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Fire Emission Inventory Development for 2022 Modeling Platform

Final Report

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RAMBOLL

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Contents

Table of Figures

Table of Tables

LIST OF ARONYMS AND ABBREVIATIONS

3-D	Three-dimensional
ABI	Advanced Baseline Imager
AM	Ante-meridian
AOD	Aerosol Optical Depth
AQRP	Air Quality Research Program
BC	Black Carbon
CA	California
CAMx	Comprehensive Air quality Model with extensions
CAMS	Copernicus Atmospheric Monitoring Service
CB6r4	Carbon Bond version 6, Revision 4
CB7r1	Carbon Bond version 7, Revision 1
C-IFS	Composition Integrated Forecasting System
CMAQ	Community Multiscale Air Quality Model
CO	Carbon Monoxide
CONUS	CONtinental US
CSV	Comma Separated Value file
ECMWF	European Centre for Medium-Range Forecasts
EPA	Environmental Protection Agency
FEER	Fire Energetics and Emissions Research
FEI	Fire Emission Inventory
FINN	Fire INventory from NCAR
FRP	Fire Radiative Power
g	gram
GEOS	Goddard Earth Observing System
GFAS	Global Fire Assimilation System
GIS	Geographic Information System
GOES	Geostationary Operational Environmental Satellite
HRRR-Smoke	High Resolution Rapid Refresh model with smoke
IS4FIRES	Integrated monitoring and modelling System for wildland FIRES project
JPSS	Joint Polar Satellite System
kg	kilogram
km	kilometer
m	meter
MDA8	Maximum Daily Average 8-hour
MISR	Multi-angle Imaging SpectroRadiometer
MODIS	MODerate resolution Imaging SpectroRadiometer
mol	mole
NASA	National Aeronautics and Space Administration
NCAR	National Center for Atmospheric Research
netCDF	network Common Data Format
NMB	Normalized mean bias
NME	Normalized mean error (unsigned, or gross)
NOx	Nitrogen oxides
OC	Organic Carbon
OM	Organic Mass
PBL	Planetary Boundary Layer
PBL500	Planetary Boundary Layer height plus 500 meters
PM	Post-meridian
PM	Particulate Matter

$PM_{2.5}$	Particulate Matter less than 2.5 microns
ppb	parts per billion
QFED	Quick Fire Emissions Dataset
RAVE	Regional Advanced baseline imager and Visible infrared imaging radiometer suite fire Emissions
s	second
SIP	State Implementation Plan
SMOKE	Sparse Matrix Operator Kernel Emissions
TCEQ	Texas Commission on Environmental Quality
ug	microgram
US	United States
VIIRS	Visible Infrared Imaging Radiometer Suite
VOC	Volatile organic compounds
W	Watt
WACCM	Whole Atmosphere Community Climate Model
WRF	Weather Research and Forecasting model
WRF-Chem	Weather Research and Forecasting model with Chemistry

EXECUTIVE SUMMARY

Fires are large emission sources affecting ozone and particulate matter concentrations over regional scales, and therefore accurate Fire Emission Inventories (FEIs) are needed for exceptional event analyses and State Implementation Plan (SIP) modeling. Emissions estimates from currently available FEIs can differ by an order of magnitude so the decision on which FEI to include in modeling may have a significant impact on modeled air quality. The TCEQ has relied upon the Fire INventory from NCAR (FINN) to characterize fire emissions in recent modeling efforts. In previous projects with the TCEQ, Ramboll (2022b; 2023) developed and updated a Python-based tool to process four different global FEIs into model-ready inputs, which allows the TCEQ to choose among other FEIs to improve model performance. At the conclusion of these projects, the tool could process: 1) FINN2.5; 2) Global Fire Assimilation System version 1.2 (GFAS1.2); 3) Quick Fire Emissions Dataset version 2.5 (QFED2.5); and 4) Fire Energetics and Emissions Research (FEER1.0). Ramboll (2023) also evaluated photochemical model performance using the different FEIs throughout April and May of 2019 when transport of smoke from biomass burning in Mexico and Central America was frequent. The Comprehensive Air quality Model with extensions (CAMx; Ramboll, 2022c) was used for that analysis. Ramboll found that the three Fire Radiative Power (FRP)-based FEIs (GFAS, QFED, FEER) all showed substantially smaller ozone biases and overall better statistical agreement with observations as compared to FINN. Recently, Ramboll has developed the capability to process a fifth FEI, Regional ABI and VIIRS fire Emissions version 2.0 (RAVE2.0). This new FEI possesses a unique combination of high temporal and spatial resolution that appears well-suited for high resolution photochemical modeling.

For SIP modeling, the TCEQ requires emission estimates of criteria pollutants from fires in the continental United States, Canada, Mexico and parts of Central America and Caribbean countries encompassed by TCEQ’s modeling domains. This project developed model-ready fire emissions for TCEQ’s 2022 SIP modeling platform from two FEIs – RAVE and GFAS1.2. In addition to developing the model-ready fire emissions, we provide comparisons of the FEIs against each other and EPA’s 2022 beta fire emissions inventory. TCEQ will base its final FEI choice on emission comparisons and tests that evaluate model results against observed concentrations for ozone, particulate matter, and other important precursors. This project will help to inform decisions on which emissions inventories are best suited for modeling platform development.

For future work, Ramboll recommends three activities to improve the FEI processor and support TCEQ’s needs:

- Add capability to process fire emissions from EPA’s emissions modeling platform.
- Conduct CAMx simulations using pre-existing modeling platforms from different years using all available FEIs, and evaluate ozone and $PM_{2.5}$ model performance against observations.
- Develop model-ready fire emissions for 2023 using multiple FEIs.

1.0 INTRODUCTION

1.1 Background

Fires are large emission sources affecting ozone and particulate matter concentrations over regional scales, and therefore accurate Fire Emission Inventories (FEIs) are needed for exceptional event analyses and State Implementation Plan (SIP) modeling. Emissions estimates from currently available FEIs can differ by an order of magnitude so the decision on which FEI to include in modeling may have a significant impact on modeled air quality. The TCEQ has relied upon the Fire INventory from NCAR (FINN[1]) to characterize fire emissions in recent modeling efforts. In previous projects with the TCEQ, Ramboll (2022b; 2023) developed and updated a Python-based tool to process four different global FEIs into model-ready inputs, which allows the TCEQ to choose among other FEIs to improve model performance. At the conclusion of these projects, the tool could process: 1) FINN2.5; 2) Global Fire Assimilation System version 1.2 (GFAS1.2[2]); 3) Quick Fire Emissions Dataset version 2.5 (QFED2.5[3]); and 4) Fire Energetics and Emissions Research (FEER1.0[4]). Ramboll (2023) also evaluated photochemical model performance using the different FEIs from which to make recommendations on the FEI(s) to include in SIP modeling. Ramboll's testing using the Comprehensive Air quality Model with extensions (CAMx; Ramboll, 2022c) showed the same large positive ozone biases that TCEQ found in their CAMx modeling using FINN fire emissions throughout April and May of 2019 when transport of smoke from biomass burning in Mexico and Central America was frequent. However, the three Fire Radiative Power (FRP)-based FEIs (GFAS, QFED, FEER) all showed substantially smaller ozone biases and overall better statistical agreement with observations. Recently, Ramboll has developed the capability to process a fifth FEI, Regional ABI and VIIRS fire Emissions version 2.0 (RAVE2.0[5]).

