Scope of Work For

Project 14-016
Improved Land Cover and Emission Factor Inputs for Estimating Biogenic Isoprene and Monoterpene Emissions for Texas Air Quality Simulations

Prepared for

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

by

Greg Yarwood
ENVIRON International Corporation

Alex Guenther
Pacific Northwest National Laboratories

Joost de Gouw and David Parrish
NOAA Earth System Research Laboratory

May 29, 2014

CONTENTS

1.0 STATEMENT OF WORK 1

1.1 Introduction 1

1.2 Background 2

1.3 Overview of Approach 2

1.4 Task Descriptions 3

1.4.1 Task 1: Estimation of Terpenoid Emission Fluxes from Aircraft Data (PNNL and NOAA) 3

1.4.2 Task 2: Development of High Resolution Land Cover Data for MEGAN Modeling in Texas and the Southeastern U.S. (PNNL) 5

1.4.3 Task 3: Emission Factor Database Development (PNNL) 6

1.4.4 Task 4: Development of MEGAN Biogenic Emission Inventories and Inventory Evaluation using Regional Photochemical Modeling (ENVIRON) 6

1.4.5 Task 5: Project Management (ENVIRON), Reporting and Presentation (PNNL, NOAA, and ENVIRON) 7

2.0 TIMELINE 9

3.0 PROJECT ORGANIZATION AND RESPONSIBILITIES 12

4.0 REFERENCES 13

1.0 STATEMENT OF WORK

1.1 Introduction

This document provides the work plan for the Texas Air Quality Research Program (AQRP) Project 14-016 “Improved Land Cover and Emission Factor Inputs for Estimating Biogenic Isoprene and Monoterpene Emissions for Texas Air Quality Simulations”. The project Co-Principal Investigators (Co-PIs) are Dr. Greg Yarwood of ENVIRON, Dr. Alex Guenther of Pacific Northwest National Laboratory (PNNL), and Dr. David Parrish and Dr. Joost de Gouw of NOAA’s Earth System Research Laboratory. The AQRP project manager is Dr. Elena McDonald-Buller at the University of Texas, Austin. The project liaison for the Texas Commission on Environmental Quality (TCEQ) is Mr. Mark Estes.

The overall goal of this project is to improve quantitative estimates of terpenoid (isoprene and monoterpene) emissions from Texas and the Southeast United States. An opportunity exists to substantially improve these estimates using recent airborne measurements. During the Southeast Atmosphere Study (SAS) 2013 summer field campaign, the NCAR C-130 aircraft and the NOAA P-3 aircraft measured terpenoid (isoprene and total monoterpenes) concentrations over Texas and surrounding states using proton transfer reaction spectrometer (PTR-MS) systems and speciated monoterpenes using gas chromatograph mass spectrometry (GC-MS) (in-situ fast-response GC-MS on the NCAR C-130 and canister sampling with laboratory GC-MS analysis for the NOAA P-3). Both aircraft have fast response vertical wind measurements suitable for applying the eddy covariance (EC) technique which provides a direct measurement of fluxes as described below. Approximately a third of the NCAR C-130 flights were designed to optimize terpenoid EC flux measurements. Measurement protocols and flight patterns of other NCAR C-130 flights and some NOAA flights were not specifically designed for terpenoid EC flux measurements, but we will investigate the possibility of estimating EC fluxes with these measurements. In addition, the availability of direct EC flux measurements and estimates of terpenoid lifetimes (based on measured ozone and OH concentrations) provide an opportunity to examine the utility of using concentration measurements (both mean values and variance measured with fast response PTR-MS) to estimate fluxes in different NOx regimes. This has the potential to greatly expand the observations available for relating terpenoid emissions to land cover distributions because of the large database of NOAA P-3 aircraft measurements. These emission estimates will be used to evaluate and improve the Model of Emissions of Gases and Aerosols from Nature (MEGAN) (Guenther et al., 2012). In addition, high-resolution land cover inputs for MEGAN will be generated and described in detail. The new and old land cover and emission factor inputs will be used to examine the sensitivity of emission and air quality model estimates to uncertainties in these inputs.

