Quality Assurance Project Plan

AQRP Project: 18-022

Development and Evaluation of the FINNv.2 Global Model Application and Fire Emissions Estimates for the Expanded Texas Air Quality Modeling Domain

Prepared for

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

By

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August 30, 2018
Version #3

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

QAPP Requirements: The QAPP describes the project description and objectives, project organization and responsibilities, model selection, model calibration, model verification, model evaluation, model documentation, and reporting procedures, as 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 following project: *Development and Evaluation of the FINNv.2 Global Model Application and Fire Emissions Estimates for the Expanded Texas Air Quality Modeling Domain*. The Principal Investigator for the project is Elena McDonald-Buller and Co-Principal Investigators are Fred Lurmann and Christine Wiedinmyer.

Electronic Approvals:

This QAPP was approved electronically on Aug. 31, 2018 by David Sullivan, The University of Texas at Austin.

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David Sullivan
Project Manager, Texas Air Quality Research Program

This QAPP was approved electronically on Aug. 30, 2018 by Vincent M. Torres, The University of Texas at Austin.

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Vincent M. Torres
Quality Assurance Project Plan Manager, Texas Air Quality Research Program

This QAPP was approved electronically on Aug. 30, 2018 by Elena McDonald-Buller, The University of Texas at Austin.

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Elena McDonald-Buller
Principal Investigator, The University of Texas at Austin

QAPP Distribution List

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David Sullivan, Project Manager

Texas Commission on Environmental Quality
Stephanie Shirley, Project Liaison

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1.0 Project Description and Objectives

Wildland fires and open burning can be substantial sources of ozone precursors and particulate matter. Air quality in Texas can be affected by fire events that occur locally, regionally, or across longer distances from within the United States or across its international borders. The Fire INventory from the National Center for Atmospheric Research (FINN) model estimates daily emissions of trace gases and particles from open biomass burning. The objectives of this project are to leverage new findings and data products from ongoing laboratory studies, surface and airborne field measurement campaigns, and satellite-based sensors in the development of FINN and to produce a fully operational, next generation global FINN application. The FINN v.2 Global Application will be used to develop fire emissions estimates for 2012-2017, a time period that includes 2016, which is the base year for the U.S. Environmental Protection Agency's (EPA's) national air quality modeling platform and likely the basis for the TCEQ's future air quality modeling. FINN performance will be assessed using a new satellite algorithm, the Multi-Angle Implementation of Atmospheric Correction (MAIAC), for aerosol optical depth (AOD) retrievals, with a focus on fire events that originate from within Mexico, Central America, or the Caribbean and influence Texas air quality. The project is a collaborative effort between the University of Texas at Austin (UT Austin), Sonoma Technology, Inc. (STI), and Dr. Christine Wiedinmyer.

2.0 Model Systems and Data

2.1 FINN

FINN is a global fire emissions model that estimates daily emissions of trace gases and particles from open biomass burning (Wiedinmyer et al., 2011). FINN v.1 was released in 2010. Global fire emissions estimates using the most recent version of FINN, v.1.5, are publicly accessible from the NCAR data portal: http://bai.acom.ucar.edu/Data/fire/. The Texas Air Quality Research Program (AQRP) Project 14-011 (McDonald-Buller et al., 2015) made targeted improvements to FINN with a special focus on needs for Texas. A new approach was developed that dramatically improved the way in which burned area was estimated from satellite-derived fire detections. Other improvements included better spatial resolution of land cover and fuel loadings in the United States, new satellite-based estimates of barren land and vegetative cover, and options to use crop-specific emission factors and fuel loadings for the United States and different land cover data resources. These modifications served as the foundation for the ongoing development of the next generation of the model, FINN v.2.

The FINN v.2 application developed as an outcome of AQRP Project 14-011 can be run on a regional scale for Texas and the CONUS, but not yet on a global scale because of its current computational demands. Its framework has been described by Wiedinmyer et al. (2011) and McDonald-Buller et al. (2015). Emissions are estimated as:

$$E_i = A\,(x,t) * B(x) * FB * ef_i$$

where E_i is the mass emission of species *i* (kg/day), A(x,t) is the area burned at time t and location x (km^2/day), B(x) is the biomass (fuel) loading at location x (g/m^2), FB is the fraction of biomass burned, and ef_i is the emission factor of species *i* (g/kg biomass burned). All biomass terms are on a dry weight basis.

