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Dust Emissions Inventory Support for Particulate Matter Modeling

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Dust Emissions Inventory Support for Particulate Matter Modeling

Final Report

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LIST OF ACRONYMS AND ABBREVIATIONS

AFDUST	Area Fugitive Dust
CAMx	Comprehensive Air Quality with Extensions
CCRS	Coarse Crustal
CDL	Cropland Data Layer
CM	Coarse Mass
CMAQ	Community Multiscale Air Quality
CONUS	Continental US
EPA	Environmental Protection Agency
EI	Emissions Inventory
FCRS	Fine Crustal
IMPROVE	Interagency Monitoring of Protected Visual Environments
LAI	Leaf Area Index
NAAQS	National Ambient Air Quality Standard
NetCDF	Network Common Data Form
MCIP	Meteorology-Chemistry Interface Processor
NASS	National Agricultural Statistics Service
NEI	National Emissions Inventory
$PM_{2.5}$	Particulate matter with a diameter of 2.5 micrometers or less
SIP	State Implementation Plan
SMOKE	Sparse Matrix Operator Kernel Emissions
SOILM	Soil Moisture
SLTYP	Soil Type
TCEQ	Texas Commission on Environmental Quality
TFs	Transport Fractions
$\mu g/m^3$	Micrograms per Cubic Meter
WBD	Windblown Dust
WBDUST	Windblown Dust Model
WRFCAMx	Pre-processor that generates CAMx meteorological input files from WRF

EXECUTIVE SUMMARY

The Texas Commission on Environmental Quality (TCEQ) uses the Comprehensive Air Quality Model with Extensions (CAMx) to assess the impact of particulate matter (PM) on air quality. In early 2024, the US Environmental Protection Agency (EPA) announced the lowering of the National Ambient Air Quality Standard (NAAQS) for PM with a diameter of 2.5 micrometers or smaller ($PM_{2.5}$) from 12.0 to 9.0 $\mu g/m^3$ (EPA 2024). Because of this change, the TCEQ will be required to perform PM modeling to support State Implementation Plans (SIP) for nonattainment areas.

For this project, Ramboll developed new Python-based tools to adjust area fugitive dust emissions inputs to CAMx, improving how these sources are represented in air quality modeling. The tools use WRFCAMx meteorological data and apply adjustments following EPA-established methods. Specifically, a processing script applies gridded "transport fractions" based on land use and landscape roughness to account for near-source deposition. The script also removes emissions on days when at least 0.01 inches of precipitation occur or when snow cover is present.

Ramboll also developed and evaluated windblown dust (WBD) emissions for the 2022 modeling year using the WBDUST v2.2 model. By incorporating the U.S. Department of Agriculture (USDA) 2022 CropScape data, the model captured seasonal and spatial changes in cropland tilling activity across the 12 km and 4 km TCEQ modeling domains. However, an initial CAMx inert screening run revealed that the model substantially overpredicted PM dust concentrations during the spring and winter—especially in March and April.

Further sensitivity testing pointed to several causes for the overpredictions: unusually high modeled wind speeds, dry soils, and sparse vegetation early in the year. The WBDUST model's unbounded saltation flux equation also led to excessive emissions during high wind events. To address this, Ramboll applied a wind stress cap and scaled WBD emissions using a scaling factor of 0.1 based on the results of the screening model performance evaluation. These adjustments greatly improved model agreement with measurements. Ramboll recommend using the Sens01 configuration—TCEQ meteorology with a wind stress cap and a 0.1 scaling factor—for future full-chemistry CAMx simulations.

1.0 INTRODUCTION

SIP modeling for PM requires estimating and processing a comprehensive emissions inventory (EI) of both gases and PM to develop accurate emissions inputs. The EI includes all major sources of PM emissions, such as mobile, stationary, and natural sources. For Texas, PM modeling is needed to support SIPs that will be required following EPA's recent tightening of the NAAQS for annual $PM_{2.5}$, which was lowered from 12.0 micrograms per cubic meter (μg/m^3) to 9.0 μg/m^3.

The purpose of this project is to develop post-processing tools to adjust area fugitive dust emission estimates and to generate windblown dust (WBD) emissions files for TCEQ's 2022 modeling platform. The fugitive dust adjustments account for near-source removal mechanisms, as well as reductions due to precipitation and snow cover. WBD emissions files were generated in a format required by CAMx using the windblown dust model (WBDUST). Both efforts are essential for accurately representing large quantities of primary PM emissions from dust-related sources in SIP modeling. The following sections provide more detail on each task.

2.0 AREA FUGITIVE DUST ADJUSTMENTS

2.1 Background

Area fugitive dust (afdust) is a major contributor to PM pollution in the United States, particularly when compared to other sources like fertilizers, airports, oil and gas operations, and nonroad equipment (Farkas et al., 2020). The afdust sector of the National Emissions Inventory (NEI) includes dust emissions from paved and unpaved roads, construction, and mining/quarrying activities. The afdust emissions play a crucial role in air quality modeling, particularly in regions with extensive industrial, agricultural, and transportation activities.

To accurately represent these emissions in air quality modeling, special adjustments need to be made to the emissions prior to modeling. These adjustments can be made following Adelman's (2012) methodology, which considers factors like land use, precipitation and snow cover. For example, PM emissions are reduced to zero in areas with sufficient precipitation, reflecting lower dust emissions under wet conditions. Land use data further refines emissions by accounting for trees and other structures that limit PM transport. These adjustments have been shown to reduce PM emissions in Texas by approximately 48% (Farkas et al., 2020).

While EPA provides tools to adjust fugitive dust emissions after processing with the Sparse Matrix Operator Kernel Emissions (SMOKE) processing system, these tools only work with model-ready emissions output from SMOKE in the Models-3/Community Multiscale Air Quality (CMAQ) Network Common Data Form (NetCDF) format along with meteorological data from the Meteorology-Chemistry Interface Processor (MCIP) files. In this project, Ramboll developed tools to process CAMx NetCDF emission files using meteorological data from WRFCAMx (also in NetCDF format). Specifically, Ramboll created Python scripts to apply adjustments and generate afdust emissions files compatible with the CAMx model.

2.2 Overview of Python Tools

As part of this project, Ramboll developed Python-based processors to adjust afdust emissions files for use with CAMx. These processors include the following key components:

- Landuse-based transport fractions (TFs) to account for near-source dust removal.
- Meteorological adjustments using WRFCAMx data, including suppression effects from precipitation, snow cover, and soil moisture.
- A streamlined processing workflow for modifying CAMx NetCDF afdust emissions files.

The adjustment process involves two main steps:

1. Generating domain-specific gridded transport fraction file.
2. Applying TFs and meteorological/precipitation reductions to the afdust emissions.

These adjustments are implemented using two Python scripts: 'create_xportfrac_file.py' and 'apply_tf_precip_afdust.py', which are executed via C-shell wrapper scripts. All these scripts are included in the project deliverable package.

2.3 Generating the Gridded Transport Fraction File

The transport fraction represents the portion of emitted fugitive dust that remains airborne and is transported beyond the immediate vicinity of the emission source. The remainder is removed near the source through deposition onto vegetation and other structures. Transport fractions by capture fraction class are provided by EPA (Eyth, 2025), as shown in Table 2-1. These transport fractions are derived from landuse classifications and empirical studies (Pouliot G. et al., 2012; Pace, 2005) on near-source dust removal.

Table 2-1. Transport fractions by capture fraction class as provided by EPA

Capture Fraction Class	Capture Percentage	Transport Fraction (TF)
Agricultural	25%	0.75
Urban Areas	60%	0.40
Grasslands/Agriculture	25%	0.75
Shrubland	20%	0.80
Forested Areas	95%	0.05
Water/Barren Land	100%	1.00

The process for generating domain-specific gridded TFs includes the following steps:

1. Mapping WRFCAMx landuse categories to the six capture classes listed in Table 2-1 and creating a 'wrfcamx_lu.csv' file.
2. Extracting gridded landuse data from the WRFCAMx files.

WRFCAMx categorizes landuse into 26 categories based on the Zhang03 Land-Surface Scheme (Ramboll, 2024). The mapping of the 26 landuse categories to the six capture classes from Table 2-1 is shown in Table 2-2.

Table 2-2. Mapping of WRFCAMx landuse categories to capture classes

WRFCAMx Landuse Category*	Landuse Category Description	Capture Class
Water	Water (Ocean)	Water
ice	Ice	Water
lake	Inland lake (Fresh)	Water
eneedl	Evergreen Needleleaf Trees	Forest
ebroad	Evergreen Broadleaf Trees	Forest
dneedl	Deciduous Needleleaf Trees	Forest
dbroad	Deciduous Broadleaf Trees	Forest
tbroad	Tropical Broadleaf Trees	Forest
ddecid	Drought Deciduous Trees	Forest
eshrub	Evergreen Broadleaf Shrubs	Forest
dshrub	Deciduous Shrubs	Shrubland
tshrub	Thorn Shrubs	Shrubland
sgrass	Short Grass and Forbs	Grasses
lgrass	Long Grass	Grasses
crops	Crops	Agricultural
rice	Rice	Agricultural
sugar	Sugar	Agricultural
maize	Maize	Agricultural
cotton	Cotton	Agricultural
icrops	Irrigated Crops	Agricultural
urban	Urban	Urban
tundra	Tundra	Water
swamp	Swamp	Grasses
desert	Desert	Water
mwood	Mixed Wood Forest	Forest
tforest	Transitional Forest	Forest

**Variables in WRFCAMx landuse (lu) file*

2.3.1 Process

The first script, 'create_xportfrac_file.py', generates a domain-specific gridded transport fraction file by assigning capture classes to CAMx landuse categories.

1) Input Processing:
   a. Loads the CSV file ('*captureclass_fractions.wrfcamx.csv*') which contains capture classes and their corresponding TFs.
   b. Processes the WRFCAMx landuse mapping file (*wrfcamx_lu.csv*) that links WRFCAMx landuse categories to the capture classes.
   c. Opens the CAMx landuse NetCDF file containing grid-specific landuse data.