The primary outputs of the proposed research will be improved land cover and emission factor inputs for the MEGAN biogenic emission model. Outcomes will include approaches for quantifying VOC emissions and relating emissions to land cover distributions in order to reduce uncertainties in emissions. The overall benefit of this project will be more accurate VOC emission estimates that can be used in Texas air quality simulations that are critical for scientific understanding and the development of regulatory control strategies that will enhance efforts to improve and maintain clean air.

1.2 Background

The exchange of gases and aerosols between the earth's surface and the atmosphere is an important factor in determining the atmospheric composition and regional air quality. Accurate quantification and simulation of these fluxes is a necessary step towards developing air pollution control strategies and for attributing observed changes to their causes. Emissions of some compounds, including sulfur dioxide and nitric oxide emitted from electric utilities, are either directly measured or can be estimated with reasonable confidence in the U.S. In contrast, large uncertainties are associated with area source emission estimates including biogenic terpenoid emissions. Current flux estimates are typically based on a few indirect measurements that may not be representative and so could be of limited use for informing regional air quality models. The need for accurate emission estimates requires a transformation of the approaches used to characterize the emissions needed as inputs for air quality models.

1.3 Overview of Approach

We will use NCAR C-130 and NOAA P-3 aircraft observations from the 2013 SAS study and NOAA P-3 aircraft observations from the 2006 Texas Air Quality Study to assess and reduce uncertainties associated with the Model of Emissions of Gases and Aerosol from Nature version 2.1 (MEGANv2.1) (Guenther et al. 2012), a widely used biogenic emissions model. In addition, we will improve the land cover and emission factor driving variables that are considered the major uncertainties associated with biogenic VOC emission estimates (Guenther 2013).

Our specific objectives include:

1. Use the eddy covariance technique to directly quantify terpenoid emission fluxes for all suitable NCAR C-130 observations during the 2013 SAS study.
2. Using the relationship between terpenoid fluxes and concentrations derived from the NCAR C-130 data, estimate terpenoid fluxes in the southeastern U.S. and Texas using NOAA P-3 aircraft observations from 2013 SAS research program and the 2006 Texas Air Quality Study.
3. Develop high-resolution (30-m) land cover inputs for MEGAN 2.1 (Leaf Area Index, plant functional type and emission factors) for Texas and southeastern U.S. using best available satellite imagery and ground measurements. Provide clear description of methods to ensure reproducibility and future modifications.
4. Use aircraft flux measurements and improved landcover data to a) determine average emission factors for various emission types and investigate variability within emission types, b) identify land cover types with unexpectedly high or low emissions that should be targeted by future studies, c) investigate relationships between foliage density (satellite based Leaf Area Index) and emissions across a given emission type, d) revise emission factors as needed based on aircraft observations.

5. Develop MEGAN biogenic emissions for regional photochemical modeling using updated land cover and emission factors for Texas and the Southeastern U.S. and compare with MEGAN emissions developed using default land cover and emission factors. Evaluate both MEGAN inventories against aircraft flux data.
6. Perform air quality modeling with the MEGAN emission inventory prepared with default inputs and the improved MEGAN emission inventories and evaluate modeled concentrations against measurements in high and low isoprene and NOx regimes.
7. Prepare recommendation as to whether MEGAN inputs developed in 3 and 4 above should be used in future TCEQ modeling.