By default the Moderate Resolution Imaging Spectroradiometer (MODIS) Rapid Fire Detections (https://firms.modaps.eosdis.nasa.gov/download/ is used for fire identification. A new approach was developed as part of AQRP Project 14-011 to estimate the burned area of each fire event on a given day. The approach assumes a 1-km^2 area per MODIS fire record, joins neighboring detections through a convex hull based on estimated scan and track sizes of the satellite pixel, and dissolves neighboring polygons to estimate a total daily burned area. Bare ground is removed from the total burned area using the Vegetation Continuous Fields (VCF) version 051 Product. (https://lpdaac.usgs.gov/version_51_vegetation_continuous_fields_release). An algorithm is applied to characterize the underlying land cover of the burned area that uses Voronoi tessellation with detection coordinates as seeds.

Various global, national, and regional land cover products are available as options for FINN. The recommendation for Texas air quality applications at the outcome of AQRP Project #14-011 was the use of the Texas regional land cover product (Popescu et al., 2011) with the U.S. Department of Agriculture National Agricultural Statistical Service Cropland Data Layer (CDL), the U.S. Forest Service Fuel Characteristic Classification System (FCCS) in the remainder of the continental U.S., and MODIS Land Cover Type (LCT) product elsewhere. This combination provides the greatest spatial resolution and specificity in land cover and fuel loadings for the Texas regional domain and CONUS. Emission factors for carbon monoxide (CO), oxides of nitrogen (NO_x), non-methane organic compounds (NMOC), ammonia (NH_3), sulfur dioxide (SO_2), fine particulate matter ($PM_{2.5}$), coarse particulate matter (PM_{10}), organic carbon (OC), and black carbon (BC) by seven broad land cover types are summarized in McDonald-Buller et al. (2015) and include options for additional crop-specific emission factors for major U.S. crop types. The fraction of biomass burned is determined based on the fraction of tree cover and fuel loadings by default in FINN using the approach of Ito and Penner (2004).

The FINN v.2 application developed as an outcome of AQRP Project 14-011 will serve as the initial starting point for the development of the FINN v.2 Global Application in this work. Development of the new application will include obtaining the Visible Infrared Imaging Radiometer Suite (VIIRS) fire detection product that offers greater spatial resolution (375m) than the current MODIS default product (1km) in the FINN preprocessor (https://earthdata.nasa.gov/earth-observation-data/near-real-time/firms/active-fire-data). Recent studies, including FIREX, FLAME-4 and SEAC^{4}RS studies, present new emission factors, fuel loadings, and other information about fire emissions. This work will also incorporate any updates to these model parameters based on the most recent literature available between 2014-2018. The FINN preprocessor will be implemented on a public domain spatial database PostGIS for better scalability to a global application. The new preprocessor tool and Interactive Data Language (IDL) code for FINN will be designed to run at a global scale on PC (desktop/workstation) systems and produce emissions estimates in an appropriate format for application in global or regional CTMs.

2.2 CAMx

CAMx is an open-source modeling system for multi-scale integrated assessment of gaseous and particulate air pollution (Ramboll, 2018). This project will use a May through September 2012 episode developed by the TCEQ to support the assessment of FINN emissions estimates. Anthropogenic and biogenic emissions and the meteorological modeling are described in https://www.tceq.texas.gov/assets/public/implementation/air/sip/hgb/HGB_2016_AD_RFP/AD_Adoption/16016SIP_HGB08AD_ado.pdf. This episode has been used to support attainment demonstrations by the TCEQ and consequently has undergone extensive evaluation. Model performance has been evaluated by the TCEQ and will not be repeated in this project. However, as with any CAMx system file transfer from the TCEQ to the Texas Advanced Computing Center (TACC), the UT Austin team will ensure that the CAMx base case sufficiently replicates the TCEQ simulation with the recognition of differences in computing platforms. The team has conducted such analyses for previous projects (e.g., McGaughey et al., 2017). Figure 1 shows the nested horizontal grid domains for the 2012 base year.

