Quality Assurance Project Plan

Project 18 – 010
A synthesis study of the role of mesoscale and synoptic-scale wind on the concentrations of ozone and its precursors in Houston

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

Prepared by

Qi Ying
Zachry Depart of Civil Engineering
Texas A&M University

John Nielsen-Gammon
Department of Atmospheric Sciences
Texas A&M University

October 2, 2018
Version #2

Texas A&M University as prepared this QAPP following EPA guidelines for a Quality Assurance (QA) Category III Project: Research model development and application. It is submitted to the Texas Air Quality Research Program (AQRP) as required in the Work Plan requirements.

QAPP Requirements: Insert here the list of sections (Project Description and Objectives, Organization and Responsibilities, Model Selection and Input Data, Model Verification, Model Evaluation and Model Documentation) prescribed in the applicable NMRL QAPP Requirements template (https://www.tceq.texas.gov/airquality/airmod/project/quality-assurance).

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 "A synthesis study of the role of mesoscale and synoptic-scale wind on the concentrations of ozone and its precursors in Houston" project. The Principal Investigator for the project is Qi Ying and John Nielsen-Gammon is the co-PI.

Electronic Approvals:

This QAPP was approved electronically on 10/2/2018 by Elena McDonald-Buller, The University of Texas at Austin.

Elena McDonald-Buller

Project Manager, Texas Air Quality Research Program

This QAPP was approved electronically on 10/2/2018 by Vincent M. Torres, The University of Texas at Austin.

Vince Torres

Quality Assurance Project Plan Manager, Texas Air Quality Research Program

This QAPP was approved electronically on 10/2/2018 by Qi Ying, Texas A&M University.

Qi Ying

Principal Investigator, Texas A&M University

QAPP Distribution List

Texas Air Quality Research Program
David Allen, Director
Elena McDonald-Buller, Project Manager

Texas Commission on Environmental Quality
Jonathan Steets, Project Liaison

Texas A&M University
Qi Ying, Principal Investigator

1.0 Project Description and Objectives

While it is known that low synoptic-scale winds and mesoscale recirculation contribute to high ozone formation in Houston, a comprehensive synthesis of all relevant data and analyses to elucidate the interaction between the mesoscale and synoptic-scale winds and air pollutants is not yet available. An improved understanding of the roles of mesoscale and synoptic-scale processes would allow researchers and policy makers to distinguish between days dominated by local emissions and those dominated by regional contributions. The overall objective of this research is to synthesize existing data, previous analyses, and photochemical model experiments to provide a comprehensive and reconciled description of how mesoscale and synoptic-scale winds affect dispersion and accumulation of air pollutants emitted in the Houston area and from other regions, and how they contribute to high ozone events. The relationship between surface winds and boundary-layer mesoscale transport features will be clarified, and a novel source- and age-resolved regional air quality model will be applied to investigate selected high ozone events with mesoscale circulations. The results from this study will facilitate a better understanding of the interaction between the mesoscale and synoptic-scale winds and air pollutants and how they contribute to high ozone events in Houston. Such information is extremely useful for understanding high ozone events as they occur and for developing appropriate control strategies and policy options for the unique Texas meteorological environment.

2.0 Organization and Responsibilities

2.1 Project Personnel

Dr. Ying will be the Principle Investigator (PI) of the project and will work with Dr. Nielsen-Gammon (Co-PI) to oversee all aspects of this project. Dr. Ying will guide one Civil Engineering (CVEN) Postdoc researcher or graduate student on the development of the source- and age-resolved model and the modeling of ozone exceedance events using the Community Multiscale Air Quality Model (CMAQ). Dr. Nielsen-Gammon will guide an Atmospheric Sciences Postdoc researcher on developing and validating quantitative relationships between surface winds and boundary-layer mesoscale transport and performing observation data analyses of key mesoscale-dominated ozone exceedance events. Dr Ying and Dr. Nielsen-Gammon will work together to prepare all required reporting documents. Dr. Ying will also be responsible for all quality assurance (QA) activities related with air quality modeling, including an audit of the data quality for the model input data and those data produced by the models. The CVEN postdoc or graduate student will perform most of the actual model simulation and generate all the data. A minimum of 10% of the input and output data will be audited by Dr. Ying. Dr. Ying and the CVEN postdoc or student will cross-examine any additional source code developed to ensure all coding errors are fixed before using the model for production runs.

2.2 Project Schedule

An overall schedule of project activities by task in shown in Table 1. The schedule assumes a start date of September 1, 2018 and end date of August 31, 2019.

