Utah Division of Air Quality

Ozone Non-Attainment Demonstration
Wasatch Front

Modeling Protocol
October 2021

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1. Introduction

1.1. Overview of Air Quality Issue

Utah's Wasatch Front often experiences exceedances of the national ambient air quality standard (NAAQS) for ozone during the summer. The US Environmental Protection Agency (EPA) has designated two areas along the Wasatch Front as Marginal Nonattainment for the 2015 Ozone NAAQS. These consist of the Northern and Southern Wasatch Front Nonattainment areas. The Northern Wasatch Front Nonattainment Area includes Salt Lake and Davis Counties and portions of Tooele and Weber Counties while the Southern Wasatch Front Nonattainment Area includes a part of Utah County.

Recent design value (DV) calculations over 2017-2019 indicate that the Southern Wasatch Front area has attained the ozone NAAQS while the Northern Wasatch Front continues to exceed with a peak DV of 77 ppb.

Ozone along the Wasatch Front has a mix of different sources, both local and non-local. These sources can also be derived from both anthropogenic and natural sources, including stratospheric transport, wildfires, biogenic emissions as well as US and international anthropogenic sources.

1.2. Related Studies

Multiple air quality modeling and monitoring studies investigating summertime ozone formation and transport along the Wasatch Front have been conducted over the past several years. A summary of select studies is provided below.

To better understand the physical processes related to the Great Salt Lake and their influence on ozone formation along the Wasatch Front, an air monitoring campaign was conducted in summer 2015, where 26 surface ozone sensors were deployed in rural and urban locations to continuously monitor ozone concentrations during that period[1]. The network of ozone monitoring sites was also supplemented by ozone sensors mounted on several vehicles, a public transit light-rail car, a news helicopter, a tethered sonde and an unmanned aerial vehicle. Findings showed that the Great Salt Lake influenced ozone concentrations along the Wasatch Front through various mechanisms. Lake-induced wind systems modulated the transport and exchange of background ozone and ozone precursors between the lake and urban environments. Nocturnal land breezes from the Wasatch Front towards the lake transported ozone precursors towards the lake. On the other hand, afternoon lake breezes transported at times air with higher ozone and precursor concentrations towards the Wasatch Front while at other times they advected cleaner air into the urban corridor. Other lake-related factors influencing ozone concentrations included the impact of lake-modulated boundary-layer depth on the vertical mixing of pollutants over the lake and along the Wasatch Front. The relatively cool lake surface in early June led to a shallow boundary layer over the lake. Moreover, it was hypothesized that the reduced lake level exposes highly reflective surfaces, leading to increased ozone production photochemistry. Potential biogenic precursor sources in the wetlands surrounding the southeastern portion of the lake are also potential contributors to ozone formation.

Another relevant study to this work is an air monitoring campaign conducted in 2020 to determine the role of canyons flows in O3 transport and formation and to help better understand sources and

[1] 2015 Great Salt Lake Summer Ozone Study. https://documents.deq.utah.gov/air-quality/planning/technical-analysis/research/northern-utah-airpollution/gsl-ozone/DAQ-2017-014353.PDF

levels of background ozone[2]. The study consisted of deploying O3 monitors at 2 urban sites as well as 4 sites located throughout Red Butte Canyon, a tributary canyon that is adjacent to Salt Lake City. The sites spanned various altitudes and measurements were conducted all year long. Findings helped better understand O3 transport patterns from canyons around the Salt Lake Valley.

Several modeling studies were also conducted, including the WRAP/WAQS 2014 shakeout study[3], which consisted of developing a regional photochemical grid model modeling platform for the western U.S. and 2014 calendar year. The platform was built to primarily help support western states in air quality planning. Other objectives included using the platform to 1) evaluate regional transport of ozone, fine particulate (PM2.5), visibility impairment and nitrogen deposition (2) support ozone, PM2.5 and/or Regional Haze SIPs (3) support National Environmental Policy Act (NEPA) air quality assessments, and (4) use, if permitting, as part of the Prevention of Significant Deterioration (PSD) program. 36/12 km domains were considered for the simulations, with the 36 km covering the continental US and the 12 km focusing on the Western US.

More recently, to evaluate the potential applicability of Section 179B provisions for the Wasatch Front Ozone Nonattainment Areas, Ramboll conducted a preliminary modeling analysis that quantitatively estimated the contribution from global international anthropogenic ozone transport to the Wasatch Front. They applied both the Community Multiscale Air Quality (CMAQ[4]) and the Comprehensive Air quality Model with extensions (CAMx[5]) photochemical models using EPA-derived meteorology and emission datasets representing conditions during 2016. They also considered two approaches, a sensitivity analysis and a source apportionment method. For the sensitivity analysis, which was conducted using CMAQ, two simulation runs were considered. These included a base case where all emission sources were included and a sensitivity scenario where emissions from international anthropogenic sources were zeroed out. The source apportionment analysis, which was conducted in CAMx, consisted of tracking emission contributions from Utah, the rest of the US, and international anthropogenic sources to total ozone at Wasatch Front monitors. Ramboll concluded that results from both approaches and models showed an underprediction in ozone on high ozone days, most likely due to a lack of local ozone production, which could lead to an overestimation in the international contributions to local DVs. Ramboll, however, estimates that the related error is likely less than 2 ppb.

1.3. Proposed Modeling Demonstration

The proposed O3 State Implementation Plan (SIP) modeling attainment demonstration builds on findings from past monitoring studies and modeling simulations for the Wasatch Front. Previous assessments will be used to help inform the modeling process and interpret the simulation results. Updated emissions inventories, findings from recent and past special research studies, most recent regulatory modeling systems (Sparse Matrix Operator Kernel Emissions (SMOKE), WRF, CAMx) will also be considered when developing the modeling platform and evaluating the model.

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[2] https://deq.utah.gov/air-quality/the-red-butte-canyon-air-mass-exchange-and-pollution-transport-study
[3] https://views.cira.colostate.edu/iwdw/docs/WRAP_WAQS_2014v2_MPE.aspx
[4] EPA, 2020. CMAQ: The Community Multiscale Air Quality Modeling System website: https://www.epa.gov/cmaq.
[5] Ramboll, 2020. Comprehensive Air Quality Model with extensions website: http://www.camx.com/home.aspx.

1.4. Key Personnel, Participants and Roles

The air quality modeling team at UDAQ will be responsible for preparing and processing the emissions as well as conducting the meteorological and photochemical grid simulations.

1.5. Involvement of External Scientific Experts

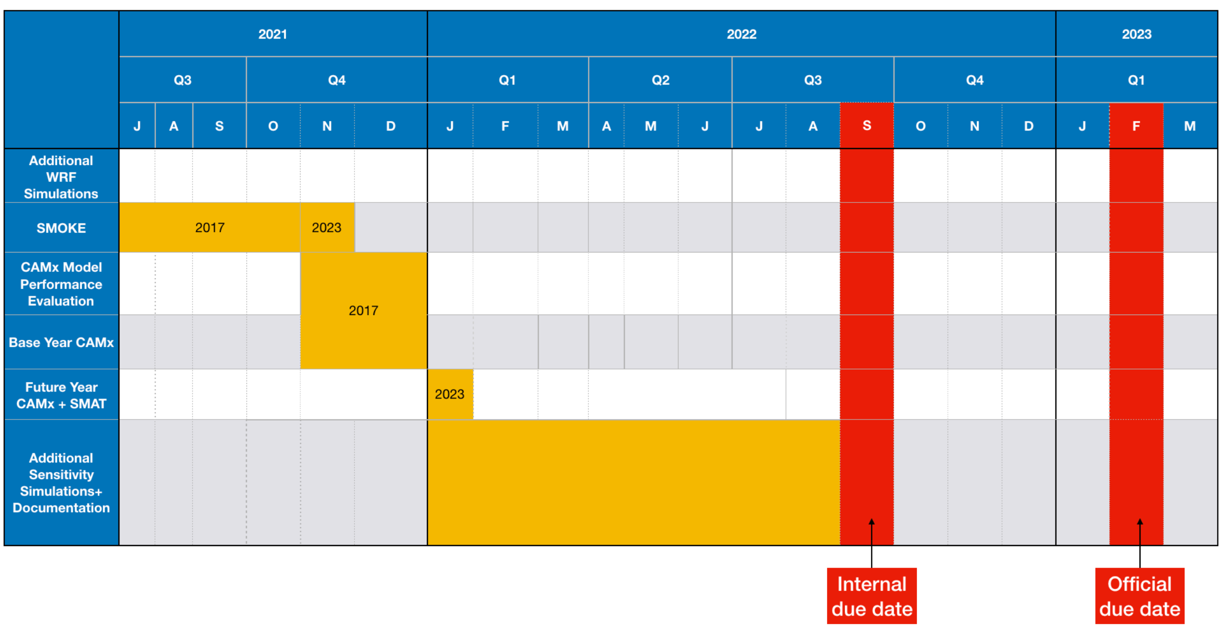
The modeling team at UDAQ will work closely with Gail Tonnesen, air quality modeler at EPA Region 8, and Alison Eyth with EPA's emissions modeling team throughout the modeling process. Communication with them has actually already been initiated and technical assistance, particularly with emissions preparation, has been provided. Regular monthly meetings between EPA and the modeling team are also already in progress. Interim deliverables (e.g. preliminary model performance evaluation results, meteorological modeling results, emissions assumptions, ...) will also be frequently shared to allow for corrective action as necessary.