The base year for EPA's national air quality modeling platform is 2016 and this will likely be the basis for future TCEQ air quality modeling. The TCEQ's future air quality model domain has been extended to include all of Mexico and large parts of Central America and the Caribbean (Figure 1b). If a 2016 modeling episode becomes available in sufficient time prior to the end of the project, it will also be used in the assessment of FINN performance.

(a) (b)

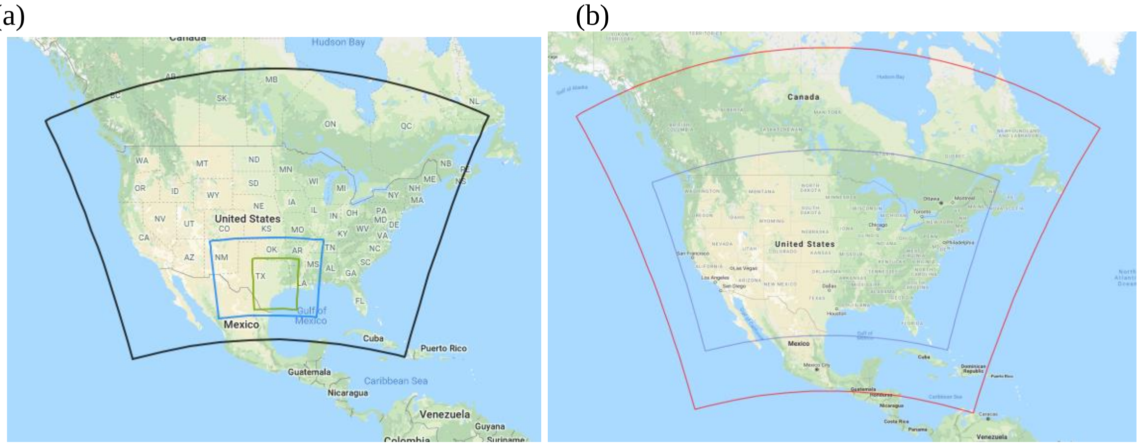

Figure 1. Nested horizontal grid domains for TCEQ's air quality modeling: (a) 2012 base year (https://www.tceq.texas.gov/airquality/airmod/data/domain) and (b) for future modeling for the 2016 base year (Estes, 2018).

3.0 Organization and Responsibilities

3.1 Project Personnel

The project will be directed by Dr. Elena McDonald-Buller (Principal Investigator) of the University of Texas at Austin, Mr. Fred Lurmann (Co-Principal Investigator) and Dr. Steve Brown of Sonoma Technology, Inc. and Dr. Christine Wiedinmyer (Co-Principal Investigator). Other staff members instrumental to the technical work include Dr. Yosuke Kimura from the University of Texas at Austin and Mr. Nathan Pavlovic from STI. Project participants and their responsibilities are listed in Table 1.

3.2 Project Schedule

An overall schedule of project activities by task is shown in Table 2.

Table 1. Project participants and their key responsibilities.

