26-015

Abstract

The Weather Research and Forecasting (WRF) model and the Comprehensive Air Quality Model with Extensions (CAMx), as used in Texas State Implementation Plan (SIP) configuration, represent the entire urban landscape of the Houston-Galveston-Brazoria (HGB) area with a single "Urban and Built-Up" category with uniform building height, surface roughness, and thermal storage across all urban grid cells within the HGB domain. As photochemical air quality models continue to increase their resolutions to kilometer and sub-kilometer scales, such a simple treatment of urban heterogeneity imposes a fundamental limit on our ability to capture the complexity of urban boundary-layer processes that directly influence and escalate the development of ozone. To address these limitations, this AQRP project aims at improving urban representations in the km-scale WRF-CAMx model through the integration of urban classification, urban morphology, and urban vegetation, which will lead to improvements in the urban planetary boundary layer (PBL) and ozone for the HGB region. In addition, Galveston Bay will be distinguished from the Gulf of America as a separate surface category to enable physically realistic representations of thermal structure and turbulence over coastal waters. Using observations from recent (2021-2023) field campaigns, which sampled the diversified landscapes of the HGB via mobile laboratories, the project will evaluate how combined refinements to urban morphological heterogeneity, urban vegetation, and different water surfaces reduce systematic biases in the PBL and ozone across the HGB region.

Specifically, the project's objectives are to answer the following scientific questions:

1. Urban classification: How does replacing the default single urban land-use category with 10 diversified Local Climate Zones (LCZs) improve the simulation of meteorological variables, PBL, ozone, and its precursors across the HGB region?
2. Urban morphology and vegetation: To what extent does integrating spatially continuous urban morphology (e.g., building heights) and LCZ-specific, high-resolution urban vegetation parameters (e.g., LAI) enhance the simulation of mechanical drag, vertical mixing, dry deposition, and emissions of biogenic volatile organic compounds (BVOCs), and thereby improve the prediction of meteorological variables, PBL, ozone, and its precursors across the HGB region?
3. Water body characterization: How do distinct thermal and physical representations of Galveston Bay and the Gulf of America influence the prediction of sea/bay-breeze evolution, marine PBL, and land-water pollutant transport across the HGB region?
4. Integrated impacts: Does the combined refinement of urban surface characteristics (morphology and vegetation) and marine/coastal surface boundaries reduce the systematic ozone predictability gap more effectively than isolated adjustments to individual model components?

The project specifically targets the AQRP Research Priorities 2026-2027: Photochemical air quality models with the goal of improving model performance in urban planetary boundary layer height and ozone at the km scale. The urban focus of the project will lead to improvements in the SIP modeling of the HGB. The delivery of new modeling approaches and input data to improve urban classification, urban morphology, and urban vegetation representations in WRF-CAMX will be transferable to air quality modeling of other urban areas in Texas.

Quality Assurance Project Plan (QAPP)

Project 26 – 015
Improving Urban Representation in the High-Resolution WRF-CAMx Model and Evaluating the Effects on PBL and Ozone Prediction

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

Prepared by

Yuxuan Wang
James Flynn
University of Houston

June 3, 2026
Version 2

University of Houston has prepared this QAPP following the Environmental Protection Agency (EPA) guidelines for a Quality Assurance (QA) Category III Project: Research Model Application Project. It is submitted to the Texas Air Quality Research Program (AQRP) as required in the Work Plan requirements.

QAPP Requirements: 1) Project Description and Objectives, 2) Organization and Responsibilities, 3) Scientific Approach, 4) Quality Metrics, 5) Data Analysis, Interpretation, and Management, and 6) 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 Quality Assurance Project Plan for the *Improving Urban Representation in the High-Resolution WRF-CAMx Model and Evaluating the Effects on PBL and Ozone Prediction* project. The Principal Investigator for the project is Yuxuan Wang.

Electronic Approvals:

This QAPP was approved electronically by:

Signed by:
Elena McDonald-Buller
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2026-07-09 | 12:28:20 CDT

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Texas AQRP

This QAPP was approved electronically by:

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Texas Commission on Environmental Quality (TCEQ)

This QAPP was approved electronically by:

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Gabriel Lee, Project Liaison, TCEQ — Date

QAPP Distribution List

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David Allen, Director
Elena McDonald-Buller, Project Manager
David Sullivan, QAPP Manager

Texas Commission on Environmental Quality
Gabriel Lee, Project Liaison

University of Houston
Yuxuan Wang, Principal Investigator
University of Houston
James Flynn, Co-Principal Investigator

1.0 Project Description and Objectives

The Weather Research and Forecasting (WRF) model and the Comprehensive Air Quality Model with Extensions (CAMx), as used in Texas State Implementation Plan (SIP) configuration, represent the entire urban landscape of the Houston-Galveston-Brazoria (HGB) area with *a single* "Urban and Built-Up" category with uniform building height, surface roughness, and thermal storage across all urban grid cells within the HGB domain. As photochemical air quality models continue to increase their resolutions to kilometer and sub-kilometer scales, such a simple treatment of urban heterogeneity imposes a fundamental limit on our ability to capture the complexity of urban boundary-layer processes that directly influence and escalate the development of ozone. To address these limitations, this AQRP project aims at improving urban representations in the km-scale WRF-CAMx model through the integration of urban classification, urban morphology, and urban vegetation, which will lead to improvements in the urban planetary boundary layer (PBL) and ozone for the HGB region. In addition, Galveston Bay will be distinguished from the Gulf of America (the Gulf) as a separate surface category to enable physically realistic representations of thermal structure and turbulence over coastal waters. Using observations from recent (2021-2023) field campaigns, which sampled the diversified landscapes of the HGB via mobile laboratories, the project will evaluate how combined refinements to urban morphological heterogeneity, urban vegetation, and different water surfaces reduce systematic biases in the PBL and ozone across the HGB region.

Specifically, the project's objectives are to answer the following scientific questions:

1. Urban classification: How does replacing the default single urban land-use category with 10 diversified Local Climate Zones (LCZs) improve the simulation of meteorological variables, PBL, ozone, and its precursors across the HGB region?
2. Urban morphology and vegetation: To what extent does integrating spatially continuous urban morphology (e.g., building heights) and LCZ-specific, high-resolution urban vegetation parameters (e.g., Leaf Area Index (LAI)) enhance the simulation of mechanical drag, vertical mixing, dry deposition, and emissions of biogenic volatile organic compounds (BVOCs), and thereby improve the prediction of meteorological variables, PBL, ozone, and its precursors across the HGB region?
3. Water body characterization: How do distinct thermal and physical representations of Galveston Bay and the Gulf influence the prediction of sea/bay-breeze evolution, marine PBL, and land-water pollutant transport across the HGB region?
4. Integrated impacts: Does the combined refinement of urban surface characteristics (morphology and vegetation) and marine/coastal surface boundaries reduce the systematic ozone predictability gap more effectively than isolated adjustments to individual model components?

2.0 Organization and Responsibilities

2.1 Key Personnel

Yuxuan Wang (PI), Department of Earth and Atmospheric Sciences, University of Houston.

- Coordinates the operations of the project and is the primary contact person.
- Leads reporting requirements such as the Work Plan (WP) (which includes a Scope of Work (SOW), detailed Budget and Budget Justification, and Quality Assurance Project Plan (QAPP)), , monthly technical reports, draft, and final reports.
- Works with University of Houston (UH) postdoctoral researcher and graduate students to perform the planned modeling analysis, including compiling urban datasets, model improvements, model simulation, and results analysis.

James Flynn (co-PI), Department of Earth and Atmospheric Sciences, University of Houston.

- Oversee quality control, data screening, and location labelling for meteorological and air pollution observations collected from various urban driving of the mobile laboratories to ensure a suitable comparison with the urban modeling.
- Advises UH graduate students and postdocs to perform the observational evaluation of model outputs.
- Assists with reporting requirements (WP, draft, and final reports).

Sergio Alvarez (Researcher 4), Department of Earth and Atmospheric Sciences, University of Houston

- Conducts data screening of observations collected from various urban driving of the mobile laboratories.

Shailaja Wasti (post-doc), Department of Earth and Atmospheric Sciences, University of Houston

- Implements the urban datasets into the high-resolution WRF and CAMx models, perform the modeling, and analyze the model results.
- Contributes to reporting (Monthly technical reports, draft, and final reports).

Two graduate students (to be named), Department of Earth and Atmospheric Sciences, University of Houston

- Assist the postdoctoral fellow in analyzing the model results and conducting the model to observation comparisons.
- Perform data downloading, regridding, and pre-processing of urban datasets and observations, post-processing and archiving of the modeling outputs.
- Contributes to reporting (Monthly technical reports, draft, and final reports).
- Assist with project data archiving and submission.

2.2 Project Schedule

The schedule for this project is listed below in **Table 1**.
Table 1. Schedule of Project Schedule.

Deliverable	Deliverable Date
Work Plan (Task 1) **Deliverable 1.1:** AQRP approved Scope of Work (SOW) **Deliverable 1.2:** AQRP approved QAPP **Deliverable 1.3:** Budget and Budget Justification	 **(1.1):** May 14, 2026 **(1.2):** May 14, 2026 **(1.3):** May 14, 2026
Progress Reports (Task 2) **Deliverable 2.1:** Monthly Technical Reports (MTR)	**(2.1):** Monthly by the 10th of the subsequent month
Urban Classification in WRF (Task 3) **Deliverable 3.1:** Report on improvements to urban classification in WRF	 **(3.1):** November 15, 2026
Urban morphology and vegetation refinement in WRF (Task 4) **Deliverable 4.1:** Report on refining urban morphology and vegetation in WRF	**(4.1):** March 15, 2027
Integration of Refined Urban and Coastal Surface Characterization into CAMx (Task 5) **Deliverable 5.1:** Report on the improved CAMx configuration and evaluation	**(5.1):** July 1, 2027
Draft Final and Final Reports (Task 6) **Deliverable 6.1:** Draft Final Report **Deliverable 6.2:** Final Report	 **(6.1):** August 1, 2027 **(6.2):** August 31, 2027

3.0 Scientific Approach

3.1 Secondary Data to be Used in the Current Analysis

3.1.1 Urban datasets

The project will use publicly available, high-resolution urban datasets that describe complementary components of the urban environment: urban classification, urban morphology, and urban vegetation. Together, these datasets provide a physically based replacement for the default single urban land-use representation used in WRF-CAMx.

