Abstract

Nitrogen oxide (NOx) emissions are key precursors to ozone formation. Accurate characterization of these emissions is critical for understanding ozone formation in both urban and regional environments, and for supporting attainment and maintenance of the ozone (O_3) National Ambient Air Quality Standards (NAAQS). Our previous work using Tropospheric Emissions: Monitoring of Pollution (TEMPO) satellite NO_2 observations demonstrated the potential to constrain NOx emissions by source sector across Texas, including Houston, Dallas-Fort Worth, and rural areas. That effort developed methods to integrate TEMPO observations with Comprehensive Air quality Model with extensions (CAMx) chemical transport model results, including flux divergence and multiple linear regression approaches, and revealed persistent discrepancies between modeled and observed NO_2 columns during September 2023. Those results indicated that on-road and off-road vehicle emissions are often underestimated especially in the morning; soil and lightning NOx contributions carry substantial uncertainties; and current inventories need better spatiotemporal allocation of emissions. Building on these findings, the proposed work will further quantify and assess uncertainties in NOx emission inventories, including in the temporalization of emissions, using refined emission inputs for selected source sectors.

To address observed model biases, this project will examine key sources of uncertainty in the regional NOx emission inventory. Specifically, the analysis will evaluate whether medium- and heavy-duty diesel vehicle tampering and mal-maintenance (T&M) prevalence is higher than currently represented in MOVES5 and update natural soil and lightning NOx emissions using state of the science approaches. EPA's technical documentation for MOVES5 recommends that T&M rates be re-evaluated and updated, suggesting that current rates may underestimate real world T&M prevalence and on-road NOx emissions in urban corridors such as Houston and Dallas-Fort Worth. Separately, outdated soil NOx and lightning NOx parameterizations may contribute to discrepancies in background NOx across agricultural regions and transitional rural-urban zones. The original and updated inventories will be evaluated using tropospheric NO_2 column retrievals from the TEMPO satellite instrument in conjunction with CAMx simulations.

This work aligns with multiple Texas Air Quality Research Program (AQRP) Research Priority Areas, as summarized in Table 1.

Table 1. How this project will respond to the AQRP Research Priority Areas.

Research Priority Area	How this project addresses the Research Priority
Improve emissions inventories	This project will improve NOx emission inventories by updating soil, on-road, and lightning sources. It will apply the updated MEGAN soil NOx module, which incorporates revised temperature and soil moisture responses, updated nitrogen inputs, and soil HONO emissions. On-road emissions will be adjusted to account for diesel vehicle T&M and lightning NOx will be updated based on recent literature. The updated inventory will be evaluated using TEMPO NO_2 measurements.
Use of satellite and other remote sensing data	TEMPO satellite measurements will be used to better understand diurnal patterns of NO_2 and their relationship to NOx emissions. TEMPO data will serve as the primary satellite dataset, and comparisons will also be made with TROPOMI data during periods of afternoon overlapping observations.

Quality Assurance Project Plan (QAPP)

Project 26 – 019
Advancing Assessment of Texas NOx Emissions and Temporal Variability using TEMPO NO_2 and CAMx

Prepared for
Texas Air Quality Research Program (AQRP)
The University of Texas at Austin

Prepared by

Tejas Shah (Principal Investigator)
Ramboll
Novato, CA

June 26, 2026
Version #4

Ramboll has prepared this QAPP following the Environmental Protection Agency (EPA) guidelines incorporating the requirements for Quality Assurance (QA) Category III: Research Model Application and QA Category III: Data Use for Secondary Purposes. The project relies on both model application and the use of secondary data, with QA procedures, including audits of selected datasets, consistent with Category III requirements. This QAPP is submitted to the Texas Air Quality Research Program (AQRP) in accordance with the Work Plan requirements.

QAPP Requirements:

1. Project Description and Objectives
2. Organization and Responsibilities
3. Scientific Approach
   - 3.1 Satellite-based observations
   - 3.2 Develop Summer 2024 CAMx Modeling Dataset
   - 3.3 Sensitivity Analysis of NOx Sources
4. Quality Metrics
5. Data Analysis, Interpretation and Management
6. Discussion of Meteorological, Photochemical, and Emissions Models
   - 6.1 Selection
   - 6.2 Calibration
   - 6.3 Verification
   - 6.4 Evaluation
   - 6.5 Documentation
7. Audits of Data Quality
8. Reporting

QA Requirements: Technical Systems Audits - Not Required for the Project
Audits of Data Quality – 10% Required
Report of Findings – Required in Final Report

Approvals Sheet

This document is a Category III and Category IV Quality Assurance Project Plan for the Advancing Assessment of Texas NOx Emissions and Temporal Variability using TEMPO NO_2 and CAMx project. The Principal Investigator for the project is Tejas Shah and Co-PIs are Dan Goldberg and Jeremiah Johnson.

Electronic Approvals:

This QAPP was approved electronically by:

Signed by:
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David Sullivan, Quality Assurance Project Plan Manager Date
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Texas Commission on Environmental Quality (TCEQ)

This QAPP was approved electronically by:

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TCEQ

QAPP Distribution List

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Ramboll
Tejas Shah, Principal Investigator

George Washington University
Dan Goldberg, Co-Principal Investigator

Ramboll
Jeremiah Johnson, Co-Principal Investigator

1.0 Project Description and Objectives

This project will quantify and assess uncertainties in NOx emission inventories using data from the Tropospheric Emissions Monitoring of Pollution (TEMPO) satellite, including uncertainties in the temporalization of emissions, by refining emission inputs for selected source sectors. We will evaluate key sources of uncertainty in the regional NOx inventory by assessing the sensitivity of on-road NOx emissions to medium- and heavy-duty diesel vehicle tampering and mal-maintenance (T&M) rates and by updating biogenic soil and lightning NOx emissions based on recent literature. TEMPO NO_2 will then be used to evaluate these updated inventories, which will provide an improved characterization of NOx emissions overall. This improved understanding will help identify which sources substantially contribute to ozone (O3) exceedance events in Texas.

In this project, we will use hourly TEMPO NO_2 data at 2 km × 4.5 km resolution, complemented by Comprehensive Air quality Model with extensions (CAMx) simulations at 4 km × 4 km spatial resolution with sector-based NO_2 source apportionment over Texas. We will first develop a comprehensive 2024 modeling dataset for CAMx covering all major source categories including on-road, nonroad, electric generating units (EGUs), soil, lightning, aircraft, and fires, along with meteorological inputs from the Weather Research and Forecasting (WRF) model and run an initial CAMx simulation using this dataset. We will then evaluate the WRF meteorological simulation to identify potential impacts on NO_2 modeling, particularly for variables that drive the diurnal NO_2 cycle. Following this, we will compare CAMx-modeled NO_2 columns with TEMPO observations to establish a baseline assessment of the 2024 NOx inventories and identify areas for improvement. Building on this baseline, we will develop NOx emissions sensitivity scenarios targeting on-road diesel vehicle T&M and biogenic soil and lightning NOx to evaluate their impact on regional NOx levels. Finally, we will assess CAMx performance using these updated on-road, soil, and lightning NOx emissions by comparing modeled NO_2 columns against TEMPO observations.

2.0 Organization and Responsibilities

2.1 Responsibilities of Project Participants

Mr. Tejas Shah will serve as PI, leading the project and coordinating with Ramboll co-PI Jeremiah Johnson and Dr. Daniel Goldberg (co-PI), who will serve as a consultant to Ramboll.

Mr. Tejas Shah will lead the development of model-ready emissions for Summer 2024, update soil NOx emissions, assess the impact of diesel vehicle T&M on on-road emissions, and oversee quality assurance for all emissions development and modeling activities. Dr. Daniel Goldberg will process the TEMPO satellite data, develop diurnal NO_2 profiles, and compare TEMPO and CAMx NO_2 columns, while also overseeing quality assurance for all satellite data processing and analysis. Mr. Jeremiah Johnson will oversee the WRF and CAMx simulations and lead quality assurance for all CAMx modeling activities.

As part of the project's QA procedures, major project outputs will be independently reviewed by qualified personnel who were not involved in producing them. For example, reviews of CAMx concentration output fields will be performed independently by Ramboll staff who did not conduct the CAMx modeling. Similar independent reviews will be conducted, as appropriate, for emissions development, satellite data processing, and other major project deliverables.

2.2 Project Schedule

The planned duration of the project is 14 months (August 2026 – September 2027). Figure 1 presents the schedule for each task and project deliverables.

