Modeling Protocol

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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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
NH3	Ammonia
NOx	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
PM2.5	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
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 5, 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 (NOx) 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 NOx 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 NOx, VOC, or NOx and VOC emissions are reduced along a spectrum of 10% to 100% reduction?

2. Expanding on Question 1, rather than looking at total NOx, VOC, or NOx 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 NOx, 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 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 modeling protocol for the LADCO ozone sensitivity project. Its intent is to detail the data collection, model configurations, modeling approaches, and quality assurance/quality control (QA/QC) processes that will be used in the project. Following US EPA

guidance documents on air quality modeling and analysis (EPA, 2014; EPA, 2018), this protocol is a comprehensive approach to the acquisition, production, assessment, archival, and documentation of all data used for the project.

Section 2: Project Overview

2.1 Management Structure

Talat Odman will be the project manager. As such, he is responsible for ensuring that the project team fulfills the project goals and objectives. Dr. Odman will be the liaison between LADCO and the project team and coordinate the team efforts. He will also lead the efforts of writing modeling protocol and final report, and analyzing and interpreting sensitivity results.

Yongtao Hu will be the data manager. He will lead and be responsible for the efforts of data collection, executing and managing all sensitivity modeling and model performance evaluation.

Armistead (Ted) Russell will be the quality assurance (QA) manager. He will review the progress of the project and its results and assure the quality of the final report. At any point during the course of the project, in consultation with the project manager and the LADCO project coordinator, he may recommend suspension of project activities and request corrective actions to meet the QA/QC standards.

2.2 Communication Procedures

The components of the LADCO project are implemented using a task structure and approach that can complete the work effectively. Each task/subtask is measured and documented for QC, and corrective action will be taken immediately if a problem is found. Prior to delivery to LADCO, all outputs from the LADCO project tasks will be assessed against the objectives stated in the project work plan to ensure that the work has been completed and quality assured. It is necessary to have feedback at all steps in the workflow to provide specific QC at the task level, and assessment of the project objectives.

Each task in the work plan will have appropriate entries for objectives, subtasks, and deliverables. The formal review and reporting is the project manager's responsibility. The QA Manager is responsible for verifying that all tasks are appropriately documented and reported, and will report any discrepancies to the project manager along with recommendations for correction. The project manager will note the QA Manager's recommendations in the monthly report to LADCO along with the corrective actions taken.

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 project work groups, teams, directors and stakeholders 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. All conference calls will be conducted through video conferencing software that facilitates presentation, exchange and archival of information. The 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.

A slide presentation containing the following elements for tasks in the LADCO project will be distributed at each monthly call:

- Work completed the previous month
- Expected work during the next month
- Difficulties encountered and corrective actions taken
- Actions awaiting LADCO input
- Status of project deliverables

2.3 Project Schedule

The project schedule is shown in Table 2-1.

Table 2-1. Project schedule

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	10/1/2020	2/28/2021							
4	Project Management and Final Report	8/1/2020	2/28/2021							

Section 3: Models and Model Inputs

3.1 Models

This section describes the modeling systems that will be used for the sensitivity modeling and analysis in the project. We have selected the following modeling systems because they present the best combination of scientific and computational formulations to satisfy the requirements of the LADCO project. The air quality model selected for this project, CAMx, follows the recommendation in the EPA Modeling Guidance (i.e., Guidance on the Use of Models and Other Analyses for Demonstrating Attainment of Air Quality Goals for Ozone, PM2.5, and Regional Haze) and Appendix W to Part 51 of 40 Code of Federal Regulations: Guideline on Air Quality Models.

3.1.1 CAMx version 7.0.0

The **C**omprehensive **A**ir quality **M**odel with e**x**tensions (CAMx) is an Eulerian photochemical transport model that includes can track gaseous and particulate air pollutants (ozone, PM2.5, PM10, air toxics, mercury) over multiple scales ranging from urban to continental (Morris et al, 2003a, 2003b). The CAMx model developed and supported by Ramboll US Corporation and its pre- and post-processors are in the public domain. In addition to the ozone and PM simulations for regulatory applications, CAMx also provides extension tools to probe source apportionment and emissions sensitivity problems. The CAMx model version 7.0.0 will be used to conduct the sensitivity simulation tasks in this project. The model will be configured with the CB6r4 (no PM) mechanism with no PM, and with Piecewise Parabolic Method (PPM) for advection solver, Eulerian Backward Iterative (EBI) method for chemistry solver ZHANG03 for dry deposition, and without bidirectional NH_3 dry deposition. CAMx is freely available for download from http://www.camx.com

CAMx Extensions and Probing Tools

- ***Decoupled Direct Method (DDM) and Higher-Order DDM (HDDM) Source Sensitivity***: This tool calculates first-order (DDM) and second-order (HDDM) gas concentration sensitivity to changes in emissions, initial conditions and boundary conditions. PM concentration sensitivity is limited to first-order DDM. (H)DDM estimates how pollutant concentrations respond (sensitivity) to source region- and category-specific changes in emission. (H)DDM can be run with Carbon Bond or SAPRC gas-phase chemical mechanisms. DDM can be run with the CF aerosol scheme, the SOAP organic partitioning algorithm, and the ISORROPIA inorganic partitioning algorithm.

New Features and Major Updates In CAMx Version 7.00

- New netCDF Input Option: CAMx now supports netCDF file formats for gridded input fields including emissions, meteorology, and initial/boundary conditions. The model can accept a mix of netCDF or Fortran binary input files for maximum flexibility and backward compatibility. CAMx can be built with netCDF-3 or netCDF-4/HDF5; the latter allows for data compression.