TASK		09/18	10/18	11/18	12/18	01/19	02/19	03/19	04/19	05/19	06/19	07/19	08/19
	month #	1	2	3	4	5	6	7	8	9	10	11	12
1. Synthesis of mesoscale wind structures in synoptic-scale context (N-G)		■	■	■	■	■							
2. Develop source and age-resolved CMAQ (SAR-CMAQ) (Ying)		■	■	■	■								
3. Analysis of interaction of mesoscale winds and ozone formation during key episodes (observation based) (N-G,						■	■	■	■	■			
4. Draft and Final Report (Ying, N-G)											■	■	■

3.0 Model Selection and Input Data

The project is designed to combine data analyses and model simulations of key mesoscale-dominated ozone exceedance events to develop a comprehensive synthesis of the evolution of ozone and its precursors on such days. The Community Multiscale Air Quality (CMAQ) model (Byun and Schere, 2006; Foley et al., 2010), developed by the United States Environmental Protection Agency (US EPA), is chosen as the base model in this study because it has an easy to use chemical mechanism preprocessor, which is essential for this project as the base photochemical mechanism will be modified to track ozone and its precursors from multiple sources simultaneously. The PI's research group has extensive experience in CMAQ model development and applications and has used CMAQ for two previous AQRP supported projects (12-006 and 14-030).

The CMAQ model domain for this study follows the Regional Planning Organization (RPO) Comprehensive Air Model with Extensions (CAMx) domains used by the TCEQ for ozone air quality modeling. Three nested domains will be used (rpo_36km, tx_12km, x_4km, see Figure 1 below). Lambert Conformal Conic projection parameters, and other details such as vertical domain structures, can be found on the TCEQ website: http://www.tceq.texas.gov/airquality/airmod/rider8/modeling/domain.

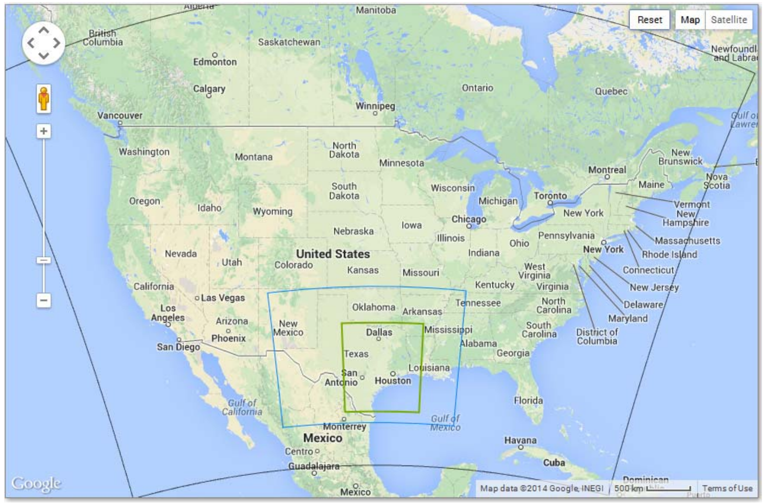

Figure 1: CMAQ modeling domains. The largest to the smallest domains are rpo_36km, tx_12km and tx_4km, as discussed in the text above.

Meteorological input data: Meteorological inputs to drive the CMAQ simulations will be generated using the most recent version (4.0) of the Weather Research and Forecasting Model (WRF) with mesoscale-optimized WRF model configuration. In view of past issues with large-scale wind errors contaminating the mesoscale simulations (Ngan et al., 2012), we will test two reanalysis data sets (the ERA5 global reanalysis from the European Centre for Medium-Range Weather Forecasts and the FNL global reanalysis from National Center for Atmospheric Research) to drive the WRF simulations. Extensive WRF model performance analysis will be conducted and the one with the best performance for synoptic and mesoscale wind patterns will be chosen as the input data for CMAQ. The input data to run WRF (i.e., the FNL and the ERA5 global analysis) have all been quality assured thus no additional QA is needed for them. Selected run scripts (at least 10%) prepared by the student (postdoc) will be examined by Dr. Ying during the QA step. Afterwards, WRF outputs will be compared with observations (acquired from the National Climate Data Center) as part of the QA process. In addition to overall model performance statistics, timeseries of predictions at stations in southeast Texas will be examined to detect any irregular model results. Input data and run scripts will be double checked for these periods identified.