The World Urban Database and Access Portal Tools (WUDAPT) LCZ framework (Ching et al., 2018) will be used for urban classification. WUDAPT classifies urban areas into 10 LCZs at a spatial resolution of 100 m (**Figure 1a**). Each LCZ represents a distinct urban form defined by building height class, building density (plan area fraction), and surface cover composition (impervious, built, and vegetated fractions). For each LCZ, WUDAPT supplies standardized, mean urban canopy parameters. These parameters define the spatial distribution of urban types across the modeling domain but do not resolve variability within a given LCZ.

The U-Surf dataset (Cheng et al., 2025) will be used for urban morphology, which provides spatially continuous, grid-cell-specific information on the three-dimensional structure of the built environment with a spatial resolution of 1 km. Unlike WUDAPT, U-Surf does not use categorical classes; instead, it supplies unique values for structural parameters, most notably building height (**Figure 1b**), for each grid cell. U-Surf therefore captures sub-LCZ spatial variability in urban structures that directly influence mechanical drag, wind shear, and building-induced turbulence.

For urban vegetation, we will utilize a recent high-resolution (500 m) LAI dataset (**Figure 1c**) (Dong et al., 2025) to replace the default LAI values in the WRF-CAMx model, which is assigned as 1 for all urban regions. These high-resolution LAI values will be aggregated by the LCZ category to derive representative biological parameters. This provides a realistic vegetative surface area for determining BVOC emissions and dry deposition velocities, directly influencing the simulated rate of ozone production and removal.

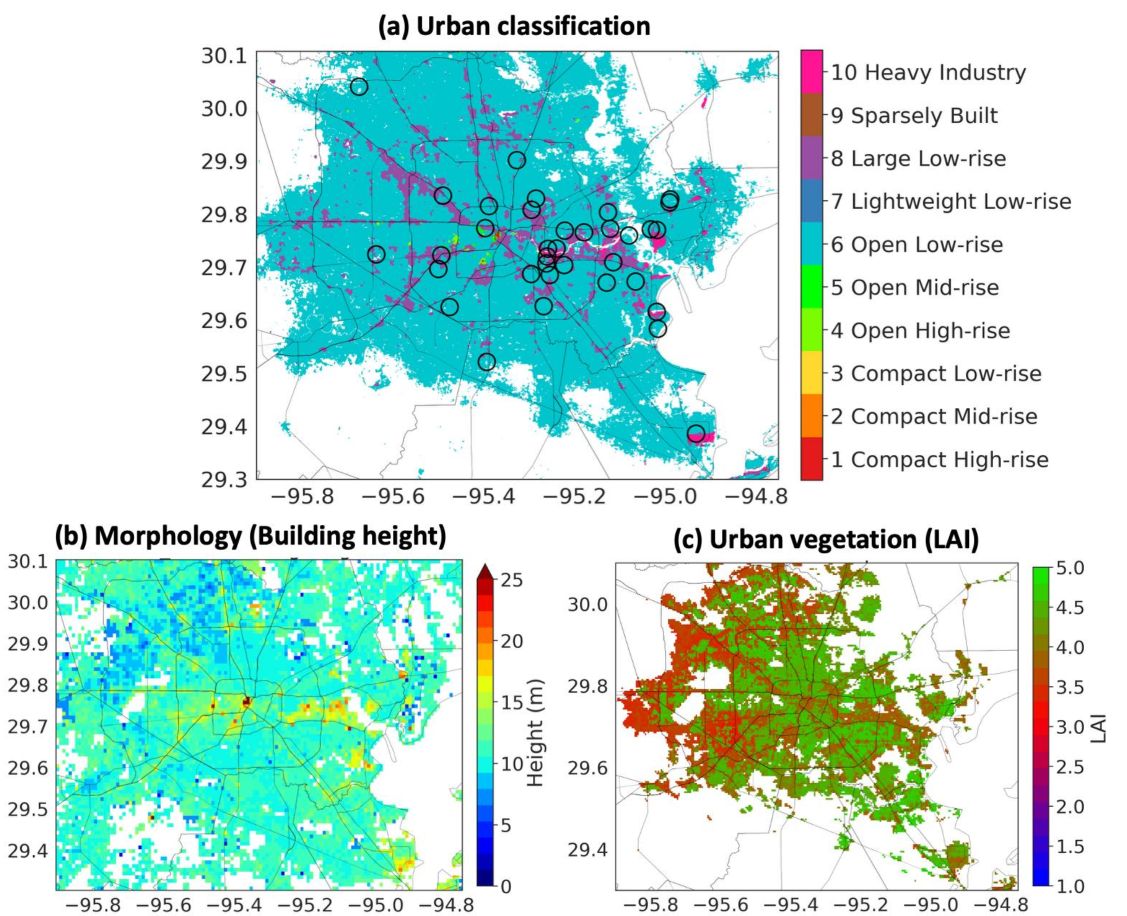

Figure 1. Urban datasets for the HGB region: (a) urban classification based on 10 WUDAPT LCZs with Continuous Air Monitoring Stations (CAMS) sites overlaid as black circles; (b) urban morphology represented by grid-scale building height from the U-Surf dataset; and (c) urban vegetation density represented by high-resolution LAI.

3.1.2 Observations to Evaluate Model Improvements

Observational datasets to evaluate model improvements include those collected across the HGB region during Tracking Aerosol Convection ExpeRiment (TRACER) (Jensen et al., 2021) and TRACER-Air Quality (TAQ) 2021–2023 field campaigns (TCEQ PGA# 582-22-32022-021; TCEQ PGA# 582-23-43296-028). Since this work explicitly targets urban environments, the focus will be on trace gas concentrations and meteorological parameters measured by the University of Houston's Mobile Air Quality Laboratory 1 (MAQL1), which sampled the diverse landscapes of the HGB over 2021-2023, with most of the routes in the urban core and industrial areas (**Figure 2b-c**). In addition, the TRACER project provided the urban-focused observations of PBL at a few sites around the HGB region, which reside in different LCZs (Kamath et al., 2024) (**Figure 2d**). Along with the campaign data, meteorological and pollutant observations from CAMS around the urban HGB region (**Figure 2a**) will be used to evaluate the WRF-CAMx model. When compared to model prediction, these urban measurements will be interpreted relative to LCZ class, urban morphology, and vegetation density. This enables direct evaluation of how refined urban surface representation influences vertical mixing, PBL development, and ozone behavior within the urban canopy.

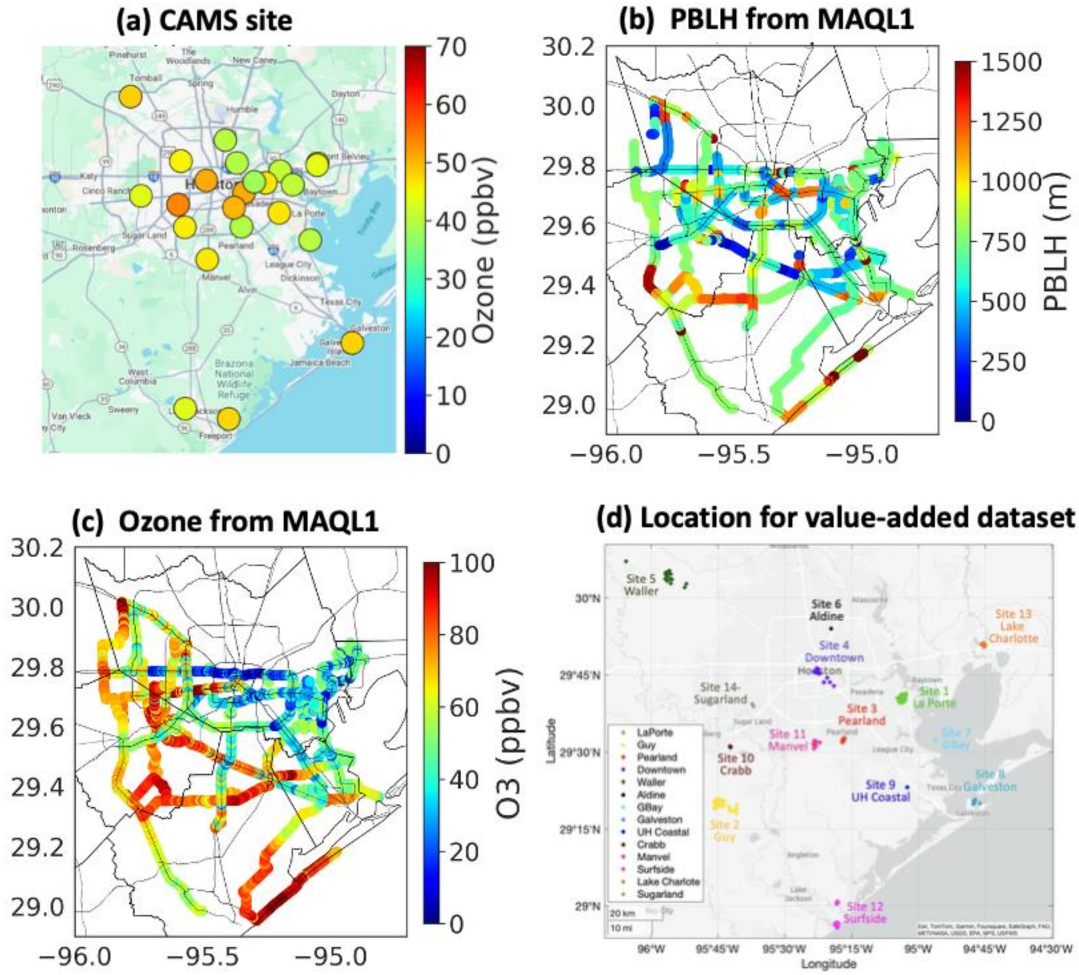

Figure 2. (a) Daytime mean ozone (ppbv) for September 2022 from the CAMS site. Spatial map of (b) Planetary Boundary Layer Height (PBLH) (m), and (c) ozone (ppbv) over the urban Houston from the MAQL1 during the TRACER field campaigns in September 2022.(d) Locations of the 14 sites included in the value-added PBLH dataset, compiled by (Kamath et al., 2024) by combining multiple datasets from the TRACER campaign.

3.2 Modeling Approach

The project will use WRF to simulate meteorological conditions and the photochemical model CAMx to simulate photochemistry during periods with elevated offshore ozone concentrations.