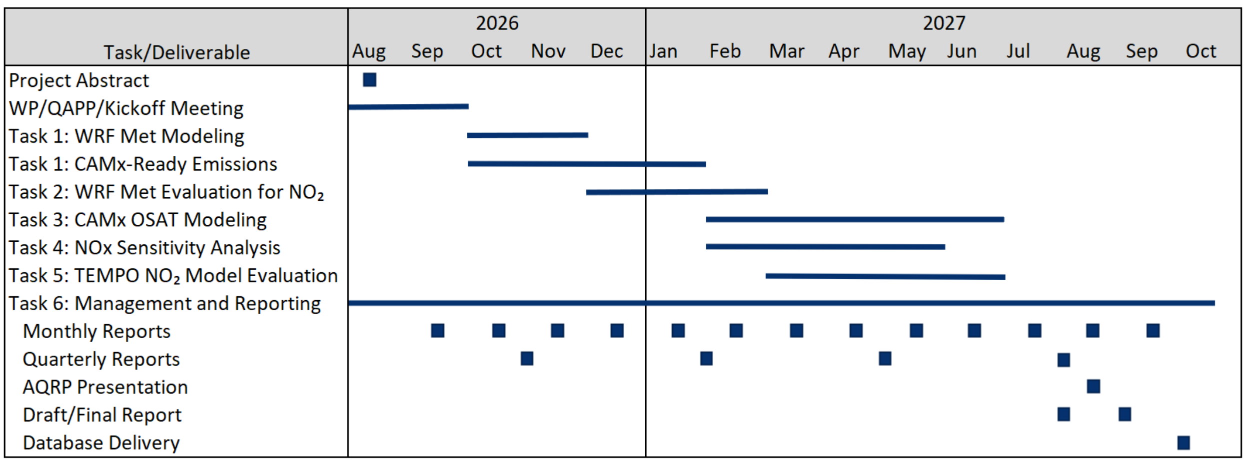

Figure 1. Planned project schedule.

3.0 Scientific Approach

3.1 Satellite-based observations

Satellites measure the column abundance of NO_2, known as the vertical column density (VCD). This project will utilize data from two satellite instruments: the Tropospheric Emissions: Monitoring of POllution (TEMPO) instrument and the Tropospheric Monitoring Instrument (TROPOMI). TEMPO was launched in April 2023 and has been acquiring measurements over North America since August 2, 2023 at a spatial resolution of 4.5 km x 2 km at its center of field of regard. TEMPO is a geostationary instrument and typically acquires measurements once per hour during daylight hours. However, the instrument has the capability to enter a “rapid scan” mode, acquiring more than one observation per hour at the same spatial resolution. TROPOMI, in contrast, is a polar-orbiting instrument with once per day coverage in the extratropics at 13:30 local time with a nadir resolution of 5.5 km × 3.5 km. TROPOMI was launched in October 2017 and has been acquiring measurements since April 30, 2018. While TEMPO has better temporal and spatial coverage over North America compared to TROPOMI, the TEMPO NO_2 algorithm is nascent compared to the more mature TROPOMI NO_2 algorithm that has been more thoroughly evaluated. Using both instruments provides cross-validation opportunities.

Satellite retrievals will be screened for clouds and erroneous measurements prior to analysis. For the TEMPO NO_2 data, we will apply a cloud fraction filter of < 0.15 and require a non-zero "qa_flag" to exclude erroneous retrievals, consistent with recommendations from the TEMPO Users' Guide. For the TROPOMI data, we will use the recommended quality filter of qa_flag > 0.75 to screen out cloud-contaminated and low-quality observations. All TEMPO and TROPOMI NO_2 data are publicly available on NASA Earthdata (https://search.earthdata.nasa.gov/). Care must be taken when interpreting satellite column retrievals as an indicator of near-surface emissions (Streets et al., 2014).

We will regrid the TEMPO and TROPOMI NO_2 data onto the CAMx model grid to enable direct comparison with CAMx outputs. This will be done using publicly available Interactive Data Language (IDL) code (Goldberg et al., 2021) which allows users to reformat data onto a wide range of grid types, including that of a model simulation. The data analysis period for both instruments will cover April through September 2024.

3.2 Develop Summer 2024 CAMx Modeling Dataset

A comprehensive 2024 emissions inventory will be developed for all major source categories, including on-road mobile, nonroad mobile, electric generating units (EGUs), aircraft, biogenic sources, lightning NOx, and fire emissions. On-road and nonroad emissions will be developed by scaling TCEQ 2023 model-ready emissions using pollutant-specific adjustment factors derived from the latest version of the MOtor Vehicle Emission Simulator (MOVES5). This approach preserves spatial allocation and temporal profiles from the base inventory while representing 2024 emission conditions. EGU emissions will be based on 2024 Continuous Emissions Monitoring (CEM) data for NOx and SO_2. Aircraft emissions will include landing, takeoff, climb, and cruise phases to better capture contributions that are often excluded or simplified in regulatory inventories. All remaining anthropogenic sectors will be taken based on the TCEQ 2023 future-year inventory, which is projected from a 2019 base-year emissions dataset.

Biogenic and lightning NOx emissions will be generated using 2024 WRF meteorological fields developed for this project. Fire emissions will be developed using Ramboll's Python-based Fire Emission Inventory (FEI) processor, with the choice of underlying fire inventory guided by recent model evaluations and data availability. Lightning emissions will be generated using a CAMx-specific LNOx preprocessor driven by WRF-derived convective parameters.

Meteorological fields for the modeling period will be generated using the Weather Research and Forecasting (WRF; Skamarock et al., 2021) model, following the TCEQ 2022 SIP configuration as closely as possible to maintain consistency with prior regulatory modeling frameworks. Chemical boundary conditions for the outer 36-km domain will be derived from the Whole Atmosphere Community Climate Model (WACCM), providing a consistent representation of large-scale chemical composition and transport influencing the regional modeling domain. Additional CAMx inputs will include updated photolysis rates and daily ozone column fields required for atmospheric photochemistry. These inputs will ensure consistency with the meteorological conditions simulated for Summer 2024.

Following completion of the full modeling dataset, an initial baseline CAMx simulation will be conducted for April–September 2024. The simulation will use CAMx version 7.40 with the CB7r3 chemical mechanism at 4 km horizontal resolution and 35 vertical layers over the East Texas domain, consistent with TCEQ SIP modeling domains. This baseline simulation will serve as the reference case for evaluating modeled NO_2 and ozone concentrations against surface observations and TEMPO satellite retrievals. It will also provide a starting point for identifying potential biases in emissions and meteorology, and for guiding subsequent sensitivity analyses.

3.3 Sensitivity Analysis of NOx Sources

We will evaluate key uncertainties in the regional NOx emission inventory, focusing on (1) diesel vehicle T&M in on-road emissions and (2) biogenic soil NOx and lightning NOx emissions.

A series of CAMx sensitivity simulations will be conducted by modifying individual emissions sources relative to the baseline 2024 inventory while keeping meteorology and boundary conditions unchanged. This approach allows the impacts of specific emissions changes to be isolated and evaluated directly. To assess the impacts of diesel T&M, we will develop several MOVES-based emissions scenarios representing different levels of medium- and heavy-duty diesel vehicle noncompliance. These scenarios will adjust inspection and maintenance (I/M) program effectiveness and shift portions of the fleet into higher-emitting categories, such as vehicles without functioning SCR, DPF, or catalyst systems. The analysis will help evaluate the potential underestimation of on-road NOx emissions in urban areas such as Houston and Dallas–Fort Worth. Sensitivity to soil NOx emissions will be evaluated using the MEGAN framework, which includes updated treatments of soil temperature and moisture response, fertilizer application, nitrogen deposition, and soil HONO emissions. These emissions will be generated using the 2024 WRF meteorological fields developed for this project. Lightning NOx emissions will also be evaluated using updated parameterizations from recent literature implemented through the CAMx lightning NOx preprocessor.

Results from the sensitivity simulations will be compared with the baseline model performance to quantify their influence on NOx and ozone concentrations. Qualitative comparisons with surface observations and TEMPO NO_2 retrievals will also be used to help identify which emissions sources contribute most to model-observation differences.

4.0 Quality Metrics

TEMPO and TROPOMI measurements will be gridded to the CAMx 4.0 x 4.0 km^2 domain retaining original quality flags, along with information about the averaging kernel, solar zenith angle, time of the day, and cloud cover. Satellite data will be screened for quality assurance flags in accordance with best practices recommended by the satellite product team, as discussed in Section 3.1.

We will calculate NO_2 vertical columns from CAMx in a manner appropriate for comparison with TEMPO and TROPOMI satellite data (between surface and ~13 km).

5.0 Data Analysis, Interpretation and Management

5.1 Data Reporting

Data reporting procedures will be documented in the project final report as discussed under Section 8. Data reduction procedures for satellite-based measurements are described in Section 3.1.

5.2 Data Validation

Data validation procedures are discussed under Sections 6.3 and 6.4.