Biogenic and anthropogenic emission data: Biogenic emissions will be generated using MEGANv2.1 with emission factors based on BEIS 3.61, as a previous AQRP supported study led by Dr. Ying (AQRP 14-030) shows that this set up leads to a better estimation of biogenic emissions of isoprene (Wang et al., 2017). We will follow the procedures applied in AQRP project #14-030 when running MEGAN, and the detailed procedures are not repeated here. Anthropogenic emissions will be generated using the National Emission Inventory (NEI). The Mexico and Canada emission from NEI will also be included. We will also work with TCEQ and AQRP manager to use Texas-specific emissions for the inner model domains if such data are available. Wildfire emissions will be based on the Fire INventory from NCAR (FINN), which has been widely used to provide fire emission for atmospheric chemical transport models. Dust emissions from wind erosion will be calculated using an online dust module in CMAQ. The input data to generate the biogenic and anthropogenic emissions (i.e., land use/land cover data, the national emission inventories, and the FINN fire inventory) all have been quality assured in the institutions that developed them, thus no additional QA is needed. Run scripts generated by the student (postdoc) (10% minimum) will be checked by Dr. Ying. Calculated emissions will be plotted (at least 10% of the data), both in the form of regional distributions and time series, and examined manually by Dr. Ying to ensure the quality of the data.

Initial and boundary conditions: Initial condition/boundary condition (IC/BC) based on CMAQ's default IC/BC files will be used for 36-km simulations. For 12 and 4-km simulations, IC and BC will be based on simulation results of the parent domain. The impact of initial conditions decrease as simulation goes on. First five days of simulation results will not be used in subsequent analysis to avoid initial condition impact. Likewise, 36-km boundary conditions only impact areas near the boundaries of the 36 km domain. The default IC and BC data are developed by the US EPA and no QA is needed. To ensure that a five-day spin-up time is enough to remove the influence of IC on model simulations, diagnostic simulations will be performed by the student (postdoc) with varying length of the spin-up time. When additional spin-up days does not lead to significant differences in modeled concentrations on target days, the appropriate spin-up days is thought to be found. This process will be done by the student (postdoc) and Dr. Ying will double check the analysis.

4.0 Model Design and Coding

The Source- and Age-Resolved Community Multiscale Air Quality (SAR-CMAQ) model represents a further development of the source-oriented CMAQ model. It is capable of tracking emissions not only by sources/source-regions but also their age since emitted into the atmosphere. In this study, the model will use reactive tracers to track NO_x and primary VOCs emitted from different sources/source-regions at different times. Additional non-reactive O_3 tracers will be introduced to track the ozone formed at different locations (including elevation) and times. In this way, we can directly quantify the amount of locally-formed vs. regional ozone and quantitatively determine when and where the ozone affecting Houston on high ozone days are formed. To track the atmospheric age of ozone precursors, we will develop a source- and age-resolved chemical mechanism. Conceptually, the age-resolved mechanism can be explained using the following reactions for NO and NO_2:

$$\mathrm{NO\_T1} + \mathrm{O_3} \rightarrow \mathrm{NO_2\_T1} + \mathrm{O_2} \qquad \text{(R1)}$$

$$\mathrm{NO\_T2} + \mathrm{O_3} \rightarrow \mathrm{NO_2\_T2} + \mathrm{O_2} \qquad \text{(R2)}$$

… …

$$\mathrm{NO\_Tn} + \mathrm{O_3} \rightarrow \mathrm{NO_2\_Tn} + \mathrm{O_2} \qquad \text{(Rn)}$$

The NO_T[1,2…n] and NO_2_T[1,2,…,n] species are used to track NO and NO_2 with different atmospheric times from fresh to aged. In the model simulation, fresh emissions of NO and NO_2 are represented by the species with T1 tags. At the end of each model hour, a time bin advance operation is performed so that $NO_2\_Ti = NO_2\_T(i-1)$ for i=1,2,…,n-1. For the last time bin, $NO_2\_Tn = NO_2\_Tn + NO_2\_T(n-1)$. The same operations will be done for NO and other tagged reactive nitrogen species. This age-resolved concept can also be applied to primary VOCs. This scheme can be easily expanded to track age-resolved species from different sources or source regions. For O_3, it is possible to introduce non-reactive ozone tracers, O_3_T1, O_3_T2, …, O_3_Tn, to represent O_3 with different atmospheric ages. At each time step, integrated process analysis (IPA) can be used to determine the ozone formation (P_{O3}) and removal rate (D_{O3}). O3_T1, which represents freshly formed O3, can be updated by equation (1) to account for ozone formation while the other O_3 tracers remain unchanged.