1.4 Task Descriptions

1.4.1 Task 1: Estimation of Terpenoid Emission Fluxes from Aircraft Data (PNNL and NOAA)

Airborne Eddy Covariance Measurements of Biogenic VOC Emissions

The preferred micrometeorological method for measuring trace gas fluxes in the turbulent boundary layer is eddy covariance. This approach is a direct measurement of the fluctuating vertical wind velocity and trace gas concentration. The flux is determined from the mean covariance between vertical wind velocity (w) and concentration (c) fluctuations. The successful demonstration of airborne eddy covariance techniques for measuring fluxes of anthropogenic VOC (Karl et al., 2009), biogenic VOC (Karl et al., 2013), NO (Hasel et al., 2005) and ozone (Lenschow et al., 1980) provides a promising approach for characterizing chemical fluxes on scales relevant for regional air quality modeling. The major components of an airborne eddy covariance flux system are 1) a system that measures vertical wind speed with a fast (typically <100 ms) response time, 2) an instrument that measures the targeted atmospheric constituent with a fast response time, and 3) a system to receive and store the data (e.g., datalogger or computer). The main challenge of the EC technique is the requirement of sampling rates on the order of 10 Hz (<100 ms response times). This is especially the case with a quadrupole PTR-MS because in order to sample more than one mass, the detector does not continuously monitor a given compound. However, Lenschow et al. (1994) demonstrated that this can be accomplished by the introduction of disjunct sampling. The random and systematic error for disjunct EC flux measurements relative to EC flux measurements can be obtained following Lenschow et al. (1994) and is typically <5%. Both the C-130 and P-3 have the components needed for EC measurements but the P-3 was used to look at a large number of masses and so

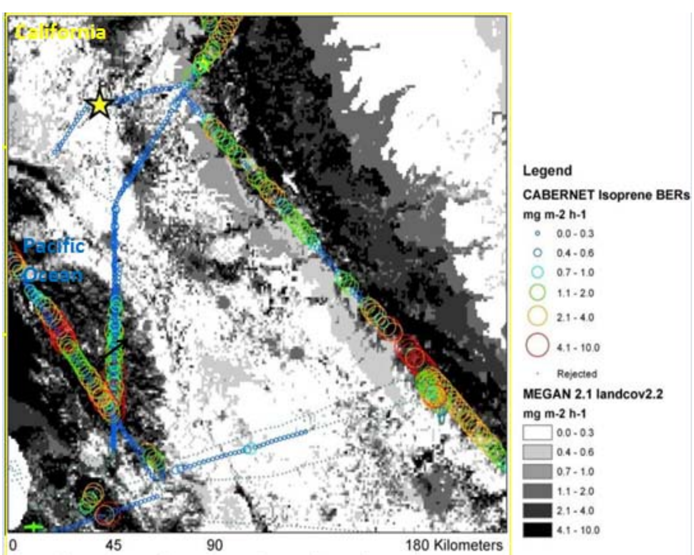

Figure 1. Example of isoprene emission factors estimated using aircraft eddy covariance flux measurements (Misztal et al. in preparation). The spatial resolution of each flux measurement is ~2 km. MEGAN model estimates are shown for comparison.

this disjunct data may not be suitable for calculating EC fluxes. We will determine if this is an acceptable error by using the C-130 data to compare the original signal with one that results if a digital filter is used to the P-3 sampling routine.

Spatially resolved eddy covariance fluxes will be obtained from wavelet analysis (Mauder et al., 2007, Karl et al., 2009, Karl et al., 2013) along flight tracks flown in the mixed layer. As shown in Figure 1, the horizontal spatial resolution of these measurements will be about 2 km (Karl et al., 2009; Misztal et al., in preparation), which provides sufficient resolution for quantifying fluxes even in heterogeneous landscapes such as oak savannas.

Karl et al. (2013) recently showed that vertical profiles of isoprene fluxes in the daytime mixed layer can be used to estimate OH concentrations. The vertical divergence in measured isoprene flux is directly related to OH concentration. These observations provide an opportunity for assessing the relationships between fluxes and concentrations under different chemical regimes (e.g., NOx levels). Figure 2A shows the flight plan used for vertical profiling and Figure 2B illustrates an example of vertical flux profiling over a site in east Texas. Preliminary observations shown in Figure 2C demonstrate that there are detectable fluxes of isoprene and total monoterpenes.

