



Project Work Plan

Evaluating Surface Ozone Sensitivity to Emissions Changes in the Great Lakes Region

Prepared by:

Georgia Institute of Technology

Prepared for:

Lake Michigan Air Directors Consortium

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Project Manager:

Talat Odman

*School of Civil & Environmental Engineering
Georgia Institute of Technology
311 Ferst Drive, Atlanta, GA 30332-0512
odman@gatech.edu
Phone: 404-894-2783 Fax: 404-894-8266*

Senior Scientist:

Yongtao Hu

*School of Civil & Environmental Engineering
Georgia Institute of Technology
311 Ferst Drive, Atlanta, GA 30332-0512
yh29@mail.gatech.edu
Phone: 404-385-4558 Fax: 404-894-8266*

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Table of Contents

List of Acronymsii
Document Change Record.....iv
Section 1: Introduction..... 1-1
 1.1 KEY PERSONNEL..... 1-2
Section 2: Work Plan 2-1
 2.1 TECHNICAL APPROACH 2-2
 2.1.1 Task 1. Project Initialization and Modeling Protocol2-2
 2.1.2 Task 2: Sensitivity Modeling to Quantify Ozone Sensitivity in the LADCO Region.....2-5
 2.1.3 Task 3. Ozone Sensitivity Analysis and Interpretation.....2-9
 2.1.4 Task 4: Project Administration and Final Report2-11
 2.2 SCHEDULE OF DELIVERABLES 2-13
 2.3 STAFFING AND EFFORT 2-14
 2.4 PROJECT BUDGET 2-14
Section 3: References..... 3-1

List of Acronyms

AMET	Atmospheric Model Evaluation Tool
AQM	Air Quality Model
BC	Boundary Conditions
BEIS	Biogenic Emission Inventory System
CAMx	Comprehensive Air quality Model with extension
CB6	Carbon Bond—Version 6
CMAQ	Community Multiscale Air Quality
CTM	Chemistry-Transport Model
DDM	Decoupled Direct Method
DMS	Dimethyl Sulfide
EBI	Euler Backward Iterative (method)
EGU	Electrical Generating Unit
EPA	Environmental Protection Agency
GIT	Georgia Institute of Technology
HDDM	High-order DDM
IC	Initial Conditions
ID	Identification
I/O API	Input/Output Applications Programming Interface
LADCO	Lake Michigan Air Directors Consortium
LAMDA	Laboratory for Atmospheric Modeling and Data Analysis
MNB	Mean Normalized Bias
MNE	Mean Normalized Error
NAAQS	National Ambient Air Quality Standards
NASA	National Aeronautics and Space Administration
netCDF	network Common Data Format
NMOC	Non-Methane Organic Compounds
NH ₃	Ammonia
NO _x	Nitrogen Oxides
OSAT	Ozone Source Apportionment Technology
PACE	Partnership for an Advanced Computing Environment
PAMS	Photochemical Assessment Monitoring Stations
PAVE	Package for Analysis and Visualization of Environmental Data
PM	Particulate Matter
PM _{2.5}	PM with an aerodynamic diameter less than 2.5 microns.
PPM	Piecewise Parabolic Method
PSAT	PM Source Apportionment Technology
RFM	Reduced Form Model
QA	Quality Assurance
QC	Quality Control
RPO	Regional Planning Organization
RRF	Relative Reduction Factor
SEMAP	Southeastern Modeling Analysis and Planning
SIP	State Implementation Plan

Ozone Sensitivity in the Great Lakes Region: Project Work Plan

SLAMS	State and Local Air Monitoring Stations
SMOKE	Sparse Matrix Operator Kernel Emissions
STN	Speciated Trends Network
TOMS	Total Ozone Mapping Spectrometer
TUV	Total Ultraviolet
UCAR	University Corporation for Atmospheric Research
US	United States
VOC	Volatile Organic Compounds
WRF	Weather Research and Forecasting model

Document Change Record

Revision	Date	Remarks
1.0	August 10, 2020	Draft version for LADCO review
2.0	September 2, 2020	Final version

Section 1: Introduction

Ozone concentrations in the LADCO region have consistently violated the National Ambient Air Quality Standards (NAAQS) for ozone over the past decades. Emissions of the ozone precursors, nitrogen oxides (NO_x) and volatile organic compounds (VOC), have decreased significantly since the 1990s and have helped to decrease monitored ozone concentrations, but ambient ozone has not declined at nearly the same rate as the ozone precursor emissions. The US EPA designated several areas in the LADCO region as nonattainment for the 2015 ozone NAAQS.

To address the ozone nonattainment issues in the LADCO region, LADCO initiated a project “Evaluating Surface Ozone Sensitivity to Emissions Changes in the Great Lakes Region” in support of emissions mitigation planning in the region. To address the ozone sensitivity modeling and analysis needs of the project, Georgia Institute of Technology (Georgia Tech) formed a skilled team to perform the tasks of this project. A contract was signed on July 15, 2020 between LADCO and Georgia Tech with Dr. Talat Odman as the project manager.