3.2.1 WRF

The meteorological model to be improved is the Weather Research and Forecasting (WRF) model, the leading mesoscale weather prediction model commonly used to drive Comprehensive Air Quality Model with Extensions (CAMx), the regulatory photochemical model. The most recent release of the Weather Research and

Forecasting (WRF) model at the time of the project execution will be used, configured with three nested domains covering the contiguous United States (12 km), Southeast Texas (4 km), and the HGB region (1.33 km) as in our previous work (Li et al., 2023; Soleimanian et al., 2023). The WRF configuration will build on our previous project (AQRP 24-021), which yielded the best performance in reproducing observed meteorological conditions and PBLH across both onshore and offshore environments.

A high-resolution baseline of the WRF model will be established by replacing the default single urban land-use category with a 10 LCZ framework using the WUDAPT datasets. This baseline will be improved by implementing three urban canopy models (UCMs) which take the urban datasets as inputs: the single-layer urban canopy model (SLUCM) (Kusaka et al., 2000; Kusaka & Kimura, 2004), the Building Effect Parameterization (BEP) (Martilli et al., 2002), and the Building Energy Model (BEM) scheme (Salamanca et al., 2010). BEM is often used together with BEP, referred to as BEP-BEM in short. To ensure that the multi-layer BEP-BEM scheme is properly resolved, vertical resolution in the lowest 100 m will be enhanced by adding ~10–15 additional vertical levels relative to the baseline configuration. The increased number of vertical layers will incur additional computational expense relative to the SIP modeling platform and AQRP 24-021 configuration, which will be documented in the project report.

In addition, Galveston Bay and the Gulf will be treated as separate water surface categories in WRF. The Gulf will retain the standard water representation from our previous AQRP project, while Galveston Bay will be assigned distinct surface properties (e.g., roughness length and albedo) to better represent its shallow, thermally responsive behavior. This refinement will likely improve the simulation of coastal PBL evolution and sea-breeze interactions affecting the urban core of the HGB region.

3.2.2 CAMx

The most recent release of CAMx version 7.3.2 will be used as the photochemical air quality model. CAMx will be configured to align with the WRF multi-nested grids. The baseline CAMx configuration will build on AQRP 24-021, which demonstrated the best performance in reproducing observed pollutant concentrations across both onshore and offshore environments (Li et al., 2023). The simulation will cover all the dates during 2021-2023 with available field campaign observations plus proper spinup. The initial conditions (IC)/boundary conditions (BC) inputs for the outmost domain are from the global 3-D model of atmospheric chemistry driven by meteorological input from the Goddard Earth Observing System (GEOS-Chem) global simulation with National Emission Inventory (NEI) 2016 nitrogen oxide (NOx) emissions scaled down to 2021-2023. The Carbon Bond version 6 revision 5 (CB6r5) is used for gas-phase chemistry, including the inorganic iodine depletion of ozone over oceanic water. Dry deposition is based on the Wesely scheme. Anthropogenic emission files with 12-km and 4-km spatial resolutions from the 2019 SIP modeling platform provided by TCEQ were used in our previous CAMx simulation with those emissions regridded to 1.33 km resolution for the HGB domain (Li et al., 2023). In the project, we will scale the 2019 SIP emissions of NOx to 2021-2023 based on scaling factors derived from TROPOspheric Monitoring Instrument (TROPOMI)-derived NOx emissions as described by (Liu et al., 2022).

CAMx represents surface-atmosphere interactions differently from WRF and therefore requires a distinct approach for incorporating high-resolution urban datasets. First, the TCEQ SIP-consistent 4 km Land Use and Land Cover (LULC) dataset will be regridded to the 1.33 km resolution for the CAMx inner domain. Second, the single urban category in the regridded 1.33 km LULC will be subdivided using the WUDAPT LCZ framework, and each urban grid-cell will be assigned one of 10 LCZ categories (LCZ 1–10). This step enables residential, commercial, and industrial environments to be represented as physically distinct urban surface types within CAMx, rather than being treated uniformly. Third, LCZ-specific urban morphology parameters will be refined using the U-Surf dataset. Grid-specific building height information from U-Surf will be aggregated by LCZ class across the HGB region to derive representative mean/median morphology values for each LCZ. These LCZ-specific morphology statistics will be used to update urban surface roughness and mixing-related parameters in the CAMx, replacing the generic values associated with the default urban category. Fourth, urban vegetation parameters will be refined using a high-resolution (500 m) observational LAI dataset described above. LAI values will be aggregated by LCZ class to derive representative vegetation densities for each urban type and will replace the default low urban LAI values in the CAMx dry deposition and vegetation parameter tables. This refinement directly improves the representation of urban ozone dry deposition and biogenic emissions, addressing known biases in ozone removal and production associated with the single-category urban treatment.

To maintain consistency with the WRF vertical layer, the CAMx vertical layer will be increased from 30 (as in the SIP modeling platform and AQRP 24-021) to ~40–45 layers, with additional layers concentrated within the lowest 100 m. The enhanced near-surface vertical resolution is intended to better represent vertical transport, mixing, dry deposition, and chemical processing within the shallow urban and marine boundary layer. The increased number of vertical layers in CAMx will further increase computational expense relative to the SIP modeling platform and AQRP 24-021 configuration, which will be documented in the project report.

4.0 Quality Metrics

4.1 Quality of Secondary Data

The secondary data quality requirements for measurements made during the 2021-2023 campaigns are based on the past experience of the investigators who collected the data and the method used. All data used will have been determined by the individual PI responsible for the collection and quality assurance/quality control (QA/QC) processes to be of final, publishable quality. We will follow the quality assurance and quality control protocols of these data sources and document the data versions used in this project. We will invite these measurement PIs to review the secondary data used after they are re-processed to match with the model's spatial and temporal resolutions. In addition, Co-PI Flynn's team will conduct careful screening of the mobile observations to remove spontaneous signals from local traffic and label the sampling locations with different urban classifications.

4.2 Quality of Modeling Data

The project will perform an in-depth evaluation of the models' performance in simulating meteorology, ozone, and precursors such as NO_2 and HCHO against both on- and offshore observations, including those from the field campaigns and routine meteorology/air quality monitoring sites. The specific focus will be on performance of the innermost domain (1.33 km x 1.33 km). We will maintain documentation files for each model run that identifies model performances compared to observations using the metrics in **Table 2**. The impact of PBL improvements on the model performance will be evaluated using difference plots and the same metrics from **Table 2** will be used to quantify the differences.

Table 2. *Performance metrics of the WRF-CAMx model.*

Performance Metrics	Formulas
Mean Bias (MB)	$MB = 1/N\sum_{i=1}^{N}(M_i - O_i)$
Mean Absolute Error (MAE)	$MAE = 1/N\sum_{i=1}^{N}\lvert M_i - O_i \rvert$
Normalized Mean Bias (NMB)	$NMB = \frac{\sum_{i=1}^{N}(M_i - O_i)}{\sum_{i=1}^{N}O_i} \times 100\%$
Correlation Coefficient (Corr. R)	$Corr.R = \frac{\sum_{i=1}^{N}(M_i - \overline{M})(O_i - \overline{O})}{\sqrt{\sum_{i=1}^{N}(M_i - \overline{M})^2}\sqrt{\sum_{i=1}^{N}(O_i - \overline{O})^2}}$
Root Mean Square Error (RMSE)	$RMSE = \sqrt{1/N\sum_{i=1}^{N}(M_i - O_i)^2}$

Note: M is the model output, O is the observation, N is the number of samples, and $\overline{M} = 1/N\sum_{i=1}^{N}M_i$, $\overline{O} = 1/N\sum_{i=1}^{N}O_i$.

5.0 Data Analysis, Interpretation, and Management

The modeling performed during the execution of this project will use both statistical and process analysis techniques using the methods described in the associated Scope of Work.

5.1 Data Reporting Requirements

The outputs from WRF and CAMx modeling will be processed as hourly means and monthly means in netCDF format. For important case days such as high ozone periods and representative PBL case days, the modeling data will also be reported as graphs to reveal key spatial features and their temporal evolution.

5.2 Validation Process

CAMx model outputs will be compared to the TCEQ 2019 modeling platform and the upcoming TCEQ 2022 modeling platform if it becomes available. WRF model outputs will be validated against reanalysis products such as High-Resolution Rapid Refresh (HRRR) outputs. Both CAMx and WRF model outputs will also be evaluated against available observations from TCEQ Continuous Ambient Monitoring Stations (CAMS). Although the SIP model and project model simulations are for different years, the objectives of the validation are to compare them in terms of (1) their performances against their respective year's observations and (2) spatial and temporal features that are expected to be persistent from year to year, such as relative gradient between urban and suburban and between land and water. The results will also be compared to modeling benchmarks from literature (Simon et al., 2012; Emery et al., 2017). Differences in modeling performance due to changes in specific modeling configurations and parameters will be quantified and documented.

5.3 Data Analysis

Descriptive (mean, median, standard error, minimum and maximum, correlation, etc.) analysis of the model-observation comparisons will be used for this project. These analyses are not expected to result in new equations or rate constants that can be used to modify model computer code.

5.4 Audits of Data Quality

To audit the quality of secondary data used in the project, a member of the research team who does not collect or compile a particular type of secondary data will review at least 10% of the data for quality assurance purposes. We will also invite colleagues and TCEQ staff who have expertise in meteorological and photochemical modeling to review the project outputs. The QA measures will include statistical analyses and graphical analyses, for example by comparing descriptive statistics and summary graphs of on- and offshore ozone from the different settings. A report on the results of the Audits of Data Quality will be included in the project Final Report.

5.5 Data Storage

The final analysis and model results will be posted to the UH server in a format conducive to import into a database at the conclusion of the project. Password protected links will be provided to the AQRP and TCEQ for download access. The data will be submitted to the AQRP archive and also archived by UH on a password protected server at hoth.geosc.uh.edu for a minimum of 3 years.

6.0 Reporting

AQRP requires certain reports to be submitted on a timely basis and at regular intervals. A description of the specific reports to be submitted and their due dates are outlined below. One report per project will be submitted (collaborators will not submit separate reports), with the exception of the Financial Status Reports (FSRs). The lead PI will submit the reports, unless that responsibility is otherwise delegated with the approval of the Project Manager. All reports 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. Report templates and accessibility guidelines found on the AQRP website will be followed.

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: Ten (10) business days after notice of intent to fund.

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 doc 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	**October 31, 2026**
Quarterly Report #2	November, December 2026, January 2027	**January 31, 2027**
Quarterly Report #3	February, March, April 2027	**April 30, 2027**
Quarterly Report #4	May, June, July 2027	**July 31, 2027**

Monthly Technical Reports (MTRs): Technical Reports will be submitted monthly to the Project Manager and TCEQ Liaison as a Word doc using the AQRP Template.