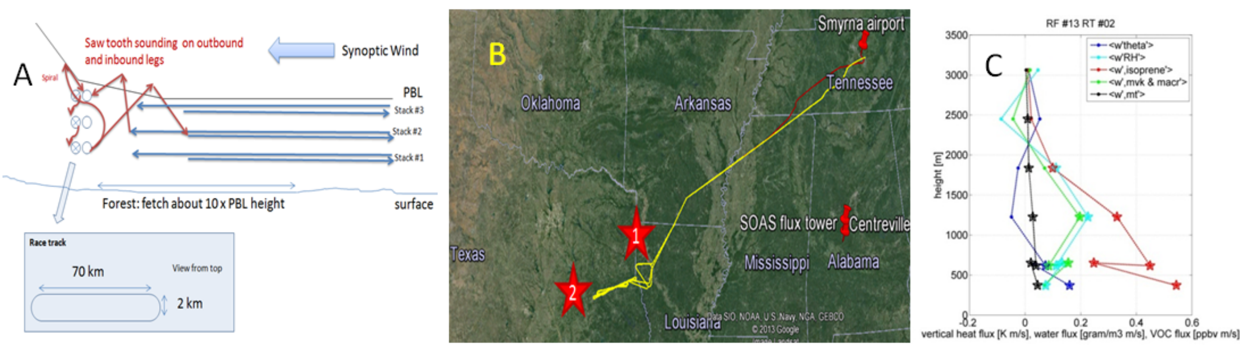

Figure 2. Panel A: Flux profiling flight pattern with stacked racetrack patterns (3 to 5 levels) with a sawtooth sounding on the inbound and outbound legs. Panel B: Example of C-130 flight track with stacked racetracks over Texas. Panel C: Vertical profiles of fluxes of water (w'RH'), sensible heat (w'theta'), isoprene (w'isoprene'), total monoterpenes (w'mt'), and isoprene oxidation products (w'mvk&macr') over Texas site #2 shown in panel B.

NCAR C-130 Aircraft VOC Measurements

Fast response VOC measurements were made on the NCAR C-130 using a custom-designed airborne PTR-MS developed at NCAR using some components manufactured by IONICON Analytik (Innsbruck, Austria) and described by Karl et al. (2013). During flights focused on BVOC fluxes, a limited suite of VOC measurements were targeted in order to increase sensitivity. Measurements typically included isoprene, total terpene, methanol, and methacrolein plus methyl vinyl ketone). A fast GC-MS measured isoprene, methyl butenol, a-pinene and other speciated monoterpenes, methanol, and many other VOC with a time resolution of about 5 minutes.

NOAA P-3 Aircraft VOC Measurements

Onboard the NOAA P-3, measurements of VOCs were made both by a custom-built PTR-MS instrument as well as from GC-MS analyses of whole air samples. While the PTR-MS measurements onboard the C-130 were focused on determining terpenoid fluxes, the PTR-MS measurements onboard the P-3 included a much broader suite of compounds to characterize anthropogenic, biogenic and biomass burning emissions as well as their oxidation products. The P-3 measurements by themselves are therefore less suitable for direct EC determination of terpenoid fluxes. We will use observations from the C-130 to assess the accuracy of flux estimates using the NOAA P-3 data. The C-130 data will be subsampled to simulate the P-3 data, which has less data for each mass to enable sampling of a greater range of masses, in order to determine the impact on the accuracy of the fluxes. We will examine potential approaches for correcting the P-3 flux estimates and to estimate the higher level of uncertainty. This will be applied to the P-3 measurements during the 2006 Texas Air Quality Study as well as the 2013 Southeast Atmosphere Study, to give information about biogenic fluxes over large parts of Texas and the Southeastern U.S.

Task 1 Deliverables:

A data file will be provided that includes time and location (latitude, longitude) and isoprene and total monoterpene fluxes estimated using eddy covariance for all flights suitable for eddy covariance measurements.

A written description of the approach used to estimate fluxes will be provided.

Monthly and quarterly progress reports documenting progress and technical issues.

1.4.2 Task 2: Development of High Resolution Land Cover Data for MEGAN Modeling in Texas and the Southeastern U.S. (PNNL)

MEGANv2.1 land cover driving variables include 1) Leaf Area Index of vegetation-covered fraction of each grid cell (LAIv), 2) Fraction of each grid cell covered by each plant functional type (PFT) (e.g., broadleaf trees, shrubs), and 3) Emission factor for isoprene and monoterpene categories for each grid cell (EF).

LAIv is an input for the MEGANv2.1 canopy environment model that simulates increases in terpenoid emissions with increasing foliage. Emissions of some compounds, such as isoprene, are emitted primarily from sunlit leaves and so emissions become saturated at high LAI levels. In addition, changes in LAIv are used as inputs to the MEGANv2.1 model to estimate leaf age which is also a driver of biogenic VOC emission variations. A database of LAIv values at 1-km spatial resolution and 8-day temporal resolution will be compiled for April to September of 2013 using MODIS satellite data. A detailed description of the approach will be provided in the final report. Python scripts which can be used to acquire additional LAIv data will be provided.