2) Calculation Methodology:
   a. Merges landuse categories with capture class data using a common identifier.
   b. Iterates through each capture class.
   c. For each class, identifies relevant landuse variables and associated fraction.

d. Calculates class-specific data by multiplying landuse variables with their respective fractions.

e. Sums these values to produce the overall transport fraction (xportfrac).

3) Output Generation:
- Creates a NetCDF file with the following variables:
    - xportfrac: Overall transport fraction across all categories.
    - Individual category-specific transport fractions as separate variables.
- Preserves and updates global attributes from the original CAMx landuse file.
- Records variable descriptions and appropriate metadata.

2.3.2 Illustrative Outputs

Example results from the TF generation process are shown in Figure 2-1. TF values range from 0 to 1. Higher values (yellow to red) correspond to open land cover types such as water bodies or sparsely vegetated areas that are more conducive to dust transport. Conversely, lower TF values reflect suppression of dust transport due to dense vegetation or other structures.

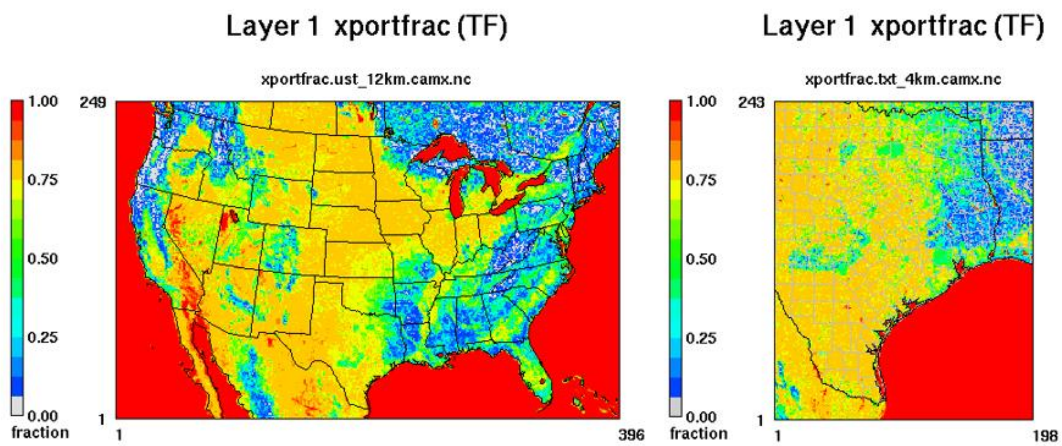

Figure 2-1. Gridded TF (xportfrac) for the 12-km Continental U.S. domain (left) and the 4-km TCEQ domain (right).

2.4 Application of TFs and Meteorological Adjustments

Meteorological conditions play a crucial role in determining fugitive dust emissions. Precipitation, soil moisture, and humidity can substantially influence the generation and suspension of dust particles in the atmosphere. Incorporating meteorological adjustments, such as precipitation and snow cover, into afdust emissions is essential for accurately representing these emissions in air quality modeling.

The afdust adjustment tool incorporates meteorological reductions using the following methodologies:

1) Snow Cover Suppression
- Snow-covered areas (snowed > 0) are assigned zero emissions since snow prevents dust generation and suspension.

$$Emissions_{snow} = \begin{cases} 0, & \text{if snow cover} > 0 \\ Emissions_{TF,} & \text{otherwise} \end{cases}$$

2) Soil Moisture-Based Adjustment

- The script extracts soil moisture (SOILM) and soil type (SLTYP) from the WRFCAMx meteorological input.
- It assigns a saturation threshold for each soil type based on literature values (Jacquemin B. and Noilhan J., 1990).
- The moisture ratio is then computed as:

$$Moisture\ Ratio = \frac{SOILM}{Saturation\,Threshold}$$

- If the moisture ratio exceeds 0.5, fugitive dust emissions are suppressed and set to zero.

$$Emissions_{soil} = \begin{cases} 0, & \text{if moisture ratio} \geq 0.5 \\ Emissions_{snow,} & \text{otherwise} \end{cases}$$

2.4.1 Process

The second script, 'apply_tf_precip_afdust.py', applies the transport fractions and meteorological adjustment factors to the afdust emissions.

1) Input Processing:
   a. Reads the transport fraction (*xportfrac*) file created in Step 1.
   b. Processes a WRFCAMx meteorology file containing snow cover, soil moisture, and soil type data.
   c. Opens the original unadjusted CAMx-ready afdust emissions file.
2) Adjustment Methodology:
   a. Transport Factor Application:
      i. Multiplies emissions by the transport fraction.
   b. Meteorological Adjustments:
      i. Snow Cover: Sets emissions to zero in grid cells with snow cover.
      ii. Soil Moisture:
         a) Maps soil types to their saturation values using predefined dictionaries.
         b) Calculates the ratio of soil moisture to soil saturation.
         c) Sets emissions to zero where this ratio exceeds 0.5.
3) Output Generation:
   - Creates a copy of the original CAMx-ready emissions NetCDF file.
   - Applies TFs and meteorological adjustments to afdust emissions.
   - Preserves the original file structure and global metadata.
   - Saves the adjusted emissions in the output CAMx-ready NetCDF file.

2.4.2 Illustrative Outputs

Figure 2-2 shows the impact of applying the afdust adjustment tools to the TCEQ 4 km domain using 2022 dust emissions and meteorological data provided by TCEQ. The first step—applying land use–based Transport Fraction (TF) adjustments—results in an approximately 40% reduction in annual dust emissions. The second step, which accounts for meteorological conditions such as soil moisture and snow cover, provides an additional 36% reduction. Together, the two-step adjustment process yields an overall reduction of about 60% in modeled afdust emissions.

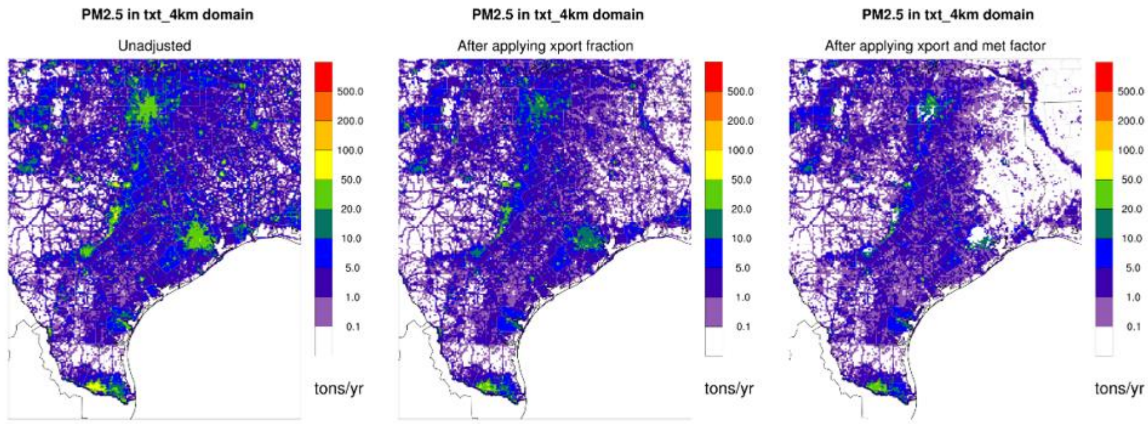

Figure 2-2. Example results after applying the afdust_adj tools to TCEQ's 4-km afdust emissions. Left: original emissions. Middle: after TF adjustment. Right: after TF and meteorological adjustments.

2.5 Python Libraries and Modules Requirements

To run both '*create_xportfrac_file.py*' and '*apply_tf_precip_afdust.py*', the required Python libraries and modules are summarized in Table 2-3, along with installation guidance. These libraries are the core set of dependencies required to run both scripts for adjusting afdust emissions. Although these scripts might run on Python 3.6, it is strongly recommended to use Python 3.7 or later, as newer versions offer improved stability, performance, and feature support.

Table 2-3. Python libraries and modules for afdust adjustment tools

Library/Module	Description	Primary Use	Installation Command
pandas	Data manipulation and analysis	Reading and merging CSV files in 'create_xportfrac_file.py'	'pip install pandas'
numpy	Numerical computation	Array operations and calculations	'pip install numpy'
xarray	Labeled multi-dimensional arrays and datasets	Reading and writing NetCDF files in both scripts	'pip install xarray'
os	Operation system dependent functionality	File path operations and file existence checks	Pre-installed
netCDF4	Creating and writing NetCDF files	Creating and modifying NetCDF files in 'create_xportfrac_file.py'	'pip install netCDF4'
sys	System-specific parameters and functions	Handling command-line arguments	Pre-installed
shutil	High-level file operations	Copying files in 'apply_tf_precip_afdust.py'	Pre-installed

3.0 WINDBLOWN DUST EMISSIONS: PROCESSING, MODELING, AND EVALUATION

3.1 Background

Windblown dust primarily originates from the Earth's crust, particularly from arid and semi-arid regions. These dust particles include crustal materials that have been eroded and lifted into the atmosphere by wind. WBD emissions are difficult to estimate due to a variety of source mechanisms and environmental factors that lead to high spatial and temporal variability (Emery et. al, 2021).

In this project, windblown dust emissions were generated in a format required by CAMx using the WBDUST model. The WBDUST model supports the use of year-specific CropScape data from the USDA's National Agricultural Statistics Service (NASS) to account for locations and extent of tilled cropland, which may be barren and potentially emissive at certain times of the year (Ramboll, 2023). This project developed 2022 CropScape data tailored for the TCEQ domains for use in the WBDUST model.