Monthly Technical Report Due Dates:

Due Dates:

REPORT	PERIOD COVERED	DUE DATE
Technical Report #1	Project Start - August 31, 2026	**September 10, 2026**
Technical Report #2	September 1 - 30, 2026	**October 10, 2026**
Technical Report #3	October 1 - 31, 2026	**November 10, 2026**
Technical Report #4	November 1 - 30, 2026	**December 10, 2026**
Technical Report #5	December 1 - 31, 2026	**January 10, 2027**
Technical Report #6	January 1 - 31, 2027	**February 10, 2027**
Technical Report #7	February 1 - 28, 2027	**March 10, 2027**
Technical Report #8	March 1 - 31, 2027	**April 10, 2027**
Technical Report #9	April 1 - 30, 2027	**May 10, 2027**
Technical Report #10	May 1 - 31, 2027	**June 10, 2027**
Technical Report #11	June 1 - 30, 2027	**July 10, 2027**
Technical Report #12	July 1 - 31, 2027	**August 10, 2027**

Financial Status Reports (FSRs): Financial Status Reports will be submitted monthly to the AQRP Grant Manager (aqrp-grant-manager@austin.utexas.edu) by each institution on the project using the AQRP FSR Template.

FSR Due Dates:

REPORT	PERIOD COVERED	DUE DATE
FSR #1	Project Start - August 31, 2026	**September 15, 2026**
FSR #2	September 1 - 30, 2026	**October 15, 2026**
FSR #3	October 1 - 31, 2026	**November 15, 2026**
FSR #4	November 1 - 30, 2026	**December 15, 2026**
FSR #5	December 1 - 31, 2026	**January 15, 2027**
FSR #6	January 1 - 31, 2027	**February 15, 2027**
FSR #7	February 1 - 28, 2027	**March 15, 2027**
FSR #8	March 1 - 31, 2027	**April 15, 2027**
FSR #9	April 1 - 30, 2027	**May 15, 2027**
FSR #10	May 1 - 31, 2027	**June 15, 2027**
FSR #11	June 1 - 30, 2027	**July 15, 2027**

FSR #12	July 1 - 31, 2027	**August 15, 2027**
FSR #13	August 1 -31, 2027	**September 15, 2027**
FSR #14	Final FSR	**October 15, 2027**

Draft Final Report: A Draft Final Report will be submitted to the Project Manager and the TCEQ Liaison. It will include an Executive Summary. 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: 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: 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, held August 2027 (exact date and time TBD) at UT Austin - West Pickle Research Campus.

7.0 References

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Scope of Work

Project #26-015

Improving Urban Representation in the High-Resolution WRF-CAMx Model and Evaluating the Effects on PBL and Ozone Prediction

Prepared for

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

By

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June 3, 2026
Version #2

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

Approvals

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Scope of Work

1. Abstract

The Weather Research and Forecasting (WRF) model and the Comprehensive Air Quality Model with Extensions (CAMx), as used in Texas State Implementation Plan (SIP) configuration, represent the entire urban landscape of the Houston-Galveston-Brazoria (HGB) area with *a single* "Urban and Built-Up" category with uniform building height, surface roughness, and thermal storage across all urban grid cells within the HGB domain. As photochemical air quality models continue to increase their resolutions to kilometer and sub-kilometer scales, such a simple treatment of urban heterogeneity imposes a fundamental limit on our ability to capture the complexity of urban boundary-layer processes that directly influence and escalate the development of ozone. To address these limitations, this AQRP project aims at improving urban representations in the km-scale WRF-CAMx model through the integration of urban classification, urban morphology, and urban vegetation, which will lead to improvements in the urban planetary boundary layer (PBL) and ozone for the HGB region. In addition, Galveston Bay will be distinguished from the Gulf of America as a separate surface category to enable physically realistic representations of thermal structure and turbulence over coastal waters. Using observations from recent (2021-2023) field campaigns, which sampled the diversified landscapes of the HGB via mobile laboratories, the project will evaluate how combined refinements to urban morphological heterogeneity, urban vegetation, and different water surfaces reduce systematic biases in the PBL and ozone across the HGB region.

Specifically, the project's objectives are to answer the following scientific questions:

1. Urban classification: How does replacing the default single urban land-use category with 10 diversified Local Climate Zones (LCZs) improve the simulation of meteorological variables, PBL, ozone, and its precursors across the HGB region?
2. Urban morphology and vegetation: To what extent does integrating spatially continuous urban morphology (e.g., building heights) and LCZ-specific, high-resolution urban vegetation parameters (e.g., leaf area index (LAI)) enhance the simulation of mechanical drag, vertical mixing, dry deposition, and emissions of biogenic volatile organic compounds (BVOCs), and thereby improve the prediction of meteorological variables, PBL, ozone, and its precursors across the HGB region?
3. Water body characterization: How do distinct thermal and physical representations of Galveston Bay and the Gulf of America influence the prediction of sea/bay-breeze evolution, marine PBL, and land-water pollutant transport across the HGB region?
4. Integrated impacts: Does the combined refinement of urban surface characteristics (morphology and vegetation) and marine/coastal surface boundaries reduce the systematic ozone predictability gap more effectively than isolated adjustments to individual model components?

The project specifically targets the AQRP Research Priorities 2026-2027: Photochemical air quality models with the goal of improving model performance in urban planetary boundary layer height and ozone at the km scale. The urban focus of the project will lead to improvements in the SIP modeling of the HGB. The delivery of new modeling approaches and input data to improve urban classification, urban morphology, and urban vegetation representations in WRF-CAM$_X$ will be transferable to air quality modeling of other urban areas in Texas.

2. Introduction

The coastal urban atmosphere is complex and challenging to model. For example, the Houston-Galveston-Brazoria (HGB) region contains high-rise buildings, dense neighborhoods with low-rise houses, extensive industrial areas, vegetation, and large adjacent water bodies. Interactions among these urban, industrial, and marine environments generate sharp spatial gradients in heat fluxes, moisture availability, and mechanical turbulence (Banta et al., 2005). These gradients strongly influence the evolution of the planetary boundary layer (PBL), sea-breeze circulations, and vertical ventilation, leading to large spatial and temporal variability in near-surface pollutant concentrations and making air quality prediction particularly challenging (Caicedo et al., 2019).

Accurately representing this heterogeneity in numerical models requires a detailed characterization of the urban and coastal surface (Mohomi et al., 2024; Pielke et al., 2011). However, commonly used photochemical air quality models often rely on simplified urban treatments that represent the entire urban landscape with a single “Urban and Built-Up” category with uniform building height, surface roughness, and thermal storage across all urban grid cells within the modeling domain. For coastal cities, models represent bay/lake and open ocean as a single “Water” class with identical physical parameters. These simple assumptions are what go into the Texas State Implementation Plan (SIP) modeling system consisting of the Weather Research and Forecasting (WRF) model and the Comprehensive Air Quality Model with Extensions (CAMx). While such simplification is justifiable for coarser-resolution global and continental-scale models incapable of resolving urban and coastal landscapes, as photochemical air quality models continue to increase their resolutions to kilometer and sub-kilometer scales, omission of surface heterogeneity in coastal urban modeling imposes a fundamental limit on our ability to capture the urban boundary-layer processes that control vertical mixing and pollutant dilution (Garuma, 2018; Masson et al., 2020).

Recent advances in high-resolution urban datasets allow urban complexity to be represented more explicitly through the urban classification approach, as exemplified by the World Urban Database and Access Portal Tools (WUDAPT) framework (Jensen et al., 2021). WUDAPT uses a physically based approach by grouping urban areas into ten Local Climate Zones (LCZs), such as compact high-rise, open low-rise residential, and heavy industrial, with each LCZ assigned with different urban canopy parameters such as impervious fraction, mean building height, and surface cover (Ching et al., 2018; Demuzere et al., 2021). While LCZs capture key differences among urban forms, they remain inherently categorical and rely on representative parameter values for each class.

This limitation can be overcome by the urban morphology approach, which uses spatially continuous datasets derived from high-resolution satellite products and lidar mapping to characterize the three-dimensional structure of the built environment at the grid-cell level. One such dataset is U-Surf (Cheng et al., 2025), which provides grid-cell–specific estimates of urban structural characteristics, most notably building height, at approximately 1 km resolution. By resolving spatial variability in mechanical drag and building-induced turbulence, urban morphology approach directly addresses processes that exert first-order control on urban PBL depth and vertical mixing (Chen et al., 2011). Together, the urban classification approach (e.g., WUDAPT) and urban morphology approach (e.g., U-Surf) provide complementary information on urban type and urban structure, enabling a more realistic representation of urban surface–atmosphere interactions needed by high-resolution photochemical models of air quality.

In addition to physical structure, urban vegetation plays an important role in ozone air quality through emissions of biogenic volatile organic compounds (BVOCs) and dry deposition but is often inadequately represented in models. Standard configurations typically assign low Leaf Area Index (LAI) values (~1.0) to urban areas, whereas high-resolution datasets over Houston indicate LAI values commonly range from 3.0 to 5.0 (Dong et al., 2025), indicating a potentially large role of urban vegetation on ozone air quality that is substantially underestimated by previous models.

To address these limitations, the project aims at improving urban and coastal representations in the high-resolution WRF-CAMx model through the integration of urban classification, urban morphology, and urban vegetation that will lead to improvements in urban PBL and ozone for the HGB region. In addition, Galveston Bay will be distinguished from the Gulf of America as a separate surface category to enable physically realistic representations of thermal structure and turbulence over coastal waters. Using observations from recent (2021-2023) field campaigns, which sampled the diversified landscapes of the HGB via mobile laboratories, and the stationary observation from the CAMS sites, the project will evaluate how combined refinements to urban morphological heterogeneity, urban vegetation, and different water surfaces reduce systematic biases in the PBL and ozone across the HGB region.

The project specifically targets the AQRP Research Priorities 2026-2027: *Photochemical air quality models* with the goal of improving model performance in urban PBL and ozone at the km scale. It is an expansion of our previous work, which improved WRF-CAMx prediction of marine PBL and offshore ozone through targeted refinements to boundary-layer-related physics (AQRP 24-021). Model performance gains from our previous work were smaller over the urban core of the HGB and the Houston Ship Channel (HSC) than offshore, and model deficiencies over these regions were found largely insensitive to further adjustments in physical parameterizations. Hence, we hypothesize that coarse and simplified representations of urban and water surfaces in the WRF-CAMx model constitute a dominant source of uncertainty limiting ozone predictability in the HGB, which prompts this project.