The objective of this project is to quantify the surface ozone changes from reducing the emissions of NO_x or VOCs from different inventory sectors and further use those information to achieve the goal by identifying optimal ozone reduction strategies for key receptor areas in the LADCO region. The key to succeed in this study is to answer the following four questions:

1. How do ozone concentrations at a receptor change when total NO_x, VOC, or NO_x and VOC emissions are reduced along a spectrum of 10% to 100% reduction?
2. Expanding on Question 1, rather than looking at total NO_x, VOC, or NO_x and VOC emissions reductions, how do ozone concentrations at a receptor change when emissions are reduced from onroad mobile gasoline vehicles, onroad mobile diesel vehicles, nonroad mobile, volatile chemical products, other nonpoint, electricity generation point, or non-electricity point sources?
3. Which combination(s) of NO_x, VOC, and inventory sector has the largest impact (reduction) on peak ozone formation periods in each receptor area?
4. What are the periods in the diel within which sectorized emissions reductions have the largest impact on mitigating daily peak ozone concentrations during ozone exceedance days? In other words, emissions reductions from which sectors and when have the largest impact on mitigating ozone exceedances in each receptor?

In order to fully meet the LADCO’s goal set on this project and answer the above key questions, the project team will use a gridded, regional-scale air quality model, the Comprehensive Air Quality Model with Extensions (CAMx), equipped with the High-order Decoupled Direct Method (HDDM) tool to simulate the changes in ozone from reducing ozone precursor emissions in the LADCO region. Analysis of the changes in ozone concentrations will focus on counties in 2015 ozone NAAQS nonattainment and maintenance areas in the LADCO region. The project team will assemble meteorology and emissions data, configure models and develop ozone sensitivity modeling simulations, and analyze, distribute and document the modeling results, in collaboration with LADCO.

This document presents the work plan for the project. Its intent is to specify the methods and approaches that will be used in the project. After a brief introduction of the key personnel in leading roles, the technical approach will be summarized for each task in Section 2. After specifying the task leader, the objective of the task is stated verbatim from the Contract. Our approach to each task is specified along with the methods to be used and the deliverables are listed along with their schedule. The staff assignments and the projected level of effort are described and the total cost of the task is given. The document ends with an overall schedule showing all the tasks together and a cost table broken down in categories at sub-task level for each task.

1.1 KEY PERSONNEL

Dr. Talat Odman, the Project Manager, is Principal Research Engineer in the School of Civil and Environmental Engineering at Georgia Institute of Technology. Dr. Odman has over 30 years of full-time research experience in the development and application of dispersion and air quality models. He led numerous projects involving development and evaluation of multiscale models; comprehensive modeling systems; chemistry and transport algorithms; advanced numerical and computational techniques; urban and regional air quality studies; and sensitivity analyses aimed at determination of the impacts of various emission sources. Scale and resolution issues, interaction of plumes with the surrounding regional atmospheres, and formation, transport and fate of ozone and particulate matter have been the focal points of his research. Among Dr. Odman's past projects, the following are the most relevant to this study.

SEMAP: Emissions and Air Quality Modeling for Southeastern Modeling and Analysis Project (SEMAP), sponsored by Southeastern States Air Resource Managers (SESARM). **Role:** Principal Investigator (PI).

VISTAS: Sensitivity Analysis and Source Apportionment for Visibility Improvement - State and Tribal Association of the Southeast (VISTAS), sponsored by Southeastern States Air Resource Managers (SESARM). **Role:** Principal Investigator (PI).

GLR O3: Improving O₃ simulations in the Great Lakes Region, Sponsored by EPRI. **Role:** Principal Investigator (PI).

Dr. Yongtao Hu is a Senior Research Scientist in the School of Civil and Environmental Engineering. Dr. Hu has twenty years of experience in the fields of regional air quality modeling and related meso-scale meteorological modeling. He is an expert on regional air quality modeling for optimizing emissions control strategies and source apportionment of particulate matter using receptor models and regional air quality models equipped with sensitivity tools. Dr. Hu was involved in several research projects related to the design of air quality control strategies at state, inter-state and federal levels and has been playing important roles in those projects by conducting or supervising simulations of meteorology, emissions, air quality and its sensitivities.

Dr. Armistead (Ted) Russell is the Georgia Power Distinguished Professor of Environmental Engineering. Dr. Russell arrived at Georgia Tech in 1996 from Carnegie Mellon University. Prof. Russell recently was a member of the National Research Council's committee on the Ozone Forming Potential of Reformulated Gasoline, and Chair of the Committee to Review EPA's Mobile Model and previously he was on the NRC's committees dealing with Tropospheric Ozone Formation and Measurement, and Risk Assessment of Hazardous Air Pollutants. He was also a member of the EPA FACA Subcommittee on Ozone, Particulate Matter and Regional Haze, the North American Research Strategy for Tropospheric Ozone and California's Reactivity Science Advisory Committee. Previously he was on the Office of Science, Technology and Policy's Oxygenated Fuels Program Review and various National Research Council program reviews.