Participant	Key Responsibilities
Elena McDonald-Buller	Principal Investigator from the University of Texas at Austin will provide overall supervision and integration of the technical work and will be responsible for the preparation and submission of the monthly progress, quarterly progress, and final reports. Dr. McDonald-Buller and/or Dr. Wiedinmyer will conduct independent audits of the input data and emissions estimates from FINN that are intended to satisfy the QA requirement of 10% audits of data quality for this project.
Fred Lurmann	Co-Principal Investigator from Sonoma Technology, Inc. who will consult with staff members at STI on the FINN/MAIAC model assessment and advise on results reporting in collaboration with Dr. McDonald-Buller and Dr. Wiedinmyer.
Christine Wiedinmyer	Co-Principal Investigator of the Cooperative Institute for Research in Environmental Sciences (CIRES) at the University of Colorado Boulder who will serve in an independent leadership and advisory role for the project. Dr. Wiedinmyer will provide guidance and supervision of the technical work including the development of the FINN v.2 Global Application and fire emissions estimates and interpretation of the FINN evaluation. She will assist Dr. McDonald-Buller with the preparation and submission of the monthly progress, quarterly progress, and final reports. Dr. McDonald-Buller and/or Dr. Wiedinmyer will conduct independent audits of the input data and emissions estimates from FINN that are intended to satisfy the QA requirement of 10% audits of data quality for this project.
Steve Brown	Senior Atmospheric Scientist at Sonoma Technology, Inc. who will provide overall guidance and coordination for completion of technical work with Dr. McDonald-Buller and Dr. Wiedinmyer. Dr. Brown will be partially responsible for the preparation of technical reports and presentations.
Yosuke Kimura	Research Associate IV at the University of Texas at Austin who will work on the development of the FINN v.2 Global Application and simulations to obtain fire emissions estimates. He will conduct the CAMx simulations to support the assessment of FINN performance.
Nathan Pavlovic	Air Quality Scientist at Sonoma Technology, Inc. who will be responsible for obtaining and preparing meteorological and satellite data sets, performing HYSPLIT dispersion modeling, comparing dispersion model results with satellite observations, comparing CAMx-estimated AOD with satellite observations, and investigating smoke impact events. Mr. Pavlovic will also be partially responsible for drafting reports and presentations in coordination with Dr. Brown and Mr. Lurmann.

Table 2. Schedule of project activities (tasks are bolded).

ID	Task	Aug 2018	Sept 2018	Oct 2018	Nov 2018	Dec 2018	Jan 2019	Feb 2019	Mar 2019	Apr 2019	May 2019	Jun 2019	July 2019	Aug 2019
1	***Development & Release of FINN v.2 Global***													
1a	*Preprocessor and Model Development*	X	X	X	X									
1b	*Accessibility for Global Scale Application*	X	X	X	X									
1c	*Porting and Testing*				X	X								
2	***FINN v.2 Global Emissions Estimates***				X	X	X	X						
3	***Assessment of FINN Performance***						X	X	X	X	X			
R	*Monthly Technical & Financial Progress*	X	X	X	X	X	X	X	X	X	X	X	X	X
R	*Quarterly*		X			X			X			X		
R	*Draft Final*											X	X	
R	*Final*													X
R	*AQRP Workshop*													X

4.0 Model Selection

The project specifically focuses on the continuing development of the FINN model and its application to Texas air quality planning and management. FINN is highly relevant to air quality modeling, offering high spatial and temporal resolution, consistency across geopolitical boundaries, and flexible options for the chemical speciation of NMOC emissions. The Texas AQRP has been instrumental in the evolution of FINN. Two previous AQRP Projects 12-018 (McDonald-Buller et al., 2013) and 14-011 (McDonald-Buller et al., 2015) have served as the foundation for the development of the next generation of the model. FINN emissions estimates from AQRP Project 14-011 have been used in air quality modeling for Texas ozone nonattainment areas conducted by the TCEQ. A major goal of this project is to complete development of the next generation global-scale model for future TCEQ applications, including in the development of fire emissions estimates and boundary conditions for its air quality modeling domain.

CAMx is an Eulerian photochemical model that allows for integrated "one-atmosphere" assessments of tropospheric air pollution (ozone, particulate matter, air toxics) over a range of spatial scales. It is publicly available and undergoes continuous review and evolution to reflect the state of the science. Although other Eulerian photochemical grid models such as the Community Multi-Scale Air Quality (CMAQ) system are available, CAMx has been used extensively for regulatory analysis to support State Implementation Plan (SIP) development and research studies of regional air quality in eastern Texas for more than fifteen years. An existing 2012 CAMx episode that was used to support the development of the most recent Texas State Implementation Plan (SIP) was selected for the evaluation of the FINN v.2 Global Application. Sensitivity studies with the CAMx episode for the purposes of assessing the effects of updates and FINN performance will involve changing only the fire emissions input data to CAMx; no other changes to input files or the CAMx configuration will be made.

