

Title: Characterization of international and domestic sources of windblown dust and contribution to fine and coarse particulate matter in Texas

Principal Investigator: Daniel Tong, George Mason University, Fairfax, VA

Abstract

Windblown dust poses increasing challenges to air quality, public health, and transportation safety. In 2025, for instance, Texas experienced the dustiest spring since the Dust Bowl era, with 42 vehicle crashes and four fatalities caused by a single dust storm on March 14, 2025. Another critical issue in Texas is that crustal materials originating from Mexico and overseas sources such as the Saharan Desert can be transported by winds into Texas. The Clean Air Act section 179B states that pollution that originates outside of US borders is not to affect National Ambient Air Quality Standards (NAAQS) compliance. Given the high stakes associated with dust risks and complexity of dust source attribution, it is important to investigate the trends of dust storms and understand their sources and contributions to fine and coarse particulate matter ($PM_{2.5}$ and PM_{10}) in this region.

The objective of this study is to understand the trends in windblown dust and its effects on $PM_{2.5}$ and PM_{10} in Texas. More specifically, we aim to 1) investigate the long-term trends in windblown dust activity in Texas and three “upwind” states (New Mexico, Oklahoma and Colorado); 2) analyze the environmental drivers of the dust trends; 3) improve dust emission model by integrating satellite-detected dust sources and updating other model inputs, and 4) quantify contributions from in-state and out-of-state dust sources to $PM_{2.5}$ and PM_{10} in Texas.

The proposed project consists of four major activities:

1) Reconstructing long-term dust trends from three ground networks. We will assemble windblown dust event records from three ground networks, including the Interagency Monitoring to PROtect Visual Environments (IMPROVE), the Texas Commission on Environmental Quality (TCEQ) air quality monitors, and National Oceanographic and Atmospheric Administration (NOAA) Integrated Surface Database (ISD). An intercomparison of these datasets will be performed to examine if there is a trend in the observed dust activity, and to identify high-dust and low-dust years for subsequent analyses and model simulations.

2) Analyzing and diagnosing environmental drivers of dust trends. Built on the lessons learned from prior studies, several environmental factors will be selected for this analysis, including both single variables such as wind speed, vegetation cover (Normalized Difference Vegetation Index (NDVI), precipitation, and soil moisture, and composite indices such as drought index and El-Nino Southern Oscillation (ENSO). Identified key factors will be used to guide model optimization.

3) Improving windblown dust emission modeling. To address the large uncertainties existing in windblown dust modeling, this task will: i) update soil texture in Mexico and the US based on a hybrid State Soil Geographic database Version 2 (STATSGO2)/Food and Agriculture Organization (FAO) derived map; ii) improve Mexico dust sources using a newly available Geostationary Operational Environmental Satellites (GOES) dust initiation map; iii) improve domestic cropland dust sources with George Mason University (GMU)/U.S. Department of Agriculture (USDA) CropScape data; and iv) conduct sensitivity tests with other key inputs, including winds, vegetation cover, surface roughness, and soil moisture.

4) Quantifying windblown dust effects on $PM_{2.5}$ and PM_{10} . We will use the optimized modeling system to quantify the effect of windblown dust emissions on $PM_{2.5}$ and PM_{10} in Texas. We choose a high-dust period and a low-dust one and use the updated model to reproduce the “relative trend”, and to assess windblown dust contributions in both periods. For each selected period, we will conduct two simulations: without and with windblown dust emissions. The dust contribution is calculated from the difference between the two simulations.

This work directly addresses the Research Priority area “Trends in wind-blown dust ($PM_{2.5}$ and PM_{10}) in Texas”. Leveraging prior work, this project will reconstruct long-term dust trends from ground stations and design a suite of dust emission improvements to reduce dust modeling uncertainties. This project also directly aims at “better characterization of the multiple sources of windblown dust and their contribution to PM_{10} and $PM_{2.5}$ ”. Although the FENGSHA is currently implemented as a module in Community Multiscale

Air Quality (CMAQ), a standalone version will be made available to the community so that it can be easily incorporated in other models such as Comprehensive Air Quality Model with Extensions (CAMx).

Quality Assurance Project Plan (QAPP)

Project 26 – 007

Characterization of international and domestic sources of windblown dust and contribution to fine and coarse particulate matter in Texas

Prepared for

Texas Air Quality Research Program (AQRP)

The University of Texas at Austin

Prepared by

Daniel Tong

George Mason University, Fairfax, VA

May 15, 2026

Version #1

George Mason University has prepared this QAPP following the Environmental Protection Agency (EPA) guidelines for a Quality Assurance (QA) Category III Project: Research Model Development and Applications and Category IV Projects: Secondary Data. 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
 - 2.1 Responsibilities of Project Participants
 - 2.2 Project Schedule
3. Scientific Approach
 - 3.1 Model Configuration and Applications
 - 3.2 Method to update soil texture and dust sources in Mexico
 - 3.3 Update domestic cropland dust source emissions
4. Quality Metrics

5. Data Analysis, Interpretation and Management
 - 5.1 Data Reporting
 - 5.2 Data Validation
 - 5.3 Data Analysis
 - 5.4 Data Storage
 - 5.5 Model Documentation
6. Audits of Data Quality
7. Reporting
8. References

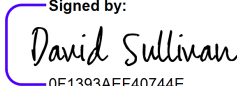
QA Requirements: Technical Systems Audits - Not Required for the Project
 Audits of Data Quality – 10% Required
 Report of Findings – Required in Final Report

Approvals Sheet

This document is a Category III Quality Assurance Project Plan for the #26-007 titled “Characterization of international and domestic sources of windblown dust and contribution to fine and coarse particulate matter in Texas” project. The Principal Investigator for the project is Daniel Tong.

Electronic Approvals:

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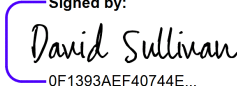
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Date

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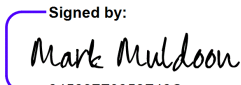
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1.0 Project Description and Objectives

The Problem: As drought becomes more frequent and severe in western Texas and surrounding areas, windblown dust poses increasing challenges to air quality, public health and transportation safety. In 2025, for instance, Texas experienced the dustiest spring since the Dust Bowl era, with 42 vehicle crashes and four fatalities caused by a single dust storm on March 14, 2025 (Wood and Edgin, 2025). Given the high stakes associated with dust risks, it is important to investigate the trends of dust storms and understand their dust sources and contributions to fine and coarse particulate matter (PM_{2.5} and PM₁₀) in this region.

Objectives: The objective of this proposed study is to understand the trends in windblown dust and its effects on PM_{2.5} and PM₁₀ in Texas. More specifically, we aim to 1) investigate the long-term trends in windblown dust activity in Texas and three “upwind” states (New Mexico, Oklahoma, and Colorado); 2) analyze the environmental drivers of the dust trends; 3) improve dust emission model by integrating satellite-detected dust sources and updating other model inputs, and 4) quantify contributions from in-state and out-of-state dust sources to PM_{2.5} and PM₁₀ in Texas.

Data used: We will use ground air quality and satellite observations, as well as numeric modeling data to address these issues. More specifically, we will conduct the following activities:

1) Reconstructing long-term dust trends from three ground networks. We will assemble windblown dust event records from three ground networks, including the Interagency Monitoring to PROtect Visual Environments (IMPROVE), the Texas Commission on Environmental Quality (TCEQ) air quality monitors, and National Oceanic and Atmospheric Administration (NOAA) Integrated Surface Database (ISD). An intercomparison of these datasets will be performed to examine if there is a trend in the observed dust activity, and to identify high-dust and low-dust years for subsequent analyses and model simulations.

2) Analyzing and diagnosing environmental drivers of dust trends. Built on the lessons learned from prior studies, several environmental factors will be selected for this analysis, including both single variables such as wind speed, vegetation cover (NDVI), precipitation, and soil moisture, and composite indices such as drought index and El-Nino Southern Oscillation (ENSO). Identified key factors will be used to guide model optimization.

3) Improving windblown dust emission modeling. To address the large uncertainties existing in windblown dust modeling, this task will: i) update soil texture in Mexico and US based on a hybrid State Soil Geographic database Version 2 (STATSGO2)/Food and Agriculture Organization (FAO) derived map; ii) improve Mexico dust sources using a newly available Geostationary Operational Environmental Satellites (GOES) dust initiation map; iii) improve domestic cropland dust sources with George Mason University (GMU)/U.S. Department of Agriculture (USDA) CropScape data; and iv) conduct sensitivity tests with other key inputs, including winds, vegetation cover, surface roughness, and soil moisture.

4) Quantifying windblown dust effects on PM_{2.5} and PM₁₀. We will use the optimized modeling system to quantify the effect of windblown dust emissions on PM_{2.5} and PM₁₀ in Texas. We choose a high-dust period and a low-dust one, and use the updated model to reproduce the “relative trend”, and to assess windblown dust contributions in both periods. For each select period, we will conduct two simulations: without and with windblown dust emissions. The dust contribution is calculated from the difference between the two simulations.

Users of the data: TCEQ air quality managers and researchers working on dust, PM_{2.5} and PM₁₀ issues in Texas and surrounding regions; the data can also be used to inform policy making, which is beyond the scope of this work.

Environmental system/setting to be modeled: This work will focus on modeling dust emissions in Texas and surrounding regions, including three neighboring states to the west and north, and northern Mexico. The scenarios considered are listed in Table 1.

