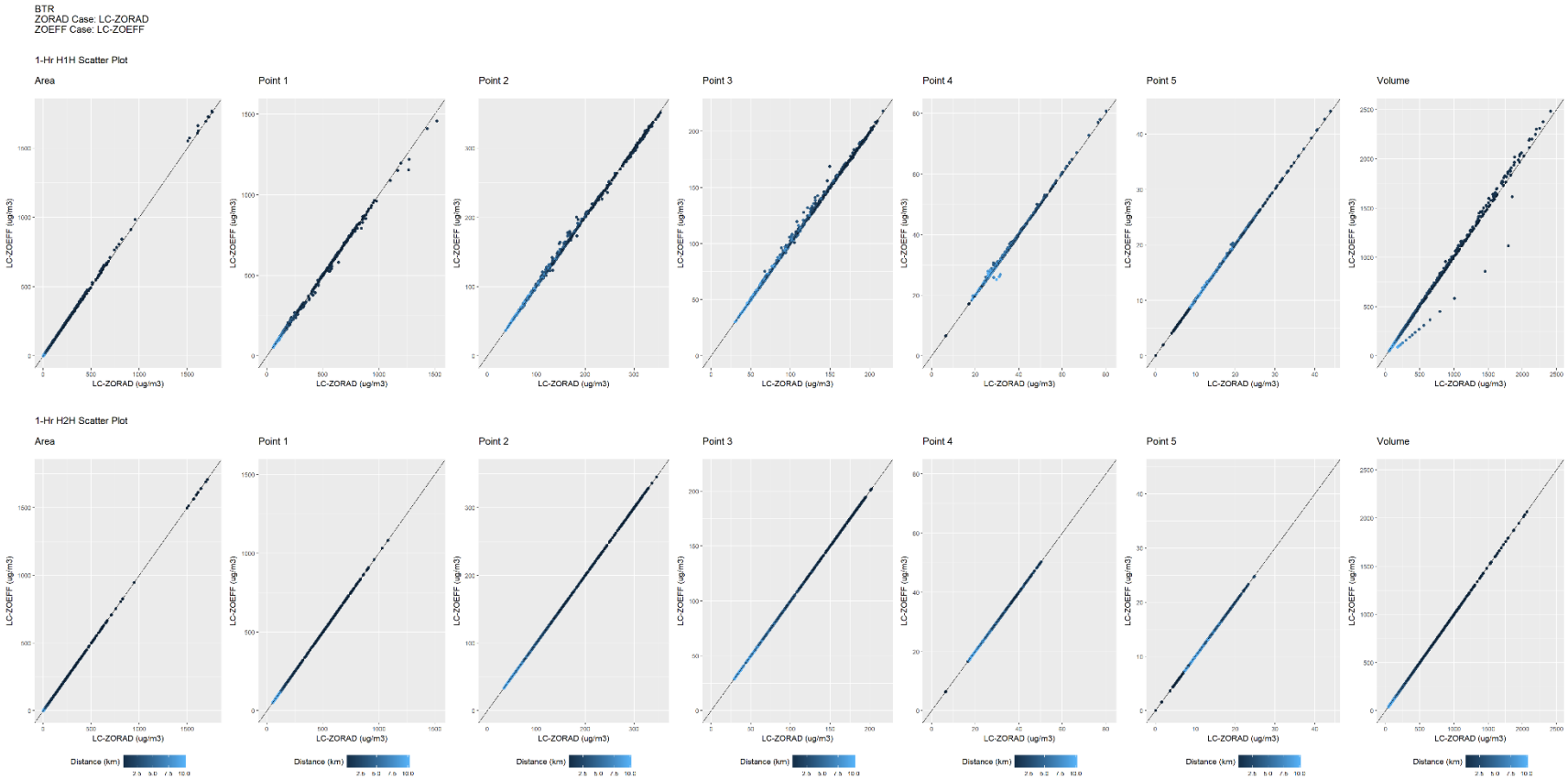
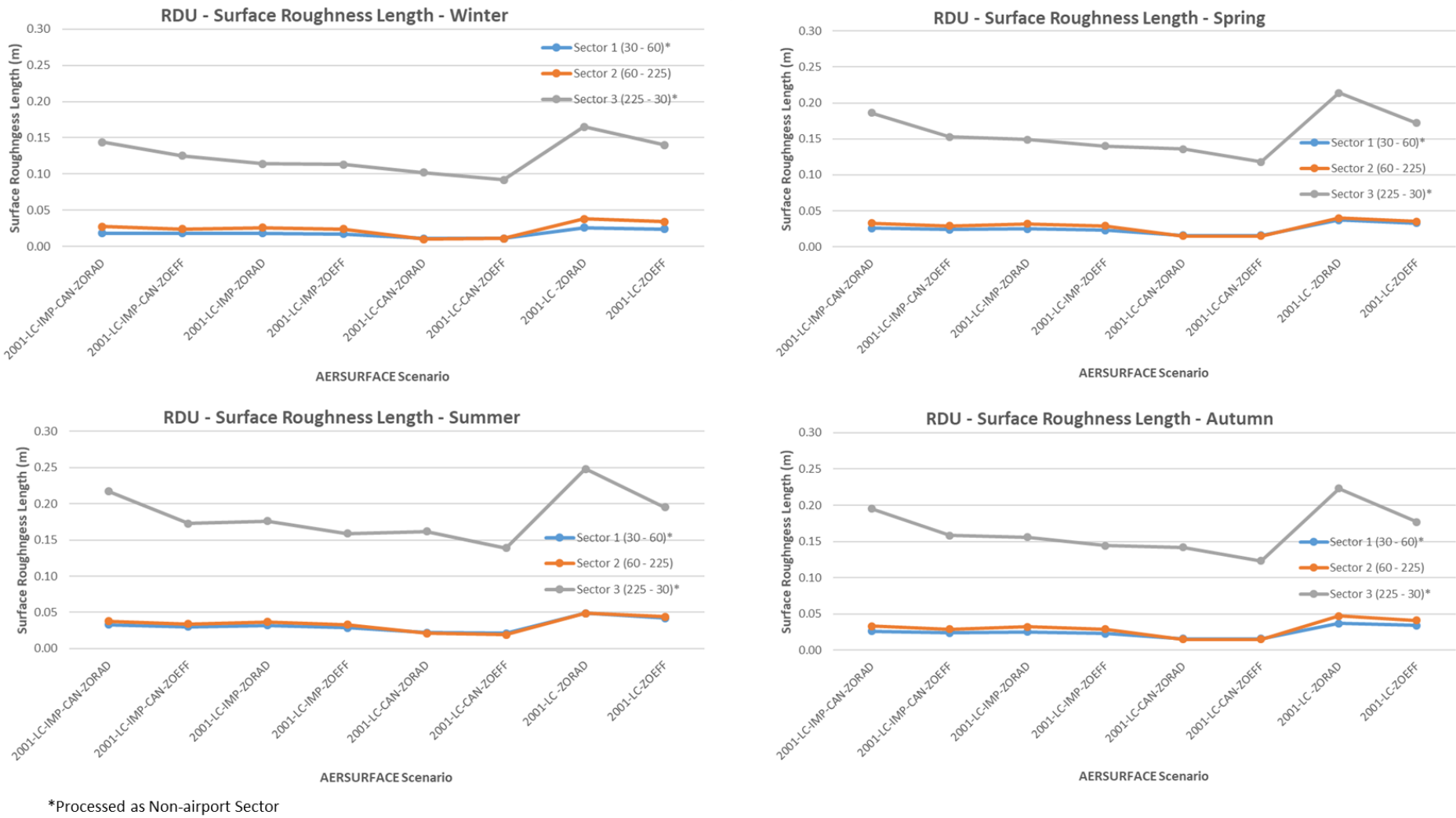