Task 2 Deliverables: Monthly and quarterly progress reports documenting progress and technical issues. Python scripts which can be used to acquire additional LAIv data.

1.4.3 Task 3: Emission Factor Database Development (PNNL)

MEGANv2.1 uses a plant functional type (PFT) scheme with 16 categories. We will develop a high-resolution (30-m) PFT database for Texas and the surrounding region by integrating the existing 30-m MEGANv2.1 PFT database and landcover data currently used by TCEQ for biogenic emission modeling. A detailed description of the approach will be included in the final report and python scripts which show each step in the process will be also provided.

Isoprene and monoterpene emission factor maps for Texas and the surrounding region will be calculated by modifying the existing 30-m MEGANv2.1 EF maps using the aircraft data described above, where available. Average values based on the aircraft flux measurements will be used to calibrate the landcover scale emission factors for PFT types within different ecoregions.

Task 3 Deliverables: Monthly and quarterly progress reports documenting progress and technical issues. Python scripts used in development of PFT database. Article in peer-reviewed journal on the results of Task 3.

1.4.4 Task 4: Development of MEGAN Biogenic Emission Inventories and Inventory Evaluation using Regional Photochemical Modeling (ENVIRON)

The objective of Task 4 is to prepare model-ready MEGAN biogenic emissions based on improved landcover and emission factor databases developed in Tasks 1-3 and to evaluate the biogenic emission inventories using a photochemical grid model. Two or more emission inventories will be developed for this project. The first inventory is a base-case biogenic emission inventory, which will be developed using the MEGAN default landcover database and default emission factors. Then, one or more improved biogenic emission inventories will be derived from the new high-resolution landcover database and Texas and Southeastern U.S. emission factor database developed under Tasks 1-3. The default and improved biogenic emission inventories will be compared against aircraft flux data and then evaluated using a photochemical model.

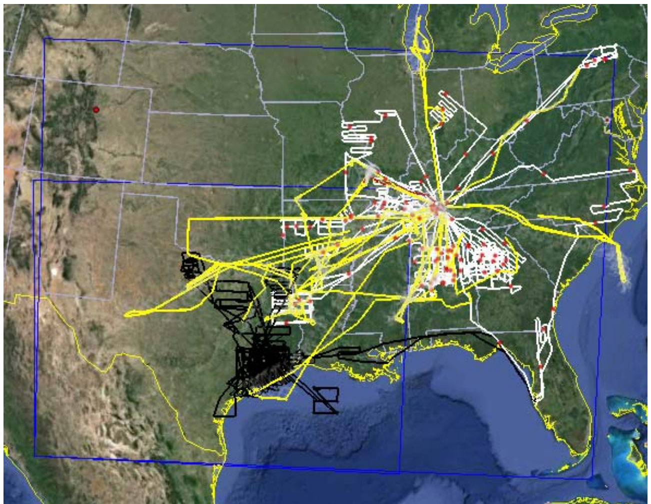

Figure 3. Proposed 12 km modeling grid and aircraft flight paths. Aircraft flight paths: SAS C-130 (yellow), SAS P-3 (white), and TEXAQS 2006 (black). TCEQ 12 km grid extent (smaller blue domain), and expanded 12 km grid (larger blue domain).

The Comprehensive Air quality Model with Extensions v6.1 (CAMx; ENVIRON, 2013) will be used to model fluxes and atmospheric concentrations of BVOCs. The modeling platform is adapted from a 2013 Texas ozone forecast modeling application developed by ENVIRON for the TCEQ (Johnson et al., 2013). The modeling domain consists of a 36 km continental-scale grid and a nested 12 km grid. The regional 12 km grid used in the forecasting project to cover Texas and surrounding states will be expanded so that it encompasses nearly all of the overland flight tracks of the C-130 and P-3 made during June-July 2013 (Figure 3). CAMx will be run from June 1-July 15, 2013 to simulate the period when C-130 and P-3 aircraft data are available. CAMx will be run with Revision 2 of the CB6 chemical mechanism (CB6r2) (Yarwood et al., 2013). The Weather Research and Forecasting (WRF) (Skamarock et al., 2008) meteorological model will be used in hindcast mode to develop the June-July 2013 meteorological fields required for input to CAMx.