TCEQ is currently developing a 2022 modeling platform supporting ozone and $PM_{2.5}$ SIPs. This project provides model-ready fire emissions for two different FEIs and comparisons among them. The project allows TCEQ to choose among these FEIs to optimize model performance.

1.2 Project Objectives

For SIP modeling, the TCEQ requires emission estimates of criteria pollutants from fires in the continental United States, Canada, Mexico and parts of Central America and Caribbean countries encompassed by TCEQ's modeling domains. This project developed model-ready fire emissions for TCEQ's 2022 SIP modeling platform from two FEIs – RAVE2.0 and GFAS1.2. In addition to developing the model-ready fire emissions, we provide comparisons of the FEIs against each other and EPA's 2022 beta fire emissions inventory. TCEQ will base its final FEI choice on emissions comparisons and tests that evaluate model results against observed concentrations for ozone, particulate matter, and other important precursors. This project will help to inform decisions on which emissions inventories are best suited for modeling platform development.

[1] https://www2.acom.ucar.edu/modeling/finn-fire-inventory-ncar
[2] https://www.ecmwf.int/en/forecasts/dataset/global-fire-assimilation-system
[3] https://gmao.gsfc.nasa.gov/research/science_snapshots/global_fire_emissions.php
[4] http://feer.gsfc.nasa.gov/data/emissions/
[5] https://sites.google.com/view/rave-emission

2.0 FEI PROCESSOR OVERVIEW

2.1 FEI Summary

The FEI processor was originally developed in 2022, updated in 2023, and designed to generate fire emissions for the following five global FEI products:

- Fire Inventory from NCAR version 2.5 (FINN2.5)
- Global Fire Assimilation version 1.2 (GFAS1.2)
- Quick Fire Emissions Dataset version 2.4 (QFED2.5)
- Fire Energetics and Emissions Research version 1.0 (FEER1.0)
- Regional ABI and VIIRS fire Emissions version 2.0 (RAVE2.0)

Descriptions and key characteristics of each of the FEIs above are available in previous reports. Table 2-1 summarizes key characteristics of three FEIs evaluated in this project. As of June 2024, EPA 2022 fire emissions from the BlueSky system are available in a beta form (hereafter, EPA2022b)[6]. As mentioned later in this report, EPA2022b does not currently have fire emissions outside of the U.S. and is not currently available to use in the FEI processor.

Table 2-1. Summary of key characteristics of select FEIs.

FEI	Horizontal Resolution	Timeframe	Frequency	Approach	Burned Area/FRP Methodology	Emissions Species	Modeling Applications
RAVE2.0	3 km^2 over North America	2021–Present	Hourly with 24-hour lag	FRP	GOES, VIIRS	NOx, total VOC, CO, SO2, NH3, OC, BC, $PM_{2.5}$	HRRR-Smoke; CMAQ; WRF-Chem
GFAS1.2	0.1°×0.1°	2003–present	Daily with 24-hour lag	FRP	MODIS	NOx, VOC, CO, SO2, NH3, OC, BC, $PM_{2.5}$	CAMS C-IFS
BlueSky via EPA	Data source dependent	Every year through 2021; 2022 beta available	Hourly	Burned area	MODIS, HMS, other	NOx, VOC, CO, SO2, NH3, OC, BC, $PM_{2.5}$	EPA emissions modeling platform (EMP)

[6] https://gaftp.epa.gov/Air/emismod/2022/v1/draft/fires/2022EMP_beta_version_fires_tech_memo.2024Apr12.pdf

2.1.1 GFAS1.2

GFAS multiplies FRP from MODIS Aqua/Terra satellite measurements by land cover specific conversion factors to obtain dry matter combustion rate estimates. GFAS then employs a sophisticated filtering system that masks spurious FRP signals from volcanoes, gas flaring and other industrial activity. GFAS includes vertical parameters – plume bottom, plume top and mean altitude of maximum injection height (described in Remy et al., 2017), all of which are derived from a plume rise model. GFAS also provides a separate injection height from IS4FIRES (Remy et al., 2017). As with the fire emissions, these vertical parameters have daily resolution which correspond to early afternoon. The European Centre for Medium-Range Forecasts (ECMWF) Composition Integrated Forecasting System (C-IFS) of Copernicus Atmospheric Monitoring Service (CAMS) utilizes GFAS1.2 for global real time fire and smoke forecasts. GFAS1.2 is available in near real-time at 0.1° resolution.

2.1.2 RAVE2.0

RAVE2.0 is a new FEI product (available 2021 onward) that utilizes a new algorithm to generate hourly 0.03° fire emissions by fusing temporally resolved GOES Advanced Baseline Imager (ABI) FRP and fine spatial-resolution (375 m) FRP from the Visible Infrared Imaging Radiometer Suite (VIIRS) on the Joint Polar Satellite System (JPSS) satellites (Li et al., 2022). RAVE2.0 is available as a near real-time product and a "re-processed" historical product that both cover North America. By contrast, the RAVE1.0 near real-time product covered North America, but the re-processed historical product covered the continental U.S. only. Hourly emissions are produced from land cover and ecoregion-specific FRP diurnal cycles using 5-minute GOES ABI FRP measurements. RAVE's combination of high temporal and spatial resolution is unique and thus appears well-suited for high resolution photochemical modeling. We use the high resolution landcover and landcover-specific diurnal profiles developed by the RAVE team for all non-RAVE FEIs, including GFAS1.2. As of May 2024, RAVE2.0 emissions for 2022 were only available for April through December. Therefore, we generated RAVE1.0 emissions for the January – March 2022 period. RAVE2.0 emissions contain optional "scaled" emission species for primary $PM_{2.5}$, organic carbon (OC), and black carbon (BC), which the RAVE team developed for NOAA forecasting applications[7]. These scaled emissions are higher than the equivalent aerosol emission species as provided in the RAVE1.0 product. Preliminary CAMx evaluation of a simulation using the scaled emissions from the RAVE2.0 FEI revealed large $PM_{2.5}$ overestimations at monitoring locations throughout the western U.S. in summer 2021. After initially providing TCEQ with the scaled RAVE2.0 emissions, we decided to provide a second set of RAVE2.0 emissions using the unscaled emissions. Emission summaries and spatial maps for RAVE2.0 in Section 3 use the scaled emissions. References to "RAVE" hereafter denote this combination of RAVE1.0 and RAVE2.0 products across 2022.