**Figure 11-39. BTR, Scatter Plots, H1H and H2H at each Receptor, 2001 LC-ZORAD Vs. 2001 LC-ZOEFF**




*Processed as Non-airport Sector

**Figure 11-40. RDU Surface Roughness Length by Season, Sector, and AERSURFACE Scenario**

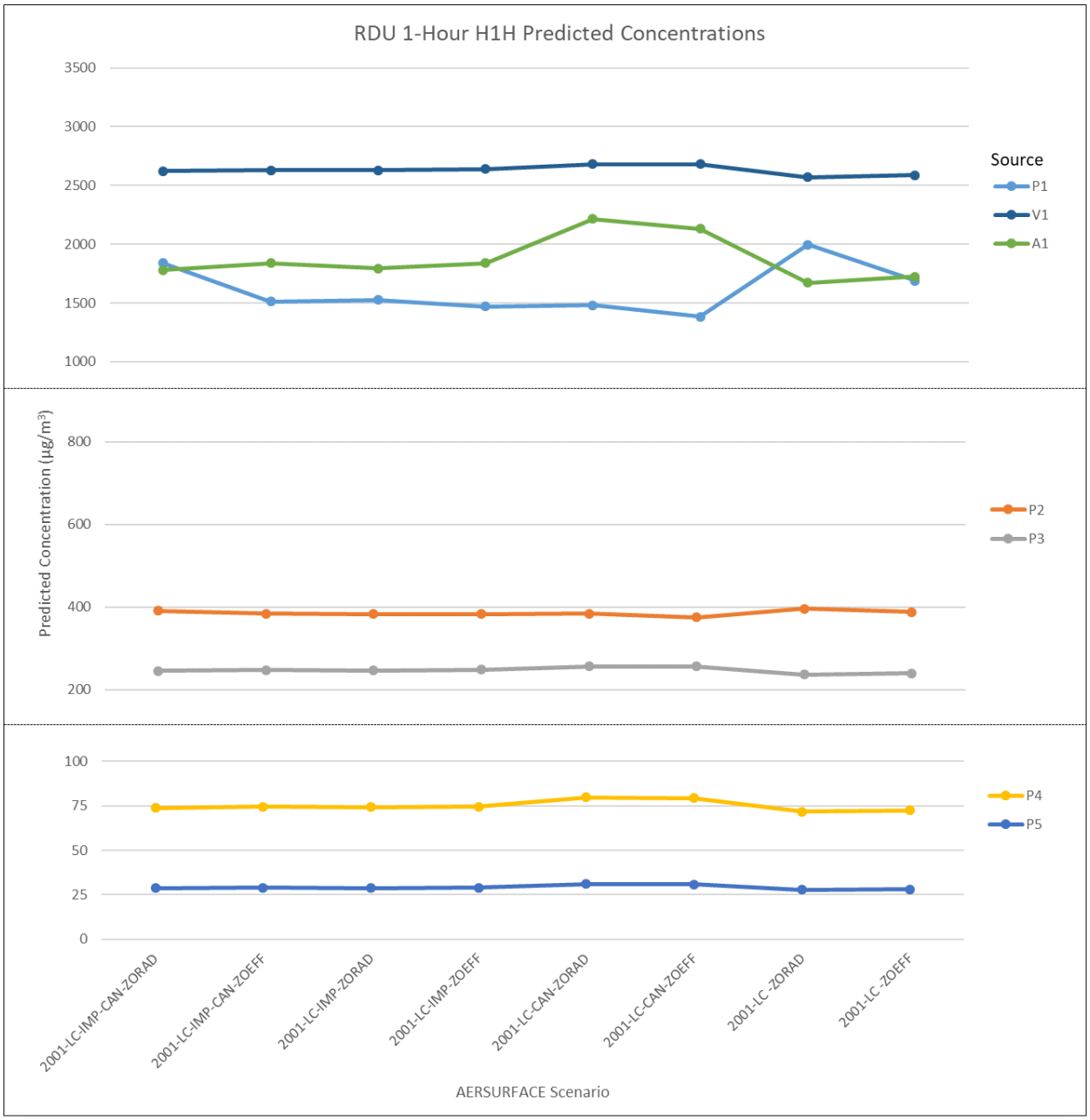



**Figure 11-41. RDU H1H Predicted Concentrations by AERSURFACE Scenario and Emission Source**

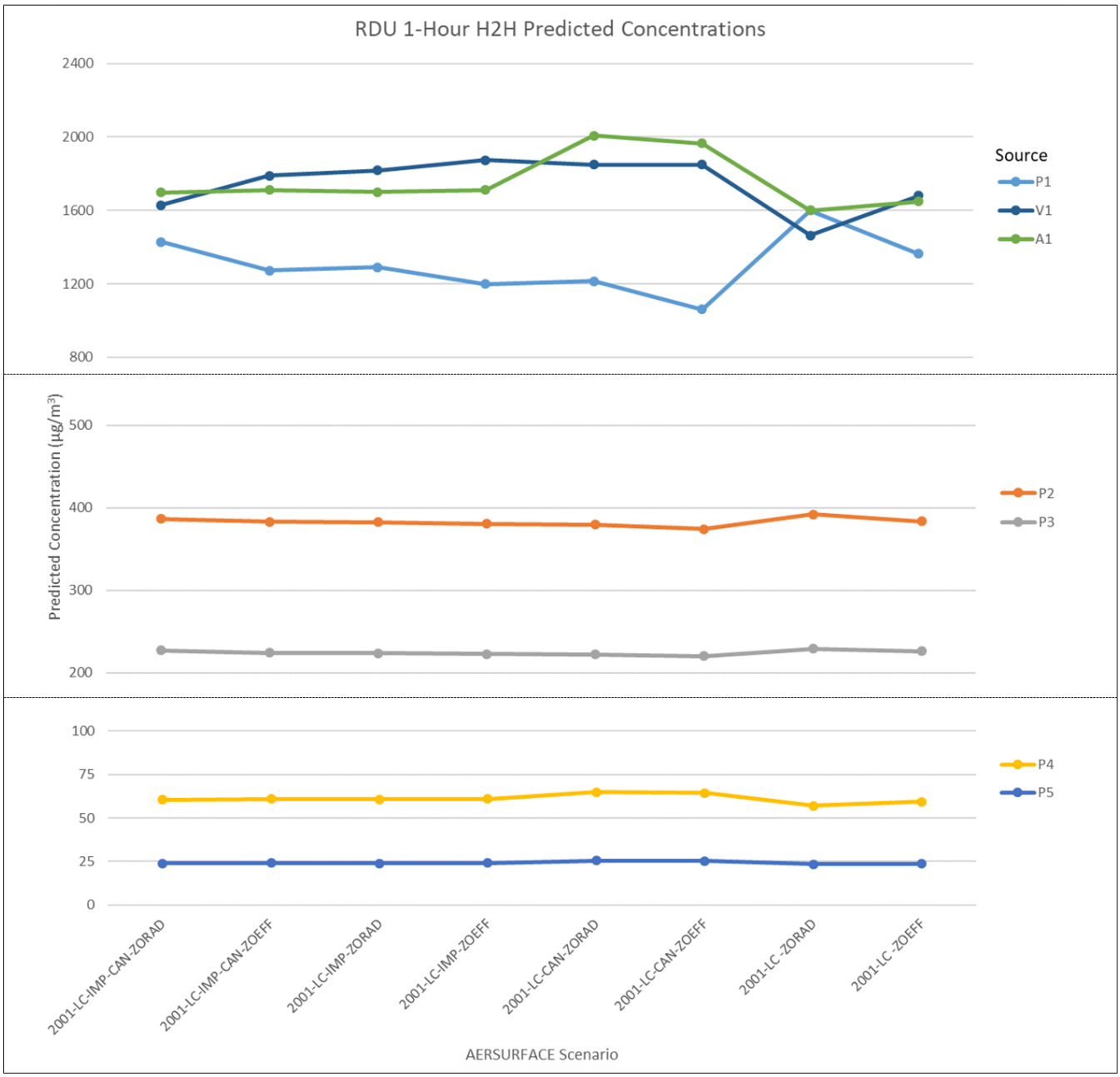



**Figure 11-42. RDU H2H Predicted Concentrations by AERSURFACE Scenario and Emission Source**

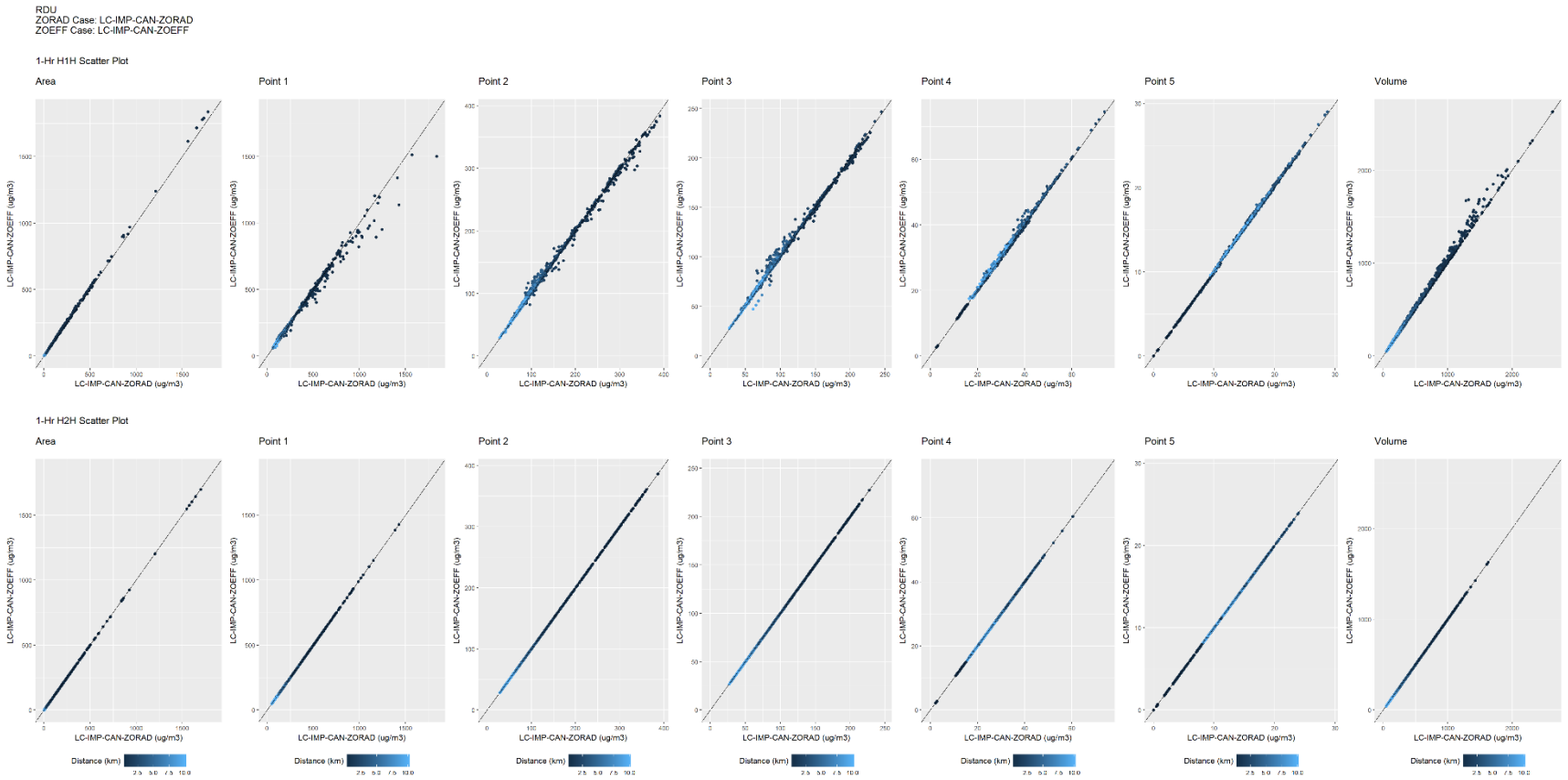



**Figure 11-43. RDU, Scatter Plots, H1H and H2H at each Receptor, 2001 Base Case, LC-IMP-CAN-ZORAD Vs. 2001 LC-IMP-CAN-ZOEFF**

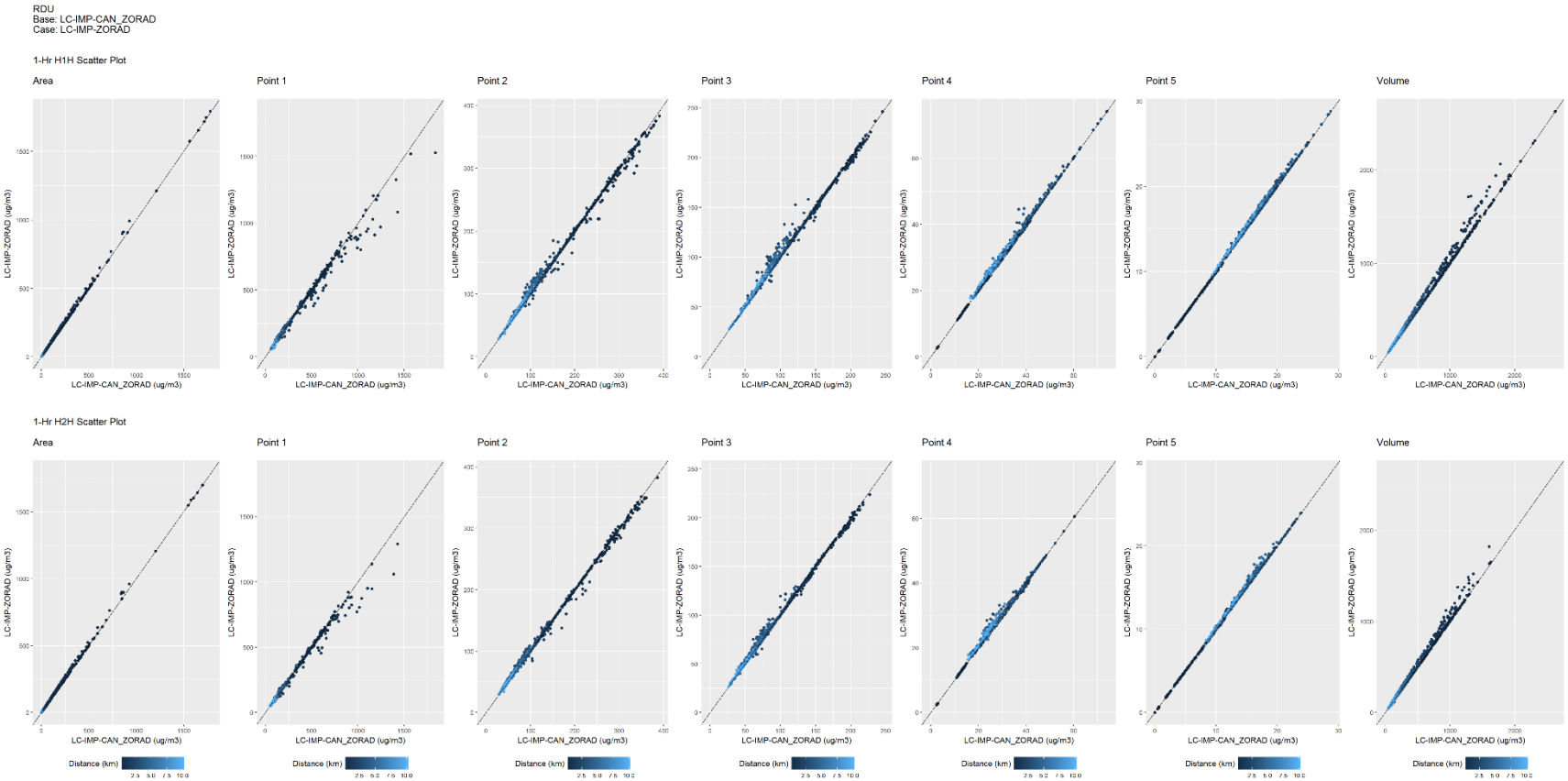



**Figure 11-44. RDU, Scatter Plots, H1H and H2H at each Receptor, 2001 Base Case, LC-IMP-CAN-ZORAD Vs. 2001 LC-IMP-ZORAD**