The modeling team also maintains a strong working relationship with Ramboll, the developer of CAMx photochemical model. Ramboll provided UDAQ with technical assistance with running the Weather Research and Forecasting (WRF) meteorological model and completed the GEOS-Chem global simulations needed for providing initial and boundary conditions for the photochemical model. Modelers at UDAQ will continue to seek technical support and feedback from Ramboll, as needed.

1.6. Schedule for Completion

A timeline for completion of the O3 attainment SIP demonstration for the Wasatch Front is provided below.

Table 1. Timeline for completion of SIP attainment demonstration.



2. Conceptual Model

Ozone exceedance events in the non-attainment area are typically associated with the following meteorological conditions:

- Presence of an upper level high pressure system that brings warmer temperatures

- Low surface winds and lack of frontal passage
- Thermally-driven upslope and downslope flows

All these conditions are conducive to ozone formation and lead to the accumulation of ozone and its precursors.

3. Model Selection

3.1. Selection Criteria

Models were selected following EPA's guidance for regulatory modeling in support of ozone attainment demonstrations[6]. Key criteria recommended by EPA for model selection include the following:

- The model should have received a scientific peer review
- The model should be demonstrated to be applicable to the problem on a theoretical basis
- Availability and adequacy of databases to support the model application
- Appropriate performance evaluations of the model or technique have shown that the model or technique is not inappropriately biased for regulatory application.
- A protocol on methods and procedures to be followed has been established
- Model has a user's guide and technical description
- The availability of advanced technical features (e.g., probing tools or science algorithms)
- When other criteria are satisfied, resource considerations may be important and are a legitimate concern.

The Weather Research and Forecasting (WRF) model will be used for meteorological modeling. The Sparse Matrix Operator Kernel Emissions (SMOKE) will be used for emissions modeling of most source categories while BEIS will be used for biogenic emissions modeling. The MOtor Vehicle Emissions Simulator (MOVES) will also be used along with SMOKE for mobile source emissions modeling. The Comprehensive Air-quality Model with Extensions (CAMx) will be used for photochemical grid modeling. These models satisfy EPA's model selection criteria and have extensively been used in past SIP demonstrations by UDAQ and other state and local agencies.

3.2. Meteorological Model

Meteorological inputs for the Wasatch Front Ozone SIP demonstration were produced using the Weather Research and Forecasting Advanced Research model (WRF-AWR) version 4.2[7]. WRF has been used successfully for previous modeling efforts in Utah, including the PM2.5 SIP for the Wasatch Front. WRF has been used on a regional and national scale for ozone non-attainment work. The WRF simulation will cover the time period of June 14th, 2017 at 12:00:00 UTC to August 2nd, 2017 at 00:00:00 UTC to generate adequate spin-up for the photochemical model.

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[6] US EPA. Modeling Guidance for Demonstrating Air Quality Goals for Ozone, PM2.5, and Regional Haze. https://www.epa.gov/sites/production/files/2020-10/documents/o3-pm-rh-modeling_guidance-2018.pdf

[7] Skamarock, W. C., Klemp, J. B., Dudhia, J., Gill, D. O., Liu, Z., Berner, J., … Huang, X. -yu. (2019). A Description of the Advanced Research WRF Model Version 4 (No. NCAR/TN-556+STR). doi:10.5065/1dfh-6p97

3.3. Emissions Model

3.3.1. SMOKE

The emissions processing model used in conjunction with CAMx is the Sparse Matrix Operator Kernel Emissions Modeling System (SMOKE version 4.7[8]). Modeling staff at UDAQ have been using SMOKE on a regular basis since 2001. The emissions processing model takes the annual, county-wide emissions inventory and reformulates it for use in the air quality model. There are three aspects to this reformulation of the inventory which, in the end, produces a refined version of the inventory for input into CAMx:

1. Temporal: Convert emissions from annual to daily, weekly and hourly values.
2. Spatial: Convert emissions from a county-wide average to gridded emissions.
3. Speciation: Break NOx, VOC, and other grouped emissions into their component subspecies using the latest, Carbon Bond 6 (CAMx CB AE6), speciation profiles.

This modeling demonstration leverages the 2016 NEI platform[9] in conjunction with 2017 inventories collected and developed by UDAQ. SMOKE is run to prepare emissions for CMAQ, and the resulting outputs are converted to UAM format to be input to CAMx. Conversion is accomplished by scripts developed as part of the 2016 platform[10]. Emissions sectors to be processed are described in the table below.

Table 2. SMOKE Emissions sectors to be processed.

Sectors	Description/Examples	Spatial	Temporal
Point/Facility Inventory	EGUs, airports, point oil and gas sources, commercial and industrial facilities	lat-lon location	Continuous Emissions Monitoring System (CEMS) data for EGUs are hourly by unit
Nonpoint (area)	fugitive dust, agricultural, residential, industrial/commercial fuel comb., gas stations, biogenics	county-based	Some nonpoint sectors are meteorologically adjusted, but most are monthly emissions and then aggregated & summed for the NEI
Onroad mobile sources	cars and trucks driving on roads	county-based	hourly emissions and then aggregated & summed for the NEI
Nonroad mobile sources	mobile sources not on roads including rec. marine, construction equip., lawn/garden, tractors	county-based	monthly (summed in the NEI)
Events	wildland and prescribed fires	lat-lon / day	hourly emissions and then aggregated & summed for the NEI

Fires are processed as 3-dimensional emissions sources in SMOKE, because CAMx does not support plume rise calculations for fires. Fires are layered in SMOKE and then converted to CAMx ptsr format. SMOKE will be run for the modeling episode duration, with additional days prior to the start of the episode to account for time needed for spin-up of the photochemical model.

[8] https://www.cmascenter.org/smoke/
[9] https://www.epa.gov/air-emissions-modeling/2014-2016-version-7-air-emissions-modeling-platforms
[10] CMAQ to CAMx conversion package: https://gaftp.epa.gov/Air/emismod/2016/v1/cmaq2camx_20nov20.zip

3.3.2. MOVES

MOtor Vehicle Emission Simulator (MOVES) is run for the State of Utah prior to SMOKE initiation. Resulting emissions from MOVES are provided in tons per day. MOVES estimates emissions from onroad motorized vehicles including passenger cars, motorcycles, minivans, sport-utility vehicles, light-duty trucks, heavy-duty trucks and buses.

3.3.3. BEIS

BEIS3.7 is leveraged in this modeling demonstration. BEIS calculates CO, VOC, and NO from biogenic sources (vegetation and soils) using land use and meteorological data. Land use and meteorological data are sourced from WRF and then processed in MCIP before being input to BEIS. Emission factors in BEIS vary from summer to winter. This modeling demonstration leverages the summertime emission factors in BEIS, because the modeling episode is limited to summer 2017.

3.3.4. Description of 3D Fires Emissions Modeling in SMOKE

Emissions from fires are calculated as 3D plumes in SMOKE using a SMOKE program called Laypoint. Laypoint uses gridded, hourly meteorological data and stack parameters to calculate the plume rise for all point-source emissions[11]. Wildland fires and burns obviously do not have stacks, so "imaginary stacks" are set at each layer in the 3D model. The "imaginary stacks" inject fire emissions into every vertical layer.

To avoid double-counting these layered fire emissions between the inner and outer domains, all fire emissions in the outer domains that are overlapped by the inner domains will be zeroed out if the photochemical model is run in a two-way nested configuration. Masking will be done using a masking script provided by EPA from their 2016 regional haze addendum platform[12].

3.4. Air Quality Model

The Comprehensive Air-quality Model with Extensions (v7.10) will be used for photochemical modeling. This model is a state-of-the-science photochemical grid model that comprises a "one-atmosphere" treatment of tropospheric air pollution (ozone, particulates, air toxics) over spatial scales ranging from neighborhoods to continents[13]. CAMx is publicly available and is an open-source system that is computationally efficient and flexible. This model meets all model selection criteria recommended by EPA. It also supports two-way grid nesting and includes a subgrid-scale Plume-in-Grid module. CAMx has also been extensively used in past ozone and PM2.5 State Implementation Plan demonstrations by UDAQ and other state and local agencies. EPA ozone guidance also explicitly mentions that CAMx along with CMAQ are the most commonly used chemical transport models for attainment demonstrations. The most recent version of CAMx (v7.10) will be used for this work. This version includes several updates including updates to chemical reactions for inorganic and simple organic species that play important roles in ozone formation.

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[11] SMOKE 4.7 manual, page 82: https://www.cmascenter.org/smoke/documentation/4.7/manual_smokev47.pdf
[12] Fires masking package:
https://gaftp.epa.gov/Air/emismod/2016/beta/2016fg_addendum/2016fg_scripts_addendum_to_2016ff.zip
[13] Ramboll. User's Guide Comprehensive Air-quality Model with extensions Version 7.10. https://camx-wp.azurewebsites.net/Files/CAMxUsersGuide_v7.10.pdf.