Dr. Russell served as Chair of EPA Council on Clean Air Compliance Analysis, Air Quality Modeling Subcommittee, Chair of CASAC panel on NO_x and SO_x Ecosystem Effects, Chair of US EPA Ambient Air Monitoring and Methods Subcommittee, and member of Clean Air Scientific Advisory Committee (CASAC), the Council on Clean Air Compliance Analysis, and Health Effects Institute Review Committee.

Section 2: Work Plan

In this section, we have organized our plan based on the tasks listed in the Contract. The technical approach is followed by the project schedule and budget.

2.1 TECHNICAL APPROACH

This section presents the technical details of how our team plans to address each of the tasks in the Contract. The response to each task is organized into four sections. We present the task leader who will be responsible for the technical oversight as well as managing the performance and deliverables for the task. We present a brief objective to demonstrate our understanding of the overall purpose of the task followed by a detailed technical approach that describes how we plan to accomplish the goals and deliverables for the task. Finally, we present the list of deliverables that we will provide to LADCO under each task.

2.1.1 Task 1. Project Initialization and Modeling Protocol

We split this task into two subtasks as below.

2.1.1.1 Subtask 1.1. Modeling Protocol

Task Leader: Talat Odman

Objective: Develop a draft modeling protocol that describes the data sources and model configuration that will be used to simulate the ozone sensitivities. Work with LADCO to identify the ozone episodes that will be simulated to quantify the ozone sensitivities in the LADCO region. Share the draft protocol with LADCO for comment and produce a final protocol that addresses the comments from LADCO.

Approach: Within 1 week of the execution of the contract, the project team will prepare and deliver to LADCO a draft version of ozone sensitivity modeling protocol. We will finalize the protocol according to LADCO comments.

We list below a broad outline of the protocol that we will develop, along with a brief description for some sections. An expanded discussion of the modeling systems, the input databases, and the model evaluation procedures and the analyzing methods are discussed in more detail under the corresponding Task descriptions.

- I) Modeling periods and modeling domain:
 - a. Select high-ozone episodes in year 2016: candidates are April 15-20, May 22-26, June 9-13, June 18-20, July 19-23, and August 3-11. To remove the impacts from the initial conditions for both concentration and sensitivity fields, we recommend modeling each episode with a 3-day spin-up period.
 - b. The modeling domain will be the LADCO 4-km domain covering the entire LADCO region (**Error! Reference source not found.**). The LADCO-4 domain is 420 columns \times 390 rows \times 35 layers. See the horizontal domain map below, the 4km domain is d02.

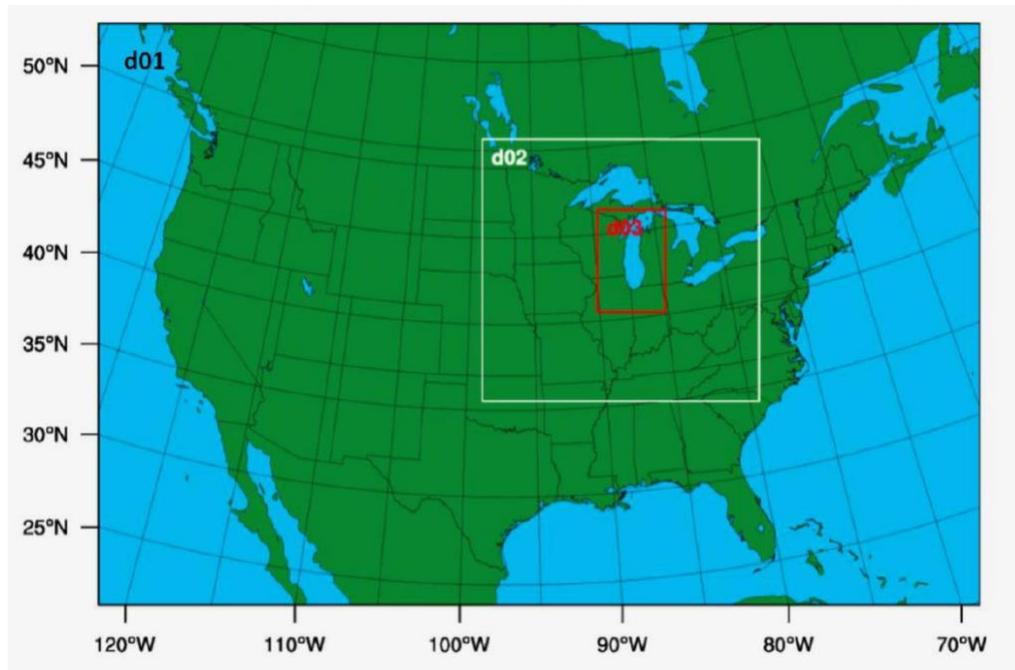


Figure 1. LADCO-4 Modeling Domain (d02).