2.1.3 EPA2022b

The United States Environmental Protection Agency (EPA) uses the BlueSky modeling framework for the U.S. National Emissions Inventory (NEI) and prepares SMOKE-ready FF10 files each year. The EPA uses Satellite Mapping Automatic Reanalysis Tools for Fire Incident Reconciliation version 2 (SMARTFIREv2) to produce inputs for BlueSky. Larkin and Raffuse (2015) and Larkin et al. (2009) describe BlueSky and SMARTFIRE as a "framework" for fire emissions modeling rather than a fire emissions model. SMARTFIREv2 and BlueSky contain a menu of choices regarding fire activity datasets, weights, algorithms (SMARTFIREv2) as well as fuels, total consumption, time rate and emissions factors (BlueSky). At the time of this writing (June 2024), emissions for 2022 are not finalized and only U.S fire emissions are available. For this project, we use EPA2022b fire emissions to compare against the RAVE and GFAS1.2 emissions generated using the FEI processor. Because

[7] Personal communication, Fangjun Li

EPA2022b emissions are not available outside of the U.S., we cannot compare RAVE and GFAS1.2 emissions to EPA2022b south of the U.S.

2.2 Justification for Choice of RAVE and GFAS1.2 FEIs

Ramboll is currently performing CAMx modeling sensitivity tests comparing the ozone and $PM_{2.5}$ impacts from all fire emission products available in the FEI processor as part of the CRC A-133 Fires study. The modeling period spans June-September 2021 over the Western/Central U.S. at 12 km resolution (including Texas; see Figure 2-1), which was a particularly active wildfire season in the West[8]. RAVE2.0 emissions had yet to be released when these simulations were conducted in early 2024, so we used RAVE1.0 emissions instead. We note that modeling results from 2021 may not be representative of those in 2022. Additionally, the CRC study does not cover April and May, when transport from fires south of Texas is typically most active.

As part of the CRC study, we produced MDA8 ozone and 24-hour $PM_{2.5}$ scatter plots for all AQS and CASTNET monitoring stations at the statewide level. We present the Texas statewide scatter plots for MDA8 ozone and 24-hour $PM_{2.5}$ in Figure 2-2 and Figure 2-3, respectively. In addition to the five sensitivity simulations using all available FEIs, we performed a simulation without any fire emissions (labeled "No Fires"). The scatter plots show that fires have only minor impacts on ozone and $PM_{2.5}$ concentrations in Texas during the June-September 2021 modeling period. Therefore, we cannot make a clear recommendation on FEI choice based on these results.

We present similar scatter plots in Figure 2-4 and Figure 2-5, but showing results over all AQS monitors across the Western/Central U.S. 12 km modeling domain shown in Figure 2-1. Overall, we find RAVE1.0 exhibits the best agreement with observations, while FINN2.5 displays the poorest agreement with observations. QFED2.5 shows large $PM_{2.5}$ overestimations. Finally, GFAS1.2 and FEER1.0 show similar performance.

Based on our findings from the CRC study and April-May 2019 evaluation performed in the 2023 TCEQ project, we selected RAVE1.0 and GFAS1.2 in consultation with TCEQ and generated model-ready emissions for both products using the FEI processor. In April 2024, RAVE1.0 emissions were replaced with RAVE2.0 emissions for the period of April-December 2022, so we re-processed emissions for this period. The RAVE1.0 FEI does not cover the entirety of the North America 36US3 domain, so we "stitched" the GFAS1.2 emissions in the areas of the 36US3 domain where RAVE1.0 emissions do not exist for the January-March 2022 period. Because the RAVE2.0 FEI covers the entirety of the North America 36US3 domain, we do not perform this stitching when using the RAVE2.0 emissions for the April-December 2022 period.

[8] https://www.fire.ca.gov/incidents/2021

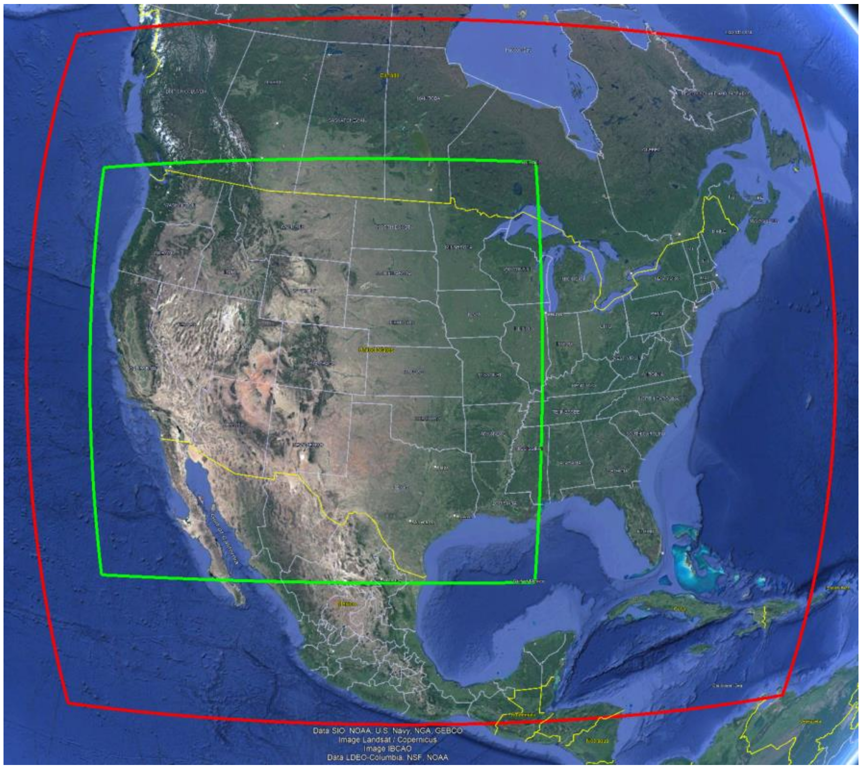

Figure 2-1. CAMx 36 km (red) and 12 km (green) modeling domains used in the CRC A-133 Fires study.