Table 1. Design of model simulation scenarios to improve dust emission modeling

Scenario	Configuration	Purpose
NoDust	Community Multiscale Air Quality (CMAQ) simulation without windblown dust emission	Baseline
Dust0	Same as NoDust, with default windblown dust emission	Default FENGSHA settings
Dust1	Dust0 + Soil texture update	Effect of soil texture update
Dust2	Dust1+ Mexico source update	Effect of Mexico source update
Dust3	Dust2+ cropland dust update	Effect of cropland dust update
Dust4	Dust3 + wind test (gusty winds vs hourly winds)	Effect of wind speed
Dust5	Dust4 + (soil moisture, vegetation, surface roughness)	Finding optimal configuration

Model evaluation: Simulated PM concentrations and aerosol optical depth (AOD) will be evaluated using ground-based and satellite observations. Surface concentrations of PM_{2.5} and PM₁₀ will be compared against ground observations from the TCEQ (in-state) and EPA Air Quality System (AQS) (out-of-state) monitors, and the IMPROVE stations (Table 2). AOD will be evaluated against the Multi-Angle Implementation of Atmospheric Correction (MAIAC) AOD product. This daily atmospheric aerosol product is generated by Moderate Resolution Imaging Spectroradiometer (MODIS) and a multi-angle atmospheric correction algorithm (Lyapustin and Wang, 2022). The aerosol optical depth (AOD) at 550

nm is obtained from the MCD19A2 Collection 6 provided by the National Aeronautics and Space Administration (NASA). A suite of statistical metrics will be used for model evaluation. The bias of a quantity is calculated as the difference between modeled (m_i) and observed (o_i) values, for the i th model-observation pair, as $\Delta_i = m_i - o_i$. We will use mean bias (MB), normalized mean bias (NMB), and mean fractional bias (MFB). To estimate errors in modeled values compared to observations, mean absolute error (MAE) and root mean squared error ($RMSE$) will be calculated. In addition, the association between simulated and observed values is measured by the correlation coefficient (r) and the index of agreement (IOA).

Table 2. IMPROVE stations information

Site Name	Site Code	State	Latitude	Longitude
Dinosaur NM	DINO1	CO	40.25	-108.967
Flat Tops	FLTO1	CO	39.9153	-107.634
Fort Collins	FOCO1	CO	40.5929	-105.143
Great Sand Dunes NM	GRSA1	CO	37.7249	-105.519
Mesa Verde NP	MEVE1	CO	37.1984	-108.491
Mount Zirkel Wilderness	MOZI1	CO	40.5383	-106.677
Ripple Creek	RICR1	CO	40.0865	-107.314
Rocky Mountain NP	ROMO1	CO	40.2783	-105.546
Rocky Mountain NP HQ	RMHQ1	CO	40.3624	-105.564
Shamrock Mine	SHMI1	CO	37.3038	-107.484
Storm Peak	STPE1	CO	40.445	-106.74
Weminuche Wilderness	WEMI1	CO	37.6594	-107.8
White River NF	WHRI1	CO	39.1536	-106.821
Bandelier NM	BAND1	NM	35.7797	-106.266
Bosque del Apache	BOAP1	NM	33.8695	-106.852
Carlsbad Caverns	CAVE1	NM	32.1783	-104.444
Gila Wilderness	GICL1	NM	33.2204	-108.235
Salt Creek	SACR1	NM	33.4598	-104.404
San Andres	SAAN1	NM	32.6869	-106.484
San Pedro Parks	SAPE1	NM	36.0139	-106.845
Wheeler Peak	WHPE1	NM	36.5854	-105.452
White Mountain	WHIT1	NM	33.4687	-105.535
Cherokee Nation	CHER1	OK	36.9562	-97.0313
Ellis	ELLI1	OK	36.0853	-99.9354
Southern Great Plains	SOGP1	OK	36.61	-97.49
Stilwell	STIL1	OK	35.7508	-94.6696
Wichita Mountains	WIMO1	OK	34.7323	-98.713
Big Bend NP	BIBE1	TX	29.3027	-103.178
Guadalupe Mountains NP	GUMO1	TX	31.833	-104.809
Houston Deer Park #2	HOUS1	TX	29.6698	-95.1285

2.0 Organization and Responsibilities

2.1 Responsibilities of Project Participants

The George Mason University team consists of Principal Investigator (PI) Daniel Tong, Co-Principal Investigator (Co-PI) Siqi Ma, and a graduate research assistant, Chang Shu. PI Tong is an associate professor working on air pollutant emission and prediction. He will be responsible for overseeing the project at GMU, organizing meetings, and preparing reports. He will work on long-term dust trend analysis and FENGSHA emission model updates. Co-PI Ma is a research scientist specializing in emission and air quality modeling. She will conduct Weather Research and Forecast (WRF) and CMAQ simulations and evaluation. The graduate research assistant will work with the PI and Co-PI in dust trend analysis and related research tasks. To ensure independent quality assurance, project deliverables will be reviewed by a team member who is not directly responsible for generating the corresponding data, code, or model outputs. Dr. Tong will perform quality assurance reviews for the emission processing and air quality model implementation. Conversely, Dr. Ma will perform quality assurance reviews of the code updates of the FENGSHA model and dust analyses. This independent cross-review process will help ensure the accuracy, consistency, and reliability of project results.

2.2 Project Schedule

The planned duration of the project is 12 months (August 2026 – July 2027). Figure 1 presents the proposed schedule for each task and project deliverable.

Tasks	Project Months from the Start Date											
	1	2	3	4	5	6	7	8	9	10	11	12
<i>Task 1. Analyzing long-term dust trends</i>												
1.1 Analyzing IMPROVE dust observations	■	■										
1.2 Analyzing TCEQ dust observations	■	■										
1.3 Analyzing weather station dust records		■	■	■								
<i>Task 2. Analyzing environmental drivers of dust trends</i>			■	■	■							
<i>Task 3. Modeling windblown dust emissions</i>												
3.1 Improving soil texture and dust sources in Mexico				■	■							
3.2 Improve domestic cropland dust source emissions						■	■					
3.3 Sensitivity tests							■	■	■	■	■	
3.4 model evaluation							■	■	■	■	■	■
<i>Task 4. Quantifying dust contributions to PM_{2.5} & PM₁₀</i>											■	■

Figure 1. Proposed project schedule.

3.0 Scientific Approach

3.1 Identifying dust events and reconstructing long-term dust trends

This project will identify dust events using three ground networks, including the Interagency Monitoring to PROtect Visual Environments (IMPROVE), the Texas Commission on Environmental Quality (TCEQ) air quality monitors, and National Oceanic and Atmospheric Administration (NOAA) Integrated Surface Database (ISD). Dust identification methods have been developed for these networks. This work will leverage and improve these methods to extend the dust observations to cover the study period of 2002-2025. The methods to reconstruct dust records from each network are described below:

a) IMPROVE Dust observations: IMPROVE is a visibility-focused aerosol monitoring network in the USA founded in 1985, managed by a consortium of Federal and state agencies (Malm et al., 1994). The network is now comprised of approximately 160 monitoring sites, including three in Texas, three in Oklahoma, eight in New Mexico, and seven in Colorado (Hand et al., 2017). The IMPROVE network has its own algorithm to estimate dust (fine soil, or soil_f) in PM_{2.5} based on elemental concentrations (Malm et al., 1994; Hand et al., 2017), while Tong et al., (2012, 2017) have developed a more comprehensive method using five dust identification criteria: 1) high PM₁₀ and PM_{2.5} concentrations; 2) low PM_{2.5}/PM₁₀ ratio; 3) high fraction of crustal elements (Si, Ca, Fe, Al); 4) low fraction of anthropogenic elements (Zn and Cu), and 5) low enrichment factor. We will compare both the trends of fine soil from IMPROVE and the trends of dust events following the algorithm by Tong et al (2012).

b) Dust observations from TCEQ ground monitors: We will also investigate the dust trends at ground monitors maintained by TCEQ. The Texas Air Monitoring Information System (TAMIS) provides PM_{2.5} and PM₁₀ data that can provide additional information on the dust trends. Compared to IMPROVE, TCEQ collects data 72-fold more frequently (hourly vs once every three days from IMPROVE). We will follow the approach developed by Ganor et al. (2009) to identify dust records from TAMIS. The Ganor et al (2009) approach identifies dust events from monitoring locations under three conditions: PM₁₀ average level exceeding 100 mg/m³, maintained for at least three hours, and with a peak PM₁₀ reaching 180 mg/m³. The Ganor approach has been improved by Lei and Wang (2013) for the US dust events.

c) Dust observations from weather stations: Weather data have been widely used in places without continuous aerosol measurements to reconstruct dust climatology (McTainsh and Pitblado, 1987; Shao et al., 2013; Lei et al., 2016; Xi, 2021; Robinson and Ardon-Dryer, 2024). This study will use the method of Robinson and Ardon-Dryer (2024), which identified windblown dust events based on wind speeds (>6 m/s), low visibility (<10 km) with or without reports in the “Present Weather Code” (PWC). Several PWCs are commonly used by weather observers to represent dust events, including blowing dust (BLDU), dust (DU), dust storm (DS), haze (HZ), severe dust storms (SS), and vicinity blowing dust (VCBLDU).

Note these methods were mostly designed to detect local or short-range transported dust events that originated in Texas or neighboring states or northern Mexico. Texas is also influenced by long-range transport of African dust. Although this study focuses on northern American dust sources, we will explore approaches to detect African dust influence through a combination of satellite observations, spatial patterns of ground monitoring, and back trajectory analysis. Large scale dust events such as trans-Atlantic dust storms can be observed by satellites. Such events are also associated with distinct spatial patterns with widespread high PM_{2.5} and PM₁₀ concentrations in the region. Back trajectory analysis can also provide transport pathway of the air mass characterized with elevated PM concentrations.