- New 3-D Emissions Input FIle: CAMx supports a new 3-D gridded emissions file in netCDF format for certain non-point source sectors that are emitted above the surface and have traditionally been input to the model as elevated point sources: e.g., wildfires, lightning NOx, aircraft, etc. The FORTRAN binary format is not supported for 3-D emission files.
- Multiple Emission Input files: CAMx supports multiple point, 2-D and 3-D gridded emission files, alleviating the need to merge all sectors into a single file. This capability is also extended to Probing Tools. Point and 2-D emissions files can be listed in any combination of netCDF or Fortran binary format. 3-D gridded emission files must be in netCDF format.

  NOTE on DDM: With this change, DDM input point source emission files can include stack lists that are entirely unique to this Probing Tool. Earlier CAMx versions required a consistent list of point sources among the core model and DDM, which was tedious. This restriction is removed.
- Bi-Directional Ammonia Surface Flux: The bi-directional ammonia algorithm of Zhang et al. (2010) has been added as an option to the original unidirectional Zhang deposition algorithm. Only ammonia is treated in the bi-directional treatment. Default landuse-dependent "emission potentials" control ammonia "compensation points" (surface concentration) along the surface-air transport circuit. When atmospheric ammonia concentration exceeds the compensation point, the net flux is from air to surface at a rate that depends on the concentration difference; in the opposite case, the net flux is from surface to air.

3.1.2 WRFCAMx and KVPATCH

The WRFCAMx program generates CAMx meteorological input files from WRF (ARW core) hourly output files. A single WRFCAMx run provides meteorological fields for a single CAMx grid, whether defined as a CAMx master coarse grid, or a nested grid. The program generates the files for any duration (from a single hour to several days). For a single day, 25 hours of meteorology must be present (midnight through midnight, inclusive) as these fields represent hourly instantaneous conditions and CAMx internally time interpolates these fields to each model time step. Precipitation fields are not time-interpolated, but rather time-accumulated, so cloud/precipitation files contain one less hour than other met files (e.g., 24 hours of cloud/precipitation vs. 25 hours other met). The CAMx physical height layer structure (meters AGL) is defined from the geopotential heights at each of WRF's "eta" levels, and thus varies in space and time. We will keep the CAMx layer structure the same as the WRF layers. Several options are available to derive Kv (vertical diffusivity) fields from WRF output. If TKE is available, Kv can be derived from this; otherwise, other options diagnose Kv from wind, temperature, and PBL parameters. We will also conduct KVPATCH program to apply minimum Kv values to layers below a user-defined height based on input landuse fields and surface layer stability within that depth.

We will use the wrfcamx-01jun20.tgz and kvpatch-02jun20.tgz to prepare meteorological inputs to CAMx.

Input Requirements

WRFCAMx reads in WRF outputs in netCDF format.

3.1.3 O3MAP and TUV4-8-CAMx7

The development of photolysis rate inputs for CAMx is crucial for the photochemical mechanisms. The O3MAP prepares ozone column input files for CAMx, and must be run prior to running the Total Ultraviolet (TUV) radiative transfer model. A CAMx-ready landuse file (from WRFCAMx) and total integrated ozone column (TOMS) data files must be supplied as input. The program assumes a constant haze turbidity value for the entire grid. Note that gaps in day-specific TOMS data at low latitudes, and high latitudes during winter, may result in zero ozone column values over portions of the modeling grid. These gaps result from the inability of polar-orbiting satellites to cover the entire globe on a daily basis. Seasonal-average TOMS input files (which have no data gaps) may be used instead; alternatively, O3MAP provides an option to fill these day-specific gaps with an average determined from valid data processed for the extraction domain. Additionally, the Total Ultraviolet (TUV) radiative transfer program (version 4.8) develops photolysis rate inputs for all CAMx CB6, and SAPRC07 photochemical mechanisms via a delta-Eddington radiative transfer model. TUV originates from UCAR (http://cprm.acd.ucar.edu/Models/TUV/). The program uses the albedo, ozone column, and haze turbidity intervals to generate a look-up table of photolysis rates to be used in CAMx. The table defines photolysis rates for several CB6 photolytic reactions over a range of solar zenith angles, altitudes, ozone column, surface UV albedo, and haze turbidity. CAMx internally adjusts the photolysis rates for cloud cover according to the cloud inputs provided to CAMx (from WRFCAMx).

We will use the o3map-31may20.tgz (for CAMx v7.0+) and tuv4.8-camx7.00-31may20.tgz (for CAMx v7.0+) to process photolysis rates as inputs to CAMx.

Input Requirements

The O3MAP and TUV programs need TOMS ozone column data from NASA web sites (https://acd-ext.gsfc.nasa.gov/anonftp/toms/omi/data/Level3e/ozone/ or https://acd-ext.gsfc.nasa.gov/anonftp/toms/omps_tc/data/ozone/).

The sequence of running these supporting programs is: WRFCAMx, KVPATCH, O3MAP, and TUV.

3.1.4 Other Support Programs

Various CAMx support programs are freely available for download from http://www.camx.com/download/support-software.aspx. If necessary, we will also employ the following programs to prepare missing inputs to CAMx.

ICBCPREP

The ICBCPREP program is used to prepare simple, static CAMx initial condition (IC) and boundary condition (BC) files in Fortran binary format.

SAICBC

The SAICBC program generates Source Apportionment tracer initial/boundary condition input files to support one-way nesting (or downscaling) from a set of third-party global or regional

photochemical model zero-out scenarios. It operates on a set of separate core-model initial/boundary conditions that were generated from the larger-scale model output scenarios.

WATERMASK

The WATERMASK program is used to convert a CAMx landuse file containing all water coverage in index=1 to a new landuse file that differentiates between salt/ocean water coverage (index=1) and fresh water coverage (index=3). It operates on Fortran binary files.