For both the base-case MEGAN emission inventory using default inputs and the improved MEGAN emission inventories, we will compare modeled and measured isoprene fluxes along the aircraft flight tracks. We will evaluate CAMx modeled concentrations against aircraft measurements for the following species: OH, isoprene, 1st generation isoprene products, isoprene nitrates, terpenes, methanol, acetone, ozone and NOx. Model performance will be stratified with respect to high and low isoprene and NOx regimes. Modeled NOx and ozone will be also evaluated against surface measurements. Changes in the CAMx chemical mechanism will be tested if the model performance evaluation indicates that this is needed.

<u>Task 4 Deliverables</u>: Monthly and quarterly progress reports documenting progress and technical issues and all MEGAN inputs and modeling files including all models and scripts used to develop MEGAN land cover and emission factor databases, CAMx modeling, and air quality evaluation.

1.4.5 Task 5: Project Management (ENVIRON), Reporting and Presentation (PNNL, NOAA, and ENVIRON)

A project report will be developed during the course of the work that fully documents all activities performed for the study, summarizing project findings and recommendations for future research, and emphasizing those findings of interest to modelers and planners at TCEQ. A draft will be submitted to AQRP and the TCEQ for review by April 30, 2015. A final report addressing review comments received on the draft will be subsequently submitted to AQRP by

June 30, 2015. The project approach and results will also be summarized in presentation format for use at AQRP meetings. The final project report will be delivered electronically and will meet State of Texas Accessibility requirements in 1 TAC 213. Electronic copies of all text, graphic, spreadsheet files and models used in the preparation of any documents related to the project reports, to document results and conclusions (e.g. sampling data, work files, etc.) or developed as work products under this Contract, shall be supplied the conclusion of the project. All copies of deliverable documents and other work products will be provided in Microsoft Word and PDF formats.

Task 5 Deliverables: Draft and final project reports, and summary presentation to AQRP in Austin, TX.

2.0 TIMELINE

The project schedule by task is presented below with associated deliverables. The project start date is assumed to be May 1, 2014. Technical work will not begin until final funding authorization by TCEQ and AQRP. The entire project will be completed by June 30, 2015.

Table 2. Schedule of project activities.

Task	2014									2015							
	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Aug	Nov
Task 1: Emission Flux Estimation		→	→	→	→												
WP/QAPP		●															
Executive Summary		#															
Task 2: Land Cover Development		→	→	→	→												
Task 3: Emission Factor Development						→	→								X		
Task 4: Emission Inventories and CAMx Modeling								→	→								
Task 5: Reporting											→	→	→				
Draft Report														●			
Final Report															●		
Project Presentation																●	
Progress Reports			■▲	▲	▲	■▲	▲	▲	■▲	▲	▲	■▲	▲	▲	■▲		■ ■

Project Report Material	●
Monthly Progress Report	▲
Quarterly Progress Report	■
Journal Article	X
Executive Summary	#

2.3 Deliverables

A description of the specific reports to be submitted and their due dates are outlined below. All reports will be written in third person and will follow the State of Texas accessibility requirements as set forth by the Texas State Department of Information Resources. Report templates and accessibility guidelines found on the AQRP website at http://aqrp.ceer.utexas.edu/ will be followed.

Executive Summary
At the beginning of the project, an Executive Summary will be submitted to the Project Manager for use on the AQRP website. The Executive Summary will provide a brief description of the planned project activities, and will be written for a non-technical audience.
Due Date: Friday, May 30, 2014

Quarterly Reports
The Quarterly Report will provide a summary of the project status for each reporting period. It will be submitted to the Project Manager as a Word doc file. It will not exceed 2 pages and will be text only. No cover page will be attached.