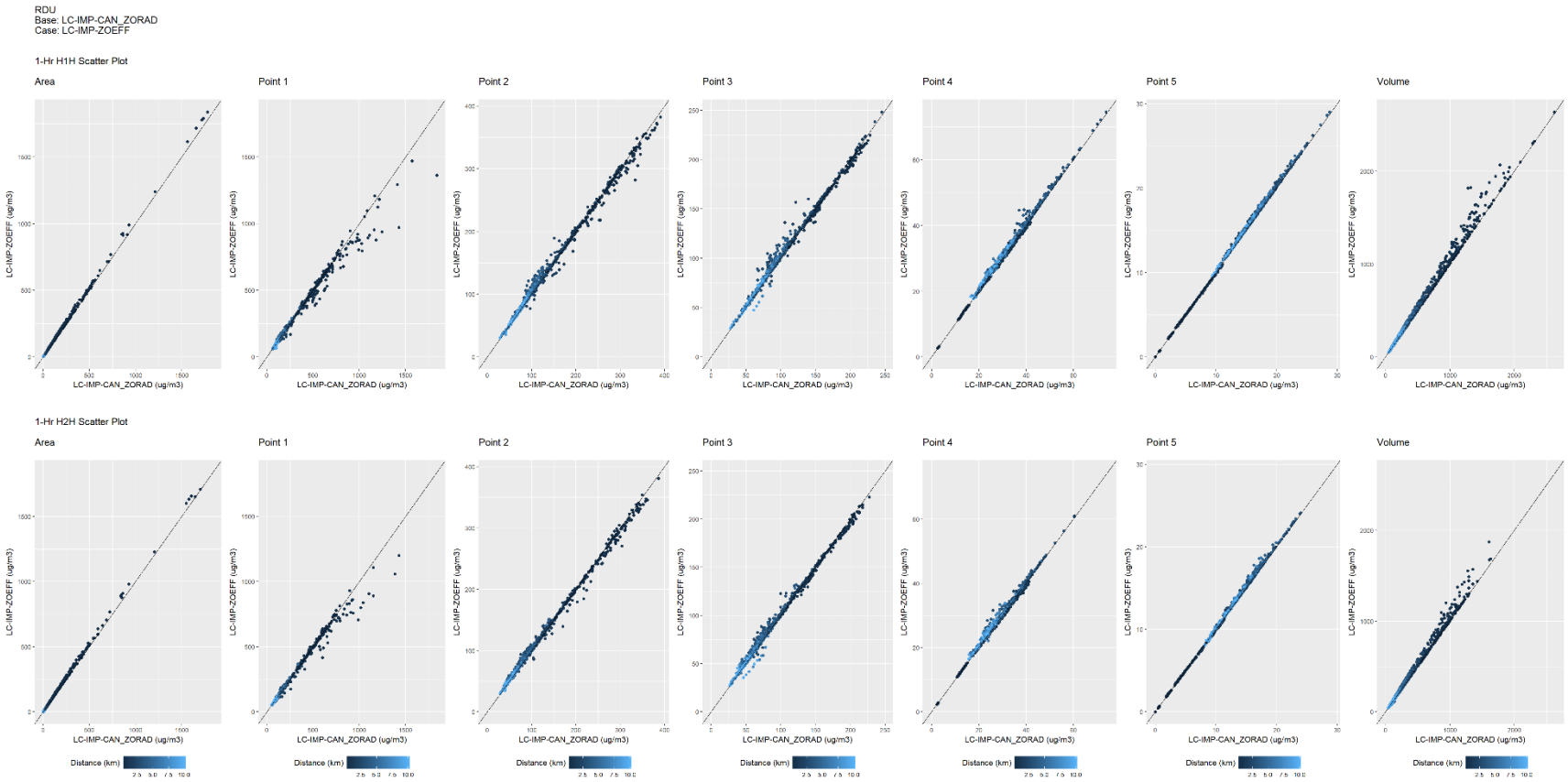



**Figure 11-45. RDU, Scatter Plots, H1H and H2H at each Receptor, 2001 Base Case, LC-IMP-CAN-ZORAD Vs. 2001 LC-IMP-ZOEFF**

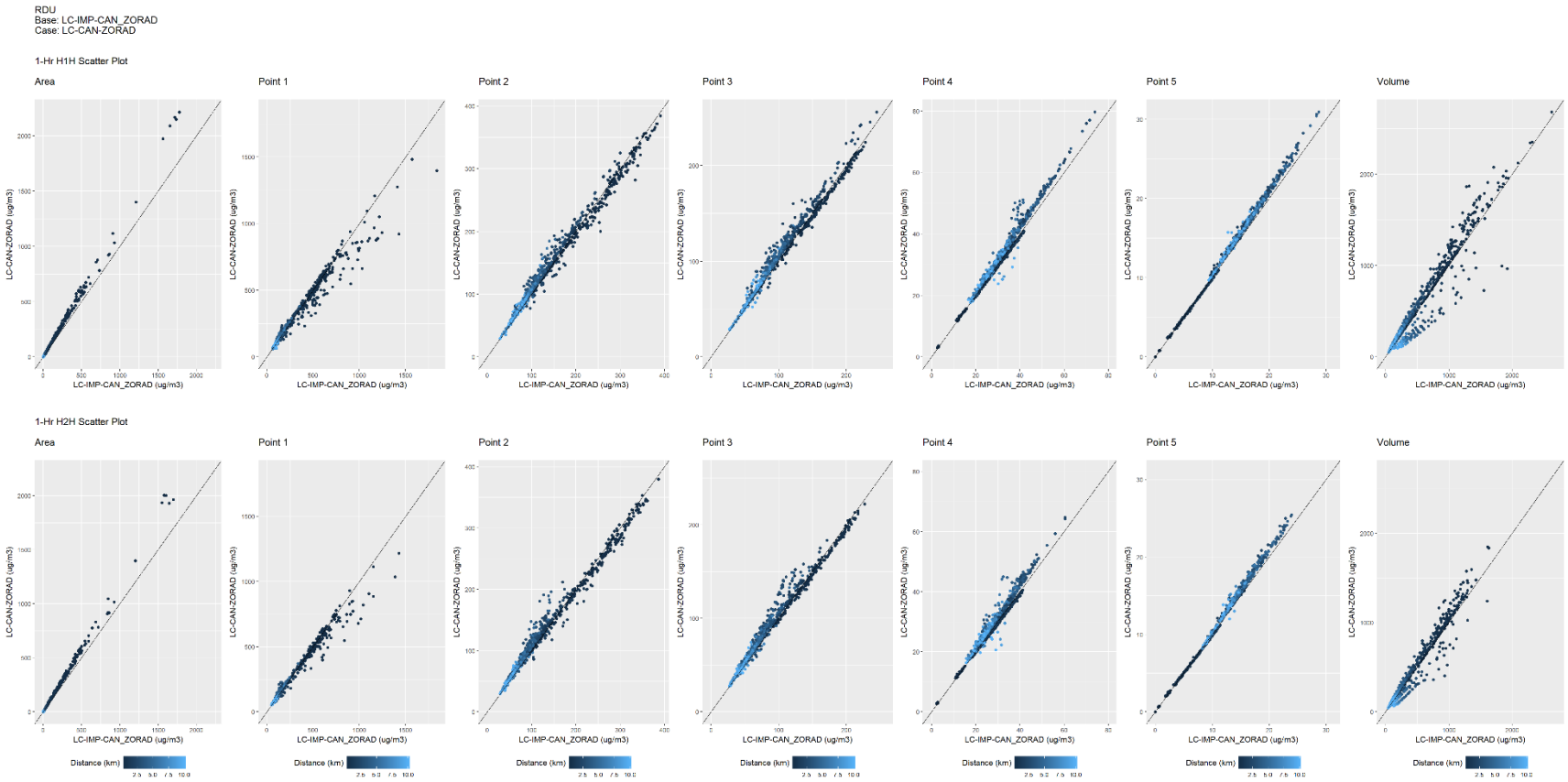



**Figure 11-46. RDU, Scatter Plots, H1H and H2H at each Receptor, 2001 Base Case, LC-IMP-CAN-ZORAD Vs. 2001 LC-CAN-ZORAD**

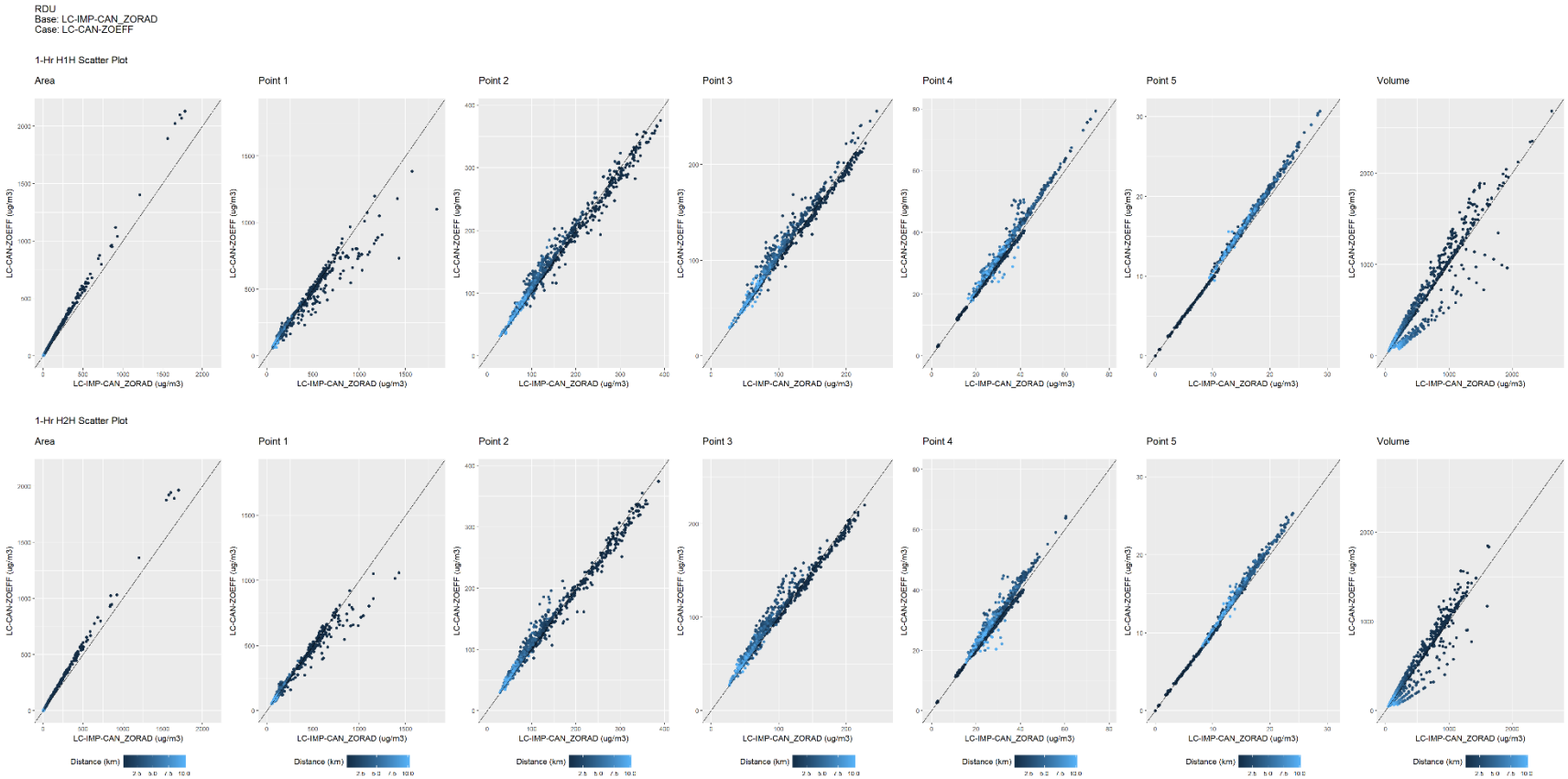



**Figure 11-47. RDU, Scatter Plots, H1H and H2H at each Receptor, 2001 Base Case, LC-IMP-CAN-ZORAD Vs. 2001 LC-CAN-ZOEFF**

