Contract No. 582-23-45978
Work Order No. 5
Tracking No. 2024-11
Task 4.2

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June 21, 2024

Biogenic Emissions Inventory Development for 2022 Modeling Platform

Final Report

PREPARED UNDER A CONTRACT FROM THE
TEXAS COMMISSION ON ENVIRONMENTAL QUALITY

The preparation of this document was financed through a contract from the State of Texas through the Texas Commission on Environmental Quality.
The content, findings, opinions and conclusions are the work of the author(s) and do not necessarily represent findings, opinions or conclusions of the TCEQ.

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Executive Summary

Biogenic emissions play a crucial role in influencing air quality in Texas and can constitute a significant portion of total volatile organic compounds (VOC) emissions in certain locations. The Model of Emissions of Gases and Aerosols from Nature (MEGAN) is one of the two most widely used biogenic emissions models to quantify isoprene and other biogenic volatile organic compounds (BVOCs) emissions. MEGAN is designed for both regional-scale and hemispheric modeling with global coverage and includes Texas-specific emission factors and vegetation characteristics data.

This project focused on developing annual biogenic emissions inputs for air quality modeling using the latest version of MEGAN (v3.2). Fine-resolution (300 m) time-varying Leaf Area Index (LAI) data for 2022 from the Copernicus Global Land Service were utilized. Additional vegetation cover inputs like growth form fractions (tree, shrub, crops, herbaceous plants) and tree species composition (e.g., the relative abundance of oaks, poplars, pines, spruce, etc.) were sourced from updated MEGAN model tailored for Texas. Biogenic emissions estimates were developed using 2022 meteorological data across TCEQ's 36 km, 12 km, and 4 km modeling domains.

1 Introduction

1.1 Background

Emissions of isoprene and other BVOCs strongly influence air quality in Texas and often dominate the total VOC emission inventory in certain areas of the state. These compounds play a critical role in atmospheric chemistry, contributing to the formation of ground-level ozone and secondary organic aerosols.

The Model of Emissions of Gases and Aerosols from Nature (MEGAN; Guenther, 2012) is one of the two widely used biogenic emissions models in the United States. It is designed for both global and regional-scale modeling and is provided with global input data coverage at a spatial resolution of ~ 1 km. The MEGAN model incorporates detailed emission factors and vegetation cover inputs, which have been refined for several urban areas in Texas (Shah et al., 2021; Ramboll, 2021a; Ramboll, 2021b).

1.2 Project Objectives

The goal of this project is to develop annual biogenic emissions for 2022 using the latest MEGAN version (v3.2) for TCEQ’s 36 km, 12 km, and 4 km modeling domains.

2 MEGAN Inputs

The MEGAN model relies on two primary inputs: landcover and environmental conditions, as summarized in Table 2-1.

In this project, fine-resolution (300 m) time-varying LAI data for the year 2022 were sourced from the Copernicus Global Land Service (CGLS). This dataset provides detailed information on vegetation density, which is crucial for estimating BVOC emissions. Additionally, vegetation cover inputs such as including growth form fractions (tree, shrub, crops, herbaceous plants) and tree species composition (e.g., the relative abundance of oaks, poplars, pines, spruce, etc.) were obtained from the latest MEGAN model tailored specifically for Texas.

Table 2-1 summarizes the detailed MEGAN inputs used in this study, including data sources and specific parameters.

2.1 Landcover

2.1.1 Leaf Area Index of vegetation-covered surfaces

- Description: LAI quantifies the amount of foliage in a landscape, representing half the total surface area of green elements of the canopy per unit of horizontal ground area. This value includes all canopy layers, including the understory, which can be significant, especially in forests. Essentially, LAI measures the thickness of the vegetation cover. MEGAN utilizes LAIv which represents the square meters of one-sided leaf area per square meter of canopy area (vegetation-covered area).
- Data Source: For this project, we obtained 300-meter resolution time-varying LAI data for the year 2022 from the Copernicus Global Land Service. This dataset provides LAI values at a 10-day temporal resolution for the entire year. The LAI300m product is distributed as global, multi-band NetCDF4 files with metadata conforming to the Climate and Forecast (CF) conventions v1.6. To integrate this global high-resolution data into the MEGAN model, we aggregated the 300-meter resolution LAI data to a 1-kilometer resolution. This aggregation was achieved using a Python script that includes a ‘coarsen’ function designed to reduce the dataset’s resolution. The processed LAI data was then provided as input to the MEGAN model, which uses the sum of growth forms to calculate the total vegetation-covered area and the LAIv needed by the MEGAN model.