4. Modeling Episode Selection

4.1. EPA Episode Selection Criteria

The following criteria were considered for selecting a modeling episode, in conformance with EPA's "Modeling Guidance for Demonstrating Attainment of Air Quality Goals for Ozone, PM2.5, and Regional Haze"[14]:

1. Time period is close to the most recently compiled and quality assured National Emission Inventory (NEI).
2. Observed concentrations during the selected time period are close to the appropriate base year design value and span a sufficient number of days. This ensures that the modeled attainment test applied at each monitor violating the NAAQS is based on multiple days.
3. Time episode is characterized by low pollution days preceding and following high pollution concentration days. This ensures that the modeling system appropriately characterizes low pollution periods, development of elevated periods and transition back to low pollution periods through synoptic cycles.
4. Time period is representative of a variety of meteorological conditions conducive to elevated ozone levels. Choose time periods which reflect a variety of meteorological conditions that frequently correspond with observed 8-hour daily maxima concentrations greater than the level of the NAAQS at monitoring sites in the non-attainment area.
5. Availability of observed ambient data, meteorology and special studies measurements for the selected time period.

4.2. Selected Episode

Summer (June 15 - 31) 2017 was selected as the modeling period, with days in June included to allow for sufficient model spin-up time. This episode was selected after a careful examination of several summertime episodes that exhibited multiple ozone exceedances. These included 2014, 2016, 2017 and 2018. Selection was based on an analysis of meteorological conditions and pollutants spatio-temporal trends to ensure that the selected time period satisfies EPA's recommended selection criteria. This included evaluating the number of ozone exceedances per episode, hourly PM2.5 concentrations as well as hourly and daily maximum 8-hr average (MDA8) ozone concentrations. Episodes that were characterized by multiple exceedances and exceedances throughout the non-attainment area were preferred. Factors including emissions and ambient data availability and the occurrence of wildfires were also considered. The availability of boundary conditions for the photochemical model was also taken into account.

Compared to the other episodes, summer 2017 was characterized by multiple exceedances, with the exceedances occurring throughout the non-attainment area and mostly in July (Figures 1-4 and Table 3).

[14] https://www.epa.gov/sites/production/files/2020-10/documents/o3-pm-rh-modeling_guidance-2018.pdf

Table 3. Number of exceedances at monitoring sites within the northern Wasatch Front O3 non-attainment area during June-September 2014, 2016, 2017 and 2018.

Time Period		Monitoring Station						
		Bountiful	Hawthorne	Herriman	Erda	Harrisville	Ogden	Brigham City
2014	Jun.	3	0	-	-	2	2	1
	Jul.	3	3	-	-	1	0	1
	Aug.	1	2	-	-	0	1	0
	Sept.	0	0	-	-	0	0	0
2016	Jun.	3	2	6	2	4	3	0
	Jul.	1	1	3	0	1	0	0
	Aug.	4	3	3	3	3	3	0
	Sept.	0	0	0	0	0	0	0
2017	Jun.	1	2	2	2	3	1	0
	Jul.	14	11	8	10	6	9	2
	Aug.	1	1	2	2	1	1	0
	Sept.	5	5	5	2	1	2	1
2018	Jun.	3	4	4	2	1	1	0
	Jul.	3	3	6	1	3	8	3
	Aug.	5	1	9	3	5	6	2
	Sept.	0	0	0	0	0	0	0

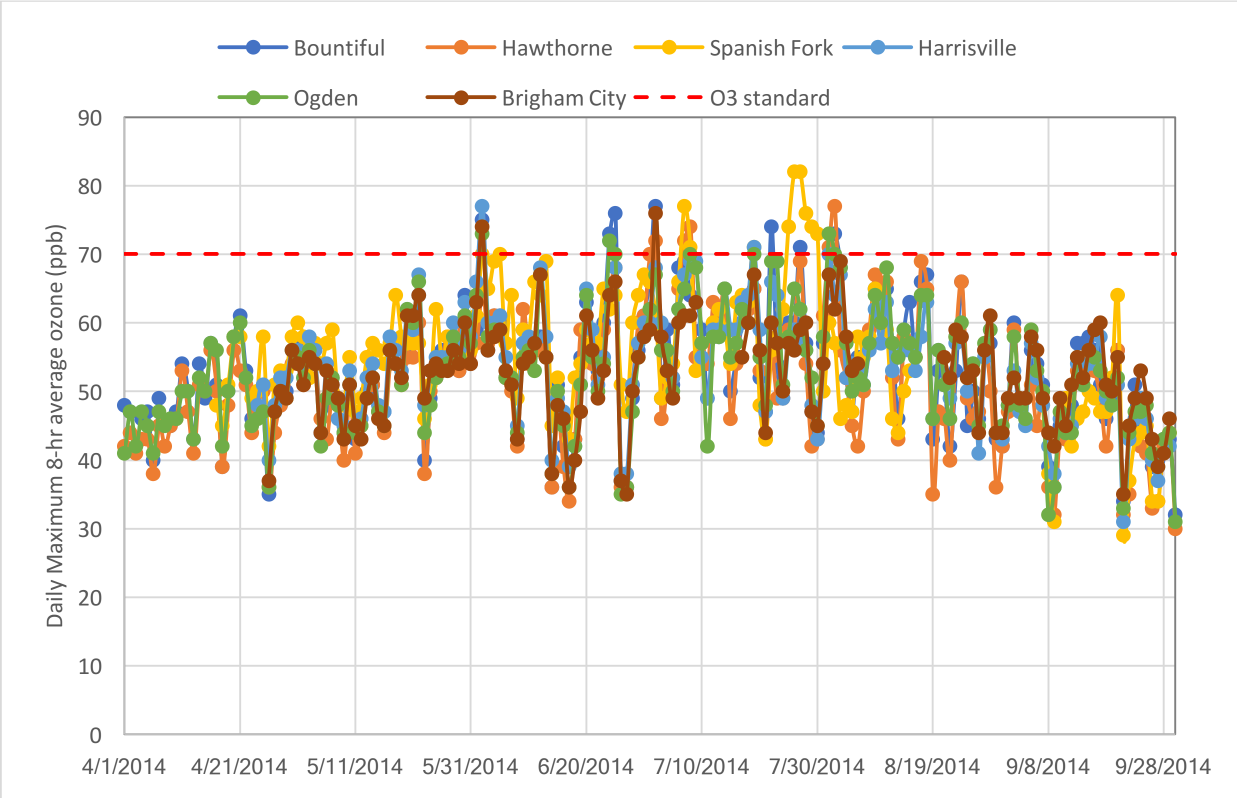

Figure 1. Maximum daily 8-hr average ozone concentration during April-September 2014.

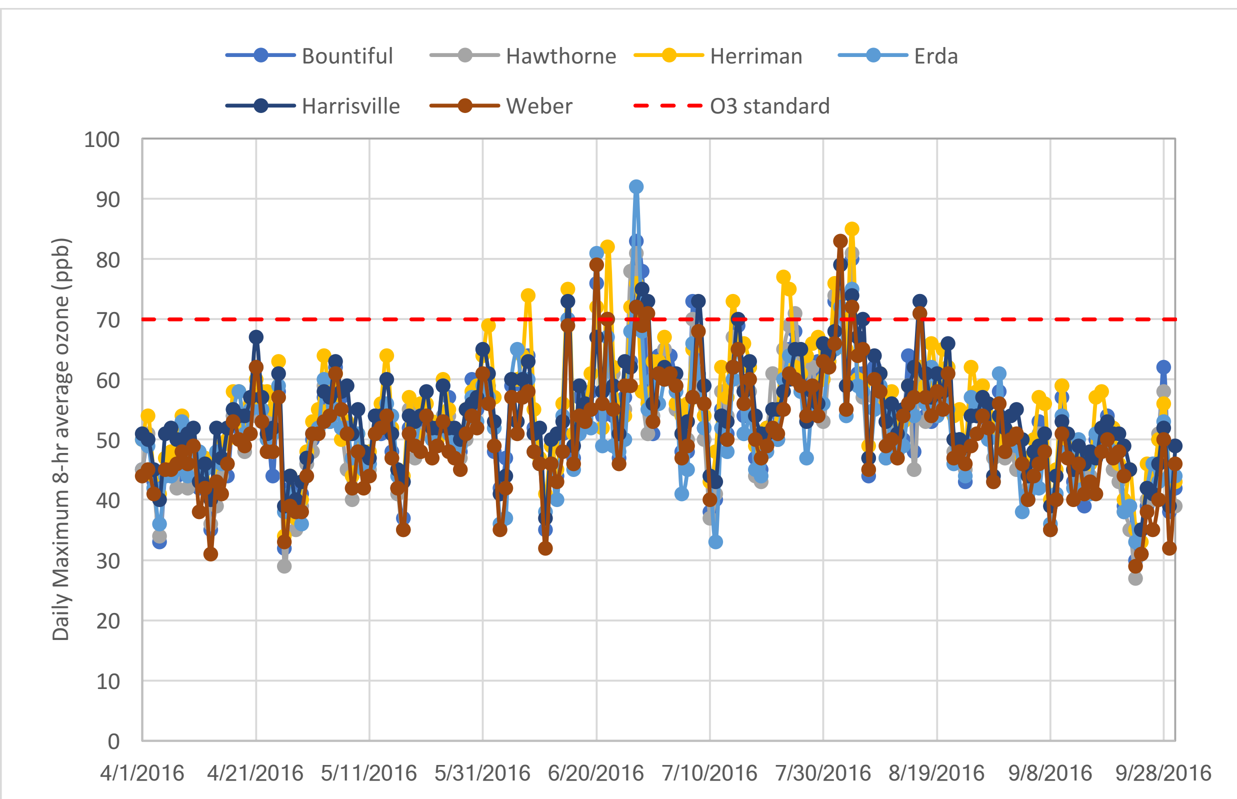

Figure 2. Maximum daily 8-hr average ozone concentration during April-September 2016.