- II) Technical approaches for simulating and analyzing ozone sensitivities
 - a. HDDM techniques
 - b. Definition of DDM parameters
 - c. RFM model built from HDDM sensitivities
 - d. Building ozone isopleth using RFM model
 - e. Other analysis tools
- III) Air Quality and Sensitivity Modeling System. For each model components listed below, we will describe the version and include the specific configuration that will be used. When possible, we will use the latest model version that is available at the time of writing the protocol.
 - a. CAMx with HDDM
 - b. CMAQ2CAMx (if necessary)
 - c. WRFCAMX (if necessary)
 - d. KVPATCH (if necessary)
 - e. BNDEXTR (if necessary)
 - f. WINDOW (if necessary)
 - g. CAMx2IOAPI
- IV) Input datasets
 - a. Emissions inputs by sector
 - b. Initial and boundary conditions
 - c. Meteorological input data

- d. Other CAMx inputs data and parameters files
 - e. Ambient ozone and precursors data
- V) Model evaluation protocol for base year, listing the various metrics that will be used, along with the software packages.
- a. Georgia Tech has extensive experience using the Atmospheric Model Evaluation Tool version (AMET2) for a number of projects including the SEMAP project. Georgia Tech has enhanced the various AMET2 features, for example plotting spatial maps. This enhanced AMET2 will help with canned production of all the analyses metrics that will be needed for a project such as this, and help the modelers focus interpreting the results of the analyses.
 - b. We will include all the relevant metrics that are commonly used in the community for model evaluation (Emery et al., 2017).
- VI) Analyses of ozone sensitivities
- a. We will specifically describe the methodologies that we will use in the analysis to answer each of the key questions for demonstrating optimal control strategies of modeled attainment of ozone goals in the LADCO region.
- VII) Quality assurance procedures, and error correction approaches
- VIII) Computer resources. This will include both software requirements (compiler, operating system) as well as hardware requirements (CPUs, disk space, etc.)
- IX) Project Schedule
- X) Documentation
- XI) Data backup and archival procedures
- a. We will include approaches to routinely and automatically backup model inputs, outputs, scripts and logs to offline media and to the Georgia Tech's PACE mass storage system.
- XII) Roles and responsibilities for product managers, along with a communication protocol to help with seamless transfer and sharing of information back and forth, not only between our team members, but also between our team and LADCO.

While the draft version of the protocol will be delivered within 1-week of the beginning of the contract, we expect it to be revised based upon feedback from LADCO. We will revise the protocol accordingly and finalize it before start of the modeling.

Deliverables:

- A draft version of sensitivity modeling protocol (1-week after the start of contract 8/1/2020).
- A final version of sensitivity modeling protocol (before the start of modeling 9/1/2020).

2.1.1.2 Subtask 1.2. Data Acquisition and Preparation

Task Leader: Yongtao Hu

Objectives:

- To acquire all 2016 CAMx input data from LADCO for the 4-km gridded O₃ sensitivity modeling
- To collect the appropriate air quality monitoring data for model performance evaluation

Approach: We will acquire the 2016 CAMx input data from LADCO, including 2016 meteorology data in either WRF or WRFCAMx formats, CAMx-ready 2016 emissions files by sector, and merged together in gridded and/or point source formats, 2016 CAMx initial conditions and hourly boundary conditions files derived from a CAMx 2016 12-km simulation. We will also collect/produce other inputs for CAMx, such as ozone columns and clear sky photolysis rates etc. We will conduct quality check on received datasets and prepare necessary CAMx input files as needed. Georgia Tech will download the ambient air quality data of ozone and ozone precursors from the website of the U.S. EPA Air Quality System (AQS).

Georgia Tech is already using various ambient air quality data for the periods considered by LADCO as part of other modeling studies of the CONUS.

Georgia Tech uses the AQS data routinely in air quality model evaluations, such as FAQS, SAMI, VISTAS, etc., and can do the same in this project if necessary. AQS compiles and provides access to datasets from multiple national observational networks/programs including STN, PAMS, SLAMS and Air Toxics. The SLAMS network provides hourly measurements of criteria air pollutants including PM_{2.5}, PM₁₀, O₃, SO₂, NO₂, CO etc. The PAMS network measures photochemical smog related species such as O₃, NO, NO₂, NO_y, Total NMOC, and 60 PAMS target VOC compounds in non-attainment areas.