5.0 Model Calibration

Versions of FINN emissions estimates have been used as part of many chemical transport model applications and studies (e.g., Kumar et al, 2012; Lin et al. 2012; Pfister et al. 2011; de Foy et al. 2011, Nuryanto, 2015; Pouliot et al., 2017; Wang and Talbot, 2017). The uncertainties of the emission estimation technique have been constrained by comparisons with other emission estimates and by the comparison of chemical transport models with satellite observations (e.g., Al-Saadi et al., 2008; Wiedinmyer et al., 2011; Paton-Walsh et al., 2012, Larkin et al., 2014; Shi et al., 2015; Pereira et al., 2016). Although limitations were identified, earlier versions of the model have shown to perform within reason for the U.S. and to be within the uncertainties of other models, such as the Global Fire Emissions Database (GFED), that are designed to support continental and global scale atmospheric modeling.

As part of AQRP Project 14-011, a thorough independent review of the code was conducted by Dr. Yosuke Kimura at the University of Texas at Austin. The review process included all lines of the IDL source code and cross-comparison of the FINN model input files. The FINN v.2 application that will be used as the starting point for this project was developed as an outcome of AQRP Project 14-011 and TCEQ feedback. McDonald-Buller et al. (2015) describe in detail the input data products and data quality assurance and auditing processes including for example, inspections of land cover rasters and the consistency of fuel loadings, burned area estimates and geometries, and comparison of vector and raster intersection methods for identifying underlying land cover in burned areas.

The new global application developed in this work will include the Visible Infrared Imaging Radiometer Suite (VIIRS) fire detection product, which will be obtained from the NASA portal: https://earthdata.nasa.gov/earth-observation-data/near-real-time/firms/active-fire-data. Visualizations of VIIRS fire detections will be compared to those from the default MODIS product for each year of interest. The VIIRS product will then be used in place of and/or in conjunction with the MODIS observations in FINN to determine and compare the magnitude and spatial effects on FINN emissions estimates. MODIS and VIIRS product quality is assessed by calibration, quality assurance and validation efforts (e.g., http://landval.gsfc.nasa.gov/). To the extent possible, the version and validation levels of products derived from satellite observations will be documented in the project final report. The sources of all satellite data, as well as the timing of retrievals of these data, will be documented.

Recent studies, including FIREX, FLAME-4 and SEAC4RS studies, present new emission factors, fuel loadings, and other information about fire emissions. This work will also incorporate any updates to these model parameters based on the most recent literature available between 2014-2018, as the team deems appropriate. Other data products will be documented to the extent possible, focusing on data sources, development, completeness, analytical, and validation methodologies.

Sensitivity studies will systematically examine how individual and collective modifications to the FINN model influence estimates of trace gas and particulate emissions from fires relative to the baseline configuration. Spatial mapping and descriptive summaries will be created for this project to facilitate the detection of anomalies and evaluation of reasonableness. The team anticipates that maps will be created using ArcGIS, PAVE, or alternative visualization software available through the Texas Advanced Computing Center (TACC). Spatial mapping and data overlays are critical components in cross-comparisons of locations with fire detections, underlying land cover and fuel loadings, and distributions of emissions. The team members have extensive experience with the development of the FINN model, its application, and evaluation of uncertainties surrounding the model inputs (ref. e.g., AQRP Project 12-018). They will apply expert judgment in the calibration of the model investigating in particular how updates to model input parameters or use of alternative input datasets affect the detection of different types of biomass burning activities and fire emissions estimates relative to the baseline configuration. In cases where an expected directional change in model predictions is inconsistent with changes in input data resources or anomalously small or large emissions estimates are evident, further investigation of discrepancies will be conducted and reconciliation approaches will be pursued.

6.0 Model Verification

This work will result in the generation of new fire emissions inventories for the years of 2012-2017. Seasonal and annual summaries of CO, NOx, VOC, and $PM_{2.5}$ emissions estimates will be generated for each year for Texas, Mexico, Central America, the Caribbean, and other geographic regions elsewhere within CONUS and internationally. A minimum of 10% of the data input to the models will be audited and reviewed in detail by a project team member that did not perform the analyses for quality assurance purposes. A minimum of 10% of the results of the analyses will be audited and reviewed in detail by a project team member that did not perform the analyses for quality assurance purposes. The results of these reviews and any quality assurance findings will be included in the final report.