OCEANIC

The OCEANIC emissions program generates aerosol emissions of sodium, chloride and sulfate, gas emissions of halomethane compounds, and gas emissions of dimethyl sulfide (DMS) using CAMx-ready meteorological and landuse files. It operates on Fortran binary file formats. It includes a merging program that allows emissions to be merged in with pre-existing CAMx-ready gridded emission files.

3.2 Modeling Domains

This section describes the horizontal and vertical modeling domains that will be simulated for the LADCO project.

3.2.1 Horizontal Domain

The LADCO modeling domain is on a Lambert Conformal Conic projection centered on 40°N and 97°W that covers the LADCO region with a 4-km grid resolution. The projection and grid definition information for the LADCO-4 modeling domain is given in Table 3-1. Figure 3-1 shows the nested LADCO modeling domains (D02 is the LADCO-4).

Table 3-1. Projection parameters for the CAMx modeling domain

Parameter	LADCO 4-km domain
Map Projection	Lambert Conformal Conic
P-alpha	33°N
P-beta	45°N
P-gamma	97°W
X-cent	97°W
Y-cent	40°N
X-orig	-132,000 m
Y-orig	-420,000 m
dx	4,000 m
dy	4,000 m
Columns	420
Rows	390
Layers	35

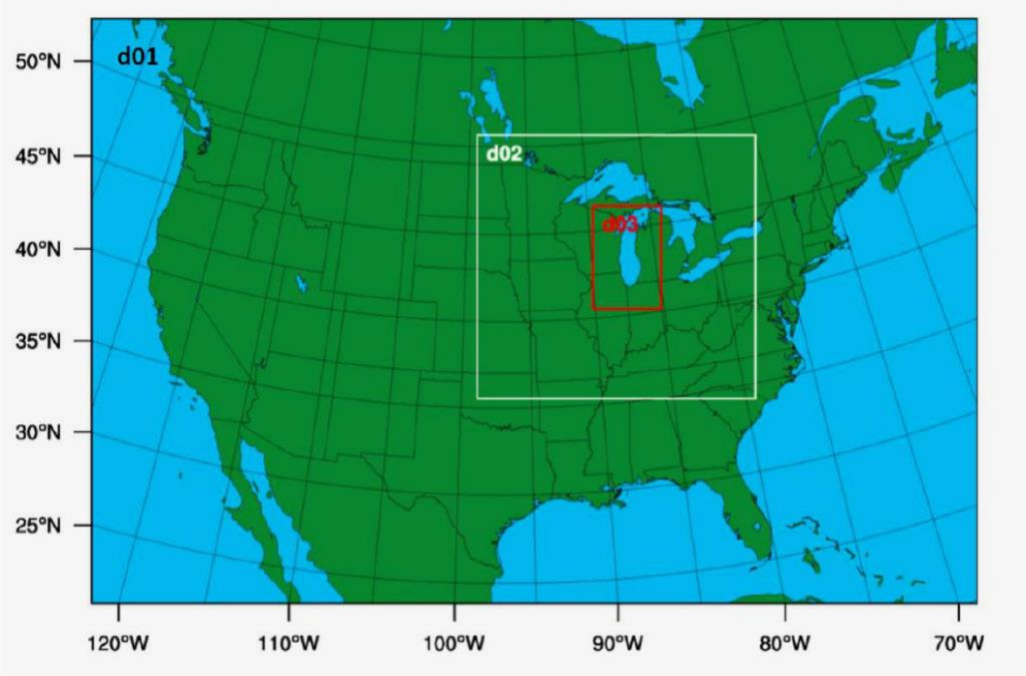

Figure 3-1. LADCO-4 Modeling Domain (denoted by d02).

3.2.2 Vertical Domain

Table 3-2 shows the vertical layer structures of the WRF and CAMx modeling domains.

Table 3-2. LADCO WRF and CAMx Vertical Layer Configurations

WRF					CAMx				
Level	Sigma	Height (m)	Pressure (mb)	Depth (m)	Level	Sigma	Height (m)	Pressure (mb)	Depth (m)
36	0.000	17,556	5000	2776	36	0.000	17,556	5000	2776
35	0.050	14,780	9750	1958	35	0.050	14,780	9750	1958
34	0.100	12,822	14500	1540	34	0.100	12,822	14500	1540
33	0.150	11,282	19250	1280	33	0.150	11,282	19250	1280
32	0.200	10,002	24000	1101	32	0.200	10,002	24000	1101
31	0.250	8,901	28750	969	31	0.250	8,901	28750	969
30	0.300	7,932	33500	868	30	0.300	7,932	33500	868
29	0.350	7,064	38250	789	29	0.350	7,064	38250	789
28	0.400	6,275	43000	722	28	0.400	6,275	43000	722
27	0.450	5,553	47750	668	27	0.450	5,553	47750	668
26	0.500	4,885	52500	621	26	0.500	4,885	52500	621
25	0.550	4,264	57250	581	25	0.550	4,264	57250	581
24	0.600	3,683	62000	547	24	0.600	3,683	62000	547
23	0.650	3,136	66750	517	23	0.650	3,136	66750	517
22	0.700	2,619	71500	393	22	0.700	2,619	71500	393
21	0.740	2,226	75300	285	21	0.740	2,226	75300	285
20	0.770	1,941	78150	276	20	0.770	1,941	78150	276
19	0.800	1,665	81000	180	19	0.800	1,665	81000	180
18	0.820	1,485	82900	177	18	0.820	1,485	82900	177
17	0.840	1,308	84800	174	17	0.840	1,308	84800	174
16	0.860	1,134	86700	170	16	0.860	1,134	86700	170
15	0.880	964	88600	167	15	0.880	964	88600	167
14	0.900	797	90500	83	14	0.900	797	90500	83
13	0.910	714	91450	82	13	0.910	714	91450	82
12	0.920	632	92400	81	12	0.920	632	92400	81
11	0.930	551	93350	81	11	0.930	551	93350	81
10	0.940	470	94300	80	10	0.940	470	94300	80
9	0.950	390	95250	79	9	0.950	390	95250	79
8	0.960	311	96200	79	8	0.960	311	96200	79
7	0.970	232	97150	78	7	0.970	232	97150	78
6	0.980	154	98100	39	6	0.980	154	98100	39
5	0.985	115	98575	38	5	0.985	115	98575	38
4	0.990	77	99050	39	4	0.990	77	99050	39
3	0.995	38	99525	19	3	0.995	38	99525	19
2	0.9975	19	99763	19	2	0.9975	19	99763	19
1	1.000	0	100000	0	1	1.000	0	100000	0