5.3 Data Analysis Procedures

Qualitative and quantitative analysis will be performed to evaluate the contribution of emissions to satellite-observed NO_2 column abundance. This effort will include: a) quantitative comparison of TEMPO and TROPOMI NO_2 data with ground-based Pandora instruments available in Texas during the 2024 modeling period; b) qualitative and quantitative comparisons of satellite NO_2 retrievals with CAMx model results; c) comparing remote sensing derived NOx emissions with known power plant emissions; d) using all available datasets to identify, explain and evaluate areas of agreement and disagreement among the different data sources.

5.4 Data Storage

All modeling and measurement data associated with this project will be stored on secure cloud-based systems with routine backup procedures to ensure data integrity and accessibility. Project data will also be archived and transferred to AQRP upon completion of the project.

6.0 Discussion of Meteorological, Photochemical, and Emissions Models

6.1 Selection

WRF and CAMx are state-of-the-science modeling systems that are regularly updated and widely used in both regulatory and research applications. These models were selected because the existing 2019 TCEQ SIP modeling platform and associated databases provide a consistent and well-established framework for our study domain. Our project team has successfully applied WRF and CAMx for comparisons with TEMPO and TROPOMI in several previous AQRP studies, including AQRP Project 24-024 (Johnson et al., 2025), AQRP Project 22-023 (Goldberg et al., 2023; 2024; Nawaz et al., 2024), and AQRP Project 20-020 (Goldberg et al., 2022; Holloway et al., 2021).

MOVES5 is the U.S. EPA's current regulatory model for estimating on-road and nonroad mobile source emissions and is the required tool for SIP-related emissions inventory development. MOVES5 was selected for this project because it is the most current version available. It incorporates updated emission rates, vehicle population data, and fuel formulation inputs relative to prior versions, making it the appropriate tool for developing 2024 on-road emission estimates and for constructing the diesel vehicle T&M sensitivity scenarios.

6.2 Calibration

WRF and CAMx are established, peer-reviewed modeling systems that are not user-calibrated in the traditional sense. The model codes are used as provided by their respective developers without modification. Calibration in the context of this project refers to the selection and adjustment of model inputs, including emissions inventory inputs, WRF configuration options, and boundary conditions, to best represent observed atmospheric conditions. These input selections will be guided by comparison of WRF meteorological outputs against surface weather observations and by comparison of CAMx output concentrations with available NO_2 and ozone measurements at TCEQ Continuous Ambient Monitoring Stations (CAMS) across Texas, with agreement assessed against accepted performance benchmarks (e.g., Emery et al., 2017).

MOVES5 is similarly a regulatory model with emission rates derived from EPA's extensive vehicle testing programs and is not user-calibrated in the traditional sense. However, key inputs that directly influence modeled NOx emissions will be reviewed and adjusted as appropriate to represent 2024 conditions.

6.3 Verification

Model verification will be performed by processing NO_2 and ozone concentrations and using visualization software to ensure that the results are in a reasonable range. The review of concentration output fields will be performed independently by Ramboll staff who did not conduct the CAMx modeling. A minimum of 10% of the data generated in this study will be audited for data quality through visualization of outputs of the CAMx photochemical modeling.

MOVES5 output files will be reviewed by a Ramboll staff member not involved in the original model setup. This independent review will confirm that: (1) run specifications (county coverage, model year, source type, and fuel inputs) are correctly configured; (2) total NOx emission rates for the baseline scenario are consistent with the TCEQ 2023 inventory within expected bounds; and (3) T&M scenarios produce higher NOx relative to the baseline as T&M fraction increases, which is the expected model behavior. Any discrepancies identified during this review will be documented and resolved prior to use in CAMx simulations.

6.4 Evaluation

Evaluation of WRF and CAMx modeling for AQRP project 22-023 is described by Goldberg et al., (2023) and Nawaz et al. (2024). Ambient NO_2 and O_3 concentrations simulated by CAMx will be compared to ground-based observations of NO_2 and O_3 at TCEQ CAMS across Texas during the modeling time period.

A 10% sample of gridded hourly NOx will be evaluated through spatial and temporal visualization. The evaluation will focus on three checks: (1) spatial patterns of on-road NOx align with the road network and population centers within the 4-km CAMx domain; (2) diurnal profiles reflect expected morning and evening rush-hour peaks; and (3) weekday and weekend profiles differ appropriately given known differences in traffic activity. Results from the CAMx baseline simulation will also provide an indirect evaluation of MOVES5 outputs through comparison of modeled NO_2 concentrations with TCEQ CAMS surface observations and TEMPO NO_2 column retrievals.

6.5 Documentation

The CAMx User's Guide is available online (http://camx-wp.azurewebsites.net/Files/CAMxUsersGuide_v7.30.pdf). Namelist files used to run CAMx will be included in appropriate technical and final reporting. Documentation for WRF is provided in Skamarock (2021) and in the user's guide (https://www2.mmm.ucar.edu/wrf/users/wrf_users_guide/build/html/index.html).

MOVES5 documentation is available through the U.S. EPA at https://www.epa.gov/moves. Differences between the baseline and T&M scenario run specifications will be explicitly documented in the final report to ensure transparency and reproducibility.

7.0 Audits of Data Quality

Per requirements for Category III projects, we will audit a minimum 10% of the input data used in all aspects of the project.

A member of the research team not involved with the creation of a dataset will review 10% or more of the dataset for quality assurance purposes. A report of the findings from these Audits of Data Quality will be included in the draft and final report. This independent review will entail data visualization and discussion of qualitative and quantitative metrics.

8.0 Reporting

As required, we will provide regular and timely submission of monthly technical reports, monthly financial status reports, and quarterly reports as well as an abstract at project initiation and, near the end of the project, submission of the draft final and final reports, according to the schedules given below.

Mr. Shah, or his designee, will electronically submit each required report to both the AQRP and TCEQ liaisons and will follow the State of Texas accessibility requirements as set forth by the Texas State Department of Information Resources per https://aqrp.ceer.utexas.edu/. All drafts of planned presentations (such as at technical conferences), or manuscripts to be submitted for publication resulting from this project, will be provided to both the AQRP and TCEQ liaisons per the Publication/Publicity Guidelines included in Attachment 6 of the subaward.

Mr. Shah will lead reporting activities with assistance from co-PIs and his team at Ramboll. Project data to be submitted to the AQRP archive will include all gridded NO_2 data from TEMPO, TROPOMI and CAMx over the study domain and period.

Abstract: At the beginning of the project, an Abstract will be submitted to the Project Manager for use on the AQRP website. The Abstract will provide a brief description of the planned project activities, and will be written for a non-technical audience.

Abstract Due Date: August 2026

Quarterly Reports: The Quarterly Report will provide a summary of the project status for each reporting period. It will be submitted to the Project Manager as a Word document file. It will not exceed 3 pages and will be text only. No cover page is required. This document will be inserted into an AQRP compiled report to the TCEQ.

Quarterly Report Due Dates:

Report	Period Covered	Due Date
Quarterly Report #1	August, September, October 2026	Thursday, October 31, 2026
Quarterly Report #2	November, December 2026, January 2027	Friday, January 31, 2027
Quarterly Report #3	February, March, April 2027	Wednesday, April 30, 2027
Quarterly Report #4	May, June, July 2027	Thursday, July 31, 2027

Monthly Technical Reports (MTRs): Technical Reports will be submitted monthly to the Project Manager and TCEQ Liaison in Microsoft Word format using the AQRP FY26-27 MTR Template found on the AQRP website.

MTR Due Dates:

Report	Period Covered	Due Date
Technical Report #1	Project Start – August 31, 2026	Thursday, September 10, 2026
Technical Report #2	September 1 – 30, 2026	Saturday, October 10, 2026
Technical Report #3	October 1 - 31, 2026	Tuesday, November 10, 2026
Technical Report #4	November 1 - 30, 2026	Thursday, December 10, 2026
Technical Report #5	December 1 - 31, 2026	Sunday, January 10, 2027
Technical Report #6	January 1 - 31, 2027	Wednesday, February 10, 2027
Technical Report #7	February 1 - 28, 2027	Wednesday, March 10, 2027
Technical Report #8	March 1 - 31, 2027	Saturday, April 10, 2027
Technical Report #9	April 1 - 30, 2027	Monday, May 10, 2027
Technical Report #10	May 1 - 31, 2027	Thursday, June 10, 2027
Technical Report #11	June 1 - 30, 2027	Saturday, July 10, 2027
Technical Report #12	July 1 - 31, 2027	Tuesday, August 10, 2027

DUE TO PROJECT MANAGER

Financial Status Reports (FSRs): Financial Status Reports will be submitted monthly to the AQRP Grant Manager (RoseAnna Goewey) by each institution on the project using the AQRP 26-27 FSR Template found on the AQRP website.