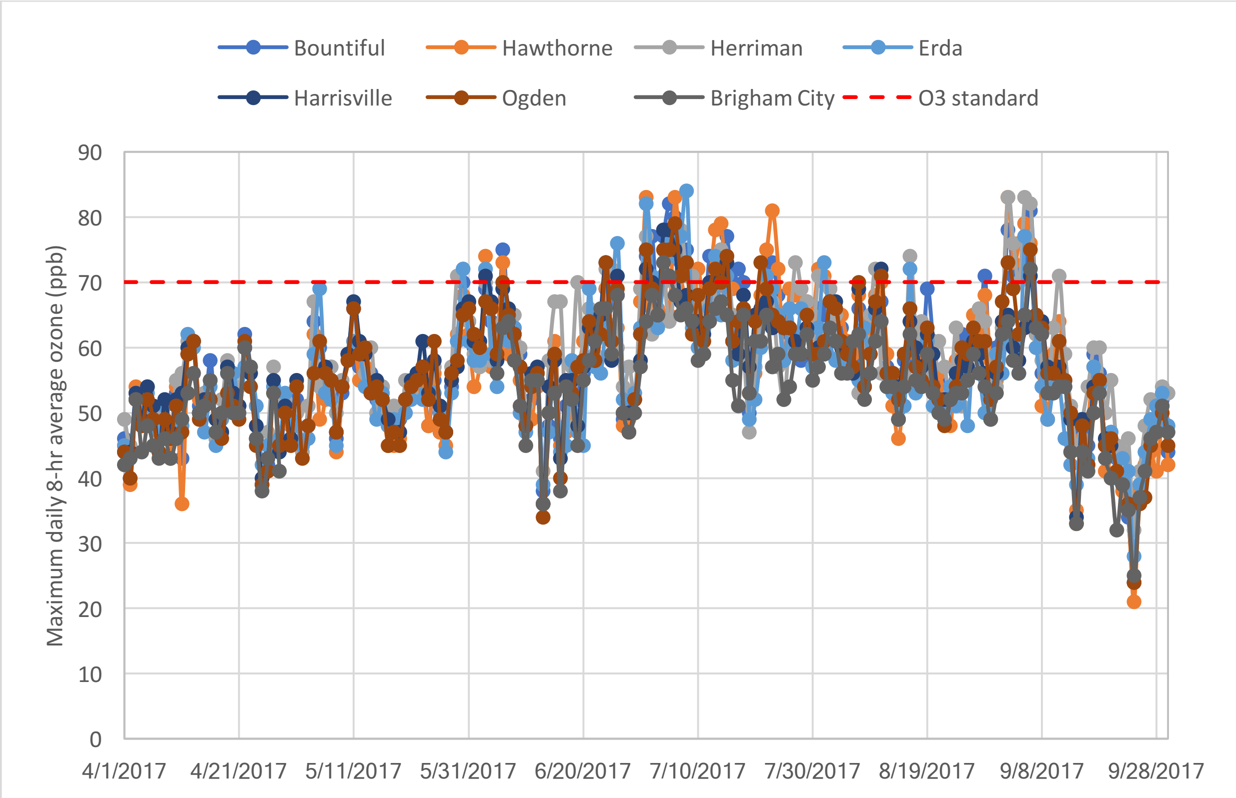

Figure 3. Maximum daily 8-hr average ozone concentration during April-September 2017.

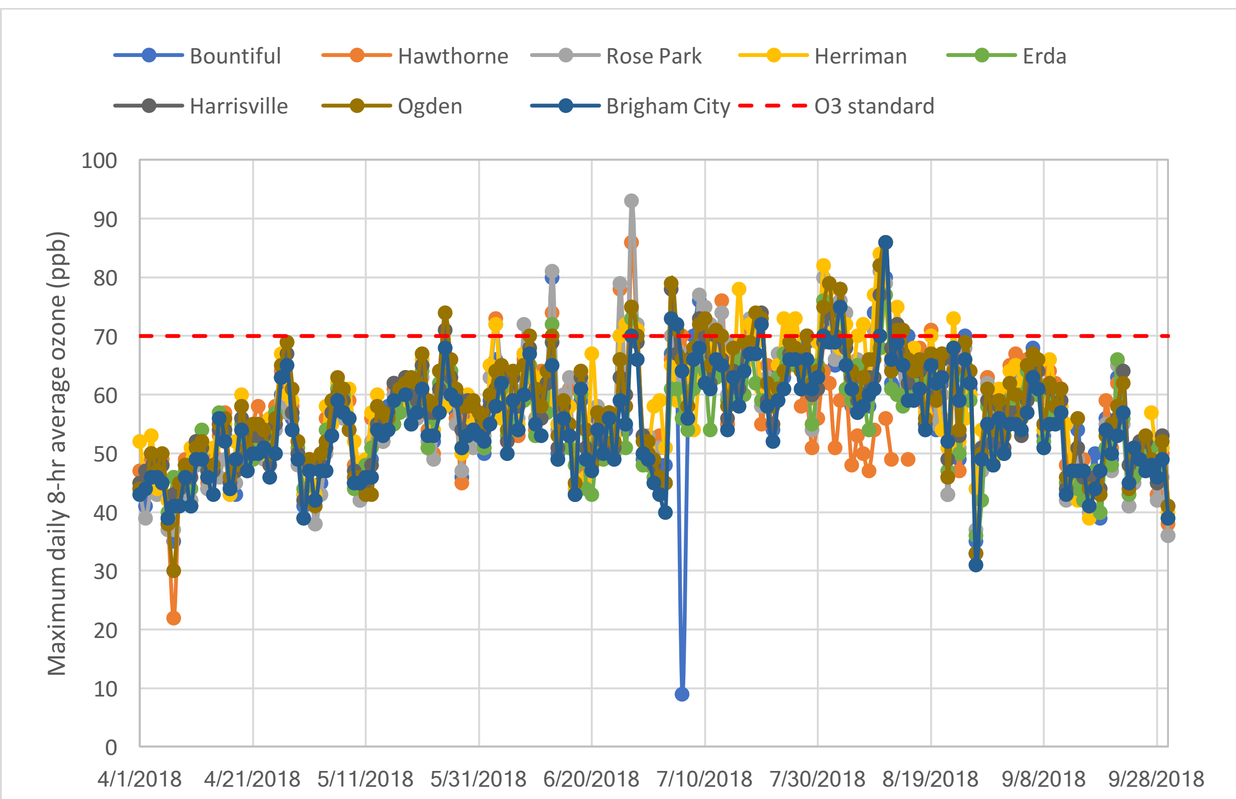

Figure 4. Maximum daily 8-hr average ozone concentration during April-September 2018.

While wildfires occurred during summer 2017, they mostly occurred during September, with wildfire smoke emissions strongly influencing ozone concentrations, as suggested by an examination of satellite imagery from the Hazard Mapping System (HMS), O3 and PM2.5 trends and backtrajectory wind analysis (Figure 5). MDA8 O3 concentrations ranged between 71-82 ppb at Bountiful station during September 2-6 when wildfires were observed and O3 exceedances were measured. PM2.5 concentrations also increased during the same time period, reaching average daily levels as high as 43 ug/m3 at that location. Since exceedances in September are most likely largely driven by wildfire emissions, the month of September is excluded from the modeling episode. Moreover, since most exceedances occurred in late June-July, early June and August are also excluded.