Deliverables:

- Complete inputs to CAMx for conducting the HDDM ozone sensitivity modeling on the LADCO-4 grid
- Observational datasets in formats that are suitable for the model evaluation software to be used in base year model performance evaluation in Task 2

2.1.2 Task 2: Sensitivity Modeling to Quantify Ozone Sensitivity in the LADCO Region

Task Leader: Yongtao Hu

Objectives:

- To set up and implement the air quality model described in the modeling protocol: use the model to simulate ground level ozone in 2016 for the time periods described in the protocol and to track the sensitivity of ozone formation to precursor emission reductions from different inventory sectors.
- To conduct a model performance evaluation of ozone and ozone precursors through comparison of the 4-km gridded modeling results to ambient observations and deliver a summary of the results to LADCO in presentation and a chapter in the final project report.
- Discuss the implications of model performance deficiencies on the subsequent sensitivity analyses and accordingly prepare presentation and final report chapter.

Approach: We will use CAMx model version 7.0.0 that is equipped with HDDM tool for the sensitivity modeling to quantify ozone sensitivity in the LADCO region. We will conduct emissions source sensitivity modeling and emissions time sensitivity modeling respectively, to fully answer the four key questions in Section 1. We will evaluate the concentration fields produced by the first CAMx-HDDM runs for base year model performance. We split Task 2 into three subtasks.

The DDM tool (Yang et al. 1997, Dunker et al. 2002, Cohan et al. 2005) or its higher-order version HDDM (Hakami et al, 2003), is an implementation of the Decoupled Direct Method (DDM) (Dunker 1984) for sensitivity analysis. The DDM method directly calculates the response of model outputs (concentrations) to inputs/parameters, i.e. the sensitivities, S_{ij} , where $S_{ij} = \partial c_i / \partial P_j$, c_i is the concentration of species i and P_j is parameter j (e.g., the emissions of NO_x). HDDM includes the second order of such sensitivities (Cohan et al. 2005, Zhang et al. 2015). HDDM is an efficient approach for

directly assessing the model responses to changes in various inputs (e.g., emissions) and parameters (e.g., rate constants), and replaces the need to use the traditional “brute force” approach of re-running a model after modifying a parameter. It is also more accurate than the brute force sensitivity analysis for very small perturbations.

2.1.2.1 Subtask 2.1: Emission source sensitivity modeling

Objective: Simulate the sensitivity of ozone formation to precursor emission reductions from the total anthropogenic emissions and from different inventory sectors.

Approach: We will conduct the sensitivity modeling runs proposed in Table 1 for the high-ozone episodes listed in Table 2 using the version 7.0.0 of CAMx with HDDM.

The CAMx-HDDM modeling will be performed on the LADCO-4 grid which has 420 × 390 cells and there will be 35 vertical layers. Each run listed Table 1 will calculate 5 DDM parameters including 1st and 2nd order sensitivities to individually defined NOx and VOCs emissions and the 2nd order cross sensitivity to NOx and VOC emissions. For total anthropogenic emissions, we designed three runs to cover a spectrum of the emissions levels that will assist in constructing the RFM model in a stepwise fashion for accuracy. This is not necessary for sectors none of which dominates in the total anthropogenic precursor emissions.

All CAMx-HDDM modeling results including DDM outputs will be converted to IOAPI format first by using the CAMx2IOAPI program and then will be post-processed for extraction of the most relevant species and conversion of hourly values to more convenient forms (8-hr maximum for ozone). CAMx-HDDM modeling results as well as converted and extracted forms will be backed up on external drives.

Deliverables:

- CAMx-HDDM model outputs results on the LADCO-4 domain and extracted receptor level results for each proposed emissions source sensitivity runs
- CAMx-HDDM run and postprocessing scripts

Table 1. Emissions source sensitivity modeling runs for subtask 2.1

Run-id	Base anthropogenic emissions	DDM emissions (NOx or VOCs)	DDM Parameters
1	100%	100% total anthropogenic	1 st & 2 nd order of NOx&VOCs (5)
2	50%	50% total anthropogenic	1 st & 2 nd order of NOx&VOCs (5)
3	10%	10% total anthropogenic	1 st & 2 nd order of NOx&VOCs (5)
4	100%	100% onroad gasoline	1 st & 2 nd order of NOx&VOCs (5)
5	100%	100% onroad diesel	1 st & 2 nd order of NOx&VOCs (5)
6	100%	100% nonroad	1 st & 2 nd order of NOx&VOCs (5)
7	100%	100% volatile chemical products	1 st & 2 nd order of NOx&VOCs (5)
8	100%	100% other non-point	1 st & 2 nd order of NOx&VOCs (5)
9	100%	100% EGU points	1 st & 2 nd order of NOx&VOCs (5)
10	100%	100% non-EGU points	1 st & 2 nd order of NOx&VOCs (5)
11	100%	100% Canada	1 st & 2 nd order of NOx&VOCs (5)

Ozone Sensitivity in the Great Lakes Region: Project Work Plan

Table 2. Modeling episodes

Episodes in 2016	Episode Days	Modeled Days (+3 ramp-up days)
June 1-26	26	29
July 19-23	5	8
August 3-11	9	12
TOTAL Days	40	49

2.1.2.2 Subtask 2.2: Emission time sensitivity modeling

Objective: Simulate the sensitivity of ozone formation to precursor emission reductions from time-split emissions of major inventory sectors.