FSR Due Dates:

Report	Period Covered	Due Date
FSR #1	Project Start – August 31, 2026	Tuesday, September 15, 2026
FSR #2	September 1 - 30 2026	Thursday, October 15, 2026
FSR #3	October 1 - 31, 2026	Sunday, November 15, 2026
FSR #4	November 1 - 31, 2026	Tuesday, December 15, 2026
FSR #5	December 1 - 31, 2026	Friday, January 15, 2027
FSR #6	January 1 - 31, 2027	Monday, February 15, 2027
FSR #7	February 1 - 28, 2027	Monday, March 15, 2027
FSR #8	March 1 - 31, 2027	Thursday, April 15, 2027
FSR #9	April 1 - 30, 2027	Saturday, May 15, 2027
FSR #10	May 1 - 31, 2027	Tuesday, June 15, 2027
FSR #11	June 1 - 30, 2027	Thursday, July 15, 2027
FSR #12	July 1 - 31, 2027	Sunday, August 15, 2027
FSR #13	August 1 - 31, 2027	Wednesday, September 15, 2027
FSR #14	Final FSR	Friday, October 15, 2027

DUE TO GRANT MANAGER

Draft Final Report: A Draft Final Report will be submitted to the Project Manager and the TCEQ Liaison. It will include an Executive Summary and a report of the findings from the Audits of Data Quality. It will be written in third person and will follow the State of Texas accessibility requirements as set forth by the Texas State Department of Information Resources.

Draft Final Report Due Date: Sunday, August 1, 2027

Final Report: A Final Report incorporating comments from the AQRP and TCEQ review of the Draft Final Report will be submitted to the Project Manager and the TCEQ Liaison. It will be written in third person and will follow the State of Texas accessibility requirements as set forth by the Texas State Department of Information Resources.

Final Report Due Date: Tuesday, August 31, 2027

Project Data: All project data including but not limited to QA/QC measurement data, databases, modeling inputs and outputs, etc., will be submitted to the AQRP Project Manager within 30 days of project completion. The data will be submitted in a format that will allow AQRP or TCEQ or other outside parties to utilize the information.

AQRP Workshop: A representative from the project will present at the AQRP Workshop in the first half of August 2027. The selected date will be updated.

9.0 References

Beirle, S., Borger, C., Dörner, S., Eskes, H., Kumar, V., de Laat, A., and Wagner, T. Catalog of NOx emissions from point sources as derived from the divergence of the NO_2 flux for TROPOMI, Earth Syst. Sci. Data, 13, 2995–3012, https://doi.org/10.5194/essd-13-2995-2021, 2021.

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Emery, C.E., Z. Liu, A.G. Russell, M.T. Odman, G. Yarwood and N. Kumar. 2016. Recommendations on statistics and benchmarks to assess photochemical model performance. J. of the Air and Waste Management Assoc., Vol. 67, Issue 5. DOI: 10.1080/10962247.2016.1265027. (https://www.tandfonline.com/doi/full/10.1080/10962247.2016.1265027).

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Scope of Work

Project #26-019
Advancing Assessment of Texas NOx Emissions and Temporal Variability using TEMPO NO_2 and CAMx

Prepared for

Texas Air Quality Research Program (AQRP)
The University of Texas at Austin

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June 26, 2026
Version #4

QA Requirements: Audits of Data Quality: 10% Required
Report of QA Findings: Required in Final Report

Approvals

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Contents

1.0 Abstract

Nitrogen oxide (NOx) emissions are key precursors to ozone formation. Accurate characterization of these emissions is critical for understanding ozone formation in both urban and regional environments, and for supporting attainment and maintenance of the ozone (O_3) National Ambient Air Quality Standards (NAAQS). Our previous work using Tropospheric Emissions: Monitoring of Pollution (TEMPO) satellite NO_2 observations demonstrated the potential to constrain NOx emissions by source sector across Texas, including Houston, Dallas-Fort Worth, and rural areas. That effort developed methods to integrate TEMPO observations with Comprehensive Air quality Model with extensions (CAMx) chemical transport model results, including flux divergence and multiple linear regression approaches, and revealed persistent discrepancies between modeled and observed NO_2 columns during September 2023. Those results indicated that on-road and off-road vehicle emissions are often underestimated especially in the morning; soil and lightning NOx contributions carry substantial uncertainties; and current inventories need better spatiotemporal allocation of emissions. Building on these findings, the proposed work will further quantify and assess uncertainties in NOx emission inventories, including in the temporalization of emissions, using refined emission inputs for selected source sectors.

To address observed model biases, this project will examine key sources of uncertainty in the regional NOx emission inventory. Specifically, the analysis will evaluate whether medium- and heavy-duty diesel vehicle tampering and mal-maintenance (T&M) prevalence is higher than currently represented in MOVES5 and update natural soil and lightning NOx emissions using state of the science approaches. EPA's technical documentation for MOVES5 recommends that T&M rates be re-evaluated and updated, suggesting that current rates may underestimate real world T&M prevalence and on-road NOx emissions in urban corridors such as Houston and Dallas-Fort Worth. Separately, outdated soil NOx and lightning NOx parameterizations may contribute to discrepancies in background NOx across agricultural regions and transitional rural-urban zones. The original and updated inventories will be evaluated using tropospheric NO_2 column retrievals from the TEMPO satellite instrument in conjunction with CAMx simulations.

This work aligns with multiple Texas Air Quality Research Program (AQRP) Research Priority Areas, as summarized in Table 1.

Table 1. How this project will respond to the AQRP Research Priority Areas.

Research Priority Area	How this project addresses the Research Priority
Improve emissions inventories	This project will improve NOx emission inventories by updating soil, on-road, and lightning sources. It will apply the updated MEGAN soil NOx module, which incorporates revised temperature and soil moisture responses, updated nitrogen inputs, and soil HONO emissions. On-road emissions will be adjusted to account for diesel vehicle T&M and lightning NOx will be updated based on recent literature. The updated inventory will be evaluated using TEMPO NO_2 measurements.
Use of satellite and other remote sensing data	TEMPO satellite measurements will be used to better understand diurnal patterns of NO_2 and their relationship to NOx emissions. TEMPO data will serve as the primary satellite dataset, and comparisons will also be made with TROPOMI data during periods of afternoon overlapping observations.

2.0 Background

Previous studies have shown the unique benefit of using spatially continuous satellite data from the TROPOspheric Monitoring Instrument (TROPOMI) and TEMPO satellite instruments to evaluate NOx emissions in regional chemical transport model (CTM) simulations (e.g., Goldberg et al., 2022; Goldberg et al. 2024a; Nawaz et al., 2024, Holloway et al., 2025; Baker et al., 2023; Hsu et al., 2026). These studies compared satellite NO_2 columns with model simulations accounting for the vertical sensitivity of the satellite measurements. Such comparisons have proven to be a powerful approach for diagnosing potential errors in estimated nitrogen oxide (NOx = NO + NO_2) emission inventories.

Recent CTM-based studies in other U.S. regions have identified systematic discrepancies between simulated and satellite-derived tropospheric NO_2 vertical column densities (VCDs; Choo et al., 2023; Goldberg et al., 2024b; Lawal et al., 2025), highlighting the need for careful evaluation of modeled NO_2 in urban corridors like Houston and Dallas-Fort Worth. In the 2010s, model-satellite intercomparisons generally found that modeled column NO_2 in rural areas was smaller than the satellite column NO_2 and larger in urban areas (Anderson et al., 2014; Canty et al., 2015; Travis et al., 2016). These studies highlighted the need to include an accurate representation of stratospheric NO_2 transport, lightning NOx (LNOx) emissions, soil NOx emissions, and NO_2 chemical recycling in model simulations when intercomparing CTMs with satellite data. These studies also highlighted that mobile NOx emissions, especially during summertime, were overestimated.

More recently and since the 2020 pandemic, it appears that NOx emission updates and modeling improvements have partially reversed some of the biases found in modeling studies of the 2010s. In a project focused on Houston (Goldberg et al., 2023), the team was able to gain evidence for a low model bias in 2021 urban NOx emissions (a modeled rural low bias still persisted as with previous studies). That project was also able to quantify neighborhood-scale and sector-by-sector NOx emission biases using a combination of satellite data, aircraft data, and sub-kilometer chemical transport models.

In a follow-up study focused on September 2023 utilizing both TROPOMI and TEMPO (Johnson et al., 2025), our team probed causes leading to the modeled NO_2 disagreements in the rural areas of Texas that could have been related to an underestimate of aircraft, soil, and/or lightning NOx emissions. Using updated aircraft cruise, soil NOx, and lightning NOx emission parametrizations, that study found a high modeled NO_2 bias in rural areas (bottom row of Figure 1).