Due Dates:

Report	Period Covered	Due Date
Quarterly Report #1	June, July, August 2014	Friday, August 30, 2014
Quarterly Report #2	September, October, November 2014	Monday, December 1, 2014
Quarterly Report #3	December 2015, January & February 2015	Friday, February 27, 2015
Quarterly Report #4	March, April, May 2015	Friday, May 29, 2015
Quarterly Report #5	June, July, August 2015	Monday, August 31, 2015
Quarterly Report #6	September, October, November 2015	Monday, November 30, 2015

Technical Reports
Technical Reports will be submitted monthly to the Project Manager and TCEQ Liaison as a Word doc using the AQRP FY14-15 MTR Template found on the AQRP website.

Due Dates:

Report	Period Covered	Due Date
Technical Report #1	Project Start – June 30, 2014	Tuesday, July 8, 2014
Technical Report #2	July 1 - 31, 2014	Friday, August 8, 2014
Technical Report #3	August 1 - 31, 2014	Monday, September 8, 2014
Technical Report #4	September 1 - 30, 2014	Wednesday, October 8, 2014
Technical Report #5	October 1 - 31, 2014	Monday, November 10, 2014
Technical Report #6	November 1 - 30 2014	Monday, December 8, 2014
Technical Report #7	December 1 - 31, 2014	Thursday, January 8, 2015
Technical Report #8	January 1 - 31, 2015	Monday, February 9, 2015
Technical Report #9	February 1 - 28, 2015	Monday, March 9, 2015
Technical Report #10	March 1 - 31, 2015	Wednesday, April 8, 2015
Technical Report #11	April 1 - 28, 2015	Friday, May 8, 2015
Technical Report #12	May 1 - 31, 2015	Monday, June 8, 2015

Financial Status Reports

Financial Status Reports will be submitted monthly to the AQRP Grant Manager (Maria Stanzione) by each institution on the project using the AQRP FY14-15 FSR Template found on the AQRP website.

Due Dates:

Report	Period Covered	Due Date
FSR #1	Project Start – June 30, 2014	Tuesday, July 15, 2014
FSR #2	July 1 - 31, 2014	Friday, August 15, 2014
FSR #3	August 1 - 31, 2014	Monday, September 15, 2014
FSR #4	September 1 - 30, 2014	Wednesday, October 15, 2014
FSR #5	October 1 - 31, 2014	Monday, November 17, 2014
FSR #6	November 1 - 30 2014	Monday, December 15, 2014
FSR #7	December 1 - 31, 2014	Thursday, January 15, 2015
FSR #8	January 1 - 31, 2015	Monday, February 16, 2015
FSR #9	February 1 - 28, 2015	Monday, March 16, 2015
FSR #10	March 1 - 31, 2015	Wednesday, April 15, 2015
FSR #11	April 1 - 28, 2015	Friday, May 15, 2015
FSR #12	May 1 - 31, 2015	Monday, June 15, 2015
FSR #13	June 1 - 30, 2015	Wednesday, July 15, 2015
FSR #14	Final FSR	Wednesday, August 15, 2015

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.

Due Date: Thursday, April 30, 2015

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.

Due Date: Tuesday, June 30, 2015

Project Data

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

AQRP Workshop

A representative from the project will present at the AQRP Workshop in June 2015.

3.0 PROJECT ORGANIZATION AND RESPONSIBILITIES

This project is being conducted by ENVIRON, PNNL and NOAA under a grant from the Texas Air Quality Research Program. The project Co-Principal Investigators (PIs) are Dr. Greg Yarwood of ENVIRON, Dr. Alex Guenther of Pacific Northwest National Laboratory (PNNL), and Dr. David Parrish and Dr. Joost de Gouw of NOAA's Earth System Research Laboratory. The Co-PIs will assume overall responsibility for the research and associated quality assurance. Dr. Guenther and Dr. de Gouw will lead the estimation of terpenoid emission fluxes from aircraft data. Dr. Guenther will direct the development of high resolution land cover data for biogenic emissions modeling in Texas and the Southeastern U.S. as well as the development of an emission factor database. Dr. Yarwood will lead development of biogenic emission inventories and will evaluate the inventory using a regional photochemical model. All Principal Investigators will contribute to the final report.