3.2 Generating the CropScape Input File

The NASS 'CropScape' mapping tool (NASS, 2025a) provides annual land cover data, including detailed crop types, across the continental U.S. (CONUS) at a 30-meter resolution. The Cropland Data Layer (CDL), available annually from 1997 to 2024, is a geo-referenced raster dataset designed to support acreage estimates for the Agricultural Statistics Board and to generate a digital, crop-specific classified product. The CDL is derived from moderate-resolution satellite imagery and extensive agricultural ground truthing, as detailed by NASS (2025b).

Ramboll downloaded the 2022 CDL data from the USDA NASS website (USDA NASS, 2025) and processed it using the suite of three Python scripts. These scripts recast the CropScape classifications into a smaller subset that aligns with the CAMx landcover categories, and reproject the 30-m raster data to gridded area fractions on the CAMx grid.

1) raster_reclassify.py – This script reclassifies CropScape's 256 pixel values into 26 CAMx LULC categories, along with 15 additional crop categories that align with the crop calendar. Three of these crop categories—cotton, corn, and rice—directly correspond to CAMx land cover types, resulting in a total of 18 distinct crop types.
2) raster_camx_grids_count.py –This script projects the reclassified 30-meter raster data onto the target CAMx modeling grid. It then uses a 'fishnet' Python function to aggregate the pixel data, counting the number of pixels within each grid cell for each of the 42 land cover categories.
3) raster_camx_grids_count2nc.py – This script calculates the fractional area of each of the 42 land cover categories within each grid cell. It then overlays a shapefile of the 48 conterminous U.S. states onto the CAMx grid, identifying the state each cell belongs to for use with the state-level crop calendar in WBDUST.

As part of this project, the third script was modified to read the latest Census Bureau TIGER U.S. States shapefile for state boundaries[1]. It was also modified to assign a value of zero to CDL pixels in border grid cells that lacked an associated state code. Additionally, minor updates were made to address compatibility issues with recent Python package upgrades.

[1] https://www.census.gov/geographies/mapping-files/time-series/geo/tiger-line-file.html

3.3 Windblown Dust Emission Processing

The current version of the WBDUST model (v2.2) was run for the entire year of 2022 over the 4 km and 12 km TCEQ modeling domains. Annual emission totals for each domain are summarized in Table 3-1. Figure 3-1 provides emission maps showing spatial distribution of fine and coarse crustal material across both domains.

Table 3-1. Annual windblown dust emission totals (in tpy) for the 12 km and 4 km domains.

Species	12-km Domain	4-km Domain
FCRS	89,300,564	321,396
CCRS	485,740,050	1,682,187
PCA	4,259,779	10,523
PFE	7,090,123	24,554
PMN	126,609	438
PMG	1,390,815	3,946
PK	2,127,222	6,577
PAL	4,431,327	15,346
PSI	14,180,246	49,108
PTI	379,828	1,315
NA	3,322,839	5,262

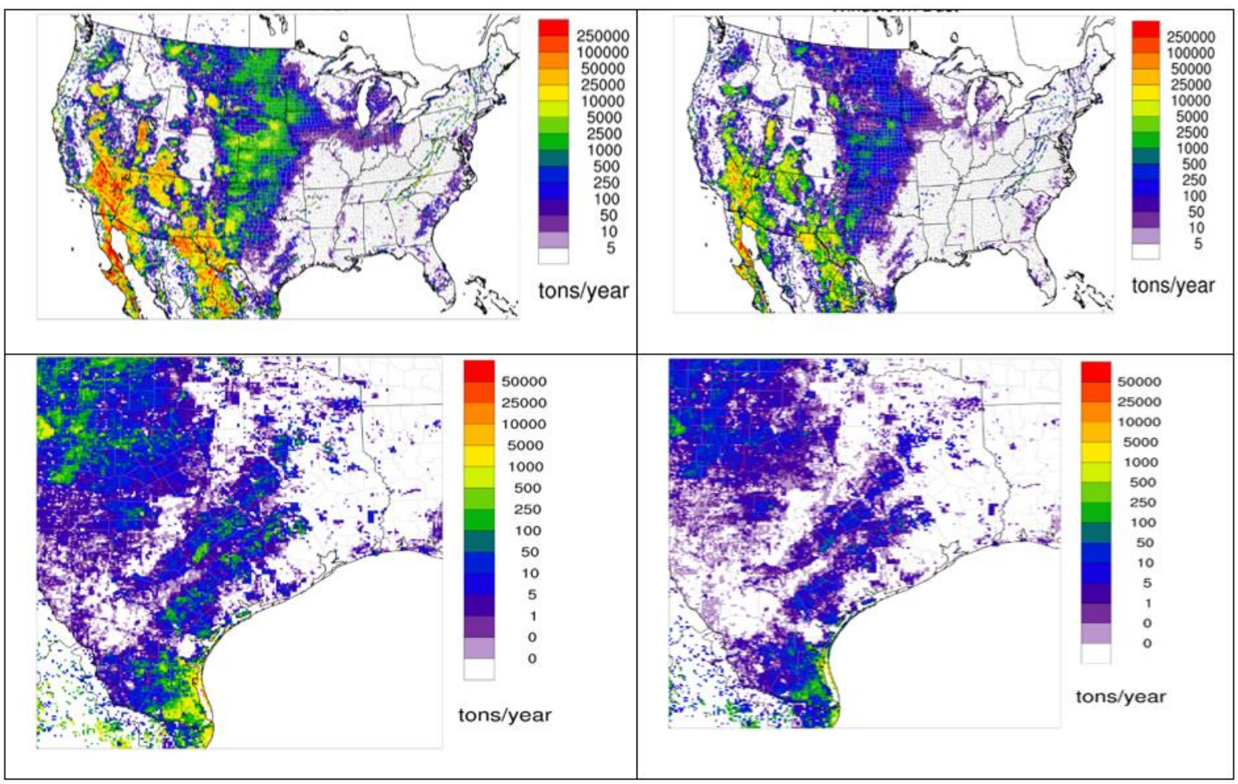

Figure 3-1. Spatial distribution of annual coarse dust (left) and fine dust (right) emission totals in the TCEQ modeling domains: 12 km resolution (top row) and 4 km resolution (bottom row).

3.4 CAMx Inert Run and Model Performance Evaluation

As part of this project, Ramboll also conducted an annual CAMx screening inert run for 2022 using TCEQ's 36/12/4km nested domain configuration with WBD emissions. Ramboll used WRFCAMx meteorological data and boundary condition files provided by TCEQ for all three domains. Ramboll then processed the model output and evaluated it against observations at selected Interagency Monitoring of Protected Visual Environments (IMPROVE) sites in and around Texas, as shown in Figure 3-2.

Figures 3-3 through 3-8 present comparisons of modeled soil elemental species (top) and modeled coarse crustal (bottom) against observations at six IMPROVE sites (BAND, BIBE, CACR, GUMO, SACR, WIMO). At all selected sites, the model overpredicted the elemental species and coarse mass significantly during the spring and winter months.

Figure 3-9 shows a time series comparison of modeled and measured 24-hour coarse PM concentrations during the typically windy and dry period of March-April 2022. CAMx-simulated coarse crustal (CCRS) concentrations are compared with IMPROVE coarse mass (CM) measurements, which are taken every three days. The model substantially overpredicted on several days and consistently reported higher concentrations at all sites throughout the analysis period.

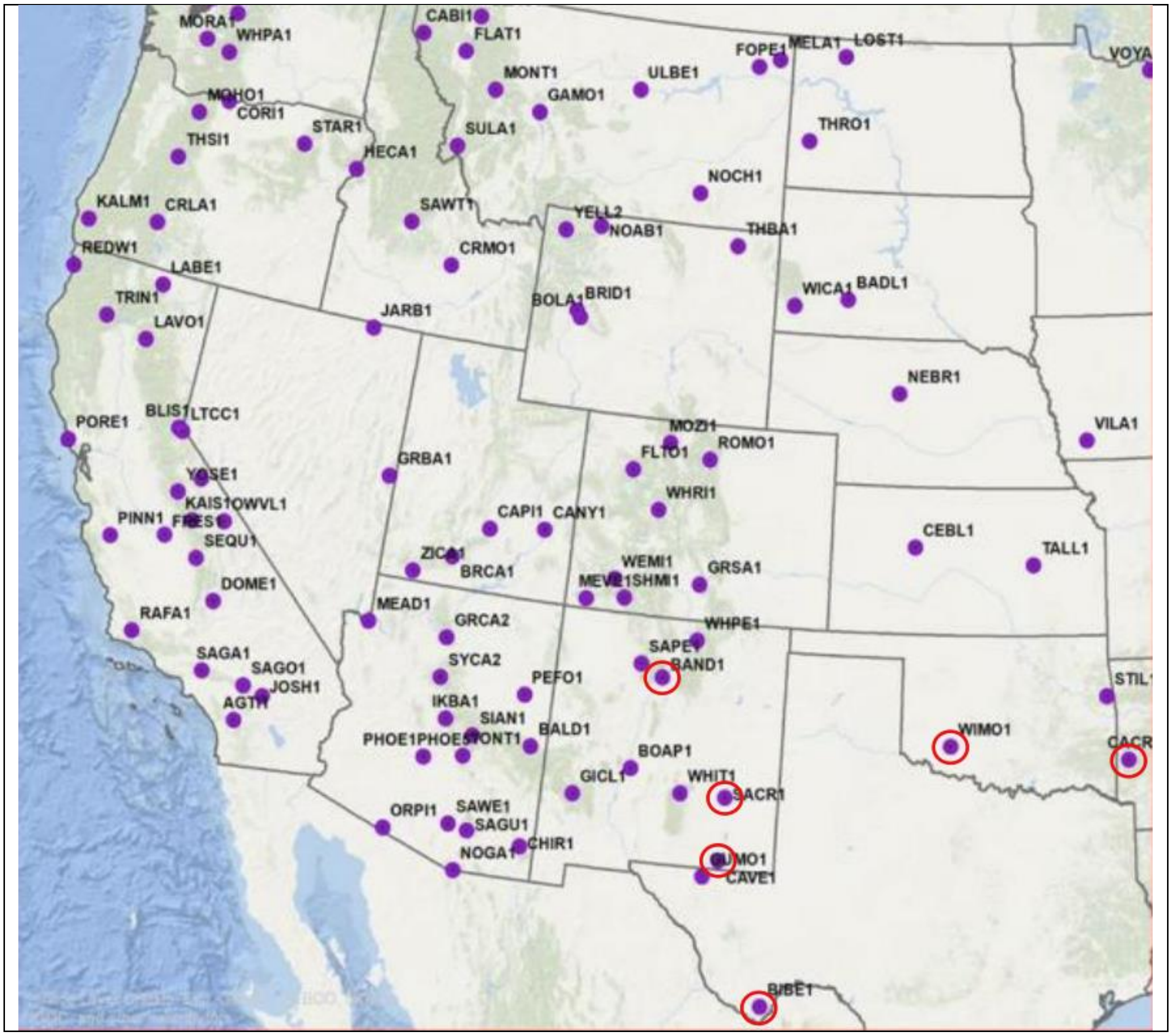

Figure 3-2. IMPROVE sites (red circled) included in the model performance evaluation of the CAMx inert run.