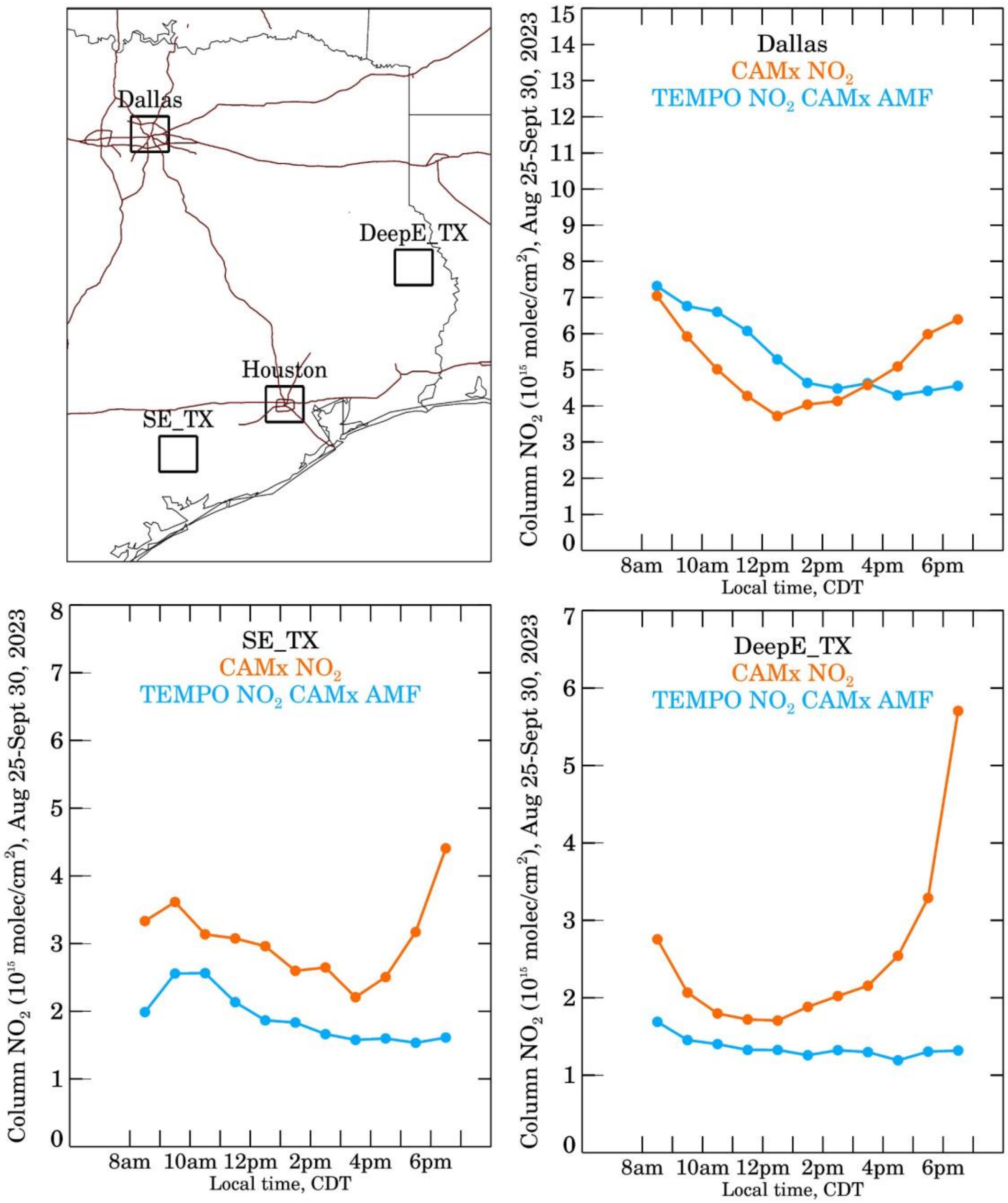

Figure 1. Comparison of TEMPO NO_2 columns with CAMx model simulations for Texas regions. Time series of TEMPO tropospheric NO_2 columns with a CAMx-derived air mass factor and CAMx tropospheric NO_2 columns are shown for three Texas regions, including urban and rural sites.

Additionally, the team found that the unique geostationary TEMPO NO_2 observations were able to isolate urban NOx emission biases during different times of day in urban areas (top right of Figure 1). Interestingly, we also found a large model-satellite NO_2 column discrepancy in all areas in the late afternoon (16:00 – 18:00 CST), which could be related to a variety of factors not limited to: an overestimate of evening rush-hour traffic emissions, a misallocation of lightning NOx emissions, an error in the diurnal temporalization of soil NOx emissions, difficulty characterizing the late afternoon to nocturnal boundary layer transition, or an error in the TEMPO observations.

When further investigating the modeled urban NOx morning underestimate (7:00 – 10:00 CST), we found the largest underestimates were near major transportation hubs (highways, downtowns, and near airports; Figure 2). Consistent with Figure 1, there was a model NO_2 overestimate in all areas in the late afternoon.

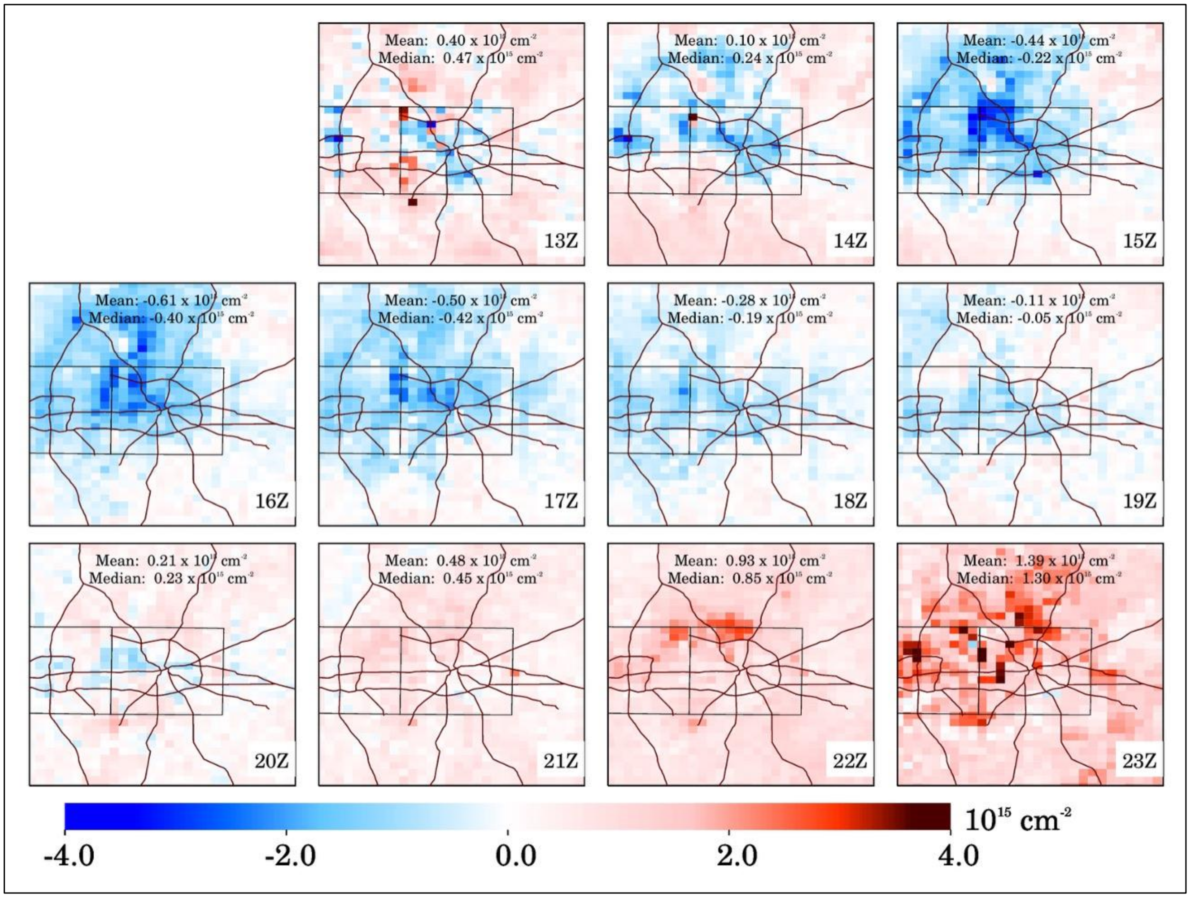

Figure 2. Monthly averaged CAMx NO_2 columns divided by TEMPO NO_2 columns with a CAMx-derived Air Mass Factor applied for each Zulu hour individually (13Z = 8 AM local during summer) during September 2023 for the Dallas-Fort Worth region.