3. Science Questions

The project will address the following scientific questions:

1. Urban classification: How does replacing the default single urban land-use category with 10 diversified LCZs improve the simulation of meteorological variables, PBL, ozone, and its precursors across the HGB region?
2. Urban morphology and vegetation: To what extent does integrating spatially continuous urban morphology (e.g., U-Surf's building heights) and LCZ-specific, high-resolution urban vegetation parameters (e.g., LAI) enhance the simulation of mechanical drag, vertical mixing, dry deposition, and BVOC, and thereby improve the prediction of meteorological variables, PBL, ozone, and its precursors across the HGB region?
3. Water body characterization: How do distinct thermal and physical representations of Galveston Bay and the Gulf of America influence the prediction of sea/bay-breeze evolution, marine PBL, and land-water pollutant transport across the HGB region?
4. Integrated impacts: Does the combined refinement of urban surface characteristics (morphology and vegetation) and marine/coastal surface boundaries reduce the systematic ozone predictability gap more effectively than isolated adjustments to individual model components?

4. Data and Modeling Approach

The project aims at improving the WRF and CAMx models, which are the regulatory models for photochemical air pollution in Texas. To better represent diversified urban landscape characteristics, urban areas of the HGB region will be classified using the WUDAPT LCZ framework (100 m resolution) (Ching et al., 2018), combined with grid-level urban morphology from the U-Surf (1 km resolution) dataset (Cheng et al., 2025). Urban vegetation will be refined using a high-resolution LAI (500 m resolution) dataset (Dong et al., 2025) aggregated by LCZ class to derive class-specific biological parameters. In parallel, Galveston Bay will be distinguished from the Gulf of America as a separate surface category with different surface characterization. While the focus of the project is on the HGB, the delivery of new modeling approaches and input data to improve urban classification, urban morphology, and urban vegetation representations in WRF-CAM_X will be transferable to air quality modeling of other urban areas in Texas.

4.1. Urban datasets

The project will use publicly available, high-resolution urban datasets that describe complementary components of the urban environment: urban classification, urban morphology, and urban vegetation. Together, these datasets provide a physically based replacement for the default single urban land-use representation used in WRF-CAMx.

The WUDAPT LCZ framework will be used for urban classification. WUDAPT classifies urban areas into 10 LCZs at a spatial resolution of 100 m (**Figure 1a**). Each LCZ represents a distinct urban form defined by building height class, building density (plan area fraction), and surface cover composition (impervious, built, and vegetated fractions). For each LCZ, WUDAPT supplies standardized, mean urban canopy parameters. These parameters define the spatial distribution of urban types across the modeling domain but do not resolve variability within a given LCZ.

The U-Surf dataset will be used for urban morphology, which provides spatially continuous, grid-cell-specific information on the three-dimensional structure of the built environment with a spatial resolution of 1 km. Unlike WUDAPT, U-Surf does not use categorical classes; instead, it supplies unique values for structural parameters, most notably building height (**Figure 1b**), for each grid cell. U-Surf therefore captures sub-LCZ spatial variability in urban structures that directly influence mechanical drag, wind shear, and building-induced turbulence.

For urban vegetation, we will utilize a recent high-resolution (500 m) LAI dataset (**Figure 1c**) (Dong et al., 2025) to replace the default LAI values in the WRF-CAMx model, which is assigned as 1 for all urban regions. These high-resolution LAI values will be aggregated by the LCZ category to derive representative biological parameters. This provides a realistic vegetative surface area for determining BVOC emissions and dry deposition velocities, directly influencing the simulated rate of ozone production and removal.

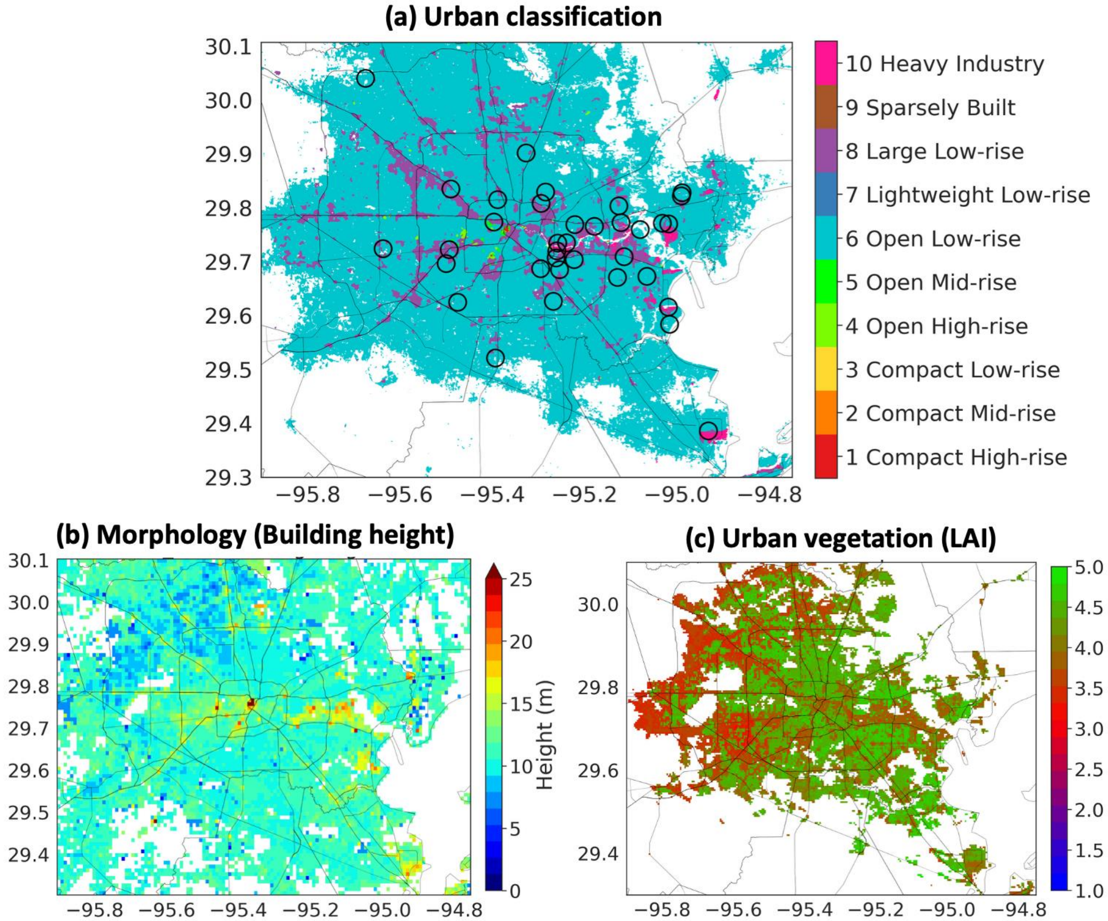

Figure 1. Urban datasets for the HGB region: (a) urban classification based on 10 WUDAPT LCZs with Continuous Air Monitoring Stations (CAMS) sites overlaid as black circles; (b) urban morphology represented by grid-scale building height from the U-Surf dataset; and (c) urban vegetation density represented by high-resolution LAI.

4.2. Improvements to WRF

The most recent release of the Weather Research and Forecasting (WRF) model at the time of the project execution will be used, configured with three nested domains covering the contiguous United States (12 km), Southeast Texas (4 km), and the HGB region (1.33 km) (**Figure 2**) as in our previous work (Li et al., 2023; Soleimanian et al., 2023). The WRF configuration will build on our previous project (AQRP 24-021), which yielded the best performance in reproducing observed meteorological conditions and PBLH across both onshore and offshore environments. WRF can be configured without an urban scheme (e.g., the SIP setting) or with one of three urban canopy models (UCMs): the single-layer urban canopy model (SLUCM) (Kusaka et al., 2000; Kusaka & Kimura, 2004), the Building Effect Parameterization (BEP) (Martilli et al., 2002), and the Building Energy Model (BEM) scheme (Salamanca et al., 2010). BEM is often used together with BEP, referred to as BEP-BEM in short. These urban schemes take the urban datasets as inputs.

In our previous project (AQRP 24-021), as well as the SIP configuration, WRF represents urban land use as a single “Urban and Built-Up” category. The WRF model configuration and physical parameterizations used for that project are summarized in **Table 1**. Urban grid cells are assigned surface properties using urban fraction scaling, where parameter values are interpolated between prescribed minimum and maximum limits. This approach does not resolve fine-scale differences among residential, commercial, and industrial areas. Under this default setting, activation of SLUCM and BEP-BEM *without high-resolution urban datasets as inputs* resulted in only modest improvements over urban regions, and persistent biases in PBLH and near-surface meteorology remained over the urban core, the HSC, and the Galveston Bay shoreline (AQRP 24-021). This is because all urban grid cells rely on the same generic urban surface description with the default single "Urban and Built-Up" category.

To address this limitation, first, the project will enhance urban classification by replacing the single urban category with 10 LCZ using the WUDAPT framework. Under this configuration, urban grid cells are assigned to one of ten LCZ categories, each associated with distinct parameter ranges. This LCZ-based representation improves the urban surface description in WRF regardless of whether UCMs are activated and enables more realistic differentiation among residential, commercial, and industrial environments. Second, the LCZ classification will be combined with grid-cell-specific urban morphology from the U-Surf dataset. Within each LCZ, mean structural values are replaced with grid-specific values derived from U-Surf, allowing spatial variability in mechanical drag, wind shear, and building-induced turbulence to be represented explicitly. By providing physically realistic building height and structural information at the grid scale, this combined LCZ - morphology framework supplies the essential inputs required for UCMs, particularly BEP-BEM. To ensure that the multi-layer BEP-BEM scheme is properly resolved, vertical resolution in the lowest 100 m will be enhanced by adding ~10–15 additional vertical levels relative to the baseline configuration. Finally, urban vegetation is refined by modifying the WRF vegetation parameter table (VEGPARM.TBL) for the ten LCZ categories using high-resolution urban LAI data. This approach replaces the default uniformly low urban LAI values with LCZ-specific vegetation properties, enabling a more realistic representation of vegetation density and associated surface energy exchange and deposition processes within urban areas.