Figure 3-3. Comparison of 2022 monthly averaged modeled and measured fine dust elemental concentrations (top) and total coarse mass concentrations (bottom) at the Big Bend (BIBE) IMPROVE site.

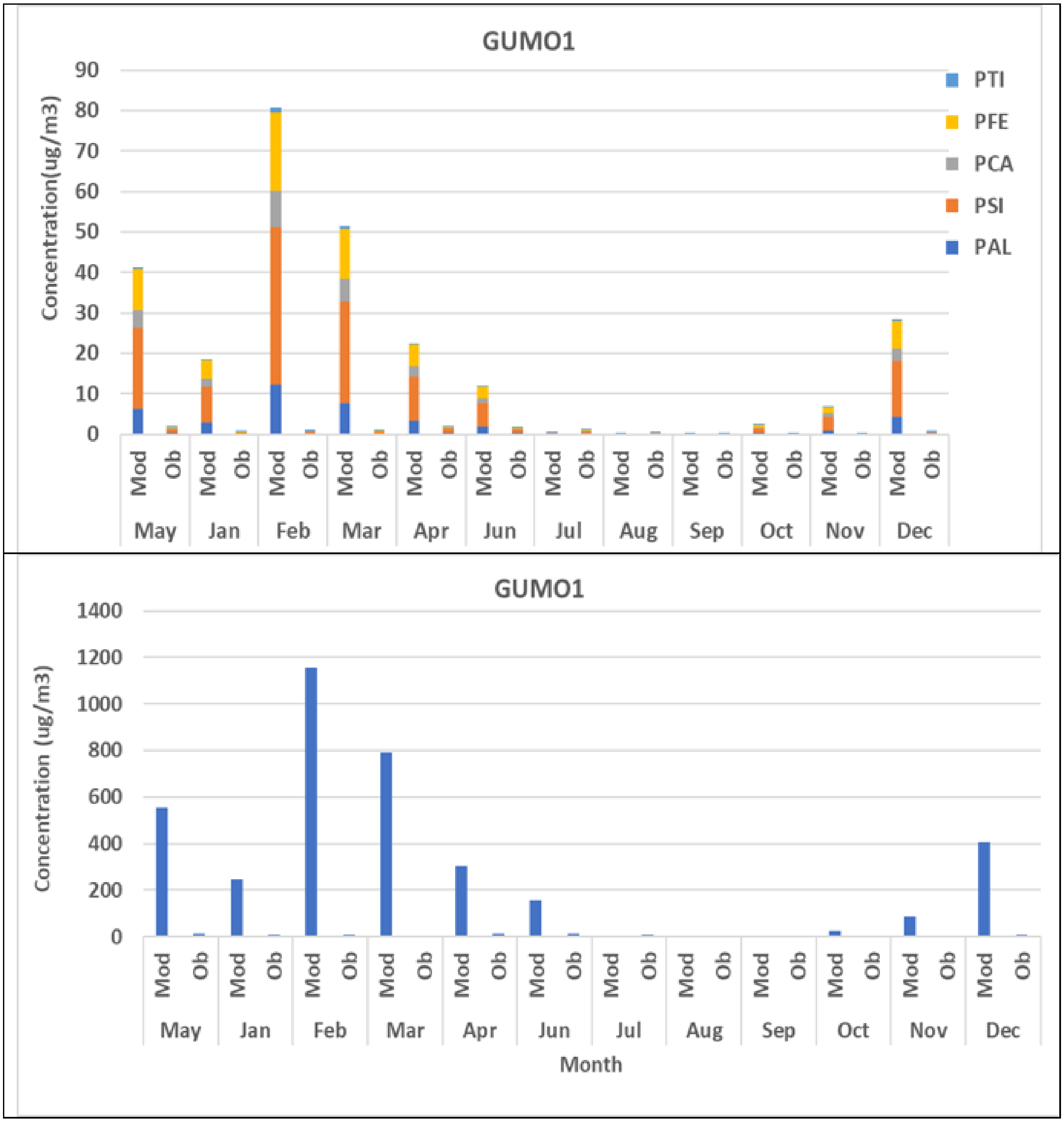

Figure 3-4. **Comparison of 2022 monthly averaged modeled and measured fine dust elemental concentrations (top) and total coarse mass concentrations (bottom) at the Guadalupe Mountains (GUMO) IMPROVE site.**

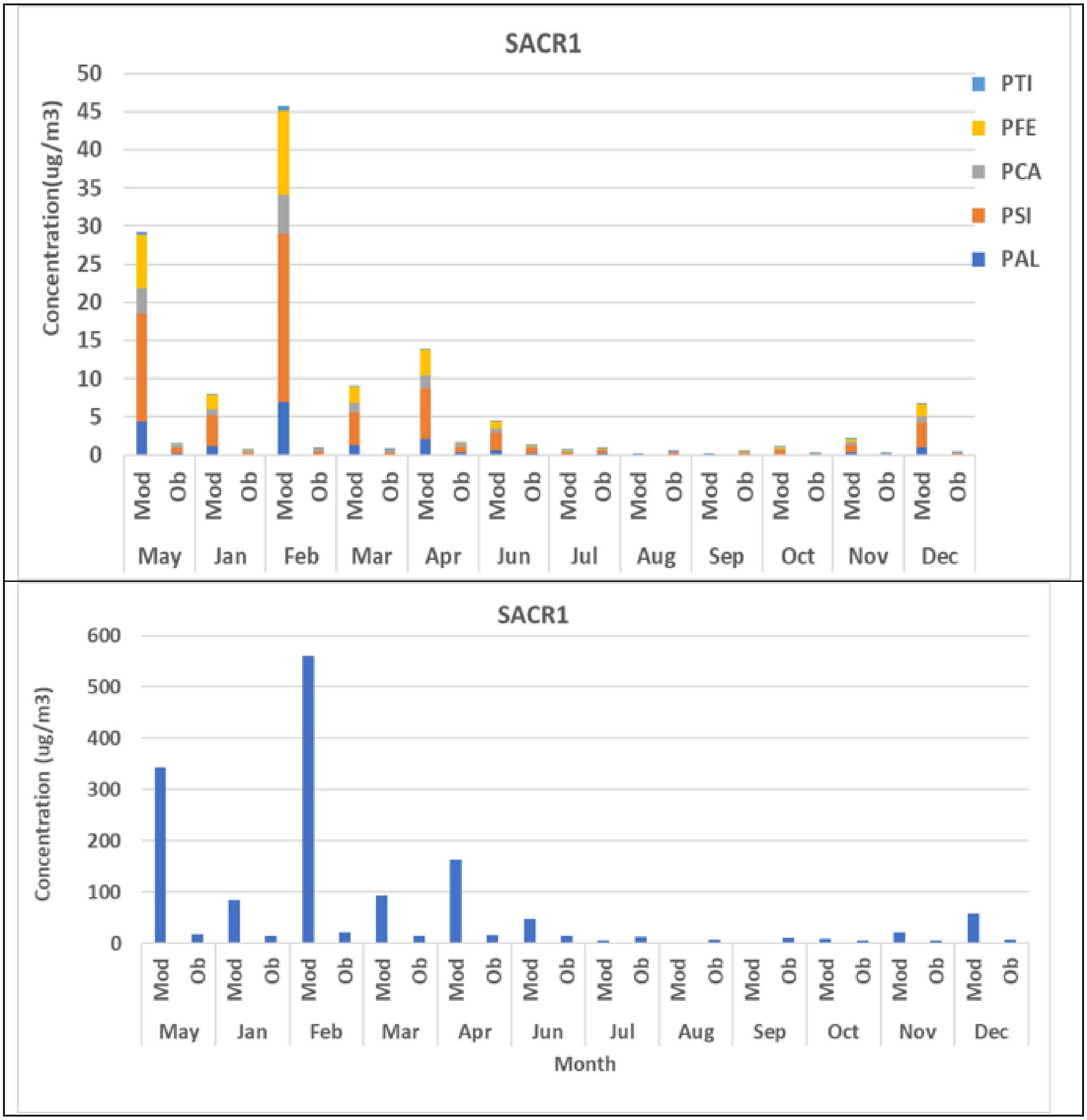

Figure 3-5. Comparison of 2022 monthly averaged modeled and measured fine dust elemental concentrations (top) and total coarse mass concentrations (bottom) at the Salt Creek (SACR) IMPROVE site.