Approach: We will conduct the sensitivity modeling runs proposed in Table 3 using version 7.0.0 of CAMx with HDDM for two high-ozone episodes: June 9-13 and July 19-23 that cover exceedance days for most areas of concern.

These runs are designed to answer the question: “What are the periods in the diel within which sectorized emissions reductions have the largest impact on mitigating daily peak ozone concentrations during ozone exceedance days? In other words, emissions reductions from which sectors and when have the largest impact on mitigating ozone exceedances in each receptor? ”.

Table 3. Emissions time sensitivity modeling runs for subtask 2.2

Run-id	DDM emissions	DDM Parameters
1	onroad gasoline NOx	1 st order of NOx from 6 time slots (6)
2	onroad gasoline VOCs	1 st order of VOCs from 6 time slots (6)
3	onroad diesel NOx	1 st order of NOx from 6 time slots (6)
4	onroad diesel VOCs	1 st order of VOCs from 6 time slots (6)
5	Nonroad NOx	1 st order of NOx from 6 time slots (6)
6	Nonroad VOCs	1 st order of VOCs from 6 time slots (6)
7	volatile chemical products VOCs	1 st order of VOCs from 6 time slots (6)
8	other non-point NOx	1 st order of NOx from 6time slots (6)
9	other non-point VOCs	1 st order of VOCs from 6 time slots (6)
10	EGU points NOx	1 st order of NOx from 6 time slots (6)
11	non-EGU points VOCs	1 st order of VOCs from 6 time slots (6)

*All runs are with 100% base anthropogenic emissions.

The CAMx-HDDM modeling will be performed on the LADCO-4 grid, which has 420 × 390 cells and there will be 35 vertical layers. Each run listed in Table 3 will calculate 6 DDM parameters consisting of 1st order sensitivities to individually defined NOx or VOCs emissions during 6 periods of a day. We split sector daily emissions into 6 time slots with 5 of them each covering 3-4 hours and 1 longer period during the night. Among the 7 sectors we don’t need NOx for volatile chemical products, VOC for EGUs, nor NOx for other non-point, due to their much smaller emission amounts than other sector emissions.

The 6 time slots during a day is proposed in local time as (1) hour 6-9, (2) hour 10-12, (3) hour 13-15, (4) hour 16-19, (5) hour 20-22 and (6) hour 23-5.

Deliverables:

- CAMx-HDDM model outputs results on the LADCO-4 domain and extracted receptor level results for each proposed emissions time sensitivity runs
- CAMx-HDDM run and post-processing scripts

2.1.2.3 Subtask 2.3: Base Year Model Performance Evaluation

Objective: Evaluate the base year simulation performance for ozone and precursors during modeled 2016 high-ozone episodes over the LADCO-4 domain, using a suite of comparisons of model outputs against AQS ground-based observations.

Approach: Model performance evaluation on limited variables, i.e. the ozone and precursors concentrations, will be performed.

Version 2.0 of the Atmospheric Model Evaluation Tool (AMET), as revised by Georgia Tech and applied in the SEMAP project, will be used to produce the analyses in the form of tables and graphic displays needed for this task. AMET2 offers the high degree of automation required to handle the large number of analyses. AMETv2.0 also greatly facilitates the import of data needed to display multiple correlations in a single plot.

In addition to the tables of the statistical performance metrics commonly used, we will display normalized mean error and normalized mean bias at each measurement site as 2-D spatial maps to help discern regional patterns in these metrics at a quick glance.

Deliverables:

- Performance evaluation results and PowerPoint presentation describing the model performance for ozone and ozone precursors during the modeling time periods
- Final report chapter on the base year model performance with a summary describing the implications of model performance deficiencies on the subsequent sensitivity analyses

2.1.3 Task 3. Ozone Sensitivity Analysis and Interpretation

Task Leader: Talat Odman

Objectives:

- Post-process the ozone sensitivity modeling results from Task 2 and present them to LADCO in a manner that describes the influence of different emissions sources on ozone in the receptor areas defined in the RFP. Of particular interest to LADCO would be a result that shows how ozone in each of the receptor areas responds to various levels of NO_x, VOC, or NO_x and VOC emissions reductions.
- Particularly answer the following four questions:
 1. How do ozone concentrations at a receptor change when total NO_x, VOC, or NO_x and VOC emissions are reduced along a spectrum of 10% to 100% reduction?
 2. Expanding on Question 1, rather than looking at total NO_x, VOC, or NO_x and VOC emissions reductions, how do ozone concentrations at a receptor change when emissions are reduced from onroad mobile gasoline vehicles, onroad mobile diesel vehicles, nonroad mobile, volatile chemical products, other nonpoint, electricity generation point, or non-electricity point sources?