3.2 Model Configuration and Applications

FENGSHA is a process-based dust emission model used to estimate windblown dust emission (Dong et al., 2016; Joshi, 2021). Considering the large discrepancy between dust observations and model prediction, several updates of the FENGSHA system will be made here. FENGSHA was originally developed by our team and is being used by the National Weather Service for real-time dust forecasts (<https://www.arl.noaa.gov/research/surface-atmosphere-exchange-home/tools-and-products/dust-research/>). First, we will improve Mexico dust sources with updated soil texture and newly available GOES dust initiation observations (Line et al., 2025). Next, we will update domestic cropland dust source emissions with GMU/USDA CropScape crop data. Third, we will design a suite of sensitivity tests to understand the effects of these sources (S) and other environmental factors on dust prediction.

The rationale of the study design is based on the nature of windblown dust emission and existing issues with existing models such as CMAQ. The process of wind-blown dust emission is controlled by several environmental variables, including wind speed, soil texture, land use type, vegetation cover, and soil moisture. The FENGSHA model calculates dust emission (vertical flux F) according to a modified Owen's equation:

$$F = \sum_{i=1}^M \sum_{j=1}^N K \times A \times \frac{\rho}{g} \times S_i \times SEP \times u_* \times (u_*^2 - u_{*ti,j}^2) \quad (1)$$

where M is the erodible land use type, N is the soil texture type, and K is the ratio of vertical to horizontal flux calculated based on the amount of clay (clay %) within the soil. A is a scaling factor (2.8–32.0), ρ is air density, g is gravitational acceleration (9.8 m s⁻²), S_i is dust source area for land type i , and SEP is the soil erodibility factor, u_* is the friction velocity, and $u_{*ti,j}$ is the threshold friction velocity for soil type j and land use type i .

In FENGSHA, the threshold friction velocity is dynamically calculated based on the presence of nonerodible elements and the change in soil moisture. The effect of soil moisture on dust emission is implemented following a two-step approach proposed by Fécan et al. (1999). First, the maximum water holding capacity (W_{max}) for each soil type is determined based on the amount of clay in the soil:

$$W_{max} = (0.0014 \times clay + 0.17) \times clay \quad (2)$$

In the case of soil moisture exceeding W_{max} , the threshold friction velocity is then adjusted (Marticorena et al., 1997) as

$$u_{*ti,j} = u_{*ci,j} \times \frac{f_{soilm\ i,j}}{Z_{eff}} \quad (3)$$

where $u_{*ci,j}$ is the initial threshold friction velocity constant, which was taken from observed data from wind tunnel experiments conducted by Gillette and coworkers (Gillette et al., 1980, 1982), and Z_{eff} is the surface roughness adjusting factor calculated with surface roughness length from the meteorology field based on Darmonova et al. (2009):

$$Z_{eff} = 1.0 - \frac{\ln(\frac{Z_0}{Z_{0s}})}{\ln(0.7 \times (\frac{122.55}{Z_{0s}})^{0.8})} \quad (4)$$

where Z_0 and Z_{0s} represent the aerodynamic and smooth roughness lengths, respectively. The term $f_{soilm\ i,j}$ is the moisture adjustment factor calculated using a revised Fécan formulation (Fécan et al., 1999):

$$f_{soilm\ i,j} = \begin{cases} 1, & \text{when } w < w_{max} \\ \sqrt{1 + 1.21(w - w_{max})^{0.68}}, & \text{when } w_{max} < w < w_{sat} \end{cases} \quad (5)$$

here w is soil moisture and w_{sat} is the saturation soil moisture limit determined by soil textures.

To reproduce the observed dust variations, we will use the GMU WRF-CMAQ-FENGSHA model (Li et al., 2021) to simulate select historic dust events. This system consists of three major components: meteorology, emission, and chemical transport models. The WRF model version 4.2.1 (Skamarock et al., 2019) is used to generate hourly meteorological fields to drive weather-dependent emission modeling and chemical transport modeling. The WRF model was configured with Morrison 2-moment microphysics scheme (Morrison et al., 2009), the Rapid Radiative Transfer Model for General Circulation Models (RRTMG) long and short-wave radiation scheme (Iacono et al., 2008), Yonsei University (YSU) PBL (planetary boundary layer) scheme (Hong et al., 2006), Pleim-Xiu land-surface model (Xiu & Pleim, 2001), Revised MM5 (Jimenez) surface layer scheme (Jiménez et al., 2012), and Grell-Freitas with radiative feedback cumulus parameterization option (Grell & Freitas, 2014). The emission inputs were provided using a hybrid emission modeling system that utilized the Sparse Matrix Operator Kernel Emissions (SMOKE) model version 4.8.1 (Baek & Seppanen, 2021) to process anthropogenic emissions, and a suite of emission models to estimate emissions from intermittent and/or meteorology-dependent sources (Tong et al., 2015). Anthropogenic emissions were taken from the US EPA 2022 NEI. Four natural sources are included: biogenic, sea salt, fire, and dust. Biogenic emissions from terrestrial plants and nitric oxide (NO) emissions from soils were predicted using the inline version of the Biogenic Emission Inventory System version 3 (BEIS3) (Pierce et al., 1998). The emissions of sea spray aerosols are calculated using an updated version of the Gong (2003) sea-spray emission parameterization (Gantt et al., 2015). The fire emissions, including wildfires, prescribed fires, and other biomass-burning sources, are calculated based on Li et al. (2021). The dust emissions are provided by the FENGSHA module described in the

previous section. The CMAQ model (version 5.4) ingests emissions and meteorology to predict spatial and temporal variations of the atmospheric pollutants, including the PM, using a revised Carbon Bond 6 gas-phase mechanism and AE7 aerosol mechanism (CB6r3_AE7_AQ) (Byun & Schere, 2006; Luecken et al., 2019).

3.3 Method to update soil texture and dust sources in Mexico

We will develop a hybrid soil texture map for both Mexico and the US. The soil texture map used in this work is a hybrid STATSGO/FAO-derived map with 16 category soil textures. The map within the US was derived from 1-km USDA-NRCS State Soil Geographic Database (STATSGO) data processed by Penn State University and the 5-min Agricultural Research Service and Food and Agriculture Organization (ARS FAO) data was used outside the CONUS. The data is processed to the grid with a resolution of $0.125^\circ \times 0.125^\circ$, which is available at the NASA Land Data Assimilation System (LDAS, <https://ldas.gsfc.nasa.gov/nldas/soils>). As to our study domain, we aggregate the 1 km PSU STATSGO data into 3 km for the grid within CONUS and downscale the LDAS soil texture map for the Mexico region.

Next, we will improve Mexico dust sources with GOES dust initiation observations by incorporating the dust initiation map developed by Line et al. (2025) to improve the dust source (S in Eq. 1) calculations in the FENGSHA module. A dust initiation factor (f_{ini}) will be derived from the inverse of the normalized dust density and applied to scale threshold friction velocity constant $u_{*ci,j}$, so that the FENGSHA model can predict dust emissions at the right location and time. The values of $u_{*ci,j}$ were initially adopted from wind tunnel experiments conducted by Gillette and coworkers (Gillette et al., 1980, 1982), which are not always suitable for being used directly in all regions.

3.4 Update domestic cropland dust source emissions

In this work, we will improve cropland dust emission in FENGSHA by updating the fractions of crop types using GMU/USDA Cropland Data Layer (CDL, Fig. 2), following Joshi (2021). In addition, the effects of agricultural activities are calculated based on the planting and harvesting calendar for each crop, allowing the vegetation fraction to vary with the change of date.

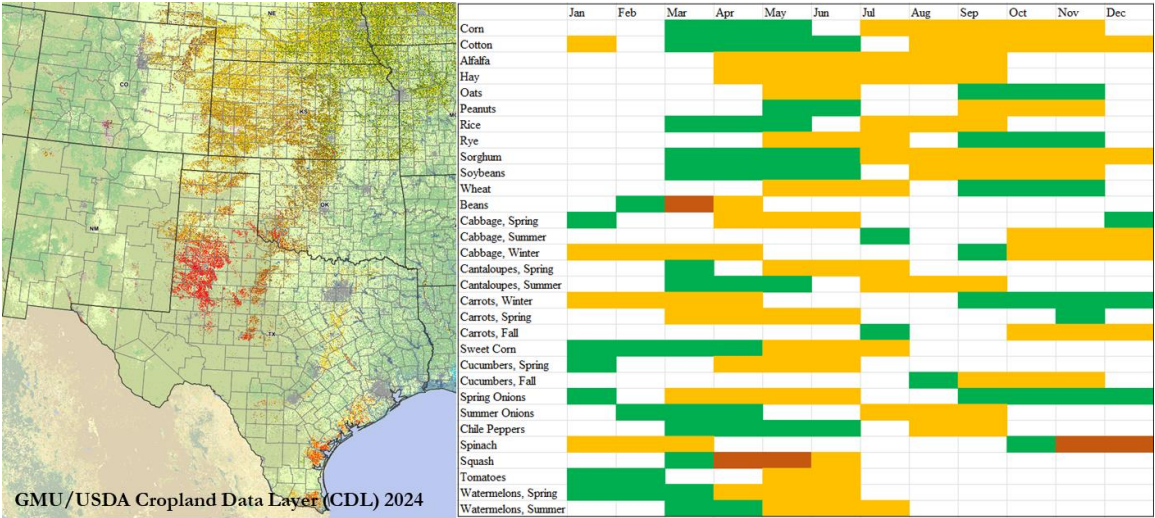


Figure 2 GMU/USDA Cropland Data Layer (CDL) in 2024 and the crop calendar in Texas (Green - planting dates, yellow - harvesting dates, and orange - overlapped dates)

4.0 Quality Metrics

Simulated PM concentrations and aerosol optical depth (AOD) will be evaluated using ground-based and satellite observations. Surface concentrations of PM_{2.5} and PM₁₀ will be compared against ground observations from the TCEQ (in-state) and EPA Air Quality System (AQS) (out-of-state) monitors, and the IMPROVE stations. AOD will be evaluated against the Multi-Angle Implementation of Atmospheric Correction (MAIAC) AOD product. This daily atmospheric aerosol product is generated by MODIS and a multi-angle atmospheric correction algorithm (Lyapustin and Wang, 2022). The aerosol optical depth (AOD) at 550 nm is obtained from the MCD19A2 Collection 6 provided by NASA. All these datasets are publicly available and have undergone standard quality assurance procedures and are appropriate for the intended application. Therefore, no project-specific quantitative data quality requirements have been established for them.