3.3 Episode Selection

This section describes the modeling periods that will be simulated for the ozone sensitivity analysis.

We will select high-ozone episodes in the year 2016; candidates are listed in Table 3-3. To remove the impacts from the initial conditions for both concentration and sensitivity fields, we recommend to model each episode with a 3-day spin-up period.

Table 3-3. 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

3.4 Input Databases

This section describes the input data that will be collected and processed to support the ozone sensitivity modeling tasks.

3.4.1 Meteorology Data

All meteorology data (as WRF outputs in netCDF format) required for the air quality modeling will be provided by LADCO. All the necessary meteorological variables will be processed through WRFCAMx along with the other support programs (KVPATCH, O3MAP and TUV). The CAMx ready meteorology data will be use by CAMx-DDM/HDDM modeling.

3.4.2 Initial and Boundary Conditions

The CAMx-DDM/CAMx-HDDM modeling require two sets of initial and boundary conditions (IC/BC), one for the air quality fields and one for the DDM/HDDM sensitivity fields. The IC/BC for DDM/HDDM sensitivity fields will be set to zeros. The IC/BC for the air quality will be provided by LADCO as derived from the 3D outputs from LADCO-12 CAMx simulations.

Georgia Tech will review the initial and boundary condition provided by LADCO. We will first run the m3stat I/O API utility on each day's file to obtain summary statistics for each day, and then plot them to visually verify the ranges of IC and BCs.

3.4.3 Emissions Data Files

The CAMx-DDM/HDDM modeling requires emissions input files for gridded emissions (emis2d/emis3d) and point emissions (mrgpt), total emissions (anthropogenic + biogenic) as standard inputs, and anthropogenic total emissions (anthropogenic only) as well as sector split emissions (separately at least for the sectors of onroad mobile gasoline vehicles, onroad mobile diesel vehicles, nonroad mobile, volatile chemical products, other nonpoint, electricity generation point, and non-electricity point sources) as DDM/HDDM inputs.

Georgia Tech will develop an in-house program to prepare the 10% level and 50% level of anthropogenic total emissions inputs files by processing the anthropogenic total emissions files

with uniform reductions. Georgia Tech will also develop an in-house program to split the sector emission files into six files specific to 6 time slots (each containing the emissions records for the specific time-slot period with other hours' emissions being zeros).

We prefer pre-merged emissions files (as SMOKE outputs in netCDF format) to be provided by LADCO. Table 3-4 2016v1 Platform Sectors List

ID	Processing Sector
afdust_adj	US area fugitive dust sources
ag	US agricultural sources
airports	US airport source
nonpt	US non-point sources
nonroad	US off-road mobile sources
np_oilgas	US non-point oil&gas sources
onroad	US on-road mobile sources
onroad_can	Canada on-road mobile sources
othafdust_adj	Canada&Mexico area fugitive dust sources
othar	Canada&Mexico area sources
othptdust_adj	Canada&Mexico point dust sources
rail	US railroad sources
rwc	US residential wood combustion sources
cmv_c1c2_12	US commercial marine vessels class 1&2
cmv_c3_12	US commercial marine vessels class 3
ptagfire3d	US agricultural fire sources
ptfire3d	US biomass fire sources
ptfire_othna3d	Canada&Mexico biomass fire sources
othpt	Canada&Mexico point sources
pt_oilgas	US point oil&gas sources
ptegu	US EGU point sources
ptnonipm	US Non-IPM point sources
beis	Biogenic sources

Table 3-5 lists the detailed pre-merged sectors from the EPA 2016v1 platform with an additional split of onroad sector into gasoline and diesel vehicles. It will be better if the pre-merged sector emissions are provided directly for the relevant sectors: onroad mobile gasoline vehicles, onroad mobile diesel vehicles, nonroad mobile, volatile chemical products, other nonpoint, electricity generation point, or non-electricity point sources with leftover sources.

Table 3-4 2016v1 Platform Sectors List

ID	Processing Sector
afdust_adj	US area fugitive dust sources
ag	US agricultural sources
airports	US airport source
nonpt	US non-point sources
nonroad	US off-road mobile sources
np_oilgas	US non-point oil&gas sources
onroad	US on-road mobile sources
onroad_can	Canada on-road mobile sources
othafdust_adj	Canada&Mexico area fugitive dust sources
othar	Canada&Mexico area sources
othptdust_adj	Canada&Mexico point dust sources
rail	US railroad sources
rwc	US residential wood combustion sources
cmv_c1c2_12	US commercial marine vessels class 1&2
cmv_c3_12	US commercial marine vessels class 3
ptagfire3d	US agricultural fire sources
ptfire3d	US biomass fire sources
ptfire_othna3d	Canada&Mexico biomass fire sources
othpt	Canada&Mexico point sources
pt_oilgas	US point oil&gas sources
ptegu	US EGU point sources
ptnonipm	US Non-IPM point sources
beis	Biogenic sources