2.1.2 Growth form

- Description: The MEGAN growth form dataset includes four primary categories of vegetation cover: crops, grass/herbaceous, shrubs, and trees. This provides a first-order characterization that can be derived from aerial imagery on a global scale. Trees are further divided into broadleaf vs. needleleaf and tropical vs. extratropical types. This subdivision allows for a detailed categorization of canopy types for the canopy environment model.
- Data Source: We utilized the MEGAN seventh-generation growth form dataset (GF7) created for the contiguous US (CONUS) as described by Yu et al. (2017). This data is accessible via DOI: 10.5281/zenodo.10939297. We obtained the CanType file from the default MEGAN3.2 input for our analysis.

2.1.3 Ecotype

- Description: While growth forms provide a basic understanding of vegetation characteristics, they are insufficient for accurately estimating BVOC emissions. This is because different tree species can exhibit significant variability in BVOC emission rates. To address this variability, ecotypes are defined as specific mixtures of vegetation types with distinct BVOC emission capacities. These ecotype distributions are derived from a combination of satellite imagery and ground-based surveys.
- Data Source: We utilized the third-generation Ecotype dataset version d (EVT3d), which is updated for the CONUS based on LANDFIRE data available at www.landfire.gov. The EVT3d dataset is accessible via DOI:10.5281/zenodo.10939297.

2.1.4 Speciation

- Description: Speciation files contain plant species composition for each major growth form type.
- Data Source: The speciation files for this project are listed in Table 2-1 and are available at DOI:10.5281/zenodo.10939297.

2.2 Soil nitrogen emission module inputs

MEGAN3.2 includes two options for estimating soil NOx emissions: the Berkeley/Dalhousie (BDSNP) and the Yienger/Levy algorithms. In alignment with TCEQ's recommendations, the BDSNP algorithm has been selected for this project. The following inputs are required by the BDSNP soil NOx emission algorithm:

2.2.1 Fertilizer Application Data

- Description: Agricultural soils enriched with nitrogen-rich fertilizers are a substantial source of reactive nitrogen to the atmosphere. Accurate data on the type, amount, and timing of fertilizer application is essential for the model.
- Data Source: Daily fertilizer application rates sourced from MEGAN3.1 represent a long-term average climatology. These data do not reflect year-specific fertilizer application rates but instead provide multi-year average climatological data.

2.2.2 Land Aridity Status

- Description: Information on whether the land is arid or non-arid is necessary for accurate emission estimates.
- Data Source: Static classification of areas as having "arid" or "non-arid" soils provided with MEGAN3.1.

2.2.3 Nitrogen Deposition

- Description: Atmospheric nitrogen deposition inputs using a multi-year global climatology.
- Data Source: Based on CESM CAM-Chem global nitrogen deposition estimates (Lamarque et al. 2012) provided with MEGAN3.1.

2.2.4 Soil biome type maps

- Description: Various biome types, characterized by their distinct vegetation and soil compositions, exhibit varying NOx emission factors influenced by diverse soil conditions and climate zones.

- Data Source: The project utilized 24 global soil biome type maps provided with MEGAN3.1.

2.3 Physical weather

- Description: Weather data is typically generated using a regional or global model such as WRF or CESM-CAM.
- Data Source: Meteorological data for the year 2022 was obtained from the TCEQ's WRF model run. This dataset was processed using the MCIP processor to extract the necessary parameters for MEGAN modeling.

Table 2-1: Summary of Landcover and Other MEGAN Inputs

Input Type	Dataset	Resolution	Temporal Resolution	Source
Leaf Area Index	LAI300m (Copernicus Global Land Service)	300 meters (aggregated to 1 km)	10 days	Copernicus Global Land Service
Canopy type	CanType2021.nc	30-seconds (~1 km)	Static	MEGAN3.2 default inputs
Growth form	GF7 (TC30s7.nc CC30s7.nc GC30s7.nc SC30s7.nc)	30-seconds (~1 km)	Static	DOI: 10.5281/zenodo.10939297
Ecotype data	EVT3d	30-seconds (~1 km)	Static	DOI: 10.5281/zenodo.10939297
Emission factor	EFv240120.csv	N/A	Static	DOI: 10.5281/zenodo.10939297
Speciation	SpeciationCrop230822.csv SpeciationHerb230822.csv SpeciationShrub230822.csv SpeciationTree230921.csv	N/A	Static	DOI: 10.5281/zenodo.10939297
Soil NO related data	soil_nitrogen_monxx.nc soil_fert_xxx.nc soil_landtype_xx.nc soil_climate_arid.nc soil_climate_non_arid.nc	1.25-degree 0.5-degree 0.25-degree 0.5-degree 0.5-degree	Monthly Daily Static (24 types) Static Static	MEGAN3.1/MEGAN3.2 default inputs