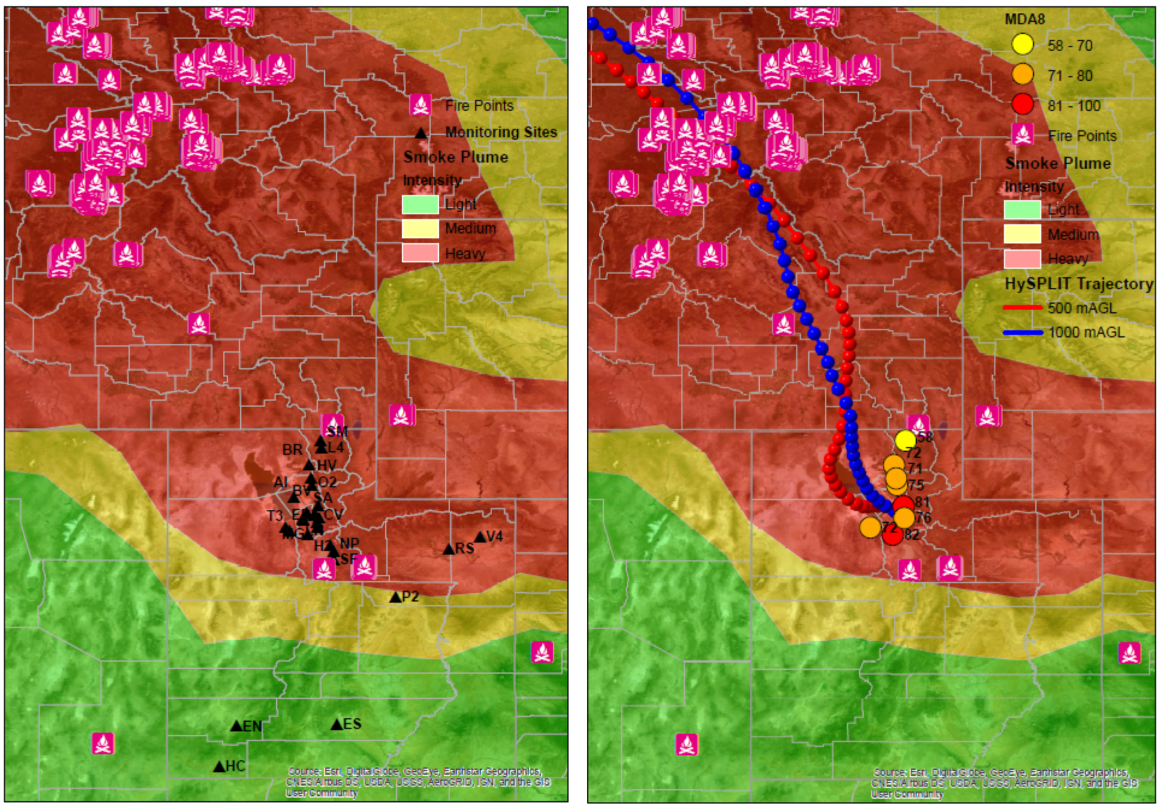

Figure 5. Fire locations, smoke plume intensity, backtrajectories and maximum daily 8-hr average (MDA8) ozone concentration on September 6 2017.

Furthermore, hourly ozone concentrations at receptor sites within the non-attainment area varied from low to high concentrations, which will help evaluate how well the model replicates both high and low ozone concentration days. This 2017 episode also corresponds to a year with the most recent currently available NEI. Routine air quality and meteorological data are also available for 2017, with this year being representative of typical conditions conducive to ozone formation. A detailed examination of synoptic patterns during the selected period showed that the majority of ozone exceedance days are characterized by an upper level high pressure system that brings warm temperatures, lack of frontal passage, low surface winds and increased solar radiation; all of which are conducive to the build-up of O3 and its precursors. While wildfire events occurred during July 2017, an examination of hourly PM2.5 concentrations (Figure 6) suggests that their influence on local O3 concentrations was not significant. With the exception of July 4-5, daily average PM2.5 concentrations on exceedance days were less than monthly average + 1 standard deviation July concentrations. GEOS-Chem boundary conditions through Ramboll via contract with the Western States Air Resources Council (WESTAR) are also available for this year.

4.3. Episodic Modeling Justification

Ozone exceedance events in the northern Wasatch Front NAA are associated with specific conditions including the presence of an upper level high pressure system, increased solar radiation, low surface winds, thermally-driven flows and lack of frontal passage. Compared with the rest of the calendar year, days affected by these conditions are relatively infrequent. Episodic modeling allows us to focus on model performance during these events. It is also computationally more efficient to concentrate on modeling these episodes. The time and effort saved allows us to make rapid improvements to our modeling platform and to conduct sensitivity simulations that help inform how the model is performing.

4.4. Base Year and Future Year Selection

2017 was selected as the base year for modeling and for conducting model performance evaluation. This year corresponds to the most recently compiled and quality assured National Emissions Inventory (NEI). Future year corresponds to 2023 with local emissions projected from the 2017 inventory.

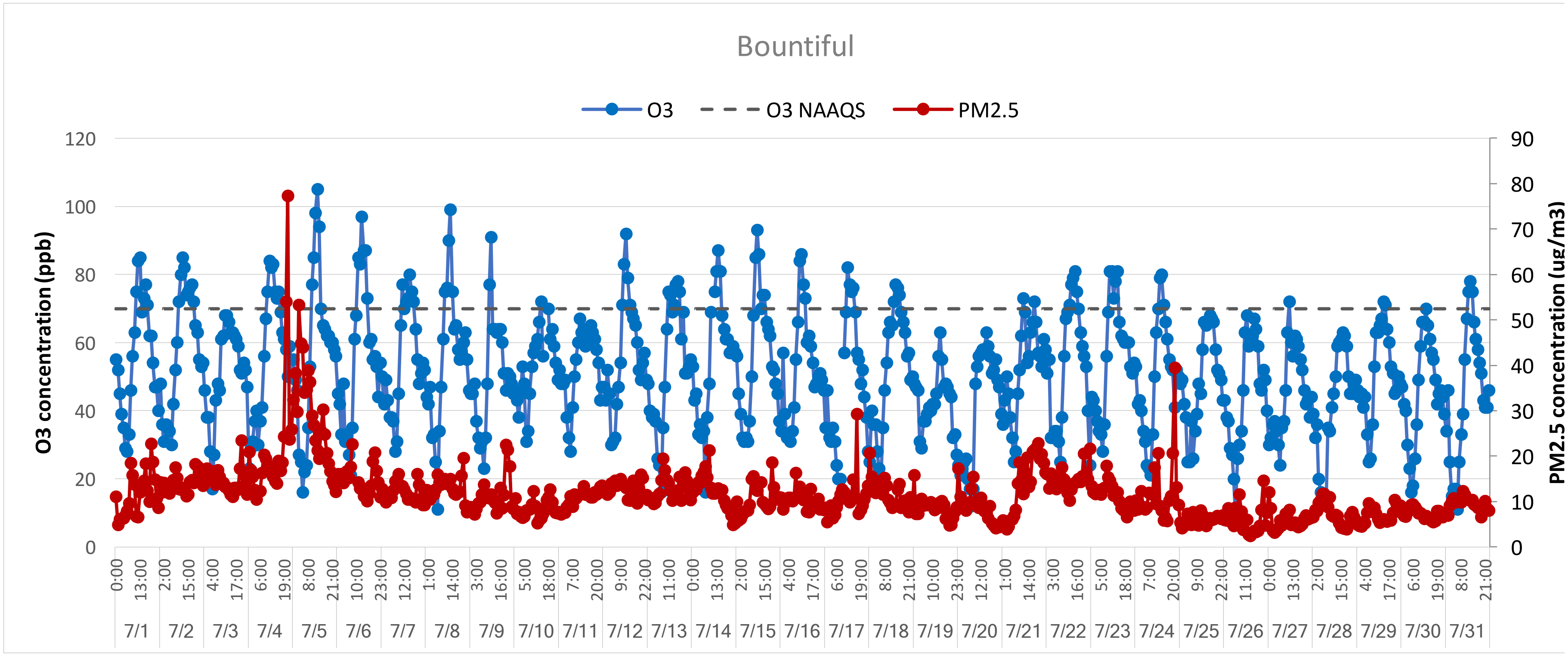

Figure 6. Hourly O3 and PM2.5 concentrations at Bountiful monitoring station during July 2017

5. Emissions Inventories

5.1. Emission Inventory Datasets

The modeling domain will consist of three 12/4/1.33 km nested grid domains (Figure 7). The 12 km domain covers the Western United States and is aligned with EPA's 12US1 domain. The 4 km domain is nested within the 12 km domain and covers the state of Utah as well as parts of neighboring states. The 1.33 km domain is nested within the 12/4 km domains and extends over the non-attainment area to provide higher resolution modeling within this area.

Figure 7. CAMx modeling domains.

12 km resolution SMOKE emissions will be determined by leveraging EPA's 12 km SMOKE outputs windowed to UDAQ's 12 km modeling domain. EPA's 12 km SMOKE run was configured according to the 2017 modeling platform. The 2017 platform inventories differ slightly from the Utah-generated inventories used in the 4 and 1.33 km SMOKE runs that will nest inside the 12 km emissions, but these differences are expected to be insignificant for the ozone attainment demonstration.

Utah emissions for the 4 and 1.33 km domains will be sourced from the Utah Division of Air Quality's 2017 Triennial Emissions Inventory. Some improvements have been made to Utah's inventories (UTEI) since their submission to the National Emissions Inventory (NEI), and those improvements are included in this modeling platform. The 2017 emissions inventory is projected to 2023 for the future year simulation.

All non-Utah emissions are sourced from the 2016 NEI as part of the EPA 2016 modeling platform[15]. UDAQ will use the 2016 platform emissions because the 2016 platform includes projected 2023 emissions needed for UDAQ's future year simulations. The 2017 platform does

[15] https://www.epa.gov/sites/production/files/2020-11/documents/2016v1_emismod_tsd_508.pdf

not have 2023 projected emissions available at this time. The 2016 platform projects the 2014 NEI to 2016. For all non-Utah states and tribes, SMOKE will process the 2016 platform projected 2014 NEI tables for the base year, and future year (Table 4). There is some inconsistency in the way the Utah and non-Utah emissions inventories were developed, however, the discrepancies are expected to have an insignificant impact on the model results.

Table 4. Emissions inventory data sources for modeling years.