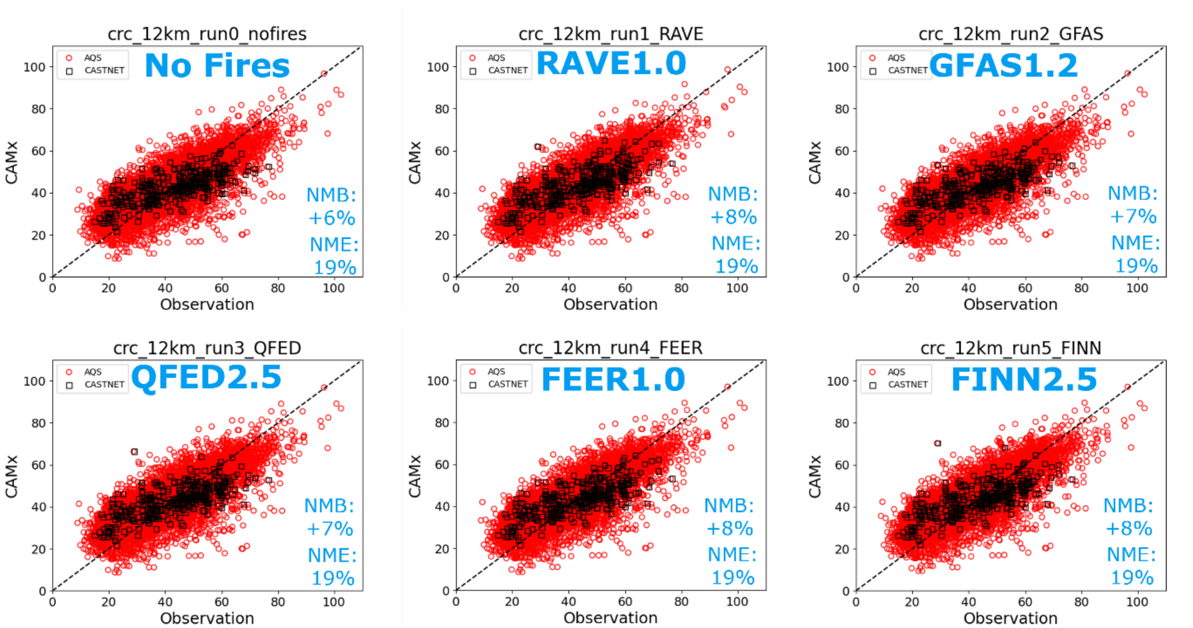

Figure 2-2. Scatter plots showing MDA8 ozone performance for No Fires (top left), RAVE1.0 (top middle), GFAS1.2 (top right), QFED2.5 (bottom left), FEER1.0 (bottom middle), and FINN2.5 (bottom left) at all Texas AQS and CASTNET monitors during June-September 2021. Adapted from CRC A-133 project.

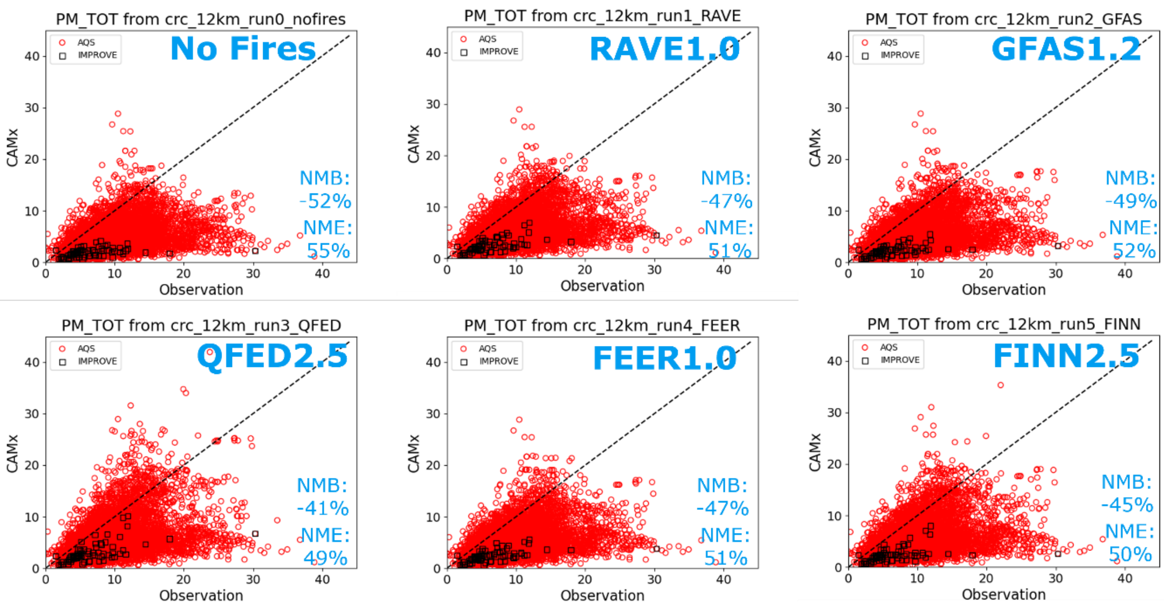

Figure 2-3. Scatter plots showing 24-hour $PM_{2.5}$ performance for No Fires (top left), RAVE1.0 (top middle), GFAS1.2 (top right), QFED2.5 (bottom left), FEER1.0 (bottom middle), and FINN2.5 (bottom left) at all Texas AQS and CASTNET monitors during June-September 2021. Adapted from CRC A-133 project.

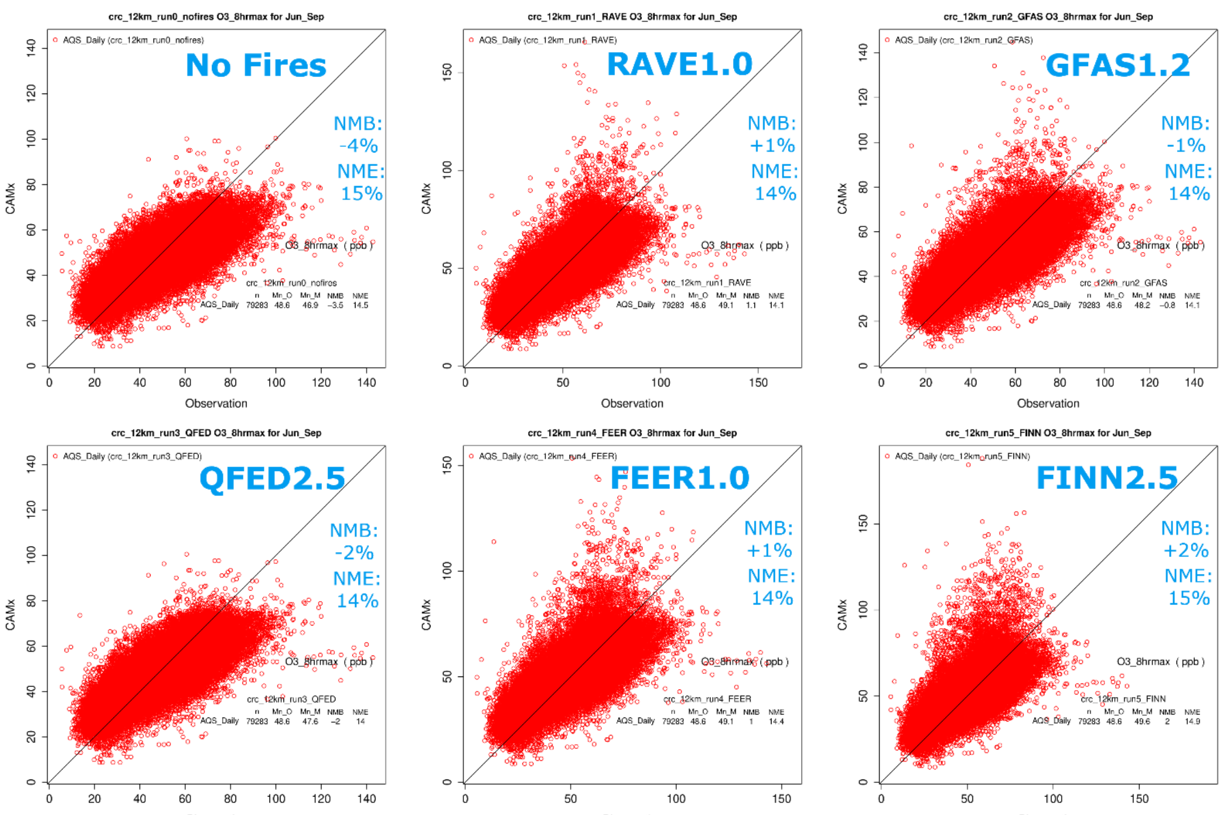

Figure 2-4. Scatter plots showing MDA8 ozone performance for No Fires (top left), RAVE1.0 (top middle), GFAS1.2 (top right), QFED2.5 (bottom left), FEER1.0 (bottom middle), and FINN2.5 (bottom left) at all AQS monitors in CRC A-133 12 km domain during June-September 2021. Adapted from CRC A-133 project.