Within the time period of interest, approximately five days will be selected for which data will be withheld from the calibration efforts and used for model verification. These days will be selected based on criteria to be established during the project. This could include for example representative regionally high or low ozone days in Texas or days with flow patterns from source regions of interest.

Evaluation of the FINN preprocessor will be assessed throughout the development process. The computational time and cost will be evaluated on test cases and the code optimized to reduce both. The preprocessor tool will be designed to process the satellite datasets, calculate burn area and overlay with fuel data. Processing at different spatial extents will be done to assess the time and computational cost of the preprocessor. Spot checks on the intermediate and output files from the preprocessor will be performed to calculate randomly selected fires to determine the accuracy of the large-scale processor. The IDL code that calculates the FINN emissions will be run at various spatial extents to assess computational and time costs. Calculations will be hand-checked for specific fires to ensure that the code is properly running. Output from the model will be compared to output from previous model versions to evaluate the impact of model changes on estimated emissions.

Once the development work has been completed, the FINN v.2 Global Application code will be ported along with descriptions, instructions for installation and use, and a sample application for testing on one or more systems at the TCEQ to ensure that it meets expectations. This activity represents an additional important quality assurance measure as the team has found in previous FINN development projects that independent review by and collaboration with the TCEQ can result in improvements to the model for Texas applications.

Estimates of NMOC emissions from FINN for 2012 will be allocated to the MOZART chemical mechanism using the most recent speciation code available and will be processed using EPS3 and exported in a format suitable for input to CAMx. Mapping of the magnitude and spatial distribution of fire emissions estimates from FINN with CAMx-ready emissions will be an important step to assure pre- and post-processing consistency and reasonableness. Speciated $PM_{2.5}$ and meteorological conditions from the CAMx model output will be used to calculate model-estimated AOD (Pitchford et al., 2007). The modeled AOD will be compared with MAIAC AOD retrievals on a daily and monthly basis at the spatial resolution of the CAMx modeling domain that covers the majority of Mexico, Central America, and the Caribbean (i.e, 36-km grid cell resolution). This process will be repeated for a 2016 CAMx episode if it becomes available from the TCEQ within a reasonable time period prior to the end of the project and has the capabilities for PM modeling.

7.0 Model Evaluation

The FINN v.2 2012-2017 fire emissions inventory output will be evaluated using independent MAIAC remote sensing data from the MODIS sensors onboard the NASA Aqua and Terra satellites. Fire smoke emissions will be used to produce predicted total column aerosol optical depth using two methods. First, AOD will be calculated for selected events based on photochemical modeling as described in Section 6.0 above. Second, the HYSPLIT model will be used to disperse smoke emissions from each fire on a daily basis using Global Data Assimilation System (GDAS0P5) meteorological data. A minimum of 10% of model-predicted AOD surfaces and 10% of MODIS AOD retrievals will be audited by an analyst who did not perform the analyses to ensure data quality. The results of these reviews and any quality assurance findings will be included in the final report. The meteorological data to be used in this effort is periodically quality assured by the producing agency (Kalnay, 1990).

Comparisons between modeled aerosols and satellite-observed aerosols will be performed to evaluate model performance. The model evaluation will be performed using both qualitative and quantitative approaches:

1. A qualitative approach will involve in-depth assessment of the agreement between modeled aerosols and satellite observations, based on examination of spatial patterns for selected fire events that impacted Texas and daily and monthly trends in aerosols. Graphical evaluation tools such as time series plots, scatter plots, quantile-quantile plots, spatial error plots, soccer plots, and bugle plots will be used.
2. A quantitative approach using statistical measures of agreement between modeled and observed aerosols, including statistics including correlation (R), coefficient of determination (R^2), normalized mean square error (NMSE), bias (FB), and the fraction of data where predictions are within a factor of two of observations (FAC2) (Chang and Hanna, 2004).