Region	Base Year (Episodic Year)	Future Year
Utah	DAQ 2017 Inventory	DAQ 2023 Projections
non-Utah	EPA 2016 platform 2016 emissions	EPA 2016 platform 2023 emissions

5.2. Emissions Development

Table 5. Spatial and temporal resolution for SMOKE platform sectors, and plume rise calculations.

Sector	Sector description	Data Source	Domain	Spatial	Inventory resolution	Plume rise
afdust_adj	Met.-adjusted area fugitive dust emissions	NEI	4 km, 1.33km	Surrogates	annual	
ag	Agricultural emissions (primarily ammonia)	NEI	4 km, 1.33km	Surrogates	annual	
airports	Emissions from airport areas	NEI	4 km, 1.33km	Surrogates	annual	
biogenics	Biogenic emissions based on the BEIS model	BEIS	4 km, 1.33km	Pre-gridded land use	computed hourly	
nonpt	Nonpoint sources not in other nonpoint sectors	UTEI + NEI	4 km, 1.33km	Surrogates & area-to-point	annual	
nonroad	Mobile sources that do not drive on roads or railroads, including recreational pleasurecraft	UTEI + NEI	4 km, 1.33km	Surrogates	monthly	
np_oilgas	Nonpoint oil and gas production-related sources	UTEI + NEI	4 km, 1.33km	Surrogates	annual	
onroad	Onroad mobile source gasoline and diesel vehicles from parking lots and moving vehicles	UTEI + NEI	4 km, 1.3km	Surrogates	monthly activity, computed hourly	
pt_oilgas	Point sources related to oil and gas production	UTEI + NEI	NA*	Point	annual	in-line**
ptegu	Point sources that are Electric generating units (EGUs)	UTEI + NEI	NA*	Point	daily & hourly	in-line**
ptnonipm	Point sources that are not EGUs nor related to oil and gas	UTEI + NEI	NA*	Point	annual	in-line**
ptfire	Point source day-specific wild and prescribed fires	SMARTFIRE	NA*	Point	daily	in-line**
ptagfire	Point source day-specific agricultural fires	SMARTFIRE	NA*	Point	daily	in-line**
rail	Locomotive sources on railroads	UTEI + NEI	4 km, 1.33km	Surrogates	annual	

**Point source sectors are not gridded. Point source sectors are applicable to all modeling domains regardless of grid resolution.*

***The term "in-line" means that the plume rise calculations are done inside of the air quality model instead of being computed by SMOKE.*

5.2.1. Oil and Gas Sources

Oil and gas sector major sources, such as refineries, large compressor stations and gas plants, are treated as point sources in SMOKE.

Some oil and gas emissions categories were gap-filled after the oil and gas inventory was collected. These categories are not associated with individual sources and do not have associated latitude/longitude coordinates, so they are treated as *nonpoint* sources. The nonpoint oil and gas sector includes emissions from the following source categories: Dehydrators, Dehydrator Combustors, Fugitives, Pneumatic Controllers, Pneumatic Pumps, RICE & Engines, Separators & Heaters, Tanks (Condensate), Tanks (Oil), Tanks (Water), Tank Combustors, Truck Loading, Well Completions (Drilling), Well Completions (Venting/Flaring), Centrifuges, Solid Waste Disposal, and Produced Water Disposal Facilities, Control Effectiveness Adjustment (Water Tanks), Control Effectiveness Adjustment (Condensate Tanks), Control Effectiveness Adjustment (Oil Tanks), Midstream Vent (maintenance, startup/shutdown, malfunction), Pipeline Leaks, Greenhouse Gas Emissions Reporting Program Additions (Gap Filling), Gas Well Venting (Blowdowns), Pipeline Blowdowns and Pigging, EPA/NOMAD Oil and Gas Tool, Associated Gas Venting, CBM Dewatering Pumps, CBM Well Venting (Blowdowns), Mud Degassing.

5.2.2. Point Sources

Point sources are those with actual emissions of 100 tons per year or more for NOx and/or VOC. These include Electric Generating Units (EGUs), oil and gas point sources, and any other source exceeding the 100 TPY threshold for a single criteria air pollutant. Each point source is associated with a unique facility ID, one or more unit IDs, and a latitude/longitude coordinate. Point sources are spatially allocated according to their unique coordinates (unlike other sectors in SMOKE, which are spatially allocated according to spatial surrogates). Point sources are elevated in SMOKE according to the source's stack height. Plume-rise calculations for elevated point sources are not computed in SMOKE.

Wildland and agricultural fires are treated as 3D point sources in SMOKE. While plume rise calculations for fires are not computed in SMOKE, fires are made to be 3-dimensional by introducing several false stacks from which fire emissions are injected into 45 vertical layers in SMOKE.

5.2.3. Area, Onroad and Nonroad Source Emissions

Area sectors include: area fugitive dust (met adjusted, US), agriculture, nonpoint, nonpoint rail, and nonpoint airports. Airports are modeled using only data from the 2016 NEI for airport emissions in Utah and in surrounding states. Agricultural emissions, including primarily emissions from livestock and fertilizer, are also modeled using only data from the 2016 NEI; Utah's agricultural emissions inventory is lower resolution than the NEI, so NEI data are leveraged for the entire modeling domain.

Nonroad and onroad mobile emissions from MOVES are treated as *nonpoint* sources. Area, onroad, and nonroad emissions are spatially allocated, temporalized, and speciated by SMOKE according to spatial surrogates, temporal and speciation profiles.

5.2.4. Biogenic Sources

Biogenic emissions are modeled using the model BEIS (Biogenic Emission Inventory System). Land use data are sourced from the Biogenic Emissions Landuse Database (BELD). The 4km modeling domain for this modeling demonstration is co-located with BELD's data tiles 14 and 8. Meteorological inputs come from a Meteorology-Chemistry Interface Processor (MCIP) run based on this demonstration's WRF inputs.

5.3. QA/QC of Model-Ready Emissions

Quality assurance and quality control (QA/QC) procedures for emissions output are completed as recommended by EPA in their Emissions Inventory Preparation for Air Quality Modeling (Base Year) training[16]. Post-SMOKE files are also visually inspected in VERDI.

6. Meteorological Model

6.1. Modeling Domains

The WRF model domains were chosen to accommodate CAMx modeling domains keyed to the US1 12 km domain used by the EPA. The three one-way nested WRF domains were set to the Lambert Conformal Conic projection with horizontal resolution of 12, 4, and 1.33 km, respectively (Figure 8).

Figure 8. WRF modeling domains

6.2. Vertical Layer Configuration

Each domain has 44 vertical levels which are identical to the EPA ORD 108km hemispheric modeling configuration (Table 6). The density of layers is greater closer to the surface but still includes adequate layer coverage in the upper atmosphere to ensure upper-level subsidence and long-range transport are represented.

[16] QA/QC: slides 69, 82, 94, 140,143
https://gaftp.epa.gov/Air/emismod/training/BaseYearEmisInvsForModelingTraining_07292019.pptx

Table 6. WRF vertical layer configuration.

WRF Eta Levels					
WRF layer	**Eta**	**Pressure**	**Height agl (m)**	**Depth (m)**	**Altitude (m)**
45	0	5000	17556	1177	18,844
44	0.0186	6767	16379	1062	17,667
43	0.0386	8667	15317	958	16,605
42	0.0596	10662	14359	878	15,647
41	0.0816	12752	13481	818	14,769
40	0.1047	14947	12662	769	13,950
39	0.1289	17246	11893	730	13,181
38	0.1543	19659	11163	699	12,451
37	0.181	22195	10464	669	11,752
36	0.2089	24846	9795	649	11,083
35	0.2383	27639	9146	626	10,434
34	0.269	30555	8519	611	9,808
33	0.3013	33624	7908	597	9,196
32	0.3352	36844	7311	585	8,599
31	0.371	40226	6727	573	8,015
30	0.408	43770	6154	537	7,442
29	0.445	47313	5617	506	6,905
28	0.483	50857	5111	479	6,399
27	0.520	54400	4632	455	5,920
26	0.557	57944	4177	433	5,465
25	0.595	61487	3744	415	5,032
24	0.632	65040	3329	396	4,617
23	0.669	68584	2933	380	4,221
22	0.707	72127	2553	365	3,841
21	0.744	75671	2188	336	3,476
20	0.780	79053	1853	282	3,141
19	0.810	81988	1571	239	2,859
18	0.837	84544	1332	203	2,620
17	0.861	86767	1128	173	2,417
16	0.881	88695	956	148	2,244
15	0.899	90377	807	127	2,095
14	0.914	91840	680	109	1,968
13	0.928	93113	571	94	1,859
12	0.939	94215	477	81	1,765
11	0.949	95174	397	70	1,685
10	0.958	96010	327	61	1,615
9	0.966	96742	266	52	1,554
8	0.972	97369	214	45	1,502
7	0.978	97920	169	39	1,457
6	0.983	98395	130	34	1,418
5	0.988	98813	96	29	1,384
4	0.991	99174	67	25	1,355
3	0.995	99487	41	22	1,329
2	0.998	99763	19	19	1,307
1	1.000	100000	0	0	1,288

6.3. Model Inputs and Settings

A summary of model inputs and settings is provided below.