3. Which combination(s) of NO_x, VOC, and inventory sector has the largest impact (reduction) on peak ozone formation periods in each receptor area?
 4. What are the periods in the diel within which sectorized emissions reductions have the largest impact on mitigating daily peak ozone concentrations during ozone exceedance days? In other words, emissions reductions from which sectors and when have the largest impact on mitigating ozone exceedances in each receptor?
- Summarize the results of the ozone sensitivity analysis in a presentation and as a chapter in the final project report. Describe the methods used for the analysis, the results of the analysis, and the interpretation of the results. Add recommendations for the optimal 2015 ozone NAAQS attainment strategies for each of the receptor areas.

Approach: We will utilize reduced form models (RFM) to construct ozone isopleths for identifying optimal ozone reduction strategies at receptor areas of concern in the LADCO region. Receptor-specific surface ozone isopleths will be used to evaluate a wide-range of ozone mitigation options, with a spectrum of NO_x, VOC, or NO_x and VOC emissions reduction levels (10%-100%) from the total anthropogenic emissions and from different inventory sectors. We will also present the HDDM sensitivities of time-split precursor emissions to show the emissions times of sectors that affect the peak ozone in receptor areas the most.

One of the powerful applications of HDDM is that one can quickly calculate the changes in ozone concentrations due to changes in ozone precursor emissions by using RFMs built from sensitivities provided by HDDM (e.g., Digar and Cohan 2010, Zhang et al. 2015, Huang et al. 2017).

The RFM proposed here represents the relationship between pollutant concentrations and the model inputs in a straightforward form and can be used in lieu of the air quality model to efficiently calculate resulted impacts from changes in model inputs to model outputs. The RFM is derived using Taylor series expansion of pollutant concentration C_i for perturbations in emissions $\Delta\varepsilon_j$, or other input parameters, as follows:

$$C_i = C_{i,0} + \sum_{j=1}^J \Delta\varepsilon_j S_{i,j}^{(1)} + \frac{1}{2} \sum_{j=1}^J \Delta\varepsilon_j^2 S_{i,j,j}^{(2)} + \sum_{j \neq k} \Delta\varepsilon_j \Delta\varepsilon_k S_{i,j,k}^{(2)}$$

where $C_{i,0}$ denotes the unperturbed concentration and $S_{i,j}^{(1)}$, and $S_{i,j,k}^{(2)}$ are the first and second order sensitivities of concentration to precursor emissions. Since we are focusing on ozone here, we will consider sensitivities to NO_x and VOC emissions.

We will utilize the above RFM to calculate the resulting ozone concentrations due to different combination of reductions in precursor NO_x and VOC emissions and plot ozone isopleths as shown in Figure 1. The ozone isopleths will be produced for the total anthropogenic emissions using the three HDDM runs of a spectrum of emissions levels by constructing the RFM model in a step-wise fashion for higher accuracy. The ozone isopleths will be also produced for each of the 7 emission sectors in Table 3. We will produce ozone isopleths for each of the 14 areas of concern as well as at each monitors or designated receptor locations in these areas.

In order to particularly answer LADCO's four questions asked in the RFP, we will also produce additional plots at receptors to present sectors' contributions to peak ozone (split as VOC and NO_x) with stacked bar charts and produce stacked bar charts plots at receptors to present contributions to peak ozone from sectors emissions at time-split level.

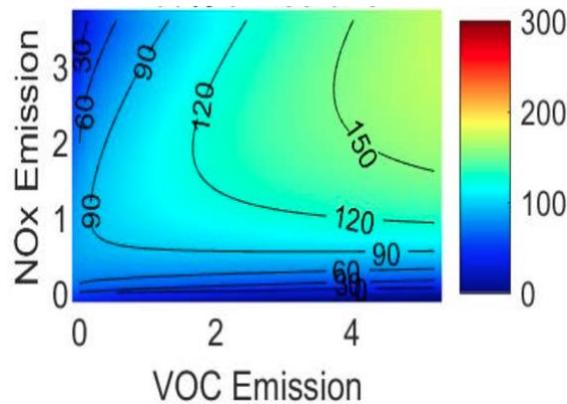


Figure 2. Example isopleths of maximum 8hr ozone concentration (in ppb) versus anthropogenic NOx and VOC emissions (2016 levels as 1.0) for Azusa, CA site on July 23, 2016, developed by using CMAQ-DDM sensitivities.

By combing the information revealed from the above ozone isopleths and sector level (and time-split level) emissions reduction impacts on peak ozone in stack bar charts, we will be able to derive optimal control paths for each receptor on exceedance days and give recommendations on which sectors' emissions to reduce.