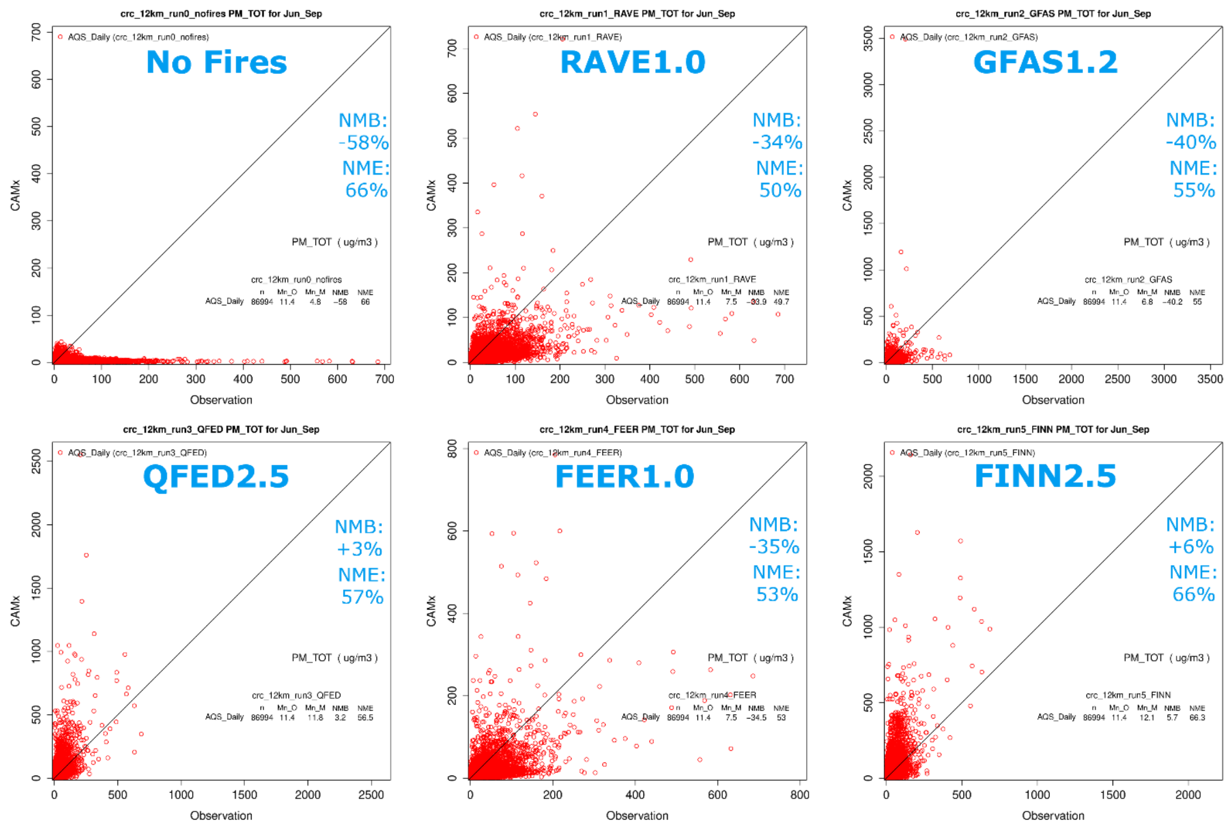

Figure 2-5. Scatter plots showing 24-hour $PM_{2.5}$ performance for No Fires (top left), RAVE1.0 (top middle), GFAS1.2 (top right), QFED2.5 (bottom left), FEER1.0 (bottom middle), and FINN2.5 (bottom left) at all AQS monitors in CRC A-133 12 km domain during June-September 2021. Adapted from CRC A-133 project.

2.3 FEI Processor Update for RAVE

We detail the FEI processing steps (regridding, species mapping, temporal and vertical allocation) in Ramboll (2023). Because the RAVE FEI was not incorporated into the FEI processor at that time, we provide the chemical species mapping file for RAVE2.0 emissions in Table 2-2. This species mapping does not use the scaled aerosol emission species discussed in Section 2.1.2.

Table 2-2. Chemical species mapping from RAVE2.0 to CAMx CB6r4 chemical mechanism.

CAMx Species	RAVE2.0 species	Scale	MW (g/mol)	G(as) or A(erosol)	Comment
CO2	CO2	1	44.01	G	
CO	CO	1	28.01	G	
SO2	SO2	1	64.04	G	
HNO3	NOx	0.18	30.01	G	#mapping developed for AQRP FINN2.0 beta project; assume NO MW based on Table 1 in Andreae and Merlet (2001)
NO	NOx	0	30.01	G	#mapping developed for AQRP FINN2.0 beta project; assume NO MW based on Table 1 in Andreae and Merlet (2001)
NO2	NOx	0.736	30.01	G	#mapping developed for AQRP FINN2.0 beta project; assume NO MW based on Table 1 in Andreae and Merlet (2001)
NTR2	NOx	0.02	30.01	G	#mapping developed for AQRP FINN2.0 beta project; assume NO MW based on Table 1 in Andreae and Merlet (2001)
PANX	NOx	0.008	30.01	G	#mapping developed for AQRP FINN2.0 beta project; assume NO MW based on Table 1 in Andreae and Merlet (2001)
NH3	NH3	1	17.04	G	
ECH4	CH4	1	16.05	G	
VOCs	VOCs	1	1	G	
POA	OC	1	1	A	#assume OC represents organic mass and not just organic carbon
PEC	BC	1	1	A	
FPRM	OC	-1	1	A	#assume OC represents organic mass and not just organic carbon
FPRM	BC	-1	1	A	
FPRM	PM25	1	1	A	#assume PM2.5 includes BC and OC
CPRM	PM25	-1	1	A	#assume PM2.5 includes BC and OC
CPRM	TPM	1	1	A	#assume TPM includes all particulate matter

3.0 2022 FIRE EMISSIONS COMPARISON

In this section, we compare 2022 annual emissions from RAVE, GFAS1.2 and EPA2022b. The RAVE and GFAS1.2 fire emissions were processed through the FEI processor for the TCEQ modeling domains. We used gridded CONUS 12US2 fire emissions to generate the maps shown in Section 3.1 and state-level emission summaries to populate the tables in Section 3.2.