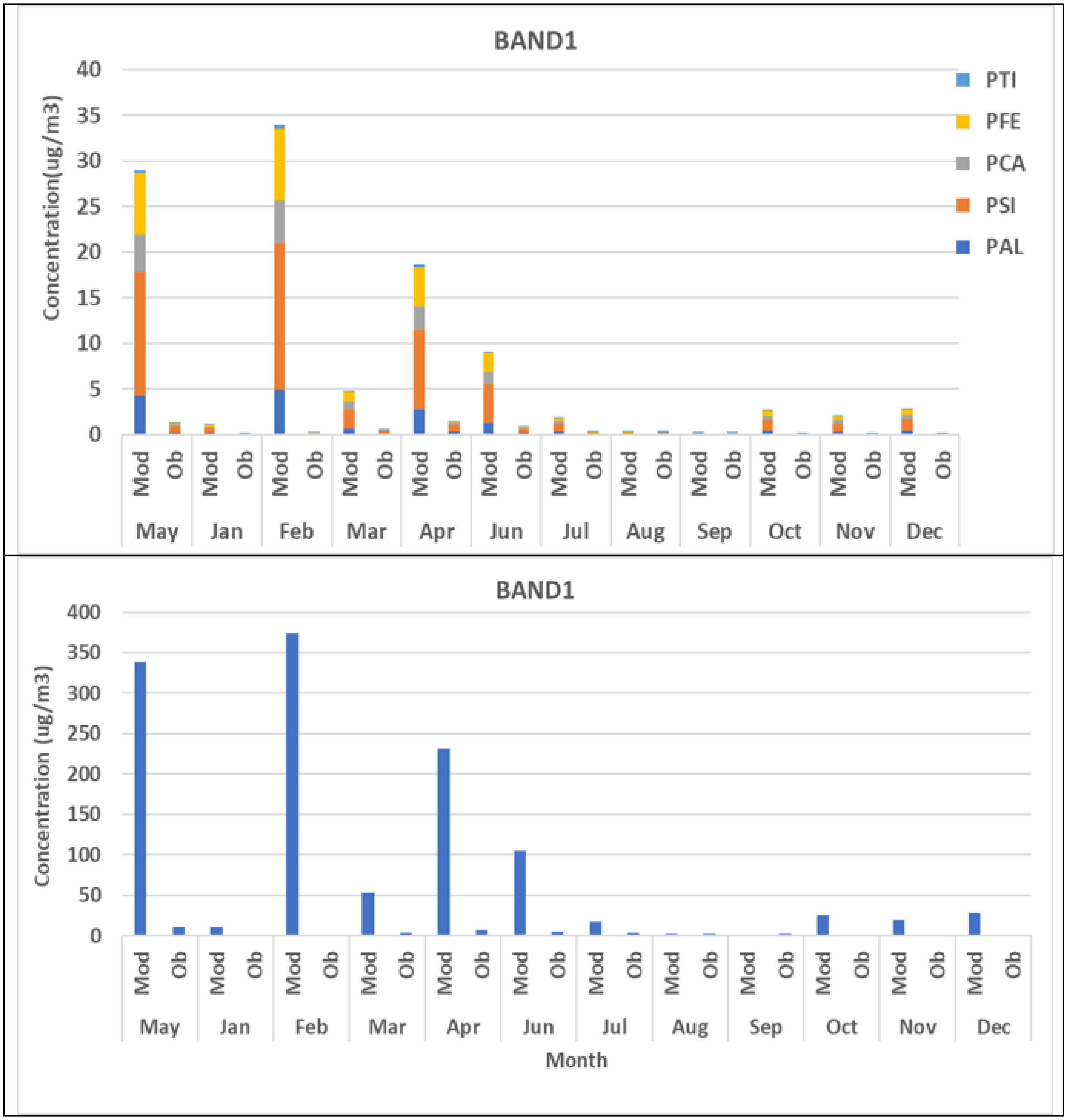

Figure 3-6. Comparison of 2022 monthly averaged modeled and measured fine dust elemental concentrations (top) and total coarse mass concentrations (bottom) at the Bandelier (BAND) IMPROVE site.

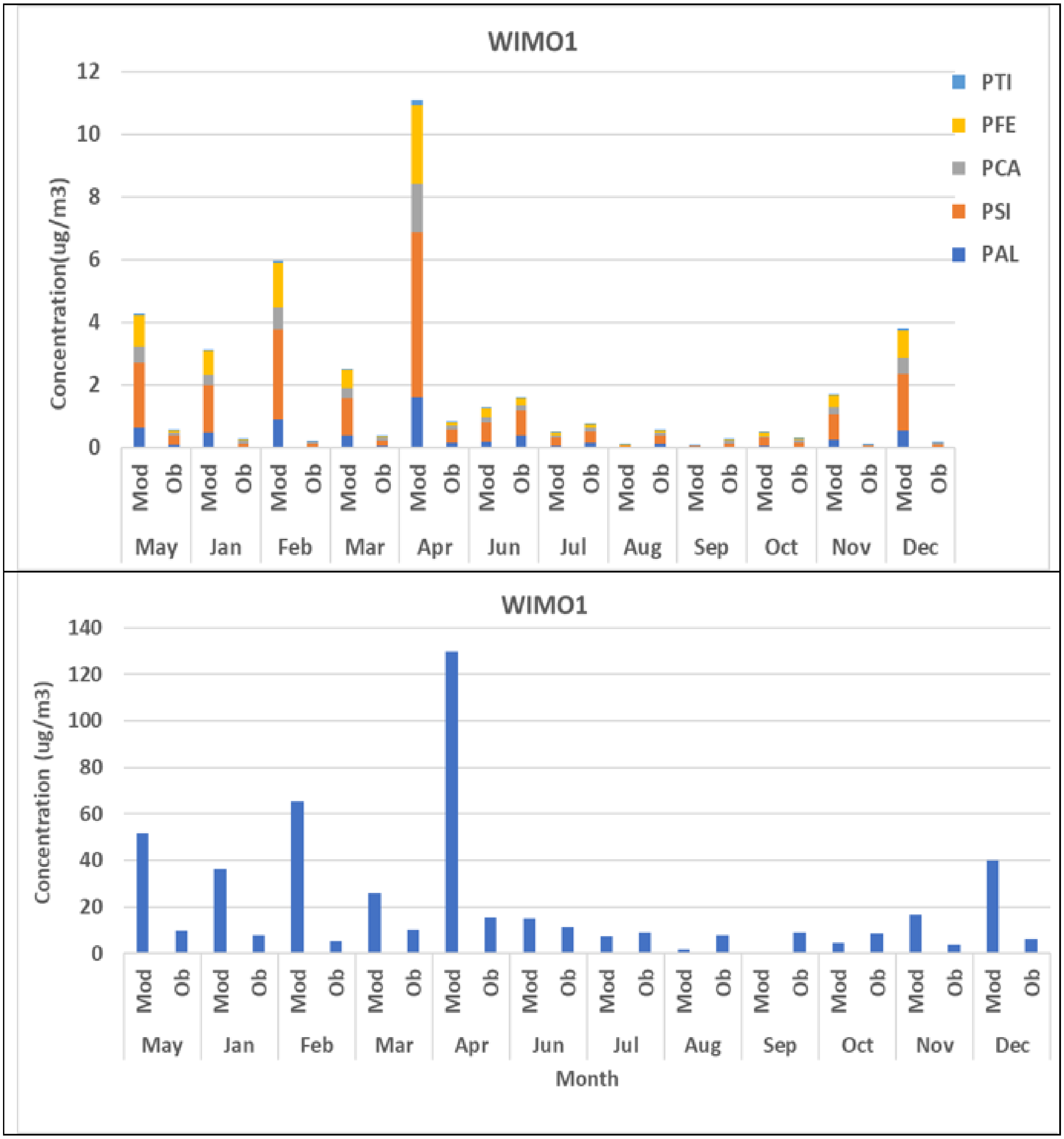

Figure 3-7. Comparison of 2022 monthly averaged modeled and measured fine dust elemental concentrations (top) and total coarse mass concentrations (bottom) at the Wichita Mountains (WIMO) IMPROVE site.