A suite of statistical metrics will be used for model evaluation. The bias of a quantity is calculated as the difference between modeled (m_i) and observed (o_i) values, for the i th model-observation pair, as $\Delta_i = m_i - o_i$. We will use mean bias (MB), normalized mean bias (NMB), and mean fractional bias (MFB). To estimate errors in modeled values compared to observations, mean absolute error (MAE) and root mean squared error (RMSE) will be calculated. In addition, the association between simulated and observed values is measured by correlation coefficient (r) and the index of agreement (IOA).

The model evaluation results will be shared with TCEQ managers and other AQRP researchers via project meetings, and also presented at conferences and published in peer-reviewed journals.

5.0 Data Analysis, Interpretation and Management

5.1 Data Reporting

Data reporting procedures will be documented in the project's final report as discussed in Section 6.0

5.2 Data Validation

Data validation for the modeling results will be conducted using the method shown in Section 4.0

5.3 Data Analysis

Qualitative and quantitative analyses will be performed to reconstruct long-term dust trends, improve the dust model performance, and analyze the impact of dust on $PM_{2.5}$ and PM_{10} . This procedure includes a) analyzing dust trends using ground-based observations; b) comparing CMAQ simulations with ground and satellite measurements; c) comparing model performances under different scenarios; d) quantifying windblown dust effects on $PM_{2.5}$ and PM_{10} .

5.4 Data Storage

All modeling and observational data associated with this project will be stored on a data server and transferred to AQRP following the completion of the project.

5.5 Model Documentation

At the end of the project, we will publish a journal paper on the FENGSHA dust emission model, which will be documented with detail, including source code, scientific equations, parameterization schemes, and input datasets. A flow chart of the underlying processes will be provided in the model scientific documentation file.

We will prepare a user's guide to accompany the release of the model code. We describe in detail known restrictions on model applications, test datasets, sample output for users to verify their model results.

6.0 Audits of Data Quality

We will audit at least 10% of the input data used across all aspects of the project. A member of the research team not involved in creating the dataset will review 10% or more of the dataset for quality assurance. A report on 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.

7.0 Reporting

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. We will submit the draft final and final reports near the end of the project.

The project PI will electronically submit each required report to both the AQRP and TCEQ and will follow the State of Texas accessibility requirements as set forth by the Texas State Department of Information Resources. At the end of the project, we will publish a journal paper on the FENGSHA dust emission model, which will be documented with detail, including source code, scientific equations, parameterization schemes, and input datasets. This will be also provided to AQRP and TCEQ.

The project PI will lead reporting activities with assistance from co-PIs and his team at George Mason University. Project data to be submitted to the AQRP archive will include all model simulations 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: May 14, 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	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 2026	July 31, 2027

Monthly Technical Reports (MTRs): Technical Reports will be submitted monthly to the AQRP Project Manager and TCEQ Liaison in Microsoft Word format using the AQRP MTR

Template found on the AQRP website.

MTR Due Dates:

Report	Period Covered	Due Date
Technical Report #1	Project Start - August, 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 (RoseAnna Goewey) by each institution on the project using the AQRP 22-23 FSR Template found on the AQRP website.

FSR Due Dates:

Report	Period Covered	Due Date
FSR #1	Project Start - August, 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	Final Report	September 15, 2027
FSR #14	Final FSR	October 15, 2027

Draft Final Report: A Draft Final Report will be submitted to the AQRP 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 15, 2027

Final Report: A Final Report incorporating comments from the AQRP and TCEQ review of the Draft Final Report will be submitted to the AQRP 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 quality assurance (QA) and quality control (QC) measurement data, metadata, databases, modeling inputs and outputs, etc., will be submitted to the AQRP Project Manager within 30 days of project completion (August 31, 2025). 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 August 2027.

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Scope of Work

Project #26-007

Characterization of international and domestic sources of windblown dust and contribution to fine and coarse particulate matter in Texas

Prepared for

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

By

Daniel Tong
George Mason University, Fairfax, VA

May 15, 2026

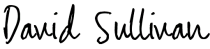
Version #1

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

Approvals

This Scope of Work was approved electronically by:

Signed by:



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2026-07-09 | 13:55:24 CDT

David Sullivan, Project Manager

Date

Texas Air Quality Research Program

This Scope of Work was approved electronically by:

Signed by:



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2026-07-10 | 01:02:35 CDT

Aristos Brandt, Project Liaison

Date

Texas Commission on Environmental Quality

This Scope of Work was approved electronically by:

Signed by:



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2026-07-09 | 13:24:14 CDT

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Date

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Contents

1.0 Abstract 4

2.0 Background..... 5

3.0 Objectives..... 6

4.0 Task Description..... 6

 Task 1. Reconstructing long-term dust trends 6

 Task 2. Analyze and diagnose environmental drivers of dust trends 7

 Task 3. Improving windblown dust emission modeling..... 7

 Task 4. Quantifying dust effects on PM_{2.5} and PM₁₀..... 13

5.0 Schedule 14

6.0 Project Participants and Responsibilities 14

7.0 References..... 14

1.0 Abstract

Windblown dust poses increasing challenges to air quality, public health and transportation safety. In 2025, for instance, Texas experienced the dustiest spring since the Dust Bowl era, with 42 vehicle crashes and four fatalities caused by a single dust storm on March 14, 2025. Another critical issue in Texas is that crustal materials originating from Mexico and overseas sources such as the Saharan Desert can be transported by winds into Texas. The Clean Air Act section 179B states that pollution that originates outside of US borders is not to affect National Ambient Air Quality Standards (NAAQS) compliance. Given the high stakes associated with dust risks and complexity of dust source attribution, it is important to investigate the trends of dust storms and understand their sources and contributions to fine and coarse particulate matter (PM_{2.5} and PM₁₀) in this region.

The objective of this study is to understand the trends in windblown dust and its effects on PM_{2.5} and PM₁₀ in Texas. More specifically, we aim to 1) investigate the long-term trends in windblown dust activity in Texas and three “upwind” states (New Mexico, Oklahoma and Colorado); 2) analyze the environmental drivers of the dust trends; 3) improve dust emission model by integrating satellite-detected dust sources and updating other model inputs, and 4) quantify contributions from in-state and out-of-state dust sources to PM_{2.5} and PM₁₀ in Texas.

The proposed project consists of four major activities:

1) Reconstructing long-term dust trends from three ground networks. We will assemble windblown dust event records from three ground networks, including the Interagency Monitoring to PROtect Visual Environments (IMPROVE), the Texas Commission on Environmental Quality (TCEQ) air quality monitors, and National Oceanographic and Atmospheric Administration (NOAA) Integrated Surface Database (ISD). An intercomparison of these datasets will be performed to examine if there is a trend in the observed dust activity, and to identify high-dust and low-dust years for subsequent analyses and model simulations.

2) Analyzing and diagnosing environmental drivers of dust trends. Built on the lessons learned from prior studies, several environmental factors will be selected for this analysis, including both single variables such as wind speed, vegetation cover (Normalized Difference Vegetation Index (NDVI), precipitation, and soil moisture, and composite indices such as drought index and El-Nino Southern Oscillation (ENSO). Identified key factors will be used to guide model optimization.

3) Improving windblown dust emission modeling. To address the large uncertainties existing in windblown dust modeling, this task will: i) update soil texture in Mexico and the US based on a hybrid State Soil Geographic database Version 2 (STATSGO2)/Food and Agriculture Organization (FAO) derived map; ii) improve Mexico dust sources using a newly available Geostationary Operational Environmental Satellites (GOES) dust initiation map; iii) improve domestic cropland dust sources with George Mason University (GMU)/U.S. Department of Agriculture (USDA) CropScape data; and iv) conduct sensitivity tests with other key inputs, including winds, vegetation cover, surface roughness, and soil moisture.

4) Quantifying windblown dust effects on PM_{2.5} and PM₁₀. We will use the optimized modeling system to quantify the effect of windblown dust emissions on PM_{2.5} and PM₁₀ in Texas. We choose a high-dust period and a low-dust one and use the updated model to reproduce the “relative trend”, and to assess windblown dust contributions in both periods. For each selected period, we will conduct two simulations: without and with windblown dust emissions. The dust contribution is calculated from the difference between the two simulations.

This work directly addresses the Research Priority area “Trends in wind-blown dust (PM_{2.5} and PM₁₀) in Texas”. Leveraging prior work, this project will reconstruct long-term dust trends from ground stations and design a suite of dust emission improvements to reduce dust modeling uncertainties. This project also directly aims at “better characterization of the multiple sources of windblown dust and their contribution to PM₁₀ and PM_{2.5}”. Although the FENGSHA is currently implemented as a module in Community Multiscale Air Quality (CMAQ), a standalone version will be made available to the community so that it

can be easily incorporated in other models such as Comprehensive Air Quality Model with Extensions (CAMx).