3.1 Annual Fire Emission Map Comparison

Figure 3-1 shows maps of 2022 annual NOx (top row), VOC (middle row), and $PM_{2.5}$ (bottom row) fire emissions for RAVE (left column) and GFAS1.2 (right column) for the TCEQ 36 km CAMx domain. We omit equivalent maps for CO emissions for brevity, but these maps were previously distributed to TCEQ. As of June 2024, EPA2022b emissions do not contain emissions outside of the U.S. Therefore, we exclude the EPA2022b emissions from this comparison. Focusing on Mexico and Central America fires, RAVE appears to detect more fires overall, which makes sense given its higher spatial resolution (0.03°) compared to GFAS1.2 (0.1°). While RAVE NOx and $PM_{2.5}$ emissions are substantially higher than those from GFAS1.2, RAVE VOC emissions appear somewhat lower than GFAS1.2. As noted earlier, the RAVE2.0 $PM_{2.5}$ emissions maps (and summaries in the next section) use the "scaled" aerosol emissions, which are higher than the aerosol emissions used in RAVE1.0.

Figure 3-2 shows maps of 2022 annual NOx (top row), VOC (middle row), and $PM_{2.5}$ (bottom row) fire emissions for RAVE (left column), GFAS1.2 (middle column) and EPA2022b (beta; right column) for the TCEQ 12 km CAMx domain. Focusing on the continental U.S. (since EPA2022b lacks non-U.S. emissions), GFAS1.2 has the least amount of fire detections compared to both RAVE and EPA2022b. In general, RAVE appears to match the EPA2022b spatial coverage of fires well, with some exceptions where RAVE shows less coverage in parts of the Central and Southeast U.S. Because EPA2022b uses reports from local agencies, it is likely that EPA2022b is picking up smaller fires in these areas compared to RAVE's satellite detection approach that is dependent on fire intensity and is subject to smoke obscuration. For regions where RAVE and EPA2022b both have fire detections, RAVE tends to show higher NOx and $PM_{2.5}$ emissions than EPA2022b, while magnitudes for VOC emissions appear to be similar.

Finally, Figure 3-3 displays similar maps as in Figure 3-2, but for the TCEQ 4 km domain which focuses on East Texas. Again, GFAS1.2 has far fewer fire detections than either RAVE or EPA2022b. The blocky appearance of the EPA2022b emissions results from disaggregation of the 12 km resolution product, which is the only resolution available. It is unclear how much the emission discrepancies for Texas fires might impact ozone and $PM_{2.5}$ concentrations within the state. From the CRC A-133 project, Ramboll's analysis of ozone and $PM_{2.5}$ model performance at Texas monitors from June through September 2021 (when smoke impacts from Mexico and Central America were minimal) showed almost no difference among simulations using different fire inventories (RAVE1.0, GFAS1.2, QFED2.5, FEER1.0 and FINN2.5). According to the detailed fire summaries provided with the EPA2022b product, about 82% of total acres burned in Texas are from agricultural and prescribed burns combined[9]. Presumably, these fires are burning during times to minimize air quality impacts.

[9] https://gaftp.epa.gov/Air/emismod/2022/v1/draft/fires/ptfire_2022_beta_all_10apr2024_daily_county_wf-rx-ag.csv

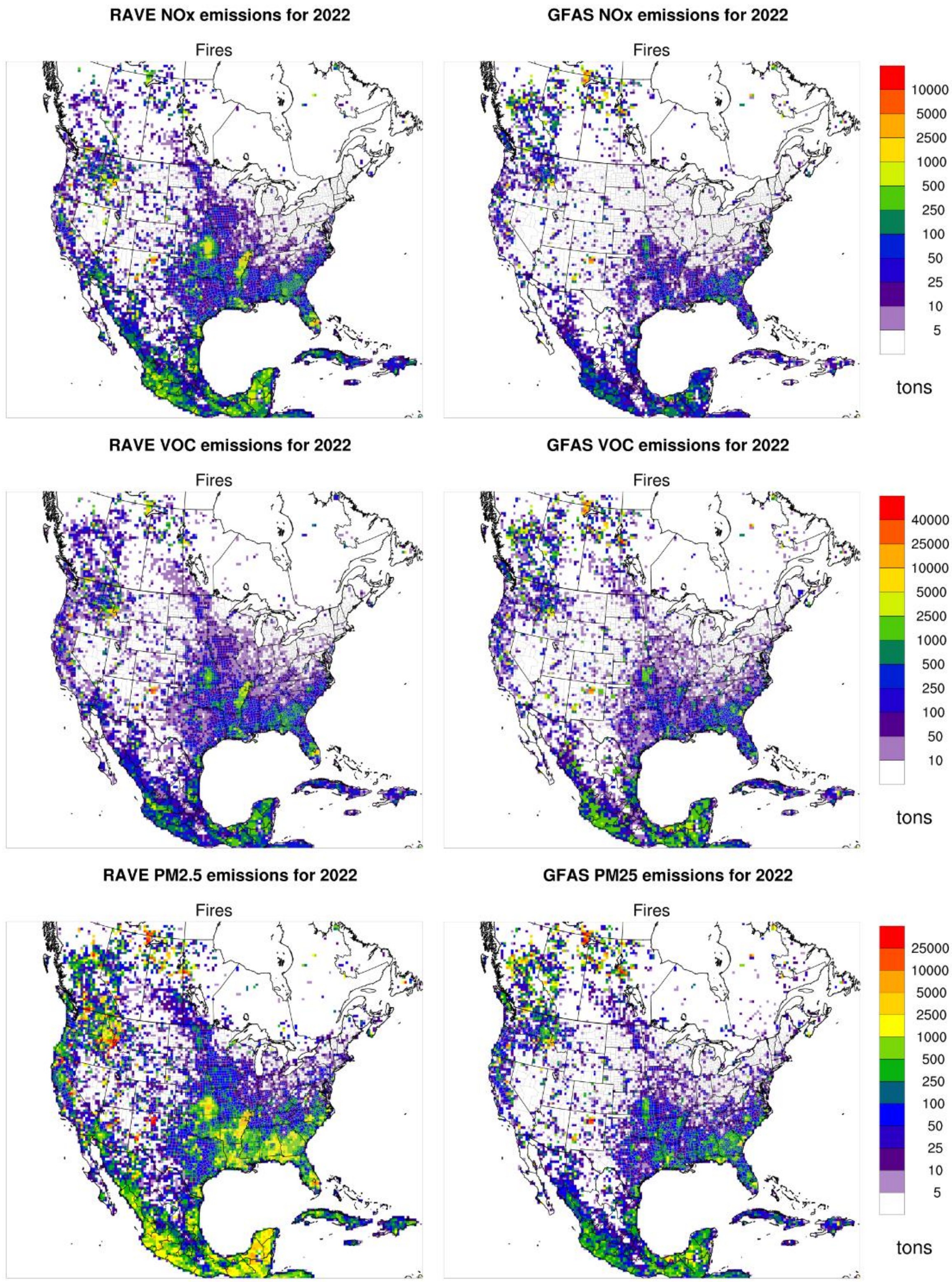

Figure 3-1. 2022 annual NOx (top row), VOC (middle row), and $PM_{2.5}$ (bottom row) fire emissions for RAVE (left column) and GFAS1.2 (right column) for the TCEQ 36 km CAMx domain.