Table 3-5. Emissions source sectors for the LADCO project

ID	Processing 2016v1 Sectors	Category	To be Used for
onroad_gasoline	a subsector of onroad	Gridded 2D	sector "onroad mobile gasoline" sensitivity
onroad_diesel	a subsector of onroad	Gridded 2D	Sector "onroad mobile gasoline" sensitivity
nonroad	nonroad + rail + airports + cmv_c1c2_12 + cmv_c3_12	Gridded 2D and point	sector "nonroad mobile" sensitivity
vcp	a subsector of nonpt	Gridded 2D	Sector "volatile chemical products" sensitivity
other_nonpt	nonpt with vcp being removed + np_oilgas + rwc	Gridded 2D	
ptegu	ptegu	Point	sector "electricity generation point" sensitivity
ptnonegu	ptnonipm+ pt_oilgas	Point and Gridded 2D	sector "non-electricity point" sensitivity
point_can	othpt	Point	track non-US point sources
onroad_can	onroad_can	Gridded 2D	track non-US onroad sources
nonpoint_can	othar	Gridded 2D	track non-US nonpoint sources
others	afdust_adj + ag + othafdust_adj + othptdust_adj	Gridded 2D	The leftover anthropogenic sources
anthropogenic_total	All the above sectors merged	Gridded 2D and Point	100%, 50% and 10% anthropogenic emissions sensitivity
fires	ptagfire3d + ptfire3d + ptfire_othna3d	Gridded 3D	Natural sources (no control sources)
oceanic	Oceanic sources	Gridded	Natural sources
beis	Biogenic sources	Gridded	Natural sources
total_emissions	anthropogenic total and natural sources merged	Gridded and Point	CAMx standard inputs

3.4.4 Other Inputs

Georgia Tech will prepare the DDM Source Area Map file required for the CAMx-DDM/HDDM run, in collaboration with LADCO with source area definition.

The source area will be defined as the entire LADCO-4 domain.

3.5 Quality Assurance and Error Correction Protocol

3.5.1 Quality assurance and Quality control

Quality assurance (QA) in the context of emissions and air quality modeling refers to ensuring that the results of the simulations are of the highest quality possible with respect to the data. Quality control (QC), on the other hand, refers to ensuring that the model simulations completed successfully and without errors. QA focuses on the quality of the data; QC focuses on the process of modeling, archiving, and documenting the data. Some analysis products, like spatial plots and simulation animations, are used for both QA and QC. Other products, such as documents of model settings are used for QC only. This section describes both the QA and QC products that we will use during the air quality and sensitivity modeling for the LADCO project to ensure high quality model results and that the modeling software performed as we expected. Specific examples showing how to apply QA/QC concepts in the application of the modeling software provide a framework for guiding the QA process during the production of air quality model results. The QA/QC framework begins with the installation of the modeling software and concludes with compiling QA summaries and notes into a final report. The result of following this framework will be highly scrutinized data that were generated by well-documented QA procedures.

3.5.2 Air Quality Data and Modeling

We will adopt rigorous QA procedures to verify the quality and accuracy of all model inputs and outputs that will be developed for the project. This will be mainly accomplished using statistical and graphical approaches. We will also conduct QC checks at every step of the modeling procedures.

Air Quality Model (AQM) Input Files

We will perform rigorous check on IC/BC files, as well as meteorology and emissions input files. The examination includes but is not limited to graphical visualization of the files, computing minimum and maximum values of the domain and verification if these lie within reasonable bounds for the entire modeling period.

AQM Output Files

For the QC purpose of eliminating any possible mistakes, we will use a rigorous naming convention for distinguishing between all episodic/sensitivity scenarios of CAMx-DDM/HDDM simulations. We will create individual directories for each model scenario, and retain unique scripts for each scenario, each episode and never reuse any script for multiple scenarios. We will retain all runtime logs from the models and routinely parse them for any error/warning messages. We will flag runs/scenarios/days that have error messages and take appropriate action to address them. The model executable, run scripts and log directories will be periodically synchronized to the archival system at GIT in near real-time. Thus, in case of disk failure, etc., we can easily reproduce these runs as necessary.

The following general procedures will be used to QC all the modeling procedures for this project:

- Verification that correct configuration and science options are used in compiling and running each component of the modeling system, where these components include the meteorology pre-preprocessor, photolysis rate calculators, chemistry-transport model (CTM) with DDM/HDDM extensions, and any other preprocessor used to prepare data for the CTM.
- Verification that correct input data sets are used when running each model.
- Verification of ambient monitoring data for use in the model performance evaluation.
- Backup and archival of critical model input and output data.

Once the model simulations are complete, we will use automated post-processing tools to perform time aggregation (daily maxima, daily average, etc.), create tile plots, time-series plots and standard min/max statistics for all species to QA them for reasonableness. We will create automated ways to parse these min/max values for each and every simulation and report anomalies to the AQM data manager for possible corrective action. All plots with summaries of QA findings will be provided at monthly meetings to LADCO and the QA manager for review and verification.

The following general procedures will be used to QA all air quality modeling simulations completed for this project:

-
- Evaluation of model results to verify that the output is reasonable and consistent with general expectations.
- Evaluation of the air quality model results against observations.
- Extraction and analysis of the sensitivity results.
- Backup and archival of all QA analysis products.