2.0 Background

As droughts have become more frequent, windblown dust poses increasing challenges to air quality, public health and transportation safety in the western United States (US). In 2025, Texas experienced the dustiest spring since the Dust Bowl era, with three large dust storms and numerous small events in less than three weeks. The dust particles greatly degraded air quality, lowering visibility and leading to dangerous driving conditions. The March 14, 2025 dust storm alone caused 42 vehicle crashes and killed four people (Wood and Edgin, 2025). The impact of these dust storms stretched beyond Texas. Strong winds carried the dust hundreds of miles north and east, leaving dust coating on cars in the Mid-Atlantic and brown snow fall in Iowa (NY Times, 2025). Besides air quality and transportation safety, exposure to dust has been associated with adverse health effects, including asthma, heart attacks, and premature mortality (Tong et al., 2023). Given the high stakes associated with these risks, it is important to investigate the trends of dust storms and understand the sources and their contributions to fine and coarse particulate matter ($PM_{2.5}$ and PM_{10}) in this region.

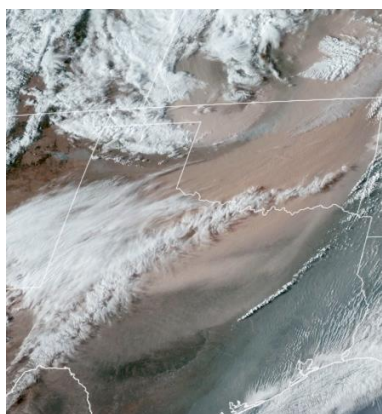


Figure 1 The March 14, 2025 dust storm observed by the GOES-R satellite that caused 42 crashes and 4 fatalities in Texas alone.

Texas is uniquely located along the North America “dust river” extending from northern Mexico to eastern US (Fig 1). Downwind to many active sources, Texas is frequently influenced by windblown dust from both in-state emissions and long-range transport of dust from neighboring states (New Mexico, Oklahoma, Colorado) (Lee et al., 2012), and international sources in Mexico (Line et al., 2025) and even Africa (Bozlaker et al., 2019; Gill et al., 2024). To what extent each of these sources affects Texas air quality, however, remains understudied.

Recent advances in dust research present new opportunities to characterize domestic and international dust sources, and their contribution to Texas air quality. Several datasets of dust climatology have been developed (Tong et al., 2012, 2017; Hand et al., 2017; Robinson and Ardon-Dryer, 2024), allowing investigation of long-term dust trends in this region. Process-based dust emission models, including FENGSHA, have been upgraded and tested in real-time air quality forecasts (Huang et al., 2025; Li et al, 2025). Finally, a 20-year record (2001–2020) of windblown dust sources (initiation points) across southwestern North America has been developed using manually analyzed Geostationary Operational Environmental Satellite (GOES) infrared imagery (Line et al., 2025). These new observations and modeling

tools make it feasible to study how windblown dust changes, where are the sources, and how much they contribute to fine and coarse PM in Texas.

3.0 Objectives

The objective of this proposed study is to understand the trends in windblown dust and its effects on fine and coarse particulate matter in Texas. More specifically, we aim to 1) investigate the long-term trends in windblown dust activity in Texas and three “upwind” states (New Mexico, Oklahoma and Colorado); 2) analyze the environmental drivers of the dust trends; 3) improve dust emission model by integrating satellite-detected dust sources and updating other model inputs, and 4) quantify contributions from in-state and out-of-state windblown dust sources to $PM_{2.5}$ and PM_{10} in Texas.

4.0 Task Description

The proposed project consists of four major tasks: 1) reconstructing long-term dust trends observed from ground networks; 2) analyzing and diagnosing environmental drivers of dust trends; 3) improving windblown dust emission module; and 4) understanding air quality effects of windblown dust emissions on $PM_{2.5}$ and PM_{10} . We provide below the detailed technical approach for each of these tasks.

Task 1. Reconstructing long-term dust trends

First, we will assemble dust observations from three ground networks, including the Interagency Monitoring to PROtect Visual Environments (IMPROVE), the Texas Commission on Environmental Quality (TCEQ) air quality monitors, and NOAA Integrated Surface Database (ISD). Dust identification methods have been developed for these networks. This work will leverage and improve these methods to extend the dust observations to cover the study period of 2002-2025. The methods to reconstruct dust records from each network are described below:

a) IMPROVE Dust observations: IMPROVE is a visibility-focused aerosol monitoring network in the USA founded in 1985, managed by a consortium of Federal and state agencies (Malm et al., 1994). The network is now comprised of approximately 160 monitoring sites, including three in Texas, three in Oklahoma, eight in New Mexico, and seven in Colorado (Hand et al., 2017). The IMPROVE network has its own algorithm to estimate dust (fine soil, or soil_f) in $PM_{2.5}$ based on elemental concentrations (Malm et al., 1994; Hand et al., 2017), while Tong et al., (2012, 2017) have developed a more comprehensive method using five dust identification criteria: 1) high PM_{10} and $PM_{2.5}$ concentrations; 2) low $PM_{2.5}/PM_{10}$ ratio; 3) high fraction of crustal elements (Si, Ca, Fe, Al); 4) low fraction of anthropogenic elements (Zn and Cu), and 5) low enrichment factor. We will compare both the trends of fine soil from IMPROVE and the trends of dust events following the algorithm by Tong et al (2012).

b) Dust observations from TCEQ ground monitors: We will also investigate the dust trends at ground monitors maintained by TCEQ. The Texas Air Monitoring Information System (TAMIS) provides $PM_{2.5}$ and PM_{10} data that can provide additional information on the dust trends. Compared to IMPROVE, TCEQ collects data 72-fold more frequently (hourly vs once every three days from IMPROVE). We will follow the approach developed by Ganor et al. (2009) to identify dust records from TAMIS. The Ganor et al (2009) approach identifies dust events from monitoring locations under three conditions: PM_{10} average level exceeding 100 mg/m^3 , maintained for at least three hours, and with a peak PM_{10} reaching 180 mg/m^3 . The Ganor approach has been improved by Lei and Wang (2013) for the US dust events.

c) Dust observations from weather stations: Weather data have been widely used in places without continuous aerosol measurements to reconstruct dust climatology (McTainsh and Pitblado, 1987; Shao et al., 2013; Lei et al., 2016; Xi, 2021; Robinson and Ardon-Dryer, 2024). This study will use the method of Robinson and Ardon-Dryer (2024), which identified windblown dust events based on wind speeds (>6 m/s), low visibility (<10 km) with or without reports in the “Present Weather Code” (PWC). Several PWCs are commonly used by weather observers to represent dust events, including blowing dust (BLDU), dust (DU), dust storm (DS), haze (HZ), severe dust storms (SS), and vicinity blowing dust (VCBLDU).

d) Intercomparison: Using the data retrieved from these three databases, an intercomparison will be performed focusing on 1) the level of agreement in dust variations by different networks; 2) whether there is a trend in observed dust activity; and 3) if there is a common year marked as high and low dust activity that can be used in subsequent analyses and model simulations. The comparison will also consider the advantages and disadvantages of each method.

Task 2. Analyze and diagnose environmental drivers of dust trends

The linkages between dust trends and some environmental variables are well established, while others are still unclear. These relationships may be geographically dependent. Field measurements and wind tunnel experiments have shown that surface wind speed, soil moisture and texture, vegetation cover, and land use types strongly affect the intensity of dust storms (Gillette et al., 1980, 1982; Shao, 2008; Lei and Wang, 2014). At inter-annual and decadal time scales, dust storm activity over the western US may be more affected by large-scale climate signals, such as drought and ocean oscillation (Shao et al., 2013). Advancing such knowledge, especially based on the existing weather/climate and aerosol products, can improve our understanding and predictability of extreme dust events in the changing future climate.

Built on the lessons learnt from prior studies (Tong et al., 2017; Kim et al., 2021), a number of environmental factors will be selected for this analysis, including both single variables such as wind speed, vegetation cover (Normalized difference vegetation index, NDVI), precipitation, and soil moisture, and composite indices such as drought index, El-Nino Southern Oscillation (ENSO), Pacific Decadal Oscillation (PDO), North Atlantic Oscillation (NAO), Pacific/North American Oscillation (PNA), and Arctic Oscillation (AO) (Tong et al., 2017). A series of statistical methods will be applied to explore the relationships between dust and these environmental factors. Identified key factors will be used to guide model optimization in Task 3.

Task 3. Improving windblown dust emission modeling

To reproduce the observed dust variations, we will use the GMU WRF-CMAQ-FENGSHA model (Li et al., 2021) to simulate select historic dust events. FENGSHA is a process-based dust emission model to estimate windblown dust emission (Dong et al., 2016; Joshi, 2021). Considering the large discrepancy between dust observations and model prediction, several updates of the FE system will be made here. First, we will improve Mexico dust sources with updated soil texture and newly available GOES dust initiation observations (Line et al., 2025). Next, we will update domestic cropland dust source emissions with GMU/USDA CropScape crop data. Third, we will design a suite of sensitivity tests to understand the effects of these sources (S) and other environmental factors on dust prediction.