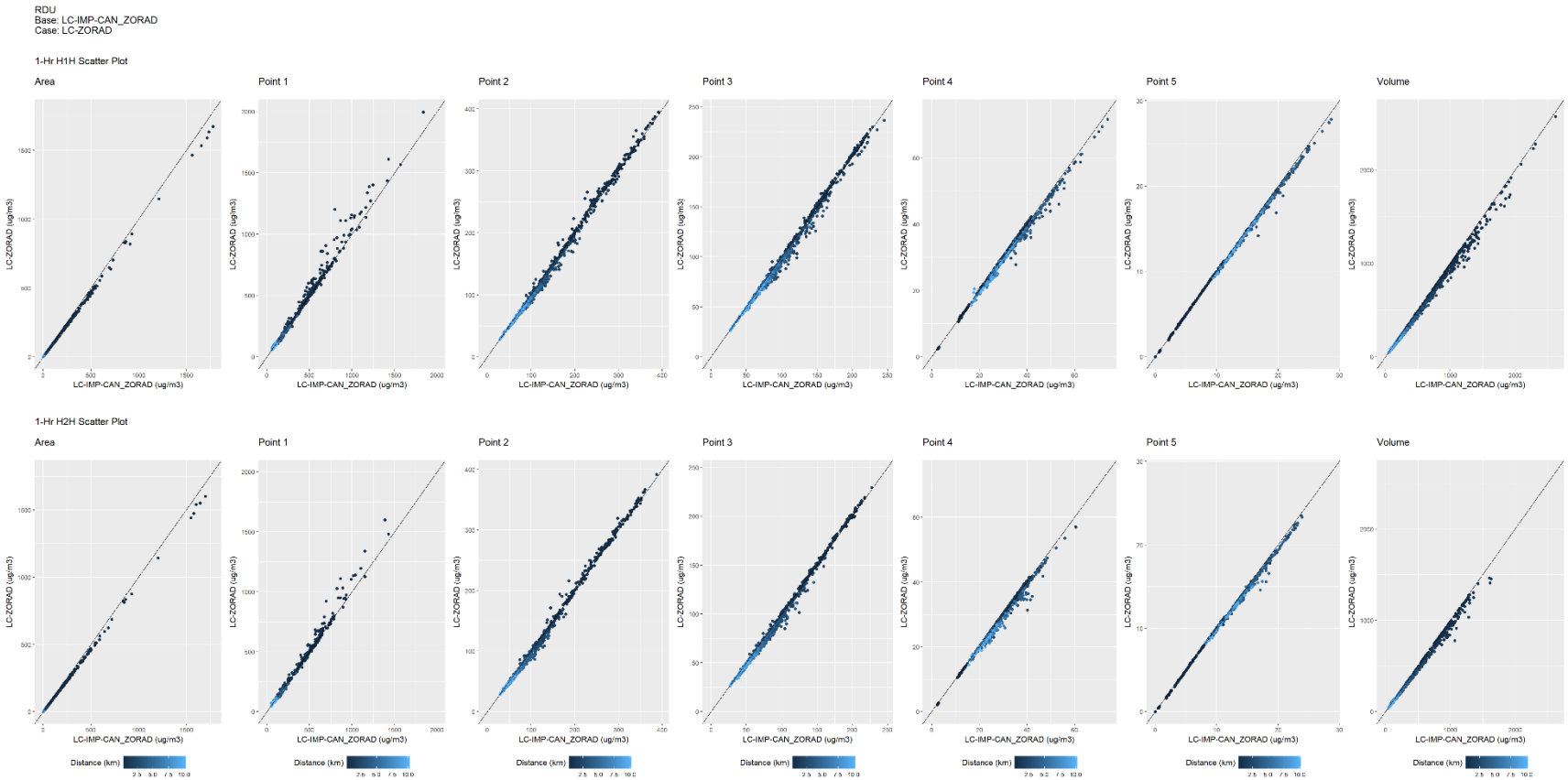



**Figure 11-48. RDU, Scatter Plots, H1H and H2H at each Receptor, 2001 Base Case, LC-IMP-CAN-ZORAD Vs. 2001 LC-ZORAD**

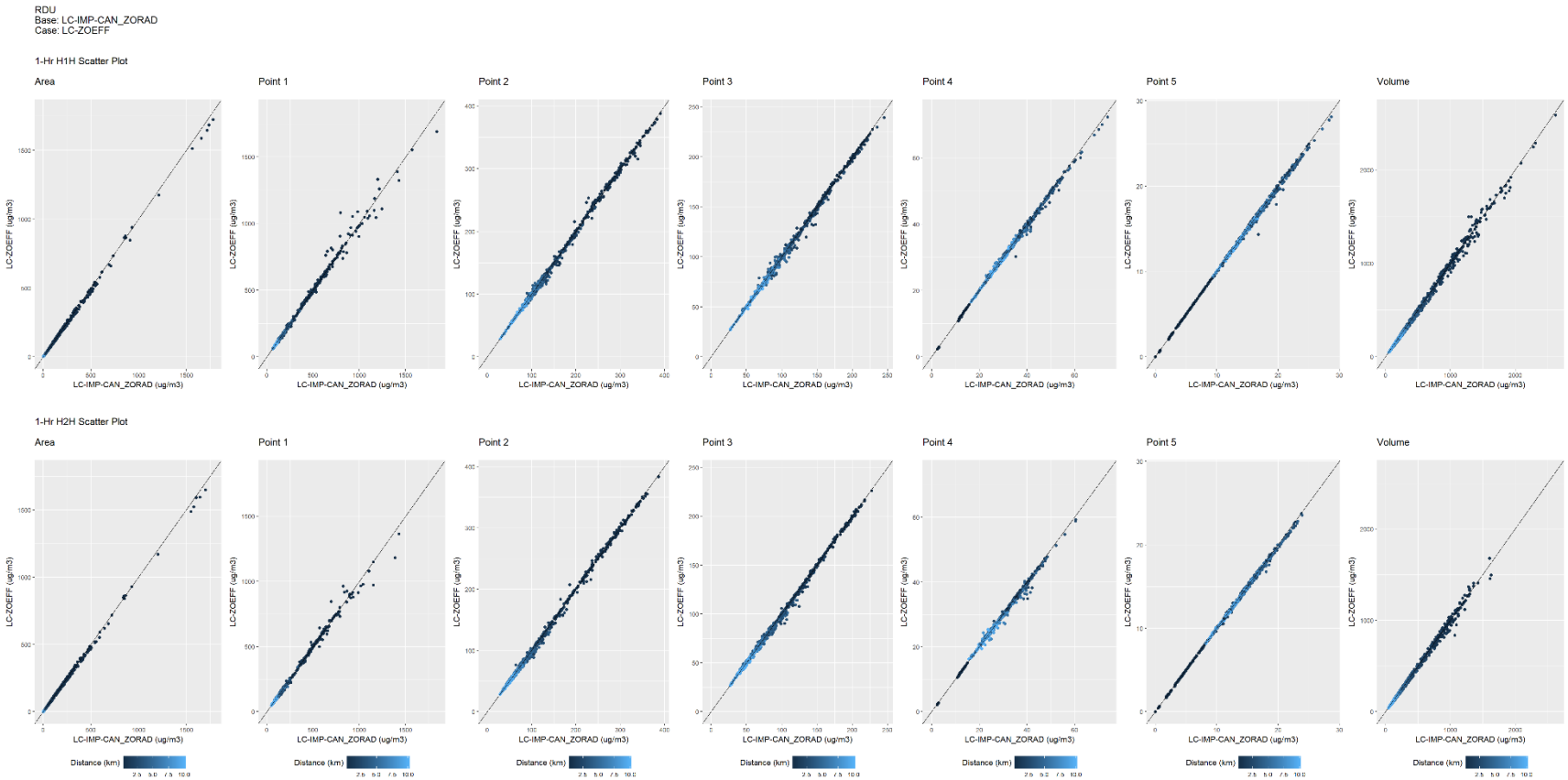



**Figure 11-49. RDU, Scatter Plots, H1H and H2H at each Receptor, 2001 Base Case, LC-IMP-CAN-ZORAD Vs. 2001 LC-ZOEFF**

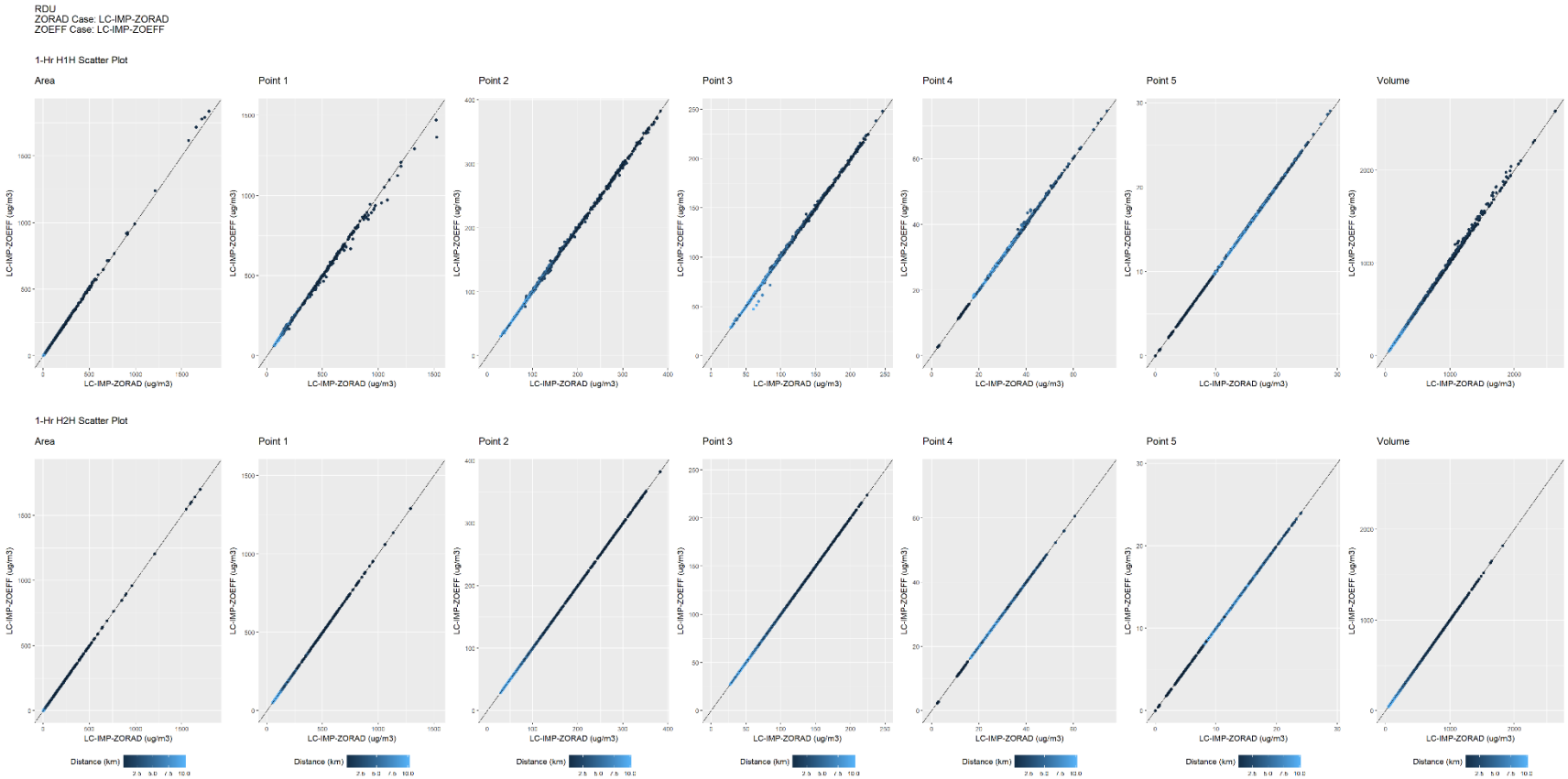



**Figure 11-50. RDU, Scatter Plots, H1H and H2H at each Receptor, 2001 LC-IMP-ZORAD Vs. 2001 LC-IMP-ZOEFF**

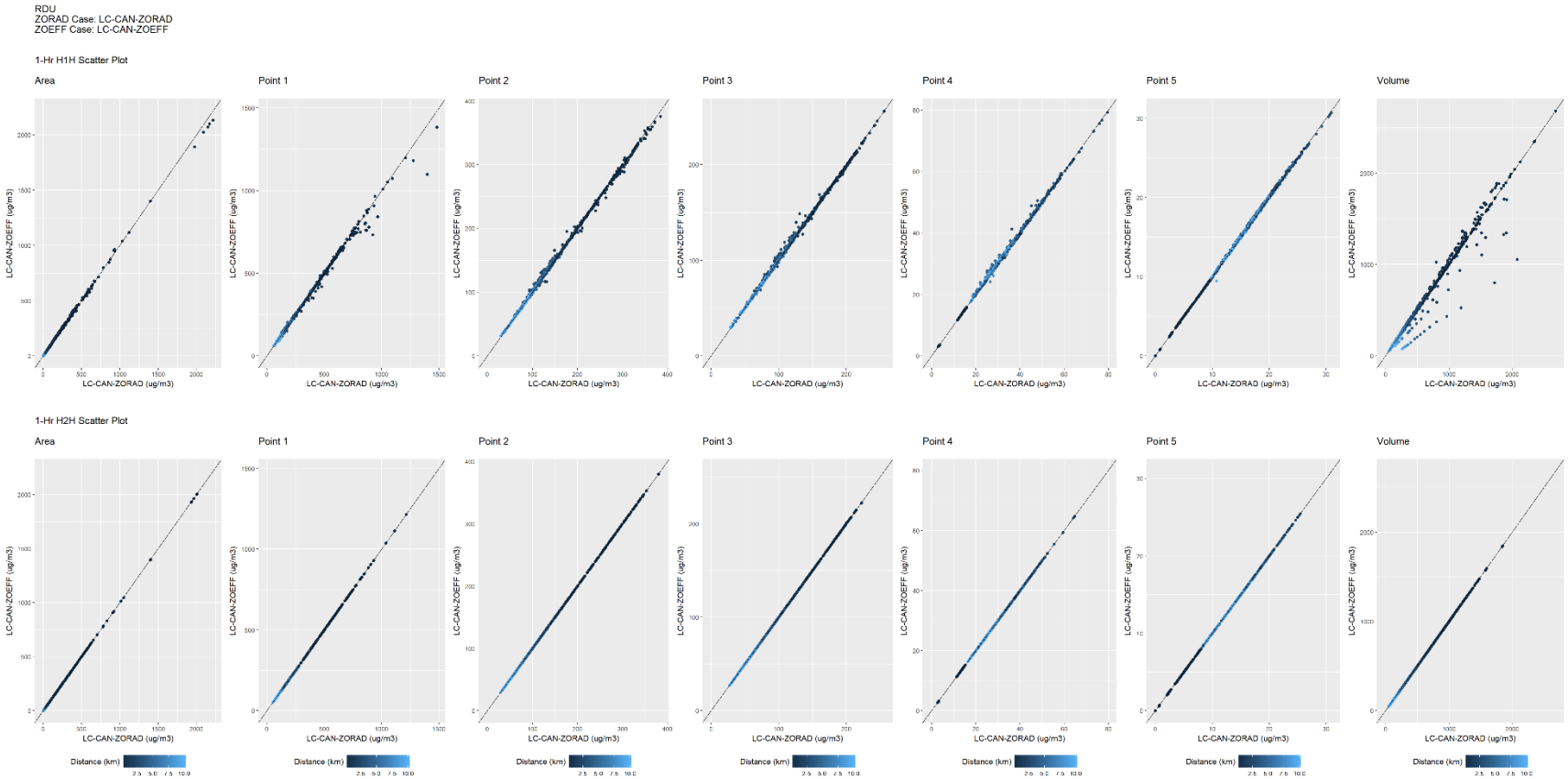



**Figure 11-51. RDU, Scatter Plots, H1H and H2H at each Receptor, 2001 LC-CAN-ZORAD Vs. 2001 LC-CAN-ZOEFF**

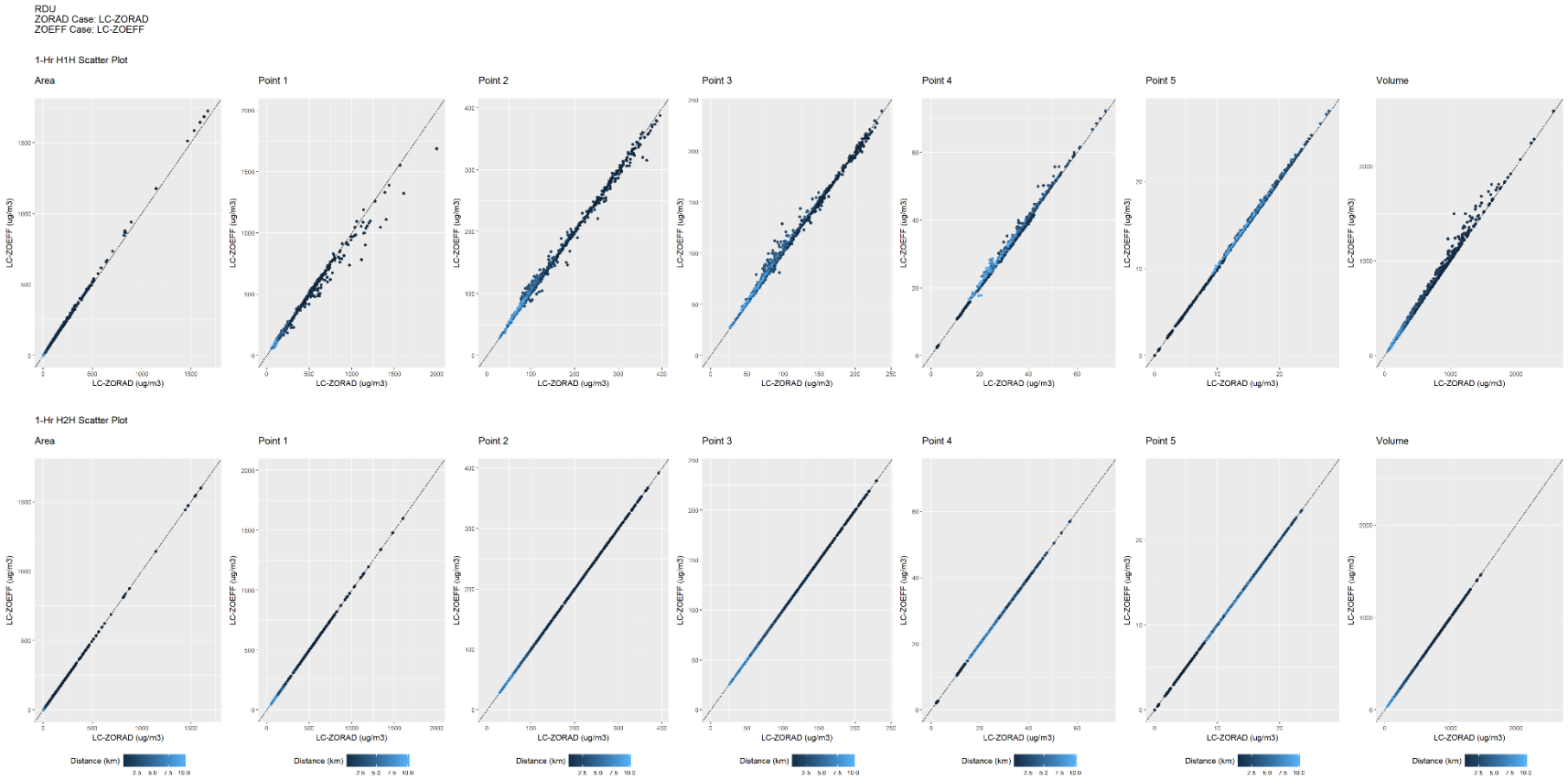



**Figure 11-52. RDU, Scatter Plots, H1H and H2H at each Receptor, 2001 LC-ZORAD Vs. 2001 LC-ZOEFF**

## 11.4 Comparison of Surface Roughness Length Estimated with 2001 NLCD (2011 Edition) and 2016 NLCD

This updated inter-comparison using AERSURFACE version 20060 is expanded to include a comparison of the estimated surface roughness length for ATL, BTR, and RDU, based