TEMPO has the ability to reshape how NOx emissions are constrained across Texas, particularly through its unique daytime temporal coverage. However, prior work was limited in temporal coverage and did not overlap with multiple months of TEMPO observations. Extending model-satellite intercomparisons across additional months will enable more robust assessment of identified inventory adjustments and allow for improved characterization of seasonally driven emission cycles, particularly soil NOx (peaks in late spring) and lightning NOx emissions (peaks in late spring and mid to late summer, depending on location). Taken together, these considerations highlight remaining opportunities to improve both the magnitude and temporal allocation of current NOx emission inventories for Texas, with biases that vary by sector, location, and time of day. The availability of multi-month TEMPO NO_2 observations, combined with regional CAMx modeling, therefore provides a timely opportunity to systematically evaluate and refine NOx emission inventories across Texas, with direct benefits for air quality modeling and regulatory applications.

3.0 Objectives

This project will evaluate key sources of uncertainty in the regional NOx inventory by assessing the sensitivity of on-road NOx emissions to medium- and heavy-duty diesel vehicle T&M rates and by updating biogenic soil and lightning NOx emissions based on recent literature. We will use TEMPO NO_2 measurements to evaluate the updated inventories which will provide an improved characterization of NOx emissions. This improved understanding will help identify which sources substantially contribute to O_3 exceedance events occurring in Texas.

4.0 Task Descriptions

The availability of high spatial and temporal resolution TEMPO NO_2 observations beginning in August 2023 enables evaluation of Texas NOx emission inventories using satellite data. In this project, we will use hourly TEMPO NO_2 data at 2 km × 4.5 km resolution, complemented by CAMx simulations at 4 km × 4 km spatial resolution with sector-based NO_2 source apportionment over Texas. A comprehensive 2024 modeling dataset will be developed to ensure temporal consistency between satellite observations and model simulations, establishing a baseline for inventory assessment and subsequent sensitivity analyses.

Task 1 will develop a complete 2024 modeling dataset for CAMx, including emissions from all major source categories (on-road, nonroad, EGUs, soil, lightning, aircraft, and fires), meteorological data from WRF, and other ancillary inputs required for CAMx simulations. An initial CAMx simulation will be performed using this dataset. Task 2 will evaluate the WRF meteorological simulation to identify potential impacts on NO_2 modeling, with a focus on variables that influence the diurnal NO_2 cycle. Task 3 will compare CAMx-modeled NO_2 columns with TEMPO observations to establish a baseline assessment of the 2024 NOx inventories. This task will provide an initial evaluation of model performance and identify areas for improvement. Task 4 will develop NOx emissions sensitivity scenarios, focusing on on-road diesel vehicle T&M and biogenic soil and lightning NOx to evaluate their impact on regional NOx levels. Task 5 will evaluate CAMx performance with updated on-road, soil, and lightning NOx emissions by comparing modeled NO_2 columns with TEMPO observations.

Task 1: Develop Summer 2024 Modeling Dataset (April–September 2024)

We will apply the latest version of the Weather Research and Forecasting (WRF; Skamarock et al., 2021) meteorological model to simulate conditions during the summer 2024 modeling period. We will follow TCEQ's 2022 SIP WRF configuration to the extent possible for consistency.

We will also develop 2024 emission estimates for major anthropogenic sectors, including on-road, nonroad, and electric generating units (EGUs), as well as for natural sources. For on-road and nonroad sources, we will generate model-ready emissions by applying pollutant-specific scalars derived from the latest MOtor Vehicle Emission Simulator (MOVES5) to TCEQ's 2023 model-ready emissions to represent 2024 emission levels. EGU emissions will be derived from 2024 continuous emissions monitoring (CEM) data for NOx and SO_2. To capture aircraft contributions, we will include aircraft climb, descent, and cruise emissions for 2024, which are typically omitted from regulatory modeling inventories. For all other anthropogenic sources, we will use the TCEQ's 2023 future year inventory, which is projected from the 2019 base year.

Biogenic and lightning NOx emissions will be developed using the 2024 WRF modeling data developed for this project. Fire emissions will be developed using Ramboll's Python-based Fire Emission Inventory

(FEI) processor, with the choice of underlying fire inventory guided by recent model evaluations and data availability. Lightning emissions will be generated using Ramboll's CAMx-specific LNOx pre-processor based on specific WRF output variables.

Additional inputs for the Summer 2024 modeling period will include updated photolysis rates and day-specific ozone column data. Boundary conditions for the outer 36-km domain will be derived from the Whole Atmosphere Community Climate Model (WACCM) global chemistry model.

Task 2: Characterizing the WRF Meteorological Influences on NO_2

Meteorology strongly influences the diurnal cycle of NO_2, especially during the early morning and late afternoon, when surface emissions and boundary layer dynamics vary most rapidly. As a result, characterizing meteorological model performance is especially important for CAMx-TEMPO comparisons because of TEMPO's coverage across all daylight hours, and especially during the day-night transition hours. Additionally, changing hourly biases in modeled column NO_2 could be partially or even exclusively driven by inadequate meteorological performance. To understand whether meteorologically-driven errors are influencing NO_2 hourly biases, we believe it is critically important to characterize the meteorological performance of the WRF simulation to assess its strengths and weaknesses.

For example, errors in boundary layer depth could lead to poor agreement in the morning and late afternoon. Errors associated with the misplacement of thunderstorms can result in a misplacement of lightning NOx emissions, which are more likely to be captured by the late afternoon TEMPO scans than the early afternoon overpasses from TROPOMI. Changing biases of wind speeds/directions could systematically affect the transport and distribution of NO_2 plumes.

Given resource constraints, we will focus on the meteorological variables that are most likely to affect NO_2 surface and column concentrations. These will include temperature and wind speed/direction measurements at the National Weather Service Automated Surface Observing System (NWS ASOS) sites, temperature and boundary layer height from the four rawinsonde launch sites at 0Z, 12Z (and 18Z when available) within the WRF 4 km East Texas domain (Fort Worth, Corpus Christi, Lake Charles, and Shreveport) and ceilometer measurements of boundary layer height from La Porte airport and Dallas Hinton. These sites have high-quality continuous observations suitable for this evaluation.

Task 3: CAMx Ozone Source Apportionment Technology (OSAT) Modeling

Using the modeling platform described in Task 1, we will run CAMx version 7.40 with CB7r3 chemistry at 4 km spatial resolution with 35 vertical layers across an east Texas model domain. A 12-km continental United States (CONUS) domain within a North American 36-km domain will provide boundary conditions to the 4-km domain. All three domains will be identical to TCEQ's SIP modeling domains. We will apply the CAMx OSAT source apportionment tool to tag NO_2 from four emission source sectors (see Table 2): on-road mobile, soil NOx, lightning NOx and all other sources. We will evaluate CAMx NO_2 and ozone surface concentrations using data collected at TCEQ Continuous Air Monitoring Stations (CAMS) within the 4 km CAMx domain. We will compute tropospheric column NO_2 (including source tagging as shown in Table 2) from CAMx layers between the surface and ~13 km as discussed in Task 5.

Table 2. Source sectors for NO_2 tagging in CAMx.

No.	Source Sector	No.	Source Sector
1	On-road mobile	3	Lightning NOx
2	Biogenic (soil NOx)	4	Other

Once preliminary results from model/satellite intercomparison are available (Task 5), the model will be re-run for short periods to test the emission updates described under Task 4. The final CAMx simulation will be compared to the initial baseline simulation as well as surface observations and TEMPO NO_2 columns.

Task 4: Sensitivity Analysis of NOx Sources

This task will evaluate major sources of uncertainty in the regional NOx emission inventory. Specifically, we will (1) assess the sensitivity of on-road NOx emissions to medium- and heavy-duty diesel vehicle T&M rates and (2) update biogenic soil NOx emissions using state of the science approaches.

MOVES5 incorporates T&M rates that account for the aggregate effect of intentional emission control disabling and neglected aftertreatment maintenance on medium- and heavy-duty diesel fleet-average emission rates. However, real-world T&M prevalence is perceived to be higher than currently assumed in MOVES5 (Fulper et al, 2025; EPA, 2020; Gurecki Allen et al, 2025), and EPA recommends that T&M rates be re-evaluated and updated (EPA, 2024). As a result, MOVES5 can underestimate on-road NOx emissions from medium- and heavy-duty diesel vehicles in urban corridors such as Houston and Dallas-Fort Worth, consistent with the morning model-to-satellite NO_2 discrepancy identified near major transportation corridors in Figures 1 and 2. To address this, we will develop multiple regional on-road emissions scenarios by applying multiplicative scale factors to MOVES5 medium- and heavy-duty diesel running exhaust emission rates, simulating T&M adjustment factors that better reflect real-world prevalence. The resulting emissions scenarios will be supplied to CAMx and evaluated against TEMPO NO_2 observations to assess their influence on modeled NOx concentrations across Texas.