6.3.1. Atmospheric Data Inputs

The NCEP North American Mesoscale (NAM) 12 km analysis dataset (ds609[17]) was used to inform the boundary conditions of the outermost (12 km) modeling domain and to initialize the innermost domains. Analysis data were used in 6-hour time intervals throughout the duration of the simulation.

6.3.2. Topographic Data Inputs

The WRF pre-processor, WPS, was run using a modified version of the MODIS-derived 21 category land use datasets at 30, 15, and 5-arcsecond resolution for the 12, 4, and 1.33 km domains, respectively. Edits to the original land use dataset are described in the following section.

6.3.3. Land Use Edits of the Great Salt Lake

The MODIS 21-category land use datasets were altered to better reflect the extent of the Great Salt Lake (GSL) following the method established by Malia et al (2018)[18]. Briefly, this method uses a GSL bathymetry dataset and buoy data to identify the extent of the lake and to better calculate the actual lake depth (instead of the single lake depth value used in the traditional MODIS dataset). Areas of the GSL that are incorrectly classified as "lake" within the geogrid files were adjusted to reflect the characteristics of unvegetated salt flats for a representative gridcell. Better representation of GSL extent and depth can impact atmospheric circulations like lake breezes[19], and should yield better meteorological model performance. Table 7 describes which variables were changed to account for a change in total lake area.

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[17] National Centers for Environmental Prediction/National Weather Service/NOAA/U.S. Department of Commerce. 2015, updated daily. NCEP North American Mesoscale (NAM) 12 km Analysis. Research Data Archive at the National Center for Atmospheric Research, Computational and Information Systems Laboratory. https://doi.org/10.5065/G4RC-1N91.

[18] Mallia, D. V. (2018). *Simulating High Impact Wildfire and Wind-Blown Dust Events Using Improved Atmospheric Modeling Methods.* Ph.D. Dissertation. University of Utah. Available at: https://collections.lib.utah.edu/ark:/87278/s6pp4hgm

[19] Blaylock, B. K., Horel, J. D., & Crosman, E. T. (2017). Impact of Lake Breezes on Summer Ozone Concentrations in the Salt Lake Valley, Journal of Applied Meteorology and Climatology, 56(2), 353-370. Retrieved Apr 29, 2021, from https://journals.ametsoc.org/view/journals/apme/56/2/jamc-d-16-0216.1.xml

Table 7. List of variables altered in the geogrid files.

Variable	Old Value & Category	New Value & Category
LAKE_DEPTH	3 meters for entire lake	Calculated from bathymetry (0.2 - 8.2 m)
LANDMASK	0 (denotes lake)	1 (denotes land)
SCT_DOM	14 (denotes lake)	11 (silty clay)
SCB_DOM	14 (denotes lake)	8 (silty clay loam)
SANDFRAC	0 (denotes lake)	0.33 (fraction of sand)
CLAYFRAC	0 (denotes lake)	0.34 (fraction of clay)
SOILTEMP	0 (denotes lake)	290.80 K
LU_INDEX	21 (denotes lake)	16 (barren/sparsely vegetated)
3-D Variables		
ALBEDO12M	8, 8, 8 (Values for J, J, A)	34, 35, 33 (Values for J, J, A)
LANDUSEF	21 (denotes lake)	16 (barren/sparsely vegetated)
SOILCTOP	14 (denotes lake)	11 (silty clay)
SOILCBOT	14 (denotes lake)	8 (silty clay loam)

6.4. Model Configuration

WRF simulations for the modeling episode were run in five-and-a-half-day increments with the first 12-hours discarded as model spin-up.

6.4.1. WRF Domain Configurations

Table 8. WRF Domain Configurations

Parameter	D01	D02	D03
Grid size (x, y)	(205, 319)	(291, 291)	(249, 381)
Vertical levels	44	44	44
Vertical coordinates	Hybrid vertical coordinate	Hybrid vertical coordinate	Hybrid vertical coordinate
Horizontal resolution	12 km	4 km	1.33 km
Land use dataset	MODIS + lakes 30 arc-second	MODIS + lakes 15 arc-second	MODIS + lakes 5 arc-second
IC/BC	NAM12km/NAM12km	NAM12km/D01	NAM12km/D02

6.4.2. Physics

Table 9. Physics Parameters used in WRF simulations.

Physics Parameter	D01 (12 km)	D02 (4 km)	D03 (1.33 km)
Microphysics	Thompson	Thompson	Thompson
Longwave and shortwave radiation	RRTMG	RRTMG	RRTMG
Land Surface Model	Noah LSM	Noah LSM	Noah LSM
Planetary Boundary Layer	MYNN	MYNN	MYNN
Cumulus Parameterization	Kain-Fritsch	Kain-Fritsch	Kain-Fritsch
Analysis Nudging	T, P	None	None

6.4.3. Additional Model Variables

CAMx requires additional output variables from the WRF simulation that are not generally included in the output files. The following variables (LANDUSEF, RA, RS, PRATEC, GSW, ZNT, RMOL, MOL, CLDFRA_DP, CLDFRA_SH, QC_CU, QI_CU, UER_KF, UDR_KF, DER_KF, DDR_KF, TIMEC_KF, and PREC_ACC) were added to the WRF output files.

6.5. Model Performance Evaluation

WRF outputs are being compared to observational data using the EPA-developed Atmospheric Model Evaluation Tool (AMET). Model performance will be submitted in a separate document, but the following is a list of analyses and statistical evaluations that are being produced for the modeling episode.

6.5.1. Observational Datasets

Meteorological observations of both surface sites and vertical soundings from the rawinsonde network were downloaded from the MADIS data archive for the 12, 4, and 1.33 km domain extents. The majority of model performance statistics are focused on sites within the 4 km domain along the Wasatch Front and the 1.33 km domain.

6.5.2. Statistical Evaluation

Multiple statistical metrics will be considered to characterize the meteorological model performance. These include:

1. Mean bias (MB): This metric averages the model/observation residual paired in time and space.
2. Root Mean Square error (RMSE): This performance statistic is a measure of the average distance between predicted and observed values.
3. Normalized Mean Bias: This statistic (in units of percent) normalized MB to the average observed value.
4. Correlation Coefficient (R2): This performance statistic measures the degree to which the modeled and observed values are linearly related. A correlation coefficient of 1 indicates a

perfect linear relationship; whereas a correlation coefficient of 0 means that there is no linear relationship between the variables.

6.5.3. Additional Performance Metrics

Monthly spatial plots and time series of temperature, relative humidity, wind direction, and wind speed are produced for a cluster of sites along the Wasatch Front. These plots can help identify if WRF is performing well diurnally or if certain regions are performing poorly compared to others. Modeled precipitation and PRISM[20] daily precipitation totals for the 4 and 12km domains will also be compared.

7. Photochemical Model

7.1. Modeling Domains

The modeling domain will consist of three 12/4/1.33 km nested grid domains. The 12 km domain covers the Western United States and is aligned with EPA's 12US1 domain. The 4 km domain is nested within the 12 km domain and covers the state of Utah as well as parts of neighboring states. The 1.33 km domain is nested within the 12/4 km domains and extends over the non-attainment area to provide higher resolution modeling within this area. Sensitivity runs will be conducted to determine whether a one-way or two-way nesting configuration will be adopted. Model performance and computational time will both be taken into consideration.

The 12/4/1.33 km nested grid modeling domain configuration is shown in Figure 9. All 44 vertical layers defined in the meteorological model will be considered for modeling. Map projection parameters and model grid definitions are also provided in Tables 10 and 11.

Table 10. CAMx model grid definitions.

Specification	12 km	4 km	1.33 km
dx x dy (m)	12,000	4,000	1,333.333
Southwest Corner X Coordinate (m)	-2,556,000	-1,644,000	-1,332,000
Southwest Corner Y Coordinate (m)	-1,728,000	-312,000	80,000
# Columns	185	186	108
# Rows	299	180	207

Table 11. Map projection parameters.

Specification	Value
Latitude of Origin	40
Central Meridian	-97
Standard Parallel 1	33
Standard Parallel 2	45
Projected Coordinate System	Lambert Conformal Conic
Geographic Coordinate System	GCS Sphere ARC INFO
Radius (m)	6370997

[20] PRISM Climate Group, Oregon State University, http://prism.oregonstate.edu, created 6 September, 2021.

Figure 9. CAMx modeling domains.

7.2. Model Inputs and Settings

The latest version 7.1 (v7.1) of CAMx will be used for this modeling demonstration.

Table 12. CAMx domain specification.

Specification	12 km	4 km	1.33 km
dx x dy (m)	12,000	4,000	1,333.333
Southwest Corner X Coordinate (m)	-2,556,000	-1,644,000	-1,212,000
Southwest Corner Y Coordinate (m)	-1,728,000	-312,000	-8,000
# Columns	185	186	210
# Rows	299	180	141

7.2.1. Initial and Boundary Conditions

Time- and space-variable initial and boundary conditions (ICs and BCs, respectively) for the outermost domain (i.e. 12-km domain) will be derived from GEOS-Chem global chemistry model outputs for 2017, with the modeling being performed by Ramboll under contract with WESTAR. Following EPA guidance, the same GEOS-Chem-derived ICs and BCs for the 2017 base case will be used for the future case and any sensitivity simulations.