3 MEGAN Modeling Approach

We employed the latest version of the MEGAN model (v3.2) with refined inputs for some urban areas in Texas to create biogenic emissions for the year 2022. TCEQ-provided meteorological data for 36 km, 12 km, and 4 km modeling domains were utilized. Due to significant uncertainties associated with their implementation, all stress algorithms in MEGAN were disabled. Additionally, the CB6 mechanism was used in the MEGAN model runs.

Disabled Features:

1. Effects of Drought
2. Ozone Stress
3. CO2 Concentrations
4. Bidirectional Exchange LAI Response
5. Emission Responses to Windstorms
6. Extreme Temperatures

The MEGAN modeling system involves three main steps:

1. **Preprocessor 'prepmegan':** This tool regrids MEGAN's landcover input data to a user-specified domain, converting parameters like LAI, growth form, and canopy type. Detailed instructions for compiling and running the preprocessor, including executing necessary scripts to generate output data in CSV format, are provided in Ramboll's technical memorandum titled "Instructions to run MEGAN3.2" dated May 6, 2022, provided to TCEQ (Ramboll, 2022).

2. **Emission Factor Processor 'MEGEFP32'**: This program calculates landscape-average emission factors for user-defined domains using gridded growth form and ecotype data prepared by 'prepmegan'. Instructions for environment setup, Python library installation, and running the 'MEGEFP32' script to produce CSV output are provided in Ramboll's memorandum mentioned earlier.

3. **Emission Calculator and Mechanism Mapper 'MEGAN3_2'**: This tool calculates biogenic emissions using input data such as LAI, emission factors, and meteorological variables. It generates outputs in a format compatible with atmospheric chemistry models like CAMx. Detailed instructions for this step, including compiling executables, configuring environmental variables, creating symbolic links to input files, and executing scripts sequentially to generate CAMx binary file outputs, are outlined in Ramboll's technical memorandum referenced above.

4 Emissions Summary and Recommendations for Future Work

Biogenic emissions play a crucial role in influencing air quality in Texas and can constitute a significant portion of total VOC emissions in certain locations. These emissions are essential inputs for atmospheric chemical transport models (CTMs) as they are widespread and ubiquitous contributors to background air chemistry. In this project, Ramboll developed biogenic emissions inputs for the year 2022. Table 4-1 summarizes these emissions simulated with MEGAN3.2 across the three TCEQ modeling domains. As expected, isoprene and terpenes make up majority of the total BVOCs.

The soil NOx emissions for the CONUS within TCEQ's 12km domain are within the range suggested by the literature and align well with a decadal mean (Huber 2023). Figure 4-1 illustrates the monthly variation in isoprene emissions within the 4km modeling domain. Since biogenic emissions correlate directly with temperature, emissions are higher in the warmer summer months, peaking in July. Figure 4-2 presents spatial plots of emissions across these modeling domains, showing a reasonable distribution for all three.

Table 4-1. Annual total BVOC and soil NOx emissions (tons/year) for 2022 in the TCEQ modeling domains estimated using MEGAN3.2

Emission Type	36km	12km	4km
Isoprene	23,549,547	15,833,473	3,117,094
Terpenes	12,991,170	7,621,641	957,187
Total BVOC	52,584,233	33,839,442	5,395,094
Soil NOx	2,762,285	2,095,482	252,194