The soil NOx parameterization in EPA's Biogenic Emission Inventory System (BEIS) model, as currently used in TCEQ's modeling platform, is outdated and likely underestimates background NOx in agricultural areas. We will evaluate the sensitivity of regional NOx concentrations to biogenic soil NOx emissions using the latest version of MEGAN, which incorporates updated temperature and soil moisture response functions, updated nitrogen deposition and fertilizer application data, and explicitly releases HONO from soils.

We will evaluate lightning NOx emissions using recent literature to identify best estimate production efficiencies (PEs). Recent satellite-based studies combining TROPOMI NO_2 observations with lightning measurements from the Geostationary Lightning Mapper (GLM) and the Earth Networks Total Lightning Network (ENTLN) suggest lower LNOx production efficiencies than many earlier modeling studies. Allen et al. (2021a) reported mean values of approximately 175 ± 100 mol NOx per flash using GLM flashes and 120 ± 65 mol NOx per flash using ENTLN flashes for U.S. convective systems during 2018–2019, generally near the lower end of the commonly cited 100–500 mol per flash range. Earlier studies and parameterizations often applied larger values, including those used in Allen et al. (2010), Ott et al. (2010), and Allen et al. (2021b).

The CAMx LNOx processor derives flash rate using CAPE diagnosed from WRF, following the surrogate approach of Luo et al. (2017) and Price and Rind (1992). Within the tropics (25°N–25°S) the processor applies a constant PE of 100 mol per flash. Outside the tropics, PE is estimated with an exponential parameterization from Pickering et al. (2016). Because PE varies spatially and cannot simply be adjusted by a single scale factor, we will explore alternative ways to modify LNOx emissions that approximate a lower effective PE.

Task 5: Comparison of NO_2 Columns between CAMx and TEMPO

We will assess CAMx-predicted NO_2 columns by comparing TEMPO data to the initial baseline simulation and simulations with updated on-road, soil, and lightning NOx emissions. TEMPO has the advantage of having spatially continuous measurements across Texas during cloud-free daylight hours and allows an evaluation of NO_2 in areas without ground monitors.

For this task, we will first re-grid the TEMPO NO_2 column data (version 4 if available, otherwise version 3 which is available as of January 2026) onto the CAMx 4 km grid. We will then re-calculate the tropospheric TEMPO NO_2 vertical columns using NO_2 and temperature vertical profile information from the WRF-CAMx simulation and averaging kernels from TEMPO. Without this step, TEMPO satellite observations would be subject to artifacts associated with their original a priori assumptions provided by the NASA GEOS-CF model. After this re-processing is completed, it is appropriate to directly compare NO_2 columns between the model and the satellite observations. Concurrently, we will calculate the CAMx column NO_2 columns using NO_2 concentration profiles, temperature, and density information from all CAMx vertical layers up to the tropopause. The TEMPO and CAMx NO_2 data will simultaneously be filtered for cloudy scenes, using the main_data_quality_flag = 0 and eff_cloud_fraction < 0.1 as recommended by the User's Guide (NASA ASDC, 2026). Filtering out cloudy scenes should not affect our analysis investigating diesel and soil NOx emissions over the entire modeling period. However, this is an important consideration in analyzing lightning NOx emissions; direct lightning NOx emissions will likely be obscured by associated convective clouds while some diffuse lightning NOx emissions from previous hours may be captured under clear skies. TEMPO NO_2 data are available for all days of our proposed modeling period with once per hour observations between the hours of 13Z to 23Z (7:00 – 17:00 CST).

Once the satellite observations and model simulation are on the same model grid, an intercomparison between the datasets can be performed. Similar to AQRP project 24-004, our team will construct time-averaged (across all days) hourly profiles, analogous to Figures 1 and 2, and evaluate NO_2 column differences, diurnal amplitudes, and spatial gradients. We will intercompare weekdays and weekends separately, as traffic patterns differ substantially between these groups of days with potential effects on ozone production rates and patterns. We will also diagnose spatial differences separately by season as soil NOx emissions are more dominant in Spring. In addition to a regionwide analysis, we will also compare NO_2 column biases (i.e., absolute bias, normalized mean bias, and diurnal amplitude bias) on a county-level scale for six representative locations in the domain: three urban (Dallas Fort Worth, Houston, San Antonio) and three rural (Deep East Texas, Southeast Texas and West Texas), similar to results shown in Figures 1 and 2.

The random uncertainties of individual TEMPO pixel measurements will be significantly reduced by aggregating to multi-month averages. Systematic biases of TEMPO NO_2 retrieval may remain, even after using high-resolution NO_2 and temperature information from the CAMx simulation; these could be related to uncertainties in the slant column fit or the surface albedo assumptions; neither of which will be modified in this work. Our team will monitor any further algorithm updates and scientific advancements that could minimize TEMPO systematic biases.

Preliminary work intercomparing surface NO_2 and TEMPO column NO_2 in Houston shows different diurnal patterns across the day, with surface NO_2 measurements showing a U-shape bottoming out at 13:30 CST, whereas TEMPO column NO_2 typically decreases across morning hours, and is flatter across most afternoon hours. Therefore, it is important that differences between TEMPO and CAMx should not immediately be interpreted as strictly issues with the NOx emission patterns. Thus, investigating temperature and boundary layer depth differences under Task 2 will be critical for proper interpretation of Task 5 results. If we find meteorological disagreements with larger biases at certain times of day, we will be less confident in linking model-satellite NO_2 discrepancies to errors in the NOx emissions inventory.

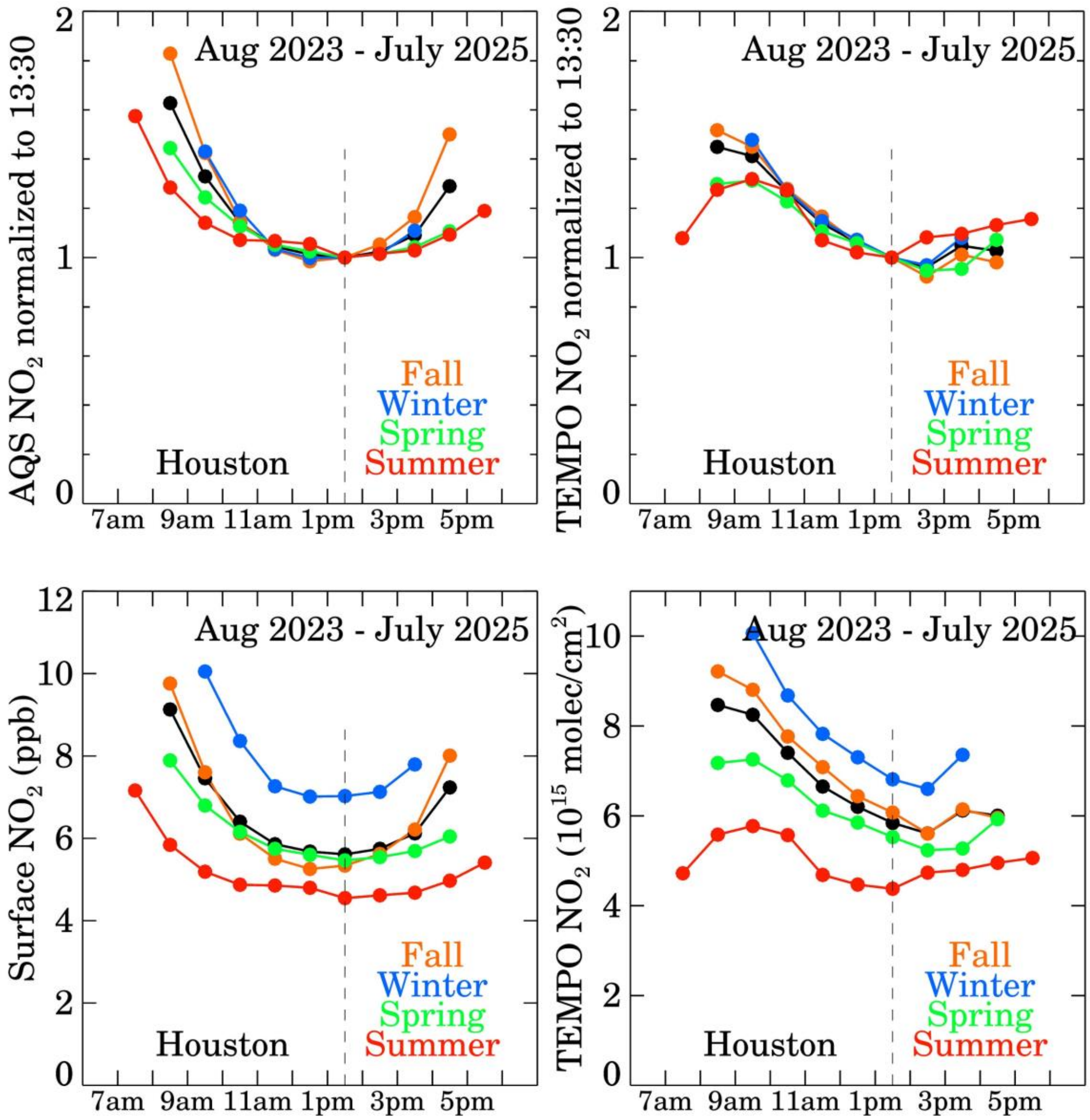

Figure 3. Diurnal cycle during daytime of NO_2 in the Houston metropolitan area between Aug 2023 – July 2025 for all surface monitors in the Air Quality System (AQS) database (left panels); TEMPO measurements (right panels). Top panels show values normalized to 13:30 CST to better intercompare diurnal variability. Bottom panels show observed units: ppb for surface monitors and 10^{15} molecules/cm^2 for TEMPO.