Section 4: Technical Approach

4.1 Simulation Identification

We will use a naming scheme for the CAMx-DDM/HDDM simulations to identify the versions of the input data, episodes and sensitivity scenarios used in the simulation. The model used to generate the results with version number (i.e., CAMx7.00) will be included in the output file names along with the date of the simulation. A three letter input data versioning prefix in the simulation identification (ID) will be used to track the version of the meteorology (digit 1), emissions (digit 2), and air quality data (digit 3). A two-digit number will then denote the sensitivity scenario of the simulation. The last digit(s) will identify the episode.

The justification for using different version IDs for the input data, episodes and sensitivity scenarios is based on our experience with similar modeling projects that required the ability to track numerous sensitivity modeling simulations. The version IDs and simulation IDs will be documented and tracked throughout the project.

4.2 General Modeling Procedures

This section describes the general procedures that we will use to process data during the project. The modeling procedures described here will be used throughout all of the modeling applications in the project. Alternative procedures that diverge from those documented in this section are described in the applicable task descriptions below.

4.2.1 Meteorology Data Preparation

We will test the WRFCAMx program, examine the outputs and compare them to the original WRF outputs. WRFCAMx will be run with no vertical layer collapsing. We will also run the KVPATCH program to apply minimum Kv values to layers below the PBL. Finally, we will run the two programs (O3MAP and TUV) to prepare photolysis rate inputs for the CAMx model.

After we make certain the results from WRFCAMx, KVPATCH, O3MAP, and TUV are satisfactory, we will process the 2016 WRF output data for the modeling periods through these programs.

4.2.2 CAMx Air Quality and Sensitivity Modeling

Initial and Boundary Conditions and Other Inputs

We will receive the initial and boundary condition files generated from 12-km CAMx run from LADCO. We will also receive gridded and point sources emission from LADCO for both the standard inputs to CAMx and for inputs specific to implement the DDM/HDDM with CAMx.

Chemical Mechanism

CAMx needs a chemical parameter file as an input to the run script. From the various options, we will use the mechanism file CAMx7.0.chemparam.CB6r4, included with the distribution.

This mechanism includes the Carbon Bond 6 gas-phase chemical mechanism with no PM treatment, which is compatible with HDDM option.

Chemistry-Transport Model with DDM/HDDM extensions

We will use CAMx V7.0.0 for conducting the ozone sensitivity modeling. As described above, meteorology to CAMx are prepared using WRFCAMx and KVPATCH. All other inputs including emissions inputs, and IC, BC and photolysis rate files will be provided by LADCO. With all the inputs, the air quality and sensitivity modeling will be conducted using CAMx V7.0.0. Georgia Tech has already installed and configured this model version on the PACE computer cluster. We will use the Intel Fortran Compiler *ifort* as the Fortran compiler for the system.

Table 4-1 shows the proposed configuration options for CAMx V7.0.0.

Table 4-1. CAMx configuration options

Model Parameter	CAMx_v7.0.0
Horizontal Advection	Piecewise Parabolic Method (PPM)
Vertical Advection	Piecewise Parabolic Method (PPM)
Horizontal Diffusion	Implicit
ACM2_Diffusion	False
Gas Chemistry Mechanism	CB6Br
Gas Chemistry Solver	Euler Backward Iterative (EBI)
Aerosol Mechanism	none
Clouds/Aqueous Chemistry	Implicit
Drydep_Model	Zhang03
Plume in Grid	none
Probing Tool	DDM/HDDM

4.3 Emission source sensitivity modeling

The objective of this task is to simulate the sensitivity of ozone formation to precursor emission reductions from the total anthropogenic emissions and from different inventory sectors.

We will conduct the sensitivity modeling runs proposed in Table 4-2 for the high-ozone episodes listed in Table 3-3 using CAMx V7.0.0 with DDM/HDDM.

The CAMx-DDM/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 4-2 will calculate 5 DDM/HDDM 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 construction reduced form model (RFM) in a step-wise fashion for accuracy. This is not necessary for sector emissions since none of them dominates in the total anthropogenic precursor emissions.

All CAMx-DDM/HDDM modeling results including DDM/HDDM outputs will be converted to I/O API 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-DDM/HDDM modeling results as well as converted and extracted forms will be backed up on external drives.

Table 4-2. Proposed 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	1st & 2nd order of NOx&VOCs (5)
2	50%	50% total anthropogenic	1st & 2nd order of NOx&VOCs (5)
3	10%	10% total anthropogenic	1st & 2nd order of NOx&VOCs (5)
4	100%	100% onroad gasoline	1st & 2nd order of NOx&VOCs (5)
5	100%	100% onroad diesel	1st & 2nd order of NOx&VOCs (5)
6	100%	100% nonroad	1st & 2nd order of NOx&VOCs (5)
7	100%	100% volatile chemical products	1st & 2nd order of NOx&VOCs (5)
8	100%	100% other non-point	1st & 2nd order of NOx&VOCs (5)
9	100%	100% EGU points	1st & 2nd order of NOx&VOCs (5)
10	100%	100% non-EGU points	1st & 2nd order of NOx&VOCs (5)
11	100%	100% Canada	1st & 2nd order of NOx&VOCs (5)

4.4 Emission time sensitivity modeling

The objective of this task is to simulate the sensitivity of ozone formation to precursor emission reductions from time-split emissions of major inventory sectors.

We will conduct the sensitivity modeling runs proposed in Table 4-3 using the CAMx V7.0.0 with DDM/HDDM for two high-ozone episodes, i.e., 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?"

The CAMx-DDM/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 4-3 will calculate 6 sensitivity parameters including 1st order sensitivities to individually defined NOx or VOCs emissions during 6 periods of a day. We will split sector daily emissions into 6 time slots with 5 of them each covering 3 or 4 hours and 1 longer period during the night. This will not be done for NOx from volatile chemical products, VOC from EGUs, or NOx from other non-point, due to their much smaller emissions amounts compared to the 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.