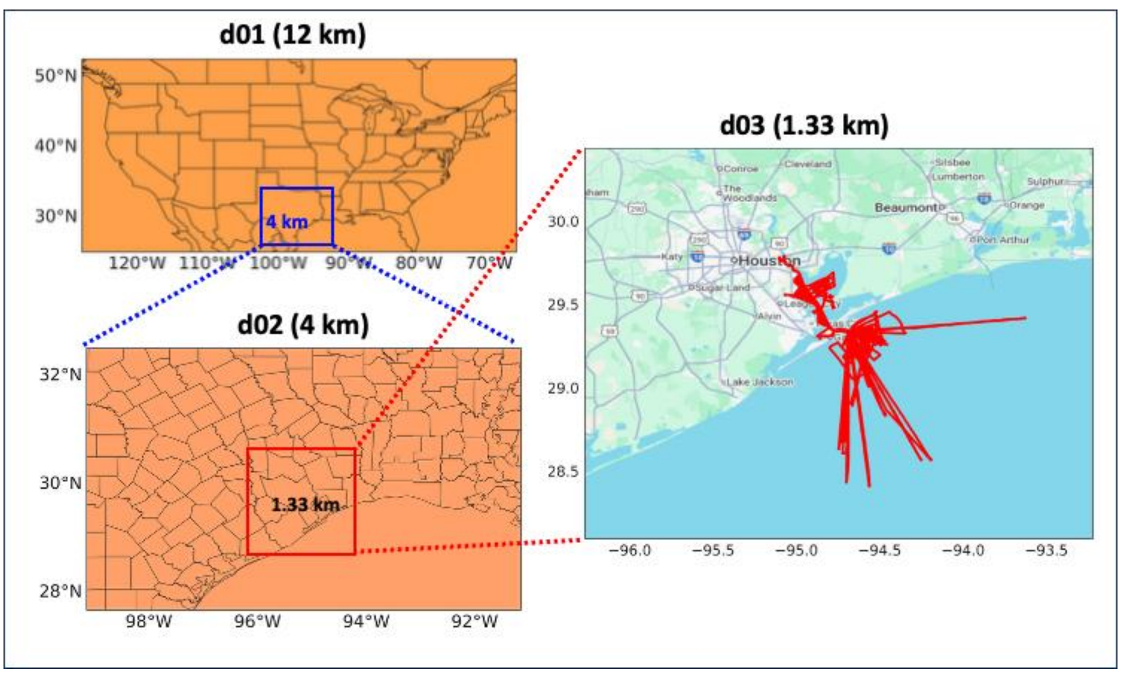

Figure 2 WRF domains showing (a) d01 (contiguous United States, 12 km x 12 km horizontal resolution), (b) d02 (Southeast Texas, 4 km x 4 km resolution), and (c) d03 (Houston-Galveston, 1.33 km x 1.33 km

resolution) regions. The red lines in d03 indicate the locations of ships that obtained measurements in September 2021, 2022, and 2023.

Table 1 WRF model configuration and physical parametrization.

Category	**Configuration**
Model	WRF-ARW v4.6.0
Domains	d01: Continental United States, 12 km × 12 km d02: Southeast Texas, 4 km × 4 km d03: Houston–Galveston region, 1.33 km × 1.33 km
Vertical Layers	45 levels from surface to 10 hPa
Initial and Boundary Conditions	High-Resolution Rapid Refresh (HRRR) (Dowell et al., 2022), for d01; nested IC/BC from parent domains for d02 and d03
PBL Scheme	Mellor-Yamada-Nakanishi-Niino Level 2.5 (MYNN2) (Nakanishi & Niino, 2009),
Surface Layer Scheme	Monin-Obukhov similarity surface layer (Chen et al., 1997),
Land Surface Model	Noah land-surface module (Chen & Dudhia, 2001),
Microphysics	Morrison double moment (2M) microphysics (Morrison et al., 2009),
Longwave and Shortwave Radiation	Rapid Radiative Transfer Model (RRTMG) (Iacono et al., 2008)
Cumulus Parameterization	New Simplified Arakawa-Schubert (NSAS) (Han & Pan, 2011)

4.3. Improvements to CAMx

The most recent release of CAMx will be used as the photochemical air quality model. CAMx will be configured to align with the WRF multi-nested grids. The baseline CAMx configuration will build on AQRP 24-021, which demonstrated the best performance in reproducing observed pollutant concentrations across both onshore and offshore environments (Li et al., 2023).

CAMx represents surface-atmosphere interactions differently from WRF and therefore requires a distinct approach for incorporating high-resolution urban datasets. CAMx does not include an internal land-surface or urban canopy model; instead, it relies on externally prepared Land Use and Land Cover (LULC) maps and land-use–dependent parameter tables to represent surface roughness, near-surface mixing, dry deposition velocities, and biogenic emissions. In our previous work, we used the 4 km LULC dataset from the TCEQ 2019 SIP release, which was derived from the National Land Cover Dataset (NLCD) and Moderate Resolution Imaging Spectroradiometer (MODIS) products. In the 4 km LULC dataset, all urban areas are represented as a single urban category, while non-urban land-use has multiple categories (e.g., cropland, forest, grassland, wetlands, and water). We did not regrid the SIP 4 km LULC file to 1.33 km; CAMx internally regridded the 4 km to the 1.33 km used in AQRP 24-021, propagating the 4 km LULC representation into high-resolution simulations.

In this work, first, the TCEQ SIP-consistent 4 km LULC dataset will be regridded to the 1.33 km resolution for the CAMx inner domain. Second, the single urban category in the regridded 1.33 km LULC will be subdivided using the WUDAPT LCZ framework, and each urban grid-cell will be assigned one of 10 LCZ categories (LCZ 1–10). This step enables residential, commercial, and industrial environments to be represented as physically distinct urban surface types within CAMx, rather than being treated uniformly. Third, LCZ-specific urban morphology parameters will be refined using the U-Surf dataset. Grid-specific building height information from U-Surf will be aggregated by LCZ class across the HGB region to derive representative mean/median morphology values for each LCZ. These LCZ-specific morphology statistics will be used to update urban surface roughness and mixing-related parameters in the CAMx, replacing the generic values associated with the default urban category.

Fourth, urban vegetation parameters will be refined using a high-resolution (500 m) observational LAI dataset described above. LAI values will be aggregated by LCZ class to derive representative vegetation densities for each urban type and will replace the default low urban LAI values in the CAMx dry deposition and vegetation parameter tables. This refinement directly improves the representation of urban ozone dry deposition and biogenic emissions, addressing known biases in ozone removal and production associated with the single-category urban treatment.

4.4. Observations to Evaluate Model Improvements

Observational datasets collected across the HGB region during Tracking Aerosol Convection ExpeRiment (TRACER) (Jensen et al., 2021) and TRACER-Air Quality (TAQ) 2021–2023 field campaigns (TCEQ PGA# 582-22-32022-021; TCEQ PGA# 582-23-43296-028) will be used to evaluate the improved WRF-CAMx described above. Although these datasets have been used in previous AQRP-funded projects, the focus of this project is different. The previous projects emphasized offshore measurements and used only the La Porte site measurements from those campaigns to evaluate the model performance of PBL and O_3 on land. The La Porte site is largely rural, and its location is also strongly influenced by marine and bay circulations. In contrast, this work explicitly targets urban environments and will primarily use observations collected by the University of Houston's Mobile Air Quality Laboratory 1 (MAQL1), which sampled the diverse landscapes of the HGB over 2021-2023, with most of the routes in the urban core and industrial areas (**Figure 3b-c**). These rich datasets have not been explored by modelers to utilize their full potential to evaluate high-resolution photochemical air quality models. Co-PI Flynn's team will conduct careful screening of the mobile observations to remove spontaneous signals from local traffic and label the sampling locations with different urban classifications. In addition, the TRACER project provided the urban-focused observations of PBL at a few sites around the HGB, which reside in different LCZs (Kamath et al., 2024) (**Figure 3d**). Along with the campaign data, meteorological and pollutant observations from Continuous Air Monitoring Stations (CAMS) around the urban HGB region (**Figure 3a**) will be used to evaluate the WRF-CAMx model. When compared to model prediction, these urban measurements will be interpreted relative to LCZ class, urban morphology, and vegetation density. This enables direct evaluation of how refined urban surface representation influences vertical mixing, PBL development, and ozone behavior within the urban canopy.