$$O_3\_T1^{int} = O_3\_T1^{t-\Delta t} + P_{O_3} \quad (1)$$

$$O_3\_Ti^{int} = O_3\_Ti^{t-\Delta t},\ i=2,3,\ldots,n \quad (2)$$

The intermediate concentrations will be updated by distributing the removal of O_3 proportionally to all tagged O_3 species:

$$O_3\_Ti^{t} = O_3\_Ti^{int} - D_{O_3}\frac{O_3\_Ti^{int}}{\sum_{j=1}^{n} O_3\_Tj^{int}}\ \ i=1,2,\ldots,n \quad (3)$$

The above scheme shows how to resolve O_3 atmospheric ages. It is easy to expand this representation to track both O_3 age and formation regions. For example, it might be useful to track at which vertical layer the O_3 is formed because wind speed and direction changes as a function of height, leading to different transport distances. Additional ozone tracers with layer designations, such as $O_3\_L1\_T1$, $O_3\_L1\_T2$, etc., can be used for such a purpose. All source codes developed to implement this will be cross-examined by Dr. Ying and the student (postdoc).

5.0 Model Calibration

The WRF model, the parent CMAQ model and the extension to the CMAQ (i.e. SAR-CMAQ) do not include parameters that need to be calibrated.

6.0 Model Verification

The SAR-CMAQ code will be verified by comparing predictions from the parent CMAQ model without the SAR feature. Theoretically, the SAR mechanism does not change the overall reaction rates and specie concentrations. The predicted concentrations for a model tracked species (e.g. NO2) when summed for all ages and sources, should have the same concentration as that of the base case. In this regard, extensive comparisons will be made to ensure that it is the case.

7.0 Model Evaluation

Judicious selection of WRF model parameterizations has been shown to lead to accurate simulations of southeast Texas mesoscale circulations (Ngan et al., 2013). In view of past issues with large-scale wind errors contaminating the mesoscale simulations (Ngan et al., 2012), we will test two reanalysis data sets (the ERA5 global reanalysis from the European Centre for Medium-Range Weather Forecasts and the FNL global reanalysis from National Center for Atmospheric Research) to drive the WRF simulations. Extensive WRF model performance analysis will be conducted and the one with the best performance for synoptic and mesoscale wind patterns will be chosen as the input data for CMAQ. Model performance statistics to evaluate WRF model results will be based on Emery et al. (Emery et al., 2001) , including mean fractional bias (MB), gross error (GE) and root mean square error (RMSE) (See Table 2 for the definition of these statistical measures). High-interest air quality episodes can then be simulated by WRF and CMAQ with confidence that the synoptic and mesoscale dynamics are properly represented. In addition to surface meteorological measurements, wind profiler data will also be utilized in the WRF model performance analysis. The analysis will be done by the student (postdoc). Dr. Ying will choose 10% of the model output and perform an independent performance analysis during the QA process. This will ensure that postprocessing programs and run scripts were correctly used in processing the data.

The SAR-CMAQ model will be evaluated extensively with available surface observation data measured at the Continuous Air Monitoring Station (CAMS) operated by TCEQ and other surface observation available in the Air Quality System (AQS) from United States Environmental Protection Agency (US EPA) throughout this episode. Both graphical and statistical measures will be used in the model performance evaluation. Graphical methods will include spatial distribution maps, scatter plots and time-series comparing model predictions to observations at regular TCEQ and EPA monitoring stations. Statistical methods will include computation of metrics of bias and error between predictions and observations for ozone and precursors using the guidance of U.S. EPA (2007). Statistical measures are shown in Table 2:

Table 2: Definition of Model Performance Statistical Measures

Statistical Measures	**Definition**
Mean bias	$\mathrm{MB} = \frac{1}{N}\sum_{i=1}^{N}(C_{m,i} - C_{o,i})$
Gross error	$\mathrm{GE} = \frac{1}{N}\sum_{i=1}^{N}\lvert C_{m,i} - C_{o,i}\rvert$
Root mean square error	$\mathrm{RMSE} = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(C_{m,i} - C_{o,i})^2}$
Normalized mean bias	$\mathrm{NMB} = \frac{\sum_{i=1}^{N} C_{m,i} - C_{o,i}}{\sum_{i=1}^{N} C_{o,i}}$