Deliverables:

- Powerpoint presentation describing and interpreting the ozone sensitivity analysis.
- Final report chapter on the ozone sensitivity analysis, including recommendations for optimal ozone control strategies in each LADCO receptor area
- Ozone isopleth and stacked bar charts for each LADCO receptor area of concerned
- Analysis software and scripts for building ozone isopleth and stacked bar charts. LADCO is interested in developing software for interactive analysis and plotting of the data using R Shiny. We will transfer the analysis and plotting software coded in R and associated datasets to LADCO for incorporation into R Shiny.

2.1.4 Task 4: Project Administration and Final Report

Task Leader: Talat Odman

2.1.4.1 Subtask 4.1: Work Plan Development

Objective: To develop a project work plan incorporating a description of the approach, methodologies and techniques to be employed, a detailed list of deliverables, the schedule for deliverables, staff assignments, and other pertinent information for each task.

Approach: This draft work plan has been developed largely from the proposal, and any comments received from LADCO will be incorporated. This draft work plan is consistent with the RFP, the executed contract, applicable federal guidance, and will be revised according to any other requirements LADCO may provide.

The approach to each task along with the methods and techniques to be employed is described in detail. In this proposal, team leaders are identified, deliverables are listed, and a schedule is laid out for each task. The projected levels of effort and associated costs as well as costs for equipment, materials, and supplies, can be found in Sections 2.3 and 2.4, respectively.

The direction received from LADCO will be incorporated into the final work plan. Work on technical tasks of the project will not begin until written authorization is received from LADCO.

Deliverables:

- Draft project work plan to LADCO (14 days from the execution of the contract).
- Revised/final project work plan revised in response to LADCO's comments on the draft project work plan (within 7 days of receipt of comments from LADCO)

2.1.4.2 Subtask 4.2: Communications

Objective: To establish effective communications and free flow of information among members in the project.

Approach: We will use state-of-the-art communication methods and a shared online workplace where conversations are organized and accessible, to coordinate the work.

Dr. Odman will regularly communicate with the LADCO project Coordinator via telephone or e-mail to provide updates and discuss any project challenges. Communications with LADCO will be accomplished through monthly conference calls. Through these calls we will provide updates on the progress of the project, and seek input and guidance. We propose to initiate all conference calls through video conferencing software that facilitates presentation, exchange and archival of information.

One of our priorities will be to quickly respond to inquiries and requests for information by the LADCO Project Coordinator. Dr. Odman will either answer questions personally or direct them to the most appropriate member of the project team.

Deliverables:

- Monthly conference calls with LADCO to provide progress updates and seek input and guidance
- Regular communications with the LADCO Project Coordinator to provide updates and discuss project challenges (as needed)
- Prompt responses to inquiries and requests for information from LADCO (as needed)

2.1.4.3 Subtask 4.3: Reports

Objective: Provide timely, accurate, and comprehensive documentation of all work conducted by the project team.

Approach: Each task leader will submit their content for collation into the project report. These task reports will document the data sources, methods, results, and lessons learned at the completion of each task. We will prepare a final project report documenting and summarizing the results of the contract work as follows. First, an outline of the report will be submitted to LADCO for review. After LADCO's approval of the outline, a draft final project report will be prepared and submitted to LADCO for review. At a minimum, the final report will contain:

- An executive summary that provides a brief overview and summary of the modeling efforts, models used, model configurations, model performance evaluation, sensitivity modeling and analysis results,
- Technical details of all technical work performed as part of the project,
- Summaries, recommendations and conclusions;
- A list of all final work products being delivered; and

Ozone Sensitivity in the Great Lakes Region: Project Work Plan

- A discussion of data accessibility and availability for review by LADCO, stakeholders, and the public.

Within two weeks of receiving comments on the draft final report from LADCO, we will submit the final report to LADCO for approval.

In addition to written, comprehensive project reports, we will provide project summaries in the form of slide presentations that can be distributed to LADCO agencies and stakeholders to inform them of our progress and findings.

Deliverables:

- Project summaries in the form of slide presentations and in the form of final report chapters (at the completion of each task with major results and at the end of the project).
- Draft and final outline of the final project report.
- Draft final project report (within four weeks of LADCO’s approval of the outline)
- Final project report (within 2 weeks of receiving comments from LADCO).

2.2 SCHEDULE OF DELIVERABLES

The schedule shown below assumes that all data needed for each task or subtask, in particular, meteorology and emissions inputs, will be available on the start date of that task or subtask.

Task	Description	Start Date	End Date	2020					2021	
				A	S	O	N	D	J	F
1	Modeling Protocol and Collecting Data	8/1/2020	8/31/2020							
2	Sensitivity Modeling and Performance Evaluation	9/1/2020	1/31/2021							
3	Analysis and Interpretation of Results	12/1/2020	2/28/2021							
4	Project Management and Final Report	8/1/2020	2/28/2021							

Section 3: References

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