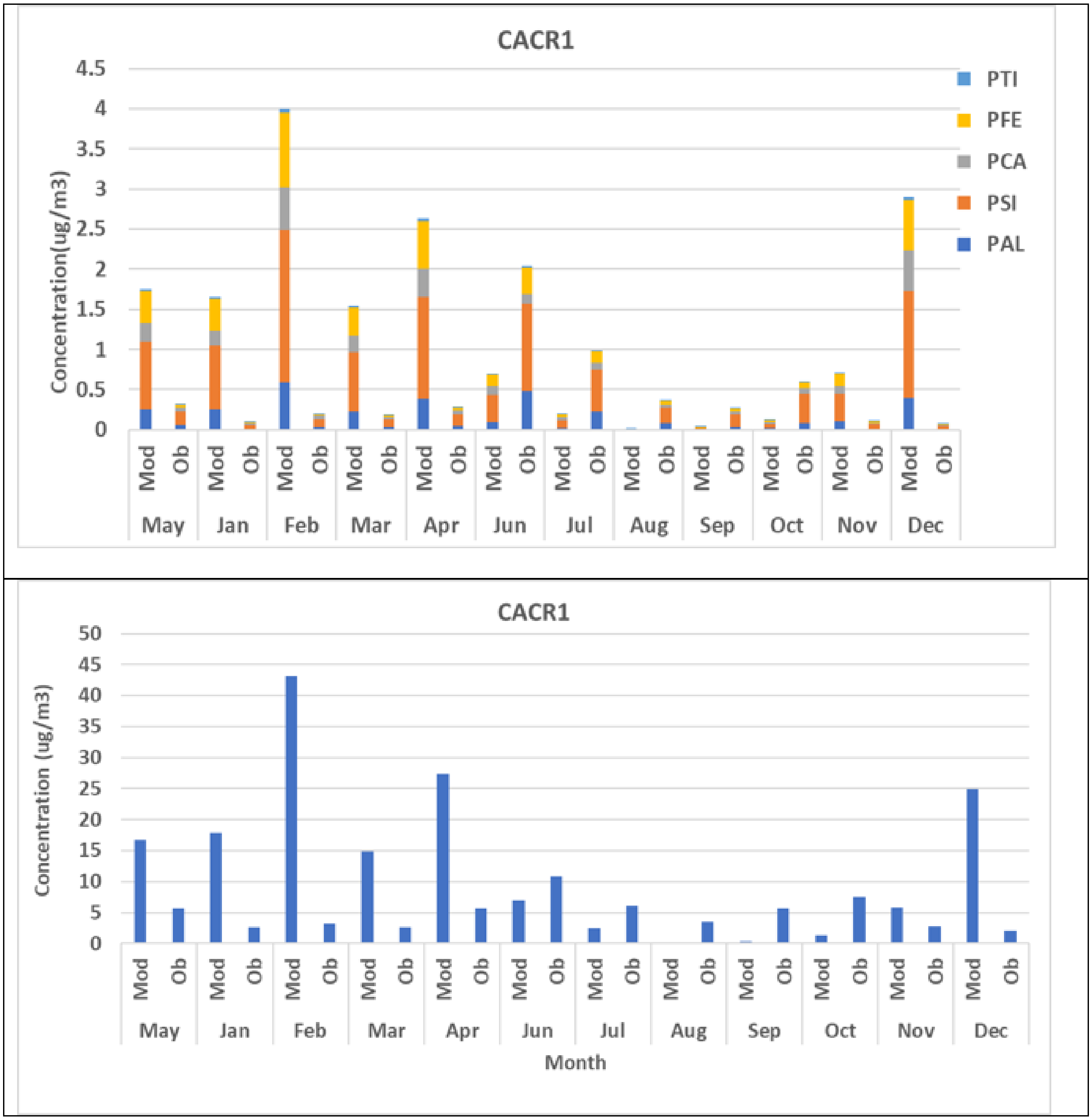

Figure 3-8. Comparison of 2022 monthly averaged modeled and measured fine dust elemental concentrations (top) and total coarse mass concentrations (bottom) at the Caney Creek (CACR) IMPROVE site.

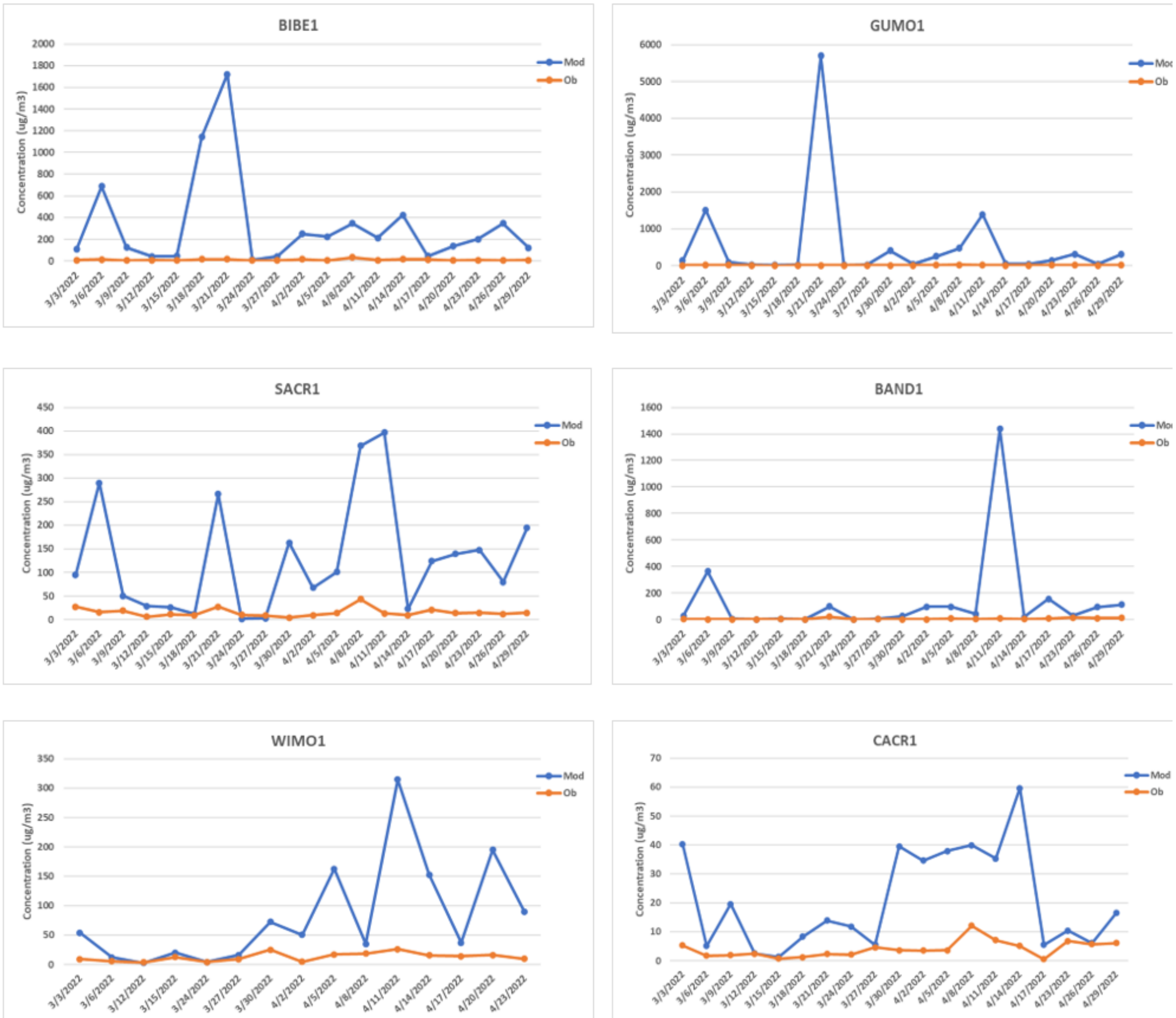

Figure 3-9. Time series of 24-hour coarse PM concentrations over March-April 2022. CAMx simulated CCRS concentrations are compared with IMPROVE CM measurements, taken every 3 days.

3.5 Sensitivity Runs and Analysis

The initial CAMx inert run (Base Case) indicated unreasonably high fine and coarse dust concentrations caused by excessive WBDUST emission estimates. Ramboll further investigated potential causes for this and conducted a series of sensitivity runs. First, Ramboll implemented diagnostics within the WBDUST model to trace the calculations for a grid cell with especially high emissions in the Rio Grande area just southeast of El Paso. The diagnostics confirmed that the emission flux equations were correctly coded and properly calculating dust emission according to the input meteorological data. As part of that investigation, Ramboll identified the following factors that contributed to the excessive emissions (in order of importance):

- Predicted persistently high wind speeds exceeding 50 miles per hour
- Predicted dry soil conditions, with moisture content below 20%
- Low default Leaf Area Index (LAI) and vegetation fraction for shrub and grasslands during early spring months (e.g., March and April), resulting in large emissive fractions of 12 km grid cells

Additionally, Ramboll realized that the dust saltation equation that initiates the dust emission process is unbounded with respect to wind speed (or more precisely, wind stress). This leads to unrealistically high emissions under extreme wind conditions. To address this, Ramboll applied a wind stress cap to limit the saltation flux, ensuring that wind stress does not exceed the threshold stress by more than 10%.

During Ramboll's investigation and discussions with TCEQ, the TCEQ staff suggested testing WBDUST with an alternative set of meteorological data, such as CAMx-ready meteorological inputs from EPA's 2022v1 modeling platform that Ramboll had previously acquired. The EPA's 12US2 grid is very similar to TCEQ's 12 km domain, except that the TCEQ domain includes three additional rows along the southern edge. EPA ran WRF for the 2022v1 platform using an alternative land surface model (P-X) employing soil moisture nudging and coupled to the ACM2 boundary layer treatment. Ramboll found substantially lower wind speeds and higher soil moisture content in EPA's meteorological files.

Ramboll conducted a set of sensitivity runs focused on evaluating the influence of meteorological inputs, applying the wind stress cap, and testing the effect of emission scaling. WBD emissions were regenerated for March and April using the following four configurations:

1) Sens01 – TCEQ meteorology, with wind stress cap and 0.1 scaling factor
2) Sens02 – EPA meteorology, wind stress cap and 0.1 scaling factor
3) Sens03 – TCEQ meteorology, wind stress cap and 1.0 scaling factor
4) Sens04 – EPA meteorology, wind stress cap and 1.0 scaling factor

Figure 3-10 compares the spatial distribution of WBD emissions (FCRS plus CCRS) between the Sens01 and Sens02 scenarios for a high emissions day (March 21), which exhibited excessively high coarse mass concentrations in the base case. The Sens01 run with TCEQ meteorology shows approximately three times higher total emissions than Sens02 with EPA meteorology, primarily due to differences in winds and soil moisture. Figure 3-11 presents a similar comparison between Sens03 and Sens04. While the spatial patterns remain consistent with those in Figure 3-10, both Sens03 and Sens04 yield a tenfold increase in emissions as expected.

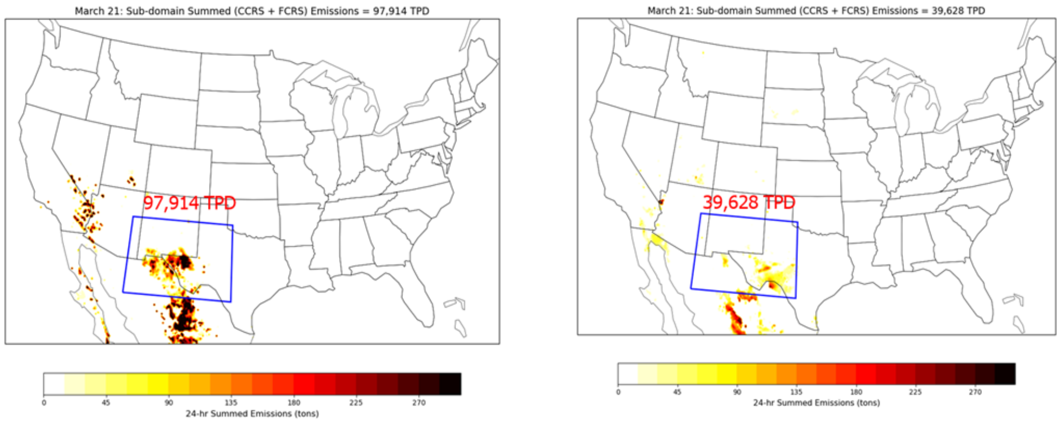

Figure 3-10. Spatial distribution of WBDUST FCRS+CCRS emissions on March 21, 2022 and emission sums on the inset sub-domain: Sens01 (left) and Sens02 (right).