Normalized mean error	$\text{NME} = \frac{\sum_{i=1}^{N} \left| C_{m,i} - C_{o,i} \right|}{\sum_{i=1}^{N} C_{o,i}}$
Mean normalized bias	$\text{MNB} = \frac{1}{N} \sum_{i=1}^{N} \frac{C_{m,i} - C_{o,i}}{C_{o,i}}$
Normalized gross error	$\text{NGE} = \frac{1}{N} \sum_{i=1}^{N} \frac{\left| C_{m,i} - C_{o,i} \right|}{C_{o,i}}$
Mean fractional bias	$\text{MFB} = \frac{2}{N} \sum_{i=1}^{N} \frac{C_{m,i} - C_{o,i}}{C_{m,i} + C_{o,i}}$
Mean fractional error	$\text{MFE} = \frac{2}{N} \sum_{i=1}^{N} \frac{\left| C_{m,i} - C_{o,i} \right|}{C_{m,i} + C_{o,i}}$
Accuracy of paired peak	$\text{APP} = \frac{C_{p,opeak} - C_{o,opeak}}{C_{o,opeak}}$
Accuracy of unpaired peak	$\text{AUP} = \frac{C_{p,ppeak} - C_{o,opeak}}{C_{o,opeak}}$

Note: C_m is the model-predicted concentration i, C_o is the observed i, and N equals the number of prediction-observation pairs drawn from all monitoring stations. The subscripts ppeak and opeak are the hours when predicted and observed peak concentrations occur.

The model performance analysis will be done by the student (postdoc). Dr. Ying will choose 10% of the model output and perform an independent performance analysis during the QA process. This will ensure that postprocessing programs and run scripts were correctly used in processing the data. This step is intended to satisfy the 10% audits of data quality required for this level/category of QAPP.

8.0 Model Documentation

Descriptions of the WRF and CMAQ model configuration, modifications, input data resources, hardware and software requirements, scripts, operating instructions, output of model runs and interpretation, and results of the model calibration, verification, and evaluation will be provided in the project final report.

9.0 Reporting

As required, monthly technical, monthly financial status, and quarterly reports as well as an abstract at project initiation and, near the end of the project, the draft final and final reports will be submitted according to the schedule below. Dr. Ying will electronically submit each report to both the AQRP and TCEQ liaisons and will follow the State of Texas accessibility requirements as set forth by the Texas State Department of Information Resources (http://aqrp.ceer.utexas.edu/). Dr. McDonald-Buller and Dr. John

Nielsen-Gammon anticipate attending and presenting at the AQRP data workshop. Draft copies of any planned presentations (such as at technical conferences) or manuscripts to be submitted for publication resulting from this project will be provided to both the AQRP and TCEQ liaisons per the Publication/Publicity Guidelines included in Attachment G of the subaward. Final project data and associated metadata will be prepared and submitted to the AQRP archive. Each deliverable and required deadline for submission are presented below.

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: 8/31/2018

Quarterly Reports: Each Quarterly Report will provide a summary of the project status for each reporting period. It will be submitted to the Project Manager as a Microsoft Word file. It will not exceed 2 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
Aug2018 Quarterly Report	June, July, August 2018	Friday, August 31, 2018
Nov2018 Quarterly Report	September, October, November 2018	Friday, November 30, 2018
Feb2019 Quarterly Report	December 2018, January & February 2019	Thursday, February 28, 2019
May2019 Quarterly Report	March, April, May 2019	Friday, May 31, 2019
Aug2019 Quarterly Report	June, July, August 2019	Friday, August 30, 2019
Nov2019 Quarterly Report	September, October, November 2019	Friday, November 29, 2019

Monthly Technical Reports (MTRs): Technical Reports will be submitted monthly to the Project Manager and TCEQ Liaison in Microsoft Word format using the AQRP FY16-17 MTR Template found on the AQRP website.

MTR Due Dates:

Report	Period Covered	Due Date
Aug2018 MTR	Project Start - August 31, 2018	Monday, September 10, 2018
Sep2018 MTR	September 1 - 30, 2018	Monday, October 8, 2018

Oct2018 MTR	October 1 - 31, 2018	Thursday, November 8, 2018
Nov2018 MTR	November 1 - 30 2018	Monday, December 10, 2018
Dec2018 MTR	December 1 - 31, 2018	Tuesday, January 8, 2019
Jan2019 MTR	January 1 - 31, 2019	Friday, February 8, 2019
Feb2019 MTR	February 1 - 28, 2019	Friday, March 8, 2019
Mar2019 MTR	March 1 - 31, 2019	Monday, April 8, 2019
Apr2019 MTR	April 1 - 28, 2019	Wednesday, May 8, 2019
May2019 MTR	May 1 - 31, 2019	Monday, June 10, 2019
Jun2019 MTR	June 1 - 30, 2019	Monday, July 8, 2019
Jul2019 MTR	July 1 - 31, 2019	Thursday, August 8, 2019

Financial Status Reports (FSRs): Financial Status Reports will be submitted monthly to the AQRP Grant Manager (Maria Stanzione) by each institution on the project using the AQRP FY16-17 FSR Template found on the AQRP website.