on the 2001 NLCD (2011 edition) and presented in the sections above, to the estimated surface roughness length based on the 2016 NLCD. Figure 11-53, Figure 11-56, and Figure 11-59 compare the landcover, percent impervious, and percent tree canopy for ATL, BTR, and RDU, respectively for the 2001 NLCD (2011 edition) to the 2016 NLCD. Figure 11-54 and Figure 11-55 compare seasonal surface roughness lengths for ATL estimated with the 2001 NLCD (2011 edition) and the 2016 NLCD. Similarly, Figure 11-57 and Figure 11-58 compare seasonal surface roughness lengths for BTR, and Figure 11-60 and Figure 11-61 compare seasonal roughness lengths estimated for RDU. In general, each of the three sites have experienced and increase in area characterized as “Developed” with an increase in the amount of impervious area and a decrease in tree canopy.

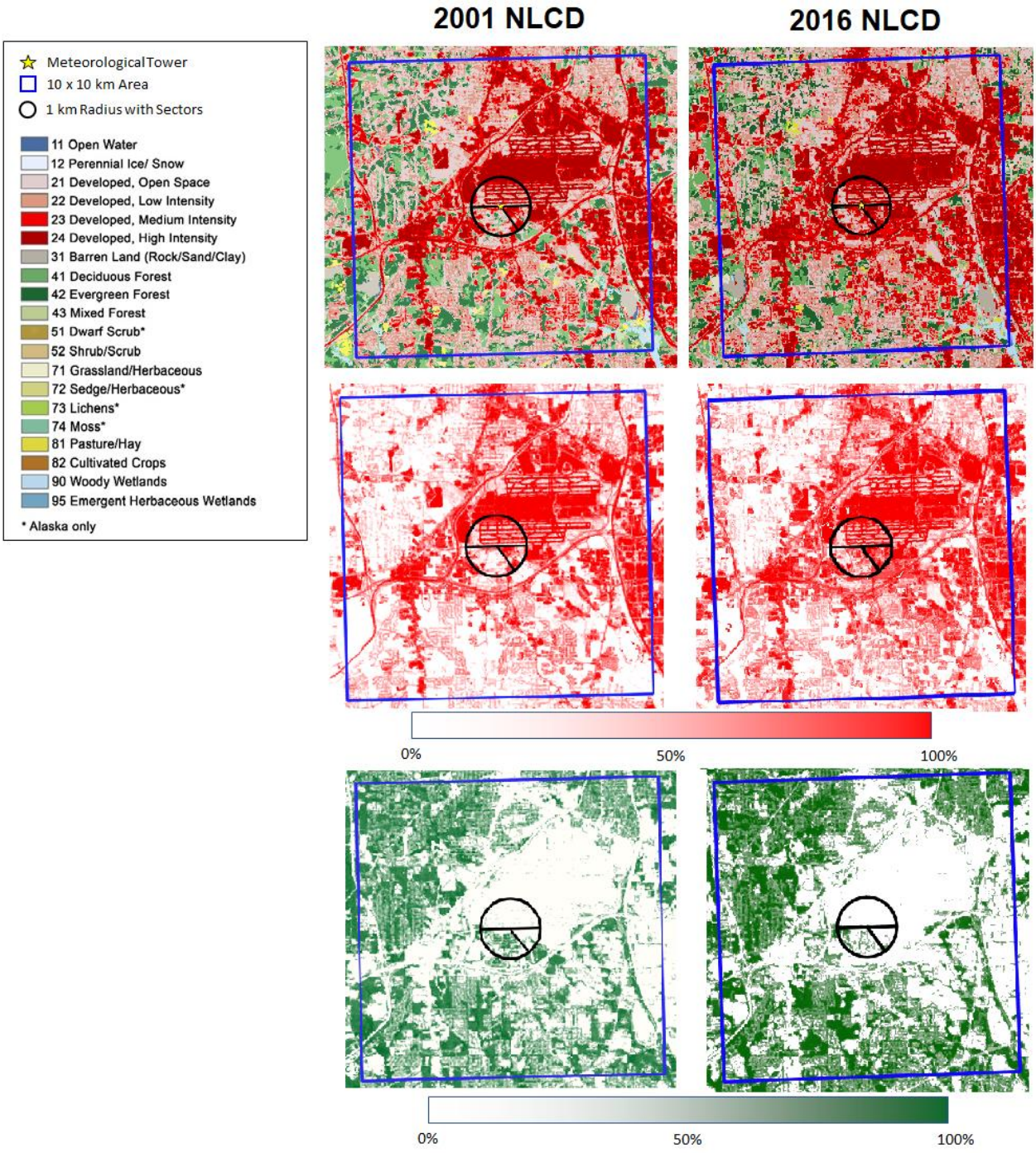



**Figure 11-53. Comparison of 2001 NLCD (2011 Edition) to 2016 NLCD for ATL Land Cover (top), Percent Impervious (middle), and Percent Tree Canopy (bottom)**