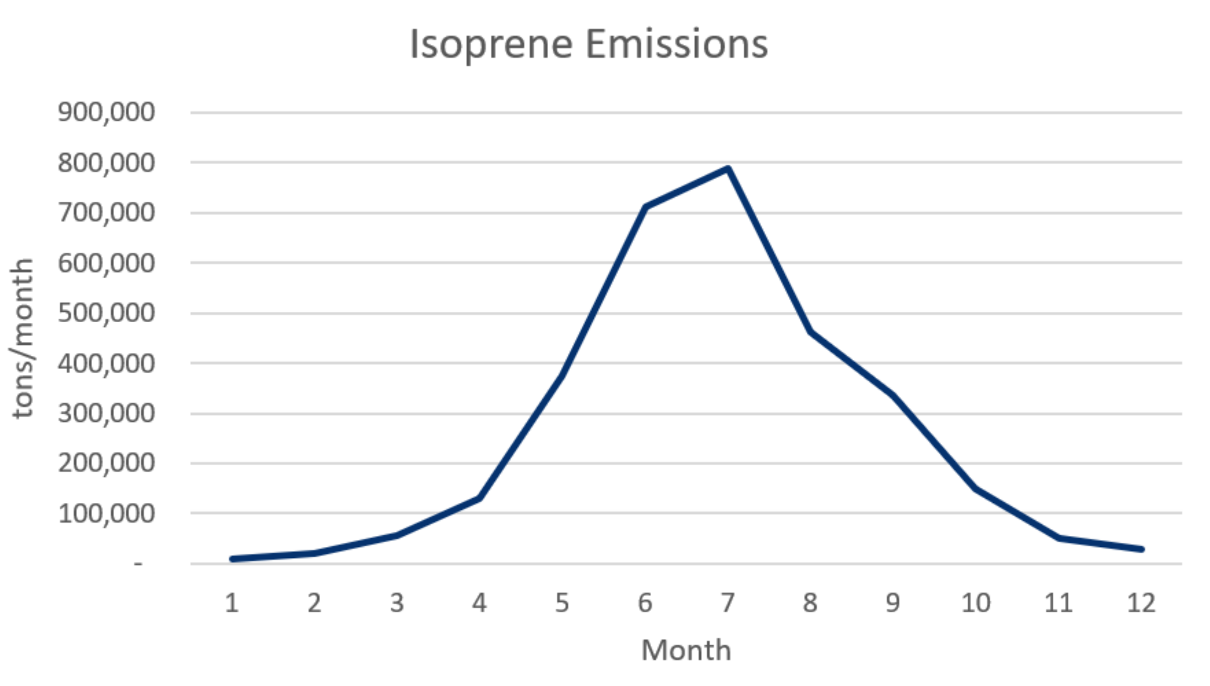

Figure 4-1. Monthly variation in isoprene emissions (tons/month) within the 4km modeling domain