Formulas for the quantitative measures of agreement include:

$$R = \frac{\overline{(C_o - \overline{C_o})(C_p - \overline{C_p})}}{\sigma_{C_p}\sigma_{C_o}} \qquad \text{Equation 1}$$

$$NMSE = \frac{\overline{(C_o - C_p)^2}}{\overline{C_p}\,\overline{C_o}} \qquad \text{Equation 2}$$

$$FB = \frac{(\overline{C_o} - \overline{C_p})}{0.5(\overline{C_p} + \overline{C_o})} \qquad \text{Equation 3}$$

FAC2= fraction of data that satisfy

$$0.5 \leq \frac{C_p}{C_o} \leq 2.0 \qquad \text{Equation 4}$$

where:

C_p: model prediction,
C_o: satellite observations,
$\bar{C}$: mean of data, and
σ_c: standard deviation of the data

Due to a variety of sources of uncertainty, such as input meteorology or error in satellite retrievals, observations and model results may show substantial divergence. Generally, an air quality dispersion model can be judged to have performed well if the modeled concentrations agree with surface measurements such that the FAC2 is greater than 50%, the relative mean bias is with about 30% or less, and the normalized mean square error is less than a factor of three (Chang and Hanna, 2004). In this analysis, performance measured may be somewhat lower due to the additional uncertainty introduced by the use of satellite observations rather than surface measurements.

8.0 Model Documentation

Descriptions of the FINN 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. McDonald-Buller or her designee 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 Mr. Pavlovic 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: Friday, August 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 required FINN data inputs, the FINN preprocessor code, IDL FINN code and ancillary files, instructions for model installation and use, emissions estimates for all study years, CAMx outputs for the available episode years, and results of the comparisons with the MAIAC AOD product 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. The draft and final project reports will describe 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

Al-Saadi, J., A. Soja, R.B. Pierce, J. Szykman, C. Wiedinmyer, L. Emmons, S. Kondragunta, X. Zhang, C. Kittaka, T. Schaack, K. Bowman, 2008, Evaluation of near real-time biomass burning emissions estimates constrained by satellite active fire detections. *Journal of Applied Remote Sensing*, v2, 021504.

Chang, J. and S. Hanna, 2004, Air quality model performance evaluation. *Meteorology and Atmospheric Physics*, 87, 167–196, https://doi.org/10.1007/s00703-003-0070-7.

de Foy, B., Burton, S. P., Ferrare, R. A., Hostetler, C. A., Hair, J. W., Wiedinmyer, C., and Molina, L. T., 2011, Aerosol plume transport and transformation in high spectral resolution lidar measurements and WRF-Flexpart simulations during the MILAGRO Field Campaign, *Atmospheric Chemistry and Physics*, 11, 3543-3563.

Estes, M, personal communication with E. McDonald-Buller, May 3, 2018.

Ito, A., Penner, J. E., 2004, Global estimates of biomass burning emissions based on satellite imagery for the year 2000, *Journal of Geophysical Research*, 109, D14S05.

Kalnay, E., M. Kanamitsu, and W. Baker (1990), Global Numerical Weather Prediction at the National Meteorological Center. *Bulletin of the American Meteorological Society*, 71, 1410–1428, https://doi.org/10.1175/1520-0477(1990)071<1410:GNWPAT>2.0.CO;2

Kumar, R., Naja, M., Pfister, G. G., Barth, M. C., Wiedinmyer, C., and Brasseur, G. P., 2012, Simulations over South Asia using the Weather Research and Forecasting model with chemistry (WRF-Chem): chemistry evaluation and initial results, *Geoscientific Model Development*, 5, 619-648.

Larkin, N.K., S. M. Raffuse, T.M. Strand, 2014, Wildland fire emissions, carbon, and climate: U.S. emissions inventories, *Forest Ecology and Management*, 317, 61–69

Lin, M., A.M. Fiore, L.W. Horowitz, O.R. Cooper, V. Naik, J. Holloway, B. J. Johnson, A.M. Middlebrook, S.J. Oltmans, I.B. Pollack, T.B. Ryerson, J.X. Warner, C. Wiedinmyer, J. Wilson, B. Wyman, 2012, Transport of Asian ozone pollution into surface air over the western United States in spring. *Journal of Geophysical Research*, 117, doi:10.1029/2011JD016961.