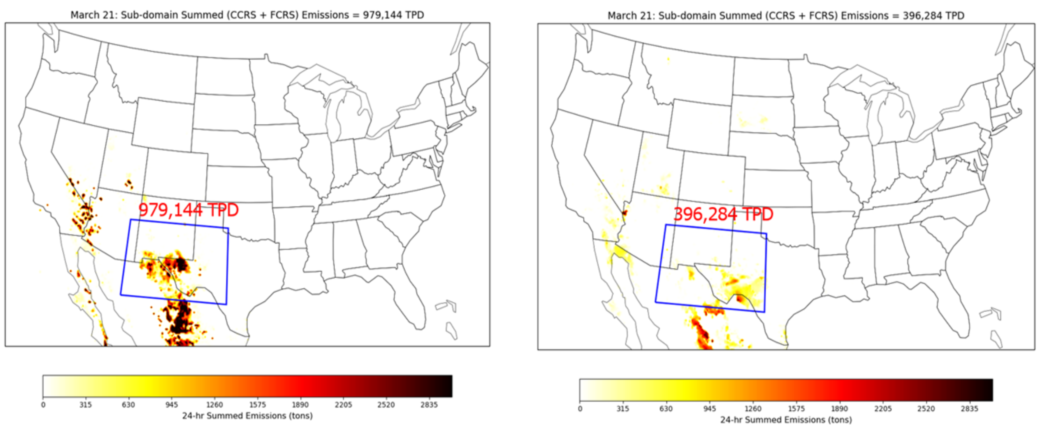

Figure 3-11. Spatial distribution of WBDUST FCRS+CCRS emissions on March 21, 2022 and emission sums on the inset sub-domain: Sens03 (left) and Sens04 (right).

Ramboll ran two CAMx inert sensitivity simulations on the 12 km grid using emissions from Sens01 and Sens04. The resulting CCRS concentrations were compared against observations at six key monitoring sites, as shown in Figures 3-12 through 3-17. At all six locations, particularly those situated near the U.S.–Mexico border (BIBE, GUMO, and SACR), both sensitivity runs showed substantial improvements in coarse mass performance compared to the Base case simulation (shown in Figure 3-9). These improvements are primarily due to the implementation of a wind stress cap, which limits the unbounded increase in emissions with wind speed, and the application of a scaling factor in Sens01 to reduce the dust flux magnitude. While both Sens01 and Sens04 reduced unreasonably high concentrations observed in the Base Case, some large over predictions on peak days persisted in each scenario.

The spatial and temporal differences in emissions and CM concentrations between the two sensitivity runs are primarily driven by variations in the underlying meteorological datasets. In high-emission areas as West Texas and southeastern New Mexico, the TCEQ meteorology showed higher wind speeds and drier soil conditions, which contributed to more frequent and intense dust emissions on peak days (e.g., March 21). In contrast, monitoring sites located in minimally emissive areas, such as CACR and WIMO in the eastern portion of the domain, experienced lower wind speeds and higher soil moisture, leading to minimal or no dust emissions. In fact, even in the Base case, large over predicted

WBDUST concentrations at the eastern sites were entirely driven by transport from west Texas and beyond rather than local emissions.

Although further reducing the emissions in Sens04 by applying a 0.1 scaling factor may bring concentrations closer to observations, preliminary results suggest that such adjustments may not provide a substantial advantage over Sens01 in terms of performance or representativeness.

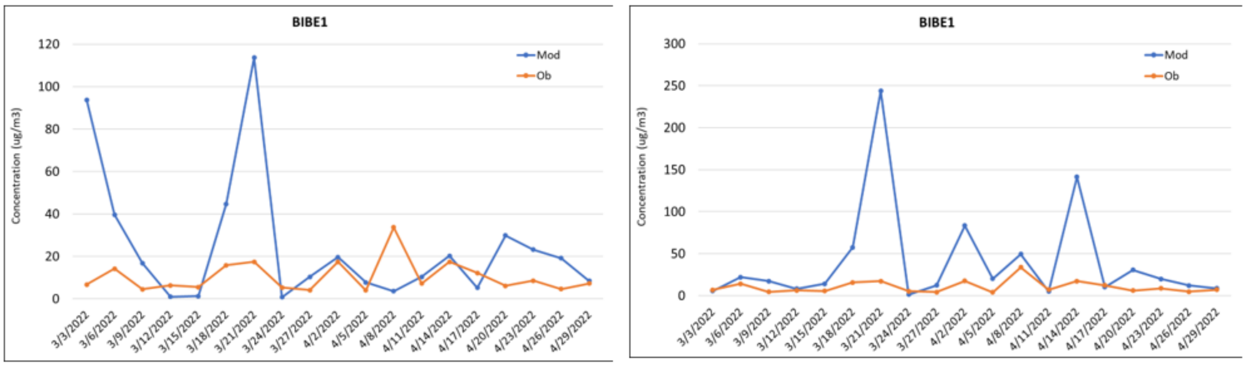

Figure 3-12. Time series of 24-hour CAMx simulated CCRS concentrations compared with IMPROVE CM measurements at BIBE site for Sens01 (left) and Sens04 (right)

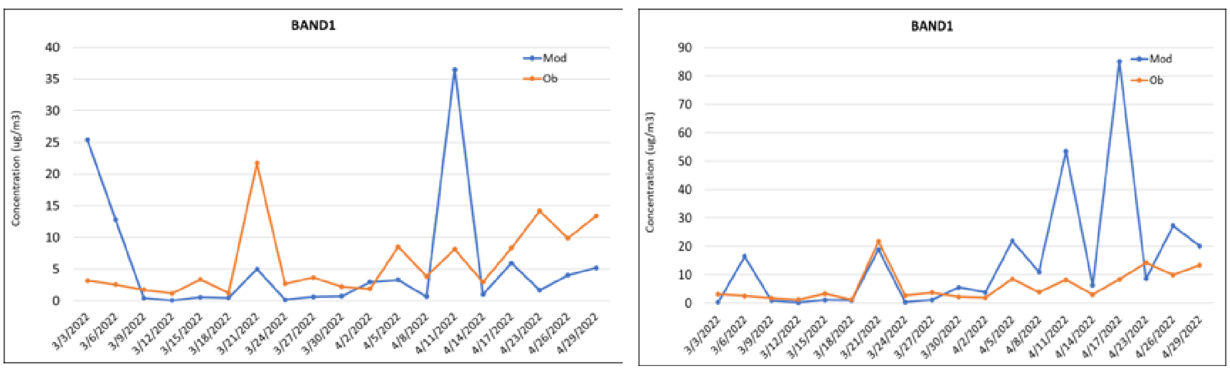

Figure 3-13. Time series of 24-hour CAMx simulated CCRS concentrations compared with IMPROVE CM measurements at BAND site for Sens01 (left) and Sens04 (right)

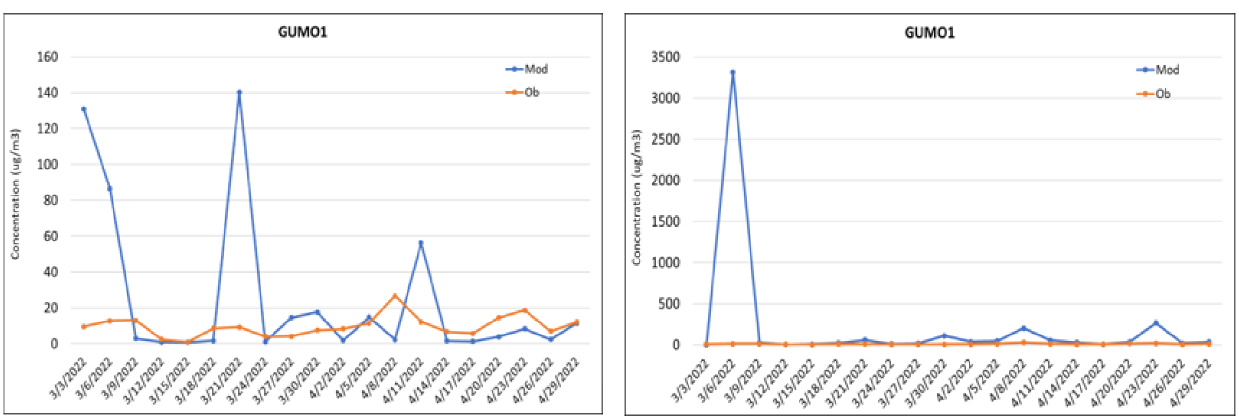

Figure 3-14. Time series of 24-hour CAMx simulated CCRS concentrations compared with IMPROVE CM measurements at GUMO site for Sens01 (left) and Sens04 (right)