The rationale of the study design is based on the nature of windblown dust emission and existing issues with existing models such as CMAQ. The process of wind-blown dust emission is controlled by several environmental variables, including wind speed, soil texture, land use type, vegetation cover, and soil moisture. The FENGSHA model calculates dust emission (vertical flux F) according to a modified Owen's equation:

$$F = \sum_{i=1}^M \sum_{j=1}^N K \times A \times \frac{\rho}{g} \times S_i \times SEP \times u_* \times (u_*^2 - u_{*ti,j}^2) \quad (1)$$

where M is the erodible land use type, N is the soil texture type, and K is the ratio of vertical to horizontal flux calculated based on the amount of clay (clay %) within the soil. A is a scaling factor (2.8–32.0), ρ is air density, g is gravitational acceleration (9.8 m s^{-2}), S_i is dust source area for land type i , and SEP is the soil erodibility factor, u_* is the friction velocity, and $u_{*t\ i,j}$ is the threshold friction velocity for soil type j and land use type i .

This work aims to improve representation of emission sources (S) for dryland and cropland, and other key inputs, including soil texture, vegetation cover, surface roughness, friction velocity, and soil moisture. In FENGSHA, the threshold friction velocity is dynamically calculated based on the presence of nonerodible elements and the change in soil moisture. The effect of soil moisture on dust emission is implemented following a two-step approach proposed by Fécan et al. (1999). First, the maximum water holding capacity (W_{max}) for each soil type is determined based on the amount of clay in the soil:

$$W_{max} = (0.0014 \times \text{clay} + 0.17) \times \text{clay} \quad (2)$$

In the case of soil moisture exceeding W_{max} , the threshold friction velocity is then adjusted (Marticorena et al., 1997) as

$$u_{*t\ i,j} = u_{*c\ i,j} \times \frac{f_{soilm\ i,j}}{Z_{eff}} \quad (3)$$

where $u_{*c\ i,j}$ is the initial threshold friction velocity constant, which was taken from observed data from wind tunnel experiments conducted by Gillette and coworkers (Gillette et al., 1980, 1982), and Z_{eff} is the surface roughness adjusting factor calculated with surface roughness length from the meteorology field based on Darmenova et al. (2009):

$$Z_{eff} = 1.0 - \frac{\ln(\frac{Z_0}{Z_{0s}})}{\ln(0.7 \times (\frac{122.55}{Z_{0s}})^{0.8})} \quad (4)$$

where Z_0 and Z_{0s} represent the aerodynamic and smooth roughness lengths, respectively. The term $f_{soilm\ i,j}$ is the moisture adjustment factor calculated using a revised Fécan formulation (Fécan et al., 1999):

$$f_{soilm\ i,j} = \begin{cases} 1, & \text{when } w < w_{max} \\ \sqrt{1 + 1.21(w - w_{max})^{0.68}}, & \text{when } w_{max} < w < w_{sat} \end{cases} \quad (5)$$

where w is soil moisture and w_{sat} is the saturation soil moisture limit determined by soil textures.

Therefore, based on results from prior dust studies (Kim et al, 2021; Joshi, 2021) and the new satellite observations (Line et al., 2025), this study will focus on addressing the following issues: 1) updating soil texture in Mexico and US; 2) improving Mexico dust sources; 3) improving domestic cropland dust sources; and 4) sensitivity tests with other key inputs (vegetation cover, surface roughness, friction velocity), following Kim et al. (2021).

3.1 Improving soil texture and dust sources in Mexico

Given frequent influence of dust emitted from northern Mexico, this work will improve dust source representation in two steps. First, we will develop a hybrid soil texture map for both Mexico and the US. The soil texture map used in this work is a hybrid STATSGO/FAO derived map with 16 category soil textures. The map within the US was derived from 1-km USDA Natural Resources Conservation Service (NRCS) State Soil Geographic Database (STATSGO) data processed by Penn State University and the 5-min Agricultural Research Service and Food and Agriculture Organization (ARS FAO) data was used outside the contiguous US (CONUS). The data are processed to the grid with a resolution of $0.125^\circ \times 0.125^\circ$, which is available at the National Aeronautics and Space Administration (NASA) Land Data Assimilation System

(LDAS, <https://ldas.gsfc.nasa.gov/nldas/soils>). As to our study domain, we aggregate the 1 km STATSGO data into 3 km for the grid within CONUS and downscale the LDAS soil texture map for the Mexico region.

Next, we will improve Mexico dust sources with GOES dust initiation observations. Dust models are often unable to reproduce dust events originated from emerging sources in northern Mexico, such as abandoned farms due to reduced water resources. Figure 2 compares observed and predicted PM_{10} concentrations during a regional dust storm on February 26, 2023. The model captures the general pattern of the dust plumes observed in the dust RGB imagery from GOES. However, it underestimates dust plumes originating from the Mexico side of the Chihuahua desert, leading to severe underprediction of PM_{10} concentrations and a delayed peak time. This implies limitations in the dust model to reproduce windblown dust emissions. To address this issue, we incorporate the dust initiation map developed by Line et al. (2025) to improve the dust source (S in Eq. 1) calculations in the FENGSHA module. A dust initiation factor (f_{ini}) will be derived from the inverse of the normalized dust density and applied to scale threshold friction velocity constant $u_{*ci,j}$, so that the FENGSHA model can predict dust emissions at the right location and time. The values of $u_{*ci,j}$ were initially adopted from wind tunnel experiments conducted by Gillette and coworkers (Gillette et al., 1980, 1982), which are not always suitable for being used directly in all regions.

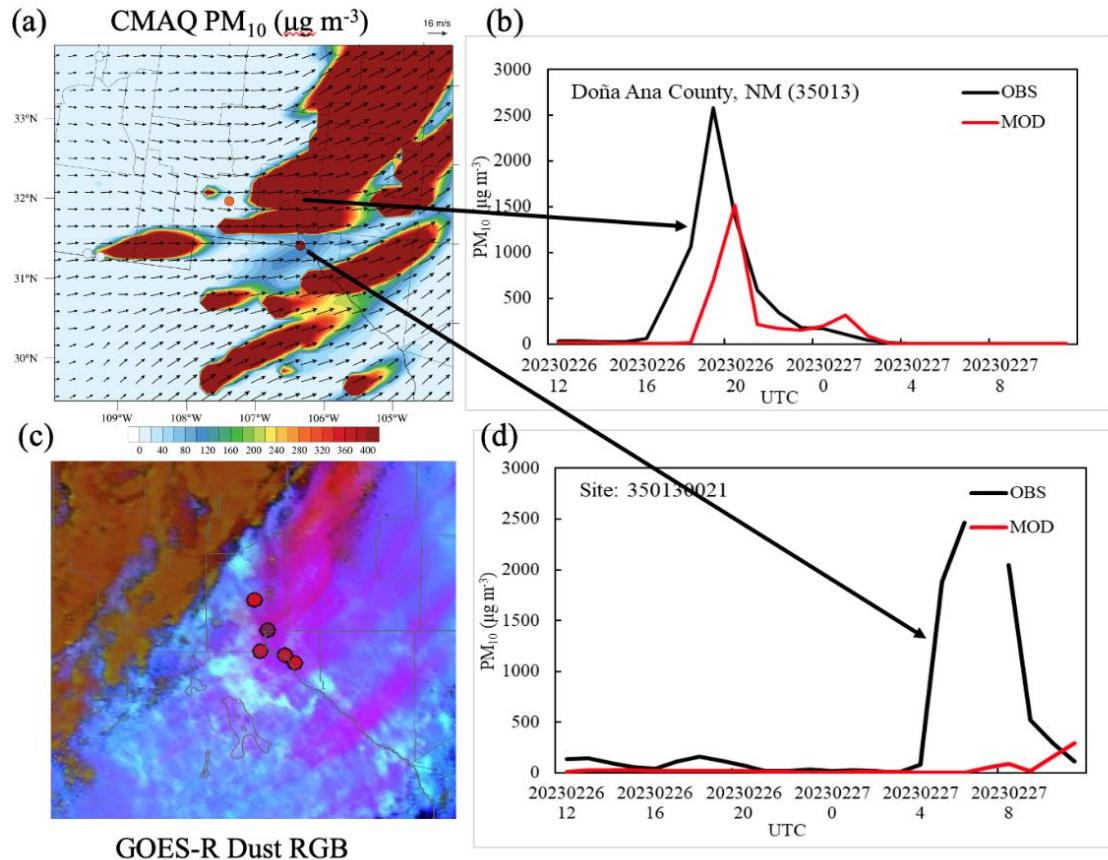


Figure 2 Comparisons of observed (OBS) and simulated (MOD) (panel a) PM_{10} during the February 26, 2023 dust events in Doña Ana County, NM (b) and El Paso, TX (d). GOES-R dust RGB (pink color) is provided at (c).

The dust initiation map (Fig. 3) highlights active dust source areas in northern Mexico and southwestern US. Several source regions can potentially impact air quality and visibility in Texas. Previous

studies using remotely sensed and in situ observations show that sand sheets are the most dust-active geomorphic surfaces, while cropland, shrubland, and grassland are the dominant dust-emitting land-use types. Cropland produces proportionately more dust emissions, and barren land exhibits high emission ratios (Lee et al., 2009; Lee et al., 2012; Junran et al., 2017). Eastern New Mexico, eastern Colorado, western Texas and Oklahoma, and northern Mexico are identified as key dust source regions affecting Texas.