Table 4-3. Proposed emissions time sensitivity modeling runs for subtask 2.2

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

*All runs are with 100% base anthropogenic emissions.

4.5 Ozone Sensitivity Analysis and Interpretation

The objectives of this task is to post-process the ozone sensitivity modeling results and present them to LADCO in a manner that describes the influence of different emissions sources on ozone in certain receptor areas. The result will show how ozone in each of the receptor areas responds to various levels of NOx, VOC, or NOx and VOC emissions reductions.

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 NOx, VOC, or NOx and VOC emissions reduction levels (10%-100%) for the total anthropogenic emissions as well as different inventory sectors. We will also present the sensitivities to time-split precursor emissions in order to show the emissions times for different sectors that impact the peak ozone in receptor areas the most.

One can quickly calculate the changes in ozone concentrations due to changes in ozone precursor emissions by using RFMs built from sensitivities provided by DDM/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 NOx and VOC emissions.

We will utilize the above RFM to calculate the ozone concentrations that would result from different combinations of reductions in precursor NOx and VOC emissions and plot ozone isopleths as shown in Figure 4-1. For higher accuracy, the ozone isopleths for the total anthropogenic emissions will be produced by constructing the RFM model in a step-wise fashion, using the three DDM/HDDM runs at 100%, 50% and 10% emissions levels. The ozone isopleths will be also produced for each of the 7 sectors in Table 4-2 (onroad mobile gasoline vehicles, onroad mobile diesel vehicles, nonroad mobile, volatile chemical products, other nonpoint, electricity generation point, or non-electricity point sources). We will produce above ozone isopleths for each of the 14 areas of concern listed in Table 4-4 as well as at each monitors or designated receptor locations in these areas.

Table 4-4. 2015 O3 NAAQS Nonattainment and Maintenance Areas in the LADCO region

Area Name	State(s)	Designation	2016-18 O3 DV (ppb)
Chicago	IL/IN/WI	Marginal	0.079
St. Louis	IL/MO	Marginal	0.074
Louisville	IN/KY	Marginal	0.075
Cincinnati	OH/KY	Marginal	0.075
Columbus	OH	Maintenance	0.069
Cleveland	OH	Marginal	0.074
Detroit	MI	Marginal	0.074
Berrien County	MI	Marginal	0.073
Allegan County	MI	Marginal	0.073
Muskegon County	MI	Marginal	0.076
Milwaukee	WI	Marginal	0.074
Sheboygan County	WI	Marginal	0.081
Manitowoc County	WI	Marginal	0.073
Door County	WI	Marginal	0.073

We will also produce stacked bar charts for each receptor to present the contributions of sectors` emissions (split as VOC and NOx) to peak ozone and from sectors` emissions at time-split level.

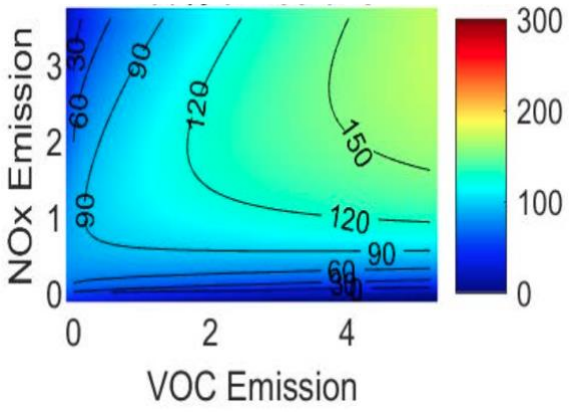

Figure 4-1. Example isopleths of maximum 8hr ozone concentration (in ppb) versus anthropogenic NOx and VOC emissions (2016 levels as 1.0) for Azusa, CA site on July 23, 2016, developed by using CMAQ-DDM sensitivities.

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.

We will produce ozone isopleth and stacked bar charts for each LADCO receptor area of concern that provide useful information in determining the most effective control strategies for specific non-attainment areas. We will prepare PowerPoint presentation describing and interpreting the ozone sensitivity analysis and a chapter in final report on the ozone sensitivity analysis, including recommendations for optimal ozone control strategies in each LADCO receptor area.

Section 5: Model Performance Evaluation Protocol

The model evaluation described in this section applies to the 2016 episodic CAMx modeling. All products, including performance statistics and graphics, will be prepared for the 100% total anthropogenic episodic runs of CAMx-DDM/HDDM over the LADCO-4 domain only.

5.1 Ambient Air Quality Data from EPA

We will collect the available surface air quality measurement data over the LADCO-4 domain for the 2016 LADCO O_3 sensitivity modeling periods. In particular, we will collect surface measurement data of air quality from the EPA database AQS, which includes STN, PAMS, SLAMS and Air Toxics networks. The following sections describe the data that we will collect for this project and the types of evaluation that will be performed with the data.

Georgia Tech uses the AQS data routinely in air quality model evaluations. AQS compiles and provides access to datasets from multiple national observational networks/programs including SLAMS and PAMS. The SLAMS network provides hourly measurements of criteria air pollutants including PM2.5, PM10, O3, SO2, NO2, CO etc. The PAMS network measures photochemical smog related species such as O3, NO, NO2, NOy, Total NMOC, and around 60 VOC compounds.

The ambient air quality measurement data that will be used for evaluating model performance are summarized in Table 5-1.