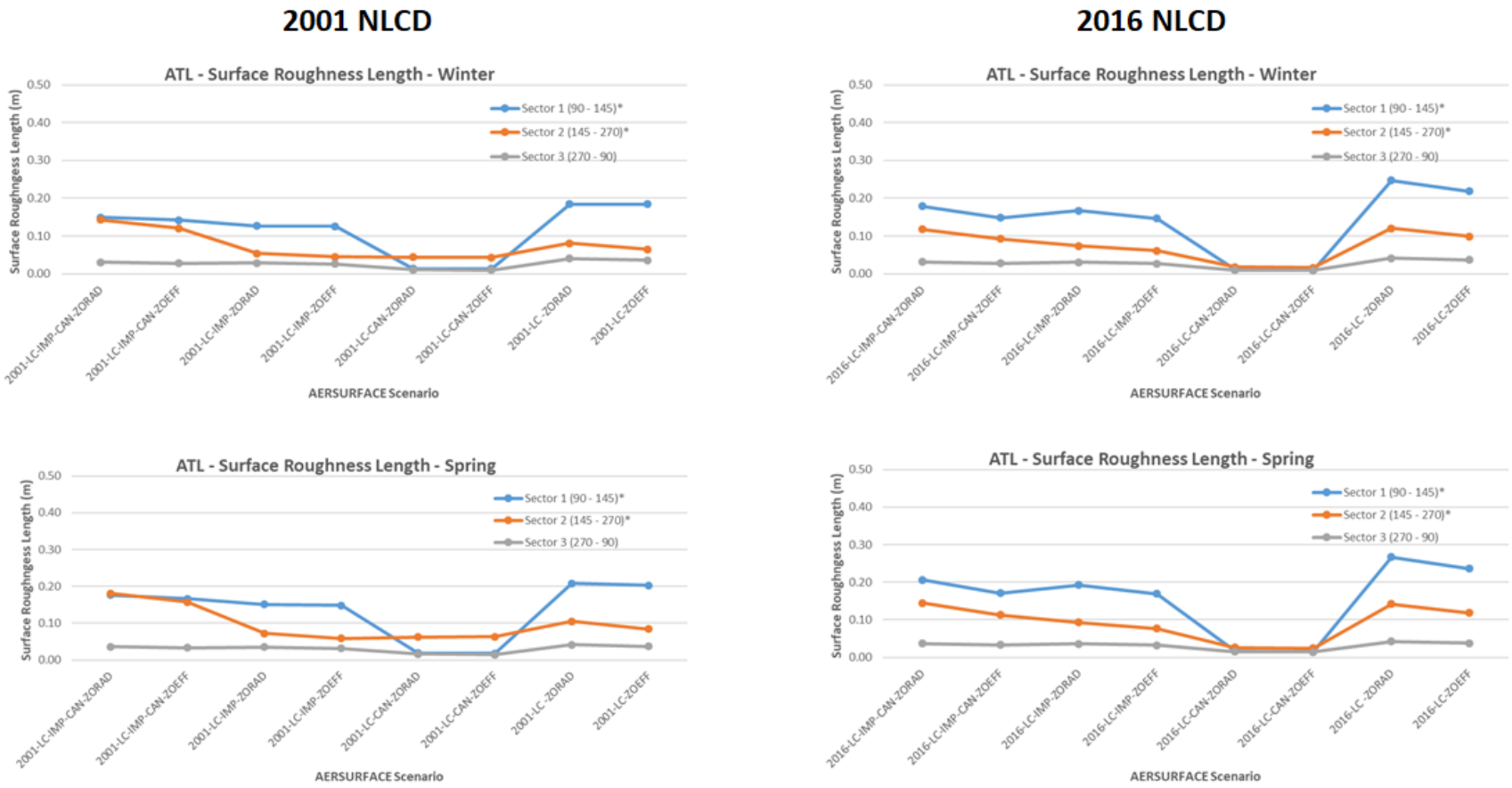



**Figure 11-54. Surface Roughness Length Estimated for ATL using 2001 NLCD (2011 Edition) and 2016 NLCD Winter Months (top), Spring Months (bottom)**

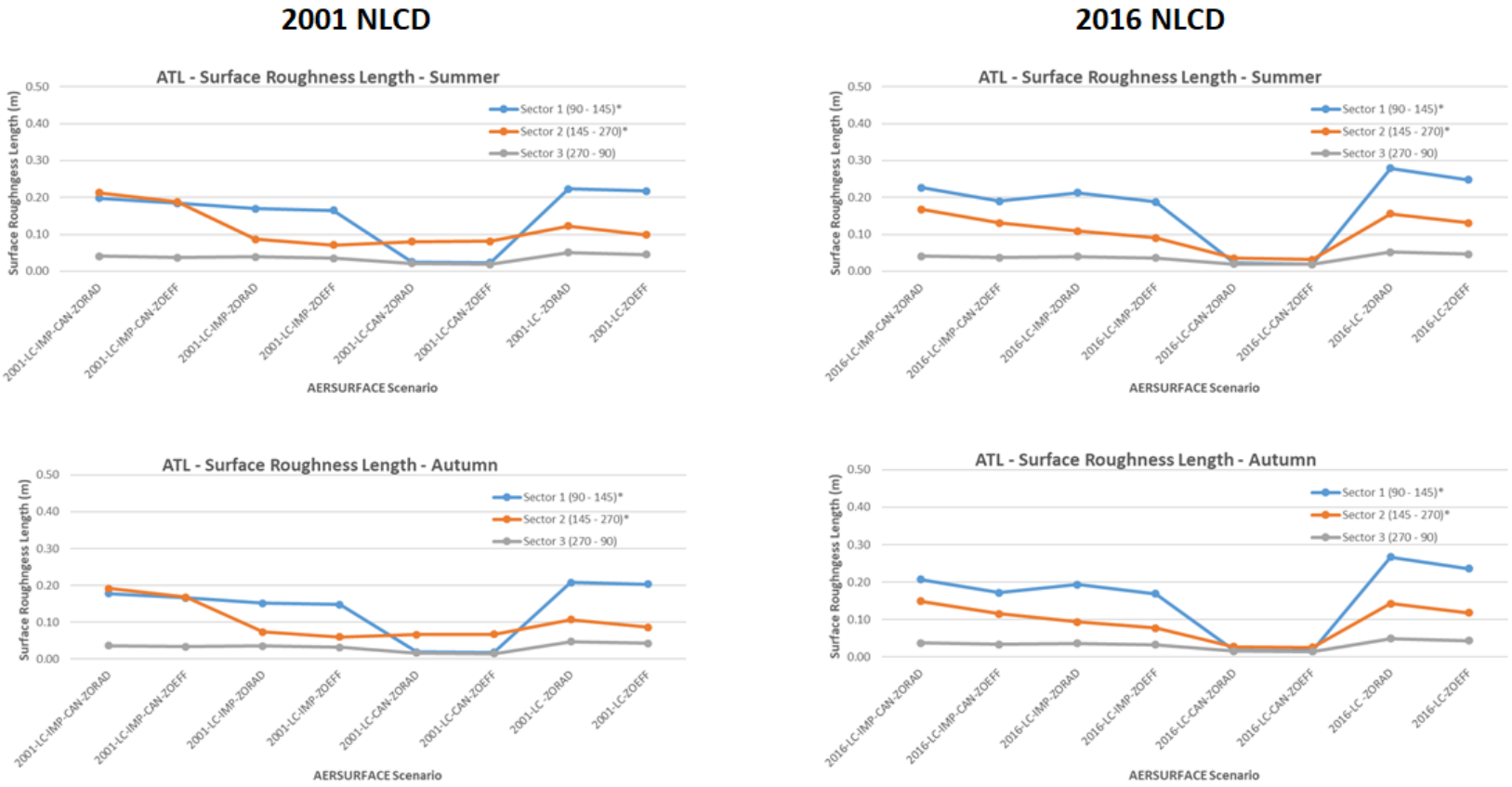



**Figure 11-55. Surface Roughness Length Estimated for ATL using 2001 NLCD (2011 Edition) and 2016 NLCD Summer Months (top), Autumn Months (bottom)**

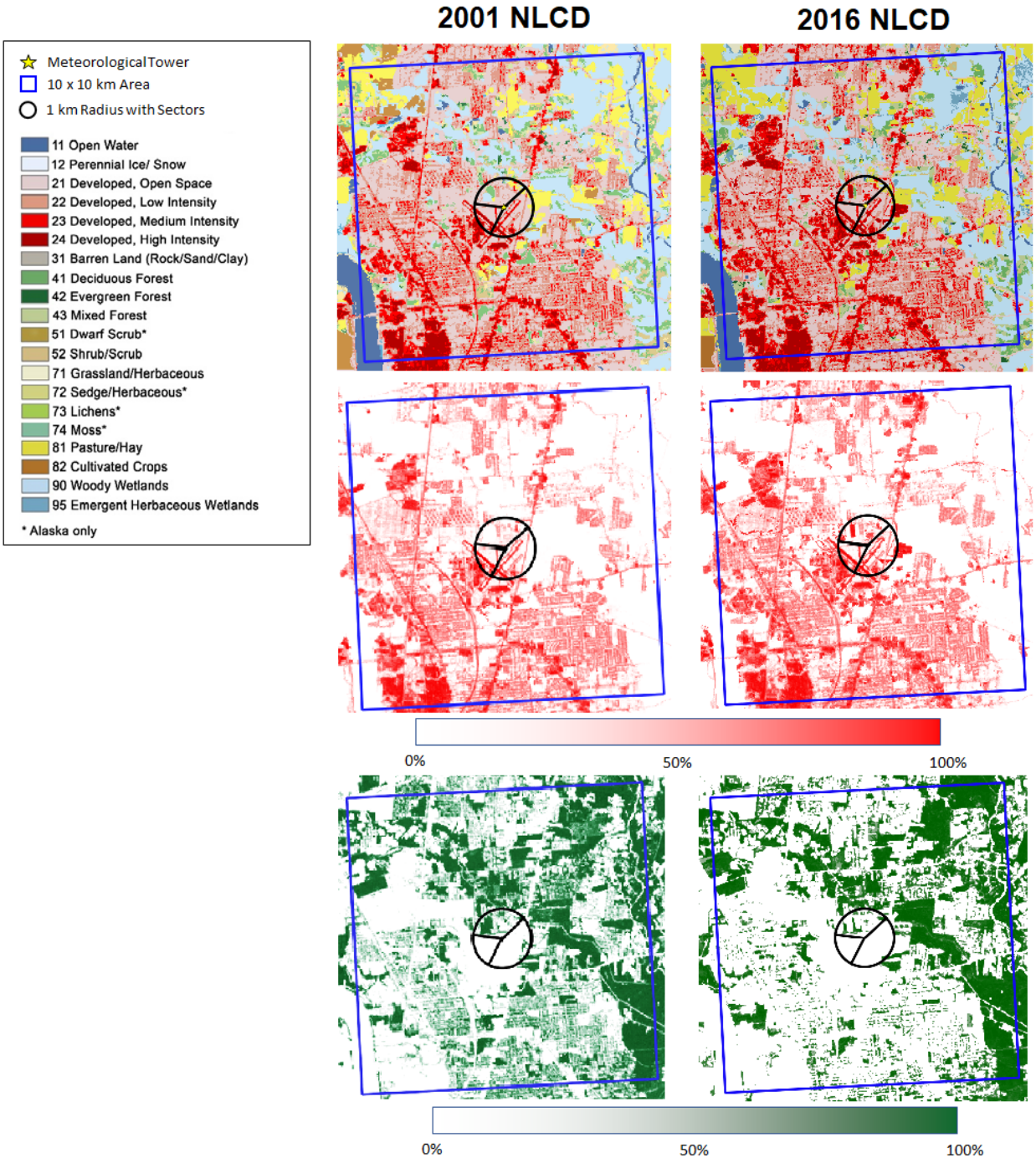



**Figure 11-56. Comparison of 2001 NLCD (2011 Edition) to 2016 NLCD for BTR Land Cover (top), Percent Impervious (middle), and Percent Tree Canopy (bottom)**