The project will be overseen by AQRP Project Manager Dr. Elena McDonald-Buller and TCEQ Project Liaison Mr. Mark Estes. The scientists working on this project and their specific responsibilities are listed in the Table below.

Participant	Project Responsibility
Dr. Greg Yarwood (ENVIRON)	Co-Principal Investigator: Project oversight; responsible for development of biogenic emission inventories, photochemical modeling and reporting
Dr. Alex Guenther (PNNL)	Co-Principal Investigator: Lead researcher; responsible for estimation of terpenoid emission fluxes from aircraft data, development of high resolution land cover data for biogenic emissions modeling, emission factor database, and contributions to final report
Dr. David Parrish (NOAA)	Co-Principal Investigator: Responsible for scientific oversight and compliance with reporting requirements
Dr. Joost de Gouw (NOAA)	Co-Principal Investigator: Lead NOAA researcher; responsible for estimation of terpenoid emission fluxes from aircraft data and contributions to final report
Dr. Susan Kemball-Cook (ENVIRON)	Lead day-to-day modeling activities and evaluation of biogenic and air quality model results against aircraft and surface data and carry out project management and report preparation
Dr. Tanarit Sakulyanontvittaya (ENVIRON)	Conduct WRF, CAMx, and MEGAN modeling and evaluation of biogenic and air quality model results
Mr. Jeremiah Johnson (ENVIRON)	Assist Dr. Sakulyanontvittaya with WRF and CAMx modeling

4.0 REFERENCES

ENVIRON, 2013. The Comprehensive Air quality Model with extensions (CAMx) homepage, http://www.CAMx.com.

Guenther, A. (2013), Biological and Chemical Diversity of Biogenic Volatile Organic Emissions into the Atmosphere, ISRN Atmospheric Sciences, 2013(doi: 10.1155/2013/786290).

Guenther, A. B., X. Jiang, C. L. Heald, T. Sakulyanontvittaya, T. Duhl, L. K. Emmons, and X. Wang (2012), The Model of Emissions of Gases and Aerosols from Nature version 2.1 (MEGAN2.1): an extended and updated framework for modeling biogenic emissions, Geosci. Model Dev., 5(6), 1471-1492.

Hasel, M., C. Kottmeier, U. Corsmeier, and A. Wieser. 2005. Airborne measurements of turbulent trace gas fluxes and analysis of eddy structure in the convective boundary layer over complex terrain. Atmospheric Research 74 (1-4):381-402.

Hildebrandt-Ruiz, L. and G. Yarwood 2013. Interactions between Organic Aerosol and NOy: Influence on Oxidant Production. Final report for AQRP project 12-012.

Johnson, J., P. Karamchandani, G. Wilson, and G. Yarwood, 2013. TCEQ Ozone Forecasting System. Prepared for Mark Esters, TCEQ. November.

Karl, T., E. Apel, A. Hodzic, D. D. Riemer, D. R. Blake, and C. Wiedinmyer 2009. Emissions of volatile organic compounds inferred from airborne flux measurements over a megacity, Atmos. Chem. Phys., 9(1), 271-285.

Karl, T., P. K. Misztal, H. H. Jonsson, S. Shertz, A. H. Goldstein, and A. B. Guenther. 2013. Airborne flux measurements of BVOCs above Californian oak forests: Experimental investigation of surface and entrainment fluxes, OH densities and Dahmköhler numbers. J. Atmos. Sci., 70, 3277–3287.

Lenschow, D. H., J. Mann, and L. Kristensen. 1994. How Long Is Long Enough When Measuring Fluxes and Other Turbulence Statistics. Journal of Atmospheric and Oceanic Technology 11 (3):661-673.

Mauder, M., R. L. Desjardins, and I. MacPherson. 2007. Scale analysis of airborne flux measurements over heterogeneous terrain in a boreal ecosystem. Journal of Geophysical Research-Atmospheres 112 (D13).

Skamarock, W. C., J. B. Klemp, J. Dudhia, D. O. Gill, D. M. Barker, W. Wang, and J. G. Powers, 2008. A description of the Advanced Research WRF Version 3. NCAR Tech Notes-475+STR. http://www.mmm.ucar.edu/wrf/users/docs/arw_v3.pdf.