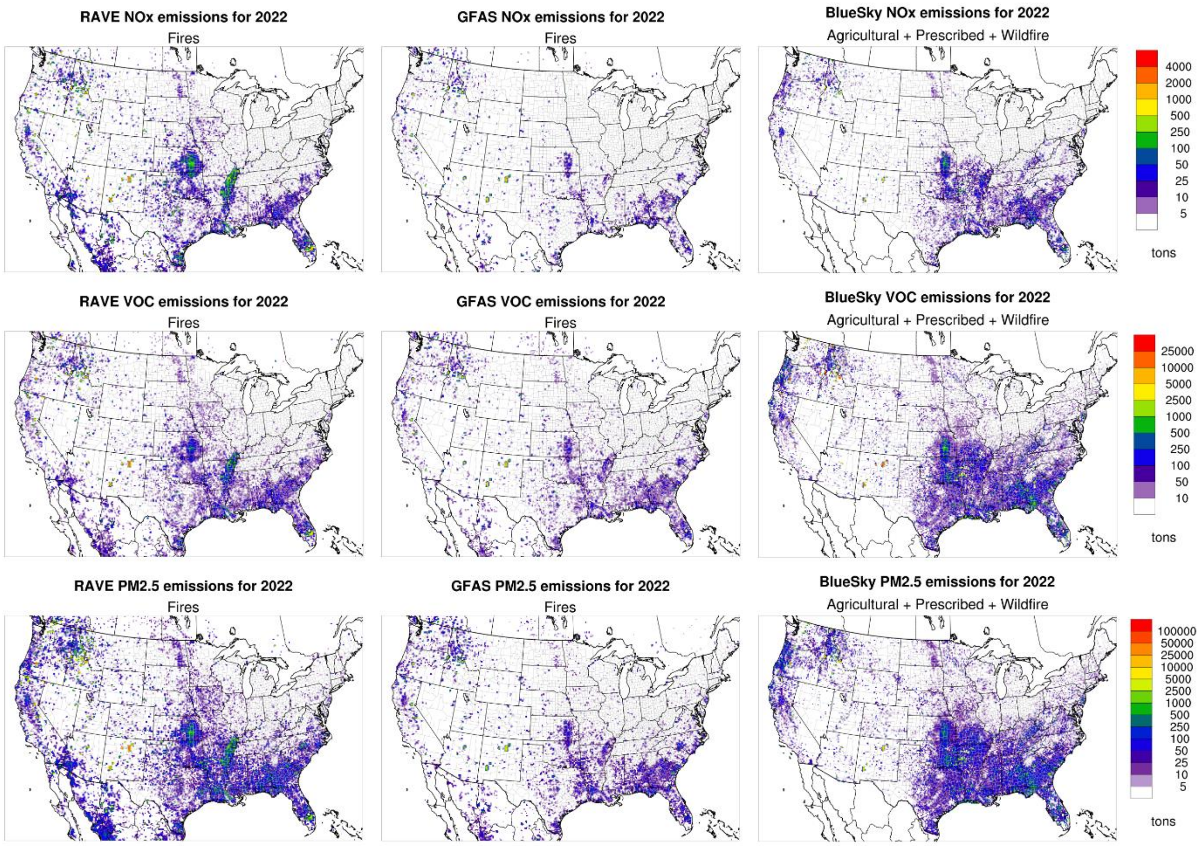

Figure 3-2. 2022 annual NOx (top row), VOC (middle row), and $PM_{2.5}$ (bottom row) fire emissions for RAVE (left column), GFAS1.2 (middle column) and EPA2022b (right column) for the TCEQ 12 km CAMx domain.