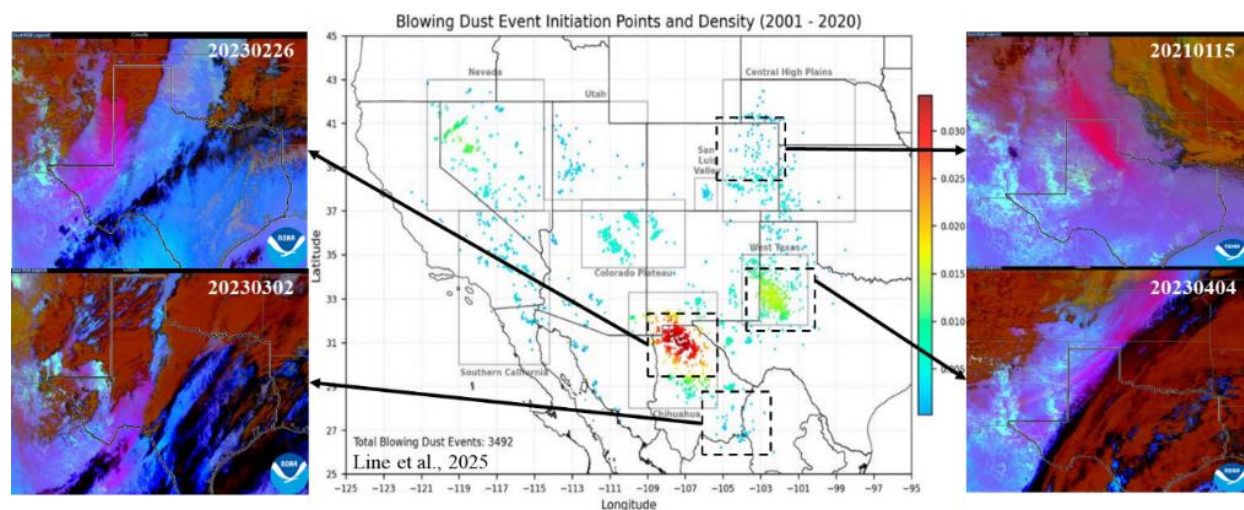


Figure 3 Satellite detection of windblown dust sources (initiation points) and emission frequency from GOES (Line et al., 2025) (central panel), along with dust RGB images of dust events originating from four different source regions that affect Texas air quality (four side panels).

3.2 Improve domestic cropland dust source emissions

The erodibility of croplands depends strongly on agricultural management practices, such as timing of cropping, planting and harvesting, and the implementation of soil conservation measures. Although crop soils are often protected by surface crusts, they become highly susceptible to wind erosion when these crusts are disturbed during agricultural activities such as tilling. This makes cropland dust modeling particularly challenging. In this work, we will improve cropland dust emission in FENGSHA by updating the fractions of crop types using GMU/USDA Cropland Data Layer (CDL, Fig. 4), following Joshi (2021). In addition, the effects of agricultural activities are calculated based on the planting and harvesting calendar for each crop, allowing the vegetation fraction to vary with the change of date. To further improve module performance, we will apply and evaluate a tillage disturbance factor to better represent the reduction in threshold friction velocity over croplands, thereby enhancing the simulation of dust emissions from agricultural soils.

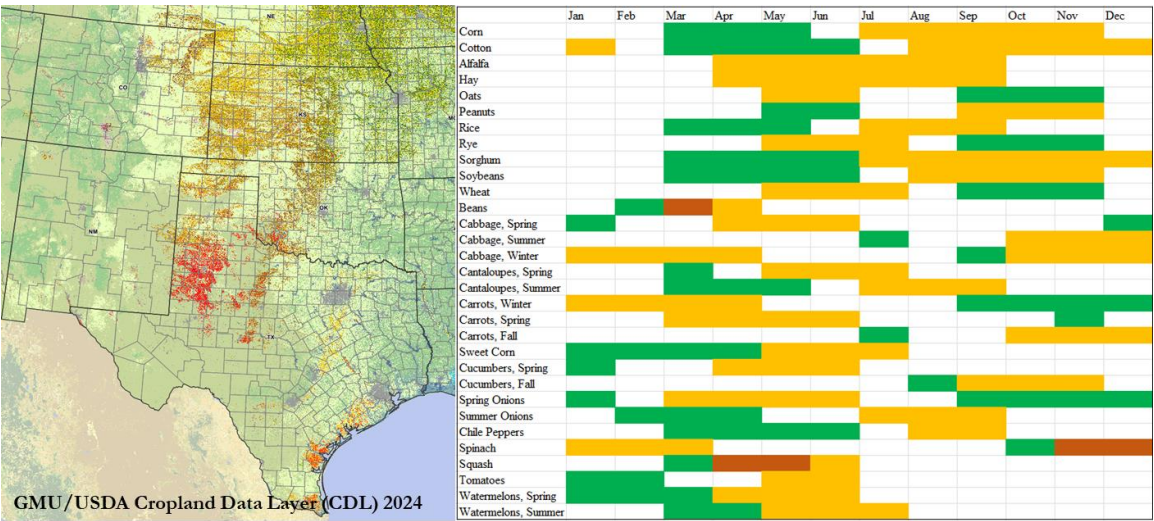


Figure 4 GMU/USDA Cropland Data Layer (CDL) in 2024 and the crop calendar in Texas (Green - planting dates, yellow - harvesting dates, and orange - overlapped dates)

3.3 Sensitivity tests to optimize dust model configuration

To tune and assess the performance of the FENGSHA module, we have designed a series of sensitivity experiments (Table 1). The noDUST case will be conducted with default CMAQ configuration at 3 km with all anthropogenic and natural emissions except windblown dust emissions, serving as the baseline scenario. The Dust0 case uses the same settings as noDUST, but with windblown dust emission module turned on. The Dust1 to Dust 5 cases represent incremental improvement of the dust modeling system, implementing and testing each update and/or perturbation, including soil texture (Dust1), GOES-based Mexico dust sources (Dust2), cropland source update with CropScape data (Dust3), hourly average winds vs gusty winds (Dust4), and other driving factors as suggested in Kim et al., (2021) and Joshi (2021) (Dust5).

All model simulations will be conducted for the four selected dust events (Fig 3) using the GMU-CMAQ system (Li et al., 2021). The meteorological, emission, and air quality models have 3 km × 3 km horizontal resolution over Texas and surroundings, with 35 sigma layers vertically and the domain top at 50 hPa. High resolution anthropogenic emission will be upscaled from the GMU 1km Neighborhood Emission Mapping Operation (NEMO) (Ma and Tong, 2022). The WRF model was driven by the meteorological fields of High-Resolution Rapid Refresh version 4 (HRRRv4) products with a horizontal resolution of 3 km × 3 km.

Table 1. Design of model simulation scenarios to improve dust emission modeling

Scenario	Configuration	Purpose
NoDust	CMAQ simulation without windblown dust emission	Baseline
Dust0	Same as NoDust, with default windblown dust emission	Default FENGSHA settings
Dust1	Dust0 + Soil texture update	Effect of soil texture update
Dust2	Dust1+ Mexico source update	Effect of Mexico source update
Dust3	Dust2+ cropland dust update	Effect of cropland dust update
Dust4	Dust3 + wind test (gusty winds vs hourly winds)	Effect of wind speed

Dust5	Dust4 + (soil moisture, vegetation, surface roughness)	Finding optimal configuration
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3.4 model evaluation

Simulated PM concentrations and aerosol optical depth (AOD) will be evaluated using ground-based and satellite observations. Surface concentrations of PM_{2.5} and PM₁₀ will be compared against ground observations from the TCEQ (in-state) and EPA Air Quality System (AQS) (out-of-state) monitors, and the IMPROVE stations (Table 2). AOD will be evaluated against the Multi-Angle Implementation of Atmospheric Correction (MAIAC) AOD product. This daily atmospheric aerosol product is generated by MODIS and a multi-angle atmospheric correction algorithm (Lyapustin and Wang, 2022). The aerosol optical depth (AOD) at 550 nm is obtained from the MCD19A2 Collection 6 provided by NASA.

A suite of statistical metrics will be used for model evaluation. The bias of a quantity is calculated as the difference between modeled (m_i) and observed (o_i) values, for the i th model-observation pair, as $\Delta_i = m_i - o_i$. We will use mean bias (MB), normalized mean bias (NMB), and mean fractional bias (MFB). To estimate errors in modeled values compared to observations, mean absolute error (MAE) and root mean squared error ($RMSE$) will be calculated. In addition, the association between simulated and observed values is measured by correlation coefficient (r) and the index of agreement (IOA).