FSR Due Dates:

Report	**Period Covered**	**Due Date**
Aug2018 FSR	Project Start - August 31	Monday, September 17, 2018
Sep2018 FSR	September 1 - 30, 2018	Monday, October 15, 2018
Oct2018 FSR	October 1 - 31, 2018	Thursday, November 15, 2018
Nov2018 FSR	November 1 - 30 2018	Monday, December 17, 2018
Dec2018 FSR	December 1 - 31, 2018	Tuesday, January 18, 2019
Jan2019 FSR	January 1 - 31, 2019	Friday, February 15, 2019
Feb2019 FSR	February 1 - 28, 2019	Friday, March 15, 2019
Mar2019 FSR	March 1 - 31, 2019	Monday, April 15, 2019
Apr2019 FSR	April 1 - 28, 2019	Wednesday, May 15, 2019
May2019 FSR	May 1 - 31, 2019	Monday, June 17, 2019
Jun2019 FSR	June 1 - 30, 2019	Monday, July 15, 2019
Jul2019 FSR	July 1 - 31, 2019	Thursday, August 15, 2019
Aug2019 FSR	August 1 - 31, 2019	Monday, September 16, 2019
FINAL FSR	Final FSR	Tuesday, October 15, 2019

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. It will also include a report of the QA findings.

Draft Final Report Due Date: Thursday, August 1, 2019

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

Final Report Due Date: Tuesday, September 3, 2019

Project Data: All project data including but not limited to QA/QC measurement data, metadata, databases, modeling inputs and outputs, etc., will be submitted to the AQRP Project Manager within 30 days of project completion (September 30, 2019). The data will be submitted in a format that will allow AQRP or TCEQ or other outside parties to utilize the information. It will also include a report of the QA findings.

AQRP Workshop: A representative from the project will present at the AQRP Workshop in the first half of August 2019.

Presentations and Publications/Posters: All data and other information developed under this project which is included in published papers, symposia, presentations, press releases, websites and/or other publications shall be submitted to the AQRP Project Manager and the TCEQ Liaison per the Publication/Publicity Guidelines included in Attachment G of the Subaward.

10.0 References

Byun, D., Schere, K.L., 2006. Review of the Governing Equations, Computational Algorithms, and Other Components of the Models-3 Community Multiscale Air Quality (CMAQ) Modeling System. Applied Mechanics Reviews 59, 51-77.

Emery, C., Tai, E., Yarwood, G., 2001. Enhanced meteorological modeling and performance evaluation for two texas episodes. Report to the Texas Natural Resources Conservation Commission, prepared by ENVIRON, Internatioanl Corp., Novato, CA.

Foley, K.M., Roselle, S.J., Appel, K.W., Bhave, P.V., Pleim, J.E., Otte, T.L., Mathur, R., Sarwar, G., Young, J.O., Gilliam, R.C., Nolte, C.G., Kelly, J.T., Gilliland, A.B., Bash, J.O., 2010. Incremental testing of the Community Multiscale Air Quality (CMAQ) modeling system version 4.7. Geosci. Model Dev. 3, 205-226.

Ngan, F., Byun, D., Kim, H., Lee, D., Rappengluck, B., Pour-Biazar, A., 2012. Performance assessment of retrospective meteorological inputs for use in air quality modeling during TexAQS 2006. Atmospheric Environment 54, 86-96.

Ngan, F., Kim, H., Lee, P., Al-Wali, K., Dornblaser, B., 2013. A Study of Nocturnal Surface Wind Speed Overprediction by the WRF-ARW Model in Southeastern Texas. Journal of Applied Meteorology and Climatology 52, 2638-2653.

Wang, P., Schade, G., Estes, M., Ying, Q., 2017. Improved MEGAN predictions of biogenic isoprene in the contiguous United States. Atmospheric Environment 148, 337-351.