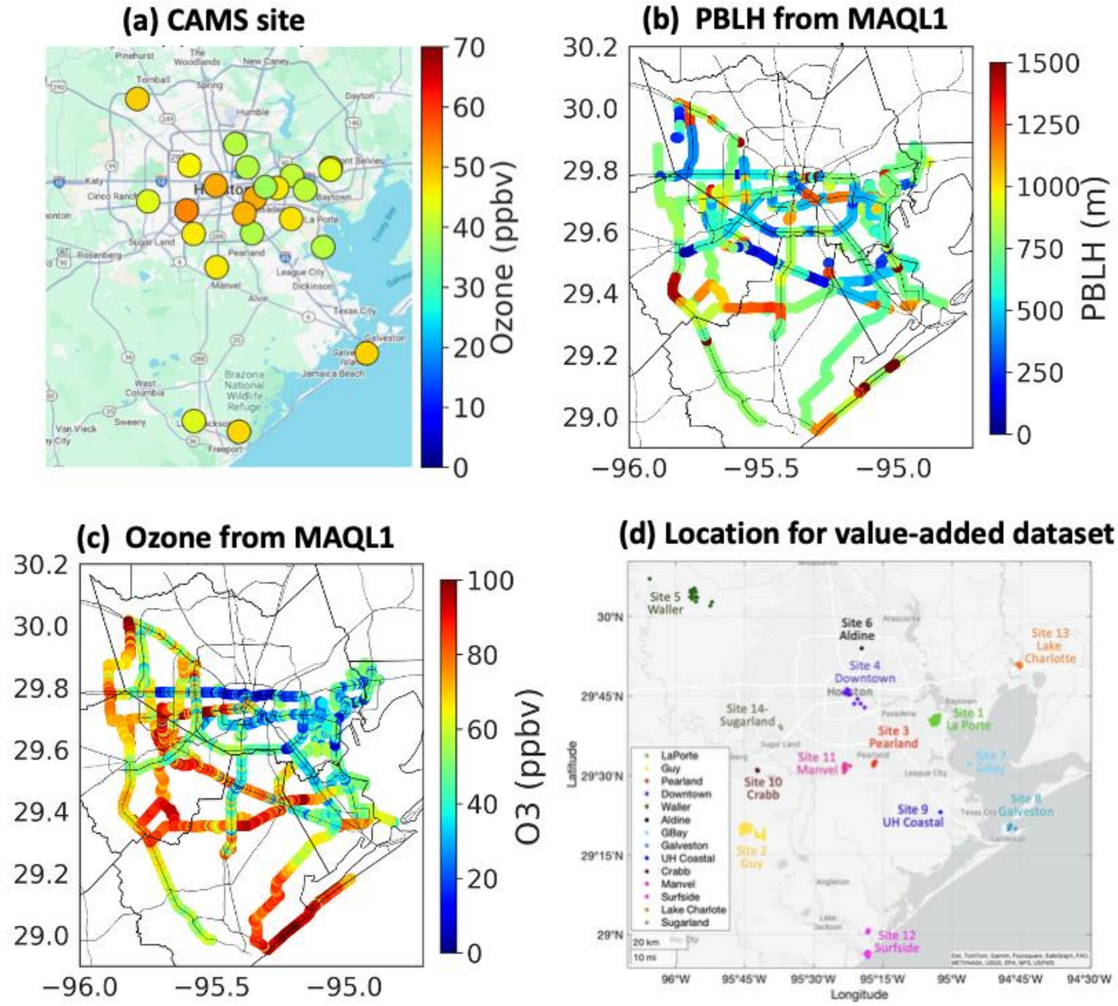

Figure 3. (a) Daytime mean ozone (ppbv) for September 2022 from the CAMS site. Spatial map of (b) PBLH (m), and (c) ozone (ppbv) over the urban Houston from the MAQL1 during the TRACER field campaigns in September 2022. (d) Locations of the 14 sites included in the value-added PBLH dataset, compiled by Kamath et al. (2024) by combining multiple datasets from the TRACER campaign.

5. Work Plan

The project includes six tasks, as shown in **Table 1**. Task 1 is Work Plan. Task 2 covers monthly technical reports. Tasks 3 - 5 are reports on specific scientific questions shown in detail below. Task 6 is draft final and final reports

5.1. Task 3: Urban Classification in WRF

Task 3 will establish a high-resolution baseline of the WRF model by replacing the default single urban land-use category with a 10 LCZ framework using the WUDAPT datasets. **Figure 4** shows the schematic overview of this task. In the previous AQRP projects and in the default WRF configuration, all urban grid cells were represented using a single generalized urban category, resulting in limited improvement in urban PBL structure even when UCMs are activated. Task 3 replaces this generic urban category with 10 LCZs using WUDAPT, producing an updated WRF baseline model with improved differentiation among residential, commercial, and industrial environments.

Output from the updated WRF baseline model will be compared to our previous AQRP simulations and against observations from the field campaign datasets. Evaluation will focus on improvements in urban PBL structure, near-surface meteorological fields, and transport-relevant processes attributable solely to the introduction of LCZ-based urban classification. This updated WRF configuration will serve as the baseline model that forms the foundation for subsequent urban morphology and vegetation refinements in Task 4 and answer part of Science Question 1.

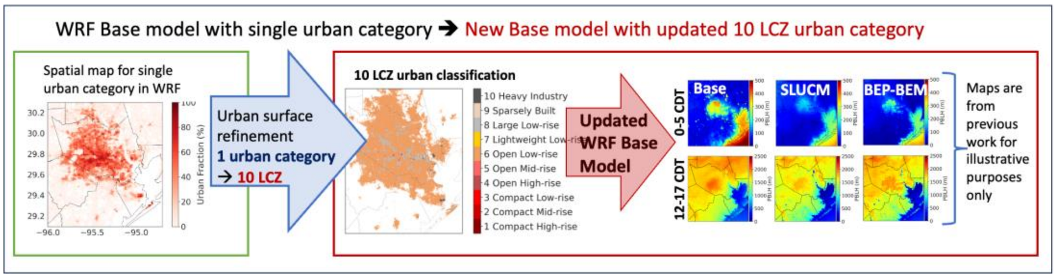

Figure 4. Schematic overview of Task 3. Transition from a WRF baseline configuration with a single generalized urban category to an updated baseline with 10 LCZs. Different UCMs (none, SLUCM, and BEP-BEM) will be tested in WRF.

5.2. Task 4: Urban morphology and vegetation refinement in WRF

Task 4 improves the WRF baseline simulation from Task 1 by introducing spatially explicit urban morphology, improved urban vegetation characterization, and refined coastal–marine surface treatment. While Task 3 introduces physically distinct urban types, it relies on mean parameter values for each class and therefore does not resolve sub-LCZ spatial variability in building structure, vegetation density, or land-water thermal contrasts. Task 4 addresses these limitations by refining key surface characteristics that directly control mechanical turbulence, vertical mixing, and surface energy exchange.

For urban morphology, categorical LCZ parameter values from Task 3 will be refined using spatially continuous urban structural and radiative information from the U-Surf dataset, such as building height, roof fraction, canyon surface fractions, emissivity, and albedo. Replacing LCZ mean values with grid-cell-specific U-Surf parameters maps allows WRF to represent realistic spatial variability in urban geometry and thermal properties that control wind obstruction, turbulence generation, and heat storage. To better represent multi-layer urban canopy physics (e.g., BEP-BEM), an additional ~10–15 vertical layers in the lowest 100 m of the atmosphere will be added, increasing the WRF vertical layer count from 45 to ~55–60. The enhanced lower-atmospheric resolution is necessary to better resolve building-height variability and vertical exchanges within the urban canopy layer. The increased number of vertical layers will incur additional computational expense relative to the SIP modeling platform and AQRP 24-021 configuration, which will be documented in the project report.

For urban vegetation, the urban vegetation will be refined using a high-resolution (500 m) LAI dataset. LAI values will be aggregated by LCZ category to derive representative mean/median values for each urban type. These LCZ-specific LAI values will replace the default urban LAI of ~1.0 in WRF, and LAI-based scaling will be applied to related vegetation parameters (e.g., stomatal resistance and surface albedo) to ensure physical consistency in surface energy exchange and dry deposition processes. BVOC emissions depend on LAI and will be updated as well according to updated LAI values.

In addition, Galveston Bay and the Gulf of America will be treated as separate water surface categories. The Gulf will retain the standard water representation from our previous AQRP project, while Galveston

Bay will be assigned distinct surface properties (e.g., roughness length and albedo) to better represent its shallow, thermally responsive behavior. This refinement will likely improve the simulation of coastal PBL evolution and sea-breeze interactions affecting the urban core of the HGB region.

Model outputs from Task 4 simulations will be evaluated against both the Task 3 baseline model and observational datasets, with a focus on changes in urban and coastal PBL structure, near-surface meteorology, and transport-relevant processes. Together, Tasks 3 and 4 establish a physically consistent, high-resolution, meteorological framework and provide a robust foundation for subsequent CAMx air quality simulations. This task will answer the meteorological aspects of Science Question 2-4.

5.3. Task 5: Integration of Refined Urban and Coastal Surface Characterization into CAMx

Task 5 will use outputs from the improved WRF simulations from Task 4 to drive CAMx, ensuring that improvements in urban and coastal meteorology and boundary layer structures are consistently transferred to the photochemical model. Because CAMx relies on externally prepared land-use data and land-use–dependent parameter tables, targeted updates to the CAMx land-use framework will be conducted in this task: (1) development of the high-resolution land-use dataset for CAMx, (2) calculation of LCZ-specific surface parameter values, and (3) implementation of these refinements in CAMx.

First, we will prepare a 1.33 km-resolution LULC dataset for the CAMx inner domain by regridding the TCEQ SIP-consistent 4 km LULC, preserving all non-urban categories. The single generalized urban category will then be subdivided into 10 WUDAPT LCZ classes, and open water will be separated into two distinct surface categories: Galveston Bay and the Gulf of America. This LCZ-based LULC will serve as the land-use input for CAMx. Second, LCZ-specific surface parameter values required by CAMx will be derived from high-resolution datasets. Urban morphology information from the U-Surf dataset will be aggregated by LCZ class to get surface roughness and near-surface mixing parameters. Urban vegetation properties will be refined using the LAI dataset. Corresponding surface parameters will also be defined for Galveston Bay and the Gulf of America to reflect their distinct thermal and mixing characteristics. Third, the improved LCZ-based LULC and associated surface parameters will be implemented within CAMx by updating land-use–dependent parameter tables and modifying the WRF-CAMx interface as needed. This ensures consistency between the refined urban and coastal surface representations used in WRF and those driving CAMx chemical transport processes.

To maintain consistency with the WRF vertical layer, the CAMx vertical layer will be increased from 30 (as in the SIP modeling platform and AQRP 24-021) to ~40–45 layers, with the additional layers concentrated within the lowest 100 m. The enhanced near-surface vertical resolution is intended to better represent vertical transport, mixing, dry deposition, and chemical processing within the shallow urban and marine boundary layer. The increased number of vertical layers in CAMx will further increase computational expense relative to the SIP modeling platform and AQRP 24-021 configuration, which will be documented in the project report.

The updated CAMx simulations are expected to exhibit improved representation of urban and coastal surface processes, leading to more realistic ozone dry deposition, biogenic emissions, and near-surface mixing, and ultimately reduced systematic ozone biases over the HGB region relative to prior SIP-based configurations. Model performance will be evaluated using urban and coastal observations from the TRACER and TAQ campaigns, CAMS observations (located primarily in urban regions), and previous AQRP simulations. By improving the simulation of ozone in the urban areas, this work strengthens the scientific basis for evaluating emission-control strategies, diagnosing source contributions, and assessing the effectiveness of regulatory measures under present-day and future scenarios. Task 5 will deliver an improved high-resolution, urban-scale CAMx modeling framework that is physically consistent with the urban-scale WRF. Outputs from Task 5 will likely address persistent sources of uncertainty in ozone predictability for the HGB region and answer the air quality aspects of Science Question 1-4.

6. Schedule and Deliverables

The schedule for this project is listed below in **Table 2**.

Table 2. Schedule of Project Schedule.