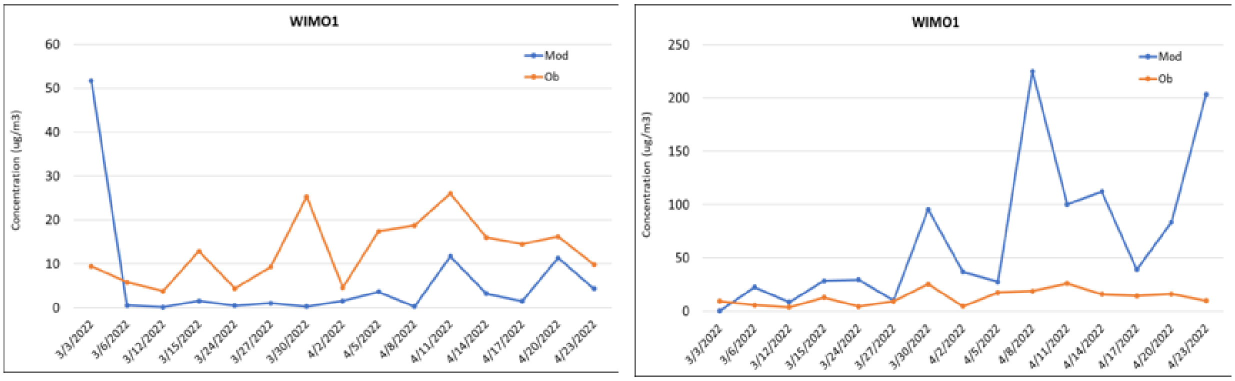

Figure 3-15. Time series of 24-hour CAMx simulated CCRS concentrations compared with IMPROVE CM measurements at WIMO site for Sens01 (left) and Sens04 (right)

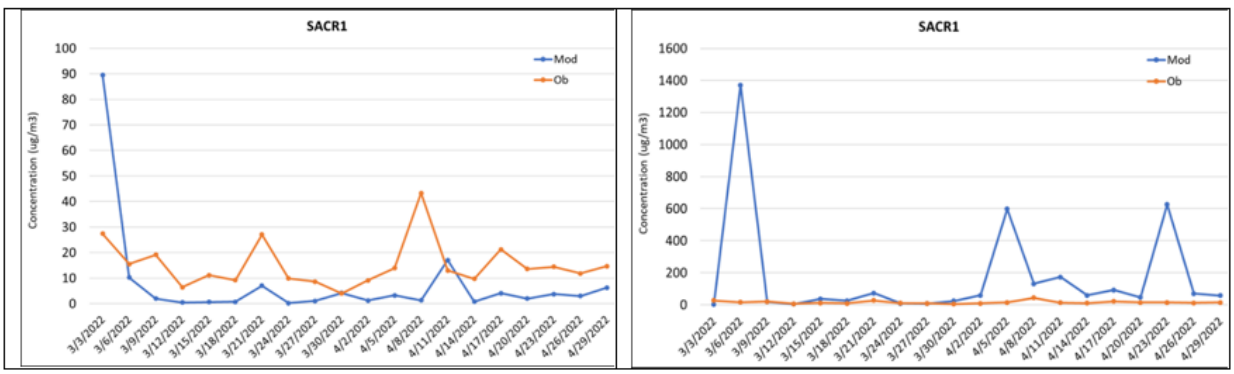

Figure 3-16. Time series of 24-hour CAMx simulated CCRS concentrations compared with IMPROVE CM measurements at SACR site for Sens01 (left) and Sens04 (right)

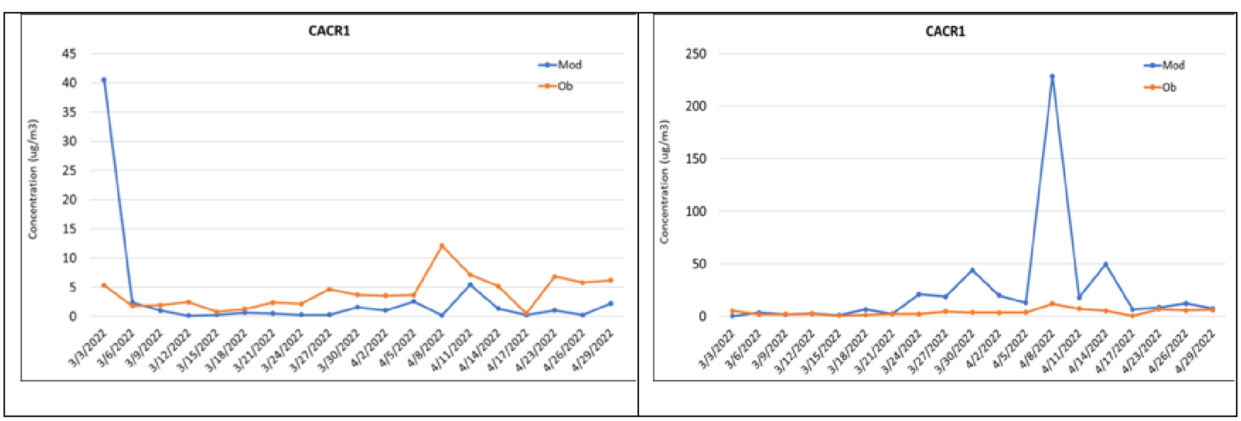

Figure 3-17. Time series of 24-hour CAMx simulated CCRS concentrations compared with IMPROVE CM measurements at CACR site for Sens01 (left) and Sens04 (right)

4.0 SUMMARY AND RECOMMENDATIONS

For this project, Ramboll developed a set of Python tools to improve how area fugitive dust emissions are represented in CAMx air quality modeling. These tools apply transport fraction adjustments and account for the effects of precipitation and snow cover. Using WRFCAMx meteorological data and EPA-established methods, the tools generate gridded transport fractions and adjust fugitive dust emissions in CAMx NetCDF format. The transport fraction adjustments reflect near-source deposition and structural barriers that reduce dust transport. These gridded transport fractions are based on land use and landscape roughness. The script also removes emissions on days when at least 0.01 inches of precipitation occur or when snow cover is present.

Ramboll also developed and evaluated WBD emissions for the 2022 modeling year using the WBDUST v2.2 model. By using 2022-specific USDA CropScape data, the modeling captured spatial and temporal variability in cropland tilling across the 12 km and 4 km TCEQ domains. However, the base CAMx screening inert run showed substantial overpredictions of coarse dust concentrations during the spring and winter, particularly in March and April.

Further sensitivity analyses identified several key factors contributing to these overpredictions: abnormally high wind speeds, dry soil conditions, and low vegetation cover during early spring. In particular, the unbounded saltation flux in the WBDUST model resulted in unrealistically high emissions under extreme wind conditions. By applying a wind stress cap and scaling the windblown dust emissions down by a factor of 0.1, based on initial model performance tests, Ramboll were able to substantially reduce those overestimates. The Sens01 configuration (TCEQ meteorology with wind stress cap and 0.1 scaling factor) is recommended for future full-chemistry CAMx simulations.

Ramboll recommend that TCEQ consider the following activities stemming from this work:

1. Further investigation and potential model updates related to the influence of meteorological inputs on WBD emission estimates, particularly for soil moisture and vegetative density as a function of month/season;
2. Full-chemistry model evaluation using different WBD emissions to understand how the WBD estimates impact overall PM performance.

5.0 REFERENCES

Adelman, Z. (2012). Memorandum: Fugitive Dust Modeling for the 2008 Emissions Modeling Platform. UNC Institute for the Environment, Chapel Hill, NC.

Emery, et al. (2021). Improving Estimates of Wind-Blown Dust from Natural and Agricultural Sources, Final Report: AQRP Project No. 20-011. Prepared by Ramboll US Consulting for the Texas Air Quality Research Program.

Environmental Protection Agency. (2024, March 6). Reconsideration of the National Ambient Air Quality Standards for Particulate Matter. Federal Register, 89(45), 16202–16406.

Eyth, A., Vukovich, J., Farkas, C., Godfrey, J., & Seltzer, K. (2025). Technical Support Document (TSD): Preparation of Emissions Inventories for the 2022v1 North American Emissions Modeling Platform. US Environmental Protection Agency, Office of Air Quality Planning and Standards, Air Quality Assessment Division.

Farkas, Caroline, Eyth, Alison, & USEPA (2020). Technical Support Document (TSD): Preparation of Emissions Inventories for the 2020 North American Emissions Modeling Platform. https://www.epa.gov/system/files/documents/2024-10/2020_emismod_tsd_dec2023_508.pdf.

George Pouliot, Heather Simon, Prakash Bhave, Daniel Tong, David Mobley, Tom Pace and Thomas Pierce (2012). Assessing the Anthropogenic Fugitive Dust Emission Inventory and Temporal Allocation Using an Updated Speciation of Particulate Matter. In book: Air Pollution Modeling and its Application XXI (pp.585-589). Also available at https://www3.epa.gov/ttnchie1/conference/ei19/session9/pouliot.pdf

Jacquemin B. and Noilhan J. (1990). Sensitivity study and validation of a land surface parameterization using the HAPEX-MOBILHY data set” in Boundary-Layer Meteorology journal (1990, v52, p93-134). Also available at https://link.springer.com/article/10.1007/BF00123180

NASS, 2025a. CropScape webpage: https://www.nass.usda.gov/Research_and_Science/Cropland/Release/index.php

NASS, 2025b. Research and Science, CropScape and Cropland Data Layers website: https://www.nass.usda.gov/Research_and_Science/Cropland/SARS1a.php

Pace, T.G. “Methodology to Estimate the Transportable Fraction (TF) of Fugitive Dust Emissions for Regional and Urban Scale Air Quality Analyses”, U.S. EPA, Research Triangle Park NC, August 2005. http://www.epa.gov/ttnchie1/emch/dustfractions/transportable_fraction_080305_rev.pdf

Ramboll. (2023). WBDUST Guide. https://www.camx.com/getmedia/wbdust.26mar24.tgz.

Ramboll (2024). CAMx v7.3 user’s guide. https://www.camx.com/Files/CAMxUsersGuide_v7.30.pdf

U.S. Department of Agriculture, National Agricultural Statistics Service. (2025). Cropland Data Layer. https://www.nass.usda.gov/Research_and_Science/Cropland/Release/index.php