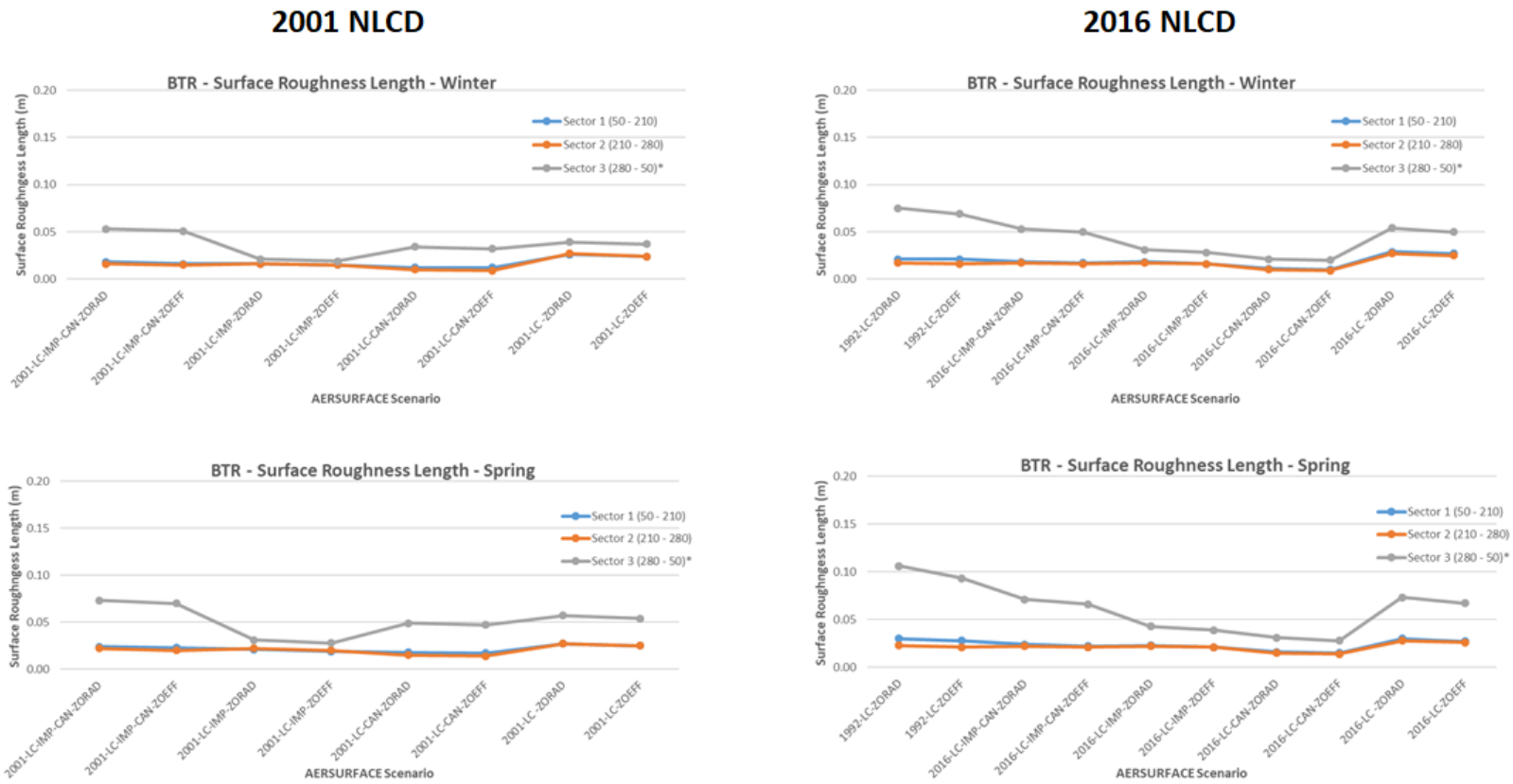



**Figure 11-57. Surface Roughness Length Estimated for BTR using 2001 NLCD (2011 Edition) and 2016 NLCD Winter Months (top), Spring Months (bottom)**

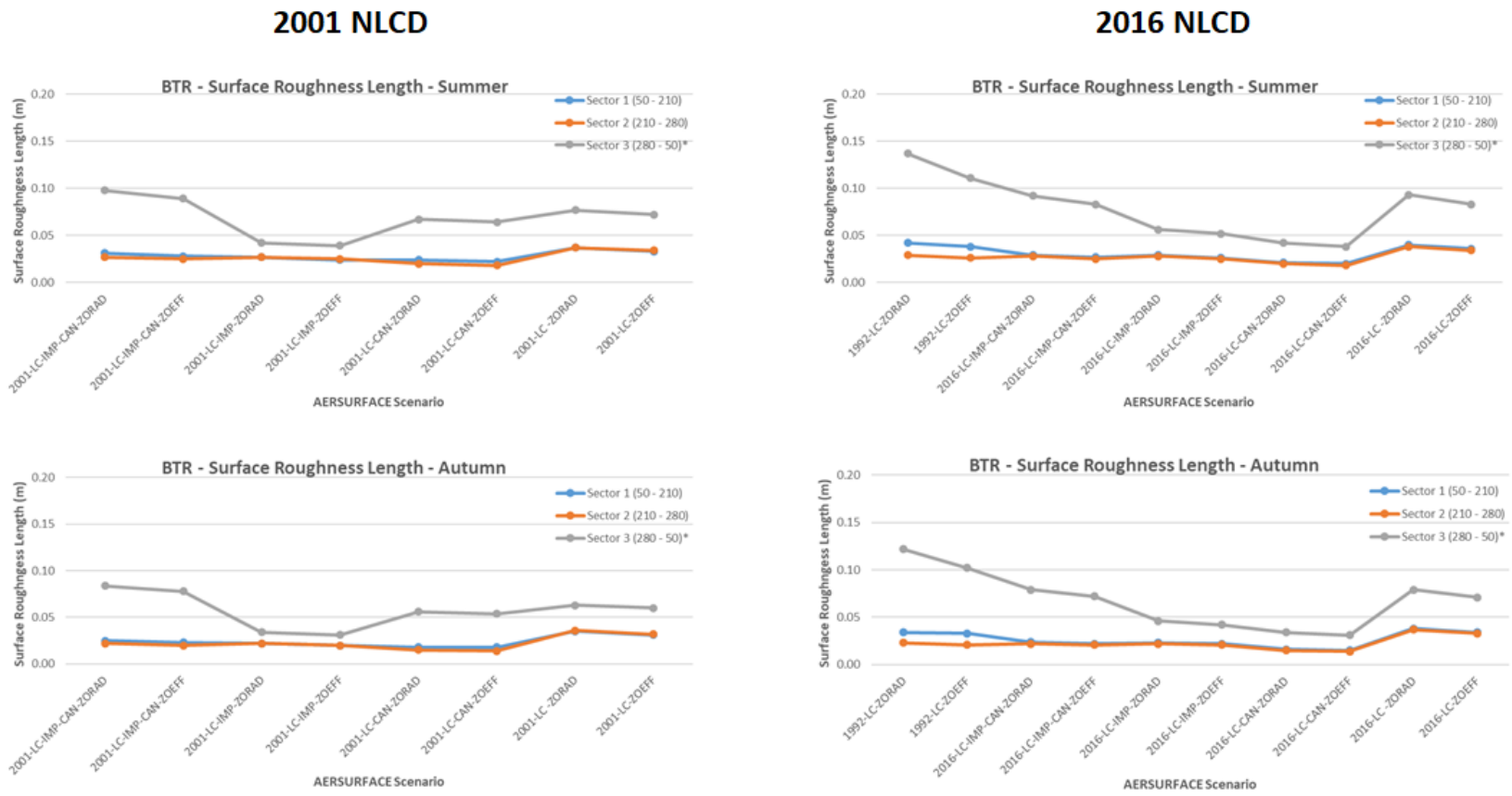



**Figure 11-58. Surface Roughness Length Estimated for BTR using 2001 NLCD (2011 Edition) and 2016 NLCD Summer Months (top), Autumn Months (bottom)**

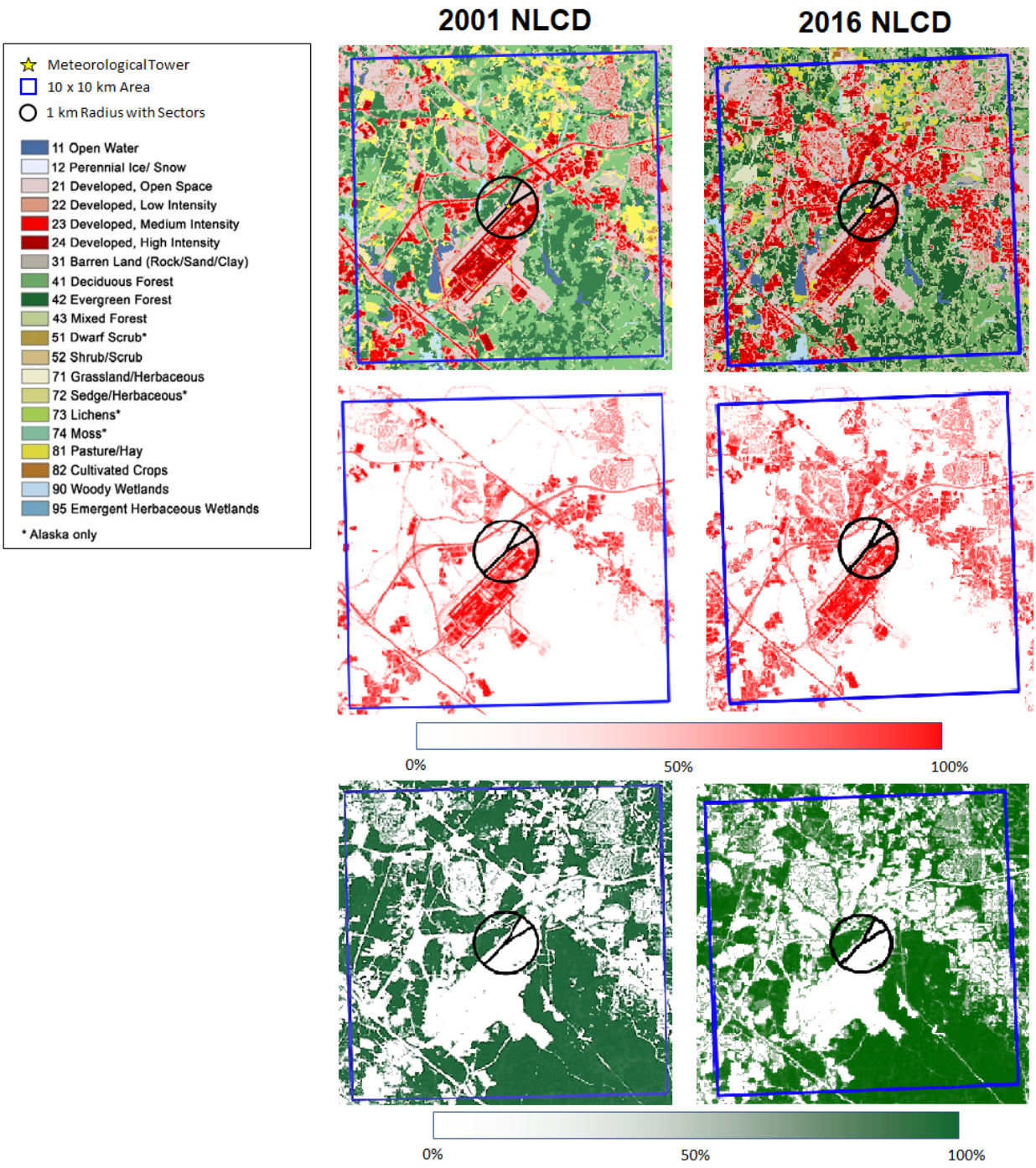



**Figure 11-59. Comparison of 2001 NLCD (2011 Edition) to 2016 NLCD for RDU BTR Land Cover (top), Percent Impervious (middle), and Percent Tree Canopy (bottom)**