As part of this task, we will compare TEMPO and TROPOMI NO_2 column data with ground-based Pandora instruments with measurements in Texas during the 2024 modeling period.

Task 6: Project Management and Reporting

At the start of the project, the team will develop and submit to the AQRP a work plan, detailed budget, and a Quality Assurance Project Plan (QAPP). At a minimum, the QAPP will conform to Category III: Research Model Application and Category IV: Secondary Data projects and with EPA (2001) QA/R-5 guidance. Once approved, the team will hold a kickoff call with AQRP and TCEQ representatives to discuss the work plan and specific details of the project, answer questions, and address anticipated issues. During the project, we will submit monthly technical and financial reports, and quarterly progress reports, adhering to AQRP requirements.

At the close of the project, we will develop a final project presentation to be delivered at the 2027 AQRP workshop at the University of Texas in Austin. The team will also produce a draft final report and a final report documenting all activities performed for the study, summarizing project findings and recommendations for future research, and emphasizing those findings of interest to modelers and planners at TCEQ. All reports developed during this project will conform to AQRP accessibility requirements and formats. The team will make available all datasets developed during the project to the AQRP and TCEQ at the end of the project.

5.0 Schedule

The planned duration of the project is 14 months (August 2026 – September 2027). Figure 5 presents the schedule for each task and project deliverable.

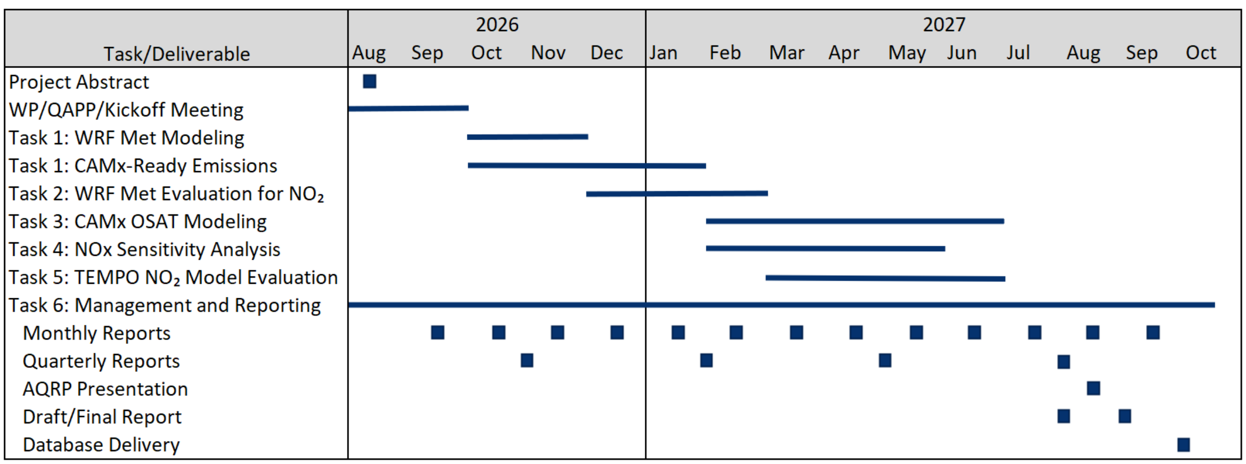

Figure 4. Planned project schedule.

6.0 Project Participants and Responsibilities

Tejas Shah (Principal Investigator) heads the Ramboll Emissions Modeling Group and is an expert in applying MOVES, MEGAN and SMOKE (including BEIS) for air quality modeling. His expertise includes emission and air quality modeling, emission inventory development, and GIS spatial analysis. He has successfully served as Principal Investigator for two previous AQRP projects: 20-007 and 18-005.

Dr. Daniel Goldberg (Co-Principal Investigator) is an Assistant Research Professor at George Washington University, using satellite observations and atmospheric models to study global air pollution at neighborhood scales. He contributed to project 24-004, evaluating updates to CAMx and NOx using

TEMPO over Texas; served as PI for project 22-023, leading the analysis of aircraft and satellite measurements; and supported project 20-020 by estimating NOx emissions from large power plants and cities using TROPOMI data.

Jeremiah Johnson (Co-Principal Investigator) leads WRF meteorological modeling for Ramboll's Air Quality Planning Group. His expertise includes meteorological and air quality modeling, fire emissions and their impact on air quality and satellite-based air quality applications. He served as PI for project 24-024 and co-PI for project 22-023, both successful AQRP projects.

Mr. Tejas Shah will lead the development of model-ready emissions for Summer 2024, update soil NOx emissions, and assess the impact of diesel vehicle T&M on on-road emissions. Dr. Daniel Goldberg will process the TEMPO satellite data, create diurnal NO_2 profiles, and compare the TEMPO NO_2 columns with CAMx NO_2 columns. Mr. Jeremiah Johnson will oversee the WRF and CAMx simulations.

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Budget and Budget Justification

Project #26-019
Advancing Assessment of Texas NOx Emissions and Temporal Variability using TEMPO NO_2 and CAMx

Prepared for

Air Quality Research Program (AQRP)
The University of Texas at Austin

By

Tejas Shah (Principal Investigator)
Ramboll
Novato, CA

Dr. Dan Goldberg (co-Principal Investigator)
George Washington University
Washington, D.C.

Jeremiah Johnson (co-Principal Investigator)
Ramboll
Novato, CA

May 14, 2026
Version #1

QA Requirements: Audits of Data Quality: 10% Required
Report of QA Findings: Required in Final Report

NOTE: The Workplan package consists of three independent documents: Scope of Work, Quality Assurance Project Plan (QAPP), and budget and justification. Please deliver each document (as well as all subsequent documents submitted to AQRP) in Microsoft Word format.

Approvals

This Budget was approved electronically by:

DocuSigned by:
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2026-07-09 | 11:35:23 CDT

RoseAnna Goewey, Program Manager — Date
Texas Air Quality Research Program (AQRP)

This Budget was approved electronically by:

Signed by:
Elena McDonald-Buller
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2026-07-09 | 12:31:05 CDT

Elena McDonald-Buller, Project Manager — Date
Texas AQRP

This Budget was approved electronically by:

Signed by:
Benjamin Yusuf
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2026-07-10 | 09:10:27 CDT

Benjamin Yusuf, Project Liaison — Date
Texas Commission on Environmental Quality

Budget and Budget Justification

Lbr Classification/Name	Loaded Hourly Labor Rate	Total Hrs	Total Dollars
P4			
Chris Emery	249.00	32	7,968
Jeremiah Johnson	249.00	80	19,920
Tejas Shah	249.00	105	26,145
Trang Tran	249.00	54	13,446
Liji David	249.00	88	21,912
Jung Chien	249.00	12	2,988
P3			
Pradeepa Vennam	214.00	52	11,128
Fiona Jiang	214.00	20	4,280
Fianna Li	214.00	70	14,980
Ling Huang	214.00	20	4,280
P2			
Anthony Gerigk	183.00	44	8,052
Blake Himes	183.00	136	24,888
P1			
William Baker	139.00	198	27,522
Support	107.00	20	2,140
Ramboll Labor Subtotal		931	189,649
Daniel Goldberg			40,000
Travel			1,000
Equipment			200
ODCs Subtotal			1,200
GRAND TOTAL		931	230,849

The team's proposed total budget is $230,849, of which $229,649 is allocated to labor charges and $1,200 to other direct costs. Ramboll's labor rates are based on fully loaded rates established with TCEQ under our current 5-year umbrella technical assistance contract. The budget includes $40,000 for Dr. Daniel Goldberg as a direct consultant to Ramboll. Ramboll will not add any additional fees to consultant costs. Roles for key personnel are provided in the Scope of Work.

Direct costs include a travel budget of $1,000 for the project Principal Investigator to attend the AQRP workshop in Austin, Texas. Direct costs also include expenses for high-volume disk drives for the data transfer at the end of the project.