7.2.2. Other Model Settings

A summary of model settings is provided in Table 13. Sea salt and lightning NOx emissions will also be calculated in CAMx by running the corresponding CAMx tools.

Table 13. CAMx model settings.

CAMx Process	v7.1 Model Configuration
Grid Interaction	One-way or Two-way nesting*
Vertical Grid Mesh	44 vertical layers, as defined by WRF
Gas-Phase Chemistry	Carbon Bond 6 revision 5
Chemistry Solver	Euler Backward Iterative
PM Chemistry	Two-mode coarse/fine scheme, ISORROPIA inorganic gas-aerosol partitioning, RADM inorganic aqueous chemistry, SOAP organic gas-aerosol chemistry
Horizontal Advection Solver	Piecewise Parabolic Method
Dry Deposition	Zhang scheme
Wet Deposition	CAMx-specific formulation
Vertical Diffusion	Standard K-theory
Vertical Advection Scheme	Implicit scheme

** Sensitivity runs will be conducted to determine whether a one-way or two-way nesting configuration will be adopted.*

7.3. Model Performance Evaluation

7.3.1. Ambient Measurements Datasets

Gaseous data collected at UDAQ ambient air monitoring networks will be used for model performance evaluation. These include typical ground-based surface measurements: ozone, NO2, NOx and CO. While limited, VOCs measurements will also be used where available. Measurements collected during special field studies will also be used for model performance evaluation. These include ozone measurements collected during summer 2015 around the Great Salt Lake[21]. Ozone measurements to be collected around the Great Salt Lake during summer 2022 as part of a follow-up study to the 2015 one will also be used.

[21] 2015 Summer Ozone Study. https://deq.utah.gov/air-quality/great-salt-lake-summer-ozone-study

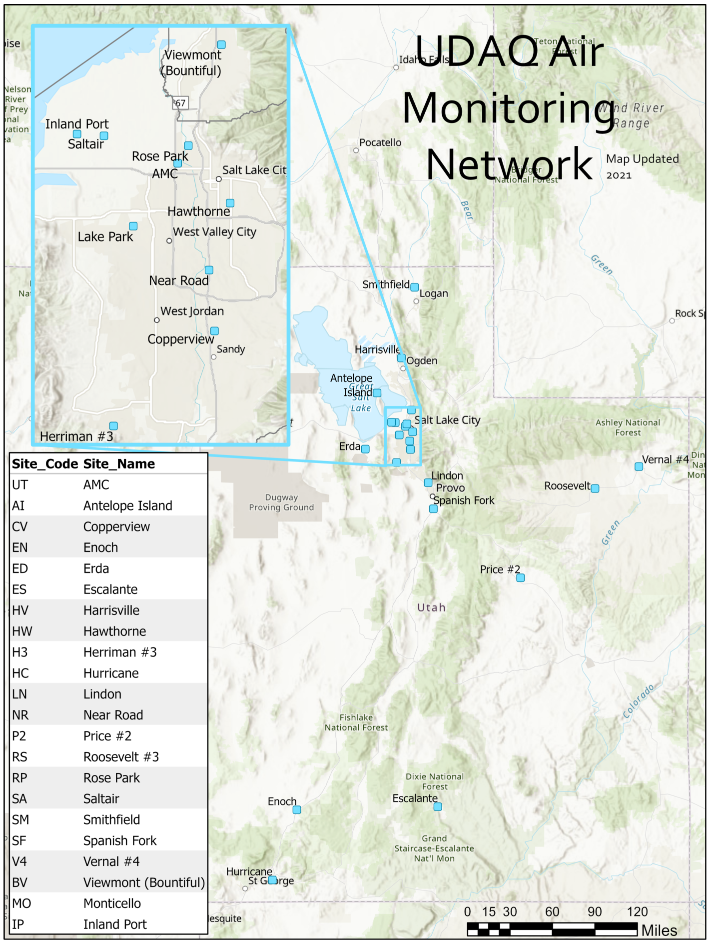

Figure 10. Map of monitoring stations with available measurements for model performance evaluation.

7.3.2. Operational Evaluation

The Operational Evaluation compares the modeled concentration estimates against concurrent observations using statistical and graphical analysis. It is aimed at determining how well the model simulates the base year observed concentrations. The Atmospheric Model Evaluation Tool (AMET) will be used for this purpose. Spatial visualization tools (VERDI) will be used as necessary.

7.3.3. Statistical Benchmarks and Metrics

Multiple statistical metrics will be considered to characterize the photochemical model performance. These include:

1. Mean bias (MB): This metric averages the model/observation residual paired in time and space.
2. Mean gross error (MGE): This performance statistic averages the absolute value of the model/observation residual paired in time and space.
3. Root Mean Square error (RMSE): This performance statistic is a measure of the average distance between predicted and observed values.
4. Normalized Mean Bias: This statistic (in units of percent) normalized MB to the average observed value.

5. Normalized Mean Error (NME): This performance statistic (in units of percent) is used to normalize the mean error relative to the average observation. This statistic averages the absolute value of the difference (model - observed) over the sum of observed values.
6. (Mean) Fractional Bias (MFB/FB): Fractional bias is determined by normalizing the MB by the average of observed and modeled concentrations.
7. (Mean) Fractional Error (MFE/FE): Fractional error is determined by normalizing the ME by the average of observed and modeled concentrations.
8. Correlation Coefficient (R2): This performance statistic measures the degree to which the modeled and observed values are linearly related. A correlation coefficient of 1 indicates a perfect linear relationship; whereas a correlation coefficient of 0 means that there is no linear relationship between the variables.

In addition to using statistical summaries, the model performance will be evaluated using graphical displays. These include:

1. Time series plots of modeled and observed concentrations at each site
2. Scatter plots of modeled and observed concentrations at each site
3. Soccer plots with purpose to visualize model performance of both bias and error on a single plot
4. Bugle plots

Model performance will be evaluated at individual monitors within the non-attainment area. Model predictions from spin-up days will be excluded from the model performance evaluation analysis. Ozone exceedance and non-exceedance days will also be evaluated separately.

7.4. Diagnostic Evaluation

The diagnostic evaluation evaluates various components of the modeling system and focuses on process-oriented evaluation. Indicator ratios and emissions sensitivity simulations will be examined to assess whether the system is NOx- or VOC-limited. Emissions perturbations will also help assess how modeled NOx, VOC and O3 respond to these changes.

8. Attainment Demonstration

8.1. Base Year Modeling

2017 WRF outputs, which represent a typical summertime ozone exceedance period, will be used for the 2017 base year simulation. The same CAMx settings, year-specific emissions and ICs/BCs as those used for the episodic year simulation will be used for this base case scenario.

8.2. Future Year Modeling

While 2023 emissions will be used for modeling the future year case, similar CAMx model configuration to that used for modeling the base case will be adopted for modeling the future year scenario. WRF outputs and ICs and BCs from the 2017 base case will also be used for the 2023 future year scenario.

Future year ozone design value projections will be made using the 2017 base case and 2023 future year CAMx simulation outputs as outlined below.

8.3. Future Year Design Value Calculation

Future year ozone design value (DV) projections will be conducted following EPA's ozone modeling guidance for SIP demonstrations[22]. At each monitoring site, the future year ozone DV (FDV) will be estimated by scaling the base year ozone DV (BDV). EPA's Software for the Modeled Attainment Test – Community Edition (SMAT-CE) software will be used for this purpose. Gridded MDA8 ozone concentrations over the modeling episode will be provided to SMAT-CE, which will identify the grid cells containing monitor locations within the NAA and will calculate a site-specific relative response factor (RRF):

$$FDV_i = RRF_i \times BDV_i \qquad \textit{where } i \textit{ corresponds to a given monitoring site}$$

A site-specific RRF, defined as the ratio of average MDA8 ozone in the future case to the average MDA8 in the base case over select highest MDA8 ozone days in the base year simulation, will be calculated. A 3x3 array of grid cells centered on the monitor will be used for this calculation, where the highest base year MDA8 ozone value in the 3x3 array will be used for both the base and future components of the RRF calculation. Different grid cell array sizes may also be considered, depending on conditions at each monitor (e.g. local topographic and geographical features). Moreover, different thresholds (e.g. ozone > 60 ppb) and factors, including model performance on high ozone days, will be considered in selecting the highest modeled ozone days.

9. Weight of Evidence Analysis

To support the modeled attainment demonstration, a weight of evidence analysis will be conducted as needed. The choice of supplemental analyses will be dependent on results from the model performance evaluation and degree of residual non-attainment in the modeled attainment test. Analyses such as modeling sensitivity tests to changes in emissions, mainly VOC perturbations, and analyses of trends in ambient concentrations and emissions, will be considered.

10. Data Storage and Archiving Plan

All completed modeling runs will be stored on UDAQ's private group space on the University of Utah's Center for High Performance Computing clusters. A detailed model performance evaluation will also be provided for the CAMx and WRF model runs.

[22] US EPA. Modeling Guidance for Demonstrating Air Quality Goals for Ozone, PM2.5, and Regional Haze. https://www.epa.gov/sites/production/files/2020-10/documents/o3-pm-rh-modeling_guidance-2018.pdf