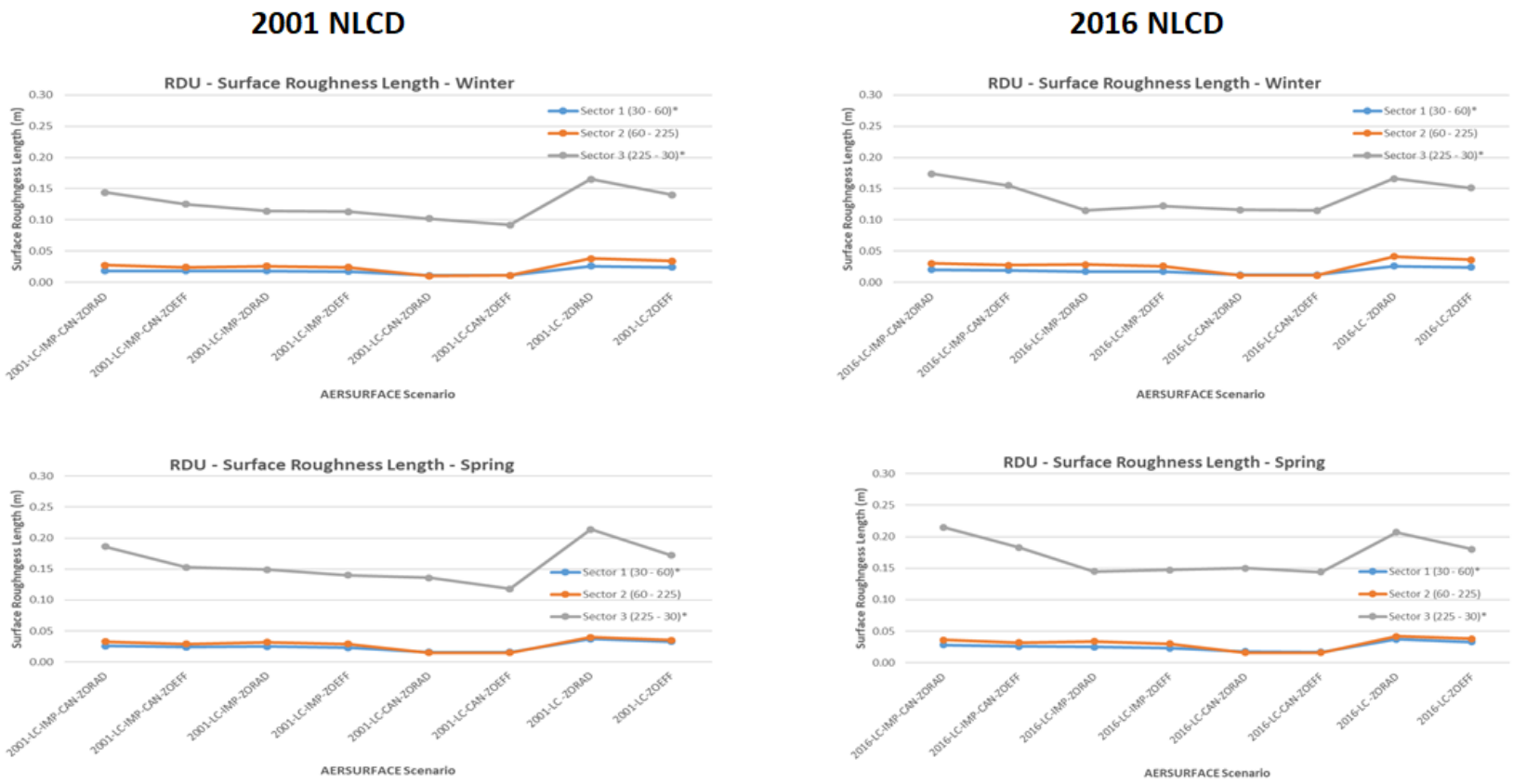



**Figure 11-60. Surface Roughness Length Estimated for RDU using 2001 NLCD (2011 Edition) and 2016 NLCD Winter Months (top), Spring Months (bottom)**

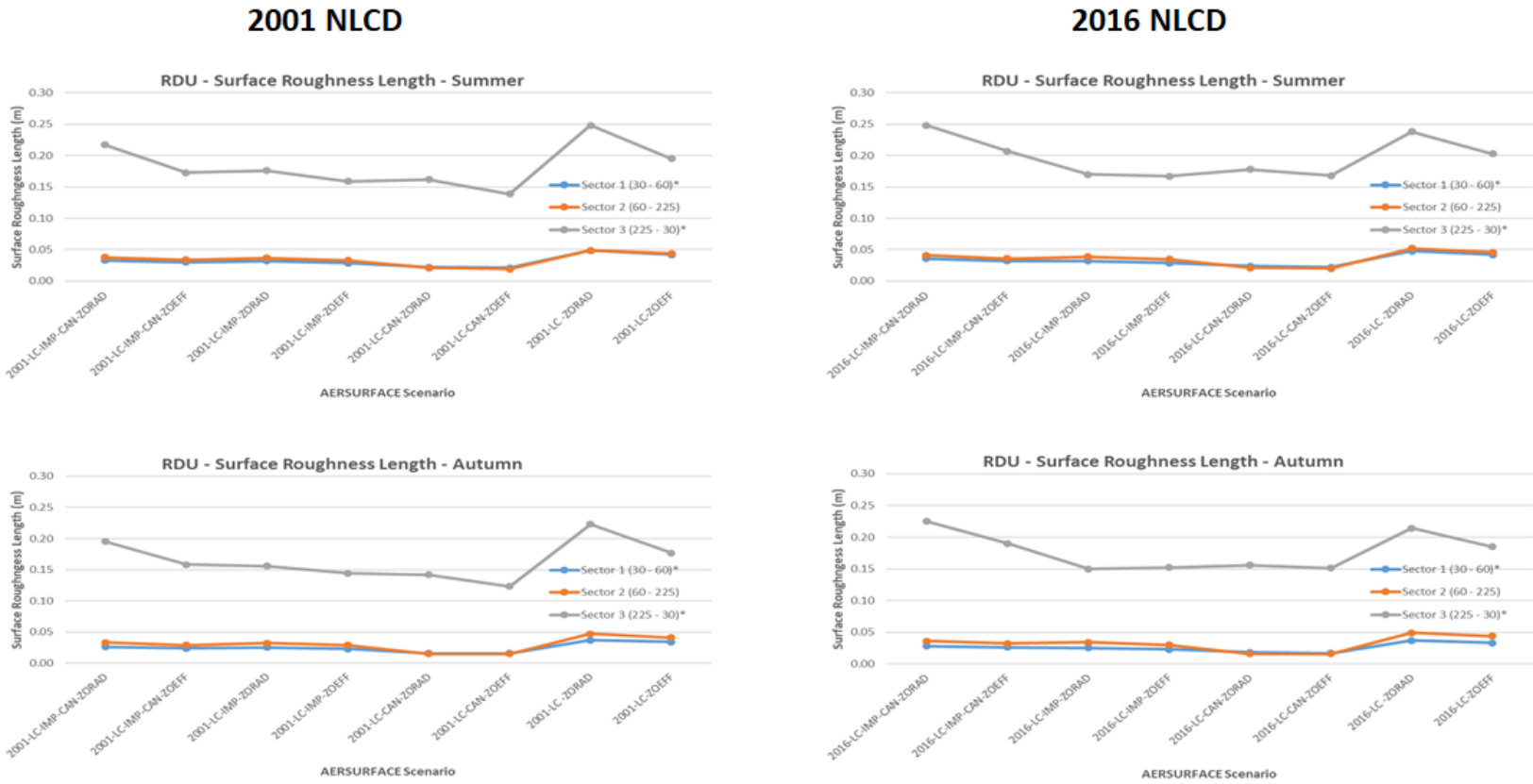



**Figure 11-61. Surface Roughness Length Estimated for RDU using 2001 NLCD (2011 Edition) and 2016 NLCD Summer Months (top), Autumn Months (bottom)**

## 12.0 Appendix H: Error and Warning Messages

E100 Invalid Pathway Specified

E105 Invalid Keyword Specified

E110 Keyword is Not Valid for This Pathway

E115 STARTING or FINISHED Out of Sequence

E120 Pathway is Out of Sequence

E125 Missing FINISHED-Runstream File Incomplete

E130 Missing Mandatory Keyword

E135 Nonrepeatable Keyword

E140 Keyword is Out of Sequence

E150 Too Few Parameters Specified for Keyword

E155 Too Many Parameters Specified for Keyword

E160 Invalid Parameter Specified for Keyword

E170 Keyword Conflict Encountered

E200 Only one of PRIMARY or SECONDARY allowed

E201 Only one of ZOEFF or ZORAD allowed

E202 Anem. height is required when ZOEFF option is used

203 A LC Data File Has Not Been Specified

E205 Invalid Keyword for Number of Sectors Specified

E206 NAD Grid Files Missing (*.los & *.las)

E208 Invalid # SECTOR Definitions for # of Sectors

W209 DBGOPT EFFRAD is not applicable with OPTIONS ZORAD

E210 SEASON Keyword Only Valid with ANNUAL and MONTHLY

W227 Calc. IBL Height < Minimum (Based on Anem. Ht.)

W228 Calc. IBL Height > Maximum (Based on Anem. Ht.)

E230 Primary Title Cannot Be Blank

W235 Secondary Title is Blank

E240 File Name is Too Long, Exceeds Maximum Length

E245 Illegal Numerical Field Encountered

E247 Anemometer Height Must Be Within the Valid Range:

E248 IBL Factor Must Be Within the Valid Range:

E250 Invalid Horizontal Datum Specified

E255 Arid Climate is Invalid with Continuous Snow

E260 Invalid Number of Sectors Specified

E265 Invalid Sector ID Specified

E266 Sector IDs Must Be Consecutive

E267 Gap or Overlap in Sector Start/End Directions

E268 Min Sector Width of 30-degrees Required

E269 Coverage For All Sectors Must Equal 360-degrees

E270 Numeric Value Out of Range

E271 Min Sector Width of 22.5-degrees Required

E275 WINTERWS Not Valid When CLIMATE = NOSNOW

E280 Invalid Month Specified

E285 Month Was Previously Assigned to a Season

E290 File does not exist

W294 Recommended use of Impervious and Canopy data

E295 Both Impervious and Canopy input files required

E296 Must use same year for NLCD, MPRV, and CNPY

W297 Not a valid NLCD year

W305 EFFRAD Not Specified on CO DEBUGOPT; Ignored

W310 GRID Not Specified on CO DEBUGOPT; Ignored

W315 TIFF Not Specified on CO DEBUGOPT; Ignored

E340 File Name is Too Long, Exceeds Maximum Length

E405 Byte Order of Processor Could Not Be Determined

E410 Byte Order of GeoTIFF Undetermined (See Log File)

E415 File is Not Correctly Identified as a TIFF File

E420 Allocation Error While Reading GeoTIFF File

W425 GeoTIFF File Does Not Contain Georeference Info

W430 GeoTIFF File Contains Unidentified Data Type

W435 Required Georeference Data Was Not Found in GeoTIFF

W440 Multiple Values Found for a GeoKey. Expecting One

E500 Fatal Error Occurred Opening a Primary I/O File

E505 Fatal Error Occurred Reading from Input File

E510 Fatal Error Occurred Reading from Temporary File

E515 Fatal Error Occurred Writing to Output File

E600 The Study Area Extends Beyond the Data File

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| United States<br>Environmental Protection<br>Agency | Office of Air Quality Planning and Standards<br>Air Quality Assessment Division<br>Research Triangle Park, NC | Publication No. EPA-454/B-24-003<br>November 2024 |