Deliverable	Deliverable Date
Work Plan (Task 1) **Deliverable 1.1:** AQRP approved Scope of Work (SOW) **Deliverable 1.2:** AQRP approved QAPP **Deliverable 1.3:** Budget and Budget Justification	 **(1.1):** May 14, 2026 **(1.2):** May 14, 2026 **(1.3):** May 14, 2026
Progress Reports (Task 2) **Deliverable 2.1:** Monthly Technical Reports (MTR)	**(2.1):** Monthly by the 10th of the subsequent month
Urban Classification in WRF (Task 3) **Deliverable 3.1:** Report on improvements to urban classification in WRF	 **(3.1):** November 15, 2026
Urban morphology and vegetation refinement in WRF (Task 4) **Deliverable 4.1:** Report on refining urban morphology and vegetation in WRF	**(4.1):** March 15, 2027
Integration of Refined Urban and Coastal Surface Characterization into CAMx (Task 5) **Deliverable 5.1:** Report on the improved CAMx configuration and evaluation	**(5.1):** July 1, 2027
Draft Final and Final Reports (Task 6) **Deliverable 6.1:** Draft Final Report **Deliverable 6.2:** Final Report	 **(6.1):** August 1, 2027 **(6.2):** August 31, 2027

7. Deliverables

AQRP requires certain reports to be submitted on a timely basis and at regular intervals. A description of the specific reports to be submitted and their due dates are outlined below. One report per project will be submitted (collaborators will not submit separate reports), with the exception of the Financial Status Reports (FSRs). The lead PI will submit the reports, unless that responsibility is otherwise delegated with the approval of the Project Manager. All reports 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. Report templates and accessibility guidelines found on the AQRP website will be followed.

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: Ten (10) business day after notice of intent to fund.

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 doc 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	**October 31, 2026**
Quarterly Report #2	November, December 2026, January 2027	**January 31, 2027**
Quarterly Report #3	February, March, April 2027	**April 30, 2027**
Quarterly Report #4	May, June, July 2027	**July 31, 2027**

Monthly Technical Reports (MTRs): Technical Reports will be submitted monthly to the Project Manager and TCEQ Liaison as a Word doc using the AQRP Template.
Monthly Technical Report Due Dates:
Due Dates:

REPORT	PERIOD COVERED	DUE DATE
Technical Report #1	Project Start - August 31, 2026	**September 10, 2026**
Technical Report #2	September 1 - 30, 2026	**October 10, 2026**
Technical Report #3	October 1 - 31, 2026	**November 10, 2026**
Technical Report #4	November 1 - 30, 2026	**December 10, 2026**
Technical Report #5	December 1 - 31, 2026	**January 10, 2027**
Technical Report #6	January 1 - 31, 2027	**February 10, 2027**

Technical Report #7	February 1 - 28, 2027	**March 10, 2027**
Technical Report #8	March 1 - 31, 2027	**April 10, 2027**
Technical Report #9	April 1 - 30, 2027	**May 10, 2027**
Technical Report #10	May 1 - 31, 2027	**June 10, 2027**
Technical Report #11	June 1 - 30, 2027	**July 10, 2027**
Technical Report #12	July 1 - 31, 2027	**August 10, 2027**

Financial Status Reports (FSRs): Financial Status Reports will be submitted monthly to the AQRP Grant Manager (aqrp-grant-manager@austin.utexas.edu) by each institution on the project using the AQRP FSR Template.

FSR Due Dates:

REPORT	PERIOD COVERED	DUE DATE
FSR #1	Project Start - August 31, 2026	**September 15, 2026**
FSR #2	September 1 - 30, 2026	**October 15, 2026**
FSR #3	October 1 - 31, 2026	**November 15, 2026**
FSR #4	November 1 - 30, 2026	**December 15, 2026**
FSR #5	December 1 - 31, 2026	**January 15, 2027**
FSR #6	January 1 - 31, 2027	**February 15, 2027**

FSR #7	February 1 - 28, 2027	**March 15, 2027**
FSR #8	March 1 - 31, 2027	**April 15, 2027**
FSR #9	April 1 - 30, 2027	**May 15, 2027**
FSR #10	May 1 - 31, 2027	**June 15, 2027**
FSR #11	June 1 - 30, 2027	**July 15, 2027**
FSR #12	July 1 - 31, 2027	**August 15, 2027**
FSR #13	August 1 -31, 2027	**September 15, 2027**
FSR #14	Final FSR	**October 15, 2027**

Draft Final Report: A Draft Final Report will be submitted to the Project Manager and the TCEQ Liaison. It will include an Executive Summary. 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: 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: 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, held August 2027 (exact date and time TBD) at UT Austin - West Pickle Research Campus.

8. Project Organization and Responsibilities

The project will be directed by two investigators: Dr. **Yuxuan Wang** (PI) and Dr. **James Flynn** (Co-PI) in the Department of Earth and Atmospheric Sciences at UH. Wang will manage the overall project and lead the modeling work, including compiling urban datasets, model improvements, model simulation, and results analysis. Wang will lead reporting requirements (GAD, QAPP, monthly reports, draft, and final reports) and supervise UH postdoctoral researcher and graduate students to perform the planned modeling analysis

Flynn will oversee quality control, data screening, and location labelling for meteorological and air pollution observations collected from various urban driving of the mobile laboratories to ensure a suitable comparison with the urban modeling. He will assist with reporting requirements (GAD, QAPP, draft, and final reports) and advise UH graduate students and postdocs to perform the observational evaluation of model outputs.

9. References

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Budget and Budget Justification

Project #26-015

Improving Urban Representation in the High-Resolution WRF-CAMx Model and Evaluating the Effects on PBL and Ozone Prediction

Prepared for

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

By

Yuxuan Wang
University of Houston

James Flynn
University of Houston

May 8, 2026
Version #1

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

Approvals

This Budget was approved electronically by:

DocuSigned by:
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RoseAnna Goewey Date
Program Manager, Texas Air Quality Research Program

This Budget was approved electronically by:

Signed by:
Elena McDonald-Buller
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Elena McDonald-Buller Date
Project Manager, Texas Air Quality Research Program

This Budget was approved electronically by:

Signed by:
Gabriel Lee
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2026-07-09 | 10:50:20 CDT

Gabriel Lee Date
Project Liaison, Texas Commission on Environmental Quality

Budget and Budget Justification

1. Budget

A. SENIOR PERSONNEL: PI, Co-PI						
	FirstName LastName	**Title**	**Monthly Rate**	**Fringe Rate**	**FTE / % Effort**	**Funds Requested**
1.	Yuxuan Wang	Principal Investigator	$13,273	16.3%	2.00	$26,545
2.	James Flynn	CoPrincipal Investigator	$8,580	26.3%	1.00	$8,580
3.			$0	0.0%	0.00	$0
	TOTAL SENIOR PERSONNEL					**$35,125**
B. OTHER PERSONNEL (SHOW NUMBERS IN BOXES)						
1	1	Other Professionals / Researcher 4	$5,602	30.4%	2.00	$11,203
2	1	Other Professionals / Postdoctoral Fellow	$4,500	33.4%	12.00	$54,000
3	2	Graduate Student	$2,300	7.0%	14.00	$32,200
	TOTAL OTHER PERSONNEL					**$97,403**
	TOTAL SALARIES AND WAGES (A+B)					**$132,528**
C. FRINGE BENEFITS (AUTOMATICALLY CALCULATED BASED ON ENTERED RATES)						
1.	Senior Personnel					**$6,567**
2.	Other Personnel					**$23,696**
	TOTAL FRINGE BENEFITS					**$30,263**
	TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A+B+C)					**$162,791**
D. PERMANENT EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5000)						
a)						$0
b)						$0
c)						$0
	TOTAL EQUIPMENT					**$0**
E. TRAVEL			**Cost per Trip**	**# of Trips**		
1.	Domestic (Incl. Canada, Mexico and U.S. Possessions)		$1,500	3		$4,500
2.	Foreign					$0
	TOTAL TRAVEL					**$4,500**
F OTHER DIRECT COSTS						
1.	Materials and Supplies					$500
2.	Professional Services - Idependent Contractors					$0
3.	Subcontracts (contracts will be issued by UT)					
	a)					$0
	b)					$0
	c)					$0
	d)					$0
4.	Tuition and Fees					$0
5.	Other					$0
	TOTAL OTHER DIRECT COSTS					**$500**
G. TOTAL DIRECT COSTS (A THROUGH F)						**$167,791**
H. TOTAL INDIRECT COSTS		**(MTDC)**	**IDC Rate:**	**15.000%**		**$25,169**
I. TOTAL COSTS						**$192,960**

2. Budget Justification

A. SALARIES

Dr. Yuxuan Wang, Principal Investigator, 16.67% effort, will be responsible for supervising all the modeling work and project reports.

Dr. James Flynn, Co-Investigator, 8.33% effort, will be responsible for supervising the quality of observational data used to compare with the model and advise on model-observation comparisons.

Sergio Alvarez, Researcher 4, 16.67% effort, will be responsible for conducting quality control, data screening, and location labelling for meteorological and air pollution observations collected from various urban driving of the mobile laboratories to ensure a suitable comparison with the urban modeling.

TBD, Postdoctoral Fellow, 100% effort, will implement the urban datasets into the high-resolution WRF and CAMx models, perform the modeling, and analyze the model results.

TBD, Graduate Research Assistant (GRA), 66.67% effort, will assist the postdoctoral fellow in analyzing the model results and conducting the model to observation comparisons.

TBD, Graduate Research Assistant (GRA), 50% effort, will perform data downloading, regridding, and pre-processing of urban datasets and observations, post-processing and archiving of the modeling outputs. The student will also assist with the model evaluation and report writing.

B. FRINGE BENEFITS

Sponsored awards are responsible for the actual fringe benefit costs incurred by each employee working on the project. Fringe benefit costs have been estimated based on historical data. However, actual costs for fringe benefits are charged (billed) to the sponsored project at the time the cost is incurred, based on salary, selected benefits package and other variables applicable to the individual employee. Total fringe benefits budget requested. Total fringe benefits budget requested: $30,263

C. EQUIPMENT

None Requested

D. OTHER DIRECT COSTS

MATERIALS AND SUPPLIES

Supplies are calculated at $500 per year for computer backup media, poster printing, and other associated supplies used to support the project effort. Total materials and supplies budgeted requested: $500

TRAVEL

Funds are requested for project personnel to travel to attend a national conference (e.g., AGU or AMS) and travel to Austin for the AQRP workshop. Travel costs in this budget are based on sponsored research travel for previous similar trips and are calculated for the domestic travel of two personnel to take one trip each. Total travel budget requested: $4500

INDIRECT COSTS

The indirect cost rate of 15% of modified/total direct costs (MTDC/TDC) is used as instructed by the AQRP's published proposal preparation instructions. Modified total direct costs shall exclude equipment, capital expenditures, charges for patient care, rental costs, tuition remission, scholarships and fellowships, participant support costs and the portion of each subaward in excess of $25,000. Total indirect cost budget requested: $25,169