Table 5-1. Surface Air Quality Data available for model performance evaluation in the Great Lakes Region

Variable	Averaging time	Database/Networks
O_3 and NO_2	hourly	SLAMS
VOCs,NO, NO_2 and NO_y	hourly (or 3hourly)	PAMS

Surface measurements from the above specific networks and from EPA AQS database are already quality-checked and well documented. Use of these existing data will be documented by archiving the data's original documentation. In addition, we will use the provided measurement uncertainty information to further screen the datasets and decide whether to exclude particular data points. Spatial plots and time series plots will be made for a visual check of outliers. Additional documentation will be provided when necessary to address the issue of particular data points that seem less reliable than others. Also, descriptive statistics (mean, standard deviation, frequency distributions, etc.) will be calculated and used for data presentation and cross comparison and to facilitate peer review. Cross-checking among the networks will be made too if applicable for further assurance of the data's reliability.

5.2 Evaluation Tool

5.2.1 Atmospheric Model Evaluation Tool (AMET) 2.0

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 tables and graphic displays needed for model evaluation. AMET2 offers the high degree of automation required to handle the large number of analyses listed. AMETv2.0 also greatly facilitates the import of data needed to display multiple correlations in a single plot.

5.2.2 Package for Analysis and Visualization of Environmental (PAVE) data

PAVE is a flexible open source application to visualize multivariate gridded environmental datasets. It will be used to create 2-D spatial plots of air quality and sensitivity data.

5.3 Evaluation Procedures of Ozone and Precursors

5.3.1 Data Specifications.

For each LADCO and non-LADCO state, we will create a table of statistics including mean normalized bias, mean normalized gross error, mean observation, mean prediction, ratio of predicted to observed means, mean bias, normalized mean bias, mean fractional bias, mean error, normalized mean error, mean fractional error, and correlation coefficient. All statistics will focus on the grid cell of the monitor, not the array of grid cells near the monitor. Separate summary tables will be created for 1-hour, 8-hour, 1-hour maximum, and 8-hour maximum ozone values using (1) no threshold and (2) a threshold of ≥60 ppb (observed value). By state, episodic values will be calculated for all sites/all days and all days/one site.

Depending on the availability of observations, these same statistics will be calculated for hourly (1-hour) ozone precursors and related gas-phase oxidants (e.g., NO_2, HNO_3, H_2O_2, NO_x, NO_y, VOCs, and VOC species).

5.3.2 Approach

For each state, we will create monthly scatter plots of observed versus predicted values for 1-hour ozone/8-hour maximum ozone values (all values, no threshold).

For each site, we will create episodic time series plots of observed versus predicted values for 1-hour ozone/8-hour maximum ozone values (no threshold). We will address whether the y-axis scale can be specific to each site so that the axis covers the full range of observed values.

- For each 14 receptors of concern, we will create scatter plots, time series, for available hourly (1-hour) ozone precursors and related gas-phase oxidants from SLAMS and, if available, PAMS sites (e.g., NO_2, NO_x, NO_y, and VOCs).

- Episodic tile plots of ozone performance (such as MNB and MNE) values.

We will compare modeled ozone statistics to commonly used evaluation criteria for ozone model performance (Emery et al., 2017). For mean normalized bias (MNB) and mean normalized error

(MNE), hourly predicted and observed ozone pairs with the observed ozone value greater than 60 ppb will be used.

Recommended performance goals and criteria will be used to help identify areas that can be improved upon in future modeling. Exceeding these levels of performance may indicate fundamental concerns with the modeling system. We will assess the implications of model performance deficiencies on the subsequent sensitivity analyses.

Section 6: Data Backup and Archival Protocol

We pack our data (typically emissions are zipped, meteorology and air quality data are not) in 8TB external hard drives and shelve them in a locked faculty office of the Ford Environmental Science and Technology Building in steel bookcases. Each drive is labeled properly and the list of its contents is inserted in the package. Electronic copies of the contents are saved on regularly backed-up drives.

Section 7: Computer Resources

The computational resources of LAMDA at Georgia Tech that will be dedicated to complete the project consist of one 2-node cluster (each node has quadruple 2.4 GHz AMD Opteron 6378 16-core processors with 128 Gigabytes memory). The 2-node cluster is managed by Georgia Tech's Partnership for an Advanced Computing Environment (PACE) team (https://pace.gatech.edu/). PACE provides Georgia Tech faculty participants a sustainable leading-edge high performance computing (HPC) infrastructure with technical support services. The PACE system provides each user with 7 Terabytes scratch space for short term (90 days) run-time usage for free and extra online longer term storage space for rent. We will rent another four 24-core compute nodes (dual-socket, 12-core Intel Xeon Gold 6226 "Cascade Lake" @ 2.7 GHz or equivalent) for 6 months in order to speed up the sensitivity modeling tasks. We will rent 20 Terabytes space for 6 months on the PACE system for online storage of the modeling input and output data.

Section 8: Project Team Roles and Responsibilities

Task 1.1. Modeling Protocol

Task Leader: Talat Odman

Task 1.2. Data Acquisition and Preparation

Task Leader: Yongtao Hu

Task 2. Sensitivity Modeling to Quantify Ozone Sensitivity in the LADCO Region

Task Leader: Yongtao Hu

Task 3. Ozone Sensitivity Analysis and Interpretation

Task Leader: Talat Odman

Task 4. Project Administration and Final Report

Task Leader: Talat Odman

Section 9: Documentation

This project will generate the following reports:

- A draft version of the sensitivity modeling protocol
- A final version of the sensitivity modeling protocol
- 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 model performance with a summary describing the implications of model performance deficiencies on the subsequent sensitivity analyses
- 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

Reports on tasks that use or develop specific data sets will include descriptions of data source(s) and methodologies used in their preparations and any information that might be critical to their use in the project (for examples, data gaps or errors). If possible, the documentation of the data will also include references (reports or publications) that may have further information on the data validity and usability.

Copies of all project reports will be retained in electronic format through the duration of the project and sent to LADCO for archival as they are generated.

Appendix A. References

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