Table 2. IMPROVE stations information

Site Name	Site Code	State	Latitude	Longitude
Dinosaur NM	DINO1	CO	40.25	-108.967
Flat Tops	FLTO1	CO	39.9153	-107.634
Fort Collins	FOCO1	CO	40.5929	-105.143
Great Sand Dunes NM	GRSA1	CO	37.7249	-105.519
Mesa Verde NP	MEVE1	CO	37.1984	-108.491
Mount Zirkel Wilderness	MOZI1	CO	40.5383	-106.677
Ripple Creek	RICR1	CO	40.0865	-107.314
Rocky Mountain NP	ROMO1	CO	40.2783	-105.546
Rocky Mountain NP HQ	RMHQ1	CO	40.3624	-105.564
Shamrock Mine	SHMI1	CO	37.3038	-107.484
Storm Peak	STPE1	CO	40.445	-106.74
Weminuche Wilderness	WEMI1	CO	37.6594	-107.8
White River NF	WHRI1	CO	39.1536	-106.821
Bandelier NM	BAND1	NM	35.7797	-106.266

Bosque del Apache	BOAP1	NM	33.8695	-106.852
Carlsbad Caverns	CAVE1	NM	32.1783	-104.444
Gila Wilderness	GICL1	NM	33.2204	-108.235
Salt Creek	SACR1	NM	33.4598	-104.404
San Andres	SAAN1	NM	32.6869	-106.484
San Pedro Parks	SAPE1	NM	36.0139	-106.845
Wheeler Peak	WHPE1	NM	36.5854	-105.452
White Mountain	WHIT1	NM	33.4687	-105.535
Cherokee Nation	CHER1	OK	36.9562	-97.0313
Ellis	ELLI1	OK	36.0853	-99.9354
Southern Great Plains	SOGP1	OK	36.61	-97.49
Stilwell	STIL1	OK	35.7508	-94.6696
Wichita Mountains	WIMO1	OK	34.7323	-98.713
Big Bend NP	BIBE1	TX	29.3027	-103.178
Guadalupe Mountains NP	GUMO1	TX	31.833	-104.809
Houston Deer Park #2	HOUS1	TX	29.6698	-95.1285

Task 4. Quantifying dust effects on PM_{2.5} and PM₁₀

Finally, we will use the optimized modeling system to quantify the effect of windblown dust emissions on PM_{2.5} and PM₁₀ in Texas. Through these sensitivity tests and evaluation, we will identify optimized configuration of the dust modeling system for this task. Ideally, we would simulate the full 20-year dust trends, but it is not feasible given the 12-month project duration. Therefore, our strategy is to choose a high-dust period and a low-dust one, based on the analysis in Task 1, and use the optimized model to reproduce the “relative trend” and to assess windblown dust contributions in both periods. For each select period, we will conduct two simulations: without and with windblown dust emissions, using the NoDust and the optimized Dust5 settings as in Table 1. The dust contribution is calculated from the difference between NoDust and Dust5.

Simulated windblown dust emissions and surface particulate matter concentration will be systematically analyzed. In particular, the analysis will focus on: 1) Can the model reproduce the high-dust and low-dust patterns between the two select periods? 2) How much do windblown dust emissions contribute to the surface PM_{2.5} and PM₁₀ at individual locations in Texas? and 3) What portions of dust emissions are from in-state and out-of-state sources?

5.0 Schedule

The planned duration of the project is 12 months (August 2026 – July 2027). Figure 5 presents the schedule for each task and project deliverable.

Tasks	Project Months from the Start Date											
	1	2	3	4	5	6	7	8	9	10	11	12
<i>Task 1. Analyzing long-term dust trends</i>												
1.1 Analyzing IMPROVE dust observations												
1.2 Analyzing TCEQ dust observations												
1.3 Analyzing weather station dust records												
<i>Task 2. Analyzing environmental drivers of dust trends</i>												
<i>Task 3. Modeling windblown dust emissions</i>												
3.1 Improving soil texture and dust sources in Mexico												
3.2 Improve domestic cropland dust source emissions												
3.3 Sensitivity tests												
3.4 model evaluation												
<i>Task 4. Quantifying dust contributions to $PM_{2.5}$ & PM_{10}</i>												

Figure 5 Planned project schedule.

6.0 Project Participants and Responsibilities

The proposed team consists of PI Daniel Tong, Co-I Siqi Ma, and a graduate research assistant (GRA). PI Tong is an associate professor working on air pollutant emission and prediction. He will be responsible for overseeing the project at GMU, organizing meetings and preparing reports. He will also work on long-term dust trend analysis and FENGSHA emission model updates. Co-I Ma is a research scientist specializing in emission and air quality modeling. She will conduct WRF and CMAQ simulations and evaluation. The graduate research assistant will work with PI and Co-I on performing dust trend analysis.

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<https://doi.org/10.1029/2021JD034687>

Budget and Budget Justification

Project #26-007

Characterization of international and domestic sources of windblown dust and contribution to fine and coarse particulate matter in Texas

Prepared for

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

By

Daniel Tong
George Mason University

Siqi Ma
George Mason University

5/15/2026
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:

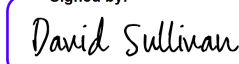
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RoseAnna Goewey, Program Manager
Texas Air Quality Research Program

Date

This Budget was approved electronically by:

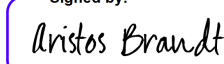
Signed by:

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2026-07-09 | 13:55:24 CDT

David Sullivan, Project Manager
Texas Air Quality Research Program

Date

This Budget was approved electronically by:

Signed by:

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2026-07-10 | 01:02:35 CDT

Aristos Brandt, Project Liaison
Texas Commission on Environmental Quality

Date

Budget and Budget Justification

George Mason University
 Characterization of international and domestic sources of windblown dust and contribution to fine
 and coarse particulate matter in Texas
 AQRP Budget

Principal Investigator: Daniel Tong

Project Dates: 7/1/2026-6/30/2027

A. SENIOR PERSONNEL: PI, Co-PI

	FirstName LastName	Title	Monthly Rate	Fringe Rate	FTE / % Effort	Funds Requested
1.	Daniel Tong	PI	\$16,996	7.4%	1.00	\$16,996
2.	Siqi Ma	Co-I	\$7,515	31.4%	6.00	\$45,089
3.			\$0	0.0%	0.00	\$0
TOTAL SENIOR PERSONNEL						\$62,085

B. OTHER PERSONNEL (SHOW NUMBERS IN BOXES)

1	0	Other Professionals / UPDATE TITLE	\$0	0.0%	0.00	\$0
2	0	Other Professionals / UPDATE TITLE	\$0	0.0%	0.00	\$0
3	1	Graduate Student	\$2,778	0.0%	12.00	\$33,333
TOTAL OTHER PERSONNEL						\$33,333

TOTAL SALARIES AND WAGES (A+B)

\$95,418

C. FRINGE BENEFITS (AUTOMATICALLY CALCULATED BASED ON ENTERED RATES)

1. Senior Personnel	\$15,416
2. Other Personnel	\$0
TOTAL FRINGE BENEFITS	\$15,416

TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A+B+C)

\$110,834

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)	\$1,763	3	\$5,290
2. Foreign			\$0
TOTAL TRAVEL			\$5,290

F. OTHER DIRECT COSTS

1. Materials and Supplies	\$6,000
2. Professional Services - Independent Contractors	\$0
3. Subcontracts (contracts will be issued by UT)	
a)	\$0
b)	\$0
c)	\$0
d)	\$0
4. Tuition and Fees	\$17,415
5. Other	\$0
TOTAL OTHER DIRECT COSTS	\$23,415

G. TOTAL DIRECT COSTS (A THROUGH F)

\$139,539

H. TOTAL INDIRECT COSTS

IDC Rate: **\$20,931**

I. TOTAL COSTS

\$160,470

NOTE: Please indicate whether you are using Modified Total Direct Costs (MTDC) or Total Direct Costs (TDC) in the calculation of indirect costs (IDC).

You may modify this template as needed to show calculation of direct or indirect costs or other project specific budgetary needs.

A. SALARIES

Dr. Daniel Tong, Principal Investigator, 33% summer effort, will be responsible for designing and leading the performance of the project as described in the goals/aims of this proposal, coordinating and leading meetings with the research team and AQRP managers and TCEQ liaison, supervising GRAs/students, preparing manuscripts for publication, prepare progress reports, etc. In addition, Dr. Tong will be responsible for generating dust storm records and revising FENGSHA dust emission module for CMAQ modeling.

Dr. Siqi Ma, Co-Investigator, 50% effort, will be responsible for improving dust emission and air quality modeling performance, and conducting model simulations to quantify dust effects on Texas air quality.

TBD, Graduate Research Assistant (GRA), 100% effort, will be responsible for analyzing IMPROVE and AQS dust trend data and identifying environmental drivers for the dust trends in Texas and surrounding regions.

B. FRINGE BENEFITS

George Mason University's negotiated fringe benefit rates for Fiscal Year 2026 are applied as follows:

Faculty 31.4%

FICA Only 7.4%

The rates quoted above shall, at the time of funding be subject to adjustment, if superseding Government approved rates have been established. Salaries, wages and fringe benefits are estimates only and will be paid and billed in accordance with University policy. Total fringe benefits budget requested: \$8,337.

C. EQUIPMENT

NA

D. OTHER DIRECT COSTS

MATERIALS AND SUPPLIES

Supplies are calculated at \$3000 per year for 50 TB data storage at \$60/TB on GMU supercomputer. Total materials and supplies budgeted requested: \$3000.

Funding is requested for publications to pay for journal page fees and for publishing colored figures. \$3,000 is budgeted based on similar projects.

TRAVEL

Funds are requested for project personnel to travel to Austin, TX to attend AQRP meetings and present findings at a professional conference. Travel costs in this budget are based on sponsored research travel

for previous similar trips and are calculated for the domestic travel of 3 staff to take 1 trip. Total travel budget requested: \$5,290.

Round trip airfare	1 trip x 3 staff x \$500 per flight	\$1,500
Lodging	1 trip x 3 nights stay x 3 staff x \$150	\$1,450
Meals and other per day	1 trip x 2 days x 3 staff x \$60	\$360
Meals and other per day	1 trip x 2 days x 3 staff x \$80	\$480
Ground transportation	From/to airports \$50 x 4 x 3 staff	\$600
Conference registration	\$900 for one national conference (1 staff)	\$900
Total requested per year		\$5,290

TUITION

Tuition is requested for each student during the academic year for 18 credits at a rate of \$607/credit. A mandatory student fee of \$163.50 per credit hour is also included. Full-Time Graduate Student Health Benefits are budgeted at \$3,552/year for students who meet the minimum requirements. Total tuition budget requested: \$17,415.

INDIRECT COSTS

The indirect cost rate of 15% of total direct costs (TDC) is used as instructed by the AQRP's published proposal preparation instructions. The total indirect requested is \$20,931.