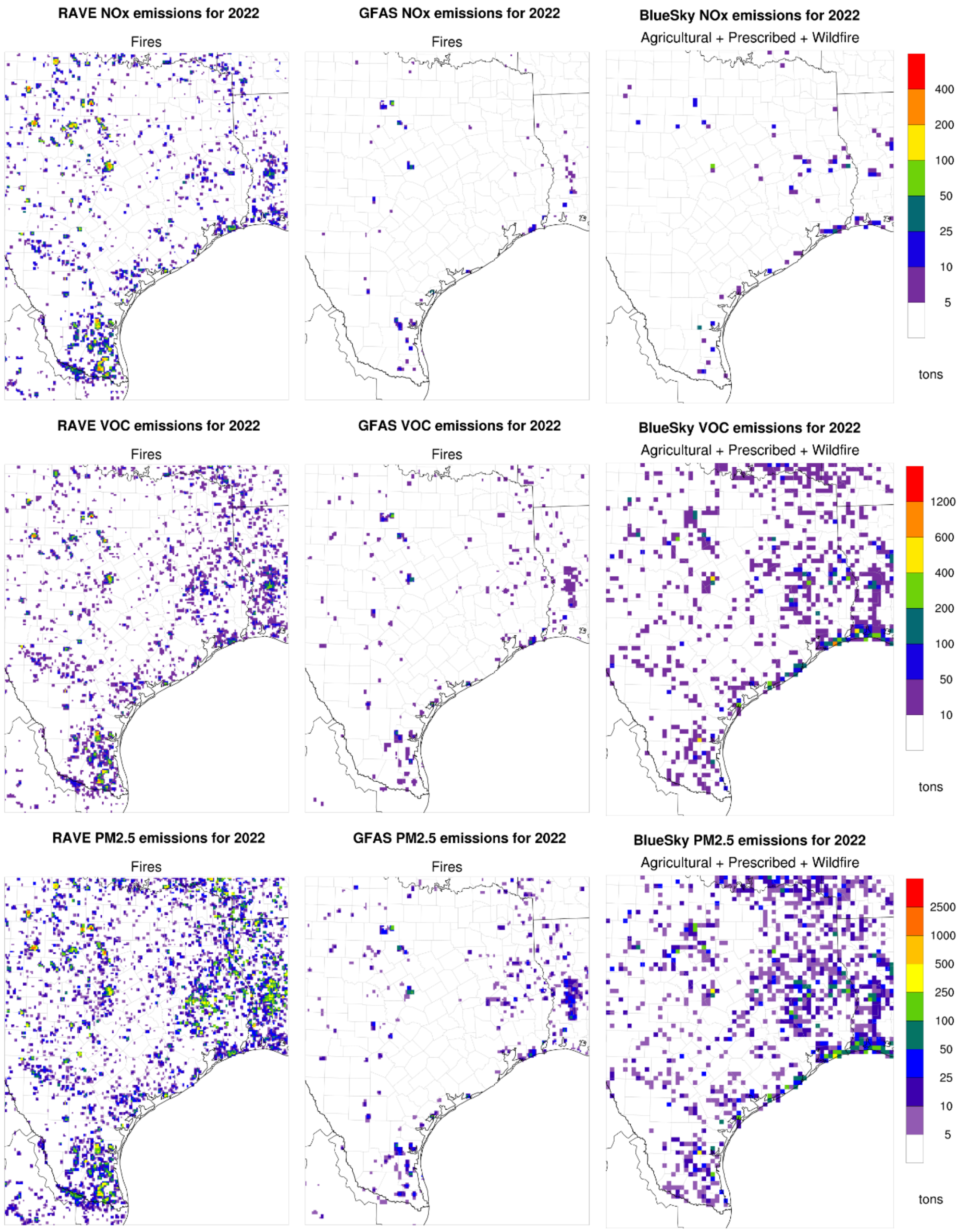

Figure 3-3. 2022 annual NOx (top row), VOC (middle row), and $PM_{2.5}$ (bottom row) fire emissions for RAVE (left column), GFAS1.2 (middle column) and EPA2022b (right column) for the TCEQ 4 km CAMx domain.

3.2 Annual Fire Emission Summaries

Table 3-1 shows annual 2022 $PM_{2.5}$ fire emissions for the EPA2022b, RAVE, and GFAS1.2 FEIs. We show similar emission summaries for NOx, VOC, and CO in Table 3-2, Table 3-3, and Table 3-4, respectively. All tables show emission totals for Texas, Contiguous U.S., Mexico, and Central America. Emission summaries for all U.S. states were provided to TCEQ previously. The RAVE 2022 annual totals include the RAVE1.0 emissions for January-March (which includes GFAS1.2 in the areas of the

North America 36US3 domain where RAVE1.0 emissions are not available) and RAVE2.0 emissions for April-December.

The emission totals shown in the tables agree with the fire emission maps presented in Section 3.1. For Mexico and Central America, RAVE $PM_{2.5}$, NOx, and CO emissions are all substantially larger than the GFAS1.2 emissions, but RAVE VOC emissions are somewhat smaller. For Texas and the Contiguous U.S., RAVE and EPA2022b agree -andGFAS1.2 has lower emissions. Both RAVE and GFAS1.2 have substantially lower VOC emissions than EPA2022b for Texas and the Contiguous U.S. While discrepancies between the RAVE and GFAS1.2 emissions are large, these totals represent the total column amount, most of which is above the surface. As discussed in the vertical allocation details in Section 2.3.4, 90% of emissions are allocated to the top 2/3 of the smoke plume with the remaining 10% allocation to the bottom 1/3 of the plume. Therefore, modeled impacts at the surface may not reflect the large emission differences among the FEIs.

Table 3-1. 2022 annual $PM_{2.5}$ emission summaries (tpy) for EPA2022b, RAVE, and GFAS1.2.

Region	EPA2022b	RAVE	GFAS1.2
Texas	156,095	121,747	42,727
Contiguous U.S.	2,211,656	3,795,745	690,433
Mexico	-	1,363,794	359,959
Central America	-	222,336	55,694

Table 3-2. 2022 annual NOx emission summaries (tpy) for EPA2022b, RAVE, and GFAS1.2.

Region	EPA2022b	RAVE	GFAS1.2
Texas	20,791	37,109	12,466
Contiguous U.S.	248,075	402,791	161,262
Mexico	-	1,080,278	81,857
Central America	-	186,421	10,699

Table 3-3. 2022 annual VOC emission summaries (tpy) for EPA2022b, RAVE, and GFAS1.2.

Region	EPA2022b	RAVE	GFAS1.2
Texas	236,514	69,279	62,078
Contiguous U.S.	3,668,084	1,235,244	860,150
Mexico	-	469,338	600,343
Central America	-	68,441	109,746

Table 3-4. 2022 annual CO emission summaries (tpy) for EPA2022b, RAVE, and GFAS1.2.

Region	EPA2022b	RAVE	GFAS1.2
Texas	1,113,116	820,400	501,132
Contiguous U.S.	15,942,561	11,182,199	6,711,102
Mexico	-	10,511,326	3,982,574
Central America	-	1,730,856	623,549

4.0 CONCLUSIONS AND RECOMMENDATIONS

Ramboll recently updated the Python FEI processor to include RAVE1.0, a new FEI that possesses a unique combination of high temporal and spatial resolution that appears well-suited for high resolution photochemical modeling. Ramboll's analysis of CAMx ozone and $PM_{2.5}$ model performance at Texas monitors during the active Western U.S. wildfire season during June-September 2021 (when smoke impacts from Mexico and Central America were minimal) showed almost no difference among simulations using different fire inventories (RAVE1.0, GFAS1.2, QFED2.5, FEER1.0 and FINN2.5). However, a broader analysis across Western U.S. states revealed superior ozone and $PM_{2.5}$ performance for RAVE1.0 compared to the other four FEIs. We therefore suggested RAVE1.0 as the first choice to develop annual 2022 model-ready fire emissions for TCEQ's modeling platform. Based on our findings from this Western U.S. Summer 2021 study and the April-May 2019 evaluation performed for TCEQ in Ramboll (2023), we selected GFAS1.2 as the second choice in consultation with TCEQ. In April 2024, RAVE1.0 emissions were replaced with a newer version, RAVE2.0 covering April-December 2022. We then generated annual 2022 model-ready emissions for both RAVE (combination of RAVE1.0 and RAVE2.0) and GFAS1.2 fire products using the FEI processor.

Next, we used the beta version of EPA's fire emissions for 2022 (EPA2022b) to compare against the RAVE and GFAS1.2 emissions generated using the FEI processor. While EPA2022b emissions outside of the U.S. are not available at this time, EPA uses FINN for Mexico and Central America fire emissions, which resulted in large positive ozone biases in Texas using TCEQ's modeling platform for April-May 2019 (Ramboll, 2023). Ramboll found similarly high positive biases for both ozone and $PM_{2.5}$ using the FINN2.5 FEI for the Western U.S. Summer 2021 evaluation. Consistent with Ramboll (2022b; 2023), comparisons of RAVE and GFAS1.2 revealed substantial differences in emissions of key pollutants for 2022 for Mexico, Central America, Texas, and the Contiguous U.S. In general, RAVE emissions agree better against EPA2022b than GFAS1.2.

Ramboll recommends three activities to improve the FEI processor and support TCEQ's needs:

- Add capability to process fire emissions from EPA's emissions modeling platform.
- Conduct CAMx simulations using pre-existing modeling platforms from different years using all available FEIs, including EPA fire emissions if available, and evaluate ozone and $PM_{2.5}$ model performance against observations.
- Develop model-ready fire emissions for 2023 using multiple FEIs.

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