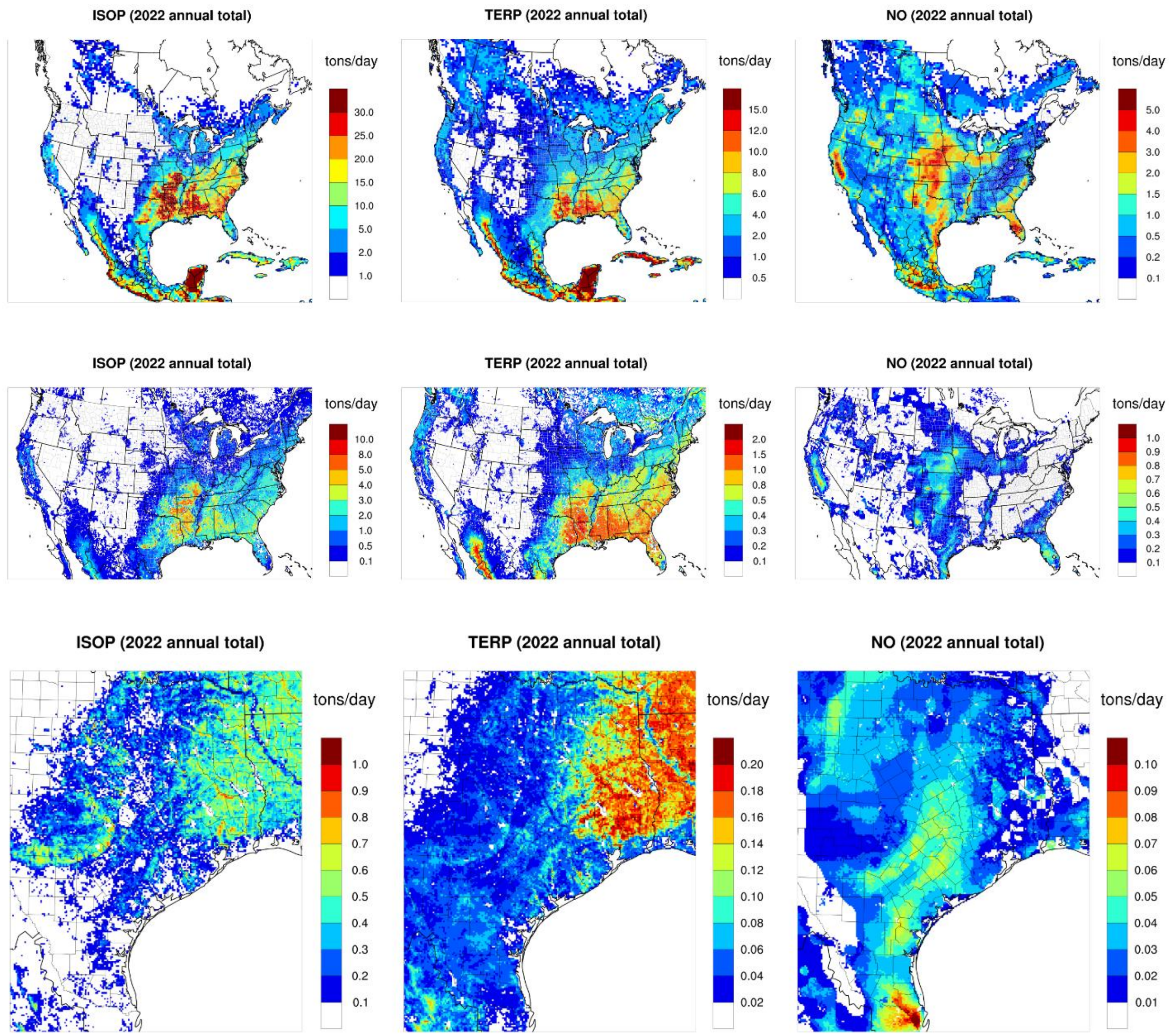

Figure 4-2. Spatial distribution of biogenic emissions (tons/day) for the year 2022 across the three TCEQ modeling domains. Top panel: 36km domain, Middle panel: 12km, Bottom panel: 4km domain.

4.1 Recommendations for future work

The TCEQ staff may benefit from a thorough evaluation of biogenic emissions:

- Evaluate biogenic emission estimates from BEIS and MEGAN using satellite, aircraft, and/or ground measurements via CAMx modeling and considering the influence of chemical mechanism in the modeling.

5 References

Copernicus Global Land Service Site. Available online: https://land.copernicus.eu/en/products/vegetation/leaf-area-index-300m-v1.0 (accessed on 1 March 2024).

Guenther, A. B., Jiang, X., Heald, C. L., Sakulyanontvittaya, T., Duhl, T. A., Emmons, L. K., & Wang, X. (2012). The Model of Emissions of Gases and Aerosols from Nature version 2.1 (MEGAN2. 1): an extended and updated framework for modeling biogenic emissions. Geoscientific Model Development, 5(6), 1471-1492.

Huber, D. E., Steiner, A. L., & Kort, E. A. (2023). Sensitivity of modeled soil NOx emissions to soil moisture. Journal of Geophysical Research: Atmospheres, 128, e2022JD037611. https://doi.org/10.1029/2022JD037611

Lamarque, J. F., Emmons, L. K., Hess, P. G., Kinnison, D. E., Tilmes, S., Vitt, F., ... & Tyndall, G. K. (2012). CAM-chem: Description and evaluation of interactive atmospheric chemistry in the Community Earth System Model. Geoscientific Model Development, 5(2), 369-411.

Ramboll (2021a). Biogenic Emission Inventory Improvements for the Waco Area.

Ramboll (2021b). Biogenic Emission Inventory Improvements for the East Texas Council of Governments.

Ramboll (2022). Technical memorandum to TCEQ: Instructions to run MEGAN3.2.

Shah et al. (2021) Texas Urban Vegetation BVOC Emission Source Inventory, Final Report, AQRP Project No. 20-007.

Yu, H., Guenther, A., Gu, D., Warneke, C., Geron, C., Goldstein, A., ... & Yuan, B. (2017). Airborne measurements of isoprene and monoterpene emissions from southeastern US forests. Science of the total environment, 595, 149-158.