McDonald-Buller, E., Y. Kimura, C. Wiedinmyer, C. Emery, 2013, The effects of uncertainties in fire emission estimates on predictions of Texas air quality, Submitted to the Texas Air Quality Research Program (Project #12-018), http://aqrp.ceer.utexas.edu/.

McDonald-Buller, E., Y. Kimura, C. Wiedinmyer, C. Emery, Z. Liu, and G. Yarwood, 2015, Targeted improvements in the Fire INventory from NCAR (FINN) model for Texas air quality planning, Submitted to the Texas Air Quality Research Program (Project #14-011), http://aqrp.ceer.utexas.edu/

McGaughey, G., Y. Kimura, E. McDonald-Buller, Replication of the TCEQ Photochemical Modeling Episode for May – September 2012 including a Performance Evaluation for Ozone in the Victoria Area, Prepared for the City of Victoria, Grant 582-16-60188, Task 2: Modeling and Assessment of Local Control Strategies, October 12, 2017.

Nuryanto, D.E., 2015, Simulation of Forest Fires Smoke Using WRF-Chem Model with FINN Fire Emissions in Sumatera, Procedia Environmental Sciences, 24, 65-69.

Paton-Walsh, C., L.K. Emmons, C. Wiedinmyer, 2012, Australia's Black Saturday fires - comparison of techniques for estimating emissions from vegetation fires. *Atmospheric Environment*, 60, 262-270.

Pereira, G., R. Siqueira, N. E. Rosário, K. L. Longo, S. R. Freitas, F. S. Cardozo, J. W. Kaiser, M. J. Wooster, 2016, Assessment of fire emission inventories during the South American Biomass Burning Analysis (SAMBBA) experiment, *Atmospheric Chemistry and Physics*, 16, 6961–6975.

Pfister, G. G., Avise, J., Wiedinmyer, C., Edwards, D. P., Emmons, L. K., Diskin, G. D., Podolske, J., and Wisthaler, A, 2011, CO source contribution analysis for California during ARCTAS-CARB, *Atmospheric Chemistry and Physics*, 11, 7515-7532.

Pitchford , M., W. Malm, B. Schichtel, N. Kumar, D. Lowenthal, J. Hand. 2007. Revised Algorithm for Estimating Light Extinction from IMPROVE Particle Speciation Data. *Journal of the Air & Waste Management Association*, 57(11), pp. 1326-1336.

Popescu, S. C., Stukey, J., Mutlu, M., Zhao, K., Sheridan, R., Ku, N. W., 2011, Expansion of Texas Land Use/Land Cover through Class Crosswalking and Lidar Parameterization of Arboreal Vegetation Secondary Investigators. Retrieved June 8, 2015 from https://www.tceq.texas.gov/assets/public/implementation/air/am/contracts/reports/oth/5820564593FY0925-20110419-tamu-expension_tx_lulc_arboreal_vegetation.pdf.

Pouliot, G., R. Gilliam, B. Eder, I. McDowell, J. Wilkins, T. Pierce, 2017, Evaluating the Wildfire Emission estimates in an Air Quality Simulation of the 2016 Southeastern United States Wildfires, International Emissions Inventory Conference, Baltimore, Maryland, August 18, 2017.

Ramboll, http://www.camx.com, 2018.

Shi, Y., T. Matsunaga, M. Saito, Y. Yamaguchi, X. Chen, 2015, Comparison of global inventories of CO2 emissions from biomass burning during 2002–2011 derived from multiple satellite products, Environmental Pollution, 206, 479-487.

Wang, Y., R. Talbot, 2017, High background ozone events in the Houston-Galveston-Brazoria Area: Causes, effects, and case studies of Central American fires, Submitted to the Texas Air Quality Research Program (Project #16-008) http://aqrp.ceer.utexas.edu/.

Wiedinmyer, C., S. K. Akagi, R. J. Yokelson, L. K. Emmons, J. A. Al-Saadi, J. J. Orlando, A. J. Soja (2011), The Fire INventory from NCAR (FINN): a high resolution global model to estimate the emissions from open burning, *Geoscientific Model Development*, 4(3), 625-641.